Ground Based, Space Based, Infrastructure, Technological Development, and State of the Profession Activities

Name: Michael Fundator

Proposing Team:

Type of Activity:
Ground Based Project
Space Based Project
Infrastructure Activity
Technological Development Activity
State of the Profession Consideration

Description: Michael Fundator after presenting at different International, National, and local Conferences and Symposiums on subjects ranging from Pure Mathematics and Probability to different DNA and RNA analyses or Magnetism and Analytical Chemistry with application of Smoluchowski equation to 1D, 2D, 3D, and multidimensional models and publishing several articles in different International Journals with affiliation with DBASSE of the National Academy of Sciences of USA, the author with MS in Statistics from Rutgers University became a winner of the World Championship in Multidimensional Time Model that was developed by an author and partially presented in 3 White Papers submitted by the author in answer to the Call for White Papers is based on Stein estimators in Statistics, multifractal, multiscale laws of turbulent equations and Quantum Mechanics approach of Bohr–Kramers–Slater to interaction of matter and electromagnetic field for evaluation of different discontinuous quantum effects in atoms, molecules, and their different formations, and could be extended to physical optics, and further to direct analysis without questionable cosmological assumptions (for instance, micro- and macro- possible relations and other) of various space investigations including Solar System objects observations that are hardly detectible, for example planets and moons paths like Uranus moons, dust rings like the newly discovered of Mercury, meteor zone predictions, with further extension to pulsars emissions and formation of Black Holes, for example Primordial that are characterized by density perturbations, early dust type stages following turbulent fluctuations of the metric, and extended to BH formed by stellar collapse along with other analytical and observational applications including Biophysics and Biochemistry.

Web link: https://sites.google.com/.../dr-michael-fundator-from-usa-wins-world-championship-201...
http://surveygizmoresponseuploads.s3.amazonaws.com/fileuploads/623127/4458621/250-ad57d859f5c9a7fa688af62831af3bd3_AstroWhitePaper.pdf
http://surveygizmoresponseuploads.s3.amazonaws.com/fileuploads/623127/4458621/250-9010b50a3aa6b0814add25b38b20d229_Rescue1111.pdf
http://surveygizmoresponseuploads.s3.amazonaws.com/fileuploads/623127/4458621/250-ff1d89d5e32053cca210ef3dc091c1f6_Astro_theory_of_motion.pdf

Ground Based, Space Based, Technological Development, and State of the Profession Activities

Name: Ashwini Sathnur

Proposing Team: Ashwini Sathnur, Capacity Development Expert in United Nations Development Programme

Type of Activity:
Ground Based Project
Space Based Project
Technological Development Activity
State of the Profession Consideration

Description: Impact of solar flares and radiation exposure on the human astronauts who are located in the low - earth - orbit or deep space regions. Realization and implementation of inclusive development and accessibility solutions in these situations and bringing about a remedy for health - related issues in such situations!

Web link: https://issuu.com/ashwinisathnur/docs/solar_flares_and_quantum_physics_ne

Ground Based, Space Based, and Technological Development Activities

Name: Thomas Maccarone

Proposing Team: Poshak Gandhi (University of Southampton), Stephen S. Eikenberry (University of Florida), Piergiorgio Casella (INAF-Rome), James F. Steiner (MIT), Gregory R. Sivakoff (University of Alberta), Alexandra J. Tetarenko (East Asian Observatory), Daryl Haggard (McGill University)

Type of Activity:
Ground Based Project
Space Based Project
Technological Development Activity

Description: We plan to submit a paper arguing for the importance of having the capability of making optical and infrared variability measurements at millisecond timescales, primarily aimed at better understanding of the physics of compact objects. This capability has long been widely available for radio astronomy, and for X-ray and gamma-ray astronomy. Historically, it was available in the optical during the era when photomultipliers were the detector of choice for photometry, but with the advent of the CCD, it has become available only in niche instrumentation. In recent years, modern, high quantum-efficiency devices have been developed that detect optical photons with millisecond or better time resolution. Some of these systems also have direct energy resolution, while in other cases, systems have been set up to use dichroics to allow observations in several filters at once. Most often, though, observatories have not considered the value of high time resolution observations in planning their facilities. As a result, the capability to make these measurements is often limited by the analog to digital conversion, or, in the cases of many satellite missions, by the accuracy of the on-board clock. The lack of optical and infrared timing capabilities on publicly available facilities is particular noticeable in the United States. We plan to illustrate briefly a few examples of cutting edge science that has been done with existing facilities, and to discuss in broad terms the type of instrumentation and policy changes that could lead to a more widespread capability of doing optical and infrared timing.

Web link:

Name: William (Bill) Doggett

Proposing Team:

Type of Activity:
Ground Based Project
Space Based Project
Technological Development Activity

Description: This Notice of Intent (NOI) to provide a paper that reviews the significant capability that has been developed through decades of in-space assembly research at NASA Langley Research Center. The work began in the late 80's and continues today, validating the feasibility of assembling predictable systems on-orbit. The paper will review early erectable structures development and associated flight experiments, discuss assembly development targeting Space Station Freedom (the precursor to the International Space Station), describe robotic and EVA laboratory assembly experiments, and conclude with a description of more recent modular assembly approaches. The capabilities described are cross cutting to astrophysics telescopes of varying sizes achieved through single or multiple launches. Certainly, in-space assembly allows the creation of large scientific observatories. However, there are many other benefits of in-space assembly that will be highlighted. One of the most important is that in-space assembly provides funding and programmatic versatility. If an instrument is lagging, it does not directly impact the mission launch. Launch what is available, and expand the capability over time. I.e., achieve scientific observations early and often to begin learning, then expand and enhance the capability as science directs and funding enables.

Web link: NA

Ground Based and Space Based Activities

Name: John Mather

Proposing Team: Eliad Peretz, NASA, JPL, Industry, Academia, ELTs, International

Type of Activity:
Ground Based Project
Space Based Project

Description: We are studying a Starshade orbiting the Earth, to work with telescopes on the ground, to image and characterize exoplanetary systems in reflected light. This would implement the top recommendation in the NAS Exoplanet Science Strategy Report: "NASA should lead a large strategic direct imaging mission capable of measuring the reflected-light spectra of temperate terrestrial planets orbiting Sun-like stars." The starshade would carry a laser beacon to enable adaptive optics at visible wavelengths. With extremely large telescopes in both hemispheres almost the entire sky is observable, and an exposure time of few minutes can image Venus, Earth, Mars, Jupiter, Saturn and possibly even comets, at distances of at least 10 pc. Exposure times of ~1 hour can produce a spectrum sufficient to measure molecules of interest for Earth at 10 pc despite terrestrial interference. With an angular resolution of milliarcseconds, planets can be seen against exozodiacal clouds 20 times brighter than ours, and orbital motions can be seen in weeks. With exposure time up to hours per visit, and visits every few days, the system could find evidence of surface features and weather on an exo-Earth. We will report on predicted scientific capabilities, a mission concept, and the required technology development. The orbiting starshade would be larger than those studied for use with space telescopes and would require modification to multiple subsystems. It could also be transferred from Earth orbit to the Sun-Earth L2 point, to work with future space telescopes.

Web link:

Name: Jason Rhodes

Proposing Team:

Type of Activity:
Ground Based Project
Space Based Project

Description: Subaru and WFIRST: A Partnership for the 2020s As part of the Japanese contribution to NASA's WFIRST mission, NAOJ has pledged 100 nights of Subaru time to be executed concurrently with WFIRST operations starting ~2025. In the lead-up to WFIRST's launch and during operations both the US (via NASA Keck time, U. Hawaii time, and other partners) and Japanese community have access, via various Time Allocation Committees (TACs), to significantly more Subaru time than this 100 nights. Moreover, WFIRST will devote 25% of its time in its 5 year primary mission (and perhaps closer to 100% of time in a possible extended mission) to competitively selected guest observer observations; coordinated Subaru observations will make for competitive WFIRST GO proposals. Thus, considerably more than 100 nights of Subaru time may be dedicated to synergistic breakthrough science with WFIRST. This white paper seeks to identify the science opportunities and observations needed to unlock the full potential of > 100 nights of synergistic Subaru time combined with WFIRST observations. This white paper is written in conjunction with the WFIRST Project, relevant WFIRST Science Investigation Teams, and the Japanese Subaru community. The content flows directly from two Subaru/WFIRST synergy meetings held in Japan in 2017 and 2018.

Web link:

Name: Rolf Jansen

Proposing Team: A large number of teams with partially overlapping memberships, involving (to date, and roughly sorted according to wavelength) NuSTAR, Chandra, XMM, HST, LBT, Subaru, GTC, J-PAS, MMT, JWST (GTO and GO), Spitzer, IRAM, JCMT, SMA, VLA, VLBA/LBO, and LOFAR, to develop the pan-chromatic coverage, spectroscopy, and time-domain monitoring of the JWST NEP Time-Domain Field.

Type of Activity:
Ground Based Project
Space Based Project

Description: The James Webb Space Telescope (JWST) North Ecliptic Pole (NEP) Time-Domain Field (TDF) is a ~14' diameter field centered at (RA, Dec)_J2000 = (17:22:47.896, +65:49:21.54), and located within JWST's northern Continuous Viewing Zone (CVZ). It is the only region in the sky where JWST can observe a clean extragalactic deep survey field of this size (or larger) at arbitrary cadence and at arbitrary orientation, and always offers the lowest possible Zodiacal background. This enables a wide range of new and exciting time-domain science of objects as faint as m_AB ~ 29 mag and/or ~10 nJy (and overall survey depths potentially reaching ~31 mag), including high redshift transient searches and monitoring (e.g., SNe), variability studies from Active Galactic Nuclei (AGN) to brown dwarf atmospheres, as well as proper motions of potential extreme scattered Kuiper Belt and Inner Oort Cloud Objects (on inbound trajectories), and of nearby Galactic brown dwarfs, low-mass stars, and ultracool white dwarfs. A JWST/NIRCam+NIRISS GTO program will provide an initial 0.8--5.0 micron spectrophotometric characterization to m_AB ~ 28.8+/-0.3 mag of four orthogonal ``spokes'' within this field. Thanks to strong community interest in development of this new field, the multi-wavelength (radio through X-ray) context is either already in hand (ground-based near-UV--visible--near-IR, 10 cm radio-continuum), in progress (6 cm radio interferometry, 850 micron, 1 and 2 mm imaging, HST UV--visible and Chandra X-ray imaging, and ground-based visible--near-IR spectroscopy), or pending. Through this APC White Paper, we call attention to the powerful synergy of large existing and planned ground- and space-based facilities, spanning the X-ray through radio wavelength range, enabled by the development of this new (ultra)deep field for time-domain science, and welcome and encourage ground- and space-based follow-up of the initial GTO observations and ancillary data throughout the 2020s and beyond, to realize its potential as a pre-eminent ultra-deep time-domain community field.

Web link: http://lambda.la.asu.edu/jwst/neptdf/

Name: Sheperd Doeleman

Proposing Team: The EHT Collaboration

Type of Activity:
Ground Based Project
Space Based Project

Description: The Event Horizon Telescope is a project that uses the technique of very long baseline interferometry (VLBI), in which radio dishes across the globe are synchronized by GPS timing and referenced to atomic clocks for stability, thereby synthesizing a single Earth-sized telescope. Through development of cutting edge instrumentation, the EHT has extended the VLBI technique to ~1.3mm wavelengths, creating a virtual telescope with the highest angular resolution possible from the surface of the Earth. The array targets two supermassive black holes with the largest known apparent event horizons in the Universe: SgrA*, the 4 million solar mass black hole at the center of the Milky Way, and the 6 billion solar mass black hole at the center of the Virgo A galaxy (M87). With an angular resolution of ~25 micro arcseconds, the EHT is designed to image the black hole 'silhouette' or 'shadow' formed by the lensed photon orbit of these two sources, which subtend 50 micro arcseconds (SgrA*) and 40 micro arcseconds (M87). A decade ago, detection of horizon-scale structure in SgrA* confirmed that imaging the photon orbit was possible, launching the EHT project. A decadal review white paper submitted to the Astro 2010 survey claimed "Steady long-term progress on improving the capability of Very Long Baseline Interferometry (VLBI) at short wavelengths has now made it extremely likely that this goal will be achieved within the next decade." With first EHT results expected in 2019, the EHT project is now aiming to expand capabilities of the array in directions that will enable new horizon-scale studies of black holes in the areas of general relativity, accretion and jet formation as detailed in an Astro 2020 science white paper. Over the coming decade, the EHT will propose to add new strategically placed VLBI elements operating at 1.3mm and 0.87mm wavelength. In parallel, development of next-generation backend instrumentation, coupled with high throughput correlation architectures, will boost sensitivity, allowing the new stations to be of modest collecting area while still improving imaging fidelity and angular resolution. The goal of these efforts is to move from imaging static horizon scale structure to dynamic reconstructions that capture the processes of accretion and jet launching in near real time. These new VLBI elements will certainly include ground-based antennas, but expansion to space platforms affords key new capability, such as the tracking of structure evolution in SgrA* that is expected to occur on minute time scales. In short, the EHT will propose a program of development that will advance the state of the art from still images to movies of black holes.

Web link: www.eventhorizontelescope.org

Ground Based, Infrastructure, Technological Development, and State of the Profession Activities

Name: Adam Bolton

Proposing Team:

Type of Activity:
Ground Based Project
Infrastructure Activity
Technological Development Activity
State of the Profession Consideration

Description: A Spectroscopic Survey Roadmap for the US Community Wide-field survey spectroscopy in the coming decades promises breakthrough science for resolved stellar populations, Milky Way structure, the evolution of galaxies and AGN, the physics of dark matter and dark energy, and the signatures of inflation from the early universe. Survey spectroscopy uniquely leverages the astrophysics potential of major imaging survey investments such as DES/DECam and LSST, as well as the astrometric and proper-motion data from Gaia. The importance of large spectroscopic survey capabilities has been recognized by the OIR System Report of Elmegreen et al. (2015), the community study on Maximizing Science in the Era of LSST (Najita & Willman et al. 2016), the report of the Cosmic Visions Dark Energy group (Dodelson et al. 2016), and the 2019 report of the Gemini-Blanco-SOAR Subcommittee of the AAAC. This white paper will present a high-level overview and roadmap for the development of wide-field spectroscopic survey capabilities for the US community, connecting the present to the 2030's through a combination of SDSS, DESI, DESI-2, MSE, and other potential future facilities. Likely topics include the following: - Top five most disruptive science applications for spectroscopic mega-surveys (~10^6-10^8 objects) in the 2020s and beyond - The multi-wavelength / multi-messenger / time-domain landscape - The international landscape - Spectroscopic mega-surveys in the context of massive archival data sets and modern big-data technologies - Comparative design and scientific reach of current, planned, and proposed facilities - Trade spaces for facility, instrument, and survey design - Major target sample densities and co-scheduling opportunities - Project timescales, phasing, and funding models to promote US community access and leadership - Key enabling technologies and methods in instrumentation, calibration, survey design, operations, data management, and spectroscopic reduction & analysis software that are common to multiple facilities and that could be optimized through coordinated effort - Critical R&D needs and long-lead-time items - Opportunities for inter-agency collaboration between astronomy (NSF) and cosmology (DOE) - Open data, accessibility, collaboration, and research inclusivity - Long-term data stewardship and interoperability between surveys

Web link:

Name: Michelle Creech-Eakman

Proposing Team: M-USIC

Type of Activity:
Ground Based Project
Infrastructure Activity
Technological Development Activity
State of the Profession Consideration

Description: The Ascendance and Importance of Ground-Based Long-Baseline Optical/Infrared Interferometry The past 30 years have demonstrated the promise of ground-based long-baseline optical/infrared interferometry (LBOI) in unexpected and important ways. Unknown phenomena and processes in nearly every area of stellar physics have been discovered, new questions are being posed about problems the community believed were solved, and even direct imaging of the environs of AGN has been achieved. Prior and existing facilities have and continue to train generations of astronomers adept at the hardware, specialized techniques, control systems, software, data reduction approaches and indeed the required systems engineering and operational knowledge for these important astronomical facilities. NASA's long-range planning also recognizes the importance of interferometry for science progress towards higher-resolution astronomy and towards overcoming current roadblocks associated with building and launching ever larger spacecraft facilities. Technologies required to push the field of ground-based LBOI forward will benefit all areas of astronomy. For instance, ground-based interferometry benefits from low-noise, small-format, high-speed detector arrays for both scientific and wave-front sensing applications; infrared fibers and integrated optics systems are used for beam transport and combination; adaptive optics systems are necessary to correct the wavefront; and easily replicated, light-weighted high-quality optics are required for nearly all astronomical applications. Students and early-career researchers benefit from the training associated with building and controlling these types of systems. They also benefit from the direct knowledge associated with conceptualizing, designing, building and integrating any type of hardware, a skill becoming lost in the profession of astrophysics today. Today's facility-class LBOI arrays and their operating entities know the promising science that interferometry still has to uncover. Indeed, having multiple facilities is advantageous to the community as each one can have different key science goals, optimized wavelength coverage, and specialized approaches to challenges they face. Cross-training of personnel and cross-fertilization of ideas improves the entire community not only of interferometrists, but also of astronomers generally. Yet today there are fewer ground-based LBOI facilities than during either the 2000 or 2010 Decadal Surveys, and there are no NASA-/NSF-driven ground-based interferometry projects; some are supported via smaller PI-scale grants. Lack of support of these ground-based facilities means observations at resolutions beyond the reach of current AO and future MCAO systems will be simply unobtainable. High angular resolution remains the least explored frontier in optical astronomy. Developments of the last 3 decades have proven the technologies, and demonstrated both guaranteed and serendipitous science; nevertheless, the potential has been scarcely tapped. This Decadal can guarantee strong productivity in the 2020's, and set the U.S. firmly on the path to an LBOI capability worthy of a national effort.

Web link:

Ground Based, Infrastructure, Technological Development, State of the Profession, and Other Activities

Name: Michelle Creech-Eakman

Proposing Team: MRO Interferometer

Type of Activity:
Ground Based Project
Infrastructure Activity
Technological Development Activity
Other Developing a technologically competent workforce

Description: Extending Imaging Resolution Beyond the ELTs The Magdalena Ridge Observatory Interferometer (MROI) is the most sensitive long-baseline optical/infrared interferometer conceived of to date in the US community. Bringing together two main collaborating institutions (New Mexico Tech and Cambridge University) with more than 100 years of combined experience in optical interferometry gained at 6 alternate facilities, the project is in the initial deployment stage of this 10-element telescope array. When completed, the MROI will have sub-milliarcsecond resolution and be capable of making deep and detailed, model-independent images of objects as faint as 14th magnitude in the near-infrared. This is approximately 4-5 magnitudes deeper than is possible today. The science enabled by facilities such as MROI is vast and is demonstrated by the thousands of existing optical interferometry science papers in the literature that have been generated over the past 30 years from more than a dozen mostly first-generation array facilities. MROI's imaging-optimized design exploits the innovations that have been tested at existing facilities but uniquely augments them with high throughput and a polarization-preserving optical train and ultra-low coherence losses. By including 10 movable telescopes and multiple stations to scale baselines to best match the science target sizes, the MROI will deliver the ability to image statistical samples (hundreds to thousands) of numerous types of faint astronomical objects which to date have only been studied at the level of tens to hundreds. Development of the full MROI site infrastructure (roads, power, water, internet, heating/cooling, vacuum), beam combining and maintenance facilities, and the first 3 telescopes and associated beam relay and delay line systems have been completed under funding from three main sources. These include: DoD directed funding, State of NM funding, and PPARC funding from the UK, totaling about $90 million by 2021 when our present contract closes. Budgeting of all hardware components for the facility is well-understood and can be costed in today's dollars at $8 million/beam line. Additional staff and science instruments set a total cost to complete the remaining 7 beam lines for the MROI facility at about $70 million. Once operational, we anticipate making as much as 50% of the array observing time available publically via existing mechanisms (e.g. NOAO) dependent on scientific program requests and operations funding; this could begin as soon as the 4th telescope and beam line are operational. We intend to request funding via NSF, NASA, and other appropriate Federal sources over the next Decade toward these goals during the 2020 Decadal period. Finally, we note that while the content of this NOI and upcoming paper is most closely associated with Ground-based Projects and Infrastructure Support, it also has synergy with several other areas including: developing a technologically competent workforce in astrophysics, requiring multi-disciplinary teams for deployment and operations of the facility, providing complementary science to many existing facilities such as ALMA, VLA, LSST and JWST, serving as a testbed for upcoming ground and space technology development in the field, and being located in close proximity to NSF's VLA outside of Socorro, NM in this majority-minority state at an HSI

STEM institution (NMT). For all these reasons MROI represents a rare and important opportunity for the U.S. Astrophysics community to consider explicitly supporting.

Web link: www.mro.nmt.edu

Ground Based, Infrastructure, and Technological Development Activities

Name: Juna Kollmeier

Proposing Team: SDSS-V

Type of Activity:
Ground Based Project
Infrastructure Activity
Technological Development Activity

Description: SDSS-V is the first optical and infrared all-sky spectroscopic survey. Targeting over six million objects, it is designed to decode the history of the Milky Way galaxy, trace the emergence of the chemical elements, reveal the inner workings of stars, investigate the origin of planets, explore the growth and cosmic evolution of accreting supermassive black holes, and study the process by which stars form and inject energy into the interstellar medium. Its all-sky and multi-epoch spectroscopy will multiply the science from the Gaia, TESS and eROSITA missions, and will form a rich legacy for future missions such as, e.g., PLATO. SDSS-V will also create a contiguous spectroscopic map of the interstellar gas in the Milky Way and nearby galaxies that is 1,000 times larger than the state of the art, uncovering the self-regulation mechanisms of galactic ecosystems. It will pioneer systematic, spectroscopic monitoring across the whole sky, revealing changes on timescales from 20 minutes to 20 years. Scientifically, it is organized into 3 "Mapper" Programs: The Milky Way Mapper – focused on spectroscopic observations of 6million objects at high spectral resolution, The Black Hole Mapper – focused on optical spectroscopy of supermassive black holes and X-ray binaries, and the Local Volume Mapper – focused on 1 sterad of hyper-resolved optical integral field spectroscopy. The full SDSS-V project involves 11 telescopes (2x2.5m, 1x1m, 8x0.16m), two observing sites, 10 spectrographs, and an international consortium of partners operating from mid-2020 through mid-2025. SDSS-V is not yet fully funded and requires support from the astronomical community to proceed with its full scope. Our anticipated APC submission will more fully describe our facility and our program to serve a broad range of science.

Web link: https://www.sdss.org/future/

Name: Bryan Miller

Proposing Team: Eric Bellm (LSST/University of Washington), Federica Bianco (New York University), John Blakeslee (Gemini), Robert Blum (LSST), Adam Bolton (NOAO), Cesar Briceno (NOAO/SOAR), Will Clarkson (University of Michigan, Dearborn), Jay Elias (SOAR), Suvi Gezari (University of Maryland), Bob Goodrich (GMT), Matthew Graham (ZTF/Caltech), Melissa Graham (LSST/University of Washington), Steve Heathcote (NOAO), Henry Hsieh (Planetary Science Institute), Jennifer Lotz (Gemini), Tom Matheson (NOAO), M. Virginia McSwain (Lehigh University), Dara Norman (NOAO), Travis Rector (University of Alaska), Stephen Ridgway (NOAO), Abi Saha (NOAO), Rachel Street (Las Cumbres Observatory), Marcelle Soares-Santos (Brandeis University), Warren Skidmore (TMT), Letizia Stanghellini (NOAO), Lou Strolger (STScI), Joanna Thomas-Osip (Gemini), and Kathy Vivas (NOAO)

Type of Activity:
Ground Based Project
Infrastructure Activity
Technological Development Activity

Description: Astronomy entered a new era of multi-messenger astrophysics (MMA) and time-domain astronomy (TDA) in 2017. The Advanced LIGO and Virgo detectors observed a gravitational wave signal consistent with a neutron star - neutron star merger and a massive observing campaign by electromagnetic (gamma rays to radio) and neutrino telescopes detected the remains of "kilonova" explosion that resulted from the merger. A month later a muon produced by a collision with a 290 TeV neutrino was detected by the IceCube Neutrino Observatory. The neutrinos origin was coincident with a known gamma-ray blazar and electromagnetic follow-up observations from gamma-ray to radio frequencies showed that the blazar was in a "flaring" state and and that blazars can be a source of high-energy neutrinos. A month after that the Pan-STARRS1 survey detected a fast-moving object on a hyperbolic orbit. Follow-up observations with a large number of optical and IR telescopes showed that `Oumuamua was the first detected asteroid/comet from another solar system. These examples show that combining information from different messengers (gravitational waves, neutrinos, high-energy particles, and electromagnetic radiation) collected on short timescales allows us to understand the nature of the sources and the physical processes involved. In the era of time-domain and multi-messenger astrophysics, timely, often rapid follow-up with a multiplicity of flexibly-scheduled observing facilities is essential, and the demand is growing rapidly. The Large Synoptic Survey Telescope (LSST) is currently under construction on Cerro Pachon near La Serena, Chile, and, based on experience with the high rate of transient candidates from the Zwicky Transient Facility, will take MMA and TDA to the next level. LSST will image the entire visible sky every few nights for ten years in order to identify variable and transient objects and make very deep, stacked images. LSST will produce thousands of alerts every few minutes from variable stars, AGN, solar system bodies, all varieties of cosmic explosions, and transients of as yet unknown forms. It will not be possible to understand the nature of some of these detections from LSST photometry alone, so observations at other electromagnetic wavelengths --- and in some cases also from neutrinos and gravitational waves --- will be required, often on very short timescales after the initial discovery. The sheer volume of alerts means that existing methods which rely on human review for filtering and responding to alert streams will not be able to keep up with LSST and many interesting targets could be missed unless new technologies and methods are developed. The most efficient use of scarce astronomer and telescope time will be attained if access to all available facilities can be streamlined, especially since many projects will want to take advantage of multiple facilities (aperture sizes and instruments). Therefore, it is imperative that the community develop systems that can handle the volume of LSST alerts and organize the use of the available follow-up resources. This issue and suggested solutions have also been explored in Chapter 9 of the 2017 study "Maximizing Science in the Era of LSST." A lot of concrete progress has been made since then and the white papers associated with this notice of intent will summarize the current state of TDA/MMA follow-up preparation and identify the needs for the next decade. We will outline a system that uses "brokers" to classify and filter alerts, target observation managers (TOMs) for science team alert and observation management, and systems of telescopes for carrying out adaptively-scheduled observations and returning reduced data to scientists. To illustrate one example of a possible strategy for effective follow-up, we will provide an update on the Astronomical Event Observatory Network (AEON) collaboration between NOAO, SOAR, Gemini Observatory, and Las Cumbres Observatory that is attempting to coordinate their follow-up resources in order to enable more efficient science as the LSST era approaches. Other facilities, including the ELTs, can be added to this system in the future. We will describe the diversity of challenges facing the scientific community regarding source follow-up and suggest how the proposed NOAO/NCOA LSST Community Science Center (LCSC) might play a role in the solutions. We will also comment on how these networks and systems fit into the broader needs of MMA.

Web link:

Name: Alistair Walker

Proposing Team: T. Abbott (NOAO), R. Blum (LSST), A. Bolton (NOAO), M. Dickinson (NOAO), J. Elias (SOAR), R. Kron (U. Chicago), J. Marshall (TAMU), P. Martini (OSU), B. Miller (Gemini), J. Najita (NOAO)

Type of Activity:
Ground Based Project
Infrastructure Activity
Technological Development Activity

Description: Revitalizing the US OIR Instrumentation Program The National Center for Optical and Infrared Astronomy (NCOA) is the proposed entity amalgamating Gemini, NOAO, and LSST (in operations phase) into a matrixed organizational structure that will (inter alia) optimize utilization of the scientific and technical staffs across the Observatories programs, and facilitate activities extending beyond those presently possible. We will describe a proposed NCOA program that, working in partnership with universities, other national laboratories and observatories, and industry, will be designed to promote development in critical technical areas for OIR instrumentation, such as detectors, active optics, optical design, fiber positioners, calibration systems, software design, and data handling infrastructure development. It will also be able to provide supplementary expertise in critical skills such as system engineering, data management, and program management, to complement the abilities of the core instrument teams. Partnering in the training of scientists and engineers will be a particularly important component. This coordinated program is aimed at revitalizing the US OIR instrumentation efforts in a cost-effective way, and directly responds to a recommendation of the recent Gemini-Blanco-SOAR AAAC review.

Web link:

Name: Knut Olsen

Proposing Team: Adam Bolton, Stephanie Juneau, Robert Nikutta, Dara Norman, Knut Olsen for the NOAO Data Lab Team

Type of Activity:
Ground Based Project
Infrastructure Activity
Technological Development Activity

Description: The Data Lab: A Science Platform for the analysis of ground-based astronomical survey data The next decade will feature a growing number of massive ground-based photometric, spectroscopic, and time-domain surveys, including those produced by DESI and LSST. Giving the broad astronomical community the tools to use these surveys for discoveries will place high demands on the services of data archive centers. As concluded by the workshop on "NOAO Community Needs for Science in the 2020s", a Science Platform for ground-based astronomical survey data should: 1) serve the pixel data with built-in tools for pixel-level alignment, analysis, and modeling of images from a variety of multi-wavelength heterogeneous imaging datasets, including pixel-level data access for spectra; 2) serve the catalog data and provide built-in tools for fast catalog coordinate cross-matching; 3) allow users to design filters for and store results and data products from transient alert stream brokers; 4) curate, preserve, and allow sharing of all survey data products; 5) allow users to bring code to the platform for modeling the data at scale and sharing derived data products; 6) provide users with access to analysis tools that include generating publication-grade figures. In this paper, we will present a roadmap for the development of such a Science Platform for ground-based astronomy. Topics will likely include: - Key science cases driving ground-based Science Platform development - Architectural features of a Science Platform - The current Science Platform ecosystem - Current and envisioned evolution of NOAO Data Lab services and features - Leveraging software industry technological developments - Reproducibility of analyses and curation of derived data products - Working within a Science Platform Network (bridging between ground-based and space-based focused Platforms)

Web link: https://datalab.noao.edu

Name: Gerard van Belle

Proposing Team:

Type of Activity:
Ground Based Project
Infrastructure Activity
Technological Development Activity

Description: Sub-Milliarcsecond Imaging in the Visible with NPOI Lowell Observatory operates the Navy Precision Optical Interferometer (NPOI), a six-beam long-baseline optical interferometer, located in Flagstaff, Arizona. The facility is supported by a partnership between Lowell Observatory, the US Naval Observatory, and the Naval Research Laboratory. NPOI is currently operational on-sky in the visible with baselines between 8 and 100 meters, conducting programs of astronomical research and imaging technology development. To enhance a capability towards true imaging of faint, complex objects, an ongoing program of upgrades is being pursued at the facility. The facility has existing infrastructure for baselines up to 432 m in length, which would constitute the longest, highest spatial resolution visible-light capability available on the planet; these baselines are expected to be on-sky within the year. Additional, funded near-term upgrades include 3 AO-assisted 1.0-m apertures feeding each beam line, new visible and near-infrared instrumentation on the back end, and infrastructure supporting baseline-wavelength bootstrapping which takes advantage of the spectral and morphological features of faint, complex objects. First light for the large, relocatable apertures is expected by fall of 2019. The large apertures will enable observations of objects brighter than 10th magnitude in J- and H-band. At its core, the system is enabled by a approach that tracks the low-resolution (and thus, high signal-to-noise), bright near-IR fringes between aperture pairs, allowing multi-aperture phasing for high-resolution visible light imaging. Science cases that match this sub-millarcsecond imaging capability include stellar surface imaging and fundamental parameters, and imaging of young stellar objects. Completing the development of this advanced facility and making it available to the US astronomical community are priorities for the NPOI team.

Web link: https://lowell.edu/research/research-facilities/npoi/

Ground Based, Infrastructure, and State of the Profession Activities

Name: Michael Blanton

Proposing Team: Sloan Digital Sky Survey

Type of Activity:
Ground Based Project
Infrastructure Activity
State of the Profession Consideration

Description: Title: "The Sloan Digital Sky Survey as an Archetypal Mid-Scale Program." In "Astro2010: The Astronomy and Astrophysics Decadal Survey," mid-scale programs were identified as the second-ranking priority among ground-based activities. The Sloan Digital Sky Survey (SDSS) represents an archetypal mid-scale program of long standing and transformative success. We intend to write a white paper describing the technical, scientific, and organizational aspects of SDSS that underpin this success. This description should inform policy planning and design of funding mechanisms in order to best enable mid-scale programs with similar levels of success in the future. Specifically, we will cover: (a) the scientific planning process for SDSS phases; (b) the public-private funding model for SDSS; (c) collaboration policies enabling successful many-institutional partnerships; (d) increasing scientific and community impact through open data policies; (e) early and mid career training opportunities in mid-scale programs; and (f) opportunities for inclusiveness efforts within mid-scale programs.

Web link:

Name: Jennifer Lotz

Proposing Team: Phil Puxley, Beth Wilman , Henry Roe, Robert Blum, Lori Allen, Adam Bolton, Steve Heathcote (NOAO)

Type of Activity:
Ground Based Project
Infrastructure Activity
State of the Profession Consideration

Description: The National Center for Optical-infrared Astronomy (NCOA) will integrate into a single Center the operational activities associated with the National Optical Astronomy Observatory (NOAO), the Gemini Observatory, and the Large Synoptic Survey Telescope (LSST), and will serve for the foreseeable future as a focal point for the federal investment in ground-based optical and infrared (OIR) astronomy. NCOA will: ● Be the U.S. national Center for U.S. public access ground-based, nighttime OIR astronomy; ● Operate and maintain U.S. public access OIR observational research facilities and related data systems; ● Develop, build, coordinate, and integrate observational, technical, and data-oriented capabilities available throughout the U.S. OIR System of federal and nonfederal assets; ● Initiate, develop, and sustain domestic and international collaborations and partnerships to advance ground-based OIR facilities and capabilities; ● Develop and advance a strategic vision for NSF-funded OIR capabilities in collaboration with community scientists, partner organizations, other U.S. OIR System operators, and NSF. The NCOA initiative is directly responsive to the recommendation of the 2010 Decadal Survey (New Worlds New Horizons in Astronomy and Astrophysics) that "NSF... should consider consolidating the National Optical Astronomy Observatory and Gemini under a single operational structure, both to maximize cost-effectiveness and to be more responsive to the needs of the U.S. astronomical community," and to the recommendation of the NRC report on Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System (Elmegreen at al. 2015) that "[t]he National Science Foundation should direct its managing organizations to enhance coordination among the federal components of medium- to large-aperture telescopes in the Southern Hemisphere, including Gemini South, Blanco, the Southern Astrophysical Research (SOAR) telescope, and Large Synoptic Survey Telescope (LSST), to optimize LSST follow-up for a range of studies."

Web link:

Name: Tim Abbott

Proposing Team: The CTIO Science Staff: Steve Heathcote, Alistair Walker, Andrei Tokovinin, Sean Points, Nicole van der Bliek, Kathy Vivas, Cesar Briceno, Alfredo Zenteno, Regis Cartier, Clara Martínez-Vázquez, Jay Elias

Type of Activity:
Ground Based Project
Infrastructure Activity
State of the Profession Consideration

Description: Title: The Observatory Ecology: Scientific and Technical Staff Ground-based optical and infrared astronomical observatories are unusual establishments, and they face unique challenges. They are necessarily physically remote from most centers of technological and academic excellence, and yet in this isolation must develop and host state-of-the-art facilities and perform leading science with them in the service of their user communities. They establish and maintain their own broad infrastructure to attract, cultivate, and support staff who are world class in their various disciplines and prepared to pursue them in a challenging environment. Some of those skills are unique to observatories and can only be learned at them. We will examine US OIR observatories from this perspective. We will develop recommendations directed at finding, training, and keeping future generations of observatory staff ensuring that they are suited to supporting the needs of the American astronomical community. These workers include instrument and telescope scientists and builders, observatory-specific technical staff, observatory-based scientific staff, data scientists, and skilled observers. This will require establishing a picture of the current state of the observatory worker's profession, and extrapolating this through anticipated changes to existing facilities and the construction and operation of future telescopes and instruments.

Web link:

Name: Lori Allen

Proposing Team: Steve Heathcote (sheathcote@ctio.noao.edu), Adam Bolton (abolton@noao.edu)

Type of Activity:
Ground Based Project
Infrastructure Activity
State of the Profession Consideration

Description: APC white paper(s) on Mid-Scale Observatories: We plan to submit one or more white papers on the capabilities of the ground-based 4m-class assets of the National Optical Astronomy Observatory (soon to be an integral part of the National Center for Optical/Infrared Astronomy, or NCOA). Properly instrumented, the wide field 4m class telescopes (Blanco in the South, Mayall in the North) will continue to be highly effective survey machines while SOAR and WIYN serve as agile platforms for time-domain follow-up. Integrated with other ground-based telescopes in both the north and the south, the mid-scale observatories can play a vital role in survey science and in bi-hemispheric follow up of transient events discovered with ZTF, LIGO/Virgo, TESS, and LSST.

Web link:

Name: John O'Meara

Proposing Team: TBD

Type of Activity:
Ground Based Project
Infrastructure Activity
State of the Profession Consideration

Description: The need for robust data services on large, ground-based OIR facilities The previous three decades have seen the development, commissioning, and operation of a variety of large (6.5+ meter) OIR telescopes on the ground with varying degrees of access to the U.S. community. Some facilities (e.g. Gemini, Keck) have associated public data archives, others offer a sampling of their data to the public, and some offer no access to their data at all. Although some archives host higher-level science products, these tend to be small releases with a specific science focus, or special positions on the sky. Essentially, most public data archives for large telescopes available to the United States OIR communities are bit-buckets for raw data. The current state of the ground-based, large-aperture OIR data archive landscape is a direct consequence of two key factors: lack of investment, and lack of will. On the investment side, instrument development teams and observatories often deprecate or eliminate data reduction pipelines and their associated infrastructure and support in the face of budget constraints. On the will side, the large-aperture OIR community has historically viewed their data as a custom, single-use object, with little attention given to the future science utility of the data, and the need to uniformly calibrate it with that utility in mind. This state of affairs is in sharp contrast with space-based facilities. To improve the situation, to best realize the scientific potential of the data from large telescopes in the OIR portfolio, and to properly integrate with robust offerings from space missions, the community and the federal agencies that fund it must invest in a comprehensive data services initiative. The envisioned initiative requires that data arriving from the telescope have uniform and robust metadata. It requires that data must have uniform calibrations and associations to the science targets. It requires near real-time processing and ingestion into archives, particularly to aid rapid-response transient and multi-messenger astronomy, and it requires those archives to be easily linked to others on the ground or in space. Realizing such an initiative will require targeted federal agency investment as specific funding opportunities associated with new instrumentation and facilities. Furthermore, targeted funding should be made available to bring the last quarter century of data as close to in-line with new data as is feasible. Beyond resources, the community itself must embrace the philosophy of the future science their data can realize, even at the cost of some on-sky time for proper calibrations. The community must likewise be willing to participate in expanding the depth and breadth of publically available data reduction and analysis software, and reward that participation accordingly.

Web link:

Ground Based and Infrastructure Activities

Name: Frank Hill

Proposing Team: Alfred de Wijn, Joan Burkepile, Steve Tomczyk, Sanjay Gosain, Valentin Martinez Plllet, Scott McIntosh

Type of Activity:
Ground Based Project
Infrastructure Activity

Description: The Ground-based Solar Observatory Network (GBSON) consists of a set of six fully-instrumented solar observing stations distributed around the world. The geographically-distributed stations would be located at international sites with longitudes, weather patterns, and technical expertise specifically selected to provide nearly continuous observations of the Sun for many years. Each GBSON station will have several solar instruments: infrared spectrograph-based spectro-polarimeter; visible-infrared tunable filter spectro-polarimeter; helioseismic doppler imager; and two coronagraphs: internally- and externally-occulted. This approach has been adequately demonstrated to succeed with existing solar networks, both research and operational. GBSON incorporates heritage and elements from a number of existing and planned operational networks: the extant Global Oscillation Network Group (GONG) operated by NSF's National Solar Observatory (NSO); the conceptual design developed for the European Union-led activity SPRING (Solar Physics Research Integrated Network); and requirements identified by the US Air-Force Research Laboratory (AFRL) for solar observations essential for future SW modeling and forecasting. Together, these stations will provide a set of observations of the solar disk and corona to facilitate research into the origins and evolution of the solar magnetic field, including its topology and eruption from the Sun. This solar data will advance research into the structure and dynamics of the solar magnetic field and interior and provide input data for the increasingly important area of space-weather forecasting. The behavior of the Sun's magnetic field as it expands into the heliosphere is the driver of space-weather phenomena that impact all bodies in our Solar System. GBSON also will help us understand the space weather conditions that may affect exoplanets orbiting other magnetically active stars. GBSON is an international effort that builds on our experience with GONG and incorporates the US expertise with that of other countries that operate synoptic programs. Once operational, GBSON will: • Measure the boundary data that propagate the magnetic connectivity from the solar surface into the heliosphere; • Map the 3-D magnetic topology of solar erupting structures in the chromosphere and corona, increasing advanced warning of space weather events from hours to days; • Anticipate processes in the solar interior and the far side that impact heliospheric conditions; and • Provide context for high-resolution observations of the Sun as well as for in situ single-point measurements throughout the heliosphere. GBSON's observations, beyond advancing solar physics, will also benefit society: they provide crucial input to operational forecasts of space weather. GBSON will eventually replace the existing GONG instruments, which have been routinely incorporated into the SW forecasts produced by many groups (e.g., the NOAA Space Weather Prediction Center; the US Air Force 557th Weather Wing; NASA's Community Coordinated Modeling Center; and the United Kingdom Meteorological Bureau). The global behavior of the Sun's magnetic field as it expands into the heliosphere is the driver of space weather phenomena that impact all bodies in our Solar System. GBSON will help us explore the underlying physics responsible for the Sun-Earth magnetic linkages that define space-weather conditions and that offer a unique laboratory to understand stellar astrospheres.

Web link:

Name: Sally Oey

Proposing Team: Jay Gallagher (Wisconsin), Tom Maccarone (Texas Tech), Michael Meyer (Michigan), Rachael Beaton (Carnegie, Princeton), Patrick Kelly (Minnesota), Claudia Scarlata, (Minnesota), et al.

Type of Activity:
Ground Based Project
Infrastructure Activity

Description: Whither The System? The Role of 1 to 5-m Telescopes in the 2020's We intend to submit an Astro2020 White Paper on the continued need for coordinated support of small and moderate aperture (1 to 5-m) telescopes to optimize the national scientific enterprise. Now that NSF is seriously considering support for substantive ELT involvement on behalf of the US community, in addition to on-going support for LSST and Gemini, the concern is that there will be no meaningful support for any smaller-class facilities. Already most of NOAO's 4-m class telescopes, with the exception of SOAR, are operating in support of large DOE or NASA survey projects, rather than general purpose astrophysics. There has been little analysis of what this means for the future of astrophysics. Yet, this would be significant, since small telescopes have made some of the most important discoveries of the current era, including dark energy, exoplanets, and gravitational-wave EM counterparts. Furthermore, the ELTs will yield very little time per capita for the community, and thus eliminating support for smaller telescopes will leave very little public access, while follow-up observations of LSST discoveries will be needed at the same time. We will discuss these issues and possible approaches for solutions.

Web link:

Name: Anish Roshi

Proposing Team: Mike Sulzer, Christiano Brum, Shikha Raizada, Jens Lautenbach, Nestor Aponte, Alessandra Pacini, Pedrina Santos, Luis Quintero, Phil Perillat, Anne Virkki, Flaviane Venditti, P. K. Manoharan, Ben Perera, Yan Fernandez, Noemi Pinilla-Alonso, Francisco Cordova, Jaime Gago, Maria Womack

Type of Activity:
Ground Based Project
Infrastructure Activity

Description: The Arecibo Observatory (AO), now under new management by the University of Central Florida (UCF), Universidad Ana G. Mendez - Recinto de Cupey (UAGM-Cupey) and Yang Enterprises, during its operational lifetime, has supported cutting-edge research in Astronomy, Planetary science and space atmospheric science. The key aspects of the telescope are its large collecting area and its excellent instrumentation. The former, specifically, has helped the telescope to make unique contributions to the different research areas. The existing extremely sensitive receivers, which operate up to about 10 GHz, are being extensively used by the research community. However, some of the upcoming or operational non-NSF facilities (such as FAST telescope in China) will out-perform Arecibo telescope in the near future. Therefore it is important to make serious investment to upgrade the telescope. The last major upgrade of the facility took place more than 20 years ago (installation of the Gregorian system). It is now time to invest on an important upgrade to keep the Arecibo research facility internationally competitive. In February 2019, AO organized a 3 day workshop titled ``Pathways to the Future of the Arecibo Observatory'' at San Juan, Puerto Rico. The purpose of this workshop was to create a shared vision of the future research that will be conducted using the telescope and to discuss potential technical upgrades that would ensure the Arecibo Observatory stays at the forefront of radio astronomy, space and atmospheric sciences and planetary sciences research. The community has suggested three major upgrades that could be implemented over the next 15 years or so. These upgrades are briefly described below. 1. Upgrading the Arecibo telescope to operate at frequencies up to about 30 GHz. This upgrade will bring back AO's uniqueness to the research community. Arecibo will then be the largest telescope in the world operating at the higher frequency range. The phenomenal sensitivity the facility can provide at these frequencies is critical to make major advances in several astronomical research areas. The research area include, but not limited to, search for spectral lines (eg. CO lines) from proto-clusters at cosmological distances and measuring the fundamental parameters of the Universe such as the Hubble constant by observing red-shifted H_2O megamaser lines. 2. Equipping the Arecibo telescope with receivers operating down to 30 MHz. With the development of technology, Radio Astronomy has migrated its operations to higher frequencies, primarily because of poorer angular resolution of the telescope at longer wavelength. Nevertheless, exclusive information about the universe are available at cosmic emission at low-frequencies as demonstrated, for example, by the recent HI 21cm line detection from epoch of reionization. The discovery potential at lower frequencies has led to a surge in low-frequency radio facilities across the world (eg. LOFAR, LWA, MWA) in the recent past. The suggested upgrade will make AO become part of these science facilities. 3. Increasing the declination coverage of the Arecibo telescope. A major limitation of the current facility is its restricted declination coverage (-1 deg to +38 deg). Increasing the declination coverage will enable Arecibo to do a variety of new science. For example, the upgraded facility will help accurate timing of larger number of milli-second pulsars for the NANOGrav project.   The detailed description of the upgrade plan will form the theme of the ``activities, project, or state of the profession consideration (APC)'' white paper.

Web link:

Name: Adam Bolton

Proposing Team: AURA/NOAO/CSDC

Type of Activity:
Ground Based Project
Infrastructure Activity

Description: NOAO's Community Science and Data Center: open-access science in the era of big surveys and big data We plan to submit a white paper overview of the Community Science and Data Center (CSDC) of NSF's National Optical Astronomy Observatory (NOAO). CSDC is NOAO's third major scientific program division, along with Kitt Peak National Observatory (KPNO) and Cerro Tololo Inter-American Observatory (CTIO). The CSDC mission is to enable broad-based astronomical community science through open access to telescopes, data sets, and data services. This mission is carried out through a suite of complementary programs in data-intensive astronomy and community science support. CSDC's programs in data-intensive astronomy are developed and operated with the twin goals of (1) enabling science now with the big public data sets of today and (2) preparing the community for science with LSST in the near future. These programs include the NOAO Data Lab, the ARIZONA-NOAO Temporal Analysis and Response to Events System (ANTARES), and the NOAO Science Data Archive. CSDC also encompasses NOAO's Time Allocation Committee and the US National Gemini Office, which together provide the US community interface to all federally funded open-access OIR observing capabilities. In the near future, CSDC will be a program within NSF's new Center for Optical and Infrared Astronomy (NCOA), along with the Gemini Observatory, LSST Operations, and the Mid-Scale Observatories (KPNO + CTIO). We will describe the synergies between CSDC and other NCOA programs that can lead to new scientific capabilities for the astronomical community in the era of data-intensive astronomy, ubiquitous time-domain and multi-messenger astrophysics, and the development of extremely large telescopes.

Web link:

Ground Based, Technological Development, and State of the Profession Activities

Name: David Kieda

Proposing Team: Cherenkov Telescope Array Stellar Intensity Interferometry Science Working Group, and Cherenkov Telescope Array

Type of Activity:
Ground Based Project
Technological Development Activity
State of the Profession Consideration

Description: Recent advances in telescope design, photodetector efficiency, and electronic data recording a high-speed data transmission and processing have given rise to a new technological capability: the opportunity to create ground-based, multi-kilometer baseline Stellar Intensity Interferometry (SII) in the visible (U/V) wavebands. This capability has the theoretical capability of imaging of stars, binary systems and other astrophysical systems with an angular resolution better than 40 micro arc-second. The recent advances which have enabled this technology include the development of high-speed silicon photomultiplier tubes, the development of 10-m class Imaging Cherenkov telescopes for ground-based Very High Energy gamma-ray astronomy, and the availability of commercially available, low cost streaming digitizers with multi-Ghz sampling rates. Additional key technologies which make this technique possible include: 1) the availability of high capacity (>10TB) RAID arrays with sustained streaming capability exceeding 1 GByte/sec 2) the availability of inexpensive high speed data transport (>10 GB/sec) on commercially available fiber optic transceivers 3) the development of the White Rabbit chipset technology, which allows synchronization of PXIe backplane clocks with better than 100 psec accuracy over 80 km distances using commercially available, inexpensive fiber optic communication cable. 4) The demonstrated ability to post-process the interferometric correlations between telescopes using a software correlator algorithm programmed into a high-speed Field Programmable Gate array. This technology makes it possible to inexpensively compute all interferometric cross-correlations in the photon arrival stream signals between each telescope in the SII telescope array in real-time/near-real time. Because the SII telescopes need only be connected through commercial fiber optic cables, a large SII telescope array can be built in a modular fashion, with individual telescopes placed in arbitrary locations and then attached to the power and communication grid. The 'modular construction' capability of an optical intensity interferometric array can also allow telescope spacings to be actively reconfigured (similar to the VLA), thereby enabling dynamic customization of the baseline sampling of the Fourier image plane to generate the desired resolution of the astrophysical target. This SII technology is compact and easily scalable, and is also deployable onto existing arrays of optical telescopes, such as the VLTI. Consequently, the technological capability is not tied to a specific instrument or hemisphere, but can be deployed on any array of suitably spaced, large diameter optical telescopes. Additional signal-to-noise improvements that will be developed in the next decade include optical polarization and also the implementation of multi-waveband intensity interferometry, thereby increasing the signal-to-noise ratio of the measured visibility, which improves the sensitivity of the technique. Multi-waveband SII (or short-wavelength optical SII observations combined with longer wavelength amplitude interferometry imaging) can measure the stellar surface of last scattering at different scale height due to the wavelength dependent opacity of the stellar envelope. Sampling the stellar atmosphere at different scale heights can provide a capability to expand the 2-D optical imaging capability of SII to three dimensions. This white paper will describe ongoing validation tests of the SII technique in the laboratory using various optical sensors and correlators, and will also describe the recent demonstration of SII measurements on nearby stars that have recently been completed as a technology demonstrator. The resolution of a typical implementation has been extrapolated to examine the potential resolution that could be achieved on a future large (km baseline) array of Imaging Air Cherenkov Telescopes for Very High Energy gamma-ray astronomy, such as the Cherenkov Telescope Array (CTA). The white paper will describe the anticipated resolution and future improvements in technology that will advance the potential resolution of SII observations during the next decade. This white paper is developed by the Stellar Intensity interferometry Science Working Group (SII-SWG) of CTA, under the organization of David Kieda (Utah -SWG leader) and Nolan Matthews (Utah - deputy SWG leader). Additional members of the SII-SWG include Monica Acosta, Instituto de Astrofísica de Canarias; Anastasia Barbano, DNPC, Universite de Geneve; Colin Carlile, Lund University; Michael Daniel, Center for Astrophysics | Harvard & Smithsonian; Dainis Dravins, Lund University; Jamie Holder, University of Delaware; Teresa Montaruli, DNPC, Universite de Geneve, Roland Walter, DNPC, Universite de Geneve; and Luca Zampieri, INAF-Osservatario Astronomico di Padova. A current listing of all the participants in the CTA Consortium can be found on this web page: https://www.cta-observatory.org/consortium_authors/.

Web link:

Name: Marc Kassis

Proposing Team: TBD

Type of Activity:
Ground Based Project
Technological Development Activity
State of the Profession Consideration

Description: Sustained instrument design incubation funding to bolster future ground-based science productivity The capabilities and complexities of new instrumentation on ground-based OIR telescopes of all aperture sizes has driven up their cost and lengthened development schedules. In some cases, future instrumentation costs for 8+ meter could exceed $50 million and build times could exceed five years after preliminary design review. At the same time, many recent instruments have far exceeded their cost and schedule estimates, requiring further, often substantial, outlays of funds and significant delays before commissioning on the telescope. While some minor cost increases and schedule slips will always be present in complicated instrumentation, the majority of major slips can be avoided via more robust instrument design development at project onset. Two NSF programs, MSIP and MSRI-1 having biannual cadences, offer funding for design studies in preparation for instrumentation with eventual costs spanning $6-70M. Both MSIP and MSRI-1 offer instrument development teams funding to mature designs in preparation for future implementation proposals specifically targeting these two programs. For astronomical instrumentation development, there are challenges with these two programs in that the MSRI-1 is not specific to the AST division at NSF and thus competition is NSF wide while MSIP has gone largely under-funded since the 2010 Decadal Survey due to budget constraints. Given the strong likelihood of instrumentation funding remaining constrained into the 2020s, even with the arrival of new telescope facilities, the need for more robust design development for projects and funding opportunities at all levels is more urgent. Here, we propose that the NSF establish a dedicated annual funding cycle for developing instrument concepts, with a focus on those instruments that directly address the strategic needs of the U.S. ground-based community as identified in the Decadal Survey and other assessments (e.g. the NAS Exoplanet Science Strategy report). A funding level of approximately $10 million would facilitate design development for multiple instrument concepts at scales across the portfolio from MRI through MSRI-2. The funds would be intended to not only support the instrument PI and science teams, but also fund the critical design components of engineering, project management, and observatory integration. Depending on the scope of the project, approximately 5-10% of the final project cost is needed to adequately define the cost and schedule of an instrument, and this funding line would provide that level of investment for multiple instrument concepts annually. This dedicated funding stream would provide significant benefit to the community: First, it would significantly decrease risk of significant cost and schedule overruns on the funding landscape. Second, it would allow instruments to better understand what 'cost box' (NSF program) they actually occupy instead of proposing to a funding level that forces significant science de-scopes post-award when detailed design shows they cannot meet budget or schedule. Finally, it would help ensure the vitality of the instrument building community by allowing new teams to properly fund their design development efforts and bring in needed external expertise.

Web link:

Ground Based and Technological Development Activities

Name: Ryan Lynch

Proposing Team: Green Bank Observatory

Type of Activity:
Ground Based Project
Technological Development Activity

Description: The Green Bank Telescope (GBT) is the US astronomical community's only open-skies, large single-dish radio telescope operating from decimeter to millimeter wavelengths. Since its inception, the GBT has been an excellent platform for developing and deploying new technology in support of a broad range of science, including fundamental physics, the transient radio sky, multi-messenger astronomy, star formation, cosmology, planetary science, and the search for life beyond Earth. The Green Bank Observatory (GBO) intends to submit APC white papers describing several small to mid-scale projects that will continue to enhance the capabilities of the GBT in support of the US scientific community. These will include: 1) A growth in the GBT's radio camera program: A cryogenically cooled 1.4 GHz phased array feed has been deployed on the GBT with sensitivity matching that of a traditional feed-horn receiver, but with seven Nyquist-sampled beams on the sky. By increasing the number of beams to fully sample the focal plane of the GBT at a wider range of frequencies (such as the important transitions of ammonia), surveys speeds for low-surface brightness gas and radio transients can be increased by factors of several to hundreds. 2) Using new digital technology to increase instantaneous bandwidth and mitigate the impact of radio frequency interference (RFI): High-speed analog-to-digital converters with good dynamic range make it feasible to digitally sample with a minimum of analog conditioning. This has the potential to increase the instantaneous bandwidth of the GBT by factors of ~3--6.5, with corresponding improvements in spectral-line survey speeds where multiple spectral transitions need to be observed, such as studies of complex molecules. Digitization closer to the receiver will also improve RFI resistance and enable novel techniques for identifying and removing RFI from final data products. 3) Developing the most sensitive radio receivers: Spectroscopic and continuum observations of compact sources benefit from single-pixel receivers with increasing bandwidth and low-noise electronics. Sensitivity improvements by up to a factor of two can be realized using emerging low-noise amplifiers and receiver designs. At high frequencies new background-limited bolometer technologies (TES, MKIDS) could improve the continuum sensitivity of the current GBT heterodyne receivers by factors of 10-100 and improve spectral-line sensitivities by factors of 2-5. 4) A data archive and scientific tool-kit for large-area surveys: The GBT is a premiere instrument for large-area surveys. By revisiting archival data with new algorithms, previously unknown sources can be discovered. Preservation of these legacy data sets, which are growing by factors of several in data volume due to higher time and frequency resolution and wider field of view, requires a significant investment in long-term public archives and state-of-the-art data processing tool kits. 5) Precision telescope control: The GBT's active surface enables observations at frequencies as high as 116 GHz. Approximately 1200-2000 hours/year at the GBO have atmospheric opacity suitable for observations in the 3-mm band, but the amount of time that can actually be used is limited to 250-500 hours/year because a) rapid temperature changes during the daytime degrade surface accuracy, limiting observations to nighttime and b) even moderate winds cause unacceptably large pointing errors. Improved techniques for monitoring and controlling the GBT's surface, as well as the ability to actively compensate for wind-induced pointing errors, can thus quadruple the time available at 3 mm, with applications to the physical conditions of dense gas, tracers of star formation, and 3-mm VLBI. 6) Enhancing radio quiet zones: The National Radio Quiet Zone is an invaluable resource but it does not protect against all RFI. The NRQZ could be made even more effective though several projects, including: a 24/7 RFI monitoring system covering 0.1--116 GHz, resources to more effectively identify and mitigate specific transmitters, and new techniques to identify and remove RFI from final data products. All areas of radio astronomy science would benefit. 7) Advanced monitor and control systems: The above enhancements will increase the complexity of the GBT and its instruments. To make the most of these improvements, it will be necessary to develop a robust, parallelized monitor and control system for the GBT. This will include multiple layers of hardware, software, and user-facing interfaces. These projects complement those presented by GBO in other APC white papers, namely: a) a fully-funded open-skies program for the GBT, b) Argus+, a 144-pixel 3-mm camera, c) a planetary transmitting radar for the GBT, and d) professional training and workforce development.

Web link:

Name: Delia Tosi

Proposing Team: South Pole cosmic ray surface detector group

Type of Activity:
Ground Based Project
Technological Development Activity

Description: South Pole surface detector array for measurements of high energy cosmic rays This NOI summarizes the plans for a project white paper that describes the existing and future surface detector array located at South Pole Station, Antarctica, designed to enhance cosmic-ray measurements for the purpose of fundamental and multi-messenger science. The study of high-energy Galactic cosmic rays (approx. 0.1 PeV - 1 EeV) represents a long-term core area of astrophysics. Measurements of cosmic rays over a broad energy range are key to understanding the most powerful accelerators in the Universe and the hadronic interactions that produce neutrinos and gamma rays. In particular, the Galaxy can be used as a test bench for model validation. In addition, cosmic rays have become valuable tool in identifying key backgrounds associated with measurements of high-energy astrophysical neutrinos. The environmental conditions at South Pole Station, Antarctica, have proven to be a nearly ideal location for intermediate and high energy cosmic-ray measurements. Of note, the IceCube Neutrino Observatory features a surface array, IceTop, that consists of frozen water tanks equipped with photosensors that detect the charged particles produced in cosmic-ray induced air showers. Complementing the deep-ice IceCube detector array, IceTop has provided new insights to particle physics in air showers, measurements of the average mass composition, and a first-time measurement of cosmic-ray anisotropy in the PeV energy range. The Antarctic cosmic-ray community is currently developing an upgrade to the IceTop array that incorporates advances in scintillator, radio and air-Cherenkov detector technologies to enhance the operation and sensitivity. In particular, the upgrade incorporates novel designs to mitigate the need for snow accumulation maintenance. Snow accumulation has impacted the performance of the existing IceTop detectors by reducing their sensitivity to the electromagnetic component of low energy showers. The three upgrade technologies provide sensitivity in a complementary energy range and offer unique handles to categorize the cosmic rays event-by-event according to their estimated mass. This will enable a study of mass-dependent anisotropy of galactic cosmic rays and the search for PeV gamma rays from the Galactic Center. It will also provide a better understanding of the atmospheric background to IceCube's neutrino measurements, and improve the use of the surface array as veto for IceCube for atmospheric neutrinos by identifying muon tracks crossing the in-ice detector produced by cosmic-ray showers as opposed to muon tracks produced by astrophysical neutrinos. It is envisioned that the IceCube-Gen2 Neutrino Observatory will feature an extended surface array with instrumentation deployed in the vicinity of the top of each string. The extended spacing will result into an energy threshold of about 10 PeV (compared to IceTop's 1 PeV), and provide an order of magnitude higher exposure in the energy range of the transition from Galactic to extragalactic sources. The described characteristics for the array design are guided by the performance of the on-going upgrade and simulations. We note that, should sufficient space be granted in the white paper submissions, the technical and scientific content described in this NOI would be combined with that of the coordinated IceCube and IceCube-Gen2 Observatory submissions.

Web link:

Name: Aaron Parsons

Proposing Team: HERA Collaboration and EDGES Team

Type of Activity:
Ground Based Project
Technological Development Activity

Description: The 21-cm signal of neutral hydrogen in the intergalactic medium at high redshift (z=6-30) is a promising probe of the large-scale structure and ionization state of the early Universe. Currently funded projects are measuring the global average (e.g. EDGES) and power spectrum (e.g. HERA, LOFAR, MWA) of this signal over the period when the first luminous objects formed (the Cosmic Dawn; z~30-12) and ionized hydrogen in the intergalactic medium (the Epoch of Reionization; z~12-6). In the 2010 decade, first-generation 21-cm instruments have pushed into the high-redshift frontier, providing first constraints, tantalizing detections, and significant technical advancements. HERA, the largest US effort in this area, is funded through 2023, and aims both to measure the 21-cm power spectrum during reionization and act as a platform for further development. Looking forward, improving measurements of the cosmological 21-cm signal and realizing science goals such as, e.g. direct imaging and cross-correlation studies, will require an on-going development program. Next-generation instruments are likely to need improvements in hardware, software, and analysis. We propose a mid-scale technical development program for exploring the Cosmic Dawn and Epoch of Reionization through ground-based radio-frequency instrumentation in the 2020s. The science goals of this program are 1) improving measurements of the global 21-cm signal through the Cosmic Dawn and Epoch of Reionization, 2) directly imaging the 21-cm field during the reionization for cross-correlation science, and 3) measuring the statistics of the 21-cm emission during the Cosmic Dawn. Technical development toward each of these goals targets concrete technical breakthroughs that can form the basis for next-generation mid-scale instruments that may be proposed late in the decade. Integral to this roadmap is the use of existing instruments and new technical demonstrators to validate performance in real-world applications. Comparing these metrics to performance specifications will determine when new mid-scale projects are proposed. The outcome of these comparisons are signposts that will determine the path taken through a proposed decision tree for choosing when projects are mature enough to propose, and whether projects are best pursued independently, as a unified US-led instrument, or as part of a larger international effort (e.g. the SKA).

Web link:

Name: Shelley Wright

Proposing Team:

Type of Activity:
Ground Based Project
Technological Development Activity

Description: PANOSETI (Pulsed All-sky all-time Near-infrared Optical Search for Extraterrestrial Intelligence) is a dedicated SETI facility that will offer a dramatic change in the landscape of technosignature searches and detection of astrophysical transients. This program aims at developing an "all-sky" optical and wide-field near-infrared pulsed SETI experiment that is capable of surveying the entire northern hemisphere. The optical component will cover a solid angle 3 million times larger than current targeted SETI searches, while also increasing dwell time per source by a factor of 10,000. PANOSETI will be the first near-infrared wide-field SETI program ever conducted. One primary goal of PANOSETI is to implement detection methods for pulsed transients and variable sources over 10 decades: nanosecond to seconds. The rapid technological advance of new fast-response optical and near-infrared detector arrays (i.e., Multi-Pixel Photon Counting; MPPC) make this program now feasible. Our design utilizes an array of Fresnel lenses, which are advantageous light-collecting apertures since their point-source spot sizes match our detector pixel sizes, and they are capable of imaging large areas of the sky at low cost. We plan to construct a geodesic dome populated with ∼100 Fresnel (0.5m) modules with fast-response detectors. The current design for optical wavelengths has each Fresnel module achieving a field of view of 9deg × 9deg with 20 arcminute per pixel, so the total geodesic dome of lenses will achieve an instantaneous sky coverage of >8,500 square degrees. Current astronomical wide-field sky surveys have poor sensitivity to optical transients or variable sources with a duration less than a second, as most sky surveys utilize low-noise (CCD or CMOS) cameras that integrate for several minutes or longer. In addition, typical instantaneous fields of view of transient surveys (e.g., Pan-STARRS, Zwicky Transient Factory, LSST) are ∼ 10 - 50 sq.degrees, with a minimum time resolution of seconds-to-minutes. There is a largely unexplored phase space of sub-second optical and near-infrared pulse widths that is perfectly suited for a technosignature survey and will enable potential new discoveries of astrophysical transient and variable phenomena. Optical and infrared SETI instrumentation that explores the very fast time domain, especially with large sky coverage, offers a prime opportunity for new discoveries that complement Multimessenger and time domain astrophysics. The PANOSETI instrument concept is therefore unique and is expected to come on-line in the next five years, offering a timely window of coupling SETI searches with multi-wavelength astrophysical fast-transient surveys.

Web link: https://oirlab.ucsd.edu/PANOSETI.html

Name: Russell Genet

Proposing Team: Russell Genet (California Polytechnic State University), David Rowe (PlaneWave Instruments), Cullen Blake (University of Pennsylvania), Rachel Freed (Institute for Student Astronomical Research), Edward Gomez (Las Cumbres Observatory), Dan Gray (Sidereal Technology), Gregory Henry (Tennessee State University), David Sliski (University of Pennsylvania), Mark Trueblood (Winer Observatory), and others in the process of joining the team

Type of Activity:
Ground Based Project
Technological Development Activity

Description: Arrays and networks of identical robotic telescopes have now been operating for three decades. Their history and current status provide the basis for considering their future evolution and potential contributions to research over the next decade. Local robotic telescope arrays can be assigned to one of three categories: (1) independent telescope arrays that are sited together and are installed and maintained as a group for reasons of economy, but are otherwise operated independently (Fairborn Observatory and MEarth); (2) summative arrays that combine observations incoherently to improve S/N (MINERVA); and (3) coherent arrays that combine observations to improve resolution (CHARA and NPOI). Unlike local arrays, networks of robotic telescope are distributed geographically to provide continuous, time-series coverage (Las Cumbres Observatory). Recent technical advances in modest-aperture robotic telescopes—reverse-engineered from large mountaintop telescopes—have resulted in the quantity production of smaller (up to 1-m) compact robotic telescopes with alt-az mounts, Nasmyth ports, and direct drives. Future versions of these production alt-az research telescopes may have larger apertures (1.5- and 2.0-m) and incorporate tip/tilt secondaries. If high resolution is not required, summative arrays of smaller robotic telescope can compete with large single telescopes in areas of "photon hungry" research (photometry and spectroscopy), thanks to the cost-versus-aperture and cost-versus-production-quantity scaling laws which favor an array of telescopes with the same equivalent aperture as a single larger telescope (thus providing the same number of photons at lower cost). For instance, an array of four 2-m robotic telescopes costs considerably less than one 4-m telescope. Such arrays, with a single command, can be transformed from four independent 2-m telescopes to one summative 4-m telescope. The effectiveness of large-aperture ground and space telescopes in the next decade (LSST, LIGO, ZTF, and TESS) will be enhanced by the supportive observations of expanded arrays and networks of robotic telescopes. A continued trend toward lower initial, operational, and support costs and the larger apertures of these production robotic telescopes should make high-quality observations affordable to a larger number of professional, student, and citizen scientist researchers. We should aim, over the next decade, for a synergistic balance between large single telescopes and the arrays and networks of smaller telescopes that will, together, produce the best science.

Web link: N/A

Ground Based Projects

Name: Steven Kahn

Proposing Team: LSST Project Science Team

Type of Activity:
Ground Based Project

Description: The LSST Project Science Team is a collection of senior scientists with major personal roles in the LSST construction. As such, they bring expert technical knowledge of the details of the design and performance of the LSST system. Our intended white paper will provide our present thinking regarding various options for the use of the LSST facility after the completion of its ten-year operational phase. These will include: (a) continuing to operate the facility as is for an extended mission; (b) relatively modest updates/improvements to the instrumentation; and (c) more extensive modifications, such as replacement of the camera with another instrument. Our intent is not to advocate for one or more of these options, but to summarize the principal technical considerations that must be taken into account.

Web link: www.lsst.org

Name: Anthony Beasley

Proposing Team: ngVLA Project Team - NRAO/AUI

Type of Activity:
Ground Based Project

Description: The National Radio Astronomy Observatory (NRAO) has engaged the broader U.S. and international scientific and technical community in the design of a next-generation Very Large Array (ngVLA), an astronomy infrastructure project under development for the National Science Foundation - Astronomical Sciences Division (NSF/AST). The ngVLA will be a radio interferometric array with 10x the sensitivity and spatial resolution of the current VLA and ALMA, operating in the frequency range of 1.2-116 GHz. It will open new windows on the Universe through ultra-sensitive imaging of thermal line and continuum emission down to milliarcsecond resolutions, and unprecedented broadband continuum polarimetric imaging of non-thermal processes. These capabilities are urgently needed to advance critical areas in modern astronomy through, e.g., the direct imaging of planet formation in terrestrial zones, studies of dust-obscured star formation and the cosmic baryon cycle, building a census of molecular gas back to cosmic reionization, and discovery/follow-up of transient phenomena on timescales from milliseconds to years in the rapidly growing era of multi-messenger astronomy. ngVLA capabilities will be optimized in the spectral region between the superb performance of ALMA in the sub-mm, and the planned SKA-1 at decimeter or longer wavelengths, resulting in a transformational instrument for the U.S. and global scientific communities. The observatory will be a synthesis radio telescope including approximately 244 reflector antennas, each of 18 meters diameter, and 19 reflector antennas each of 6 meters diameter, operating in a phased or interferometric mode. The facility will be operated as a proposal-driven instrument with the science program determined by Principal Investigator (PI)-led proposals. Data will generally be delivered to PIs and the broader scientific community as Science Ready Data Products – automated pipelines will calibrate raw data and create higher level data products (typically image cubes) – that will be made available through an observatory science archive. Data exploration tools will allow users to analyze the data directly from the archive, reducing the need for data transmission and reprocessing at the user's institution. The ngVLA project is presently in the development and early conceptual design phase. The project intends to advance to NSF MREFC candidacy, formal design, and eventual construction through demonstrated strong community support for the science enabled by the ngVLA, a technically realizable design, and a defensible cost estimate. The project schedule advances the design through 2024, with construction starting in 2025, early science commencing in 2028, and a transition to full operations by 2034. In consultation with the NSF, the NRAO will continue to engage the astronomical community to obtain further consensus on the needs, priorities, and requirements for the proposed telescope. A key opportunity to showcase ngVLA alignment with community priorities is through the exploration of ngVLA scientific goals and open review of our development and design efforts at the Astro2020 Decadal Survey. We look forward to presenting our project progress and the compelling science enabled by the ngVLA as the Decadal Survey conducts both the scientific review and CATE process for projects.

Web link: http://ngvla.nrao.edu/

Name: Greg Taylor

Proposing Team: on behalf of the LWA project

Type of Activity:
Ground Based Project

Description: The first station of the Long Wavelength Array (LWA1) became operational in November 2011, and provides unique capabilities to the US community between 10 and 88 MHz (Taylor et al. 2012, JAI, 1, 50004; Ellingson et al. 2013, IEEE Transactions on Antennas and Propogation, 61, 2540). With support from NSF and AFRL the LWA1 has been operated as a University Radio Observatory with regular calls to the community for observing proposals. With funding from the Air Force Office of Scientific Research, we built and commissioned a second LWA station at the Sevilleta National Wildlife Refuge (LWA-SV) 70 km NE of LWA1. To date 125 investigators from over 40 institutions have made use of the LWA facilities, and have authored 60 refereed papers. We can also combine the LWA1 and LWA-SV with the Very Large Array (VLA) of the National Radio Astronomy Observatory (NRAO) for a factor of 360 improvement in resolution, and a factor of 5 improvement in sensitivity over the stand-alone LWA1. This new instrument, known as the Expanded LWA (ELWA), provides 10 arcsecond resolution and 10s of mJy sensitivity, greatly expanding the scientific capability. We propose to further develop the Long Wavelength Array (LWA) swarm telescope concept (Dowell & Taylor 2018, JAI, 7, 1850006) that will produce a powerful instrument for investigating the Universe and engaging students at Universities and Colleges across the US. The swarm concept is to place LWA mini-stations of 48 dipoles along with full stations of 256 dipoles at interested colleges and Universities across the continental US. The highly regarded decadal surveys of prospective research are recommending telescope arrays that have significant capabilities, but also overwhelming complexity and costs. These barriers result in black-box instruments where students have little opportunity to understand the inner workings. We are exploring a novel model for realizing a continental scale telescope array that is much more accessible to students. This will energize a multi-disciplinary community, and result in increased opportunities for students to learn about instrumentation as well as science. At the same time, this will also result in a powerful instrument, the Long Wavelength Array swarm, for exploring the Universe at low frequencies. The exploration of this electromagnetic window has recently led to a bonanza of exciting scientific results including the discovery of cosmic dawn, new types of radio transients, and new insights into pulsars.

Web link: lwa.unm.edu

Name: Gregg Hallinan

Proposing Team:

Type of Activity:
Ground Based Project

Description: The DSA-2000 will be a world-leading radio survey telescope and multi-messenger discovery engine for the US community. As an evolution of the 110-antenna DSA-110, the array will consist of 2000 x 5 m dishes instantaneously covering the 0.7 – 2 GHz frequency range. The DSA-2000 will be the first true radio camera, outputting science-ready image data with a spatial resolution of 3.5''. It will have equivalent point-source sensitivity to the SKA-mid array, but with ten times the survey speed (equivalent to >500x the current VLA survey speed), and is envisaged as a survey instrument in advance of the ngVLA, and as a counterpart survey instrument to the LSST. In a five-year prime phase, the DSA-2000 will image the entire viewable sky (~30,000 deg2) repeatedly over sixteen epochs, detecting >1 billion radio sources in a combined full-Stokes sky map with 500 nJy/beam rms noise. As a radio survey instrument it will be unprecedented relative to any instrument existing or planned. Continuum survey data will trace star-formation and accretion back to the epoch of reionization, uniquely unaffected by dust obscuration, and will provide a new window on stellar activity and compact object physics in our own Galaxy. A billion source radio catalog will be a powerful cosmological tool, particularly when combined with other multi-wavelength data, and can be used to measure the dark energy equation of state, constrain primordial non-Gaussianity, measure the cosmic radio dipole, investigate cosmic magnification bias and potentially measure weak lensing. The array will revolutionize the field of radio transients, with >105 transients detected in each epoch with accompanying spectro-photometry for characterization and excellent localization for host galaxy identification. High-spectral resolution (24 kHz; ~5 km/s at 1.4 GHz) all-sky and deep field image cubes will enable resolved HI kinematics and morphologies for galaxies out to redshift z~0.5, tracing the role of gas inflow in star formation on all scales and probing the gaseous interface and accretion physics between galaxies and the IGM. This includes tracing the gas content in our own Milky Way to unprecedented detail. These same data will provide a map of galaxies in the local volume with a range of applications from detection of the Integrated Sachs-Wolfe Effect to providing a reference catalog for localization of nearby gravitational wave events. In addition, the array will be a cornerstone for multi-messenger science, serving as the principal instrument for the US pulsar timing array community, and by searching for radio afterglows of compact object mergers detected by LIGO and Virgo. The array will simultaneously detect and localize ~103- 104 FRBs each year, realizing their ultimate use as cosmological tool. Previous and planned radio surveys (NVSS, FIRST, VLASS) have had immense and sustained impact on US astronomy. The DSA-2000 represents a transformation of the radio survey paradigm, with potential impact and science return comparable to that ushered in by the Sloan Digital Sky Survey (SDSS). If constructed, it will change the course of radio astronomy in the US, providing a data set easily accessible to the entire astronomical community.

Web link:

Name: Shri Kulkarni

Proposing Team: Vikram Ravi & Jens Kauffmann

Type of Activity:
Ground Based Project

Description: Observations of explosions at early times provide some of the best clues to the progenitor and to the physics of explosions. In fact, it is now routine for prompt observations to be undertaken at X-ray, UV and optical wavelengths. In the radio band such observations have to be undertaken at high frequencies owing to synchrotron self absorption or free-free absorption. The US has a number of facilities which, if coordinated, can provide a world-class facility for these unique observations. Our white paper will be written in consultation with key players of high frequency radio facilities.

Web link:

Name: Terry Herter

Proposing Team: CCAT Consortium

Type of Activity:
Ground Based Project

Description: CCAT-prime is a 6-m, off-axis, low-emissivity, large field-of-view submillimeter telescope that is being independently funded and built by a consortium consisting of Cornell University, a German partnership of three institutions led by the University of Cologne, and a Canadian partnership of eight institutions led by the University of Waterloo. It will be located at 5600-m on Cerro Chajnantor in the Atacama Desert of Northern Chile. First light will occur in the last quarter of 2021. CCAT-prime delivers an extraordinarily wide diffraction-limited field-of-view: from 2 deg. in diameter at 860 GHz (0.35 mm) to 8 deg. at 100 GHz (3 mm). CCAT-prime will have two first light instruments, a multiband wide-field camera with both a broadband camera and narrow band imaging spectrometer, and a multi-beam heterodyne spectrograph. Planned science investigations will include the following: - Trace the formation and large-scale three-dimensional clustering of the star-forming galaxies from the epoch of reionization through "cosmic noon" through wide-field spectroscopy using the [CII] 158-micron line; - Constrain feedback mechanisms and test cosmological simulations by measuring the thermodynamic properties of galaxy clusters via the Sunyaev-Zel'dovich effects on the cosmic microwave background (CMB); - Measure CMB Rayleigh scattering for the first time to improve constraints on new particle species, and characterize polarized dust foregrounds that limit constraints on inflation; - Investigate the matter cycle from the assembly of clouds to star formation and feedback in the Milky Way and nearby galaxies using the submillimeter [CI] lines to trace the CO dark molecular gas, and mid-J CO lines to trace the warm, active molecular gas in regions of turbulent dissipation and feedback.

Web link: http://www.ccatobservatory.org/

Name: Benjamin Monreal

Proposing Team:

Type of Activity:
Ground Based Project

Description: Each of the ELT-class telescopes under construction in the 2020s carries a price tag above $1B. Although these are on the low end of costs once extrapolated from fitting power laws to historical telescope budgets, but do not leave the field with an encouraging path forward. The ELTs do not have the resolution and planet-imaging power of an OWL-class telescope, and at the same time they are not really testbeds for technologies that might be affordable at OWL scale in the future. In 2018 we proposed a telescope mount/configuration called WAET (Wide Aperture Exoplanet Telescope) which aimed to use familiar technologies in a configuration with an intrinsically favorable cost scaling law. WAET telescopes have a very long, narrow filled aperture, with one axis stretched (say 100--300m) for high-resolution science, and the other axis only wide enough (say, 2--6m) for adequate light collection. This aperture shape is particularly well suited for exoplanet direct imaging and spectroscopy, since separating a planet from its host starlight is essentially a one-dimensional problem, and systems are sufficiently often aligned with the telescope's one good axis. Rather than having an alt-az mount of the whole telescope structure, WAET has a one-degree-of-freedom tiltable siderostat placed in front of the one-degree-of-freedom sliding primary---the optical equivalent to the Kraus-type radio telescope, but with more capable pointing. Our paper showed that these mounts are intrinsically low-cost and scaleable, leading to observatories dominated by the costs of primary mirror cells. Moreover, the design is intended to have low technical risk and can utilize familiar optical design, segmentation plans, cophasing, etc.; indeed most mirror/mount engineering issues appear far easier than the corresponding problems in alt-az mounts. The familiar/already-solved nature of most of WAET's components allows us to make early cost estimates with some confidence. For example, applying Keck-like primary mirror costs to 100 m x 2 m instrument (called "hWAET") yields a $155M construction cost estimate; a riskier design---using OWL-based cost estimates for a spherical primary---reaches 300 m x 5 m ("kWAET") at a cost of only $280M. In contrast to the 20-year design and construction lifetime of EELTs, we argue that discovery-ready WAET telescopes at the 100~m scale can be realized quickly, both due to the funding profile and the engineering simplifications. In this whitepaper, we will review the general concept for WAET-mounted telescopes; suggest three specific examples for possible implementation, and estimate the science reach of each; and review what we see as the key sources of design, performance, and cost uncertainty. We will suggest followup design studies which could answer these questions in the early 2020s and permit us to begin constructing 100+ meter telescopes before 2030.

Web link: http://www.phys.cwru.edu/~bmonreal/waet.html

Name: Nicholas Scott

Proposing Team:

Type of Activity:
Ground Based Project

Description: Dust is common throughout stellar systems. The architecture of stellar systems may be typically composed of a distant cold debris disk (< 100K), a warm exozodiacal disk (≈ 300K), and a hot inner dust disk (1000K or more). Hot dust, near the sublimation temperature of 1400K for silicates, is rare in photometric surveys of Sun-like stars, but interferometric surveys have resolved warm/hot dust around a large fraction of stars observed (about 20% of main sequence A-K, Absil et al. 2013, Ertel et al. 2014). This is surprising because most cold debris belts detected are collisionally dominated, mutual collisions in planetesimal belts grind the dust down to blowout size before the P-R drag effect has a chance to operate. Infrared interferometry has provided the first unambiguous resolved detections of hot dust around main sequence stars (Absil et al. 2006), showing an unexpectedly dense population of (sub)micrometric dust grains close to their sublimation temperature. A comprehensive picture of the nature of these inner warm and hot dust components is of specific interest to future exoplanet detections. The origin and composition of dust in the sublimation region and its relation to other reservoirs of dust is of particular interest for planetary formation models. As found in the case of Fomalhaut (Lebreton et al. 2013, Su et al. 2016), there is likely a connection between these hot interferometrically detected dust disks and the harder to detect warm exozodiacal dust in the habitable zone. In this way, near-infrared (NIR) interferometric studies can observe the tip-of-the-iceberg of stellar systems exozodiacal dust, providing details such as composition and grain size of dust, as well as statistics on the correlation of dust populations and stellar properties. Inner dust regions may exhibit a high degree of variability, and detecting such variability on short timescales may reveal the dust origin and replenishment. Models suggest that dust located in the region where NIR disks are found has a removal timescale on the order of a few years (Wyatt 2008). For many such systems the Keplerian orbits are on the order of weeks. The dust must be continually replaced (unlikely, e.g. Wyatt et al. 2005, Lebreton et al. 2013) or its production is a punctuated chaotic bombardment fueled by asteroid collision or comet infalls. The bombardment model suggests that these systems with debris disks are undergoing a several million year period of instability wherein comets and rocky bodies are colliding and infalling, producing dust. This would lead to variability in the density of the disk and thus a variation in the flux. A third model describes nano-grains trapped in the host star's magnetic field (Rieke et al. 2016).. Our group is currently involved with the CHARA Array, VLTI, and LBTI to study inner dust disks with high precision. Interferometry provides the angular resolution necessary to directly detect near-infrared (NIR) excesses originating within 1 AU of the star. The JouFLU beam combiner at the CHARA Array has been capable of measuring interferometric visibility to a very high precision (mean calibrated visibilities of 1-2% with 0.1% possible), providing high dynamic ranges at small angular separations. The capability of CHARA/JouFLU to study this inner region to such high precision is unique in the Northern Hemisphere. Stars known from the (Absil et al. 2013) exozodiacal disks survey to have a K-band excess and the earlier (di Folco et al. 2007) and (Absil et al. 2008) surveys provides coverage over a long time span that could be used to search for variations in the disks. Comparing the new visibility measurements of the disks to the early data collected by the survey has suggested that in some cases these exozodis are highly variable. An observing campaign to revisit the systems has shown variability on the order of weeks for some targets. This science case, motivates a new project to improve JouFLU in order provide better sensitivity (K>=5), accuracy (sigma V= 0.1%), and spectral resolution (R=5 to R=50) by replacing the aging fiber combiner with integrated optic components and the NICOMS detector with a modern NIR system. Thereby preserving and improving the existing CHARA high precision interferometric capability in the Northern Hemisphere in the interest of constraining exozodi over a broader range of wavelengths than currently available. If the hot dust phenomenon is indeed a signpost of ongoing bombardment by large cometary bodies that can potentially strip a planetary atmosphere or replenish it with volatiles, its detection would have serious implications for the architecture of exoplanetary systems and habitability of any inner rocky planets.

Web link:

Name: Douglas Gies

Proposing Team:

Type of Activity:
Ground Based Project

Description: We are planning an expansion of the Georgia State University Center for High Angular Resolution Astronomy (CHARA) Array to expand the horizon of milliarcsecond astronomy. The CHARA Array is an optical/IR long baseline interferometer located at the Mount Wilson Observatory in California. The Array consists of six, 1 meter telescopes in a Y-configuration with baselines up to 330 meters, the largest available in the world. With its suite of beam combiners, the Array can measure the angular diameters of stars (including exoplanet host stars), their surface features, their circumstellar environments, the motions of hitherto unresolved binary stars, and the inner regions of Active Galactic Nuclei. The CHARAx2 plan envisions an expansion to eight, 2 meter class telescopes. This addition will more than double the resolving power, number of baselines, number of closure phases, and telescope aperture size at the CHARA Array. The plan will enable studies of fainter and more distant targets while providing the sensitivity to map stellar surface features in unprecedented detail and explore their magnetic, convection, and mass loss properties. The project will be directed by GSU in conjunction with the CHARA Collaboration that includes the University of Michigan and the National Optical Astronomy Observatory. However, the CHARAx2 program will provide community access to the telescopes and beam combiners through the NOAO peer-review system, so it will serve as a national facility for users. In addition, software and pipelines will be developed to allow non-experts to pursue easily imaging and other investigations of stars and their environments. The CHARA Array expansion will provide the community with outstanding opportunities for research in high angular resolution astronomy and will help foster expertise in high angular resolution methods in the next generation of astronomers.

Web link: www.chara.gsu.edu

Name: Christoph Baranec

Proposing Team:

Type of Activity:
Ground Based Project

Description: Large area surveys will dominate the next decade of astronomy, and the main limitation to science will be the thorough followup and characterization of their extremely numerous discoveries. The deployment of robotic laser adaptive optics on our nations mid-sized telescopes will be crucial for the sensitive and rapid characterization of these survey targets. The soon to be commissioned Robo-AO-2 system on Maunakea will combine near-HST resolution imaging across visible and near infrared wavelengths and will enable high-acuity, high-sensitivity follow-up observations of several tens of thousands of objects per year. Robo-AO-2 will also respond to target-of-opportunity events within minutes, minimizing the time between discovery and characterization, and will interleave different programs with its intelligent queue. We also look forward to future systems such as the Rapid Transient Surveyor that will provide additional adaptive optics assisted integral field spectroscopy - and can be replicated for modest-sized facilities around the world.

Web link: http://robo-ao.org

Name: Tim Bastian

Proposing Team: For design and implementation planning: T. Bastian, B. Chen, D. Gary, C. Lonsdale, P. Saint-Hilaire, J. McTiernan, D. Wertheimer, V. Pillet, S. White, G. Hallinan, S. Weinreb

Type of Activity:
Ground Based Project

Description: A project white paper will be submitted to Astro2020 on a next-generation radioheliograph, a ground-based, solar-dedicated, radio telescope designed to perform ultra-broadband imaging spectropolarimetry, better known as the Frequency Agile Solar Radiotelescope (FASR). FASR will image the Sun from roughly 50 MHz to 20 GHz, or at wavelengths spanning 1.5 cm to 6 m. The emission at these wavelengths originates at heights ranging from the middle chromosphere up into the corona as much as several solar radii above the photosphere. In essence, FASR will image the solar atmosphere in 3D and will do so on time scales commensurate with the physical processes that occur there – as short as 10 ms but more typically 1 s. In other words, for each pixel of a radio image of the Sun, the polarized radio spectrum will be measured as a function of time. Alternatively, thinking in terms of a dynamic spectrum – a record of polarized intensity as a function of time and frequency – an image is available for every frequency-time bin. Such measurements enable a number of powerful diagnostics to be brought to bear on outstanding problems of interest: - Chromospheric and coronal magnetic fields: FASR will exploit unique diagnostics to make quantitative measurements of chromospheric and coronal magnetic fields under both quiet conditions and, uniquely, during solar flares and coronal mass ejections, both on the solar disk and above the limb. - Non-radiative heating of the chromosphere and corona: FASR will constrain chromospheric and coronal heating mechanisms – by nanoflares and/or resonant wave heating – through detailed magnetic, density, and electron temperature measurements of the solar atmosphere. - The physics of solar flares: FASR is extremely sensitive to nonthermal radio emission from energetic electrons and coherent radio bursts. It will localize and characterize the site(s) of magnetic energy release and the spatiotemporal evolution of the electron distribution function in flares, placing powerful constraints on acceleration and transport mechanisms. - The science of space weather: FASR will be sensitive to the eruption of coronal mass ejections, the shocks they produce, the associated radio bursts, and the associated solar energetic particles (SEPs). As a 3D imager, FASR will observe space weather drivers as a coupled system. Each of these broad elements of FASR science is also relevant to fundamental questions in astrophysics: magnetic energy release, particle acceleration, shocks. They are also relevant to specific branches of astrophysical inquiry: late-type stars, magnetic activity, exo-space weather, and the habitability of exoplanets. Measurements by FASR will be highly complementary to O/IR measurements by instruments like the Daniel K. Inouye Solar Telescope (DKIST) or the Solar Coronal Magnetism Observatory (COSMO). Coronal magnetic measurements by DKIST and COSMO will only be possible above the solar limb. FASR will make coronal measurements of magnetic field both above the limb and on the solar disk. FASR will also be highly complementary to space-based instruments like the Solar Dynamics Observatory/Atmospheric Imaging assembly, which images thermal plasma in discrete temperature ranges. FASR will image the spatiotemporal evolution of emission from nonthermal electrons from keV to MeV energies. With the recent loss of the Ramaty High Energy Solar Spectroscopic Imager (RHESSI) mission, which performed imaging spectroscopy at hard X-ray and gamma-ray wavelengths, there is no current or planned mission that will span the energy range that FASR will observe. FASR will have a rather direct societal impact through its study of the science of space weather. In fact, FASR will contribute directly to two of the five critical phenomena identified by the NSTC/OSTP Space Weather Operations, Research, and Mitigation Subcommittee - solar radio bursts and ionizing radiation (SEPs). It has strong potential to contribute to research to operations (R2O) elements of space weather forecasting as well as respond to operational imperatives (O2R). FASR has been considered by previous decadal surveys, both in astronomy and astrophysics, and in solar and space physics. It has received a high ranking every time, including a number one ranking for "small" projects by the solar and space physics decadal. It was reviewed by the CATE process in Astro2010 and was described as "doable now". However, as a mid-scale ground-based project, NSF has not had an appropriate funding mechanism in place to enable construction. That has now changed. The team has submitted a proposal to the new NSF Mid-scale Research Infrastructure RI-1 opportunity to update the design and to develop a project execution plan. A proposal for funding FASR construction will then be submitted through the NSF Mid-scale Infrastructure RI-2 opportunity in approximately three years.

Web link: coming

Name: Miguel Mostafa

Proposing Team: GRAND Collaboration

Type of Activity:
Ground Based Project

Description: The Giant Radio Array for Neutrino Detection (GRAND) aims to answer one of the most important questions in astrophysics: what is the origin of ultra-high-energy (UHE) cosmic rays? It will achieve this, indirectly, by looking for ultra-high-energy neutrinos and UHE gamma rays; and directly, by collecting large numbers of UHE cosmic rays. GRAND has been designed to discover and study the sources of neutrinos with energies exceeding 10^17 eV, even in the most disadvantageous scenarios, in which the neutrino flux is two orders of magnitude below current upper limits. More specifically, the projected sensitivity of GRAND for neutrinos is ~4x10^-10 GeV cm^-2 s^-1 sr^-1; i.e., about 10 times better than other planned instruments. Moreover, the sub-degree angular resolution will allow GRAND to search for point sources, both steady and transient, and perform UHE neutrino astronomy. GRAND will be the largest cosmic-ray detector, with a detection rate of UHE cosmic rays 20 times larger than currently operating experiments. Already within its first 3 years, GRAND will be competitive for the measurement of the cosmogenic UHE gamma-ray flux regardless of the composition of UHE cosmic rays. GRAND goals also include studying fundamental neutrino physics, astrophysical radio transients, and the cosmic epoch of reionization. GRAND will be a leading-edge instrument for astronomy and cosmology. The large sky coverage, high duty cycle, and stringent background rejection will allow to discover large numbers of astrophysical radio transients, such as fast radio bursts and giant radio pulses, and the 21-cm signal from the epoch of reionization. Thus, GRAND will facilitate not only the study of UHE cosmic-ray sources, but also of the cosmic radio background, and of the opacity to UHE gamma rays. When searching for UHE neutrinos, cosmic rays, and gamma rays, the strategy of GRAND is to detect the coherent radio emission (in the 50-200 MHz range) coming from extensive air-showers produced by the interaction of cosmic particles of energies above 10^17 eV with the Earth's atmosphere. GRAND will profit from the renaissance experienced by the field of radio detection thanks to drastic technological, theoretical, and numerical advances. It will take active part in the development of the radio technique and make exquisite autonomous measurements of radio emissions from inclined particle air-showers. The GRAND project consists of several stages, separated in time and scope, ultimately leading to the creation of the GRAND observatory. The GRAND observatory will be a distributed experiment consisting of several arrays of detectors, each with ~10,000 antennas over an area of approximately 10,000 km^2, summing up to a combined size of 200,000 antennas over 200,000 km^2. The stages of the project will be used to optimize the technical layout of the observatory, as well as to jump-start its scientific output. Several sites in China fulfill the design requirements, making it the leading candidate to host GRAND. This is where the prototyping stages of GRAND will be deployed. In parallel, the Collaboration is evaluating the deployment of GRAND sub-arrays in several other locations around the world. Currently, the Collaboration is focusing on the pathfinder stage called GRANDProto300, which will collect large numbers of cosmic rays in the energy range 10^16.5-10^18 eV, where the transition between Galactic and extragalactic sources should happen. GRANDProto300 will consist of a 300-antenna array over 200 km^2, aiming to demonstrate the autonomous radio-detection technique, in particular for inclined air-showers. The array of antennas will be complemented by muon detectors which will boost the accuracy of the primary cosmic-ray observables, and cast light on the muon discrepancy issue at these energies.

GRANDProto300 is expected to be deployed in 2021, in the Qinhai province in China. Many high-precision high-energy astroparticle experiments are projected to be built in this new multi-messenger era. GRAND completes the picture at the highest energy front. The GRAND Collaboration consists of approximately 50 scientists from 12 countries. The Collaboration includes experts in radio detection (mechanics, low-noise amplifiers, electronics, power harvesting), communications (layout, protocol, antennas, electronics), central data acquisition (trigger formation, run control, event building), monitoring (monitoring hardware, sensors, slow control, alarm system), theory (modeling, scientific motivation, sensitivity calculations, simulations), and outreach.

Web link: http://grand.cnrs.fr

Name: Pamela Klaassen

Proposing Team: Tony Mroczkowski, Claudia Cicone, James Geach

Type of Activity:
Ground Based Project

Description: Observations in the sub-millimeter/millimeter wavelength range reveal the properties of many phases of baryonic matter. Single dish telescopes at these wavelengths are able to recover these often large scale structures, from the Cosmic Microwave Background (CMB) right through to our own Solar System. Large (e.g. 50-m class) single dish telescopes with large fields of view can achieve this with significantly lower confusion limits than current single dish telescopes, and are extremely complementary to powerful sub-mm/mm interferometers such as ALMA that can deliver highly detailed studies but cannot map large-scale structures or perform new large surveys to open up discovery space. A wide-field photometric and spectroscopic survey of the (sub-)mm sky is the most powerful tool to probe galaxy evolution, from Cosmic Dawn to the present day, local, Universe. In the sub-mm, galaxy populations can be mapped in 3D, jointly tracking the co-moving evolution of star formation and their molecular reservoirs across the bulk of cosmic time. Such a telescope is also uniquely capable of capturing, and following, the cycling of warm and cold baryons in and out of galaxies across scales of several arcminutes (100's of kpc), a process that, despite being crucial to galaxy evolution, has so far remained observationally elusive. It would provide a powerful, ground-based view of the warm/hot, ionized gas in large scale structures such as galaxies, groups, and clusters through observations of the Sunyaev-Zel'dovich effect.More locally, whether through determining how unique our Edgeworth-Kuiper belt is, learning about the variable nature of star formation, or shaping our general understanding of the properties of cool molecular gas,dust, magnetic fields, and hot ionized gas in our Galaxy, there are many unique science drivers for a 50m class single dish telescope capable of spanning this wavelength range. The Atacama Large Aperture Submillimeter Telescope (AtLAST) aims to fill this wavelength-science gap, bringing at least 1 degree squared field of view and covering frequencies from 35 to 950GHz (roughly 8-0.3 mm, to complement the ALMA bands), and allowing high sensitivity observations of the full (sub-)mm sky across multiple spatial scales. We envision AtLAST to be an international partnership operating a facility telescope with an instrument suite providing high-resolution multi-beam spectroscopy, ultra-wideband wide-field spectroscopy for lower spectral resolution mm/sub-mm tomography, and ultra-wide-field multi-chroic polarimetric imaging capabilities. We expect this (dome-less) facility could be built within 15 years, and to last at least 30, based on the lifetimes of current mm and sub-mm telescopes (e.g. IRAM 30m and JCMT). Building on the legacies of the modern deep and wide Galactic and extragalactic surveys, from radio wavelengths to x-ray, we are entering a golden age of survey science, with missions such as the SKA, SPICA, SPHEREx, eROSITA and LSST coming online in the next 5-15 years. And while ALMA can follow-up many of the discoveries from these facilities in exquisite detail, there is an important gap in survey capabilities at mm/sub-mm/Far-IR wavelengths. For this, a large (~ 50m) single dish telescope, with a significant instantaneous field of view, covering a wide wavelength range is required. Current single dish facilities are either too small, which results in high confusion limits, or too far north, resulting in significant mis-matches in observable sky with ALMA. All suffer from having too small a field of view for efficient mapping. Current interferometers, which will have significantly lower confusion limits, suffer from small fields of view and spatial filtering. To cover this wavelength range requires a high-elevation, dry location, such as the

Chajnantor plateau (~5000 meters above sea level), which has better sub-mm atmospheric conditions than most other sites on Earth, is more accessible than the South Pole, and, having the same sky accessible as ALMA, ensures ALMA follow-up campaigns will be possible for all regions observed with AtLAST.

Web link: atlast-telescope.org

Name: Daniel Eisenstein

Proposing Team: DESI Collaboration

Type of Activity:
Ground Based Project

Description: We plan to submit a white paper to describe the Dark Energy Spectroscopic Instrument (DESI). DESI is a major new spectrograph being built for the Kitt Peak National Observatory 4-m Mayall telescope, primarily through funding from the US DOE Office of Science High-Energy Physics division. DESI features 5000 robotically positioned fibers covering an 8 sq deg field of view, feeding a bank of mid-resolution high-throughput optical spectrographs. DESI construction is nearing completion, with on-sky commissioning expected late in 2019. The DESI Collaboration will then conduct a major galaxy/quasar redshift survey using 5 years of dedicated time. The survey is designed for the study of dark energy but the data set will be useful for a variety of science applications. The white paper will briefly summarize the current status and survey plans for DESI and then describe possibilities for continued DESI operations beyond the initial 5 year survey.

Web link: https://www.desi.lbl.gov

Name: Nepomuk Otte

Proposing Team:

Type of Activity:
Ground Based Project

Description: Trinity: An Air-Shower Imaging System for the Detection of Ultrahigh-Energy Neutrinos Trinity is a proposed air-shower imaging system optimized for the detection of earth-skimming tau neutrinos with energies between 10^7 GeV and 10^10 GeV. Trinity will pursue three major scientific objectives. The first one is to extend the measurement of the astrophysical neutrino flux by IceCube to higher energies. This will narrow in on possible sources of these neutrinos based on spectral features of the measured flux as well as the arrival direction of the detected neutrinos. The second objective is to find the sources of ultrahigh-energy cosmic rays (UHECR). Ultrahigh-energy neutrinos are generated through interactions of UHECRs with cosmic microwave background photons. The detection of these "cosmogenic" neutrinos provides a unique handle to study the origin and composition of UHECR. The third objective is to test fundamental neutrino physics at the highest energies. Trinity will image air showers from a mountain by collecting Cherenkov and fluorescence light, which is produced when a particle shower develops in the atmosphere. The technique is well established and widely used by the very high-energy gamma-ray community (CTA, H.E.S.S., MAGIC, and VERITAS) and the UHECR community (Telescope Array, Pierre Auger). The energy and the arrival direction of the shower-initiating particle can be reconstructed based on the recorded images within a few tens of percent and a fraction of a degree, respectively. The projected sensitivity of Trinity is comparable to that of proposed radio detectors like ARA, ARIANNA, GRAND, and RNO. A study of various configurations of Trinity can be found in an article submitted to PRD https://arxiv.org/abs/1811.09287. A preliminary list of participants is: Nepomuk Otte (Georgia Institute of Technology) Jim Adams (U. of Alabama-Huntsville) Roberto Aloisio (GSSI, Italy) Luis Anchordoqui (CUNY) Jim Beatty (U. of Ohio) Mario Bertaina (INFN, Italy) Francesca Bisconti (INFN, Italy) Anthony M. Brown (Durham University) Juan Cortina (CIEMAT, Madrid, Spain) Abe Falcone (Penn State U.) Jamie Holder (U. of Delaware) Eleanor Judd (LBNL) Philip Kaaret (U. of Iowa) Dave Kieda (U. of Utah) John Krizmanic (CRESST/GSFC/UMBC) Ivan De Mitri (INFN) Abelardo Moralejo (IFAE, Barcelona, Spain) Kohta Murase (Penn State U.) Angela Olinto (U. of Chicago) Mary Hall Reno (U. of Iowa) Marcos Santander (U. of Alabama) Frederic Sarazin (Colorado School of Mines) Floyd Stecker (GSFC) Ignacio Taboada (Georgia Institute of Technology) Lawrence Wiencke (Colorado School of Mines)

Web link:

Name: Petra Huentemeyer

Proposing Team: The Southern Gamma-ray Survey Observatory Alliance

Type of Activity:
Ground Based Project

Description: With the successful development of facilities for the detection of neutrinos and gravitational waves, as well as the deployment of next-generation gamma-ray detectors such as the Cherenkov Telescope Array (CTA), the next decade will provide a wealth of scientific opportunities in multimessenger astronomy. Studies of the non-thermal universe probe some of the most significant unresolved questions in astrophysics, including the location and properties of cosmic accelerators, transient astronomical events, the nature of dark matter, and searches for physics beyond the Standard Model. While CTA will be a powerful facility for the detection and high-precision measurement of sources emitting high-energy gamma rays between 10 GeV and 100 TeV, the broader astrophysics community recognizes that crucial support roles will be played by ground-based, high-duty cycle, wide-field gamma-ray facilities that continuously survey the sky in the space and time domain. This is a notice of intent to submit a white paper on a next-generation wide field-of-view survey instrument in the Southern Hemisphere sensitive to gamma rays and cosmic rays from tens of GeV to hundreds of TeV. This facility will build and improve upon the successful experience of the HAWC Gamma-ray Observatory, a survey instrument with nearly 100% duty cycle and large field of view. Located in Mexico, HAWC has discovered new TeV sources and source classes, set new world-leading limits on dark matter decay and annihilation, and played a crucial role in multi-messenger observations. HAWC's synergy with current and planned detectors such as IceCube, LIGO/Virgo, Fermi, and CTA has inspired an ambitious Chinese effort (LHAASO) in the Northern Hemisphere that uses a similar design. Recent discoveries such as a kilonova associated with merging neutron stars, a gamma ray burst with photons detected up to 300 GeV, and a detection of neutrinos from a flaring active galactic nucleus (AGN) all point to the need for a next generation all-sky instrument in the Southern Hemisphere. The pursuit of a Southern Hemisphere survey instrument brings together scientists with experience in many very-high energy observatories including HAWC, ARGO-YBJ, H.E.S.S., MAGIC, VERITAS, IceCube, Super-K, and Auger. A survey instrument provides daily unbiased monitoring of variable sources including nearby AGN and near-realtime alerts to other instruments. Its archival data set will enable studies of regions of the sky before and after alerts from other experiments are reported. Sensitivity to particle accelerators in the local Galactic neighborhood is one of the greatest strengths of a wide-field next-generation detector. The detection of very extended TeV gamma-ray emission around the pulsars Geminga and PSR B0656+14 has revealed that nearby pulsars likely strongly influence their surroundings, leading to an interpretation of this newly discovered emission as halos of TeV-scale gamma rays that are produced by electrons and positrons interacting with the ambient interstellar radiation field outside the classical pulsar wind nebulae. A wide-field-of-view ground array instrument is ideally suited to study the acceleration and propagation of particles within these halos in unprecedented detail. A next-generation VHE ground array will also uniquely contribute to the search for and study of sources of cosmic rays with energies in excess of 1 PeV (a.k.a. PeVatrons) and help constrain their maximum acceleration energies. Like HAWC and LHAASO, such a facility will perform sensitive indirect searches for dark matter and Lorentz Invariance Violation, and provide a unique platform for studying astroparticle physics with the Sun above 1 TeV. Our project is committed to the ideals of open science. All gamma-ray data will be made publicly available after a brief proprietary period. We envision an approach similar to those practiced by existing NASA missions such as Fermi, Swift, NuSTAR, and CTA, which provide a data archive and science tools for the astrophysics and astronomy community. In addition, we will explore ways in which communities beyond astrophysics, e.g. cosmology and particle physics, may use data at all levels from the observatory. We propose, for the first time, to provide a formal guest investigator program for a TeV all-sky instrument. While the team members have experience in and are working on a number of methods to make data from their respective observatories public, this represents an even more ambitious and sweeping plan for data dissemination that is not restricted only to high-level data products. The goal is for observatory data to be prepared in a way that will make it straightforward for a diverse science community to access and combine them – a necessity for any astrophysics experiment in the multi-messenger era. It is expected that a site and detector type decision will be made within the next 3 years.

Web link: https://www.sgso-alliance.org/

Name: John Carlstrom

Proposing Team: Submitted on behalf of the CMB-S4 Science Collaboration and pre Project Development Team (over 200 scientists) by collaboration co-spokespersons Julian Borrill and John Carlstrom

Type of Activity:
Ground Based Project

Description: We intend to submit an APC white paper on CMB-S4, a major ground-based Cosmic Microwave Background experiment. CMB-S4 was conceived by the community during the 2013 Snowmass physics planning activity as the path forward to realize the enormous potential of CMB measurements for understanding the origin and evolution of the Universe, from the highest energies at the dawn of time through the growth of structure to the present day. The broad science reach extends to powerful millimeter-wave transient searches for multimessenger astronomy and even to exploration of the outer solar system. There are three primary transformative science goals for CMB-S4: 1. Measure the imprint of primordial gravitational waves on the CMB polarization anisotropy, quantified by the tensor-to-scalar ratio r. CMB-S4 will provide a detection of $r \geq 0.003$. If inflation is the correct description of our Universe and occurred near the GUT scale, then r is predicted to be at these levels. In the absence of a signal, CMB-S4 will be designed to constrain $r < 0.001$ at the 95% confidence level, over an order of magnitude more stringent than current constraints. 2. Detect or strongly constrain departures from the thermal history of the Universe predicted by the standard model of particle physics. Many well-motivated extensions of the standard model to higher energies predict low-mass relic particles. Departures from the standard history are quantified by the contribution of light relic particles to the effective number of relativistic species in the early Universe, Neff. CMB-S4 will constrain $\Delta N_{eff} \leq 0.06$ at the 95% confidence level allowing detection of, or constraints on, a wide range of light relic particles even if they are too weakly interacting to be detected by lab-based experiments. 3. Conduct a unique synoptic Legacy Survey of nearly half the sky at centimeter to millimeter wavelengths. CMB-S4 will provide maps of all the mass in the Universe between us and the CMB last scattering surface by measuring the gravitational lensing of the CMB; maps of the hot and cold intergalactic medium using the interactions of the CMB with ionized gas; catalogs of galaxy clusters out to the highest redshifts at which they exist; and catalogs of emissive sources, both quiescent and time-varying. These legacy products will provide highly complementary data for investigations of dark energy, modifications to general relativity, and neutrino properties. They will also provide a unique and powerful probe of the influence of baryonic feedback on the formation of galaxies and clusters of galaxies. The Legacy Survey will also serve the broader astronomical community, for instance opening up mm-wave transient searches in the era of multi-messenger astronomy, and even enabling exploration of the outer solar system. It will provide a powerful and synergistic complement to major upcoming astronomical surveys and facilities, such as LSST, WFIRST, and JWST. CMB-S4 was recommended by the 2014 Particle Physics Project Prioritization Panel (P5) report Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context and by the 2015 NRC report A Strategic Vision for NSF Investments in Antarctic and Southern Ocean Research. The concept was refined by the joint NSF-DOE Concept Definition Task Force (CDT), a subpanel of the Astronomy and Astrophysics Advisory Committee (AAAC). The CDT report provides clear guidance on the science goals and measurement requirements for CMB-S4 along with a strawperson instrument design, schedule and cost. The CMB-S4 Science Collaboration was officially established shortly after the CDT report was accepted. The collaboration and the interim project office bring together the entire CMB community as well as the considerable expertise at the U.S. national laboratories. CMB-S4 is envisioned to be a joint agency program with roughly comparable support from NSF and DOE. The construction phase is expected to be funded as an NSF MREFC project and a DOE HEP MIE project, with a total (combined) project cost of order $600M. CMB-S4 will use proven existing technology that has been developed and demonstrated by CMB experimental groups over the last decade, but scaled up to unprecedented levels. The CMB-S4 design uses cryogenically cooled superconducting transition-edge-sensor detector arrays (a total of 500,000 TES detectors) deployed on three high-throughput 6-m class telescopes and eighteen 0.5-m class mm-wave telescopes, designed for unprecedented precision and rejection of systematic contamination, located at the exceptional mm-wave sites developed at the South Pole and the high Chilean Atacama plateau. The plan includes full internal characterization of astronomical foreground emission; large cosmological simulations and improved theoretical modeling; and computational methods for extracting minute correlations in massive, multi-frequency data sets.

Web link: http://cmb-s4.org

Name: Carlo Baccigalupi

Proposing Team: e-CMB Coordinators & ELFS Group

Type of Activity:
Ground Based Project

Description: - Description The European Low Frequency Survey (ELFS) is a project developed within the European Coordination for Cosmic Microwave Background Polarization Experiments (ECMB Coordinators -- wiki.e-cmb.org). The ECMBC aims at coordinating ground-based CMB polarization experiments supported by European institutions and developing them into a new plan for the mid-term (now to mid next decade) and for the long-term (second half of the next decade). The project's main target is to deploy and operate two novel CMB observatories, one in the Northern and one in Southern Hemispheres, with locations to be determined, covering the entire sky, in a frequency range extending from the C to the W bands. European cryo-HEMT technology has reached top-level performance for low frequency applications, and major progress is being achieved at higher frequencies with KID and TES detectors. Research laboratories located in France, Germany, Italy, Spain and UK are developing new instruments, either already in operation or expected to deliver impacting results in the near future. Specifically, new CMB polarization data are either available or soon-expected by a number of probes, such as the S-PASS and C-BASS Radio Surveys, the measurements of the QUIJOTE Telescope, the CCAT-prime Large Telescope, the forthcoming LSPE project combining ground-based and balloon-borne observations, the NIKA2 project developing detectors for SZ measurements, and the QUBIC bolometric interferometer. These probes are delivering novel results concerning the Cosmic Microwave Background polarization, while shedding new light on the astrophysical processes in our own Galaxy related to Galactic Synchrotron and Anomalous Dust Emission, and populations of extra-Galactic Radio Sources. These results drive the modelling of polarized low frequency foregrounds for all planned observatories (from the ground, balloon and space) targeting the CMB polarization B-modes from primordial gravitational waves and lensing. Concerning the former point, recent evidence from the quoted observatories call for accurate measurements of the Galactic polarized synchrotron in order to be able to disentangle the B-modes from diffuse Galactic foregrounds, expected to dominate at all frequencies and in all sky regions, on super-degree and degree scales where the cosmological signal is expected. The ELFS project is strategic and complementary to major efforts already on-going worldwide. In particular, this plan is intended as a European contribution to the ground-based CMB-S4 project, as well as a low-frequency complement to future space missions such as LiteBIRD. - Implementation The implementation of the project would proceed in two phases. In the short-to-mid-term, the analysis of acquired data and the deployment of the instruments currently being developed will proceed in parallel with the design and prototyping of the ELFS telescopes and the detector arrays. In the 5-40GHz range, these will be based on HEMT low noise amplifiers and digital polarimeters, ensuring continuous frequency coverage with high frequency resolution. In the 90-120GHz range we will use KID detectors building on already mature technology. The second phase of the project will include the definition of the ELFS observing sites, the development of the deployment of the new 6-meter class telescopes and/or re-use of existing ones, followed by the actual observations and analysis in phase with the quoted complementary efforts from the ground and space. All aspects of this Project need to be implemented in close connection among groups working on science case, hardware, simulations, and data analysis. Robust scientific requirements need to be specified to ensure that the

ELFS instruments will serve as a powerful CMB probe as well as a monitor of Low Frequency Foregrounds, with an optimal degree of complementarity to the current US efforts from the ground and to planned satellite projects currently involving space agencies in Japan, the US, and the EU. In particular, we are keen to implement instrument/telescope interfaces to be standardized with US-S4 facilities, to maximize potential synergy and flexibility. We plan to submit proposals to the European Research Council (Synergy Grant 2019 or 2020), for supporting the first phase. At the same time, we will bring the project to the attention of National funding institutions currently supporting on-going experiments in a coordinated effort. In the long term we plan to approach the European Strategy Forum on Research Infrastructures (ESFRI) for the ambitious long term plan.

Web link: wiki.e-cmb.org

Name: Amber Bonsall

Proposing Team: Green Bank Observatory

Type of Activity:
Ground Based Project

Description: Green Bank Planetary Radar System Implementation An Infrastructure Activity Notice of Intent Submitted to the Astro2020 Decadal Survey Committee Points of Contact: Amber Bonsall (Green Bank Observatory), Patrick Taylor (Lunar and Planetary Institute), Edgard Rivera-Valentin (Lunar and Planetary Institute), Joseph Lazio (Jet Propulsion Laboratory, California Institute of Technology) Radar investigations have played a crucial role in the ongoing study of planetary bodies within our Solar System. Planetary radar has contributed greatly to our understanding of a wide range of topics, from orbital rotation to surface structures. Radar is a relatively inexpensive and effective way of acquiring essential information on planetary objects and gain the basic knowledge needed to plan out potential future space missions. Tracking Near Earth objects (NEOs) / Near Earth asteroids (NEAs) forms a substantial portion of current planetary radar observations. Using radar imaging techniques, we are able to accurately predict the paths of objects that may potentially intercept or pass very close to earth. Currently, the two main transmitting stations for planetary radar within the United States are Arecibo (305 m) in Puerto Rico and Goldstone (70 m) in California (which is part of NASA's Deep Space Network). To date, the Green Bank Telescope (GBT), has only played a role in bi-static observations as a receiving station with other transmitting antennas. The GBT has greatly aided in increasing the resolution when receiving transmissions from Goldstone. The GBT has also been critical in conducting observations of NEAs when an object was too close for the observations to be performed monostatically. We intend to submit an APC White Paper for the construction and deployment of a planetary radar transmitting system for the GBT at the Green Bank Observatory in West Virginia. This would be a medium power transmitter operating at a frequency no higher than ~30 GHz. The creation of a third radar station in the US would be very beneficial to the radar community. Arecibo and Goldstone have limitations such as sky coverage (Arecibo), time accessibility (Goldstone), and frequency coverage (both). Adding planetary radar capabilities to the GBT will provide the astronomical community with a 100 m class telescope possessing flexible scheduling and sky coverage. This Notice of Intent addresses the requirements stated in the Planetary Systems area of the following scientific Astro2020 White Papers: "Radar Astronomy for Planetary Surface Studies" (Campbell et al.); "Planetary Radar Astronomy with Ground-Based Astrophysical Assets" (Taylor et al.); "Structure of Terrestrial Planets and Ocean Worlds" (Margot et al.); "Ground-Based Observations of Small Solar System Bodies: Probing Our Local Debris Disk" (Lovell et al.); "Emerging Capabilities for Detection and Characterization of Near-Earth Objects (NEOs)" (Milam et al.).

Web link:

Name: Anze Slosar

Proposing Team: Cosmic Visions Stage II 21cm working group

Type of Activity:
Ground Based Project

Description: We propose a revolutionary low-resolution, ultra-wide band radio telescope that will survey half the sky at frequencies from 200MHz - 1100MHz. The instrument will be composed of a regular grid of 256x256 closely-packed 6m dishes operating as an interferometric transit telescope, and will rely on modern data-processing techniques to image the radio sky in real time, allowing for both static sky and transient science. Its frequency, resolution, and sky coverage are complementary to premier radio telescopes such as SKA and ngVLA coming online today and in the next decade. It also complements similar experiments, such as HERA, that operate at lower frequencies and target the Epoch of Reionization signal. The primary goal of the instrument is a census of the Universe between redshifts z~0.3 to 6 through intensity mapping of the redshifted 21cm emission line, detection of millions of fast radio bursts, continuous monitoring of pulsars, and characterization of the transient sky at these frequencies. This experiment will provide, as its primary scientific goals: i) A precise determination of the expansion history and growth rate from the deep pre-cosmic acceleration era (z~6) to today (z~0.3) from a single instrument, placing very strong constraints on properties of dark energy and theories of modified gravity. ii) Observations, or constraints, on the presence of inflationary relics in the primordial power spectrum, improving existing constraints by an order of magnitude. iii) Observations, or constraints, on primordial non-Gaussianity with unprecedented precision, improving constraints on several key numbers (including those forecasted by upcoming experiments) by an order of magnitude. iv) Detections of millions of fast radio bursts, providing insights into the physics of their origin, and potentially using them as novel probes of cosmology and fundamental physics. v) Nearly continuous monitoring of thousands of pulsars, providing new insights into the physics of compact objects. vi) Using the enormous processing power afforded by developments in the telecommunications industry, characterization of the transient sky at 200-1100MHz over large cadence times, enabling time-domain and multi-messenger astronomy at unprecedented depths. In addition, the program will offer capabilities for numerous new methods to study cosmological signals including weak lensing and field transformation. We envision this project to be developed in collaboration between the US Department of Energy and the National Science Foundation, and to have a combined construction cost in the range of $100m-$500m. It could be hosted at already developed radio observatory sites, including several in the US, or those hosting the SKA in South Africa and Western Australia. This concept is a development of an earlier 21cm "Stage 2" concept presented as one of the roadmaps emerging from the Cosmic Visions Dark Energy committee.

Web link: https://arxiv.org/abs/1810.09572

Name: Richard Ellis

Proposing Team:

Type of Activity:
Ground Based Project

Description: We propose a large aperture (10-12m class) optical spectroscopic survey telescope with a field of view comparable to that of LSST. Such a facility would enable transformational progress through highly-multiplexed spectroscopy because of its ability to access a large fraction of objects from LSST and Euclid/WFIRST beyond the reach of 4m class spectroscopic instruments. An ESO-sponsored study (arXiv 1701.01976) discussed the scientific potential of such a facility in undertaking ambitious new surveys in Galactic astronomy, extragalactic astronomy, and cosmology. In galactic astronomy, such a facility would revolutionize our understanding of the assembly and enrichment history of the Milky Way and the role of dark matter through chemo-dynamical studies of tens of millions of stars in the Local Group. Fundamental discoveries would be made by extending `chemical tagging' via much larger samples (the effectiveness scales as the square of the sample size) and an increased number of elements (such as those beyond the iron peak). Emission and absorption line spectroscopy of $z < 1$ galaxies at high density, and high redshift galaxies with $2 < z < 5$ can be used to constrain dark energy, modified gravity, and neutrino masses as well as directly charting the evolution of the `cosmic web' and its connection with galaxy evolution. The facility would also have synergistic impact, e.g. in following up `live' and `transpired' transients found with LSST and in providing targets and the local environmental conditions for follow-up studies with next generation ground-based telescopes and future space missions. Spectroscopy will always be a primary tool of ground-based astronomy that yields unique astrophysical insight into the chemical composition and radial velocities of stars, accurate galaxy redshifts, measures of internal motions, the nature of stellar populations, non-thermal sources, and the ionizing radiation field in a variety of extragalactic sources over cosmic time. The impact of highly-multiplexed spectroscopy on 2-4m class telescopes such as SDSS and 2dF has been far-reaching and providing such a capability on a dedicated 10-12 meter platform is clearly the next logical step given the current investment in deep panoramic imaging. The ESO study considered various telescope options based on the science requirements from the Galactic, extragalactic and transient science cases. Following preliminary optical designs, it recommended a versatile 10-12 meter Cassegrain telescope. Designed at f/2.86 with a 159 micron per arcsecond plate scale for efficient fiber coupling, the three-lens corrector (1.8 m diameter largest lens) acts also as an atmospheric dispersion corrector providing a corrected 5 square degree field of view with image quality better than 1 arcsec over 360-1300nm. The 1.43m diameter focal plane provides near-optimal multiplexing power given constraints on the size of optical lenses. For instance, by using the positioner mechanism adopted by the DESI survey, more than 15,000 positioners can be hosted with minimal technology advances. Scaling fiber number and primary collecting area, the facility would be 20 to 30 times more powerful than DESI. The design also offers an additional gravity invariant focal plane with improved image quality that could host a next-generation panoramic IFU. We recommend a conceptual design study for a spectroscopic facility consisting of a large diameter telescope, fiber system, and spectrographs collectively optimized for multiple-object spectroscopy in the context of a detailed scientific case. A number of novel technical developments may be practical in improving performance and reducing cost, including the use of special purpose fibers offering higher blue transmission, miniaturized electric motors for a higher density of fiber positioners, and curved/Germanium CCDs or CMOS detectors for optimized fast spectrograph cameras. We recommend the US community establish links with the European community and other international communities in planning for such a powerful facility in the southern hemisphere.

Web link: https://arxiv.org/abs/1701.01976

Name: Stephen Eikenberry

Proposing Team: Anthony Gonzalez (University of Florida), Jeremy Darling (University of Colorado), Zachary Slepian (University of Florida), Guido Mueller (University of Florida), John Conklin (University of Florida), Paul Fulda (University of Florida), Sarik Jeram (University of Florida), Chenxing Dong (University of Florida), Amanda Townsend (University of Florida)

Type of Activity:
Ground Based Project

Description: A Cosmic Accelerometer Nearly a century after the discovery that we live in an expanding Universe, and two decades after the discovery of accelerating cosmic expansion, there remains no direct detection of this acceleration via redshift drift – a change in the cosmological expansion velocity versus time. Because cosmological redshift drift directly measures the Hubble parameter H(z), it is arguably the cleanest possible measurement of the expansion history, and can potentially strongly constrain dark energy models (e.g. Kim et al. 2015). The challenge is that the signal is small -- the best observational constraint presently has an uncertainty that is several orders of magnitude larger than the expected signal (Darling 2012). Nonetheless, direct detection of redshift drift is becoming feasible. With a dedicated experiment it should be possible to detect redshift drift with only a five-year observational baseline. We propose the development and operation of a novel "Cosmic Accelerometer" to enable the first direct detection measurement of the change in velocity of the expansion of the Universe and provide a new, complementary means of constraining the dark energy equation of state. This experiment relies on several key technological developments that enable ultra-precision velocity measurements of distant Lyman-alpha gas clouds. The first, which represents a major advance in light collection, is a technique that synthesizes large-aperture-equivalent telescopes by using photonic technology to link modules of multiple small telescopes. Rather than a single telescope mirror, the array combines light from a large number of low-cost single telescopes, pooling their light and feeding it to a scientific detector system. Crucially, this scalable design has construction costs which are 10 times lower than equivalent traditional large-area telescopes. This critical cost reduction is achieved through the use of inexpensive, commercial off-the-shelf small telescopes, guidance sensors, fiber optics, and control computers. These technologies have all seen significant enhancements in the "performance-to-cost" ratio in recent years, enabling us to augment and combine them with innovations in software and 3D-printed opto-mechanics to produce a scalable high-performance, low-cost telescope array. Second, ultra-precision radial velocity measurements of the required accuracy can now be achieved via the combination an actively stabilized, high-resolution spectrograph and a laser frequency comb. While the basic approach here is similar to that currently used to find extrasolar planets around other stars, the simultaneous optimization of LFC and spectrograph designs produces a uniquely capable system for ultra-precision radial velocity measurement. Finally, the combination of all these technologies also enables a novel observing strategy where the Cosmic Accelerometer can simultaneously measure the velocities of distant objects in the Universe while recording the speeds of bright nearby stars at large separations in the sky. While the individual stellar velocities are not sufficiently stable to calibrate the acceleration due to Dark Energy, the Cosmic Accelerometer can use their ensemble average to calibrate the velocity measurements to accuracies of < 1 cm/s. Importantly, each of these technologies have been demonstrated at the "proof-of-concept" level. A byproduct of this calibration will be RV measurements for exoplanets associated with calibration stars that are higher precision than the best current exoplanet searches. We will present in the full white paper a detailed description of the instrument design, and the aperture and precision requirements required for this science. Full construction for such a facility would cost less than $100M, and would yield dark energy constraints complementary to currently planned next generation experiments and missions.

Web link:

Name: Steven Tomczyk

Proposing Team: Ed DeLuca, Sarah Gibson, Enrico Landi, Haosheng Lin, Daniel Seaton, Jie Zhang

Type of Activity:
Ground Based Project

Description: The Coronal Solar Magnetism Observatory Magnetism plays an important role in a diverse range of astrophysical phenomena such as star formation, accretion disks and jets, black holes, pulsars, quasars and active galactic nuclei. Magnetic fields influence the universe on spatial scales ranging from microscopic to the size of galaxy clusters. Yet despite the ubiquity of magnetic influences, our detailed understanding of the role of magnetism in many astrophysical contexts is rudimentary. This is particularly true in the case of the solar atmosphere. Magnetism plays the principal role in structuring and heating the million-degree coronal plasma and the continual eruption of magnetic flux into the solar atmosphere drives all solar activity including high-energy radiation, energetic particles, flares and coronal mass ejections (CMEs). These phenomena are responsible for "Space Weather" and have important consequences for human assets in space and on the ground. Despite the dominant role of magnetism in the solar corona, routine measurements of the strength and direction of coronal magnetic fields are currently not available. The Coronal Solar Magnetism Observatory (COSMO) is a unique ground-based facility designed to address the shortfall in our capability to measure magnetic fields and plasma properties in the large scale solar atmosphere. The COSMO suite of instruments will work in synergy to address the following scientific objectives: 1. What is the evolution of magnetic and plasma properties that leads to prominence eruption and CME initiation? 2. What determines the magnetic and thermodynamic structure of the corona, and its evolution along the solar cycle? 3. How is the corona heated and how is the solar wind accelerated? 4. How can we improve space weather prediction? The science questions and the instrument requirements they drive can be addressed by a suite of three synoptic ground-based telescopes working in unison to enable the study of the solar atmosphere as a coupled system. COSMO comprises: (1) a large coronagraph (LC) with a 1.5-m aperture to measure the magnetic field, temperature, density, and dynamics of the corona; (2) an instrument for monitoring magnetic fields and plasma properties of the chromosphere and prominences (ChroMag); and (3) a white light K-coronagraph (K-Cor) to measure the density structure and dynamics of the corona and CMEs. The National Center for Atmospheric Research along with partner institutions the University of Michigan, the University of Hawaii, George Mason University, the Smithsonian Astrophysical Observatory, and the University of Colorado will engage with industry partners to develop COSMO. The unique observations provided by COSMO will complement and leverage other space- and ground-based investments like NASA's Parker Solar Probe and the National Solar Observatory's Daniel K. Inouye Solar Telescope. COSMO was endorsed in the latest Solar & Space Physics Decadal Survey and described as one of the projects "exemplifying the kind of creative approaches that are necessary to fill gaps in observational capabilities and to move the survey's integrated science strategy forward."

Web link: www2.hao.ucar.edu/cosmo

Name: Abigail Vieregg

Proposing Team: The Radio Neutrino Observatory (RNO)

Type of Activity:
Ground Based Project

Description: The Radio Neutrino Observatory (RNO) is a proposed next generation ~100 km^2 radio neutrino detector at the South Pole. RNO will extend the reach of multi-messenger astrophysics to highest energies, from 10 PeV to more than 10 EeV and enable investigations of fundamental physics at energies unreachable by particle accelerators on Earth. IceCube has discovered a cosmic neutrino flux extending to an energy of ~10 PeV, and RNO will enable the discovery of ultra-high energy neutrinos at yet higher energies. Above an energy of 100 PeV RNO's sensitivity will be an order of magnitude higher than that of any existing instrument. RNO will probe source acceleration mechanisms and discover the sources that produce neutrinos at these extreme energies. RNO brings together a broad collaboration from the in-ice radio neutrino community, and incorporates design aspects of previous experiments, such as ARA, ARIANNA, and ANITA, for an instrument will meet these ambitious science goals. RNO will consist of 61 stations of antennas deployed near South Pole. As a result of a broad design study each station will have both deep and surface components, which are both required for optimal sensitivity, sky coverage, event angular and energy reconstruction capability, and background rejection. The power and communications infrastructure will be designed for minimal maintenance and will leverage on IceCube's data operations at the South Pole. We will present the RNO design and its motivation in terms of its unique, multi-messenger science program, as well as the timeline for deployment and results. The RNO project, which is focused on discovery, will also set the stage for the IceCube-Gen2 neutrino facility, which will expand from discovery-level instruments (IceCube and RNO) to a full multi-messenger astronomy facility. IceCube-Gen2 is planning a radio component, and will build on the technical approach of RNO to reach its science goals at the highest energies.

Web link:

Name: David Williams

Proposing Team: The Cherenkov Telescope Array Consortium

Type of Activity:
Ground Based Project

Description: Very high-energy gamma rays are the highest energy photons in our Universe--coming from some of the most extreme environments--and are a cornerstone of multi-messenger astrophysics. Gamma rays can be produced by relativistic particles accelerated at supernova shock waves, close to black holes and neutron stars, and in the energetic jets formed by active galaxies. The Cherenkov Telescope Array (CTA), a ground-based observatory for very high-energy gamma rays, will provide a complete, unbiased survey of our Milky Way, together with detailed studies of individual sources, and unprecedented sensitivity to transient and multi-messenger events. The extragalactic reach of CTA will increase from redshifts of ~0.9 accessible to current instruments out to ~2, near the peaks in the active galactic nuclei and gamma-ray burst source populations. In addition, CTA will reach the sensitivity to probe the natural cross section for particle dark matter self-annihilation in a mass range above the reach of current and near-term direct detection and particle production experiments. An extensive discussion of the science made possible by CTA is described in the study "Science with the Cherenkov Telescope Array," https://arxiv.org/abs/1709.07997. CTA is planned as two arrays to have coverage of both the southern and northern sky: 99 telescopes with 3 sizes to cover a wide range of gamma-ray energies (20 GeV-300 TeV) at Paranal in Chile and 19 telescopes on La Palma in Spain to cover 20 GeV-30 TeV. CTA will far exceed the capabilities of existing instruments, with a factor of 5 to 20 improvement in sensitivity, a much larger field of view, and broader energy coverage. Such an instrument was a recommended large ground-based project in the Astro2010 decadal survey, and the CTA Consortium embodies a unified, worldwide effort working toward that goal. With about ~75 U.S. members, it has developed the CTA concept and is designing and prototyping telescopes. The CTA Observatory organization has been formed to prepare for CTA and the organization of a European Research Infrastructure Consortium (ERIC) for construction and operation is underway. Construction is expected to begin soon and to last about five years. The U.S. participants in CTA have developed and prototyped a novel, higher-performance design for the "medium-sized" telescope covering the core energy range 100 GeV-10 TeV and aim to lead the construction of a number of telescopes for CTA. While CTA as a whole is a large project, with an overall budget of about $500M, the U.S. participation in CTA is envisioned at the mid-scale level, proposed to the mid-scale programs at the National Science Foundation. The U.S. participants in CTA are represented by an Executive Committee with the following members: David A. Williams, UCSC (Chair); Vladimir Vassiliev, UCLA (Deputy Chair); Wystan Benbow, SAO; David Kieda, Utah; Nepomuk Otte, Georgia Tech; Justin Vandenbroucke, Wisconsin; and Scott Wakely, Chicago. In addition, Rene Ong, UCLA, serves as the Co-Spokesperson of the (whole) CTA Consortium; Jamie Holder, Delaware, serves as the CTA Consortium Deputy Science Coordinator; and David Kieda and Nolan Matthews, both of Utah, serve as the Leader and Deputy Leader, respectively, of the CTA Stellar Intensity Interferometry Science Working group. A current listing of all the participants in the CTA Consortium can be found on this web page: https://www.cta-observatory.org/consortium_authors/.

Web link: https://www.cta-observatory.org

Name: Michael Fitzgerald

Proposing Team:

Type of Activity:
Ground Based Project

Description: This white paper will argue for the Planetary Systems Imager (PSI), a modular instrument suite for the Thirty Meter Telescope (TMT) that enables a broad range of sensing and characterization capabilities with a particular focus on high-contrast applications. Built on a core capability of wavefront control and starlight suppression, PSI combines science backends providing imaging, polarimetry, integral field spectroscopy, and high-resolution spectroscopic capabilities across a wide range of wavelengths (0.6–5 µm, as well as a thermal channel at 10 µm). This instrument is very well suited to address major questions in the formation and evolution of planetary systems that will be relevant in the Giant Segmented Mirror Telescope era. Addressing these questions relies on our leveraging of the diffraction-limited resolution and light-gathering power of TMT, both of which will enable us to directly study gaseous, icy, and rocky planets at a range of equilibrium temperatures. A driving goal is the ability to detect biosignatures in the atmospheres of terrestrial planets in the habitable zones of nearby low-mass stars. The instrument's sensing capabilities will enable a wealth of other studies, from solar system to extragalactic astronomy. In this white paper we will present the scientific justification for building this instrument, the required technical capabilities, and discuss the feasibility of achieving these with the proposed architecture.

Web link:

Name: Neelima Sehgal

Proposing Team: Simone Aiola (Flatiron Institute), Francis-Yan Cyr-Racine (Harvard University & University of New Mexico), Simon Dicker (University of Pennsylvania), Bhuvnesh Jain (University of Pennsylvania), Bradley Johnson (Columbia University), Mathew Hasselfield (Penn State), Gil Holder (University of Illinois), Daan Meerburg (University of Cambridge), Tony Mroczkowski (European Southern Observatory), Sigurd Naess (Flatiron Institute), Daisuke Nagai (Yale University), Laura Newburgh (Yale University), Michael Niemack (Cornell University), Neelima Sehgal (Stony Brook University & Flatiron Institute), Anze Slosar (Brookhaven National Laboratory), David Spergel (Flatiron Institute)

Type of Activity:
Ground Based Project

Description: A millimeter-wave survey over half the sky, that spans frequencies in the range of 30 to 500 GHz, and that is both an order of magnitude deeper and of higher-resolution than currently funded surveys would yield an enormous gain in understanding of both fundamental physics and astrophysics. By providing such a deep, high-resolution millimeter-wave survey (about 0.5 uK-arcmin noise and 15 arcsecond resolution at 150 GHz), CMB-HD will enable major advances. It will allow 1.) the use of gravitational lensing of the primordial microwave background to map the distribution of matter on small scales (k ~ 10 h Mpc^{-1}), which probes dark matter particle properties. It will also allow 2.) measurements of the thermal and kinetic Sunyaev-Zel'dovich effects on small scales to map the gas density and gas pressure profiles of halos over a wide field, which probes galaxy evolution and cluster astrophysics. In addition, CMB-HD would allow us to cross critical thresholds in fundamental physics: 3.) ruling out or detecting any new, light, thermal particles, which could potentially be the dark matter, and 4.) testing a wide class of multi-field models that could explain an epoch of inflation in the early Universe. Such a survey would also 5.) monitor the transient sky by mapping the full observing region every few days, which opens a new window on gamma-ray bursts, supernovae, fast radio bursts, and variable active galactic nuclei. Moreover, CMB-HD would 6.) provide a census of planets, dwarf planets, and asteroids in the outer Solar System, and 7.) enable the detection of exo-Oort clouds around other solar systems, shedding light on planet formation. The combination of CMB-HD with contemporary ground and space-based experiments will also provide powerful synergies. CMB-HD will deliver this survey in 7 years of observing 20,000 square degrees, using multiple new 25-meter-class off-axis cross-Dragone telescopes to be located at Cerro Toco in the Atacama Desert. The telescopes will field about 2 million detectors in total. The CMB-HD survey will be made publicly available, with usability and accessibility a priority.

Web link: http://adsabs.harvard.edu/abs/2019arXiv190303263S

Name: Paolo Privitera

Proposing Team: The Pierre Auger Observatory

Type of Activity:
Ground Based Project

Description: The Next Decade of the Pierre Auger Observatory The Pierre Auger Observatory is the world's largest detector for ultra-high-energy cosmic rays (UHECRs). In its first decade of operation, the Pierre Auger Observatory has sharpened the view of the UHECR sky significantly. With data collection scheduled for the next decade with AugerPrime, an ambitious scientific program is planned. When Auger turned on, multimessenger astrophysics was considered a distant, possibly unreachable goal. Today, the detection of gravitational waves by Advanced LIGO and of extragalactic neutrinos by IceCube has opened exciting possibilities to advancement of science through multimessenger observations. This leap forward was enabled by the long-term operation of large-aperture observatories (and the patience of their scientists and funding agencies). The detection by Auger of ultra-high energy neutrinos or photons may be around the corner and is one of the goals of the continuing operation in the next decade. Auger is uniquely positioned for a serendipitous discovery, thanks to its sensitivity in this energy range which equals or exceeds that of any other existing instrument. Auger's discovery of a dipole demonstrates that accumulating statistics is absolutely essential to detect the subtle manifestations of UHECR sources in the sky. Also, we have started to observe hints of anisotropies – e.g. a hot spot and possible correlation with starburst galaxies. With the increased statistics from continuing operation of the observatory, the dipole will be characterized in detail, and these other observations will be confirmed or disproved. The primary goal of the Pierre Auger Observatory in the next decade is to discover the origin of UHECRs. Additional statistics will certainly solidify the evidence for anisotropy, but to properly address this question an improved detector is required. In fact, our data suggest that a mixed composition of some sort is present over a wide energy range, complicating the search for UHECR sources and the interpretation of the observed spectral features. The Fluorescence Detector (FD) has provided exquisite measurements of composition, but it is limited by its 14% duty cycle. To fully harness the power of statistics, the sensitivity to composition of surface array detectors must be improved. With these motivations, the Pierre Auger Observatory is undergoing a significant upgrade of its experimental capabilities. The AugerPrime upgrade will measure separately the muonic and electromagnetic components of extensive air showers, thereby enhancing the ability of the observatory to study UHECR composition, composition-assisted anisotropies and hadronic interaction effects at the highest energies. AugerPrime consists of a 4 square meter scintillator-based surface detector (SSD) and a radio detector (RD) added atop each water Cherenkov detector (WCD), This allows separation of the muonic and electromagnetic (EM) parts of the shower by exploiting the different responses of the different detector types to each component. The WCD has good sensitivity to both muonic and EM components while the SSD and RD are predominantly sensitive to the EM component. Shower universality and matrix methods are used to correct for differences in the EM response for each detector type. In addition to providing independent measurements of the EM component, the SSD and RD are complementary in their solid angle coverage, with SSD being optimized for showers of zenith angles smaller than 60 degrees, and RD optimized for inclined showers with higher zenith angles. Additionally, underground muon detectors in a denser part of the surface array will enhance the accuracy in the energy range of the transition from Galactic to extragalactic sources. The detector upgrade will also help us to scrutinize hadronic interactions models presently constituting a major systematic uncertainty, and improve the search for ultra-high-energy photons by a better identification of muon-poor showers. In an interdisciplinary study with broader impact, the FD will also measure transient luminous events in the ionosphere above the Cordoba region known for the highest flash rate of strong lightning in the world. This lightning is connected to strong high convective storms that may offer a proxy for storms of the future as global temperatures rise.

Web link: https://www.auger.org/

Name: F. Peter Schloerb

Proposing Team: Grant Wilson, Min Yun, Alexandra Pope, Gopal Narayanan, Neal Erickson

Type of Activity:
Ground Based Project

Description: The scientific case for a large aperture single-dish telescope has become more --- not less --- apparent since the completion of ALMA. It is understood that single-dish telescopes can carry out some observational programs more efficiently than the ALMA array. Moreover, these technical advantages are best exploited on facilities where large blocks of observing time can be dedicated to a single project. In particular, we note that a large single-dish, equipped with modern focal plane arrays, has continuum mapping capabilities that greatly exceed that of ALMA at the resolution of the single dish, and large scale spectral line imaging projects are also competitive with similar programs on ALMA. Given these basic facts, valuable surveys and large scale mapping programs should be undertaken with a single-dish telescope rather than waste valuable ALMA time pursuing the same result. To be a true complement to ALMA, the large single-dish telescope needs to have a large diameter so that its angular resolution and sensitivity approach that of ALMA. Unfortunately, at this time, no such instrument is readily available to the US astronomical community. Therefore, in this notice of intent, we propose to present a plan to make a 50m-diameter millimeter-wave antenna available to that community. Our proposal has the benefit that the telescope --- the Large Millimeter Telescope --- is already built and has instrumentation coming on line that will allow a true scientific complement to ALMA to be realized immediately at the beginning of the next decade. The 50m-diameter Large Millimeter Telescope (LMT) has been built atop an extinct, 4600m, volcanic peak in the state of Puebla, Mexico. The LMT is a joint project of the Mexican scientific community, led by the Instituto Nacional de Astrofísica, Óptica, y Electónica, located in Puebla, and the University of Massachusetts Amherst. The telescope is designed to operate at wavelengths between 0.85 and 4 millimeters. The large aperture and collecting area provide the sensitivity (~3 Jy/K), resolution (5-18 arcsecs) and mapping speed that is necessary to complement current and next generation of (sub-)mm ground-based interferometers, single-dish telescopes and far-IR satellite experiments. The LMT is an "open-air" antenna with no enclosure to obstruct its view. This configuration gives the optimum performance under the best observing conditions, particularly for measurements with sensitive, broadband continuum systems. The LMT site at 19 degrees latitude is seasonal, with best conditions from October through May. In the winter months approximately 25% of the time is suitable for submillimeter observations. The telescope has already established a track record through "early science" observations using the inner 32.5m of the antenna carried out from 2013-2017. The full 50m-diameter surface was completed in 2018; final alignment and commissioning is now being completed. The suite of instruments that are already available at the LMT will provide a powerful capability for observers in the next decade. The LMT currently has installed: (1) the Redshift Search Receiver, an ultra wide band spectrometer which covers nearly the full 3mm atmospheric window simultaneously from 73-111 GHz; (2) AzTEC, a 144-pixel continuum camera for 1.1mm wavelength; (3) SEQUOIA, a 16-element focal plane array for spectral line mapping in the 85-115 GHz; and (4) a 1.3mm dual polarization SIS receiver for observations from 200-280 GHz. Within the next year, LMT will add two additional instruments: (1) TolTEC (which will replace AzTEC), a 7000-element LEKID array with simultaneous imaging and polarimetry at wavelengths of 2.2, 1.4, and 1.1 mm; and (2) a 16-element focal plane array of SIS receivers for the 1.3mm atmospheric window. Access to the LMT is currently limited to the collaborating partners, with astronomers in Mexico receiving 70% of the observing time and the University of Massachusetts Amherst receiving 30%. The collaborating partners are responsible for providing the necessary operating funds to support use of their own time allocation. Consequently, there are only limited observing opportunities for research teams outside of the collaboration. We seek to present a proposal for consideration by Astro 2020 that would provide "open skies" access to the LMT. The plan will include: (1) investments in telescope infrastructure to improve its overall performance and ease of use by the general astronomical community; (2) investments in additional instrumentation for the telescope that will make each hour of observing time more productive; (3) funding to provide technical support to the "open skies" users; and (4) funding to cover the actual costs of operating the facility during the "open skies" time.

Web link: www.lmtgtm.org

Name: Felix Lockman

Proposing Team: The Green Bank Observatory

Type of Activity:
Ground Based Project

Description: The Green Bank Observatory will propose that the National Science Foundation fully fund and operate a 100-meter class, filled aperture, radio telescope for use by the U.S. astronomical community for at least 6500 hours of "open skies" scientific proposals annually. The telescope should operate well between 100 MHz and the atmospheric cutoff at 116 GHz, be equipped with state of the are receivers and detectors, and be located in a geographical region that provides natural terrain shielding from interfering sources, as well as legal protection from new transmitters over a wide area. It should be able to observe at least 80% of the entire celestial sphere, and have the ability to track an object for the entire time that it is at least 5 degrees above the horizon. It should have the ability to switch between diverse instruments in its focal plane in just a few minutes, and be able to be controlled and operated remotely. The telescope will require a dedicated staff of scientists, electronic engineers, software and mechanical engineers to ensure that it will operate reliably for at least 6,500 hours of "open shutter" time each year. A key feature of the proposed instrument is that if will offer "open skies" access so that it is used for the best peer-reviewed projects. As importantly, it should offer the training ground for students that is increasingly absent from remote astronomical facilities. It should thus be located within reasonable travel distance of the majority of U.S. astronomers. It should be located near the Eastern part of the U.S. in order that it can be used for very long baseline interferometry both with telescopes in Europe and those in the western US, and because it is a prime location for bi-static radar studies from transmitters at the Goldstone and Arecibo facilities. As an instrument whose use is determined competitively, it is impossible to describe its exact scientific program. However, as its capabilities will be unique worldwide, we can safely assume that it will be involved in the following: Bi-static radar studies of objects in the solar system allowing asteroid orbits to be predicted accurately; Spectroscopy of interstellar molecules with an emphasis on organic chemistry, discovering new molecules and understanding their formation mechanisms; Wide-field mapping of molecular clouds with a high spatial dynamic range to reveal the conditions for star formation; Studies of pulsars and other compact objects, including searches for new pulsars and long-term monitoring of pulsars for the detection of gravitational radiation; Studies of low surface-brightness 21cm HI emission around galaxies to understand their formation and evolution; Making high resolution maps of the Sunyaev-Zeldovich effect in galaxy clusters to show the history of assembly of these most massive objects; Long-baseline very high angular resolution studies of active galactic nucleii, accretion disks around black holes, and other phenomena. The GBT will provide sensitivity that is essential to these studies; Studying atomic and molecular gas in the Milky Way's central molecular zone and the Fermi Bubble wind; Measuring the molecular content of galaxies near and far, to understand how the gas content relates to the formation and evolution of galaxies.

Web link:

Name: Felix Lockman

Proposing Team: Green Bank Observatory

Type of Activity:
Ground Based Project

Description: The Green Bank Observatory will propose to construct a 144-pixel radio camera for spectroscopic studies in the 3mm band to operate as an open skies instrument on the Green Bank Telescope (GBT). The new camera, called Argus+, will be a 9 times larger version of the current Argus 16-pixel camera with improved detectors to provide a ten times increase in mapping speed. With an angular resolution of 7" - 10", the sensitivity of the 100-meter diameter GBT, and 144 pixels it will provide high spatial dynamic range maps of interstellar molecules that are critical in understanding the process of star formation, from the scale of entire galactic disks to the sub-parsec scale of interstellar filaments. The Argus+ project will also include a new spectrometer allowing multiple molecular species to be observed simultaneously at high spectral resolution. Because the Argus+ camera is a scaled version of an existing instrument with few changes except for the use of improved components, it has a low technical risk. The new spectrometer will be constructed from readily available commercial components and will have only a single operational mode, greatly simplifying its design and reducing its cost. The US astronomical community has no access to any instrument with similar capabilities. The GBT with Argus+ will be unequalled worldwide for wide-area 3mm spectroscopic mapping, and will be a critical complement to ALMA, which has high angular resolution but a small field of view.

Web link:

Name: Saurabh Jha

Proposing Team: Federica Bianco (Delaware), W. Niel Brandt (Penn State), Gaspar Galaz (PUC), John Gizis (Delaware), Saurabh W. Jha (Rutgers), Sugata Kaviraj (Hertfordshire), Jeffrey A. Newman (Pittsburgh), Aprajita Verma (Oxford), W. Michael Wood-Vasey (Pittsburgh)

Type of Activity:
Ground Based Project

Description: We plan to submit an APC white paper considering the science cases for continued operation of the Large Synoptic Survey Telescope after its 10 year main survey concludes circa 2032. We will explore science-driven future operational modes considering three scenarios: 1. No modifications to the telescope or camera, but complete flexibility to undertake new observing strategies, cadence, sky coverage, exposure time, etc., building on the discoveries and scientific progress made during LSST operations and the global scientific landscape. 2. Minor modifications to the camera, e.g., new filters. 3. Replacement of the camera with another instrument (e.g., a wide-field multiplexed spectrograph, near-infrared camera) or other major modifications to the telescope. The LSST Project is planning to submit an APC white paper on technical considerations for these three approaches. Our community-based white paper will be complementary, focusing on the scientific opportunities and new ways the community could interface with LSST (e.g., a proposal-driven process). We also plan to explore an appropriate timeline for decisions about the future of LSST given the context of other facilities that may come online in the 2020s (ELTs, JWST, other wide-field ground- and space-based imaging and spectroscopic capabilities, etc.) and the likely future scientific priorities in the 2030s. Our proposed white paper falls a bit into a gap between the science white papers previously solicited and the typical APC white papers. Because we are looking at one single facility, LSST, it seemed more appropriate to submit this as an activity/project.

Web link:

Name: Wenda Cao

Proposing Team: New Jersey Institute of Technology, National Solar Observatory, and Big Bear Solar Observatory

Type of Activity:
Ground Based Project

Description: We propose a project to build a dual Fabry-Perot, imaging spectro-polarimeter operating in the near infrared, as a second generation instrument for for the Daniel K. Inouye Solar Telescope (DKIST) in the coming decade. The instrument would be based on the significant heritage of Fabry-Perot-based, imaging spectrometers in solar physics. Such an approach has been demonstrated to be very valuable in exploring the dynamics of the extended structures or sparse events present in the solar atmosphere, allowing features to be resolved at the diffraction limit over the full field-of-view, thanks to post-facto image reconstruction, while permitting high-precision spectroscopy (R ~ 100,000) and spectropolarimetry. Such instruments have been widely deployed in the visible range, providing significant insight on the photosphere and chromospheric behavior, often through comparison to modern, 3D, MHD modeling of the solar atmosphere. One of the first-light instruments for DKIST will be the Visible Tunable Filter (VTF), which will be a comparable instrument operating in the range of 500-860 nm. However, this spectral range excludes several key spectral diagnostics of the photosphere, chromosphere, and corona. These include the Fe I 1565 nm line formed deep in the photosphere, the He I 1083.0 nm line formed in the upper chromosphere, the Fe XIII 1074.7 nm coronal line, and the CO overtone band at 2200 nm. Imaging spectroscopy of these lines will provide powerful diagnostics of the solar atmosphere. While all of these lines are accessible with other first light instruments on DKIST, none provide the rapid coverage of an extended field of view and the ability to apply image reconstruction to achieve consistent, diffraction limited imaging. Therefore, we propose to extend these capabilities to the infrared by developing a second generation instrument that would provide spectral imaging in the interval 1000–2200 nm. This instrument would be based on dual Fabry-Perot interferometers (or a single Fabry-Perot for coronal imaging), provide a field of view of 60-100", and allow rapid scanning of multiple spectral lines in sequence. Spectropolarimetric capabilities would allow the retrieval of magnetic field information at all heights in the solar atmosphere. It is expected that such an instrument would be able to address a broad range of scientific studies for the extended community. Given the improvement of atmospheric seeing conditions in the infrared, there should be significant amounts of the AO-corrected observing time available for such an instrument. The whitepaper will detail basic scientific requirements for such an instrument, a strawman design, and a development outline. The proposers have extensive experience in construction and operation of similar instruments, including the Visible Imaging Spectrometer (VIS) and Near Infrared Imaging Spectropolarimeter (NIRIS) at the Big Bear Solar Observatory and the Interferometric Bidimensional Spectropolarimeter (IBIS) at the Dunn Solar Telescope.

Web link:

Name: Jennifer Marshall

Proposing Team: Maunakea Spectroscopic Explorer

Type of Activity:
Ground Based Project

Description: Maunakea Spectroscopic Explorer (MSE) is the first of the future generation of massively multiplexed spectroscopic facilities. MSE is designed to enable transformative science, being completely dedicated to large-scale multi-object spectroscopic surveys, each studying thousands to millions of astrophysical objects. MSE uses an 11.25 m aperture telescope to feed 4,332 fibers over a wide 1.52 square degree field of view and has the capability to observe at a range of spectral resolutions, from R~3,000 to R~40,000. with all spectral resolutions available at all times across the entire field. With these capabilities, MSE will be able to collect a number of spectra equivalent to an entire SDSS Legacy Survey every eight weeks, but is designed to excel at precision studies of faint astrophysical phenomena. MSE provides a natural next step beyond what is envisioned for the current and imminent generation of multi-object spectroscopic instruments; it is the only 10 meter-class dedicated spectroscopic facility of its kind under development anywhere in the world, and no current facility combines the aperture, field-of-view, multiplexing, and survey power of MSE. The scientific impact of MSE will be made possible and attainable by upgrading the existing 3.6 m Canada-France-Hawaii Telescope (CFHT) infrastructure located on Maunakea, Hawaii, the premier US-based site for ground-based optical and infrared astronomy. The Maunakea site has excellent free-atmosphere seeing (0.4 arcsecond median seeing at 500 nm) and access to the entire northern sky and more than half of the southern sky (covering 55% of the LSST footprint). In order to minimize environmental and cultural impacts to the site, and also to minimize cost, MSE will replace CFHT with an 11.25 m aperture telescope while retaining the current summit facility footprint. MSE will greatly benefit by building on the 40+ years of technical and community experience of CFHT throughout the development of the project. MSE's wide range of high-impact primary science programs cannot be addressed by existing facilities. For example, in studies of the nearby Universe no other survey spectrographs target the UV region of the visible spectrum at sufficiently high resolution to measure stellar chemical abundances to reveal the nature of the production sites of r-process elements, enabling for the first time a complete understanding of the nucleosynthesis of every element on the Periodic Table. At high redshift, great advances will soon be made in cosmology thanks to next-generation massively multiplexed spectroscopic instruments like DESI and PFS, but these facilities do not have the sensitivity and fiber density to efficiently probe the structure of the Universe with adequate spatial detail to measure primordial non-gaussianity and neutrino masses at the 5-sigma precision level. In many other MSE science cases, it would be impossible to ever make enough observations of single objects using existing or planned facilities to execute the highest impact science programs. Moreover, MSE will provide critical follow-up for multi-wavelength imaging surveys, such as those of LSST, Gaia, Euclid, the Wide Field Infrared Survey Telescope, the Square Kilometre Array, and the Next Generation Very Large Array. This new generation of facilities is already beginning to collect enormous datasets of billions of faint objects, datasets which will grow exponentially over the coming decade. MSE provides essential follow-up for millions of these faint sources. In this respect, MSE enables an important synergy between wide-field imaging surveys and pointed follow-up by GMT, TMT, and ELT, by providing the essential filtering of the immensely large survey datasets. The project is poised to tackle global themes bridging a significant advance in capabilities in the upcoming generation of astronomical facilities. The stand-alone science potential of MSE is awesome, but moreover the strategic importance of MSE within the international network of astronomical facilities cannot be overstated. MSE is an international collaboration with currently one official US partner, University of Hawaii, in addition to the astronomical institutes in Australia, Canada, China, France, and India. However, fully one-quarter of the nearly 400-member MSE Science Team are based in the US, and much of the recent science development activities and scientific leadership in the project has been led by US-based scientists. Both NOAO and Texas A&M are "observers" in the MSE project, having expressed interest in joining the project in the near future, and 7 additional US institutions have begun discussions with the project to make plans for joining soon. Clearly there is a strong and growing interest and support for the MSE project within the US astronomical community. As a result, the MSE project intends to submit an APC white paper to the Astro2020 Decadal Survey for the prioritization process.

Web link: https://mse.cfht.hawaii.edu/

Name: Stephen Eikenberry

Proposing Team: Anthony Gonzalez (University of Florida), Thomas Maccarone (Texas Tech University), Joseph Harrington (University of Central Florida), Nicholas Law (University of North Carolina), Robert Quimby (San Diego State University), Misty Bentz (Georgia State University), Sarik Jeram (University of Florida), Amanda Townsend (University of Florida)

Type of Activity:
Ground Based Project

Description: Low-cost Transient Spectroscopy Facility As astronomy moves into the era of large-scale time-domain surveys, we are seeing a shift in both scientific focus and observing strategies for the coming decades. The Large Synoptic Survey Telescope (LSST) is the highest priority for US ground-based astronomy for the next decade. Meanwhile, other surveys have already begun to produce tremendous amounts of scientific data on rare and transient events (e.g., the Zwicky Transient Facility and its precursor Palomar Transient Factory, Pan-STARRS, SkyMapper, CRTS, ATLAS, Evryscope, and many others). These facilities generate a flood of new transient and variable sources – a flood that will reach biblical proportions with the advent of LSST. A key strategic challenge for astronomy is enabling sufficient spectroscopic followup. Spectroscopy is important for confirming the basic nature of these transient — particularly for new classes of objects. It is essential for discerning their physical properties (temperature, composition, radial velocity, outflows, etc.) and the evolution of those properties with time. While there is significant and ongoing effort within the community to develop coordinated plans for spectroscopic follow-up (e.g., Matheson et al. 2013), the sheer rate of interesting targets makes enabling sufficient follow-up a daunting challenge. Moreover, even with the high discovery rate, the density of targets on the sky is quite low – typically < < 1 per square degree per night (even for LSST). Thus, the multi-object spectroscopic facilities developed in recent decades provide little or no advantage for most time-domain followup. This strategic gap motivated us to develop the PolyOculus technology, a major advance in light collection. PolyOcculus uses photonic multiplexers to combine the light from many small, inexpensive telescopes to synthesize a large aperture and feed a spectrograph. This scalable design costs 1/10 of equivalent large-area telescopes. The cost reduction is achieved by using commercial off-the-shelf small telescopes, guidance sensors, fiber optics, and control computers, all of which have recently seen big improvements in their cost/performance ratios. Combined with innovations in software and 3D-printed opto-mechanics, they produce a scalable, high-performance, low-cost telescope array. Based on our calculations and simulations, and confirmed by our own laboratory tests and published results on fiber coupling efficiency from other groups, the net performance of this approach for a given equivalent aperture is that of a standard telescope with an additional throughput loss of ~15% (sensitivity reduction of ~7-8%). Meanwhile, the PolyOculus system can reduce costs for even modest apertures by 80%, and by 90% for larger apertures, due to economy of scale. Finally, because of the multi-aperture nature of this system, it is possible to sub-divide the array to look at multiple targets simultaneously, with the partitioning of aperture driven by the brightness of each target. As part of the broader spectroscopic follow-up efforts by the US community, we propose deployment of a network of longitudinally-distributed PolyOculus arrays in the southern hemisphere to enable nearly continuous spectroscopic follow-up of LSST targets of interest. This route provides a cost-effective means of maximizing the scientific productivity of LSST. In parallel, we plan to make the PolyOculus technology available to other institutions (or consortia), enabling the procurement of spectroscopic facilities with collecting areas equivalent to several-meter-diameter telescopes for the cost of current small (< 1-meter diameter) telescopes. These low-cost spectroscopic facilities would enable a wide range of spectroscopic applications, including LSST follow-up of LSST and other transient survey triggers.

Web link:

Name: Francis Halzen

Proposing Team: IceCube

Type of Activity:
Ground Based Project

Description: The IceCube Neutrino Observatory and Upgrade detector array This NOI summarizes the plans for a project white paper that describes the existing IceCube Neutrino Observatory and the on-going construction of the Upgrade detector array. The IceCube Neutrino Observatory is the world's largest neutrino telescope, providing leading sensitivity for measurements of neutrinos from approximately 5 GeV to beyond the PeV-scale. Constructed via a NSF MREFC grant between 2004 and 2010, IceCube instruments more than a cubic-kilometer of the deep glacial ice near the Amundson-Scott South Pole Station, Antarctica. The glacial ice behaves as both the Cherenkov medium and support structure for the IceCube in-ice array. Cherenkov radiation emitted by secondary charged particles produced in neutrino interactions in or near the active detector volume carries the information of the neutrino's energy, direction, arrival time, and flavor. Digitized waveforms from each deployed optical sensor provide the record of the event signatures in IceCube. Through the application of advanced reconstruction algorithms and analysis techniques on a dataset collected over the first 3 years of (nearly perfect) operation of the full IceCube array, the project discovered the first evidence for a high-energy flux of neutrinos of astrophysical origin. This flux was later independently confirmed utilizing an alternative channel in IceCube (muon neutrino events). To date, the significance of these two measurements of the astrophysical neutrino flux individually exceed 6 sigma compared to the background expectation from atmospheric neutrinos. While the flux of high-energy neutrinos has now been well established, the sources of these neutrinos have remained elusive. The first link between these cosmic messengers and an astrophysical source occurred on September 22, 2017, when IceCube detected a well-reconstructed (track-like) 290 TeV neutrino event (IC-170922A) that triggered an alert to the international astronomy community. The subsequent follow-up measurements by astronomical instruments across the electromagnetic spectrum identified a blazar (TXS 0506+056) in an enhanced state of activity coincident with the neutrino direction. Further investigation of the IceCube archival data in this region of the sky revealed a burst of neutrinos (13±5) coincident with TXS 0506+0056 in 150 days between 2014 and 2015. The combination of these two spectacular events is the first compelling evidence, after nearly 8 years of intensive activity by the international collaboration, for a source of the observed IceCube high-energy neutrino flux. In order to evolve beyond the initial discovery era of astronomy with neutrinos, it is necessary to improve the sensitivity of the detector in a few of the key areas that neutrino telescopes share with the broad suite of astronomical instruments: exposure and pointing resolution. For the current IceCube detector, a few tens of well-reconstructed high-energy events (muon neutrinos that induce a muon with a long track in the detector, providing an enormous lever arm for angular reconstruction) are observed each year with angular resolutions between 0.5 and 1 degree. Compared to typical astronomical instruments, with pointing of $\lesssim$0.1 degrees, this angular resolution introduces a large uncertainty when identifying single sources, in particular in heavily populated regions of the sky. To provide the first important step in closing this gap, the IceCube Upgrade, currently in the construction phase, will deploy 7 new strings of instrumentation in a dense configuration near the centre of the existing deep-ice array. An advanced calibration program, using state-of-the-art dedicated devices deployed on the Upgrade strings, will improve our knowledge of the natural ice inside the detector making it possible to enhance our reconstruction algorithms and control systematic uncertainties. In doing so, it is anticipated that recalibration of the existing and future IceCube data will improve substantially on current resolutions. The resultant improved vertex resolution will improve key analyses sufficiently to effectively double the current detection rate at the TeV-PeV scale. In addition, the improved calibration information combined with the increased photocathode coverage will significantly enhance the measurements of fundamental neutrino properties across the broad band of accessible energies; in particular below ~50 GeV where world-leading sensitivity of atmospheric neutrino oscillations, including stringent tests of unitarity of the neutrino mixing matrix via tau neutrino appearance, are anticipated. Beyond IceCube and the Upgrade, the international collaboration envisions a second generation (Gen2) neutrino observatory with the ultimate goal of realizing mature neutrino astronomy. We note that, should sufficient space be granted in the white paper submissions, the technical and scientific content described in this NOI would be combined with that of the coordinated IceCube-Gen2 Observatory (in-ice and surface array) submissions.

Web link: https://icecube.wisc.edu

Name: Darren Grant

Proposing Team: IceCube-Gen2

Type of Activity:
Ground Based Project

Description: The second generation (Gen2) IceCube Neutrino Observatory in-ice detector array This NOI summarizes the plans for a project white paper that describes the vision for a future in-ice detector array associated with the IceCube second generation (Gen2) neutrino observatory at South Pole Station, Antarctica. IceCube, the world's preeminent neutrino observatory, announced the discovery of a high-energy astrophysical flux in 2013, realizing a more than 50 year vision that neutrinos could be utilized as probes of the extreme universe. On September 22, 2017, IceCube alerted the astronomical community of a high-energy (290 TeV) astrophysical neutrino event, IC-170922A. The subsequent follow-up campaign by more than 20 astronomical instruments around the globe observed blazar TXS 0506+056 in an enhanced flaring state. Inspection of the IceCube archival data subsequently uncovered a strong neutrino flare in the direction of TXS 0506+056 in 2014. Taken with the 2017 measurements, IceCube provided the first compelling evidence for a link between high-energy cosmic neutrinos and an extreme astrophysical object; effectively launching the field of neutrino astronomy. To push to the ultimate goal of mature neutrino-based astronomy will require an increased collection rate relative to IceCube combined with improved pointing resolutions. IceCube-Gen2, a next generation observatory at the South Pole, is envisaged to achieve this goal. The primary element of the observatory is a deep-ice optical detector that encompasses the existing IceCube array and increasing the detection volume from the current 1 cubic-km to an instrumented volume of nearly 10 cubic-km. The conceptual Gen2 detector design demonstrates that the anticipated diffuse flux above 100 PeV is measurable. Improving the measurements of the diffuse astrophysical flux folds directly into the search for the individual sources. In particular, the significant increase in instrumented area of the Gen2 high-energy array (HEA) opens new sensitivity to fluxes from individual sources much fainter than the current IceCube limits; an approximate order of magnitude increase in sensitivity to a single point source (assuming an E-2 flux) made possible with the Gen2 HEA detector. Put another way, with such an increase in sensitivity in place, including the anticipated improvements in pointing resolution, the significance of the coincidence between IC-170922A and TXS 0506+056 would have conservatively been about a factor of four higher. A full-scale in-ice radio array is also an envisaged part of the Gen2 Observatory for measurements of ultra-high-energy neutrinos. The radio array follows the technical approach of the proposed Radio Neutrino Observatory (RNO), while achieving an additional factor of 5 increase in event rate to neutrinos above ~30 PeV. The radio array complements the energy reach of the optical deep ice detector, providing significant enhancement of the astrophysical neutrino signal in the overlap region between the two detector arrays, and new sensitivity at the GZK cutoff region (EeV-scale) and beyond. Finally, co-located with the area of the deep strings of optical detectors, a large-scale array of surface detectors that would detect cosmic ray air showers above a few tens of TeV is also under evaluation by the international cosmic ray community (discussed in a separate white paper), and could potentially provide the ability to veto atmospheric muons, and hence atmospheric neutrinos, complementing the measurements of high-energy astrophysical neutrinos. The IceCube-Gen2 Observatory conceptual design, discussed in this white paper, evaluates the potential impact of the deep in-ice optical detector on future high-energy astrophysical neutrino measurements. The extended sensitivity to ultra-high energy neutrinos with the in-ice radio array is also described. We note that, should sufficient space be granted in the white paper submissions, the technical and scientific content described in this NOI would be combined with that of the IceCube observatory and Upgrade, and Gen2 surface array submissions.

Web link: https://icecube.wisc.edu/science/beyond

Name: Gaetano Sivo

Proposing Team: John Blakeslee, Jennifer Lotz, Morten Andersen, Henry Roe, Scot Kleinman, Andy Adamson, Paul Hirst, Laure Catala, Eduardo Marin, Stephen Goodsell, Natalie Provost, Ruben Diaz, Hwihyun Kim, Julia Scharwächter, Gianluca Lombardi, Marie Lemoine-Busserolle, Mark Chun, Mark Ammons, Julian Christou, Charlotte Bond, Christian Veillet, John O'Meara, Suresh Sivanandam, Paolo Turri, Peter Wizinowich, Carlos Correia, Benoit Neichel, Jean-Pierre Véran, Simone Esposito, Masen Lamb, Thierry Fusco, Francois Rigaut, Eric Steinbring

Type of Activity:
Ground Based Project

Description: Over the past two decades, major Observatories in both the Northern and Southern Hemispheres have developed Adaptive Optics (AO) systems in order to achieve near-diffraction limited observations and have been delivering unique high spatial resolution science data to the astronomical community (ALTAIR, GeMS, and GPI at Gemini; NAOS, SPHERE, GALACSI, GRAAL at ESO; FLAO, ARGOS, LINC-NIRVANA at LBTL; KECK-AO at Keck; AO188 and SCExAO at Subaru; MagAO at Magellan; and many more). The coming generation of extremely large telescopes such as the Thirty Meter Telescope, the Giant Magellan Telescope and the European Extremely Large Telescope are all designed with AO intrinsically embedded into their operations. Thus, AO will be a central part of their standard observing modes and has been a strong factor in optimizing their designs. In parallel, the US community will also have access to two revolutionary new optical-infrared facilities: the Large Synoptic Survey Telescope (LSST) and the James Webb Space Telescope (JWST). These two facilities will enable unprecedented science at high resolution (in the case of JWST) and in the time domain (with LSST). However, neither of these important facilities will be able to provide high-cadence long-duration monitoring of variable phenomena at high angular resolution. Wide Field Adaptive Optics systems, such as Multi-Conjugate AO (MCAO: Beckers 1988, Rigaut & Neichel 2018), Laser Tomographic AO (LTAO: Tallon & Foy 1990), Multi-Object AO (MOAO: Gavel 2004), and Ground Layer AO (GLAO: Rigaut 2001) represent the path forward for such scientific accomplishments. For instance, an MCAO system providing a corrected field-of-view over a wide area and fully integrated into a dynamically scheduled 8m-class telescope feeding imaging and spectroscopic scientific instruments would provide this capability over a field similar in size to that of JWST. Increasing the efficiency of the AO observations is essential. Embedding the AO system into the telescope design itself can vastly improve its efficiency, and integrating an Adaptive Secondary Mirror (ASM) coupled to a GLAO system is the key element in achieving this goal. The total number of optical surfaces decreases significantly with an ASM, limiting the loss from thermal emissivity and improving the overall throughput. An ASM also facilitates access to the full range of powerful, modern AO systems, from narrow field (< 30") LTAO, SCAO, and XAO, to medium field (< 3') MCAO, to wide field (>8') GLAO and MOAO systems. The main advantage of a GLAO system is that it provides "super-seeing" observations (2 to 3 times better resolution compared to natural seeing), which is the equivalent in terms of signal-to-noise of increasing the primary mirror surface area by 50% or more. Indeed, the GLAO correction greatly enhances the efficiency of almost all science observations and enables a range of other Galactic and extragalactic science cases that can only be achieved with high spatial resolution. Thus, providing the US community with a powerful GLAO system driving a state-of-the-art ASM would vastly improve the efficiency and capability of current 8-m class telescopes in advance of the ELT era, and create new synergies with those facilities when they come online.

Web link:

Name: Nancy Chanover

Proposing Team:

Type of Activity:
Ground Based Project

Description: We discuss the importance of retaining community access to 4m class telescopes in the upcoming decade for a number of applications, including (but not limited to) transient follow-up observations, high-risk, high-reward observations, instrumentation test beds, and student training. In the era of big glass and the current development of extremely large telescopes, there is no question that telescopes of increasingly large apertures will be required for numerous advancements in observational astronomy and astrophysics. Furthermore, large ground-based surveys such as the Sloan Digital Sky Survey (SDSS) and the Large Synoptic Survey Telescope (LSST) are contributing to a paradigm shift in terms of the mode in which ground-based observational astronomical research is being conducted, with many researchers now using data mining techniques to take advantage of the enormous data volume rather than making single PI-led observations from a telescope. However, ground-based facilities such as the Zwicky Transient Factory (ZTF) and LSST, as well as space missions such as the Transiting Exoplanet Survey Satellite (TESS), will yield numerous discoveries of interesting targets that require follow-up observations in order to be better characterized. It is in this realm of time domain follow-up observations that 4m-class telescopes can play a significant role, provided that their relative ease of access is retained. Telescopes of this class with capabilities such as remote observing and flexible scheduling will be particularly well-suited for time domain follow-up observations, which often require rapid turnaround from the time of discovery to subsequent characterization. Ground-based telescopes also serve as an important testing ground for innovative but potentially risky observations. New observational experiments can be developed and tested with 4m-class telescopes, in some cases demonstrating the limitations of this aperture size and hence the need for more advanced capabilities. Time Allocation Committees on the more competitive larger telescopes will be more receptive to proposals for which proof-of-concept observations were conducted. In some cases a high-risk observation on a 4m class telescope will be successful, thus telescopes of this class can be used by astronomers to test out new observing strategies or techniques with potentially a high scientific yield. In addition to the scientific discoveries that will be enabled by observations with 4m-class telescopes, such telescopes can also be used as instrumentation test beds. For both space-based and ground-based instrumentation, heritage is an important factor in selection. Ground-based telescopes that are accessible for the testing and demonstration of new technologies and instrumentation will play a critical role in the definition of future instrument suites for larger telescopes and satellites. Finally, 4m-class telescopes can serve as an important resource for training future generations of astronomers. In the era of big data and large astronomical surveys, students may gain new skills in the areas of data mining, but without practical experience at a telescope they may lose sight of the origins and limitations of those data. Students need to understand where their data come from in order to effectively analyze them! The experience of working with instruments and telescopes first-hand, from developing an observing plan to conducting the observations and then analyzing their data, provides students with an end-to-end understanding of what goes into the planning of the data pipelines in the larger surveys. The 4m class telescopes are ideally suited for developing the skills and training for future ground-based astronomers who may not end up using telescopes themselves, instead taking advantage of the large data produced by ground- and space-based surveys.

Web link:

Name: David Schlegel

Proposing Team:

Type of Activity:
Ground Based Project

Description: The Beast is a proposed ground-based experiment to measure Inflation parameters and dark energy from galaxy redshifts, and near-field cosmology from spectroscopy and kinematics of Milky Way stars, through an observing program of hundreds of millions of targets. The Beast would be located at Las Campanas Observatory in the southern hemisphere, and would fully access to LSST imaging for target selection. The Beast is designed to dramatically increase the multiplexing and survey speed compared to spectroscopic experiments currently under construction. The telescope design utilizes a 6.5-meter diameter primary mirror of identical prescription to those fabricated by the University of Arizona Mirror Lab (two of which are in use in the Magellan-1 and Magellan-2 telescopes). A secondary mirror and 6-lens corrector delivers a 4 square degree field-of-view at Cassegrain focus. The focal plane will be filled with an automated fiber positioning system capable of targeting 20,000 objects simultaneously over a wavelength range of 360 to 980 nm, with the possibility of extending this wavelength range further into the infrared. The cosmology key project is designed to measure primordial non-Gaussianity as predicted by large classes of Inflation models. These models are typically described by the dimensionless parameter, f_{NL}. By measuring redshifts to 200 million galaxies at $z>2$, the Beast promises to cross the threshold of measuring non-Gaussianity at limits of $f_{NL} < 1$. This complements the capabilities of future CMB experiments that will be sensitive to single-field Inflation. The Beast will advance tests of theories of Dark Energy, and test posited modifications to General Relativity. The galaxy redshift surveys will be supplemented with Lyman-alpha forest maps at $z>2$, where the Beast will have sensitivity to the forest in tens of millions of galaxy spectra enabling IGM tomography. The near-field cosmology key project is designed to reach the edge of the Milky Way galaxy. Both the kinematics and chemical tags for a hundred million stars will allow precise characterization of Milky Way streams and dissolved substructure. The resulting map will expose the detailed subtructure and accretion history of the outer galaxy, testing dark matter models. The Beast is proposed as a partnership between Carnegie Obesrvatories, DOE/OHEP, and partner universities. Our conceptual plan is that telescope construction and operations would be managed by Carnegie Observatories, and instrument construction would be managed by Lawrence Berkeley National Lab. Data operations would make use of the DESI system as operated on the NERSC computing platform. Our approach thus harnesses the power of efficient mid-scale facility construction (i.e. the Magellan telescopes) and survey design and operation (i.e. the SDSS/DESI surveys). The Beast is designed to be a cost-effective approach to achieving a survey speed 12X faster than the Dark Energy Spectroscopic Instrument (DESI). The 6.5-m primary mirror has 3X the collecting area of DESI, yet is no more challenging in the optical design for the focal plane and the spectrographs. The telescope costing is based upon the Magellan 6.5-m telescopes, and the instrument costing is based upon the DESI experiment. The focal plane would be a further development of a DESI robotic positioning system to 20,000 fibers at a smaller pitch.

Web link:

Name: Adrian Lee

Proposing Team: The Simons Observatory Collaboration (https://simonsobservatory.org/board.php)

Type of Activity:
Ground Based Project

Description: The Simons Observatory (SO) is a ground-based cosmic microwave background (CMB) experiment sited in the Atacama Desert in Chile that promises to provide breakthrough discoveries in fundamental physics, cosmology, and astrophysics. The SO will observe in six frequency bands from 30 to 270 GHz and perform two surveys. The first survey is a deep, degree-scale survey of 10% of the sky with 0.5m-aperture telescopes to search for the signature of primordial gravitational waves emanating from the Big Bang epoch. The second survey is a wide-field, arc-minute-resolution survey of 40% of the sky with a 6m-aperture telescope aimed at broad set of science goals including: A search for evidence of elementary particle light relics, such as extra neutrinos and axions. A constraint or measurement of the neutrino hierarchy and the sum of the neutrino masses by measurements of gravitational lensing of the CMB. * A search for the signature of Dark Matter annihilation. *A characterization of the evolution of Dark Energy by simultaneously measuring growth of structure and the expansion rate. *A characterization of baryonic feedback in galaxy formation. *A legacy gravitational lensing data set that can be combined with optical survey data to greatly increase the power of both data sets. *A Sunyaev-Zel'dovich-effect galaxy-cluster survey that can be combined with future x-ray surveys such as eROSITA. *A rich catalog of IR-bright galaxies. *A wide-field survey that will yield serendipitous detections of radio bursts. The science case for the Simons Observatory has been detailed in a comprehensive forecast paper (JCAP 1902 (2019) 056 arXiv:1808.07445). The Simons Observatory is funded for its initial configuration of three 0.5m-diameter Small-Aperture Telescopes (SATs) and one 6m-diameter Large-Aperture Telescope (LAT) with a total of 80,000 detectors. A five year observing program is partially funded. We plan to seek the remainder of the operations funding and an expansion of telescopes, detectors, and observation duration. Such an expansion offers a highly cost-efficient way to make rapid progress on high-priority CMB science goals of longer term projects including CMB-S4.

Web link: https://simonsobservatory.org/

Name: Jared Males

Proposing Team:

Type of Activity:
Ground Based Project

Description: We intend to submit an APC white paper describing plans for an "extreme" adaptive optics (ExAO) system for the Giant Magellan Telescope (GMT). This instrument concept, currently called "GMagAO-X", is based on using existing deformable mirror (DM) and wavefront sensor (WFS) detector technology to implement a 21,000 actuator, 2000 Hz system. Combined with state of the art coronagraphy, GMagAO-X will enable detection and characterization of exoplanets at extreme contrast ratios in groundbreaking variety. This will include young giant planets (both from thermal emission and in the H-alpha acretion signature), older giant planets in reflected light, and temperate terrestrial planets orbiting nearby late-type stars in reflected light. GMagAO-X will also enable studies of circumstellar disks at unprecedented angular resolution in the visible and near-IR. Since it is based on existing proven technology, GMagAO-X can be available at, or shortly after, first light of the GMT, allowing the observatory to deliver groundbreaking exoplanet science almost immediately.

Web link: https://magao-x.org/gmagao-x/

Name: Mark Dickinson

Proposing Team: For the US ELT Program: Lori Allen, NOAO, lallen@noao.edu Taft Armandroff, UT Austin, director@astro.as.utexas.edu Rebecca Bernstein, GMTO, rab@carnegiescience.edu Michael Bolte, UC Santa Cruz, mbolte@ucsc.edu Adam Bolton, NOAO, bolton@noao.edu Mark Dickinson, NOAO, med@noao.edu Christophe Dumas, TMT, cdumas@tmt.org Debra Elmegreen, Vassar College; AURA, elmegreen@vassar.edu James Fanson, GMTO, jfanson@gmto.org Gary H Sanders, TMT, sanders@tmt.org Robert Shelton, GMT, rshelton@gmto.org Edward C. Stone, Caltech, ecs@srl.caltech.edu

Type of Activity:
Ground Based Project

Description: The National Science Foundation's (NSF's) National Optical Astronomy Observatory (NOAO), the Giant Magellan Telescope Organization (GMTO) and the Thirty Meter Telescope International Observatory (TIO) will submit an APC white paper that will make the case for federal investment in TMT and GMT and the US Extremely Large Telescope Program (US-ELTP). Two projects with US leadership are developing ELTs, one in the Northern Hemisphere and one in the Southern Hemisphere. The US Extremely Large Telescope Program (US-ELTP) represents a unified direction for future US federal investment in this next generation of giant optical-infrared telescopes through a partnership between NOAO, TIO and GMTO. The US-ELTP proposes to leverage the significant progress that has been made in developing two consortia of US universities, foundations and international partners supporting the GMT and TMT. The two projects have committed to work in partnership with NOAO to provide access to these observatories for all US-based astronomers through merit-based peer review built, in part, around a set of Key Science Programs (KSPs). In response to a call by NOAO, community-based teams have developed concepts for a set of exemplar KSPs that cover a broad range of astronomical research, including the study of our solar system, extra-solar planets, astrobiology, star and planet formation, stars and stellar physics, resolved stellar populations, galaxy evolution, supermassive black holes, cosmology, and multi-messenger astrophysics. In addition to the KSPs, discovery-class science programs will enable focused ELT observing programs to be carried out by smaller teams of investigators. This two-hemisphere ELT system will provide the U.S. science community with greater and more diverse research opportunities than can be achieved with a single telescope, hence more opportunities for making substantial progress in key areas of astronomy that can be uniquely enabled over a roughly 10-year timescale. All celestial objects are accessible with 100% sky coverage, and 50% sky overlap creates a high potential for simultaneous or complementary observations of the same objects with different instruments. A separation of seven hours in longitude creates valuable opportunities for time-domain research, especially for rapidly changing phenomena that benefit from long-duration, high-cadence observations. The goal of the US-ELTP is to secure 25%, or more, of the observing time on each of the GMT and TMT, for open access by the whole U.S. community. A federal contribution by NSF in the capital and operations phases of these two exciting projects provides a unique opportunity to significantly broaden U.S. public access to the next generation of optical-infrared telescopes. The two projects are mature and have well developed designs, schedules and cost estimates. The trilateral collaboration will use this joint APC white paper to make the case for support of each of the telescope projects (TMT and GMT) and for the overall US-ELTP concept.

Web link: https://www.noao.edu/us-elt-program/

Name: Dimitri Mawet

Proposing Team: Michael Fitzgerald, Quinn Konopacky, Charles Beichman, Nemanja Jovanovic, and the HISPEC/MODHIS team

Type of Activity:
Ground Based Project

Description: High-resolution Infrared Spectrograph for Exoplanet Characterization HISPEC (High-resolution Infrared Spectrograph for Exoplanet Characterization) is a proposed instrument concept for the W.M. Keck Observatory, and a pathfinder for the MODHIS project (Multi-Object Diffraction-limited High-resolution Infrared Spectrograph) on the Thirty Meter Telescope. HISPEC/MODHIS builds on diffraction-limited spectrograph designs such as Palomar-PARVI and LBT-iLocator, both of which rely on adaptively corrected single-mode fiber feeds. Seeing limited high-resolution spectrographs, by virtue of the conservation of beam etendue, have to grow in volume following a D^3 power law (where D is the telescope diameter), and are subject to daunting challenges associated with their enormous size (e.g. mechanical flexure and thermal stability). On the other hand, diffraction-limited spectrograph designs fed by single mode fibers are completely decoupled from the telescope input, enjoying order of magnitude smaller sizes, intrinsic stability of the instrument and line spread function. On the flip side, the spectrograph efficiency is directly proportional to the quality of the delivered diffraction-limited point spread function, and thus the performance of the adaptive optics (AO) system. AO technologies have matured rapidly over the past two decades and have now come of age. AO systems have become mainstream on current large ground-based telescopes, and are baselined for future extremely large telescopes. HISPEC/MODHIS will take R>100,000 spectra of one or possibly a few objects in a ~10" field-of-view sampled at the diffraction limit (~10 mas scale), simultaneously from 0.95 to 2.5 µm (Y band to K band). The scientific scope is broad and ranges from exoplanet infrared extreme precision radial velocities, transit and close-in exoplanet spectroscopy (atmospheric composition and dynamics, RM effect), spectroscopy of directly imaged planets (atmospheric composition, spin measurements, Doppler imaging), brown dwarf characterization, stellar physics/chemistry, proto-planetary disk kinematics/composition, Solar system (e.g. comets), extragalactic science, and cosmology (cosmological constants and the Hubble expansion in real time). HISPEC/MODHIS features a compact and cost-effective design optimized to fully exploit the existing Keck-AO and TMT-NFIRAOS infrastructure and boost the scientific reach of both Keck Observatory and TMT soon after first light, providing unprecedented capabilities to the US community. The instrument concept uses best design practices for extreme precision high-resolution spectroscopy, and is based on the latest single-mode infrared fiber, grating, detector, and Laser Frequency Comb technologies.

Web link:

Name: Scott Ransom

Proposing Team: NANOGrav Management Team (SMR, X. Siemens, M. McLaughlin, J. Cordes, A. Brazier, S. Burke-Spolaor, and I. Stairs) for the rest of NANOGrav

Type of Activity:
Ground Based Project

Description: NANOGrav is a gravitational wave (GW) observatory in the nanohertz band and currently involves 40 institutions and more than 100 individuals. It is a very long-term project and spans multiple Decadal Surveys. Gravitational waves are measured by using an array of spin-stable millisecond radio pulsars as a Galactic-scale detector, a so-called Pulsar Timing Array (PTA). NANOGrav's investigations of nanohertz GWs will provide insight into the demography, environments, and merger history of the largest supermassive black holes in the Universe out to a redshift of approximately 1, while the same pulsar observations will provide a wide variety of gravity and compact-object related astrophysics. The low frequencies of the GWs necessarily require continuous precision metrology over time spans of decades using large radio telescopes, and the project is well underway: we are currently preparing our 14-year data release using timing data from the Green Bank and Arecibo Telescopes. The NANOGrav project includes coordination of observations using North American telescopes (the aforementioned GBT and Arecibo, as well as the JVLA and CHIME), curation of data into the indefinite future, and development and application of state-of-the-art statistical inference methods for characterizing gravitational waves. Significant activity centers on the mitigation of astrophysical and instrumental perturbations of pulsar arrival times. In particular, the growing incidence of radio frequency interference requires continual characterization and development of mitigation algorithms. Another key element is the continued incorporation of improvements to the solar system ephemeris developed by the Jet Propulsion Laboratory that allows reference of pulsar arrival times to the solar system barycenter. Conducting state-of-the-art PTA science requires weekly to monthly monitoring observations of 100-200 pulsars at 1-3 GHz frequencies on 100- to 300-m class (i.e. GBT to Arecibo equivalent) radio telescopes. NANOGrav currently observes ~80 pulsars with the GBT and Arecibo using ~1400 hr/yr. Data from the last 14 years have lead to astrophysically important constraints on the GW emission from the cosmological population of black holes. In the next decade, NANOGrav will improve its GW sensitivity in part by timing more pulsars with increased cadence and by deploying new instrumentation on current telescopes, in particular receivers with much larger bandwidths (from 0.7-4 GHz). GW sensitivity is proportional to the number of pulsars in a PTA, and so discovering additional, high-quality pulsars in big-data surveys is a high priority. These surveys will benefit from multi-beam receivers and phased array feeds that allow faster survey speeds, and will require ample data storage and machine learning in order to identify astrophysical candidates. We expect the NANOGrav PTA to expand up to ~200 pulsars, requiring ~2000 hr/yr on telescopes at least as large as the 100- to 300-m telescopes we are currently using. As GW sensitivity increases substantially with timing baseline, improvements will also accrue by incorporating new data from other sensitive radio telescopes that will come online over the next ten to fifteen years. New telescopes include those in North America that are now being proposed, such as the DSA2000 and the ngVLA, along with other telescopes around the world that provide important sky coverage to southern pulsars (such as the SKA, should the US have access). NANOGrav requires a large team that is carefully managed and includes the training of students in astrophysics, big data analysis, and instrumentation. Education and public outreach is an integral part of our effort and will intensify in the next decade as we move into GW detection and characterization in the nanohertz band. During that time, we expect NANOGrav to grow in multiple ways, including the numbers of its members and collaborators, and international relations will be increasingly important and demand significant attention.

Web link: nanograv.org

Name: Mark Dickinson

Proposing Team: For the US Extremely Large Telescope Program: Lori Allen, NOAO, lallen@noao.edu, Taft Armandroff, UT Austin, director@astro.as.utexas.edu, Rebecca Bernstein, GMTO, rab@carnegiescience.edu, Michael Bolte, UC Santa Cruz, mbolte@ucsc.edu, Adam Bolton, NOAO, bolton@noao.edu, Mark Dickinson, NOAO, med@noao.edu, Christophe Dumas, TMT, cdumas@tmt.org, Debra Elmegreen, Vassar College/AURA, elmegreen@vassar.edu, James Fanson, GMTO, jfanson@gmto.org, Patrick McCarthy, GMTO, pmccarthy@gmto.org, Gary H Sanders, TMT, sanders@tmt.org, Robert Shelton, GMT, rshelton@gmto.org, B. Thomas Soifer, Caltech, btsoifer@caltech.edu, Edward C. Stone, Caltech, ecs@srl.caltech.edu, Jeremy Weirich, AURA, jweirich@aura-astronomy.org

Type of Activity:
Ground Based Project

Description: The National Science Foundation's (NSF's) National Optical Astronomy Observatory (NOAO), the Giant Magellan Telescope Organization (GMTO) and the Thirty Meter Telescope International Observatory (TIO) will submit an APC white paper that will make the case for federal investment in TMT and GMT and the US Extremely Large Telescope Program (US-ELTP). Two projects with US leadership are developing ELTs, one in the Northern Hemisphere and one in the Southern Hemisphere. The US Extremely Large Telescope Program (US-ELTP) represents a unified direction for future US federal investment in this next generation of giant optical-infrared telescopes through a partnership between NOAO, TIO and GMTO. The US-ELTP proposes to leverage the significant progress that has been made in developing two consortia of US universities, foundations and international partners supporting the GMT and TMT. The two projects have committed to work in partnership with NOAO to provide access to these observatories for all US-based astronomers through merit-based peer review built, in part, around a set of Key Science Programs (KSPs). In response to a call by NOAO, community-based teams have developed concepts for a set of exemplar KSPs that cover a broad range of astronomical research, including the study of our solar system, extra-solar planets, astrobiology, star and planet formation, stars and stellar physics, resolved stellar populations, galaxy evolution, supermassive black holes, cosmology, and multi-messenger astrophysics. In addition to the KSPs, discovery-class science programs will enable focused ELT observing programs to be carried out by smaller teams of investigators. This two-hemisphere ELT system will provide the U.S. science community with greater and more diverse research opportunities than can be achieved with a single telescope, hence more opportunities for making substantial progress in key areas of astronomy that can be uniquely enabled over a roughly 10-year timescale. All celestial objects are accessible with 100% sky coverage, and 50% sky overlap creates a high potential for simultaneous or complementary observations of the same objects with different instruments. A separation of seven hours in longitude creates valuable opportunities for time-domain research, especially for rapidly changing phenomena that benefit from long-duration, high-cadence observations. The goal of the US-ELTP is to secure 25%, or more, of the observing time on each of the GMT and TMT, for open access by the whole U.S. community. A federal contribution by NSF in the capital and operations phases of these two exciting projects provides a unique opportunity to significantly broaden U.S. public access to the next generation of optical-infrared telescopes. The two projects are mature and have well developed designs, schedules and cost estimates. The trilateral collaboration will use this joint APC white paper to make the case for support of each of the telescope projects (TMT and GMT) and for the overall US-ELTP concept.

Web link: https://www.noao.edu/us-elt-program/

Name: Benjamin Shappee

Proposing Team: Robo88

Type of Activity:
Ground Based Project

Description: As discussed in the previous, Astro-2010 Decadal survey, large area surveys will dominate the next decades of astronomy. The NSF, NASA, The Moore Foundation, and the Air Force Research Laboratory, have recently invested more than $20 million combined to expand and construct the next generation of public, all-sky transient surveys that will scan the sky faster and more thoroughly. Combined, these surveys now pore over the entire sky from seven different sites worldwide (five in the northern hemisphere) every ~12 hours. Each survey has a different specialization, depth, and cadence, but between them, nearly every supernova, active galactic nucleus flare, tidal disruption event, kilonova (neutron star mergers and gravitational wave sources), and moving object in the nearby universe will be spotted. However, simple detections are insufficient; characterization through high angular resolution images, deep imaging, and spectra are then required to separate the unexpected, exceptional objects from more common events and to identify groups of objects for more in-depth studies. Currently, less than 10% of the transients reported to the International Astronomical Union (IAU) Transient Name Server (TNS) have been spectroscopically classified since January 2016. Furthermore, the Large Synoptic Survey Telescope (LSST; the top priority ground-based project from Astro-2010; ~$700 million) will increase the number of discoveries manyfold. Unfortunately, the labor-intensive design of current classification efforts will not efficiently scale to take full advantage of the opportunities provided by these new surveys. Using Robo88, we will take an ambitious new approach. We will perform the first ever, robotic, automated, public classification survey. All parts of the survey, from target ingestion to classification to announcement, will be automated. We will robotically trigger on alerts from UH-affiliated transient surveys also located in Hawai`i (ASAS-SN, ATLAS, PanSTARRS) to allow us to go from discovery to spectroscopic classification in less than 20 minutes. We will also automatically ingest triggers from other public surveys (e.g., the ZTF survey). We will more than double the current number of supernovae (SNe) classified each year by the entire worldwide community at low cost with a small team. We will quickly and efficiently sift the thousands of public transients announced to identify the rare objects where large, concerted follow up efforts will be focused and quickly announce these classifications to the community in near real time. By making our data public, we will amplify the scientific output from the transient community as a whole, who are then be able to follow up specific sources with a wide range of ground- and space-based resources. Additionally, our survey will lead to a large number of smaller scientific projects that are self-contained and well-suited for graduate and undergraduate research projects. Training the next generation of transient astronomers is particularly important with the LSST-era on the horizon and the robotic classification strategy described here will need to be duplicated at numerous 2-8m telescopes in the upcoming decade to classify a fraction of the oncoming wave of sources that will be discovered. While this project is ambitious, the challenges are well-understood and similar engineering and software solutions already exist making risks minimal.

Web link:

Space Based, Infrastructure, Technological Development, and State of the Profession Activities

Name: Lynn Allen

Proposing Team: Harris Civil and Commercial Imaging

Type of Activity:
Space Based Project
Infrastructure Activity
Technological Development Activity
State of the Profession Consideration

Description: HabEx Primary Mirror Process Capability -- PI - Conrad Wells This white paper will discuss Harris' readiness to fabricate a 4 M monolithic primary mirror to the surface figure tolerances required for space based coronagraphy. The process development and investments needed to finish the HabEx mirror will create a set of cutting-edge tools that will enable other coronagraph, UV and general astronomical missions.

Web link:

Name: Lynn Allen

Proposing Team: Harris Civil and Commercial Imaging

Type of Activity:
Space Based Project
Infrastructure Activity
Technological Development Activity
State of the Profession Consideration

Description: LUVOIR technology sections… Co-PIs - Conrad Wells and Matt East Large space telescopes such as LUVOIR depend on strategic investments for program success. This report identifies activities and technologies which will advance LUVOIR WFE (wavefront error) stability without losing sight of the logistics of scale, static WFE requirements and implementation. The most cost-effective activities and technologies which will enable LUVOIR WFE stability are presented, alongside practical telescope performance considerations.

Web link:

Space Based, Infrastructure, Technological Development Activities

Name: Michele Vallisneri

Proposing Team:

Type of Activity:
Space Based Project
Infrastructure Activity
Technological Development Activity

Description: The last decade has seen the rise of a new kind of astronomy, characterized by inference and discovery in large survey databases, and by the joint analysis of datasets gathered across facilities, frequency bands, and even messenger particles. Astronomical data archives have grown in power and sophistication to support this mode of research, and have increasingly begun to "take the computation to the data," transforming what were once static catalogs into dynamical, multifaceted computational ecosystems. We believe that these trends will be even more amplified in the scientific exploitation of data from space-based gravitational-wave observatories such as LISA. LISA is effectively an omnidirectional antenna, and most of its sources will be "on" throughout the duration of the mission: it follows that the accurate analysis of almost all LISA sources (whether individually, or as populations) will require a sophisticated global fit supported by a new kind of high-performance, interoperable data archive. In other words, the LISA dataset will only be truly open to the broader astronomical community if it is made alive as a smart computational object that fully embodies the most accurate representations of the instrument and of the many families of gravitational signals that it will capture. The opportunity for multimessenger investigations of Galactic and extra-Galactic sources adds another dimension of complexity and user requirements. We advocate a strong program of research and development in the theoretical bases, technological implementation, and human interfaces of gravitational-wave data archives. Such a program will undoubtedly benefit greatly from observing and supporting the evolving practice of ground-based gravitational-wave science.

Web link:

Space Based and Infrastructure Activities

Name: David Sheikh

Proposing Team:

Type of Activity:
Space Based Project
Infrastructure Activity

Description: The NASA HabEx concept mission final report has identified depositing a high-reflectance uniform-reflectance coating on a 4-m mirror as a key technology that requires development to enable HabEx. ZeCoat Corporation is currently developing the required coating technology under a NASA Astrophysics grant (APRA), and we are in the process of installing a new coating facility with river barge access, that will allow us to coat large mirrors 4 to 7-meters in diameter. This white paper will provide information regarding our plans to develop the needed coating technology and the new infrastructure required for the HabEx and LUVOIR concept missions. The new coating facility is near St. Louis, Missouri and is located with direct access to the Mississippi river.

Web link:

Name: Brad Cenko

Proposing Team:

Type of Activity:
Space Based Project
Infrastructure Activity

Description: I will highlight the importance of the Explorer program within the NASA Astrophysics Division for the broader astronomical community. I will also provide suggestions for how to improve the Explorer program going forward.

Web link:

Name: Marshall Perrin

Proposing Team: John Grunsfeld (NASA), Jon Arenberg (Northop Grumman), Bradley Peterson (OSU), Benjamin Reed (NASA GSFC), Gordon Roesler (Robots in Space LLC), Hsiao Smith (NASA GSFC), and colleagues

Type of Activity:
Space Based Project
Infrastructure Activity

Description: Maximizing Science Lifetime for NASA's Flagship Missions: Robotic Refueling and Servicing of JWST and WFIRST Missions that cost billions of dollars ought to last longer than five or ten years. Hubble has remained at the forefront of discovery for three decades, enabled by five servicing missions by astronauts. For telescopes operating at distant Earth-Sun L2, robotic servicing can similarly enable mission lifetimes measured in decades, not years. The most compelling need is refueling: unlike in LEO, observatories at L2 must burn fuel for orbit maintenance and momentum management. Fuel consumption thus sets an inevitable upper lifetime to any mission, even if all other systems remain fully operational. Refueling breaks this bound. In the next few years, NASA's Restore-L mission will demonstrate in-space refueling of the Landsat 7 spacecraft, along with related capabilities for robotic servicing and assembly. Restore-L is part of an increasingly capable landscape of space robotics systems, driven by the needs of commercial space and other government agencies. These flight-proven capabilities will be available to support NASA's high-value astronomy missions. In-space servicing can extend mission lifetimes by replenishing consumables, enhance science capabilities by delivering new instruments, and correct anomalies to restore science operations. JWST should be able to be refueled, though details of approach and refueling operations around the delicate sunshield require more study. WFIRST is designed to be refueled and serviced, potentially upgraded with new instruments sometime in the 2030s. The space environment at L2 is relatively benign in several ways compared to LEO or GEO, so in principle very long lifetimes are possible for these observatories. While L2 is more distant than LEO or GEO, that poses no fundamentally new barriers for robotic servicing; it will be easier than operating robotic arms on the surface of Mars. In our white paper we will discuss the specific operations needed for refueling JWST and WFIRST, their relevant observatory hardware (e.g. machine vision targets, fuel ports), and how available robotic capabilities can meet these needs. We will outline two potential paths for refueling these observatories: cislunar servicing, in which spacecraft thrusters are used to return from Earth-Sun L2 to cislunar space (e.g. Earth-Moon L1) for refueling there prior to return to L2, and in situ servicing, by a visiting robotic tender dispatched to L2. Beyond refueling, as WFIRST development continues, a greater or lesser degree of in-space servicability can be enabled through a "menu" of design choices, providing flexibility to enable select servicing options while remaining within budgetary constraints. We recommend that in the 2020s, NASA SMD should support and partner with other NASA divisions and external partners in further maturing these capabilities. And in the early to mid 2030s, NASA should undertake a "Restore-L2" mission to refuel and extend the science operations lifetime of JWST, WFIRST, or both.

Web link:

Name: Varoujan Gorjian

Proposing Team:

Type of Activity:
Space Based Project
Infrastructure Activity

Description: A New Approach for Funding Cubesats to Maximize Science Return The current NASA model of funding cubesats is through the Astrophysics Research and Analysis (APRA) program. That is also the program where NASA's highly successful balloon and suborbital rocket programs are funded. Unfortunately this approach makes orbital missions, which have very different needs, compete with semi-ground based efforts. We argue that for NASA to maximize the science return from cubesats, a new approach should be adopted that accommodates the differences in these two very different types of missions. Right now all aspects of a proposed cubesat are to be funded through APRA with the exception of the launch. This includes the spacecraft bus, navigation after launch, the instrument, the data downlink, and the science team. This is in stark contrast with rockets where, not only the launch, but the bus is paid for by NASA, and there is no downlink requirement. Finally in terms of the amount of data acquired, cubesats fly for one to two years acquiring gigabytes of data which the minutes-long flight of rockets and the (at most) weeks-long flight of balloons will never generate. This last step in the scientific productivity of any mission puts the cost of cubesats at a great disadvantage when competed against balloons and rockets which lack those requirements. If NASA chooses to keep funding cubestas through APRA, then it must afford the same advantages that it affords the balloons and rockets where more than the cost of launch is covered by NASA. One approach may be that NASA acquires a set of buses for which proposers will write instrument proposals. By going after a standard bus (much like suborbital rockets) the proposal process will also be more of an apples-to-apple comparison with rockets. Another approach may be that cubesats are afforded their own funding line where they only compete against other cubesats. Regardless of how the building and launch of cubesats is funded, in the realm of data acquisition and analysis, there is a final step where cubesats need an additional service to maximize their science return that rockets and balloons don't need. That need is long term archiving of large amounts of data. With the potential of gigabytes of data from upcoming cuebsat missions, that responsibility could be funded and incorporated into one of the already exiting NASA archives (e.g. IRSA or MAST). This would allow reduced data to be accessible for future astronomers thus maximizing the science per dollar for these missions.

Web link:

Space Based, Technological Development, and State of the Profession Activities

Name: Lynn Allen

Proposing Team: Harris Civil and Commercial Imaging

Type of Activity:
Space Based Project
Technological Development Activity
State of the Profession Consideration

Description: Predictive thermal control – PI - Keith Havey Thermal stability is one of the most critical technologies to enable coronographic and other picometer-stable optical systems. Harris and NASA investments in predictive thermal control provide a roadmap to meet these stability requirements. Predictive thermal control is a method to directly link telescope imaging performance (wavefront, alignment) to thermal control system output. This white paper will outline the technology and advancements made using PTC for optical system stability and provide a roadmap of investment options to advance the TRL level for future space missions.

Web link:

Name: Lynn Allen

Proposing Team: Harris Civil and Commercial Imaging

Type of Activity:
Space Based Project
Technological Development Activity
State of the Profession Consideration

Description: Low strain mounting techniques for Lynx x-ray optics. – PI – Keith Havey Low strain mounting of the Lynx mirrors is essential to the image quality. Mount strain must be managed during mirror assembly with precision fixturing, temperature and humidity control, as well as knowledge of the cure shrinkage of the adhesive system. For the silicon mirror design, the large number of segments for Lynx necessitates a time-efficient, deterministic, and high-quality process.

Web link:

Name: Nan Yu

Proposing Team:

Type of Activity:
Space Based Project
Technological Development Activity
State of the Profession Consideration

Description: Precision measurements in space can help better our understanding of physics in areas such as the nature of gravity, dark matter, dark energy, and the fundamental physics at the Planck scale. The white paper discusses research and activities for maturing new precision measurement technologies and applying them to space experiments in astrophysics and fundamental physics.

Web link:

Name: Ewan Douglas

Proposing Team:

Type of Activity:
Space Based Project
Technological Development Activity
State of the Profession Consideration

Description: CubeSats have the potential to expand astrophysical discovery space, complementing ground-based electromagnetic and gravitational-wave observatories. The CubeSat design specifications (http://www.cubesat.org) help streamline delivery of instrument payloads to space. In space, scientific measurements of gamma rays, X-rays, ultraviolet, infrared, and long-wave radio waves are possible without atmospheric attenuation, planners have more options for tailoring orbits to fit observational needs and may have more flexibility in rapidly rescheduling observations to respond to transients. With over 800 CubeSats launched by the end of 2017, there has been a corresponding increase in the availability and performance of commercial-off-the-shelf (COTS) components compatible with the CubeSat standards, from solar panels and power systems to reaction wheels for three axis stabilization and precision attitude control. These commercially available components can help reduce cost and schedule for CubeSat missions, allowing more resources to be directed toward scientific instrument payload development and technology demonstrations.   Despite the severe restrictions that CubeSats have in size, weight, and power (SWaP) which also limit aperture size without the development and use of more complex deployables, CubeSat constellations or swarms can still enable improved spectral, temporal, and spatial coverage of astrophysical targets. CubeSats can also be used for technology demonstrations; while such demonstrations may not be able to make the desired scientific observations on a CubeSat platform, they can reduce risk and increase the technology readiness level of key elements of future scientific instruments, such as detectors, actuators, optical sub-assemblies, and drive electronics. Previous and ongoing CubeSat projects have already contributed astrophysical measurements to the scientific community, and NASA has selected several new CubeSat missions for flight or for concept development. Most of these astrophysics missions focus on short wavelength observations and precision photometry. Technology development is ongoing to address implementing longer-wave infrared measurements, which require power-efficient cooled detectors compatible with CubeSat resource constraints. Work is also underway toward precision ranging and formation flying constellations that would be necessary for applications such as distributed imaging or interferometry, including challenges such as temporal, spectral, and gain calibration of instruments across multiple spacecraft. The desire for future astrophysics CubeSats to operate over longer mission lifetimes and in orbits with less benign radiation environments than low Earth orbit will require either development of radiation tolerant or hardened CubeSat components, comprehensive testing and qualification of COTS CubeSat components for operation in harsher environments, or both.   Examples of astrophysics nanosatellite flight missions that have already launched include the Cosmic X-Ray Background Nanosatellite (CXBN) mission,(Simms, L. M. et al. CXBN: a blueprint for an improved measurement of the cosmological x-ray background. in Proc. SPIE 8507, 850719-850719?12 (2012).) the Bright Target Explorer (BRITE) (Baade, D. et al. Short-term variability and mass loss in Be stars - I. BRITE satellite photometry of eta and mu Centauri. A&A 588, A56 (2016)) and the Arcsecond Space Telescope Enabling Research in Astrophysics (ASTERIA).(Pong, C. M. et al. (2011).) CXBN-2 was launched in 2012 to observe the diffuse X-ray background and help understand the underlying physics of the early universe. The BRITE constellation of nanosatellites has demonstrated millimagnitude photometry of Be stars. The Arcsecond Space Telescope Enabling Research in Astrophysics (ASTERIA), delivered and launched in 2017, is designed to provide part-in-a-million photometry using a piezoelectrically stabilized image plane detector to search for transiting terrestrial exoplanets around bright stars. We will discuss the value already provided by the current missions, describe several other already selected flight astrophysics observation and technology demonstration CubeSats, discuss other relevant astrophysics applications for CubeSats such as gravitational wave event follow-up, and assess what additional instrumentation and technology development areas, such as cooled detectors and high-data rate communications, are still needed in order to maximize benefit from a CubeSat astrophysics platform. In the era of time domain astronomy, rapid, multi-wavelength follow-up of interesting targets in the ultraviolet (UV) and X-Ray is of particular interest. For example, recent UV observation of electromagnetic emission coincident with gravitational-wave detection of a binary neutron star coalescence was recorded by the 30 cm SWIFT UV Optical Telescope with 120 second observationsfootnote{Evans, P. A. et al. Science (2017). doi:10.1126/science.aap9580). A constellation of independent CubeSats with somewhat longer exposure times could provide simultaneous follow-up to multiple such events. Observations of exoplanet transits are also being developed, such as the Compact Homodyne Astrophysics Spectrometer for Exoplanets (CHASE) and the Star Planet Activity Research CubeSat (SPARCS). CubeSats complement existing suborbital balloon and sounding rocket programs by demonstrating longer mission durations, longer exposure times, and higher altitudes at the expense of reusability and aperture.

Web link:

Space Based and Technological Development Activities

Name: Peter Michelson

Proposing Team: Robert Byer, Stanford University, rlb@stanford.edu, Sasha Buchman, Stanford University, sbuchman@stanford.edu, John Lipa, Stanford University, jlipa@stanford.edu, Ilya Mandel, Monash University, ilya.mandel@monash.edu, Shally Saraf, Stanford University, saraf@snnelectronics.com

Type of Activity:
Space Based Project
Technological Development Activity

Description: mLISA: Mid-Frequency-Band Space Gravitational Wave Observatory for the 2020 Decade
We propose the geocentric mission mLISA (mid-frequency-band LISA) to detect GWs in the band 10 mHz - 1 Hz, bridging between LIGO/VIRGO and LISA - with useable sensitivity to 10 Hz. This band can be accessed at reasonable cost, earlier than the LISA schedule, and with substantial science return. mLISA will enable the timely development in the US of this game-changing field. We envision that the US would take the lead for mLISA while the European community continues as lead for LISA. mLISA will meet the GW science objectives in the NASA's Astrophysics Visionary Roadmap and Science Plan and the most important GW science goals in the 2010 "New Worlds, New Horizons" astrophysics decadal survey. The mission concept envisions a geocentric spacecraft formation with arm length between 73,000 km (geosynchronous) to 629,000 km (Earth-Lunar 3, 4, 5 Lagrange points). Substantial cost savings will be realized by synergy with the LISA technology development program and by testing critical systems in parallel, utilizing small satellites. mLISA and LISA technologies are similar; macroscopic inertial sensors and laser interferometry between a triangular spacecraft constellation. We summarize the expected mLISA science results, with unpredicted discoveries also a possibility: Enhanced BBH parameter estimation: observations will occur well before the LIGO/VIRGO band, resulting in precise source parameter estimations and allowing precise tests of the "no hair theorem" and other GR strong-gravity tests. Sky localization: BNS sources will have quasi-constant frequencies for many years over most of the mLISA bandwidth, thus allowing their localization to a few arcminutes. Type IA supernova progenitors: The question of the creation of type IA supernovae would be answered by an IA observation and the detection, or lack thereof, of a coincidental GW event. Mergers in the presence of third bodies: GW mergers in the mLISA band will carry the imprint of nearby third bodies, (massive black holes, centers of massive core-collapsed globular clusters). Evolutionary history of compact object binaries: The GW decihertz range will improve the understanding of their formation and evolution. Stochastic background: Mid-band detections could allow the observation of the cosmological GW background. Element formation: Additional detections of BH-NS or NS-NS mergers will improve the understanding of the formation of heavy elements Improved measurements of Hubble constant: High event-rates will allow (~100 mergers) determination of H to < 5% and over a much larger volume. Primordial black hole (PBH) formation: PBHs are theorized to have been generated during the early Universe by several mechanisms. Numerous GW detections will allow to differentiate between mechanisms. Extreme and Intermediate Mass Ratio Inspirals: These are expected to radiate predominantly in the band where LISA and mLISA achieve their best sensitivities. Massive Black Holes: mLISA will characterize the parameters of coalescing BBHs with masses in the 10^3 to 10^5 M⨀ range, with precision comparable or better than LISA. Massive Black Hole Formation: mLISA will search for mergers leading to the creation of massive black holes in the centers of galaxies, distinguishing between scenarios for their formation.

Intermediate Mass Black Holes (IMBH): mLISA has the optimal band for IMBH, ~10^3 M$\odot$, detection; observable as either mergers or inspirals of compact stellar mass objects. Galactic Binary Calibrators: mLISA will study optically identified stellar-mass galactic - the "calibrators". mLISA's cost and development duration are comparable to previous medium scale NASA observatories: 2003 Spitzer Infrared Space Telescope-$720M, 2008 Fermi Gamma-ray Space Telescope-$720M, 2009 Kepler Observatory-$550M), 2010 Solar Dynamics Observatory-$817M. mLISA will be comparable to the large Earth Sciences missions ($500M - $800M) recommended in the National Academies' 2018 decadal report and the Planetary Sciences small, robotic missions into our solar system ($500M + ~$150M) selected by NASA in 2015 for further study. Use of off-the-self satellites, an option never considered by previous GW mission concept studies, will result in a mLISA mission cost in line with astrophysics probe-class missions. Our estimate is based on the conclusions reached by a mLISA study performed at JPL in late January 2016. The study relied on previous TEAM-X cost estimates of other GW mission concepts updated with newly available satellites and launching vehicle costs, the option of using a single test mass on board each satellite, and reduced costs for the constellation to communicate to the ground. The geocentric mLISA orbit allows the reduction of its launch payload to about 2,000 kg, from the 5,000 kg estimate for LISA, while also greatly reducing the operational complexity. Note that historic trends show mission costs scaling with mass.

Web link:

Name: David Hobbs

Proposing Team:

Type of Activity:
Space Based Project
Technological Development Activity

Description: GaiaNIR The Gaia mission is currently a very successful ESA project and is delivering 5 parameter astrometry, photometry and radial velocities over the whole sky with astrometric accuracies down to a few tens of micro-arcseconds. A weakness of Gaia is that it only operates at optical wavelengths. However, much of the Galactic centre and the spiral arm regions, important for many studies, are obscured by interstellar extinction and this makes it difficult for Gaia to deeply probe. This problem could be overcome by switching to the Near Infra-Red (NIR) but this is not possible with CCDs. Additionally, to scan the entire sky and make global absolute parallax measurements the spacecraft must have a constant rotation and this requires that the detectors operate in Time Delayed Integration (TDI) mode, increasing their complexity. A clear improvement on Gaia is to go into the NIR and such a proposal has been made to ESA (Hobbs, et al. 2016) who have subsequently studied the mission concept in detail (GaiaNIR – Study to enlarge the achievements of Gaia with NIR survey). The study found that a TDI solution would give similar accuracies as Gaia despite doubling the wavelength range. However such TDI technology for NIR detectors does not readily exist with state-of-the-art scientific NIR detectors being based on Hybrid technology (i.e. HgCdTe on CMOS multiplexers). The science cases for GaiaNIR have been outlined by Hobbs, et al. 2016 and in a proposed collaboration on this project with the US now being submitted as an Astro2020 science white paper, "All-Sky Near Infrared Space Astrometry", Barbara McArthur, et al. 2019. Additionally a further white paper on this topic will be submitted to ESA's continuation of the Cosmic Vision call, called Voyage 2050, in August of this year. The science return from such a mission is very promising but a solution to the technology problem of implementing TDI in NIR detectors must now be found. There are a number of possible approaches to developing TDI-NIR detectors 1) A hybrid solution which uses a HgCdTe NIR detector layer bump bonded to a Si CCD. The idea is that the photons are detected in the surface NIR layer and transferred to the Si buried channel at each pixel location. Charge can then be easily moved with very high transfer efficiency along the pixels of the same column in sync with the charge generation, thus achieving TDI. What is not known yet is how efficiently the charge can be transferred from the NIR detection layer to the Si CCD and if both materials can be operated at the same temperature. The US company Teledyne-e2V with offices in the UK have discussed this as a possible solution but laboratory tests are needed. 2) Using a CMOS sensor with TDI capability in the underlining Si multiplexer. CMOS image sensors are slowly starting to take over from CCD technology but TDI remains a challenge. A possible way forward here is to avoid the standard approach of directly converting charge to voltages at the output of each pixel and instead convert voltages to digital words which can be summed up as the image moves across the TDI array. This typically results in large noise but Teledyne-e2V have shown that by using an innovative pixel architecture noise-free charge transfer be achieved using standard CMOS technology (see Mayer, F. et al. 2017). 3) Ge detectors are new but show promise, due to the lower band gap, photodetectors based on Ge can detect NIR radiation of significantly longer wavelengths than possible with Si detectors (see Leitz, C.W., et al. 2018). Clearly this technology is new and requires further development to see if it can be used for our application with low noise and optical+NIR capabilities. The purpose of this NOI is to highlight the technology needed for a NIR Gaia-like astrometry mission, i,.e. NIR detectors with TDI capability. A number of approaches have already been identified but detailed studies are needed in the coming years to assess the best approach and to develop laboratory demonstrators before full scale production of such devices can be undertaken. Hobbs, D. et al, 2016, https://ui.adsabs.harvard.edu/#abs/2016arXiv160907325H Mayer, F. et al., 2017, First measurements of true charge transfer TDI using a standard CMOS technology, Proceedings of SPIE, Vol. 10564, http://adsabs.harvard.edu/abs/2017SPIE10564E..0NM Leitz, C.W., et al., 2018, Development of germanium charge-coupled devices, Proceedings of SPIE Vol. 10709, High Energy, Optical, and Infrared Detectors for Astronomy VIII.

Web link: http://sci.esa.int/future-missions-department/60028-cdf-study-report-gaianir/

Name: Stephen Rinehart

Proposing Team:

Type of Activity:
Space Based Project
Technological Development Activity

Description: The Path to Interferometry in Space: Toward the NASA Astrophysics Roadmap's Vision of the Future Astrophysicists have made tremendous discoveries over the past fifty years aided by the advent of ever-more powerful facilities. These facilities came into being through the dedicated efforts of many scientists, over the course of decades, guided by a vision of awaiting scientific possibility. We follow this tradition by presenting a long-term vision for the future of astronomy, a future where it is possible to probe very fine angular scales with interferometers; we also discuss the steps that could be taken in the coming decade to realize this future. Many compelling science questions can only be answered with angular resolution far beyond current capabilities. A first example is the imaging of exoplanets. While new facilities are being proposed that will greatly advance our understanding of exoplanets, these distant worlds will be unresolved for some time to come. Meanwhile, spectroscopic instruments will observe a blend of different planetary features: the atmosphere, clouds, surface water, and land, and clouds will make accurate interpretation of transit spectroscopy even more challenging. However, with the capability of making a multi-pixel map (8x8 pixels, for instance), it will become possible to distinguish the different sources of emission. This breaks degeneracies inherent in spatially unresolved spectroscopy and provides details on the sources of different spectral features, opening the door to studies of energy transport and atmospheric dynamics, diurnal cycles and seasonal variations, and climates. It would also enable the resolution of biomarkers such as chlorophyll – features easily lost in a spatially-unresolved spectrum. To make a map with 10 resolution elements across an earth-size exoplanet at a distance of 5 pc (assuming λ = 500nm) would require an angular resolution of 1.7 microarcseconds. This corresponds to a single aperture telescope with a diameter of 74 kilometers – impractical in the extreme. An interferometer of comparable size would also be daunting, but could be achieved with an array of smaller (and practical) apertures. This highlights one of the key advantages of interferometers. Historically, astronomers have been limited by both collecting area and angular resolution, and both of these limitations could be mitigated by building larger apertures. However, collecting area grows faster with aperture diameter than angular resolution, and there comes a point where the value of additional collecting area is overshadowed by the need for angular resolution. In the far-infrared, where photons are plentiful but angular resolution is intrinsically lower, existing and proposed facilities are already approaching this point. Interferometry disentangles the engineering response to these two requirements, allowing separate optimization for sensitivity (total collecting area) and angular resolution (maximum baseline). In addition to the study of exoplanets, science cases across all of astrophysics would benefit from high angular resolution observations. It would be possible to image the surfaces of white dwarfs, allowing direct observation of the surface pulsations of these compact objects. This would provide a unique window into the equation of state of degenerate matter – a new laboratory for fundamental physics. We could also image main sequence stars, using spatially-resolved asteroseismology to study stellar interiors and to gain new insights into stellar structure and evolution. Those same observations would allow us to solve the puzzle of solar/stellar magnetic dynamos, enabling a true predictive model of magnetic cycles. At the other end of the size spectrum, we could carry out detailed studies of distant galaxies. We would be able to map broad line regions of active galactic nuclei, see the accretion disk of the black hole at the heart of a galaxy, and ultimately gain new insight into the engine and feedback mechanisms that drive the evolution of these galaxies. We could study accretion disks, protoplanetary disks, mass transfer in binary systems, the formation of stars, and the final stages of stellar evolution. An interferometer with the resolution needed to map exo-Earths is likely many decades away, but incremental steps along the path to such a facility can be taken with space-based interferometric missions which themselves have powerful scientific rationales. The first of such missions is possible now: modest far-infrared interferometers designed to explore the formation of planetary systems and the development of habitable conditions on extrasolar planets are feasible with existing technology. In coming decade, investments in ground-based testbeds, suborbital experiments, and perhaps a first-generation space-based interferometer will strengthen the foundation for more ambitious future missions. As recognized by the community-generated NASA Astrophysics Roadmap, Enduring Quests/Daring Visions, it is on this foundation that the future of space astronomy will rest.

Web link:

Name: Scott Gaudi

Proposing Team: N/A

Type of Activity:
Space Based Project
Technological Development Activity

Description: Scientific Drivers for a Great Successor to the Hubble Space Telescope The Hubble Space Telescope (HST) has been, without question, the most publicly impactful science-driven mission ever flown by NASA. Generations of people from all over the globe have been affected, driven, and influenced by the tremendous science that HST has produced. This inspiration will undoubtedly continue while HST remains in operation. However, HST will eventually reach the end of its life, and when this happens, there will be a void due to the loss of some of the science capabilities afforded by HST to astronomers world-wide. In particular, no other existing or planned observatory can undertake high-resolution UV imaging and spectroscopy. The previous 2010 Decadal Survey, "New Worlds, New Horizons (NWNH)," noted this void, stating in particular that: "Studies of the intergalactic medium, which accounts for most of the baryons in the universe, at more recent times could be transformed by an advanced UV-optical space telescope to succeed the Hubble Space Telescope (HST), equipped with a high-resolution UV spectrograph." – NWNH, p. 190 "The cycling of gas from galaxies to the surrounding intergalactic medium and back again could also be studied with a ground-based Giant Segmented Mirror Telescope, using high-resolution optical spectra to study gas absorption lines highlighted by background quasars along many sight-lines, but a future UV space mission will be needed for a complete inventory." – NWNH, p. 203 "Key advances could be made with a telescope with a 4-meter-diameter aperture with large field-of-view and fitted with high-efficiency UV and optical cameras/ spectrographs operating at shorter wavelengths than HST." – NWNH, p. 220 They further noted that realizing such a mission called for further technology development, specifically with regard to detectors, coatings, and optics. The large strategic missions that are the successors to HST, first JWST and then WFIRST, will continue to spark the interest of the public in space-based astronomy. However, in order to ensure continued US prominence in the arena of large strategic space-based astrophysics missions, as well as to ensure a seamless transition after WFIRST, a future flagship mission must be "waiting in the wings." Anticipating this need, NASA has gone to great lengths to ensure that there exist four candidate large strategic mission concepts, specifically HabEx, LUVOIR, Lynx, and Origins, that have advanced and mature designs, as well as detailed technology assessments and development plans. Two of these concepts, HabEx and LUVOIR, are responsive to the recommendation of the previous Decadal Survey regarding a UV-capable mission. Either represent a more powerful successor to HST, with UV-to-optical capabilities that range from significant enhancement to orders-of-magnitude improvement. At the same time, technological and science advances over the past decade make it not only feasible, but also economically advantageous, to marry such a mission with one that will also address one of the most profound questions of humankind: is there life outside the solar system? Although this is not a new idea, we argue that it is one that is only now technologically and scientifically realizable. While differing greatly in architecture and scope, the HabEx and LUVOIR mission studies have largely the same basic science drivers. Both are Great Observatories capable of addressing some of the most fundamental questions in astrophysics and planetary science, as well as being able to directly detect and take spectra of Earthlike planets orbiting sunlike stars, and thereby search for signs of habitability and perhaps even biosignatures. Acknowledging that the constraints that must be considered by the Astro2020 Decadal Survey may be difficult to anticipate, or may even change over time, the HabEx and LUVOIR studies together present eleven different architectures. All of these architectures enable groundbreaking science, including the direct imaging and characterization of exoplanets. The HabEx and LUVOIR mission studies therefore offer a "buffet" of options to the Astro2020 Decadal Survey, with corresponding flexibility in budgeting and phasing. The time is now to start the development a large strategic mission that will be a great successor to HST, and will not only answer some of the most fundamental questions in astrophysics and planetary science, but may also finally answer the question of whether or not there is life elsewhere in the Universe.

Web link:

Name: Herman Marshall

Proposing Team:

Type of Activity:
Space Based Project
Technological Development Activity

Description: The field of soft X-ray polarimetry is in a nascent stage and could be routine by the end of the 2020s. A sounding rocket instrument has been proposed to NASA with a limited bandpass but there have not been any approved or implemented missions. Here, we consider the soft X-ray band to be 0.1-1.0 keV. In our method, multilayer-coated mirrors are used as Bragg reflectors at the Brewster angle. We start with a dispersive X-ry spectrometer, consisting of grazing incidence optics that focus the incoming X-rays and then dispersed by high efficiency gratings. The spectrometer disperses to three laterally graded multilayer-coated mirrors (LGMLs) at 45degrees to the optical axis, achieving polarization modulation factors over 90%. The lateral grading changes the wavelength of the Bragg peak linearly across the mirror, matching the dispersion of the spectrometer. By dividing the entrance aperture into sectors, the intensities of the dispersed spectra after polarizing by the LGMLs give the three Stokes parameters needed to determine the source polarization. With imaging detectors (e.g., CCDs), we obtain polarization information along dispersed spectra, making the instrument a spectropolarimeter. The sounding rocket experiment, dubbed Rocket Experiment Demonstration of a Soft X-ray Polarimeter (REDSoX Polarimeter, name used with permission of Major League Baseball) is designed to measure linear X-ray polarization in the 0.16-0.35 keV band, targeting Mk 421, which is commonly modeled as a highly relativistic jet aimed nearly along the line of sight. Such sources are likely to be polarized at a level of 20% or more due to strong magnetization of jet plasma and is detectable in a 300 s exposure even if it is as low as 12%. Isolated neutron stars and pulsars with strong magnetic fields would be targets for future flights. Due to effects of vacuum birefringence predicted in quantum electrodynamics, we expect 80-100% polarization from such stars, which should be detectable in a sounding rocket flight. Our technological approach has significant promise for future orbital missions that would extend the bandpass to 1 keV. It is actually somewhat difficult to predict the scientific return due to the lack of any prior measurements in this band and the lack of extensive theoretical predictions. An orbital soft X-ray polarimeter would achieve a minimum detectable polarization (MDP) of 4% for a source at 1% as bright as Mk 421 with the same components as the REDSoX Polarimeter in a few days of observation. For an isolated neutron star such as RXJ0720-3125, the MDP would be 9% in each of 10 pulse phase bins in the same amount of time. Spectropolarimetry with an orbiting polarimeter could be used to test the nature of absorption features in the atmospheres of neutron stars and examine the reflected continuum between emission lines in Sy 2 galaxies, among other scientific goals. Laboratory development has also been proposed to expand the bandpass to cover the entire 0.1-1.0 keV band and increase the performance of the components. An instrument working in this band would complement observations in the 2-8 keV band by the Imaging X-ray Polarimetry Explorer (IXPE) and similar instruments as well as soft X-ray imagers. The design with a wider bandpass is being considered as one instrument on the X-ray Polarimetry Probe (XPP, see separate white paper).

Web link:

Name: Jonathan Grindlay

Proposing Team: Jonathan Grindlay (CfA), Branden Allen (CfA), Jaesub Hong (CfA), Scott Barthelmy (NASA/GSFC)

Type of Activity:
Space Based Project
Technological Development Activity

Description: Time-domain Astrophysics has never had a truly full-sky, full-time Telescope system for imaging and spectroscopy of electromagnetic radiation from astronomical objects. Only Gravitational Wave telescopes (LIGO/VIRGO) and Neutrino detectors (ICECUBE) have had this full-sky/full time capability to study the Universe. Photon collecting telescopes have been (nearly) full-sky, since the 1973 discovery (announcement) of Gamma-ray Bursts, but were not imaging or truly spectroscopic and with source location capability comparable to LIGO (>~100-1000 deg^2). This is now changing, and Astro2020 should be made aware of this, for it bodes well for a new era of Time-domain Astrophysics (TDA). The basic idea is simple, and only made possible by the exponential increase in capability of putting relatively low mass and cost wide-field telescopes on SmallSats in space. This is particularly true for photon counting, wide-field coded aperture X-ray telescopes, similar to (but more advanced than) the Burst Alert Telescope (BAT) on the Neil Gehrels Swift Observatory, which is dedicated to discovery and study of Gamma-ray Bursts (GRBs) and (primarily) accreting black hole sources in the 15 - 150 keV band. For the past 5 years, the Hard X-ray Imaging group at Harvard (Grindlay, Allen and Hong) have been developing increasingly higher resolution photon counting imaging X-ray detectors (CdZnTe; CZT, room-temperature operatopm) with wide-field coded aperture imaging that can be made relatively compact and low mass because pixel scales for smart readout can be made very small (300micron). We are completing a NASA supported Concept Study to put such a telescope on a SmallSat (~90 x 70 x 60cm) and will propose to fly it on a Mission of Opportunity to do new studies of black hole Low Mass X-ray Binaries (BH-LMXBs) and high energy transients with much finer source localization (~20 arcsec) and energy band (3 - 200 keV) than ever obtained. Why is this relevant or interesting for Astro2020? Because: 1. The cost of this telescope, with sensitivity ~3X better than BAT and yet mass (spacecraft included, with 10arcsec pointing) only 55 kg, and with ~1GB/day of data downlinked via rapidly expanding Broadband access from LEO, is estimated to be ~$8M for the first prototype, but only ~$3M for multiple copies. 2. and now the Real Motivation: with 32 of these SmallSats, launched ~4-8 at a time into ~20-40deg inclination orbits, the FULL SKY is imaged to 1 arcmin resolution with < 5-10arcsec source locations CONTINUOUSLY. 3. NO LIGO or VIRGO event is missed for lack of coverage; ALL GRBs are detected and located, opening up the z >6 Universe for long-awaited studies of the SFR(z) and evolution of the EOR(z) for studies of growth of structure PROVIDED there is rapid nIR-midIR imaging and spectrocopic followup from space with a facility like the proposed Probe-Class mission, Time-domain Spectroscopic Observatory (TSO) described in 7 White Papers submitted to Astro2020. 4. The SmallSat Constellation mission described we have named as the **4pi X-ray Imaging Observatory (4piXIO)** which could be flown and maintained as a SMEX class mission. Details are described in a paper submitted to SPIE (Grindlay et al 2019). 5. Bottom line? SmallSats are the new Discovery Engine. For many areas of Astrophysics in the 2020s, SmallSat Constellations can and will play a major role in science planning. These can/will affect what Flagship Missions can accomplish that would not be possible (e.g. prompt alerts) otherwise.

Web link:

Space Based and State of the Profession Activities

Name: Henrique Schmitt

Proposing Team:

Type of Activity:
Space Based Project
State of the Profession Consideration

Description: The Promise of Interferometry from Space in the Near Future High spatial resolution is a major driver of scientific discovery and development in astrophysics. However, in several areas of research, such as direct exo-planet detection, star formation and black hole environment studies, the telescope diameters needed to further advance the field are prohibitively large (100 m to several times the diameter of Earth). This limitation, combined with the fact that some of the observing bands can only be accessed from space (X-rays, ultraviolet, far-IR), points towards the need to invest in the development of space interferometry over the next few decades. NASA's astrophysics road map (Enduring Quests Daring Visions) has identified a series of short, medium and long range key scientific goals, several of which can only be achieved with interferometry from space. We will review the current state of the field of interferometry, both from the ground and space. We will discuss the advantages of going to space (broad wavelength coverage, baselines longer than Earth-diameter, stability, sensitivity, …), as well as which scientific fields (exo-planet detection, star formation, black hole environment and accretion disk characterization, gravitational wave, CMB polarization, …) would benefit the most from such facilities in the next few decades. Technological advances needed in order to address some of these key scientific goals will also be considered.

Web link:

Space Based Projects

Name: Jason Glenn

Proposing Team: Jason Glenn, Katherine Alatalo, Rashied Amini, Lee Armus, Andrew Benson, C. Matt Bradford, Jeremy Darling, Peter Day, Jeanette Domber, Duncan Farrah, Adalyn Fyhrie, Mark Shannon, Brandon Hensley, Sarah Lipscy, Bradley Moore, Sebastian Oliver, Benjamin Oppenheimer, David Redding, Michael Rodgers, Erik Rosolowsky, Raphael Shirley, John Steeves, Alexander Tielens, Carole Tucker, Gordon Wu, Jonas Zmuidzinas

Type of Activity:
Space Based Project

Description: GEP is a concept for a mid- and far-infrared (IR) space observatory purpose-designed to answer important questions about the evolution of star-formation and massive black holes in galaxies. GEP will measure star-formation rates and detect AGN even under conditions of heavy extinction. It will measure supermassive black hole accretion rates to address the connection between the masses of stellar populations and supermassive black holes. The same observations enable GEP to measure metallicities with extinction-free tracers to observe growth of metals over the last 2/3 of the Universe's age. In nearby galaxies, GEP will observe feedback between star-formation, AGN, and the interstellar medium (ISM) to understand the processes that regulate star-formation. By mapping nearby galaxies and the Galactic ISM, GEP will reveal the energy balance of the ISM by measuring the interstellar material mass, ionization state, and the local radiation field using fine-structure transitions of ions and polycyclic aromatic hydrocarbon (PAH) molecules. GEP will have a 2.0 m, 4 K telescope that will enable sensitivity limited by astrophysical sources: zodiacal dust emission and Galactic dust emission. GEP will have one scientific instrument with two modules: an imager, GEP-I, and a dispersive spectrometer, GEP-S. GEP-I will have 23 photometric bands distributed on the focal plane: 18 resolution R = 8 bands from 10–95 μm designed to measure photometric redshifts with PAHs and five resolution R = 3.5 bands from 95 to 400 μm to measure dust spectral energy distributions (SEDs) encompassing the SED peak to beyond z = 2. GEP S will be comprised of four long-slit grating spectrometers with spectral resolution R = 200 from 24 to 193 μm. Both modules will utilize arrays of kinetic inductance detectors (KIDs) cooled to 100 mK by a multistage adiabatic demagnetization refrigerator backed by a hybrid Joule-Thomson and Stirling cryocooler, which will also cool the telescope and coupling optics. GEP will achieve its goals with large, multi-tiered surveys for galaxies detected by their mid/far-IR emission from dust, PAHs, and atomic fine-structure lines. GEP will conduct two types of surveys: photometric with GEP-I and spectroscopic with GEP-S. The photometric survey areas will be 3, 30, and 300 sq deg, and an all-sky survey. The photometric redshift precision of galaxies will typically be $\sigma z \leq 0.1$. The spectral surveys will cover a range of low- and high-ionization atomic fine-structure lines. Spectral surveys will consist of 'blind' surveys utilizing a long-slit configuration and follow-up, deep pointed observations of galaxies identified in the photometric surveys, and the regions of the Milky Way and nearby galaxies. From mid/far-IR dust emission, PAHs, and atomic fine-structure lines, star formation rates and SMBH accretion rates will be calculated, and the abundances of metals in the atomic, molecular, and solid (dust) phases of the interstellar medium will be measured. Infrared luminosity functions of galaxies will be assembled as a function of redshift probing well below L* over large enough volumes to be immune to the effects of cosmic sample variance that often plague small-area surveys. By correlating physical properties as a function of redshift and environment, GEP will address the compelling science questions with unique data that cannot be obtained by any other means. GEPs observations will be highly complementary to current and future observatories that target UV and optical emission from stars and gas: it will probe properties of star-formation and the star-forming ISM rather than stellar masses and warm or hot ISM. More than 100 million galaxies will be detected, with mid-IR/far-IR SEDs measured, and redshifts obtained for more than 1 million galaxies. GEPs capability will be a major step forward in studies of star-forming galaxies over a significant fraction of cosmic time through a unique combination of medium-band photometry and spectroscopy that will never have been used before in an IR space observatory.

Web link:

Name: Jordan Camp

Proposing Team: Transient Astrophysics Probe team

Type of Activity:
Space Based Project

Description: We propose the Transient Astrophysics Probe (TAP), an observatory designed to greatly advance our astrophysical understanding of the transient Universe. TAP will feature the characterization of electromagnetic (EM) counterparts to Gravitational Waves (GW) involving mass scales from neutron stars (NS) to 109 M$\odot$ Supermassive Black Hole (SMBH) Binaries. TAP will also target a broad variety of time-domain astrophysical phenomena involving compact objects. To enable these scientific goals, we propose a multi-instrument platform, with rapid, high-sensitivity transient follow-up over a broad energy range. Wide-field X-ray (0.4 sr) and gamma-ray monitors (4π sr), a high-resolution sensitive X-ray telescope (0.8 deg2), and a wide-field infrared telescope (1 deg2) comprise the complementary instrument suite. This combination will discover transients deep into the Universe, and enable astrophysical characterization through broadband observations. The TAP observatory requires only one modest path of technology development, and fits credibly within the $1B cost cap. TAP science is directly responsive to the goals set forth by the Astro2010 Decadal Survey and the NASA Astrophysics Roadmap in the areas of gravitational waves and time domain astrophysics. The most exciting avenue of investigation in the TAP discovery space will be the astrophysical characterization of GW signals. The recent LIGO/Virgo discovery of a binary NS merger and its subsequent Multi-Messenger follow-up has generated enormous interest in future observation of EM counterparts to GW sources. TAP will host a set of X-ray and near-IR instruments that will provide an optimal means for follow-up and localization of GW detections by the LIGO-Virgo-KAGRA-LIGOIndia network of observatories, as well as X-ray follow-up of detections from the planned space-based GW observatory LISA (assuming launch dates for TAP and LISA are both in the late 2020s/early 2030s). Counterparts to very massive GW sources identified by Pulsar Timing Arrays (PTAs) are also likely to be detectable. TAP will follow up all GW events expected from multiple facilities across the GW frequency spectrum, spanning the BH range from a few to billions of solar masses. The scientific output will be prodigious, including insights in cosmology, nucleosynthesis, the engines of gamma-ray bursts (GRBs), the interaction of merging accretion disks, and tests of MHD/GR models of merging compact objects. In addition, TAP will address a multitude of transient astrophysical phenomena associated with compact objects (black holes and neutron stars; BHs and NSs) in a large range of environments, cosmic explosions (GRBs, Supernovae; SNe), and the launch and acceleration of matter in relativistic jets (Active Galactic Nuclei, AGN; Tidal Disruption Events, TDEs). Through its support of a broad user community in targeted as well as follow-up observations, TAP can be described as a "next-generation Swift observatory", with each of its instruments achieving roughly an order of magnitude improvement in performance relative to the corresponding Swift instruments. TAP will also enable the characterization of the high redshift Universe and the epoch of reionization by detecting GRBs to redshifts $z > 10$, addressing the nature of the first stars and inhomogeneous chemical evolution during its first manifestations. It will provide a bonanza of detections of tidal disruptions and core-collapse SN (ccSN) shock breakouts, in both near (using the WFI) and deep (using the XRT) fields, at sensitivities more than a factor of 10 higher than previous instruments including the all-sky monitor MAXI and Swift XRT, respectively. In its survey mode, TAP will perform a deeper and wide survey of the X-ray sky, most notably AGN, whose variability determination will allow us to effectively distinguish them as candidates for LISA and PTA GW counterparts. When TAP is not chasing newly discovered transients (onboard or following up sources from other facilities), it will conduct a broadband sky survey. There will be considerable synergy in the time-domain X-ray and IR observations afforded by TAP with other time-domain facilities including LSST (optical), and LOFAR and SKA (radio). Inspired by the model of the highly successful Swift mission, sensitive X-ray, optical and IR rapid follow-up instruments will provide valuable information on each detected transient or monitored source to a broad user community.

Web link: https://asd.gsfc.nasa.gov/tap/

Name: Yun Wang

Proposing Team: ATLAS Probe Team

Type of Activity:
Space Based Project

Description: The observational data from recent years have greatly improved our understanding of the Universe. However, we are far from understanding how galaxies form and develop in the context of an evolving "cosmic web" of dark matter, gas and stars, and the nature of dark energy remains a profound mystery 20 years after the discovery of cosmic acceleration. Understanding galaxy evolution in the context of large-scale structure is of critical importance in our quest to discover how the Universe works. This requires very large spectroscopic surveys at high redshifts: very large numbers of galaxies over large co-moving volumes for robust statistics in small redshift bins ranging over most of cosmic history. In particular, we need to map the cosmic web of dark matter using galaxies through most of cosmic history; this requires in addition a redshift precision of ~0.0001 (i.e., slit spectroscopy), and continuous IR coverage only possible from space. These observational requirements also enable definitive measurements on dark energy with minimal observational systematics by design. A very high number density wide area galaxy redshift survey spanning the redshift range of $0.5< z< 4$ using the same tracer, carried out using massively parallel wide field multi-object slit spectroscopy from space, will provide definitive measurements that can illuminate the nature of dark energy, and lead to revolutionary advances in particle physics and cosmology. The currently planned projects do not meet these science goals. JWST has slit spectroscopic capability, but a relatively small FoV, thus unsuitable for carrying out surveys large enough to probe the relation between galaxy evolution and environment in a statistically robust manner. Both Euclid and WFIRST employ slitless grism spectroscopy, which increases background noise and will limit their capability to probe galaxy evolution science. Euclid and WFIRST spectra only cover wavelengths below 2 microns, severely restricting opportunities to measure multiple diagnostic emission lines. Euclid and WFIRST, and the ground-based project DESI, will significantly advance our understanding of the nature of dark energy, but they do not provide definitive measurements for its resolution, due to limits inherent to each. The lack of slit spectroscopy from space over a wide FoV is the obvious gap in current and planned future space missions. ATLAS Probe fills this gap in order to address the fundamental questions on galaxy evolution and the dark Universe. ATLAS (Astrophysics Telescope for Large Area Spectroscopy) Probe is a concept for a NASA probe-class space mission that will achieve groundbreaking science in the fields of galaxy evolution, cosmology, Milky Way, and the Solar System. It is the spectroscopic follow-up space mission to WFIRST, boosting its scientific return by obtaining deep 1 to 4 micron slit spectroscopy in three tiered galaxy redshift surveys (wide: 2000 sq deg; medium: 100 sq deg; deep: 1 sq deg) for most of the galaxies imaged by the ~2000 sq deg WFIRST High Latitude Survey at $z>0.5$. ATLAS spectroscopy will measure accurate and precise redshifts for ~ 200M galaxies out to $z = 7$ and beyond, and deliver spectra that enable a wide range of diagnostic studies of the physical properties of galaxies over most of cosmic history. ATLAS Probe and WFIRST together will produce a 3D map of the Universe over 2,000 sq deg, the definitive data sets for addressing science goals spanning four broad categories: (1) Revolutionize galaxy evolution studies by tracing the relation between galaxies and dark matter from galaxy groups to cosmic voids and filaments, from the epoch of reionization through the peak era of galaxy assembly; (2) Obtain definitive measurements of dark energy and tests of General Relativity using galaxy clustering; (3) Probe the Milky Way's dust-enshrouded regions, reaching the far side of our Galaxy; (4) Characterize Kuiper Belt Objects in the outer Solar System. ATLAS Probe is a 1.5m telescope with a FoV of 0.4 sq deg, and uses Digital Micro-mirror Devices (DMDs) as slit selectors. It has a spectroscopic resolution of R = 1000, and a wavelength range of 1-4 microns. ATLAS has an unprecedented spectroscopic capability based on DMDs, with a spectroscopic multiplex factor ~6,000. ATLAS is designed to fit within the NASA probe-class space mission cost envelope; it has a single instrument, a telescope aperture that allows for a lighter launch vehicle, and mature technology (DMDs can reach TRL 6 within two years). The pathfinder for ATLAS Probe, ISCEA (Infrared SmallSat for Cluster Evolution Astrophysics), has been selected by NASA for a mission concept study. We anticipate ATLAS Probe to be launch ready by 2030. ATLAS Probe will lead to transformative science over the entire range of astrophysics.

Web link: http://atlas-probe.ipac.caltech.edu/

Name: Kerri Cahoy

Proposing Team:

Type of Activity:
Space Based Project

Description: We propose to use satellite laser guide stars to improve the stability of large segmented telescopes, by enabling them to perform fast and effective wavefront control. One application of this is to exoplanet direct imaging (although imaging of any faint objects would benefit). This approach can be demonstrated between a satellite with a narrow beam laser transmitter that can fine point to a ground-based segmented telescope with AO. The laser guide star transmit terminals are easily brighter than vmag -4, compared with sodium laser guide stars which are typically vmag 9-10. The transmit modules can be based on TRL9 free space laser communications technology, which has been demonstrated from GEO to LEO and GEO to ground since 2005 or earlier. The laser guide star wavelength can be out of band from the science band, and the laser guide stars can also be used for photometric calibration. With increases in performance from CubeSats, which have now performed interplanetary missions, it is possible to build several cost-effective laser guide star transmitting spacecraft that can formation fly along the line of sight from the observing telescope (on the ground or in space) to targets. The satellite laser guide star systems relax stability requirements on primary segmented apertures by increasing the capability of the wavefront sensing and control system (more photons) and also allow the observing system to reach more and fainter targets.

Web link:

Name: Paul Ray

Proposing Team: STROBE-X Steering Committee and Science Working Group

Type of Activity:
Space Based Project

Description: We present the Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays (STROBE-X), a probe-class mission concept selected for study by NASA. It combines huge collecting area, high throughput, broad energy coverage, and excellent spectral and temporal resolution in a single facility. STROBE-X offers an enormous increase in sensitivity for X-ray spectral timing, extending these techniques to extragalactic targets for the first time. It is also an agile mission capable of rapid response to transient events, making it an essential X-ray partner facility in the era of time-domain, multi-wavelength, and multi-messenger astronomy. Optimized for study of the most extreme conditions found in the Universe, its key science objectives include: (1) Robustly measuring mass and spin and mapping inner accretion flows across the black hole mass spectrum, from compact stars to intermediate-mass objects to active galactic nuclei. (2) Mapping out the full mass-radius relation of neutron stars using an ensemble of nearly two dozen rotation-powered pulsars and accreting neutron stars, and hence measuring the equation of state for ultradense matter over a much wider range of densities than explored by NICER. (3) Identifying and studying X-ray counterparts (in the post-Swift era) for multiwavelength and multi-messenger transients in the dynamic sky through cross-correlation with gravitational wave interferometers, neutrino observatories, and high-cadence time-domain surveys in other electromagnetic bands. (4) Continuously surveying the dynamic X-ray sky with a large duty cycle and high time resolution to characterize the behavior of X-ray sources over an unprecedentedly vast range of time scales. STROBE-X's formidable capabilities will also enable a broad portfolio of additional science.

Web link: https://arxiv.org/abs/1903.03035

Name: Christopher Walker

Proposing Team: University of Arizona (Lead), Southwest Research Institute, Jet Propulsion Laboratory, NASA Wallops Flight Facility, Ball Aerospace Corporation

Type of Activity:
Space Based Project

Description: Our team will submit a white paper describing an inflatable 15 meter class space telescope suitable for operation from radio to THz frequencies (a.k.a. the Far-Infrared). The Orbiting Astronomical Satellite for Investigating Stellar Systems (OASIS) will be able to probe conditions and search for biogenic molecules (e.g. water) in the habitable zones of nearby planetary systems and in the products of outgassing from solar system objects (planets, moons, comets, and asteroids). The telescope consists of an inflatable, metallized spherical reflector secured to a spacecraft bus via an inflated deployable conical support structure. Light passes through the transparent, front hemispherical surface and reflects off the metallized back surface. The reflected waves come to a focal line at ~1/4 of the reflector's radius of curvature, ~24 meters. A spherical corrector, formed from optical components, then collapses the focal line to a focal point for the detectors (e.g. coherent and incoherent). The wide FOV of a spherical reflector allows the emergent beam to be redirected through wide angles without the need of adjusting the attitude of the spacecraft/telescope. The innovative inflatable structure allows packaging of a large aperture telescope within available launch volumes/masses. At launch the entire telescope fits within a ~1 m^3 volume. The proposed effort directly addresses NASA's Strategic Goal 1.1; Understanding the Sun, Earth, Solar System, and Universe. The soaring cost of JWST suggests the traditional approach to realizing large space apertures is reaching its practical limit. The OASIS concept breaks with tradition and will serve as a pathfinder for a new generation of large space telescopes capable of seeking out harbingers of life within the solar system and beyond. Spherical reflectors have been used in space and ground based systems since the early 1960's. The largest space-based structures were Echo I (30.5 m, 1960) and II (41.1 m, 1964). These 0.5 mil thick, aluminized Mylar spheres were deployed in space and used as passive reflectors, with microwave signals from ground stations being reflected off their outer skins. During this same time period the Arecibo radio telescope with a 305 m spherical reflector was built. Spherical reflectors are far easier to make and have far greater off-axis scanning abilities (1000's of beams) than parabolic reflectors (~10's of beams). Under the NASA Innovative Advanced Concept (NIAC) Program our team conducted a Phase I and II design study that brought together inflatable and spherical reflector technologies for the first time and demonstrated the possibility of realizing light weight, high performance, large aperture telescopes. OASIS will be placed in an Earth trailing orbit and used to probe the water content and mass of stellar systems out to ~250 pc. It can also be used to study water outgassing and D/H ratios from moons, comets, etc. in our own solar system. These observations will be used to probe for the presence of subsurface bodies of water and investigate the origin of Earth's oceans. OASIS can also be used to determine the physical conditions within the nuclei and disks of nearby galaxies. The OASIS instrument package is derived from the detector development efforts for Herschel, SOFIA, STO, and GUSTO. The estimated cost of the OASIS mission is < $250M and, therefore, fits within the cost cap of a NASA MIDEX mission.

Web link:

Name: Davd Ardila

Proposing Team:

Type of Activity:
Space Based Project

Description: Small satellites (SmallSats; < 180 kg) provide astrophysics with new avenues for access to space. We'll argue that there are scientific and technological questions that can be addressed by using SmallSat plattforms, but astrophysics that has yet to take full advantage of these opportunities. We will describe the current SmallSat revolution, the Astrophysics problems that are amenable to a SmallSat solution, as well as areas where more technical development is needed.

Web link:

Name: Jeremy Heyl

Proposing Team: Colibrì Collaboration

Type of Activity:
Space Based Project

Description: Colibrì is a proposed X-ray telescope designed to unveil the mysteries of neutron stars and black holes. Nature's densest objects, neutron stars and black holes, can grow by feeding on (accretion) disks of nearby material, can launch material at speeds near that of light (in what is called relativistic jets), and can warp the very space-time surrounding them. By feeding several arrays of transition-edge x-ray detectors with collecting optics, Colibrì will be able to detect over 250,000 X-rays each second from bright X-ray sources in the energy range of 100 eV to 25 keV, and measure the energy of each photon with a precision of a few eV and its arrival time with a precision of 100 ns. By combing high-time-resolution, high-throughput and high-energy resolution, Colibrì observations could answer important questions: * What is the structure of the spacetime surrounding black holes? * How are relativistic jets launched? * What are the masses and radii of neutron stars? * How is material transported in accretion disks?

Web link: http://www.colibri-telescope.ca

Name: Max Joshua

Proposing Team:

Type of Activity:
Space Based Project

Description: The Twinkle Space Mission is a space-based observatory that has been conceived to measure the atmospheric composition of exoplanets. This cost-effective spacecraft is being constructed on a short timescale in the UK and is planned for launch in 2022. The satellite uses a high-heritage satellite platform and instrumentation built by a consortium of UK and European institutes. It will carry a 0.45m telescope with two scientific instruments: a visible spectrograph based on UVIS (which is currently flying on the ExoMars Trace Gas Orbiter) and an infrared spectrograph. Together, these spectrographs provide simultaneous wavelength coverage from 0.4 to 4.5µm with resolving power up to R=250. The spacecraft will be launched into a Sun-synchronous low-Earth polar orbit at ~700km, and will have a baseline lifetime of seven years. Twinkle will have the capability to provide high-quality visible and infrared spectroscopic characterisation of hundreds of bright exoplanets, including at least 100 currently-known exoplanets. It will also be capable of follow-up photometric observations of 1000 or more exoplanets. Photometric measurements, taken simultaneously in the visible and the infrared bands, will allow orbital parameters of systems to be well-constrained and enable precise measurements of transit timing variations present in multiple planetary systems. The exoplanet targets observed by Twinkle will be composed of known exoplanets discovered by existing and upcoming ground- and space-based surveys, including TESS, GAIA, K2, CHEOPS, WASP and HATSouth. Thanks to its pointing and tracking capabilities, Twinkle will also be able to observe solar system objects including asteroids, comets, the outer planets and their moons. Twinkle could provide a spectroscopic population study of asteroids and comets to study their surface composition, following up on the discoveries of LSST. Given that Twinkle's instrumentation has been optimised for observing exoplanets, it will also be able to obtain high-SNR spectra of the outer planets and moons in our solar system within very brief exposure times. Twinkle's wavelength coverage and position above the atmosphere will make it particularly well-suited for studying spectral features that are obscured by telluric lines from the ground, including hydration features, organics, silicates and CO_2. While Twinkle has been designed with these exoplanet and solar system science cases in mind, the spacecraft itself is a general observatory which will provide on-demand observations of targets at the requests of its users. Scientists worldwide can access telescope time on Twinkle through a simple, streamlined process, and then decide freely how to allocate their observing time. The spacecraft will be available to researchers based in the US; this upcoming white paper will provide details on the model and the science interests of the US community. More information about the mission is available at www.twinkle-spacemission.co.uk

Web link: www.twinkle-spacemission.co.uk

Name: James Thorpe

Proposing Team: LISA

Type of Activity:
Space Based Project

Description: Note to the committee: We understand that Astro2020 will address LISA through a tailored process. This NOI is intended to provide a helpful basis for developing that process. The Laser Interferometer Space Antenna (LISA) is a space-based observatory of gravitational waves currently under development by the European Space Agency (ESA), NASA, and several European national agencies. LISA will provide access to the milliHertz frequency band of the gravitational wave spectrum, a regime that is populated with a rich mixture of astrophysical sources including tens of thousands of resolvable compact binary systems in the Milky Way, captures of stellar-remnant black holes by massive black holes in the nuclei of nearby galaxies, and mergers of massive black holes out to redshifts of 20 or more. Observations of these sources will provide insight into a number of important questions in cosmology, astrophysics, and fundamental physics including the formation and evolution of massive black holes, the nature of gravity, and the end states of stellar evolution. There is also the tantalizing, though necessarily uncertain, possibility of unforeseen sources in the milliHertz band which could have an even greater impact on our understanding of the Universe. Further details into specific LISA science applications can be found in a number of white papers which have been submitted to the Astro2020 Science White Paper Call. The LISA mission concept, which has been steadily developed over several decades, calls for a triangular constellation of three spacecraft separated by 2.5 million kilometers. Each spacecraft carries a pair of reference masses which act as freely-falling test particles to enable measurement of passing gravitational waves. Reaching LISA sensitivities requires that these test masses limit their deviations from inertial motion to accelerations at the femto-g level, a challenging requirement that was demonstrated by the LISA Pathfinder spacecraft in 2016. An optical interferometry system is used to monitor fluctuations in the distance between the LISA spacecraft at the level of picometers. This system is built on heritage from LISA Pathfinder, which demonstrated sub-picometer optical metrology over short baselines; the Laser Ranging Instrument on GRACE-FO, which demonstrated sub-nanometer ranging over ~300km baselines; and dedicated LISA technology development activities in the US and Europe over the past two decades. The LISA mission concept (arXiv:1702.00786) was proposed by a group of European and US scientists and selected by ESA in the summer of 2017 to fulfill the Gravitational Universe science theme (arXiv:1305.5720), which was selected in 2013 as the science theme for the 3rd Large-class mission in ESA's Cosmic Vision Programme. Today's LISA shares all of the important characteristics of the NASA-led LISA mission concept that was recommended as the 3rd priority in the large mission category in 2010's New Worlds, New Horizons report. The constellation is a full triangle, providing important polarization information, while the baseline mission duration is four years with mission extension possible to ten years. This is consistent with Recommendation 4-4 of the 2016 Midterm Assessment which stated that "One goal of U.S. participation should be the restoration of the full scientific capability of the mission as envisioned by NWNH". ESA will serve as the lead agency for LISA, with significant contributions to the science instrument, science operations, and analysis expected from a consortium of European national agencies and NASA. ESA and NASA are currently collaborating under a Letter of Agreement which allows the agencies to cooperate on a range of formulation activities. In 2017, NASA created the NASA LISA Study

Office to coordinate NASA's LISA activities with the primary near-term goal of identifying a specific set of US contributions to LISA that provide maximum benefit to the US community while satisfying programmatic and cost constraints. In addition to the LISA Study Office, NASA also convened the NASA LISA Study Team, a community group which represents the potential future LISA user base and provides input to help guide the activities of the Study Office and NASA HQ.   NASA is currently funding five separate technology development efforts as well as studying a number of potential contributions to the spacecraft platform and science operations. Under the current budget guidance from NASA HQ and the Office of Management and Budget, NASA would be able to provide a subset of these potential contributions. A consolidated set of US contributions to LISA will be defined and agreed upon prior to ESA's "mission adoption" milestone, currently expected in late 2023. Input from Astro2020 will be an important factor in determining the scope of the US contributions and the nature of the US community's participation in LISA science.

Web link: http://lisa.nasa.gov

Name: Sara Heap

Proposing Team: CETUS Probe Mission Concept

Type of Activity:
Space Based Project

Description: The CETUS mission concept is a 1.5-m wide-field UV telescope that will be a worthy successor to Hubble, a companion to multi-wavelength survey telescopes of the 2020's, and a scout for extremely large ground-based telescopes. With its wide-field camera, multi-object slit spec-trograph, and point source/long-slit spectrograph, CE-TUS will not only maintain observational access to the ul-traviolet (UV) after Hubble is gone but also will provide new capabilities that were unavailable to Hubble. These new capabilities will enable CETUS to address 9 of the 20 Key Science Questions posed by Astro2010. We expect that the cost to NASA for CETUS over its full lifecycle (Phases A-F) will be $1B or less.

Web link:

Name: Alexey Vikhlinin

Proposing Team: Lynx mission study team

Type of Activity:
Space Based Project

Description: Lynx is one of the four large mission studies commissioned by NASA in 2016. Lynx is the next-generation X-ray observatory which will provide unprecedented X-ray vision into the otherwise invisible Universe with unique power to directly observe the dawn of supermassive black holes, reveal the drivers of galaxy formation, trace stellar activity including effects on planet habitability, and transform our knowledge of endpoints of stellar evolution. These science goals will be enabled by a mission design that combines lightweight X-ray mirrors with a high-definition X-ray imager with 0.5" pixels, a microcalorimeter with 0.3 eV energy resolution, and a large effective area grating spectrometer with a resolving power of 7500. Just as importantly, these features will facilitate a broadly capable observatory for the community that is able to tackle not only the known outstanding key science questions but whatever new problems are revealed in the coming decade.

Web link: https://www.lynxobservatory.com

Name: Sara Heap

Proposing Team: Study Team:Jim Burge, Martin Valenti (Arizona Optical Systems); Charles Cox (Collins Aerospace); Bill Danchi (GSFC); Kelly Dodson, Greg Mehle, Matt Tomic (NGIS-San Diego); W. Eckles (NGIS Gilbert); Brian Fleming (U. of Colorado); Sally Heap (U. Maryland); Tony Hull (U. New Mexico); Steve Kendrick (Kendrick Aerospace Consulting); Stephan McCandliss (JHU); Coralie Neiner (Paris Obs./Meudon); Shouleh Nikzad (JPL); John MacKenty (STScI); Lloyd Purves, Manuel Quijada, Mike Rhee (GSFC); David Redding (JPL); Dave Sheikh (ZeCoat); Oswald Siegmund (Berkeley Space Science Laboratory); Robert Woodruff (Woodruff Consulting) Science Investigators: R. Bezanson, L. Bianchi, J-C Bouret, D. Bowen, B. Cenko, W. Danchi, S. Driver, E. Dwek, B. Fleming, K. France, P. Gatkine, S. Gezari, J. Greene, M. Hayes,T. Heckman, E. Hodges-Kluck, S. Heap; D. Kunth, A. Kutyrev, T. Lanz, J. MacKenty, S. McCandliss, H. Moseley, C. Neiner, G. Östlin, C. Pacifici, M. Rafelski, J. Rigby, D. Spergel, I. Roederer, D. Stark, A. Szalay, T. Tripp, J. Trump, A. van der Wel, S. Veilleux, K. Whitaker, R. Wyse

Type of Activity:
Space Based Project

Description: This letter is to declare our intent to present a Probe-class mission concept called CETUS to Astro2020 in July 2019. CETUS is a 1.5-m wide-field UV telescope that will be a worthy successor to Hubble, a companion to multi-wavelength survey telescopes of the 2020's, and a scout for extremely large ground-based telescopes. With its wide-field camera, multi-object slit spec-trograph, and point source/long-slit spectrograph, CE-TUS will not only maintain observational access to the ul-traviolet (UV) after Hubble is gone but also will provide new capabilities that were unavailable to Hubble. These new capabilities will enable CETUS to address 9 of the 20 Key Science Questions posed by Astro2010. We expect that the cost to NASA for CETUS over its full lifecycle (Phases A-F) will be $1B or less.

Web link:

Name: Angela Olinto

Proposing Team: POEMMA collaboration

Type of Activity:
Space Based Project

Description: The Probe Of Extreme Multi-Messenger Astrophysics (POEMMA) is a probe Class B mission designed to observe ultra-high energy cosmic rays (UHECRs) and cosmic neutrinos (CNs) from space. POEMMA will monitor colossal volumes of the Earth's atmosphere to detect extensive air showers (EASs) produced by extremely energetic cosmic messengers: UHECRs above 20 EeV over the full sky and cosmic neutrinos above 20 PeV. POEMMA is comprised of two identical observatories flying in formation to detect EASs in mono and stereo modes. Each observatory is composed of a 4-meter photometer designed with Schmidt wide (45 degrees) field-of-view (FoV) optics and a spacecraft bus. The photometer focal surface has a hybrid design for two complementary capabilities: a fast (1 microsecond) fluorescence ultraviolet camera and an ultrafast (10 nanosecond) optical Cherenkov camera. EASs from UHECRs and cosmic neutrinos are observed from an orbit altitude of 525 km and a range of attitudes in the dark sky. POEMMA will point from close to the nadir, to optimize stereo fluorescence observations, to about 47 degrees from the nadir to monitor the Earth's limb (located at 67.5 degrees) for Cherenkov emission from CN (below the limb) and UHECR (about 2 degrees above the limb) airshowers. POEMMA will provide a significant increase in the statistics of observed UHECRs at the highest energies over the entire sky and will have a target of opportunity (ToO) follow-up program for cosmic neutrinos from extremely energetic transient astrophysical events. POEMMA will: Discover the nature and origin of the highest-energy particles in the universe. Where do UHECRs come from? What are these extreme cosmic accelerators and how do they accelerate to such high energies? What is the UHECR composition at the highest energies? What are the magnetic fields in the extragalactic and galactic media? How do UHECRs interact in the source, in extragalactic and galactic space, and in the atmosphere of the Earth? Discover neutrino emission above 20 PeV for extreme astrophysical transients. What is the high-energy neutrino emission of gravitational wave events? Do neutron-star binary emit neutrinos when they coalescence? What causes fast-luminous optical transients? Do gamma-ray bursts, blazar flares, and other transients produce neutrinos above 20 PeV? Probe particle interactions at extreme energies. POEMMA can test models with physics Beyond the Standard Model (BSM) through cosmic neutrino observations from tens of EeVs to tens of ZeVs. Observe Transient Luminous Events contributing to understanding the dynamics of the Earth's Atmosphere including extreme storms. Observe Meteors contributing to understanding the dynamics of meteors in the Solar System. Search for Exotic particles such as nuclearites. POEMMA will provide new Multi-Messenger Windows onto the most energetic environments and events in the universe enabling the study of new astrophysics and particle physics at these otherwise inaccessible energies.

Web link:

Name: Aki Roberge

Proposing Team: LUVOIR Mission Concept Study Team

Type of Activity:
Space Based Project

Description: The Large UV/Optical/IR Surveyor (LUVOIR) mission concept is one of four Decadal Survey Mission Concepts studied in preparation for the Astro2020 Decadal Survey. This guest observer-driven observatory will enable revolutionary breakthroughs in astrophysics, solar system science and exoplanet science. Astrophysics research envisioned includes star and planet formation, ISM studies, galaxy formation and evolution, and cosmological studies from the epoch of reionization forwards. Powerful remote sensing observations of solar system bodies will be enabled. And finally, the major science driver for the design of the LUVOIR observatory is characterization of large numbers of diverse exoplanets. This includes spectroscopy of sufficient numbers of potentially habitable planets to constrain the frequency of habitable, Earth-like conditions and enable searches for global biospheres. The LUVOIR study, which began in Jan 2016, is led by a Science and Technology Definition Team (STDT) chaired by Profs. Debra Fischer (Yale) and Bradley Peterson (Ohio State). The study office and engineering team are located at NASA Goddard Space Flight Center. Over the last three years, the LUVOIR study has greatly benefited from broad participation of scientists, technologists, and engineers drawn from academic institutions (US and international), other NASA centers, and the aerospace industry. During the study, the LUVOIR Team developed a set of compelling science questions and goals. These were translated into observational needs, which were used to determine the necessary telescope and instrumentation characteristics. The engineering team has turned those characteristics into two complete observatory designs: LUVOIR-A, with a 15-m diameter, on-axis primary telescope mirror; and LUVOIR-B, with an 8-m diameter, off-axis primary. Both telescopes are segmented and deployable, intended for a single launch. The basic LUVOIR design is highly scalable and responsive to a changing landscape in launch vehicles, as demonstrated by the LUVOIR-B architecture. Further, both observatories were designed to be serviceable, either by robots or astronauts. This design choice was driven by the goal of providing decades of transformative science, in the tradition of the Hubble Space Telescope and other Great Observatories, and brings the added benefit of reducing the complexity of integration and testing on the ground. Four science instruments were studied and designed: ECLIPS, an ultra-high contrast NUV/optical/NIR coronagraph with imaging and spatially resolved spectroscopic capabilities; HDI, a high resolution, wide-field NUV/optical/NIR imaging camera; LUMOS, a UV/optical multi-object spectrograph with FUV imaging capability; and POLLUX, a UV point-source spectropolarimeter. POLLUX was studied and designed by a consortium of European institutions, with support from the French Space Agency (CNES). This instrument suite spans a total wavelength range from the far-UV (100 nm) to the near-IR (2.5 microns). The studied instruments represent a subset of those that could be chosen for LUVOIR, either in the first or a subsequent generation. Additional instrument ideas have been provided by the US and international community. The major technological challenges for LUVOIR are driven by the following scientific need. The coronagraph must be able to obtain direct spectra of Earth-like exoplanets in the habitable zones of Sun-like stars, i.e., observe planets that are 10 billion times fainter than their stars at optical wavelengths. Obtaining such high contrast (about 10 times better than the current state-of-the-art) demands an exquisitely stable wavefront impinging on the occulting masks within the coronagraph. The LUVOIR observatories were designed to achieve this goal by 1) minimizing mechanical and thermal disturbances throughout the observatories 2), utilizing multiple levels of metrology and active wavefront control, and 3) designing coronagraphs that are more tolerant of the expected wavefront errors. The LUVOIR team has created a technology development plan and schedule to demonstrate the system-level performance of these designs; some of this work is already in progress through NASA-funded industry studies. Finally, realizing such a large and complex observatory as LUVOIR will require careful attention to project management. The LUVOIR Final Report will also present ideas and suggestions, both from our team and from industry partners, for improved management and engineering practices learned from previous large missions. We are planning to prepare a classified appendix for the Final Report, so that industry partners and other governmental agencies may provide the most up-to-date technical information; we would appreciate consideration of how Astro2020 will handle that material. Thus, the LUVOIR Team hopes to make this scientifically revolutionary observatory feasible in the coming decades. More info on LUVOIR and the study, including the Interim Report, can be found at http://asd.gsfc.nasa.gov/luvoir/.

Web link: http://asd.gsfc.nasa.gov/luvoir/

Name: Asantha Cooray

Proposing Team: Cosmic Dawn Intensity Mapper (CDIM) Probe Mission Study

Type of Activity:
Space Based Project

Description: The Cosmic Dawn Intensity Mapper (CDIM) will transform our understanding of the era of reionization when the Universe formed first stars and galaxies, and UV photons ionized the neutral medium. CDIM goes beyond the capabilities of upcoming facilities by carrying out wide area spectro-imaging surveys, providing redshifts of galaxies and quasars during reionization as well as spectral lines that carry crucial information on their physical properties. CDIM will make use of unprecedented sensitivity to surface brightness to measure the intensity fluctuations of reionization on large-scales to provide a valuable and complementary dataset to 21-cm experiments. The baseline mission concept is an 83-cm infrared telescope equipped with a focal plane of 24 x 2048^2 detectors capable of R = 300 spectro-imaging observations over the wavelength range of 0.75 to 7.5 µm using Linear Variable Filters (LVFs). CDIM provides a large field of view of 7.8 deg^2 allowing efficient wide area surveys, and instead of moving instrumental components, spectroscopic mapping is obtained through a shift-and-stare strategy through spacecraft operations. CDIM design and capabilities focus on the needs of detecting faint galaxies and quasars during reionization and intensity fluctuation measurements of key spectral lines, including Lyman-α and Hα radiation from the first stars and galaxies. The design is low risk, carries significant science and engineering margins, and makes use of technologies with high technical readiness level for space observations. The only technological development item essential for the mission is the development of R=300 linear variable filters, from existing technology that is readily available for low R observations (the recently-selected MIDEx mission SPHEREx will have R=40-150 LVFs). CDIM can be easily extended or scientific operations reconfigured for us as a general purpose astronomical facility, allowing a number if studies including those that are essential for time-sensitive observations such as LISA electromagnetic counterpart searches. CDIM is a NASA-funded Probe mission concept study, with engineering design work led at JPL. CDIM is supported by a science team from educational and research institutions based in US and Europe. The mission easily meets the NASA cost target for a Probe mission of less than $1B, including launch and science operations.

Web link:

Name: Scott Gaudi

Proposing Team: The HabEx Study Team

Type of Activity:
Space Based Project

Description: For the first time in human history, technologies have matured sufficiently to enable an affordable space-based telescope mission capable of discovering and characterizing habitable planets like Earth orbiting nearby bright sunlike stars. Such a mission can also be equipped with instrumentation with unique capabilities that will enable broad and exciting general astrophysics and planetary science not possible from current or planned ground-based or space-based facilities. The Habitable Exoplanet Observatory, or HabEx, has been designed to be the Great Observatory of the 2030s, with community involvement through a competed and funded Guest Observer (GO) program. HabEx is a 4-meter diameter telescope with ultraviolet (UV), optical, and near-infrared (near-IR) imaging and spectroscopic capabilities. HabEx has three driving science goals: • HabEx will seek out nearby worlds and explore their habitability. A pervasive and fundamental human question is: Are we alone? Astronomy has recast this elemental inquiry into a series of questions: Are there other Earths? Are they common? Do any have signs of life? Space-based direct imaging above the blurring effects of Earth's atmosphere is the only way to discover and study Earth-sized planets in Earth-like orbits about sunlike stars. With unparalleled high-contrast direct imaging and spectroscopy, HabEx will find dozens of rocky worlds and over a hundred larger planets around mature stars. HabEx will characterize many of these exoplanets by determining orbits and obtaining multi-epoch broadband spectra. Of particular interest for investigations of Earth-like exoplanets, HabEx will be able to robustly detect water vapor, molecular oxygen, ozone, and Rayleigh scattering, if these features have spectral signatures (e.g., column densities) similar to that of modern Earth. In addition, HabEx will be able to detect other potential biosignature molecules, such as methane and carbon dioxide, if they have concentrations higher than modern Earth. For our nearest neighbors, HabEx will also search for evidence of surface liquid water oceans on exo-Earth candidates. • HabEx will map out nearby planetary systems and understand the diversity of the worlds they contain. With high-contrast 12×12 arcsec2 (equivalent to 36×36 AU2 at a distance of 3 pc) observations using an instrument in conjunction with an external starshade, HabEx will be the first observatory capable of providing complete "family portraits" of our nearest neighbors. HabEx will be able to characterize exo-analogs of Earth and Jupiter, as well as exo-analogs to the zodiacal dust disk and the Kuiper belt. HabEx is also expected to find and characterize a diversity of worlds that have no analogs in our solar system, including super-Earths and sub-Neptunes. Discoveries around the nearest stars will provide detailed planetary system architectures, enabling tests of planet formation theories, studies of exoplanetary diversity, and investigations of planet-disk interactions. HabEx will place our solar system into the context of other exoplanetary systems for the first time. • HabEx will enable new explorations of astrophysical systems from our own solar system to galaxies and the universe by extending our reach in the UV through near-IR. HabEx will be NASA's Great Observatory in the 2030s. Observing with a large aperture from above the Earth's atmosphere in an era when neither HST nor JWST are operational, HabEx will provide the highest-resolution images ever obtained at UV and optical wavelengths. These capabilities allow for a broad suite of unique, compelling science that cuts across the entire NASA astrophysics portfolio, including topics as diverse as the life cycle of baryons, cosmic ionizing background sources, the first generations of stars and supernovae, constraints on dark matter models, the local cosmic expansion rate, protoplanetary disks, and novel observations of our own solar system. This "Great Observatory" science, which will account for about 50% of the HabEx primary mission and likely 100% of any extended mission, will be selected through a competed GO program, taking advantage of the community's imagination and priorities to maximize the science return of the mission. The preferred HabEx architecture is a 4-meter, monolithic, off-axis telescope that is diffraction-limited at 0.4 μm, launched on an SLS 1B launch vehicle to an Earth-Sun L2 orbit. HabEx has two complimentary starlight suppression systems: a coronagraph and a starshade, each with their own dedicated instruments for exoplanet imaging and spectroscopy. HabEx also has an imaging camera and a spectrograph, together capable of observing from ultraviolet to near-IR. All of the enabling technologies for HabEx are TRL 4 or above. The twelve TRL 4 technologies are related to coronagraphy, the starshade, low-noise detectors, and large mirrors. The HabEx study also considers eight other lower-cost architectures, each with fewer enabling technologies requiring development than the preferred architecture.

Web link: https://www.jpl.nasa.gov/habex/

Name: Rhonda Morgan

Proposing Team: HabEx design team

Type of Activity:
Space Based Project

Description: We intend to submit a white paper about the technology maturity and development roadmaps for the Habitable Exoplanet Observatory (HabEx) Concept study. HabEx is one of four concept studies sponsored by the NASA Astrophysics Division as potential future flagship missions. A white paper that summarizes the HabEx mission will be submitted separately. This white paper will cover the technology maturity and paths of development. The contributors are the members of the HabEx STDT and design team. Since the 2010 Decadal Survey, the technologies needed for direct imaging of exoplanets advanced significantly. NASA investment in these technologies, prioritized in the 2010 Decadal Survey (NRC 2010), have ripened to a maturity to enable direct imaging of earthlike exoplanets. The investment in the WFIRST CGI has matured coronagraph architectures, deformable mirrors (DMs), and electron multiplying CCD detectors (EMCCDs). The Starshade to TRL 5 (S5) task became an official project to develop starshade technologies to TRL 5 by 2023. ESA/LISA-pathfinder demonstrated microthrusters (NASA contribution) and, along with Grace Follow-On, utilized laser heterodyne metrology. Monolith mirror fabrication state of the art has reached a diameter of 4m with the Daniel K. Inoue Solar Telescope (DKIST) and European Extremely Large Telescope (E-ELT) secondary mirror. These technologies collectively, together with the lift capacity of the SLS, enable a HabEx project start as early as 2025 with very modest additional investment. For the first time since the discovery of exoplanets, an exo-Earth direct imaging mission can be conceived to start in less than ten years, possibly as soon as five years. All of the technologies required for HabEx have been identified and assessed. From a technology standpoint, HabEx is low risk. Currently, in March 2019, all HabEx technologies are TRL 4 or 5. By 2023, via current funding, more than 82% of the HabEx technologies will be TRL 5. The remaining 18% will remain TRL 4 until additional funding is allocated. HabEx technologies are significantly more mature, now and in 2023, than JWST was in 1998 (Coulter 1998), just before submittal to the 2000 Decadal survey. JWST had 1 technology at TRL 2, 3 at TRL 3, 4 at TRL 4, and 3 at TRL 5. The HabEx Observatory design utilizes technologies that are state of the art or near to state of the art with clear paths of development. The design philosophy favors high Technology Readiness Level (TRL) to minimize risk. We discuss the technology maturity for the baseline architecture and the alternative architectures studied. The baseline HabEx Architecture is a 4m unobscured telescope with both a coronagraph and a free-flying starshade. The telescope has a 4m diameter monolithic primary mirror and a secondary mirror on rigid-body actuators. The telescope quality is driven by the pristine, stable wavefront required by the coronagraph instrument. An alternative point design is a 3.2 m diameter on-axis segmented telescope with only a starshade. The starshade suppresses the starlight before it enters the telescope, allowing the segmented telescope optical performance and stability to be significantly looser than for a coronagraph, thus enabling a segmented primary mirror design that can meet stability requirements with minimal advancement from the state of the art. We assess the exoplanet-driven technologies of HabEx, including starshades, coronagraphs, deformable mirrors, low order wavefront control, 4 m aperture mirrors, large mirror coating uniformity, jitter mitigation with microthrusters, segmented mirror stability, and low-noise detectors. References: Coulter, Daniel R. 1998. "Technology development for the Next-Generation

Space Telescope: an overview." Space Telescopes and Instruments V National Research Counsel. 2010. "New Worlds, New Horizons in Astronomy and Astrophysics." National Academies Press. 215-217.

Web link:

Name: Doug Lisman

Proposing Team:

Type of Activity:
Space Based Project

Description: Starshades are an emergent starlight suppression technology adopted by flagship exoplanet imaging mission studies, such as the HABEX space telescope mission and the Remote Occulter (RO) ground telescope mission. The baseline HABEX starshade is 52-m in diameter and the baseline RO starshade is around 100-m in diameter. Significant risk to the overall astrophysics program can be mitigated by first executing a smaller starshade mission that will also deliver compelling exoplanet science at an earlier date. The WFIRST Rendezvous Probe Study Mission is one early mission example that uses a 26-m diameter starshade to leverage the already planned WFIRST telescope that provides spectrometer access to water and oxygen features in the NIR. The intent of this space project based whitepaper will be to present a lower cost mission option. The target mission cost is below $500M. The general approach will be to focus on detecting ozone at rocky planets in the UV. Ozone is a robust biosignature gas that indicates the presence of oxygen at the otherwise undetectable level of 0.1% of PAL, that is thought to be present on Earth for a significant fraction of its history. Ozone also has a very prominent feature in the UV (Hartley-Huggins band) that is readily detectable with a relatively small starshade and small telescope with a simple photometer instrument. An attractive telescope option is to leverage the 1-m UV telescope for the CASTOR mission now under study by the Canadian Space Agency (CSA). Unfortunately, CASTOR is not yet funded and it is cost prohibitive to include its full cost. The approach is therefore to co-launch a small starshade with an even smaller and fully costed telescope, but design the starshade to also accommodate the a separately funded 1-m CASTOR telescope, or 1.5-m CETUS telescope, that may rendezvous with the starshade at a later date. The primary mission objectives would all be met with the co-launched telescope, but enhanced performance is possible with a larger telescope. A preliminary telescope aperture is 0.75-m. A preliminary starshade diameter is 16-m. This low-cost design is expected to provide good habitable zone access at about 6 nearby stars. A subsequent rendezvous with a larger telescope (1-1.5 m) will more than double the number of stars with good habitable zone access. It is important to note that while the detection and characterization of rocky planets is the driving science requirement, this small mission will also greatly advance our understanding of exozodiacal light and planetary system diversity.

Web link:

Name: David Bennett

Proposing Team: WFIRST Microlensing Science Investigation Team

Type of Activity:
Space Based Project

Description: Community Involvement in the WFIRST Exoplanet Microlensing Survey WFIRST is NASA's first flagship mission with pre-defined core science programs, which include the WFIRST Exoplanet microlensing survey. If we can maximize community involvement in these WFIRST core science programs, it will be beneficial to both the astronomical community and to the advance of science. The previous NASA project that most closely parallels the science of the WFIRST exoplanet microlensing program is Kepler, and the Kepler experience can be used to help design an effective WFIRST exoplanet microlensing. Also, microlensing is an exoplanet detection method that is perceived to have a more challenging learning curve than the transit method used by Kepler, and the number of microlensing experts is small. Thus, efforts to engage the astronomical community in this program are likely to be even more important than the successful efforts for Kepler. Community engagement requires the production of high-level data products, such as high quality photometric light curves, microlensing models for single and multiple-lens microlensing events, lens-source relative proper motion measurements, and exoplanet detection efficiencies. Furthermore, WFIRST will be most productive if the community is able to assist in the development of the survey plans for both the core exoplanet microlensing science and additional science that the WFIRST microlensing survey enables. According to current plans, some of the high level science products will be produced by the WFIRST Project team and some will be produced by the WFIRST Microlensing Science Implementation Team. We propose to add a WFIRST Microlensing Community Science Group that would be open to volunteers who are able to work productively with the Science Implementation Team. Members of this Community Science Group would be provided materials to help them learn how to analyze microlensing data, and they would have the opportunity to help the Science Implementation Team develop new analysis methods. These new methods could help to advance science goals other than the exoplanet microlensing science, or they could help to directly address the primary science goals of the exoplanet microlensing survey. While this Community Science Group would be open to volunteers, there should also be the opportunity for members to be funded if they are able to significantly advance the science to be produced by the WFIRST exoplanet microlensing survey.

Web link:

Name: Randall McEntaffer

Proposing Team: X-ray Grating Probe Team

Type of Activity:
Space Based Project

Description: In the discussion of the International X-ray Observatory (IXO) in New Worlds, New Horizons, two key instrumental capabilities were identified for meeting the scientific objectives. These were an X-ray calorimeter array and an X-ray grating spectrometer. ESA's Athena mission incorporates a calorimeter with capabilities comparable to those planned for IXO, but it is lacking a grating spectrometer. While an Explorer class grating mission (effective area ~300 cm2, $\lambda/\Delta\lambda$ ~ 2500) can address many of the IXO science objectives, an X-ray Grating Spectroscopy Probe (XGS-P) providing higher spectral resolving power ($\lambda/\Delta\lambda > 5000$) and higher throughput (effective area > 1000 cm2) in the soft X-ray band (5-50 Å) could fully achieve and go beyond the IXO science objectives. A partial list of key science questions include: What is the role of matter and energy feedback from supermassive black holes in the evolution of galaxies? What is the distribution of hot baryons? What are the basic characteristics of our hot Galactic halo? What are the characteristics of the solid phase of material along the line-of-sight to extragalactic sources? How do young stars accrete? What are the dynamics of hot star winds? How do extreme events in our Universe evolve over time? A concept probe study for a Notional X-ray Grating Spectrometer (N-XGS) was completed earlier this decade and is included in the NASA X-ray Mission Concepts Study Project Report, August 2012 (http://pcos.gsfc.nasa.gov/studies/x-ray-mission.php). The optical design of XGS-P would be very similar to that of N-XGS, but could also take advantage of recent developments in X-ray mirror, grating, and detector technologies. The instrument suite would likely consist of two or more independent, objective grating spectrometers operating in parallel. The telescope would have a modular design with several telescope sections contributing to the total collecting area. Each sector would feed an array of gratings that disperse the spectrum onto an array of CCDs. The modular design maximizes spectral resolving power by only sampling a fraction of the total telescope PSF while also allowing for increased effective area through the incorporation of multiple independent spectrometers. The performance requirements for XGS-P ($\lambda/\Delta\lambda > 5000$, effective area > 1000 cm2, bandpass < 2 keV) could be realized in the near future through existing technologies. X-ray telescope technologies are rapidly advancing, and methods such as those using polished Si optics are capable of fabricating and aligning mirrors to reliably produce Wolter-I telescopes with PSFs < 5", HEW. Furthermore, diffraction grating technologies are currently at TRL of 4 with a clear path to TRL 5. Gratings have recently demonstrated the highest resolving powers and diffraction efficiencies measured to date. The detectors would be composed of CCDs and electrical subsystems similar to those used on previous X-ray missions and are already at a high TRL as a result. System level tests incorporating these technologies are already planned and will reduce the most critical technical risk for a Probe mission. Even though developments are currently being made in all the key areas for a grating spectroscopy probe, mission specific developments to reach TRL 6 would still take time given the different focal length, module size requirements, alignment budgets, etc. that will be specific to the final design and unique from what is currently being developed. A proper study of an XGS-P capable of achieving the science goals listed above is necessary to accurately assess cost and spacecraft requirements. This study should be performed after a conceptual design is formulated using the state-of-the-art for the various spectrometer technologies. However, a rough order of magnitude cost and estimate of mission requirements for XGS-P can be based upon the previous N-XGS study, which had similar optical designs and spacecraft demands. Costs drivers such as mass, power, and launch vehicle are similar and the cost study performed for N-XGS can be used as a basis for XGS-P. This cost came out to be $784M, including reserves. This is dominated by the Payload (~$166M), Spacecraft (~$229M), and Launch Vehicle ($140M) with the remainder divided between the other various WBS elements. The N-XGS basis for spacecraft requirements includes a mass of 828 kg, power of 646/1451 W (observing/peak), 10 Mbps downlink, and 58 Gbit of storage. These numbers include 30% contingency. The prime mission would have a lifetime of 3 years and a goal of 5 with an orbit at L2. Pointing requirements include control of 45" over 200 ks, knowledge of 1.3" (3σ, per axis), and jitter of 0.2" RMS for frequencies above 15 Hz.

Web link:

Name: Richard Mushotzky

Proposing Team: AXIS

Type of Activity:
Space Based Project

Description: We intend to propose the Advanced X-ray Imaging Satellite (AXIS) for consideration by the 2020 Decadal survey. AXIS will build upon Chandra's two decades of discovery and dramatically enhance the science of high angular resolution X-ray imaging in the next decade. It will have 10x more collecting area than Chandra, a sharper than Chandra resolution on-axis, and subarcsecond resolution over a 24'x24' field of view. This mission will not only complement the next generation of astronomical observatories (such as JWST, WFIRST, LSST, SKA, ALMA, TMT, ELT, CTA), but also vastly enhance the study of the unique science of the high-energy universe, which requires X-ray observations. As seen by the strong synergy between Chandra and XMM-Newton, the ability to have a high throughput spectroscopic mission (Athena) flying at the same time as a high resolution X-ray imager vastly increases the science phase space. We will build on the mirror technology program that was started by the Constellation-X/IXO program, the goals of which is to produce high angular resolution lightweight X-ray optics at reasonable cost, utilizing precision polishing of single-crystal silicon mirrors. At present, this technology has achieved ~1.3" angular resolution for individual mirror segments and builds on recent developments in the semiconductor industry: (i) the inexpensive and abundant availability of large blocks of monocrystalline silicon; and (ii) revolutionary advances in rapid, deterministic, precision polishing of mirrors. The baseline detector is similar to the Chandra CCD, but benefits from 25 years of technology development, allowing better photon localization and much faster readout. A detailed engineering study at the GSFC/IDL and MDL showed that AXIS could be launched by 2030 within the $1B Probe cap. The single technology area needing new development is the construction of a high-throughput, lightweight, high angular resolution X-ray mirror. The necessary mirror technology development is already underway and funded. The AXIS science objectives are directly responsive to the goals set forth by the Astro2010 Decadal Survey and the NASA Astrophysics Roadmap: (i) origin, evolution and physics of supermassive black holes; (ii) astrophysical drivers of galaxy formation, including the AGN and stellar feedback and the intergalactic medium outside galaxies and clusters as the ultimate sink of feedback products; (iii) microphysics of cosmic plasmas using galaxy clusters and SNR; (iv) transient and variable universe, including rapid response to ToOs. Most of the AXIS observing time will be allocated to guest observations, ensuring a broad range of science. Authors: Professors: Richard F. Mushotzky (Maryland), Amy J. Barger (Wisconsin), Nico Cappelluti (Florida), George Chartas (South Carolina), Andrew C. Fabian (UK), Elena Gallo (Michigan), Martin Hardcastle(UK), Eileen T. Meyer (Maryland), Samar Safi-Harb (Canada), Christopher S. Reynolds (UK), Francesco Tombesi (Italy), Roberto Gilli (Italy) Research Fellows: Michael Koss (Washington), Erin Kara (Maryland), Rafael Eufrasio (Maryland), Lía Corrales (Michigan), Helen R. Russell (UK), Bradford Snios (Massachusetts), Stephen A. Walker (Maryland), James Aird (UK) Research Staff : Carey M. Lisse (Maryland), Michael Loewenstein (Maryland),, Maxim Markevitch (Maryland), Abraham D. Falcone (Pennsylvania), Catherine E. Grant(Massachusetts), Edmund Hodges-Kluck(Maryland), Eric Miller (Massachusetts), John Mulchaey(California), Hui Li (New Mexico) ,Robert Petre (Maryland) Andrew J. Ptak (Maryland), Randall K. Smith (Massachusetts), Lynne Valencic (Maryland), Brian J. Williams (Maryland), Lisa M. Winter (New Mexico), Hiroya Yamaguchi (Japan) William W. Zhang (Maryland)

Web link: http://axis.astro.umd.edu/

Name: Mark McConnell

Proposing Team: Matthew Baring (Rice), Peter Bloser (LANL), Michael Briggs (UAH), Eric Grove (NRL), Shuichi Gunji (Yamagata Univ), Dieter Hartmann (Clemson), R. Marc Kippen (LANL), Chip Meegan (MSFC), Bernard Phlips (NRL), Rob Preece (UAH), Jim Ryan (UNH), W. Thomas Vestrand (LANL), Bing Zhang (UNLV)

Type of Activity:
Space Based Project

Description: The LargE Area burst Polarimeter (LEAP) is a Small Complete Mission (SCM) proposed as a Mission of Opportunity (MoO) designed to improve our understanding of astrophysical jets through the study of Gamma Ray Bursts (GRBs). After years of investigating time variability and spectra, now is the time to study GRBs in a new and revolutionary way—using gamma-ray polarimetry. This instrument provides the first high sensitivity measurements of polarization for a large number of GRBs, offering an unprecedented opportunity to probe the inner workings of GRB jets. LEAP is a highly sensitive modular Compton polarimeter, designed as an externally mounted ISS payload to study the prompt emission of GRBs using both polarimetry (30-500 keV) and spectroscopy (5 keV - 5 MeV). The baseline investigation, conducted by a highly experienced team of investigators, is achieved in a two-year mission using a single passive, robust, high-heritage instrument based on well-established scintillator/photomultiplier tube technology. The LEAP science goal is to improve our understanding of astrophysical jets and the environment surrounding newborn black holes. LEAP achieves this goal by conducting a sensitive study of high energy polarization of prompt GRB emission that is associated with the formation of ultra-relativistic jets. Definitive polarization measurements for a large sample of events address four key science objectives related to this goal: 1) to determine the jet magnetic field structure (random or ordered); 2) to determine the jet composition (dominated by matter or Poynting flux); 3) to determine the jet energy dissipation process (internal shocks or reconnection); and 4) to determine the prompt emission mechanism(s). LEAP achieves these objectives by measuring the polarization and spectra of GRBs to differentiate between theoretical models, and by using detailed energy and time resolved polarization studies of the brightest bursts. The ISS is a unique platform capable of providing the resources necessary for such an ambitious mission. With a launch date in 2022, LEAP provides sufficient sensitivity and sky coverage to make sensitive polarization measurements for at least 75 GRBs over a two-year mission. The intrinsic properties of the instrument allow for localization of brighter GRB events to ~5°, following the approach employed by the earlier gamma-ray missions CGRO-BATSE and Fermi-GBM. GRB locations will be disseminated in near-real time through the Gamma-ray Coordinates Network (GCN) to the broader scientific community.

Web link:

Name: Philip Horzempa

Proposing Team:

Type of Activity:
Space Based Project

Description: Star Watch high-definition astrometry Probe Point of Contact: Philip Horzempa Summary Description: The Star Watch extreme-precision astrometry mission (0.1 – 1.0 uas) Probe-class mission is the best, and perhaps only, means of discovering a nearby Earth Analog in the coming decade. This is NASA's top astrobiology goal. The technology required to build a Michelson interferometer capable of this precision was developed under NASA's SIM project. That effort built flight-quality hardware that underwent validation testing at high levels of integration, retiring most technical risk (achieving TRL-8) after 10 years and an investment of $600 million. Star Watch will build on that invaluable engineering heritage, incorporating advances in the state-of-the-art since 2010. These include the development of smaller, lighter beam launchers and corner cubes for laser metrology, attitude-control micro-thrusters that eliminate disturbances from reaction wheels, and advanced fringe detectors. The technology pioneered by Star Watch, the first long-baseline Michelson Interferometer in space, represents an important investment for the future of space astronomy. Picometer-level laser metrology developed for Star Watch is required for future segmented-mirror large space telescopes. In addition, all of NASA's proposed Vision Missions, such as the Exo-Earth Mapper, Black Hole Mapper and Cosmic Dawn Mapper, require the use of precision interferometry. Star Watch will provide a path to those missions. No other Astrophysics Probe mission concept comes close to this level of technical readiness to proceed to ATLO. There are no analogs to Star Watch. It is unique and is a natural next step in the effort to detect, and characterize, exoplanets. Star Watch will enable access to the realm of temperate Terrestrial worlds for the first time, measuring their masses and orbits. This can be achieved by the middle of the 2020s, i.e., 20-25 years before Direct Imaging by space telescopes. In the search for, and survey of, other worlds, it is incumbent on the exoplanet community to bring all tools to bear. The science measurements that Star Watch will provide cannot be duplicated by other means. No Earth Analog has yet been discovered. We expect that they exist. Star Watch will discover whether that assumption is correct. Anticipated Sponsor: NASA Current Status: Phase B

Web link:

Name: Nancy Levenson

Proposing Team: Participating individuals have had leading roles in current strategic missions

Type of Activity:
Space Based Project

Description: Large, strategic space missions provide unique value to advance science and national interests. They offer advanced capabilities at the technological frontier, and they are able to respond as the scientific landscape changes. These missions enable science at all scales, and open, competitive access supports the most compelling research. Broad use of current strategic missions has produced high-impact and diverse results. Stable and systematic archives add value, promoting repeated use of data sets for novel investigations. Well-managed strategic missions are worth the investment they require.

Web link:

Name: Kenji Hamaguchi

Proposing Team: the SMILE team

Type of Activity:
Space Based Project

Description: A sensitive survey of the MeV gamma-ray sky is very important for astrophysics with important atomic nuclear lines, electron-positron annihilation lines, pion-decay emission and continuum emission from cosmic-ray particles. The study, however, has been hampered by lack of sensitive MeV detectors because MeV photons do not focus but scatter with the Compton process - earlier MeV instruments cannot constrain the direction of each incoming photon at a reasonable accuracy. There has been almost no progress in this field since COMPTEL onboard CGRO in 1990, which detected 63 gamma-ray sources in the sky. Tanimori et al. in Kyoto University, Japan, have developed an electron tracking Compton camera, which tracks the trajectory of an electron ionized by each MeV gamma-ray photon, in addition to the information obtained with the conventional Compton cameras (Tanimori et al., 2017, NatSR, 7, 41511, Tanimori et al., 2015, ApJ, 810, 28). This enables to constrain the direction of each MeV photon incoming within 4 steradian at an accuracy of ~degrees. They successfully launched SMILE II, a prototype of this instrument, with a one-day balloon flight from a NASA facility in Australia in 2018 April and detected Crab, Galactic electron-positron annihilation lines and extra-galactic extended gamma-ray emission at above 5 sigmas. This is an order of magnitude more sensitive than the gamma-ray detector onboard INTEGRAL. They believe that the sensitivity will easily improve by an order of magnitude by increasing the detector efficiency and even further by upgrading electronics, which should realize a spatial resolution of ~1 degree. Our goal is to launch a space observatory with this camera for an all sky MeV gamma-ray survey, hopefully lead by NASA. The current team is very small - Tanimori, T., Takada, A. (Kyoto University, Japan) and Hamaguchi, K. (UMBC). We also wish to find strong US partners, including those who have experiences in performing survey style observatory missions.

Web link:

Name: John Tomsick

Proposing Team: John Tomsick (UCB), Steven Boggs (UCSD and UCB), Andreas Zoglauer (UCB), Jarred Roberts (UCSD), Thomas Siegert (UCSD), Alex Lowell (UCSD), Eric Wulf (NRL), Eric Grove (NRL), Bernard Phlips (NRL), Terri Brandt (GSFC), Alan Smale (GSFC), Carolyn Kierans (GSFC), Mark Amman (independent), Dieter Hartmann (Clemson), Hsiang-Kuang Chang (NTHU, Taiwan), Pierre Jean (IRAP, France), Peter von Ballmoos (IRAP, France)

Type of Activity:
Space Based Project

Description: The Compton Spectrometer and Imager (COSI) is a wide-field-of-view telescope designed to survey the gamma-ray sky at 0.2-5 MeV, performing high-resolution spectroscopy, wide-field imaging, and polarization measurements. This APC white paper describes a COSI design for a Small Explorer mission (called COSI-SMEX in some Astro2020 science white papers) and the capabilities of such a mission. COSI will map the Galactic positron annihilation emission, revealing the mysterious concentration of this emission at the center of our Galaxy in unprecedented detail. COSI will elucidate the role of supernovae and other stellar populations in the creation and evolution of the elements by mapping tracer elements. COSI will map 26Al with unprecedented sensitivity, perform the first mapping of 60Fe, search for young, hidden supernova remnants through 44Ti emission, and enable a host of other nuclear astrophysics studies. COSI will also study compact objects both in our Galaxy and AGN as well as gamma-ray bursts (GRBs), providing novel measurements of polarization as well as detailed spectra and light curves. The COSI field of view and localization capabilities make it powerful for searches of electromagnetic counterparts to gravitational wave and high-energy neutrino detections. COSI will also address science topics related to the cosmic MeV background as well as the Galactic gamma-ray continuum, establishing the energy distribution of high-energy cosmic rays. The heart of COSI is a stacked array of germanium cross-strip detectors, which provide for high efficiency, high resolution spectroscopy, and precise 3D positioning of photon interactions. As COSI is a Compton telescope, the 3D positioning is required to carry out the Compton reconstruction. We accomplish this using the MEGAlib software package. The detectors are housed in a cryostat and cryogenically cooled. They are shielded on five sides, reducing the background and defining the field of view to be 25% of the sky. The COSI shields are active scintillators, extending COSI's field of view for detection of GRBs and other sources of gamma-ray flares to approximately 50% of the sky. COSI will be in low-Earth orbit and will operate similarly to the Fermi mission, with North-South rocking of the field of view around the zenith direction to enable complete sky coverage. COSI has been developed through NASA's APRA program, including successful operation during high-altitude balloon flights. The project is a collaboration between UC Berkeley's Space Sciences Laboratory, UC San Diego, the Naval Research Laboratory, and Goddard Space Flight Center, and includes science partners at Clemson University, National Tsing Hua University, and the Institut de Recherche en Astrophysique et Planétologie.

Web link: http://cosi.ssl.berkeley.edu/

Name: Martin Elvis

Proposing Team:

Type of Activity:
Space Based Project

Description: Idea: THE CASE FOR PROBE-CLASS NASA ASTROPHYSICS MISSIONS Goals: Astrophysics spans an enormous range of questions on scales from individual planets to the entire cosmos. To address the richness of 21st century astrophysics requires a corresponding richness of telescopes spanning all bands and all messengers. Most of these spectral bands, or measurement sensitivities, require space-based missions. Historically NASA has addressed this need for breadth with a small number of strategic-class missions and a larger number of Explorer missions. While the Explorer program continues to flourish, there is a large gap between Explorers and strategic missions. A fortunate combination of new astrophysics technologies with new, high capacity, low $/kg to orbit launchers, and new satellite buses allow for cheaper missions with capabilities approaching strategic mission levels. NASA has recognized these developments by calling for "Probe-class" mission ideas for mission studies. Twenty-seven proposals were received and 10 were funded. The submissions spanned most of the electromagnetic spectrum from GeV gamma-rays to the far infrared, and the new messengers of neutrinos and ultra-high energy cosmic rays. The key insight from the Probes exercise is that order-of-magnitude advances in science performance metrics are possible across the board for initial cost estimates in the range $0.5B - $1B. We advocate that the Astro2020 Decadal recommend a new line item for Probes be instituted in the NASA Astrophysics Division budget within the wedge for large new missions. This line would set a mission cost cap, as in the successful NASA Planetary Division's New Frontiers program. The Probes line needs to be a significant fraction of the budget over the decade covered by Astro2020. Probes will have costs in the range from just above the Explorer cap ($250M without launch vehicle) up to $1B, the nominal lower bound for a strategic mission. A cadence of 2 - 3 probes per decade would be desirable. In order to encourage a range of Probe cost levels, a division into sub-categories analogous to the SMEX/MIDEX division could be implemented. The Probes line would need to be protected against being raided to pay for cost overruns in flagship missions, as the Explorer program is now. There are multiple possible ways to implement a Probes line to reap the maximum advantage for science. Information about participating individuals The primary contact was lead author on the 2010 Decadal White Paper "A Vigorous Explorer Program". Most of the listed Proposing Team members are part of Probe Study teams, including all of the Study PIs and many of their co-Is. We expect the proposing team to grow significantly by the time of submission of the White Paper. The 10 Probe study PIs are: Jordan Camp, Asantha Cooray, W. Danchi, Jason Glenn, Shaul Hanany, Richard Mushotzky, Angela Olinto, Peter Plavchan, Paul Ray, and Sara Seager.

Web link:

Name: Sara Seager

Proposing Team: Starshade Rendezvous Probe Mission

Type of Activity:
Space Based Project

Description: Starshade Probe Mission: Sara Seager, Jeremy Kasdin, Jeff Booth, Andrew Gray, Andrew Romero-Wolf, and the Starshade Probe Team The past two decades have yielded a tremendous number of exoplanet discoveries employing several different planet-finding techniques, including transits, radial velocity, microlensing, and ground-based direct imaging. Thousands of exoplanets are now known to exist, and as many as one in five stars like the Sun may host a rocky planet in the habitable zone (HZ). Space-based direct imaging is the next frontier of discovery for exoplanet science, and a space-based direct imaging mission is ultimately required to find and characterize other Earth-like planets. The Starshade Rendezvous Probe Mission is a space-based direct imaging mission focused on discovering and characterizing exoplanets around a dozen of our nearest neighbor sun-like star systems. The starshade has its own spacecraft and launches separately to rendezvous on orbit and operate in formation with the Wide Field Infrared Survey Telescope (WFIRST) observatory. The Starshade Rendezvous Probe is a realizable, highly capable, and first-of-its-kind mission that will enable a deep-dive exoplanet investigation around our neighboring star systems. The Starshade Rendezvous Probe Mission is one of ten competitively selected, NASA-funded Probe studies. The science team has formulated two overarching questions to guide the mission study: • Is the Earth unique as compared to small planets orbiting our nearest neighboring sun-like stars? • How does the solar system compare to the planetary systems orbiting our nearest neighboring sun-like stars? In order to begin addressing these questions, the Starshade Rendezvous Probe Mission has three science objectives on the topics of: habitability and biosignature gases; brightness of zodiacal dust disks; and giant planet atmosphere metallicity. The science objectives are carried out by an observing program crafted from a careful balance between the search for new exoplanets and the spectral characterization of known giant exoplanets. Key factors in mission design are: end-to-end photon efficiency of the observing system, inner working angle (IWA), the exoplanet-star flux ratio of the target systems, the derived starshade design (petal shape, size, etc.), time, and the fuel it takes to align the starshade and telescope system for each target. The mission design traded all these factors, and more, to arrive at a design of the probe spacecraft and starshade payload to achieve the science objectives. The starshade payload design is directly derived from the technology currently being developed by NASA's Exoplanet Program Office as part of its activity to mature starshade technology to Technology Readiness Level (TRL) 5, "Starshade to TRL 5" or S5. The probe payload is a 26 m starshade (10-meter-diameter inner disk with twenty-four 8-meter petals), along with equipment required for formation flying. Significant progress has been made on all technological fronts for the starshade payload. The development plan ensures the starshade technology is ready for the Starshade Rendezvous Probe to rendezvous with WFIRST less than a year after its launch. The starshade spacecraft performs the retarget and formation control maneuvers. The WFIRST 2.4 m telescope and its spacecraft, in development by NASA, includes starshade-ready requirements. These requirements ensure hardware needed to support the Starshade Rendezvous Probe is in place for the future mission. The requirements encompass formation flying equipment and a broadband instrument for planet detection and spectral characterization. The impact on WFIRST for starshade readiness is minimized with the lowest cost and lowest risk approach to meet requirements.

Imaging and spectra for detection and characterization of planets, as well as relative imaging for formation flying, is done with existing instruments within the Coronagraph Instrument (CGI) on WFIRST. The White Paper will also briefly report on a Starshade Dedicated Probe Mission, a concept where a starshade is paired with a roughly 1 m telescope and co-launched on the same launch vehicle. Either Starshade Probe opportunity, both realizable in the next decade, allows NASA to gain operational experience in space with a telescope-starshade observing system. The value of such experience focused on one of NASA's highest priority goals is difficult to overstate—it would inform the design and operation of all such future observatories. The cost to achieve the science and obtain this experience fits within the proposed cap of a Probe Class mission. In particular, leveraging WFIRST is the only way to achieve such scientific value at a cost of less than $1B, and in less than 10 years. With the WFIRST modest telescope aperture and existing instrumentation capabilities, the Starshade Rendezvous Probe bridges the gap between census missions like Kepler and a future space-based flagship direct-imaging exoplanet mission, such as the Habitable Exoplanet Observatory (HabEx).

Web link:

Name: Marc Postman

Proposing Team: Marc Postman (STScI), Christopher Howk (U. Notre Dame), Jeyhan Kartalhepe (R.I.T.), Kevin France (U. Colorado at Boulder), Giada Arney (NASA/GSFC), Margaret Meixner (STScI), Courtney Dressing (UC Berkeley), Molly Peeples (STScI), Andy Ptak (NASA/GSFC), Shawn Domagal-Goldman (NASA/GSFC), Stephan McCandliss (JHU), Raymond Simons (JHU), Nimish Hathi (STScI), Chris Stark (STScI), Gregory Snyder (STScI), Mario Gennaro (STScI), and many more.

Type of Activity:
Space Based Project

Description: The Importance of Flagship Missions in a Balanced Space-Astronomy Program Flagship space astronomy missions are designed to push the scientific envelope to entirely new places and to address questions that cannot be answered in any other way. This often requires these ambitious missions to surpass existing capabilities by a factor of ten or more. Hubble's Cosmic Origins Spectrograph flew in 2009 with more than 30x the sensitivity of STIS, installed in 1997. The Mid-IR Imager (MIRI) on the James Webb Space Telescope (JWST) will offer combined resolution and sensitivity metrics that are 1 million times better than Spitzer. The Wide-Field Infra-red Survey Telescope (WFIRST) will survey the sky with a telescope the same size as Hubble but with 100 times the field of view. And the next generation of missions being envisioned for the 2030 era will supersede the capabilities of HST, JWST, WFIRST, and Chandra in their respective wavelength regimes by factors of 100 or more. Highly capable and ambitious space observatories, accessible to thousands of researchers in the U.S. and across the world, are a vital part of NASA's portfolio not only because the scientific revolutions that they herald are not achievable by any array of smaller missions but also because they truly inspire all of humankind with their remarkable new views of cosmos. Indeed, flagship missions play a crucial role in promoting and maintaining public awareness of science and NASA's efforts to conduct science in space. The breadth of science enabled by observatory-class missions yields a constant stream of science results that inspire the public. These large strategic missions are expensive and thus it is critical that we understand how they fit into the astronomical facility ecosystem. Using historical budget data from NASA we will dispel some misconceptions about large missions. For example, the data show that NASA's flagships have not significantly impacted the annual funding allocated to Explorer missions or the levels of annual funding for research programs. More importantly, we will highlight the many key advances and advantages that flagship missions bring to the astronomy community. Smaller scale missions are well suited for initial surveys of large areas of the sky, especially when opening a new wavelength window. Such surveys can provide exciting results that have profound impact on our understanding of the universe, as we have seen with ROSAT, COBE, IRAS, Galex, WMAP, WISE, Kepler, and Planck (to name a few). We will show, however, that for many scientific breakthroughs, from obtaining spectra of the first galaxies to imaging the first supermassive black holes to characterizing the atmospheres of terrestrial exoplanets, there is no substitute for raw effective collecting area coupled with high angular resolution. Physics tells us a large aperture is a requirement. Flagships provide access to state-of-the-art facilities to researchers at all career stages and at all types of institutions – from small colleges to R1 universities and from museums to national labs. NASA's great observatories all carry out peer-reviewed, highly competitive, and open selections for observing time. In these reviews, scientific merit is emphasized above all other criteria, giving graduate students access to as much scientific capability as the most senior professor. In this sense, flagships provide unique training opportunities for students and postdocs to succeed with the best available equipment. NASA's current (and future) flagship missions include substantial funding to enable and support the research by U.S. investigators. In the period 2010 – 2015, grant funding from the Hubble, Chandra, and Spitzer guest observer and archival research programs averaged about $55M per year. In addition, ~25 postdoctoral positions are funded each year as part of the Hubble program. This represents a significant investment back to the community to ensure the scientific potential of these observatories is fully realized. Furthermore, the data reduction pipelines and data archive systems that have been built and continuously improved over time by NASA's Science Centers ensures that any researcher can rapidly access the highest quality data regardless of the size or location of their home institution. Building any advanced space telescope comes with cost and schedule risks. We can – indeed, we must – do better than we have in the past. There are key lessons that have been identified from our most challenging missions, like JWST, that must be applied as we proceed on to the next generation of missions. But the biggest scientific questions that await us, especially those questions we don't yet even know to ask, will ultimately lead to the need for new, large, powerful, and space-based eyes on the universe.

Web link:

Name: Scott Wakely

Proposing Team:

Type of Activity:
Space Based Project

Description: The Next Generation Magnetic Spectrometer in Space – An International Science Platform for Physics with Cosmic Rays at Lagrange Point 2 This note serves as our notice of intent to submit a white paper to the Decadal Survey describing a major new space-based magnet spectrometer mission, which addresses a number of key science questions in multi-messenger astrophysics, cosmic-ray physics and particle physics. Several of these questions have emerged in the last decade, as a result of the tremendous success of recent high-precision space missions, such as AMS-02, Fermi/LAT, and PAMELA. These instruments have revealed unexpected features in the cosmic-ray matter and antimatter flux spectra that have challenged much of our traditional understanding of particle astrophysics, across a range of topics. These topics include questions of cosmic-ray origins, high-energy particle acceleration and propagation mechanisms, and the nature of dark matter. These questions, and others, will be addressed by employing a suite of sophisticated detector systems designed to improve on existing instrumentation in both precision and in energy reach. By combining a thin, but large-volume 1 Tesla high-temperature superconducting solenoid magnet with proven hybrid tracking technology and innovative "cubic" calorimetry designs, this instrument will achieve a 100TV maximum detectable rigidity with an effective 100 m2sr acceptance. The central calorimeter features a depth of 70 radiation lengths and 4 nuclear interaction lengths. This instrumentation will allow us to probe, with high statistics and high precision, the positron and electron spectra to 10 TeV, the anti-proton spectrum to 10TV, and the nuclear cosmic-ray component to 1016 eV, past the cosmic-ray knee. For the first time this instrument will have the acceptance and resolution needed to probe the cosmic-ray anti-deuteron spectrum with high precision. In addition, it will vastly expand our sensitivity to heavier cosmic antimatter, and it will provide measurements of cosmic gamma rays with excellent angular and energy resolution covering the full sky continuously. In particular it will provide high-resolution survey measurements of VHE gamma rays to energies beyond the TeV scale with angular resolution comparable to optical telescopes. The instrument will be installed on a satellite platform and operated for 10+ years at Lagrange Point 2 (L2). This positioning will be necessary to avoid interactions of the instrument solenoid with the Earth's magnetic field. Given the science requirements, the full payload has a mass of 45 tons and hence will require new heavy-lift launch capabilities, such as the NASA's Space Launch System, which has been under development since 2011. A plausible timeline for instrument definition, design, development, and testing would target a launch date in 2030, though this will require an early commitment from the agencies and the community to perform necessary R&D tasks. This will include some level of underlying technology development, as well as a prototyping test of the high temperature superconducting solenoid magnet system in space. Stefan Schael and Scott Wakely

Web link:

Name: Karl Stapelfeldt

Proposing Team: Exo-C Science and Technology Definition Team

Type of Activity:
Space Based Project

Description: "Exo-C" is a concept for a dedicated "probe"-scale mission for coronagraphic imaging of exoplanetary systems. A detailed mission study was carried in 2013-2015 under the sponsorship of the NASA Astrophysics Division, with a light update made in 2017. It was steered by a community STDT, with detailed design work by the Jet Propulsion Laboratory and a Cost and Technical Evaluation (CATE) provided by the Aerospace Corporation. The mission was desgned to be capable of taking optical spectra of nearby exoplanets in reflected light, discovering previously undetected planets, and imaging structure in a large sample of circumstellar disks. It would obtain unique science results on planets down to super-Earth sizes and serve as a technology pathfinder toward an eventual flagship-class mission to find and characterize habitable Earth-like exoplanets. Our white paper will present the mission/payload design and highlight steps to reduce mission cost/risk relative to previous coronagraph mission concepts. Key elements are an unobscured telescope aperture, an internal coronagraph with deformable mirrors for precise wavefront control, and an orbit and observatory design chosen for high thermal stability. Exo-C has a similar telescope aperture, orbit, lifetime, and spacecraft bus to the highly successful Kepler mission. Much of the needed technology development (pointing control, wavefront correction, high contrast integral field spectroscopy, detector flight readiness) has been pursued by the WFIRST coronagraph project development work. Mission performance, mass, power, and cost estimates have also benefited from deteailed work by the WFIRST CGI team. Its three year science mission would return spectal characterizations of 1-2 dozen exoplanets and detailed images of hundreds of circumstellar debris disks too tenuous for subarcsecond imaging with ALMA. Exo-C is a backup option to WFIRST CGI; nominally it could be implemented within seven years from project start. This paper will summarize the study final report completed in March 2015, with updates on performance and technical readiness as of spring 2019.

Web link: https://exoplanets.nasa.gov/exep/about/exoc/

Name: Julie McEnery

Proposing Team: AMEGO team (https://asd.gsfc.nasa.gov/amego/team.html)

Type of Activity:
Space Based Project

Description: The Allsky Medium Energy Gamma-ray Observatory (AMEGO) is a probe class mission that will provide ground breaking new capabilities for multi-messenger astrophysics - identifying and studying the astrophysical objects that produce gravitational waves and neutrinos; along with a rich menu of additional science in astrophysical jets, compact objects, dark matter and nuclear line spectroscopy. AMEGO will cover the energy range from 200 keV to over 20 GeV, with more than an order of magnitude improvement in sensitivity relative to previous missions. AMEGO provides breakthrough capabilities in three areas of MeV astrophysics: nuclear line spectroscopy will provide new insight into the currently topical area of element formation in dynamic environments; polarization capabilities will uniquely probe conditions and processes in astrophysical jets and in the magnetospheres and winds of compact objects; a wide field of view and broad energy range provide outstanding capability in time domain and multi-messenger astrophysics with excellent synergies with observations at other wavelengths. Developments in detector technology since the last major mission in medium energy gamma-ray astrophysics enable a transformative probe class mission. AMEGO has been optimized for excellent flux sensitivity (more than order of magnitude improvement relative to COMPTEL), broad energy range (200 keV -> 20 GeV), and large field of view (2.5 sr, or 20% of the sky). AMEGO has a factor of ~5 improvement in angular resolution below 200 MeV relative to Fermi-LAT. Its good energy resolution (~2-5% FWHM) below 5 MeV, combined with large effective area will enable ground-breaking nuclear line spectroscopy. Additionally, below 5 MeV, AMEGO will provide polarization measurements of transient and steady sources. The instrument performance has been extensively modeled using GEANT4 via MEGAlib (a simulation suite widely used in the gamma-ray community). The implemented detector geometries have been made publicly available to facilitate easy comparison with other instrument concepts. AMEGO will be in a low inclination, low Earth orbit and will be operated in an all-sky survey mode to view the entire sky every three hours. The AMEGO subsystems and spacecraft have undergone preliminary engineering and costing studies to provide confidence that this mission is buildable within the probe class cost envelope. The field of multi messenger astrophysics, the identification and study of astrophysical objects that produce gravitational waves, neutrinos and cosmic-rays, has burst into prominence in the past few years. By the end of the next decade, it will no longer be sufficient to simply find and identify electromagnetic counterparts, the focus will be on leveraging joint electromagnetic and gravitational wave/neutrino/cosmic-ray observations to address compelling science questions on the nature of these extreme sources. The peak power output of electromagnetic counterparts lies in the gamma-ray band for the objects identified so far - short gamma-ray bursts (GRB) as gravitational wave counterparts and blazars (active galaxies whose jets are aligned to our line of sight) for neutrino counterparts. AMEGO will detect a large number (60-100) of well localized short GRB per year (c.f. ~10/year with Swift-BAT). Combined with gravitational wave detections of the merging neutron stars, AMEGO observations will constrain theories of general relativity and will provide unique insight into the early, most explosive phase of the neutron star merger. AMEGO's polarization capability will provide a window into the physical conditions in the relativistic jet of the GRB. For very nearby merger events, AMEGO will directly observe gamma-ray lines from the nuclear processes that also power the optical and IR radiation seen in the kilonova. All extragalactic sources of MeV gamma-rays are candidate neutrino sources: AMEGO will detect over 500 long GRB/year, and hundreds of blazars with peak power in the MeV band - known to be the most luminous and powerful objects of their type. AMEGO observations (including polarization measurements) will be fundamental to constrain the composition of the high energy particles in the jets of neutrino emitting objects. These data, combined with neutrino observations by IceCube and KM3NET will identify and provide key insights to understand nature's most extreme accelerators. AMEGO will provide essential observations and breakthrough science in partnership with the enhanced gravitational wave and neutrino observations expected towards the end of the next decade. AMEGO is a large international team of around 200 scientists across 80 institutions with extensive experience designing and building gamma-ray telescopes (ASCOT, COSI, COMPTEL, Fermi-LAT, AGILE, EGRET). Over the past two years the team has worked together to develop the instrument concept, robustly evaluate AMEGO's scientific performance through high fidelity detector simulations and explore the science questions that AMEGO will address.

Web link: https://asd.gsfc.nasa.gov/amego/

Name: Thomas Low

Proposing Team: SRI International

Type of Activity:
Space Based Project

Description: The Institute for Defense Analyses points out several reasons for pursuing Assembly and Manufacturing on orbit in its January 2017 Paper P-8335. When considering a key technology to support Astrophysics research it is imperative to layout the clear requirement for in-space assembly and spacecraft servicing. SRI International offers up an example, but undoubtedly others will have similar offerings. Robots in space are nothing new, but we are taking a different approach to the problem. Current space robots are based on large systems, making it difficult to maneuver around objects and to access confined areas. SRI is working on what we believe will be a key component to In Space Assembly of Large Space-based Observatories. We call our robot Qbot. Qbot's small size and dexterity enables us to perform delicate operations in space. Qbot is being developed from the Taurus Robotic System. Taurus is among SRI's most recent dexterous manipulation platform. This robot was developed to delicately disassemble explosive devices. Its technological heritage reaches all the way back to what would eventually become the Da Vinci surgical robot. Taurus is a direct descendent of the M7 surgical robot, which was tested on NASA sponsored microgravity flights, as well as underwater in NASA NEEMO 9 campaign. Many hands make light work. Fleets of Qbots could perform tasks much quicker than a single system. Traditional systems operate by themselves and are subject to single point failures whereas fleets of Qbots have no such single point of failure. SRI International conducted experiments on board NEEMO 9 to explore remote operation of a dexterous manipulation system. We were particularly interested in how time lag and bandwidth limitations affected performance. Test results highly informed many of our current research undertakings, which are exploring how to perform delicate tasks like robotic surgery or splicing electronic hardware together in high latency and low bandwidth environments. As part of our vision of cooperative robotics for space operations, we are exploring the use of multi-agent frameworks to control large numbers of robot systems. The PACT framework is the basis of much of the multi-agent work performed at SRI and is based on the Lumen single agent framework. Each agent embodies certain beliefs, desires and Intents. It has been used to successfully control fleets of UAVs. In the context of cooperative robots, instead of prescribing which robot or agent does which action at a certain time, we provide the system with a series of tasks and the overall goal. We allow the agents to autonomously construct the build sequence and task the individual robots to achieve the desired outcome. The integration of the PACT framework into robotic systems was originally motivated by our microfactory platform. Microfactory is an SRI invented platform that harnesses a large number of robots the size of a quarter to create large scale products. Manually programming thousands of individual robots becomes an arduous task. PACT allows us to provide high level inputs to a robot fleet and obtain low level coordinated outputs. SRI has developed an integrated Virtual Reality training system which will develop and inform the required Artificial Intelligence to meet the needs of the multi-agent framework. SRI has also developed a novel technology called ElectroAdhesion (EA) which would be ideal for facilitating InSpace Assembly of large space-based observatories. Electroadhesion enables docking for manufacturing parallelization and responsive rearrangement without risking damage to sensitive materials. It also allows for propellant-less movement across large space structures. EA is also designed specifically to provide a method for eliminating debris from the assembly process. SRI's suite of robotic technologies enable massive on-orbit structures, increasing in scale as additional materials are brought on-orbit. Qbot is SRI's CubeSat robot. We have been working on Qbot, a system that combines SRI's Taurus robotic and Artificial intelligent systems with commercial small satellite technology. Singly, Qbot can be used to effect satellite inspection and repair. As fleets, they can work to assemble large structures in space. They can also be used in deep space exploration, and assist astronauts Current Space Robotic Systems - Single platform design reduces system dexterity (e.g. arms aren't long enough to reach distant parts simultaneously) - Large scale prevents access to the tight spaces within satellites - Large size = costly dedicated launch service Qbot Fleets - Multiple Qbots enable parallelization for rapid task completion - Independent systems provide near infinite reach and reconfiguration - Multiple Qbots enables specialization for specific tasks - Robustness through numbers – A single Qbot failure can be overcome through redundancy

Web link: https://www.sri.com/atsd/robotics-systems

Name: Keith Jahoda

Proposing Team: F. Kislat, H. Krawczynski, H. Marshall, T. Okajima

Type of Activity:
Space Based Project

Description: Introduction: The promise of X-ray polarization measurements to provide insight into the geometry and source mechanisms of high energy sources has been recognized since the sounding rocket and OSO-8 observations of the Crab nebula in the 1970s. However, it is only now that a sensitive and dedicated mission is under development: the NASA Imaging X-ray Polarimetry Explorer (IXPE) Small Explorer with an anticipated launch in 2021. Although IXPE is expected to be a revolutionary observatory, detecting X-ray polarization in the 2-8 keV band from a few dozen sources, it will be limited in collecting area and band width. The X-ray Polarization Probe (XPP) is designed as a second generation instrument with improved sensitivity, bandpass, and imaging resolution. The XPP concept fits within the proposed Probe class of missions, addressing key astrophysical questions at a cost of not more than ~$1B. Instrumentation: Three co-aligned telescopes simultaneously measure X-ray polarization from ~0.1 – 60 keV. Two of the telescopes are optimized for effective area and simultaneously illuminate three instruments which cover the entire 0.1 – 60 keV band while the third telescope is optimized to provide 10 arcsec imaging over a band comparable to IXPE. Many classes of X-ray sources, and in particular neutron stars and black holes, are unresolved and isolated sources. For these sources, simultaneous observations with modest angular resolution and three distinct instruments are possible. Just in front of and just be-hind the focal spot, a time projection photoelectric polarimeter, sensitive from 2 – 10 keV and a Compton polarimeter sensitive from 6 – 60 keV provide broad band spectrally resolved polarimetry of many non thermal processes. For many compact objects, the bulk of the emitted energy is in this band, and we expect to probe the geometry and energetics of the central engines. The time projection photoelectric polarimeters are similar to the detectors designed for the GEMS/PRAXyS mission, but are equipped with a rear window so that higher energy photons can pass through this detector and illuminate the Compton polarimeter based on the design employed on the X-Calibur balloon payload. Within the optical path that illuminates these detectors, three sets of Critical Angle Transmission gratings disperse lower energy X-rays towards graded multilayers, arranged to reflect only one linear polarization onto imaging detectors. The gratings themselves are transparent above 2 keV and supported by mounting structures which provide only modest obscuration. With gratings oriented at three different angles relative to the optical path, the gratings provide instantaneous measurement of the Stokes I, Q, and U parameters. Azimuthal asymmetries in the sensitivity of any of the three instruments are mitigated by rotation of the entire observatory about the line of sight. A third telescope, optimized for imaging performance and co-aligned with the other telescopes, illuminates a photoelectric pixel polarimeter similar to the IXPE detectors, and enables imaging studies of spatially extended objects including supernova remnants and jets. All of the detector technology is currently available. All of the components of the grating polarimeters are demonstrated as a system in a laboratory experiment, and the individual components used in other applications. The time projection photoelectric polarimeters were developed to TRL-6 for the GEMS mission, and the Compton polarimeter has flown as part of the X-Calibur balloon payload. The imaging photoelectric polarimeters have been developed for IXPE. Mission: The XPP mission is feasible using existing technologies, as demonstrated during a mission design study in the NASA Glenn Research

Center COMPASS design center. Estimates of a mission cost, based on analogy costing from known instruments development costs, and modelled costs for spacecraft and operations indicate that XPP can be developed for ~ $1.0B, including 30% reserves on the hardware development. We present estimates of Observatory efficiency and performance, describe the key design parameters of the mission, and introduce some of the observational questions which XPP can address.

Web link:

Name: William Danchi

Proposing Team:

Type of Activity:
Space Based Project

Description: NOI for Cosmic Evolution Through UV Spectroscopy (CETUS) Probe Mission Concept White Paper CETUS PROBE STUDY TEAM as defined by on the "List of Participants" who contributed to the CETUS Final Report submitted to NASA Headquarters on March 4, 2019 J. Arenberg (1), A. Bartoszyk (2), R. Bezanson (3), L. Bianchi (4), D. Bowen (5), J. Burge (6), B. Cenko, M. Choi, W. Danchi (2), K. Dodson (6), S. Driver (7), G. Durbeck, E. Dwek (2), W. Eckles (8), B. Fleming, K. France (9), P. Gatkine, S. Gezari (10), Q. Gong (2), J. Greene (5), S. Heap (10), T. Heckman (4), E. Hodges-Kluck (11), T. Hull (12), S. Kendrick (13), R. King (2), A. Kutyrev (2, 10), T. Lanz (14), J. MacKenty (15), S. McCandliss (4), G. Mehle (1), E. Mentzell, S. Moseley (2), S. Nikzad (16), L. Purves, , B. Rauscher, M. Rhee, S. Riall, J. Rigby (2), I. Roederer (11), N. Schur, S. Seipel (2), D. Sheikh (17), O. Siegmund (18), R. Simmons, W. Smith (2), D. Spergel (5), D. Stark (19), E. Stoneking (2), A. Szalay (4), S. Tompkins (2), J. Trump (20), A. Vandewel (21), M. Valente (6), J. Valerga (18), S. Veilleux (10), A. Waczynski (2), K. Whitaker (20), R. Woodruff (22), , R. Wyse (4) Institutions: 1. Northrup Grumman Innovative Solutions (NGIS) – Redondo Beach 2. NASA Goddard Space Flight Center (NASA GSFC) 3. Yale University 4. Johns Hopkins University 5. Princeton University 6. Arizona Optical Systems (AOS) 7. University of Western Australia 8. NGIS – Gilbert 9. University of Colorado 10. University of Maryland 11. University of Michigan 12. University of New Mexico 13. Kendrick Aerospace Consulting 14. Observatoire de la Côte d'Azur 15. Space Telescope Science Institute 16. NASA Jet Propulsion Laboratory (NASA JPL) 17. ZeCoat 18. University of California – Berkeley, Space Sciences Laboratory 19. University of Arizona 20. University of Connecticut 21. University of Ghent 22. Woodruff Consulting Additional contributions from: C. Neiner, Paris Observatory, Collins Aerospace, Harris, Schott AG, Schott Suisse, and Materion. ABSTRACT/DESCRIPTION: The CETUS mission concept utilizes a 1.5-m wide-field UV telescope with an instrumentation suite consisting of a wide-field camera, multi-object spectrograph, and high-resolution echelle spectrographs. CETUS is designed for a five-year mission life in a SEL2 orbit, with enough propellant and other consumables to operate successfully for up to ten years. Its SEL2 orbit provides constant sunlight, thermal stability, constant contact with Earth, the ability to view 2 pi steradians of the sky at any time and 4 pi steradians of the sky every 6 months. This orbit enables efficient surveys and a high probability of being able to quickly observe any transient event. The above features will allow CETUS to not only maintain equivalent or better observational access to the ultraviolet (UV) after Hubble is gone, but also be a companion to multi-wavelength survey telescopes starting operations in the 2020's, and a scout for the extremely large ground-based telescopes that will operational starting the mid-to-late 2020s and beyond, and a provider of discoveries that can be pursued by other space telescope concepts, such as HabEx or LUVOIR. The starting point for the CETUS mission concept was the Astro2010 panel's recommendation for a more capable UV-optical telescope to follow Hubble. Examples of some of Astro2010's Key Scientific Questions that CETUS can address include: • What is dark matter? • What are the flows of matter and energy in the circum-galactic medium? • What controls the mass-energy-chemical cycles within galaxies? • How do cosmic structures form and evolve? • How do black holes grow, radiate, and influence their surroundings? • Do habitable worlds exist around other stars?

However, the Astro2010 questions were not the end point for the CETUS design. New capabilities and new observations were also designed in, such as lithium-flouride mirror coatings effective at shorter wavelengths and a quick slew capability to observe transient events. Thus, CETUS not only allows for revolutionary progress on the questions listed above, but also for discoveries that we cannot anticipate at this moment in time. Just as Hubble was not specifically designed to discover Dark Energy, it was able to do so because it had a broad instrument suite. Similarly, Hubble was not designed specifically to take some of the first transit spectra of exoplanets around nearby stars, it was able to do so, again because of its broad instrumentation suite. The broad reach of CETUS' instruments will allow it achieve the unexpected.

Web link:

Name: Matthew Bolcar

Proposing Team: Co-signers will be included, but the list is not yet final.

Type of Activity:
Space Based Project

Description: Serviceability of Astronomical Assets at Sun-Earth L2 As the Hubble Space Telescope has demonstrated, the value of extending the operational lifetime of a space-science asset through servicing cannot be understated. As all future large-scale missions are required by Congress to be serviceable, several organizations have begun developing the technology and infrastructure necessary to maintain these assets. In this white paper, we will review the capabilities that currently exist and that are being developed that can enable the servicing of large observatories and other scientific assets at the 2nd Sun-Earth Lagrange point (SEL2). These capabilities include autonomous robotic, tele-robotic, and human-assisted servicing.

Web link:

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Type of Activity:
Space Based Project

Description: CASTOR (The Cosmological Advanced Survey Telescope for Optical and UV Research) is a proposed Canadian-led flagship mission that would provide high-resolution imaging and spectroscopy in the UV/optical (0.15–0.55 um) spectral region. The imager would cover a ~0.25 degree field of view simultaneously imaged in three bands with the possibility of grism spectroscopy, a capability ~100x that of HST in terms of survey speed. A multi-object spectrograph covering an adjacent field of view would also provide moderate to high-resolution UV spectroscopy. This versatile mission would far surpass any ground-based optical telescope in terms of sensitivity and angular resolution. It would provide complementary capabilities to the longer-wavelength data from the Euclid and WFIRST missions as well as the ground-based Large Synoptic Survey Telescope (LSST). The UV imaging and spectroscopic capability would enable a wide range of science including understanding the physics of star formation from our galaxy to the distant universe, the atmospheres of exoplanets, improving dark energy constraints and the properties of the outer solar system. Co-authors: Peter Capak capak@caltech.edu Jason D Rhodes jason.d.rhodes@jpl.nasa.gov Jessie Christiansen jessie.christiansen@caltech.edu Olivier Dore olivier.p.dore@jpl.nasa.gov Andreas Faisst afaisst@ipac.caltech.edu Carl Grillmair carl@ipac.caltech.edu Janice Lee janice@ipac.caltech.edu Shapiro, Charles A (389E) charles.a.shapiro@jpl.nasa.gov Melanie Simet melanie.simet@gmail.com Harry Teplitz hit@ipac.caltech.edu Côté, Patrick patrick.cote@nrc-cnrc.gc.ca Hutchings, John John.Hutchings@nrc-cnrc.gc.ca Ludovic Van Waerbeke waerbeke@phas.ubc.ca Balogh, Michael (SMTP)(UWaterloo) mbalogh@uwaterloo.ca Sarah Gallagher sgalla4@uwo.ca Maria Drout maria.drout@utoronto.ca Kim Venn < kvenn@uvic.ca>; Jason Rowe jrowe@ubishops.ca Jason Rowe jrowe@ubishops.ca Kavelaars, JJ JJ.Kavelaars@nrc-cnrc.gc.ca Alan.Scott@Honeywell.com Alan.Scott@Honeywell.com Jean-Francois Lavigne jean-francois.lavigne@ca.abb.com Paul Harrison paul.harrison@magellan.aero

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Name: Shaul Hanany

Proposing Team: James Bartlett, Nicholas Battaglia, Jamie Bock, Julian Borrill, Jeff Booth, David Chuss, Brendan Crill, Jacques Delabrouille, Mark Devlin, Alexander van Engelen, Laura Fissel, Raphael Flauger, Daniel Green, Colin Hill, Hannes Hubmayr, Bill Jones, Lloyd Knox, Alan Kogut, Charles Lawrence, Jeff McMahon, Tim Pearson, Clem Pryke, Marcel Schmittfull, Amy Trangsrud,

Type of Activity:
Space Based Project

Description: Building upon a legacy of successful measurements, the next decade holds tremendous potential for new, exciting cosmic microwave background discoveries, to be delivered by the Probe of Inflation and Cosmic Origins (PICO). The PICO mission is the result of a study funded by NASA in preparation for the 2020 decadal survey. It is an imaging polarimeter that will scan the sky for 5 years in 21 frequency bands spread between 21 and 799~GHz. It will produce ten independent full-sky surveys of intensity and polarization with a final combined-map noise level equivalent to 3300 Planck missions for the baseline required specifications, and according to our current best-estimate would perform as 6400 Planck missions. With these capabilities, unmatched by any other existing or proposed platform, PICO is poised to provide the following advances. It could determine the energy scale of inflation and give a first, direct probe of quantum gravity, or constrain broad classes of inflationary models at levels not achievable by sub-orbital instruments. The mission will have a deep impact on particle physics by measuring the minimum expected sum of the neutrino masses with 4 sigma confidence, rising to 7 sigma if the sum is near 0.1~eV. Reaching the 4 sigma level can only be achieved with an instrument that can measure the polarization of the CMB on the largest angular scales, a measurement best done from space. PICO will either detect or strongly constrain deviations from the standard model of particle physics by counting the number of relativistic species in the early universe. Its data will constrain generic models of dark matter, and enable a search for primordial magnetic fields with sufficient sensitivity to rule them out as the sole source for the largest observed galactic magnetic fields; and it will improve by a factor of 300 the constraint on cosmic birefringence, and thus constrain string theory-motivated axions. PICO will elucidate the processes affecting the evolution of cosmic structures. It will measure the optical depth to reionization tau with an error sigma(tau) = 0.002, limited only by the small number of spatial modes available in the largest angular scale CMB polarization. A space based platform is best suited for measurements on the largest angular scales. LambdaCDM leaves fundamental questions open. Premier among them is the unknown content of the majority of the Universe. PICO data will reduce the allowed volume of uncertainty in a 12-dimensional LambdaCDM parameter space by a factor of nearly a billion relative to current Planck constraints. PICO's maps of the Milky Way will be used to resolve long-standing questions about our own Galaxy and it will give deep, full-sky legacy maps with which astrophysicists will constrain the early phases of galaxy evolution; investigate the early phases of cluster evolution; perform a census of cold dust; make cosmic infrared background maps of the anisotropies due to dusty star-forming galaxies; map magnetic fields in 70 nearby galaxies; and study how magnetic fields are generated through a combination of turbulence and large-scale gas motion. Only a space mission like PICO will provide such full-sky legacy maps. Similar to its successful predecessors, WMAP and Planck, PICO will conduct observations from L2, a location proven to give thermal stability. It will execute ten redundant, full-sky surveys, each complete within 6 months. The scan pattern on the sky, which is optimized for control of polarimetric systematic uncertainties, ensures that the measured I, Q, and U Stokes parameters can be reconstructed by each of the 12,996 polarization-sensitive detectors. With its broad frequency coverage, PICO is better equipped than any other current or planned instrument to separate the detected signals into their original sources of emission. The large multiplicity of independent maps and sky surveys, and the stable thermal environment will give control of systematic uncertainties unmatched by any other platform. The science PICO will deliver addresses some of the most fundamental quests of human knowledge. Its science advances will enrich many areas of astrophysics, and will form the basis for the cosmological paradigm of the 2030s and beyond. We recommend a start for the mission in the next decade.

Web link: https://sites.google.com/umn.edu/picomission/home

Name: Jonathan Grindlay

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Type of Activity:
Space Based Project

Description: Time-domain Astrophysics (TDA), a foundation of Astronomy, has become a major part of current and projected (2020's) astrophysics. While much has been derived from temporal measures of flux and color, the real physics comes from spectroscopy. With LSST coming on line in 2022, with TDA one of its original drivers, the deluge of Transients and new types of variables will be truly astronomical. With multi-wavelength targeted EM surveys and multi-messenger (e.g. LIGO-international and super ICECUBE), and the possibility of full-sky/full-time X-ray imagers (e.g. the 4pi X-ray Imaging Observatory, 4piXIO, discussed in a separate NOI), the discovery of new Transients and Variables will flood telescopes on the ground and in space, and this just for multi-band imaging without spectroscopy. In this NOI, and subsequent White Paper, we briefly summarize several long-standing major science objectives that can be realized with TDA imaging and spectroscopy (nUV – mid-IR) from space. TSO can achieve, for the first time, fundamental science objectives that require deep and prompt spectroscopy of Transient phenomena, as for the following examples: 1. Deep nIR to mid-IR spectra of optically dark gamma-ray bursts (GRBs) provide the only direct detection possibility of PopIII stars from their brief Gamma-ray Bursts from core collapse. Imaging discovery (over 4-bands) down to AB ~28 will identify them, and R = 200 spectra to AB ~26 will measure redshifts and thus the star formation rate SFR(z) back to z ~15. 2. Optically dark GRBs (AB < 23.5) will enable Epoch of Reionization (EOR) mapping of structure back to z ~10-12. 3. Prompt followup of Short GRBs, with or beyond LIGO detection, will enable direct detection of their Kilonova afterglows as now confirmed for NS-NS mergers and likely also BH-NS mergers which enable mapping r-process nucleosynthesis. 4. Reverberation mapping (RM) of flaring Quasars continually being discovered and followed with LSST coverage will enable the first large scale surveys for SMBH mass measures back to z ~8. TSO can measure the RM "gold standard" Hbeta line width and strength at 4.5 microns to directly measure SMBH mass vs. z. TSO is a Probe-class concept for a 1.3m telescope with rapid slew capability that would be launched into an L2 orbit, where its extended baffle allows it to point within 5 – 8min to ~90% of the full sky, avoiding Sun by >30 degrees. Alternatively, it could be launched into a Geosynch orbit around Earth for ~80% sky coverage (excluding Sun, Earth, Moon). Geosynch has higher radiation backgrounds (which can be shielded) but significantly simpler and lower cost operations with continuous contact with White Sands if TSO were over Columbia (and LSST!). The TSO focal plane has been designed for both 4-band imaging and spectroscopy from 0.3 to 5 microns with 4 detectors (H2RG arrays) in parallel. TSO thus provides rapid access over a unique broad band and high sensitivity that ELTs on ground and Flagship missions in space can not achieve on their own. ROM costing studies indicate that TSO, with 30% Reserves, can be done for $0.75B.

Web link:

Name: John MacKenty

Proposing Team: SYNERGY Explorer Mission Concept

Type of Activity:
Space Based Project

Description: We will describe the SYNERGY Explorer Mission concept and support the value of competitively selected small and medium scale missions. The SYNERGY mission provides a large area survey in the near ultra-violet (200 – 320 nm) with imaging and low-resolution spectroscopic sensitivity sufficient to map star formation and neutral gas at redshifts representing the peak of galaxy growth. A natural successor to the GALEX Explorer mission, SYNERGY can be implemented using existing technologies (e.g. HST or Euclid CCD detectors). Offering a field of view of several square degrees, providing imaging sensitivity to >26 AB mag and low resolution (R~200) slit-less spectroscopy to >22 AB mag in surveys covering several 1000 square degrees in two years, and with arc second resolution comparable to ground based surveys, the existing GALEX datasets are surpassed by two orders of magnitude with data commensurate to existing and planned large area surveys. Beyond its immediate scientific objectives, an ultraviolet mission such as SYNERGY would add considerable value to existing and planned larger projects (e.g. LSST and WFIRST) by including data at shorter wavelengths at comparable resolution. In addition, the SYNERGY concept illustrates the potential of a robust Explorer Program to provide capabilities within the suite of observational capabilities not provided by larger missions (e.g. providing ultraviolet observations in the post-HST era).

Web link:

Name: David Leisawitz

Proposing Team: Origins Space Telescope Science and Technology Definition Team (STDT), see https://asd.gsfc.nasa.gov/firs/team/

Type of Activity:
Space Based Project

Description: Title: The Origins Space Telescope: a NASA Decadal 2020 Mission Concept Authors: The Origins Space Telescope Science and Technology Definition Team (STDT) STDT and other study team members are listed on our website at https://asd.gsfc.nasa.gov/firs/team/ The Origins Space Telescope (Origins) mission concept study explores the origin of life's essential elements: carbon (C), oxygen (O), and nitrogen (N), as well as the dust from the first stars, through their buildup in galaxies, to the creation of habitable planetary systems to the transport of water to habitable worlds. Origins and its suite of instruments utilize next-generation detectors and operate with spectral resolving power from ~3 to 3x10^5 over wavelengths from 2.8 to 590 microns. The telescope and instruments are cryocooled to 4.5 K, and the light collecting area, 25 m^2, match that of the James Webb Space Telescope (JWST), resulting in an astrophysical background-limited sensitivity that is >1000 times better than prior far-IR missions. Origins' stable mid-IR spectrograph obtains 2.8 to 20 microns spectra of exoplanets orbiting nearby M stars with ~5 parts per million precision. Origins' survey spectrometer maps tens of square degrees over the entire 25 to 590 microns at R~300, and makes pointed observations from 25 to 590 microns at R~3x10^4 and at selected lines between 100 and 200 microns at R~3x10^5. Origins' far infrared imaging camera maps the sky at 50 or 250 microns and offers polarization measurement capability. Origins' agility enables imaging surveys spanning thousands of square degrees in the far-infared to spot rare interesting objects and with sufficient sensitivity to probe the early Universe. The Origins design is based on the Spitzer architecture and applies many lessons from the JWST experience. Origins reduces risk through minimal reliance on deployments. A robust technology development plan culminates in the availability of mature detectors (Technology Readiness Level 6) by the mid-2020s, in time for Origins to be launched by 2035. Half of a typical galaxy's starlight is obscured by dust and emitted in the infrared. Origins' infrared instruments measures this "obscured" emission to transform our understanding of how galaxies and supermassive black holes evolve. Origins measures the mass of planet-forming material in thousands of circumstellar disks. It follows the trail of water from the birth of the planet-forming disk to the assembly of pre-planetary materials, and in comets to understand the origin of Earth's oceans. Building upon and greatly extending the discoveries by JWST and ground-based extremely large telescopes, Origins characterizes the atmospheres of exoplanets around nearby M dwarf stars and identify habitable worlds. In these exoplanets, Origins detects the spectroscopic fingerprints of molecules such as ozone, methane, nitrous oxide, carbon dioxide, and water, potentially revealing atmospheres in chemical disequilibrium attributable to life. Origins is not only capable of addressing known questions, but its vast discovery space will allow astronomers in the 2030s to understand new phenomena and ask new and important questions about our origins in the Universe. Origins is envisioned as a strategic mission for the community following the tradition of the Great Observatories. Origins is a NASA-led mission with international partners. This study has garnered significant international interest and includes instrument studies contributed by Japan (JAXA) and Europe (CNES-led consortium) and ex-officio international team members. For more information about Origins, see our two websites: https://origins.ipac.caltech.edu https://asd.gsfc.nasa.gov/firs/

Web link: https://origins.ipac.caltech.edu

Name: Kristin Madsen

Proposing Team: HEXP team

Type of Activity:
Space Based Project

Description: Title: HEX-P: The High-Energy X-ray Probe. The High-Energy X-ray Probe (HEX-P) is a next-generation high-energy X-ray observatory with broadband (1-200 keV) response that has ~40 times the sensitivity of any previous mission in the 10-80 keV band and >100 times the sensitivity of any previous mission in the 80-200 keV band. Intended to launch contemporaneously with Athena, HEX-P will provide fundamental new discoveries that range from resolving ~90% of the X-ray background at its peak, to measuring the cosmic evolution of black hole spin, to studying faint X-ray populations in nearby galaxies. In its baseline configuration, HEX-P will have three co-aligned, grazing incidence Wolter-I optic modules. One nested module will have ~390 shells with Ni/C multilayer-coated mirrors to achieve the wide bandpass with a half power diameter of the point spread function of 15". The HEX-P focal plane is directly derived from technologies developed for NuSTAR. Each detector has a high-atomic number sensor (CdZnTe or CdTe) coupled with the next-generation of the ASIC developed at Caltech for NuSTAR. Improvements in the technological development allows for finer spectral and energy resolution while maintaining the low-noise, low-power, and high performance of the NuSTAR detectors. With this leap in observational capability, HEX-P will address a broad range of science objectives beyond any planned mission in the hard X-ray bandpass. HEX-P will probe the extreme environments around black holes and neutron stars and map the growth of supermassive black holes and probe the effect they have on their environments. HEX-P will resolve the hard X-ray emission from dense regions of our Galaxy to understand the high-energy source populations and investigate potential dark matter candidate particles through searches for decay channel signatures from axions and sterile neutrinos. If developed and launched on timescale similar to Athena, HEX-P would support simultaneous observations, greatly enhancing Athena's ability to probe a range of phenomena from the detailed physics of black hole accretion to hot, merger-driven shocks in clusters — both of which have continua extending to high energy, where sensitivity above 10 keV is essential to interpreting their spectra. HEX-P addresses science that is not planned by any flagship-class missions, and is beyond the capability of an Explorer-class mission.

Web link:

Name: Alan Kogut

Proposing Team:

Type of Activity:
Space Based Project

Description: Small distortions about a blackbody spectrum for the cosmic microwave background probe a fundamental property of the Universe: its thermal history. Spectral distortions provide new insight into processes within the standard model of cosmology while testing for new physics outside this model. We describe the current state of distortion science and show how technologically achievable advances could improve existing measurements by four orders of magnitude to open a vast discovery space for astrophysics, cosmology, and particle physics.

Web link:

Name: John Krizmanic

Proposing Team: John Krizmanic (PI: CRESST/GSFC/UMBC), Neerav Shah, Alice Harding (GSFC), Chris Shrader, Mike Corcoran (GSFC/CU), Steve Stochaj, Kyle Rankin, Daniel Smith, Krishna Kota, Hyeongjun Park, Laura Boucheron (NMSU), Asal Naseri (SDL/USU)

Type of Activity:
Space Based Project

Description: The Virtual Telescope for X-ray Observations (VTXO) will use lightweight Phase Frensel Lenses (PFLs) with near diffraction-limited performance in a virtual X-ray telescope with ~1 km focal length and with ~50 milli-arcsecond angular resolution. While laboratory tests of PFLs have achieved near diffraction-limited angular resolution in the X-ray band, they require long focal lengths to achieve this quality of imaging. VTXO is formed by using precision formation flying of two SmallSats: a smaller OpticsCraft that houses the PFLs and a larger DetectorSat that contains an X-ray camera and propulsion for the formation flying. The baseline flight dynamics uses an elliptical orbit to allow the formation to hold in an inertial frame around perigee for an extended period. VTXO's fine angular resolution enables measuring the environments closer to the central engines in compact X-ray sources, allowing for the study of the effects of dust scattering halos nearer to the central objects in Cygnus X-3 and GX 5-1, the search for dust scattering echoes nearer to the central object in X-ray transients, and the search for sub 0.1 arcsecond structures in the plerion nebula around the Crab pulsar and in the wind environments ambient to bright X-ray binaries such as Cyg X-1. The fine angular resolution could also potentially resolve structure in the enigmatic Be star Gamma Cassiopeiae, resolve X-ray sources in regions of high stellar density, and allow for studying the effects of space weather on nearby exoplanets. VTXO is currently under development as one of the selected NASA Astrophysics SmallSat Study proposals. The VTXO SmallSat and instrument designs, mission description, and science performance will be described. Additionally, the science performance of missions using larger PFLs that could achieve milli-arcsecond to micro-arcsecond imaging with high X-ray sensitivity will also be presented

Web link:

Name: Daniel Apai

Proposing Team: Nautilus

Type of Activity:
Space Based Project

Description: Science Goals: Now and in the next two decades the only currently-conceived method that has the potential to characterize in detail the atmospheres of a large number (hundreds to thousands) of small (Rp < 4 REarth) exoplanets is transit spectroscopy. NASA's TESS mission is set to deliver the largest bounty yet of small exoplanets in the vicinity (∼30–300 pc) of the solar system. With 10,000–20,000 new exoplanet discoveries and candidates, the TESS exoplanet sample will offer a unique opportunity to transform our understanding of the atmospheres of small exoplanets – if a sufficiently large number of these planets can be characterized via spectroscopy. The concentrations of many key atmospheric absorbers and the atmospheric structure can be determined for individual planets. With a library of high-quality spectra, entire planet populations can be studied in the same manner, also enabling statistical assessment of connections within planet properties, evolution, and composition for the first time. The goal of the Nautilus Unit Telescope is to assess the atmospheric diversity of small exoplanets with unprecedented quality to enable large-scale statistical studies of exoplanet formation and atmospheric evolution. The Nautilus Unit Telescope is a probe-class concept based on an ultralight and large-diameter (8m-class) optical element. Nautilus will establish a library of exoplanet transmission spectra with unprecedented quality: it will obtain order-of-magnitude higher quality (signal-to-noise ratio and spectral resolution) transmission spectra than possible with present-day and planned telescopes. The spectral library will enable large-scale statistical studies of exoplanet formation and atmospheric evolution by following up the scientifically most interesting exoplanets identified by NASA's TESS mission. Novel Technology: Our mission concept utilizes multi-order diffractive engineered material (MODE) lenses, a novel optical technology being developed to provide a very large-aperture and ultralight light-collecting element. In Nautilus the large-diameter MODE lens replaces the primary mirror, thereby providing powerful light-gathering capabilities that exceed present and near-future capabilities. MODE lenses can be produced using a combination of optical free-form fabrication and pressure-molding, enabling cost-effective production of large optics. In addition, telescopes based on MODE lenses have order-of-magnitude more forgiving tolerances to misalignments than reflecting telescopes. Therefore, MODE lenses have the potential to significantly reduce mass and correspondingly offer cost advantages over traditional mirror-based telescopes. In addition to the science goals of the mission, our mission concept will also demonstrate large MODE-lens-based space telescopes as a lower-cost and lower-weight alternatives of space-borne reflecting telescopes with an architecture conceivably scalable to a future space-array of such unit telescopes.

Web link:

Name: Charles (Matt) Bradford

Proposing Team: BLISS science team and JPL Astronomy & Physics

Type of Activity:
Space Based Project

Description: Title: The Space Infrared Telescope for Cosmology and Astrophysics: Mission Overview and Potential US Contributions. Introduction: How did the diversity of galaxies we see in the modern Universe come to be? When and where did stars within them forge the heavy elements that give rise to the complex chemistry of life? How do planetary systems, the Universe's home for life, emerge from dusty interstellar material? Mid- and far-infrared wavelengths are uniquely well-suited to study key questions in modern astrophysics, because these wavebands are immune to dust obscuration that plagues observations in the UV and optical. In particular sensitive spectroscopy in the mid- and far-IR will naturally overcome source confusion and provide quantitative diagnostics to assess astrophysical machinery deep in the interiors of dusty objects. Mission Overview: The far-IR (wavelengths beyond the ~20 microns) is poised for a revolutionary advance in sensitivity with the combination of a cold telescope and sensitive far-IR detectors now available. The SPace Infrared telescope for Cosmology and Astrophysics, SPICA, is a European-Japanese collaboration to launch a cryogenic space observatory designed to achieve true background limited performance with a 2.5-meter primary mirror cooled to below 8 K. ESA has selected SPICA as one of the 3 candidates for the Cosmic Visions M5 mission, and JAXA has indicated commitment to their portion of the collaboration. ESA and JAXA have invested in a joint concurrent study, and a collaboration framework has gelled. ESA will provide the silicon-carbide telescope, science instrument assembly, satellite integration and testing, and the spacecraft bus. JAXA will provide the passive and active cooling system (supporting the T< 8K telescope), cryogenic payload integration, and launch vehicle. The ESA phase-A study is underway now; the downselect among the three candidates will occur in 2021, and the expected launch is around 2031. Instruments: SPICA will have 3 instruments. JAXA's SPICA mid-infrared instrument (SMI) will offer imaging and spectroscopy from 12 to 38 microns. It is designed to complement JWST MIRI with wide-field mapping (broad-band and spectroscopic), R~30,000 spectroscopy with an immersion grating, and an extension to 38 micron with antimony-doped silicon detector arrays. A far-IR polarimeter from a French-led consortium will provide dual-polarization imaging in 3 far-IR bands. A sensitive far-IR spectrometer SAFARI is being provided by a consortium led by SRON Holland. It will provide full-band instantaneous coverage over the full 35-230 micron band (longer wavelength extension is under study) using four R=300 grating modules. A Fourier-transform module which can be engaged in front of the grating modules will offer a boost to the resolving power, up to R=4,000 at 100 microns. Potential US Contributions: As a member of the SAFARI consortium, a US team is working with the European team to contribute the two long-wavelength detector arrays and spectrometer modules (covering ~100 to 320 microns) for SAFARI through a NASA Mission of Opportunity. This initiative, called BLISS, leverages NASA expertise in superconducting detectors, as well as success with background-limited spectrographs in the submillimeter / millimeter; we expect it to be under consideration by the NASA Explorer program as the Survey convenes. Another role for the US is to build on the heritage with Spitzer, WISE, and JWST to collaborate with the JAXA SMI team by providing large-format (~Mpixel) mid-IR impurity-band detector arrays, potentially reaching out to 38 microns, where massive spatial-spectral survey speed is a unique opportunity with the cold telescope.

Web link:

Name: Rhonda Morgan

Proposing Team: ExEP Standards Definition and Evaluation Team

Type of Activity:
Space Based Project

Description: The NASA Exoplanet Exploration Program office established the Standards Definition and Evaluation Team (SDET) in 2016 to provide a common comparison of exoplanets yield between HabEx and LUVOIR. The SDET will deliver a final report to NASA headquarters at the same time that the LUVOIR and HabEx final reports are delivered, currently planned as end of August 2019. The SDET final report will be an independent assessment of the exoplanet yield of the direct imaging mission concept studies LUVOIR and HabEx. The work of the standards team is to ensure common assumptions and methods, to provide transparent, common metrics for comparing the missions. Just as the flagship concept studies are submitting white papers in addition to their final reports, the SDET will submit a white paper summarizing our final report. The analysis is performed using the Exoplanet Open-Source Imaging Mission Simulator (EXOSIMS), a modular, Python mission simulation software publicly available at https://github.com/dsavransky/EXOSIMS). Using EXOSIMS, realistic mission observing constraints, and dynamically responsive scheduling, we simulate the exoplanet detection and characterizations over Monte Carlo realizations of synthetic planets around nearby stars. EXOSIMS creates synthetic planets around nearby stars, then schedules observations on the target list and responds dynamically to the results (detections and characterizations) of those observations. The observing simulation is run on thousands of synthetic universes in a Monte Carlo manner. EXOSIMS uses realistic mission observing constraints, such as solar keep out and starshade fuel use. We use identical astrophysical inputs and the observing scenarios of each concept to evaluate a common comparison of the detection and spectral characterization yields of HabEx and LUVOIR. HabEx is evaluated for the 4m hybrid starshade and coronagraph architecture, the 4m coronagraph only architecture, and the 3.2 m starshade only architecture. LUVOIR is evaluated for the 15 m and 9 m architectures. Yield analysis shows that both concepts can directly image and spectrally characterize earth-like planets in the Habitable zone and that each concept has complementary strengths. While this is related to a science white paper submitted by Chris Stark on exoplanet yield analysis, it is not a duplicate. Chris' paper focused on trends in the possible design space while this paper will analyze specific point designs of the HabEx and LUVOIR flagship concept studies. Team Members: Dr. Rhonda Morgan Lead, NASA Exoplanet Exploration Program, JPL Dr. Dmitry Savransky Cornell University Dr. Chris Stark Space Telescope Science Institute Dr. Avi Mandell NASA Goddard Space Flight Center Dr. Ruslan Belikov NASA Ames Research Center Dr. John Krist NASA Jet Propulsion Laboratory Dr. Eric Nielson SETI, IR Direct Imaging Expert Dr. Peter Plavchan, George Mason University Flagship Concept Study STDT Liaisons: Courtney Dressing Caltech (LUVOIR) Karl Stapelfeldt ExEP (HabEx) Klaus Pontoppidan Space Telescope Science Institute (OST) The charter for the standards team is found at: https://exoplanets.nasa.gov/system/internal_resources/details/original/562_ExSDET_Charter.pdf

Web link:
https://exoplanets.nasa.gov/system/internal_resources/details/original/562_ExSDET_Charter.pdf

Name: Paul Goldsmith

Proposing Team: Paul Goldsmith, Darek Lis, Youngmin Seo

Type of Activity:
Space Based Project

Description: Water is an exceptionally important molecule for astrophysics, astrochemistry, and astrobiology. It has unique biogenic value, is a key player in critical phases of star formation, and is a powerful tracer of critical processes in molecular cloud evolution and of feedback from new stars. The water that ends up in the biospheres of habitable planets could form relatively soon before the planet itself forms, or it could come from the protostellar/protoplanetary disk from in which the planet forms. That disk water, in turn, could well have come from the dense core out of which the disk collapsed, and that dense core could have incorporated water from the filamentary cloud in which it was formed. Thus, planetary water could be "inherited" from earlier phases, or be formed "in situ" in any of the above steps. Tracing the trail of water attempts to answer where the water in habitable planet biospheres was formed by tracing distinctive characteristics (e.g. D/H ratio or ortho-to-para ratio) from one evolutionary stage to another. It thus requires measuring essential characteristics of water along with quantitative determination of the amount of water in these different stages. This is necessarily a multi-wavelength, multi-observatory endeavor. Observations of water ice to be carried out with JWST and SPHEREx are closely linked to observations of water vapor being discussed here. The relatively warm water in planetary atmospheres has been studied by Spitzer and will be studied with JWST and WFIRST. Water in the inner regions of disks can be studied in the infrared by the HIRMES instrument on SOFIA. But to probe the cooler water in the outer portions of disks as well as at the earlier phases in the interstellar medium requires observation of the lowest transitions of the H2O molecule. These are the 557 GHz transition of ortho-H2O and the 1113 GHz transition of para-H2O. There are also lines of the various isotopologues H218O, H217O, and HDO that are required to fully characterize water's history as well as deal with opacity effects in the common isotopologue. These submillimeter transitions can only be observed from space, as telluric absorption is severe at airplane and balloon altitudes, with the solar system is completely blocked even at 42 km altitude. Thus, a space mission is required to study comprehensively this vitally important molecule. A range of technical advances have made an observatory focused on the submillimeter transitions of water and its isotopologues feasible for a MIDEX class mission. These include improvements in the sensitivity of SIS mixers (more than a factor 2 better than those on Herschel/HIFI), and low-power high-bandwidth digital spectrometers that allow operating a multi-band system yielding high observing efficiency. Finally, space-qualified cryocoolers are available for a reasonable cost that can cool the submillimeter components to 2K, as required for optimum operation of SIS mixers. The result is that with a 3m to 4m class telescope we can envision a mission that will • Observe the ortho- and para- transitions to determine the formation and history of water in 300 interstellar clouds, typically 10x weaker than those studied with HIFI. • Measure water line profiles in 100 dense cores typically 4x weaker than L1544 • Image the water distribution in 10 cores • Measure water in 10 disks 2x more distant than TW Hya; assume 200 targets and 5% detection rate • Measure D/H and other isotopic ratios in 25 comets With these observational data we will • determine water formation pathways and water processing in interstellar clouds • test models of oxygen chemistry and cold water formation by measuring the abundance of water in dense cores • measure water in protoplanetary disks to test theories of snowline location in disks • test theories of the origin of the Earth's water by measuring the D/H ratio & isotopic abundance ratios in comets • test chemical models of solar system formation by measuring water abundance in minor bodies including asteroids and comets A 5-year WATER TRAIL mission will deliver key information to answer the critical question of how conditions for habitability in forming planetary systems develop. Through measurements of the abundance of water, its isotopic composition and ortho-to-para ratio (OPR) in different stages of the evolutionary sequence from interstellar clouds to dense cores, to disks and finally to planetary systems, this program will determine the formation pathways for water and its inheritance from one stage to the next. A key goal is to understand why the Earth is wet and predict what extrasolar systems are most likely to have Earthlike planets.

Web link:

Name: Daniel Apai

Proposing Team: Jonathan Arenberg (Northrop Grumman Aerospace Systems), Alex Bixel (Univ. Arizona), Dae Wook Kim (Univ. Arizona), Rongguang Liang (Univ. Arizona), Tom D. Milster (Univ. Arizona), Benjamin V. Rackham (Univ. Arizona), Glenn Schneider (Univ. Arizona)

Type of Activity:
Space Based Project

Description: Science Goals: Now and in the next two decades the only currently-conceived method that has the potential to characterize in detail the atmospheres of a large number (hundreds to thousands) of small (Rp < 4 R_Earth) exoplanets is transit spectroscopy. NASA's TESS mission is set to deliver the largest bounty yet of small exoplanets in the vicinity (30–300 pc) of the solar system. With 10,000–20,000 new exoplanet discoveries and candidates, the TESS exoplanet sample will offer a unique opportunity to transform our understanding of the atmospheres of small exoplanets – if a sufficiently large number of these planets can be characterized via spectroscopy. The concentrations of many key atmospheric absorbers and the atmospheric structure can be determined for individual planets. With a library of high-quality spectra, entire planet populations can be studied in the same manner, also enabling statistical assessment of connections within planet properties, evolution, and composition for the first time. The goal of the Nautilus Unit Telescope is to assess the atmospheric diversity of small exoplanets at unprecedented quality to enable large-scale statistical studies of exoplanet formation and atmospheric evolution. The Nautilus Unit Telescope is a probe-class concept based on an ultralight and large-diameter (8m-class) optical element. Nautilus will establish a library of exoplanet transmission spectra with unprecedented quality: it will obtain order-of-magnitude higher quality (signal-to-noise ratio and spectral resolution) transmission spectra than possible with present-day and planned telescopes. The spectral library will enable large-scale statistical studies of exoplanet formation and atmospheric evolution by following up the scientifically most interesting exoplanets identified by NASA's TESS mission. Novel Technology: Our mission concept utilizes multi-order diffractive engineered material (MODE) lenses, a novel optical technology being developed to provide a very large-aperture and ultralight light-collecting element. In Nautilus the large-diameter MODE lens replaces the primary mirror, thereby providing powerful light-gathering capabilities that exceed present and near-future capabilities. MODE lenses can be produced using a combination of optical free-form fabrication and pressure-molding, enabling cost-effective production of large optics. In addition, telescopes based on MODE lenses have order-of-magnitude more forgiving tolerances to misalignments than reflecting telescopes. Therefore, MODE lenses have the potential to significantly reduce mass and correspondingly offer cost advantages over traditional mirror-based telescopes. In addition to the science goals of the mission, our mission concept will also demonstrate large MODE-lens-based space telescopes as a lower-cost and lower-weight alternatives of space-borne reflecting telescopes with an architecture conceivably scalable to a future space-array of such unit telescopes.

Web link: http://nautilus-array.space

Name: Sara Price

Proposing Team: Dr. Daniel Castro and Dr. Martin Elvis

Type of Activity:
Space Based Project

Description: We intend to prepare a white paper that is focused on proposing a set of complementary smaller missions ranging across the electromagnetic spectrum. Building upon our science white paper, entitled "Picturing a Panchromatic Past and Future", this contribution to the APC white paper call will set forth a path for translating the accomplishments and technological advances gained by a multiwavelength observing model to the emerging context of the coming decade of astronomy. Over the past couple of decades, panchromatic access to the Universe has become the accepted standard as a result of regular simultaneous observations by the three missions collectively called the "Great Observatories": Chandra, Hubble, and Spitzer. Working from our own knowledge of the Chandra X-ray Observatory, solidified by an intensive review of all Image Releases and Press Releases by Chandra over the past two decades in connection with their associated publications, we will explain the importance of the astronomy community's continuation of this unprecedented view of the Universe for the next generation of discoveries. In support of extending this widely acknowledged "Golden Era" of astronomy and astrophysics, we will summarize a new paradigm of several smaller space-based missions that will work together with the upcoming flagship mission JWST to detect different types of radiation such as X-rays, radio waves, and infrared light. It is our sincere hope that this innovative model will allow astronomers to conduct expansive surveys and multi-messenger efforts that involve collaboration between missions and uncover new frontiers in perception.

Web link:

Name: Sean McWilliams

Proposing Team: John Baker, Peter Bender, Emanuele Berti, Robert Caldwell, John Conklin, Neil Cornish, Kelly Holley-Bockelmann, Brittany Kamai, Shane Larson, Jeffrey Livas, Deirdre Shoemaker, Tuck Stebbins

Type of Activity:
Space Based Project

Description: The successes of the Advanced LIGO and Advanced Virgo detectors have initiated the era of gravitational-wave (GW) astronomy by opening the ~30-1000 Hz frequency band. However, the seismic noise wall will inevitably limit the sensitivity of future ground-based instruments below the ~10 Hz range. At the other extreme of very low frequencies, pulsar timing arrays (PTAs) like NANOGrav are pushing into the range of predicted signal strengths, but are sensitive to a narrow range of frequencies below ~10 nHz. With the overwhelming success of LISA Pathfinder, ESA is leading the development of LISA to open up part of the midband of the GW spectrum. While the LISA band is rich in science targets, the combined efforts of LISA, future PTAs, and future ground-based instruments will still leave the 10 nHz-10 microHz and the 0.1 Hz-10 Hz bands uncovered. We propose a range of preliminary studies to prepare for LISA follow-on recommendations in Astro2030, with the goal of achieving greater sensitivity and extending the frequency coverage across the full GW band. Considering the long lead times required for major Astrophysics missions, we propose that significant investment in mission concept studies, theoretical support, and technology development for LISA follow-on missions should begin now. The most effective mission concepts will only emerge with coming advances in the field and the results of further concept studies. Fortunately, many approaches to extending the covered band or improving our sensitivity within a covered band build naturally on LISA technology, so a program of development work can be pursued at this early stage without specifying the mission concept. Any follow-on GW detector will likely be driven by advances in inertial references, micronewton propulsion, lasers, laser stabilization, small ultra-stable telescopes, and interferometry. Aside from development of component technologies, improving the ability to localize individual sources or to observe a weak stochastic background would both benefit substantially from adding independent networked instruments, or by including additional spacecraft in the constellation. In the LISA band, achieving greater sensitivity will naturally increase the amount of information that can be measured from each observed massive black-hole binary merger and EMRI, and would also increase the EMRI rate. The addition of spacecraft or entire constellations, even at the same level of sensitivity as LISA, would greatly enhance the search for a primordial background like that predicted by some models of inflation, and would greatly improve our ability to localize sources. Observations in the 0.1-10 Hz band would allow us to accomplish a number of new science goals. Intermediate mass black holes in binaries would merge in this band, providing unambiguous evidence of their existence. Also, the observation of a gravitational-wave signal accompanying a type IA supernova would strongly support a binary white dwarf merger origin for type IAs. This band would also be ideal for providing improved and advanced localization of the stellar-mass sources that will merge in the ground-based band, aiding the observation of electromagnetic counterparts. Improving sensitivity at high frequencies primarily requires more powerful lasers with improved frequency stability, larger telescopes to reduce photon shot noise, more stable optical benches with improved thermal isolation, and higher precision phase-measurement devices. Alternatively, improving low frequency sensitivity would facilitate observation of ever more massive black-hole binaries at ever lower redshifts. The development of such an instrument would require improved gravitational reference sensors, which house and shield free-falling test masses. Increasing the performance of these instruments requires lower residual pressures, reduced Brownian noise on the test mass, improved thermal stability, test mass materials and coatings with lower magnetic susceptibility and improved electrostatic properties, reduced electrostatic actuation noise via more stable voltage references, and reduction of spacecraft-induced gravitational noise, to name a few. Aside from hardware developments, many of these science goals require the development of novel data analysis methods, for example simultaneously characterizing the full set of sources as observed by a swarm of spacecraft and/or across multiple wavebands employing multiple instruments. Since the current generation of ground-based detectors is already pushing the state of the art in theoretical waveform modeling, the new types of sources, enormous signal-to-noise ratios, and extremely long durations of many of these signals require breakthroughs in modeling accuracy and efficiency. What we have described is likely a small subset of the issues facing a future space-based observatory that will complement or go beyond LISA. Significant investment in the coming decade will be needed to ensure the US maintains an active role in the field of gravitational-wave astronomy in the decades to come.

Web link:

Name: Krzysztof Gorski

Proposing Team:

Type of Activity:
Space Based Project

Description: Ongoing and future campaigns of high sensitivity measurements of the cosmic microwave background (CMB) anisotropies in temperature and polarization aim for the discovery and follow-on characterization of the imprints of the very early universe physics, usually expressed via inflationary models, and the anticipated detection of the so-called polarization anisotropy B-modes. These efforts target extraordinarily faint signals, which can only reveal cosmological signatures in CMB polarization anisotropy after a very high fidelity separation of foreground emission from the Galaxy and other astronomical sources. Foregrounds at high frequencies (mostly dust emission above 100GHz) and at low frequencies (mostly synchrotron and free-free emission below 100GHz) are presently best known through the legacy data of WMAP and Planck CMB space missions. Both of these experiments, originally designed to target CMB temperature anisotropies, were not high quality polarimeters. Usage of single aperture telescopes for multi-frequency observations resulted in generally low angular resolution of the low frequency measurements of these missions. Our current knowledge of low frequency polarized microwave sky is hence limited in angular resolution, and sensitivity (due to a systematic sensitivity differential in favor of high frequency instruments). Furthermore, polarized synchrotron sky maps derived from WMAP and Planck legacy data (with the greatest impact of, respectively, their ~20 and ~30 GHz channel maps – both noisy and lowest resolution in both experiments) are not sufficiently consistent to support adequate removal of foreground signals at higher frequencies (say ~150 GHz, a typical target for the most sensitive observations with bolometric receivers) to reveal an unblemished view of the primordial B-modes at all angular scales larger than about 1 degree. Improvement of this situation is necessary both for the assurance of success in correct interpretation of the future, inflation testing CMB polarization observing campaigns, and for spawning a wide range of advances in our knowledge of the Galaxy, including new insights into its magnetic field, and extragalactic radio sources. Since the primordial B-mode anisotropies are imprinted on angular scales between ~1 deg and a full sky, and on all those scales they are dominated by foreground emission, high fidelity, low frequency polarization measurements on the entire sky will be required. This paper describes the motivation and need for significant improvements of the space based measurements of polarization anisotropies of the microwave sky at low frequencies up to ~100 GHz. We argue that these advances in the field of space measurements of CMB polarization anisotropies are possible during the decade of 2020s thanks to (1) demonstrable technological maturity of the required detectors, (2) plausible availability of satellite platforms capable of supporting considerably larger telescope apertures than those employed by WMAP and Planck (necessary for angular resolution gains), and (3) lessons learned from WMAP and Planck that will lead to optimization of space measurements of CMB polarization. Unlike the most sensitive bolometric detectors that require costly cooling systems to support operations at temperature ~100mK – and provide most likely the ultimate means of measurements of the ultra-faint CMB B-mode polarization anisotropies at frequencies above ~100 GHz – the low frequency measurements can be performed with less demanding and costly cooling systems. Post-WMAP and -Planck, dedicated space measurements of full sky, low frequency CMB polarization anisotropies are necessary for the healthy development of the field, and can be made cost-effectively – we argue that they should be undertaken in the decade of 2020s.

Web link:

Name: Ruslan Belikov

Proposing Team: ACEND

Type of Activity:
Space Based Project

Description: Alpha Centauri (aCen) offers a unique opportunity to directly image an exo-Earth with a telescope ~3 smaller than what is required to do the same around any other FGKM star, and 10x smaller than required for a star 13pc away. This is because aCen is not merely the closest star system to the Sun, it is ~3x closer than any other Sun-like star and has a habitable zone ~3x wider in sky angle than any other FGKM star. The proximity of aCen does not merely make it the tip of the iceberg for direct imaging of Earth-like exoplanets, it is its own iceberg. It is also a comparatively easy stepping stone towards the search for exo-Earths around other stars. A small space telescope (~40cm) equipped with a sufficiently powerful starlight suppression system is sufficient to enable a direct image of an exo-Earth around Alpha Centauri A or B. Several studies and concepts have been developed taking advantage of this opportunity, corresponding to different points in the trade space and different funding mechanisms: ACESat, Project Blue, ACEND. This white paper will describe this family of concepts, along with the technology necessary to enable them. Astrophysical considerations and noise are manageable for such a mission. Planetary orbits inside 2.5 AU are stable around both stars, including the complete habitable zones around both stars. We know planets can form around aCen because they have been detected around similar binaries. Binarity complicates the calculation of occurrence rates, but latest Kepler estimates range from about 20-50% for potentially habitable planets around single stars, and over 1 planet per star on average. For a ~40cm telescope, contrast of zodiacal light is ~2e-10. Contrast of exozodiacal light is constrained to be less than ~2e-8 if aCen has 100 zodis of exozodi (its currently known upper limit). Both can be removed by post-processing as described below. Extragalactic background is extinguished because aCen is in the plane of the Milky Way. Galactic star density is high in the field of aCen and there is a 3% chance of confusion of an exo-Earth with a background star in any one image, but the great proper motion of aCen (4"/year) will eliminate confusion. In almost all cases, the apparent brightness and proximity of the stars compensates for a small aperture of the telescope. A small space telescope can achieve 2e-11 post-processed contrast floor for both stars by a combination of two new technologies: Multi-Star Wavefront Control (MSWC), which achieves 1e-8 raw contrast for both stars, and Optical Difference Imaging (ODI), which suppresses the floor to 2e-11. Such powerful post-processing is enabled by spending 2 years on imaging Alpha Centauri and generating a much larger number of images (tens of thousands over two years on the same star system) than is typically available for direct imaging analysis. Successful strides have been made in developing these technologies, and this work needs to continue in order to make them flight-ready. The baseline design for a telescope is a full SiC 40cm off-axis system, with lambda/25 end-to-end wavefront error. Active thermal control maintains 10C operation with 0.1C stability. A Low Order Wavefront Sensor providing 0.5mas stability has been demonstrated in the lab. The required orbit is mid-Earth orbit or higher to minimize interruptions of line of sight to Alpha Centauri, as well as to achieve the required thermal stability of the payload. A small coronagraphic telescope capable of imaging Earth-like planets around Alpha Centauri will also be of significant benefit to WFIRST, LUVOIR, and HabEx. A small telescope can image bands complementary to WFIRST (e.g. blue), which can enable the detection of Rayleigh scattering. Furthermore, although WFIRST is expected to make giant leaps in space-based coronagraphy, it is not currently designed to image aCen. Efforts are under way to enable this, but a specialized smaller telescope specifically designed for aCen may achieve greater sensitivity on that system than a larger general-purpose telescope with many targets. A small mission can also provide characterization targets around aCen for WFIRST, without the need for WFIRST to search for them. The benefits to LUVOIR and HabEx are even greater, because a small telescope imaging aCen provides significant technology demonstration value in binary star suppression. In terms of angular resolution and photon flux, a small telescope imaging Alpha Centauri is similar to HabEx imaging of a similar star system at around 10pc. Furthermore, this mission can provide high-value targets for LUVOIR and HabEx, before they are launched, saving valuable search time and increasing the impetus for those missions.

Web link:

Name: Adrian Lee

Proposing Team: The LiteBIRD Collaboration (http://litebird.jp/eng/?page_id=10)

Type of Activity:
Space Based Project

Description: LiteBIRD is a proposed satellite that will search for primordial gravitational waves emitted during the cosmic inflation era (around 10^–38 sec after the beginning of the Universe). It goal is to test representative inflationary models (single-field slow-role models with large field variation) by performing an all-sky CMB polarization survey. Primordial gravitational waves are expected to be imprinted in the CMB polarization map with special patterns, called "B-modes". If we succeed to detect them, it will provide entirely new and profound knowledge on how our Universe began. From the viewpoint of high-energy physics or elementary particle physics, the observation of the primordial CMB B-modes is very important because it will allow us to search for physics at ultra high-energy scales, which are not accessible with man-made accelerators. Measurements of CMB polarization will open a new era of testing theoretical predictions of quantum gravity, including those by superstring theory. LiteBIRD is being proposed by a collaboration that is led by JAXA (PI: Masashi Hazumi) and includes U.S. participation in bolometric detectors, cold readout electronics, and cryogenics. Europe is also a major participant and plans to contribute telescope optics for the upper half of the frequency range, polarization modulators for that range, and the sub-K cryo-coolers. JAXA plans to provide the launch vehicle, telescope optics and polarization modulator for the lower half of the frequency range and some of the cryocoolers. Canada will provide the 300K readout electronics. JAXA is currently in phase A1, and the launch is planned for 2027. The U.S. team will propose a Mission of Opportunity to NASA.

Web link: http://litebird.jp/eng/

Name: James Buckley

Proposing Team: Advanced Particle-astrophysics Telescope (APT) collaboration

Type of Activity:
Space Based Project

Description: APT is a mission concept for a future spacebased experiment for ivy energy gamma-ray and cosmic-day studies. The instrument concept is based on two primary science objectives: (1) sensitivity to thermal WIMP dark matter across the entire natural parameter space (with more than an order of magnitude improvement in sensitivity compared with Fermi and (2) sensitive detection (with 30m^2 str exposure) abd sub-degree localization of the MeV electromagnetic counterparts of gravitational wave sources. The detector would use scintillating fibers and a distributed CsI calorimeter to acieve good pair, andmultiple Compton sensitivity with a minimum number of SiPM readout channels. A Falcon 9 heavy could put the instrument in n L1 orbit where the up-down symmetry of the instrument would provide an enormous j stantabeous FoV. A MiDEX or Probe implementation are possible.

Web link: N/A

Name: Imran Mehdi

Proposing Team: o I. Mehdi, Jet Propulsion Laboratory, USA o M. C. Wiedner, Sorbonne Université, Observatoire de Paris, Université PSL, CNRS, France o A. Baryshev, Kapteyn Astronomical Institute, The Netherlands o V. Belitsky, Group for Advanced Receiver Development (GARD), Sweden o V. Desmaris, Group for Advanced Receiver Development (GARD), Sweden o A. DiGiorgio, Istituto Nazionale di Astrofisica-Istituto di Astrofisica e Planetologia Spaziali, Italy o J,-D. Gallego, Centro Astronómico de Yebes, Spain o M. Gerin, Sorbonne Université, Observatoire de Paris, Université PSL, CNRS, France o P. Goldsmith, Jet Propulsion Laboratory, USA o F. Helmich, SRON Netherlands Institute for Space Research and Kapteyn Astronomical Institute, The Netherlands. o W. Jellema, SRON Netherlands Institute for Space Research and Kapteyn Astronomical Institute, The Netherlands. o A. Laurens, CNES, France o C. Risacher, IRAM, France

Type of Activity:
Space Based Project

Description: Title: Heterodyne Receiver for Origins Space Telescope (HERO) The instrument suite on Origins has been designed to provide the revolutionary capabilities that will enable addressing the main science questions: How does the Universe work? How did we get there? Are we alone? However, and especially for the second question, the need for velocity-resolved profiles of selected far infrared and submillimeter lines has been clearly established. Indeed, accessing the velocity field provides another dimension for probing the physical and chemical conditions at scales finer than those provided by the angular resolution of the telescope itself. The Heterodyne Receiver for Origins (HERO) has been designed as a unique probe of the very beginning stages of the Trail of Water, and as an important complementary tool for its intermediate (protoplanetary) and ultimate (comets) steps. This means accessing the ground state transitions of water vapor in its two spin symmetry states, and those of its isotopologue H218O, plus at least two lines from HDO and the HD ground state transition, and providing a spectral resolution of at least R = 10^6 for those lines. HERO will be electronically tunable around a wide frequency range providing spectroscopic coverage of numerous other lines important for understanding astrophysical processes. To enable these measurements, HERO is envisioned as a multi-band multi-pixel instrument that can provide simultaneous measurements for multiple signals. Because of cost restrictions of the overall satellite mission, HERO is currently a low risk upscope option complementing and enhancing the baseline instrument suit. The frequency band of interest is from 486 to 2700 GHz (617 to 111 µm) continuously with two polarization and 9 pixels but in a minimum number of bands. HERO will be the first heterodyne focal plane array receiver designed for a space project and covers wider frequency range than any existing or prior heterodyne receiver. As satellite resources are limited this requires the use of innovative technologies to drastically reduce the heat dissipation, mass and the power consumption of the receiver subsystems and components. Optics and Local Oscillators have to be developed for a very wide Radio Frequency (RF) bandwidth (45%) while maintaining excellent characteristics, low loss for the optics, and high power output created at high efficiency over a wide bandwidth for the LOs. Mixers, low noise amplifiers and ASIC spectrometers have to have large IF bandwidth (> 6 GHz) for observation of complete line profiles. The sensitivity of the mixers needs to be increased, the low noise amplifiers need to dissipate very little power (< 0.5mW) and have low noise (< 4K), and the spectrometers have to be very power efficient while covering many GHz bandwidth with MHz resolution (< 1W/ 6GHz).

Web link:

Infrastructure, Technological Development, and State of the Profession Activities

Name: Laura Trouille

Proposing Team: Zooniverse

Type of Activity:
Infrastructure Activity
Technological Development Activity
State of the Profession Consideration

Description: Citizen science has become a proven and commonly used method of distributed data analysis, enabling research teams to solve problems involving large quantities of data, taking advantage of the inherently human talent for pattern recognition and anomaly detection. Zooniverse is the largest platform for online citizen science, host to over 140 projects across the disciplines with 1.7 million registered participants around the world. At a time when citizen science is gaining prominence across the world, Zooniverse has become a core part of the research infrastructure landscape. Zooniverse projects have led to 200 peer-reviewed publications, including 126 from astronomy alone (see zooniverse.org/publications and the significant contributions from Galaxy Zoo, Radio Galaxy Zoo, Planet Hunters, Exoplanet Explorers, Planet Four, Space Warps (lensed galaxies), Supernova Hunters, Andromeda Project (star clusters), Backyard Worlds (brown dwarfs and Planet 9), Disk Detective, the Milky Way Project (GLIMPSE disk of our galaxy), Solar Stormwatch, and Moon Zoo). These projects have established a track record of online citizen science producing quality data for use by the wider scientific community. Furthermore, the serendipitous discoveries made by Zooniverse volunteers over the years have transformed frontier fields of research. For example, the discovery of Boyajian's star through Planet Hunters and Backyard Worlds finding the oldest white dwarf known to host a dusty disk -- both have pushed forward our understanding of the formation and evolution of stars and planetary systems. The number of projects supported by Zooniverse has recently experienced rapid growth, an acceleration which is a result of the launch in July 2015 of the free Project Builder Platform (zooniverse.org/lab) which enables anyone to build and deploy an online citizen science project at no cost, within hours, using a web browser-based toolkit. The Project Builder is transformative; prior to its development a typical online citizen science project required months to years of professional web development time. Zooniverse went from launching 3-5 projects a year to launching 26 in 2016, 44 in 2017, and over 50 in 2018. To effectively and efficiently tackle the enormous data rates and volumes astronomy and astrophysics is facing, while also preserving the capacity for serendipitous discovery, key is to leverage the complementary strengths of humans and machines. Zooniverse thoughtfully integrates human and machine efforts to optimize for both efficiency and volunteer engagement, while striving to safeguard and encourage opportunities for serendipitous discovery. In its simplest form, a number of projects have used volunteer classifications to generate training sets for automated methods to efficiently classify all remaining data. More complex integration includes combining volunteer classifications with the machine learning results, active learning, using machine learning to guide volunteer training, application of clustering algorithms combined with volunteer efforts to identify unknowns, etc. For example, Zooniverse's GravitySpy.org combines the crowd-sourcing power of citizen science with machine learning to support the characterization of glitches in gravitational wave (GW) data. It is an essential component of the data processing pipeline for GW research. Furthermore, Zooniverse has become integral to the planning for large projects, such as LSST. It is a key component of the LSST Education and Public Outreach system, and will allow scientists to quickly search both transient and static data from this extremely large survey. In order for citizen science to continue serving as a powerful research tool for the astronomy and astrophysics community, it is essential that funding opportunities exist to support these efforts. Specifically, we argue that astrophysics as a whole benefits from the provision of an open and rich platform from which to build citizen science projects. Participating Individuals: Dr. Laura Trouille - VP of Citizen Science at the Adler Planetarium in Chicago, Zooniverse co-PI, Research Associate at Northwestern University; Dr. Chris Lintott - Professor of Astrophysics at the University of Oxford, Zooniverse PI and founder; Dr. Lucy Fortson - Professor and Associate Head, School of Physics & Astronomy (SPA) and the Minnesota Institute for Astrophysics at the University of Minnesota - Twin Cities; Zooniverse co-founder.

Web link: zooniverse.org

Name: Arfon Smith

Proposing Team:

Type of Activity:
Infrastructure Activity
Technological Development Activity
State of the Profession Consideration

Description: Title: Sustaining community-driven software in astronomy Authors: Arfon Smith, Erik Tollerud, Adrian Price-Whelan, Jamie Kinney, Ivelina Momcheva, Joshua Peek, Brigitta Sipocz, Dan Foreman-Mackey Software is an integral and growing part of the scientific endeavor: Responsible for driving the control systems of instruments, the operation of surveys, the processing of raw data products, the extraction of physical parameters, and the theoretical modeling of physical systems. Software is critical to all parts of modern scientific research. Astronomical software environment has changed rapidly over the last decade, largely driven by broader changes in the cultural 'norms' of modern software development and a shift towards open source software being the dominant method of technology creation. Large experimental projects (such as LSST, JWST, DESI, DKIST) are writing extensive code bases and releasing these tools as open source software. In parallel, large community-driven projects (like Astropy or SunPy, and yt) are using open development models to build large software packages by pooling the effort of individual astronomers into shared packages. At the same time, individuals are becoming increasingly likely to distribute and share their code broadly with the astronomical community and mechanisms for publishing these software products have expanded as a result. In the 2020s, many communities will face the challenge of working with petabyte-scale datasets for the first time. In this data intensive future, where software permeates scientific investigation, it is critical that the contributions of research software engineers working in academic environment are recognized and that the system at large develops mechanisms for sustaining the projects and the individuals responsible for this work. In this white paper, we will outline some of the progress being made both inside and outside of astronomy on how to sustain community-developed, open source software. We will then make recommendations to the decadal committee on how the astronomical community can adapt to better support this critical work in the future.

Web link:

Infrastructure, Technological Development, and Other Activities

Name: Bruce Elmegreen

Proposing Team: Conrad Albrecht, Hendrik Hamann, Siyuan Lu

Type of Activity:
Infrastructure Activity
Technological Development Activity
Other Data Management and Analysis

Description: PAIRS-ASTROSCOPE In the last decade, astronomical facilities have collected vast amounts of survey and pointed data using instruments with rapidly growing fields of view and survey speeds. The current archive is massive, it is growing exponentially in parallel with general technology, and it will continue to grow like this with new data from LSST, SKA, WFIRST, Euclid and other wide-field mapping telescopes. The investments to obtain these data are large as well, in billions of dollars. Current technology to find and use the data effectively are rapidly getting outdated, however, and only the tip of the iceberg of all this information is likely to have been turned into insights so far. We propose to design and prototype a highly-parallel Petascale database for astronomical use that is based on IBM's PAIRS-GEOSCOPE, a data and analytics platform of similar scale currently used for Earth science [1]. PAIRS (PAIRS = "Physical Analytics Integrated Data Repository and Services") receives several TB/day of satellite ground-cover data and places it in a fixed hierarchical coordinate system of Earth Longitude and Latitude with grid sizes ranging from micro-arcsecs to degrees in steps of factors of 2. For astronomical use, the grid could have a similar range, as desired. All incoming data are interpolated and placed at a level where source pixels are fully resolved, i.e. at the Nyquist sampling scale. Such placement allows seamless mosaicking of chosen regions at any scale using source images of any orientation and size. Different timestamps for data are on the same spatial grid in a third dimension. The benefits of the proposed system include the following: • Data can be accessed directly and with local processors without opening or moving files, which is often the rate-limiting step in analyzing and processing information. • Data from similar spatial locations are placed nearby in storage, allowing scalability. • Data reduction is highly efficient, allowing complex queries to combine various entries, e.g., finding the SED from all observations as a function of time for a particular location. • Data are stored only at the level of their native resolution; calculations to interpolate or combine pixels for comparison between different data sources are done on-the-fly. • Vector data (points, lines, polygons) are easily incorporated. PAIRS organizes data using a key-value store, e.g. HBase on Hadoop [2-4]. In HBase all data are managed as key-value pairs on a distributed file system, which extends over many servers controlled by a master. Map/Reduce queries or analytical tasks using e.g. Apache Spark [5] are executed in parallel (mapped) and then merged (reduced), providing highly scalable performance [6,7]. Unlike relational databases, key-value stores are scalable to hundreds of Petabytes [8]. Contiguous patches of multi-dimensional (space-time) data are indexed by one-dimensional keys for optimal performance in writing, reading, and downstream analytics. Corresponding data are stored as values in HBase. In this way the storage taken by the key becomes negligible compared to the data it represents. Reading/writing each key-value pair processes the patch of data at once, significantly enhancing performance. Each HBase table has multiple columns for each location, where each column is assigned a different physical quantity. For astronomy, the columns may be, e.g., passbands or spectral channels. MapReduce and Apache Spark can execute jobs directly on HBase tables, so analytics are parallelized. IBM Research has already designed and built PAIRS-GEOSCOPE at Petascale and offers it as a cloud service. It is scalable over the next decade to hundreds of TB/day uploads and hundreds of PetaBytes storage. A similar data/analytics platform would be of great value for astronomy. It could hold both public and proprietary data (using access controls) and provide LINUX-based parallel analytics capabilities to multiple users. The system could be implemented and managed by an American Astronomical Data Facility, or be available as a cloud service. The IBM team that developed PAIRS consists of about a dozen people with physics and computational backgrounds. The primary contact for this white paper (BGE) is an astronomer. [1] Lu, S. etal. 2016, IEEE Int. Conf. Big Data, IEEE Explore, 2672; [2] Lam, C. 2010, Hadoop in action, Manning Pub. Co.; [3] Zikopoulos, P. etal. 2011 Understanding big data: Analytics for enterprise class Hadoop and streaming data, McGraw-Hill Osborne; [4] Dimiduk, N., etal. 2013, HBase in action Manning Shelter Island; [5] Zaharia, M., etal. 2016, Comm. ACM 59.11, 56; [6] Dean, J., Ghemawat, S., 2008, Comm. ACM, 51.1, 107; [7] Ekanayake, J., etal. 2008, IEEE 4th Int. Conf. on eSci., 277; [8] DeCandia, G., etal. 2007, ACM SIGOPS Op.Syst.Rev., 41, 205

Web link: https://www.ibm.com/us-en/marketplace/geospatial-big-data-analytics

Infrastructure and Technological Development Activities

Name: Joseph Lazio

Proposing Team: Joseph Lazio (Jet Propulsion Laboratory, California Institute of Technology), Patrick Taylor (Lunar & Planetary Institute), Amber Bonsall (Green Bank Observatory)

Type of Activity:
Infrastructure Activity
Technological Development Activity

Description: The past decade has shown an unexpected diversity of planetary systems, knowledge of which may continue to increase with on-going and future projects and missions. Throughout the various studies, the properties of the solar system and the characteristics of the solar system planets have served both as "ground truth" and points of contrast against which to compare other planets. Planetary radars have served as crucial infrastructure in obtaining data about the solar system planets—they have provided ranging and orbital data to navigate spacecraft to planetary bodies; ranging data to complement spacecraft studies of planetary interiors; and studies of the surfaces and interiors of terrestrial planets. The Nation's radar infrastructure, and indeed the much of the world's planetary radar infrastructure, is based on astronomical and deep space telecommunications infrastructure, namely the radar transmitters at the Arecibo Observatory and the Goldstone Solar System Radar (part of NASA's Deep Space Network), along with the Green Bank Telescope as a receiving element. Access to these facilities for planetary radar should be sustained in order to enable continued studies of solar system bodies for comparison and contrast with extrasolar planetary systems. Over the next decade, beyond the required continued operations of existing systems, there are a number of activities that could or will occur * The U.S. could lead international engagement in broadening the use of astronomical facilities in other countries for radar observations, either in a bistatic mode (U.S. planetary radar transmits-separate antenna receives) or with the development of new planetary radar transmitters; and * Continued research and technology development for more reliable radar transmitters, enabling longer lifetimes and lower operational costs, and the use of phased interferometric arrays for planetary radars. This Notice of Intent addresses the infrastructure required generally for the Planetary Systems Thematic Area of the science white papers and the topics discussed in the following specific science white papers: * "Radar Astronomy for Planetary Surface Studies" (Campbell et al.); * "Planetary Radar Astronomy with Ground-Based Astrophysical Assets" (Taylor et al.); * "Structure of Terrestrial Planets and Ocean Worlds" (Margot et al.); * "Emerging Capabilities for Detection and Characterization of Near-Earth Objects (NEOs)" (Milam et al.); and * "Ground-based Observations of Small Solar System Bodies: Probing Our Local Debris Disk" (Lovell et al.).

Web link:

Name: Brian Williams

Proposing Team: XRISM Laboratory Astrophysics Working Group

Type of Activity:
Infrastructure Activity
Technological Development Activity

Description: Title: Laboratory Astrophysics Needs for X-ray Calorimeter Observatories The next generation of X-ray observatories that employ microcalorimeters will revolutionize the field of X-ray spectroscopy for a variety of sources. Optimizing the science return of these missions will require that analysis tools be capable of reliably modeling and interpreting high-resolution X-ray spectra. Hitomi showed that more work is urgently needed on both fronts. To prepare for this mission, and the next generation of high spectral resolution X-ray telescopes in general, significant progress needs to be made in understanding the underlying atomic physics behind astrophysical processes. This white paper will summarize the work that has been done thus far in the field of laboratory X-ray astrophysics, with the goal of identifying the most relevant tasks related to laboratory astrophysics that are still outstanding. Broadly speaking, this includes tracing science requirements and identifying the laboratory measurements needed to achieve them. We are attempting to identify which measurements are the highest priority, as well as which areas of laboratory astrophysics are most deficient. We are also exploring the consistency between the various spectral modeling software packages and codes, as well as studying how modeling software should take into account uncertainties on atomic models and measurements.

Web link:

Name: Rashied Amini

Proposing Team: Steve Chien, Lorraine Fesq, Ksenia Kolcio, Sara Seager

Type of Activity:
Infrastructure Activity
Technological Development Activity

Description: Enhanced and Enabled Astrophysical Observations with System-Level Autonomy A system-level autonomy framework enables a complex system to accomplish stated goals while observing and reacting to changes within the system and its operating environment without traditional human intervention. As witnessed in automotive and aviation sectors, system-level autonomy has realized capabilities only previously imagined. The impact of these capabilities on our ability to observe the universe will be just as revolutionary. The missions and systems currently under study for the Astro2020 Decadal are larger in size and more complex than past missions, with larger platforms, actuated optics, multiple flight systems, and complicated focal planes. With this new complexity come new threats to nominal operations and the ability of a mission to return the science without disruption. Increasing the degree of autonomy is enhancing to all space- and ground-based observatories by defining resilient operations where science can continue despite anomalies, and increasing observing capability while reducing costs. Additionally, system-level autonomy enables new mission architectures, such as those with large numbers of flight systems providing distributed apertures. Observing systems experience anomalies that disrupt science. As spacecraft become more complex to support more precise and complex instrumentation, as exemplified by the Surveyor-class missions under evaluation for the Astro2020 Decadal, the rate of disruption will increase. For spacecraft, the current state-of-the-practice is traditional fault protection, whose function is to enter a mode that is fail-safe at the expense of science. Imken 2018 has shown that these events correspond to about a 4% inoperability period, or just over 14 days per year, with 3σ confidence. Adopting an autonomous framework unlocks an alternative fault protection strategy of fail-operational, where spacecraft dynamically adapt to observed health through the integrated use of on-board diagnosis and responsive planning and execution. This strategy enables resilient system operations that retain the ability to reschedule science operations despite disruption. This approach has the potential to resolve over 50% of anomalous conditions that result in down-time due to spacecraft safing. System-level autonomy offers more resiliency than just protecting against spacecraft safing. Not all flight hardware works as expected nor do all ground-commanded operations. With increasingly complicated instruments, like coronagraphs or deformable optics, current knowledge of and access to system-level resources are required for operation. Nevertheless, the operation of payloads is currently open-loop and can result in termination of observations and lost science opportunities should one command fail. An autonomous observing system can respond to minor failures by exploring different strategies to retry or attempt other corrective measures to retain observational efficiency. An extensible autonomous framework defines a clear distinction between system-level and function-level control that is generic to the mission system; thus, patterns of behavior on one mission can be utilized on other missions to reduce development, testing, and operational costs. System-level autonomy can also be extended to ground-based observatories that can respond dynamically to weather and sky conditions to execute alternate observations when scheduled observations are not possible. Even where automated scheduling is employed, e.g. using STScI Spike, this framework will offer better utilization of observatory time and increased science return by integrating automated execution. In addition to enhancing missions under evaluation, system-level autonomy will enable brand new architectures. Here, the ability to plan and schedule operations for a single spacecraft can be generalized to support multiple spacecraft using multi-agent autonomy. This will allow for robust design of architectures that use multiple spacecraft. Complex, interferometric missions – like LISA – are enabled. Similarly, transient event missions, such as those observing multi-messenger signals or a follow-on for the 15-year old Swift/Gehrels, can be designed at lower cost as transient response no longer needs to be custom designed for that given mission, but is designed as a trivial extension to existing autonomous planning/execution capabilities. An example of the system-level autonomy framework described here is currently under development at NASA JPL, utilizing the Multi-Mission Executive (MEXEC) planning/execution and Model-based Off-Nominal State Detection and Identification (MONSID)* on-board health diagnosis software. The first mission to demonstrate system-level autonomy defined by this framework is Arcsecond Space Telescope Enabling Research in Astrophysics (ASTERIA), a cubesat observing exoplanet transits. This framework is unique and builds on decades of autonomy research at NASA JPL. Jet Propulsion Laboratory, California Institute of Technology *Provided by Okean Solutions under the NASA SBIR Program.

Web link:

Name: Randall Smith

Proposing Team:

Type of Activity:
Infrastructure Activity
Technological Development Activity

Description: The current generation of X-ray grating spectrometers on Chandra and XMM-Newton have modest sensitivity, largely due to a combination of modest resolution (typically 300-1000) and low efficiency (~< 10%). The next generation of X-ray gratings, however, have already demonstrated far higher resolution and efficiency, capabilities that will transform the field. These gratings are planned for use on Explorers, Probes, and Flagship missions, so the time is right to prepare for the high quality spectral data that will be returned by these missions. The highest resolution grating data available, from the Chandra HETG, has already shown the limitations of existing atomic data for modeling; improvements are needed in laboratory measurements of wavelengths, radiative and collisional transition rates, as well as ionization and recombination cross sections. To prepare for these proposed missions, significant progress needs to be made in understanding the theoretical atomic physics as well. This white paper, in concert with a paper focusing on microcalorimeter missions, will summarize the work that has been done thus far in the field of laboratory X-ray astrophysics, with the goal of identifying the most relevant tasks related to laboratory astrophysics that are still outstanding. This includes tracing science requirements from missions such as Arcus, XGS-P, and Lynx and identifying the laboratory measurements needed to achieve them. A preliminary prioritization of these needs will be provided, including possible new facilities that will be required. We are also exploring the consistency between the various spectral modeling software packages and codes, as well as studying how modeling software should take into account uncertainties on atomic models and measurements.

Web link:

Name: Molly Peeples

Proposing Team:

Type of Activity:
Infrastructure Activity
Technological Development Activity

Description: On the need for synthetic data and robust data simulators in the 2020s As observational datasets become larger and more complex, so too are the questions being asked of these data. Data simulations, i.e., synthetic data with properties (pixelization, noise, PSF, artifacts, etc.) akin to real data, are increasingly required for several purposes, including: (1) testing complicated measurement methods, (2) comparing models and astrophysical simulations to observations in a manner that requires as few assumptions about the data as possible, (3) predicting observational results based on models and astrophysical simulations for, e.g., proposal planning, and (4) mitigating risk for future observatories and missions by effectively priming and testing pipelines. In this white paper, we will advocate for an increase in using synthetic data to plan for and interpret real observations as a matter of routine. This will require (1) facilities to providing robust data simulators for their instruments, telescopes, and surveys, and (2) making synthetic data publicly available in archives (much like real data) so as to lower the barrier of entry to all.

Web link:

Name: Andreas Zoglauer

Proposing Team:

Type of Activity:
Infrastructure Activity
Technological Development Activity

Description: Coordinating Simulation and Data Analysis-Tool Development Efforts for Future High-Energy Space Missions Currently, a wide plethora of space-borne gamma-ray telescopes is under development or envisioned (COSI, AMEGO, eASTROGAM, Burstcube, Glowbug, Adept, LOX, and many more). They employ a wide range of detector systems (Materials: Ge, Si, CdTe, CdZnTe, CsI, NaI, SrBr2, LaBr3, and many more; technologies: semiconductor pixels, bars, strip detectors, simple scintillators, Anger-camera-like systems etc.) and cover a wide range of science goals (gamma-ray burst, supernovae, novae, nucleosynthesis, black holes, neutron stars/pulsars, and many more). However, despite all these differences, these future instruments have many steps in their data-analysis chain in common: 1. They all require thoroughly verified Monte-Carlo simulations for initial performance estimates, and later response simulations for their science analysis. 2. The all need to simulate and model the space radiation environment. 3. For all these instruments, the simulations need to be extremely well benchmarked with calibrations, and thus a detector effects engine needs to be employed to noise the ideal simulations (energy resolution, position resolution, thresholds, trigger criteria, etc.). 4. Many of these instruments have similar calibration needs (at least energy calibration and for some instruments depth calibration, position calibration, threshold determination, overflow determination, charge sharing determination, and many more). 5. All Compton and pair telescopes have the need for event reconstructions techniques to find the interaction sequence of the gamma rays and their secondaries in the detector, as well as tools to identify background. 6. Similarly, the high-level data analysis has many common approaches, from iterative imaging techniques to Compton telescopes, GRB localization with scintillators, to spectral analysis, polarization analysis and more. In addition, the techniques to generate and store the response matrices for all these are similar. As consequence, there are significant synergies to be found from having a common, easily expandable, and reusable software toolset which can be the basis of the software development of all these future gamma-ray missions. These synergies range from reduced man-power for developing new tools, less code duplication, the availability of already well-tested tools, to having a toolset which can reliably and reproducibly predict the performance of future instruments and enables direct comparisons of these instruments by eliminating uncertainties arising from simulations, background models, detector effects, and analysis. Currently, these needs are partially fulfilled by the open-source toolkit MEGAlib, the "Medium-Energy Gamma-ray Astronomy library" (Zoglauer et al 2006). MEGAlib was originally developed for the MEGA Compton and pair telescope, and is currently the main simulation and data analysis toolset of COSI. However, at least parts of the toolset, have been applied to a wide variety of NASA sponsored instruments ranging from astrophysics (Comptel, NCT/COSI, NuSTAR, Hitomi, ComPair/AMEGO, X-Calibur, BurstCube, Factel, and more), solar physics (e.g. GRIPS), but also to ground-based Compton cameras for environmental monitoring (e.g. HEMI, Ares) and nuclear medicine. However, while some specific developments for MEGAlib are sponsored by APRA (e.g. COSI imaging, AMEGO event reconstruction), maintaining MEGAlib and assisting all these NASA projects currently happens on a pure volunteer basis without any support. To fully reach the synergies, a more coordinated effort is required. These efforts have to support for a example a more generalized detector effects engine, calibration system, and especially support for full maintenance, continuous testing, documentation, user support, and specific extensions for individual missions. In summary, besides just supporting the development of new detector systems, with the increasing complexity of these systems an equal effort has to be put into developing the simulations and data analysis tools for the next generation of gamma-ray space mission. Since many elements of the analysis pipeline are reusable between different projects and missions, a more coordinated effort has to be launched to make the tools better available for different projects. While this is especially true for gamma-ray astronomy, the same holds true for many other energy bands.

Web link: http://megalibtoolkit.com

Infrastructure, State of the Profession, and Other Activities

Name: Dara Norman

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Type of Activity:
Infrastructure Activity
State of the Profession Consideration
Other Workforce

Description: The Growing importance of a Tech Savvy Astronomy and Astrophysics Workforce In the coming era of large surveys and big datasets, we cannot reach our scientific goals without developing and retaining highly capable scientists who are also engaged with technological advances in computing. With a goal of advancing scientific discovery through the collection of data, we must commit and dedicate resources to building both the skills and competencies of the astronomy and astrophysics workforce. This includes those in the workforce that will be using data to advance science as well as, those supporting the infrastructure that make those discoveries possible. This means promoting training in topics like software, algorithms, statistics and the use of tools and services for the community. Training in software engineering best practices, data management and access technology and infrastructure for supporting staff are also required. Those who support this scientific discovery infrastructure will also need career support and development. This WP will outline what is currently available and what still needs to be accomplished to build the tech savvy astronomy and astrophysics workforce that will elevate scientific discovery in the 2020s.

Web link:

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Type of Activity:
Infrastructure Activity
State of the Profession Consideration
Other Workforce

Description: Elevating the Role of Software as a Product of the Research Enterprise Software is a critical part of modern research and yet there is generally poor support across the scholarly ecosystem for its acknowledgement, citation, and in turn measuring its impact. The majority of academic fields rely on a one-dimensional credit model whereby academic articles (and their associated citations) are the dominant factor in the success of a researcher's career. In the petabyte era of astronomical science, making it possible to easily cite software and measure its impact is going to be critical for maximizing the scientific return of these datasets and retaining those individuals who specialize in developing these tools. Evolving beyond the one-dimensional credit model requires overcoming several key challenges including the current scholarly ecosystem and scientific culture concerns. This WP will present these challenges and suggest practical solutions for elevating the role of software as a product of the research enterprise.

Web link:

Name: Amanda Bauer

Proposing Team: Amanda Bauer, Britt Lundgren, William O'Mullane, Lauren Corlies, Meg Schwamb

Type of Activity:
Infrastructure Activity
State of the Profession Consideration
Other Outreach, Education, Communications

Description: There exists a new opportunity in the realm of large surveys and data facilities for online education and outreach activities to have a huge impact on society. In order to meet the public demand for mobile-friendly and intuitive user interfaces, and a discovery space driven by social media, the development of digital activities should be guided by centralized EPO teams who can create, evaluate, and disseminate innovative EPO activities in a way that astronomers can tap into. This means that we must commit and dedicate resources to education, outreach, and communication professionals who can provide strategy, oversight, training, and instill best practices to maximize the impact of outreach efforts and increase accessibility of science results within the public field of vision. EPO teams should draw on astronomical expertise, education theory and practice, user interface and user experience skills, software engineering skills, and communication experts. This White Paper will outline some examples of what is currently available and work that needs to be done to maximize the impact of ongoing outreach efforts and elevate society's engagement with the process of scientific discovery in the next decade.

Web link:

Infrastructure and State of the Profession Activities

Name: Kelly Holley-Bockelmann

Proposing Team:

Type of Activity:
Infrastructure Activity
State of the Profession Consideration

Description: Despite the clear enthusiasm from the astronomy community, gravitational wave science is still considered a niche area with restricted collaborations; there are few access points for astronomers to learn about and participate in gravitational wave science. There is much basic science and coordination to do to maximize the scientific return from this field. The next decade requires a major initiative to build a robust, open, and well-connected scientific community that includes astronomers, physicists, data scientists, and instrumentalists. We strongly believe that founding the field of gravitational wave astronomy requires not only the standard scientific support associated with new missions and surveys, but also programmatic support to the scientific community that is novel and designed to intentionally build basic capacity and broaden US participation in LISA science. We recommend adopting the tenets of successful evidence-based programs for increasing participation in astronomy.

Web link:

Name: Alina Kiessling

Proposing Team: Tri-Agency [NASA, NSF, DOE] tri-project [LSST, WFIRST, Euclid] Cosmological Simulations Task Force (TACS); Nick Battaglia, Andrew Benson, Andrew Hearin, Katrin Heitmann, Shirley Ho, Zarija Lukic, Michael Schneider, Elena Sellentin, Joachim Stadel

Type of Activity:
Infrastructure Activity
State of the Profession Consideration

Description: Numerical simulations have become increasingly sophisticated over the last several decades and their role in cosmological surveys has correspondingly experienced enormous growth. Numerical simulations are now integral to forecasting and survey formulation, in addition to the eventual analysis of the observational data. Developing and exploiting the numerical simulations requires large computing and storage resources as well as people with specialized expertise to develop the modeling and analysis pipelines and database approaches. Many of the tasks are common between the major cosmological surveys and it is therefore strongly advisable to evaluate common approaches and resource sharing between the surveys. Additionally, investigations of scientific gains that can be reaped from joint pixel analysis efforts have been initiated; such investigations rely on the availability of shared synthetic catalogs that can be used across the surveys and are based on the same underlying cosmological simulations. The shift from Stage 3 to Stage 4 cosmological surveys has been underway for the last several years and during this time the role of cosmological simulations in the surveys has undergone a shift from being a research and development (R&D) effort to being a key element of the Stage 4 survey infrastructure. Elements that are considered part of the survey infrastructure are deemed as essential to the success of the survey and have traditionally included efforts like ground operations, analysis pipelines, and data management pipeline development, but not cosmological simulations. However, although it is currently widely accepted that cosmological simulations are essential to upcoming Stage 4 surveys, the funding and support for these efforts is still largely only being covered by competitively selected R&D proposals. As a result, key work is difficult to undertake in a timely or planned manner due to the uncertainty of proposal selection. This has resulted in efforts to date being limited to the few groups that have been successful in securing short-term funding and resources for very specific tasks. Added to this challenge is the reality that students and postdocs working on cosmological simulations and synthetic sky generation have historically had very little success in securing permanent jobs in the field. Consequently, the number of people available to contribute to these efforts is consistently low and the "next generation" are being lost to more secure and higher-paying jobs in data science. This issue should be recognized as a pervasive problem in the field that is deserving of more focused consideration, perhaps by encouraging US National Labs and the Agencies to develop a program for more long-term employment options for highly skilled simulators. This white paper will begin by introducing "extreme-scale" simulations followed by large simulation campaigns, which are the two primary classes of simulation required for upcoming cosmological surveys. Next, the generation of synthetic sky maps and the challenges to this effort will be discussed, followed by an analysis of how simulations are essential to investigating and mitigating systematic effects. The role of simulations in developing advanced statistical techniques will then be introduced and the white paper will conclude by presenting an argument for the development of a common archival infrastructure to share simulation products. The purpose of this white paper is to clearly detail cosmological simulation efforts that are essential to the success of the upcoming Stage 4 cosmological surveys, including the Large Synoptic Survey Telescope (LSST), the Wide Field Infrared Survey Telescope (WFIRST), and Euclid. The white paper will also highlight work that is still required and focuses on collaborative efforts that will benefit two or more of the surveys. This white paper should make it clear that providing joint resources between the surveys will enable efficient development and sharing of simulations and related analysis tools. However, the current support for a program of this nature is not well established since these activities are often viewed as survey infrastructure tasks rather than as a broader research and development activity. Consequently, funding that, in particular, supports work across surveys (and therefore Agencies) is sparse. The most promising solution is a focused collaboration between the surveys and Agencies that will enable the most efficient use of resources and will facilitate rapid development in key areas that are currently experiencing only moderate progress due to this lack of support.

Web link:

Infrastructure Activities

Name: Thomas Matheson

Proposing Team: ANTARES project

Type of Activity:
Infrastructure Activity

Description: The Arizona-NOAO Temporal Analysis and Response to Events System (ANTARES) project is a collaboration between the National Optical Astronomy Observatory and the University of Arizona Computer Science Department to build a software system that can efficiently and effectively filter time-domain alerts at the scale and rate expected from the Large Synoptic Survey Telescope (LSST). The LSST data management team anticipate ten million alerts per night, every night, for the ten-year survey. Without tools to process and filter this alert stream, we will not take full advantage of the extraordinary opportunity that LSST presents for time-domain astronomy. ANTARES is designed to be flexible and meet the broad needs of the US astronomical community. We are already filtering public alerts from the Zwicky Transient Facility in real time and providing value-added alerts directly to astronomers. This includes simple filters such as objects near known extragalactic sources, alerts in M31, known Solar System objects, nuclear transients, and alerts with high variability, brightness, or (detection) significance. We also have a Jupyter Hub notebook that allows users to write their own filters and submit them for incorporation into the system. Alerts can be viewed via the ANTARES web portal or using data streaming technology. The ANTARES system fulfills the needs of many science use cases in the era of large-scale time-domain surveys. It can identify alerts that require rapid follow up, such as short-lived objects like .Ia supernovae, as well as objects that benefit from extremely early observations, like almost all supernovae. If an astronomer has a classically scheduled night for follow up, it can provide lists of relatively common transients on demand. ANTARES also supports watch lists, where astronomers can provide a list of their favorite objects and get a direct message when one of them alerts. It can perform triage on the large volume of alerts from LSST and provide substreams of interest that are within the capacity of individuals or teams of astronomers. In addition, we maintain a database of all alerts with their added annotations that astronomers can use to search for and characterize objects with longer time scales such as periodic variables. Our white paper will describe the current ANTARES suite of capabilities, our plans for future expansion, our scalability tests to prepare for LSST alerts, and our operations plan to enable exploitation of all the time-domain science LSST will offer. Our decisions about development will be guided by community input.

Web link: https://antares.noao.edu/

Name: Brian Giovannonni

Proposing Team:

Type of Activity:
Infrastructure Activity

Description: A consequence of our improved understanding of the Universe and our place in it is that future Astrophysics missions must envision richer data sets. NASA has enabled an infrastructure that permits future Astrophysics missions to deliver richer and more complex data sets. Importantly, this infrastructure has been and is being implemented without requiring funding from NASA's Astrophysics Division, but it is available to future Astrophysics missions. This Notice of Intent outlines both the current status of that NASA infrastructure and development plans into the next decade. Often, the science return from a mission is dictated by how much science data can be returned. As only one example, in order to meet its prime science objectives, the Kepler mission selected only portions of the focal plane to transmit to the ground, rather than transmitting all of the data recorded—while Kepler data have been used to address questions beyond the initial science mission, the experience from the archives of both space missions and ground-based telescopes amply demonstrates the power of being able to achieve scientific results beyond those initially planned from a telescope. Had the full Kepler data volume been able to be transmitted to the ground, even more discoveries would continue to be possible. We stress that Kepler is only such example, similar experience has been observed for the Planck mission and others. NASA's Deep Space Network (DSN) is a series of large, sensitive antennas distributed around the world. While known primarily for enabling Planetary Science missions, the DSN has been or will be integral to a number of Astrophysics missions including Chandra, XMM-Newton, and the James Webb Space Telescope. With an increasing number of Astrophysics missions likely to be in orbits around the Earth-Sun L2 point or in cis-lunar space, the DSN can play a critical role in ensuring the maximum possible data return. Among the various improvements planned for the DSN in the next decade are * Increased capability at higher frequencies (specifically near 26 GHz), which enables higher data rates by virtue of larger bandwidths available and is already planned for use by JWST to return its required data volume; and * Additional antennas at each of the three Complexes, with two more antennas being delivered to the Madrid Complex in the early part of the decade and an additional antenna at each of the Goldstone and Canberra Complexes subsequently. NASA's Advanced Multi-Mission Operating System (AMMOS) is a suite of software tools and services designed to facilitate the rapid construction of low-cost and reliable mission operations and data processing capabilities for robotic missions. Among the various Astrophysics missions that have already incorporated AMMOS capabilities are the Hubble Space Telescope, Spitzer Space Telescope, and the Kepler mission. Among the various improvements planned for the AMMOS in the next decade are * An implementation for the "cloud," allowing processing without requiring dedicated on-site hardware; and * Enhanced data visualization, allowing both rapid assessment of spacecraft health and initial capabilities to examine science data before higher level data products are produced. Looking further into the decade, NASA is moving also into the era of optical communications. Astrophysics missions at the Earth-Sun L2 point are particularly well positioned to exploit the higher data rates available from optical communications—a spacecraft at the E-S L2 point is always opposite the Sun and therefore viewed at night. Consequently, demands on the ground station are reduced (e.g., no requirement to shield against scattered sunlight). Further, even modest apertures on the ground, such as 4 m in diameter, can yield substantial data rates.

In principle, partnerships with existing astronomical facilities could result in significant increases in capability for Astrophysics missions. Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Web link:

Name: Joshua Pepper

Proposing Team:

Type of Activity:
Infrastructure Activity

Description: Many projects in current exoplanet science make use of catalogs of known exoplanets and their host stars. These may be used for demographic, population, and statistical studies, or for identifying targets for future observations. The ability to efficiently and accurately conduct exoplanet science depends on the completeness, accuracy, and access to these catalogs. In this white paper, we argue that the long-term support and maintenance of exoplanet archives is of crucial importance to the community, and that funding agencies should see to it that these facilities are appropriately supported.

Web link:

Name: Nicholas Siegler

Proposing Team: N. Siegler (JPL), H. Thronson (NASA GSFC), R. Mukherjee (JPL), B. Peterson (OSU), M. Greenhouse (NASA GSFC), R. Polidan (PSST), & J. Grunsfeld (NASA retired)

Type of Activity:
Infrastructure Activity

Description: Building the Future of Astrophysics: In-Space Assembly of Large-Aperture Space Observatories Unless there is a paradigm change in space observatory design during the time period considered by the Astro2020 Decadal Survey, the apertures of future space observatories – and their scientific discoveries – may be severely limited by the cost and risk of fitting in a single-vehicle launch. Current concepts for future observatories employ designs to permit self-deployment from a single launch in a manner similar to that of JWST. The complexity involved in engineering these designs and the associated verification and validation processes is very significant. Consequently, these incur major cost and risk impacts. NASA's Astrophysics Division has chartered our team to study the benefits of robotic in-space assembly (iSA) as compared to the current approach of automated deployment from a single fairing. The question posed by NASA asks, "When is it worth assembling space telescopes in space rather than building them on the Earth and deploying them autonomously from single launch vehicles?" Our study has engaged a large community of subject matter experts from astrophysics, optics, robotics, large structures, spacecraft design, orbital dynamics, launch systems, systems engineering, and costing. It has involved over 100 participants from multiple NASA centers, commercial industries, other government agencies, and academic institutions. Through community consensus, we selected an off-axis, UVOIR telescope architecture as our notional reference telescope architecture to use as a basis for evaluating the risk and cost of iSA with four different apertures: 5, 10, 15, and 20 meters. Our whitepaper will present findings from this study, including the relative cost and risk postures. Even absent the issue of cost and risk, current designs for the largest future space observatories strain the capabilities of plausible launch vehicles, specifically their fairing volume and mass-to-orbit. Some of the current concepts saturate the capabilities of existing launch systems and are predicated on the future availability of the SLS Cargo vehicle. Unless alternatives are developed in the near future, as scientific performance frequently depends upon a high power of the aperture, we can foresee a time when major scientific discoveries enabled by large-aperture UVOIR observatories eventually plateau. ISA is an alternative to self-deployment of large apertures in space. There have been significant advances over the last decade such that iSA might reduce cost, mitigate risk, and increase science by enabling increasingly large apertures. Examples of these advances include: • Space robotics, via significant NASA and DoD investments in satellite servicing, and success of the ISS and Shuttle robotics. • Lower-cost commercial launch vehicles, as demonstrated most recently by SpaceX's Falcon and Falcon Heavy • Autonomous rendezvous and berthing (or docking) as demonstrated at the ISS and with DARPA's Orbital Express ISA represents a new paradigm in space telescope deployment that includes: • Modularization, allowing ground testing of elements of a very large telescope • Programmatic funding profile flexibility • Launches by lower-cost medium-lift vehicles appropriate to each payload • Standardized interfaces • Assembly by robotic arms • In-space servicing and upgrading, including repairing, preventive maintenance, and instrument/sub-system change-out • In-space adjustability and correctability This approach appears to be less risky and enables observatories that are more capable, designed to last decades, than is the case with self-deployed, single launch-vehicle missions. For example, the assembly of a large observatory using individual modules with standard interfaces may reduce the time to perform integration and testing on the ground, as well as troubleshooting anomalies. Assembling modularized subsystems in space eliminates the need to architect designs that require folding large structures into smaller launch vehicles and deploying them safely using hundreds of deployment structures and release mechanisms. We will submit simultaneously to NASA with our whitepaper an extensive report that will answer several questions about iSA including: 1. At what telescope aperture is iSA necessary? 2. At what telescope aperture (or cost) would it be less expensive to assemble the telescope in space rather than deploy autonomously? 3. What risks does iSA mitigate compared to autonomous deployment? What risks are increased? 4. How would a very large telescope (> 15 meters diameter) be assembled in space? And what would that cost? 5. What technologies are required to enable such an assembly? What is the state-of-art and what are the technology gaps? What demonstration missions may be required? 6. What are the roles of astronauts, if any? 7. Why now? Our work to date may be found at https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

Web link: https://exoplanets.nasa.gov/exep/technology/in-space-assembly/

Name: Brian O'Shea

Proposing Team: TBD

Type of Activity:
Infrastructure Activity

Description: Approximate title: Computational needs for astronomy and astrophysics in the 2020s
Description: Large-scale computation is critical to both observational and theoretical astrophysics, and its impact will inevitably grow in the 2020s as observational data volumes increase (from, e.g., the LSST, SKA, and WFIRST) and as numerical models of astrophysical phenomena grow in size and complexity to address them. In this paper, we will make some predictions about both the quantity and variety of computational needs in the astrophysics community in the 2020s, and discuss the need to rally community support around national cyber-infrastructure to support advances in astrophysics.

Web link:

Name: Lee Armus

Proposing Team: Tom Megeath (U. of Toledo), David Ciardi (IPAC/NExSci), Lia Corrales (U. of Michigan), Martin Elvis (CfA), Suvi Gezari (U. of Maryland), Allison Kirkpatrick (U. of Kansas), Ralph Kraft (CfA), Massimo Marengo (U. of Iowa), Stephan McCandliss (Johns Hopkins), Michael Meyer (U. of Michigan), J. D. Smith (U. of Toledo), Sarah Tuttle (U. of Washington)

Type of Activity:
Infrastructure Activity

Description: NASA's Great Observatories, extended by other space-based observatories such as Fermi or Herschel, have opened up the electromagnetic spectrum from space, providing sustained access to wavelengths not accessible, or greatly compromised, from the ground due to Earth's atmosphere. The first Great Observatory, Hubble, was launched in 1990, and three of the four (Hubble, Spitzer and Chandra) are still operating today. Each of these observatories have delivered huge gains in sensitivity and/or resolution. Together, they have provided the scientific community with an agile and powerful suite of telescopes with which to attack broad scientific questions and react to a rapidly changing scientific landscape. This access has become a central feature of modern astrophysics, where phenomena are now routinely observed across the electromagnetic spectrum from the ground and space. As the existing Great Observatories and other existing space based observatories age, or are decommissioned, community access to these wavelengths will diminish, with an accompanying loss of scientific capability. This white paper analyzes the importance of multi-wavelength observations and examines the options available for maintaining panchromatic space capabilities. This is done in three parts. We summarize the science achieved by multi-wavelength astronomy by the Great Observatories, focusing on three main paths by which panchromatic observations impact science: by providing (approximately) simultaneous multi-wavelength observations of time variable phenomena, by providing commensurate capabilities across the electromagnetic spectrum, and by allowing for concurrent studies of phenomena in multiple wavelength regimes. We then consider the scientific landscape of the next decade and discuss areas where the panchromatic coverage achieved through space based observatories are necessary to address key astrophysical problems. We highlight the gaps in wavelength coverage and scientific capabilities that are anticipated over the next 10-20 years as current spaced-based observatories age or are decommissioned. We then identify the corresponding scientific impacts that these gaps will create, in terms of loss of discovery space, the ability of the community to address key questions, and the flexibility for the community to react to a rapidly evolving scientific landscape. Finally, we examine options for maintaining multi-wavelength coverage from space over the next decades. These include both an expanding set of strategic missions of large and intermediate sizes that provide broad community access and concurrent capabilities. We also address the importance of maintaining communities with expertise in different spectral regimes to enable future missions that take full advantage of advances in technology..

Web link:

Name: Kristin Madsen

Proposing Team: IACHEC

Type of Activity:
Infrastructure Activity

Description: Scientific results are, now more than ever, obtained as a synergy between observatories, and the physical interpretation relies heavily on good instrumental cross-calibration knowledge, which is bounded by the resources devoted to calibration. Examples of scientific problems that have been limited by instrumental calibration include the neutron star equation of state from X-ray bursts and isolated neutron stars (involving e.g., NICER, Chandra, and RXTE), cosmological contribution of dark matter derived from total masses of galaxy clusters (involving XMM and Chandra), the contribution of active galaxies to the cosmic X-ray background (involving XMM, Chandra, and NuSTAR), and atomic processes in astrophysical plasmas in galaxy clusters, stars, and the interstellar medium (involving Hitomi, Chandra, and XMM). For the last decade, the International Astronomical Consortium of High-Energy Calibration has performed a crucial role in organizing the high-energy community into a common forum for discussion and solution of calibration and cross-calibration issues. Since 2006, the IACHEC has been hosting annual workshops attended by calibration scientists from past, current, and near-term high-energy observatories. Organized into working groups, IACHEC members cooperate to provide standards and procedures for calibration that are useful for every high energy mission. The main goal of the IACHEC is to optimize the scientific value of current missions by improving the cross-calibration among existing instruments, creating new standards for analysis, and optimizing calibration plans of future missions. Because of the IACHEC's past efforts, up-coming and future X-ray mission will benefit from a large knowledge database, which is curated and organized for the benefit of the community. Examples of missions that followed these recommendations were NuSTAR, Hitomi, AstroSAT, Insight-HXMT, and most recently, NICER. Differences in the sensitivities of operating instruments require a stable of calibration sources with a variety of spectral shapes and flux levels. Unvarying, soft, thermal X-ray spectra, as found in supernova remnants, clusters, and white dwarfs, are well suited for CCD and grating instruments but not for instruments with their main bandpasses above 5 keV. Hard, bright, non-thermal spectra, such as quasars and blazars, are preferred for calibration above 5 keV but care must be taken to find the right brightness in order to avoid pile-up in CCD instruments while higher fluxes are required for calibration above 25 keV. The IACHEC has included variable sources through the organization of cross-calibration campaigns that can involve many observatories. The results from these studies and campaigns have been published to: 1) guide the scientific community in understanding the calibration systematics in datasets spanning several instruments; 2) guide future observatories in their calibration planning; 3) advise the community on the best practices in data analysis. The IACHEC is operated on an entirely voluntary basis without direct funding; the time invested is donated by the instrument scientists of the contributing missions. However, with the increasing ages of missions, there is a constant pressure to decrease the calibration budget (in both time and manpower), due to the perception that mature missions should be well-calibrated, as typically the calibration is more well tested for an aged observatory. The IACHEC is utilizing its resources on a best effort basis but with an increasing portfolio of operating missions, resolving cross-calibration issues between observatories is not progressing at the rate desired by the scientific community, based on user group imperatives. The problem of calibration is therefore presently not just one of data shortage but also of manpower; it is an issue that needs to be addressed more holistically in the next decade. We also advocate that calibration should no longer just be viewed as an instrument specific activity, performed within the respective instrument teams only, but as a whole, using knowledge gained from many observatories and cross-calibration between them.

Web link:

Technological Development, State of the Profession, and Other Activities

Name: Vinay Kashyap

Proposing Team: Andy Ptak (GSFC), Aneta Siemiginowska (CfA), Andreas Zezas (Crete), Doug Burke (CfA), David van Dyk (Imperial), Xiao-Li Meng (Harvard), Thomas Lee (UC Davis), Yang Chen (Michigan)

Type of Activity:
Technological Development Activity
State of the Profession Consideration
Other Cross-disciplinary

Description: Meeting the Challenges of Next Generation Data New space borne telescopes like XRISM and Athena will soon be launched with calorimeters on board, collecting high-spectral resolution and high-cadence high-energy photons. Such data pose special challenges to astrophysics because the quality of the data will far outstrip the methods currently employed to analyze such data. At the high counts limit, the spectra will reveal the imperfections in the atomic data, and at the low counts limit, result in biased results and inferences due to the limitations of methodology. With the high collecting areas of planned telescopes, examples of both instances will be common. In the high signal-to-noise limit, handling systematic errors like properly modeling imperfections in the atomic data will be important. Also in that case scientists will want to fit complex models to the data which often require advanced techniques to be tractable. Conversely scientists also want to stretch the limits of facilities and often search for faint sources or faint features in sources at the low S/N limit, resulting in biased results and inferences due not using optimal statistical methodologies. We will demonstrate the pitfalls of ignoring these issues, and review some methods that are currently being developed. We argue that such efforts must be supported by funding cross-disciplinary programs. Failure to do so will mean sub-optimal utilization of the capabilities that are being implemented in new telescopes.

Web link:

Technological Development and State of the Profession Activities

Name: Aron Wolf

Proposing Team:

Type of Activity:
Technological Development Activity
State of the Profession Consideration

Description: Pointing repeatability and stability (jitter) requirements for large space telescope missions are difficult to meet with current reaction wheel-based architectures. The reaction wheels themselves are typically the largest pointing disturbance on the spacecraft. Micro-thrusters have potential for reducing the cost and technical risks of achieving demanding pointing stability performance. Both cold-gas and colloidal micro-thrusters were demonstrated on the Laser Interferometer Space Antenna (LISA) Pathfinder mission, and cold-gas micro-thrusters have also flown on European Space Agency (ESA) missions. In 2017, a preliminary feasibility study conducted by the NASA Engineering and Safety Center (NESC) GN&C Technical Discipline Team (TDT) showed the potential for improved jitter performance with cold-gas micro-thrusters in low-fidelity simulations of a large, observatory-class spacecraft. Following up on this study, the NESC is conducting a more in-depth, higher fidelity assessment to investigate the benefits of microthrusters, in comparison with traditional architectures, for a variety of observatory-class mission concepts with tight pointing stability requirements. performance is the primary focus of this NASA Engineering and Space Center (NESC) task. This study could show a pathway to reducing the cost and risk of satisfying demanding pointing stability requirements for some missions, by using microthrusters instead of isolation systems and other complex solutions required in some cases with reaction wheels.

Web link:

Name: Erik Tollerud

Proposing Team:

Type of Activity:
Technological Development Activity
State of the Profession Consideration

Description: This White Paper will discuss the state of reproducibility in Astronomy. More specifically, it will discuss both the nature of the very concept of "reproducibility" as it applies to astro (primarily but *not* exclusively in an observational context), both in the traditional scientific sense of experimental reproducibility and a more specific sense of reproducing deterministic results from e.g. astronomy software. It will also discuss both cultural and technological limitations that prevent or limit such reproducibility, and some suggestions for how the field might improve in this area in the 2020s.

Web link:

Name: Jonathan Arenberg

Proposing Team:

Type of Activity:
Technological Development Activity
State of the Profession Consideration

Description: Northrop Grumman Aerospace Systems is planning to submit three APC white papers covering the following areas of interest to the decadal survey; 1. "Lessons Learned from Flagship Development", A state of the profession paper discussing lessons learned from past Flagship developments. These lessons will be distilled in suggestions for technology and design development, policy and legislative changes that can and will improve engineering productivity and implementation performance for the next Flagship mission. This paper will make all efforts to collect co-authors from all of the recent Flagships, Spitzer, Chandra and JWST. 2. "Viability of Actively Cooled Telescopes", A state of the profession paper discussing recent analysis done on several designs for the Origins Space Telescope. These various analyses come to roughly the same conclusions, namely that the requisite temperatures of ~4.5K can be achieved a small number of current state of the art coolers. This paper will discuss other needs to insure a rapid and efficient maturation of the design of an advanced cryogenic telescope. 3. "Cost, Schedule and Risk Modeling for Lynx Mirror Production" This state of the profession paper introduces a recently published operations research analysis of cost, schedule and risk for the Lynx production problem. This model is based on well-known results from queuing theory. The paper will discuss how this model will guide the technology and manufacturing process development, be validated with data and transition into a tool for determinative and quantitative management of the Lynx production process.

Web link:

Name: William O'Mullane

Proposing Team:

Type of Activity:
Technological Development Activity
State of the Profession Consideration

Description: The demise of the filesystem An architecture for data processing and science exploitation. William O'Mullane, Niall Gaffney, Frossie Economou, Arfon Smith Infrastructure Activity, State of the Profession Currently we tend to reinvent and implement many services in many data centers. Some standards e.g. IVOA have helped define interfaces yet we still implement this differently in each location. Industry is also moving, an important trend in computing infrastructure currently it towards object stores rather than posix file systems. This actually has some advantages for portability of processing but it also causes problems for many current systems. We propose a reference architecture for data processing and access. This would allow us to concentrate effort on a limited number of implementations of each component. The architecture will span science access portal type services down to low level storage and and compute services. Such an architecture will allow components to be constructed collaboratively in an open sourced manner which can then be deployed in multiple data centers. It would also allow use of commodity services where a appropriate e.g for compute and storage.

Web link:

Technological Development Activities

Name: Alexander Szalay

Proposing Team:

Type of Activity:
Technological Development Activity

Description: We are spending hundreds of millions of dollars to create high value data sets, over periods of decades (Sky Surveys). Yet, there is no plan for a sustained preservation and active use for these high value data sets. The paper will discuss some of the relevant aspects and challenges involved.

Web link:

Name: Elliot Carol

Proposing Team: Lunar Resources, Inc.

Type of Activity:
Technological Development Activity

Description: Idea: In-space deposition system to deposit bare aluminum coatings in the vacuum of space for future UV direct imaging and spectroscopic astrophysical observations. Description: Vacuum vapor deposition (vacuum deposition) is an advanced terrestrial manufacturing technology used to produce functional coatings and thin film materials on Earth. This process has been modified for in-space manufacturing applications during University of Houston's/NASA's Wake Shield Facility (WSF) program. By leveraging space's vacuum environment, the WSF program demonstrated that vacuum deposition technology is able to be deployed and successfully produce advanced thin film semi-conductors materials in the vacuum of low-earth-orbit (LEO). Lunar Resources, Inc., the corporate spin-out of the WSF program and the technology leader of in-space vacuum deposition, is leveraging the WSF program to develop in-space vacuum deposition technology to produce functional coatings and thin film materials. These materials include absorptive, emissive and reflective coatings which are fabricated in space to produce mirrors, antennas, reflectors, synthetic aperture radars, and photovoltaic cells for space applications. There remains a technological gap of high reflective short UV wavelength coatings between 91-105nm. Bare Al is able to resolve this gap as the average reflectivity for bare Al is above 90% from 100 to 1200 nanometers. It also has the additional benefit that is not sensitive to polarization and angle of incidence and so provides consistent high reflectance throughout the near-ultraviolet, visible and near-infrared regions as it is not coating in a protective layer.3 However, bare Al oxidizes rapidly when in contact with Earth's atmosphere. In order to overcome the challenges of depositing bare aluminum, LRI proposes the deposition of bare Al optical coatings in the vacuum of space. Such a deposition process can be delivered by Lunar Resources' SDS, designed to deposit uniform optical coatings over a large area. The SDS would overcome: a.) the oxidation challenges of depositing coatings in Earth's atmosphere; b.) eliminate the requirement of protective coatings; c.) and have the additional benefit of depositing coatings unconstrained by the size and capabilities of terrestrial vacuum chambers; d.) eliminate the challenges of launching and deploying large mirrors. The development of the SDS would result in the production bare aluminum coated optical mirrors with >85% reflectivity in the 90-110nm shortwave UV spectrum able to be deposited on effectively unlimited aperture sizes and extremely low areal densities for space-based UV and EUV/FUV astronomy. The goal of the proposed "Technological Development Activity" would raise the maturity of in-space deposition of optical Al coating from a TRL 5 to a TRL 7 through a in-space vacuum deposition program.

Web link:

Name: Brendan Crill

Proposing Team: Exoplanet Exploration Program

Type of Activity:
Technological Development Activity

Description: Technology Challenges for the Study of Exoplanets and the Search for Habitable Worlds In support of the Astro 2020 decadal survey committee's call for Activity, Project, or State of the profession whitepapers, we intend to submit a whitepaper informing the committee of key technology challenges for studying the diversity of worlds in the Galaxy and in searching for habitable planets using a space telescope. Observations of habitable planets outside of our solar system require technologies enabling the measurement of (1) spectral signatures of gases in their atmospheres, and (2) planetary mass. In some cases, performance requirements are 1-2 orders of magnitude from the current state-of-the-art. These gaps in technology performance are in the areas of: starlight suppression (for reflection or emission spectroscopy; coronagraphs or starshades, contrast stability, detector sensitivity, collecting area, spectroscopic sensitivity, radial stellar motion sensitivity, and tangential stellar motion sensitivity (extreme precision radial velocity and astrometry). Our whitepaper will inform the Decadal Survey panel of the current state of the art and present a path to readying the technology for use in a flight mission.

Web link:

Name: Jonathan Crass

Proposing Team: Andrew Bechter, Eric Bechter, Charles Beichman, Cullen Blake, David Coutts, Justin R. Crepp, Tobias Feger, Robert J. Harris, Nemanja Jovanovic, Dimitri Mawet, Peter Plavchan, Christian Schwab, Gautam Vasisht

Type of Activity:
Technological Development Activity

Description: Without improvement, radial-velocity instruments will limit our ability to study some of the most interesting planetary systems from future transit missions. RV precisions at the 10cm/s level are required to fully confirm earth-like analogues, provide masses and measure density to the 1-5% level from these missions. Additionally, this RV capability will also be important to allow for efficient target selection for facilities such as the James Webb Space Telescope (JWST). Without this level of precision, the ability of the exoplanet field to continue to develop a holistic picture of planetary systems will stall. Instrument stability is only a part of the challenge; we must develop techniques to overcome the intrinsic RV signatures imposed on spectra by stellar activity to detect planetary signatures below 1m/s. Simulations show promise that this can be achieved by using high-resolution spectra (R>150,000), however this requires a large telescope aperture to achieve sufficient signal-to-noise. Seeing-limited spectrographs on these large telescopes require large instrument volumes to achieve this high spectral resolution due to their intrinsic properties. These are challenging to stabilize and therefore another solution must be found. A promising way forward is to use single-mode fibers to inject light to a spectrograph using adaptive optics. This mitigates many of the error terms facing current generation seeing-limited RV instruments while simultaneously offering the capability of high resolution spectroscopy within a compact optical footprint. Investment in this technique provides a viable solution to achieve precision RV measurements on large aperture telescopes. We will present the status of the technique, on-going work to bring the first generation of precision astronomical single-mode fiber fed spectrographs on sky, and future avenues for precision spectroscopy measurements.

Web link:

Name: Harley Thronson

Proposing Team: H. Thronson (NASA GSFC), R. Barry (NASA GSFC), P. Hughes (NASA GSFC), Z. Leszczynkski (Aerospace Corp.), A. Lowndes (Nvidia), J. Mason (NASA GSFC), N. Memarsadeghi (NASA GSFC), J. Parr (FDL), S. Samadi (Innovim), & G. Varsi (NASA Re'td)

Type of Activity:
Technological Development Activity

Description: The Challenge: The National Academies' Decadal Surveys are widely regarded as the "gold standard" of strategic planning, prioritization, and policy recommendations for the physical sciences. The seventh for astronomy and astrophysics, Astro2020, recently began and will, as was the case for the six previous Surveys, have profound implications for both NASA and NSF. A major challenge facing every strategic planning activity in astronomy is to assess vast amounts of information in the form of images, surveys, and spectra, as well as increasing numbers of research papers, reports, proposals and previous planning documents. And the amount of this material shows no signs of decreasing in years ahead. In addition, Astro2020 will confront the reality of severely constrained available budgets at the same time as proposed "strategic" mission concepts that are increasingly sophisticated and complex, and may well cost many billions of dollars. This situation will require a depth of analysis, as well as sophistication in developing policy recommendations, likely to exceed by a large factor that of previous Surveys. Although a daunting challenge, we contend that advances in artificial intelligence (AI) and machine learning (ML) over the past several years are making available to strategic planners, tools that have the potential to assist in making possible substantive predictions, prioritizations, and recommendations with greater confidence than is currently possible. Our multi-institutional team is assessing emergent cognitive technologies, along with data analytics, to augment and accelerate conventional strategic planning processes. We intend to submit to Astro2020 a white paper summary of the feasibility and utility of objective AI-enhanced systems to significantly improve the assessment of advancements and discoveries in astronomy and astrophysics. Such systems may be deployed before the end of Astro2020 and be used by scientific panels to prioritize future programs and projects. Background: Since the emergence of AI in the 1950s, early AI techniques were applied to different fields of astronomy. For example, an ESO course in 1990 applications of AI in astronomy included proposal processing and scheduling, full text retrieval (e.g., the ADS), and galaxy classification. Since then progress has been steady in applying AI/ML to other problems. AI algorithms have been employed over the years to (1) classify Type Ia supernova to better measure cosmic distances, (2) classify exoplanets, and (3) select features in multi-dimensional data. The rapid maturity of AI/ML and advanced analytics techniques were not available a decade ago to augment strategic prioritization processes (e.g., the Decadal Surveys) with the capability to predict promising, unrecognized avenues of research, mission design, and technology investments, taking advantage of the digitization of research papers and technology notes (e.g., automated literature and other systematic reviews, text/paper summarization, and relevant paper citation finding, etc.). Of particular relevance to the work that we are carrying out are advances in the machine learning discipline of Natural Language Processing (NLP). NLP allows machines to develop lexical and semantic parsing, understanding, and decision-making using large, unstructured or structured heterogeneous knowledge, for example of research papers and similar documents, technology memos, patents, and public scientific discussion. This capacity allows NLP to better rank and cluster science questions and research outcomes, reveal new concepts, match ideas with existing scientific intellectual structures, and identify previously unrecognized relationships among research areas and teams. Several breakthroughs in NLP only several months ago that utilize a "language modeling method" (https://arxiv.org/abs/1802.05365) suggest an era of better understanding the relationships and rate of emergence – that is, prediction – of new concepts. This is a promising development in strategic planning, where the rapidly growing data volumes are making empirical assessment increasingly challenging. Consequently, our white paper will describe an AI-augmented methodology to support current Decadal Survey processes to produce a balanced portfolio, for example, of near-term/high-confidence and high-risk/high-return opportunities. Background Reading: Numerous papers exist for the general reader to learn how AI/ML might give unrecognized and useful insights to augment the traditional processes, so that both the time of practicing scientists and the funds provided by taxpayers may be deployed for maximum return, e.g., various authors, Science 355, 468ff (2017)]. As one example, Clauset [Science 355, 477–480 (2017)] surveyed the emerging field of the "science of science" and the predictability of scientific discovery. NASA's Frontier Development Laboratory specializes in cross-discipline collaboration using AI techniques to accelerate research initiatives across SMD objectives (https://frontierdevelopmentlab.org/).

Web link:

Name: Eric Bellm

Proposing Team:

Type of Activity:
Technological Development Activity

Description: Scheduling Discovery in the 2020s The 2020s will be the most data-rich decade of astronomy in human history. On the ground and in space, powerful facilities like LSST, JWST, massive multi-object spectroscopic surveys, and a wide variety of smaller robotic and queue-based telescopes will be repeatedly scanning the sky. However, without additional effort we are unlikely to realize the full scientific potential of our investments in these instruments. As the scale and complexity of our surveys and instruments increase, the problem of scheduling (which observations, in what order?) becomes more critical. First, prudence dictates maximizing the efficiency of facilities with high development costs and finite lifetimes. Second, key scientific projects---including identifying unseen populations of compact objects, understanding stellar binarity, and discovering and classifying rare classes of transients---require complex history-dependent observational sequences. To date most scheduling of astronomical facilities has relied on very basic approaches: typically manual scheduling by human operators, or perhaps simple "greedy" algorithms with basic objective functions. We argue that these approaches are insufficient for the scientific needs of the 2020s. Thankfully, knowledge from fields such as Operations Research is beginning to percolate into astronomy. Surveys such as LCO, ALMA, ZTF, and LSST are applying new algorithms to improve their efficiency and quantitative scientific throughput. However, much work remains to be done, including linking the typically separate stages of observation and data analysis to provide real-time feedback maximizing progress towards the scientific goal--the so-called "fifth paradigm" of science. We provide an overview of key research directions as well as recommendations for scientists, facilities, and agencies to facilitate progress in the field.

Web link:

Name: David Reitze

Proposing Team: LIGO Laboratory

Type of Activity:
Technological Development Activity

Description: The LIGO Laboratory intends to submit a white paper in the category 'Technological Development Activity' on the research and development needed to build more sensitive ground based gravitational-wave detectors. A group of white papers describing the science that would come from a network of improved ground based gravitational-wave detectors, the so called 3rd generation detectors, have been submitted by members of the GWIC (Gravitational Wave International Committee) and the LIGO (Laser Interferometer Gravitational-wave Observatory) Laboratory. The research and development program needed to enable the design and construction of the 3rd generation detectors to carry out the scientific program is the substance of the project white paper we will submit. It is critical to note that we are not yet in a position to propose a specific 3rd generation detector design, however, we expect to be able to do this in the mid years of the current decadal process based on the program we outline in the technical white paper. The key issue for the 3rd generation detectors is to bring the discoveries we have made into the main stream of both astronomy and physics. The measurement of the gravitational waves from compact binary systems such as the coalescence of binary black holes and neutron stars have given us a benchmark for the detection sensitivity. The 3rd generation detectors are intended to explore the nuclear and gravitational physics within these systems and will bring gravitational-wave astronomy firmly into cosmology. We are aware of the importance of being able to couple gravitational-wave astronomy to electromagnetic and particle astronomy, as elegantly demonstrated in the follow up to the binary neutron star coalescence. To carry out multi-messenger astronomy 3rd generation detectors will require a network, most likely 3 detectors well-distributed around the world. European gravitational wave detection groups are actively working on the design of a 3rd generation detector while Australian groups are beginning to study how they might contribute to a 3rd generation network. We anticipate that the project white paper will include the following items: 1) An engineering study for the design and construction of a 40km arm length L-shaped interferometric gravitational-wave detector with a sensitivity improvement of close to a factor of 10 over the next improvement we hope to make in the 4km systems (the currently funded A+ Project). The study needs to identify construction sites and, most importantly, provide realistic costs. The study also needs to evaluate the progress that will be made in detector technology and design for a phased approach for the 3rd generation detectors (much as LIGO did in the beginning). The initial phase is anticipated to use the technology developed for the A+ 4km upgrade. 2) An outline for a program of laboratory research and prototyping to convert existing detector components and designs to the longer arms, increase the capability to test larger heavier test masses and suspension systems and to develop the technology for the second phase of the 3rd generation which involves cryogenics, new materials for test masses and different wavelength lasers and optical components. 3) A program to forge an international collaboration for the construction and operation of a unified 3rd generation network of gravitational-wave detectors.

Web link:

Name: Nemanja Jovanovic

Proposing Team:

Type of Activity:
Technological Development Activity

Description: Enabling the next generation of scientific discoveries by embracing photonic technologies The fields of Astronomy and Astrophysics are technology limited. As is commonly the case, with the advent and application of new technologies to Astronomy, a flood of new discoveries that alter our understanding of the Universe follow (e.g. recent cases include the LIGO instrument and GRAVITY instrument at the VLT telescope). In addition, some areas of astronomy, specifically the field of astronomical spectroscopy is rapidly approaching an impasse: the size and cost of instruments, especially multi-object and integral field spectrographs for extremely large telescopes (ELTs) is pushing the limits of what is feasible as they require optical components that are at the very edge of the physical size and performance that can be achieved. For these reasons, astronomers are constantly looking to expand their arsenal of new technologies, including photonic technologies that provide an avenue to miniaturization and simplification. Photonic technologies can provide advanced functionalities like spectral filtering, spectral dispersion, frequency comb generation and spatial filtering, the latter owing to the fact they operate at the diffraction limit. Operating at the diffraction-limit eliminates the instrument size dependence on telescope aperture. The prospect of miniaturization of astronomical instrumentation has been one of the primary motivators thus far. Integrated photonic spectrographs (IPS) for example include the equivalent of the collimator, disperser and camera optics in a monolithic format and could enable spectrograph instruments that are up to an order of magnitude smaller in each of the 3 linear dimensions (3 orders of magnitude smaller in volume). As deflection scales with the cube of the length, a compact IPS-based instrument would reduce deflection by 3 orders of magnitude and significantly improve thermal stability owing to the fact that the entire spectrograph is made from a single material. In addition, since photonic devices operate at the diffraction-limit they are typical fed by a single-mode fiber (SMF). A SMF offers a temporally invariant output beam profile that is independent of changes to the input, which means that the spectral line spread function (SLSF) of such a device is extremely stable and can be calibrated with high precision. This is an immensely powerful property that would eliminate the effects of variable slit pointing and modal noise in RV machines, or fluctuations in the fringe contrast in an interferometric beam combiner, for example. This property offers the benefit that the science instrument performance is entirely decoupled from the performance of the telescope, adaptive optics system and injection and can in most cases be located in a remote area of the observatory, which can greatly relax constraints on the design of the telescope, reducing cost and complexity. Finally, if the beam is fed via a SMF, numerous other photonic technologies could be exploited besides spectrographs, including fiber Bragg gratings and micro-ring resonators for spectral filtering, as well as compact etalons and frequency combs for wavelength calibration. Astronomers have long been aware of the potential of photonics, which manifested in 2009 with the creation of the new sub-field of "astrophotonics". Although there have been some new technology demonstrations over the past decade and some prototypical instruments built based on photonic components, this has not transpired into the expected wave of fully optimized photonic-based instruments deployed into routine operation at global observatories. There are four possible explanations for this: Difficulty of coupling efficiently to devices which has recently been demonstrated through on-sky tests to be solvable Cost and effort of re-optimizing existing photonic components for niche astronomy applications. Immaturity of some photonic components and technologies and A conservative mentality amongst astronomical instrumentation designers, instrument review panels and funding bodies.   The goal of this white paper is to draw attention to photonic technologies and offer a status of the field to increase exposure and promote these solutions to address the concern factors listed above, which will allow them to be considered in future instrument design. Photonics can solve challenging instrument design limitations for both ground and space borne instruments alike and with endorsement from the National Academy of Sciences decadal survey will ensure that such innovative solutions are no longer overlooked for the next generation of ELTs and space missions.

Web link:

Name: Gordon Roesler

Proposing Team: Robots in Space LLC

Type of Activity:
Technological Development Activity

Description: In considering new astrophysics instrument concepts for the 2030 time frame, the Decadal Survey membership must be made cognizant of the state of space-suitable robotic technology. In a separate white paper, the participants in the multi-institutional In-Space Assembled Telescope (iSAT) study will describe how robotic assembly could be enabling or enhancing for large diameter optical instruments. This submission will complement the iSAT white paper by surveying the state of development of current space robotics programs. The programs to be reported will include: • The FREND robotic arms being built by MDA-US Systems (a subsidiary of the satellite manufacturer SSL), which support the DARPA Robotic Servicing of Geosynchronous Satellites and the NASA Goddard Restore-L programs • The Dragonfly robotic arm, also under development at MDA-US Systems, of the NASA In-Space Robotic Manufacturing and Assembly (IRMA) program • The Canadarm3 robotic arm being developed by MDA of Canada for the Lunar Orbit Platform-Gateway • Smaller robotic arms for space applications being developed by Oceaneering Space Systems, Motiv Space Systems and Tethers Unlimited, Inc. • The MDA US-developed robotic arm on the Curiosity MSL • The robotic arm developed by Motiv Space Systems for the Mars 2020 mission • The JEMRMS robotic system of JAXA currently operating on ISS • The arm developed by the German Aerospace Center (DLR) for the DEOS mission These programs are relevant to the Decadal Survey because the robotic systems are of a scale and capability relevant to in-space assembly. This submission will also complement white papers that are anticipated to be submitted by JPL, NASA Langley, NASA Goddard, Lockheed Martin, SRI, and the U.S. Naval Research Laboratory, describing the accomplishments in space robotics at each of those institutions.

Web link: www.robots-in.space

Name: Lee Feinberg

Proposing Team:

Type of Activity:
Technological Development Activity

Description: The whitepaper will describe our progress in building high speed interferometric spatial metrology systems that are now measuring picometer precision, picometer level measurements made of Webb size mirror dynamics, ultrastable thermal control that has been demonstrate to sub-milli-Kelvin control, picometer level actuators that operate at 1 hz and have been independently characterized to picometer levels, speckle measurements of a composite sample made to sub-picometer precision, and lastly the latest test results from our ongoing milli-Kelvin controlled ULE subscale mirror. I think it makes helps paint a story that picometer structures are feasible (which I feel more confident about now but there's more to do).

Web link:

Name: Laura Coyle

Proposing Team: ULTRA Study Team (Ball Aerospace, Harris Corp., Northrup Grumman Corp., SGT, Space Telescope Science Institute)

Type of Activity:
Technological Development Activity

Description: This white paper will summarize the key findings from Phase 1 of the Ultra-Stable Large Telescope Research and Analysis (ULTRA) study. The study was awarded to our industry team (Ball Aerospace, Harris Corp., Northrup Grumman Corp., Northrup Grumman Corp. Innovation Systems, SGT and the Space Telescope Science Institute) through the NASA ROSES-17 solicitation, element D.15 – which calls for a one-year system-level engineering design and modeling study for a >10-m class UV/optical/IR segmented-aperture telescope with sub-nanometer wavefront stability. This challenging stability requirement is driven by the science goal to directly image and characterize exo-Earths with a high contrast coronagraph. Two mission concepts requiring sub-nanometer stability are the Large UV/Optical/Infrared Surveyor (LUVOIR) and the Habitable Exoplanet Observatory (HabEx), both of which are under consideration by the 2020 Astrophysics Decadal Survey. This study augments the work completed by the LUVOIR and HabEx Science and Technology Definition Teams (STDTs) and their NASA center engineering teams by identifying and prioritizing key technologies for near-term development that will result in credible system architectures. While this study uses these mission concepts (especially LUVOIR) to perform specific assessments, the findings are applicable to similar architectures with comparable stability needs. Our approach is a holistic systems architecture study treating the observatory, telescope and coronagraph as a complete system and considering the impacts of instability in both the temporal and spatial domains. It is guided via the formalism of error budgets, where sub-system allocations are compared to current capabilities, often including trade studies of potential technologies or approaches. Technology gaps are identified where current capabilities will not meet allocations and roadmaps are provided to prioritize and propose a path forward for development of the most urgent technologies.

Web link:

Name: Olivier Guyon

Proposing Team:

Type of Activity:
Technological Development Activity

Description: There are very compelling science goals that drive the development of exoplanet characterization machines that can realize the power of Giant Segmented Mirror Telescopes. However there reaching those goals requires advances in the achievable contrast and inner working angle on large segmented apertures beyond what has been demonstrated to date. In this white paper we present a technology development roadmap to reaching those contrast goals, including demonstration and facilitization on current- and next-generation facilities in the laboratory and on large telescopes. This roadmap enables improvements both in the "raw" contrast delivered by the wavefront control and starlight suppression systems, as well as in the final contrast realized through the combination of specialized backend instrumentation and post-processing techniques. Milestones along this road map include the development of high-speed high-actuator-count deformable mirrors, the refinement of high-speed low-noise detectors as applied to both pupil- and focal-plane wavefront sensing, predictive wavefront control, sensor fusion, coherent differential imaging, and specialized low-order mode sensing and control techniques.

Web link:

Name: Harley Thronson

Proposing Team: H. Thronson (NASA GSFC), R. Barry (NASA GSFC), P. Hughes (NASA GSFC), Z. Leszczynkski (Aerospace Corp.), A. Lowndes (Nvidia), J. Mason (NASA GSFC), N. Memarsadeghi (NASA GSFC), J. Parr (FDL), S. Samadi (Innovim), & G. Varsi (NASA Re'td)

Type of Activity:
Technological Development Activity

Description: Augmenting Scientific Strategic Planning With Artificial Intelligence and Machine Learning The Challenge: The National Academies' Decadal Surveys are widely regarded as the "gold standard" of strategic planning, prioritization, and policy recommendations for the physical sciences. The seventh for astronomy and astrophysics, Astro2020, recently began and will, as was the case for the six previous Surveys, have profound implications for both NASA and NSF. A major challenge facing every strategic planning activity in astronomy is to assess vast amounts of information in the form of images, surveys, and spectra, as well as increasing numbers of research papers, reports, proposals and previous planning documents. And the amount of this material shows no signs of decreasing in years ahead. In addition, Astro2020 will confront the reality of severely constrained available budgets at the same time as proposed "strategic" mission concepts that are increasingly sophisticated and complex, and may well cost many billions of dollars. This situation will require a depth of analysis, as well as sophistication in developing policy recommendations, likely to exceed by a large factor that of previous Surveys. Although a daunting challenge, we contend that advances in artificial intelligence (AI) and machine learning (ML) over the past several years are making available to strategic planners, tools that have the potential to assist in making possible substantive predictions, prioritization, and recommendations with greater confidence than is currently possible. Our multi-institutional team is assessing emergent cognitive technologies, along with data analytics, to augment and accelerate conventional strategic planning processes. We intend to submit to Astro2020 a white paper summary of the feasibility and utility of objective AI-enhanced systems to significantly improve the assessment of advancements and discoveries in astronomy and astrophysics. Such systems may be deployed before the end of Astro2020 and be used by scientific panels to prioritize future programs and projects. Background: Since the emergence of AI in the 1950s, early AI techniques were applied to different fields of astronomy. For example, an ESO course in 1990 applications of AI in astronomy included proposal processing and scheduling, full text retrieval (e.g., the ADS), and galaxy classification. Since then progress has been steady in applying AI/ML to other problems. AI algorithms have been employed over the years to (1) classify Type Ia supernova to better measure cosmic distances, (2) classify exoplanets, and (3) select features in multi-dimensional data. The rapid maturity of AI/ML and advanced analytics techniques were not available a decade ago to augment strategic prioritization processes (e.g., the Decadal Surveys) with the capability to predict promising, unrecognized avenues of research, mission design, and technology investments, taking advantage of the digitization of research papers and technology notes (e.g., automated literature and other systematic reviews, text/paper summarization, and relevant paper citation finding, etc.). Of particular relevance to the work that we are carrying out are advances in the machine learning discipline of Natural Language Processing (NLP). NLP allows machines to develop lexical and semantic parsing, understanding, and decision-making using large, unstructured or structured heterogeneous knowledge, for example of research papers and similar documents, technology memos, patents, and public scientific discussion. This capacity allows NLP to better rank and cluster science questions and research outcomes, reveal new concepts, match ideas with existing scientific intellectual structures, and identify previously unrecognized relationships among research areas and teams. Several breakthroughs in NLP only several months ago that utilize a "language modeling method" (https://arxiv.org/abs/1802.05365) suggest an era of better understanding the relationships and rate of emergence – that is, prediction – of new concepts. This is a promising development in strategic planning, where the rapidly growing data volumes are making empirical assessment increasingly challenging. Consequently, our white paper will describe an AI-augmented methodology to support current Decadal Survey processes to produce a balanced portfolio, for example, of near-term/high-confidence and high-risk/high-return opportunities. Background Reading: Numerous papers exist for the general reader to learn how AI/ML might give unrecognized and useful insights to augment the traditional processes, so that both the time of practicing scientists and the funds provided by taxpayers may be deployed for maximum return, e.g., various authors, Science 355, 468ff (2017)]. As one example, Clauset [Science 355, 477–480 (2017)] surveyed the emerging field of the "science of science" and the predictability of scientific discovery. NASA's Frontier Development Laboratory specializes in cross-discipline collaboration using AI techniques to accelerate research initiatives across SMD objectives (https://frontierdevelopmentlab.org/).

Web link:

Name: Lynn Allen

Proposing Team: Harris Civil and Commercial Imaging

Type of Activity:
Technological Development Activity

Description: 1. Harris Mirror Technology -- PI: Rebecca Borelli. Recent technology advancements show significant promise in the ability to reduce the cost, schedule and risk associated with producing large, segmented lightweight primary mirrors (PMs) and monolithic optics larger than Hubble Space Telescope (HST) to surface figure error (SFE) qualities across low-, mid- and high-spatial frequency regimes and surface micro-roughness required for current and future astronomical systems. This white paper will describe the present state-of-the art technology, manufacturing capability and metrology for large, low-thermal expansion material mirrors at Harris and then define the development and demonstration path to next generation technology for use in a wide range of applications, including missions such as LUVOIR, HabEx, CETUS and others.

Web link:

Name: Matthew Bolcar

Proposing Team: Co-signers will be included, but the list is not yet final.

Type of Activity:
Technological Development Activity

Description: Compatibility of High-Contrast Coronagraphy with UV Astronomy There is a widely held belief that optical and near-infrared (NIR) high-contrast coronagraphic observations are incompatible with a telescope that can operate in the ultraviolet (UV). This belief stems from the fundamental properties of the optical coatings that are used to enable UV sensitivity, and the stringent wavefront requirements for high-contrast imaging. Recent developments in both fields, however, have shown that this belief is incorrect. In this white paper, we intend to summarize recent investigations that show that there is nothing that fundamentally prohibits broadband, high-contrast coronagraphic imaging from being performed with a system that is also capable of UV astronomical observations.

Web link:

Name: Peter Timbie

Proposing Team: Low-z and EOR 21-cm communities

Type of Activity:
Technological Development Activity

Description: Development of the hardware, calibration methods and data analysis for large compact radio arrays dedicated to intensity mapping of the 21-cm line has proven to be more difficult than imagined twenty years ago when such telescopes were first proposed. Despite tremendous technical and methodological advances, there are several outstanding questions on how to optimally calibrate and analyze such data. On the positive side, it has become clear that the outstanding issues are purely technical in nature and can be solved with sufficient development activity. Such activity will enable science across redshifts, from early galaxy evolution in the pre-reionization era to dark energy evolution at low redshift. The white paper will propose funding for development of: i) hardware a) hardware for accurate distribution of timing signals, ensuring the telescope remains phase calibrated while undergoing thermal expansion and similar environmental effects; b) hardware and software methods for precise, per-antenna calibration of the primary beam, relying on drones, tethered balloons, or perhaps even dedicated micro-satellites. While several groups are beginning to attempt this, such methods have not been demonstrated to the required precision; c) exploration of low-power hardware and efficient data-taking software solutions for digitization and channelization at the telescope feed, enabling cleaner systematics and simpler system design; ii) cross-experiment software infrastructure for data analysis and calibration of compact radio arrays. The problems presented here touch both on the methodology (optimal algorithms have yet to be demonstrated) and software engineering problems (data volumes are incredibly large and complex). a) Improved calibration procedures to better characterize sidelobe response and mode-mixing; b) Removal of extremely large foregrounds; c) rfi removal; d) Techniques for wide-field imaging iii) support for small dedicated test-bed instruments and participation in existing initiatives, both US-led and international, enabling development and testing of methods presented in points i-ii; We believe that with rather modest investment of resources, such R&D will enable current experiments to extract maximum science while paving the way for future and even more exciting telescopes.

Web link: none

Name: Jonas Zmuidzinas

Proposing Team: Jason Austermann (NIST), James Aguirre (U Penn), Matt Bradford (JPL), Peter Day (JPL), Mark Devlin (U Penn), Darren Dowell (JPL), Pierre Echternach (JPL), Juan Estrada (Fermilab), Jiansong Gao (NIST), Jason Glenn (CU Boulder), Sunil Golwala (Caltech), Steven Hailey-Dunsheath (Caltech), Johannes Hubmayr (NIST), Brad Johnson (Columbia), Henry Leduc (JPL), Philip Mauskopf (ASU), Ben Mazin (UCSB), Seth Meeker (JPL), Omid Noroozian (NRAO), Rashied Amini (JPL), Jack Sayers (Caltech), Erik Shirokoff (Chicago), Peter Timbie (Wisconsin), Joaquin Vieira (Illinois), and Grant Wilson (UMass)

Type of Activity:
Technological Development Activity

Description: The fundamental role that detectors play in astronomy and cosmology is very clear. It is less well appreciated that advancement of detector technology occurs over multi-decade timescales and requires significant resources. CCDs required several decades of development from their invention in the late 1960s to the launch of HST in 1990. Similarly, the SIS receivers that enable ALMA, the infrared arrays that enable JWST, and the mm-wave detectors that brought us precision CMB cosmology each required over three decades of development. Although Decadal Survey reports have historically advocated support for detector technology, given the importance of detector technology and the long timescales involved, we believe that the Astro2020 survey should examine this important issue more closely. Key science challenges, e.g. exoplanet characterization, place severe requirements on detector performance (Rauscher+ 2016, JATIS 2). As outlined below, large opportunities remain for improving detector technology across the spectrum, from millimeter wavelengths to x-rays. Indeed, all four flagship mission concepts presented by NASA to Astro2020 – Habex, LUVOIR, Lynx, and OST – would strongly benefit from improved detectors. Low-temperature detectors have long offered the prospect of exquisite sensitivity and versatility, but practical implementations proved elusive. This is now changing. Invented two decades ago (Day+ 2003, Nature 425; Zmuidzinas 2012, Annu. Rev. Cond. Mat. Phys. 3; Mauskopf 2018, PASP 130), superconducting kinetic inductance detectors (KIDs or MKIDs) are now being deployed in a number of astronomical instruments. Worldwide, there are now some two dozen research groups actively developing KIDs. The first KID instruments (e.g. MUSIC, Maloney+ 2010, Proc. SPIE 7741, or MAKO, Swenson+ 2012, Proc. SPIE 8452) operated at millimeter and submillimeter wavelengths, and this band remains a central focus of KID development. New mm/submm KID instruments include the recently commissioned NIKA2 mm-wave camera on the IRAM 30m telescope (1.2-2 mm; Adam+ 2018, A&A 609), and the TolTEC mm-wave imaging polarimeter is now being constructed for the 50m Large Millimeter Telescope in Mexico (Bryant+ 2018, Proc. SPIE 10708). KIDs enable construction of mm/submm instruments with far higher pixel counts than previously possible. This motivates the Astro2020 science white paper entitled ``The case for a submillimeter SDSS: a 3D map of galaxy evolution to z=10'' (Geach+, astro-ph 1903.04779). An important element in this vision are on-chip mm/submm spectrometers enabled by KID technology, developed by the SuperSpec (1 – 1.5 mm; Wheeler+ 2018, Proc. SPIE 10708) and DESHIMA (1 mm; Endo+ 2019, astro-ph 1901.06394) collaborations. The extension of KID technology into the far-infrared provides a basis for mission concepts such as the Galaxy Evolution Probe (GEP; Glenn+ 2018, Proc SPIE 10698) as well the flagship-class Origins Space Telescope (OST) being reviewed by Astro2020. Indeed, KIDs have made substantial progress towards space applications. The EU-funded SPACEKIDs program demonstrated KID arrays suitable for far-infrared imaging on a cold space telescope (Baselmans+ 2017, A&A 601). Sensitivity required for space far-infrared spectroscopy has also been demonstrated using quantum capacitance detectors (Echternach+ 2018, Nature Astronomy 2), a technology related to KIDs. Importantly, the SPACEKIDs arrays meet other critical requirements such as cosmic ray susceptibility (Karatsu+ 2019, Appl. Phys. Lett. 114). KIDs recently flown on the OLIMPO balloon payload (Masi+ 2019, astro-ph 1902.08993) demonstrated satisfactory cosmic-ray response. A substantially more capable KID-based (250-500 um) balloon payload will fly soon (BLAST-TNG; Lourie+ 2018, Proc. SPIE 10708), and construction of a new KID balloon experiment, the Terahertz Intensity Mapper (TIM; http://obscos.astro.illinois.edu/tim/), has started. Existing CMB experiments use kilopixel-scale arrays of mm-wave superconducting TES bolometers and do not require the dense multiplexing associated with KIDs. However, scaling TES technology to meet CMB-S4 requirements will be challenging, motivating KID-based alternatives (e.g., McCarrick+ 2018, A&A 610; O'Brient+ 2018, SPIE Proc 10708). Notably, the CORE mission proposed to ESA's Cosmic Vision program baselined KIDs (0.5–5 mm; de Bernardis+ 2018, J. Cosmology & Astroparticle Phys.). The pioneering work of the Mazin UCSB group has stimulated rapidly growing interest in KIDs for optical and near-infrared (OIR) wavelengths. In contrast to CCDs, KIDs offer photon counting with zero read noise, microsecond time resolution, significant energy resolution (currently R=Lambda/DeltaLambda~10), and essentially perfect rejection of cosmic rays. The UCSB group has demonstrated an instrument on the 5m Hale telescope at Palomar (DARKNESS; 800-1400 nm; Meeker+ 2018, PASP 130) and is commissioning the MKID Exoplanet Camera on the 8m Subaru telescope (MEC; Walter+ 2018, Proc. SPIE 10702). The use of KIDs on the TMT and other ELTs is now being considered carefully. There is considerable potential to improve the performance and array size of OIR KIDs, and their potential impact should not be underestimated.

Web link:

Name: John Monnier

Proposing Team:

Type of Activity:
Technological Development Activity

Description: Title: A Realistic Roadmap to Formation-Flying Space Interferometry. This White Paper will lay out a realistic roadmap to achieve a technology demonstration of formation-flying space interferometry within the coming decade.

Web link:

Name: John Monnier

Proposing Team:

Type of Activity:
Technological Development Activity

Description: Title: Setting the Stage for the Planet Formation Imager This white paper will describe a next-generation infrared interferometer capable of imaging planet-forming disks with milli-arcsecond angular resolution. The Planet Formation Imager (PFI) would deliver breakthroughs in understanding the key active stages of planet formation, allow detection of giant exoplanets and their circumplanetary accretion disks, as well as enable a variety of new galactic and extragalactic science cases. Here we discuss the technology challenges that must be solved in the coming decade before PFI can become a reality.

Web link:

Name: Kendra Short

Proposing Team: Exoplanet Exploration Program Starshade Technology (S5) development team

Type of Activity:
Technological Development Activity

Description: Summary: In 2016 NASA's Astrophysics Division (ApD) approved a focused starshade technology development activity to bring starshade technology to Technical Readiness Level 5 (TRL5). This activity is known as S5 (Starshade Technology to TRL5). After a year of planning, community engagement and technical trade studies, a comprehensive Technology Development Plan for S5 was approved by NASA ApD and the activity continued into the execution phase in FY19. This whitepaper will provide current status of the progress and technology advancements achieved as part of the Starshade Technology Development activity. Science Motivation and Mission Applicability: The goal of NASA's starshade development activities is to mature the required technologies to the point at which starshades could be integrated into potential future exoplanet detection and characterization missions. Among the objectives of such missions are to discover Earth-like planets in the habitable zones of Sun-like stars and to characterize the atmospheres of these planets, including the search for signs of life. Starshades and internal coronagraphs are the two categories of starlight – suppression technologies with the greatest potential to be used in such missions over the next two decades. The TRL of a technology cannot be evaluated independently of the mission in which it will be used. The S5 activity takes as its working assumption that the Starshade Rendezvous Mission (SRM) would be the first starshade mission. The Key Performance Parameters (KPPs) the starshade must meet to reach TRL5 flow down from the Starshade Rendezvous mission concept study. The starshade KPPs for the HabEx mission are, as of this writing, identical to those for Starshade Rendezvous. The most significant difference between these two starshades would be their sizes: the WFIRST rendezvous starshade would be about 26m in diameter, and the HabEx starshade about 52m. Approach to Technology Development: The comprehensive S5 Technology Development Plan is available on the ExEP Technology webpage (https://exoplanets.nasa.gov/technology/starshade). Five critical technologies will be matured to TRL5 before the end of 2023 using testbeds, analysis, simulations and hardware development and test. Fifteen Technology Milestones (MS) have been defined with the key performance parameters and the hardware fidelity required to meet TRL5. The Exoplanet Exploration Program Technology Assessment Committee (ExoTAC) has reviewed and endorsed these milestones as appropriately defined and comprehensively representing the achievements necessary to reach TRL5. The ExoTAC will review and endorse the final reports written against each Milestone achievement as they occur. Below is a brief synopsis of each the technology areas. Starlight Suppression – The goal of the starlight suppression technology is to demonstrate that small-scale starshade masks can reach 1x10-10 instrument contrast at the inner working angle in narrow and broad band visible light and Fresnel number ≤ 15. In addition, S5 will validate a contrast vs. shape model to within 25% accuracy by testing masks with deliberate shape errors that induce contrast between 10-9 and 10-8. Scattered Sunlight – The goal of the scattered sunlight technology is focused on reducing sunlight scattered off the starshade edges. Edges that can limit scattered sunlight to acceptable levels (V> 25mag) will be fabricated and performance measured. Formation Sensing and Control – The goal of the formation sensing and control is to demonstrate the ability to sense and control the lateral offset between the starshade and the telescope maintaining the desired contrast long enough for full science integration. The technology required is a validated technique for sensing lateral displacements of the starshade from the line of sight between the telescope and exoplanet host star to the necessary precision and accuracy. Mechanical Shape Accuracy and Shape Stability – The goal of the mechanical shape and position technologies is to demonstrate the ability to design and manufacture the starshade mechanical elements which can provide the petal shape accuracy and stability to meet the contrast requirements. Relevant environments include stow, launch, deploy, and on-orbit environmental conditions. This is accomplished through test and analysis of varying scales and fidelity of hardware (petal shape accuracy +/- 70 micron; petal position accuracy +/- 300 micron; petal shape stability +/- 80 micron; petal position stability +/- 200 micron).

Web link: https://exoplanets.nasa.gov/exep/technology/starshade/

Name: Alison Nordt

Proposing Team: Lockheed Martin Advanced Technology Center

Type of Activity:
Technological Development Activity

Description: Technology Roadmaps have been established for each of the four flagship missions through industry cooperation with the mission Science Technology Definition Teams. Industry partners have been investing Internal Research and Development (IRAD) funds to advance the readiness levels (TRL) of key technologies. Further work is needed to achieve the goal of TRL-6 by mission PDR. TRL advancement is achieved through a combination of laboratory demonstrations, environmental testbeds, subscale flight experiments and validated integrated models. For the Large Ultra Violet Optical InfraRed (LUVOIR) observatory, ultra-stable opto-mechanical systems is a key performance characteristic that fundamentally dictates the coronagraph system performance and its ability to detect and characterize exo-Earths. One of the enabling technologies for ultra-stable systems on the roadmap as outlined by the LUVOIR Science and Technology Definition Team (STDT) in their Interim Report (September 2018) is the Vibration Isolation and Precision Pointing System (VIPPS). The LUVOIR VIPPS enables the telescope to achieve extreme pointing and image stability, while still meeting the line-of-sight agility requirements consistent with its astronomical Surveyor goals, by physically separating the telescope from the spacecraft and sunshield. The payload controls overall payload attitude and telescope line-of-sight by pushing against the spacecraft inertia using a set of six non-contact voice coil actuators, while the spacecraft controls its inertial attitude such that interface stroke and gap are maintained. Since the telescope is physically separated, the disturbances and structural excitation of the spacecraft and sunshield do not propagate to the telescope, enabling extreme stability across a broad frequency range. Under such an architecture, individual isolation of spacecraft disturbance sources is not needed, and knowledge of the spacecraft structural dynamics is not needed to achieve the required system dynamic line-of-sight and wavefont error stability. The VIPPS concept was originally conceived as the Lockheed Martin (LM) Disturbance Free Payload (DFP). Through ambient full-scale laboratory demonstrations, component environmental testing and extensive integrated modelling, LM has achieved TRL-4 at the system level for this technology over years of internal investment. LM has developed a technology maturation plan that will bring the DFP technology to TRL-6 within the next 5 years. A combination of methods - specifically tests, demonstrations and analyses - will be used to prove, in a relevant environment, that the technology is ready for LUVOIR mission insertion. With appropriate government investment this TRL advancement can be achieved and the technologies required for the next generation flagship missions are credibly within reach. This paper will show an overview of the technology development approach, enumerate a planned sequence of activities that achieves system TRL-6, and describe areas of needed investment to support LUVOIR's technology needs.

Web link:

Name: John Steeves

Proposing Team: Charles Lawrence, Todd Gaier, David Redding, Randall Bartman, Wes Schmitigal

Type of Activity:
Technological Development Activity

Description: The demanding science goals of the 2020 Decadal Survey Mission Concepts impose significant technological requirements on their associated telescopes. These concepts call for deployed apertures as large as 15 meters in diameter (LUVOIR), operational temperatures as low as 4 Kelvin (OST), and exquisite optical quality (LUVOIR, HabEx). Methods to construct extremely large telescopes using in-space assembly techniques are also under development (iSAT), producing their own unique set of technological difficulties. Active telescopes – those that can first sense and subsequently correct static and/or dynamic optical errors - can alleviate many of the challenges associated with these missions by providing in-situ wavefront correction capabilities in a variety of operating conditions. This greatly reduces the manufacturing requirements on the telescope as a whole, and can also provide a level of assurance against unknown thermal distortions, gravity release effects, imperfect STOP models, long-term material creep, and dynamical disturbances. Furthermore, active telescopes can provide a substantial reduction in the cost/complexity associated with telescope I&T, as on-orbit performance specifications can be achieved under a variety of test conditions (i.e. room/cryogenic temperatures, 0g/1g). Here we provide a description of the primary components of active telescopes, their performance requirements for future missions, and how they operate together in an integrated system. In particular, the technologies that we will focus on include active primary mirrors, metrology systems, and picometer-precision wavefront sensing and control techniques. An overview of the current state of the art and ongoing/future plans for technical development will be provided.

Web link:

Name: Brian Nord

Proposing Team:

Type of Activity:
Technological Development Activity

Description: Science at the Edge: Algorithms and Statistics for the Next Generation of Scientific Discovery At present, the process of hypothesis-generation in astronomy has two pathways. One is theoretical, wherein predictions from theory provide hypotheses that can be tested with observations. The other is observational, wherein surprising objects and patterns are found in data and later explored. As theory comes to depend on larger and larger simulations, and observational data sets grow to surpass the petabyte scale, both pathways are under threat. With such large data sets, the classical mode of visual, human exploration has become too slow and painstaking to find new objects and new correlations. But without new hypotheses in the 2020s, there will be no astronomy in the 2030s. We argue that the path forward is through the construction of intuitive, trustworthy, robust, and deployable algorithms for the exploration of large, high-dimensional data sets. Investigations show that purpose-built machine learning algorithms, coupled with deep sub-domain knowledge, can successfully pull out hitherto unknown objects, significantly advancing our understanding of our universe. Unfortunately, any successful exploration requires a) deep algorithmic and implementation knowledge, b) deep physical and observational domain knowledge, c) continued support and development, and d) luck. Deep algorithmic knowledge is necessary because off-the-shelf algorithms usually need significant adaptation to work with heteroscedastic and censored astronomical data. Deep observational domain knowledge is needed because outlier objects are often artifacts and surprising trends may be imprints of the data collection method. Deep physical domain knowledge is needed to make sense of the result, and understand its place in the cosmos and in the research ecosystem. Finally, not all searches will return results; a modicum of luck is needed. The confluence of these elements is rare, and technology for bringing them to bear on next-generation data sets has not yet been developed. We, therefore, propose that funding agencies fund the creation and maintenance of ``discovery engines'' --- tools that allow astronomers without deep algorithmic knowledge to explore the edges of data spaces, hunting for outliers and new trends. These engines should be hosted near the data when needed but should be initiated by the astronomical and methods communities.

Web link:

Name: Vandana Desai

Proposing Team: Vandana Desai, Rachel Akeson, Gregory Dubois-Felsmann, Steve Groom, George Helou, Mark Lacy, Joseph Mazzarella, Knut Olsen, Josh Peek, Arfon Smith, Harry Teplitz

Type of Activity:
Technological Development Activity

Description: Astrophysics science archives are experiencing tremendous growth in data volume, variety, and velocity. The demands of science that takes advantage of this growth are pushing the scope of existing astrophysics archive services. As a result, astronomers are increasingly likely to encounter "Big Data" problems: finding, downloading, storing, visualizing, and analyzing large, complex data sets. A proposed response to these problems has been the concept of a "science platform", which blends the traditional archive role of data storage with a new role of computation near the data. Science Platforms are being developed by several data-oriented institutions, but with complementary purposes and some differences in approaches. Future science cases will not be limited to Big Data analyses on monolithic data sets; they will involve the combination of large data sets from multiple archives. We advocate for open communication between and coordination of these independent development efforts to ensure interoperability, for maximum benefit to the astronomical community. We recommend that Science Platforms 1) adopt an open-source approach to software development; 2) use a modular architecture design to encourage sharing; 3) adopt best practices, standards, and protocols developed by the community whenever possible; 4) expose APIs to clients and services to enable reuse; and 5) maintain the computing resources and high-quality connectivity needed for shared use by the community. This Science Platform Network could be realized through development of a thin software layer providing transformations between the extant systems and archives, and by establishment of a coordinating group to ensure interoperability.

Web link:

Name: Michael Mook

Proposing Team:

Type of Activity:
Technological Development Activity

Description: Naval Research Laboratory capabilities for Space Telescope Manufacturing, Assembly, and Servicing The US Naval Research Laboratory (NRL) has developed a world-class capability in space robotics with immediate benefit to the future of astrophysics. While currently focused on delivering the robotic payload for DARPA's Robotic Servicing of Geosynchronous Satellites (RSGS) mission, we are concurrently working to realize the enormous potential of in-space assembly (ISA) and robotic servicing. Many of the RSGS-derived algorithms, code, avionics, robotics arms, end- effectors/tools and techniques are directly applicable to large space structure assembly, precision alignment and calibration. NRL simulation and test facilities provide world-class physical simulation of the space environment and spacecraft/robotic systems, which is needed to develop and demonstrate ISA tools and techniques. NRL's newly constructed precision, cable-driven gravity off-loader was designed specifically for ISA experimentation and extends to degrees to which assembly operations are accurately simulated. Since the late 1990's NRL has steadily developed capabilities for robotic servicing. Algorithms were developed and implemented on desktop computers, with COTS cameras, and commercial university-grade robotic arms. Having demonstrated the feasibility of grappling to existing, unmodified spacecraft interfaces (marman ring or bolt hole), NRL focused on development of a spaceflight qualified robotic arm, prototype end-effector tools, sensors, and flight-traceable control, machine vision, and path planning software. The facilities and equipment were primarily funded by the Navy and the R&D was largely funded by DARPA. NRL repeatedly demonstrated autonomous grappling of these heritage spacecraft interfaces in the laboratory (2008) and subsequently demonstrated autonomous inspection, release of a representative "stuck" solar array (2012), and teleoperated installation of multi-use bracket along with a representative payload on a structural model of a heritage bus (2017). As the US government developer of the RSGS payload, NRL will incorporate all of these capabilities into the DARPA servicer. It is certainly possible to include other capabilities once the primary mission demonstration is complete. The robotic arm includes a tool changer and the ability to capture a small satellite delivering new tools or other materials/consumables. In considering new orbiting space telescope concepts for the 2030 time frame, the decadal survey membership must be aware of the state of spaceflight-rated robotics technologies. In a separate white paper, the Naval Research Laboratory will describe how technology and procedures derived from the Robotic Servicing of Geosynchronous Satellites (RSGS) satellite servicing program could help enable robotic assembly and subsequent servicing for large diameter optical instruments. The technologies to be described will include: • The FREND robotic arms, which were designed for the RSGS mission and are being built by MDA-US. The FREND arms are, to date, the only spaceflight-qualified arms in existence intended for use in geosynchronous and more distant orbits. The NASA Goddard Restore-L programs is also using the FREND arms for LEO servicing. • RSGS algorithms and controls, including compliance control, robot arm trajectory planning, and visual servoing. • The REU arm control electronics, a joint design by MDA-US, Broadreach Engineering, and NRL. • The camera and lighting system • The Integrated Robotics Workstation, NRL's robotic operations and teleoperations ground control system. • RSGS-specific validation and verification procedures • RSGS-derived Concepts of Operations • NRL's world-class microgravity robotic test and validation facilities. This submission will also complement white papers that are anticipated to be submitted by JPL, NASA Langley, NASA Goddard, Lockheed Martin, SRI, and NASA's In-Space Assembled Telescope (iSAT) study, describing the accomplishments in space robotics at each of those institutions.

Web link:

Name: Nithyanandan Thyagarajan

Proposing Team: Judd Bowman, Adam Beardsley

Type of Activity:
Technological Development Activity

Description: We intend to propose a technology development program to yield highly efficient signal and data processing in order to enable the next generation of large radio interferometer arrays needed in the 2020 decade and beyond. High priority upcoming science objectives for the 2020s include: 1) the search for habitable exoplanets by characterizing exoplanet magnetospheres using circularly polarized transient radio emission produced when a planet's magnetosphere interacts with charged particles from the parent star, 2) discovering and utilizing explosive astrophysical phenomena such as Fast Radio Bursts (FRB) to study the IGM at cosmological distances to characterize dark matter, and 3) millisecond pulsars (MSP) to detect the gravitational wave background. These activities will influence the design of new instruments in the near- and long-term future and drive new telescopes to consist of large numbers of antennas to achieve the required sensitivity. New instruments on the horizon such as expansions of the Long Wavelength Array (LWA), the Deep Synoptic Array (DSA-2000), the Hydrogen Epoch of Reionization Array (HERA), the Canadian Hydrogen Intensity Mapping Experiment (CHIME), and eventually the realization of the Square Kilometre Array (SKA), plan to tackle these challenges by providing large collecting areas (for sensitivity) through many thousands of small telescopes, large fields of view, continuous monitoring, and time-domain information over the entire sky. These plans pose computational and data-rate challenges. In many cases, the costs associated with signal processing are a substantial fraction of the total telescope budget. Current radio interferometer architectures rely on correlation-based aperture synthesis for imaging, whose computing and overall costs scale as N^2 (square of the number of antennas) and thus will not scale well to the requirements of very large arrays. In addition, the data rates are too high to sustain continuous monitoring. Thus, extrapolation of current signal processing architectures will be too expensive and will not be effective at enabling the instruments needed. The proposed technology development program will yield a signal processing and imaging architecture that has been developed to address these challenges and enable cost-effective implementation of large radio arrays. It should be pursued as a high-priority outside of the selection of any particular telescope concept. The first realization of such a high performance imaging architecture, the E-field Parallel Imaging Correlator (EPIC), has already been successfully demonstrated on the existing LWA. Rather than perform the N^2 cross-multiplications needed in a typical FX radio correlator, EPIC grids antenna voltages onto an aperture and performs two-dimensional FFTs to directly yield electric field images of the sky. For large, densely-packed arrays, the performance costs as well as data rates can be decreased by a few orders of magnitude, and provide real-time and continuous imaging capabilities over the wide fields of view, thereby making these arrays much more efficient at a diverse range of time-domain discoveries and simultaneous wide-field monitoring relative to their existing capabilities. EPIC has shown it can enhance LWA's capabilities significantly in the area of all-sky, high time-resolution imaging. The scale of the LWA instrument (256 antennas) represents a transition to even larger scale instruments of the future. The high performance imaging architecture is directly extensible and in fact will be beneficial to a host of other current and next-generation of large interferometer arrays. These include the Owens Valley LWA (OVRO-LWA), portions of the DSA-2000, other LWA stations, HERA, CHIME, SKA, etc. and their future expansions. Continued support from NSF programs such as the MSIP and the ATI will be critical in the development of such advanced technologies to realize the full potential of large, modern radio interferometer arrays to address the key science questions of the 2020s.

Web link:

Name: Nithyanandan Thyagarajan

Proposing Team: Greg Taylor, Jayce Dowell, Judd Bowman, Adam Beardsley

Type of Activity:
Technological Development Activity

Description: We intend to propose a new signal and image processing architecture on a proposed network of Long Wavelength Array (LWA) stations of antennas operating at long radio wavelengths. This high performance direct imaging architecture, named E-field Parallel Imaging Correlator (EPIC), will significantly enhance the capabilities of these individual stations as well as that of the whole network. Currently, there are two LWA stations operating in New Mexico, namely LWA1 and LWA-Sevilleta (LWA-SV). They consist of 256 dual-polarization dipole antennas each with a field of view covering the entire hemisphere operating at radio frequencies 10-90 MHz. This network of LWA stations is being proposed to expand across the USA with individual stations being managed by separate institutions granting enhanced access to users, particularly students. Such LWA stations denote a transition from traditional radio interferometer paradigm to what is referred to a large-N small diameter (LNSD) paradigm due to the presence of a large number of small elements effectively filling a large aperture. Such a paradigm poses challenges to data processing and imaging in traditional architectures because they rely on a correlation-based architecture whose computational and overall costs scale with the square of the number of individual antennas. Besides computational costs, the bandwidth requirements are also extremely demanding especially for fast time-domain applications. With such computational and bandwidth costs, next-generation telescopes will be challenged by the processing demands over the next decade with the existing traditional architectures. The EPIC architecture is designed to address these challenges as modern arrays are expected to expand in size tremendously. With minimal interference to existing architecture and operations, we successfully deployed the EPIC architecture on the LWA-SV station as a parallel and alternate architecture for imaging in addition to the existing traditional, correlation-based architecture. As a result, it has significantly enhanced the time-domain capability of the LWA-SV station. For example, EPIC has enabled the increase of cadence of all-sky imaging from 1 per second to >1000 per second. With all-sky imaging at millisecond cadence, the LWA-SV station now has the capability to observe and characterize fast time-domain astrophysical phenomena over the entire hemisphere. We intend to propose the deployment of EPIC processing architecture on the proposed "swarm" of LWA stations across the USA. With such a deployment, each station will be capable of independently imaging the sky thereby enabling the study of ionospheric conditions at different locations, help in the elimination of coincidences and false detections when searching and monitoring for rare events of astrophysical importance. Fast imaging on sub-millisecond timescales with EPIC and event detection can immediately be communicated across the network to trigger a network-wide observing will be an added benefit of EPIC. In addition, the deployment of EPIC architecture also opens possibilities of hybrid imaging schemes across the different stations wherein individual stations can image on larger angular scales while the full network can image at much finer angular resolutions. This expansion of the LWA network denotes the next step in the transition of modern arrays further towards the LNSD paradigm. Thus EPIC can not only broaden the scientific and technological capabilities of this proposed network of LWA stations, but also address the larger goal of transforming the data processing paradigm for even larger telescopes of the future such as the Square Kilometre Array, next-generation VLA, etc.

Web link:

Name: Gerard van Belle

Proposing Team:

Type of Activity:
Technological Development Activity

Description: The Speckle Revolution Speckle interferometry, a technique that saw its birth in the mid-1970s, has been undergoing a quiet revolution in the astronomical community in the last decade. The original implementations, greatly limited by the detector technology of the time, has been significantly rejuvenated by the advent of modern, low-noise, high-speed detectors in visible. Specifically, the availability of electron-multiplying CCD detectors (EMCCDs) has made possible low-cost, diffraction limited imaging that competes well with adaptive optics in terms of sensitivity, contrast ratios, and inner working angles. We see significant opportunity for further development of this technique in the coming decade. Coupling speckle imaging with simultaneous wavefront sensing can greatly enhance the image reconstruction capabilities, as well as high-speed computing resources that are now commonly available. Recently developed low-noise, high-speed detectors in the near-infrared that complement the visible light capabilities of EMCCDs make that spectral regime open to the technique, where substantially less atmosphere turbulence could extend the already considerable sensitivity of speckle. Additional, non-civilian developments in speckle that have recently been reported in the open literature may be of value in astronomical community as well. The rapid proliferation of new speckle cameras in the past two years highlight its value for follow-up of extrasolar planet candidates, and for investigating stellar multiplicity and orbits. We anticipate continued development of this technology to provide a compelling option for an even broader range of diffraction-limited operations at current and future large apertures.

Web link:

Name: Philip Hinz

Proposing Team:

Type of Activity:
Technological Development Activity

Description: This Notice of Intent is for technological development activities in telescope-integrated adaptive optics, specifically large format deformable mirrors, as well as associated wavefront sensors, guide star beacons, and sophisticated software control systems. Adaptive optics (AO) is an important enabling technological capability for ground-based optical/IR telescope facilities. Further, its value increases for large aperture telescopes where the telescope diameter becomes increasingly large compared to the coherence length of the turbulence. Impactful scientific and technical applications include high contrast imaging of exoplanetary systems, ground-layer and multi-conjugate turbulence correction for multi-object studies over wide fields of view, and high spectral resolution observations with more compact instruments. A key aspect of furthering adaptive optics utilization in current and future facilities, is to develop approaches that lead to it being used as routinely as possible. Ideally, the adaptive optics system would be integrated into the telescope facility. We advocate for increased technology development in several key areas that will enable the next generation of AO systems integrated into medium and large ground-based telescopes. As a specific example, large-format deformable mirrors can be used as part of the telescope optics (adaptive secondary mirrors (ASM), or similar implementations) and provide one technical area of advancement. Current ASM implementations on the MMT, LBT, and VLT facilities suggest the approach is viable. However, more development is needed to make such an approach routine. Electronics have progressed significantly in the last two decades becoming smaller, faster, and cheaper, allowing development of high speed, large format deformable mirrors that are more economical and maintainable. Additional improvements can be made in the area of actuator efficiency and deformable shell fabrication. Developing improved technology for large format deformable mirrors will advance science on current generation telescopes where AO could routinely become part of the facility operations for optimized observations. The technologies explored will also open pathways to similar science with telescopes such as the GMT and TMT planned for the next decade.

Web link:

Name: Imran Mehdi

Proposing Team: Imran Mehdi, Paul Goldsmith, Jose Siles, Boris Karasik, Jon Kawamura, Goutam Chattopadhyay, Maria Alonso, Darren Hayton, John Pearson, Jacob Kooi, Jorge Pineda, Darek Lis, Bruce Bumble, Dan Cunnane (all JPL)

Type of Activity:
Technological Development Activity

Description: Title: Next Generation of Heterodyne Far-Infrared Arrays Spectral lines are vital tools for astronomy, particularly for studying the interstellar medium, which is widely distributed through the volume of our Milky Way and of other galaxies. Broadband emissions, including synchrotron, free-free, and thermal dust emissions give astronomers important information. However, they do not give information about the motions of, for example, interstellar clouds, the filamentary structures found within them, star-forming dense cores, and the photon-dominated regions energized by massive young starts. For study of the interstellar medium, spectral lines at submillimeter wavelengths are particularly important for two reasons. First they offer the unique ability to observe a variety of important molecules, atoms, and ion, which are the most important gas coolants (fine-structure lines of ionized and neutral carbon, neutral oxygen), proves of the physical conditions (high-J transitions of CO, HF, fine-structure lines of ionize nitrogen), and of obvious biogenic importance (H2O). In addition, high resolution observation of spectra line offer the unique ability to detangle the complex motions within these regions and, in some case, to determine their arrangement along the line of sight. To accomplish this, spectral resolution high enough (R>10^7) to resolve the spectral lines of interest is required. At submm-wave frequencies, diffraction gratings and Fabry-Perot interferometers are severely limited by diffraction, and they have not be able to reach R as high at 10^7. Heterodyne systems, on the other hand have no limitation to obtaining R at 10^7 or even higher. They provide velocity-resolved spectroscopy information that in the past decade has transformed our understanding of the interstellar medium. To gain a complete picture of the universe requires extensive spectral-line imaging. Building up such a three-dimensional (two angular and one frequency or velocity) image, one spectrum at a time is obviously time consuming. The development of arrayed heterodyne receivers has been drive by the need to make more effective use of valuable observing time. A concerted technology development effort is thus required to enable a THz instrument in space with 100-1000's of pixels, however, such an instrument must require orders of magnitude lower resources (such as mass and power) from existing implementations. Technological advancement is needed to develop novel coupling structures, mixers, multipliers and other receiver components that provide very broadband operation across the 300 GHz to 10 THz range. Optically pumped sources might enable researchers to circumvent fast roll off of electronic sources. Novel superconducting mixer technology that allows for operation above 4K and and larger IF bandwidths would be necessary for receivers in the 2 THz range and higher. Mixers approaching quantum-limited sensitivity must be demonstrated on a robust level where they can be easily manufactured. Low-noise amplifiers which require very little power and extremely low noise (< 1K) are also required. Backend IQ spectrometers that can provide bandwidth of 12 GHz would enable single sideband receivers with enhanced science throughput. Technology development is also needed to demonstrate compact receiver systems with dual-polarization and side-band separating functionality. Heterodyne interferometers also offer the possibility of substantially increasing angular resolution without having to use very large single dish telescopes. Instruments enabled by this technology will probe an enormous range of physical scales and environments in our universe. Probing the first steps of water from giant molecular clouds in the ISM to cold dense cores will investigate the trail of water. Tracing the properties and origin of cosmic rays, characterizing the turbulent kinematics will address how the formation of filaments controls the star formation activity.

Web link:

State of the Profession and Other Activities

Name: Kathleen Mandt

Proposing Team:

Type of Activity:
State of the Profession Consideration
Other Management

Description: There is a growing awareness within the space science community that greater coordination and collaboration is needed between the four communities represented by the Divisions of the NASA Science Mission Directorate. As an example, the Exoplanet Science Strategy (NAS, 2018) specifically points out that such collaboration is needed to advance exoplanet science and calls for a coordinated effort throughout the entire space science community. However, this need for coordination is not limited to the exoplanet community. The impact of space weather on the Earth and the planets in our solar system requires coordination between the Earth Science, Planetary and Heliophysics communities. Efforts to understand our habitable heliosphere in the context of astrospheres observed outside of our solar system requires coordination between the Heliophysics, Astrophysics and Planetary communities. In order to address this growing need, we outline specific steps that can be taken by NASA and by the space science community. However, it is important to note that the only way that this effort can be successful is if it is initiated within NASA and is supported through directed resources provided by NASA to the community.

Web link: https://docs.google.com/document/d/1XTx9G7ym9wf8SWH0-pAPXtDKOeWQII3GBV8N2jagD40/edit?usp=sharing

Name: Dara Norman

Proposing Team: Dara Norman NOAO dnorman@noao.edu, T. J. Brandt GSFC t.j.brandt@nasa.gov, Nancy D. Morrison University of Toledo nancy.morrison@utoledo.edu, Sarah Tuttle University of Washington tuttlese@uw.edu, Julie Rathbun PSI rathbun@psi.edu, Zach Berta-Thompson Department of Astrophysical and Planetary Sciences, University of Colorado Boulder Zachory.BertaThompson@Colorado.EDU, Edmund Bertschinger MIT edbert@mit.edu, Nancy Chanover NMSU nchanove@nmsu.edu, Karen Knierman ASU karen.knierman@asu.edu, Aparna Venkatesan University of San Francisco avenkatesan@usfca.edu, Kim Coble University of San Francisco kcoble@sfsu.edu, Jonathan Fraine STScI jfraine@stsci.edu , Adam Burgasser University of California, San Diego aburgasser@gmail.com, Marie Lemoine-Busserolle Gemini Observatory mbussero@gemini.edu

Type of Activity:
State of the Profession Consideration
Other Advisory Committees/Panels

Description: Providing a Timely Review of Input Demographics to Advisory Committees Advisory panels and committees, for programs, projects, agencies, observatories, etc. should strive to be inclusive and involve as diverse a population of astronomers as possible consistent with the needs for scientific and technical expertise. However, these panels and committees can only be so large in order to be effective. Therefore, we recommend that any advisory panels or committees that solicit community input also collect and review demographic information about who has engaged in the advisory process through other mechanisms (WPs, townhalls, invited speakers, etc.), This review will allow for process transparency, assessment of process inclusion, as well as the opportunity to expose any biases or exclusions of significant sectors of the astronomical community. The advisory panel or committee and/or the advisee can then decide how to address (i.e., either mitigate or acknowledge) any concerns in the final report.

Web link:

Name: Lou Strolger

Proposing Team: Lou Strolger and Neill Reid

Type of Activity:
State of the Profession Consideration
Other Recommendations to agencies/organizations

Description: In an effort to reduce biases, Space Telescope Science Institute (STScI) decided to adopt a dual-anonymous review in its time allocation process in which the identities of both the proposers and the reviewers are withheld until after the science program is selected. The results of the change (after one cycle of implementation) have so far been encouraging, with the success rates of female PI no longer systematically lagging below the success rates of their male counterparts. Coupled with trends in the increase of the fraction of proposals led by women, and the overall increase in the number of new investigators receiving time, STScI is poised to increase the participation of women with this powerful and impactful research resource. STScI reached this decision after much consideration and consultation. We constituted a working group to investigate methods for dual-anonymous reviews in sciences, and to evaluate the impact of carrying these methods our time allocation process. We also solicited input and opinions from the community. What we implemented was indeed a unique but familiar hybrid of methods used in the anonymous review of manuscripts, but also the more typical peer-reviewed time allocation reviews. We will discuss the work done in reaching the decision to go with a dual-anonymous review process, the unique features of the review as it stands and how we think those roles may change, and the lessons learned after the first cycle of implementation. We will also provide some recommendations to other agencies and organizations who may are considering adopting similar processes for their peer-reviewed resource allocations.

Web link:

Name: Dara Norman

Proposing Team: Dara Norman (NOAO) dnorman@noao.edu, Natalia Lewandowsha (Green Bank Observatory) nlewando@nrao.edu, Karen Knierman (Arizona State Univ) karen.knierman@asu.edu, Terri Brandt (NASA/GSFC) t.j.brandt@nasa.gov, Zack Berta-Thompson (U of Colorado) zach.bertathompson@colorado.edu, Nancy Chanover (New Mexico State University) nchanove@nmsu.edu, Jena Whitley (U Texas-Arlington) jenawhitley@gmail.com, Aparna Venkatesan University of San Francisco avenkatesan@usfca.edu, Adam Burgasser University of California, San Diego aburgasser@gmail.com, Marie Lemoine-Busserolle Gemini Observatory mbussero@gemini.edu

Type of Activity:
State of the Profession Consideration
Other Funding, Research Inclusion

Description: Tying Research Funding to Progress in Inclusion The US professional astronomy and astrophysics fields are not representative of the diversity of people in the nation. For example, 2017 AIP reports show that in 2014, women made up only about 20% of the faculty in astronomy and physics departments, and the numbers for under-represented minorities (men and women) were, and remain, dismally low. Furthermore, research funding (e.g., grants) is currently not tied to metrics or progress on the inclusion of underrepresented and disenfranchised groups. "Broadening Participation" in the field must be about workforce and research participation, not just public outreach and education. In this white paper, we present examples of metrics to be assessed, and where possible, examples of how some groups in the field are currently addressing and using these metrics to improve research inclusion. These include project/program activities that: promote diversity and inclusion in research (e.g. SDSS' COINS); promote access to data and other resources for all, (e.g. NOAO's Data Lab, other science platforms); promote opportunities for "Open Collaboration", especially to researchers from small and underserved institutions (e.g., LSST science collaborations).

Web link:

Name: Gourav Khullar

Proposing Team: The Astrobites Collaboration

Type of Activity:
State of the Profession Consideration
Other Public outreach, education research, policy, diversity and inclusion

Description: Astrobites is a graduate-student organization that publishes an online astrophysical literature blog (astrobites.org), and has published brief and accessible summaries of more than 1800 articles from the astrophysical literature since its founding in 2010. Our graduate-student generated content is widely being utilized as a pedagogical tool to bring current research into higher education classrooms. Astrobites is using its content and crowdsourced knowledge of writers, editors and science communication experts - all graduate and ex-graduate students - to aid in the development of communication skills, and contribute to science communication efforts across the globe. Moreover, our broader astronomy-affiliated activities, including education research on Astrobites in undergraduate and graduate classrooms, science policy outreach, diversity and inclusion work, and press coverage of American Astronomical Society meetings are paving the way for a multi-faceted approach to science communication and outreach. This white paper will lay out our content and approach in order to encourage the consumption and implementation of accessible and inclusive outreach by the broader astronomy community.

Web link: https://astrobites.org

Name: Gourav Khullar

Proposing Team: Diversity Equity and Inclusion Journal Club and collaborators (Dept. of Astronomy & Astrophysics, University of Chicago)

Type of Activity:
State of the Profession Consideration
Other Equity, Diversity, Inclusion, Accessibility

Description: Diversity, equity and inclusion are core values in many astronomy and physics departments across the US. Within the broader astronomy and astrophysics community, however, lack of inclusive spaces and support puts at risk our current and potential colleagues from under-represented groups. This white paper explores the channels through which early career scientists can steer constructive change through the creation of grassroots movements in astronomy departments. These movements focus on cultivating safe spaces and implementing low-barrier, high-impact initiatives tailored to solve systemic issues within their respective communities. In this work we will share our experiences organizing local movements (such as journal clubs, resource hubs, peer education initiatives) as early career scientists, as well as crowdsourced knowledge from our collaborators (who are experts on access, equality, and social justice) for the benefit of the broader astrophysical community.

Web link:

State of the Profession Activities

Name: Stuart F. Taylor

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Presentation on Barriers to Participation: How junior scientists are being dishonestly harrassed, bullied, and forced from continuing their scientific activity. How these behaviors constitutes fraudulent publications by contriving the results of targeted authors to be delayed until after more compliant but later starting scientists become favored to publish first. How societies, funders, journals, institutions, research groups, and all collaborators must work together to correct such disgraceful behaviors including quietly going along with targeting people and censoring reports of keeping people out. The lack of mechanisms for recourse to enable targeted persons to resume their group participation is such a disgrace that the State of the Profession of Astronomy in 2019 must first be considered to be an embarrassment. (This follows the contribution from ten years ago by S.F. Taylor. No improvement has occurred this decade.)

Web link: astrostuart.blogspot.edu

Name: Emily Moravec

Proposing Team: Ian Czekala, Katherine Follette

Type of Activity:
State of the Profession Consideration

Description: We intend to summarize the response from 56 early-career astronomers at a focus session convened by the National Acadamies of Science, Engineering, and Medicine in October 2018. During the discussion sessions at this focus session, we discussed the decadal survey (content, structure, input, early-career involvement, and dissemination), topics concerning our career bracket in particular (career preparation and the hiring process), and the scientific, technological, and professional trajectory of our field. In particular, we give specific recommendations concerning the incorporation early-career voices in the decadal survey, ensuring diverse input to the decadal survey, the successfully dissemination of the results of the decadal survey, adequately training astronomers in big data, the support of research aims of big data, changes to the job application process, career preparation (whether academic or non-academic), and the removal of structural barriers to the inclusion of disadvantaged groups. Our document will reflect the authors distillation of the various opinions expressed at the event concerning these topics that our community and this survey should consider.

Web link: http://sites.nationalacademies.org/SSB/SSB_185166

Name: David Hogg

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: University-based, multi-institutional (and in particular global) projects require non-trivial collaboration rules. These rules exist to manage and encourage internal scientific investigations and publications, to make sure that the project builders get credit, and to deliver data products and documentation to the outside world. The diversity of projects that have been organized and executed over the last two decades have delivered a natural experiment in how these rules ought to be structured. Here we summarize the findings of this natural experiment and make recommendations for future projects.

Web link:

Name: David Hogg

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: The Decadal process is exceedingly important to global astrophysics and almost all sources of funding in the US. It has some oddities, however: The Decadal Survey chairs and panel members are appointed by an unspecified process. The panels take advice non-uniformly from white papers, and don't report on what was and was not influential. The impact for an individual or for the field of authoring and endorsing white papers is obscure. A large amount of time is spent by all members of the community on parts of the process that aren't obviously relevant to the final reports. The Decadal Survey reports are not evaluated, reviewed, or endorsed by any democratic process in the community. For all of these reasons, there is a danger that the Decadal process violates norms that we have for academic decision making, peer review, intersectional inclusivity, and democracy. I comment on these and suggest changes that might improve the process for 2030.

Web link:

Name: Kevin Marvel

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: I will provide a detailed description of the American Astronomical Society, its current projects and programs, including descriptions of our journals, their current business models, our meetings and other details of importance for understanding the role the Society plays within the astronomical profession.

Web link:

Name: Kathryn Johnston

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Power, Privilege and Leadership in Academia: - Academic institutions aspire to be meritocracies of the mind where humans can congregate to push the boundaries of our knowledge. This white paper reviews many of the human interactions and reactions that can impede these ideals. The focus is on how interactions at the individual level can combine and reinforce each other in destructive patterns of behavior. Collectively, these patterns manifest as challenging work environments that can stymie creativity and innovation. The paper outlines some ideas on how careful acknowledgement and deliberate actions might break these destructive cycles. The importance of individual faculty jointly taking the responsibility to make these steps as the embodiment of their institutions is emphasized.

Web link:

Name: Monica Vidaurri

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: While planetary protection standards are mandatory for all exploration missions, it is rare that scientists, scholars, and scientific policy writers make note or regard these standards. NASA has protectionary standards set in place for robotic missions, but a 2018 NAS report describes these standards as "inadequate". For crewed missions, these standards are non-existent, though they will be the most difficult to create and implement due to the human body's microbiota. As stated in the NAS Review of Planetary Protection Strategies, the progression of these standards has not gained much ground since the days of the Viking landers. Additionally, the new and quickly evolving private industry and non-federal space actors largely experience regulatory gaps when it comes to protection standards, adherence to international space customs, and subsequent bioethical standards. With Mars2020, Europa Clipper, and the inevitable exploration of other bodies in the solar system including ocean worlds, NASA, relevant UN committees (COSPAR and UNOOSA), and all international space agency partners must lead the effort to create and enforce strict planetary protection standards, as well as an enforcement pathway with delegated authority for future robotic and crewed space exploration, including tourism and commercial activities. In addition to setting international norms to be used in space law, all leaders and participants in space exploration must also adopt anti-colonization standards and protocol to ensure equal and fair participation in space, and thus allowing for only purely peaceful scientific purposes for exploration while ensuring minimal contamination. This white paper sets planetary protection as a function of bioethics and international custom, the most common precursor to international law. The paper addresses outdated and non-existent standards with regards to planetary protection and cooperation with private industry, from a policy and international law perspective. The paper also outlines different pieces of legislation (NASA Procedural Requirements, Directives, and International Law) as well as techniques to establish new protectionary standards to be used as procedural framework, and how they can be edited to include private partnerships, tourism, and other relevant new developments in space science. With respect to all of this, the role of planetary protection offices is also defined and strengthened with regards to future problems they will face, including but not limited to: private industry mission advising and mandatory regular assessment, cooperation, coordination, and advising with a space agency's government, coordination with the astro-sciences, and establishing anti-colonization norms. The paper offers recommendations on how to implement new planetary protection and anti-colonization norms within and between agencies, governments, and private entities. The question of how exactly these norms become universal is addressed, as well as setting the framework for predicting, finding, and implementing new techniques and technologies pertaining to planetary protection and space law as time goes on and space science is improved.

Web link:
https://docs.google.com/document/d/1VHGWJOZbSJgQnBs5R3j_zzYfwJ9J_QqftEmyvo_leTQ/edit?usp=sharing

Name: Gurtina Besla

Proposing Team: G. Besla (U. Arizona), D. Huppenkothen (U. Washington), E. Schneider (Princeton), N. Lloyd-Ronning (LANL), S. Jacobson (Northwestern), S. Naoz (UCLA), A. Peter (OSU), B. Burkhart (Rutgers), P. Behroozi (U. Arizona), C.K., Chan (U. Arizona), S. Morrison (Missouri State), H. Nam (LANL), et al.

Type of Activity:
State of the Profession Consideration

Description: Astro2020 State of the Profession: Training the Future Generation of Computational Researchers The assembled team is comprised of a diverse group of faculty, staff and postdoctoral fellows actively conducting computational research using both local and national HPC facilities. Motivation: Training the next generation of computational researchers and preparing all students for careers in Astronomy, Physics and industry will require universal computational literacy, innovative education models and equitable access to high-performance computing (HPC) facilities. The 2018 report from the Committee on STEM Education of the National Science & Technology Council explicitly states that in order to build a strong foundation for STEM Literacy we must ensure that "every American has the opportunity to master basic STEM concepts, including computational thinking". The "grand challenges" facing the field of Astronomy and Physics over the next 10 years will require innovative and advanced computational methods to solve. In particular, the fields of Astronomy and Physics are generating massive data sets from observational surveys (e.g., the Large Synoptic Survey Telescope LSST; 15 terabytes a night), large-scale experiments (e.g., Event Horizon Telescope EHT, 10 petabytes a run), and simulations (e.g., the Illustris Cosmological Simulations, 265 terabytes in total). The resulting petabyte-scale data sets require advanced computational methods to analyze. Clearly, computational thinking and the ability to solve complex problems with data and computational methods, are currently the critical skills for student success in Astronomy and Physics. Despite the above realities, the implementation of computational training in undergraduate Astronomy and Physics programs is occurring sporadically across the nation, and follows no shared curricula, relying instead on a per-instructor model where the decision to teach computational classes is largely driven by faculty interest and expertise. Since faculty with computational expertise are often located at institutions with in-house HPC facilities, these compounding factors create an imbalance of access to computational training across the nation. This White Paper: We will outline a set of concrete recommendations for NSF, NASA, DOE, National HPC Facilities and the field at large to promote the growth and development of a generation of computational researchers and a user base for national HPC facilities that reflect the demographics of the undergraduate population in Astronomy and Physics.

Web link:

Name: Alyson Brooks

Proposing Team: AAS CSMA

Type of Activity:
State of the Profession Consideration

Description: Despite the fact that many guides exist to best practices in hiring, many astronomers are still encountering unethical (and sometimes illegal) behavior when being considered for a position. Here we highlight some unethical practices that should be eliminated, and highlight the best practices that we should all be striving for.

Web link:

Name: David Soderblom

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Research scientists in support of facilities and missions The success of both ground- and space-based facilities and missions relies critically on a high level of technical support and also on the involvement of scientists who themselves use those facilities and missions. This white paper demonstrates some of the innovations that such staff have produced and reaffirms the value of independent researchers in effective support of astronomy.

Web link:

Name: Jeffrey Hall

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: The AAS Committee on Light Pollution, Radio Interference, and Space Debris will submit a State of the Profession paper on the three topics within our purview. There are many current developments in these three areas that make such an an overview timely. In the area of light pollution, we are seeing a worldwide transition from legacy outdoor lighting systems to LED, typically with white LEDs being the default solution. Even low-color-temperature white LEDs create, lumen for lumen, twice the sky glow of the currently widely used high pressure sodium. We are at risk of a dramatic increase in sky glow worldwide from the transition to LED - and are already seeing it in many areas. The increasing opportunities for commercial ventures in space pose the risk of a continued proliferation of space debris and spurious transients via projects such as artificial meteor swarms or space-based advertising with cubesats. And the RF landscape is becoming increasingly crowded due to the need for ongoing advances in wireless connectivity and other pressures, putting bandpasses used for sensitive information relevant to astronomy at risk. In this white paper, we will outline the principal risks in each area, and we will specify key principles and policy points that the AAS and other advocates can use in mitigating the threats to astronomy posed by these developments.

Web link:

Name: Monica Vidaurri

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Numerous studies and previous white papers have stressed the need for increased diversity and inclusion in academic institutions. Additionally, many large institutions such as the NSF, NAS, AAS, NASA, ACS, and numerous other institutions have publicly stated the need for directly endorsing inclusionary investment. It is critical that these diversity initiatives also stress retention of the diverse populations that institutions need more of. Bridge programs are one way to increase diversity and retain diverse populations at institutions. Mostly used by universities at the high school to undergraduate or undergraduate level, bridge programs take many forms. For example, there are bridge programs that partner with a school and an employer relative to a certain field and help the student gain experience either as an intern or with a mentor from the field. Other bridge programs are designed specifically for first-generation students, helping integrate the students into college courses by providing them with mentorship, course help, internship opportunities, and a support system. The same can be applied for post-bac to masters, and masters to PhD students. Though there are many types of bridge programs, the purpose of these programs is to quite literally "bridge" historically underrepresented minorities to an experience or program that they would otherwise not have access to or have very limited access to. Bridge programs not only increase diversity of a field, but they work to market rising stars and recruit new areas of thinking, rather than having institutions continue to hire those that have been historically successful in school, well-represented, and have had seemingly unlimited resources, time, and benefit of location. In working to erase internal biases held in higher institutions, both educational and workforce, bridge programs work to reflect a more understanding and open-minded educator and PI generation. By mentoring and teaching underrepresented minorities (URMs), bridge programs work to erase internalized biases, including but not limited to: homogeneity, racial/religious bias, sex-based discrimination, etc. Though there is very little statistical data on these bridge programs, a master study by Ashley et al. (2017) gathered recorded student responses of their bridge programs. After studying 30 different bridge programs, the study found that, of the 46 published reports monitoring and measuring their successes, each program met requirements of remediation, content knowledge, maximization of GPA, sense of belonging in the field, increases in research participation, networking, interest, and other categories. This white paper discusses the importance of bridge programs in increasing diversity in the workforce and in schools. This white paper will analyze what makes a successful bridge program, their future importance with regards to diversity and inclusion, and suggestions for implementing bridge programs for both federal and non-federal institutions. In addition, the white paper includes a call for the presence of social scientists/sociologists working closely with bridge programs, in order to provide adequate statistical analyses of these programs so that the data may be used by institutions wanting to create a bridge program. The paper addresses inevitable ethical implications of starting a bridge program. Institutions on either side of a bridge program/implementing the program must be adequately financially, psychologically, and physically prepared to ensure that URM students are getting the experience needed, and with the right resources. The paper also breaks down everything to consider when starting a bridge program, and how to effectively ensure that the students involved receive the mentorship, experience, and resources that they deserve.

Web link: https://docs.google.com/document/d/1O7PsuivwvjBXMvHIWzWC7oEVRsXIlFnz6GMz-88RN5Q/edit?usp=sharing

Name: Gillian Nave

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Almost everything we know about the Universe has been discovered through the light that reaches us from the stars, galaxies, nebulae, and other astrophysical objects. The analysis of this light using spectroscopy has yielded information about the size, chemical composition, temperature, and dynamics of astrophysical objects from the size of planets to galaxies. Critical to this analysis has been atomic spectroscopy and the analysis of the wavelengths, energy levels, transition probabilities, isotopic and hyperfine structure, and excitation rates of atoms and ions. No field of science requires more from atomic data than astrophysics, with new astronomical spectrographs placing ever increasing demands on the quality and quantity of the data. However, the number of people active in atomic spectroscopy has been shrinking for many decades. The situation is particularly acute in experimental work where only a handful of groups remain around the world. While theory has made substantial progress, it is impossible to calculate parameters such as wavelengths and transition probabilities to the accuracy needed for detailed spectroscopic analysis. However, funding for atomic spectroscopy in the USA has decreased in real terms over the past decade. Past support has come from the NSF Atomic, Molecular, and Optical program, but that division has not funded atomic spectroscopy for over 20 years. The same is true for the Department of Energy (DOE), which stopped funding atomic spectroscopy several years ago. US support for atomic spectroscopy now comes from the NASA Astrophysics Research and Analysis (APRA) and Astrophysics Data Analysis (ADAP) programs, and the NSF Division of Astronomical Sciences (AST). However, the number of awards made by these programs is small and has decreased over the past decade. The few remaining groups in atomic spectroscopy are not sufficient to sustain the field without substantial increases in funding and personnel. Only one university in the US has students in experimental spectroscopy of the low ionization stages that are in highest demand. In almost all of the groups the principal investigators are within 10 years of retirement age and it is not clear where their replacements could come from. The loss of just one person in each of the groups could mean the demise of the laboratory. This is even true for the Atomic Spectroscopy Group at NIST, where the widely-used Atomic Spectra Database has come under increasing pressure from decreasing Federal budgets. It would be very hard to re-establish these groups in the future. The situation is not much better in other countries. If the current trends persist, by the time new UV telescopes are launched (e.g. LUVOIR) there will be no people left who know how to calibrate them or measure required data for the interpretation of their spectra. The same may be true for instruments on new large ground-based telescopes currently under construction. We urge the committee to address these problems in their report.

Web link:

Name: Nancy Morrison

Proposing Team: Committee on the Status of Women in Astronomy

Type of Activity:
State of the Profession Consideration

Description: The American Astronomical Society's Committee on the Status of Women in Astronomy (CSWA) intends to submit one or more white papers on the state of our profession. During 2018 the CSWA began an effort to gather information about what are seen by our communities as the areas of key importance beyond scientific research that the AAS, its divisions, and its relevant committees (including the CSWA itself) should focus on as we move into the 2020s. The goal is to use this information to (1) develop one or more white papers that will be submitted to the Decadal Survey as a part of the call for papers on an activity, project, or state of the profession consideration and to (2) develop a new strategic plan for the CSWA for the 2020s. Our strategy has been to first identify the key areas and potential activities that could be undertaken in these areas by the AAS, its divisions, or relevant committees. We have taken all the input we have received so far and created a survey based on that information. The survey is organized around 4 key areas: Harassment and Bullying; Creating Inclusive Environments; Professional Development, Hiring, and Retention; and Professional Ethics, and also provides an opportunity to provide additional feedback and suggestions. The survey is completely confidential and anonymous– we are not gathering any personally identifiable information, nor are we capturing any information on who is accessing the survey. The survey will be open until Tuesday, April 23, 2019. It can be accessed at: https://tinyurl.com/y4o9yeuf Once the survey is closed, the CSWA (and potentially other interested individuals) will compile the results. Assuming that one or more of the highest priority items in our four key areas, or additional input that is provided, is appropriate for a white paper submission (or submissions), we will the formulate white paper(s) around that.

Web link:

Name: Aparna Venkatesan

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: A Path to Equity in Science Prizes We present a brief overview of the main prizes and awards by demographics in astronomy and physics, revealing that we are still far from achieving gender and race equity in prizes in our field. We share reflections on what factors throughout the entire process in awarding prizes (nomination, award rules, review, and final choices) might interfere with achieving equity. We suggest a list of changes, some gradual and some immediate, so that prize nominee pools and recipients can reflect the realities and demographics of today's scientific work. These include recognizing that today's groundbreaking discoveries, particularly in experimental areas, are collaborative rather being limited to a handful of individuals, and that some awards may need to honor enduring legacy achievements posthumously rather than strictly being awarded during the scientist's lifetime. This becomes especially important when we consider the documented effects of a hostile work climate, racism and harassment on scientists falling seriously ill and/or leaving the field. In addition, we need to consciously move away from persistent myths in scientific culture, such as inherent brilliance or solitary genius (Norman 2019), which fuel significant bias in subjective assessments, such as for prizes and awards. Given all these factors, prizes, like all privilege, tend to accumulate at a certain tier of institutions and in specific academic lineages. We therefore urge funding agencies to consider all these factors, and assess where a grant or award would be a game changer for an individual or institution. Far more women and underrepresented minorities would be amongst prize winners if the process and rules reflected the large diverse workforce in astronomy and physics today.

Web link:

Name: Lia Corrales

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Researchers, students, and staff can experience barriers and discrimination at all levels, from interpersonal interactions to the institutional structure. This includes the physical setup of a building, implicit and explicit bias, and harassment from peers and mentors. To make real change, people at the top of the funding and mentoring chain need to invest in inclusive practices. We will address concrete, research based practices for training leaders to create and sustain an inclusive research and learning environment.

Web link:

Name: Lia Corrales

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Common classroom teaching strategies can exclude or prevent success for students from marginalized backgrounds, from reviewing the syllabus on the first day of class, to the final exam. This document will review common missteps and solutions for structuring a syllabus, lecture, introducing pronouns, and exams. Introductory classes are a common place where students from marginalized backgrounds choose to leave the science track. We will evaluate structural changes to teaching that may help retain them.

Web link:

Name: Joseph Ribaudo

Proposing Team: TBD

Type of Activity:
State of the Profession Consideration

Description: This White Paper will highlight the role Primarily Undergraduate Institutions play within the profession, addressing issues related to employment, resources and support, research opportunities and productivity, and educational and societal impacts, among others. While being led by the Principal Author, this White Paper will summarize the thoughts, concerns, and experiences of dozens of professional astronomers with experience working at, or attending, Primarily Undergraduate Institutions. The co-author contributions will span the career stage spectrum, allowing this White Paper to provide perspective from a substantive cross-section of the astronomy community. As part of the White Paper we will attempt to quantify the growth within the profession of Primarily Undergraduate Institution-affiliated professional astronomers and highlight the distinct opportunities for the astronomy community that exist within the context of Primarily Undergraduate Institutions. We will also identify some of the unique challenges and obstacles that students and faculty of Primarily Undergraduate Institutions routinely face, while outlining a variety of supporting structures and resources that the community can pursue or adopt that will address these issues. In the end, this White Paper will provide a view of the profession as lived and experienced by faculty and students of Primarily Undergraduate Institutions, highlighting the unique opportunities available over the next decade and beyond for a profession focused on fostering and maintaining an inclusive, supportive, and diverse community.

Web link:

Name: David Whelan

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Mid- to large-scale astronomical surveys are becoming routine sources of data for astronomers. This shift has enabled novel research activities and has democratized them to the extent of making large datasets available to anyone with an internet connection. As a side effect, fewer astronomers are being trained on the basics of telescope operation. The dangers associated with this reduced training include the risk that professional astronomers lose their ability to discern instrumental from astrophysical signals in their data and that statistical studies of large sample sizes supplant detailed studies of smaller selected samples and single objects, which distances the presented results from relevant physics. Additionally, there is a real risk that technical skills that were once associated with professional practitioners will be relegated to the realm of support staff and amateurs. This may result in the average population of professional astronomers possessing inferior technical skills in observing, and therefore less creativity in the pursuit of their research. We will discuss the state of hands-on observing within the profession, including: information about professional observing trends; the role that amateurs can take moving forward; student telescope training, beginning at the undergraduate and graduate levels, as a key to ensuring a fresh technical understanding among astronomers; the impact of telescope training on using survey data effectively; and the need for modest investments in new, standard instrumentation at mid-size aperture telescope facilities to ensure their usefulness for the next decade.

Web link:

Name: Ellen Bechtol

Proposing Team: Keith Bechtol, Segev BenZvi, Lauren Corlies, Peter Couvares, Amy Furniss, Joey Shapiro Key, Jim Madsen, Frank McNally, Reshmi Mukherjee, Marcos Santander, Jazmine Zuniga-Paiz

Type of Activity:
State of the Profession Consideration

Description: Pursuing Diversity, Equity and Inclusion in Multimessenger Astronomy Collaborations Over the Coming Decades The lack of diversity in astronomy, physics, and astrophysics is well documented (Merner & Tyler 2017, Porter & Ivie 2019), and evident in educational institutions as well as scientific research collaborations. Broadening participation in the field is important from an ethical and social justice perspective. At the same time, a more diverse collaboration improves scientific output and therefore benefits the field at large (Chubin & Malcolm). Multimessenger research collaborations are addressing the lack of diversity by following some best practices to create inclusive and welcoming environments. Across the field, there has been concerted effort to establish and adopt code of conduct statements, for both virtual and in-person meetings as well as in everyday working environments. Several collaborations, including IceCube, VERITAS, LIGO, and LSST have formed diversity, equity, and inclusion (DEI) working groups or task forces. Sustaining these efforts is an ongoing challenge, and it is not uncommon for DEI working groups go dormant when a committed leader moves on or time pressures become too severe. In response to the Astro2020 Decadal Survey process, the Multimessenger Diversity Network is giving notice of intent to submit a state of the profession white paper. The Multimessenger Diversity Network (MDN) is a community of representatives from multimessenger astronomy research collaborations—currently IceCube, LIGO, LSST, and VERITAS, with other members expected to join in the future—focused on increasing diversity in the field. The MDN shares knowledge, experiences, and training and develops resources and practices around broadening participation. In the white paper, we will focus on actionable recommendations for research collaborations and funding agencies that recognize and increase awareness of DEI efforts. With few exceptions, diversity and inclusion work in research collaborations is volunteer-based and parallels the voluntary nature of education and outreach (E&O) work. Even where there is dedicated staff for education and outreach, DEI work is not part of the job descriptions for those staff. In a survey of 131 members of the Dark Energy Survey, respondents indicated they would be encouraged to get involved with E&O work if they felt supported to allocate time to it (53%), if E&O were an explicit part of job duties (46%), and if E&O were more highly regarded among peers (39%) (Farahi, Gupta, Krawiec, Plazas, & Wolf, 2018). The lack of time, professional regard, and explicit job commitment to DEI are often anecdotally cited by collaboration members as reasons for not getting involved with DEI work. Factors leading to improved and sustained DEI efforts and support for DEI work within collaborations will be researched. When possible, specific examples and case studies from MDN members will be used, along with research from the fields of astronomy and physics. Possible resources include collaboration members, especially those who serve on DEI working groups, and print sources including "Inclusive Astronomy 2015," "LGBT+ Inclusivity in Physics and Astronomy: A Best Practices Guide," and the "Final Report of the 2018 AAS Task Force on Diversity and Inclusion in Astronomy Graduate Education." Finally, best practices from the larger STEM field will be researched, drawing on work such as the National Academy of Sciences' "Sexual Harassment of Women: Climate, Culture, and Consequences in Academic Sciences, Engineering, and Medicine." Recommendations based on our findings will be presented along

with guidelines to evaluate their implementation. Members of large science collaborations are often under time constraints and immense pressure not only to do scientific work but also to teach, serve on committees, and mentor students. The recommendations and evaluation guidelines will consider sustainability of the efforts from the unique perspective of a science collaboration. Multimessenger astronomy collaborations and their funders have an opportunity to play a leading role in creating a more diverse, inclusive, and equitable profession. As efforts to broaden participation in the field at the K-12 and undergraduate through postdoctoral levels are underway, science collaborations must also do their part to successfully create inclusive and welcoming environments for future generations of scientists.
References Chubin, D.E. and Malcolm, S.M., "Making a Case for Diversity in STEM Fields", Inside Higher Education, October, 6, 2008 and references therein. Farahi, A., Gupta, R.R., Krawiec, C., Plazas A.A., Wolf, C.R.,, "Astronomers' and Physicists' Attitudes Towards Education & Public Outreach: A Case Study with The Dark Energy Survey." May, 2018. arXiv:1805.04034 Merner, L., and Tyler, J. "African American, Hispanic, and Native American Women among Bachelors in Physical Sciences & Engineering", AIP Report November 2017. Porter, A.M., and Ivie, R. "Women in Physics and Astronomy, 2019", AIP Report, January 2019.

Web link:

Name: Thomas Loredo

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: This State of the Profession white paper will highlight the growing role data science is playing in astronomy, and make recommendations regarding how best to support: (1) basic astronomical data science research, (2) development and maintenance of software and other data science infrastructure, (3) broad-based training of astronomers in essential statistical and computational skills, and (4) career paths focusing on interdisciplinary astronomy/data science research.

Web link:

Name: Jason Wright

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: We intend to submit a paper on the state of the field of technosignatures. The primary category of the submission will be Planetary Systems (especially extrasolar planets, exobiology and the search for life beyond the solar system). The field of technosignatures also interacts with the topics of Stars and Stellar Evolution, Resolved Stellar Populations, Galaxy Evolution, and Multi-Messenger Astronomy and Astrophysics. The paper will be led by Jason Wright and may have many co-authors and co-signers from the technosignatures search community. It will discuss the state of the field, and make recommendations for how the NSF and NASA can improve it. The search for life beyond the solar system—a major component of the Planetary Systems thematic area of the Astro2020 Decadal process—includes the search for technological life. "Technosignatures," by analogy with biosignatures, are signs of life, including communicative transmissions and other technologies. In general, the search for technosignatures is synonymous with "SETI" (Tarter 2007). Arguments for the existence of technosignatures are a simple extrapolation and complement to arguments for other biosignatures, and indeed it is not clear a priori whether technosignates should be easier or harder to detect. Searches for technosignatures also provide many ancillary benefits, and can drive discovery across astronomy (see, e.g., Wright 2018). As with biosignatures, the exoplanet revolution of the last decade has strengthened the case for searches for technosignatures. Many past recommendations from National Academies reports, NASA roadmaps, and Decadal surveys contain vaguely positive language about searches for technosignatures, but erroneously conclude that the field is adequately and properly funded by private, philanthropic means. On the contrary, such philanthropic funding is illustrative of the inherent merit of the endeavor and the capacity for the scientific community to put such funding to good use, and so actually argues *for* the topic's inclusion in a balanced federal science portfolio. The Decadal survey should not just endorse the search for technosignatures as a worthy scientific endeavor, but should explicitly recommend that it be funded at NASA and the NSF. Recently, "technosignatures" has been added to the ROSES2019 call in the XRP and Exobiology sections. This recent inclusion is welcome, and should be endorsed by the Decadal survey and recommend to be a persistent feature in future ROSES documents. Technosignatures remains, however, somewhat homeless at NASA. For instance: not all searches for technosignatures are focused on planetary systems (some focus on other galaxies, or perform all-sky searches for instance), and so many worthy projects will not be in-scope at XRP. Inconsistencies regarding the inclusion of technosignatures work in ROSES2019 also persist (Tarter et al. 2018): for instance, Exobiology still explicitly excludes radio and microwave technosignatures for no clear reason. The Decadal survey should emphasize that technosignatures is a broad field, and that projects involving aspects of predicting, modeling, or searching for technosignatures across a range of astrophysics should be explicitly encouraged to compete for funding in the most relevant calls across NASA's portfolio. While NASA and the NSF have supported a few scattered SETI efforts since 1993, to the best of our ability to determine, the average funding level over the past 25 years has been less than 1 FTE/year. This has translated into a lack of training and professional development: there have been only 5 PhDs awarded in the field (ever). The Decadal should thus recommend that NSF support educational programs, including the development of a graduate curriculum, and support professional development at all levels to train the next generation of SETI researchers. Tarter, J. 2007 Highlights of Astronomy 14, 14 Tarter, J. et al. 2018 White paper https://doi.org/10.5281/zenodo.2539473 Wright, J. T. 2018 White paper arXiv:1801.04868

Web link:

Name: Juna Kollmeier

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: I intend to write a position paper on support for theoretical astrophysics in the 2020-2030 timeframe. I will argue that material support for theory groups, centers, and individual theorists is essential for the future --- this is even more true given the truly staggering community investment in observational facilities. The training and nurturing of the next generation of theorists is crucial to maintaining a vibrant field. The White Paper will address this issue including ideas for the support of theory in the 2020-2030 timeframe.

Web link:

Name: Emily Levesque

Proposing Team: AAS Publications Committee

Type of Activity:
State of the Profession Consideration

Description: The American Astronomical Society journals - ApJ, AJ, ApJ Letters, and the ApJ Supplement Series - are a vital asset of our professional society and the most widely-read and frequently-cited journals in the field of astronomy. The AAS internally maintains and publishes our own high-profile journals, a rarity among scientific disciplines that allows us to maintain both a high acceptance rate and a high impact factor. The costs associated with operating our own journals within AAS currently include support for personnel, materials, and online operations. As the AAS is not a commercial publisher, funding to support our journals' operating costs comes from a combination of subscription fees and page charges. However, the current cultural push to shift academic publishing to Open Access (OA) will eventually remove subscription as a revenue stream for journals; this will likely result in an increase in page charges. The existing page charge model, which requires individual authors to pay page charges out of their grants or even out of pocket, is already burdensome to some researchers. This model can disproportionately impact early-career scientists, underrepresented members of the community, and individuals working at smaller and minority-serving institutions, problems that will be exacerbated in the OA era. As a result, a discussion of alternative and innovative models for funding page charges and publishing costs needs to be a crucial part of the Astro2020 decadal survey if we wish to continue supporting the sustainable and accessible publication of US research in AAS journals.

Web link:

Name: Joel Kastner

Proposing Team: American Astronomical Society Committee on Employment

Type of Activity:
State of the Profession Consideration

Description: Our white paper will address the general question: "What are the employment prospects of PhD astrophysicists, both within and outside academia, over the coming decade?" We intend to discuss trends in astronomy and astrophysics employment over the past decade in various sectors including government, industry, and academia, and the future implications of these trends. Areas we might explore include the rise of jobs in the data science industry, trends in the rate of PhDs awarded, and the availability of postdocs and permanent positions in astronomy and astrophysics. We will consider whether and how these and other recent trends break with past trends in astronomy and astrophysics careers, as well as what these and other developments may portend for the future of the field. We will highlight the skillsets that have enabled astrophysicists to flourish in each employment sector. Where appropriate, will will also make recommendations for explicit professional development activities that might provide the necessary complementary skills and access to networking that are necessary to optimize employment opportunities for PhD astrophysicists. The AAS Employment Committee will coordinate closely with other AAS committees and entities in developing this WP.

Web link:

Name: Kathryn Williamson

Proposing Team: Travis Rector (University of Alaska Anchorage), Chris DePree (Agnes Scott College), Geoff Clayton (Louisiana State University), James Lowenthal (Smith College), Knut Olsen (National Optical Astronomy Observatory), Caroline Roberts (Georgia State University)

Type of Activity:
State of the Profession Consideration

Description: From a social, environmental, and political standpoint climate change is the most important scientific topic of our time. The need to address climate change has become immediate, with only 12 years to reduce carbon emissions to 50% of pre-1990's levels in order to avoid potentially irreversible and catastrophic effects (Intergovernmental Panel on Climate Change Special Report 2018). With the rise of attention given to the Green New Deal, the Paris Agreement, Climate Strikes, and natural disasters, the issue of climate change has become interdisciplinary in every sense of the word. Recent surveys by the Yale Program on Climate Change Communication show that the majority of Americans are concerned about climate change, but their perception and understanding of climate change is far behind the scientific consensus. Therefore, communication is central to understanding these interdisciplinary connections and raising awareness. Astronomers are well-positioned to make a difference, especially from an educational perspective. Introductory astronomy courses ("Astro 101") reach as many as 250,000 students per year (Fraknoi 2001), many of whom are non-science majors and future educators. For many, an introductory astronomy course is their last formal education in the sciences. So this is their last chance to learn the science behind climate change. We are also leaders in scientific outreach programs, with planetaria alone reaching as many as four million visitors nationwide per year. Furthermore, as part of their professional service, astronomers give countless public talks and outreach events that reach other vitally important educational spaces, such as national parks and public libraries. These are three additional reasons why astronomers are well positioned to teach climate change in formal and informal education settings: (1) Climate science is closely related to astronomy; and most astronomers already know enough about the basics to teach it. It is also closely connected to "Astro 101" topics, so much so it would be awkward to not teach it. (2) Astronomers are highly regarded, and in some ways more trusted than other branches of science because our research is less controversial. And (4) we cannot be accused of being "in it for the money" because we do not receive funding for climate science. Indeed, it is helpful for people to hear about climate science from all scientists, because it is connected to all branches of science. Building our capacity to teach about climate science as astronomers will, therefore, open opportunities for interdisciplinary collaboration and discussion, and a more unified voice from all scientists. This White Paper will be a call to action to astronomers to not only teach about climate change, but to take a scholarly approach that supports sharing of ideas and documentation and assessment of lesson plans and effective outreach tools. The goal is to encourage and prepare astronomers to advance climate literacy among students and the general public, and inspire them to take real and effective action. We also wish for astronomy as a profession to identify ways in which our practice can engage in sustainable practices that reduce our carbon footprint.

Web link:

Name: Asantha Cooray

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: This is the era of big astronomy, both from the ground and from space. This growth in astronomical research and research discoveries is also visible both in the number of PhDs conferred by universities and the number of postdoctoral fellows in the field. In the US, universities now confer around 200 PhDs per year in astronomy, a 100% growth in less than two decades from an average around 100 in mid 2000s. Astronomy departments in US universities that award PhD degrees enrolled close to 1250 graduate students. While these are numbers from astronomy departments, a similar growth in physics PhDs related to cosmology or related subjects also add to number of post-PhD junior scientists searching for postdoctoral employment in astrophysics in the US every year.The growth is also visible in the overall structure of large science collaborations. Close to 500 of the 1200 members of the Euclid Consortium are junior scientists, either graduate students or postdoctoral fellows that will be looking for permanent positions in the field in a few years. Unfortunately, the number of permanent scientific and academic positions has not kept up at the same rate. In the US, the average number of permanent positions advertised in the American Astronomical Society's Job Register over the last five years is at the level of 75 per year. This number is also consistent with the number of entries listed on the "astro rumor mill," an open-sourced website the astronomy community uses to gauge the academic job market. This significant disconnect between academic departments graduating more PhD students in astronomy and the number of available permanent academic positions in the field is concerning. What is the meaning of an astronomy PhD? One that has trained students and junior scientists for primarily an academic/research appointment or one that has trained students for new employment opportunities in the field? Should funding agencies such as NASA and NSF pay attention to this disparity between PhD growth and permanent positions and place certain requirements on grants and contracts so that the community is capable of addressing the broader problem? Is there space under NSF's broader impacts to make viable changes? This white paper is aimed at addressing issues related to academic employment, how the community should train PhD-level graduate students and its junior scientists, and why the Astro2020 Decadal survey may want to consider this overall issue and recommend some actionable items to funding agencies. The white paper will provide a list of recommendations, based on input received from the broader community, including former PhD students and postdocs in astronomy that have made successful transitions to jobs outside of the academia.

Web link:

Name: Bradley Peterson

Proposing Team: Ken Sembach (STScI), Scott Gaudi (Ohio State), Aki Roberge (NASA GSFC), John O'Meara (Keck Observatory)

Type of Activity:
State of the Profession Consideration

Description: The astronomy and astrophysics Decadal Surveys have assumed an increasingly central role in determining future directions for the field, in large part because the most ambitious programs and facilities are so costly that they cannot be undertaken without broad community support. As will be argued elsewhere, the major space astrophysics missions, while costly, provide a commensurate scientific and societal impact. As major missions become more capable and expensive, they also take longer to execute. Consider, for example, the highest-ranked space astrophysics projects from earlier Decadals: for Hubble, Chandra, and Spitzer, the time elapsed between recommendation by the Decadal and actual launch was 18, 17, and 12 years, respectively. JWST will easily break the record (19 years and running). In each case, varying levels of concept studies preceded submission to the Decadal. An important contributing factor to the high cost and long development times for the major missions is the immaturity of the observatory designs and many of the required technologies at the time the mission is recommended. JWST, most notably, had multiple immature technologies, including segmented beryllium mirrors, a multi-layer sunshield, and in-space deployment of the telescope and sunshield; development of these many technologies contributed significantly to escalating costs and schedule delays. NASA has attempted to address proactively the intertwined issues of cost, schedule, and technology maturity of major missions. In 2013, NASA Astrophysics commissioned a team to develop a 30-year vision for the future of space astrophysics that was ambitious and broadly based. The result of this study, "Enduring Quests, Daring Visions: A Thirty-Year Roadmap for NASA Astrophysics," identified three major intermediate-term missions: The Large Ultraviolet Optical Infrared Surveyor (LUVOIR), the X-Ray Surveyor (renamed Lynx), and the Far-Infrared Surveyor (renamed the Origins Space Telescope or OST). The Roadmap Team did not attempt to prioritize these future large missions, as that is the purview of the Decadal Committee. Beginning in Jan 2016, NASA commissioned Science and Technology Definition Teams (STDTs) to develop these three large mission concepts, along with a fourth drawn from the Astro2010 Decadal Survey, the Habitable Exoplanet Observatory (HabEx). The specific charge of the STDTs was to identify the science investigations that are likely to still be important at the end of the next decade and identify immature technologies that NASA needs to develop in order to carry out these ambitious science investigations. Each mission concept study is intended to serve as a "proof of concept" demonstrating compelling science and a feasible, if not yet realizable, observatory. As a result of the STDT studies, NASA and the Decadal Committee are being presented with four large mission concepts that are at a level of detail and rigor that is unprecedented for NASA missions at this stage of development. No large mission concepts presented to any prior Decadal Survey were as mature. Further careful evaluation of the Technology Readiness Levels (TRLs) was performed and detailed Technology Development Plans were prepared. NASA's goal is to raise all elements to higher TRLs and thus retire much of mission risk prior to Phase A. We make the following points: (1) NASA and the scientific community are looking to the Decadal Committee for bold scientific vision. An important component of that vision will be identifying the most compelling science that should be done with a large strategic mission like those of the STDT mission concept studies. Identification of a future large mission should be done by this Decadal in order to maintain NASA's balanced portfolio throughout the coming decade. (2)

The Decadal Committee should use mature large observatory concepts – one of the four mission concepts under study or another mission concept with similar maturity – as proof that a bold scientific vision is not only forward looking, but feasible with well-developed technology roadmaps and risk assessment. While implementation of a recommended mission will occur well after the Decadal Survey, the STDT concept studies serve as a credible demonstration that NASA, industry, and the astronomical community can provide realistic starting points for further concept maturation during implementation. The Decadal Committee would also be sending a strong message to NASA that such efforts are valued and that investments in early mission concept studies should be considered as input into future Decadal Surveys as well. NASA and the astrophysics community has begun establishing better practices for prioritizing and enabling large strategic missions, following the recommendations of several NAS studies. We urge the Astro2020 Decadal to ensure that these efforts are not in vain.

Web link:

Name: Karen O'Neil

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Beyond its impact to the astronomical sciences, Green Bank Observatory contributes in a unique and expansive manner to society. During the next decade, Green Bank Observatory's Education and Public Outreach programs will continue to leverage the technical village that is the Observatory (its staff and facilities) to create unique STEM learning experiences that combine the science, engineering, and coding work that is done here with real-world educational experiences for K-16 students and educators and professional scientists. Learning by doing is the philosophy behind all Observatory STEM programs. Additionally, the Observatory will continue to use internships, co-ops, and a fair and balanced approach for all staffing decisions to maximize the opportunities for diversity within the staff. Green Bank Observatory's strategic goals emphasize broadening participation in STEM by cultivating future generations of scientists and engineers, to maximize the scientific knowledge of current scientists and engineers, and to engage the public in dynamic programming that will instill a greater appreciation for the value of radio astronomy, scientific discovery, and STEM in general.

Web link: https://greenbankobservatory.org/education/

Name: Karen ONeil

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: NSF INCLUDES Alliance: Expanding the First2 STEM Success Network The NSF INCLUDES Alliance: Expanding the First2 STEM Success Network (First2 Network) aims to improve the persistence of first generation college STEM majors through their first two years of college. The success of the Alliance rests on three critical approaches. First, it improves student preparation for and transitioning to college. Second, it endeavors to replace ingrained institutional practices that stifle the development of STEM self-sufficiency. Undergraduate students are at the center of all activities—co-creators of solutions. Embedded in this idea is the FIRST Ambassadors program that guides undergraduate students to explore the disconnect between home life and STEM education, while reaching out to hometown students, their collegiate institutions and state legislators. Finally, the Alliance will advance our knowledge of barriers to success and solutions that increase the success of first-generation students in STEM.

Web link: https://first2network.org/

Name: Nicholas McConnell

Proposing Team: Co-authors will include Lisa Hunter (UCSC/ISEE), Scott Seagroves (College of St. Scholastica), Austin Barnes (UCSC/ISEE), and Rafael Palomino (UCSC/ISEE). Additional co-authors TBD.

Type of Activity:
State of the Profession Consideration

Description: In order to represent the demographics of society at large, the U.S. professional astronomy community must overcome entrenched structural features and professional norms that contribute to underrepresentation of women, racial and ethnic minorities, and other marginalized groups. As a complement to structural changes toward making astronomy more equitable, professionals at all levels should strive to align their individual practices with approaches that are shown by research to counteract pervasive biases and support the career development of both majority and underrepresented individuals. We will describe how effective professional development can support equitable and inclusive professional practices (e.g., leading teams, mentoring, teaching), and characteristics of professional development that can effectively transform practice in these areas. The same characteristics are relevant for professional development in a range of other activities (e.g., project management, data science). Successful adaptation of individual practice occurs when one implements new concepts or approaches and persists in using them over the long term. This is the outcome of effective professional development, and depends on the amount of time invested in training, opportunities for metacognition, grounding in disciplinary context, and implementation of new methods with coaching. We will recommend measures that departments and institutions can take to support individuals in gaining effective professional development, and in measuring its outcomes. We will recommend that national funding agencies support professional development initiatives informed by research and whose efficacy can be demonstrated, and that incorporate equity and inclusion as an essential aspect of professional skills.

Web link:

Name: Lisa Hunter

Proposing Team: TBD

Type of Activity:
State of the Profession Consideration

Description: Developing a diverse and inclusive workforce in astronomy Workforce development -- the preparation and advancement of a diverse and effective workforce -- in astronomy demands attention to a range of different career pathways, such as scientific users, telescope operations, and instrument builders. Currently, women, African Americans, Hispanics and Latinx, American Indians, Alaskan Natives, Native Hawaiians and other Pacific Islanders are underrepresented in all aspects of the telescope workforce. We will describe the importance of broadening participation to maximize the scientific return of telescopes and in becoming valued members of the local community where they are located. We will argue that broadening participation requires more than bringing more underrepresented groups into the field and requires reflection and change within the scientific and technical communities that currently make up the telescope workforce. There is a large body of knowledge about why people leave science and engineering during college, graduate education, and career positions, as well as well-documented biases and discrimination that can inform workforce development efforts. This paper will outline goals and measurable outcomes that the telescope community can use to guide the development of effective workforce development efforts, including short-term indicators of success. It will also differentiate outreach, education, and human resources, which can complement and partner with workforce development initiatives, but have different goals, strategies, and partners, and require very different expertise. The paper will recommend that: 1) dedicated resources, expertise, and leadership are needed for effective telescope workforce development; and 2) workforce development activities should begin during telescope construction.

Web link:

Name: Jason Hylan

Proposing Team: Co-signers will be included but the list is not yet final.

Type of Activity:
State of the Profession Consideration

Description: Managing Flagship Missions to Reduce Cost and Schedule NASA's flagship missions are incredibly complex systems in terms of their scope, capability, and development. It is, unfortunately, common for flagship missions to cost more and take longer to develop than predicted. These overruns make it more difficult for each subsequent flagship mission to win approval and gain traction. Flagship missions are a series of highly nested subsystems that pose unique problems when compared to more traditional instrument and spacecraft designs. They typically have an overall architecture that is very complex; they typically require a tremendous amount of technology development; they typically involve many contractors and subcontractors with many associated contracts; and they typically involve staff from all over the world. While many of the same management principles used on smaller instruments and spacecraft are relevant, managing flagship missions requires an evolution of those current best practices to better address the specific needs and nuances of these missions. Early architecture development and organization is critical to ensuring that technology is developed in a usable manner. Likewise, technology development must be done early enough to intelligently inform iterations on the architecture, all of which optimize the development of requirements and preliminary designs. Schedules must be optimized at the mission level, not at the level of each individual product. Funding must be at appropriate levels at appropriate times to enable efficient parallel paths to minimize late schedule risks. Items, such as mirror segments for large telescopes, that aren't the traditional "one-off" type of hardware must be viewed differently so that they can be mass produced and assembled in less time. An early and holistic approach to addressing the development of the mission from architecture development to design to planning for integration and test methodologies needs to be planned for upfront. This paper explores how lessons learned from previous flagship missions could be used to better manage flagship missions in the future.

Web link:

Name: Antonio Porras

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: I intend to submit a white paper that highlights the importance to bridge the gap of astronomy research opportunities between the United States citizens, DACA recipients, and Central American graduate students. Nature of the idea: Many countries in the Caribbean and Central America have struggled to keep a continuous unified collaboration that propels astronomy to move forward. Some countries lack solid programs in astrophysics at a graduate level (Levato 2007). Collaborations of Central American astronomers emerged in the 1990s up until the early 2000s when the Astronomical Observatory of Honduras was created with the purpose of fostering academic international relations between neighboring countries (Pineda Carias 2004). Through the involvement of Central American students to US research opportunities in astronomy, the collaborative relationships between these two regions may develop a wider range of research opportunities yielding access to students with diverse socioeconomic backgrounds. Goals: -To increase fellowship opportunities in national agencies in the graduate level for DACA and Central American students - To implement funding requirements that require recognition of intersectional challenges and obstacles historically marginalized students face in Central America and across the United States when considering students for graduate admissions Information about participating individuals: Antonio J. Porras: Costa Rican-American first-year graduate student in astrophysics at Vanderbilt University.

Web link: https://costarica-us-bridge.weebly.com/

Name: Gisella de Rosa

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: This white paper will describe a new initiative by the Women in Science Forum at Space Telescope Science Institute that offers new and uniform guidelines on binary gender representation goals for each scientific committee and recommendations on how to achieve them in an homogeneous way, as well as metrics and tools to track progress towards defined goals. By creating diverse committees and making them aware of, and trained on implicit bias, we expect to create a diverse outcome in the activities they generate, which in turn will advance science further and faster. These guidelines have been adopted by all of STScI's scientific committees and are in the process of being applied to all of STScI's committees.

Web link:

Name: Ivelina Momcheva

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Measuring and understanding long term trends in the astronomical workforce is crucial for driving policies and decisions that will shape the landscape for new researchers in the next decade. In particular, concerns have been raised about the growing number of astronomy PhDs, the lengthening of the postdoc phase, the number of available tenure-track positions and the scarcity of women and minorities in senior positions. These trends impact career expectations and satisfaction, recruiting, hiring, promotion and retention. While longitudinal demographic surveys of the astronomical workforce are scarce and not yet long-term, some valuable insights can be gained by studying publication records. In this white paper we will present the summary of an analysis of the publication histories of >10,000 US PhD recipients since 1970 as a function of numerous factors including gender, PhD-granting institution and the award of a fellowship. We will summarize the long term trends we see and make recommendations on policies that will be helpful in supporting the community in the next decade.

Web link:

Name: Julia Roman-Duval

Proposing Team: Laura Prichard, Cristina Oliveira, Antonella Nota

Type of Activity:
State of the Profession Consideration

Description: We will present the results of a survey of the factors limiting conference attendance, and what practices could help achieve better diversity in astronomical conference attendance.

Web link:

Name: Thomas Greene

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: The Astronomy profession profits from the hard efforts of many mostly young people who will not continue to work in our field. Universities, established Astronomy professionals and their societies need to do better at supporting students and postdocs who do not continue in our field. This includes informing them of alternative career paths and helping prepare them for their transitions.

Web link:

Name: Will Armentrout

Proposing Team: Green Bank Observatory

Type of Activity:
State of the Profession Consideration

Description: The Role of Observatories in Professional Astronomy Training It is important to support strong professional training programs at observatories if we are to continue to build ever-greater generations of telescopes and maintain a competitive edge in astronomy worldwide. As astronomers move from being wavelength experts to being phenomenological experts, their in-depth understanding of astronomical instrumentation and the inherent limitations of those instruments is also waning. As a result, the expertise needed to accurately understand astronomical data and its restrictions is also in decline. We will submit a white paper focusing on: 1) Telescope training: Programs like the Green Bank Observatory's Single Dish Workshop and National Radio Astronomy Observatory's mobile training sessions for the VLA and ALMA can serve as a model for other observatories. Whether on site or at a remote training facility, these types of telescope training programs are crucial for ensuring our national suite of telescopes are used to their potential by a wide-variety of astronomers. 2) Professional advancement: Internships for undergraduate and graduate students at observatories serve as a bridge into observational astronomy and instrumentation. Professional astronomers working at primarily undergraduate-serving institutions can stay engaged in current research through continuing education programs. 3) Flexible instrument and software experimentation: The largest astronomical observatories have necessarily rigid operations. Nevertheless, we must retain the ability to deploy experimental student or university-led instruments and software. This empowers students and professionals to understand the full path of a photon as it travels from an astronomical source to a spectra or image in a FITS file. This ensures that flaws in routines or data and the limits of instrumentation are well understood. It also creates a pool of experts that will create the next data reduction routines and data products. Our white paper will focus on successful programs that address all these needs, and how they can be scaled-up and applied throughout the field.

Web link:

Name: Alessandra Aloisi

Proposing Team: TBD

Type of Activity:
State of the Profession Consideration

Description: Unconscious Bias in the Astronomical Profession: Universal Recommendations to improve Fairness, Inclusiveness, and Representation (Un)conscious bias affects every aspect of the astronomical profession, from the most scientific activities (such as invitations into collaborations, proposal selection, grants allocation, paper review process, and invitations to attend and speak at conferences) to activities more strictly related to career progression (i.e, reference letters, fellowships, hiring, promotions, and tenure). Unconscious bias is still the main hurdle to achieve excellence, as the most diverse talents do encounter bigger challenges and difficulties to reach the same milestones than their more privileged colleagues. Over the past few years, STScI has designed a set of guidelines and measurable goals to increase diversity representation in our scientific activities. We have constructed methods and tools to specifically raise awareness of (un)conscious bias in everyday scientific activities including career-related matters and STScI sponsored fellowships, conferences, workshops, and colloquia. STScI has also addressed the issue of unconscious bias in its peer reviews processes by anonymizing the submission and evaluation of Hubble Space Telescope (and soon to be James Webb Space Telescope) observing proposals. In this white paper we will present our plan to standardize these methods with the expectation that these universal recommendations will truly increase diversity and inclusion in Astronomy if applied consistently throughout all the scientific activities of the astronomical community.

Web link:

Name: Nicole Cabrera Salazar

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Despite many years of diversity programming, the field of astronomy has seen little increase in the participation and retention of people of color. Research has shown that the high attrition rate of people of color in science can be attributed to a chilly workplace climate, where feelings of isolation and a sense of not belonging are prevalent. In this paper we will discuss the importance in shifting focus from diversity to integration and provide examples of effective programming.

Web link:

Name: Brian O'Shea

Proposing Team: TBD

Type of Activity:
State of the Profession Consideration

Description: Approximate title: Training astrophysics students for a broad spectrum of careers
Description: The vast majority of students who pursue degrees in astronomy and astrophysics do not pursue academic careers -- according to the American Institute of Physics Statstical Research Center, they end up in a huge variety of careers, including engineering, computer hardware and software development, business and finance, K-12 teaching, and industrial research and development. While an astronomy or astrophysics degree is excellent training in many ways, the job market changes much more rapidly than college and university curricula. In this white paper, we examine the misalignment between the undergraduate and graduate astrophysics curricula at typical universities and the needs of employers, and propose ways in which these curricula can be modified to better prepare students for the full spectrum of possible careers.

Web link:

Name: Aparna Venkatesan

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Collaboration with Integrity: Indigenous Knowledge in 21st Century Astronomy As the professional astronomy community endeavors to be more equitable and inclusive, it is becoming increasingly evident that there is an interconnection between astronomical scientific and educational activities and Indigenous Knowledge (IK). From the historical understanding of the cosmos and unique perspectives of time and space originally perceived by Indigenous peoples, to conflicts over the expansion of telescope facilities on sacred tribal or Indigenous lands, it has become more important than ever to respect, dialog, and partner with Indigenous people and communities in our scientific endeavors. The richness of astronomical traditions from various Indigenous cultures can be juxtaposed with western astronomy in a way that enhances science education and research while honoring the integrity and authenticity of Indigenous perspectives. Traditional IK concepts of "Space and Place", and IK values of collaboration with integrity (e.g., Cosmic Serpent), deep listening, and sustainability, are relevant for both improved communication of astronomical research with the broader community and better understanding of community tensions over proposed astronomical facilities. We share specific initiatives pioneered by the Indigenous Education Institute, the 'Imiloa Astronomy Center in Hawai'i, and I-Wise (Indigenous Worldviews in Informal Science Education) that demonstrate successful examples of co-creating scientific discoveries through understanding and embracing the deep historical, cultural and traditional language base of Indigenous science. These initiatives' highly successful outcomes demonstrate how the future vitality and capability of the astronomy and astrophysics work force can be greatly strengthened by honoring IK, while helping to create a scientific enterprise that is more sustainable and inclusive. Such efforts have created a successful model of collaboration with integrity between western and Indigenous perspectives that deserves serious consideration for sustained funding at local and institutional levels.

Web link:

Name: Federica Bianco

Proposing Team: LSST Science Collaborations

Type of Activity:
State of the Profession Consideration

Description: The Large Synoptic Survey Telescope (LSST) project includes the construction of a telescope and instrumentation and a 10-year survey of the southern hemisphere sky. The survey is expected to begin in 2023. LSST, with its transformational potential in nearly all astrophysics domains, from Solar System asteroids to the origin of the Universe itself, was identified as the US flagship ground-based astronomical project in the 2010 Decadal Survey. LSST construction costs and most of the operation costs are supported by NSF and the DOE. The LSST data will be public to all US scientists, and while the LSST project will generate a revolutionary dataset, the responsibility, pleasure, and burden of turning it into science falls onto the scientific community. However, as of now there is minimal support for scientific activities in preparation for LSST in the US. Without this, the scientific productivity of the survey will be compromised. The science activities surrounding LSST happen primarily in the LSST Science Collaborations (SCs): teams (8 presently), originally formed by the LSST Project in 2008 to provide a forum to engage the community in interacting with the LSST Project, and make the scientific case that was presented to the 2010 decadal survey. The SCs are now formally independent of the LSST Project and gather over 1000 scientists from 6 continents, roughly half of them in the US. The SCs are a unique, diverse, geographically distributed network of scientists collaboratively addressing questions ranging from fundamental physics to data science. They are immensely valuable to the LSST Project, providing scientific expertise that guides the survey design, including construction of the data processing pipeline and insight that guides advocacy for the survey, educating other scientists and the public about the promise of LSST. They have done so for a decade, operating largely on a volunteer, non-compensated basis. The co-authors of this NOI represent the LSST SCs. This unusual mode of operation, where the science preparation for such an important and complex survey is not actively funded, causes significant vulnerabilities. The order-of-magnitude increase in data volume and huge discovery space in the time domain require major preparatory efforts to simulate LSST data, to develop and validate analysis methods, and to create data analysis pipelines. These activities, at the level of both science collaboration infrastructure and individual R&D efforts, need a robust funding mechanism before the survey starts in 2023. Given that LSST data volumes are not amenable to off-the-shelf analysis techniques, the scientific success of the project also requires robust investigator grants programs during the next two decades. Without support in these forms, the US investment in the construction and operation of LSST cannot offer the expected - and deserved - rate of scientific return. We advocate that the funding agencies provide a solid framework to fund LSST preparatory science and commit to continue to support investigators' research through the course of the survey.

Web link:

Name:

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: According to recent research, the participation and retention rates of marginalized people in astronomy, including but not limited to people of color, gender and sexual minorities, and people with disabilities, can be mitigated by the creation of spaces that counter negative interactions with the dominant group. Counterspaces create important opportunities for marginalized people to combat isolation, foster community along shared experiences, and develop a science identity. In this paper, we will review the research on counterspaces and discuss the importance of their creation and support in astronomy programs across the US.

Web link:

Name: Laura Trouille

Proposing Team: Citizen Science Platforms in Astronomy

Type of Activity:
State of the Profession Consideration

Description: Through this white paper, we seek to highlight the unique and transformative role that citizen science plays within the astronomy and astrophysics community's education and outreach efforts. From learning impacts in formal and informal education settings to changing attitudes towards science and scientists to creating pathways for under-represented minorities into STEM, citizen science has proven to be a unique and effective tool. This white paper will be written collaboratively by leads of several citizen science platforms, including Laura Trouille, Lucy Fortson, and Chris Lintott (Zooniverse), Marc Kuchner (NASA Citizen Science advisor and lead for Zooniverse Disk Detective and Backyard Worlds), Elizabeth MacDonald (Aurorasaurus), and John Keller (RECON). What is now called citizen science - the involvement of the general public in research - has a long history. An early example is Edmund Halley's study of timings during the 1715 total solar eclipse, which included observations from a distributed, self-organized group of observers. In recent decades, citizen science has gained renewed prominence, boosted in part by technological advances and digital tools which have enabled new modes of public engagement in research and facilitated research projects that investigate questions from data at scales beyond the professional research community's resource capacity. As the field of citizen science matures, there are a growing number of quality opportunities for the public to engage in. CitizenScience.gov lists over 400 in-person and online citizen science opportunities. We will present a series of case studies showcasing the different modes for engaging the public in real research, the numbers and demographics of participants, and the tremendous impact both on the research as well as on learning, attitudes, and career trajectories. We will also present a series of case studies of the use of astronomy-based citizen science in formal classroom settings at the K-12 and undergraduate levels. Citizen science in classroom settings provides unique opportunities to engage students in the process of scientific discovery while making real and valued scientific contributions and is well aligned with research-supported educational practices. This white paper is not meant to provide an exhaustive list of existing efforts; rather, we will focus on a few specific citizen science approaches and platforms and highlight the impacts, lessons learned, and opportunities. In addition to presenting case studies, we will highlight research findings documenting the transformative impact of citizen science, including highlighting the major contributions to astronomy research results and discoveries, increased representation of women and minorities in the scientific process, changing attitudes towards science and scientists, increases in confidence, scientific literacy, and domain knowledge, increased research interests, and creating new pathways into the STEM workforce pipeline. A key theme throughout will be to emphasize that these positive impacts are made possible because these citizen science platforms provide students and the general public the opportunity to contribute in meaningful and valued ways to real research, have a low barrier to entry and a high threshold of possibility (e.g., from data collection to co-authoring research articles), etc. Through the lessons learned across our citizen science platforms and a review of the literature, we will provide an overview of the challenges, promise, and future opportunities for citizen science within astronomy and astrophysics.

Web link:

Name: Jennifer Bartlett

Proposing Team: American Astronomical Society's Working Group on the Preservation of Astronomical Heritage

Type of Activity:
State of the Profession Consideration

Description: Throughout the ages, astronomy has extensive and well-documented legacy that can best be described as "new tools, new universes." Whenever we have enhanced our tools of perception, from the eye, to the telescope, and then adding photography, spectroscopy, and electronic and digital technologies to the telescope, our understanding of what the universe is has changed in revolutionary ways. Preserving these tools is essential to appreciating how our concept of what the universe is, and where we are in it, has changed. While records of earlier observations have potential to support future scientific research, some items are primarily of historical interest, but they provide critical perspective on what works and what has been superseded. Today's professionals have a responsibility to their predecessors and their successors to conserve this legacy and ensure that it remains available to future scientists and historians of science. Thus, the preservation and utilization of these materials should be an integral part of the strategic plan for American astronomy in the coming decade. Preserving the tools, as well as records of how they were used, is essential to understanding how we have come to know what we know in astronomy, how astronomy relates to other sciences, and how the culture of astronomy has evolved. These materials include the papers, letters, diaries, memos and notebooks of astronomers and the institutions in which they worked as well as the physical artifacts, such as instruments, that they used to accomplish their research. Just as critical is to preserve the records of observatories and other institutions devoted to astronomy that are the expression of community priorities and how those priorities changed over time. As a natural science, astronomy preserves a record of natural changes on the cosmic level. Of vital interest is the preservation of observations that capture otherwise inaccessible earlier epochs, which includes maintaining their legibility. Such scientific data may be recorded in astronomical photographs, technical drawings, observers' notebooks, and other working papers. These documents must be digitized in order to be exploited by modern scientific techniques; however, digitization does not eliminate the need to retain the original. In addition, astronomical observations that were initially recorded digitally are themselves at risk of becoming unreadable as technology changes. In some cases, a legacy resource may have competing historic and scientific value. An astronomer's journal may provide evidence of the techniques used and the development theories proposed as well as contain unpublished measurements. Alternatively, annotations on a photographic plate show how it was used in the past but may obscure a field of current interest. In the case of the journal, digitization and transcription make the information available to both historians and scientists. In the case of the photographic plate, preserving the annotations interferes with digitizing the underlying image for use in a new generation of astronomical research. For an instrument or a site in use for decades, the modernization necessary to its continuing viability for research may damage or eliminate its historic character. In the past decade, awareness of our multifaceted astronomical heritage has been growing. In addition, the data science techniques developed to support large surveys also provide opportunities to mine older observational archives in ways their creators could not have foreseen. Therefore, the time is ripe to assess the overall condition of our astronomical heritage, its value from both historical and scientific viewpoints, the infrastructure available to conserve it, and the funds required to maintain it; to prioritize activities to preserve the resources that are at greatest risk; and, to develop recommendations for handling emerging situations. In doing so, we continue our traditions of exploring of our universe, our perceptions of it, and our place within it.

Web link:

Name: Denise Smith

Proposing Team: Co-Signers will include: Gordon Squires, Kathleen Lestition, Lynn Cominsky, Anya Biferno

Type of Activity:
State of the Profession Consideration

Description: This whitepaper will describe a model for enabling science learning that is based upon a partnership between multiple institutions with a direct connection to the scientists and the science associated with space-based missions and data archives spanning the full range of modern astrophysics.

Web link:

Name: Alexander Rudolph

Proposing Team: AAS Task Force on Diversity and Inclusion in Astronomy Graduate Education

Type of Activity:
State of the Profession Consideration

Description: At the January 2017 AAS meeting in Texas, the AAS Council (now the AAS Board of Trustees) approved the creation of a Task Force on Diversity and Inclusion in Graduate Astronomy Education. The Task Force held its first meeting in November 2017. At that first meeting, the Task Force members, to facilitate the work of the Task Force, approved the creation of three working groups. Each working group was co-chaired by two Task Force members who recruited additional members from the community. These working groups took primary responsibility for soliciting input from the community around their topic and developing the recommendations contained in this report. In addition, presentations were made to the four AAS Diversity committees (CSWA, CSMA, SGMA, and WGAD) by the Task Force liaisons from each committee to directly solicit their input and feedback. The committees were also given a chance to review this report in draft form to comment. All recommendations were discussed and approved by the entire Task Force. Details of each recommendation, and the justification behind it, including references from social science research supporting the recommendation, are found in the main report. Evidence-based resources and tools that will help in the implementation of the recommendations are included in the Appendices. Appendix II of the report contains details of the Task Force creation and timeline of activities. The report of the Task Force will be modified into a white paper on diversity and inclusion in astronomy graduate education. In addition to sharing the task force recommendations to department and the AAS with the Astro2020 community, the white paper will have additional recommendations to funding agencies. The goal will be to provide a roadmap to the community to enhance diversity and inclusion in the field of astronomy, and to provide actionable, fundable recommendations to the funding agencies to support this work.

Web link: https://aas.org/education/aas-task-force-diversity-and-inclusion-graduate-astronomy-education

Name: Scott Gaudi

Proposing Team: N/A

Type of Activity:
State of the Profession Consideration

Description: Rethinking the Decadal Surveys The astrophysics decadal surveys have largely served us admirably, and we recognize their incredible strategic importance in moving our field forward. However, we argue that due to the changing landscape of our field along many different fronts, including the importance of ever more capable strategic missions and facilities, is it time that we reconsider the scope, impact, and longevity of these surveys. Traditionally, the Decadal Surveys have been considered self-contained (within a decade), and as such not far reaching, nor containing a long-term vision for the field. We argue that we have reached a point in our field where this model is no longer completely sufficient. Focusing on NASA in particular, the large strategic missions prioritized in the decadal surveys cannot be contained within ten-year timespans, and indeed many never have been. The most compelling large strategic missions being considered today will take more than a decade to develop and launch, and we should account for this fact in crafting the optimal strategy for the future of US astrophysics. Along the same lines, missions that were previously prioritized should not be re-competed every ten years. While it is important that we reassess our priorities on a regular basis, we should also be cognizant of the fact that our field moves at a pace that is not necessarily aligned with arbitrary divisions of time. There are compelling arguments that the optimal strategy for NASA astrophysics is a balanced portfolio that includes both large strategic missions and smaller competed missions. Large strategic missions will inevitably lead to giant scientific leaps forward that will shift long-held beliefs and paradigms, but will also require over ten years to develop and launch. At the same time, a dedicated line of smaller missions that are not prescribed, but are rather competed, is needed to react nimbly to new developments. Furthermore, in practical terms, the cancellation of large strategic missions (either because they are not re-prioritized or are cancelled for other reasons) will undermine the legitimacy of the decadal surveys, make it difficult-to-impossible to craft viable (let alone optimal) fiscal and technological development schedules for these missions, and jeopardize the goal of a balanced portfolio. Such cancellations establish a dangerous precedent, whereby the priorities of the previous decadal surveys can be negated with relative ease, thereby undermining their very purpose. They also erode the ability of NASA to collaborate with foreign partners on these missions. Such partnerships are becoming increasingly important as large missions become ever more capable, but also grow in cost and scope. Finally, in order to maintain a balanced portfolio, we should plan well ahead to facilitate the smooth transition between the launch of one large mission and the development of the next. Such transitions require a carefully-planned continuity of early mission studies and technology development, as well as maintenance of the funding required to perform these preparatory activities. Therefore, it is important that advanced mission concepts be planned and studied well in advance and so are "waiting in the wings" to be the next large strategic mission. In this way, we ensure a future with paradigm-shifting missions like the Hubble Space Telescope, the James Webb Space Telescope, and the Wide Field Infrared Survey Telescope; missions that are not only essential for maintaining US preeminence in space-based astronomy, but also for maintaining NASA as household brand. Perhaps more importantly, NASA's Great Observatories are a source of continual inspiration to the public, act to increase the public's scientific literacy, help to attract the next generation of scientists who are increasingly drawn from traditionally underrepresented groups, and ultimately serve to enrich our society.

Web link:

Name: Adam Burgasser

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: What to do About the GRE? The Challenges and Outcomes for Elimination, Optionalization, and Implementing True Holistic Review The General Record Exam (GRE) and Physics Subject GRE (PGRE) are standard admission diagnostics for the majority of Physics and Astronomy graduate programs. Several decades of research have shown that GRE and PGRE scores are weakly correlated with a few academic metrics, such as first semester grades, qualifying exams, and some faculty evaluations. However, they have shown little to no correlation with PhD completion, time to completion, publications, and other research metrics. On the other hand, many studies–including those conducted by the GRE's publisher ETS–have found that traditionally underrepresented groups (and US citizens) consistently score lower on these exams, exacerbating existing inequities in the field. Reduced performance on the GRE can be attributed to many issues unrelated to graduate potential which are preferentially experienced by underrepresented groups, such as stereotype threat, imposter syndrome, limited curriculum at small institutions, limited access to test preparation, and the high cost of retaking an exam. With at least 25% - and perhaps up to 40% - of Physics and Astronomy triaging graduate applicants below a threshold score (which ETS explicitly recommends against), the GRE has become a more effective tool to suppress diversity than to measure promise for graduate study. In January 2016, the American Astronomical Society endorsed a resolution encouraging Astronomy graduate programs to limit the use of GRE scores in admissions, stating: "Given the research indicating that the GRE and PGRE are poor predictors of graduate student success, that their use in graduate admissions has a particularly negative impact on underrepresented groups, and that they represent a financial burden for many students in pursuing advanced degrees in the astronomical sciences, the AAS recommends that graduate programs eliminate or make optional the GRE and PGRE as metrics of evaluation for graduate applicants." Partly in response to this call, roughly 45% of graduate degree programs in Astronomy (including some Physics and Planetary Science departments and joint programs) have now either eliminated the PGRE as a requirement or have made reporting of the exam score optional; a smaller fraction of programs have also reduced use of the GRE in admissions. As programs transition to this format, they are finding increased application rates and more diverse applicant pools, as well as a greater admissions burden and occasional backlash to the elimination of numerical metrics. In this white paper, we will survey the state of the use of the PGRE and GRE in Astronomy graduate programs, and report from programs that have reduced their use the implementation strategies, challenges and outcomes of their efforts. From these inputs and the contemporary literature, we provide recommendations on how to approach the use of the GRE in admissions requirements, spanning the spectrum from elimination to integration into a truly holistic evaluation process.

Web link: https://aas.org/governance/society-resolutions#GRE

Name: Adam Burgasser

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Implementing and Advancing the Nashville Recommendations In June 2015, 160 astronomers, sociologists, policy makers and community leaders convened the first Inclusive Astronomy meeting at Vanderbilt University in Nashville, TN. In our field, this represented the first meeting with the express goal of discussing issues that negatively affect people along multiple axes of underrepresented identities. One of the outcomes of this meeting was an extensive set of recommendations aimed at changing the practices, policies, cultures and environments at a variety of institutions to remove the barriers against and improve the climate for historically underrepresented groups in Astronomy. The recommendations are organized under four primary categories: removing barriers to access; creating inclusive climates; improving inclusion and access to power, policy, and leadership; and establishing a community of inclusive practice. They are also broken down by the institutions for which they are most suited and the timescales for implementation. The Nashville Recommendations have made an impact, through both specific initiatives (e.g., removing or making optional the GRE from admissions criteria, informing the AAS Task Force on Diversity and Inclusion in Graduate Education, the establishment of a new inclusive Site Visit Program) and as inspirations for other scientific communities. In 2016, the American Astronomical Society endorsed the Vision Statement for the Recommendations, and compiled the Recommendations in 2017 on a wiki to serve as a living, working archive. The intention of this portal was to help groups develop their own plans to improve equity and inclusion at their specific institution, while providing a forum to share strategies for and barriers to implementation, short- and long-term outcomes, and the development of best practices. Despite the clear utility and immediate need for it, few have utilized this portal, and it is unclear to what degree the Nashville Recommendations are effectively reaching the community. In this white paper, we will discuss how to move forward with the Nashville Recommendations in terms of increasing community participation and implementation, while building on the Recommendations to achieve sustainable, long-term outcomes.

Web link: https://tiki.aas.org/tiki-index.php?page=Inclusive_Astronomy_The_Nashville_Recommendations

Name: Kevin Stevenson

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: One of the primary goals of the astrobiology community in particular, and the broader astrophysical and planetary science communities in general, is the detection of biosignatures on habitable worlds. Habitability is typically defined as the ability of a planet to sustain liquid water on its surface. The detection of specific combinations of molecules would provide evidence of biosignatures, which suggests biological interactions between atmospheric and surface processes. In the near-term, JWST transmission spectroscopy observations of rocky planets orbiting M dwarfs will be our best opportunity to search for biosignatures. However, JWST's instruments were not designed for the high-precisions (< 10 ppm) needed to detect biosignatures and it is unclear how well they will perform. One way of estimating the detector performance prior to the successful launch and deployment of JWST is through current space-based facilities such as Hubble and Spitzer. JWST's near-IR detectors share a similar heritage to Hubble's WFC3/IR detector. Similarly, JWST's mid-IR detector is functionally similar to Spitzer's IRAC 5.8 and 8.0 micron detectors. The goal of this activity is to quantitatively assess the noise floors of the WFC3/IR and IRAC instruments using publicly-available time-series data. This will yield a first-order estimate of how well JWST is expected to perform under similar conditions and how successful it will likely be in its search for biosignatures.

Web link:

Name: Kim Coble

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: The importance of supporting astronomy education research, curriculum development and dissemination, and professional development for teaching astronomy

Web link:

Name: Robert Hurt

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: The astronomy visualization (astroviz) community comprises a cross section of scientists, developers, and artists who collectively create the imagery that deeply influences the public (and scientific) perception of the profession. The scope of the field covers visual presentations of data (imaging, tabular, simulation) as well as diagrammatic and artistic representations of astrophysical concepts. Much of the community is centered around a broad cross-section of public communications and outreach (formal and informal) but fully encompasses professional research communications as well. Interests range from graphical support for press releases and outreach materials, research publications, video and multimedia presentations, and immersive experiences (planetariums, VR). The goal of this white paper would be to establish the scope and significance of this community to the astronomy field, and to identify key needs and support to maximize its impact in the coming decade. Benefits to enhancing the cohesion of this group as an established community of practice include: - Increased potential for collaboration - Opportunities for professional development for practitioners and the extended astronomical research community - Access to shared community tools and techniques - Improved opportunities for sharing assets within and beyond the visualization community - Elevation of the overall quality of scientific visualizations through collaborations and mentorships Needs for integrating this group as a more effective community of practice include: - Improved visibility of astroviz practitioners and products within the astrophysics community - Increase opportunities for communication within the astroviz community - Periodic visualization-oriented conferences to provide face-to-face meeting and collaboration opportunities - Coordination with established science conferences to offer visualization-related threads (e.g. AAS workshops, sessions) Contributors to this white paper will include: Kim Arcand (Chandra X-ray Center/Harvard-Smithsonian Center for Astrophysics) Robert Hurt (Caltech/IPAC) Janice Lee (Caltech/IPAC) Lars Lindberg Christensen (European Southern Observatory) David Delgado (NASA/Jet Propulsion Lab) Brandon Lawton (Space Telescope Science Institute) Timothy Rhue (Space Telescope Science Institute) Gordon Squires (Caltech/IPAC) Mark Subbarao (Adler Planetarium) Frank Summers (Space Telescope Science Institute) Ryan Wyatt (California Academy of Sciences)

Web link:

Name: Shane Larson

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Modern astronomy increasingly features large, global teams with expertise from many fields and disciplines. Students and early career scientists who are working in large scientific collaborations acquire equally diverse capabilities as a result of being immersed in these collaborative inter-disciplinary environments. The stark contrast between the number of graduate students and postdocs in astronomy and the total number of faculty positions in astronomy available in a given year points to a basic tenet of our field: many of the junior scientists we train are not going to become academics. Students who attempt to make the transition from academia into other fields, by choice or design, often find themselves adrift without adequate guidance or sage advice. One of the primary reasons is that academic faculty are seldom well-versed in what the transition from the academy to the industrial workforce looks like, what skills and aspects of scientific training are the most marketable, or what kinds of broad opportunities may exist for people with advanced degrees in physics and astronomy. This whitepaper will examine a series of straw proposals for a long term investments in faculty development, focusing on improving mentorship, improving awareness of the universality of an "astronomy skillset", and building connections between academic astronomers and the external marketplace through university and industrial partnerships that already exist as part of the astronomy enterprise.

Web link:

Name: Gordon Squires

Proposing Team: Gordon Squires (Caltech/IPAC), Janesse Brewer (23.4 Degrees), Sandra Dawson (TMT) and the organizing committee of the "Making the Case" workshop

Type of Activity:
State of the Profession Consideration

Description: Making the Case: Principles for Workforce, Education, Public Outreach and Communications (WEPOC) Although there is a general sense and agreement that large science projects and facilities should engage in workforce, education, public outreach and communications (WEPOC), there are remarkably few concrete guidelines as to what this means in practice. Within projects funded by the NSF or NASA, the landscape and expectations of WEPOC programming has frequently shifted and the value of this work has alternately been deemed essential at one end of the spectrum, or deemed superfluous at the other. It is noteworthy and that while many of these projects engage WEPOC specialists as part of their team, their experience, access to leadership, specific roles and functions can be quite different. Each of these skilled professionals is finding solutions to project-specific problems, however they would benefit from a forum to share leadership-level lessons learned and create practical roadmaps for future large science projects. In an April 2017 workshop at Caltech, WEPOC leaders from high energy physics and astronomy projects from around the world participated in a candid forum for considering fundamental questions regarding WEPOC for large science projects: • What is the value of WEPOC to the projects and their communities? • How, when and where should WEPOC be defined, developed and implemented? • What are the barriers and challenges in developing strategic plans and programs? • How do you make the case of the value of WEPOC to the leadership in these projects? In this whitepaper will we summarize the outcomes of this ongoing work, including an evidence-based set of rationales that establish the critical nature of WEPOC in science projects. A further outcome will be framed within a set of eight principles and practices for future world-class science projects to implement: ♣ A phased WEPOC plan should be initiated in the conceptual stage, adequately resourced, and be aligned with the project. ♣The project has a responsibility to consider the WEPOC requirements of its partners and the wider community. ♣ WEPOC enables the project to fulfill an obligation to be respectful, responsive and an integral part of the site community. ♣ WEPOC leaders should be integrated into the leadership structure with access to the decision-making bodies. ♣ WEPOC staff should hold relevant professional WEPOC qualifications and/or experience and undertake continuous professional development. ♣ Holding to a similar standard as the other elements of the science project, WEPOC programs should be reviewed by peers. ♣ WEPOC should include evaluations appropriate to the individual WEPOC activities. ♣ Successful WEPOC activities are inclusive and promote diversity. Additional leaders in astronomy and high-energy physics have been invited to endorse these maxims based on their own experience of how science projects most effectively advance their WEPOC goals, and we hope that this will be adopted as cornerstone principles for WEPOC in the decade ahead.

Web link: https://conference.ipac.caltech.edu/wepoc2017

Name: Alicia Aarnio

Proposing Team: AAS Working Group for Accessibility & Disability

Type of Activity:
State of the Profession Consideration

Description: Accessible Astronomy: Policies, Practices, and Strategies to Increase Participation of Astronomers with Disabilities In 2015, the Inclusive Astronomy conference was held to bring attention to the barriers to success, lack of access, and unsupportive climate encountered by astronomers from minoritized identities. One outcome of this meeting was the establishment of an accessibility/disability advocacy group within professional astronomy. The Working Group on Accessibility and Disability (WGAD) was organized by a coalition of disabled astronomers and allies and is supported by the American Astronomical Society (AAS). The WGAD has since focused on AAS-level initiatives to increase the accessibility of publications, databases, and professional meetings. There is an urgent need to expand these accessibility efforts beyond the professional society and into the wider astronomical community. Our ultimate goals are the removal of physical, technological, and pedagogical barriers to access, and provision of greater support for the career progress and retention of disabled astronomers. In the decades since the creation of the Americans with Disabilities Act (ADA), it has become clear that individual academic departments and research institutions will only undertake the necessary cultural and infrastructure changes if motivated by clear guidelines from funding organizations. In this white paper, we outline the major barriers to access within the educational and professional practice of astronomy. We present the current best practices for inclusivity and accessibility. These include classroom practices, institutional culture, support for infrastructure creation, hiring processes, and outreach initiatives. We present specific ways--beyond simple compliance with the ADA--that funding agencies, individual astronomers, and institutions can work together to make astronomy as a field more accessible, inclusive, and equitable.

Web link:

Name: Daniel Wolf Savin

Proposing Team: 2018-2019 Executive Committee Members of the Laboratory Astrophysics Division of the American Astronomical Society: Randall Smith, Phillip C. Stancil, Farid Salama, Roberto Mancini, Daniel Wolf Savin, Crystal Brogan, Michael C. McCarthy, Stefanie N. Milam, Kenneth M. Nollett, John C. Raymond, Ella M. Sciamma-O'Brien, Artemis Spyrou

Type of Activity:
State of the Profession Consideration

Description: Laboratory astrophysics is the Rosetta stone that helps us to unlock the mysteries of the Cosmos. The next decade of astronomical exploration will require significant laboratory astrophysics advances into our understanding of the underlying processes that drives much of the Universe. Major astrophysical advances will come from these studies, but no academic department has taken intellectual ownership for the laboratory astrophysics field. Maximizing the scientific return from the next decade of astronomical exploration will require a rejuvenation of laboratory astrophysics faculty and a corresponding restoration of funding from NASA, NSF, and DOE for such studies.

Web link:

Name: Patrick McCarthy

Proposing Team: Taft Armandroff, Christoph Dumas, Robert Goodrich, Buell Jannuzi

Type of Activity:
State of the Profession Consideration

Description: A large fraction of the spending in astronomy, at the NSF and private institutions, is allocated to the operation of observational facilities. As new and larger facilities are developed, decisions will need to be made regarding operations budgets and the impact of operations on life-cycle costs and the health of annual operations and research budgets. A group of scientists involved in the operations of current facilities and the planning for operations for future ground-based observatories intend to submit an APC White Paper that examines operating costs and the scaling of operation costs with aperture, complexity, and capital cost. This White Paper is not an activity or a project, so we intend to submit this as a "state of the profession" white paper. Federal spending on facility operations must be balanced against funding for research. Our community will be engaged in conversations around these issues as part of the decadal survey and in the years that follow. The intention of the group writing this White Paper is to provide data and analysis that will inform the discussion.

Web link:

Name: Gordon Squires

Proposing Team: Gordon Squires (Caltech/IPAC), Janesse Brewer (23.4 Degrees), Sandra Dawson (TMT) , Lisa Hunter (UCSC),

Type of Activity:
State of the Profession Consideration

Description: Models for Inclusiveness, Diversity, Workforce, Education, Public Outreach and Communications in Large International Science Projects and Facilities Large international science projects come with large international challenges. In this white paper we will advocate for a process to develop strategic inclusion, diversity, workforce, education, public outreach and communication plans and programs for these projects. While many large astronomy projects of the past were approached on national levels, science projects of the future are more and more requiring intellectual and financial contributions from multiple countries. This is true in both ground- and space-based astronomy facilities. These projects are highly collaborative and involve scientific and engineering talent from multiple institutes and countries to build and operate. Additionally, these projects come with resource requirements that require countries and institutions to pool their funding and their resources, instead of attempting these large projects individually. Furthermore, each of these projects stands to advance our collective understanding of our world, and our universe, in significant ways. Inviting stakeholders and the public to share in the journey and the findings is also part of these efforts for a number of reasons, including the risk that a lack of public support could result in de-funding or under-funding of these science projects. The complexity of this work cannot be overestimated. The science projects are international with multiple teams, time zones, languages, budget cycles, cultural and public perspectives on science, governance structures, and project management styles. These, and a host of other issues, creates a number of challenges even outside the complex scientific and engineering questions. In addition, the public demand for knowledge and information about this work drives the need to include teams of specifically trained and dedicated staff in the areas of Diversity and Inclusion (DI), Workforce development, Education, Public Outreach, and Communication (WEPOC) strategic planning and programming. Furthermore, the environment in which international science projects are being developed has changed and thus elevates or exposes certain challenges: Specifically, the white paper will provide a recommended framework to address issues such as: • Models for education and public communications/outreach in large-scale (international) research infrastructure projects • Local community involvement / social benefits / collateral benefits programs • Large-scale international research infrastructure & international diplomacy • Crisis communication for large-scale international research infrastructure projects Critical elements of this are asking the right questions and designing the WEPOC architecture to allow for a nimble and iterative approach to strategy, problem-solving, and resourcing. This paper will draw from conclusion from the "Broadening Participation in Future Telescopes" workshop in December 2018 and the "Making the Case: Outreach and Communications for Large, International Science Projects" workshop in April 2017.

Web link:

Name: Alan Hirshfeld

Proposing Team: AAS Historical Astronomy Division (HAD)

Type of Activity:
State of the Profession Consideration

Description: The Historical Astronomy Division's mission is to advance general interest and academic research in topics relating to the historical nature of astronomy, including the application of historical records to modern astrophysical problems. HAD sessions at the national AAS meetings provide the opportunity to disseminate new findings about the history of astronomy, promote discussion among attendees, and provide the wider astronomy community with an accurate historical context in which to frame the various areas of modern-day astrophysical research. A HAD committee will be formed to develop a State of the Profession white paper that will detail HAD's relationship to the AAS plus its ongoing efforts pertaining to the study of the history of astronomy. Among these is the Astronomy Genealogy Project (AstroGen) which will list as many as possible of the world's astronomers with their academic parents (also known as thesis advisors, supervisors, promotors, directors, or guides) and enable readers to trace both academic ancestors and descendants. HAD works closely with the Working Group on the Preservation of Astronomical Heritage (WGPAH), which is preparing a related white paper on the identification and preservation of astronomical structures, instruments, and records for the purposes of astronomical and historical research, teaching of astronomy, and outreach to the general public.

Web link:

Name: Julia Roman-Duval

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: We will present the results of a survey of the factors limiting conference attendance, and what practices could help achieve better diversity in astronomical conference attendance. [This is a resubmission. I would like to retract the previous version of my NOI]

Web link:

Name: Kaiu Kimura

Proposing Team: Imiloa Astronomy Center of Hawaii

Type of Activity:
State of the Profession Consideration

Description: Underrepresentation of Native Americans, Native Hawaiians, and Alaska Natives in STEM-related fields is both significant and persistent. In 2009, this group comprised only 1% of the science and engineering workforce (NSF 2011). Young people in Indigenous communities throughout the U.S. continue to struggle with the balancing act of growing up between Indigenous and non-Indigenous discourses of culture and participation (Faircloth & Tippeconnic 2010; NEA & NIEA 2010). In addition to a diverse pool of scientists and educators who can bring new perspectives to science and to the public understanding of science, the U.S. needs a well-informed, scientifically literate society that includes opportunities that account for and value Indigenous voice. If we engage everyone in the intersection of Native and Western worldviews, the larger value is to open doors for the next generation of Native youth (Barnhardt & Kawagley 2010; Brayboy & Castagno 2008). Scientists and science educators are beginning to recognize the importance and place of traditional Indigenous language and knowledge in our understanding of the natural world, and to engaging Native students disconnected from the process and knowledge of science (Aikenhead & Michell 2010). Work by Willard Gilbert (2011) demonstrates that recognizing and integrating cultural and linguistic intellectual strengths of Native youth in an academically rigorous and culturally relevant and responsive manner improves academic achievement while simultaneously revitalizing and preserving traditional cultural knowledge. The ʻImiloa Astronomy Center of Hawaiʻi, in partnership with the Maunakea and Haleakalā Astronomical Observatories and the College of Hawaiian Language at the University of Hawaiʻi at Hilo offers the A Hua He Inoa (AHHI) nomenclature project that is making ground-breaking history as we establish Hawai'i as the first place in the world to weave traditional practices into the official naming of astronomical discoveries. This collaborative effort is shifting global paradigms by including Native Hawaiian speaking youth into the process of astronomical discovery naming. Youth that participate in this project engage with astronomical researchers and Hawaiian language experts to learn about recent discoveries while also engaging in the creative process of naming these discoveries. These youth are gaining an appreciation for the Hawaiian culture as it relates to the universe and are also gaining an understanding of the unlimited potential for future fusions of culture and science. With the successes that we've experienced in Hawaiʻi, we hope to share and help replicate this experience with other indigenous and astronomical communities across the nation. As Hawaiʻi celebrates 35 years of revitalizing Hawaiian language revitalization, we acknowledge the capacity and relevance of the Hawaiian language -- and the worldview that it informs -- in modern contexts. Collaboration between the Hawaiian and astronomical research communities can further advance these efforts while simultaneously elevating and deepening the work of modern astronomical research. Indigenous cultural traditions, as applied to astronomical research and education, are an opportunity for indigenous youth to deepen their roots in their culture while expanding their scientific understanding of the universe. Efforts like AHHI ultimately help to broaden the field of astronomy while also bringing indigenous language and knowledge to the forefront by bringing deeper cultural meaning to the scientific progress made in recent years and in years to come. National Research Council (NRC). 2009. Learning Science in Informal Environments: People, Places and Pursuits. Washington, DC: National Academies Press. National Science Foundation (NSF).

2011. Diversity in the Federal Science and Engineering Workforce. http://www.nsf.gov/statistics/infbrief/nsf11303 Faircloth, S. C. and J. W. Tippeconnic III. 2010. The Dropout/Graduation Crisis Among American Indians and Alaska Native Students: Failure to Respond Places the Future of Native Peoples at Risk. http://www.civilrightsproject.ucla.edu/research/dropouts/faircloth-tippeconnic-Nativeamerican-dropouts-2010.pdff National Education Association (NEA) and National Indian Education Association (NIEA). 2010. Native Education101: Basic Facts About American Indian, Alaska Native, and Native Hawaiian Education. http://www.niea.org/data/files/policy/nativeeducation101.pdf Barnhardt, R. and O. Kawagley. 2010. Alaska Native Education: Views from Within. Alaska Native Knowledge Network. Brayboy, B. and A. E. Castagno. 2008. How Might Native Science Inform "Informal Science Learning?" National Research Council Board on Science Education. Aikenhead, G. and H. Michell. 2010. Bridging Cultures: Indigenous and Scientific Ways of Knowing Nature. Pearson Canada. Gilbert, W. 2011. Developing Culturally Based Science Curriculum for Native American Classrooms. In: Reyhner, J. W. S. Gilbert and L. Lockard (Eds.), Honoring Our Heritage: Culturally Appropriate Approaches for Teaching Indigenous Students (pp. 43-55). Flagstaff, AZ: Northern Arizona University.

Web link: https://imiloahawaii.org/news/a-hua-he-inoa-8e3ax?rq=AHHI

Name: Jessica Lu

Proposing Team: Jessica Lu (UC Berkeley), Michael Fitzgerald (UCLA), Richard Dekany (Caltech), Shelley Wright (UC San Diego), Sarah Tuttle (University of Washington), Marshall Perrin (STScI), Cynthia Froning (UT Austin), Jennifer Lotz (Gemini Observatory), Lisa Hunter (UC Santa Cruz), Laird Close (University of Arizona), Katie Morzinski (University of Arizona), Nicholas McConnell (UC Santa Cruz), Claire Max (UC Santa Cruz), Sarah Kendrew (ESA/STScI), Quinn Konopacky (UC San Diego), Vanessa Bailey (JPL/Caltech), Erika Hamden (University of Arizona), Renate Kupke (UC Santa Cruz), Christoph Baranec (University of Hawaii)

Type of Activity:
State of the Profession Consideration

Description: This Notice of Intent is for a white paper submission on the state of professional development and education in adaptive optics and, more broadly, optical and infrared instrumentation in the US. Astronomy and astrophysics is very much a technology-driven field; each time a new telescope or instrument is built, unanticipated discoveries emerge. Adaptive optics (AO) has been one of these transformational technologies as it has enabled ground-based telescopes to realize their full potential and image at their diffraction limit. AO development has led to the discovery of the supermassive black hole at the Galactic Center, the first images and spectra of extra-solar planets, and direct evidence for the existence of dark subhalos as predicted by cold dark matter models. AO is increasing in importance thanks to (1) new flavors of AO that will deliver spatial-resolution improvements over larger fields of view and over a broader range of optical and infrared wavelengths, (2) the use of wave-front sensing and active optics in future large space telescopes (JWST, LUVOIR, HabEx), and (3) the advent of larger (20-40 m) ground-based telescopes that are being built with AO at first light. Despite the importance of AO instrumentation and technology development to US astronomy, the US does not train a sufficient number of AO scientists to fulfill the AO needs of US telescopes now and into the future. In large part, this is due to limited funding for AO and also AO systems being designed and built at the telescopes themselves (e.g. Keck AO, Gemini MCAO, TMT AO, GMT AO). Only a few AO systems have been built in whole or part at US university labs where students have extensive opportunities to participate (e.g. Gemini Planet Imager, Robo-AO at Caltech and UH, Magellan AO and LBTI AO at U of Arizona, Lick AO at UCSC). This stands in contrast to other countries where nearly all AO projects are being developed with active participation of students and postdocs even in large-scale projects (e.g. TMT AO at NRC in Canada, VLT and E-ELT AO at universities across France and Italy, Gemini MOAO at Dunlap Institute/U Toronto in Canada, GeMS MCAO and some Keck AO at ANU in Australia, GRAVITY AO at MPE in Germany). As a result, it is difficult to hire AO scientists at US universities and telescopes and frequently we must hire from Europe or Canada instead. In the longer term, this also puts the US at a competitive disadvantage as much of the AO technology innovation is still performed abroad in labs affiliated with universities where access to students and postdocs allows for easier exploration of new ideas. More broadly, the field of astronomical instrumentation sits at the intersection of science, technology, and engineering and benefits from cross-disciplinary and diverse ideas. Unfortunately, those who work in this field are not as diverse; the fraction of women (< 20%) is at least a factor of two below astronomy as a whole. Additionally, the fraction of women as well as minorities (< 10%) is well below the national population. The participation of women and underrepresented minority (URM) groups within the field of astronomical instrumentation and technology, including adaptive optics, can be increased through intensive training and mentorship at the senior undergraduate and early graduate level in both astronomy and engineering fields. In order to address the US shortage of AO scientists as well as underrepresentation of women and minorities in the broader OIR instrumentation field, we advocate for increased support for training and mentoring the next generation of adaptive optics and OIR instrumentalists. Such support could come in the form of (1) internship and visiting scholars programs at labs/telescopes, (2) student training supplements in NSF funding of large instrumentation projects, (3) travel awards for Jr. scientists to attend SPIE or other instrumentation-focused conferences, (4) summer schools aimed at undergraduate and graduate students, (5) use of inclusive and equitable training methods in instrumentation courses, (6) retention and advancement of women and underrepresented minorities in the field with instrumentation-inclusive grad and postdoc fellowships, and (7) training programs for instrumentalists that establish inclusive professional practices.

Web link:

Name: Brian Nord

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Collaboration and Education at the Edge: Algorithms and Statistics Development in the Next Decade of Discovery The past decade has seen rapid change in the algorithmic, computational, and statistical landscape. We have seen the rise of new ``standard'' programming languages and libraries (e.g. python and astropy). There has been a proliferation of new algorithmic and statistical techniques --- from improvements in image processing and compression to the rise of deep neural networks as a powerful suite of tools for machine learning. We have seen the rise of new computational modalities, such as cloud computing and "software as a service." Even the basic mechanics of computation is undergoing a shift, with the availability of specialized hardware such as GPUs and TPUs, which require a new domain of knowledge to efficiently deploy solutions. Moreover, there is no reason to expect the pace of innovation to drop off anytime soon. The rapid pace of advancement means that it is no longer possible for a single astronomer or even a small team of astronomers to build the necessary depth of expertise in all of these areas. Yet these technologies may be critical to maximizing the scientific reach of new research. New technologies spring up quickly, and the astronomical community needs to balance the cost of learning the new technologies with the benefits they provide. It is not reasonable to expect every astronomer to keep up with all of the advances. In cases where collaborations exist today, there can be a variety of complicating challenges. There is currently no established marketplace for matching difficult problems in the astronomy domain to relevant experts outside an astronomer's network. The resulting in-depth collaborations have start-up overhead as the external experts learn enough about the problem domain to be helpful. Short-term engagements can suffer from a lack of depth or insufficiently productionized solutions. Even in longer-term engagements, there can be misalignment between the parties due to the different incentives. For example, statisticians and computer scientists in academia are primarily recognized for only the novel contributions to their own fields. Papers that apply existing methodologies to new problems are not considered significant contributions to their fields. Similarly, members of the astronomy community are not fully recognized for their algorithmic contributions. In education, we have started to make progress in providing a foundation in statistics and algorithms. However, it is not uniformly available across our community: there is significantly smaller access at smaller colleges and for communities that are traditionally underrepresented in astronomy, physics, and computing. The determination of what constitutes an appropriate curriculum will require a balance of priorities. We should provide the foundations of statistics/algorithmic design appropriate for the broader science community, as well as teach specialized skills (e.g., optimization, compilers) that may benefit a smaller, but crucial, set of researchers who will engage in the development and implementation of computing and software frameworks. We recommend that a new approach for interdisciplinary collaboration and education be adopted within astronomy. New modalities for the long-term engagement of algorithmic and statistical expertise outside of astronomy will need to be developed. Open educational resources that can be used in teaching statistics, and algorithms, and machine or computational learning will require coordinated and sustained efforts to integrate current resources within a broad curriculum and to make them easily accessible.

Web link:

Name: Jorge R. Padial Doble

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: The 2010 decadal survey report suggested actionable and reasonable measures to increase diversity and minority participation in astronomy. However, reaching the predicted percentage of astronomy Ph.D.'s among minorities over the next 30 years may require more effort than previously estimated. We aim to understand the impacts of various methods that strive to improve equity and diversity in astronomy. As a group of underrepresented graduate students, we shall submit a detailed report on the efficacy of proposed measures and suggest improvements towards achieving parity in astronomy.

Web link:

Name: Maura McLaughlin

Proposing Team: NANOGrav

Type of Activity:
State of the Profession Consideration

Description: Building a diverse and resilient pipeline for astrophysics is critical to the health of the field over the next decade and beyond. In this whitepaper, we will describe the education and outreach efforts used in the NANOGrav collaboration over the past decade and the lessons learned from them. We will also compare them to efforts of other collaborations and to the best practice recommendations in the field. Our model involves using NANOGrav science to inspire broad audiences through public lectures and outreach and also through online, multi-media content. We then seek to inform students at all levels through specialized talks in schools using the infrastructure of the Science Public Outreach Team (SPOT) program. We further engage students through participation in real-word research with cutting edge facilities. The Pulsar Search Collaboratory (PSC) program is one example of this model. We educate students interested in STEM careers about our science and possibilities at twice-yearly undergraduate workshops and, finally, train populations of students in our specific discipline through our Student Teams of Astrophysics ResearcherS (STARS) program. This pyramid of education and outreach activities requires mindful training of students and postdocs in science communication and leadership skills. These education and outreach efforts must also be coupled with thoughtful mentoring of graduate students and postdocs in order to ensure retention of students in STEM fields.

Web link: http://nanograv.org/outreach/

Name: Doug Simons

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: The Future of Maunakea Astronomy Given the importance of the Maunakea Observatories to the field of astronomy in the 21st century, ensuring a bright future for this billion-dollar research complex has broad impact. Of particular importance is the renewal of the Master Lease for the Maunakea Science Reserve (MKSR), which expires in 2033. A White Paper will be submitted that summarizes the challenges and opportunities ahead and the various strategies underway that build off the 50 years of astronomy on Maunakea. Solutions to recent conflicts will be found through multilateral dialog, open minded and open hearted listening, and a community wide sense of ownership and pride in the future of Maunakea as a whole. A range of programs are underway to drive broad community support for MKSR Master Lease renewal including – • Increased media coverage of the existing astronomy outreach programs, building them into even larger programs in some cases. • Improved government relations, through on-going dialog with legislators, the Governor's office, County officials, etc. • An infusion of new community outreach programs that invert the paradigm, bringing the community into the observatories, rather than relying mostly on observatory staff going into the field (classrooms). • Provision of innovative education, environmental, and cultural opportunities for the community through unprecedented and unconditional philanthropy • Advancement of indigenous culture through 'Ōlelo Hawai'i (Hawaiian language) • Focusing a positive message about the future of Maunakea with special emphasis on what the future of Hawai'i astronomy means to the keiki (children) of Hawai'i, who will in a real sense "inherit" these remarkable facilities as members of their technical, administrative, and scientific staffs • Promoting community based management of Maunakea consistent with the Office of Maunakea Management, Maunakea Management Board, Kahu Kū Mauna, Comprehensive Management Plan, etc. • Establishing a lasting community based vision for the future of Maunakea that informs policy and decision making about the summit of Maunakea in all respects. In summary, the nature of the challenges in Hawai'i to sustaining the Maunakea Observatories well into the future, as well as the multi-faceted strategy designed to ensure a bright future for Maunakea astronomy, will be presented.

Web link:

Name: Adam Burgasser

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Setting Data Free: Challenges and Opportunities in Astronomical Data Archival and Dissemination in the 2020s Data is the currency of science, by which discoveries are made, ideas emerge, and theories are tested and revised. In Astronomy, the inflow of data has become a deluge, as instruments become increasingly multiplexed, synoptic astronomy becomes standard practice at increasing sampling rates, and automated facilities deliver data at rates approaching 10s-100s TB/day. Data mining is an increasingly essential tool to explore these complex, multi-format, panchromatic datascapes. Equally essential is coordination among instrument makers, facilities, data portals, software developers, publishers and scientists to extract and communicate the science emerging from these datastreams. Making these data freely accessible is fundamental to the process of science, enabling verifiability, integration into future studies, and application of new analysis methods. Data access is also an equity issue, as it enables students, teachers, and researchers at small academic institutions, K-12 schools, industry organizations, and "citizen scientists" the opportunity to work directly with the scientific data often made possible by public funding. The NSF has codified the importance of data accessibility within its funding model, requiring grants to include data managements plans and directing investigators "to share with other researchers, at no more than incremental cost and within a reasonable time, the primary data, samples, physical collections and other supporting materials created or gathered in the course of work under NSF grants." How are these data to be delivered? Major astronomy data archives, such as MAST, IRSA, HEARSAC, NOAO, and others, have spent decades developing various protocols for ingesting, processing, organizing, and disseminating multi-mission datasets through searchable online platforms. Individual observatories are also making their data available through stand-alone archives (e.g., Keck) or aggregators (e.g., IRTF @ IRSA), dealing with multiple instruments and data types. Groups and individuals release or maintain their own datasets, through privately-hosted platforms and third-party archives. Journals are also engaged in data sharing by providing digital tables and "data behind the figure" for individual papers. Despite the many efforts to assure data reaches the community, there are significant barriers to assuring that data are broadly accessible in formats useful for users, issues that will only amplify as data volumes increase. These include, but are not limited to: Lack of dedicated funding opportunities to develop data archives, including hardware, software/interfaces, and maintenance, particularly at the individual/group/facility level; Lack of consistent standards among existing large archives, instruments & facilities, journals, and group & individual efforts; Lack of training in data curation or dissemination of best practices; Challenges in converting "historical" media (paper, film, magnetic tape, DVDs, etc.); Technical and technological challenges in the long-term storage, organization, and dissemination of very large-scale datasets (Petabyte/Exabyte); and Lack of enforcement of data sharing policies. In this white paper, we will briefly examine these issues, advocate for increased attention to the data access problem, and advocate for prioritizing and implementing solutions, which may include but are not limited to: Full commitment to and enforcement of archival and public dissemination of primary data products, particularly by public funding agencies, facilities, journals, and community organizations such as the AAS; Coordination between instrument developers, telescope administrators, archival administrators, journal managers, software engineers, and scientists to develop common standards and data formats, and resources to pursue this work; Resources to develop and implement archival systems and data warehouses aligned with these standards; Centralized systems to allow individuals/groups/small facilities to disseminate data following common standards; Dissemination of best practices and tools for adoption at the individual/group/facility level, and training and curriculum development in data curation and archival practices; and Full implementation and funding support of Virtual Observatory (USVOA, IVOA) programs to lead coordination of many of the efforts described above.

Web link:

Name: Kathryn Chandra

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: There have been many studies examining barriers for students from underrepresented groups advancing in Astronomy, which include test anxiety, impostor syndrome, stereotype threat, sexual harassment, discrimination, etc. While the statistical and theoretical investigation of these issues are important, it is also important to hear from those who are actively experiencing these issues and how it erodes initiative, confidence, and aspiration. In this White Paper, I will describe my personal experience as an undergraduate Astrophysics major trying to pursue academics and research while facing several exceptional barriers and setbacks. It is well understood that Astrophysics is perceived to be a "difficult" major when compared to social sciences or even various STEM majors. It has come to my attention that astrophysicists are held to a standard that they must "know everything, " or that, "math must be so easy" for them because of how rigorous the courses are. The automatic assumption is that people could only pursue this major if they meet a socially set standard of intelligence. This creates the notion that, by definition of being in this major, these stereotypes must apply to them. The need to live up to these societal stereotypes enhance an already competitive environment. Thus, when one is struggling or can not meet these socially set expectations, it could lead to an erosion of initiative, confidence, and aspiration. My intention is to not only make these issues less "theoretical" and more "experiential", but also normalize discourse regarding mental health within the Astronomy community, in the hopes of drawing closer attention to the actual impediments of future astronomers like myself.

Web link:

Name: Cameron Hummels

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: The Increasing Need to Support Community-Based Software Nearly all aspects of modern astrophysics rely extensively on computers, including the reduction and analysis of observational data, the design and modeling of instruments, and the execution of theoretical simulations. The rise of computation has produced a need for robust, versatile, and freely-available software. The benefits provided by open-source software in astronomy are significant: (1) reducing errors through increased code review; (2) enhancing reproducibility in results; and (3) democratizing our field by providing everyone with the tools previously only accessible to large research groups. However, despite these enormous advantages to astronomy as a whole, the status of community-driven software projects is still precarious. These efforts require the commitment of many contributors over thousands of person-hours to develop, document, test, and maintain these codebases over long periods. These tasks do not easily fit into the current grant system for funding, nor do they match with the citation-as-credit reward structure present in our field. While funding sources have been negotiated for a few high-profile open-source projects, most of these efforts are largely sustained by academics in their free time. Thus, hurdles remain in how to support community-driven software, both financially and in recognition for their developers and maintainers. As our field moves into the next decade, community-based software projects will require broad support at the institutional, agency, and community level for funding and hiring decisions to ensure software keeps pace with the exponential technological growth of the physical sciences.

Web link:

Name: Mary Edwards

Proposing Team:

Type of Activity:
State of the Profession Consideration

Description: Corning Incorporated has continued to improve material and processes for lightweight mirrors in support of space-based optical systems. ULE glass is ideally suited for high performance stable optics. This paper will provide an overview of recent material improvements aimed at superior thermal performance, including the ability to tailor individual pieces of glass to have essentially zero thermal expansion at chosen temperatures. The slight dependence of the material's CTE (coefficient of thermal expansion) with temperature can be reduced further with custom heat treatments. This produces a material which can be leveraged by the HabEx, LUVOIR, and LISA teams to achieve increased stability compared with today's existing state of the art telescopes. Recent facility improvements will be described, which position Corning to manufacture ultralightweight mirror blanks up to 4 meters in diameter. Much of the necessary infrastructure is already in place and will be described. Proven mirror bonding processes, including frit bonding and low temperature fusion, will be discussed. Corning has produced hundreds of mirror blanks for various applications, ranging from 8" to 2.5m in size. Most operate near room temperature; others are used in cold environments. Such optics have been proven to have high strength, high reliability, and long term stability. Recent advances in both bonding techniques will be presented, along with custom metrology developed to assess the extremely small changes in material systems already pushing the limits of measurement capability.

Web link: http://www.corning.com/worldwide/en/products/advanced-optics/product-materials/aerospace-defense/telescope-mirror-lens-blanks.html

Other Activities

Name: H. Philip Stahl

Proposing Team:

Type of Activity:
Other Technology State of Art

Description: Deriving a telescope wavefront stability specification for exoplanet imaging with a stellar coronagraph via a methodical error budget approach. Performing exoplanet science with an internal coronagraph requires an ultra-stable wavefront. Achieving this stability imposes never before required performance specifications upon the telescope and requires a new approach systems engineering. The telescope and coronagraph must be specified and designed as an integrated system. This paper describes a systems engineering process that can be applied to any potential telescope/coronagraph combination. The process starts with a top-level error budget for a desired science sensitivity. For direct imaging, the error budget's two main branches are photometry and systematic errors. The photometric side is estimated using well proven methodology, and includes photon and detector noise. The remainder of the error is assigned to systematic errors and reserve. Systematic errors are the product of the expected disturbances (including wavefront stability) and their associated sensitivities. The bulk of the effort then is focused on computing sensitivities using diffraction modeling of the stellar leakage, core throughput, and the light level in the dark zone arising from error in each expected mode. To illustrate the process, four representative architectures are evaluated: two vector-vortex and a hybrid Lyot coronagraph in combination with an off-axis monolithic telescope; and, an apodized pupil Lyot coronagraph with an on-axis hexagonal segment telescope (similar to the Webb Telescope aperture or the potential Large UV/Optical/IR Surveyor (LUVOIR) decadal mission).

Web link:

Name: H. Philip Stahl

Proposing Team:

Type of Activity:
Other Technology State of Art

Description: Parametric cost model for space and ground optical telescope assemblies: Parametric cost models can be used by designers and project managers to compare cost between major architectural cost drivers and allow high-level design trades; enable cost-benefit analysis for technology development investment; and, provide a basis for estimating total project cost between related concepts. The NASA Marshall Space Flight Center has developed a 5-parameter cost model that explains 92% (Adjusted R2) of the cost variation in a database of 46 total ground and space telescope assemblies (OTA), where OTA is defined to include primary & secondary mirrors, and structure that connects the mirrors. Additionally, mission level costs as a function of work breakdown structure is analyzed for a small subset of the dataset.

Web link:

Name: Mark Swain

Proposing Team:

Type of Activity:
Other flagship mission capability

Description: The scientific benefit of maintaining exoplanet transit spectroscopy capability over the 1-5 micron interval in the post JWST timeframe will be explored. Specific consideration be given to the possible role of this capability on US flagship mission concepts given current and planned NASA and ESA missions.

Web link:

Name: Rebecca Koopmann

Proposing Team: Undergraduate ALFALFA Team

Type of Activity:
Other Undergraduate Research and Education

Description: We present key results from a highly successful model of undergraduate research and education over the past decade, the Undergraduate ALFALFA (Arecibo Legacy Fast ALFA) Team (UAT), an NSF-sponsored 23-institution collaboration. The UAT was founded to promote undergraduate research and faculty development within the context of the extragalactic ALFALFA HI blind legacy survey project . One principal objective of the UAT is to provide long-term collaborative research opportunities for faculty and students from a wide range of public and private undergraduate-focused colleges. Through doing this, the UAT has demonstrated a highly successful model for peer mentoring and training, student retention, enhancing faculty and student research success in small astronomy programs, student pathways to STEM careers, and inclusion of more women and minorities in leadership roles. Partnering with Arecibo and Green Bank Observatories in the past 11 years, the UAT has worked with more than 334 undergraduates (40% women, 35% members of underrepresented groups) and 32 (48% women) faculty, offering annual workshops, observing runs, research projects (academic year and summer), and presentation of results and networking at national meetings. 137 alumni (42% women) have attended graduate school, 91 in physics or astronomy and most in a STEM field. The majority of those not in graduate school are pursuing careers in STEM fields, including teaching and engineering/industry. This modest investment from the NSF has therefore yielded rich results and successful outcomes for several hundred UAT student alumni and faculty. We suggest that this model may be applied to other research projects that aim to involve undergraduate and graduate students in cutting-edge projects in a large collaboration or legacy astronomy projects through long-term mentoring and participation. This approach has a strong, demonstrable impact on the health of the project itself, science education, and equity/inclusion in astronomy.

Web link: http://egg.astro.cornell.edu/alfalfa/ugradteam/ugradteam.php

Name: Julie Crooke

Proposing Team:

Type of Activity:
Other Alternative Funding Approaches for Large Strategic Missions

Description: Since the 1950s, the Department of Defense (DoD) has been taking advantage of No-Year congressionally appropriated funding for their large programs such as aircraft carriers, fighter jets, helicopters and tankers. There are multiple reasons that this has occurred. There is also precedence for upfront funding of large projects within NASA, including the Apollo program, the ISS, and even the space shuttle that replaced Challenger. There are multiple documented and published lessons learned from NASA demonstrating that inadequate funding profiles lead to cost and schedule breaches. While funding profile is not alone in causing these breaches, its affect should be understood and the potential benefit of No-Year Appropriation, Annual Appropriation, Multiple-Year Appropriation, Front-Loaded phased funding and other funding considerations needs to be explored within the context of flagship missions.

Web link:

Name: Natalie Batalha

Proposing Team: Nexus for Exoplanet System Science (NExSS)

Type of Activity:
Other Interdisciplinary Research Coordination

Description: Solar system exploration and SETI searches are well-established pathways for conducting the search for life beyond Earth. However, a third pathway emerged with the discovery of the first exoplanets orbiting Sun-like stars in the 1990s. NASA's Kepler Mission catalyzed the search by demonstrating that temperate, terrestrial-size worlds are abundant throughout the Galaxy. In 2013, NASA released a 30-year roadmap for astrophysics that includes the remote detection of biosignatures on exoplanets using star suppression technology in space. Teams have since been commissioned to explore design concepts based on Kepler science results and strategic technology development. This progress manifested itself as a new national priority. In 2017 Congress added a 10th objective to US aeronautical and space activities: "Section 20102(d) of title 51, United States Code, is amended by adding at the end the following: (10) The search for life's origin, evolution, distribution, and future in the universe." This broad support is an opportunity for space sciences at NASA to implement reasoned policies, practices, and procedures to drive the discovery of extrasolar worlds, as well as the search for life. This white paper will examine existing procedures and practices as they pertain to exoplanet science and astrobiology, in order to identify hurdles inhibiting progress. It will also provide potential paths around these hurdles, so the scientific promise of our community can be realized. Many of these ideas are borne out of work within NASA's Nexus for Exoplanet System Science (NExSS), a cross- and inter-disciplinary research coordination network of scientists focused on planetary habitability. The network has fostered strategic thinking and participation in programmatic activities leading to insight and observations. Herein, we describe four areas where we see potential to advance exoplanet science with strategic policies and practices: 1) cross-division collaboration, 2) Decadal Survey processes, 3) strategic JWST programs, and 4) synergies between human exploration and space science.

Web link: https://nexss.info/

Name: Abigail Vieregg

Proposing Team: ANITA/PUEO

Type of Activity:
Other suborbital, NASA long-duration balloon

Description: KEY OBJECTIVES: We propose a next generation ultra-high energy particle astrophysics detector, the Payload for Ultrahigh Energy Observations (PUEO), based on the highly successful Antarctic Impulsive Transient Antenna (ANITA) payload. ANITA has completed four long-duration balloon flights searching for signatures of ultra-high energy neutrinos interacting in the Antarctic ice sheets, producing radio-frequency impulses via the Askaryan effect: coherent radio Cherenkov emission from electromagnetic cascades. Gurgen Askaryan's theoretical work on this process in the 1960s has engendered a host of particle astrophysics techniques for detection of both neutrinos and cosmic rays at the highest energies, both before and after its confirmation in 2001 at the Stanford Linear Accelerator. Over the last decade, ANITA has produced among the best current limits on cosmogenic neutrinos -- those ultra-high energy cosmic neutrinos that result from interaction of the 2.7K cosmic microwave background with ultra-high energy cosmic rays throughout the universe. ANITA's constraints have eliminated a host of theoretical flux models for cosmogenic neutrinos, but the impetus to determine and characterize this so-called `guaranteed' flux of neutrinos remains as strong as ever. ANITA has also seen a handful of anomalous cosmic-ray like events which could be a hint of beyond-standard model physics. ANITA's methodology is sound and the payload itself is mature, but the sensitivity is lacking to conclusively demonstrate the nature of these anomalies and to reach the elusive cosmogenic flux. We propose major augmentations that will increase the acceptance by an order of magnitude, while building carefully on the existing gondola and its infrastructure, to enable a smooth transition to a significantly more science-capable payload in PUEO. METHODS AND TECHNIQUES: The most critical parameter in the sensitivity of instruments that exploit the Askaryan effect, and related radio-impulse generation in cosmic-ray extensive air showers, is the energy threshold, and this scales almost directly with the total antenna collecting area. ANITA flew up to 48 quad-ridged horn antennas, each with effective areas (or gains) that were nearly optimized for the constraints of the payload launch envelope. However, radio-frequency interference reduced the usefulness of the lowest frequencies near 200 MHz. We propose to move the low-end cutoff frequency to 300 MHz, avoiding the interference issues, and allowing us to increase the number of antennas by more than a factor of two. An even more important improvement will come from coherent phased-array approaches to triggering the system, substantially improving the threshold compared to the previous incoherent trigger. The combination of these effects will improve the reach by an order of magnitude in terms of event rate compared to the most recent ANITA-IV payload, a major advance in sensitivity, that warrants the new payload designation of PUEO. PERCEIVED SIGNIFICANCE: The cosmogenic neutrino flux has not yet been detected in any form; lower energy neutrino measurements by the IceCube detector at the South Pole are of great interest, but are unrelated to cosmogenic neutrinos. PUEO's detection of, or stringent constraints on, this flux will have immediate and important consequences on our understanding of the origin and evolution of the universe, specifically our understanding of the nature of the ultra-high energy accelerators throughout the universe. In addition, PUEO will be able to conclusively resolve the nature of the anomalous events seen by ANITA, which may currently challenge fundamental particle physics. By virtue of a very large instantaneous point-source effective neutrino area, up to two orders of magnitude more than IceCube in the EeV energy range, PUEO will also have the capability to observe point source transients that are not visible to smaller aperture neutrino detectors. PUEO, at a small fraction of the cost of a large ground-based facility like IceCube, will establish an observatory class suborbital instrument for measurements of the highest energy particles in the universe.

Web link:

Name: Charles Mudd

Proposing Team:

Type of Activity:
Other Public Policy and Law

Description: Astronomy, Astrophysics, and Space Policy and Law An integral component of a robust Astro2020 Decadal Survey involves the perspective of public policy and law affecting the broader astronomy, astrophysics, and space sector. The relationship between the sector, on the one hand, and applicable public policy, on the other hand, involves dynamic aspects which deserve focus. Of course, the entire Astro2020 survey seeks to influence public policy by guiding budget allocations for discovery, research, and their projects over the next several years. As such, the proposed white paper would not duplicate what will be effectuated through scientific and other aspects of the process. Rather, the intended focus will be on (a) the existing state of laws that affect the sector and policy decisions; (b) proposals for substantive changes in existing domestic law that will improve and facilitate the goals identified through the Astro2020 process; and, (c) the state of related international policy and law. In the context of the latter category, particular focus can be directed toward policy discussions taking place in the United Nations Office for Outer Space Affairs ("UNOOSA"). Having concluded the First United Nations Conference on Space Law and Policy in September 2018, and with plans for the second conference to occur in 2019, there exists a real effort to develop an international direction toward policy and law affecting sovereign nations and their citizens – both natural persons and entities. Some of these topics include mitigation of space debris, ownership of space resources, and space traffic management. In particular, these policy areas affect and could directly impact the Astro2020 ambitions. The domestic aspects of space policy and law should then be viewed in the context of the efforts to create a broader international consensus. In particular, focus would be made on concerns identified in the sector community including, but not limited to, the L2 Lagrangian point and its congestion potential. An effort could also be made to address the potential aspects of international and private partnerships. An effort could be made from the policy and legal perspective to address some of the impediments to international collaboration previously identified and determine whether policy directions might mitigate them to some degree. In sum, the focus would be on guiding specific and broader policy directions that need to be addressed on a domestic and international scale to effectuate the longer term aspirations and objectives of the Astro2020 process. This perspective would be to help formulate broader, "long-term advice." It would be hoped that a white paper from a specific policy and legal focus could compliment the substantial efforts from others in the forthcoming Decadal Survey and the key science priorities identified.

Web link: