Astro2020 Science White Paper

Opportunities in Time-Domain Extragalactic Astrophysics with the NASA Near-Earth Object Camera (NEOCam)

Thematic Areas: ☐ Planetary Systems ☐ Star and Planet Formation
☐ Formation and Evolution of Compact Objects ☐ Cosmology and Fundamental Physics
☐ Stars and Stellar Evolution ☐ Resolved Stellar Populations and their Environments
☐ Galaxy Evolution ☐ Multi-Messenger Astronomy and Astrophysics

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Abstract (optional):

This White Paper motivates the Time Domain Extragalactic Science case for the NASA Near-Earth Object Camera (NEOCam). NEOCam[1] is a NASA Planetary mission, currently in Phase A, whose goal is to discover and characterize asteroids and comets, to assess the hazard to Earth from near-Earth objects, and to study the origin, evolution, and fate of asteroids and comets. However, NEOCam will cover 68% of the 'extragalactic sky' ($|b| > 30$ deg), and as NEOWISE-R has recently proved, infrared light curve information is now vital for characterizing the $\gtrsim$10 million AGN candidates identified from their IR emission. As such, for relatively very little additional cost, adding the capacity for additional data processing (and/or alerting) would have a massive scientific and legacy impact on extragalactic time domain science.

Time Domain Extragalactic Science Now and into the Net Decade

Having started in the 2010s with Pan-STARRS, PTF and ZTF, with the arrival of LSST, time domain extragalactic science will be a mature field in the 2020s. However, only with the advent of the Wide-field Infrared Survey Explorer (WISE) and Near-Earth Object Wide-field Infrared Survey Explorer Reactivation missions (NEOWISE-R) has the field of extragalactic science had its first scientifically interesting time-domain mid-infrared dataset (NPR:: I *think* this is true??!!)

Continuing the NASA IR Space Telescope Legacy

As the Infrared Astronomical Satellite (IRAS; 1983 January 25th launch), the Spitzer Space Telescope (SSC; 2003 August 25th launch) and the Wide-field Infrared Survey Explorer (WISE; 2009 December 14th launch) satellites all show how powerful infrared space telescopes, with moderate-sized primary mirrors are.

NEOCam would survey the Solar System at two simultaneous thermal IR bandpasses. but would also provide a synoptic survey of two-thirds of the thermal infrared sky at 4 - 5.2μm and 6 - 10μm using a large field of view of 11.56 square degrees.

The NASA Near-Earth Object Camera (NEOCam)

OVERVIEW: NEOCam is a NASA Planetary mission, currently in Phase A, whose goal is to discover and characterize asteroids and comets, to assess the hazard to Earth from near-Earth objects, and to study the origin, evolution, and fate of asteroids and comets. NEOCam is a single-instrument, 50cm diameter telescope that will observe in two simultaneous channels, called NC1 and NC2, which cover wavelengths of 4.0-5.2 μm and 6.0-10.0μm, respectively. There are four Teledyne 2k$\times$2K HgCdTe arrays per channel with 3.00" pixels in each. The entire celestial sphere between ecliptic latitudes of +40° to -40° will continually be mapped over the course of the 5-yr mission, and over 12 yr for the design lifetime. *NEOCam will provide a synoptic survey of two-thirds of the thermal infrared sky at 4-5.2 microns and 6-10 microns.*

CADENCE: Estimates of on-board overheads and resulting orbit quality are still being refined, but the current data cadence is as follows. The observing pattern consists of a four-peat of a six-position dither (a quick sequence of six images with 28s integration time each) with 2h gaps between each repeat. This four-peat will recur $\sim$13.2d later as long as the 75d visibility window is still open. Afterward, there will be a gap of 215d until the next visibility window opens and the

[1] https://neocam.ipac.caltech.edu/

pattern begins again. On average in a typical visibility window, there are $\sim$23 of these six-position dither sequences (a little less than 6 four-peats), $\sim$234 over 5yr, and $\sim$562 over 12yr.

DEPTH: Each of the six-position dither sequences is expected to have an S/N=5 sensitivity of 65-120 μJy for NC1 and 110-280 μJy for NC2, for low to high zodiacal backgrounds.

DATA PRODUCTS: NEOCam processing will create images and lists of characterized sources from each individual exposure and each stacked six-dither position sequence. It will also create differenced images by subtracting a static reference image, and a list of the characterized transient detections also produced. Because the goal of NEOCam is to provide and characterize moving objects within the solar system, coadd and source extractions over longer timescales are not provided, the one exception being yearly builds to create new static images (without any source detection or characterization) of the sky to use in image differencing. No alerting mechanism is provided for astrophysical transient events.

To realize the full potential of the NEOCam data for astrophysical research, additional data products and alerting infrastructure are needed, as discussed below. For a relatively small investment, NASA can leverage the existing NEOCam data to cover a wide range of extragalactic, time-domain, research.

In particular, extragalactic science has always benefitted from space-based IR operations, and this will continue in the 2020s with JWST, as well as new very wide-field observatories such as NEOCam.
Here we highlight 3 particular extragalactic science cases all of which have a time-domain aspect. These are Type Ia SNe; "Changing Look Quasars" and IR variable signatures of Gravitational wave events. As such, these range in established techniques via very recent progress to brand new parameter space.

NEAR-INFRARED VARIABILITY: A CORNERSTONE OF AGN AND QUASAR INVESTIGATIONS IN THE NEXT DECADE AND BEYOND

The circumnuclear dust absorbs the AGN illumination and reradiates the absorbed energy in the IR. The IR emission at wavelengths longward of $\lambda > 1\mu$m accounts for at least 50% of the bolometric luminosity of type 2 AGNs. For type 1 AGNs, $\sim$10% of the bolometric luminosity is emitted in the IR (e.g. see Fig. 13.7 of Osterbrock & Ferland 2006). A near-IR "bump" (excess emission above the $\sim$2–10μm continuum), generally attributed to hot dust with temperatures around $\sim$1200– 1500K (near the sublimation temperatures of silicate and graphite grains), is seen in a few type 1 AGNs (Barvainis 1987; Rodriguez-Ardila & Mazzalay 2006).

As discussed in detail in Stern et al. (2005, ApJ, 631, 163), the lack of strong polycyclic aromatic hydrocarbon emission in powerful AGNs, along with the IR flux $\lambda_{\rm rest} < 5\mu$m flux of AGNs being dominated by power-law emission rather than a composite stellar spectrum, leads to the AGNs being significantly redder than t hat of lower-redshift galaxies.

NEAR-INFRARED VARIABILITY CASE STUDY: SUPER-LUMINOUS SUPERNOVA IN AGN TORUS

Assef et al. (2013, ApJ, 772, 26; 2018, ApJS, 234, 23) have led the field in identifying large AGN candidate samples from selected from the Wide-field Infrared Survey Explorer (WISE) observations. From their most reliable study, Assef et al. (2018, ApJ, 866, 26) present spectroscopic observations of some of the most infrared variable extragalactic candidates to constrain their nature. *They find that from a sample of 45 objects with strong IR variability, only seven show significant optical variability.*

Further investigations reveals that one of these objects, WISEA J094806.56+031801.7 is most likely a super-luminous supernova (SLSN) with total radiated energy to be $E = 1.6 \pm 0.3 \times 10^{52}$ erg, *making it one of the most energetic SLSNe observed.* Based on the lack of change in mid-IR color throughout and after the transient event, the speculation is that the location of the SLSN is within the torus of the AGN.

INVESTIGATION AGN AND QUASAR CENTRAL ENGINES VIA THE "CHANGING LOOK" PHENOMENON:

– Ross et al., Stern et al.
– but redder...
With infrared emission from AGN associated with structures ∼a few light months to ∼several light years from the central engine accretion disk and photon source, variable AGN observed in the UV/optical during the early/mid 2020s from LSST will be NEOCam extragalactic time domain sources.

– links to 'ERQs' ??
– UFOs in the Seyferts (PDS456; Hamman et al.??)

CONNECTING AGN ACTIVITY IN THE IR WITH MULTI-MESSENGER BLAZARS: With the electromagnetic association with GW1708017 (e.g., Abbott et al. 2017, 2017PhRvL.119p1101A Abbott et al. 2017, 2017ApJ...848L..12A Abbott et al. 2017, 2017ApJ...848L..13A Cowperthwaite et al. 2017, 2017ApJ...848L..17C Soares-Santos, et al. 2017, 2017ApJ...848L..16S)
and the neutrino emission from the direction of the blazar TXS 0506+056
The era of "multi-messenger astronomy"
The 3rd Generation Ground-based Gravitational-wave Observatory Network ("3G") and the ESA-NASA Laser Interferometer Space Antenna (LISA).
Neutrino emission from the direction of the blazar TXS 0506+056 (IceCube Collaboration; 2018, Science, 361, 146; 2018, Science, 361, 147).

– Full LIGO mode – LISA

– "ROI" in e.g. Exgal science for just the further data analysis.

NEOCam:: 65 - 120 μJy for NC1 and 110-280 μJy for NC2;
WISE:: 0.08, 0.11 for W1/2 mJy, i.e. 80 and 110 μJy.

Outstanding Issues in Variable Extragalactic Astrophysics	
Scientific Motivation	NEOCam Requirements
THE PHYSICS OF ACCRETION	
Investigate "hot" and "cold" mode accretion in the quasar population; determine the rates and timescales characterising the Changing Look Quasar (CLQ) population.	Identify and characterize all the CLQs in DESI, LSST, WISE and NEOCam footprint.
Probe and determine the physical state of the inner parsec of the quasar central engine.	Rapid analysis and response for NEOCam quasar light curves.
OBSCURED ACCRETION AND GALAXY FORMATION	
Establish the relative importance that major mergers, minor mergers, cold streams and secular evolution have towards the growth of SMBHs across cosmic time.	Deep optical imaging data from LSST combined with searching for post-starburst signatures in NEOCam light-curves.
Establish the bolometric output and origin of IR emission, and determine presence of extreme outflows in the quasar population (??!!)	NIR and MIR spectroscopy of a representative NEOCam AGN sample
Establishing the range of SED parameter space the quasars occupy by a multi-wavelength multi-epoch "truth table dataset".	Build "The Quasar SED Rosetta Stone" using X-ray, UV/optical, IR data as well as repeat optical observations from LSST, NEOCam, spectroscopy.
Discover the physical conditions under which SMBH grew at the epoch when most of the accretion and star formation in the Universe occurred ($z \sim 1-4$).	Perform a complete census of AGN across $z \sim 0-8$, focussing on $z = 1-4$ using the very wide-field surveys to boost statistics for rare objects and medium-deep multiwavelength datasets to sample the faint-end of the luminosity function.
GALAXY-SCALE FEEDBACK	
Establish the theoretical impact of extreme outflows in the $z \sim 2-3$ quasar population	Next-generation Hydro-simulation modelling.
Understand how the accretion disks around black holes launch winds and outflows and determine how much energy these carry. Quantify the amount of "Maintenance/Jet/Kinetic" mode and "Transition/Radiative/Wind" mode feedback.	Connect accretion disk theory and models to cosmolgocial-scale hydro simulations for a holistic theory of "quasar feedback"
MULTI-MESSANGER ASTROPHYSICS	
Identify the EM counterparts for $\sim 10^6$ M$_\odot$ supermassive binary black holes; Identify the EM counterparts for neutrino events.	

References