Mid-scale RI-1 (M1:DP) Keck-FOBOS:
Building Comprehensive, Data-Driven Models of a Universe in Transition

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[[**10-page limit, excluding references. This Mid-scale Research Infrastructure-1 "Design" proposal requests funds to complete the preliminary instrument design for the Fiber-Optic Broadband Optical Spectrograph (FOBOS) and build frameworks for enabling data-driven science goals via a FOBOS Public Survey.**]]

1. Intellectual Merit

1.1. Scientific Justification. [[**3/4 page**]]

Led by NSF's Large Synoptic Survey Telescope (LSST) which deploys in 2023, astronomy is entering a new era of unprecedented deep-imaging data sets that will survey huge volumes of the universe when it was only one-half or one-third its current age. These epochs mark important but poorly understood transitions in cosmic history. Early galaxies were emerging from a "primordial soup" of gas and dust, assembling now fossilized structures that may be detected even within our own Milky Way. Meanwhile, the rate of cosmic expansion was beginning to accelerate, as the Universe became increasingly dominated by "Dark Energy," whose origin remains the single greatest mystery in astronomy and cosmology today.

Since Edwin Hubble's observations over 100 years ago, major advances in our understanding of the universe have come from the two-step process of first taking images of the sky to locate sources of interest and then obtaining information-rich spectroscopy to reveal the nature of those sources. A modern example is the Sloan Digital Sky Survey (SDSS) whose combination of panoramic "imaging" followed by dedicated spectroscopy yielded an unprecedented sample of over 1 million galaxies, mapping the present-day universe and making SDSS the most highly cited survey in the history of astronomy.

LSST's all-sky images will be 1,000 times deeper and detect far more distant galaxies than SDSS, but **no current U.S. facility is capable obtainng the spectroscopic followup** at a level required to capitalize on our $1B investment in LSST. In fact, SDSS-like spectroscopic followup of 1 million galaxies at LSST distances would require 300 years of observing on the largest telescopes with current instrumentation!

The only way forward is encapsulated in one of NSF's "10 Big Ideas," namely *Harnessing the Data Revolution* in order to maximize the information content of LSST via machine learning of optimally-designed spectroscopic training sets. This proposal presents a connected approach to the three critical components in this endeavor: 1) Development of statistical approaches to specific and ambitious data-science challenges that will address key questions about transitional epochs in cosmic history; 2) Design of FOBOS, a state-of-the-art spectroscopic facility on one of the world's largest telescopes optimized for obtaining spectroscopic training sets; 3) Design and execution of a "Public Survey" with this facility as well as a data-serving platform to provide spectroscopy and training data to the U.S. community. This MSRI-1 design proposal lays out the path for maximizing the panoramic imaging of LSST with spectroscopic followup. Through a subsequent MSRI proposal we will deliver on our goals with an instrument deployment in 2026 and completed spectroscopic followup as LSST concludes in 2029.

We address data science challenges in four research areas in order to guide our instrument and survey design:

(1) Significantly more powerful probes of Dark Energy and Cosmology
(2) Comprehensive understanding of the proto-galaxy ecosystem at $z \sim 2$

(3) Archaeological studies of our own Milky Way galaxy and its satellites to unravel their specific journeys through this transition.
(4) Time domain spectroscopy...?

1.2. **Research Community Priority.** [[**3/4 page**]]

The need for spectroscopic followup in the LSST era was made clear in the National Research Council's 2015 report, "Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System" (Council, 2015) which made the following recommendation:

> The National Science Foundation should support the development of a wide-field, highly multiplexed spectroscopic capability on a medium- or large-aperture telescope in the Southern Hemisphere to enable a wide variety of science, including follow-up spectroscopy of Large Synoptic Survey Telescope targets. Examples of enabled science are studies of cosmology, galaxy evolution, quasars, and the Milky Way.

In addition to this report, further details of spectroscopic needs for LSST in all science areas were disseminated after a 2013 workshop on this topic organized by the National Optical Astronomy Observatory (NOAO). Based on these recommendations, we propose the Keck-FOBOS instrument coupled with a suite of data-driven tools to address LSST's spectroscopic requirements at a final cost 20 times less than a new Southern Hemisphere facility. Located in Hawaii, Keck-FOBOS would have access to greater than 70% of the LSST footprint, more than adequate for our primary goal of building powerful spectroscopic training sets. FOBOS would complement future ambitious facilities that could cover wider areas (several deg^2 per pointing) at shallower depths.

The need for deep spectroscopic followup is particularly acute for LSST's major cosmological probes which rely on "photometric redshifts." Newman et al. (2015) summarize the case and describe a redshift survey which, if carried out with Keck-FOBOS, would increase LSST's Dark Energy Figure-of-Merit by a factor of 50% at a cost of less than 5% of the LSST budget. The urgent case for spectroscopic redshift training has been the subject of numerous publications (e.g., Laureijs et al., 2011; Masters et al., 2015; Hemmati et al., 2018).

Meanwhile, the astronomy community recognizes that the coming era of "Big Data" astronomy culminating in LSST necessitates "harnessing the data revolution. Wide-spread community interest in advanced data science techniques continues to grow amidst calls for educational structures, conference series, and research funding to support the growth of a new field, "Astroinformatics," which exploits the interface between astrophysics and statistics (Borne et al., 2009). Astronomy's largest organizations, including the American Astronomical Society and the International Astronomical Union, have supported active working groups on astroinformatics and astrostatistics since 2015. LSST itself has built the Informatics and Statistics Science Collaboration and partnered with NSF to fund the Data Science Fellowship Program to train astronomy graduate students in data science techniques. Our proposal builds on and contributes to these ongoing efforts.

1.3. **Data-Driven Science Challenges.** We introduce data science challenges in three science areas that will be addressed in this proposal. Each enables significant advances in our understanding of transitional epochs in cosmic history by leveraging FOBOS-derived spectroscopic training sets to maximize the information that can be extracted from LSST.

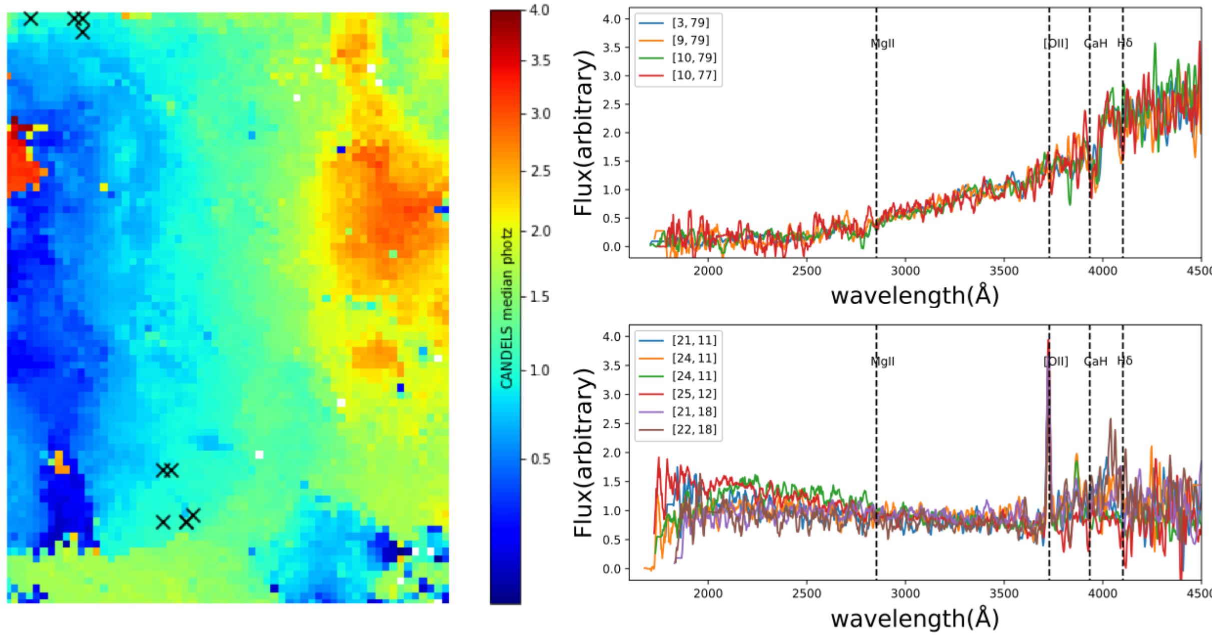

FIGURE 1. *Left:* A Self-Organizing Map (SOM) from Hemmati et al. (2018) visualizing the relationship between broadband galaxy brightness in different broadband filters (projected along the x and y axes) and observed spectroscopic redshift (indicated by the color map). SOMs guide the optimal construction of training samples by highlighting which galaxy classes require targeting. *Right:* Remarkably, the spectra associated with localized SOM regions are surprisingly similar, not just the associated redshifts.

1.3.1. *Enhancing Dark Energy Probes via Precision Cosmic Distances.* [[**1 page**]]

The 2011 Nobel Prize in Physics was awarded for the discovery of an era of acceleration in the expansion rate of the universe that sets in when the universe was roughly half its current age. This accelerated expansion is often attributed to a mysterious "Dark Energy," but the amplitude of this vacuum energy density is 120 orders of magnitude smaller than what naive models would predict.

Dark Energy is perhaps the single most important unsolved problem in cosmology and astrophysics. As such, it has inspired enormous world-wide effort and the construction of dedicated ground and space-based facilities. These include LSST, Euclid, and WFIRST. The goal of these experiments is the precision mapping of cosmic structure. Because this structure expands as the universe expands, precise measures of cosmic structure allow us to reconstruct the cosmic expansion history, and at sufficient levels of detail, distinguish among various Dark Energy models.

Many of the most important cosmological probes require galaxy "redshifts," a Doppler-like shift in the observed wavelengths of emitted light, as distant galaxies appear to recede from us as a result of cosmic expansion. Cosmological models, which provide access to Dark Energy parameters, are constrained in part via the conversion of redshift into distance. Accurate redshifts are conventionally derived via spectroscopy by fitting the observed wavelength locations of spectral features. Less precise redshifts, so-called "photometric redshifts" (or photo-zs) can be estimated with imaging photometry alone, a compelling option for large and faint data sets where spectroscopic redshifts are infeasible. But, "to infer cosmological parameters not limited by systematic errors, accurate redshift measurements are needed" (Hemmati et al., 2018).

Spectroscopic redshifts are critical for both the training of photometric redshift algorithms and for calibrating results in order to correct for biases. Complete photo-z training samples can *increase the Dark Energy Figure of Merit in LSST by 50%* (Newman et al., 2015).

Data Science Challenge 1: Obtain precise LSST Photometric Redshifts ($\sigma_z/(1+z) \lesssim 0.005$ at i(AB) $<$ 25.3) with Targeted Training Sample sizes of $<$10k. Our proposed FOBOS instrument is ideally suited to providing the spectroscopic training defined in Newman et al. (2015), but a complete program would require a 400-night investment in 10 m telescope time. This challenge demands a reduction in the required FOBOS training sample by a factor of ∼4 via clever application of state-of-the-art machine learning techniques.

Neural network trained photo-zs have long been recognized for providing the best precision when sufficient training sets are available (e.g. Bundy et al., 2006), and significant effort is underway in optimizing their application to future cosmological imaging surveys. Hemmati et al. (2018) for example have exploited Self-Organizing Maps (SOMs, Fig 1) to sort multiband photometric data by observed redshift in order to select optimized training samples for spectroscopic followup.

1.3.2. *A Comprehensive Picture of the Proto-galaxy Ecosystem.* [[**1 page**]]

A critical transition in evolution of galaxies in our Universe emerges when one considers the volumetric star-formation rate as a function of cosmic time

- cosmic star-formation rate shows the unique phases of the growth of galaxies in the Universe

- the detailed cause for the decline in the CSFR since z 2 remains unclear, but it could be thought of as the starvation of galaxies from the rapid gas accretion they enjoyed in the early universe.

- the outbreak of star-formation sparked by free-falling accretion of gas is now stymied by the size of the galaxies themselves.

- a number of fundamental properties of galaxies have emerged over the past 30 years: mass, size, metallicity, star-formation rate, angular momentum, and gas fraction. Environment

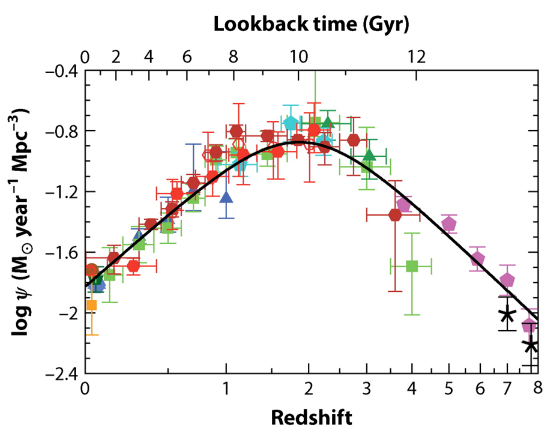

FIGURE 2. From Madau & Dickinson (2014)

The rate at which stars have been born in the Universe has varied dramatically over cosmic history. At roughly half its current age, the Universe was on average forming 10 stars for every one star formed today [[**ref**]]. At these epochs, galaxies looked rather different then they do now, dominated by all-consuming star-formation regions [[**ref**]]. These morphologies are only seen in rare star-burst galaxies in the Local Volume [[**ref**]]. The

1.3.3. *Unraveling the Formation History of our Local Group of Galaxies.* [[**1 page**]]

1.3.4. *Time Domain.* [[**1/2 page**]]

2. Project Implementation

This proposal supports design work from November 2019 through September 2021 on the Keck-FOBOS instrumentation and the interface between the instrument design and the envisioned FOBOS Public Survey plan, associated operational modes, advanced data analysis tools, and final data products. Design work on the complete package of hardware, software, and data product deliverables is necessary to maximize the science return of the FOBOS Project. Having advanced each of these key components through preliminary design, we will request NSF MSRI-2 funding in 2021 to build and deploy the instrumentation at the telescope, carry out the survey, and publicly serve the data products. FOBOS would see first light in 2025 and carry a total cost of $32M (without contingency in 2019 dollars). While we focus the current request on work required for the preliminary design phase, we outline the overall project plan and final deliverables in order to motivate this work.

2.1. **Keck-FOBOS Instrument Concept.** **[[1 page]]**

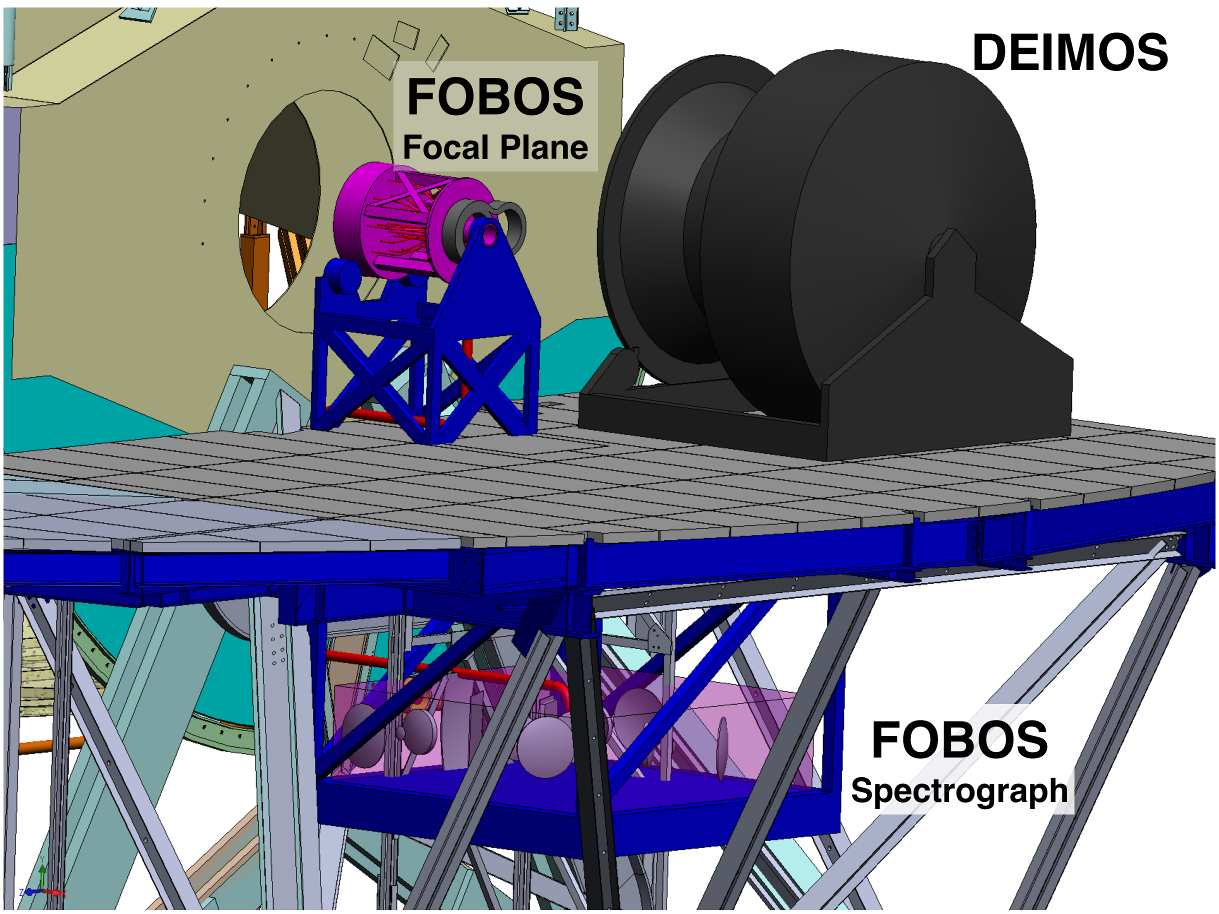

Figure 3. Rendering of FOBOS instrument systems deployed at the Keck II Nasmyth port. By mounting the FOBOS spectrographs under the Nasmyth platform, other instruments like DEIMOS can maintain access to the telescope.

Mounted at the Keck II Telescope's Nasmyth focus, the Fiber Optic Broadband Optical Spectrograph (FOBOS) will be one of the most powerful spectroscopic facilities in the next decade. FOBOS consists of several key components (Fig). A compensating lateral atmospheric dispersion corrector (CLADC) ensures that target light from all wavelengths falls on allocated fibers while also correcting image aberrations at the edges of the 20 arcmin diameter Keck field that result from the telescope design. The final lens surface in the 3-lens CLADC also serves as the mounting plate for roaming Starbugs fiber positioners. Starbugs patrol a large on-sky area, enabling flexible targeting configurations that can be dynamically adjusted during observations.

A total of 1800 150 μm core diameter fibers are deployed at the curved focal plane, which rotates and translates to maintain image positions as the telescope tracks across the sky. The fiber run is kept at less than ~10 m to maintain high throughput at UV wavelengths, and special care is given to stress-relief cabling to minimize variable focal ratio degradation over the fiber run.

Sets of 600 fibers feed each of three identical spectrographs. Each spectrograph uses a series of dichroics to divide the fiber output into four wavelength channels with combined coverage from 310 to 1000 nm and mid-channel spectral resolutions of $R \sim 3500$. The dispersed light in each channel is focused by an f/1.1 catadioptric camera and recorded by an on-axis CCD mounted at the center of the first camera lens element. Spectrographs are mounted in a temperature controlled housing installed under the Nasmyth Deck to allow space for other Keck instruments to access the Nasmyth port. The end-to-end instrument throughput is greater than 30% at all wavelengths.

FOBOS includes observatory level systems for precise instrument calibration using dome-interior screen illumination, a metrology system for accurate fiber positioning, and guide cameras for field acquisition and guiding. The instrument design envisions future upgrades including alternate collecting modes that deploy multiple fiber bundles, feeds to other fiber-based spectrographs at different wavelengths or spectral resolutions, and the ability to support and benefit from image corrections with Ground-Layer Adaptive Optics.

2.2. **Keck-FOBOS Instrument Design Effort.** [[**1 page**]]

Keck-FOBOS will complete its current conceptual design phase in October 2019. Funding from this proposal will support preliminary design beginning in November 2019. A detailed schedule of activities is attached. Major components of the preliminary design effort are described below.

Atmospheric Dispersion Compensator (ADC). The opto-mechanical design, tolerancing, lens cell design, motion systems, and software controls design of the ADC will be completed. We will complete a competitive bid selection of optics vendors so that upon passing the the FOBOS Preliminary Design Review (PDR), large lens procurement can begin immediately. This procurement is a long-lead item in the overall schedule.

Focal Plane System. The final ADC lens element serves as the focal plane mounting plate for the fiber positioners. This focal plane system must rotate and translate to track the field and refraction angles from the ADC. Mechanical design, including flexure analysis and the selection of drive mechanisms and vendors will be completed. This system also defines one of the interfaces to the Keck Telescope and must comply with Keck Observatory space envelopes, servicing needs, and other requirements. The focal plane system also interfaces with guide cameras for field acquisition and guiding.

Starbugs fiber positionsers. Starbugs are a positioning technology developed and deployed by the Australian Astronomical Observatory (AAO) which has partnered with our team to generate a conceptual design for Starbugs in the context of FOBOS. Design requirements for Starbugs in FOBOS are more relaxed than the currently on-sky TAIPAN instrument thanks to the larger physical plate scale at Keck. AAO will serve as a vendor during preliminary design but is interested in exploring a partnership and in-kind contribution model in the construction phase. In addition to the Starbugs themselves, a fiber metrology system (for accurate closed-loop positioning) will also be developed.

Fiber System. We will complete the optical design and processing plan for affixing forward optics lenses to each fiber's head (these demagnify and speed up the beam for proper fiber coupling). A micro-lens array solution will be developed for a central, fixed-position 4.5-arcsec diameter IFU for fast source acquisition. With vendors selected, we will be ready to begin prototyping. We will research anti-reflective coating vendors and options and detail throughput and stress performance specifications. This workpackage also includes the stress-relief cable system and fiber termination hardware and processing.

Spectrographs. The optical systems and components (slit, collimator, dichroics, gratings, and camera), an analysis of acceptable tolerances and performance, their mechanical supports, software controls, and the overall enclosure will all be advanced through preliminary design. Vendors for major components will complete competitive bids. Detectors, cryostats, read-out electronics and systems for thermal management will be designed and associated vendor relationships secured. We will complete a preliminary assembly and integration plan.

Calibration System. This package includes design of an interior dome screen and projection system for injecting calibration sources with sufficient spatial uniformity and stability into the instrument. We will work with the Observatory to develop an integration and controls plan. No such calibration system currently exists at Keck.

Auxiliary Systems. Design of auxiliary systems includes Nasmyth platform interfaces, utilities access, fiber routing and support, thermal control and vibration control systems.

2.3. **Design of Public Survey and Training Sets.** [[**1 page**]]

2.4. **Target Allocation with Artificial Intelligence.** [[**1/2 page**]]

Afforded the flexibility of the Starbugs positioning system, we envision a target allocation package that - maintains a database with observational progress on individual targets in the survey and - dynamically reallocates fibers based on real-time assessments of the aggregate S/N of each target to meet the specific need of each science case.

This requires significant design and testing of a combined software package and hardware interface. Specific considerations involve (1) fast and robust reduction procedures (cf. MaNGA DOS) that can assess the aggregate data and (2) a responsive database with a schema optimized for real-time decision making to select targets for (re)acquisition while accounting for collision limitations. Provided enough design effort, this lends itself to a machine-learning application.

2.5. **Pulicly Available Automated Data Products.** [[**1/2 page**]]

The advanced products of the survey will be delivered to the public via the Keck Observatory Archive (KOA). However, beyond the raw data, the survey will provide reduced and derived products immediately (cf. MaNGA DAP). The latter will be true of both the data from the public survey (released immediately) and indeed *any* data taken with the FOBOS instrument after the nominal 18-month proprietary period. For the latter, we will encourage involvement of the program PI in refining the data-reduction and data-analysis software and its execution to garner the most from its application to their data. Community involvement in a common software development obviates the need for different groups to retread old ground.

3. Broader Impacts

"include a discussion of student training, increased participation of underrepresented groups and a description of tangible benefits to the wider U.S. research community (access, data products, technology, etc.)."

3.1. Student training. [[**1/4 page**]]

3.2. ISEE?. [[**1/2 page**]]

3.3. Data Science Major in Astrophysics. [[**1/4 page**]]

"Preliminary proposals must include an outline of ongoing operations and maintenance plans, including an estimate of any needs for ongoing, NSF-supported operations and maintenance that may be requested outside of the Mid-scale RI program."

"Results from Prior NSF Support should not be included. Also, links to URLs may not be used." **no more than 2 pages for references**

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Budget and Budget Justification

"including budgets for any subawards. For preliminary proposals cost estimates may be preliminary estimates with the Basis of Estimates (BoE) included. Copies of vendor quotations should not be included in preliminary proposals. If the budget includes contingency, that contingency should cover the "known unknowns" and be used to mitigate identified risks."

Facilities, Equipment, and Other Resources:

In order for NSF, and its reviewers, to assess the scope of a proposed project, all organizational resources necessary for, and available to a project, must be described in this section of the proposal. Proposers should describe only those resources that are directly applicable. The description should be narrative in nature and must not include any quantifiable financial information. Proposers should include a description of the internal and external resources (both physical and personnel) that are expected to be available to the project. Such information must be provided in this section, in lieu of other parts of the proposal (e.g., Budget Justification, Project Description).

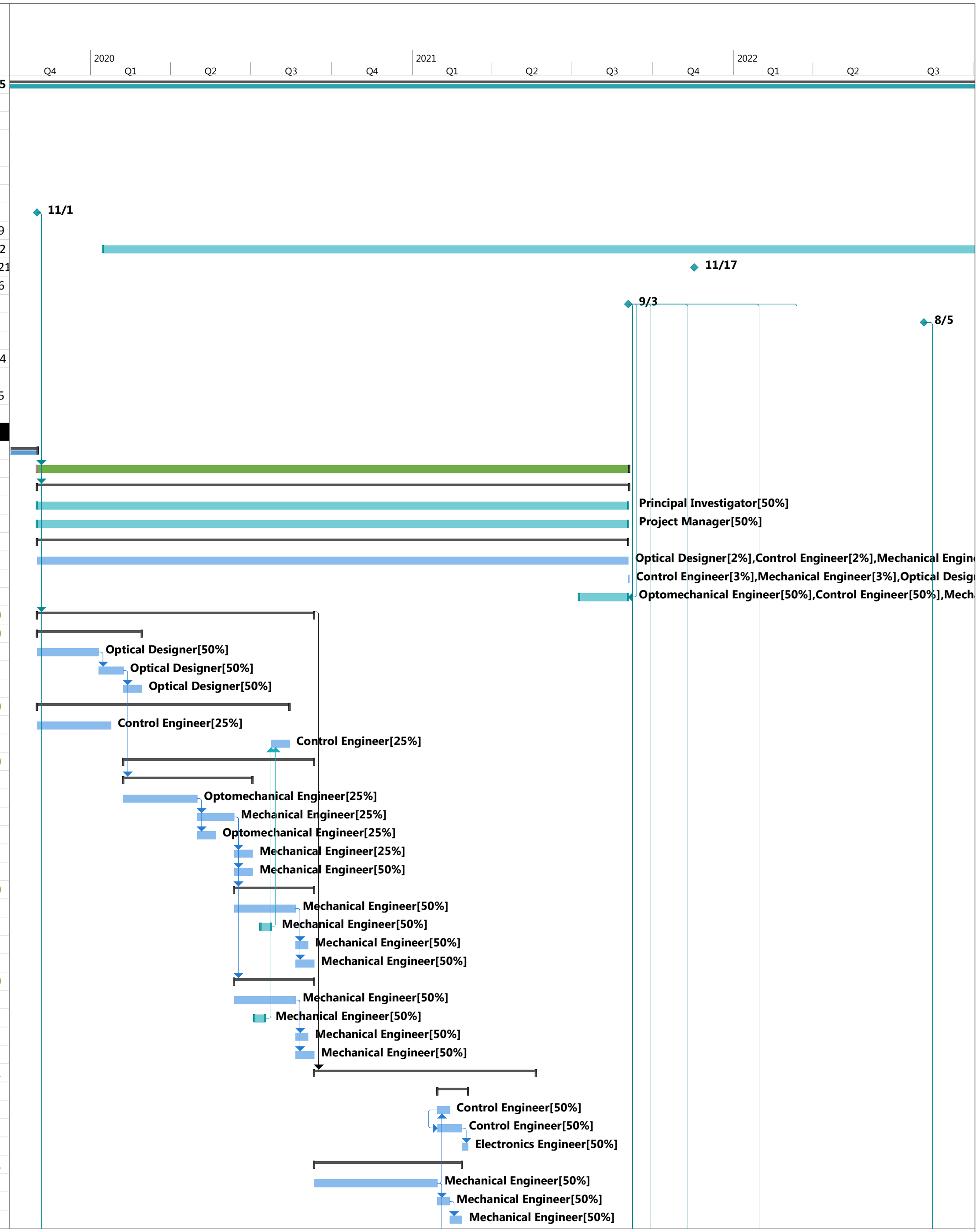
Supplementary Documents:

(to be entered in the Supplementary Documents section of FastLane)

(1) A list of the major team members, their affiliations, and their role in the project;
(2) A list of Partner Organizations to be funded via subawards, and the role of each in the project;
(3) An outline of the Project Execution Plan (PEP).

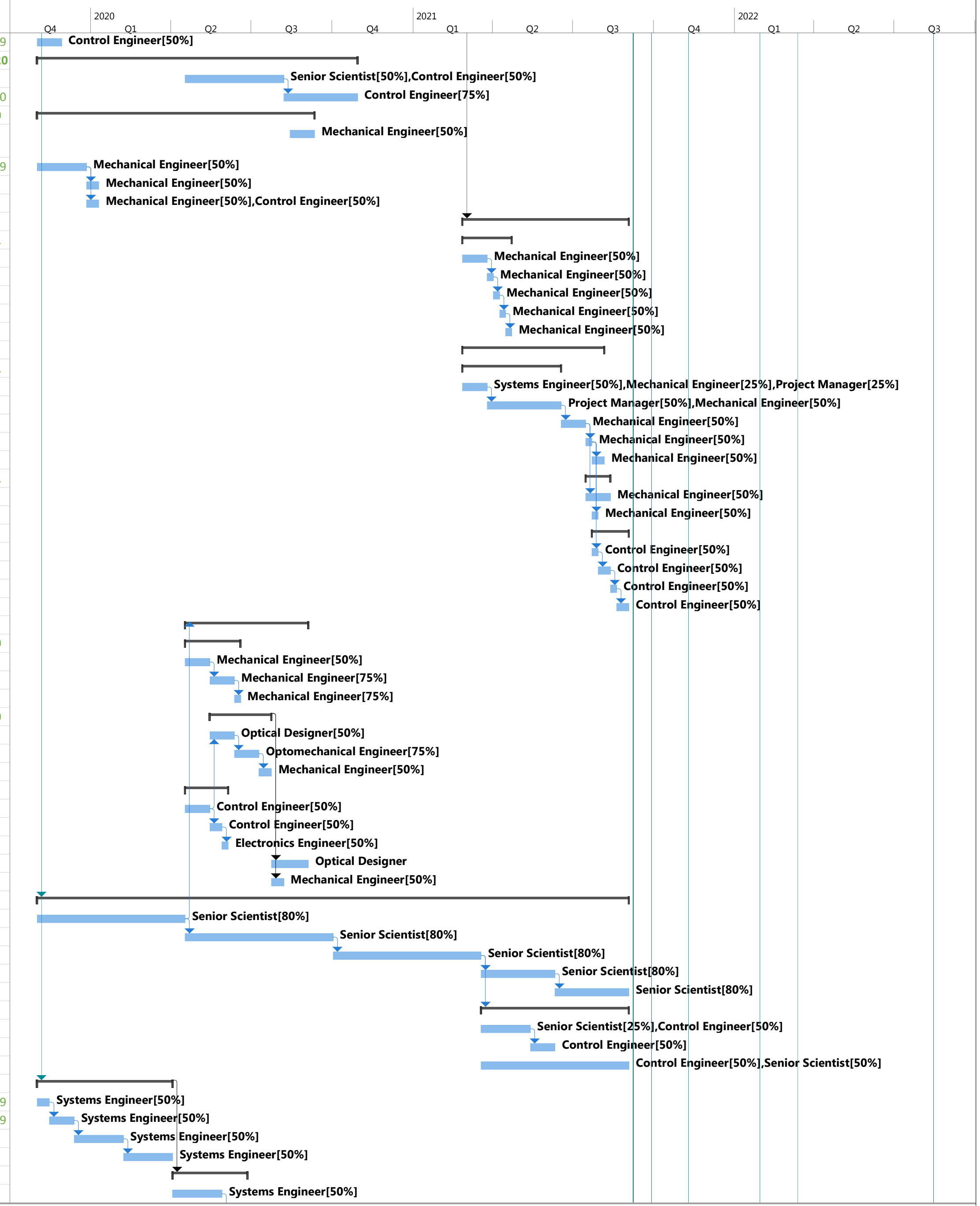
(See the LFM/MFG. Greater detail will be required in invited full proposals should that occur. See Full Proposal Preparation section for further information.)

ID		WBS	Task Mode	Task Name	Duration	Start	Finish
1		1		**FOBOS**	**1704 days?**	**Fri 2/1/19**	**Wed 8/13/25**
2		1.1		Project Start (Check WP date)	0 days	Mon 5/1/17	Mon 5/1/17
3		1.2		CoD Mini Grant I			
4		1.3		LBNL work shop	0 days	Thu 1/18/18	Thu 1/18/18
5		1.4		UCLA work shop	0 days	Fri 5/4/18	Fri 5/4/18
6		1.5		CoD Mini Grant II	0 days	Sun 7/1/18	Sun 7/1/18
7		1.6		CoD Mini Grant III	0 days		
8		1.7		Conceptual Design Review	0 days	Fri 11/1/19	Fri 11/1/19
9		1.8		MSRI-1 Proposal	0 days	Wed 2/13/19	Wed 2/13/19
10		1.9		MSRI-1 Funding coverage	36 mons	Wed 1/15/20	Tue 10/18/22
11		1.10		MSRI-2 Proposal	0 days	Wed 11/17/21	Wed 11/17/21
12		1.11		MSRI-2 Funding coverage	921 days	Wed 10/19/22	Wed 4/29/26
13		1.12		Preliminary Design Review	0 days	Fri 9/3/21	Fri 9/3/21
14		1.13		FDR1 (gate for long lead item purchases)	0 days	Fri 8/5/22	Fri 8/5/22
15		1.14		FDR2 (gate for full production)	0 days	Fri 7/7/23	Fri 7/7/23
16		1.15		Fabrication complete	0 days	Thu 11/28/24	Thu 11/28/24
17		1.16		Pre-ship review	0 days	Thu 3/20/25	Thu 3/20/25
18		1.17		First Light	0 days	Wed 8/20/25	Wed 8/20/25
19		1.18		Start of Science Operations	0 days	Wed 2/4/26	Wed 2/4/26
20		~~1.19~~		~~<New Task>~~			
21		**1.20**		**Conceptual Design**	**655 days**	**Mon 5/1/17**	**Fri 11/1/19**
69		**1.21**		**Preliminary Design**	**481 days?**	**Fri 11/1/19**	**Fri 9/3/21**
70		**1.21.1**		**Central Project Level Management**	**481 days?**	**Fri 11/1/19**	**Fri 9/3/21**
71		1.21.1.1		Principle Investigator	480 days	Fri 11/1/19	Thu 9/2/21
72		1.21.1.2		Project Management	480 days	Fri 11/1/19	Thu 9/2/21
73		**1.21.1.3**		**Systems Engineering**	**480 days**	**Fri 11/1/19**	**Thu 9/2/21**
77		1.21.1.4		Team meetings (leads meetings 2/year)	480 days	Fri 11/1/19	Thu 9/2/21
78		1.21.1.5		Weekly meetings	1 day?	Fri 9/3/21	Fri 9/3/21
79		1.21.1.6		PDR review prep	2 mons	Fri 7/9/21	Thu 9/2/21
80		**1.21.2**		**Atmospheric Dispersion corrector**	**225 days**	**Fri 11/1/19**	**Thu 9/10/20**
81		**1.21.2.1**		**Optical Design**	**85 days**	**Fri 11/1/19**	**Thu 2/27/20**
82		1.21.2.1.1		ADC Preliminary optical design (CLADC trade s	10 wks	Fri 11/1/19	Thu 1/9/20
83		1.21.2.1.2		Optical tolerance (Optical and Opto-mechanic	4 wks	Fri 1/10/20	Thu 2/6/20
84		1.21.2.1.3		Vender visits	3 wks	Fri 2/7/20	Thu 2/27/20
85		**1.21.2.2**		**Software/Controls Design**	**205 days**	**Fri 11/1/19**	**Thu 8/13/20**
86		1.21.2.2.1		Software architecture development	3 mons	Fri 11/1/19	Thu 1/23/20
87		1.21.2.2.2		Review of selected electromechanical systems	3 wks	Fri 7/24/20	Thu 8/13/20
88		**1.21.2.3**		**Mechanical Design**	**155 days**	**Fri 2/7/20**	**Thu 9/10/20**
89		**1.21.2.3.1**		**Optical Cell Design**	**105 days**	**Fri 2/7/20**	**Thu 7/2/20**
90		1.21.2.3.1.1		Mechanical Lens mount detailed design	12 wks	Fri 2/7/20	Thu 4/30/20
91		1.21.2.3.1.2		FEA on lens mount (thermal and Delta)	6 wks	Fri 5/1/20	Thu 6/11/20
92		1.21.2.3.1.3		Tolerance analysis	3 wks	Fri 5/1/20	Thu 5/21/20
93		1.21.2.3.1.4		Design of handling fixtures	3 wks	Fri 6/12/20	Thu 7/2/20
94		1.21.2.3.1.5		Design of mount tooling	3 wks	Fri 6/12/20	Thu 7/2/20
95		**1.21.2.3.2**		**ADC articulation mechanism design**	**65 days**	**Fri 6/12/20**	**Thu 9/10/20**
96		1.21.2.3.2.1		Detailed design of mechanism	10 wks	Fri 6/12/20	Thu 8/20/20
97		1.21.2.3.2.2		Drive system selection	2 wks	Sun 7/12/20	Thu 7/23/20
98		1.21.2.3.2.3		Design assembly and handling tooling	2 wks	Fri 8/21/20	Thu 9/3/20
99		1.21.2.3.2.4		FEA/Tolerance analysis	3 wks	Fri 8/21/20	Thu 9/10/20
100		**1.21.2.3.3**		**ADC rotation mechanism design**	**65 days**	**Fri 6/12/20**	**Thu 9/10/20**
101		1.21.2.3.3.1		Detailed design of mechanism	10 wks	Fri 6/12/20	Thu 8/20/20
102		1.21.2.3.3.2		Drive system selection	2 wks	Sun 7/5/20	Thu 7/16/20
103		1.21.2.3.3.3		Design assembly and handling tooling	2 wks	Fri 8/21/20	Thu 9/3/20
104		1.21.2.3.3.4		FEA/Tolerance analysis	3 wks	Fri 8/21/20	Thu 9/10/20
105		**1.21.3**		**Field rotation and translation system**	**180 days**	**Fri 9/11/20**	**Thu 5/20/21**
106		**1.21.3.1**		**Software/controls PD**	**25 days**	**Fri 1/29/21**	**Thu 3/4/21**
107		1.21.3.1.1		Selection of drive components	2 wks	Fri 1/29/21	Thu 2/11/21
108		1.21.3.1.2		Software architecture development	4 wks	Fri 1/29/21	Thu 2/25/21
109		1.21.3.1.3		Cabling and utility schematic	1 wk	Fri 2/26/21	Thu 3/4/21
110		**1.21.3.2**		**Field Rotator Mechanical PD**	**120 days**	**Fri 9/11/20**	**Thu 2/25/21**
111		1.21.3.2.1		Detailed design of mechanism	5 mons	Fri 9/11/20	Thu 1/28/21
112		1.21.3.2.2		Drive system selection	2 wks	Fri 1/29/21	Thu 2/11/21
113		1.21.3.2.3		Flexure estimates	2 wks	Fri 2/12/21	Thu 2/25/21

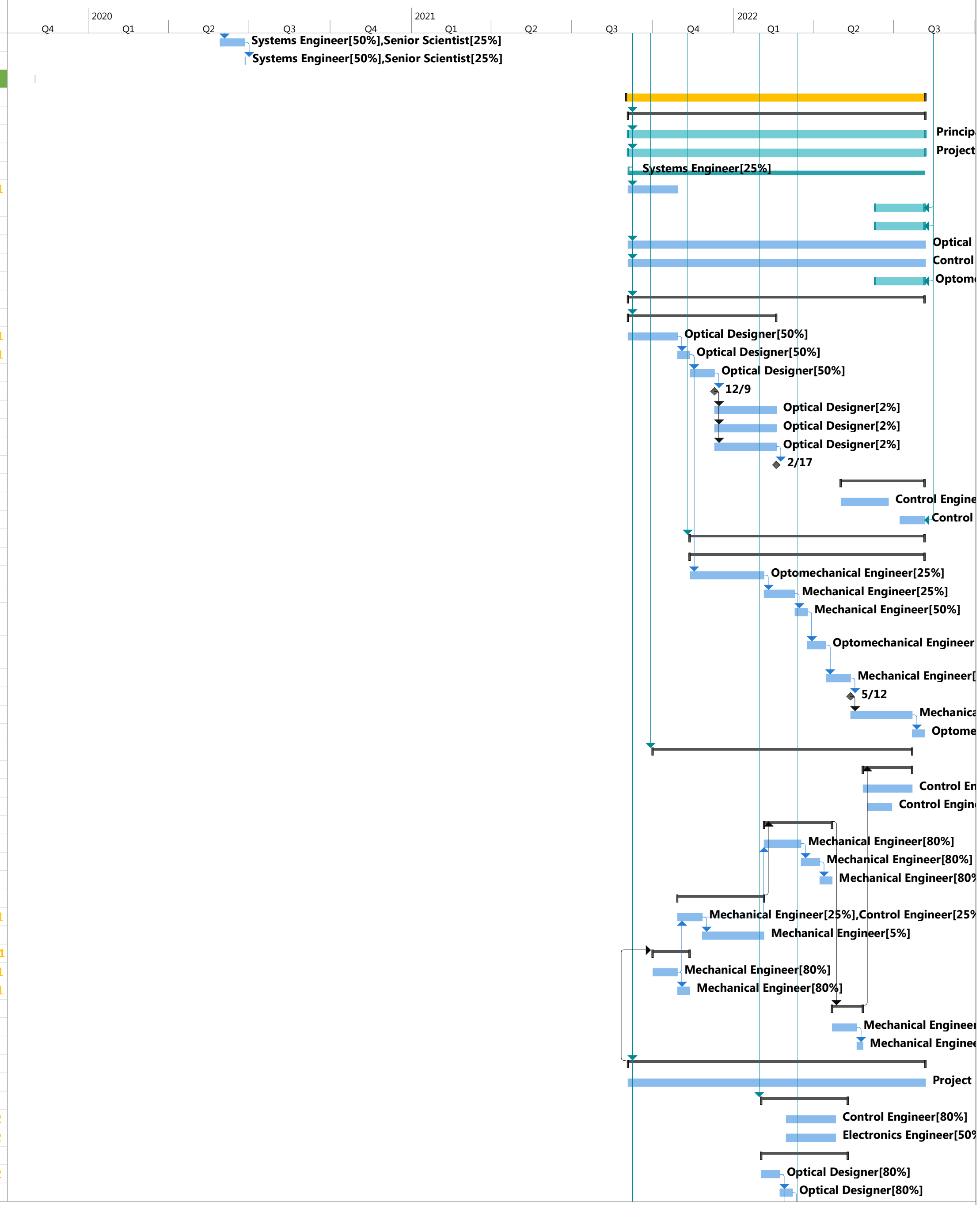


ID		WBS	Task Mode	Task Name	Duration	Start	Finish
114		1.21.3.3		Field Tilt Mechanical PD	80 days	Fri 1/29/21	Thu 5/20/21
115		1.21.3.3.1		Hexapod vendor selection	3 mons	Fri 1/29/21	Thu 4/22/21
116		1.21.3.3.2		Interface detailed design	2 wks	Fri 4/23/21	Thu 5/6/21
117		1.21.3.3.3		Flexure estimates	2 wks	Fri 5/7/21	Thu 5/20/21
118		1.21.3.4		Focal plane interface PD	30 days	Fri 1/29/21	Thu 3/11/21
119		1.21.3.4.1		Focal plane interface design	2 wks	Fri 1/29/21	Thu 2/11/21
120		1.21.3.4.2		Space constraint development for FFP & GAW	4 wks	Fri 2/12/21	Thu 3/11/21
121		1.21.3.5		Telescope interface PD	20 days	Fri 4/23/21	Thu 5/20/21
122		1.21.3.5.1		FPM to SUPT design	2 wks	Fri 4/23/21	Thu 5/6/21
123		1.21.3.5.2		Mass, waste heat, utility estimates	2 wks	Fri 5/7/21	Thu 5/20/21
124		1.21.4		Robotic focal plane and associated development	360 days	Fri 11/1/19	Thu 3/18/21
125		1.21.4.1		AAO Contract development	6 mons	Fri 11/1/19	Thu 4/16/20
126		1.21.4.2		PD contract with AAO Starbugs	12 mons	Fri 4/17/20	Thu 3/18/21
127		1.21.4.3		PD contract with AAO Focal plane	12 mons	Fri 4/17/20	Thu 3/18/21
128		1.21.5		Guiding/acquisition system and wave front sensin	50 days	Fri 2/12/21	Thu 4/22/21
129		1.21.5.1		Software/controls PD	30 days	Fri 2/12/21	Thu 3/25/21
130		1.21.5.1.1		Camera selection	2 wks	Fri 2/12/21	Thu 2/25/21
131		1.21.5.1.2		Software architecture & Keck interface IDC	4 wks	Fri 2/26/21	Thu 3/25/21
132		1.21.5.1.3		Cabling and utility schematic	1 wk	Fri 2/26/21	Thu 3/4/21
133		1.21.5.2		Optical PD	10 days	Fri 2/26/21	Thu 3/11/21
134		1.21.5.2.1		Guide system forward optics design	2 wks	Fri 2/26/21	Thu 3/11/21
135		1.21.5.3		Mechanical PD	15 days	Fri 3/12/21	Thu 4/1/21
136		1.21.5.3.1		Forward optics support design/camera interfa	2 wks	Fri 3/12/21	Thu 3/25/21
137		1.21.5.3.2		Guide system to FPM interface design	1 wk	Fri 3/26/21	Thu 4/1/21
138		1.21.5.4		GLAO upgrade path study	1 mon	Fri 3/26/21	Thu 4/22/21
139		1.21.6		Fiber system	260 days	Fri 4/17/20	Thu 4/15/21
140		1.21.6.1		Forward Optics PD	165 days	Fri 4/17/20	Thu 12/3/20
141		1.21.6.1.1		Forward Optics Optical PD	165 days	Fri 4/17/20	Thu 12/3/20
142		1.21.6.1.1.1		Single Fiber Forward optics PD	10 wks	Fri 4/17/20	Thu 6/25/20
143		1.21.6.1.1.2		IFU lenslet coupling optics PD	10 wks	Fri 6/26/20	Thu 9/3/20
144		1.21.6.1.1.3		Coatings vender research	4 wks	Fri 9/4/20	Thu 10/1/20
145		1.21.6.1.1.4		Performance estimates	3 wks	Fri 11/13/20	Thu 12/3/20
146		1.21.6.1.2		Forward Optics Mechanical design	110 days	Fri 6/26/20	Thu 11/26/20
147		1.21.6.1.2.1		Single fiber Optomechanical PD	6 wks	Fri 6/26/20	Thu 8/6/20
148		1.21.6.1.2.2		IFU lenslet coupling Optomechanical PD	10 wks	Fri 9/4/20	Thu 11/12/20
149		1.21.6.1.2.3		Tolerance analysis	2 wks	Fri 11/13/20	Thu 11/26/20
150		1.21.6.2		Cable Design PD	260 days	Fri 4/17/20	Thu 4/15/21
151		1.21.6.2.1		Bug interface PD	4 wks	Fri 11/27/20	Thu 12/24/20
152		1.21.6.2.2		Cable jacketing and mapping plan	6 wks	Fri 11/27/20	Thu 1/7/21
153		1.21.6.2.3		Slit termination PD	4 wks	Fri 1/8/21	Thu 2/4/21
154		1.21.6.2.4		Fiber support system	8 wks	Fri 2/5/21	Thu 4/1/21
155		1.21.6.2.5		End to end performance estimates	2 wks	Fri 4/2/21	Thu 4/15/21
156		1.21.6.2.6		Testing and validation	180 days	Fri 4/17/20	Thu 12/24/20
157		1.21.6.2.6.1		Test stand development	6 mons	Fri 4/17/20	Thu 10/1/20
158		1.21.6.2.6.2		Test stand automation	2 mons	Fri 10/2/20	Thu 11/26/20
159		1.21.6.2.6.3		Testing plan	4 wks	Fri 11/27/20	Thu 12/24/20
160		1.21.7		Spectrograph	345 days	Fri 11/1/19	Thu 2/25/21
161		1.21.7.1		Spectrograph optical PD	345 days	Fri 11/1/19	Thu 2/25/21
182		1.21.7.2		Spectrograph opto-mechanical PD	195 days	Fri 4/17/20	Thu 1/14/21
183		1.21.7.2.1		Bench and structural support PD	1 mon	Fri 4/17/20	Thu 5/14/20
184		1.21.7.2.2		Slit PD	2 wks	Fri 5/29/20	Thu 6/11/20
185		1.21.7.2.3		Collimator support PD	6 wks	Fri 5/15/20	Thu 6/25/20
186		1.21.7.2.4		Dichroic support PD	4 wks	Fri 6/26/20	Thu 7/23/20
187		1.21.7.2.5		Grating support PD	4 wks	Fri 7/24/20	Thu 8/20/20
188		1.21.7.2.6		Shutter interface PD (assumes vender shutter	2 wks	Fri 8/21/20	Thu 9/3/20
189		1.21.7.2.7		Camera optomechanical PD	4 mons	Fri 8/14/20	Thu 12/3/20
190		1.21.7.2.8		System analysis	30 days	Fri 12/4/20	Thu 1/14/21
191		1.21.7.2.8.1		Optics mounts FEA	4 wks	Fri 12/4/20	Thu 12/31/20
192		1.21.7.2.8.2		CTE analysis's of full optics train	2 wks	Fri 1/1/21	Thu 1/14/21
193		1.21.7.3		Spectrograph Control PD	160 days	Fri 11/1/19	Thu 6/11/20
194		1.21.7.3.1		Robotic Systems PD	40 days	Fri 4/17/20	Thu 6/11/20
195		1.21.7.3.1.1		Component selection	4 wks	Fri 4/17/20	Thu 5/14/20
196		1.21.7.3.1.2		Control Architecture	4 wks	Fri 5/15/20	Thu 6/11/20

ID	WBS	Task Mode	Task Name	Duration	Start	Finish
197	1.21.7.3.2		Detector thermal control PD	4 wks	Fri 11/1/19	Thu 11/28/19
198	**1.21.7.4**		**Detector PD**	**260 days**	**Fri 11/1/19**	**Thu 10/29/20**
199	1.21.7.4.1		Detector Requirements	4 mons	Fri 4/17/20	Thu 8/6/20
200	1.21.7.4.2		Detector readout PD	3 mons	Fri 8/7/20	Thu 10/29/20
201	**1.21.7.4.3**		**Cryostat PD**	**225 days**	**Fri 11/1/19**	**Thu 9/10/20**
202	1.21.7.4.3.1		Cryostat mechanical design (Vacuum, structural, utility feeds)	4 wks	Fri 8/14/20	Thu 9/10/20
203	1.21.7.4.3.2		Detector support PD	8 wks	Fri 11/1/19	Thu 12/26/19
204	1.21.7.4.3.3		Preliminary thermal modeling	2 wks	Fri 12/27/19	Thu 1/9/20
205	1.21.7.4.3.4		Preliminary integration plan	2 wks	Fri 12/27/19	Thu 1/9/20
206	**1.21.8**		**Support systems**	**135 days**	**Fri 2/26/21**	**Thu 9/2/21**
207	**1.21.8.1**		**Naysmith platform interface cart PD**	**40 days**	**Fri 2/26/21**	**Thu 4/22/21**
208	1.21.8.1.1		Support cart PD	4 wks	Fri 2/26/21	Thu 3/25/21
209	1.21.8.1.2		Deploy kinematic interface design	1 wk	Fri 3/26/21	Thu 4/1/21
210	1.21.8.1.3		Utility plan (deploy & stow)	1 wk	Fri 4/2/21	Thu 4/8/21
211	1.21.8.1.4		Stow position cover	1 wk	Fri 4/9/21	Thu 4/15/21
212	1.21.8.1.5		Deployment sequence	1 wk	Fri 4/16/21	Thu 4/22/21
213	**1.21.8.2**		**Spectrograph platform PD**	**115 days**	**Fri 2/26/21**	**Thu 8/5/21**
214	**1.21.8.2.1**		**Structural support/modifications to existing**	**80 days**	**Fri 2/26/21**	**Thu 6/17/21**
215	1.21.8.2.1.1		Requirements development	4 wks	Fri 2/26/21	Thu 3/25/21
216	1.21.8.2.1.2		RFP development	3 mons	Fri 3/26/21	Thu 6/17/21
217	1.21.8.2.2		Thermal enclosure design	4 wks	Fri 6/18/21	Thu 7/15/21
218	1.21.8.2.3		Utility schematic and load requirements	1 wk	Fri 7/16/21	Thu 7/22/21
219	1.21.8.2.4		Vibration isolation plan	2 wks	Fri 7/23/21	Thu 8/5/21
220	**1.21.8.3**		**Fiber routing and support PD**	**20 days**	**Fri 7/16/21**	**Thu 8/12/21**
221	1.21.8.3.1		Static fiber support system	4 wks	Fri 7/16/21	Thu 8/12/21
222	1.21.8.3.2		Stow to deploy fiber handling	1 wk	Fri 7/23/21	Thu 7/29/21
223	**1.21.8.4**		**Support systems controls PD**	**30 days**	**Fri 7/23/21**	**Thu 9/2/21**
224	1.21.8.4.1		FP deploy/stow state system PD	1 wk	Fri 7/23/21	Thu 7/29/21
225	1.21.8.4.2		Spectrograph Health monitoring system	2 wks	Fri 7/30/21	Thu 8/12/21
226	1.21.8.4.3		Thermal enclosure requirements	1 wk	Fri 8/13/21	Thu 8/19/21
227	1.21.8.4.4		Interlock architecture PD	2 wks	Fri 8/20/21	Thu 9/2/21
228	**1.21.9**		**Calibration system**	**100 days**	**Fri 4/17/20**	**Thu 9/3/20**
229	**1.21.9.1**		**Calibration screen design**	**45 days**	**Fri 4/17/20**	**Thu 6/18/20**
230	1.21.9.1.1		Screen to Dome interface PD	4 wks	Fri 4/17/20	Thu 5/14/20
231	1.21.9.1.2		Screen material selection	4 wks	Fri 5/15/20	Thu 6/11/20
232	1.21.9.1.3		Vender selection	1 wk	Fri 6/12/20	Thu 6/18/20
233	**1.21.9.2**		**Calibration lamp design**	**50 days**	**Fri 5/15/20**	**Thu 7/23/20**
234	1.21.9.2.1		Lamp optical PD	4 wks	Fri 5/15/20	Thu 6/11/20
235	1.21.9.2.2		Lamp optomechanical PD	4 wks	Fri 6/12/20	Thu 7/9/20
236	1.21.9.2.3		Lamp interface structure	2 wks	Fri 7/10/20	Thu 7/23/20
237	**1.21.9.3**		**Controls PD**	**35 days**	**Fri 4/17/20**	**Thu 6/4/20**
238	1.21.9.3.1		Power supply/lamp selection	4 wks	Fri 4/17/20	Thu 5/14/20
239	1.21.9.3.2		Controls PD	2 wks	Fri 5/15/20	Thu 5/28/20
240	1.21.9.3.3		Utility schematics	1 wk	Fri 5/29/20	Thu 6/4/20
241	1.21.9.4		Performance evaluation	6 wks	Fri 7/24/20	Thu 9/3/20
242	1.21.9.5		Integration plan	2 wks	Fri 7/24/20	Thu 8/6/20
243	**1.21.10**		**Data reduction pipeline**	**480 days**	**Fri 11/1/19**	**Thu 9/2/21**
244	1.21.10.1		FOBOS sim development	6 mons	Fri 11/1/19	Thu 4/16/20
245	1.21.10.2		Simulations to support design choices	6 mons	Fri 4/17/20	Thu 10/1/20
246	1.21.10.3		Target aggregator development plan	6 mons	Fri 10/2/20	Thu 3/18/21
247	1.21.10.4		DRP development plan	3 mons	Fri 3/19/21	Thu 6/10/21
248	1.21.10.5		DAP development plan	3 mons	Fri 6/11/21	Thu 9/2/21
249	**1.21.11**		**Operations software**	**120 days**	**Fri 3/19/21**	**Thu 9/2/21**
250	1.21.11.1		Operations software architecture development	2 mons	Fri 3/19/21	Thu 5/13/21
251	1.21.11.2		Telescope IDC	1 mon	Fri 5/14/21	Thu 6/10/21
252	1.21.11.3		Prototype user interface	6 mons	Fri 3/19/21	Thu 9/2/21
253	**1.21.12**		**System integration and test**	**110 days**	**Fri 11/1/19**	**Thu 4/2/20**
254	1.21.12.1		Staging plan update	2 wks	Fri 11/1/19	Thu 11/14/19
255	1.21.12.2		Facility and tooling requirements development	1 mon	Fri 11/15/19	Thu 12/12/19
256	1.21.12.3		Detailed testing plan 'back end' Draft 1	2 mons	Fri 12/13/19	Thu 2/6/20
257	1.21.12.4		Detailed testing plan 'front end' Draft 1	2 mons	Fri 2/7/20	Thu 4/2/20
258	**1.21.13**		**System deployment and commissioning**	**61 days**	**Fri 4/3/20**	**Fri 6/26/20**
259	1.21.13.1		Keck integration plan Draft 1	2 mons	Fri 4/3/20	Thu 5/28/20



ID		WBS	Task Mode	Task Name	Duration	Start	Finish
260		1.21.13.2		FOBOS commissioning plan Draft 1	1 mon	Fri 5/29/20	Thu 6/25/20
261		1.21.13.3		Commissioning acceptance matrix Draft 1	0.05 mons	Fri 6/26/20	Fri 6/26/20
262							
263		1.22		Final Design One	243 days?	Wed 9/1/21	Fri 8/5/22
264		1.22.1		Central Project Level Management	241 days	Fri 9/3/21	Fri 8/5/22
265		1.22.1.1		Principle Investigator	241 days	Fri 9/3/21	Fri 8/5/22
266		1.22.1.2		Project Management	241 days	Fri 9/3/21	Fri 8/5/22
267		1.22.1.3		Systems Engineering		Fri 9/3/21	
268		1.22.1.3.1		Work package IDC development	8 wks	Fri 9/3/21	Thu 10/28/21
269		1.22.1.3.2		Risk analysis	8 wks	Fri 6/10/22	Thu 8/4/22
270		1.22.1.3.3		Requirements flow down	8 wks	Fri 6/10/22	Thu 8/4/22
271		1.22.1.4		Team meetings (leads meetings 2/year)	241 days	Fri 9/3/21	Fri 8/5/22
272		1.22.1.5		Weekly meetings	241 days	Fri 9/3/21	Fri 8/5/22
273		1.22.1.6		FDR-1 review prep	2 mons	Fri 6/10/22	Thu 8/4/22
274		1.22.2		Atmospheric Dispersion corrector	240 days	Fri 9/3/21	Fri 8/5/22
275		1.22.2.1		Optical Design	120 days	Fri 9/3/21	Thu 2/17/22
276		1.22.2.1.1		Final Optical ADC design	8 wks	Fri 9/3/21	Thu 10/28/21
277		1.22.2.1.2		Develop drawings and specifications for optics	2 wks	Fri 10/29/21	Thu 11/11/21
278		1.22.2.1.3		Development of RFQ's for prism construction	4 wks	Fri 11/12/21	Thu 12/9/21
279		1.22.2.1.4		Release RFQ's to venders	0 days	Thu 12/9/21	Thu 12/9/21
280		1.22.2.1.5		Competitive bid (Materials)	10 wks	Fri 12/10/21	Thu 2/17/22
281		1.22.2.1.6		Competitive bid (polishing)	10 wks	Fri 12/10/21	Thu 2/17/22
282		1.22.2.1.7		Competitive bid (coating)	10 wks	Fri 12/10/21	Thu 2/17/22
283		1.22.2.1.8		Vender Selection	0 days	Thu 2/17/22	Thu 2/17/22
284		1.22.2.2		Software/Controls Design	69 days	Mon 5/2/22	Fri 8/5/22
285		1.22.2.2.1		Prototype software (simulated load)	2 mons	Mon 5/2/22	Fri 6/24/22
286		1.22.2.2.2		Key word development	1 mon	Fri 7/8/22	Fri 8/5/22
287		1.22.2.3		Mechanical Design	190 days	Fri 11/12/21	Thu 8/4/22
288		1.22.2.3.1		Optical Cell Design	190 days	Fri 11/12/21	Thu 8/4/22
289		1.22.2.3.1.1		Mechanical Lens mount detailed design	12 wks	Fri 11/12/21	Thu 2/3/22
290		1.22.2.3.1.2		Final FEA of lens cells and documentation	5 wks	Fri 2/4/22	Thu 3/10/22
291		1.22.2.3.1.3		Set acceleration limits for optics (operations and seismic)	2 wks	Fri 3/11/22	Thu 3/24/22
292		1.22.2.3.1.4		Lens Cell and related components production drawings	3 wks	Fri 3/25/22	Thu 4/14/22
293		1.22.2.3.1.5		Develop RFQ for lens cell fab	4 wks	Fri 4/15/22	Thu 5/12/22
294		1.22.2.3.1.6		Release RFQ for lens cell manufacturing	0 days	Thu 5/12/22	Thu 5/12/22
295		1.22.2.3.1.7		Bid lead time	10 wks	Fri 5/13/22	Thu 7/21/22
296		1.22.2.3.1.8		Vender selection	2 wks	Fri 7/22/22	Thu 8/4/22
297		1.22.3		Field rotation and translation system	210 days	Fri 10/1/21	Thu 7/21/22
298		1.22.3.1		Software/controls FD	40 days	Fri 5/27/22	Thu 7/21/22
299		1.22.3.1.1		Prototype software (simulated load)	2 mons	Fri 5/27/22	Thu 7/21/22
300		1.22.3.1.2		key word development	1 mon	Wed 6/1/22	Tue 6/28/22
301		1.22.3.2		Field Rotator Mechanical FD	55 days	Fri 2/4/22	Thu 4/21/22
302		1.22.3.2.1		Detailed design of mechanism	6 wks	Fri 2/4/22	Thu 3/17/22
303		1.22.3.2.2		Shop drawings	3 wks	Fri 3/18/22	Thu 4/7/22
304		1.22.3.2.3		Flexure estimates	2 wks	Fri 4/8/22	Thu 4/21/22
305		1.22.3.3		Field Tilt Mechanical FD	70 days	Fri 10/29/21	Thu 2/3/22
306		1.22.3.3.1		Hexapod RFQ development	4 wks	Fri 10/29/21	Thu 11/25/21
307		1.22.3.3.2		RFQ lead time	10 wks	Fri 11/26/21	Thu 2/3/22
308		1.22.3.4		Focal plane interface FD	30 days	Fri 10/1/21	Thu 11/11/21
309		1.22.3.4.1		Focal plane interface FD	4 wks	Fri 10/1/21	Thu 10/28/21
310		1.22.3.4.2		Focal plane interface Shop drawings	2 wks	Fri 10/29/21	Thu 11/11/21
311		1.22.3.5		Telescope interface FD	25 days	Fri 4/22/22	Thu 5/26/22
312		1.22.3.5.1		FPM to SUPT FD	4 wks	Fri 4/22/22	Thu 5/19/22
313		1.22.3.5.2		Shop drawings	1 wk	Fri 5/20/22	Thu 5/26/22
314		1.22.4		Robotic focal plane and associated development	241 days	Fri 9/3/21	Fri 8/5/22
315		1.22.4.1		Robotic focal plane development contract	241 days	Fri 9/3/21	Fri 8/5/22
316		1.22.5		Guiding/acquisition system and wave front sensin	70 days?	Tue 2/1/22	Mon 5/9/22
317		1.22.5.1		Software/Controls FD	2 mons	Tue 3/1/22	Mon 4/25/22
318		1.22.5.2		Cabling schematics and ele FD	2 mons	Tue 3/1/22	Mon 4/25/22
319		1.22.5.3		Optical FD	70 days?	Tue 2/1/22	Mon 5/9/22
320		1.22.5.3.1		Optics FD	3 wks	Tue 2/1/22	Mon 2/21/22
321		1.22.5.3.2		Production drawings	2 wks	Tue 2/22/22	Mon 3/7/22



ID		WBS	Task Mode	Task Name	Duration	Start	Finish
322		1.22.5.3.3		Optics bid package development	0.8 wks	Tue 3/8/22	Fri 3/11/22
323		1.22.5.3.4		Bid lead time	8 wks	Mon 3/14/22	Fri 5/6/22
324		1.22.5.3.5		Vender selection	1 day?	Mon 5/9/22	Mon 5/9/22
325		**1.22.5.4**		**Mechanical FD**	**50 days**	**Tue 2/22/22**	**Mon 5/2/22**
326		1.22.5.4.1		Mechanical FD	4 wks	Tue 2/22/22	Mon 3/21/22
327		1.22.5.4.2		Shop drawings	2 wks	Tue 3/22/22	Mon 4/4/22
328		1.22.5.4.3		Focal plane interface definition	4 wks	Tue 4/5/22	Mon 5/2/22
329		**1.22.6**		**Fiber system and forward optics**	**170 days**	**Fri 9/3/21**	**Thu 4/28/22**
330		**1.22.6.1**		**Forward optics prototyping (single fiber mode)**	**115 days**	**Fri 9/3/21**	**Thu 2/10/22**
331		1.22.6.1.1		Prototype design	1 mon	Fri 9/3/21	Thu 9/30/21
332		1.22.6.1.2		Prototype optical drawings	2 wks	Fri 10/1/21	Thu 10/14/21
333		1.22.6.1.3		Prototype optics order	10 wks	Fri 10/15/21	Thu 12/23/21
334		1.22.6.1.4		prototype optomechanical drawings	2 wks	Fri 10/1/21	Thu 10/14/21
335		1.22.6.1.5		prototype optomechanical production	6 wks	Fri 10/15/21	Thu 11/25/21
336		1.22.6.1.6		prototype assembly	1 wk	Fri 12/24/21	Thu 12/30/21
337		1.22.6.1.7		prototype testing	6 wks	Fri 12/31/21	Thu 2/10/22
338		**1.22.6.2**		**Forward optics FD (single fiber mode)**	**25 days**	**Fri 2/11/22**	**Thu 3/17/22**
339		**1.22.6.2.1**		**Optical Design**	**20 days**	**Fri 2/11/22**	**Thu 3/10/22**
340		1.22.6.2.1.1		Optical FD	2 wks	Fri 2/11/22	Thu 2/24/22
341		1.22.6.2.1.2		Optical tolerance analysis	1 wk	Fri 2/25/22	Thu 3/3/22
342		1.22.6.2.1.3		Performance prediction	1 wk	Fri 3/4/22	Thu 3/10/22
343		**1.22.6.2.2**		**Optomechanical Design**	**15 days**	**Fri 2/25/22**	**Thu 3/17/22**
344		1.22.6.2.2.1		Forward optics Opto-mechanical FD	2 wks	Fri 2/25/22	Thu 3/10/22
345		1.22.6.2.2.2		Tolerance analysis	1 wk	Fri 3/11/22	Thu 3/17/22
346		**1.22.6.3**		**Forward optics FD (IFU mode)**	**35 days**	**Fri 3/11/22**	**Thu 4/28/22**
347		**1.22.6.3.1**		**Optical Design**	**30 days**	**Fri 3/11/22**	**Thu 4/21/22**
348		1.22.6.3.1.1		Optical FD	3 wks	Fri 3/11/22	Thu 3/31/22
349		1.22.6.3.1.2		Optical tolerance analysis	2 wks	Fri 4/1/22	Thu 4/14/22
350		1.22.6.3.1.3		Performance prediction	1 wk	Fri 4/15/22	Thu 4/21/22
351		**1.22.6.3.2**		**Optomechanical Design**	**20 days**	**Fri 4/1/22**	**Thu 4/28/22**
352		1.22.6.3.2.1		Forward optics Opto-mechanical FD	3 wks	Fri 4/1/22	Thu 4/21/22
353		1.22.6.3.2.2		Tolerance analysis	1 wk	Fri 4/22/22	Thu 4/28/22
354		**1.22.6.4**		**Cable Design FD**	**135 days**	**Fri 9/3/21**	**Thu 3/10/22**
355		1.22.6.4.1		Fiber selection	2 wks	Fri 9/3/21	Thu 9/16/21
356		1.22.6.4.2		Fiber quote lead time	6 wks	Fri 9/17/21	Thu 10/28/21
357		**1.22.6.4.3**		**Cabling FD**	**125 days**	**Fri 9/17/21**	**Thu 3/10/22**
358		1.22.6.4.3.1		Slit termination FD	2 wks	Fri 9/17/21	Thu 9/30/21
359		1.22.6.4.3.2		Cable FD	6 wks	Fri 10/1/21	Thu 11/11/21
360		1.22.6.4.3.3		Cable RFQ development	4 wks	Fri 11/12/21	Thu 12/9/21
361		1.22.6.4.3.4		RFQ lead time	2 mons	Fri 12/10/21	Thu 2/3/22
362		1.22.6.4.3.5		Vender selection	1 wk	Fri 2/4/22	Thu 2/10/22
363		1.22.6.4.3.6		Vender contract development	4 wks	Fri 2/11/22	Thu 3/10/22
364		1.22.6.5		testing plan refinement	8 wks	Fri 2/11/22	Thu 4/7/22
365		**1.22.7**		**Spectrograph**	**235 days**	**Fri 9/3/21**	**Thu 7/28/22**
366		**1.22.7.1**		**Spectrograph optical FD**	**235 days**	**Fri 9/3/21**	**Thu 7/28/22**
367		**1.22.7.1.1**		**System level optical FD**	**120 days**	**Fri 9/3/21**	**Thu 2/17/22**
368		1.22.7.1.1.1		System optical layout FD	4 mons	Fri 9/3/21	Thu 12/23/21
369		1.22.7.1.1.2		Tolerance analysis	2 mons	Fri 12/24/21	Thu 2/17/22
370		**1.22.7.1.2**		**Grating**	**115 days**	**Fri 2/18/22**	**Thu 7/28/22**
371		1.22.7.1.2.1		Final FSE design	4 wks	Fri 2/18/22	Thu 3/17/22
372		1.22.7.1.2.2		Production drawings and documents packa	4 wks	Fri 3/18/22	Thu 4/14/22
373		1.22.7.1.2.3		RFQ development	4 wks	Fri 4/15/22	Thu 5/12/22
374		1.22.7.1.2.4		Bid lead time	10 wks	Fri 5/13/22	Thu 7/21/22
375		1.22.7.1.2.5		Vender selection	1 wk	Fri 7/22/22	Thu 7/28/22
376		**1.22.7.1.3**		**camera**	**210 days**	**Fri 9/3/21**	**Thu 6/23/22**
377		1.22.7.1.3.1		Final Optical Design	6 wks	Fri 9/3/21	Thu 10/14/21
378		1.22.7.1.3.2		Cryostat IDC finalization	4 wks	Fri 10/15/21	Thu 11/11/21
379		1.22.7.1.3.3		Production drawings and documents packa	10 wks	Fri 11/12/21	Thu 1/20/22
380		1.22.7.1.3.4		RFQ development	10 wks	Fri 1/21/22	Thu 3/31/22
381		1.22.7.1.3.5		Bid lead time	10 wks	Fri 4/1/22	Thu 6/9/22
382		1.22.7.1.3.6		Vender selection	2 wks	Fri 6/10/22	Thu 6/23/22
383		**1.22.7.2**		**Spectrograph opto-mechanical FD**	**50 days**	**Fri 3/4/22**	**Thu 5/12/22**
384		1.22.7.2.1		Bench ICD to module FD	1 mon	Fri 3/4/22	Thu 3/31/22

ID		WBS	Task Mode	Task Name	Duration	Start	Finish
385		1.22.7.2.2		Grating mount ICD FD	1 wk	Fri 5/6/22	Thu 5/12/22
386		1.22.7.2.3		Camera ICD and Optomechanical requirements development	4 wks	Fri 3/4/22	Thu 3/31/22
387		1.22.7.2.4		Envelop and utility requirements for SUPT	2 wks	Fri 4/1/22	Thu 4/14/22
388		**1.22.7.3**		**Spectrograph Control FD**	**20 days**	**Fri 4/1/22**	**Thu 4/28/22**
389		1.22.7.3.1		Detector thermal control FD	4 wks	Fri 4/1/22	Thu 4/28/22
390		**1.22.7.4**		**Detector FD**	**225 days**	**Fri 9/3/21**	**Thu 7/14/22**
391		1.22.7.4.1		Detector requirements FD	4 mons	Fri 9/3/21	Thu 12/23/21
392		1.22.7.4.2		Detector vender visits	2 wks	Fri 12/24/21	Thu 1/6/22
393		1.22.7.4.3		Detector RFQ	3 mons	Fri 1/7/22	Thu 3/31/22
394		1.22.7.4.4		Vender selection	1 wk	Fri 4/1/22	Thu 4/7/22
395		1.22.7.4.5		Detector readout FD	3 mons	Fri 4/8/22	Thu 6/30/22
396		**1.22.7.4.6**		**Cryostat FD**	**225 days**	**Fri 9/3/21**	**Thu 7/14/22**
397		1.22.7.4.6.1		Cryostat mechanical design (Vacuum, structural, utility feeds)	4 wks	Fri 9/3/21	Thu 9/30/21
398		1.22.7.4.6.2		Detector support FD	8 wks	Fri 4/8/22	Thu 6/2/22
399		1.22.7.4.6.3		Final FEA and report	2 wks	Fri 7/1/22	Thu 7/14/22
400		1.22.7.4.6.4		FD integration plan	2 wks	Fri 7/1/22	Thu 7/14/22
401		1.22.8		Support systems	226 days	Fri 9/3/21	Fri 7/15/22
402		**1.22.8.1**		**Naysmith platform interface cart FD**	**70 days**	**Fri 9/3/21**	**Thu 12/9/21**
403		1.22.8.1.1		Support cart FD	4 wks	Fri 9/3/21	Thu 9/30/21
404		1.22.8.1.2		Support cart FEA (deflection, principle modes)	2 wks	Fri 10/1/21	Thu 10/14/21
405		1.22.8.1.3		Support cart shop drawings	2 wks	Fri 10/15/21	Thu 10/28/21
406		1.22.8.1.4		Stow position cover shop drawings	2 wks	Fri 10/29/21	Thu 11/11/21
407		1.22.8.1.5		Weldment RFQ	8 wks	Fri 10/15/21	Thu 12/9/21
408		**1.22.8.2**		**Spectrograph Platform FD**	**66 days**	**Fri 4/15/22**	**Fri 7/15/22**
409		1.22.8.2.1		RFP release	1 day	Fri 4/15/22	Fri 4/15/22
410		1.22.8.2.2		Bidders walk though	1 wk	Fri 4/15/22	Thu 4/21/22
411		1.22.8.2.3		RFP lead time	3 mons	Mon 4/18/22	Fri 7/8/22
412		1.22.8.2.4		Review of A&E proposals	1 wk	Mon 7/11/22	Fri 7/15/22
413		**1.22.8.3**		**Support system controls FD**	**30 days**	**Fri 10/1/21**	**Thu 11/11/21**
414		1.22.8.3.1		FP deploy/stow logic FD	2 wks	Fri 10/1/21	Thu 10/14/21
415		1.22.8.3.2		Deploy stow cable FD	2 wks	Fri 10/15/21	Thu 10/28/21
416		1.22.8.3.3		Deploy stow final schematics and cable drawir	2 wks	Fri 10/29/21	Thu 11/11/21
417		**1.22.8.4**		**Fiber routing and support FD**	**20 days**	**Fri 11/12/21**	**Thu 12/9/21**
418		1.22.8.4.1		Final fiber length	1 wk	Fri 11/12/21	Thu 11/18/21
419		1.22.8.4.2		Static fiber support FD	2 wks	Fri 11/19/21	Thu 12/2/21
420		1.22.8.4.3		Shop drawings static fiber support	1 wk	Fri 12/3/21	Thu 12/9/21
421		1.22.9		Calibration system	75 days	Fri 9/3/21	Thu 12/16/21
422		**1.22.9.1**		**Calibration screen FD**	**75 days**	**Fri 9/3/21**	**Thu 12/16/21**
423		**1.22.9.1.1**		**Structural support**	**55 days**	**Fri 9/3/21**	**Thu 11/18/21**
424		1.22.9.1.1.1		Structural support FD	2 wks	Fri 9/3/21	Thu 9/16/21
425		1.22.9.1.1.2		Dome interface final check	1 wk	Fri 9/17/21	Thu 9/23/21
426		1.22.9.1.1.3		Structural support production drawings	2 wks	Fri 9/24/21	Thu 10/7/21
427		1.22.9.1.1.4		Vender RFQ	6 wks	Fri 10/8/21	Thu 11/18/21
428		**1.22.9.1.2**		**Screen material selection**	**45 days**	**Fri 9/17/21**	**Thu 11/18/21**
429		1.22.9.1.2.1		Screen FD	2 wks	Fri 9/17/21	Thu 9/30/21
430		1.22.9.1.2.2		Screen production documents	2 wks	Fri 9/24/21	Thu 10/7/21
431		1.22.9.1.2.3		Vender RFQ	6 wks	Fri 10/8/21	Thu 11/18/21
432		**1.22.9.1.3**		**Calibration lamp FD**	**50 days**	**Fri 9/3/21**	**Thu 11/11/21**
433		1.22.9.1.3.1		Lamp optical FD	2 wks	Fri 9/3/21	Thu 9/16/21
434		1.22.9.1.3.2		Lamp optomechanical FD	4 wks	Fri 9/17/21	Thu 10/14/21
435		1.22.9.1.3.3		Telescope attachment FD	2 wks	Fri 10/15/21	Thu 10/28/21
436		1.22.9.1.3.4		Shop drawings	2 wks	Fri 10/29/21	Thu 11/11/21
437		**1.22.9.1.4**		**Calibration control FD**	**18 days**	**Fri 11/12/21**	**Tue 12/7/21**
438		1.22.9.1.4.1		Cable schematic FD	1 wk	Fri 11/12/21	Thu 11/18/21
439		1.22.9.1.4.2		Cable production drawings	1 wk	Fri 11/19/21	Thu 11/25/21
440		1.22.9.1.4.3		Cable quotes	1.6 wks	Fri 11/26/21	Tue 12/7/21
441		1.22.9.1.4.4		Control software FD	2 wks	Fri 11/19/21	Thu 12/2/21
442		**1.22.9.1.5**		**Deployment Plan**	**25 days**	**Fri 11/12/21**	**Thu 12/16/21**
443		1.22.9.1.5.1		Screen integration	2 wks	Fri 11/12/21	Thu 11/25/21
444		1.22.9.1.5.2		Lamp integration	1 wk	Wed 12/8/21	Tue 12/14/21
445		1.22.9.1.5.3		Controls integration	2 wks	Fri 12/3/21	Thu 12/16/21
446		1.22.10		Data reduction pipeline	241 days	Fri 9/3/21	Fri 8/5/22

ID		WBS	Task Mode	Task Name	Duration	Start	Finish
447		1.22.10.1		Data Lead (design choice support)	241 days	Fri 9/3/21	Fri 8/5/22
448		1.22.11		System integration and test	140 days	Wed 9/1/21	Tue 3/15/22
449		1.22.11.1		Facility upgrade requirements	3 mons	Wed 9/1/21	Tue 11/23/21
450		1.22.11.2		Back end final integration plan	2 mons	Wed 11/24/21	Tue 1/18/22
451		1.22.11.3		Front end final integration plan	2 mons	Wed 1/19/22	Tue 3/15/22
452		1.22.12		System deployment and commissioning	80 days	Wed 3/16/22	Tue 7/5/22
453		1.22.12.1		Keck integration plan FD	2 mons	Wed 3/16/22	Tue 5/10/22
454		1.22.12.2		FOBOS Commissioning plan FD	1 mon	Wed 5/11/22	Tue 6/7/22
455		1.22.12.3		Commissioning acceptance matrix FD	1 mon	Wed 6/8/22	Tue 7/5/22
456