Standardized Space Telescopes for the Future of Scientific Discovery

Final Report 2025

Keck
INSTITUTE FOR SPACE STUDIES

Standardized Space Telescopes for the Future of Scientific Discovery

Symposium Date:

April 21-23, 2025

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Study Report prepared for the W. M. Keck Institute for Space Studies (KISS).

Sponsored by Renaissance Philanthropy, this Symposium is part of a program to democratize access to tools for scientific discovery in space.

The research was conducted partly at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004).

Pre-Decisional Information — For Planning and Discussion Purposes Only

DOI: 10.26206/rv06k-mqx02

Recommended citation (long form):

S. Anunsen, J. Bell, R.Hedrick, S. Higbee, S. Hosseini, E. Huff, K. Iott, J. Kollmeier, P. Larson, Lawrence, D. Levine, C. Levit, D. Mawet, J. Morse, B. Ramamurthy, S. Redmond, J. Rhodes, D. Scognamiglio, A. Tohuvavohu, A. Trangsrud, A. Tripathi, S. Tuttle, D. Van Buren, G. Vasisht, S. Waldman (Eds.) 2025. "Standardized Space Telescopes for the Future of Scientific Discovery." Report prepared for the W. M. Keck Institute for Space Studies (KISS), California Institute of Technology.

Recommended citation (short form):

A. Tohuvavohu, J. Rhodes (Eds.) 2025. "Standardized Space Telescopes for the Future of Scientific Discovery." Report prepared for the W. M. Keck Institute for Space Studies (KISS), California Institute of Technology.

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Executive Summary

Transformative science and exploration require broader access to space telescopes

- Telescopes in space offer huge advantages relative to ground observation:
    - Access to the full electromagnetic spectrum, much of which does not make it to the Earth's surface.
    - Unaffected by atmospheric turbulence that fundamentally limits high-resolution observations over wide fields, even with adaptive optics, and limits precision measurement, including exoplanet transits and more.
    - Unaffected by atmospheric glow that produces a foreground source limiting sensitivity, allowing space telescopes to detect low-surface brightness structures.
    - Not limited by the diurnal day-night cycle, and much higher intrinsic efficiency and operating duty cycle.
- The current oversubscription of existing space observatories demonstrates the clear science demand. A constellation of standardized space telescopes allows a broader range of observing programs to be awarded, including new researchers and more high-risk, high-reward science.
- A standardized science instrument would address multiple research objectives. The ability to host community-built instruments, with simple interfaces to spacecraft and mission teams lowers the technical and financial barriers to participation, thereby increasing the science output across a fleet of telescopes.
- While preliminary and spanning science cases have been identified, the most compelling and impactful discoveries could lie in the unknowns that this paradigm-shifting architecture will unlock.

Implementation Strategy: A focused, startup-inspired team of ~10 engineers developing demonstration missions on aggressive but feasible timelines, with immediate funding for the first pathfinder mission targeting launch within 2 years.

New opportunities are possible beyond existing telescopes and funding mechanisms.

- Existing space telescope funding mechanisms generally target individual science missions, resulting in significant mission customization to maximize capability against specific science objectives within the allowed cost and schedule.
- Space telescope development can benefit from adopting frameworks common for ground-based telescopes. This approach creates a fixed platform combining telescope optics and observatory infrastructure with standardized interfaces that accommodate focal-plane instruments. Scientific infrastructure built almost a century ago continues delivering breakthrough science by updating instruments using this framework.

The increasing commercialization of space presents an opportunity for the space science community.

- Standardized optics, other observatory flight hardware, and spacecraft buses can reduce mission costs.
- Telescopes designed to fit into economical launch envelopes, further reduce cost.
- Spacecraft bus hardware and ground station communications are becoming as ubiquitous as internet infrastructure and are key enabling elements.

Standardized space telescope fleets can drive breakthrough discovery, democratize access, and benefit from iterative technology development.

- Critical astronomy, cosmology, exoplanet, and planetary science questions can be answered using the baseline ~1m UVOIR space telescope, broadening access to transformative science and exploration.
- Such a standardized space telescope can also complement existing capabilities and serve as a testbed and pathfinder for future flagship telescope development.

Success requires focused, fast-moving, mission-driven implementation.

- To realize the first demonstration mission, a core team of less than 10 co-located engineers in a dedicated facility is needed. Such a team must adopt a startup-inspired team culture and be prepared to learn fast and implement quickly.
- The first demonstrator space telescope needs to be funded immediately. Timing is key, with laser focus on a pre-specified and clear execution pathway with quantifiable technical milestones and defined deliverables on an aggressive but feasible schedule. Having 1-2 successor telescopes being planned in parallel will help moderate the natural risk aversion that comes with a single shot and produce a team that learns and adapts while building.

Development should use a capability-driven approach, with targeted efforts in key areas that enable broad applications.

- Leverage standardization and readily available subsystems to minimize non-recurring engineering costs, optimizing for future volume production where possible.
- Pointing stability was identified as a top priority development effort since jitter acceptance levels drive the spacecraft bus requirements. Many science cases that benefit from space-based observations require pointing stability beyond that available from standard buses.

Introduction

Space telescopes possess immense power to perform transformative science and capture public imagination. However, achieving compelling instrumentation coupled with substantial aperture has challenged the field for decades. Advancing astronomical discovery requires embracing new approaches that accelerate development, reduce costs, and expand access to space telescopes. By adopting more agile, cost-effective designs and standardization, we can build upon the revolutionary insights of observatories like the Hubble Space Telescope (HST) and the James Webb Space Telescope (JWST) while fostering greater innovation and broadening opportunities for exploration and engagement.

In the past decade, commercial spaceflight has achieved order-of-magnitude reductions in launch costs for typical payloads, enabling a New Space era with dramatically cheaper and more standardized spacecraft, components, and satellite communication. Unfortunately, the cost of quality astronomical telescopes and large optical systems has not experienced similar declines in cost or build times. The conventional space telescope development model that NASA, other space agencies, and academia practice involves novel and bespoke designs custom-tailored and highly optimized for particular scientific questions. While this approach eventually delivers breakthrough science (albeit at a significant cost), it carries a high and often unacknowledged opportunity cost.

The industry has achieved cost reductions through iterative engineering and standardized design: learning rapidly, eliminating constant non-recurring engineering, and benefiting from economies of scale. The astrophysics community has made an implicit trade in its approach to mission development, driven by the assumption that the science return and discovery potential of one bespoke telescope exceeds that of 20 or more standardized ones. However, a standardized platform does not necessarily entail reduced performance or a strictly unchanging design. A well-designed program with iterative improvement can yield faster and lower-cost best-in-class performance.

Renaissance Philanthropy funded, and the Keck Institute for Space Studies (KISS) at the California Institute of Technology co-hosted a three-day Symposium in April 2025. The objective was to break the conventional space telescope development paradigm by establishing a scalable pathway to build and deploy a standardized platform for high-performance space telescopes, ensuring that cutting-edge orbital-class observatories become accessible to a broader scientific community.

The Symposium focused on identifying several driving science goals this new approach to space telescope development would enable and the engineering and execution strategy required to realize this vision. By bringing together experts in planetary science, astronomy, and cosmology, the Symposium sought to define scientific requirements for a versatile but standardized Ultra-Violet Optical Infrared (UVOIR) telescope platform, ensuring that the proposed design can address a wide range of research objectives from probing the origins of the Universe to searching for signs of life while being optimized for rapid iterative development and manufacturing.

In parallel, the Symposium united instrument scientists and engineers from academia, JPL, and industry to tackle the engineering challenges inherent to the rapid, iterative development of standardized platforms. Key focus areas included:

- **Designed-for-Manufacture Scientific Tools**: Developing instruments optimized for volume production without sacrificing performance
- **Precision Optics in a New Engineering Paradigm**: Exploiting novel design approaches to achieve high-performance optical systems within relaxed size, weight, and power constraints.

- **High-Throughput Calibration and Qualification**: Establishing streamlined processes that ensure science-quality performance without lengthy testing cycles of traditional methods
- **Iterative Manufacturing and Low-Cost Satellite Approaches**: Pioneering production techniques that enable rapid build, test, and launch cycles
- **Programmatic Impact of Abundant, Low-Cost Data and Changes to the Scientific Ecosystem**

This integrated effort provides a clear execution pathway for producing a standardized, 1-meter class UVOIR telescope platform that meets current scientific needs and serves as a testbed for future enhancements and larger systems. The output of this KISS co-hosted Symposium will help empower the scientific community and industry partners to accelerate innovation and usher in a new era of astronomical discovery by laying out a clear pathway toward rapid, cost-effective telescope deployment.

With that pathway in hand, the next step is to import the ground community's most powerful habit: iteration. Ground facilities advance through small, targeted allocations that enable fast experiments and quick learning, yielding unique discoveries. Replicating a standardized space platform brings that cadence to orbit—lower cost and risk expand access, enable finely targeted scientific goals and niche instrumentation, and open a far larger discovery space by letting us adjust observing parameters and learn from each flight. The science goals that follow focus on a few starting areas that can kick off this iterative flywheel.

1 Science Goals

Rather than summarizing an exhaustive list of potential science cases for a single 1-meter class UV-optical-IR telescope, let alone a fleet of such telescopes with varied instrumentation, we seek to identify compelling bounding science cases. We have not selected these science cases as being the most transformative, but rather as science cases that set bounding requirements on one or more aspects of observatory architecture and operations capabilities or highlight unique capabilities with a multi-telescope program. We have selected the science cases outlined here to provide breakpoints in mission architecture to drive near-term design decisions. We do not seek to set requirements on the range of instrumentation available across the telescope fleet. Instead, we assume that compelling and varied instrumentation will be available to accomplish the science goals below.

In principle, the value of a program like this lies entirely in opening up a frontier in space-based mid-scale science and instrumentation development that has been the exclusive provenance of NASA and/or other government agencies to a broader set of academic, industrial, and private stakeholders. If successful (reliable, cost-effective, and high-cadence), we envision many new scientific areas would be ripe for development owing to superior observing conditions in space at all wavelengths and apertures.

As such, the science cases listed here are illustrative and not exhaustive. We restrict the science cases we have identified to a 1-meter UVOIR platform, although there is substantial interest from the astronomical community in larger apertures. The illustrative and non-exhaustive list of science cases the Symposium identified include:

- Kinematic weak lensing for dark energy
- Solar system monitoring for planetary dynamics
- Exoplanet spectroscopy for atmospheric characterization
- Microlensing parallax for dark compact objects

- Rapid characterization for explosive and transient phenomena
- Surveys of stellar evolution and star formation

1.1 Kinematic Weak Lensing

The distribution of matter on the largest cosmic scales is highly sensitive to the properties of dark energy. Most structure is composed of dark matter and cannot be directly observed. Current cosmological experiments map this structure by taking advantage of the weak gravitational lensing effect, where massive structures produce tiny distortions in images of distant background galaxies. While subtle and difficult to measure, weak gravitational lensing is our most direct window into dark cosmic structures and one of the strongest probes of dark energy. Weak lensing measurements are a primary science driver for the Nancy Grace Roman Space Telescope, the Vera Rubin Observatory, and the Euclid space mission, and have been a major focus of dark energy investigations for multiple decades.

Shape noise, the intrinsic uncertainty in galaxy shapes and orientations before lensing, ultimately limits these measurements. Euclid, Roman, and Rubin address shape noise by making measurements averaging hundreds of millions of galaxies. Recent work has shown that spatially-resolved spectroscopic measurements can also essentially eliminate shape noise. For disk galaxies like the Milky Way, we can infer the intrinsic, unlensed shape by measuring the galaxy's rotation speed. Lensing measurements that use galaxy kinematics are an order of magnitude more powerful than current measurements but are not possible at a cosmologically relevant scale with any existing facility.

These measurements require detecting Doppler shifts from galaxy rotation (a few tens of km/s) in the outskirts of disk galaxies, which means observing faint diffuse emission from bright emission lines like H-alpha at spectral resolutions of R>3000 and sub-arcsecond angular resolution across large numbers of galaxies in wide survey fields. These measurements don't require a large aperture. Current observatories will provide strong constraints in the distant Universe (redshifts > 0.5). Still, in the nearby Universe, where dark energy's dynamical effects are likely strongest, traditional weak lensing methods may have exhausted the available signal when the current experiments are finished. A new approach focused on mass-producing kinematic measurements of bright galaxies could dramatically improve constraints on dark energy by more than an order of magnitude, and a meter-class optical space telescope can perform this measurement.

Requirements: Field of view, stability, data volume, orbit, resolution, pointing stability.

1.2 Solar System Observations

Despite being in our cosmic backyard, the dynamics of planets in our Solar System remain unknown and underexplored. High spatial resolution and high temporal cadence imaging of giant planet (and satellite) atmospheres and magnetospheres will unveil the dynamic processes in our Solar System, including atmospheric circulation, volcanic activity, weathering, magnetic dynamos, subsurface ocean dynamics, and more. Hubble and JWST's recent observations have been sparse and infrequent, leading to critical gaps in our understanding of these systems.

Consistent monitoring observations at ~0.1" resolution, from the UV through IR, throughout planets' diurnal and seasonal cycles will lead to breakthroughs in understanding these systems and ensure future planetary probes target the most compelling scientific targets and questions.

Requirements: Wavelength range, orbit, resolution, tracking.

1.3 Exoplanets

A meter-class space telescope can conduct high-cadence, multi-target, and multi-angle spectroscopy of transiting and phase-curve planets at scale. Starting with one and building over time to a collection of telescopes with broad spectral coverage from 300 - 1000 nm, these instruments are equipped with moderate-resolution spectrographs offering a fundamentally new observational capability for exoplanet characterization.

Unlike monolithic observatories, a fleet of telescopes enables simultaneous observations of different planets or repeat monitoring of the same system, capturing time-variable phenomena such as atmospheric dynamics, cloud evolution, or stellar activity modulation. By spreading observations across independent platforms, the constellation breaks the single-transit bottleneck and introduces temporal diversity into spectral retrievals. Multi-platform observations can also provide a bulwark against instrumental systematic noise-contaminating retrievals at the edge of the measurement limit.

The visible wavelength range these telescopes access is optimal for detecting scattering slopes, alkali metals (Na I, K I), and photochemical hazes, features that complement the infrared focus of flagship missions like JWST and ARIEL. With coordinated phase curve monitoring and potential polarimetric capabilities, the fleet can uniquely probe planetary albedo, cloud asymmetry, and scattering particle properties (Stam 2008).

JWST offers exceptional mid-infrared sensitivity for atmospheric retrievals (Beichman, Benneke et al. 2014), and ARIEL is designed for systematic infrared spectroscopy of hundreds of hot planets (Tinetti, Drossart et al. 2018). However, neither mission provides high-throughput access to the near-UV and visible wavelengths most sensitive to atmospheric escape, particle scattering, and haze formation. These processes dominate in sub-Neptunes and super-Earths and are especially important for temperate planets around M dwarfs. A fleet of small telescopes with stable, well-calibrated visible spectrophotometry and optional polarimetric capabilities would enable detailed studies of transit depths, phase-resolved brightness variations, and polarization signatures within a uniform, scalable architecture. This network would fill the spectral and temporal gaps larger missions leave while laying the groundwork for population-level studies of atmospheric diversity and evolution beyond the PLATO and Roman era.

Requirements: Wavelength range, orbit, pointing stability.

1.4 Microlensing Parallax

Gravitational microlensing offers a unique method for detecting compact objects that emit little or no light, such as free-floating planets and isolated black holes, through the magnification of background stars. Measuring microlensing parallax provides a critical enhancement to this technique: subtle distortions in the light curve that Earth's orbital motion induces or that simultaneous observations from a distant platform in space create. When coordinated with a space-based observatory such as Nancy Grace Roman, this parallax signal produces a characteristic deformation in the light curve shape and a measurable time delay between the signals recorded at each location. These dual signatures enable direct inference of the lens mass and distance, breaking long-standing degeneracies between lens mass, distance, and relative velocity that affect ground-based surveys.

Roman's wide-field, high-cadence survey of the Galactic bulge will detect thousands of microlensing events per season, but coordinated observations from one or more smaller telescopes can amplify its full scientific return.

A meter-class telescope in space can contribute significantly to this effort by capturing parallel light curves from a spatially separated vantage point. A field of view matching Roman's 0.25 square degree is ideal for meaningful parallax measurements in coordination with Roman. Microlensing does not require high angular resolution to resolve the lens and source, which are typically blended. However, a pixel scale of 0.2″ offers important advantages: improved photometric precision in crowded fields, better mitigation of blending, and the ability to extract higher-fidelity light curves, especially for events in the most densely populated regions of the bulge.

This coordinated approach transforms single-band light curves into precision tools for Galactic astrophysics, yielding a complete census of dark compact objects in the Milky Way, including planetary-mass lenses, stellar remnants, and black holes. Moreover, microlensing parallax probes the distribution and kinematics of these populations, shedding light on the end stages of stellar evolution and the structure of the Galactic disk and halo. Roman's position at L2 offers an ideal baseline for parallax measurements, particularly for long-duration or low-mass events. A networked strategy combining Roman with agile, lower-cost platforms expands this method’s reach, opening a new window on the unseen mass in our galaxy.

Requirements: Orbit, field-of-view, photometric stability.

1.5 Transient Detection and Characterization

As time-domain surveys such as Roman, Rubin, and Euclid come online, they will dramatically expand our ability to discover fast-evolving transients across the optical sky. The early photometric and spectroscopic follow-up needed to unlock the full scientific return of these discoveries remains limited, particularly in the UV and IR. Such follow-up observations are critical to catching the early phases of explosive events such as Type Ia, kilonovae, and fast blue optical transients. With low-resolution spectroscopy, we can constrain these transients' progenitor systems, explosion mechanisms, and local environments.

In the context of cosmology, such observations are essential for improving Type Ia supernovae standardization, reducing systematics from dust extinction, population drift, and light-curve calibration, thereby strengthening dark energy constraints. Transients provide a window into galaxy evolution. Compact object mergers trace old stellar populations, and their spatial distribution across cosmic environments encodes how galaxies and dark matter halos assembled. Measuring transient rates based on host galaxy properties (e.g., star formation, metallicity, mass) requires a coordinated observational strategy using multiple telescopes operating in parallel across complementary wavelengths. A fleet of meter-class telescopes optimized for a specific band (UV, optical, or NIR) would enable simultaneous discovery and characterization.

Despite a huge investment in survey facilities, no high-performance space telescope is well-matched to characterize the transients we discover. Even at the 1-meter scale, space-based telescopes can play a powerful role in this landscape. By avoiding atmospheric absorption and background, 1-meter-class telescopes in orbit are uniquely positioned to provide rapid, high-cadence coverage in the UV and IR, wavelengths largely inaccessible from the ground. Deployed in low Earth orbit or beyond, such a network could provide real-time response to alerts from wide-field surveys and build time-series datasets at cadences of minutes to hours. This approach does not require large apertures, and 1-meter mirrors strike a balance between sensitivity, cost, and agility, allowing for scalable, multi-node architectures that can work in synchrony with larger facilities like JWST, Roman, and ground-based observatories.

Requirements: Wavelength range, availability, latency

1.6 Stellar Evolution and Star Formation

Despite the growing catalog of planets discovered outside our solar system, fundamental questions remain about the formation rate and processes for solar systems: How frequently do solar systems form? How does feedback work at the individual star-forming region scale? To answer these questions, we must: 1) characterize global properties and star formation histories and efficiencies in massive star-forming regions in the Milky Way; 2) understand how environment and feedback mechanisms influence the process of star and planet formation; 3) track the evolution of and derive survivability criteria for low-mass protoplanetary disks in massive star-forming regions, similar to where the Solar Nebula likely formed.

We can achieve this via a systematic high spatial resolution UV survey of a statistically significant sample of visible star-forming environments in the Milky Way, Magellanic Clouds, and nearby galaxies. However, Hubble is the only instrument capable of (parts of) this and cannot dedicate the time required for a program of this scope.

A 1-meter class UV/optical telescope dedicated to this science program could image all massive star-forming regions within 2.5 kpc of the Sun through a common set of continuum and emission-line filters with sufficient spatial resolution (~0.1") to distinguish Solar System-scale objects and structures. [For scale, 0.1" resolution at the distance of the Orion Nebula is ~40 AU, approximately the radius of the Solar System.] Furthermore, it could identify all exposed proto-planetary disks in nearby massive star-forming regions, where most low-mass stars form, and quantify their sizes, orientations, opacities, and distributions.

Requirements: Field of view, resolution, wavelength range.

2 Science Goals' Constraints on Space Telescope Platform Design

With the spanning set of science programs above, we show breakpoints and thresholds for the space telescope platform performance.

Table 1. Space Telescope Platform Performance Breakpoints and Thresholds

	Spectroscopic Survey	Solar System	Exoplanet Spectroscopy	Microlensing Parallax	Transient followup	Stellar Evolution
Field of View (FoV)	0.25 deg2	-	-	>0.25 deg2	-	>0.25 deg2
Angular resolution	0.25"	0.2"	-	0.2"	-	0.2"
Stability	<<0.25" over 1000s	-	-	<<0.2"	<1" over 100s	-
Min wavelength (nm)	-	120	120	-	180	180
Max wavelength (nm)	-	1000	>2000	-	2500	1000
Non-sidereal tracking	-	Yes	-	-	-	-
Data Volume	High	-	Low	High	Low	-

3 Instruments

Silicon, photonic, and other sensor technology performance is rapidly advancing, with continuous improvements in sensitivity, noise, energy resolution, timing, fidelity, and other parameters. The generational timescale for these advances has dropped to approximately one year, driven by commercial imaging, semiconductor, and lithography industries. Alongside this, device physicists are making strides with photonic sensors, kinetic inductance detectors, and single photon counting devices, to name just a few. These devices can exploit more information at the focus of optical systems, leading to better sensitivity and fundamentally new science opportunities, even in the same optical package. Instruments with technology that exists today can achieve Hubble-level sensitivity behind a 1-meter telescope platform.

Unfortunately, progress and innovation in bulk optics fabrication and assembly have moved much slower. The current pathway to doing useful science in space with the latest sensors is a multi-decade process that involves slowly maturing the technology readiness level (TRL) for spaceflight. The result is that when we launch our space telescopes, they are often decades behind state of the art in the instrument and sensor package, despite tremendous low-hanging gains available in effective sensitivity for the same telescope.

Analysis of Hubble, JWST, and ground-based telescope capabilities and proposals shows that key instrument parameters can enable vast, perhaps inexhaustible, science yield and tremendous community interest and demand. We have identified these workhorse instruments as 1) a broad-band, multi-octave, medium-resolution spectrograph (UV-to-IR) and 2) a high-resolution wide-field imager that can integrate different filters in its filter selection wheel. One of these instruments would fly on every mission, with only minor adaptations between flights (new filters, coatings, etc). Standardizing these workhorse instruments will enable a fully standardized space telescope platform, resulting in cost and risk reductions throughout the mission chain.

However, new instruments and technology are required to push the frontier of knowledge. A standardized de-risked UVOIR telescope platform could remain state of the art, perform breakthrough science, and help advance technology for future larger space telescopes by providing an instrument slot at the focal plane for new community instruments that meet a standard defined Interface Control Document (ICD). The approach that maximizes scientific yield and minimizes risk will be to pair this with a workhorse instrument that is de-risked and flies on every mission. This ensures that every flight will deliver high-yield science data and simultaneously relieves the reliability constraints on the community instrument, allowing high-risk, high-reward technology development. The program would not levy requirements on the community instrument beyond compliance with the ICD and Do No Harm.

The requirement to support two instruments at the focal plane (workhorse and community) drives upstream requirements on the size of the telescope's field of view. The telescope should also minimize the field correction the instruments require to consolidate the non-recurring engineering (NRE) in the telescope. The programmatic goal thereby shapes the telescope design.

Table 2. Workhorse Spectrometer Characteristics

Characteristic	Why Not Lower	Minimum	Maximum	Why not higher
Band	Contamination control, coatings, detectors	180nm	1000nm	Silicon Detector Limits, cooling of the detector
Effective area	Science Cases	600 cm^2	-	Coatings, mirror size, and obscurations and detector QE
Slit Width (variable)	Throughput pointing and spot size	0.1 arcsec	10 arcsec	Spectral and spatial resolution drop
Target ABmag SNR5, 15 ks	Capability Driven	20	22	Effective area, spectral resolution
Band Extensibility	Contamination control, coatings, detectors	110	1600	Thermal noise from warm optics, cold stop

Table 3. Workhorse Imager Characteristics

Characteristic	Why Not Lower	Minimum	Maximum	Why not higher
System point source ABmag	Capabilities-Driven	24	27	System Throughput
Image Resolution	Cost and WFE budget	0.1"	0.25"	Science cases impacted
Filter Bands	Science Case	4	11	Wheel size
Wavefront Sensing	Early missions have a high risk	Phase Retrieval, Focus Diversity?	Shack-Hartman WFS	Cost + Complexity

4 Community Instruments and Technologies

The workshop identified the following technologies as compelling targets for early-generation community instruments.

4.1 Spatial Heterodyne Spectrometer (SHS)

The Spatial Heterodyne Spectrometer (SHS) is an interferometric technique with no moving parts, offering ultra-high spectral resolution and high sensitivity even from modest-aperture telescopes. SHS delivers resolving power exceeding R > 100,000, comparable to 10-meter-class ground-based observatories, and operates from compact, space-based platforms. Unlike traditional imaging grating spectrometers that require large aperture telescopes to achieve similar resolution, SHS achieves this performance without the need for massive optics. Furthermore, Fourier Transform Spectrometers (FTS) and Fabry–Pérot interferometers demand extremely tight alignment tolerances and mechanical precision in space, making them complex and expensive to deploy. SHS offers the best of both worlds: a grating spectrometer's simple, robust design with the spectral performance of FTS and Fabry–Pérot instruments without the associated cost or complexity.

Applications include:

- High-resolution volatile detection on Mars, Venus, Titan, and icy moons to support geologic and atmospheric evolution studies.
- Circumgalactic medium (CGM) characterization is aligned with key priorities from the Astrophysics Decadal Survey.

- Detection and analysis of astrospheres and their role in stellar wind environments.
- High-sensitivity interstellar emission line spectroscopy for interstellar medium (ISM) diagnostics.
- All-sky surveys at ultra-high spectral resolution to capture faint, narrow spectral features across diverse astrophysical sources.

4.2 Far Ultraviolet (FUV) Imager

The far ultraviolet (broadly defined here as 90-200 nanometers) would be valuable for a range of science cases with a 1-meter telescope. For context, the most recently flown FUV imager was the FUV channel of the GALEX mission, which has been decommissioned. Because this bandpass is infrequently targeted, it is ready for serendipitous discoveries.

The far ultraviolet (FUV) is a rich astrophysical regime, containing a great deal of information about young and large "hot stars" that fuel emission from galaxies and the supernovae that eject material into the warm, hot intergalactic medium (WHIM). An abundance of diagnostic emission and absorption lines indicate the temperature and metallicity of the material observed, providing a deep physical understanding of complex galactic systems. Stars, including potential exoplanet hosts, are also important to characterize in this regime. Better stellar characterization will help us maximize the capabilities of next-generation exoplanet instruments.

An FUV imager is also crucial for following up on transients that the Rubin Observatory and the Roman Space Telescope will discover. Many transients are active in the FUV, including hot accretion disks around stars, interacting systems, and variable stars ejecting hot gas shells. Recent advances in FUV reflective coatings have greatly reduced contamination risks while achieving reflectance comparable to standard visible coatings across most of the bandpass.

4.3 High-Contrast Imaging

High-contrast imaging aims to use coronagraphs and starshades to detect and characterize Earth-sized exoplanets around Sun-like stars directly. This requires suppressing starlight by factors exceeding 10^{10} through precise wavefront control, ultra-stable pointing, and specialized telescope designs. Roman's Coronagraph Instrument will demonstrate this technology in space but with limited scope and duration. The next major high-contrast imaging mission, the Habitable Worlds Observatory (HWO), won't launch before the 2040s.

This gap allows small, affordable space telescopes to serve as technology testbeds. These platforms can rapidly advance high-contrast imaging capabilities, including coronagraphs, starshades, UV optics, wavefront control, and formation flying, particularly in the ultraviolet. Flight demonstrations can mature key technologies and inform HWO design decisions that must be made soon.

These missions can also conduct valuable science, studying bright exoplanets and circumstellar disks. This would bridge the gap between Roman and HWO while maintaining community expertise and broadening participation in space-based high-contrast imaging.

4.4 Interferometry

Current ground and space-based large optical and infrared telescopes have reached the practical limits of segmented mirrors. Future facilities like the Extremely Large Telescope (ELT), Thirty Meter Telescope (TMT), and Giant Magellan Telescope (GMT) use segmented mirrors for unprecedented light-gathering power. In space, JWST and the planned Habitable Worlds Observatory (HWO) represent the peak of this approach, using segmented primary mirrors to achieve large apertures within launch vehicle constraints.

These systems face inherent limitations. Precise mirror segment alignment (co-phasing) is critical for high-quality images and requires nanometric accuracy on JWST and picometer accuracy on HWO. The complexity and cost of building and maintaining such large structures are substantial.

The future of optical astronomy may shift toward space-based interferometric arrays using multiple small, cost-effective telescopes. Coordinating multiple 1-meter telescopes across kilometer-scale baselines can create a virtual aperture far exceeding any single instrument. This approach dramatically improves resolving power and allows scalable increases in light-collecting areas while offering flexibility, redundancy, and incremental upgrades.

While this symposium focused on launching an initial low-cost 1-meter space telescope, the transformative potential lies in coordinating a fleet of such telescopes. This architecture enables next-generation interferometric techniques, including precision formation flying for optical interferometry and intensity interferometry that relies on precise photon timing rather than nanometer-level structural control. Space-based intensity interferometry can achieve diffraction-limited imaging at UV wavelengths impossible from the ground, enabling ultra-high angular resolution and new scientific discoveries.

5 Engineering and Execution Roadmap

While individual space telescopes with many of the technical characteristics described above have been previously developed or fielded, these have typically cost ~$1B for a diffraction-limited meter-class space telescope. Realizing a standard platform that not only achieves cost reductions at the constellation level via amortization of NRE across many units but also fundamentally breaks the high starting cost of first-article science missions will require adopting a capabilities-driven approach, with substantially different risk posture and engineering strategies that prioritize rapid iterative development. Any organization committed to enabling this vision must be focused and committed to higher risk, engineering-driven, and iterative scientific mission development. No existing organization or conventional actor in space science has yet demonstrated this capacity.

Pulling on the experience of workshop participants who have fielded constellations of space imaging systems for commercial and other applications, we derived the following heuristics and philosophies driven by real-world lessons learned at scale.

Plan for Con-Ops. Plan for a day in the life over a week in the life. Sketch how the mission will operate, who, and what's automated early on. Update based on findings within the ground and space segments and the program's means, capabilities, and ambitions.

Keep the project low viscosity. Keep the management very close to the problem. Keep a small team. Minimize formal boards before Unit-1/2; use lean technical reviews. An engineering board shouldn't exist until the first unit launches. Don't have a science board driving science requirements until the second unit launches.

Plan for turnover and growth. Keep a documented wall of truth to extract information and document information from key personnel to limit the risk that any individual’s departure from the small executing team is fatal to the program. Expect the team to grow and plan for onboarding and aligning to the mission.

Plan your craft builds to determine which things to automate. Recognize that scaling to production requires automating key elements. Some activities automate more easily than others, so actively decide which elements to automate based on validated learnings from early builds.

Use the correct management method for the topic. Waterfall can work for hardware, Agile for software, and manage the interfaces, knowing the limitations of each. Plan for your lessons learned appropriately as well. Software lessons may be folded in quickly and on-orbit. It takes time to reveal hardware findings, and long lead times mean they take longer to incorporate in follow-on revisions. Test plans should specifically take this into account to find issues early.

Buy telescope stability through Size, Weight, and Power. Due to market forces, launch vehicles, and spacecraft buses are becoming more performant and cheaper. Spend volume, mass, and power to lessen the engineering challenges of the telescope.

Develop workhorse instruments. Identify what makes specific instruments workhorse instruments on ground and space-based observatories. Develop a small number of instruments that fulfill this need on a standardized space telescope and quickly retire risks on these instruments. Leave room for the space remote sensing science community to deliver high-risk, high-reward instruments to supplement these workhorse instruments. Developing instruments in parallel with the space telescope front-end optics ensures that the telescope serves real-world instrument needs, that interfaces make sense, and allows the product to mature.

Plan for reliability at the constellation level rather than the unit level. The binomial reliability nomograph is unforgiving at small sample sizes. Getting to high confidence in reliability is doing something many times, so get to it. This requires relaxing the risk posture usually maintained for space missions.

Progression of Missions and Questions

We identified the following execution roadmap to guide the iterative development approach to a low-cost, high-performance, standardized telescope platform.

Unit 0: Sub-scale Pathfinder and Jitter Management Platform

- Can the organization executing this mission design, license, build, test, launch, and operate a space telescope?
- Can the organization procure market-available subsystems and tie them into a performant space telescope?
- Can compelling scientific data be delivered to the astronomical community rapidly? Can we incorporate feedback into the full-scale design and operations?
- Can we manage jitter in a way architecturally relevant to the needs of a 1m mission?
- Can having real on-orbit spacecraft unlock data purchase or observing time purchase agreements that enable new funding models?

Mission Description	System Architecture	Targeted Risk Reduction
Unit 0: Pathfinder	<0.5m aperture OTA Low-pass passive isolation achieves image stability, active fine guidance, and fast steering. Science Imager with a fixed filter Develop core ground system science product automation processes Launch: SpaceX Rideshare XL Plate T+18 months from program start	Build the organization Operate a space telescope Deliver first science data Validate 1.0m requirements Leverage in-space assets to unlock new earned income pathways

Unit 1: Core Telescope Technology Demonstrator and Interface Validation

- Can the spacecraft and telescope operate reliably in space, delivering usable science data (optical quality, pointing, and stability)?
- Do the standardized instrument interfaces (mechanical, power, data) function in orbit?
- Can we successfully define a fixed ‘instrument box’ (envelope, mounting, connectors) that all payloads must fit, like a trailer hitch model?
- How smooth is the workhorse instruments' design, integration, and pre-launch process?
- What do early users (academia, agencies, international partners) expect regarding access, control, and data?
- What changes must we make to incorporate customer learning?
- Are there software, comms, or thermal system blockers that need addressing before scaling?

Mission Description	System Architecture	Targeted Risk Reduction
Unit 1: First 1.0m	Custom 1.0m OTA, version 1.0 Image Stability via full-scale 2-stage passive/active Workhorse Imager with filter wheel Workhorse Spectrometer Wavefront Sensor in Community Instrument Slot Science product automation No community instrument Launch: SpaceX Rideshare cake-topper T+30 months from program start	Programmatic growth to 1.0m telescope ownership, larger bus, larger launch Scaling of jitter management to 1.0m Demonstration of resolving capability and wavefront characterization Generation of high-quality, useful science product

Unit 2: First External Instrument Integration

- Can we successfully incorporate hardware and software lessons learned from Unit 1?
- Can we integrate and operate external instruments, including simultaneous or sequential functionality among 2+ payloads?
- What engineering support do third-party payloads need, and can we standardize implementation with minimal customization?
- What supporting materials (APIs, docs, emulators, testing tools) do customers need to onboard smoothly?
- What does the full customer journey look like from integration to science return, and how can we streamline it?
- How do customers perceive value, and what pricing models (flat fees, subscriptions, shared time) are viable?

Mission Description	System Architecture	Targeted Risk Reduction
Unit 2: Baseline 1.0m	Custom 1.0m OTA, version 1.1 Image Stability via iteration on full-scale 2-stage passive/active Workhorse Imager with filter wheel Workhorse Spectrometer First Community Instrument Slot Science product automation Launch: SpaceX Rideshare cake-topper T+42 months from program start	Incorporate hardware lessons learned from integration, launch, and operation. Demonstrate integration of community instrument Scale and improve observation throughput, including ground analysis Demonstrate scaled value to scientists and customers

Unit 3: Scaled Operations and Multi-instrument Demonstration

- Can the platform operate at scale, reliably supporting multiple instruments or users at once?
- Can we exercise variants to the design that expand capability in key requirements, such as dedicated UV or SWIR variants that require minimal NRE?
- Does the mission cadence and system performance align with annual or semi-annual 1-meter build cycle plans?
- Which subsystems (hardware or software) must evolve to support scaling to larger (or smaller) telescopes?
- Are service margins viable, is there a sustained operations model, cost recovery, and access modalities?
- Are customers willing to pay for longer-term access, and is there a precise product-market fit for a general-purpose 1-meter telescope?

Mission Description	System Architecture	Targeted Risk Reduction
Unit 3: Variant 1.0m	Custom 1.0m OTA, version 1.2 + bandpass variant Workhorse Imager Workhorse Spectrometer Additional community instruments Launch: SpaceX Rideshare cake-topper or super heavy-lift launch vehicle rideshare T+48 months from program start	Drive unit costs down so that margins close per unit launched Continue Scaling observation throughput, including ground analysis Expand into new wavelengths

Unit 4+: Scaled Operations and Standardized Implementation

Close the organizational business case with unit profits/value, justifying the overhead. Reach sustainability at the organizational level.

- Build a reusable mission ops stack (commanding, telemetry, health monitoring, scheduling).
- Offer a self-service web interface for users to manage payloads and retrieve data.
- Provide a customer-side test harness to validate the instruments' pre-integration.
- Deliver simple data products (e.g., raw, calibrated) and avoid custom pipelines.

- Use a standardized launch interface on super-heavy launch vehicles and favor batch rideshare launches.
- Centralize all instrument integration to avoid variability and ensure quality control.
- Maintain a list of pre-certified instruments or define a streamlined certification process.
- Leverage proven instruments from past missions to reduce development time.
- Avoid over-customization and resist selling to too many market segments too early.
- Focus on dependability and availability, not maximum performance; build trust through reliability.

Mission Description	System Architecture	Targeted Risk Reduction
Unit 4+: Mature 1.0m	Custom 1.0m OTA, version 1.3+ Workhorse Imager Workhorse Spectrometer Additional community instruments Launch: Super heavy-lift launch vehicle rideshare mini-constellations T+54 months from program start	Streamline, focus on sustainability and high-impact activities and models Achieve economies of scale to close organization business case Explore the bounds of the Serviceable Available Market, and check the next mission against market demand

6 Programmatic Implementation

While the scientific and engineering aspects of developing a standardized fleet of small space telescopes were the focus of the Symposium, we identified project management and programmatic aspects as critical enablers for success. The Symposium discussion highlighted the following project management and programmatic principles.

6.1 Project Management and Decision Making

Project success relies on a clear and streamlined project management structure and clear decision-making processes. Key project roles include a director, a lead systems engineer, and a mission assurance engineer. To realize the first demonstration mission, a core team of less than 10 co-located engineers in a dedicated facility is needed. Such a team must adopt a startup-inspired team culture and be prepared to learn fast.

The Director's role should be to understand and manage cost and schedule and provide timely decision-making. The Director will need a Lead Systems Engineer to coordinate all technical efforts and requirements for verification and validation and, eventually, a lead Mission Assurance engineer who can independently assess the production quality of the spacecraft bus and the workhorse instrument and track any observatory-level issues.

To help manage the cost and schedule of the unit-N telescope, we could manage the project in phased sprints with a target budget and schedule sub-allocated to each sprint. For example:

- Sprint 1: defining and signing subcontracts for a workhorse instrument and .5m mirror.
- Sprint 2: working on stability hardware needed to improve jitter.

This structure would help gather data on the team's ability to execute on cost and schedule in short sprints and then recalibrate the overall schedule and expenses based on execution while also correcting systemic management problems.

6.2 Capability-Driven Systems Engineering Approach for Rapid Iteration Timelines

Developing standardized space telescopes on rapid timelines requires a systems engineering approach that defines capabilities from design choices rather than enforcing strict, top-down requirements. We must prioritize fixed time horizons to first light and tightly controlled budgets alongside scientific value. This framework treats the telescope development effort as a flight test program, much like those used in high-performance aircraft or rocket development.

Once we establish a basic design for the first mission, we identify risks and create test plans to mitigate them in ground-based, flight-like conditions. To leverage industrial capabilities, we incorporate off-the-shelf optics, electronics, and satellite bus components into hardware-in-the-loop testing, which reduces time and risk.

Accurate pointing and meaningful data collection rely on performance across both the telescope subsystems and the satellite bus. We must choose between building a custom platform around the telescope or designing a telescope robust enough to function with commercial satellite buses. Since failures often occur at interfaces, we must be clearly and consistently communicating design criteria, particularly when different organizations own the telescope, instruments, and bus.

These efforts define the telescope's capabilities, enabling us to match them to scientific objectives. We track improvement proposals through a change management system and incorporate them into future flights. Following a flight test model, early missions must gather enough data to identify and diagnose causes of anomalies or failures.

To support this, we will include supplemental instrumentation, a mission operations plan, data storage and forwarding capabilities, and robust ground infrastructure for performance analysis. Because multiple flight units from different generations will be under development or in operation simultaneously, we will ensure that lessons learned from one unit transfer effectively across the entire fleet.

6.3 Project Execution Location

A key management decision involves where to execute the project. To optimize cost and schedule, the ideal situation is owning or controlling the site where the observatory gets integrated. Workhorse instruments, spacecraft buses, and components like fine guidance sensors, detectors, or stability hardware can be created and tested at various locations. The key to maintaining schedule control and therefore cost and quality is controlling where everything comes together. If that location is at the chosen bus vendor, the program must strategize how to maintain their attention over time. The program must be realistic about whether it will be one of the vendor's most important customers or likely a small fish in their pond.

6.4 Cost Reduction enabled by sequential telescope production

Addressing the scarcity of mid-scale astronomical instruments in space requires substantially reducing the cost to manufacture, launch, and operate advanced technology while maintaining the reliability necessary for space operations.

Organizations that have succeeded in similar challenges have operated as small, tightly integrated units with strong centralized leadership. Skunkworks, SpaceX, and NASA's faster/better/cheaper programs in the 1990s achieved exceptional results at low cost through rapid decision-making, risk tolerance, organizational alignment, and strict requirements control. However, the Skunkworks model did not address democratizing access to science capabilities.

Combining faster/better/cheaper principles with engagement across financial, institutional, and scientific stakeholders creates a new model for science programs. Sequential telescope launches provide manufacturing and operations experience that increases reliability and reduces costs. They establish a proven track record that builds stakeholder trust. They also enable controlled capability expansion that improves science return while maintaining cost control.

The financial approach discussed in this Symposium opens doors to institutions that lack funding for full-scale space instruments. Supporting community groups with space-design aspects also allows groups without institutional knowledge of these specialized procedures to enter the field. This architecture enables iterative design between launches, which has proven valuable and successful for suborbital missions while maintaining low costs. Space agencies need people capable of leading flagship missions, but opportunities to gain necessary experience are limited. Projects like the sub-orbital program or the one discussed in this Symposium develop people uniquely capable of running flagship missions quickly.

7 Conclusion

This report will be the foundation for a scalable, repeatable approach to space telescope development, ultimately democratizing access to orbital-class observatories. This Symposium hopes to empower the scientific community and industry partners to accelerate innovation and usher in a new era of astronomical discovery by laying out a pathway toward rapid, cost-effective telescope deployment.

Commercial constellations like Planet Labs achieve daily global Earth imaging using distributed modest satellites. Similarly, a space-based astrophysical fleet can use distributed apertures to enable new observational approaches. Deployed in shared or complementary orbits, such a system can deliver capabilities that surpass single platforms, independent telescopes, or even larger ground-based arrays. A constellation of 1-meter space telescopes can collaborate for wide-field surveys, time-domain monitoring, and rapid-response observations or simultaneously operate in parallel to pursue multiple science goals.

Compelling science opportunities include continuous monitoring of astrophysical transients such as supernovae and tidal disruption events; coordinated spectroscopy of exoplanet transits; UV absorption-line surveys of the circumgalactic medium; and multi-angle observations of solar system bodies and microlensing events. The fleet can also act as a persistent sky monitor for electromagnetic counterparts to gravitational waves and fast radio burst events or be the first step towards a synthetic aperture observatory with reconfigurable baselines.

This type of project seeks to provide space-based astronomy infrastructure to the greater scientific community, so communication and outreach will be important. This tremendous opportunity spans a) students, schools, and individual researchers accessing data, b) research groups, institutes, and international agencies building instruments, and c) philanthropists, industrial partners, and non-profits providing material support. The core challenge of such a program is the alignment of these overlapping but disparate interests while controlling costs and achieving a rapid launch cadence.

8 Path Forward

Critical to achieving this report's vision is identifying an aligned funding source with a shared vision and common understanding of the iterative engineering approach necessary for platform development and a commitment to multiple flights. The baseline mission design led by a committed scientist-engineer and a director who can quickly make decisions and navigate the high-dimensional capability-driven parameter space should begin immediately, alongside cohering a capable and committed engineering team. To maintain a lean team, this leader should combine the skill set and mentality normally fulfilled by project scientist and project manager roles. Costing, vendor identification, and key technical risk reduction activities, including long-lead time item procurement, are critical steps that should be accelerated ahead of conventional practice. A firm launch date is a focused and motivating beacon. Therefore, a launch date for the first demonstration mission should be a top-level requirement, similar to some solar system planetary and fly-by probes. Broader scientific community engagement is necessary to ensure product-market fit for the standard platform, and this should proceed in parallel, but the engineering team must be insulated from this to avoid slowing down the execution of the demonstration mission.