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Abstract. We present a new approach to building a modular segmented space telescope that greatly leverages the heritage of the Hubble Space Telescope and the James Webb Space Telescope. The modular design in which mirror segments are assembled into identical panels allows for economies of scale and for efficient space assembly that make a 20-m aperture approach cost effective. This assembly approach can leverage NASA's future capabilities and has the power to excite the public's imagination. We discuss the science drivers, basic architecture, technology, and leveraged NASA infrastructure, concluding with a proposed plan for going forward. [DOI: 10.1117/1.OE.52.9.091802]

Subject terms: space telescope; James Webb Space Telescope, space assembly; deployment; robotics; human space operations; International Space Station; libration points.

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1 Introduction

Space telescopes provide unique and important vantage points to study the universe free from the blur, thermal background and absorption of the earth's atmosphere. As with all telescopes, larger space telescope apertures improve the resolution and sensitivity and thus are critical to enabling new capabilities. An historic example of the power of space telescopes is provided by images from the Hubble Space Telescope (HST). HST's resolution over a large field of view was a major step beyond ground capabilities and opened up a wealth of new scientific discoveries. Picking up from Hubble, the James Webb Space Telescope (JWST) will provide a major increase in collecting area and sensitivity and extend the wavelength range into the near- and mid-infrared while maintaining HST's resolution, thus laying the groundwork for a large array of new science. Deployment of JWST at the Sun-Earth L2 libration point (SEL2) further enhances its performance by minimizing the influences of the Earth-Moon system, particularly thermal effects and stray light intrusion.

Looking beyond JWST, we propose an observatory incorporating a new level of modularity that exploits economies of scale in both mirrors and structure to enable a new class of much larger space telescopes that can be cost effective and readily assembled in space. Modularity can provide a foundation for 20-m and larger apertures, unleashing another major step in scientific observation capabilities and further capitalizing upon the observational benefits of an SEL2 orbital deployment.

This new approach leverages the knowledge and experience gained in servicing HST, designing and building the segmented and alignable JWST telescope, and in building and maintaining the International Space Station (ISS). The level of modularity proposed is not only ideal for space assembly but also enables a more cost-effective solution that utilizes economies of scale in the manufacturing, integration, and testing of mirrors and structures. The modularity proposed complements and leverages NASA's future capabilities, including human and robotic capabilities for assembly and servicing, and both the Space Launch System (SLS) and commercial launch vehicles. In addition, the architecture utilizes active on-orbit wavefront sensing and control with updates every few minutes to greatly relax passive stability requirements (14 days for JWST) that would be a major cost and performance driver for a large backplane. It achieves this new active capability using the image-based methods proven for JWST without requiring complex onboard metrology systems. This modular and alignable architecture also allows for incremental verification of mirror panels on the ground and not a full-up system test, which would not be feasible.

We propose this architecture for a 20-m class ultraviolet (UV)-Optical (i.e., ultraviolet-visible) telescope enabling new capabilities in the study of earth-like planets and other exciting new capabilities due to high resolution and high sensitivity. A similar modular approach can also enable space telescopes in other spectral regions (e.g., a far-infrared telescope with angular separability that avoids target confusion). Moreover, it provides a natural basis for telescopes scaled to even larger apertures. Through a combination of international collaboration, leveraging both heritage telescope technologies and facilities and a wide range of future NASA capabilities, we believe this can be accomplished at the cost equivalent of a great observatory. We see this as a logical step in a long term space telescope strategy for NASA and its international collaborators.

2 Science Drivers

A 20-m class UV-optical space telescope will enable an era of remarkable astrophysical discoveries. While the science case for 8- to 10-m class space telescopes has been previously contemplated (e.g., Green et al.[1] and Postman et al.[2,3]), the sensitivity and angular resolution of a 20-m UV-optical space telescope will allow us to enter a completely new regime of science. We briefly summarize three particular areas of investigation here. Note that these are just a few of the many exciting investigations enabled by a 20-m class space telescope, which of course will yield an even greater number of as-yet unimagined discoveries.

2.1 *Habitable Exoplanets*

The number of potentially habitable exoplanets that can be spectroscopically characterized scales as roughly the cube of the space telescope aperture. A 20-m space telescope with sensitivity across the 0.3- to 2.4-μm wavelength range will definitively answer the question "Is there life elsewhere in the Galaxy?" It will be capable of obtaining $R = 100$ spectra for well over 1000 exoplanets (assuming an on-board coronagraph capable of a contrast ratio of 10^{-10} at $3\lambda/D$) out to a distance of 145 light years from the sun. Most importantly, it can obtain a $S/N = 10$ spectrum at a spectral resolution of $R = 100$ for most of these systems in less than 3 h of integration time!

Broadband disc-averaged photometry with $S/N = 20$ can be obtained in a mere 30 min of integration in most cases. At such a pace, one can map the longitudinal distribution of land-water-cloud cover ratios on hundreds of exoplanets using time-resolved imaging and spectroscopy. See Fig. 1 for an example of such a reconstruction that was done by Cowan et al.[4] for Earth. A 20-m space telescope provides such a potent observational capability that it will not only allow us to spectroscopically detect biomarkers on these potentially habitable worlds but will also enable the measurement of the land-to-water coverage ratios, potentially detect red edge absorption from vegetation, and measure seasonal variations in these values, heralding a true era of remote sensing of exosolar planets.

2.2 *Stellar Population Histories*

A 20-m space telescope will, for the first time, enable the reconstruction of complete star formation histories (spanning 10 Gyr) for ~500 galaxies beyond the Local Group, opening the full range of star formation environments to exploration. This would be a major leap in our observational capabilities that would lead directly to a comprehensive and predictive theory of galaxy formation and evolution. Our only direct insight into the stellar assembly process of modern-day galaxies comes from sifting through their resolved stellar populations to reconstruct the star formation history, chemical evolution, and kinematics of their various structures.[5] *Resolved stellar populations are cosmic clocks.* Their most direct and accurate age diagnostic comes from observations that can resolve the individual, older stars that comprise the main sequence turnoff. But the main sequence turnoff rapidly becomes too faint to detect with any existing telescope for any galaxy beyond the Local Group. This greatly limits our ability to infer much about the details of galactic assembly because the galaxies in the Local Group are not representative of the galaxy population at large. A 20-m space telescope will allow us to reach well beyond the Local Group.

HST cannot and JWST will not reach any large galaxies besides our Milky Way and M31 because they lack the required angular resolution. A 20-m space telescope can reach 10-Gyr-old stars in ~500 galaxies beyond the Local Group, including 68 giant spirals and 12 giant ellipticals, and can extend our reach even beyond the Coma Sculptor Cloud. Having such a range of environments and galaxy types to study will finally allow us to truly test our understanding of star formation and galaxy assembly.

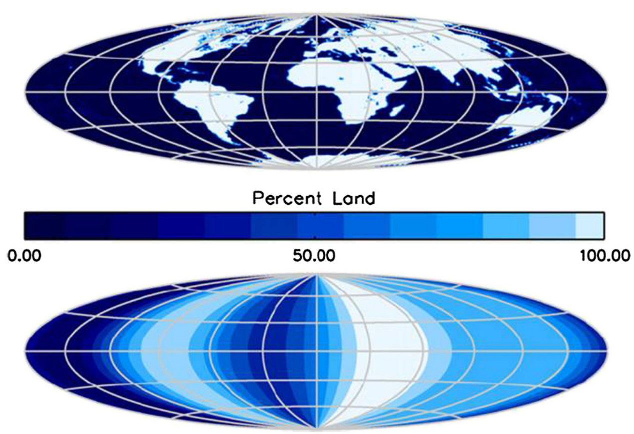


Fig. 1 Aitoff projection of land coverage fraction on Earth.[4]

2.3 *Dark Matter Dynamics*

Dwarf spheroidal galaxies (dSph), the faintest galaxies known, are extraordinary sites to explore the properties of nonbaryonic dark matter. A key reason for this is the discovery that all 19 dSph satellites of the Milky Way, covering more than four orders of magnitude in luminosity, inhabit dark matter halos with the same mass ($\sim 10^7 M_{SUN}$) within their central 300 pc.[6] Owing to their small masses, dSphs have the highest average phase space densities of any galaxy type, and this implies that for a given dark matter model, phase-space limited cores will occupy a larger fraction of the virial radii. Hence, the mean density profile of dSph galaxies is a fundamental constraint on the nature of dark matter.

Current facilities, including ground telescopes and HST, are unable to measure transverse proper motions to the accuracy needed to determine the necessary phase space density profile slopes within dSph galaxies. A 20-m space telescope, however, can perform the essential astrometric measurements. The SEL2 halo orbit, the likely operating locale for a 20-m space telescope, is far more thermally stable than low earth orbit (LEO), and the sensors and actuators put in place to maintain the structure to the precision necessary for exoplanet science would allow the telescope to achieve one-sigma astrometric errors of 0.005 pixels. Depending on the field of view of the imager, a 20-m space telescope will be able to measure transverse proper motions for at least 200 stars per dwarf galaxy. This will make such a facility capable of providing some of the best constraints on the nature of dark matter.

3 Architecture

The development of a large space telescope is driven by science goals (which include outreach and education) and affordability.[7] Achieving the scientific goals described in Sec. 2 requires a 20-m class UV-optical telescope diffraction limited at a wavelength of 0.5 μm, the highest possible throughput, an orbital deployment with minimal exposure to illumination from Earth and the moon, and with adequate stray light rejection to capitalize fully upon this orbital deployment. Although detailed analysis is still required, these considerations support an SEL2 deployment for the telescope, which has added advantages in terms of long term, highly precise pointing stability.

Affordability, of course, is of at least equal importance with scientific merit, and much of the discussion in this paper addresses cost effective solutions to the technology, design, and architecture of this space telescope. We have followed a few basic principles in our architecture development to achieve the most cost-effective space telescope solution:

- Leverage JWST lessons and technological heritage in mirror systems, structures, pointing and control, and wavefront sensing and control to reduce technological uncertainty and risk. Start with robust system margins built into the architecture for mass, thermal management, and stability. This includes active control of the primary mirror system, easing structural requirements on the backplane.
- Use economies of scale to reduce costs, especially for the primary mirror. Leverage robotic and human space assembly capabilities to enable these economies.

The result of applying these cost savings principles is the architecture shown in Fig. 2. For maximum leverage, we have chosen the mirror segment size (1.3 m flat-to-flat) and control authority (6 degrees of freedom plus radius of curvature) to be directly traceable to JWST. Since this is a UV-optical system, the system will need to be diffraction limited at 0.5 μm, which will drive the performance needed for individual mirrors and the primary mirror stability. To achieve the stability, we propose an active control using a hybrid guider/wavefront sensor as proposed for the ATLAST 9.2 m concept.[8]

Behind the primary mirror assembly itself is the large structure that holds the mirrors. While there is a trade between active control of mirrors at high bandwidth, we have baselined a stiff backplane that is dynamically isolated from the spacecraft. The stiffness requires a deep structure, but since thermal stability is not a driver it can be made of standard composites (or even aluminum). In the configuration shown in Fig. 3, the entire backplane can be constructed from two panel types. This means that nonrecurring costs for jigs, stands, and procedures is only required for two structural designs. On JWST, the wings and center section represent two geometries but the backplane is made of a very sophisticated composite structure tailored for high thermal stability due to the passive design. The "panels" of structure we propose can also be built in assembly line fashion using integration techniques developed for JWST:

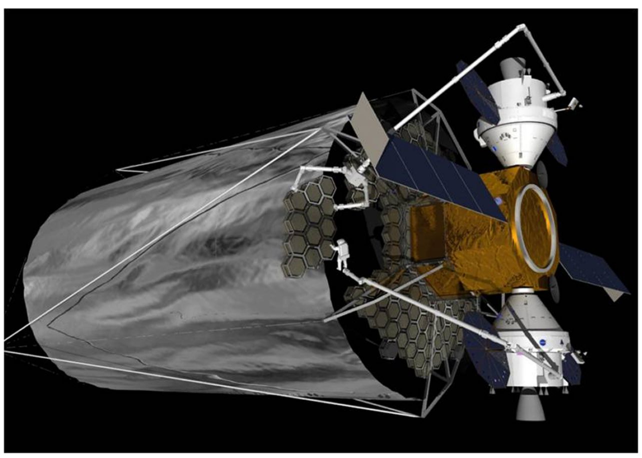


Fig. 2 Notional 20-m telescope robot/astronaut installation of panels.

- The large robotics assembly system used on JWST can be used to install individual mirrors on these panels.
- The interfaces between structural elements can utilize heritage concepts from both HST servicing (e.g., latches and connectors) and the microdynamically stable hinges and joints used on JWST.

To minimize the time and resources required for assembly in space, we propose ground assembly of two mirror panel configurations; 12 and 16 mirrors, as illustrated in Fig. 3. This allows some of the most demanding tasks to be accomplished on the ground: installing individual mirrors on the backplane panels, checking their optical quality and functionality, and verifying that they can be phased to a master prescription. Prelaunch acceptance testing would only require functional, vibration, acoustic, and thermal vacuum testing. Although the panels are to be assembled together in space, individual mirror attachments would be designed so that each mirror could be removed, for example by using a robot normally stowed on the telescope but out of the light path that can span the front of the primary mirror for maintenance and servicing.

In-space assembly of modules would greatly leverage servicing experience from HST and the ISS, which combined human intervention and telerobotics with advanced latch systems. Latches connecting mirror panels would be preloaded to assure dynamic stability similar to JWST. Since individual assembly tasks can be fully programmed, simulated, and practiced on the ground, robots could well perform the majority of tasks. Direct human involvement would be reserved for real-time anomaly resolution and troubleshooting (avoiding the extended latency and inefficiency of control from the ground).

The key aspect of this large, segmented, and paneled architecture is the economy of scale cost savings (see Fig. 4) that enable large-scale production of even high-technology items such as modern automobiles and iPods. Economy of scale is also key to the Thirty-Meter Telescope (TMT) ground observatory that leveraged the 10-m Keck segmented methodology to implement a design with 492 (or more) segments.[9] As is shown in Fig. 4, comparison of normalized data from the first 18 segments of both JWST and a major large ground segmented telescope shows that after 12 segments the cost per segment was reduced by nearly 40%. Discussions with experts in composite materials suggest that similar savings could also be expected in other materials and that the biggest investment will be in nonrecurring engineering and facilitization. Note that much (not all) of the required facilitization for the 20-m UV-Optical space telescope has been accomplished by JWST.

The UV-optical application has the further cost saving advantage over JWST of not requiring expensive cryogenic testing. Moreover, the candidate mirror materials, ULE® and silicon carbide/nanolaminate (Actuated Hybrid Mirrors, or AHMs), are highly compatible with assembly line

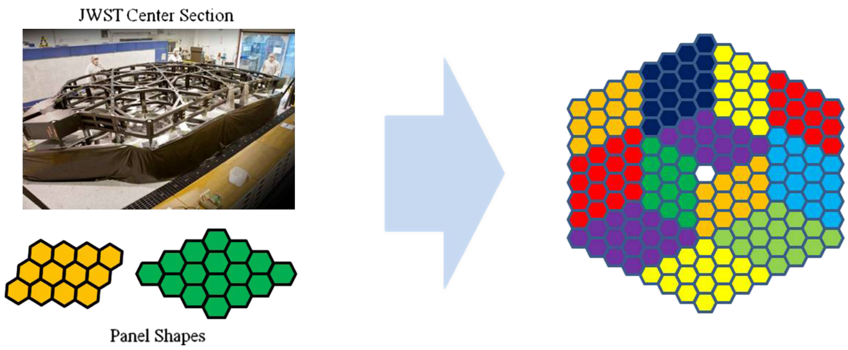


Fig. 3 Primary mirror buildup.

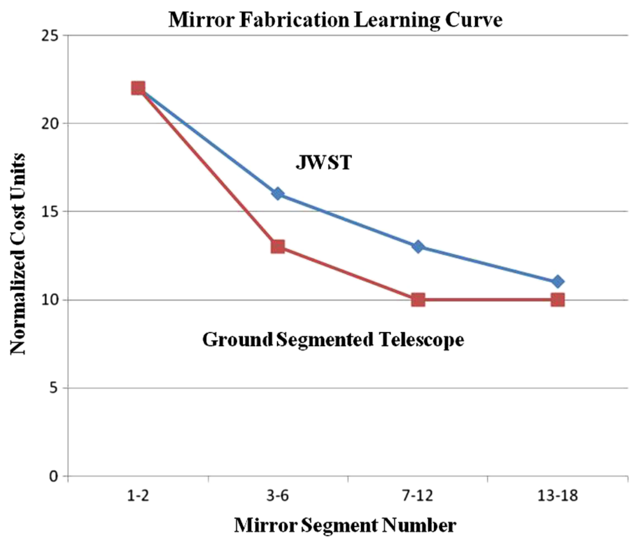


Fig. 4 Economies of scale.

processing. Experience has shown that the cost of the primary mirror for JWST was ∼10% of the mission cost.[10] This figure included the costs of expensive cryogenic processing, handling, and testing that is not required for a UV-optical mirror. While some improvements will be needed in the final metrology of mirrors to achieve 5 nm RMS UV-optical class quality, the number of extra polishing iterations is minimal and therefore not a cost driver beyond the initial nonrecurring engineering. While a grassroots cost estimate based on the mirror technology chosen will be required, we believe that economy of scale advantages will enable a 20-m telescope with a primary mirror that is no more than 10% of the overall observatory cost.

Unlike the 9.2-m ATLAST concept, we have selected an assembled light pipe sunshield (as shown in Fig. 2) to protect the optical train from the sun, earth, and moon, both for stray light and thermal control. Since mass is not a major driver in this modular architecture, particularly if we use the SLS for launch, we do not need the more complex deployment required by the 9.2-m planar sunshield.

The modularity of this space telescope assembly concept has a major added benefit: it makes the system serviceable and assures it an extended life.

- Like ground telescopes that last for decades with periodic instrument upgrades, we believe this observatory could have a 50-year plus lifetime. In this sense, the cost to build, service, and operate the telescope is amortized over an extended period and the cost/science ratio is thereby improved.
- The actual assembly infrastructure in robots and human capabilities will maximally leverage the NASA mission as a whole and will not be a direct cost to this mission.
- In addition, the modularity, scale, and scientific importance of this mission can, like TMT and JWST, lead to an international collaboration that can distribute the costs of development among many participants.

Cost prediction for space systems is inherently subject to uncertainty and error, but Stahl et al.[11] provide a rationale that suggests that the MAST system cost model could be approximated in important aspects by models for ground telescopes. These latter models are characterized by cost reductions as a function of time (i.e., costs are a function of year of development). The authors base this upon the observation that a new ground telescope tends to be a "variation upon a theme," while "Most space telescopes are unique, one of a kind designs which require the invention of new technology just to exist." MAST has elements of both models, most notably because it will draw heavily upon the technology, expertise, and facilities of JWST; however, it will still require innovative technology development, such as achieving and maintaining the precision primary mirror figure and finish required for coronagraphy. In so doing, it will also become a "variation upon a theme," while its larger components (primary mirror, light pipe, structure) will make use of economies of scale that minimize costs. We also believe that size alone will not invalidate the conclusions of Stahl and his co-authors, and that these components will remain a minority percentage of the overall cost of the telescope. Therefore, although an accurate cost prediction will not be possible short of highly detailed system/cost modeling, we believe that the actual cost of a 20-m class UV-Optical Observatory can be in family with the great observatories and can enable equally great advances in science.

4 Telescope/Observatory Technologies

Due to past technology advances, the vast majority of the required technology is already available at Technology Readiness Level (TRL) 6 or above.[12] However, there are several technologies in which development along alternate paths could provide significant cost and risk reduction. These include mirrors and coatings, wavefront sensing and control (WFS&C), structures and dynamic control, and certain scientific instruments. These represent the key development enhancements that help achieve the performance required of a large UV space observatory. A short review of each of these technologies is provided in the following discussion. In general, these technologies (in at least one form) have attained a flight-ready TRL for longer wavelengths and smaller systems, but can be enhanced to provide margin on achieving the required performance in the UV and in a very large telescope.

4.1 *Mirror and Coating Technologies*

Any analysis of a large optical system must include the primary mirror assembly (PMA) as a central topic of consideration. When a space telescope system is so large that a segmented PMA is required to enable launch, the increased precision needed for UV imaging brings the complication to an entirely new level. Both glass mirrors[13,14] and silicon-carbide based actuated hybrid mirrors (AHM)[15] may meet the stringent requirements with additional technology development, and have been developed to advanced states through programs such as the Advanced Mirror System Demonstrator (AMSD) and JWST. A representative example from AMSD is shown in Fig. 5.

At a high level, the mirror quality must be on the order of 5 to 10 nm RMS at 5 Å smoothness out to the edge. It is helpful to break mirror figure and surface requirements down by spatial frequency content in order to better understand the processing challenges of fabrication:

- Low spatial frequency errors: These address areas from the full mirror diameter down to dimensions of ∼50 mm.
- Mid-spatial frequency errors: From 50 mm down to 0.1 mm (100 μm), including management of edge roll-off errors between segments.
- High spatial frequency errors: From 100 μm down to 1 μm.

For UV systems, protected aluminum is the preferred coating. Although there are lithium-based coatings that perform better in the far-UV, they tend to absorb water and degrade quickly prior to launch. Potentially, some development work could enhance the UV performance over aluminum without the negative impacts associated with the lithium-based coatings. Figure 6 shows the reflectivity of gold, silver, and aluminum over a broad wavelength band.

4.2 *Wavefront Sensing and Control*

Wavefront sensing and control (WFSC) for the 20-m telescope will follow the active approach proposed for the ATLAST 9.2 m and patented by Feinberg et al.[16] The approach involves a hybrid sensor in which the WFSC sensors and guiders are part of the same instrument using a beam splitter so that WFSC is performed on a reflected portion of the guide star. The hybrid sensors are placed in the outside corners of the field, allowing field diversity for aligning the secondary mirror and consistent with the approach used to align JWST. The key technologies that need work to fully enable this are on-orbit WFSC which requires implementation on flight qualified digital signal processors (or equivalent) and slightly improves sensing performance which is mostly a function of the hybrid instrument calibration. Since high-contrast instruments like the Visible Nulling Coronagraph (VNC) may require a stable secondary mirror, there is also a trade on how to sense secondary mirror motion which could involve using the coronagraph data itself or implement a laser truss for the secondary mirror.

4.3 *Structures and Dynamic Control Technologies*

Like the tolerances required of the optics, the supporting structures[17] also must be highly stable over time.

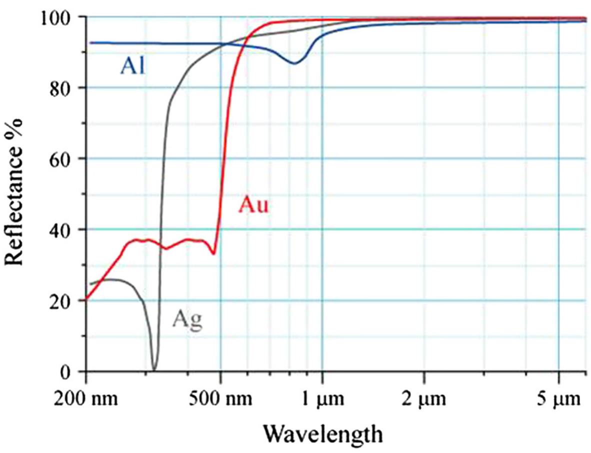


Fig. 6 Reflectivity data for gold, silver, and aluminum.

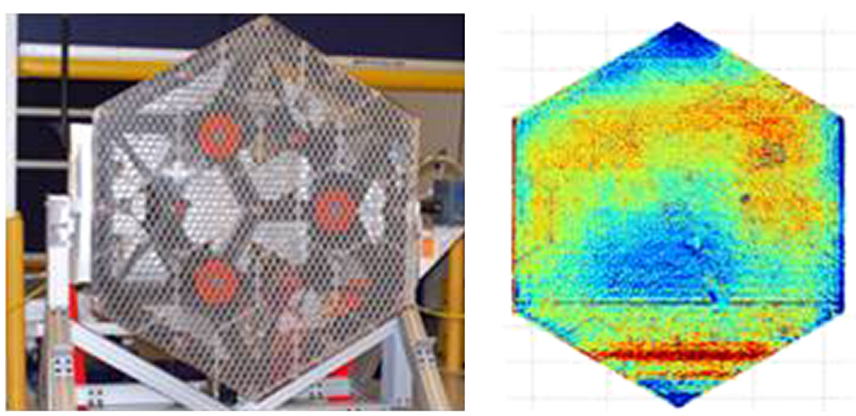


Fig. 5 1.4-m ultralightweight mirror, passive surface figure of 8.2 nm RMS.

Vibration contributions must be minimized, but the ability to limit input disturbances is constrained. Future vibration mitigation will most likely be required to further reduce the dynamic response using an active dynamic control system[18] that is incorporated into the structure. These can be, for example, piezoelectric based mounting systems [for example, the Active Isolation Mount System (AIMS)] or voice coil proof masses. The performance shown in Fig. 7 is based on the 2.5-m dynamic testbed at Exelis and demonstrates the ability of an active system to reduce the dynamic response of the system.

4.4 *High-Contrast Coronagraphy*

Enabling very exciting exoplanet science with a 20-m segmented telescope requires advanced coronagraphic technologies already being pursued for smaller space telescopes. This technology enables high-contrast observations (1e-10), but compatibility with a segmented pupil is required for the proposed ~20-m architecture. A key technology that enables high contrast with a segmented pupil is the VNC, which is ideally suited for a segmented system since the pupil is already composed of hexagonal elements. Work on this has been progressing at a rapid pace, and Lyon et al.[19] have reported significant progress in a laboratory testbed. Additional work on the VNC approach and work on adapting competing coronagraphy approaches to segmented apertures are a top priority for enabling exoplanet science on the 20-m observatory.

5 Infrastructure Technology and Considerations

The observatory system will depend upon interaction with and support from multiple elements of an extensive infrastructure, ground- and space-based; scientific, operational, and commercial; and existing or newly developed. Many of the existing elements will be useable in their current form or with relatively minor enhancements, and will not be discussed here. Such elements include:

- Science tasking and data interpretation. These can be provided by existing organizations, most notably the Space Telescope Science Institute (STScI) and the international astronomical community. HST and JWST provide accurate guides and models.
- Communications and control. These functions will be provided by the same or analogous systems as used for JWST, notably a ground station at the STScI and the NASA Deep Space Network (DSN) for the actual data transmission and reception.

The observatory will place special demands upon other elements of the infrastructure, and these are discussed in the following subsections.

5.1 *Launch Systems*

Specific details of the launch systems required will depend upon the final flight architecture selected for the mission, as discussed in Sec. 3 above. Two principal cases can be identified, each of which imposes particular requirements on the launch system:

- Direct launch of either a complete observatory or constituent subsystems for assembly in the final operational orbit. Given the order of magnitude of the probable system masses, launch of a complete observatory on a single vehicle will only be possible using some variant of the Space Launch System (SLS), pictured in Fig. 8.
- Launch of observatory components to an intermediate assembly point [e.g., the ISS or its neighborhood, Geostationary orbit, or the Earth-Moon L2 (EML2) libration point] followed by transfer of a (nearly) complete observatory to the final orbit.

Adequate launch vehicles (in terms of launch mass and volume capability) already exist[20] in some form now or are in varying stages of development. In many cases, launch will be limited more by available volume than by available mass capability.

5.2 *Infrastructure Technologies for Observatory Assembly*

There are several basic strategies for deploying the telescope once it is in space: unassisted component deployment with no assembly (i.e., JWST), human assisted assembly, robotically assisted assembly, and a combination of these two. Since this paper assumes a telescope too large to be folded

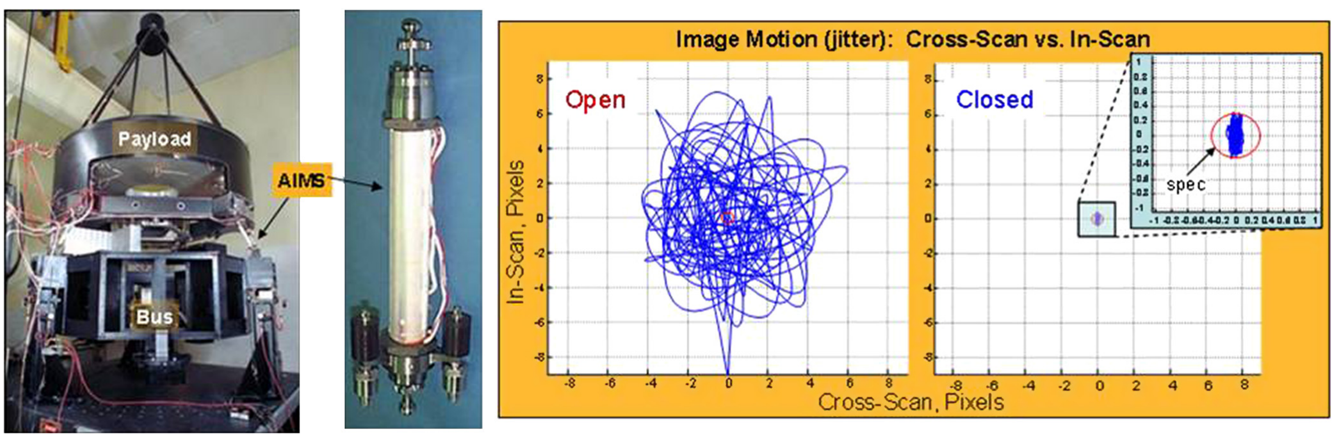
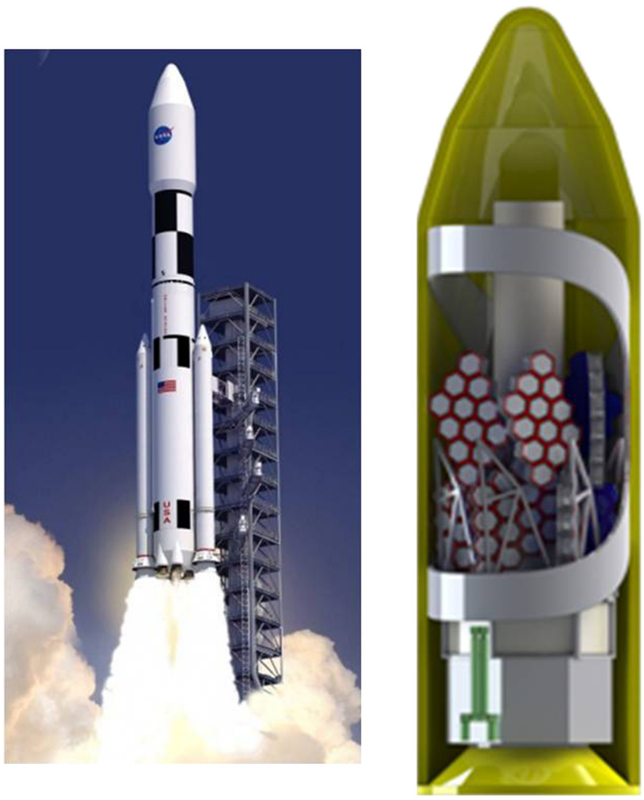


Fig. 7 Effectiveness of 2.5-m dynamic testbed for control of dynamic disturbances.



(a) (b)

Fig. 8 Space Launch System (SLS). (a) Launch vehicle. (b) Panels in notional shroud.

into any planned launch shroud, unassisted component deployment will not be considered, and all deployment strategies include assembly of at least the primary mirror. Thus, there will be basic trades between human and robotically assisted assembly, complicated by multiple possible combinations and permutations. For example, robot assemblers can (conceivably) either be integral to the telescope itself or entirely separate space vehicles that perform functions for several scientific observatories. Much will clearly depend upon the development of both manned space capabilities and infrastructures and those of robots (and telerobots) in the coming few years.

Moreover, these trades will be significantly affected by the location (or locations, since partial and final assembly may occur in different orbits) in which assembly is accomplished. Four possibilities are of possible interest: LEO, probably in the vicinity of the ISS; geostationary orbit (GEO); in the final halo orbit at SEL2 or enroute thereto; or in Earth-Moon L2 (EML2) halo orbit.

A thorough systems engineering analysis of all of the possible combinations of these deployment strategies must await a detailed mission concept study, but Table 1 is intended to identify some of the relationships and considerations that must be included in the full analysis. Note that, if an Earth-Moon libration point is selected for observatory assembly, there could be increased opportunities for architectural flexibility, such as providing a remote servicing base for the observatory and creating opportunities for international collaborations. With the large light baffle and active control, lunar orbits not previously considered may also be viable

Table 1 Candidate observatory deployment strategies.

	LEO/ISS	GEO	SEL2/enroute	EML2
Human assembly	High legacy	Not Legacy	Difficult	Possible
Robot assembly	Available	Possible	Possible	Possible
Combinations[a]	Available	Unlikely	Unlikely	High value

[a]e.g., a human operator directly within a near-real-time robotic control loop.

and we consider defining the orbit a key next step in architecture planning.

6 Plan Forward

JWST experience clearly demonstrated that mission targeted technology investment is the most efficient strategy since it assures that technology requirements are founded directly upon mission needs. This technology investment strategy must stand on three bases: top-level scientific requirements, technology roadmapping, and detailed assembly and operations architecture studies.

6.1 *Science Drivers*

Identifying the key science drivers will help formulate details of the telescope requirements, in turn impacting the basic architecture. For example, precision pointing requires a very stable platform that may drive the stiffness of the assembled backplane or the need for active control. In the same vein, a decision to prioritize exoplanet observations can drive the need for an actively controlled secondary mirror and would require increased responsiveness in the control system architecture.

6.2 *Technology Roadmap*

The proposed telescope architecture has no need for new, enabling technologies in any of its critical paths. However, the system performance would be significantly enhanced and the return on investment increased from the success of a small number of technology developments in parallel paths. A few key examples include finer resolution actuators, vibration isolation systems, onboard digital signal processing, and replicated mirrors that fully meet UV-optical requirements. These all have established technology bases, so the requisite technology development lies mainly in reducing cost, improving margins, and minimizing risk. To manage these developments, a technology roadmap will be needed that includes selection points and off-ramps at times that phase with expected system evaluations and decisions.

6.3 *System Architecture*

Since the observatory must be addressed in the context of the total NASA program, early system architecture studies to evaluate the assembly methods and best locations for assembly and operations are a critical step. For example, the NASA robotic and human roadmaps must be factored in to assure maximum synergies. These studies can help develop the servicing and robotic interface requirements that would allow for real demonstration of assembly techniques on ISS. As another example, SLS is a highly attractive launch vehicle for the observatory, but it must not exceed certain minimum levels of contamination and vibro-acoustic loads. We believe these architecture studies could happen quickly and should target the highest-priority interfaces first, such as inter-panel connectivity.

7 Conclusion

The case has been made that development of a 20-m class space observatory is well supported both from a science needs perspective and from a technical feasibility perspective. Moreover, it has also been shown that it is both feasible and mutually beneficial to leverage this development with other programs: NASA Exploration, International, and Commercial. The approach, heavily drawn from the heritage of programs such as HST, ISS, and JWST, is modular and can be adapted for several scientific requirements and at variable size scales.

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Biographies and photographs of the authors not available.