An Evolvable Space Telescope for Future UV/Opt/IR Astronomical Missions

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1. Introduction and overview

The Evolvable Space Telescope is a new architectural approach to building future large observatories in space that is intended to break the cost curve and make large (>10 m) telescopes affordable within the flat NASA budget (*Proc. SPIE* 9143, Space Telescopes and Instrumentation , 2014). To be affordable future flagship observatories must identify and implement new development concepts while providing the much improved resolution and light collecting power required to do forefront science. It is our contention that, given the annual funding cycle that NASA must meet, the root cause of the cancellation or delay risks run by a Flagship class mission is the annual cost of the mission. As development costs consume too great a percentage of the annual NASA budget~~-~~and threaten all other missions, the science community and NASA begin to consider draconic measures to reduce the annual cost of the Flagship mission: e.g., cancellation or program down-sizing and/or extension. There is an alternative approach that enables the development of future large observatories and accommodates NASA's annual budget constraint.

We propose an Evolvable Space Telescope (**EST**) architecture where the design, development, construction, and launch of the future large space telescope will be conducted in a several stages, each providing a complete telescope fully capable of valuable scientific observations. Stage 1 will form the core of the observatory and will perform selected high priority science observations at the initial launch date. Succeeding Stages will build upon the Stage 1 observatory at several year increments (nominally 3 – 5 years between launches), and will add additional mirrors, structures, and instruments to the Stage 1 telescope. This approach can be implemented for any of the normal incidence mission concepts, UV through Far-IR, in the NASA study call.

2. Key Science Questions

Stage 1 of the EST has a 4 x 12 meter sparse aperture primary with an exoplanet coronagraph instrument and/or a starshade and a UV imaging spectrometer located at the prime focus of the telescope. Prime focus instruments have the very high transmittance and very low residual intrinsic polarization characteristic of uncomplicated optical systems with few fold mirrors and near-normal incidence optics to reduce the presence of the unwanted ghost PSF (Breckinridge, J. B., W. T. Lam and R. Chipman, Publ. Astron. Soc. Pacific, **127**, May 2015 – in press). Starshades have higher starlight suppression in the UV so would also benefit from the higher throughput. Wavelength coverage of the coronagraph/starshade system is from 100 to 1000 nm and wavelength coverage of the 2-mirror surface UV spectrometer is 90 to 350 nm. This EST Stage 1 4 x 12 meter telescope provides high angular resolution with a minor signal to noise ratio reduction because of the reduced collecting area of a sparse aperture.
Across the wavelength band the coronagraph has an angular resolution (after processing) of about 10 milliarcseconds at a predicted contrast level of approximately 10^{-9}. UV coronagraphs have the advantage of a relatively narrow inner working angle and access to observing high-energy phenomena such as aurora to understand the role of magnetic fields in planet formation. A magnetic field associated with an exoplanet provides surface protection from high-energy radiation and thus increases the probability of carbon-based life forms. Key science questions for this EST Stage 1 include atmospheric spectra of exoplanets (for example) to characterize water vapor and examine UV absorption of CO. With minimum background polarization to calibrate out precision measurements of Rayleigh scatter in the atmospheres of exoplanets will be possible. Polarization will be useful to discriminate between planetary atmospheres that are clear, have tropospheric clouds or stratospheric haze. Precision polarization measurements from an exoplanet have been shown to be able to reveal information about climate, orbital elements, atmospheric aerosols, surface characteristics, and possibly chemistry.

All aspects of UV Astrophysics, including star and galaxy formation and evolution, the origin of heavy element, gas flows into and out of galaxies, inter-galactic medium composition and structure, dust and molecule formation in stellar winds, and the re-ionization of the universe can also expect major advances from this same EST architecture. The prime focus architecture provides a much higher throughput because of only two reflections prior to entering the science instrument, significantly increasing the effective aperture. Combining this architecture with advanced UV mirror coatings would enable the science community to produce revolutionary UV science discoveries.

EST Stages 2 and 3 are, respectively, filled 12-meter and 20-meter apertures. The science possible with either of these two large telescopes is well known and thoroughly documented in the community.

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3. Technical Capabilities

Table 1 describes the engineering concept and the technical capabilities of each of the three stages of the EST. Stage 1 requires the launch of 2 segments and a prime focus instrument assembly along with a metrology structure to separate the mirrors from the prime focus. The Stage 2 and 3 components are robotically docked, in a fashion similar to that commonly used by the space station. At each Stage the optical structure is then autonomously aligned to form a working optical telescope.

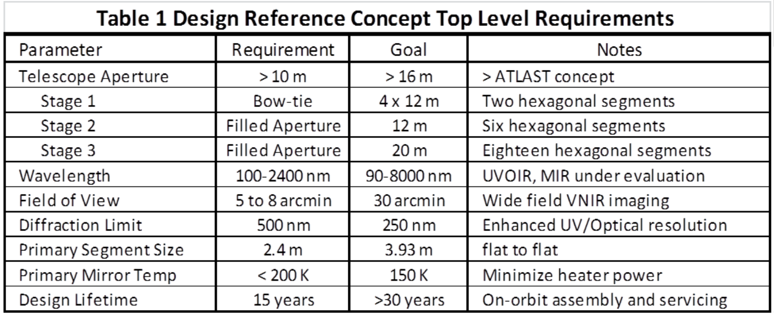
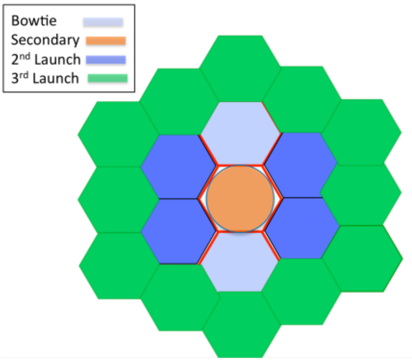


Table 1 Design Reference Concept Top Level Requirements

Parameter	Requirement	Goal	Notes
Telescope Aperture	> 10 m	> 16 m	> ATLAST concept
Stage 1	Bow-tie	4 x 12 m	Two hexagonal segments
Stage 2	Filled Aperture	12 m	Six hexagonal segments
Stage 3	Filled Aperture	20 m	Eighteen hexagonal segments
Wavelength	100-2400 nm	90-8000 nm	UVOIR, MIR under evaluation
Field of View	5 to 8 arcmin	30 arcmin	Wide field VNIR imaging
Diffraction Limit	500 nm	250 nm	Enhanced UV/Optical resolution
Primary Segment Size	2.4 m	3.93 m	flat to flat
Primary Mirror Temp	< 200 K	150 K	Minimize heater power
Design Lifetime	15 years	>30 years	On-orbit assembly and servicing



4. Relevance to the Four Mission Concepts

The EST architecture is relevant to any normal incidence system including the Far-IR Surveyor, Habitable-Exoplanet Imaging Mission, and the UV/Optical/IR Surveyor.

5. New Technologies

Technology developments needed for EST are:

- To take advantage of the prime focus design for UV imaging and spectroscopy, UV coatings with high reflectivity from 90 to 300 nm and UV-VIS coatings with uniform and high phase and amplitude reflectivity having minimum residual polarization are required.
- Development of starlight suppression systems to enable imaging of exoplanets
  - Development of Starshade starlight suppression systems suitable for large telescopes
    - Architectures capable of deploying ~60 m starshades
    - Formation flying sensors and algorithms necessary for maintaining alignment
  - Innovative coronagraph architectures
    - Coronagraphs that employ elements low internal polarization and nano-structured masks and stops to control the complex field and enable terrestrial-exoplanet contrast levels at the 10^{+10} levels. Innovative designs to radially achromatize coronagraphs are needed for broad-band performance.
    - Coronagraph architectures desensitized to telescope system vibration with innovative, high performance WFSC systems optimized for coronagraphy.
- Mirror segments technology at <40 kg/m^2 with built-in metrology fiducials in response to a well-defined assembly and alignment methodology
- Technology for robotic assembly, latching, maintenance, and servicing of large telescopes in deep space
- Technology for autonomous precision alignment and wavefront control of optical elements for space telescopes

6. Large Mission Needed?

The EST architecture is best applied to a large mission, ultimately providing an affordable 20-meter class aperture, assembled in space over time, using moderate size launch vehicles. The EST architecture is easily scaled to any size large telescope. Utilizing 4 meter segments ultimately yields a 20 meter filled aperture, whereas utilizing 2 meter segments would yield a 10 meter class filled aperture at Stage 3. Large missions are needed because the characterization of terrestrial exoplanets requires spectra on objects >30th magnitude. Large apertures are required to collect enough photons for a reasonable integration time and to control unwanted radiation at the required very narrow inner working angles. We propose that studies of future large normal incidence astrophysics missions explore using the Evolvable Space Telescope architecture outlined in this white paper as their baseline approach.