An Evolvable Space Telescope for the Far Infrared Surveyor Mission

C. F. Lillie[a], R.S. Polidan[b] J. B. Breckinridge[c], H. A. MacEwen[d], M. R. Flannery[b] and D. R. Dailey[b]
[a]Lillie Consulting LLC, [b]Northrop Grumman Aerospace Systems, [c]Breckinridge Associates LLC, [d]Reviresco LLC

1. Introduction and overview

In an era of flat NASA budgets, we need to find more affordable ways to build large space telescopes. We believe the root cause for the delay or cancellation of a Flagship class mission is the annual cost of the mission. When development costs consume too large a share of the annual NASA budget it threatens all other missions, and the science community and NASA must consider drastic measures to reduce the annual cost of the Flagship mission: i.e., schedule extension, down-sizing or cancellation. To be affordable, future flagship observatories must identify and implement new technology AND new development concepts, as well as providing the greatly improved resolution and light collecting power necessary to answer cutting-edge science questions.

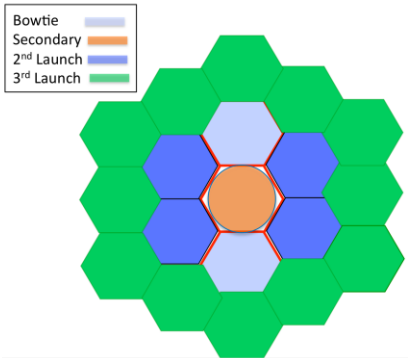
We have been studying observatory architectures where the design, development, construction, and launch of the future large space telescope will be conducted in several stages, each providing a complete telescope fully capable of forefront scientific observations. One approach to building future large space observatories that is intended to break the cost curve and enable large (>10 m) telescopes to be developed within a flat NASA budget is an Evolvable Space Telescope (*Proc. SPIE* 9143-40, Space Telescopes and Instrumentation, 2014). Stage 1 would form the core of the observatory and provide a major improvement over existing observatories operating at the planned launch date. Succeeding Stages would augment the Stage 1 observatory at several year increments (nominally 5 years between launches) by adding additional mirrors, structures, and instruments to the Stage 1 telescope. This approach could be implemented to meet the requirements of three of the four large mission concepts that Paul Hertz has directed the PAGs to consider: i.e., the Far-IR Surveyor, the Habitable-Exoplanet Imaging Mission, and the UV/Optical/IR Surveyor. In this paper we focus on the FIR mission, but also show how UV and exoplanet science questions could be addressed.

2. Key Science Questions

About half of all the energy emitted by stars and galaxies since the Universe began is found in the Far Infrared (FIR) region of the spectrum (~25 to 500 microns). Observations in the FIR thus have great potential for answering fundamental questions about the formation and evolution of our universe, i.e., (1) How did the first stars and black holes in the universe form and evolve; (2) How do massive Black holes in galactic nuclei effect star formation in their host galaxies; (3) How does the FIR spectral energy distribution evolve over cosmic timescales; (4) How do stars of different masses evolve from interstellar clouds to stellar and planetary systems; (5) How do the conditions for planet habitability arise during star, disk and planet formation; and (6) What is the nature of the FIR background? The thermal emission from dust associated with star formation peaks in the FIR, and unique spectral features identify the underlying physics, including the dust particle size, composition, and evolutionary processes in the dense interstellar medium. Fine structure lines in the FIR give information on the temperature balance in these regions; red-shifted features from the mid-IR provide diagnostics for the conditions in galactic nuclei; and hundreds of FIR molecular features, especially simple hydrides, provide unique diagnostics for the build-up of complex organic molecules and water which are important for assessing the habitability of exo-planetary systems. The FIR science possible with future space telescopes has been thoroughly documented in the Far-IR/Sub-mm Community Plans and white papers presented to the National Academy's 2010 survey for astrophysics in the next decade. Key UVOIR and exoplanet science questions have been documented in the ATLAST and AURA HDST study reports.

3. Technical Capabilities

Table 1 describes the engineering concept and the technical capabilities of each of the three stages of a space telescope that would be developed, launched, assembled and operated in the 2030's and beyond. The first Stage telescope would consist of two ~4-m hexagonal mirror segments, a prime focus instrument module and a support structure to separate the instruments from the primary mirror. A sunshield would provide thermal protection for the telescope, and a spacecraft bus would provide the necessary power, communications and attitude control. Stage 2 and Stage 3 components are robotically docked, in cis-lunar space or at L2, 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.



Parameter	Requirement	Goal	Notes
Telescope Aperture	≥ 10 meters	≥ 16 meters	≥ ATLAST
Stage 1	Bow-tie	4 x 12 m	Two hexagonal segments
Stage 2	Filled Aperture	12 m	Twelve hexagonal segments
Stage 3	Filled Aperture	20 m	Eighteen hexagonal segments
Wavelength	100-2400 nm	0.09-670 m	UVOIR, Far-IR under evaluation
Field of View	5 to 8 arcmin	30 arc-min	Wide Field V/NIR Imaging
Diffraction Limit	500 nm	200 nm	Enhanced UV/Optical resolution
Primary Segment Size	1.97 m	3.93 m	3.93m flat-flat
Primary Mirror Temp	≤ 200K	100K	Minimize heater powe, MIR obs.
Design Lifetime	15 years	> 30 years	On-orbit assembly and servicing

Stage 1 of the EST has a 4 x 12 meter sparse aperture primary mirror and a prime focus instrument module with room for three or four instruments: e.g., a FIR imager and spectrometer, a heterodyne instrument, an Mid-IR imaging spectrometer, a wide field camera for the UVOIR, an exoplanet coronagraph, and a UV spectrometer. Prime focus instruments have the very high transmittance and very low residual polarization characteristic of optical systems with few fold mirrors and near-normal incidence optics that reduce the presence of the unwanted ghost images. The instrument complement for each stage would depend on the science drivers that could be best addressed with 12 x 4-m sparse aperture, a 12-m filled aperture, and a 20-m filled aperture. Note, the Stage 1 telescope can be rotated around its line of sight, and images acquired at roll angles of 0, 60 and 120 degrees can be combined to achieve the spatial resolution of a 12-m filled aperture.
The spatial resolution of the Stage-1 and Stage-2 telescopes will thus range from 0.5 to 10 arc-seconds for the FIR instruments (25-500 microns), 0.1 to 0.5 arc-sec for the mid-IR (5-25 μ), 20 to 100 mill-arc-seconds for the near IR (0.9 to 5 μ), 6 to 20 mas for the Visible (0.3 to 0.9 μ) and 1.9 to 6.3 mas for the UV instruments (0.09 - 0.35μ).

The resolution of the Stage 3, 20-m EST will be 40% better than Stage 2: i.e., 6 arc-seconds at 500 microns. This evolvable telescope will thus have 3.5x and then 5.8x better spatial resolution than Herschel. With a primary mirror temperature of ~100K, the Stages 1 and 2 telescopes will provide ~7 times greater sensitivity than Hershel and the Stage 3 EST will have ~20 times greater sensitivity. We currently envision the installing a larger sunshield for the Stage 3 20-m telescope. It may be possible optimize this telescope for FIR observations by adding one or two more layers to the sunshield and cool the primary mirror to ≥ 40K. At this temperature the telescope would be ~800 times for sensitive than Herschel.

4. Relevance to the Four Mission Concepts

An evolvable telescope 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 a Far-Infrared Surveyor mission are:

- Mirror segments technology at <40kg/m^2 with built-in metrology fiducials in response to a well defined assembly and alignment methodology
- New technology for assembly, maintenance, and servicing of large telescopes in deep space
- Development of Sunshields suitable for 12-m to 20-m space telescopes
- New technology for autonomous alignment of optical structures for space optical systems
- Heterodyne sensors with improved sensitivity
- Improved cooling systems for FIR instruments

6. Are Large Missions Needed?

This evolvable architecture is best applied to a large mission, ultimately providing an affordable ~~a~~ 20-meter aperture, assembled in space over time, using commercial launch vehicles. This architecture is easily scaled to any size large telescope. Utilizing 4-m segments ultimately yields a 20-m filled aperture, while 2-m segments would yield a 10-m filled aperture at Stage 3. Large missions are needed because the characterization of terrestrial exoplanets requires spectra of objects >30th magnitude. Large missions are also needed to provide the sensitivity, spatial resolution and spectral resolution required for a Far-IR Surveyor mission that answers the scientific questions raised by Herschel.