NASA SBIR 2017 Phase I Solicitation

S2.03 Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescope

Lead Center: MSFC

Participating Center(s): GSFC, JPL

Technology Area: TA8 Science Instruments, Observatories & Sensor Systems

This subtopic matures technologies needed to affordably manufacture, test or operate complete mirror systems or telescope assemblies. Solutions are solicited in the following areas:

- Components and Systems for potential EUV, UV/O or Far-IR mission telescopes.
- Technology to fabricate, test and control potential UUV, UV/O or Far-IR telescopes.

Specific needs are listed in the Technical Challenges Section. New for 2017 are two areas using additive manufacturing technology:

- Lightweight mirror substrates for Far-IR with < 100 nm rms cryo-deformation at 10K.
- Ultra-stable support structures for potential telescope assemblies: 0.5 meter LISA, 4-m monolithic HabEx, or 12-m segmented LUVOIR.

Proposals must show an understanding of one or more relevant science needs, and present a feasible plan to develop the proposed technology for infusion into a NASA program: sub-orbital rocket or balloon; competed SMEX or MIDEX; or, Decadal class mission.

An ideal Phase I deliverable would be a precision optical system of at least 0.25 meters; or a relevant sub-component of a system; or a prototype demonstration of a fabrication, test or control technology leading to a successful Phase II delivery; or a reviewed preliminary design and manufacturing plan which demonstrates feasibility. While detailed analysis will be conducted in Phase II, the preliminary design should address how optical, mechanical (static and dynamic) and thermal designs and performance analysis will be done to show compliance with all requirements. Past experience or technology demonstrations which support the design and manufacturing plans will be given appropriate weight in the evaluation.

An ideal Phase II project would further advance the technology to produce a flight-qualifiable optical system greater than 0.5 meters or relevant sub-component (with a TRL in the 4 to 5 range); or a working fabrication, test or control system. Phase I and Phase II mirror system or component deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. A successful mission oriented Phase II would have a credible plan to deliver for the allocated budget a fully assembled and tested telescope assembly which can be integrated into the potential mission; and, demonstrate an understanding of how the engineering specifications of their system meets the performance requirements and operational constraints of the mission (including mechanical and thermal stability analysis).

Successful proposals will demonstrate an ability to manufacture, test and control ultra-low-cost optical systems that can meet science performance requirements and mission requirements (including processing and infrastructure issues). Material behavior, process control, active and/or passive optical performance, and mounting/deploying issues should be resolved and demonstrated.

Technical Challenges

To accomplish NASA's high-priority science requires low-cost, ultra-stable, large-aperture, normal incidence mirrors with low mass-to-collecting area ratios. After performance, the most important metric for an advanced optical system is affordability or areal cost (cost per square meter of collecting aperture). Current normal incidence space mirrors cost $4 million to $6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to between $100K/m^2 to $1M/m^2.

Specific metrics are defined for each wavelength application region:

Aperture Diameter for all wavelengths

- Monolithic: 1 to 8 meters
- Segmented: > 12 meters

For UV/Optical

- Areal Cost < $500K/m^2
- Wavefront Figure < 5 nm RMS
- Wavefront Stability < 10 pm/10 min
- First Mode Frequency 250 to 500 Hz
- Actuator Resolution < 1 nm RMS

For Far-IR

- Areal Cost for Far-IR < $100K/m^2
- Cryo-deformation for Far-IR < 100 nm RMS

For EUV

- Slope < 0.1 micro-radian

Also needed is ability to fully characterize surface errors and predict optical performance.

1. Optical Components and Systems for potential UV/Optical Missions

Large UV/Optical (LUVOIR) and Habitable Exoplanet (HabEx) Missions

Potential UV/Optical missions require 4 to 16 meter monolithic or segmented primary mirrors with < 5 nm RMS surface figures. Active or passive alignment and control is required to achieve system level diffraction limited performance at wavelengths less than 500 nm (< 40 nm RMS wavefront error, WFE). Additionally, potential Exoplanet mission, using an internal coronagraph, requires total telescope wavefront stability on order of 10 pico-meters RMS per 10 minutes. This stability specification places severe constraints on the dynamic mechanical and thermal performance of 4 meter and larger telescope. To meet this requirement requires active thermal control systems, ultra-stable mirror support structures, and vibration compensation.

Mirror areal density depends upon available launch vehicle capacities to Sun-Earth L2 (i.e., 15 kg/m^2 for a 5 m fairing EELV vs. 150 kg/m^2 for a 10 m fairing SLS). Regarding areal cost, a good goal is to keep the total cost of the primary mirror at or below \$100M. Thus, an 8-m class mirror (with 50 m^2 of collecting area) should have an areal cost of less than \$2M/m^2. And, a 16-m class mirror (with 200 m^2 of collecting area) should have an areal cost of less than \$0.5M/m^2.

Key technologies to enable such a mirror include new and improved:

- Mirror substrate materials and/or architectural designs.
- Processes to rapidly fabricate and test UVO quality mirrors.
- Mirror support structures that are ultra-stable at the desired scale.
- Mirror support structures with low-mass that can survive launch at the desired scale.
- Mechanisms and sensors to align segmented mirrors to < 1 nm RMS precisions.
- Thermal control (< 1 mK) to reduce wavefront stability to < 10 pm RMS per 10 min.
- Dynamic isolation (> 140 dB) to reduce wavefront stability to < 10 pm RMS per 10 min.

Also needed is ability to fully characterize surface errors and predict optical performance via integrated opto-mechanical modeling.

Potential solutions for substrate material/architecture include, but are not limited to: ultra-uniform low CTE glasses, silicon carbide, nanolaminates or carbon-fiber reinforced polymer. Potential solutions for mirror support structure material/architecture include, but are not limited to: additive manufacturing, nature inspired architectures, nano-particle composites, carbon fiber, graphite composite, ceramic or SiC materials, etc. Potential solutions for new fabrication processes include, but are not limited to: additive manufacture, direct precision machining, rapid optical fabrication, roller embossing at optical tolerances, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality components. Potential solutions for achieving the 10 pico-meter wavefront stability include, but are not limited to: metrology, passive, and active control for optical alignment and mirror phasing; active vibration isolation; metrology, passive, and active thermal control;

Ultra-Stable Balloon Telescopes and Telescope Structures

Multiple potential balloon and space missions to perform Astrophysics, Exoplanet and Planetary science investigations require a complete optical telescope system with 0.5 meter or larger of collecting aperture. 1-m class balloon-borne telescopes have flown successfully, however, the cost for design and construction of such telescopes can exceed \$6M, and the weight of these telescopes limits the scientific payload and duration of the balloon mission. A 4X reduction in cost and mass would enable missions which today are not feasible. Space-based gravitational wave observatories (eLISA) need a 0.5 meter class ultra-stable telescope with an optical path length stability of a picometer over periods of roughly one hour at temperatures near 230K in the presence of large applied thermal gradients. The telescope will be operated in simultaneous transmit and receive mode, so an unobstructed design is required to achieve extremely low backscatter light performance.

Exoplanet Balloon Mission Telescope

A potential exoplanet mission seeks a 1-m class wide-field telescope with diffraction-limited performance in the visible and a field of view > 0.5 degree. The telescope will operate over a temperature range of +10 to -70 C at an altitude of 35 km. It must survive temperatures as low as -80 C during ascent. The telescope should weigh less than 250 kg and is required to maintain diffraction-limited performance over:

- The entire temperature range.
- Pitch range from 25 to 55 degrees elevation.
- Azimuth range of 0 to 360 degrees.
- Roll range of –10 to +10 degrees.

The telescope will be used in conjunction with an existing high-performance pointing stabilization system.

Planetary Science Balloon Mission Telescope

A potential planetary balloon mission requires an optical telescope system with at least 1-meter aperture for UV, visible, near- and mid-IR imaging and multi/hyperspectral imaging, with the following optical, mechanical and operational requirements:

Optical Requirements:

- ? 1-meter clear aperture.
- Diffraction-limited performance at wavelengths ? 0.5 ?m over entire FOV.
- System focal length: 14.052-meters.
- Wavelength range: 0.3 – 1.0 ?m and 2.5 – 5.0 ?m.
- Field of view: 60 arc-sec in 0.3 – 1.0 ?m band, 180 arc-sec in 2.5 – 5.0 ?m band.
- Straylight rejection ratio ? 1e-9.

Mechanical/Operational Requirements:

- Overall length: ? 2.75 meters.
- Overall diameter: ? 1.25 meters.
- Mass: ? 250 kg.
- Temperature: -80 to +50°C.
- Humidity: ? 95% RH (non-condensing).
- Pressure: sea level to 1 micron Hg.
- Shock: 10G without damage.
- Elevation angle range: 0° to 70° operating, -90° to + 90° non-operating.

Other Requirements:

- Must allow field disassembly with standard hand tools.
- Maximum mass of any sub-assembly < 90 kg.
- Largest sub-assembly must pass through rectangular opening 56 by 50 inches (1.42 by 1.27 meters).

2. Optical Components and Systems for potential Infrared/Far-IR missions

Large Aperture Far-IR Surveyor Mission

Potential Infrared and Far-IR missions require 8 m to 24 meter class monolithic or segmented primary mirrors with ~ 1 ?m RMS surface figure error which operates at < 10 K. There are three primary challenges for such a mirror system:

- Areal Cost of < $100K per m^2.
- Areal Mass of < 15 kg per m^2 substrate (< 30 kg per m^2 assembly).
- Cryogenic Figure Distortion < 100 nm RMS from 300K to <10K.

Infrared Interferometry Balloon Mission Telescope

A balloon-borne interferometry mission requires 0.5 meter class telescopes with siderostat steering flat mirror. There are several technologies which can be used for production of mirrors for balloon projects (aluminum, carbon fiber, glass, etc.), but they are high mass and high cost.

3. Fabrication, Test and Control of Advanced Optical Systems

While Sections 1 and 2 detail the capabilities need to enable potential future UVO and IR missions, it is important to note that this capability is made possible by the technology to fabricate, test, and control optical systems. Therefore, this subtopic also encourages proposals to develop such technology which will make a significant advance of a measurable metric.