NASA SBIR 2018 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): GRC, GSFC, JPL, LaRC

Technology Area: TA8 Science Instruments, Observatories & Sensor Systems

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.Â 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.Â 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.Â 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.Â 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).Â Material behavior, process control, active and/or passive optical performance, and mounting/deploying issues should be resolved and demonstrated.

Technical Challenges

To accomplish NASAs high-priority science requires low-cost, ultra-stable, large-aperture, normal incidence mirrors with low mass-to-collecting area ratios.Â After performance, the most important metric for an advanced optical system is affordability or areal cost (cost per square meter of collecting aperture).Â Current normal incidence space mirrors cost $4 million to $6 million per square meter of optical surface area.Â 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 CostÂ < $500K/m^2$.
- Wavefront FigureÂ < 5 nm RMS.
- Wavefront StabilityÂ < 10 pm/10 min.
- First Mode FrequencyÂ 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:

- SlopeÂ < 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.Â 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).Â Additionally, potential Exoplanet mission, using an internal coronagraph, requires total telescope wavefront stability on order of 10 pico-meters RMS per 10 minutes.Â This stability specification places severe constraints on the dynamic mechanical and thermal performance of 4 meter and larger telescope.Â 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).Â Regarding areal cost, a good goal is to keep the total cost of the primary mirror at or below $100M.Â Thus, an 8-m class mirror (with 50 m^2 of collecting area) should have an areal cost of less than $2M/m^2.Â 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.Â 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.Â 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.Â 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.Â 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.Â 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.Â The telescope will be operated in simultaneous transmit and receive mode, so an unobstructed design is required to achieve extremely low backscatter light performance.

Balloon Planetary Telescope

Astronomy from a stratospheric balloon platform offers numerous advantages for planetary science. At typical balloon cruise altitudes (100,000 to 130,000 ft.), 99%+ of the atmospheric is below the balloon and the attenuation due to the remaining atmosphere is small, especially in the near ultraviolet band and in the infrared bands near 2.7 and 4.25 Âµm. The lack of atmosphere nearly eliminates scintillation and allows the resolution potential of relatively large optics to be realized, and the small amount of atmosphere reduces scattered light and allows observations of brighter objects even during daylight hours.

For additional discussion of the advantages of observations from stratosphere platforms, refer to â€œPlanetary Balloon-Based Science Platform Evaluation and Program Implementation - Final Report,â€ Dankanich et. al. (NASA/TM-2016-218870, available from https://ntrs.nasa.gov/).

To perform Planetary Science requires a 1-meter class telescope 500 nm diffraction limited performance or Primary Mirror System that can maintain < 10 nm rms surface figure error for elevation angles ranging from 0 to 60 degrees over a temperature range from 220K to 280K.

Phase I will produce a preliminary design and report including initial design requirements such as wave-front error budget, mass allocation budget, structural stiffness requirements, etc. trade studies performed and analysis that compares the design to the expected performance over the specified operating range.Â Development challenges shall be identified during Phase I including trade studies and challenges to be addressed during Phase II with subsystem proof of concept demonstration hardware.Â If Phase II can only produce a sub-scale component, then it should also produce a detailed final design, includingÂ final requirements (wave-front error budget, mass allocation, etc.) and performance assessment over the specified operating range.

Additional information about Scientific Balloons can be found at https://www.csbf.nasa.gov/docs.html.

Telescope Specifications:

- DiameterÂ Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â > 1 meter
- System Focal LengthÂ Â Â Â Â Â Â Â Â 14 meter (nominal)

- Diffraction Limit Â Â Â Â Â Â Â Â Â Â Â Â Â Â Â < 500 nm
- MassÂ < 300 kg
- ShockÂ 10G without damage
- ElevationÂ 0 to 60 degrees
- TemperatureÂ 220 to 280 K

Primary Mirror Assembly Specifications:

- DiameterÂ > 1 meter
- Radius of CurvatureÂ Â Â Â Â Â Â Â Â Â 3 meters (nominal)
- Surface Figure ErrorÂ Â Â Â Â Â Â Â Â < 10 nm rms
- MassÂ < 150 kg
- ShockÂ 10G without damage
- ElevationÂ 0 to 60 degrees
- TemperatureÂ 220 to 280 K

2.0Â 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 Î¼m RMS surface figure error which operates at < 10 K.Â 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.Â 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.

3.0 NIR LIDAR Beam Expander TelescopeÂ

Potential airborne coherent LIDAR missions need compact 15-cm diameter 20X magnification beam expander telescopes.Â Potential space based coherent LIDAR missions need at least 50-cm 65X magnification beam expander telescopes.Â Candidate coherent LIDAR systems (operating with a pulsed 2-micrometer laser) have a narrow, almost diffraction limited field of view, close to 0.8 lambda/D half angle.Â Aberrations, especially spherical aberration, and surface roughness in the optical telescope can kill the signal.Â Additionally, the telescope beam expander must maintain the laser beamâ€™s circular polarization.Â The incumbent telescope technology is a Dahl-Kirkham beam expander.Â Technology advance is needed to make the beam expander more compact while retaining optical performance.

4.0 Fabrication, Test and Control of Advanced Optical Systems

Finally, this sub-topic also encourages proposals to develop technology which makes a significant advance the ability to fabricate, test or control an optical system.