NASA SBIR 2014 Phase I Solicitation

S2.03 Advanced Optical Systems

Lead Center: MSFC

Participating Center(s): GSFC, JPL

his subtopic solicits solutions in the following areas:

- Optical Components, Coatings and Systems for potential x-ray missions.
- Optical Components, Coatings and Systems for potential UV/Optical missions.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

The primary emphasis of this subtopic is to mature technologies needed to manufacture, test or operate complete mirror systems or telescope assemblies. Section 3 contains a detailed discussion on specific technologies which need developing for each area.

The 2010 National Academy Astro2010 Decadal Report specifically identifies optical components and coatings as key technologies needed to enable several different future missions, including:

- Light-weight x-ray imaging mirrors for future large advanced x-ray observatories.
- Large aperture, light-weight mirrors for future UV/Optical telescopes.
- Broadband high reflectance coatings for future UV/Optical telescopes.

The 2012 National Academy report “NASA Space Technology Roadmaps and Priorities” states that one of the top technical challenges in which NASA should invest over the next five years is developing a new generation of larger effective aperture, lower-cost astronomical telescopes that enable discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects. To enable this capability requires low-cost, ultra-stable, large-aperture, normal and grazing incidence mirrors with low mass-to-collecting area ratios. To enable these new astronomical telescopes, the report identifies three specific optical systems technologies:

- Active align/control of grazing-incidence imaging systems to achieve < 1 arc-second angular resolution.
- Active align/control of normal-incidence imaging systems to achieve 500 nm diffraction limit (40 nm rms wavefront error, WFE) performance.
- Normal incidence 4-meter (or larger) diameter 5 nm rms WFE (300 nm system diffraction limit) mirrors.

Finally, impacting potential space telescopes, NASA is developing a heavy lift space launch system (SLS). An SLS with an 8 to 10 meter fairing and 80 to 100 mt capacity to LEO would enable extremely large space telescopes.

Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors. These potential future space telescopes have very specific mirror technology needs. UV/optical telescopes (such as ATLAST-9 or ATLAST-16) require 1 to 3 meter class mirrors with < 5 nm rms surface figures. IR telescopes (such as SAFIR/CALISTO) require 2 to 3 to 8 meter class mirrors with cryo-deformations < 100 nm rms. X-ray telescopes (such as GenX) require 1 to 2 meter long grazing incidence segments with angular resolution < 0.5 arc-sec and surface micro-roughness < 0.5-nm rms.

Technical Challenges:

In all cases, the most important metric for an advanced optical system (after performance) is affordability or areal cost (cost per square meter of collecting aperture). Currently both x-ray and 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 less than $1M to $100K/m^2.

Successful proposals shall provide a scale-up roadmap (including processing and infrastructure issues) for full scale space qualifiable flight optics systems. Material behavior, process control, active and/or passive optical performance, and mounting/deploying issues should be resolved and demonstrated.

Optical Components, Coatings and Systems for Potential X-ray Missions

Potential x-ray missions require:

- X-ray imaging telescopes with <1 arc-sec angular resolution and > 1 to 5 m^2 collecting area.
- Multilayer high-reflectance coatings for hard x-ray mirrors (similar to NuSTAR).
- X-ray transmission and/or reflection gratings.

Regarding x-ray telescope, multiple technologies are needed to enable < 1 arc-sec x-ray observatories. These include, but are not limited to: new materials such as silicon carbide, porous silicon, beryllium; improved techniques to manufacture (such as direct precision machining, rapid optical fabrication, slumping or replication technologies) 0.3 to 2 meter diameter mirror shells or segments; improved metrology, performance prediction and testing techniques; active control of mirror shape; new structures for holding and actively aligning of mirrors in a telescope assembly.

For example, the Wide-Field X-Ray Telescope (WFXT) requires a 6 meter focal length x-ray mirror with 1 arc-sec resolution and 1 m^2 of collecting area. One implementation of this mirror has 71 concentric full shell hyperbola/parabola pairs whose diameters range from 0.3 to 1.0 meter and whose length is 150 to 240 mm (this length is split between the H/P pair). Total mass for the integrated mirror system (shells and structure) is < 1000 kg. For individual mirror shells, axial slope errors should be ~ 1 arc-sec rms (~100 nm rms figure error for 20 mm spatial frequencies) and surface finish should be < 0.5 nm rms.

Additionally, potential Heliophysics missions require a grazing incidence telescope with an effective collecting area of ~3 cm^2 for 0.1 to 4 nm wavelengths, 4 meter effective focal length, 0.8 degree angle of incidence and surface roughness of 0.2 nm rms.

Regarding x-ray coatings, future x-ray missions require multilayer depth gradient coatings with high broadband reflectivity for 5 to 80 keV energy photons.

Regarding improved metrology and performance prediction, technology is needed to fully characterize x-ray mirrors (and mandrels) and predict their angular resolution performance. Potential solutions include (but are not limited to): both sub-aperture stitching (in the lateral direction) to acquire data over the entire optical surface, and merging/interpolating data with different spatial frequency domains. This can be done using different surface measuring instruments with different fields of view and resolutions.

Successful proposals will demonstrate an ability to manufacture, test and control a prototype 0.25 to 0.5 meter diameter x-ray mirror assembly; or, to coat a 0.25 to 0.5 meter class representative optical component; or, to characterize and performance predict a 0.5 to 1.0 meter class x-ray mirror or mandrel. An ideal Phase I project would deliver a sub-scale component such as a 0.25 meter x-ray precision mirror; or demonstrate a prototype metrology system capable of characterizing the optical surface morphology of an x-ray component and predicting its angular performance. An ideal Phase II project would further advance the technology to produce a space-qualifiable 0.5 meter mirror, with a TRL in the 4 to 5 range; or deliver a metrology system capable of characterizing 0.5 to 1.0 meter class x-ray mirrors (or mandrels) and predicting their angular resolution performance. Both Phase I and Phase II deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.

Optical Components, Coatings and Systems for Potential UV/Optical Missions

Potential UV/Optical missions require:

- Large aperture, light-weight mirrors.
- Broadband high reflectance coatings.

Regarding large aperture mirrors, future UVOIR missions require 4 to 8 or 16 meter monolithic or segmented primary mirrors with < 10 nm rms surface figures. 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. 60 kg/m^2 for a 10 m fairing SLS).

Regarding broadband reflectance coating, future UVOIR missions require coatings with broadband reflectivity > 60% and uniform polarization from 90 nm to 2500 nm which can be deposited onto a 2 to 4 to 8 meter mirror substrate. Additionally, the coatings need to have > 90% reflectivity from 450 nm to 2500 nm. Future EUV missions require coatings with reflectivity > 90% from 6 nm to 200 nm which can be deposited onto mirror substrates as large as 2.4 meters in diameter.

Successful proposals will demonstrate an ability to manufacture, test and control ultra-low-cost precision 0.25 to 0.5 meter optical systems; or to coat a 0.25 to 0.5 meter representative optical component. Potential solutions include, but are not limited to, new mirror materials such as silicon carbide, nanolaminates or carbon-fiber reinforced polymer; new fabrication processes such as 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 mirrors or lens segments. Solutions include reflective, transmissive, diffractive or high order diffractive blazed lens optical components for assembly of large (16 to 32 meter) optical quality primary elements.

Potential solutions to improve UV reflective coatings include, but are not limited to, investigations of new coating materials with promising UV performance; new deposition processes; and examination of handling processes, contamination control, and safety procedures related to depositing coatings, storing coated optics, and integrating coated optics into flight hardware. An ability to demonstrate optical performance on 2 to 3 meter class optical surfaces is important.

An ideal Phase I deliverable would be a precision mirror of at least 0.25 meters; or a coated mirror of at least 0.25 meters. An ideal Phase II project would further advance the technology to produce a space-qualifiable mirror greater than 0.5 meters, with a TRL in the 4 to 5 range. Both Phase I and Phase II deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase II would also include a mechanical and thermal stability analysis.