NASA SBIR 2019 Phase I Solicitation

S2.04 X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics

Lead Center: GSFC

Participating Center(s): JPL, MSFC

Technology Area: TA8 Science Instruments, Observatories & Sensor Systems

X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics

The National Academy Astro2010 Decadal Report identifies studies of optical components and ability to manufacture, coat, and perform metrology needed to enable future X-Ray observatory missions such as Next Generation of X-Ray Observatories (NGXO).

The Astrophysics Decadal specifically calls for optical coating technology investment for future UV, Optical, Exoplanet, and IR missions while Heliophysics 2009 Roadmap identifies the coating technology for space missions to enhance rejection of undesirable spectral lines, improve space/solar-flux durability of EUV optical coatings, and coating deposition to increase the maximum spatial resolution.

Future optical systems for NASAs low-cost missions, CubeSat and other small-scale payloads, are moving away from traditional spherical optics to non-rotationally symmetric surfaces with anticipated benefits of free-form optics such as fast wide-field and distortion-free cameras.

This subtopic solicits proposals in the following three focus areas:

- X-Ray manufacturing, coating, testing, and assembling complete mirror systems in addition to maturing the current technology.
- Coating technology including Carbon Nanotubes (CNT) for wide range of wavelengths from X-Ray to IR (X-Ray, EUV, LUV, VUV, Visible, and IR).
- Free-form Optics design, fabrication, and metrology for CubeSat, SmallSat and various coronagraphic instruments.

S2.04 supports variety of Astrophysics Division missions. The technologies in this subtopic encompasses fields of X-Ray, coating technologies ranging from UV to IR, and Free-form optics in preparation for Decadal missions such as the Habitable Exoplanet Observatory (HabEx), Large UV Optical Infrared Surveyor (LUVOIR), and Origins Space

Telescope (OST).

Optical components, systems, and stray light suppression for X-ray missions: The 2010 National Academy Decadal

Report specifically identifies optical components and the ability to manufacture and perform precise metrology on them needed to enable several different future missions (NGXO). The NRC NASA Technology Roadmap Assessment ranked advanced mirror technology for new x-ray telescopes as the #1 Object C technology requiring NASA investment.

Free-form Optics: NASA missions with alternative low-cost science and small size payload are increasing. However, the traditional interferometric testing as a means of metrology are unsuited to free-form optical surfaces due to changing curvature and lack of symmetry. Metrology techniques for large fields of view and fast F/#s in small size instruments is highly desirable specifically if they could enable cost-effective manufacturing of these surfaces. (CubeSat, SmallSat, NanoSat, various coronagraphic instruments)

Coating for X-ray, EUV, LUV, UV, Visible, and IR telescopes: Astrophysics Decadal specifically calls for optical coating technology investment for: Future UV/Optical and Exoplanet missions (THEIA or ATLAST). Heliophysics 2009 Roadmap identifies optical coating technology investments for: Origins of Near-Earth Plasma (ONEP); Ion-Neutral Coupling in the Atmosphere (INCA); Dynamic Geospace Coupling (DGC); Fine-scale Advanced Coronal Transition-Region Spectrograph (FACTS); Reconnection and Micro-scale (RAM); & Solar-C Nulling polarimetry/coronagraph for exoplanet imaging and characterization, dust and debris disks, extra-galactic studies and relativistic and non-relativistic jet studies (VNC).

Typical Phase I deliverables, based on sub-elements of S2.04, include:

- X-ray optical mirror system: Analysis, reports, and prototype
- Coating: Analysis, reports, software, demonstration of the concept and prototype
- Freeform Optics: Analysis, design, software and hardware prototype of optical components

Expected TRL for this project is 3 to 6.

X-Ray Mirror Systems Technology

NASA large X-Ray observatory requires low-cost, ultra-stable, light-weight mirrors with high-reflectance optical coatings and effective stray light suppression. The current state-of-art of mirror fabrication technology for X-Ray missions is very expensive and time consuming. Additionally, a number of improvements such as 10 arc-second angular resolutions and 1 to 5 m^2Â collecting area are needed for this technology. Likewise, the stray-light suppression system is bulky and ineffective for wide-field of view telescopes.

In this area, we are looking to address the multiple technologies including: improvements to manufacturing (machining, rapid optical fabrication, slumping or replication technologies), improved metrology, performance prediction and testing techniques, active control of mirror shapes, new structures for holding and actively aligning of mirrors in a telescope assembly to enable X-Ray observatories while lowering the cost per square meter of collecting aperture and effective design of stray-light suppression in preparation for the Decadal Survey of 2020. Additionally, we need epoxies to bond mirrors that are made of silicon. The epoxies should absorb IR radiation with wavelengths between 1.5 um and 6 um that traverses silicon with little or no absorption, and therefore can be cured quickly with a beam of IR radiation. Currently, X-Ray 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 $100 K/$m^2$.

The 2010 National Academy Decadal Report specifically identifies optical components and the ability to manufacture and perform precise metrology on them needed to enable several different future missions (NGXO).

The NRC NASA Technology Roadmap Assessment ranked advanced mirror technology for new x-ray telescopes as the #1 Object C technology requiring NASA investment.

Typical Phase I deliverables, based on sub-elements of S2.04, include:

- X-ray optical mirror system: Demonstration, analysis, reports, software and hardware prototype

Expected TRL for this project is 3 to 6.

Coating Technology for X-Ray-UV-OIR

The optical coating technology is a mission-enabling feature that enhances the optical performance and science return of a mission. Lowering the areal cost of coating determines if a proposed mission could be funded in the current cost environment. The most common forms of coating used on precision optics are anti-reflective (AR) coating and high reflective coating.

The current coating technology of optical components needed to support the 2020 Astrophysics Decadal process. Historically, it takes 10 years to mature mirror technology from TRL-3 to 6. To achieve these objectives requires sustained systematic investment.

The telescope optical coating needs to meet low temperature operation requirement. Itâ€™s desirable to achieve 35 K in future.

A number of future NASA missions require suppression of scattered light. For instance, the precision optical cube utilized in a beam-splitter application forms a knife-edge that is positioned within the optical system to split a single beam into two halves. The scattered light from the knife-edge could be suppressed by CNT coating. Similarly, the scattered light for gravitational-wave application and lasercom system where the simultaneous transmit/receive operation is required, could be achieved by highly absorbing coating such as CNT. Ideally, the application of CNT coating needs to achieve:

- Broadband (visible plus Near IR), reflectivity of 0.1% or less
- Resist bleaching of significant albedo changes over a mission life of at least 10 years
- Withstand launch conditions such vibe, acoustics, etc.
- Tolerate both high continuous wave (CW) and pulsed power and power densities without damage. ~10 W for CE and ~ 0.1 GW/cm^{2}Â density, and 1 kW/nanosecond pulses
- Adhere to the multi-layer dielectric or protected metal coating including Ion Beam Sputtering (IBS) coating

Coating for X-ray, EUV, LUV, UV, Visible, and IR telescopes: Astrophysics Decadal specifically calls for optical coating technology investment for: Future UV/Optical and Exoplanet missions. Heliophysics 2009 Roadmap identifies optical coating technology investments for: Origins of Near-Earth Plasma (ONEP); Ion-Neutral Coupling in the Atmosphere (INCA); Dynamic Geospace Coupling (DGC); Fine-scale Advanced Coronal Transition-Region

Spectrograph (FACTS); Reconnection and Micro-scale (RAM); & Solar-C.

Laser Interferometer Space Antenna (LISA) requires low scatter HR coatings and low reflectivity coatings for scatter suppression near 1064 nm. Polarization-independent performance is important.

Nulling polarimetry/coronagraph for Exoplanets imaging and characterization, dust and debris disks, extra-galactic studies and relativistic and non-relativistic jet studies (VNC).

Desired deliverables for this include analysis, reports, software, demonstration of the concept and prototype.

Expected TRL for this project is 3 to 6.

Free-form Optics

Future NASA science missions demand wider fields of view in a smaller package. These missions could benefit greatly by free-form optics as they provide non-rotationally symmetric optics which allow for better packaging while maintaining desired image quality. Currently, the design and fabrication of freeform surfaces is costly. Even though various techniques are being investigated to create complex optical surfaces, small-size missions highly desire efficient small packages with lower cost that increase the field of view and expand operational temperature range of un-obscured systems. In addition to the free-form fabrication, the metrology of free-form optical components is difficult and challenging due to the large departure from planar or spherical shapes accommodated by conventional interferometric testing. New methods such as multibeam low-coherence optical probe and slope sensitive optical probe are highly desirable.

Specific metrics are:

- Design: Innovative reflective optical designs with large fields of view (> 5Â°) and fast F/#s
- Fabrication: 10 cm diameter optical surfaces (mirrors) with free form optical prescriptions with surface figure tolerances are 1-2 nm rms, and roughness < 5 Angstroms. Larger mirrors are also desired for flagship missions for UV and coronagraphy applications, with 10cm^{-1}Â diameter surfaces having figure tolerances <5nm RMS, and roughness <1 Angstroms RMS
- Metrology: Accurate metrology of â€˜freeformâ€™ optical components with large spherical departures (>1 mm), independent of requiring prescription specific null lenses or holograms.

NASA missions with alternative low-cost science and small size payload are increasing. However, the traditional interferometric testing as a means of metrology are unsuited to free-form optical surfaces due to changing curvature and lack of symmetry. Metrology techniques for large fields of view and fast F/#s in small size instruments is highly desirable specifically if they could enable cost-effective manufacturing of these surfaces. (CubeSat, SmallSat, and NanoSat).

Desired deliverables for this include demonstration, analysis, design, software, and hardware prototype of optical components.

Expected TRL for this project is 3 to 6.

References:

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- The Habitable Exoplanet Observatory (HabEx) is a concept for a mission to directly image planetary systems around Sun-like stars. HabEx will be sensitive to all types of planets; however its main goal is, for the first time, to directly image Earth-like exoplanets, and characterize their atmospheric content. By measuring the spectra of these planets, HabEx will search for signatures of habitability such as water and be sensitive to gases in the atmosphere possibility indicative of biological activity, such as oxygen or ozone. The HabEx study interim report is available at: https://www.jpl.nasa.gov/habex/pdf/interim_report.pdf
- The Large UV/Optical/IR Surveyor (LUVOIR) is a concept for a highly capable, multi-wavelength space observatory with ambitious science goals. This mission would enable great leaps forward in a broad range of science, from the epoch of re-ionization, through galaxy formation and evolution, star and planet formation, to solar system remote sensing. LUVOIR also has the major goal of characterizing a wide range of exoplanets, including those that might be habitable - or even inhabited. The LUVOIR Interim Report is available at: https://asd.gsfc.nasa.gov/luvoir/.
- The Origins Space Telescope (OST) is the mission concept for the Far-IR Surveyor study. NASA's Astrophysics Roadmap, Enduring Quests, Daring Visions, recognized the need for an Origins Space Telescope mission with enhanced measurement capabilities relative to those of the Herschel Space Observatory, such as a three order of magnitude gain in sensitivity, angular resolution sufficient to overcome spatial confusion in deep cosmic surveys or to resolve protoplanetary disks, and new spectroscopic capability. The community report is available at: http://science.nasa.gov/media/medialibrary/2013/12/20/secure-Astrophysics_Roadmap_2013.pdf

X-Ray Mirror Systems Technology

- NASA High Energy Astrophysics (HEA) mission concepts including X-Ray missions and studies are available at https://heasarc.gsfc.nasa.gov/docs/heasarc/missions/concepts.html.

Coating Technology for X-Ray-UV-OIR

- Laser Interferometer Space Antenna (LISA) is a space-based gravitational wave observatory building on the success of LISA Pathfinder and LIGO. Led by ESA, the new LISA mission (based on the 2017 L3 competition) is a collaboration of ESA and NASA.

- More information could be found at https://lisa.nasa.gov

Free-form Optics

- A presentation on application of Freeform Optics at NASA is available at https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20170010419.pdf