NASA SBIR 2016 Phase I Solicitation

S2 Advanced Telescope Systems

The NASA Science Missions Directorate seeks technology for cost-effective high-performance advanced space telescopes for astrophysics and Earth science. Astrophysics applications require large aperture light-weight highly reflecting mirrors, deployable large structures and innovative metrology, control of unwanted radiation for high-contrast optics, precision formation flying for synthetic aperture telescopes, and cryogenic optics to enable far infrared telescopes. A few of the new astrophysics telescopes and their subsystems will require operation at cryogenic temperatures as cold a 4-degrees Kelvin. This topic will consider technologies necessary to enable future telescopes and observatories collecting electromagnetic bands, ranging from UV to millimeter waves, and also include gravity waves. The subtopics will consider all technologies associated with the collection and combination of observable signals. Earth science requires modest apertures in the 2 to 4 meter size category that are cost effective. New technologies in innovative mirror materials, such as silicon, silicon carbide and nanolaminates, innovative structures, including nanotechnology, and wavefront sensing and control are needed to build telescopes for Earth science.

Subtopics

S2.01 Proximity Glare Suppression for Astronomical Coronagraphy

Lead Center: JPL

Participating Center(s): ARC, GSFC

This subtopic addresses the unique problem of imaging and spectroscopic characterization of faint astrophysical objects that are located within the obscuring glare of much brighter stellar sources. Examples include planetary systems beyond our own, the detailed inner structure of galaxies with very bright nuclei, binary star formation, and stellar evolution. Contrast ratios of one million to ten billion over an angular spatial scale of 0.05-1.5 arcsec are typical of these objects. Achieving a very low background requires control of both scattered and diffracted light. The failure to control either amplitude or phase fluctuations in the optical train severely reduces the effectiveness of starlight cancellation schemes.

This innovative research focuses on advances in coronagraphic instruments, starlight cancellation instruments, and potential occulting technologies that operate at visible and near infrared wavelengths. The ultimate application of these instruments is to operate in space as part of a future observatory mission. Measurement techniques include imaging, photometry, spectroscopy, and polarimetry. There is interest in component development and innovative instrument design, as well as in the fabrication of subsystem devices to include, but not limited to, the following areas.

Starlight Suppression Technologies

- Image plane hybrid metal/dielectric, and polarization apodization masks in linear and circular patterns.
- Transmissive holographic masks for diffraction control and PSF apodization.
- Sharp-edged, low-scatter pupil plane masks.
- Low-scatter, low-reflectivity, sharp, flexible edges for control of scatter in starshades.
- Systems to measure spatial optical density, phase inhomogeneity, scattering, spectral dispersion, thermal variations, and to otherwise estimate the accuracy of high-dynamic range apodizing masks.
- Pupil remapping technologies to achieve beam apodization.
- Techniques to characterize highly aspheric optics.
- Methods to distinguish the coherent and incoherent scatter in a broad band speckle field.
- Coherent fiber bundles consisting of up to 10,000 fibers with lenslets on both input and output side, such that both spatial and temporal coherence is maintained across the fiber bundle for possible wavefront/amplitude control through the fiber bundle.

Wavefront Measurement and Control Technologies

- Small stroke, high precision, deformable mirrors and associated driving electronics scalable to 10,000 or more actuators (both to further the state-of-the-art towards flight-like hardware and to explore novel concepts). Multiple deformable mirror technologies in various phases of development and processes are encouraged to ultimately improve the state-of-the-art in deformable mirror technology. Process improvements are needed to improve repeatability, yield, and performance precision of current devices.
- Instruments to perform broad-band sensing of wavefronts and distinguish amplitude and phase in the wavefront.
- Integrated mirror/actuator programmable deformable mirror.
- Multiplexers with ultra-low power dissipation for electrical connection to deformable mirrors.
- Low-order wavefront sensors for measuring wavefront instabilities to enable real-time control and post-processing of aberrations.
- Thermally and mechanically insensitive optical benches and systems.
- Optical Coating and Measurement Technologies:
- Instruments capable of measuring polarization cross-talk and birefringence to parts per million.
- Highly reflecting, uniform, broadband coatings for large (> 1 m diameter) optics.
- Polarization-insensitive coatings for large optics.
- Methods to measure the spectral reflectivity and polarization uniformity across large optics.
- Methods to apply carbon nanotube coatings on the surfaces of the coronagraphs for broadband suppression from visible to NIR.

Other

- Methods to fabricate diffractive patterns on large optics to generate astrometric reference frames.
- Artificial star and planet point sources, with 1e10 dynamic range and uniform illumination of an f/25 optical system, working in the visible and near infrared.
- Deformable, calibrated, collimating source to simulate the telescope front end of a coronagraphic system undergoing thermal deformations.
- Technologies for high contrast integral field spectroscopy, in particular for microlens arrays with or without accompanying mask arrays, working in the visible and NIR (0.4 - 1.8 microns), with lenslet separations in the 0.1 -0.4 mm range, in formats of ~140x140 lenslets.

S2.02 Precision Deployable Optical Structures and Metrology

Lead Center: JPL

Participating Center(s): GSFC, LaRC

Planned future NASA Missions in astrophysics, such as the Wide-Field Infrared Survey Telescope (WFIRST) and the New Worlds Technology Development Program (coronagraph, external occulter and interferometer technologies) will push the state of the art in current optomechanical technologies. Mission concepts for New Worlds science would require 10 - 30 m class, cost-effective telescope observatories that are diffraction limited at wavelengths from the visible to the far IR, and operate at temperatures from 4 - 300 K. In addition, ground based telescopes such as the Cerro Chajnantor Atacama Telescope (CCAT) requires similar technology development.

The desired areal density is 1 - 10 kg/m^2 with a packaging efficiency of 3-10 deployed/stowed diameter. Static and dynamic wavefront error tolerances to thermal and dynamic perturbations may be achieved through passive means (e.g., via a high stiffness system, passive thermal control, jitter isolation or damping) or through active opto-mechanical control. Large deployable multi-layer structures in support of sunshades for passive thermal control and 20m to 50m class planet finding external occulters are also relevant technologies. Potential architecture implementations must package into an existing launch volume, deploy and be self-aligning to the micron level. The target space environment is expected to be the Earth-Sun L2.

This subtopic solicits proposals to develop enabling, cost effective component and subsystem technology for deploying large aperture telescopes with low cost. Research areas of interest include:

- Precision deployable structures and metrology for optical telescopes (e.g., innovative active or passive deployable primary or secondary support structures).
- Architectures, packaging and deployment designs for large sunshields and external occulters.
- In particular, important subsystem considerations may include:
- Innovative concepts for packaging fully integrated subsystems (e.g., power distribution, sensing, and control components).
- Mechanical, inflatable, or other precision deployable technologies.
- Thermally-stable materials (CTE < 1ppm) for deployable structures.
- Innovative systems, which minimize complexity, mass, power and cost.
- Innovative testing and verification methodologies.

The goal for this effort is to mature technologies that can be used to fabricate 16 m class or greater, lightweight, ambient or cryogenic flight-qualified observatory systems. Proposals to fabricate demonstration components and subsystems with direct scalability to flight systems through validated models will be given preference. The target launch volume and expected disturbances, along with the estimate of system performance, should be included in the discussion. Proposals with system solutions for large sunshields and external occulters will also be accepted. A successful proposal shows a path toward a Phase II delivery of demonstration hardware scalable to 5 meter diameter for ground test characterization.

Before embarking on the design and fabrication of complex space-based deployable telescopes, additional risk reduction in operating an actively controlled telescope in orbit is desired. To be cost effective, deployable apertures that conform to a cubesat (up to 3-U) or ESPA format are desired. Consequently, deployment hinge and latching concepts, buildable for these missions and scaleable to larger systems are desired. Such a system should allow <25 micron deployment repeatability and sub-micron stability for both thermal and mechanical on-orbit disturbances. A successful proposal would deliver a full-scale cubesat or ESPA ring compatible deployable aperture with mock optical elements.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop the relevant subsystem technologies and to transition into future NASA program(s).

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

Lead Center: MSFC

Participating Center(s): GSFC, JPL

This subtopic solicits solutions 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.

Please note: an emphasis regarding mirror systems is the mirror substrate support structure. The Technical Challenges contains information on specific technologies which need developing for each area.

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.

This subtopic matures technologies needed to affordably manufacture, test or operate complete mirror systems or telescope assemblies. Traditionally, this subtopic matured technology from TRL3 to TRL4. Now, there is an additional opportunity to propose in Phase II for an effort larger than a traditional Phase II for the purpose of maturing demonstrated component level technologies (TRL4) to demonstrated system level technologies (TRL6) by using them to manufacture complete telescope systems. A requirement of this option is that there must be an identified NASA program that will fly the developed new technology system.

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.

Introduction

The 2010 National Academy Astro2010 Decadal Report specifically identified large light-weight mirrors as a key technology needed to enable potential Extreme Ultraviolet (EUV), Ultraviolet/Optical (UV/O) and Infrared (IR) to Far-IR missions.

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 the discovery of habitable planets, facilitate advances in solar physics, and enable the study of faint structures around bright objects.

Finally, NASA is developing a heavy lift space launch system (SLS) with an 8 to 10 meter fairing and 40 to 50 mt capacity to SE-L2. SLS will enable extremely large space telescopes, such as 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths.

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. Specifically needed for a potential UVO mission are normal incidence 4-meter (or larger) diameter mirrors with 5 nm RMS surface figure error; and, active or passive alignment and control of normal-incidence imaging systems to achieve 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 performance requirement requires ultra-stable mirror support structures. Finally, specifically needed for potential IR/Far-IR missions are normal incidence 8-meter (or larger) diameter mirrors with cryo-deformations < 100 nm rms.

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). 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 $\$1M/m^2$.

Development is required to fabricate components and systems to achieve the following Metrics:

- Areal Cost < $\$500K/m^2$ (for UV/Optical).
- Areal Cost < $\$100K/m^2$ (for Infrared).
- Monolithic - 1 to 8 meters.
- Segmented > 4 meters (total aperture).
- Wavefront Figure < 5 nm RMS (for UV/Optical).
- Cryo-deformation < 100 nm RMS (for Infrared).
- Slope < 0.1 micro-radian (for EUV).
- Wavefront Stability < 10 pm/10 min (for Coronagraphy).
- Actuator Resolution < 1 nm rms (UV/Optical).

Finally, also needed is ability to fully characterize surface errors and predict optical performance.

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

This subtopic solicits proposals in the following areas:

- Components, Systems, and Technologies of potential X-Ray missions.
- Coating technologies for X-Ray, EUV, Visible, and IR telescopes.
- Free-form Optics surfaces design, fabrication, and metrology.

This subtopic focuses on three areas of technology development:

- X-Ray manufacturing, coating, testing, and assembling complete mirror systems in addition to maturing the current technology.
- Coating technology for wide range of wavelengths from X-Ray to IR (X-Ray, EUV, Visible, and IR).
- Free-form Optics design, fabrication, and metrology for CubeSat, SmallSat and Visible Nulling Coronagraph (VNC).

A typical Phase I proposal for X-Ray technology would address the relevant optical sub-component of a system with necessary coating and stray light suppression for X-Ray missions or prototype demonstration of a fabricated system and its testing. Similarly, a Coating technology proposal would address fabrication and testing of optical surfaces for a wide range of wavelengths from X-Ray to IR. The Free-form Optics proposals tackle the challenges involved in design, fabrication, and metrology of non-spherical surfaces for small-size missions such as CubeSat, NanoSat, and visible nulling coronagraph.

In a nutshell, a successful proposal demonstrates a low-cost ability to address NASAs science mission needs and technical challenges specified under each category of Technical Challenges.

Introduction

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-spherical surfaces with anticipated benefits of freeform optics such as fast wide-field and distortion-free cameras.

Technical Challenges

X-Ray Optical Component, Systems, and Technologies

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^2 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. 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$.

Coating Technologies for X-Ray, EUV, Visible, and IR Telescopes

The optical coating technology is a mission-enabling feature that determines 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 current coating technology of optical components needs to achieve TRL-6 by approximately 2018 to support the 2020 Astrophysics Decadal process. A number of optical coating metrics specific each wavelength are desired as:

The Optical Coating Metrics

- X-Ray Metrics:
  - Multilayer high-reflectance coatings for hard X-Ray mirrors similar to NuSTAR.
  - Multilayer depth gradient coatings for 5 to 80 KeV with high broadband reflectivity.
  - Zero-net-stress coating for iridium or other high-reflectance elements on thin substrates (< 0.5 mm).
- EUV Metrics:
  - Reflectivity > 90% from 6 nm to 200 nm and depositable onto a < 2 meter mirror substrate.
  - UVOIR Metrics:
  - Broadband reflectivity > 60% and uniform polarization from 90 nm to 2500 nm and depositable onto 2, 4, and 6 meter mirror substrates.
- Non-Stationary Metric:
  - Non- uniform optical coating to be used in both reflection and transmission that vary with location

and optical surface. Variation pertains to ratio of reflectivity to transmissivity, optical field amplitude, phase, and polarization change. The optical surface area ranges from1/2 to 6 cm.

Scattered Light Suppression Using Carbon Nanotube (CNT) Coating

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 ~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 density, and 1 kW/nanosecond pulses
- Adhere to the multi-layer dielectric or protected metal coating including Ion Beam Sputtering (IBS) coating

Freeform Optics Design, Fabrication, and Metrology

Future NASA missions with alternative low-cost science and small-size payload are constrained by the traditional spherical form of optics. These missions could benefit greatly by the freeform optics as they provide non-spherical optics with better aerodynamic characteristics for spacecraft with lightweight components to meet the mission requirements. Currently, the design and utilization of conformal and freeform shapes are costly due to fabrication and metrology of these parts. 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. For the coronagraphic applications, freeform optical components allow coronagraphic nulling without shearing and increase the useful science field of view. In this category, freeform optical prescription for surfaces of 0.5 cm to 6 cm diameters with tolerances of 1 to 2 nm rms are needed. In this respect, the freeform refers to either 2nd order conic prescription with higher order surface polished onto it or without underlying conic prescription with no steps in the surface. The optics with underlying conic prescription would need to be in F/# range of F/2 to F/20. In addition to the freeform fabrication, the metrology of freeform 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.

Ultra-Stable X-Ray grazing-incident Telescopes for Sub-Orbital Balloons and Rocket-borne Missions

Technology maturation to build complete low-cost, lightweight X-ray telescopes with grazing-incident optics that can be flown on potential long duration high-altitude balloon-borne or rocket-borne missions. The focus here is to reduce the areal cost of telescope by 2x such that the larger collecting area can be produced for the same cost or half the cost.