NASA 2019 SBIR Subtopic:

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

H. Philip Stahl, Ph.D.

Sub-Topic Manager

NASA 'Optics' Award Statistics Total

	Phase 1	Phase 2
2005	21% (8/38)	71% (5/7)
2006	28% (8/29)	63% (5/8)
2007	36% (4/11)	50% (2/4)
2008	59% (10/17)	50% (4/8)
2009	56% (9/16)	50% (4/8)
2010	50% (11/22)	11% (1/9)
2011	28% (7/25)	20% (1/5)
2012	28% (8/29)	50% (4/7)
2014	54% (7/13)	33% (2/6)
2015	48% (10/21)	20% (3/8)
2016	29% (7/24)	33% (2/6)
2017	39% (11/28)	**40% (4/10)**
2018	**23% (6/26)**	
Total	35% (106/299)	43% (37/86)

S2.03 “Advanced Optical Systems for UVO & IR”

	Phase 1	Phase 2
2015	50% (5/10)	20% (1/5)
2016	42% (3/7)	33% (1/3)
2017	70% (7/10)	33% (2/6)
2018	25% (3/12)	
Total	46% (18/39)	29% (4/14)

S2.04 “X-Ray Mirrors, Coatings and Free-Form”

	Phase 1	Phase 2
2015	45% (5/11)	66% (2/3)
2016	24% (4/17)	33% (1/3)
2017	22% (4/18)	50% (2/4)
2018	21% (3/14)	
Total	27% (16/60)	50% (5/10)

2018 SBIR S2.03 'Normal Incidence'

Phase I	12 Submitted	3 Funded

Boulder Nonlinear Systems: Programmable Phase Nulling Interferometer

OptiPro Systems: Additive Manufacturing of Silicon Carbide Mirrors

Thermal Expansion Solutions: Ultra-Stable ALLVAR Alloy Development

Phase II	TBD Submitted	TBD Funded

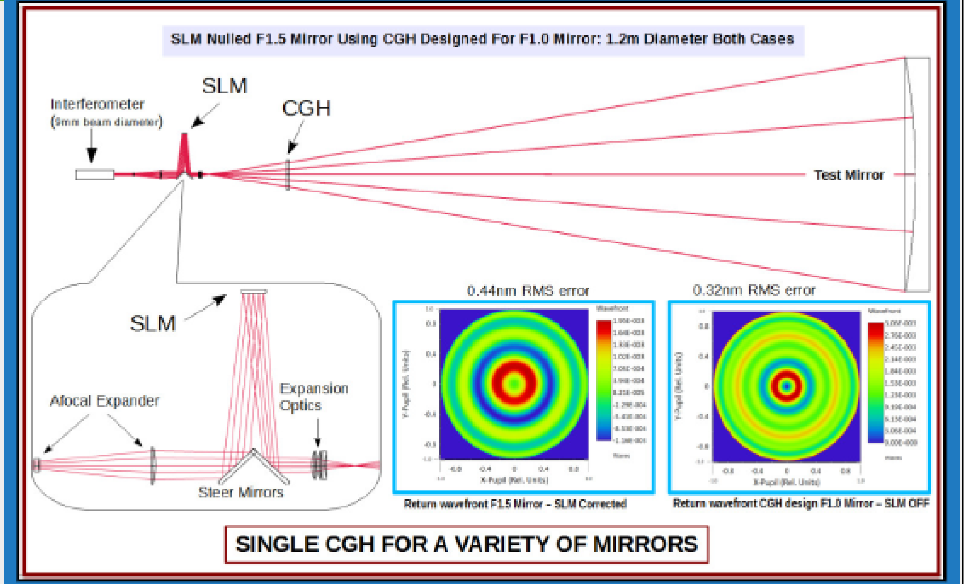
S2.03-5162 - Programmable Phase Nulling Interferometer for Giant Mirrors

PI: Hugh Masterson , Boulder Nonlinear Systems, Inc. - Lafayette, CO

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

A programmable phase nulling interferometer is proposed for testing of giant telescope mirrors, using a liquid crystal on silicon spatial light modulator (SLM). The SLM extends the use of a CGH, designed for a single aspheric mirror, to a range of mirrors in an aperture F-number trade space as residual phase error from the CGH is corrected by the SLM. Vibration free phase shifting interferometry can be performed by adding SLM piston phase. Temporal nulling of air current based phase error may be possible. SLMs have 1000^{th} wave phase control or better. In Phase I, a system will be constructed with a 512x512 SLM in a brassboard Twyman-Green interferometer to null test a 10 inch F3.5 or F4 parabolic mirror. Quality and repeatability tests of the null will be performed and measures to eliminate artifact due to SLM modulo 2π phase wraps will be implemented. In Phase II a full prototype will be constructed with a 1536x1536 SLM, and a CGH.



TECHNICAL OBJECTIVES AND WORK PLAN

The technical objectives are the construction of a brassboard SLM based Twyman-Green nulling Interferometer on a floating optical table. An F3.5 to F4 10 inch parabolic mirror will be null tested with the SLM without the need of a CGH. An algorithm will be modified to achieve fast convergence on the null and measures to eliminate artifacts due to modulo 2π phase wraps on the SLM will be implemented. Repeatability measurements of the residual wavefront error on the null will be performed and the effectiveness of measures to remove the phase wrap artifacts will be determined. The outcome of the research will be presented in a final report and the requirements for continued development to the Phase II prototype level will be outlined. The brassboard system will be controlled by a labVIEW executable and delivered to NASA

NASA APPLICATIONS

Optical test metrology for giant telescope mirrors; beam steering for satellite communication links; holographic optical trapping.

NON-NASA APPLICATIONS

Optical test metrology for giant telescope mirrors; optical test metrology for small scale commercial and custom optics; ground and satellite based beam steering; holographic optical trapping in biotechnology; multi-photon microscopy in biotechnology.

TRL

Estimated

1 2 3 4 5 6 7 8 9

FIRM CONTACTS

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SBIR · STTR America's Seed Fund™ POWERED BY SBA

S2.03-1853 - Additive Manufacturing of Silicon Carbide Mirrors

PI: Scott DeFisher , OptiPro Systems, LLC - Ontario, NY

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

Due to its mechanical and thermal properties, SiC is an ideal material for many demanding space applications. 3D printing near-net shapes in SiC will increase design freedom and reduce production cost. This research will have significant impact for space exploration. The development will generate new knowledge about the additive manufacturing of SiC and enable the production of SiC mirrors. Unlike existing processes, such as hot pressing, slip casting, or polymer binding, the new approach to be studied does not rely on high temperatures/pressures in a mold or a polymer binder that serves as the preliminary support structure until it is removed by sintering. Rather, sodium hydroxide will be applied to SiC powder in a powder bed, liquid binder-jetting process to oxidize the SiC to form an amorphous silica layer. When heated, this amorphous layer will crystallize to form a network of connecting rods and plates between the adjacent SiC grains through secondary crystal growth. This represents a transformative step forward in additive manufacturing that is applicable not only to SiC.

TECHNICAL OBJECTIVES AND WORK PLAN

The technical objectives in this proposal will focus on demonstrating the feasibility to 3D print SiC material. With this we will be able to estimate any realized cost savings for manufacturing flight ready SiC mirrors. Finally, we will develop conceptual designs of a 3D printing machine to be optimized for increased precision. There is the potential that this technology can be expanded to other materials also. We would propose to build this prototype machine if awarded a phase II.
To accomplish this we will work with UNC Charlotte to perform the basic science effort into creating the 3D SiC samples and test them for material quality compared to traditional manufacturing methods. OptiPro will then perform finishing operations on the samples to demonstrate the ability to achieve optical quality of the material. Finally we will develop a conceptual additive powder bed printer that would be built in a phase II effort.
This effort will provide the plan for cost effective production of SiC mirrors and has the potential to be used for other mateirals as well in the future.

TRL

Estimated

1	2	3	4	5	6	7	8	9
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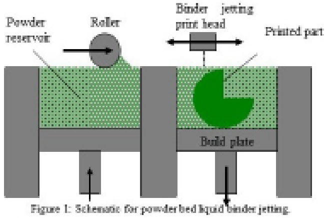

Figure 1: Schematic for powder bed liquid binder jetting.

NASA APPLICATIONS

The work proposed in this effort can have a direct effect on NASA's potential LUVOIR and HabEx missions. It can also have applications in the Balloon Planetary Telescope and many CubeSat applications. Long term there is development potential to scale up to larger optical surfaces.

NON-NASA APPLICATIONS

This technology has the potential to dramatically reduce the cost of light weighted SiC mirrors. There are many applications for space and aerospace applications that it could fill a need for. There is also a strong possibility that this technology could lead to additive manufacturing of other mateirals as well as new optical ceramics.

FIRM CONTACTS

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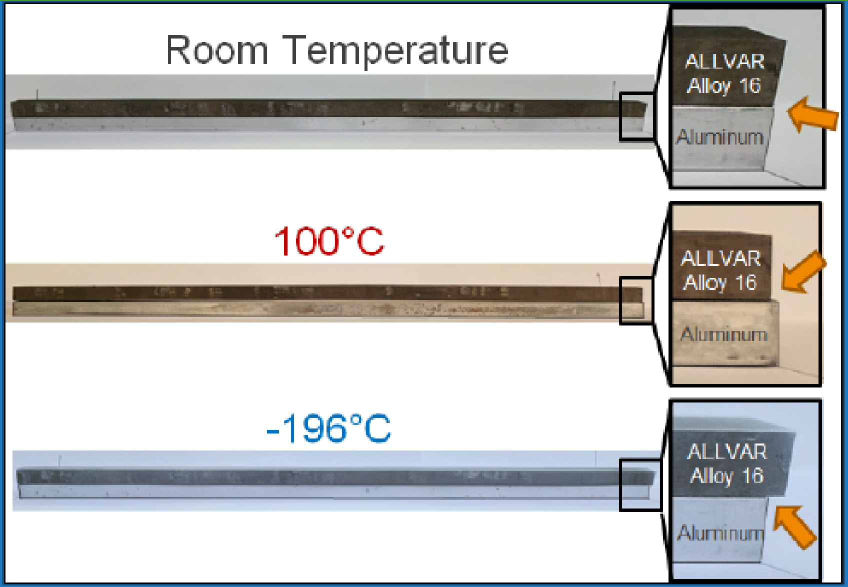
S2.03-7013 - Ultra-Stable ALLVAR Alloy Development for Space Telescopes

PI: James Monroe , Thermal Expansion Solutions, Inc - College Station, TX

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

ALLVAR Alloys 16 shrinks when heated and expands when cooled, known as negative thermal expansion (NTE). This opposite effect from most materials allows Alloy 16 to compensate for positive thermal expansion (PTE) materials. We have created a new material for athermalizing optics made from any type of mirror material by welding Alloy 16 to other titanium based alloys to create a specified thermal expansion coefficient. Currently, achievable coefficients of thermal expansion (CTE) range between -16 ppm/K, Alloy 16's CTE, to +8.6 ppm/K, Ti64's CTE, at 20°C. This provides a new alternative material to currently used carbon fiber composite metering structures and trusses used in optics. If these new metals can be manufactured to have ultra-stability, they could be used as metering structures in EUV/Optical/IR large area telescopes, coronagraphs for exo-planet searches, and smaller telescopes and optical benches for space-based gravitational wave observatories.



TECHNICAL OBJECTIVES AND WORK PLAN

The ultimate goal of this effort is to create alternative ultra-stable telescope metering structures using ALLVAR Alloys. The key objectives of this Phase I project include 1) developing and evaluating ALLVAR Alloy stabilization processes and 2) developing a bonding technique to enable pm-tests in Phase II. To achieve key objective 1, a factorial design of experiments scheme will study thermal cycling and warm processing effects on ALLVAR Alloy 16's dimensional stability. ALLVAR Alloy tube will be back extruded, dilatometry samples cut and subjected to stabilization treatments, and the dimensional and CTE stability studied over time. The results will enable modification of the current ALLVAR Alloy metering structure manufacturing process to enhance the material's dimensional stability. To achieve key objective 2, polishing and hydroxide bonding techniques will be evaluated at the University of Florida in preparation for sub-pm/√Hz measurements in Phase II. Deliverables for this project are a report outlining the ALLVAR Alloy stabilization and hydroxide bonding processes and a set of stability samples that will be studied through a Phase II project. A Phase II project will use ultra-high stability measurements to further evaluate the stabilization processes developed in Phase I and understand the effects of welding and radiation on ALLVAR Alloy's dimensional stability.

NASA APPLICATIONS

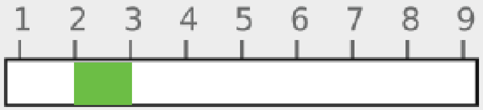
A new material with picometer stability can potentially improve support structures for optic systems critical to NASA's Science Mission Directorate, like LUVIOR or HabEX. There are other potential opportunities in the manufacture of ultra-stable coronograph hardware, support structures for deformable mirrors, telescope steering, and star tracker markets. ALLVAR metals can also be used to make balloon telescopes for exoplanet discovery and cryogenic far infrared telescopes.

NON-NASA APPLICATIONS

ALLVAR's unique negative thermal expansion properties can compensate for thermal focus shift in refractive infrared optics used for nightvision, UVAs, missiles, and sub-sea applications. This allow infrared optics manufacturers to reduce the size and weight of their optics. ALLVAR Alloy's unique properties are also starting to get the attention of composite and glass companies. We see potential collaboration with companies in these areas for support hardware and transition piece applications.

TRL

Estimated



FIRM CONTACTS

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2018 SBIR S2.04 ‘X-Ray & Freeform’

Phase I 14 Submitted 3 Funded

Faraday Technology: Robust FARADAYIC CNT Based Coating for Scattered Light Suppression

Optimax Systems: Improving Freeform Manufacturing using a Unique Deflectometry Enclosure

Reflective X-ray Optics: Non-Iridium X-Ray Coatings for Lynx and other Future Missions

Phase II TBD Submitted TBD Funded

S2.04-1032 - Robust FARADAYIC CNT Based Coating for Scattered Light Suppression

PI: Dan Wang , Faraday Technology, Inc. - Englewood, OH

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NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

The proposed black coating technology addresses the need for low reflectivity surfaces for optical components such as detectors, solar coronagraphs, telescope housings and baffles where stray light reduction is vital. Low reflective coatings (reflectivity of ~0.1% or less) in the broad spectral range should withstand aggressive space environments and launch conditions with marginal impact on their adhesion and optical performance. A promising candidate with an outstanding absorptance is chemically vapor deposited layers of carbon nanotubes. However, these coatings are typically grown by expensive and thermally based techniques and can be difficult to apply to complex structures. The proposed innovation is a low-cost, efficient and scalable manufacturing process for the deposition of durable, low reflectivity carbon nanotube black coatings based on the use of pulse reverse electrophoretic deposition. This technology will enable controlled, conformal deposition of highly dense, vertically aligned multi-walled carbon nanotube black coatings on simple and complex shapes and sharp edges.

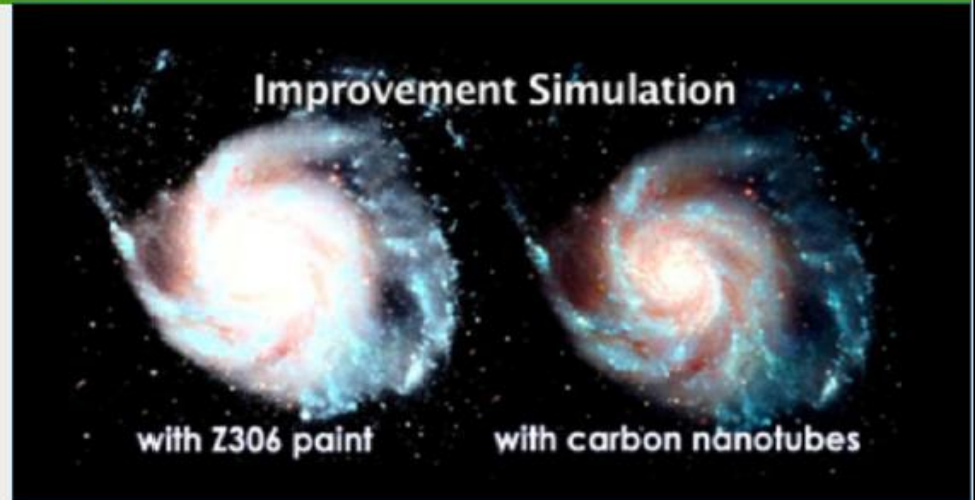
TECHNICAL OBJECTIVES AND WORK PLAN

Phase I objective is to demonstrate feasibility of a scalable, low-cost manufacturing process to deposit durable, low reflectivity carbon nanotube black coatings based on pulsed electrophoretic deposition. This technology will enable conformal deposition of carbon nanotube black coatings on complex shapes and sharp edges on commonly used spacecraft materials. Specific objectives are 1) design/build an electrophoretic deposition cell, 2) demonstrate pulsed electrophoretic deposition of dense, vertically aligned carbon nanotubes, 3) demonstrate the potential to meet functional performance specifications, including durability in severe conditions, 4) complete a preliminary techno-economic analysis. In Phase I, Faraday will develop an electrophoretic bath and manipulate the pulse parameters to deposit dense, vertically aligned carbon nanotubes onto substrates, and characterize the coatings to show the potential of achieving the desired reflectivity of 0.1% or less, measure uniformity and morphology and demonstrate the potential for durability. A preliminary techno-economic will be done to show the potential to reduce the cost while maintaining required optical properties. Phase II would optimize deposition parameters, elucidate their effect on scattered light suppression and thermal-structural performance, process alpha-scale components. Phase I deliverables are required reports.

TRL

Estimated

1 2 3 4 5 6 7 8 9 (estimated range: 2–5)



NASA APPLICATIONS

The key first customer for the proposed technology is NASA and their prime contractors for space missions. The applications include optical components where broadband absorption of electromagnetic radiation is critical, including for detectors and high-sensitivity optical systems. Solar coronagraphs and space-borne instruments, for example telescope housings and baffles, require stray light reduction.

NON-NASA APPLICATIONS

In addition to the NASA's space missions, availability of black optical coating technology might open up new markets such as military applications including missile seeker, surveillance, night vision cameras, thermal imaging and shielded windows. We also envision this technology application in other areas including: electronics and telecommunications, semiconductors, solar panels, automobile industry or any other technology that suffers from scattered light reflection.

FIRM CONTACTS

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S2.04-4372 - Improving freeform manufacturing using a unique deflectometry enclosure

PI: Todd Blalock , Optimax Systems, Inc. - Ontario, NY

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

The goal of this NASA Phase 1 SBIR is to develop and investigate a unique multi-camera, multi-monitor deflectometry enclosure to improve the manufacturing of freeform optics. This proposed innovation would increase efficiency of the freeform manufacturing process by greatly reducing the time to measure the mid-spatial frequency errors of the freeform part. This would reduce the time and therefore cost of freeform manufacturing.

Freeform optics are improving optical design and allowing new optical systems with greater precision and smaller form factors. This innovation will allow these new optical surface to be realized at lower costs; a critical need for NASA and other optical system designers.

TECHNICAL OBJECTIVES AND WORK PLAN

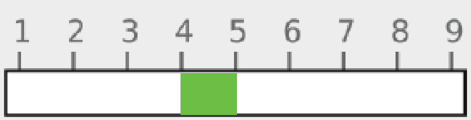
Technical Objectives:
1. Model best configuration for this multi-camera, multi-monitor deflectometry system.
2. Calibration of system
3. Software development and synchronizing data acquisition.
4. Verify mid-spatial frequency error using calibration artifact.
The work plan includes:

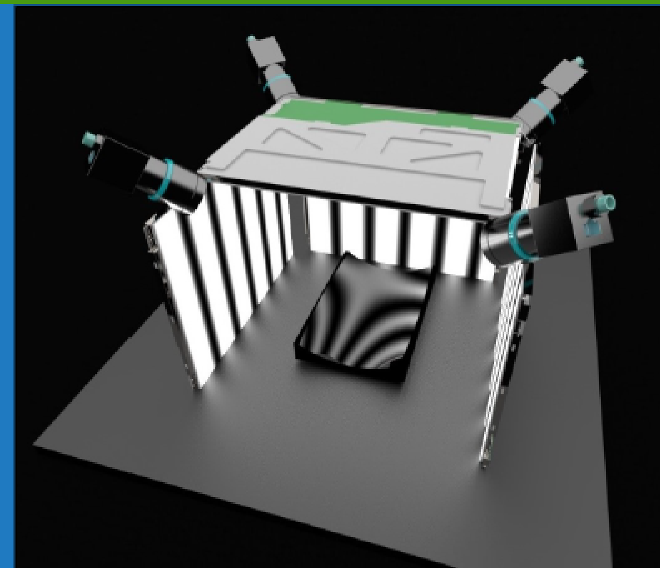
- Performing ray-trace modeling and rendering for optimizing design.
- Set-up test bed for deflectometry system
- Development of user friendly GUI based software to do testing and analysis.
- Compare results with other metrology techniques (interferometry, CMM, profilometer)

This will will provide the foundation for integrating this non-contact metrology system into manufacturing that will reduce cost of freeform production.

TRL

Estimated





NASA APPLICATIONS

Freeform based optical systems provide better optical performance in smaller footprint. NASA applications include
Exo-planet Imaging systems - Freeform optics would improve performance with fewer optics in a smaller footprint.
LUVOIR Ultraviolet Multi Object Spectrograph - Operating in the UV would require fewer optics in as smaller package.
Origins Space Telescope (OST) - This telescope operating in the infrared High performance freeform optics would solve the requirement of

NON-NASA APPLICATIONS

Freeforms

Freeform optics are quickly becoming part of many commercial and military optical systems. Many optical designers are starting to use freeform optics to achieve optical performance (less aberrations), lighter weight optical systems through a reduced number of components, and an increased ability to go off axis with smaller and tighter packages. Examples of commercial uses of freeforms include:

- Heads-up displays
- Compact imaging systems
- Augmented and Virtual reality display systems

S2.04-4972 - Non-iridium X-ray coatings for Lynx and other future missions

PI: David Windt , Reflective X-ray Optics, LLC - New York, NY

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

- Lynx is the high-energy flagship mission under consideration for the 2020 Astrophysics Decadal Survey. It will have high collecting area and sub-arcsecond angular resolution in the X-ray band from 0.1 to 10 keV.
- Lynx will use a light-weight, nested X-ray telescope constructed from precisely-formed thin-shell mirror substrates with reflective coatings.
- However, sub-arcsecond angular resolution will not be possible using thin-shell mirrors unless we can effectively mitigate film-stress-driven deformation of the individual X-ray mirrors after deposition of the reflective coating.
- Iridium coatings provide high reflectance in the Lynx band, but have exceedingly high stress.
- We propose therefore to develop low-stress, non-iridium coatings that use optical interference for high X-ray reflectance, in order to facilitate high collecting area and sub-arcsecond angular resolution.

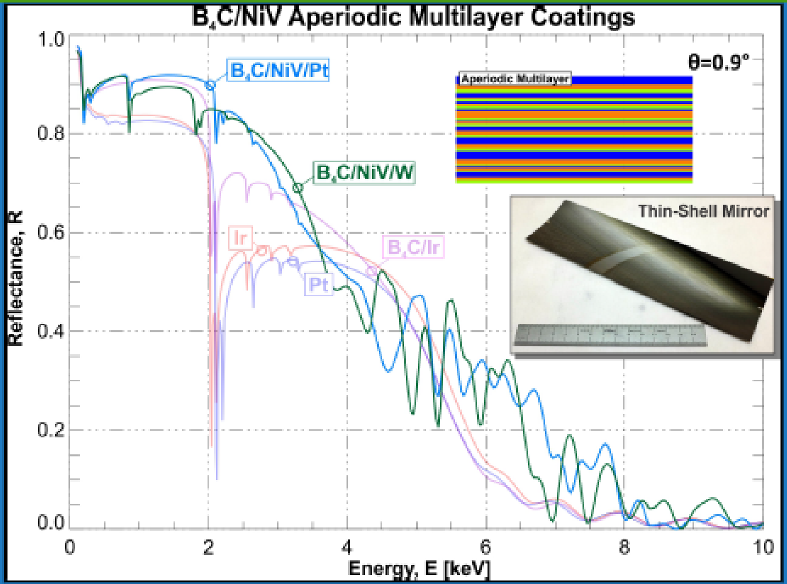
TECHNICAL OBJECTIVES AND WORK PLAN

- The proposed effort aims to develop low-stress, high-X-ray-reflectance optical interference coatings for Lynx, using in place of iridium (Ir) either platinum (Pt) or tungsten (W) layers, in combination with layers of various light elements.
- Prototype coatings will be designed and fabricated using established facilities and methods.
- X-ray reflectance, film stress, surface roughness, and other relevant properties will be measured, also using established facilities and methods.
- The Phase I deliverable will comprise a detailed technical report summarizing our findings, expected to include a successful performance demonstration of one or more prototype low-stress, high-X-ray reflectance coatings suitable for Lynx.

TRL

Estimated

1 2 3 4 5 6 7 8 9



NASA APPLICATIONS

The low-stress, high-reflectance X-ray coatings that we propose to develop are critically needed for the construction of light-weight X-ray telescopes having sub-arcsecond angular resolution, as required for NASA's Lynx mission now under consideration for the 2020 Astrophysics Decadal Survey, and for other future missions as well.

NON-NASA APPLICATIONS

The new X-ray coatings potentially can be used to develop high-resolution X-ray optics for a variety of other applications outside of space science, including instruments for next-generation light sources (FELs, etc), plasma physics, atto-second physics, and others.

FIRM CONTACTS

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2017 SBIR S2.03 ‘Normal Incidence’

Phase I 10 Submitted 7 Funded

Arctic Slope Technical Services, Additively Manufactured, Thermally Stable Telescope Mirror Substrates

CFE Services, Lightweight, Stable Optical Benches in Silicon Carbide and Beryllium

Dallas Optical Systems, Additive Manufactured Very Light Weight Diamond Turned Aspheric Mirror

Goodman Technologies, 3D Printed Silicon Carbide Scalable to Meter-Class Segments for Far-Infrared Surveyor

Mentis Sciences, Silica-Silica Mirror Substrate Fabrication Technology

Soter Technology, Rapid Fabrication of High Stability Optical Mirror Blanks

Peregrine Falcon Corp, Advanced Athermal Telescopes

Phase II 6 Submitted 2 Funded

Dallas Optical Systems, Additive Manufactured Very Light Weight Diamond Turned Aspheric Mirror

Goodman Technologies, 3D Printed Silicon Carbide Scalable to Meter-Class Segments for Far-Infrared Surveyor

NASA SBIR/STTR Technologies

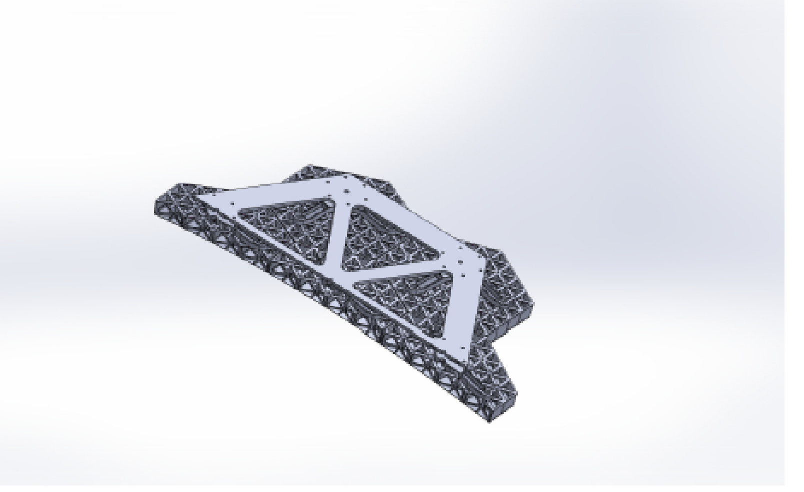
S2.03-9674 - Additive Manufactured Very Light Weight Diamond Turned Aspheric Mirror

PI: John Casstevens
Dallas Optical Systems, Inc. - Rockwall, TX

Identification and Significance of Innovation

Very stable dia. turned additively manufactured mirror completed Ph I.
Low cost, ultra-light and stiff mirrors of Aluminum made Ph I.
Manufacture of an aluminum 0.6 meter segmented spherical mirror made of a diamond turned central hexagonal segment surrounded by six diamond turned off-axis hexagonal spherical mirrors.
Low cost, very low areal density, very stiff metal mirror

Estimated TRL at beginning and end of contract: (Begin: 5 End: 6)



Technical Objectives and Work Plan

---DOS will design the mirrors to be additively manufactured to optimize strength, stiffness and areal density consistent with very low cost.
---Work closely with Stratasys(SDM), to build ultra lightweight on-axis and off-axis aluminum segments for a diamond turned 0.6 meter mirror made of one on-axis sphericalhexagonal mirror surrounded by six off-axis spherical hexagonal mirror segments.
--Radial, axial and azimuth datums and assembly features will be built by AM and diamond turning to allow precise and repeatable assembly of mirror segments. Optical testing of the assembled spherical mirror is much easier and less expensive than aspheres.
---Development of state of the art AM technology for thermally stable Al10SiMg aluminum mirrors produced in Phase I will be continued.
--- DOS will conduct thermal stability studies and develop efficient machining methods of thin wall superalloy mirrors for to NiP plating.
--- DOS work with ARC Specialties Inc. and Laser Welding Solutions Inc. to develop welding technology.

NASA Applications

NASA's mission in space research includes such far-reaching projects as Deep Space Optical Communication (DSOC), Advanced Technology Large Aperture Telescope (ATLAST), Terrestrial Planet Finder, Orbiting Wide Angle Light Collector, Cosmic Microwave Background Polarization (CMB-Pol), the Single Aperture Far-IR (SAFIR), the Sub-millimeter Probe of the Evolution of Cosmic Structure (SPECS) and Wide Field InfraRed Space Telescope (WFIRST).

Non-NASA Applications

This innovative mirror manufacturing technology is applicable to all these projects as well as any military, scientific or commercial application requiring low cost light weight mirror optical components.

Firm Contacts

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NASA SBIR/STTR Technologies

S2.03-9933 - 3D Printed Silicon Carbide Scalable to Meter-Class Segments for Far-Infrared Surveyor

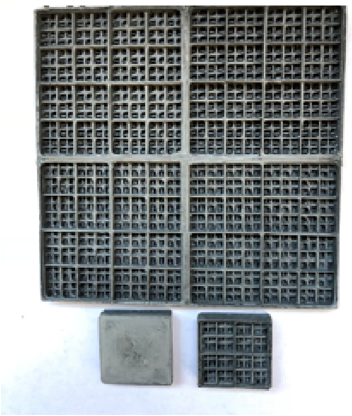
PI: William Goodman

Goodman Technologies, LLC - Albuquerque, NM

Identification and Significance of Innovation

- Demonstrated ***3D Printing and Additive Manufacture of Silicon Carbide***
- Demonstrated ***SiC-SiC nanocomposites and High SiC content Reaction Bonded SiC***
- ***3 Provision Patents Filed*** and Reported to NASA NTSR.
- ***Prototype Mirror Substrate scaled 16X with no limit to size.***
- ***Achieved 10 kg/square meter areal density*** on first attempt with gradient lattice
- Ability to print 1.44 square meter in 1-day on a single small printer.
- ***Print 20-m aperture in 230 days with 1 small printer.***
- Partially replicated a mirror surface.
- Process ***directly traceable to manufacturing in microgravity.***

Estimated TRL at beginning and end of contract: (Begin: 4 End: 5)



Technical Objectives and Work Plan

The overarching goal of Phase II is to use 3D printing and additive manufacturing (3D/AM) processes to produce the greenbody components, that when assembled and ceramized, can yield a large meter-class silicon carbide primary mirror substrate suitable for the NASA *Gondola for High Altitude Planetary Science (GHAPS)* mission, and exhibits traceability to future missions such as OST and LUVOIR which may require 1.5 to 2.5 meter mirror segments. This goal was discussed with Roy Young (NASA MSFC GHAPS OTA), Monica Hoffman (GHAPS Project Manager, NASA GRC, and Ron Eng the NASA MSFC Phase I PM. **Our objectives are directly traceable to multiple COR priorities defined in the 2016 and 2017 PATRs. Phase II Work Plan includes: 1) Optimize Feedstock for Large Optics, 2) Modify 1.2-m "Big Bird" printer for In Situ Cure, 3) Print Powered Aspheres, 4) Design/Print 25-cm Pathfinder Surrogate traceable to GHAPS 1-m PM, 5) Print parts for GHAPS PM, 6) Improve Replication, 7) Microgravity Studies.**

NASA Applications

- GHAPS and other Balloon Experiments Requiring Dimensional Stability and Robustness
- Low Cost, Rapidly Manufactured Telescopes for LASERCOM
- Manufacturing in Microgravity on ISS and Deep Space Gateway
- Origins Space Telescope (FIR) Primary Mirror Segments
- LUVOIR Primary Mirror Segments
- HabEx
- ELISA and LISA

Non-NASA Applications

- Low cost, lightweight, dimensionally stable telescopes
- Lasercom, Astronomy, Imaging, Remote Sensing
- Optical instruments/telescopes for imaging, surveillance, recon
- Atmospheric and ocean monitoring
- Imagery and mapping for resource management, disaster relief.
- Airborne, shipborne and land-based laser beam directors

Firm Contacts

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2017 SBIR S2.04 ‘X-Ray, Freeform & Coating’

Phase I 18 Submitted 4 Funded

Applied Sciences, Pyramid Nanostructured Coatings for Stray Light Suppression,

Mindrum Precision, Pre-Collimator Chemical Milling for X-ray Telescopes,

Voxtel, Freeform Optics for Optical Payloads with Reduced Size and Weight

ZeCoat, Battery-Powered Process for Coating Telescope Mirrors in Space

Phase II 4 Submitted 2 Funded

Applied Sciences, Pyramid Nanostructured Coatings for Stray Light Suppression,

Voxtel, Freeform Optics for Optical Payloads with Reduced Size and Weight

NASA SBIR/STTR Technologies

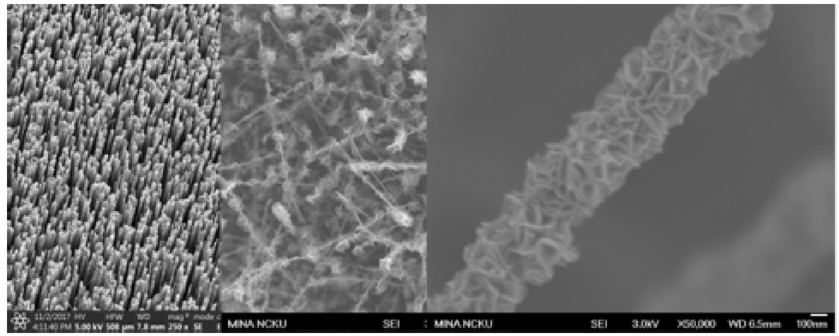
S2.04-8778 - Pyramid Nanostructured Coatings for Stray Light Suppression

PI: Carla Lake

Applied Sciences, Inc. - Cedarville, OH

Identification and Significance of Innovation

Vertical arrays of carbon nanotubes have been shown to yield values as low as 0.1 % of total hemispherical reflectance the complexities and cost with fabrication pose significant barriers to capturing this level of stray light suppression. The current work is directed to capturing the same or comparable levels of reflectance SCCNTs which can be readily-applied and cured at room temperature. Applied Sciences SCCNT coatings demonstrated a total hemispherical reflectance of 1%, 5x better than the legacy material – Z306, in Phase I. The proposed innovation is practical and affordable SCCNT coatings into an aerospace qualified polymer for stray light suppression. In Phase II, the cost and simplicity of this approach will be exploited to optimize reflectance over the desired spectral range. The SCCNT can be tuned for absorption/scattering over a broad spectral region by altering the geometry and functionality. Additionally, a novel method of graphene growth on SCCNF offers further enhancement of absorption of stray light, at low cost and ease of application.



Estimated TRL at beginning and end of contract: (Begin: 3 End: 7)

Technical Objectives and Work Plan

The objective of the Phase II proposal is to create exceptionally black coatings based on polymer coatings enhanced with carbon nanomaterials, including nanotubes and dope graphene. The methodology will continue to emphasize nanotextured polymers as well as electrostatically deposited nano materials. In particular ASI will optimize the SCCNT-loaded Z306 material system, as well as perform optimization of the PDMS stamping of pyramidal nanostructures into the polymer coating. The optimized materials will be extensively characterized in laboratory and relevant environments in order to elevate the technical readiness level (TRL) from 3 to 7.

The proposed Phase II work plan is divided into three distinct segments. The first is materials improvement, development and optimization effort, the second segment focus on extensive materials characterization, testing, and advancement of the TRL of the stray light suppressant coating/material. The third segment focuses on scalability, quality control and the advancement of the MRL of the coating material technology.

NASA Applications

Stray light control components for space telescope applications – Optical System Housing, Baffles and Apertures, Sensors and detectors, Spectrometers, Camera applications, Beam Dumps

Non-NASA Applications

Telescopes, binoculars, night vision goggles,
Laser safety screens
Mobile phone cameras
Automotive applications
Blackbody radiators

Firm Contacts

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NASA SBIR/STTR Technologies

S2.04-8407 - Freeform Optics for Optical Payloads with Reduced Size and Weight

PI: Paul Harmon
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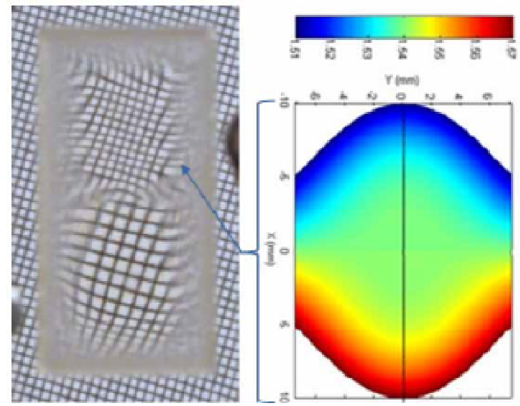
Identification and Significance of Innovation

To address NASA's need for robust optics compatible with space platforms of constrained size and weight, freeform optics that combine the benefits of freeform surfaces and volumetric freeform gradient-index (GRIN) optical materials will be demonstrated. The gradient-index contours of the volumetric freeform GRIN materials can be used to implement optical power and reduce geometric and chromatic aberrations. And, when freeform surfaces are included, heretofore unavailable degrees of design freedom are made available. The new degrees of freedom can be used to implement complex high-order polynomial optical functions, allowing reductions in the size and weight of the system, with machining tolerances that are relaxed due to the freeform homogeneous optical elements. As the 3D-GRIN optics are capable of achromatic performance, they can replace freeform mirrors. By virtue of the nanofillers used in the nanocomposite 3D-GRIN optics, they are hard, strong, easy to polish and machine, robust to temperature variation, and can be made radiation tolerant.

Estimated TRL at beginning and end of contract: (Begin: 3 End: 4)



Planar 3D GRIN profiles implementing two bicubic phases- one the inverse of the other

Technical Objectives and Work Plan

Technical Objectives:

- Gradient index contrast of n => 0.2 (> 0.3 goal),
- Demonstration of scatterless transparent from 400 nm to 2000 nm
- Characterization of refractive index over the -50 oC to 100 oC temperature range
- Demonstration of high-order radially variable and axially variant lenses, 1-mm to 100-mm (f/2 to f/20)
- Demonstration of high-order polynomial functions in planar 3D-GRIN optical elements
- Demonstration of high-order polynomial functions in hybrid freeform-surfaced 3D-GRIN elements

Work Plan:

1. Systems engineering and requirements definition
2. Optical design and multi-variant optimization
3. Optimization and characterization of nanocomposite inks and films
4. Demonstration of temperature stability of symmetric radially and axially varying GRIN lenses
5. Characterization of high-order polynomial optical functions implemented in: 3D-GRIN and freeform-surfaced 3D-GRIN elements
6. Temperature testing

NASA Applications

- Adaptive optics
- Phase correctors
- Telescopes
- Optical communications
- Small-satellite optics

Non-NASA Applications

Camera lens, laser optics, rifle sight, computational imaging, contact lens, endoscope, industrial inspection, photovoltaics, solid state lighting.

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Any Questions?

NASA 2019 SBIR Subtopic:

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

H. Philip Stahl, Ph.D.

Sub-Topic Manager

IMPORTANT for Proposals: Commercialization Plan

Starting this year, no proposal can achieve the highest rating without a strong commercialization plan.

Preference may be given to companies that have successfully leveraged NASA's SBIR investment.

Commercialization metrics include:

- Disclosure of technology and/or process development/improvement via New Technology Report.
  - If no new technology is developed, then why are we making the investment?
  - Companies that consistently say that nothing new was produced by the SBIR investment may be penalized.
- Patents resulting from SBIR investments.
- Commercialization of SBIR developed innovation as measured by new revenue and employment.
- Use of the innovation by a NASA program.

IMPORTANT: Success Stories

Success Stories are essential for keeping SBIR Subtopic funded.

To help justify the Optics SBIR Sub-Topics, please send to Ron Eng or myself a one page success story summary of your past SBIR contracts.

Please include:

- Name of contract and amount of award
- How have you commercialized the innovation
- What new revenue or new employment can be traced to the SBIR investment
- Has the innovation been used in a NASA (or other government) program, etc.
- Was the innovation patented

Generic Instructions to Proposer

Define a customer or mission or application and demonstrate that you understand how your technology meets their science needs.

Propose a solution based on clear criteria and metrics

Articulate a feasible plan to:

- fully develop your technology,
- scale it to a full size mission, and
- infuse it into a NASA program

Deliver Demonstration Hardware not just a Paper Study, including :

- documentation (material behavior, process control, optical performance)
- mounting/deploying hardware

New for 2019

The SBIR Program is using new software to create the RFP and I do not know how it will be structured. But, it should contain the elements discussed in the following charts.

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

To accomplish NASA's high-priority science requires low-cost, ultra-stable, large-aperture, normal incidence mirror systems with low mass-to-collecting area ratios. Where mirror system is defined as substrate, supporting structure, and actuation and thermal systems.

Subtopic solicits solutions in the following areas:

- **Components and Systems for potential EUV, UV/O or Far-IR missions**
- **Technology to fabricate, test and control potential UUV, UV/O or Far-IR telescopes**
- **Technology to fully characterize surface errors and predict optical performance**
- **Telescopes that enable sub-orbital rocket or balloon missions.**

Subtopic's emphasis is to mature technologies needed to affordably manufacture, test or operate complete mirror systems or telescope assemblies.

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.

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.

Metrics

The most important metric (after performance) is affordability. Current normal incidence space mirrors cost $4 million to $6 million per square meter. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to less than $1M to $100K/m2.

Technology Metrics:

Aperture for all wavelengths except Far-IR

- Monolithic: 1 to 8 meters
- Segmented: 3 to 20 meters

For UV/Optical

- Areal Cost < $500K/m2
- Wavefront Figure < 5 nm RMS (via passive design or active deformation control)
- Wavefront Stability < 10 pm/10 min
- First Mode Frequency 60 to 500 Hz
- Actuator Resolution < 1 nm RMS
- Optical Path-length Stability < 1 pm/10,000 seconds for precision metrology
- Areal density < 15 kg/m2 (< 35 kg/m2 with backplane)
- perating Temperature Range of 250 to 300K

For Far-IR

- Aperture diameter 1 to 4 m (monolithic), or 5 to 10 m (segmented)
- Telescope diffraction-limited at <30 microns at operating temperature 4 K
- Cryo-Deformation < 100 nm RMS
- Areal cost < $500K/m2
- Production rate > 2 m2 per month
- Areal density < 15 kg/m2 (< 40 kg/m2 with backplane)
- Thermal conductivity at 4 K > 2 W/m*K
- Survivability at temperatures ranging from 315 K to 4 K

For EUV

- Surface Slope < 0.1 micro-radian

Deliverables

An ideal Phase 1 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 2 delivery; or a reviewed preliminary design and manufacturing plan which demonstrates feasibility. While detailed analysis will be conducted in Phase 2, 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 2 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 1 and Phase 2 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 2 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).

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/m2 for a 5 m fairing EELV vs. 150 kg/m2 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 m2 of collecting area) should have an areal cost of less than $2M/m2. And, a 16-m class mirror (with 200 m2 of collecting area) should have an areal cost of less than $0.5M/m2.

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

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.

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

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.

Fabrication, Test and Control of Advanced Optical Systems

Future UV/Optical/NIR telescopes require very precise and ultra-stable mirror systems.

- Subtopic encourages proposals to develop technology which makes a significant advance in the ability to fabricate and test precision optical systems.

- Subtopic encourages proposals for technology (wavefront sensing, metrology, and verification and validation) to enable optical systems with wavefront stability to < 10 pm RMS over intervals of ~10 minutes.

  The ~10-minute stability period is driven by current wavefront sensing and control techniques that rely on stellar photons from the target object to generate estimates of the system wavefront.

  Current methods of wavefront sensing include image-based techniques such as phase retrieval, focal-plane contrast techniques such as electric field conjugation and speckle nulling, and low-order and out-of-band wavefront sensing that use non-science light rejected by the coronagraph to estimate drifts in the system wavefront during observations.

  New methods may include of using out-of-band light to improve sensing speed and spatial frequency content, new control laws incorporating feedback and feedforward for more optimal control, new algorithms for estimating absolute and relative wavefront changes, and the use of artificial guide stars for improved sensing signal to noise ratio and speed.

  Current methods of metrology include edge sensors (capacitive, inductive, or optical) for maintaining segment cophasing, and laser distance interferometers for absolute measurement of system rigid body alignment. Development of these techniques to improve sensitivity, speed, and component reliability is desired. Low power, high-reliability electronics are also needed.

- Also needed are techniques for system verification and validation at the picometer level during I&T.

  High speed spatial and speckle interferometers are currently capable of measuring single-digit picometer displacements and deformations on small components in controlled environments. Extension of these techniques to large-scale optics and structures in typical I&T environments is needed.

Components/Systems for potential Infrared/Far-IR missions

Far-IR Surveyor is a cryogenic far-IR mission, which could be either a large single-aperture telescope or an interferometer.

Common requirements:

- Telescope operating temperature ~4 K
- Telescope diffraction-limited at 30 microns at the operating temperature
- Mirror survivability at temperatures ranging from 315 K to 4 K
- Mirror substrate thermal conductivity at 4 K > 2 W/m*K
- Zero or low CTE mismatch between mirror substrate and backplane

Divergent requirements:

- Large single-aperture telescope:
  - Segmented primary mirror, circular or hexagonal
  - Primary mirror diameter 5 to 10 m
  - Possible 3 dof (tip, tilt and piston) control of mirror segments on orbit
- Interferometer:
  - Monolithic primary mirrors
  - Afocal, off-axis telescope design
  - Primary mirror diameter 1 to 4 m

Success metrics:

- Areal cost < $500K/m2
- Areal density < 15 kg/m2 (< 40 kg/m2 with backplane)
- Production rate > 2 m2 per month
- Short time span for optical system integration and test

NIR LIDAR Beam Expander Telescope

Potential airborne coherent LIDAR missions need compact 15-cm diameter 20X magnification beam expander telescopes. Potential space based coherent LIDAR missions need at least 50-cm 65X magnification beam expander telescopes. 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. Aberrations, especially spherical aberration, in the optical telescope can decrease the signal. Additionally, the telescope beam expander should maintain the laser beam's circular polarization. The incumbent telescope technology is a Dahl-Kirkham beam expander. Technology advance is needed to make the beam expander more compact with less mass while retaining optical performance, and to demonstrate the larger diameter.

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 μm. 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 "Planetary Balloon-Based Science Platform Evaluation and Program Implementation - Final Report," Dankanich et. al. (NASA/TM-2016-218870, available from https://ntrs.nasa.gov/)

Dankanich identified a minimum requirements for a Planetary Science balloon that would address the majority of the questions posed in the 2013 Planetary Science Decadal Survey: 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.

Balloon Planetary Telescope

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. 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.

If Phase II can only produce a sub-scale component, then it should also produce a detailed final design, including final requirements (wave-front error budget, mass allocation, etc) and performance assessment over the specified operating range.

Telesocpe and Primary Mirror Assembly Specifications:

• Diameter	> 1 meter
• Radius of Curvature	3 meters (nominal)
• System Focal Length	14 meters (nominal)
• Surface Figure Error	< 10 nm rms
• Telescope Diffraction Limit	< 500 nm
• Primary Mirror Mass	< 150 kg
• Telescope Mass	< 300 kg
• Shock	10G
• Elevation	0 to 60 degrees
• Temperature	220 to 280 K

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

Any Questions?