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)	**40% (2/5)**
2019	**30% (7/23)**	
Total	35% (113/322)	43% (39/91)

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)	33% (1/3)
2019	55% (5/9)	
Total	48% (23/48)	29% (5/17)

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)	50% (1/2)
2019	28% (2/14)	
Total	24% (18/74)	50% (6/12)

2019 SBIR S2.03 ‘Normal Incidence’

Phase I 9 Submitted 5 Funded

- **Advanced Systems & Technologies:** Reconfigurable Optoelectronic Mirror Evaluation (ROME) System
- **Optimax Systems:** Mitigation of Mid-Spatial Frequency Errors
- **Polaronyx:** Large SiC Mirror Support Architecture Manufacturing
- **Quartus Engineering:** CUBESAT
- **Voxtel:** Compact high-degree-of-freedom Freeform Beam Expander Optics

Phase II TBD Submitted TBD Funded

S2.03-3668 - Reconfigurable Optoelectronic Mirror Evaluation (ROME) System

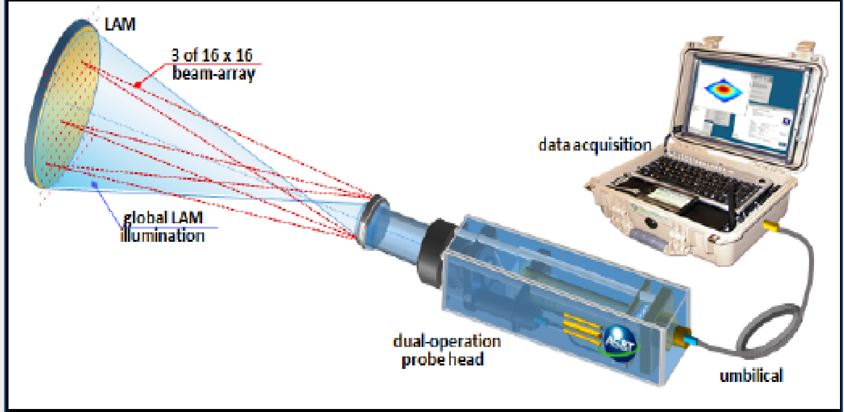
PI: Vladimir Markov , Advanced Systems & Technologies, Inc. - Irvine, CA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

NASA space missions require ultra-stable large aperture mirror (LAM) telescopes with long-term structural stability >10 pm. An active fine-tuning of the support structure is required to achieve this level of accuracy in the dynamic stability of LAMs, which became available owing to novel technology that enables fabrication of the multi-element assembly for space telescopes.

Advanced Systems & Technologies, Inc proposes to develop a Reconfigurable Optical Mirror Evaluation System and Technique (ROME S&T) with its operation based on the AS&T proprietary beam-array vs global Laser Doppler Velocimetery (LDV). ROME uses a blend of the data generated from the global and beam-array measurements of the vibration modalities of the LAMs mirror surface and its support structure, i.e. the "frame". The targeted performance specification of the fully-developed ROME system will be in the picometers to micrometers range, experiencing transient dynamics at frequencies from 10 to 104 Hz, or as dictated by the technology needs for accurately measuring the dynamics of the packaged LAM segments.



TECHNICAL OBJECTIVES AND WORK PLAN

The overall goal of this project is to develop, integrate and demonstrate the performance of the novel optical test and evaluation platform for dynamics characterization of LAMs with their diameter in excess of 1.5m. The general Phase I objective of this effort is to establish the proof of operation of the ROME S&T approach and its viability to measure and characterize the dynamics of the LAM-representative specimens in various drive regimes, proving a 10 pm accuracy for a 500 Hz vibrational frequency (first harmonic).

The following specific objectives have been set for the Phase I program: Establish ROME operating parameters pertinent to NASA required characterization of LAM dynamics with the picometer-level displacement at frequencies from 10Hz to 10 kHz; Design ROME system with the switchable global to beam-array mode sensor operation; Conduct lab tests to demonstrate NASA required sensitivity; Establish the model to correlate data for local vs global measurements; Establish provisional Phase II design.

These objectives will be met through the Work Plan that consists of the following tasks: (1) Kickoff Meeting, (2); (2) Establish ROME system requirement; (3) Analyze, model and optimize ROME design; (4) Implement breadboard and validate its operation; (5) Establish Phase II design; (6) Explore ROME commercial potentials; (7) Reporting and includes 4 Milestones.

NASA APPLICATIONS

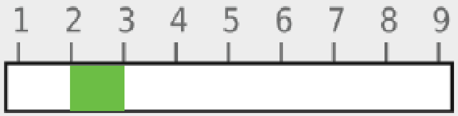
The ROME systems contributes toward detection of the vibrational signatures in large space optical systems and their complex dynamics. ROME also offers a new technology for validation of the performance of space and ground telescopes through measurement of complex structural dynamics of their mirror assembly and the support structure.

NON-NASA APPLICATIONS

ROME S&T market area is not limited to validation of space deployed optical systems. Commercial potential arising directly from the proposed program include customers involved in the development and manufacturing of various types of MEMS devices, including deformable mirrors and micro-mirror arrays. ROME S&T is equally applicable for characterization of vibrational noise in the automotive industry

TRL

Estimated



FIRM CONTACTS

Vladimir Markov
Advanced Systems & Technologies, Inc.
EMAIL: vmarkov@asatechinc.com
PHONE: (949) 733-3355

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S2.03-3687 - Mitigation of Mid-Spatial Frequency Errors

PI: Jennifer Coniglio , Optimax Systems, Inc. - Ontario, NY

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

Freeform optics allow optical designers freedom to reduce payload weight and size to reduce NASA's cost. However, freeform fabrication (single point polishing) can impart mid-spatial frequency (MSF) errors, which are especially detrimental to optics, disrupting diffraction-limited UV and VIS image quality. Correcting MSF errors often requires artisan skill, which is costly and risky if the technique is lost. This proposal seeks to establish feasibility of capturing artisan technique data via an off-the-shelf collaborative robot by producing a SiC or Si freeform optic. Data will be gathered to create and refine machine learning algorithms to attempt to match the results of the robotic process to the artisan process using metrology to compare results of the two techniques. A Phase II project would extend the database and apply the algorithm to tool-path generation for a fully automated MSF smoothing process. This extension could also be to a larger / more extreme freeform. Automation of the MSF smoothing procedures will help increase efficiency and reduce cost of freeform optics.

TECHNICAL OBJECTIVES AND WORK PLAN

Objective 1: To prove the feasibility of using a collaborative robot in a machine learning paradigm as an MSF mitigation process by finishing a Si demonstrator optic.
Objective 2: Create and implement data compilation process to capture relevant artisan input and polishing parameters, using an off-the-shelf collaborative robot system. Explore these data in comparison with current tool paths.
Objective 3: Create a digital learner and establish training protocol using partial database. Create a workflow designed to test ability to match results of artisan process and robotic smoothing algorithm using metrology.
Objective 4: Using the information developed in Objectives 1, 2, and 3, build a plan to scale up to robotic polishing via the "Smoothing Routines" generated previously. Later advancements will include development and testing of robust smoothing algorithms derived from metrology.

Deliverables will include an Si demonstrator freeform optic with minimal MSF errors. The process developed will eventually reduce risk, lead time, and cost of freeform optics.

TRL

Estimated

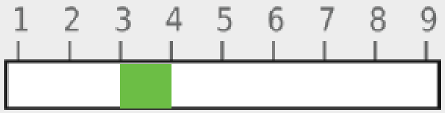
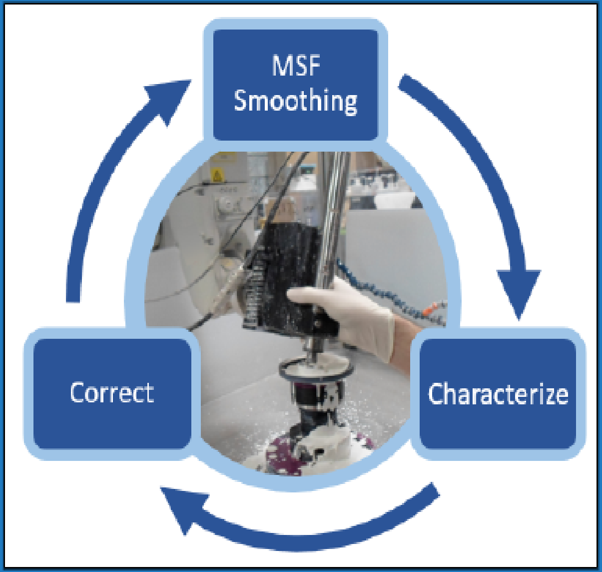


IMAGE TITLE: HERMES concept



NASA APPLICATIONS

NASA's goals hinge on improved optics with reduced payload size and weight. Freeform optic performance at reduced cost, especially for SiC or Si clad SiC substrates (with its desirable thermal and stiffness characteristics), interests NASA. The proposed technology is germane to UV and other projects such as exo-planet imaging systems, LUVOIR Ultraviolet Multi-Object Spectograph, the Origins Space Telescope, Terrestrial Ecology, Thermal IMager for Europa Reconnaissance and Science, Soft X-Ray telescopes, and Cube/Nano-cube optical payloads.

NON-NASA APPLICATIONS

Cost-effective mid-spatial frequency error reduction can be applied to numerous Optimax freeform markets. Freeform optics can decrease system size improve quality for existing commercial applications such as beam shaping, corrector plates, conformal windows, heads-up displays, compact imaging systems, augmented and virtual reality systems, and reflective, non-imaging illumination components.

FIRM CONTACTS

Jennifer Coniglio
Optimax Systems, Inc.
EMAIL: jconiglio@optimaxsi.com
PHONE: (585) 265-1020

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S2.03-2649 - Large SiC Mirror Support Architecture Manufacturing

PI: Jian Liu , Polaronyx, Inc. - San Jose, CA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

- All in one fabrication process. This seamless process will enable low cost and reliable mirror operation.
- Controlled melting temperature and thermal stress. This is the most efficient and practical way to control defects and make super large high strength and high-quality engines.
- Hybrid AM processes (local powder bed fusion system and powder injection system) enable efficient manufacturing of parts with various types of structures, and correction of defects during the process.
- Reduced micro-structure and grain size by combining CW laser with pulsed lasers. By changing pulse width, the microstructure can be manipulated to meet specific requirement of engine design (combustion chamber, nozzle, diffuser, etc.).
- By changing laser parameters, structural (such as various types of lattice) components can be created.
- The same laser can be tuned to do both AM & SM in one scanning setup, which doubles the machine's capability and increases productivity without adding any cost.
- NDI is integrated to guide the fully automated AM and SM system for real time characterization and control.

TECHNICAL OBJECTIVES AND WORK PLAN

Objective 1: To design super large area AM & SM process for fabrication of large SiC mirror support architecture.

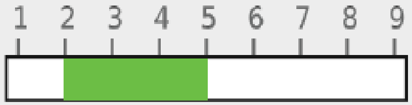
Objective 2: To design and develop the control process of SLAM. This will help us understand and optimize the SLAM system.

Task 1: Design of SLAM and Process Development for Large SiC Support Architecture. In this task, we will investigate in details of gantry systems, both PBF subsystem and powder injection subsystem, mounting tools, assembly fixtures, sensing subsystems and subassembly, AM process selection, and SM process. A complete SLAM system will be designed with high confidence. The process development includes laser beam shaping, powder spreading and injection rate and angle, autofocus, scanning, process monitor, melting/welding process parameters adjustment, AM/SM scan pattern adjustment (pulsed modulated control: adjust pulse number, amplitude, and interval), molten area image characterization and analysis, AM parameter database, NDI characterization and AM/SM quality data.

Task 2: Sensing and Quality Control for Large SiC Support Architecture. Taking full advantage of the 3D printing capability, we will revisit the design of SLAM by taking out redundant sections and optimize to fit 3D printing. Both powder bed fusion and powder injection process control (density and defects) will be further studied along with integration with the SM.

TRL

Estimated



NASA APPLICATIONS

In addition to NASA's SiC support structure manufacturing, the proposed high power fiber laser AM system can be used in other applications, such as space vehicle, ship, aircraft, and satellite manufacturing. PolarOnyx will develop a series of products to meet various requirements for commercial/military deployments.

NON-NASA APPLICATIONS

- 3D printing uses various technologies for building the products for all kinds of applications from foods, toys to rockets and cars. The global market is projected to reach US$44 billion by year 2025.
- Medical devices and biomedical instrumentation, which consists of surgical and infection control devices, general medical devices, cardiovascular, home healthcare, and other devices.

FIRM CONTACTS

Jian Liu
Polaronyx, Inc.
EMAIL: jianliu@polaronyx.com
PHONE: (408) 573-0930

S2.03-4264 - SBIR NASA CUBESAT Phase 1 Technical Proposal

PI: Alexander Halterman , Quartus Engineering Incorporated - San Diego, CA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

The 2017 decadal survey called out a need to reduce mission costs for space-based earth observation. To meet this need, Quartus Engineering Incorporated (Quartus) is proposing leveraging analytical models and existing opto-mechanical designs to provide a shift in the approach to the development of space-based optical systems for deployment on CubeSats and small satellite platforms. If the appropriate work is done to validate the analytical tools used to design optical components and subsystem designs, beyond a specific use case, these tools could be used to adapt current component and subsystem designs to new missions. This approach could lead to semi-custom precision optical systems for space applications, much in the same way spacecraft bus suppliers support the science community. This SBIR proposes the validation of the designs and analytical tools used to assess the SAGE IV Pathfinder telescope for structural, thermal, optical performance (STOP), so these designs and analytical tools can be used to accelerate development and reduce costs of future NASA and other science missions.

TECHNICAL OBJECTIVES AND WORK PLAN

The overall objective is the validation of the existing component level designs and STOP analysis performed on the SAGE IV Pathfinder development project. Since the SAGE IV Pathfinder optical subassemblies and mounting schemes were designed to be thermally insensitive, the first goal is to develop a test station with modified optics & optical mounts from which optical performance metrics measurable above the noise floor. The output from this test will be used to correlate finite element analysis (FEA) predictions and validate the corresponding FEA output STOP metrics due to thermal loading. Subsequently, the test station can then be utilized to confirm the SAGE IV Pathfinder results are as small as predicted.

The work plan is divided into three sections. Section 1 (one month PoP) for preliminary design, analysis, and test planning to perform necessary trade studies to define the four proposed test set configuration and the optical performance targets. Section 2 (two week PoP) for detailed design, analysis, and test planning to utilize all takeaways from Section 1 and finalize the design, FEA, and test setup, and all drawings for procurement of hardware. Section 3 (three months PoP) for procurement, testing, and correlation.

The deliverables will be monthly status reports to document progress and a final report at completion of Phase I.

TRL

Estimated

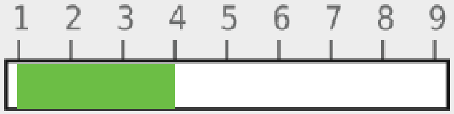
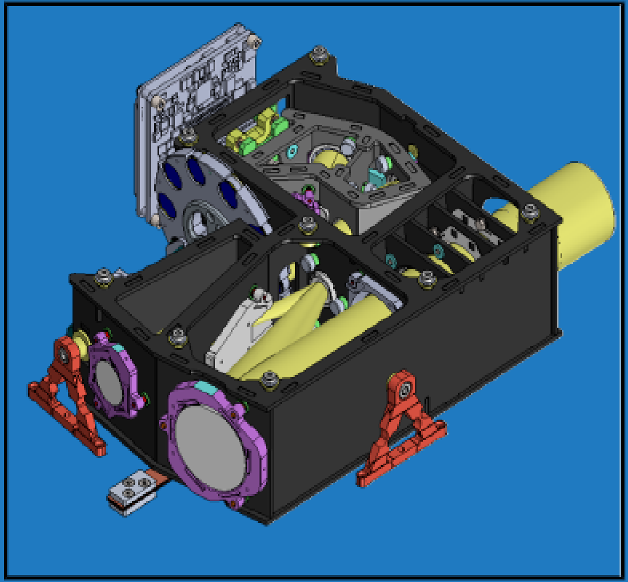


IMAGE TITLE: Sage IV System Model



NASA APPLICATIONS

As mentioned at the start of this proposal, the 2017 decadal survey called for a means to reduce costs of earth observation missions. The work outlined in this proposal is a step in this direction. By taking an existing optical instrument, in this case the SAGE IV Pathfinder telescope, and expending the effort to validate the analysis tools and designs beyond a specific application, it allows for the extrapolation of this design to other use cases.

NON-NASA APPLICATIONS

Being able to use the same tools and methodology to existing systems reduces the uncertainty associated with the cost and schedule of building a complex optical system for the first time, which translate to reduced schedule and cost risks associated with a new mission. This allows complex one-off optical systems to leverage economy of scale in a way typically unavailable to commercial missions.

FIRM CONTACTS

Alexander Halterman
Quartus Engineering Incorporated
EMAIL: alex.halterman@gmail.com
PHONE: (858) 875-6000

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S2.03-3536 - Compact High-Degrees-of-Freedom Freeform Beam-Expander Optics

PI: Hooman Akhavan , Voxtel, Inc. - Beaverton, OR

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

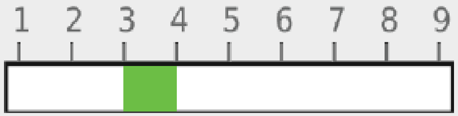
- The high degrees of design freedom achieved with freeform index gradients and freeform-surfaced optics provide precise wavefront control
- Large index gradients allow for both optical power and aberration correction
- Non-axial freeform (Δx, Δy, Δz) gradient profiles easily implemented
- Nanofillers impart desirable mechanical and environmental properties
- Optical nanocomposites proven radiation and atomic oxygen tolerant, low outgassing, strong, and operational over temperatures
- Nanocomposites highly transmissive over wide band, including 2.0-microns, using robust fluorinated polymer hosts
- Optics may be printed with mechanical housings, opaque baffles, and other structures

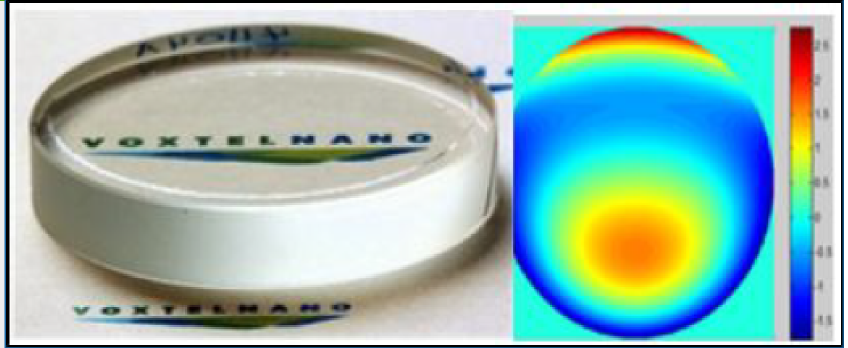
TECHNICAL OBJECTIVES AND WORK PLAN

- With NASA, refine lidar technique and NASA mission requirements and derive specification
- Perform design trade study
- Demonstrate high transmission over 350-nm to 5-micron spectral band
- Demonstrate optical index variations greater than 0.2 (0.3 goal)
- Model on-axis and off-axis afocal beam expander designs, including reflective and refractive (GRIN) optics
- Down-select preferred beam expander design(s)
- Fabricate and characterize optics for 15-cm- to 60-cm-diameter beam-expander telescope optical systems, with magnifications of 20x to 65x respectively
- Perform environmental and reliability testing
- Deliverables: Sample 20X beam expander optics, interim reports including test data, final report

TRL

Estimated





NASA APPLICATIONS

The innovation has widespread application for NASA missions requiring compact, high-performance optics, including those for small satellites, laser-ranging and lidar instruments, integral imaging spectroscopy, and demanding optical instruments.

NON-NASA APPLICATIONS

The innovation has widespread use in amateur astronomy, cell-phone cameras, holographic displays, integral imaging devices, optical microscopy, and consumer and industrial optical systems.

FIRM CONTACTS

Debra Ozuna
Voxtel, Inc.
EMAIL: debrao@voxtel-inc.com
PHONE: (971) 223-5646

2019 SBIR S2.04 ‘X-Ray, Freeform & Coating’

Phase I 14 Submitted 2 Funded

- **OptiPro Systems:** Chromatic Interferometric Probe
- **OptiPro Systems:** Advanced Nanometer Coordinate Measuring Machine

Phase II TBD Submitted TBD Funded

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S2.04-3272 - Advanced Nanometer Coordinate Measuring Machine

PI: David Mohring , OptiPro Systems, LLC - Ontario, NY

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

The proposed innovation is a new, non-contact coordinate measuring machine (CMM) with the capability that could push into the nanometer regime, for both as-built prescription / figure error metrology, as well as alignment of mirrors with respect to each other. The measurement platform the Advanced Nanometer Coordinate Measuring Machine (ANCMM) will have the capability to measure the prescription and mid to low order surface error for meter class mirror segments, cylindrical shells and freeform surfaces.

The ANCMM will enable larger, lower cost, and higher quality freeform and aspheric optics, bridging the present gap between commercial CMM and interferometry, and, for many applications, replacing areal interferometry as the primary means of feedback to optical fabrication and requirements verification. This work will push CMM technology into the realm currently dominated by expensive, complex and error-prone optical testing. Current and near-future, large optics applications would benefit by reducing their fabrication cost, schedule and improving their technical risk posture.

TECHNICAL OBJECTIVES AND WORK PLAN

Technical objectives of the Phase I work are to consider and evaluate the essential technologies that comprise an ANCMM system, namely the CMM configuration, probe sensor capabilities, position feedback loop, software requirements and environmental controls/compensations needed for an ANCMM system to fulfill its metrology potential and deliver nanometer resolution. The work plan will analyze existing solutions implemented for high resolution, accurate metrology platforms and determine the factors that are most likely to limit the measurement performance of the ANCMM and verify which can be controlled, measured or otherwise compensated with suitable metrology and software.

The individual parameters influencing each requirement must be analyzed to determine the most cost effective way to optimize the parameter. Freeform and cylindrical optical systems are sensitive to surface figure error over wide spatial bands. The software plan would include a structure function method which is able to characterize slope, and root mean squared error over large spatial frequency bands.

The deliverable from the Phase I project is a Final Report that documents the analytical and experimental tests, conducted at UNCC Center for Precision Metrology and OptiPro Systems, yielding a resultant high-level ANCMM design to be built in Phase 2.

TRL

Estimated

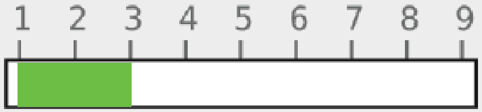
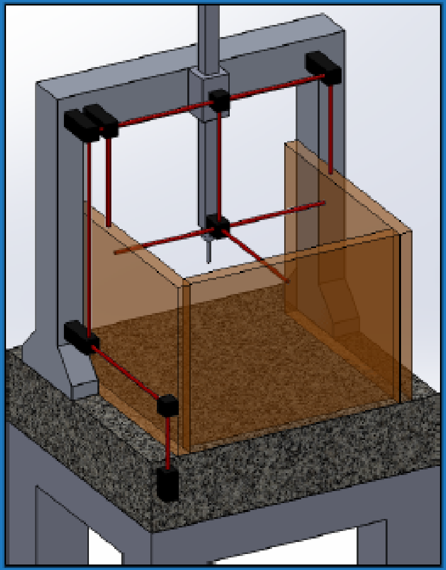


IMAGE TITLE: ANCMM Zerodur Reference



NASA APPLICATIONS

NASA projects can utilize optical test solutions that do not need a custom null lens or at least could use a CMM to cross check results from a traditional optical test. Current and future applications:

-Lynx X-Ray Surveyor optics; Prescription test & system alignment

-LISA; system alignment

-LUVOIR; improve cost/schedule on primary mirror segment fabrication; improve quality and cross check optical results on secondary mirror (figure error and prescription)

-Freeform optics of all sizes; as-built prescription; figure error (low order form error)

NON-NASA APPLICATIONS

The ANCMM platform would reduce the reliance on custom null lens techniques (e.g., computer generated holograms, reflective/refractive nulls). Applications include: Freeform Mirrors,Aspheres & ACylinders,Single Point Diamond Turned Surfaces,Diffractive Optics,Freeform Illumination Lenses,Corrector Optics

FIRM CONTACTS

David Mohring
OptiPro Systems, LLC
EMAIL: dmohring@optipro.com
PHONE: (585) 265-0160

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S2.04-3275 - Chromatic Interferometric Probe

PI: James Munro , OptiPro Systems, LLC - Ontario, NY

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

The proposed innovation is a non-contact chromatic phase-measuring interferometric probe capable of measuring the surface form of a free-form telescope optic to sub-nanometer levels, over a millimeter range in Z. The probe retains all the benefits of a chromatic optical probe (large measurement range and small spot size) as well as the benefits of an interferometer (high accuracy and repeatability, and speed).

The probe has been computer simulated, and we expect sub-nanometer measurement performance at a rate of 10,000 datum/second, on surfaces sloped up to 60°, with a 10um spot size. These characteristics are important because 1) the ability to measure highly sloped surfaces eliminates the need for rotational stages, 2) high-speed small-spot-size probing opens the door to MSF error measurement, 3) the large (1mm) measurement range minimizes the amount of Z-motion steps the probe must make during a measurement scan of a large-sag optic, and 4) the sub-nanometer performance means the measurement uncertainty won't consume a large portion of the optics error budget.

TECHNICAL OBJECTIVES AND WORK PLAN

The technical objectives of the Phase I work are to address and mitigate the major risk items of the probe, including 1) confirming that the probe's calculated optical power budget is accurate, 2) confirming that the assumptions used in the development of the probe to date are accurate, and 3) confirming that the probe can indeed produce a bright high-contrast fringe pattern at the output of the spectrometer.

The work plan includes tasks for constructing all four arms of the probe's chromatic interferometer on a testbed. The source, measurement, and reference arms will be constructed serially, with key optical signals measured and documented as appropriate. The output arm, including the spectrometer and software, is a long-duration task that must be executed in parallel with the preceding tasks. When the probe is fully assembled on the testbed it will be characterized for light throughput and fringe contrast, after which it will be transported to UNCC for further testing in an environmental chamber.

The deliverable from the Phase I project is a Final Report that documents the high-level design of the probe, the relevant optical signal levels (in confirmation of the optical power budget, etc.) and repeatability information obtained from testing at OptiPro and UNCC facilities.

TRL

Estimated

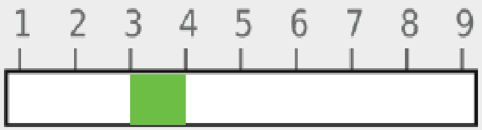
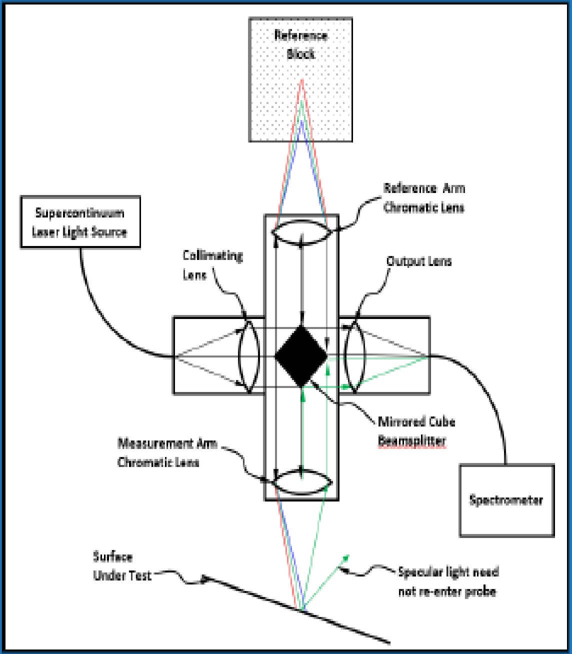


IMAGE TITLE: Probe Block Diagram



NASA APPLICATIONS

The proposed metrology system can be used for sub-nanometer surface metrology of free-form optical components with large spherical departures, such as the optics for X-Ray telescopes, and, especially, for UVOIR telescope optics.

NON-NASA APPLICATIONS

Non-destructive sub-surface metrology.
Optical coherence tomography of industrial and biomedical specimens.

FIRM CONTACTS

Matthew Carlson
OptiPro Systems, LLC
EMAIL: NA
PHONE: (585) 265-0160

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 3 Submitted 1 Funded

Thermal Expansion Solutions: Ultra-Stable ALLVAR Alloy Development

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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

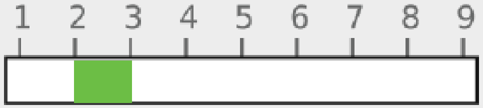
ALLVAR Alloys 16 shrinks when heated and expands when cooled, known as negative thermal expansion (NTE). This opposite effect from most materials allows Alloy 16 to compensate for positive thermal expansion (PTE) materials. We have created a new material for athermalizing optics made from any type of 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.

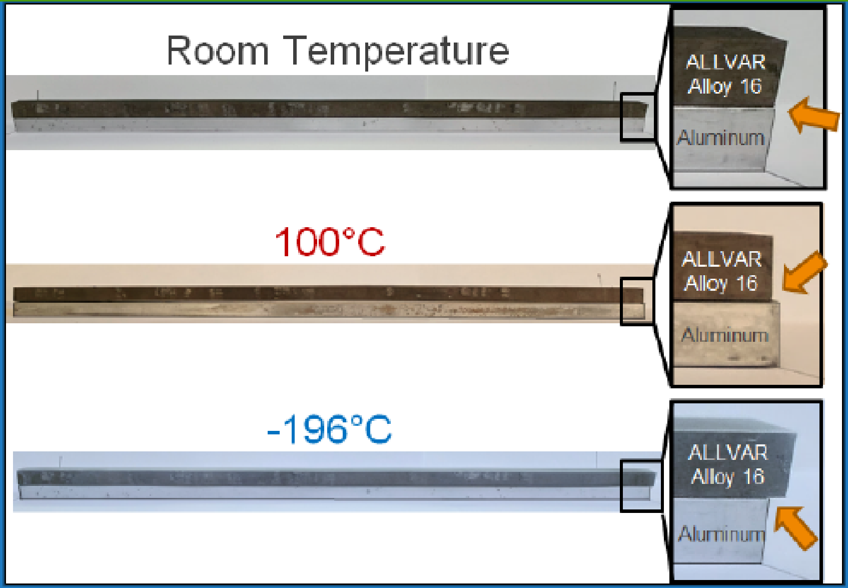
TECHNICAL OBJECTIVES AND WORK PLAN

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.

TRL

Estimated





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.

FIRM CONTACTS

James Monroe
Thermal Expansion Solutions, Inc
EMAIL: jamesamonroe@allvaralloys.com
PHONE: (956) 789-3723

2018 SBIR S2.04 ‘X-Ray, Freeform & Coating’

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	2 Submitted	1 Funded

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

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

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

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

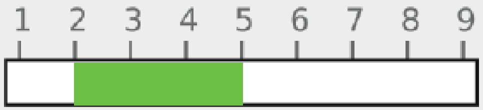
The proposed black coating technology addresses the need for low reflectivity surfaces for optical components such as detectors, solar coronagraphs, telescope housings and baffles where stray light reduction is vital. Low reflective coatings (reflectivity of ~0.1% or less) in the broad spectral range 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.

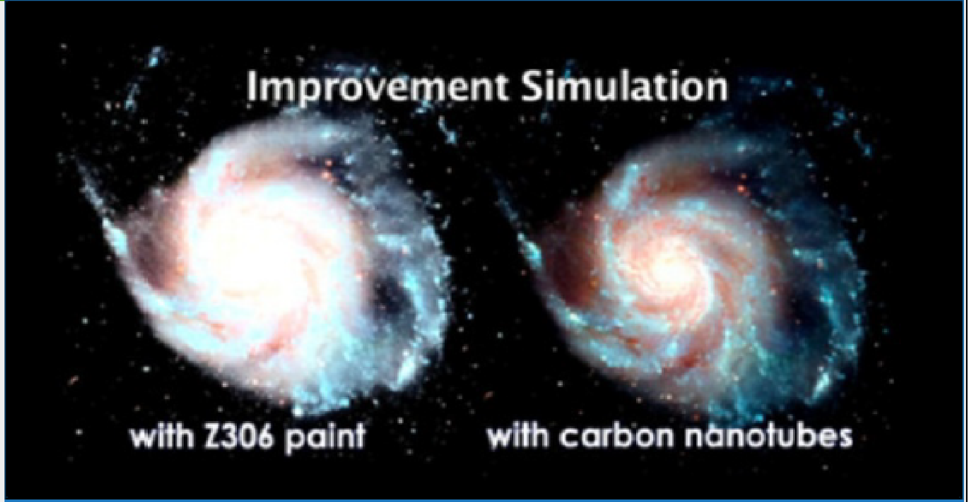
TECHNICAL OBJECTIVES AND WORK PLAN

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





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

E. Jennings Taylor
Faraday Technology, Inc.
EMAIL: jenningstaylor@faradaytechnology.com
PHONE: (937) 837-7749

Gender Analysis

A recent study found a gender bias in the award of science proposals.

So, I undertook an analysis of the S2.03 and S2.04 proposals since 2008.

	Total			P1 Submitted		P1 Awarded		P2 Awarded	
	P1 Submit	P1 Award	P2 Award	Male	Female	Male	Female	Male	Female
Total	221	87	27	198	23	80	7	24	3
Percentage		39%	12%	90%	10%	92%	8%	89%	11%
Percentage of Gender Awarded						40%	30%	30%	43%
do not delete									
2019	23	7	0	20	3	6	1	0	0
2018	26	6	2	24	2	6	0	2	0
2017	17	11	4	17	0	11	0	4	0
2016	16	7	2	13	3	7	0	2	0
2015	23	10	3	21	2	9	1	2	1
2014	15	6	2	13	2	6	0	2	0
2012	25	6	3	23	2	6	0	3	0
2011	25	7	1	22	3	7	0	1	0
2010	21	10	1	18	3	8	2	1	0
2009	16	7	4	15	1	6	1	3	1
2008	14	10	5	12	2	8	2	4	1

NOTES:

- Phase 1 Award statistics may be better if persons who did work were listed as PI.
- The total of 23 female PI Phase 1 proposals have been from only 6 companies.
- A plurality of the female PI Phase 1 proposals have been from a single company.

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: Commercialization Plan

Reminder: 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

SBIR Call for Proporsals

S2.03 has defined 6 ‘Scope’ Topics (sponsor ‘center’):

- Large UV/Optical (LUVOIR) and Habitale Exoplanet (HabEx) Missions (GSFC & MSFC)
- Optical Components & Systems for Infrared/Far-Infrared Missions (MSFC)
- Balloon Planetary Telescope (GRC)
- NIR LIDAR Beam Expander Telescope (LaRC)
- Low-Cost Compact Reflector for NIR/SWIR Optical Communications (GRC)
- Fabrication, Test and Control of Advanced Optical Systems (GSFC & MSFC)

Each scope topic has its own performance metrics and desired deliverable.

These are not exclusive – proposals addressing other problems are welcome.

S2.03 Introduction

Accomplishing NASA’s high-priority science at all levels (flagship, probe, mid-ex, sm-ex, rocket and balloon) requires low-cost, ultra-stable, normal incidence mirror systems with low mass-to-collecting area ratios. Where a mirror system is defined as the mirror substrate, supporting structure, and associated actuation and thermal management systems.

Subtopic solicits proposals for all relevant mirror system topics, including (but are not limited to):

- Large UV/Optical (LUVOIR) and Habitabe Exoplanet (HabEx) Missions
- Optical Components and Systems for Potential Infrared/Far-Infrared Missions
- Balloon Planetary Telescope
- NIR LIDAR Beam Expander Telescope
- Low-Cost Compact Reflector for NIR/SWIR Optical Communications
- Fabrication, Test and Control of Advanced Optical Systems

Each scope topic has its own performance metrics and desired deliverables.

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 ability to manufacture, test or 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.

LUVOIR and HabEx

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. Potential enabling technologies include: active thermal control systems, ultra-stable mirror support structures, athermal telescope structures, athermal mirror struts, ultra-stable low CTE/high-stability joints, 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.

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, joints and mechanisms that are athermal or zero CTE at the desired scale
- Mirror support structures, joints and mechanisms that are ultra-stable at the desired scale
- Mirror support structures with low-mass that can survive launch at the desired scale
- Mechanisms and sensors to align segmented mirrors to < 1 nm RMS precisions
- Thermal control (< 1 mK) to reduce wavefront stability to < 10 pm RMS per 10 min
- Dynamic isolation (> 140 dB) to reduce wavefront stability to < 10 pm RMS per 10 min

Also needed is ability to fully characterize surface errors and predict optical performance via integrated opto-mechanical modeling. Potential solutions for substrate material/architecture include, but are not limited to: ultra-uniform low CTE glasses, silicon carbide, nanolaminates or carbon-fiber reinforced polymer. 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.

Infrared/Far-Infrared Missions

Goal is to take advantage of relaxed tolerances from long wavelength (30 micrometer) diffraction-limited performance in the fully-integrated optical telescope assembly to minimize the total mission cost through innovative design and material choices and novel approaches to fabrication, integration, and performance verification.

Requirements:

- Telescope operating temperature ~4 K
- Aperture Diameter 1 to 4 meters
- 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

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

Balloon Telescope

Balloon platforms offers advantages for planetary science. At 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 near UV and IR bands near 2.7 and 4.25 µm.

Specifications:

Diameter	> 1 meter
Diffraction Limit	< 500 nm
Telescope System Focal Length	14 meter (nominal)
Primary Mirror Radius of Curvature	3 meter (nominal)
Telescope Mass	< 300 kg
Primary Mirror Mass	< 150 kg
Shock	10G without damage
Elevation	0 to 60 degrees
Temperature	220 to 280 K
Spectral Range	300 nm to 5 micrometers

SOA Zerodur or ULE mirrors require light weighting to meet mass limitations, and cannot meet diffraction limited performance over the wide temperature range due to the coefficient of thermal expansion limitations.

Phase I will produce a preliminary design including requirements such as wave-front error budget, mass allocation budget, structural stiffness requirements, etc. 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.

For additional information, 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/)

NIR LIDAR Beam Expander Telescope

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. Additionally, technology for non-moving scanning of the beam expander output is needed.

SOA is a COTS beam expander with a 15-cm diameter primary mirror, a heavy aluminum structure, an Invar rod providing thermally insensitive primary-to-secondary mirror separation, and a manually adjustable and lockable variable focus setting by changing the mirror separation.

Critical gaps include

1) 50-70 cm diameter primary mirror beam expander that features near-diffraction limited performance, low mass design, minimal aberrations with an emphasis on spherical, characterization of the polarization changes vs. beam cross section assuming input circular polarization, a lockable electronic focus adjustment, both built-in and removable fiducial aids for aligning the input laser beam to the optical axis, and a path to space qualification; and
2) 15-cm diameter primary mirror beam expander with the same features for airborne coherent lidar.

Desired Deliverables: Detailed design or a small prototype or a full-sized beam expander.

Low-Cost Compact Reflector for Optical Communications

The need exists for a low cost methodology to produce compact (for ex., cubeSAT-class), scalable, diffraction limited, athermalized, off-axis reflective-type, optics for NIR/SWIR-band communication applications. Typically, specialty optical aperture systems are designed and built as “one-offs” which are inherently high in cost and often out of scope for smaller projects. A Phase I would investigate current compact off-axis reflective designs and develop a trade space to identify the most effective path forward. The work would include a strategy for aperture diameter scalability, athermalization, and low cost fabrication. Detailed optical designs would be developed along with detailed structural, thermal, optical performances (STOP) analyses confirming diffraction limited operation across a wide range of operational disturbances, both structural dynamic and thermal. Commercial of the shelf (COTS) NIR/SWIR optical communication support hardware should be assumed towards an integrated approach, including fiber optics, fast steering mirrors, and applicable detectors. Phase II may follow up with development of prototypes, built at multiple aperture diameters and fidelities.

Desired Deliverables Description: Prototype unobscured telescope with the required scale size

State of the Art and Critical Gaps

Currently, the state of the art for reflective optical system for communications applications are:

1) On-axis or axisymmetric designs are typically used for (space) optical comm and imaging, which inherently are problematic due to the central obscuration.

2) Off-axis designs provide superior optical performance due to the clear aperture, however, are rarely considered due to complex design, manufacturing, and metrology procedures needed.

Optical Communication enable high data-rate downlink of science data. The initial motivation for this scalable off-axis optical design approach is for bringing high-performance reflective optics within reach of laser communication projects with limited resources. However, this exact optical hardware is applicable for any diffraction limited, athermalized, science imaging applications. Any science mission could potentially be able to select from a “catalog” of optical aperture systems that would already have (flight) heritage and reduced risks.

Fabrication, Test and Control of Advanced Optical Systems

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

- Proposals are encouraged to develop technology which advances ability to non-destructively characterize CTE homogeneity in 4-m class Zerodur and 2-m class ULE mirror substrates to an uncertainty of 1 ppb/K and a spatial sampling of 100 x 100. This characterization capability is needed to select mirror substrates before they undergo the expense of turning them into a light-weight space mirror.
- Proposals are encouraged for system technologies for achieving ultra-stable wavefronts of < 10 pm RMS over intervals of ~10 minutes. Potential solutions include new technologies for wavefront sensing and control, metrology, and verification and validation of optical system wavefront stability.
  - New sensing methods may include: new techniques 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.
  - New metrology methods may 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.
  - Finally, techniques are needed for system verification and validation at the picometer level during integration and test (I&T).

An ideal Phase 1 deliverable would be 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 relevant sub-component (with a TRL in the 4 to 5 range); or a working fabrication, test or control system.

Any Questions?