NASA 2024 SBIR Subtopic:

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

H. Philip Stahl, Ph.D.

Sub-Topic Manager

Scope Analysis

First two 2024 Sub-Topics are virtually identical to 2023.

Special Topics Change from year to year.

<table>
<tr><th>2021</th><th>2022</th><th>2023</th><th>2024</th></tr>
<tr><td>LUVOIR & HabEx</td><td>UVOIR</td><td colspan="2">Materials, Substrates, Structures, & Mechanisms for Adv Optical Systems (from balloon or CubeSAT to Probe or Flagship from UVO to Far-IR)</td></tr>
<tr><td>Telescope for CubeSAT</td><td>CubeSAT</td><td colspan="2">Fabrication, Test, and Control of Optical Components and Telescopes (for all wavelengths and operating temperatures)</td></tr>
<tr><td>NIR LIDAR Telescope</td><td>Special Topics:
LISA Epoxy
Ultra-Stable</td><td>Special Topic #1: Near Angle Scatter (~100 milli-arc-sec)</td><td>Special #1: Polarization Birefringence Mapper</td></tr>
<tr><td>Balloon Planetary</td><td>Balloon</td><td>Special Topic #2: Ultra-Stiff Biologically Inspired Substrates</td><td>Special #2: Integrated Flexure Interface</td></tr>
<tr><td>Far-IR Missions</td><td>Far-IR</td><td></td><td>Special #1: Near Angle Scatter</td></tr>
<tr><td>Fab, Test & Control</td><td>Fab, Test & Control</td><td></td><td></td></tr>
</table>

2023 Scope Analysis

Used Award Statistics to justify new Scopes

- Combined Mirror and Mechanism technology has most proposals (68%)
- Fabrication, Test & Control gets 2nd most proposals (26%)
- ‘Focused’ Special Topics are effective.

Awards					
	2016 to 22	2023	Total		
Phase 1 Award/Submission	29/78	6/15	35/93		
	37%	40%	38%		
Phase 2 Award/Submission	10/26		10/26		
	38%		38%		
Phase 1 Scope				**Selection %**	**Proposal %**
Mirrors & Mechanisms	21/55	1/8	22/63	**35%**	**68%**
Fabrication, Test & Control	7/20	4/4	11/24	**45%**	**26%**
Special Topics	1/3	1/3	2/6	**33%**	**6%**

Gender Analysis

Continue to monitor Gender Statistics for signs of bias:

- Proposal Submitted may not represent community demographics
- In 2023 only 5% of proposals are submitted by a female – need more.
- Award statistics are similar for male and female.

	Total			P1 Submitted			P1 Awarded			P2 Awarded		
	P1 Submit	P1 Award	P2 Award	Male	Female	%	Male	Female	%	Male	Female	%
Total	317	116	41	280	37	STD	103	13	STD	36	5	STD
Percentage		37%	13%	88%	12%	50%	89%	11%	29%	88%	12%	76%
Percentage of Gender Awarded							37%	35%		35%	38%	
2023	20	7	0	19	1	5%	7	0	0%			
2022 (1 male minority)	27	5	3	23	4	15%	4	1	4%	2	1	33%
2021	20	8	4	15	5	25%	6	2	13%	4	0	0%
2020	29	9	2	25	4	14%	6	3	12%	1	1	50%
2019	23	7	5	20	3	13%	6	1	5%	5	0	0%
2018	26	6	2	24	2	8%	6	0	0%	2	0	0%
2017	17	11	4	17	0	0%	11	0	0%	4	0	0%
2016	16	7	2	13	3	19%	7	0	0%	2	0	0%
2015	23	10	3	21	2	9%	9	1	5%	2	1	33%
2014	15	6	2	13	2	13%	6	0	0%	2	0	0%
2012	25	6	3	23	2	8%	6	0	0%	3	0	0%
2011	25	7	1	22	3	12%	7	0	0%	1	0	0%
2010	21	10	1	18	3	14%	8	2	11%	1	0	0%
2009	16	7	4	15	1	6%	6	1	7%	3	1	25%
2008	14	10	5	12	2	14%	8	2	17%	4	1	20%

NASA 'Optics' Award Statistics Total

	Phase 1	Phase 2
2005 to 14	36% (72/200)	45% (28/62)
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)	71% (5/7)
2020	31% (9/29)	33% (2/6)
2021	40% (8/20)	66% (4/6)
2022	19% (5/27)	**60% (3/5)**
2023	**35% (7/20)**	**% (/)**
Total	35% (142/402)	46% (53/115)

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)	60% (3/5)
2020	42% (6/14)	20% (1/5)
2021	36% (4/11)	33% (1/3)
2022	13% (2/15)	**50% (1/2)**
2023	**40% (6/15)**	**% (/)**
Total	39% (41/104)	34% (11/32)

2023 SBIR S12.03 'Normal Incidence'

Phase I 15 Submitted 6 Funded

- **Cornerstone Research:** Cellular Optimization of Additively Produced Mirror Substrates for In-space Imaging
- **OptiPro Systems:** Sub-nanometer CMM for Mirror Surface Metrology
- **OptiPro Systems:** Elastic Emission Machining of Substrates for EUV, Optical, and Infrared Optics
- **OptiPro Systems:** Ultrahigh Precision CTE Measurements
- **Relative Dynamics:** Metalens Near InfraRed Telescope
- **Soter Technology:** Improved Computer Generated Holograms for Testing Aspheric and Freeform Optics

Phase II TBD Submitted TBD Funded

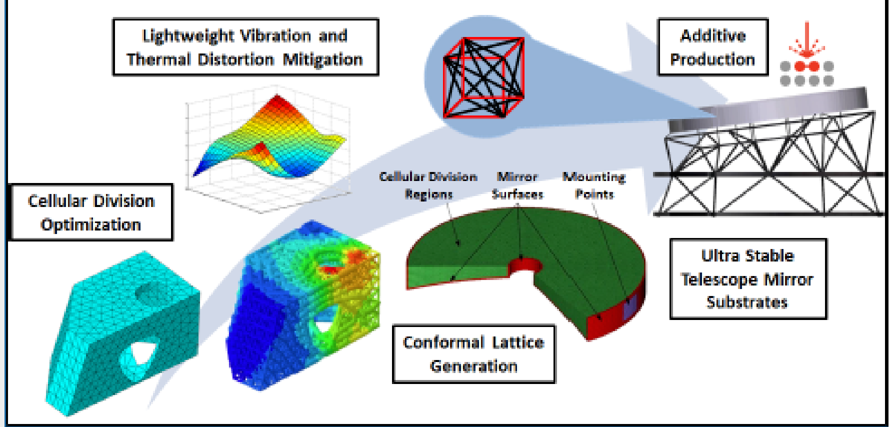
S12.03-1142 - Cellular Optimization of Additively Produced Mirror Substrates for In-space Imaging

PI: James Davidson , Cornerstone Research Group, Inc. - Miamisburg, OH

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

- Enables telescope stability for high-contrast imaging required for coronagraph deployment.
- Reduces weight of in-space mirror substrates and optical support structures by innovative design techniques.
- Generates structures incorporating high stiffness, passive vibration damping, and low thermal distortion.
- Takes advantage of the current state of additive manufacturing materials and technologies to produce designs.



TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

Technical Objectives

1. To Define Requirements and Establish Design Formulation
2. To Implement Computational Design Approach for Efficient Imaging Stability
3. To Produce Mirror Substrate Design and Experimentally Validate Performance
4. To Prepare for Phase II Demonstration

Work Plan

Task 1: Define Design Criteria and Numerical Formulation
Task 2: Integrate Analysis Driving Metrics into the Design Tool Supporting Design Optimization
Task 3: Evaluate Algorithm Performance by Mirror Substrate Design, Fabrication, and Testing
Task 4: Assess Results & Prepare for Phase II

Proposed Deliverables

1. Technical report document results of Phase I demonstration
2. Final report documenting technology challenges addressed; state of the art prior to and after this program; development and innovations executed; remaining barriers; and plans for further development, maturation, and technology insertion

TRL

Estimated

1	2	3	4	5	6	7	8	9
	■							

NASA APPLICATIONS

- Telescopes addressing COR, ExEP, and PCOS program missions
- Monolithic and segmented mirror substrates for in-space telescopes
- Lightweight telescope structures supporting enhanced stability
- Launch and propulsion structures requiring vibration mitigation

NON-NASA APPLICATIONS

- In-space laser communication assemblies
- Automotive and transportation structures design
- Unified structural and thermal heat exchangers

FIRM CONTACTS

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S12.03-1413 - Sub-nanometer CMM for Mirror Surface Metrology

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

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NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

The quality of optical components determine the performance of advanced space telescopes and Earth-observation satellites. At the same time, cost is a factor in telescope design, and compact telescopes may be less expensive. Future telescopes may be able to improve both performance and cost metrics using freeform optics, which lack rotational symmetry, and fast F/# designs using optics with steep curvature.

One sticking point is the difficulty of precisely measuring the shape of freeform and fast F/# surfaces, requiring a challenging combination of 1) measurement resolution, 2) measurement range (surface sag), and 3) acceptance angle (steep slopes). A further challenge is the ability to measure the error of these surfaces, often specified to be on the order of 5nm RMS, with a metrology accuracy of 10% of the tolerance, or 0.5nm.

In this proposal, we introduce a Sub-Nanometer Coordinate Measuring Machine (SNCMM) that is anticipated to have sub-nanometer measurement accuracy when used for measuring large-area, freeform, or optically fast surfaces.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

For a SNCMM to function accurately, the test-piece being measured must be positioned in a manner such that the surface under test is positionally stable for the duration of the measurement. In particular, the test-piece cannot vibrate, move in any one of the six Cartesian degrees of freedom, nor change shape or deform – all at the tens of picometer level.

The technical objectives of the Phase I project therefore is to demonstrate, with benefit of the OptiPro Nanometric Probe, the stability performance of a novel test-piece positioning sub-system. Specifically, we aim to design, construct, and exercise a proof-of-concept testbed that demonstrates the performance of the novel positioning sub-system.

The deliverable at the end of the Phase I project is a Final Report that includes detailed results from the proof-of-concept testbed demonstration, an analysis of these results, and a path to redress any shortcomings uncovered during execution of the project.

TRL

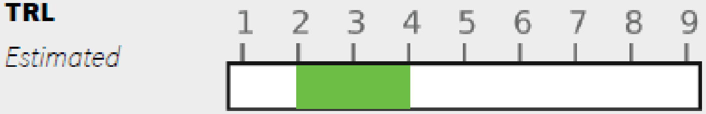
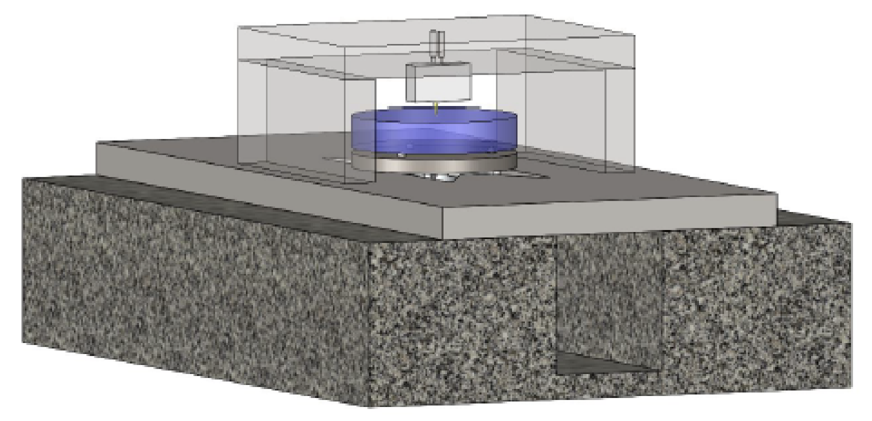


IMAGE TITLE: Phase I SNCMM Testbed



NASA APPLICATIONS

Potential NASA applications include metrology of freeform and other optical components for NASA missions, including flagship/decadal missions, small satellites, and everything between. Some specific applications:

- Origins Space Telescope (OST) and the Habitable Worlds Observatory, which may use freeform optics.
- Lynx, Advanced X-ray Imaging Satellite (AXIS), and other X-ray telescopes.
- Large telescope mirrors, such as those for the Habitable Worlds Observatory and OST, requiring sub-nanometer metrology.

NON-NASA APPLICATIONS

The proposed metrology probe would benefit many applications, including:

- Metrology of high-precision optical components for commercial products such as those used in lithographic steppers.
- Metrology of X-ray and neutron mirrors (Department of Energy).

FIRM CONTACTS

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S12.03-1871 - Ultrahigh Precision CTE Measurements

PI: Max Perrin , OptiPro Systems, LLC - Ontario, NY

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

A 2023 NASA-stated objective is to keep the total cost of a telescope's primary mirror well below $100M. Much of this cost is incurred during the machining and post processing of the mirror blank. If the blank is defective and it goes unnoticed prior to machining, the final mirror must be scrapped. Thus, a significant cost savings can be realized if the blank is non-destructively analyzed for CTE homogeneity prior to machining. Our innovation uses the OptiPro Nanometric Probe to analyze mirror blank for CTE in homogeneity that would cause uneven thermal expansion, thus disrupting the geometry of the mirror. We believe our Nanometric Probe will detect CTE defects in the single-digits parts-per-billion. If a defect is found, the blank can be scrapped before any machining costs are incurred.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

The overarching technical objective of the Phase I work is to determine if the basic CTE-measuring configuration based upon a pair of Nanometric Probes performs as expected. Specifically, the objectives of the Phase I effort include:

- Construct the CTE-measuring testbed.
- Confirm that the temperature within the test enclosure can be controlled to the desired level of precision and uniformity.
- Confirm the accuracy of the CTE-measuring testbed by measuring the CTE of various known materials such as aluminum, stainless steel, invar, and Zerodur, and comparing the measured results to commonly accepted values.

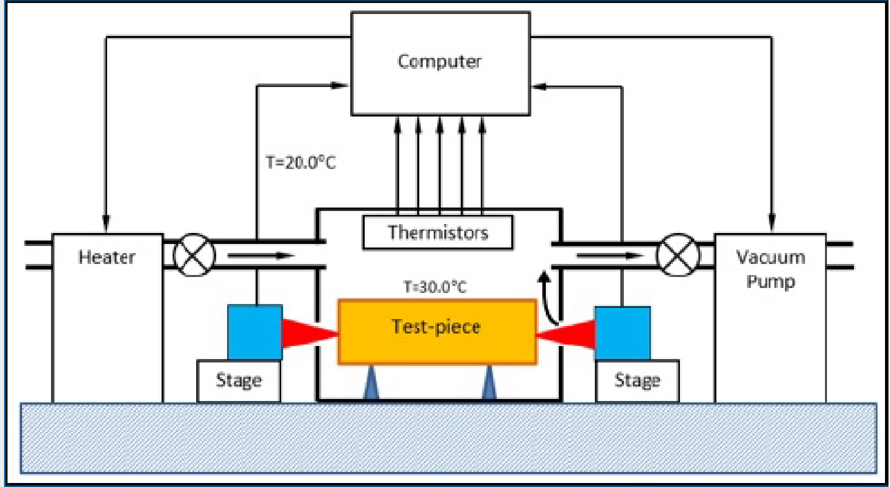
If awarded a Phase I contract, OptiPro Systems plans to design and build a CTE-measuring testbed which we will then operate to meet the stated objectives.

TRL

Estimated

1 2 3 4 5 6 7 8 9

IMAGE TITLE: PhI CTE Metrology Testbed



NASA APPLICATIONS

Ability to non-destructively screen low CTE mirror blanks for defects

- scalable to include extremely large test-pieces
- expected accuracy ranges of the parts per billion level
- resulting in significant cost reduction in labor and materials

This scalable non-contact metrology process is intended for use on telescope mirrors for the HabEx and UVOIR missions. Furthermore, the CTE measurement system will eliminate the uncertainty that a mirror will not suffer from CTE-related issues when in use.

NON-NASA APPLICATIONS

- Ability for manufacturers to non-destructively test low CTE materials for defects prior to manufacturing. They may also choose to market the products as "individually tested".
- Consumers of low CTE materials may want to test them prior to processing, saving the time and cost of manufacturing a defective piece of raw material.

FIRM CONTACTS

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S12.03-1867 - Elastic Emission Machining of Substrates for EUV, Optical, and Infrared Optics

PI: Michael Rinkus , OptiPro Systems, LLC - Ontario, NY

NASA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

The need for highly accurate, cost efficient, deterministic polishing methods on a variety of materials is apparent. Diffraction limited and low weight normal-incidence mirror systems are required to enable and enhance telescopes for missions of all sizes, from CubeSats at sub 100mm optic sizes to Probe or Flagship missions which need mirrors and mirror segments on the order of several meters. These missions also vary in operating wavelength; from ultraviolet to far-infrared. Light-weighting of mirrors is also a key performance objective. With light-weighting, print through of the support structure onto the optical surface can occur, reducing the quality and imposing difficult to correct surface figure errors.
In this proposal, we offer a means to both achieve nanometer tolerances on standard optical surfaces and capable of mitigating support print through on light-weighted mirrors. This process, Elastic Emission Machining, is a highly precise and stable chemical material removal method and will be accomplished on Zerodur and ULE, common materials used for their thermal stability.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

Elastic Emission Machining can achieve such tolerances and has been already demonstrated by OptiPro on Silicon substrates. EEM causes low-energy non-damaging collisions to occur between particulates and the substrate surface. This type of material removal process does not inject heat into the surface, nor does it damage the atomic lattice structure, allowing for no sub-surface damage.
The technical objectives of the Phase I project focus on improving the polishing capabilities of EEM as well as providing a method for mitigating support print through on light-weighted Zerodur and ULE optics.
Specifically, we aim to:

1. Determine the polishing compound pairing to both Zerodur and ULE
2. Characterize the removal rate for the most successful combinations
3. Achieve and exceed the following surface figure finishes:
    1. Mid-spatial frequency (6 – 60 cycles per aperture (CPA)) errors <5nm RMS
    2. High-spatial frequency (>60 CPA) < 1.5 nm RMS
    3. Microroughness <0.5nm RMS
4. Polish light-weighted ULE and Zerodur substrates utilizing EEM to determine:
    1. EEM's natural impact on print through error
    2. EEM's capability to correct print through error

The deliverables at the end of the Phase I are the final report which will include detailed results of the above goals, stating how each was attempted and ultimately met, and the sample light-weighted substrates produced through the completion of the work tasks.

TRL

Estimated

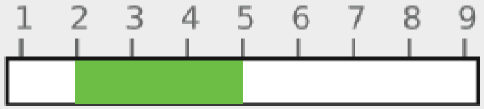
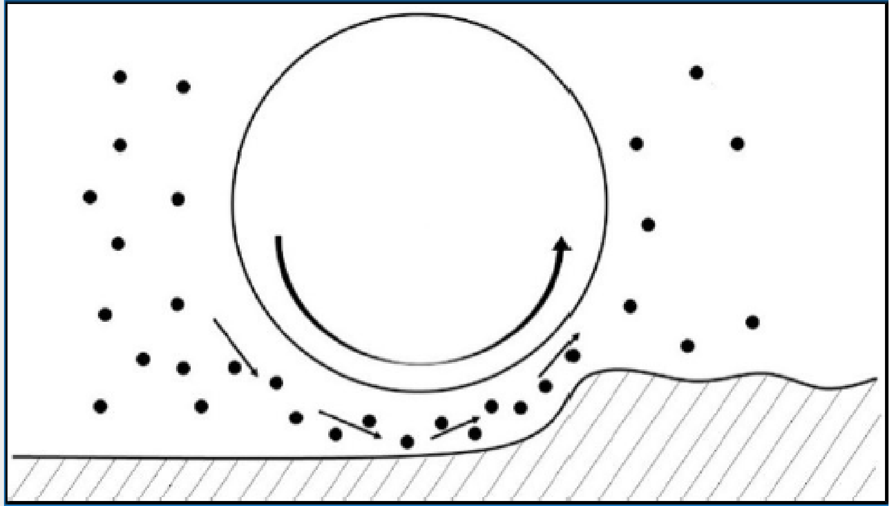


IMAGE TITLE: ElasticEmissionMachining



NASA APPLICATIONS

With the capability to manufacture ULE and Zerodur optical components to the diffraction limit, NASA will be able to ensure that their telescopes, CubeSats, and Flagship missions have highest opportunity for success, enabling and enhancing future systems. OptiPro's Elastic Emission Machining Platform, with the success of this proposed SBIR project, will be capable of manufacturing any light-weighted optical component, made of Silicon, ULE or Zerodur, to the diffraction limit of their operating wavelength.

NON-NASA APPLICATIONS

EEM has proven its capabilities on diffraction limited Silicon polished for use in the Department of Energy's Synchrotron and Linear X-ray accelerators, which also use Zerodur and ULE in their beamline systems. Extreme Ultraviolet Lithography systems also use Zerodur and ULE in their systems and with the ever-growing need for microchips, more efficient and accurate optics are needed.

FIRM CONTACTS

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S12.03-1272 - Metalens Near InfraRed Telescope

PI: Michael Krainak , Relative Dynamics, Inc. - Laurel, MD

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NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

NASA needs system technology solutions that enable or enhance telescopes for missions of any size (from balloon or CubeSat to Probe or Flagship) operating at any wavelength from UV/optical to mid/far-infrared. The RDI's solution is the Metalens Near InfraRed Telescope (MeNIRT).

- MeNIRT provides a lightweight telescope that greatly eases mass limitations with optical to mid-IR diffraction-limited performance over the wide temperature range. Using flat optics and athermalized continuous carbon fiber telescope structure greatly reduces coefficient of thermal expansion (CTE) limitations and gravity sag.
- Using flat on-axis optics, MeNIRT does not have a telescope central obscuration. The Metalens is manufactured for mass production using standard silicon lithography. The new commercial design tools for silicon flat optics in combination with the continuous carbon fiber structure provide a straight-forward method for design, manufacture, and test.
- MeNIRT provides a path to flat optics and athermal telescopes for science missions with wavelengths from the ultraviolet to the far-infrared.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

1. Design the telescope system - Our baseline proposed system is a refractor telescope with an 8 cm f/2 objective silicon metalens and a ~1 cm glass asphere eye-piece for use in the SWIR (~1550 nm).

- Examine the trade-space of f/#, aperture-size, and wavefront quality for the baseline telescope system.
- Analyze and compare system performance using commercial software (e.g., MetaOptic Designer). To make the large system computation manageable, RDI will use a a proven scaling method.

Deliverable: Telescope system trade study, analysis, and comparison.

2. Optical design of the telescope-objective silicon-metalens. Xingjie Ni (subcontractor at Penn State), has proven recently developed inverse design technique.

- Design and analyze a large metalens (baseline: 8 cm f/2 objective silicon metalens) using inverse design techniques for a near-infrared optical communication telescope.

Deliverable: Optical design and analysis for a large metalens

3. Design the telescope opto-mechanical structure

- Investigate layer architecture and chemical composition methods to provide a path to a near-zero CTE telescope structure.

Deliverable: Telescope opto-mechanical structure design with a path to athermal performance

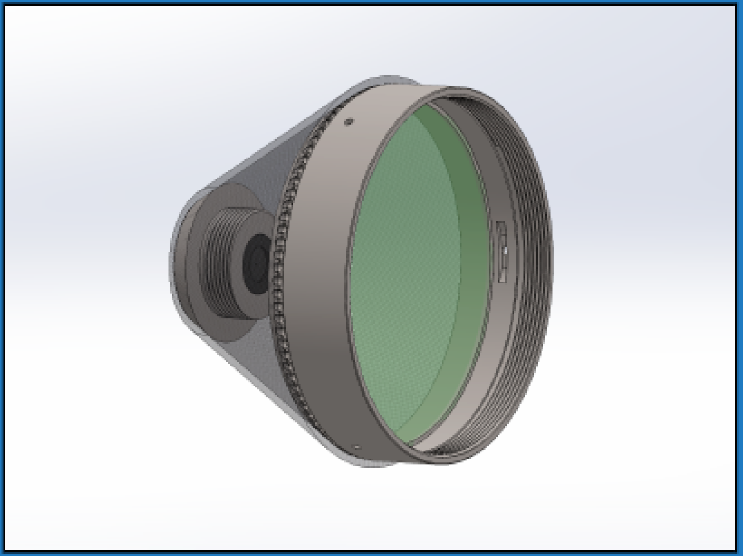
TRL

Estimated

1 2 3 4 5 6 7 8 9

(Estimated TRL bar spans 2 to 3)

IMAGE TITLE: Metalens NIR Telescope



NASA APPLICATIONS

Metalenses are potentially revolutionary in optical imaging due to their flat nature and compact size, multispectral acquisition and even off-axis focusing. Metalenses can be used in many NASA science missions (e.g., cameras, spectroscopy from UV to microwave, lidars) and spacecraft technologies using optics (e.g., star trackers, optical communication and navigation). Near-term NASA applications are IR, MIR and NIR optical systems for large spacecraft and UV to microwave systems for CubeSat and small satellite optical systems.

NON-NASA APPLICATIONS

$10 billion+ market with applications in machine vision, robotics, and industrial systems. Government and commercial imaging satellite optics. Future high volume applications include cellphone camera modules, wearable displays for augmented and virtual reality, machine vision, automotive and security cameras. Start-up companies: Tunoptix: https://www.tunoptix.com/; Metalenz: https://metalenz.com/

FIRM CONTACTS

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S12.03-2442 - Improved Computer Generated Holograms for Testing Aspheric and Freeform Optics

PI: David Strafford , Soter Technology, LLC - Leesburg, VA

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NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

Aspheric and Freeform optics are extremely effective, but expensive solutions to challenging optical system designs. Our idea aims to reduce the cost of testing non-spherical optics using Computer Generated Holograms (CGH) by reducing the long alignment time usually present in using CGHs, while also expanding the capabilities of CGHs, and by extension the optics they can produce. State of the art testing makes use of CGHs, which often come with challenging alignment requirements to compensate for the nature of CGHs. These Holograms can cost around $20,000 to procure for optics of half meter size, a large chunk of that is design the manufacturer needs to do on top of the surface you provide them, following which the testing cost using these Holograms can be around an additional 25% of that, on top of the initial setup cost of precision measurement tools to position them even before performing an optical test. Our method should reduce both the design cost on the CGH providers end, and reduce the cost of aligning the CGH on our end by half or better.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

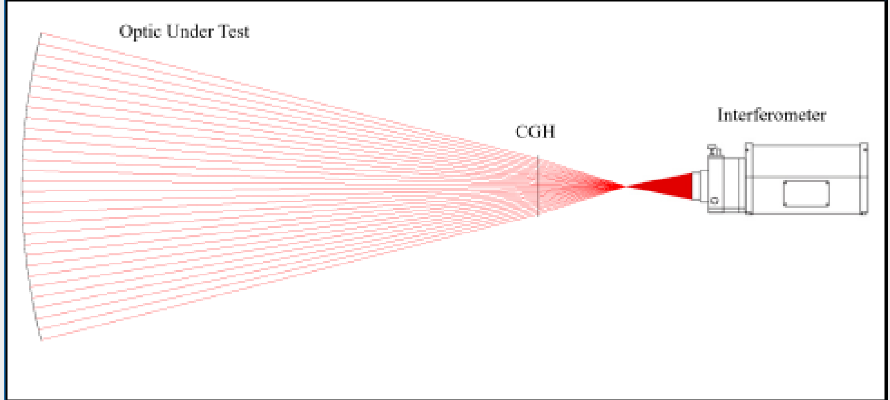
The objectives of this proposal are to prove that our method can increase the total aspheric departure of a surface under test, can decrease the alignment difficulty present in conventional CGHs, and increase the resolution of the CGHs to be used. We believe we can do this by designing and analyzing a CGH that contains prints of our method along with prints of conventional methods, and measuring their effectiveness at wavefront manipulation in the manner that is most beneficial to optical testing. By measuring this wavefront, we can quantify the comparison of our aspheric accuracy of each of our proposed methods. With some engineering time before ordering this Hologram, we can determine the most effective set of prints to apply to the hologram such that we get the most data out of a single hologram to substantiate our method. We aim to deliver to NASA a set of data that concretely proves that our method is an improvement in the reduction of error caused by on axis CGHs, with a goal to prove it is comparable to conventional expensive methods at reduced implementation difficulty and price. We will document the process and theory such that should further research be deemed appropriate, progress can continue smoothly to a more efficient solution. This effort will deliver a final report detailing analytical and experimental results.

TRL

Estimated

1 2 3 4 5 6 7 8 9

IMAGE TITLE: CGH test of an asphere



NASA APPLICATIONS

NASA has displayed continued interest in large, highly aspheric and free-form mirrors and lenses, and a method to test more aspheric surfaces while also decreasing alignment costs would be highly advantageous to the manufacturing of these surfaces.

NON-NASA APPLICATIONS

CGHs are a key technology for testing aspheric and free-form optics. This method would provide the industry with an easier method for measuring aspheric surfaces, at lower cost, and providing the capability to measure more challenging aspheres and free-forms. This will assist NASA programs, DoD programs, IC programs, and the US commercial earth observing satellite market.

FIRM CONTACTS

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2022 SBIR S12.03 ‘Normal Incidence’

Phase I 15 Submitted 2 Funded

- **Nanosonic:** Low Viscosity High Strength Adhesive with Low-CTE
- **Output Technologies:** Low-Cost High-Performance Metal Matrix Composite for Advanced Optical Systems

Phase II 2 Submitted 1 Funded

- **Nanosonic:** Low Viscosity High Strength Adhesive with Low-CTE

S12.03-1490 - Low Viscosity, High Strength Adhesive Materials with Low CTE

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PI: William Harrison , Nanosonic, Inc. - Pembroke, VA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

NASA needs a novel low viscosity, UV curable adhesive that possess high strength, high glass transition temperatures and low coefficient of thermal expansion for precision bonding of Laser Interferometer Space Antenna and other stable structure applications. The proposed HybridSil UV curable epoxy silane adhesive shall be engineered to rapidly set in minutes to afford submicron precision alignment of a telescope without prolonged support of placement equipment.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

Technical objectives are: 1. Synthesize UV cured epoxy silane precursors, 2. Formulate fast-setting adhesives with low CTE, and 3. Characterize the chemical, thermal, and mechanical properties of the cured adhesive.

Deliverables to include:

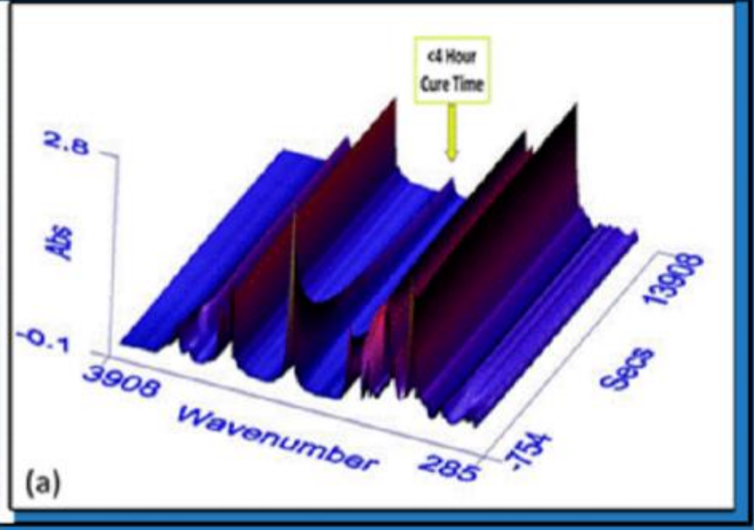
- IT Security Management Plan
- Kickoff meeting within 30 days of contract start
- Progress reports due at monthly intervals documenting program technical progress
- Phase I downselected HybridSil UV setting epoxy silane for NASA analysis and feedback (at least one pint)
- Final technical briefing to outline Phase I progress and identify Phase II work plan / objectives by program manager)
- Final report due at contract completion
- New Technology Report
- Final New Technology Summary Report

TRL

Estimated

1	2	3	4	5	6	7	8	9
	■	■	■					

IMAGE TITLE: Fast-cure HybridSil Resin



NASA APPLICATIONS

NASA needs low viscosity, UV curable adhesives with high strength, high glass transition temperatures and low coefficient of thermal expansion for precise bonding of Laser Interferometer Space Antenna (LISA) and other stable structure applications. These UV curable adhesives are used as potting and encapsulant materials in electronics.

NON-NASA APPLICATIONS

Aliphatic UV curable materials are used as wood finishings, adhesives, UV stable coatings, automotive protectant coatings, optical fibers coatings and cable jackets. Epoxy adhesive and resins with low CTE properties are used widely in optical and electrical components.

FIRM CONTACTS

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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)	100% (2/2)
2020	20% (3/15)	100% (1/1)
2021	44% (4/9)	100% (3/3)
2022	25% (3/12)	**66% (2/3)**
2023	**20% (1/5)**	
Total	28% (29/102)	66% (14/21)

2023 SBIR S2.04 'X-Ray, Freeform & Coating'

Phase I	5 Submitted	1 Funded

Nanovox: Wideband Inorganic Freeform Optics

Phase II	TBD Submitted	TBD Funded

S12.04-2561 - Wideband Inorganic Freeform Optics

PI: Hooman Akhavan , Nanovox, LLC - Beaverton, OR

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

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

Optical designers are limited by the degrees of freedom (DOF) of existing optical processes and materials. To correct aberrations, designers must assemble multiple shaped lenses of different dispersion materials, causing system size to balloon. Moreover, whereas in the visible spectral range there are multitude different materials, there is a scarcity of materials in the infrared. Freeform three-dimensional (3D) Gradient index (GRIN) optics significantly reduce lens counts. The ability to create custom index and dispersion materials, on demand, allows for bespoke optical materials to be fabricated to meet application requirements.

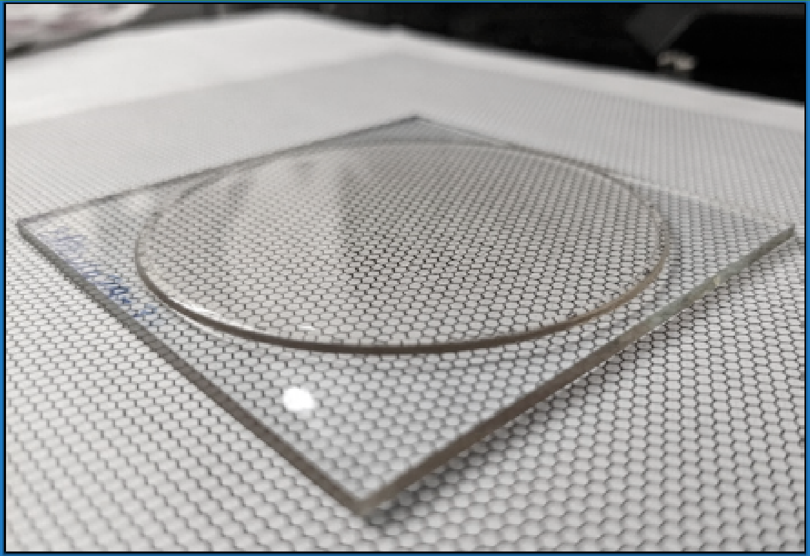
TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

- Identify material library for UV, Vis-SWIR, MWIR, LWIR spectral bands.
- Demonstrate densified optical element with good flatness.
- Fabricate proof-of-concept freeform GRIN optical element with UV-MWIR response.
- Develop Phase II design focused on testbed of specific NASA science mission.

TRL

Estimated

1	2	3	4	5	6	7	8	9
		■						



NASA APPLICATIONS

Applications include space exploration, remote sensing, astronomy, and Earth observation. In space exploration, they improve the performance of telescopes, spectrometers, and cameras. In remote sensing, they enhance the accuracy of measurements for atmospheric, land, and ocean studies. In astronomy, they enable high-resolution imaging and spectroscopy of distant objects. In Earth observation, they improve imaging and sensing capabilities for monitoring natural resources, climate change, and environmental hazards.

NON-NASA APPLICATIONS

Markets for compact optics with reduced aberrations include consumer electronics, such as smartphones and augmented reality headsets, as well as medical devices for diagnostic and surgical applications, industrial inspection systems, metrology, and high-resolution microscopy, and in autonomous vehicles, LiDAR systems, and aerospace industries.

FIRM CONTACTS

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2022 SBIR S2.04 ‘X-Ray, Freeform & Coating’

Phase I   12 Submitted   3 Funded

- **A-Z INNOVATIVE SOLUTIONS LLC:** Low-cost Ultra-high Precision X-Ray Mirror Surface Deterministic Finishing
- **HighRIOptics:** Binary Pseudo-Random Array (BPRA) standards for Inspection and Calibration of Cylindrical Wavefront Interferometry
- **OptiProSystems:** Wide Range Chromatic Interferometric Probe

Phase II   3 Submitted   2 Funded

- **HighRIOptics:** Binary Pseudo-Random Array (BPRA) standards for Inspection and Calibration of Cylindrical Wavefront Interferometry
- **OptiProSystems:** Wide Range Chromatic Interferometric Probe

S12.04-1446 - Binary Pseudo-Random Array (BPRA) standards for Inspection and Calibration of Cylindrical Wavefront Interferometry

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

PI: Keiko Munechika , HighRI Optics - Oakland, CA

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

High-accuracy metrology is vitally essential in manufacturing and optimally using ultra-high-quality free-form mirrors designed, for example, for space X-ray telescopes to manipulate X-ray light with nanometer-scale wavelengths. Due to the shorter wavelength, requirements to the surface figure (shape) and finish (roughness) of X-ray mirrors are many orders of magnitude more stringent than for visible-light optics. The metrology integrated into X-ray mirror manufacturing must ensure the accuracy of optical surface fabrication on the sub-nanometer level over large-area (on the scale of a meter and even more) strongly aspherical optical elements. Metrology technology has not kept up with the advancement in fabrication technologies. The deficiencies in the metrology, rather than in the fabrication technologies, primarily limit the optical quality. As an adage says, "If you can't measure it, you can't make it."

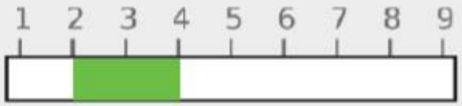
TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

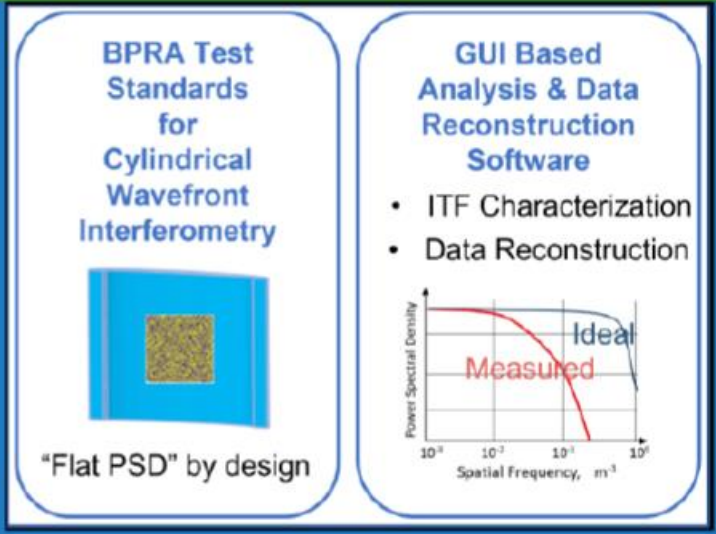
The goal in Phase I is to demonstrate the efficacy of using Binary Pseudo-Random Array test standards for inspection and calibration of Cylindrical Wavefront Interferometry. BPRA test standards suitable for middle and low spatial frequency will be developed on a cylindrical substrate. CWI measurements will be made by the LBNL Advanced Light Source (ALS) X-Ray Optics Laboratory (XROL) team, using a 6-in aperture ZYGO Fizeau interferometer, equipped with a Cylindrical Transmission Reference and/or a Conical Computer Generated Hologram diffraction element. The second, subcontractor, Rochester Scientific will develop the dedicated software suitable for the reconstruction of 2D metrology data with highly asymmetrical sampling. Phase I Proposed Deliverables are:

1. Fabricated highly randomized 2D BPRA test samples with minimum feature sizes in the ranges between 2.5 µm – 15 µm. One of the BPRA test standards will be delivered to NASA Goddard Space Flight Center for evaluation.
2. Demonstration of application of the ITF calibration to the reconstruction of surface metrology data measured with Fizeau Interferometers, available at the LBNL XROL.

TRL

Estimated





NASA APPLICATIONS

The technology will enable superior fabrication and performance characterization of large-area & strongly-aspherical grazing-incidence X-ray mirrors for X-ray telescopes by improving the metrology methodology. The capability for a full-dynamic-range ITF characterization of the metrology tool and data reconstruction to recover "true" optical surface has never been available before. The technology can be easily integrated with the existing metrology systems at NASA.

NON-NASA APPLICATIONS

Using sophisticated full-spatial-frequency ITF characterization and beyond-resolution reconstruction of the metrology data, this product will bring existing metrological tools to their highest possible performance level; it will improve the optical quality of optics, reduce the cost of fabrication, and enable faster improvements in future designs of the instrumentation by equipment manufacturers.

FIRM CONTACTS

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S12.04-2190 - Wide Range Chromatic Interferometric Probe

PI: Robert Niederriter , OptiPro Systems, LLC - Ontario, NY

NON-PROPRIETARY DATA

IDENTIFICATION AND SIGNIFICANCE OF INNOVATION

The quality of optical components determine the performance of advanced space telescopes and Earth-observation satellites. At the same time, cost is a factor in telescope design, and compact telescopes may be less expensive. Future telescopes may be able to improve both performance and cost metrics using freeform optics, which lack rotational symmetry, and fast F/# designs using optics with steep curvature.

One sticking point is the difficulty of precisely measuring the shape of freeform and fast F/# surfaces, requiring a challenging combination of 1) measurement resolution, 2) measurement range (surface sag), and 3) acceptance angle (steep slopes).

In this proposal, we offer improved metrology of freeform and fast F/# optical components by fundamental enhancements to our Chromatic Interferometric Probe platform that extend the measurement range and acceptance angle. Specific innovations include: 1) increased measurement range using multiple reference paths, and 2) increased acceptance angle by improving light collection efficiency and optimizing interference fringe contrast.

TECHNICAL OBJECTIVES AND PROPOSED DELIVERABLES

The technical objectives of the Phase I project focus on improving the capabilities of OptiPro's Nanometric Probe for measurement of freeform, fast F/#, and large diameter optical components while maintaining sub-nanometer performance.

Specifically, we aim to:

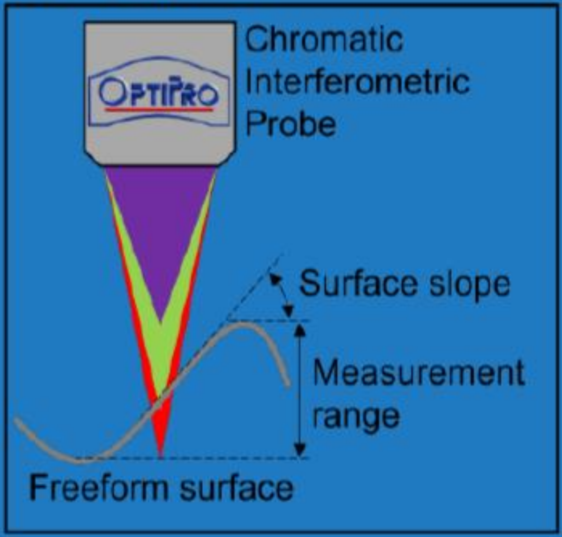
1. Demonstrate proof-of-concept for increased measurement range of low-coherence interferometers.
2. Design and construct a multi-element chromatic lens with long measurement range.
3. Determine the best path(s) forward to increase acceptance angle of optical metrology probes.

The deliverables at the end of Phase I are a final report including detailed results from the proof-of-concept demonstration, analysis of multiple paths to increase the acceptance angle, and a preliminary design of a long-measurement-range, large-acceptance-angle Nanometric Probe with sub-nanometer performance.

TRL

Estimated

IMAGE TITLE: Wide Range Probe



NASA APPLICATIONS

Potential NASA applications include metrology of freeform and other optical components for NASA missions, including flagship/decadal missions, small satellites, and everything between. Some specific applications:

- Origins Space Telescope (OST) and Large UV/Optical/IR Surveyor (LUVOIR), which may use freeform optics.
- Lynx, Advanced X-ray Imaging Satellite (AXIS), and other X-ray telescopes.
- Large telescope mirrors, such as those for the Habitable Exoplanet Observatory (HabEx), OST, and LUVOIR, requiring sub-nanometer metrology.

NON-NASA APPLICATIONS

The proposed metrology probe would benefit many applications, including:

- Metrology of high-precision optical components for commercial products
- Metrology of x-ray and neutron mirrors (Department of Energy)
- Vibration analysis of mechanical components and machines

FIRM CONTACTS

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Any Questions?

NASA 2024 SBIR Subtopic:

“**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.

If you have not already so done, please send Ron Eng or myself 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

Convince the Reviewer:

- You understand how your technology solves a high priority Problem.
    - 2022 Astrophysics Biennial Technology Report (https://apd440.gsfc.nasa.gov/technology.html)
    - 2022 Exoplanet Exploration Program Technology Gap List (https://exoplanets.nasa.gov/internal_resources/2269/)
- You understand State of Art of how Problem is or is not being solved.
- Your solution is better than the State of the Art

Articulate a feasible plan to:

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

Deliver Hardware not just a Paper Study, including:

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

DISCLAIMER

The following may or may not be what is published.

Introduction

Accomplishing NASA’s high-priority science at all levels (flagship, probe, Medium-Class Explorers (MIDEX), Small Explorers (SMEX), rocket, and balloon) requires low-cost, ultra-stable, normal-incidence mirror systems with low areal density.

Mirror system is defined as the mirror substrate, supporting structure, and associated actuation and thermal management systems.

After performance (diffraction limit, stability, collecting area), the most important metric is affordability (cost per square meter), followed by mass.

Proposals must show understanding of one or more relevant science need and present a feasible plan to develop the proposed technology for infusion into a mission.

Successful proposals will demonstrate an ability to manufacture, test, or control 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.

SBIR Call for Proporsals

S12.03 has defined 3 Scopes:

- Scope 1 Materials, Substrates, Structures, and Mechanisms
- Scope 2 Fabrication, Test, & Control of Components and Telescopes
- Scope 3 Special Topics:
  - Polarization Birefringence Mapper
  - Integrated Flexure Interface
  - Near Angle Scatter

Scopes are defined based on specific applications, technology gap needs, or operating wavelength regime.

Each scope has its own metrics and desired deliverables.

Proposals addressing other problems are welcome.

Habitable Worlds Observatory (HWO)

The primary near-term need is technologies to enhance/enable the Habitable Worlds Observatory (HWO).

HWO desires 6-m aperture telescope with better than 500 nm diffraction-limited performance (40 nm rms transmitted wavefront) achieved either passively or via active control operating at 250 to 270K (nominal). Optical components need to have <5 nm rms 0-G surface figures.

Additionally, to enable coronagraphy, the HWO requires total telescope wavefront stability of less than 3 pm rms.

Potential enabling technologies include: ultrastable mirror substrate and support structures (60 to 500 Hz first mode), athermal telescope structures, athermal mirror struts, ultrastable joints with low coefficients of thermal expansion (CTE), vibration compensation or isolation of >140 dB, and active thermal control of < 1 mK.

Materials, Substrates, Structures, and Mechanisms for Advanced Optical Systems

Mirror systems enable missions (from balloon or CubeSat to Probe or Flagship) operating at any wavelength from UV/optical to mid/far infrared.

Scope solicits technologies associated with the opto-mechanical aspects of mirror systems the substrate (material and core structure), supporting structure, with associated mechanisms.

Opto-Mechanical technology often determines the ability of a mirror system to meet its performance specifications (figure, mass, stability, thermal, etc.)

Also important is validated integrated structural thermal optomechanical performance (STOP) models for predicting 'in use' performance.

After performance, the most important metric is affordability.

Scope details specific performance specifications for different mission classes:

- Balloon Missions EUV, UVO and Mid IR
- Space Far IR Missions
- Space UVO Missions
- CubeSAT Missions

Fabrication, Test and Control of Advanced Optical Systems

Mirror systems enable missions (from balloon or CubeSat to Probe or Flagship) operating at any wavelength from UV/optical to mid/far-infrared.

Scope solicits technologies associated with fabrication, test and sense/control of mirror systems.

- Given that deterministic fabrication is relatively mature, technology advances are solicited that reduce cost for large mirrors by increasing remove rates while producing smoother surfaces (less mid-spatial error).
- High-contrast imaging of exoplanets using a coronagraph requires wavefront stability <3 pm rms. This requires wavefront sensing, metrology, and verification/validation.
- Actuators are needed to align and co-phase segmented aperture mirrors to diffraction-limited tolerances. Depending upon the mission, these mechanisms may need precisions of <1 nm rms and the ability to operate at temperatures as low as 10 K.

Special Topics:

#1: Polarization Birefringence Mapper

- To detect and characterize exo-Earths around Sun-like stars, the Habitable World Observatory (HWO) requires mirrors with polarization birefringence uniformity on the order of 1% over its full aperture. This special topic solicits an instrument to map polarization birefringence for the purpose of qualifying flight mirror coating processes and acceptance testing flight mirrors after coating. Flight mirrors may have diameters from 1.5-m to 6-m. It is desired to characterize polarization properties at scientifically relevant wavelengths with 20% spectral bandwidth between 350 and 1800 nm (stretch goal of 100 to 2500 nm).

#2: Integrated Flexure Interface

- Investigate integration of flexures or otherwise complaint mounting interfaces into a mirror substrate over 1-meter in diameter. The goal is a reduction in overall mass and size of the substrate and support structure by taking advantage of new manufacturing technologies to reduce part count. A successful project will show minimal mirror surface deformation when mounted to an over-constrained (non-kinematic) interface at various gravity orientations

#3: Near Angle Scatter

- Near Angle Scatter from surface microroughness, optical coating columnar structure, surface defects, contamination, radiation exposure AND micrometeoroids impacts can limit the ability to detect and characterize Earth-like planets in the habitable zones of Sun-like stars. Models, validated by experiment, that predict scattered light amplitude at angular separation from the host star from 40 to 500 milli-arc-seconds as a function of these sources are needed to help define component specifications for a potential 6-m mission to perform exo-Earth science.

Any Questions?