NASA SBIR Subtopic:

Funding History

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)	
Total	36% (72/200)	46% (26/56)

“Advanced Optical Systems” Award Statistics

	Phase 1	Phase 2
2005	22% (2/9)	100% (1/1)
2006	29% (6/21)	50% (3/6)
2007	33% (1/3)	100% (1/1)
2008	75% (3/4)	50% (1/2)
2009	66% (2/3)	66% (2/3)
2010	33% (4/12)	00% (0/3)
2011	33% (4/12)	00% (0/3)
2012	30% (3/10)	33% (1/3)
2014	66% (2/3)	
Total	35% (27/77)	41% (9/22)

“Optical Manufacturing & Metrology” Award Statistics

	Phase 1	Phase 2
2005	21% (6/29)	67% (4/6)
2006	25% (2/8)	100% (2/2)
2007	38% (3/8)	33% (1/3)
2008	54% (7/13)	50% (3/6)
2009	46% (6/13)	33% (2/6)
2010	70% (7/10)	17% (1/6)
2011	23% (3/13)	50% (1/2)
2012	20% (3/15)	66% (2/3)
2014	50% (5/10)	
Total	35% (42/119)	47% (16/34)

“Adv Tech Telescope for Balloon Mission” Statistics

	Phase 1	Phase 2
2012	50% (2/4)	100% (1/1)
Total	50% (2/4)	100% (1/1)

2014 SBIR S2.03

Phase I	3 Submitted	2 Funded

Broad-Band Reflective Coating Process for Large UVOIR Mirrors, ZeCoat

Advanced Mirror Material System, Peregrin Falcon

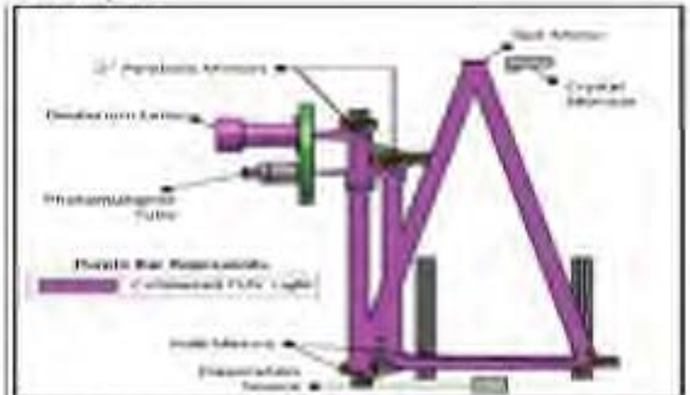
Phase II	TBD Submitted	TBD Funded

NASA SBIR/STTR Technologies

S2.03-8965 - Broadband Reflective Coating Process for Large FUVOIR Mirrors

PI: David Sheikh

ZeCoat Corporation - Torrance, CA



Identification and Significance of Innovation

ZeCoat Corporation will demonstrate a coating process for making broadband reflective coatings suitable for very large mirrors (4+ meters). ZeCoat offers a means to build upon the best known and proven coating recipe for metal-fluoride protected aluminum coatings (the GSFC 3-step process)1 by: 1) utilizing ZeCoat's unique precision motion-controlled deposition system to uniformly apply a 5-nm layer over a large area, 2) protecting mirror assemblies from damaging high temperatures by heating only the mirror surface using radiant heat, 3) using an FUV reflectometer (120-nm to 180-nm) integrated into the coating chamber to optimize the coating process 4) using a layer of Sn to protect LiF from degradation due to atmospheric moisture and organic contamination during ground storage and then re-evaporate the tin in space. Normal incidence, 4-meter class UVOIR mirrors have been cited as a high NASA priority by multiple government review panels.

Estimated TRL at beginning and end of contract: (Begin: 2 End: 3)

Technical Objectives and Work Plan

Technical Objectives
Metric/SBIR Goals:
Reflectance (90-nm to 110-nm): > 60%
Reflectance (110-nm to 200-nm): > 85%
Reflectance (200-nm to 2500-nm): > 90%
Surface Roughness: <5 A RMS
Coating Stress ≤ 60 MPa
Humidity: 95% RH, 50 C, 24 hour
Moderate Abrasion: 20 rub, 5 psi, cheese cloth
Thermal Cycling: -80 + 50 C (ten cycles)
Adhesion: ASTM Tape Test

Work Plan
1. Radiant heating test for metal-fluoride deposition
2. Comparison of FUV reflectance by radiant and other heating methods
3. Determine minimum thickness of cold coat fluoride for protecting Al in vacuum
4. Apply 5-nm coating layers over 1.2-m area and measure uniformity
5. Apply thin layers at high-evaporation rates over 1.2-m area
6. Test Sn as protection for fluoride and re-evaporation characteristics

NASA Applications

The ultimate goal of this research is to apply a UVOIR coating developed by ZeCoat to a future NASA space-based observatory such as ATLAST. We are also interested in coating smaller mirrors such as in the ICON mission.

Non-NASA Applications

Upon development, ZeCoat will offer for sale UV coatings for commercial purposes such as microlithographic processes operating in the 100-nm to 200-nm wavelength range. Potential customers include, but are not limited to, AFRL, Boeing, Northrop Grumman, and Lockheed Martin.

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NASA SBIR/STTR Technologies

S2.03-9217 - Advanced Mirror Material System

SBIR
STTR

PI: Robert Hardesty
The Peregrine Falcon Corporation - Pleasanton, CA

Identification and Significance of Innovation

This innovation will bring together recent laboratory developments and mature the technology so that complete mirror and telescope assemblies can be reliably and robustly produced. This proposed innovation will lower the cost of space mirrors from their current state of the art of $5.4 m/m2 to less than $1.5 m/m2 while maintaining low weight, high stiffness and high performance for x-ray, neutron and UV/optical mirrors. Large athermal optical systems can be produced with this approach.

Estimated TRL at beginning and end of contract: (Begin: 1 End: 3)

Technical Objectives and Work Plan

1. This innovation will reduce the cost of space borne mirrors by a factor of over 4.
2. This innovation will maintain stiffness, low density, and performance while reducing cost.
3. The innovation will be able to produce optics up to 10 m in size.
4. The innovation can be applied to both UV/optical systems and x-ray/neutron mirrors.
5. This material system will provide a stable and precision optical system that can enable x-ray telescopes to reach accuracies to less than 1 arc second.
6. Maintain optical system performance with the surface roughnesses of less than 5 nm RMS.
7. Utilize existing emittance and absorption coatings within the design of the advanced material system allowing for traditional and typical thermal control.
8. Provide conventional means to integrate the mirrors into their subsequent assemblies.

NASA Applications

Potential uses, first and most obvious are for the applications currently under consideration for NASA large optical systems. That in and of itself will be a substantial technological success that will enable the advancement of the current state of the art of the innovation. In addition, this technology will be adaptable to other satellite programs.

Non-NASA Applications

This development for both UV/optical and x-ray optics can be applied to many research and development applications here on earth. Fast scan mirrors and surveillance systems rely upon low density, high stiffness and high performance optics. In addition, commercial and military optical systems, particularly Earth observation satellites and other systems could benefit from this technology.

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NON-PROPRIETARY DATA

2014 SBIR S2.04

Phase I 10 Submitted 5 Funded

- **Figuring and Polishing Precision Optical Surfaces,** OptiPro
- **Manufacture of Free-Form Optical Surfaces with Limited Mid-Spatial Frequency Error,** Optimax
- **Optical Metrology of Aspheric and Freeform Mirrors,** OptiPro
- **Innovative Non-Contact Metrology Solutions for Large Optical Telescopes,** SURVICE Engineering
- **Monolithic Gradient Index Phase Plate Array,** Voxtel

Phase II TBD Submitted TBD Funded

NASA SBIR/STTR Technologies

S2.04-9407 - Optical Metrology of Aspheric and Freeform Mirrors

PI: David Mohring
OptiPro Systems LLC - Ontario, NY

Identification and Significance of Innovation

Telescope satellites such as Chandra, and XMM-Newton have provided detailed images into the formation of our universe and the study of black holes. New and future missions like the Wide Field X-ray Telescope (WFXT) promise to provide even more detail. These telescopes all require high precision optical surfaces that have tight optical specifications, and slope requirements of less than 1 arc-sec rms. OptiPro Systems proposes development of a metrology system that would provide feedback for manufacturing these precision optics as well as final metrology of global form error and mid-spatial frequency content. We envision that the work performed in Phase I would lead to a system to be designed and built which delivered to NASA if awarded a Phase II. OptiPro, as a metrology system builder, is uniquely positioned to transition the technology to many optical component fabricators, which will ultimately lead to the most cost effective solution for NASA for programs such as WFIRST and NGXO.

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

Technical Objectives and Work Plan

The goal of Phase I will be to determine the best non-contact measurement sensor to be implemented on a large scale measurement platform. OptiPro will perform the tasks listed to development a system that can be implemented in optical fabrication facilities to assist in the cost effective manufacturing of NASA precision optical mirror components.
1.Evaluate and test UltraSurf sensors. 2.Grind and polish samples for surface form and slope measurement. 3.Validate UltraSurf accuracy and resolution features. 4.Develop breadboard software analysis and fabrication process interface. 5.Concept design of a large scale measurement platform. 6.Determine sensor system adaptability to fabrication equipment for in-situ measurements.

NASA Applications

UltraSurf and the in-situ machine metrology from OptiPro will be used for accurate measurement of the following NASA optical components: -forming mandrels used to produce multiple segmented shell mirrors for the International X-Ray Observatory (IXO) and (NAGO)and X-ray mirrors for WFXT. - aspheric and freeform optical surfaces required by LISA and WFIRST... - measuring of the segmented types of telescope systems such as the Advanced Technology Large Aperture Space Telescope (ATLAST).

Non-NASA Applications

- U.S. Military aspheric, freeform and conformal optics. Non-contact measurement of optical injection mold inserts. Commercial automotive heads-up displays. Commercial LED lighting reflectors. - Medical scanning systems. Solar power intensifiers, Solar power mirror guidance optics.

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NASA SBIR/STTR Technologies

S2.04-9405 - Manufacture of Free-Form Optical Surfaces with Limited Mid-Spatial Frequency Error

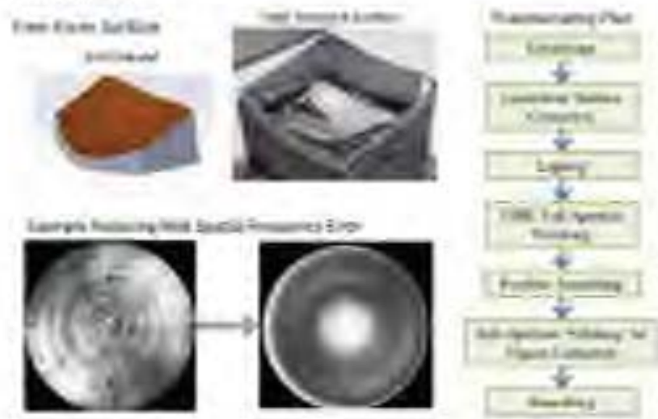
PI: Katherine Medicus
Optimax Systems, Inc. - Ontario, NY

Identification and Significance of Innovation

Our proposed innovation is a robust manufacturing process for free-form optical surfaces with limited mid-spatial frequency (MSF) error. NASA and others have a direct and critical need for high quality free-form optical components. Free-forms improve the optical performance of many types of optical systems compared to aspheres. MSF error is a major concern with free-forms as the standard method for manufacturing (sub-aperture polishing) can lead directly to large MSF error. MSF error is a surface height error in the spatial regime between roughness (micro) and irregularity (macro). MSF errors dramatically degrade performance in optical systems.

Our free-form manufacturing process is differentiated by full aperture polishing, called VIBE, and by the proposed smoothing step. The VIBE step does not create MSF error as the sub-aperture process does and smoothing reduces any inherent MSF error. In this manner, we will manufacture free-form optical surfaces without MSF errors.

Estimated TRL at beginning and end of contract: (Begin: 2 End: 3)



Technical Objectives and Work Plan

Our technical objectives are three fold: 1) Determine most feasible smoothing parameters, 2) Determine feasibility of smoothing for free-forms for reduced mid-spatial frequency error, and 3) Determine the effectiveness of using a computer generated hologram (CGH) for free-form measurements.

The work plan is as follows:

1. Design free-form surface
2. Design CGH with features in free-form for easy alignment
3. Perform Smoothing Study
   a. Determine smoothing parameter inputs
   b. Design experiment to test smoothing parameters on test pieces
   c. Run and analyze results of smoothing experiment
4. Generate free-form
5. Polish free-form in two paths: with and without smoothing before figure correction
6. Sub-Aperture Figure Correction
7. Final smoothing step
8. Measure free-form in all steps of the polishing process
   a. Evaluate irregularity at all steps with CMM
   b. Evaluate mid-spatial and irregularity with CGH after polishing steps
9. Perform analysis to determine best polishing path

NASA Applications

Free-form optical surfaces with limited mid-spatial frequency error have many applications in NASA's optical systems. Specific examples of NASA optical systems that are improved by free-form surfaces are x-ray and UV imaging instruments on weather satellites, the IHMCD spectrometer at the Kitt Peak National Observatory and three mirror telescope systems. Specific programs that have tight mid-spatial frequency specifications are the International X-ray Observatory and the Jovian planet finder.

Non NASA Applications

As with the NASA applications, almost any optical system can have better performance with free-from surfaces with limited mid-spatial frequency errors. Specific areas of focus are high energy laser systems like the National Ignition facility, in extreme ultraviolet lithography, and in x-ray synchrotrons such as the facilities at Brookhaven And Argonne National Labs.

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NASA SBIR/STTR Technologies

S2.04-9095 - Figuring and Polishing Precision Optical Surfaces

PI: David Mohring
OptiPro Systems LLC - Ontario, NY

Identification and Significance of Innovation

Telescope satellites such as Chandra, and XMM-Newton have provided detailed images into the formation of our universe and the study of black holes. New and future missions like the Wide Field X-ray Telescope (WFXT) promise to provide even more detail. These telescopes all require high precision optical surfaces that have tight optical specifications, and slope requirements of less than 1 arc-sec rms. OptiPro Systems proposes further development of its polishing platforms (UltraSmooth and UltraForm) for manufacturing these precision optics as well as metrology of global form error and mid-spatial frequency content. We envision that the work performed in Phase I would lead to a system to be designed and built which delivered to NASA if awarded a Phase II. OptiPro, as a machine builder, is uniquely positioned to transition this technology to many optical component fabricators, which will ultimately lead to the most cost-effective solution for NASA for programs such as WFIRST and NGXO.

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

Technical Objectives and Work Plan

Our main goal during Phase I will be to demonstrate the UltraSmooth Finishing process combined with the UltraForm Finishing on a 0.25 meter mirror with minimal mid spatial frequency errors. The grinding, polishing and measurement of the final surface will drive the conceptual design requirements of the large scale meter class platform. The objectives of Phase I can be summarized as:
1 Design & manufacture the USF tooling required for the 0.25 meter mirror 2 Grinding and UFF polishing of the fused quartz mirror 3 Metrology and mid spatial frequency analysis of UFF Polished Surface 4 USF toolpath software development incorporating the new tooling for 0.25 meter mirror 5 Metrology and mid spatial frequency analysis of USF Polished Surface 6 Preliminary design of a meter class USF machine.
Phase I process development effort will be focused on developing and documenting the process to remove and measure mid spatial slope errors on a 0.25 meter mirror optical surface. If awarded a Phase II, OptiPro Systems will scale up the capabilities demonstrated during Phase I to a large optical mirror shape defined by NASA and design and build a meter class UltraSmooth Finishing machine to be delivered to NASA or a NASA component manufacturer.

NASA Applications

UltraForm Finishing and UltraSmooth Finishing will provide finishing capabilities for the following NASA optical components:
-forming mandrels used to produce multiple segmented shell mirrors
-Hard and Soft X-Ray mirror telescopes for the International X-Ray Observatory (IXO) and (NGXO)
- aspheric and freeform optical surfaces required by LISA and WFIRST
- measuring of the segmented types of telescope systems such as the Advanced Technology Large Aperture Space Telescope (ATLAST).

Non-NASA Applications

- U.S. Military aspheric, freeform and conformal optics
- Polishing of optical injection mold inserts
- Commercial automotive heads-up displays
- Polishing of freeform reflectors for lighting applications
- Solar power intensifiers and mirror guidance optics
- Department of Energy X-Ray Optics

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NON-PROPRIETARY DATA

NASA SBIR/STTR Technologies

S2.04-9255 - INNOVATIVE NON-CONTACT METROLOGY SOLUTIONS FOR LARGE OPTICAL TELESCOPES

PI: John Ebersole

SURVICE Engineering Company, LLC - Belcamp, MD

Identification and Significance of Innovation

While there are numerous contact-based metrology tools available for dimensionally inspecting large multi-segmented assemblies, they are not suitable for use on highly reflective surfaces or are otherwise unacceptable for use on high-precision optics. At the conclusion of our SBIR Phase I effort, we will have established the feasibility of a new and innovative non-contact, high-precision metrology approach for dimensionally inspecting multi-segmented mirrors in an as-installed configuration. The non-contact measurement technology will be usable from a safe distance to minimize damaging the mirrors, even with all mirror segments assembled in the final telescope configuration. Our innovative solution will be applicable to all mirrors, regardless of the prescription/optical-design and fabrication of the mirrors. Our Phase-I-feasibility/Phase-II-prototype-demonstration program will lead to a fully deployable system for use by NASA in Phase III.

Estimated TRL at beginning and end of contract: (Begin: 2 End: 3)

Technical Objectives and Work Plan

? Investigate the technical feasibility of applying the proposed technologies to non-contact measurement scanning of mirror segments

? Quantify measurement errors associated with the techniques for comparison to NASA requirements

? From the evaluated alternatives, downselect the most favorable solution approach to address the SBIR requirements

Using our in-house optical test bed, SURVICE will evaluate several promising technologies ? with the goal of being able to demonstrate (in Phase II) a viable application of one or more of these technologies, or derivatives thereof, for segmented telescope mirror measurements. Working with NASA and our academic team-member, SURVICE will enumerate the physical requirements for each technique as well as outline the data processing workflow and computational resources required.

For each of the techniques that are determined to be viable solutions, the SURVICE team will quantify measurement errors for locating key features of the mirror segments. This will include an analysis of the error sources and suggestion of opportunities to optimize the techniques as appropriate and where required in order to meet NASA requirements.

At the conclusion of our Phase I research, SURVICE will select a technology

NASA Applications

SURVICE is becoming established as an important conduit for transitioning innovative metrology technologies to major Federal programs. With segmented mirrors being the likely or preferred type of construction for most future large optical telescopes, there will be many Phase III opportunities to employ the solution to NASA and European telescope programs. The results of our effort will lead to new uses of our precision metrology technologies for manned and unmanned aircraft and spacecraft.

Non-NASA Applications

The developed technology will have numerous applications to existing and new aircraft and spacecraft, manned and unmanned, military and commercial. We will take advantage of and build upon our successes in the effective use of SBIR funding to transition solutions to multiple users via our Phase I-III commercialization efforts.

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NASA SBIR/STTR Technologies

S2.04-8914 - Monolithic Gradient Index Phase Plate Array

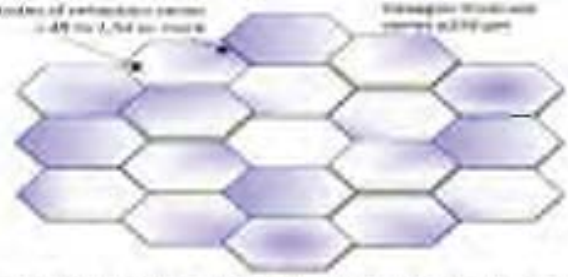
PI: Charles Dupuy
Voxtel, Inc. - Beaverton, OR

Identification and Significance of Innovation

The "piston errors" and aberrations of the mirror segments used in large telescopes, are typically measured with on-board optical instruments, usually a dispersed Hartman sensor (DHS) and/or dispersed fringe sensor (DFS). Calibrating and testing of the wavefront sensors are typically performed using custom-built fused silica phase plate arrays. The manufacture and assembly of each custom phase plate array is time-intensive and expensive.

Proposed is a gradient index (GI) phase plate array (PPA), which integrates the corrections of the DHS, an intermediate smoothing phase plate, and the DFS. This reduces the number of phase plates required, from three to one, and allows for the PPA t be used in the pupil plane, allowing for more precise calibration. The monolithic construction of the innovation significantly reduces development time and cost.

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



VIRGO Printed Phase Plate Array constructed by , varying both thickness (for piston alignment error) as well as local index of refraction (shown with blue shading) to correct wavefront aberrations.

Technical Objectives and Work Plan

Objectives:

1. Model NASA requirements and translate to materials and process parameters
2. Engineer the optical materials required to fabricate the Phase Plate
3. Engineer the joint modes necessary to achieve the optical path length control required
4. Fabricate and characterize a proof-of-concept "breadboard" Phase Plate

Work Plan:

A. Requirements Definition and Performance Modeling
B. Optical Material and Processing Technologies Optimization
C. Optical Component and Breadboard Fabrication
D. Optical Test and Characterization

NASA Applications

Spatial filter arrays (SFAs) have attracted great interest because of its wide applications, including coronagraph imaging, nulling interferometer, wavefront controls, wavefront compensation, free-space laser communications, adaptive optics, atmospheric compensation, and synthetic aperture imaging.

Non-NASA Applications

The military applications are similar to NASA's. The commercial applications, of this general technology, include low-profile cell phone camera lenses, smart glasses, solar concentrators, eye glasses & ophthalmic goods, night vision goggle lenses, 3D led films, microlens arrays, 3D imaging, CMOS photonics & optical backplanes, endoscopy & medical optical instrumentation, and military optics.

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2012 SBIR S2.03

Phase I 10 Submitted 3 Funded

Low-Stress Silicon Cladding for Surface Finishing Large UVOIR Mirrors, ZeCoat Corp

Broad-Band EUV Multilayer Coatings for Solar Physics, Reflective X-ray Optics, LLC

Composite Single Crystal Silicon Scan Mirror Substrates, Onyx Optics, Inc

Phase II 3 Submitted 1 Funded

Low-Stress Silicon Cladding for Surface Finishing Large UVOIR Mirrors, ZeCoat Corp

NASA SBIR/STTR Technologies

S2.03-8249 - Environmentally Stable UVOIR Reflective Coating for Large Mirrors

PI: David Sheikh
ZeCoat Corporation - Encinitas, CA

Identification and Significance of Innovation

ZeCoat Corporation will develop an affordable, environmentally stable, broadband UVOIR reflective coating (100-nm to 2500-nm) for large mirrors. A chamber integrated, FUV reflectance monitoring system (100-nm to 200-nm), will be used to optimize the coating process. By maintaining a constant coating geometry, ZeCoat's motion-controlled evaporation process is directly scaleable to mirrors 4-meters in diameter.
ZeCoat proposes three process innovations: (1) application of a positive pressure of pure nitrogen gas outside the coating the chamber to reduce oxidation of the aluminum reflector while under vacuum; (2) the use of a pulsed DC ion assist process to create a dense metal-fluoride protective layer; (3) removal of aluminum oxide contamination by ion etching, just prior to applying a protective metal-fluoride over-coat.
Normal incidence 4-meter class UVOIR telescopes have been cited as a high NASA priority by multiple government review panels.

Estimated TRL at beginning and end of contract: (Begin: 2 End: 3)

Technical Objectives and Work Plan

Objectives
Metric Goal
Technical Objectives:
1. Reflectance (100-nm to 200-nm)>83%
2. Reflectance (200-nm to 1500-nm)> 80%
3. Reflectance (1500-nm ? 2500-nm)> 95%
4. Surface Roughness After Coating<5 A RMS
5. Coating Stress< 85 MPa
6. Humidity 80C/60 RH, 24 hour
7. Thermal Cycling -80 + 150 C (ten cycles)
8. Adhesion ASTM Tape Test

Work Plan (Tasks)
1. Effect of neutralization filament contamination
2. Reflectance degradation of Al coating under vacuum
3. Degradation of Al coating with 5-nm of LiF substrate roughness
4. Surface roughness of 1-micron LiF
5. Scatter of Al (300-nm to 400-nm)
6. Environmental testing of Al/LiF coatings
7. Deliverables

NASA Applications

The ultimate goal of this research is to apply a UVOIR coating developed by ZeCoat, to a future NASA space-based observatory.

Non-NASA Applications

ZeCoat plans to offer through its website, a standard line of environmentally stable mirror products for microlithographic applications (157-nm and 193-nm).

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2012 SBIR S2.04

Phase I 15 Submitted 3 Funded

Advanced Optical Metrology for XRAY Replication Mandrels and Mirrors, Aperture Optical Sciences Inc

Light Weight, Scalable Manufacturing of Telescope Optics, ReliaCoat Technologies, LLC

Low Cost Method of Manufacturing Space Optics, ORMOND, LLC

Phase II 3 Submitted 2 Funded

Light Weight, Scalable Manufacturing of Telescope Optics, ReliaCoat Technologies, LLC

Low Cost Method of Manufacturing Space Optics, ORMOND, LLC

NASA SBIR/STTR Technologies

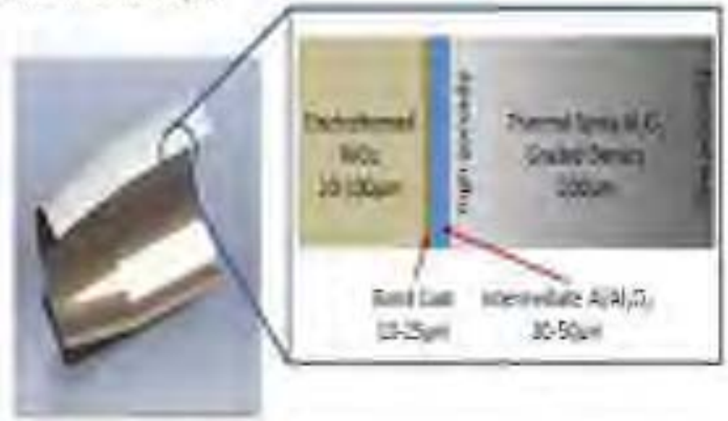
S2.04-9446 - Light Weight, Scalable Manufacturing of Telescope Optics

PI: Christopher Jensen
ReliaCoat Technologies, LLC - East Setauket, NY

Identification and Significance of Innovation

X-ray telescopes utilize large nested reflectors to facilitate the collection from distant objects. Traditionally these reflectors are made from 20 mm thick glass ceramic Zerodur. This has limitations on the number of nested reflectors. State-of-the-art observatories, such as XMM-Newton, use nickel reflectors made via an electroforming replication process. Thickness of the NiCo currently is about 1 mm to provide structural stiffness but this limits number of shells as the density of Ni is far greater than Zerodur. The proposed innovation seeks a hybrid solution: use the electroforming technology with NiCo but substitute for significant portion of the metal with a low density ceramic composite. This is accomplished by thermal spraying of 200 micron thick multilayer on the 100 micron NiCo with subsequent release of the entire assembly. This process can result in an order of magnitude reduction in telescope weight and thus cost savings in terms of launch vehicle requirements.

Estimated TRL at beginning and end of contract: (Begin: 3 End: 5)



Technical Objectives and Work Plan

The focus of this program is to develop a lightweight, density graded ceramic coating to be used as a support structure for a thin nickel/cobalt electroformed optical reflectors. Phase I results showed that through judicious selection of materials, design of layered architecture and optimal processing it is feasible to produce such low density reflector structures. Phase II effort will build on the phase I accomplishment by tackling critical issues of processing and scale-up to optimize this new X-ray telescopic design and manufacturing solution. The key technical objectives are listed below which will be addressed through clearly defined 9 task work plan which will be executed by ReliaCoat Technologies in partnership with Smithsonian Astrophysical Observatory.

-In partnership with SAO, finalize layered architecture design as enabled by the process to ensure critical acceptance criteria.
-Optimize material and processing parameters to meet the multifunctional objectives in terms of density and stiffness while ensuring no thermal or mechanical damage to the electroformed optic.
-Characterize the process at coupon level and extend to component level.
-Scale-up process to demonstrate fabrication of two demonstration reflectors in the 15 and 25 cm outer diameter and 62 cm length.
-Perform full X-ray reflectivity measurement of two nested reflectors telescope at MSFC.

NASA Applications

X-ray astronomy continues to be important for NASA. Chandra, XMM-Newton and Suzaku observatories have contributed profoundly to discoveries. Future X-ray explorer missions, successor to Nu-STAR, benefits greatly from the improved resolution of the optics. Future X-ray astronomy missions such as Smart-X will require large effective area and will utilize a segmented optic. Our innovation to fabricate thin, lighter weight, substrates enhances capabilities for future X-ray telescope technology.

Non-NASA Applications

The hybrid manufacturing being investigated combining metal alloy plating with ceramic backing can be contemplated for various applications in DoD and commercial sectors. Possibilities exist for multi-spectral systems in areas of defense telescopes, commercial space exploration and medical imaging. Other applications include graded liners for gun-barrels, solid-oxide fuel cells and membranes.

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NASA SBIR/STTR Technologies

52.04-9968 - Low Cost Method of Manufacturing Space Optics

PI: Dan Alberts
ORMOND, LLC - Auburn, WA

Identification and Significance of Innovation

As ground and space based optics become larger and the use of difficult to machine materials becomes more desired, cost, risk and schedule are setting limits to the feasibility of many projects.

This SBIR will make available a new manufacturing technology that will increase feasible large optics design options, significantly reduces the manufacturing time, cost and risk involved in producing large optics components. Specifically addressed are cutting, near net shaping and light weighting of glass and ceramic optical components. This technology generates reduced sub-surface damage and residual stress compared to grinding.

Machining materials such as ULE or SiC is often performed at Ormond but it needs to be developed to a point where risk is acceptably low and NASA and its contractors understand the technical performance and cost.

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

Technical Objectives and Work Plan

The primary objective of the Phase II program is to develop and build a workstation that is capable of light weighting the 1/3 scale AMTD-2 mirror. It will be capable of lightweighting large mirrors at rates many times faster than conventional grinding.

This same workstation will be capable of supporting scale up work, performing rough semi-elliptical optic form machining, and cutting large mirror cores.
The Phase II technical objectives include:

-Develop a manufacturing workstation that is capable of high speed light weighting the 1/3 scale AMTD mirror.
-Demonstrate that the technology is scalable to support full scale mirror fabrication.
-Provide economic data to NASA and contractors.

These objectives will be accomplished by performing the following:

-Perform additional process development to support the specification of a workstation.
-Design and build a 6-axis machine that is capable of supporting the operating parameters that were determined to be required under Phase I.

NASA Applications

This program is structured to primarily address NASA AMTD-2 needs but the Phase II project will support broad a range of NASA space and ground based optics programs.

Raytheon has stated in a letter of support this technology is a critical reduce machining and fabrication times and risk in processing ceramic and glass ceramic substrates and that the process has potential applicability to JDEM, DOD, LISA, ICESAT, ATLAST, CLARREO, ACE.

Non NASA Applications

This SBIR supports any application where brittle materials are machined, especially applications where challenging ceramics such as SiC must be machined in bulk. One application is the ceramic armor industry, which represents a huge market. The technology will be commercialized through technology licensing that will allow the large NASA primes to implement it in their own facilities.

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2012 SBIR E3.02

Phase I	4 Submitted	2 Funded

Low Cost, Cosmic Microwave Background Telescope, Vanguard

Affordable, Ultra-stable CVC SiC UVOIR Telescope for BENI Mission, TREX

Phase II	1 Submitted	1 Funded

Low Cost, Cosmic Microwave Background Telescope, Vanguard

NASA SBIR/STTR Technologies

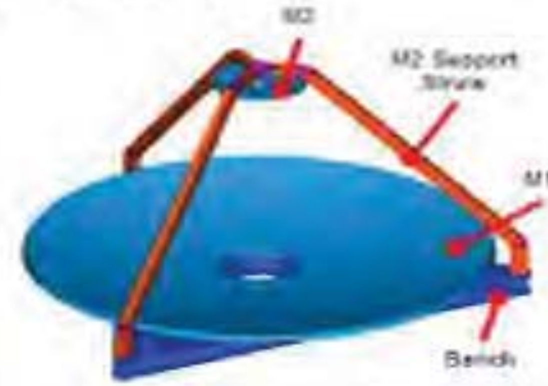
E3.02-8944 - Low Cost, Cosmic Microwave Background Telescopes (P-NASA12-003-1)

SBIR
STTR

PI: Jeffrey Loomis
Vanguard Space Technologies, Inc. - San Diego, CA

Identification and Significance of Innovation

The proposed innovation is a 2.5 meter aperture, on-axis, lightweight, low cost, composite telescope as illustrated. The envisioned telescope may be suitable for use on Super BLAST-pol in 2016. The telescope design and manufacturing technologies, especially those for the primary mirror, can be scaled up and applied to off-axis surfaces for future Cosmic Microwave Background (CMB) mission configurations such as MuSE and BOBCAT. To reduce recurring cost, the proposed innovation is designed to be recovered and reused to the extent possible after landing. Bolted and pinned joints allow disassembly and reassembly. Most Super BLAST-pol components can be designed to fit into recovery vehicle/airplane volumes in Antarctica. For Phase 2, Vanguard Space Technologies' (Vanguard) goal is to deliver a 2.5 meter, composite, on-axis, telescope demonstrator by building upon the success of the Phase I effort.



Estimated TRL at beginning and end of contract: (Begin: 4 End: 6)

Technical Objectives and Work Plan

The Phase I results suggest that development and delivery of a flyable, state-of-the-art, 2.5 meter telescope demonstrator for Super BLAST-pol during Phase II is feasible from technical, cost, and schedule perspectives. For Phase II, Vanguard's overall objectives are to successfully engineer, fabricate, and deliver one complete telescope within 24 months for $1.5M. To minimize technical risk and successfully deliver the product on time Vanguard plans to leverage existing materials and technologies and staff the program with a success-oriented team with extensive, relevant experience. After Kick-off, the 14-month, nonrecurring phase will begin and include telescope engineering, coupon fabrication and test, a small pathfinder reflector panel demonstration, M1 mold and cart fabrication, M1/M2 strut tools, assembly fixtures, a critical design review, component and assembly drawings, and work instructions. A CDR is scheduled to be held within 9 months ARO. A 14 month, recurring phase is proposed and will begin 10 months ARO or approximately 1 month after CDR. Recurring activities include raw material procurement, composite component fabrication, M1 coating, M2 machining, telescope integration, and alignment verification. To be conservative from a schedule perspective, the 24 month plan includes 9 weeks of reserve margin.

NASA Applications

Vanguard met with Alan Kogut at GSFC on 11/7/13. The technology may also be of interest to a future NASA GSFC program currently referred to as BOBCAT. BOBCAT is still in the concept/design phase and open to change. The current design envisions an on-axis system (similar to BLAST), but other constraints (principally the height of the secondary relative to the dewar floor) may lead the project to a more compact off-axis design of the crossed Dragone type.

Non NASA Applications

Northrop Grumman, Baltimore, MD, an aerospace prime contractor, was contacted on November 5, 2013, and briefly informed of our activities. NG expressed interest in the technology and Phase 1 results. Vanguard will meet with NG personnel within 1-2 months.

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2011 SBIR S2.05

Phase 1 13 Submitted 3 Funded

Cryogenic & Vacuum Compatible Metrology Systems; Flexure Engineering

Optical Fabrication & Metrology of Aspheric & Free Form Mirrors; OptiPro

Very Large Computer Generated Holograms for Precision Metrology of Aspheric Optical Surfaces; Arizona Optical Metrology

Phase II 2 Submitted 1 Funded

Optical Fabrication & Metrology of Aspheric & Free Form Mirrors; OptiPro

NASA SBIR/STTR Technologies

S2.06-8333 - Optical Fabrication and Metrology of Aspheric and Freeform Mirrors

PI: David Mohring
OptiPro Systems LLC - Ontario, NY

Identification and Significance of Innovation

UltraForm Finishing is a deterministic sub-aperture polishing machine which allows for the finishing of complex shapes with a variety of materials. OptiPro has and is continuing to develop processes for a number of these optics, including toric, off-axis parabolic, and freeform shapes. These processes can be applied to mirrors required by NASA. Our proposal focuses on the mandrel requirements of the International X-Ray Observatory (IXO, now NGXO), however this technology is applicable to large lightweight monolithic metallic mirrors and other off-axis parabolic mirrors. The IXO/NGXO flight mirror assembly includes 60 mirror modules, each containing approximately 150 pairs of mirror segments.

Estimated TRL at beginning and end of contract: (Begin: 4 End: 6)

Technical Objectives and Work Plan

OptiPro will build a 6-axis UFF300 machine and deliver to MSFC at the end of the contract. Continued development of the Graphical User Interface for freeform shapes will be done. We will develop optimized finishing conditions for mandrel shapes, by looking at abrasive types and sizes, belt types, and Ultrawheel durometers. The pressure mapping system will be used to model UFF removal function for algorithm development. The raster grinding approach of the UFF will be optimized to minimize mid-spatial frequencies. Peter Blake at Goddard Space Flight Center had provided OptiPro with a letter of support for this phase II effort (See addendums at the end of the proposal). In it he requests that we try to process up to 4 mandrels that he is currently in possession of. Figure 6 shows one of these mandrels. We would propose that during the second year of this phase II effort we would work on correcting these mandrels for GSFC. The work would have the benefit of utilize the previous research efforts to obtain as good of a surface as possible. Work would plan to be performed on the NASA UFF 6-axis polishing machine at OptiPro.

NASA Applications

This technology could be used for cost effective fabrication of mirrors and other optical services for NASA programs such as LISA, WFIRST and IXO, now the Next Generation X-Ray Observatory (NGXO) technology development program, as well as Advanced Technology Large Aperture Space Telescope (ATLAST).

Non-NASA Applications

This work has a variety of Non-NASA applications including but not limited to conformal windows for defense applications, freeform glass shapes for advanced solar collectors, high precision molds, and aspheric optic production. We continue to find new ways to use this technology, and believe that more applications will be found as we further develop the technology.

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Any Questions?

NASA 2015 SBIR Subtopic:

S2.03 “Advanced Optical Systems”
S2.04 “Optical Manufacturing and Metrology”
E3.02 ”Adv Tech Telescope for Balloon Mission”

H. Philip Stahl, Ph.D.
Sub-Topic Manager

Disclaimer – Release Date was supposed to be Fri Nov 21

2015 NASA SBIR Solicitation was issued on Fri Nov 14

To view the Solicitation online, please visit: http://sbir.nasa.gov/.

Phase I submissions are due 1/28/15. Only questions requesting clarification of the proposal instructions and administrative matters can be answered. NASA cannot answer questions pertaining to the intent of the technical Topics and/or Subtopics. If a firm has more specific questions (regarding the applicability of their technology offerings under the Solicitation, for instance), you're encouraged to consult the Helpdesk, as well. To contact the Helpdesk, send an email to sbir@reisys.com or call (301) 937-0888.

Proposers seeking clarity regarding SBIR Select Subtopic descriptions may submit questions to NASA for a period of 10 business-days after the Solicitation opens. Questions must be submitted on-line via the NASA SBIR/STTR website (http://sbir.nasa.gov) using the "Question and Answer Form" located below each Subtopic description in the SBIR Select Solicitation.

Since Call is Public, I may discuss the contents (and only the contents) of Call.

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

Instructions for Proposers

When you visit: http://sbir.nasa.gov/:

S2.03 **Advanced Optical Systems and Fabrication/Testing/Control Technologies for EUV/Optical and IR Telescope** seeks solutions for 3 technical areas that are based on specific performance metrics (none of which may I discuss)

- 3.1 Optical Components and Systems for potential UV/Optical missions
- 3.2 Optical Components and Systems for potential Infrared/Far-IR missions
- 3.3 Fabrication, Test and Control of Advanced Optical Systems

Select: **Advanced Technology Telescope for Balloon and Sub-Orbital Missions** seeks solutions for technical area that are based on specific performance metric (none of which may I discuss).

- 3.1 Ultra-Stable 1-meter Class UVOIR Telescope
  - 3.1.1 Exoplanet Mission Telescope
  - 3.1.2 Planetary Mission Telescope
- 3.3 Infrared Interferometry Mission Telescope
- 3.4 Balloon Gondola with Precision Pointing System

S2.03:

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

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

Subtopic solicits solutions in the following areas:

- **Components and Systems for potential EUV, UV/O & IR missions**
- **Technology to fabricate, test and control potential UUV, UV/O & IR telescopes**

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

Ideal Phase 1 deliverable would be a precision optical system of at least 0.25 meters, or a relevant sub-component of a system, or a prototype demonstration of a fabrication, test or control technology. Phase 1 mirror system or component deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials.

Successful proposals will demonstrate an ability to manufacture, test and control ultra-low-cost optical systems that can meet flight 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.

Technical Need

To accomplish NASA's high-priority science requires low-cost, ultra-stable, large-aperture, normal incidence mirrors with low mass-to-collecting area ratios.

Specifically needed for potential UVO missions are normal incidence 4-meter (or larger) diameter 5 nm rms surface mirrors; and, active/passive align/control of normal-incidence imaging systems to achieve < 500 nm diffraction limit (< 40 nm rms wavefront error, WFE) performance. Additionally, recent analysis indicates that an Exoplanet mission, using an internal coronagraph, requires total telescope wavefront stability of less than 10 pico-meters per 10 minutes.

Specifically needed for potential IR/Far-IR missions are normal incidence 12-meter (or larger) diameter mirrors with cryo-deformations < 100 nm rms.

Also needed is ability to fully characterize surface errors and predict optical performance.

Metrics

In all cases, the most important metric for an advanced optical system (after performance) is affordability or areal cost (cost per square meter of collecting aperture). Current normal incidence space mirrors cost $4 million to $6 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 5 to 50 times, to less than $1M to $100K/m2.

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

- Areal Cost — < $500k/m2 — (for UV/Optical
- Areal Cost — < $100k/m2 — (for Infrared)
- Monolithic: — 1 to 4 meters
- Segmented: — > 4 meters — (total aperture)
- Wavefront Figure — < 5 nm rms — (for UV/Optical)
- Cryo-deformation — < 100 nm rms — (for Infrared)
- Slope — < 0.1 micro-radian — (for EUV)
- Thermally Stable — < 10 pm/10 min — (for Coronagraphy)
- Dynamic Stability — < 10 pm — (for Coronagraphy)
- Actuator Resolution — < 1 nm rms — (for UV/Optical)

Optical Components/Systems for potential UV/O missions

Potential UV/Optical missions require 4 to 8 or 16 meter monolithic or segmented primary mirrors with < 10 nm rms surface figures and < 10 pm per 10 min stabilty. 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. 60 kg/m2 for a 10 m fairing SLS). Regarding areal cost, it is necessary 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**
- **Mechanisms and sensors to align segmented mirrors to < 1 nm rms precisions**
- **Thermal control to reduce wavefront stability to < 10 pm rms per 10 min**
- **Vibration isolation (> 140 db) to reduce phasing error to < 10 pm rms**

Also needed is ability to fully characterize surface errors and predict optical performance via integrated opto-mechanical modeling.

Optical Components/Systems for potential IR/Far-IR missions

Potential Infrared and Far-IR missions require 12 m to 16 m to 24 meter class segmented primary mirrors with ~ 1 μm rms surface figures which operates at < 10 K.

There are two primary challenges for such a mirror system:

- **Areal Cost of < $100K per m2.**
- **Cryogenic Figure Distortion < 100 nm rms**

Fabricate, Test & Control Advanced Optical Systems

While Sections 3.1 and 3.2 detail the capabilities need to enable potential future UVO and IR missions, it is important to note that this capability is made possible by the technology to fabricate, test and control optical systems. Therefore, this sub-topic also encourages proposals to develop such technology which will make a significant advance of a measurable metric.

Select:

Advanced Technology Telescope for Balloon and Sub-Orbital Missions

Advanced Technology Telescope for Balloon/Sub-Orbital Missions

This sub-topics purpose is to mature component level technologies (TRL4) to system level technologies (TRL6) by using them to manufacture complete telescope systems which will fly on a high-altitude balloon or sub-orbital rocket mission.

Examples of desired advances include, but are not limited to:

- Reduce the areal cost of telescope by 2X to 4X such that larger collecting areas can be produced for the same cost or current collecting areas can be produced for half the cost.
- Reduce the areal density of telescopes by 2X to 4X such that the same aperture telescopes have half the mass of current state of art telescope (less mass enables longer duration flights) for no increase in cost.
- Improve thermal/mechanical wavefront stability and/or pointing stability by 2X to 10X.

Maturation will be demonstrated by building one or more complete telescope assemblies to be flown on potential long duration balloon or sub-orbital rocket experiments.

While proposals will be accepted for potential missions in any spectral range from x-rays to far-infrared/sub-millimeter, this year's sub-topic is soliciting proposal specifically for:

- **Ultra-Stable 1-meter Class UVOIR Telescope**
  - **Exoplanet Mission Telescope**
  - **Planetary Mission Telescope**
- **Infrared Interferometry Mission Telescope**
- **Balloon Gondola with Precision Pointing System**

Instructions to Proposers

Successful proposals shall provide a credible plan to deliver for the allocated budget a fully assembled and tested telescope assembly which can be integrated into a potential balloon or sub-orbital mission to meet a high-priority NASA science objective. Successful proposals will demonstrate an understanding of how the engineering specifications of their telescope meet the performance requirements and operational constraints of a potential balloon or sub-orbital rocket science mission.

Phase-1 delivery shall be 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.

Please note: all offerors are highly encouraged to team with a potential user for their telescope and include that individual in their proposal as a science mission co-investigator.

Technical Challenge

- Scientists continue to develop new, more sophisticated experiments for flight on high-altitude balloons and sub-orbital rockets.
- These require large, light weight, low cost optics, with well-behaved properties over a wide temperature range.
- There are currently several options, including glass, aluminum, and carbon fiber. Each of these has both advantages and disadvantages.
- All of the above have been used for balloon experiments, but increasing aperture sizes, and the need for multiple large optics for interferometers, is driving up the total cost of optics, such that ~10-20% of a new balloon budget can be spent on optics.
- Thus, new low cost methods or materials are needed.

Ultra-Stable 1m Class UVOIR Telescopes

1-m class balloon-borne telescopes have flown successfully, however, the cost of such telescopes can exceed $6M, and the weight of these telescopes limits the scientific payload and duration of the balloon mission.

A 4X reduction in cost and mass would enable missions which today are not feasible.

3.1.1 Exoplanet Mission Telescope

A potential exoplanet mission seeks a 1-m class wide-field telescope with diffraction-limited performance in the visible and a field of view > 0.5 degree. The telescope will operate over a temperature range of +10 to -70 C at an altitude of 35 km. It must survive temperatures as low as -80 C during ascent. The telescope should weigh less than 150 kg and is required to maintain diffraction-limited performance over: a) the entire temperature range, b) pitch range from 25 to 55 degrees elevation, c) azimuth range of 0 to 360 degrees, and d) roll range of –10 to +10 degrees. The telescope will be used in conjunction with an existing high-performance pointing stabilization system.

3.1.2 Planetary Mission Telescope

A potential planetary balloon mission requires an optical telescope system with at least 1-meter aperture for UV, visible, near- and mid-IR imaging and multi/hyperspectral imaging.

Infrared Interferometry Mission Telescope

A balloon-borne interferometry mission requires 0.5 meter class telescopes with siderostat steering flat mirror. There are several technologies which can be used for production of mirrors for balloon projects (aluminum, carbon fiber, glass, etc.), but they are high mass and high cost.

Balloon Gondola with Precision Pointing System

A potential exoplanet mission seeks a gondola that can interface with a stratospheric balloon (such as one provided by CSBF).

The gondola shall be able to operate for at least 24hrs at a float altitude of at least 35Km; and 3-5hrs during the ascent from ground to altitude.

It must be able to point a 1 m class telescope (including back end optics and with a mass of 150kg) at a specific target and stabilize it along its three axes to 2 arc-seconds or better on each axis (1 sigma). The pointing accuracy shall be 1/2 deg or better during the day and 1 arc minute or better during the night (1 sigma). The required pitch range of motion is 25 to 55 deg elevation, the azimuth range of is 0 to 360 deg, and the roll range of motion is –10 to +10 deg.

The gondola maximum weight shall be 700 kg or less.

Any Questions?