NASA Small Business Innovative Research (SBIR) Subtopic S2.04

“X-Ray Mirror Systems Technology, Coating Technology: X-Ray, Ultraviolet (UV), Optical and Infrared (IR), and Free-Form Optics”

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Outline

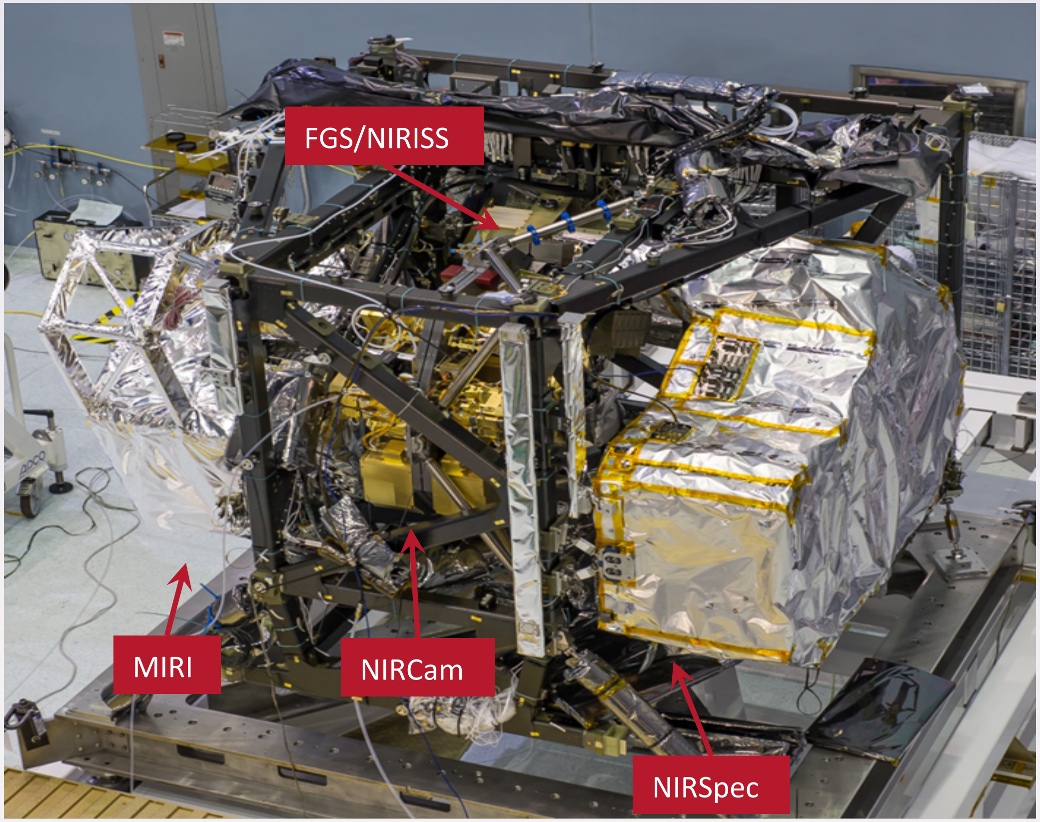
- Overview of NASA / GSFC Optics Branch

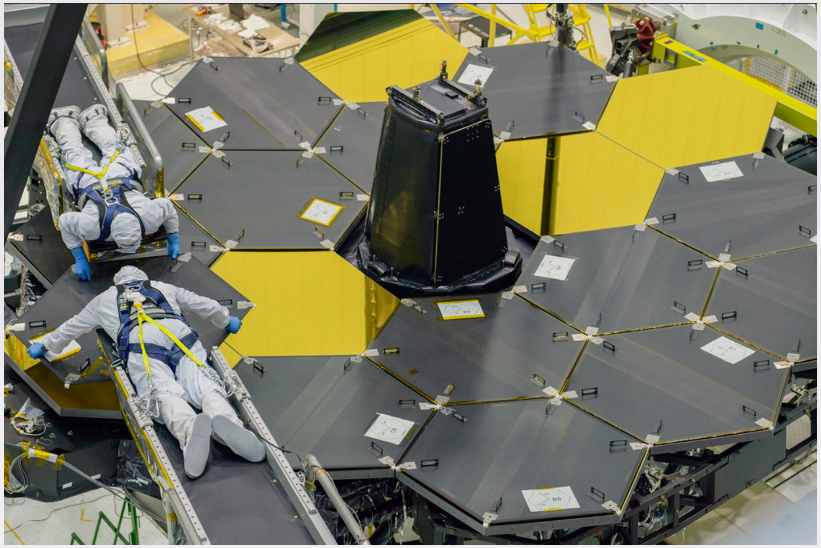
- SBIR Topic: S2. Advanced Telescope Systems
- SBIR Subtopic: S2.04
    - X-Ray Mirror Systems Technology
    - Optical Coatings from X-Ray, Extreme UV (EUV) to Optical and IR
    - Free-Form Optics Design, Manufacturing and Metrology

Goddard Optics Branch, Code 551

- Alignment, Integration & Test
- Components
- Design
- Fabrication
- Wavefront Sensing & Control

Alignment, Integration & Test





Optical Telescope Element (OTE) build-up at NASA Goddard (Harris Corp. & GSFC)

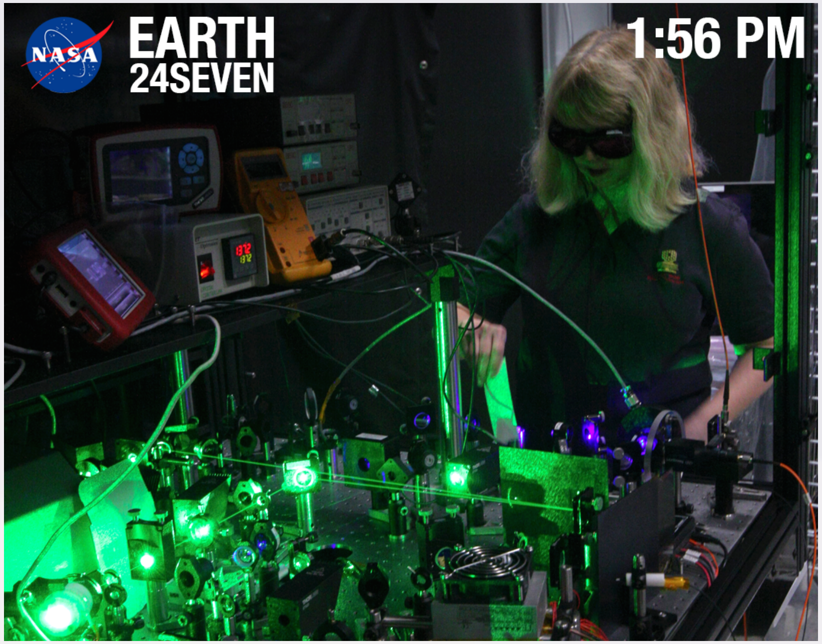
Full integration of science instruments into the Integrated Science Instrument Module (ISIM) at GSFC

Alignment, Integration & Test (Continue)

Optical Telescope Element (OTE) at NASA Goddard (Harris Corp. & GSFC)

Science payload integrated to the telescope at NASA Goddard (Harris Corp. & GSFC)

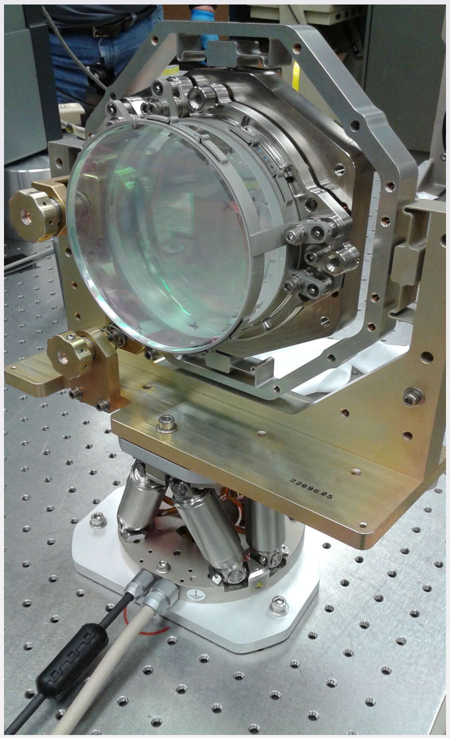
Components



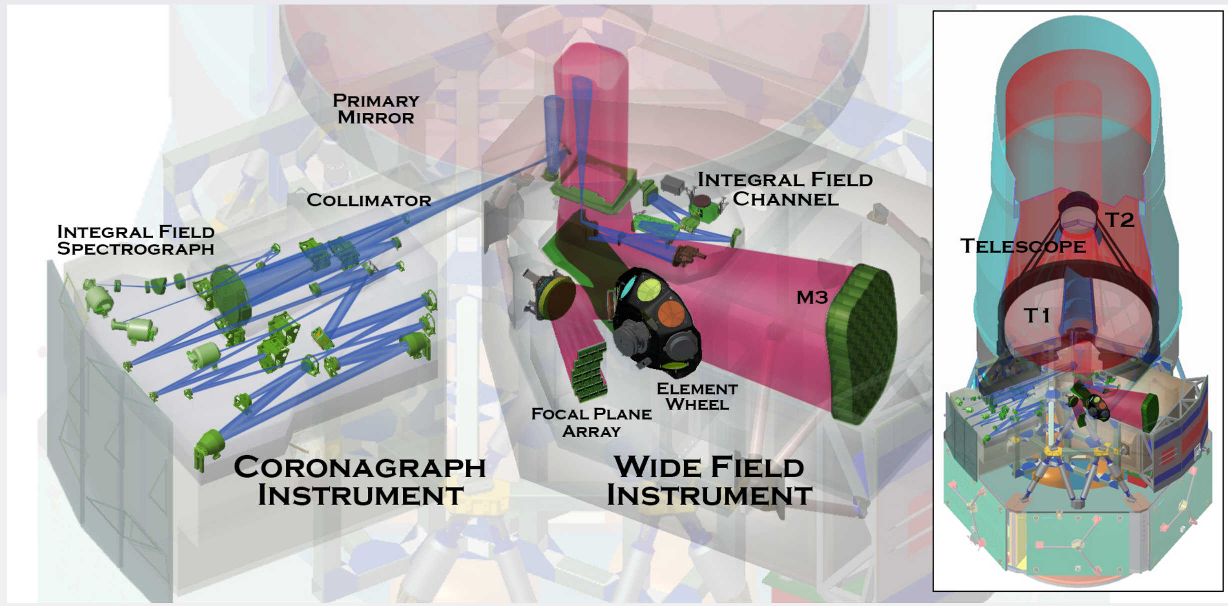
Goddard Laser for Absolute Measurement of Radiance (GLAMR) is required for improving instrument model parameterization

Goddard integrating sphere to compare three different field instruments used to calibrate data from satellites such as Landsat

Design



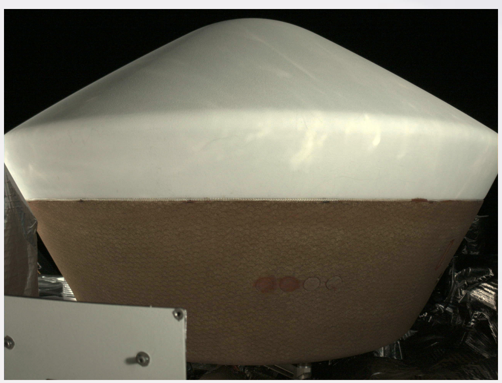
3 element grating prism prototype for (WFIRST)



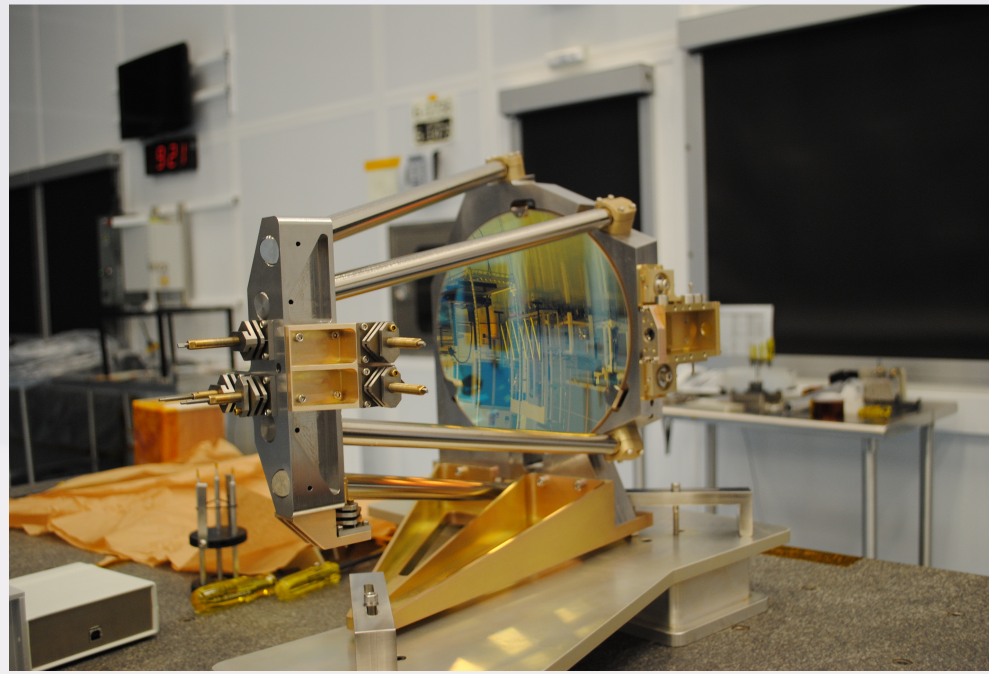
Wide Field Infrared Space Telescope (WFIRST) payload consists of Wide-Field Instrument (right) containing Wide-Field Channel and Integral Field Channel, and Coronagraph Instrument (left).

Design (Continued)

Origins-Spectral Interpretation-Resource Identification Security--Regolith Explorer (OSIRIS-Rex) Visible and Near-IR Spectrometer (OVIRS) mirror characterization

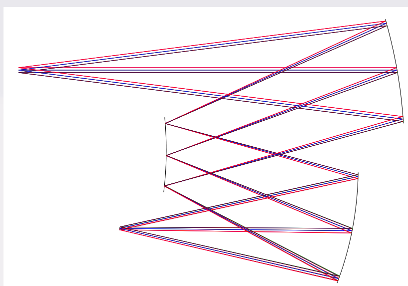
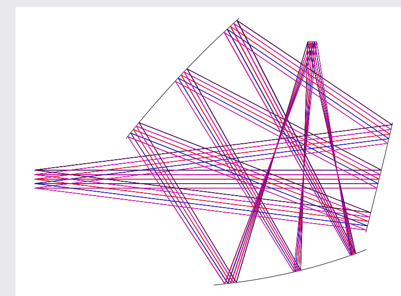
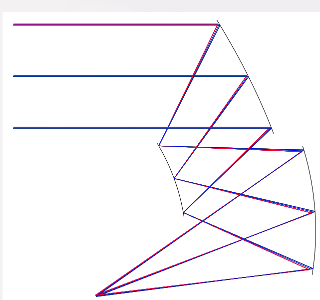
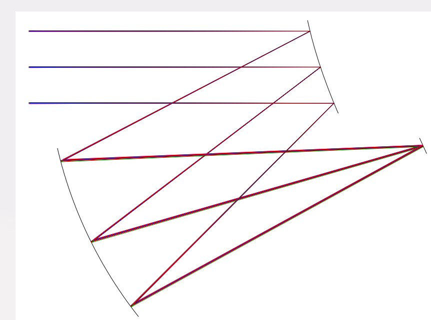


StowCam First Light, September 22, 2016

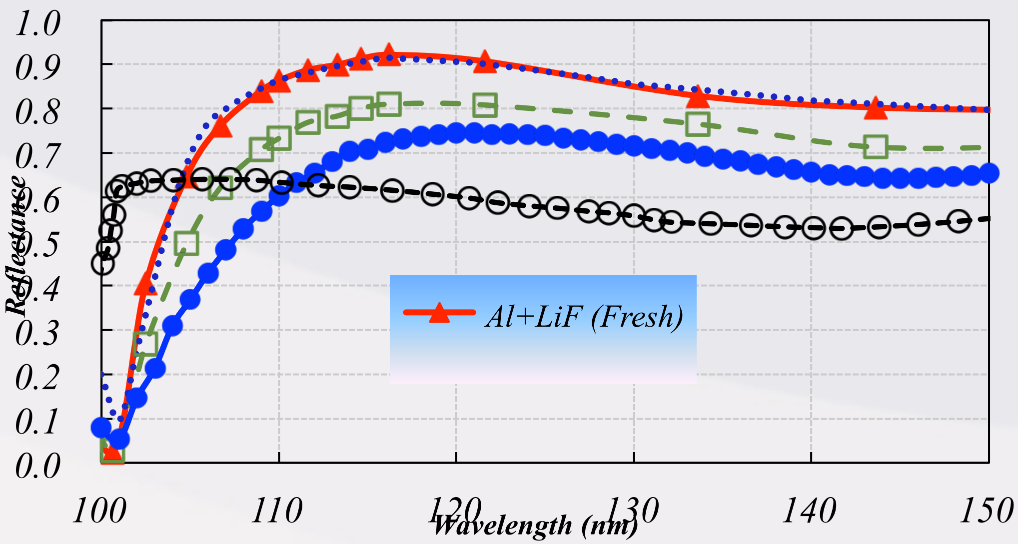


Evolved Laser Interferometer Space Antenna (eLISA) first generation off-axis telescope tested and validated for stray light. Currently, 2^{nd} generation telescope is being procured to test thermal stability

Freeform optics enable:

Traditional		***Freeform***
 Traditional Conic Relay	• Volume Reduction • Wider FOV • Better Image Quality • Faster systems	 Freeform Optics Relay
 Asphere Telescope	• Remove Mirrors	 Freeform Telescope

Fabrication



Coating recipe: Al (43nm, ambient)+LiF(8nm, ambient) +LiF(16.4nm, 250°C); R_{ave}(100-150nm): 59% (FUSE) 75% (LiF) LiF has to be deposited to optimize the 100-121 nm spectral range

Acquisition of new FUV spectrophotometer (McPherson 225) With spectral range of 90-200 nm. Windowless H2 purged source

Wavefront Sensing and Control

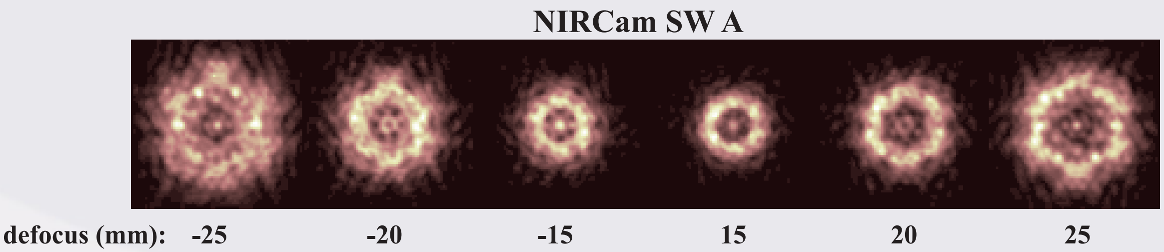
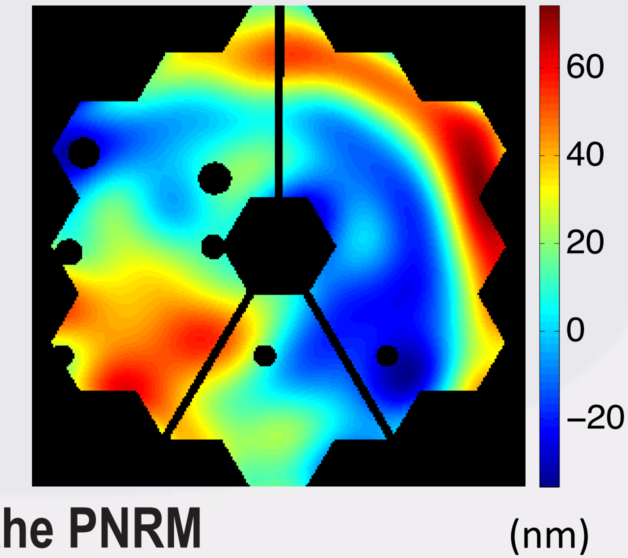
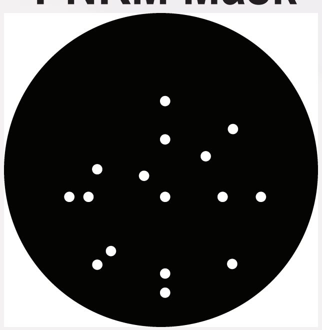


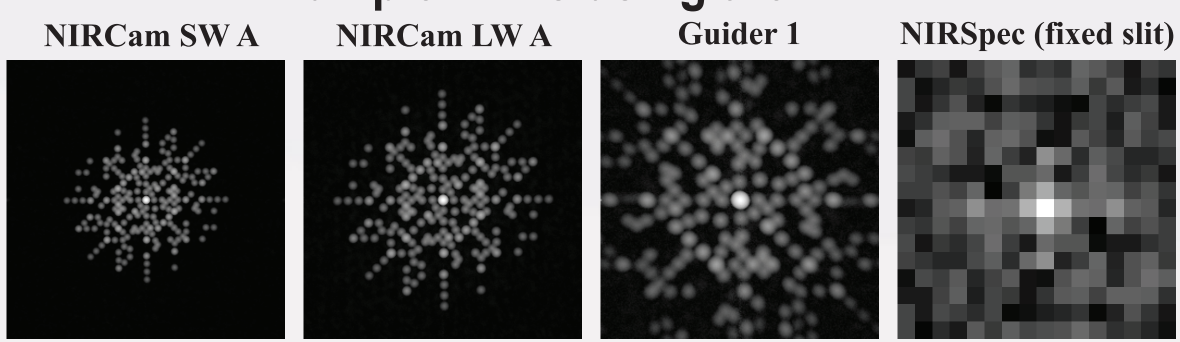
Image-Based Wavefront Sensing (sample Input and Results from ISIM CV3, of a field point in Near Infrared Camera (NIRCam-A) Short Wavelength SW



PNRM Mask



Example MTFs using the PNRM



Use of Pseudo-Nonredundant Mask (with ISIM CV3 test data)

SBIR Subtopic S2.04

- **X-Ray Mirror Systems and Components Technology**
- **Optical Coatings from X-Ray, EUV to Optical and IR**
- **Free-Form Optics Manufacturing and Metrology**

X-Ray Mirror Systems Technology

- Optical Components, systems, stray-light suppression for X-Ray missions
- Light-weight, low-cost, ultra-stable mirrors for large X-Ray observatories
- Stray-light suppression systems (baffles) for large advanced X-Ray observatories
- **Horizon:** 1 to 3 years, mature the technology in advance of decadal 2020 proposal call
- **State of Art:** costly and time consuming to produce X-Ray mirrors. Require improvement to about 10 arc-seconds of angular resolution
- The current stray light suppression is bulky and ineffective for wide-field of view telescopes. We seek significant reduction in both expense and time
- **Importance:** Very-high value, critical need where no feasible competitor and only government is the major player in this technology

Subtopic:	(S2.04, X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics)
Manager:	(Ron Shiri / GSFC, Kunjithapatham Balasubramanian / JPL, Philip Stahl / MSFC, Mikhail Gubarev / MSFC)
Center(s):	(GSFC, JPL, MSFC)

Optical Components, Systems, and Stray Light Suppression for X-Ray Missions - Light-weight, low-cost, ultra-stable mirrors for large X-Ray observatory - Stray light suppression systems (baffles) for large advanced X-Ray observatories - Ultra-stable low-cost light-weight X-Ray telescope using grazing-incidence optics for high altitude balloon-borne and rocket-borne mission	**Science Traceability**	The 2010 National Academy Decadal Report specifically identifies optical components and the ability to manufacture and perform precise metrology on them needed to enable several different future missions (NGXO) The NRC NASA Technology Roadmap Assessment ranked advanced mirror technology for new x-ray telescopes as the #1 Object C technology requiring NASA investment.
	Need Horizon	1 to 3 years, Need to mature technology in advance of proposal Decadal 2020
	State of Art	It's very costly and time consuming to produce X-Ray mirrors. Most of SOA requiring improvement is ~ 10 arc-seconds angular resolution. SOA stray light suppression is balky and ineffective for wide-field of view telescopes. We seek significant reduction in both expense and time. Reduce the areal cost of telescope by 2X such that the larger collecting area can be produced for the same cost or half the cost.
	Importance	Very high – Critical need, no feasible competitors. X-Ray mirror technology is inherently in government. There is no commercial application.

Coating Technology: X-Ray, Extreme UV to Visible and IR

- Metrics for X-Ray:
  - Multilayer high-reflectance coatings for hard X-Ray mirrors
  - Multilayer depth gradient coatings for 5 to 80 keV with high broadband reflectivity
  - Zero-net stress coating of iridium or other high reflectance elements on thin substrates (< 0.5 mm)
- Metric for EUV:
  - Reflectivity greater than 90% from 6 nm to 200 nm and depositable onto < 2 meter mirror substrate
- Metric for UVOIR:
  - Broadband reflectivity greater than 60% and uniform polarization from 90 nm to 2500 nm and depositable onto 2, 4, and 8 meter mirror substrate
- Non-Stationary Optical Coating:
  - Used in both reflection transmission that vary with location on the optical surface. The variation refers to ratio of reflectivity transmissivity, optical field amplitude , phase, and polarization change.
  - The optical surface range of diameter is 0.5 cm to 6 cm that could either be flat, conic or free-form

Coating Technology: X-Ray, Extreme UV to Visible and IR (Continued)

- **Horizon:** 1 to 3 years, mature the technology in advance of decadal 2020 proposal call
- **State of Art:** costly and time consuming to produce X-Ray mirrors. Require improvement to about 10 arc-seconds of angular resolution
- The current stray light suppression is balky and ineffective for wide-field of view telescopes. We seek significant reduction in both expense and time
- **Importance:** Very-high value, critical need where no feasible competitor and only government is the major player in this technology

Mirror Technology Days 2016

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Optical Coatings for X-Ray, EUV, LUV, UV, Visible, and IR Telescopes

- Meet low temperature operation requirement

Metrics for X-Ray:

- Multilayer high-reflectance coatings for hard X-Ray mirrors
- Multilayer Depth Gradient Coatings for 5 to 80 keV with high broadband reflectivity.
  Zero-net-stress coating of iridium or other high reflectance elements on thin substrates (< 0.5 mm)

Metrics for EUV:

- Meet temperature requirement, 35 Kelvin
- Reflectivity > 90% from 6 nm to 90 nm onto a < 2 meter mirror substrate.

Metrics for LUVOIR:

- Meet temperature requirement, 35 Kelvin
- Broadband Reflectivity > 70% from 90nm-120nm (LUV) and > 90% from 120nm-2.5um (VUV/Visible/IR).Reflectivity Non-uniformity < 1% 90nm-2.5um
- Induced polarization aberration < 1% 400nm-2.5um depositable onto a 1-8m substrate

Non-stationary Optical Coatings:

- Used in reflection & transmission that vary with location on the optical surface.

Carbon Nanotube (CNT) Coatings:

- Broadband Visible to NIR, Reflectivity of 0.1% or less, adhere to the multi-layer dielectric or protected metal coating

Science Traceability	Astrophysics Decadal specifically calls for optical coating technology investment for: Future UV/Optical and Exoplanet missions (HabEX or LUVOIR) Heliophysics 2009 Roadmap identifies optical coating technology investments for: Origins of Near-Earth Plasma (ONEP); Ion-Neutral Coupling in the Atmosphere (INCA); Dynamic Geospace Coupling (DGC); Fine-scale Advanced Coronal Transition-Region Spectrograph (FACTS); Reconnection and Micro-scale (RAM); & Solar-C Nulling polarimetry/coronagraph for exoplanet imaging and characterization, dust and debris disks, extra-galactic studies and relativistic and non-relativistic jet studies
Need Horizon	1 to 3 years Affordable high-performance optical component system technology needs to achieve TRL-4-5 by approximately 2018 to support the 2020 Astrophysics Decadal process. Heliophysics missions need mirror technology sooner. Historically, it takes 10 years to mature mirror technology from TRL-3 to 6. To achieve these objectives requires sustained systematic investment. 1 to 5 years for CNT coating applications.
State of Art	Current X-Ray is defined by NuSTAR Current EV is defined by Heliophysics (80% reflectivity from 60 to 200 nm) Current UVOIR is defined by Hubble. MgFl2 over-coated Aluminum on a 2.4 meter mirror. This coating has birefringence concerns and a marginally acceptable reflectivity between 100 and 200 nm.
Importance	Very High – optical technology is mission enabling. The technical capabilities of the optical systems will determine performance and science return.

Free-Form Optics: Design, Manufacturing, Metrology

- Freeform Optical Surfaces
  - 0.5 cm to 6 cm diameter optical surfaces (mirrors) with free form optical prescriptions with surface tolerances about 1-2 nm rms
  - Freeform refers to either 2^{nd} order conic prescription with higher order surface polished onto it or without underlying conic prescription but such that is no steps in the surface.
  - The optics with underlying conic prescription would need to be in F/# range of F/2 or F/20
- Metrology of Freeform Optics
  - Component metrology is difficult because of very large departure from the planar or spherical shapes that can be accommodated by conventional interferometric testing
  - New Methods such as multibeam low-coherence optical probe and slope sensitive optical probe are highly desirable
- **Horizon:** 3 to 5 years
- **State of Art:** Never been done before
- **Importance:** Highly desirable, allows efficient, small package, and lower cost that expands operational temperature range in un-obscured system. It allows coronagraphic nulling without shearing and increases the useful science field-of-view

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Free-Form Optical Surfaces

- 0.5 cm to 6 cm diameter optical surfaces (mirrors) with free form optical prescriptions with surface tolerances are 1-2 nm rms.
- The Optics with large field of view and fast F/#s. Optical freeform surfaces enabling additional degrees of freedom to reduce volume and eliminate traditional design constraints on the surface.
- Metrology of 'freeform' optical components is difficult. New methods such as multibeam low-coherence optical probe and slope sensitive optical probe are highly desirable

Science Traceability	NASA missions with alternative low-cost science and small size payload are increasing. However, the traditional interferometric testing as a means of metrology are unsuited to freeform optical surfaces due to changing curvature and lack of symmetry. Metrology techniques for large fields of view and fast F/#s in small size instruments is highly desirable specifically if they could enable cost-effective manufacturing of these surfaces. (CubeSat, SmallSat, NanoSat, various coronagraphic instruments)
Need Horizon	3 to 5 years
State of Art	Early stages of development. Improve optical surfaces with large field of view and fast F/#s.
Importance	High – Highly desirable, allows efficient, small package, and lower cost that expands operational temperature range in un-obscured system. Can allow new coronagraphic instruments that adhere to high-contrast imaging while maintains high throughput.

Conclusion

- GSFC has a robust and productive SBIR program in the Optics, with high quality proposals being submitted every year, leading to advances in key Optics Technologies. Companies with successful SBIR efforts have submitted high quality New Technology Reports (NTRs)
- Focus areas,
  - X-Ray Optical Systems, Mirrors, Coating, and Components
  - Optical Coating from X-Ray to UV + Optical + IR
  - Freeform Optics Design, Development, and Metrology