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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Participating Managers from MSFC and JPL

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Outline

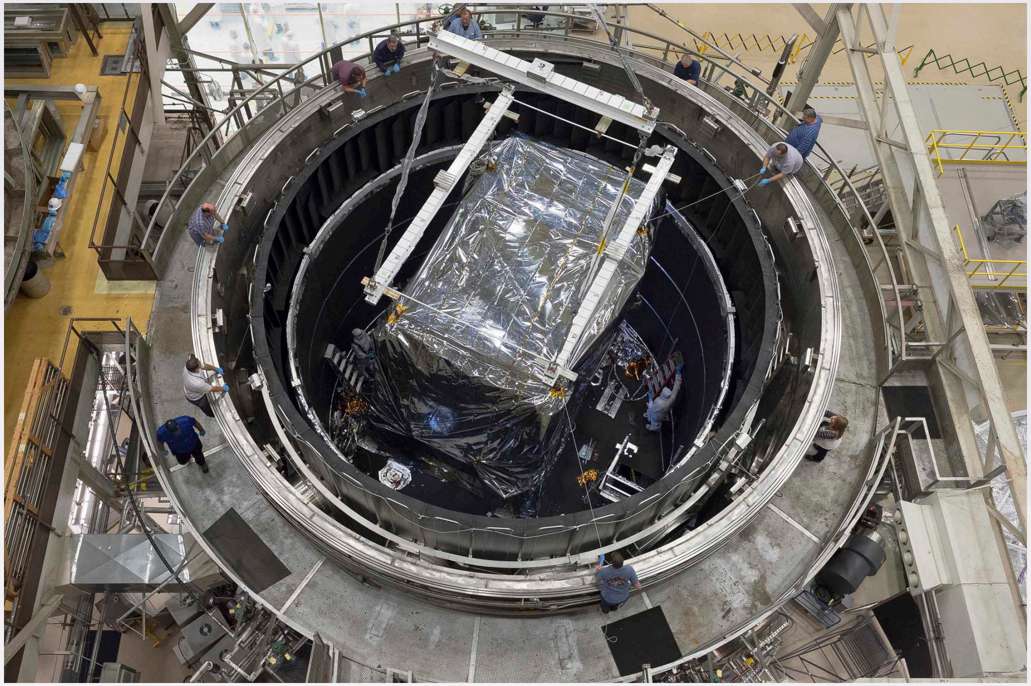
- Overview of NASA / GSFC Optics Branch

- 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

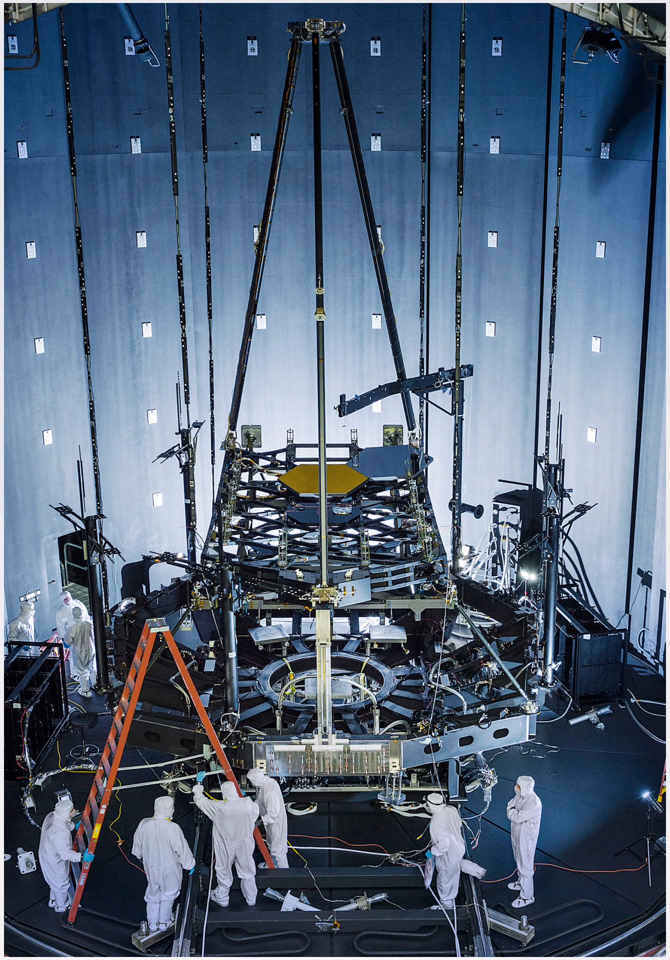
Goddard Optics Branch, Code 551

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

Alignment, Integration & Test

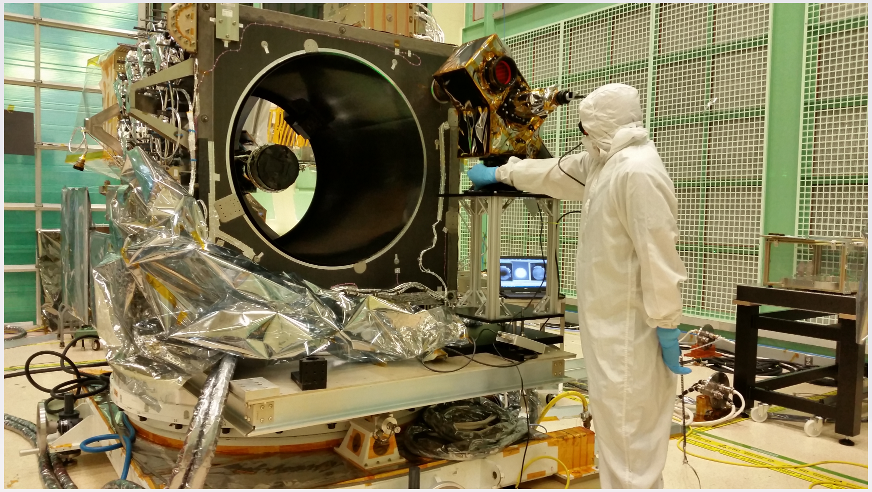


James Webb Space Telescope (JWST) Integrated Science Instrument Module (ISIM) lowered into the thermal vacuum chamber at Goddard Space Flight Center for the final cryogenic test (CV3)

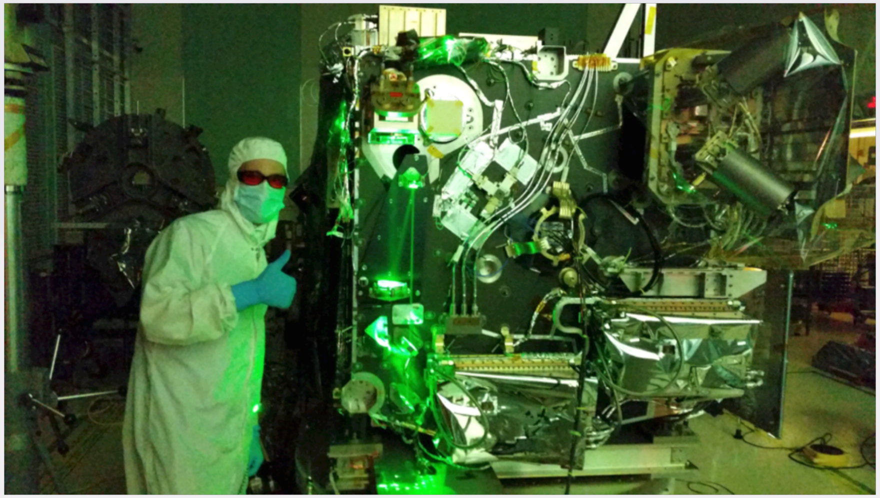


Pathfinder pushed into the Chamber-A at Johnson Space Center in Houston for Optical Ground System Equipment (OGSE2)

Alignment, Integration & Test (Continue)

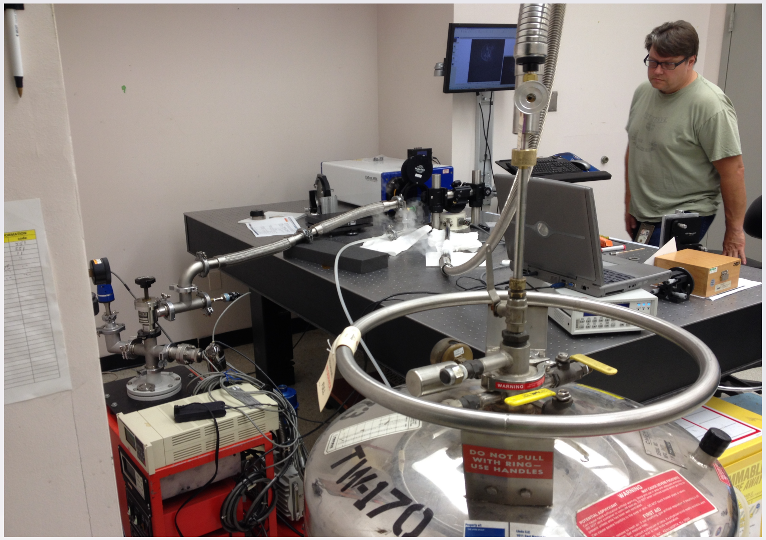


Ambient Testing of Advanced Technology Large-Aperture Space Telescope (ATLAST) Instrument Reflector Telescope Assembly

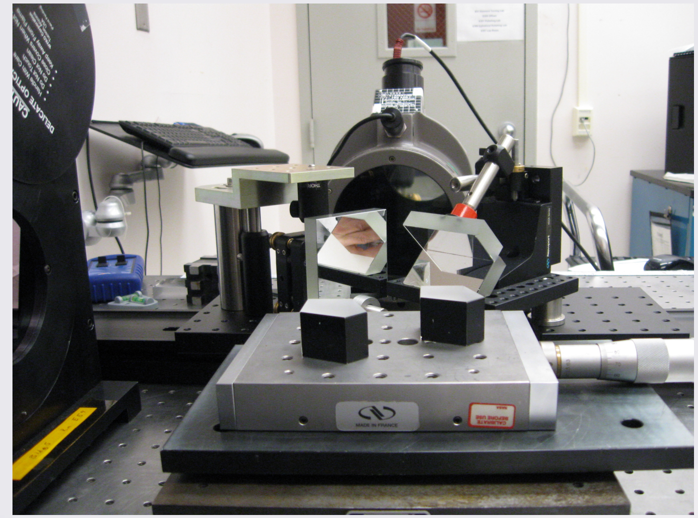


Advanced Topographical Laser Altimeter (ATLAS) Instrument Optical Bench with Flight Laser Illuminating Transmitter system beam path

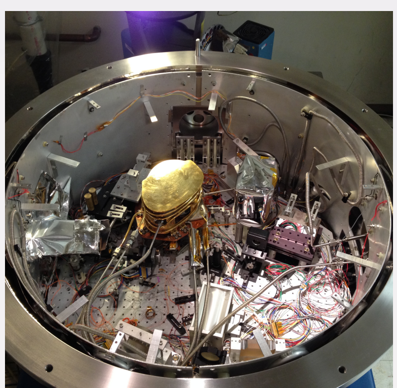
Components



Etalon reflector flatness testing using interferometry at cryogenic temperature



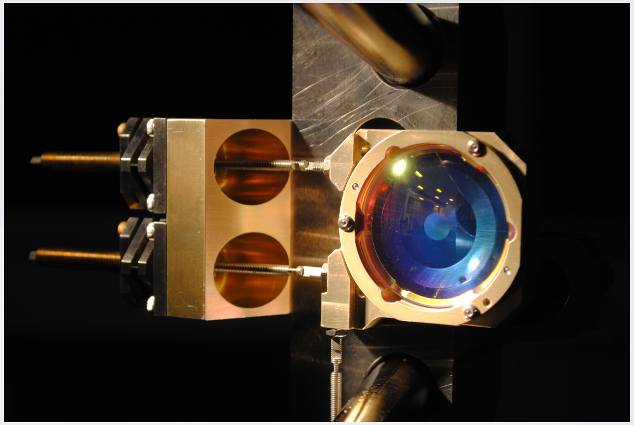
2-Axis autocollimator used to measure mirror deviation



Cryogenic High Accuracy Refraction Measuring System (CHARMS) facility to characterize material properties of prismatic samples for Transiting Exoplanet Survey Satellite (TESS) program

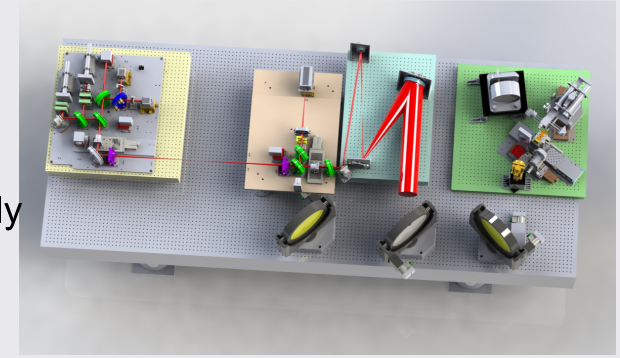
Lateral Transfer Retro-Reflector (LTR)

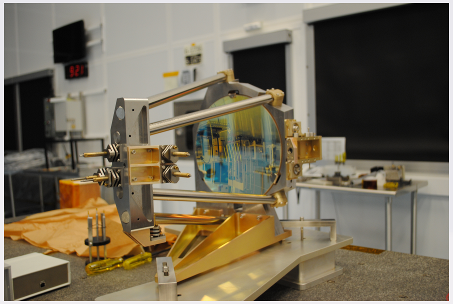
Design



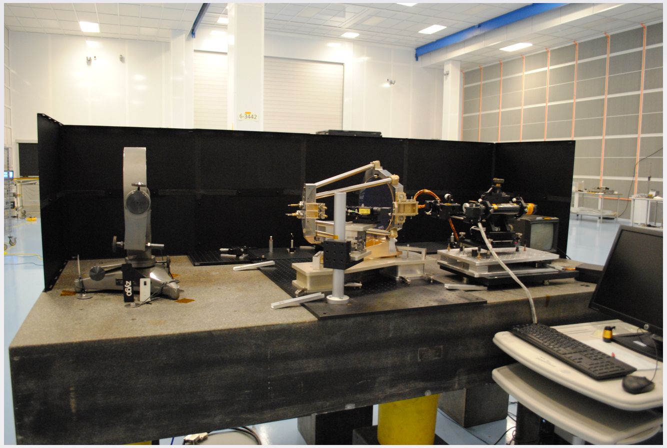
Close-up of the secondary mirror and adjustable mirror for the Evolved Laser Interferometer Space Antenna (eLISA) Prototype telescope. The design is an optimized Cassegrain with a Schwarzschild collimator/projector

Laser Communication Relay Demonstration (LCRD) optical assembly





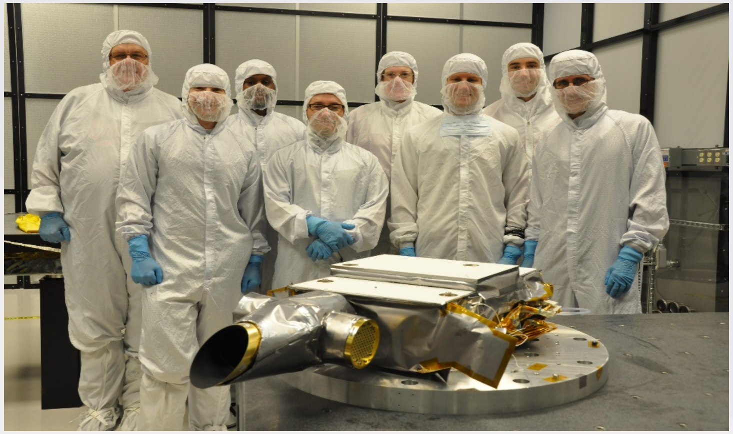
Primary mirror of the eLISA Prototype telescope with adjustable mirror mount for the secondary mirror



Optical test setup for eLISA Prototype telescope showing a double-pass test configuration with a Laser Unequal Path Interferometer (LUPI) on the right putting light into the small-beam entrance of the telescope

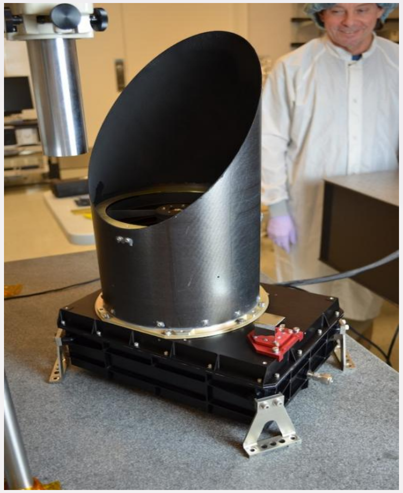
Design (Continued)

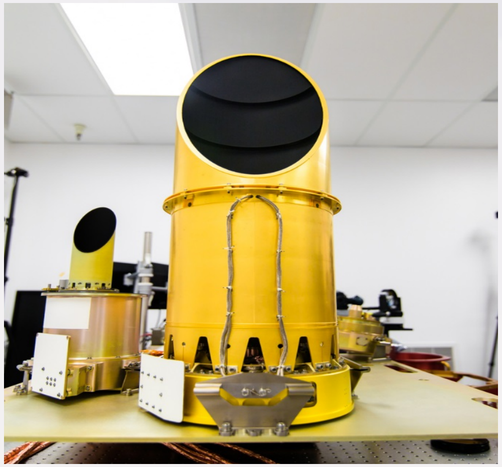
OSIRIS-REx Optical Instruments Delivered



Origins-Spectral Interpretation-Resource Identification Security--Regolith Explorer (OSIRIS-Rex) Visible and Near-IR Spectrometer (OVIRS) mirror characterization, completed at GSFC, June 2015

OSIRIS-REx Camera Suite (OCAMS) consisting of the PolyCam, MapCam and SamCam delivered June 2015





OSIRIS-REx Thermal Emission Spectrometer (OTES) delivered June 2015

OSIRIS-REx Navigation Cameras (NavCams) delivered July 2015

Design (Continued)

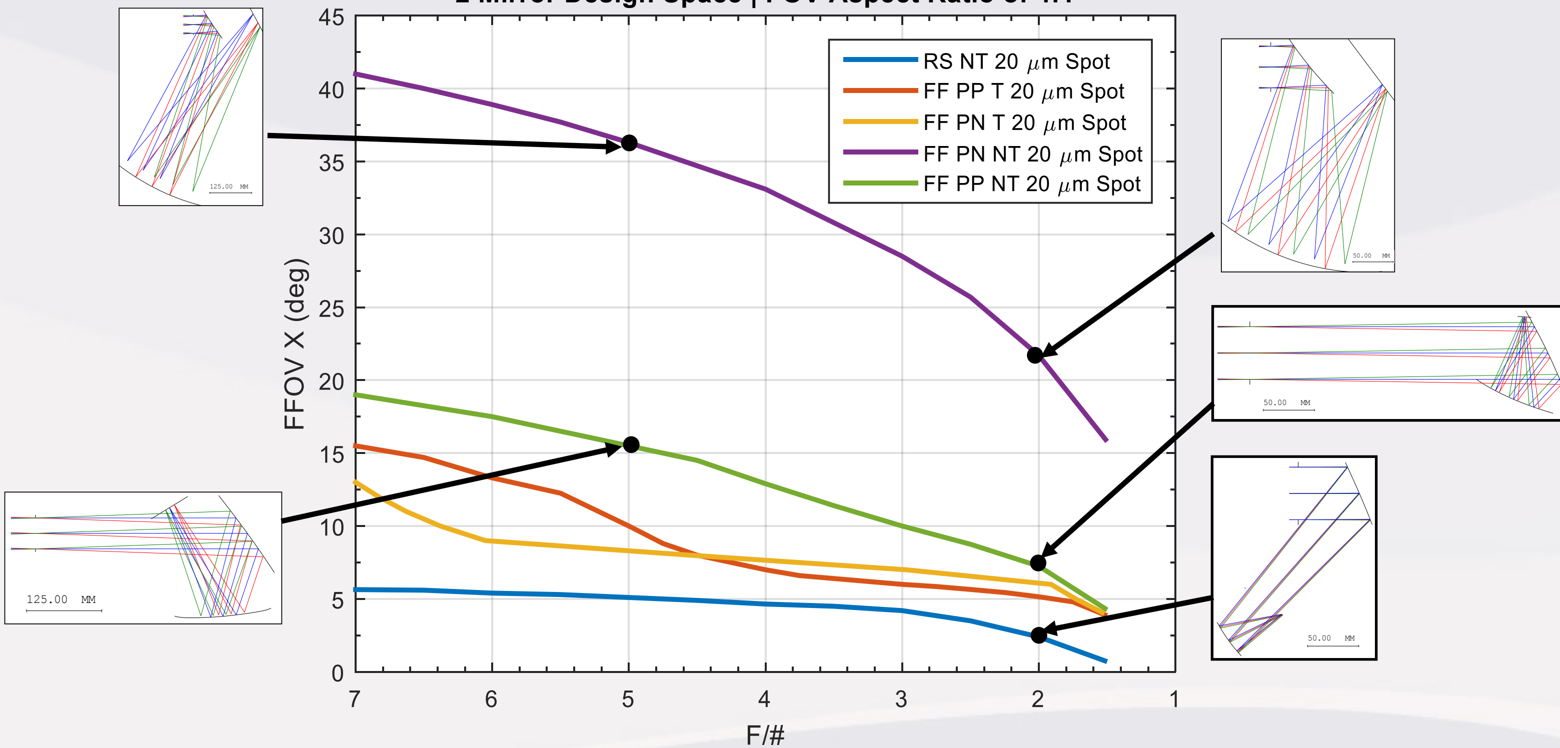
Freeform Design Space

- RS: Rotationally Symmetric
- FF: Freeform
- NT: Non-telecentric
- FFOV: Full Field of View

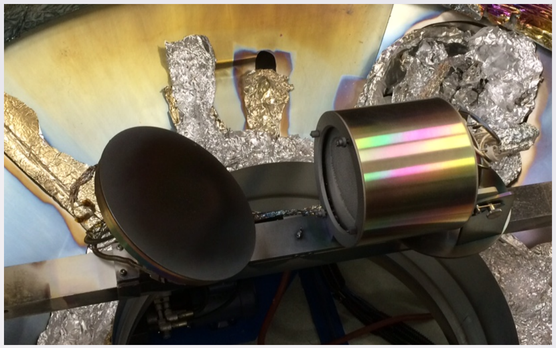
Design Comparison FOV vs. F/#

- T: Telecentric
- PN: Positive/Negative Tilt
- PP: Positive/Positive Tilt

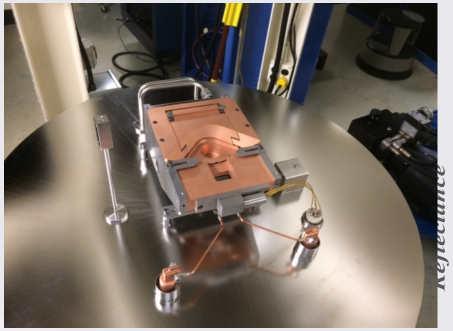
2 Mirror Design Space | FOV Aspect Ratio of 4:1



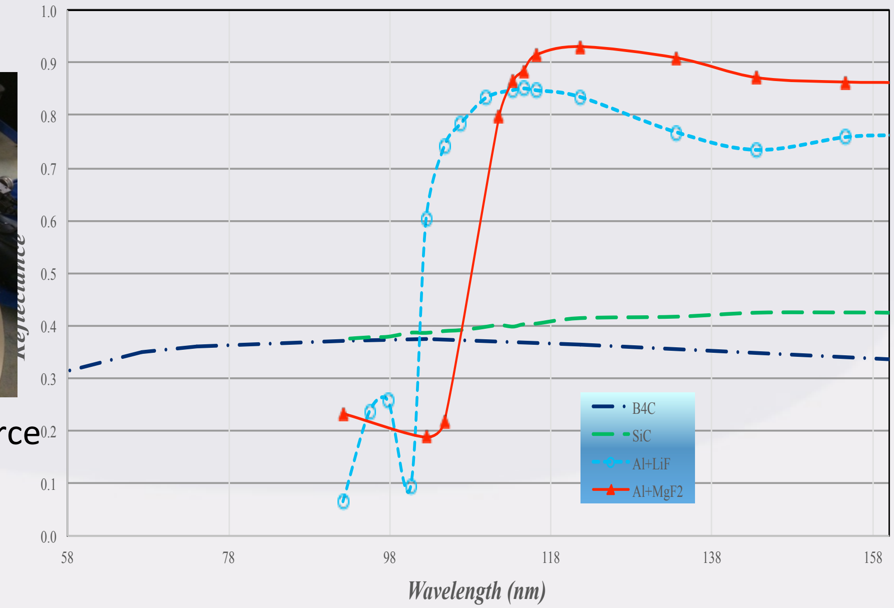
Fabrication



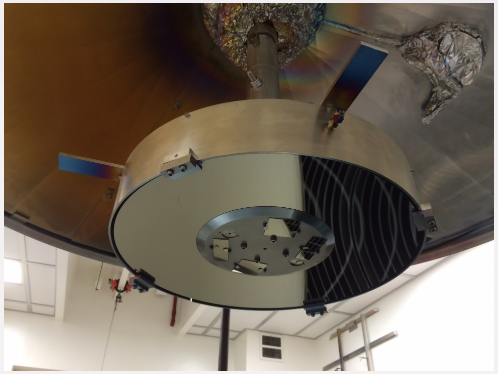
Ion Beam Sputtering Deposition Setup



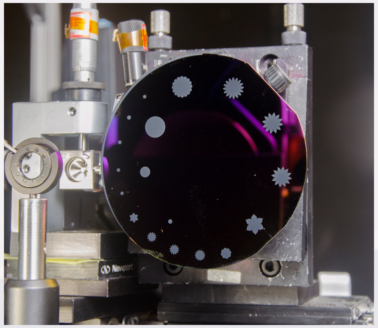
E Beam Deposition Source



Reflectance plot showing state of the art material for extreme ultraviolet to far ultraviolet

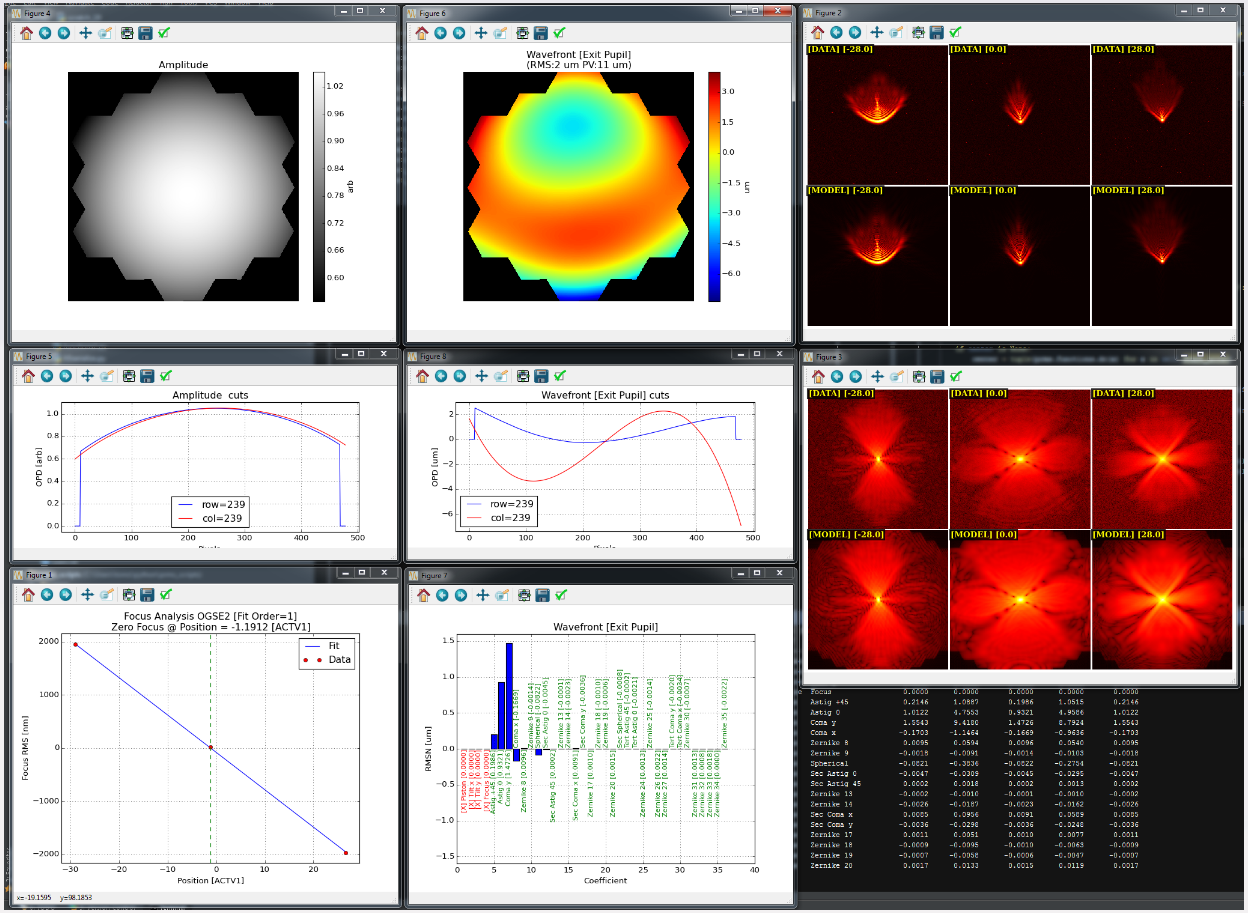


UHV chamber top Cover with recently aluminum and silicon carbide coated mirror substrate.



Carbon nanotube (CNT) coating on silicon substrate with thin film of alumina

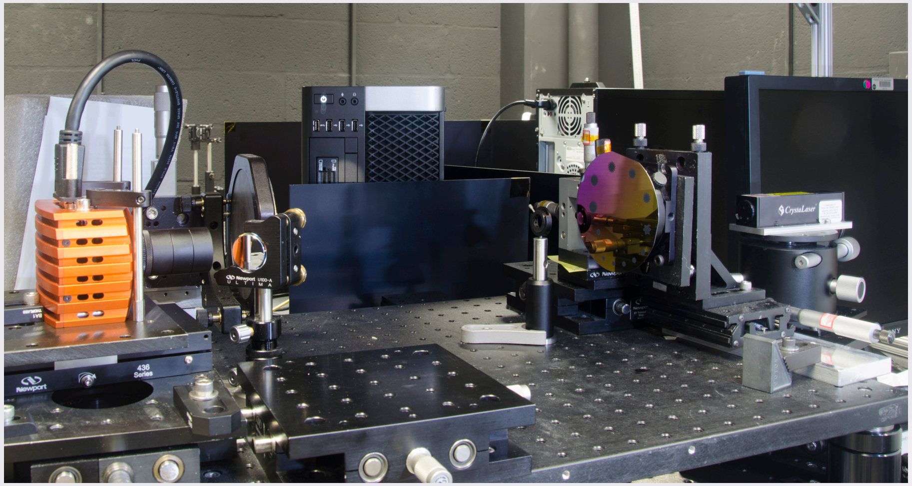
Wavefront Sensing and Control



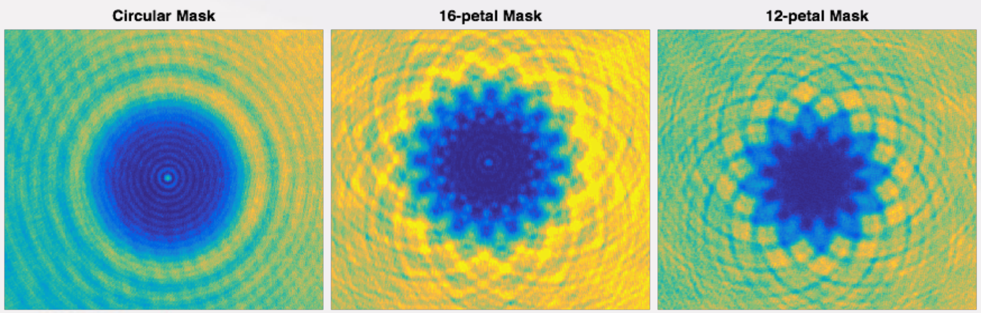
Phase Retrieval Metrology System (PRMS) during JWST OGSE2 testing at Johnson Space Center. The phase retrieval was done on half-pass data

Wavefront Sensing and Control (Continue)

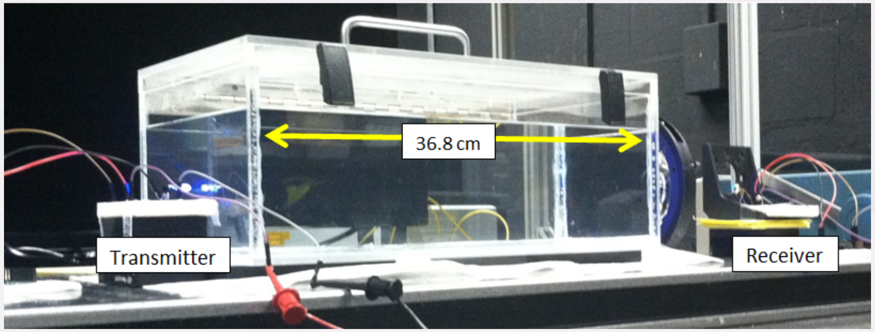
Advanced Wavefront Sensing & Control (WFSC) computation using FPGAs enables 'on-board' autonomous sensing and control for real-time correction



Reflective optical test bed to suppress the bright spot using the carbon nanotubes (CNT) coated petal-shape masks



Poisson spot suppression using CNT coated petal-shape masks in reflective mode



Underwater Wireless Optical Communication

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 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

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 **(New)**	**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
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Optical Coatings for X-Ray, EUV, Visible, and IR Telescopes 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: - Reflectivity > 90% from 6 nm to 200 nm onto a < 2 meter mirror substrate. Metrics for UVOIR: - Broadband reflectivity > 95% from 300 nm to 5 microns and low emissivity in the IR -Broadband reflectivity > 60% and uniform polarization from 90 nm to 2500 nm to be deposited onto a 2, 4, 8 meter mirror substrate. Non-stationary Optical Coatings: - Used in reflection & transmission that vary with location on the optical surface. Carbon Nanotube (CNT) Coatings **(New)** - 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 (THEIA or ATLAST) 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 (VNC)
	Need Horizon	1 to 3 years Affordable high-performance optical component system technology needs to achieve TRL-6 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 for two different reasons. First, the technical capabilities of the optical systems will determine performance and science return. Second, the areal cost will determine whether a given mission will ever be funded in the current cost environment.

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 2nd 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

Mirror Technology Days 2015

Subtopic:	(S2.04, X-Ray Mirror Systems Technology, Coating Technology for X-Ray-UV-OIR, and Free-Form Optics
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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. The optical surfaces with Free form enabling additional degrees of freedom to reduce volume and eliminate traditional design constrains 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 with 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, VNC)
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. It allows coronagraphic nulling without shearing and increases the useful science field of view.

- FY15 Funded Proposals:
  - Free-Form Optics: Two Phase-I proposals
  - X-Ray Optics: Three Phase-I proposals
  - Coating: none
- FY14 Funded Proposals:
  - Metrology: One Phase-II proposal. This technology in continuation of Phase-I proposal advances the current state of precision metrology on large optics unavailable earlier
- Deliverables are software tool, publication, methodology, analysis, and prototype

History	This subtopic is continuation from the previous year
Subtopic	Minor modifications

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