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 Mangers from MSFC and JPL
Presenter: Dr. Peter Blake, GSFC

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Outline

- Overview of NASA / GSFC Optics Branch

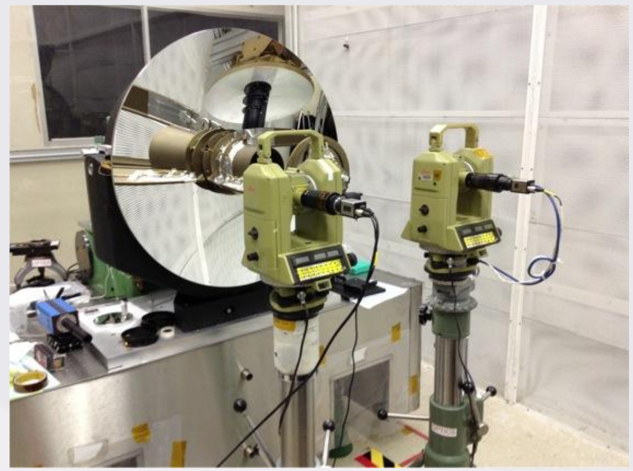
- SBIR Topic: S2. Advanced Telescope Systems
- SBIR Subtopic: S2.04
    - X-Ray Mirror Systems Technology
    - Optical Coatings from X-Ray, Extreme UV (EUV) to Optical and IR
    - Free-Form Optics Design, Manufacturing and Metrology

Goddard Optics Branch, Code 551

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

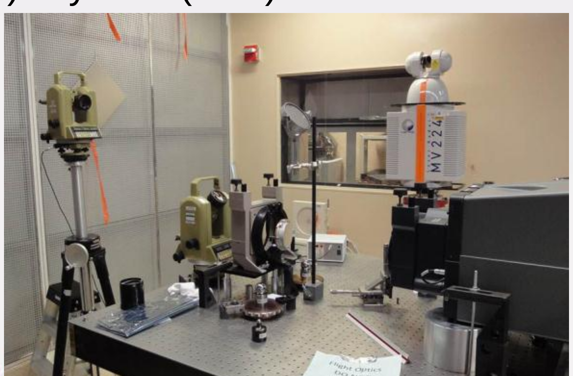
Alignment, Integration & Test

James Webb Space Telescope (JWST) Integrated Science Instrument Module (ISIM) CryoVac (CV2) test



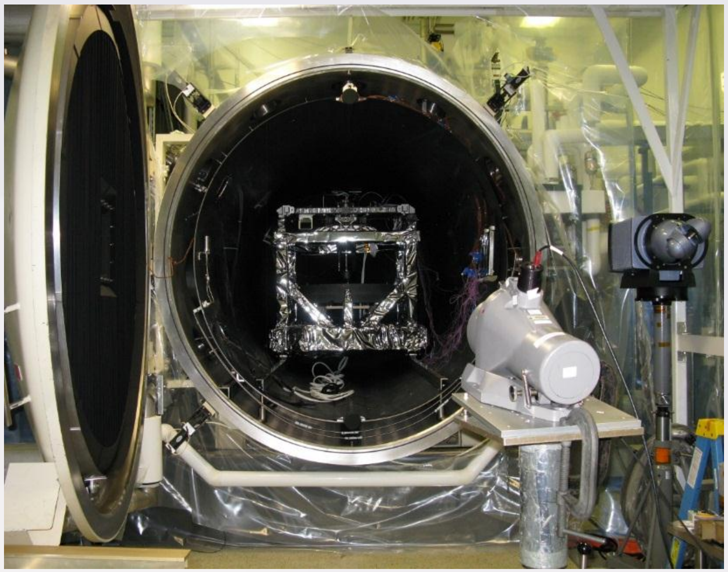
Ambient Testing of Advanced Technology Large-Aperture Space Telescope (ATLAS) Receiver Telescope Assembly

Global Precipitation Measurement (GPM) alignment and verification

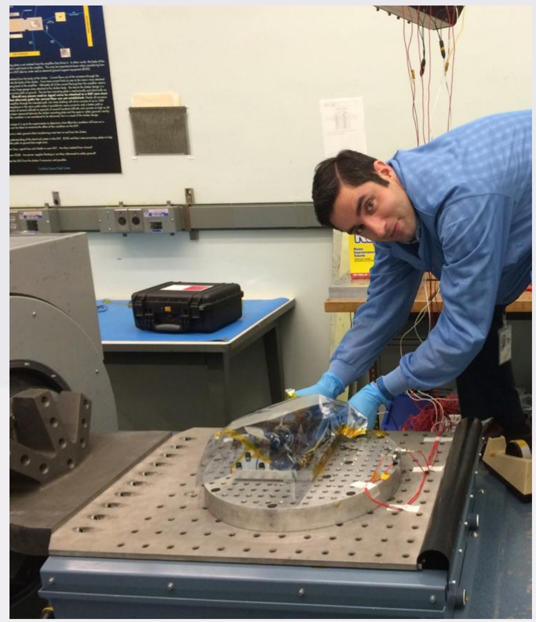


Origins-Spectral Interpretation-Resource Identification Security--Regolith Explorer (OSIRIS-Rex) Visible and Near-IR Spectrometer (OVIRS) mirror characterization

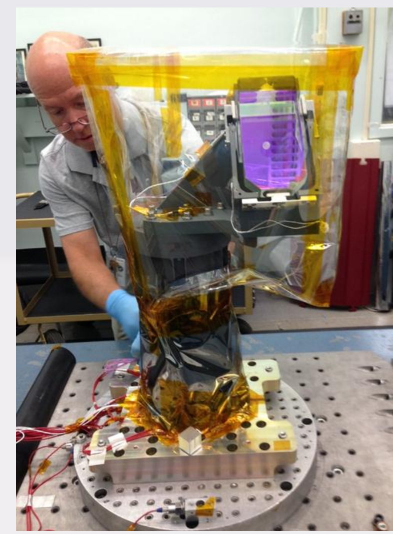
Components



ATLAS Receiving Telescope Assembly (RTA) and Ground Support Equipment (GSE) in the Optical Calibration Lab (OCL) thermal vacuum chamber before door closed

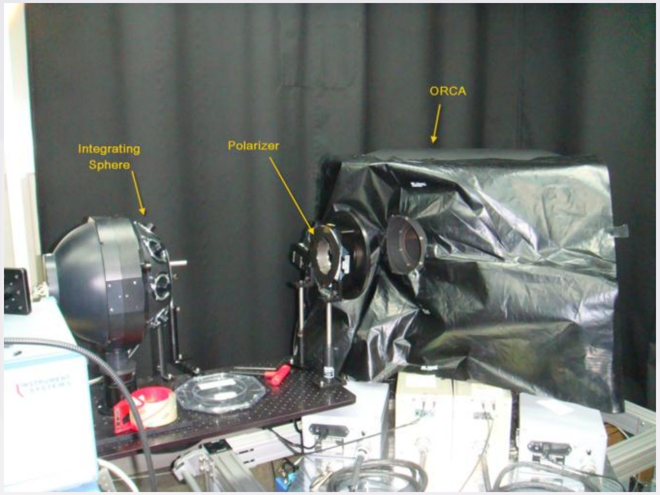


Vibration testing for Satellite Servicing Capabilities Office (SSCO)

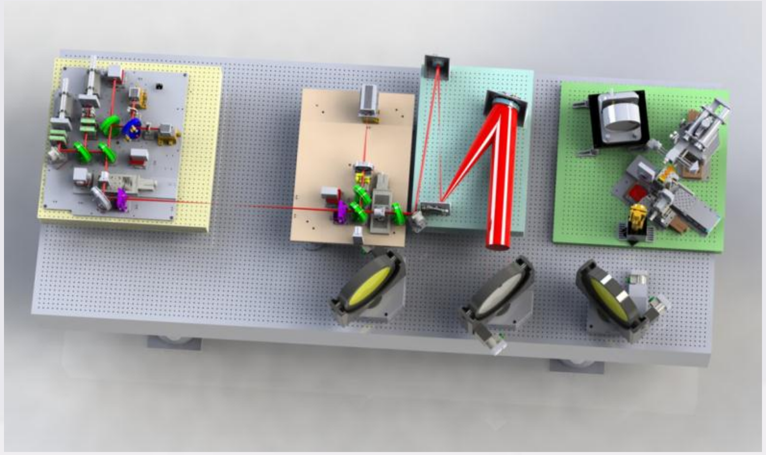


Flight Transmit of Lateral Transverse Retroreflectors (LTR) in vibration testing

Design



Ocean Radiometer for Carbon Assessment (ORCA) prototype

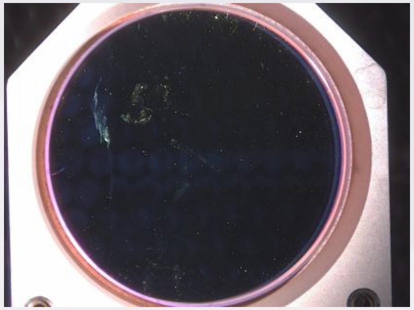


Laser Communication Relay Demonstration (LCRD) optical assembly

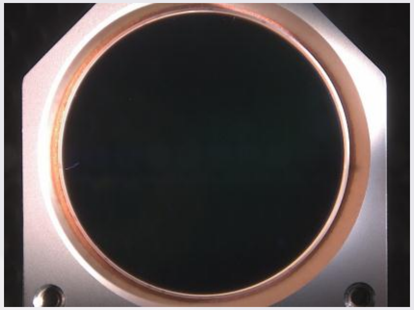
Image of parking lot taken while ORCA was rotating at 6 Hz.

Fabrication

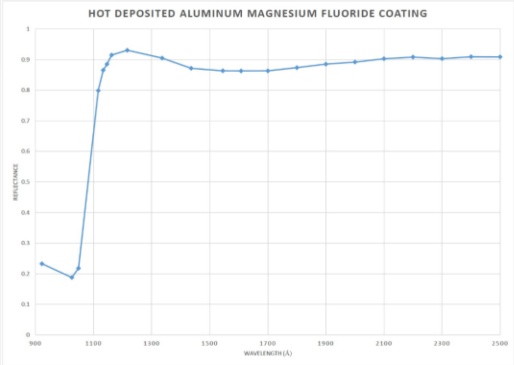
Pre-Clean



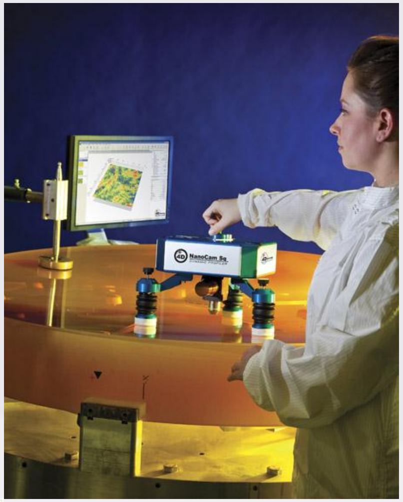
Post-Clean



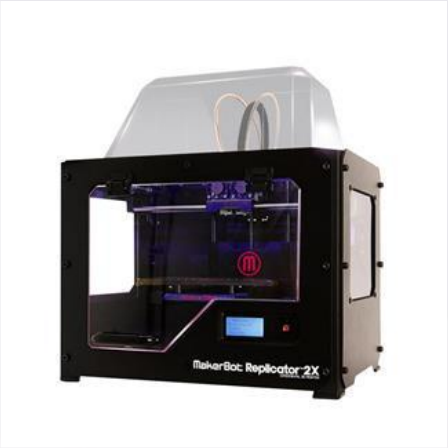
Fold mirror, detailed inspection and contamination cleaning



Coating design using aluminum magnesium fluoride

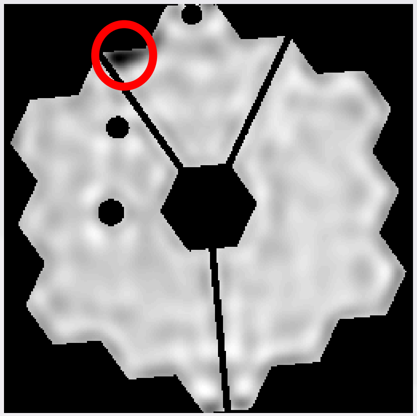


‘NanoCam Sq’ dynamic optical profiler

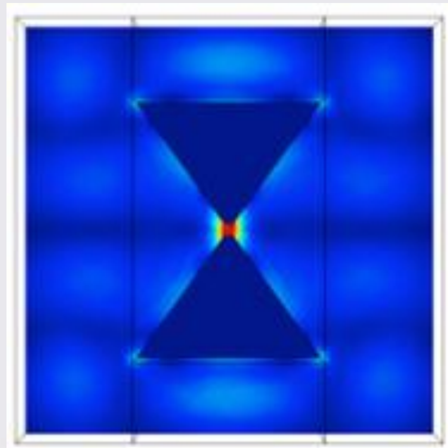


‘Replicator 2X’ 3D printer for optical prototyping

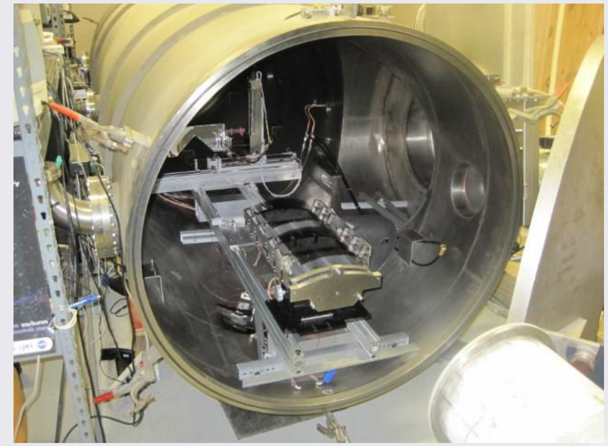
Wavefront Sensing and Control



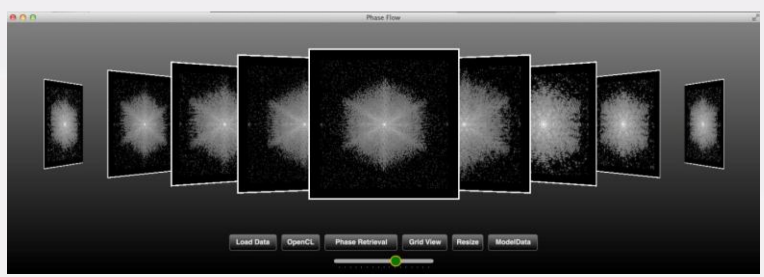
Phase Retrieval, Discovered vignette in a corner of Optical Simulator of the JWST Optical Telescope Element (OSIM) Mid-Infrared Instrument (MIRI) pupil during CryoVac (CV2) test



Plasmonic resonance of nano-antenna in space-based photon detectors



Area 200, X-Ray chamber in support of Next Generation X-Ray Optics (NGXO)



Phase Retrieval using rad-hard real-time on-board autonomous sensing and control

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)
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 (**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.
	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 2014

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Manager:	(Ron Shiri / GSFC, Kunjithapatham Balasubramanian / JPL, Philip Stahl / MSFC)
Center(s):	(GSFC, JPL, MSFC)

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) (**New**) Metrics for EUV: - Reflectivity > 90% from 6 nm to 200 nm and depositable onto a < 2 meter mirror substrate. Metrics for UVOIR: -Broadband reflectivity > 60% and uniform polarization from 90 nm to 2500 nm and depositable onto a 2 to 4 to 8 meter mirror substrate. Non-stationary Optical Coatings: - Used in both reflection and transmission that vary with location on the optical surface. Vary, as used herein, refers to ratio of reflectivity to transmissivity, optical field amplitude, phase, and polarization change. The optical surface range of diameters is 1/2 cm to 6 cm that could either be flat, conic, or free-form. (**New**)	**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.
	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 there are no steps in the surface.
  - The optics with underlying conic prescription would need to be in F/# range of F/2 to 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. Free form 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 to F/20 (**New**) - Metrology of 'freeform' optical components is difficult because of very large departures 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 - (**New**)	**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	Never been done before
	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.

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