Marshall Space Flight Center Optics Capabilities

Mirror Technology Days
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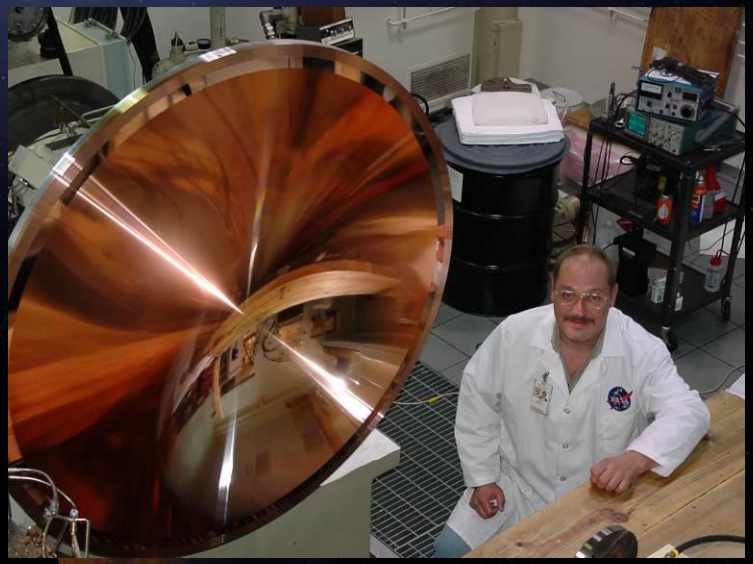
Roy Young
ES34 Technical Assistant
Optics and Imaging Branch
Space Systems Department
NASA/Marshall Space Flight Center
Huntsville, AL 35812

roy.young@nasa.gov

Precision Engineering/Diamond Turning



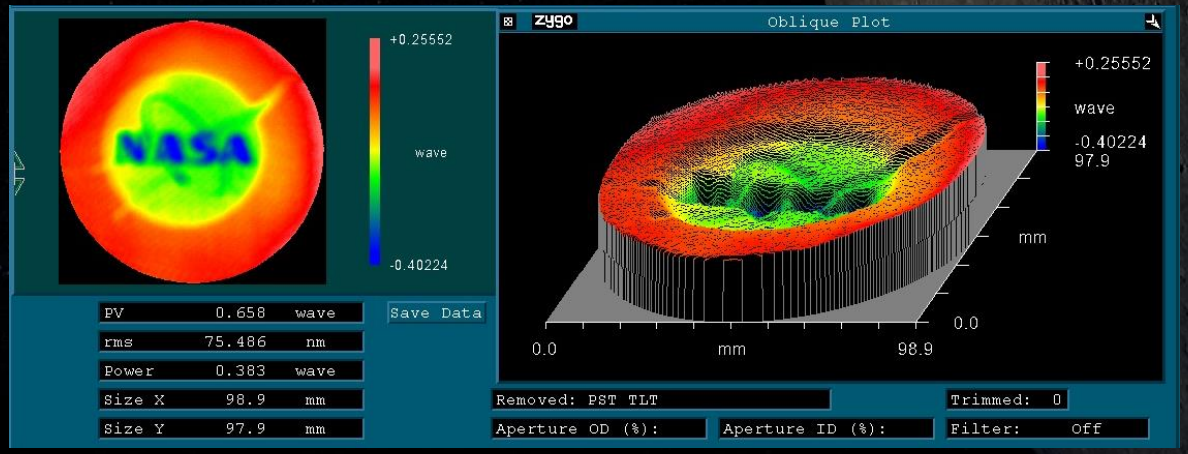
1.5 m copper mold for pressing Fresnel lenses cut under Space Act Agreement

MOORE M-40

Facility currently consist of two ultra high precision diamond turning machines with face turning capabilities of 2 meters and 0.4 meters, cylinder turning to 1 meter, one EDM and two high precision CNC machine tools and conventional machine tools. Extensive metrology support is available.

Optical Shop

- Equipment includes curve generators, spindle grinders/polishers, a Blanchard, an edger and a 48 inch continuous polisher.
- Custom built polishing machines that are capable of polishing X-ray mirror mandrels 40 - 500 mm in diameter and 305 - 610 mm in length to less than 5 arcsec in figure error and less than 4 Å roughness.
- Zeeko IRP600 Intelligent Robotic Polisher able to grind and polish parts up to 600 mm in diameter to a surface roughness of 5 Å.
- OptiPro 300 6-axis Ultra Free Form Polisher able to grind and polish parts up to 300 mm in diameter to a surface roughness of 5 Å, provided under SBIR.



NASA logo ground into a glass flat in approximately 1 hour on the Zeeko.

Metrology Facilities/Equipment

Zygo Interferometers

- 32 in. GPI
- 18 in. Mark IV

Zeiss Coordinate Measuring Machine

- 1 micron accuracy
- parts up to 1 m

Zygo NewView optical profilometers

- Sub Angstrom vertical resolution.
- Sub micron lateral resolution.

Vertical Long-Trace Profilometer

- One of two in existence
- Incorporates rotary air bearing table
- Scan Length: 0.7 m
- Range: 10 m rad.
- Accuracy: 10 nm surface height (theoretical)
- Cylinders/shells up to 0.7-m long x 0.75-m diameter

Stray Light Test Facility (SLTF)

CLASS 10K CLEAN ROOM
AND CHAMBER

OPPOSITE: END OF ROOM TUBE

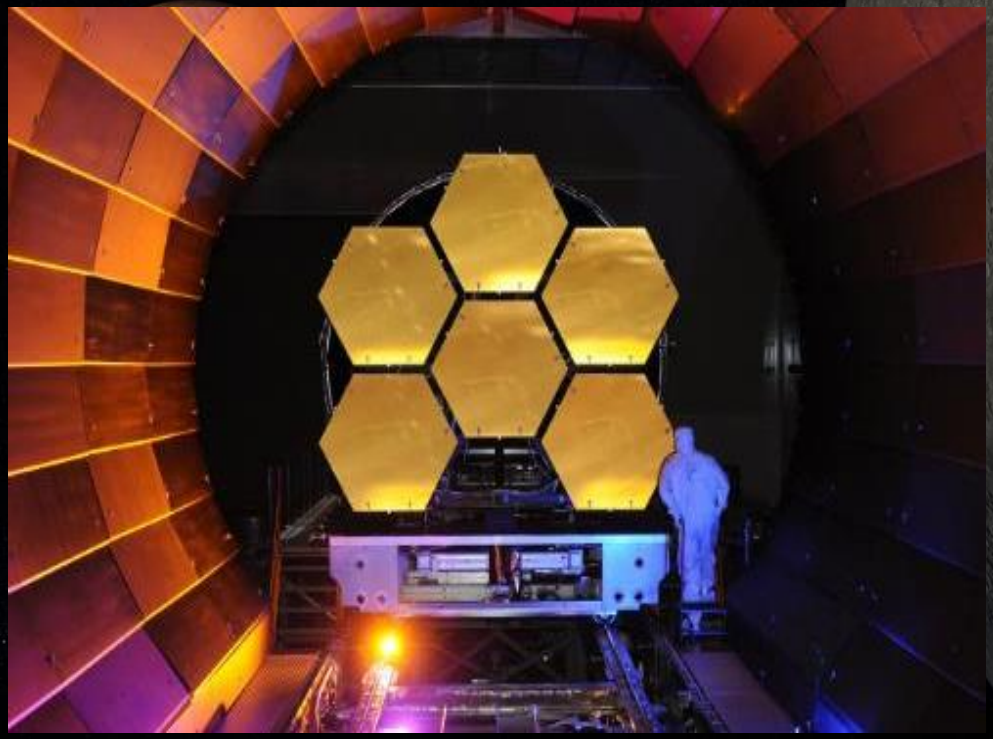
MAIN CHAMBER AND PREP AREA

- **3 by12-m test volume for baffle or mirror**
- **1.3-m diameter, 82-m long section**
- **1.5-m diameter, 10-m isolatable section**
- **Pumped with cryo-pump: $<10^{-7}$ torr**
- **Measured baffle rejection ratios up to 10^{15}**
- **Currently used to test x-ray optics up to 1-m dia.**

X-Ray and Cryogenic Facility (XRCF)

James Webb Space Telescope flight mirror segments were tested in the (XRCF), as well as the Chandra X-ray telescope and numerous other flight hardware components. The test chamber offers the unique capability for simulating a space environment with low temperature and pressure.

- **7.3 x 22.8 m Polished Stainless Steel 10-7 Torr Vacuum Chamber**
- **Full 155 to 355K Thermal Shroud – Helium shroud to 20K**
- **Vibration Isolated via Seismic Mass**
- **5DOF Remote Controlled Test Stand**



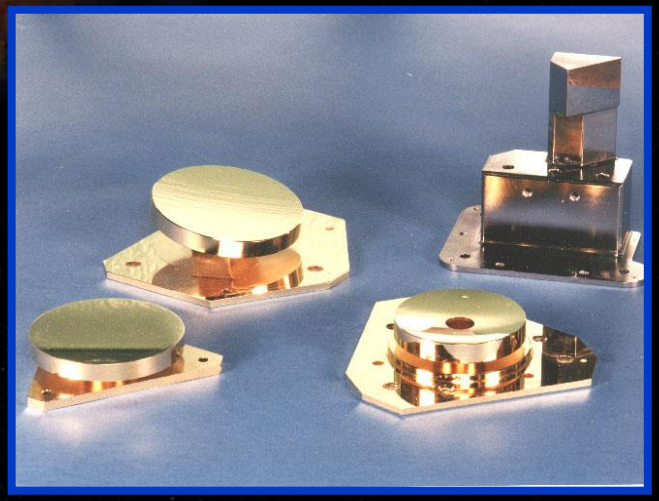
JWST mirror segment testing

Shooting Star Inflatable Concentrator

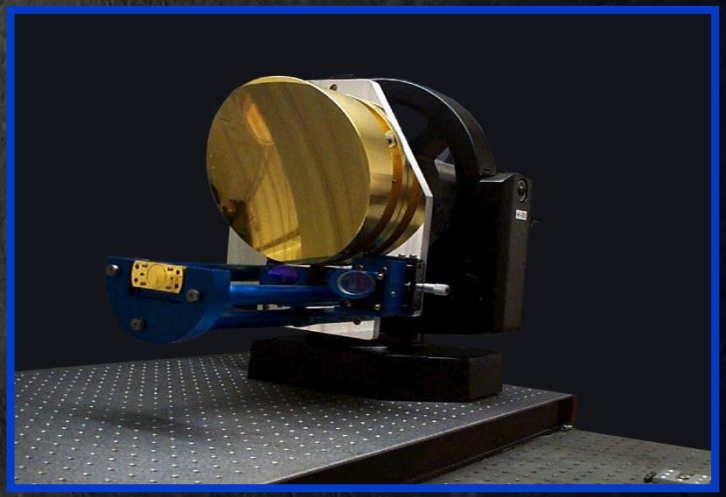
FLIGHT MIRROR DEVELOPMENT

Solar X-ray Imager Mirror on GOES-12 satellite

UV Imager Mirrors on POLAR satellite



Composite Infrared Spectrometer (CIRS) Mirrors on CASSINI

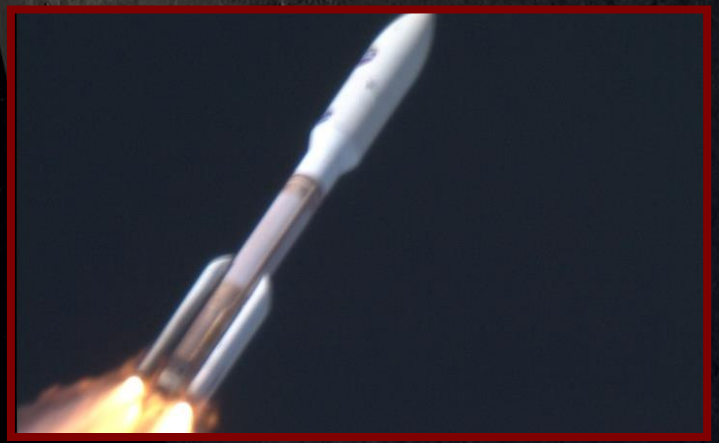


Sparcle Lidar Beam Expander (flight certified but not flown)

WB-57 Ascent Video Experiment

- Supplied the optical system for the airborne imaging of the Space Shuttle at launch and portions of the reentry.
- Operates in unpressurized nose ball of a WB-57 aircraft at 50-60,000 foot altitude
- Visible & NIR, Schmidt-Cassegrain, 28 cm diameter primary mirror, 2.8-meter focal length
- Completed the design using COTS equipment
- Manufactured the optical bench and performed the optical integration
- Environmentally tested the system prior to flight.
- System continues to be flown in support of Eastern Test Range and KSC launches.

STS-115 – September 9, 2006

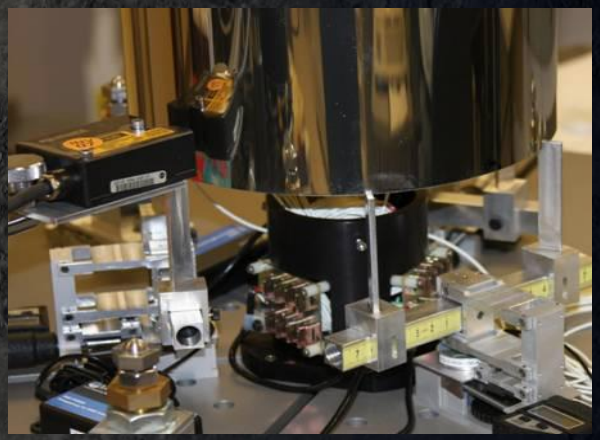


Pluto New Horizons – January 19, 2006

Replicated X-ray Optics

Astronomical Roentgen Telescope X-Ray Concentrator (ART-XC)

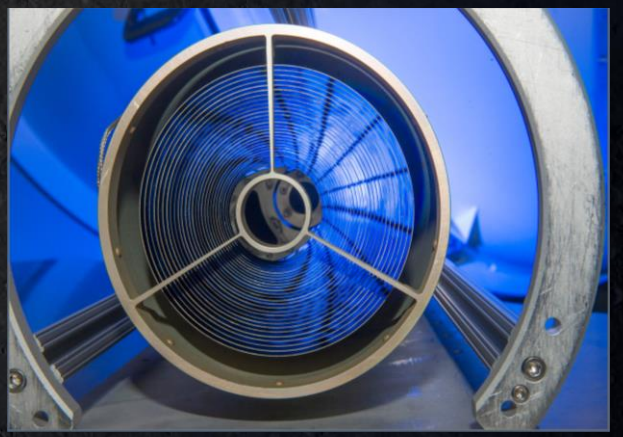
- Manufactured for the Russian Spectrum Mission
- 28 precision mandrels for the replication of ~ 200 mirror shells (15 arcsec figure, 5 Å roughness)
- 30 keV (0.083 - 1.24 nm), Wolter 1, 5.0 to 14.9 cm mirror diameter, 2.7-meter focal length
- Produce 7 flight modules plus 1 spare unit including mirror housings and support spiders
- Tested modules in Stray Light Facility



Shell alignment

Focusing Optics X-Ray Imager (FOXSI)

- FWHM accuracy of 8 arcsec with a roughness of less than 4Å
- 5-15 KeV (0.16 - 2.5 nm), Wolter 1, 7.6 to 10.2 cm mirror diameters, 2.0-meter focal length
- Launched on a sounding rocket Nov, 2012
- Added additional shells for FOXSI-2, flow in 2015



Module in Handling Fixture

High Energy Replicated Optics (HERO)

- Successful balloon flight in New Mexico in 2001 and with additional mirror mandrels/shells for broader energy range, re-flew at Alice Springs in 2009
- Super HERO proposed

Replicated Optics Manufacturing Process

1. CNC machine, mandrel formation from Al Bar

2. Chemical clean and activation & Electroless Nickel (EN) plate

3. Precision turn to sub-micron figure accuracy

4. Polish and superpolish to 3-4 Å finish

5. Metrology – **repeat Step 4 until surface finish met**

6. Ultrasonic clean and passivation to remove surface contaminants

7. Electroform nickel shell onto mandrel

8. Separate optic from mandrel – reuse mandrel for next shell

8. Align shells into module

9. Test module

Normal Incidence Sounding Rockets

Solar Ultraviolet Magnetospheric Investigation (SUMI)

- SUMI flew on a sounding rocket in 2010
- λ=155 & 280 nm, Ritchey–Chrétien, 30 cm diameter primary
- Provided primary and secondary mirrors, heat rejection mirror, four fold mirrors, two off-axis parabolas and two diffraction gratings

SUMI Integration

High Resolution Coronal Imager (Hi-C)

- Hi-C launched on a sounding rocket on July 11, 2012 and obtained the highest resolution images of the Sun's corona ever acquired
- λ=193 Å, Cassegrain, 22 cm diameter primary mirror, 23.0-meter focal length
- Provided the primary and secondary aspheric mirrors to the Smithsonian Astrophysics Observatory (SAO)
- The primary was hand polished to a slope error of .09 arcsec and the secondary to .25 arcsec

Hi-C Primary polishing

MSFC Partnerships Office

Reimbursable SAA - Money coming into NASA

- Permits the partner to use NASA goods, services, facilities, or equipment to advance the partner's own interests
- Primary benefit to partner that is consistent with NASA's mission.

Non-reimbursable SAA - No funds exchanged

- Used to support collaborative technology development, outreach activities and educational partnerships.
- Mutually beneficial activity that furthers NASA's mission
  - Not used to obtain services from partner
- Look for "quid pro quo" contribution between NASA and partner.

Identify opportunity – Could NASA assist me with this?
Evaluate the possibility to partner – Is the opportunity within NASA's authorization
Develop agreement jointly – NASA and the partner agree on scope, schedule and cost
Capture and finalize the agreement – Coordination ensures a timely review and approval
Execute the agreement – another successful partnership with NASA begins

Contact: Sam Ortega sam.ortega@nasa.gov 256-544-9294

Summary of MSFC Unique Capabilities

- **MSFC has a unique capability to manufacture and test grazing incidence optics.**
  - The capability to develop, fabricate and test electroformed nickel optics at MSFC is unique in the United States; in fact, there are only two such capabilities in the world, the other residing in Italy.
  - MSFC has state of the art metrology capabilities to test and verify that the grazing incidence mirrors meet design requirements.
  - The SLTF is an alternative to the XRCF providing flexibility to rapidly adjust test set-ups and conditions for hardware testing
- **MSFC world class optical capabilities include: Moore M-40 Diamond Turning Machine, OptiPro 300 Ultra Free Form Polisher, Vertical Long Trace Profilometer (VLTP), X-Ray Cryogenic Facility (XRCF) and Stray Light Facility**
- **MSFC is a vital participant in manufacturing and testing optics for a range of customers. Partnerships exists with NASA/GSFC, NASA/KSC, Dept. of Energy, National Institute of Health, DARPA, SAO, MIT, UC Berkley, University of Iowa and others.**