National Aeronautics and
Space Administration

Optical Systems

A Unique Solution for X-ray Astronomy

Marshall is the sole domestic source for high-energy X-ray full-shell (Wolter Type I) replicated optics and one of only two sources in the world. This method uses electroformed nickel replication (ENR) fabrication to create extremely precise grazing-incidence optics necessary for high-energy observations. Nickel mirror shells are electroformed onto a figured and super-polished aluminum mandrel and then released by differential thermal contraction.

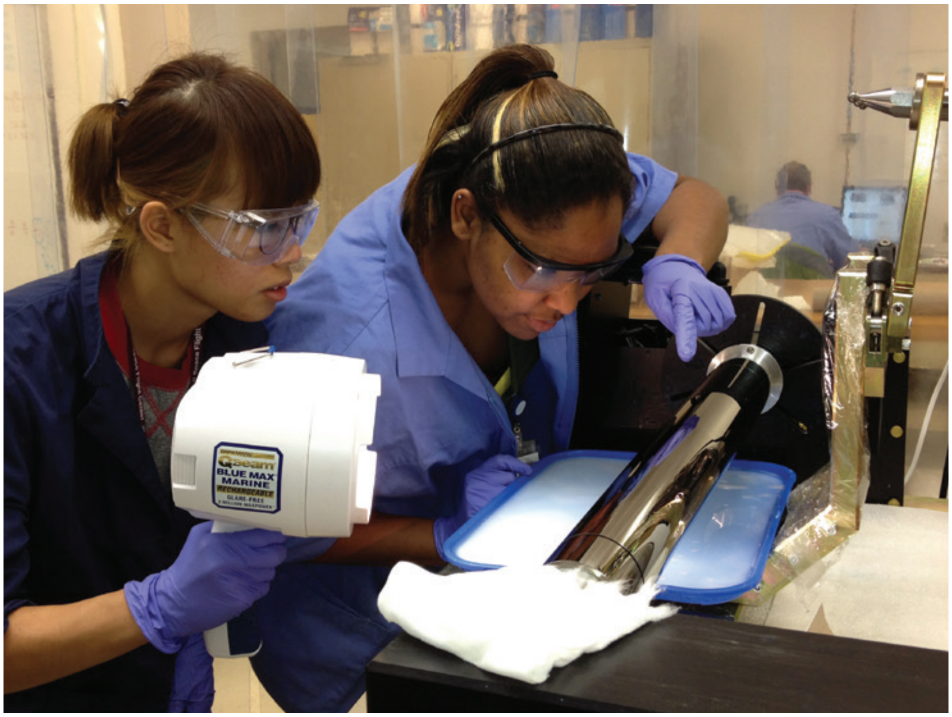
A distinct advantage of the ENR process is that the resulting mirror shells are inherently very stable, which permits good figure accuracy and hence very good angular resolution (image sharpness). Multiple identical copies can be made from a single mandrel for simple repeat fabrication—a significant cost savings over traditional fabrication methods.

Some of the characteristics of the shells created by this method include:

- Resolution as good as 10 arcsec half-power diameter
- Diameters from 2 to 50 centimeters
- Focal lengths from 1 to 10 meters
- Thickness as low as 50 micron
- Bare nickel, gold, iridium, or multilayer coatings
- Optics for soft and hard (up to 70 keV) X-rays

At-A-Glance

Space science research involves continually advancing the state-of-the-art in optics technologies, especially in astrophysics where maximizing the efficiency of optical systems (the amount of light collected per unit mass of instrument and spacecraft) is critical to the next generation of missions. The unique thermal and gravity conditions of the space environment also drive specialized optics expertise requirements. Marshall has developed a unique replicated optics process, which will be key to future high performance applications, and the Center has unique expertise in optics related to X-ray applications.



ENR fabrication enables fast, affordable production of X-ray optics for next-generation instruments.

Marshall has seen great success with this process, and a number of instruments flown in recent years have used ENR nested-shell optics for performing high-energy astrophysics and heliophysics observations. As the scientific community begins looking toward the next generation of X-ray telescopes to follow the Chandra X-ray Observatory, this process provides a key enabling technology for next-generation X-ray instruments that can be produced affordably and efficiently.

Solving Unique Problems in Optics and Instrument Development

Marshall's optical systems capability is composed of several functional organizations, with specialists in replicated cylindrical optics manufacturing, traditional optics manufacturing as well as metrology and testing. This team has earned a reputation as the "emergency room" for optical projects that run into technical challenges. The group is known for its ability to solve optical and opto-mechanical issues as well as manufacture custom solutions.

Marshall's optical systems team works closely with the scientific community both at the Center and at institutions around the world to develop optical instruments that enable groundbreaking scientific discovery and advance understanding of the universe. These include:

- Extensive history with optical systems development dating from the Apollo era, with support to major projects from Skylab to the James Webb Space Telescope (JWST)
- Unique capability for replicated optics manufacturing of grazing-incidence optics needed for high-energy astrophysics, X-ray astronomy, and heliophysics

Marshall's expertise in metrology, optical manufacturing, and optical testing is recognized and sought by customers from around the world. Frequently called in to solve tough technical challenges on other projects, the team at Marshall has been instrumental in optical systems design for NASA and the broader scientific community for more than 40 years. The Center's expertise in optical systems attracts customers from other government agencies, academia, and international space organizations.

Enabling Advances in Space-Based Astronomy

Marshall's legacy in optical systems traces its roots to the development of the Apollo Telescope Mount (ATM) on Skylab and the X-ray telescope on the second High Energy Astronomy Observatory (HEAO-2). Since then, Marshall has been involved in development of a broad cross-section of the Agency's optical instruments. Notably, Marshall played a significant role in NASA's Great Observatories, especially in managing the Hubble Space Telescope and in managing the development, flight, current operations, and guest science observer program of the Chandra X-ray Observatory. Most recently, Marshall has supported the testing of the James Webb Space Telescope flight primary mirror segments and primary mirror backplane structural support in the X-ray and Cryogenic Facility (XRCF). Support of JWST by XRCF began in 1999 with testing of structural and optical configuration within the program.

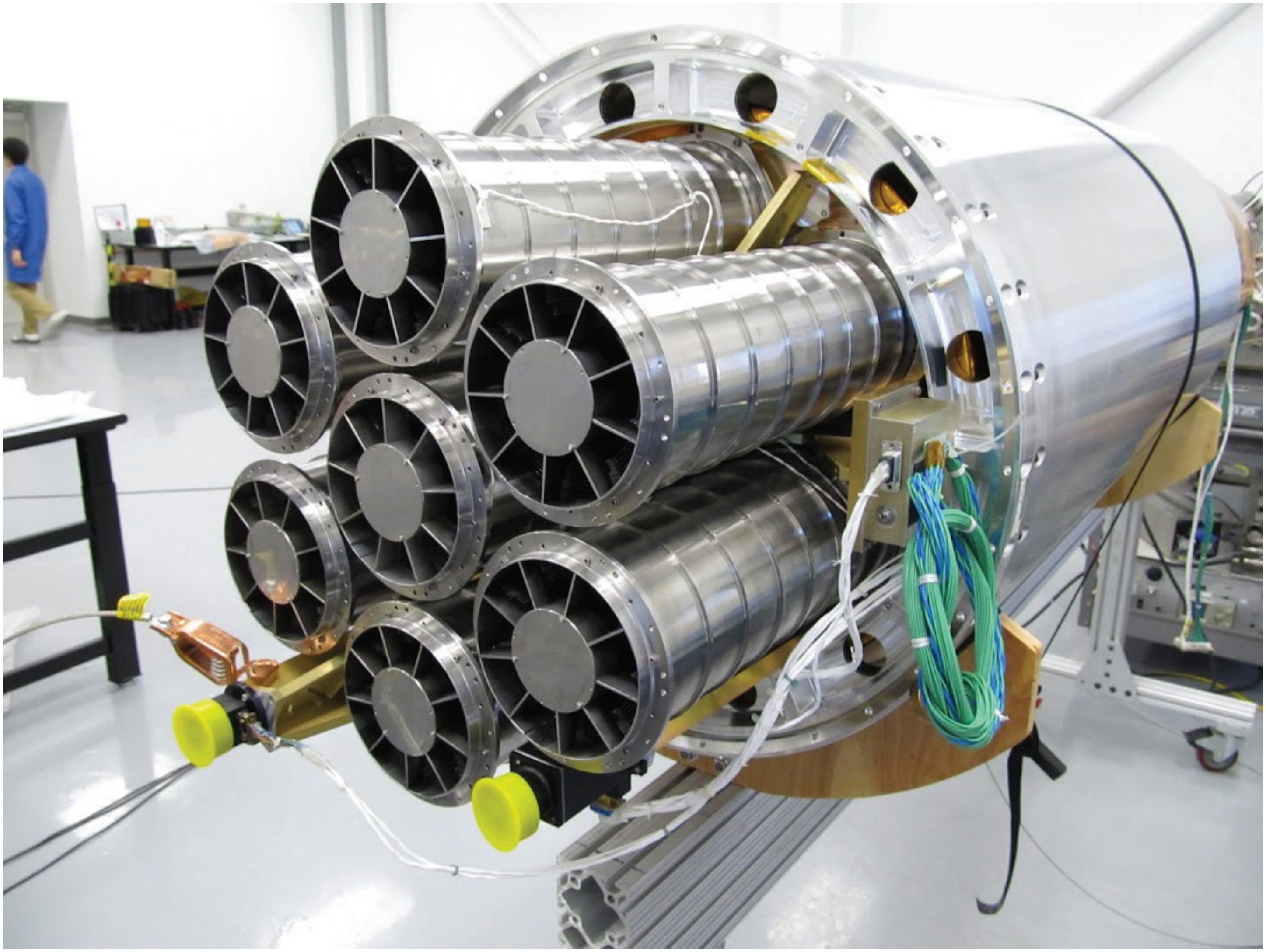
In addition to the Great Observatories, Marshall has supported a broad array of smaller missions, including the High-Resolution Coronal Imager (Hi-C), the Focusing Optics X-ray Solar Imager (FOXSI) sounding rocket, the High-Energy Replicated Optics for Exploring the Sun (HEROES) training mission, and the Russian-led Astronomical Roentgen Telescope – X-ray Concentrator (ART-XC).

Chandra X-ray Observatory

Marshall began work on Chandra in the mid-1970s. Over the course of Chandra's development, the Center refined its core capability in X-ray optical systems design. Marshall oversaw the manufacture, coating, and alignment of Chandra's nested mirrors to unprecedented exactitude, enabling the immense scientific return of this Great Observatory.

High Resolution Coronal Imager (Hi-C)

Hi-C, launched in July 2012 on a NASA sounding rocket, captured the highest-resolution images ever taken of the sun's corona. The instrument, operating in the extreme ultraviolet region of the spectrum, incorporated some of the finest mirrors ever made. Scientists and engineers from Marshall and the Smithsonian Astronomical Observatory worked together to deliver the instrument.



Marshall's ENR optics process has been successfully demonstrated on instruments like FOXSI.

Focusing Optics X-ray Solar Imager (FOXSI)

FOXSI used a set of seven grazing-incidence telescopes developed at Marshall to examine barely visible solar nanoflares at multiple wavelengths. Using the Center's unique replicated optics manufacturing capability, the extremely sensitive and highly reflective optics were designed at significantly lower cost than traditional optical systems.

Optical Calibration and Testing

X-ray and Cryogenic Facility (XRCF)

The XRCF is the world's largest optically clean cryogenic and X-ray test facility. Built in 1975 to test and calibrate HEAO-2, the XRCF was extensively modified during 1989–1991 to perform full-scale calibration tests for Chandra. In 1999, the facility was upgraded to perform cryogenic testing. The facility consists of a 1,700-foot-long X-ray guide tube, an instrument chamber, and two clean rooms (Class 1,000 and 10,000). The extremely clean instrument chamber test vacuum has all electrical and fluid interfaces needed for running tests. Cryogenic and vacuum pumps provide typical test pressures of less than 10^{-6} Torr.

The facility has two interferometers for optically measuring structural distortions that occur during cryogenic testing of telescope mirrors. Both interferometer systems offer fast, quantitative surface figure measurement that is relatively insensitive to the effects of vibration. These instruments can detect thermal distortions as small as a few nanometers. More than 30 cryogenic test operations have been completed since 1999, most in support of JWST.

In addition to the large vacuum chamber, the facility has a smaller, more cost-effective cryogenic and cryogenic optical testing chamber for subscale testing of smaller instruments. The helium-cooled chamber achieves test pressures and temperatures comparable to those of the large chamber, but in about one-tenth the time. It uses control and data acquisition systems similar to those of the larger chamber and uses the same interferometer systems. More than 25 cryogenic test operations have been completed in the small chamber since it was commissioned in 2001.

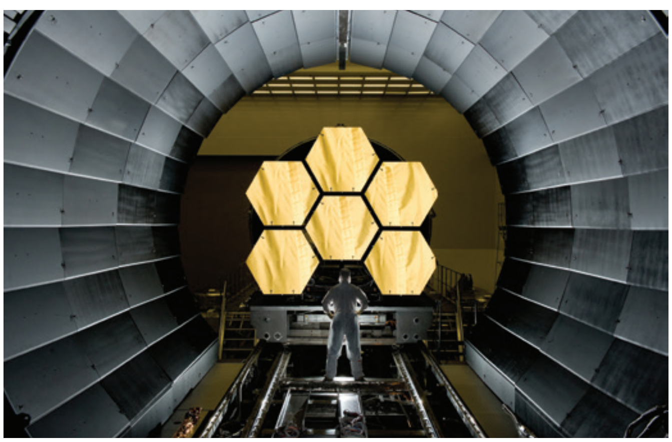
Straylight Test Facility (SLTF)

This facility vacuum tests telescope baffle systems to determine whether they meet their performance requirements. A pulsed laser beam shines on the front of the baffle system and the focal plane detects how much light is scattered. The angle of the laser beam varies to any needed angle. The facility can distinguish unwanted stray light from the target's light.

The SLTF is also used as an X-ray test facility with 100-m beam path. X-ray test range is from soft to hard X-rays with mirror sizes to about 1 meter in diameter. With a 100-m beam path and 10^{-7} torr vacuum capabilities, the SLTF is also used to test 1-m class X-ray detection systems.

The Straylight Test Facility consists of:

- 3m x 12m test volume for mirror
- 1.3m diameter by 82m long section
- 1.5m diameter by 10m isolatable section
- Pumped with cryopumps; 10^{-7} torr
- Measure telescope baffle rejection ratios over 15 orders of magnitude



The XRCF supported JWST with cryogenic testing of the flight mirrors and structural components.

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