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Flight programs and X-ray optics development at MSFC

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Abstract. The X-ray astronomy group at the Marshall Space Flight Center (MSFC) is developing electroformed nickel/cobalt x-ray optics for suborbital and orbital experiments. Suborbital instruments include the Focusing X-ray Solar Imager (FOXSI) and Micro-X sounding rocket experiments and the HEROES balloon payload. Our current orbital program is the fabrication of mirror modules for the Astronomical Roentgen Telescope (ART) to be launched on board the Russian-German Spectrum Roentgen Gamma Mission (SRG). A second component of our work is the development of fabrication techniques and optical metrology to improve the angular resolution of thin-shell optics to the arcsecond-level.

Key words. Optics: replicated – Optics: x-ray

1. Introduction

HEROES, for High Energy Replicated Optics to Explore The Sun is a collaborative effort between MSFC & Goddard Space Flight Center to modify an existing MSFC-developed balloon-borne hard X-Ray telescope (20-75 keV) to observe the Sun.[1] HEROES is designed to make both daytime solar and nighttime astrophysical observations within the same balloon flight, and will continue to demonstrate the quality of MSFC-developed optics. HEROES utilizes 8 MSFC-fabricated hard-x-ray mirror modules, with approximately 14 shells in each, and 8 supporting x-ray detectors, gondola and astrophysical pointing system and is scheduled to fly in Fall 2013.

FOXSI, for Focusing Optics X-ray Solar Imager is a sounding-rocket-based payload led by the University of California, Berkeley and consisting of x-ray optics provided by MSFC and focal plane detectors provided by Japan (Krucker et al. 2011). The purpose of the payload is to measure the weak coronal output with good angular resolution (better than 10 arc seconds FWHM) and against bright footprints. The imager utilizes 7 MSFC-fabricated x-ray mirror modules. A FOXSI-1 configuration, with 7 mirrors in each x-ray module flew in November 2012. MSFC is now producing 3 additional shells per module to boost high-energy response for the next flight, FOXSI-2, scheduled for 2014.

Micro-X is a sounding rocket based payload consisting of x-ray optics (provided by MSFC) and a calorimeter detector led by MIT (Figueroa-Feliciano et al. 2012). Micro-X will fly in early 2015 and make high-

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[1] http://heroesballoon.wordpress.com/about/

spectral-resolution images of supernova remnants Puppis A and Cas A. Fabrication of the 0.5-m-diameter Micro-X optics has just begun.

MSFC has designed and is fabricating four Astronomical Roentgen Telescope (**ART**) (Pavlinsky et al. 2012) x-ray optics modules under an International Reimbursable Agreement between NASA and with Russian Space Research Institute (IKI) for launch on board the Russian-German Spectrum Roentgen Gamma Mission (SRG) at the end of 2014. Each module has 28 nested shells giving 65 sq. cm on-axis effective area at 8 kev with an angular resolution requirement of <60 arcseconds (Gubarev et al. 2012).

2. Technology development

A **multi-beam long trace profiler (LTP)** is under development at NASA's Marshall Space Flight Center (Kilaru et al. 2011) to increase the efficiency of metrology of replicated X-ray optics. A traditional LTP operates with a single laser beam that scans along the test surface to detect slope errors. While capable of exceptional surface slope accuracy, the LTP single beam scanning has a slow measuring speed and thus metrology efficiency can be increased using multiple beams that can scan a section of the test surface at a single instance. The multi-beam long trace profiler components have been fabricated, tested individually and assembled into a breadboard to demonstrate viability.The system resolution due to the detector-lens pair is estimated to be ~0.23 microrad. This study forms the groundwork for a future modular metrology approach where-in an entire length of a test surface can be measured in a single instance using multiple optical beams. Multiple frequencies can also be measured simultaneously. A vacuum coating technique,**differential deposition**, is being investigated at MSFC to reduce X-ray mirror figure errors, thereby improving their achievable resolution (Kilaru et al. 2010). The technique has been successfully implemented on synchrotron optics for fine figure correction (Alcock & Cockerton 2010). Simulations at MSFC showed that the best strategy was to correct the deviations in stages – beginning with low-spatial frequency (large amplitude) corrections using a wider slit, and then addressing the higher-spatial frequencies with progressively decreasing slit-sizes. The technique was demonstrated on medical-imaging X-ray optics. Profile metrology data was used to estimate the necessary correction and material of varying thickness was deposited via RF sputtering on the inside of the shell to reduce the figure deviations. Improvements in the overall surface profiles were observed and an RMS slope error improvement from 12 arc secs to 7 arc secs was obtained. In these tests our metrology capability limited the implementation of the technique to coarsest (5 mm spatial extent) deviation corrections. Currently development is focused on implementing the technique on the X-ray shells being fabricated for astronomical applications. The relatively larger diameter of these shells enables the use of non-contact interferometric profile measurement techniques, making it possible to measure and correct much finer (1 mm spatial extent) features so much larger improvements in angular resolution are expected.

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