X-ray Evaluation of the MaGIXS Nickel-Replicated Mirrors

Patrick Champey\textsuperscript{1}
August 15, 2019

Athiray Panchapakesan\textsuperscript{2}, Amy R. Winebarger\textsuperscript{1}, Ken Kobayashi\textsuperscript{1}, Sabrina Savage\textsuperscript{1}, Jacqueline Davis\textsuperscript{1}, Charlie Griffith\textsuperscript{1}, Jeffery K. Kolodziejczak\textsuperscript{1}, and Brian D. Ramsey\textsuperscript{1}

1. NASA Marshall Space Flight Center, Huntsville, AL 35812
2. Universities Science Research Association, Huntsville, AL 35899
The Marshall Grazing Incidence X-ray Spectromter (MaGIXS)

**Experiment Overview:**

- Solar sounding rocket experiment
- 2020 Launch – WSMR, NM
  - Black Brandt - IX
- NASA MSFC developed optics, optical bench, detector
- Partner institutions:
  - SAO – mirror mounting and alignment
  - MIT & Izentis LLC. – grating design and fabrication
Science Goals: Probe Coronal Heating

- Measure the temperature distribution (Differential Emission Measure) of the solar corona
- Measure the elemental abundance in the solar corona

Observation Goals:

- Energy range: 0.57 – 1.3 keV (0.91 – 2.16 nm)
- Energy resolution: ~1 eV (0.005 nm)
- Slit spectrograph with 260” slit length
- 6” spatial resolution along slit
Wolter-I Telescope:
- Nickel Replicated
- Focal length = 1090 mm
- Diameter = 150 mm
- Graze angle = 1.0°

Spectrometer:
- Nickel Replicated
- Finite conjugate pair
- Focal length = 594 mm
- Planar varied-line-space grating
- 1.3° blaze

Detector:
- CCD camera
- e2v 2k x 2k frame-transfer
- 2k x 1k active region
- 15 μm pixels

*Aperture defined by planar grating: effective aperture ~36°
Instrument Layout

Telescope Section

Spectrometer Section

Telescope Mirror Assembly (TMA)

Interface to Rocket

Spectrometer Mirror Assembly (SOA)

CCD Camera

~3 m Experiment Section

NSROC – Telemetry, Boost Guidance, FTS, Recovery
Mirror Fabrication

- Mandrels diamond turned
- Lap polished
- Replicated engineering shells
- Deterministic polishing
- Lap polished for surface roughness
- Replicated flight shells

**RMS slope error of mandrel figure**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wolter-I P</td>
<td>~4.0”</td>
<td>19.5”</td>
<td>0.72” 0.99”</td>
<td>6.4”</td>
</tr>
<tr>
<td>Wolter-I H</td>
<td>~6.0”</td>
<td></td>
<td>1.26” 1.51”</td>
<td></td>
</tr>
<tr>
<td>Spec. P</td>
<td>~8.0”</td>
<td>22”</td>
<td>1.5” -</td>
<td>4.0”</td>
</tr>
</tbody>
</table>

MaGIXS Mandrel on Zeeko IRP 600X

MaGIXS Spectrometer Mandrel

*See paper 11119-30 by Jackie Davis, MSFC*
Mirror Shells

Wolter-I Telescope

Spectrometer Mirrors - Single Paraboloid

254 mm (~10")

150 mm (~6")

84 mm (~3.3")

80 mm (~3.1")
SLF X-ray Tests in Stray Light Facility (SLF), MSFC

- 5' diameter guide tube
- 10' diameter test chamber
- Bell jar with 3-axis stage
- 3-Axis stage: pitch, yaw and focus

Detector: Andor Ikon-L
- 2k x 2k CCD
- 13.5 um pixels

Retractable aperture mask
Effective aperture
103 m beamline
X-ray source
5' diameter guide tube
10' diameter test chamber

8/26/2019 SPIE Optics + Photonics - Champey et al. 11119-43 8
TMA Best Focus Image

- plate scale = 2.5 arcsec/pix
- Pixel size = 13.5 μm

**Modeled PSF - 2D Gaussian**

- FWHM (x,y) = 10.02", 10.55"
- Symmetric Gaussian PSF
6 mm Intra-Focus

Radial profiles, $\Delta \theta = 1$ degree

- **FWHM** = 5 pixels (12.5")
- **HPD** = 12.5"

![Radial profiles graph]
Effective Aperture

- PSF yields "bowtie" shape
- Spatial along bowtie
- Spectral dispersion across bowtie

Through-focus effective aperture
- Effective aperture has “S” shaped curvature
- Contributes to PSF

TMA - Best Focus
HPD = 70.05µm (13.4"")

Δf = -6.0 mm
• Half power diameter (HPD) measured at each focal position

• **Green** = Full aperture

• **Red** = Masked aperture

• Similar depth of focus ~1 mm
Spectrometer Mirror PSFs

- 594 mm focal length
- plate scale = 5 arcsec/pix
- Pixel size = 13.5 μm
Defocused Spec. Mirror

- Deterministic polishing over 100 degree region
- Qualitative improvement in figure (annulus) over polished region
- Measurements with aperture mask not completed
Predicted On-Axis Performance

- Multiplied TMA full aperture PSF with a mask representing slit
- Convolved SM1 and SM2 images
- Convolved SM1, SM2 and TMA sub-aperture image

<table>
<thead>
<tr>
<th></th>
<th>W-I</th>
<th>SM1</th>
<th>SM2</th>
<th>RSS</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPD</td>
<td>13”</td>
<td>21”</td>
<td>20”</td>
<td>31”</td>
</tr>
</tbody>
</table>

HPD = 159.83μm (30.58")
Current Progress – TMA Focusing

- SLF HPD measurements
- Dotted line is a fit to SLF HPDs
- + = XRCF measured HPD
On-Axis Focus Check

First off axis pointing

"seq2"

Second off axis pointing
Also labeled “seq2”, but after 17:15

Third off axis pointing
“seq3”

Final off axis pointing
“seq4”

First off axis pointing
“seq2”
MaGIXS is a high-resolution imaging spectrometer – solar sounding rocket mission
  - Solar active region
  - 0.57 – 1.3 keV (~ 1 eV resolution)

Mandrels polished using deterministic technique

Replicated shells tested at the MSFC SLF

Predicted on-axis HPD ~ 30”

Future work includes continued development for image analysis techniques
  - Envision these types X-ray image data to supplement metrology