A reflection grating spectrometer for X-ray Surveyor

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Talk outline

• X-ray grating background
• State of reflection grating technologies
• Development roadmap
• Trade studies/next steps/next level
X-ray Surveyor context

- 10 m focal length, 0.5” telescope HPD
  - 24 µm at focal plane
    - Readout requires <12 µm resolution elements
- \( R = 5000 \) (0.2-1.2 keV; mirror has good response up to 2 keV)
  - Grating dispersion gives 4 mÅ spectral lines
  - \( R = 31,000 \) at 200 eV (62 Å, 2\(^{nd}\) order)
  - \( R = 28,000 \) at 1.2 keV
  - \( R = 29,450 \) at 2.0 keV
  - No need to subaperture
- 4000 cm\(^2\) with 50% optics coverage (retractable arrays)
  - \( \sim 2 \) m\(^2\) total leaves 1 m\(^2\) for the grating array
  - Requires 40% efficiency from gratings + detectors
    - Changes to 32% if mirror \( A_{\text{eff}} = 2.5 \) m\(^2\)
Diffraction gratings

Transmission Grating

In-plane Reflection Grating

Off-plane Reflection Grating

Incident Light

+1st Order

0th Order

-1st Order

Incident Light

+1st Order

0th Order

-1st Order

Incident Light

-1st Order

0th Order

+1st Order
Off-plane diffraction gratings

\[ \sin(\alpha) + \sin(\beta) = \frac{n\lambda}{d \sin(\gamma)} \]
Fabrication

- Utilizes common nanofab tech
- Developed since Con-X
- Recent advancements due to e-beam lithography
Fabrication results
29.5° blazed grating

Images courtesy of Dmitriy Voronov, LBNL
Diffraction efficiency testing of blazed grating

• Synchrotron tested at LBNL Advanced Light Source (Eric Gullikson)

• Fabricated in collaboration with Howard Padmore’s group, specifically Dmitriy Voronov

• Variable line spacing – 160 nm to 159.75 nm
• Blazed profile – 54.7°

• 10 x 30 mm on silicon
• Coated – 5 nm Cr/30 nm Au
Very high diffraction efficiencies

Measured Diffraction Efficiencies for Select Orders and Best-Fit PCGrate Model

>35% in diffracted orders
Previous resolving power results

- Tested at MSFC SLF
- Using slumped glass optics from GSFC
- Preliminary analysis
  - 6th order Al Kα₁, Kα₂
  - LSF same as 0 order
    - Aberration free
- \( R \sim 3250 \)
  - 3460 = natural line width limited (2.4 mÅ)
- Tested on small, laminar profile, variable line spaced grating
The first complete next-gen off-plane grating

- Large format
  - 75 x 96 x 0.5 mm

- Variable line spacing
  - 7x 0.25 nm steps for 8x periods: 158.25 – 160 nm
  - Matches 8.4 m optic

- Blazed
  - 54.7°

- Replicated onto fused silica
  - ~1 μm peak-to-valley flatness over piece

- Coated with 5 nm Cr/15 nm Au

- Final fabrication product – flight component
Grating alignments

- The spectrum from each grating must overlap at the focal plane
- This must be done for 100s – 1000s of gratings

<table>
<thead>
<tr>
<th>Representative alignment numbers taken from <em>Arcus</em></th>
<th>Grating Alignment Requirements (FWHM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>0.6 mm</td>
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<tr>
<td>Y</td>
<td>0.4 mm</td>
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<tr>
<td>Z</td>
<td>0.2 mm</td>
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<tr>
<td>Pitch (X)</td>
<td>15 arcsec</td>
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<td>Yaw (Y)</td>
<td>24 arcsec</td>
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<tr>
<td>Roll (Z)</td>
<td>5 arcsec</td>
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</tbody>
</table>
Current alignment studies

- Theodolite
- Collimator
- Grating
- Field lens
- WFS
- Laser
- Beam splitter
- Yaw camera
- Yaw Laser
- Folding mirrors
- Grad student
Aligned grating modules

• 4x full format gratings aligned $\leq \pm 10''$ in rotational DOFs, $\leq \pm 0.2$ mm in translational DOFs
• Needs upgraded metrology and environmental control
  • Solutions exist
X-ray alignment testing, pre-shake

- The team is currently at MSFC testing
- Limitation – single optic requires actuation of grating stack

- PANTER
  - X-ray testing with SPO scheduled for September
Vibration testing of aligned module

- Vibration tested yesterday using NASA’s General Environmental Verification Standard
- Qualification
  - $\frac{1}{4}$ G sine sweep
- Aligned module passed qualification in likely worst case scenario
- Post-vibe X-ray testing this weekend
Development Roadmap

• Near-term development driven by current projects
  • SAT ending this year, RTF ending next year
  • OGRE suborbital rocket launch in 2018
  • Arcus instrument studies

• Summary
  • Large format, flight-like gratings have been fabricated, aligned, and tested

• Ongoing diffraction efficiency testing
  • Full format imprint undergoing testing at BESSY PTB
  • Plan to test imprint at ALS (post move)

• Resolving power tests currently ongoing at MSFC
  • Full format, blazed, full illumination test

• Various areas should be improved/studied
  • Imprint process, stress allocations, surface metrology, alignment metrology and control
Possible studies/Trade space in XRS context

- Trade space exists in resolving power, not in effective area
  - Proper formats
    - Larger gratings, larger modules = easier to align (fewer elements, potentially thicker substrates)
  - Substrate materials
    - Flat silicon
    - Direct write
  - Coating materials
    - Low stress/high reflectivity
  - Groove density
    - Large trade space that effects focal plane size, and thus, bandpass
  - Variable line spacing limit and effect on spectral resolving power
    - Are 0.1 nm steps necessary/sufficient
  - Tunable blaze angle
    - Higher blaze = higher dispersion = more resolving power, but potential focal plane effects
  - Profile roughness
    - Understand roughness evolution from etch to imprint to coating
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