The IXO- X-ray Grating Spectrometer (XGS)

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## Key Performance Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
<th>Science Goals</th>
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</thead>
<tbody>
<tr>
<td><strong>Mirror Effective Area</strong></td>
<td>3 m² @ 1.25 keV, 0.65 m² @ 6 keV with a goal of 1 m², 150 cm² @ 30 keV with a goal of 350 cm²</td>
<td>Black hole evolution, large scale structure, cosmic feedback, EOS, Strong gravity, EOS, Cosmic acceleration, strong gravity</td>
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<tr>
<td><strong>Spectral Resolution</strong></td>
<td>( \Delta E = 2.5 \text{ eV} ) within 2 x 2 arc min (0.3 – 7 keV) ( \Delta E = 10 \text{ eV} ) within 5 x 5 arc min (0.3 - 7 keV) ( \Delta E &lt; 150 \text{ eV} @ 6 \text{ keV} ) within 18 arc min diameter (0.1 - 15 keV) ( \frac{E}{\Delta E} = 3000 ) from 0.3–1 keV with an area of 1,000 cm² for point sources ( \Delta E = 1 \text{ keV} ) within 8 x 8 arc min (10 – 40 keV)</td>
<td>Black Hole evolution, Large scale structure, Missing baryons using tens of background AGN</td>
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<tr>
<td><strong>Mirror Angular Resolution</strong></td>
<td>( \leq 5 \text{ arc sec HPD} ) (0.1 – 10 keV), 30 arc sec HPD (10 - 40 keV) with a goal of 5 arc sec</td>
<td>Large scale structure, cosmic feedback, black hole evolution, missing baryons, Black hole evolution</td>
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<tr>
<td><strong>Count Rate</strong></td>
<td>1 Crab with &gt;90% throughput. ( \Delta E &lt; 200 \text{ eV} ) (0.1 – 15 keV)</td>
<td>Strong gravity, EOS</td>
</tr>
<tr>
<td><strong>Polarimetry</strong></td>
<td>1% MDP on 1 mCrab in 100 ksec (2 - 6 keV)</td>
<td>AGN geometry, strong gravity</td>
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<tr>
<td><strong>Astrometry</strong></td>
<td>1 arcsec at 3σ confidence</td>
<td>Black hole evolution</td>
</tr>
<tr>
<td><strong>Absolute Timing</strong></td>
<td>50 µsec</td>
<td>Neutron star studies</td>
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</tbody>
</table>
Grating mirror coverage assumption:
• Selected $1.1 \text{m} < R < 1.9 \text{m}$; two sectors of $22.5^\circ$
• 2.4 kg incl 20% margin each box

XGS camera assumptions:
• Mass ~ 20.4kg incl margins.
• Power ~65 W incl margin + 3W CCD thermal control
• No translation stage needed at 3 σ error level
• Refocusing mechanism needed

Two grating designs under consideration:
CAT – Critical Angle Transmission Grating
OGS – Off-Plane Grating Spectrometer
Critical-Angle Transmission Grating Spectrometer (CAT-GS)

- Based on Chandra TGS heritage
- Similar to Chandra: Low weight, relaxed alignment tolerances
- Improvements:
  - Blazed transmission gratings -> use of higher orders -> higher spectral resolution
  - Broadband high-efficiency gratings -> large effective area
  - Sub-aperturing -> higher spectral resolution

Strawman configuration:
- Cover two opposing pairs of outer mirror modules (2 x 30°)
- Effective area > 1,000 cm² (E < 1 keV)
- Resolution E/ΔE > 4500 (FWHM) (E = 0.3 – 1.0 keV)
- Mass (gratings + camera w/o elec.) 25-45 kg

Ralf Heilmann et al.
Critical-Angle Transmission Grating Spectrometer: Blazed transmission enabled by the CAT grating

• CAT grating combines advantages of transmission gratings (relaxed alignment, low weight) with high efficiency of blazed reflection gratings.
• Blazing achieved via reflection from grating bar sidewalls at graze angles below the critical angle for total external reflection.
• High energy x rays undergo minimal absorption and contribute to effective area at focus.

CAT grating principle

Grating equation:
\[ m \lambda = p \left( \sin(\theta) + \sin(\beta_m) \right). \]

\( m \) = diffraction order

Blazing: \( \beta_m \approx \theta \)

High reflectivity:
\( \theta < \theta_c = \) critical angle of total external reflection

Strawman:
- Silicon grating, \( \theta = 1.5^\circ \)
- \( p = 200 \) nm
- \( b = 40 \) nm
- \( d = 6 \) \( \mu \)m
- aspect ratio \( d/b = 150 \)

Efficiency comparison with Chandra gratings

Ralf Heilmann et al.
Critical-Angle Transmission Grating Spectrometer: CAT grating fabrication and testing

- Monolithic silicon structure with integrated support bars
- 200 nm period
- Achieved design goal of 6 µm tall, 40 nm wide grating bars

Scaning electron micrographs of 200 nm-period CAT gratings
(a) Top view
(b) Bottom view
(c) Cross section

CAT grating schematic

Comparison between data and theory: ~ 80-100% of theoretical diffraction efficiency

Ralf Heilmann et al.
Randall McEntaffer (Iowa), Web Cash, (Colorado), Chuck Lillie, Suzanne Casement, Dean Dailey (Northrop Grumman Space Tech.)

Raytrace determination of CCD position at the focal plane. Blue boxes are 30 mm x 30 mm CCDs (one for zero order camera), red lines are zero order, 12 Å, 24 Å, 36 Å, and 41 Å
Mirror Modules Fasten using 3 Point Mount Attachments
- NAS1352 Screw
- MS21043 Nut

Each Module is Adjustable for Tip/Tilt & Piston Adjustment as Needed

An individual lightweighted grating

30 Mirror Modules

100 mm
## OPG-XGS Mass Matrix

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Mass per (kg)</th>
<th>Total Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
<td>30</td>
<td>0.83 (w/ gratings &amp; fasteners)</td>
<td>25</td>
</tr>
<tr>
<td>Grating Thermal</td>
<td>1</td>
<td>5 (MLI, heaters, temp sensors, harness, and control circuit)</td>
<td>5</td>
</tr>
<tr>
<td>Mount Platform</td>
<td>1</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>CCD camera</td>
<td>1 (w/ 10x ~3 cm x 3 cm CCDs)</td>
<td>11 (head, shielding, TE cooler)</td>
<td>11</td>
</tr>
<tr>
<td>CCD electronics</td>
<td>1</td>
<td>15 (box, wiring &amp; boards)</td>
<td>15</td>
</tr>
<tr>
<td>CCD thermal</td>
<td>1</td>
<td>Included in CCD camera mass</td>
<td></td>
</tr>
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Total Mass = 75 kg