Lynx X-ray Grating Spectrometer

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XGS Science topics/requirements

- **Diffuse baryons**
  - Census, mapping, metallicity in cosmic web
  - Content in galactic halos
  - Milky Way - rotational and turbulent velocity of hot halo gas

- **Black holes**
  - Kinematics and physical characteristics of warm absorbers near SMBHs
  - XRB and ULX spectroscopy, with some time resolution

- **Stellar atmospheres**
  - Photosphere absorption of neutron stars in GCs and SNR
  - Coronae and flares
  - Young star accretion
  - Winds around BHs (XRBs & ULXs)

- **Require R > 5000, effective area ~4000 cm²**
  - soft X-rays: 0.2-2.0 keV

- **These require further guidance from STDT**

- Can be addressed by Off-Plane Grating (OPG) and Critical Angle Transmission (CAT) grating technologies
Grating Spectrometer Overview

- Removable grating arrays aft of mirrors
- Fixed readout array in focal plane
- Blazed gratings; only orders on one side are utilized (smaller readout).
- No low energy high-resolution spectroscopy on Athena
CAT and OPG Spectrometers: Commonalities

- Blazing into higher orders/larger angles: Increased resolving power.
- Maximum resolving power: \((\text{Dispersion distance or “throw”})/(\text{PSF plate scale projected onto dispersion axis})\).
- Sub-aperturing boosts resolving power.
- Aberrations reduce resolving power.
- High diffraction efficiency over broad band due to angles of grazing incidence onto grating surfaces being below the critical angle.
- Band limited on short wavelength side by critical angle.
- Different orders overlap spatially: detectors sort orders.
- Detector pixels oversample PSF.
- Tradeoff between short wavelength cutoff and resolving power.
Off-Plane Gratings (OPGs)

- Offer very high diffraction efficiency and high spectral resolving power
- Individual grating elements aligned into a grating module then integrated into a grating array behind the optics
- Require dedicated detector

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

- ~60% absolute diffraction efficiency over wide band
- High efficiency per order
- Low surface roughness
- Measure smoother facets over larger areas to approach 100% groove efficiency
• MSFC Stray Light Facility (SLF)
  • 6th order Al Kα₁ and Al Kα₂
  • Resolving power ~3900 (λ/δλ)
    • After removing contributions from source size and natural line widths
  • Small format grating, 25 x 32 mm
  • Laminar groove profile (no blaze)
  • Partial illumination

• Recent SLF test on large format grating (75 x 96 mm)
• Resolution limited to ~900
• Fabrication errors need to be addressed
OPG Alignment

• Optical alignment methods have been developed at PSU and SAO

• Modules have been aligned, performance tested and environmentally tested at full NASA GEVS levels, e.g.
  • Vibe Qualification
    • ¼ G sine sweep
    • 14.1 G RMS: Steps = [3, 5, 7.1, 10, 14.1] – 2 dB per step, hold each step 20 sec, hold 14.1 G for 60 seconds

• Should consider several factors for LSF error budget
  • Astigmatism, period error, alignment (plates and modules), and thermal
• Use same technology as the HDXI
• Sensors arranged in an arc
• Zero order camera plus spectra detectors

Example readout:
• Assumes 10 m focal length, 0.5” telescope HPD (≤24 μm pixels), blaze wavelength 60 Å 1st order, 0.5” grating induce defocus, results in R~10,000
Critical Angle Transmission Gratings (MIT)

Advantages:
- low mass
- transparent at higher energies
- relaxed alignment & figure tolerances
- high diffraction efficiency
- demonstrated $R > 10,000$

- Gratings, camera, and focus share same Rowland torus.
- Blazed gratings; only orders on one side are utilized (smaller detector).
- Only fraction (50%) of mirrors is covered: “sub-aperturing” boosts spectral resolution.
Critical Angle Transmission Gratings (MIT)

- 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.

Grating equation:

\[ m \lambda = p (\sin(\theta) + \sin(\beta_m)), \]

\( m = \text{diffraction order} \)

Blazing: \( \beta_m \sim \theta \)

High reflectivity:

\( \theta < \theta_c = \text{critical angle of total external reflection} \)

Strawman:

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

200 nm pitch CAT grating bars
Recent Results

32 mm x 32 mm
No Measurable Loss of Resolving Power
Pt-coated CAT gratings with GSFC slumped glass mirror pair: $R > 11,000$ in 18th order at 0.834 nm

- $R \sim 24,000$ in 18th order (best fit) and $R > 11,700$ (95% confidence) with $\sim 1''$ mirror LSF (GSFC slumped glass P&H pair).

- $R \sim 3100$ in 9th order with first 12m-focal length SPO with $\sim 2.5''$ optic LSF (Arcus MIDEX proposal).

- Survived shake&bake.
Grating Trades and Needs

• Many details depend on focal length and array coverage

Trades
• What is performance metric for each science goal?
  • Does more effective area or more resolving power make sense in each case?
• Effective area vs. resolving power
  • Telescope coverage (vs. subaperture effect)
  • Higher energy throughput vs. high blaze angle
• Detector considerations
  • High order vs. detector energy resolution
  • One readout vs. two

Needs
• IDL needs: CCD readout camera, grating array mechanism, mechanical and thermal tolerances, pointing, mass, power, cost
• Technology development roadmap: SAT grants; deeper gratings, larger gratings, smaller supports, mounting and alignment schemes, coating with metals
• Other needs: Ray-tracing for resolving power and area error budgets
Back-up slides