# Soft X-Ray Critical-Angle Transmission Grating Spectrometer for the International X-Ray Observatory

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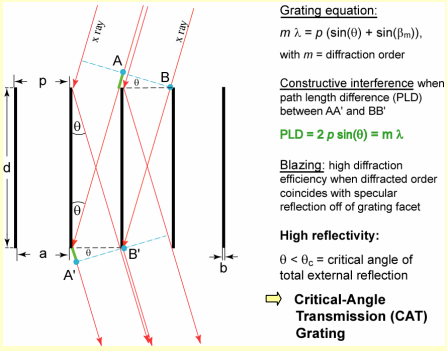
**ABSTRACT:** We have developed a new type of soft x-ray diffraction grating. This critical-angle transmission (CAT) grating [1-4] combines the advantages of traditional transmission gratings (very low mass, extremely relaxed alignment and flatness tolerances) with those of x-ray reflection gratings (high efficiency due to blazing in the direction of grazing-incidence reflection). In addition, grating spectrometers based on CAT gratings are well-suited for co-existence with high-energy focal plane microcalorimeter detectors as planned for the International X-Ray Observatory, since most high-energy x rays are undeflected and arrive at the telescope focus. We have previously micro-fabricated 574 and 200 nm-period prototypes of the smooth, high-aspect ratio, and sub-micron period structures necessary for efficient CAT gratings through interference lithography, anisotropic etching of silicon crystals, and critical-point drying. X-ray test have demonstrated high-efficiency blazing in accordance with theoretical predictions. We will describe the CAT grating principle and design, fabrication, and x-ray efficiency measurements, and discuss various high-resolution (E/ΔE ~ 5000), high-effective area (up to 10,000 cm²) implementations for a CAT grating spectrometer.

[1] R. K. Heilmann, M. Ahn, E. M. Gullikson, and M. L. Schattenburg, "Blazed High-Efficiency X-Ray Diffraction via Transmission through Arrays of Nanometer-Scale Mirrors", *Opt. Express* **16**, 8658 (2008).
[2] R. K. Heilmann, M. Ahn, and M. L. Schattenburg, "Fabrication and Performance of Blazed Transmission Gratings for X-Ray Astronomy", *Proc. SPIE* **7011**, 701106 (2008).
[3] K. Flanagan, *et al.*, "Spectrometer Concept and Design for X-Ray Astronomy Using a Blazed Transmission Grating", *Proc. SPIE* **6688**, 66880Y (2007).
[4] M. Ahn, R. K. Heilmann, and M. L. Schattenburg, "Fabrication of Ultrahigh Aspect Ratio Freestanding Gratings on Silicon-on-Insulator Wafers", *J. Vac. Sci. Technol. B* **25**, 2593 (2007).

## Blazed Transmission Grating Design for Soft X Rays




Grating equation:

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

with $m$ = diffraction order

Constructive interference when path length difference (PLD) between AA' and BB'

$PLD = 2p\sin\theta = m\lambda$

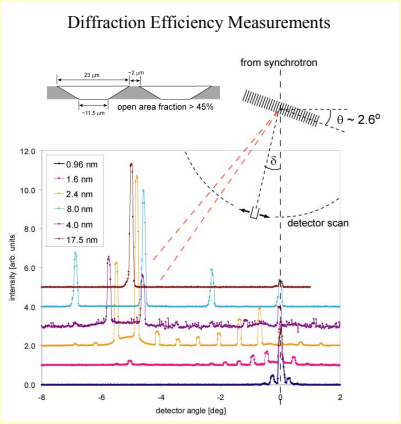
Blazing: high diffraction efficiency when diffracted order coincides with specular reflection off of grating facet

**High reflectivity:**

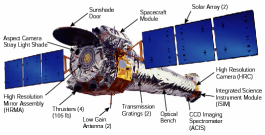
$\theta < \theta_c$ = critical angle of total external reflection

⇨ **Critical-Angle Transmission (CAT) Grating**

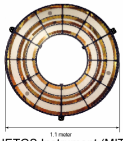
## Diffraction Efficiency Measurements



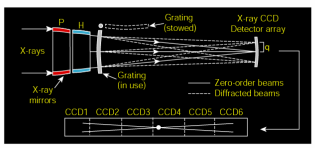

## *Chandra* Heritage: High Energy Transmission Grating Spectrometer (HETGS)



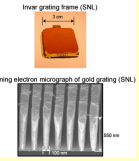

*Chandra* Telescope

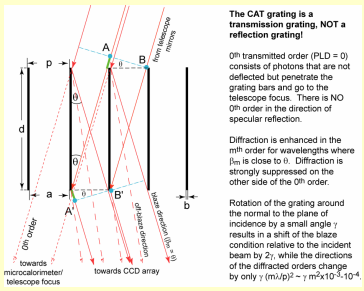


1.1 meter
HETGS Instrument (MIT)

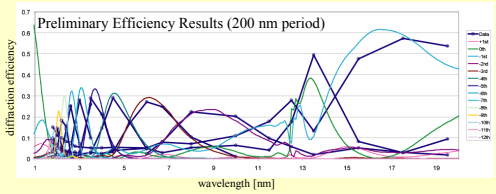



Rowland Torus Transmission Grating Geometry and CCD Readout Array

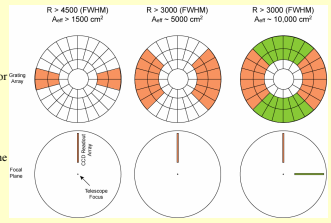


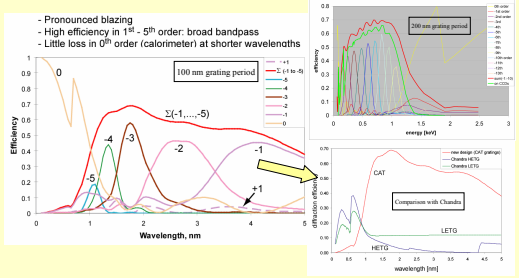

## Preliminary Efficiency Results (200 nm period)



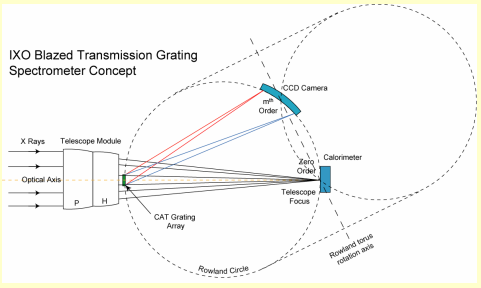

## Potential for High Resolution and Large Effective Area at Low Mass and Relaxed Alignment Tolerances




## Silicon CAT Grating Efficiency Predictions




## IXO Blazed Transmission Grating Spectrometer Concept




Only partial aperture coverage needed for minimum effective area requirement:
Sub-aperturing leads to increased spectral resolution
(taking advantage of anisotropic mirror scatter at grazing incidence)

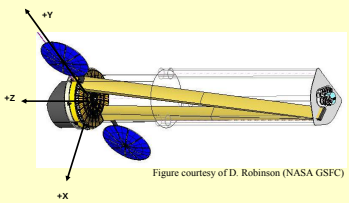
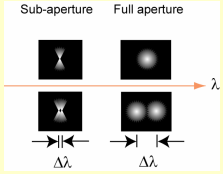
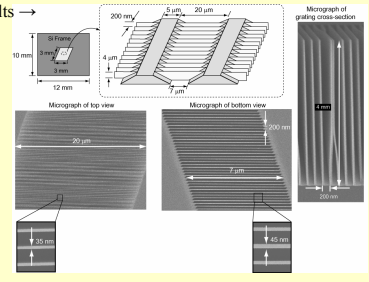


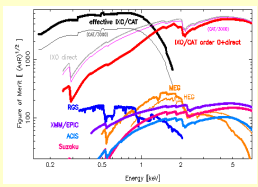

Figure courtesy of D. Robinson (NASA GSFC)




## 200 nm-period CAT Grating Fabrication Results →




Order of Magnitude Improvement in Figure of Merit for Soft X-Ray Spectroscopy




**Future Plans:**
- Fabricate larger CAT gratings with higher aspect ratios and higher throughput.
- More detailed ray-tracing of CAT Grating Spectrometer.

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See also http://space.mit.edu/home/dph/ixo/ (IXO/CAT-GS Development)
http://snl.mit.edu/ (Space Nanotechnology Laboratory)