Lynx X-ray Grating Spectrometer

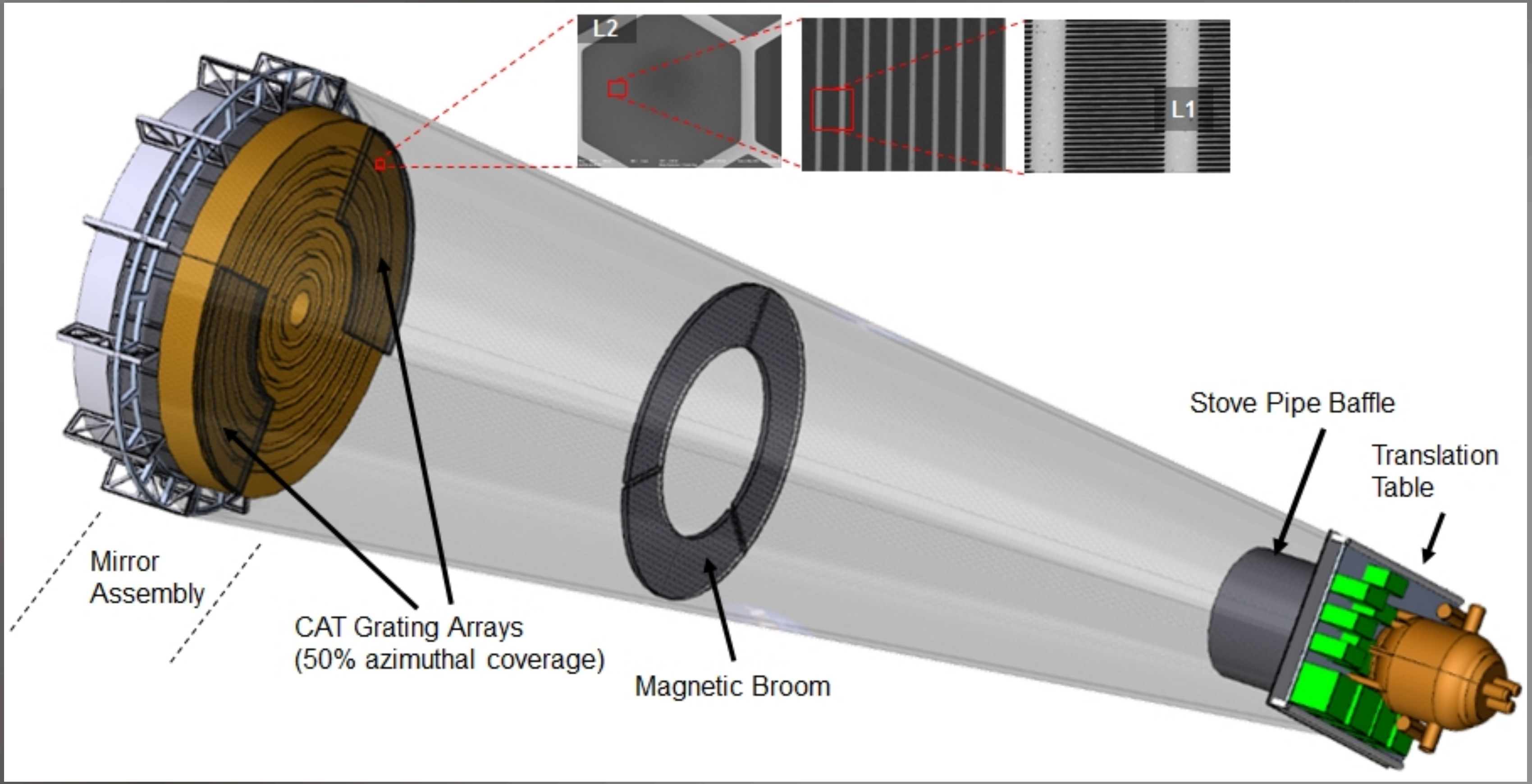
Ralf Heilmann[1] & Randy McEntaffer[2]
IWG Co-chairs and Grating Leads, on behalf of the IWG Grating Team
[1]MIT Kavli Institute for Astrophysics and Space Research
[2]Penn State University

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 cm^2*

  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



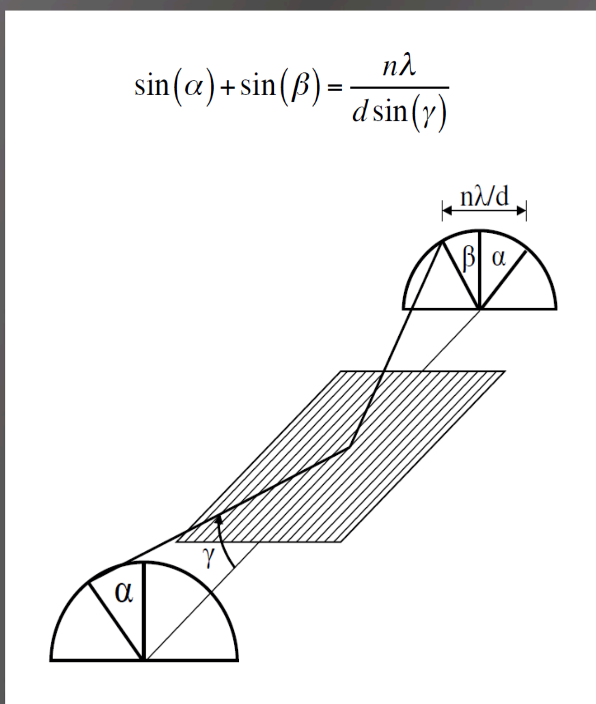
- Removable grating arrays aft of mirrors
- Fixed readout array in focal plane
- Blazed gratings; only orders on one side are utilized (smaller readout).
- No low energy high-resolution spectroscopy on Athena

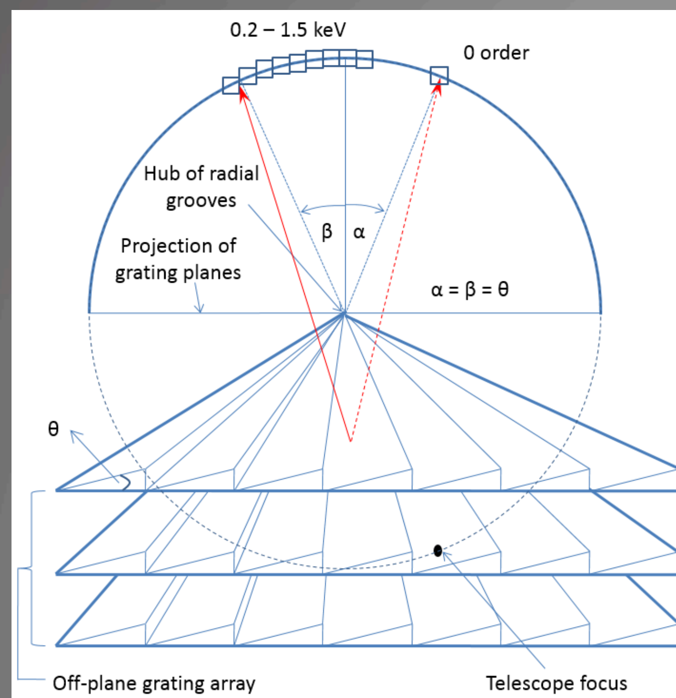
CAT and OPG Spectrometers: Commonalities

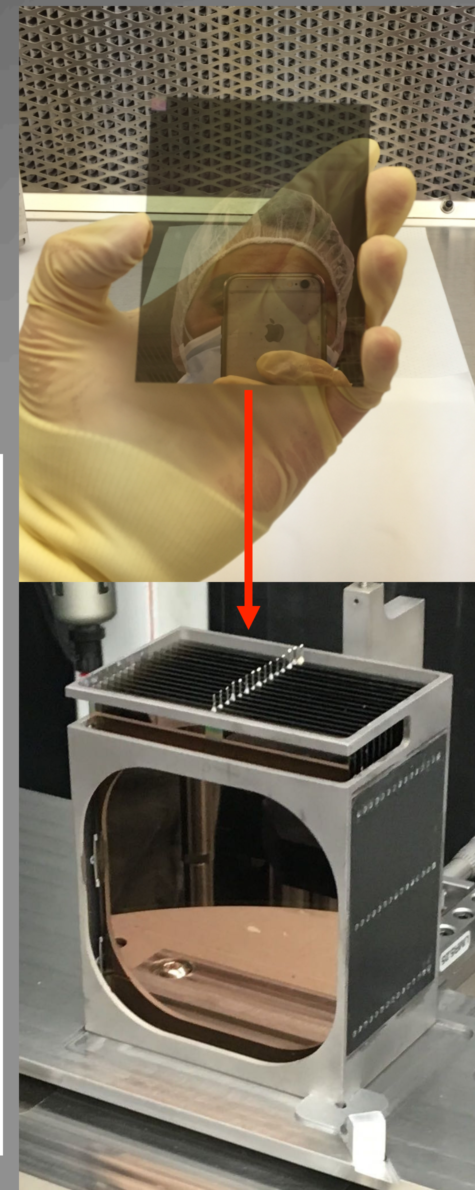
- Blazing into higher orders/larger angles: Increased resolving power.
- Maximum resolving power: (Dispersion distance or "throw")/(PSF plate scale projected onto dispersion axis).
- Sub-aperturing boosts resolving power.
- Aberrations reduce resolving power.
- High diffraction efficiency over broad 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

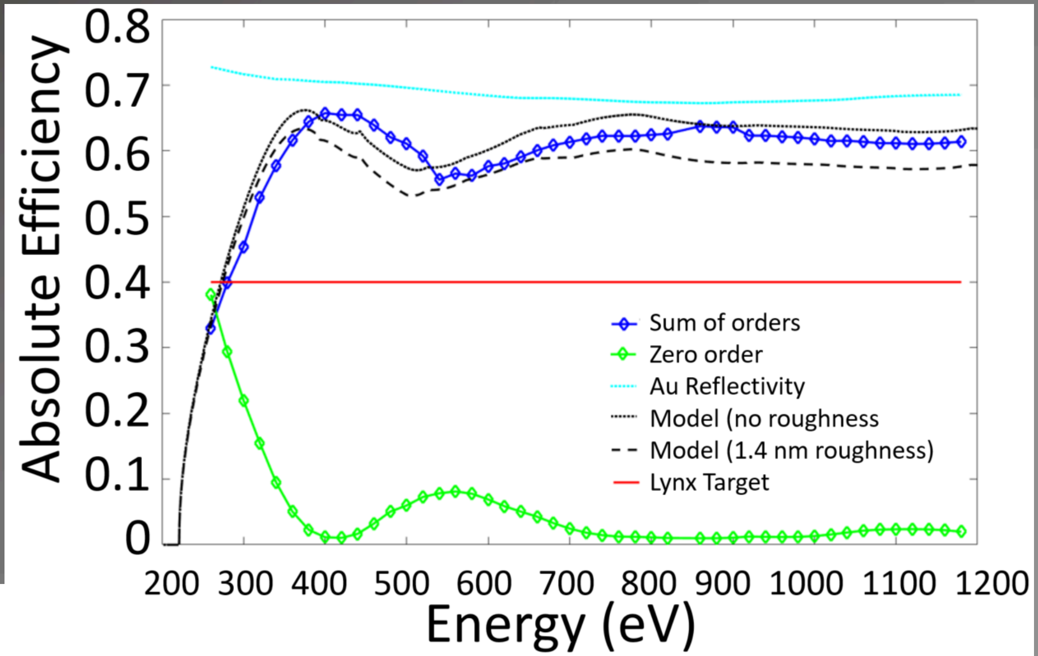


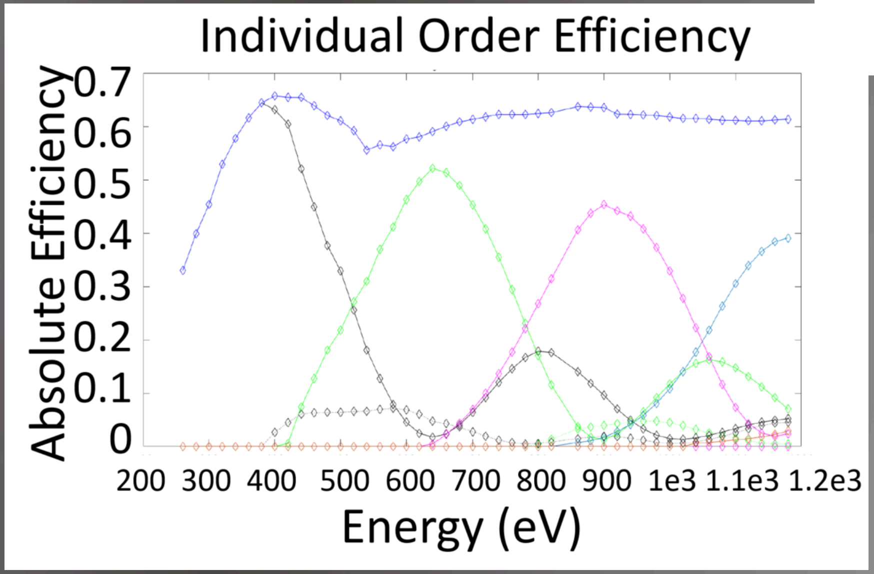


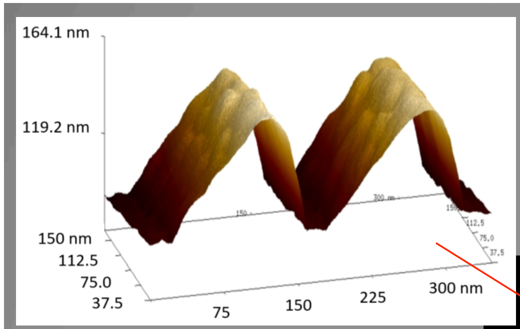


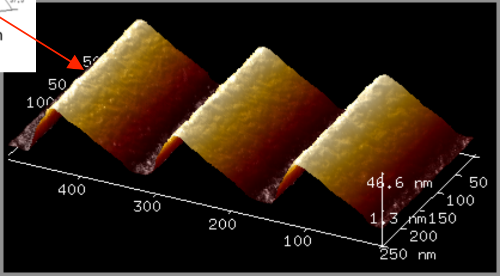
OPG Diffraction Efficiency

- ~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





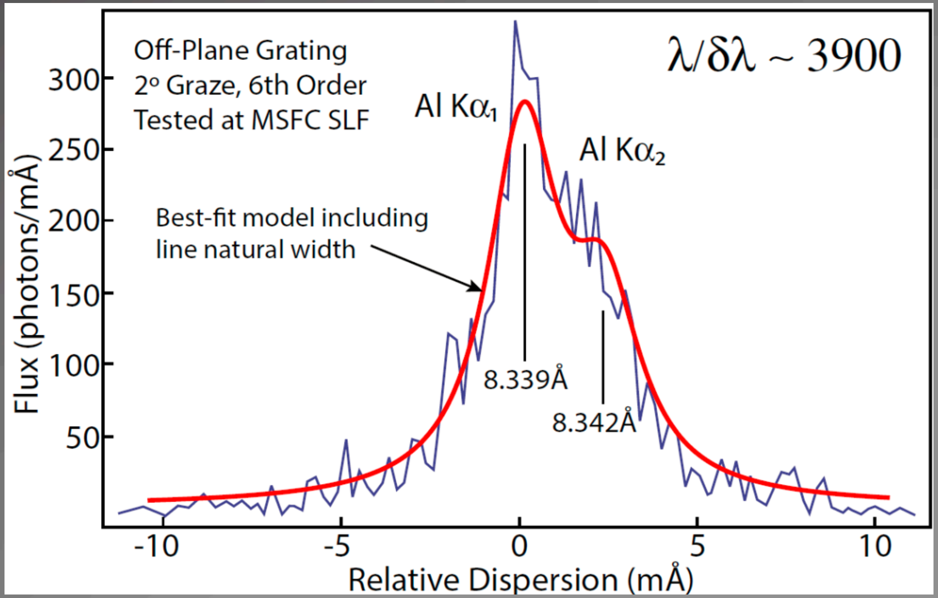


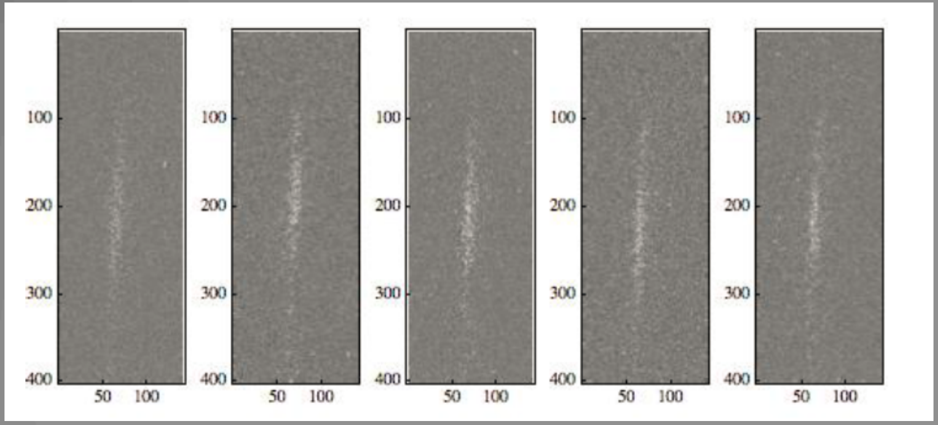


OPG Spectral Resolving Power

- MSFC Stray Light Facility (SLF)
  - 6^{th} order Al $K\alpha_1$ and Al $K\alpha_2$
  - Resolving power ~3900 ($\lambda/\delta\lambda$)
    - After removing contributions from source size and natural line widths
  - Small format grating, 25 x 32 mm
  - Laminar groove profile (no blaze)
  - Partial illumination

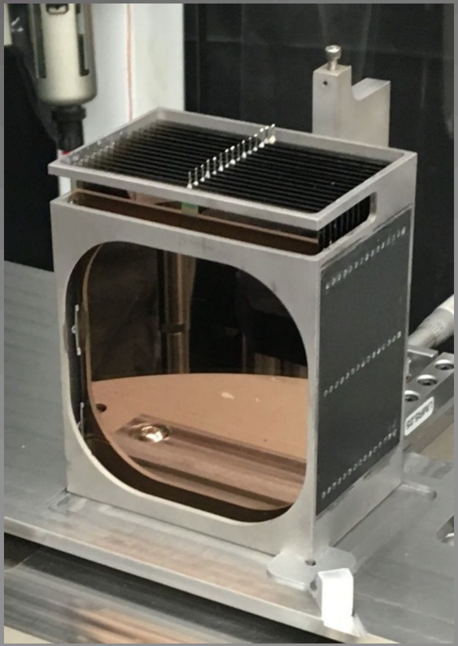
  - Recent SLF test on large format grating (75 x 96 mm)
  - Resolution limited to ~900
  - Fabrication errors need to be addressed

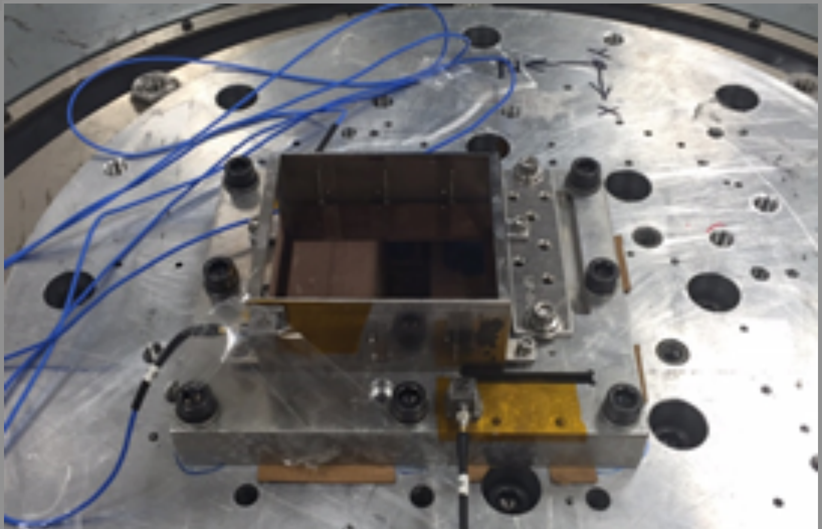




OPG Alignment

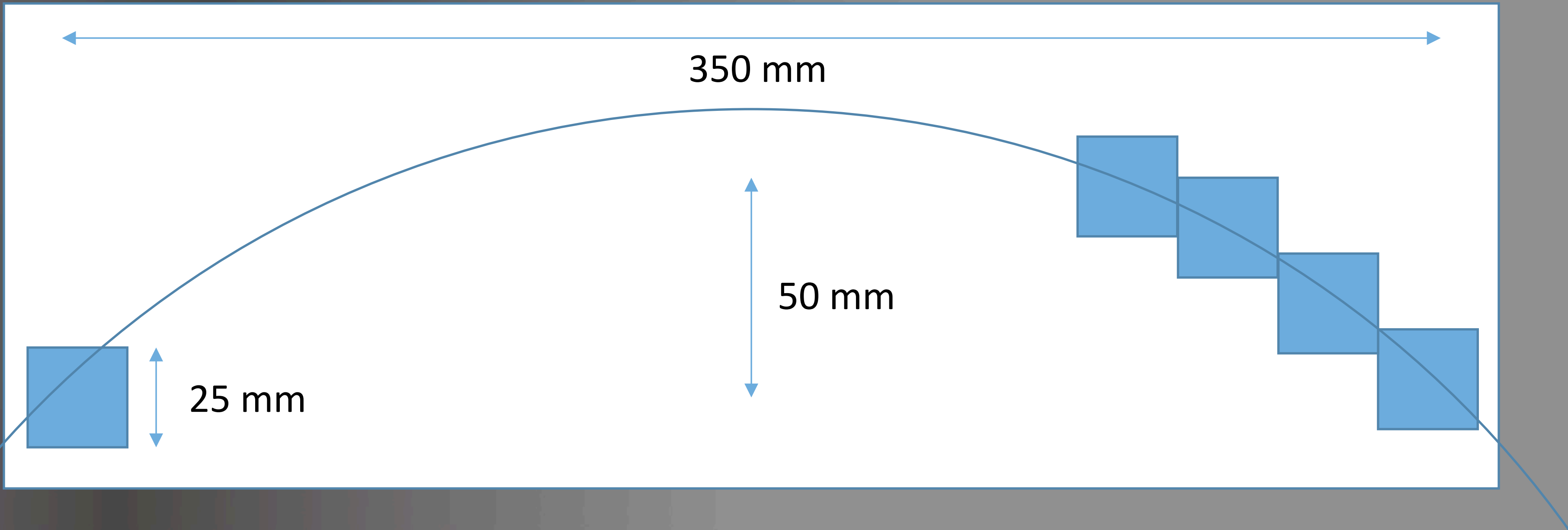
- Optical alignment methods have been developed at PSU and SAO
- Modules have been aligned, performance tested and environmentally tested at full NASA GEVS levels, e.g.
  - Vibe Qualification
    - ¼ G sine sweep
    - 14.1 G RMS: Steps = [3, 5, 7.1, 10, 14.1] – 2 dB per step, hold each step 20 sec, hold 14.1 G for 60 seconds
- Should consider several factors for LSF error budget
  - Astigmatism, period error, alignment (plates and modules), and thermal



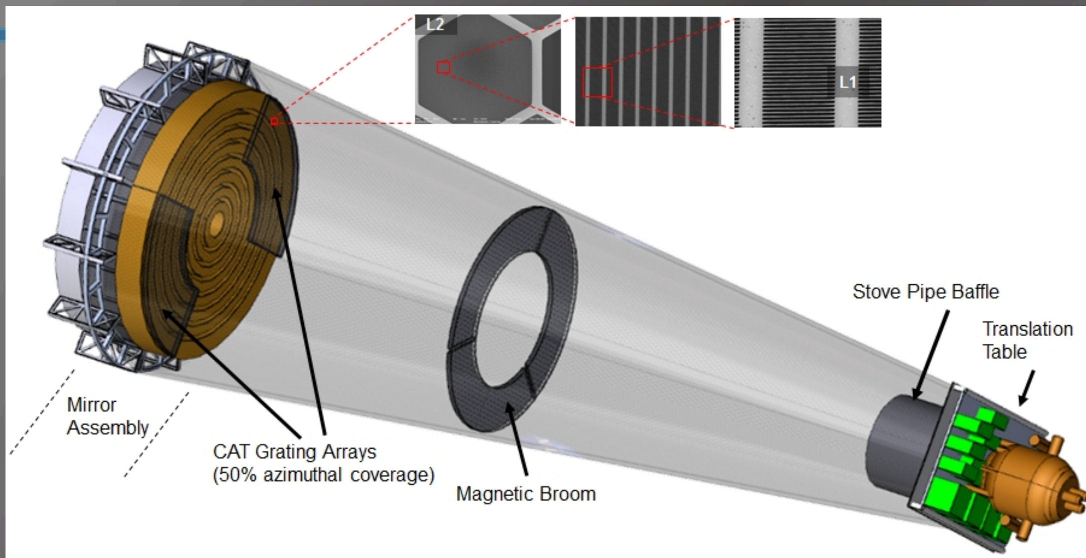


OPG Focal Plane

- 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 1^{st} order, 0.5” grating induce defocus, results in R~10,000

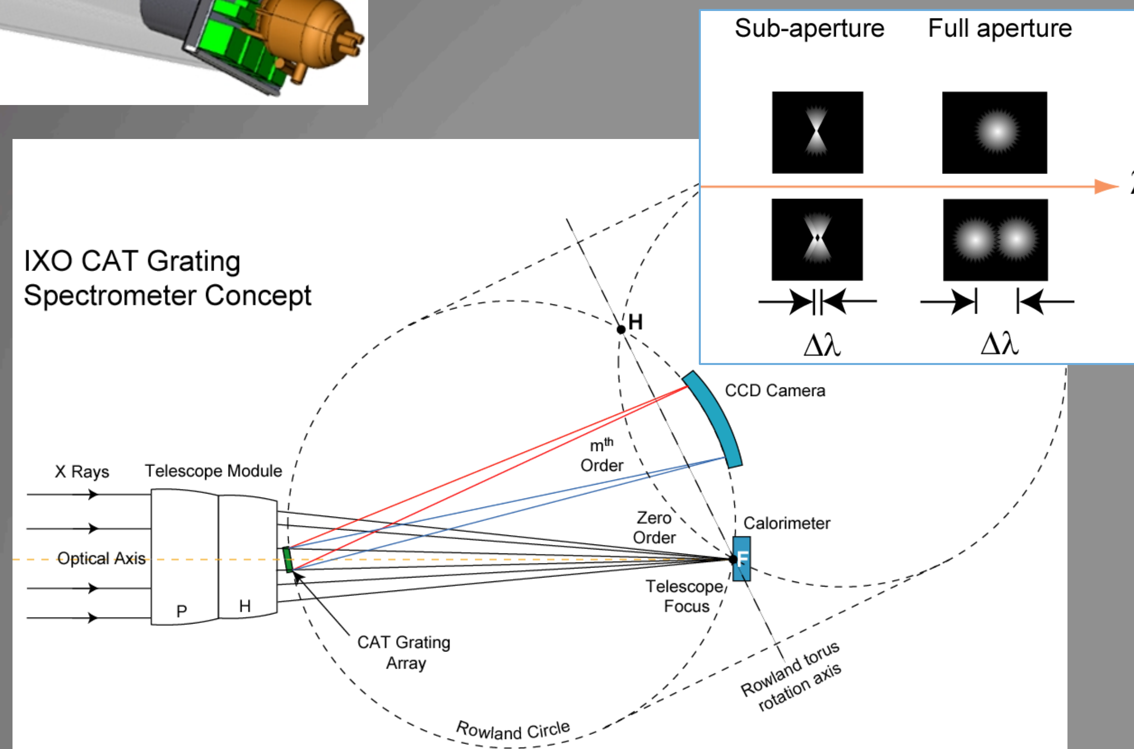


Critical Angle Transmission Gratings (MIT)



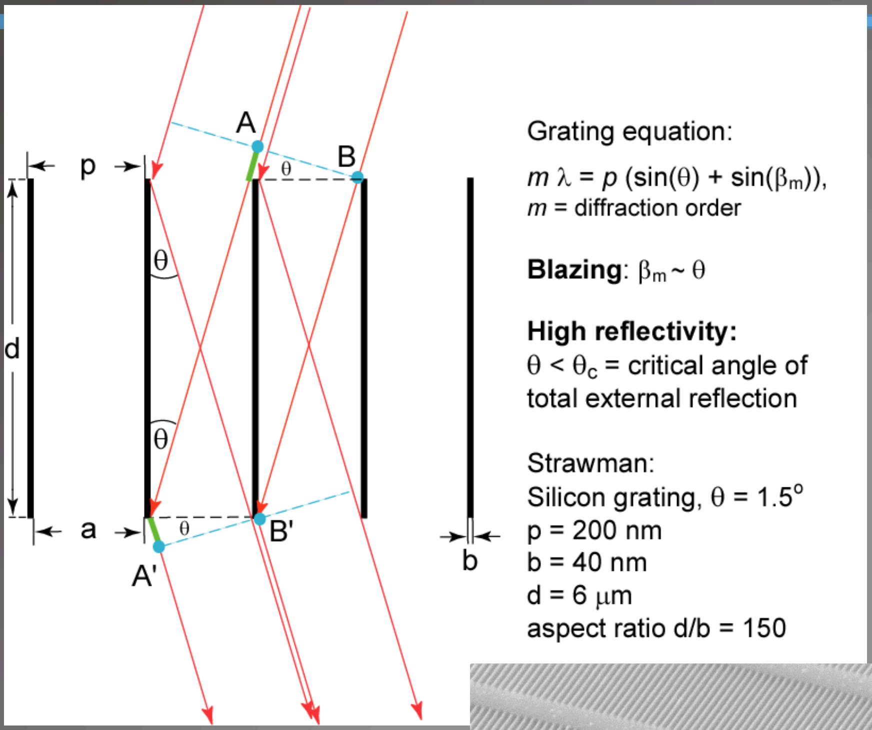
Advantages:
- low mass
- transparent at higher energies
- relaxed alignment & figure tolerances
- high diffraction efficiency
- demonstrated R > 10,000

- 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.

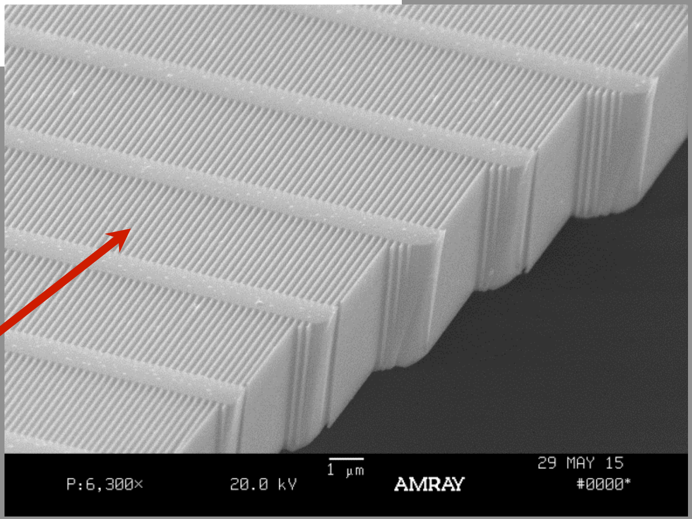


Critical Angle Transmission Gratings (MIT)

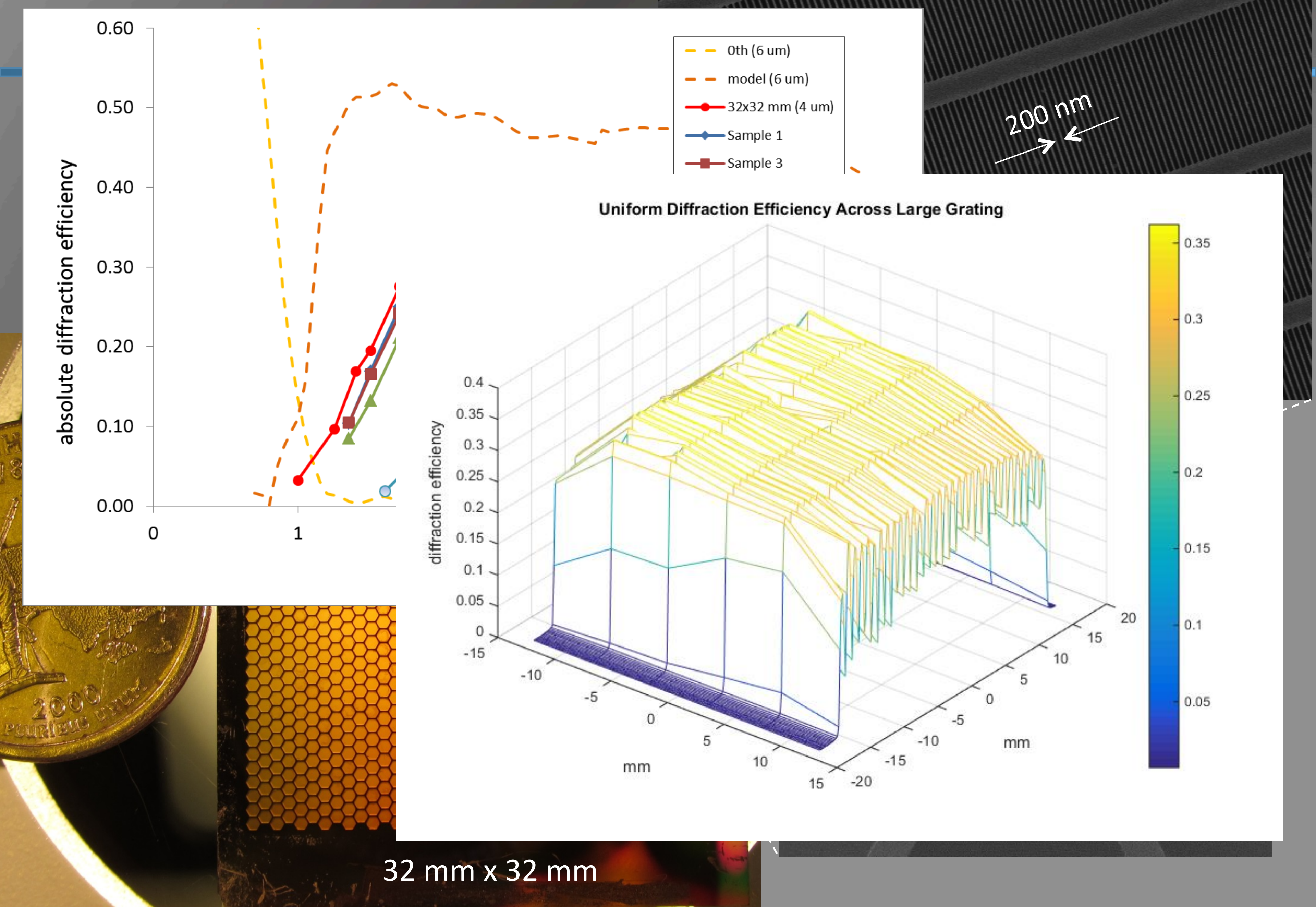
- CAT grating combines advantages of transmission gratings (relaxed alignment, low weight) with high efficiency of blazed reflection gratings.
- Blazing achieved via reflection from grating bar sidewalls at graze angles below the critical angle for total external reflection.
- High energy x rays undergo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



200 nm pitch
CAT grating bars

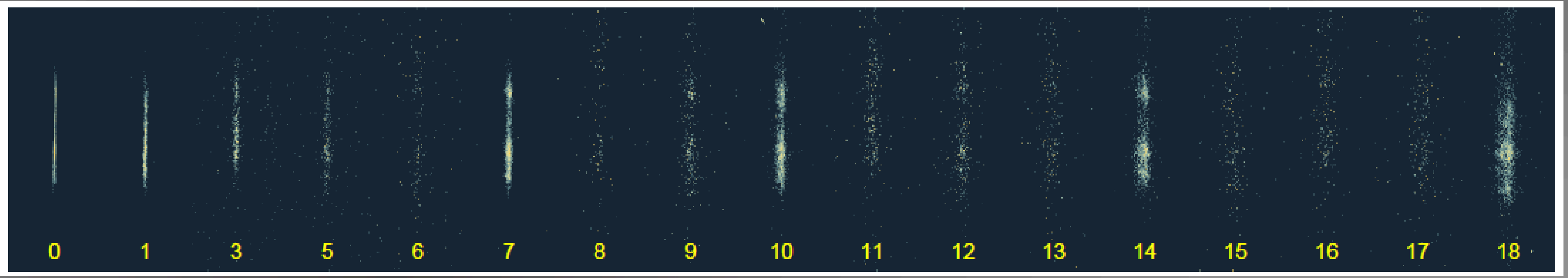


Recent Results

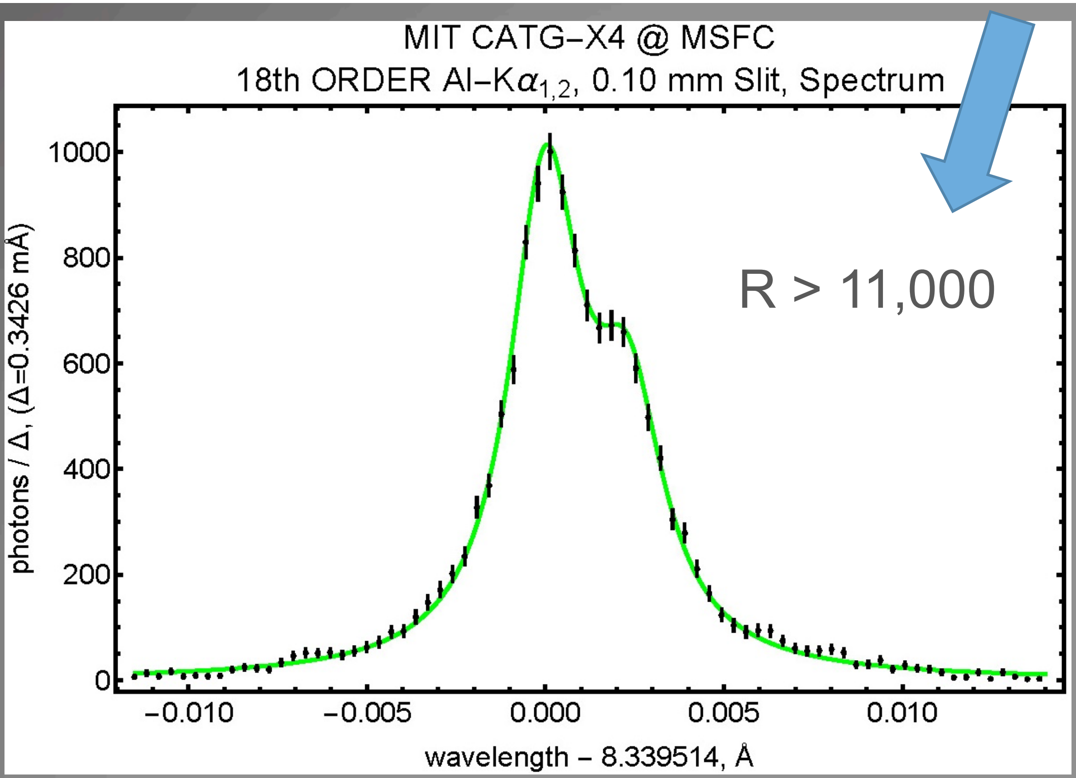


No Measurable Loss of Resolving Power

Pt-coated CAT gratings with GSFC slumped glass mirror pair: R > 11,000 in 18th order at 0.834 nm



- R ~ 24,000 in 18th order (best fit) and R > 11,700 (95% confidence) with ~ 1” mirror LSF (GSFC slumped glass P&H pair).
- R ~ 3100 in 9th order with first 12m-focal length SPO with ~ 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

detection strong lines, $W \gg \tilde{\Delta} E$: $$M_\ell = \sqrt{\sum_{i=1}^{n} A_i},$$

detection weak lines, $W \ll \tilde{\Delta} E$: $$M_\ell = \sqrt{\sum_{i=1}^{n} \frac{A_i}{\Delta E_i}}.$$

velocity strong lines, $W \gg \tilde{\Delta} E$: $$M_\mathrm{v} = \sqrt{\sum_{i=1}^{n} \frac{E_i^2 A_i}{(\Delta E_i)^2}},$$

velocity weak lines, $W \ll \tilde{\Delta} E$: $$M_\mathrm{v} = \sqrt{\sum_{i=1}^{n} \frac{E_i^2 A_i}{(\Delta E_i)^3}}.$$

Jelle Kaastra for IXO

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