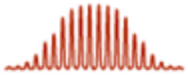
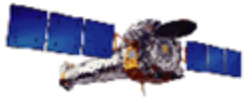


Space Nanotechnology Laboratory
Massachusetts Institute of Technology



Critical-Angle Transmission Gratings for the International X-Ray Observatory

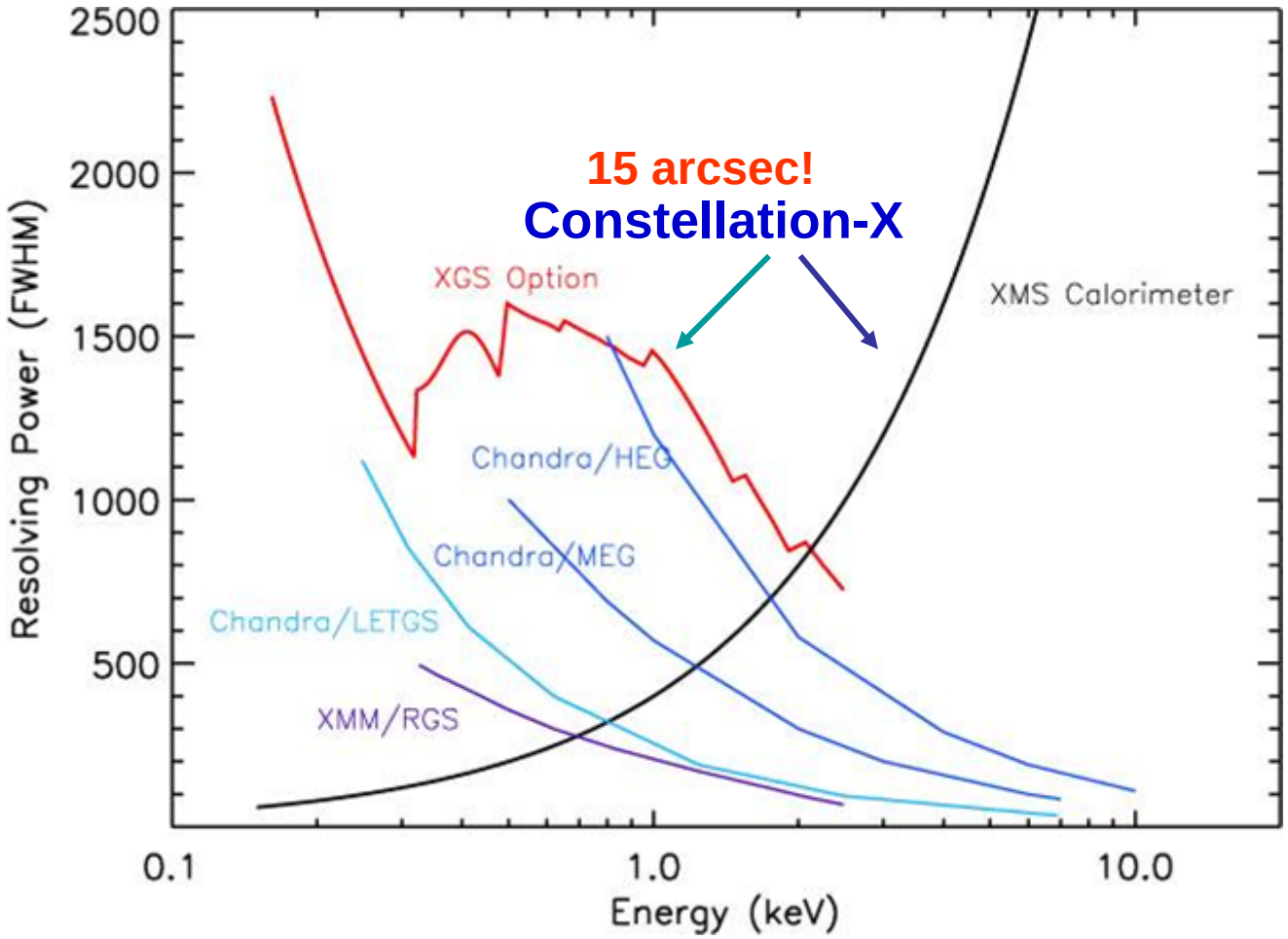
Ralf K. Heilmann,
Minseung Ahn, and Mark L. Schattenburg

Space Nanotechnology Laboratory
MIT Kavli Insitute for Astrophysics and Space Research
Massachusetts Institute of Technology

Con-X/IXO Facility Science Team Meeting
NASA GSFC, Greenbelt, MD, Aug. 20, 2008

MIT Kavli Institute for Astrophysics and Space Research

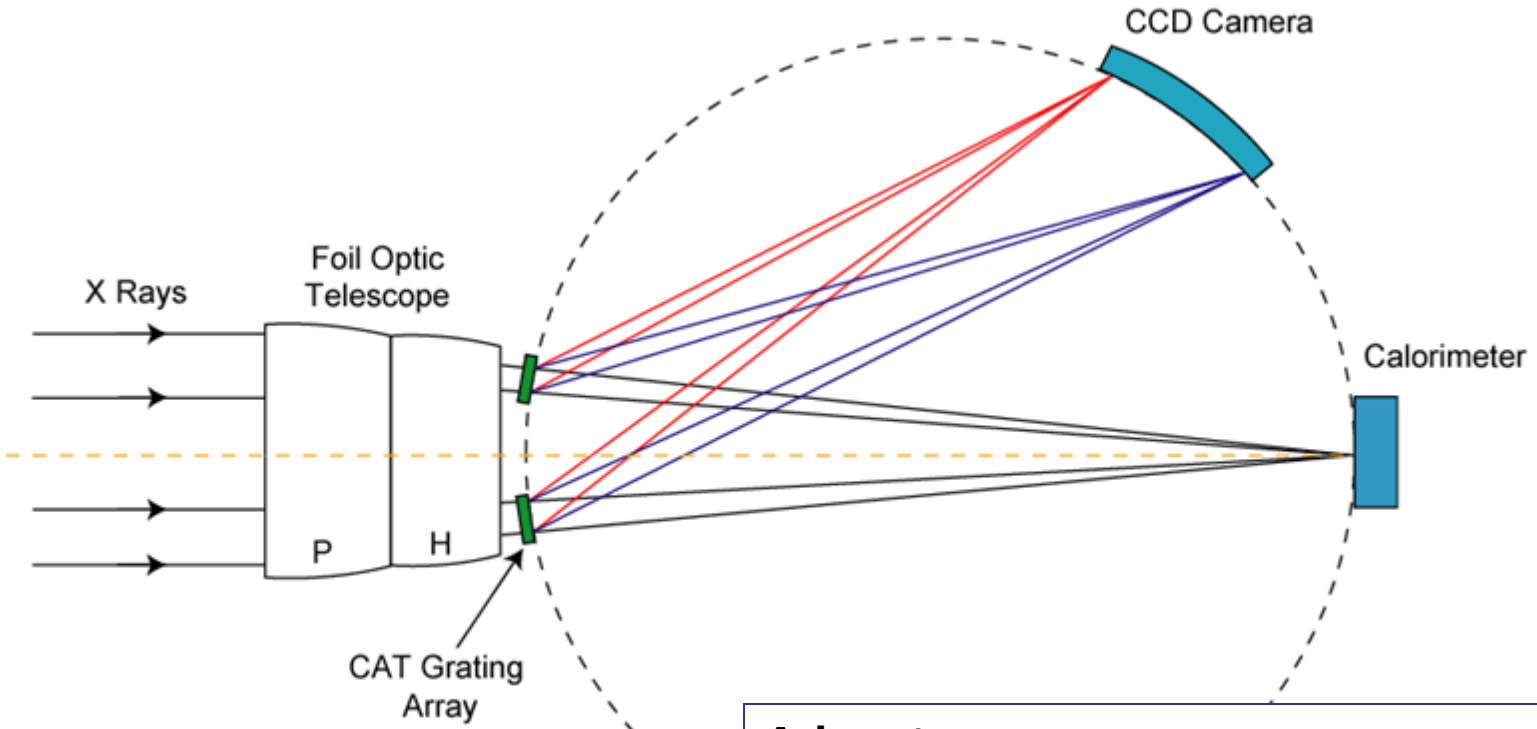
Constellation-X spectral resolution compared to previous missions



Grating (XGS) with a fixed $\Delta\lambda$ dispersion provides higher spectral resolution at low energies, while fixed $\Delta\mathbf{E}$ of a calorimeter (XMS) provides higher spectral resolution at higher energies

Heilmann et al., CAT gratings for IXO

IXO CAT (Critical-Angle Transmission) Grating Spectrometer Concept



- IXO: 5 arcsec telescope
- CAT gratings blazed 3 deg from optical axis

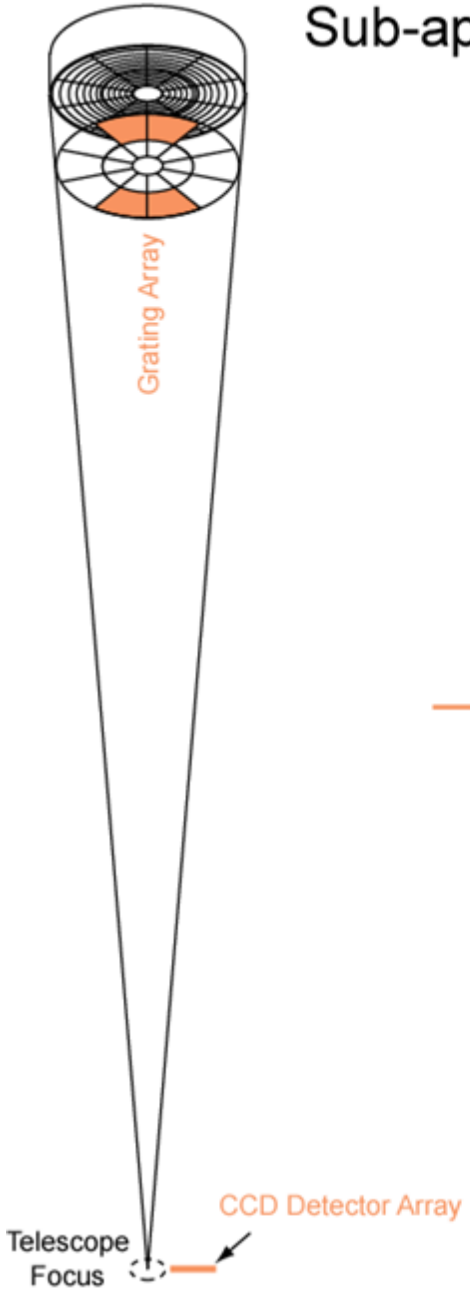
⇒ **<R> ~ 2000**

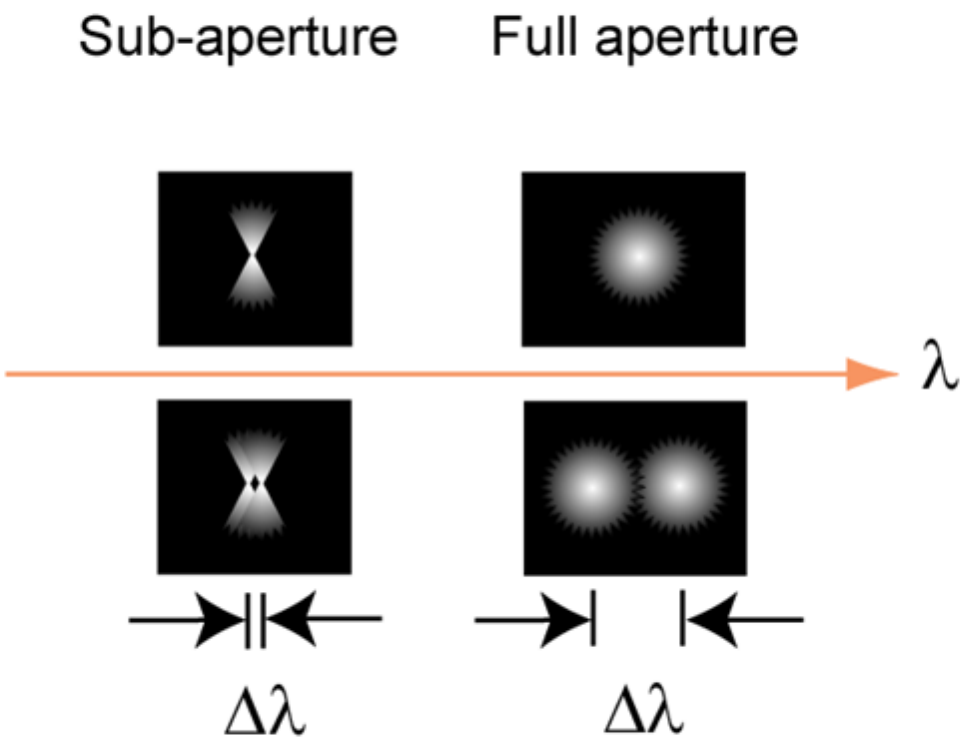
without sub-aperturing!

Advantages:

- low mass
- relaxed assembly tolerances
- high diffraction efficiency
- up to 4X dispersion of Chandra HETGS
- no pos. orders (i.e., smaller detector)

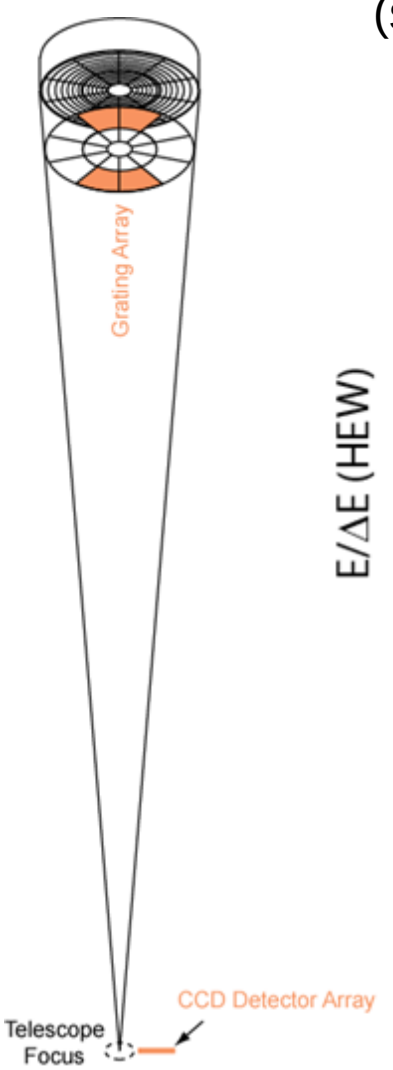
Sub-aperturing/shaping the PSF to increase the resolution

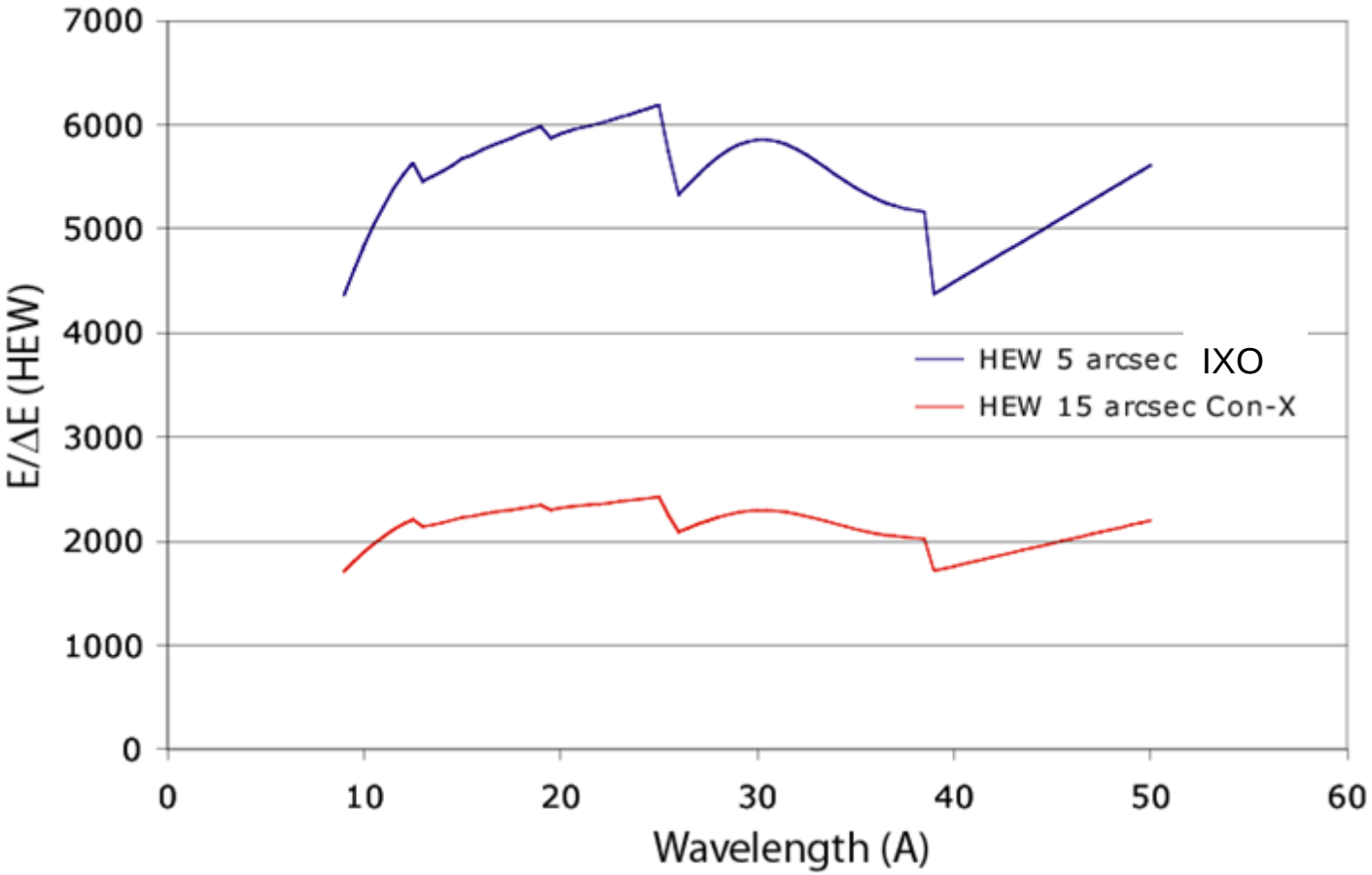




Efficiency-Weighted Resolving Power (HEW)

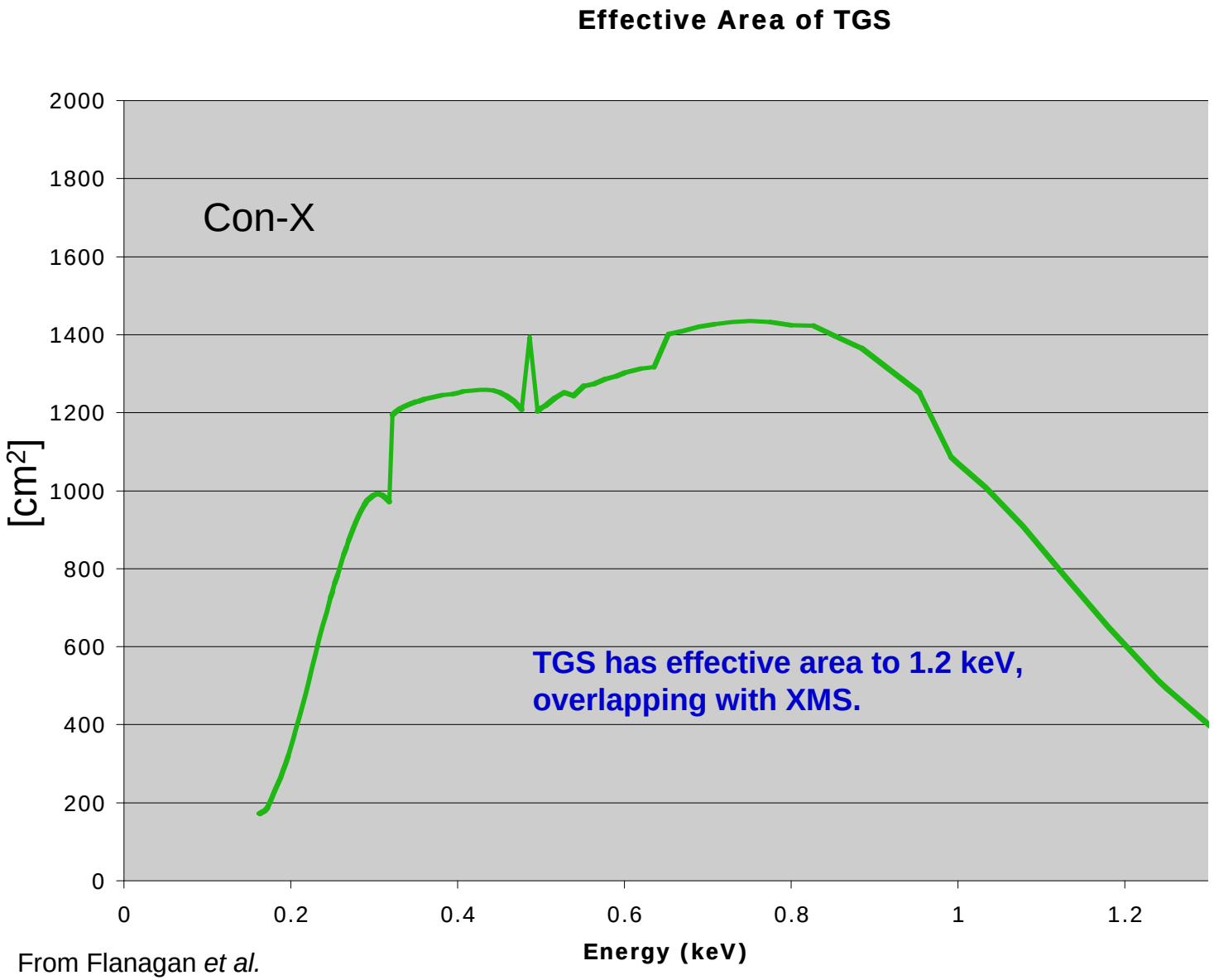
(sub-apertured, two opposing 72 deg segments)





From Flanagan *et al., Proc. SPIE* 6688 (2007)

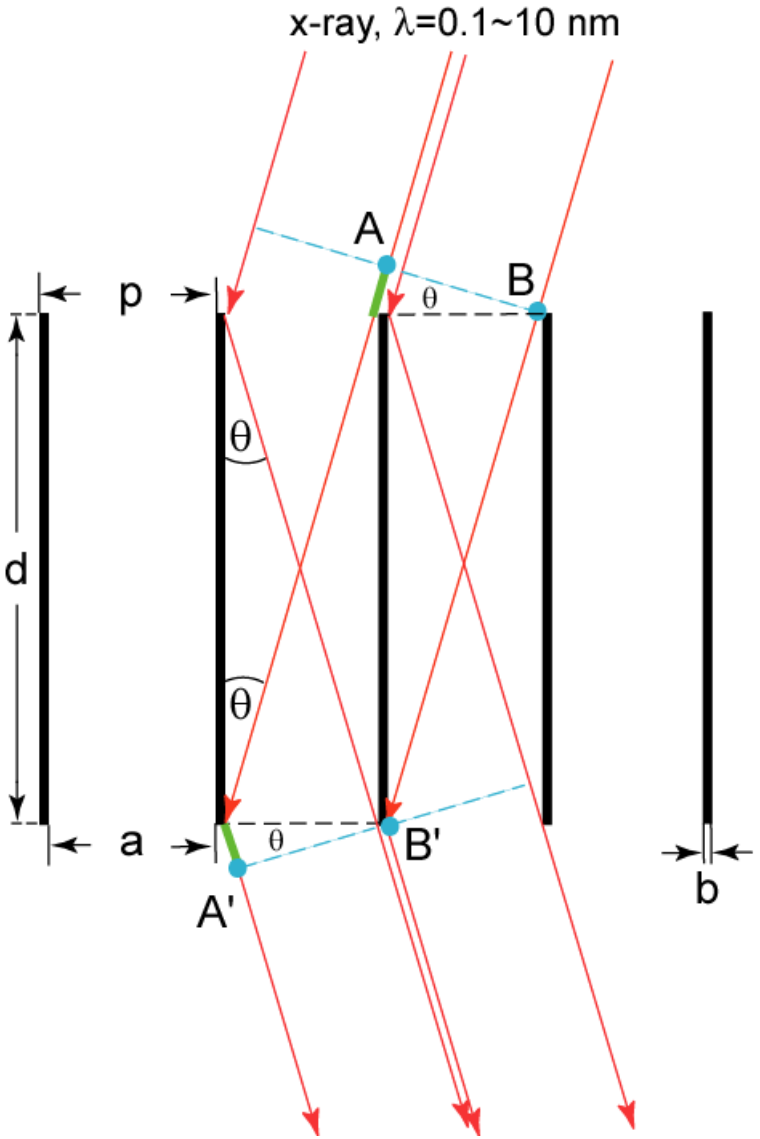
Effective Area of TGS provides high spectral resolution to 1keV and above



IXO: need less than 2 x 36 deg segments covered by CAT gratings

From Flanagan *et al.*

Critical Angle Transmission (CAT) Grating



Constructive interference when:
path length difference (PLD)
between A' and B'

PLD = 2 *p* sin(θ) = m λ

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

Refractive index and critical angle for x-ray and EUV :

$n=1-\delta+i\beta$, $\delta<<1$, $\beta<<1$, $\beta\neq 0$

$\theta_c=(2\delta)^{1/2}$: ~1 ~ 2°

High reflectivity when:

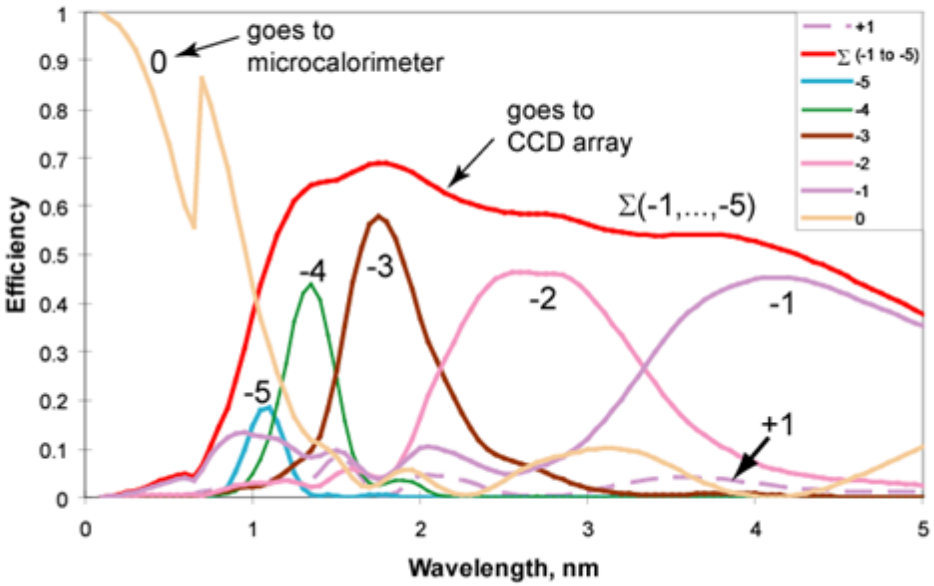
$\theta < \theta_c$, total external reflection

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

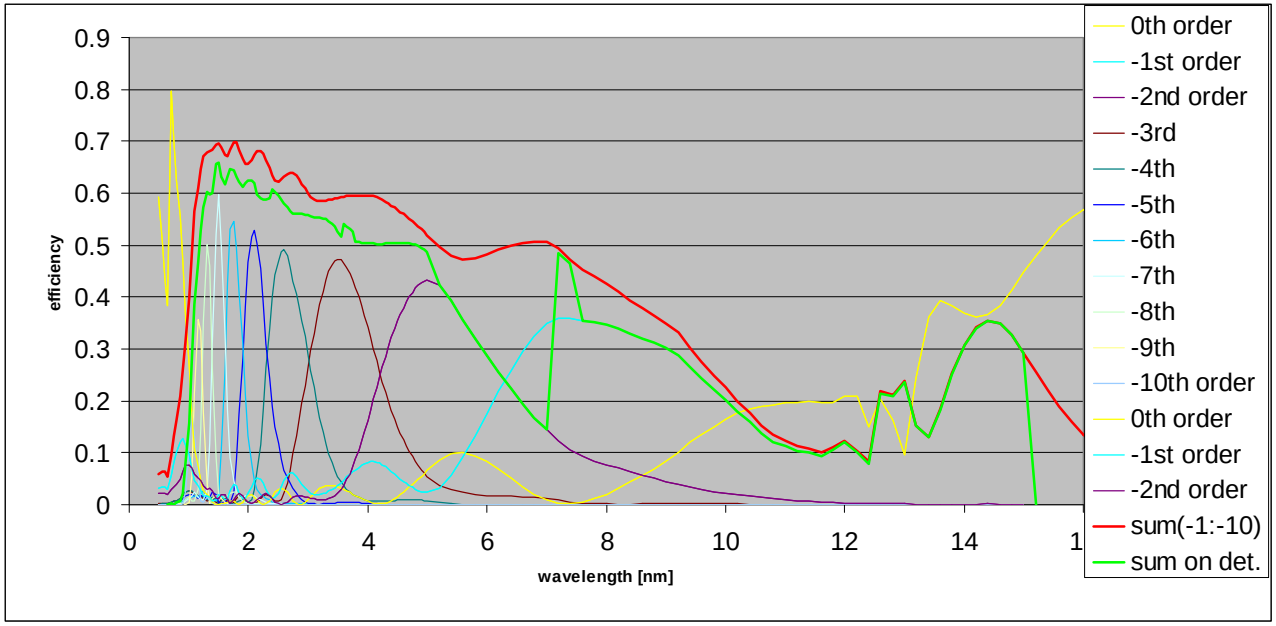
See also Heilmann *et al.*, Opt. Express 16, 8658 (2008)

Predicted Silicon CAT Grating Diffraction Efficiency: (blaze 3 deg from 0th order)

- Pronounced blazing
- High efficiency in 1st - 5th order: broad bandpass
- Little loss in 0th order (calorimeter) at shorter wavelengths



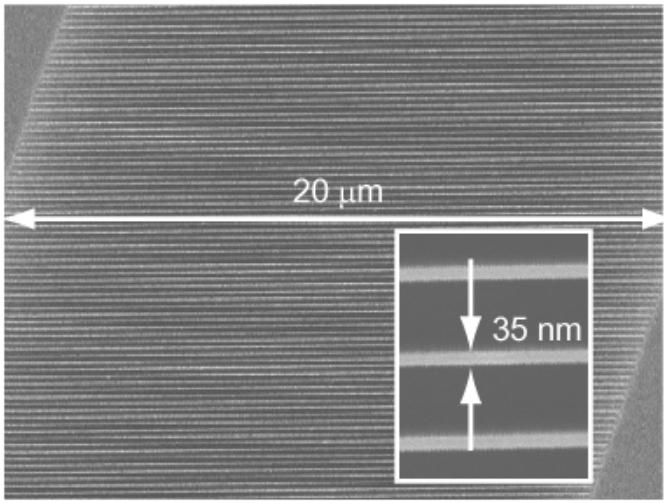
period
p = 100 nm



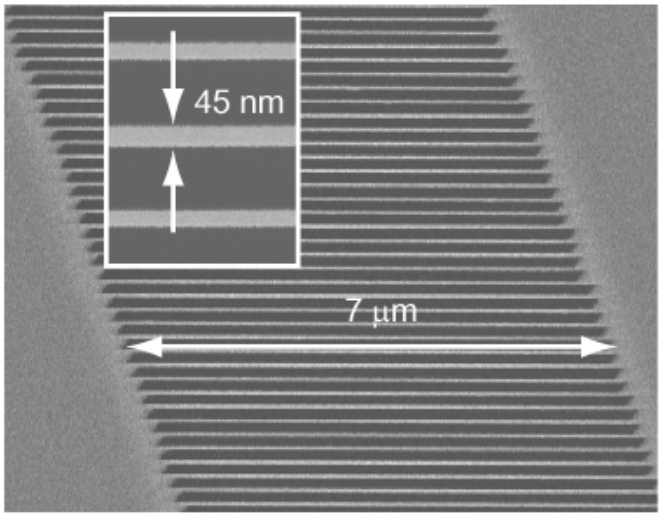
period
p = 200 nm

Recent 200 nm-period CAT grating fabrication results

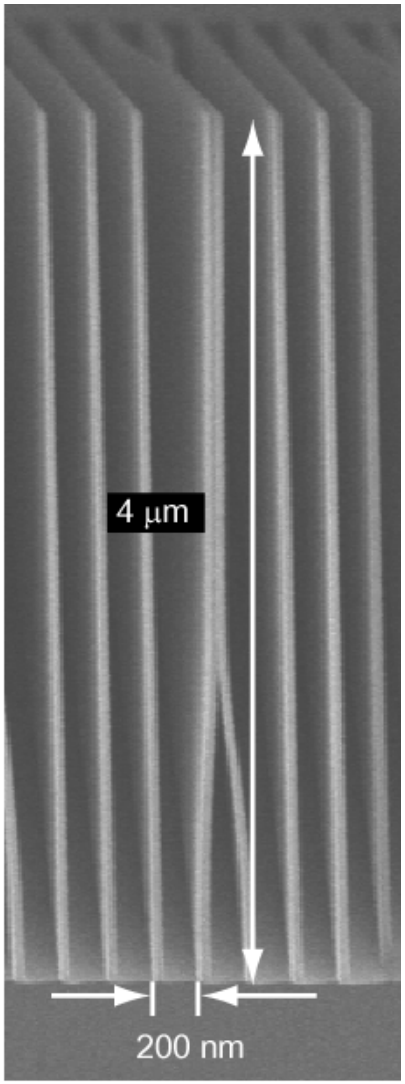
- Smaller period
- Smaller sidewall angle
- Higher etch anisotropy
- Larger process latitude
- Larger open area



(a)



(b)

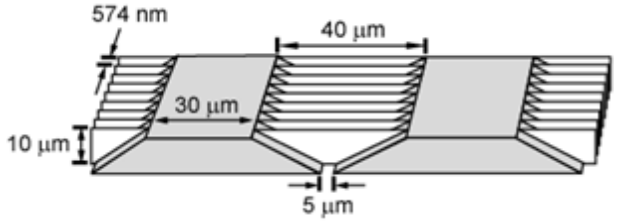


(c)

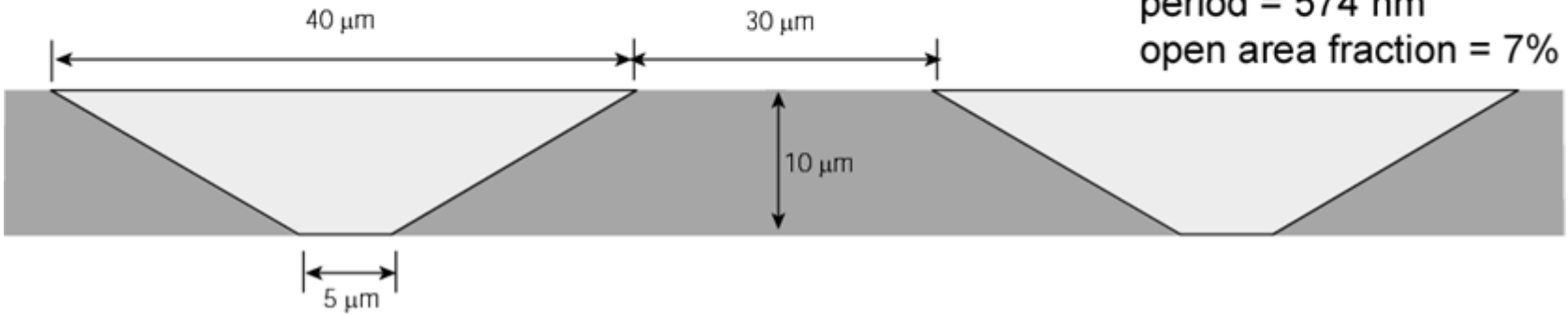
Scanning electron micrographs:

(a) Top view
(b) Bottom view
(c) Cross section (destructive)

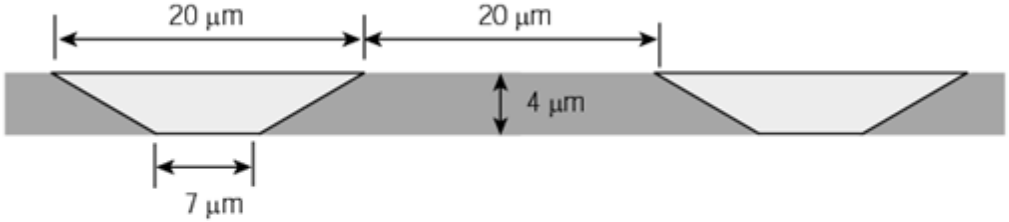
CAT grating fabrication development up to date:



May 2007



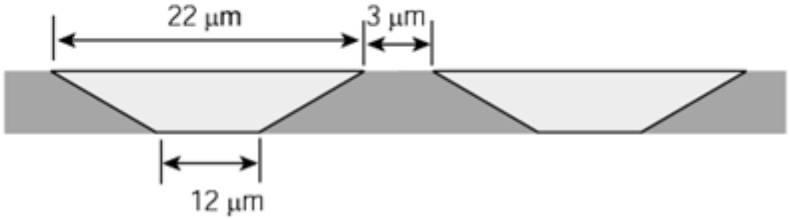
period = 574 nm
open area fraction = 7%



open area fraction:

17.5%

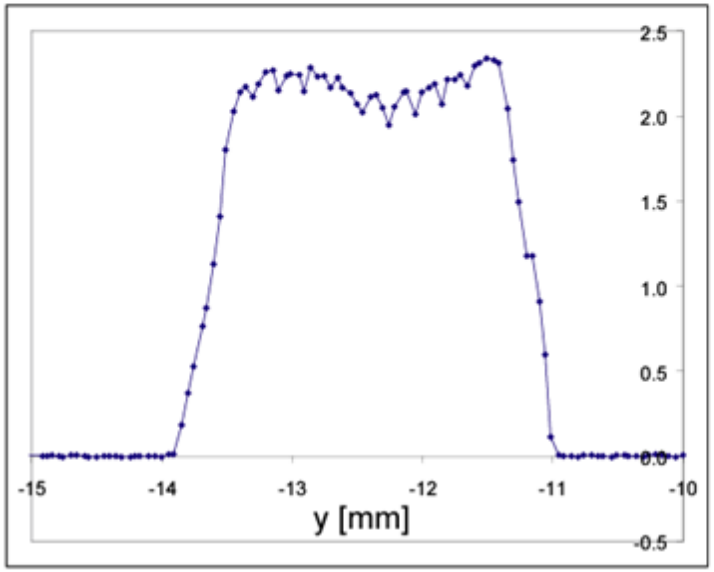
period = 200 nm

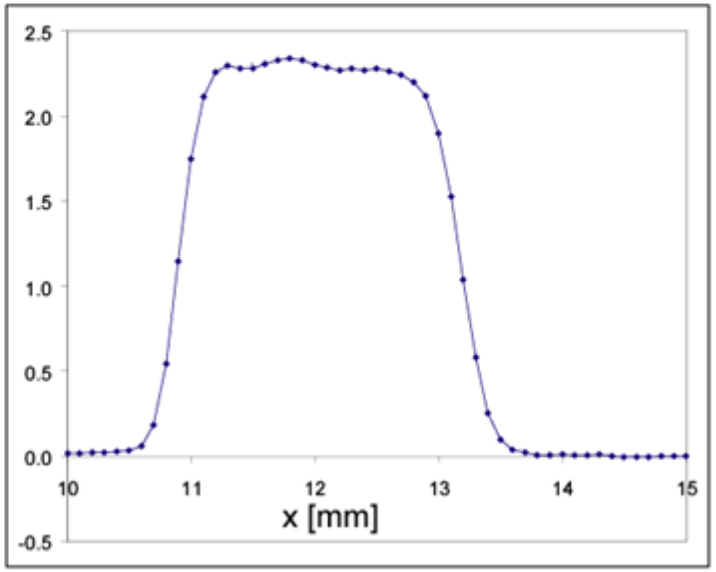


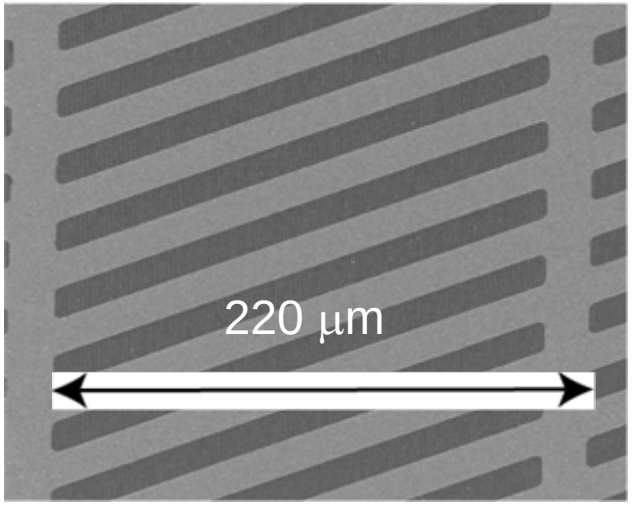
48% June 2008

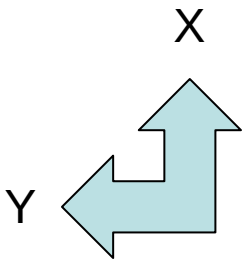
⇒ X-ray tests

Grating Homogeneity: Scanning grating through beam, detector on blaze



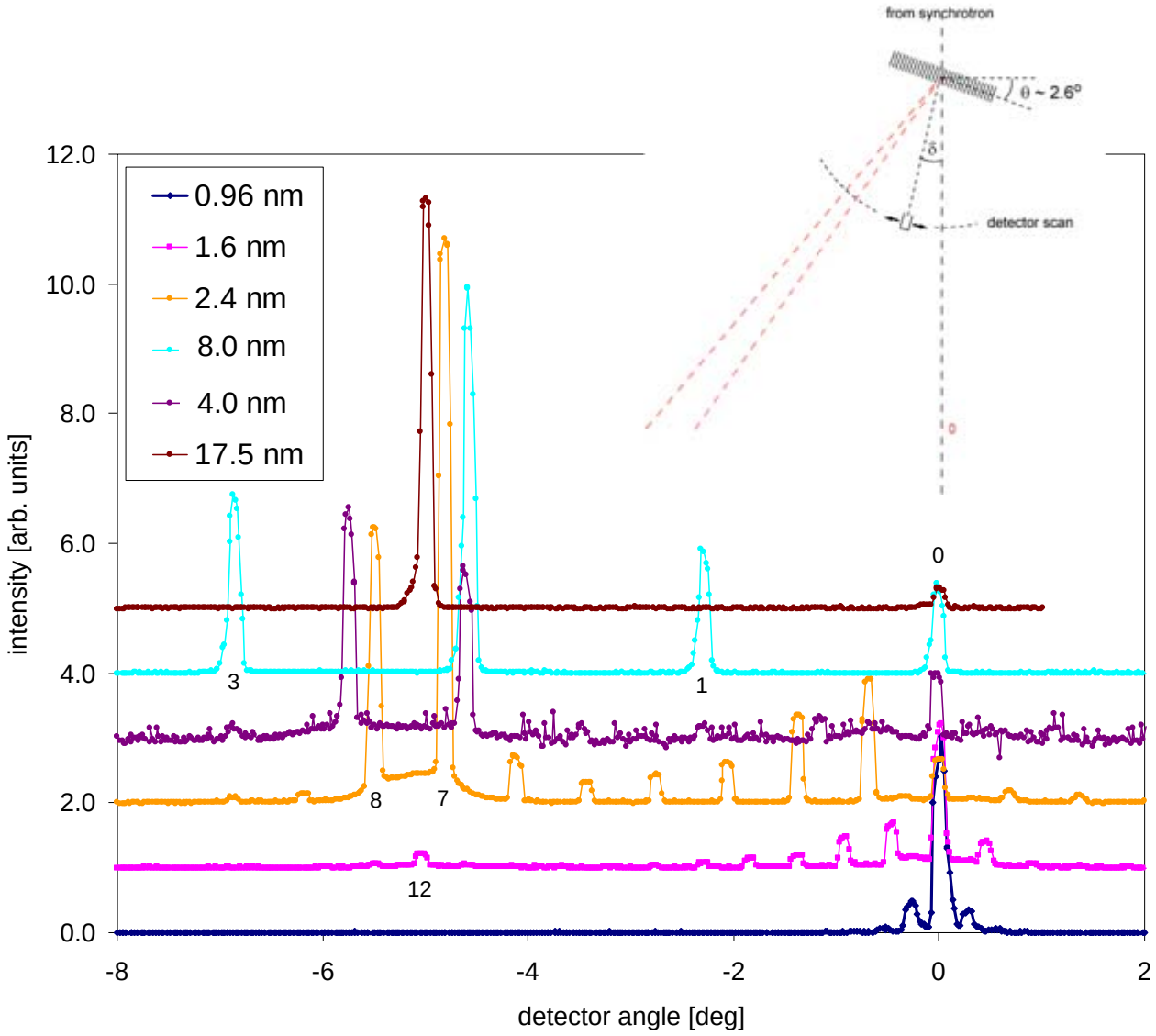






Heilmann et al., CAT gratings for IXO

First x-ray data from 200 nm-period CAT gratings



- strong blazing
- reduced blazing
  for λ with $\theta_c(\lambda) < \alpha$
- 0^{th} order transmitted
  at shortest wavelengths
  (CAT grating becomes
  weak phase grating)

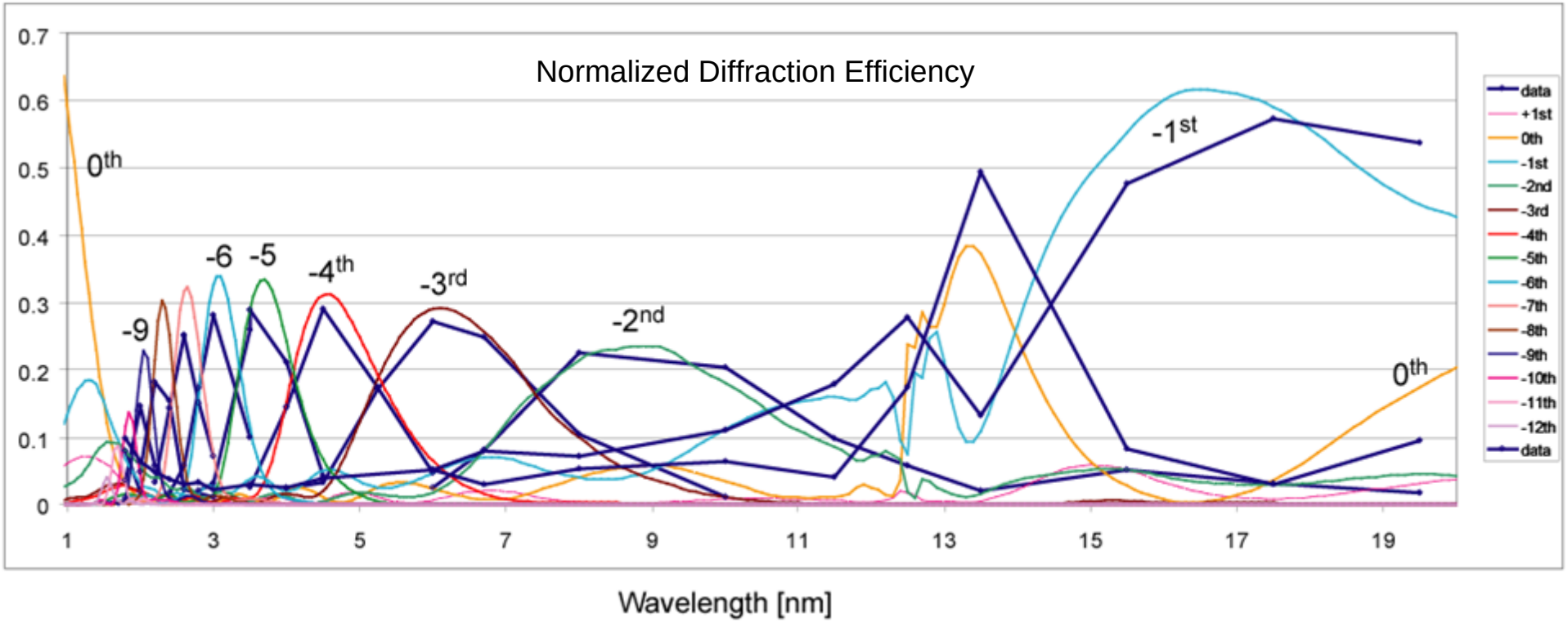
α = 2.6 deg
(blaze 5.2 deg from 0^{th} order)

Raw data
(not normalized)

Heilmann *et al.*
Proc. SPIE 7011 (2008)

Diffraction Efficiency: Theory and Experiment

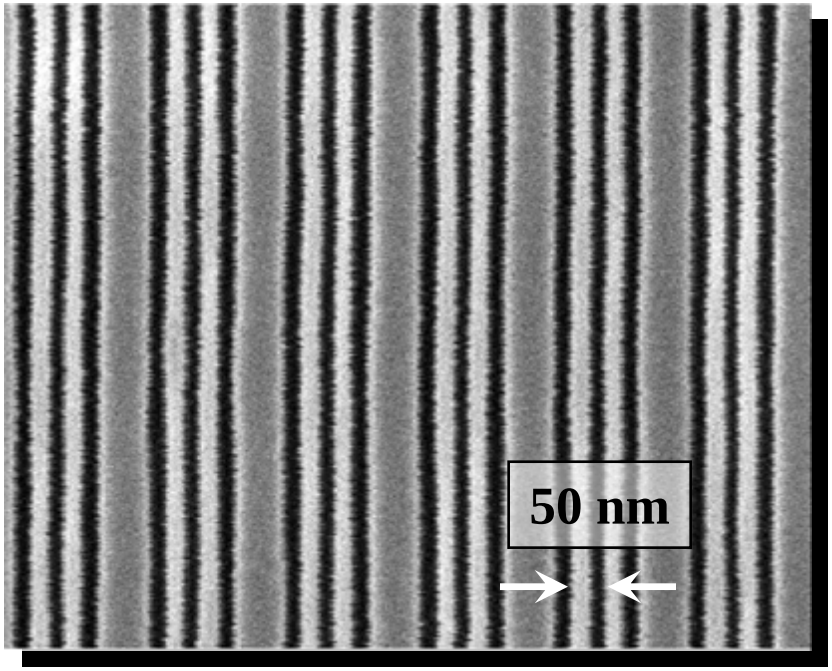
p = 200 nm, θ = 2.6 deg (blaze at 5.2 deg. from 0th order)



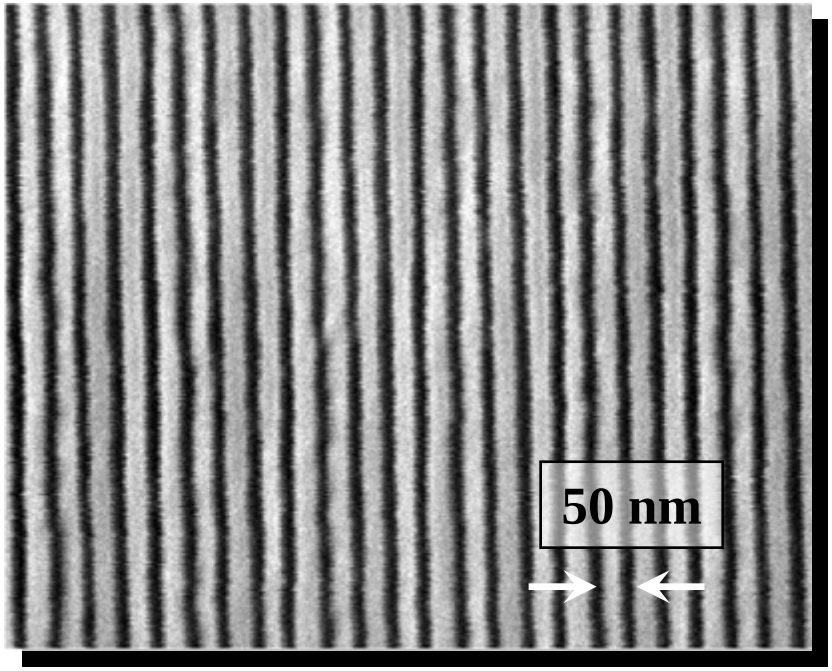
Four-fold Multiplication: 50 nm-period Grating

Chang *et al*., Opt. Lett. 33, 1572 (2008)

Three grating levels



Four grating levels



- In-house IL capabilities for large-area gratings down to 50 nm period.

Summary

- Demonstrated high-efficiency blazing in soft x-ray transmission gratings, close to theoretical predictions.
- Critical-Angle Transmission (CAT) gratings combine advantages of transmission and reflection gratings (low mass, relaxed tolerances, high diffraction efficiency).
- Blazing for higher orders enables TG spectrograph with high resolution (~ 2000 – 6000).
- Effective area requirements easy to satisfy, lots of room for trades.
- Need to increase open area.
- Need to increase grating bar aspect ratio (100 → 150).
- 200 nm period might be sufficient, but can go to 100 nm period if needed.

Acknowledgements

- Chih-Hao Chang, Yong Zhao (multilevel interference lithography)
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