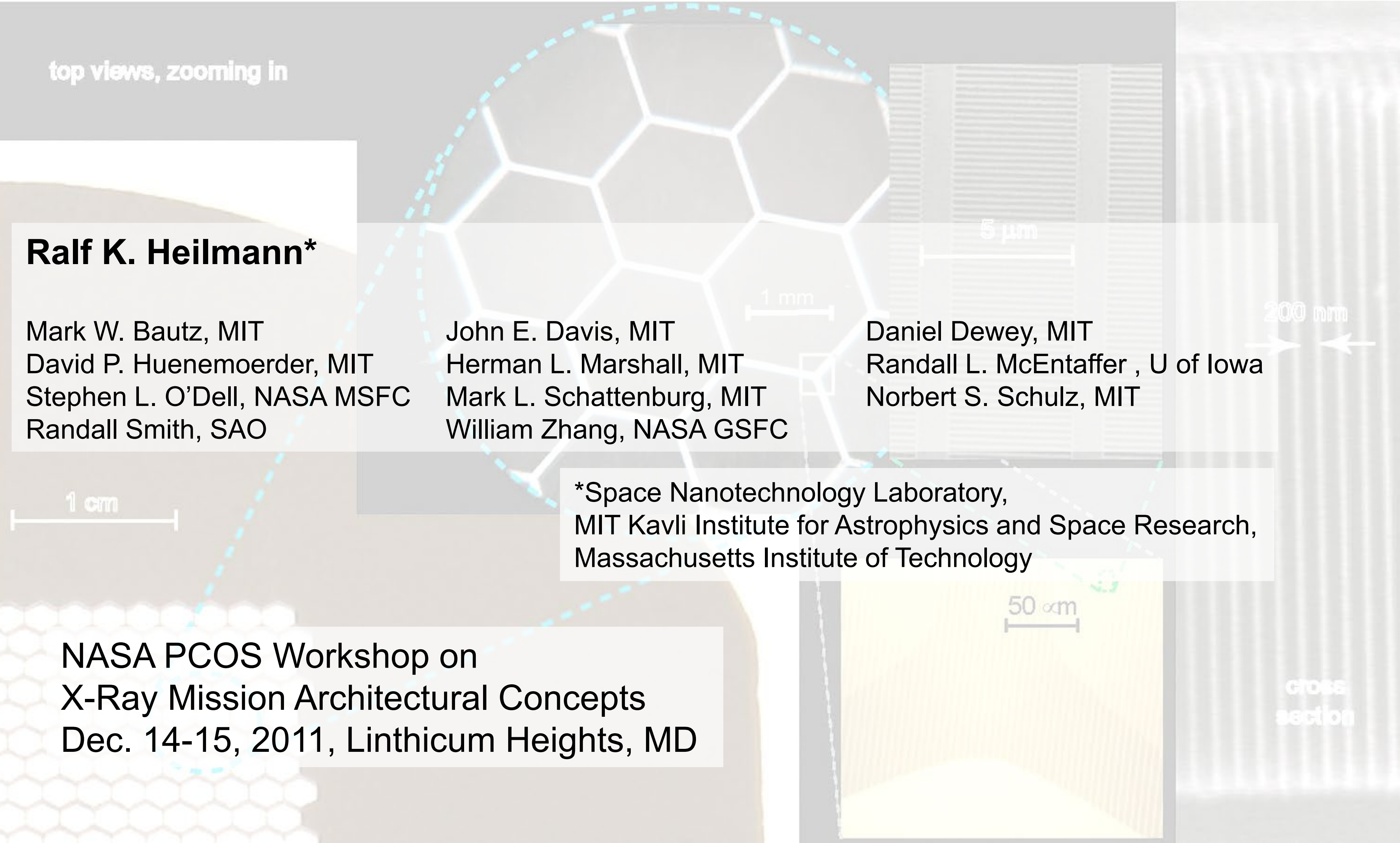
Critical-Angle Transmission (CAT) Gratings for High Resolution, Large Area Soft X-Ray Spectroscopy



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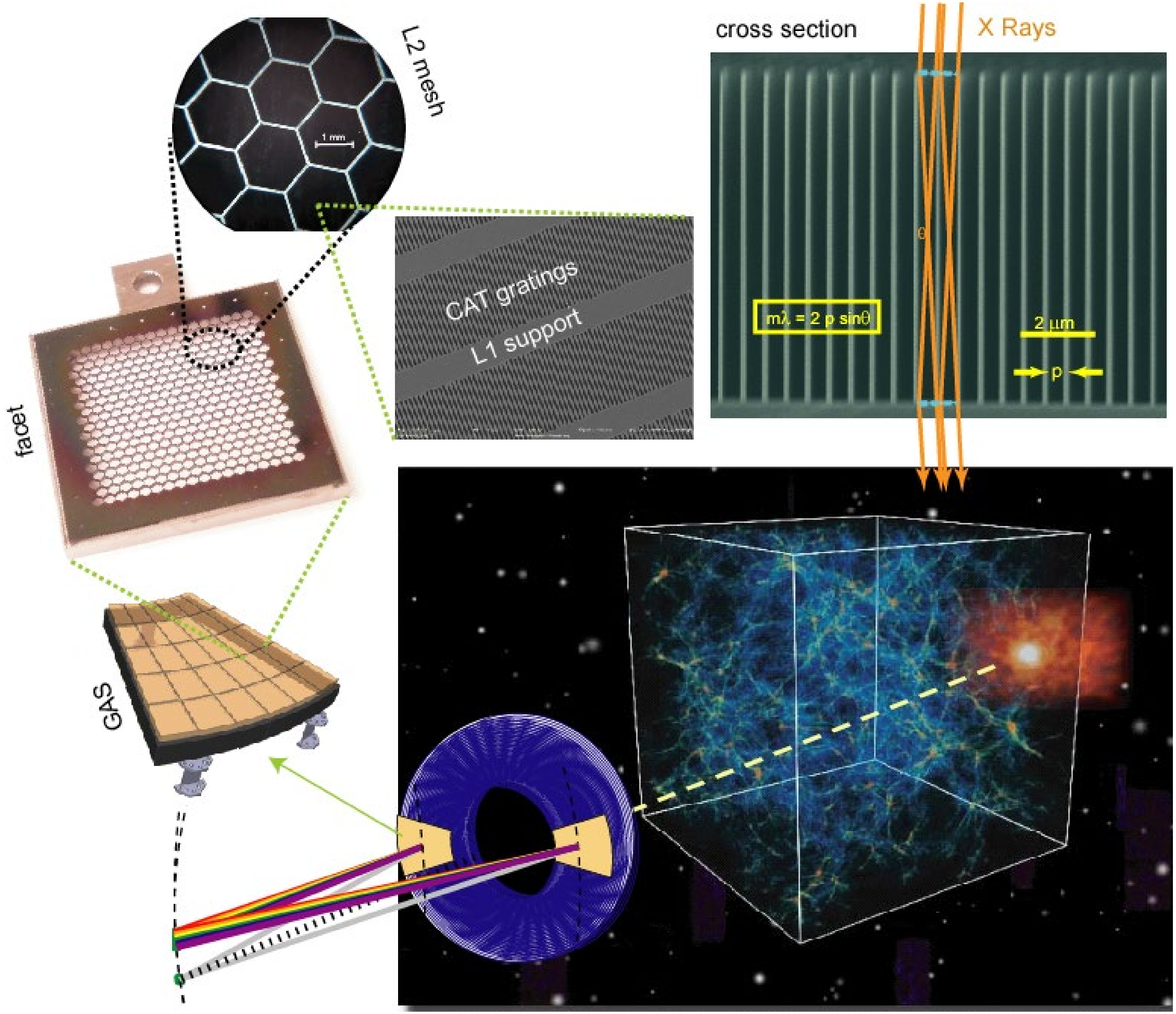

Space Nanotechnology Laboratory

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Why High-Resolution Soft X-Ray Spectroscopy?

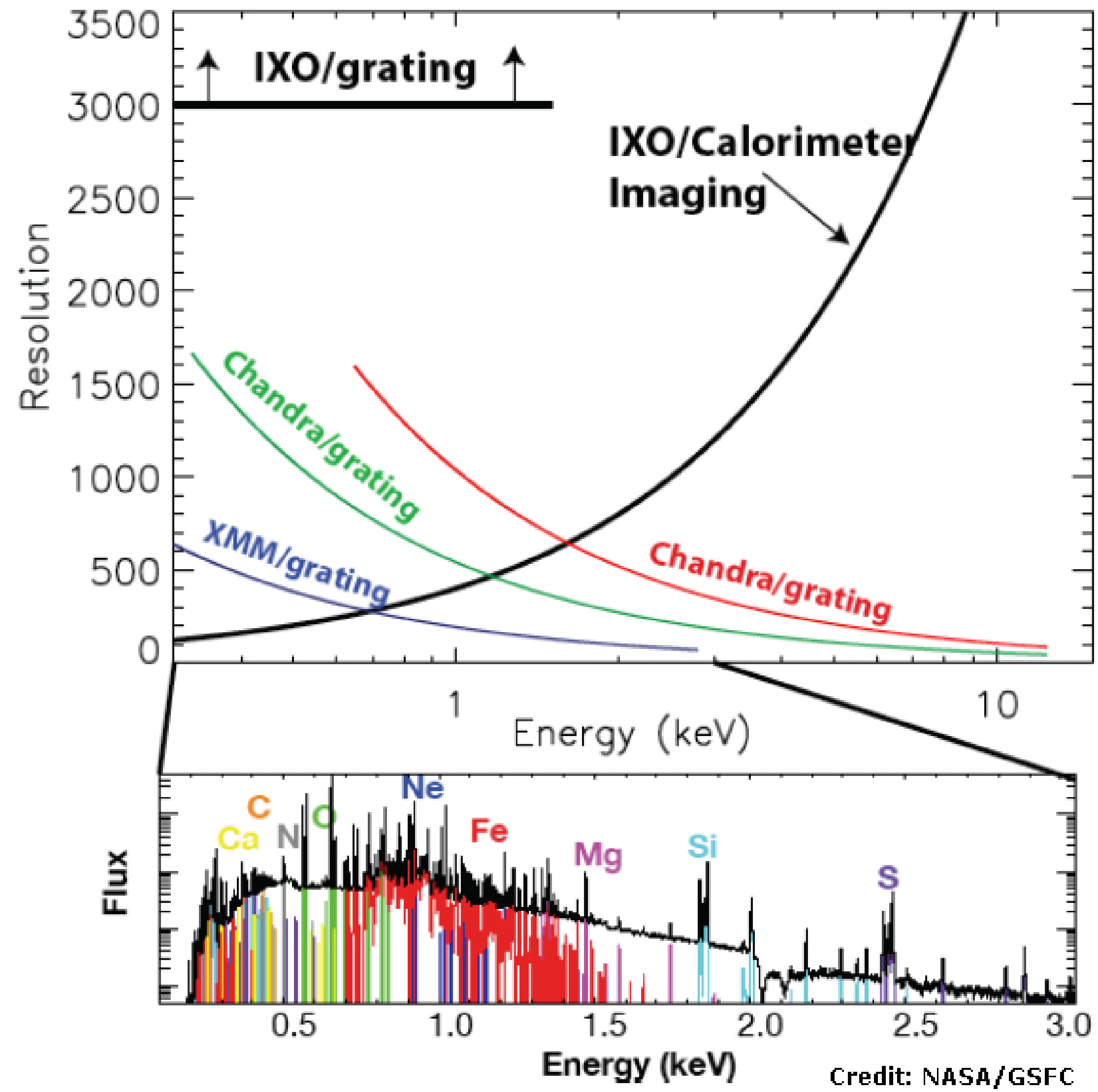
- It addresses three IXO science questions:
  - How does Large Scale Structure evolve?
  - How does Cosmic Feedback work?
  - How does matter behave at very high density?

  (see also AEGIS, AXSIO, and SMART-X presentations)

- Measurement Technique:
  - Resolve the absorption and emission signatures of atomic ions in the soft x-ray band (~ 0.3 – 1 keV) which reveal temperatures, compositions, and dynamics of the involved plasmas.

Why Diffraction Gratings?

- Detectors with fixed energy resolution (microcalorimeters, etc.) can not provide high resolving power in the soft x-ray band.

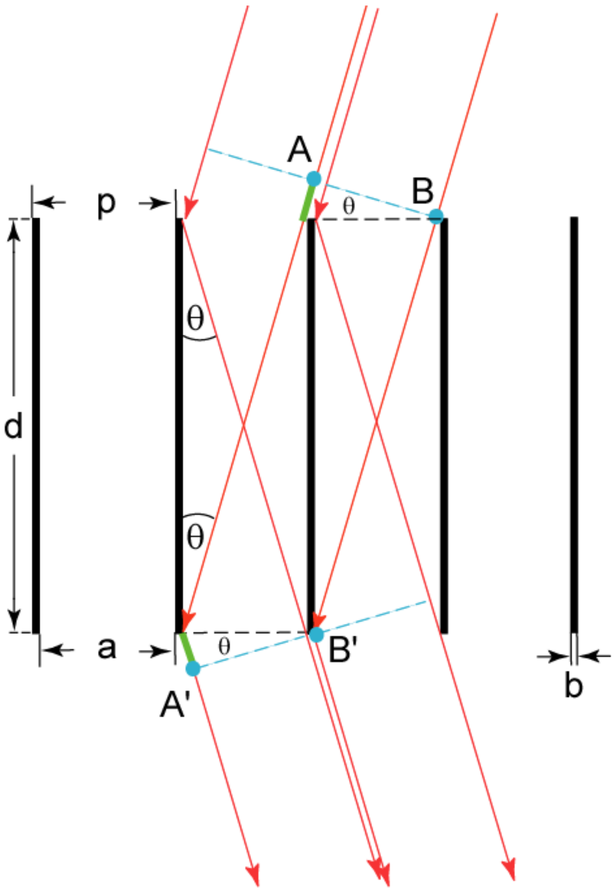


Why CAT Gratings?

CAT gratings are blazed transmission gratings that combine the advantages of traditional transmission gratings (Chandra HETG) and blazed reflection gratings (XMM RGS):

Property	Reflection gratings	HETGS (*Chandra*)	CATGS
Mass	High	Low	Low
Diffraction efficiency	High	Low	High
Alignment and figure tolerances	Tight	Relaxed	Relaxed
Transparency at higher energies	Zero	Mid	High
Polarization sensitivity	High	Low	Low

CAT Grating Principle and Theory



Grating equation:

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

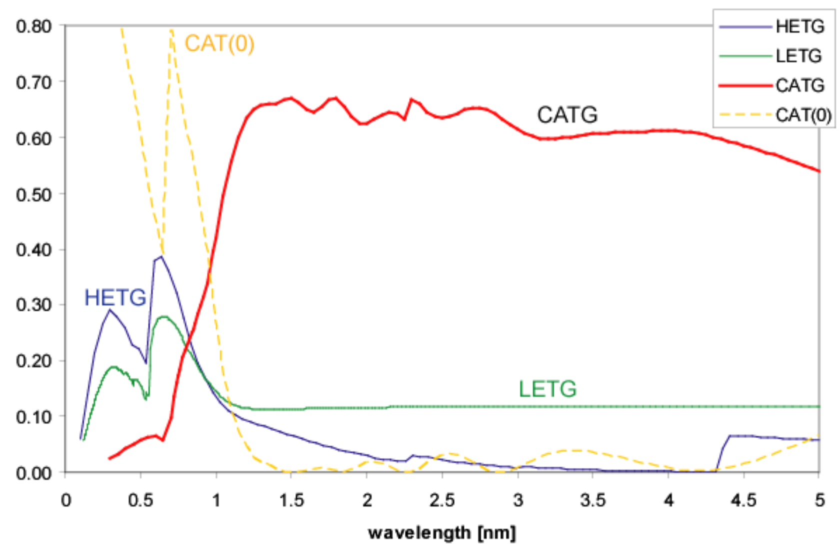
Blazing: $\beta_m \sim \theta$

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

Strawman:
Silicon grating, $\theta = 1.5^{o}$
p = 200 nm
b = 40 nm
d = 6 μm
aspect ratio d/b = 150

- 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.

Efficiency comparison with Chandra gratings

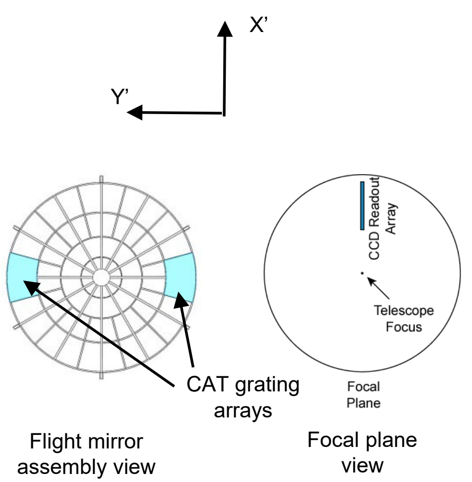


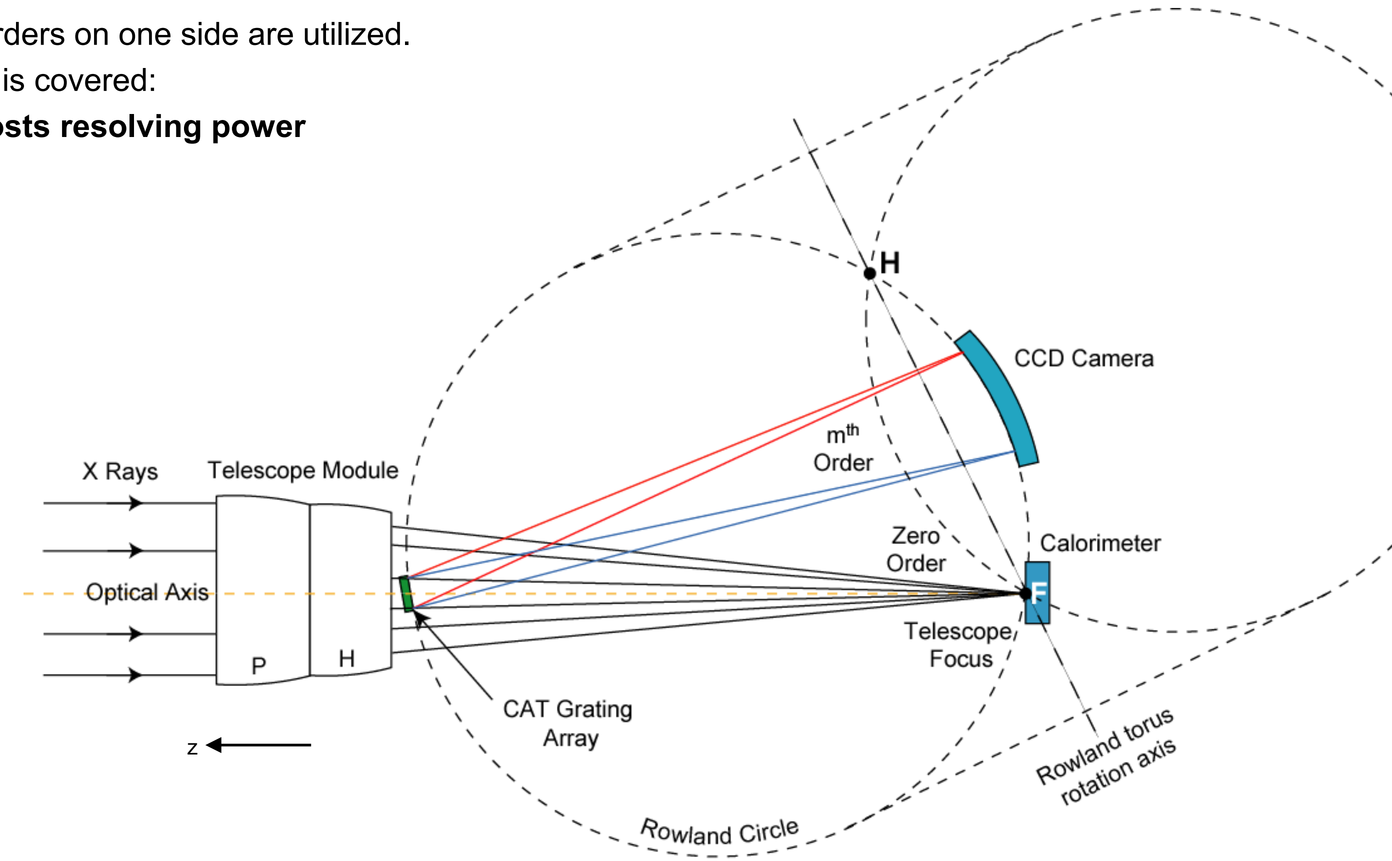
Critical-Angle Transmission (CAT) Grating Spectrometer Concept

Advantages:
- low mass
- relaxed alignment & figure tolerances
- high diffraction efficiency
- up to 10X dispersion of Chandra HETGS
- no positive orders (i.e., smaller detector)

- Optical Design:
  - Wolter I telescope mirrors.
  - Diffraction gratings in converging beam just aft of mirrors.
  - Gratings, camera, and focus share same Rowland torus.
  - Blazed gratings; only orders on one side are utilized.
  - Only fraction of mirrors is covered:

    “sub-aperturing” boosts resolving power

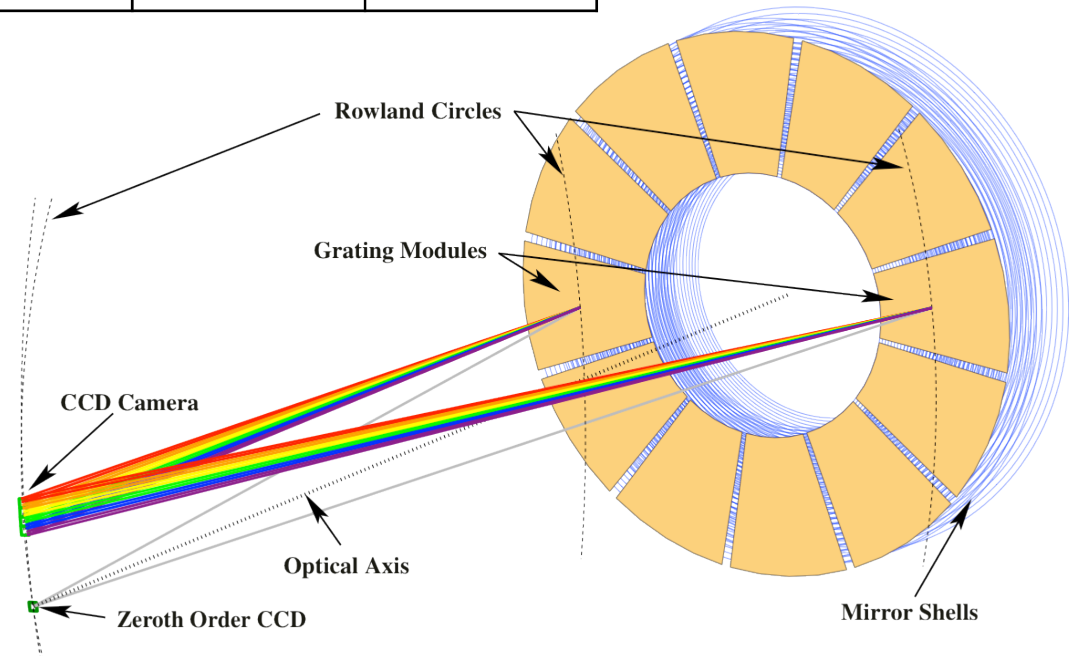




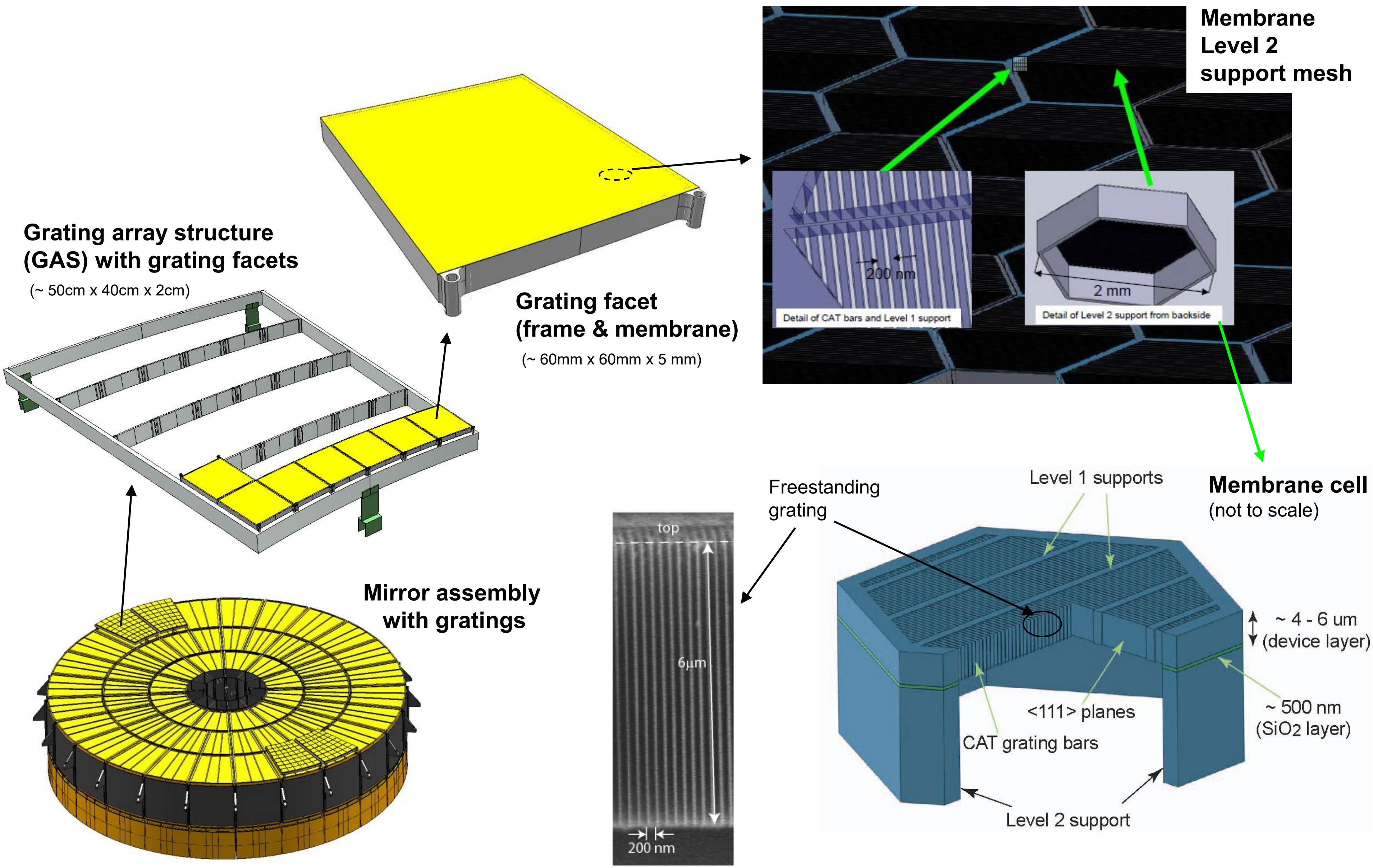
CAT Grating Spectrometer Mission Concepts

Mission	Optic PSF [arcsec]	Focal length [m]	CAT-XGS eff. area [cm^2]	Sub-aperture (azimuth) [deg]	Resolving power E/ΔE
IXO	5	20	> 1000	2 x 30	~ 3500-4000
AXSIO	10	10	> 1000	2 x (2 x 30)	> 3000
AEGIS	10	4.4	~ 1400	6 x (2 x 30)	~ 3000-4000
SMART-X	0.5	10	~ 4000	~ 2 x 90	> 5000

Example: AEGIS

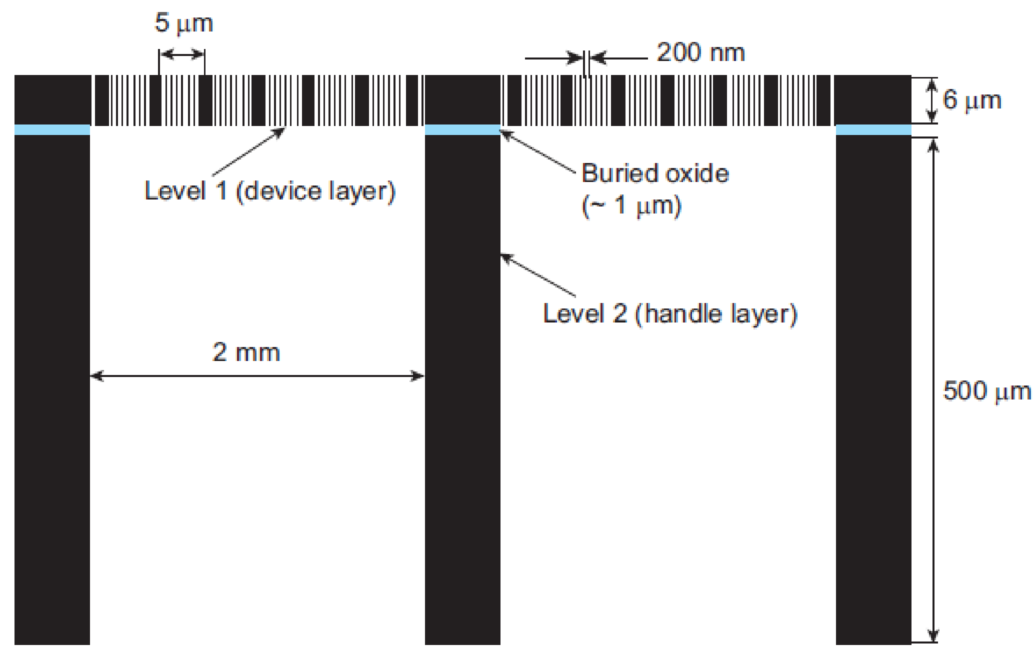


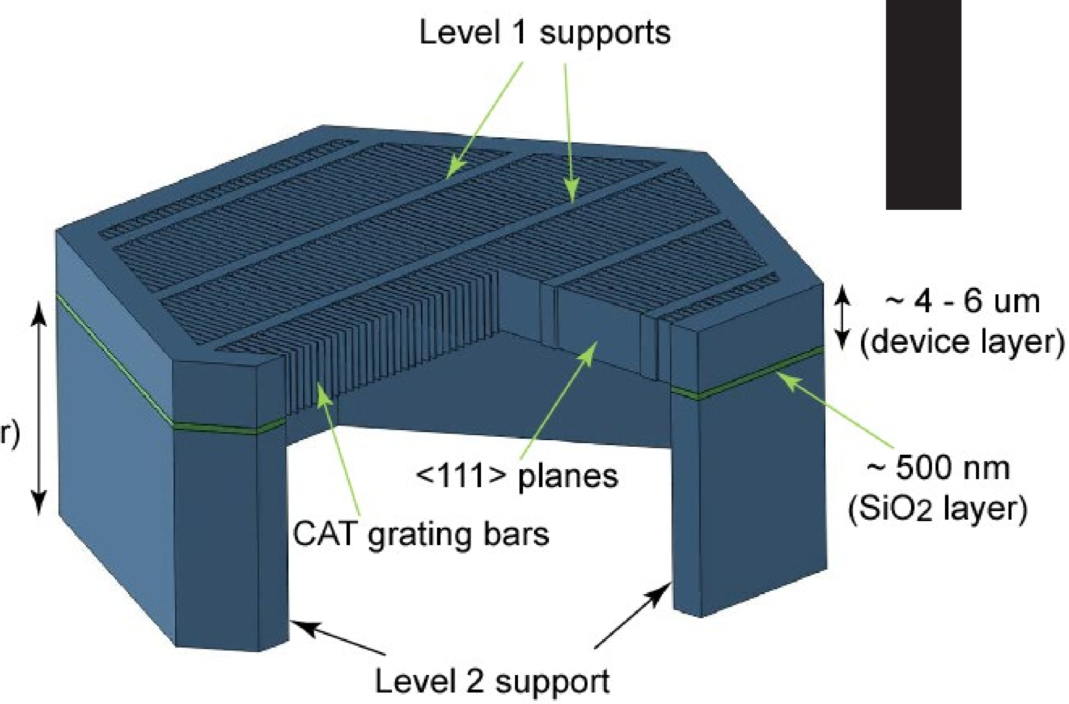
Grating Assembly Structural Hierarchy



Fabrication Goal: Large Area CAT Grating Membrane with Two Support Levels

Silicon-on-insulator (SOI) wafer
Front side: CAT gratings and Level 1 supports
Back side: Level 2 supports





Mount array of hexagons (grating membrane) to machined frame (Level 3 support)

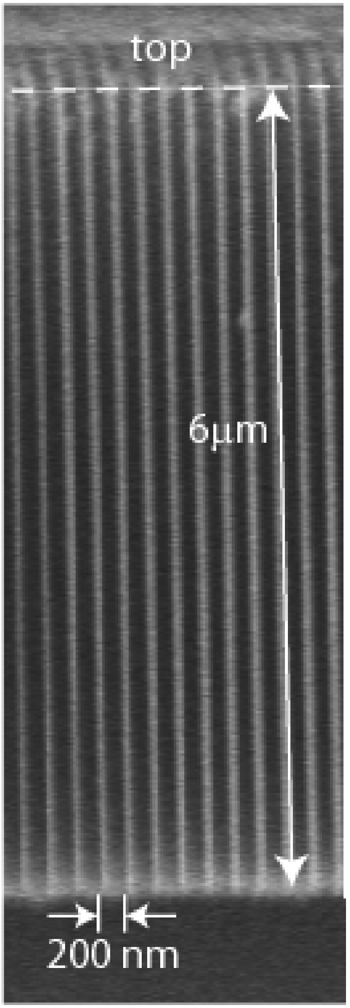
CAT grating fabrication and testing (past)

- Monolithic silicon structure with integrated L1 support bars from SOI device layer
- 200 nm period
- achieved IXO design goal of 6 μm tall, 40 nm wide grating bars
- wet etch in KOH gives smooth side walls

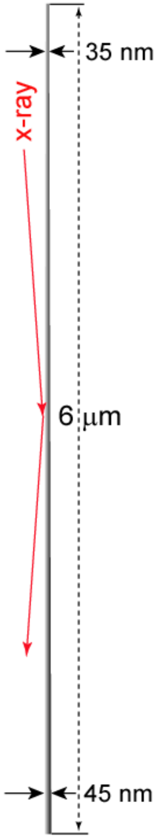
However:

- Level 1 supports broaden & rob area
- Small gratings without Level 2 support mesh

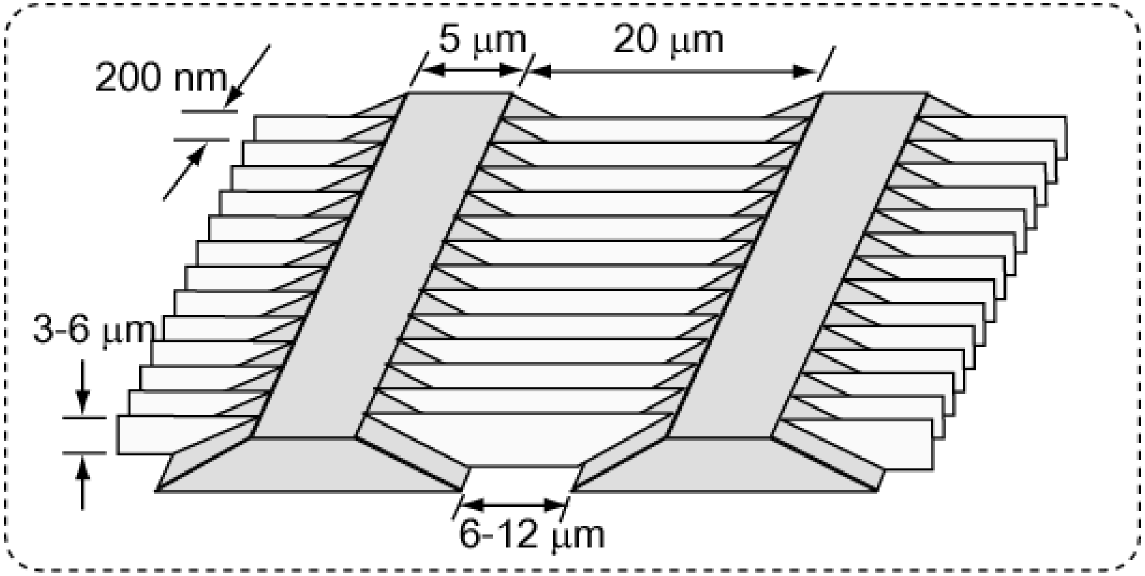
Scanning electron micrograph of cleaved cross section of 200 nm-period CAT grating



Grating bar cross section (drawn to scale)



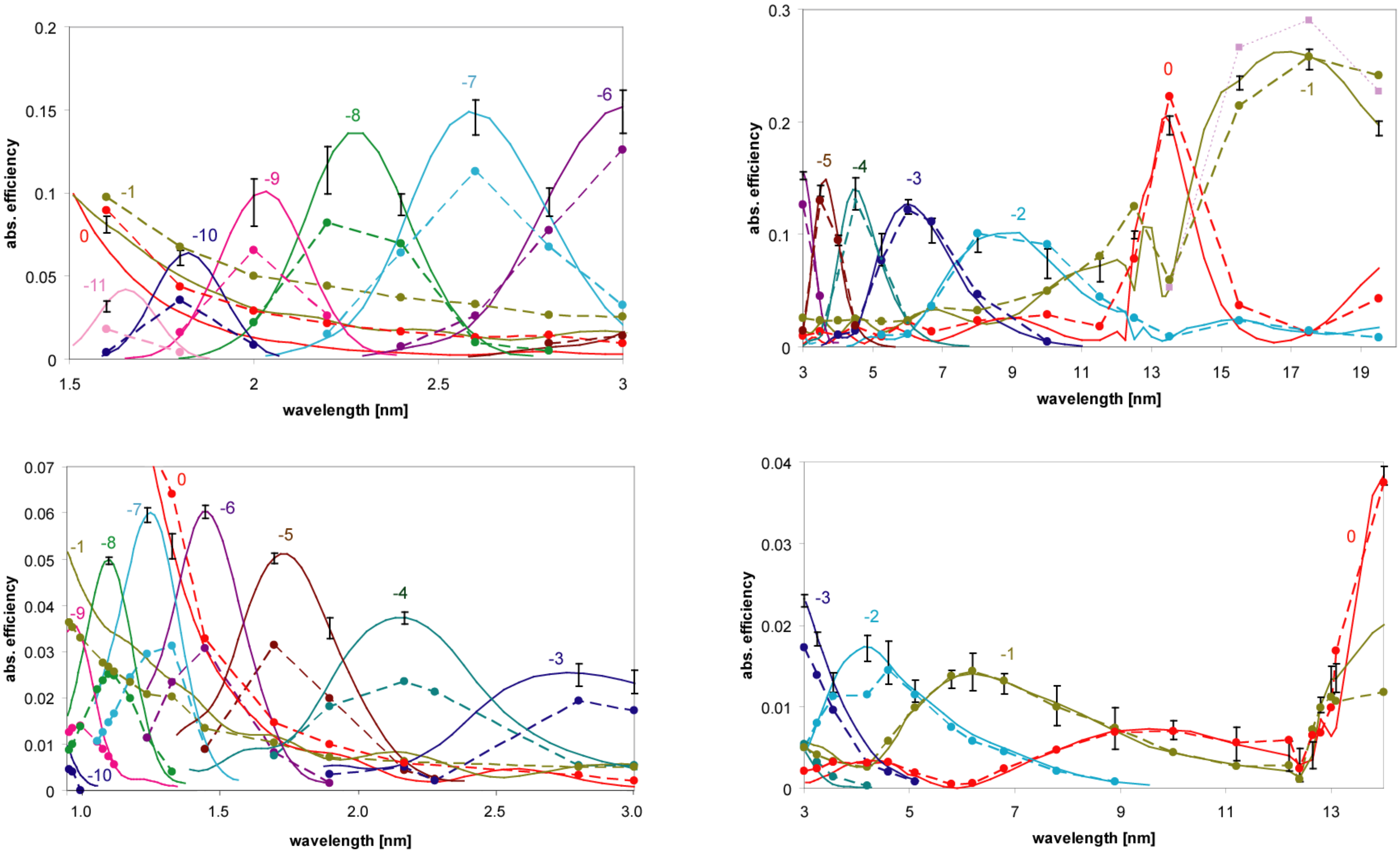
CAT grating schematic



X-ray data analysis of diffraction efficiency from wet-etched CAT gratings

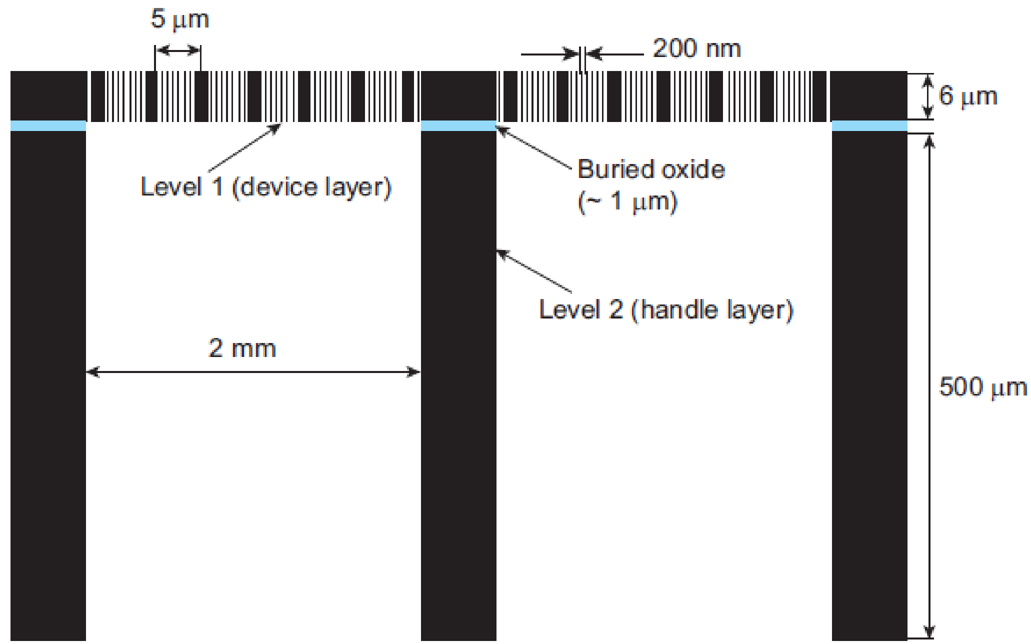
Lines – theory; points – measurement/experimental data (see Heilmann *et al*., Appl. Opt. **50**, 1364-1373 (2011) for details)

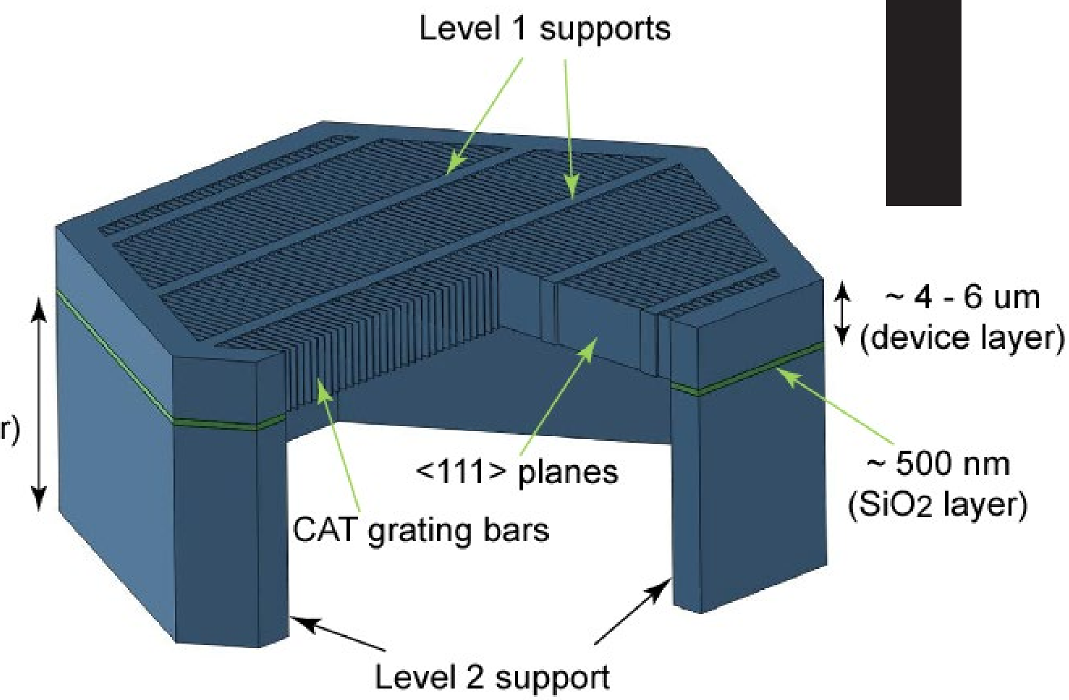
2 different samples



Deep Reactive-Ion Etching of Front and Back Sides + KOH polish

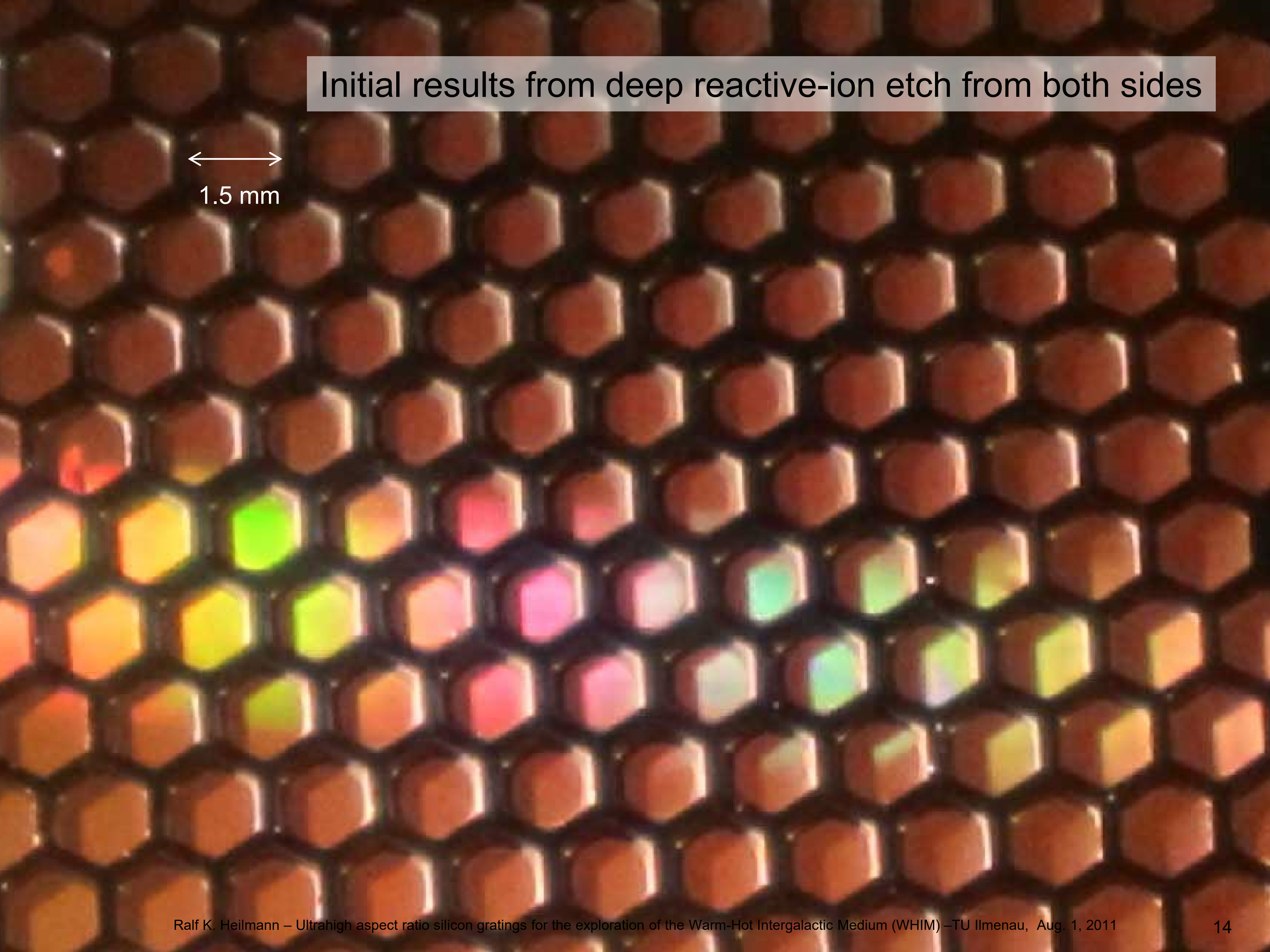
Silicon-on-insulator (SOI) wafer
Front side: CAT gratings and Level 1 supports
Back side: Level 2 supports

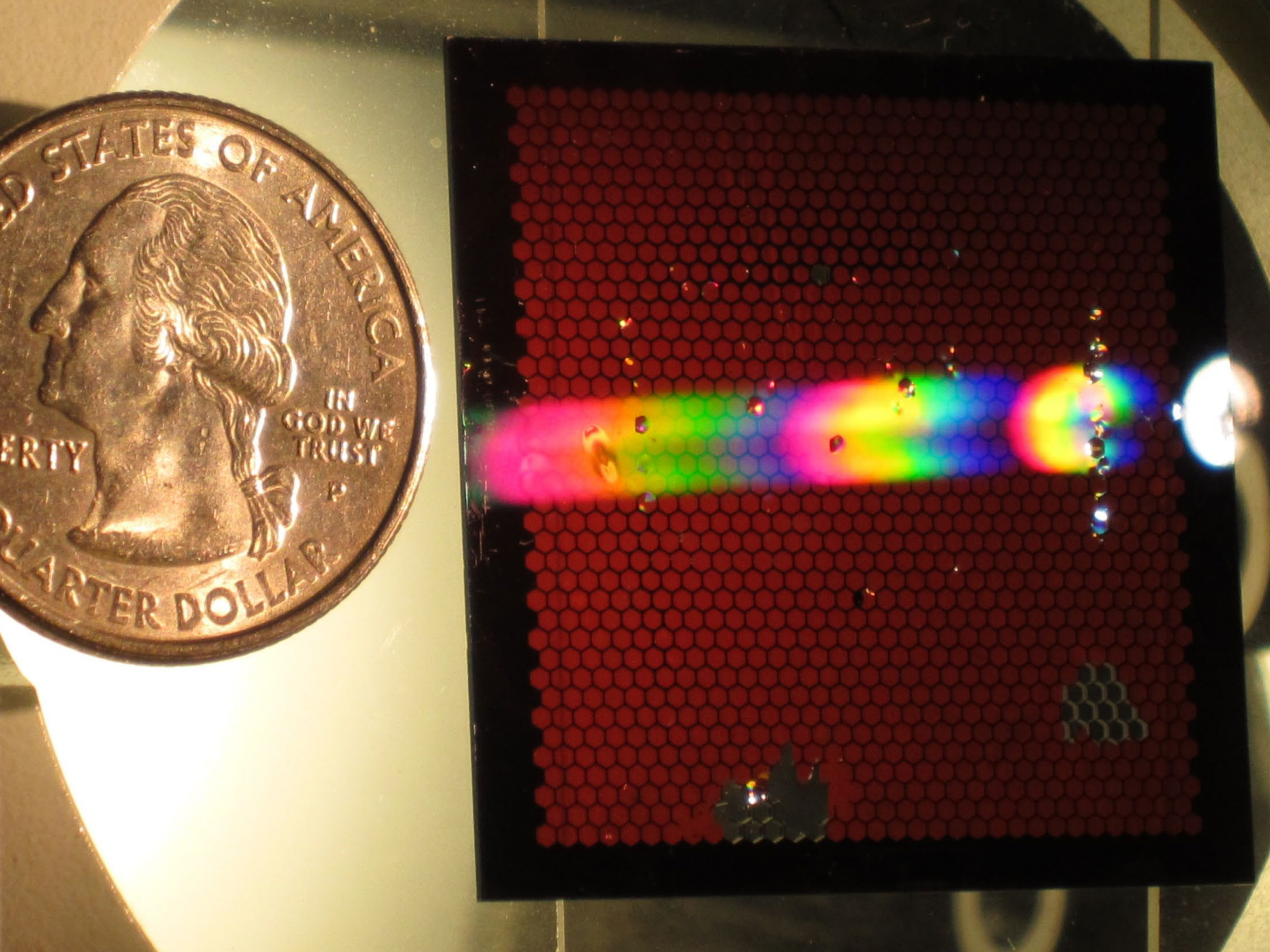




Mount array of hexagons (grating membrane) to machined frame (Level 3 support)

Initial results from deep reactive-ion etch from both sides

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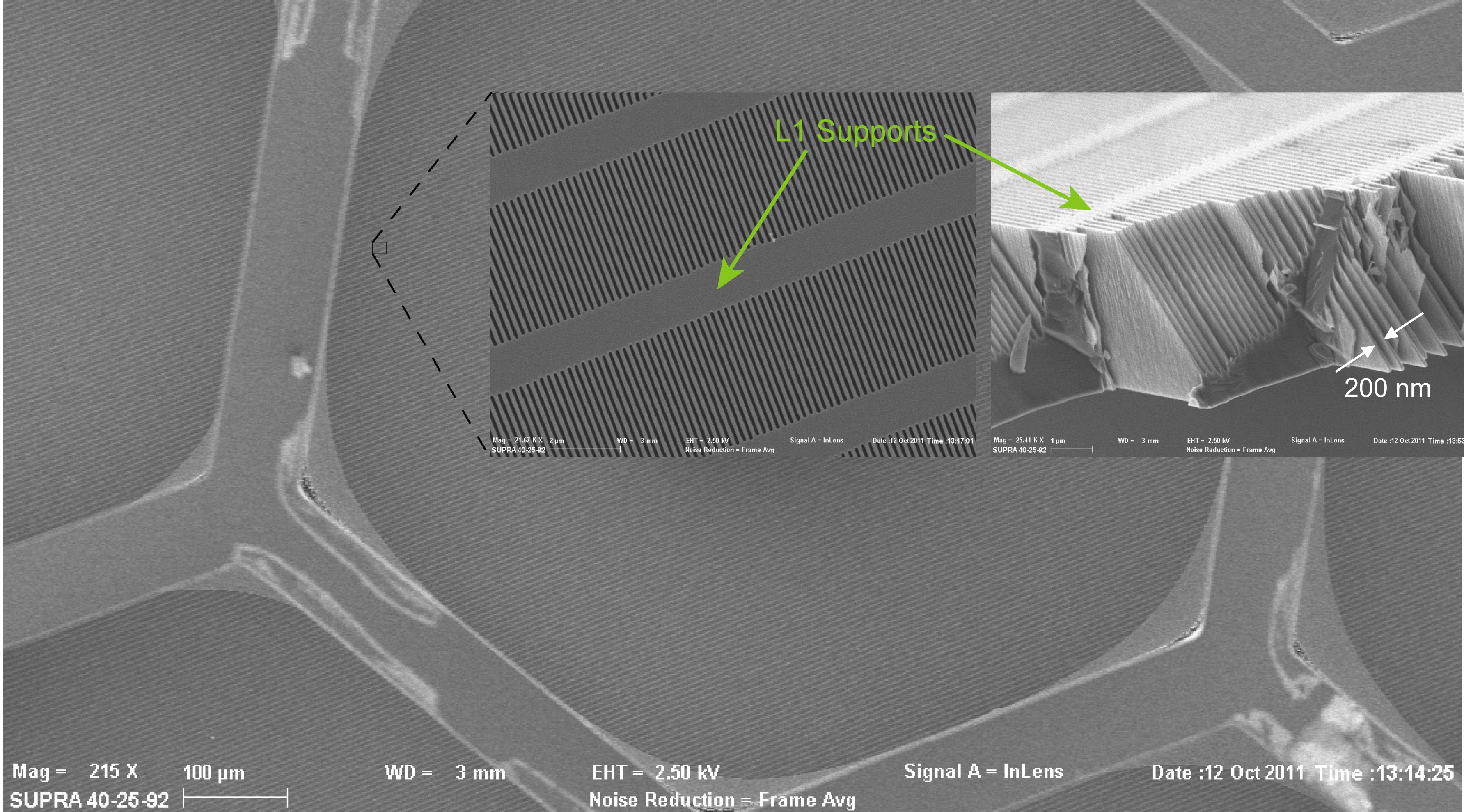
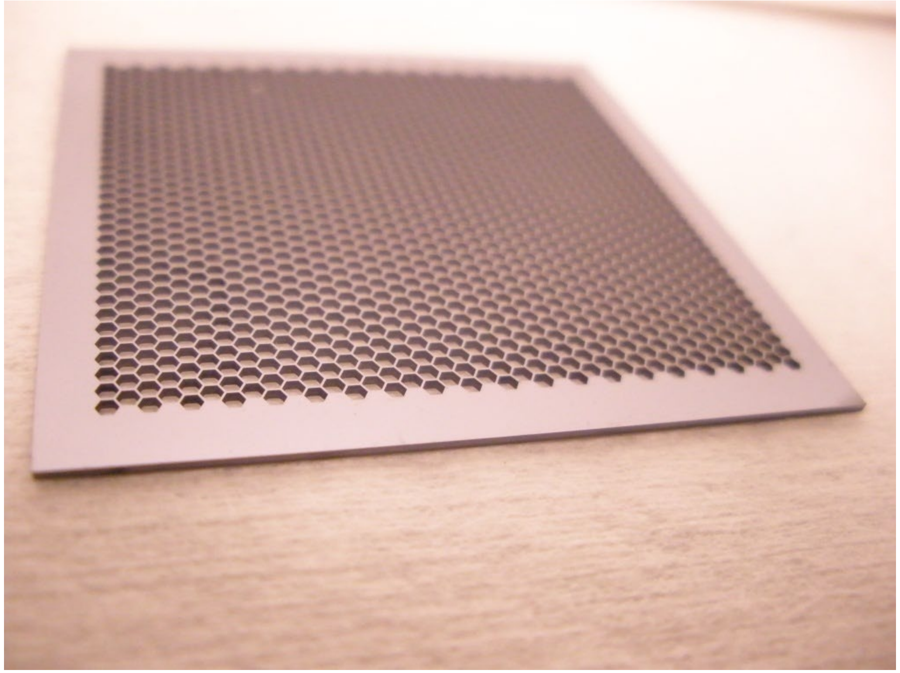
Deep Reactive-Ion ("dry") Etching Results

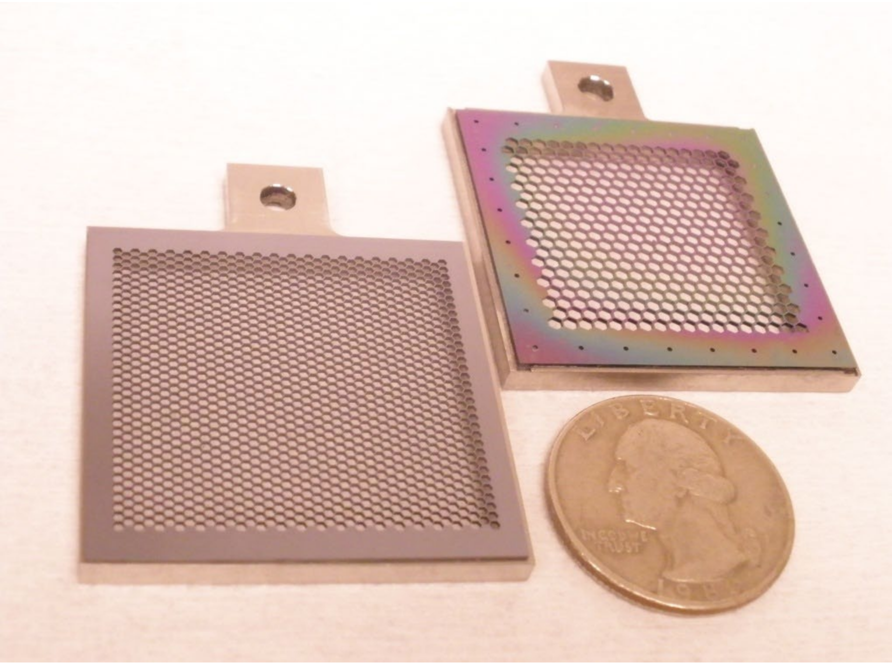
- Large area (31x31mm^2) gratings with two levels of support
- Minimal broadening of L1 supports



Level 2 support mesh and facet frames

- Fabricating Si L2 support mesh membranes with ~90% open area
- Bonding (epoxy, reactive bonding) of membranes to different facet frame materials (Invar, H-Invar, Hexoloy SiC, etc.)
- Investigate mechanical/elastic properties of bonded facets, (shake & bake) compare to finite element models, optimize design





CAT Grating Development Plans

- CAT grating technology at TRL3.
- Demonstrate wet "polish" of (rough) dry etched grating bars.
- Minimize L1 and L2 supports in the same sample (previous "records": 92% and 90% open area, respectively, for single level).
- Optimize mechanical design of L1 and L2 supports and facet frames.
- Continue vibration, shock, and thermal tests.
- Test resolving power in spectrometer test setup with multiple gratings (TRL4).
- Environmental testing of CAT grating breadboard (TRL5) by end of 2013.
- TRL6 mission specific (grating size, throughput, blaze angle).

Beyond current designs:

- Increase blaze angle and/or energy range using high-Z materials (via atomic layer deposition – ALD).
- Chirp gratings to reduce aberrations for larger gratings (SMART-X).
- Automation to reduce cost for many-m^2 arrays.

Our Nanofab Experts

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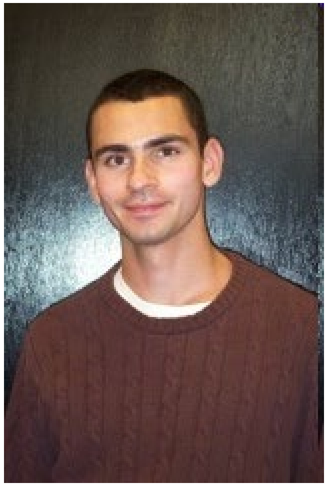

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