A reflection grating spectrometer for X-ray Surveyor

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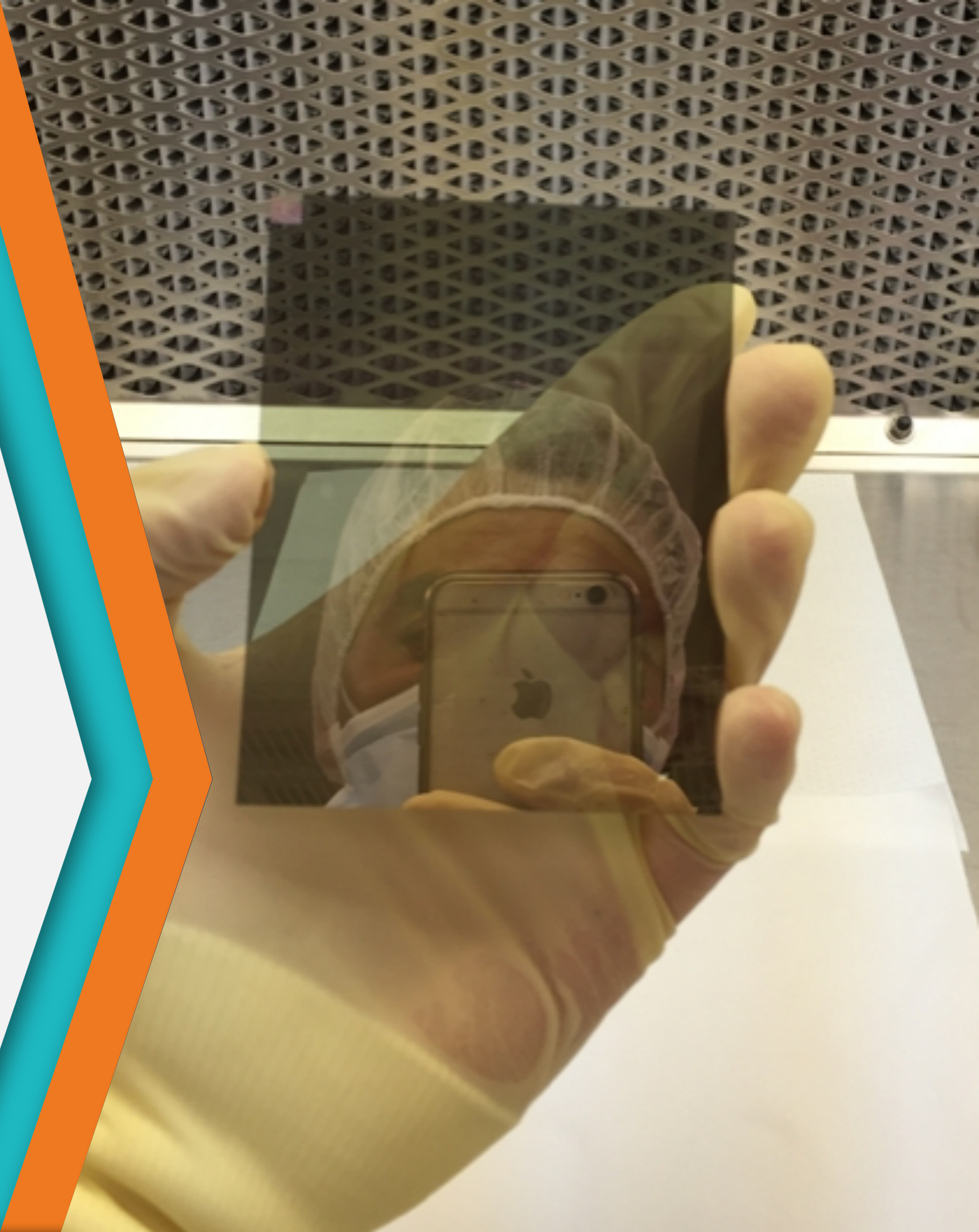


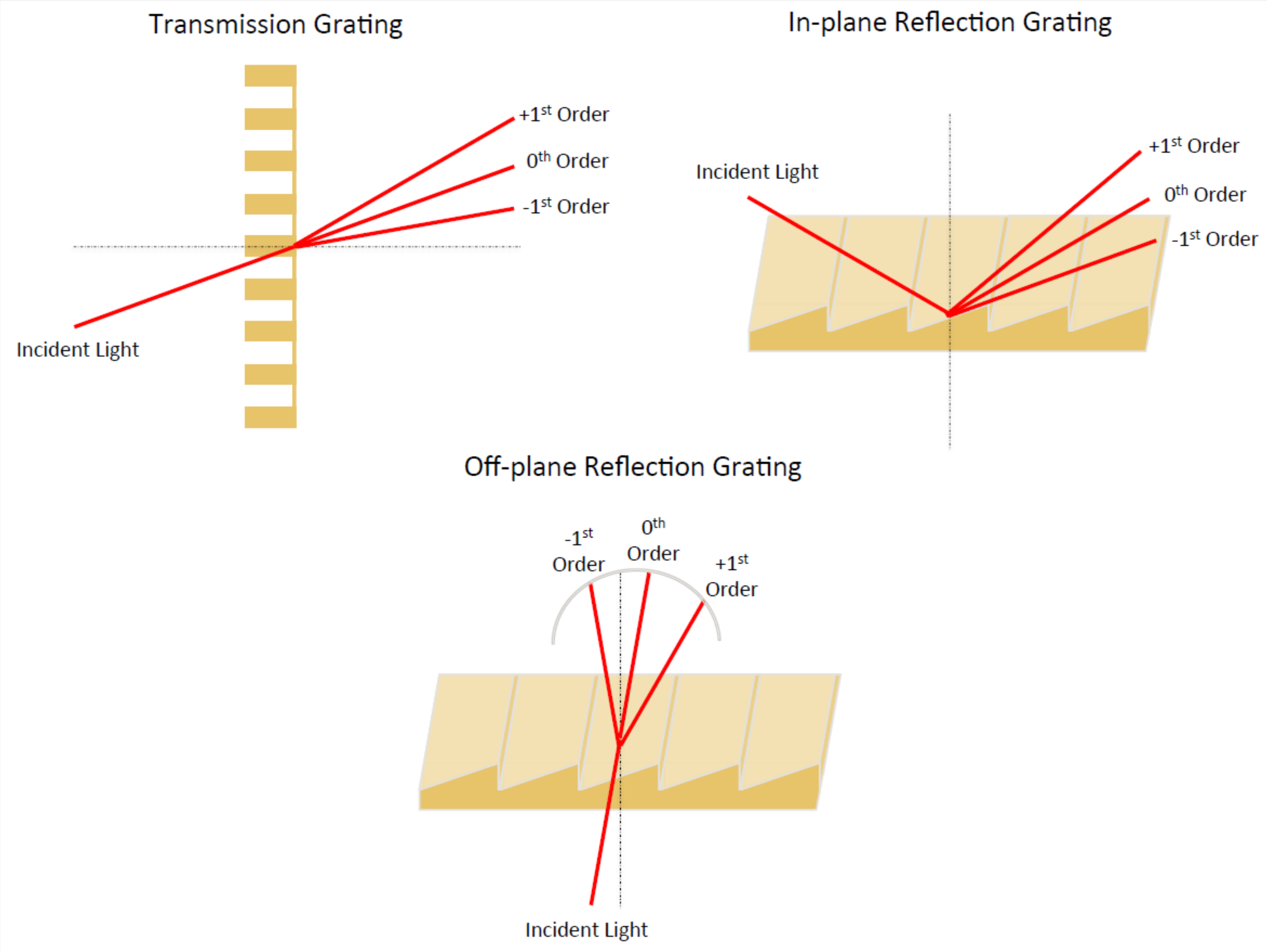
Talk outline

- X-ray grating background
- State of reflection grating technologies
- Development roadmap
- Trade studies/next steps/next level

X-ray Surveyor context

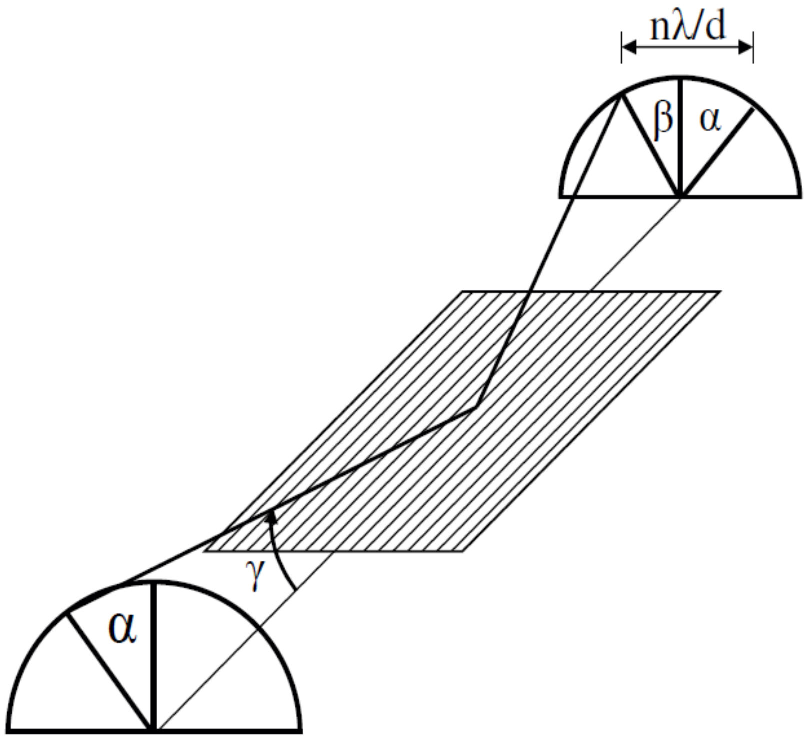
- 10 m focal length, 0.5″ telescope HPD
  - 24 μm at focal plane
    - Readout requires <12 μm resolution elements
- R = 5000 (0.2-1.2 keV; mirror has good response up to 2 keV)
  - Grating dispersion gives 4 mÅ spectral lines
  - R = 31,000 at 200 eV (62 Å, 2nd order)
  - R = 28,000 at 1.2 keV
  - R = 29,450 at 2.0 keV
  - No need to subaperture
- 4000 cm^2 with 50% optics coverage (retractable arrays)
  - ~2 m^2 total leaves 1 m^2 for the grating array
  - Requires 40% efficiency from gratings + detectors
    - Changes to 32% if mirror A_{eff}= 2.5 m^2

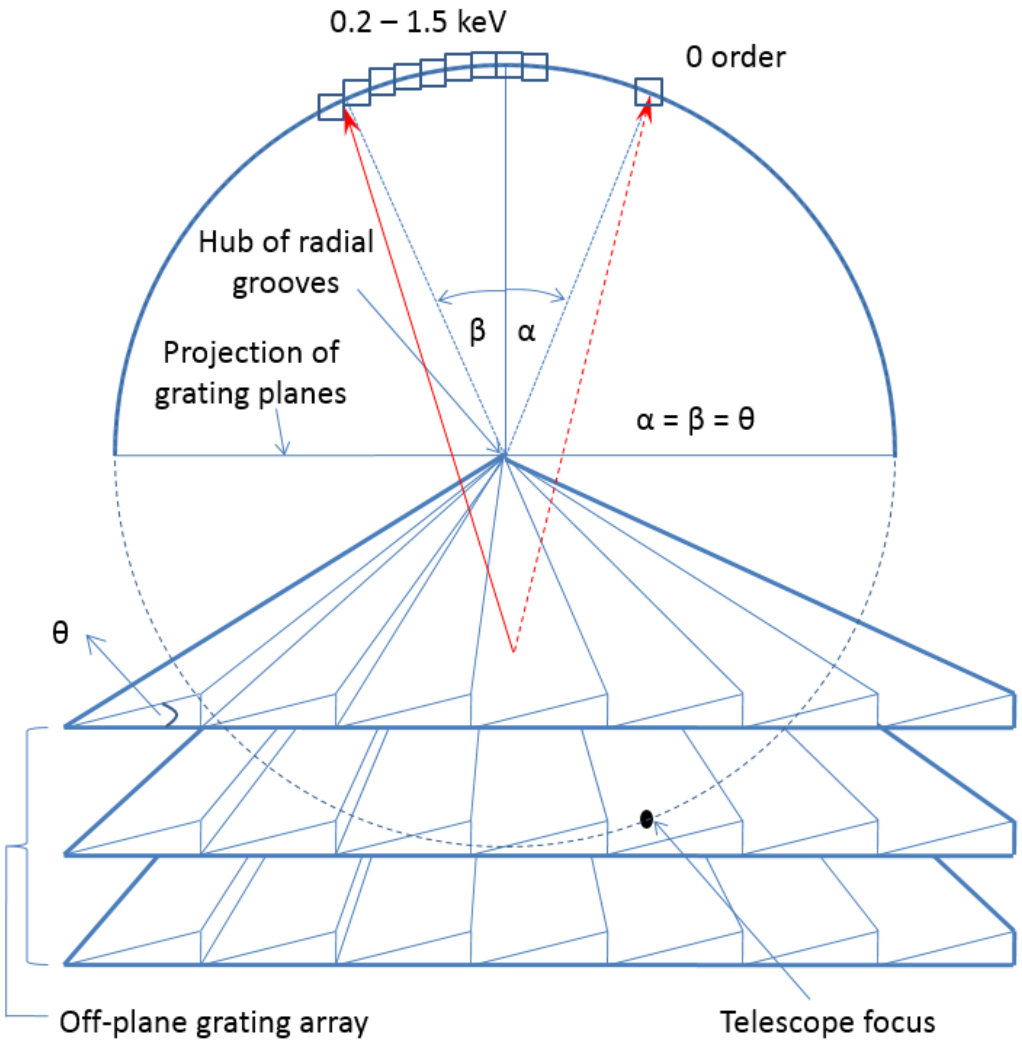
Diffraction gratings



Off-plane diffraction gratings

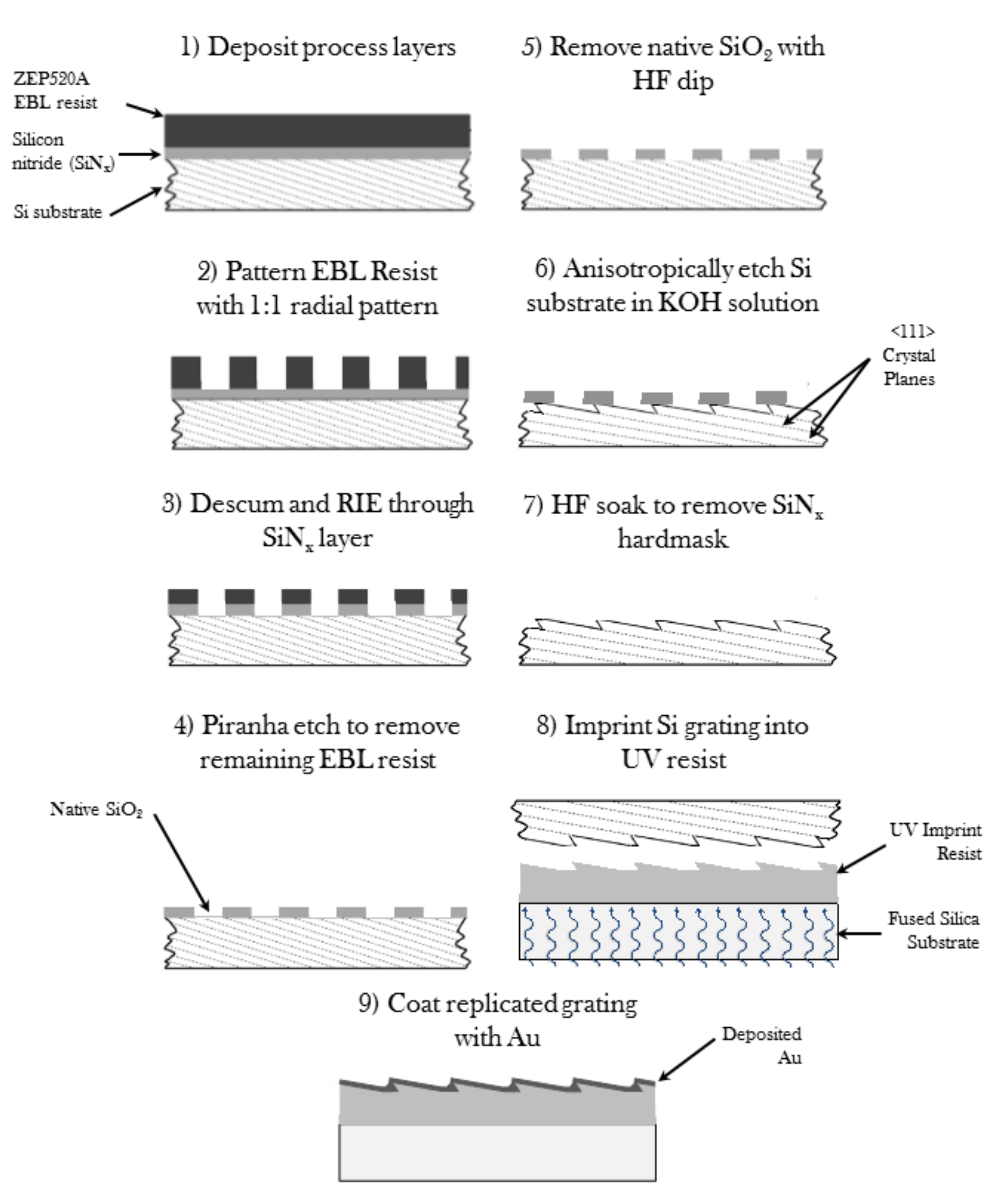
$$\sin(\alpha)+\sin(\beta)=\frac{n\lambda}{d\sin(\gamma)}$$



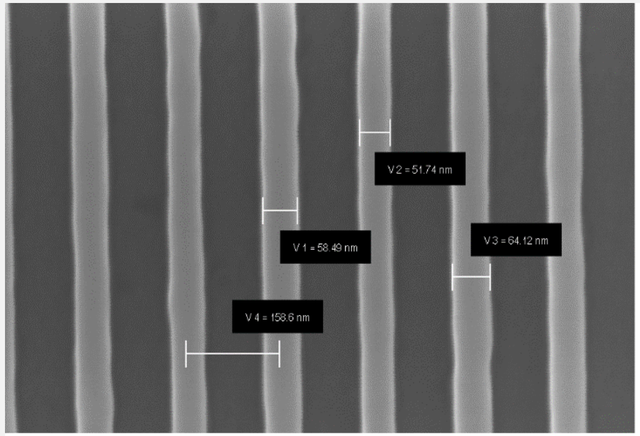


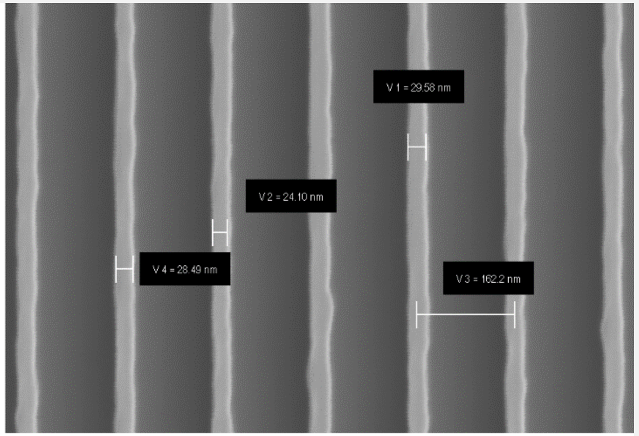
Fabrication

- Utilizes common nanofab tech
- Developed since Con-X
- Recent advancements due to e-beam lithography



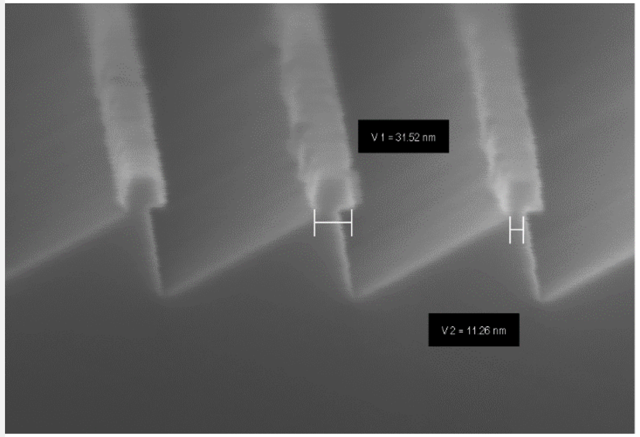
Step 2

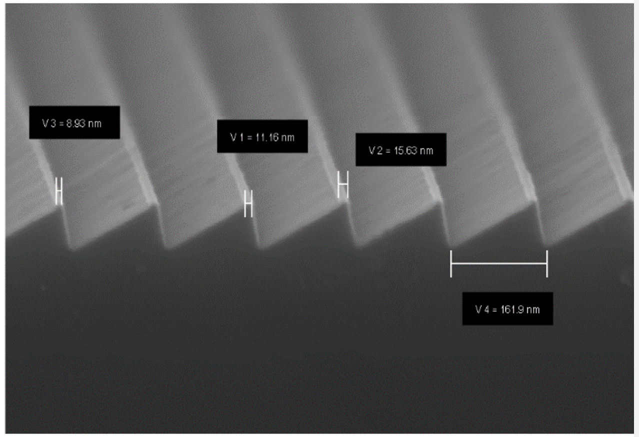




Step 6

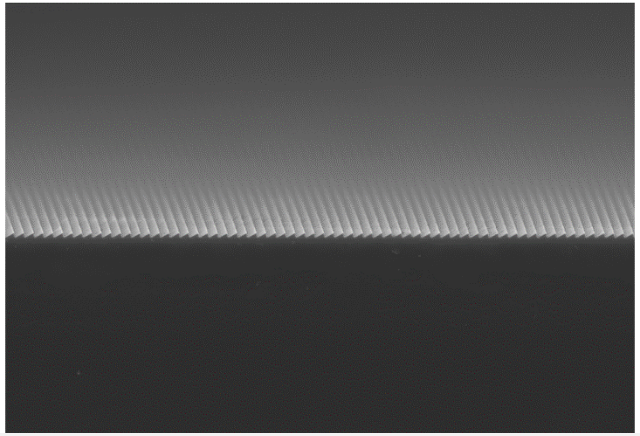
Step 6





Step 7

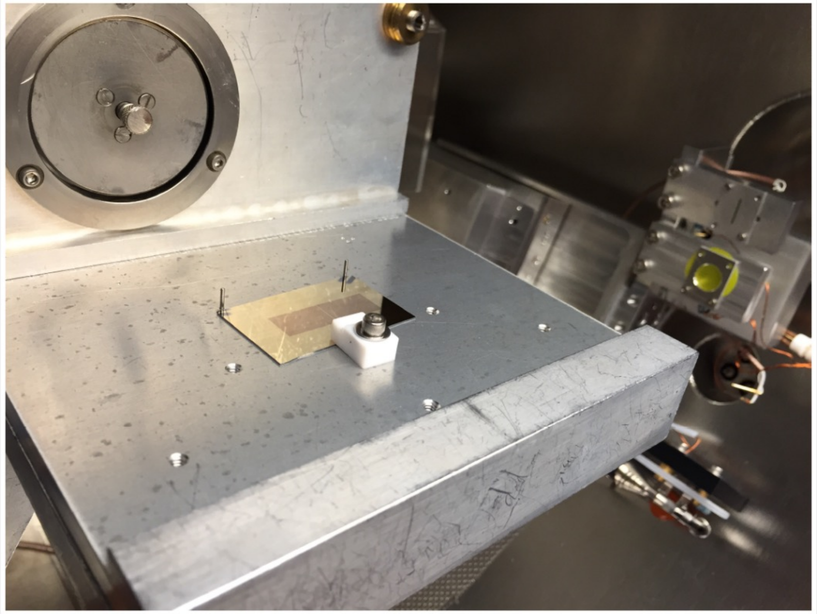
Fabrication results
29.5° blazed grating

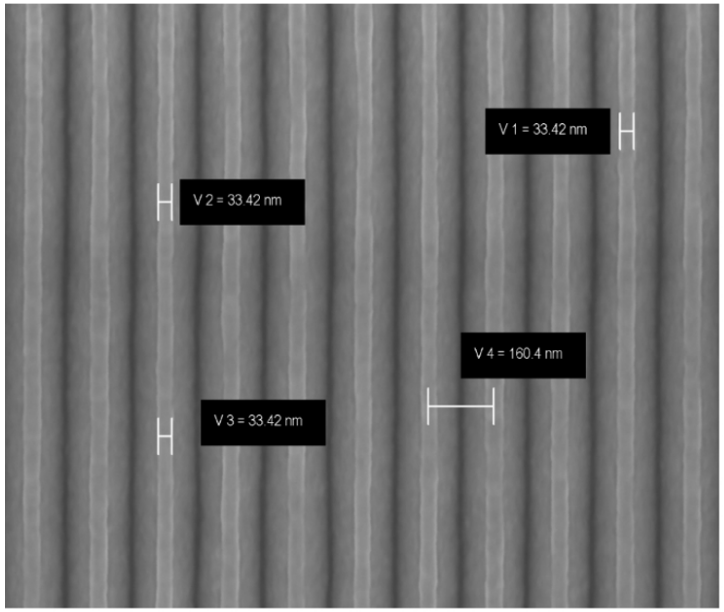


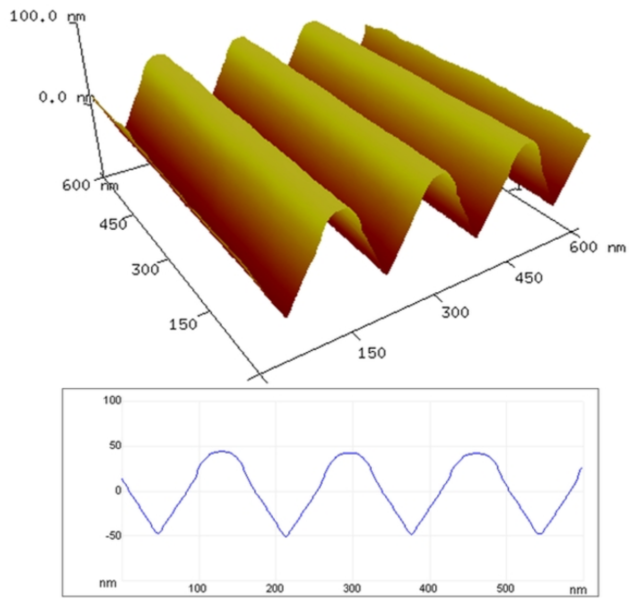
Images courtesy of
Dmitriy Voronov, LBNL

Diffraction efficiency testing of blazed grating

- Synchrotron tested at LBNL Advanced Light Source (Eric Gullikson)
- Fabricated in collaboration with Howard Padmore’s group, specifically Dmitriy Voronov

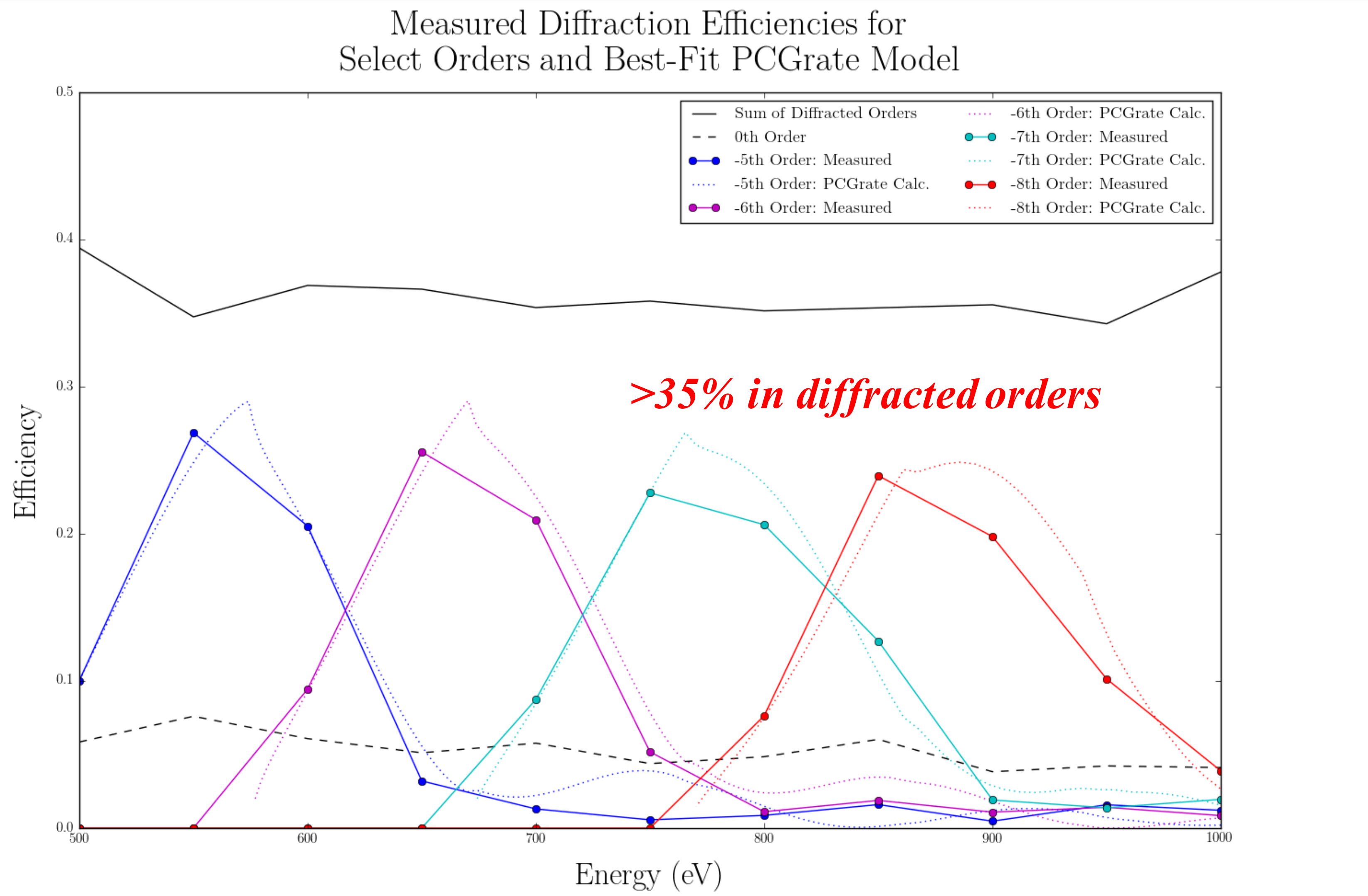




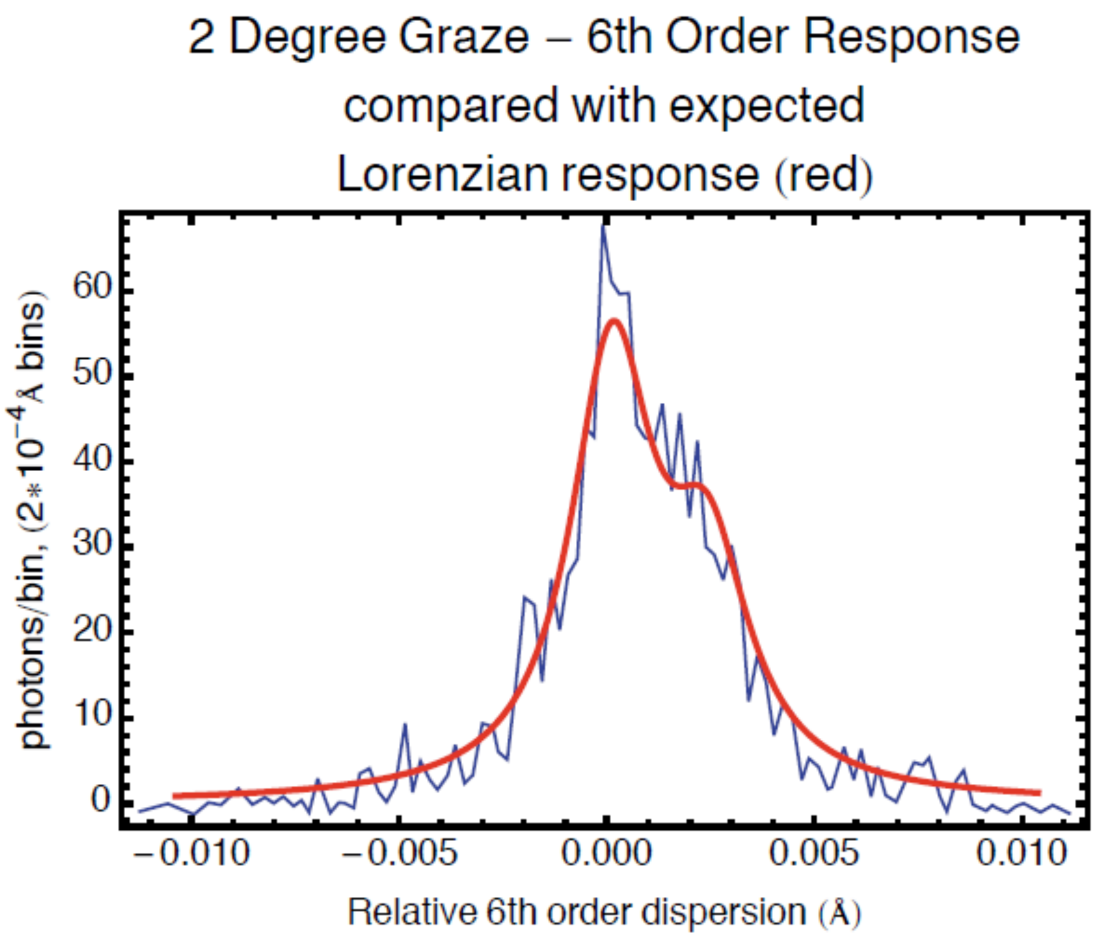


- Variable line spacing – 160 nm to 159.75 nm
- Blazed profile – 54.7°
- 10 x 30 mm on silicon
- Coated – 5 nm Cr/30 nm Au

Very high diffraction efficiencies

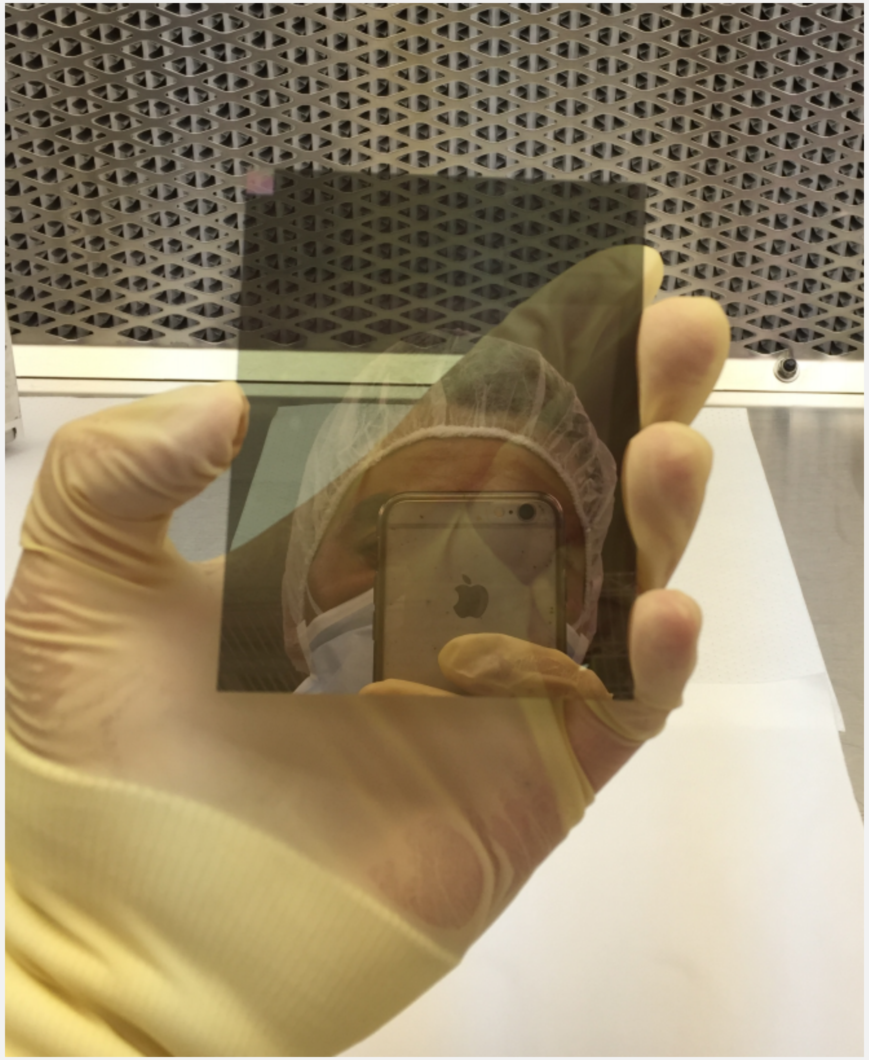


Previous resolving power results



- Tested at MSFC SLF
- Using slumped glass optics from GSFC
- Preliminary analysis
  - 6th order Al K ✔$_1$, K ✔$_2$
  - LSF same as 0 order
    - Aberration free
  - **R ~ 3250**
    - 3460 = natural line width limited (2.4 mÅ)
- Tested on small, laminar profile, variable line spaced grating

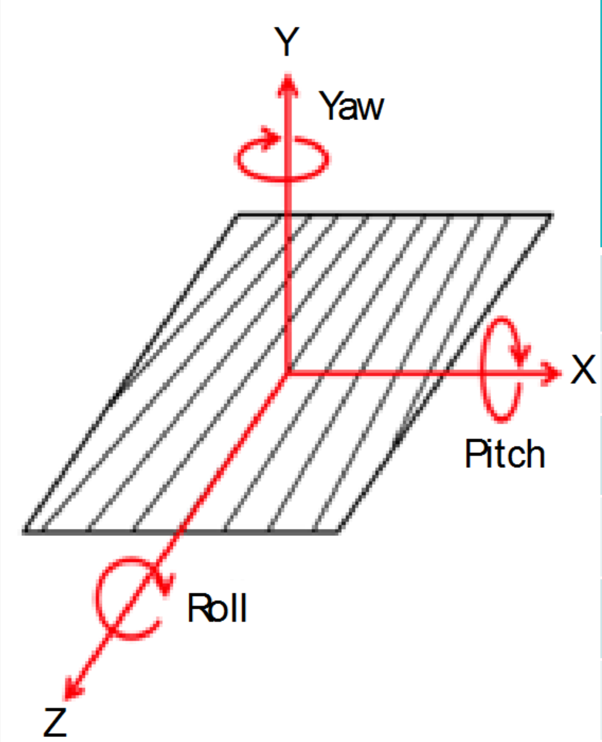
The first *complete* next-gen off-plane grating



- Large format
  - 75 x 96 x 0.5 mm
- Variable line spacing
  - 7x 0.25 nm steps for 8x periods: 158.25 – 160 nm
  - Matches 8.4 m optic
- Blazed
  - 54.7°
- Replicated onto fused silica
  - ~1 µm peak-to-valley flatness over piece
- Coated with 5 nm Cr/15 nm Au
- Final fabrication product – flight component

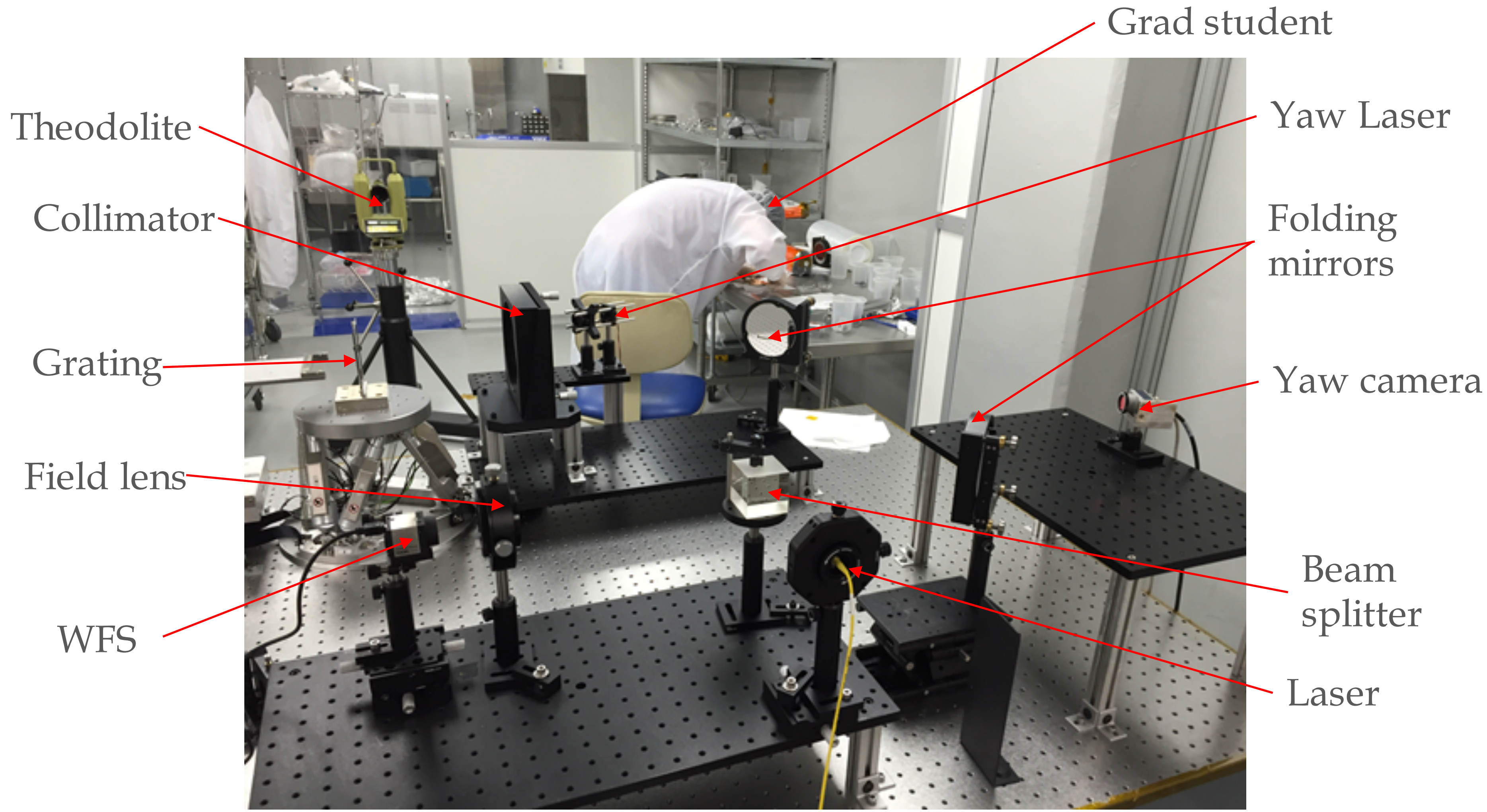
Grating alignments

- The spectrum from each grating must overlap at the focal plane
- This must be done for 100s – 1000s of gratings

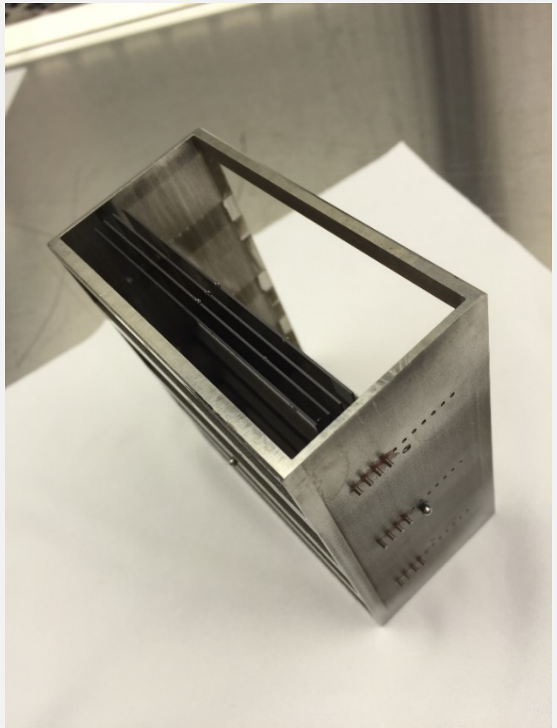


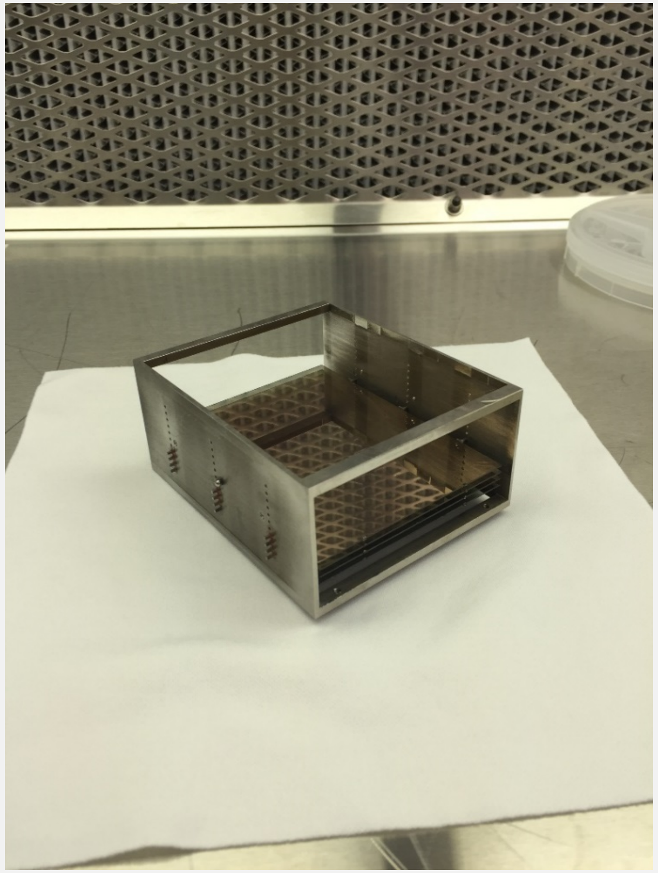
Representative alignment numbers taken from *Arcus*	Grating Alignment Requirements (FWHM)
X	0.6 mm
Y	0.4 mm
Z	0.2 mm
Pitch (X)	15 arcsec
Yaw (Y)	24 arcsec
Roll (Z)	5 arcsec

Current alignment studies



Aligned grating modules

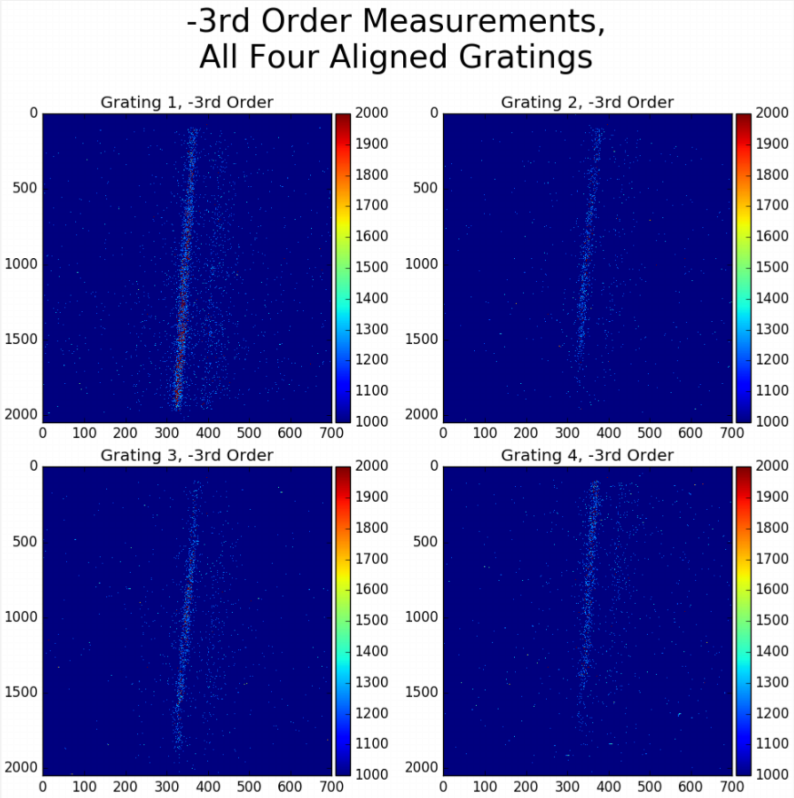


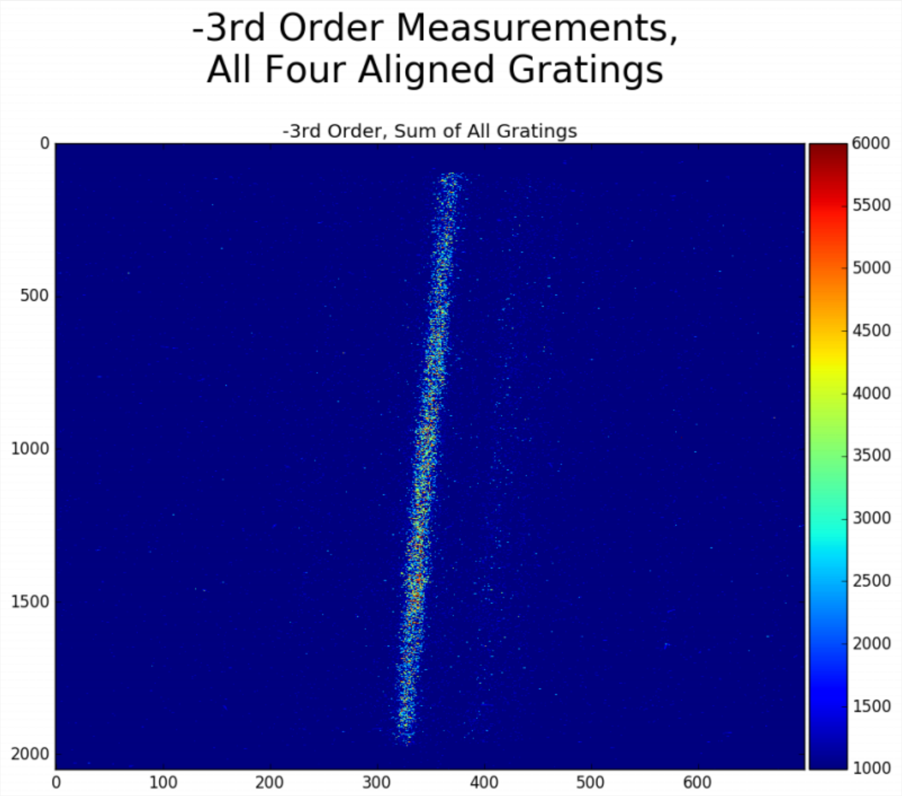


- 4x full format gratings aligned ≲±10″ in rotational DOFs, ≲±0.2 mm in translational DOFs
- Needs upgraded metrology and environmental control
  - Solutions exist

X-ray alignment testing, pre-shake

- The team is currently at MSFC testing
- Limitation – single optic requires actuation of grating stack

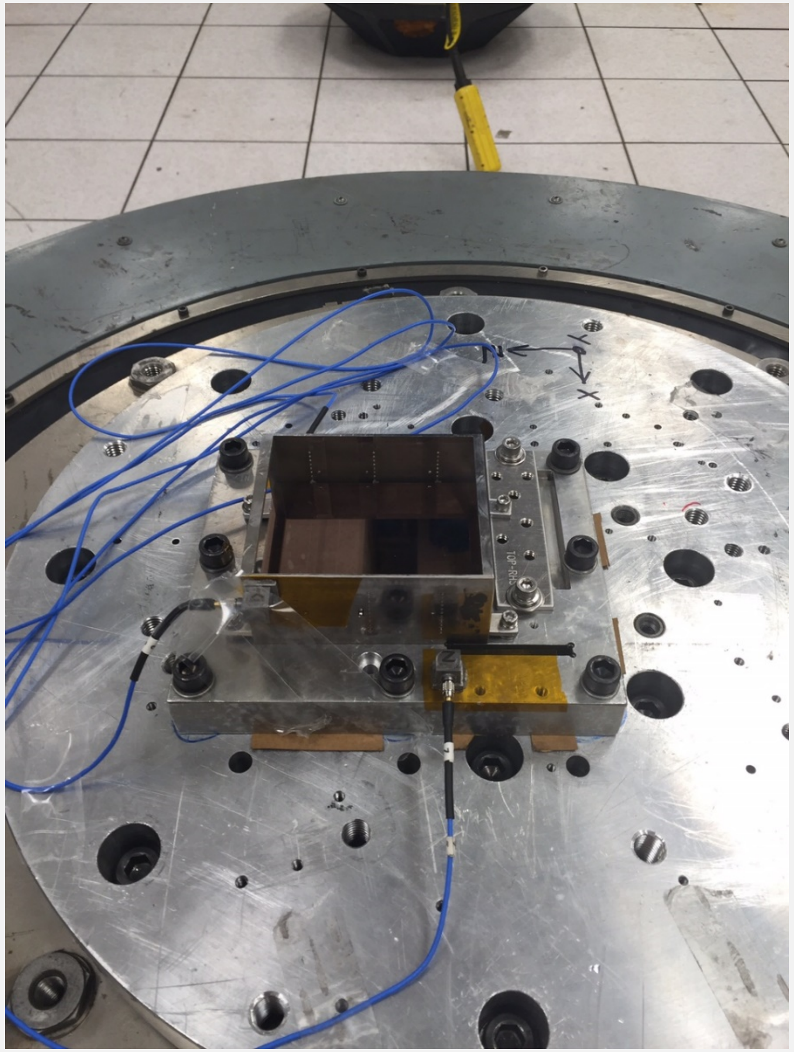




- PANTER
  - X-ray testing with SPO scheduled for September

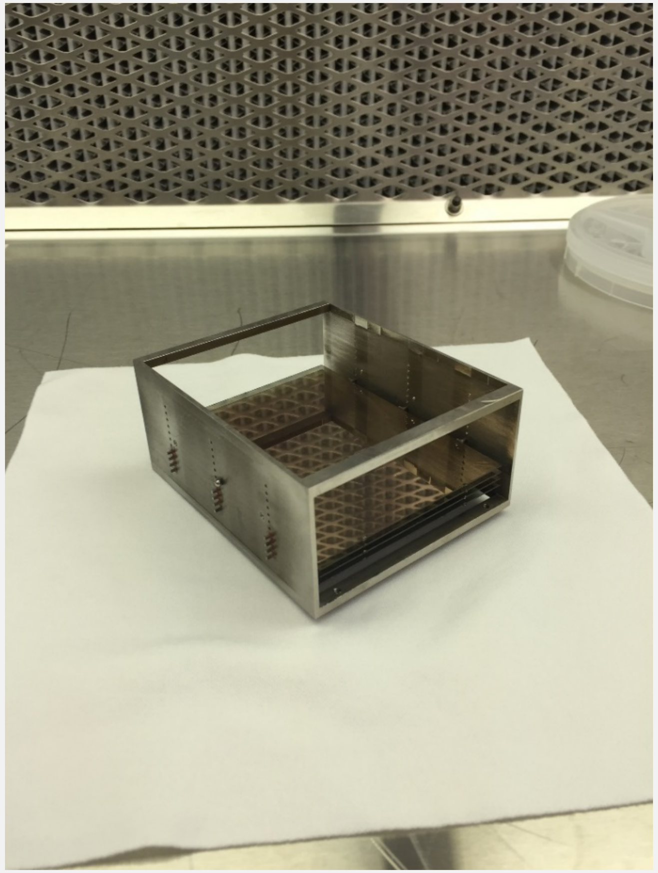
Vibration testing of aligned module

- Vibration tested yesterday using NASA's General Environmental Verification Standard
- 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
- Aligned module passed qualification in likely worst case scenario
- Post-vibe X-ray testing this weekend



Development Roadmap

- Near-term development driven by current projects
  - SAT ending this year, RTF ending next year
  - OGRE suborbital rocket launch in 2018
  - *Arcus* instrument studies
- Summary
  - Large format, flight-like gratings have been fabricated, aligned, and tested
- Ongoing diffraction efficiency testing
  - Full format imprint undergoing testing at BESSY PTB
  - Plan to test imprint at ALS (post move)
- Resolving power tests currently ongoing at MSFC
  - Full format, blazed, full illumination test
- Various areas should be improved/studied
  - Imprint process, stress allocations, surface metrology, alignment metrology and control



Possible studies/Trade space in XRS context

- ***Trade space exists in resolving power, not in effective area***
- Proper formats
  - Larger gratings, larger modules = easier to align (fewer elements, potentially thicker substrates)
- Substrate materials
  - Flat silicon
  - Direct write
- Coating materials
  - Low stress/high reflectivity
- Groove density
  - Large trade space that effects focal plane size, and thus, bandpass
- Variable line spacing limit and effect on spectral resolving power
  - Are 0.1 nm steps necessary/sufficient
- Tunable blaze angle
  - Higher blaze = higher dispersion = more resolving power, but potential focal plane effects
- Profile roughness
  - Understand roughness evolution from etch to imprint to coating

Acknowledgements

- Collaborators
  - SAO – Randall Smith, Ryan Allured, Casey DeRoo, Peter Cheimets, Ed Hertz
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