

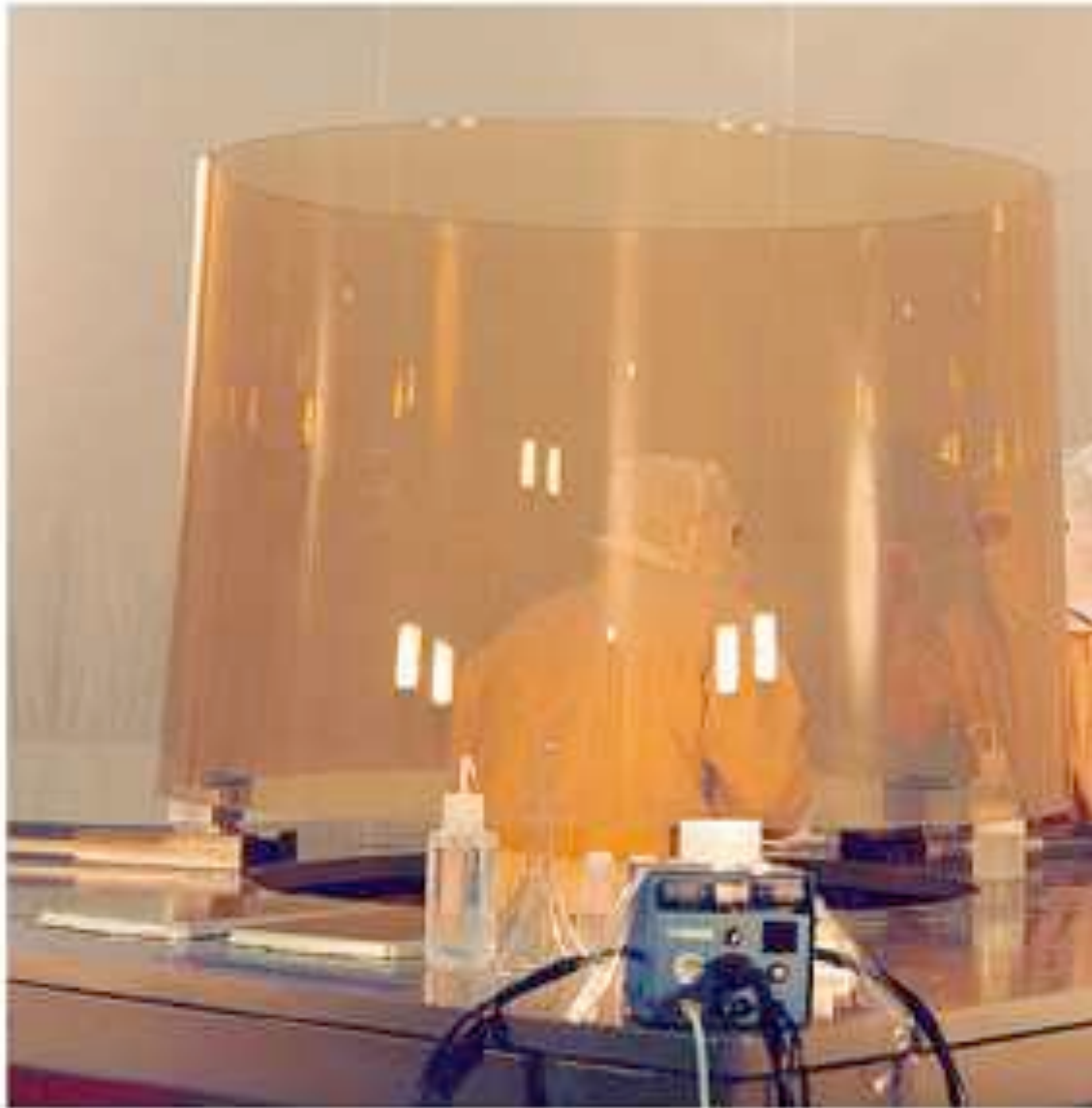
# Fabrication Strategies for Light Weight X-ray Optics

Presented by Mel Ulmer<sup>a</sup>

Co-Authors: Michael E. Graham, Semyon Vaynman, Matvey Farber,  
Jonathan Echt, Steve Ehlert, Alex Vaynman, Steven Wang, Robert Stern,  
Lawrence Shing, Yong Chu, Mark Smith, Asit Biswas

a: e-mail [m-ulmer2@northwestern.edu](mailto:m-ulmer2@northwestern.edu); phone 847.491.5633; web page

<http://www.astro.northwestern.edu/~ulmer>



HDOS Chandra Mirror blank

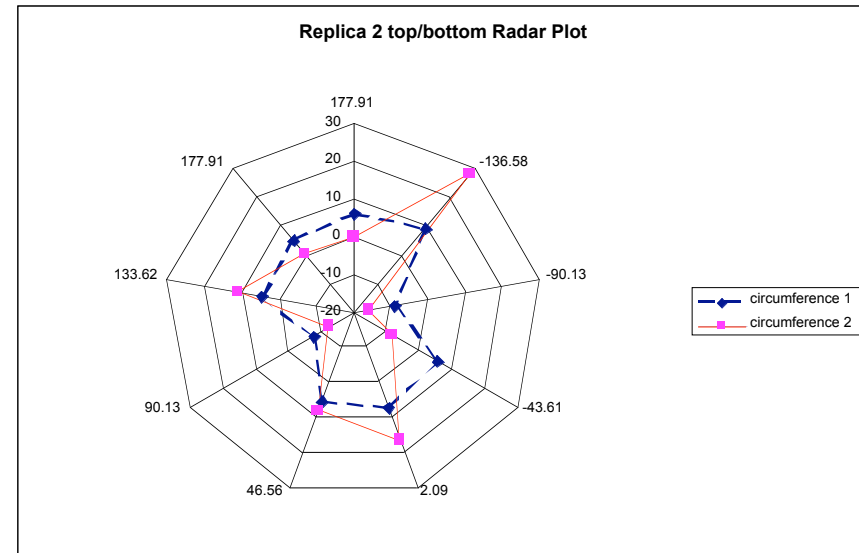
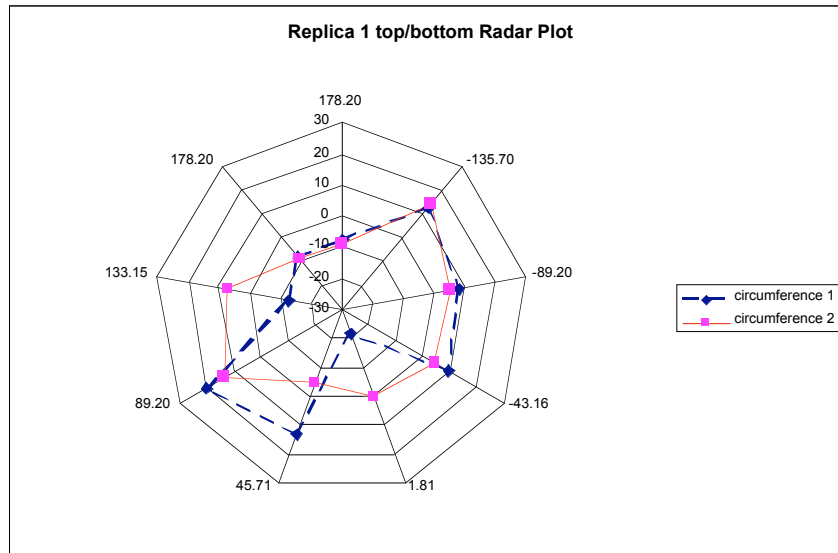
# Proof of concept study for light weight X-ray and visible light optics

X-ray optics  
geometry; 3  
cm diameter.  
cylinder

“hockey  
puck”  
for  
visible  
light  
optics; 6  
cm  
diameter



# Top/bottom az scans



Thanks to David Content NASA/GSFC

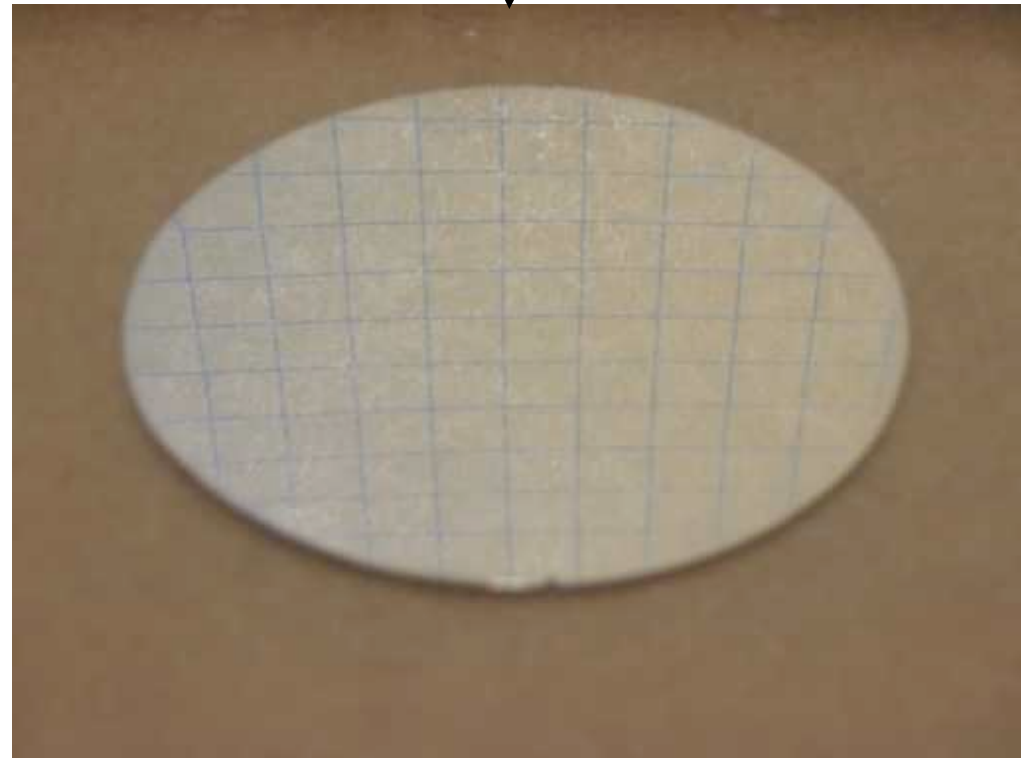
Ni/sprayed/Ni laminated 5 cm dia. flat: areal density, 2 kg/m<sup>2</sup>; 140 μm front/back of and 120 μm of sprayed micro-spheres; 7.3 gm = 3.7 kg/m<sup>2</sup>



Mirror and mandrel together, both 5 nm smooth

NB for cryo mirror applications, dipping in liquid N<sub>2</sub> had no effect

Straight line test on flat; profiler measurements show deviation from flat of  $1/3 \lambda$  (600 nm); smoothness on 5 nm 10-100 micron scale

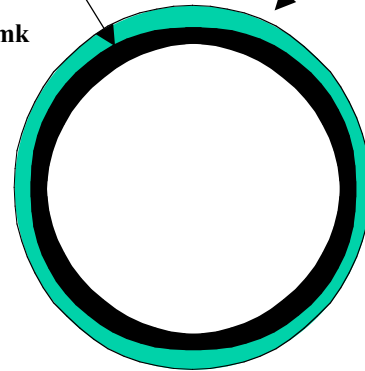


# Background info re micro-spheres, Part I

## Current State-of-the-Art

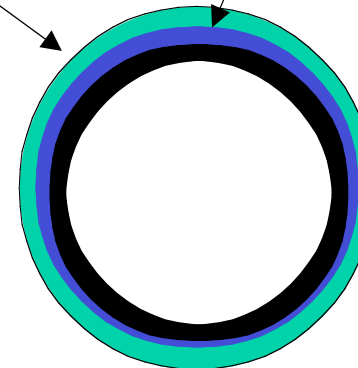
### Hollow Mullite Spheres

Density= .6-.7 gm/cc  
Strength= 5-7,000 psi  
size 1 micron-1000 microns  
Low Thermal conductivity=.3 W/mk



Ni Coating

### SiC Coating



Second  
Generation

### Mullite/Ni Cermet Composite Properties

(Dependent on Ni Content)

Plasma Sprayed Shapes (60 -70% Microspheres Retained)

- Thermal Conductivity= .7 - 5.5 W/mk
- Density= .8-.85 gm/cc(6% Wt Ni coating)  
2.0-2.3 gm/cc (40 -50% Wt Ni Coating)
- Crush Strength = 8-9,000 psi
- CTE= 10-15 micron/m C
- Flexure= 4-22,000 psi
- Compression= 10-50,000 psi
- Modulus= 2-9 MSI

### Proposed Mullite/SiC/Ni Composite

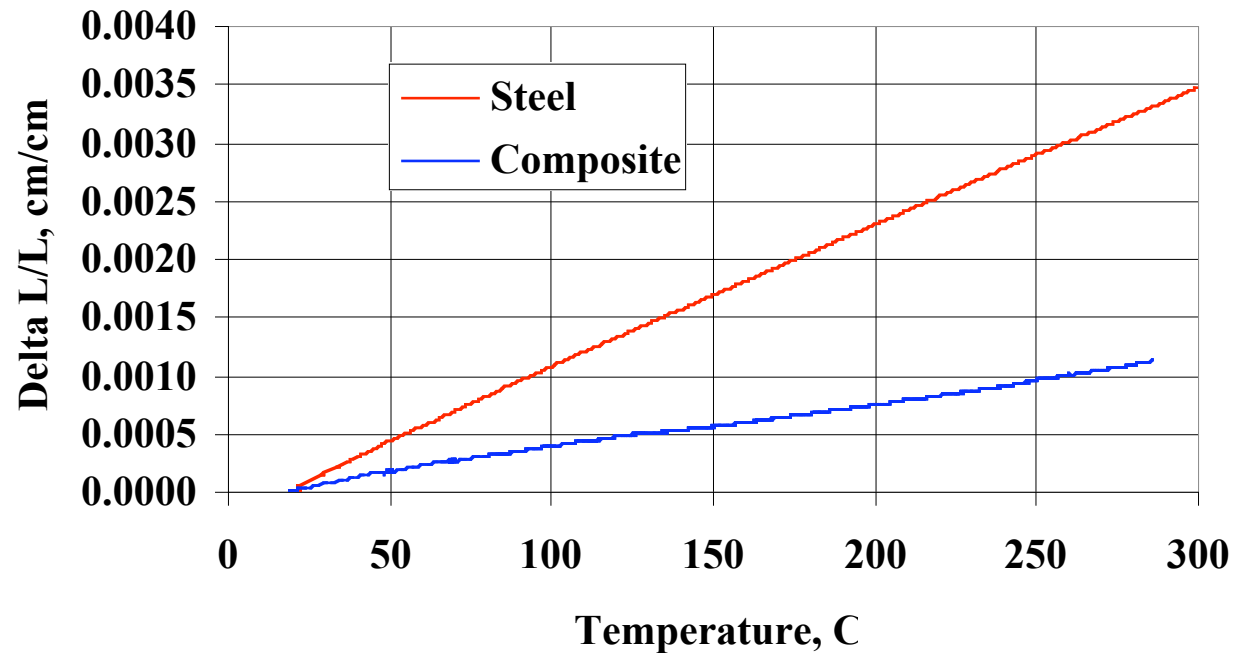
Density= .9 -1.0 gm/cc

SiC= 3-6 % Wt

Ni= 6% Wt

Increased Crush strength, Increased microsphere  
spray retention, Inc Composite strengths with  
lower Metal Content, Lower CTE





For cylinder:

CTE about  $4.2 \cdot 10^{-6}$  versus  $2.4 \cdot 10^{-6}$  CVD SiC

Density =  $4.7 \text{ g/cm}^3$  versus  $3.2 \text{ g/cm}^3$  CVD SiC

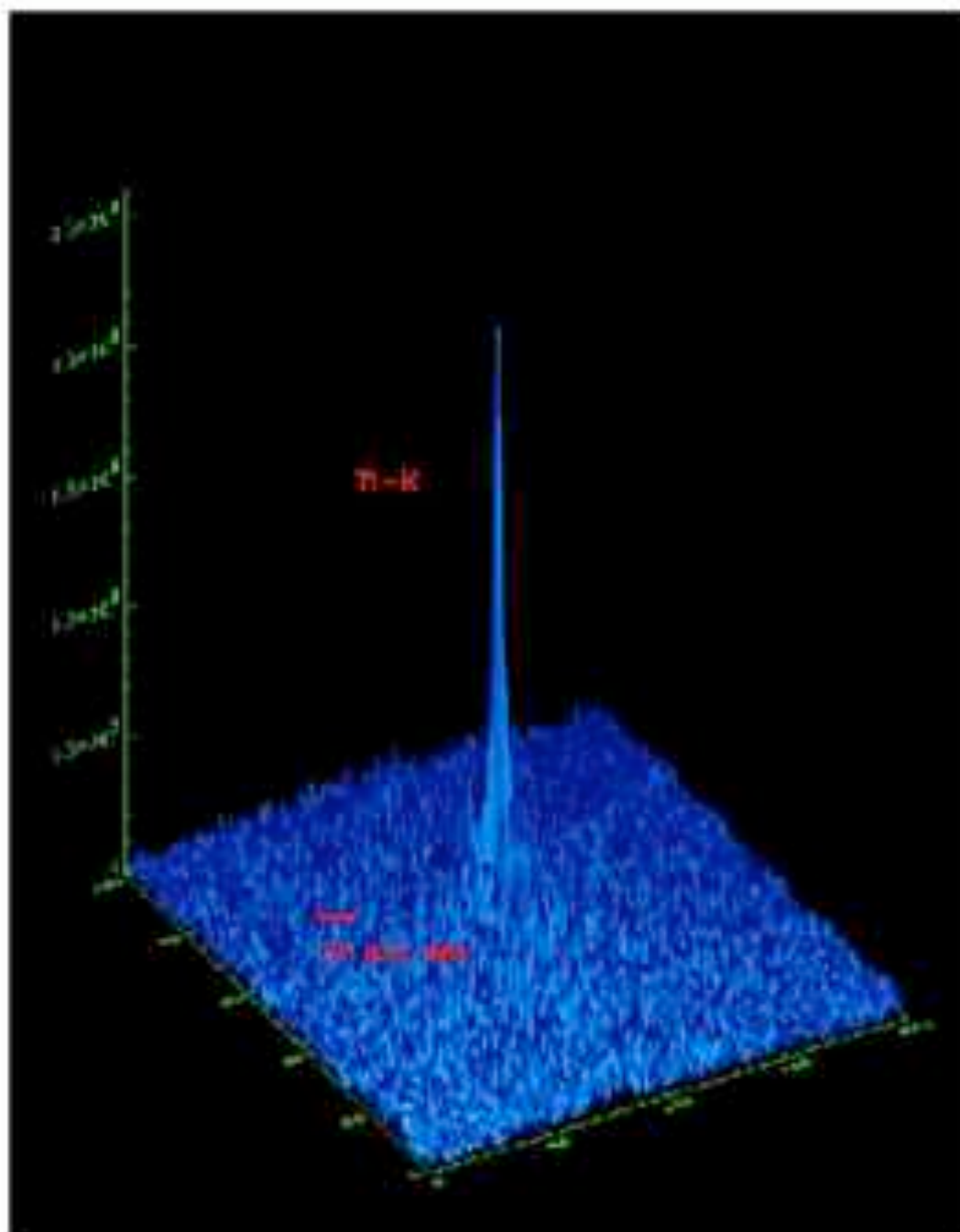




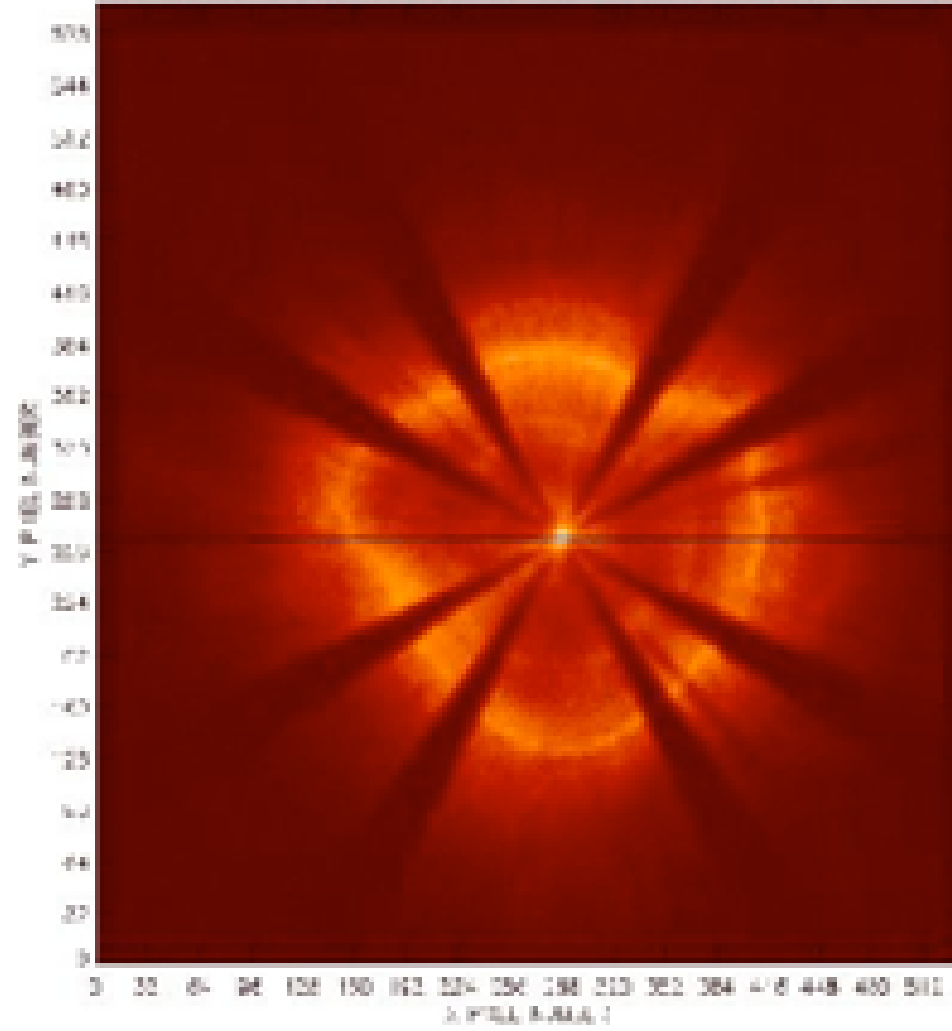


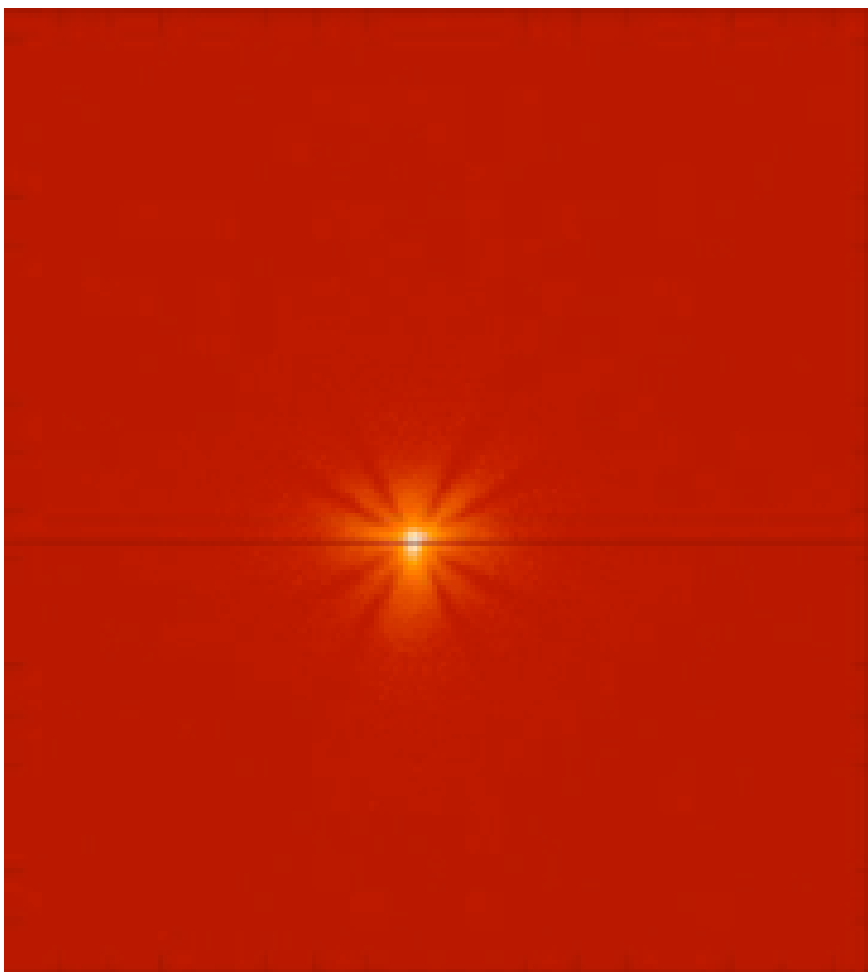


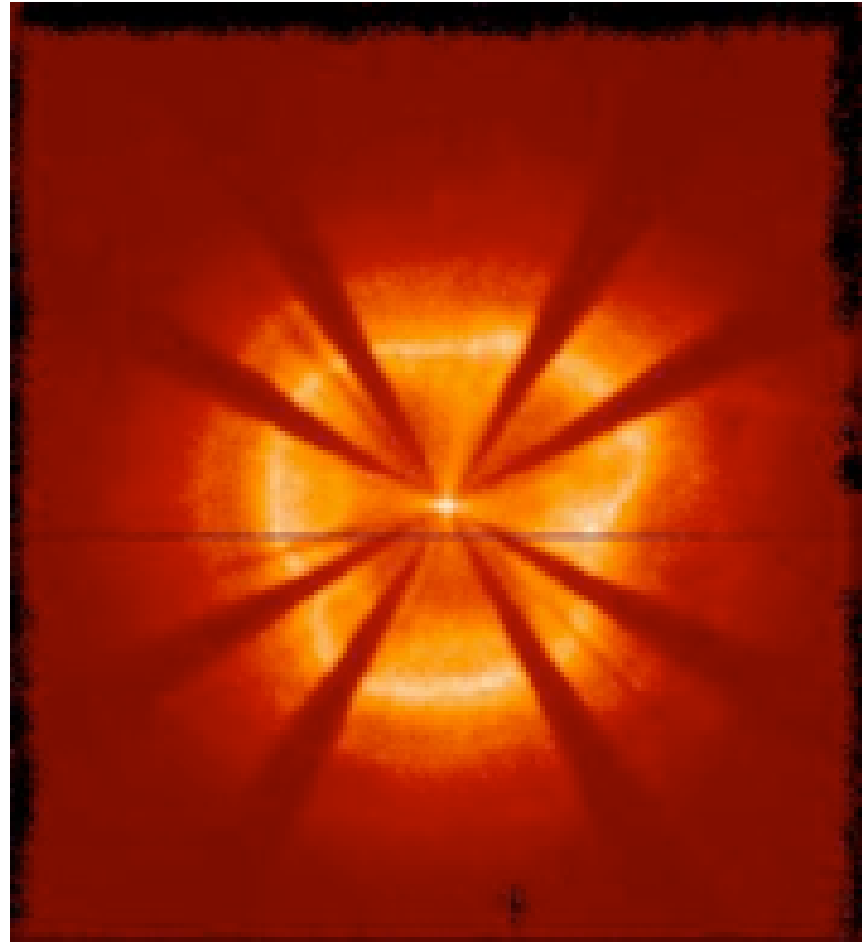




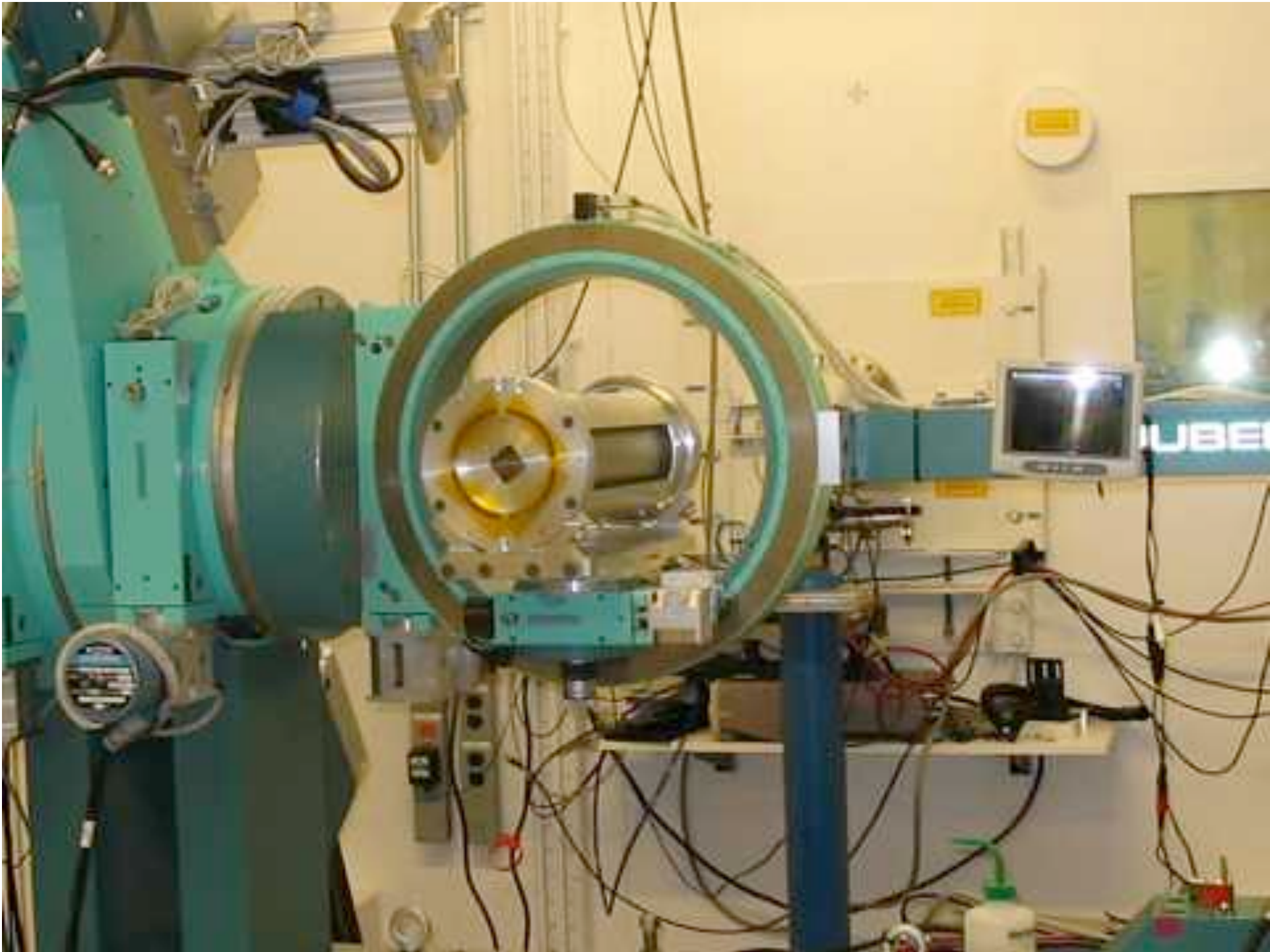
00094-00-2-A03 8352-3-30 AdP - B DATE: Tue 20/02/2012

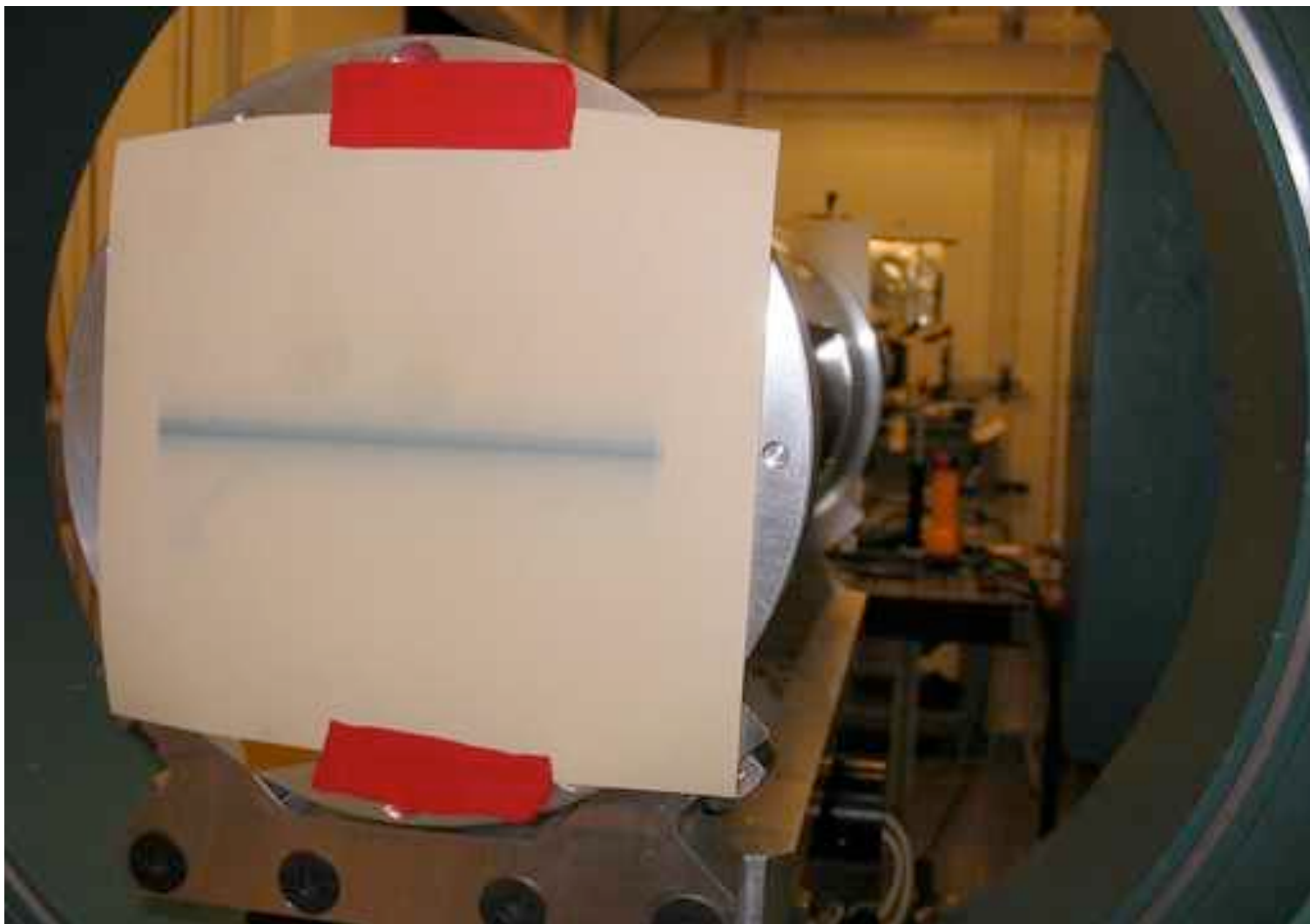




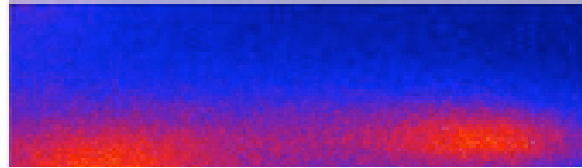




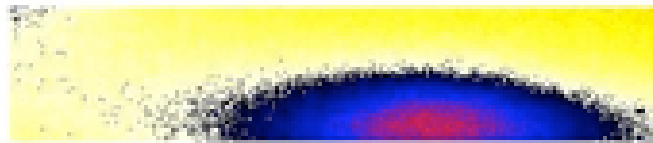


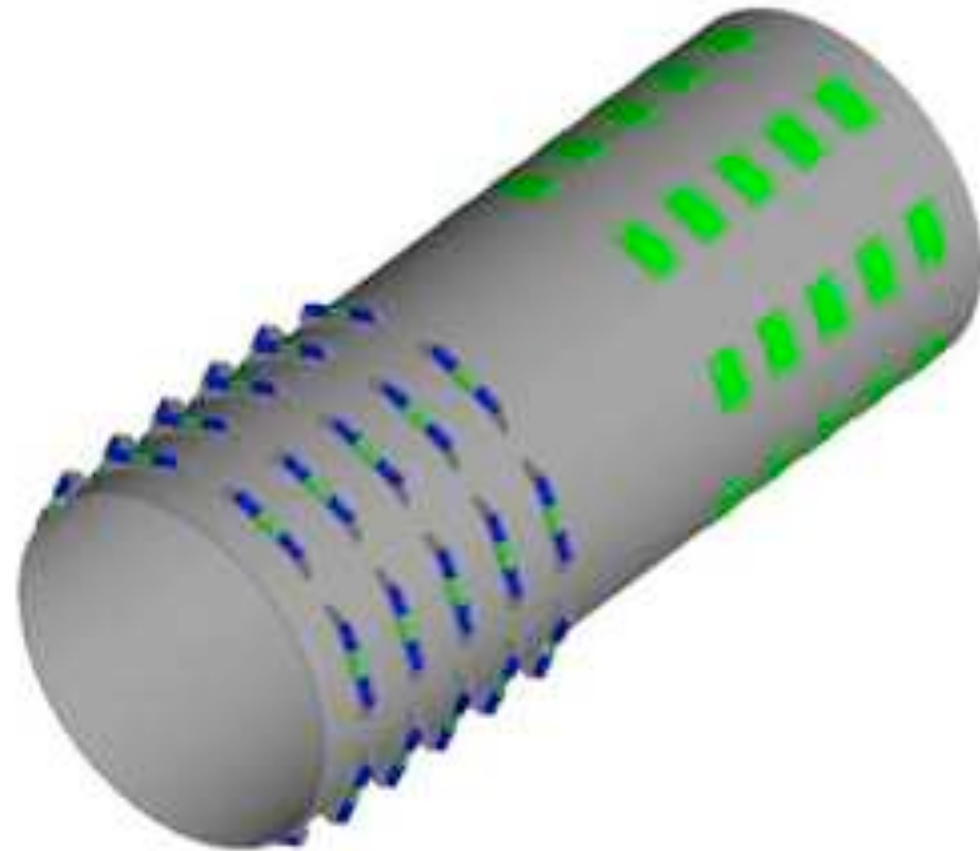


7 keV out of focus

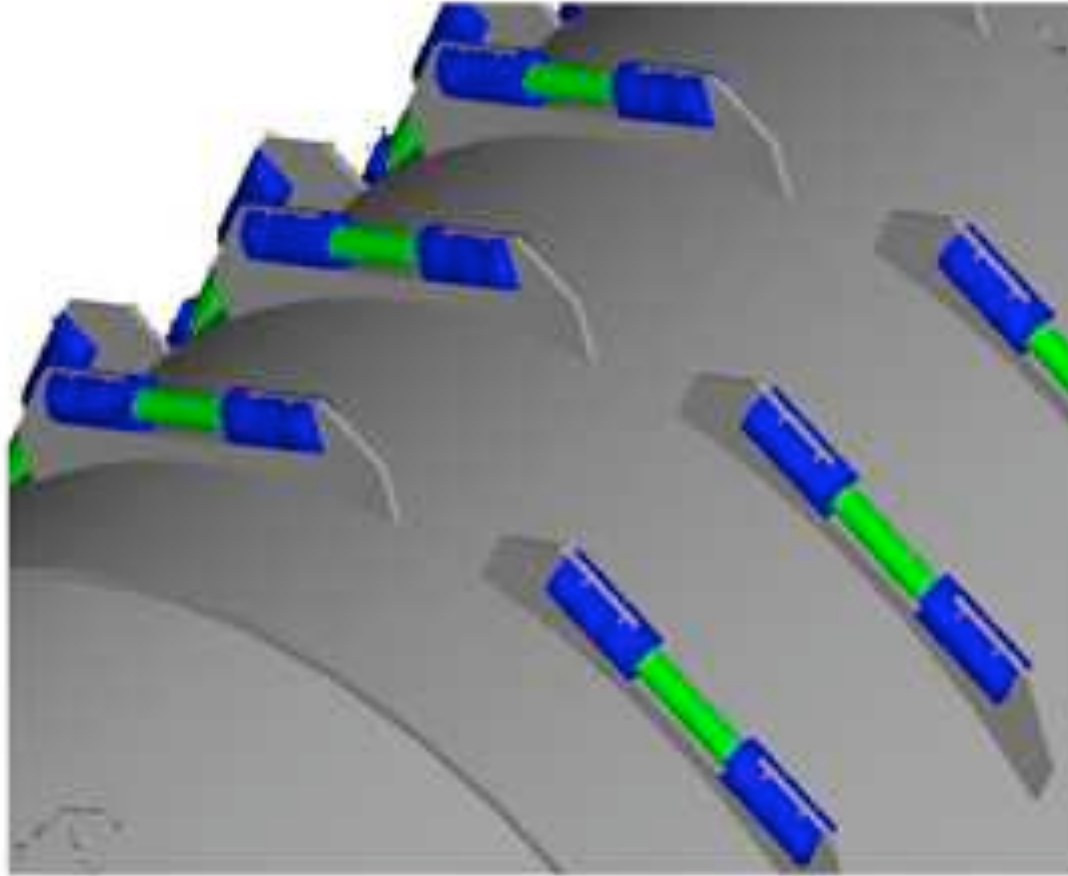


7 keV in focus 30 arc sec FWHM

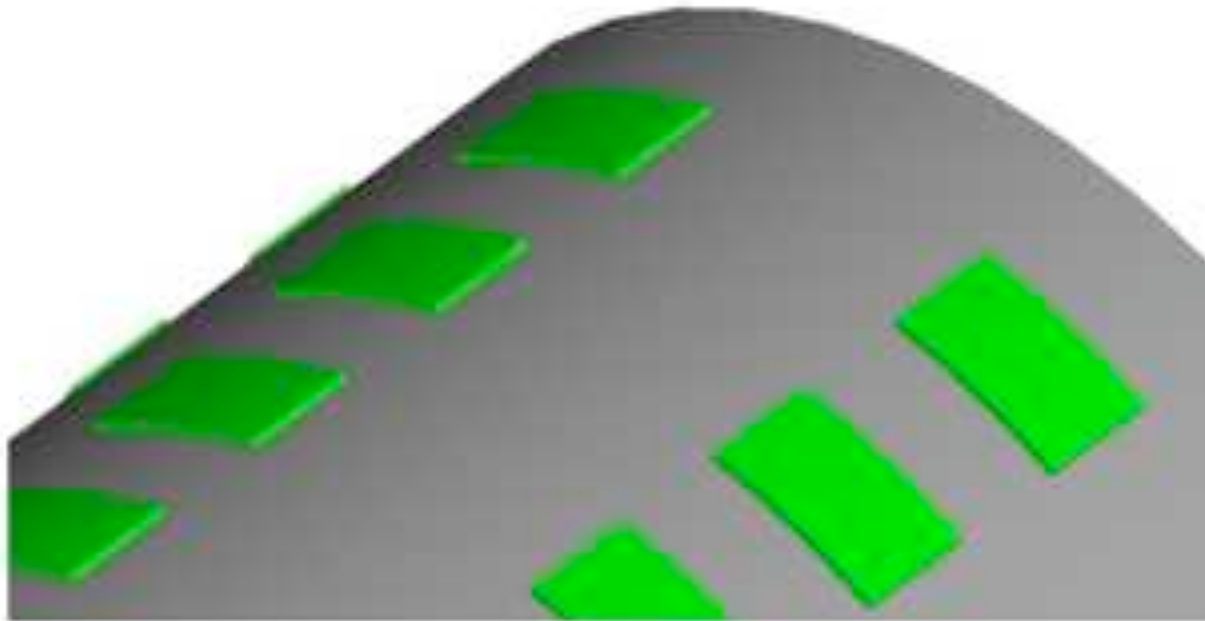




Two Actuator Concepts



Integrated Co-fired stack approach



Flex Patch Approach



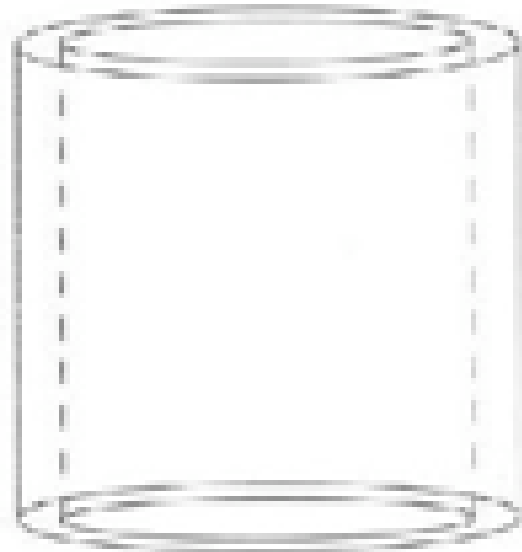
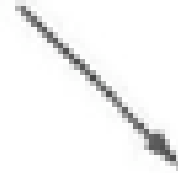
Rotisserie



Sputtering Gun



**Mandrel & Multilayer**



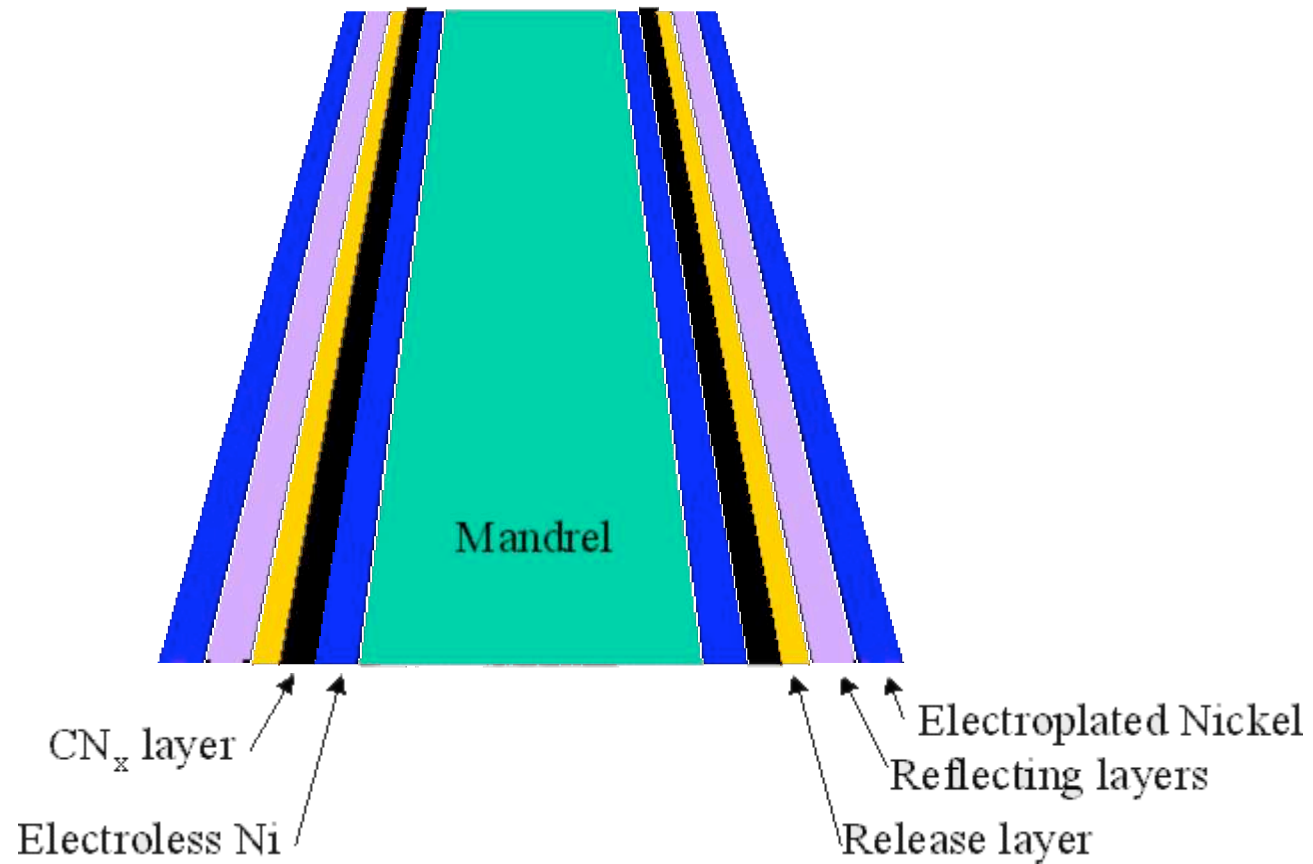
**Mandrel with electrodeposited nickel**





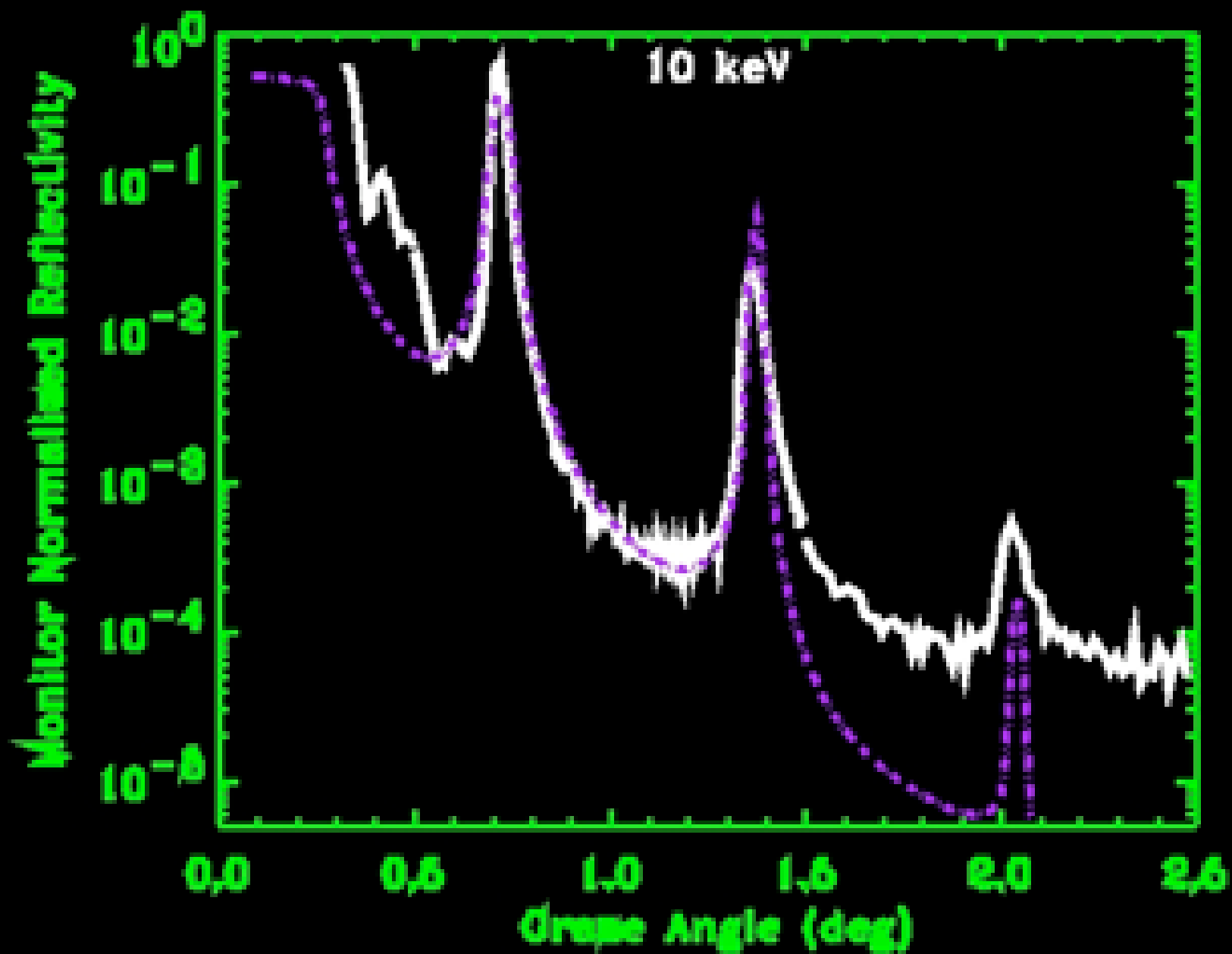
Removed Electroform.  
Multilayers on inside.

# Coated Mandrel

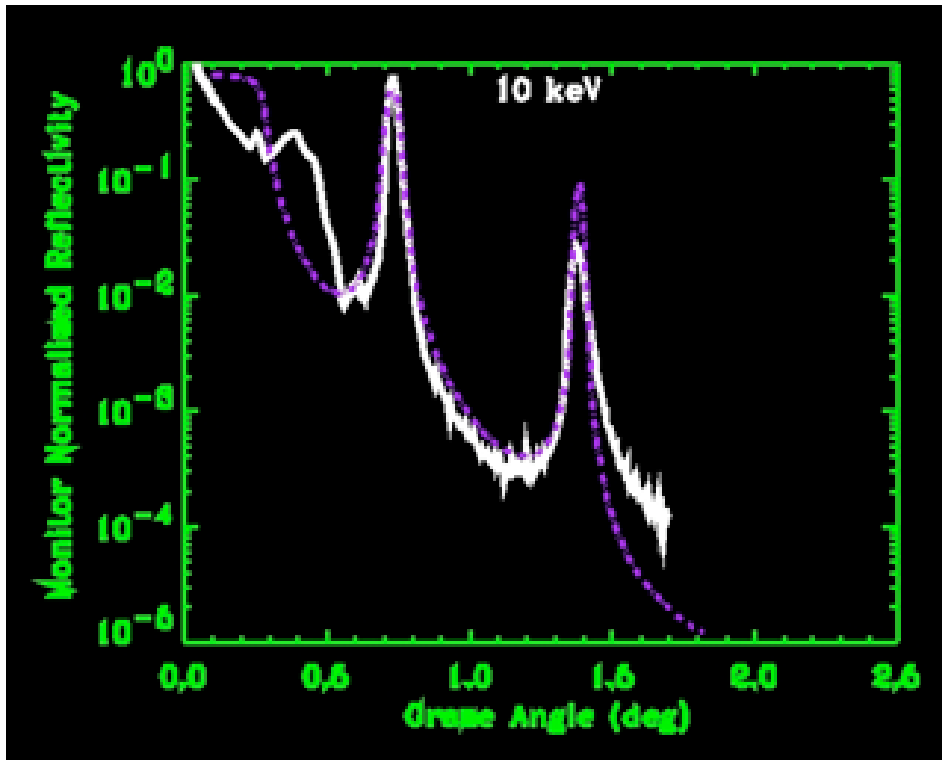




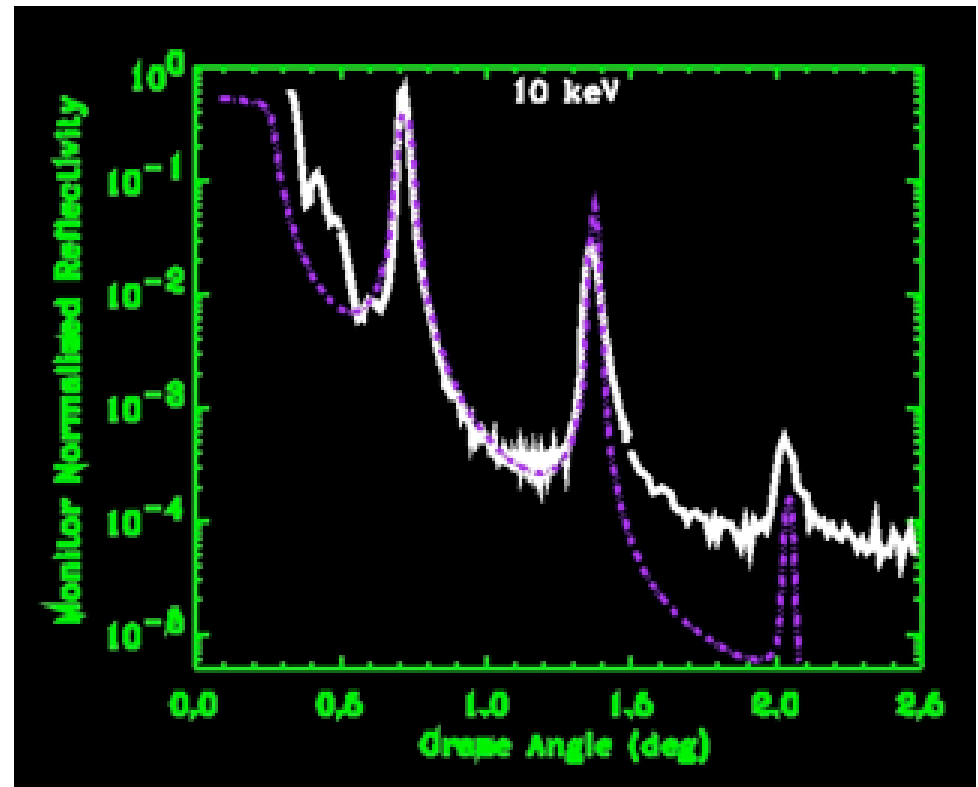




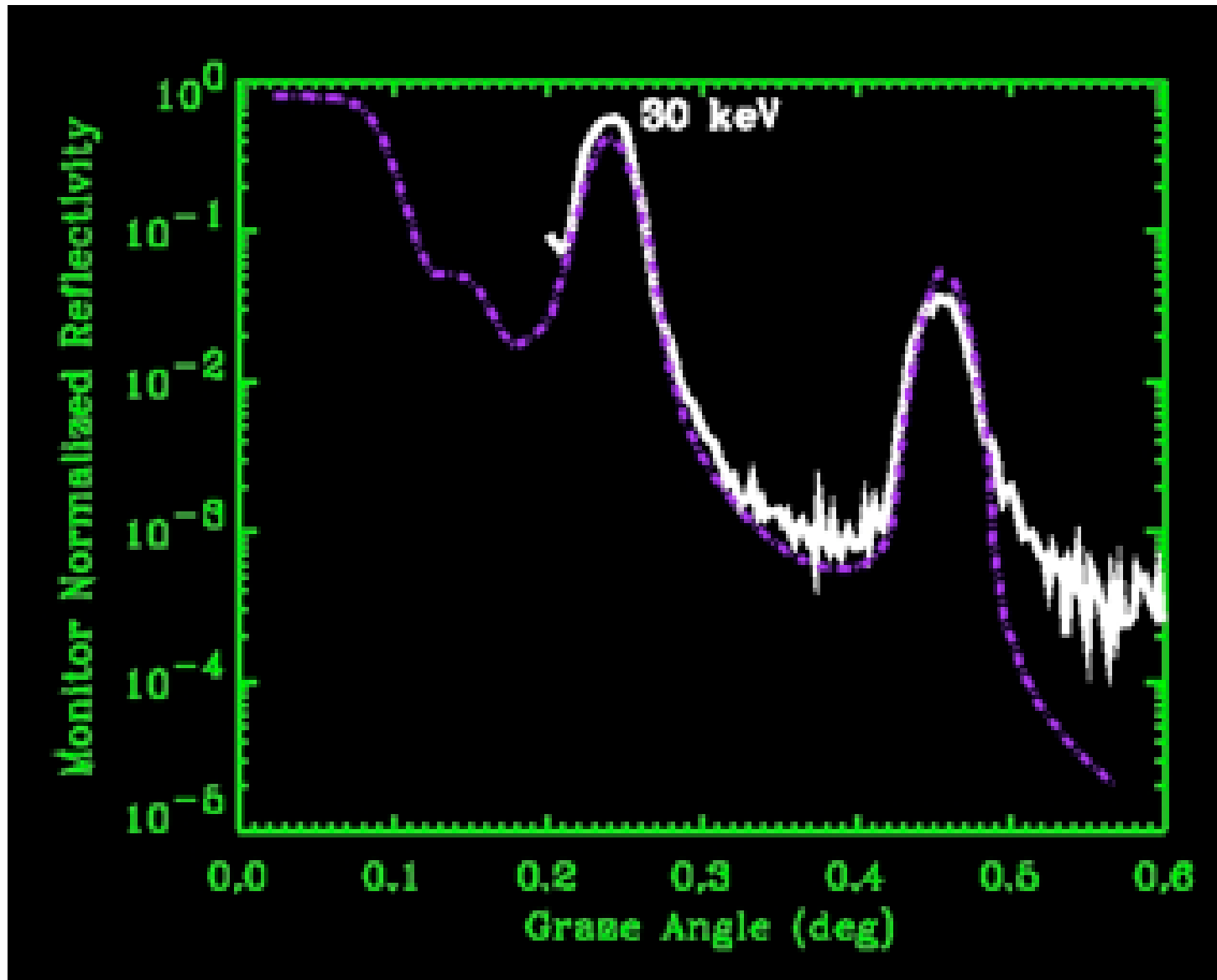
Two different orientations about optical axis, same energy; W/Si 5.29 nm



About 90 deg rotation



# Higher Energy



## Concluding Remarks:

- Plasma spray shows promise for light weight mirrors, and actuators are fall back
- Facilities available to test with and without Actuators
- Technology Exists to Enhance High Energy Reflectivity

Funding Sources: LM Independent Research Program

NASA Space Grant to Illinois

NASA STTR