# From x-ray telescopes to neutron focusing

Mikhail V. Gubarev[1], Boris Khaykovich[2], Brian Ramsey[1], David Moncton[2], Suzanne E. Romaine[3], Richard E. Rosati[3], Ricardo Bruni[3], Lee Robertson[4], Lowell Crow[4], Vyacheslav Zavlin[5] , Haile Ambaye[6] and Valeria Lauter[6]

[1] Space Science Office, NASA Marshall Space Flight Center, Huntsville, AL 35812;
[2] Nuclear Reactor Laboratory, Massachusetts Institute of Technology, 123 Albany Street, MA 02139;
[3] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138;
[4] Oak Ridge National Laboratory, Oak Ridge, TN 37831;
[5] Universities Space Research Association, 320 Sparkman Drive, Huntsville, AL35805
[6] Spallation Neutron Source, Neutron Scattering Science Division, Oak Ridge National Laboratory, Oak Ridge, TN, 37831

# Neutron optics

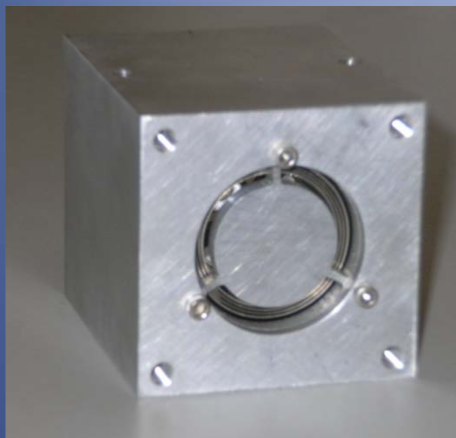
- ✓ The refraction index is less than unity for most of materials for neutrons and x-rays. The highest reflectivities for thermal and cold neutrons would be obtained with a pure nickel surface.
- ✓ Imaging optics based on the Wolter optical geometries developed for the x-ray grazing incidence beams can be designed for the neutron beams.
- ✓ MSFC has an active development program in grazing-incidence, ***nickel***-electroformed replicated optics for use in x-ray astronomy. This opens a possibility to develop a *grazing incidence* ***neutron*** *imaging optics…*

***Possible applications***

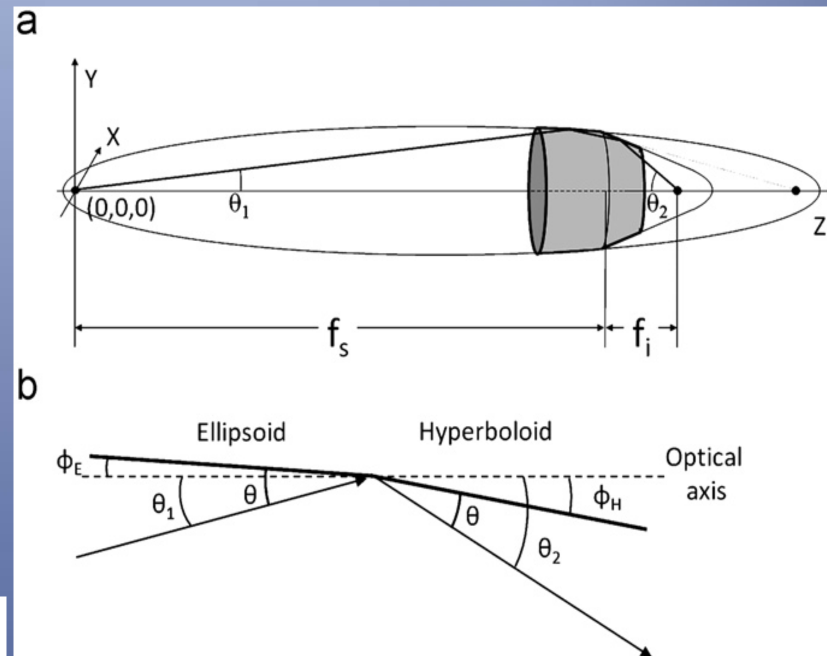
- *Neutron microscopy and radiography*
- *Small-Angle Neutron Scattering Analysis*
- *Light element analysis and detection*

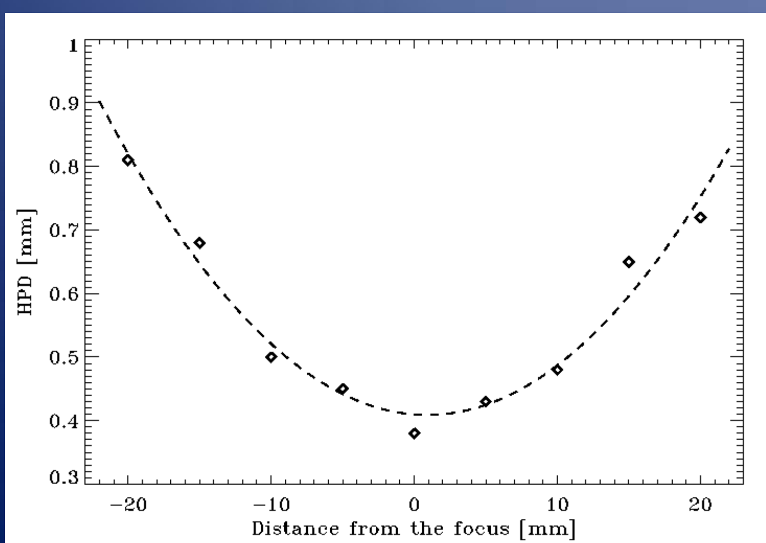
The test mirror installed in the neutron beamline National Institute of Standards and Technology's Center for Neutron Research

# Neutron Optics – X-ray test



A neutron imaging system contains four nested ellipsoid-paraboloid nickel mirrors.



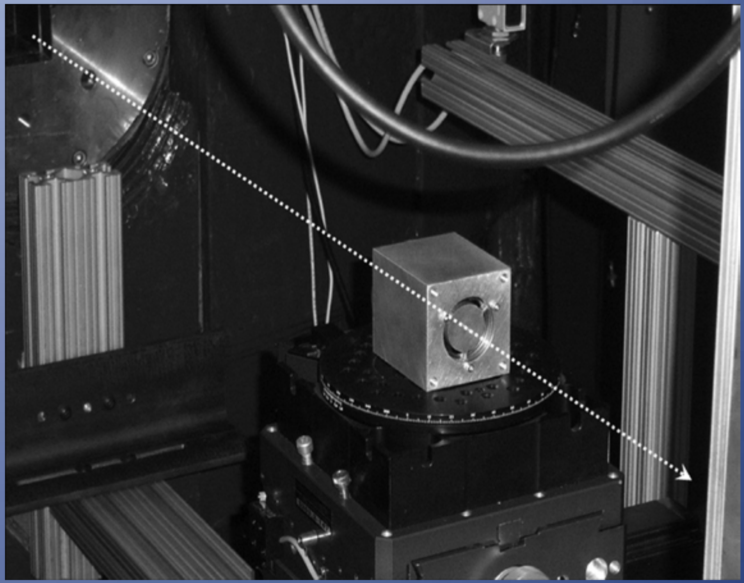




| Placement | HPD (mm) | FWHM (mm) | |
|---|---|---|---|
| Direct | 1.48 | 0.39 | --- D = 640 mm (the distance between the source and the optics) |
| Reverse | 0.38 | 0.13 | --- D = 2560 mm |

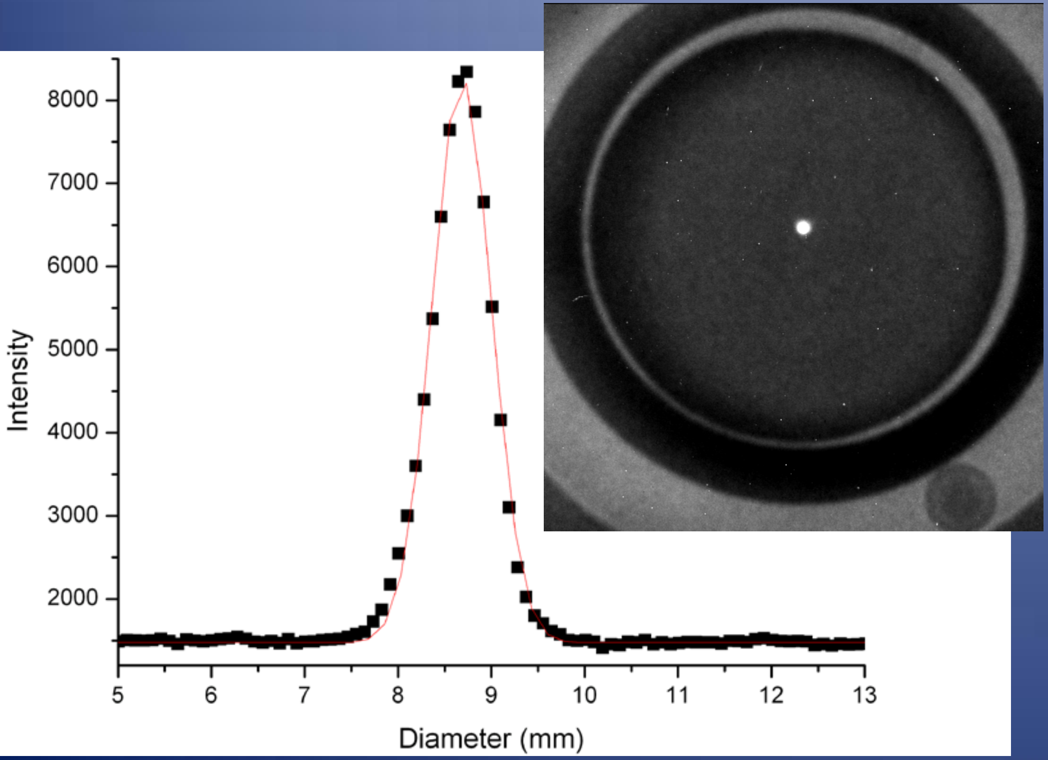
All numbers are as measured at the detector.
The source spot size is smaller than 0.01 mm.

# Neutron optics at MIT Reactor

Cd pinhole source: diameter 2.08mm
Source-to-mirrors distance = 2496 mm
Mirrors-to-detector distance = 640 mm
Magnification M=3.9

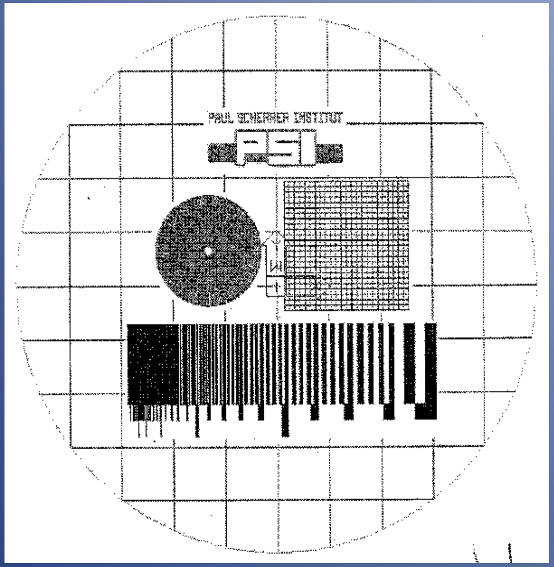


Optics at the neutron beamline at the MIT Reactor. The neutron beam follows the dashed arrow

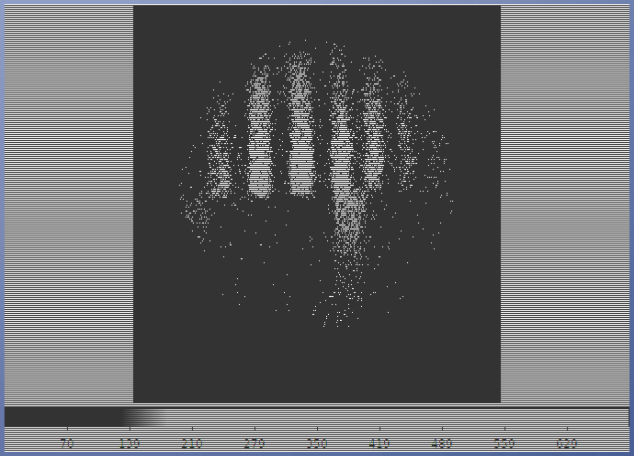


# Neutron imaging

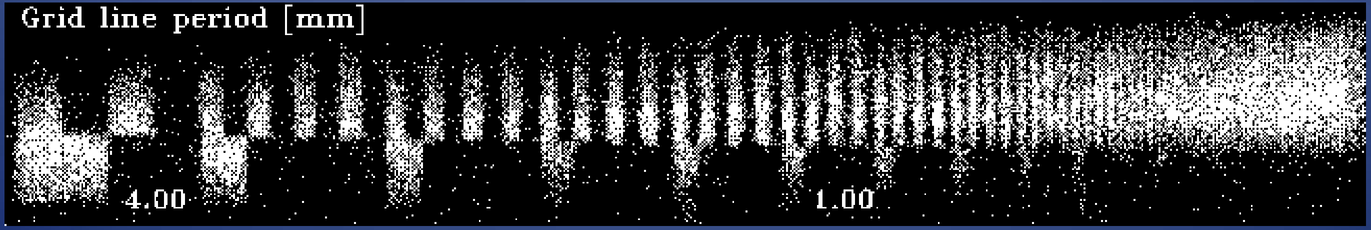
The imaging properties of the microscope has been tested at the instrument development beamline at HFIR (CG1-D).




The schematic of the GD test object.



Sample of the neutron image collected using the grazing incidence microscope. Two line periods are presented on the image. Three left periods are 1.43 mm, that correspond to 0.715 mm wide lines. Three right periods are 1.18 mm, that corresponds to 0.69 mm wide lines.




The microscope is capable to resolve the period of 0.290 mm

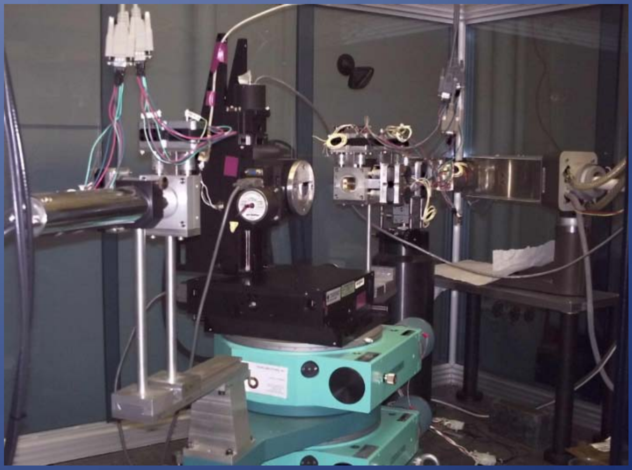
# Neutron multilayer coatings

Challenge – neutron sources have low brilliance and existing beamlines have tight space to place optics

Optics is small. To increase throughput the multilayer coatings are desired

Need for multilayer replication technique

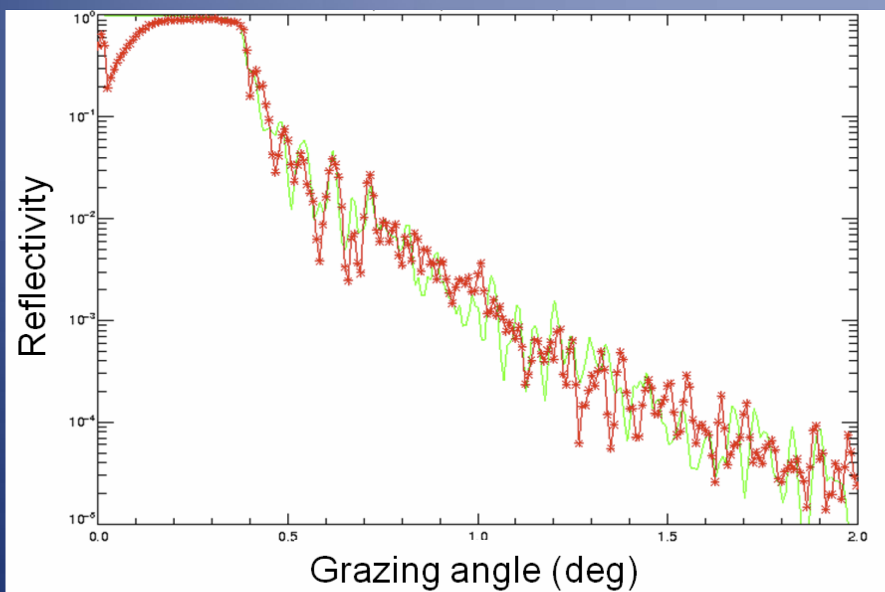
SAO DC magnetron sputtering chamber has 22 inch diameter x 14 inch height.



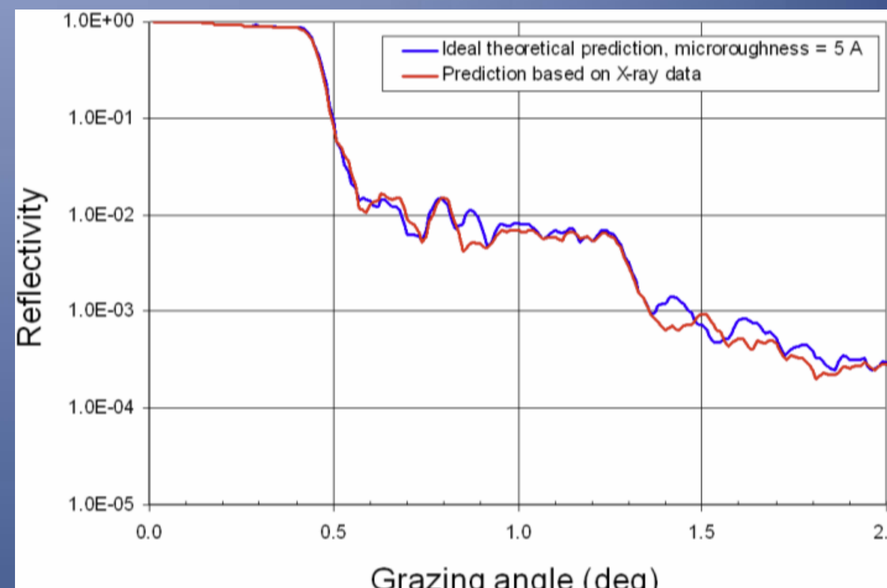
SAO two circle diffractometer used for reflectance measurements

# Neutron multilayer coatings

NiC/Ti continuously graded film with m=2.0, R=90%, N=19 on SPFS




*X-ray reflectivity (red) and a model fit (green),* taken using λ = 1.54 Å. Layer thicknesses are: 85 Å< NiC < 390 Å; 71 Å < Ti < 141 Å.




Simulated data for neutron reflectivity *at wavelength of 2.35 A*vs. graze angle of theNiC/Ti continuously graded film. Red is predicted response based on 1.54 Å X-ray data; Blue is ideal prediction based on interface microroughness of 5 Å.

# Future work

- Neutron reflectivity measurements
- Transfer the coating process to nickel flats
- Replication from the flats
- Replication from curved mandrels

# Summary

- Neutron imaging optics is under development
- The imaging capabilities have been demonstrated at the ORNL
- Neutron multilayer replication technique is under development

# Acknowledgements


- Research supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Awards # DE-FG02-09ER46556 and DE-FG02-09ER46557.

- Research at Oak Ridge National Laboratory's Spallation Neutron Source was sponsored by the Scientific User Facilities Division, Office of Basic Energy Sciences, U. S. Department of Energy.