X-ray mirror metrology using SCOTS: Software Configurable Optical Test System

Optical Metrology @ NSLSII

Mourad Idir

Konstantine Kaznatcheev, Shinan Qian

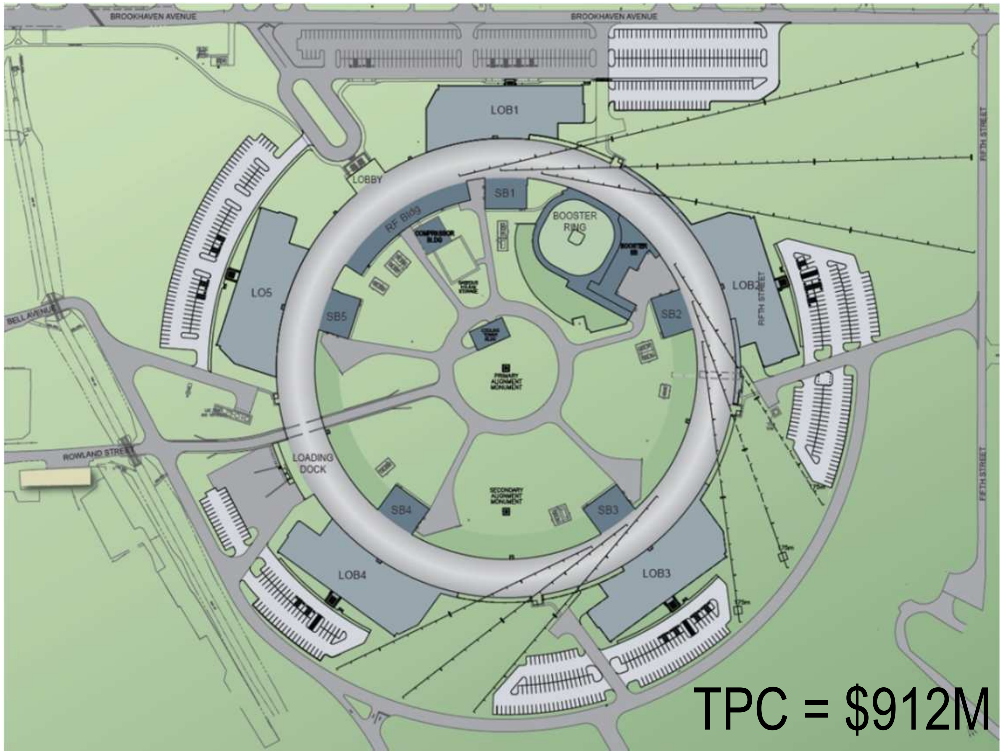
U.S. DEPARTMENT OF ENERGY

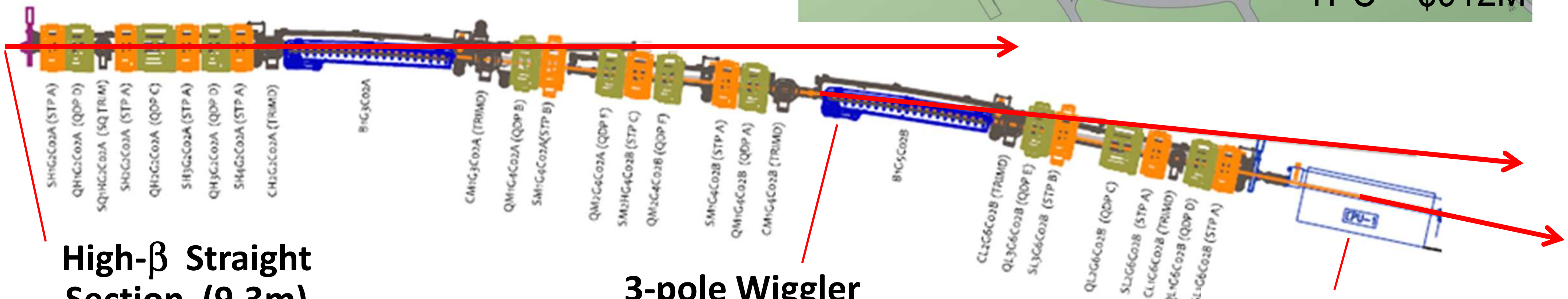
BROOKHAVEN NATIONAL LABORATORY

BROOKHAVEN SCIENCE ASSOCIATES

NSLS-II: Optimized 3rd Generation SR

- 3 GeV, 500 mA, Circumference 791 m
- Low emittance: **ε_x= 0.55, ε_y= 0.008 nm-rad**
- High brightness/flux from **soft to hard x-rays**
- Small beam size: σ_y= 2.6 μm, σ_x= 28 μm
- Pulse length (rms)   ~15 psec
- **27 insertion device beamlines**
- **31 BM / 3PW / IR beamlines**
- Full built-out includes at least **<u>58 beamlines, plus canted IDs</u>**





High-β Straight Section (9.3m)

3-pole Wiggler Bending Magnet

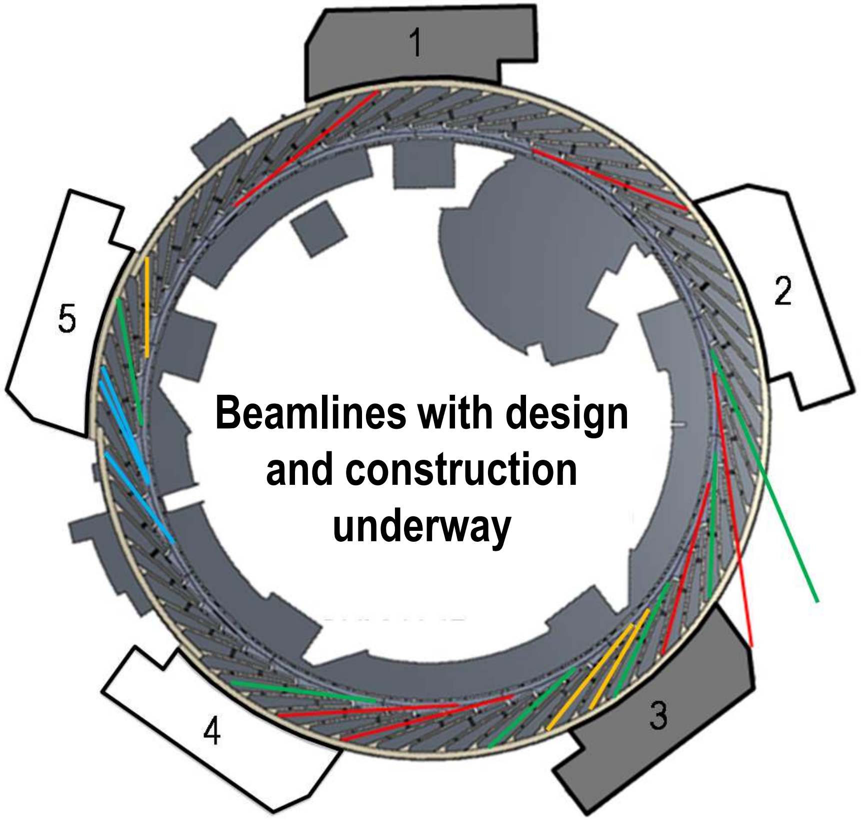
Low-β Straight Section (6.6m)

Key Project Milestones

Aug 2005	**CD-0**, Approve Mission Need	(Complete)
Jul 2007	**CD-1**, Approve Alternative Selection and Cost Range	(Complete)
Jan 2008	**CD-2**, Approve Performance Baseline	(Complete)
Jan 2009	**CD-3**, Approve Start of Construction	(Complete)
Feb 2009	Contract Award for Ring Building	(Complete)
Aug 2009	Contract Award for Storage Ring Magnets	(Complete)
May 2010	Contract Award for Booster System	(Complete)
Feb 2011	1st Pentant Ring Building Beneficial Occupancy	(Complete)
Feb 2011	Begin Accelerator Installation	(Complete)
Feb 2012	Beneficial Occupancy of Experimental Floor	(Complete)
Mar 2012	Start LINAC Commissioning	(Complete)
Jan 2013	Start Booster Commissioning	
Jul 2013	Start Storage Ring Commissioning	
Apr 2014	Projected Early Completion; Ring Available to Beamlines	
Jun 2014	Early Project Completion; Ring Available to Beamlines	
Jun 2015	**CD-4**, Approve Start of Operations	

NSLS-II Beamlines Underway

18 Beamline Construction Projects Underway
21 Simultaneous Endstations (SE)
28 Total Endstations (TE)



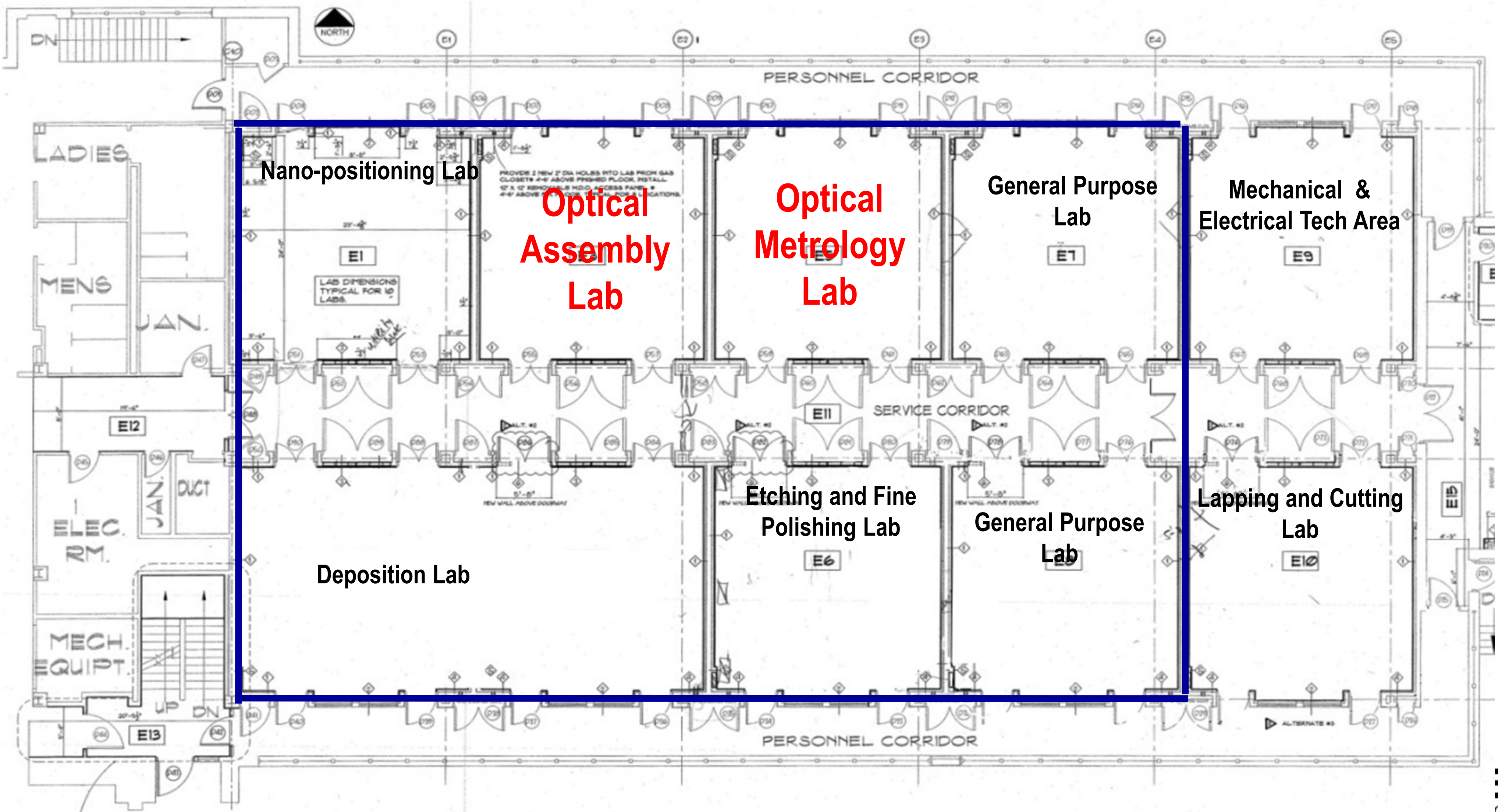
22 additional beamlines (25 SE) have been proposed by the user community and approved by the SAC and NSLS-II but are not yet funded

Beamline ConstructionProjects	SE	TE
NSLS-II Project Beamlines		
• Inelastic X-ray Scattering (IXS)	1	1
• Hard X-ray Nanoprobe (HXN)	1	1
• Coherent Hard X-ray Scattering (CHX)	1	1
• Coherent Soft X-ray Scat & Pol (CSX)	2	2
• Sub-micron Res X-ray Spec (SRX)	1	1
• X-ray Powder Diffraction (XPD)	1	1
NEXT MIE Beamlines		
• Photoemission-Microscopy Facility (ESM)	2	3
• Full-field X-ray Imaging (FXI)	1	1
• In-Situ & Resonant X-Ray Studies (ISR)	1	2
• Inner Shell Spectroscopy (ISS)	1	1
• Soft Inelastic X-ray Scattering (SIX)	1	1
• Soft Matter Interfaces (SMI)	1	2
NIH Beamlines		
• Frontier Macromolecular Cryst (FMX)	1	1
• Flexible Access Macromolecular Cryst (AMX)	1	1
• X-ray Scattering for Biology (LIX)	1	1
Type II Beamlines		
• Spectroscopy Soft and Tender (NIST)	2	6
• Beamline for Materials Measurements (NIST)	1	1
• Microdiffraction Beamline (NYSBC)	1	1
TOTAL	**21**	**28**

NSLS-II Experimental Facilities R&D Program

R&D Labs: Total ~5000 ft^2 space, incl. 4,200 ft^2 ISO 7 (Class 10000) clean rooms

Around 500 ft^2 space for the Optical Metrology Lab.



NSLSII

Major Optics Instrumentation

Equipment

- *Thin Film Deposition facility*
- *Crystal Fabrication facility*

- ***Optical Metrology***

Activities

- *Thin film based optics fabrication*
- *X-ray optics Simulation*
- *Kinoform lenses R&D*
- *Optical Metrology*

- *Hard x-ray optics R&D*
- *Nanopositioning effort*

Foreseen R&D activities

- *At Wavelength Metrology (TEST beamline approved)*
- *Advanced Deterministic Polishing/ deposition activities (IBF …)*

OUTLINE

1. SCOTS for X-ray optics metrology
2. Some Metrology R&D @ NSLS II
3. Conclusion - Perspectives

X-ray mirror metrology using SCOTS: Software Configurable Optical Test System

Peng Su, Yuhao Wang
James H. Burge

Mourad Idir, Konstantine Kaznatcheev
Shinan Qian

THE UNIVERSITY OF ARIZONA
TUCSON ARIZONA

Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN
NATIONAL LABORATORY

NSLS-II

College of Optical Sciences

LOFT
Large Optics Fabrication & Testing

Photo From
Mars 2012

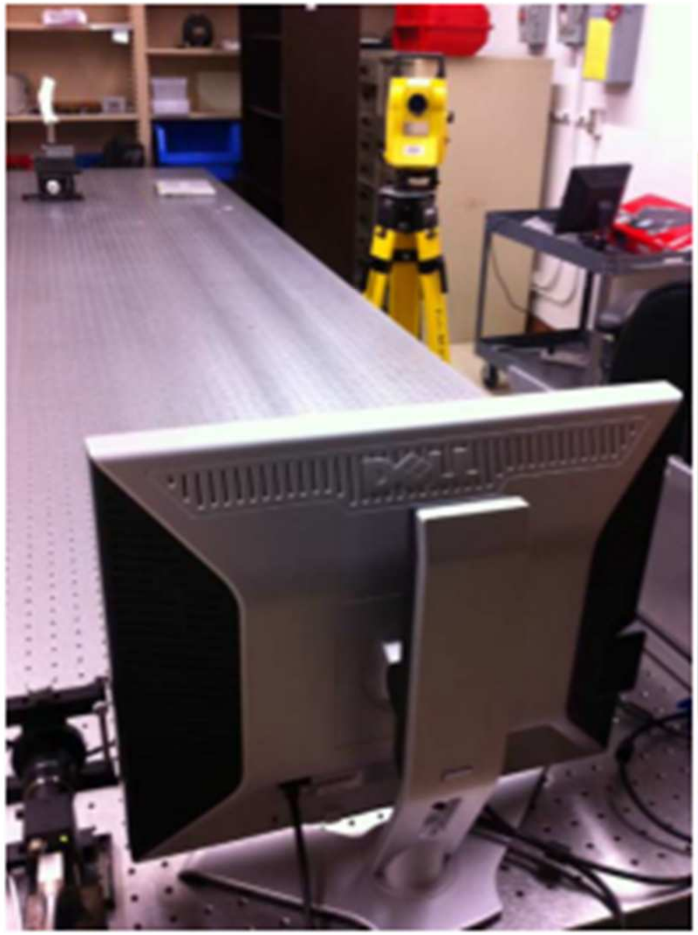
BROOKHAVEN SCIENCE ASSOCIATES

BROOKHAVEN
NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

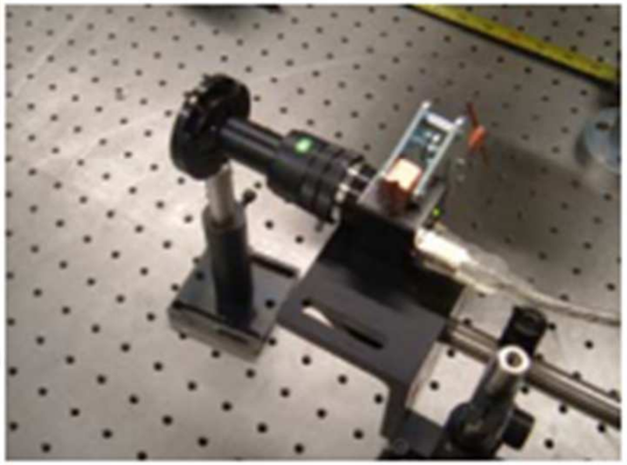
U.S. DEPARTMENT OF
ENERGY

X-ray mirror metrology using SCOTS: Software Configurable Optical Test System

In SCOTS's simplest configuration, all that is needed to perform the test is a screen to illuminate the test surface with fringe pattern (grating) and a camera to use the reflected image to determine the surface gradients.



Geometric layout and experiment setup of the SCOTS test for spherical mirror



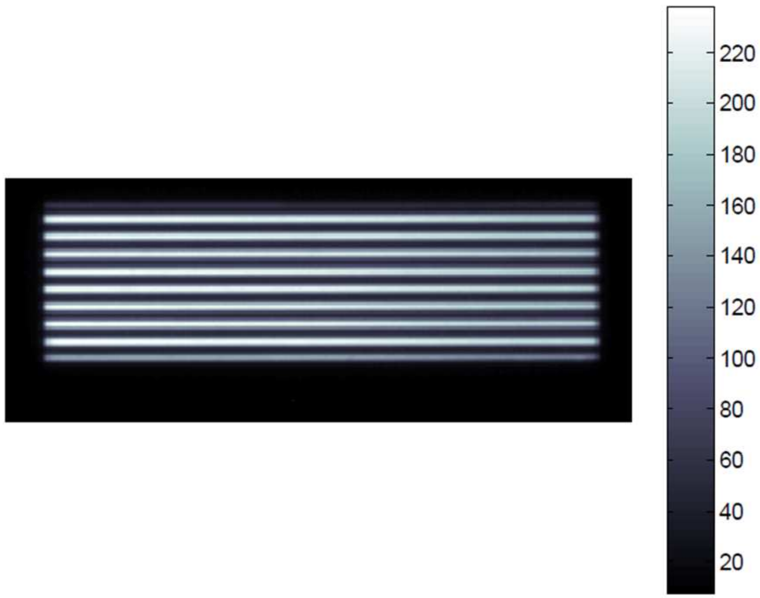
X-ray mirror metrology using SCOTS: Software Configurable Optical Test System

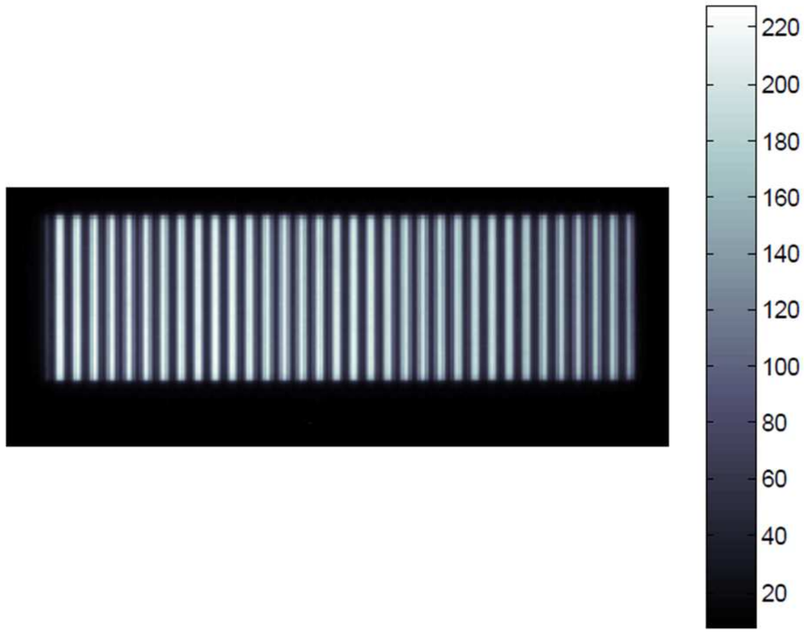
EXPERIMENTAL CONDITION

- 3 m experimental set up was chosen to increase slope measurement sensitivity
  (Also because we have a 3 m optical table)
- The Screen is a commercial dell screen 19”, pixel size 0.294 mm
- The Camera is a commercial 1/3” CCD firewire camera, pixel size 3.75 μm, 1288 × 964.
- The Camera lens f= 50 mm, industry machine vision lens
- ~440 pixels on the mirror
- 0.22 mm/pixel (good spatial resolution)
- Speed was not optimized, roughly we used the video speed to take data;
- No real effort on the Temperature condition (classical AC Room)

X-ray mirror metrology using SCOTS: Software Configurable Optical Test System

The method employs for data collection and reduction is based on the classical phase-shifting approach, in which the test surface is illuminated with sinusoidal fringes.
We calculate the slopes from the phase of the fringes





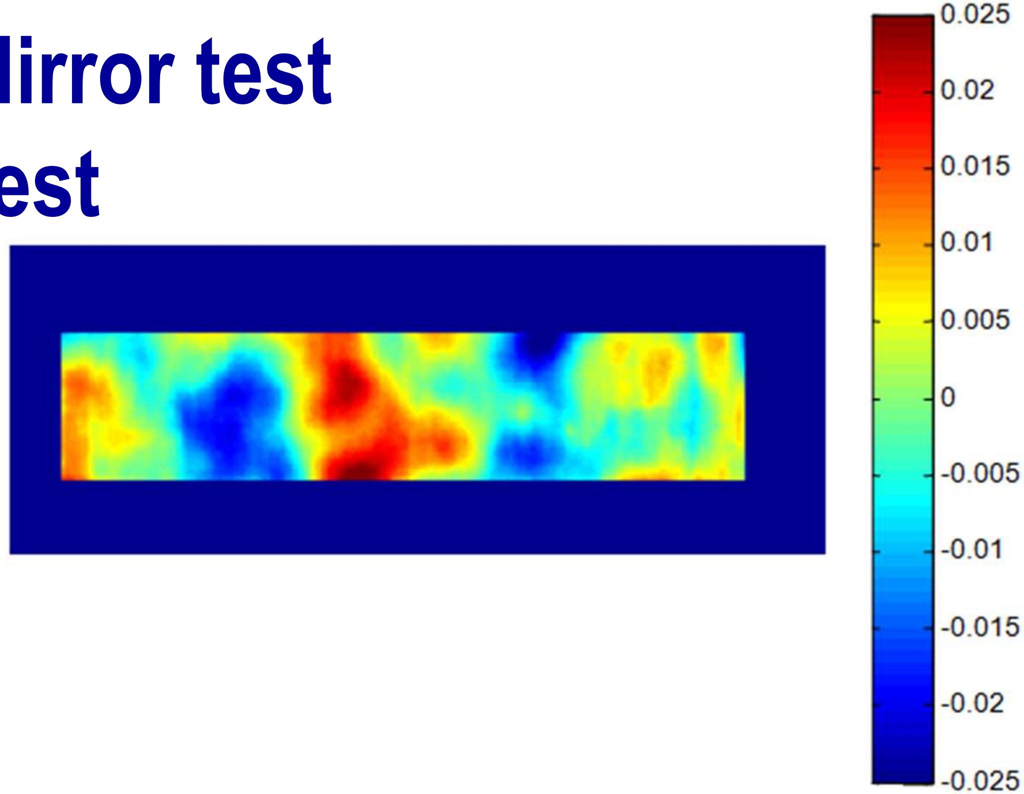
16 step phase shifting is used for data collection and reduction.
Data from each phase shift is an average of 2048 single image.

X-ray mirror metrology using SCOTS: Software Configurable Optical Test System

Integrated surface data, rms=8nm (unit: micron).

Spherical Mirror test

1st Test

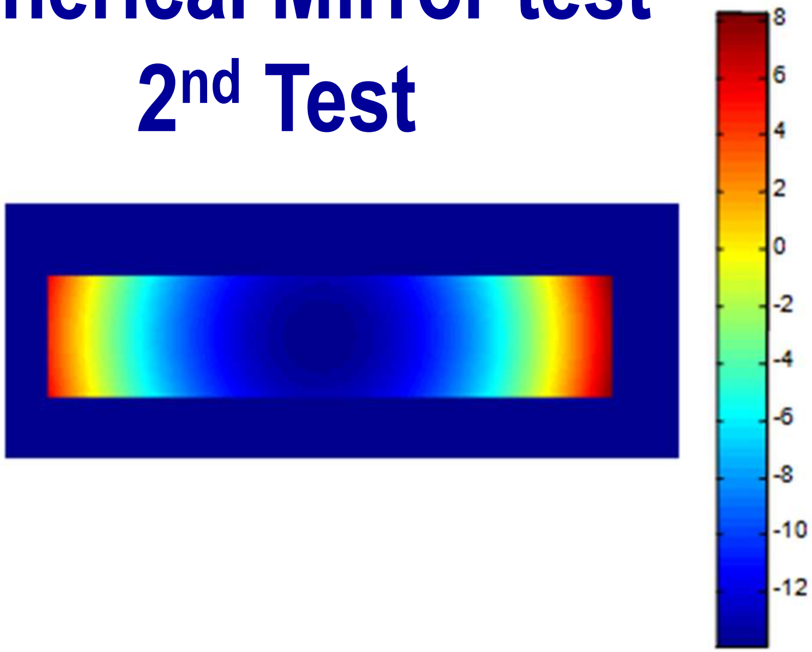


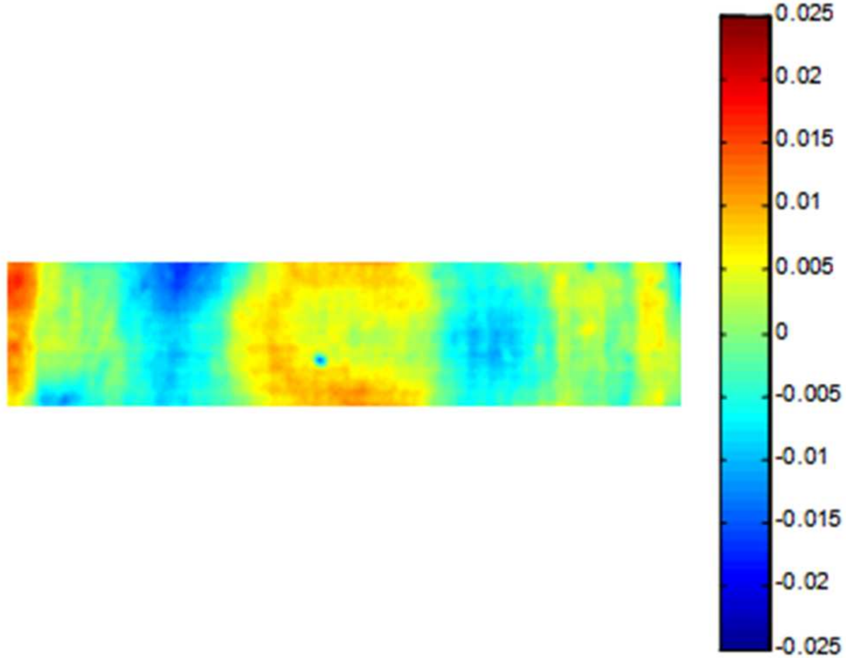
Data after integration, the rms errors are 8 nm.

This includes the systematic components from system test geometry, mainly primary spherical aberration. This can be modeled and removed by accurately measuring the system geometry, for instance with a laser tracker.

X-ray mirror metrology using SCOTS: Software Configurable Optical Test System

Spherical Mirror test
2nd Test

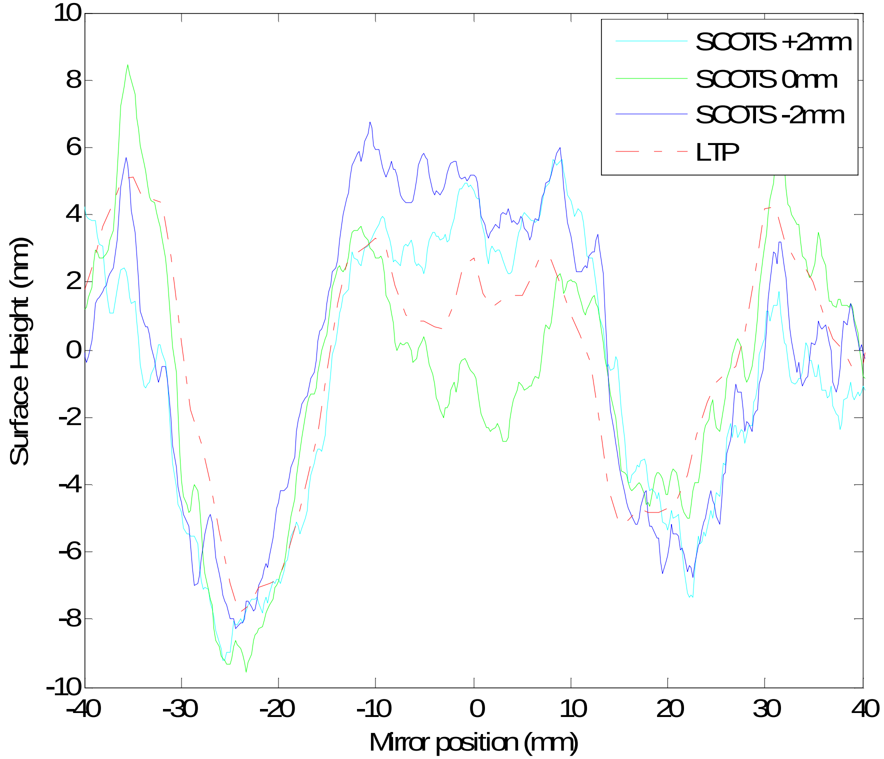


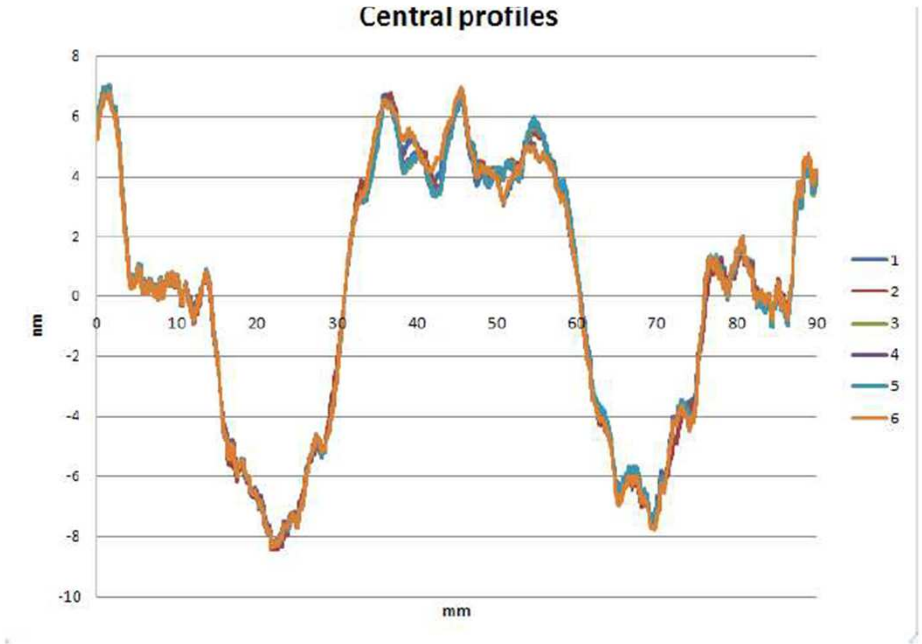


Sphere surface map, Calculated radius R= 54.15m;
Residual Surface map rms ~ 4 nm.

Calibration from the flat is applied (unit: micron)

1st test : X-ray mirror spherical metrology using SCOTS: Software Configurable Optical Test System





SCOTS Residual 4 nm rms

R = 54.15 m

LTP Residual 3.5 nm rms

R = 54.29 m

Stitching interferometry Data

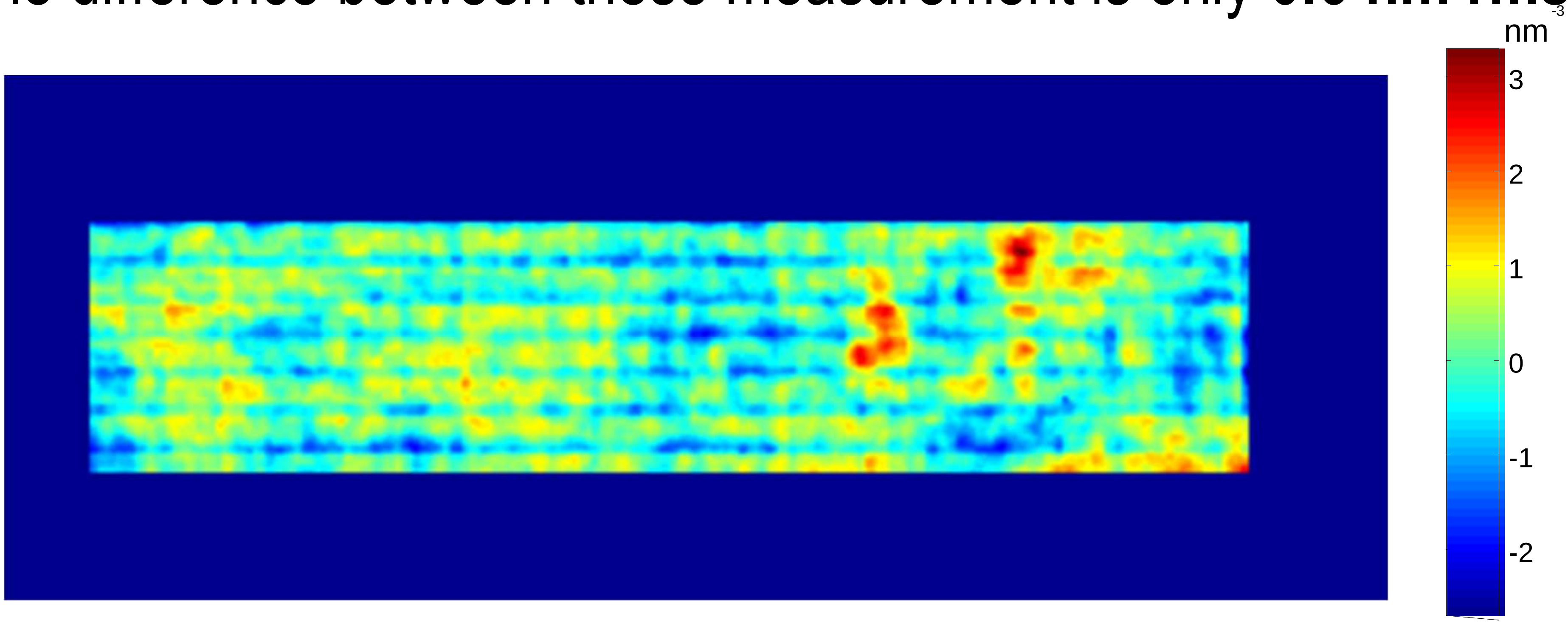
Residual 4.1 nm rms

R = 54.3 m

Demonstration of SCOTS possibility

For the x-ray mirror, we reconfigure the test by rotating the screen 180° and remeasure the mirror.

The difference between these measurement is only **0.6 nm rms**



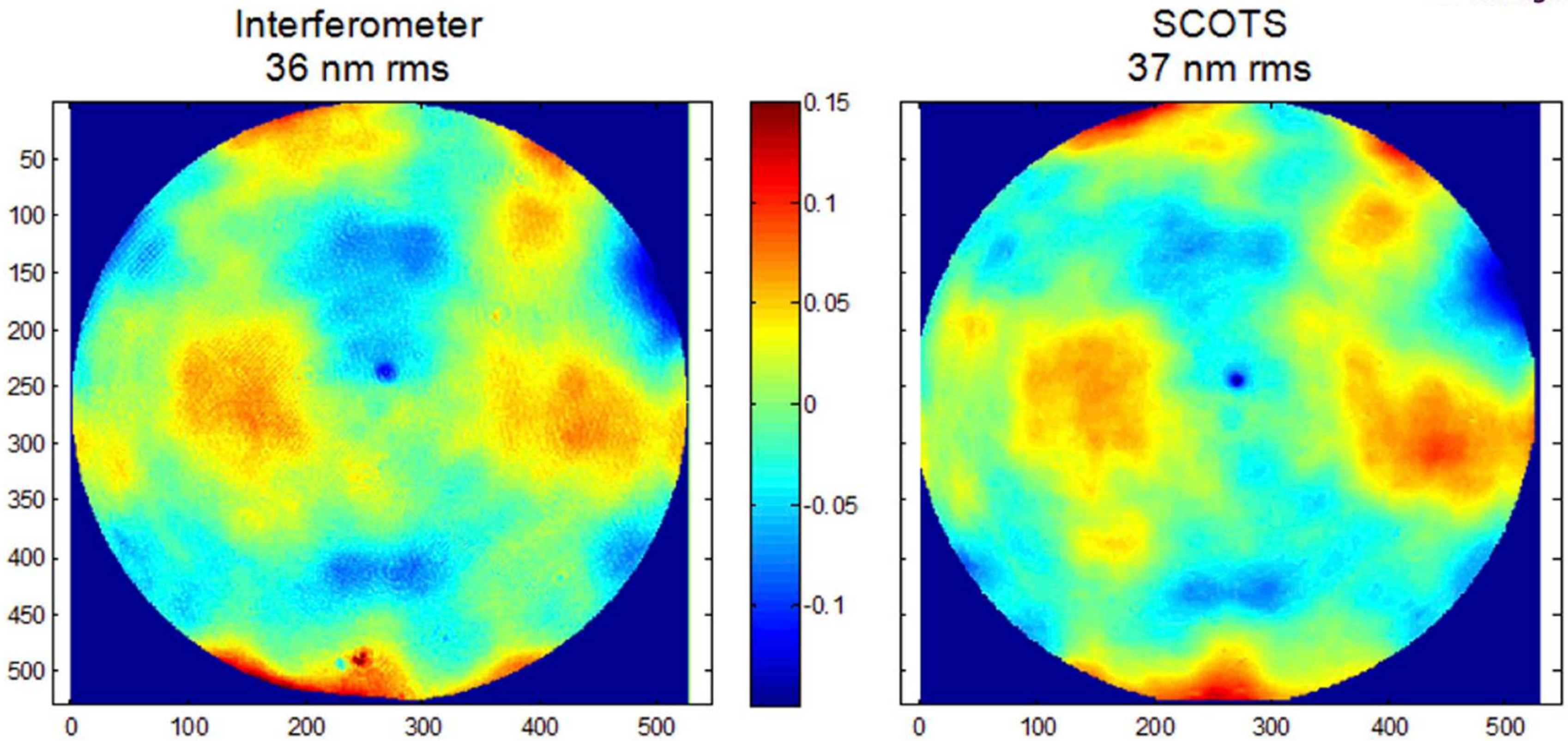
SCOTS – measuring 4m sphere

LOFT Large Optics Fabrication & Testing

THE UNIVERSITY OF ARIZONA TUCSON ARIZONA

Previous results and interferometry comparison

College of Optical Sciences



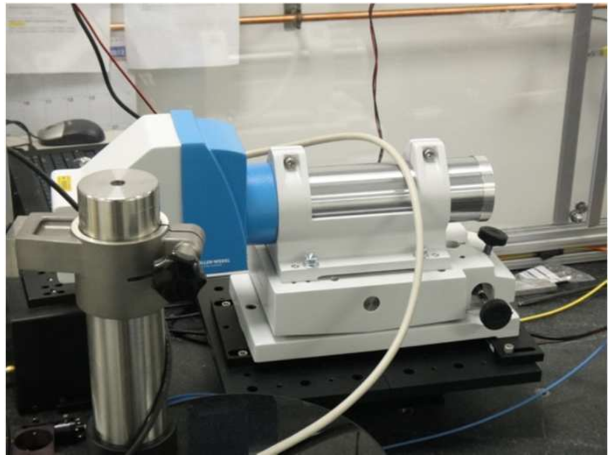
Comparison of 3.75m fold-sphere measured by interferometer and SCOTS.

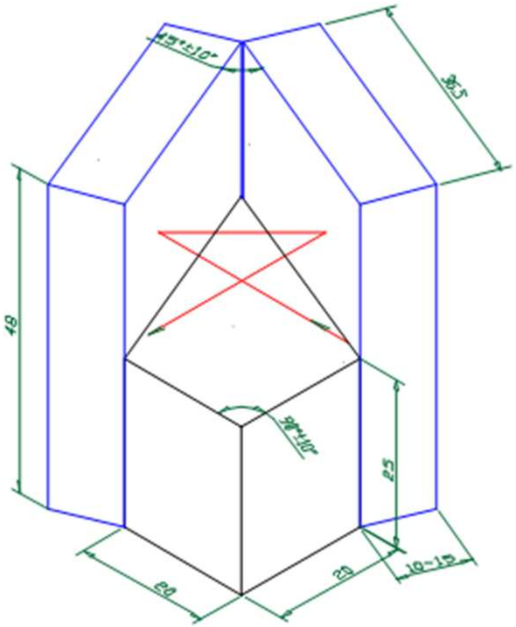
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

Optical Metrology R&D

Optical Metrology R&D



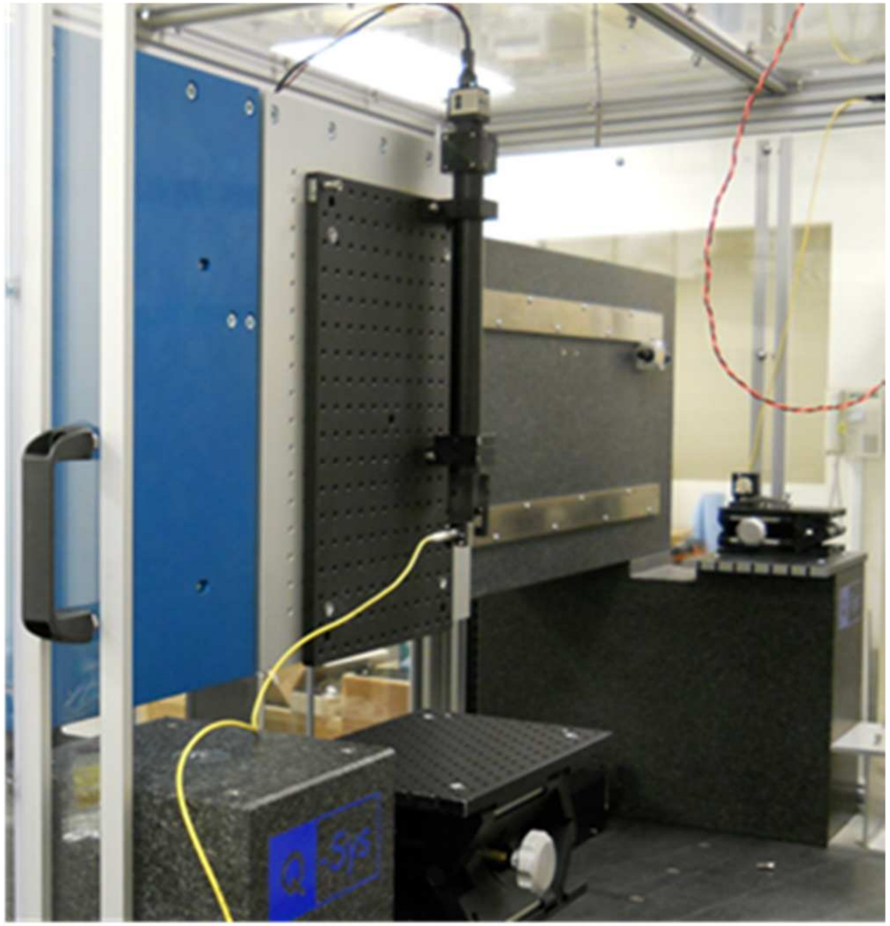


Travel has been maximized at 1500 mm

Optical Platform ~ 200 kg

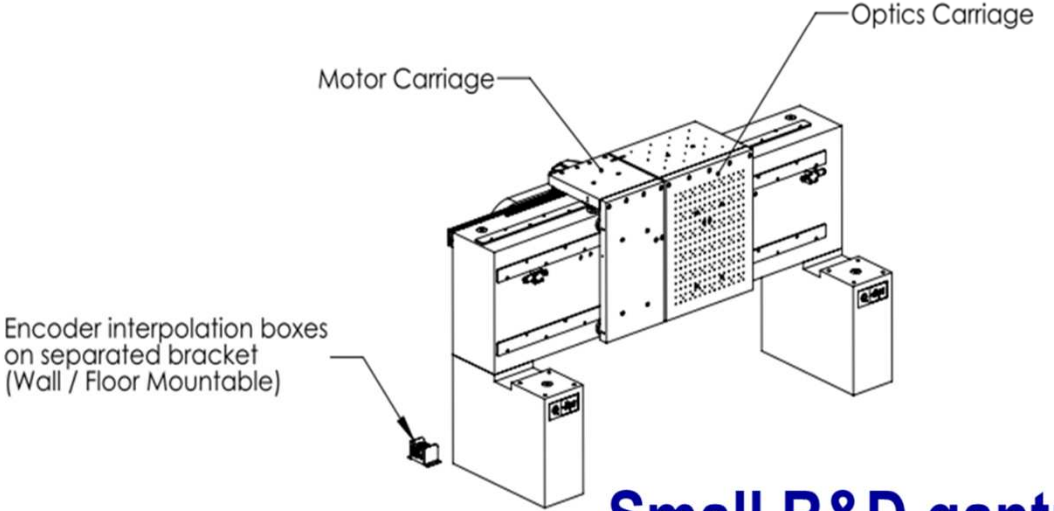
Optical Head ~ 25 kg

Optical Metrology R&D



The nano-accuracy surface profiler (NSP) with extended angle test range is under development: Scanning optical head combined with bypass non-tilted reference, F=400mm, 2D CCD camera, fixed working distance 50mm

Travel range : 990mm



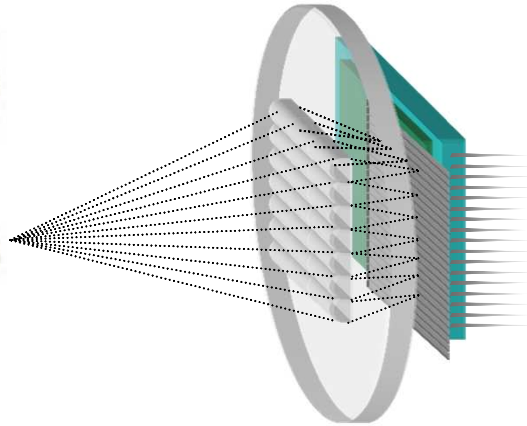
Small R&D gantry

SSH-LTP 2nd Generation

Stitching **S**hack **H**artmann head for **L**ong **T**race **P**rofiler : **SSH-LTP**

Simulations (preliminary)
- **Spatial resolution 1.25mm**
- **Expected performances: 50 nrad rms**

1st TEST Schedule Oct Nov 2012



Imagine Optic

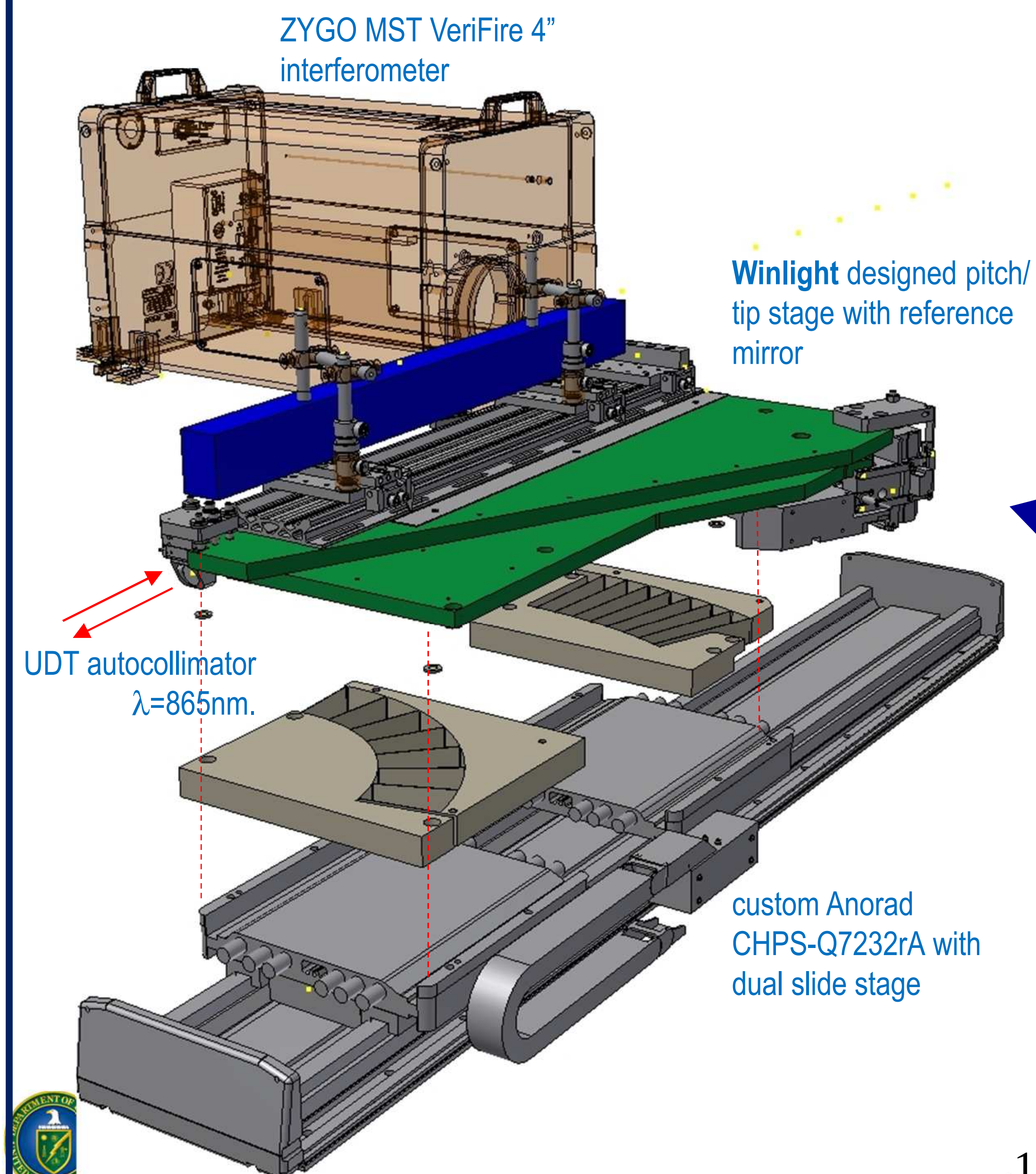
Imagine Optic/France

U.S. DEPARTMENT OF ENERGY

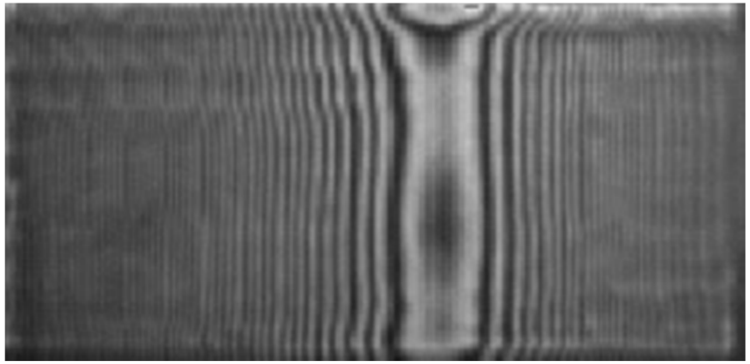
BROOKHAVEN NATIONAL LABORATORY

BROOKHAVEN SCIENCE ASSOCIATES

Stitching Fizeau-based Optical Metrology Station

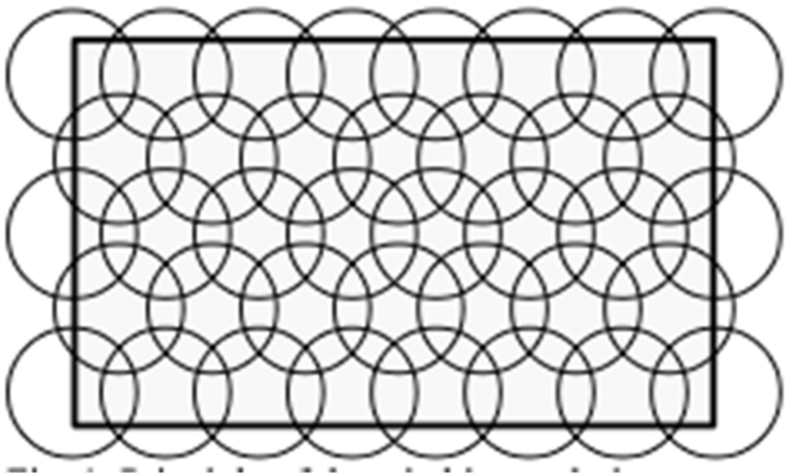


Interferogram of elliptical mirror
L=100, focus at 128 mm; glancing angle 3.65mrad (15keV)



~40mm (~2um)

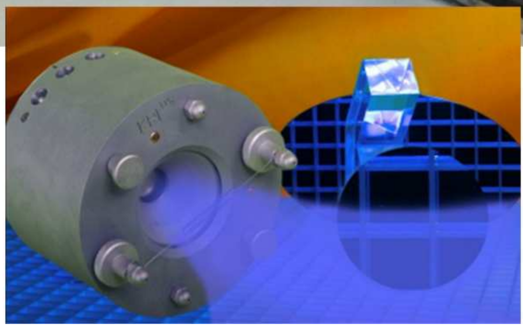
Possible Solution
Stitching Interferometry

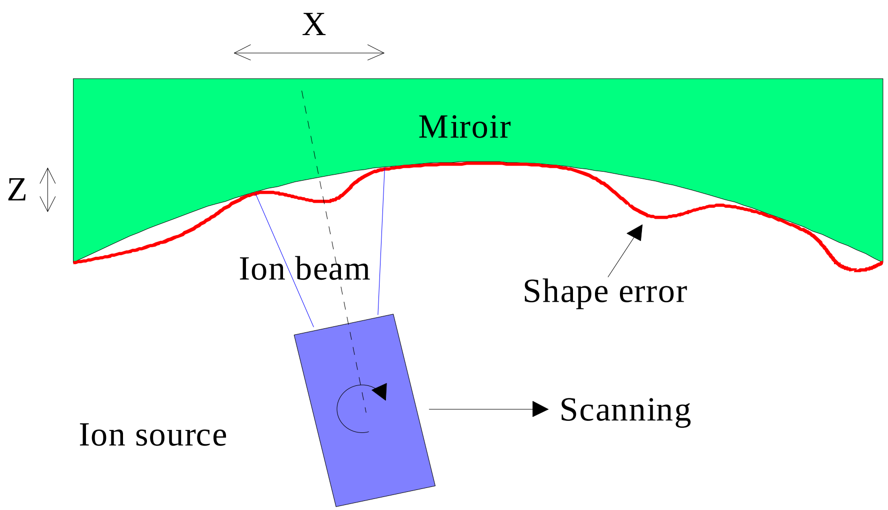


R&D : Ion Beam Polishing

Internal NSLS II Collaboration : optical Metrology and Optical Fabrication Groups

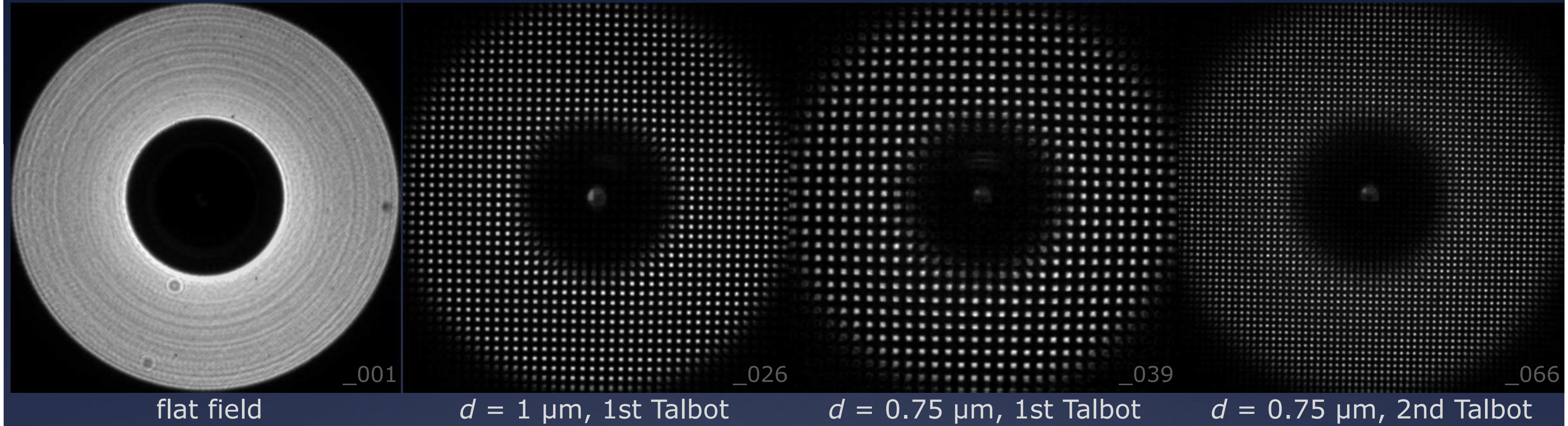
Ion Beam Figuring (IBF)

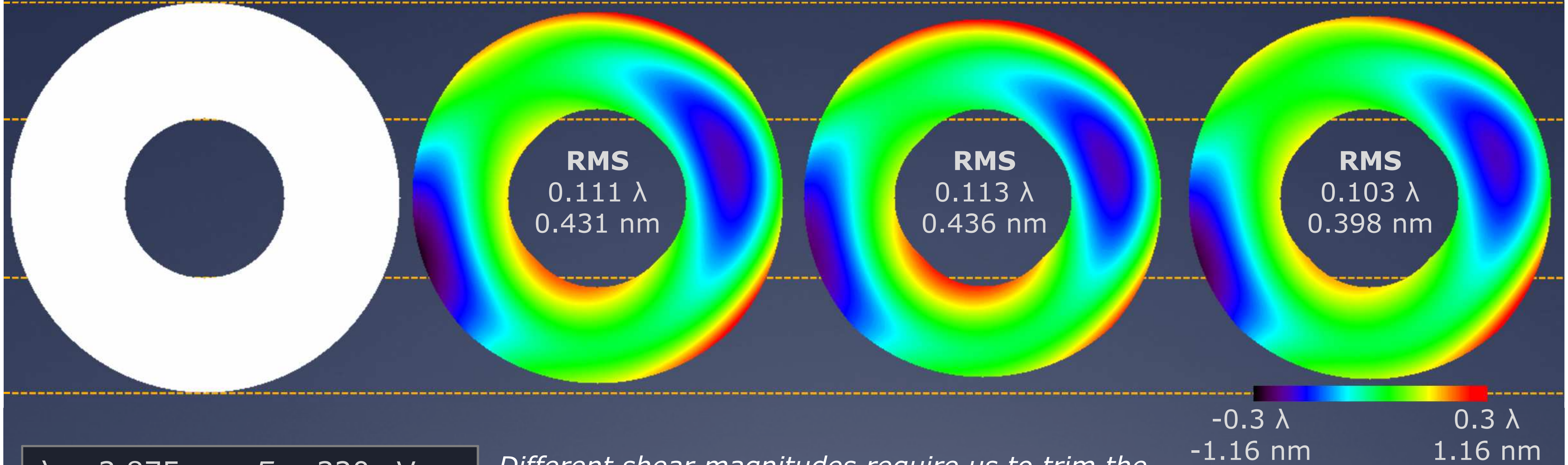




- Last step in figuring/polishing process of optics
- Sputtering of unwanted material
- Correction of long spatial wavelengths (X ~ cm)
- Correction of small thickness (Z < μm)

Analysis of Zoneplate Shearing Interferometry





λ = 3.875 nm, *E* = 320 eV
ZP: *D* = 240 μm, Δ*r* = 25 nm
NA = 0.0775

Different shear magnitudes require us to trim the analysis domain by 20–24 pixels (out of ~380) along the edges. RMS values are calculated on the different domains. Calculated wavefronts are the average of 12, 11, and 9 images, respectively.

Data Collection: 3/02/12, **Konstantine Kaznatcheev**, kaznatch@bnl.gov • Data Analysis: 3/23/12, **Kenneth Goldberg**, KAGoldberg@lbl.gov

CONCLUSION

A software configurable optical test system (SCOTS) based on the geometry of the fringe reflection was used for mirror metrology. This system is low-cost, flexible, high-dynamic-range test that can rapidly, robustly, and accurately measure large, highly aspherical shapes such as solar collectors, astronomical optics and x-ray mirrors

In SCOTS's simplest configuration, all that is needed to perform the test is a projector to illuminate the test surface with a light pattern and a CCD camera to use the reflected image to determine the surface gradients.

Next Step : Target specifications:

- Target mirrors: 300 mm diameter aspherical mirror with maximum surface sag of ~200 microns.
- System slope measurement precision: 0.1 μrad rms or better

Some R&D project are also underway

NOM Type System – New LTP Optical Head
Stitching SH and Stitching interferometry
At Wavelength Metrology

Acknowledgements

Muriel Thomasset for the LTP measurement
ZEMETRICS for the stitching measurement

Q-SYS, Imagine Optic, WinlightX

Josep Nicolas (ALBA)
Simon Alcock, Kawal Sawhney (Diamond Light Source)
Lahsen Assoufid (APS)
Ken Goldberg (CXRO)

funding: DOE Contract No. DE-AC02-98CH10886

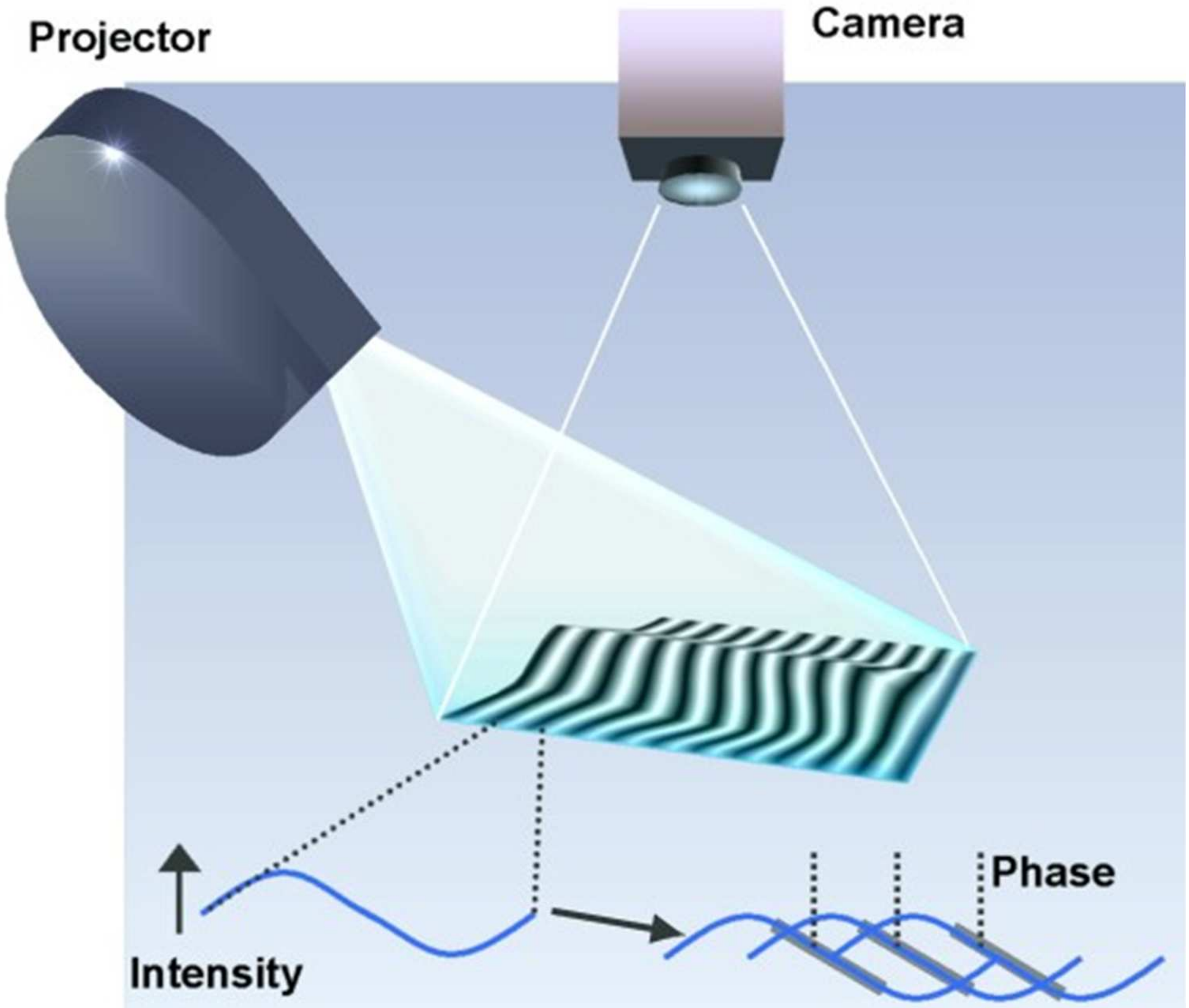
Optical Metrology @ NSLSII

THANK YOU FOR YOUR ATTENTION

U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

X-ray mirror metrology using
SCOTS: Software Configurable Optical Test System



In SCOTS's simplest configuration, all that is needed to perform the test is a screen to illuminate the test surface with fringe pattern (grating) and a camera to use the reflected image to determine the surface gradients.

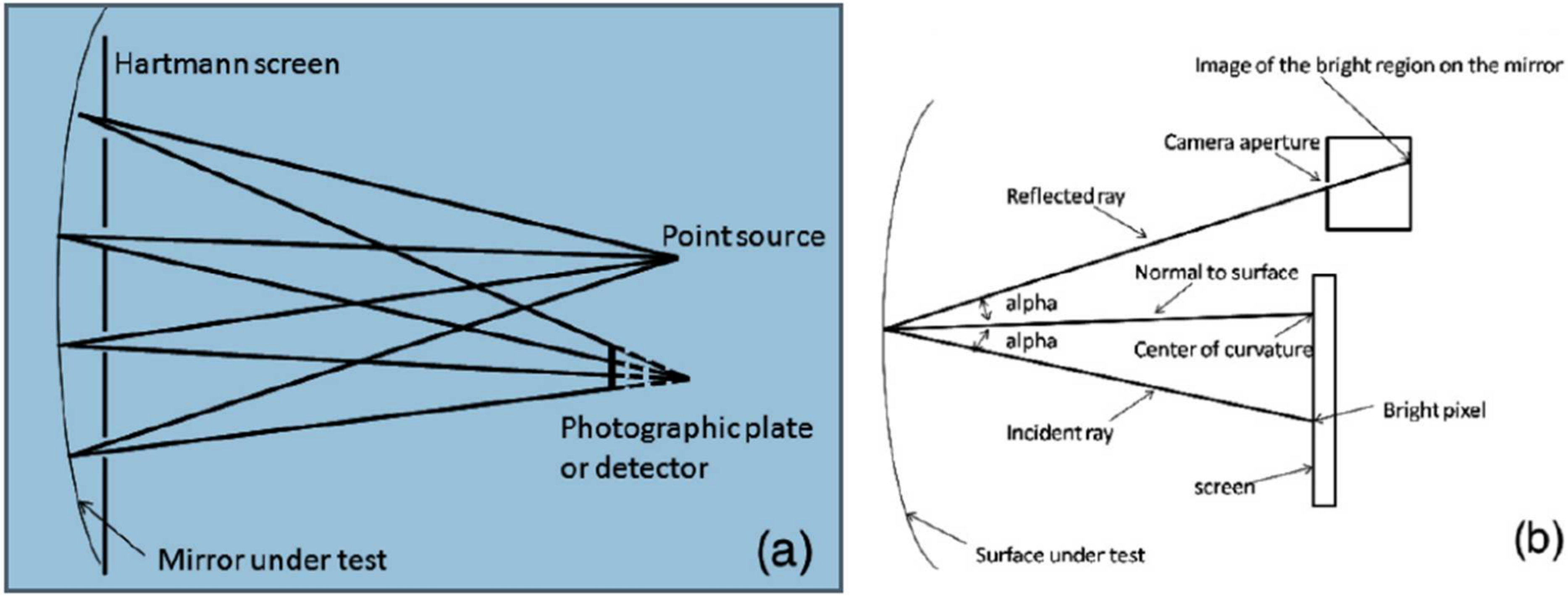


Fig. 1. Comparison of the test geometry for (a) a Hartmann test and (b) the SCOTS.

$$w_x(x_m, y_m) = \frac{\frac{x_m - x_{\text{screen}}}{d_{m2\text{screen}}} + \frac{x_m - x_{\text{camera}}}{d_{m2\text{camera}}}}{\frac{z_{m2\text{screen}} - w(x_m, y_m)}{d_{m2\text{screen}}} + \frac{z_{m2\text{camera}} - w(x_m, y_m)}{d_{m2\text{camera}}}},$$

$$w_y(x_m, y_m) = \frac{\frac{y_m - y_{\text{screen}}}{d_{m2\text{screen}}} + \frac{y_m - y_{\text{camera}}}{d_{m2\text{camera}}}}{\frac{z_{m2\text{screen}} - w(x_m, y_m)}{d_{m2\text{screen}}} + \frac{z_{m2\text{camera}} - w(x_m, y_m)}{d_{m2\text{camera}}}},$$

(1)