X-Ray Optical Metrology for Nanofocusing (LDRD)

Developing effective beamline wavefront measurement strategies

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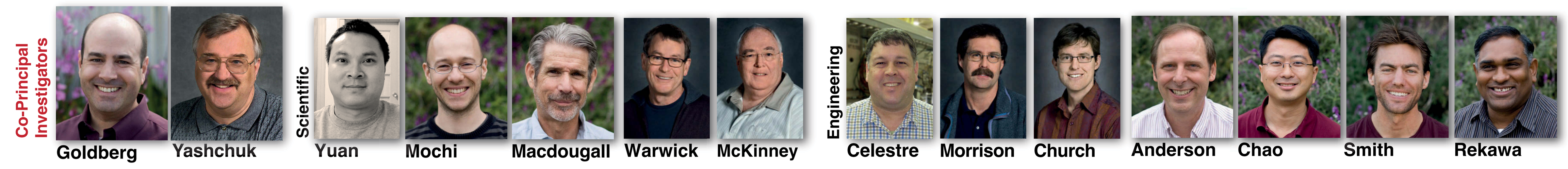
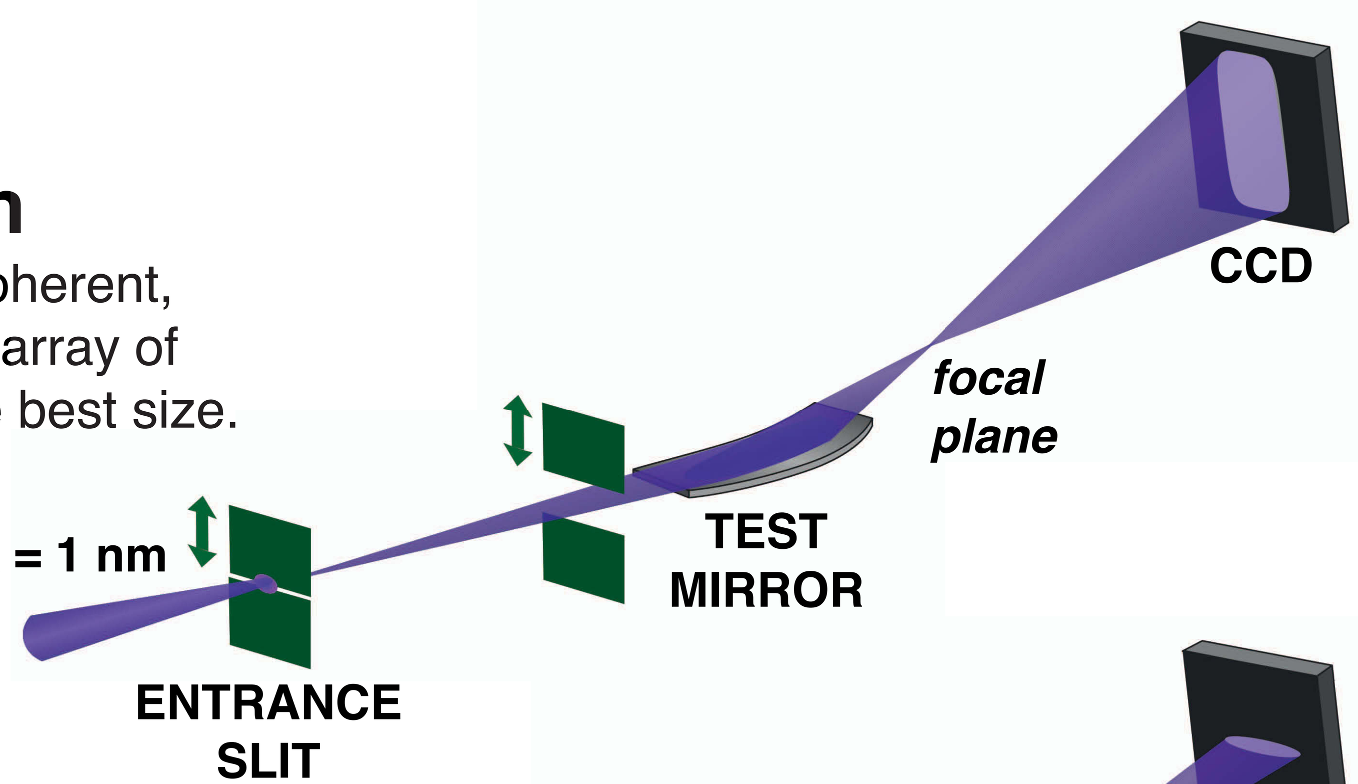


Aberrated and misaligned mirrors undo the benefits of high-brightness light sources. We are developing *in situ* mirror optimization techniques with sub-50-nrad accuracy using interferometry & coherent x-ray optics techniques.

Using a series of measurement techniques that share compatible hardware, our testing strategy works from coarse to fine alignment. Inter-comparison leads to a deeper understanding of measurement sensitivity and accuracy. Soft x-ray *nanofocusing* can be achieved and maintained using this approach.

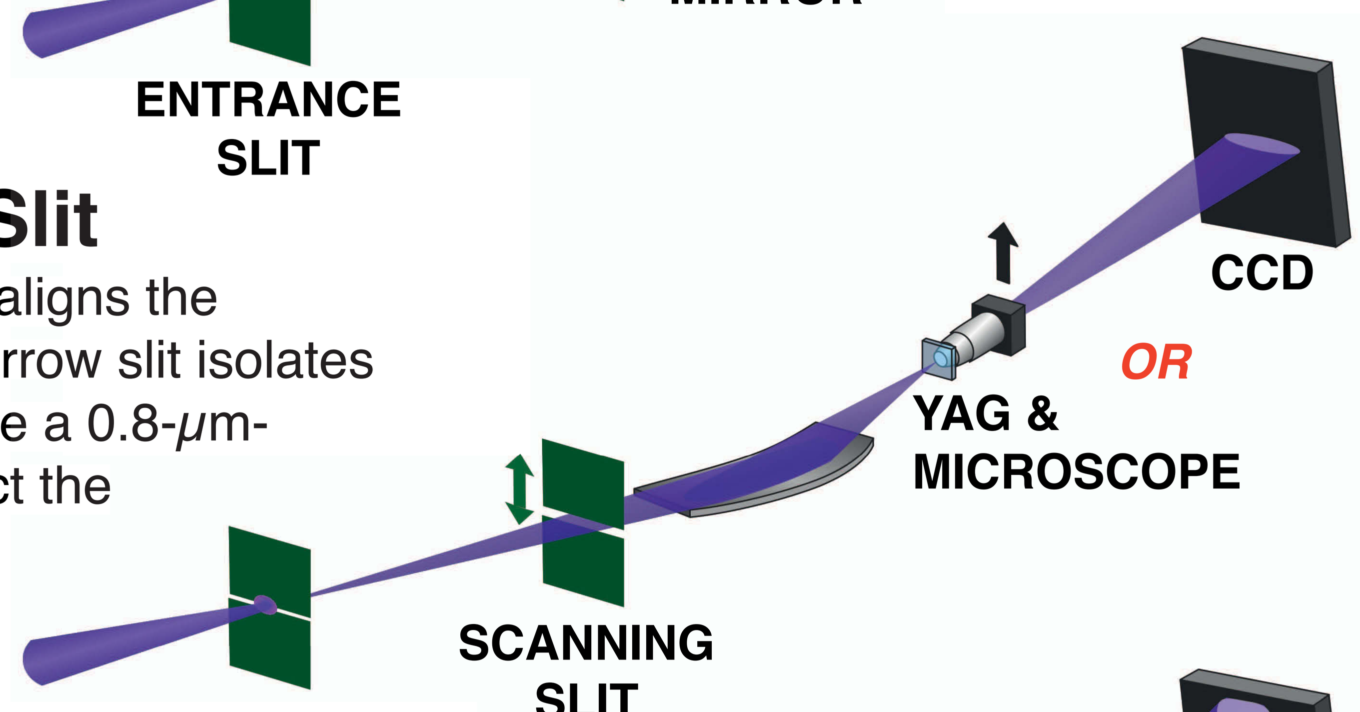
1. Coherent Illumination

A sub-*µm* entrance slit produces a coherent, cylindrical illuminating wavefront. An array of nanofabricated slits lets us select the best size.



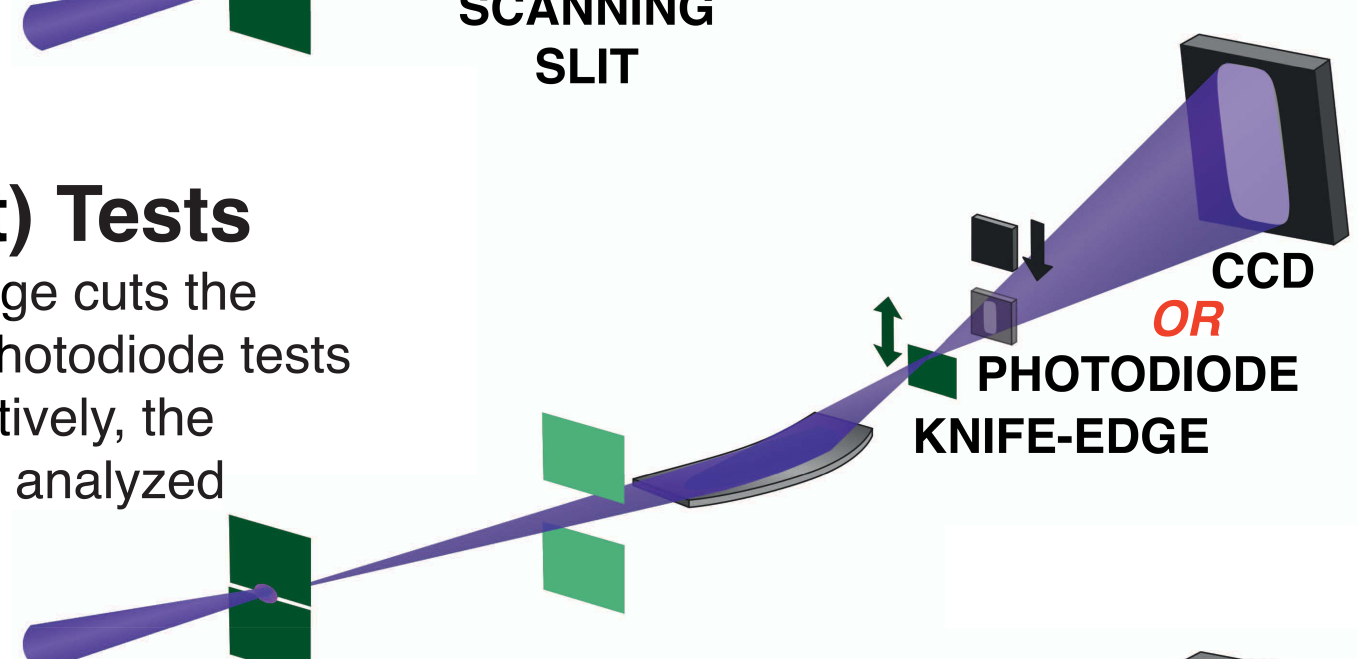
2. Upstream Scanning Slit

The scanning slit test effectively pre-aligns the mirror's tilt to minimize coma. The narrow slit isolates each part of the mirror in turn. We use a 0.8-*µm*-resolution YAG microscope, or project the beam onto a CCD far downstream.



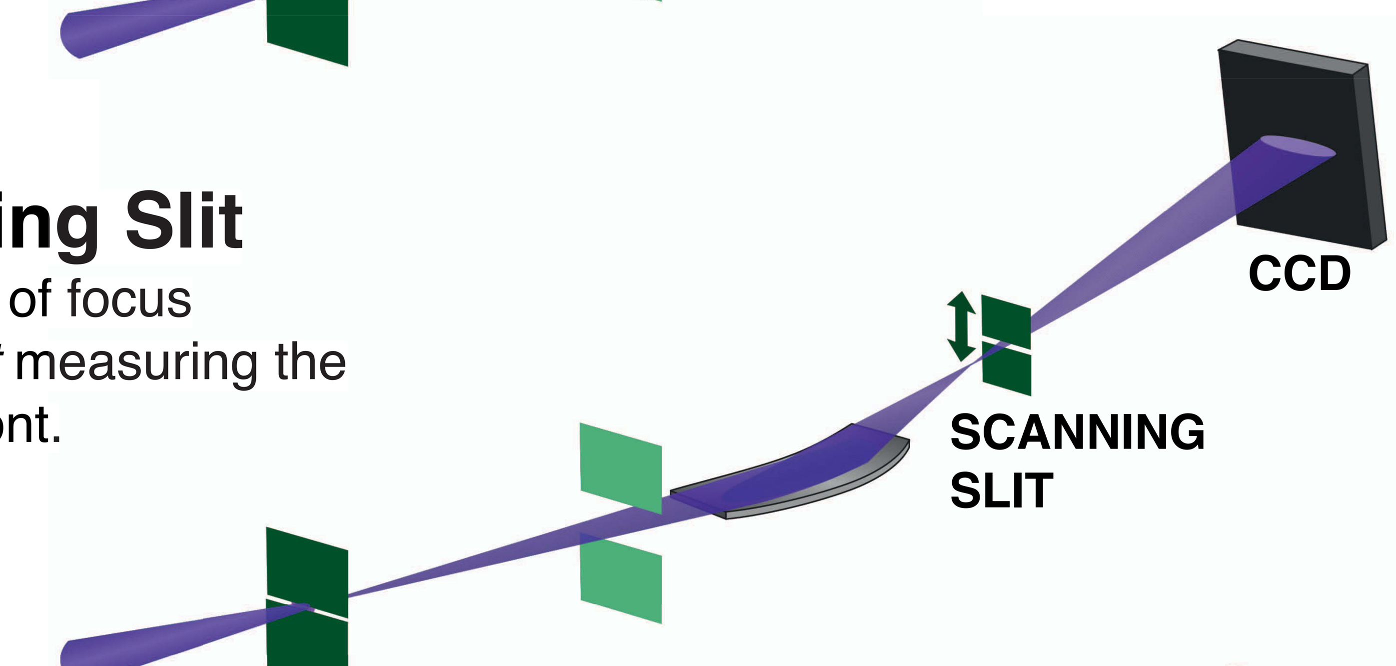
3. Knife-Edge (Foucault) Tests

A scanning (nanofabricated) knife-edge cuts the beam near focus. A single-element photodiode tests the spot size unambiguously. Alternatively, the projected shadow of the knife can be analyzed to reconstruct the wavefront slope.



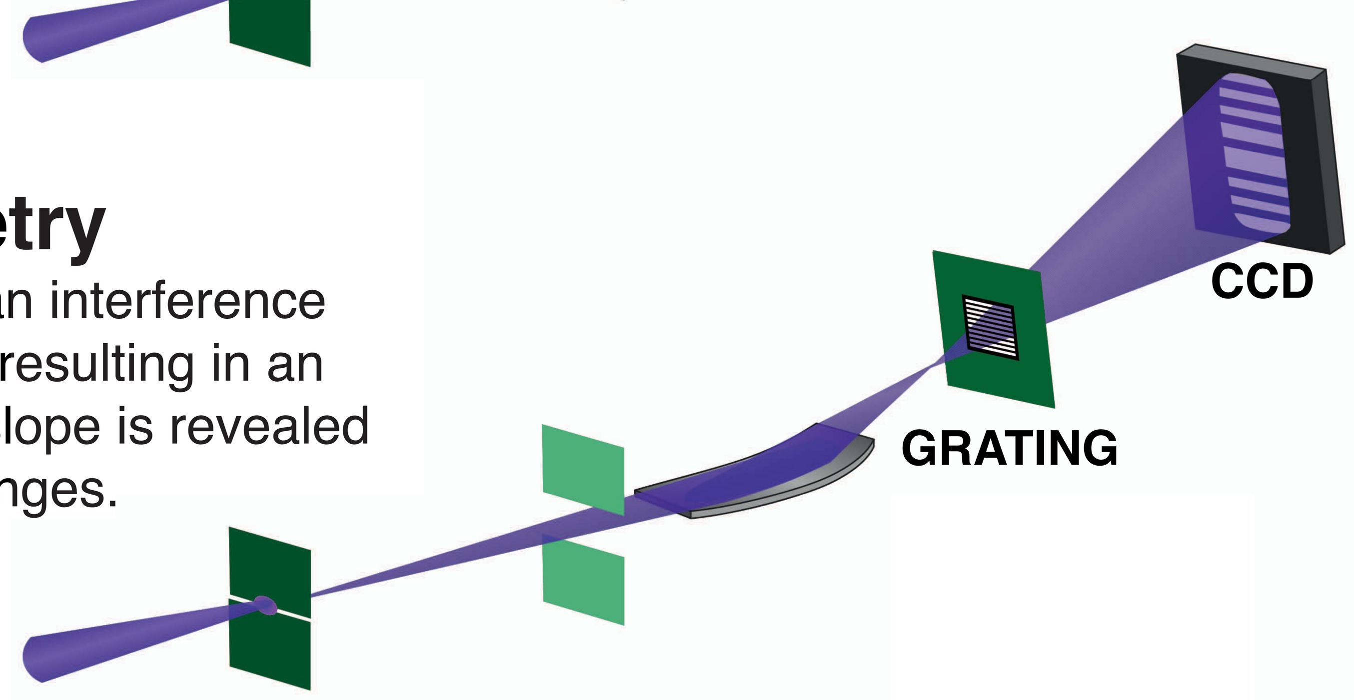
4. Downstream Scanning Slit

A narrow scanning slit downstream of focus performs a temporal *Hartmann-test* measuring the wavefront slope across the wavefront.

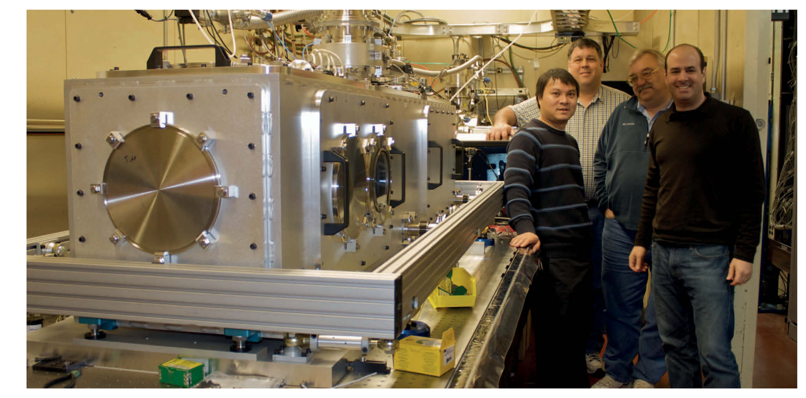


5. Shearing Interferometry

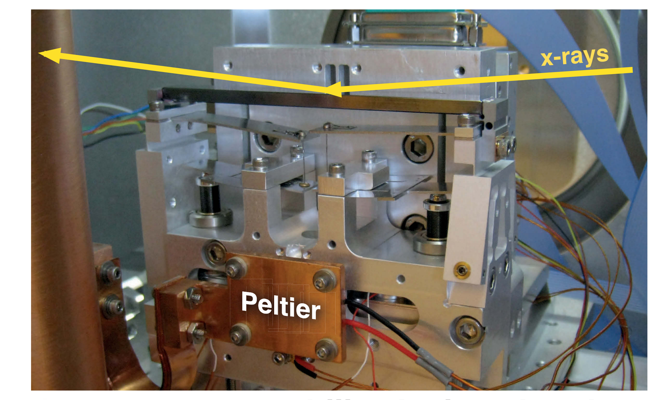
Coarse diffraction gratings produce an interference of displaced wavefronts at the CCD, resulting in an interference pattern. The wavefront slope is revealed in the positions of the interference fringes.



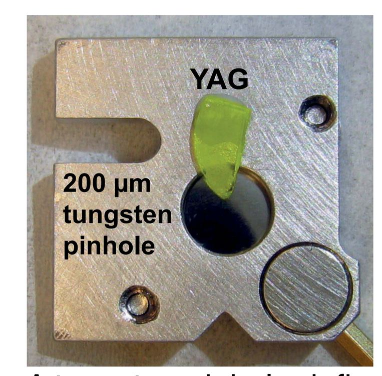
Our goal is to adapt these methods to new and existing beamlines where brightness and wavefront preservation are critical.



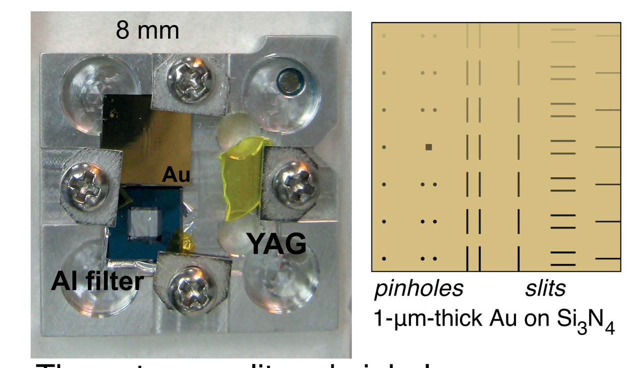
A versatile **mirror-metrology test chamber** is now installed at ALS Beamline 5.3.1. The chamber isolates the optical elements from external vibration.



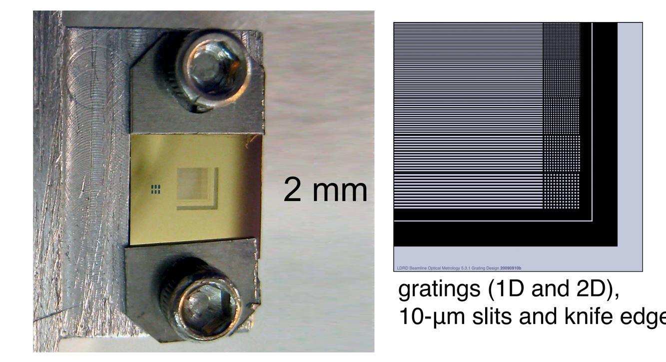
A **temperature-stabilized mirror bender** remains stabile under several degrees of ambient temperature variation.



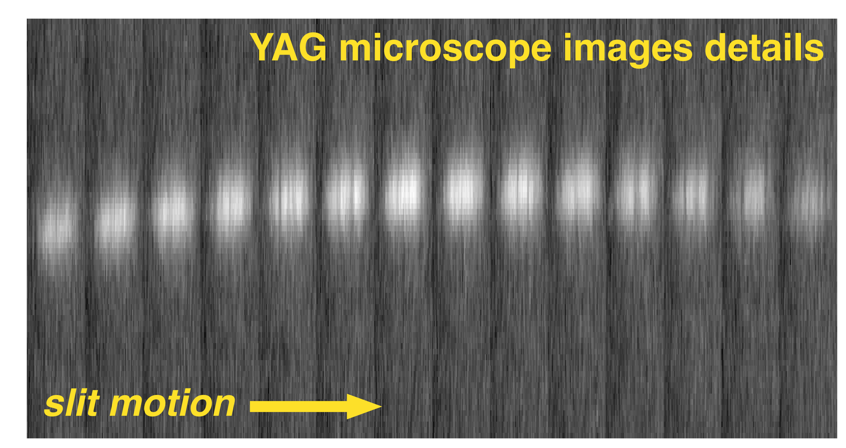
A tungsten pinhole defines the beam upstream of the entrance slit array.



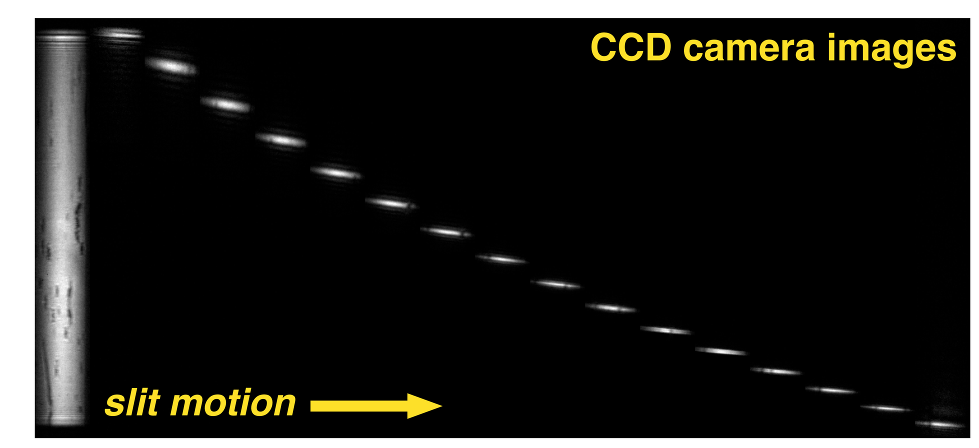
The entrance slit and pinhole nanostructure generates the illuminating wavefront.



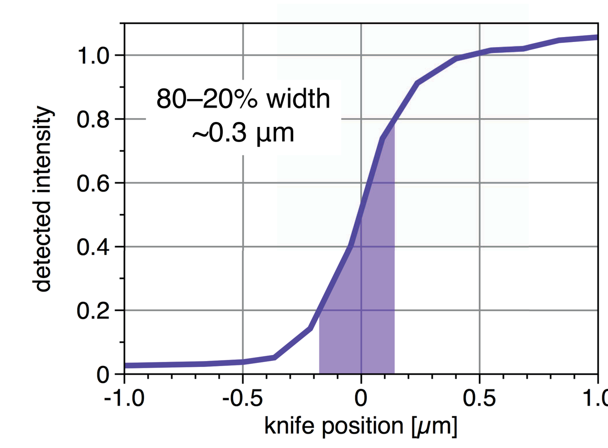
The image-plane 1D and 2D testing nanostructures are fabricated into a single compact pattern.



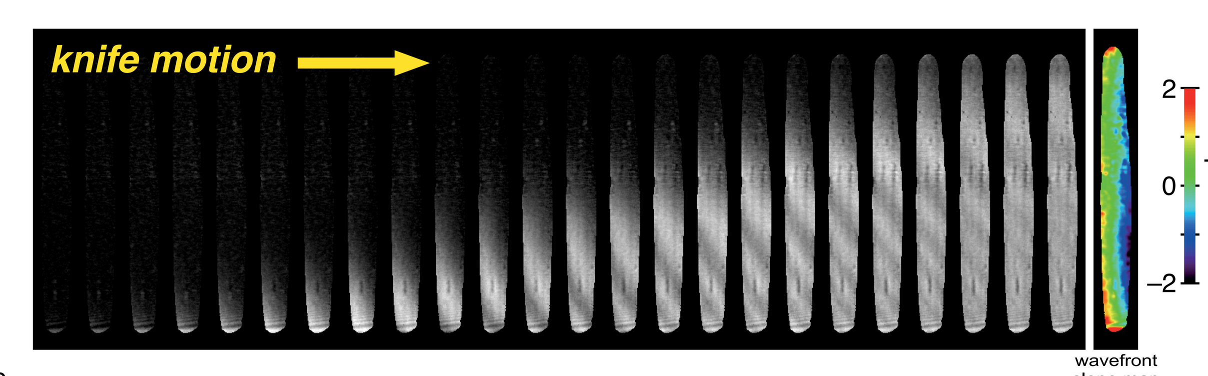
A series of (stretched) images from the YAG microscope shows the beam position motion during a slit scan. A linear regression procedure find the optimal mirror tilt.



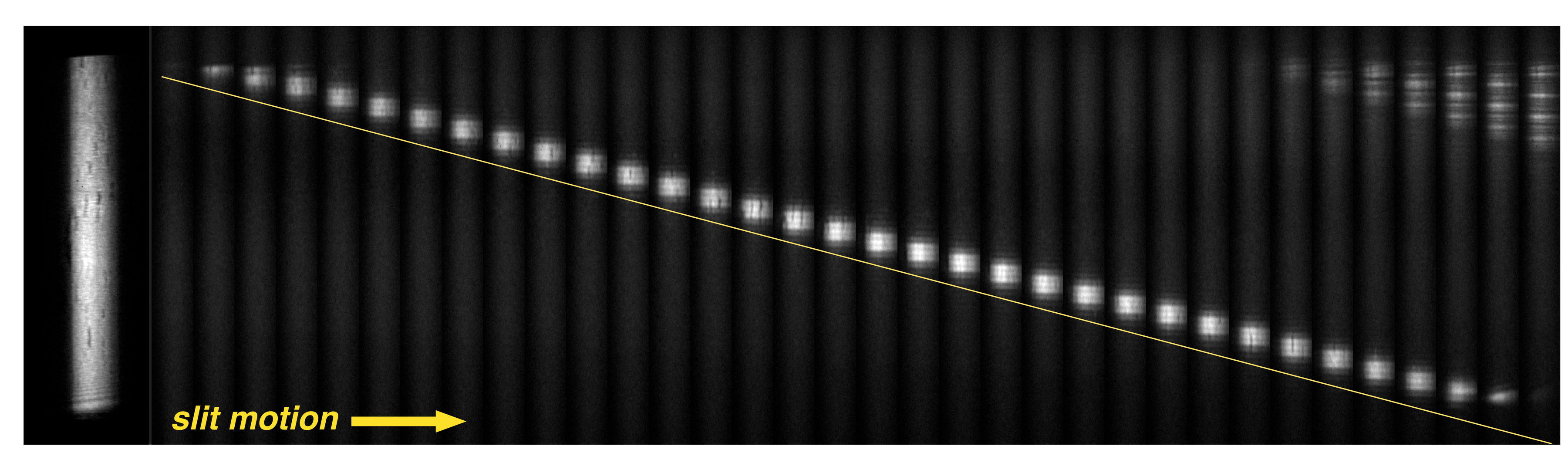
(Left) The illuminated pupil on the CCD. As the slit is scanned, the CCD records a series of beam positions that reveal the local mirror slope. Oblique incidence causes predictable non-linearity.



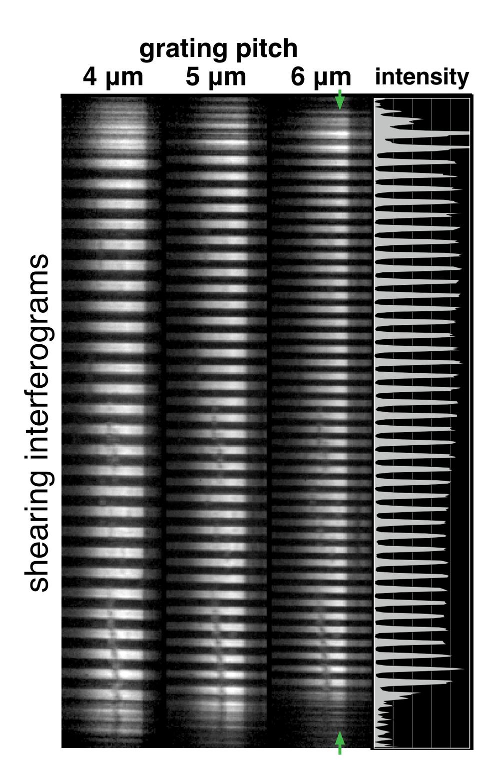
The conventional knife-edge test proves the width of the focal spot, but provides little additional wavefront information.

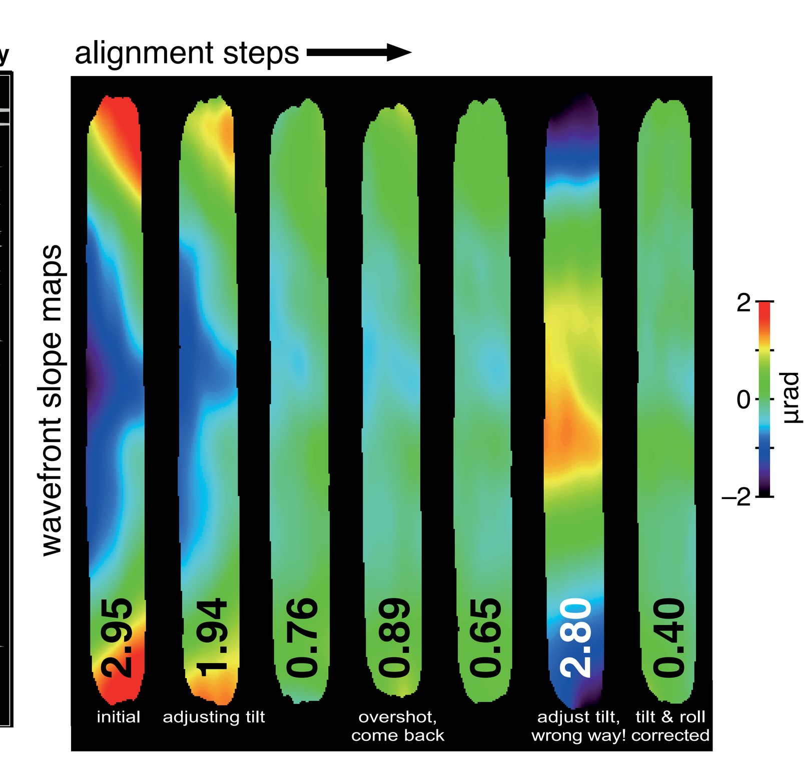


Analyzing the (normalized) shadow of the knife, projected onto the CCD camera, allows the wavefront slope to be extracted. Here, uncorrected mirror roll error is evident both in the amplified tilt of the shadow and in the wavefront slope map (right).



With the scanning slit positioned downstream of focus, the beam position on the detector makes nearly linear steps as the slit moves across the beam. Non-linearities reveal wavefront slope aberrations.





High contrast interference patterns (left) for three different gratings are recorded and converted to wavefront slope maps. The slope errors (RMS µrad are shown) are used to perform fine alignment in steps. Note, no mirror bending was applied here.

***In situ* wavefront metrology for beamline optics**

- Development on ALS BL 5.3.1 & others
- Performing mirror alignment, and optimization on the beamline
- Detailed cross comparisons: scanning slits, knife-edge, shearing, (Hartmann)
- Comparison with LTP (visible-light, *ex situ* pre-alignment)
- The future is 2D KB focusing tests
- Transfer these techniques to other beamlines

Acknowledgment: This work was supported by the Laboratory Directed Research and Development Program of Lawrence Berkeley National Laboratory under U.S. Department of Energy Contract No. DE-AC02-05CH11231.