Coherent Diffractive Imaging with Curved Beams

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ARC Centre of Excellence for Coherent X-ray Science

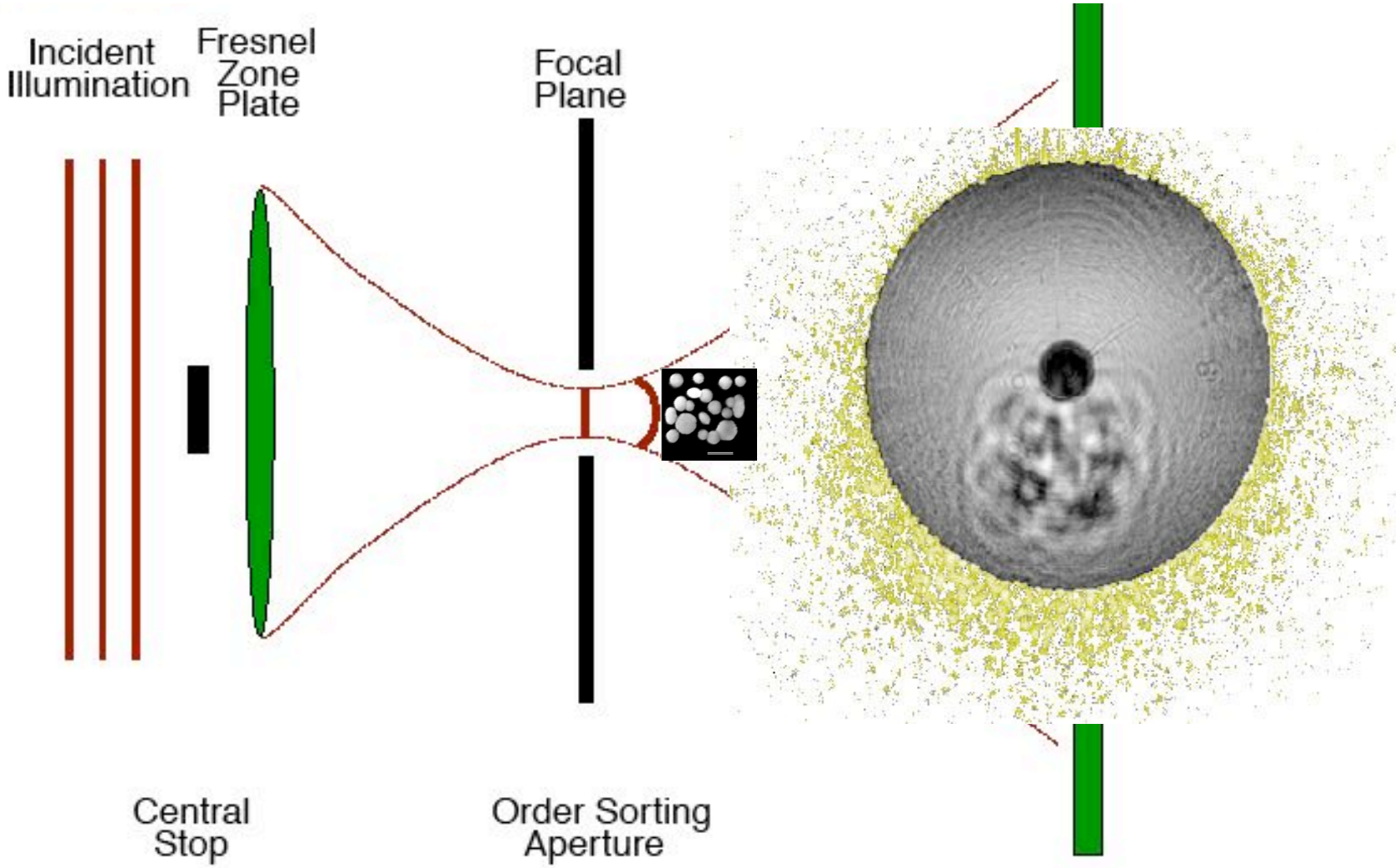
Experimental Physics Program

- Keith Nugent
- Chanh Tran
- Garth Williams
- Mark Pfeifer
- Brian Abbey
- Rob Norman
- Benedicta Arhatari
- Eugeniu Balaur
- Jesse Clark
- Corey Putkunz
- Kevin Hannah
- Lachlan Whitehead
- Sam Flewett
- Kaushal Vora

Outline

- Illustrative Experiment
- Planned Instrumentation

Fresnel CDI


Incident Illumination
Fresnel Zone Plate
Focal Plane
Central Stop
Order Sorting Aperture

Why FCDI?

- Unique Solution
- Faster Convergence
- Periodic Objects
- Robustness to Partial Coherence
- Beam as Support

K.A.Nugent, A.G.Peele, H.N.Chapman and A.P.Mancuso, *Unique phase recovery for nonperiodic objects*, Physical Review Letters, 91, 203902 (2003)

K.A.Nugent, A.G.Peele, H. M. Quiney and H.N.Chapman, *Diffraction with wavefront curvature: A path to unique phase recovery*, Acta Crystallographica, A61,373 (2005)

H. M. Quiney, K. A. Nugent, A. G. Peele *"Iterative image reconstruction algorithms using wavefront intensity and phase variation,"* Optics. Lett., 30, 1638 (2005)

G. J. Williams, H. M. Quiney, A. G. Peele, K. A. Nugent *"Coherent Diffractive Imaging and Partial Coherence"* Phys. Rev. B, 75, 104102 (2007)

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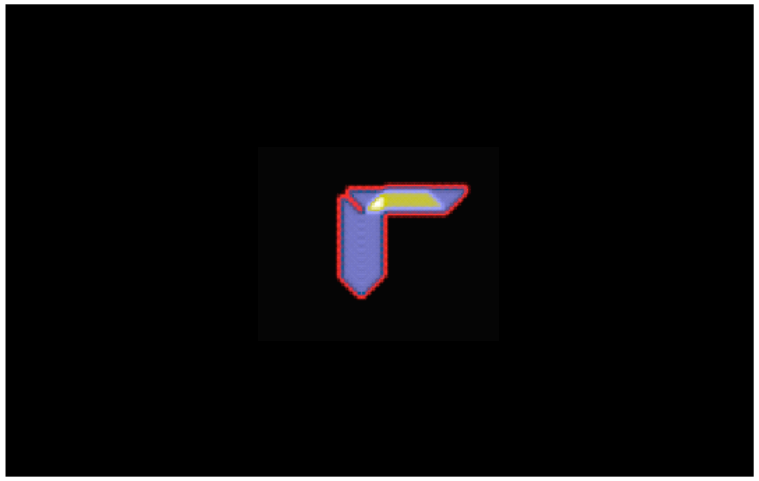
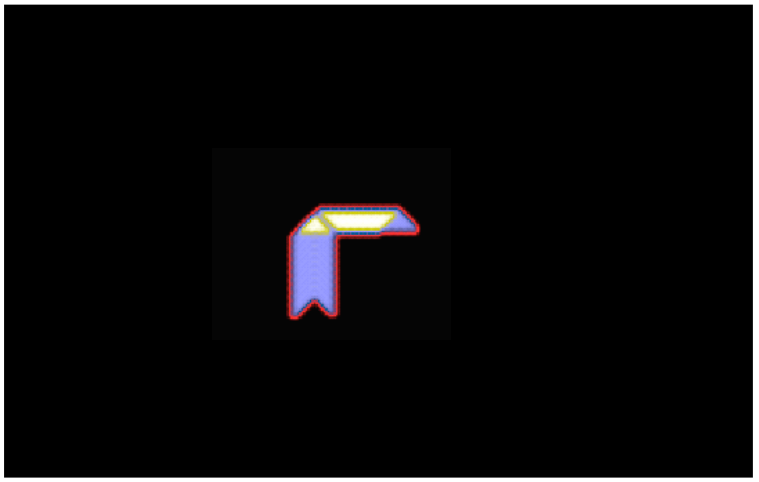
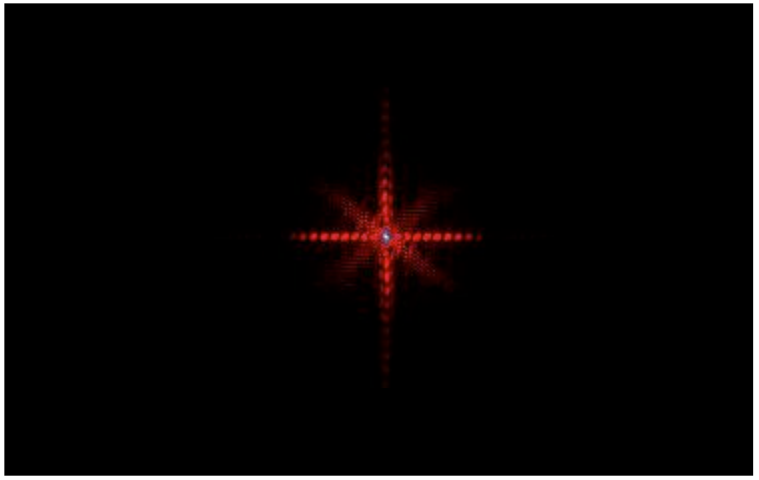
Unique Solution





$f(r) \otimes g(r)$

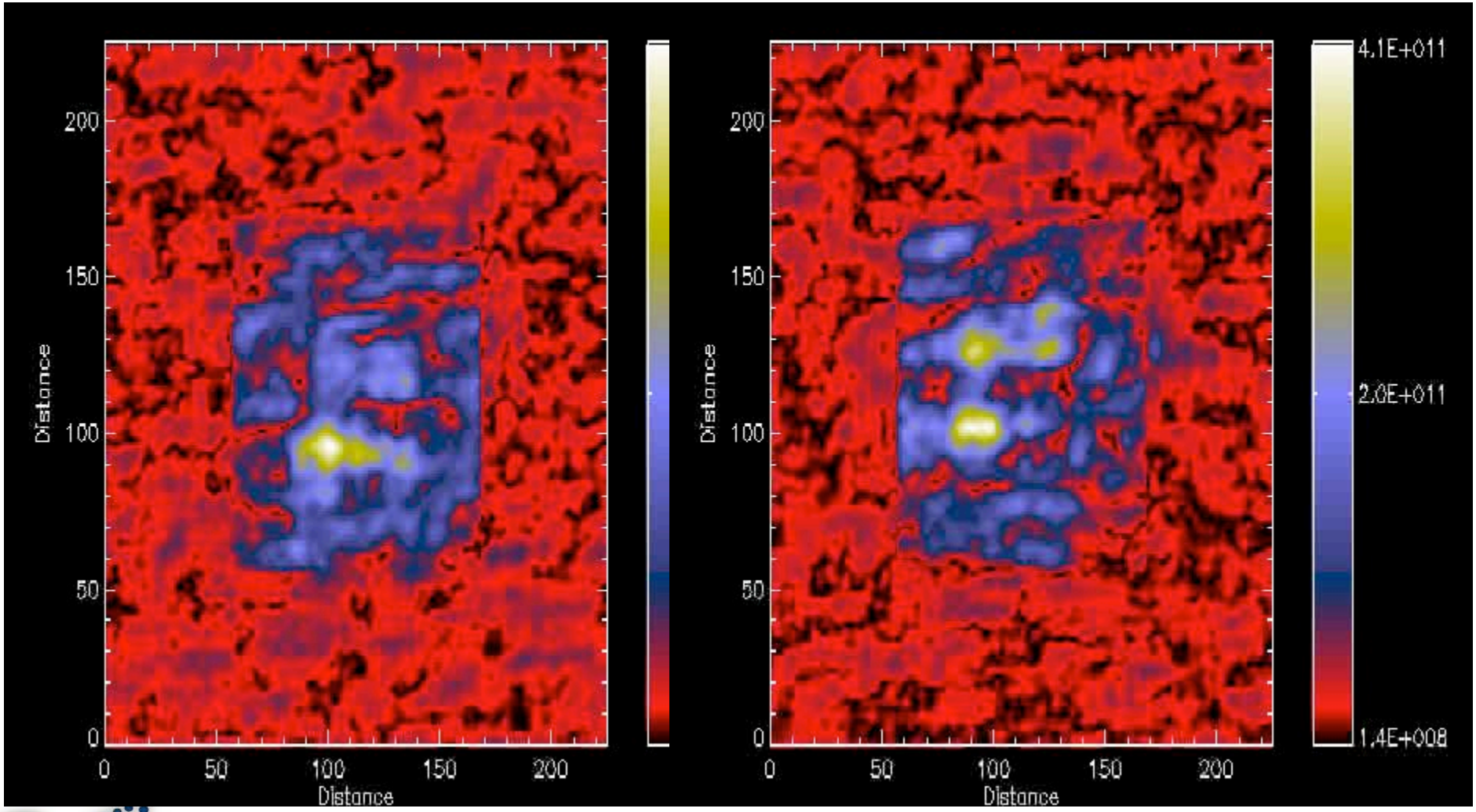
$I=FG(FG)^*$



$f(r) \otimes g^*(-r)$

$I=FG^*(FG^*)^*$

Unique Solution

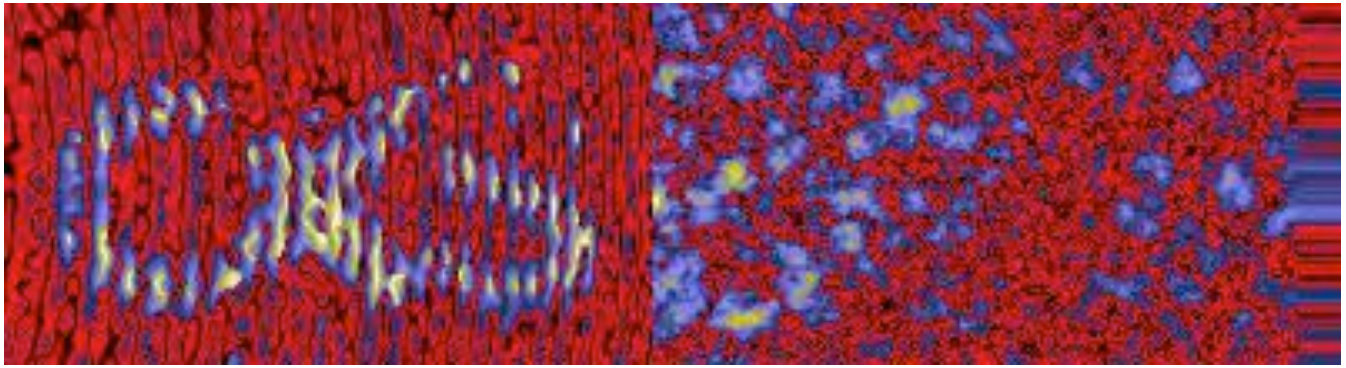


Faster Convergence

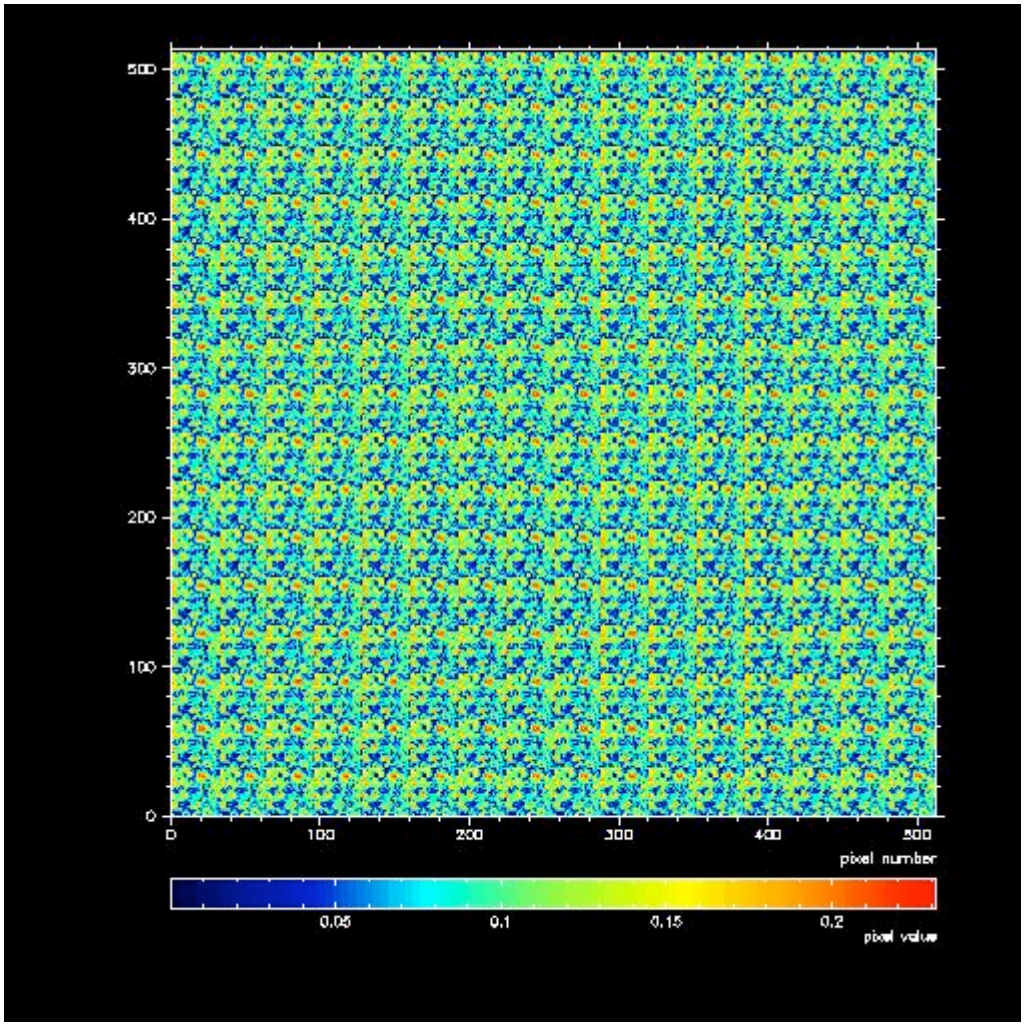
Original

Curved beam illumination

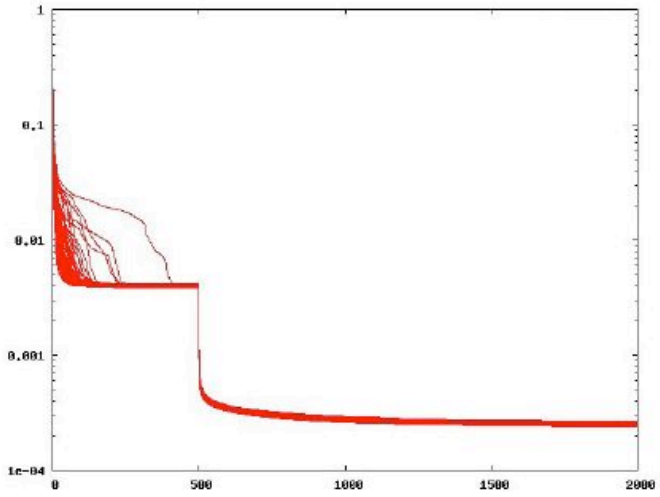
Plane wave illumination



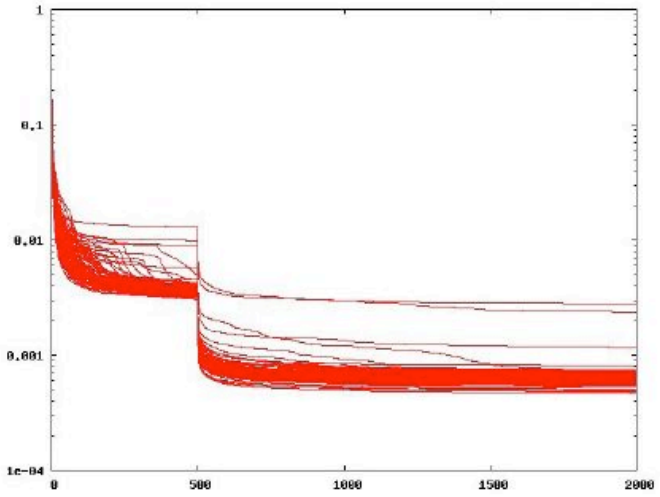
Periodic Objects



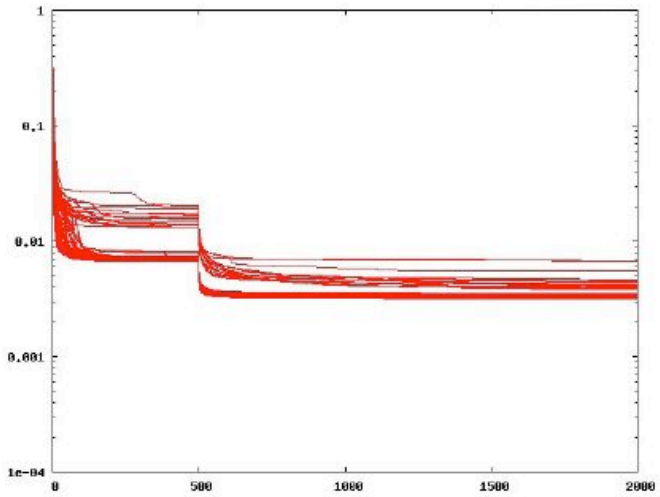
Robustness to Partial Coherence



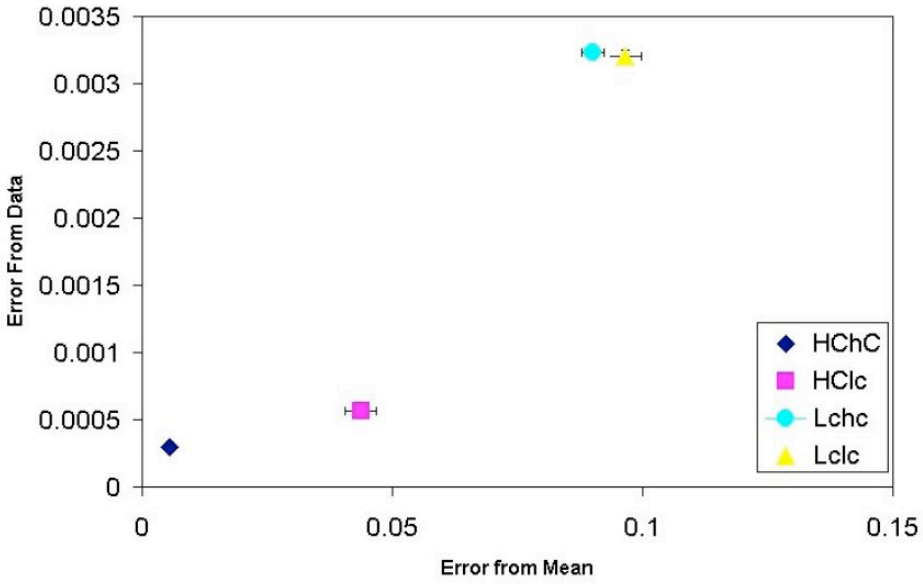
(a)HChc Error



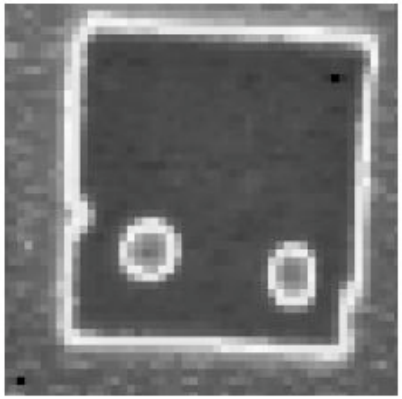
(b)HClc Error

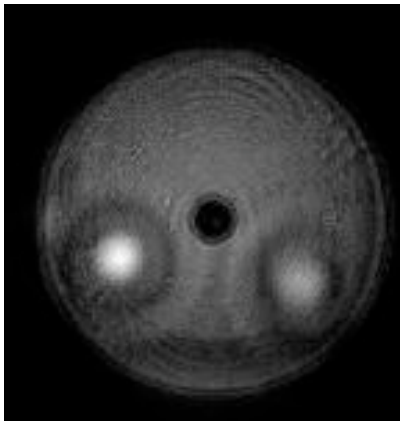


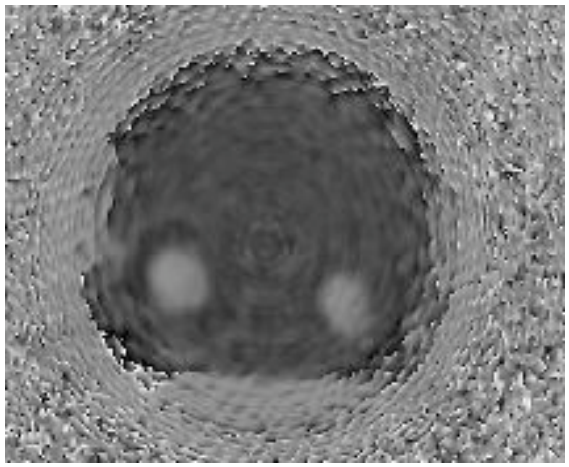
(c)LChc Error



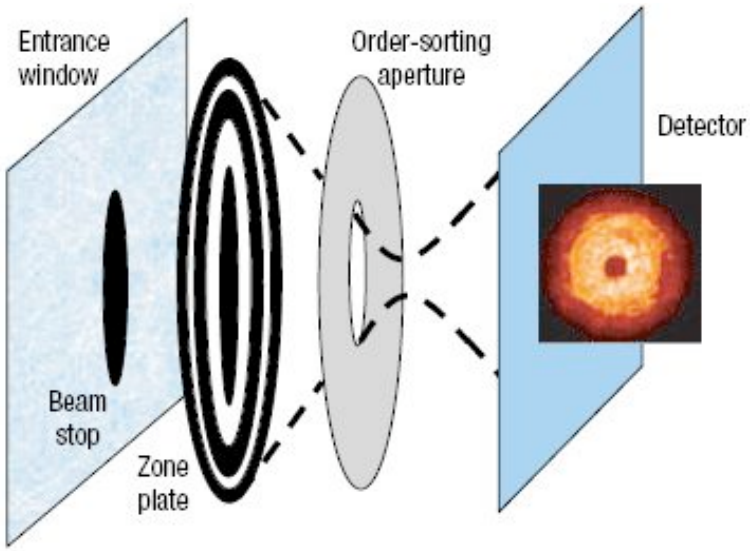
Beam as a Support

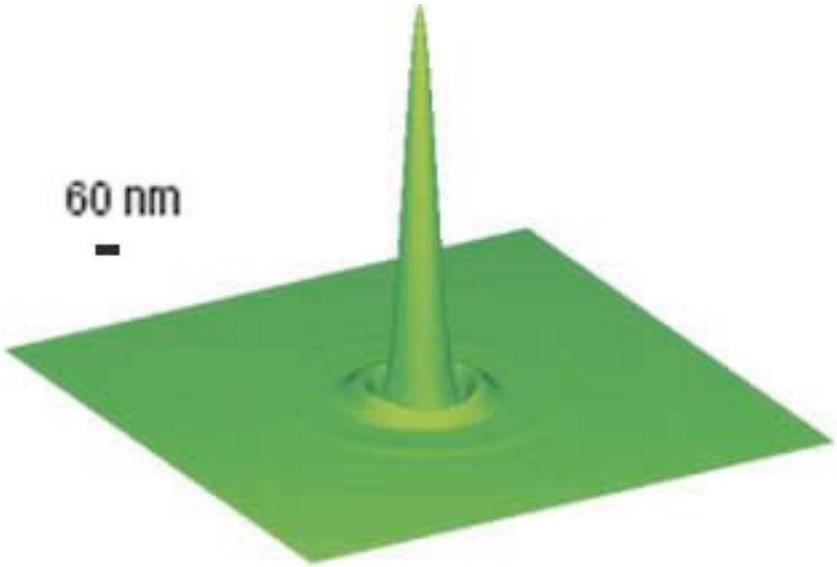






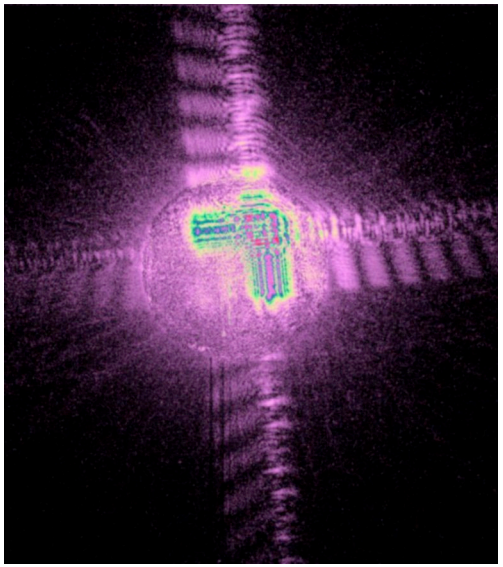
FCDI at Work

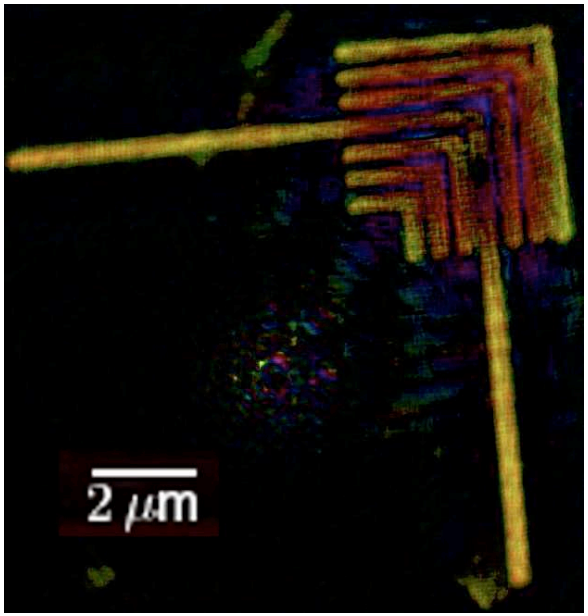




H. M Quiney, A. G. Peele, Z. Cai, D. Paterson and K. A. Nugent,
"Diffractive Imaging of Highly Focussed X-Ray Fields," Nature Physics, 2, 101-104 (2006)

FCDI at Work





G. J. Williams, H. M. Quiney, B. B. Dhal, C. Q. Tran, A. G. Peele, D. Paterson and M. D. de Jonge,
"Fresnel coherent diffractive imaging," Phys. Rev. Lett., 97, 025506 (2006).

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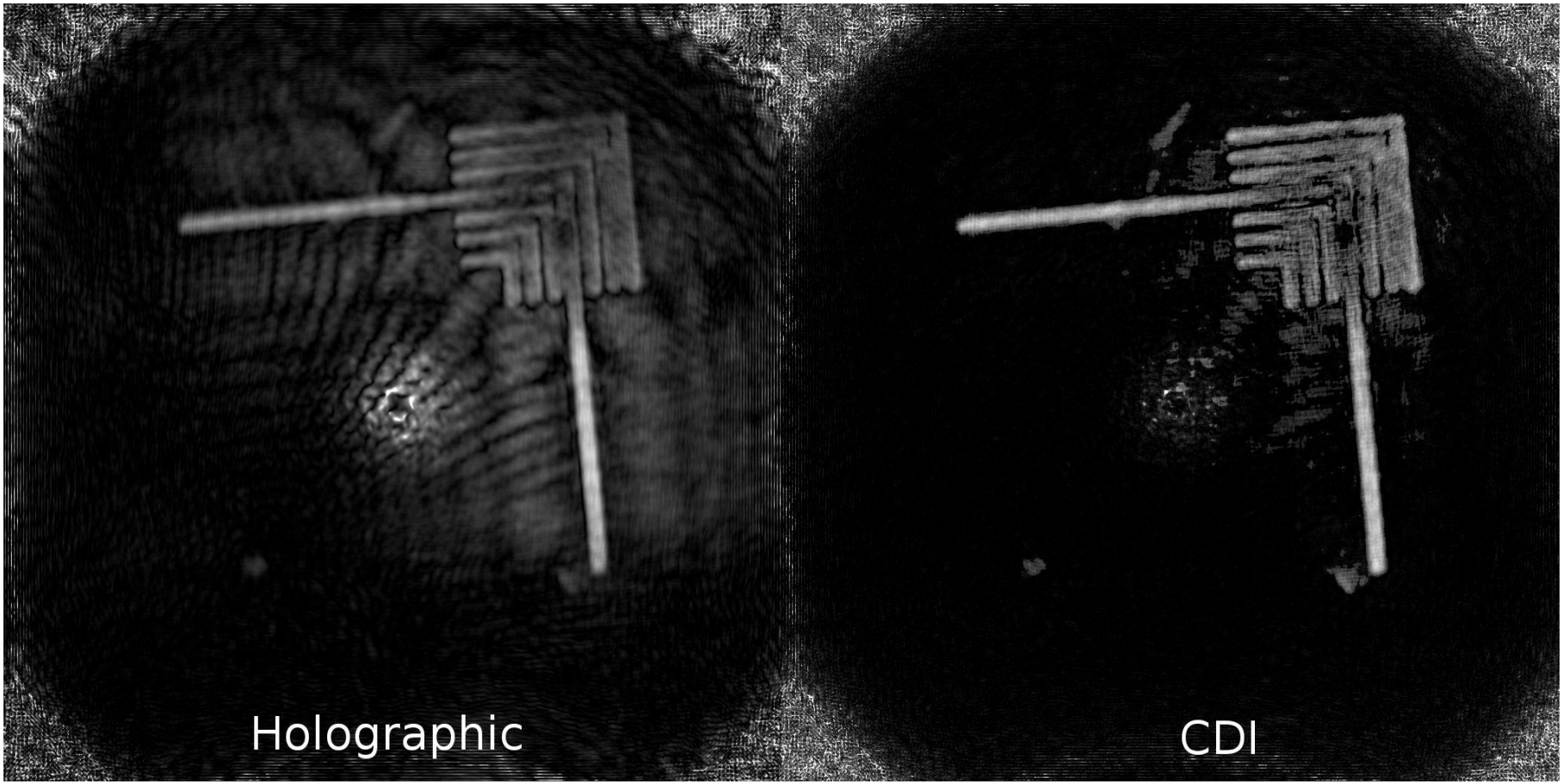
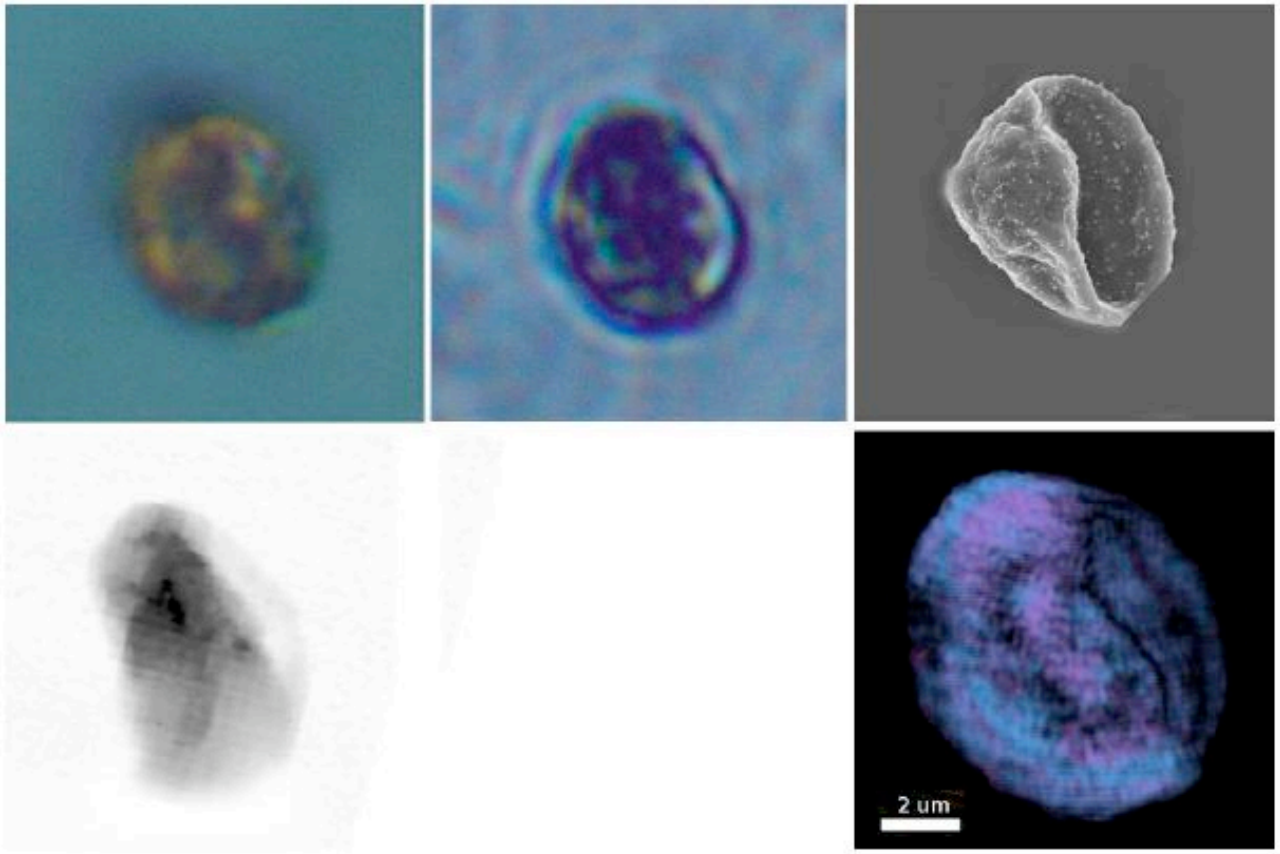
Holographic vs Iterative



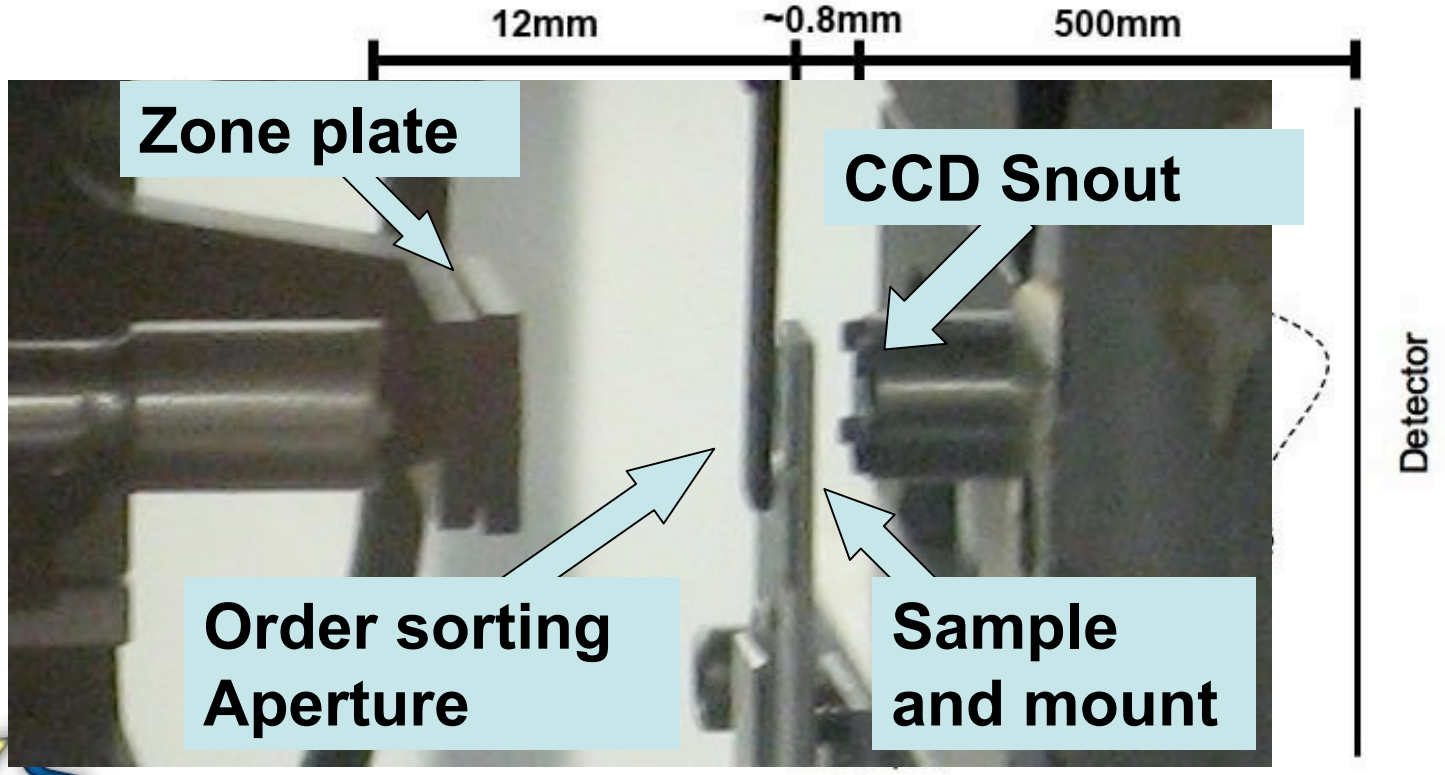
FCDI at Work



G J Williams et al, in prep.

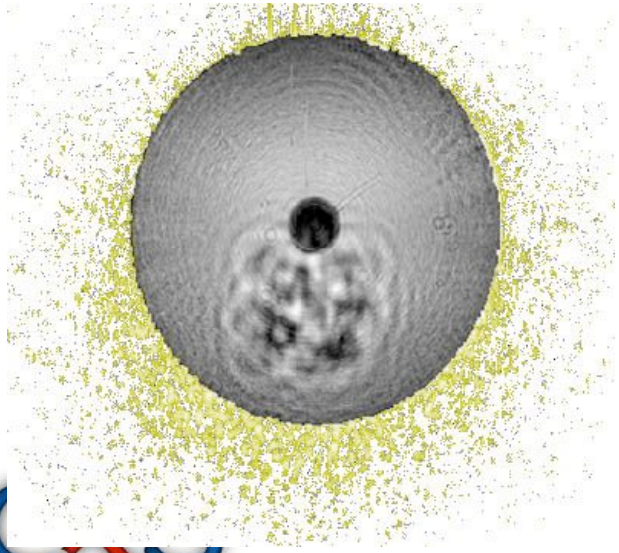
Experimental Setup

- Beam line 2-ID-B of the Advanced Photon Source
- Energy of 1.83 keV (6.77 Å)

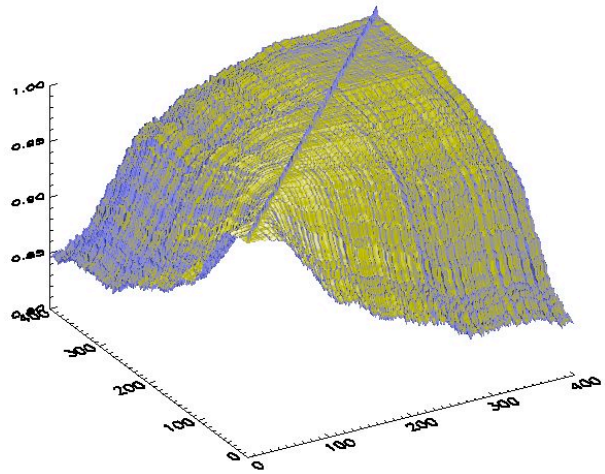


Data

- To achieve sufficient signal to noise requires many frames to be summed together
- Systematic effects reduce the number of frames that can be summed
  - Motion in illuminating beam
  - Beam intensity variations
  - Thermal drift



An example of data collected in the experiment. Scatter outside the illumination (yellow) is 5 orders of magnitude less than inside.



3D correlation map used to identify well correlated frames of data.

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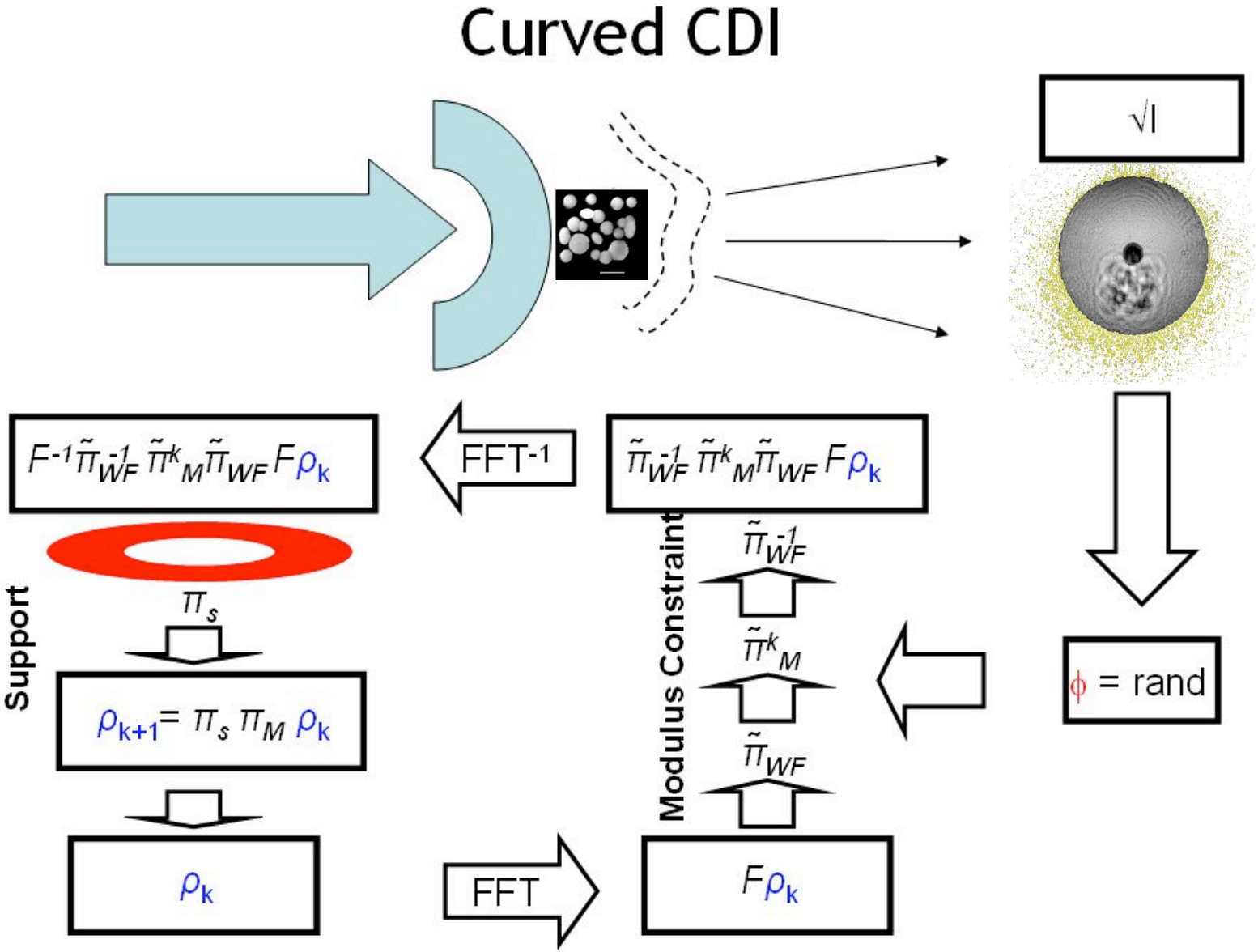
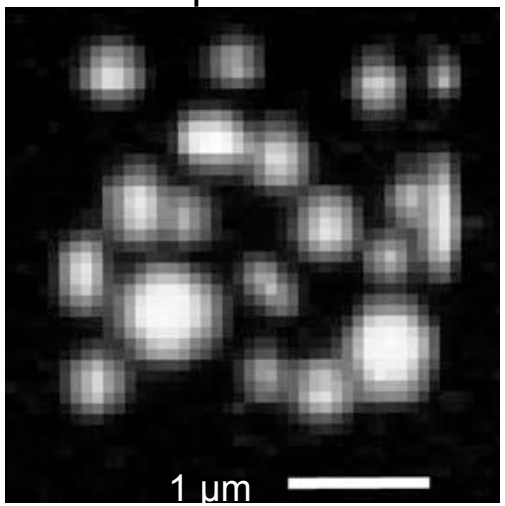
Phase retrieval Algorithm

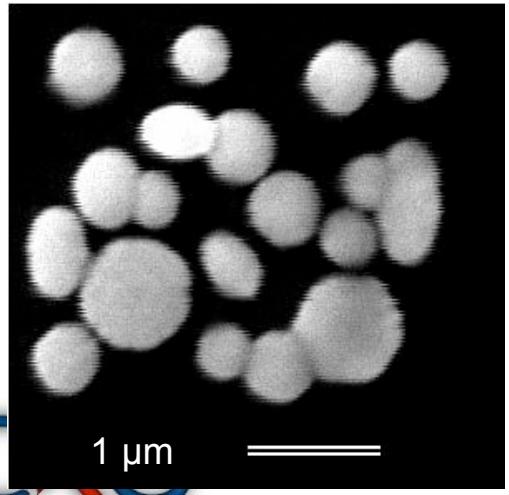


Reconstruction of gold microstructures

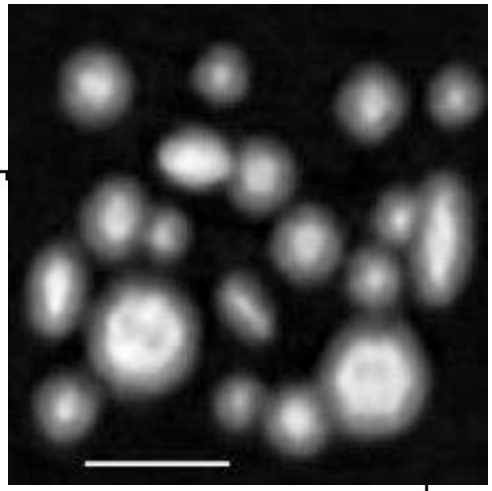
STXM image of the sample



SEM image of the sample



Reconstruction of sample



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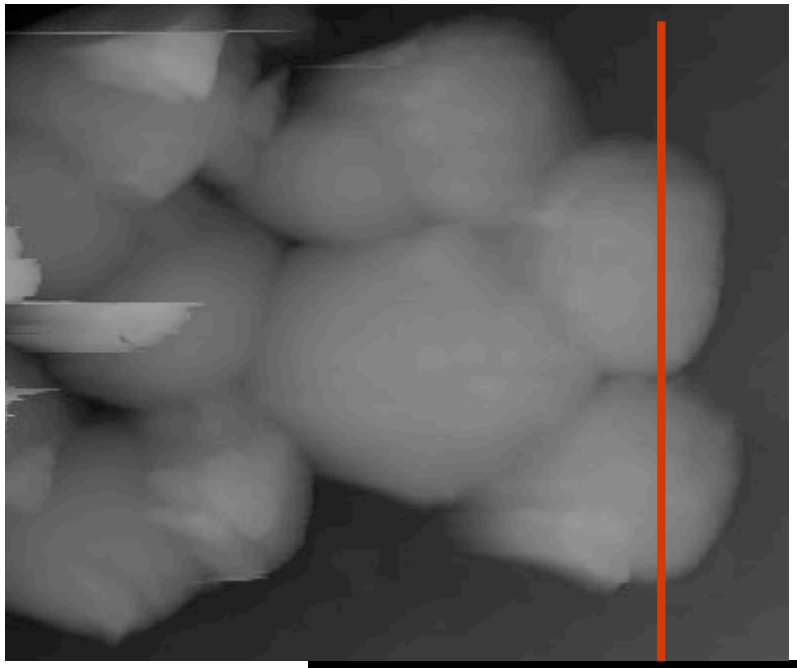
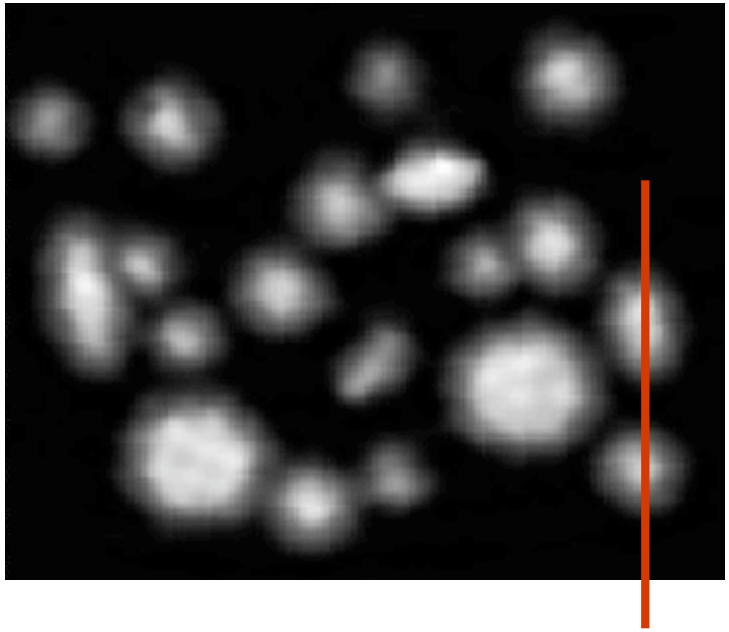
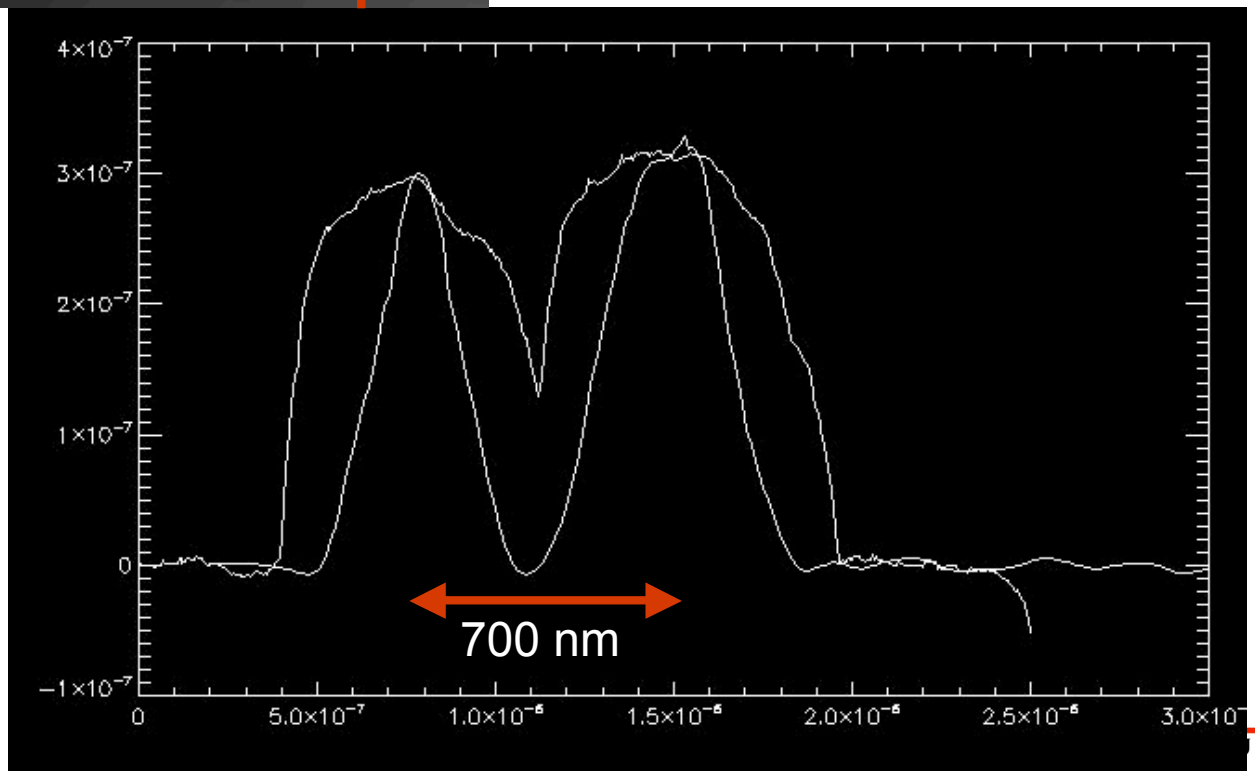




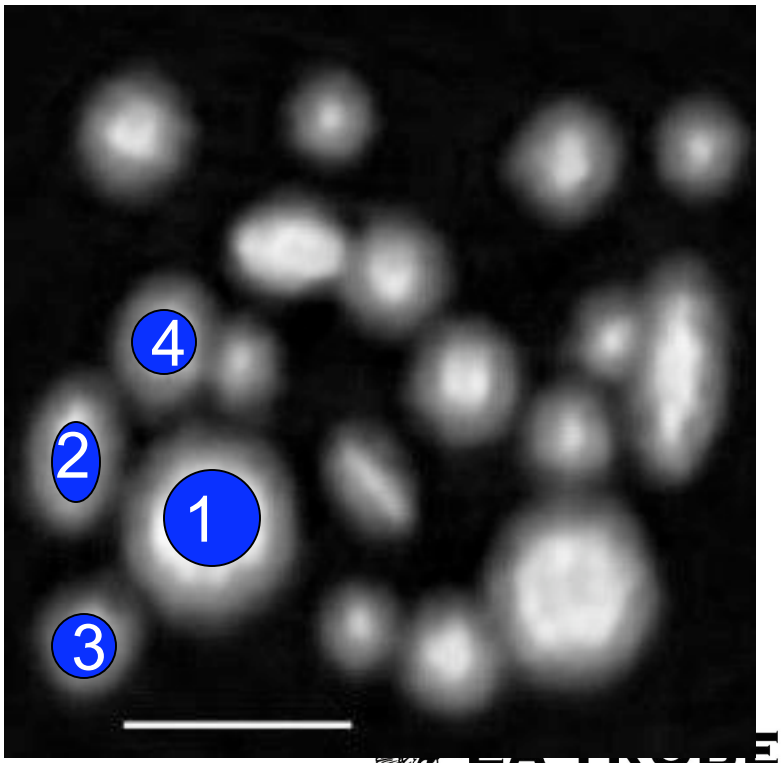
300 nm

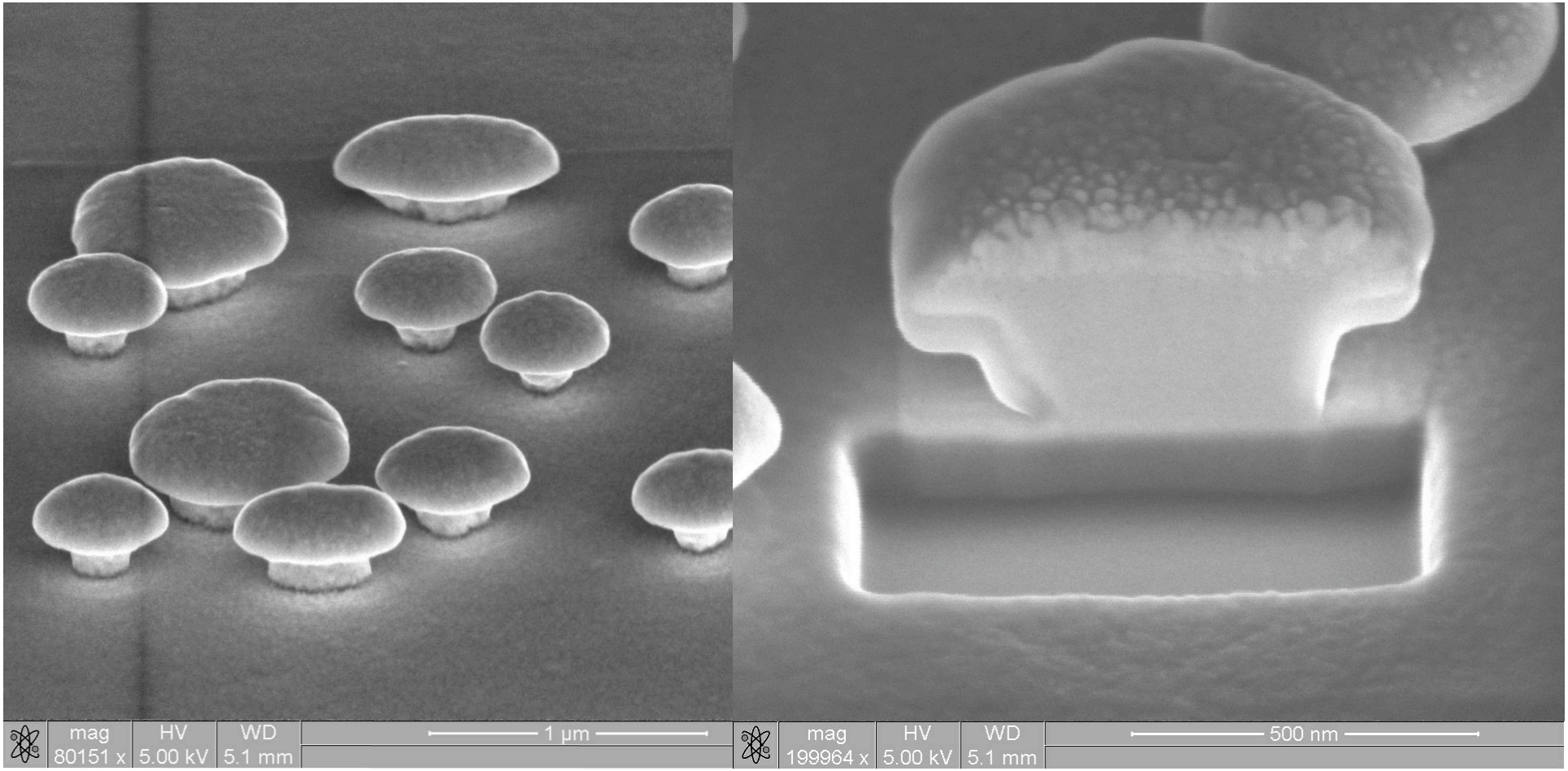

4×10⁻⁷
3×10⁻⁷
2×10⁻⁷
1×10⁻⁷
0
−1×10⁻⁷
0
5.0×10⁻⁷
1.0×10⁻⁶
1.5×10⁻⁶
2.0×10⁻⁶
2.5×10⁻⁶
700 nm

Recovered thickness

- Quantitative analysis of reconstructed phase
- Allows calculation of thickness for homogenous object

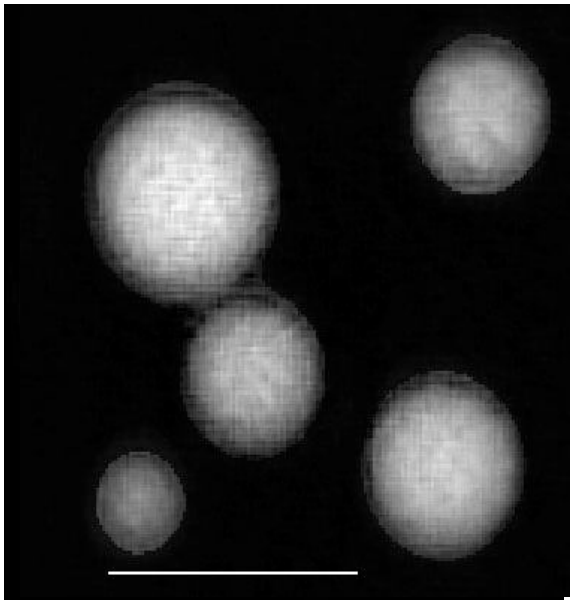
Region	AFM (nm)	FCDI (nm)	% Difference
1	375	366	2.4
2	344	355	3.2
3	308	296	3.9
4	344	324	5.8

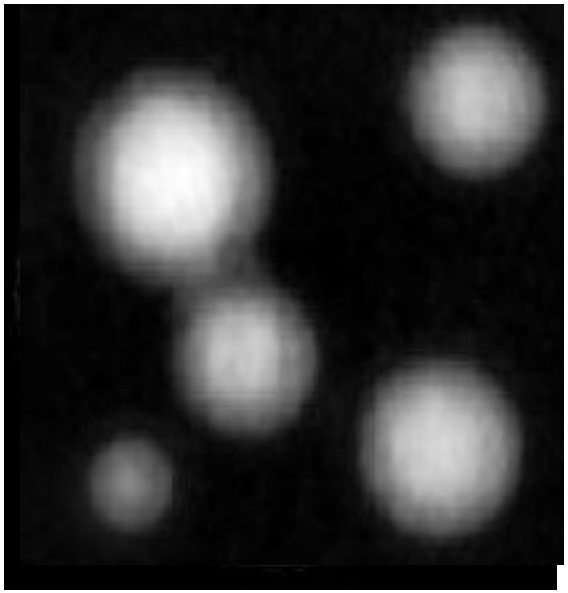


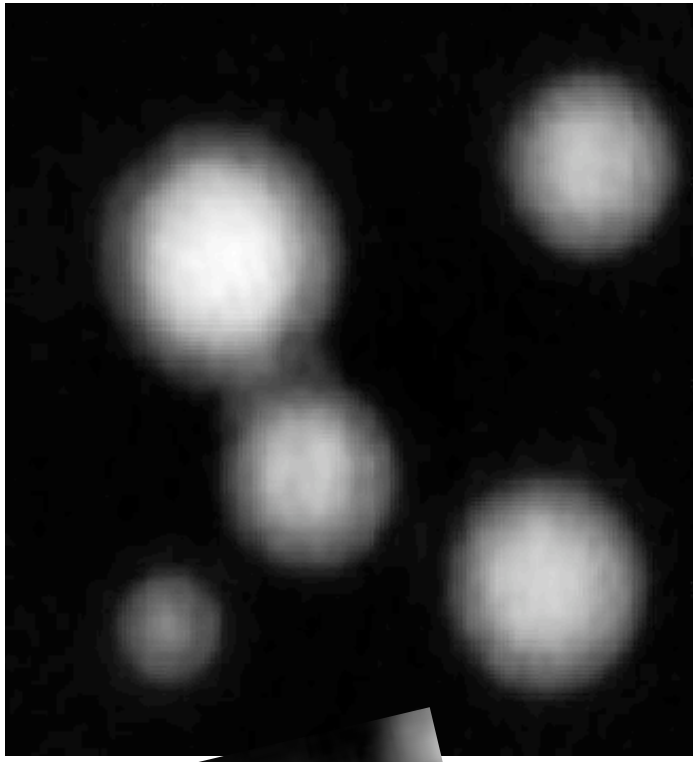

mag
80151 x
HV
5.00 kV
WD
5.1 mm
1 µm
mag
199964 x
HV
5.00 kV
WD
5.1 mm
500 nm

Sources of Error

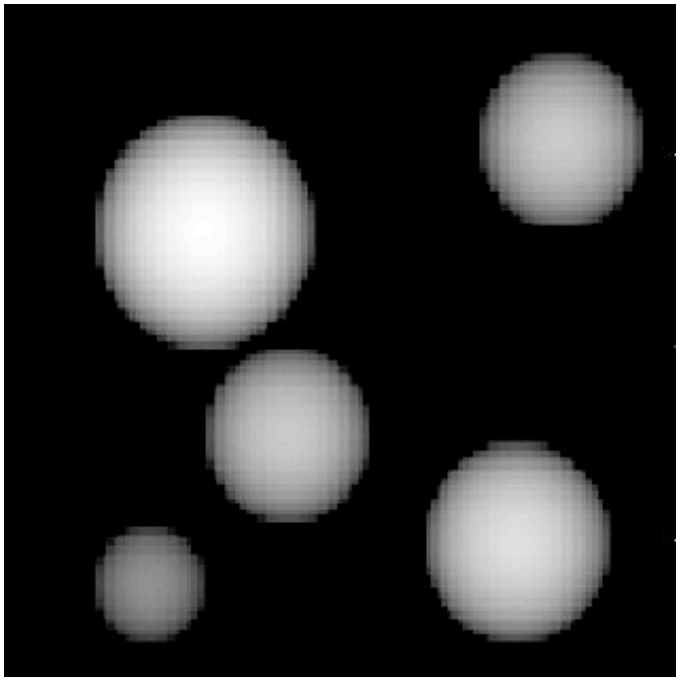
- Simulated effects
  - Intensity variations in illuminating beam
  - Sample motion
  - Zone plate motion
  - Low flux at the detector

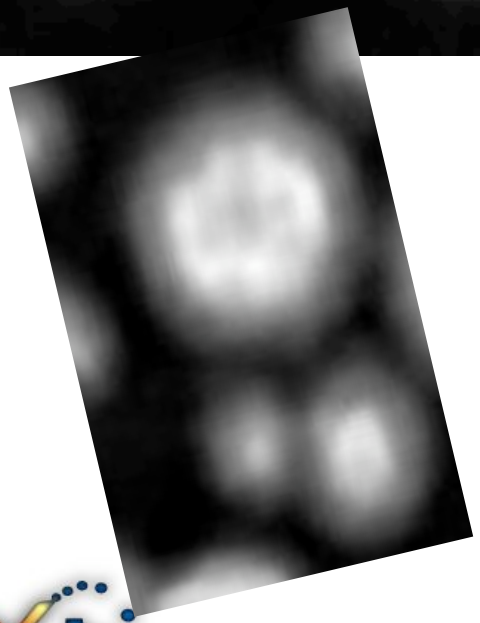




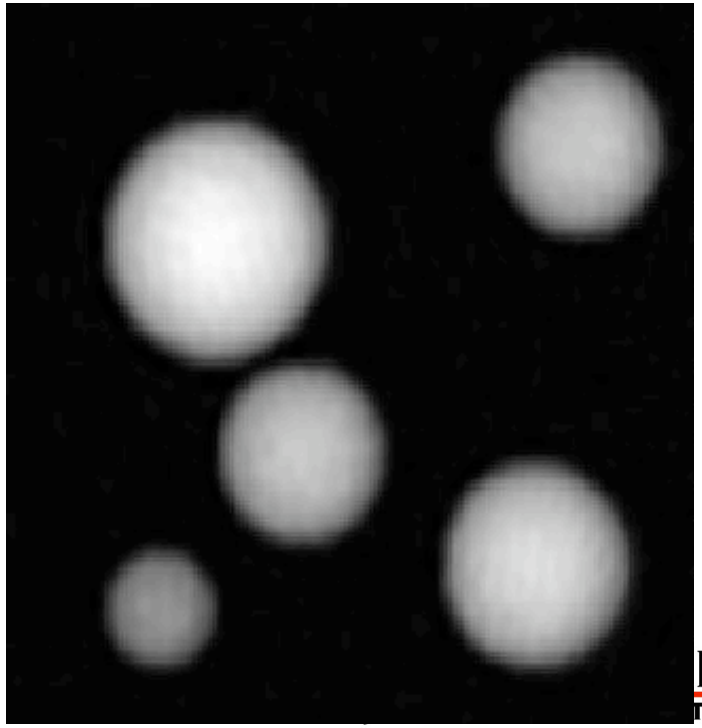


100 nm



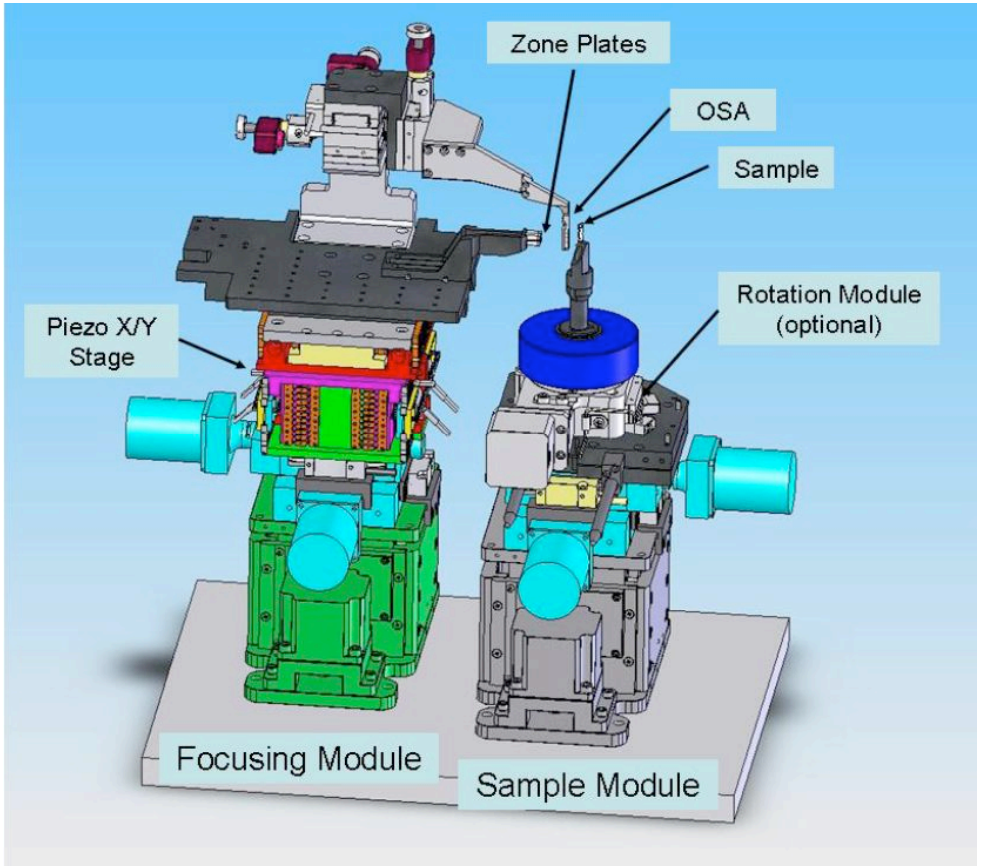


10 nm



Instrumentation

- 0.25 – 12 keV compatible
- HV compatible
- < 2 nm stability
- Drift < 0.1 nm/s @ ± 0.2 ˚C
- 10 nm circle of confusion

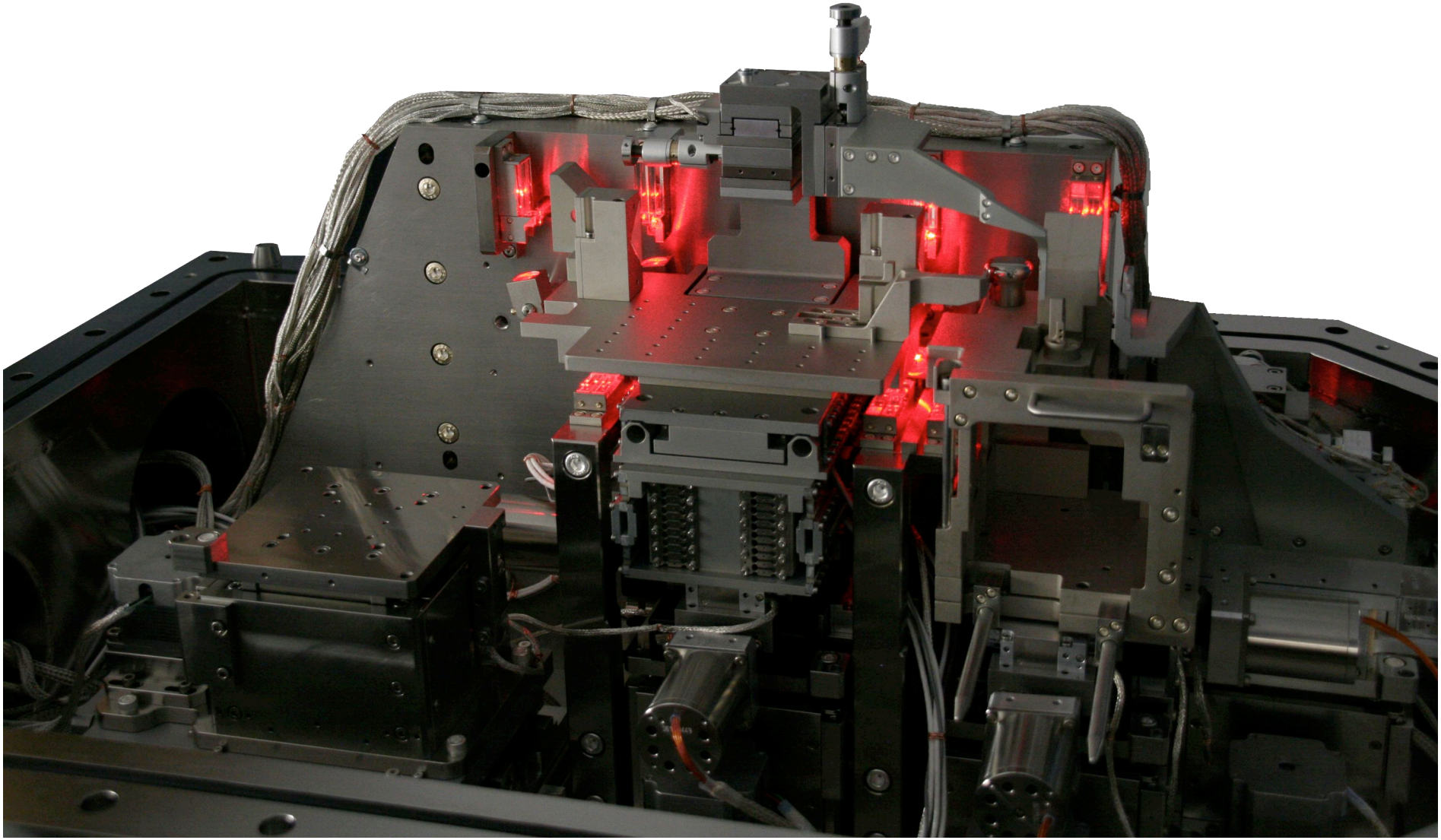


Xradia Inc.

Stage Specifications

Stage Stack	Axis	Travel [mm]	Optical Encoder Resolution [µm]
Zone Plate	Stepper X	±10 (±5 LDDM encoded)	0.1
	Stepper Y	±6 (±5 LDDM encoded)	0.1
	Stepper Z	±10 (±5 LDDM encoded)	0.1
	Piezo X	0.015	(0.2 nm resolution with LDDM)
	Piezo Y	0.005	(0.2 nm resolution with LDDM)
Sample	Stepper X	±10 (±5 LDDM encoded)	0.1
	Stepper Y	±6 (±5 LDDM encoded)	0.1
	Stepper Z	±10 (±5 LDDM encoded)	0.1
	Rotation (Theta)	+/- 180 degrees	<0.1 degree resolution
OSA	Stepper X	±5	0.1
	Stepper Y	±5	0.1
	Stepper Z	±5	0.1
PH	PicoMotor X	±5	open loop – no optical encoder
	PicoMotor Y	±5	open loop – no optical encoder

Table 2: Travel Ranges and encoder resolutions



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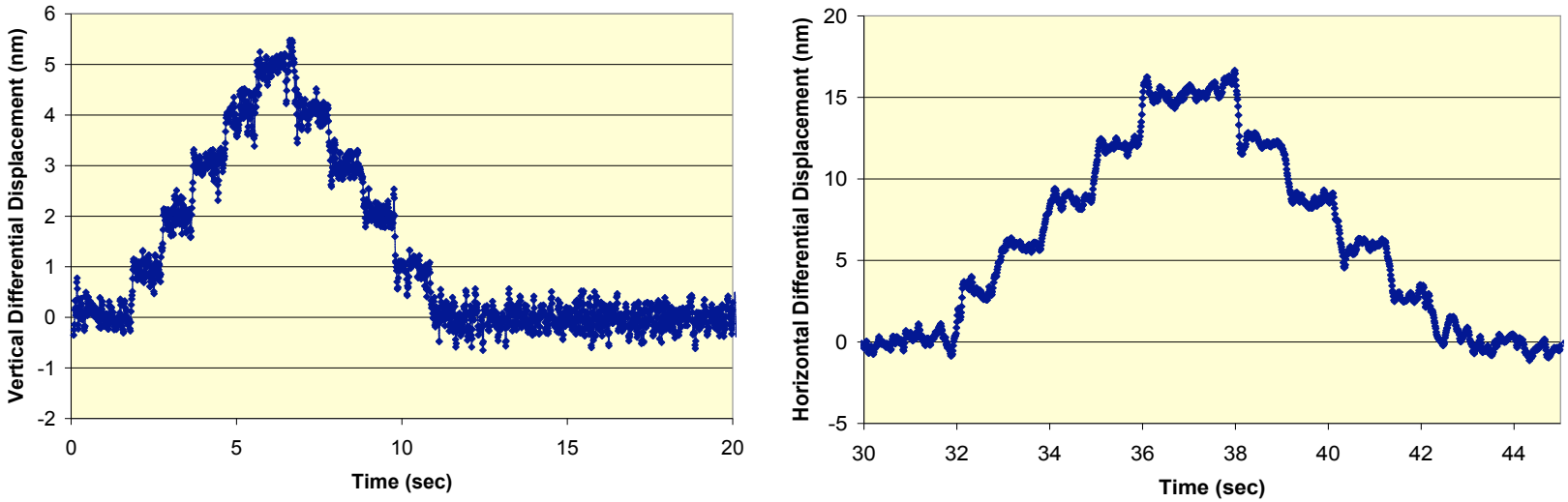
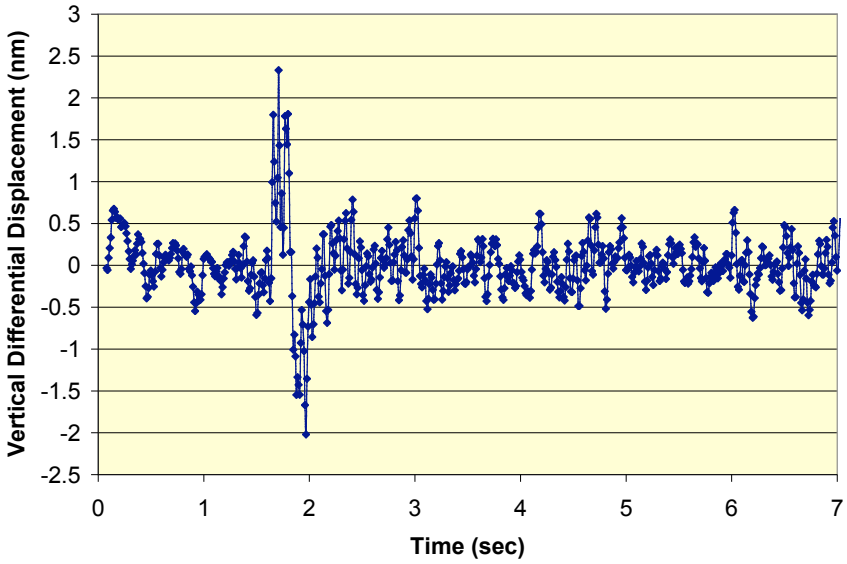
X-ray nanoprobe prototype

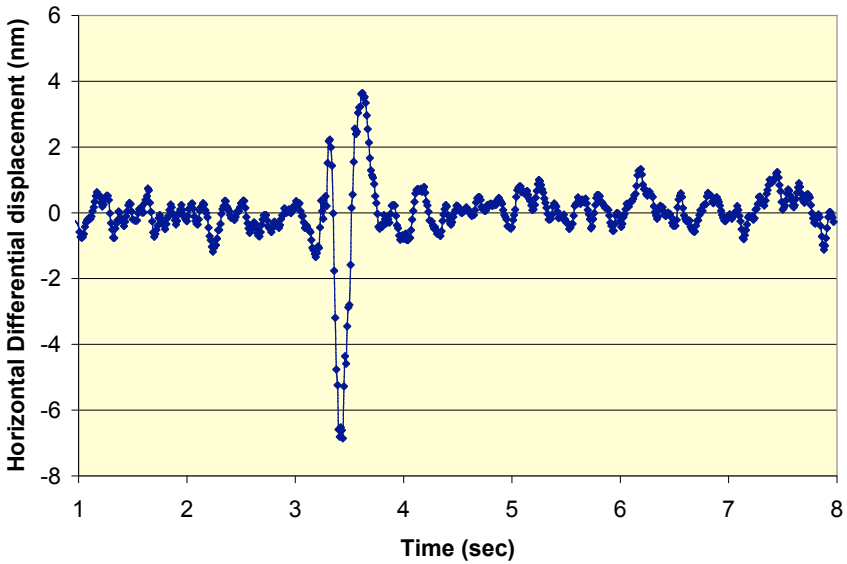


Closed-loop differential displacement test for the prototype scanning stage system for the x-ray nanoprobe at the APS 8-ID-E station, horizontal: left side; vertical: right side. A series of 1-nm and 3-nm differential vertical and horizontal displacement steps (between zone-plate holder and sample holder) have been demonstrated with closed-loop control.

D. Shu et al **High Precision Positioning Mechanisms for a Hard X-ray Nanoprobe Instrument,** MEDSCI 2006, Hyogo, Japan
http://medsi2006.spring8.or.jp/proc/21_1.pdf

X-ray nanoprobe prototype

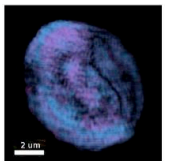


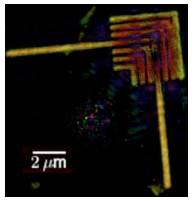


Active vibration control test for the prototype scanning stage system for the x-ray nanoprobe at the APS 8-ID-E station, vertical: left side; horizontal: right side. During this test, the closed-loop control system performed a damping action to a single external mechanical disturbance (an 80-kg mass dropped to the floor from a 0.2-m height at a distance of 3 m).

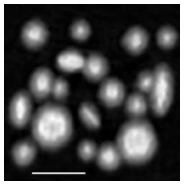
D. Shu et al **High Precision Positioning Mechanisms for a Hard X-ray Nanoprobe Instrument,** MEDSCI 2006, Hyogo, Japan
http://medsi2006.spring8.or.jp/proc/21_1.pdf

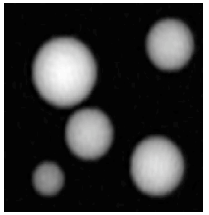
END

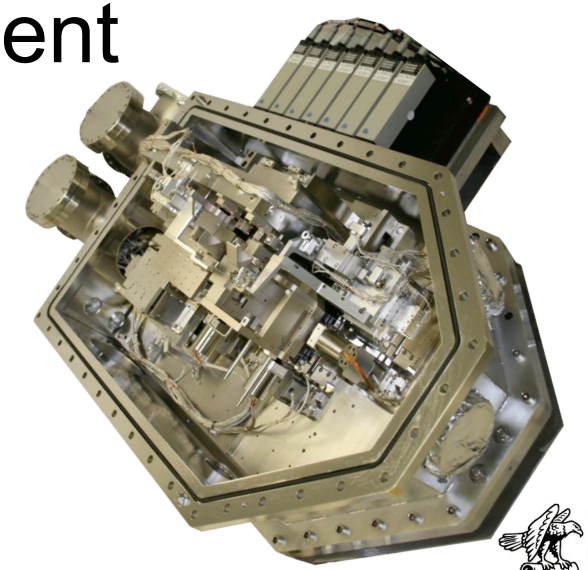




- Doing FCDI is possible at 3rd generation sources
- Quantitative solutions are possible
- High Resolution Imaging is possible…
- With the right equipment







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