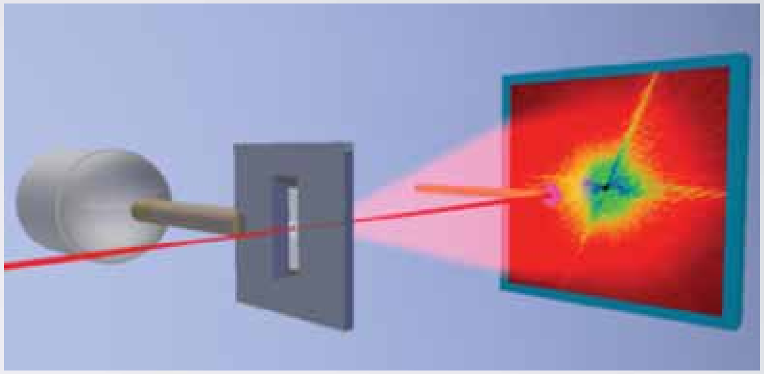
MASSIVELY PARALLEL HOLOGRAPHY AND OTHER COHERENT METHODS

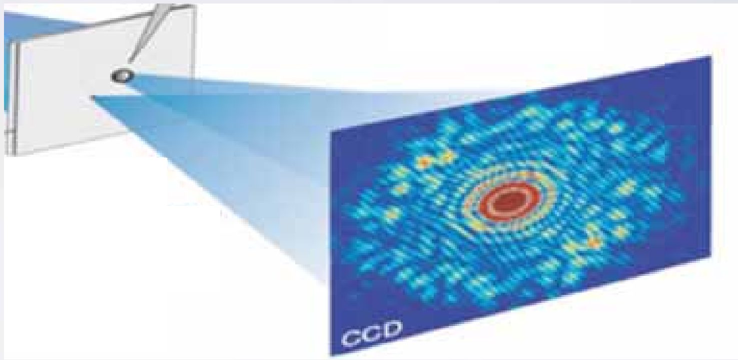
Stefano Marchesini -Advanced Light Source
Lawrence Berkeley Lab

DIFFRACTIVE TECHNIQUES

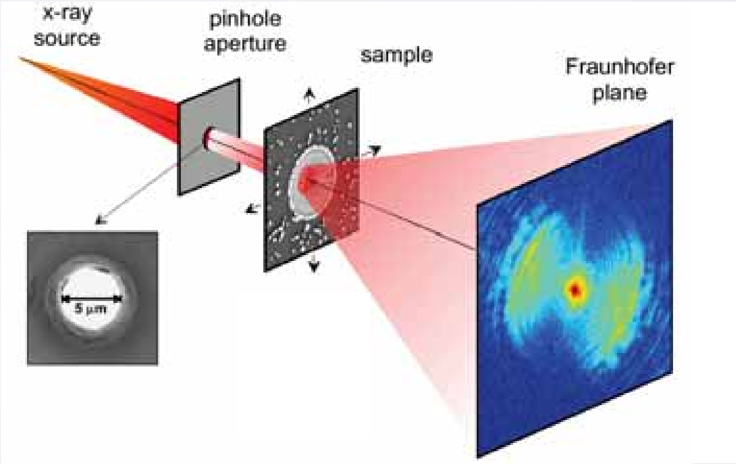
- Diffractive imaging



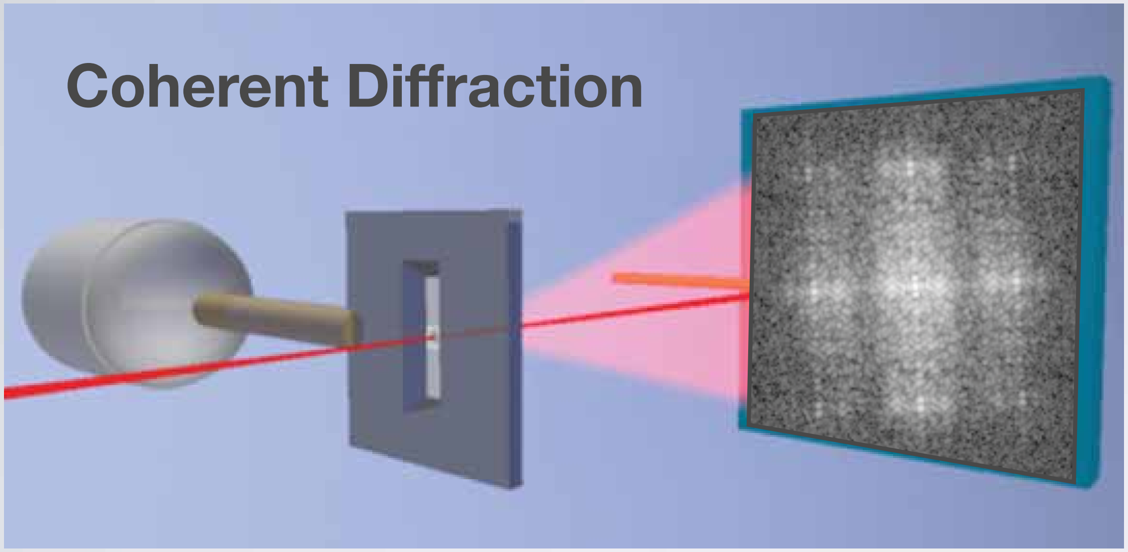
- Holography



- Ptychography



Coherent diffractive imaging



Resolution extended by phasing alogirhtms

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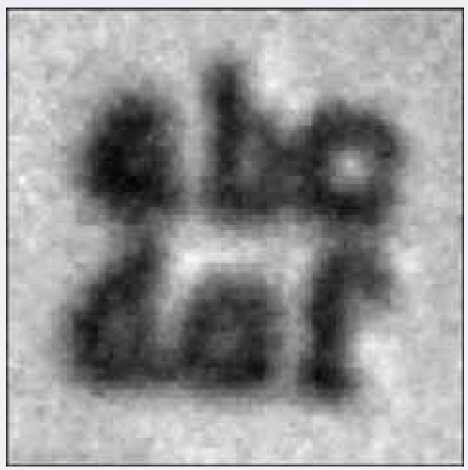

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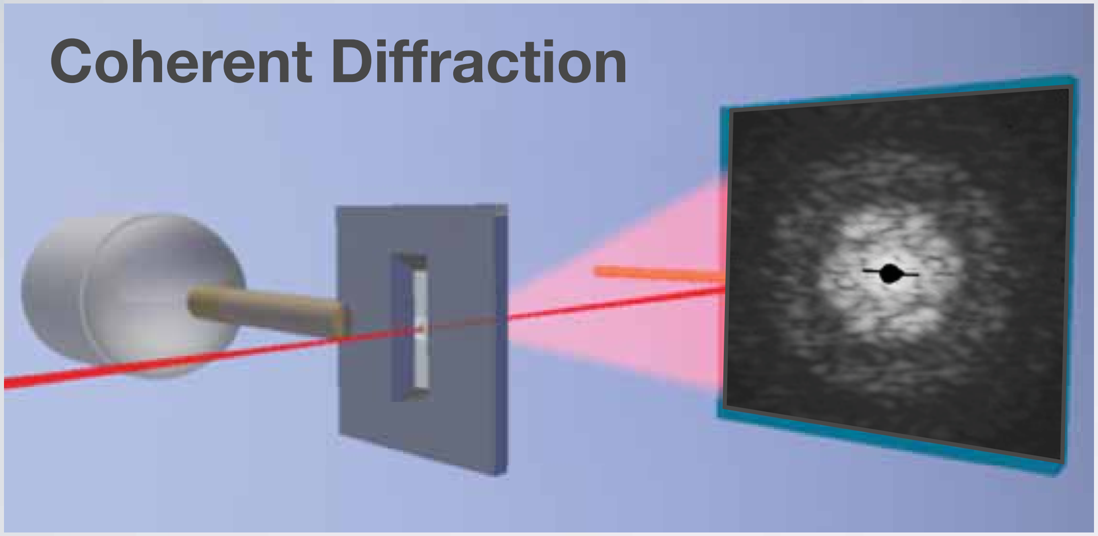
nature International weekly journal of science

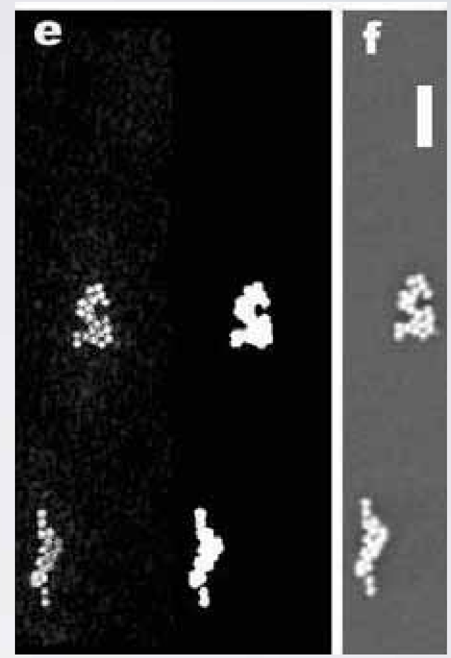
J. Miao, P. Charalambous, J. Kirz & D Sayre,Nature 400, (1999)

Ab-initio cohrent diffractive imaging



Find sparsest solution by iteratively shrinking the support

CDI SEM



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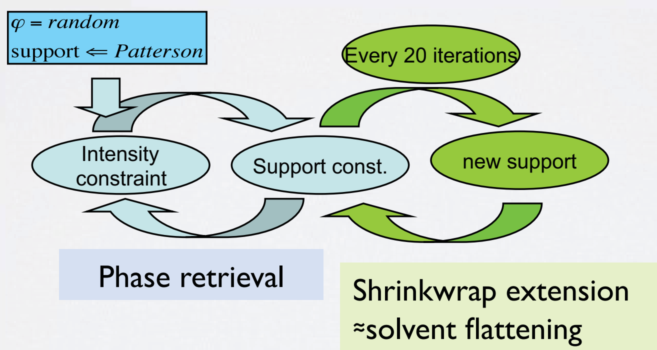
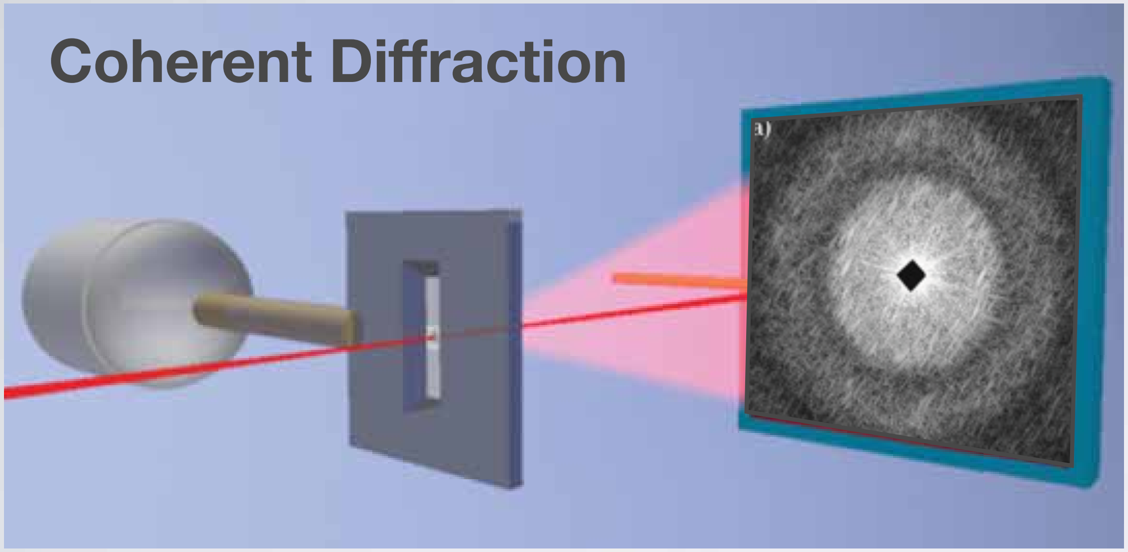
+



Physical Review B
condensed matter and materials physic

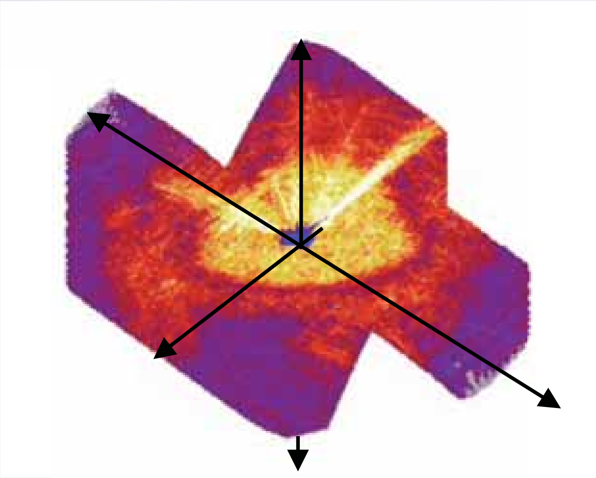
S. Marchesini, H. He, H. N. Chapman et al. PRB 68, 140101(R) (2003),

THREE DIMENSIONAL CDI



- Established billion-element phasing

Diffraction data

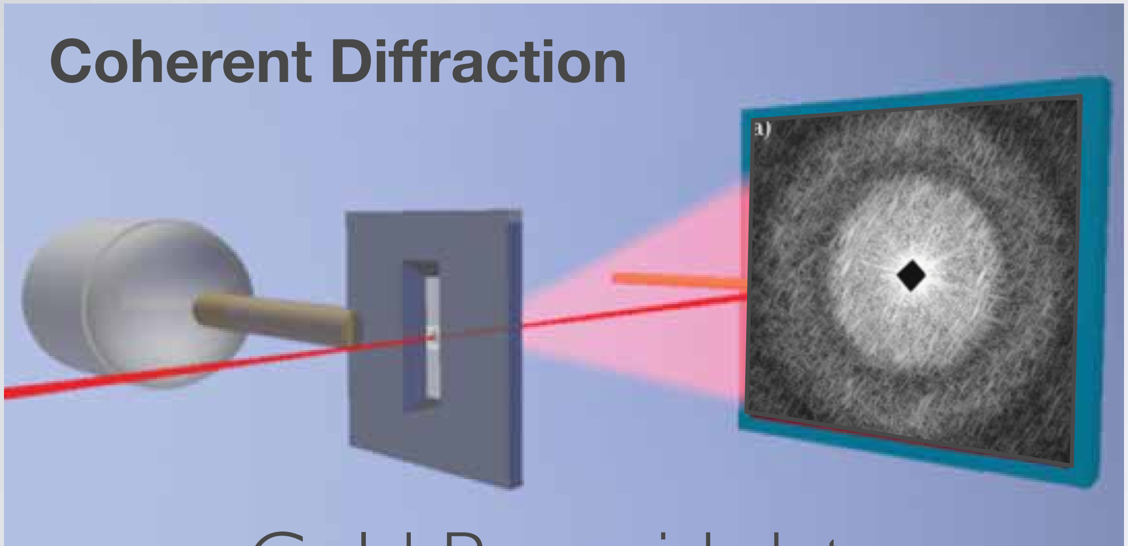


ab-initio Reconstruction

- 15 nm resolution

Journal of the Optical Society of America A
H. N. Chapman, A. Barty, S. Marchesini, et al. JOSAA 23, 1179-1200 (2006)

3D HOLOGRAPHY

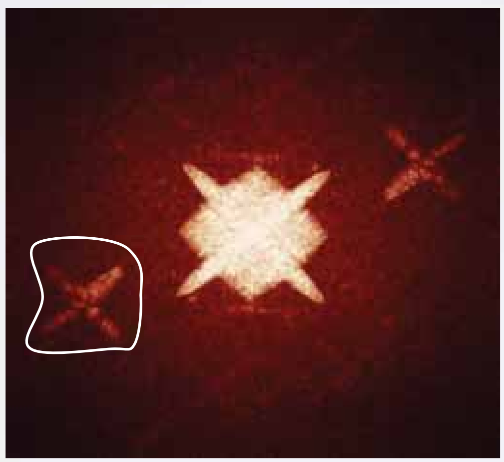


A gold ball acted as reference for tomo-holography

Gold Pyramid data

CDI

Hologram

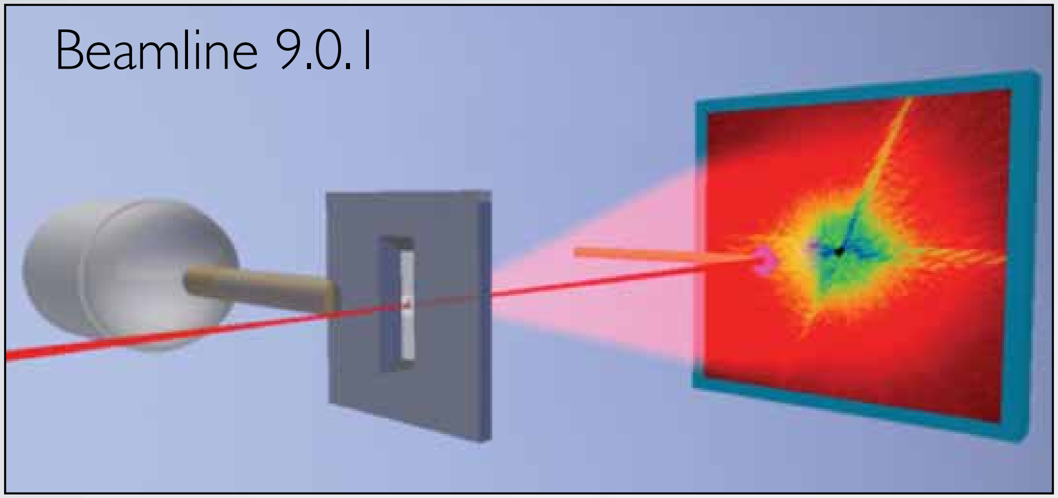


- direct inversion by FFT
- image convolved with reference ball

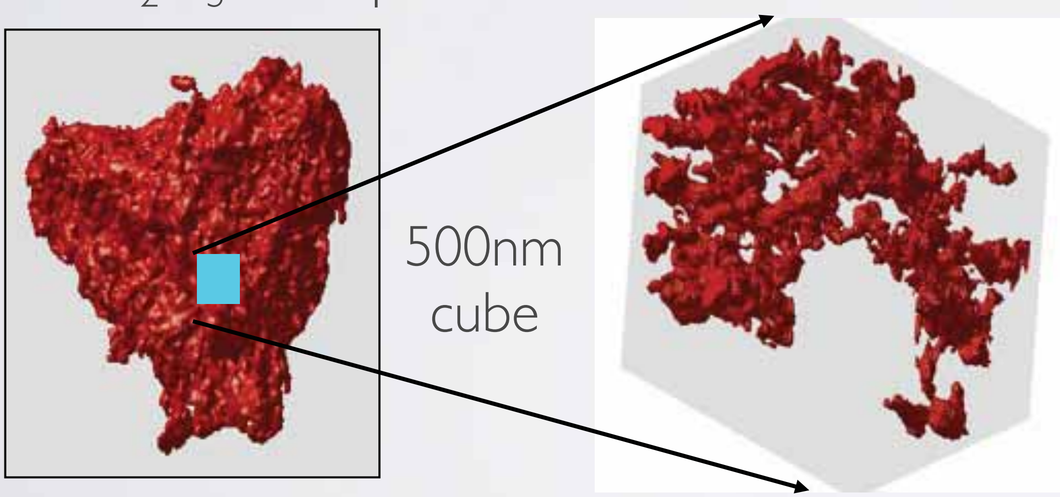
S. Marchesini, H. N. Chapman, A. Barty

Proc. 8th Int. Conf. X-ray Microscopy
IPAP Conf. Series 7 pp.353-356

NANOFOAM STRUCTURE BY COHERENT DIFFRACTION EXPLAINS ITS MECHANICAL PROPERTIES.



Ta_2O_5 foam particle



Diffractive imaging reveals micron size objects 3D structural information at 15 nm resolution.

Bulk image explains structural weakness.

Suggests methods to improve nanofoam strength.

Applicable to large class of porous materials.

VOL 321 **SCIENCE**

EDITORS' CHOICE

Physical Review Letters

A. Barty, S. Marchesini, H. N. Chapman et al.
PRL 101, 055501 (2008)

DIFFRACTIVE TECHNIQUES

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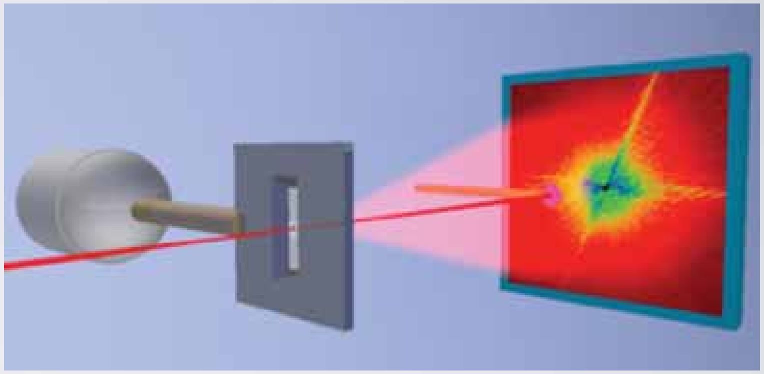
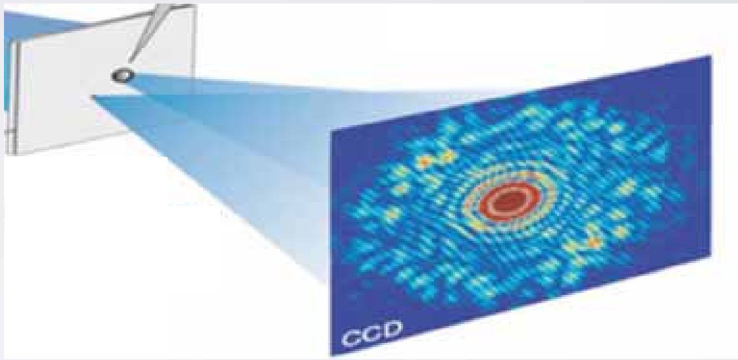


- Holography



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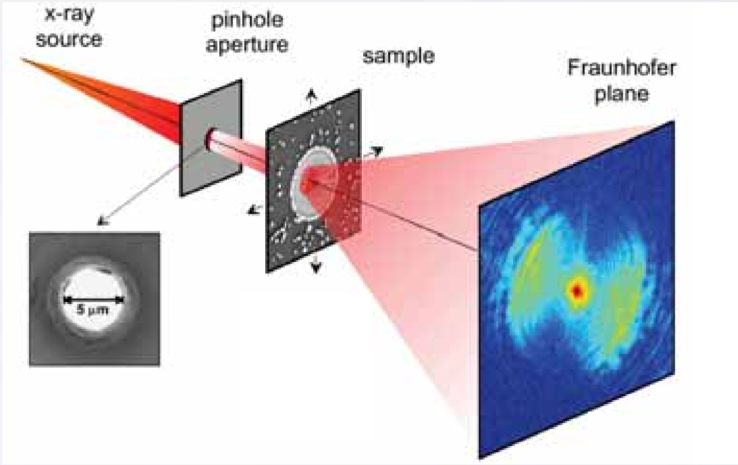
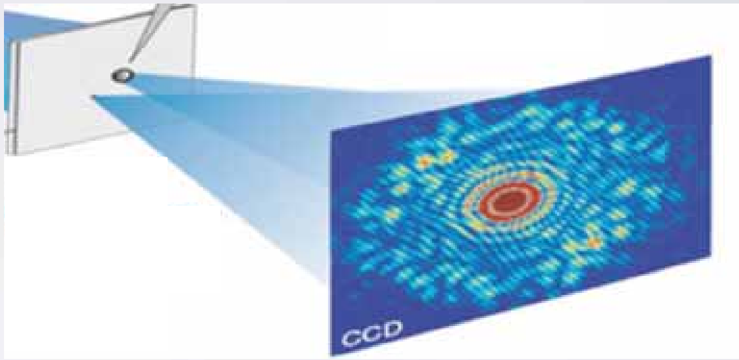
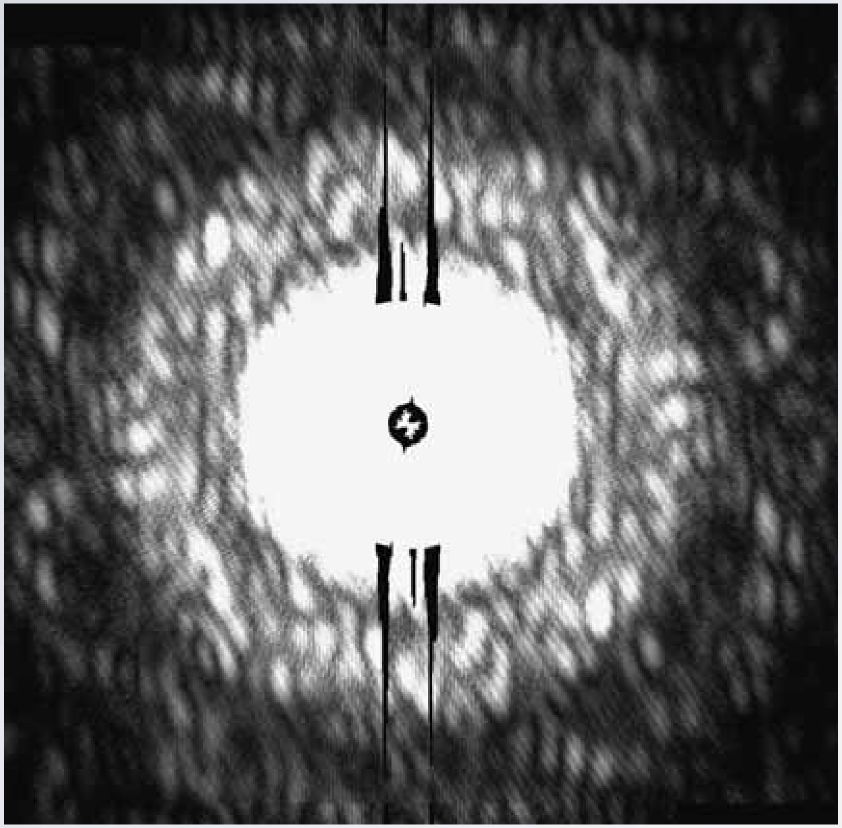
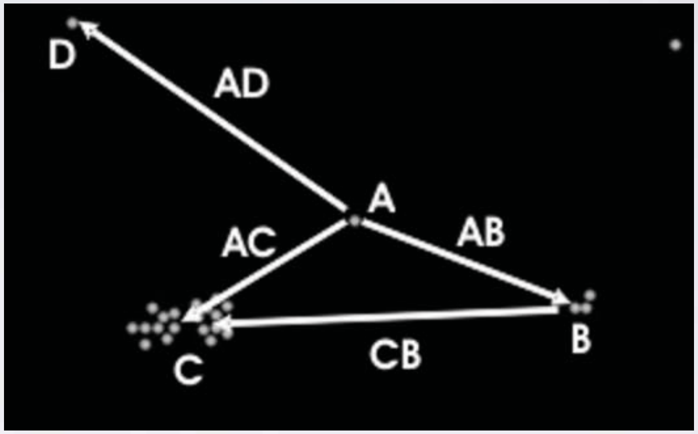


- Holography

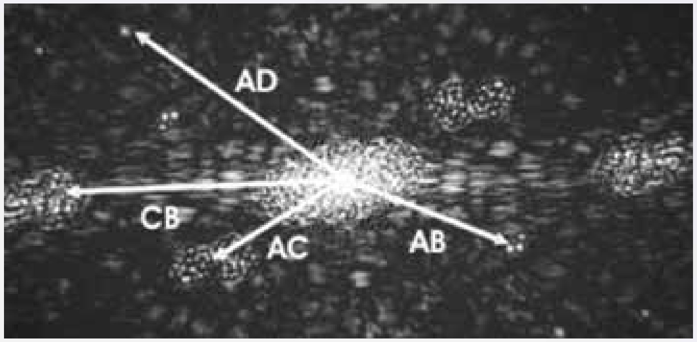


SPARSE OBJECTS ARE EASIER TO PHASE: THEY CONTAIN HOLOGRAMS





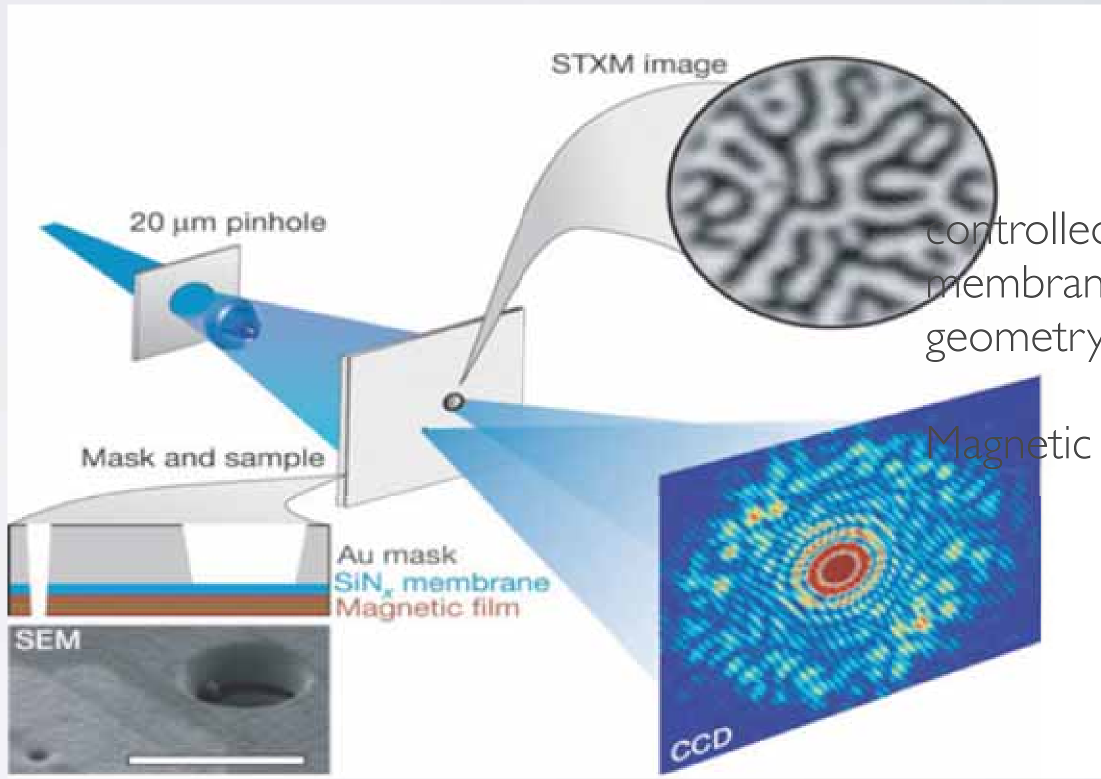
gold nanosphere clusters on Si_3N_4



- direct inversion by FFT
- image convolved with reference ball

H. He, S. Marchesini, M. Howells, et al. Acta Cryst. A59, (2003).

SPECTRO-HOLOGRAPHY



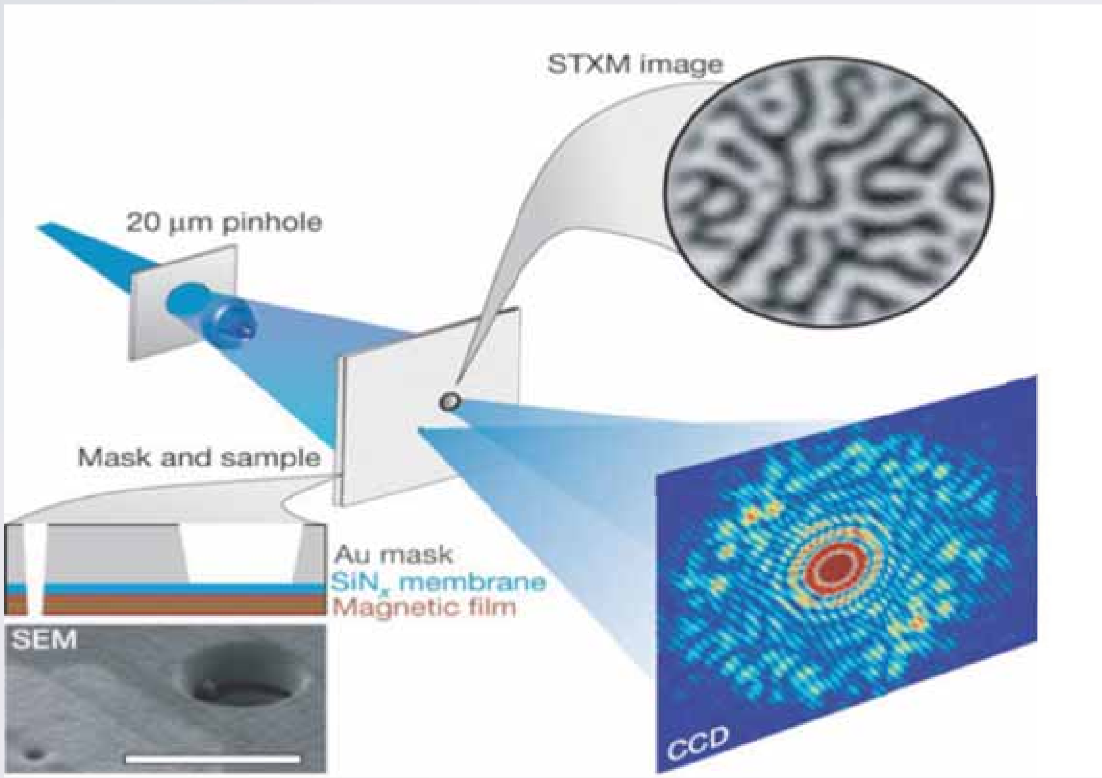
controlled pinhole-membrane geometry by FIB

Magnetic contrast

nature International weekly journal of science

S. Eisebitt, J. Lüning, W. F. Schlotter et al. Nature 432, 885 (2004)

X-RAY HOLOGRAPHY WITH A PINHOLE



- irect inversion
- eference wave is weak
- ade off between brightness
  d resolution

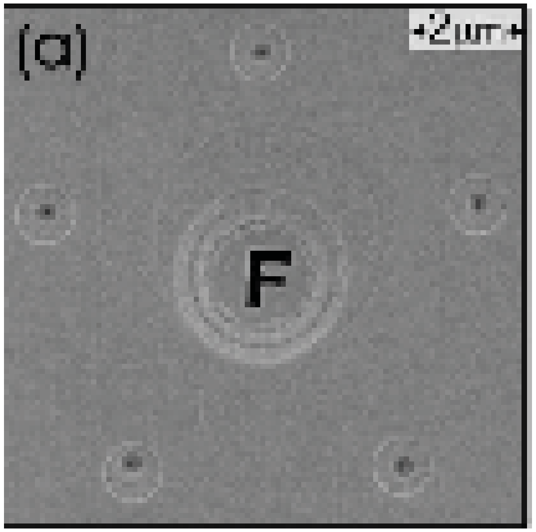
nature International weekly journal of science

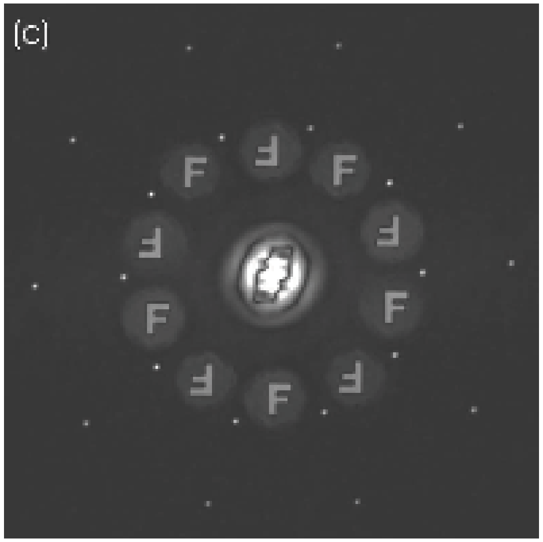
S. Eisebitt, J. Lüning, W. F. Schlotter et al. Nature 432, 885 (2004)

Multi-reference X-ray holography

W. F. Schlotter, et al

Multiple references

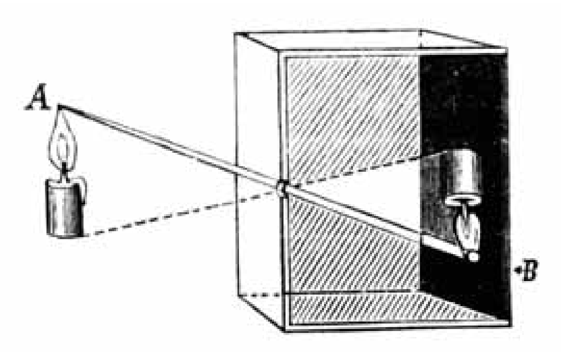




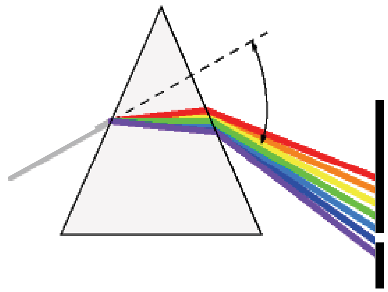
Problems: loose many coherent photons
Need more pixels: larger object-> larger sampling

Coded aperture imaging

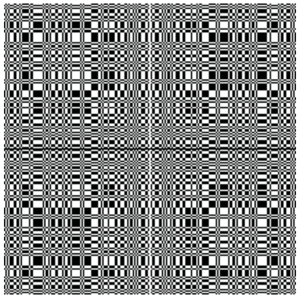
Pinhole camera



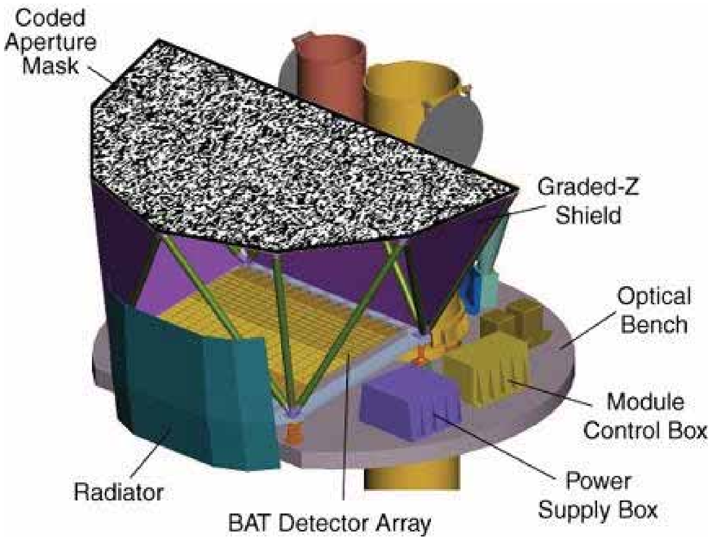
spectroscopy



Resolution or SNR
Solution: use a uniformly redundant array

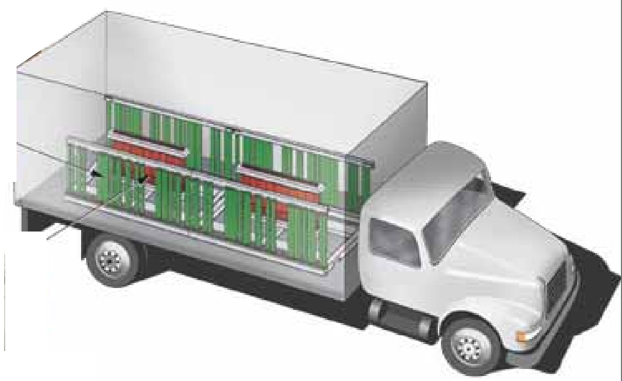


γ-ray astronomy



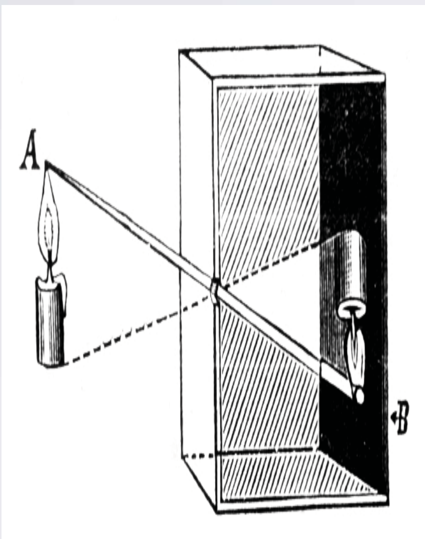
Medical imaging

Homeland security



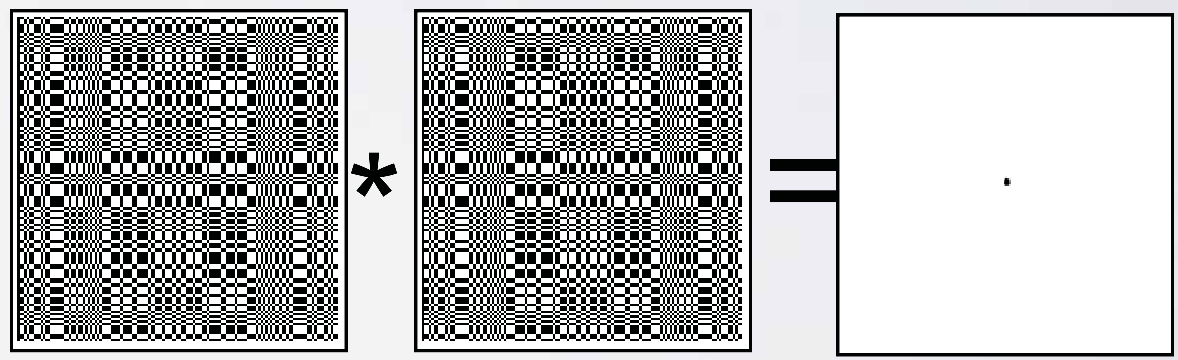
X-RAY HOLOGRAPHY WITH MANY PINHOLES

Pinhole camera



trade off between brightness and resolution

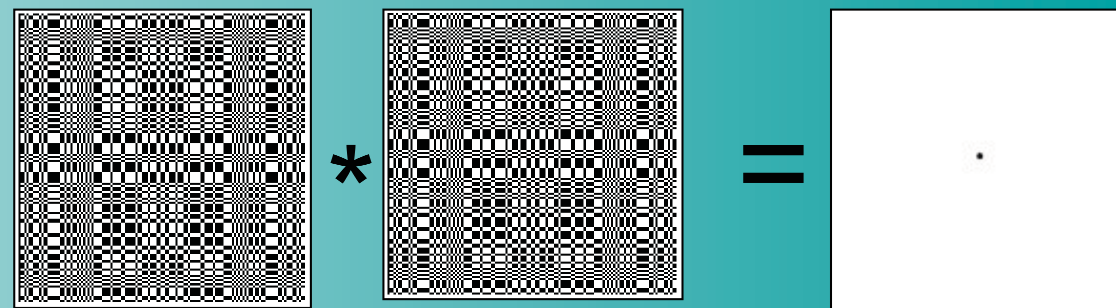
The “magic trick”:
An extended object with point-like autocorrelation (uniformly redundant array)



Coded aperture holography overcomes resolution/brightness limitations

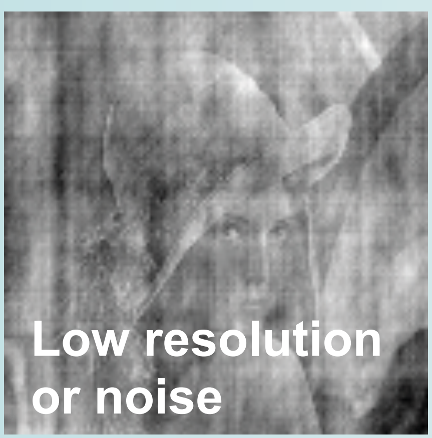
One point creates a hologram, many points create overlapping holograms: like a pinhole camera with many pinholes.

The “magic trick”:
An extended object with point-like autocorrelation (uniformly redundant array)

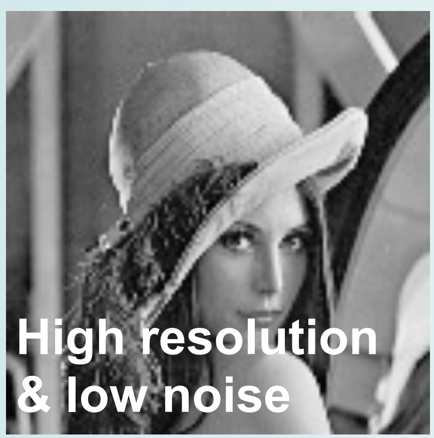


Same number of photons

Fourier transform holography

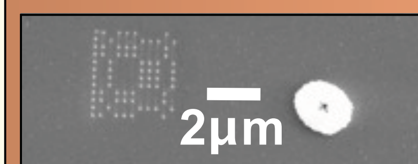


with coded apertures:
High resolution, low noise



Brightness and resolution improved by orders of magnitude by placing a coded aperture near a specimen

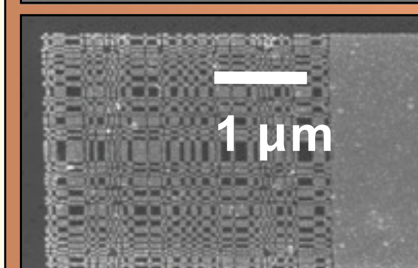
samples



Focused Ion Beam (50 nm res)

S. Boutet

SLAC



E- beam lithography (12 nm res)

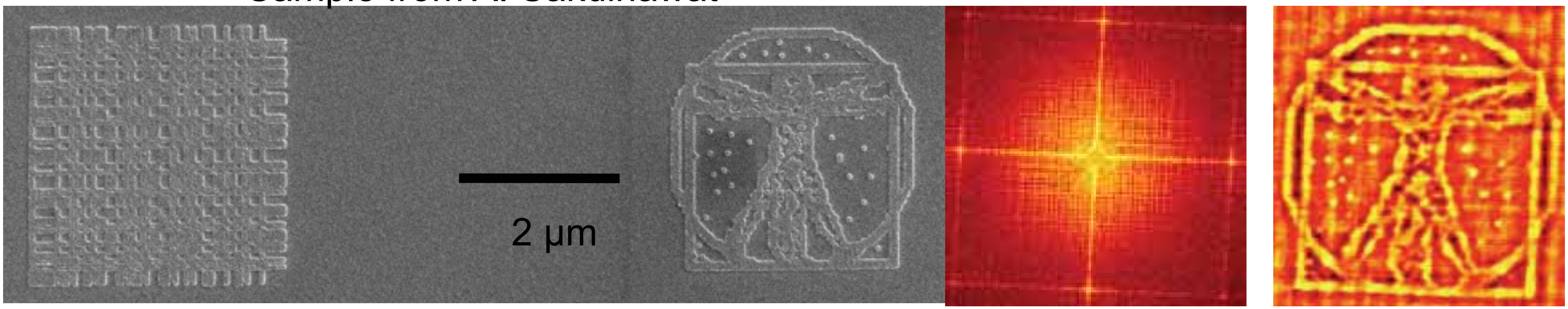
Sakdinawat

CXRO

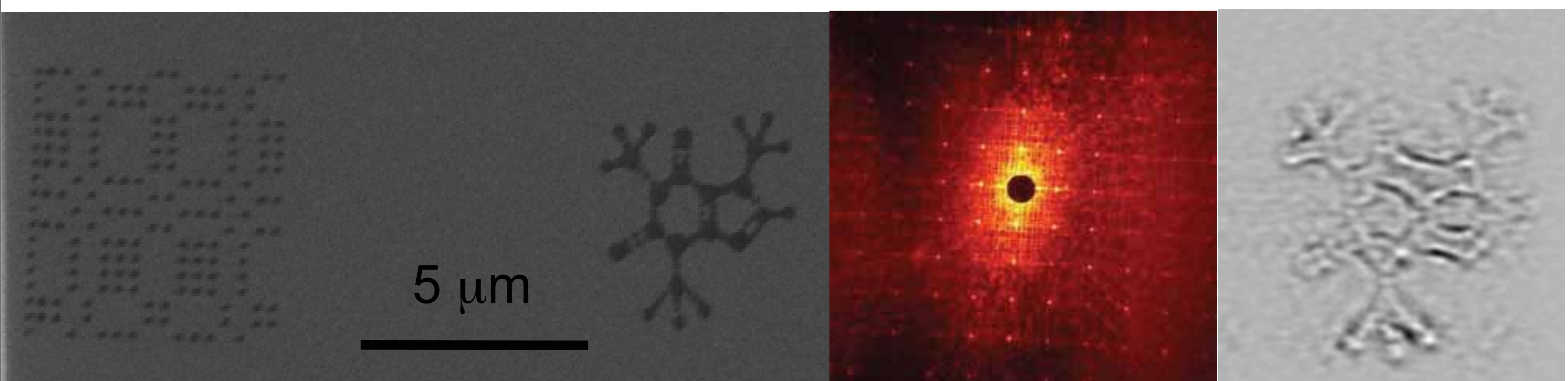
Ultrafast, ultrabright, ultra high resolution
X-ray holography with coded apertures

λ=2.2 nm Resolution=43 nm, SNR X ~70

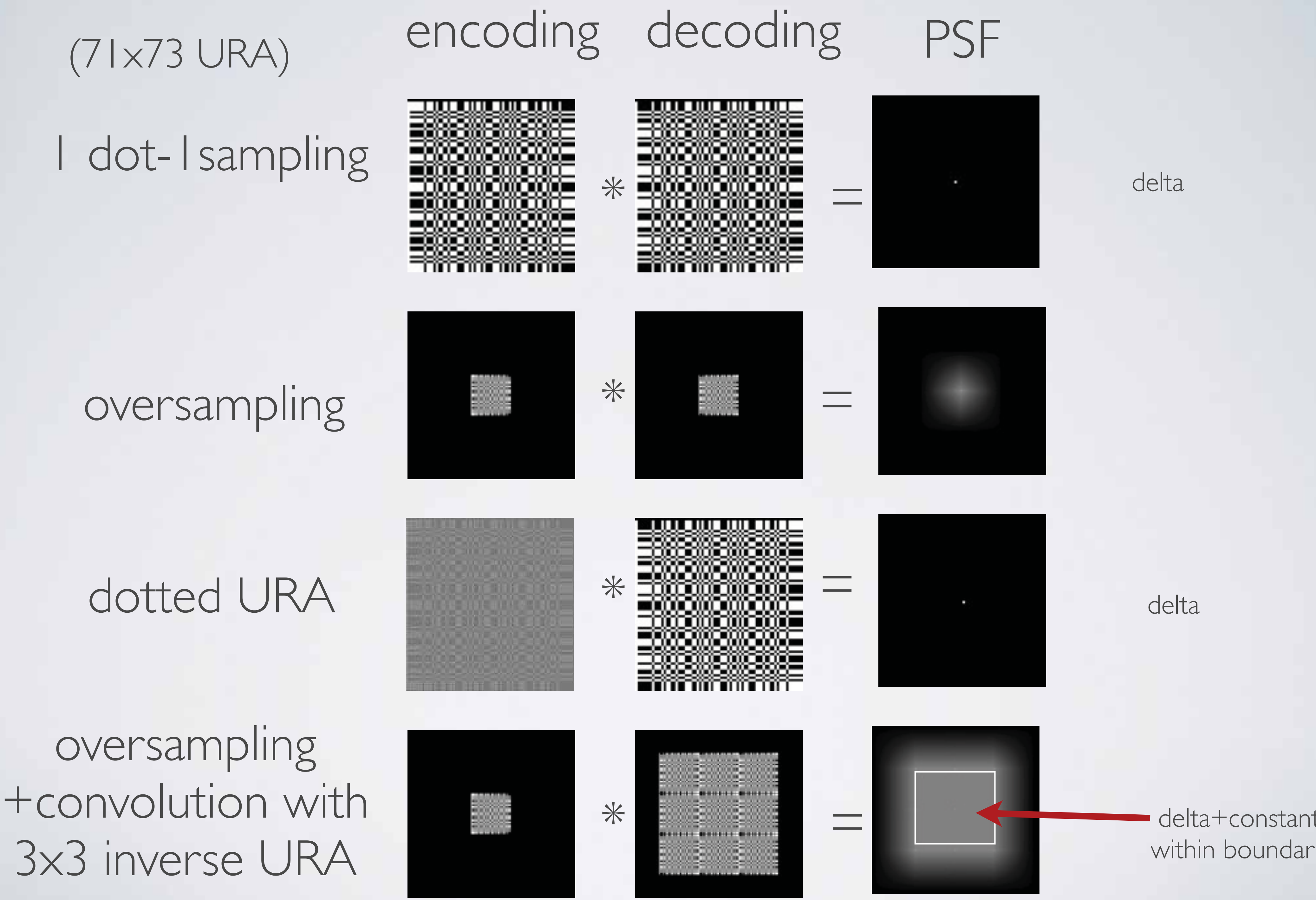
Sample from A. Sakdinawat

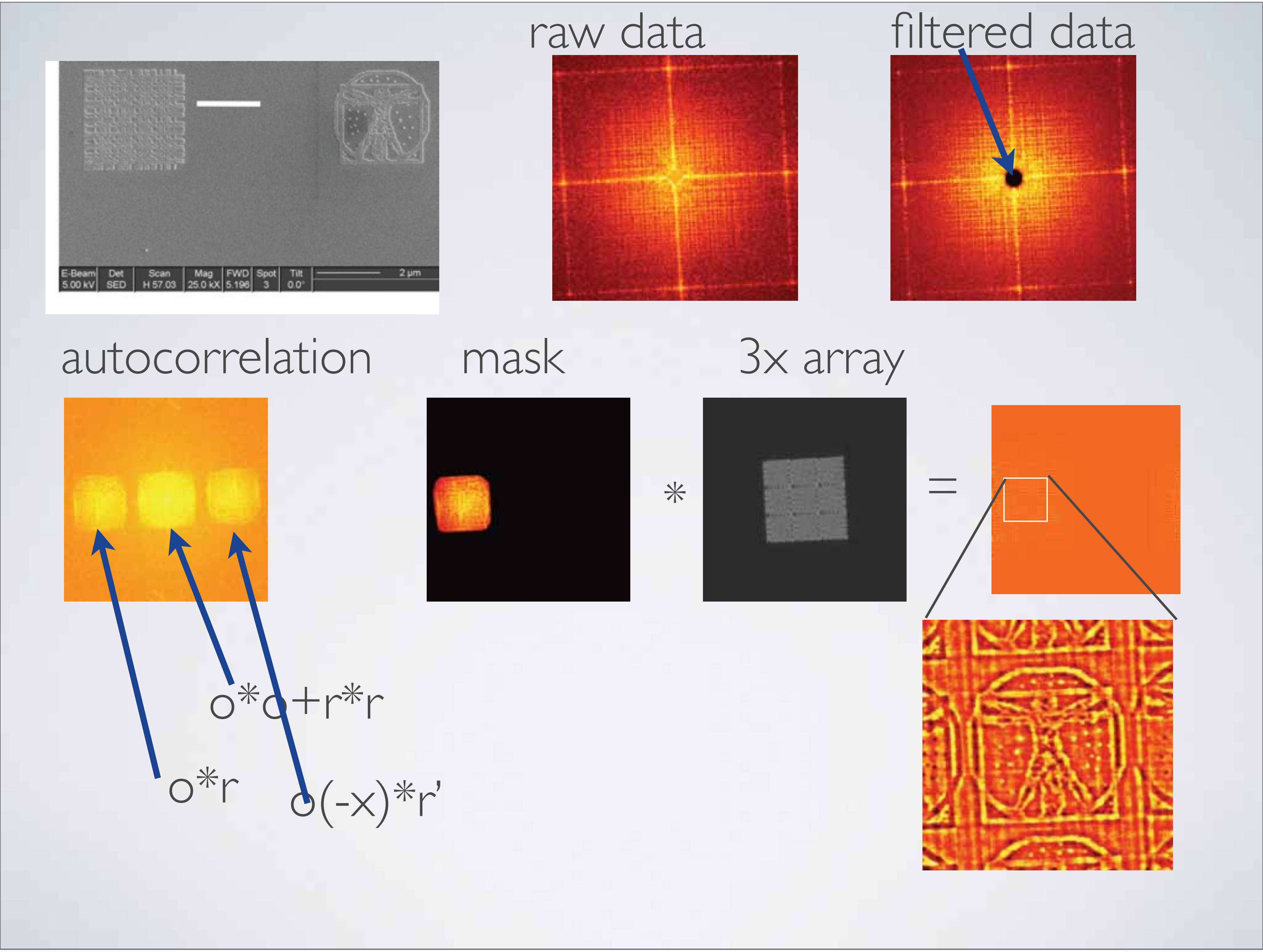


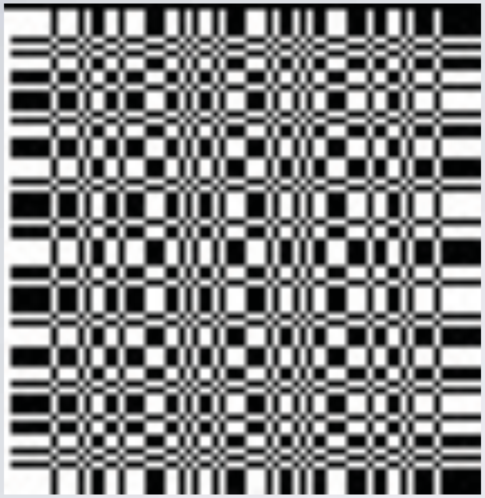
Δt=10 fs, λ=13.5 nm, Res~100 nm



*: cyclical convolution (with FFTs)

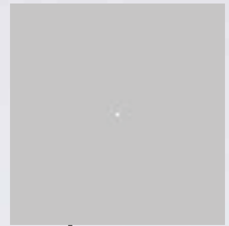



raw data
filtered data
E-Beam 5.00 kV
Det SED
Scan H 57.03
Mag 25.0 kX
FWD 5.196
Spot 3
Tilt 0.0°
2 µm
autocorrelation
mask
3x array
*
=
o*o+r*r
o*r
o(-x)*r'

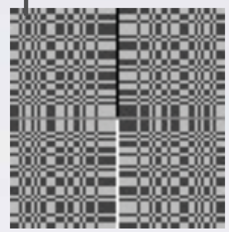


FFT

abs

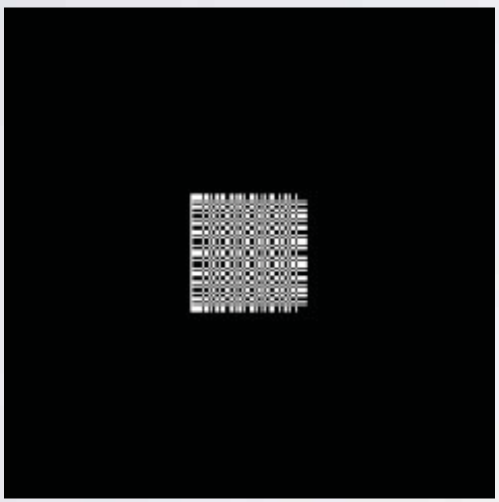


phase



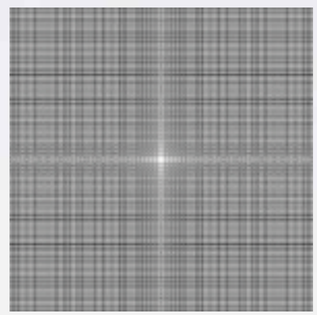
constant power spectrum except in the middle, depending on additive constant

0-padding <---> oversampling



FFT

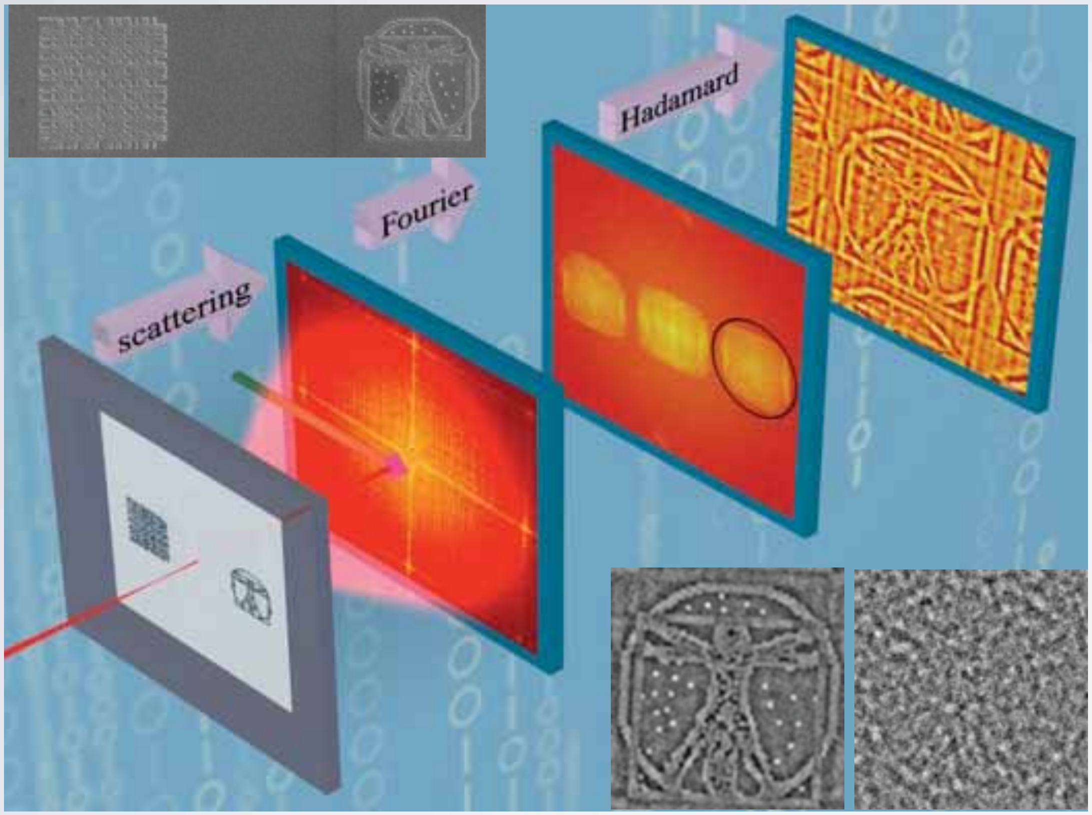
abs



phase

power spectrum is not constant when oversampling

Combining X-ray holography with coded aperture imaging improves brightness by orders of magnitude.



- reduced exposure by orders of magnitude at ALS.
- femtosecond hologram obtained at FEL.
- Resolution extended beyond nanofabrication limits by phasing methods.

nature photonics

S. Marchesini, S. Boutet, A. Sakdinawat, et al. Nat. Phot. 2, 560 - 563 (2008).

Ultrafast, ultrabright, ultra high resolution
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λ=2.2 nm Resolution=43 nm, SNR X ~70

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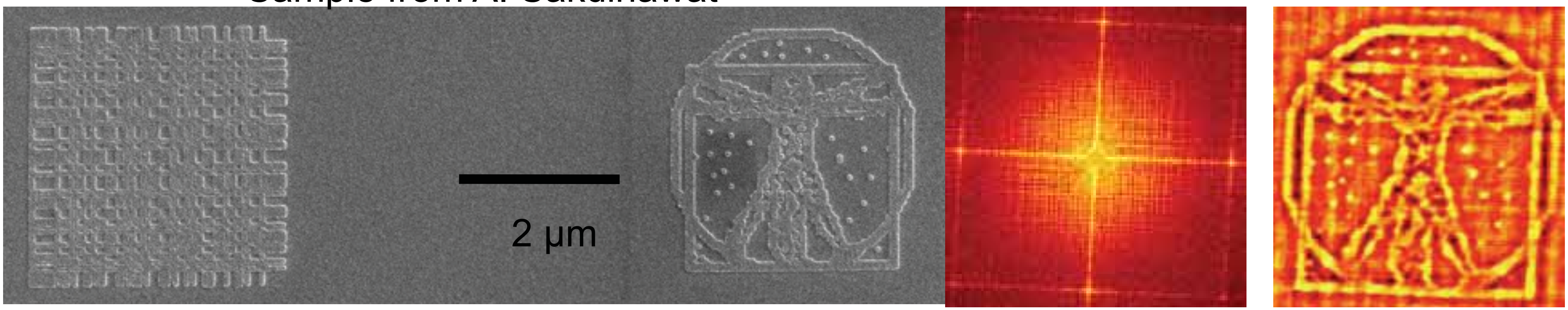
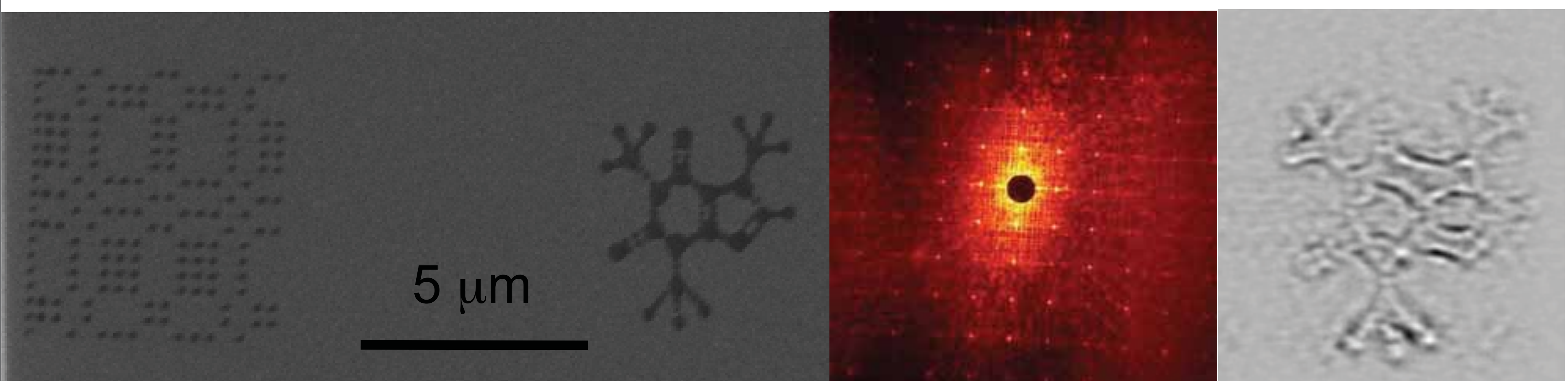


Δt=10 fs, λ=13.5 nm, Res~100 nm



DIFFRACTIVE TECHNIQUES

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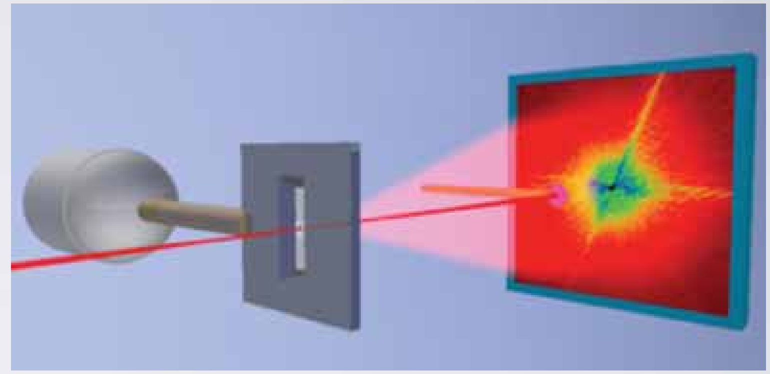

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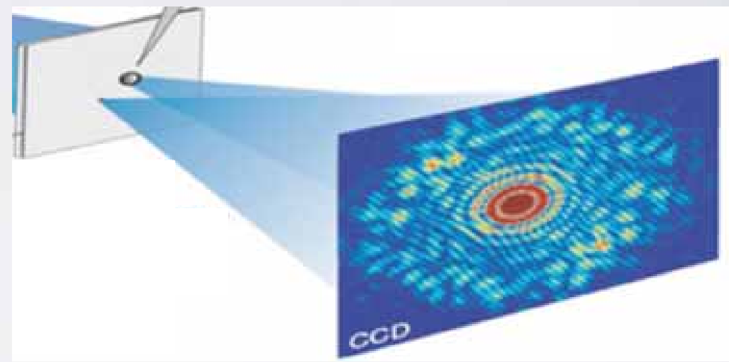
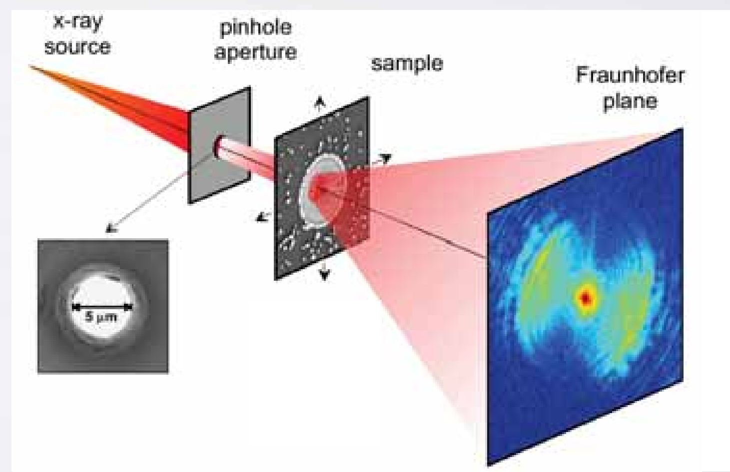
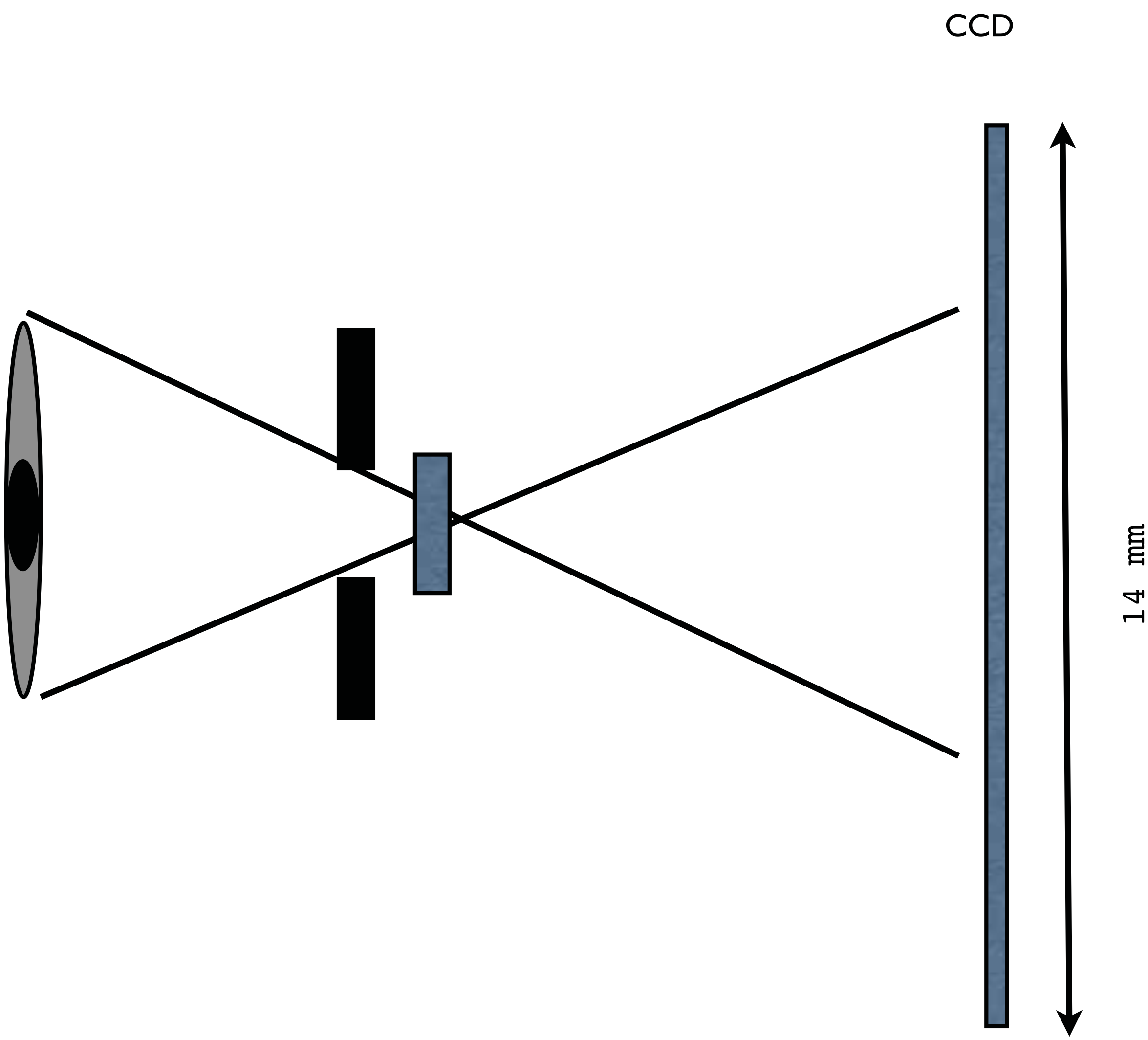


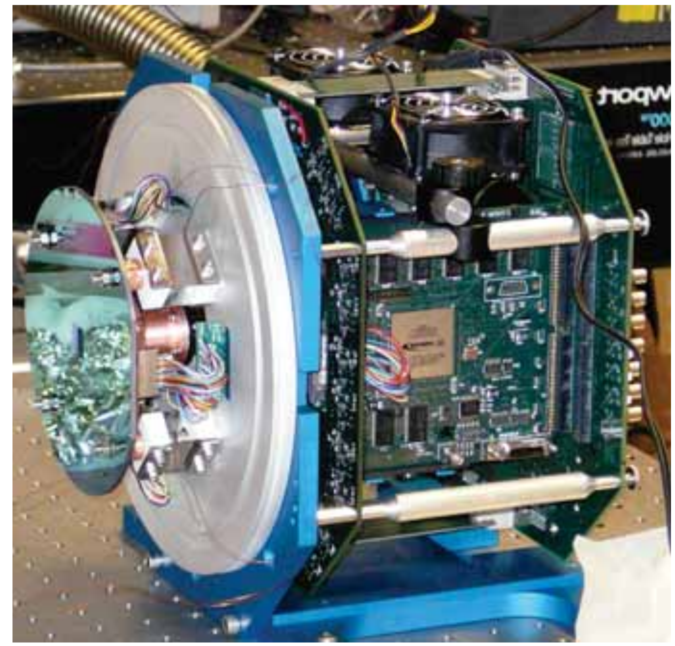
- **Ptychography**



Scanning Diffractive imaging

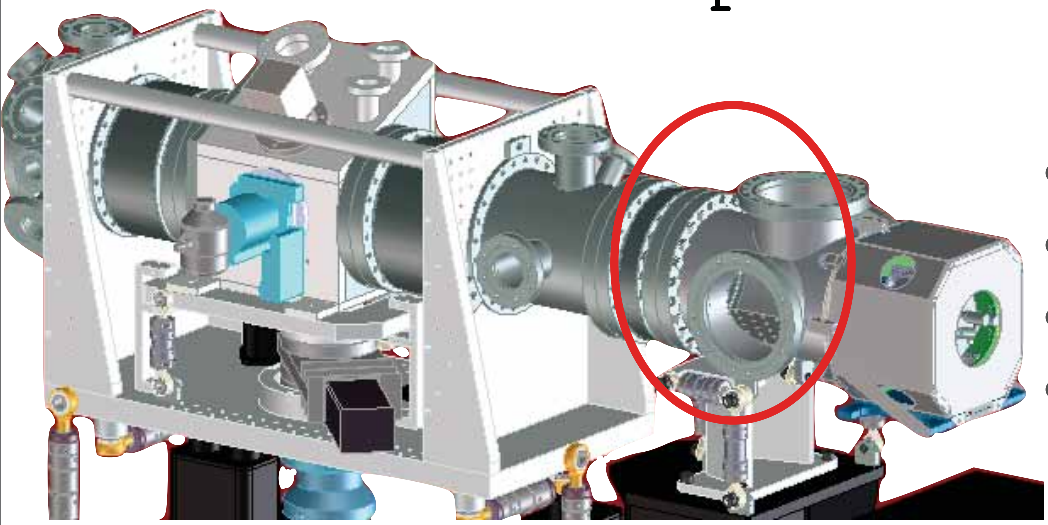


fCCD (Denes, Padmore...)

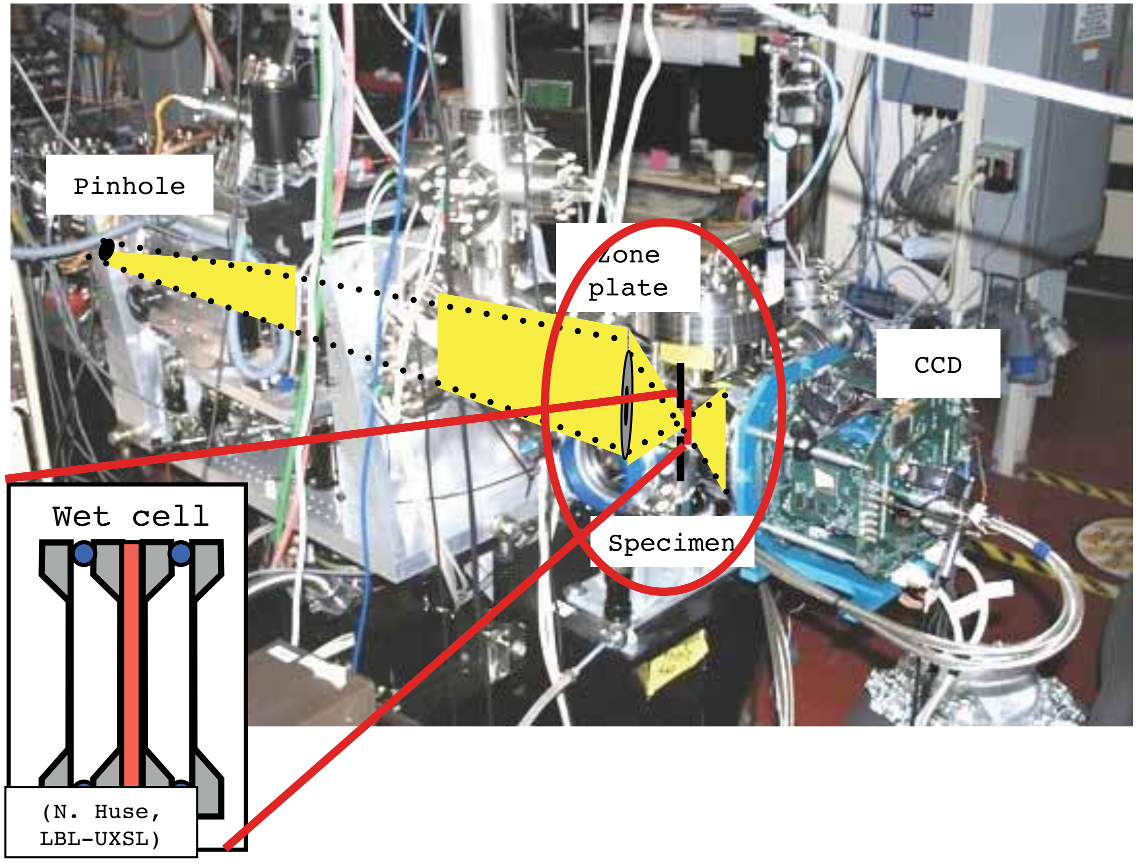


```
480x480 pixels
5 msec readout
```

FY10- Experimental demonstration

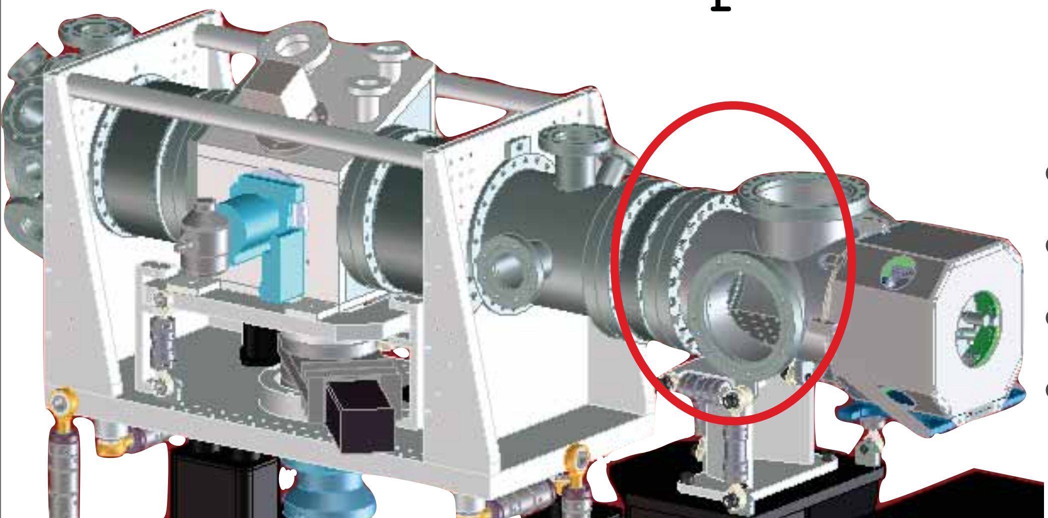


- Implemented ptychography at 750 eV
- wet cell
- 2 10^3 photons/(10 nm)^3/second
- 50 MB/second 4 TB/day



Scanning	Diffraction

FY10- Experimental demonstration



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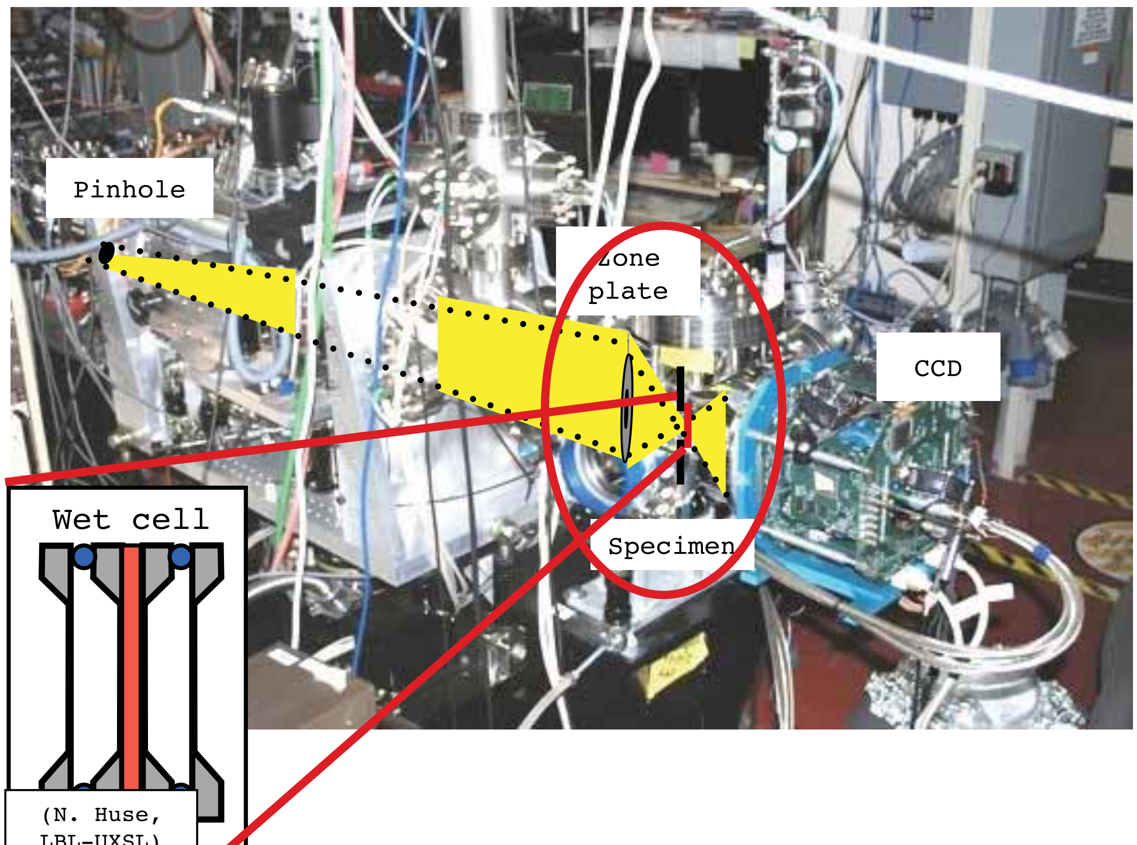
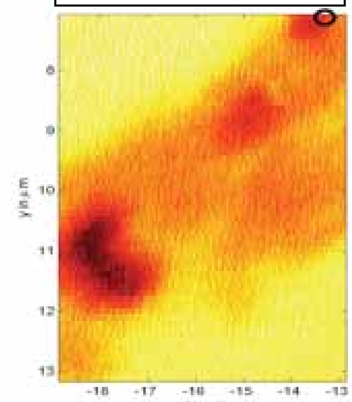
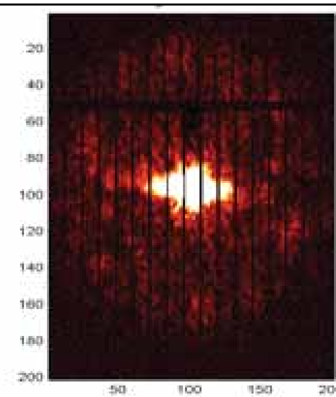


Scanning



Diffraction



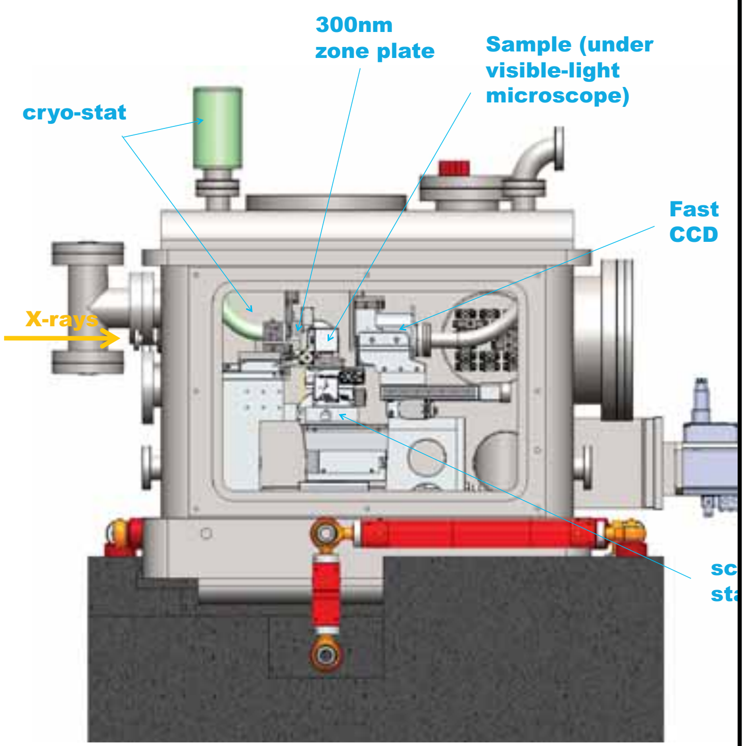
What we want to build:
Nanosurveyor : a unique tool for nanoscience

Microscope installed

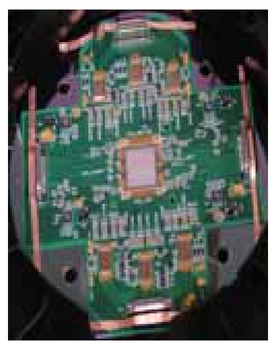
200 frame / sec CCD
- developed at LBNL

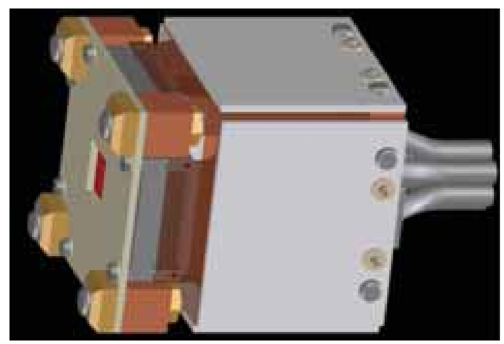
High performance computing
- use of NERSC infrastructure

int'l workshop
https://sites.google.com/a/lbl.gov/nanosurveyor-workshop-nov2010/
LBNL Nov 22-23 2010



10 Gbps





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F. Maia, C. Yang [arXiv:1105.5628]

CXIDB

Coherent X-ray Imaging Data Bank

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COSMIC -Coherent scattering & Microscopy meeting Aug 2-3 (LBL)