3D Ptychography with Differential Aperture Microscopy

Gene E. Ice
Oak Ridge National Laboratory

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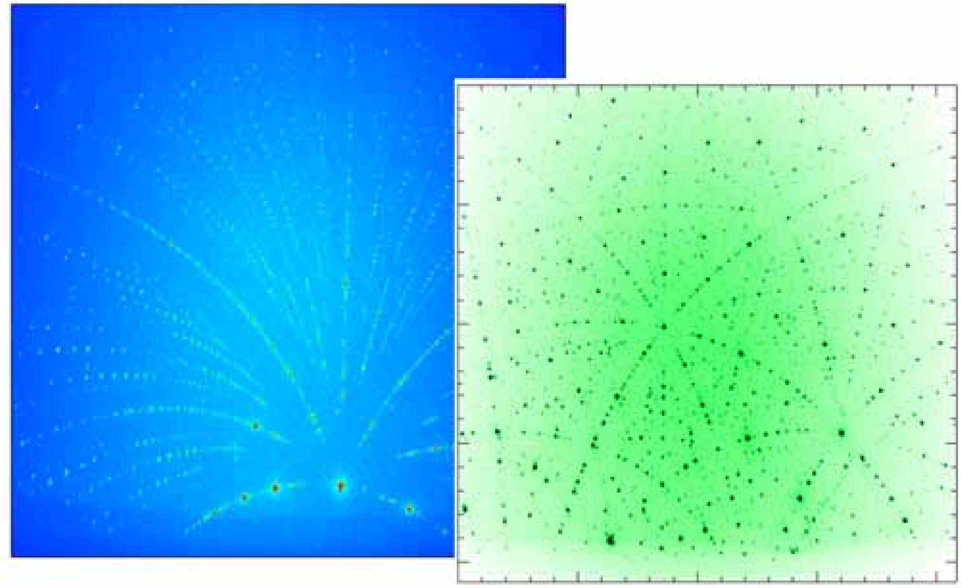
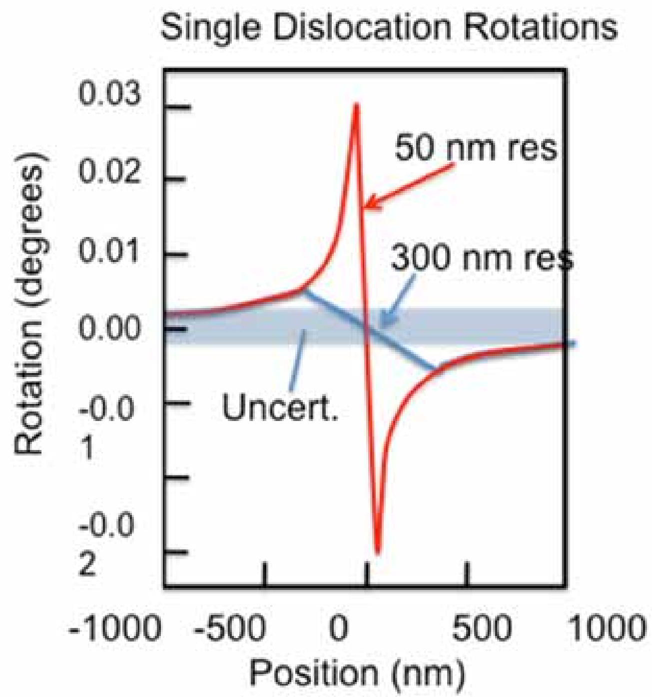
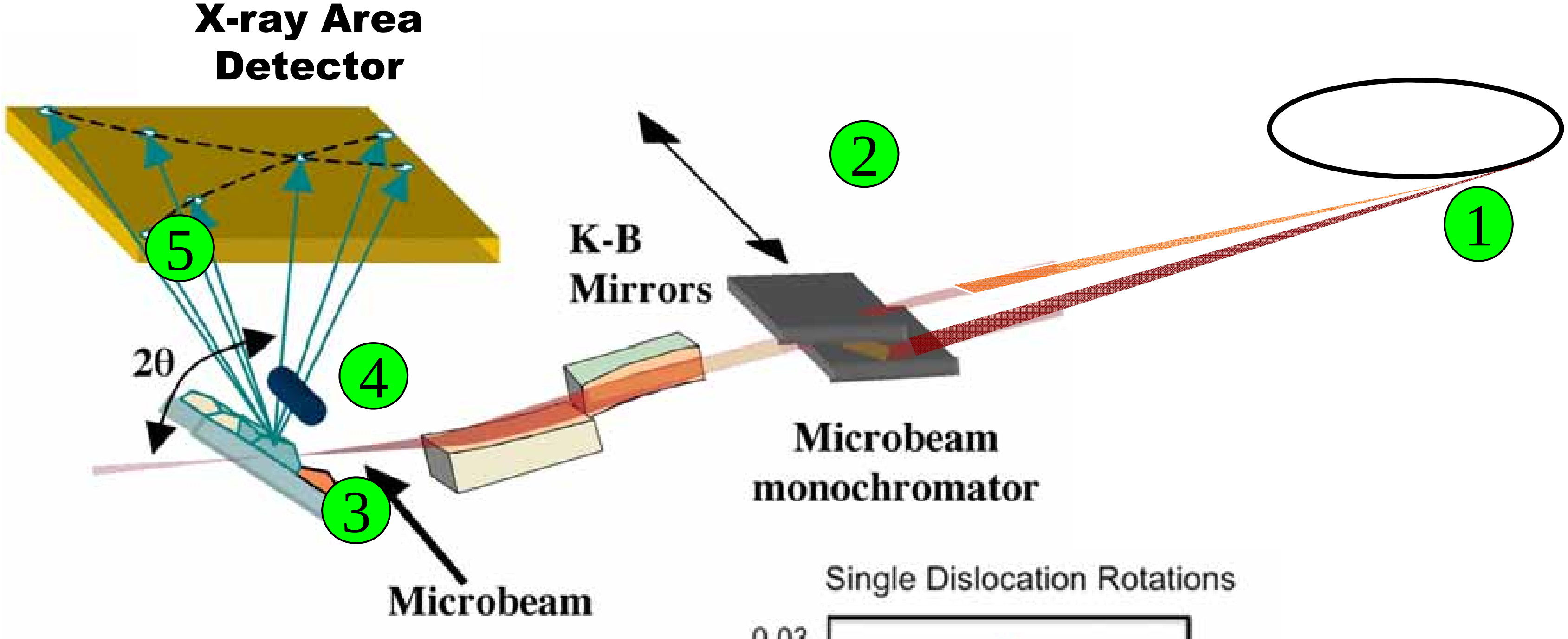
Vision builds on existing expertise

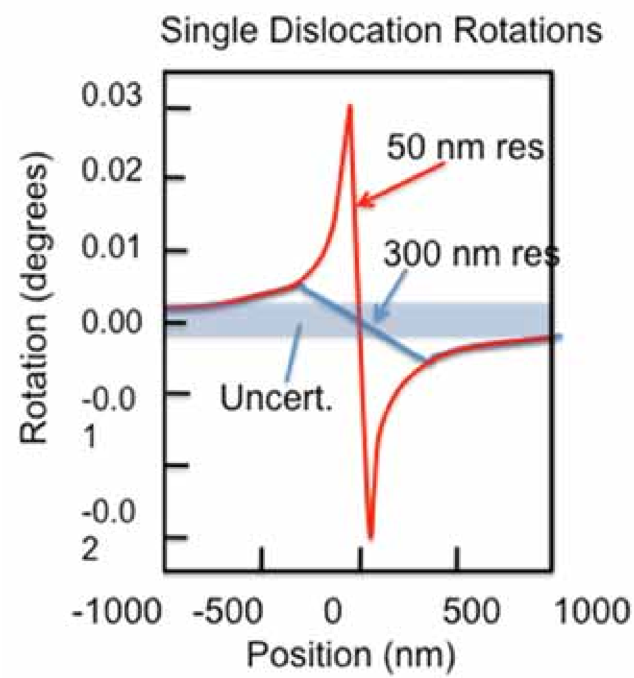
- **Achromatic X-ray infrastructure developed on 34-ID-E to study local structure and defects**
- **Elastic strain tensor**
- **Pushes envelope of what is possible**





Existing infrastructure near what is needed to observe and characterize discrete defects deep in sample

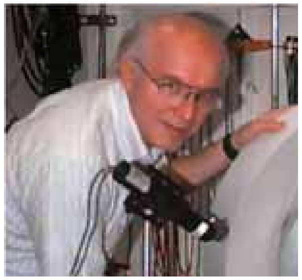




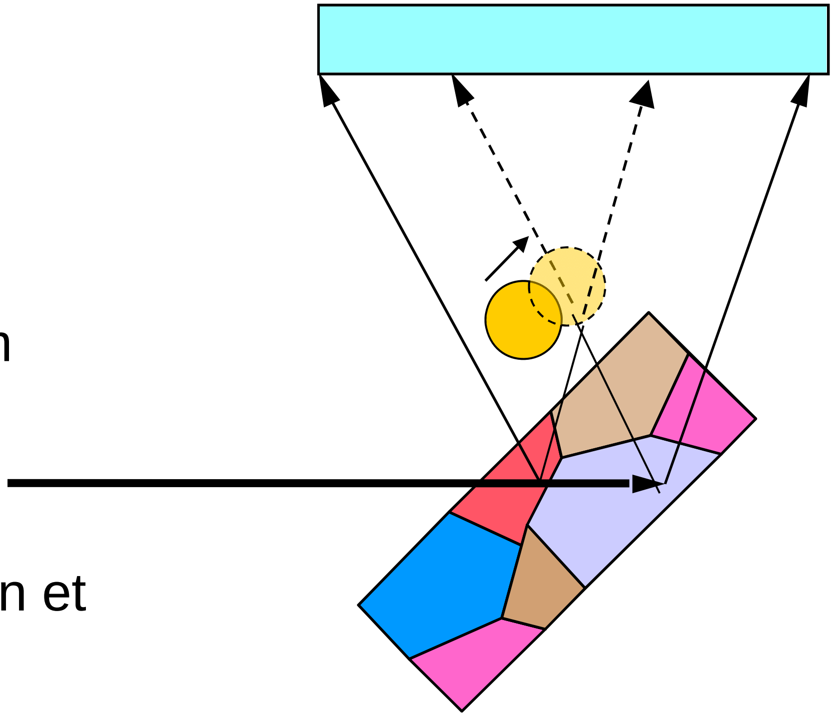
<0.25 x 0.25 x 0.5 μm^3
strain~$5x10^{-5}$ (~10 fm)

Improve spatial resolution
Improve sensitivity to rotations

Differential aperture microscopy resolves submicron along incident beam!



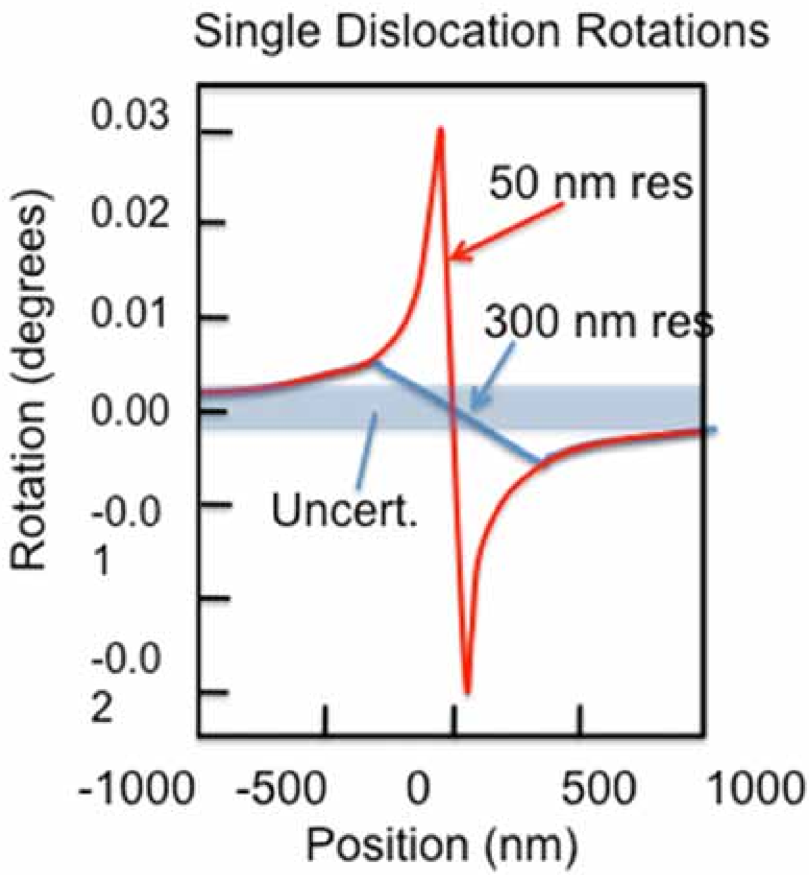
- Simplifies data interpretation
- Submicron Z resolution
- Isolates weak diffraction from strong
- First demonstration by Larson et al. on deformed Cu -



We are pushing in two directions

- **Improve spatial resolution of focused beam**

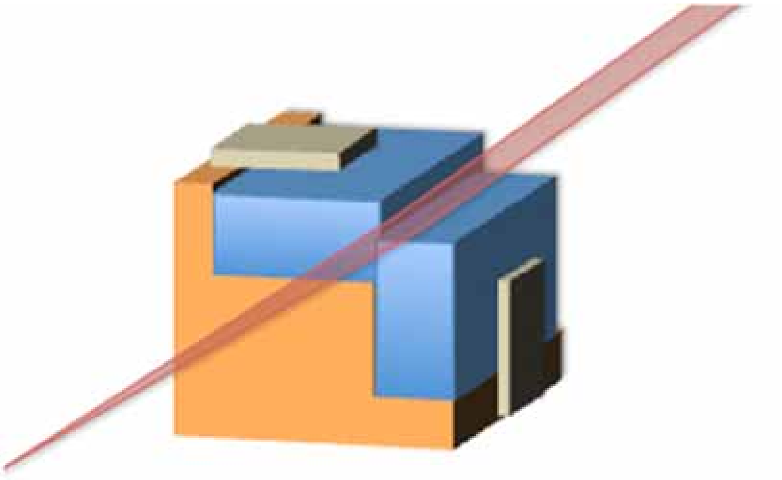
- **Explore achromatic coherent diffraction methods**

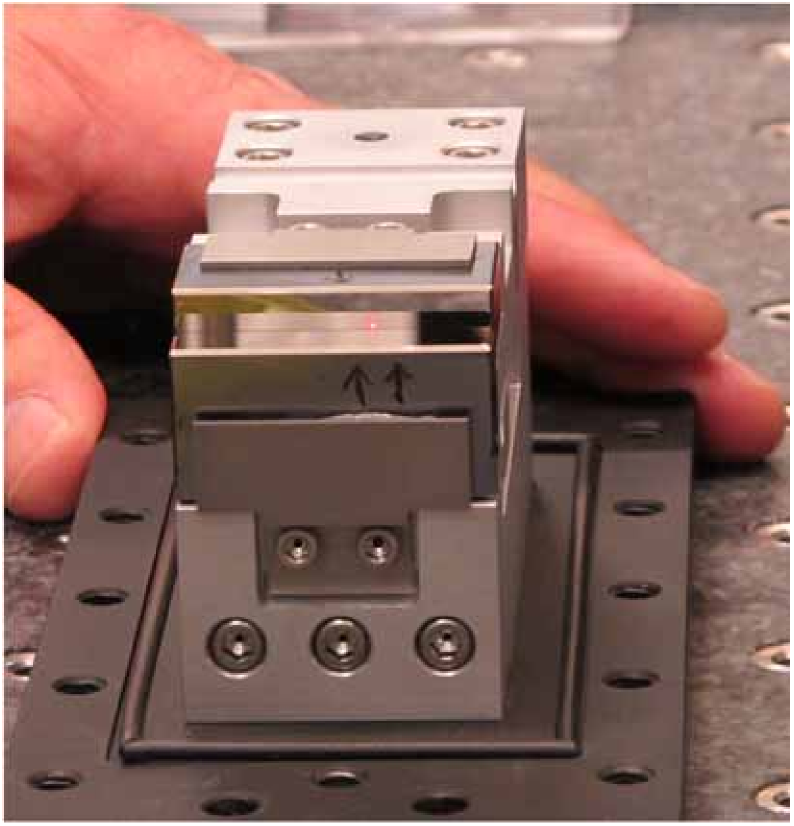


Nested (Montel) optics will push spatial resolution

- **More compact**
- **Improved thermal/vibration stability**
- **First tests**
  - **~150 nm beams**
  - **Increased intensity**
- **50-100 nm very practical**

- **More recent tests ~100 nm resolution**



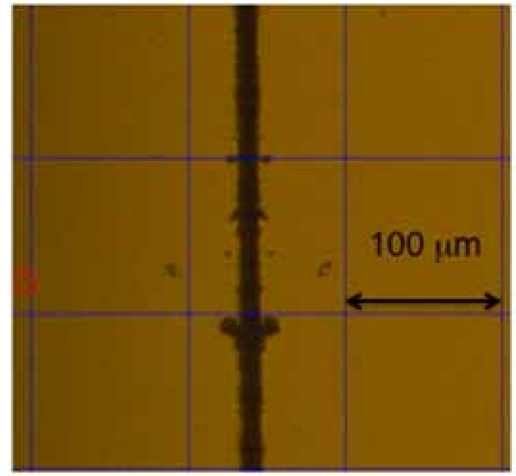


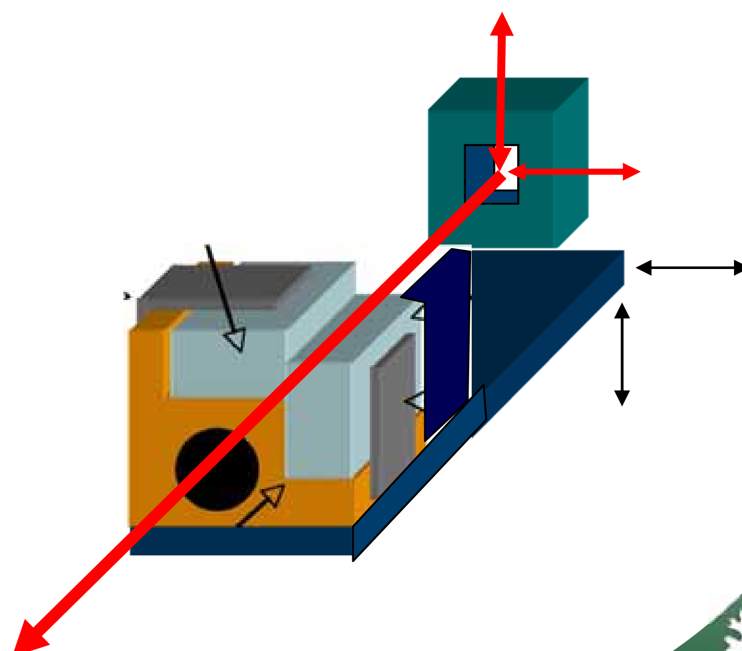
New approaches will address remaining technical challenges

- **Low figure errors at edge-small spot**

- **Figured edge shape-higher efficiency**

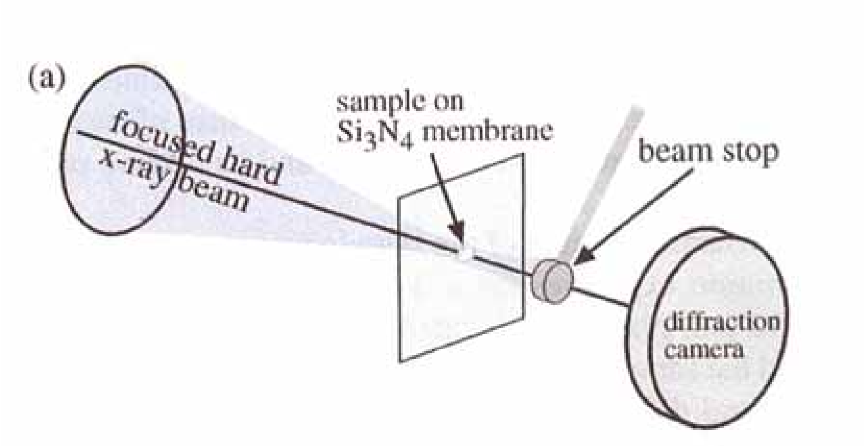
- **Novel alignment/angle control**





Focused-beam Coherent Imaging Offers Significant Advantages

- **Full field imaging**
- **Nm resolution**
- ***Focusing improves resolution at expense of field-of-view***



Schroer et al. Phys. Rev. Lett. **101** (2008)

10^8 photons/s x 600 seconds=6 x 10^{10} $\rightarrow$5 nm

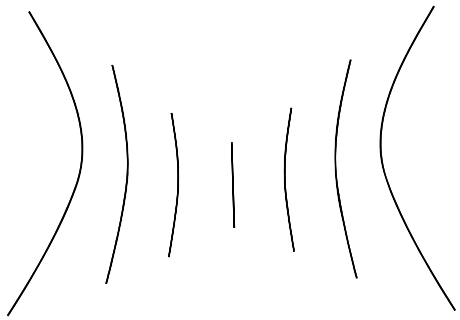
In 100x100 nm^2

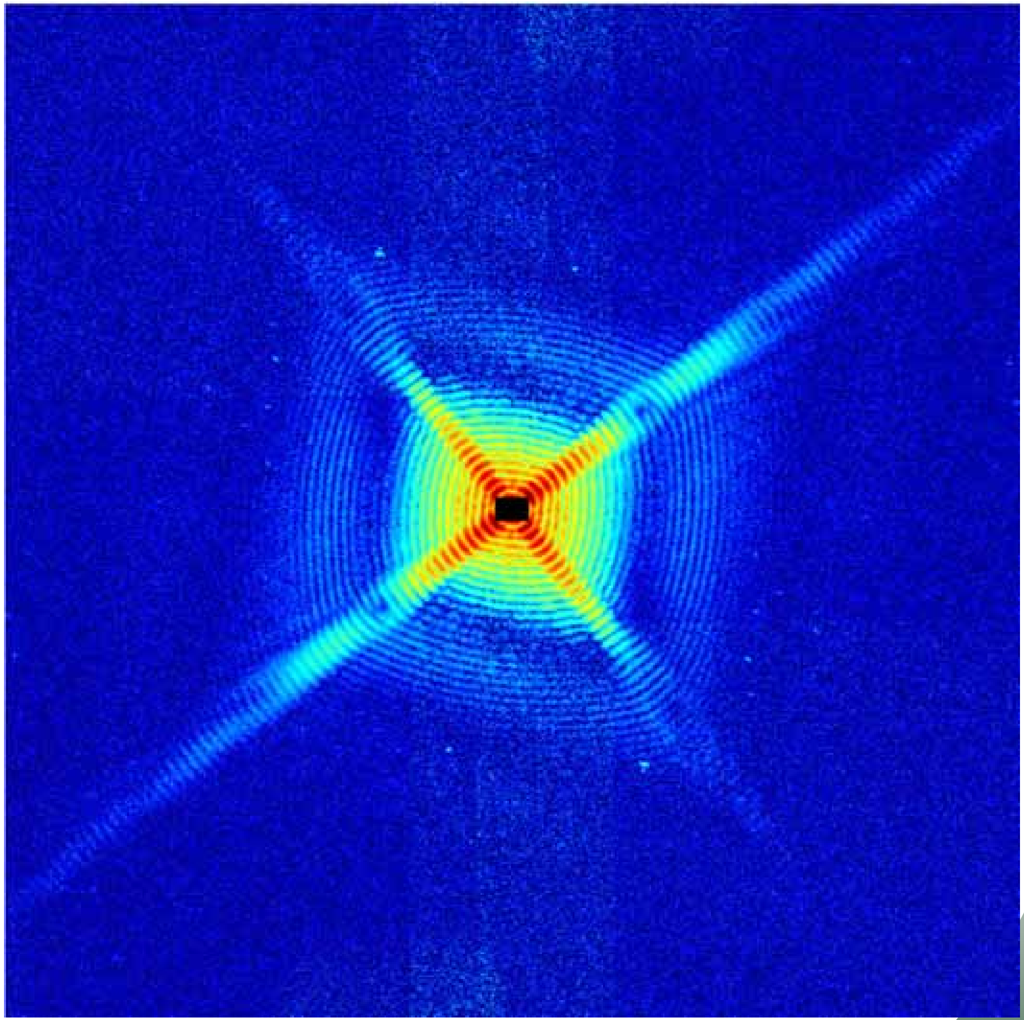
~ 2 x $10^{14}$$\rightarrow$0.2 nm

In 10x10 nm^2

Takahashi et al. reach 2 nm resolution with 1 µm beam

- **Diffraction-limited focusing (Osaka mirrors)**
- **Treat beam as plane wave at focus**





Takahsi et al. Phys. Rev. B 82 21412 (2010).

Challenges

- **Sample damage/ heating**
  - **Heating of a thin sample**

$$\Delta T = \frac{P_o}{2\pi\mu K}\left(\frac{1}{2} + \ln\left(\frac{r_1}{r_2}\right)\right)$$

  - **$\Delta T_{Aluminum}$=10 ° C @ 4 x 10^{14} 20 keV x-rays/sec**

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Radiation-induced melting in coherent X-ray diffractive imaging at the nanoscale

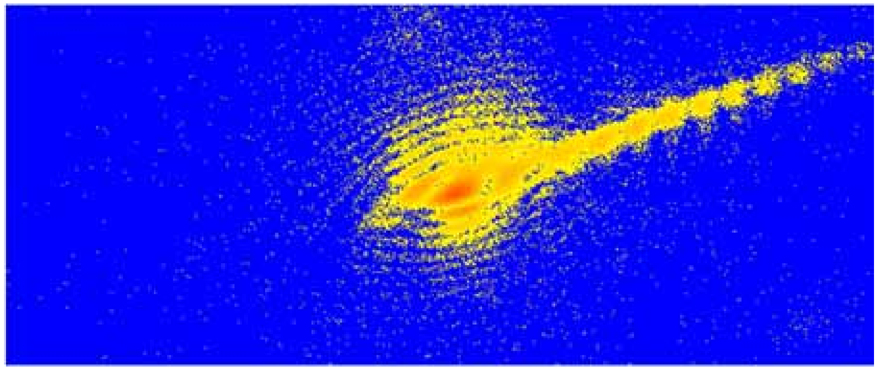
O. Ponomarenko *et al.*

Synopsis

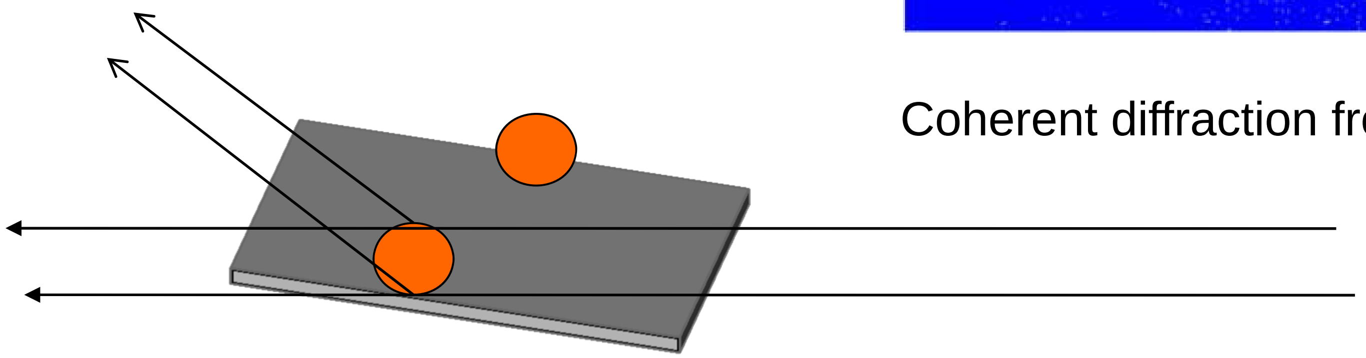
- **Reconstruction of topologic defects (dislocations)**
- **Signal-to-noise**
- **Extended objects-ptychography**
- **Extended 3D objects**

Coherent diffraction in Bragg mode offers strain sensitivity-but additional Challenge

- **Must collect multiple reflections to measure strain tensor-rotate sample**



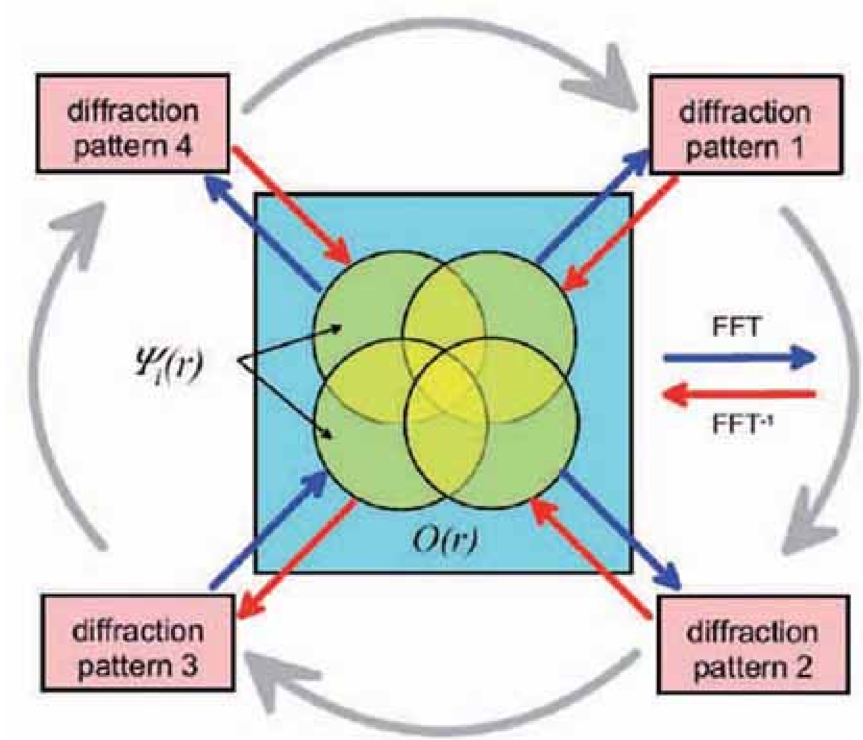
Coherent diffraction from a Au nano particle



Robinson et al. approach
Most studies to date on small isolated particles

Can Achromatic Methods Extend Lensless Diffraction Imaging?

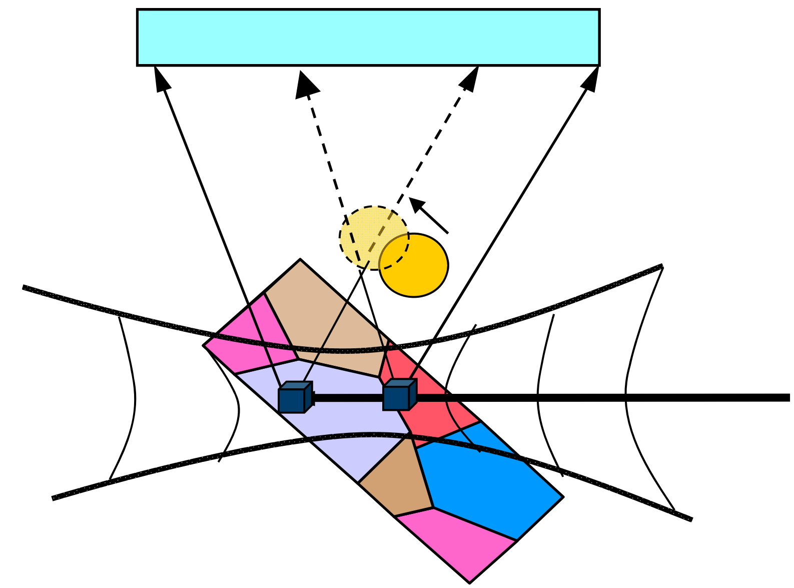
- **Diffraction imaging provides strain tensor 4 Bragg reflections**
  - **Multiple Bragg reflections accessed *by Energy Scans***
  - ***NO SAMPLE ROTATIONS***



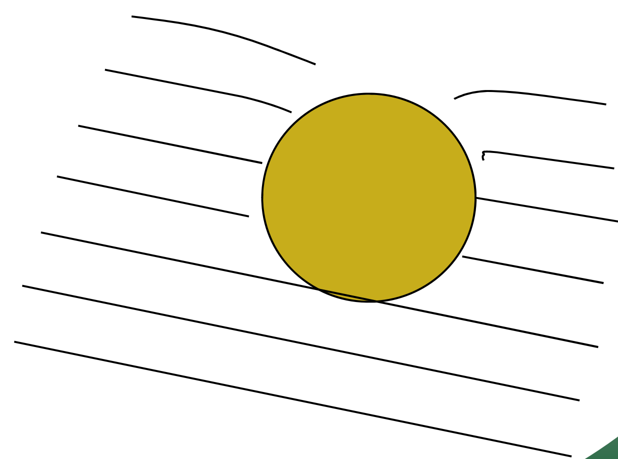
- **Ptychography subdivides sample complexity in two dimensions.**

- **What about 3rd?**

Real revolution will be to extend ptchography to 3 dimensions

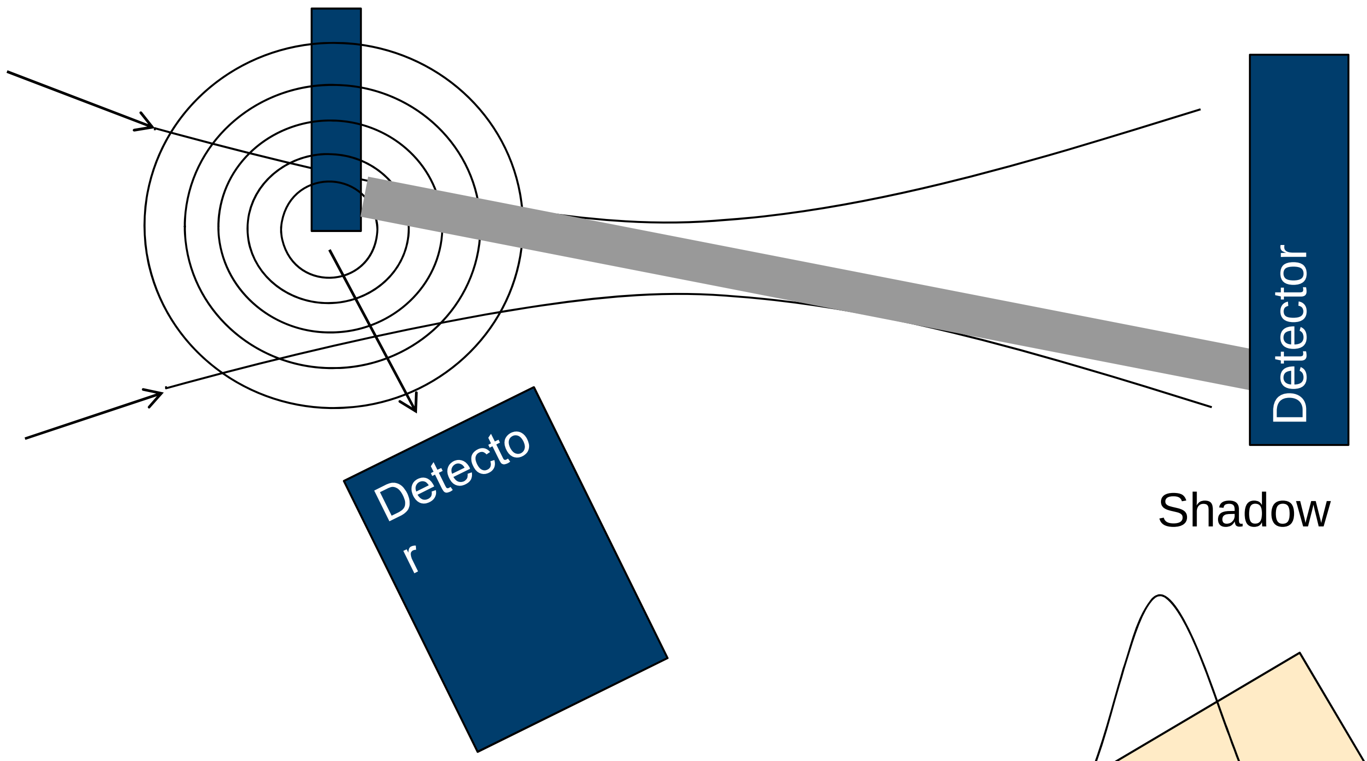


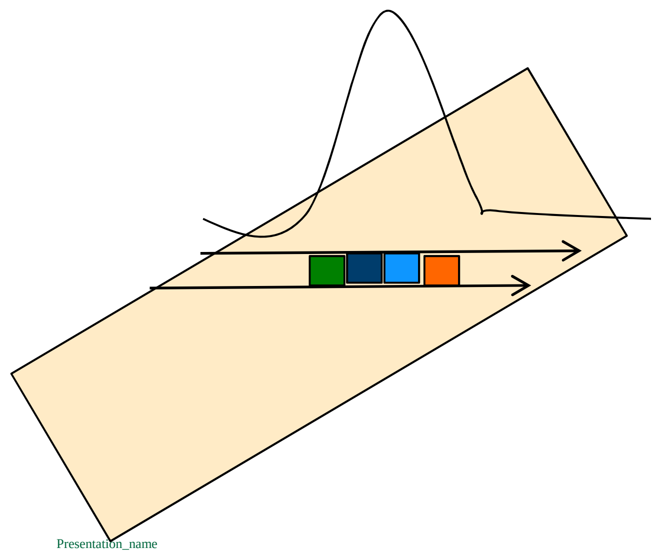
- Differential aperture provides additional spatial information
  - Resolves discrete particles with non-overlapping diffraction
  - Can it be used to determine regions contributing coherently, partially coherently and incoherently



- Aperture will itself diffract intensity

Osaka group uses diffraction from knife edge to achieve nm spatial resolution

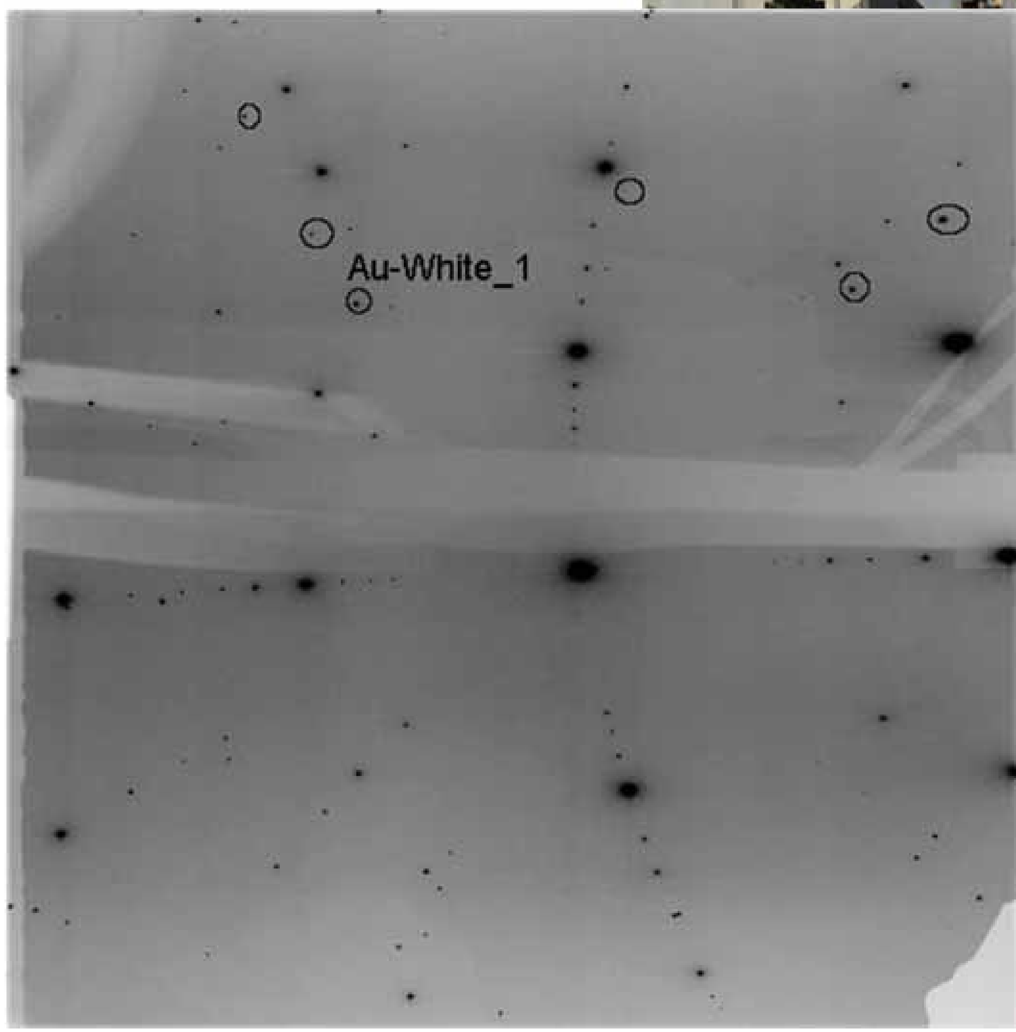




First experiments begun

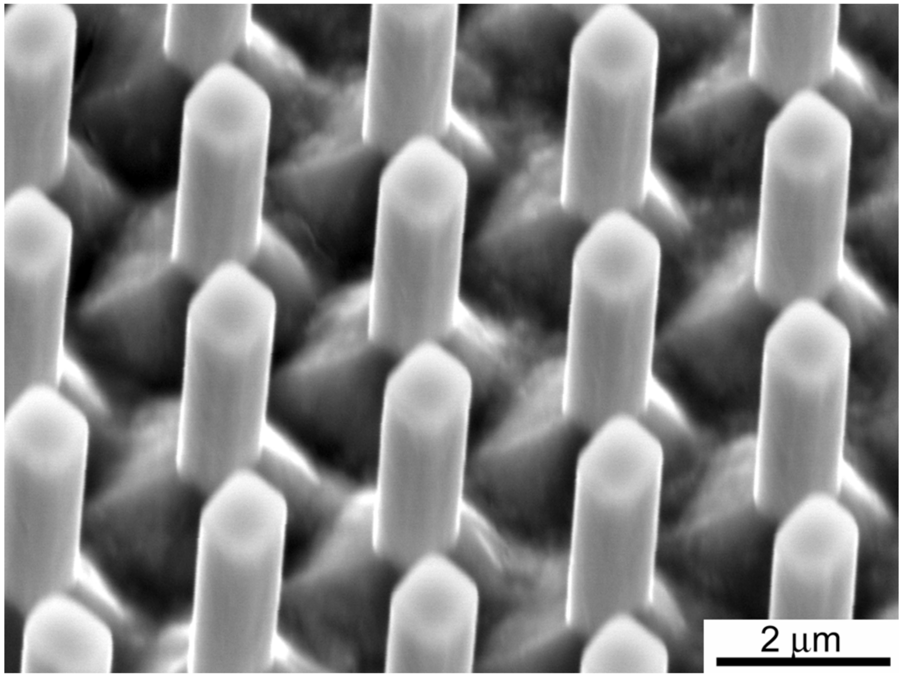
- **Nanoscale particles indexed with white beam**

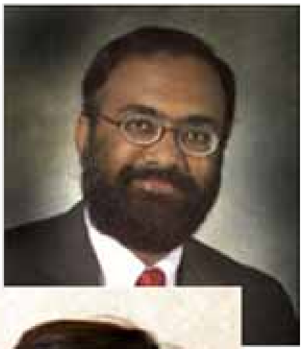
- **<u>However</u> simple surface samples <u>*do not*</u> work well with white beam <u>*or*</u> high intensity monochromatic beams**



Eutectic pillar samples (Bei/George) provide stable sample

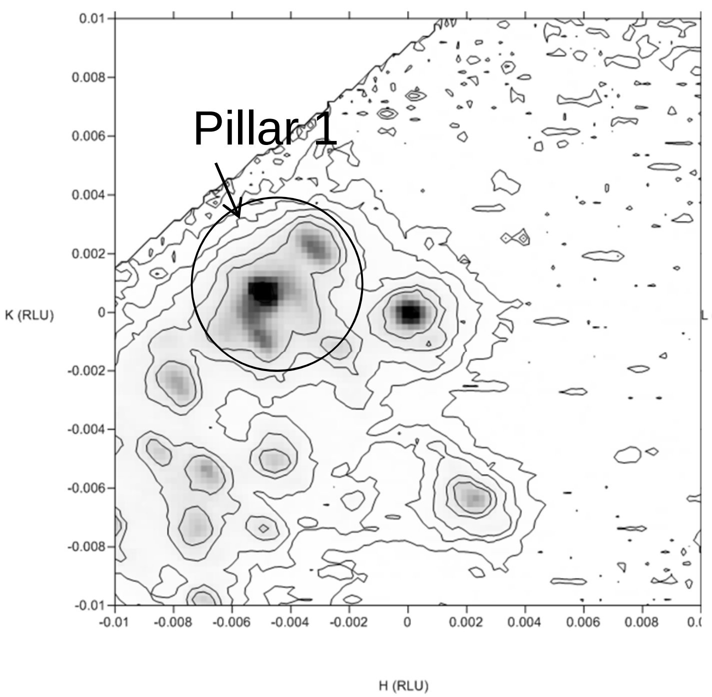
- **Locked into matrix**
- **Complicated with multiple pillars illuminated simultaneously**

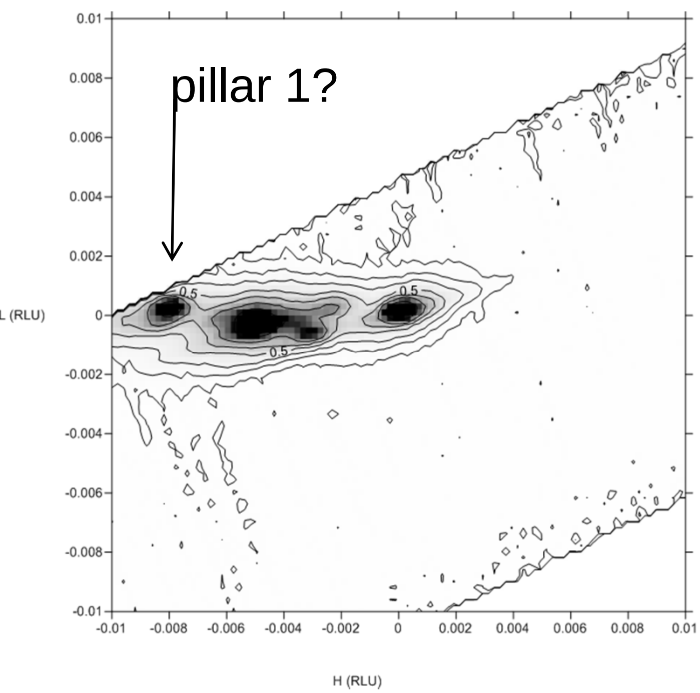




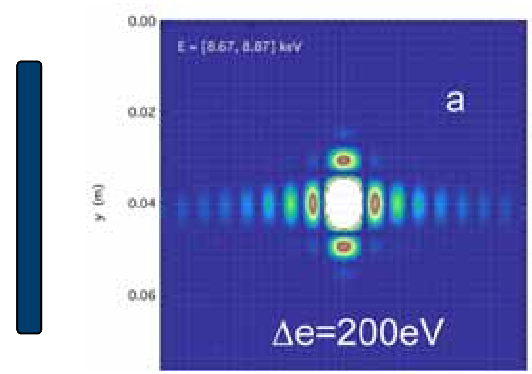
***Really need 3D ptychography*!**

High Q-space resolution helps separate Mo/NiAl pillar scattering



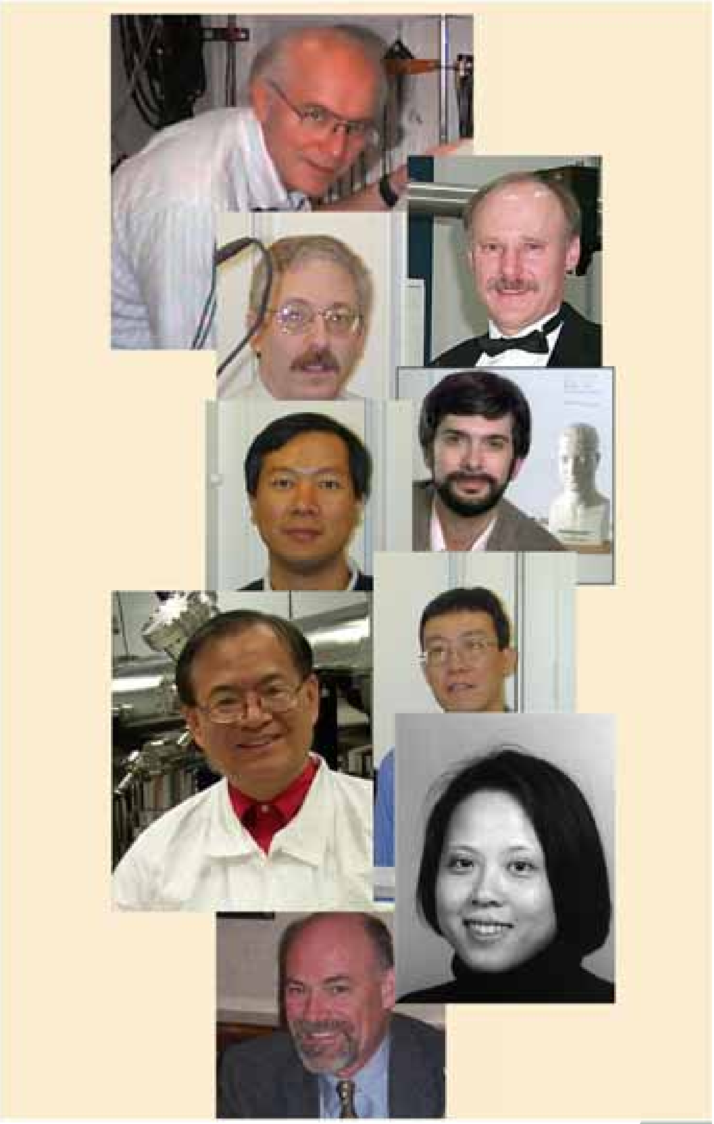


Real space



Summary

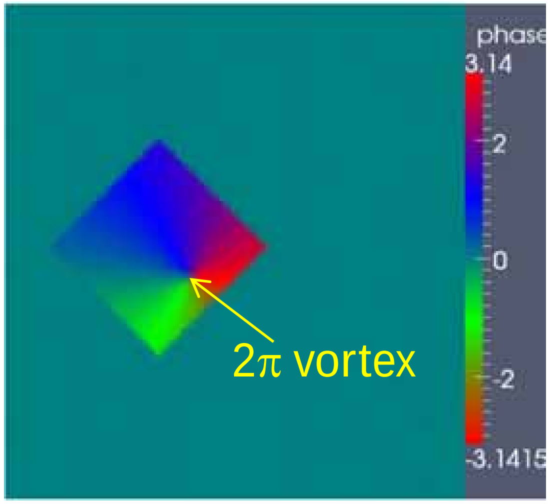
- X-ray imaging needed for things that can't be done with electrons.
  - Buried samples
  - 3D samples
  - Samples in environmental chambers
- New approaches needed to study real materials.
  - 3D ptychrography
  - Energy scanning methods for reciprocal space mapping
- Existing achromatic hardware provides model for future



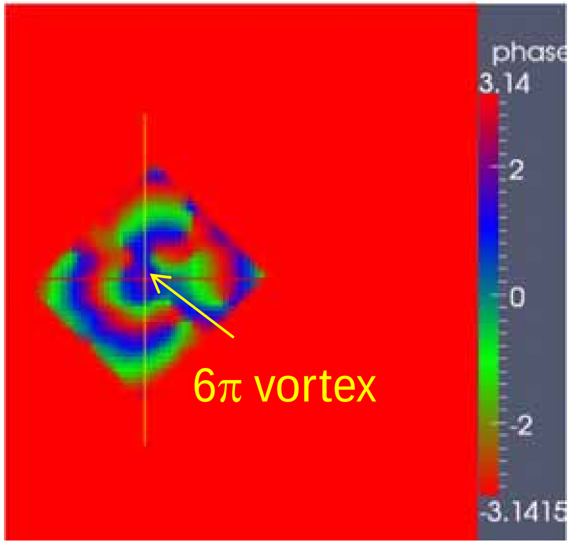
Reconstruction of dislocation still an unsolved challenge

- Temporary solution compare to models

- Work on alternatives-ptychography near dislocation to characterize strain field



Sample



Reconstruction