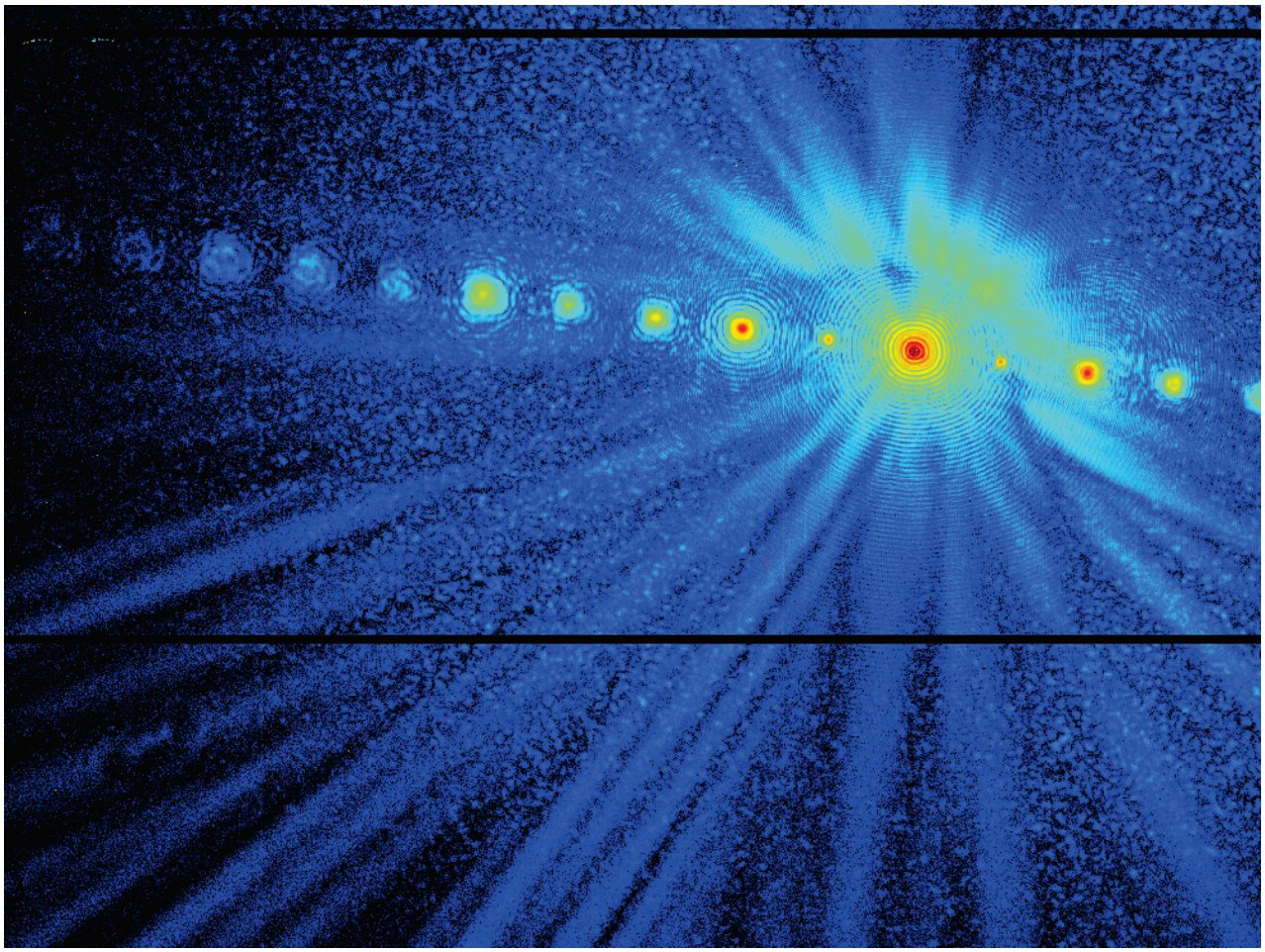
Ptychography at the Cornell ERL



Pierre Thibault

Technische Universität München

XDL workshop – June 6-7 2011

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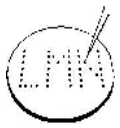

C. David, J. Vila
Micro- & Nano-
Technology, PSI

R. Wepf et al., Electron
Microscopy, ETH Zurich

P. Kraft, B. Schmidt
SLS Detector Group

K. Jefimovs,
EMPA, Switzerland

P. Schneider, R. Müller
Biomechanics, ETH Zurich

I. Schlichting et al.,
MPImF Heidelberg

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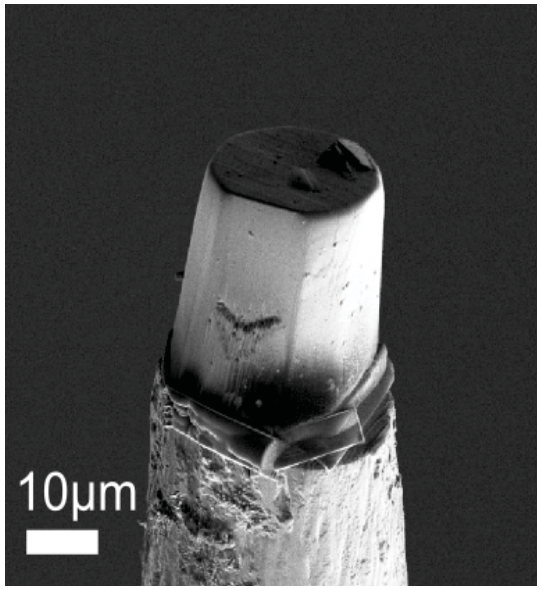
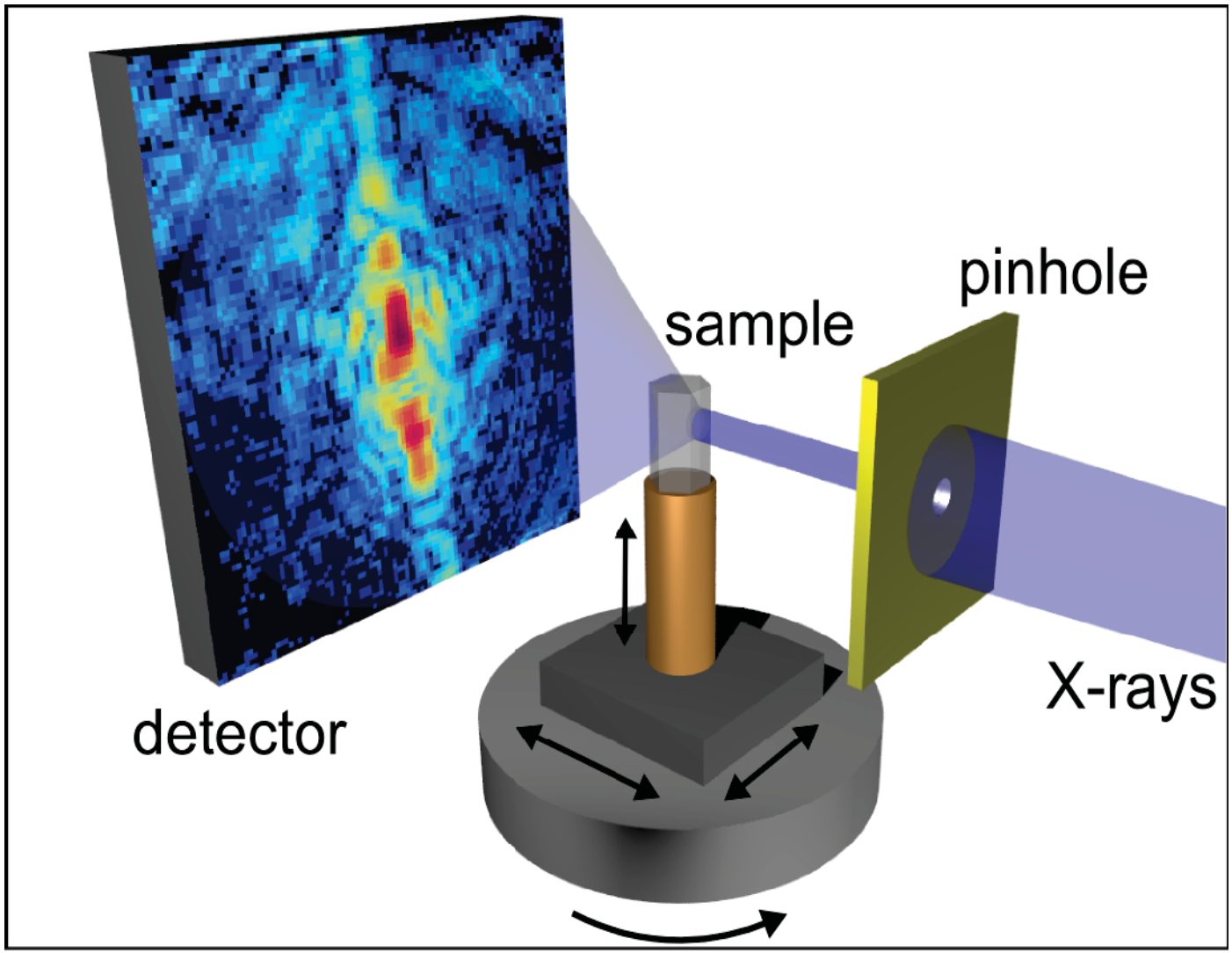
DFG-Cluster of Excellence Munich Centre for Advanced Photonics

Ptychography in 3D

Bone science application

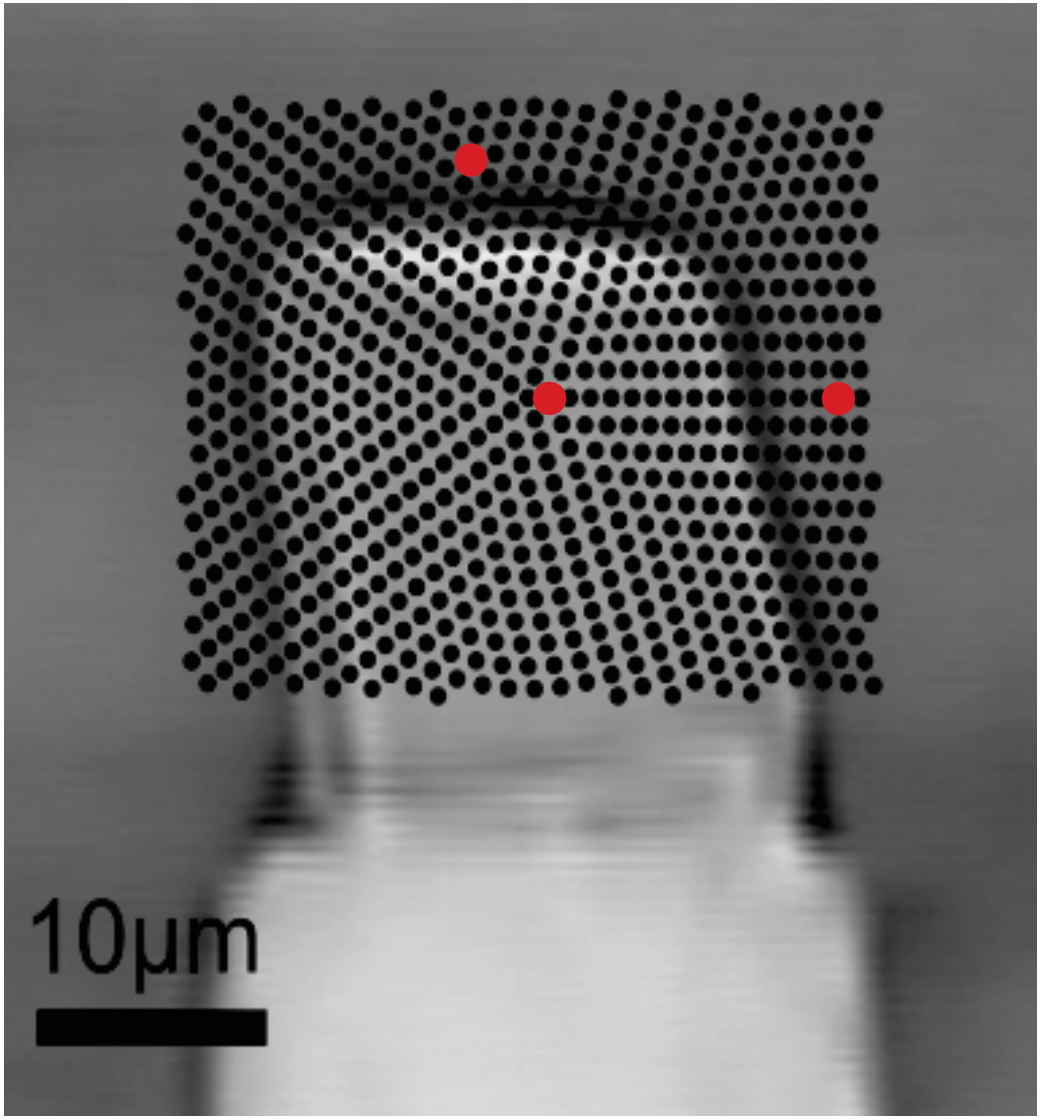


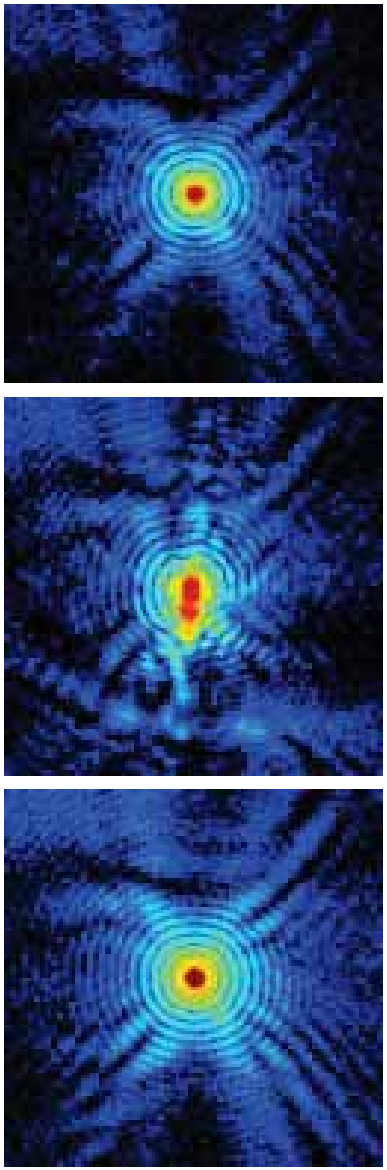
murine femur
(prepared with
focused ion beam)



M. Dierolf, A. Menzel, P.T. *et al.,* Nature **467**, p. 436 (2010).

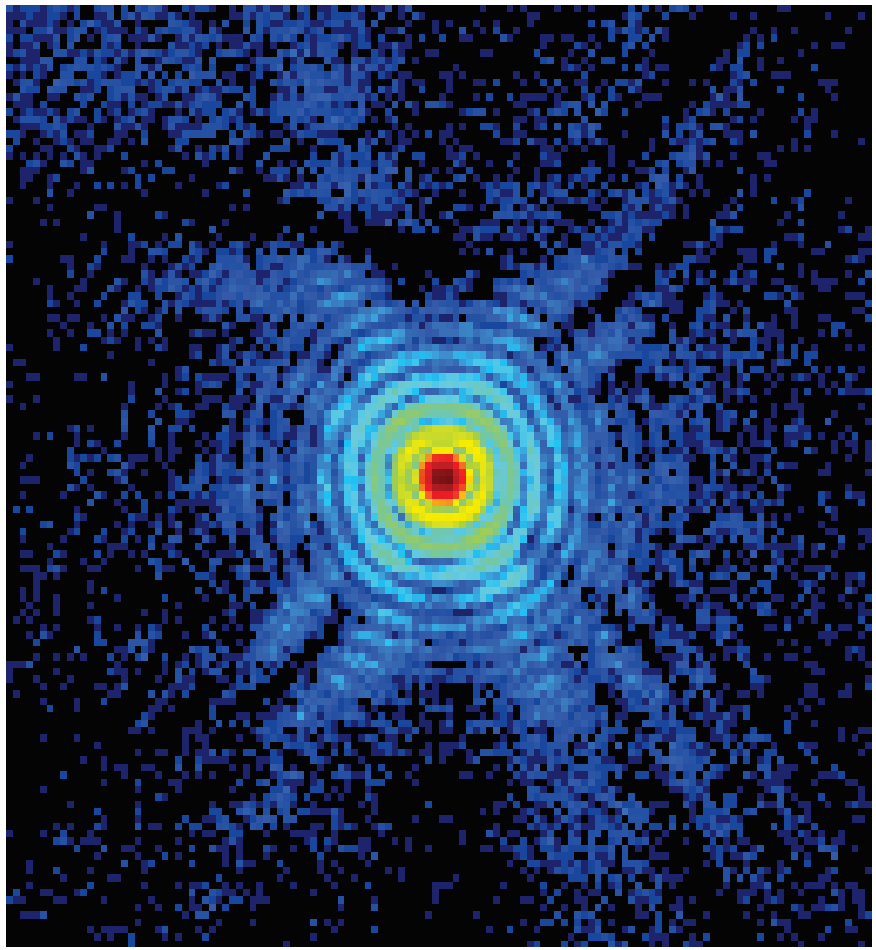
Collection of diffraction data





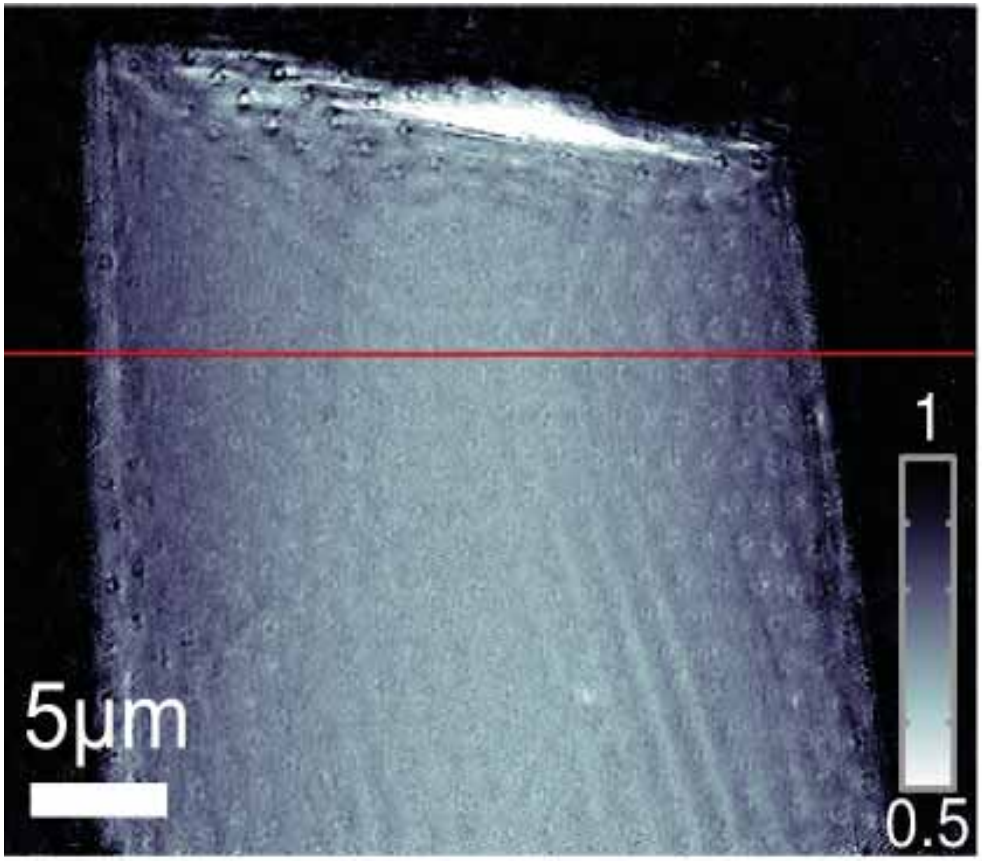
A few of the 127424 collected diffraction patterns.

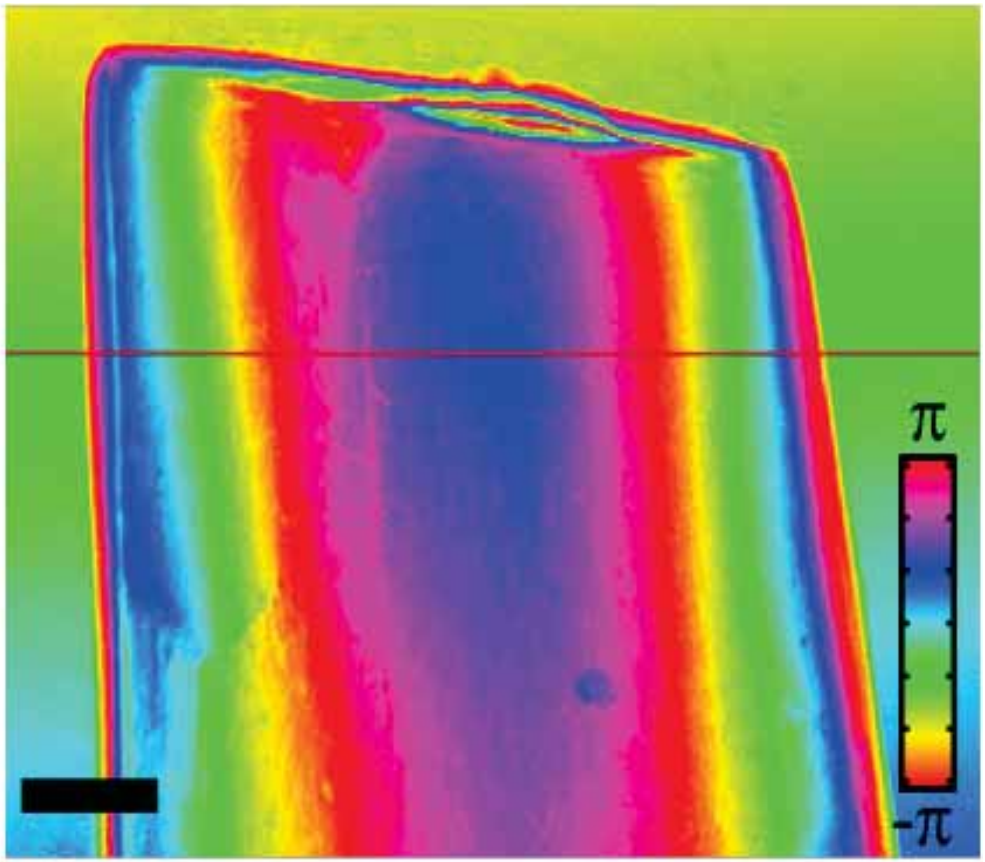
Collection of diffraction data

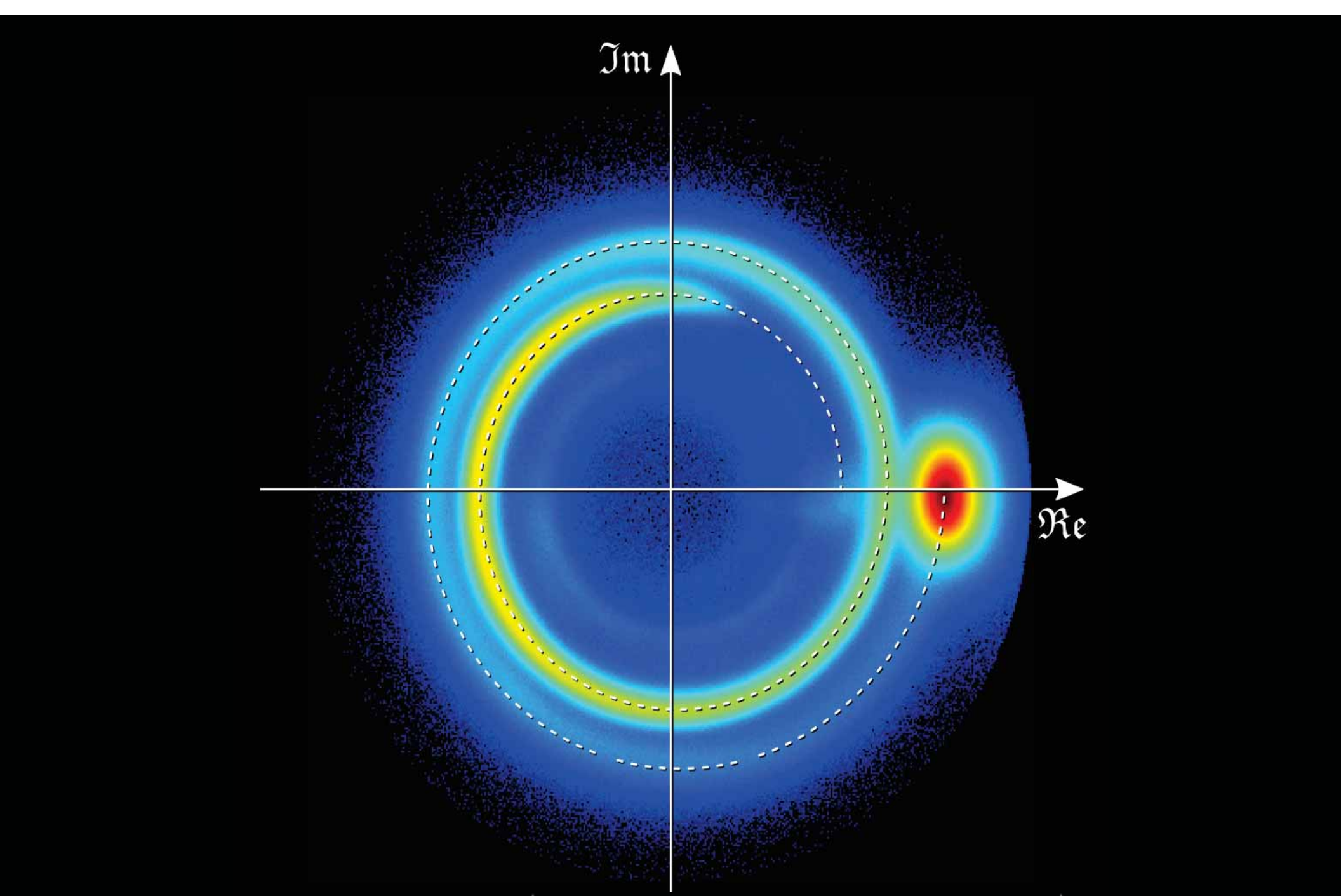


A few of the 127424 collected diffraction patterns.

Reconstructed projection

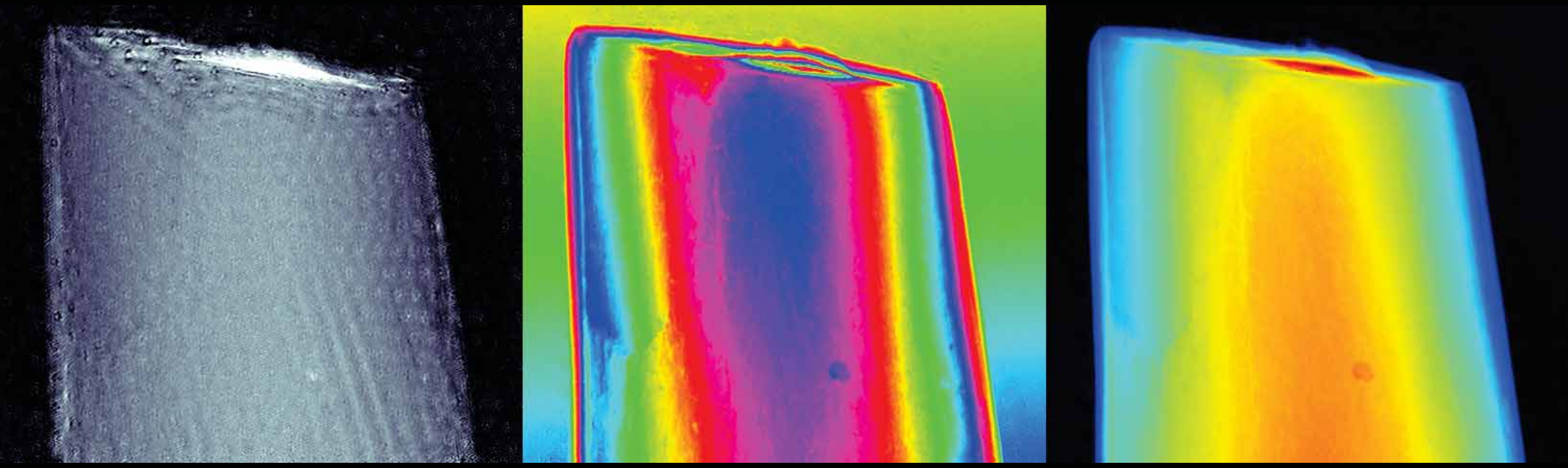






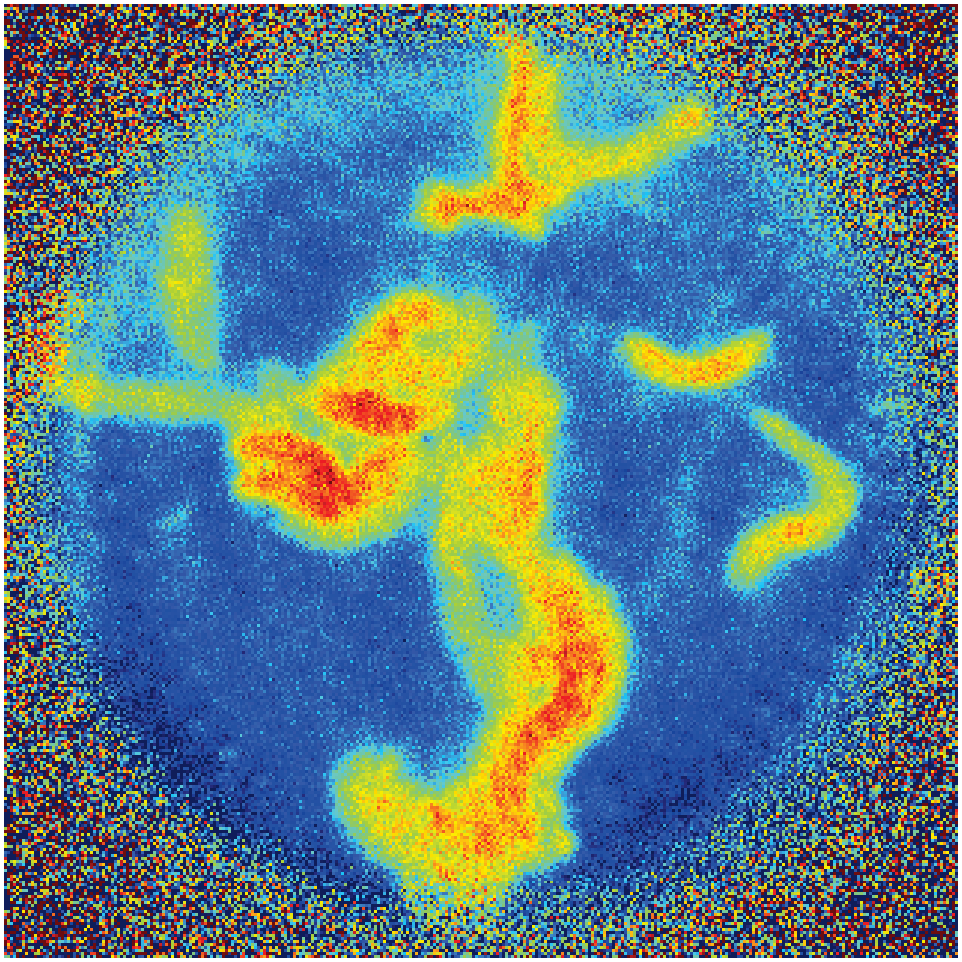
$$T(x,y)=\exp\left(\frac{2\pi i}{\lambda}\int \delta(x,y)+i\beta(x,y)\,dz\right)$$

amplitude **phase** **unwrapped phase**

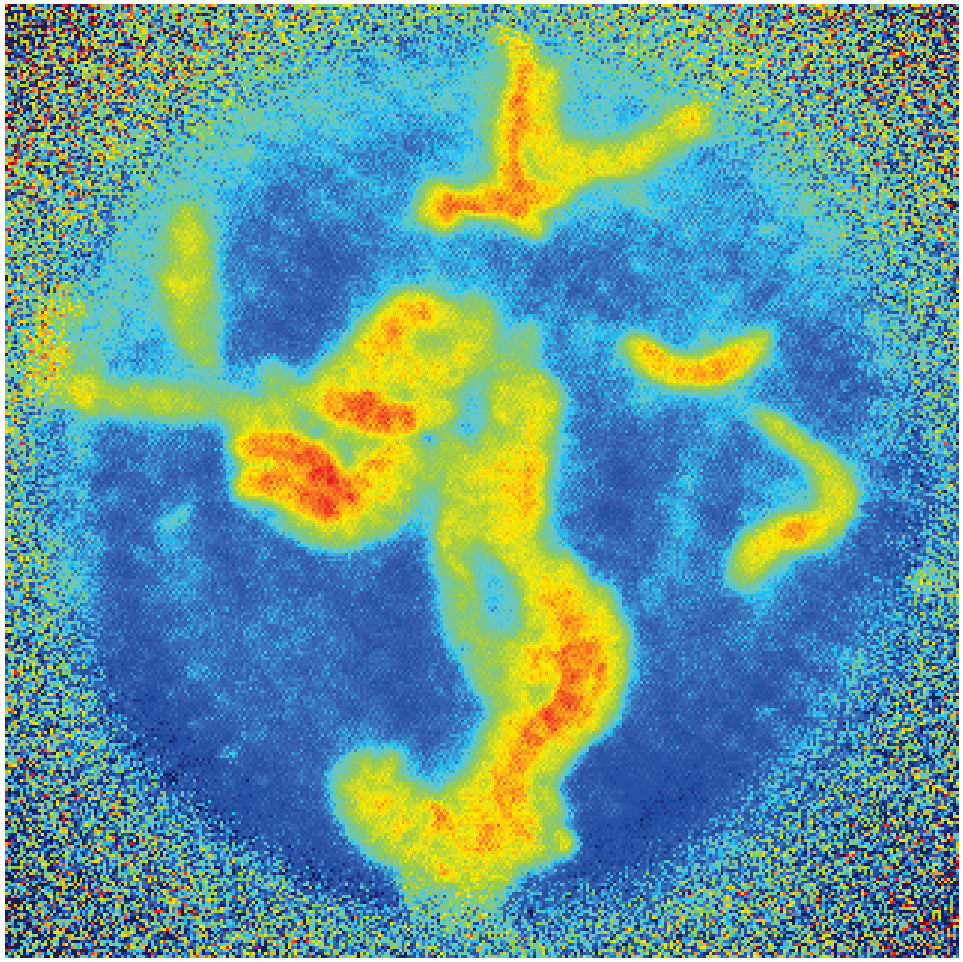


Projections covering 0 to 180 degree in 1 degree steps.
Realigned with respect to each other.

Ptychography & maximum likelihood



difference map solution



max-likelihood solution

A bit of epistemology...

A bit of epistemology...

What do I know and how do I know it?

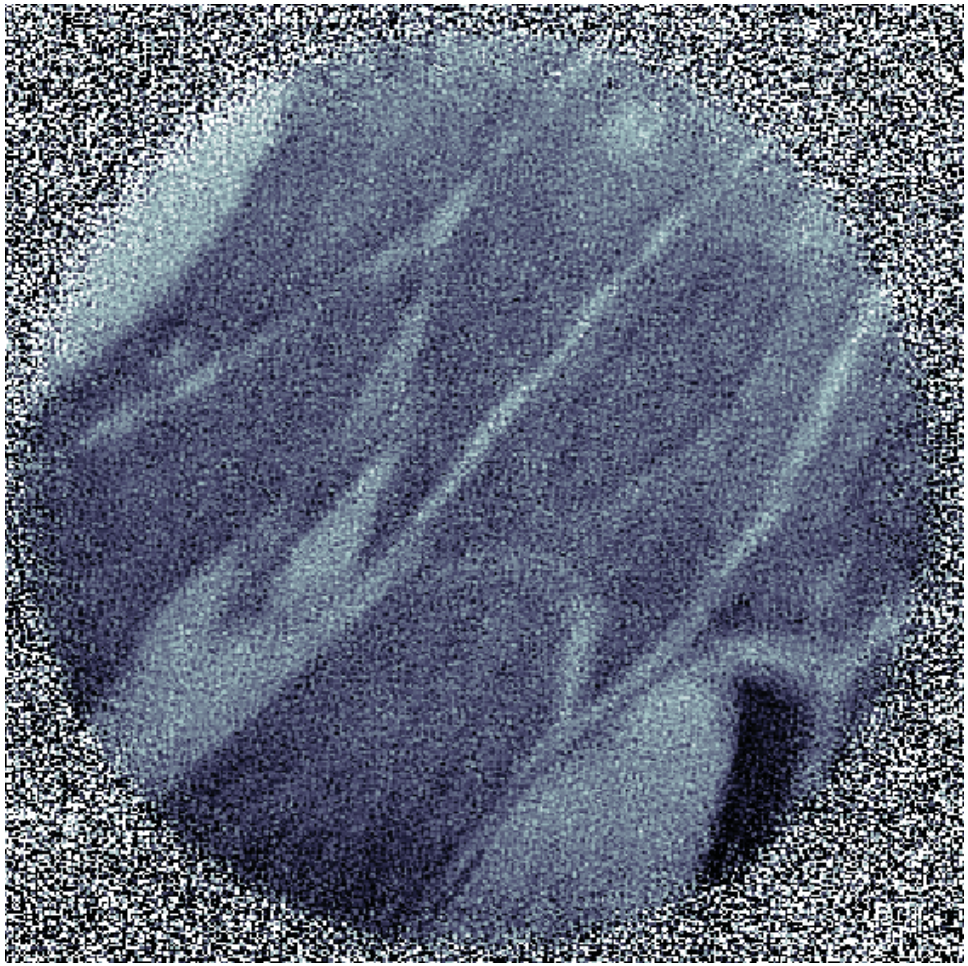
What do I know I don't know?

What I know can be known

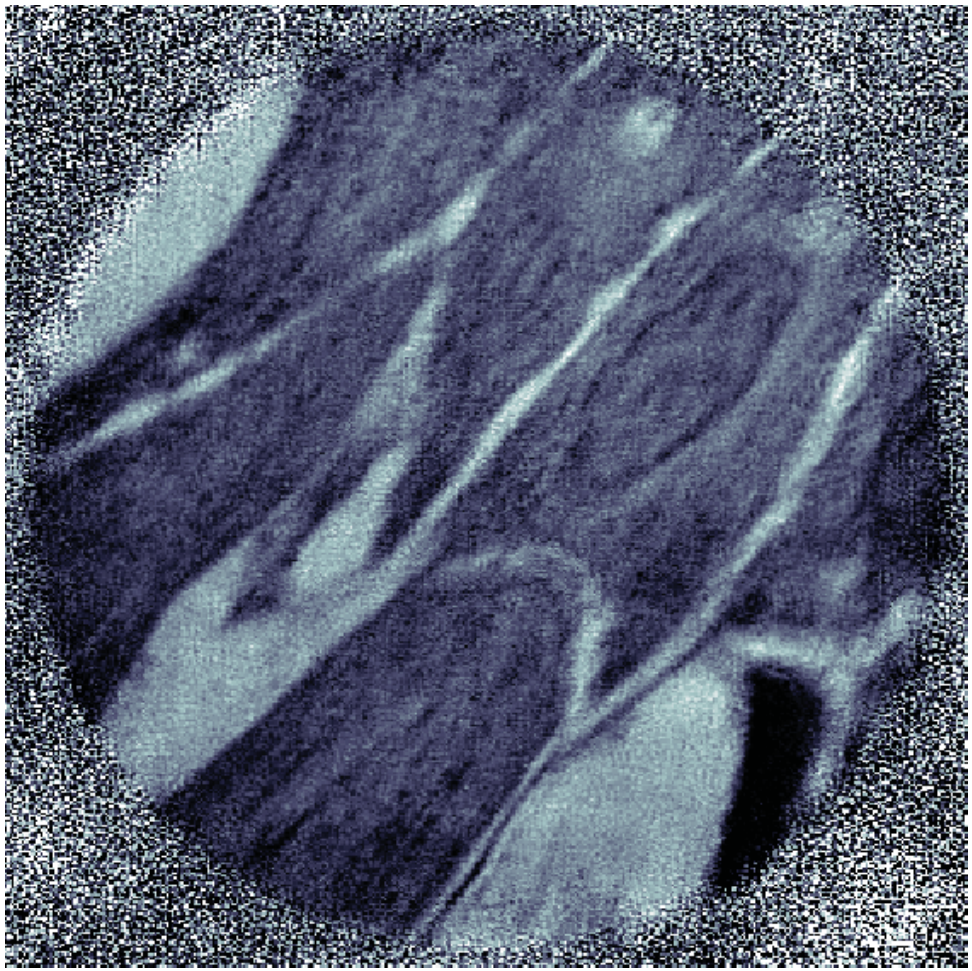
- Lensless imaging!
- Probe reconstruction in ptychography
- Low coherence : Fourier holography (polyCDI!)
- Poor stability: multiple short exposure

Ptychography on weak objects

Spreading the signal to correct for mechanical drift



10 scans
(2250 diffraction patterns)



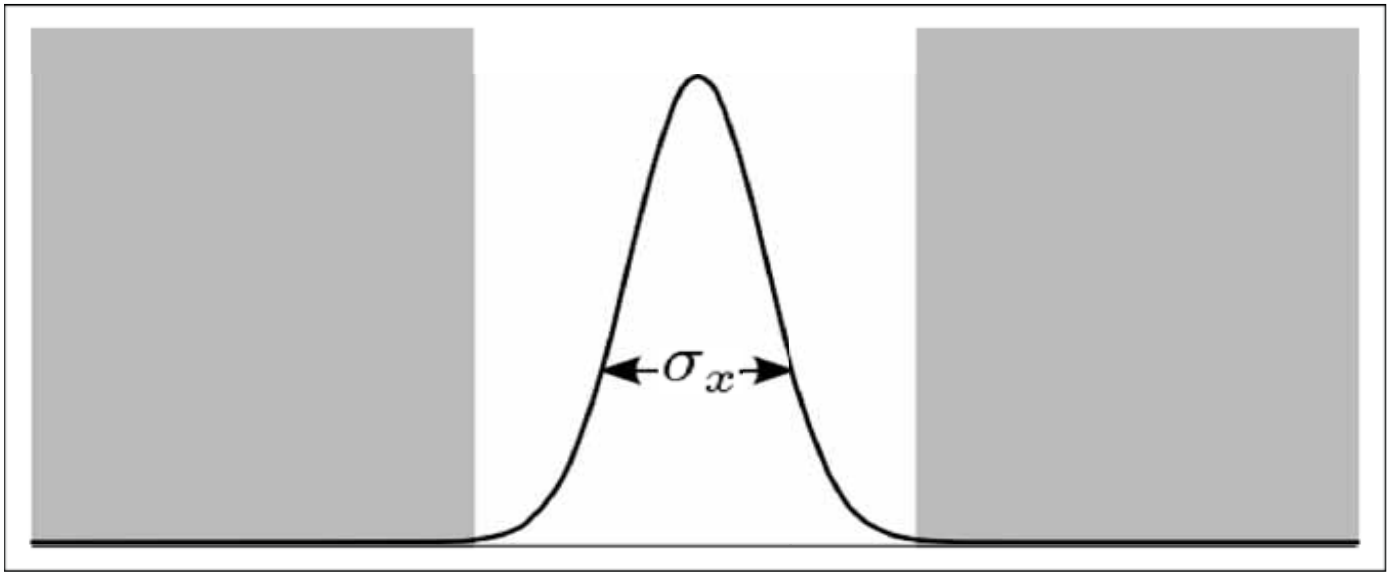
170 scans
(38350 diffraction patterns)

What I know I don't know

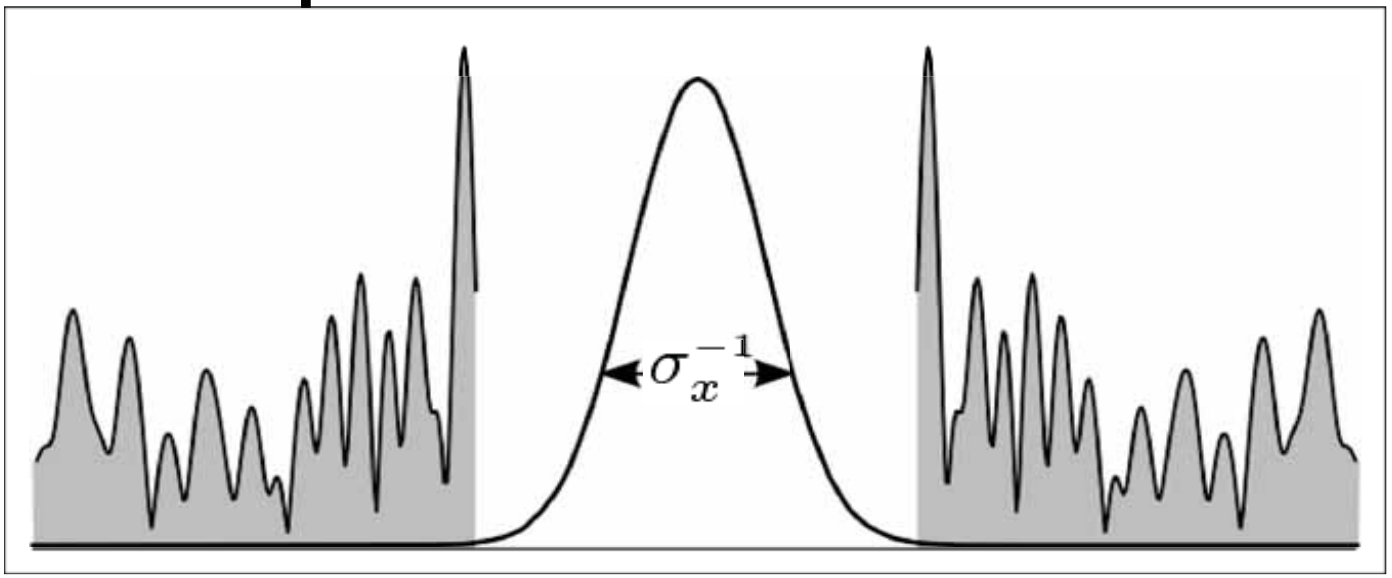
- Missing central data
- Crystalline domain registration
- Scanning patterns in ptychography
- ...

Missing data

Real space

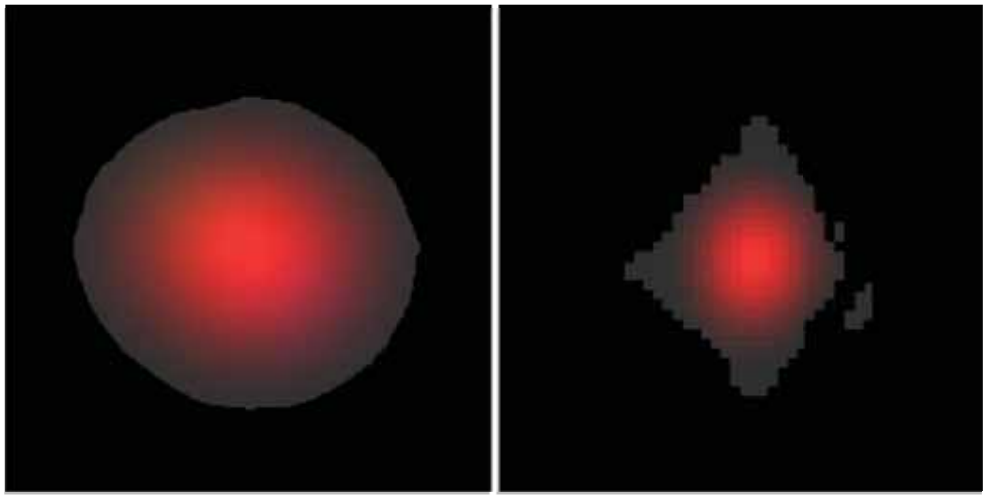
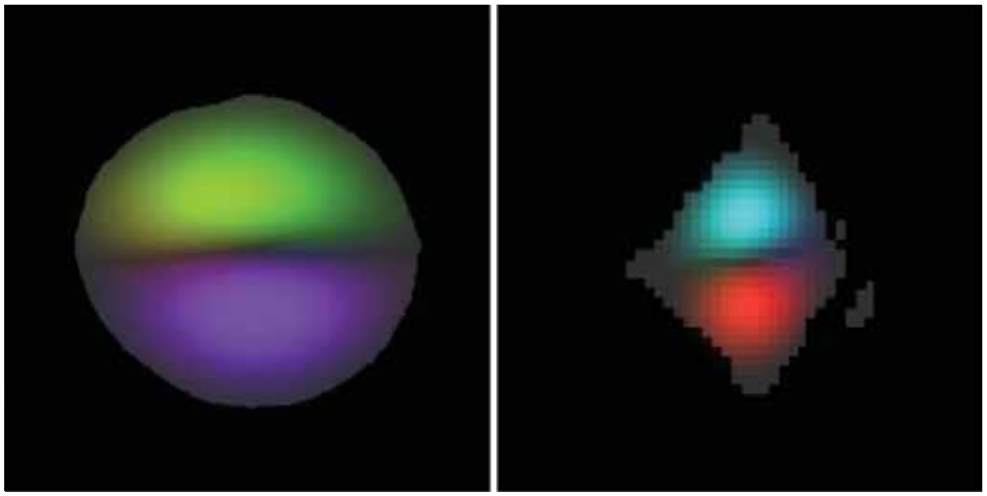
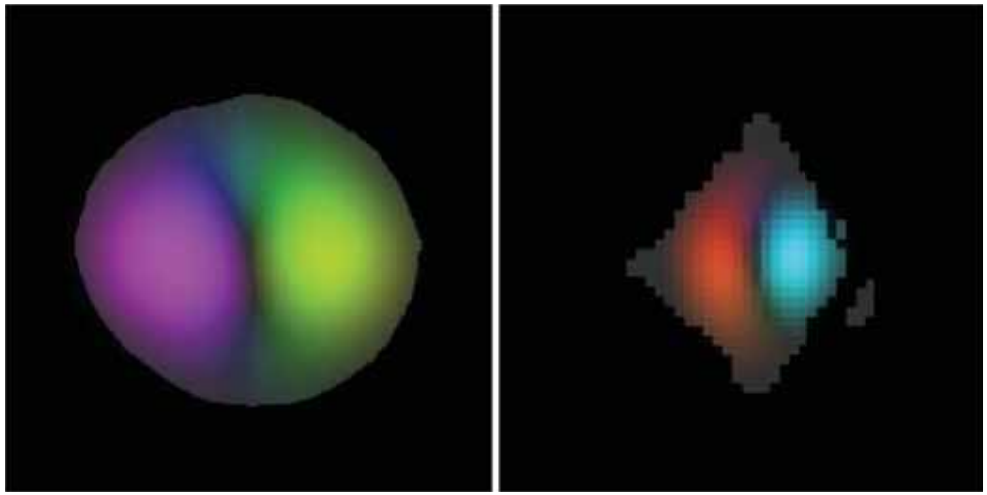
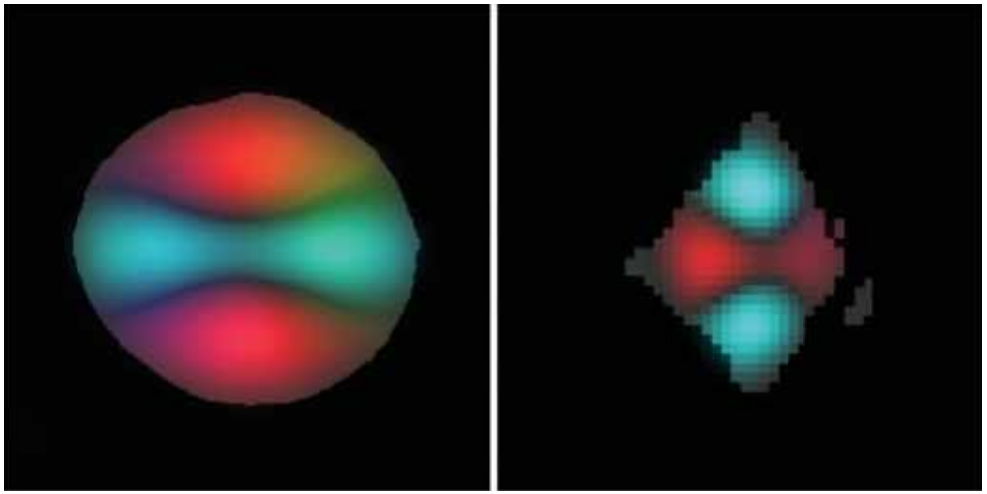


Fourier space



Weakly constrained modes

Identifying weakly constrained degrees of freedom

Ptychography

“raster grid pathology”

A solution:

$$\psi_j(\mathbf{r}) = P(\mathbf{r} - \mathbf{r}_j)O(\mathbf{r})$$

Define:

$$P'(\mathbf{r}) = P(\mathbf{r})f(\mathbf{r})$$
$$O'(\mathbf{r}) = O(\mathbf{r})/f(\mathbf{r})$$

These are also solutions if they satisfy:

$$\psi_j(\mathbf{r}) = P'(\mathbf{r} - \mathbf{r}_j)O'(\mathbf{r})$$

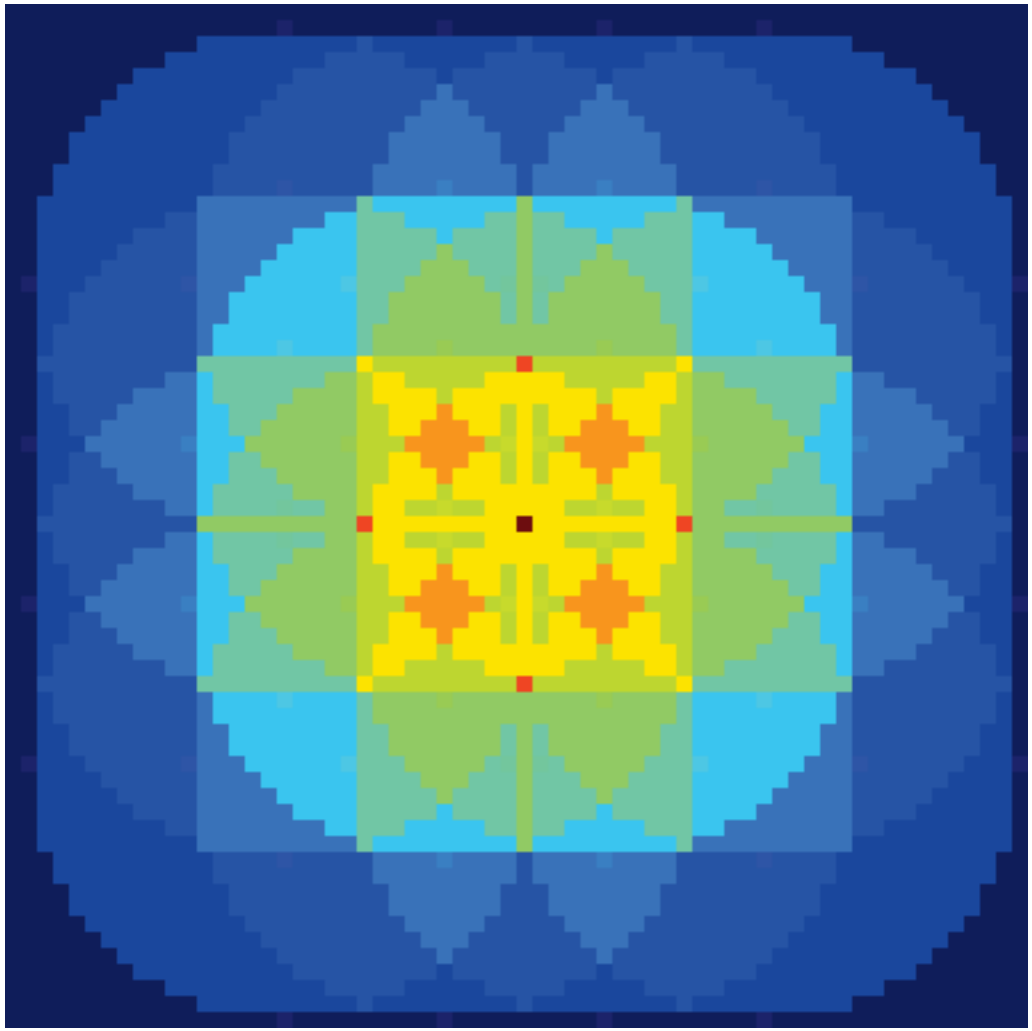
That is,

$$f(\mathbf{r}) = f(\mathbf{r} - \mathbf{r}_j) \quad \forall j$$

Thibault *et al.,* Ultramicroscopy, **109**, 338 – 343 (2009)

Degrees of freedom in ptychography

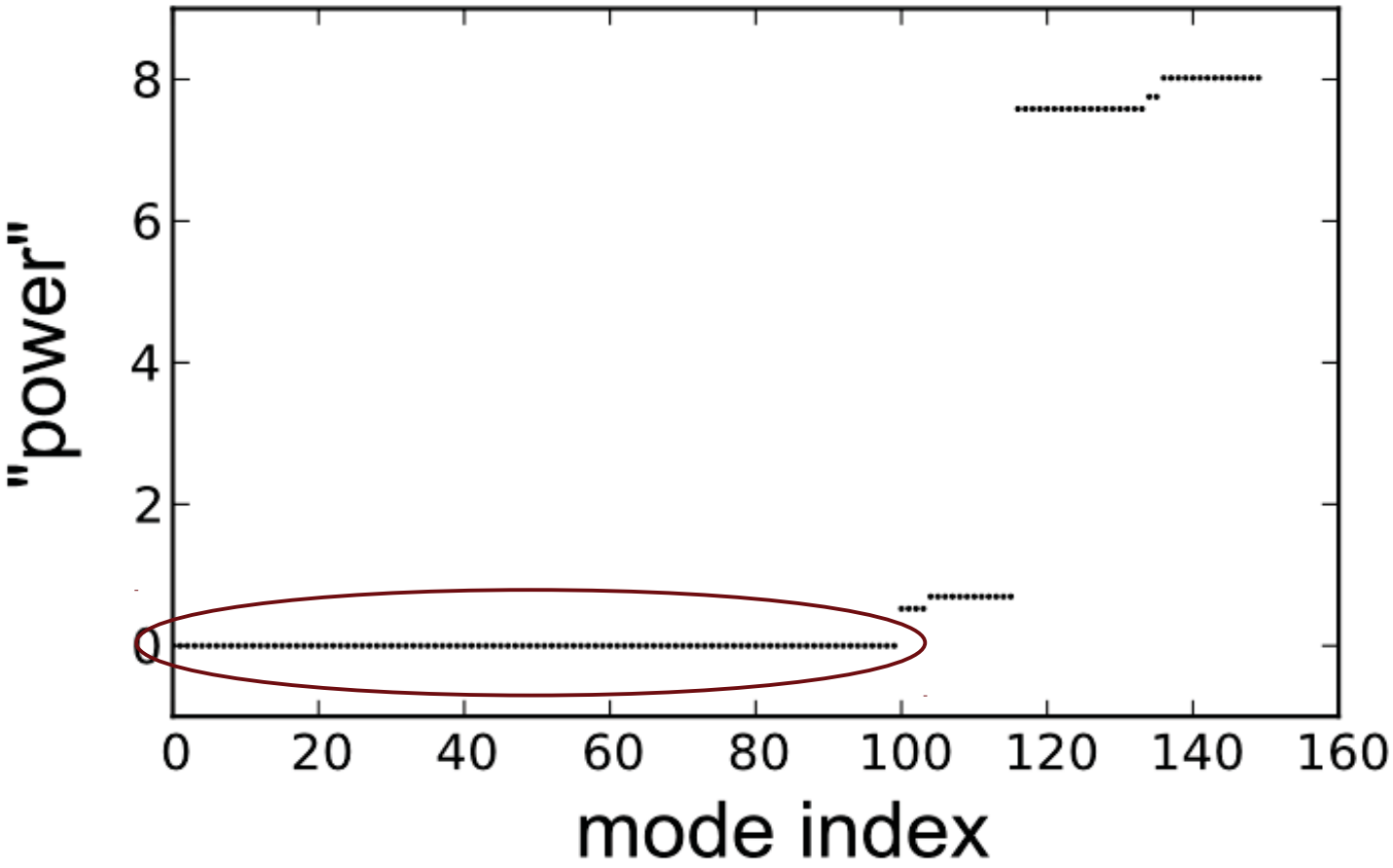
“Raster grid pathology”



Degrees of freedom in ptychography

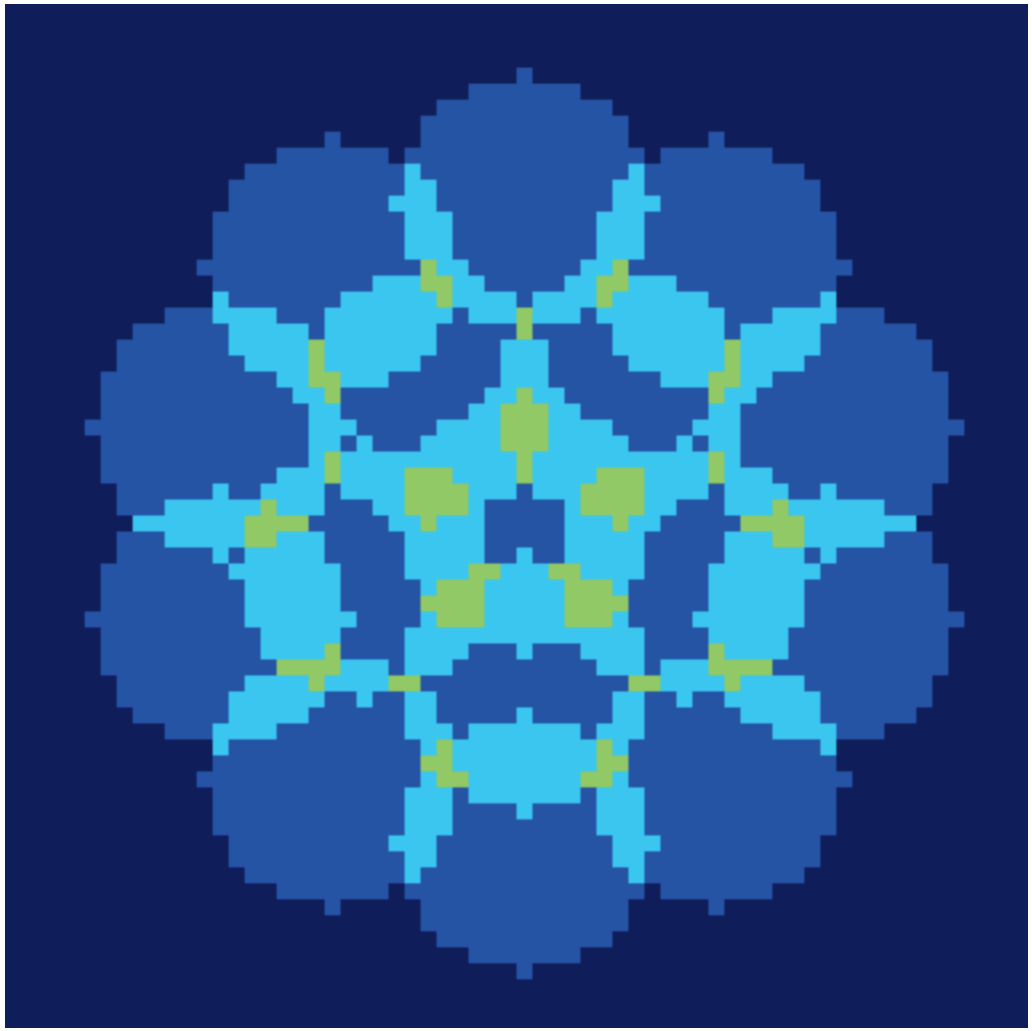
“Raster grid pathology”

Mode expansion of the probe/object system

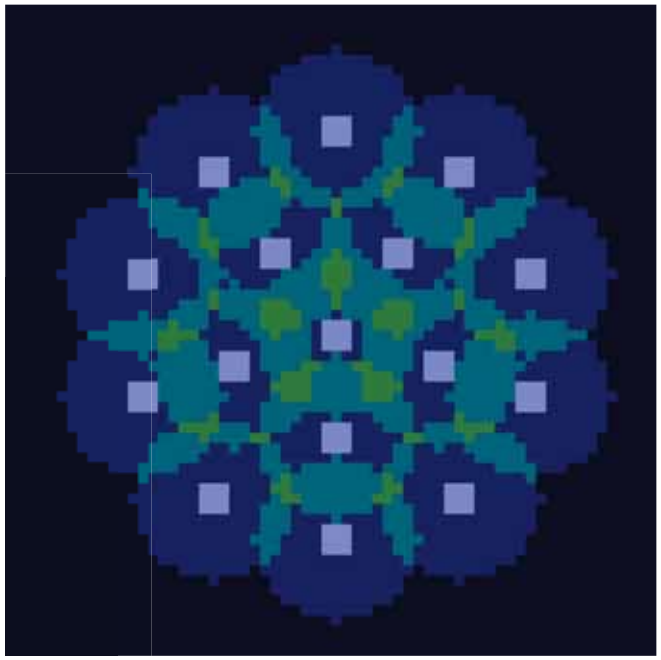


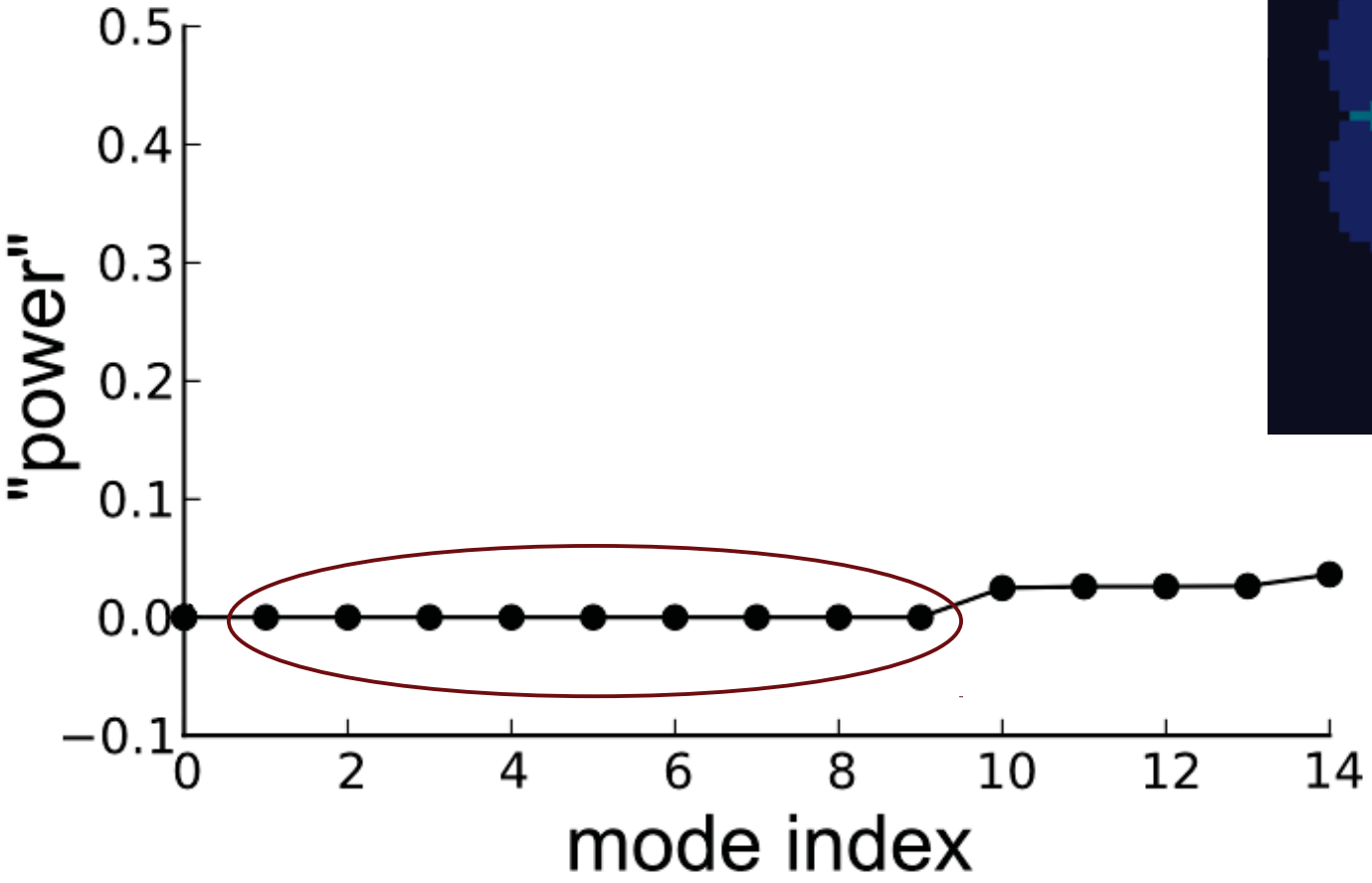
Degrees of freedom in ptychography

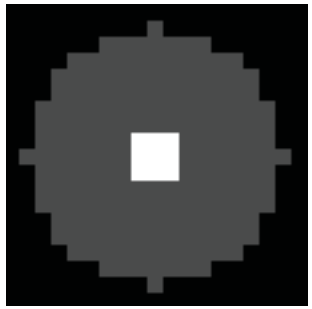
“Raster grid pathology”



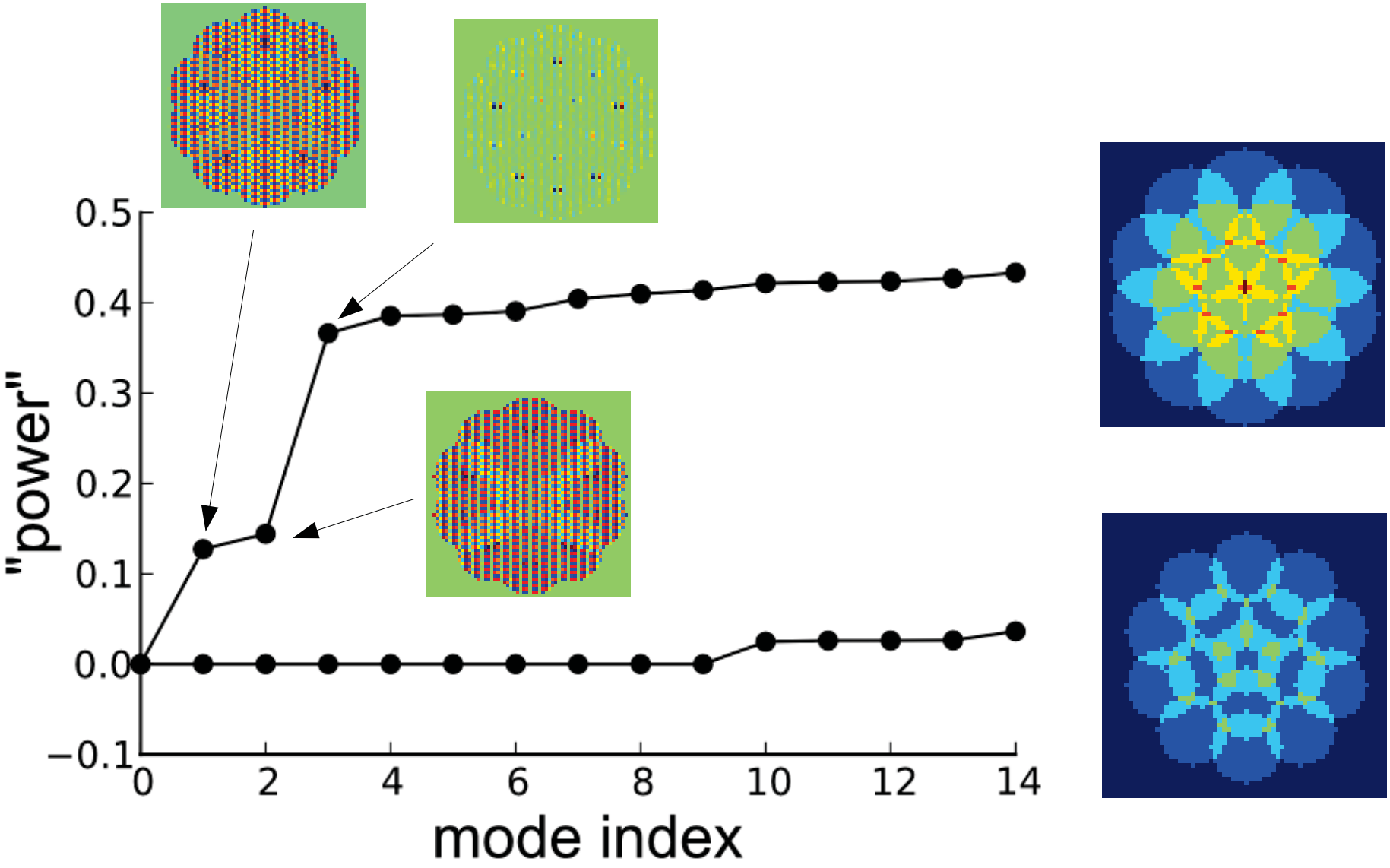
Degrees of freedom in ptychography





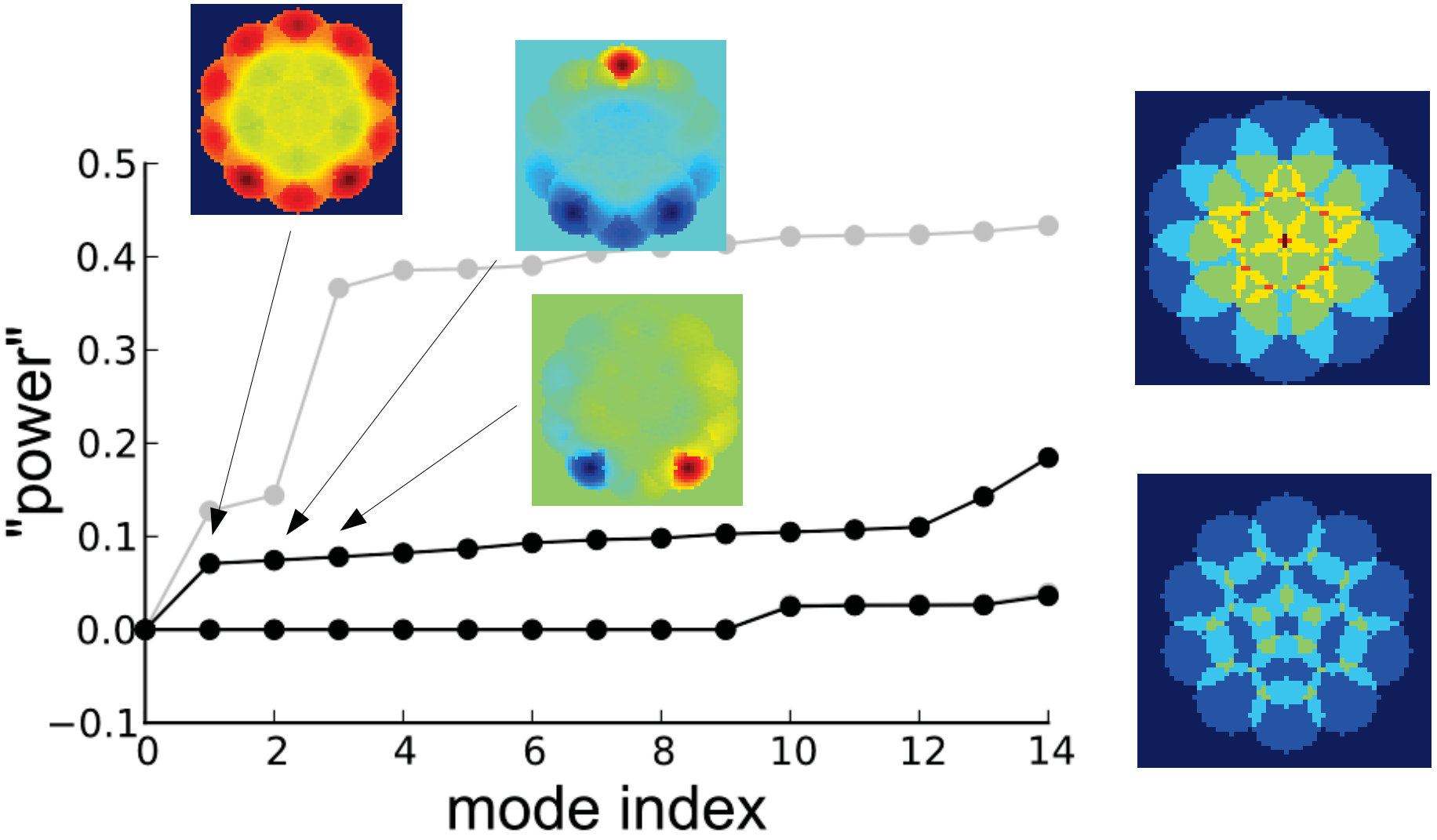


Degrees of freedom in ptychography



Degrees of freedom in ptychography

Including central missing Fourier data

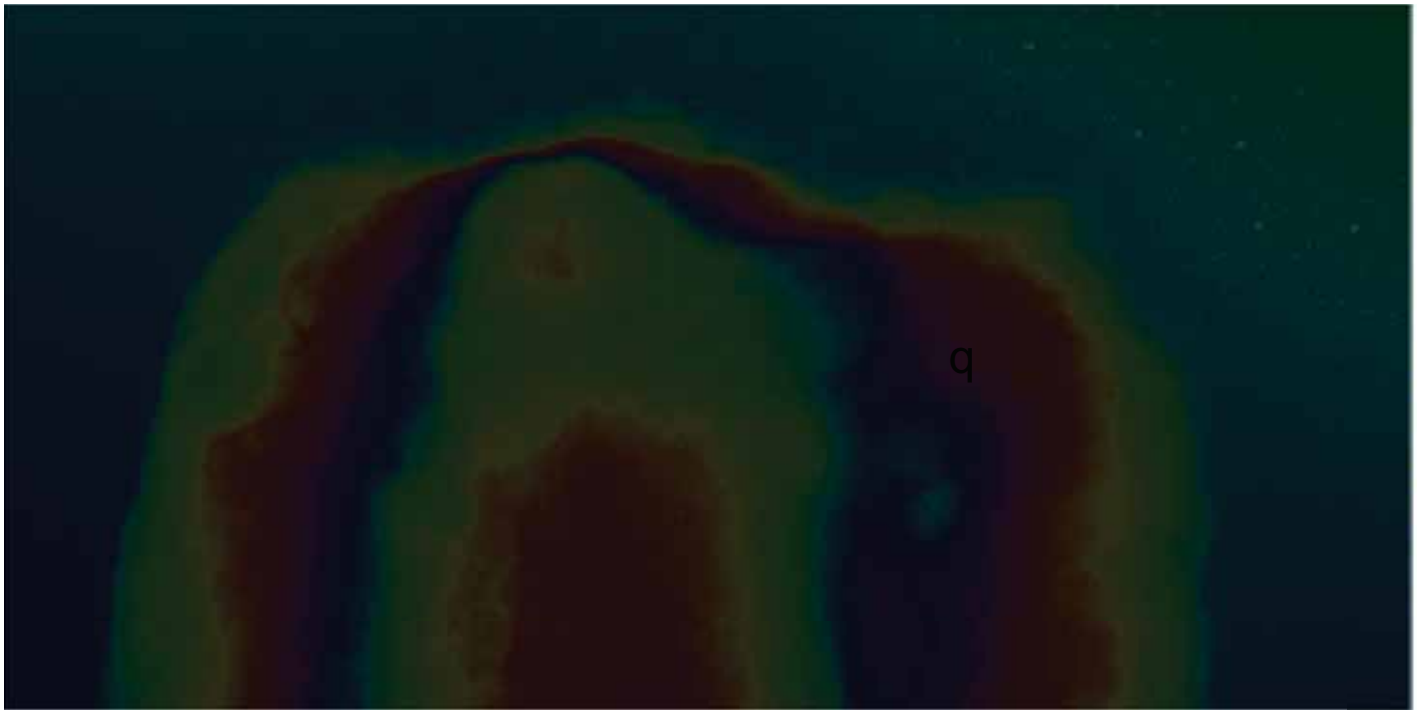


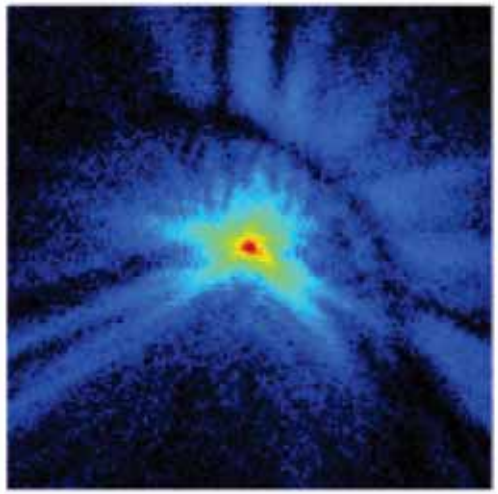
Ptychography @ ERL

A few crazy and no-so-crazy ideas

- Continuous acquisition scans
  - Multimodal (fluorescence, photo-electrons, …)
  - Real-time reconstruction? In 3D?
  - Automated or user-guided sample motion

Flexible scanning





Ptychography @ ERL

A few crazy and no-so-crazy ideas

- Continuous acquisition scans
  - Multimodal (fluorescence, photo-electrons, …)
  - Real-time reconstruction? In 3D?
  - Automated or user-guided sample motion
- Hard X-ray local ptycho-tomography
  - Volumes of interest inside mm-size objects

Ptychography @ ERL

A few crazy and no-so-crazy ideas

- Continuous acquisition scans
  - Multimodal (fluorescence, photo-electrons, …)
  - Real-time reconstruction? In 3D?
  - Automated or user-guided sample motion
- Hard X-ray local ptycho-tomography
  - Volumes of interest inside mm-size objects
- 3D Bragg ptychography
- ...

Applications

- Quantitative multi-scale imaging
  - Biological tissues (esp. bone)
  - Cracks, porous structures, alloys
  - Nano-devices
- Chemical mapping
- Strain mapping