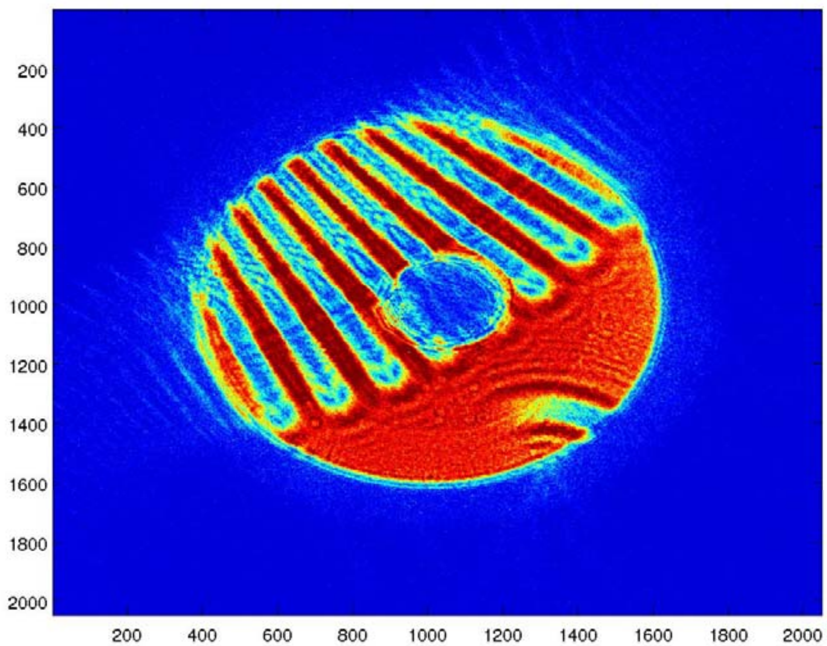
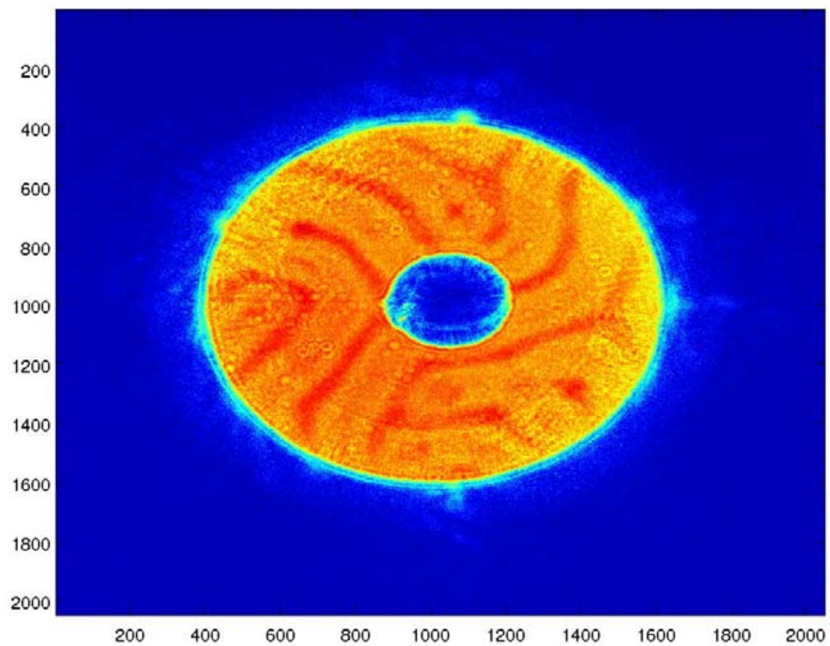
Ptychographical Fresnel Coherent Diffractive Imaging

Sebastian Dietze



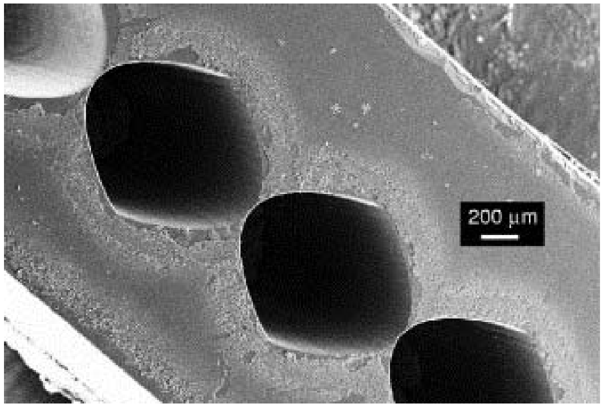


Outline

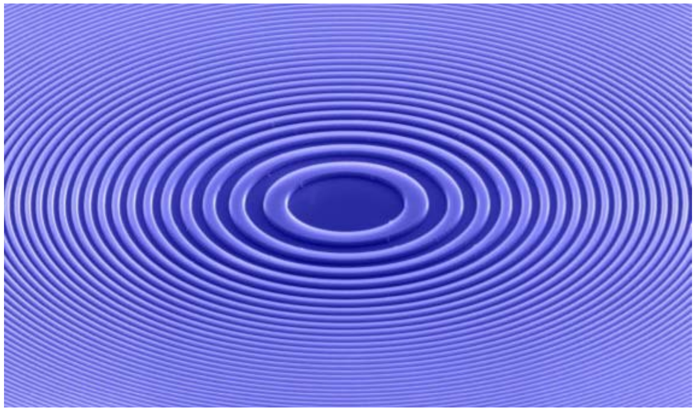
- Why go lensless?
- Coherent Diffraction Imaging (CDI) phase retrieval Techniques
- Fresnel Keyhole Method
- Combining FCDI and PIE

Limitations of Focusing Optics

- Fabrication Limits
  - Aberrations, Cost, Efficiency
- Practical Limits
  - Alignment, Degradation

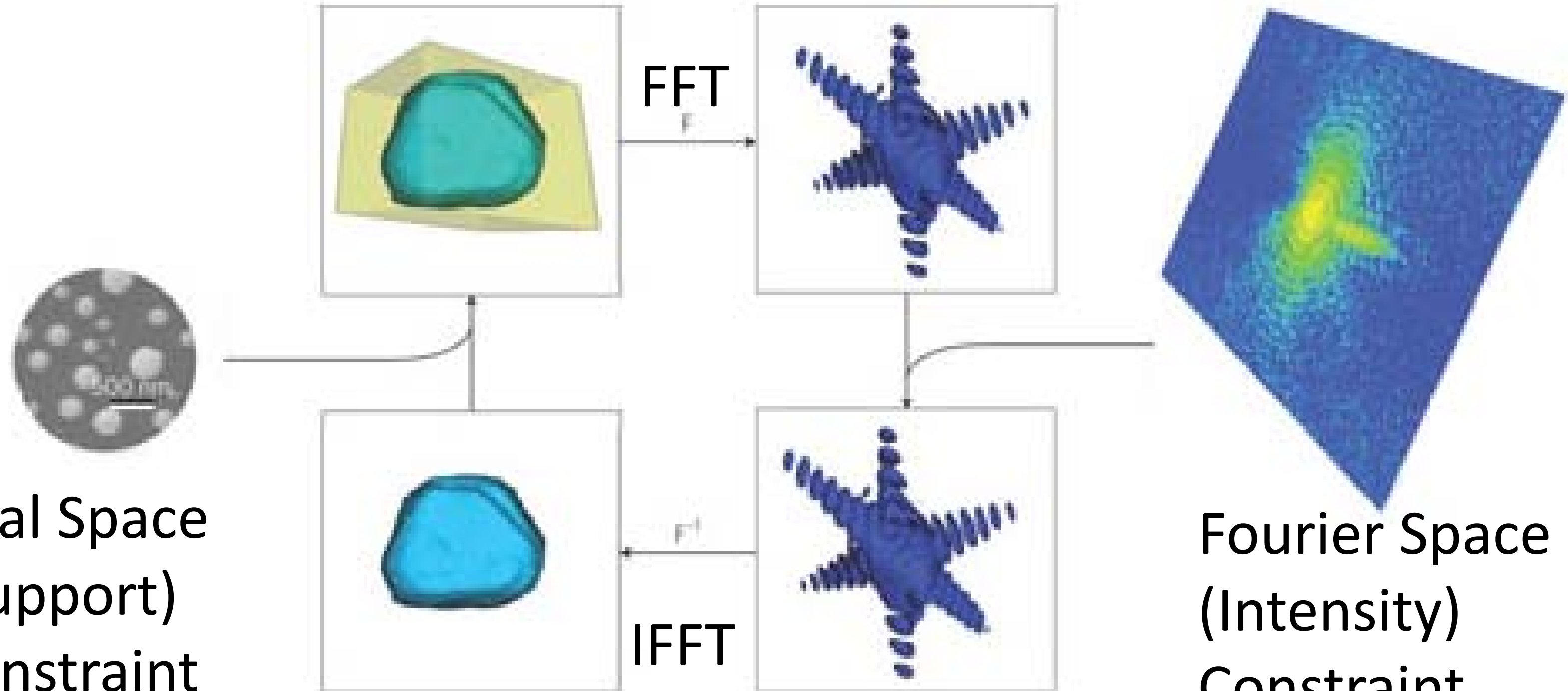


Parabolic Planar Compound Lens
A. Artemiev. NIMPRA. **543** 322 (2005)



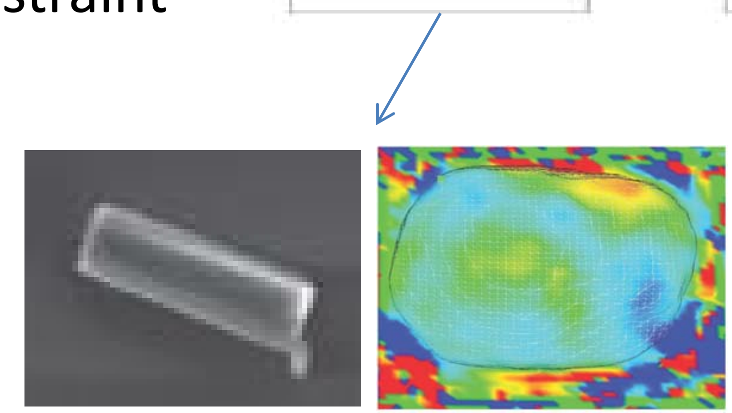
Silicon Fresnel zone plates for high heat load.
J. Vila-Comamala. Micr Eng **85** No. 5-6 (2008)

HIO Phase Retrieval Algorithm



Real Space
(Support)
Constraint

Fourier Space
(Intensity)
Constraint

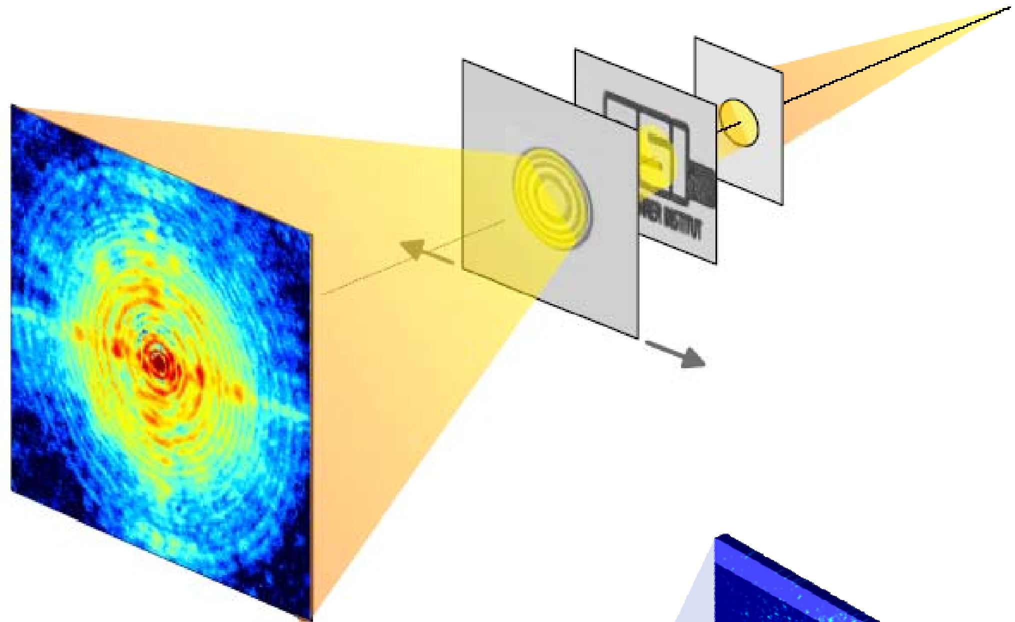


End result obtains the full complex reconstruction showing particle and strain

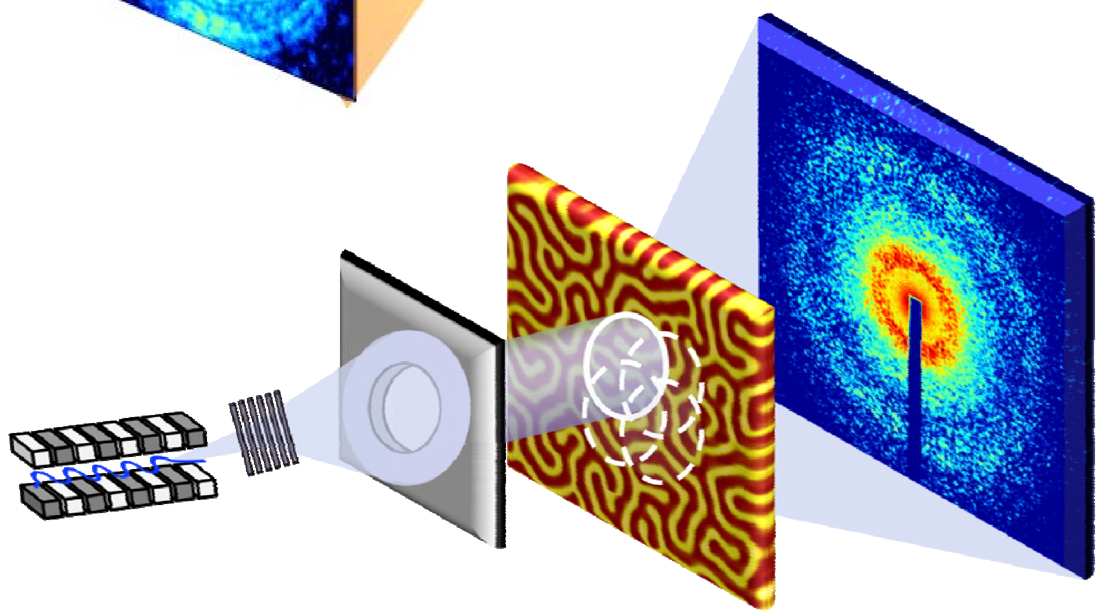
I. Robinson, R. Harder. Nature Materials 8, 291 (2009)

Complimentary Images

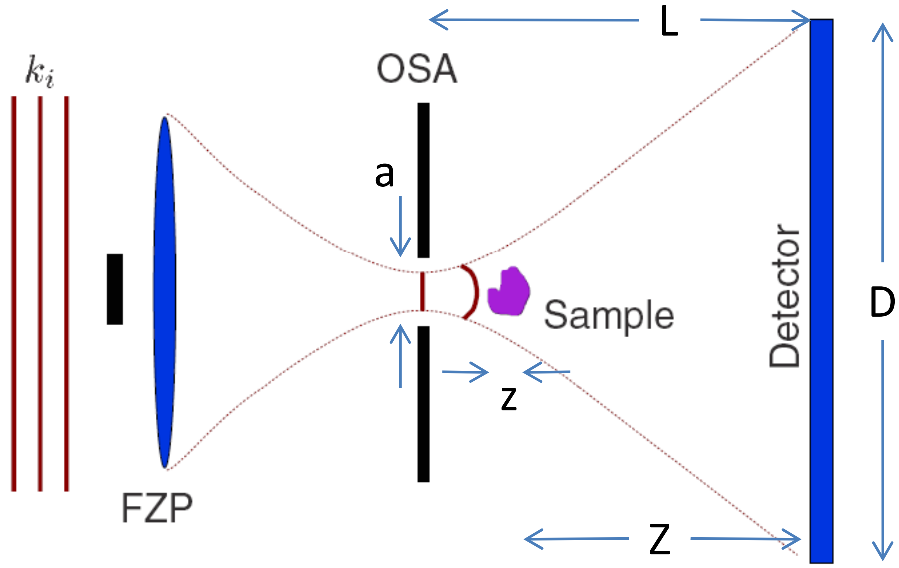
Phase Shift:
Multiple exposures with phase shifted wave front.
I. Johnson et al.PRL **100** 155503 (2008)



Ptychography :
Multiple exposures with significant overlapping region



Fresnel Imaging



G. Williams. PRL **97** 025506 (2006)

Required Conditions

Far Field: $Z \gg D$

Thin sample: $z \ll Z$

Alternatively,

$$\frac{a^2}{\lambda L} \gtrsim 1 \qquad \lambda \ll L$$

Resolution will be wavelength limited, not FZP resolution limited

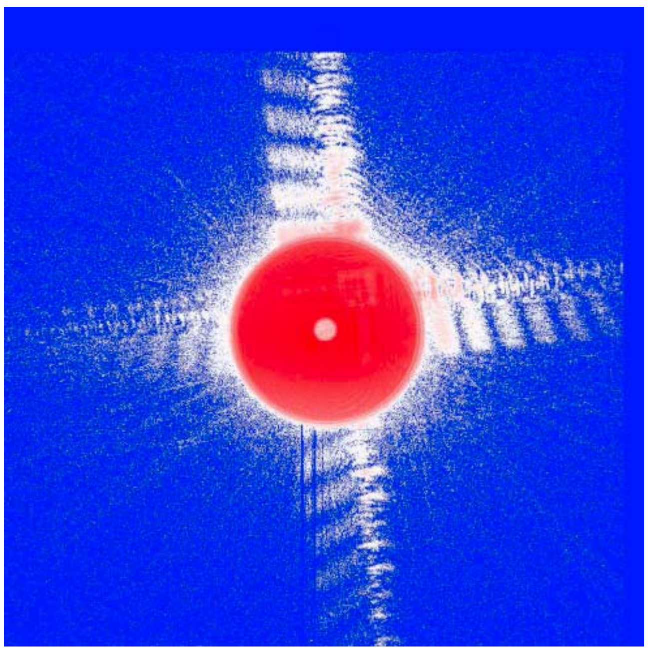
$$F_s(\boldsymbol{R}) = \frac{1}{Z} e^{ikZ} \int d^2r\, s(\boldsymbol{r})\, \Psi(\boldsymbol{r}) e^{i\frac{k\rho^2}{2Z}} = FrT2D\{s(\boldsymbol{r})\} \qquad \boldsymbol{\rho} = \boldsymbol{R} - \boldsymbol{r}$$

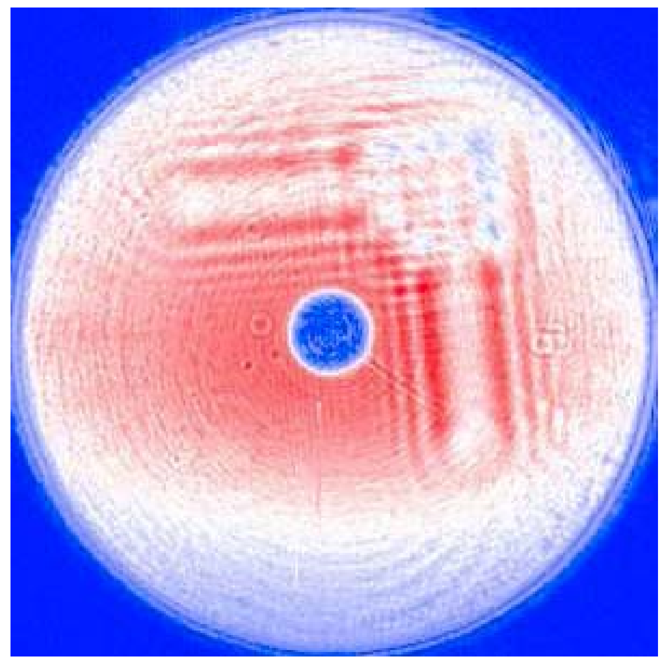
$$F_t(\boldsymbol{R}) = t\left(\frac{L-Z}{L}\boldsymbol{R}\right) \Psi(\boldsymbol{R})$$

R is vector in detector plane and
r is vector in sample x-y plane

Keyhole

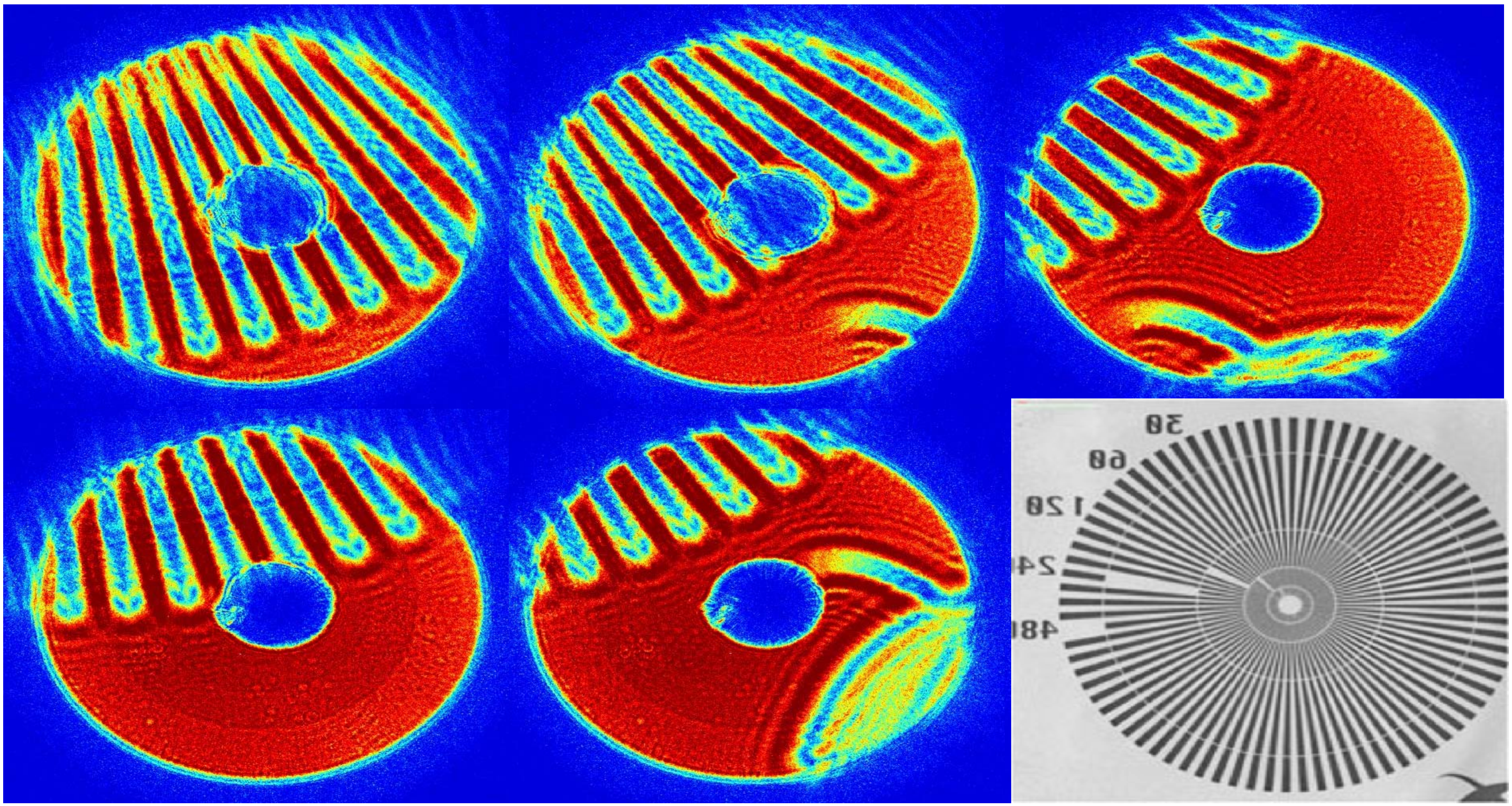
The central region is an in-line hologram using a curved wave front. Propagate back to sample plane to obtain additional real space constraint for phase retrieval algorithm.





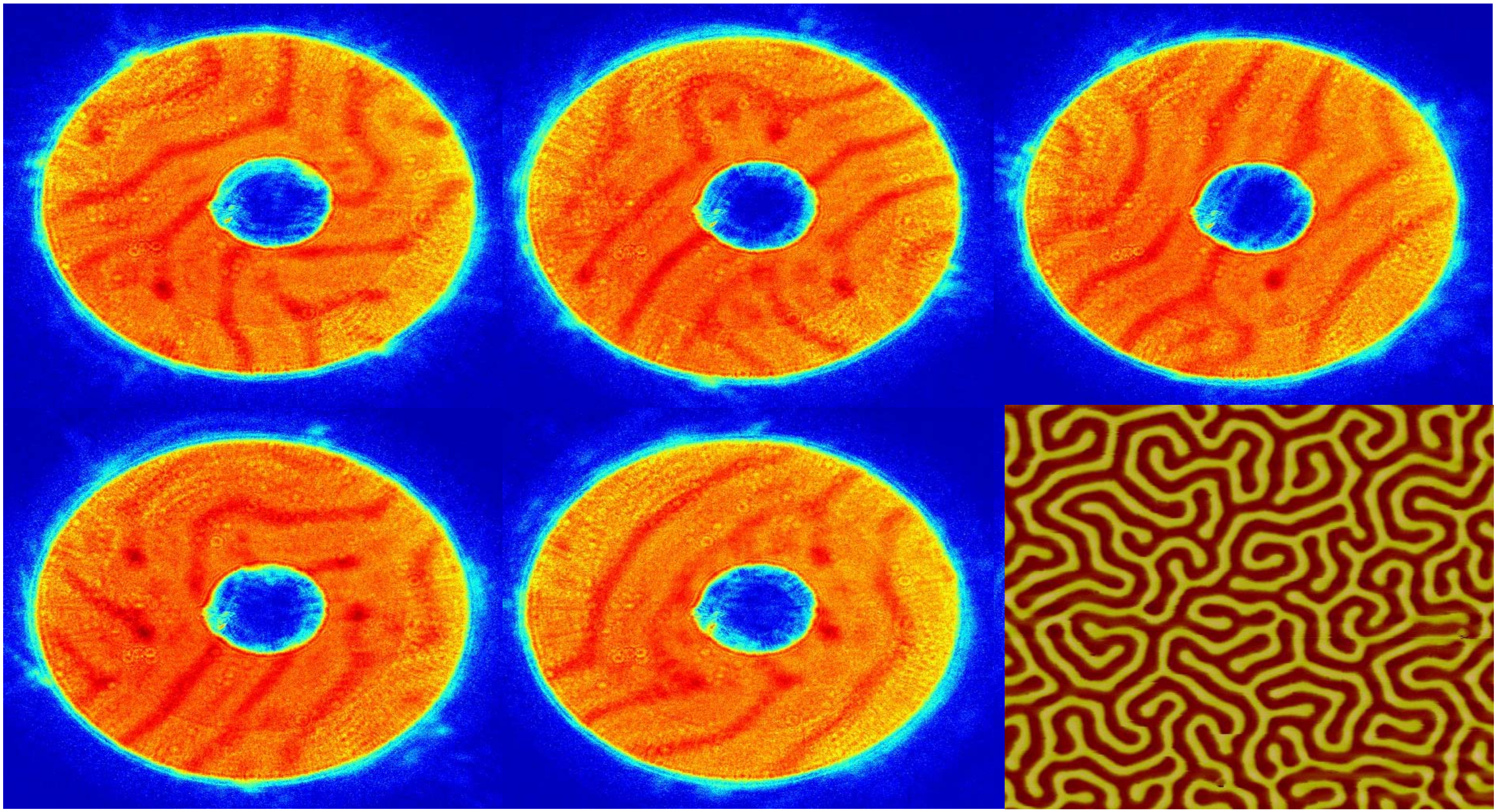
G. Williams. PRL **97** 025506 (2006)

PFCDI on AU Test Pattern



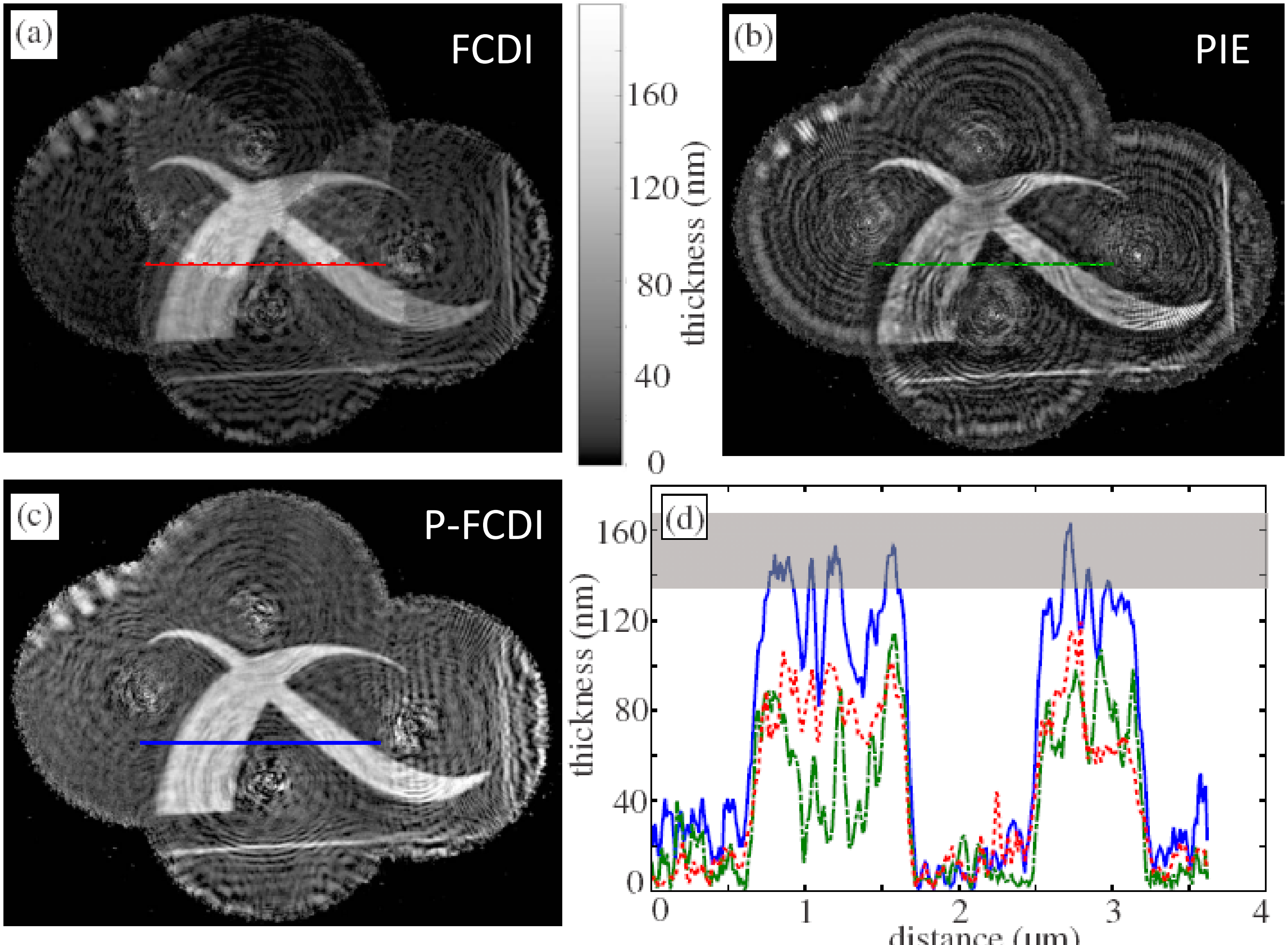
Tripathi et al.

PFCDI on GdFe Stack



Tripathi et al.

Comparison of Reconstruction

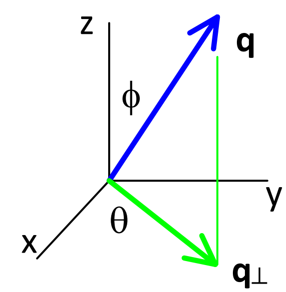


D. Vine et al. Phys Rev A **80** 063823 (2009)

Azimuthal Symmetry in 2D Diffraction in Fraunhoffer regime using Elastic Scattering

For thin films, can use a 2D FT of scattering density to obtain diffraction pattern

$$F(\boldsymbol{q}_\perp) = FT2D\{f(\boldsymbol{x}_\perp)\} = \int d\boldsymbol{x}_\perp f(\boldsymbol{x}_\perp) e^{i\boldsymbol{q}_\perp \cdot \boldsymbol{x}_\perp}$$



$$\boldsymbol{q}_\perp = \frac{2\pi}{\lambda}(a\hat{x} + b\hat{y})$$

$$a = \sin(\phi)\cos(\theta)$$

$$b = \sin(\phi)\sin(\theta)$$

The complimentary point is at

$$\phi' = \phi \quad \theta' = \theta + \pi \longrightarrow \boldsymbol{q}'_\perp = -\boldsymbol{q}_\perp$$

The C.C. of FT2D at complimentary pt is,

$$F^*(\boldsymbol{q}'_\perp) = \int d\boldsymbol{x}_\perp f^*(\boldsymbol{x}_\perp) e^{i\boldsymbol{q}_\perp \cdot \boldsymbol{x}_\perp}$$

Therefore if f(x) is real, the intensities are equal.

$$I(\boldsymbol{q}'_\perp) = |F(\boldsymbol{q}'_\perp)|^2 = I(\boldsymbol{q}_\perp)$$

Diffraction; Contrast Mechanism

$$O_{\pm}(\boldsymbol{r}) = e^{-\mu_o t} e^{\pm m_z(r)\mu_c t} = e^{-\mu_o t}\left[\cosh\left(m_z(\mathbf{r})\,\mu_c t\right) \pm \sinh\left(m_z(\mathbf{r})\,\mu_c t\right)\right],$$

$$\begin{aligned} I = \frac{I_+ + I_-}{2} &= \frac{1}{2}[|FT\{P(\mathbf{r})O_+(\mathbf{r})\}|^2 + |FT\{P(\mathbf{r})O_-(\mathbf{r})\}|^2] \\ &= e^{-2\mu_o t}\left[\left|FT\left\{P(\mathbf{r})\cosh\left(m_z(\mathbf{r})\,\mu_c t\right)\right\}\right|^2 \right. \\ &\quad \left. + \left|FT\left\{P(\mathbf{r})\sinh\left(m_z(\mathbf{r})\,\mu_c t\right)\right\}\right|^2\right]. \end{aligned}$$

$$\begin{aligned} I = e^{-2\mu_o t}\Big[&|FT\{P(\mathbf{r})\}|^2 \\ &+ \left(\mu_c t\right)^2 \Big[|FT\{P(\mathbf{r})m_z(\mathbf{r})\}|^2 \\ &+ \frac{1}{2}(FT\{P(\mathbf{r})\}^* FT\{P(\mathbf{r})m_z^2(\mathbf{r})\} + C.C.)\Big] + \mathcal{O}\left\{\left(\mu_c t\right)^4\right\}\Big]. \end{aligned}$$

$$I \approx e^{-2\mu_o t}\left[|FT\{P(\mathbf{r})\}|^2 + \left(\mu_c t\right)^2 |FT\{P(\mathbf{r})m_z(\mathbf{r})\}|^2\right].$$

A. Tripathi et al. (2010)