

Lensless imaging via ptychography

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Project summary

supervisor Oscar Branson, a final-year PhD student at the Earth Science Department in Cambridge. His research is primarily concerned with biomineral microstructures (i.e. shells produced by living organisms) and how these are affected by environmental changes such as acidification.

aim high resolution images of various fossil shells using two different microscopy techniques, the more interesting of them being ptychography

schedule 2 weeks for experiment preparation
3 days for experiments at the DLS synchrotron near Didcot, Oxfordshire
1 1/2 weeks for data processing

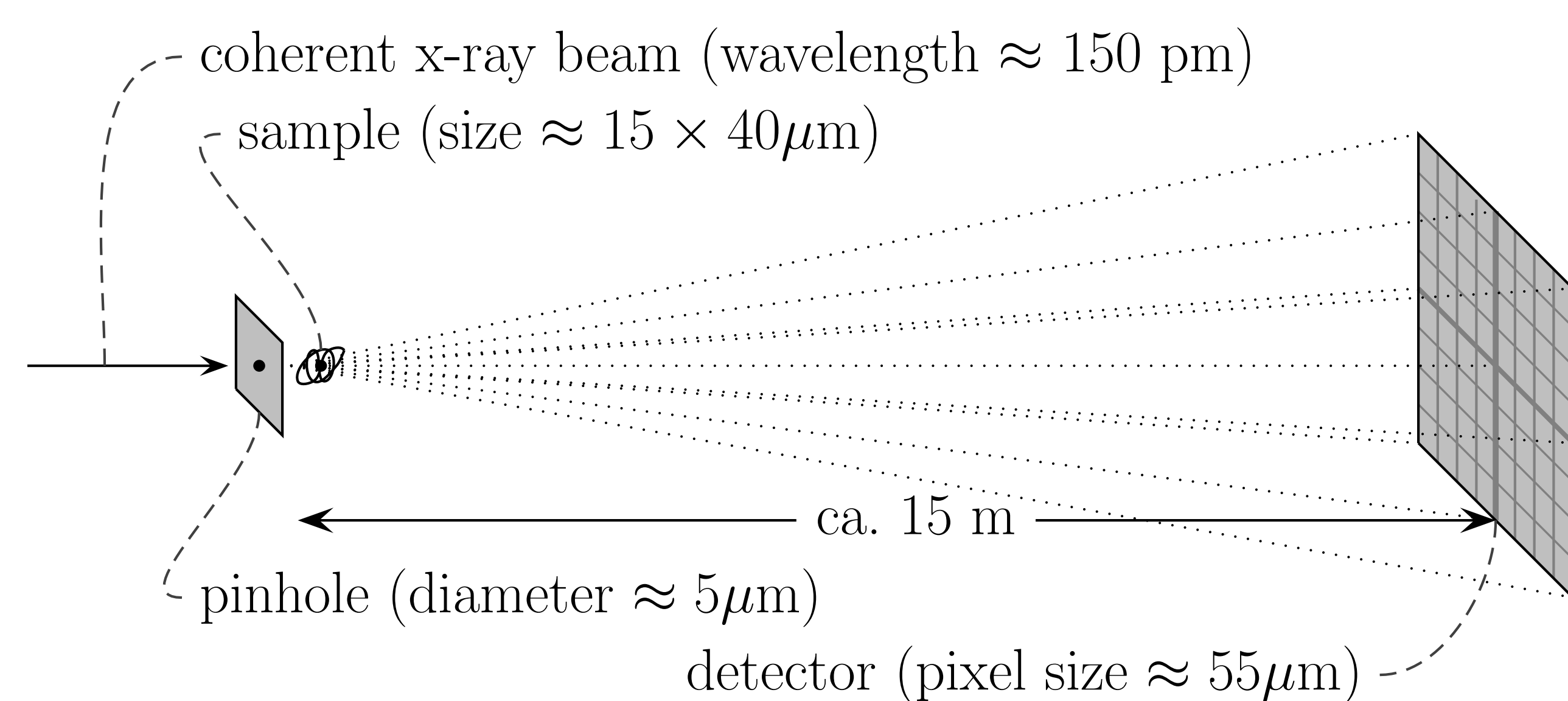
What is ptychography?

Ptychography is a microscopy technique originally conceived in the 1970s by Walter Hoppe, a German physicist, as a solution to the **phase problem** in x-ray/electron crystallography [1]: Whenever we measure light or any other kind of electromagnetic radiation, we can only measure the intensity, i.e. the amplitude, of the incoming waves. Phase information can only be measured indirectly. A more or less straightforward idea is to use a reference beam, which leads to holography. Ptychography offers an alternative method which does not require a reference beam.

The **setup** used in our experiments can be seen in the box below. If we remove the sample, it is basically the same setup used for slit or diffraction experiments: A pinhole is placed into a beam of coherent light of a given constant wavelength and its diffraction pattern (far field) is measured at a detector screen placed at some distance from the pinhole. The sample is placed right behind the pinhole and can be moved parallel to the pinhole plane.

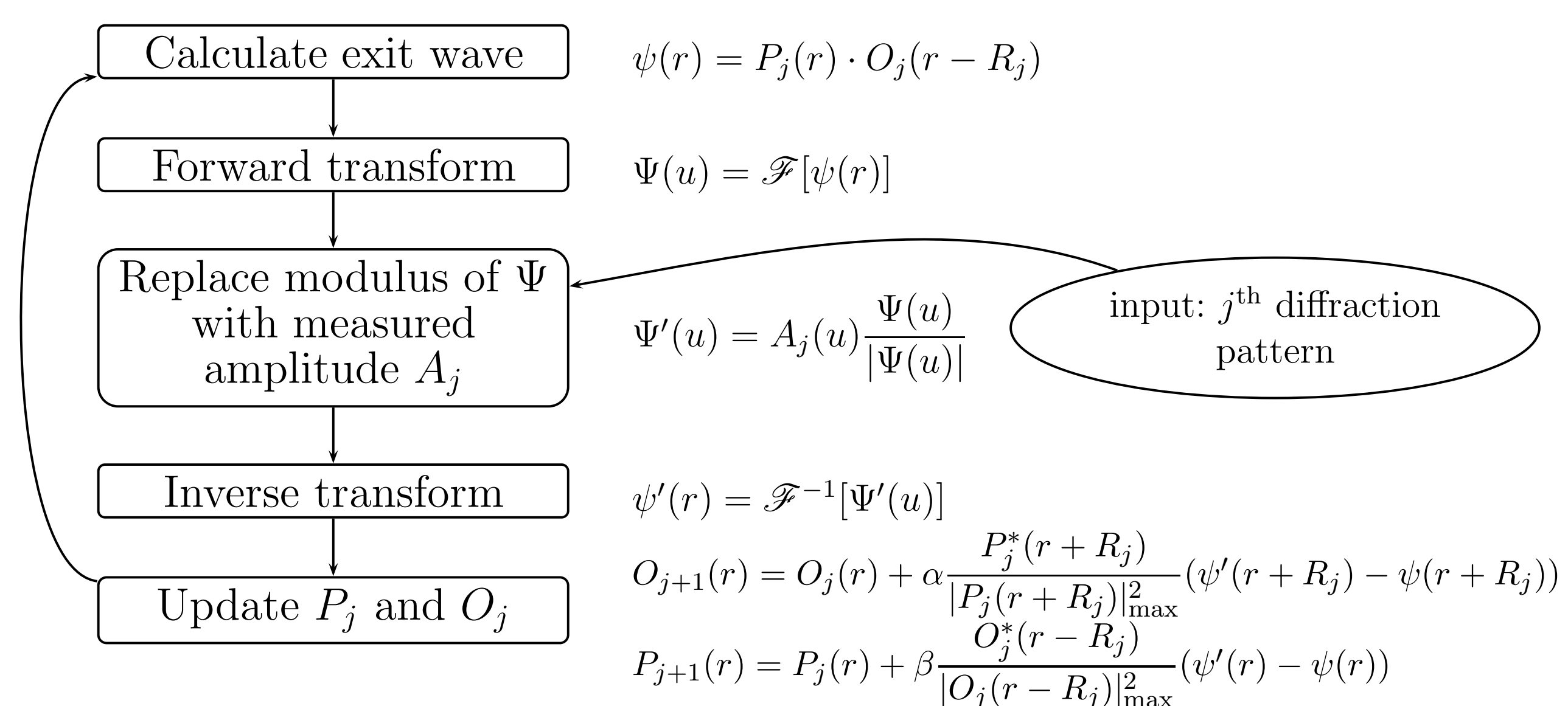
The **idea of ptychography** is to take many diffraction patterns of the same object with slightly different object-to-pinhole positions, thereby obtaining many overlapping pictures. This creates enough redundancy to reconstruct the phase information via an iterative algorithm.

The setup



The main steps of the ptychography algorithm

We used a slightly modified version of the ePIE algorithm described in [2] and implemented it in MATLAB. The main ingredients are two complex valued functions P and O , the "probe" and the object function: P describes the exit wave behind the pinhole and O is the image of the object, describing how much light the sample transmits and what phase change it induces. Both functions are updated in each iteration step of the algorithm. Initial guesses P_0 and O_0 are used at the start of the algorithm.



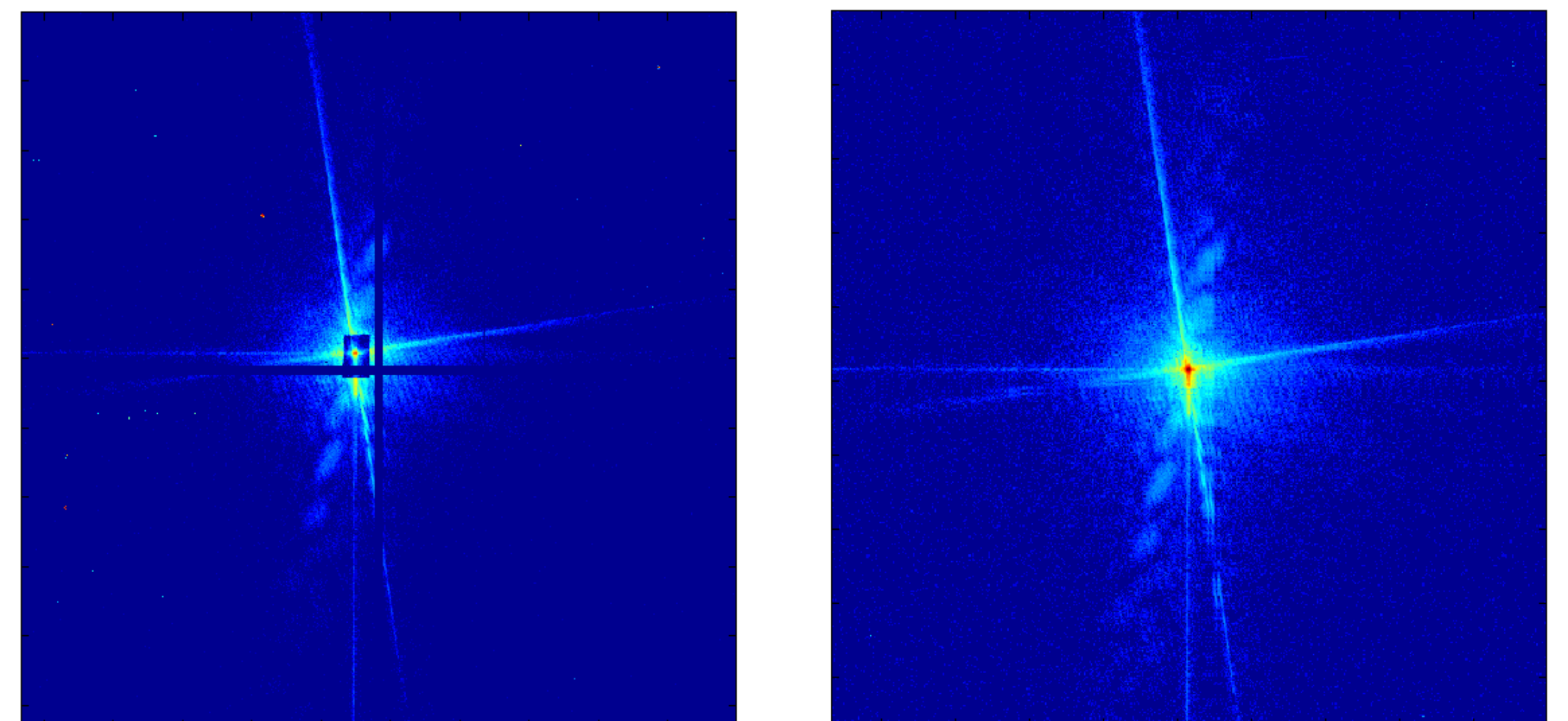
The flowchart above shows the main steps of each iteration: First, the previous guesses P_j and O_j are used to calculate the exit wave ψ behind the sample, taking into account the relative pinhole-to-sample position R_j corresponding to the j^{th} diffraction pattern. The wave Ψ at the detector screen is the Fourier transform \mathcal{F} of ψ . The diffraction pattern is then used to update the modulus of Ψ . Finally, both the probe and object functions are updated. The parameters α and β determine the stepsize. This process is repeated for all diffraction patterns (in a random order) several times.

Aerial view of the DLS synchrotron [3]



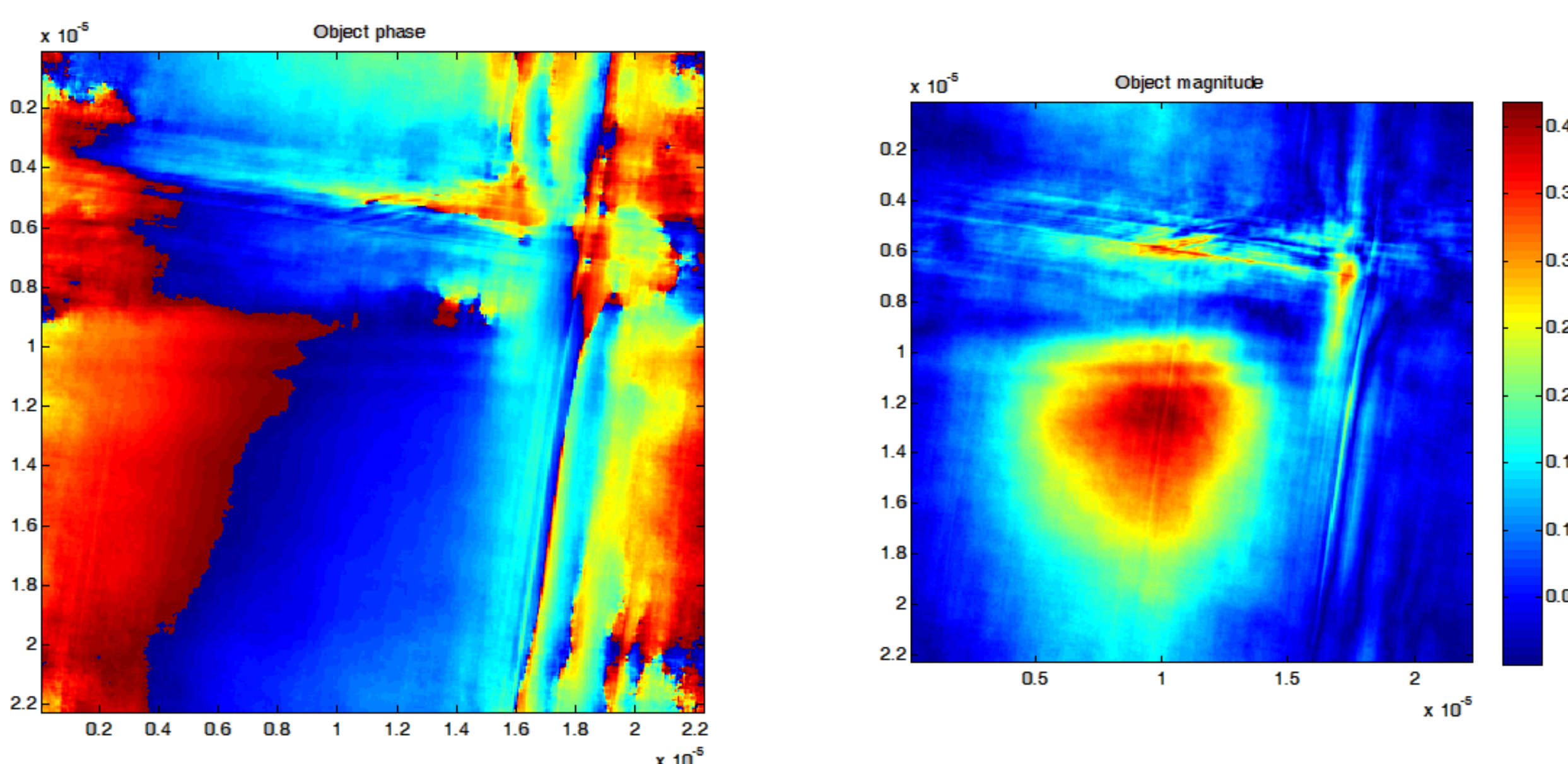
Raw data preparation

Before we could apply the ptychography algorithm, the raw data had to be modified in order to minimise the effect of several error sources. On the right below, a modified diffraction pattern is shown next to the original image. The most prominent feature on the left is the beamstop, which protects the detector. The gaps between the four detector panels are also clearly visible on the left. In addition to these obvious problems, we also had to remove detector defects and hot pixels.



First results

Below, one can see the object function (phase left, amplitude right) corresponding to the series of diffraction patterns from which the example above was taken. The picture shows the rough shape of the sample (the upper corner of a rectangle), but unfortunately fails to show some more refined structures. Apart from intrinsic inaccuracies of the measured data, the implementation of the algorithm might be a source of errors. However, more time would be needed to optimise the algorithm, and it is not clear whether the raw data admits a much better result at all.



References

- [1] J. M. Rodenburg, *Ptychography – early history and 3D scattering effects*, Proc. SPIE 8678, Short-Wavelength Imaging and Spectroscopy Sources (2012)
- [2] A. M. Maiden, J. M. Rodenburg, *An improved ptychographical phase retrieval algorithm for diffractive imaging*, Ultramicroscopy 109 (2009), pp. 1256-1262
- [3] http://www.ong-science.org.uk/wp-content/uploads/2011/10/10EC2256_Diamond_aerial_view.jpg