

DESY Summer Student Programme

Fourier Transform Holography

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The knowledge of atomic and molecular structure is fundamental in physics, chemistry and biology. Therefore, it is not surprising that even today scientists try to find new techniques for structural investigations. Recently a new method, high resolution X-ray holography has emerged. It is based on the same principles as traditional holography with visible light. A coherent wave (called the reference wave) illuminates the object and the detector surface. The intensity modulation caused by the interference between the reference wave and the wave scattered by the object (called the object wave) is recorded. This interference pattern contains both the phase and the magnitude information of the object wave. From this interference pattern the original wavefront can be reconstructed, giving the arrangement of the objects.

Lensless Fourier Transform Holography (FTH) is of interest, because of its potential to readily achieve high spatial resolution images.

The hologram of the object is made by recording the interference pattern between the object beam and a number of reference beams. Each reference beam interferes with the object beam and forms a sub hologram. Thus the composite hologram upon reconstruction gives multiple images. The reference source for lensless Fourier holography usually lies in the sample plane.

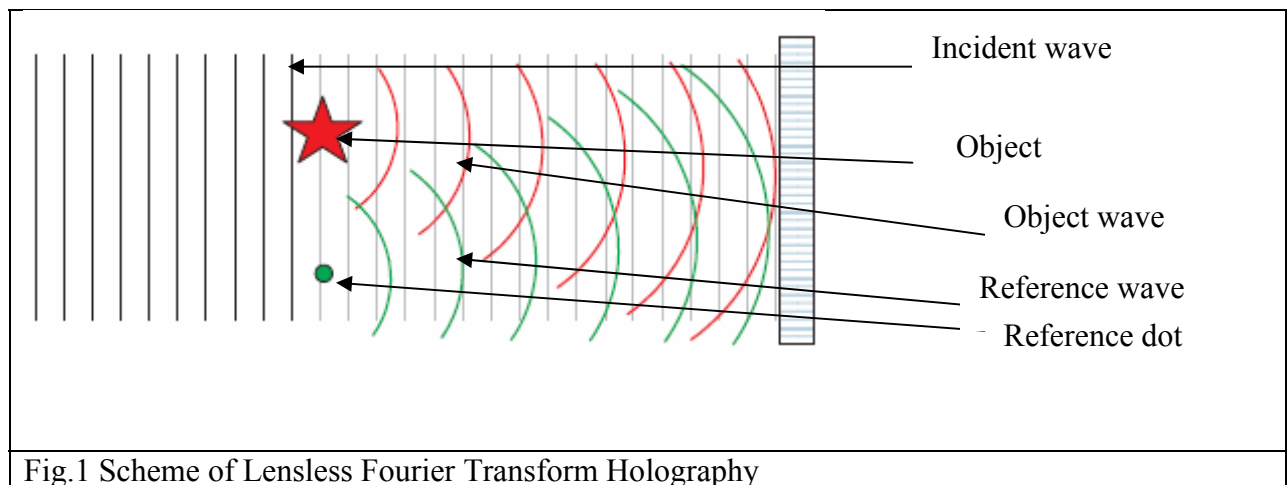


Fig.1 Scheme of Lensless Fourier Transform Holography

When the sample is far from the detector ($d^2/\lambda z \ll 1$, where d - detector radius, z – distance between detector and the sample, λ - wavelength) the diffraction pattern is the Fourier transformation of the wave from the object and reference light source. FTH exploit the convolution of the two apertures to form an image by exchanging a sample for one aperture and delta function for the other. Delta function aperture is the reference while the other aperture which contains the unknown sample is the object.

Reconstructing a real space image of the object entails recovering the encoded phase information. This is simply accomplished by calculating the two dimensional Fourier transformation of the recorded hologram by fast implementation of the discrete Fourier transformation. The real space image of the object that appears in the reconstruction is the spatial convolution of the actual object with the reference.

My task was to reconstruct a “gold cross” sample from 2 different datasets that differ with the distance from sample to detector, and to find a convenient way to analyze soft x-ray holography data.

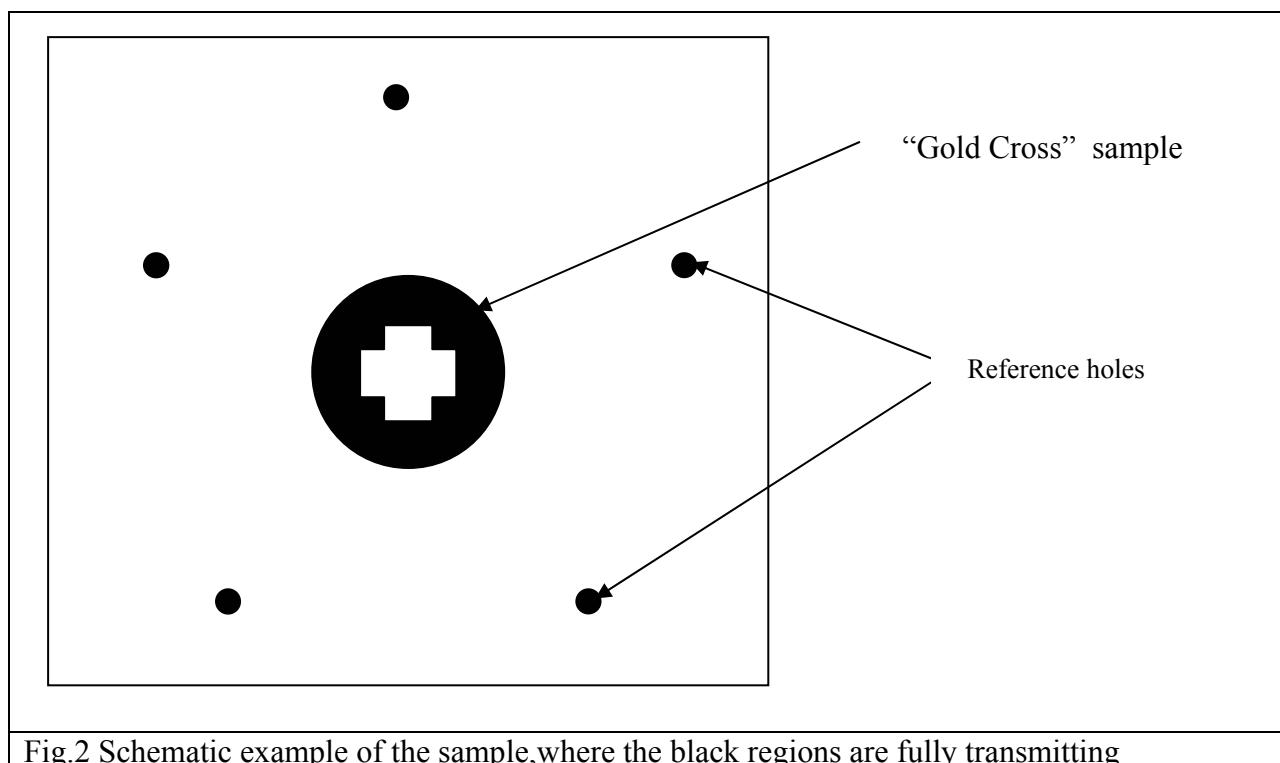


Fig.2 Schematic example of the sample, where the black regions are fully transmitting

The first step of the procedure was the correction of the obtained data for dark noise. Dark noise is the result of thermoelectron generation with the pixels of CCD matrix during the exposition time.

That's why we make so called "dark images" with the same exposure time as the data images. We can easily subtract this dark noise from the data image and hence remove its effect.

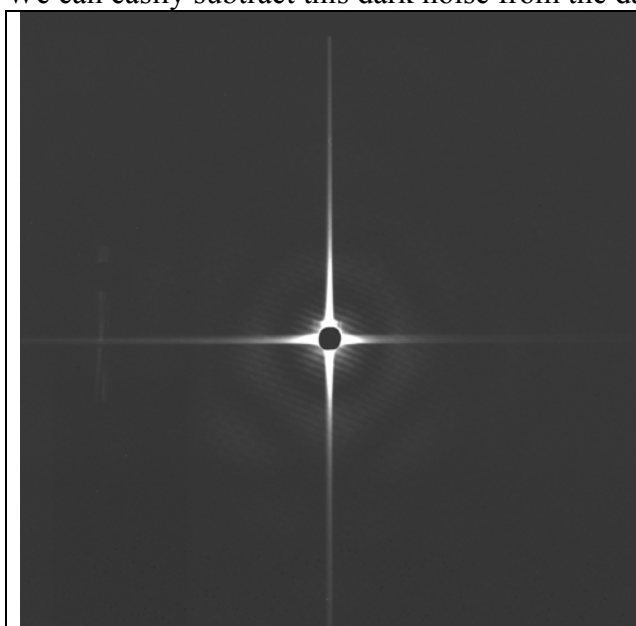


Fig.3 first dataset

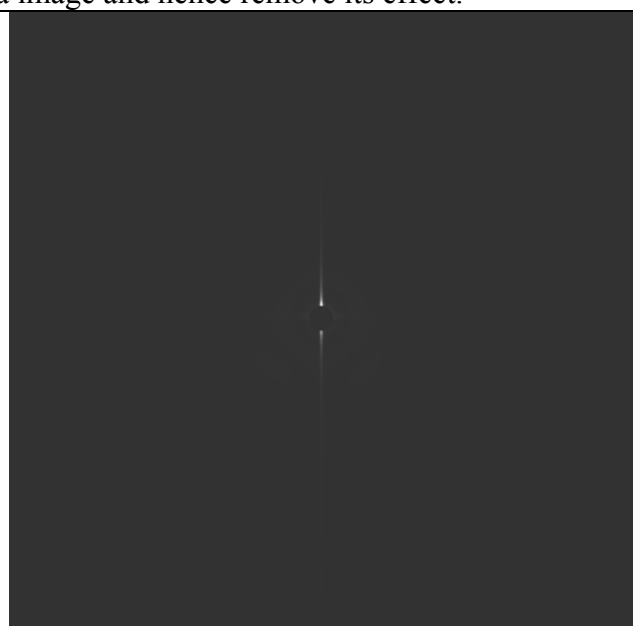


Fig.4 second dataset

For the first dataset was also averaged by using imagej binner plugin – averaging 2*2 pxls regions. The Fourier transformation of these pictures are

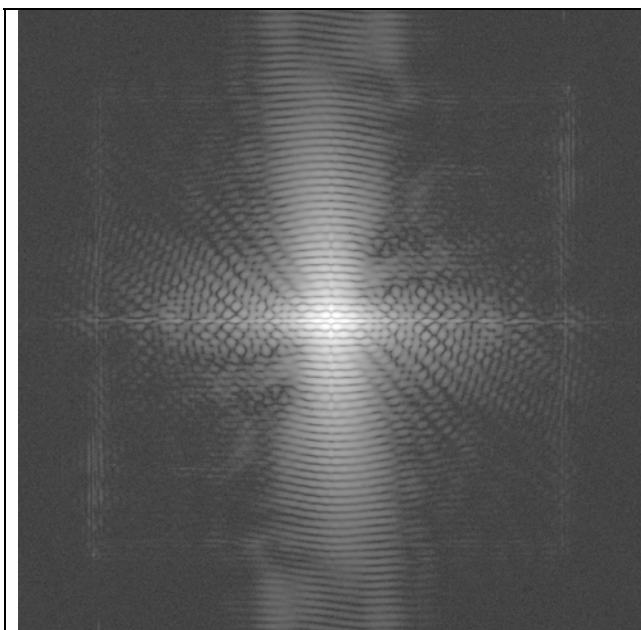


Fig.5 FFT of first dataset cleared picture

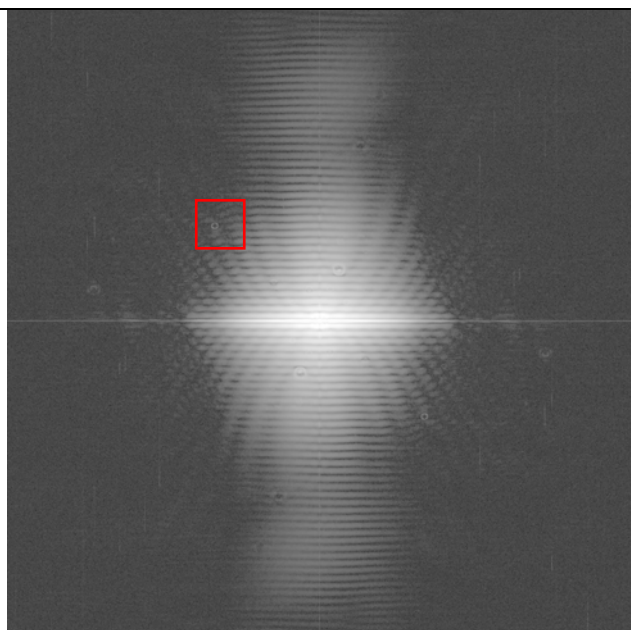


Fig.6 FFT of second dataset cleared picture

In the FFT image of second dataset we can see the cross

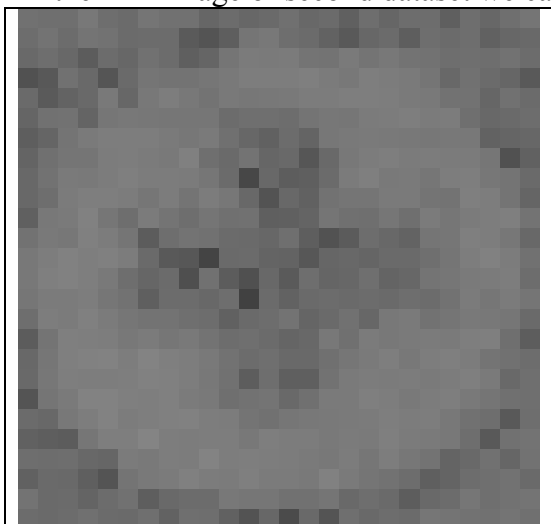


Fig.7 One of the crosses from above
10x zoom

One of the problems in reconstructing the sample is intensity from collimation slits. To get the information we need to put the mask on the data images, filled with average background.

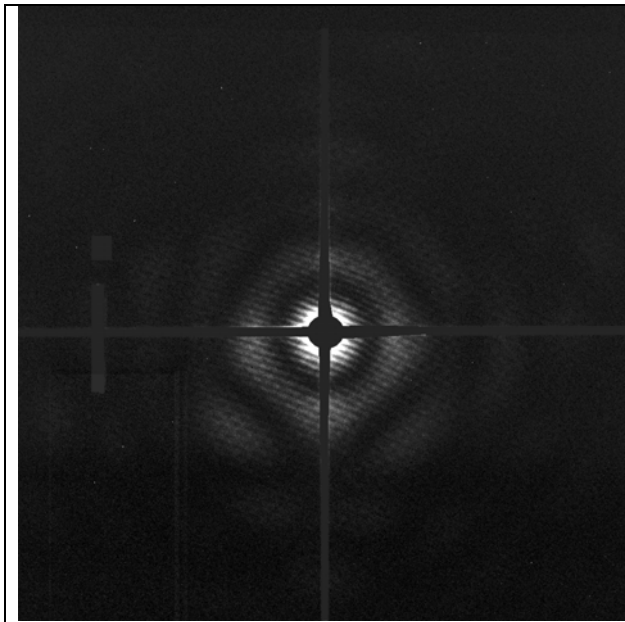


Fig.8 First dataset binned, with mask

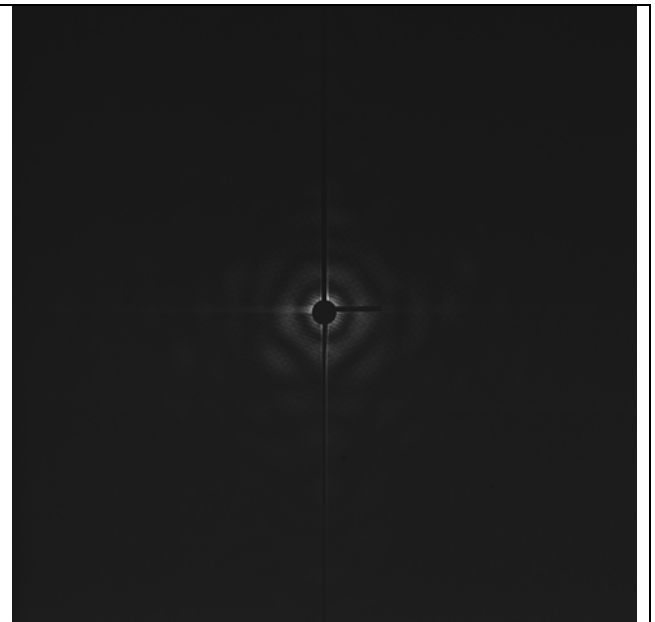


Fig.9 second dataset with mask

The FFT of these data pictures

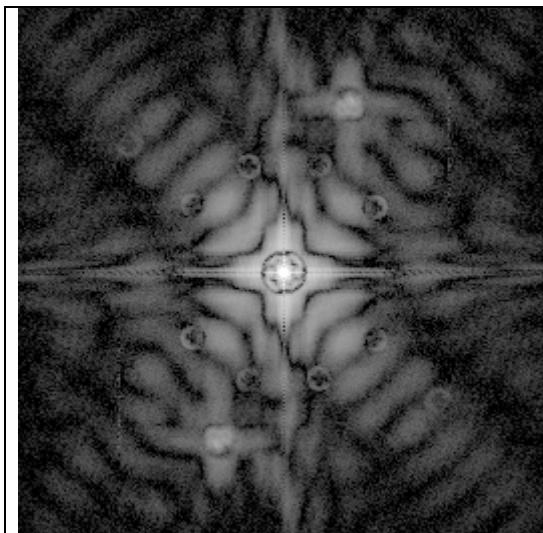


Fig.10. FFT of first dataset binned, with mask

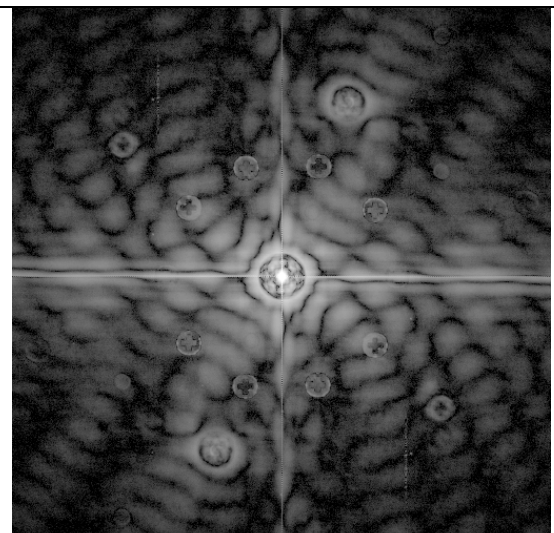


Fig.11. FFT of second dataset with mask

We can observe 8 crosses on each reconstructed image.
To fit the mask better with the background, we smooth the mask with a Gaussian function.

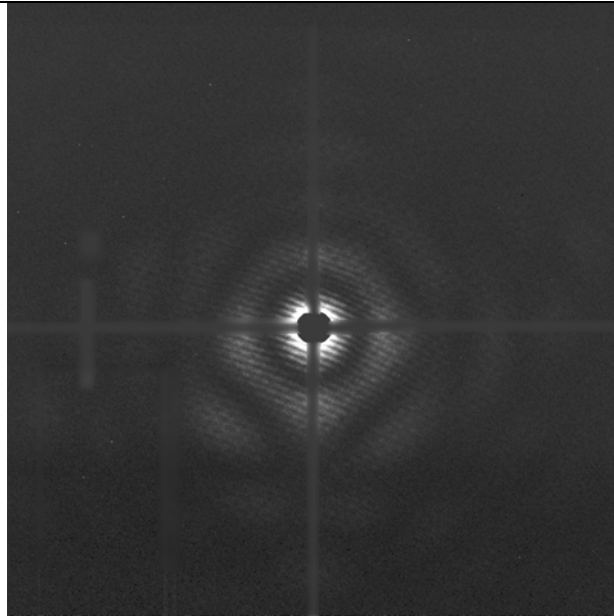


Fig.12. First dataset – binned with smoothed mask

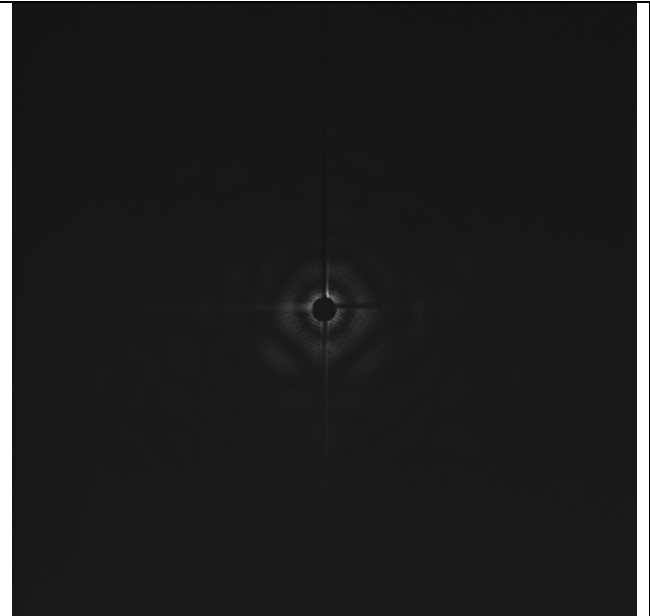


Fig.13. Second dataset – with smoothed mask

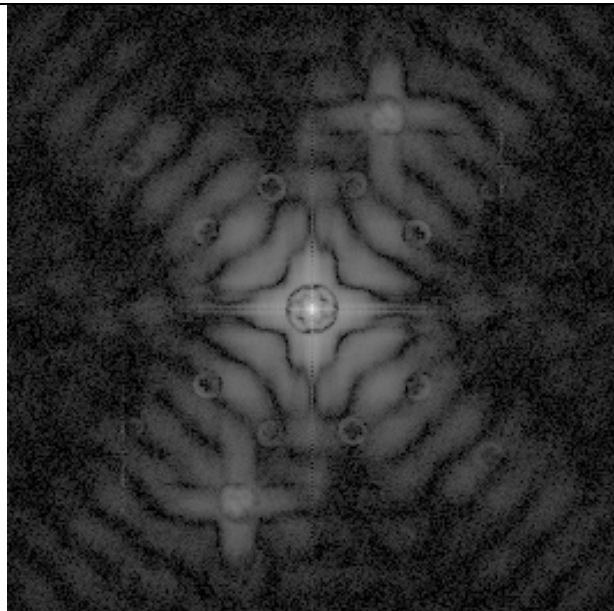


Fig.14. FFT of first dataset –binned, with smoothed mask

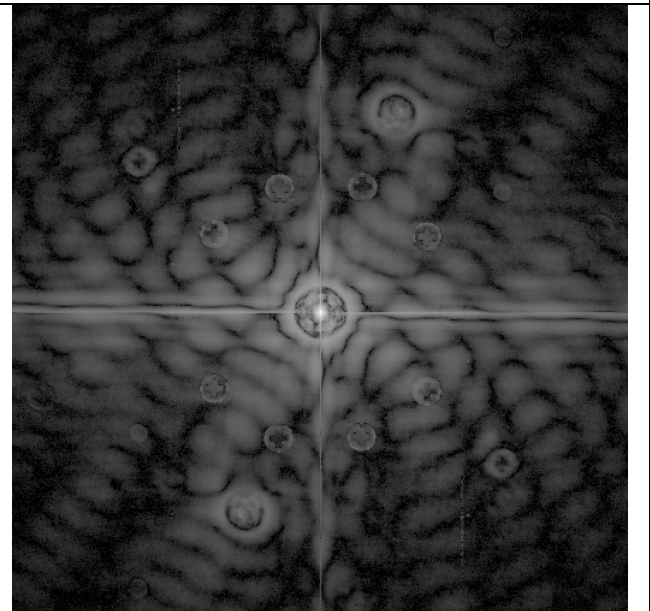


Fig.15. FFT of second dataset –with smoothed mask

Part of information is lost because of beamstop, so the next step is smoothing the beamstop with the same function

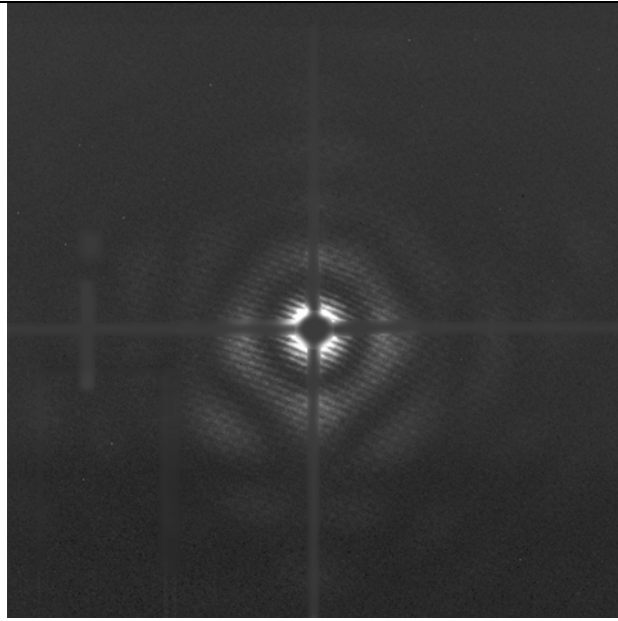


Fig.16. First dataset –binned, with smoothed mask and beamstop

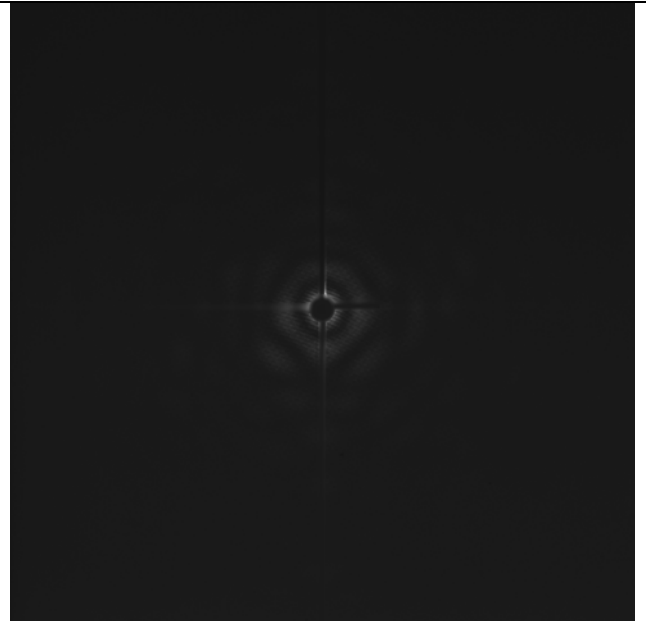


Fig.17. Second dataset –with smoothed mask and beamstop

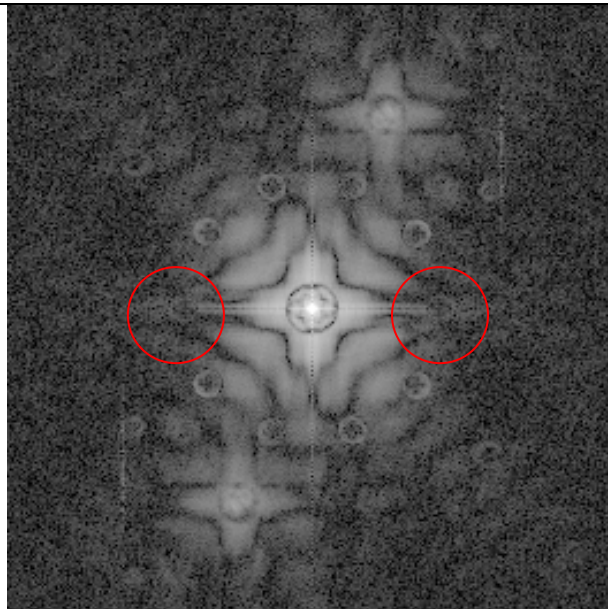


Fig.18. FFT of first dataset –binned, with smoothed mask and beamstop

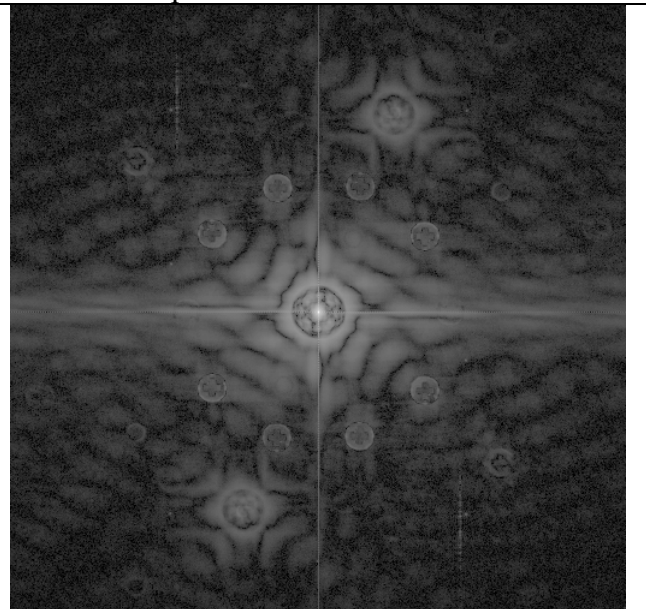


Fig.19. FFT of second dataset –with smoothed mask and beamstop

Following the FFT of the first dataset 2 more crosses are visible.
For the first dataset an FFT of only the center of the picture was also preformed.

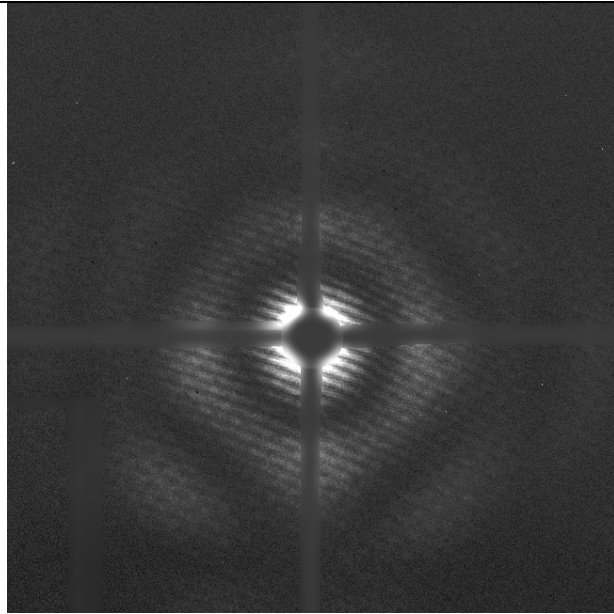


Fig.20. First dataset –binned, with smoothed mask and beamstop – center of image

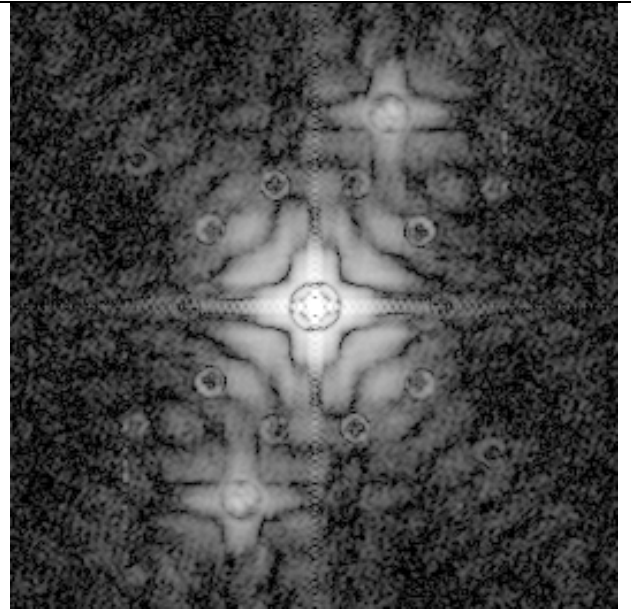


Fig.21. FFT of first dataset –binned, with smoothed mask and beamstop – center of image

To better reconstruct the sample by improving the statistics in the reconstructed image we need to cut the crosses out from FFT image, correlate them and sum. There is too few pixels per cross in the first dataset, so we have used 10 times rescaling to mediate the possibility that there is a shift less than one pixel.

Correlated images of the first dataset

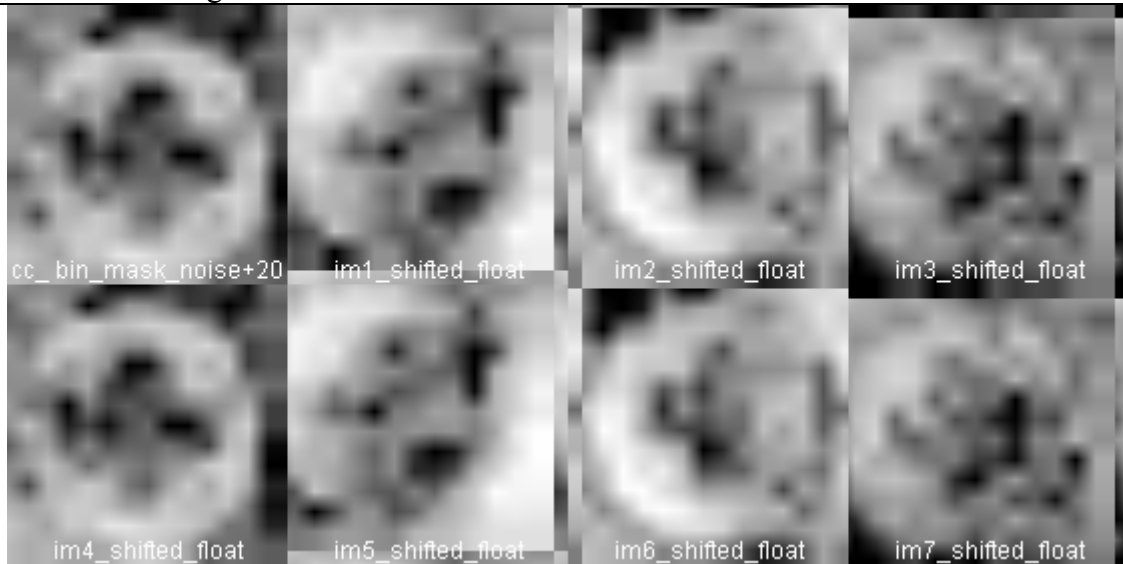


Fig.22. Binned with mask

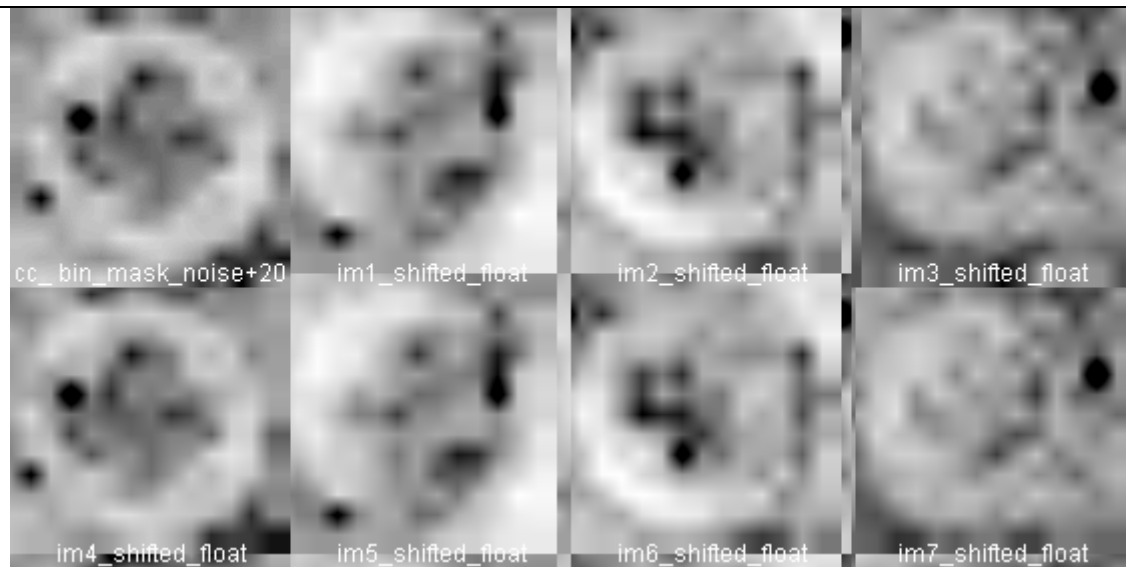


Fig.23. Binned with smoothed mask

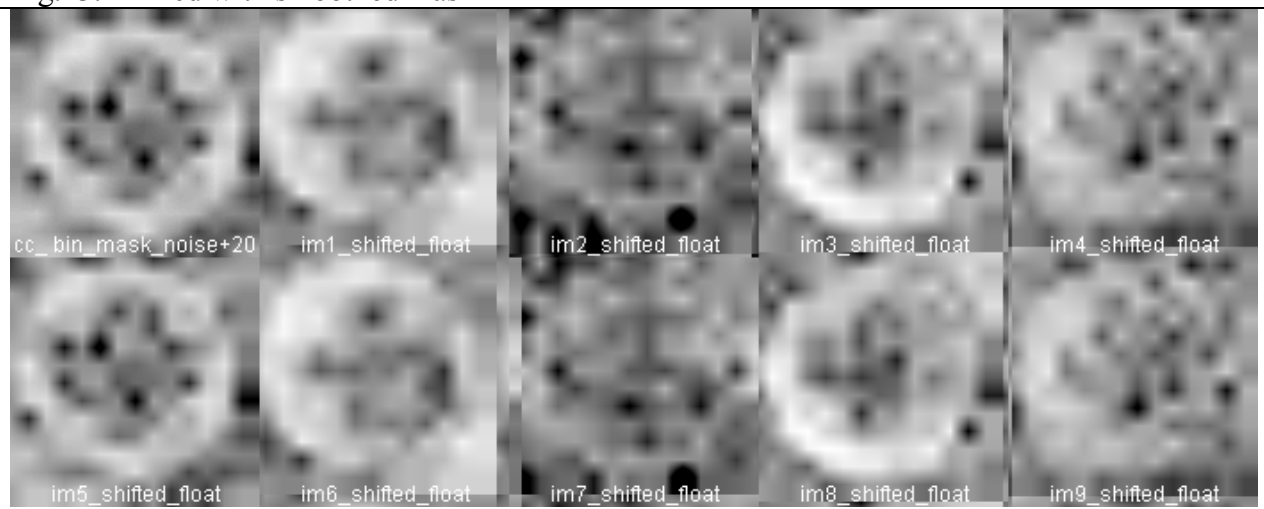


Fig.24. Binned with smoothed mask and beamstop

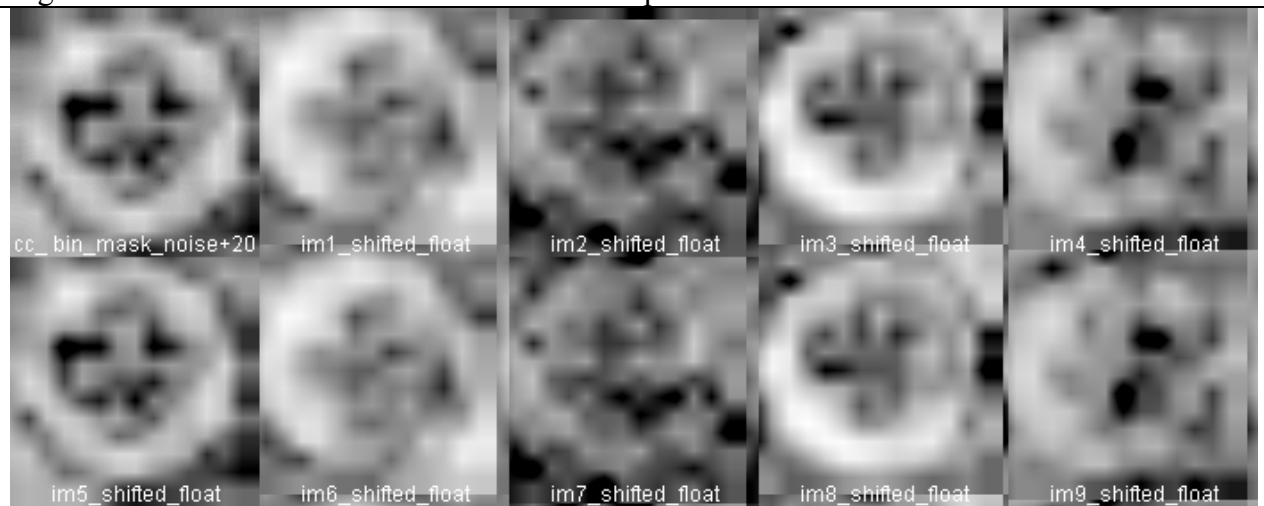
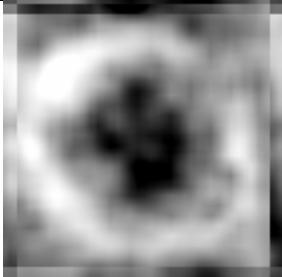
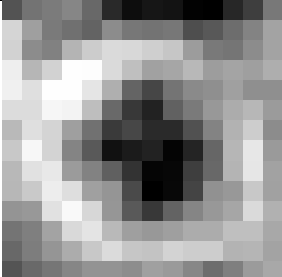
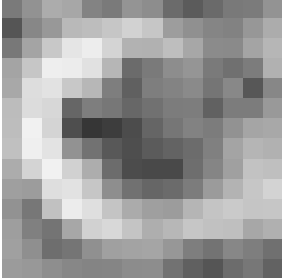
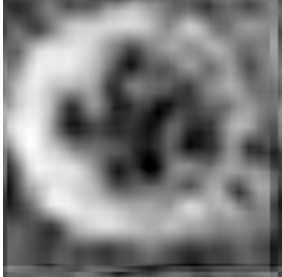
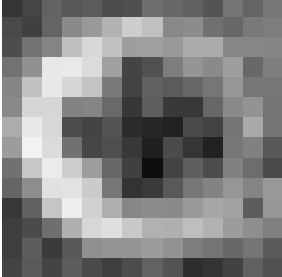
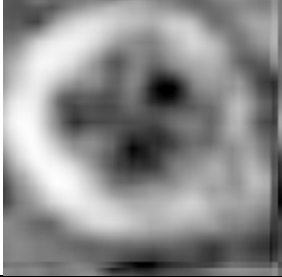
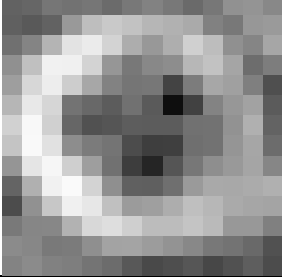


Fig.25. center of binned with smoothed mask and beamstop

Crosses reconstruction

140*140 pxl		14*14 pxl (10 times zoom)	
	Fig.26.Binned with mask		Fig.27. Binned with mask
	Fig.28. Binned with smoothed mask		Fig.29. Binned with smoothed mask
	Fig.30.Binned with smoothed mask and beamstop		Fig.31.Binned with smoothed mask and beamstop
	Fig.32.Binned with smoothed mask and beamstop – center		Fig.33.Binned with smoothed mask and beamstop – center

Reconstruction of second dataset crosses

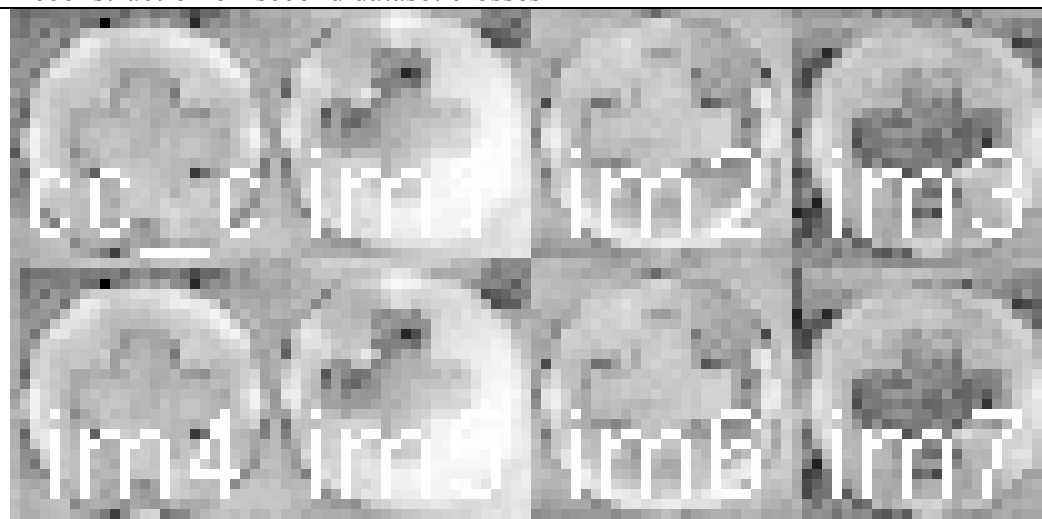


Fig.34. With mask



Fig.35. With smoothed mask

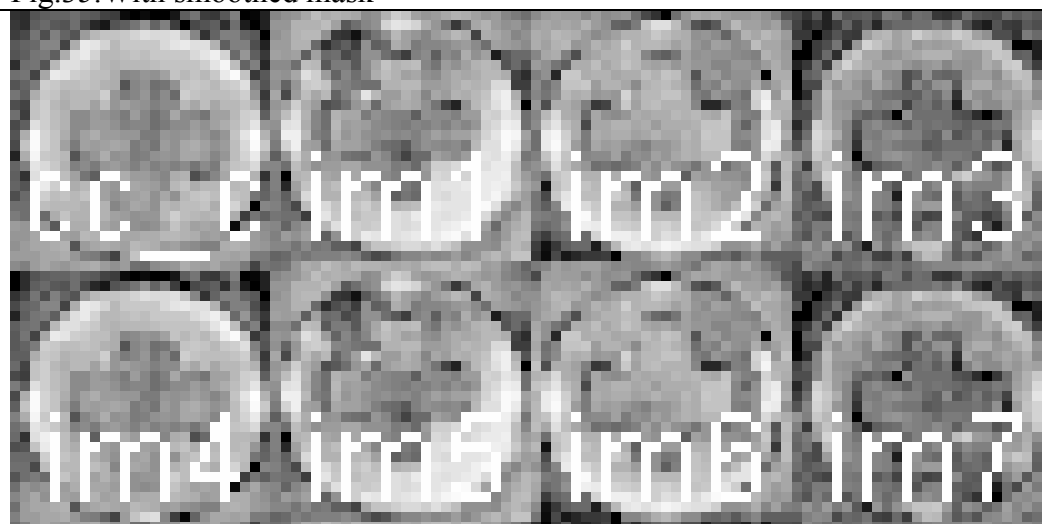


Fig.36. With smoothed mask and beamstop

26*26 pix (10 times zoom)

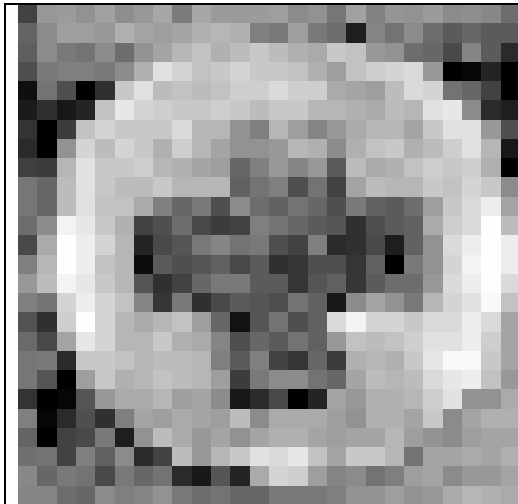


Fig.37.With mask

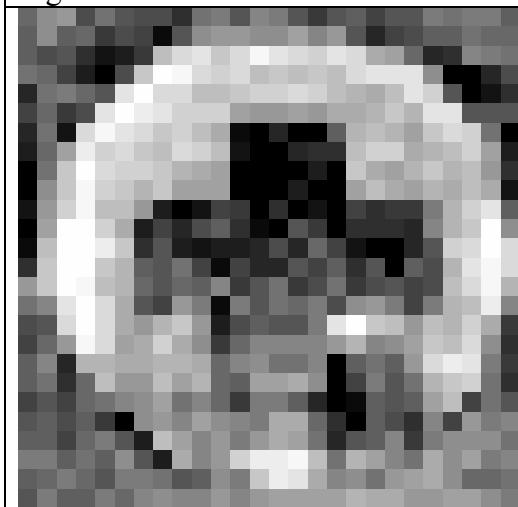


Fig.38.With smoothed mask

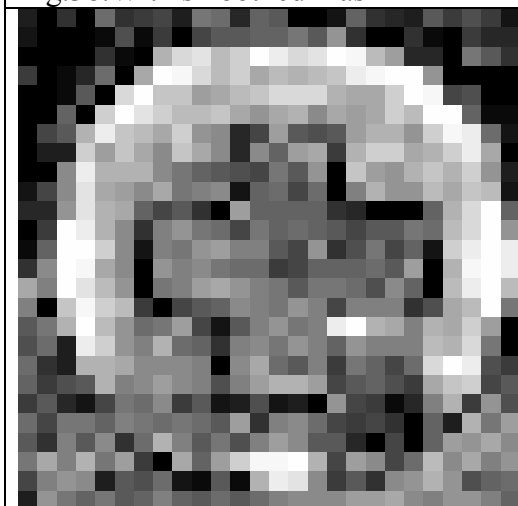


Fig.39.With smoothed mask and beamstop

In conclusion, Fourier holography is a good method to obtain directly an image through one operation - Fourier transformation. However the resolution is limited, and the obtained data are not ideal due to noise, missing information because of beamstop, parasitically scattered intensity from collimating slits. We may use some algorithms to improve the images despite these effects, for example – putting the mask filling it with average background, smoothing it and smoothing the beamstop.

Another problem is the intensity from the collimating slits is higher than intensity from the sample. To improve the image data a mask should be applied over the intensity and filled with the average background. To fit the mask to the background the mask should be smoothed.

Part of the information is obscured by the beamstop. To improve that somewhat, we use beamstop smoothing, which makes the FFT image appear less noisy and the crosses more contrasting.

Data obtained by Fourier Transform Holography is easy to analyze by using the FFT. For our sample reconstructions we cut the crosses out from FFT image, correlate them and average them to produce the best quality composite image. If there are too few pixels per cross, we use 10 times resizing to mediate the possibility that there is a shift of less than one pixel. We do this to average out random fluctuations and improve the contrast of the reconstructed image. However this does not influence the structural noise. Despite these circumstances with appropriate analysis we are able to reconstruct successfully our “Gold Cross” sample.