Two-photon Interference

—— From HBT interferometer toward incoherent diffraction imaging

Shanghai Institute of Optics and Fine Mechanics

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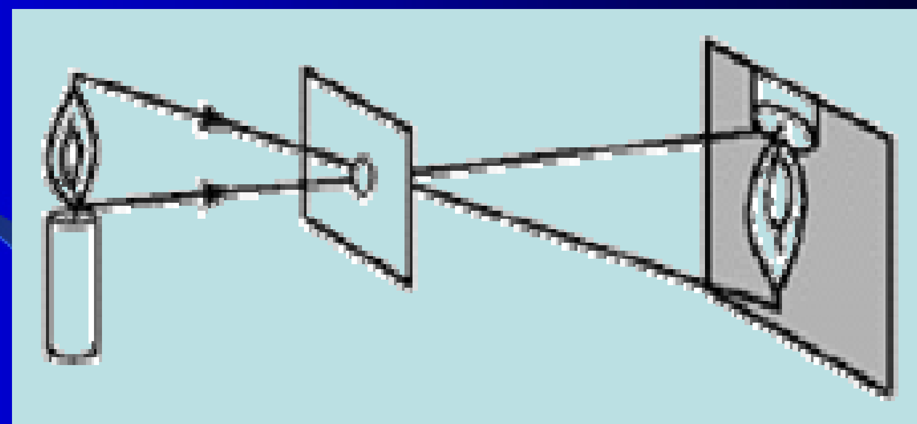
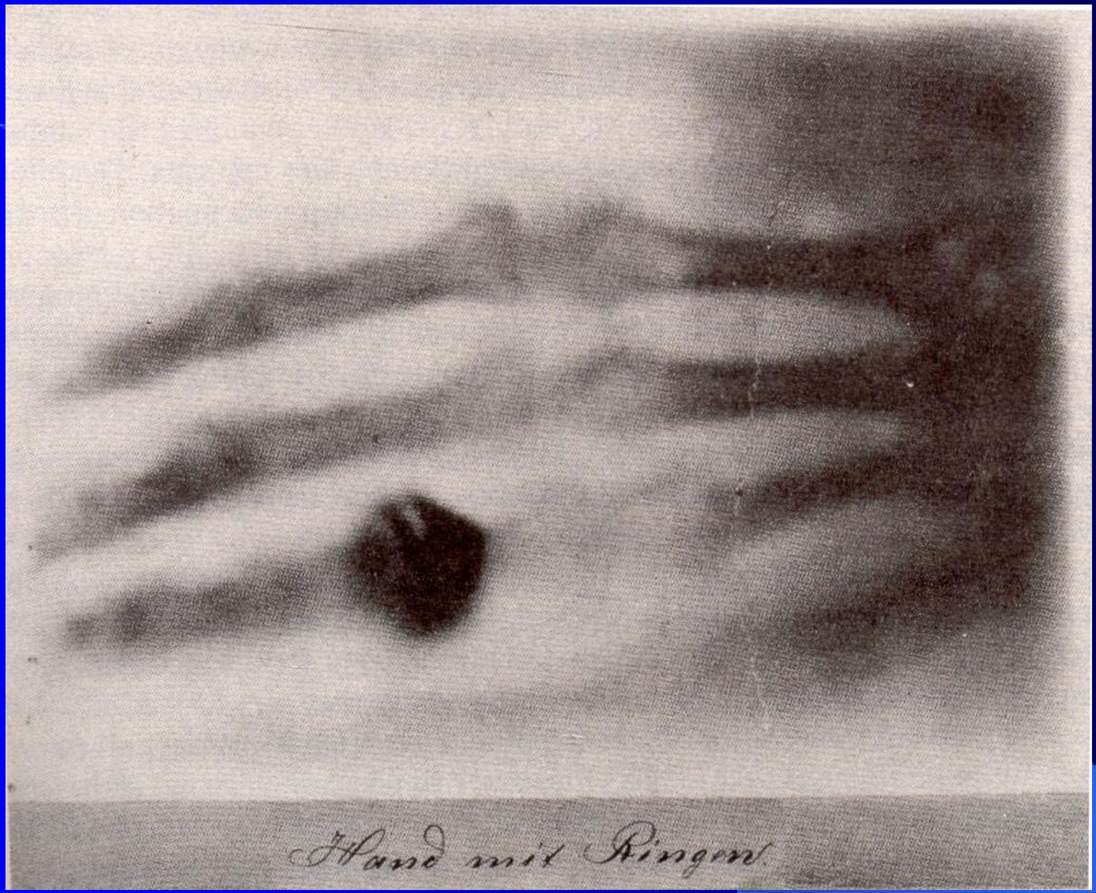
Light propagates as a straight line



“景光之人煦若射，下者之入也高，高者之入也下。”　——《墨经》

X-ray attenuate imaging



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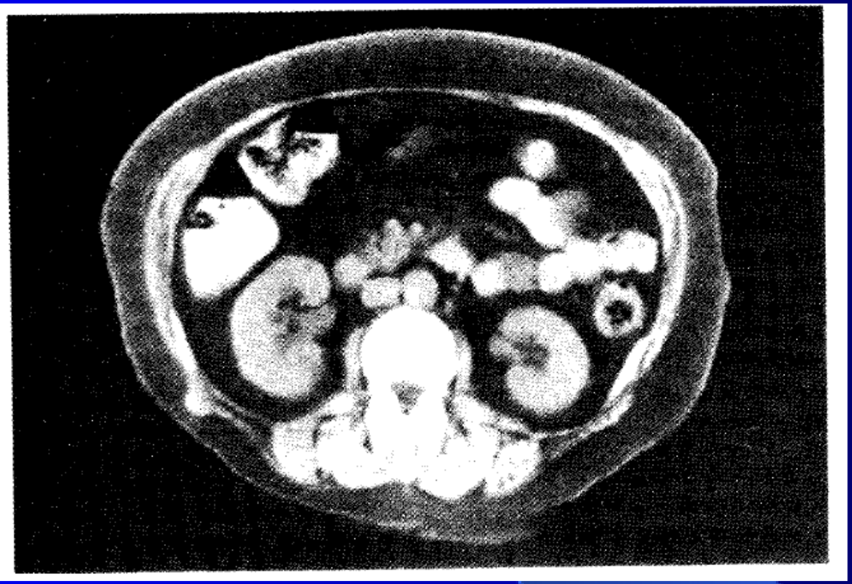
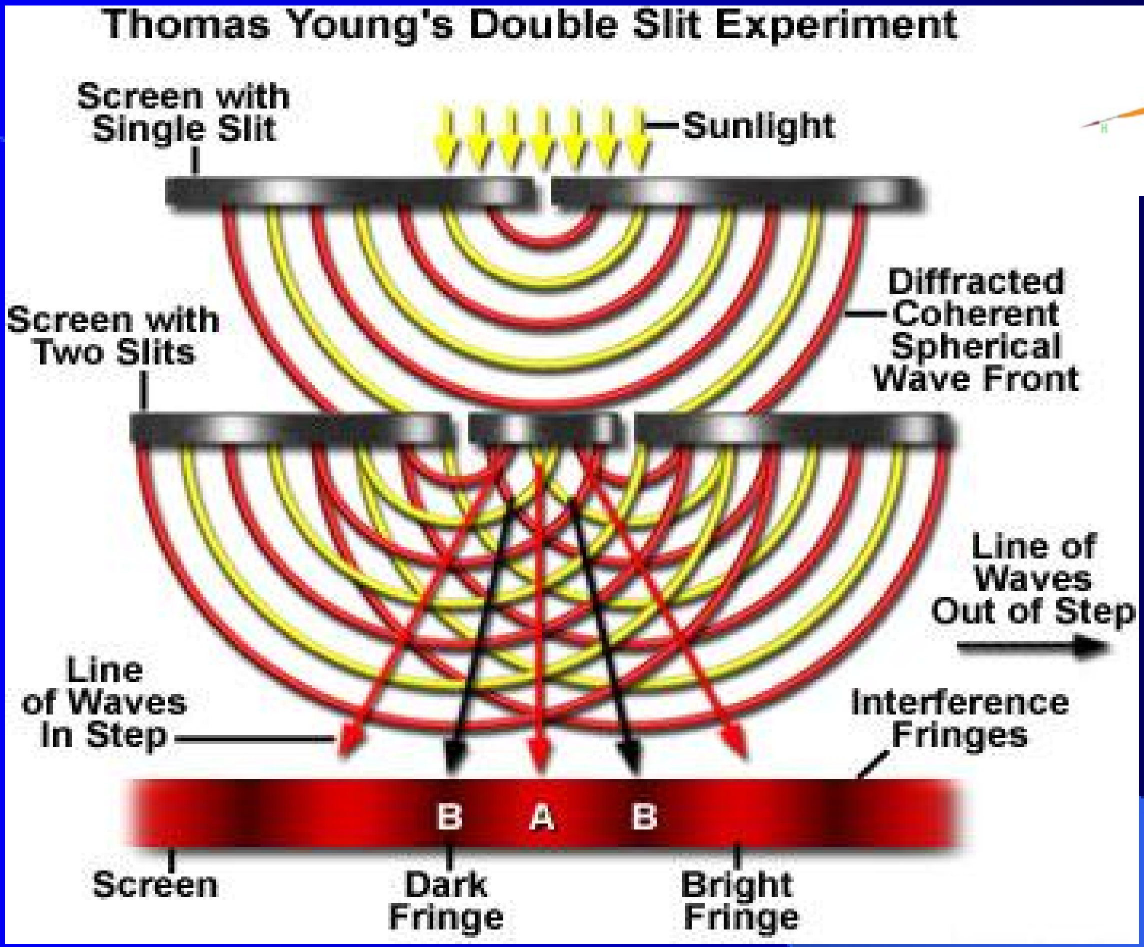
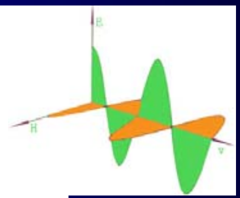
X-ray Computed Tomography



X-ray CT scan taken through the kidneys. G. N. Hounsfield, ”Computed medical imaging”, Nobel Lecture, 8 December, 1979.

Light propagates as Electromagnetic Wave





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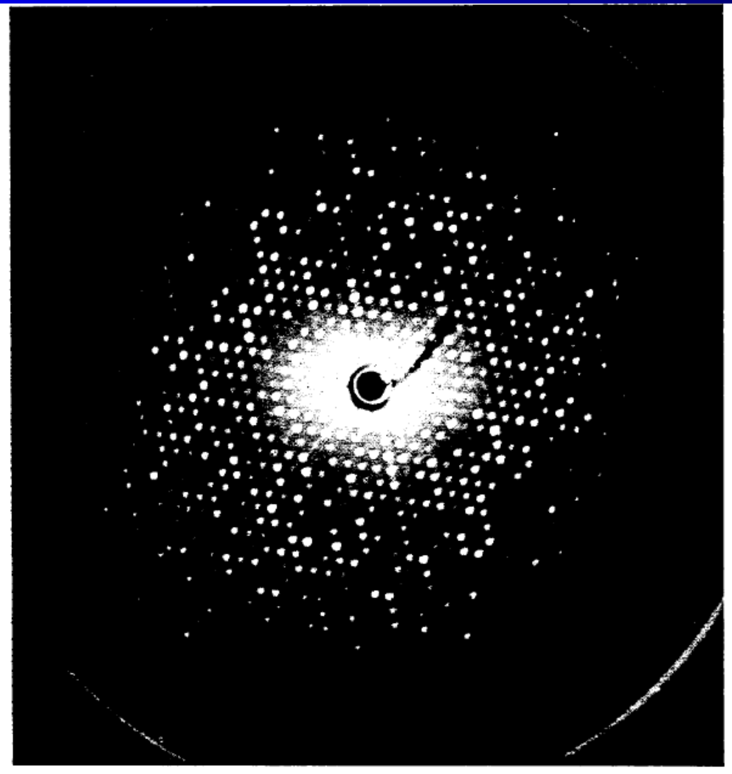
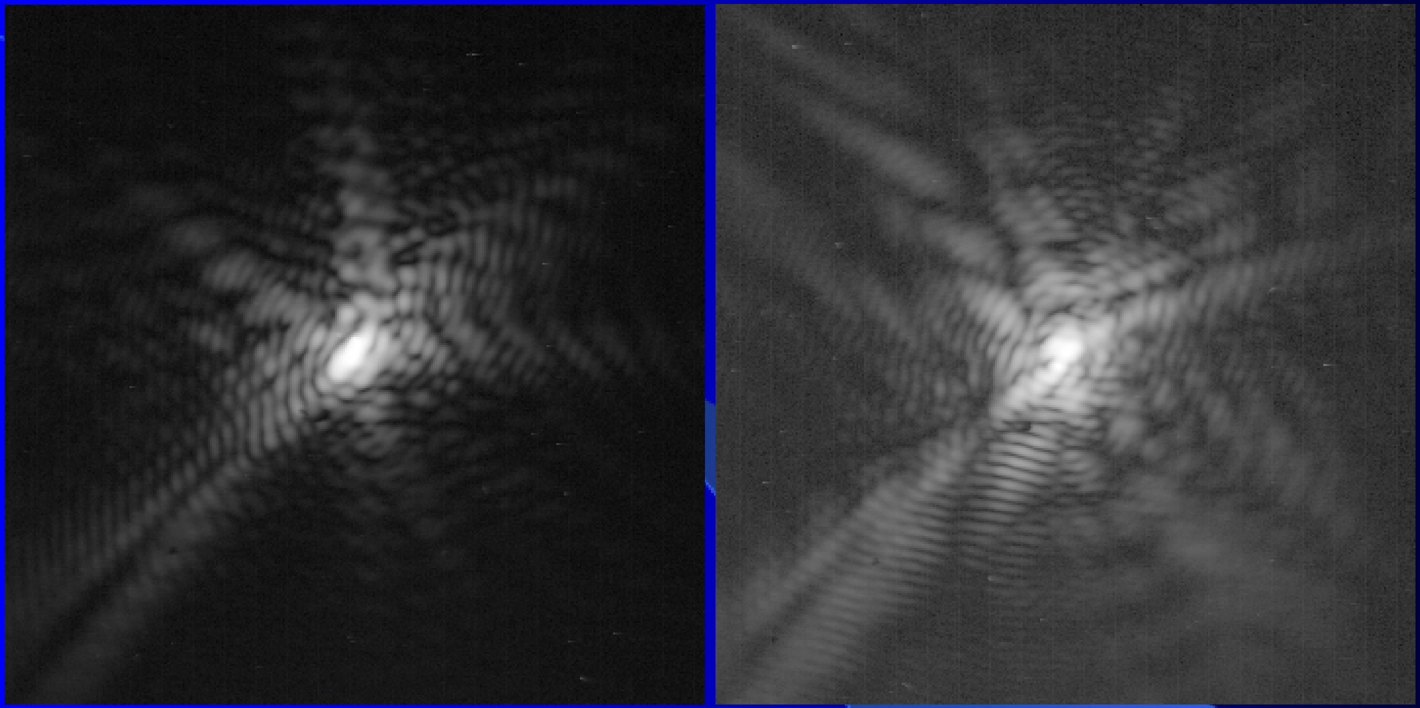
X-ray Diffraction Pattern From a Haemoglobin Crystal



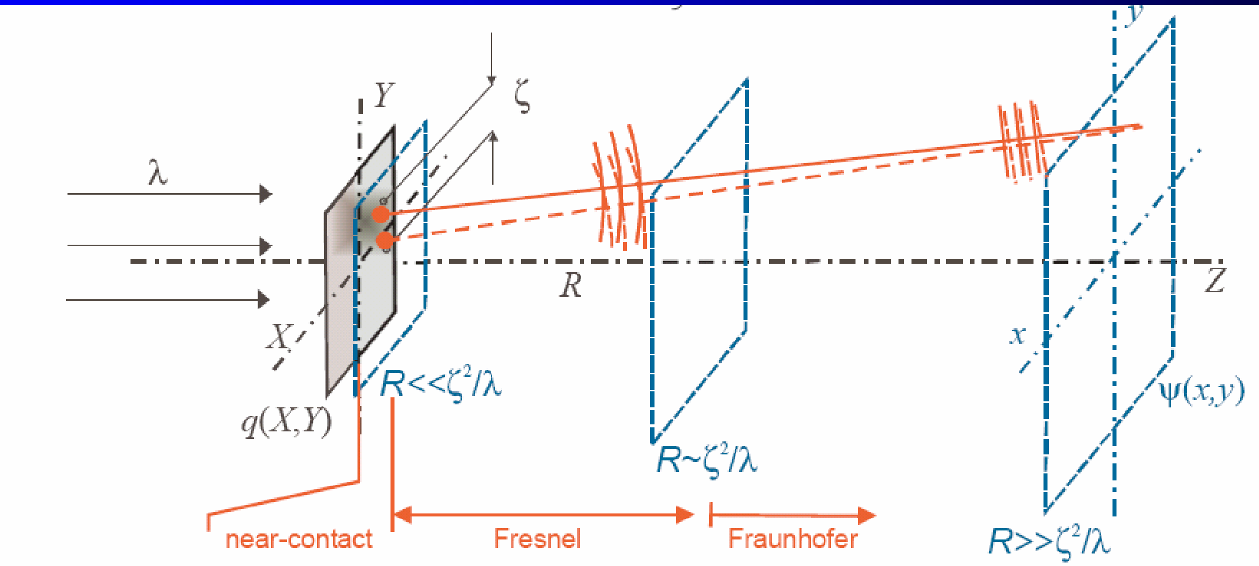
Max F. Perutz, “X-ray analysis of haemoglobin”, Nobel Lecture, December 11, 1962

Diffraction patterns from yeast cells



(Results from Stony Brook group)

Attenuate Imaging, Phase-contrast Imaging and Fourier-transform Diffraction



- Near contact: only absorption contrast
- Fresnel: feature of size ζ appears in phase contrast
- Fraunhofer: ψ Fourier transform of q (e.g., protein crystallography)

(One-photon absorption and interference)

Transverse Coherent Length for Thermal Source and Fraunhofer Distance

Transverse coherence length:

X_{coh} = wavelength*D_{obj}/(2*pi*R_{source});

Fraunhofer distance:

Z >> D_F = pi*X_{sample}^2/wavelength;

For R_{source} =100um, wavelength=1nm, D_{obj}=60m, X_{sample} = $X_{coh:}$

X_{coh} = 100um, L_F = 30m

Coherent X-ray Diffractive Imaging

Is it possible to get coherent diffractive pattern with incoherent illumination?

No limits on the source size\sample size!

Unnecessary for long objective distance!

Is it possible to get Fourier-transform diffraction pattern at Fresnel distance?

Unnecessary for long Fraunhofer distance !

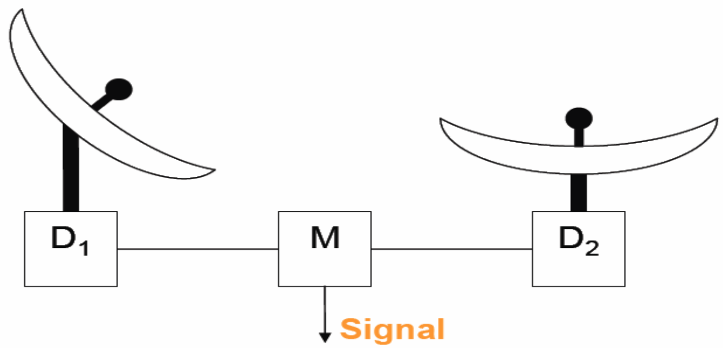
Conventional Optics → No!

HBT Interferometer
The two photon interference

R. Hanbury Brown and R. Q. Twiss

Intensity interferometry

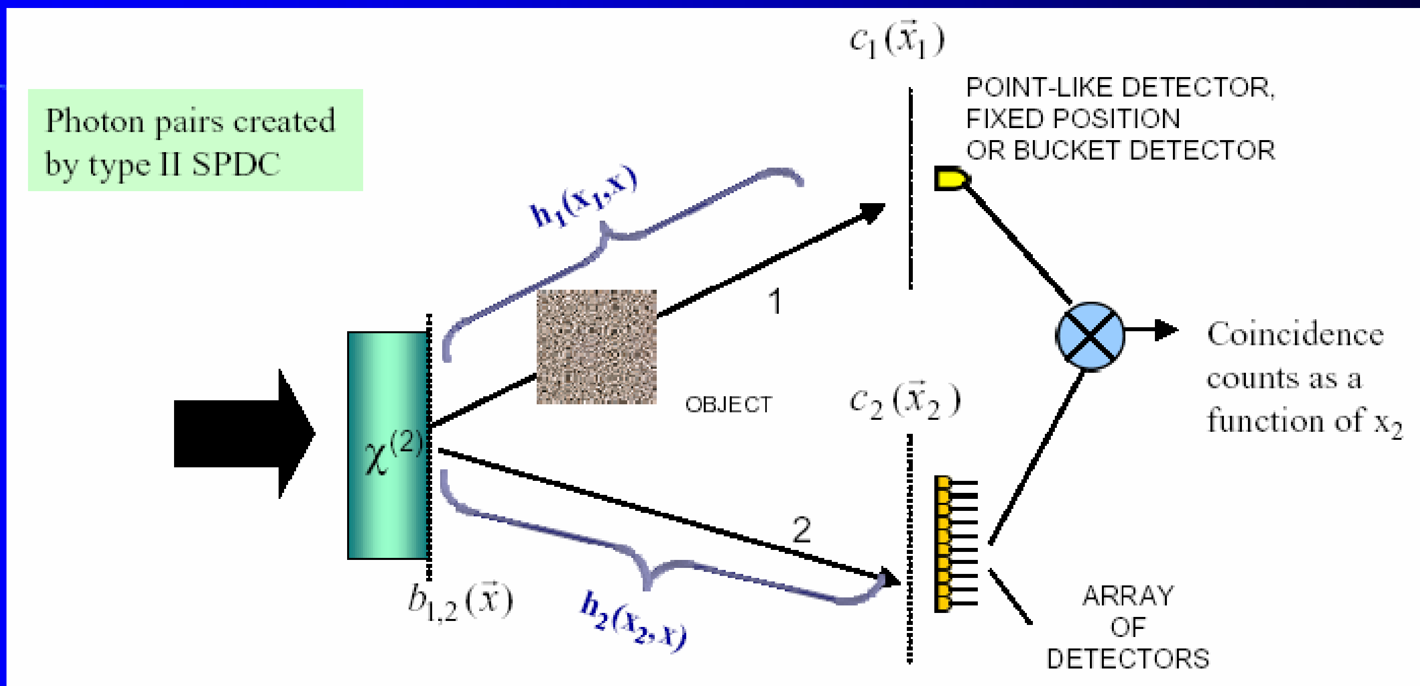
Two square-law detectors



Ordinary (Amplitude) interferometry measures $G^{(1)}(r,t,r',t')=\langle E^{(-)}(r,t)E^{(+)}(r',t')\rangle$

Intensity interferometry measures $G^{(2)}(r,t,r',t')=\langle E^{(-)}(r,t)E^{(-)}(r',t')E^{(+)}(r',t')E^{(+)}(r,t)\rangle$

Two-photon Interference in Imaging



In 1994, Belinsky and Klyshko found that “ghost” imaging (diffraction) can be performed with entangled incoherent light by exploiting the spatial correlation between two entangled photons.

“Ghost” Imaging or Quantum Imaging

- “Ghost imaging” is named because the imaging of an object, diffractive or geometrical, would appear as a function of the position in the path that actually never pass the object.
- Is the quantum entanglement necessary for “ghost” imaging?
- Can we perform “ghost” imaging with thermal incoherent light?

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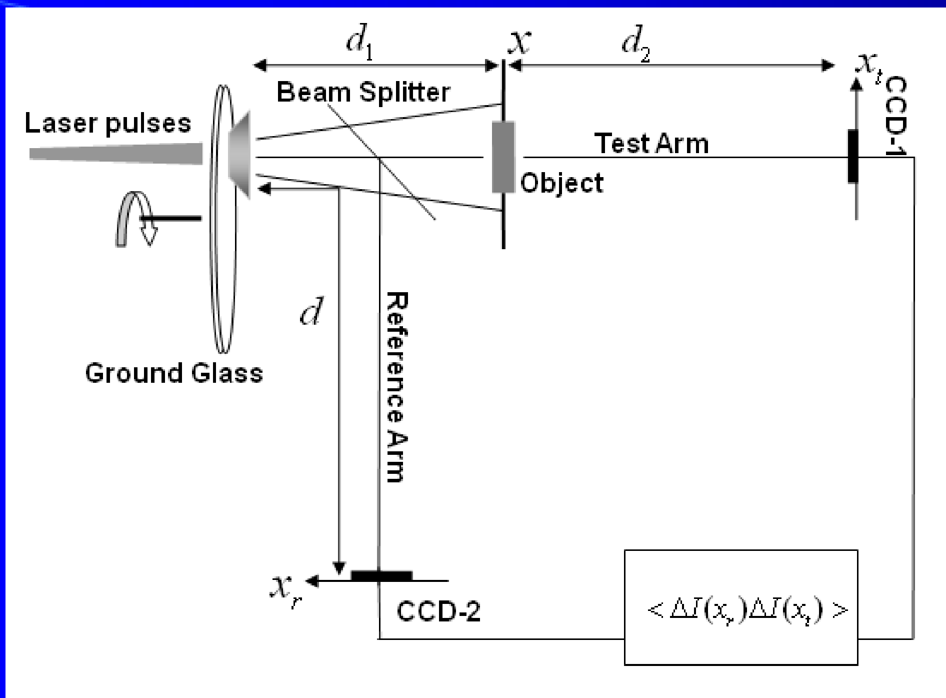
Experiment on Lensless Fourier-transform "Ghost" Diffractive Imaging



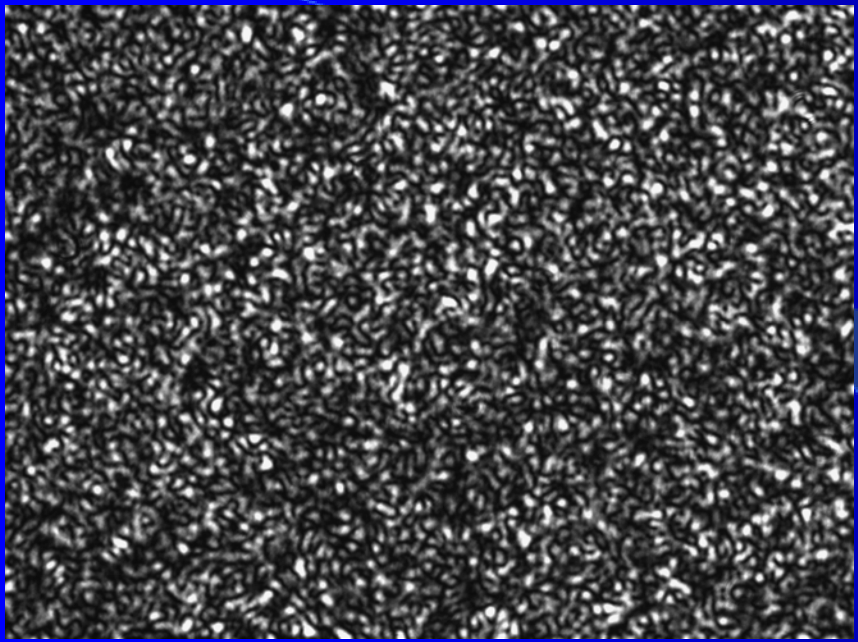
Experimental setup for the lensless Fourier-transform ghost diffractive imaging

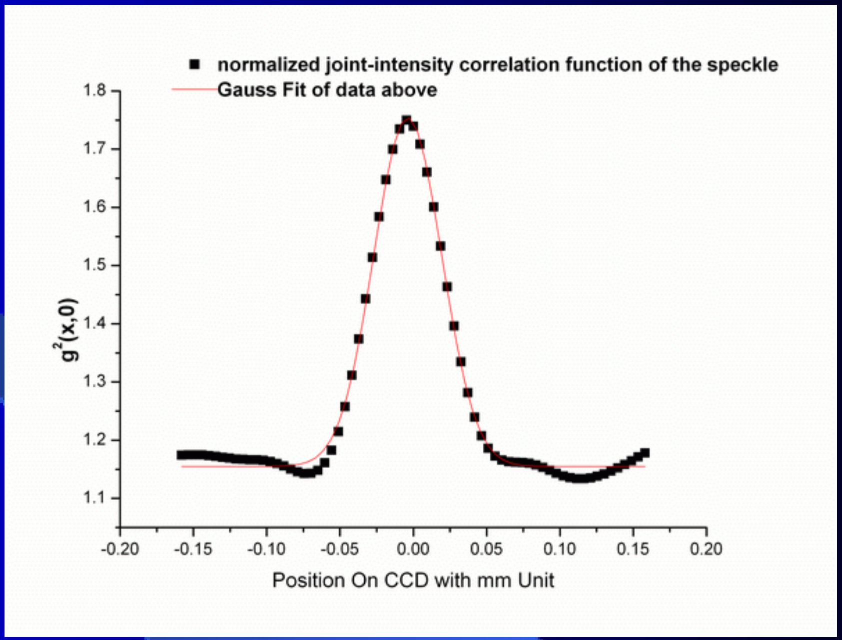
The pseudo-thermal source is obtained by illuminating a pulsed Nd:YAG laser beam with the wavelength of 0.532 um into a slowly rotating ground glass disk.

A non-polarizing beam splitter splits the radiation into two distinct optical paths.

$d = d_1 + d_2$;

Experiment on Lensless Fourier-transform "Ghost" Diffractive Imaging





Second correlation function of the pseudo-thermal light:

$g^{(2)} = 1$ ⟶ coherent light; $g^{(2)} = 2$ ⟶ thermal light;

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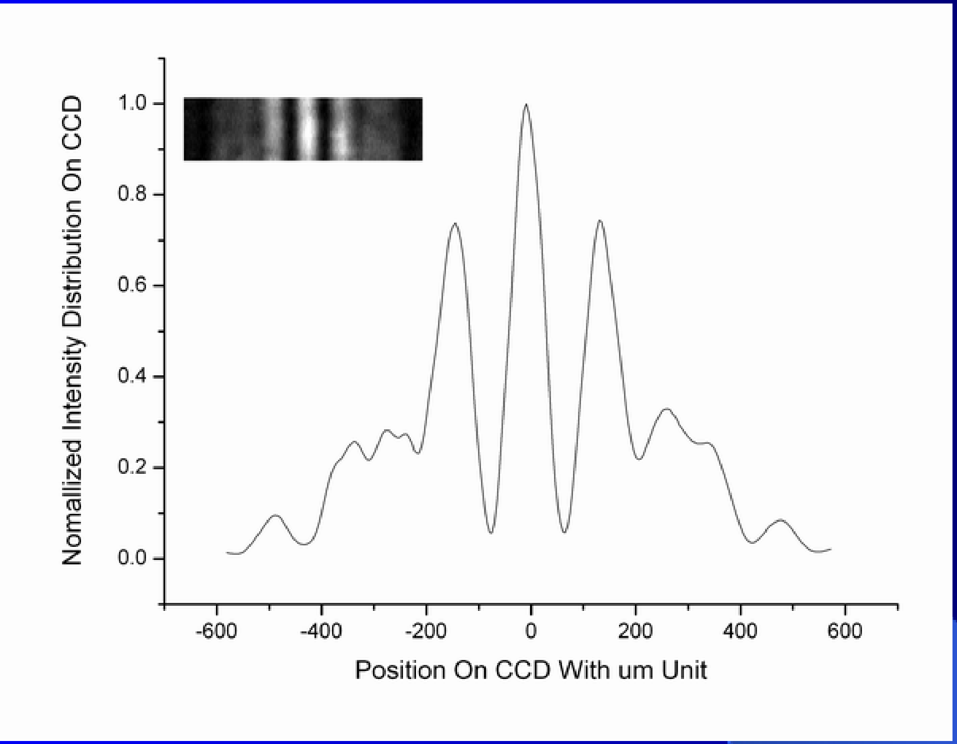
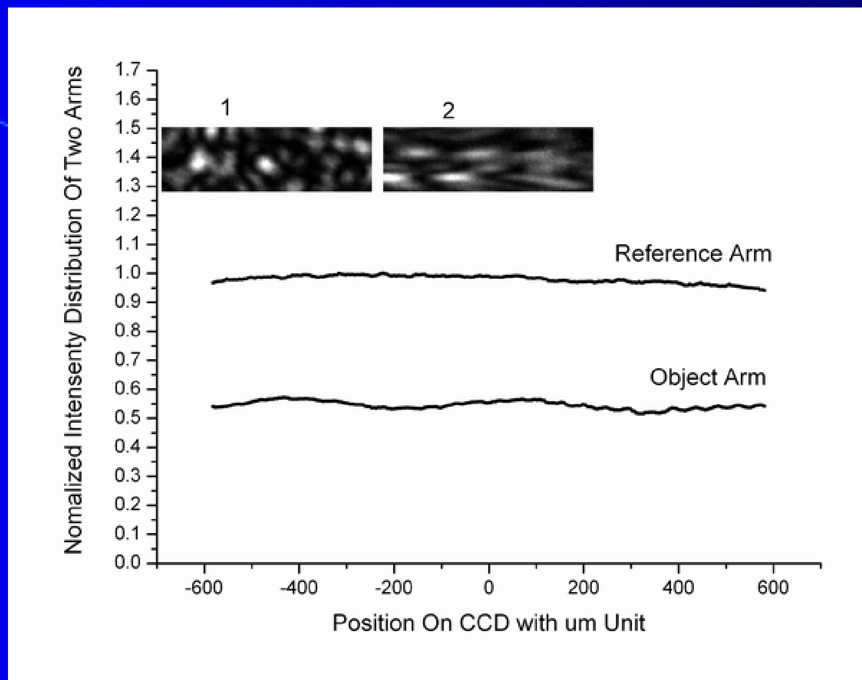
Lensless Fourier-transform "Ghost" Diffractive Imaging for Amplitude-only Sample



The two slits are separated by 302um and have a width of 105um.

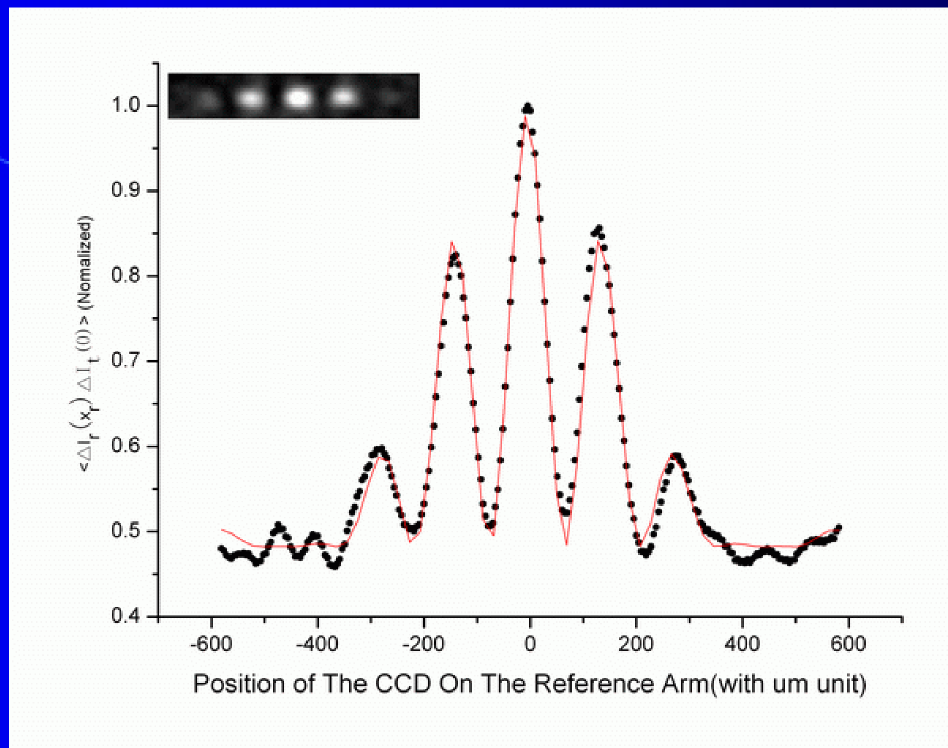
Fresnel diffraction pattern recorded in the test arm when the Young's double-slit was illuminated by laser;

Lensless Fourier-transform "Ghost" Diffractive Imaging for Amplitude-only Sample



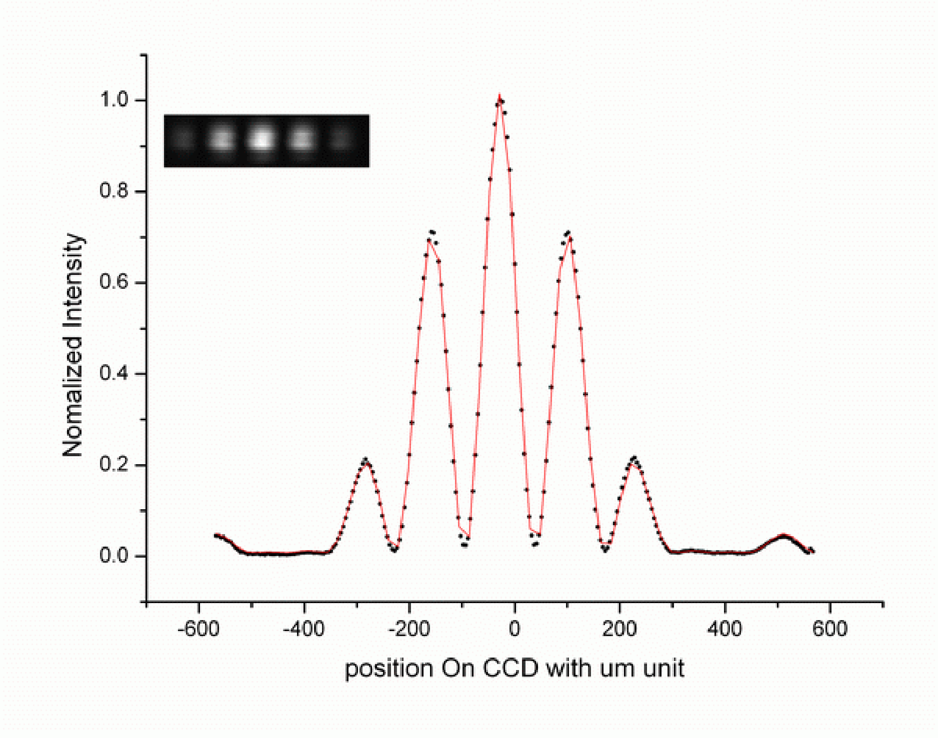
Instantaneous intensity distribution (top) and the cross-sections of averaged intensity distribution (bottom) of 1-reference arm, 2-test arm when the object was illuminated by pseudo-thermal light;

Lensless Fourier-transform “Ghost” Diffractive Imaging for Amplitude-only Sample



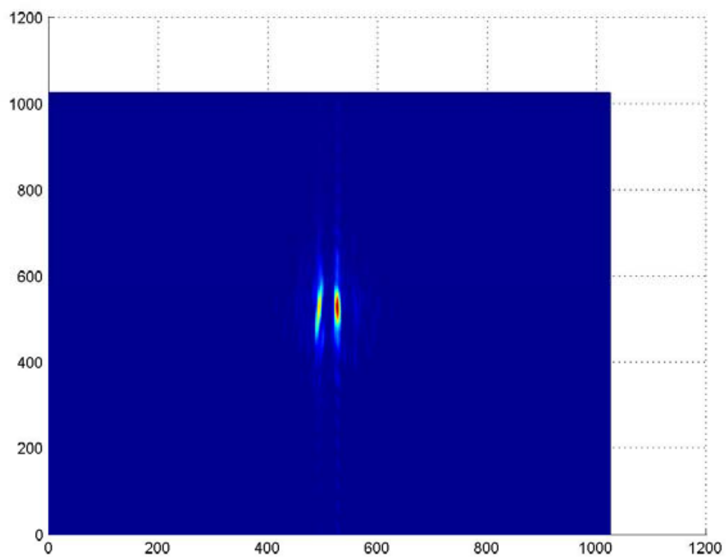
Fourier-transform diffraction pattern obtained by the correlation of the intensity fluctuations when the object was illuminated by pseudo-thermal light.

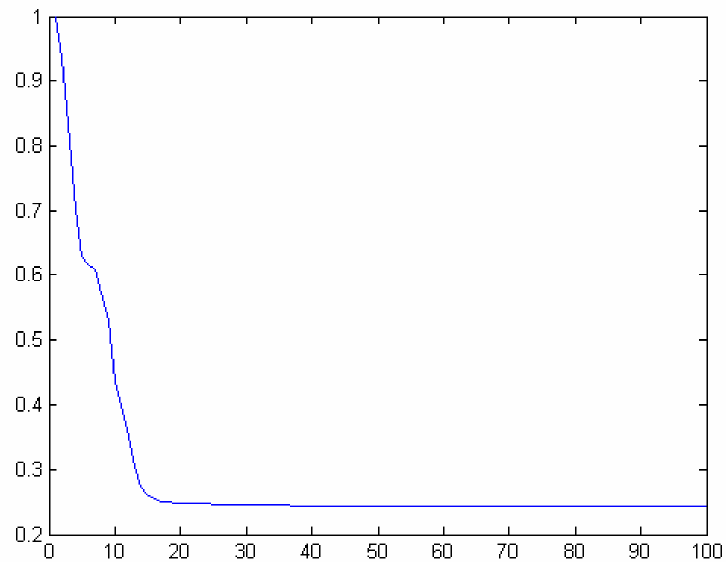
Lensless Fourier-transform "Ghost" Diffractive Imaging for Amplitude-only Sample



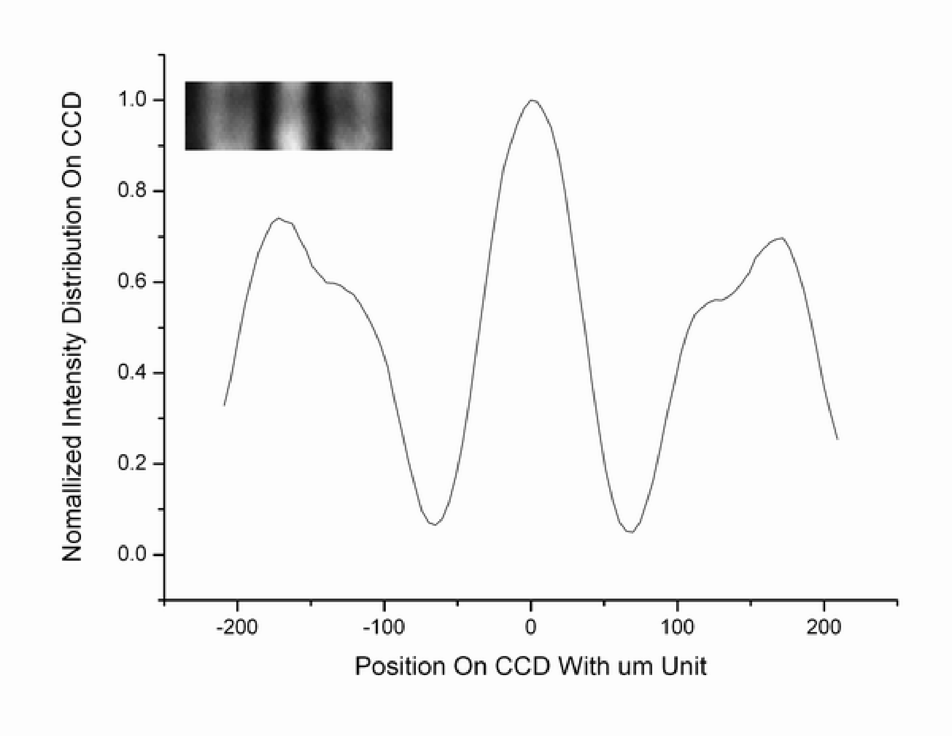
Standard Fourier-transform pattern got by a single-lens 2-f system (f=75mm) illuminated by laser

Lensless Fourier-transform “Ghost” Diffractive Imaging for Amplitude-only Sample





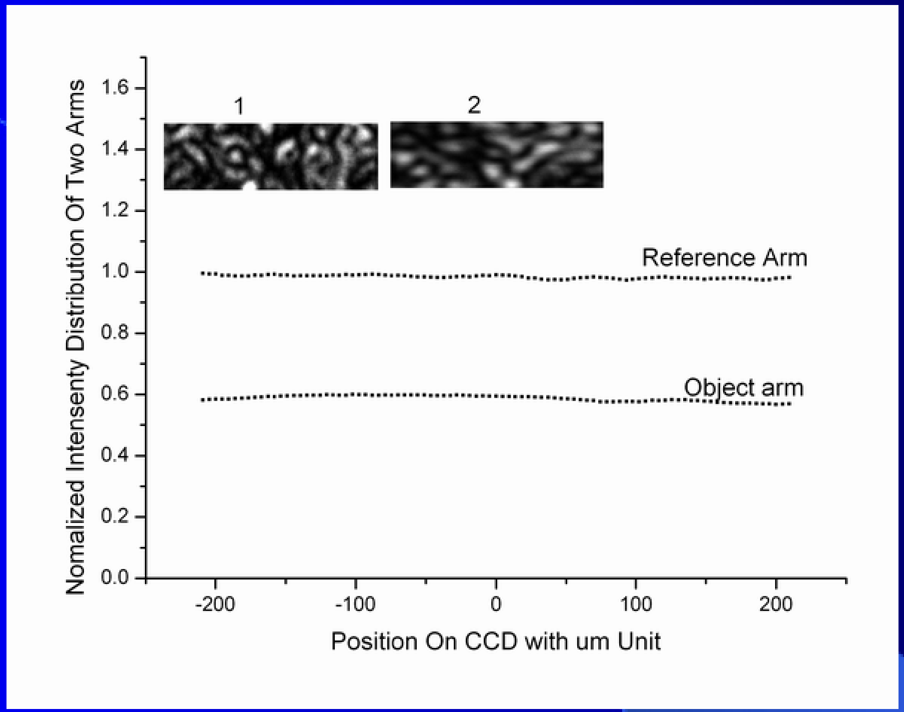
Lensless Fourier-transform "Ghost" Diffractive Imaging for Pure-phase Sample



The pure-phase object was made by etching two grooves with width of 225um and separated by 375um on a quartz glass.

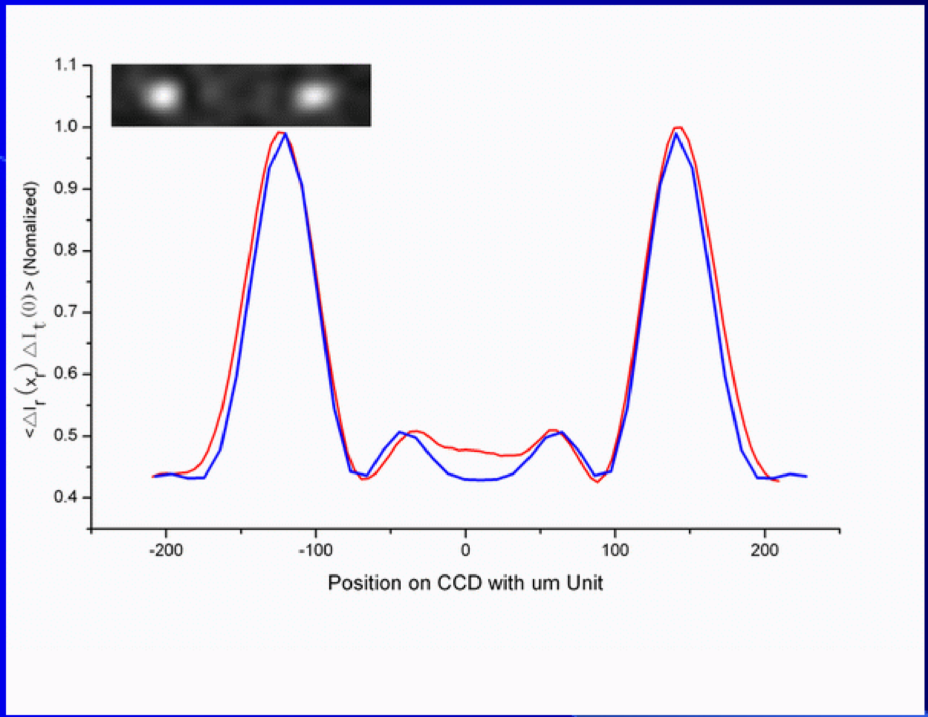
Fresnel diffraction patterns recorded in the test arm when the pure-phase double-slit was illuminated by laser

Lensless Fourier-transform "Ghost" Diffractive Imaging for Pure-phase Sample



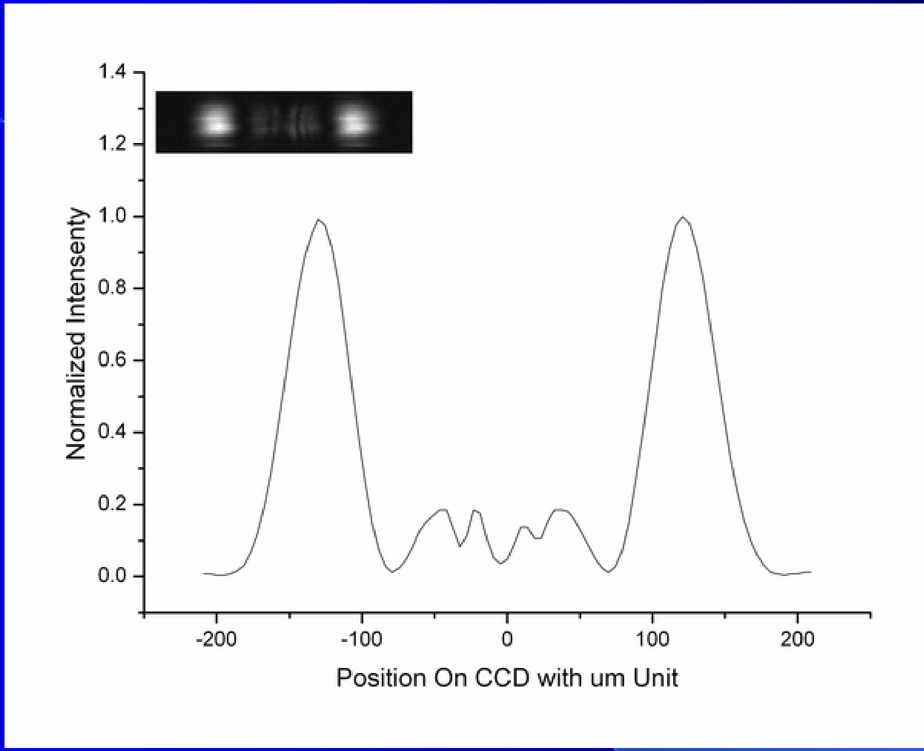
Instantaneous intensity distribution (top) and the cross-sections of averaged intensity distribution (bottom) of 1-reference arm, 2-test arm when the object was illuminated by pseudo-thermal light

Lensless Fourier-transform "Ghost" Diffractive Imaging for Pure-phase Sample



Fourier-transform diffraction pattern obtained by the correlation of the intensity fluctuations when the pure-phase double-slit was illuminated by pseudo-thermal light.

Lensless Fourier-transform "Ghost" Diffractive Imaging for Pure-phase Sample



Standard Fourier-transform pattern got by a single-lens 2-f system (f=75mm) illuminated by laser

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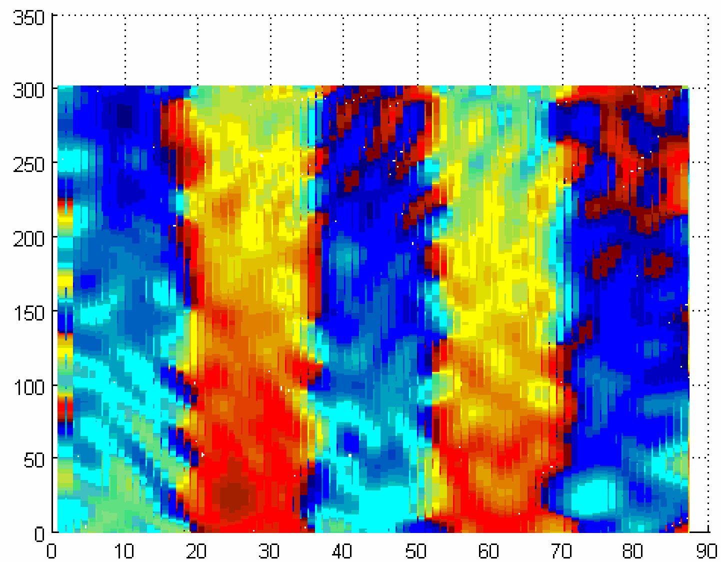

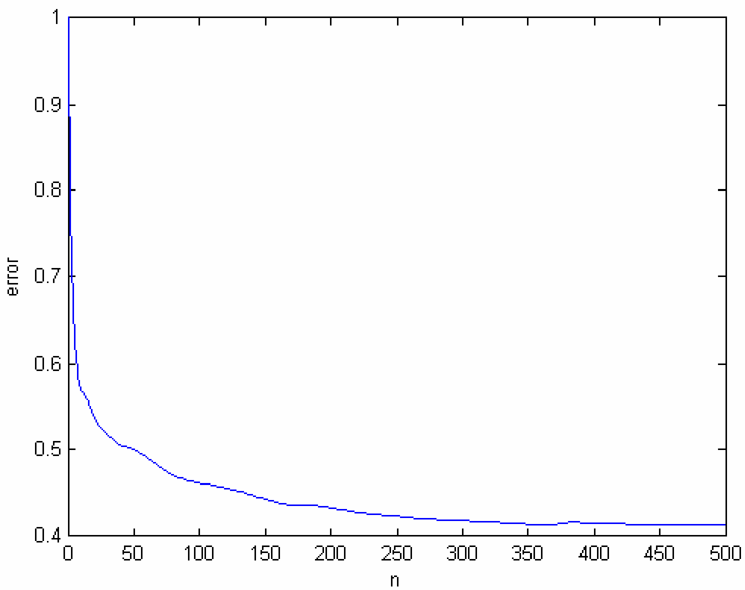

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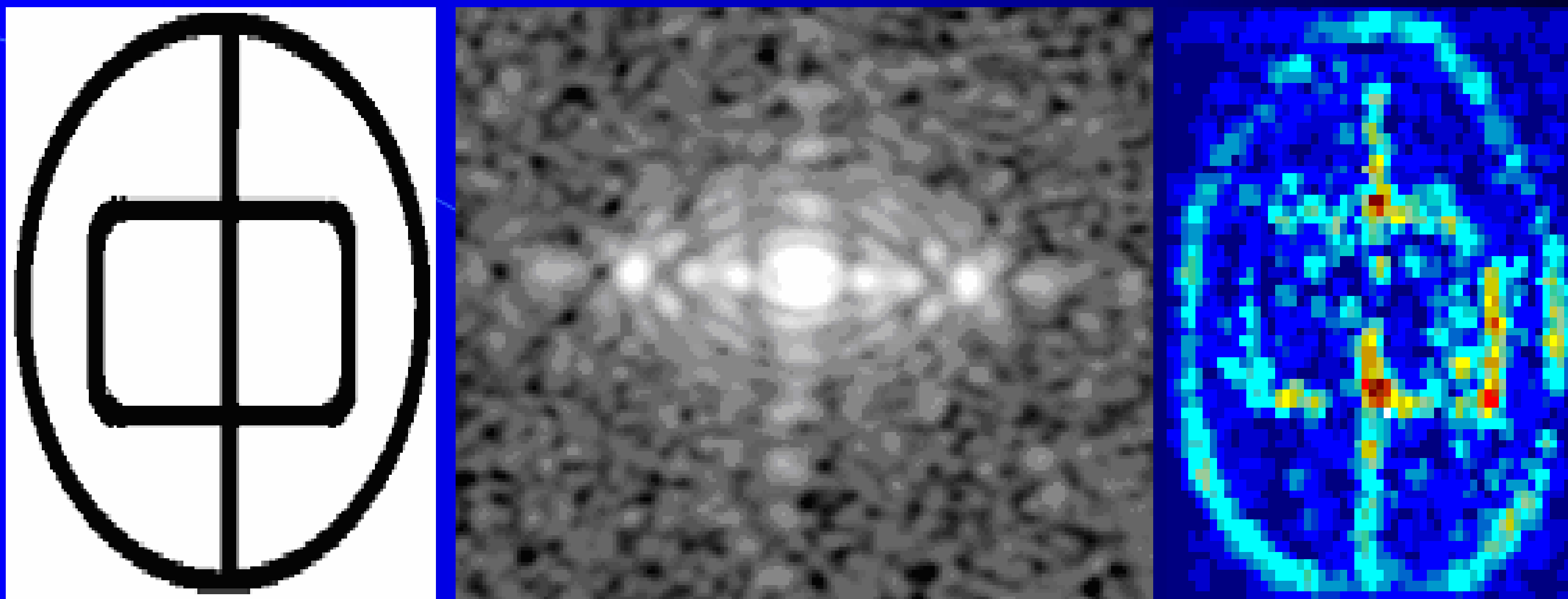
部分实验结果



（a）　　　　（b）　　　　（c）

（a）反射式“中”字圆环样品图；（b）反射式“中”字圆环强度关联无透镜傅立叶变换像；（c）反演恢复得到成像物体。

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