

Mask Encoding of Light Fields for Capture by Conventional Cameras

Papers_ID: 0004

Consider a 2D camera that can capture 4D light fields

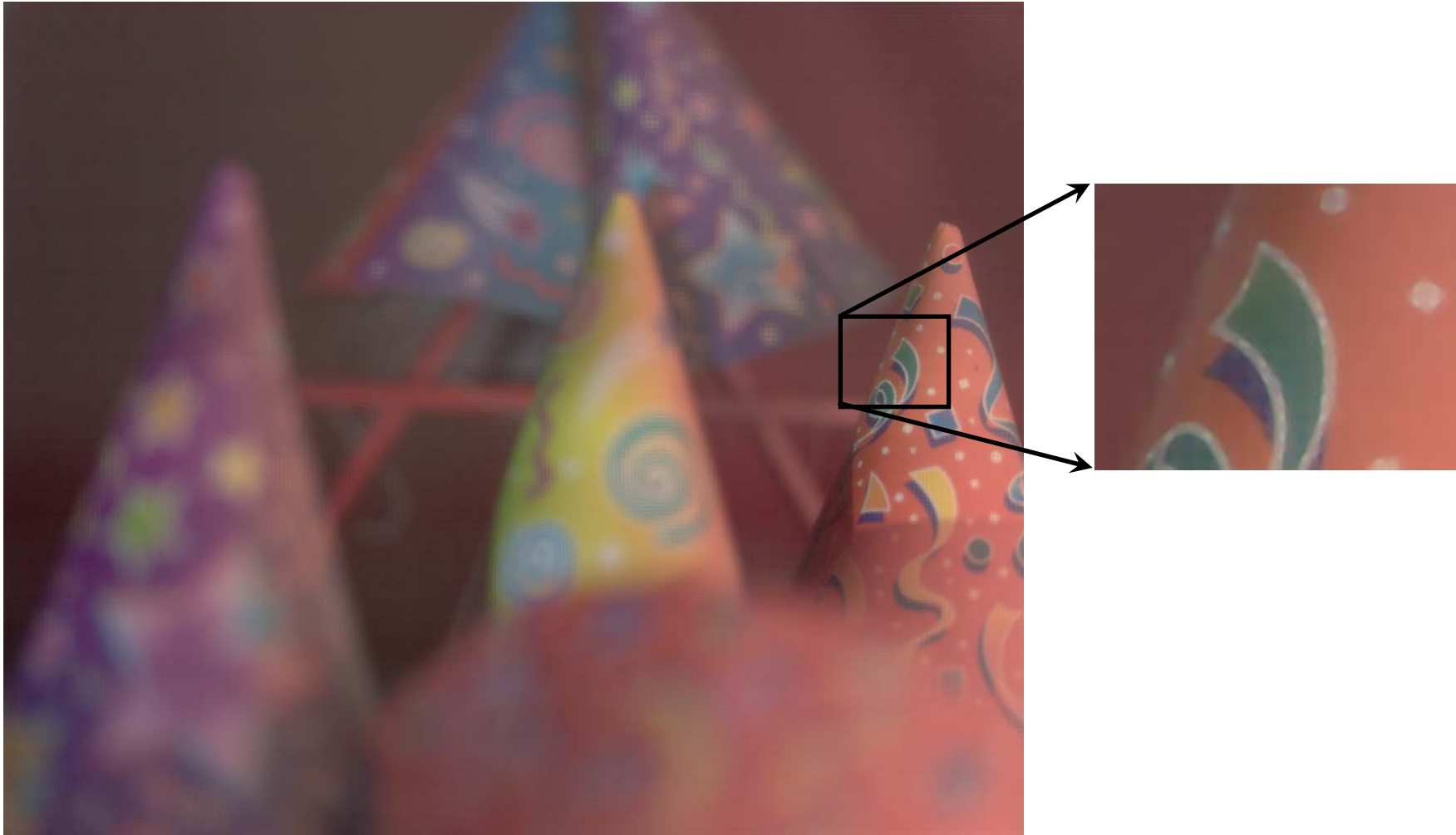


2D Sensor image



Video showing refocusing
from 4D light field

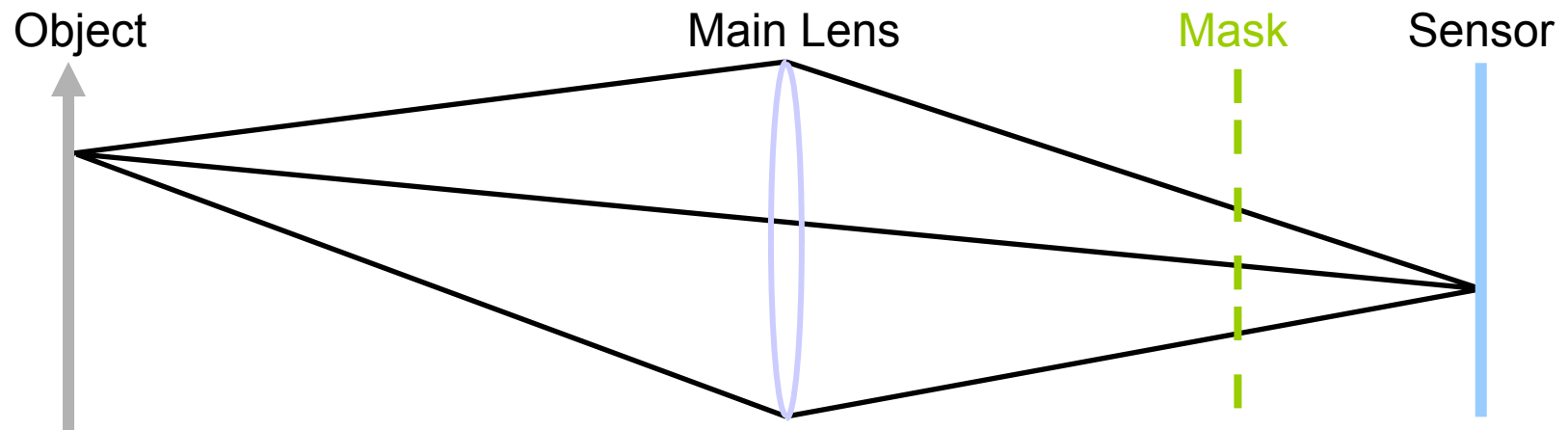
as well as high resolution image of focused parts of scene



High resolution image of in focus parts of the scene

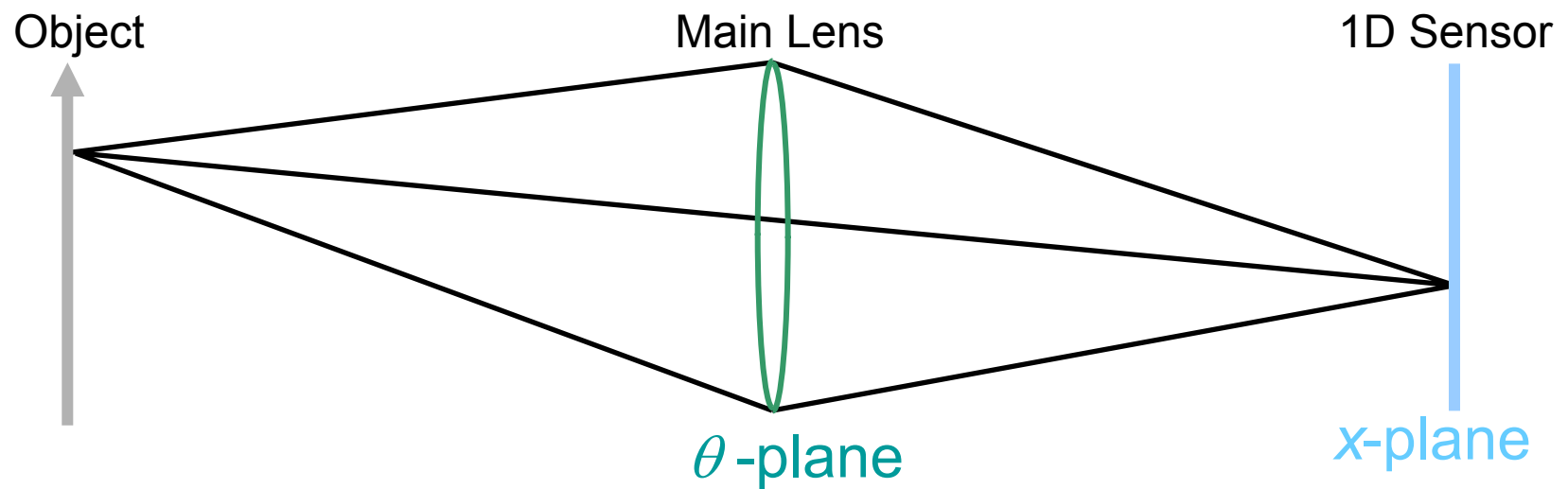
Using only a mask placed inside the camera

No additional optics

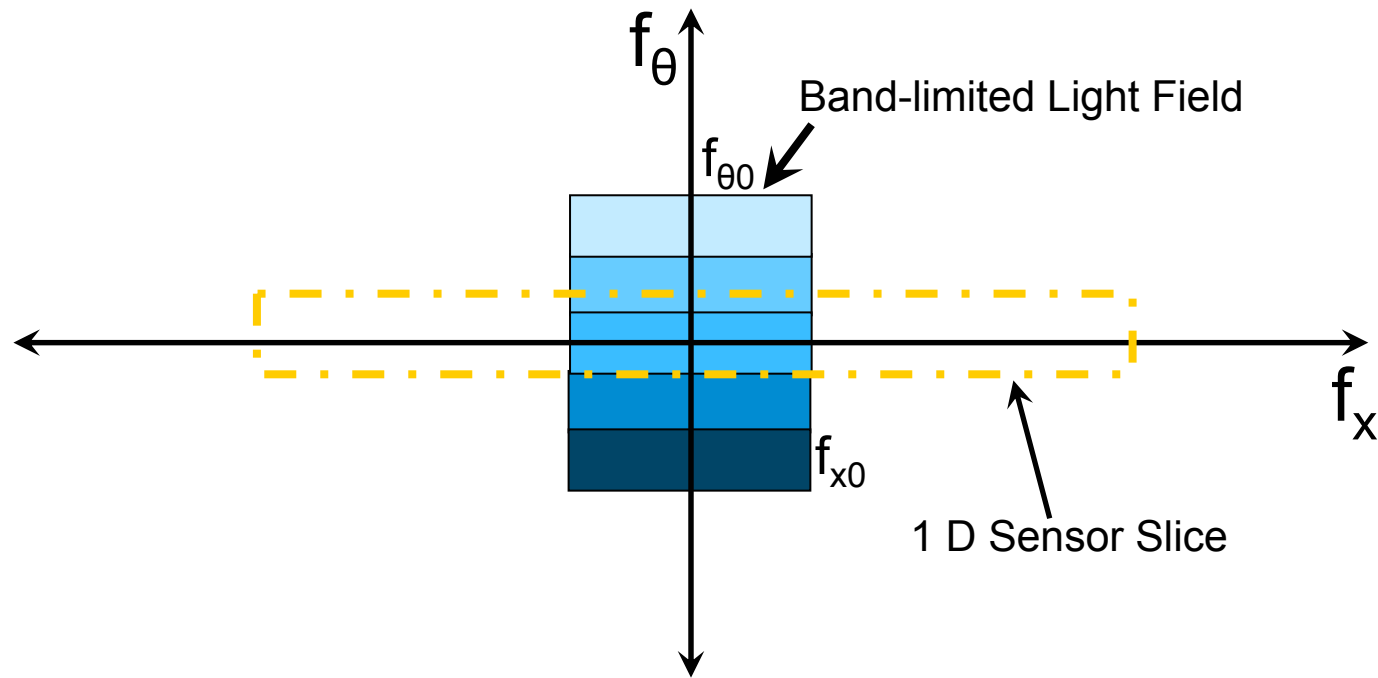


Heterodyne Light Field Camera

Consider the plane parameterization of 2D light field $I(x, \theta)$

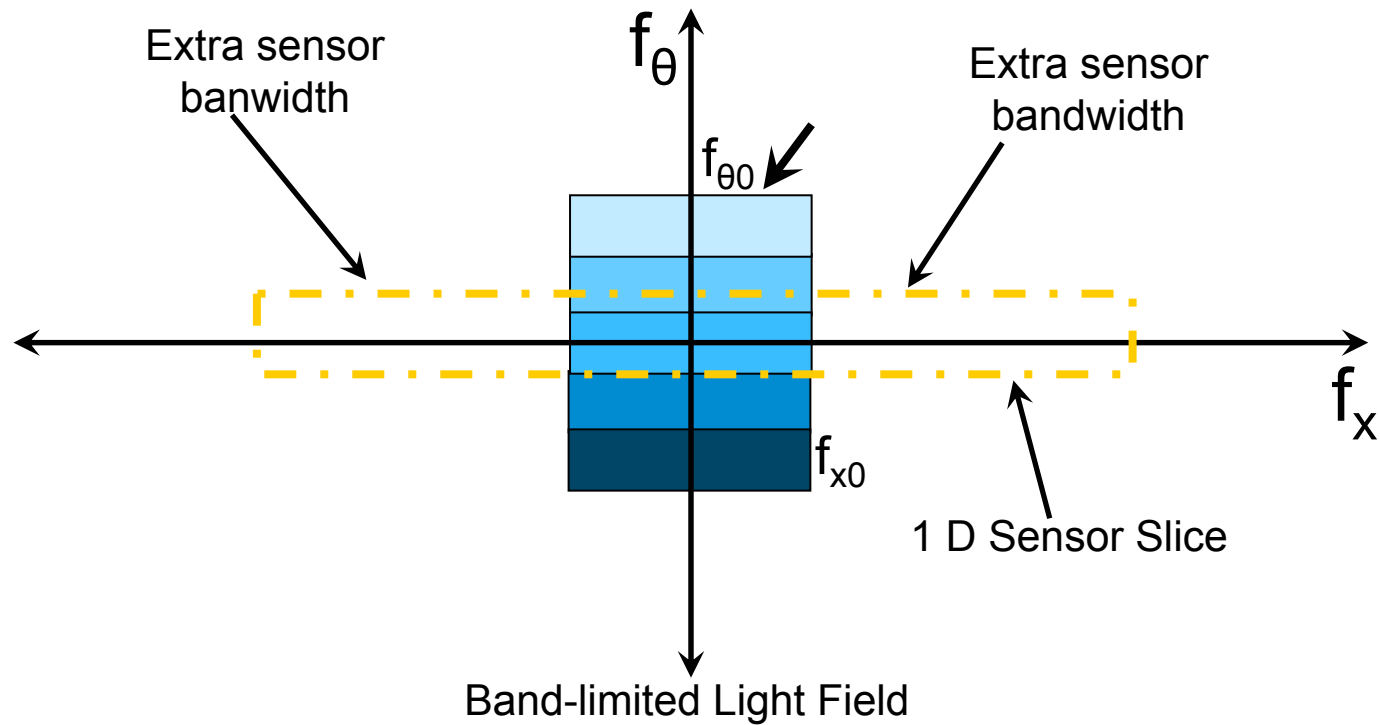


In Fourier domain, the sensor image corresponds to a slice of the light field

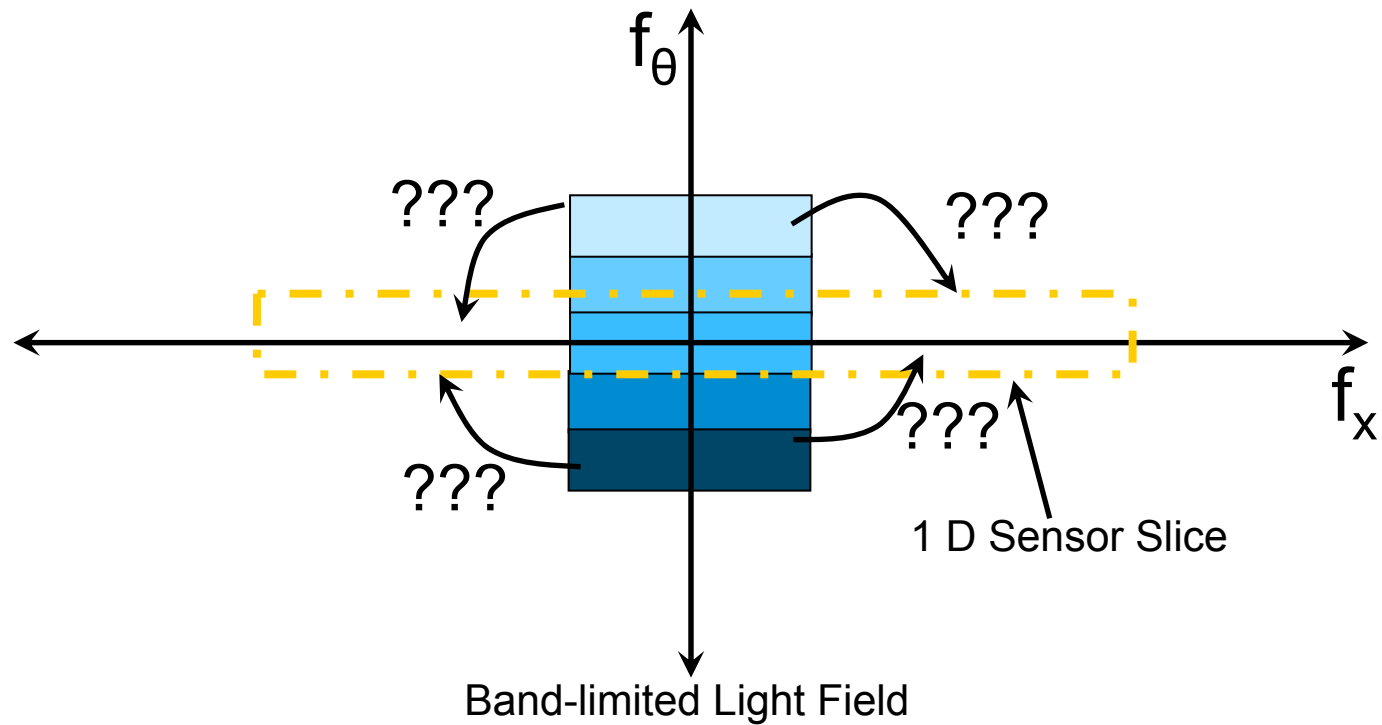


Fourier Light Field Space

Even though sensor has high bandwidth, it cannot capture the extra *dimension* of the light field

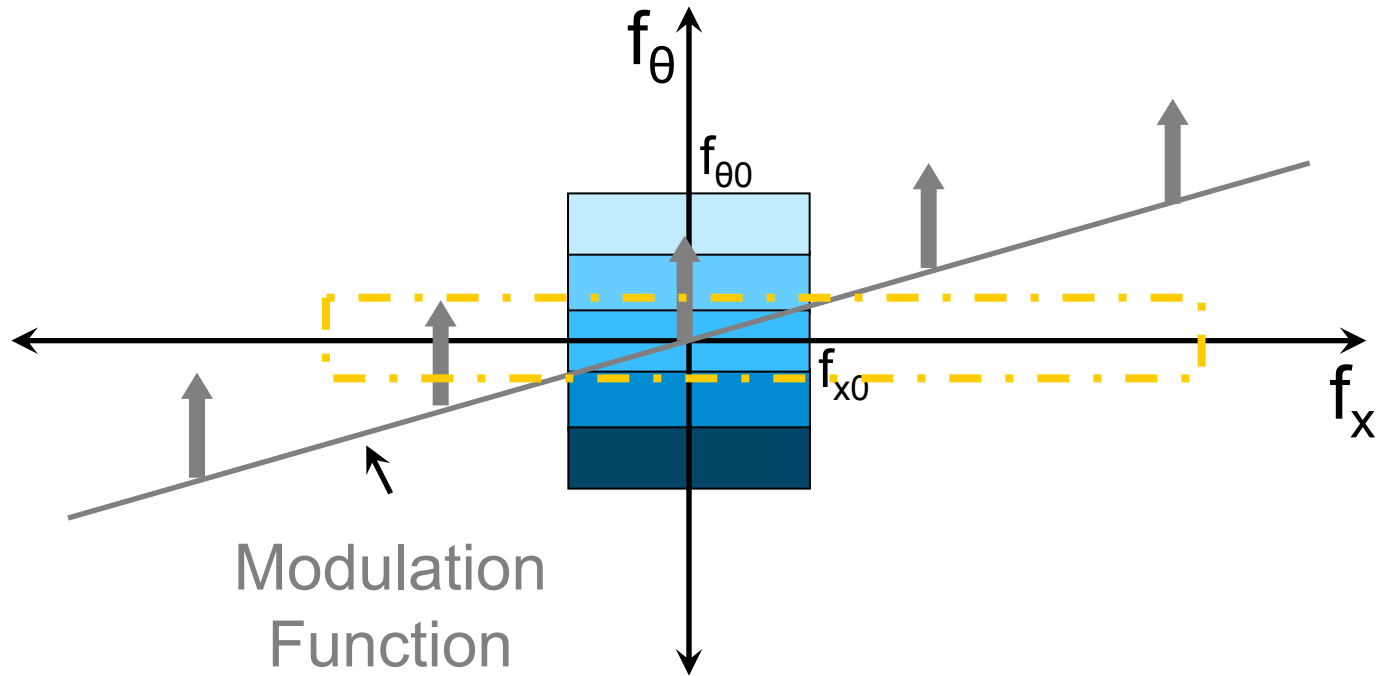


We need to distribute the energy in 2D light field to 1D sensor plane

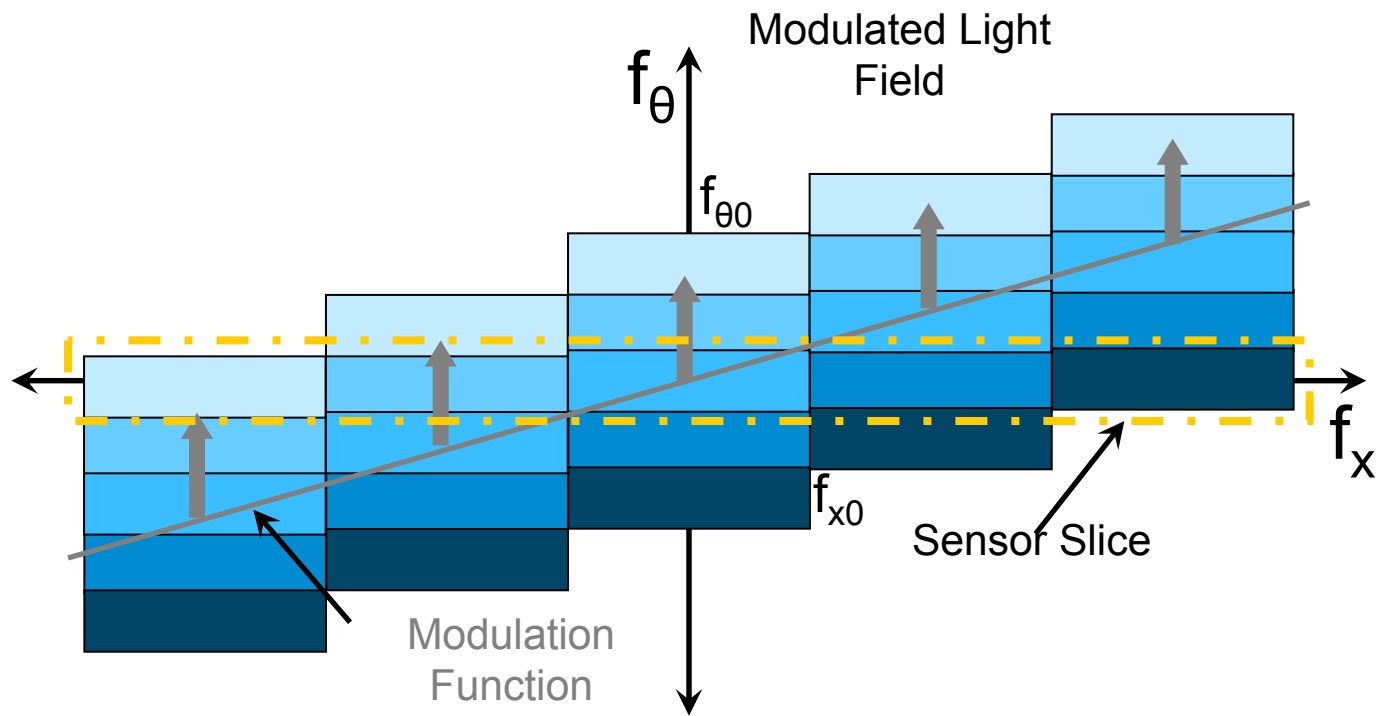


Solution: Modulation Theorem

Make spectral copies of 2D light field

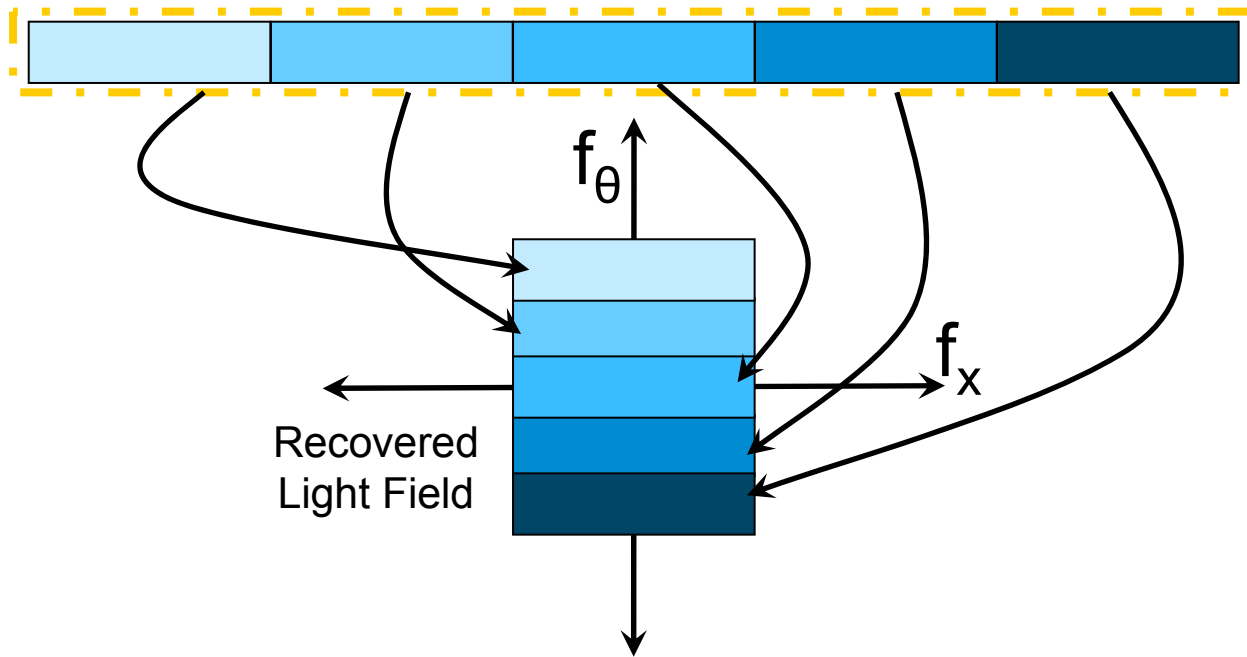


Such that the sensor slice can capture the entire light field information

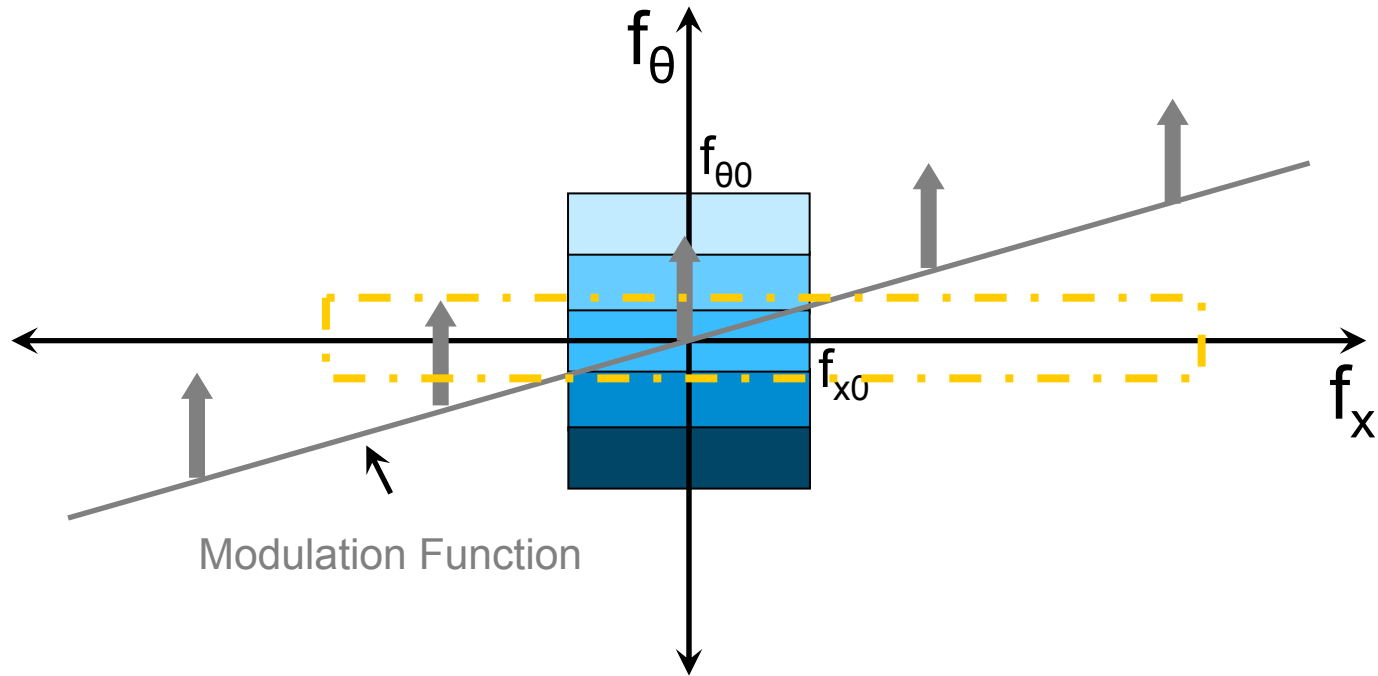


How to recover light field from sensor slice?

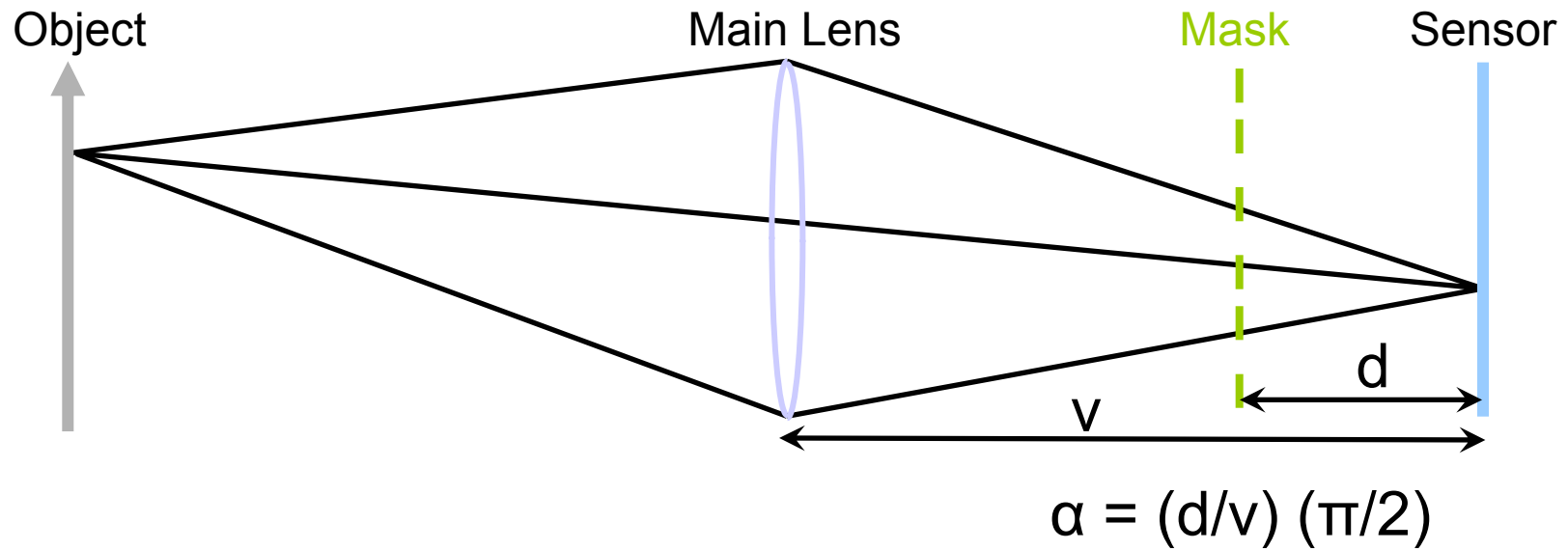
Simple *reshaping* in Fourier Domain



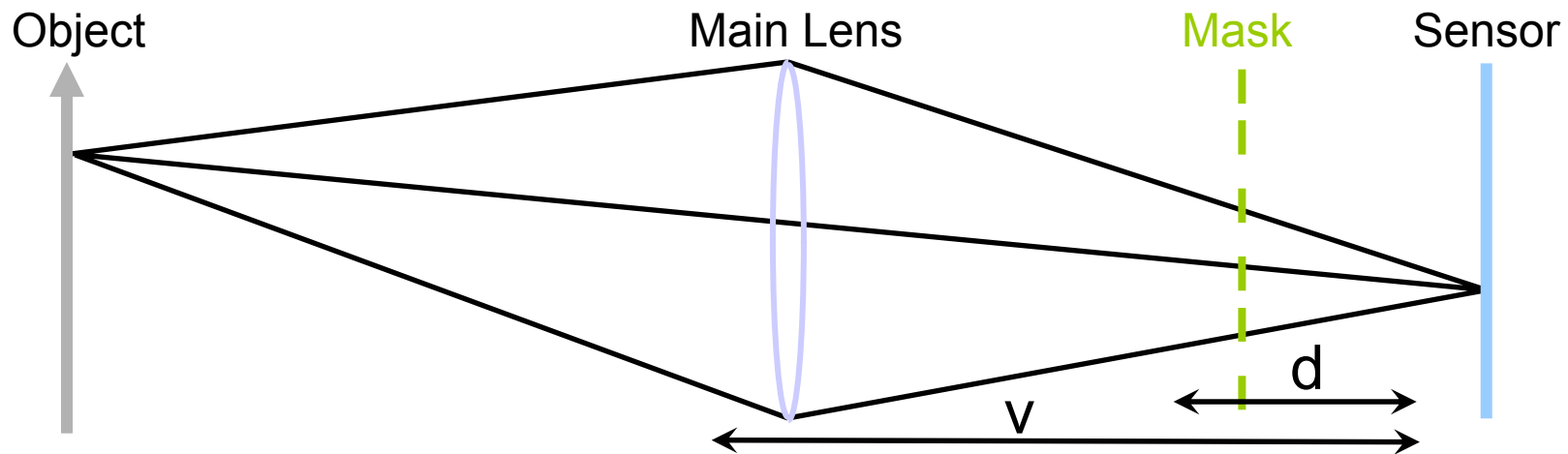
Key Idea: Modulate the light field using a set of slanted impulses



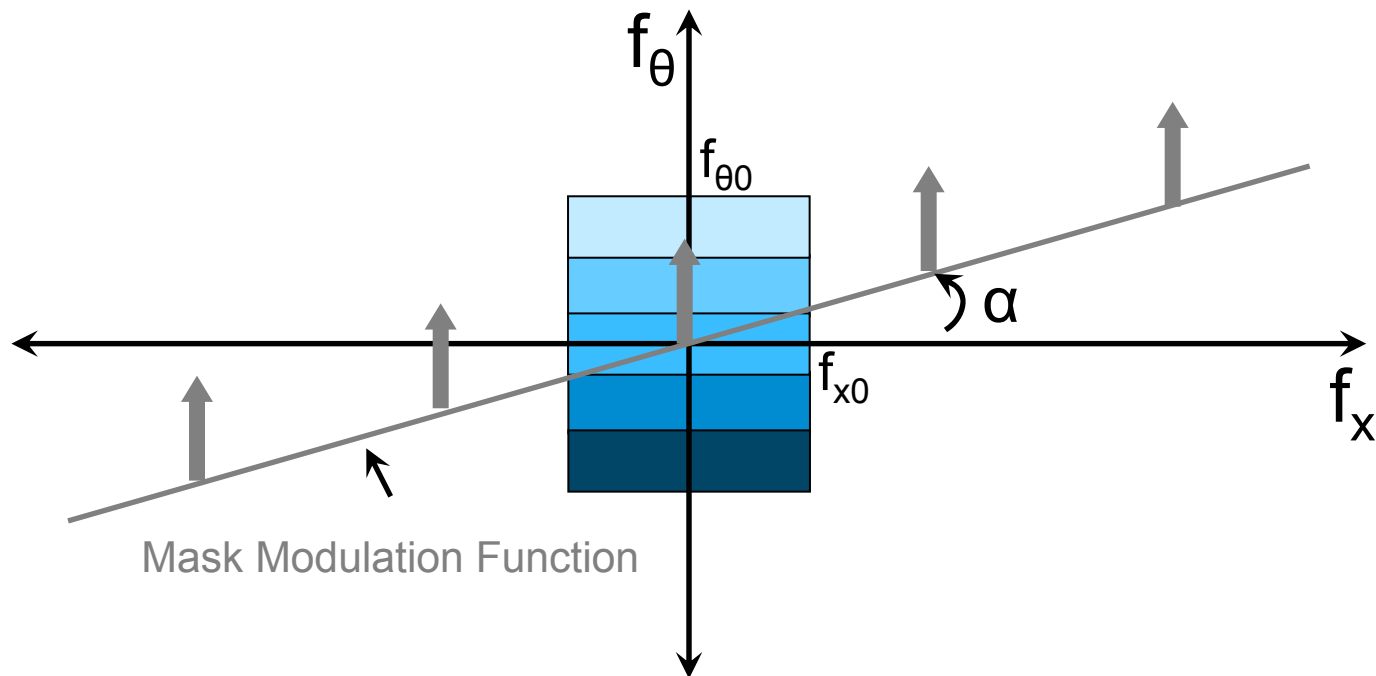
Such modulation can be achieved by simply placing a mask inside the camera!!



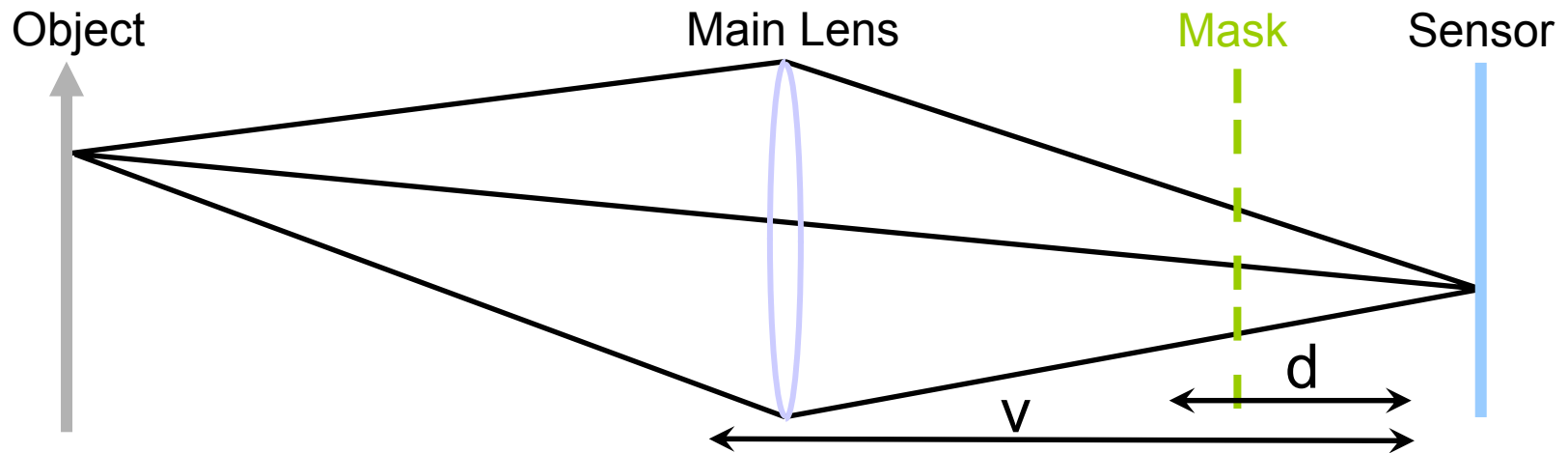
Relationship between primal and Fourier domain



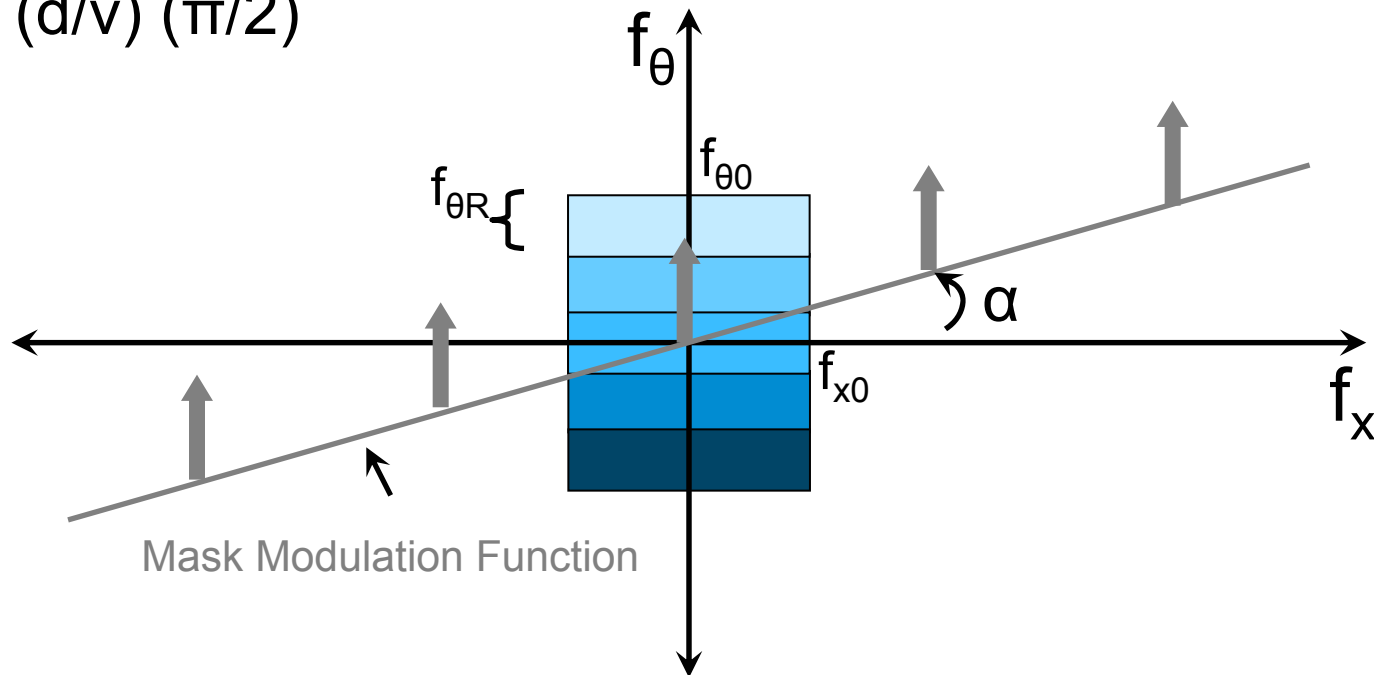
$$\alpha = (d/v) (\pi/2)$$



Optimal mask location is given by alpha, depends on $f_{\theta R}$, $f_{\theta 0}$ and f_{x0}



$$\alpha = (d/v) (\pi/2)$$



Fourier transform of optimal 1D mask pattern is a set of 1D impulses

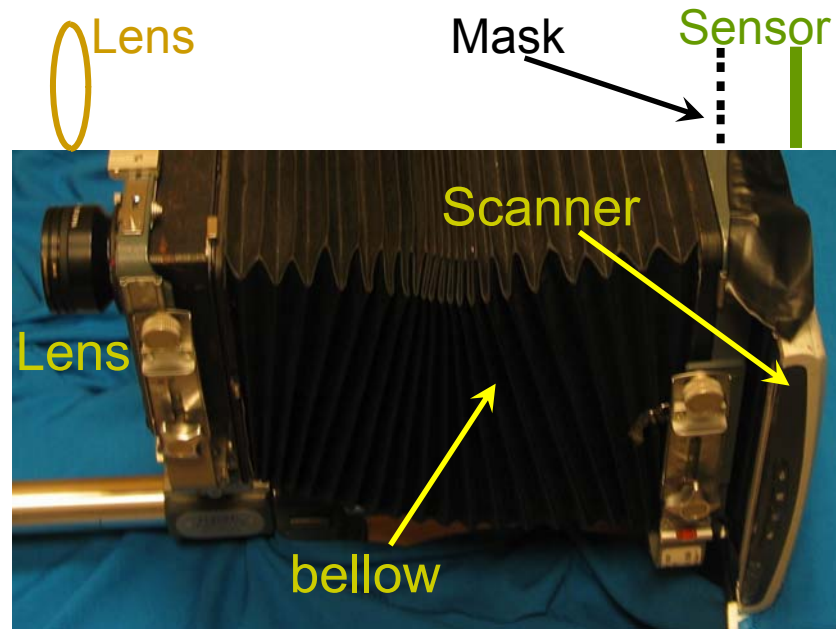


Optimal 1D Mask is sum of cosines

Optimal 2D mask: Sum of cosines in 2D

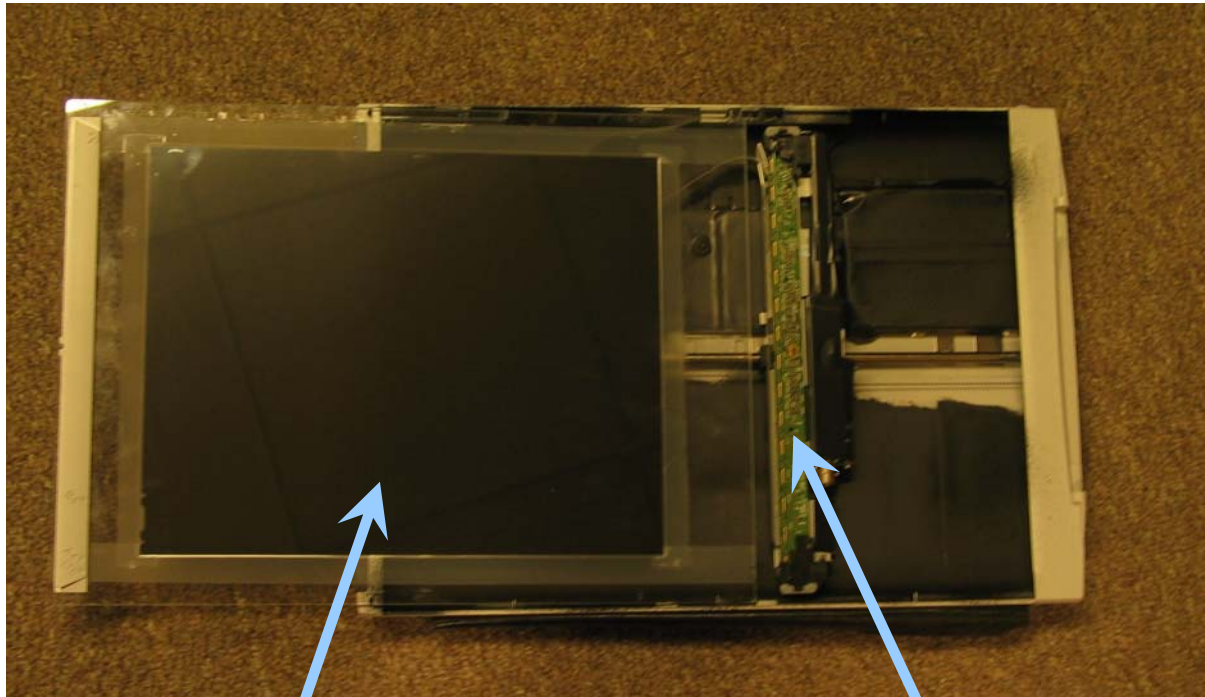
Number of angular samples = Number of impulses
in Fourier transform of the mask along that
dimension

Implementation



Light Field Camera

We use Canon flatbed scanner as the sensor and Nikkor lens in front. The mask is placed is about 1 cm in front of the sensor.



Scanner sensor

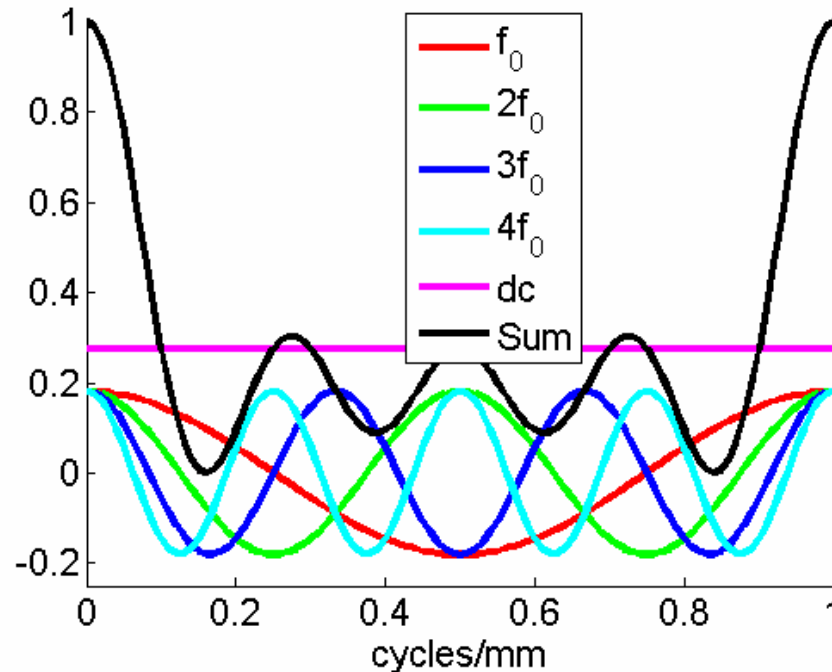
Mask is placed under a glass sheet. It is moved on top of the scanner sensor when taking pictures. The above mask is sum of cosines of frequencies 1, 2, 3 and 4 cycles per mm. Since it has 4 harmonics, it can provide $2 \cdot 4 + 1 = 9$ angular samples as it will have 9 impulses in its Fourier transform.



$1/f_0$

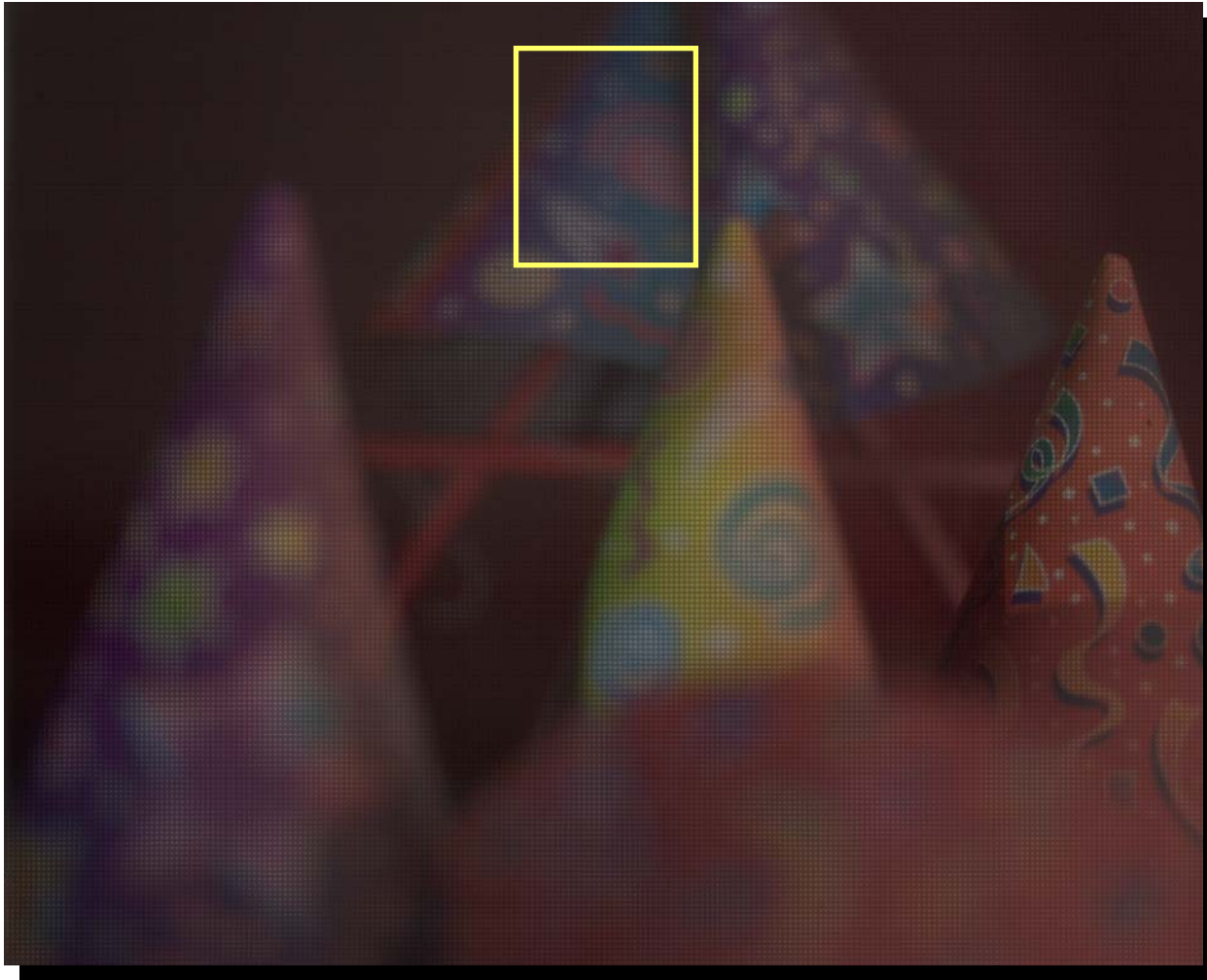
Zoom in of the
cosine mask

Cosines of fundamental frequency and its harmonics

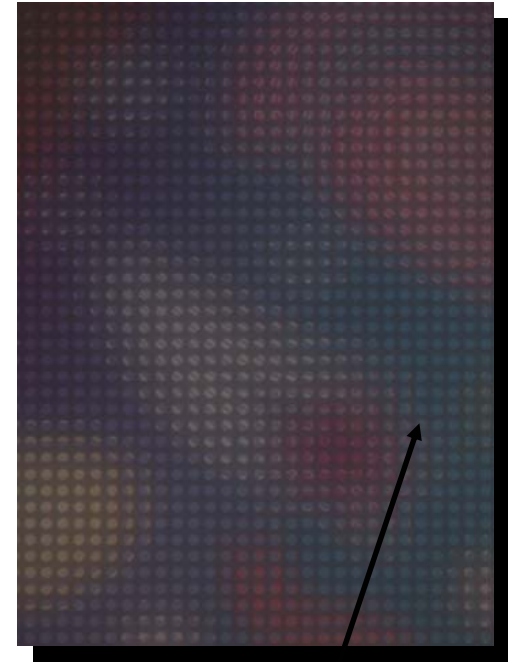


Mask is the sum of cosines with four harmonics. Plot shows the cosines. Since the physical mask cannot have negative values, a constant needs to be added.

Results



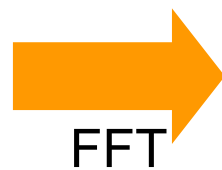
2D Sensor image



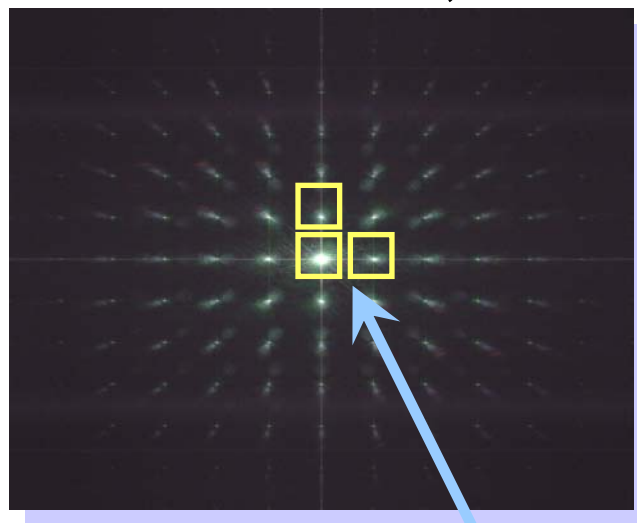
Zoom in showing
the effect of cosine
mask

Computing 4D Light Field

2D Sensor image, 1629*2052



2D Fourier Transform, 1629*2052

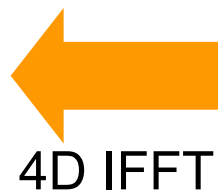


9*9=81 such tiles



Reshape 2D tiles into 4D planes

181*228*9*9

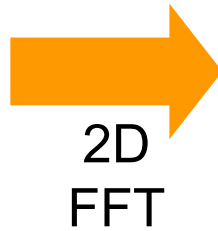


4D Light Field

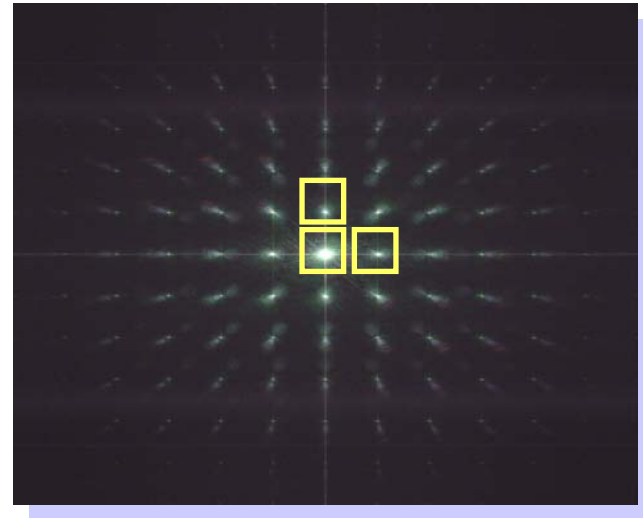
181*228*9*9

Refocusing: Take slices of 4D Fourier transform

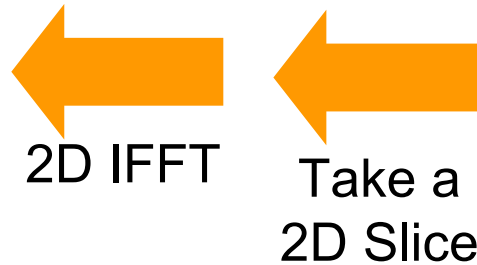
2D Sensor image, 1629*2052



2D Fourier Transform



Reshape 2D tiles into
4D planes
181*228*9*9

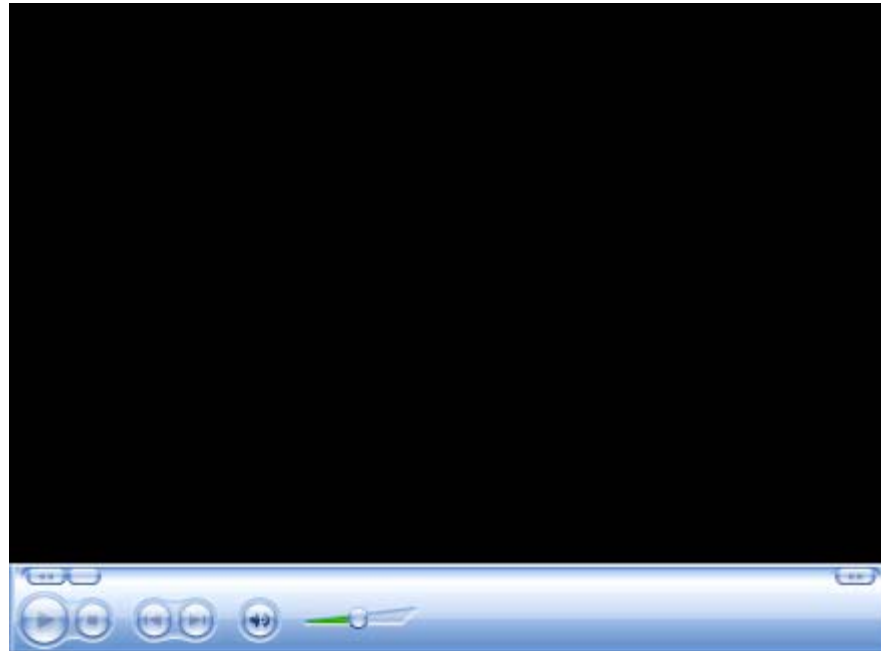


181*228
refocused image

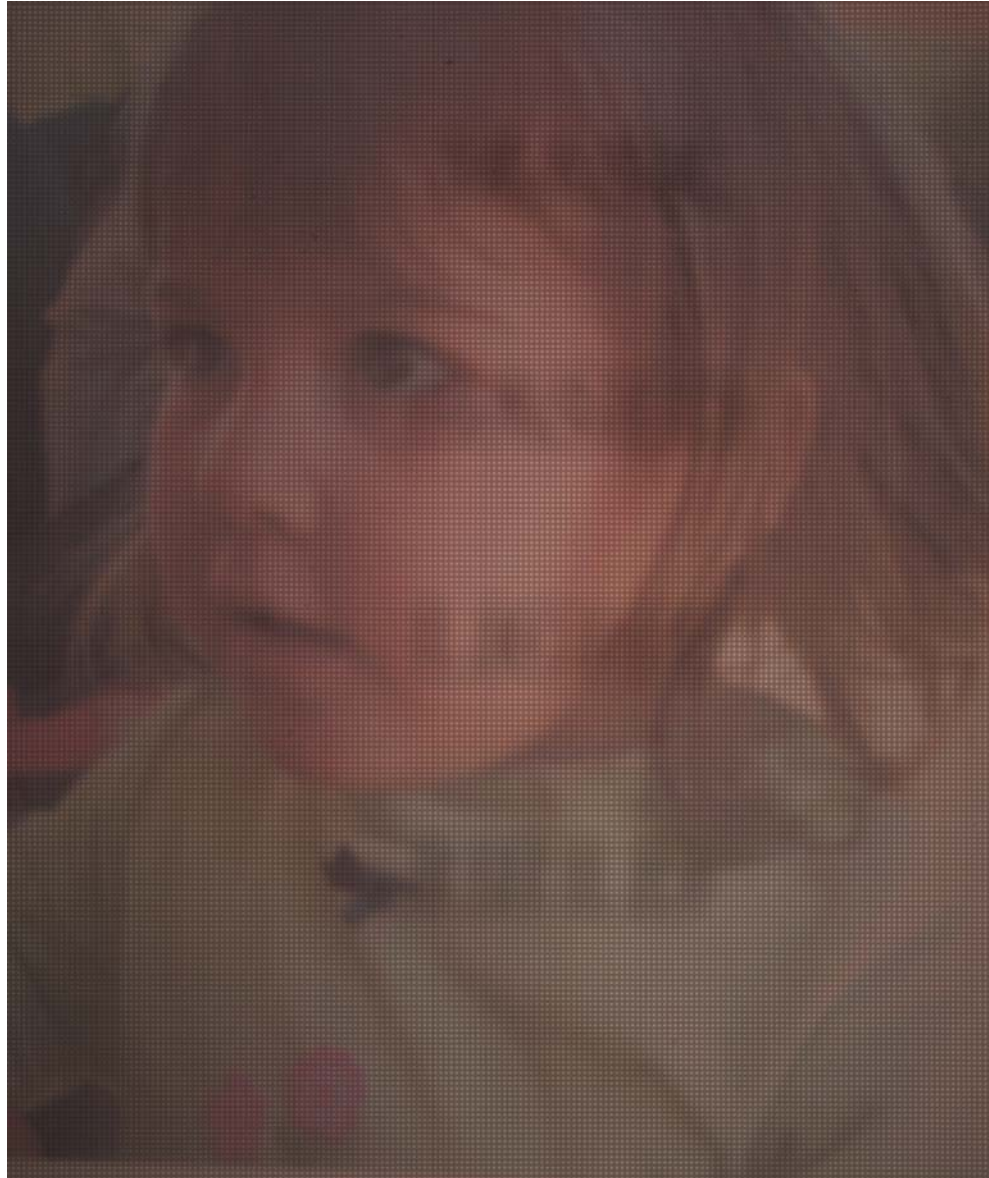
Demonstrating parallax between two
of the views



Video showing Views



Refocusing of transparent layers



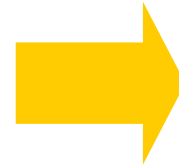
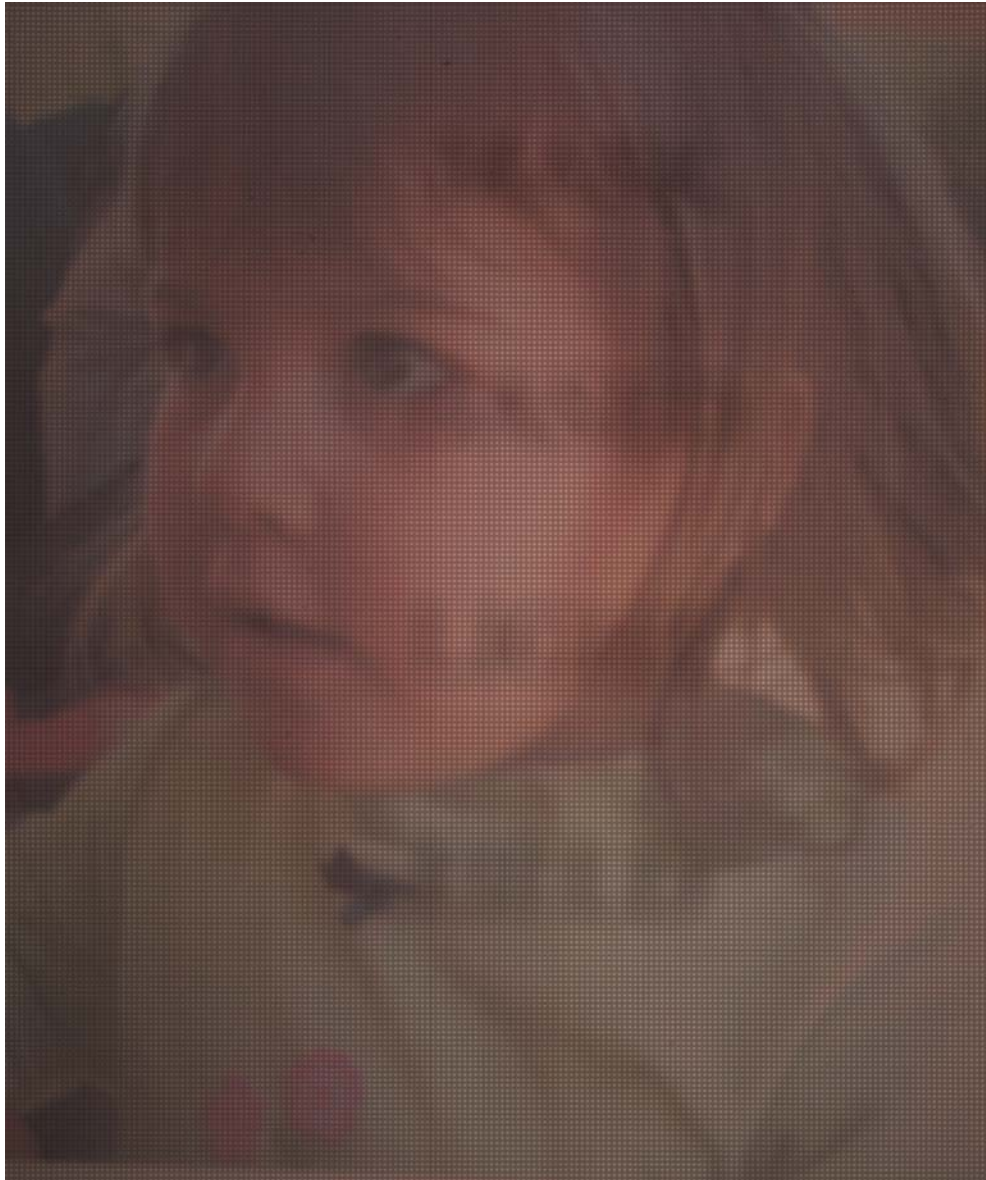
2D sensor image. The scene consist of a transparent glass sheet in front with text written on it.

Refocusing of transparent layers



High resolution image of the focused parts of the scene

Refocusing of transparent layers

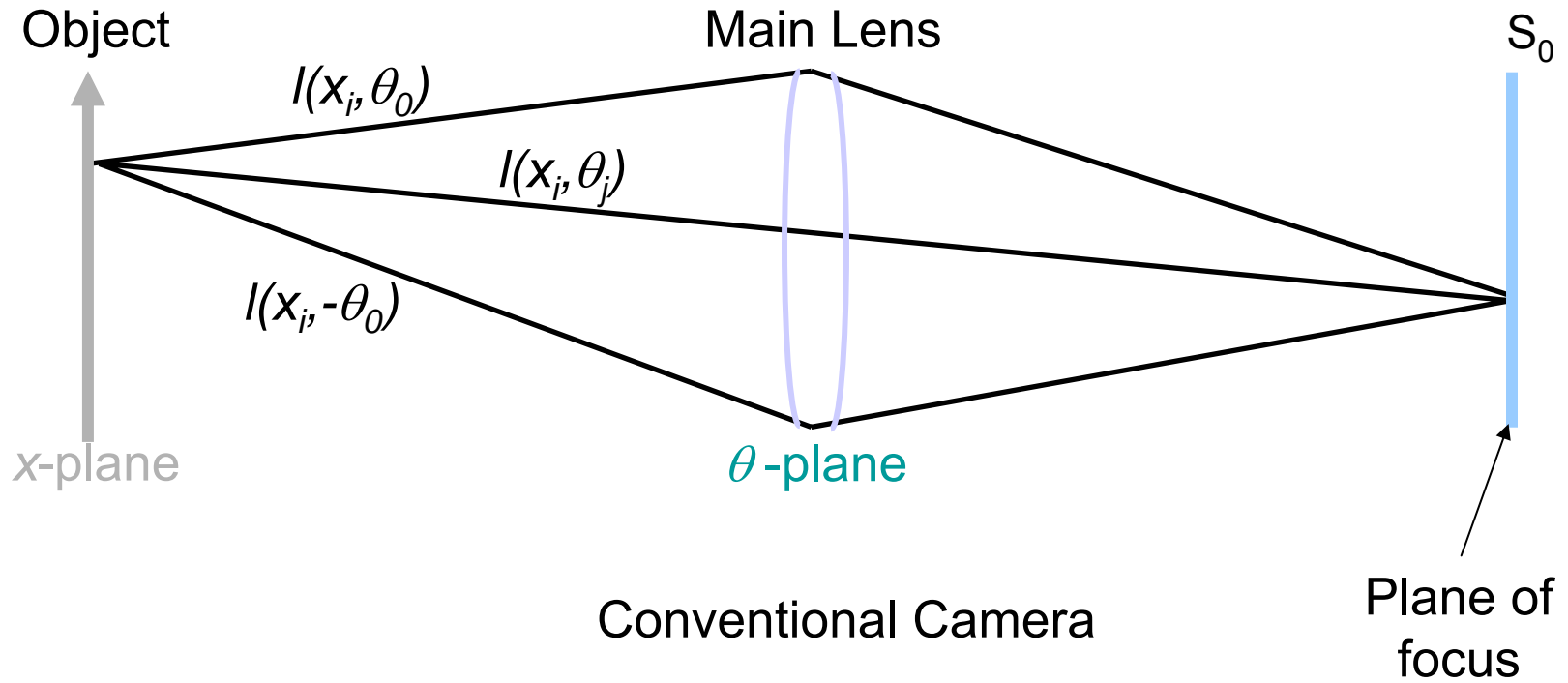


Low resolution refocused
image on the glass sheet
in front

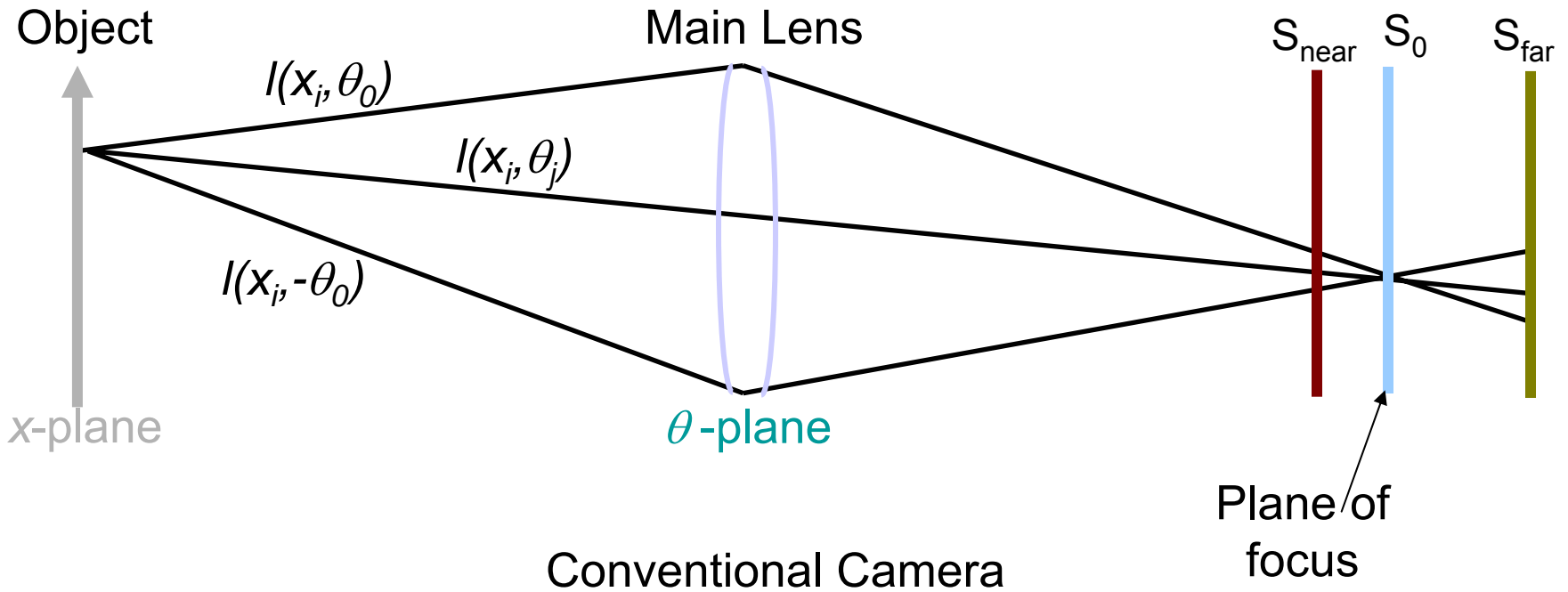
Encoded Blur Camera for Extended Depth of Field

(for Layered Lambertian Scenes)

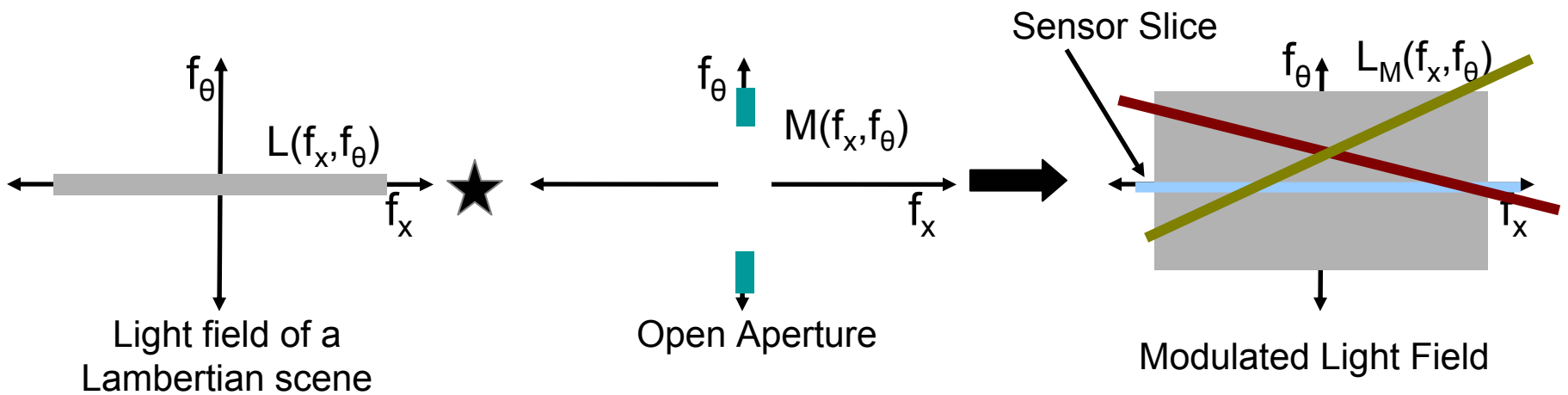
We analyze out of focus deblurring in 4D Fourier space



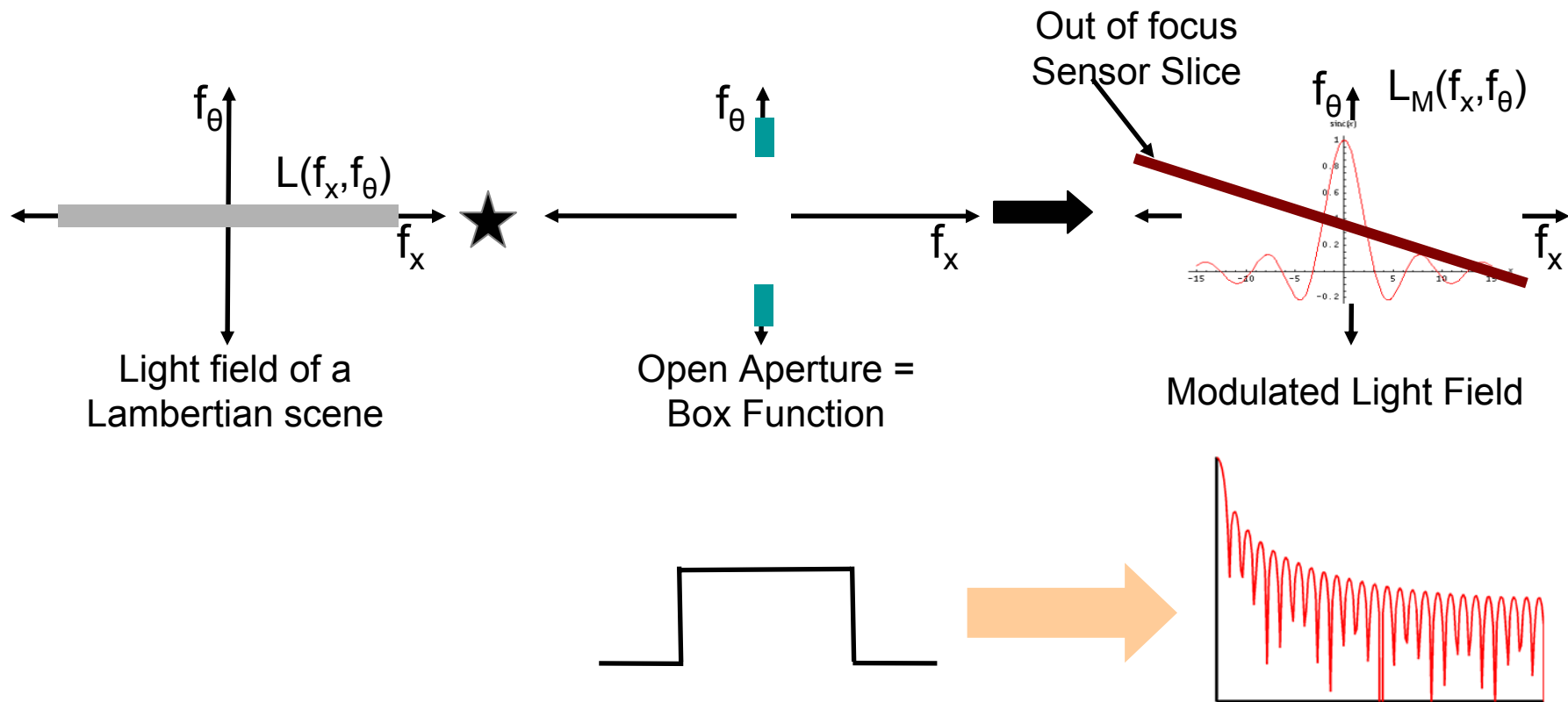
In Fourier domain, the image is a slice of light field



Conventional Camera

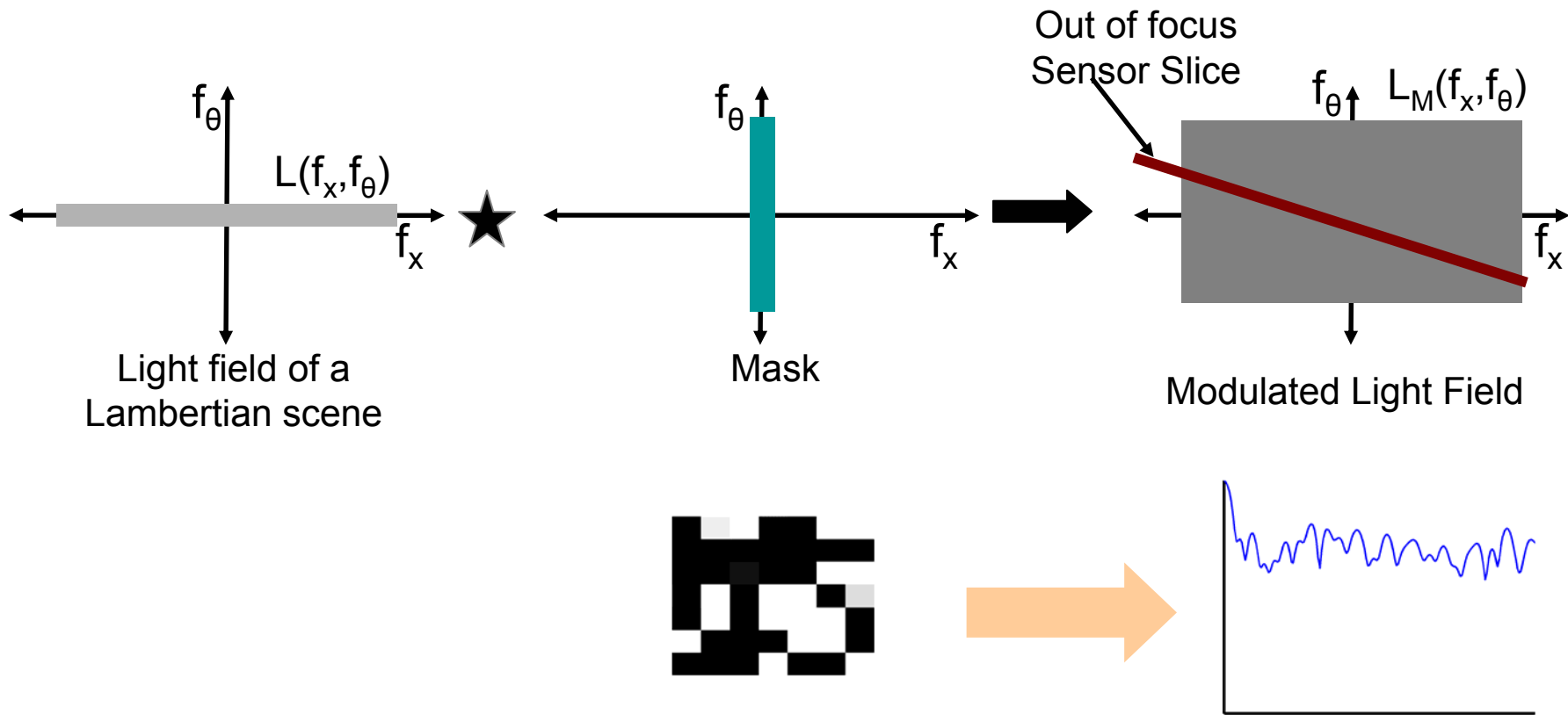


For conventional camera, aperture is box and it modulates the light field with sinc



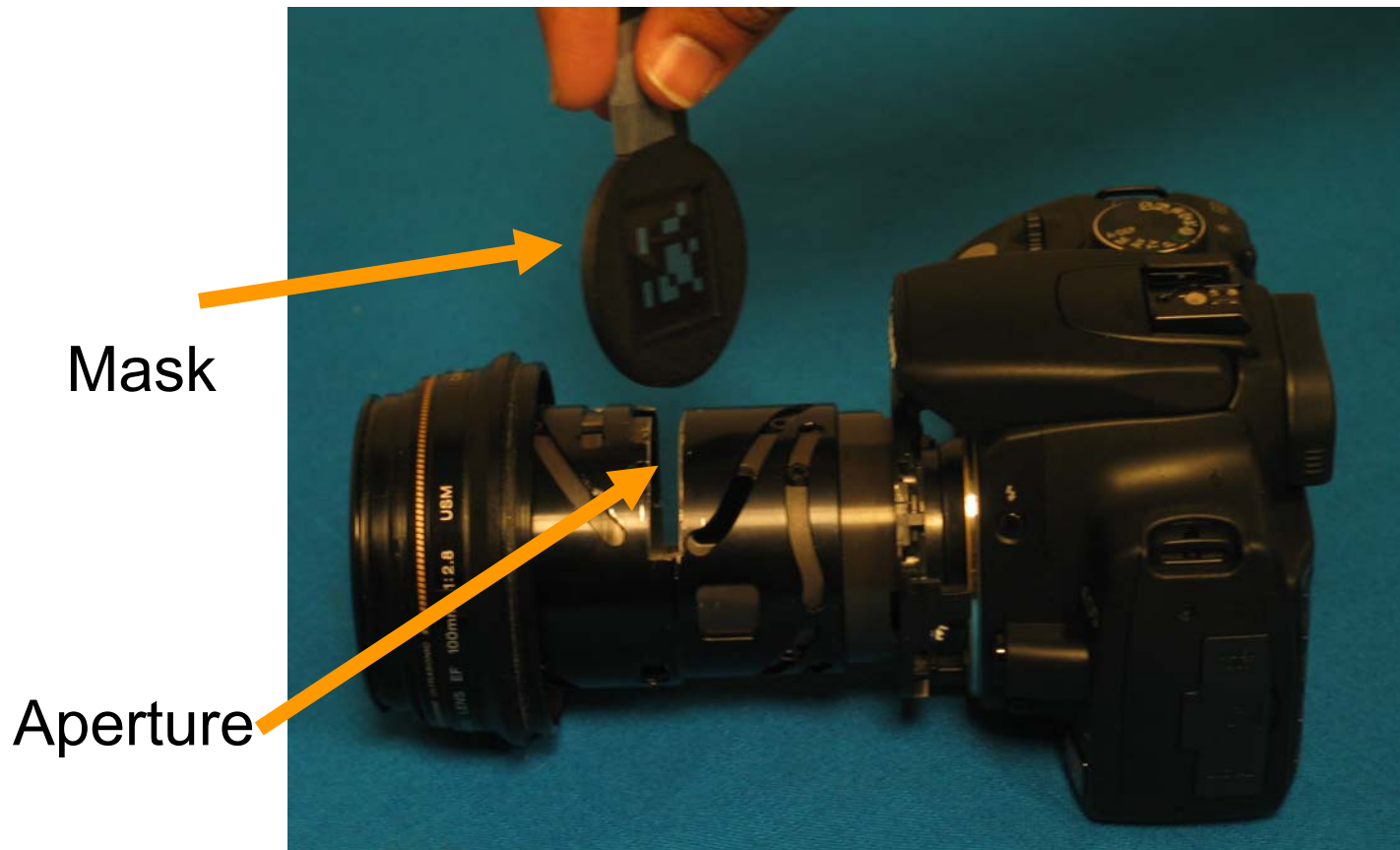
High Frequencies are lost in out of focus images

By putting a mask at the aperture, the aperture modulation function is *replaced* by the mask modulation function



High Frequencies are preserved if broadband mask is used

Implementation



Canon EF 100 mm 1:1.28 Lens,
Canon SLR Rebel XT camera

Digital Refocusing



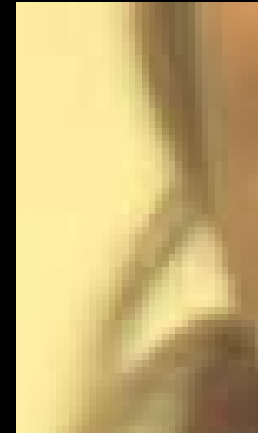
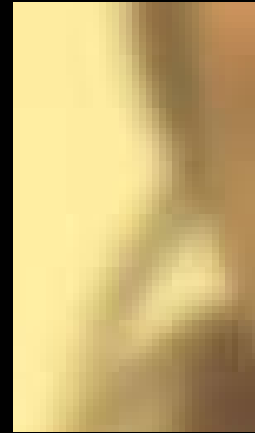
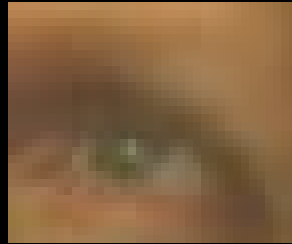
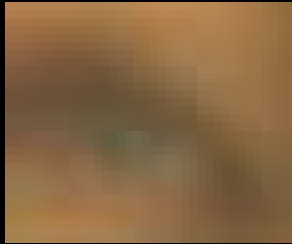
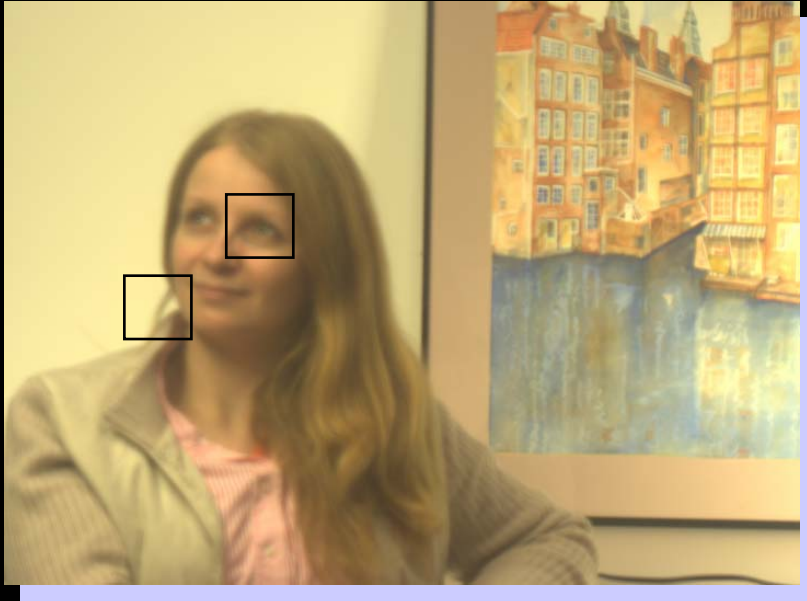
Captured Blurred Image

Digital Refocusing



Refocused Image on Person

Digital Refocusing



Digital Refocusing



Captured Blurred Image

Digital Refocusing



Refocused Image on Person

Spatially Varying PSF



Captured Blurred Image

Spatially Varying PSF

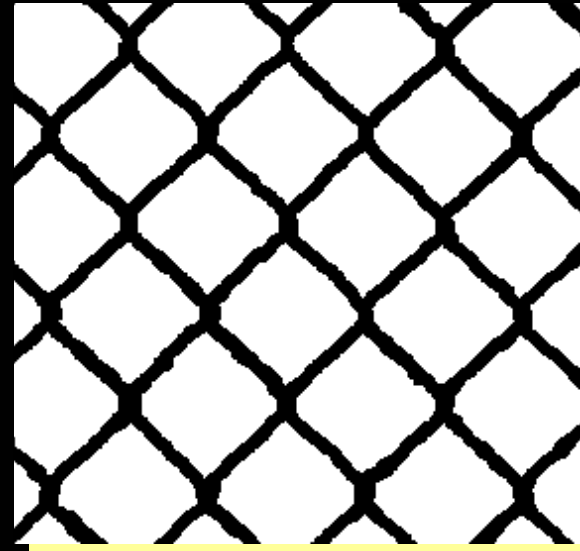


All in focus Image

Deblurring in presence of partial occluders



Captured Photo



Mask for occluders



Least Squares
Deblurring



Weighted Least
Squares Deblurring

Comparison with Small Aperture Image



Small Aperture
Image



Captured
Blurred Image



Deblurred
Image

Comparison with Traditional Camera

Encoded Blur Camera



Traditional Camera

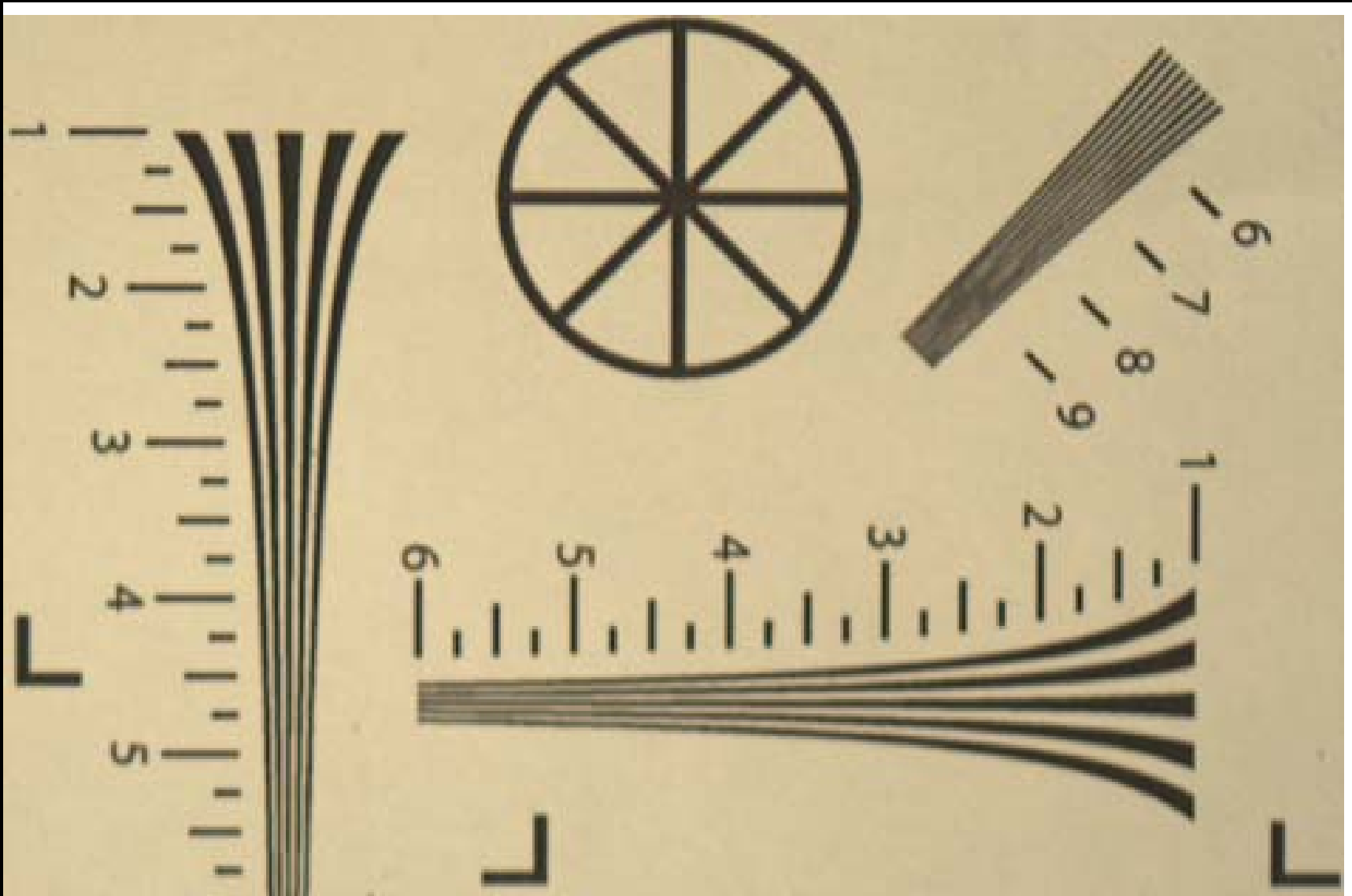


← Captured →
Blurred Image



← Deblurred →
Image

Comparison on ISO-12233 Resolution Chart

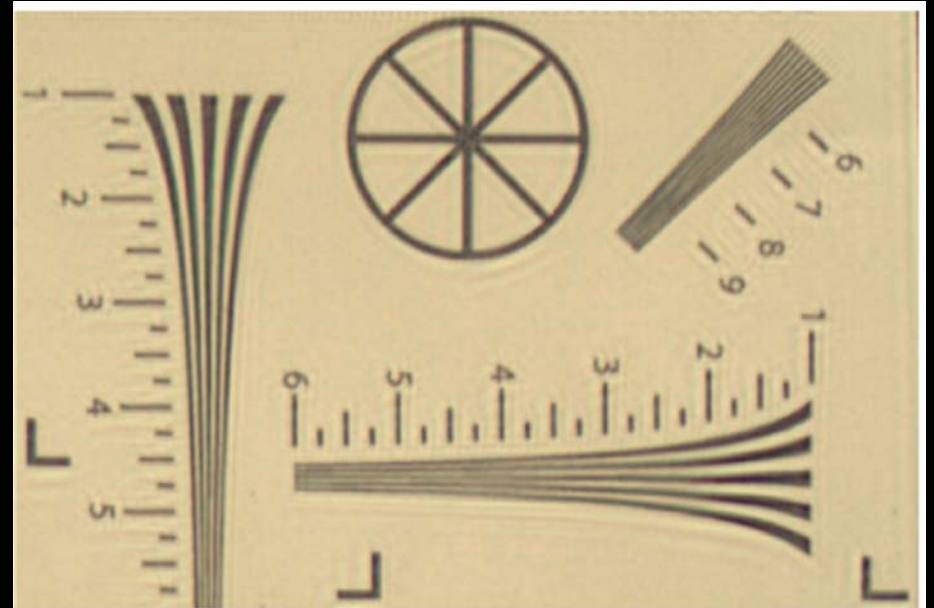
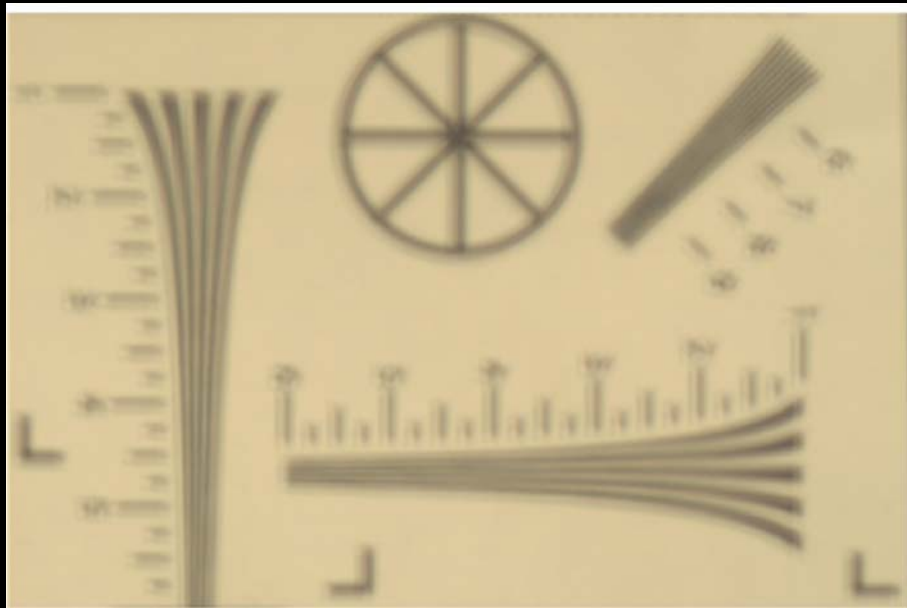


In Focus Image

Comparison on ISO-12233 Resolution Chart

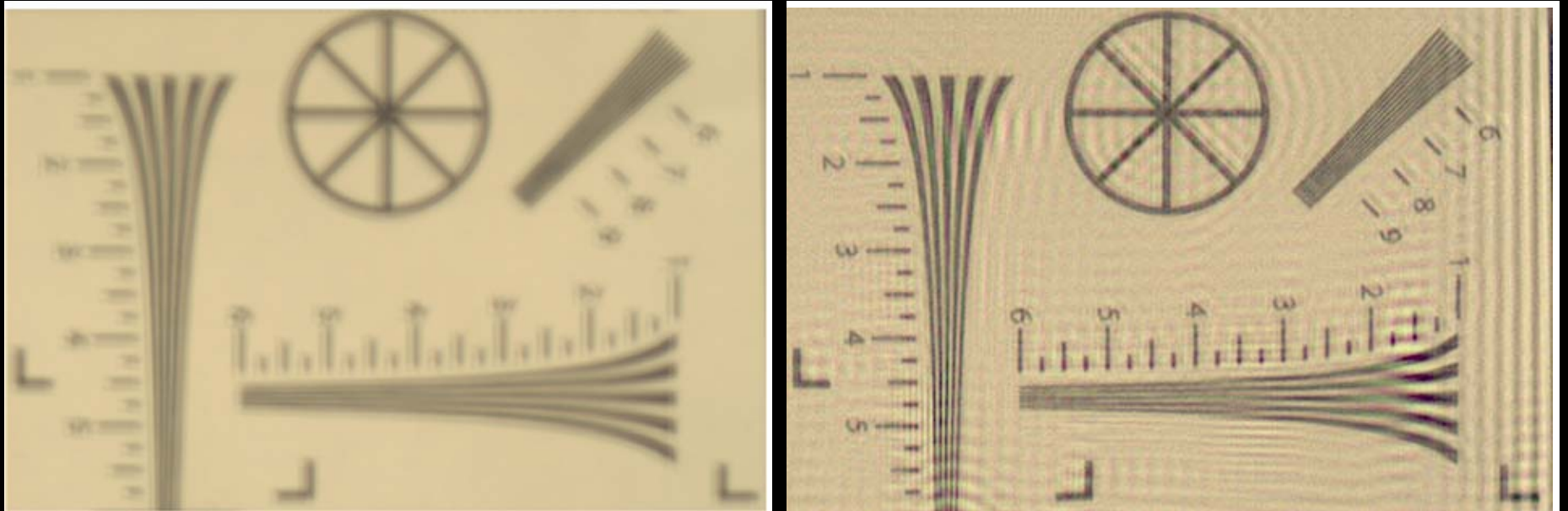
Blurred Image

Deblurred Image



7 by 7 Mask

Comparison on ISO-12233 Resolution Chart



25 by 25 Mask

Artifacts due to diffraction are present

Motion blur + Defocus Blur



The out of focus person is shaking a coke can.

Motion blur + Defocus Blur



The out of focus person is shaking a coke can. We can account for out of focus blur resulting in an in-focus motion blurred image.