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# Fast High Energy Transients and Lobster Eye Optics

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Detecting High Energy Fast Transients

- Large field of view – 1000's square degrees or larger
- High angular resolution - ~1 arcmins
- High sensitivity - ~10^{-9} ergs cm^{-2} s^{-1} 0.3-6 keV
  - in short exposures – ~1-10 sec

- Lobster Eye Telescopes have the unique potential to provide the above!

MPOs and Lobsters in Space

- Bepicolumbo MIXS – square pore MPOs
  - launch October 2018
- SVOM MXT – narrow field lobster telescope
  - launch 2021
- SMILE – CAS+ESA – SXI lobster module
  - Launch ?
- TAO-ISS – wide field lobster module
  - originally proposed NASA Dec 2014
- Einstein Probe – 12 wide field lobsters
  - China – launch 2020's
- Theseus SXI – wide field lobsters
  - Proposed ESA M4 2014
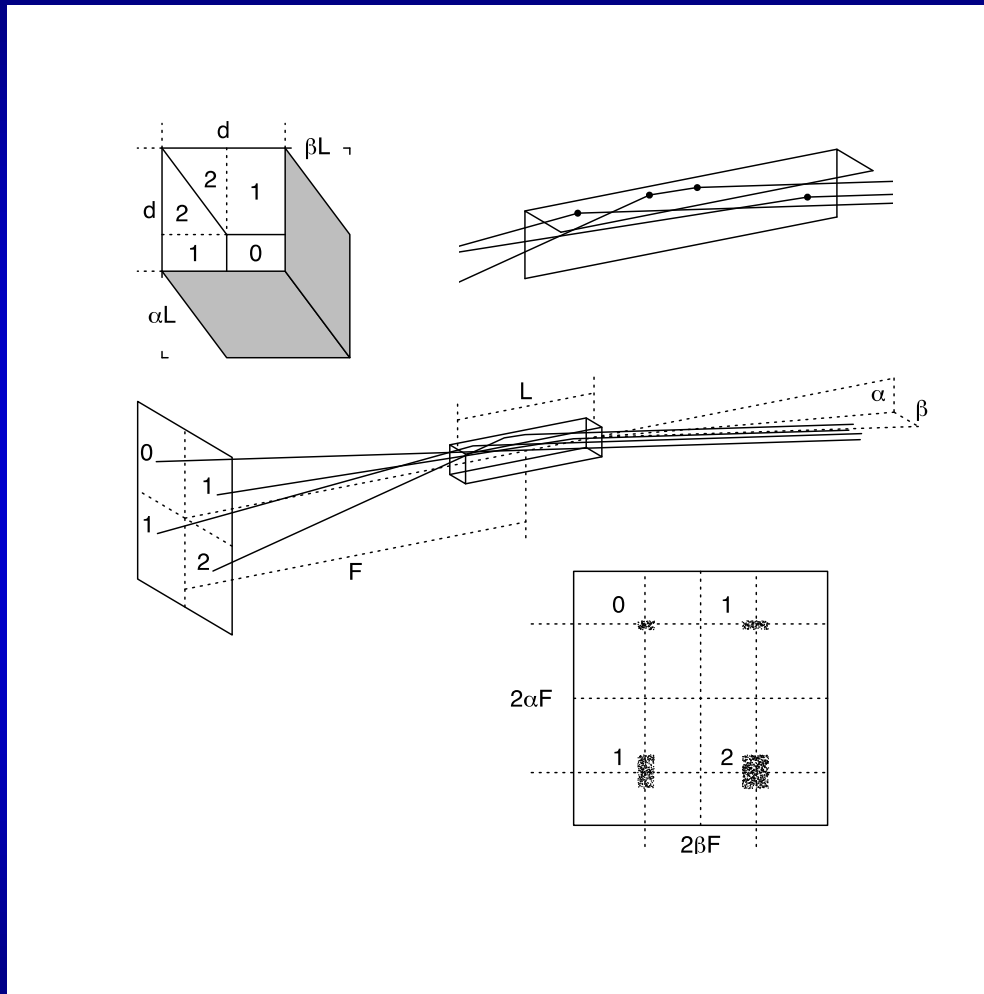- TAP – Transient Astrophysics Probe - NASA 2017 – wide field lobsters
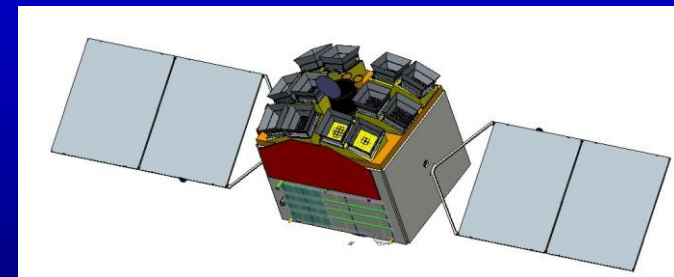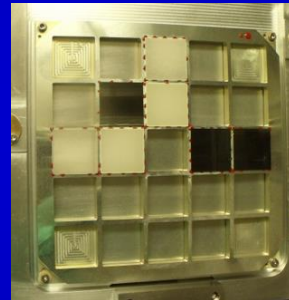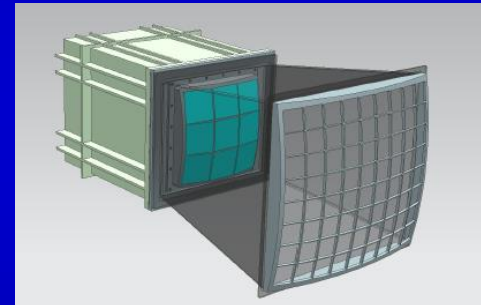
Square Pore MCPs (MPOs)

- Glass plate – thickness L=1.0-2.5 mm – transmission ~60%
- Square pores size d=20 or 40 μm, wall~4 μm,   L/d~25-125
- Slumped to spherical form R_c=2F
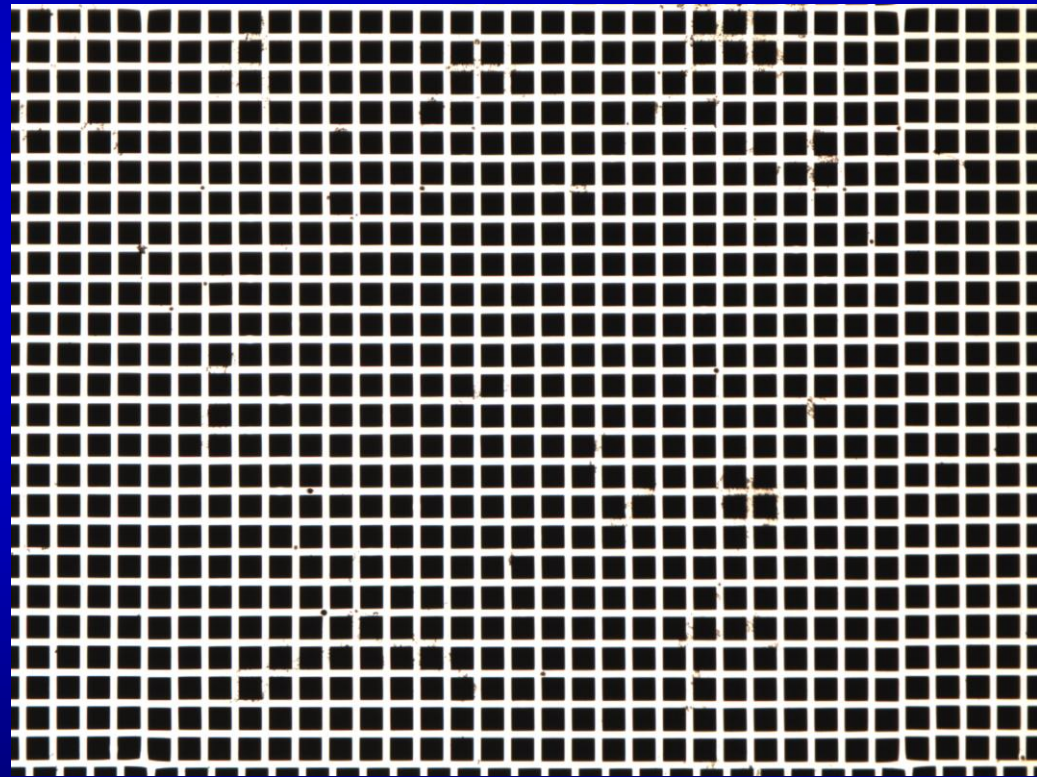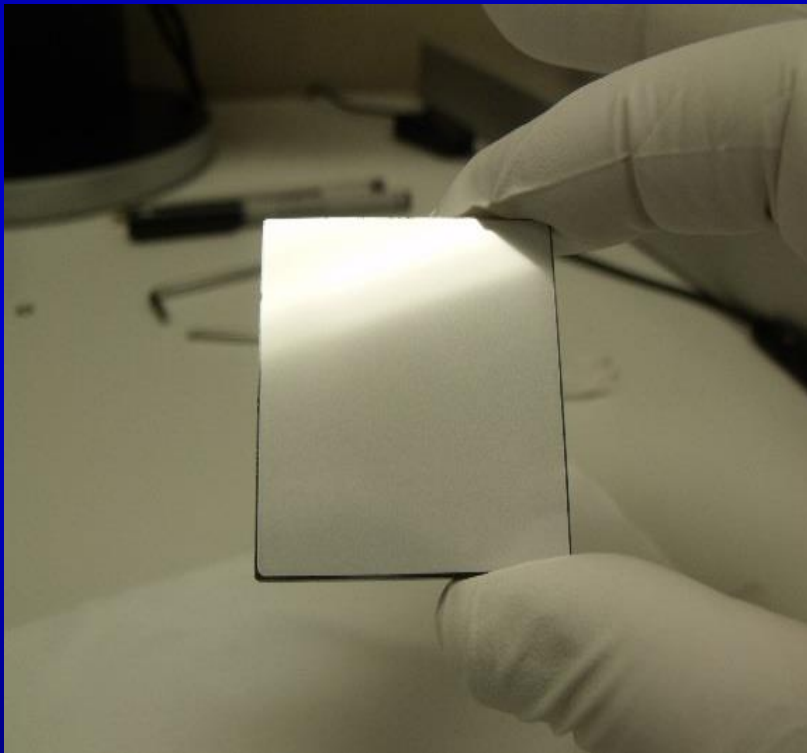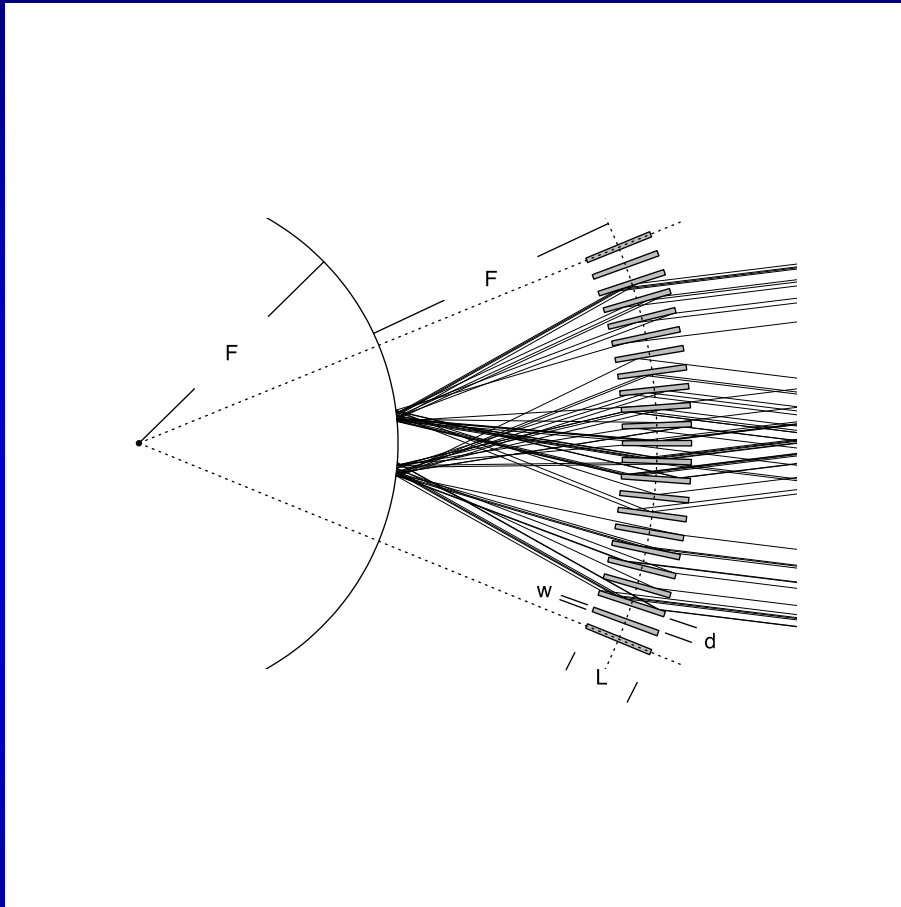
One Square Pore - Lobster Geometry

Each pore splits the aperture into 4 beams

0 reflection
1 reflection α
1 reflection β
2 reflections α,β

All 4 beams are offset from the pore axis by angles α and β

Lobster Geometry – Wide Field

Pores packed on spherical surface radius $R_c=2F$

Pores point to a common centre of curvature

Focal surface spherical radius F

1 reflection – line focus

2 reflections – true focus

No limit to FOV
If optic wide enough no vignetting

Originally described by Angel 1979

Effective Aperture and PSF

- Distributions of flux from the array of pores
  - 2 reflections from adjacent walls – focused spot
  - 1 reflection –   cross-arms
  - 0 reflections – straight through
  - Multiple reflections from opposite walls
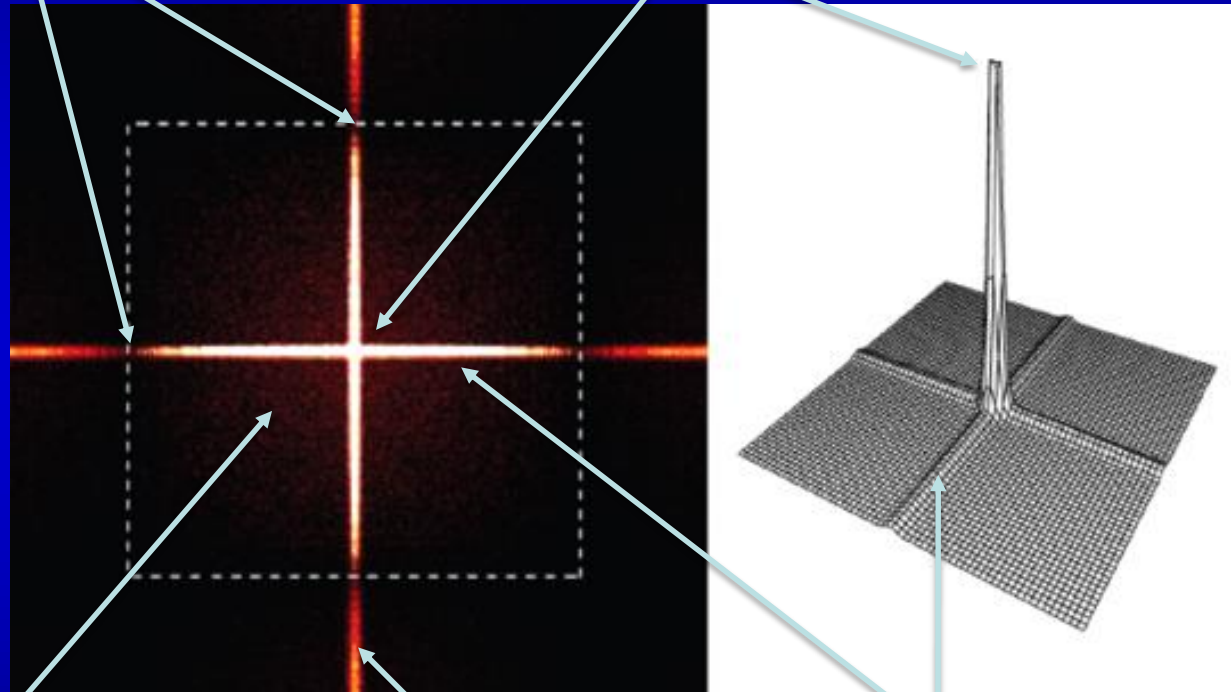- Aperture circle radius $F.d/L(2\sqrt{2}+1)$
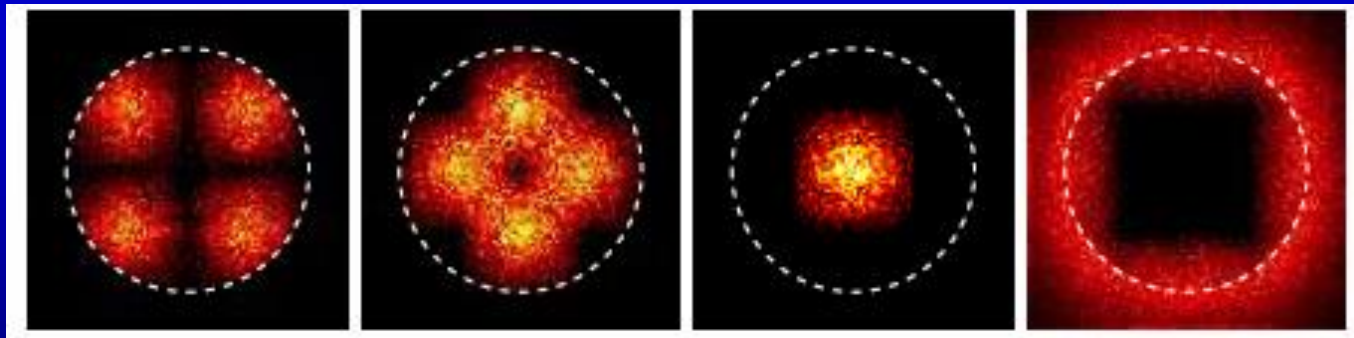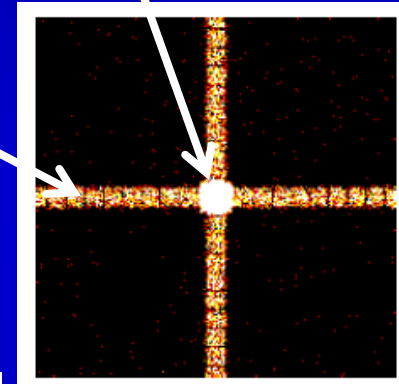
| 2 adjacent | 1 | 0 | N opposite |

Point Spread Function

zero at off-spot angle
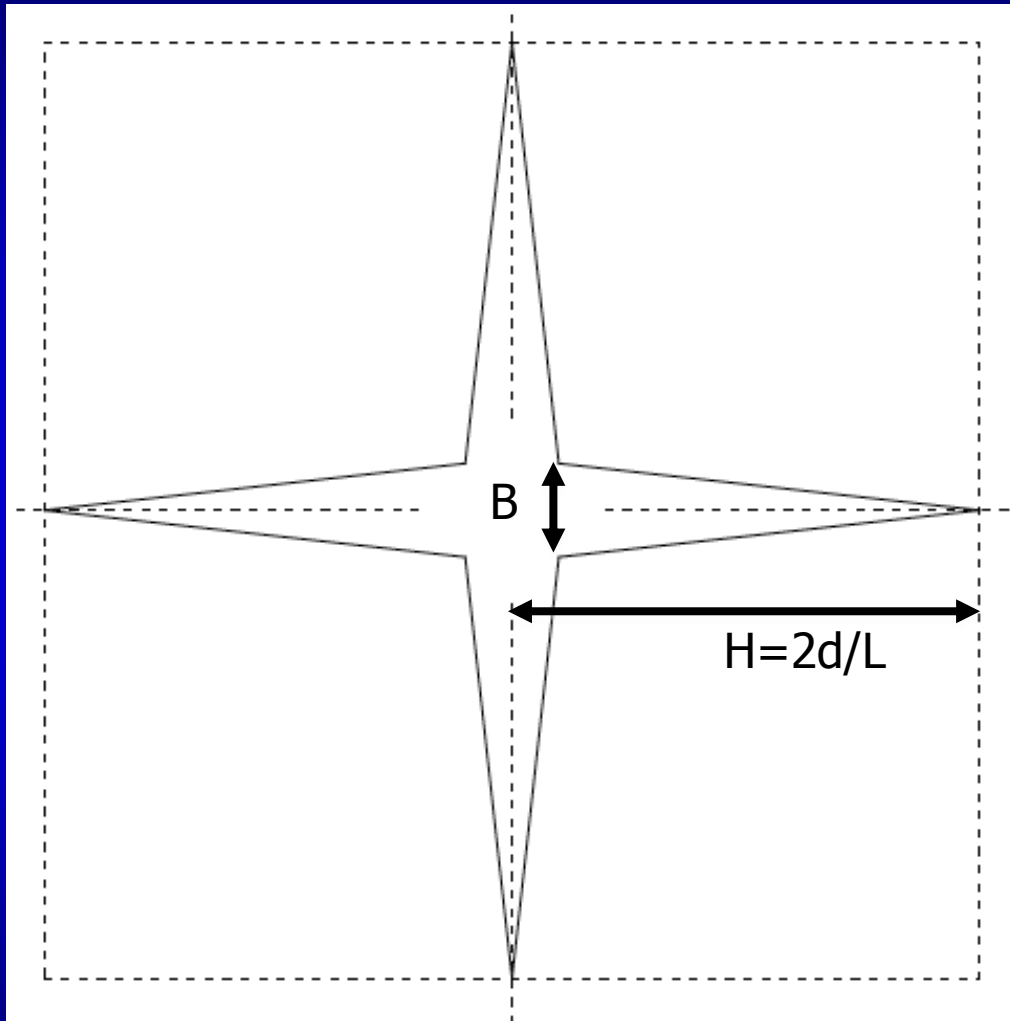$\theta = 2d/L$

2-reflection focused spot

0-reflection diffuse patch

3-reflection cross-arms

1-reflection cross-arms

Lobster Eye Cross-beam

A conventional circular (or square) beam is not useful

Instead we define a cross-beam

Adjust B so that cross-beam contains 50% of detected flux from source B_{HEW}

B_{HEW} is a robust measure of the angular resolution

Lobster Eye PSF - Model Function

$f(x)=1/(1+(2x/G)^2) + \eta(1-(y/H)^2)$

$f(y)=1/(1+(2y/G)^2) + \eta(1-(y/H)^2)$
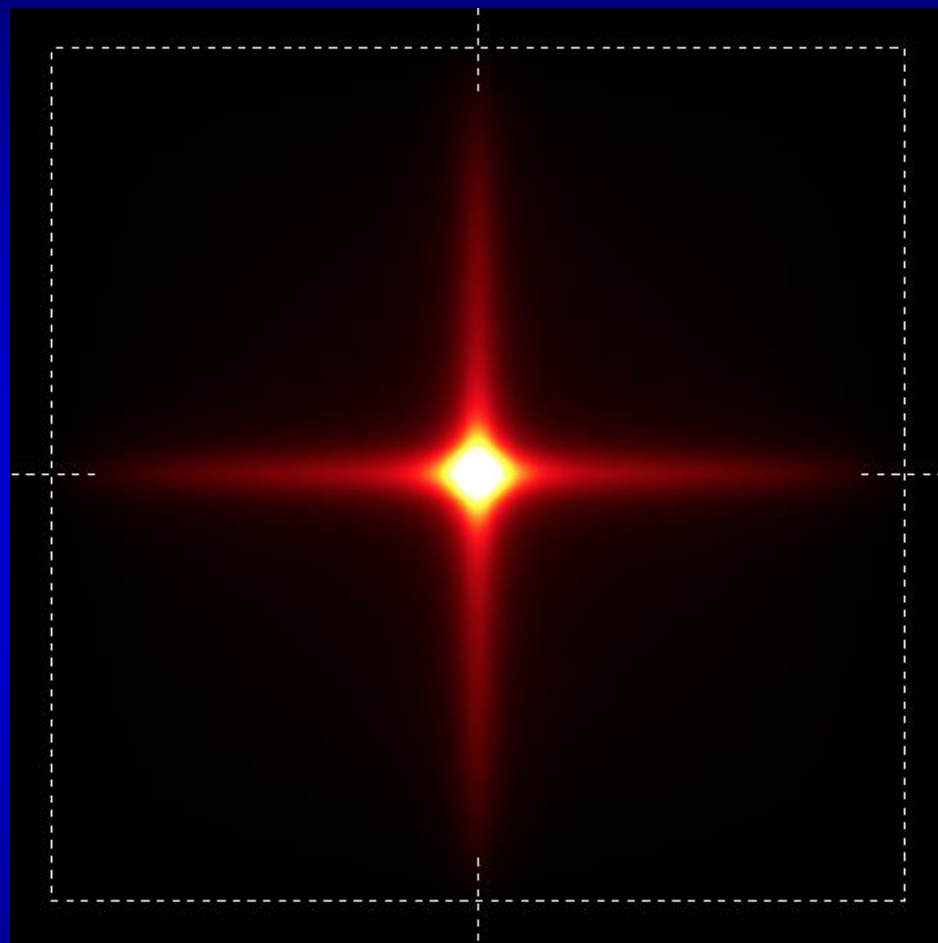
$F(x,y)=f(x).f(y)/(1+\eta)^2$

3 parameters:
  1) G Lorentzian width (FWHM)
  2) $H=2d/L$
  3) η is brightness of cross arms
     wrt to central spot (depends
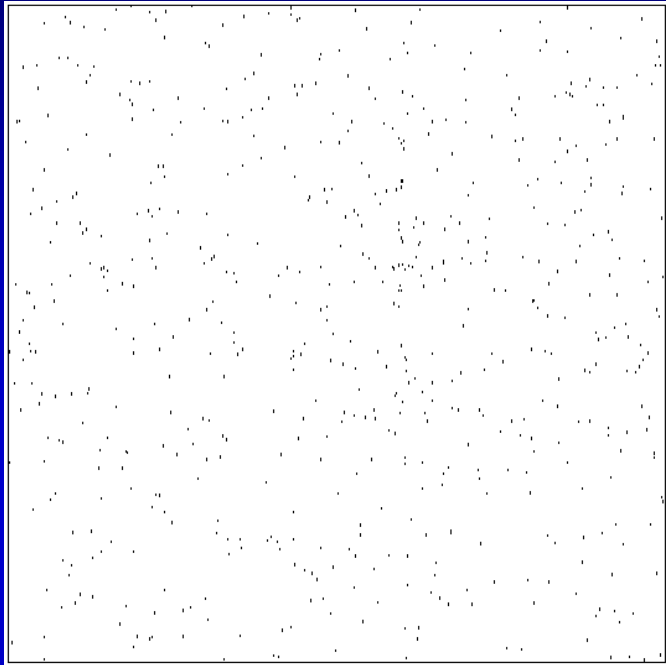   on reflectivity in pores)

Peak set at $F(0,0)=1$
$\iint F(x,y)dxdy=A_{psf}$ area of PSF in
focal plane

Effective beam size $\sqrt{A_{psf}}$ ($\sim B_{hew}$)

Focusing advantage = Collecting area/A_{psf}

Lobster eye event binning using model PSF

Perform a cross-correlation binning of events to create image
$$I(i,j) = \sum_k F(i-x_k, j-y_k)$$

~530 background counts
~50 source counts
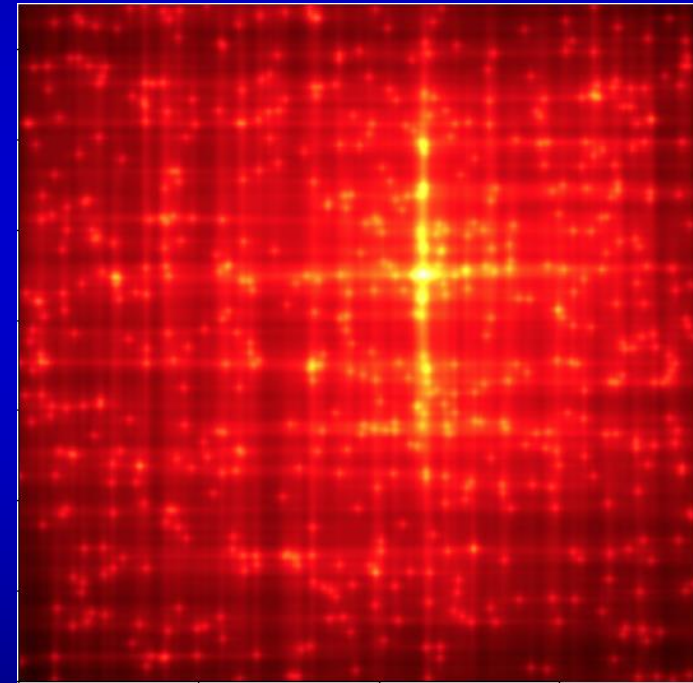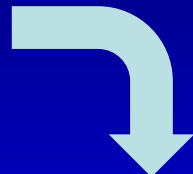
X-ray event distribution from detector
Event k at x_k, y_k

Equivalent to the cross-correlation with the mask pattern used for a coded mask telescope

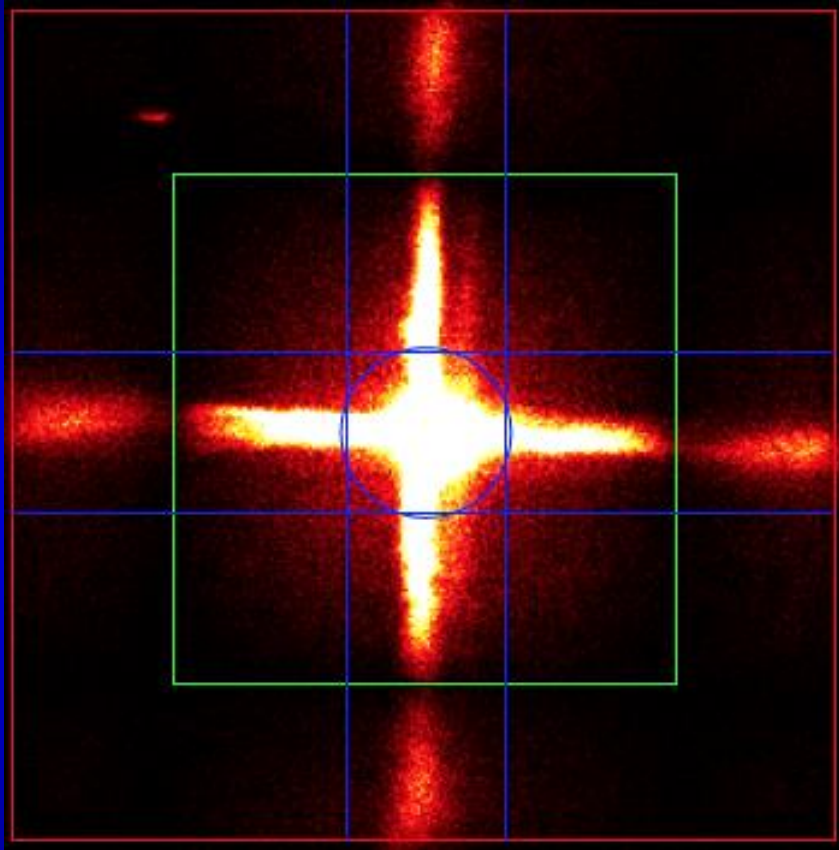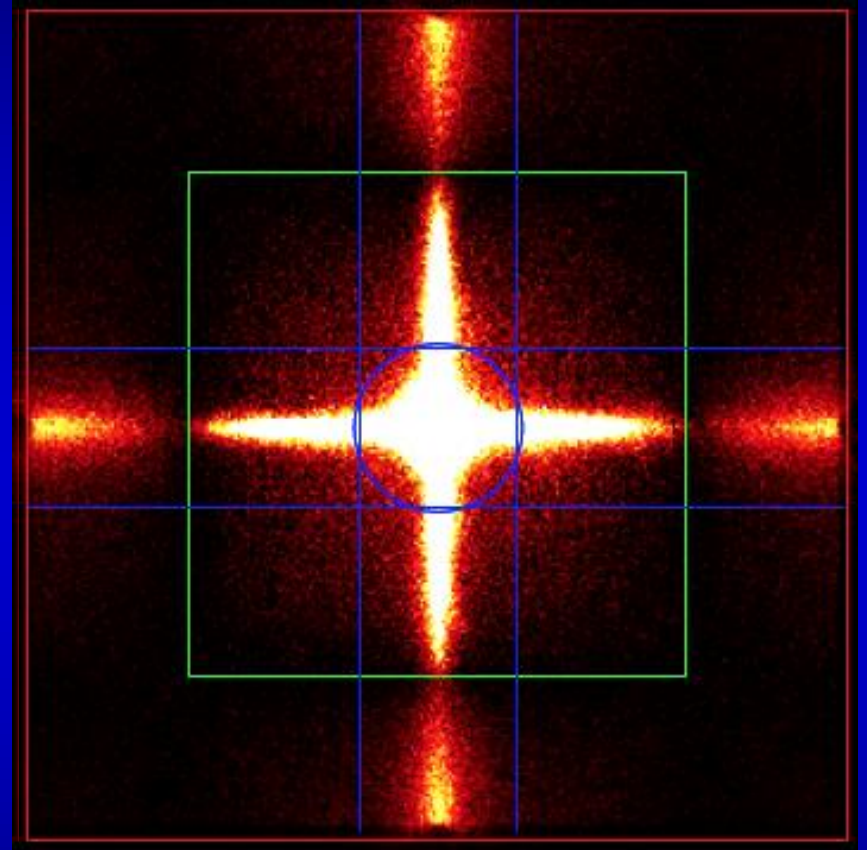Can use this for the on-board search algorithm

Binned image pixel i,j

Measured PSF at 1.49 keV

X-ray data – Leicester TTF

Simulated PSF

Latest Results - Summary

40 x 40 mm MPO
Radius of curvature 750 mm (F=375 mm)
Pore size d=20 microns
Thickness L=1.2mm
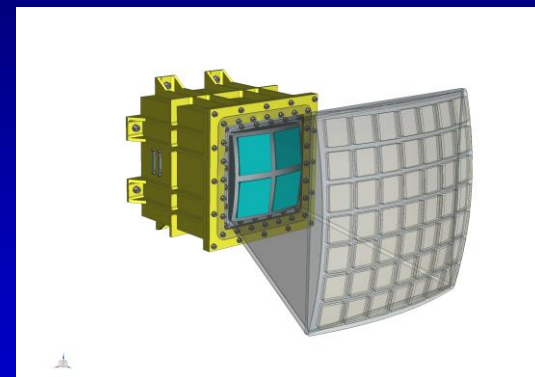   L/d=60
Coated with Iridium to give high reflectivity

F=300 mm, module mass 18 kg

Efficiency ~94% theoretical
Collecting area at 1.49 keV in full PSF   5.4 cm^2

Angular resolution = 6 arcmins (B_{hew}=4 arcmins)
Focusing advantage ~90 (c.f. coded mask – factor = 0.5)

- We have MPOs with high efficiency – collecting area close to optimum
- We aim to improve the angular resolution to ~5 arcmins – this will further increase the focusing advantage and location accuracy
- We can use the PSF model and perform lobster eye event binning to detect the faint fast transients