Finding X-ray Transients In the Post Konus-WIND et al. Era

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Konus-WIND 25
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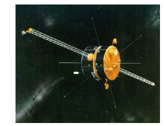
Konus-Wind et al. Era

Chasing GRBs and Transients

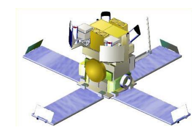
- CGRO — 5th April 1991
  - BATSE (to 4th June 2000)

- WIND — 1st November 1994
  - Konus-WIND Experiment

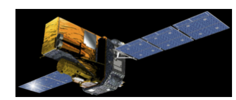


- BeppoSAX — 30th April 1996
  - LECS, WFC (to 29th April 2003)

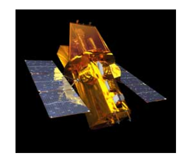
- HETE-2 — 9th October 2000
  - FREGATE, SXC, WXM (to March 2006)



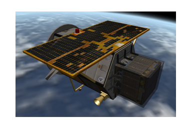
- INTEGRAL — 17th October 2002
  - SPI-ACS, IBIS



- Swift — November 20th 2004
  - BAT, XRT, UVOT



- AGILE — 23rd April 2007
  - GRID, SA



- Fermi — 11th June 2008
  - LAT, GBM

Wide-Field X/Gamma-ray Transient Detectors

- All existing wide-field hard X-ray and Gamma ray detectors derive prompt source positions using collimation or masks or tracks – e.g. Swift BAT
- Accurate positions come from follow-up using focusing instruments – soft X-ray, optical, IR… - e.g. BeppoSAX LECS, Swift XRT
- Focusing optics concentrate the flux and produce an image – high sensitivity and accurate positions
- Can't use focusing optics for wide-field hard X/Gamma-ray instruments
- But can use focusing optics for wide-field soft X-ray imaging

Future Wide Field Instruments

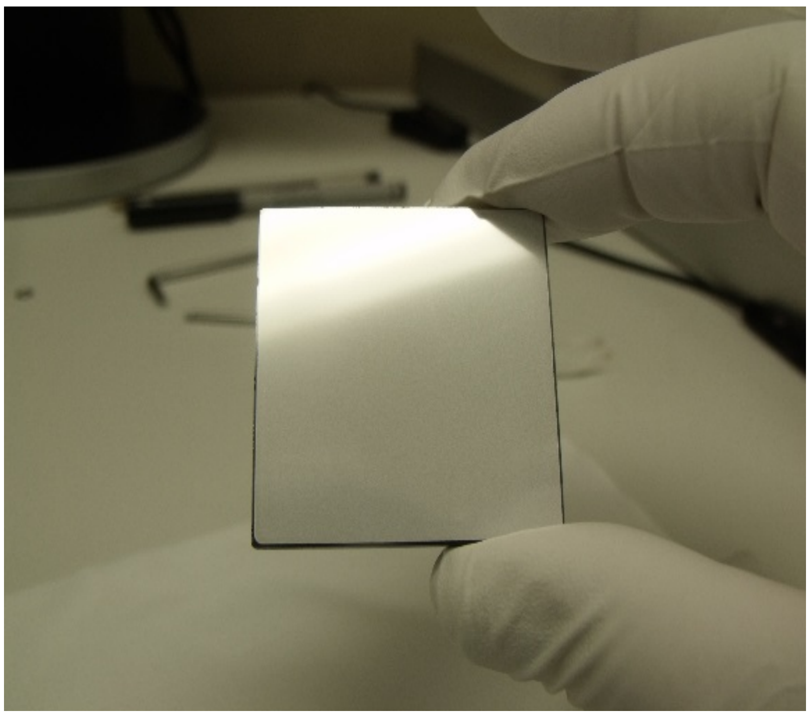
- There are many proposed soft X-ray wide field instruments
  - Theseus SXI – ESA
  - Einstein Probe WXT – China
  - TAP WFI – NASA
  - Gamow Explorer LEXT – NASA
  - HiZ GUNDAM WFXM– ISAS/JAXA M-class
  - …
- All designed to detect and locate high energy astrophysical transients like GRBs
- All utilize lobster eye X-ray optics
- All have very similar specifications for the optics performance
- All can be implemented using an array or arrays of Micro Pore Optics (MPOs)
- All use CCD or CMOS imaging detectors – energy band 0.2-10 keV

Specifications for Detecting X-ray Transients

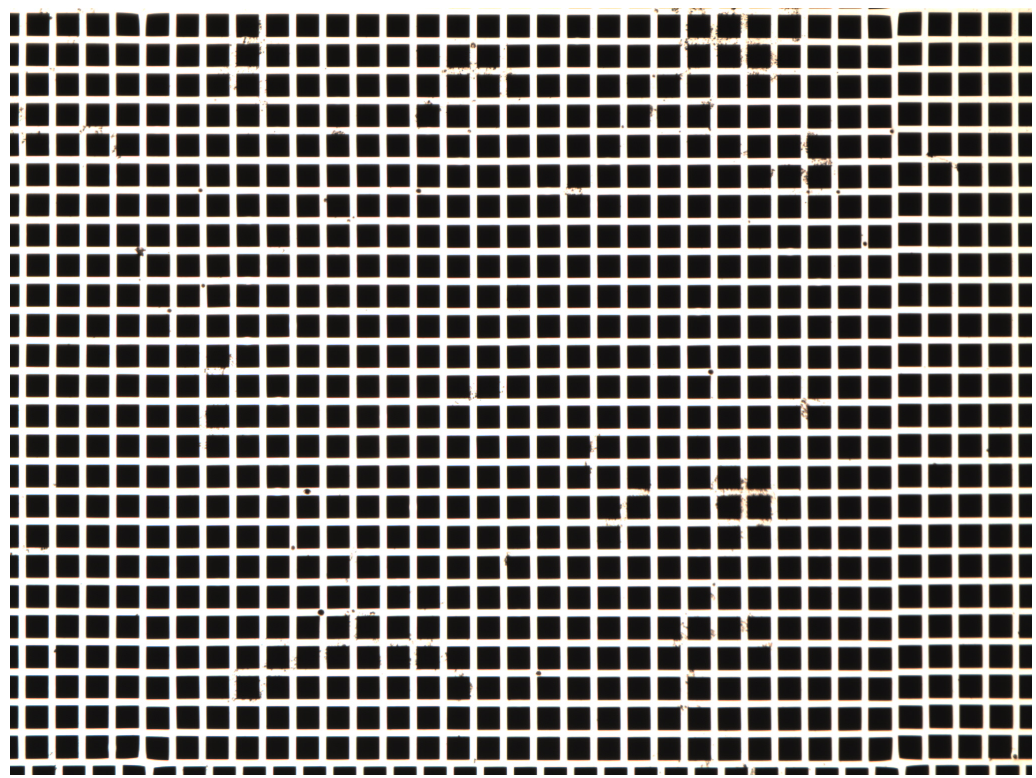
- Large field of view – 1000's square degrees or larger
- High angular resolution - ~1 arcmins
- High sensitivity - $\sim 10^{-9}$ ergs cm^{-2} s^{-1} 0.3-6 keV
  - in short exposures – ~1-10 sec
- Lobster Eye Telescopes have the unique potential to provide the above!
- Currently available Micro Pore Optics (MPOs):
  - Can provide the large FOV – arrays of MPOs
  - Have the required efficiency in the soft X-ray band to provide the required collecting area
  - Don't quite have the angular resolution to meet the location accuracy requirements – development in progress and we expect to meet the requirements in 1-2 years

Square Pore MPOs

- Micro Pore Optics MPOs – realized using square pore Micro Channel Plates (MCPs)
- Glass plate full of square holes – thickness L=1.0-2.5 mm – transmission ~60%
- Square pores size d=20 or 40 µm, wall~5.8 µm or ~11.5 µm L/d~25-125
- Slumped to spherical form R_c=2F - R_c 600-2000 mm, focal length F=300-1000 mm

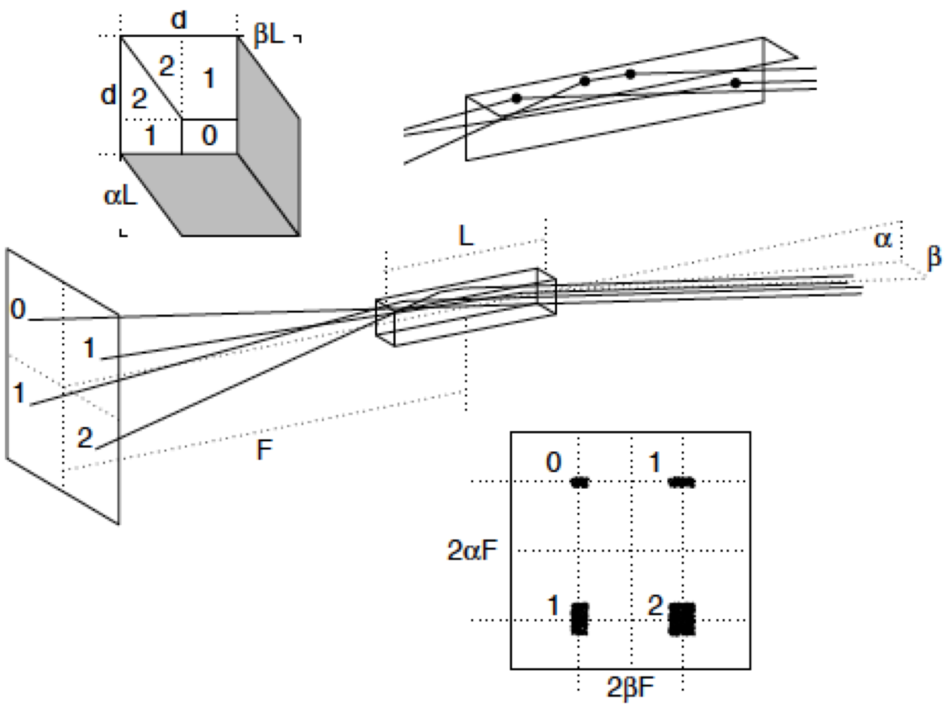


Photonis square pore MCP



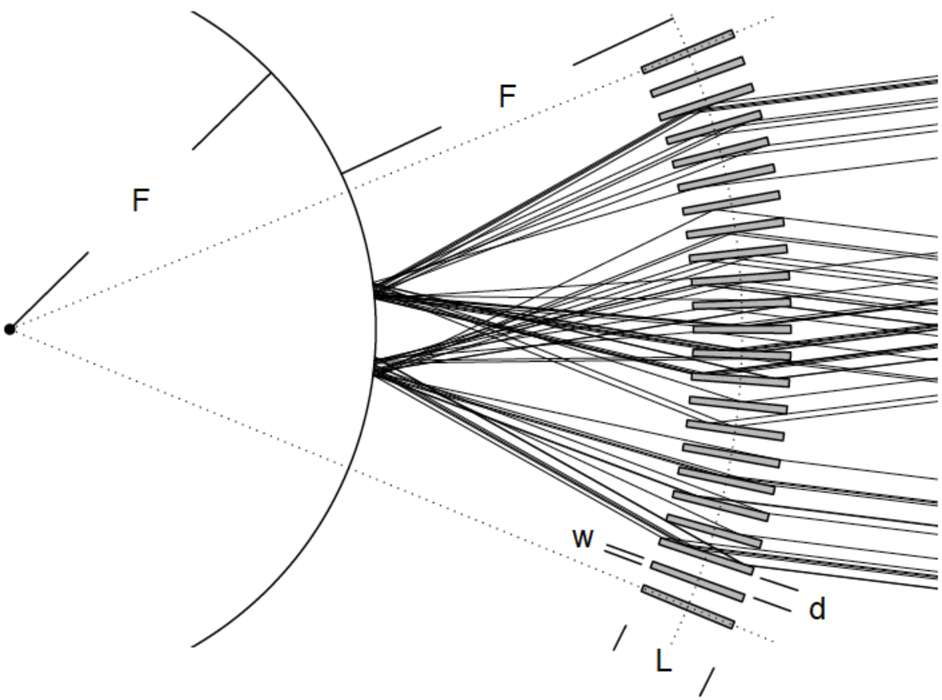
Action of a Single Pore

- Each pore splits the incident beam into 4 beams
  - 0, 1, 1 or 2 reflections

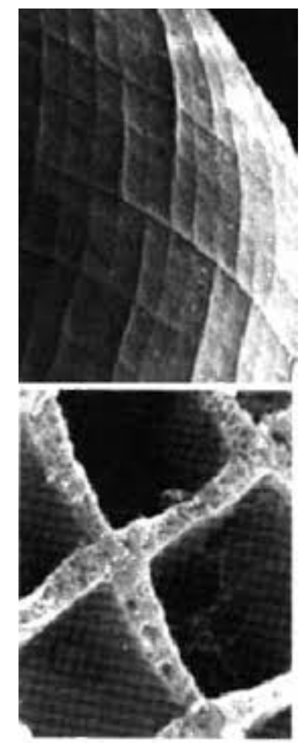


Lobster Eye X-ray Optics

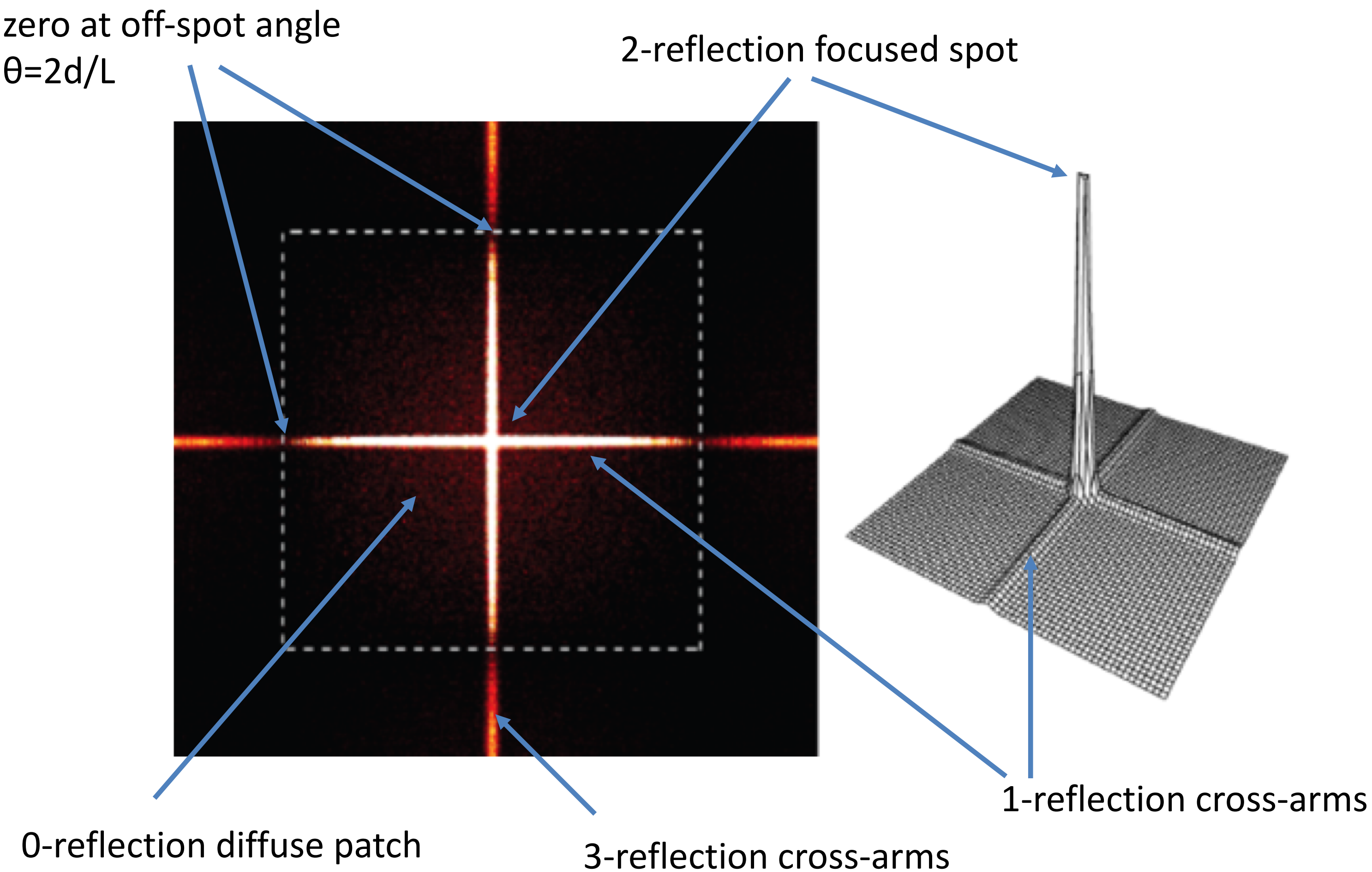
- An array of pores on a spherical surface focus X-rays
- The 4 beams from every pore line up to form a point spread function
- The field of view only limited by size of optic or detector
- In principle can image the whole sky with a single optic!



Real lobster eye



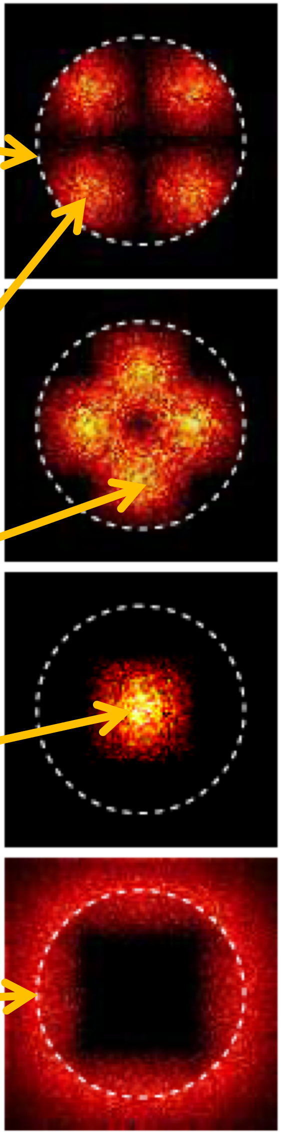
Lobster Eye Point Spread Function



Effective Aperture on Sphere

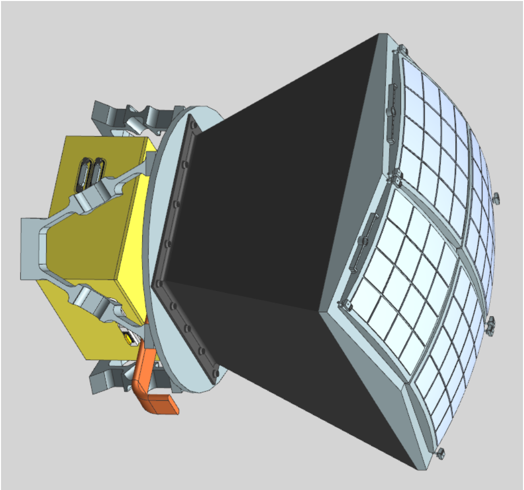
- Aperture circle for a particular source
  - Centre – source axis
    - line from source to centre of curvature of MCO
  - radius F.d/L(2√2+1)

- Distributions of flux from the array of channels
  - 2 reflections from adjacent walls – focused spot
  - 1 reflection – cross-arms
  - 0 reflections – straight through
  - Multiple reflections from opposite walls

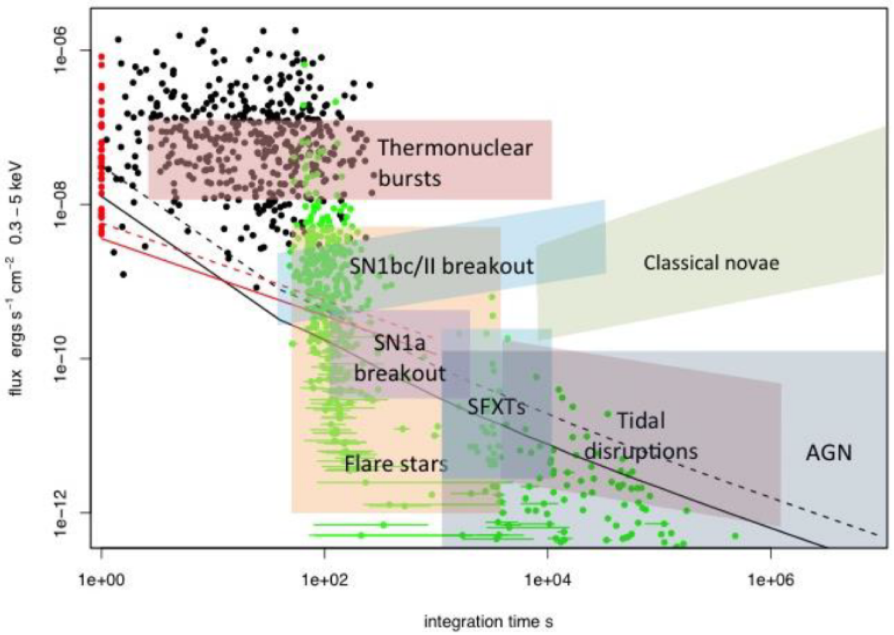


Wide Field Lobster Eye Modules

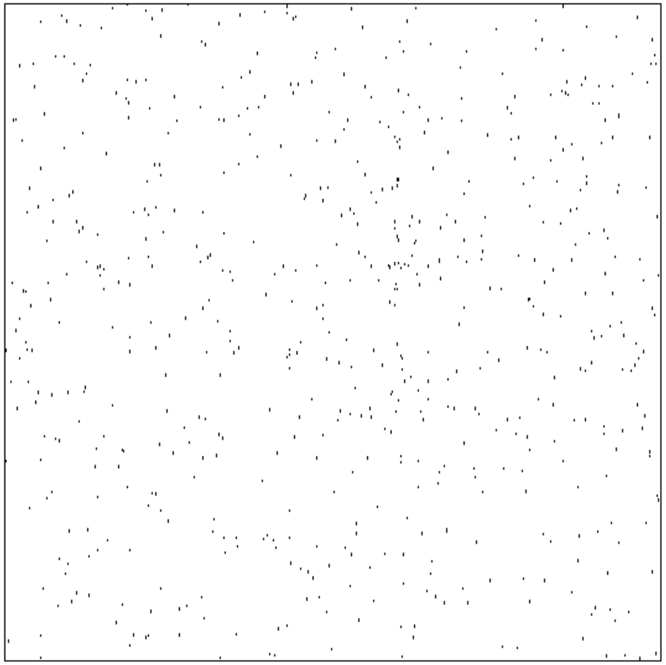
- For example proposed for
  - ISS Lobster - submitted to NASA Dec 2014
  - Theseus SXI – ESA M4 Dec 2014
- Field of view ~1/6 steradian per module – 6 modules give 1 steradian
- Angular resolution ~5 arc mins – source positions < 30 arc secs



F=300 mm, module mass 20 kg
MPO array 8x8 – 64 MPOs



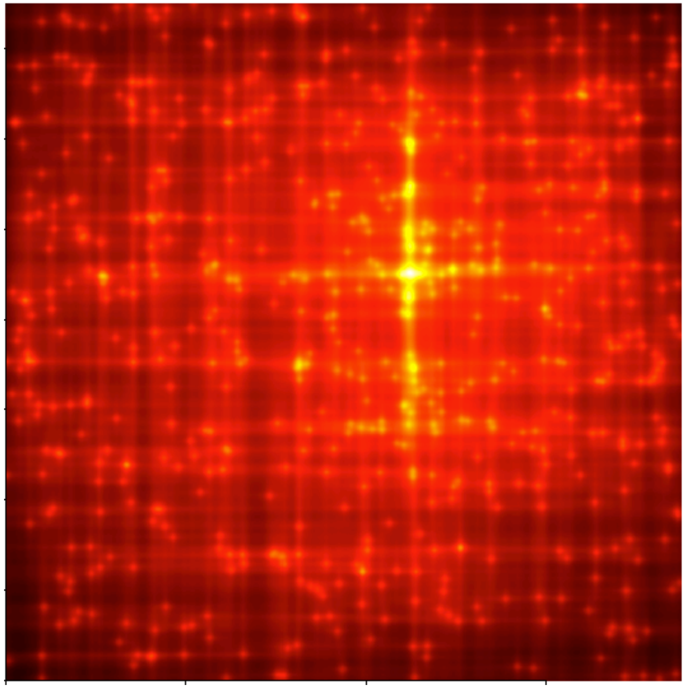
Lobster Eye Event Binning



X-ray event distribution from detector
Event k at x_k, y_k

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

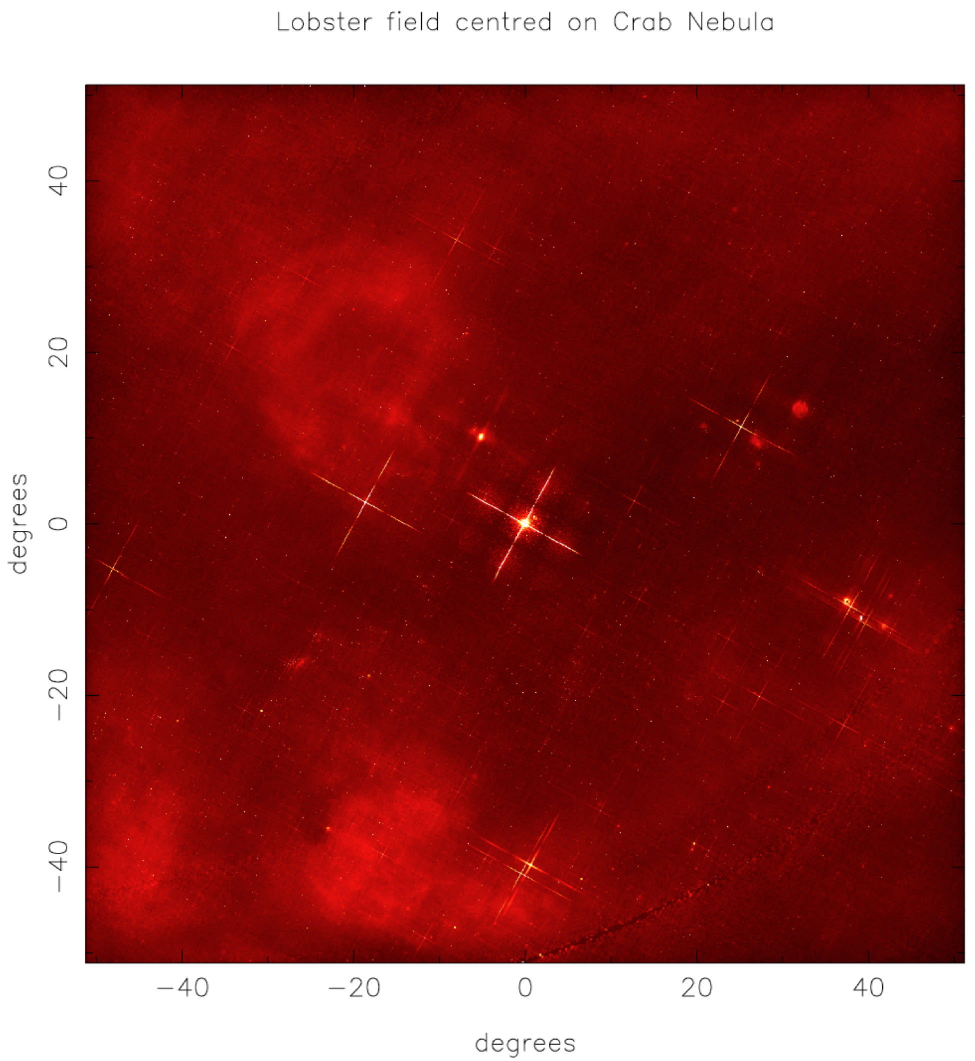
~530 background counts
~50 source counts



Binned image pixel i,j

Equivalent to the cross-correlation with the mask pattern used for a coded mask telescope
Can use this for the on-board search algorithm
Required sensitivity is easily achieved

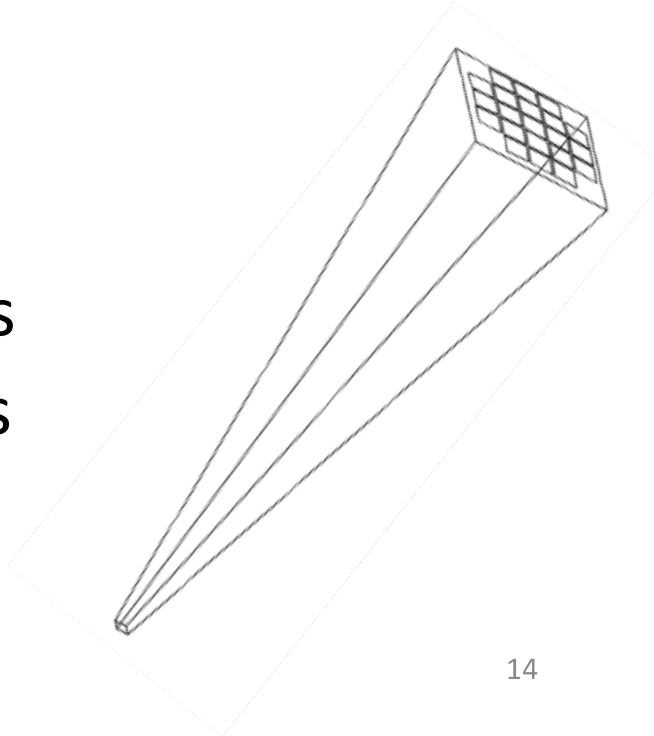
Lobster Eye Wide Field Imaging



- Deep exposure simulation of the field around the Crab Nebula
- Using the RASS point source and diffuse soft X-ray data base
- Get an image of point sources and diffuse emission – angular resolution ~5 arcmins

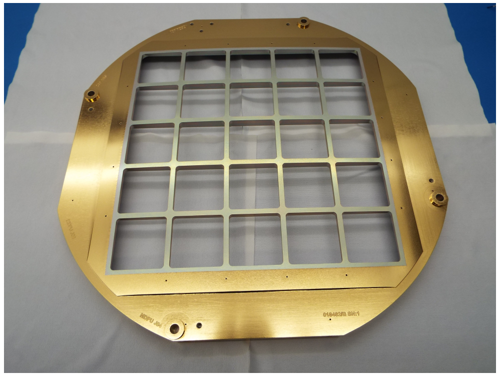
SVOM MXT – the real thing!

- Narrow field follow up soft X-ray telescope for the French-Chinese mission SVOM
- Lobster eye optic supplied to CNES by University of Leicester using Photonis MPOs
- MXT optic – 5x5 array of MPOs
  - Focal length ~1 m
  - Collecting area ~25 cm^2 at 1 keV
  - Field of view of optic 6x6 degrees
  - Angular resolution ~7 arcminutes
  - Collecting area ~25 cm^2 at 1 keV

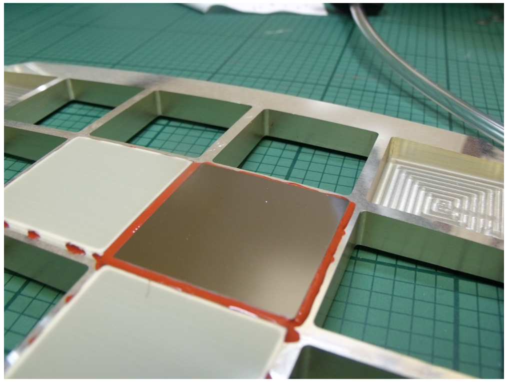


Integration of the MPO Array

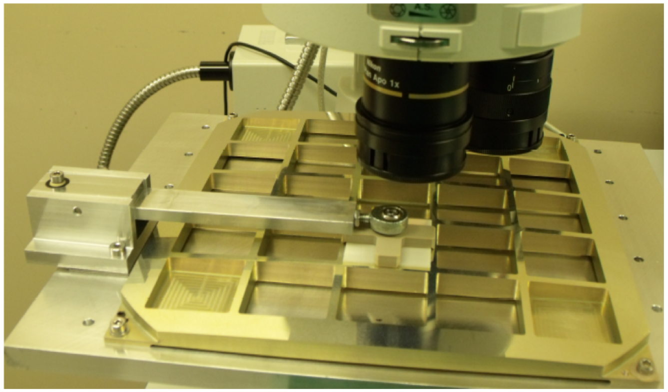
- Aluminium support frame
- Accurately machines to spherical form, radius ~2000 mm, +- 10 microns
- Radius of curvature of frame matches RoC of MPOs
- Accurate alignment of MPOs controlled using jigs and a microscope
- MPOs glued to frame using a continuous glue line



SVOM MXT STM frame

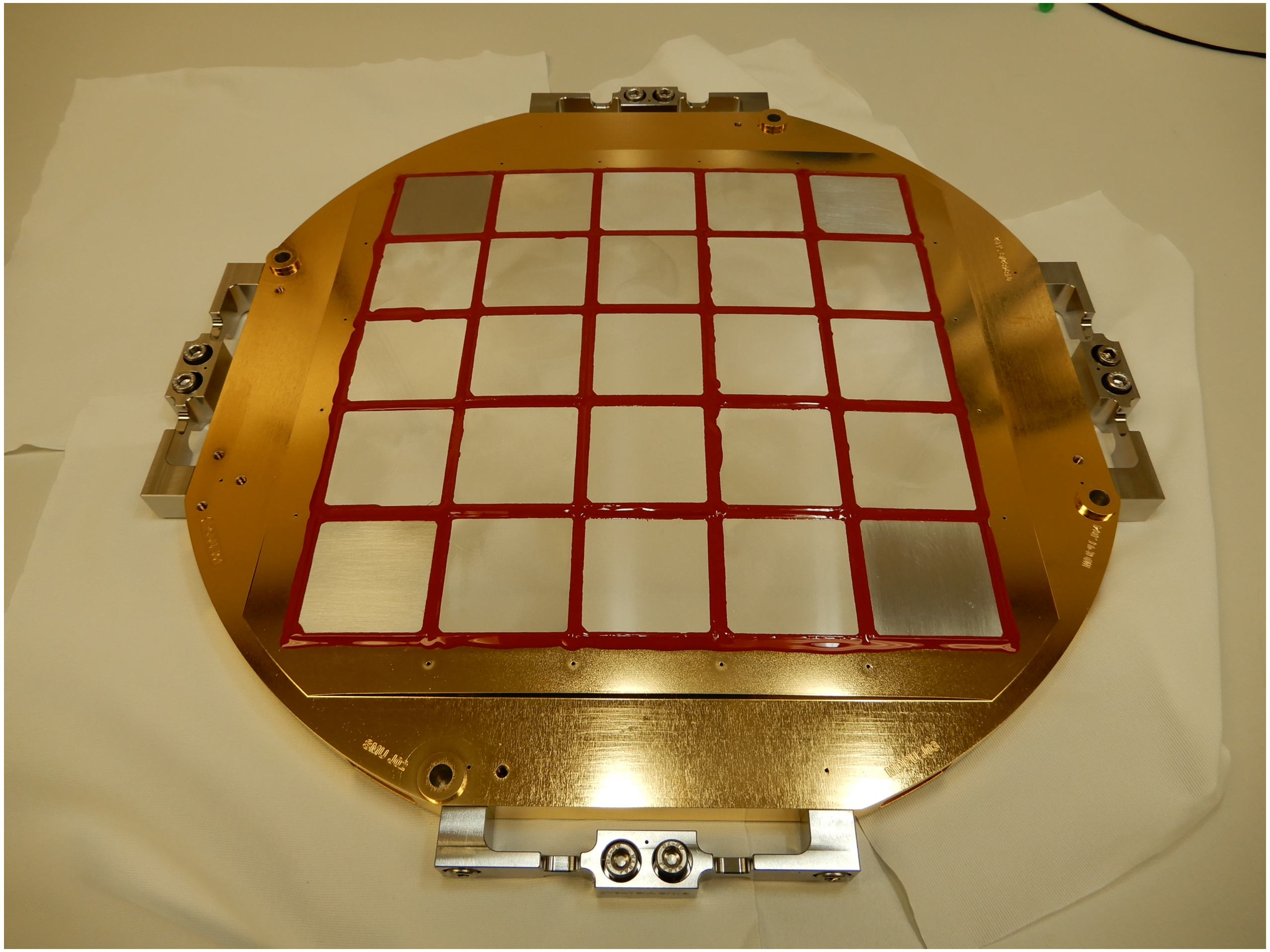


MPOs fixed using a continuous glue line



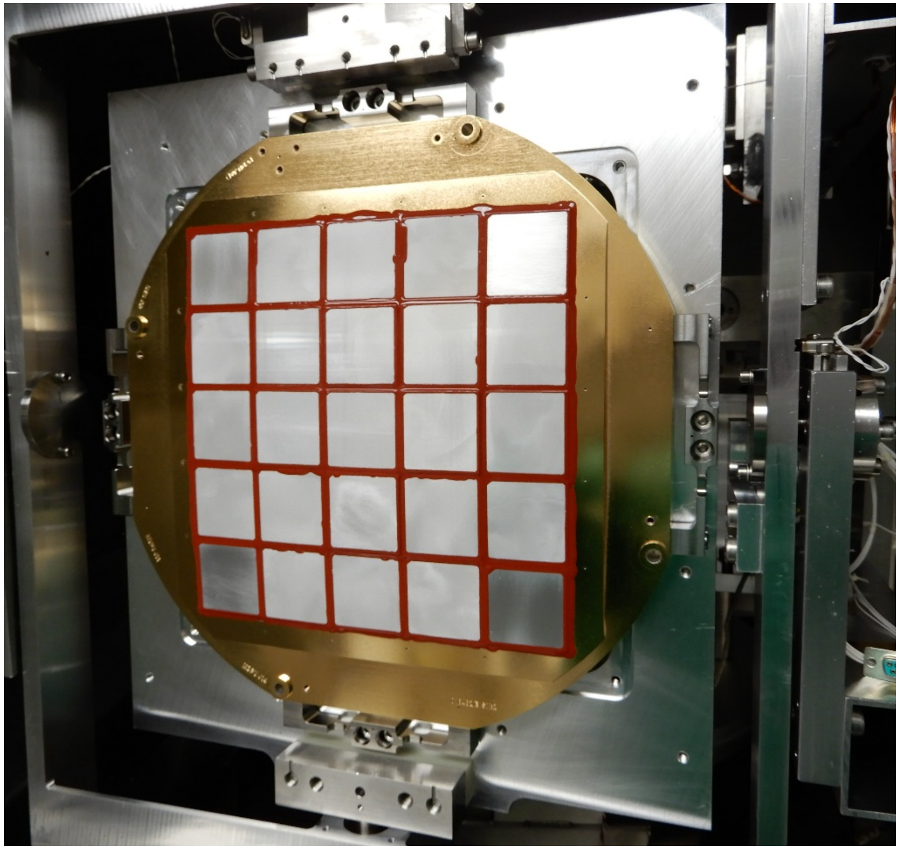
Integration jig

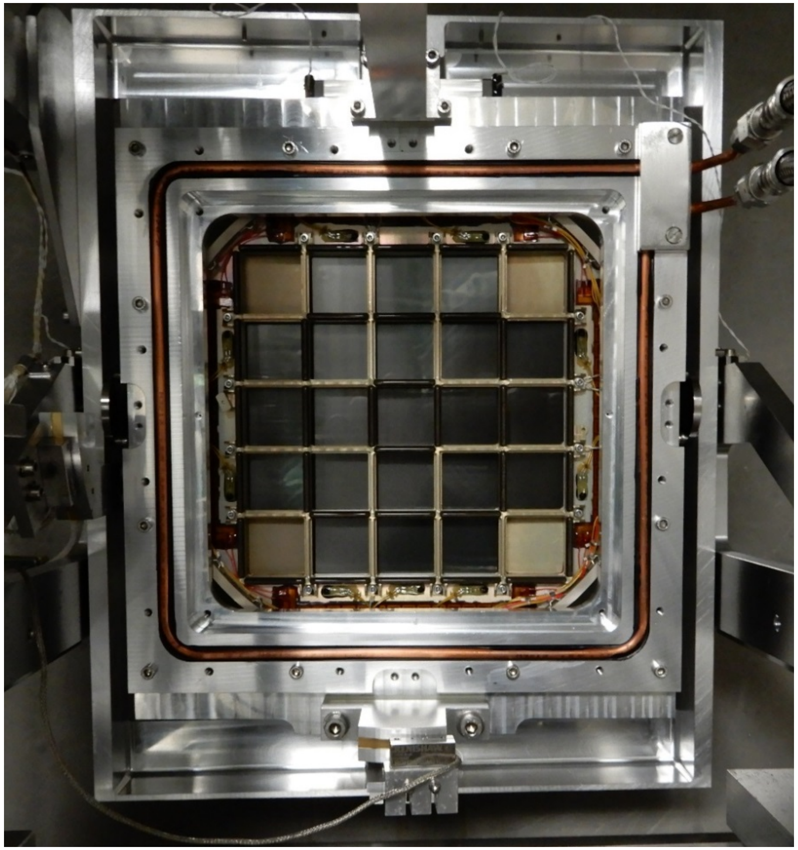
MXT QM Optic Complete



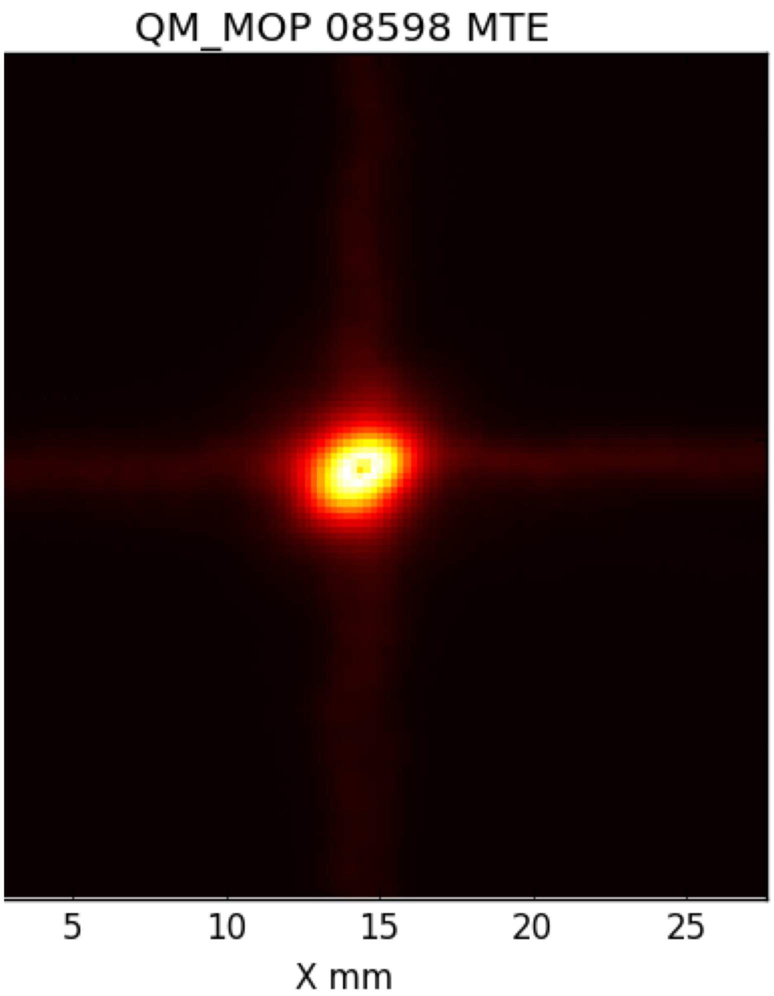
Total mass ~1.2 kg

X-ray Testing at Leicester



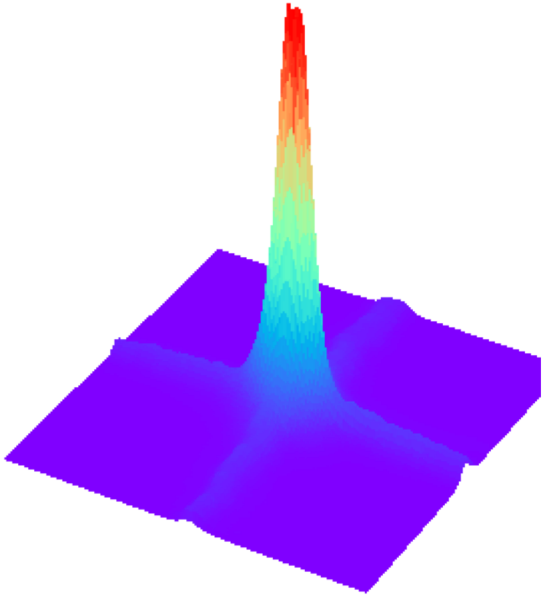


First Light – Al K 1.49 keV



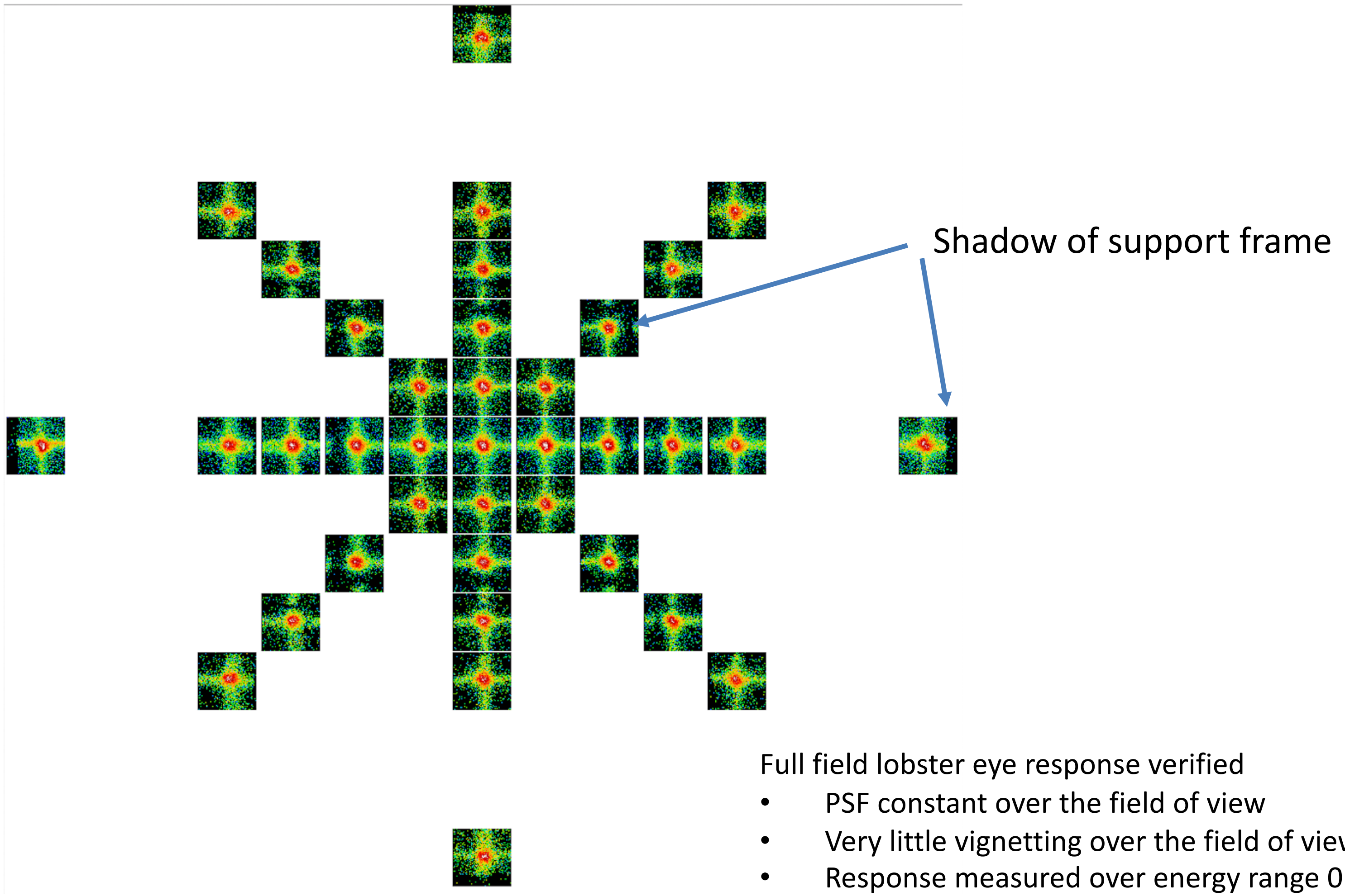
QM_MOP 08598 MTE

Angular resolution ~10 arcminutes
Effective area ~25 cm^2



Improvements in subsequent builds – expect angular resolution ~7 arcminutes

QM Optic Tested at Panter Facility MPE



Full field lobster eye response verified

- PSF constant over the field of view
- Very little vignetting over the field of view
- Response measured over energy range 0.27 – 8.05 keV

Summary

- Lobster eye X-ray optics can be used for finding soft X-ray transients
  - Large field of view – 1000s square degrees
  - High sensitivity - can detect >90% GRBs
  - Accurate positions ~1 arcminute
- They work
  - Square pore MPOs have been used to construct the first full size lobster eye optic – 5x5 array
  - First light of a full array - SVOM MXT QM optic
- Energy range 0.2-10 keV
  - Get GRB positions using soft X-rays – observe prompt + afterglow
  - Need a hard X-ray detector to see the simultaneous gamma ray emission
  - Follow-up in visible, IR, radio… using the accurate position
- Theseus SXI uses lobster eye optics
  - see next talk by Lorenzo Amati