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

Dick Willingale
Physics and Astronomy, University of Leicester, UK

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Konus-Wind et al. Era

Chasing GRBs and Transients

- CGRO
  - BATSE (to 4\textsuperscript{th} June 2000)
- WIND
  - Konus-WIND Experiment
- BeppoSAX
  - LECS, WFC (to 29\textsuperscript{th} April 2003)
- HETE-2
  - FREGATE, SXC, WXM (to March 2006)
- INTEGRAL
  - SPI-ACS, IBIS
- Swift
  - BAT, XRT, UVOT
- AGILE
  - GRID, SA
- Fermi
  - LAT, GBM

5\textsuperscript{th} April 1991
1\textsuperscript{st} November 1994
30\textsuperscript{th} April 1996
9\textsuperscript{th} October 2000
17\textsuperscript{th} October 2002
November 20\textsuperscript{th} 2004
23\textsuperscript{rd} April 2007
11\textsuperscript{th} June 2008
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 – $\sim$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

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

2-reflection focused spot

3-reflection cross-arms

1-reflection cross-arms

0-reflection diffuse patch
Effective Aperture on Sphere

• Aperture circle for a particular source
  – Centre – source axis
    • line from source to centre of curvature of MCO
    – radius \( F.d/L(2\sqrt{2}+1) \)

• 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

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

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
Required sensitivity is easily achieved

Binned image pixel \( i,j \)
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
MXT QM Optic Complete

Total mass ~1.2 kg
X-ray Testing at Leicester
First Light – Al K 1.49 keV

Angular resolution ~10 arcminutes
Effective area ~25 cm²

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

Shadow of support frame
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