A very wide field focusing telescope for Synoptic studies in the soft X-ray band

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Synoptic Telescopes, (Broad Coverage of Sky in Time and Space)

Examples

Optical	Pan-Starrs, the Large Synoptic Survey Telescope(LSST)
Radio	Square Kilometer Array
Gamma-ray	**Fermi** (formerly GLAST), **20 MeV to 300 GeV**.
Hard X-ray	**BAT** coded mask on **Swift, 15 to 150 keV**
X-ray	**RXTE All-Sky Monitor & MAXI, 2 to 10 keV***
Soft X-ray	(Subject of this paper), **0.5 to 6 keV**

***MAXI** also has a smaller area detector, **0.5 to 10 keV**

Variable Soft X-ray Sources

Stellar flares and Cataclysmic Variables

Appearance of Transient X-ray source

Change in state of compact binary, “low, hard” to “high soft” state

AGN: Intensity rise and fall from SMBH absorbing star

AGN: transient absorption by orbiting cloud

X-ray burst sources

Very high redshift gamma-ray bursts that appear as X-rays

X-ray afterglows of gamma-ray bursts

X-ray flashes

“Orphan” X-ray afterglows of gamma-ray bursts?

Supernova, that are **not** type 1a

Details of RXTE ASM and MAXI, Both Scan Continuously

Instrument	**Location**	**Area***	**Field of View**	**Future**
RXTE ASM	Low Earth orbit	90*cm^2	0.5 ster	~ 1 year
MAXI X-ray	Space Station	5000	0.05	? (limited)
MAXI Soft X-ray	“ “	90	0.05	
ASTROSAT	(a copy of RXTE, built and to be launched by India)			

The RXTE ASM consists of 1D coded masks at an angle of 24 deg

MAXI consists of collimated proportional counters and a CCD array

ASM & MAXI scan the sky continuously and have small fields of view

While the ASM has detected a few GRBs it misses most. MAXI has detected at least 3 GRBs in about 6 months.

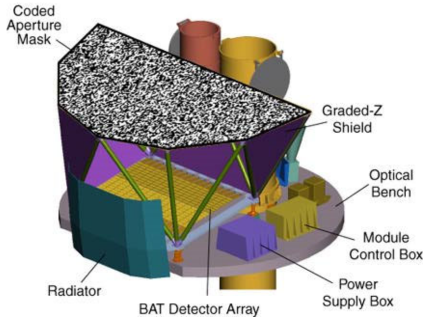
Requirements

- Have large fraction, i.e. few ster, of sky in field of view at all times,
- Quickly obtain good positions of sites where change occurred
- Transmit positions of gamma-ray bursts and X-rays flashes immediately to network of robotic and human controlled telescopes who observe the afterglows in radio, IR, visible, UV, and X-ray bands
- Obtain positions good enough to optically indentify the host galaxy and measure its redshift, Finding the most distant galaxy seen so far, Z = 8.2, was the result of identifying the optical counterpart at the position of a gamma-ray burst afterglow.

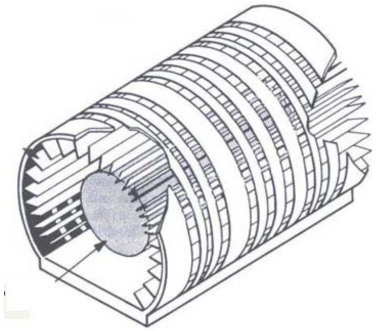
Three Types of Wide Field Detectors

2D Coded Mask

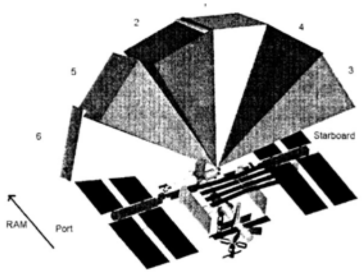
BAT of Swift



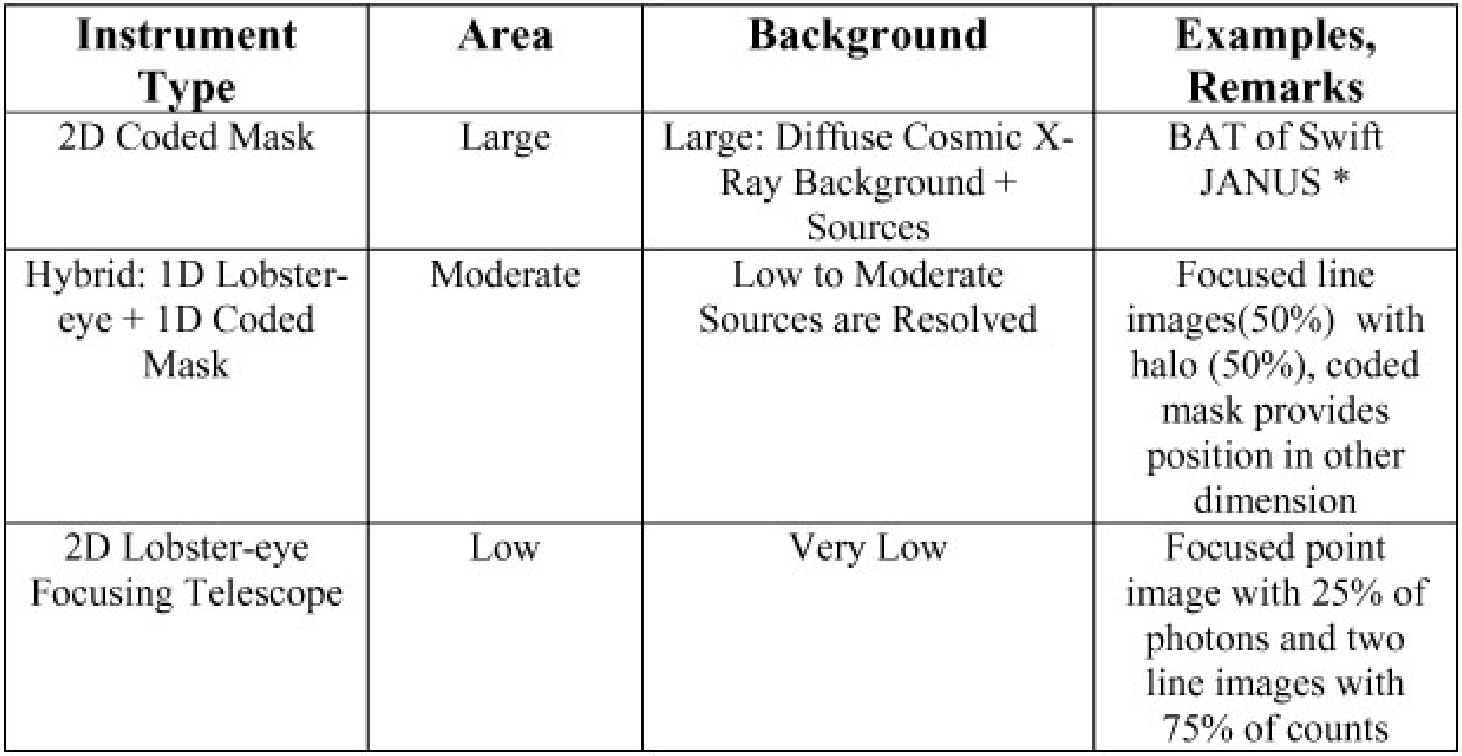
Hybrid, 1D Lobster-eye
+ 1D Coded Mask



2D Lobster-eye for
The ISS, (status uncertain)



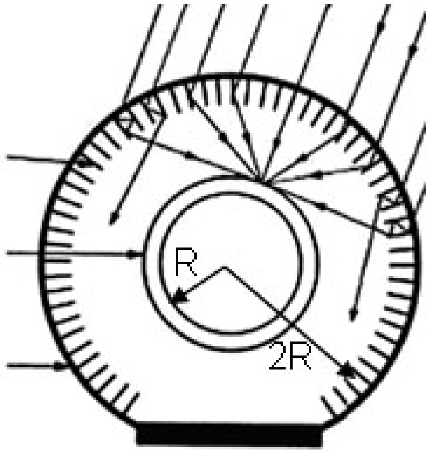
Very Large Field of View X-ray Detector Systems



Instrument Type	Area	Background	Examples, Remarks
2D Coded Mask	Large	Large: Diffuse Cosmic X-Ray Background + Sources	BAT of Swift JANUS *
Hybrid: 1D Lobster-eye + 1D Coded Mask	Moderate	Low to Moderate Sources are Resolved	Focused line images(50%) with halo (50%), coded mask provides position in other dimension
2D Lobster-eye Focusing Telescope	Low	Very Low	Focused point image with 25% of photons and two line images with 75% of counts

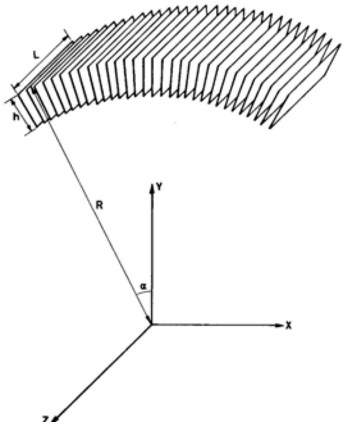
*JANUS X-Ray Flash Monitor was selected for study as possible Small Explorer

Lobster-eye Telescopes



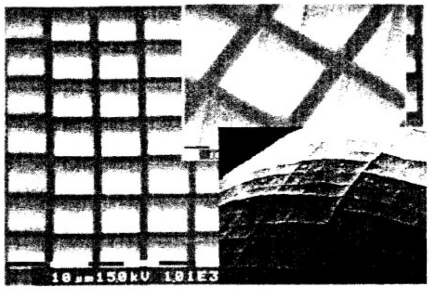
<u>1 D</u> lobster-eye + 1 D mask

Optics are moderately heavy, ~100 kg stack of flat mirrors



<u>2 D</u> (square, slumped channel plate optics are very lightweight

Two orthogonal stacks of reflectors are very heavy

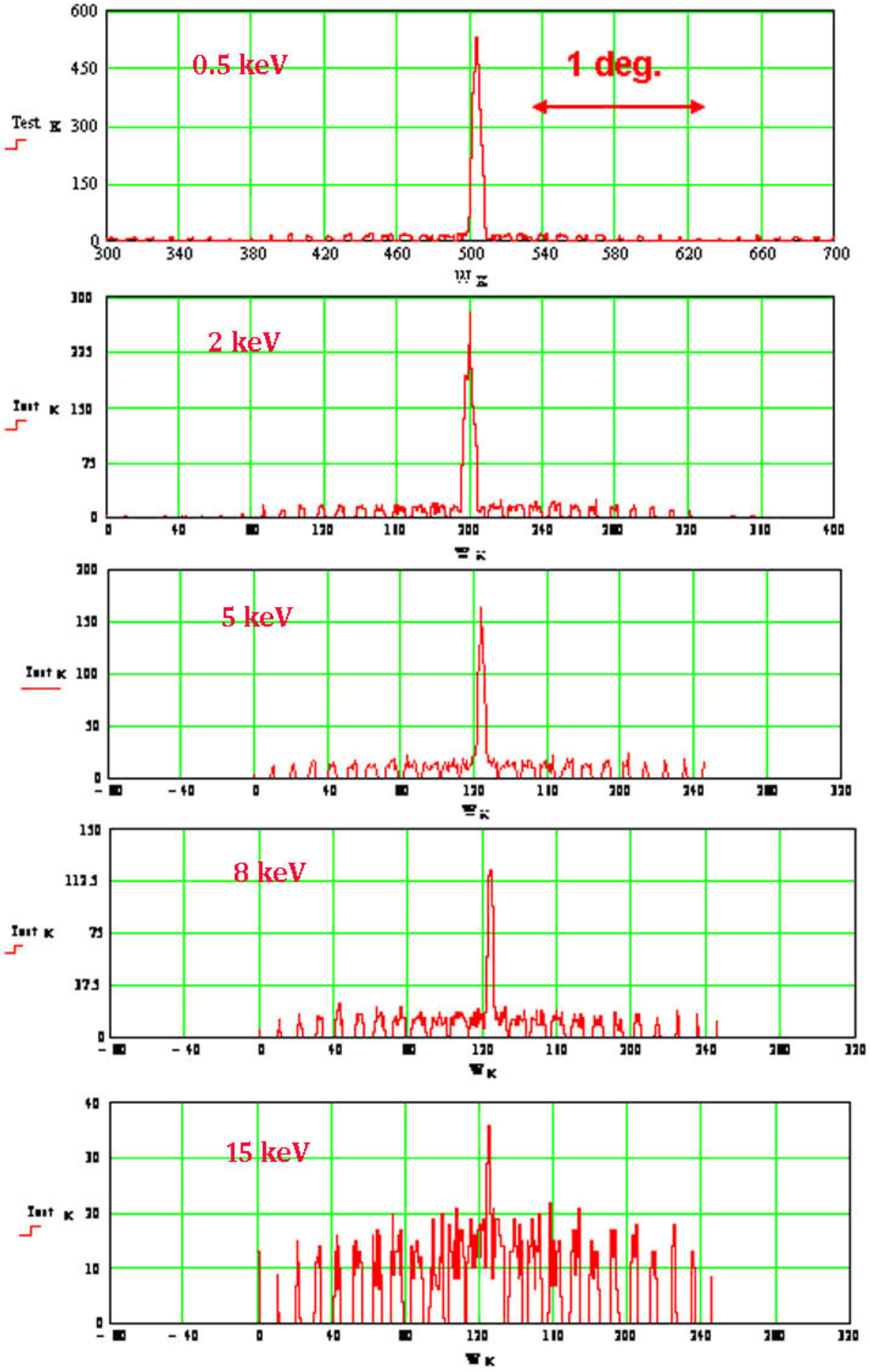


Theoretical Point source response of 1D Lobster-eye telescope at several energies.

Point (actually a line along the full length of the detector in the other dimension) plus a 1D halo limited by the collimating action of the reflectors

Point component has ~50 % of power for E < 3 keV with a FWHM of 3.5 arcminutes.

Power within point component Decreases above 3 keV



Parameters for estimating the effective area by ray tracing

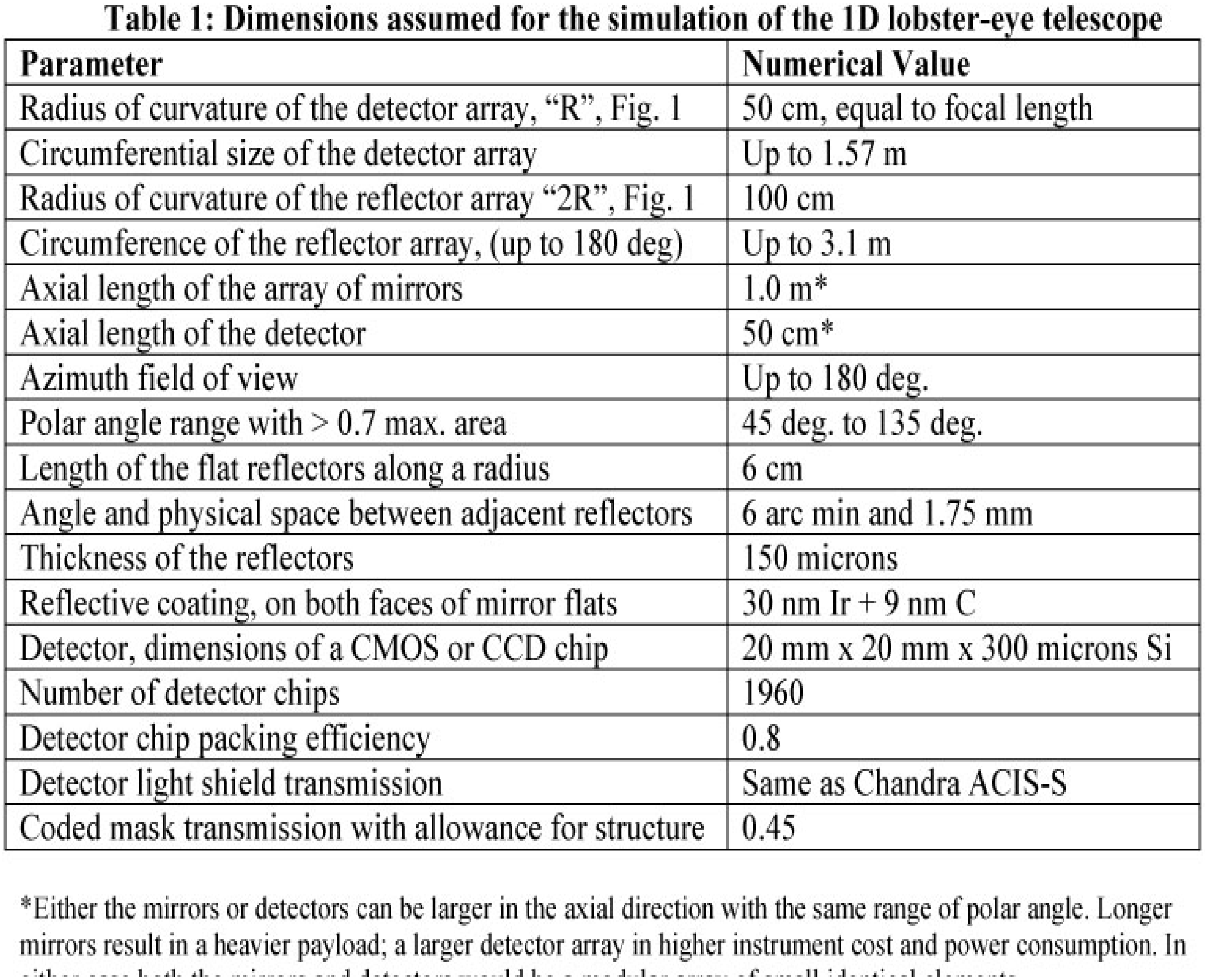
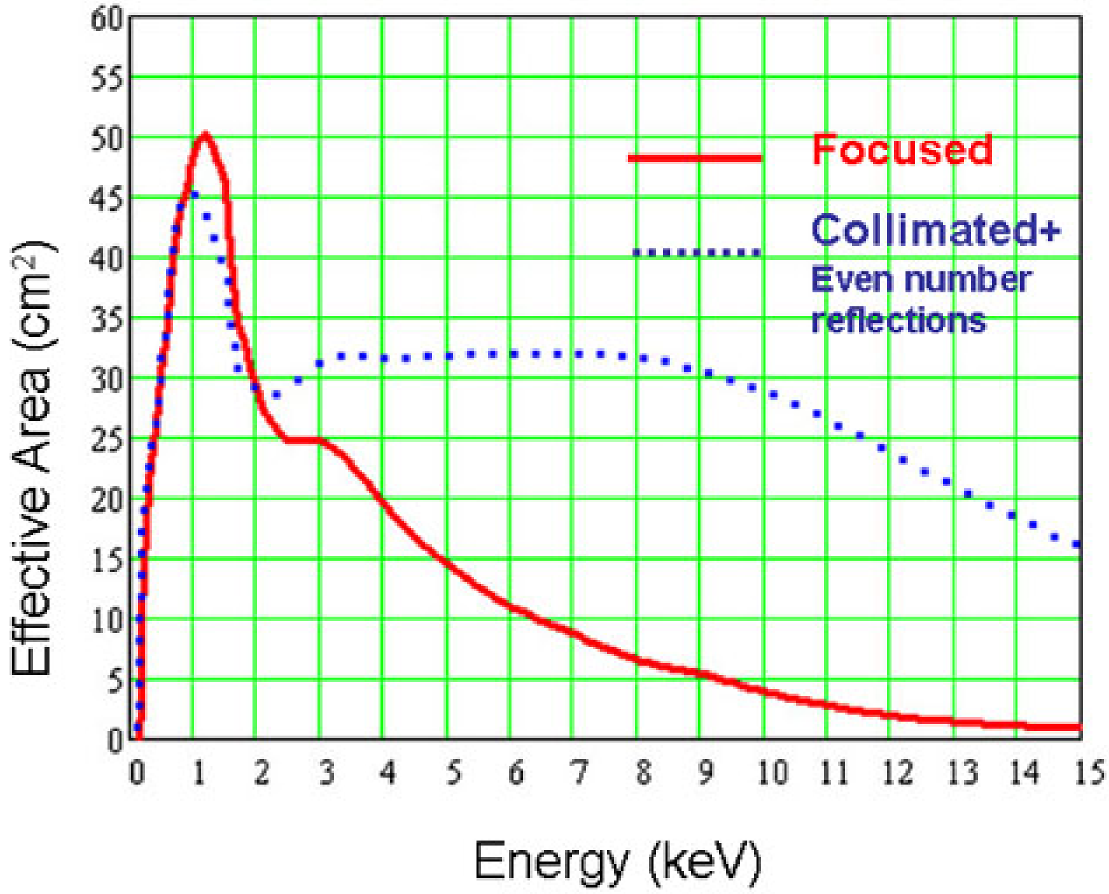


Table 1: Dimensions assumed for the simulation of the 1D lobster-eye telescope

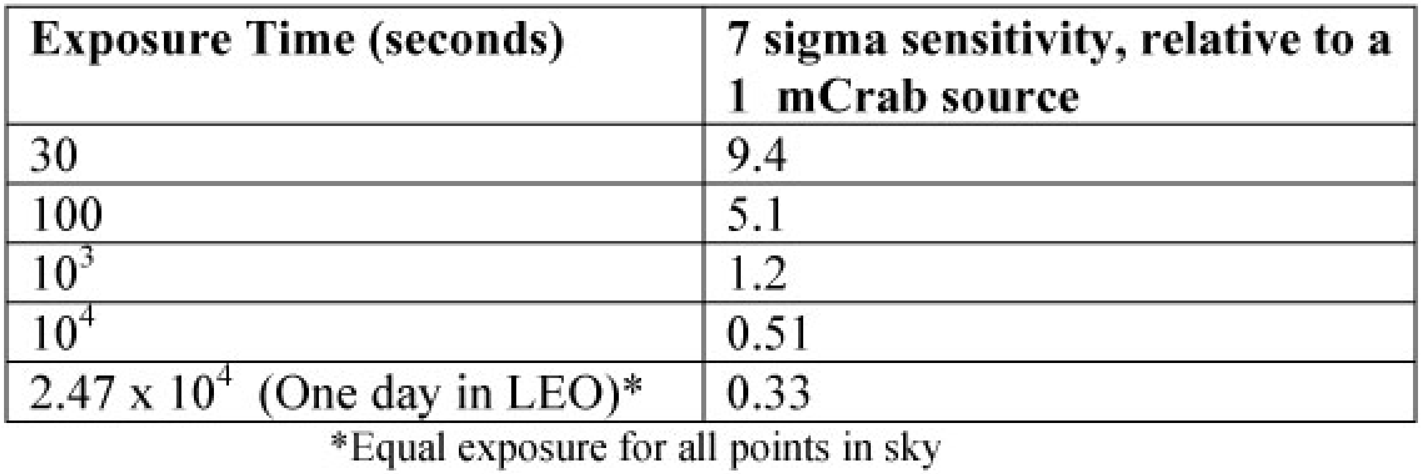
Parameter	**Numerical Value**
Radius of curvature of the detector array, "R", Fig. 1	50 cm, equal to focal length
Circumferential size of the detector array	Up to 1.57 m
Radius of curvature of the reflector array "2R", Fig. 1	100 cm
Circumference of the reflector array, (up to 180 deg)	Up to 3.1 m
Axial length of the array of mirrors	1.0 m*
Axial length of the detector	50 cm*
Azimuth field of view	Up to 180 deg.
Polar angle range with > 0.7 max. area	45 deg. to 135 deg.
Length of the flat reflectors along a radius	6 cm
Angle and physical space between adjacent reflectors	6 arc min and 1.75 mm
Thickness of the reflectors	150 microns
Reflective coating, on both faces of mirror flats	30 nm Ir + 9 nm C
Detector, dimensions of a CMOS or CCD chip	20 mm x 20 mm x 300 microns Si
Number of detector chips	1960
Detector chip packing efficiency	0.8
Detector light shield transmission	Same as Chandra ACIS-S
Coded mask transmission with allowance for structure	0.45

*Either the mirrors or detectors can be larger in the axial direction with the same range of polar angle. Longer mirrors result in a heavier payload; a larger detector array in higher instrument cost and power consumption. In

Theoretical effective area for focused line image and halo



Estimated Sensitivity Relative to 10^{-3} Crab Nebula*



Exposure Time (seconds)	7 sigma sensitivity, relative to a 1 mCrab source
30	9.4
100	5.1
10^3	1.2
10^4	0.51
2.47×10^4 (One day in LEO)*	0.33

*Equal exposure for all points in sky

For comparison the sensitivity of the RXTE ASM and MAXI are both 10 - 20 mCrab per day in “uncrowded fields”

***The configuration of the telescope has NOT been validated by an engineering analysis**

Comparison of 1D Lobster-eye + coded mask with 2D Coded Mask

With the same dimensions both would use the same position detector system, a large 2D array of CCD or CMOS chips

1D Lobster-eye	**2D Coded Mask**
Heavier weight	Lighter weight
Less effective area	More effective area
Easier detection, see new line image	Source not localized
Monitor all known sources and multiple transients	Difficultly resolving sources
Low background	Very high background
Easy to find position	Difficult to find position*
Moderate data rate	Very high data rate

*Can use software system developed for Swift detection of GRBs but have problem working against higher background from known strong sources all over field of view plus higher level of diffuse cosmic X-rays

Comparison with JANUS (2D coded Mask) and 2D Lobster-ISS

It is difficult to compare a concept which has not been validated by an engineering analysis with two instruments that presumably have. Also JANUS is smaller than Lobster 1D because its payload devotes space and mass to include an IR telescope

The 30 second 7 sigma sensitivity of JANUS is 240 mCrab
“ “ “ “ “ “ “ Lob 1D “ 9.4 mCrab

1 day sensitivity of Lobster-ISS is 0.10 mCrab* Field of view: 0.8 ster
“ “ “ Lobster-1D is 0.33 mCrab** “ “ “ 4 ster

* No. sigma not stated ** 7 sigma

Stated 1D sensitivity of Lobster-ISS is higher. However, that assumes source is constant throughout the day. With only 4 cm^2 of effective area, at 2 keV Lobster-ISS will be photon limited with fainter or shorter duration transient sources. On the ISS it would view a region of the sky for only 6.25% of each 5400 second orbit.. Aboard the ISS it is likely to have missed the 400 second flare from a supernova seen serendipitously by the Swift XRT, and many X-ray flashes. Not known if and when Lobster-ISS will be constructed and installed on the International Space Station.

Summary and Conclusions

- Any of the three wide field X-ray telescopes types aboard its own spacecraft would have the ability to view a significant portion of the sky continuously to detect and obtain light curves of various types of transient X-ray sources.

- The lobster-eye telescopes have been built only as small test pieces. The 2D coded mask benefits from the experience of the Swift BAT but operations in the soft X-ray band will have to contend with a much higher background and threat of confusion from more intense discrete sources and higher level of diffuse cosmic X-rays.

- All three require a very large format position sensitive detector. Detectors for the lobster-eye telescope would have to be curved to match the figure of their focal planes. It could be a solid state array or a large area position sensitive proportional counter with the appropriate curvature.

- The 1D lobster-eye/1D coded mask offers the best combination of effective area, field of view, and simplicity of data management. Despite the large size it is much easier to construct than the narrow field Wolter X-ray telescopes. The optics of a system with a 4 ster field of view and a focal length of 50 cm would have a mass approaching 100kg. Adding the estimated mass of spacecraft system the entire payload is compatible with a Taurus spacecraft. Smaller scale versions could be built, and/or the field of view reduced to lower the mass for a smaller spacecraft.