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Recent Progress with Lobster-Eye Telescopes

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Abstract. The Lobster Eye X-ray telescopes represent innovative devices for deep sky monitoring. The recent status of the prototype developments and calculations is briefly presented and discussed.

1. Introduction

For years, the only way to build an X-ray all-sky monitor was to use some kind of indirect imaging technique. All these techniques are limited in sensitivity by the fact, that signal from source experiences the noise from all photons detected over the whole detector (or the time), whereas in focussing techniques, signal from source is affected only by noise from a small part of the detector. Although these techniques serve us well, it is time to get more.

Design of focussing X-ray telescope is guided by the fact, that X-rays reflect only at grazing angles ($\sim$ 1 deg). Wolter design, which is widely used in X-ray missions, consists of coaxial nested paraboloid/hyperboloid mirrors sharing one focus. Despite of potentially large effective area and a good spatial resolution ($\sim$1 arcsec), the field of view (FOV) of such a system is very poor ($\sim$1 deg). This is the reason for which this system can not be used as a good focussing all-sky monitor (it took 6 months to complete the ROSAT All Sky Survey).

Schmidt (1975) and Angel (1979) proposed focussing system where photons reflect at grazing angles and which can be designed theoretically with a 4π FOV. Its name comes from an analogy with the structure and function of the eye of a crustanean like lobster.

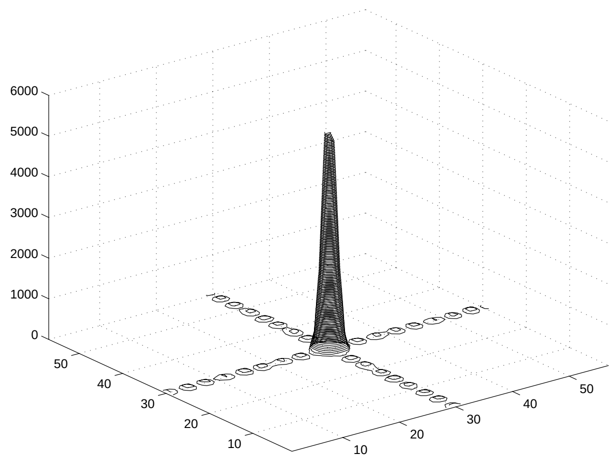

Figure 1. Theoretical PSF (ray-tracing simulation), 1 keV design, 1.5 keV photons, $f = 375$ mm, plate thickness $t = 100$ μm, distance $a = 300$ μm, 56x56 pixels, 1 px = 120 μm, will be blurred for the real LE

Lobster Eye (LE) systems haven't been used in any mission yet. Two concepts are in development at present: (1) Microchannel plates (Fraser et al, 2002), where channels are built from many thin straws put together and melted to held the shape, and (2) Precise arrangement of thin coated flats. In this paper, we will refer on (2).

2. Lobster eye description

The LE design in general consists of two sets of perpendicular reflecting plates (if only one set is used we obtain one-dimensional LE system enabling scanning observations, unfortunatelly with substantially lower gain). If reflecting plates are aligned side by side on sphere of radius R, the focal points create the sphere of radius $R/2$.

The Schmidt design can be created by putting another set of reflecting plates in front of the first set. These two sets are perpendicular to each other. The Angel design consists of a large number of tiny square cells each manufactured separately.

3. Prototypes

There exist several prototypes of LE optics (see table 1). Gain and spatial resolution are very important here. Gain currently achieved in prototypes ranges from 200 to 600. Recent estimations of the limiting flux are about 10^{-12} erg cm^{-2}s^{-1} for daily observations (scanning mode) and 10^{-14} erg cm^{-2}s^{-1} for pointed observations (Inneman et al., 2000, 2002).

Module	plate dimensions d(mm)/l(mm)/t(mm)	distance a(mm)	foc. length f(mm)	res. r(')	FOV (°)	energy keV
macro	300 / 300 / 0.75	10.8	6000	7	16	3
middle	80 / 80 / 0.30	2.0 0	400	20	12	2
mini 1	24 / 30 / 0.10	0.3	900	2	5	5
mini 2	24 / 30 / 0.10	0.3	250	6	5	5
micro	3 / 14 / 0.03	0.07	80	4	3	10

Table 1. The Lobster-Eye prototypes developed so far

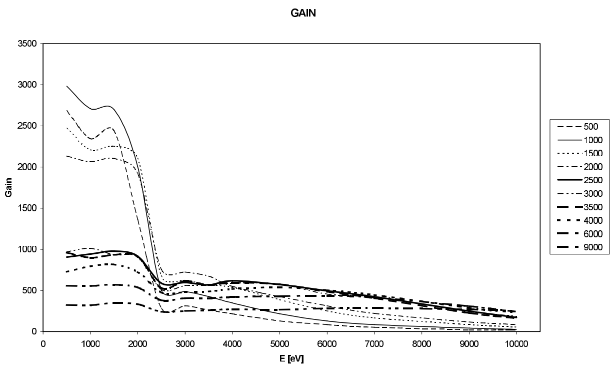

Figure 2. Simulated gain, designs for different energies (right sidebar in the image), $f = 375$ mm, Au coated plates, roughness $\sigma = 1$ nm, thicknes $t = 100$ μm, distance $a = 300$ μm

4. Ray-tracing

We have developed a kind of ray-tracing code for testing and designing LE systems. We have already performed some optical measurements together with ray-tracing model to verify our results and to find out the effect of imperfect LE fabrication and/or various foil distortions. We plan to make similar measurements in X-rays.

We have proposed several prototypes of LE optics. Our starting point was the desired angular resolution (~4 arcmin) and focal length $f = 375$ mm and we combined it with existing technology used to create recent prototypes. The chosen parameters are consistent with the proposed Lobster ISS mission. We have designed these prototypes to get an optimal gain in several energy bands.

We have run our ray-tracing tests on all of these proposed prototypes. Although the modelled FWHM fulfils the expectations (and are, in fact, even better achieving angular resolutions better than 1 arcmin), it will be blurred somewhat for manufactured prototypes. This can be compensated by changing the design a little, but still fully in the scope of the existing technology. We obtained gain-energy distribution for all the designs. We have used the definition of gain as the ratio of the number of photons detected inside the FWHM area with the LE optics to the number of photons detected without the LE optics.

We are about to use these models to estimate the limiting fluxes and to simulate observations. The image restoration represents a very interesting problem. We also continue in technology development.

5. Discussion

Because of its high sensitivity and reasonable spatial resolution, the total number of the observable sources would be several orders of magnitude higher than the number of sources observable by any of current X-ray all-sky monitor.

It will play the important role in two different areas of X-ray observations. Scanning the entire sky several times a day, it would be able to detect prompt X-ray emission from objects like gamma-ray bursts, X-ray flashes, novae or supernovae. It would be also very helpful in discovering of new transient objects. At the opposite part of the time scale lies the other LE advantage. Observing the whole sky periodically for several years it would provide us data about long variability of objects like active galactic nuclei or X-ray binaries.

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References

Angel, J. R. P.: Lobster eyes as X-ray telescopes, ApJ233, 364-373 (1979)

Schmidt, W. K. H.: A proposed X-ray focusing device with wide field of view for use in X-ray astronomy, Nucl. Instrum. and Meth. 127, 285-292 (1975)

Inneman, A., Pina, L., Hudec, R., Ticha, H., Brozek, V.: Innovative X-ray optics for astrophysics, Proc. of the SPIE, Vol. 4783, pp 156-164 (2002)

Innneman, A., Hudec, R., Pina, L.: Progress in lobster-eye X-ray optics development, Proc. SPIE Vol. 4138, p. 94-104 (2000)

Fraser, G. W., et al.: LOBSTER-ISS: an imaging X-ray all-sky monitor for the International Space Station, Proc. SPIE Vol. 4497, p. 115-126 (2002)