GRBS AND LOBSTER EYE X-RAY TELESCOPES

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Abstract. A large majority of GRBs exhibit X-ray emission. In addition, a dedicated separate group of GRB, the XRFs, exists which emission dominates in the X-ray spectral range. And the third group of GRB related objects (yet hypothetical) are the group of off-axis observed GRBs (orphan afterglows). These facts justify the consideration of an independent experiment for monitoring, detection and analyses of GRBs and others fast X-ray transients in X-rays. We will present and discuss such experiment based on wide-field X-ray telescopes of Lobster Eye type. We show that the wide field and fine sensitivity of Lobster Eye X-ray All-Sky Monitor make such instruments important tools in study of GRBs.

1 Introduction

The X-ray sky is highly variable, rich in variable and transient sources of both galactic as well as extragalactic origin. Among physically most important transient sources, the detection of Gamma Ray Bursts (GRBs) in X-rays confirms the feasibility of monitoring, detecting and study of these phenomena by their X-ray emission (either prompt or afterglow, *e.g.* Amati *et al.* 2004 & Fontera *et al.* 2004). For classical GRBs, the X-ray afterglows are detected in $\sim 90\%$ of the cases (De Pasquale *et al.* 2003). Moreover, there are X-ray rich GRBs, (hypothetical) orphan GRBs (detectable in X-rays but not in gamma-rays due to different beaming angle) and XRFs which can be detected and studied in X-rays. However, since these events cannot be predicted, and are relatively rare, very wide-field instruments are required. They must achieve high sensitivities and provide precise

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Fig. 1. The crayfish eye under optical microscope. On the picture right the surface square cells (covered by protecting membrane) are clearly visible.

localizations in order to effectively study the objects. Novel wide field X-ray telescopes with imaging optics are expected to represent an important tool in future space astronomy projects in general, especially those for deep monitoring and surveys in X-rays over a wide energy range. The Lobster-Eye (LE) wide field X-ray optics has been suggested by Schmidt (Schmidt 1975, orthogonal stacks of reflectors) and by Angel (Angel 1979, array of square cells). Up to 180 deg FOV may be achieved with these devices. This X-ray optics offers an opportunity to achieve very wide fields of view (FOV, 1000 square degrees and more) while the widely used classical Wolter grazing incidence mirrors are limited to roughly 1 deg FOV (Priedhorsky *et al.* 1996; Inneman *et al.* 2000).

2 Lobster eye X-ray telescopes

The LE telescopes in Schmidt arrangements are based on perpendicular arrays of double-sided X-ray reflecting flats. In the first prototypes developed and tested, double-sided reflecting flats produced by epoxy sandwich technology as well as gold coated glass foils have been used (Inneman *et al.* 1999). More recently, micro Schmidt lobster eye arrays with foils thickness as low as 30 microns have been developed and tested in order to confirm the capability of these systems to achieve fine angular resolutions of order of a few arcmin (Fig. 1). The thin foils are separated by 70 microns gaps in these prototypes. On the other hand, large lobster eye systems with Schmidt geometry have been designed and constructed, achieving dimensions up to $300 \times 300 \times 600$ mm (Fig. 1). Their optical and X-ray optical tests (Fig. 2) have confirmed the expected performance according to calculations (computer ray-tracing). The calculations and the measurement results indicate that the lobster eye telescope based on multi array of modules with thin and closely spaced glass foils (analogous to those already assembled and tested) can meet the requirements *e.g.* of the ESA ISS Lobster mission (including the angular resolution and with better transmission) and can hence represent an alternative to the recently suggested MCP technique (Fraser *et al.* 2002).

Fig. 2. The two arrangements of the LE X-ray optics.

The Angel LE systems consist of numerous square cells of very small size (about 1×1 mm or less at lengths of order of tens of mm, *i.e.* with the length/size ratio of 30 and more) are to be produced. Test modules with LE Angel cells have been successfully produced. The linear test module has 47 cells 2.5×2.5 mm, 120 mm long (*i.e.* length/size ratio of almost 50), surface microroughness 0.8 nm, $f = 1300$ mm. Another test module is represented by a L-shaped array of $2 \times 18 = 36$ cells of analogous dimension. The surface microroughness of the replicated reflecting surfaces is better than 1 nm.

3 Astrophysics with LE X-ray monitor

Deep (limiting flux of 10^{-12} erg cm $^{-2}$ s $^{-1}$ can be easily achieved for daily scanning observation) X-ray sky monitoring with large FOVs (*e.g.* FOV of 6×180 deg can be easily assembled on the space vehicles) is expected to contribute significantly to various fields of modern astrophysics (2009). A few most important examples are listed below.

MODULE	size	plate thickness	distance	length	eff. angle	focal length	resolution	field of view	energy
	d(mm)	t(mm)	a(mm)	l(mm)	a/l	f(mm)	r(arcmin)	(°)	(keV)
macro	300	0.75	10.80	300	0.036	6000	7	16	3
middle	80	0.3	2	80	0.025	400	20	12	2
mini 1	24	0.1	0.3	30	0.01	900	2	5	5
mini 2	24	0.1	0.3	30	0.01	250	6	5	5
micro	3	0.03	0.07	14	0.005	80	4	3	10

Fig. 3. The LE laboratory samples assembled and tested in the Czech Republic.

(1) Gamma Ray Bursts (GRBs). Detection rates of nearly 20 GRBs/year can be obtained for the prompt X-ray emission of GRBs, taking into account the expected GRB rate 300/year. (2) X-ray flashes. Detection rates of nearly 8 X-ray flashes/year are expected, assuming XRF rate of 100/year. (3) X-ray binaries. Because of their high variability in X-rays they will be one of major targets in LE observations. LE will be able to observe their short-time outbursts by long-term extended monitoring. Almost all galactic XRB are expected to be within the detection limits. (4) Stars. Because of the low X-ray luminosity of ordinary stars, only nearby stars are expected to be observable. We estimate the lower limit of ordinary stars observable by the LE telescope as 600. The sampling rate of LE observations will be sufficient enough to observe sudden X-ray flux increases during flares while still having the capability of monitoring the variability on time scales of years. (5) Supernovae. The LE telescope should be able to detect the theoretically predicted thermal flash lasting for ~ 1000 sec for the first time. Together with the optical SNe detection rate and estimates of the LE FOV we estimate the total number of SNe thermal flashes observed by the LE experiment to ~ 10 /year. More details on the advantages of LE X-ray telescopes in scientific analysis of SNe are given in Sveda *et al.* 2005. (6) AGNs. Active Galactic Nuclei will surely be one of the key targets of the LE experiment. LE will be able to monitor the behavior of the large (~ 1000) sample of AGNs providing long-term observational data with good time sampling (hours). (7) X-ray transients. The LE experiment will be ideal to observe X-ray transients of various nature due to its ability to observe the whole sky several times a day for a long time with a limiting flux of about 10^{-12} erg cm $^{-2}$ s $^{-1}$. More and fainter X-ray transients are expected to be detected by the LE sky monitor enabling the detailed study of these phenomena. (8) Cataclysmic Variables. Cataclysmic Variables (CVs) are very active galactic objects, often showing violent long-term activity in both the optical and X-ray passband (outbursts, high/low state transitions, nova explosions) as well as rapid transitions between the states of activity. Search for the relation of the optical and X-ray activity is very important – monitoring of a large number of CVs is necessary to catch them in various states of activity.

4 Conclusions

The various prototypes of both Schmidt as well as Angel arrangements have been produced and tested successfully, demonstrating the possibility to construct these

lenses by innovative but feasible technologies. Both very small Schmidt lenses (3×3 mm) as well as large lenses (300×300 mm) were developed, constructed, and tested (1999, 2000). Promising results were obtained in studies of LE X-ray monitors for small satellites and related tests (2009, 2009, 2011). This makes the proposals for space projects with very wide field lobster eye optics possible for the first time. The LE All Sky Monitor is capable to detect around 20 GRBs and 8 XRFs yearly and this will surely significantly contribute to the related science. Another LE application may be the investigation of X-ray emission from atmospheric triggers such as Terrestrial Gamma-Ray Flashes (TGF).

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