PROCEEDINGS OF SCIENCE

LOBSTER: X-ray astrophysical facility

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We report on the astrophysical aspects – with emphasis on the study of microquasars – of very wide-field X-ray telescopes with high sensitivity. The prototypes are very promising, allowing the proposals for space projects with very wide-field Lobster-eye X-ray optics to be considered. The novel telescopes will monitor the sky with unprecedented sensitivity and angular resolution of the order of 1 arcmin. They are expected to contribute essentially to study of various astrophysical objects such as AGN, SNe, Gamma-ray bursts (GRBs), X-ray flashes (XRFs), galactic binary sources including microquasars, stars, CVs, X-ray novae, various transient sources etc.

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Introduction

The X-ray sky including the known and yet unknown microquasars is highly variable, rich in variable and transient sources of both galactic as well as extragalactic origin. Among the 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., [1] and Fontera et al., [5]). For classical GRBs, the X-ray afterglows are detected in ∼90% of the cases (De Pasquale et al., [3]). Moreover, there are X-ray rich GRBs, (hypothetical) orphan GRBs (detectable in X-rays but not in gamma-rays due to the 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 localizations in order to effectively study the objects. 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 wide-field X-ray optics has been suggested in the seventies by Schmidt ([10]) (orthogonal stacks of reflectors) and by Angel ([2]) (array of square cells). Up to 180 deg field of view (FOV) may be achieved. This novel X-ray optics offers an excellent opportunity to achieve very wide 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., [9], Inneman et al., [8]).

Lobster eye X-ray telescopes

Two basic types of Lobster Eye Wide Field X-ray telescopes have been proposed. The 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., [7], see also Table 1). More recently, micro Schmidt lobster eye arrays with the foil thickness as low as 30 microns have been developed and tested to confirm the capability of these systems to achieve fine angular resolutions of the order of a few arcmin. The thin foils are separated by 70 micron gaps in these prototypes. On the other hand, large lobster eye systems with Schmidt geometry have been designed and constructed, achieving the dimensions up to $300 \times 300 \times 600$ mm (Fig.1). Their optical tests have confirmed the expected performance according to the 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 a better transmission) and can hence represent an alternative to the recently suggested MCP technique (Fraser et al., [4]).

For the alternative Angel Lobster lenses, numerous square cells of a very small size (about 1×1 mm or less at the lengths of the order of tens of mm, i.e. with the length/size ratio of 30 and more) are to be produced. This demand can be also solved by a modified innovative replication technology. 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

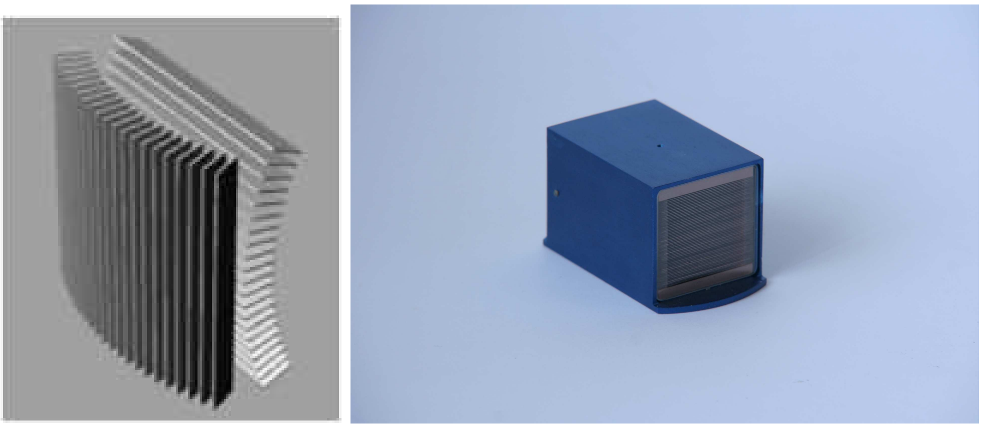

Figure 1: The principle of Lobster Eye Optics in Schmidt arrangement (left) and the LE Schmidt Mini test module (right).

microroughness 0.8 nm, $f = 1300$ mm. Another test module is represented by an 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.

From the technological point of view, the fact that the modular concepts of Schmidt LE modules, of the large segmented Wolter telescopes (such as IXO), and of large segmented K-B telescopes are similar is important: all are based on either planparallel or curved flats and foils. This means that the development of high quality X-ray reflecting foils and flats with high mechanical stiffness and low volume density is extremely important for most of the future X-ray astronomy large-aperture projects. The segmented K-B telescopes have the advantage of being highly modular on several levels. All segments are rectangular boxes with the same outer dimensions (Gorenstein, [6]).

Table 1: The single Lobster Eye Schmidt modules developed so far by our collaboration. Here the plates have the dimensions of $d \times l \times t$ and are arranged with spacing a. The modules have the focal length f and the field of view FOV and are optimized for the energy given in the last column.

Module	size d[mm]	thickness t[mm]	distance a[mm]	length l[mm]	foc. length f[mm]	resolution r[arcmin]	FOV [°]	energy [keV]
macro	300	0.75	10.80	300	6000	7	16	3
middle	80	0.3	2	80	400	20	12	2
mini 1	24	0.1	0.3	30	900	2	5	5
mini 2	24	0.1	0.3	30	250	6	5	5
micro	3	0.03	0.07	14	80	4	3	10

Science

Deep (limiting flux of 10^{-12}erg cm^{-2}s^{-1} can be easily achieved for daily scanning observa-

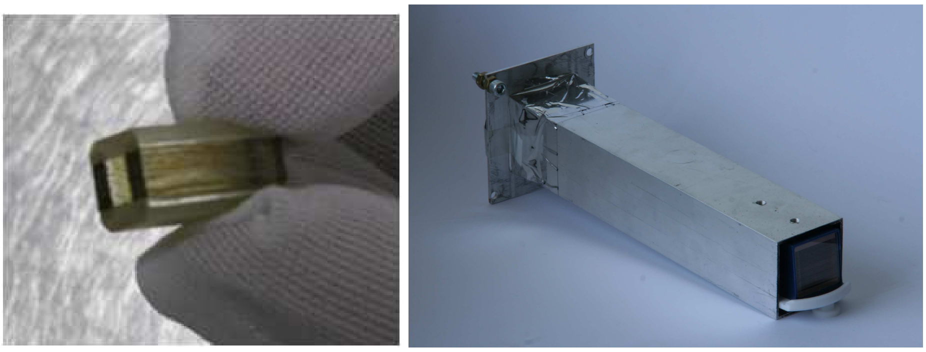

Figure 2: The Micro LE test module (left) and the LE Schmidt telescope with $f = 250$ mm (right).

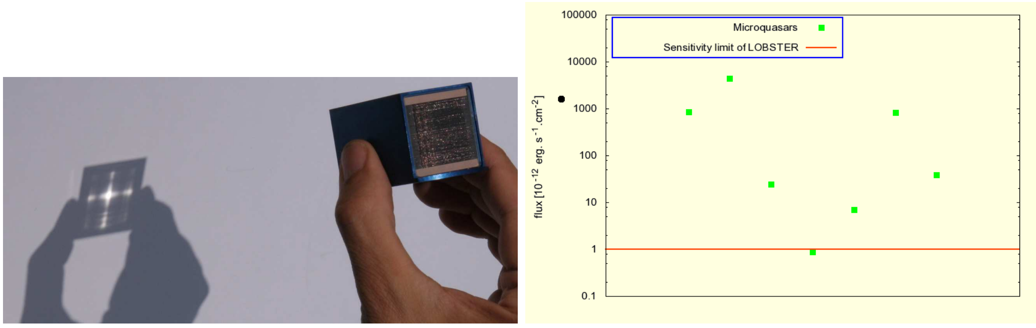

Figure 3: The imaging performance of the Sun in the optical light by the LE Mini Schmidt objective (left) and comparison of the catalogued X-ray fluxes of 7 known microquasars with the LE ASM detection limit (right).

tion) X-ray sky monitoring with large FOVs (e.g. FOV of 6×180 deg can be easily assembled on the space station ISS) is expected to contribute significantly to various fields of modern astrophysics. A few most important examples are listed below.

(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 (XRFs). Detection rates of nearly 8 X-ray flashes/year are expected, assuming XRF rate of 100/year. (3) X-ray binaries (XRBs). Because of their high variability in X-rays they will be one of the major targets in LE observations. LE will be able to observe their short-time outbursts by long-term extended monitoring. Almost all galactic XRBs 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 timescales of years. (5) Supernovae (SNe). The LE telescope should be able to detect the theoretically predicted thermal flash lasting for $\sim$1000 sec for the first time.

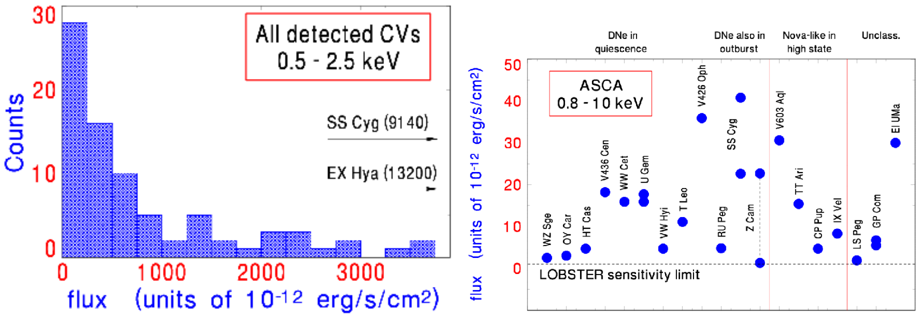

Figure 4: The numbers of all known CVs observable by Lobster Eye ASM (left) and the various types of CVs within the sensitivity limit of LOBSTER ASM (right).

Together with the optical SN detection rate and estimates of the LE FOV we estimate the total number of SN thermal flashes observed by the LE experiment to be ~10/year. (6) Active Galactic Nuclei (AGNs). They 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 for observing 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 (CVs). They 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.

Conclusions

Analysis and simulations of Lobster-eye X-ray telescopes have been carried out. They have indicated that these innovative devices will be able to monitor the X-ray sky at an unprecedented level of sensitivity, an order of magnitude better than any previous X-ray all-sky monitor. Limits as faint as 10^{-12} erg cm^{-2}s^{-1} for daily scanning observation as well as the angular resolution < 4 arcmin in soft X-ray range are expected to be achieved allowing monitoring of all classes of X-ray sources, not only X-ray binaries, but also fainter classes such as AGNs, coronal sources, CVs, as well as fast X-ray transients including GRBs and the nearby type II SNe.

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) have been developed, constructed, and tested. This makes the proposals for space projects with very wide field lobster eye optics possible for the first time.

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