# Astrophysics with LOBSTER

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**Abstract** We report on astrophysical aspects of fully innovative 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 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, stars, CVs, X-ray novae, various transient sources, etc.

**Key words:** X-ray telescopes — X-ray optics

## 1 INTRODUCTION

The X-ray sky is highly variable, rich in variable and transient sources of both galactic as well as extra-galactic 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 and Fontera et al. 2004). For classical GRBs, the X-ray afterglows are detected in ∼ 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 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 70ies 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. This novel X-ray optics offers an excellent 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

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. 1999, see also Table 1). 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. The thin foils

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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 tests 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).

**Table 1** LE Schmidt modules developed so far by our collaboration. Here plates have dimensions of $d \times l \times t$ and are arranged with spacing $a$. The modules have focal length $f$, field of view FOV, and are optimized for the energy.

| Module | size | thickness | distance | length | foc. length | resolution | FOV | energy |
|---|---|---|---|---|---|---|---|---|
| | $d$ [mm] | $t$ [mm] | $a$ [mm] | $l$ [mm] | $f$ [mm] | $r$ [arcmin] | [°] | [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 |

For the alternative Angel Lobster lenses, numerous square cells of very small size (about $1 \times 1$ 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. This demand can be also solved by modified innovative replication technology. Test modules with LE Angel cells have been successfully produced. The linear test module has 47 cells $2.5 \times 2.5$ 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.

From the technological point of view, the fact that the modular concepts of Schmidt LE modules, of the large segmented Wolter telescopes (such as XEUS), 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 1998).



**Fig. 1** The large Lobster Eye telescope prototype ($300 \times 300$ mm plates, Schmidt arrangement) represents the largest Lobster telescope test module constructed so far.

## 3 SCIENCE

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 $6 \times 180$ 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.
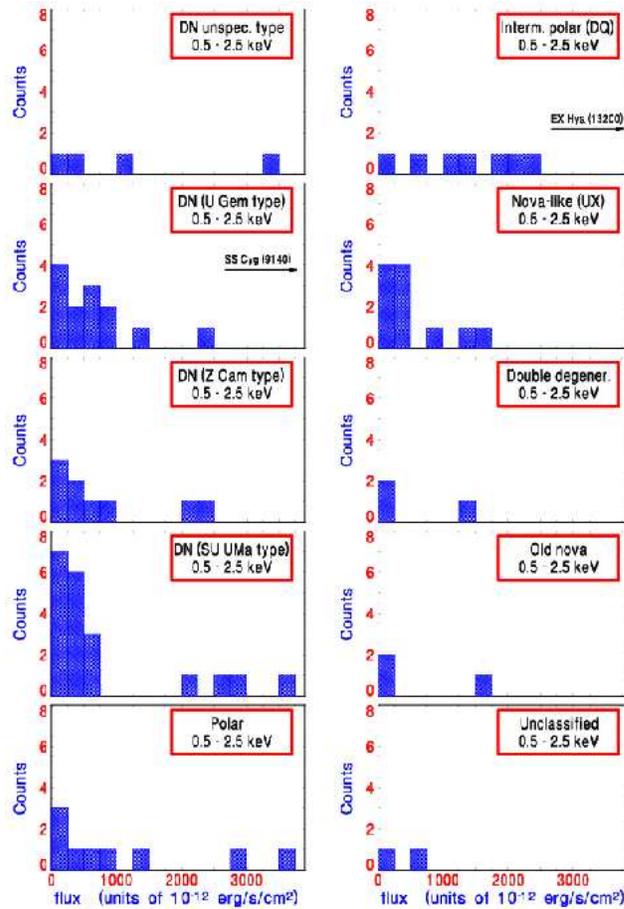


**Fig. 2** The numbers of known CVs observable by Lobster Eye ASM according to their individual types.

(1) Gamma Ray Bursts (GRBs). Detection rates of nearly 20 GRBs year$^{-1}$ can be obtained for the prompt X-ray emission of GRBs, taking into account the expected GRB rate 300 yr$^{-1}$. (2) X-ray flashes. Detection rates of nearly 8 X-ray flashes/year are expected, assuming XRF rate of 100 yr$^{-1}$. (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 $\sim$1000 s 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
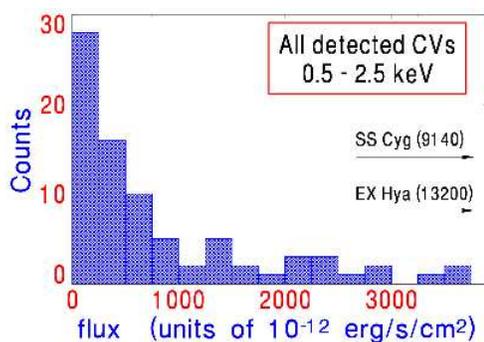
**Fig. 3** The numbers of all known CVs observable by Lobster Eye ASM.
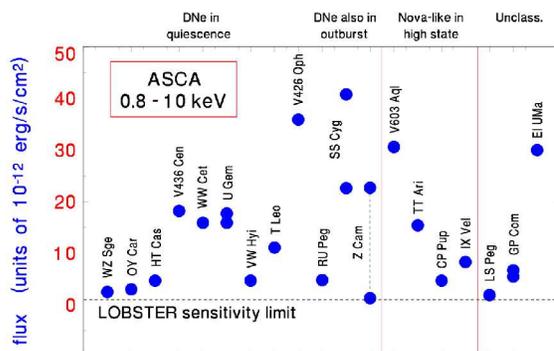


**Fig. 4** The various types of Dwarf Novae within the sensitivity limit of LOBSTER ASM.

experiment to $\sim$10 year$^{-1}$. (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 ( $\sim$ 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. Most up to now X-ray observations of CVs: (i) Snapshots catching selected CVs in a particular state of activity, (ii) In most cases the transitions between the states are not covered, and (iii) Poor statistics of phenomena and objects (deeper studies available for only a few CVs). Important classes of CVs for LOBSTER are Non-magnetic dwarf novae (DNe), Supersoft X-ray sources (SSXSs), Classical novae (CNe), and Polars with soft X-ray excess.

## 4  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, cataclysmic variables, as well as fast X-ray transients including gamma-ray bursts and the nearby type II supernovae.

The Lobster optics based All Sky Monitor is capable to detect around 20 GRBs and 8 XRFs yearly and this will surely significantly contribute to the related science. More details on the advantages of LE X-ray telescopes in scientific analysis of SNe are given in Sveda et al. 2005. 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 ($3 \times 3$ mm) as well as large lenses ($300 \times 300$ 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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