PROCEEDINGS OF SCIENCE

Nano-sat lobster eye soft x-ray monitor

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The idea of a satellite providing monitoring of specified sky areas in soft X-rays is presented. Observation plan could include also e.g. searching for X-ray afterglows of gamma-ray bursts. The spacecraft could be of the nano-satellite class. Using of Schmidt lobster optics is proposed. Design study of the optics is presented. The results of experimental tests of the specimen of the optics indicate that the mission is feasible.

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1. Introduction

Most of existing and past X-ray satellites perform pointing to a sample of object with a limited observing time allocated for a given object. This strategy enables to study faint sources with high temporal and/or spectral resolution. Mission performing long-term (weeks or months) monitoring of specific sources is lacking. However, long-term observations are required for better unterstanding of some sources, e.g. low mass X-ray binaries (LMXB) and high mass X-ray binaries (HMXB). Small and relativelly cheap nano-satellite mission could perform long-term monitoring of specific sky areas, e.g. Galactic nucleus containing plenty of such sources.

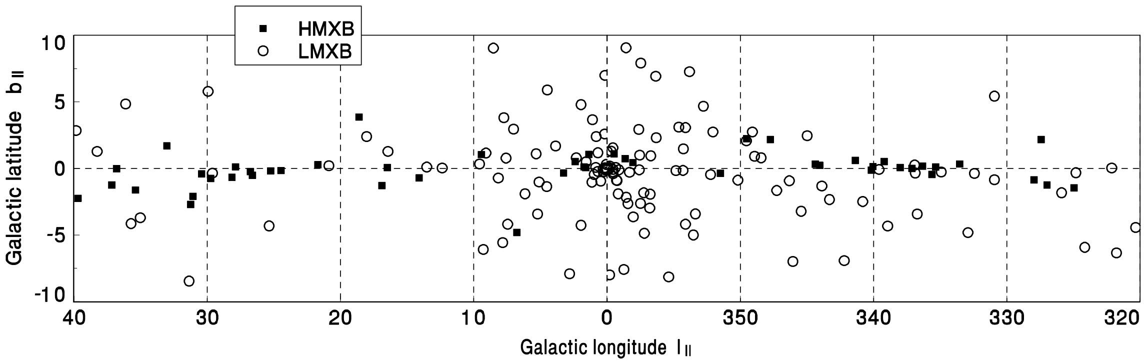
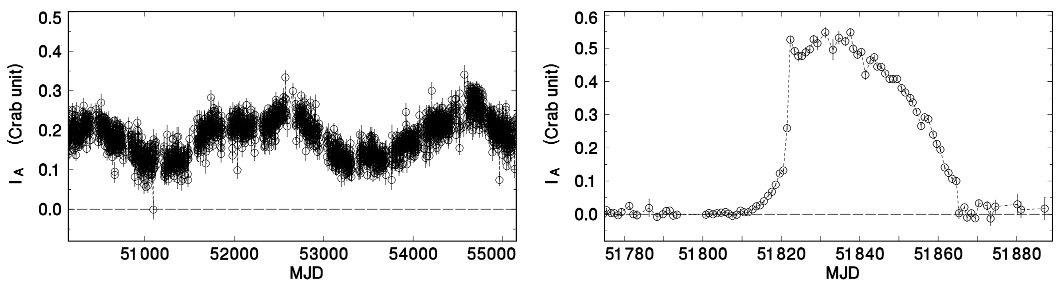


Figure 1: The field of the center of the Galaxy ($20^\circ \times 80^\circ$). The positions of known LMXBs and HMXBs are marked.

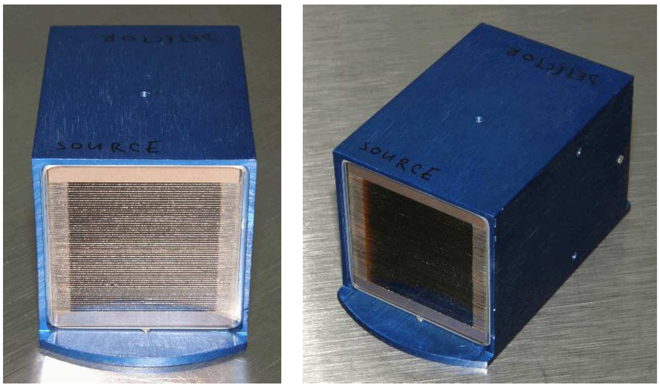
Other interesting places for long-term observations are e.g. Large Magellanic Cloud or Crab nebula. As other part of a scientific program, the satellite could e.g detect x-ray afterglows of gamma-ray bursts.

Using of small instrument with field of view in order of square degrees or more is assumed. As seen below on typical light curves, its sensitivity has to be sufficient to measure intensity in order of 100mCrab at energies of order of keV with time resolution of days. Instrument has to have sufficient angular resolution to identify the sources.



(a) The light curve of a persistent source GX 3+1 (b) The outburst of a transient source Aql X-1

Figure 2: Examples of light curves observed by ASM/RXTE in the 1.5-3 keV band



(a) (b)

Figure 3: Prototype lobster eye P-25

2. Schmidt lobster eye optics

The lobster eye (LE)[1, 2] represents one of the types of grazing incidence reflective X-ray optics. In particular, the Schmidt design[1] uses two orthogonal sets of reflecting surfaces, each set focuses in one direction. In comparison with other types of reflective X-ray optics, the main advantage of LE is its large field of view (FOV). up to approx. 100 square degrees[1]. Specimens of this optics were developed in various sizes and focal lengths. including sizes and focal lengths acceptable for nano-sized satellites.

One of such prototypes is called P-25 (Fig. 3), it was manufactured in Rigaku Innovative Techonologies Europe s.r.o., Prague, Czech Republic. Each of horizontal and vertical systems of mirrors consists of $n = 60$ flat reflecting plates made of glass and coated by gold of RMS microroughness 1 nm. The plates (mirrors) have dimensions 24×24 mm and their thickness is $t = 0.1$ mm. Average width of the space between the mirrors is $a = 0.3$ mm. The LE has $f = 250$ mm focal length, that is acceptable for nano-satellite, e.g. 3U or 6U cubesat. Prototype P-25 is designed for optimal efficiency at 1 keV photon energy. Performances of this lobster eye were tested in visible light[7] as well as in X-rays[8, 9] using 35 meters long X-ray beam-line in INAF-OAPA, Palermo, Italy[11, 12]. Measured spatial resolution around 13 arcmins is sufficient for identification of sources. Sensitivity estimated from measured data for 1ks exposure supposing 100% quantum efficiency of a detector is approx. 36mCrab. This value is around one order worse than the theoretical but it is sufficient for proposed mission. For named reasons, the optics for the nano-sized mission is feasible

3. Spacecraft

CubeSat[29] spacecraft seems to be the easiest and the cheapest approach to the spacecraft concept. The basic unit of the CubeSat spacecraft has diameters around $10 \times 10 \times 10$cm. The spacecraft is supposed to be of the maximal allowed dimensions $3 \times 2 \times 1$ cube units, i.e. totally approx. $30 \times 20 \times 10$cm.

Three cube units (approx. $10\times10\times30$cm) are supposed to be reserved for the telescope. Because attitude sensing of accuracy in order of arcmins is necessary, using of star tracking camera as an attitude sensor is supposed. One cube unit (approx. $10\times10\times10$cm) is reserved for the star tracking camera. Two remaining cube units (approx. $10\times10\times20$cm) remain for other systems like power, control, communication, etc. Two units should be sufficient, because CubeSats commonly are usually of 1 unit size and they contain these systems. The draft of the spacecraft arrangement is drawn on Fig. 4. Detailed technological study is a subject of further research.

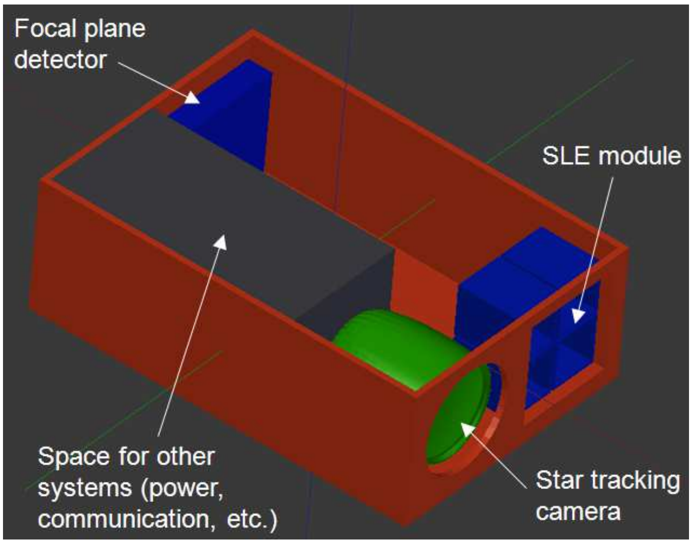


Figure 4: Spacecraft concept

4. Proposed optics for nano-sized mission

Preliminary spacecraft study [10, 30] showed that the distance between the front of the optics to the focal plane can be extended to 335mm and the input area can be increased to 8×8 cm Mirror depth is supposed to be left at 24mm as the prototype P-25 has. Supposing 5mm distances between the front of the optics and the active area and between active areas of the vertical and the horizontal subsystem, the corresponding focal lengths of subsystems are 318mm and 289mm. Using of commercially available flat thin glass of thicknesses 100μm or 280μm is supposed.

The optimal design respecting the presented assumptions was found by simplified ray tracing procedure [27] to get as large effective collecting area as it is possible at 1keV photon energy Using of gold coating of same properties (e.g. microroughness) as on P-25 was supposed. The following parameters were found [30]. Design A: Mirror thickness 100μm, 100 mirrors per set, average mirror spacing 0.8mm between central planes of mirrors. Design B: Mirror thickness 280μm, 72 mirrors per set, average mirror spacing 1.1mm between central planes of mirrors.

Resulting images obtained by simplified ray-tracing procedure[27] at photon energy 1keV are shown in figure 5. Level of gray is in logarithmic scale and it corresponds to amplification of incoming flux (gain, defined below) in a corresponding point. Calculated field of view of both designs reaches $7.2^\circ\times7.9^\circ$. Graphs of calculated effective input area and sensitivity are shown

E [keV]	0.5	0.75	1	1.25	1.5	1.75	2	2.25	2.5
Design A	3.0	5.0	7.0	9.1	13	20	36	190	230
Design B	3.1	5.2	7.2	9.5	14	24	45	230	280

Table 1: Theoretical sensitivity per 1ks exposure in $\times 10^{-11}$erg/cm^2/s on dependence on photon energy

in Fig.6. FWHM spatial resolution at energies 0.5 to 2keV reaches 5arcmins for design A and 6arcmins for design B.

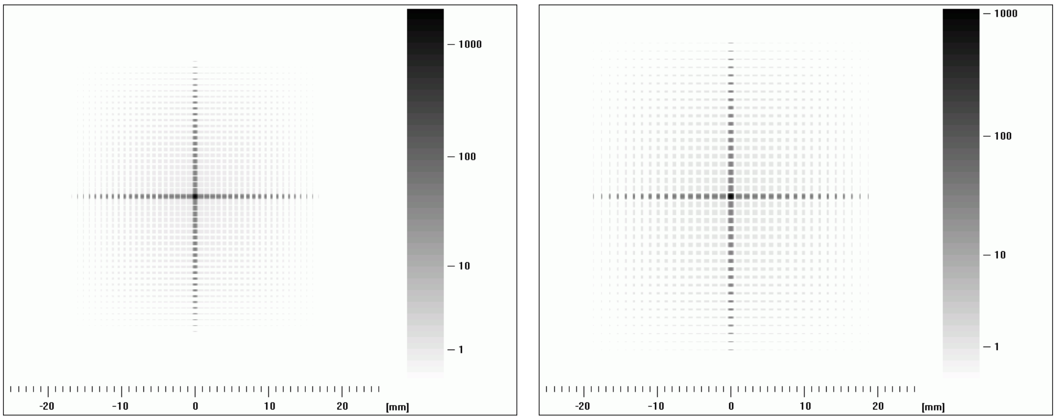
As a detector, CCD with passive cooling is supposed to be used. For the mission, CCD of resolution 1024×1024 pixels with active area 37×37mm^2 is available. Four such detectors can be formed to square of total active area 74×74mm^2 with neglectable dead area. Quantum efficiency is almost 100% in supposed region 0.5 to 2keV. These performances are excellent, therefore properties of the entire telescope are determined mainly by the suggested optics.

Sensitivity per 1ks exposure was estimated by the assumption that the object is detected if at least 100 photons come to the focus. Data are tabulated in Tab. 1 and shown in Fig. 6

As an example of obtained image, simulations of imaging of the Galatic center were performed. The results are shown in Fig. 7. Sources positions intensities were acquired from[28]. The instruments values in counts per second were converted using a factor $1\text{cps} = 10.4 \cdot 10^{-12}$erg/cm^2/s that is, for soft energies, recommended by the manual attached to ROSAT data. More details about the proposed optics are presented in paper[30].

5. Conclusions

The lobster eye represents the proper type of optics for space x-ray monitors. Small and relatively cheap nano-satellite Schmidt lobster eye mission can take long-term monitoring of specific sky areas. It can monitor tens of sources at once for long time (weeks, months). The mission seems to be feasible.



(a) Design A (b) Design B

Figure 5: Basic image at energy 1keV

Acknowledgments

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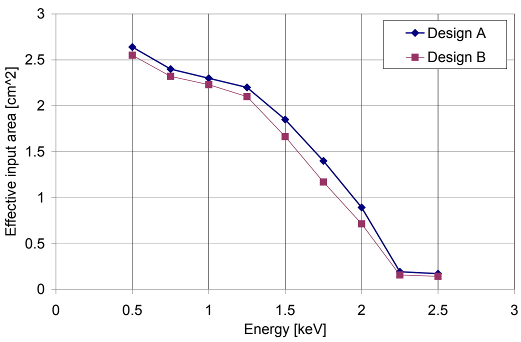
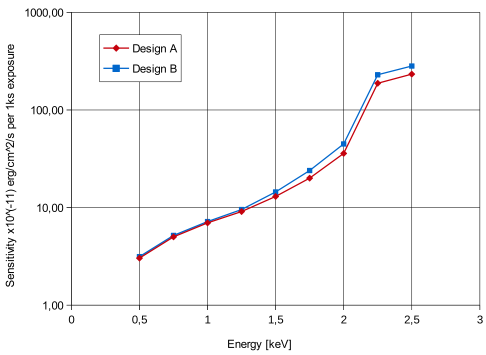
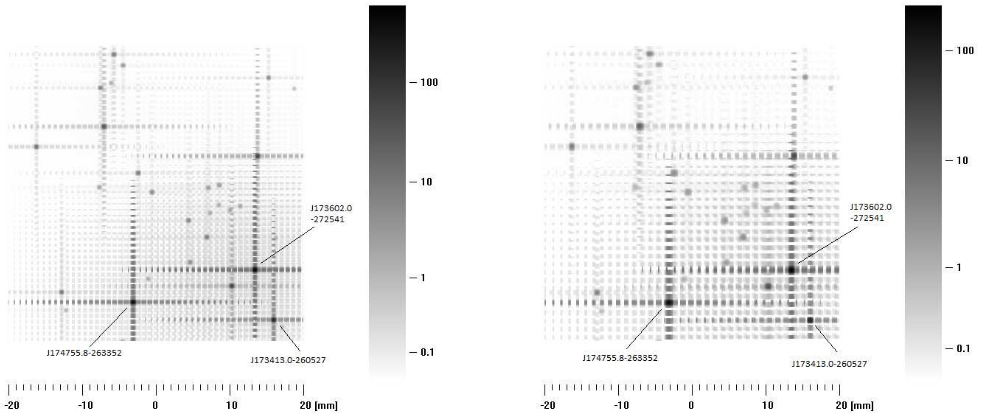


(a) Effective collecting area



(b) Sensitivity per 1ks exposure

Figure 6: Sensitivity per 1ks exposure in dependence on photon energy



(a) Design A (b) Design B

Figure 7: Simulation of imaging of the Galactic centre. The center of the area has coordinates RA= 17h 45m 40s, $\delta = -29°00'28''$. The imaged area corresponds to the supposed field of view of $7.2° \times 7.9°$. The horizontal axis is aligned with right ascension, the vertical with declination. The dimension is scaled is millimeters in the focal plane. Level of gray corresponds to measured flux. The scale at the right hand side is in number of photons/cm^2/s in the corresponding point of the detector.

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