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LOBSTER EYE X-Ray Wide Field Telescopes and Monitors: Recent Progress

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Wide field X-ray monitors of Lobster Eye (LE) type were demonstrated to play an important role in modern astrophysics. We report on recent progress with emphasis on miniature LE telescopes.

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1. Introduction

The Lobster Eye (LE) X-ray optics was originally proposed by Schmidt (1975) and Angel (1979). Since then, numerous test specimens of Lobster Eye telescopes were designed and tested (e.g. Inneman et al. 1999; Hudec et al. 2000, 2003, 2004; Tichy et al. 2009, 2011). The Lobster-Eye (LE) X-ray telescope can be miniaturized for an application in picosatellites. The LE telescopes are novel wide field X-ray telescopes with the field of view (FOV) of typically 100 sq. deg. A classical X-ray optics of Wolter type has the FOV of only 1 deg or less. The LE optics are based on a real analogy with the lobster eyes.

Wide field X-ray monitors of Lobster Eye type were demonstrated to play an important role in modern astrophysics (e.g. Hudec et al. 2007; Sveda et al. 2004). The most important scientific cases are briefly summarized below. (1) A long-term (months) measurement of the light curves of bright persistent X-ray binaries in the direction toward the center of the Galaxy in the soft X-ray band, and (2) Detection and measurement of the light curves of bright transient events of X-ray binaries in the direction toward the center of the Galaxy in the soft X-ray band.

2. Recent Progress

The first miniature 1 dimensional (1D) LE X-ray telescope is now ready for 2017 launch onboard the Czech VZLUSAT1 cube satellite mission (Pina et al., 2015). There is a Medipix pixel detector in the focal plane. The working energy range, due to use of 1D LE optics, is 3 to 30 keV.

The objectives Czech 2U CubeSat mission are as follows: development, manufacturing, qualification and experimental verification of products and technologies in Earth orbit (TRL increase). Main goal: verification of wide-field optical system for X-ray monitoring in the energy range 3 - 40 keV which is based on Lobster Eye (LE) optics and Timepix detector. Launch is planned in 2017 within QB50 mission.

3. Lobster Eye for VZLUSAT-1

There is 1D Lobster Eye module with focal length 250 mm onboard the VZLUSAT cubesatellite. This will be the 1st Lobster Eye X–ray telescope in space. The LE optics module is composed of 182 wedges and 90 reflective double-sided gold-plated foils (thickness of 150 microns). The input aperture is 29 x 19 mm and the active part of the foils is 19 mm in width and 60 mm in length. Outer dimensions are 29 x 31 x 60 mm and the working energy range is, due to 1D arrangement and hence only one reflection, 3 to 20 keV.

There is Timepix detector in the telescope focal plane. This is hybrid semiconductor pixel detector with 256 x 256 pixels 55 microns each, and 14 mm x 14 mm detector area. The focal detector was developed in frame of the Medipix Collaboration in the Institute of Experimental and Applied Physics (IEAP) of the CTU in Prague. The detector allows measuring of energies in range of 3 – 40 keV in each pixel. The detector is suitable for high-resolution and high-sensitivity X-ray and low-energy gamma-ray applications in space.

The main goal of this experiment is experimental verification of new technologies and designs (novel LE miniature telescope with Schmidt X–ray optics and Timepix detector) in space. If this

concept will be confirmed in real space experiment, then analogous experiments could be proposed for future X–ray astrophysics space missions. For monitoring experiments (monitors) the optics use increases the signal/noise ratio i.e. resulting in better sensitivity. These experiments can typically provide daily limiting flux of order of 10^{-12} erg/s/cm^2 assuming proper pointing and/or sky scanning.

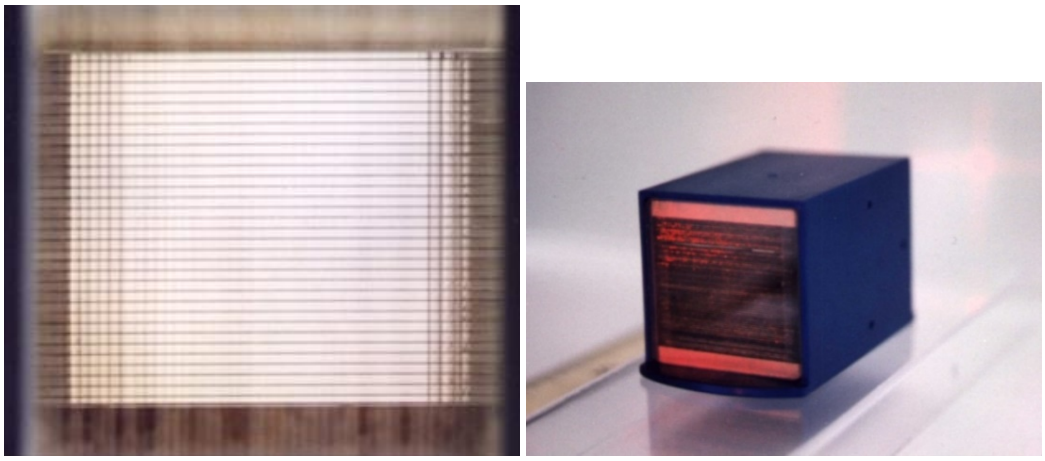

Figure 1: Lobster Eye X Ray Optics modules in Schmidt 2D LE arrangement (left) .

Even miniature LE X–ray telescopes may perform scientific astrophysical tasks as follows. Astrophysics research (wide-angle all sky monitoring of X-ray objects), Solar monitor (for imaging of X-ray solar flares), Space weather monitoring (distinguishing the particles, electrons and photons), and Earth weather monitoring (e.g. X–ray counterparts of Terrestrial Gamma Ray flashes TGFs).

There are also larger satellites planned with LE X–ray telescopes onboard, such as ESA SMILE (Branduardi-Raymont et al. 2016, 2017). ESA–China SMILE satellite with innovative instrumentation onboard including Lobster Eye X-ray telescope will study X-rays from the magnetosphere.

4. Biomimetics (of eyes of sea animals) in general

Lobster Eye Optics will go to the space this year, as described above. But there are also other mirror based animal (mostly sea) eyes, some recent new discoveries, worth to study in detail for possible technical applications. The author is currently also leading several student projects in this regard. The motivation is understanding the very specific mirror eyes of sea animals may help to design and develop special optics for scientific applications, to understand the way mirror eyes work, to learn what are the advantages of these eye arrangements, and to find out whether these optics can be used in advanced devices, e. g. in astronomy.

Strange eyes of deep sea fish Rhynchohyalus natalensis can serve as an example. The fish has 4 eyes, 2 with lens and 2 with mirror surfaces. These mirrors are formed by large number of small mirrors perhaps in analogy to active mirror optics.

The animal mirror eyes in general are based on multilayers of material with alternating high and low refractive indices, with interference of light reflected from the upper and lower surfaces of each layer, and with high sensitivity to light.

Figure 2: Czech 2U nanosatellite VZLUSAT1 with miniature X-ray telescope onboard. In the orbit, the satellite will be extended to 3U, using deployable structure.

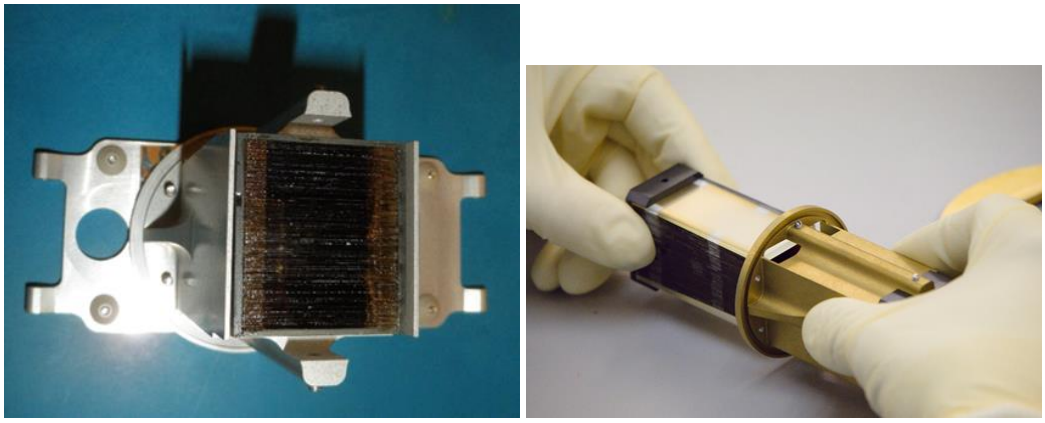

Figure 3: The 1D LE X-ray Optics module for the VZLUSAT cubesatellite.

In addition to that, we study the animal Lobster eyes in detail, as these animal eyes are NOT ONLY imaging device but: allows image reconstruction/deconvolution in lobster brain, allows adaption to light low/high, allows protection against light damage, and recognize polarized light.

5. Conclusions

The recent progress in LE X-ray monitors is demonstrated by miniature LE telescope prepared for 2017 launch on Czech cubesat VZLUSAT1. Even miniature LE X–ray telescopes may provide usable scientific results. Larger LE telescopes are under study for application on larger but still

small cubesatellites (e.g. 8U or 16U). These satellites may offer cost effective alternative to large and expensive X–ray satellites.

Acknowledgments

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