IL NUOVO CIMENTO Vol. 28 C, N. 4-5 Luglio-Ottobre 2005
DOI 10.1393/ncc/i2005-10166-5

Lobster X-ray All Sky Monitor—Novel experiment for monitoring GRBs and XRFs(*)

L. Sveda(1), R. Hudec(2), L. Pina(1)(3) and A. Inneman(3)

(1) *Czech Technical University, Faculty of Nuclear Sciences and Physical Engineering*
Brehova 7, 11519 Prague, Czech Republic
(2) *Astronomical Institute of Academy of Sciences of the Czech Republic*
Fricova 298, 25165 Ondrejov, Czech Republic
(3) *Reflex s.r.o. - Novodvorska 994, 14221 Prague, Czech Republic*

(ricevuto il 23 Maggio 2005; pubblicato online il 28 Ottobre 2005)

Summary. — We present a brief review of the X-ray All-Sky Monitor (ASM) based on Lobster Eye (LE) optics. The system will observe the whole sky in soft X-rays with the limiting flux up to two orders of magnitude better than current ASMs.

PACS `95.55.Ka` – X- and γ-ray telescopes and instrumentation.
PACS `95.75.Mn` – Image processing (including source extraction).
PACS `95.80.+p` – Astronomical catalogs, atlases, sky surveys, databases, retrieval systems, archives, etc.
PACS `95.85.Nv` – X-ray.
PACS `98.70.Rz` – γ-ray sources; γ-ray bursts.
PACS `01.30.Cc` – Conference proceedings.

1. – Multi-Foil technology

Lobster Eye optics is a wide field reflecting optics working at grazing incidence mode. Hence, it is ideal for imaging in X-rays, where photons reflect only at grazing angles.

There exist several technologies for manufacturing the optics. One is Micro-Channel Plate (MCP) technology [1], where the reflecting channels are typically built up of a large number of narrow glass tubes aligned side by side creating a kind of comb, or an Angle design [2] of the Lobster Eye in other words. The rays reflect from the inner side of the walls and focus on a curved focal plane.

The other technology is Multi-Foil Optics (MFO) technology, where the reflecting channels are created from two rectangular sets of suitably aligned thin reflecting surfaces, mostly the gold-coated glass. The design is in fact consistent with the Schmidt design [3] of the Lobster Eye (LE). A more detailed review is in [4].

The design is quite flexible and can be used for laboratory purposes as well for astronomical. To enhance the reflectivity in X-rays in both cases, the reflecting surfaces have

---

(*) Paper presented at the “4th Workshop on Gamma-Ray Burst in the Afterglow Era”, Rome, October 18-22, 2004.

to be coated with some heavy metal like gold (Au) or nickel (Ni). If only a single energy band / reflecting angle is desired, a multi-layer coating can be simply applied.

2. – ASM

Our concept is to use the optics mentioned above in a scanning All-Sky Monitor (ASM) working in soft X-rays, at energies $\sim 1\,\mathrm{keV}$.

Hence, we have designed and simulated and optimized it in the energy range 0.5–10.0 keV. The resulting optics has reflecting surface dimensions $78.0\times 78.0\times 0.1\,\mathrm{mm}^3$ with gaps between the surfaces (channel diameter) 0.3 mm and focal length $f = 375\,\mathrm{mm}$. The reflecting surfaces are gold coated. The Field of View (FOV) of the optics is $\sim 6\times 6\,\mathrm{deg}^2$ while the theoretical (simulated) angular resolution is better than 4 arcmin.

Naturally, the gain defined in any possible way, falls down near the 2.5 keV limit, because the reflectivity of the gold-coated surface falls. The optics can be used only after a longer exposing time above this limit. The simulations show that below this limit the limiting flux $\sim 10^{-12}\,\mathrm{erg/s/cm}^2$ in daily scans can be reached for observations near the orbit plane.

The detector needed for this optics is $40\times 40\,\mathrm{mm}^2$ large with optimal size of pixels 100–150 μm. The detector should be able to work as a photon counting device with time resolution better than 1 second as will be shown in further text.

The idea is to combine the optics, the detector working as a photon counting device, the casing, and necessary electronics into a single unified block. A number of identical blocks rigidly aligned onto an orbiting body will be able to see the whole sky several times per day, once for each orbit.

3. – Scanning observation simulations

The simulations of pointed observations using the ray-tracing code have already been performed and results published [5]. We can summarize, that a point source is transformed into a single bright peak with much dimmer cross structure with bars parallel to the reflecting surfaces. While the central peak is formed by photons reflected twice, once from horizontal surfaces and once from vertical surfaces, the cross structure is formed by photons reflected only once, either from horizontal surfaces or from the vertical. The relative height of a central peak if compared to the cross structure is larger for lower energies.

Because in case of the ASM, the scanning mode instead of pointed mode of observations is crucial, we have simulated and studied the properties of a single module in scanning mode.

The longer exposition of the source near the pole of the orbit is plotted in fig. 1. The source moves along a circle around the pole. Our detector is working as a photon counting device, hence we have time stamp for each of the received photons. If combined with the orientation of the telescope in a given time, we can estimate the original photon incoming direction and project it to a virtual detector plane. The result is plotted in the upper part of fig. 2. Unfortunately, the result of such a direct reconstruction is clearly not perfect.

In fact, we have to include the astrometrical shift correction. We have constructed a list of point sources at a perfectly defined positions and measured the positions of point sources at the detector in case of pointed observation. There exists a systematic shift, which has to be taken into account. If this correction is applied, the reconstruction works much better as can be seen in the lower part of fig. 2.

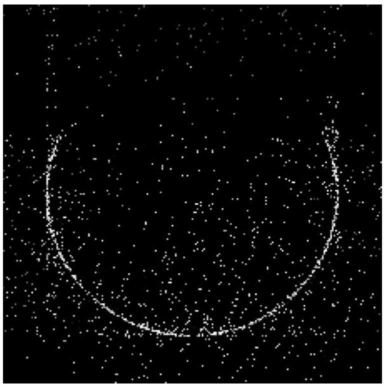

Fig.1

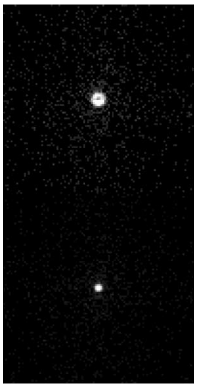

Fig. 2

Fig. 1. – An example of a single point source near the pole of the orbit . A long exposition is presented here. The detector is 400 × 400 pixels large, $100 \times 100\,\mu\mathrm{m}^2$ each.

Fig. 2. – An example of reconstructed data from fig. 1. Top: peak detail with no astrometrical corrections, down: astrometrical corrections applied. Dimensions of the figure are 2 × 100 × 100 pixels.

In fact, the reconstructed PSF as in fig. 2 heavily depends on the off-orbit distance, *e.g.* the angular distance of the source from the orbit plane. The peak itself is reconstructed mostly as a peak for all the off-orbit distances, but the cross structure changes substantially. For observations near the orbit, the cross structure remains a cross structure. For larger off-orbit distances, the cross becomes more like the Maltese cross, *i.e.* the thickness of the cross increases with the larger distance from the central peak. For near the pole sources, the cross structure is blurred completely and creates a kind of halo around the central peak.

Additionally, the shape of reconstructed PSF depends on the overall time during which the data were gathered, or during which the source was active. The most simple explanation is near the orbit pole. If the source is active only for a short time, the cross structure is blurred into the shape of a Maltese cross only, while if the source is active during the whole orbital period, a uniform halo is created.

The shape of the central peak is given mostly by the time resolution of our detector. If the time stamp for each photon is given with sufficient accuracy, the reconstruction works quite well. If the time stamp is known with poor accuracy, the central peak is blurred in the direction of the orbit. The result of simulation is plotted in fig. 3.

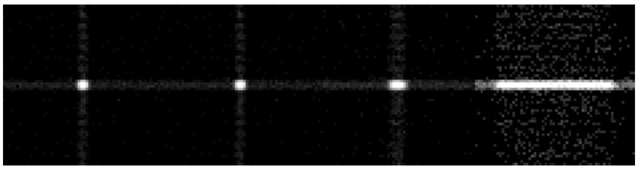

Fig. 3. – Effects of limited time resolution. Four images for time resolution 0.0 s, 0.1 s, 1.0 s, and 10.0 s (left to right are given). Each image has 60 × 60 pixels, $100 \times 100\,\mu\mathrm{m}^2$ each. The orbital period was 90 min.

4. – GRB and X-Ray Flashes

Obviously, Lobster Eye's ability to observe a large portion of the sky in one moment together with the all-sky coverage will serve as a GRB/XRF finder, precise position localizer, and prompt emission detector.

If the LE mentioned above is used, the longest time of the source visibility for in-orbit sources is $\sim 90\,\mathrm{s}$. This time is comparable with the typical length of a GRB/XRF. In fact, we will be typically able to see either the beginning of the event or the end, not both of them. Nothing will be observable at the next revolution in most cases. Fortunately, GRB/XRF are very bright sources in soft X-rays ($\sim 10^{-8}\,\mathrm{erg/s/cm^2}$) and just one revolution is enough to see the sources far above the detection limit (orders of magnitude).

We can make a simple estimate on the number of observable events. The solid angle instantly observable by the ASM is $\sim 30 \times (6 \times 6)\,\mathrm{deg}^2$ (30 modules to cover instant FOV $6 \times 180\,\mathrm{deg}^2$), *i.e.* 2.57 % of the sky. Only the overall year event rate is needed if the average duration of an event is $\sim 100\,\mathrm{s}$, visibility of at least part of an event is required, and event distribution over the sky is considered random. The lower boundary for the GRB average event rate can be estimated by detection rates for BATSE or SWIFT missions [6], *e.g.* $\sim 300\,\mathrm{yr}^{-1}$. Hence a total number GRB events should be $\geq 15\,\mathrm{yr}^{-1}$. The estimates of XRFs rates are $\sim 100\,\mathrm{yr}^{-1}$ [7], hence a total rate $\geq 5\,\mathrm{yr}^{-1}$ can be expected in case of XRFs.

These numbers are relatively small if compared to other GRB devoted missions such as SWIFT. On the other hand, the potential in localizing/observation of XRF in cooperation with some other missions seems to be very interesting, because all other missions need the gamma-ray counterpart as the initial trigger or has typically much narrower FOV or less sensitive/accurate X-ray instrument onboard. The ability to fast and precisely localize the sources, to measure the prompt emissions, and to work cooperatively with other instruments makes the LE ASM a valuable part of the future GRB/XRF exploration fleet, although GRB/XRF sources will be just a part of LE ASM scientific targets.

* * *

We acknowledge the support by the Grant Agency of the Academy of Sciences of the Czech Republic, grant A3003206.

REFERENCES

[1] Fraser G. *et al.*, `http://www.src.le.ac.uk/projects/lobster/Repository/LISSproposalfinal.pdf`
[2] Angel J. R. P., *ApJ*, **233** (1979) 364-373.
[3] Schmidt W. K. H., *NucIM*, **127** (1975) 285-292.
[4] Hudec R. *et al.*, *Proc. SPIE*, **4857** (2003) 578-586.
[5] Sveda L. *et al.*, *Proc. SPIE*, **5539** (2004) 116-125.
[6] Chincarini G. *et al.*, *MmSAI*, **74** (2003) 138.
[7] Heise J. *et al.*, *X-Ray Flashes and X-Ray Rich Gamma Ray Bursts*, in *Gamma-Ray Burst in the Afterglow Era*, edited by Costa E. *et al.* (Springer, Berlin Heidelberg) 2001, p. 16.