33RD INTERNATIONAL COSMIC RAY CONFERENCE, RIO DE JANEIRO 2013
THE ASTROPARTICLE PHYSICS CONFERENCE

All-Sky Monitor in Hard X-Rays and Soft Gamma-Rays with Wide-Field Gamma-Ray Telescope Gammascope

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Abstract: The main goal of this project is to develop an all-sky monitor to study astrophysical transient phenomena such as cosmic gamma-ray bursts (GRBs), supernovae and novae, outbursts in X-ray binaries and pulsars, active galactic nuclei variability during simultaneous all-sky observations in hard X-rays and soft gamma-rays (0.02–2.0 MeV) and optics. Study of these phenomena is very timely in view of fundamental problems of modern natural history such as origin and evolution of the Universe, the nature of dark matter and dark energy, the space-time structure and matter properties in very high electromagnetic and gravitation fields. In particular, the study of GRBs is one of the main goals of modern astrophysics. Being one of the most powerful events in the Universe, GRBs are not studied well up to now because we do not understand adequately its central engine. From the other hand GRBs give us the independent cosmological test and could be used to study the evolution of very early Universe.
The experiment main feature is the possibility of simultaneous observations of GRBs in gamma-rays and optics. Hitherto mainly the so-called afterglow, i.e. the response of the medium of an explosion in the GRB source, was observed in optics. The Gammascope instrument is constructed to detect contemporaneously the optical and gamma emission of the GRB at the instant of explosion. From this point it continues the line of Lomonosov mission, which assumes the multi-wave study of GRB prompt emission. However the Gammascope is qualitatively a new step because it is expected to obtain the gamma-ray images of the large sky areas, and it will significantly improve the accuracy of the GRB localisation.

Keywords: GRB, Gammascope, Gamma-ray telescope.

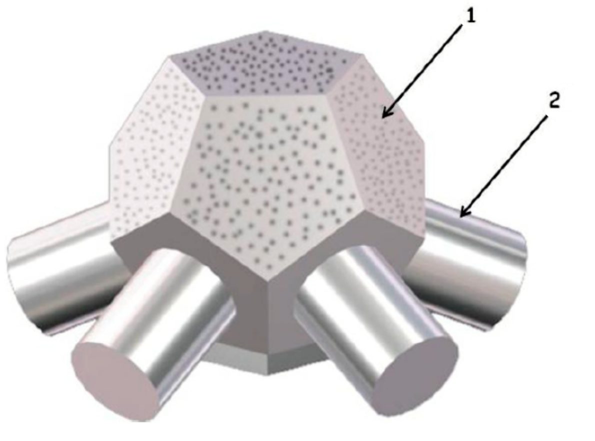

Figure 1: The general view of a wide field-of-view hard X-ray monitor: 1 - marks the coding mask element; 2 - marks one of the PSD modules.

1 Composition of Gammascope

The Gammascope instrument consists of the wide-field gamma-ray telescope (WFGRT) sensitive from ~ 10 keV up to 1.0 MeV photons, and the number of wide-field optical cameras (WFOC). WFGRT (see Fig. 1) is an arrangement of identical units of position-sensitive detector (PSD) modules and coding mask. It also could include the separate electronic unit.

The coding mask should be most similar to spherical. In practice, it is made as the arrangement of six separate identical pentagonal elements, which are mounted on the special construction of a dodecahedronal shape.

The WFGRT position-sensitive detector consists of the 6 modules, which are placed on the bottom surface of a special dodecahedron construction in such a way that each PSD module is opposite to coding mask pentagonal element. Gamma-radiation passing the neighbouring mask element also reach the mentioned PSD module enlarging its field-of-view (FOV). The combination of FOV of all PSD modules cover the whole semi-sphere. Each PSD module is based on NaI(Tl)/CsI(Tl) phoswich detector. The NaI(Tl) part consists of a large number (~ 100) of relatively small pixels (1.5×2.0 cm^3). CsI(Tl) crystal placed under the pixels is used as an active shield to protect NaI(Tl) array from locally produced gamma-quanta.

In the optimal case six WFOCs should be co-aligned to the each PSD - coding mask element combination, thus the WFOC field ($20^\circ \times 20^\circ$) will be totally covered by the larger field of WFGRT PSD module (60° FWHM). Due to its very high cost and power consumption, really the number of WFOCs may be less than the number of PSD modules - 3 or 4.

The instrument's effective area and exposure time should be maximal for detection of the weakest sources, the maximal number of the gamma-ray bursts etc. As the universal parameter of the experiment's survey sensitivity the value $\Omega \times T \times S$ (i.e. the multiplication of instrument's FOV solid angle Ω, total time of experiment T and effective area S) could be used [1]. The minimal detectable fluxes for the proposed coding mask all-sky monitor were calculated for $T = 1$ year, $\Omega = 2$ sr and $S = 500$ cm^2 with the use of the expected background level estimated from the data of GRIF experiment onboard MIR orbital station [2]. The survey sensitivity of the proposed all-sky monitor is about $2 \cdot 10^{-4}$ cm^{-2}s^{-1}MeV^{-1} in 0.1–1.0 MeV energy range. It is of the same order as the survey sensitivity of the IBIS/INTEGRAL instrument near 100 keV and the COMPTEL/CGRO instrument at 1 MeV.

2 Instrument status

To the present the design documentation of separate modules and units is elaborated, but we consider the update of the NaI(Tl) pixels by faster scintillating crystals of $LaBr_3$:Ce.

Mathematical modelling of gamma-quanta interaction in detector units were made and image reconstruction technique was elaborated with the use of software allowing to obtain the sky map in the equatorial co-ordinates in scanning mode.

To optimise the image reconstruction algorithm the instrument response on the point-like source with given intensity was modelled for different source positions. To estimate the opportunities of sky map reconstruction by the summing of exposures, the scanning of sky by the instrument FOV due to the spacecraft motion was modelled for real experiment conditions. As the result the possibility of separation of near placed sky sources as well as revealing of weak sources at the background from more bright objects with intensity higher more than 10 times was confirmed. Fig. 2 clearly shows that in the case of continuous scanning of the sky by the instrument FOV, it is possible to separate different sources in the Galactic Centre.

As the result of this simulation the possibility of spatial resolution of the tightly place point sources with the luminosity difference up to order of 10, was confirmed for the real background conditions of low-orbital satellite.

Note, that energy coverage of Gammascope is well suited to measure the peak energy of the GRB prompt emission spectrum what makes this hard X-ray monitor a valuable addition to the UFFO-100 instrumental suite, able to provide an estimate to the redshift of detected GRB using peak-energy-z relation.

Besides the analysis of possible adaptation of the main instrument units and modules to the space experiment conditions was done. It means that we have technical proposals on the PSD module construction and electric circuits as well as on the telemetric control of the instrument. The necessary output data volume was estimated.

The main parameters of the monitor Gammascope are given below/

- Total mass of the instrument - 160 kg.
- Mass of the detector - 130 kg.
- Applied power - $\sim$ 100 W.
- Data flow: 1 GRB data from each optical camera - 500 Mb, 1 day data from gamma-telescope - 500 MB.
- Geometry factor - 0.3 m^{2}sr.
- Angular resolution (FWHM) - $\sim 2°$.
- Energy range - 0.05–1.0 MeV.
- Energy resolution (for 662 keV line) - $< 12\%$.
- Effective area - $\sim$ 500 cm^2.
- Sentitivity for 10^6 s observation time - $\sim$ 30 mCrab.

References

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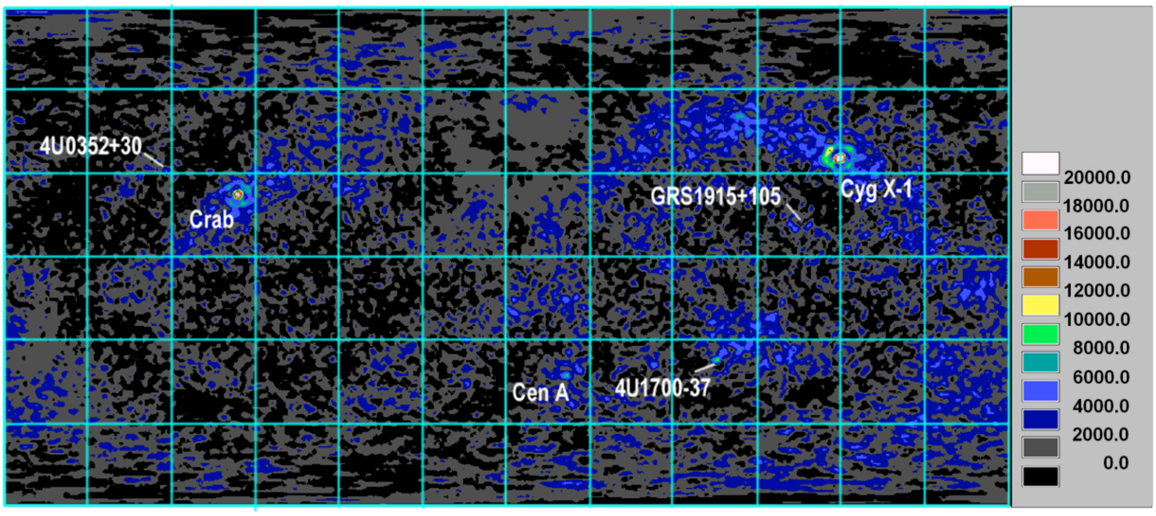

Figure 2: Reconstructed image of the Galactic plane for one orbit exposure data of Gammascope collected in a survey-mode. Point sources with quite different X-ray luminosity are well separated and identified in the map.