THE IMAGE RECONSTRUCTION MODELLING IN THE SPACE EXPERIMENT WITH WIDE-FIELD GAMMA-RAY TELESCOPE WITH THE USE OF INTEGRAL SKY MAPS.

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ABSTRACT

The INTEGRAL sky maps were used for the simulations of the image reconstruction in the space experiment with a wide field (~2π sr) coding mask telescope elaborated for the all-sky monitoring in gamma-rays (0.05-1.0 MeV). The sky maps calculated with the use of INTEGRAL catalogue allow to estimate advantages of all-sky monitor observations with such instrument in hard X-rays and soft gamma rays. One can also consider the expected observation conditions for some known galactic and extragalactic sources.

1. THE PRINCIPLES AND PARAMETERS OF CODING MASK ALL-SKY MONITOR.

The proposed wide-field soft gamma-ray telescope for the energy range 0.05-1.0 MeV is a coding mask instrument with quasi-spherical configuration, widening its field of view up to 2π sr. Such field of view together with imaging capability provide the all-sky mapping and, as a result, the continuous monitoring of hard X-ray and soft gamma-ray sources as well as the study of gamma-ray bursts and other transient phenomena..

The angular resolution in the all-sky monitoring experiment should be enough to locate the observed objects with accuracy, sufficient for their identification. The number of point sources well known in hard X-rays is about 100 (the First IBIS/ISGRI catalogue [1] has 123 objects detected in 40-100 keV energy range) and it is essentially less at higher energies of detected photons. The most of the sources expected to be observed in soft gamma-rays are extra Galactic, which large-scale distribution over the sky is quite random. Thus angular resolution ~2°-3° will be quite acceptable for the observation almost of the all sky excluding some regions near the Galactic Centre, where source density is much more higher than mean value over celestial sphere. Such angular resolution can be achieved in a coding mask telescope with the position resolution ~1.5 cm and the distance between the position sensitive detector (PSD) and coding mask ~0.5 m.

In this work we present the results of the image reconstruction modelling in the space experiment with the proposed coding mask all-sky monitor. We considered the quasi-spherical configuration realized by placing 6 plates of coding mask and 6 modules of PSD at the planes of a dodecahedron (see fig.1). The angular dependence of the relative effective area for such instrument arrangement is shown in fig.2. One

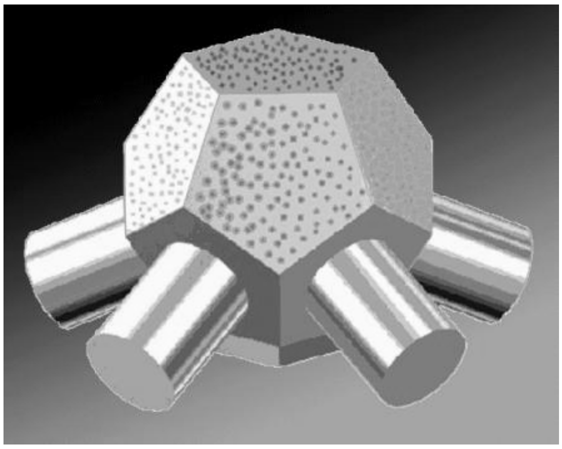

Fig. 1. The view of the instrument.

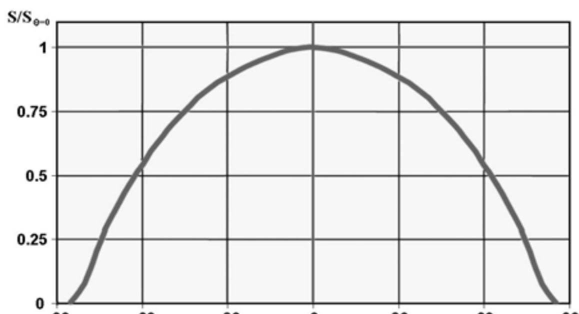

Fig. 2. The instrument's beam.

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can see that the quasispheric shape of the detector provides the wide FOV with ~120° FWHM.

Each PSD unit is based on the array of 61 small scintillator crystals. The best efficiency and energy resolution for γ-quanta with energy about several hundred keV give the size of the detecting crystals ∅1.5 cm. The size of each transparent element of the mask (the opaque elements can be used in the case of “antimask”) was taken the same as the diameter of the detecting crystal (∅1.5 cm). The coding mask’s elements were arranged in pseudorandom pattern which is the same for each plane of the dodecahedron.

The coding mask plates should be made of tungsten. A large CsI(Tl) layer can be used as an active shield from the background radiation produced in the spacecraft material. The parameters of the considered coding mask all-sky monitor space experiment are presented in table 1.

Table 1. The parameters of the coding mask all-sky monitor experiment.

Total mass of the instrument Mass of the detector	≤ 160 kg ≤ 130 kg
Applied power	≤ 95 W
Data flow per day*	≤ 32 Mb
Geometry factor	0.3 m^2·sr
Angular resolution	2°-3°
Energy range	0.05-1.0 MeV
Energy resolution (for 661keV line)	≤ 15%
Effective area	~500 cm^2
Sentitivity for 10^6 s observation time	~30 mCrab

* Minimal value needed for the continuous monitoring in several energy channels.

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 Ω·T·S (i.e. the multiplication of instrument’s FOV solid angle Ω, total time of experiment T and effective area S) could be used [3]. The minimal detectable fluxes for the proposed coding mask all-sky monitor were calculated for T = 1 year, Ω = 2π 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 $2\cdot10^{-4}$ $cm^{-2}\cdot s^{-1}\cdot MeV^{-1}$ in 0.1-1.0 MeV energy range. It is of the same order than the survey sensitivity of the IBIS/INTEGRAL instrument near 100 keV and the COMPTEL/CGRO instrument at about 1 MeV. To be compared the sensitivity of both experiments was recalculated for the conditions of the 1 year all-sky monitoring experiment, assuming equal exposure for all sky regions including extragalactic part of the sky. The 1 year experiment with the proposed coding-mask monitor allows to detect the sources about one order weaker than 3C273 quasar during the all-sky observations.

2. THE MODELING OF THE SKY MAPPING.

The measured numbers of counts in each detecting crystal are used as the initial data for the image reconstruction in the instrument’s FOV. The image is obtained by the multiplication of the row of counts and the response matrix. The result is a column of the flux estimations in a number of the points chosen in the FOV (θ, φ coordinates are used). About 20000 points are needed for 1° separation. The preliminary subtraction of the mean number of counts for each PSD unit corrects the reconstructed image for the smooth surface which appear because of the difference in the angles between each PSD unit axis and the direction to the source. The pentagonal element of the coding mask and the single source image are shown in fig. 3 to illustrate the image reconstruction in the instrument’s FOV for the 1 frame of the experimental data.

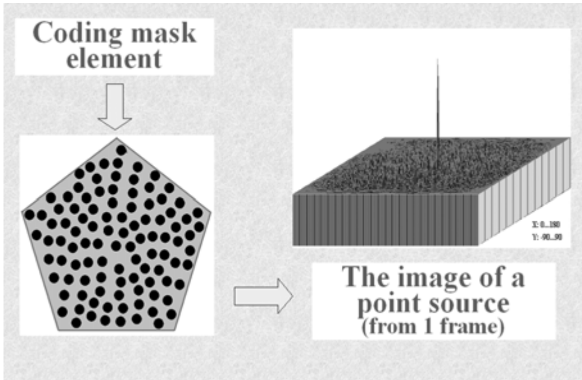

Fig. 3. The image reconstruction (1 frame)

The 1 frame map is useful for very short events (γ-ray

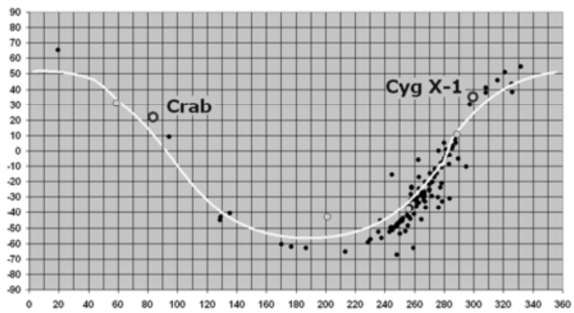

Fig. 4. The Galactic plane orbital scanning.

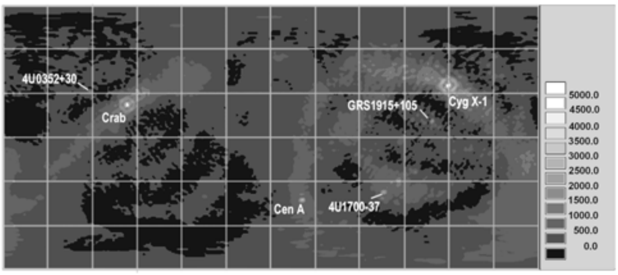

Fig. 5. The reconstructed image of the sky. The background was not taken into account.

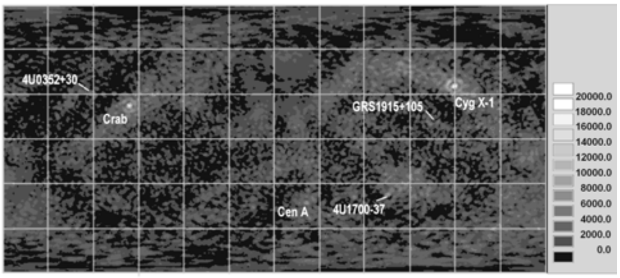

Fig. 6. The reconstructed image of the sky. The expected low orbit background was considered (1 day exposure).

bursts, etc.). The best sensitivity of the survey experiment for the monitoring of the weak sources can be achieved by adding a number of 1 frame images to the total sky map in (α, δ) coordinates. These 1 frame images can be obtained during the orbital scanning of the sky when the instrument is directed to the zenith. The real data about orientation of the NEGA1/GRIF instrument onboard "Mir" OS [2] were used for the modeling of the orbital scanning (1 orbit, 1165 frames). Fig. 4 shows a line composed from the points of the orientation.

The sources from the First IBIS/ISGRI Soft Gamma-Ray Galactic Plane Survey Catalogue [1] are also shown in fig. 4. The data about their position and fluxes were used for the test of the imaging capability of the coding mask all-sky monitor. The modelling was made in order to test the angular resolution of the proposed experiment with chosen parameters in the low energy part of its range, where the number of the sources is maximal. The procedure of the image reconstruction was also tested for the appearance of the false irregularities. It is most important for hard energy part of the range, in particular for the correct study of the 511 keV diffuse radiation. During the orbital scanning the surface noise decreases in comparison with 1 frame image. Nevertheless some smooth structures can appear because of the non-uniform scanning.

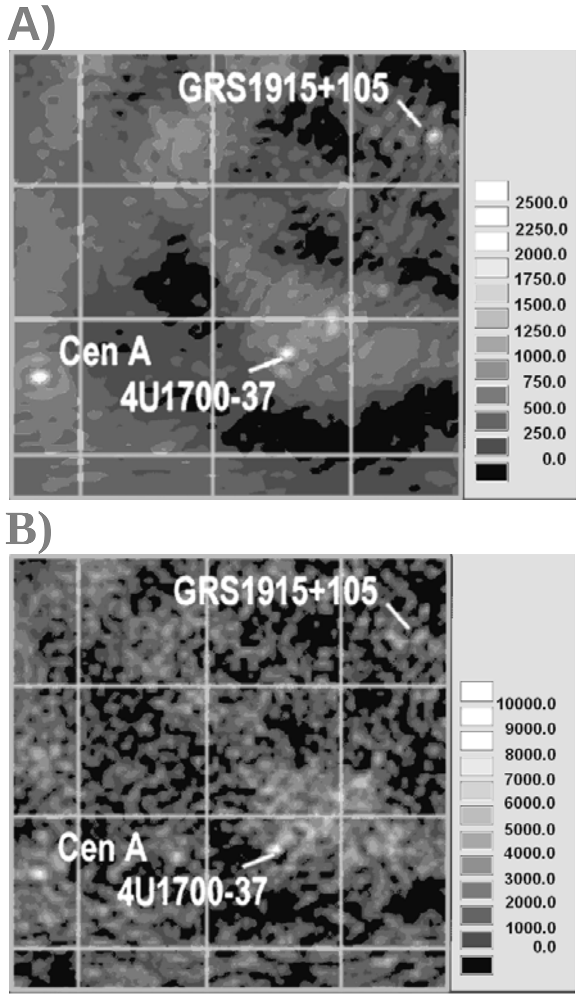

Fig. 7. The reconstructed images of the region of 100 mCrab sources. A) No background included. B) the result of modelling with the low orbit background (1 day exposure).

Fig. 5 shows the sky map reconstructed for the case of the orbital sky scanning which was described above. This image was calculated without background, so it can be considered as the approximation of the image, obtained during the very long period of observations with the same instrument orientation for each orbit. The main hard sources could be seen (the sources brighter than 100 mCrab are marked). The procedure of "witenning" of the brightest sources Cyg X-1 and Crab may decrease the smooth surface as well, as the circles around these sources. This leads to better contrast in the regions of the weak sources. The precession of the orbit will also improve the map.

The result of the image reconstruction when the background was taken into account is shown in fig. 6. The background rates of the detecting crystal were estimated from the background rates of the PX2/GRIF instrument onboard "Mir" OS [2] being equal ~2 s^{-1} for 1.5cm crystal in 40-100keV energy range (outside the radiation belts). The expected background onboard smaller satellite is some less. The map in fig. 6 was obtained for the same orbital scanning, as in previous case. The time of observation was taken ~1 day (16 orbits).

Fig. 7 shows the region of the weak sources in detail. It can be seen, that the sources Cen A and 4U1700-37 are observable at the significance level ~5σ, corresponding the probability of 1 random peak for the all map less than 1%. So the survey sensitivity of the proposed experiment with coding mask all-sky monitor is ~30 mCrab for the time of observation 10^6s.

The precession of the satellite orbit leads to comparatively uniform distribution of the instrument's orientation directions (for the time of observation greater than several months). The addition of many sky images (frames) obtained for the cases of different orientation of the instrument sufficiently decrease the ripple on the final sky map. The non-uniformity of the ripple on 1-year map will be also significantly less than uniformity of the ripple on 1-day image (fig. 6, 7) and will not affect the sensitivity.

3. REFERENCES

1. Bird, A.J., Barlow, E.J., Bassani, L et al., *ApJ*, 607, L33, 2004
2. Kudryavtsev, M.I., Svertilov, S.I., Bogomolov, V.V and Bogomolov A.V. *Adv. Space Res*., Vol. 22, No.7, 1053, 1998
3. Kudryavtsev, M.I., Svertilov, S.I., Bogomolov, V.V and Bogomolov A.V. *Adv. Space Res*., Vol. 22, No.7, 1057, 1998