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Solar gamma-ray spectrometer GRIS onboard the International Space Station

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GRIS (Gamma and Roentgen Irradiation of the Sun) is a scientific instrument for detection of hard X-rays and gamma-rays of solar flares with the energies from 50 keV to 200 MeV and for registration of solar neutrons with energies above 30 MeV. The experiment will be performed since 2019 onboard the International Space Station. The instrument includes two spectrometers: a low energy spectrometer based on a fast scintillator with high energy resolution 3.5-4.5% at 662keV ($LaBr_3$(Ce) or $CeBr_3$) and dimensions ø7.62×7.62 cm, and a high energy spectrometer based on CsI(Tl) scintillator ø12×15 cm (which is also intended for neutron registration). The apparatus will be mounted on the oriented platform outside the Zvezda service module.

Simulated response of the detectors to background radiation and to solar flares of different magnitudes and compositions obtained with GEANT4 toolkit confirms the instrument's possibility to measure different components of the solar flares spectra: narrow gamma lines, pion decay component, etc. with a sufficient confidence due to the usage of two types of detectors.

Key words: GRIS, solar flares, solar x-ray and gamma-ray radiation, solar neutrons, space gamma-ray spectrometer, cosmic gamma-ray background.

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1. INTRODUCTION

The solar flare is a huge explosion in solar atmosphere occurring as a result of energy release when the configuration of solar magnetic fields is changing (so-called magnetic reconnection). Electrons, protons and ions, accelerated by released energy, propagate along magnetic loops and interact with ambient plasma. These interactions produce hard x-rays, gamma rays and neutrons via direct (e.g. bremsstrahlung) or secondary processes (e.g. exited nuclei or secondary particles generation). The x-ray and gamma-ray spectrum of a powerful solar flare is complicated because of a wide variety of emission processes involved. Measurable emission quantities (such as fluence, time history and shape) of different components of an energy spectrum convey information about primary energy release and particle acceleration mechanism.

Accelerated electron interactions with ambient solar plasma produce a bremsstrahlung emission in energy range from few keV to a few hundred MeV with power-low spectrum. If angular anisotropy of accelerated electron beams exists, linear polarization of the bremsstrahlung emission can be observed. In addition, photospheric x-ray albedo may be a cause for x-ray polarization (*Jeffrey, 2014*).Quasi-periodic pulsations of bremsstrahlung emission intensity with period from millisecond to a few seconds are also be of some interest. These pulsations could be the result of from some magnetohydrodynamic oscillations in the source region or may be due to the modulation of electron acceleration and the injection mechanisms (*Dmitriev, 2007*), (*Rao, 2010*).

Protons and alpha particles accelerated up to 10-30 MeV/nucleon can generate in nuclear reactions with nuclei of solar plasma a narrow gamma-line emission in 0.3-8 MeV energy range. Such interactions also produce neutrons that may be captured by hydrogen nuclei with emitting of 2.223 MeV photons or escape out of sun atmosphere. Fast of them (with energy ≥30 MeV) can reach the Earth orbit before their decay. The interactions of more energetic protons (> 300 MeV) with ambient nuclei produce pions. Charged pions ultimately decay into electrons and positrons which emit bremsstrahlung and annihilation 511 keV line. The neutral pions decay into two gamma-ray that form a broad peak with a maximum at about 70 MeV.

Currently several scientific space instruments measure solar hard x-rays, gamma rays and neutrons. RHESSI is the instrument for solar imaging spectroscopy in energy range from 3 keV to few MeV with high spatial and spectral resolution

(*Lin, 2002*). The instrument allows obtaining a great amount of important data both about spectral composition of solar flare radiation and about localization of these radiation sources. Fermi Gamma-ray Space Telescope is not a special solar mission. However, it measures solar flares radiation by Gamma-ray Burst Monitor (GBM) in the energy range 8 keV – 40 MeV and by Large Area Telescope (LAT) in the range 20 MeV – 300 GeV due to wide fields of view of the instruments. LAT has observed high-energy gamma rays in M-class solar flares with durations above 12 hours (*Ackermann, 2014*). There are other non-solar x-ray and gamma-ray instruments that can detect solar flares radiation and that currently operate in space, for example Wind/Konus (*Pal'shin, 2014*) and Suzaku/WAM (*Endo, 2010*). The solar neutron detector FIB on the ISS (energy range 35-120 MeV) has measured weak neutron fluxes associated with modest X-ray flares as well (*Muraki, 2012*).

2. GRIS EXPERIMENT DESCRIPTION

GRIS (Gamma and Roentgen Irradiation of the Sun) is a scientific instrument for a spectroscopy of hard X-ray and gamma-ray of solar flares with the energy from 50 keV to 200 MeV and for registration of solar neutrons with energy above 30 MeV. The simultaneous measurement of different components of solar flare gamma-ray spectra (bremsstrahlung radiation, narrow gamma lines, pion decay component, etc. as well as direct solar neutrons) with a reasonable efficiency, energy resolution and speed of response is an important advantage of the instrument. Jointly with other instruments (radio/UV/x-ray imagers) GRIS observations in a broad energy range will allow to investigate solar flares evolution during the phase of electrons, protons and ions acceleration and to obtain data for improving theoretical models.

The experiment has been included in the Russian ISS scientific program. The apparatus will be installed onboard the Russian Orbital Segment of the ISS in 2019. Additional goals of the instrument are: measurement of the radiation levels of the ISS environment, registration of Gamma-ray bursts (GRBs) and Terrestrial gamma-ray flashes (TGFs).

GRIS instrument consists of two units: a detector unit which will be mounted outside the Zvezda service module of the ISS and an electronic unit designed to connect the detector unit with the ISS interfaces and placed inside the module. GRIS detector unit includes two spectrometers: a low energy spectrometer (LES) based on $LaBr_3$(Ce) or $CeBr_3$ ø7,62×7,62 cm scintillator and a high energy spectrometer (HES) based on CsI(Tl) scintillator with dimensions ø12×15 cm. The energy range of LES is 50 keV – 15 MeV. A distinctive feature of LES detector is a fast scintillator with high energy resolution (about 3 – 4 % @ 662 keV). A high count rate detector is required since considerable fluxes of solar hard x-ray may occur. Also a high resolution ability is the essential feature for measuring nuclear lines in solar flares spectra. HES is intended for gamma-ray registration in the energy range 200 keV - 200 MeV and for solar neutrons registration with energy above 30 MeV. CsI(Tl) crystal has a lesser resolution (about 7-8 % for 662 keV line) but greater dimensions, that is important for high energy gamma ray and neutron registration.

Another feature of CsI(Tl) is a different shape of scintillation pulse from neutron and gamma-ray. The signal processing electronics relying on this difference generates some discrimination parameter (for example: slow component to total signal ratio, see fig.3). GRIS spectrometers characteristics are represented in Table 1.

HES spectrometer is surrounded by two anticoincidence shield detectors (ACDs) based on a polystyrene scintillator with a thickness of 1.5 cm. The first one represents a dome and covers CsI(Tl) crystal from above. As the shape of the scintillator is complicated, four 18 mm photomultipliers tubes (PMTs) are used in the read out system to improve the light collecting homogeneity. The second ACD shields the backward direction. Together with CsI(Tl) they form a phoswich detector and are viewed by the same PMT. Signals of the bottom shield detector and CsI(Tl) crystal are discriminated by signal processing electronics due to difference between pulse shapes of both scintillators. The shield detectors are intended to reduce the charged particles background count rate (primarily for relativistic protons and alpha particles rejection), because their flux exceeds solar high energy gamma ray (above few tens MeV) and neutrons fluxes considerably.

Another difficulty for orbital measurements is the instability of the instrument response as short term (due to changes in the detectors temperature during orbital movement for example) as long term (due to slow degradation of scintillator light output and optical contact during the whole mission). To parry these effects the detector is provided with two in-flight calibration systems. The first one is a ^{60}Co tagged gamma-ray source. This source provides two gamma lines (1.17 MeV and 1.33 MeV) with suppressed background continuum and is used for calibration of the energy ranges of both detectors. However, HES spectrometer has a very wide energy range. The calibration gamma lines are far from the high energy bound

(200 MeV) and cannot be used for precise calibration. For this reason, a two LEDs (light emitted diodes) calibration system like the ones described in *(Friend, 2012)* will be used. This system not only provides calibration peak at one point of the energy range but many points in the whole of the range. Scheme of GRIS detector unit is represented on figure 1.

Energy scales of both spectrometers are divided in two subranges. Each of the subranges produces two kind of data: spectra and count rate of intensimeters. The intensimeter is a counter with relatively broad energy window and rearranging thresholds. Each of the subranges consists of ten intensimeters. Their main advantage is a short accumulation time compared to the spectral data. This kind of data may be useful for investigation of rapidly varying processes like Quasi-periodic pulsations of flare emission or gamma ray bursts. Neutron and gamma ray discrimination data is formed into a two-dimensional matrix. The first dimension of this matrix is a deposited energy spectrum and the second one is a spectrum of the discrimination parameter. Thus, it could be possible to obtain neutron energy deposed spectrum separated form gamma ray spectrum. Preliminary information about accumulation time and number of channels of the spectra, the intensimeters and the neutron-gamma matrix is represented in Table 2.

Solar flares as well as GRBs and TGFs are relatively rare events and there is no need to keep the best time resolution of the data continuously. To cut down the data volume two operation mods of the instrument are provided: the monitoring mod, which will be used almost all the time and the flare mode, which can be turned on by a trigger signal. For the trigger generation LES spectrometer has two subsidiary intensimeters with rearranging thresholds. Count rates of the intensimeters are analyzed independently by the signal processing electronics. Two different event identification algorithms relied on event count rate excess over background can be used simultaneously. An additional task of these intensimeters is to obtain TGFs' time profiles with ultimate time resolution 20 μs.

False trigger signals may occur because of magnetosphere particle events, i.e. when the ISS passes the radiation belts or electron precipitations. To reduce amount of the false triggers, switching over to the flare mode could be blocked at the particular regions of the orbit: South Atlantic Anomaly and high latitude regions.

GRIS will be mounted on the biaxial oriented platform outside the Zvezda service module of the ISS. This platform will be used for maximization of the Sun observation time inside the detectors field of view (30°). However, the service life of the oriented platform in active mode is considerably shorter than the experiment duration. Another two instruments can also be mounted on the same platform. The operation programs of these instruments may be not related to the Sun observation tasks. For these reasons, the platform will not be in a solar tracking mode continuously, but will be switched to this mode sometimes on command from a mission control center. Some command generation algorithm based on solar activity regions behavior is developed at the present time.

According to the Korolev Rocket and Science Corporation "Energia" specialists calculation, the period of time when the Sun is not shaded from GRIS by the Earth or the ISS massive elements is equal to 52 per cent. Our analysis shows that in case when the transmission time of the commands for the platform is short enough (within the next 24 hours), the number of X and M class flares which may be observed completely or partly inside the detectors field of view is at least 31 per cent.

Since GRIS does not consist of any elements to narrow its angular sensitivity (like a collimator), the flares occurring when the detectors is not pointed to the Sun can be measured. But quality of these data may be worse because of the less effective length of the crystals and possibility to shade a spectrometer by the load-bearing elements of the detector unit or by another spectrometer.

3. INVESTIGATION TESTS OF THE GRIS DETECTOR PROTOTYPES

GRIS spectrometers prototypes were developed for characteristics investigation and calibration methods examination. LES detector prototype is an assembly of $LaBr_3$(Ce) scintillator ø1×1" and PMT R6233-100. The FWHM @ 662 keV is 3.1% for this assembly. It is a typical resolution for detectors based on $LaBr_3$(Ce). HES detector prototype is an assembly of CsI(Tl) ø10×15 cm and PMT R6233. This prototype has an excellent resolution (FWHM 5,9% @ 662 keV) for a big CsI(Tl) crystal based detectors. This is a result of ESR film reflector usage (*Janecek, 2012*).

High energy resolution and high count rate ability of LES are obtained due to very high light output with a very short decay time of the scintillator (for $LaBr_3$(Ce) 60-65 ph/keV and ~16 ns respectively). However, if energy deposit in the crystal exceeds a few MeV, photo detector saturation (PMT for our case) may take place because of a very intensive light flash. As the consequence a non-proportionality of the detector response can result (*Quarati, 2013*). CsI(Tl) is less fast (50-55 ph/keV and ~1 us respectively), but PMT saturation may take place for energy deposit in crystal above few tens of MeV. Therefore, precision calibrations in total energy ranges of both detectors are necessary for measuring of deviation degree from proportionality.

Gamma-lines are produced by radio isotopes (^{137}Cs, ^{60}Co, Pu-Be) and neutron interactions on hydrogen (2.2 MeV line), iron (7.6 MeV line) and nitrogen (10.8 MeV line) were used for the LES prototype calibration (*Trofimov, 2013*). The HES prototype was calibrated by LED pulser which is similar to one described in (*Vicic, 2003*). Fig.2 represents the results of calibration in the operational energy ranges for both detectors: response curves for described gamma-lines (top panels) and deviation of line positions from proportionality response.

CsI(Tl) light pulse can be described by a sum of fast and slow decay components with time constants of about 0.7 us and 7 us respectively. The intensity ratio of these components and time constant of the fast component depend on ionization density of interacting particles (*Benrachi, 1989*). Gamma-rays and neutrons are neutral particles and their registrations are realized via reaction products. Fast electrons are produced due to gamma-ray interactions with detector substance and neutron interaction generates secondary protons, alpha particles and nuclei. One of our older investigations shows that these CsI(Tl) features allow to discriminate gamma ray and neutrons for the energies at least up to 15 MeV (*Kotov, 1999*). And no doubt that ability of particle discrimination holds true for higher energies.

Fig.3 represents the 3D spectrum with pulse-shape discrimination of alpha and gamma particles obtained with the HES prototype. The total integral is the sum of fast and slow components. The tail integral is equal to pulse integral from 2.25 to 12 us that corresponds mainly to slow component. The figure of merit (FOM) for this spectrum equals eight. FOM definition is represented in (*Flaska, 2013*)

4. RESPONSE SIMULATION

The ability of the instrument to detect solar flare radiation with a sufficient confidence is mostly determined by effective area of the detectors and the background count rate. For estimation of these parameters Monte Carlo method and GEANT4 toolkit were used. A mathematical model of the detector unit with dimensions, mass and chemical composition similar to those of GRIS detector unit was developed. Since it is necessary to take secondary particles contribution for background simulation into account the Zvezda module with mass of 24 metric tons was also included in this model.

The results of LES and HES detectors efficiency area GEANT4 simulation for gamma and neutron irradiation are represented in Fig.4. Though the ACD shield detectors are intended for charge particles rejection only, they greatly reduce the efficiency of high-energy gamma and neutron particles registration. This is the result of the shield detectors response to secondary particles, which appear as products of primary particles interaction with the detectors substance.

Radiation belts, primary cosmic rays (mainly protons), cosmic diffused gamma-rays (CDGR), secondary protons, neutrons and gamma-rays (Earth albedo), and activation of detectors substance are the main sources of background count rate for gamma-ray detector in the ISS orbit.

Although significant fluxes of trapped radiation take place in the radiation belts, they affect detectors for the minor part of time during orbital motion. For the ISS it is mainly the South Atlantic Anomaly (SAA), which occurs in a local region of space. Primary cosmic rays and secondary proton, gamma ray and neutron fluxes are not stationary too. They depend on the solar cycle and the current orbit position (due to effect of the geomagnetic cutoff of the primary cosmic rays). But, these fluxes together with CDGR and substance activation continuously affect detectors in the whole orbit and determine a minimum background count rate level.

A background model was developed for estimation of GRIS background count rate in the equatorial region of the ISS orbit (altitude about 400 km) far away from the South Atlantic Anomaly. For this model primary and secondary cosmic proton spectra obtained by Alpha Magnetic spectrometer (AMS) (*Alcaraz, 2000*), CDGR and the Earth gamma-ray albedo spectra measured by Swift/BAT and CGRO/EGRET instruments (*Ajello, 2008*) (*Perty, 2004*), calculated spectra of the Earth neutron albedo represented in (*Drozdov, 2010*) were used. We also used $LaBr_3$(Ce) intrinsic activity spectrum for the LES detector background estimation (*Quarati, 2012*).

In order to verify the background model we simulated background response of Natalya-2M (*Kotov, 2011*) and Fast x-ray monitor (FXM) (*Trofimov, 2011*) instruments of CORONAS-PHOTON mission and compared these results with the measured data which had been obtained by the instruments during orbital operation in 2009. Simulated and measured deposited energy spectra generally exhibit good agreement in the energy range from 50 keV to 1500 MeV. The spectra do not differ more than two times.

The simulation results of GRIS detectors response to irradiation of the Background model are represented in Fig. 5. Main contributions to count rate of both detectors are CDGR and the gamma-ray albedo. Although $LaBr_3$(Ce) intrinsic activity dominates in the energy range 0.3 – 3 MeV for LES detector. ACD shield detectors of HES considerably decrease registration of proton events for deposited energy higher than 10 MeV and they are not efficient in lower energy range due to secondary gamma-rays registration. This gamma-radiation is produced by proton interacting with substance of the detector unit and the Zvezda module. For this reason we refused to use shield detectors for LES spectrometer. Response to the neutron albedo exhibits the similar behavior as the protons, but intensity is much less: secondary gamma-rays registration for the deposited energy up to 10 MeV, and direct neutrons for higher energies.

Our simulation has not considered detectors substance and surrounding materials activation. Based on analysis of Natalya-2M measurements and similar investigation of RT-2 background (CORONAS-PHOTON mission) (Sarkar, 2011) we conclude that the activation enhances background count rate by about two times in the energy range up to 6 - 10 MeV for both detectors.

It is also important to note that background radiation is much more intensive in high latitude regions of the orbit (45-50° for the ISS). The proton flux increases by a factor of fourteen and gamma-ray albedo increasing to be of the same order. It means that high latitude measurements will be considerably obstructed because of the increase in background count rate.

In order to estimate the instrument sensitivity and expected maximum count rates we also simulated the detectors response to solar flares with different magnitude and spectral composition. Two solar events were considered: the flare with bright nuclear lines emission measured by RHESSI on July 23, 2003 (GOES class X4.8) (*Lin, 2003*) (*Share, 2003*) and X17 flare with pion-decay component in the spectrum observed by SONG instrument on October 28, 2003 (*Kuznetsov, 2011*).

Fig.6a) represents the LES detector response to the X4.8 solar flare. The brightest nuclear lines in the flare spectrum are marked. Also, background count rate spectra for two cases are represented. The first one is the response of the LES detector to the all components of the Background model (curve 2). The second one is the sum of the Background model and $LaBr_3$(Ce) intrinsic activity deposited spectra (curve 4). Obviously, $LaBr_3$(Ce) intrinsic activity leads to a considerable decrease of the LES detector sensitivity to most of the nuclear lines. $CeBr_3$ scintillator has about two orders lower intrinsic activity than $LaBr_3$(Ce) (*Quarati, 2013*). Using of $CeBr_3$ for the LES detector will provide better sensitivity to the nuclear lines emission in spite of 33% worse energy resolution than $LaBr_3$(Ce).

We also estimated the detectors maximum count rate and dead time for this flare using the time curves data represented in (*Lin, 2003*): LES max count rate equals 2×10^4 counts/s (low energy threshold 30 keV) and dead time of 2%, HES count rate is about $1{,}5\times10^3$ counts/s (low energy threshold 200 keV) and dead time of 1,5%.

Fig.6b) shows the HES detector response to the huge flare of X17 class in the energy range 1-200 MeV. Two phases of the flare are represented: the first phase mostly consists of continuum (non-pion) component and the second phase has pion-decay component domination. Due to sufficient height of the CsI(Tl) crystal (8 radiation length) the HES detector allows to detect the pion-decay component in the solar flare spectrum with high quality. Also, the ACD detectors efficiently reduce background for high energy gamma ray (about 20 times at 100 MeV) and considerably improve the HES detector sensitivity. Max count rate of HES for this flare is estimated as 2×10^4 counts/s, and dead time is about 20%.

5. CONCLUSION

This publication mainly discusses x-ray and gamma-ray registration aspects. Solar neutron registration as well as background conditions and investigation of the detectors response demand careful consideration and will be presented in the separate publication.

The two detectors approach of GRIS makes it possible to measure different spectral components of the high magnitude solar flare in the broad energy range: considerable fluxes of the bremsstrahlung x-ray (due to the fast scintillator of LES), narrow nuclear lines with high energy resolution (better than Fermi / GMB or Wind / Konus instruments, but worse than RHESSI), high energy pion component (it is beyond the energy range of all instruments except Fermi / LAT) and solar neutrons (that available only for FIB instrument). Simulation and measurement results confirmed that GRIS detectors in spite of their moderate scale have sufficient sensitivity and energy resolution to resolve these tasks, at least for the high magnitude solar flares (neutrons were not considered in this paper). Performed analysis has shown that the Zvezda module of the ISS provides suitable conditions for solar gamma measuring experiment.

The main scientific task of GRIS experiment is to obtain x-ray and gamma-ray spectra of solar flares in the broad energy range 50 keV – 200 MeV and to register solar neutrons with energies above 30 MeV. Relying on these data it is possible to obtain spectral parameters of the accelerated electrons and protons as well as temporal behavior of fluxes of these particles. It should be noted that any high magnitude solar flare is a unique event. And gamma ray and neutron data obtained for such flare simultaneously with observation in the other energy ranges of the electromagnetic spectrum (radio , ultraviolet and x-ray imagers) and particles fluxes (neutron monitors and space charged particles detectors) can provide data to improve theoretical models of the Solar flare.

Due to the wide field of view GRIS can observe other short duration gamma events like GRBs and TGFs. Fine time resolution (up to 20 μs) and large volume of LES spectrometer will be useful for the detailed investigation of the TGFs time profiles, as well as LES and HES broad energy ranges can be used to obtain the spectral characteristics of GRBs in high energy region.

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REFERENCES

Ackermann M., Ajello M., Albert A. et. al. "High-energy Gamma-Ray Emission from Solar Flares: Summary of Fermi Large Area Telescope Detections and Analysis of Two M-class Flares" // 2014. Ap J. Vol. 787. P. 15

Ajello M., Greiner J., Sato G. et al. " Cosmic x-ray background and earth albedo spectra with Swift BAT" // 2008, ApJ, Vol. 689, P. 666-677.

Alcaraz J., Alvisi D., Alpat B. et al. "Cosmic protons"// 2000. Phys. Letters. B402. P 215-226

Benrachi F., Chambon B.,Cheynis B. at al. "investigation of the performance of CsI(Tl) for charged particle identification by pulse-shape analysis" // 1989, NIM-A, Vol. 281 P. 137-142.

Endo A., Minoshima T., Morigami K., at al. "A Catalog of Suzaku/WAM Hard X-Ray Solar Flares" // 2012 Publ. Astron. Soc. Japan Vol. 62. P. 1341-1349.

Dmitriev P.B., Kudryavtsev I.V., Lazutkov V.P. et al. "Peculiarities of X-ray emission of the solar flare on 29 October 2002" // 2007, Int. Journal of Geomagnetism and Aeronomy, Vol. 7, GI2001.

Flaska M., Faisal M., Wentzloff D. and Pozzi S. "Influence of sampling properties of fast waveform digitizers on neutron-gamma-ray, pulse shape discrimination for organic scintillation detectors" // 2013. NIM A. Vol. 729. P. 456-462.

Friend M, Franklin G.B., Quinn B. "An LED pulser for measuring photomultiplier linearity" // 2012. NIM-A. Vol. 676. P. 66-69.

Jaffrey N "The spatial, spectral and polarization properties of solar flare X-ray sources" // 2014 PhD thesis. University of Glasgow.

Janecek M. "Reflectivity Spectra for Commonly Used Reflectors" // 2012. IEEE Transactions On Nuclear Science, vol. 59, no. 3.

Kotov Yu.D., Arkhangelsky A.I., Yurov V.N. et al. "Characteristics of the Natal'ya-2M Satellite Device for the Detection of Neutrons with Energies above 5MeV" // 1999 . Instrum. and Exper. Techn., Vol. 42 N. 5 P. 590-595.

Kotov Yu.D., Yurov V.N., Lupar E.E. et al. "The NATALYA-2M spectrometer of high energy radiations for the CORONAS-PHOTON space project" // 2011 Sol. Sys. Res. Vol. 45, P. 97-122.

Kuznetsov S.N., Kurt V.G., Yushkov B.Y. et al. "Gamma-Ray and High-Energy-Neutron Measurements on CORONAS-F during the Solar Flare of 28 October2003" // 2011. Solar Phys. Vol. 268. P. 175.

Lin R.P., Dennis B.R., Hurford G.J. et al. "The Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI)" // 2002. Sol. Phys., Vol. 210. P. 3-32

Lin R.P., Krucker S., Hurford G.J. et al. "RHESSI observations of particle acceleration and energy release in an intense solar gamma-ray line flare"// ApJ. 2003. V. 595, P. 69-76.

Muraki Y., Koga K., Goka T. et al. "Measurement by FIB on the ISS: Two Emissions of Solar Neutrons Detected" // 2012, Advances in Astronomy, Vol. 2012, ID 379304.

Pal'shin V.D., Charikov Yu.E., Aptekar R.L. et al. "Konus-Wind and Helicon-Coronas-F Observations of Solar Flares" // 2014 Geomagnetism and Aeronomy Vol. 54 No. 7 P. 943-948.

Perty D. "The Earth's Gamma-ray Albedo as observed by EGRET" // 2005, AIP Conf. Proc. Vol. 745, P. 709-714.

Quarati F.G.A., Khodyuk I.V., Eijk C.W.E. et al. "Study of ^{138}La radioactive decays using $LaBr_3$ scintillators" // 2012 NIM-A Vol. 683 P. 46-52.

Quarati F.G.A., Dorenbos P., Biezen J. et al. "Scintillation and detection characteristics of high-sensitivity $CeBr_3$ gamma-ray spectrometers"// 2013 NIM-A Vol. 729. P. 596-604.

Rao A.R., Malkar J.P., Hingar M.K. et al. "RT-2 detection of quasi-periodic pulsations in the 2009 july 5 solar hard x-ray flare" // 2010, ApJ, Vol. 714, P. 1142-1148.

Sarkar R., Mandal S., Debnath D. et al. "Instruments of RT-2 experiment onboard CORONAS-PHOTON and their test and evaluation IV; background simulations using GEANT-4 toolkit" // 2011. Exp. Astron., Vol. 29, P. 85-107

Share G.H., Murphy R.J., Skibo J.G. et al. "High resolution observation of the solar positron-electron annihilation line"// ApJ. 2003. V. 595, P. 85-88

Trofimov Yu. A., Yurov V.N., Kotov YuD. et al. “The experiment with the fast X-ray monitor (BRM) instrument onboard the CORONAS-PHORON satellite” // 2011 Sol. Sys. Res. Vol. 45, P. 146-152.

Trofimov Yu.A., Lupar E.E., Yurov V.N. Linearity of the Energy Scale of a Detector Based on a $LaBr_3$(Ce) Scintillator // 2013. Instrum. Exper. Techn., Vol. 56 No. 2 P. 151-155.

Vicic M., Sobotka L.G., Williamson J.F. et al. “Fast pulsed UV light source and calibration of non-linear photomultiplier response// 2003. NIM-A, Vol. 507. P. 639-642.

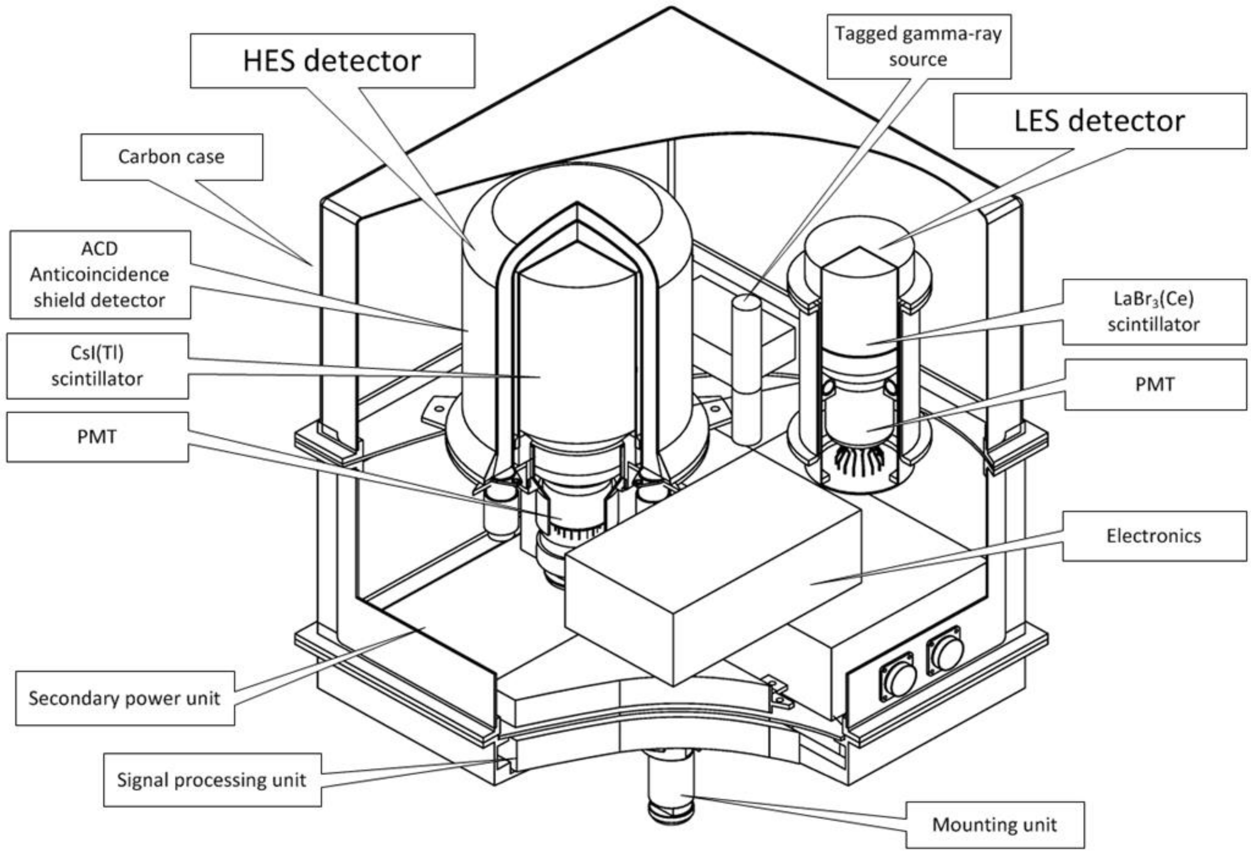


Fig.1 GRIS detector unit

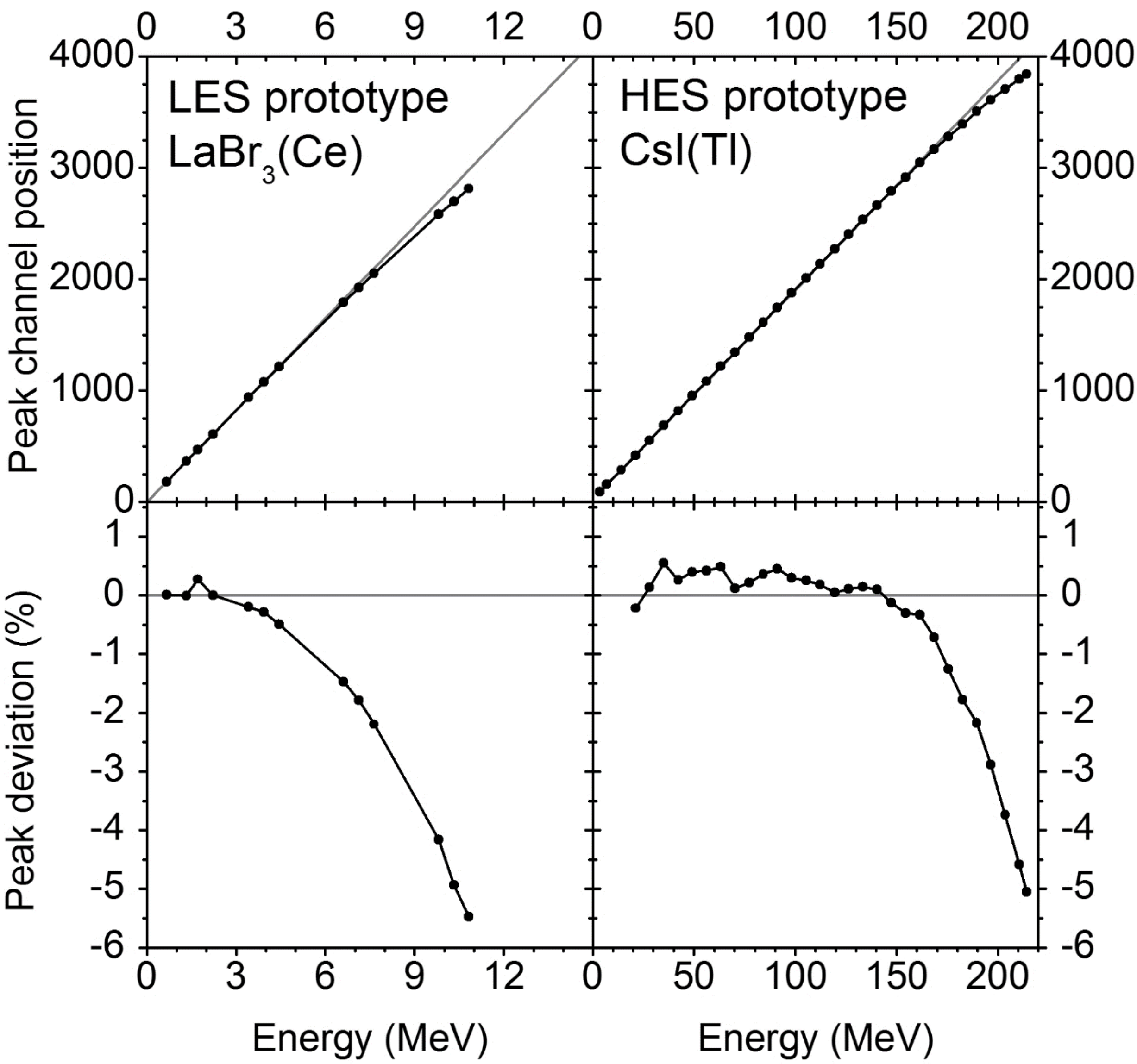


Fig.2 The LES and HES prototypes response proportionality. Top panels: response curves, bottom panels: deviation degree from proportionality. Grey straight line corresponds to proportionality response

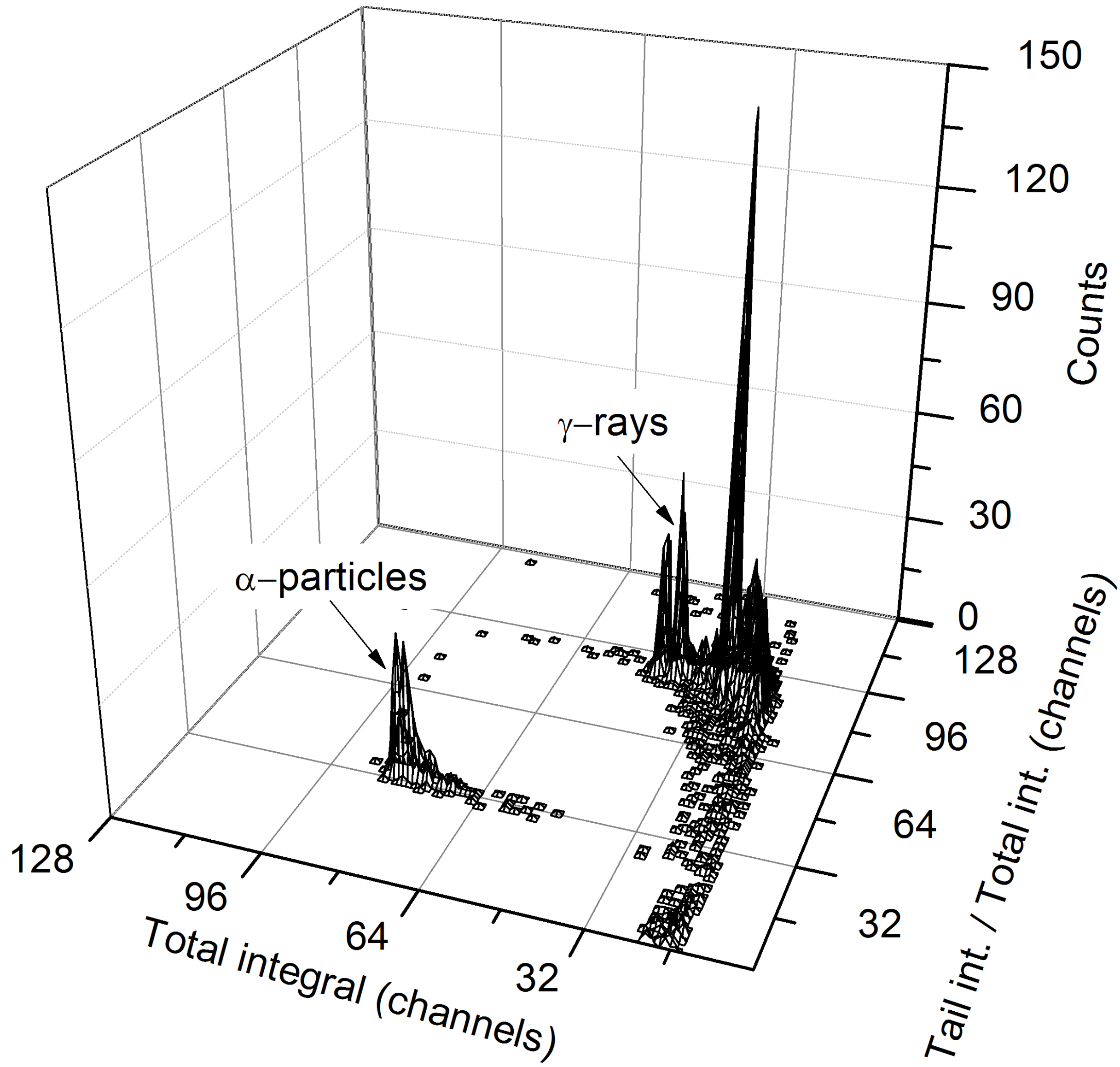


Fig.3 HES prototype pulse-shape discrimination spectrum of alpha and gamma particles from the sources ^{241}Am, ^{137}Cs u ^{60}Co.

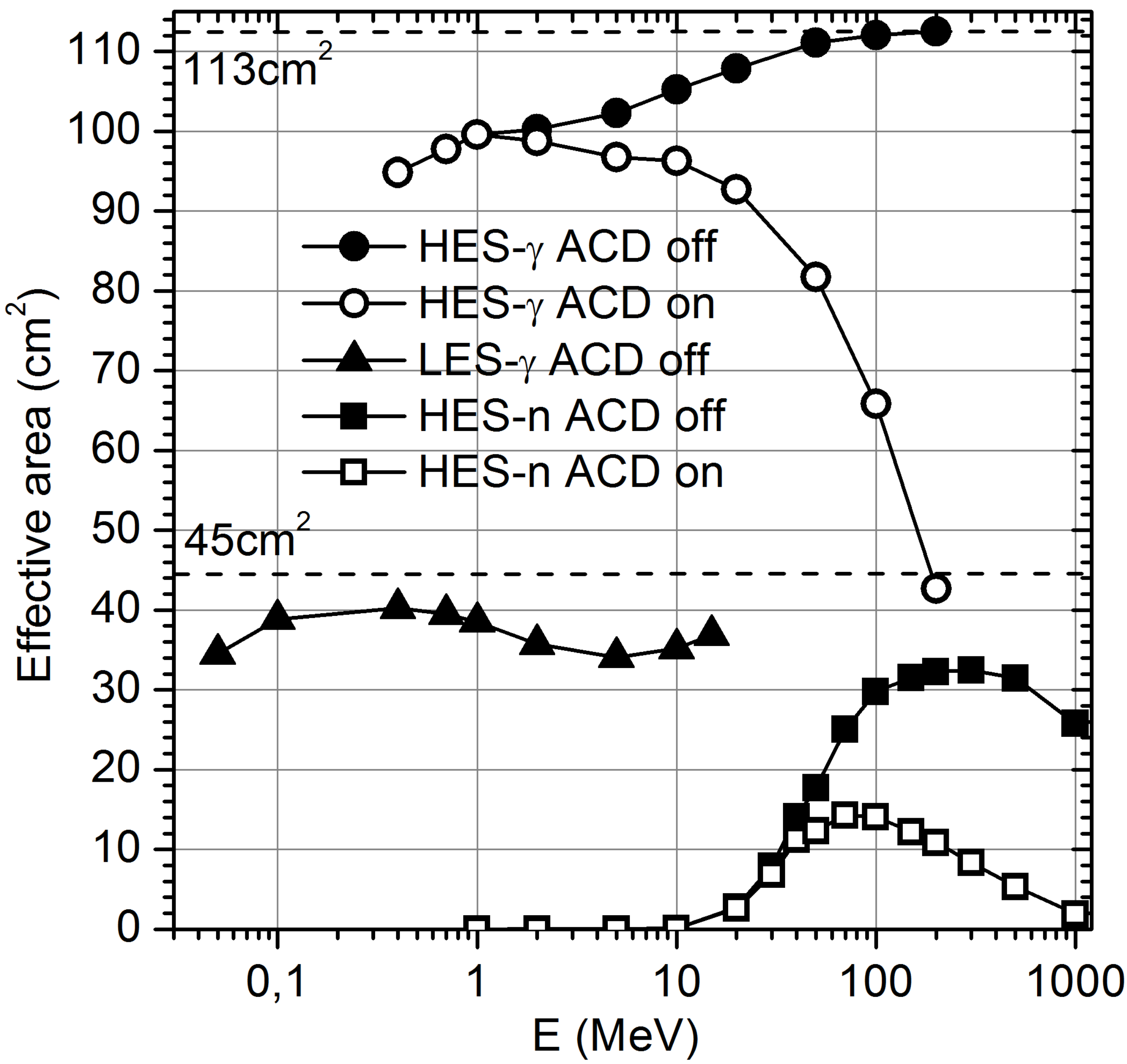


Fig.4 Efficiency areas of LES and HES detectors. Dashed lines correspond to geometry areas of detectors.

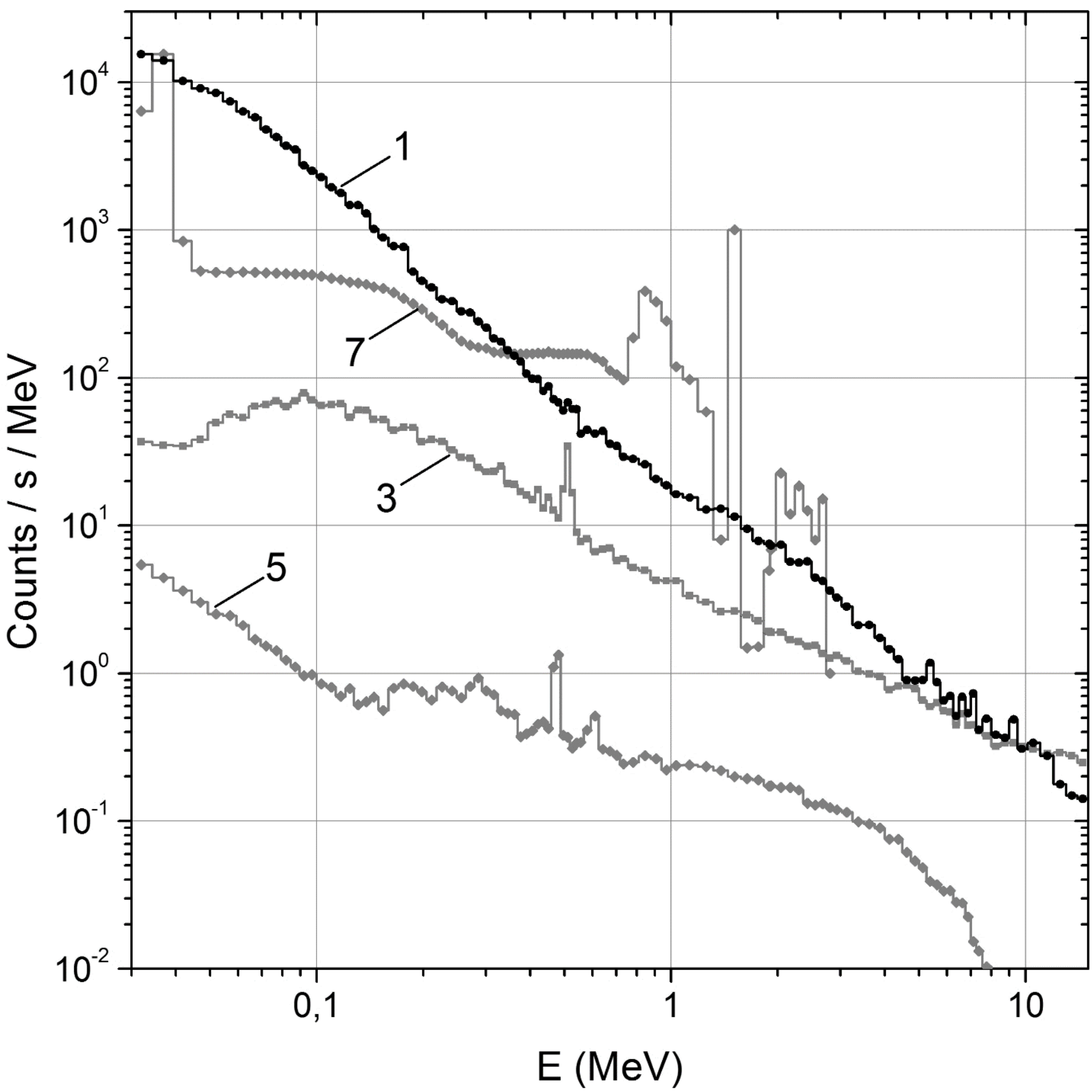


Fig.5 a)

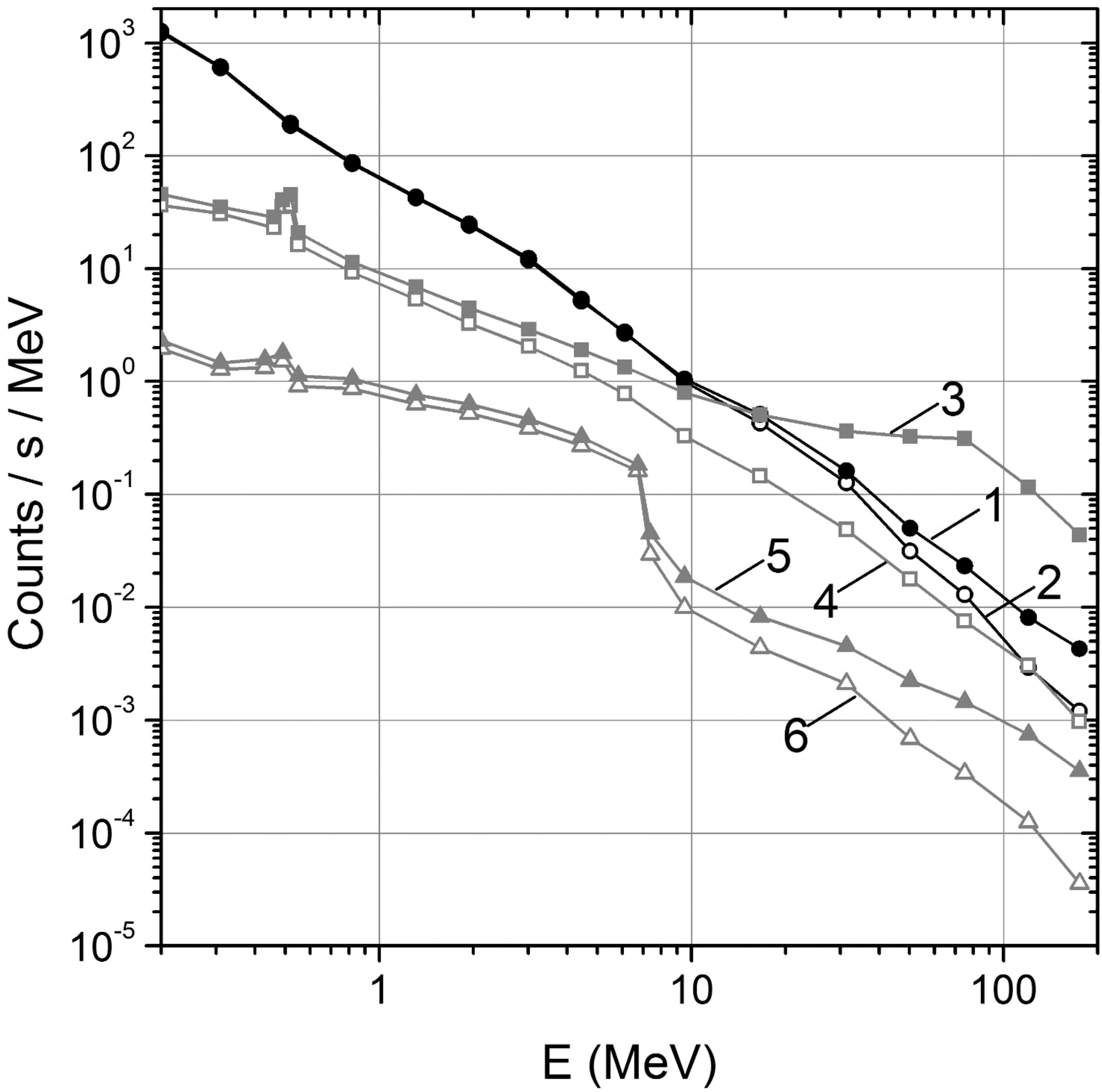
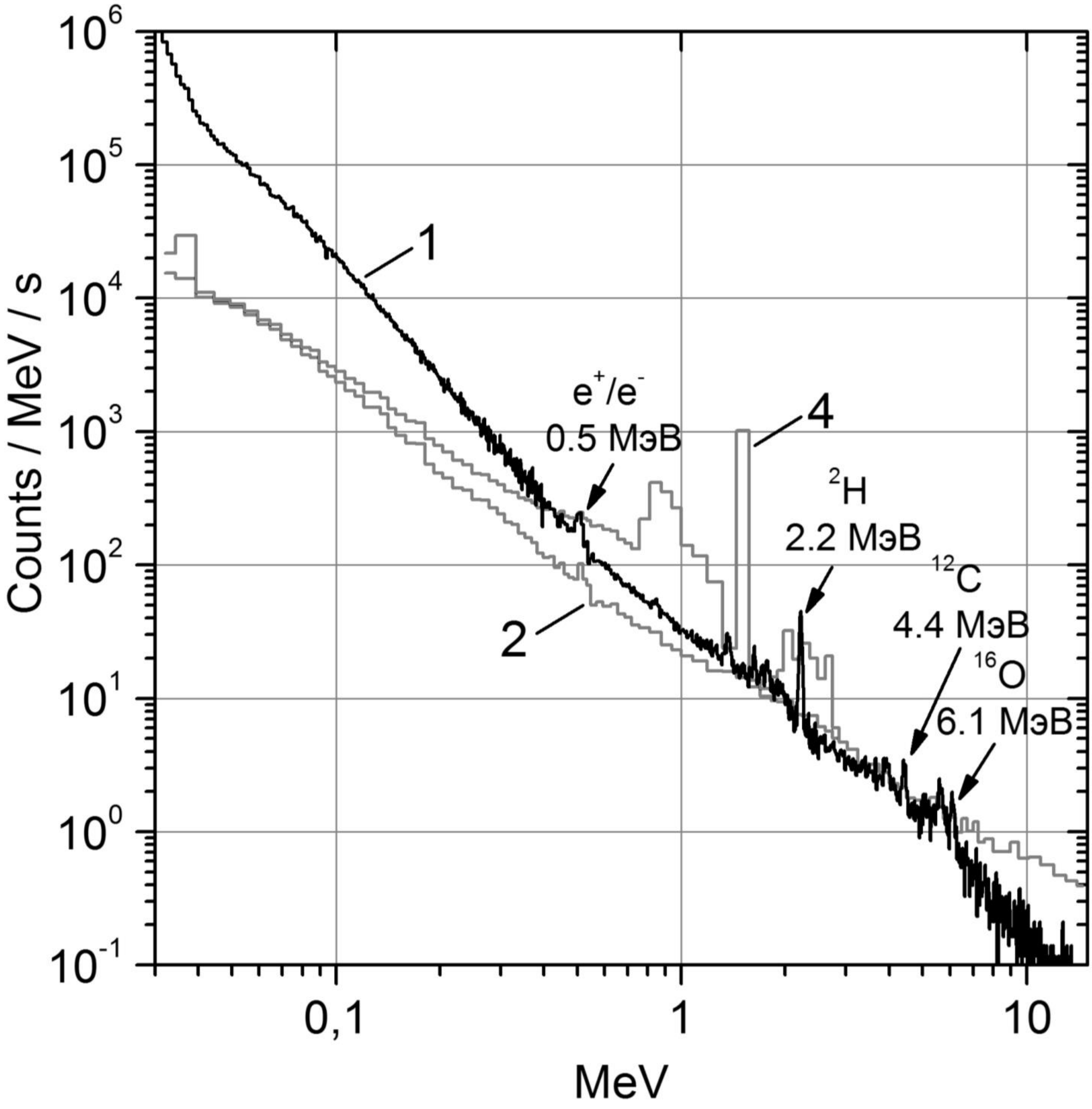


Fig.5 b)

Fig.5 The simulation results of GRIS detectors response to irradiation of the Background model for a) LES and b) HES. 1 –CDGR + the gamma ray albedo deposited spectra with ACD off (or without ACD for LES), 2 – the same as 1, but ACD on, 3 – primary and secondary protons with ACD off, 4 - the same as 3, but ACD on, 5 – the neutron albedo with ACD off, 6 - the same as 3, but ACD on, 7 - $LaBr_3$(Ce) intrinsic activity.



Counts / MeV / s
10^6
10^5
10^4
10^3
10^2
10^1
10^0
10^-1
0,1
1
10
MeV
1
2
4
e+/e-
0.5 MэВ
2H
2.2 MэВ
12C
4.4 MэВ
16O
6.1 MэВ

Fig.6 a)

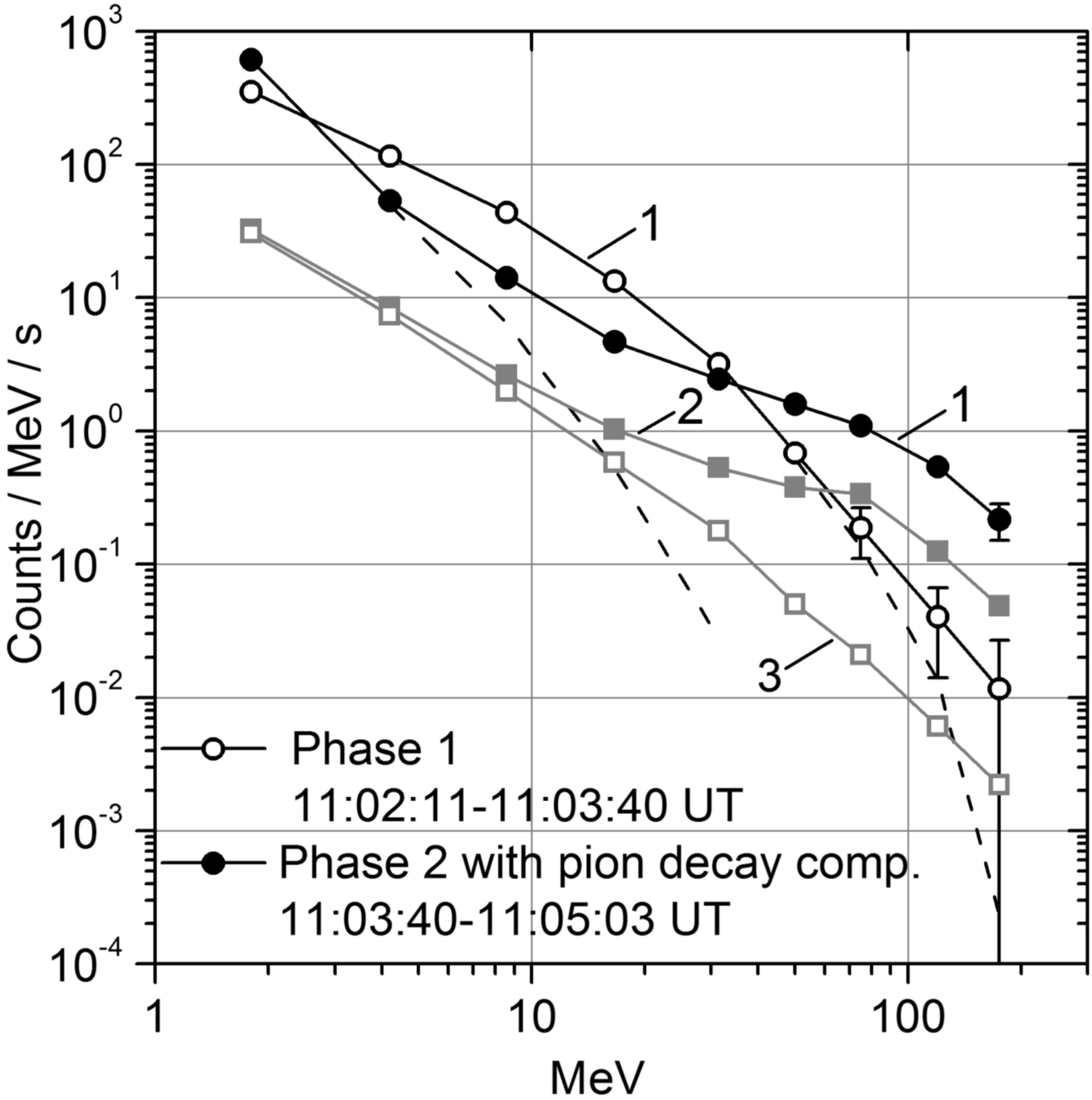


Fig.6 b)

Fig.6 The simulation results of the GRIS detectors response to the solar flares: a) LES to flare X4.8 23.07.2002, b) HES to flare X17 28.10.2003, the dashed line is a continuum (non-pion) component of the flares spectra, 1- deposited spectra of the flares, 2 – deposited spectra of the Background model with ACD off (or without ACD for LES), 3 – the same as 2, but ACD on, 4 - deposited spectrum of the Background model + $LaBr_3(Ce)$ intrinsic activity.

Table 1 GRIS spectrometers characteristics

Detector unit mass	30 kg
Detector unit power	30 W
High Energy Spectrometer (HES)	
Prime detector	CsI(Tl) scintillator ø12×15 cm
Gamma Energy range	0.2 to 200 MeV
Gamma energy resolution	8 % FWHM @662 keV
Neutron energy range	>30 MeV
n/γ discrimination quality	1/1000 (expected)
Low Energy spectrometer (LES)	
Prime detector	$LaBr_3$(Ce) or $CeBr_3$ ø7.62×7.62 cm
Gamma-ray energy range	0.05 to 15 MeV
Gamma-ray energy resolution	3.5-4.5% FWHM @ 662 keV

Table 2 Preliminary parameters of GRIS measurement data

	Data type	Number of channel / channel capacity	Flare mode accumulation time (s)	Monitoring mode accumulation time (s)
LES subrange 1 0.05-2 MeV	Spect.	2048 / 2 byte	1	10
	Intens.	10 / 2 byte	0.01	0.1
LES subrange 2 0.4-15 MeV	Spect.	2048 / 2 byte	10	100
	Intens.	10 / 2 byte	0.1	1
HES subrange 1 0.2-10 MeV	Spect.	1024 / 2 byte	10	100
	Intens.	10 / 2 byte	0.1	1
HES subrange 2 1-200 MeV	Spect.	1024 / 2 byte	10	100
	Intens.	10 / 2 byte	1	10
HES n/γ 1-200 MeV	Matrix	128×128 / 2 byte	100	1000