Signal experiment onboard the Interhelioprobe spacecraft

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Abstract

Experiment SIGNAL is planned to take place on board the spacecraft (SC) INTERHELIOPROBE. A xenon gamma-ray spectrometer is to be used in the experiment. The gamma-ray spectrometer in question has been chosen because of its characteristics permitting detailed probing of solar gamma-radiation under rough experimental conditions. The equipment is able to provide: high energy resolution (5-6 times better than that of scintillation detectors), good performance at high temperatures, steady operation at significant vibroacoustic load, and high radiation resistance of working substance. The aforesaid properties of the xenon gamma-ray spectrometer meet goals and objectives of the experiment SIGNAL.

Keywords: xenon; gamma-ray detector; energy resolution

1. Introduction

Basic physical processes taking place on the Sun were also discovered on other stars: an oscillation, sun-spots, flares, deep and long active minimums, etc. Research of the Sun provides possibilities of testing star evolution models, as well as studying main problems of physics of plasma, nuclear physics, cosmology and elementary particle physics.

A lot of experiments concerning the Sun have been carried out with the use of satellites and balloons. However, some issues such as problems of energy accumulation, acceleration and generation of different particles and some

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other have not been solved yet. Moreover, solar processes affect Earth’s climate and biosphere as well as magnetic field in near-Earth space.

Currently, the SC INTERHELIOPROBE is being developed. Various devices are intended to be installed onboard for measurement of electromagnetic radiation (from ultraviolet to gamma-ray radiation) and fluxes of charged and neutral particles.

The spacecraft will move along the spiral trajectory, approach the Sun at a distance of 40 radiuses of the Sun and then go beyond the plane of the ecliptic at 30°.

The trajectory of the spacecraft will be altered by spacecraft’s own propulsion device and gravitational interaction with Venus.

The paper presents objectives set for the experiment SIGNAL, and gives description of the xenon gamma-ray spectrometer design, as well as its physical and technical characteristics.

2. Objectives of the SIGNAL experiment

1) Linear radiation and continuum study over the energy range 30 keV - 5 MeV occurring during solar flares. Results to be obtained:
   • \(^7\)Be and \(^7\)Li nuclei proportion, \(^4\)He(\(\alpha\),n)\(^7\)Be\(^*\) and \(^4\)He(\(\alpha\),p)\(^7\)Li\(^*\) forming in the nuclear reaction, accelerated \(\alpha\)-particle fluxes in the solar atmosphere, as well as angular anisotropy extent of \(\alpha\)- particle motion;
   • certain \(\gamma\)-lines intensity to determine various nuclei quantitative composition such as, \(^{56}\)Fe (0.84 and 1.24 MeV), \(^{24}\)Mg (1.37 MeV), \(^{26}\)Ne (1.63 MeV), \(^{28}\)Si (1.78 MeV), \(^{12}\)C (1.99 and 4.43 MeV), and \(^{14}\)N (2.31 MeV) in the solar atmosphere;
   • intensity of \(\gamma\)-line 2.22 MeV for study of light elements in solar fusion processes. The \(\gamma\)-line is emanated at thermal neutrons capture by protons or by \(^3\)He generating deuterium or tritium correspondently. The \(\gamma\)-line intensity contains unique information about \(^3\)He concentration, which will help understand subphotosphere of the Sun;
   • solar atmosphere temperature magnitude over the width of \(\gamma\)-line 0.511 keV, as its width is dependent on temperature as \(T_{1/2}\);
   • results of particle acceleration processes study at the time of bursts, by means of measurement of their time profiles and \(\gamma\)-lines intensity ratio over various energy ranges;
   • concentration of \(^3\)He during solar flare according to the \(\gamma\)-line intensity measurement data, occurring in \(^3\)He direct reaction (0.937, 1.04 and 1.08 MeV);
   • B and C class study results of week solar flare generating gamma rays, permitting the study of spectrum continuum shape in detail as well as determination of the range, where nonthermal component starts to prevail;

2) Research into Galactic and Metagalactic gamma-ray bursts. Results to be obtained:
   • fluxes and spectra of \(\gamma\)-radiation in interplanetary space at various distances from the Sun; energy spectra, time profiles, and dynamics of GRB progress for better understanding of particle acceleration and interaction at the time of a burst, which will lead, in turn, to the phenomena model improvement;
   • time fluctuations of \(\gamma\)-radiation background fluxes along the orbit of SC INTERHELIOPROBE, with subsequent evaluation of radiation environment in various parts of interplanetary space;

3) Registration of charged particles fluxes along the trajectory of SC. Data to be obtained:
   • measurement of cosmic rays charged component near the Sun, which is significant for analysis of solarwind motion in circumsolar space as well as for space weather prediction.

3. Description of the SIGNAL device

General view of the SIGNAL device and layout of its main units are shown in Fig.1. It consists of xenon gamma-detectro (XeGD) (1), which is, basically, an impulse cylinder ionization chamber, filled with compressed xenon gas (Vlasik[1],Ulin[2] and Elokhin[3]) and scintillation detectors (ACD) (2), surrounding XeGD to provide anticoincidental shielding against charged cosmic radiation component. ACD is constructed of two endcaps made up of
polyvinyltoluene disk scintillator and a barrel section built with polyvinyltoluene plates. Silicone Photomultipliers will be used for a light registration from scintillators.

At the bottom of the device, there are a power supply stabilization and voltage transformation unit (3) and digital signal processing unit DSPU (4). DSPU based on FPGA implements processing of analog signals from XeGD and SiPM, accumulation of experimental data, control and running of the SIGNAL device as well as communication with airborne telemetry of the SC.

All the units of SIGNAL device are located on the same base (5), and covered with protective case (6). The device is to be secured to one of the lateral faces of the SC by means of six fixture elements.

The entire device is protected by overall shield to avoid its exposure to direct solar radiation. Besides, structural components of the SC and other pieces of scientific equipment are practically out of XeGD’s field of vision. Main physicotechnical characteristics of the SIGNAL equipment are given in Table 1.

### Table 1. Main physicotechnical characteristics of the SIGNAL device.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range of registered $\gamma$-quanta (MeV)</td>
<td>0.03-5</td>
</tr>
<tr>
<td>Energy resolution over the gamma-ray line 662 keV (%)</td>
<td>$1.7 \pm 0.3$</td>
</tr>
<tr>
<td>Gamma-quanta detection efficiency 662 keV (%)</td>
<td>$2.0 \pm 0.5$</td>
</tr>
<tr>
<td>Mass of the equipment (kg)</td>
<td>6.0±0.5</td>
</tr>
<tr>
<td>Outer dimensions (mm)</td>
<td>420x280x265</td>
</tr>
<tr>
<td>Voltage of power supply (V)</td>
<td>$(+24–27)$</td>
</tr>
<tr>
<td>Power consumption (W)</td>
<td>15±5</td>
</tr>
<tr>
<td>Operating temperature range (°C)</td>
<td>0 -100</td>
</tr>
</tbody>
</table>

Typical energy spectra of gamma-ray sources $^{137}$Cs and $^{133}$Ba measured by means of a XeGD prototype are shown in Fig. 2 and Fig. 3.
The SIGNAL device is intended to operate continuously in two modes. Idle and gamma-ray burst registration ones. Idle regime provides for gamma-ray spectra measurement and analyzing for the purpose of GRB detection. If a gamma-ray burst has not been detected, the system goes to GRB registration mode to provide gamma-ray spectrum with auxiliary information. Data are stored in intermediate memory to be further prepared for telemetry transmission to the Earth. Operation modes have different spectrum acquiring time that depends on an intensity of detecting events and a duration of a GRB time profile. Transition from idle mode to registration mode will be implemented automatically on the basis of detector’s load analysis.

The SIGNAL device is planned to be turned on upon the Earth orbital injection of the SC and upon completion of all checking systems functioning operations. Scientific equipment SIGNAL should then operate continuously all the way during the flight of the spacecraft.
4. Conclusion

Currently, development of the scientific equipment SIGNAL is at the stage of preparation of design documentation and SIGNAL device model manufacturing. The equipment in question is being developed at NRNU MEPhI. Launch date is established for October 2015.

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References