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Magnetometer application for GAMMA-400 telescope switching into the mode with increased low energy charged particles intensity registration

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Abstract

GAMMA-400 is an international project of a high apogee orbital astrophysical observatory for studying the characteristics of high-energy gamma-emission, electrons/positrons and light nuclei fluxes. The energy range for γ-rays and electrons/positrons registration in the main aperture is from ~0.1 GeV to ~3.0 TeV. Also, this aperture allows high energy light nuclei fluxes characteristics investigation. Moreover, special aperture configuration allows registering of gamma-quanta, electrons (positrons) and light nuclei from the lateral directions too.

The spacecraft GAMMA-400 orbit will be located in the Earth's magnetosphere and will pass front shock wave from magnetosphere interaction with the solar wind, turbulent-transition region, magnetopause and so on. During the satellite's movement through various Earth's magnetosphere regions its anticoincidence detectors will register high intensity fluxes of low energy charged particles captured by the magnetic field. The working area sections of GAMMA-400 detector systems used as anticoincidence shield are about 1 m^2 each. The high intensity low energy charged particles flux influence on anticoincidence detectors should be taken into account during particle identification.

This article presents a comparison between Earth's magnetosphere theoretical model according to SPENVIIS package and real data measured by detectors onboard THEMIS series satellites. The differences between these two datasets indicate that the calculated data are not sufficient to make short time predictions of variations of magnetic induction in the outer magnetosphere. A special trigger marker flag will be produced by GAMMA-400 counting and triggers signals formation system accordingly to the data of two onboard magnetometers. This flag's presence leads to special algorithms execution start, putting the plastic detectors into a dedicated working mode taking into account possible high count rates of external detector layers.

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Keywords: GAMMA-400, THEMIS, SPENVIS, magnetosphere protons and electrons fluxes, anticoindence detectors

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1. Introduction

GAMMA-400 (Gamma Astronomical Multifunctional Modular Apparatus) is an international high orbital astrophysical observatory now being designed to search for dark matter signatures, study Galactic and extragalactic gamma-ray sources, diffuse emission, gamma-ray bursts and high-precision measurements of cosmic-ray electrons, positrons, and nuclei spectra [1, 2].

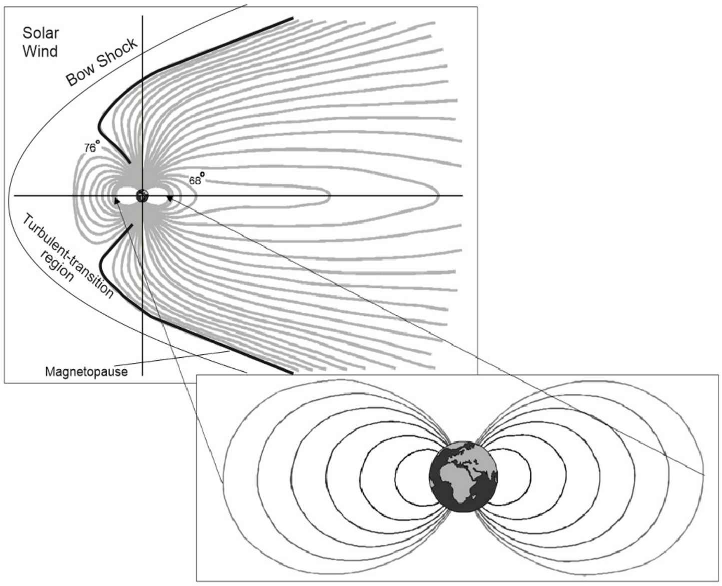

Fig.1 The scheme of the Earth, a magnetic field model [5].

The Earth's magnetosphere is formed by the Earth's magnetic field interactions with the solar wind plasma flow. This process deforms the Earth's basically dipolar magnetic field, compressing the field lines on the day side and stretching them out to form a long magnetotail on the night side – see Fig. 1. On the day side, the magnetosphere extends out to a distance of approximately 10 Earth radii (under quiet conditions), while the magnetotail extends several hundred Earth radii in the anti sunward direction. The magnetosphere contains several large-scale regions with different plasma energy and density: front shock wave from magnetosphere interaction with the solar wind, turbulent-transition region, magnetopause and so on. The Earth's magnetosphere is highly responsive to changes in solar wind dynamic pressure and interplanetary magnetic field orientation. The energy from its interaction with the solar wind influences various magnetospheric processes. For example, it can be released later in magnetotail substorms. Such events are often followed by charged particle precipitations caused by magnetic field reconnection, both registered in several high apogee satellite experiments. The particle flux during precipitations can reach 10^3-10^5 particles/(cm^2·s) or more [3] – for example, see Fig. 8, panels (a) and (b). The spacecraft GAMMA-400 orbit will be located in the Earth's magnetosphere [1] and influence of such intensive events on the anticoincidence detectors should be taken into account during particles identification.

2. GAMMA-400 and its orbit in the Earth magnetosphere

GAMMA-400 scientific apparatus consists of KONUS-FG gamma-ray burst monitor and GAMMA-400 gamma-telescope, which includes anticoincidence system AC, converter-tracker, time-of-flight system, position-sensitive calorimeter, neutron detector, scintillation detectors of the calorimeter (SDC), lateral detectors (LD), magnetometer and star sensor [1, 2] – see Fig. 2a.

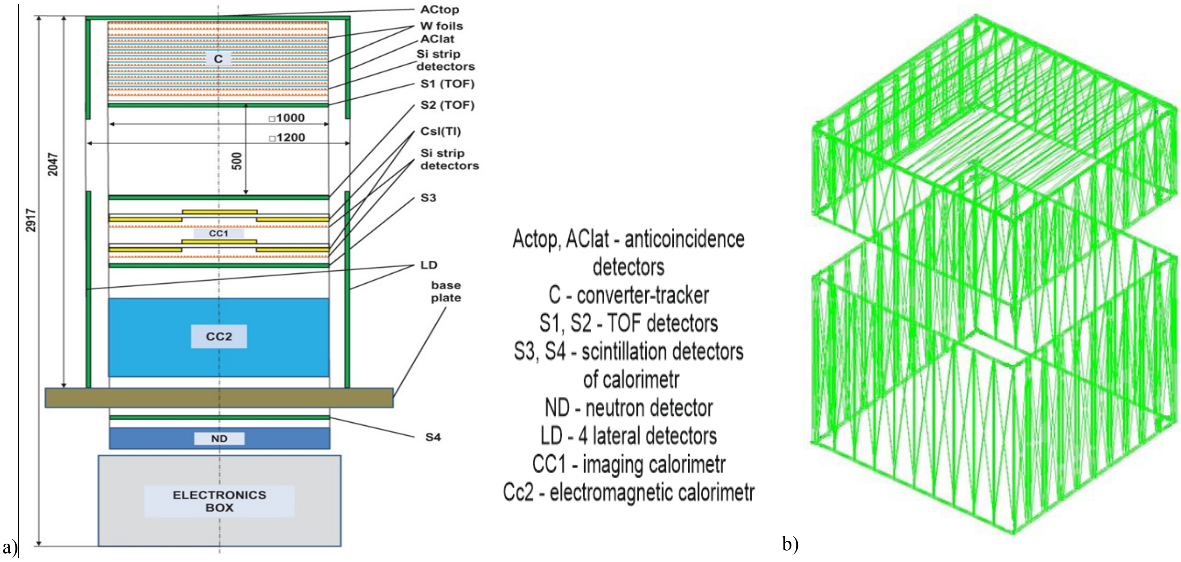

Fig.2. GAMMA-400 principal scheme (a), and configuration of AC and LD (b).

Particles of various natures are identified by the counting and triggers signals formation system using fast signals ($t \leq 10$ ns) from plastic scintillation detectors of the calorimeter, time-of-flight system, calorimeter lateral detectors, ACtop and AClat [1]. Fast pulses ($t \sim 100$ ns) from amplitude discriminators of CsI(Tl)-based individual detectors of calorimeters CC1 and CC2 are also included in analysis. Electrons (positrons) and nuclei are identified by signals in the ACs, while gamma-quanta are recognized by lack of signal in the ACs taking in the account methods of backsplash rejection specially designed for GAMMA-400 [4].

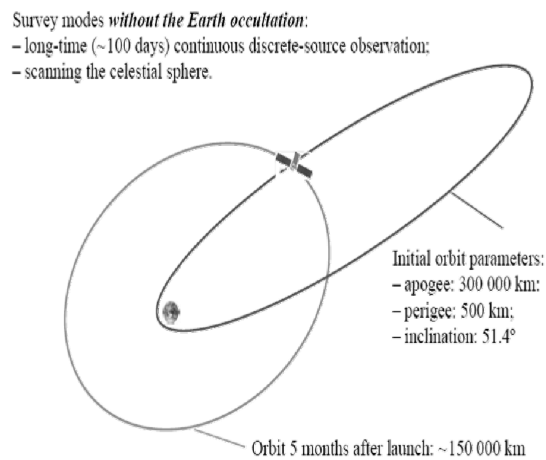

Fig.3 Initial orbit parameters and orbit five months after launch.

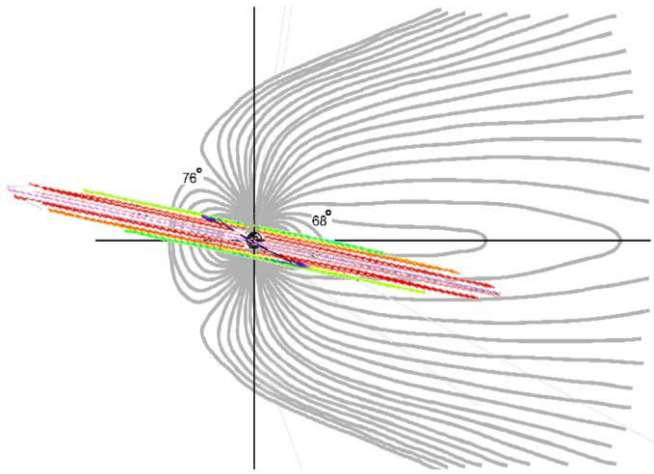

Fig.4. Modeling of the altitude dependence on the satellite coordinates during spacecraft GAMMA-400 moving in the Earth magnetosphere (initial stage: perigee ~500 km, apogee ~300000 km, inclination ~51.8°, orbit period is ~7 days).

Three apertures provide events registration from both upper and lateral directions. The working areas of GAMMA-400 anticoincidence systems detector's layers are about 1 m^2 each. High intensity background low energy charged particles flux influence on anticoincidence detectors should be taken into account during particles identification [4]. Detectors ACtop, AClat and LD are used as anticoincidence shield in the main aperture. The configuration of AC and LD is shown at the Fig. 2b. In the additional aperture anticoincidence provides by LD, S4 and S2 section of TOF, in the lateral one it supplied by LD, S3 and S4. Each system S2, S3, S4, AC and LD consists of two detector layers based on polyvinylyltoluene BC-408 with thickness of 1 cm and density of 1.032 g/cm^3. GAMMA-400 is surrounded by electro-vacuum thermal insulation (EVTI) based on layers consisting of polyamide-6 [-NH-$(CH_2)_5$-CO-] with 1.1 g/cm^3 density and 0.7 mm thickness, covered by 10 μm thick aluminum sputtering on both sides.

The orbit of GAMMA-400 spacecraft will be almost entirely in the Earth's magnetosphere. The initial orbit parameters for GAMMA-400 orbit are [1, 2]: apogee 300000 km, perigee 500 km, and inclination 51.8°. The orbit period is ~7 days. After approximately 230 days the GAMMA- 400 orbit will leave the Earth's radiation belts and then will change from elliptical to approximately circular with radius 150000 km. Evaluations of GAMMA-400 spacecraft orbit are shown in Fig. 3. The result of altitude dependence on satellite coordinates modeled during spacecraft GAMMA-400 moving in the Earth`s magnetosphere during the initial stage is presented in Fig. 4.

Low energy charged particles will be mostly absorbed in the EVTI and external layers of plastic detectors used as anticoincidence shield in corresponding aperture. But the working areas of the GAMMA-400 detector systems used as anticoincidence shield are about 1 m^2 each section. During intensive precipitations caused by magnetic field reconnection possible particle flux was more intensive than 10^3-10^5 particles/(cm^2·s) and its influence on anticoincidence detectors should be taken into account during particles identification.

3. THEMIS satellite series and the Earth's magnetosphere short time variations.

THEMIS satellite data were used to estimate low-energy background particle flux short time variations dependence on the magnetic induction B module deviations in the Earth`s magnetosphere. THEMIS (Time History of Events and Macroscale Interactions during Substorms) is a series of five satellites designed in order to further understanding of substorm instabilities nature. The main mission objectives [6, 7] are to study the interaction mechanisms of substorms and their individual components, as well as determine the cause of substorm aurora.

The array of spacecraft and ground observatories allows researchers to determine when and where substorms begin, thereby distinguishing between models that begin with current disruption in near-Earth magnetotail and those that begin with magnetic reconnection in distant magnetotail. The same array of spacecraft and ground observatories allows conclude the links between the observed in the magnetotail phenomena and ones in the ionosphere.

Table 1.The characteristics of THEMIS satellites.

Name of the satellite	NORAD number	Apogee for the first stage	Apogee for the second stage
THEMIS A	30580	15.4 Re	10 Re
THEMIS B	30581	15.4 Re	30 Re
THEMIS C	30582	15.4 Re	20 Re
THEMIS D	30797	15.4 Re	12 Re
THEMIS E	30798	15.4 Re	12 Re

THEMIS was launched on February 17, 2007. During the first summer season (May-September 2007), a series of THEMIS spacecraft were on the same orbit with an apogee in dayside magnetosheath. During the second summer season (May-September 2008) the THEMIS spacecrafts orbits allowed them to simultaneously observe pristine solar wind, foreshock, magnetosheath, and outer magnetosphere.

TLE format was used for THEMIS satellite coordinates representation. TLE format was defined by NORAD group (North American Aerospace Defense Command) [9]. TLE data represents a set of orbit elements for a satellite in Earth orbit, from the start beginning till present time [10]. The NORAD numbers for THEMIS satellites series are listed in the Table 1.

The data obtained during the first two stages of THEMIS satellites operation (see Table 2) are used for magnetosphere variations estimation. GAMMA-400 orbit will be crossing the all magnetosphere regions THEMIS satellites passed – see Fig. 5 and Fig. 6: shock wave front from interaction with solar wind, turbulent-transition region, magnetopause, magnetotail and magnetospheric neutral surface. The comparison of THEMIS satellites and GAMMA-400 orbits are presented at Figs. 5-6 and 8.

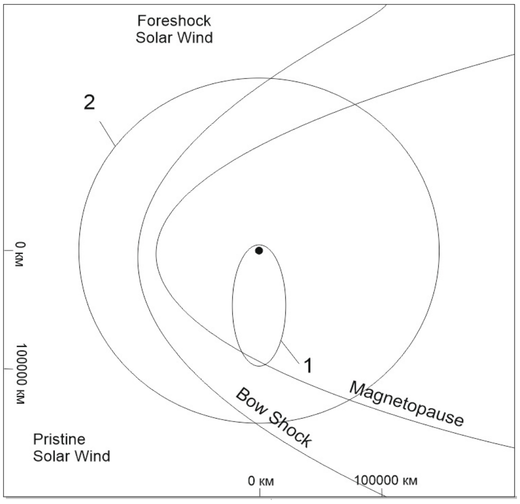

Fig. 5. Type 1 stage: Injection or "Coast" Phase 02/15/07 - 09/15/07: 1 - orbit of THEMIS satellites [8]; 2 - static GAMMA-400 orbit.

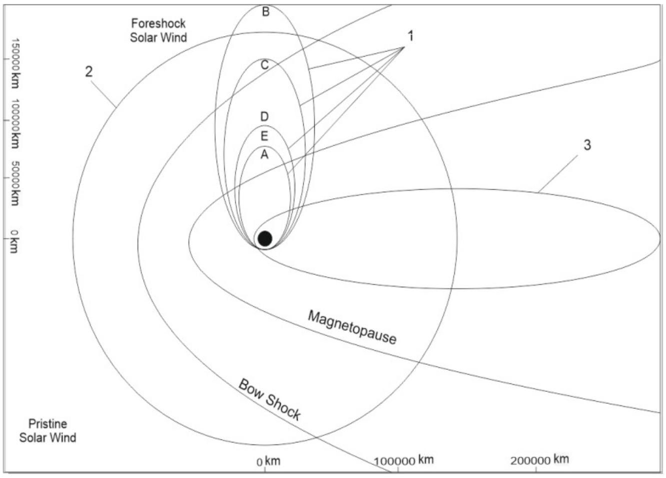

Fig. 6. Type 2 stage: Orbit Placement Phase 09/15/07 - 12/15/07: 1 - orbit of THEMIS satellites [8]; 2 - static GAMMA-400 orbit; 3 - initial orbit of GAMMA-400.

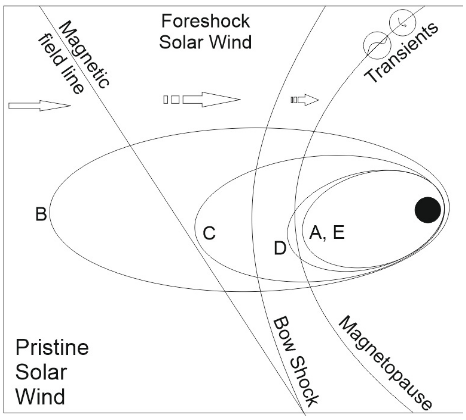

Fig. 7. Modeling of the five THEMIS satellites moving in Earth magnetosphere [6].

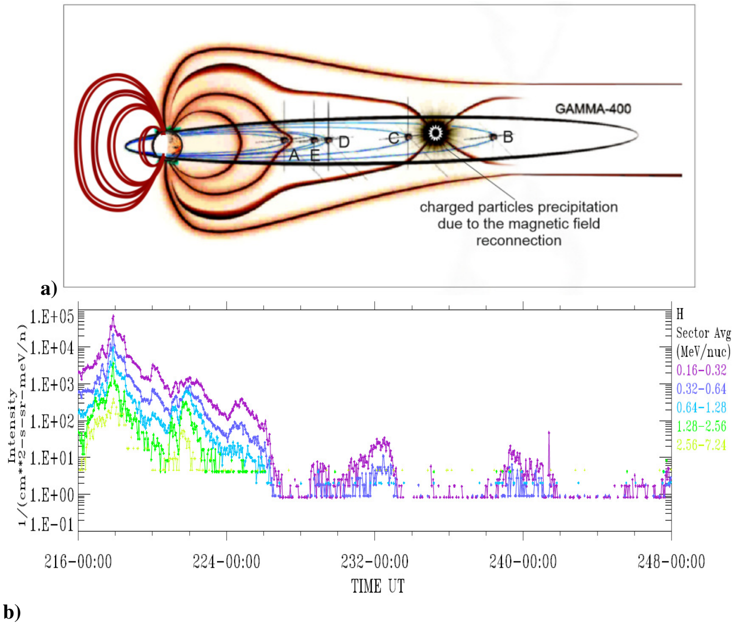

Fig. 8. The orbits of the satellites THEMIS [8] and GAMMA-400 in Earth's magnetosphere (a) and the variation of charged particles flux according to the THEMIS data [3] (b).

This article presents the results of analysis of two datasets containing information about magnetic induction module. First dataset was simulated by the software package SPENVIS (Space Environment Information System) [15-18] and the other one measured by the magnetometer and the electrostatic analyzer installed onboard THEMIS B satellite. Satellite data from 17.02.2007 to 15.12.2007 corresponding to the most remarkable moments of time when the satellite THEMIS B pass through such areas of magnetosphere: magnetopause, transitional area and shock wave were selected and processed. Real THEMIS data and SPENVIS calculated data often don't coincide as the predicted situation sometimes strongly differs from the observable. Fig. 9a shows the difference between the standard magnetosphere model [5, 11] and the real magnetic lines configuration accordingly to THEMIS data [3].

Table 2. Different stages of the THEMIS satellite mission.

Stage	Distance 1	Distance 2	Characteristic	Number of period for type 1 stage (time interval)	Number of period for type 2 stage (time interval)
Injection or "Coast" Phase	15.4 Re apogee		Right after launch, all spacecraft are lined up in the same orbit	1 (02/15/07 - 09/15/07)	
Orbit Placement Phase			The orbit placement phase is also called "Dawn phase" because the orbits apogees are on the dawn side of the magnetosphere.	2 (09/15/07 - 12/15/07)	
Tail Science Phase	Probe 1 apogee is at 30 Re, Probe 2 at 20 Re, Probes 3 and 4 at 12 Re, and Probe 5 at 10 Re.	Orbits are approximately 12 Re. The probes are separated by approximately 500 km to 3000	In the tail science phase the orbit apogees are in the magnetotail.	3 (12/15/07 – 04/15/08), 7 (12/15/08 – 04/15/09)	11 (03/02/10 - 05/31/10), 15 (03/16/11 - 06/22/11), 19 (04/13/12 - 10/14/12), 23 (06/11/13 - 09/17/13), 27 (06/29/14 - 10/16/14)
Radiation Belt Science Phase			The radiation belt science phase is also called the "Dusk phase" because the orbits apogees are on the dusk side of the magnetosphere.	4 (04/15/08 - 06/15/08), 8 (04/15/09 - 06/15/09)	12 (06/01/10 - 09/01/10), 16 (06/23/11 - 09/29/11), 20 (10/15/12 - 11/26/12), 24 (09/18/13 - 12/24/13), 28 (10/17/14 - 01/21/15)
Dayside Science Phase			In the dayside science phase the orbits apogees are on the dayside of the magnetosphere.	5 (06/15/08 - 10/15/08), 9 (06/15/09 - 09/30/09)	13 (09/02/10 - 11/30/10), 17 (09/30/11 - 01/05/12), 21 (11/27/12 - 03/03/13), 25 (12/25/13 - 03/10/14), 29 (01/22/15 - 05/12/15)
Dawn Science Phase	Probes 3 and 4 have apogees at 12 Re, and Probe 5 has an apogee at 13 Re.		The orbits apogee is on the dawn side of the magnetosphere.	6 (10/15/08 - 12/15/08)	
			In the dawn science phase the apogee of the P3, P4, and P5 orbits are on the dawnside of the magnetosphere.	10 (12/29/09 - 03/01/10), 14 (12/09/10 - 03/15/11), 18 (1/06/12 - 04/12/12), 22 (3/04/13 - 06/10/13), 26 (03/11/14 - 06/28/14), 30 (05/13/15 - 08/30/15)	
Tail Science Phase	In the tail science phase the apogee of P3, P4, and P5 are approximately 12 Re. The probes are separated by 1000 km to a few Earth radii at apogee.		MMS (Magnetospheric Multiscale) is at opposition to the dayside, and VAP (Van Allen Probes) are in the dusk sector.	31 (08/31/15 - 12/19/15)	
Dusk Science Phase	In the dusk science phase the apogees of P3, P4, and P5 are approximately 12 Re. The probes are separated by distance from 1000 km to a few Earth radii at apogee.		MMS is at opposition in the dawn sector, and VAP is in the dayside sector.	32 (12/20/15 - 04/08/16)	
Dayside Science Phase,	In the dayside science phase the apogees of P3, P4, and P5 are approximately 12 Re. The probes are separated by distance from 1000 km to a few Earth radii at apogee.		MMS is at opposition in the tail sector, and VAP is in the dawn sector.	33 (04/09/16 - 07/27/16)	

Fig. 10 and Fig. 11 show the difference between magnetic induction B modules calculated using SGP4 model and the real data of THEMIS B sensors. It is possible to show that the short time variations of magnetic field and particles fluxes occur earlier according to SPENVIS modeled data than is obtained by THEMIS B sensors.

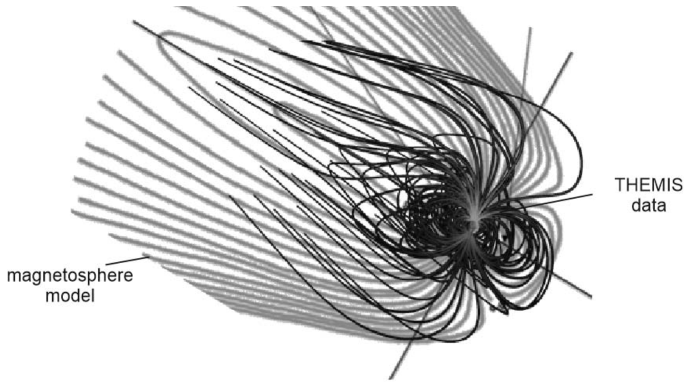

Fig. 9 The difference between the standard magnetosphere model (grey) [5, 11] and real magnetic lines configuration accordingly to THEMIS data (black) [3].

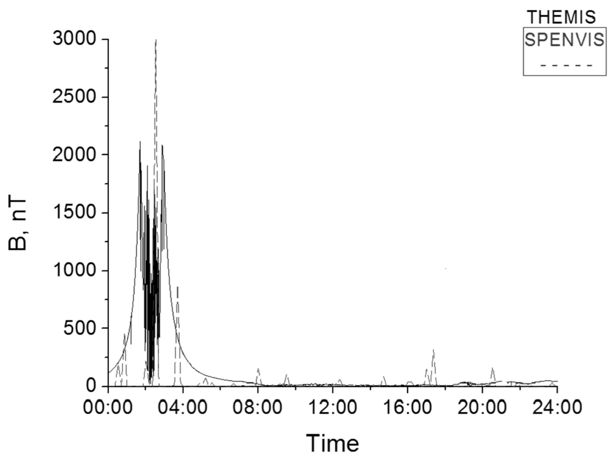

Fig. 10. The magnetic induction B modules value dependence on time. Plasmosphere. 27.02.2007.

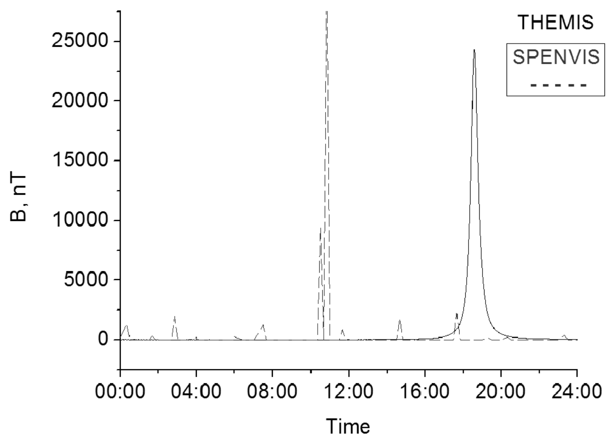

Fig.11 The magnetic induction B modules value dependence on time. Plasmosphere. 18.04.2007.

Therefore, the calculated data are not sufficient for short time magnetic induction variation predictions in the outer magnetosphere. Magnetometer could be used for estimations of charged particles count rate rise beginning due to analysis of magnetic induction variations.

Together with the γ-telescope GAMMA-400, the space observatory will include two magnetometers. If the magnetometer registers sharp increase in magnetic induction B modules value, it is necessary to expect a fast rise of low energy particles fluxes. A special trigger marker flag will be produced by the counting and triggers signals formation system of GAMMA-400 accordingly to the magnetometer data. This flag’s presence leads to special algorithms execution start, putting the plastic detectors into a dedicated working mode taking into account possible high count rates of external detector layers.

4. Conclusion

The results of analysis of two datasets containing magnetic induction module are presented. First dataset was simulated by SPENVIS (Space Environment Information System) software package and the other one obtained by the magnetometer and the electrostatic analyzer installed on THEMIS B satellite.

The comparison between the Earth`s magnetosphere theoretical model according to SPENVIS package and the real data measured by detectors onboard THEMIS series satellites allows to conclude that the calculated data are not sufficient for short time magnetic induction variations predictions in the outer magnetosphere. A magnetometer could be used for estimations of charged particles count rate rise beginning due to analysis of magnetic induction variations. If the magnetometer registers sharp increase in magnetic induction B modules value, it is necessary to expect a fast rise of low energy particles fluxes.

During high apogee satellite experiment GAMMA-400 operation the most part of the low energy charged particles will be absorbed in the electro-vacuum thermal insulation and external layers of plastic detectors used as anticoincidence shield in corresponding apertures. But the working areas sections of GAMMA-400 detector systems used as anticoincidence shield are about 1 m^2 each. During intensive precipitations caused by magnetic field reconnection particle fluxes more intensive than 10^3-10^5 particles/(cm^2·s) are possible and their influence on anticoincidence detectors should be taken into account during particles identification. A special trigger marker flag will be produced by the counting and triggers signals formation system of GAMMA-400 accordingly to the data of two onboard magnetometers. This flag's presence leads to special algorithms execution start, putting the plastic detectors into a dedicated working mode taking into account possible high count rates of external detector layers.

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