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ON THE PITCH-ANGULAR DISTRIBUTION OF THE ENERGETIC PARTICLES ACCELERATED DURING A STRONG MAGNETIC STORM IN THE EARTH'S RADIATION BELTS

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Abstract. Long-term measurements of energetic particles onboard the CORONAS-F satellite are used to found pitch-angular distribution (PAD) of electrons and protons freshly trapped in Earth's radiation belts (ERB) during magnetic storms. Dependence of the counting rate on the relative orientation of particle detector for different configurations of particle pitch-angular distribution is calculated. Comparison of calculations with results of experiment has shown that the pitch-angular distribution of trapped energetic protons and electrons becomes anisotropic with a maximum near to 90°. We observe long maintenance of enhanced radiation in the magnetosphere after strong magnetic storms.

1. Introduction

ERB undergo significant changes during strong magnetic storms: there appear fluxes of freshly accelerated subrelativistic and relativistic energetic electrons in the outer electronic belt; solar protons with energy 1-20 MeV are captured in a proton belt [Lazutin et al., 2007]. As a measurements of these excessive fluxes at L<6 have been made, with rare exception, by low-altitude satellites, their pitch-angular distribution is not known. At the same time, this characteristic is important both for understanding of physics of the processes in radiation belts after magnetic storms, and for an estimation of applied consequences for space weather.

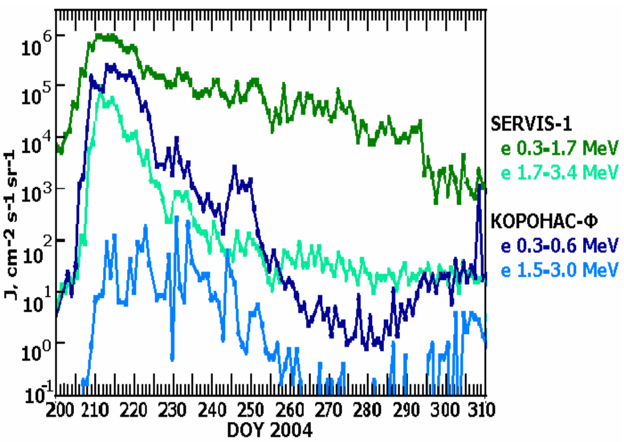

Fig. 1. Electrons fluxes at L=3, measured by detectors onboard CORONAS-F and SERVIS-1 in July - October, 2004.

The magnetic storm of July, 22-30, 2004 has led to significant growth (more than by two orders) fluxes of protons with energy 1-15 MeV and electrons 0.3-3.0 MeV in radiation belts at L>2.5. The first results of the analysis of particles fluxes dynamics during a storm and the subsequent temporal changes have been published in [Lazutin et al., 2008, Hasebe et al., 2008]. Measurements were carried out by charged particles spectrometers onboard two low-altitude satellites CORONAS-F and SERVIS-1, which had similar polar orbits with different altitudes. We have registered intensity decrease of energetic particles in all channels of telescope onboard CORONAS-F in September, 2004 which could not be explained by natural variations in the belt because of the detector onboard SERVIS-1 has not shown similar variations (fig. 1). We have assumed that the detector orientation (angle between the axis of the detector and Earth's magnetic field line) influence on its count rate, that is possible if the pitch-angular distribution of particles is anisotropic. Our calculations not only have proved this assumption, but also have allowed us to determine character of pitch-angular distribution of freshly trapped particles.

2. Description of the experiment

CORONAS-F satellite operates from July, 30, 2001 till December, 2005. Its orbit was polar, practically circular and had an inclination of ~82.5°. The altitude of an orbit - 500 km in an initial stage of work, and it gradually decreased to ~350 km at 2005. The MKL spectrometer onboard CORONAS-F satellite has consisted of two semiconductor detectors with thicknesses of 0.05 mm and 2.0 mm and a CsI crystal with the thickness of 1.0 cm that was surrounded by an anti-coincidence plastic scintillator with thickness equal to 0.5 cm. The geometry factor was ~0.4 $cm^2 sr$. Electrons from 0.3 up to 12 MeV and protons from 1 up to 90 MeV in different energy ranges were registered [Kuznetsov et al., 2002]. Data on fluxes of electrons with energy 0.3-0.6, 1.5-3 and 3-6 MeV and protons in the channel 1-5 MeV were used in this work.

The aperture of a telescope was ~23°. Owing to the satellite orbit precession, the inclination of the charged particles detector versus the Earth's magnetic field line changed, that has allowed us to determine the kind of particles pitch-angular distribution. The angle of the detector inclination (ψ) changed from 0 up to 180° with quasi-period of about 6 months.

The decrease of the count rate of electron and proton channels in September 2004 was observed when the detector has been directed along the magnetic field line. Fig. 2a and 2b illustrate this statement. The histogram of electrons count rate in the channel 1.5-3 MeV and results of calculation of the telescope inclination angle from the telemetry data base are shown. One can see that the amplitude of the intensity decrease is more pronounced at small distances from the Earth according to character of change the detector inclination angle. Such decrease indicates the trapped character of pitch-angular distribution of particles. It's interesting to determine the function of particles pitch-angular distribution more precisely.

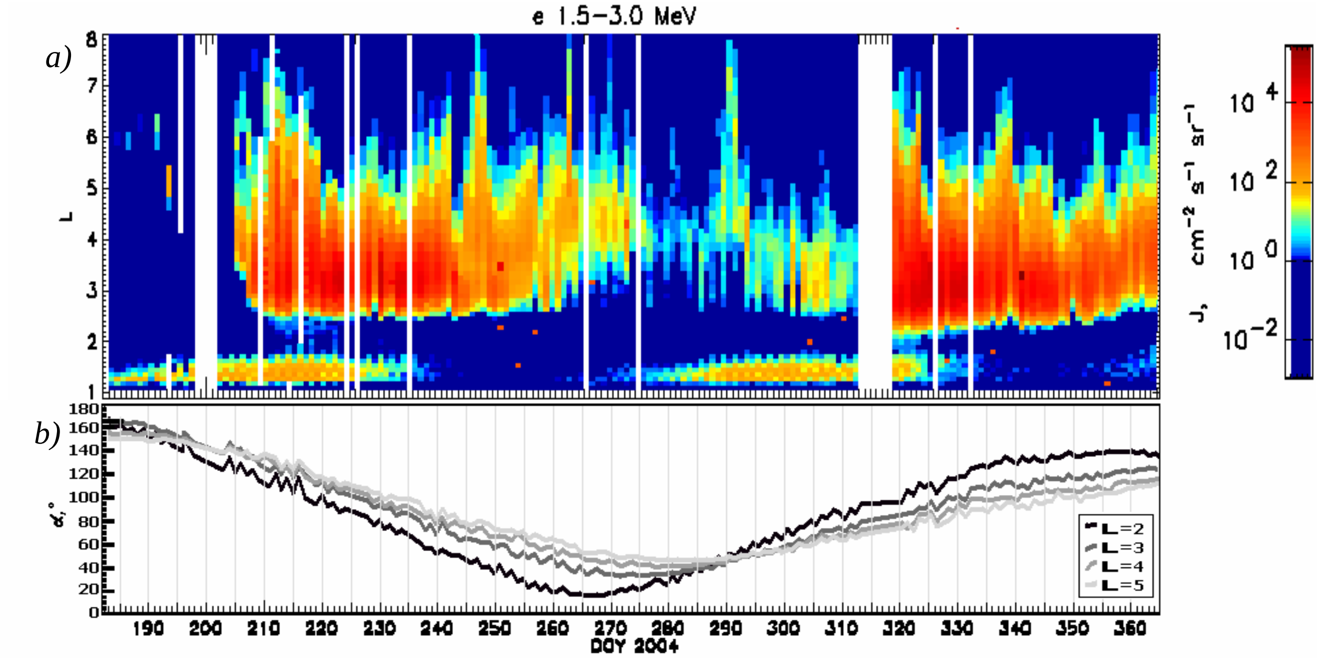

Fig. 2. **a)** Dynamics of electrons fluxes latitude distributions during the period July-December, 2004, measured by the detector onboard the CORONAS-F satellite (at orbits of the satellite passing through the area of the Southern - Atlantic anomaly.)
b) Orientation of the detector (angle between the axis of the detector and the magnetic field line) at L = 2, 3, 4, 5 along the satellite trajectory.

3. Calculation of pitch-angular distribution of particles

Pitch-angular distribution (PAD) of particles was set as

$$p_{pitch}(\alpha) = \frac{dJ}{d\alpha}(\alpha) = \sin^{n}(\alpha),$$

where α - pitch-angle, and *n* - the anisotropy factor dependent on type and energy of particles and distance of a drift orbit from the center of the Earth. The isotropic distribution corresponds to a factor *n*=1. The flux of particles registered by the detector at the given orientation, P(ψ), is determined by the formula

$$P(\psi) = \int_0^{90^\circ} d\beta \sin\beta \, p_{det}(\beta) \int_0^{360^\circ} d\varphi \frac{p_{pitch}(\alpha(\psi,\beta,\varphi))}{\sin\alpha(\psi,\beta,\varphi)}$$

where ψ - angle between the axis of the detector and the magnetic field

β - angle between a direction of movement of the particle and an axis of the detector

φ - angle between planes {direction of the particle movement; axis of the detector} and {magnetic field; axis of the detector},

$$\alpha(\psi,\beta,\varphi) = \arccos(\cos\psi\cos\beta + \sin\psi\sin\beta\cos\varphi)$$

(see fig. 3)

Setting values ψ *(L, t)*, calculated by the data on trajectory and orientation of the satellite during the period from July till October, 2004, we changed values of the parameter n, achieving the correspondence of a calculated variation of the detector count rate with the measured one. Results of comparison for the channel measured electrons with energy 0.3-0.6 MeV at *L*=3 are shown on fig. 4. Electrons pitch-angular distribution in this case is described by expression (1) with *n*=15-20.
Values of *n* for the electrons with smaller energy at *L* from 1.2 up to 3 and the protons 1-5 MeV channel have been found as well. Fluxes of protons with energy more than 12 MeV by this time decreased to the background level.

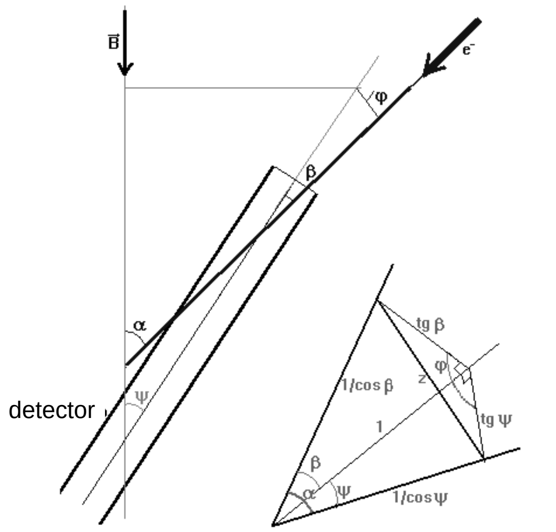

Fig. 3. For the definition of computation parameters.

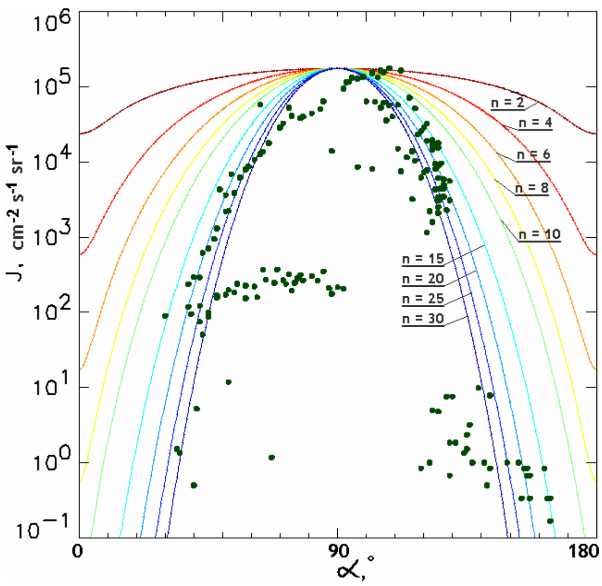

Fig. 4. Dependence of the detector count rate on its orientation for electrons with energy 0.3-0.6 MeV. (points). Calculated values of the detector count rate at the assigned pitch-angular distribution for various n. (lines)

The estimation of the anisotropy parameter n shows, that for all considered energy channels and ranges L the value of n is not less then 5. In the inner belt n values are smaller than at the outer drift shells, between 5-15 for electrons in channels 0.3-0.6 MeV and 1.5-3 MeV. In an outer belt *n*>15 for electrons 0.3-0.6 MeV, between 10-15 for electrons 1.5-3 MeV and can be more than 5 up to 20 for electrons with energy of 3-6 MeV. Clear dependence on electrons energy was not revealed. In the 1-5 MeV protons channel the parameter n is equal to 2-6 at *L*<2.2.

Discussion

During the quiet time energetic electrons in radiation belts are stable trapped; n factor is from 2 at *L*=5 up to 5.5 at *L*=3 [Thorne et al., 2005]. Protons usually have normal PAD, but during magnetospheric disturbances it may be transformed to a flat distribution outside of a loss cone or into the “head and shoulders” one - with the expressed maximum close to 90° and flat at smaller pitch-angles [Biriukov et al., 1984].

Pitch angle distribution of solar cosmic rays protons, penetrating inside the magnetosphere, is isotropic before their capture into the close drift orbits. During magnetic storms recovery phase magnetosphere returns to the pre-storm configuration, which can lead to the growth of both normal and field-aligned components of particle energy due to the betatron and Fermi acceleration accordingly. Therefore the initial PAD of post-storm population of trapped protons (and electrons as well) can have various PAD depending on the actual magnetosphere dynamics and the initial particle distribution function.

Joint processes of acceleration and pitch-angle diffusion finally will lead to the trapped particle distribution, however it is not known a priori, how fast this distribution will be established, and what will be the final shape of PAD. Results of this work show that anisotropic distribution is established not longer than for 10-20 day, and that the degree of anisotropy is big, similar to that of stable radiation belt.

It is necessary to note, that the used technique has some restrictions. First, the form of PAD can have more complex character, than was accepted at calculations. Second, the form of the spectrum and the degree of anisotropy can vary in time that was not taken into account here.

Nevertheless, results of this work are important not only for understanding of physical processes of radiation belts relaxation after strong magnetic storms, but also for practical space weather applications as essentially enhanced proton and energetic electrons ("killers") fluxes remain in the magnetosphere for a long time, for months.

Conclusion

At the analysis of energetic electrons and protons temporal variations measured onboard the CORONAS-F and SERVIS-1 satellites the difference between character of intensity decreasing in some intervals of time was revealed. The following explanation of this effect was offered: change of an inclination angle of the detector with narrow field of view onboard CORONAS-F versus to the vector of a magnetic field line can lead to modulation of counting rate in a case of anisotropic pitch-angular distribution of particles in the trapping region.

The inclination of the detector in relation to the magnetic field line has been calculated by the data on the satellite trajectory and magnetic field model IGRF for second half of 2004.

Then for the real detector aperture, inclination angle, particle energy channels and different assumed anisotropy factor *n* we have calculated resulting counting rates and compare it with measured intensity variations during September and October 2004.

It has been shown that both electrons and protons in the enhanced radiation belts have the trapped distribution with a high anisotropy factor *n*~5-20 at *L* from 2.5 up to 4.5 for electrons and *n*~2-6 at *L*<2.2 for protons in a wide energy range.

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References

Birykov A.S., Ivaniva T.A., Kovrygina L.M., Kuznetsov S.N., Sosnovets E.N., Tverskaya L.V., Kudela K., Boundary of solar cosmic ray penetration into the magnetosphere according to data of "Intercosmos-17" and "Cosmos-900", Acta Phys. Slov., v34, # 2-3, 153-160, 1984

Hasebe N., K. Sukurai, M. Hareyama , L. Lazutin, E. Muravieva, Yu. Goceljuk, I. Myagkova, B. Yushkov Variations of the radiation belts energetic particles after the july 22-30, 2004 magnetic storms, This issue , 2008

Kuznetsov S.N., K.Kudela, S.P. Ryumin, Y.V. Gotselyuk // CORONAS-F satellite - tasks for study of particle acceleration, Adv. Sp. Res. 30 (2002)

Lazutin L. L., Kuznetsov S. N., and Podorolsky A.N., Creation and distruction of the solar proton belts during magnetic storms, Geomag. and Aeronomy, V.47, # 2, p 187-197, 2007

Lazutin L., E. Muravieva, N. Hasebe, K. Sukurai and M. Hareyama. Comparative analysis of the energetic electron and solar proton dynamics during strong magnetic storms. , This issue, 2008

Thorne R. M., T. P. O'Brien, Y. Y. Shprits, D. Summers, and R. B. Horne. Timescale for MeV electron microburst loss during geomagnetic storms. Journal of Geophysical Research, vol. 110, a09202, doi:10.1029/2004ja010882, 2005