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Cosmic rays cut–off in approach of dipole and homogeneous field for Jupiter system

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Abstract

The strong Jovian magnetic field results in cosmic rays cut-off by the dipole magnetic field up to GV rigidity. The magnetospheric magnetic field in the inner magnetosphere inside of the Ganymed orbit strongly distorbed by the equatorial magnetodisk field. In the area close to the equatorial plane the magnetodisk field is directed opposite to the dipole magnetic field, however in the outer magnetosphere the magnetodisk field reverses its direction. This results in enhancement of the effective dipole magnetic moment compared to planetary Jupiter dipole moment up to 3 times (see [1]). We studied the rigidity cut-off in Jupiter system at Io, Europe and Ganymede orbits. In our work we have used a generalization of the Stormer analysis for a dipole field by introducing additionally a homogenous magnetic field directed northward (opposite to planetary magnetic field). Such an analysis gives us the possibility to estimate the contribution of solar event particles to the total radiation dose a spacecraft in the Jovian system is exposed to. Also we can estimate the escape rate of energetic particles from trapped radiation zone to interplanetary space. In this process Jupiter serves as a source of energetic particles in Solar system.

1. Introduction

The motion of charged particles in a magnetic dipole field was considered in detail at the beginning of the XX century by Norwegian mathematician and geophysicist Carl Stormer [2]. In his first works he attempted to explain the origin of aurorae by modeling mathematically trajectories of charged particles in a dipole magnetic field.

Jupiter is the largest planet in the solar system and it also has the longest magnetosphere. The distance from the magnetopause to the center of the planet is from 45 to 100 Jupiter radii at the subsolar point. In the inner magnetosphere at a distance of 5,9 Jupiter radii from the center of the planet as a result of volcanic activity of moon Io multicomponent plasma is formed. This has a significant impact on the magnetic field of Jupiter. The external uniform magnetic field in a general case for Jupiter is composed of three components:

$$\vec{b}_0 = \vec{B}_{int} + \vec{B}_{cf} + \vec{B}_{disc},$$

where B_{int} - interplanetary magnetic field (1 nT), B_{cf} - Chapman-Ferraro field, B_{disc} - magnetic field of the plasma disc (200 nT). We considered the structure of Jupiter's field in a uniform external field, without regard to the field created by the plasma disc and the influence of solar wind. We built allowed and forbidden zones for the movement of different particles and performed magnetic cut-off analysis.

Summary and Conclusions

We obtained the formula for the calculation of the vertical cut-off rigidity in the presence of an external field. According to this formula we calculated the cut-off rigidity at the orbits of Jupiter's moons - Io, Europa and Ganymede. We calculated the minimum energy required for the arrival to the equator of sphere with radius corresponding to the orbit of each moon.

$$R_G = \frac{300(2M + R_J^3 b_0)^2}{(4R_J\gamma)^2 M} \cos^4 \lambda$$

where Rj - Jupiter radii, M - Jupiter's magnetic moment. A constant γ determines the moment impulse for critical particle trajectory. This constant changes due to the homogeneous field term. The ratio of the magnetic field b_0 to the dipole field at Stormer radii determine variations of R_G. It is mainly connected with new value of

$$\gamma = -(1 + \frac{b_0 C_{st}^3}{4M}),$$

where C_{st} is the Stormer radius of the particle. For homogeneous field strength which is equal to the dipole field at Stormer radii the cut-off rigidity can decrease by half.

Using the theory of motion of charged particles in a magnetic dipole field developed by Carl Stormer we can describe the penetration of galactic and solar cosmic rays of the magnetosphere of Jupiter. The structure of allowed and forbidden zones for three cases are shown on the figure 1.

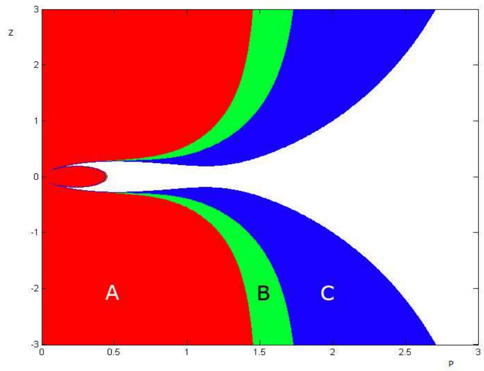

Figure 1: The structure of allowed and forbidden zones for three cases.

AB - forbidden zone in case of absence of an external field; A - forbidden zone in the case of an external field directed opposite to magnetic dipole moment field; ABC - forbidden zone in the case of an external field codirected with the magnetic moment of the dipole field

When adding an external field the size of the allowed zone may increase, and in accordance with the formula, polar regions can be reached by particles with smaller rigidities (and, thus, lower energies). The external field can be attributed to the increase of the interplanetary field during increased solar activity.

Calculation of cut-off rigidity for the orbits of three moons of Jupiter is of great practical importance for spacecrafts.

References

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[2] Stormer C.,(1955), *The Polar Aurora*, Clarendon Press, Oxford.