Calculation of Cosmic-Ray Proton and Anti-proton Spatial Distribution in Magnetosphere

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Abstract

We calculated the motion of protons and anti-protons around the Earth to show their spatial distribution. The protons and antiprotons from decay of albedo (produced) neutorons and antineutrons can represent the concentration in the SAA region. The antiprotons concentrate more than the protons because of the higher energy spectra.

1 Introduction

The charged cosmic-ray particles are flying around the Earth as well known trapped radiation belts. The experimental data in the low orbit showed the concentration in the both geomagnetic poles and the SAA (South Anomaly of Antarctica) region[3]. Their energy and flux are important problems as the radiation environment. The recent balloon experiments[5] have been disclosing the energy spectra of antiprotons around the Earth. The observation of spatial distribution and energy spectra of antiprotons are planned in the near future international space station observatory.

2 Method

2.1 Equation of motion of the charged particle

The motion of the charged particle is descrived by the Newtonian equation with the Lorentz force as follows.

$$\frac{d\mathbf{P}}{dt} = \frac{q}{m}(\mathbf{P} \times \mathbf{B}) \tag{1}$$

The $\mathbf{P}$ represents the momentum of a particle, of which mass and charge are m and q. The $\mathbf{B}$ shows the magnetic field. The Earth's magenetic field is approximated by the dipole field. This motion was well examined and predicted the existence of the radiation belts by Störmer[1]. Actually it was very suprizing that Van Allen et al found them with the early spacecrafts. Recenty the whole spatial distributions of main components, protons and electrons are revealed[3]. But the spatial distribution of antiprotons are not clear due to very few amounts.

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The real geomagnetic field is measured and integlated in the IGRF (international geomagnetic reference field)[4]. This form is numerically expressed by the spherical harmonic functions and some Gauss coefficients. We used the static field of the year 2000 and the degree 12. The equation should be solved by the computer calculation. In this simulation, the Runge-Kutta-Gill method is applied. The time step dt is changed by actively controlled from 10 micro seconds to 10 mili seconds, the shorter time as the closer to the Earth, in order to keep the accuracies and to save the computing time. We set the time limit for one particle to 10 minutes, enough to decide whether trapped or not. The space limit is set from A (Earth radius) + 20 km, the top surface of atomospher (in Stratosphere), to ten times of A, the Magnetosphere limit.

2.2 Initial injection model

In the first model, the uniform distribution of cosmic ray protons is assumed. The Energy is chosen beteween 10 MeV and 10 GeV. The protons start from the edge of magnetosphere 10 A within the injection angle 30 degree by the Monte Carlo method. Almost of these of low energy are reflected by the geomagnetic field. A little of them reach to the Earth, mainly to the North and South poles though they depend on the energy. In the second model, the protons start from the top of atomsphere. They are called as albedo protons. Almost of them escape from the magnetosphere and others arrive to the Earth. Very few particle stay in the trapped radiation belts. In the third model, the protons start at the any place near the Earth. For the neutrons start from the top of atomosphere same as albedo protons but they decay to protons and electrons in proper time. So the protons can start at any place and their directions are out-going. In this model a few of them can become the trapped protons. The fractions of three states from the three models at typical energies are shown in the Table 1. The results of antiprotons are almost same as the table.

4 Results and Discussions

The simulation was carried out for protons[2] and antiprotons[5] with the different energy spectra. The numerical functional spectra based on experiments are used. The index parameters were set as, $a1 = -1.0$, $a2 = 1.5$. The mode energy E_m of proton spectrum was set to 0.3 GeV in the Solar minimum period. Otherwise the mode energy of antiproton spectra was set to 2 GeV. And the 10^5 events are simulated for each model case.

$$F(E) = 1/\{CE^{a1} + E^{a2}\},\ where\ C = -a2/a1 * E_m^{a2-a1} \tag{2}$$

The model 1 leads that some parts of particles reach in both geomagnetic poles, though almost of particles escape from the magnetosphere. Otherwize the

Table 1. Fractions of states (Escape,Arrive,Trap).

Data Source	Energy (GeV)	escape (%)	arrive (%)	trap (%)
Model 1	0.01	99.6	0.4	0
(*Cosmic*	0.1	99.4	0.6	0
Ray)	1.0	99.2	0.9	0
	10.	95.1	4.9	0
Model 2	0.01	9.0	89.7	1.4
(*Albedo*	0.1	11.5	88.2	0.3
proton)	1.0	18.4	81.6	0
	10.	57.3	42.7	0
Model 3	0.01	59.0	15.4	25.6
(*Decayof*	0.1	68.4	21.0	10.6
neutron)	1.0	80.4	18.2	1.4
	10.	89.9	10.1	0

model 2 and 3 could make the trapped particles in radiation belts. It looks that the model 3 can make more but this may be not so much because of the long neutron decay time. These are actually competed. Once the particle is trapped it stay for the long time. The simulation for the long period is needed. As many particles were trapped in the different radiation belts, the spatial distribution of protons were examined. We found that the SAA in space station height (@400km) was formed by the model 3 as shown in Fig.1. The model 2 can not make the enough trapped particles. So this suggests that the antiprotons decayed from albedo antineutrons should be trapped in the radiation belts. The drift motion of the proton and antiproton is same but the direction of rotation is different. The results show that the antiprotons could concentrate more than protons, because antiproton energies are higher than protons. We found that antiprotons concentrate at the northern-west part of SAA region while protons diffuse widely.

Then we plotted the height distribution on the cross sectional plane including the SAA side and the oposite side. We could see the shape of radiation belts and its antisymmetry. The more detailed analysis will be done.

References

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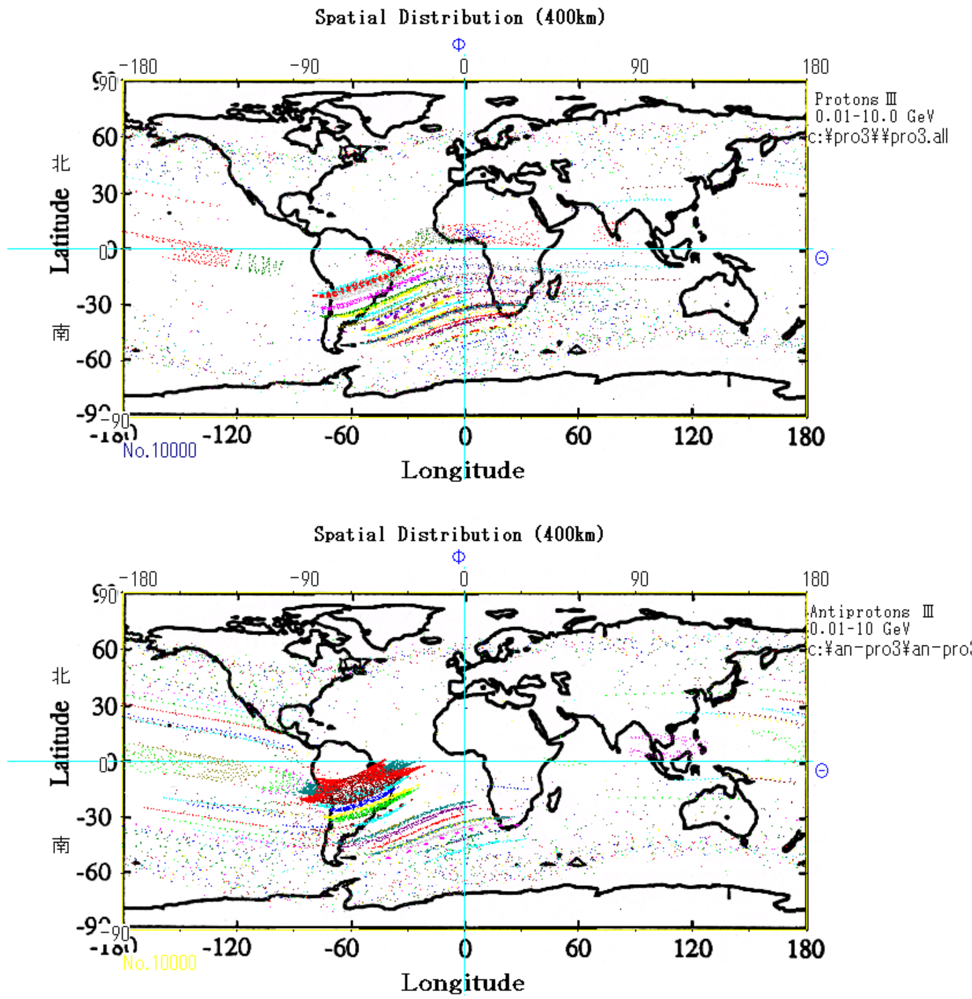

Fig. 1. The world spatial distribution of protons and antiprotons in space station altitude. The dots shows the particle trajectories.