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The Simulation of Cosmic Ray Ion Trapping by Geomagnetic Field

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Abstract

The numerical model for simulation of high energy cosmic ray ion trapping in geomagnetic field is presented. This model allows to simulate the ion penetration into Earth's magnetosphere, their step by step stripping in the residual atmosphere and subsequent trapping in geomagnetic field.

Using this model the trapping efficiency, ratio between interplanetary and trapped ion fluxes, temporal evolution of ion charge states were obtained for 30 MeV/n single charged oxygen ions.

The developed technique allows to simulate pitch-angle distributions, energy spectra of trapped anomalous component of cosmic rays (ACR). These distributions can be compared with the experimental results. The proposed model can be used to predict the charge distribution of trapped ions, which could not be directly measured in experiment today.

1 Introduction.

The main source of heavy ion fluxes in Earth's radiation belt is considered to be the interplanetary anomalous cosmic rays (ions H, He, C, N, O, Ne and Ar). The possibility of ACR to be trapped by geomagnetic field was proposed by Blake and Friesen 1977. They reasoned that singly ionized ions having high rigidity can penetrate into the lower L-drift shells. These ions moving in upper atmosphere lose one by one its remaining electrons by stripping. Their rigidity decreases and depending of its pitch-angle ion could be trapped by geomagnetic field into stable orbit. To confirm or to deny this model it is necessary to compare the calculated ratio between the trapped ion and interplanetary ACR fluxes with taking into account the efficiency of trapping and accumulation of ions and experimental data. Last years SAMPEX (Selesnick et al. 1995) and ADEOS (Kohno et al. 1997) satellites carried out the extensive experimental investigation as the interplanetary ACR fluxes and fluxes of geomagnetically trapped nuclei. However the quantitative theory of ACR ions trapping does not exist today.

We developed the numerical model which allows to simulate the efficiency of trapping and accumulation of ACR ions and to obtain the charge distribution of trapped ions, their spatial distributions and spectra.

2 Modeling technique.

The goal of proposed method is the simulation of separate trajectories of ions penetrating into magnetosphere from interplanetary space and moving in it with taking into account the processes of step by step stripping in residual atmosphere, their trapping in geomagnetic field and drift around the Earth in radiation belt. Then the data base of trajectories with all particle characteristics is collected and the efficiencies of trapping and accumulating are evaluated as well as the charge and pitch-angle distributions and energy spectra of trapped ions.

Since the efficiency of simulations of trapping process for particles moving from the boundary of magnetosphere is extremely low, we applied the following technique. Using the invariance of the equations of charged particle movement in magnetic field with respect to time inversion we simulate the trajectories of ions going out of the investigating zone of trapping "switching off" stripping and energy loss processes. On the second step the particles were followed moving with taking into account all interactions in upper atmosphere.

Here the results of modeling of 30 MeV/n oxygen ion trapping in the geomagnetic field are presented. At the first stage the set of trajectories for ions going out of studied zone (H = 800 km, L = 2.5, longitude φ = 7°) was obtained. The distribution of the initial directions was taken isotropic at the top hemisphere,. Then the trajectories were followed in the opposite directions with taking into account the step by step stripping and ionization energy losses.

The equation of the particle movement in the magnetic field was solved by 4-th order Runge-Kutta method. The used Earth's magnetic field model included as internal (IGRF'96 with 10 harmonics) and external sources (T-96). We utilized MSISE-90 atmosphere model. Cross sections of step stripping of orbital electrons for oxygen ions in energy range 5-200 MeV/n in upper atmosphere gases was evaluated in (Bakaldin et al. 1999). The ionization energy losses of ions were calculated by Bete-Bloch formula.

3 Results of simulations.

About 1000 oxygen ion trajectories were simulated using the above described technique. Each trajectory followed along about 10 drift revolutions around the Earth. In fig. 1 one of them corresponding to a case of momentary stripping of an ion with charge equal to +1 is presented. Considerable number of particle trajectories had step stripping.

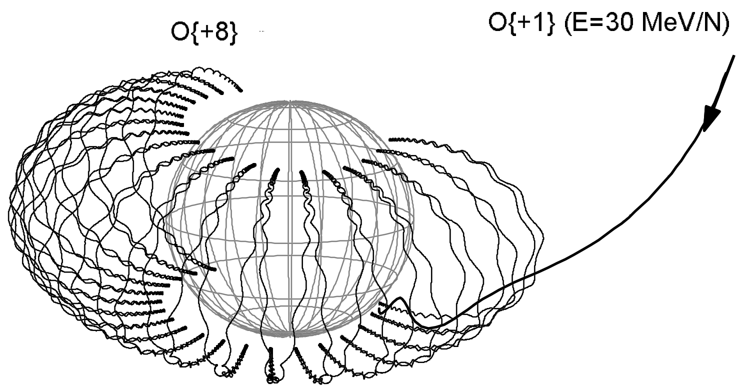

Fig. 1. One of the simulated trajectories of the oxygen ions.

Temporal evolution of charge states of trapped ions is present in fig. 2. As it is seen trapping of ions occurs in various charge states however only ions with charge + 6 ÷ + 8 are long lived.

The dependence of L-shell number and magnetic field value in the mirror points on time for oxygen ions stripped up to charge states + 6 ÷ + 8 are shown in fig.3. It is seen from this figure that the oxygen ions with initial energy 30 MeV/n could be trapped in studied zone only at L = 2, being only in full ionized state.

The ratio of trapped ion flux between the flux of interplanetary ACR could be estimated by the following expression:

$$\frac{J_T(E,t)}{J_I(E,t)} \cong \frac{P(E)\times\tau(E)}{\tau_B(E)}, \text{ where}$$

P(E) - probability of ion trapping by geomagnetic field;
$\tau_B(E)$ - bouns period;
$\tau(E)$ - the life time of trapped ion.

For oxygen ion with $Zi=8$; E=30 MeV/n trapped on L=2.0÷2.2 the following values were obtained: $P\approx0.018$, $\tau=7.7\times10^3$ s, $\tau_B\approx0.8$ s, whence $J_T/J_I\approx174$.

This result agrees with the conclusions of SAMPEX experiment (Selesnick et al. 1995).

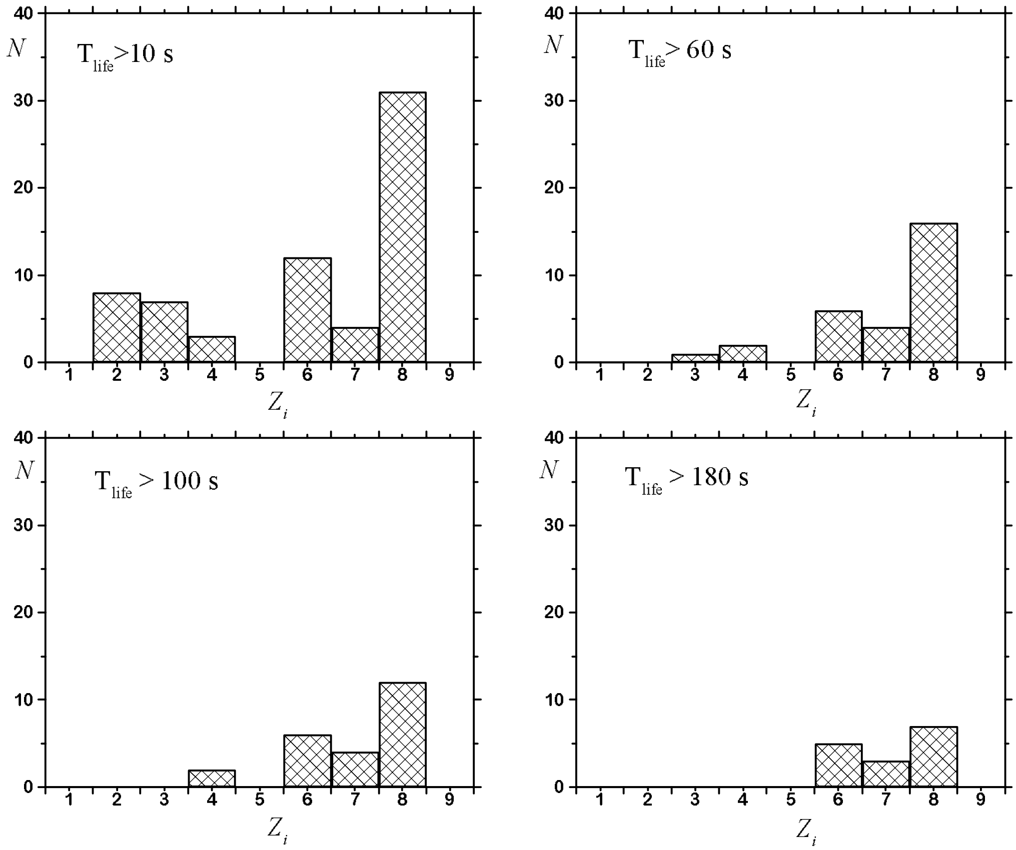

Fig. 2. The temporal evolution of the charge states of geomagnetically trapped ions.

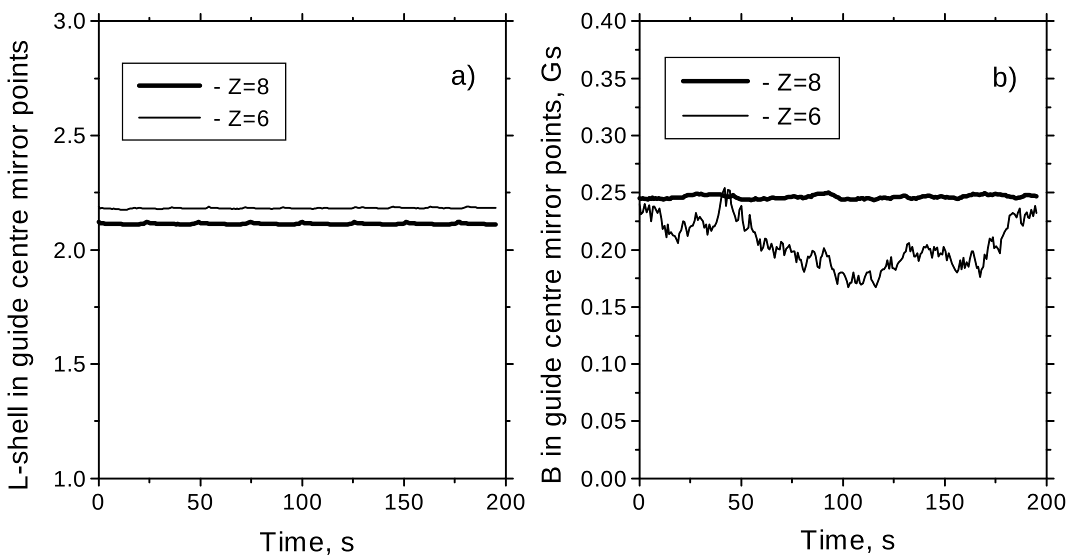

Fig. 3. The L-shell a) and induction of the Earth magnetic field b) in mirror points versus time for trapped oxygen ions for charge states O^{+6} and O^{+8}.

4 Conclusions.

In frames of the obtained results presented above we can conclude that:

1) The trapping efficiency of ACR oxygen ions by the Blake and Friesen mechanism. is sufficiently high to explain measured trapped nuclei flux values.
2) The life time of trapped ions does not exceed several days. Therefore temporal behaviors of trapped nuclei and interplanetary ACR ions intensities have to be the same.
3) The ACR oxygen ions can be trapped in various charge states but only ions with charge +6 ÷ +8 have the life times more then $T_{life} > 100$ s.
4) Since the life time of stable trapped ions is rather small the unstable ones could play a significant role in formation of trapped heavy ion fluxes.

Acknowledgement

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References

Bakaldin, A., Koldashov, S., Shevel'ko V., Voronov, S. 1999, Journ. of Tech. Phys. (to be published).

Blake, J., and Friesen, L. 1977, Proc. of the 15th ICRC, Plovdiv, v.2, 341.

Kohno, T., Yamagiwa, I., \& Matsumoto, H. 1997, Proc. of the 25th ICRC, Durban, v. SH4-6, 317.

Selesnick, R.,Cummings, A., \& Stone, E. 1995, J. Geophys. Res., 100, A6, 9503.