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QUASIPERIODICAL MODULATION OF THE CHARACTERISTICS OF QUASITRAPPED PROTONS MOTION IN THE GEOMAGNETIC FIELD AS A CONSEQUENCE OF MORPHOLOGICAL FEATURES OF THE TRAJECTORIES

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Abstract. On the basis of numerical simulations of equations for relativistic proton motion in a stationary magnetic field morphological analysis of quasitrapped particle trajectories has been performed. It is noted that trajectories of this type usually have a petal-like shape element with two reflection points located in one hemisphere. A periodicity of particle distribution function over the time of quasitrapped motion in the geomagnetic field is found. It results from conservation of the shape and size of the petal-like element. The absence of periodicity of this origin in particle distribution over asymptotic directions is shown.

Introduction

The trajectories of relativistic protons in the range of penumbra rigidities are extremely complex /1,2/ (see Fig. 1,2). The analysis of motion equation for the field of geomagnetic dipole shows a possibility of periodic motion for the particles /3/. However, most of these trajectories are unstable. Usually such particles make several revolutions around the Earth and leave the geomagnetic trap. Unfortunately, detailed study of such motion, analysis of its stability, examination of the particle distribution over asymptotic directions, and research of the morphological pattern are possible only by numerical calculations.

In this work on the basis of numerical modeling, a study of morphological features of quasitrapped trajectories in the geomagnetic asymmetric field has been performed. The hypothesis about quasiperiodic modulation of some characteristics of the quasitrapped motion was clarified. Another purpose was to examine the distribution of asimptotic longitudes for relativistic protons in the range of penumbral rigidities.

We would like to note that this research is not only of academic fundamental interest, but has also an essential methodical significance in modeling the response of the neutron monitor to the arrival of space rays /5,6/.

The method of modeling

Trajectories and asymptotic direction calculations were carried out with a familiar technique reducing to the reciprocal integration of the relativistic motion equation of a charged particle in the geomagnetic field.

$$\gamma(\partial^2 \mathbf{r} / \partial t^2) = Ze(\partial \mathbf{r} / \partial t)\times\mathbf{B}\ m$$

where γ is the Lorentz-factor, r is the radius-vector of a particle, **B** is the magnetic induction vector, Ze is the charge of a particle. The integration was performed by the Runge-Kutta- Felberg method of 4-5 order. The magnetospheric field was represented by the Tsyganenko-89 model.

It was noted, that the trajectory of motion of quasitrapped relativistic proton in the geomagnetic field is characterized by the large extent and complexity (quantitatively complexity of a site of a trajectory can be characterized by a total rotation angle of a speed vector direction on the given site). Mathematically it means a large instability of the solution of equation (1) in the final point and imposes special requirements on the accuracy of the calculations. This is a specific feature of the trajectory calculations in the present work.

To increase the reliability of the results the calculations were performed with double accuracy, which required updating some applied programs. Each trajectory was controlled by the return integration method /5,6/

Discussion

In this work we continued study of morphological features of quasitrapped motion in the real (asymmetric) magnetic field of the Earth. The characteristic features of this motion were described in detail in the previous papers /5,6/. Quasitrapped motion has both features of morphological similarity with drift trajectories (the elemets of quasiperiodicity: drift in the equatorial plane, periodic changes of coordinate Z, sites with cyclotronic rotation), and essential differences from the drift trajectories. In the present study the main attention was drawn to the differences.

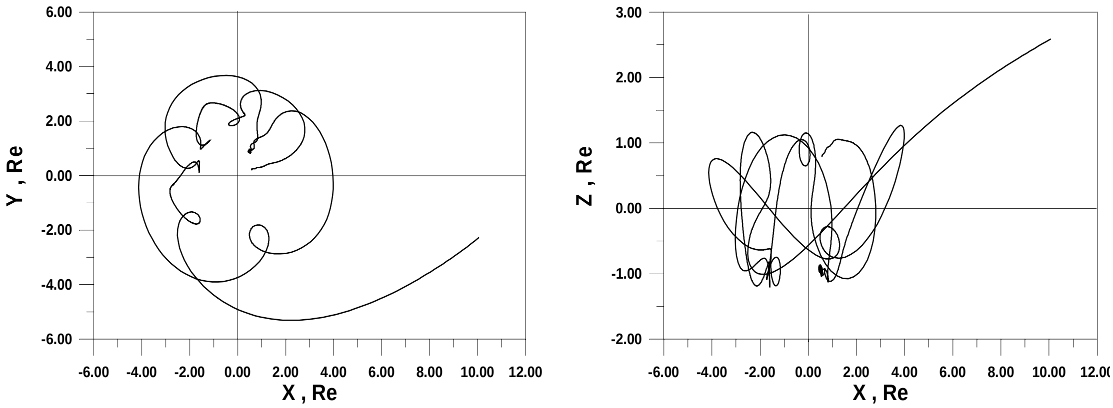


Fig. 1. Two projections of one quasitrapped trajectory. Moscow. Rigidity 2.418GV

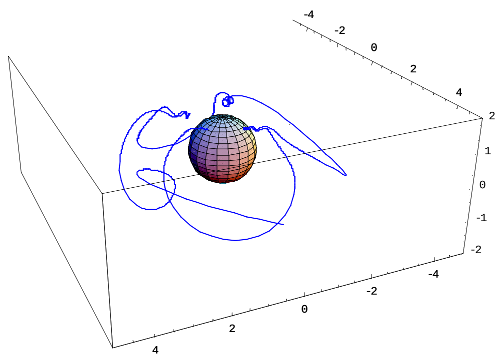
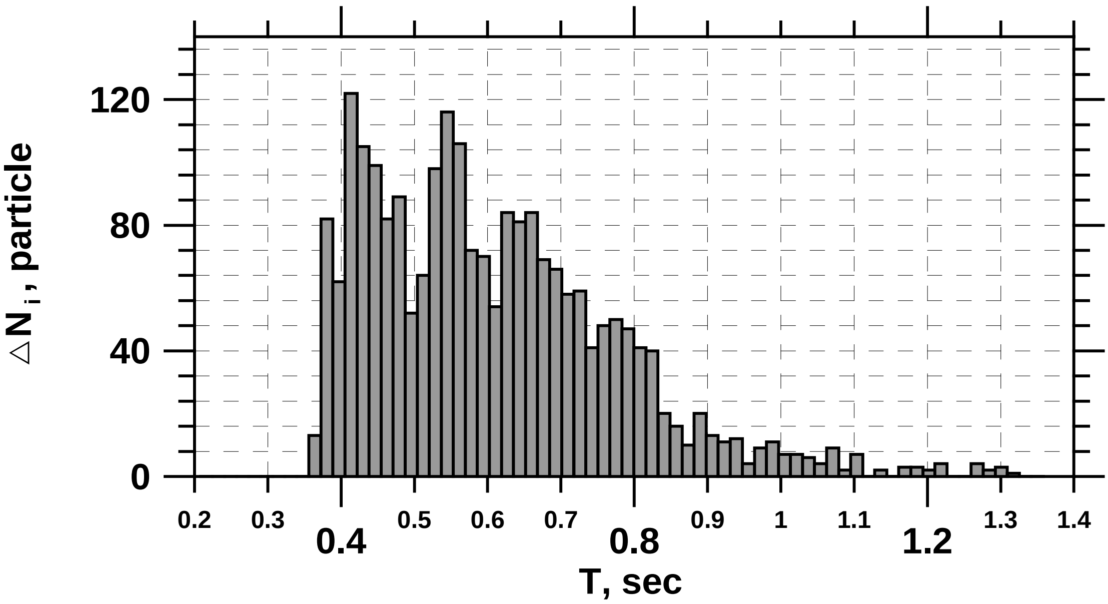


Fig.2 Axonometric projection of quasidrift trajectory. Moskow. Rigidity 476 GV/

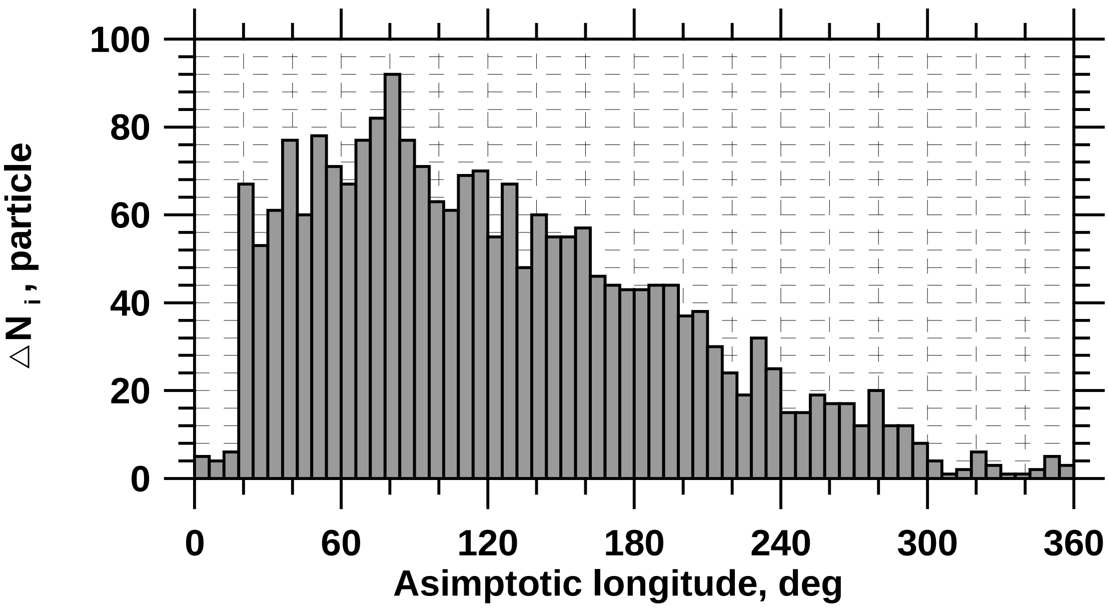
Even for quasiadiabatic drift of particles of smaller rigidities /8,9/ a difference in latitude of reflection points in the northern and southern hemispheres /8,9/ is observed. For the trajectories considered this difference gets more significant. The complete absence of sites with cyclotronic rotation in the opposite hemisphere is observed. One can see the petal-like shape element of the trajectories, connecting two reflection points of a particle in one hemisphere (Fig. 2).

This element occurs in most of penumbra trajectories. However, it is never observed for drift and quasiadiabatic drift trajectories /8, 9/. This element is morphologically constant and can “appear” or "drop out" of the trajectory only as a whole. This means that modulation or even discrete behavior of certain characteristics (such as asymptotic directions, times of staying in a geomagnetic trap, coordinates of output points, etc.) of the quasidrift motion considered is possible. Verification of this hypothesis can be performed only numerically. The results of the appropriate calculations are presented in Fig. 3a.

It is seen from Figure 3b that the distribution function of the particles, depending on the time of quasitrapped staying in the geomagnetic trap, exhibits rather distinct maxima. Intervals between the maxima are approximately equal to 0,12 s, which nearly corresponds to the time of proton motion along one petal-like shape element of the trajectory. It is an essential argument verifying the phenomenon of quasiperiodic modulation of quasitrapped time, which is connected with the petal-like shape element.



a)



b)

Fig. 3 Penumbra of Moscow station:

a) Distribution function of the particles depending on the time of quasitrapped staying in the geomagnetic trap.

b) Distribution function of the particles depending on the asymptotic directions.

Figure 3b shows that a similar quasiperiodic modulation of the asymptotic directions is absent. This result is of major importance at modeling the response of the neutron monitor with applying the technique described in /5,6/.

In summary, it is necessary to note that the above quasiperiodicity of the quasidrift motion characteristics of this type can be expected for laboratory plasma (e.g. for beams of particles).

Conclusions

1) Analysis of the trajectories of quasitrapped relativistic protons in the geomagnetic field reveals both features of morphological similarity with the drift trajectories (i.e. elements of quasiperiodicity: drift in the equatorial plane, periodic changes of the Z coordinate, sites with cyclotronic rotation), and essential difference from them. The distinctions include either a petal-like shape element with two reflection points located in one hemisphere or difference in the location of the reflection points in the northern and southern hemispheres.
2) The quasiperiodic modulation of the distribution function of the particles depending on the time of quasitrapped staying in the geomagnetic trap is established .It is shown to be connected with a relative constancy of characteristics of the petal-like shape element, which is present in most of trajectories.
3) In distribution of asymptotic longitudes of quasitrapped relativistic protons a periodic modulation is not found.

References

1) D. J. Cooke, J. E. Humble, Shea M.A., Smart D.F., N. Lund, I. L. Rasmussen, B. Byrnak, P. Goret, N. Petrou – On Cosmic-Ray Cut-Off Terminology // Nuovo Cimento, 1991, Vol. 14 C, N. 3, P 213-234.
2) Martin A. Rays Pomrantz Relativistic Solar Cosmic //Journal of The Franklin Institute , Pergamon press , Oxford , New York , vol . 298 ,№ 4 ,October 1974.
3) B. Rossi, S. Olbert - Introduction to the Physics of Space //Moscow, "Atomizdat", 1974 .
4) L.I. Dorman, V. S. Smirnov, M. I. Tyasto - Cosmic rays in the geomagnetic field //Moscow.: Science, 1971.
5) V. V. Pchelkin, E. V. Vashenyuk - Quasidrift of the high energy cosmic ray paticles in geomagnetic field // Proc. of MEPHI Scientific session - 2001, Moscow, 22-26 January 2001, p 57-58.
6) V. V. Pchelkin, E. V. Vashenyuk - Quasidrift effects and problem of penumbra of cosmic rays // Bull. Acad. Sci. of Russ, Phys.Ser. – 2001. - V.65, N3, P.416-421.
7) H. Alfven, C.-G. Felthammar -Cosmical Electrodynamics.// Moscow, "Mir", 1967.
8) Amirkhanov I.V., Iyyina A.N., IlyinV.d. and Yushkov B. Yu.- On the nonadiabatic theory of charged particles motion in the geomagnetic dipole field.// Cosmic Research, 29. 243-249,1991.
9) Amirkhanov I.V., Zhidkov E.P., IlyinV.D. Kuznetsov S.N. and Yushkov B. Yu. - Nonadiabatic motion of energetic protons motion of energetic protons motion in the geomagnetic dipole field. //Bull. Acad. Sci. USSR, Phys. Ser., 52, 129-131, 1988.