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On a Local Time Dependence of the Energetic He Ion Space Distribution

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Abstract

The L distribution of 1 - 9 MeV/nuc helium ion flux observed with the low altitude Japanese OHZORA satellite has a multipeak structure, different from one flux maximum of proton radiation belt and two flux maxims of electron radiation belt. The peak fluxes of 1 - 3 MeV/nuc He ions are located at L=1.35-1.6, L ~ 1.8 - 2.3 (only in 1984), and L = 2.8 - 3.2. Recently, two low altitude satellite SAMPEX (1992 – up to now) and MIDORI (1996-97) missions reported new observations of energetic He flux peaked at L ~ 2 and show the existence of stable (at least with lifetime of several years) flux there at higher energies above 10 MeV/nuc in contrast to the lower energies. To analyze the nature of the multipeak structure and the origin of the L=2 helium flux we studied magnetic local time dependence of the peak helium fluxes observed by OHZORA. The 1 - 3 MeV/nuc helium ion flux exhibits strong local-time variation at L ~ 3 having several times greater flux at the evening side at MLT = 17-21 hours than at the other MLT sides. The one of possible explanation of the flux variation with MLT is that ~ 1 MeV/nuc helium ions do not drift around the Earth and are located at L about 3 due to the ion interactions with the Earth's electric morning-evening field.

1 Introduction:

The study of origin and dynamics of energetic charged particles confined in the Earth's magnetosphere and the Solar effects are of utmost importance as they influences the atmospheric environment or the Space Weather. The region of Brazilian Magnetic Anomaly where the terrestrial magnetic field is lowest - is especially interesting for the studies of the above mentioned phenomena. The most prominent, the radiation belts approach closest to the Earth in this region. The knowledge of the inner magnetosphere and all the geophysical phenomena are essentially obtained from data collected in the Brazilian Anomaly region by experiments on board low orbiting satellites. In this paper we present the results of analysis the trapped energetic helium ion flux data (1.2 - 9.2 MeV/nuc) obtained by the Japanese OHZORA satellite operated at 350 - 850 km altitude in polar orbit during 1984 - 1987 near solar minimum.

In spite of the fact that energetic helium ions trapped in the magnetosphere were discovered in the sixties by Krimigis and Van Allen (1967) the spatial distribution, temporal evolution, energy spectrum and sources of the trapped helium ions remains sketchy and not well understood. Now it is known that the helium fluxes are highly dynamical (Pugacheva et al., 1996), have complicated space distribution observed by SAMPEX (Cummings et al., 1994), by MIDORI (Kato et al., 1999), and by OHZORA spacecraft (Gusev et al., 1997), and very sharp energetic spectrum dependent on L-shells.

2 Multipeak Structure of Helium Ion Space Distribution:

In Figure 1 we demonstrate the L distributions of helium ion flux of two energy channels, 1.2 - 3.2 MeV/nuc and 3.2 - 9.2 MeV/nuc, observed with HIP device on board of OHZORA satellite. The distributions have a multipeak structure, different from one flux maximum of proton radiation belt and two flux maxims of electron radiation belt. The peak fluxes of 1 - 3 MeV/nuc He ions are located at L=1.35-1.6, L ~ 1.8 - 2.3, and L = 2.8 - 3.2. The flux at L ~ 2 existed only in 1984. The more energetic 3.2 - 9.2 MeV/nuc helium ion flux has also two peak space distribution, but in 1984 only, during 1985, and 1986 years the distribution has only one low L peak at L ~ 1.6. It could be thought that multipeak structure in space distribution is the characteristic feature of only low energy He ion fluxes. But it is not quite so.

The recent results of Solar Anomalous and Magnetospheric Particle Explorer (SAMPEX) satellite indicates existence of two L shell (at L~ 1.25 and L~ 1.85) flux maxims for trapped 7-15 MeV/nuc He ions (Cummings et al., 1993). Similar results are also obtained for more energetic He ions (40-100 MeV/nuc) from the ONR-604 instrument on CRRES satellite (Chen et al, 1994). Recently, Japanese MIDORI (1996-97) mission reported new observations of energetic He flux peaked at L ~ 2 and showed an existence of stable (at least with lifetime of several years) flux there at higher energies above 10 MeV/nuc in contrast to the lower energies 1 – 9 MeV/nuc (Kato et al., 1999). Operational mode of CRRES, SAMPEX, and MIDORI satellites are 09/1990 - 10/1991; 1992 up to date; and 08/1996 - 07/1997, correspondingly. The He flux peak at L ~ 2 was observed in 1990 by CRRES, in 1992 up to now by SAMPEX and continued to be observed in 1996-1997 by MIDORI that means that the flux possibly exists there more than 6 - 7 years.

Concerning possible origin of the He ion flux, it is difficult to suggest that in the energy range of about 10 MeV/nuc, Anomalous Cosmic Ray (ACR) Helium Ions are populated this flux peak, because to penetrate to L ~ 2 even from westward, ACR Heluim ion needs to have rigidity R equal to about 3.5 GeV/c. The rigidity of ion is given by:

$$R = A / Q \sqrt{2 m_p E}$$

where A is the ion atomic number, Q is its charge state number, m_p is the proton mass and E is kinetic energy per one nucleon; 10 - 15 MeV/nuc Helium ion even with Z=1 has rigidity only 670 MeV/c that is not enough to reach this low L.

It was suggested that a possible source of He flux at L = 2 is the remnants of solar particles trapped during substorms. Actually, increases of energetic He flux of 4 - 13 MeV/nuc corresponding to geomagnetic substorm in March 1991 were observed by Japanese AKEBONO satellite, but He ions injected at L = 2.2 were depleted within a year as it was shown by Kohno et al., (1995). Several injections of energetic He to low L during 1989 – 1991 were observed with AKEBONO by Kohno et al (1995), but the fluxes have lifetime of about 1 - 2 years and could not explain existence of He ion flux increase at L ~ 2 during several years.

The origin of the trapped He at L ~ 2 is still unknown. To understand the origin of the flux, Kato et al, (1999) analyzed the pitch angle distribution of O and He ions at L ~ 2 - 2.5. They found that the angle distributions are different: the one for oxygen is asymmetric in relation to 90°, has peak at 100 - 110° showing that enough particles come to this place from the top of geomagnetic field line. At the same time He ion angle distribution has traditional characteristic of trapped radiation: maximum flux is located at the angle 90° Thus, it is explicitly shown that He ions at L ~ 2 are trapped and differ from ACR component.

3 Local Time Dependence of Helium Ion L-Distributions:

To analyze the nature of the multipeak structure we studied magnetic local time (MLT) dependence and anisotropy indexes of trapped He ions observed by OHZORA at L-shells corresponding to three He flux peaks: L = 1.35 - 1.8; L = 1.8 - 2.4 and L = 2.4 - 3.5. In Figure 2 we plotted MLT dependence of 1.2 - 3.2 MeV/nuc He flux at L = 2.4 - 3.5 where a flux peak was observed only in low energy channel of OHZORA HIP device: the flux is several times greater at the evening side at MLT = 17-21 hours than at the other MLT sides. For comparison we placed in the Figure 2 also MLT dependence of 0.19 - 3.2 MeV electron flux observed by OHZORA at the same L- shell ranges. Electrons demonstrate more or less opposite MLT dependence: they have several times greater flux at the morning side at MLT 5 - 7 hours. MLT dependence of energetic electron flux space distribution observed by OHZORA was also communicated by Fung et al (1999, COSPAR31). At the lower L-shells, L = 1.8 - 2.4, we obtained local time dependence for data of 1984 when He flux increase at L = 2 was observed. MLT variation of space distribution at this L-shell is a little different: He flux still has small increase at the evening side and shows a little increase at the morning side. At the lowest L-shells, L = 1.35 - 1.8, local time dependence of space distribution is practically absent.

The one of possible explanation of the He flux variation with MLT is shown in Figure 3. This Figure is taken from the book of Roederer (1970) and demonstrates how morning-evening Earth's electric field distorts drift trajectories of charged particles. Low energy positive charged particles do not drift around the Earth and have closed, vortical trajectories near L about 3 - 5 due to the ion interactions with the Earth's electric morning-evening field. Negative charged particles, such as electrons, need to have similar effect at the morning side, that is in accordance with observations.

In favor of hypothesis of morning-evening electric field influence on charged particle drift trajectories at middle L-shells testifies the data of pitch-angle distributions of He ions. These data are also plotted in Figure 2. We studied the distributions at L = 2.4 - 3.5 for different MLT: for evening and for morning sides and found that an anisotropy index is 3.2 ± 1 for morning side and is 9.55 ± 2 for evening side, where He ion increases were observed. It means that MLT dependence of He flux is more pronounced for particles with greater pitch-angles, that is exactly what one could expect when Earth's electric field influence on particle drift trajectories. A similar local time dependence of anisotropy index of MeV energy He ions was recently observed near the top of geomagnetic field lines by Spjeldvik et al (1999) on POLAR spacecraft: the MeV helium ion anisotropy at the top of field lines was systematically found to be higher in the dusk sector than in the dawn sector. For example, anisotropy index of 1.2 - 2.05 MeV/nuc helium ions at L = 3.5 - 4 in the morning side is 3.75 ± 1 and in the evening side is 6.5 ± 1. Thus, MLT effects on helium ion anisotropy that we observe at the foot of magnetic field lines are qualitatively similar to the MLT effects at the top of lines.

4 Conclusion:

The undertaken attempt to describe stable magnetospheric proton fluxes with numerical theory is important for 2 reasons: at the present time we need to know more exactly stable conditions of Space Weather in the nearest Earth's space in connection with its intensive colonization today; for the future predictions of particle dynamics, necessary for human security in space, we need to take possession the perfect theoretical methods of descriptions both stable and dynamical magnetospheric phenomena.

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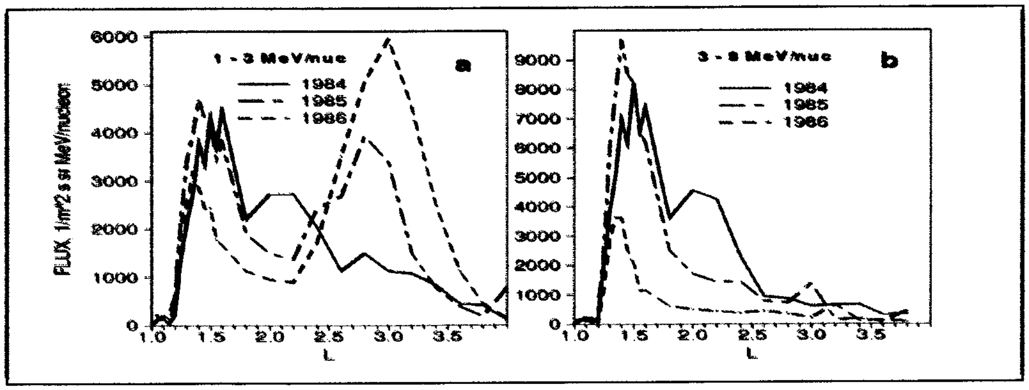

Figure 1. L-distribution of annually averaged He ion fluxes.

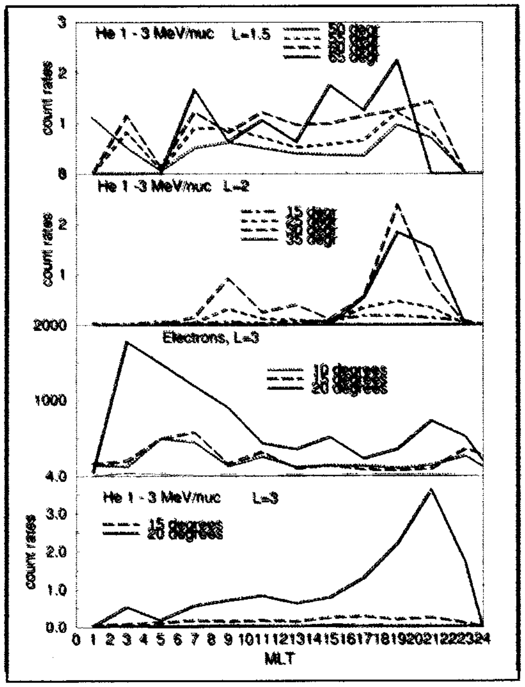

Figure 2. MLT dependence of He ion flux at L=1.5;2.0;3.0.

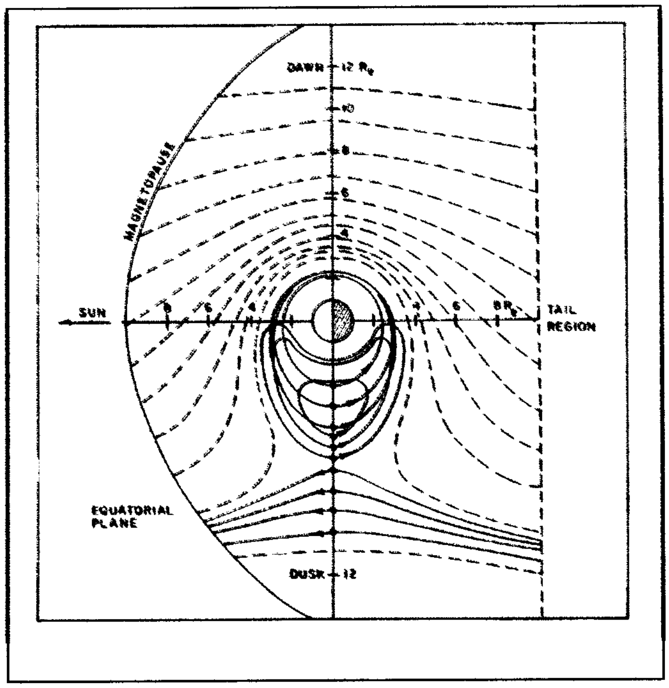

Figure 3. Trajectories of positive charged particles in the geomagnetic field with the morning-evening electric field.