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He and Ne isotopes in radiation belts observed by HIT onboard TSUBASA Satellite

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The energetic heavy ions from helium to iron were observed by Heavy Ion Telescope (HIT) onboard the TSUBASA satellite from March, 2002 to September, 2003 in the geostationary transfer orbit. Their isotopes were also separated that the mass resolution is ~ 0.24 amu for helium isotopes and ~ 0.35 amu for neon isotopes. ^{3}He and ^{4}He for helium with 20 – 40 MeV/n and ^{20}Ne and ^{22}Ne for neon with 50 – 100 MeV/n in the quiet periods were analyzed to obtain the spatial and temporal variation of fluxes of both isotopes. The enhancement of ^{3}He flux as compared with ^{4}He one in the region than $2L$ was found, while no neon isotopes were observed in the same region. Moreover, the ratios of ^{3}He/^{4}He and ^{22}Ne/^{20}Ne in the region than $3L$ are comparable to those of galactic cosmic rays. These results might suggest that the injection and loss mechanism of heavy ions differ between inner and outer radiation belts.

1. Introduction

The observations on both short-term and long-term spatial and temporal evolution of trapped particles provide us the vital clue to understand the injection and loss processes of them in the radiation belts inside magnetosphere. Up tp present, however, the observations of energetic heavy ions and their isotopes in the earth's radiation belts have been performed by only a few satellites, while those of light elements and electrons have been done with many satellites. As for the case of isotopic composition, only a few observation results have been available because the identification of particle masses is difficult. So, the observations of heavy ions and their isotopes is important for understanding their origin by getting such unique information.

Isotopic ratio of energetic helium ions, ^{3}He/^{4}He, is to be much enhanced in radiation belts when compared with solar abundance 10^{-4}. The observations such as CRRES[1], SAMPEX[2] and NINA[3] reported the enhancement of the ratio which reached higher than 1 in the inner radiation belts at $L \lesssim 2$ for the energy range less than 100 MeV/nucleon. In theoretical simulation, Selesnick and Mewaldt suggested the ^{3}He isotopes originated from the interaction of protons with residual atmosphere.[4] However, the origin of ^{3}He has not become cleared as yet.

The Mission Demonstration Test Satellite-1 (MDS-1), called "TSUBASA" Satellite, provided a good opportunity to study various important problems in radiation belts. This report shows the L-distribution of fluxes of helium and neon isotopes in quiet periods, except for the periods associated with SEP event and Coronal Mass Ejections. Then, we discuss the origin of heavy isotopes in the radiation belts.

2. Observation

The TSUBASA satellite was operated from February, 2002 to September, 2003. It was in the geostationary transfer orbit with a perigee of 500 km and an apogee of 36000 km at the inclination of 28.5° which corresponds to $L \approx 1 \sim 10$. Its orbital period was of 10 hours and 35 min and its spin rate was of 5 spins/min. The satellite was equipped with the Space Environment Data Acquisition equipment (SEDA) consisting of four instruments, whose aim was to survey the radiation environment in the Earth's magnetosphere.

One of them, Heavy Ion Telescope (HIT), was designed to measure energetic ions in space by 2 layers of position sensitive Si detectors and 16 PIN typed Si detectors. To reject both low energy ions and electrons, a particle window made of 2.1 mm thick aluminum was devised in front of the Si detector stack. The details of instruments were reported by Matsumoto *et al.*[5]. The mass resolution for helium iostopes were of 0.24 amu in rms in the energy range 20∼40 MeV/nucleon, whereas that for neon isotopes were of 0.35 amu in 50∼110 MeV/nucleon.

3. Results and Discussion

The time profile of helium elemental flux integrated for all L-value is shown in Fig. 1. Many peaks associated with SEP events were seen in the first half term than in the last half term. In these peaks, three X-class flares such as those on April 21, 2002 (X1.5) are included. Hereafter, we use the data in term I to IV displayed arrow line in Fig. 1 based on quiet period (see the thick red line), which are defined less than 100 helium counts per day.

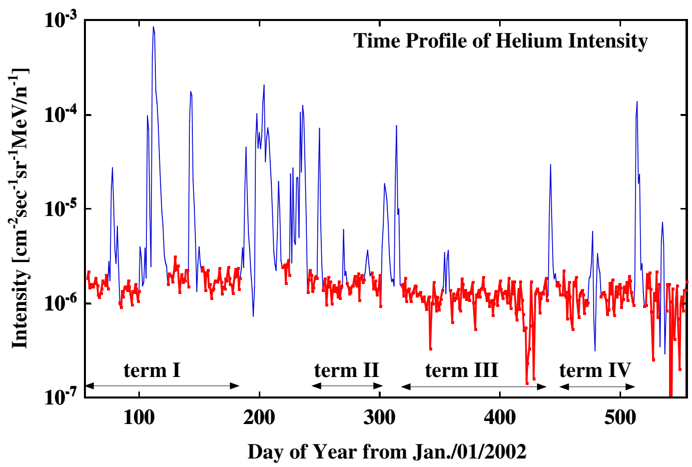

Figure 1. The time profile of helium flux during whole mission period. the quiet period was shown by thick red line.

Figure 2 shows the variation in the L-distribution of helium isotope fluxes, ^{3}He (blue square) and ^{4}He (red circle), with left axis and their ratio (green diamond), ^{3}He/^{4}He, with right axis in four quiet terms. Both fluxes of helium isotopes are enriched and fluctuated in $L < 3$, throughout whole observaing time. Looking at them in detail, there is a dip or slot of ^{4}He flux around $3 - 4L$ in each of the first two terms, while such a dip is around $2L$ in the later two terms. The situation for ^{3}He is almost the same as for ^{4}He, but such slots are not clearly seen. In contrast, the both fluxes are stable in outer L region more than $4L$.

The ratio of helium isotopes obtained by us varied dynamically its value among these terms as fluctuating both isotope intensity. At $L \sim 1 - 1.5$ in first term, the ratio is a value of about 3, being much grater than solar abundance as the order of 10^{-4}. This result is comparable to those of past observations as CRRES[1], SAMPEX[2] and NINA[3] has done. On the other hand, the ratio in $L > 5$ is almost constant of $0.3 \sim 0.5$ that are two or three times larger than those of BESS[6] and IMAX[7], though their energy range was from a few 100 MeV/n to a few GeV/n as galactic cosmic rays (GCRs).

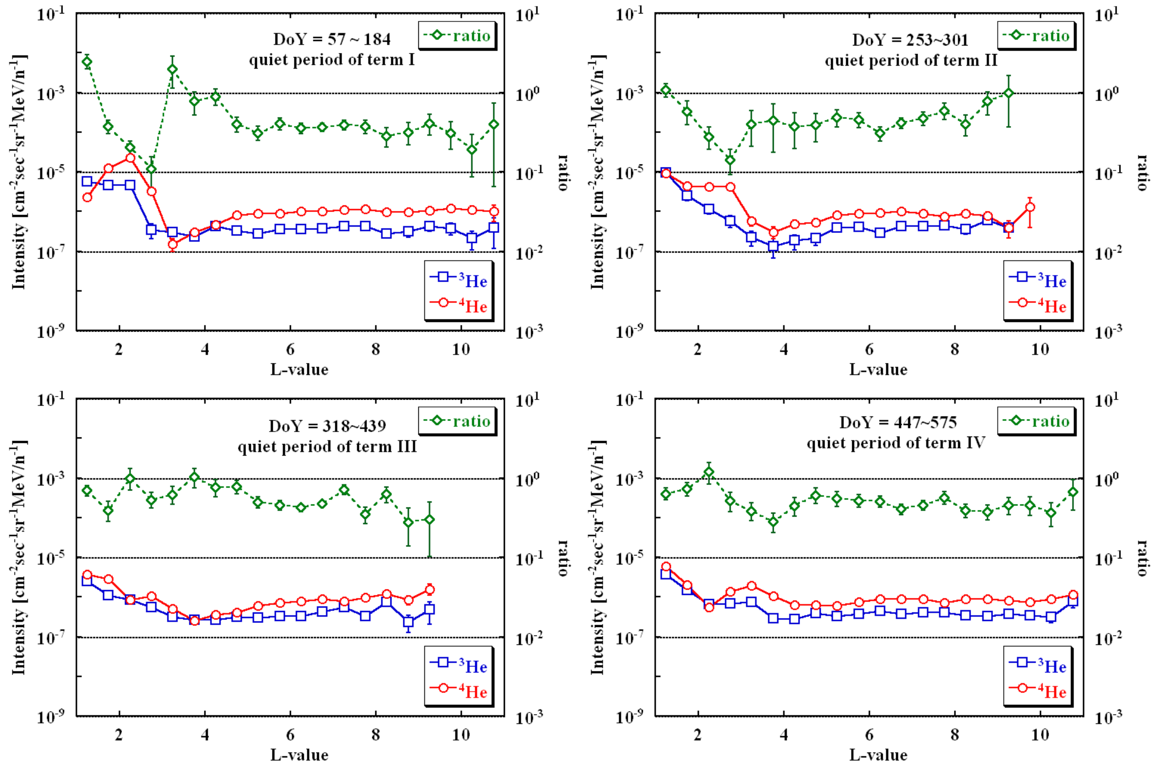

Figure 2. The L-distribution of the helium isotopes. The number in each panel corresponds to the number of term in Fig. 1.

Figure 3 shows neon isotope fluxes and their ratio , ^{22}Ne/^{20}Ne, as same as previous figure, which are summarized for four quiet terms due to small statistics of Ne isotopes. We found that there is no neon in less than $3L$, while their fluxes and ratio is stable in more than $4L$. The left plots in Fig. 3 is average in all L value. The ratio of neon isotopes obtained by this work is ~ 0.7 which is similar to one of GCRs as 0.6 at several hundreds MeV/n reported by ACE/CRIS.[8]

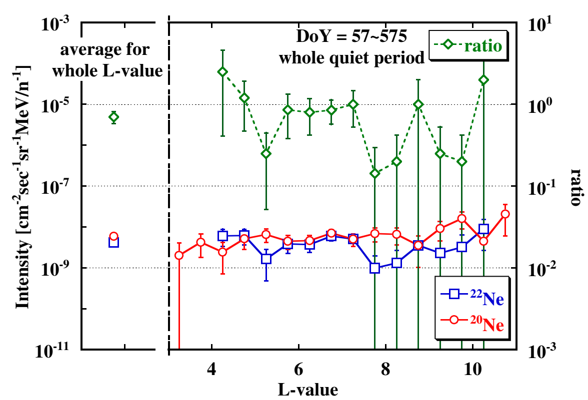

Figure 3. The L-distribution of the neon isotopes in whole quiet period.

Here, we note that these results did not take into account contamination effect of fragment particles produced by the interaction in aluminum window. However, these effect is not effective for helium ratio due to small amount of about one third comparing to heavier nuclei more than helium in which C and O are dominated.

Moreover, since the window of 2.1 mm-thickness-aluminum correspond to only 0.54 g/cm^2, most of the particles pass through the window without the interaction. For the neon isotopes, we may be unable to neglect this effect because heavier nuclei such as Mg, Si and Fe are more abundant. Therefore, these fluxes and ratios will go down when taking into account the contamination effect.

These results suggest that the trapped isotopes in outer radiation belt are identified as GCRs components. The both ratios of He and Ne isotopes are similar to those of GCRs and the pitch angle distribution of He element which was measured by the dose monitor onboard TSUBASA was rather isotropic in outer radiation belt.[9] Whereas the injection and loss mechanism of them in inner radiation belt have not been cleared as yet. The He isotopes, ^{3}He, with 20 – 40 MeV/n in less than $3L$ is more enhanced in their flux than its outer region, while the neon isotopes with 50 – 100 MeV/n dose not seems to exist despite that they are easily able to penetrate to the lower L region. These facts seem to indicate that trapped heavy ions between inner and outer radiation belts are different in origin.

4. Conclusion

This report presented the fluxes and ratios of trapped He and Ne isotopes observed by HIT/TSUBASA and discuss the their origin. The results obtained are summarized as follows:
1.The fluxes of He isotopes are more enhanced in inner radiation belt than outer one.
2. He fluxes in $L < 3$ are varied, while they are rather stable in its outer region.
3. There are Ne isotopes only in $L > 4$ and its intensity is stable.
4. The isotope ratios of He and Ne are similar to those of GCRs in outer radiation belt, while the ratio of He spreads its value from 0.1 to 3 in inner one.

Based on these results, we suggest that the heavy isotopes trapped in the outer radiation belt may have been originated from GCRs, but their origin in the inner belt differs from that in the outer one.

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