A Statictical Study of ^{3}He Enhancement in the High-Energy Solar Particles

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Abstract

Energetic particle observations of the ERNE instrument (*the Energetic and Relativistic Nuclei and Electron experiment*) onboard the Solar and Heliospheric Observatory enable the measurements of the ^{3}He flux beyond 15 MeV nucleon^{-1} with a good statistical resolution. An overview of the ERNE observations for the period from 8 February 1999 to 7 December 2000 is reported and a comprehensive statistical study is performed to learn regularities of ^{3}He enhancements in the high-energy range of 15–30 MeV nucleon $^{-1}$. Significant intensities of ^{3}He are detected in all event days with ^{4}He intensity exceeding ≈ 0.5 ion per (m^2 s sr MeV nucleon^{-1}). The abundance ratio ^{3}He/^{4}He is measured to vary within the range $\sim$ 0.003–2, which is well above the corresponding solar wind value. A histogram of the daily ^{3}He/^{4}He ratio reveals a sharp maximum at ^{3}He/^{4}He ≈ 0.01.

Observations and analysis

The early studies of the ^{3}He-rich solar energetic particle (SEP) events are mostly made in low energies, $\sim$ 1 MeV nucleon^{-1}, (Kocharov & Kocharov 1984, Reames, Meyer, & von Rosenvinge 1994, and references therein) but some measurements beyond 10 MeV nucleon^{-1} has been also carried out (Clayton, Guzik, & Wefel 2000, Bakaldin et al. 2003, Torsti et al. 2002, 2003, and references therein). This survey of SEP events is based on the particle flux measurements by ERNE/HED particle telescope (Torsti et al. 1995) from 8 February 1999 till 7 December 2000. Both helium isotopes, ^{3}He and ^{4}He, were detected in the energy channel 15-30 MeV nucleon^{-1} and the average geometric factor for the studied isotopes in this channel is 30.5 cm^2 sr. During the selected period there were some data gaps lasting from few hours to couple of days when either the spacecraft, or more often, the instrument was not in the observation mode. There were also a couple of strong solar events, like the events in 14 July 2000 and 9 November 2000, producing the extreme particle fluxes exceeding the analysis capacity of ERNE. In those occasions, the data have been excluded from the analysis.

Figure 1 plots time profiles of ^{3}He and ^{4}He daily count rates during 1999-2000. The slowly-changing line in the uppermost panel shows a lower limit for

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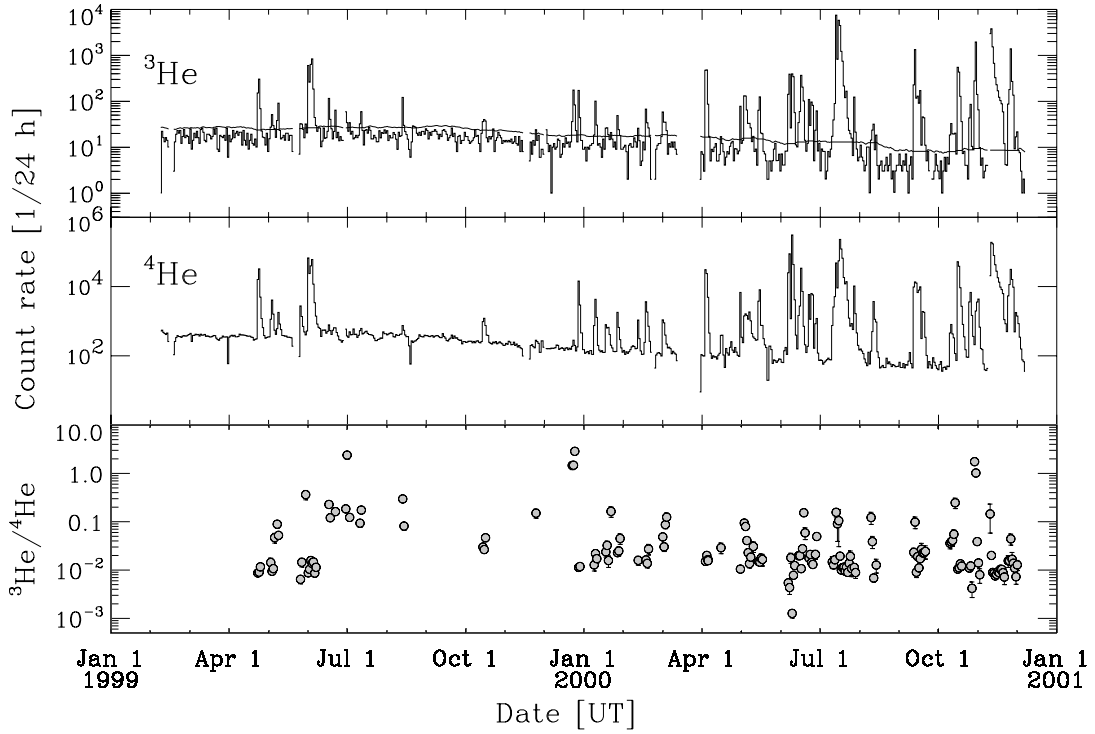

Fig. 1. Daily count rates of ^{3}He and ^{4}He in the energy range 15-30 MeV nucleon^{-1} (histograms) and the abundance ratio ^{3}He/^{4}He on the ^{3}He event days.

the selection of ^{3}He events. This selection limit is defined to be the gliding average count rate of the preceding non-event period raised by a twofold statistical error. In the survey period ERNE made observations of at least 12 hours duration in 626 days and the total number of the observation days was 633. The ^{3}He and ^{4}He count rates exceeded the event selection limit during 167 (26 %) and 239 (38 %) days respectively. The lowest panel of Figure 1 shows the ^{3}He/^{4}He ratios on the ^{3}He event days.

Figure 2 shows the distribution of day numbers over ^{4}He intensity for all days when the ^{4}He event limit was exceeded and the similar distribution containing only the ^{4}He event days accompanied by a detectable ^{3}He flux (left axis for both). Points in Figure 2 indicate the proportion of ^{3}He enhancement days compared to the ^{4}He event days (right axis). When the ^{4}He intensity increases from ~ 0.003 to ~ 0.3 ^{4}He ion per (m^2 s sr MeV nucleon^{-1}), the ^{3}He association rises fast and for events with ^{4}He intensity in excess of ≈ 0.5 (m^2 s sr MeV nucleon^{-1})$^{-1}$ the ^{3}He association becomes absolute. All high intensity helium events contain a measurable amount of the ^{3}He isotope.

The left panel in Figure 3 shows the daily average ^{3}He intensities versus the ^{4}He intensities on the ^{3}He event days with galactic background reduced. In

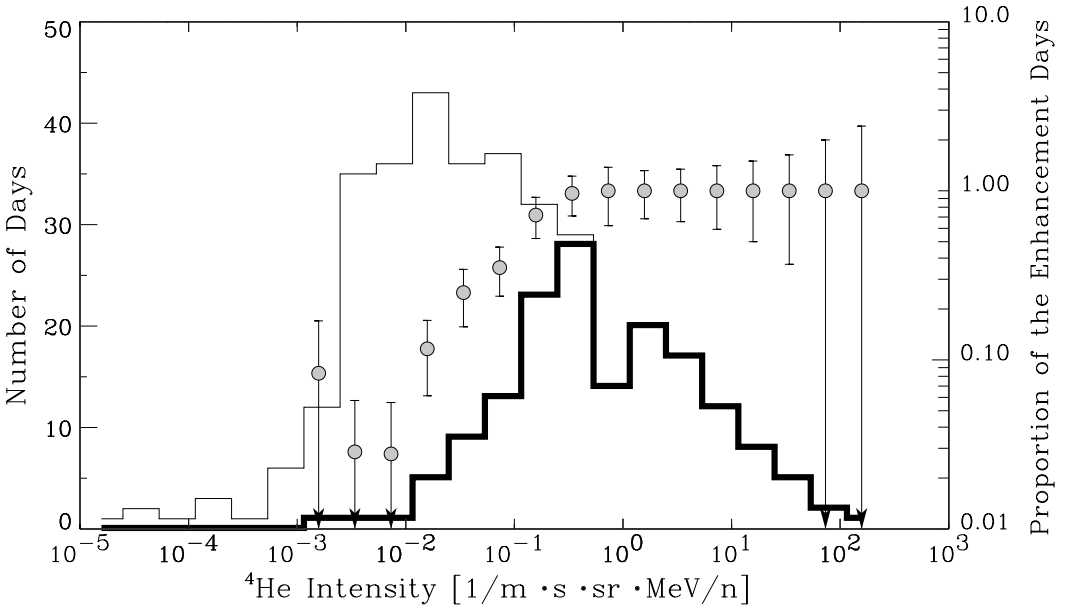

Fig. 2. Histogram of the daily average background-subtracted intensity of ^{4}He (thin line) and the ^{4}He intensity only on the ^{3}He event days (thick line). The points show the proportion of ^{3}He enhancement days in the ^{4}He event days.

the scatter plot one can see a clear correlation between the ^{3}He and ^{4}He intensities. Most of the events are located between the ^{3}He/^{4}He ratio lines 0.005 and 0.05, especially in the strong events. In the right panel there is shown a statistical distribution of the ^{3}He enhancement days over the ^{3}He/^{4}He ratio. A sum of a Gaussian type distribution and a quadratic function is fitted to the distribution. The fitting is carried out by GAUSSFIT routine of IDL. The new feature in the distribution is a narrow peak at ^{3}He/^{4}He ~ 0.01. It is not what one might expect on the basis of the impulsive-gradual SEP paradigm in the Reames' (1995) formulation, and in the earlier formulations of mid-1980's there is told nothing about the ^{3}He/^{4}He. The results of the survey can be summarised as follows:

1. Significant fluxes of ^{3}He ions have been detected in all ^{4}He events with intensity exceeding ≈ 0.5 ion of ^{4}He per (m^2 s sr MeV nucleon^{-1}),

2. The most frequent ^{3}He abundance is ^{3}He/^{4}He ~ 0.01. It seems that widely used 'normal' abundance ratio ^{3}He/^{3}He $\approx 5 \times 10^{-4}$ finds no support in the experimental data.

3. At lower frequency, the ^{3}He/^{4}He ratio is observed to be as high as ~ 0.1–1.

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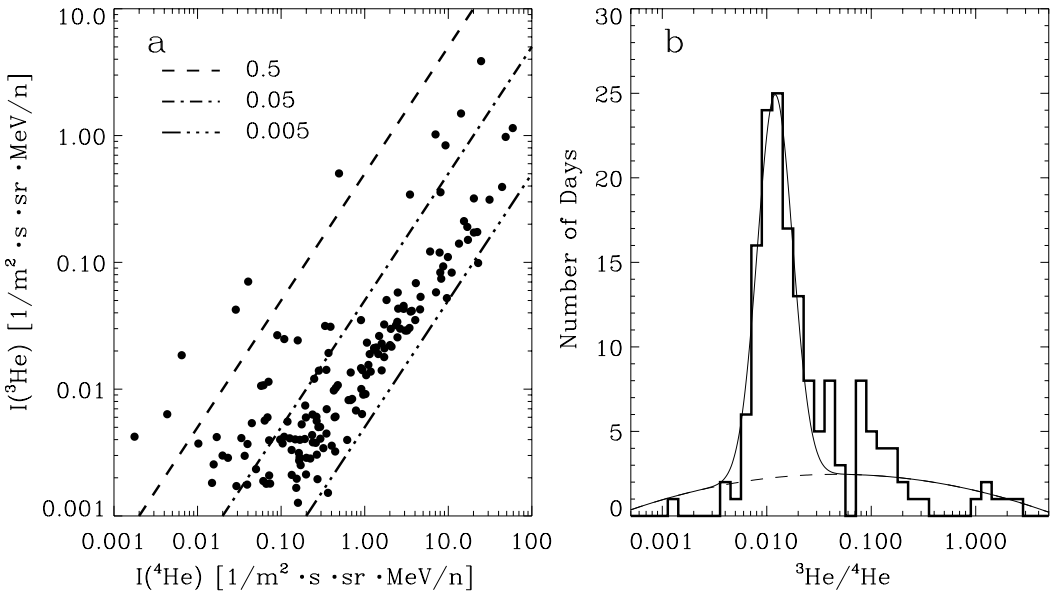

Fig. 3. Scatter plot of ^{3}He intensity vs. ^{4}He intensity, with background reduced, on the ^{3}He event days in the energy channels 15-30 MeV nucleon^{-1} (left panel) and the corresponding histogram of the daily abundance ratio ^{3}He/^{4}He (right panel). Dashed lines in the left panel indicate the 0.005, 0.05 and 0.5 levels of ^{3}He/^{4}He ratio.

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