Characteristics of ^{3}He-Rich Energetic Particle Events Observed with the SIS Instrument on ACE

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Abstract

We report observations of ^{3}He-rich solar energetic particle (SEP) events made with the Solar Isotope Spectrometer (SIS) aboard the Advanced Composition Explorer (ACE) spacecraft. SIS has been measuring helium isotopes above $\sim$ 4 MeV/nucleon since August 1997 using a dE/dx vs. total-energy sensor system employing large-area silicon solid-state detectors. We show examples of the helium isotope data being collected by SIS. Using data such as these it is possible to characterize the properties of ^{3}He-rich events including isotopic abundances, intensities, spectral hardness, and timing characteristics. These data can be correlated with other sources of information for the same events including particle measurements made at lower energies and observations of electromagnetic radiations from the flare site. Results of these types of analyses will be presented at the conference.

1. Introduction:

Since the discovery that some small solar energetic particle (SEP) events can have enhancements of the ^{3}He abundance by several orders of magnitude over typical solar system values (Hsieh & Simpson, 1970), these events have been the subject of intensive study. It is now realized that these events, which generally have an "impulsive" time profile, are distinct in their characteristics and their origins from larger, "gradual" events. The present understanding of these classes of SEP events has recently been reviewed by Reames (1999).

One of the central goals of NASA's Advanced Composition Explorer mission is to further the understanding of the origin of both types of SEP events and to use data on energetic particle abundances to improve our knowledge of the composition of the solar atmosphere. ACE makes measurements of energetic nuclei in SEP events with four instruments covering an energy range from $\sim$ 50 keV/nuc to $>$ 100 MeV/nuc (Stone et al., 1998a). In this paper we concentrate on observations made with the Solar Isotope Spectrometer (Stone et al., 1999b) which covers the upper end of this energy range.

SIS uses a two stacks of large-area silicon solid state detectors to identify the nuclear charge and mass of particles using the dE/dx vs. total energy technique. The first two detectors in each stack are position sensitive to provide a measurement of particle trajectories as well as energy losses. The lower limit of the SIS energy interval depends on the thickness of the front detector and the thin foil window in front of it as well as on the electronic threshold of the second detector. This lower limit is approximately 4 MeV/nuc for He.

2. Examples of SIS ^{3}He-Rich Event Observations:

During more than 15 time periods between the start of data collection on 27 August 1997 and the beginning of May 1999, SIS has observed SEP events with ^{3}He/^{4}He ratios exceeding the value $\sim$ 10% commonly ascribed to this class of events (Reames, 1999). Energy spectra tend to be soft and produce measurable ^{3}He count rates only in the first few ranges of the SIS instrument. Figure 1 contains plots of ^{3}He and ^{4}He vs. time in a "classic" ^{3}He-rich impulsive event observed on 9 September 1998 (day 252). These data were obtained from He nuclei stopping in the second SIS position sensitive detector and correspond to an energy interval $\sim$ 4 to 5 MeV/nuc. The two isotopes have similar time profiles with an impulsive rise and an approximately exponential decay. Examining the browse data from

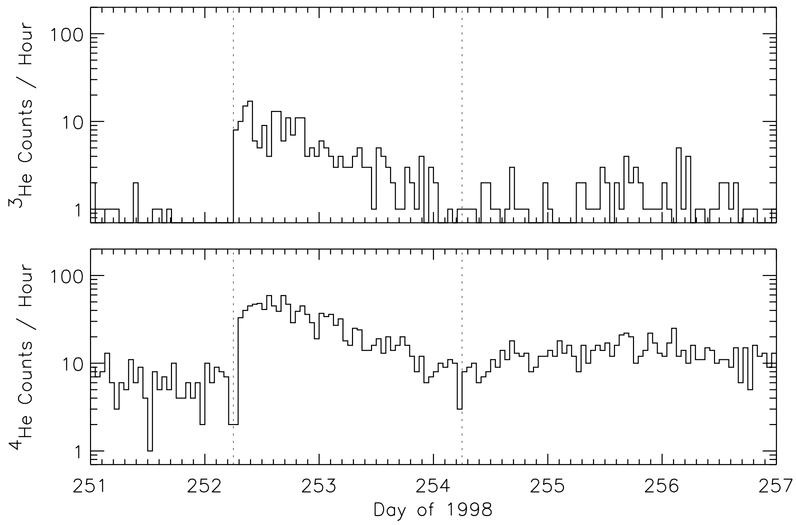

Figure 1. Temporal variation of ^{3}He and ^{4}He in SIS Range 0 during the ^{3}He-rich SEP event of 9 September 1998 (98:252). The dotted lines indicate the time period over which the histogram in Fig. 2 was accumulated.

the EPAM and ULEIS instruments on ACE one notes that an impulsive electron event was observed and that the ^{3}He enhancement is also seen at lower energies. This event had enhanced abundances of heavy elements which were measured with the ULEIS and SEPICA instruments, as well as with SIS. SIS heavy element measurements in this event are discussed by Slocum et al. (1999). Examination of the Solar and Geophysical Data for the time of this event reveals a complex set of Hα flares, x-ray flares, and radio bursts, but it is not immediately clear which are associated with the particles observed at ACE.

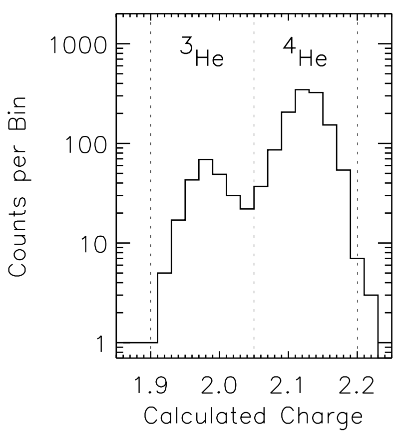

Figure 2. Histograms of calculated charge for the time interval indicated in Fig. 1.

Figure 2 shows a histogram of calculated charge for the He nuclei observed in the 9 September event. In the dE/dx vs. total energy technique the quantity derived as a measure of the particle identity depends on charge and, more weakly, on mass (Stone et al., 1999b). Thus the histogram contains two peaks, one for ^{3}He and one for ^{4}He. The dotted lines in the Fig. 2 show the intervals used for obtaining the count rates plotted for each isotope in Fig. 1. The ratio of peak areas, with a minor correction for the different energy per nucleon thresholds for the two isotopes, gives the ratio of particle intensities which in this case is $\sim$ 10–20%.

Other ^{3}He-rich events observed by SIS are significantly more complex. An example of such an event from 21 March 1999 (day 80) is shown in Figures 3 and 4. The time dependences of the ^{3}He and ^{4}He count rates (Fig. 3) show a ^{3}He increase at approximately 80.25 without any clear accompanying increase of ^{4}He. Half a day later at 80.7 there is a clear ^{4}He increase with a possible further increase of ^{3}He, although the latter observation is problematical due to limited statistics. Finally, another day later at 81.9 there is a large ^{3}He increase, again without accompanying ^{4}He. Solar and Geophysical Data indicate weak Type III radio bursts might be associated with the particle injections, but no Hα or x-ray flares are noted at appropriate times. Furthermore there do not appear to be associated electron events in the EPAM data. Thus at present we do not know whether the three SEP injections that occur in the 1999:080-081 period arose from the same region on the Sun as one commonly finds for events so closely spaced in time. If these events are associated, the large composition differences going from ^{3}He-dominated to ^{4}He-dominated and then back to ^{3}He could provide a useful test for models of the origin of ^{3}He-rich events.

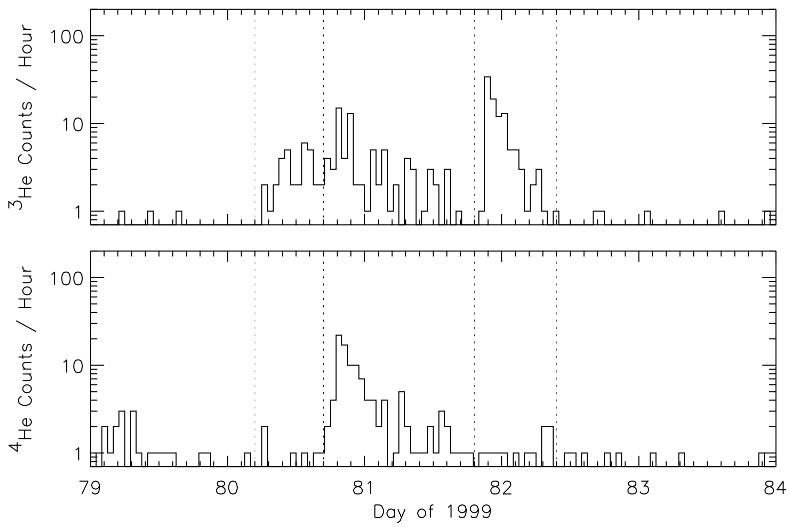

Figure 3. Temporal variation of ^{3}He and ^{4}He in SIS Range 0 during the ^{3}He-rich SEP event of 21 March 1999 (99:080). The dotted lines indicate the three time periods over which the histograms in Fig. 4 were accumulated.

3. ^{3}He in Larger SEP Events

"Impulsive" SEP events are frequently identified from sizeable enhancements of ^{3}He that they contain. For this purpose a threshold ratio of $\sim 10\%$ ^{3}He/^{4}He is commonly adopted (Reames, 1999). This value is a factor of 200 greater than the typical solar wind ratio and is based more on limitations of previous instrumentation used for resolving ^{3}He in SEP events than on any theoretical expectations for the composition in these events. Thus it is of interest to look for SEP events in which the ^{3}He/^{4}He ratio is less than 10% but still significantly greater in the average ratio in the solar corona.

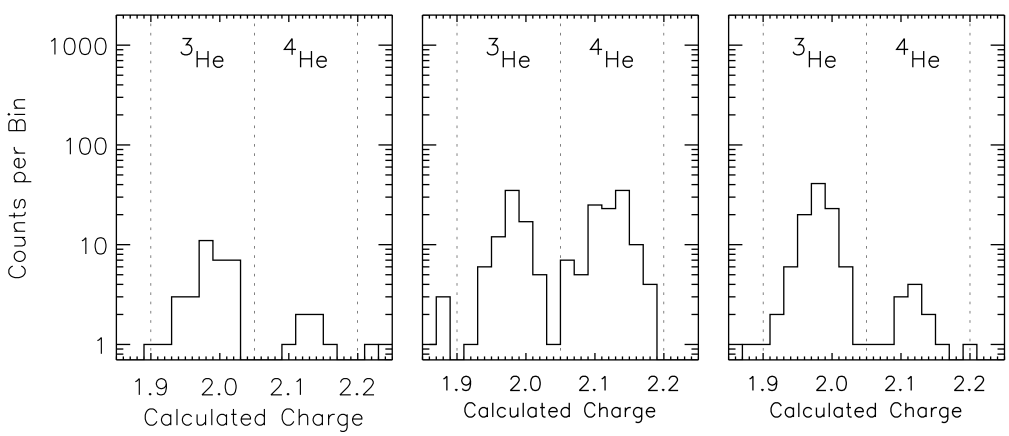

Figure 4. Histograms of calculated charge for the time intervals indicated in Fig. 3.

Figure 5 shows helium charge histograms for four SEP events discussed by Cohen et al. (1999) in which are observed large enhancements of the Fe/O ratio as well as a variety of other element and isotope ratios. Particle intensities in these events where significantly greater than in the events discussed above. From the SIS data for He stopping in the second position-sensitive detector (not shown) we can only set an upper limit of a few percent for the ^{3}He/^{4}He ratio because contamination of the ^{3}He region by background produced by the ^{4}He is at approximately this level. However, the larger samples of He measured in these events allow us to use higher energy He events that penetrate deeper into the instrument. The data in Fig. 5 are for particles stopping in the fifth detector. For these events we have multiple measurements of charge among which we can require consistency. Furthermore, we are not dependent solely on the position sensitive detectors for the energy loss measurements. With this data set we are able to achieve significantly better background rejection in the ^{3}He region and are therefore sensitive to lower ^{3}He/^{4}He ratios. For three of the four SEP events shown in Fig. 5 we have a distinct ^{3}He peak and find ^{3}He/^{4}He ratios ranging between $\sim 0.3\%$ and 3%.

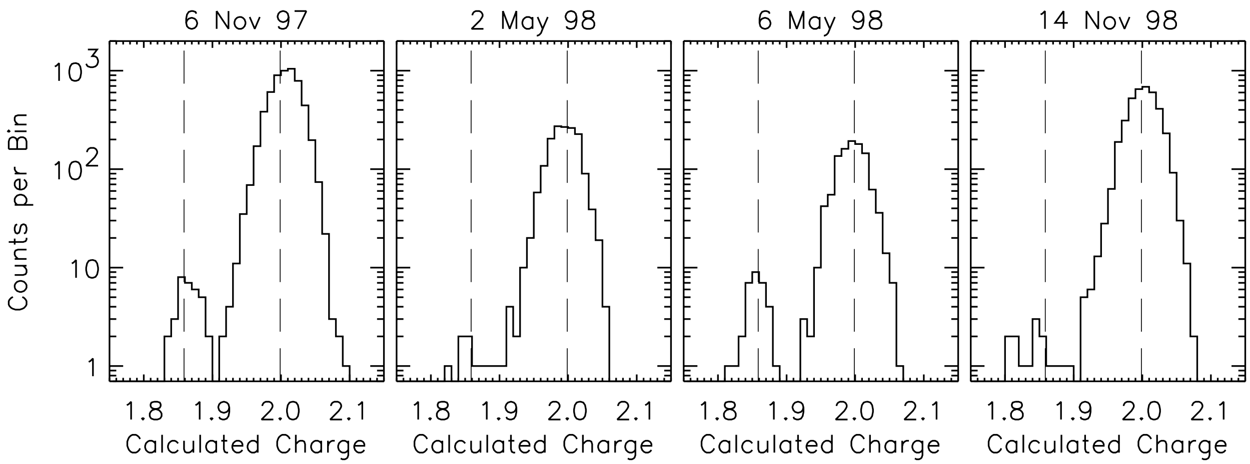

Figure 5. Histograms of calculated charge from SIS range 3 for four larger SEP events with high Fe/O ratios (Cohen et al. 1999). Dashed lines indicating the approximate centers of the ^{3}He and ^{4}He peaks are plotted at the same position in each panel.

Although these events have a number of characteristics commonly associated with impulsive events, it is not yet clear that this is the appropriate classification. As ACE continues to increase its sample of observed SEP events during the coming solar maximum it will be of interest to determine whether the small events with large ^{3}He enhancements and the larger events with smaller ^{3}He enhancements are really distinct populations or whether they simply represent two ends of a continuum.

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