1. INTRODUCTION

In recent years it has become clear that the particles in the "gradual" solar energetic-particle (SEP) events are accelerated at shock waves driven out from the Sun by fast coronal mass ejections (CMEs), and *not* in solar flares (Kahler *et al.* 1984; Kahler 1992, 1994; Gosling 1993; Reames 1995, 1997, 1999; Reames *et al.* 1996). Measurements of ionization states of Fe suggest that ambient (unheated) coronal material provides the seed population, even for particles that are shock-accelerated to energies up to 600 MeV/amu (Tylka *et al.* 1995).

In large SEP events, the theory of self-generated waves has been employed to understand both the acceleration of the particles at interplanetary shock waves in time equilibrium (Lee 1983) and the transport of particles outward from a source near the Sun (Ng & Reames 1994; Reames & Ng 1998). The scattering of particles by hydromagnetic waves is a time-dependent non-linear process in which particles can amplify or damp waves in such a way that the particle transport is drastically modified.

Recent papers by Ng, Reames, & Tylka (1999a, b) report on a dynamic simulation of the evolution in time and space of the particles and waves associated with an outbound shock. This model assumes that particles are injected with power-law spectra and coronal element abundances at the position of the shock, but then follows the subsequent evolution of the distribution functions of particles and waves in detail. As the particles stream out from the shock, different species at the same velocity are scattered differently depending upon their charge-to-mass ratios, *Q/A*. This model explained the observed (Tylka, Reames, & Ng 1999a, b) systematic variations in element abundance ratios like Fe/O, for example, in terms of differential scattering of Fe and O in the proton-generated Alfvén waves. However, a truly surprising feature of the model of Ng et al. (1999a, b) was its prediction of the initial behavior of He/H.

Ions resonate with waves of wave number $k_{res}=B/\mu P$, where B is the magnetic field strength, μ is the ion's pitch angle, $P=pc/Qe$ is its magnetic rigidity, and p its momentum. When ions of given velocity propagate through a background Kolmogorov wave spectrum with a $k^{-5/3}$ dependence, those with higher *Q/A* are scattered more. Hence, the earliest arrivals, with $\mu \sim 1$, will be the species with highest rigidity (lowest *Q/A*) and a ratio such as Fe/O will begin at high values and then decline with time. Any abundance ratio of high-rigidity/low-rigidity ions at the same velocity, including He/H, should behave in the same way, beginning at high values and declining with time. However, early observers (*e.g.* Witte et al. 1979; Mason et al 1983) were surprised to find that ratios of the fitted time profiles of He and H occasionally *rose* initially as a function of time. These observers admitted that they did not understand the behavior. However, they did not compare the spectra of events with rising and falling He/H and the phenomenon was not reexamined when more-sensitive instruments became available.

According to Ng et al. (1999a, b) the early rise can occur because the earliest protons, of 2 MeV, for example, have yet to generate waves, but 2 MeV/amu He resonates with waves created by ~8 MeV protons that arrived much earlier. Obviously, this effect will occur only if there are "enough" ~8 MeV protons to matter, *i.e.* in "large" events.

Furthermore, the effect will be most pronounced for magnetically well-connected events because their rapid onsets magnify differences in transport.

We note that the addition of flare-accelerated particles, with abundances such as enhanced Fe/O, can also affect the initial ratios (Reames 1990). However, with the new calculations of Ng et al. (1999a, b) it now seems more likely that most of the early peaks in Fe/O result from transport rather than from the presence of an additional flare source. In any case, flares are extremely unlikely to contribute material with *suppressed* He/H.

In this paper, we compare some observational examples of the initial behavior of abundance ratios such as He/H and Fe/O in "large" and "small" events and we examine the related proton spectra that define the meaning of event size. In the comparison, we use observations from the *Wind*, *ISEE 3*, and *IMP 8* spacecraft.

2. INITIAL ABUNDANCE BEHAVIOR AND PROTON SPECTRA

Figure 1 compares the time dependence of hourly-averaged intensities and abundances of several ion species in the gradual SEP events of 1998 May 6 and 1998 September 30. Peak proton intensities are more than an order of magnitude larger, depending on energy, in the second event than in the first. Both events show a decline in Fe/O as a function of time. However, while the May 6 event shows a rapid early decline in He/H, especially at low energies, the event of September 30 shows a dramatic early rise in He/H lasting about 8 hrs at the lowest energies.

We examine the evolution of the proton energy spectra in the two events in Figure 2. Times of the 2-hr averaged spectra labeled A-D in Figure 2 are spaced at 4-hr intervals and are noted along the time axis of Figure 1. In contrast to the steep spectra in the May 6 event, the spectra in the large September 30 event appear to be affected by the streaming limit (Ng & Reames, 1994; Reames & Ng 1998) out to at least 10 MeV for ~12 hours. During this period there are as many protons at ~8 MeV as at 2 MeV at 1 AU in this large event, so it is not surprising to see appreciable scattering and suppression of low-energy He that persists for several hours. Of course, it is the cumulative effect of the proton-generated waves from the source to the observer that increases the scattering of He and reduces He/H. The shape of the local proton spectrum merely exposes this same complex underlying behavior. According to the theory (Ng et al. 1999a, b), the actual amplitude and duration of the rise phase in He/H, as for other ratios such as Fe/O, depends upon several parameters, including the injected intensity at the shock and the shock compression ratio and their radial dependences.

To find additional events with clear unobstructed onsets, we have returned to the historic database. In Figure 3 we compare two such events, both from W50°. While Fe/O ratios are more poorly determined by *ISEE 3* than by *Wind*, the events in Figure 3 show the same qualitative behavior as those in Figure 1. In fact, the rather complex behavior of Fe/O in the 1978 September 23 event is very similar to that previously reported for the 1998 April 20 event by Tylka *et al.* (1999a). The latter event also has rising He/H.

Proton energy spectra for the 1978 September 23 event in Figure 4 again show the pronounced flattening out to 10-20 MeV that are characteristic of streaming-limited spectra. Spectra for the 1981 April 24 event are beginning to show limiting only at the lowest energies.

3. CONCLUDING REMARKS

The initial rise in He/H is a sign of non-Kolmogorov Alfvén-wave spectra that are evolving with time. Proton spectra that are initially flattened at low energies and enhanced at high energies are consistent with the generation of initially steepened wave spectra that preferentially scatter He relative to H in the onsets of large SEP events. The flattened spectra are themselves the product of streaming-limited transport (Lee, 1983; Ng & Reames 1994; Reames & Ng 1998; Reames 1999). The rising He/H ratios probe the cumulative effect of these steepened wave spectra from the shock out to 1 AU; they add another unique feature to the growing list of observational consequences of particle-generated waves. In an era of measurement of rare elements and isotopes, it is ironic that proton observations can still provide fundamental new understanding.

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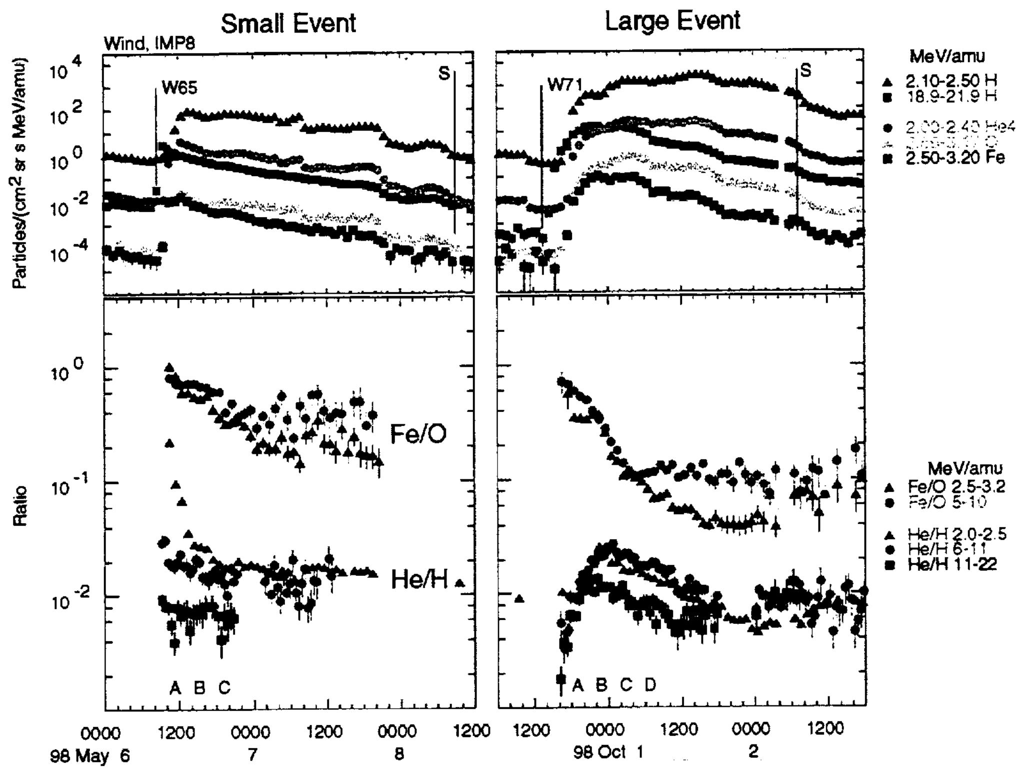

Fig. 1. Intensities and abundances of ion species *vs.* time are compared for the small 1998 May 6 SEP event and the large 1998 September 30 event. The initial rise in He/H and corresponding fall in Fe/O are clear in the September 30 event.

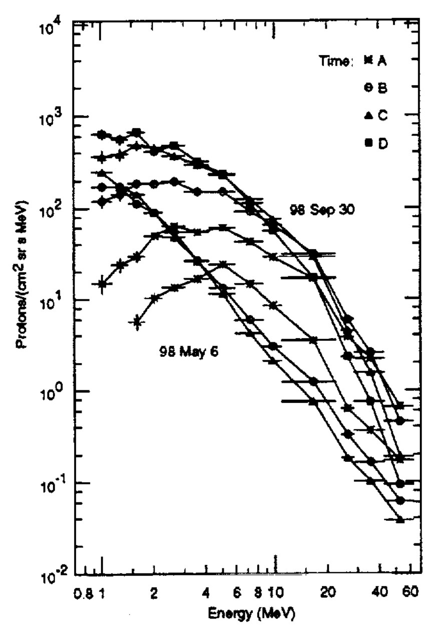

Fig. 2. Proton energy spectra are shown at several times, labeled A-D, corresponding to the times noted along the time axis in Figure 1.

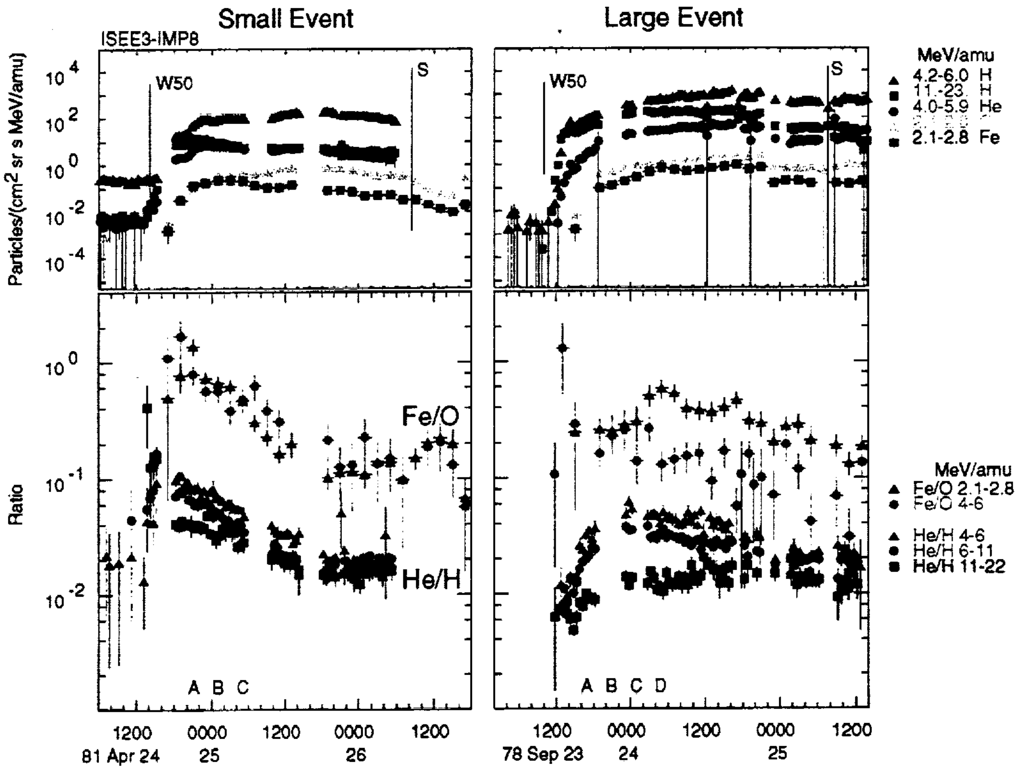

Fig. 3. Intensities and abundances of ion species *vs.* time are compared for the small 1981 April 24 SEP event and the large 1978 September 23 event.

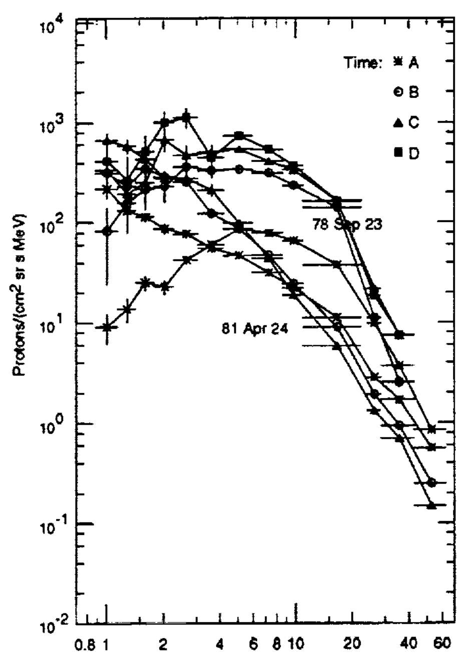

Fig. 4. Proton energy spectra are shown at several times, labeled A-D, corresponding to the times noted along the time axis in Figure 3.