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## VARIATIONS IN ELEMENTAL COMPOSITION OF SEVERAL MEV/NUCLEON IONS OBSERVED IN INTERPLANETARY SPACE

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### ABSTRACT

We have surveyed six years of accumulated ISEE-3 and IMP-8 data to study variations in elemental relative abundances among the different populations of energetic (1.5 to >10 MeV/nuc) ions seen in interplanetary space. We present evidence suggestive that heavy ion enrichments may be organized (with substantial scatter) by a rigidity scaling factor  $A/Z^*$  over the range H to Fe. We also show some data to support the hypothesis that shock-associated particles are probably accelerated from ambient energetic fluxes.

**1. Introduction.** The elemental composition of solar energetic particle (SEP) events has been the subject of a number of recent studies [1,2,3,4,5,6]. This paper is a report of results from a new, ongoing study of low energy (1-10 MeV/nucleon) elemental composition with combined data from the Goddard particle experiments on ISEE-3 and IMP-8.

**2. Abundance Distributions.** We have identified nearly 150 separate events, which occurred between 1978 and 1983, with >50 Oxygen counts in the ISEE-3 energy band 1.9 to 2.8 MeV/nucleon. Of these events, we can associate about one-half with solar flares. The other periods are either shock-associated or of unknown origin. Figure 1 contains histograms of the abundance ratios H/O, He/O, C/O, Si/O and Fe/O constructed from event averages of the flare events. The arrows indicate median values in the distributions. Data for He and heavier ions comes from the ISEE-3 experiment, data for H and again He comes from IMP-8. We note that the He/O, C/O and Si/O distributions are narrow compared to H/O or Fe/O and that there is a high abundance tail in the Si/O distribution.

Histograms constructed using our identified shock events or from those increases that are of unknown origin tend to follow the same

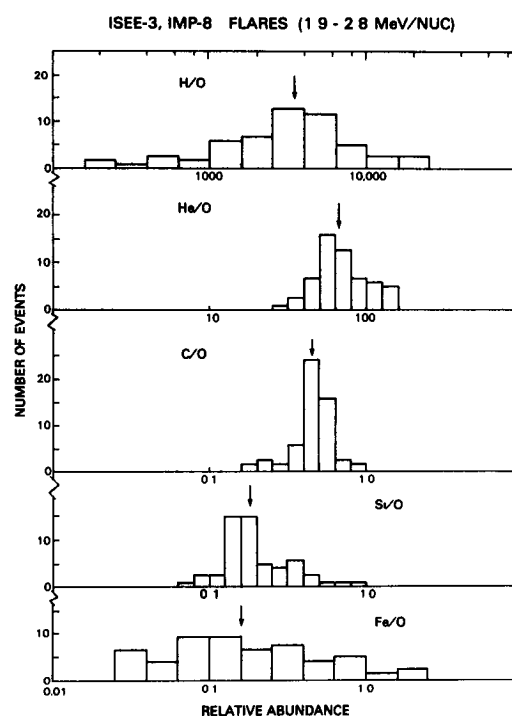


Fig. 1. Abundances in flare events.

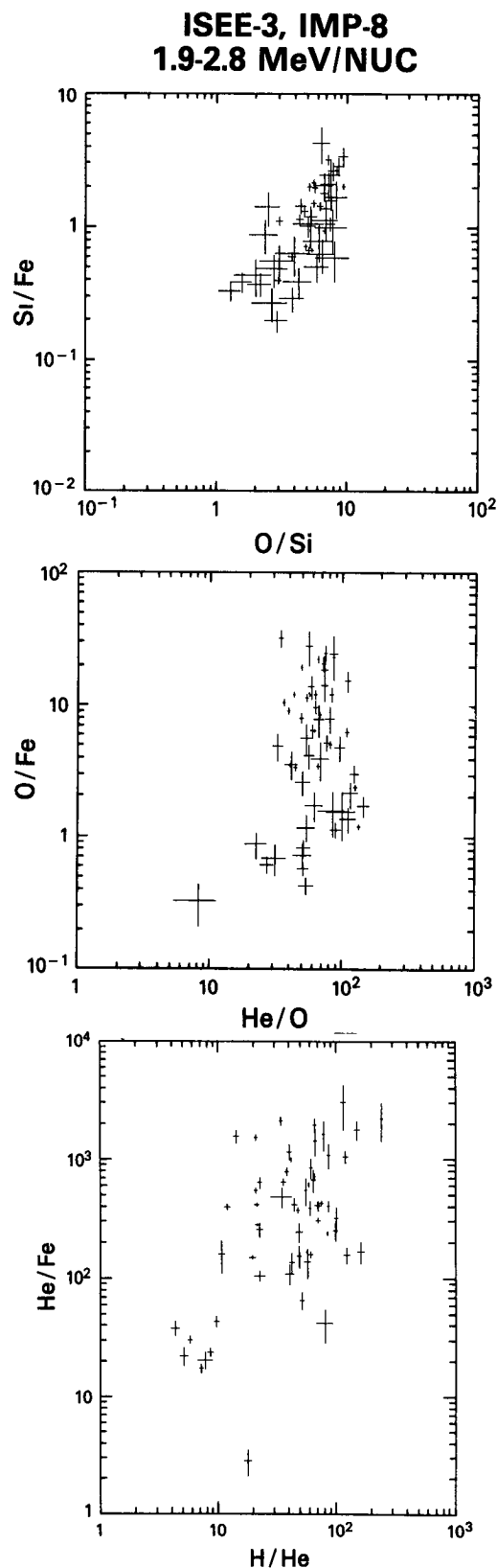
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general range and distribution of values as the flare events in Figure 1, except that there are fewer Fe-enriched events.

**3. Abundance Correlations.** An important question in the interpretation of heavy-ion enrichments is whether atomic number ( $Z$ ), atomic mass ( $A$ ) or the rigidity-scaling factor mass divided by effective charge ( $A/Z^*$ ) best organizes the enrichment factors for different elements. Note that  $A/Z^*$  for H:He:O:Si:Fe fall in the approximate ratios 1.0:2.0:2.2:2.6:4.0, using the charge state measurements of [7]. Thus the relative histogram widths in Figure 1 are consistent with  $A/Z^*$  as the organizing parameter, in that largest differences in  $A/Z^*$  give rise to the widest distributions.

To further explore this idea, we present a series of scatter plots of the flare data in Figures 2a-2c. Figure 2a shows O/Si versus Si/Fe. The trend as seen (larger O/Si imply larger Si/Fe, a positive slope) is the trend expected given that heavy ion enrichments increase monotonically with e.g. increasing  $A/Z^*$  [1,2,3,4,6]. Note the common factor of the Si abundance in the denominator of O/Si and the numerator of Si/Fe. If variations (from whatever cause) in O and Fe were not correlated with variations in Si, we might still find an apparent correlation in the ratios because of this common factor but with a negative slope. The amplitude of the random variations determines whether such an effect will be seen. Figure 2b shows He/O versus O/Fe. Given the narrow distribution of He/O in Figure 1, it is not surprising that we find,

Fig. 2. Scatter plots of flare abundance ratios: (a) O/Si vs Si/Fe, (b) He/O vs O/Fe, and (c) H/He vs He/Fe.



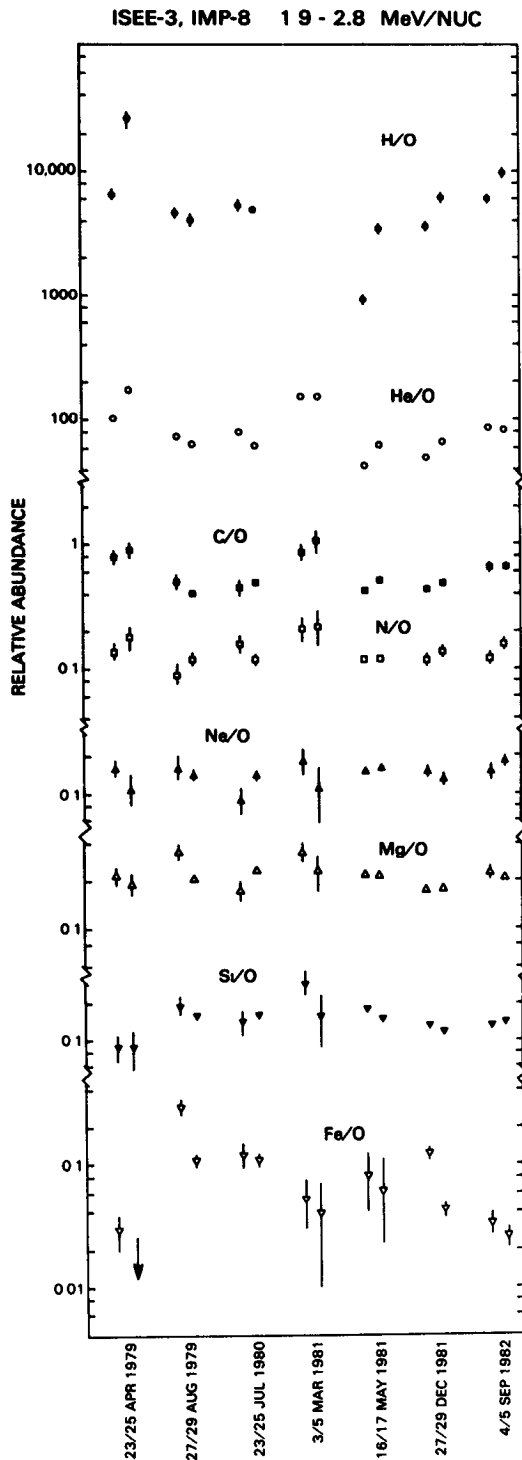


Fig. 3. Abundances for 7 pairs of events (ambient energetic flare particles and shock-associated particles).

at best, only a slight positive slope to the correlation. This plot is also consistent with  $A/Z^*$  organization since the scaling factors for He and O are similar. It is not easily understood in terms of organization by Z or A separately. Random variations would again give a negative slope, if any, to the plot.

A plot of higher energy (7.2-12.5 MeV/nucleon) He/O to O/Fe in fact shows such a negative slope. This higher energy data is consistent with the published ratios of McGuire et al. (1979,1985) but we emphasize that such a negative slope is ambiguous because of the common factor in the ratios. That the nature of these plots changes with energy may be only a consequence of the increased scatter in the relative fluxes at the higher energies.

Figure 2c shows H/He versus He/Fe. Here too there is a suggestion of positive slope (possibly larger in magnitude than that of He/O versus O/Fe) but the trend is obscured by the overall scatter in the data. If  $A/Z^*$  organizes the data overall, we would expect H/He to be positively correlated with He/Fe or O/Fe. We note that H and He spectral slopes are generally not equal [2,8,9]; the unequal spectral slopes may be largely responsible for the scatter. Other explanations for a general coincidence of low H/He ratios with higher Fe abundances (for instance, special plasma conditions required in the source region for an Fe enrichment to take place [10]) are also clearly possible.

4. A Source Population for Shock-associated Particles. A quite different question of concern to us is that of the source population in shock-associated energetic particle

flux increases. In particular, if these particles are locally accelerated, then we might expect the shock particles to mirror the abundances of ambient energetic particle fluxes. In Figure 3, we have plotted elemental abundances as pairs of events (event-averaged abundances preceding the shock particles and abundances in the flux peak associated with the shock) for a select set of events. In these events, the ambient peak was separable from the shock peak (at the energy range of the composition data, again from 1.8-2.8 MeV/nucleon) and both averaged fluxes were sufficient to satisfy the >50 Oxygen count limit. Those events with unusual composition (e.g. high C/O ratios) were expected to be the most useful in testing the hypothesis. Unfortunately, few events satisfied the selection criteria and these had mostly average composition. In general, we do believe the abundance pairs as plotted are consistent with local acceleration of the shock-associated particles from the ambient energetic populations. The plot does not however provide strong positive evidence for the idea. We note that variation in H/O between the ambient and shock particles might be expected because the energy spectra are steepened generally at shocks and because the ambient H and He spectra do not have the same slope. Fe/O is complicated by the kind of temporal variations that occur in many events [6,11,12], specifically where Fe/O is higher at the event onset than near the shock arrival time.

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