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Isotopic Composition of SEP Neon as Measured by ACE/ULEIS

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Abstract

Since its August 1997 launch, the Ultra-Low-Energy-Isotope (ULEIS) instrument onboard the ACE spacecraft has observed over two dozen solar energetic particle (SEP) events with sufficiently large fluences for isotopic measurements of neon. In the 0.5 - 3 MeV/nucleon range these events show remarkable variability of both the elemental and isotopic compositions. In this report, we present preliminary measurements of the $^{22}Ne/^{20}Ne$ ratio for these SEP events. We have further selected two subsets of the data according to whether $^{3}He/^{4}He > 0.007$. For the ^{3}He-poor subset, we find that $^{22}Ne/^{20}Ne$ shows only a weak dependence on Fe/Mg and is marginally consistent with a constant value of 0.064 ± 0.008 — within statistical uncertainty of the solar wind value of 0.073. The $^{22}Ne/^{20}Ne$ data for the ^{3}He-rich subset, on the other hand, shows a significant correlation with Fe/Mg and can be described by a power-law in Fe/Mg with a power-law index of 1.05 ± 0.25. This value is much larger than expected from the simple charge to mass dependence derived by Breneman and Stone (1985) for the elemental abundances.

The Ultra-Low-Energy-Isotope (ULEIS) instrument is part of the Advanced Composition Explorer (ACE), launched in August 1997 (Mason *et al.* 1998). The ACE spacecraft contains a large collection of modern instruments designed to measure elemental and isotopic composition over an energy range covering the solar wind up through galactic cosmic-rays. The ULEIS instrument is a time-of-flight mass spectrometer with a geometry factor of 1 cm^2 sr, designed to measure protons through iron in the energy range ~ 0.1 - 10 MeV/nucleon. The excellent mass resolution ($\sigma < 0.2$ amu for oxygen at 1 MeV/nucleon) and low background of ULEIS allow precise isotopic measurements of solar energetic particles (SEPs) which were unavailable before ACE. By studying the variations in isotopic and elemental abundances, we hope to gain insight into the acceleration mechanisms that produce SEPs and ultimately to measure the isotopic composition of the sun.

We have analyzed the ULEIS data for the first year and a half of operation, and have selected 24 events for this study. We require that the fluence of the event be large enough to give adequate statistics to measure $^{22}Ne/^{20}Ne$, Fe/Mg in the 0.8 - 3.0 MeV/nucleon energy range and $^{3}He/^{4}He$ in the 0.5 – 1.5 MeV/nucleon range. These energy ranges give the optimum mass resolution and counting statistics for the measurements. The events were then grouped according to the $^{3}He/^{4}He$ ratio, also measured by ULEIS. An event is classified as ^{3}He-rich if $^{3}He/^{4}He > 0.007$ and ^{3}He-poor if $^{3}He/^{4}He \leq 0.007$. Figure 1 shows Fe/Mg versus $^{3}He/^{4}He$ for the events of this study. We use Fe/Mg here, rather than the more common Fe/O, because Fe and Mg have nearly identical first ionization potentials (FIPs). This removes possible FIP fractionation, which is known to affect the elemental abundances but should not affect the isotopes. As can be seen in the figure, the data all fall well above the solar wind value of $^{3}He/^{4}He \sim 4.9\times10^{-4}$ (Coplan *et al* 1984). While there is no unique value to separate the ^{3}He-rich events, the value 0.007 tends to place most of the clearly "impulsive" events on the high side and the clearly “gradual” events on the low side. We note that identifying all of these events as either “impulsive” or “gradual” would be very useful. However, we have found that classifying events in this manner is by no means straightforward, so we leave this work to a future study.

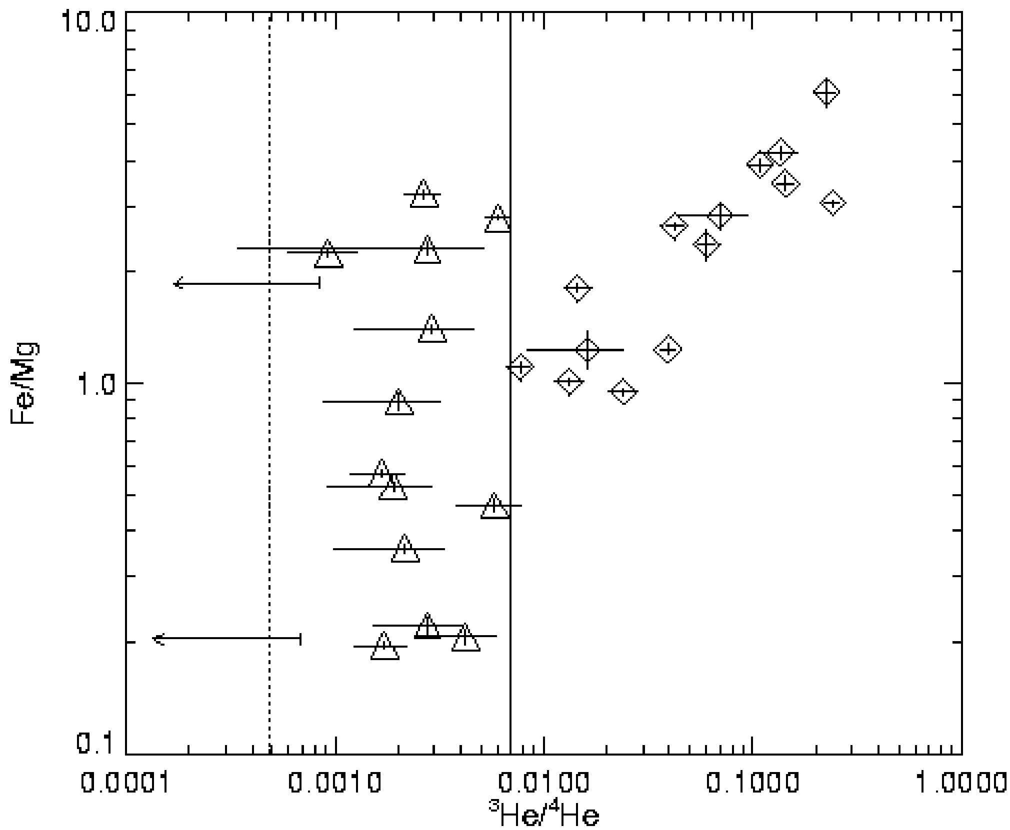

Figure 1. Fe/Mg versus ^{3}He/^{4}He for the events of this study. The vertical dotted line corresponds to the solar wind value. The solid line is the value used to select ^{3}He-rich (diamonds) and ^{3}He-poor events (triangles).

Figure 2. shows the ACE/ULEIS mass histograms in the 0.8 – 3.0 MeV/nucleon energy range for all the ^{3}He-rich (top panel) and all the ^{3}He-poor (bottom panel) events. As can be seen, the ^{3}He-rich events have, on average, a larger ^{22}Ne/^{20}Ne ratio than the ^{3}He-poor events. Figure 3 shows the ^{22}Ne/^{20}Ne versus Fe/Mg in this same energy range. Again, the top panel consists of the ^{3}He-rich events and the bottom panel the ^{3}He-poor events. The dotted lines in the figure show the solar wind abundances, ^{22}Ne/^{20}Ne = 0.073 (Anders. and Ebihara 1982) and Fe/Mg = 1.333 (Geiss *et al.* 1994), and the solid lines show the best fit power-law to the data. . The power-law indices are 1.05 ± 0.25 (chi^2/ν= 0.3) for the ^{3}He-rich events and 0.29 ± 0.1 (chi^2/ν= 1.2) for the ^{3}He-poor events. When the ^{3}He-poor events are fit to a constant value then we find ^{22}Ne/^{20}Ne = 0.064 ± 0.008 (chi^2/ν= 1.5).

Breneman and Stone (1985) found that the enhancements and depletions of the elemental abundances of SEP events with respect to the solar values could be fit with a power-law in the charge to mass ratio, Q/M. If we assume that such a relationship also holds for the isotopes then, assuming Q_{Mg}/Q_{Fe} =0.66 which remains approximately true even as Q_{Fe} and Q_{Mg} vary, then ^{22}Ne/^{20}Ne should change as a power-law in Fe/Mg with a power-law index of 0.23 (dashed lines in figure 3). This is in reasonable agreement with the ^{3}He-poor events, but it is at least a factor of 4 too low for the ^{3}He-rich data.

If the energetic particles can be regarded as test particles in an electromagnetic field then their behavior should be completely governed by their velocity and Q/M. Because the difference in Q/M for ^{22}Ne and ^{20}Ne is only 10%, much smaller than the ~40% difference in Q/M for Mg and Fe, it is quite surprising that, for the ^{3}He-rich data, the variations in ^{22}Ne/^{20}Ne are so large when compared to the variations in Fe/Mg.

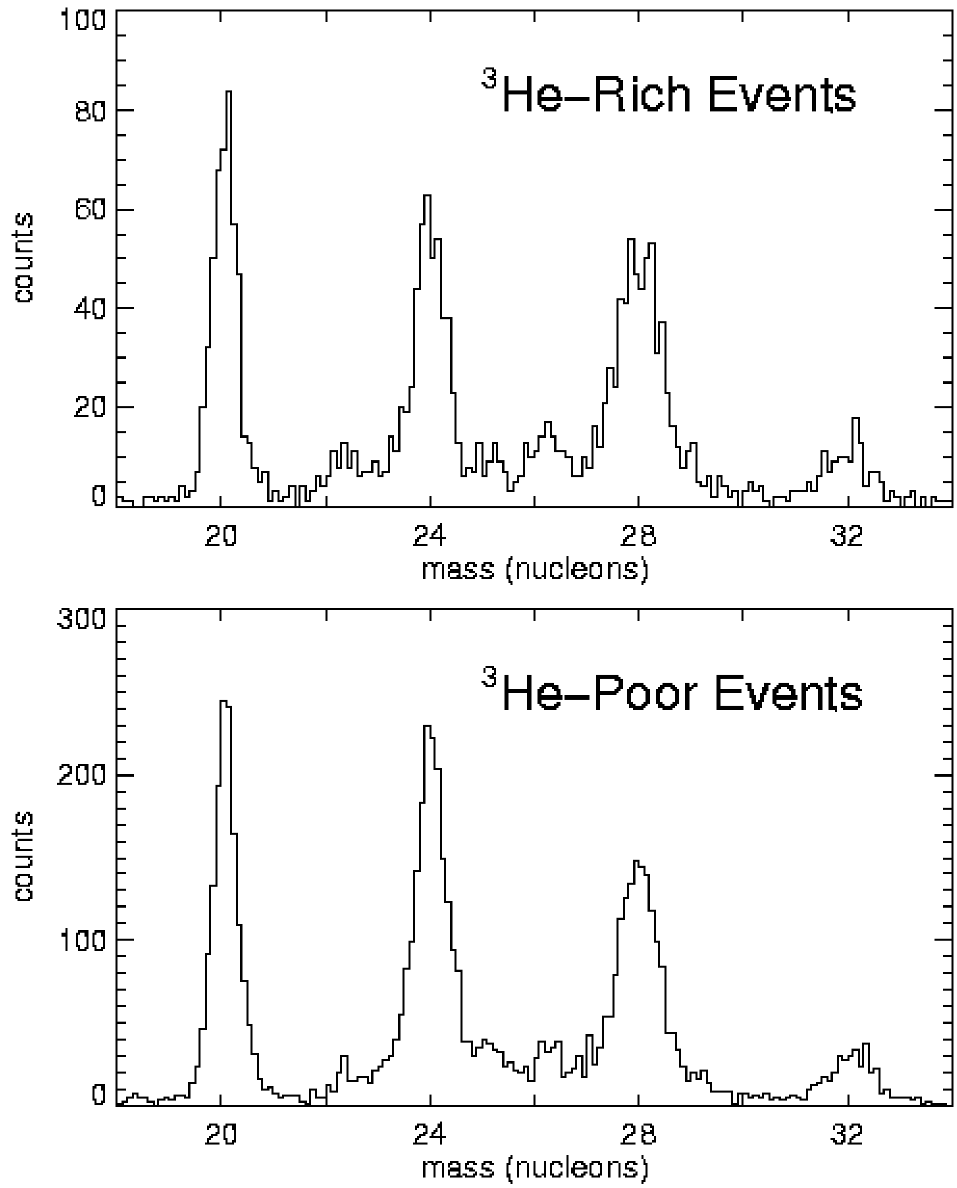

Figure 2. Mass histogram of 0.8 - 3.0 MeV/nucleon ACE/ULEIS data for all the ^{3}He-rich data (top panel) and all the ^{3}He-poor data (bottom panel). Note the enhancement in ^{22}Ne in the ^{3}He-rich data compared to the ^{3}He-poor data, despite only slight differences in the Ne/Mg/Si/S abundance ratios.

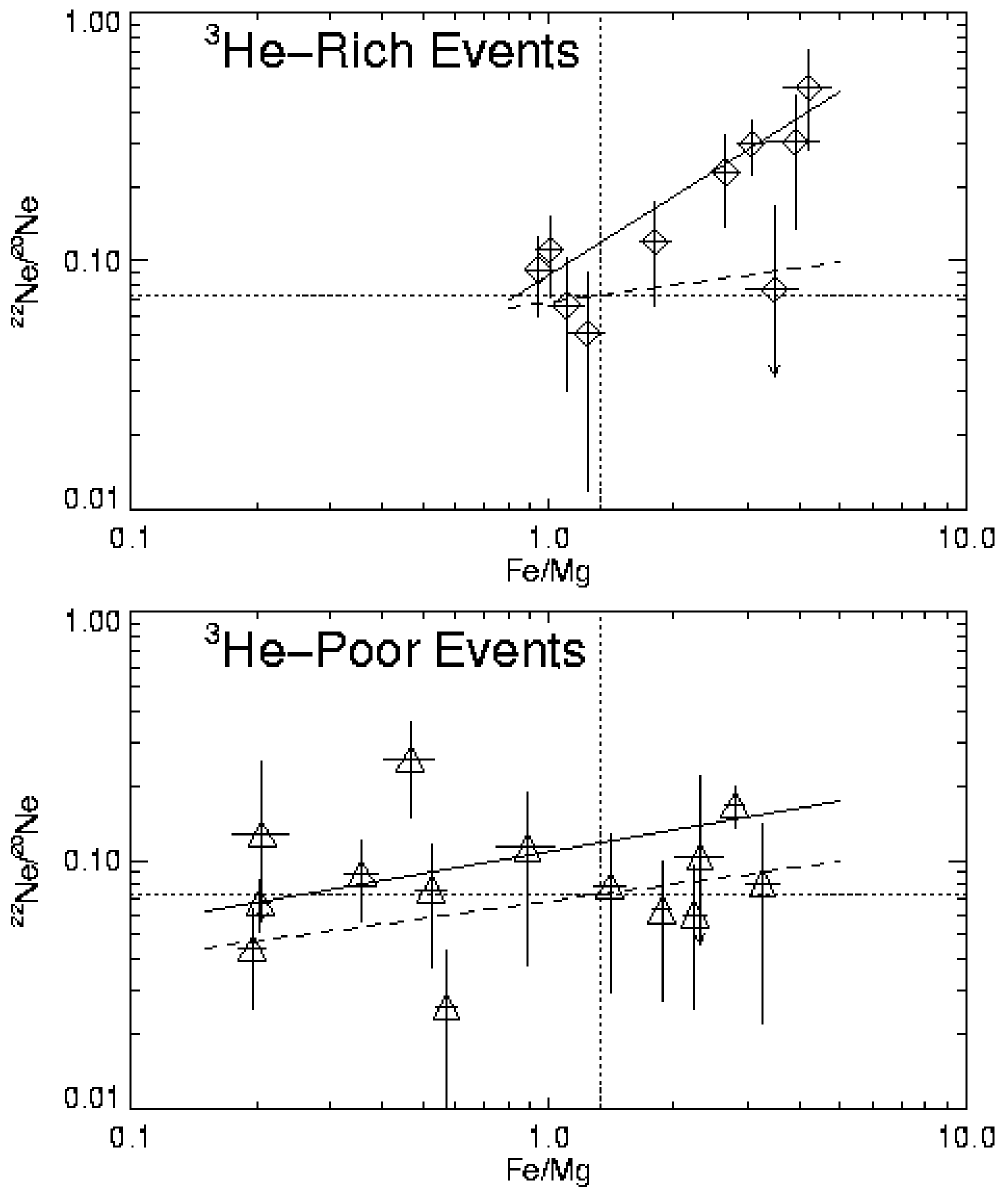

Figure 3. $^{22}Ne/^{20}Ne$ versus Fe/Mg measured at 0.8 - 3.0 MeV/nucleon for ^{3}He-rich events (top panel) and for ^{3}He-poor events (bottom panel). The dotted lines show the solar wind values. The solid lines are the best fit power-law to the data, and the dashed lines are the expected variation if the fractionation depends upon a power law with respect to Q/M.

References

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