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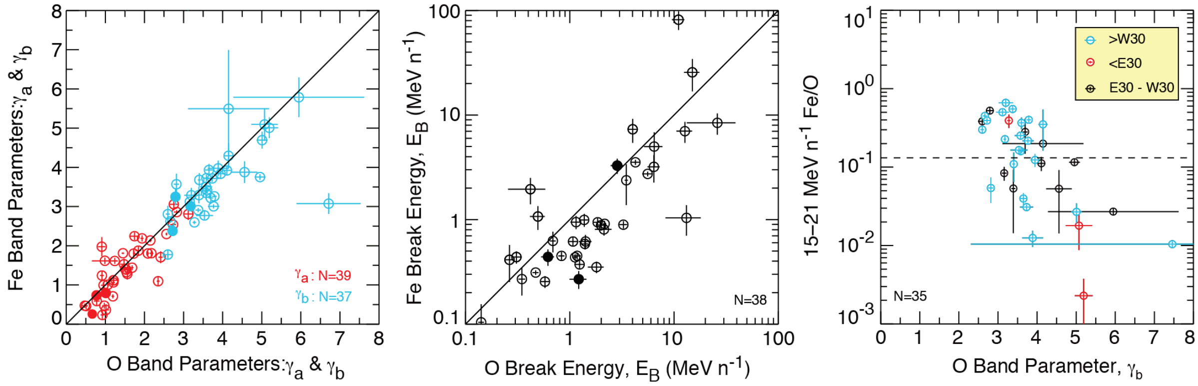
Behavior of Fe and O Spectra in Large Solar Energetic Particle Events

The energy spectra of heavy ion species accelerated during large gradual solar energetic particle (SEP) events associated with coronal mass ejections (CMEs) are often represented by two broken power-laws with distinct low and high energy spectral slopes. The absolute values of the power-law slopes and the location of the transition or break energy provides important clues about how the SEPs are accelerated by CME-driven shocks and transported out into the interplanetary medium.



Scatterplots of Fe vs. O Band function fits for large gradual SEP events. Left panel: γ_a (red) and γ_b (blue). Middle panel: E_{Fe} vs. E_O. The solid line indicates the one-to-one relationship. Right panel: O γ_b vs. ~15-21 MeV/nucleon Fe/O. N=number of events plotted.

We surveyed ~0.1-100 MeV/nucleon O and Fe fluence spectra during 46 isolated, large gradual SEP events observed at ACE during solar cycles 23 and 24. Most SEP spectra are well represented by the double power-law Band function with normalization constant, low-energy (γ_a) and high-energy spectral slopes (γ_b), and break energies (E_O and E_{Fe}). We find that the O and Fe spectral slopes are similar and most spectra steepen above the break energy, probably due to common acceleration and transport processes affecting different ion species (left panel). The Fe spectral breaks typically occur at lower energies compared with those of O (middle panel), and spectral slopes above the break energies depend on the origin of the seed population; larger contributions of suprathermal flare material result in higher Fe/O ratios and flatter spectra at higher energies (right panel).

Our results also showed that SEP events with steeper O spectra at low energies and higher break energies are associated with slower CMEs, while those associated with fast (>2000 km/s) CMEs and ground level enhancements or GLEs have harder or flatter spectra at low and high energies, and O break energies between ~1-10 MeV/nucleon. The latter events are enriched in ^{3}He and higher energy Fe, and have Fe spectra that roll-over at significantly lower energies compared with O, probably because Fe ions with smaller Q/M ratios can escape from the distant shock more easily than O ions with larger Q/M ratios. These results show that SEP spectral properties result from many complex and competing effects, namely Q/M-dependent scattering, shock properties, and the origin of the seed populations, all of which must be taken into account to develop a comprehensive picture of CME-associated large SEP events. For further details see, Desai et al., Astrophysical Journal, Vol. 816, 68, 2016; doi:10.3847/0004-637X/816/2/68.

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