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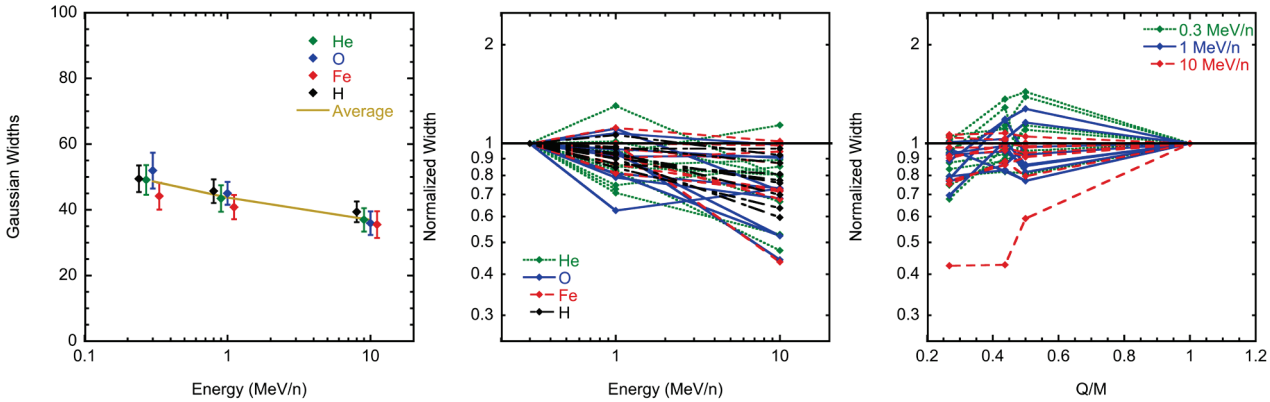
Longitudinal Distributions of Solar Energetic Particle Heavy Ions



Left: *Average distribution widths in degrees as a function of energy for H, He, O, and Fe as determined by fitting longitudinal distributions of 10 three-spacecraft SEP events.* ***Middle:*** *Distributions widths (normalized at 0.3 MeV/n) as a function of energy for the individual events.* ***Right:*** *Distributions widths (normalized to H) as a function of charge-to-mass (Q/M) for the individual events. Lines in the middle and right panel connect values from the same event; color and type distinguish the energy.*

Understanding how energetic particles are injected and transported from the Sun through the interplanetary medium is critical to accurate forecasting of related radiation hazards. Disentangling the effects of acceleration versus those of transport is particularly difficult from single-spacecraft measurements at 1 AU. Multi-spacecraft studies utilizing near-Earth satellites such as ACE and the twin STEREO spacecraft have yielded several results that point toward efficient and rapid distribution of particles throughout the inner heliosphere, at least under certain conditions.

To further our understanding of these results, we have used ACE and STEREO 10 MeV/n oxygen data to select 41 large SEP events observed by at least two spacecraft during 2011-2014. Ten of these events were observed by all three spacecraft, which allowed us to investigate the longitudinal distribution of event integrated fluences for each individual event. With the addition of SOHO and GOES data, we examined the longitudinal widths (i.e., sigmas of fitted Gaussian distributions) of H, He, O, and Fe at 0.3, 1 and 10 MeV/n. Although there have been previous surveys of the longitudinal distribution of SEPs, there has not been one which focuses on heavy ions to address the role of charge-to-mass (Q/M)-related processes or examined so broad an energy range.

For the three-spacecraft events, we find an average width of 43±1°, similar to previous studies; however there is a clear energy dependence (left panel of the figure above) with the distribution narrowing with increasing energy. Although there is significant variability in the widths from event to event, the individual results also show an energy dependence (middle panel). Such a dependence is consistent with the lower energy ions being accelerated and released over a larger portion of the shock or for a longer time period over which the shock expands. It could also result from more field line meandering and/or co-rotation experienced by the slower ions as they propagate to 1 AU.

To examine the Q/M dependence of the widths, we assumed charge states of 1, 2, 7, and 15 for H, He, O, and Fe (respectively) and normalized the individual results to the widths obtained for H. Surprisingly there is no clear dependence of the widths on Q/M (right panel). This suggests that cross-field diffusion and other rigidity-related processes are not the dominant means of particle spread in longitude.

More details can be found in Cohen et al. *ApJ*, *in press,* 2017.

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