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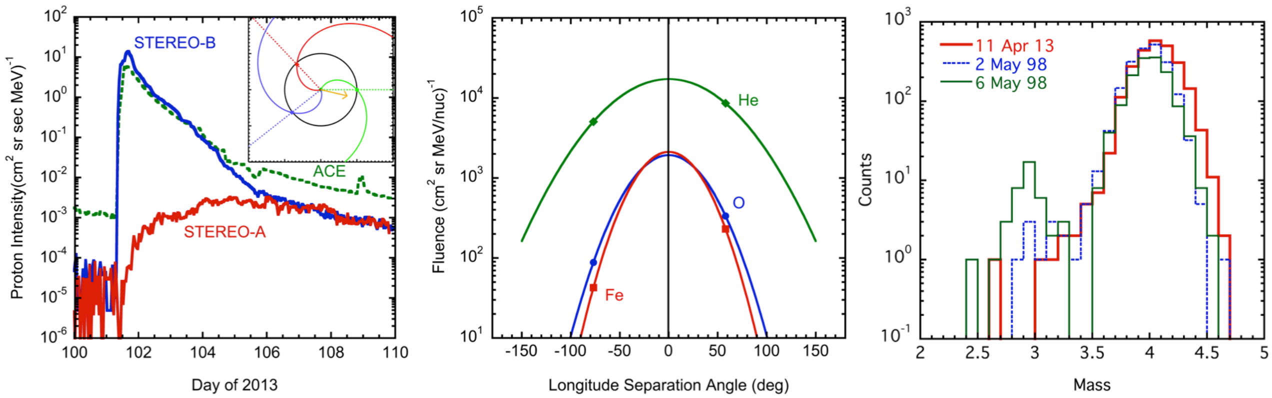
Longitudinal Distribution of Solar Energetic Heavy Ions



Left: *Proton intensities (10-30 MeV) for the 11 April 2013 event from STEREO-A, ACE (background corrected) and STEREO-B; (inset) relative longitudes of the spacecraft and flare.* ***Middle:*** *Longitude distributions of He, O, and Fe at 12-33 MeV/nuc from event-integrated fluences at STEREO-B (58°) and ACE (-77°).* ***Right:*** *He mass histograms from ACE/SIS for this event and two cycle-23 Fe-rich SEP events.*

During the rise to solar cycle 23 maximum, ACE observed several large solar energetic particle (SEP) events with surprisingly enhanced Fe/O abundances. These events typically also had ^{3}He/^{4}He values 4-10 times the solar wind value. Although there was a consensus that flare-accelerated SEP material was being mixed with shock-accelerated material, there was debate as to how this occurred: through direct mixing or by shock acceleration of remnant flare suprathermal ions. One possible discriminator is the longitudinal dependence of the Fe/O ratio, which can be best measured by multiple spacecraft. Such an opportunity presented itself on 11 April 2013 when an M6.5 X-ray flare occurred in active region 11719, accompanied by a moderately fast (~800 km/s) and wide (~150°) coronal mass ejection. The resulting SEP event was observed by ACE and both STEREO spacecraft (left panel), although only STEREO-B and ACE observed heavy ions at measureable intensities with energies >10 MeV/nuc.

The longitude of the footpoint of the magnetic field line passing through each spacecraft was determined assuming a Parker spiral corresponding to the observed solar wind speed (the relative positions of the three spacecraft are given in the left panel inset). In the middle panel the He, O, and Fe event-integrated fluences (at 12-33 MeV/nuc) from ACE and STEREO-B are plotted versus the longitudinal separation between these magnetic footpoints and the flare location. Assuming a Gaussian distribution centered at the flare location, the longitudinal dependences of the elemental fluences are given by the solid curves. These suggest a Fe/O ratio ~1 at positions magnetically connected directly to the flare, although the longitudinal dependence of the Fe/O ratio is not strong; the ratio decreases by only 44% over 135° (from STEREO-B to ACE). This is consistent with the direct flare contribution scenario proposed by Cane et al. (2003, 2006). The alternative scenario of Tylka et al. (2005) in which SEP composition is determined by the orientation of the shock and the composition of the seed particle population is another possible interpretation of the fact that both ACE and STEREO-B observed enhanced Fe/O abundance ratios despite neither being magnetically well connected to the flaring region. In this interpretation, the fact that the measured composition was slightly different at the two spacecraft might result from a longitudinal dependence to the orientation of the shock and/or the composition of the seed particle population. Given the large separation between the two spacecraft, this is not unreasonable.

Surprisingly, unlike the Fe-rich events of cycle 23, the 11 April 2013 event did not exhibit enhanced ^{3}He/^{4}He ratios. He mass histograms from ACE/SIS are shown in the right panel for this event and two cycle-23 events. The 6 May 1998 event exhibited the largest (4%) ^{3}He/^{4}He ratio and 2 May 1998 the lowest (< 0.2%) of the Fe-rich events of cycle 23. The 11 April 2013 event appears to have less ^{3}He than in 2 May 1998. Additional details on this event are given in Cohen et al. (ApJ, 793, 35, 2014).

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