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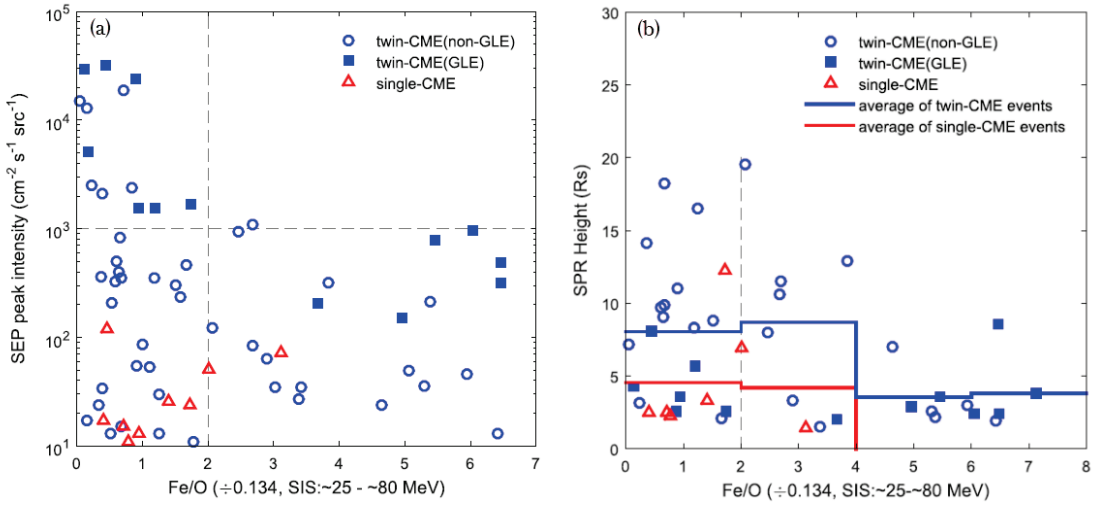
Seed Population in Large Solar Energetic Particles (SEPs) and the Twin-CME Scenario



Panel (a)*: Peak intensity of large SEP events plotted vs. the normalized Fe/O ratio.* ***Panel (b)****: Solar particle release (SPR) height near the Sun in each SEP event plotted vs. Fe/O. Blue and red symbols indicate large SEP events associated with twin-CME and single-CME events, respectively. Circles are non-GLE SEPs and squares are GLEs.*

It has been suggested that Ground-Level Enhancements (GLE) and other large SEP events are more likely caused by twin-CMEs than single CMEs [Gopalswamy et al. JGR, 2004; Li et al., SSR, 171, 2012, Ding et al, ApJ, 763, 2013]. In the twin-CME scenario, the shock driven by the preceding CME provides both an elevated turbulence level and enhanced seed population at the main CME-driven shock. However, since the inferred acceleration site is close to the Sun, confirming the existence of enhanced turbulence and/or seed populations via in-situ observations is hard. Recently, Ding et al. examined the event-integrated iron to oxygen ratio (Fe/O) above 25 MeV/nuc for large SEP events in solar cycle 23, in an attempt to reveal the effect of preceding CMEs on the seed population.

An enriched Fe/O ratio (>2.0x) has been suggested as an indicator of flare material (Cane et al. 2006). In the Figure above, the peak flux intensities of large SEP events are shown in *panel (a)* as a function of the normalized event-integrated Fe/O ratio. All events with Fe/O>2.0 are twin-CME events except one, and all single-CME events have normalized Fe/O ratios ≤ 2.0 except one. For twin-CME events, the normalized Fe/O ratio has larger scatter, and many events have Fe/O ratios > 2.0, suggesting the presence of flare seed material, likely from pre-flares. *It is also found that most extremely large SEP events, defined as having Ip > 1000 pfu, are twin-CME events, but all but one have Fe/O ≤ 2.0.* We suggest that these events have Fe/O ≤ 2.0 because in order to generate these events the intensity of the seed particles has to be large and comparing to pre-flares, pre-CMEs can produce more seed particles, so the Fe/O ratio in these event are coronal-like rather than flare-like. Furthermore, the event-integrated intensity of extreme events shows no correlation with flare class or CME speed (see Figure 3 in Ding et al., ApJ, 812, 2015). This is expected in the twin-CME scenario since the key factor leading to a large SEP event is the seed population and/or the presence of strong turbulence, not flare class or CME speed.

As shown in *panel (b)*, the intensity of GLE events is usually larger than those of other SEP events, suggesting the seed population for GLE events is larger than non-GLE SEP events. And events with higher Fe/O values tend to have lower SPR heights, confirming earlier results of Reames [ApJ, 706, 2009] for GLE events. This also agrees with the twin-CME scenario. Furthermore, the SPR height for GLE events are often lower than 5Rs, suggesting that plenty of seed particles must exist very low in the corona in order to generate a GLE event. For additional details and references, see Ding et al., [ApJ, 812, 2015].

This item was contributed by L.G. Ding (NUIST, China) and G. Li (University of Alabama/Huntsville). Address questions and comments to gang.li@uah.edu. *For earlier ACE News Items see ACE News Archives.*