# ACE News #156 – October 26, 2012
# A New Explanation of Energy-Shift Phenomena in Solar Energetic Particles

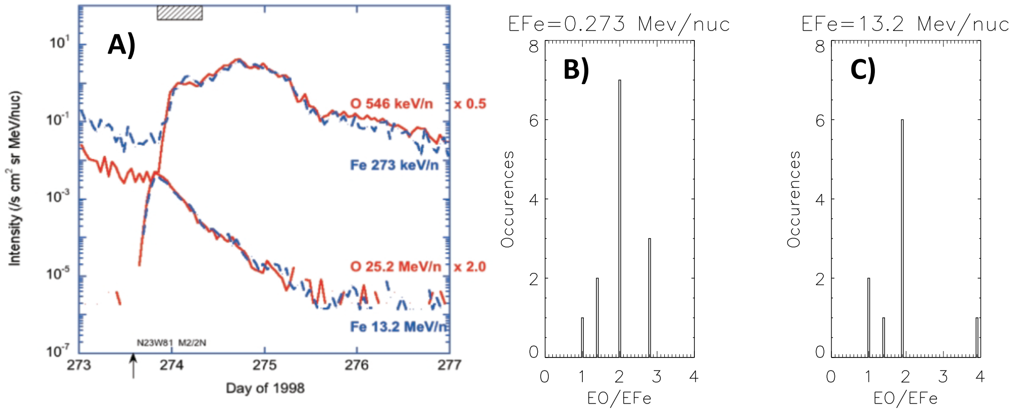


Figure. A) The "energy-shift" phenomena observed by ACE/ULEIS on September 30, 1998. The factor ($E_O/E_{Fe}$) found in 14 SEP events for B) $E_{Fe}$=0.273 MeV/n and C) $E_{Fe}$=13.2 MeV/n. Mason *et al.* [2006].

It has been 6 years since Mason *et al.* [*ApJ*, **647**, L65-L68, 2006] drew attention to a remarkable aspect of the behavior of energetic ions in some solar energetic particle (SEP) events. If the intensity histories j(E,t) of ions of two species (O and Fe) were compared for two *different* values of energy/nucleon ($E_O \neq E_{Fe}$) by normalizing their hour-averaged intensities near the maximum of the event, their histories remained almost identical for more than a day (Fig. A). The most probable value of the ratio was $E_O/E_{Fe}=2$ for the 14 SEP events reported (see Figs. B and C) for Fe energies differing by a factor ~50 ($E_{Fe}$=0.273 MeV/n and $E_{Fe}$=13.2 MeV/n).

Explanations for this "energy-shift" were later offered in the literature using diffusion-convection transport equations with adjustable propagation parameters, e.g., Sollitt *et al.* [*ApJ*, **679**, 910-919, 2008]. Recently Roelof [*AIP Conf. Proc., in press,* 2012] derived a different transport equation that describes the "reservoir"-like decay phase of SEP events characterized by small field-aligned intensity gradients [Roelof *et al.*, *J. Geophys. Res. Lett.,* **19**, 1243-1246, 1992] that immediately implies the energy-shift.

$$\partial \ln f/\partial t + [\xi v\mathbf{b}+\mathbf{V}_\perp+(2/3)\varepsilon\nabla\times(\mathbf{B}/B^2)]\cdot\nabla \ln f +(1/3)(\nabla\cdot\mathbf{V}_\perp)\partial \ln f/\partial \ln p = - vB\partial(\xi/B)/\partial s$$

In the above equation: f = phase-space density = $j/p^2$; ξ = pitch-angle anisotropy parallel to the magnetic field ($\mathbf{B}=\mathbf{b}B$); ds = differential distance along the field line; $\mathbf{V}_\perp$ = plasma velocity transverse to **B**, p = mv = particle momentum; and ε = (total energy/charge) for non-relativistic ions. Note that v and ξ appear only as a product, and in the decay phase of SEP events $\xi v \approx 2(\gamma+1)V_\parallel$ according to the Compton-Getting effect. Thus if the ion species exhibit similar power-law intensity spectral slopes ($\gamma = -\partial \ln j/\partial \ln E$), then the factor (ξv) is correspondingly independent of ion species. The only parameter remaining in the equation is (ε), since $d\ln p = (1/2)d\ln\varepsilon$, so if two ion populations in an SEP event are ordered solely by energy/charge at some time $t = t_0$, then their intensities must evolve identically for all $t > t_0$ and we will have the situation depicted in Figure A. However, when we express ε = EM/Q in terms of mass/charge, we see that the energies/nucleon for the two ion species must be in the ratio $E_O/E_{Fe} = (M/Q)_{Fe}/(M/Q)_O$. Mason *et al.* [2006] quote from the literature representative charge values in these energy ranges $Q_O$ = 6.67 and $Q_{Fe}$ = 11.67. Since $M_O$ = 16 and $M_{Fe}$ = 56, demanding the same energy/charge results in $E_O/E_{Fe}$ = 2.0 as in the event in Fig. A. The variation of values for $E_O/E_{Fe}$ found in the 14 events (Figs. B and C) is not inconsistent with the range of values for $Q_O$ and $Q_{Fe}$ in different SEP events, supporting the interpretation that "reservoir" decay phases of SEP events are ordered simply by total energy/charge (ε).

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