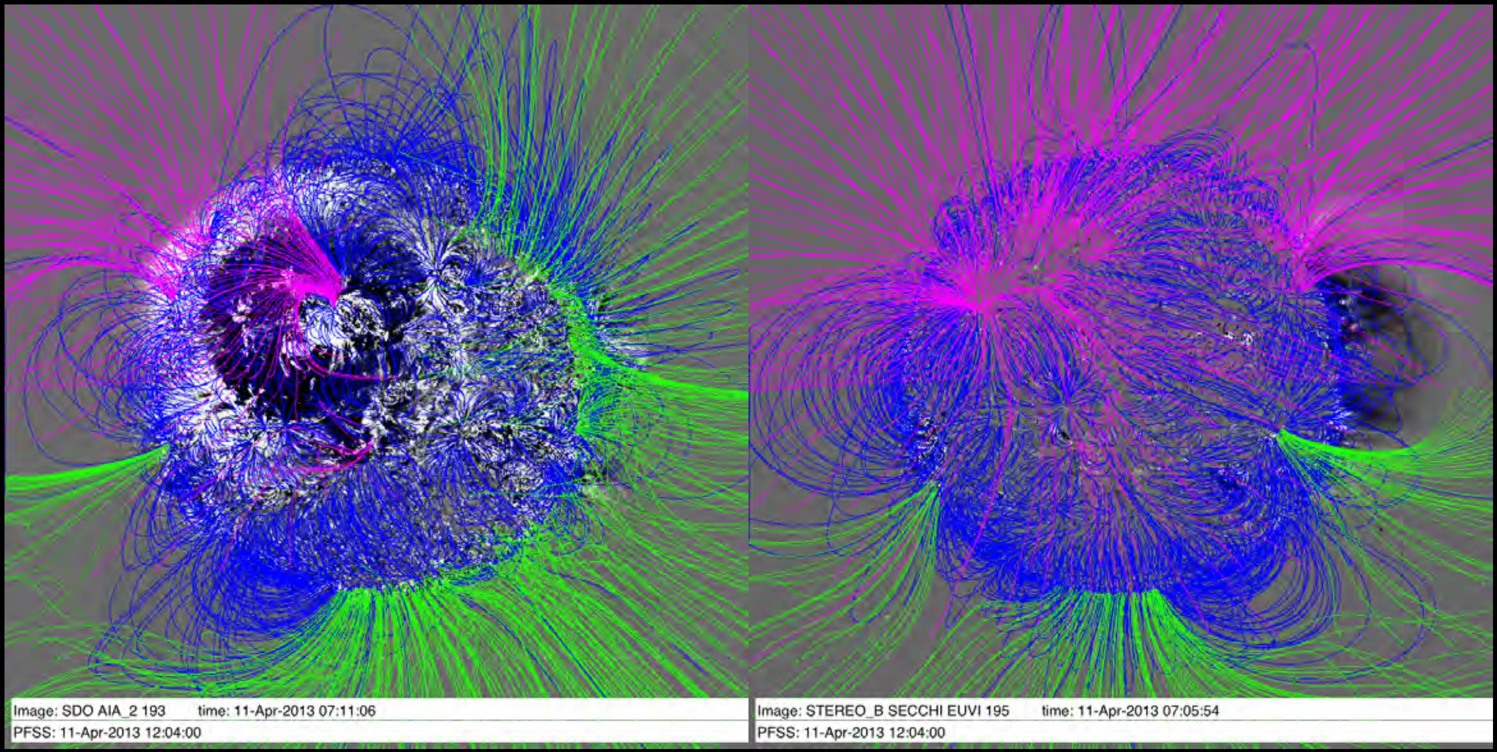
The Relation of Solar Electron Events with EUV Waves Revisited for Solar Cycle 24 Events



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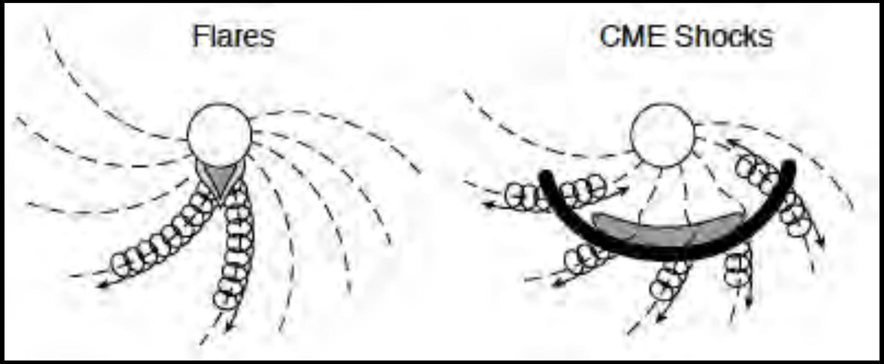
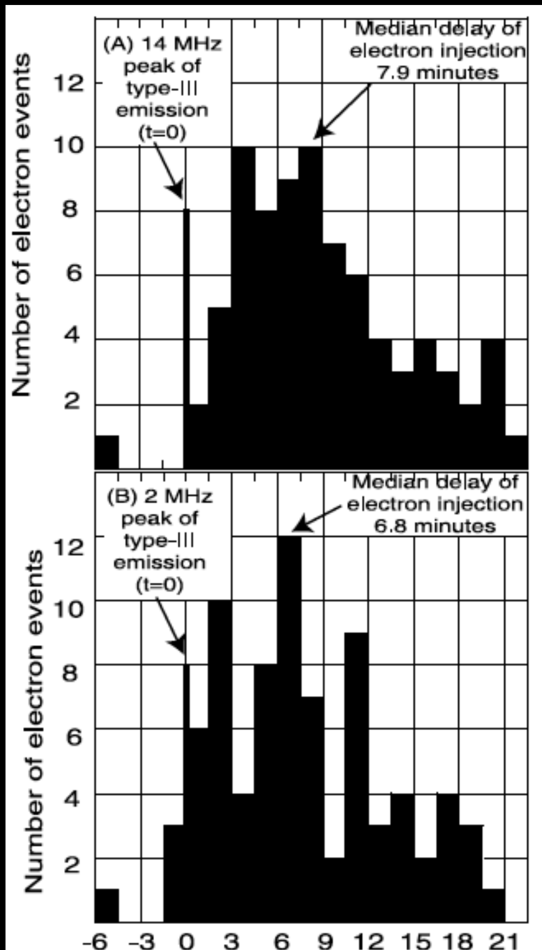
Two Classes of SEP Events

	^{3}He-rich (impulsive)	gradual
Particles	electron-rich	proton-rich
$^3He/^4He$	~ 1 (enrichment 2000 times)	~ 0.0005
Fe/O	~ 1.234 (enrichment 8 times)	~ 0.155
H/He	10	100
Q_{Fe}	$\sim +20$	$\sim +14$
Duration	hours	days
Longitudinal cone	$< 30°$	$\leq 180°$
Metric radio bursts	III, V	II, III, IV, V
Coronograph	–	CME
Solar wind	–	ipl. shock
Event rate/a	~ 1000	~ 10

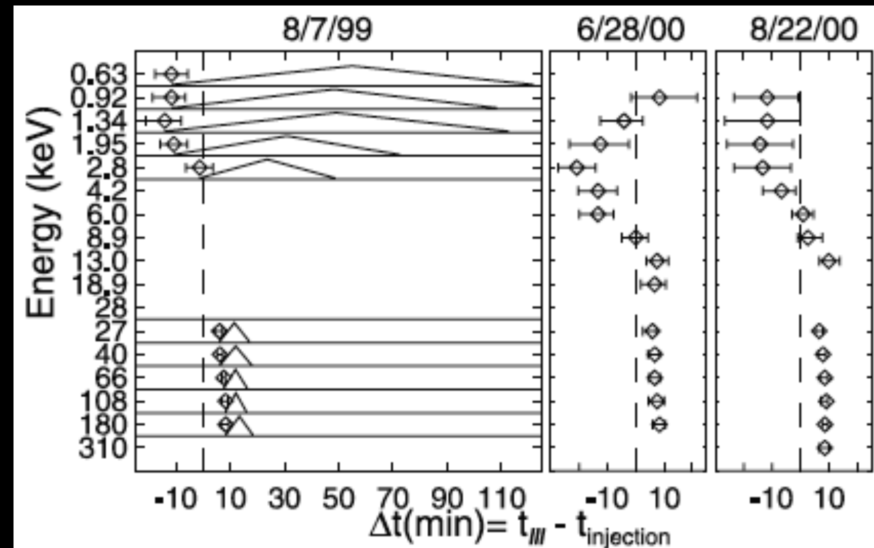


Electrons are universal, also observed in gradual SEP events. But the cartoons like this regarding SEP origin are discussed primarily for ions.

Electron Events and Type III Radio Bursts



Haggerty and Roelof (2002):
38-315 keV beam-like electrons



L. Wang et al.(2006): Wind 3DP

>30 keV electrons sometimes observed later than the start of the associated type III burst

Involvement of CMEs?

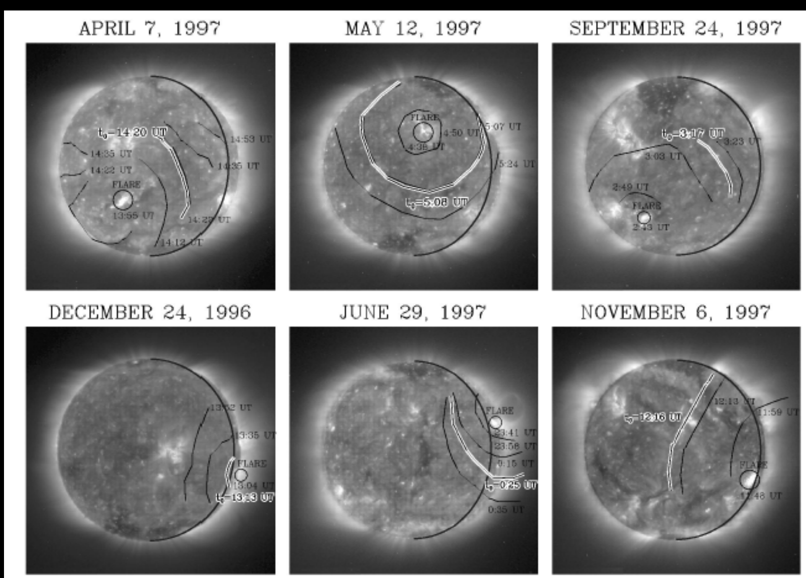
EUV waves – one of low coronal signatures of CMEs

EUV Waves and SEP Events

Proton events associated with an EIT wave – Torsti et al. 1998, 1999

Electron events association with EIT waves – Krucker et al. 1999

The relations are understood in terms of the premise that the particle release in a SEP event starts when the moving acceleration region intersects field lines connecting to the observer (Cliver et al.1982).



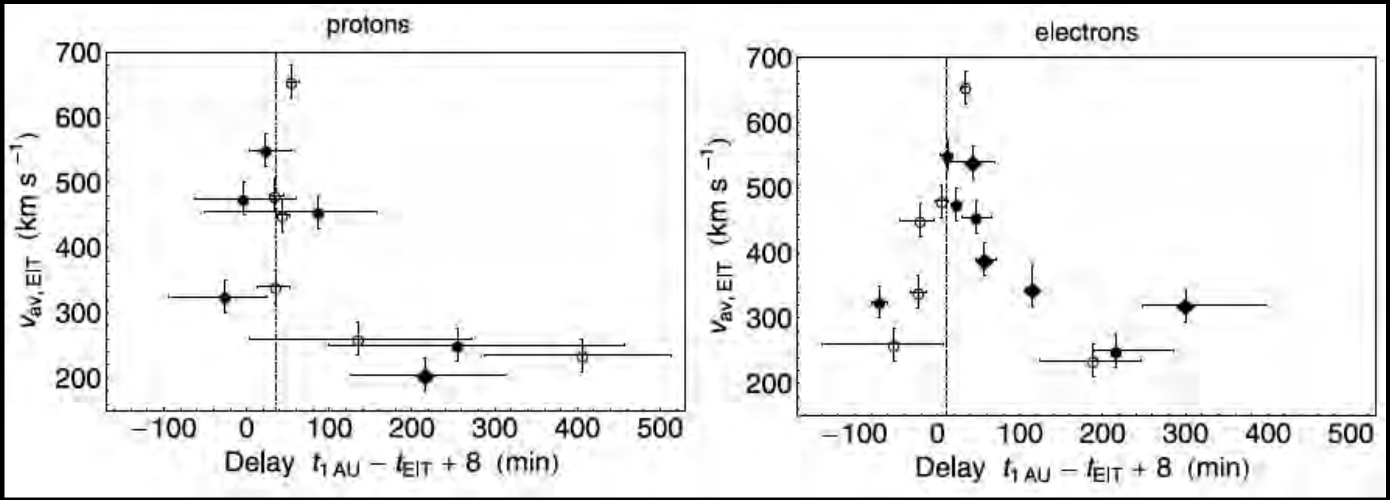
Krucker et al. 1999

Electron events from ill-connected longitudes have delayed onsets, but the EIT wave was found too slow to account for the delay.
EIT waves: 200-400 km s^{-1}, compared with Moreton waves: 500-2000 km s^{-1}

Waves at higher altitudes propagate faster, and they may reduce the discrepancies → need to understand the acceleration region in 3D.

EUV Waves and SEP Events

Study by Miteva et al. (2014): Compared the extrapolated arrival time of the EUV wave at the footpoint of the Parker spiral with the particle onset in the 26 eastern SEP events that were though to have no direct magnetic connection to the Earth.

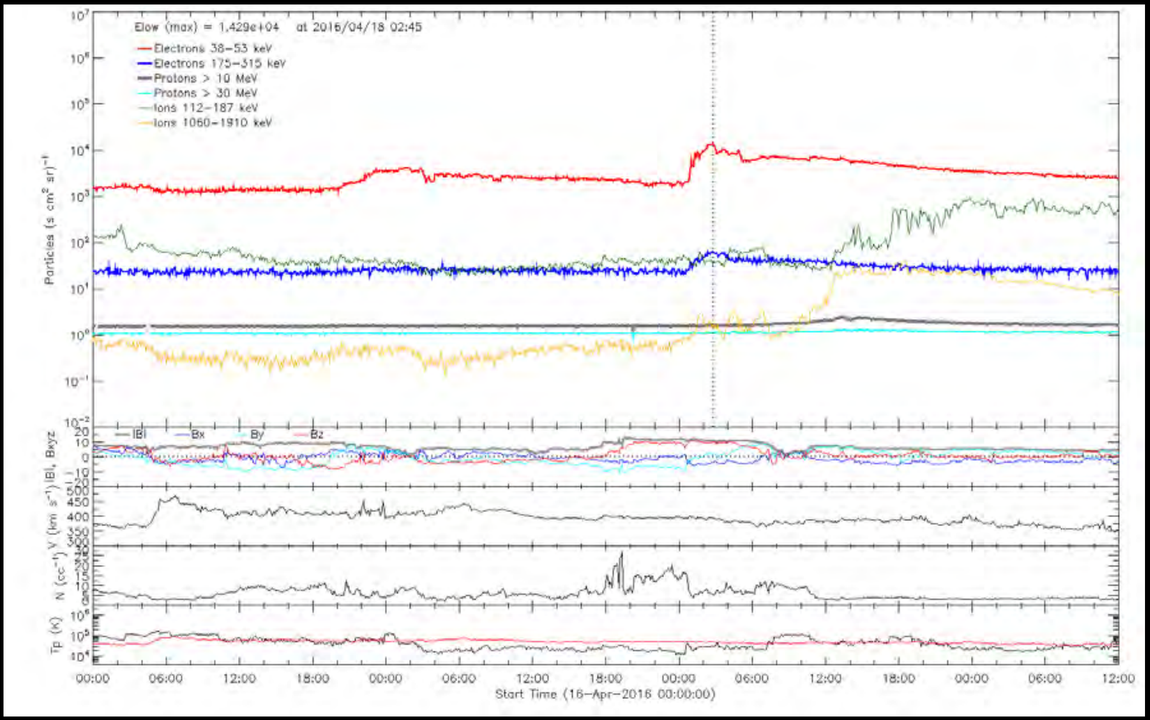


They agreed with Krucker et al. (1999) that EUV waves arrive too late for electrons because of the 4 events in the negative X in the above plot (right). But they did not reject those in which waves arrive too early.

We revisit this with solar cycle 24 events with enhanced observations of EUV waves by SDO/AIA. We also study the magnetic footpoint of the observer, rather than the well-connected longitude of the Parker spiral.

Solar Cycle 24 Near-Relativistic Electron Events

We select electron events after May 2010, using 5 min-resolution ACE browse data, including 10 and 30 MeV protons, ~100 keV and ~1 MeV ions, and solar wind (magnetic field and plasma) data.



Selection criteria include:

- Clean onset of electrons
- Onset not too slow
- Not within an ICME
- No large enhancement of low-energy ions

About 80% of intense events ($>10^4$ (s cm^2 sr)$^{-1}$ in EPAM 38-53 keV) selected above are associated with EUV waves.

Release Time of Electrons

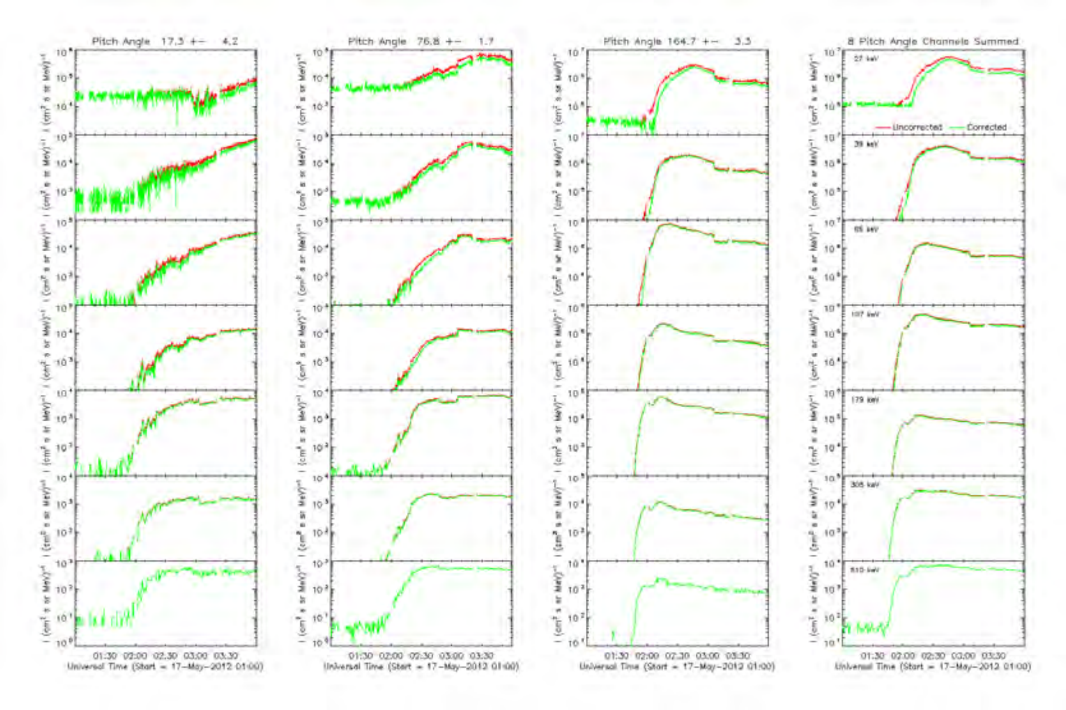
Here we use the time shift (rather than velocity dispersion) method on the Wind/3DP 48–84 keV and SOHO/EPHIN 0.67–3 MeV channels, assuming the range of the path length of 1.05–1.5 AU that translates to the transit times in the range of 9 and 4 minutes in these channels.

We tried velocity dispersion analysis, which should give the particle release time and the path length. But it not only yielded big uncertainties, but also the assumption may be often inappropriate (that particles in all energies are released simultaneously onto the same field lines and that they propagate scatter-free).

We down-selected 50 electron events associated with EUV waves, which have the combined uncertainty of the electron release time less than 15 minutes.

Correction of Wind 3DP Data

For 3DP data, we correct the flux for contamination produced by ~15% of incident electrons that scatter out of the detector (Wang 2009).



The effect of the correction turns out to be negligible at channels above 50 keV. These data in 8 pitch angle bins (only 3 shown) are also used to find anisotropy. Most of our events show some anisotropy.

EUV Wave and the Magnetic Footpoint of the Observer (Connection Point)

Magnetic footpoint of the observer at L1:

- Assume the Parker spiral with observed v_{sw} for R $\geqq$ 2.5 Rs
- Use SolarSoft-based PFSS model for R < 2.5 Rs

No assumption (e.g. circular) on the shape of the EUV wave, no extrapolation

Out of the 50 events, only 3 have the EUV wave traverse the connection point within ±10 minutes from the electron release time. EUV waves arrive more than 10 minutes too early in 29 events, more than 10 minutes too late in 2 events. In the remaining 16 events, the EUV wave never arrives.

The connection point (in cyan) was reached by the wave 8 minutes earlier than the earliest window of the release time of electrons.

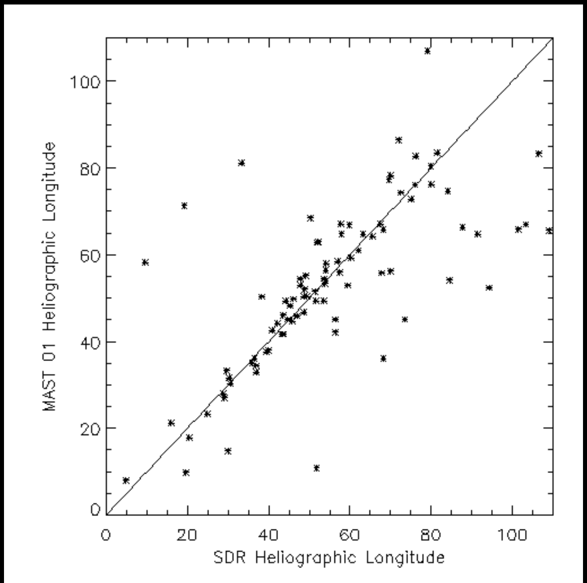
The source region is N11 W76. The connection point is far into the southern hemisphere. The diffuse front almost contacted it, but not quite.

The propagation was highly asymmetrical (as found in EUVI-A data), and there was hardly any indication of the wave on the disk.

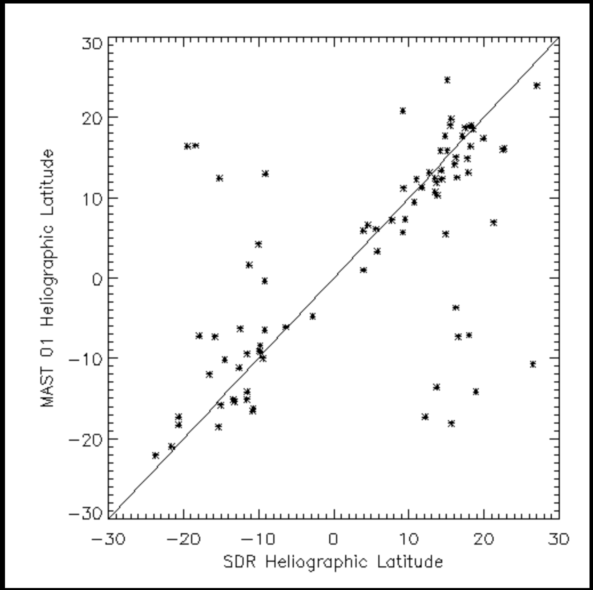
How Well Do We Know the Connection Point?

In 20% of the cases, the solar and in situ polarities mismatch, suggesting that the Parker spiral +PFSS mapping may not always work.

Compare the Parker spiral + PFSS mapping with Predictive Science's mapping. It is again the Parker spiral beyond 30 Rs, but between 1 Rs and 30 Rs the MHD model "MAST" is used.



Longitude



Latitude

Overall, the two mappings agree with each other, but there are differences. It is possible that both may be far from the reality. Note that we do not have full surface magnetic field observations.

Summary

- Although EUV waves often accompany SEP events, the timing study like this indicates that they may not be important in understanding the origin or angular distribution of SEP events.
- Few cases where the electrons were released as the EUV wave reached the connection point may have been just by coincident.
- The 3D structure of the shock should be more important. Which part of the shock corresponds to the EUV wave may depends on individual cases. Numerical models are important for understanding the relation between CME-driven shocks and EUV waves.
- Our knowledge of the Sun-Earth (or more broadly heliospheric) magnetic field is limited. One important factor is the lack of simultaneous observations of the full disk (including polar regions.)