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Why do Fast and Wide CMEs not always produce observable SEPs?

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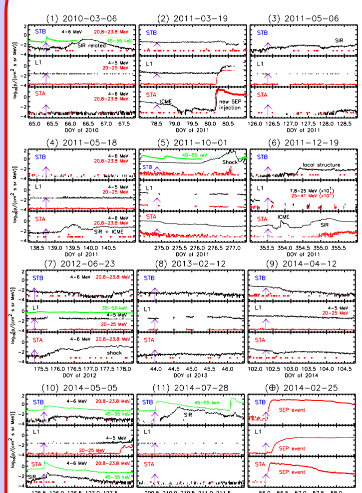
[1] Motivation

- Large Solar Energetic Particle (SEP) events tend to be associated with fast and wide coronal mass ejections (CMEs) [e.g., Gopalswamy et al. 2008, Cliver & D'Huys 2018]
- However, not all fast and wide CMEs produce large SEP events [e.g., Marque et al. 2006, Swalwell et al. 2017, Gopalswamy et al. 2017].
- Possible reasons include:
  1) No magnetic connection between the particle source and the spacecraft (S/C).
  2) No particles are released at the time of the solar eruption that could contribute to the SEP prompt component and/or provide a seed population for shock acceleration.
  3) A pre-event seed population was absent or weak.
  4) Inefficient particle acceleration at the CME-driven shock (as a whole) or at the portion magnetically connected to the S/C.
  5) Particles are accelerated but do not propagate to the S/C.
- From the CDAW LASCO CME catalog, we selected fast (plane-of-sky speed > 1000 km/s) and wide (plane-of-sky angular width >120 deg) CMEs between 2009 January 1 and 2014 September 30, and determined whether >20 MeV protons were detected by either SOHO, STEREO-A or STEREO-B.
- **Of 123 fast and wide CMEs, 11 did not produce a >20 MeV proton intensity increase at ANY of the three spacecraft.**
- We analyze the factors that may have contributed to the non-observation of >20 MeV protons following these 11 CMEs.

[2] Energetic Particle Observations



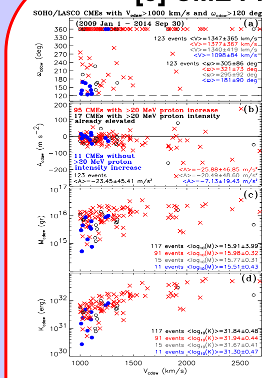
- **Fig 1.** ~20 MeV proton (red), ~4 MeV proton (black), and ~45 keV electron (green) intensities from (top to bottom) STEREO-B, near-Earth spacecraft (L1) and STEREO-A for the 11 events without >20 MeV proton increases after fast/wide CMEs (purple arrows), plus a "control" event (2014 Feb 25) with a >20 MeV proton event at all three locations.

Electron intensities are only shown if there is an increase free of contamination.

~4 MeV proton intensity-time profiles might be affected by local structures (i.e. SIRs and ICMEs).

- **Some of the events occurred after unrelated SEP events or CIR-associated particles filling the inner heliosphere. Absence of seed particles from pre-existing events do not explain the lack of >20 MeV protons.**

[3] CME Properties

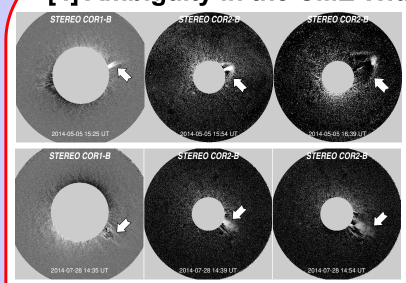


- **Fig 2.** (a) Angular width, (b) Acceleration, (c) Mass and (d) Kinetic Energy versus Speed for the CMEs with >20 MeV proton events (x), without observed proton events (●) or unclear due to elevated pre-event intensities (O).
- **CMEs without observed >20 MeV protons tend to be slower, narrower, less massive and with less kinetic energy** (consistent with the trends inferred in previous studies, e.g., Kahler & Vourlidas 2013).
- Panel (b) shows that fast CMEs tend to decelerate, whereas the accelerations of CMEs without >20 MeV protons are comparatively small.

LASCO CME (CDAW) Date/hh:mm (UT) (1)	V_{cdaw}/ω_{cdaw} [km s^{-1}/deg] (2)	A_{cdaw}/M_{cdaw} [m s^{-2}/10^{15}gr] (3)	Eruption Site[a] Long/Lat (time) (4)	V_{fit}/ω_{fit} (Time) [km s^{-1}/deg (UT)] (5)	$V_{cactus}/\omega_{cactus}$ [km s^{-1}/deg] (6)	Type III ~1 MHz duration (time, intensity, spacecraft) (7)
1 2010 Mar 06/07:51	1009/127°	14.1/3.0	250/N24 (07:03)	1059/074° (07:24-09:39)	1348[d]/107°	4 min (07:19-07:23, 1.41×10^5, Wind)
2 2011 Mar 19/12:12	1102/140°	21.3/3.4	52-67/S28-S17[b] (11:33)	691[e]/107° (12:39-14:39)	1201/060°	0 min (0, STA)
3 2011 May 06/08:48	1024/169°	04.8/4.5	263/N19 (08:30)	1065/174° (08:54-10:54)	1275/142°	<1 min (08:54-08:54, 1.26×10^4, STB)
4 2011 May 18/18:24	1105/>126°	07.5/6.3	320/N10 (18:02)	1201/161° (18:36-19:54)	1602/158°	7 min (18:16-18:23, 1.42×10^6, STA)
5 2011 Oct 01/20:48	1238/Halo	-10.1/8.8	120/N23 (20:26)	1132/190° (20:40-22:39)	1294/196°	15 min (20:31-20:46, 5.07×10^6, STB)
6 2011 Dec 19/12:36	1092/154°	-22.0/3.9	73/S17 (12:00)	1402/094° (13:30-14:42)	1329/064°	5 min (12:07-12:12, 2.41×10^4, STA)
7 2012 Jun 23/07:24	1263/Halo	-29.1/10.0	67-80/N20-N10[b] (06:50)	1296/208° (07:54-09:30)	1953/360°	<1 min (07:05-07:05, 1.95×10^4, STA)
8 2013 Feb 12/23:12	1050/165°	00.5/8.8	167-173/S31-S24[b] (21:30)	1049/178° (23:24-00:42)	1117/118°	0 min (0, Wind)[f]
9 2014 Apr 12/07:24	1016/139°	-12.6/5.2	~205/S15 (07:06)	1015/097° (07:54-09:24)	1736/060°	30 min (07:10-07:40, 2.33×10^4, STB)
10 2014 May 05/15:24	1069/124°	-08.3/1.4	~252/N14 (15:12)[c]	1225/091° (15:54-16:54)	1953/012°	14 min (15:13-15:26, 1.43×10^5, STB)
11 2014 Jul 28/14:30	1110/127°	-44.5/7.6	259/S10 (13:57)[c]	0989/122° (14:39-15:39)	1491/034°	18 min (13:57-14:15, 1.34×10^5, Wind)
⊕ 2014 Feb 25/01:25	2147/Halo	-158.1/22.0	103/S12 (00:39)	2170/250° (00:45-01:54)	–	23 min (00:48-01:11, 8.13×10^6, STB)

- **Table 1**. Parameters of the 11 CMEs without >20 MeV protons (plus a control event with SEPs) from the CDAW and CACTus catalogs, and from an ellipsoid fit to the outermost front of the CME

[4] Ambiguity in the CME Widths

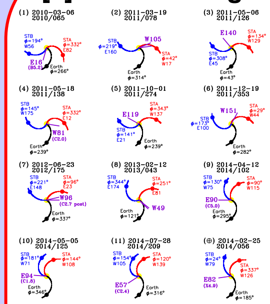


- **Fig 3.** Coronagraph images for events 10 and 11 that evolved from a narrow jet-like structure into a wide CME. The CACTus catalog gives narrow widths for these CMEs that would have not met our selection criteria.

- **Fig 4.** The CME for event 2 was formed by two substructures, a southern portion (white arrow at speed >1000 km/s) and an equatorial portion (red line, ~690 km/s). The CDAW speed is for the southern portion and the width includes both structures. Either structure alone would not meet our criteria.

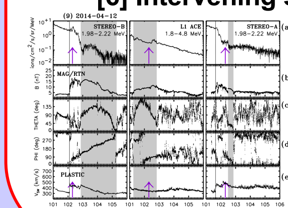
- **Catalogued CME parameters should be carefully re-assessed, especially the evolution of the CME width.**

[5] Nominal Magnetic Connections



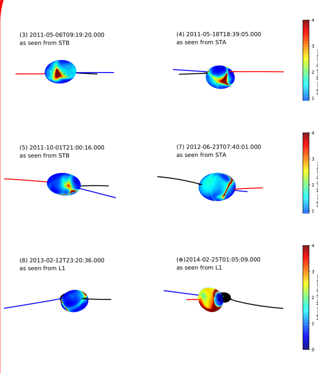
- **Fig 5.** Locations of the solar source, and the nominal magnetic connections of STEREO-A (STA), STEREO-B (STB) and near-Earth observers, at the time of the 11 fast/wide CMEs without >20 MeV protons.
- **The absence of >20 MeV protons at all 3 S/C is not usually consistent with a lack of magnetic connection between the spacecraft and the SEP source.**

[6] Intervening structures



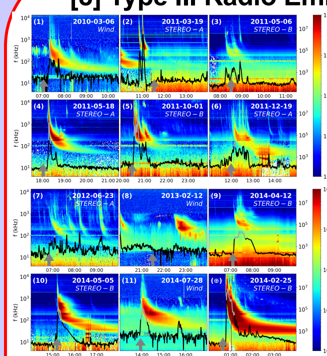
- **Intervening interplanetary structures may affect the nominal field connections and the arrival of particles at each S/C.**
- For example, CME 9 (**Fig. 6**) occurred when the three spacecraft were immersed in unrelated ICMEs.

[7] CME-driven Shock Properties



- We use sequences of EUV and white-light coronagraph images from 3 S/C to fit an ellipsoid to the outermost CME front (interpreted as the CME-driven shock).
- Combining with MHD MAST coronal simulations [Lionello et al. 2009], we estimate the shock parameters (e.g., Alfven Mach number M_A).
- **Fig 7.** Distribution of M_A over the fitted surface for events 3, 4, 5, 7, 8 plus the control event as seen from the indicated spacecraft. Blue, black and red lines indicate field lines connecting to STEREO-B, L1 and STEREO-A.
- In contrast to the shock associated with the control event, **the high-M_A regions of the shocks without >20 MeV proton intensity enhancements are limited in extent.**
- If these limited regions did accelerate >20 MeV protons, their absence at all 3 S/C would place significant constraints on particle spreading in the corona and interplanetary medium.
- Apart from M_A, other factors e.g., conditions for particle escape from the shock, seed populations, upstream field turbulence, and particle transport after release, could play a role in whether SEPs are observed by a S/C.

[8] Type III Radio Emissions



- Large SEP events are nearly always associated with bright long-lasting Type III emissions [e.g., Cane et al., 2002].
- Type IIIs are generally attributed to the escape of electrons produced at the time of the parent eruption
- **Fig 8** shows DH radio observations around the times of the CMEs without >20 MeV protons (arrows) from the S/C closest to the solar event longitude. Black traces show the ~1 MHz time-intensity profile.
- **DH radio emissions accompanying these CMEs are weak, especially at high (>2 MHz) frequencies where the type III bursts are of very short duration or not detectable,** though in some cases, related emissions at lower frequencies suggest that electrons were released.
- CMEs 2, 7 and 8 were generated by large filament eruptions and did not produce type III emissions at high frequencies.
- Apart from the control event, type II bursts were observed only in event 5.
- MacDowall et al. [2009] found that the type III duration at ~1 MHz tends to increase with the >25 MeV proton intensity, being <20 min for events without SEPs. Similarly, the ~1 MHz emissions for our events have very short durations (indicated by the gray tracks; Table 1 Column 7)

[9] Conclusions

- A small percentage (11 out of 123 events, i.e. ~9%) of the selected fast and wide CMEs do not have observable >20 MeV protons at the STEREO and near-Earth spacecraft (cf. **[1]** and **[2]**).
- These CMEs are among the narrowest in our sample. However, catalogued CME widths should be carefully assessed (cf. **[3]** and **[4]**).
- DH type III radio bursts accompanying these CMEs tend to be weak, in particular at high frequencies, suggesting little or no particle acceleration/release at the time of the parent eruption (cf. **[8]**).
- The high Mach number regions of the shocks driven by these CMEs tend to be narrower than those for CMEs associated with widespread SEP events (cf. **[7]**).
- Occasionally, intervening structures may hinder the arrival of SEPs at a nominally connected S/C (cf. **[6]**), but a full assessment of the transport conditions for these events is beyond the scope of the present study.
- **While the high-Mach number regions of the associated shock fronts are of limited extent, we conclude that the main characteristic that seems to distinguish fast/wide CMEs without observable >20 MeV proton enhancements is a deficit in the release of particles at the time of the solar eruption, as evidenced by the weak or absent high-frequency type III radio emissions.**
- **A puzzle that remains is how these fast/wide CMEs were produced with only modest signatures of energetic particle release.**