Different Electron and Protons Onset Times of SEP Events

H. Xie , N. Gopalswamy, O.C. St. Cyr

NASA/GSFC

Motivation and Background

Krucker et al., APJ, 542, L61-64, 2000

- There were two classes of proton events:

  1. Scatter-free proton events (1.1 – 1.3 AU).
  2. Scattering proton events (~2AU).

- Electrons range from (20- 400 KeV) were released simultaneously and were traveling scatter-free .

- Group 1) protons (0.03-6 MeV) were found to be released in 0.5 -2 hrs late than electrons.

- Electrons and protons have similar pitch-angle distributions, implying that the longer path length in class 2 was due to particle trapping near the Sun and released (or accelerated) later in the high corona.

- While the low-energy protons have delayed release times, they speculated high energy protons were released together with electrons.

29 Major SEP events during solar cycle 24

17 SOHO SEPs
12 STEREO SEPs

Events selected from CDAW Major SEP list
(35 with intensity > 10 pfu in Goes >10 MeV proton channel)

http://cdaw.gsfc.nasa.gov/CME_list/sepe/

Note:

1. SOHO and STETEO SEP events are those events magnetically well connected to Earth and STEREO A or B respectively.
2. 6 events with ERNE and EPHIN data gap have been excluded.

Data and Method

- SOHO Electron, Proton Helium Instrument (EPHIN)

  in electron (0.25-0.7 MeV)
- SOHO Energetic and Relativistic Nuclei and Electron instrument (ERNE)

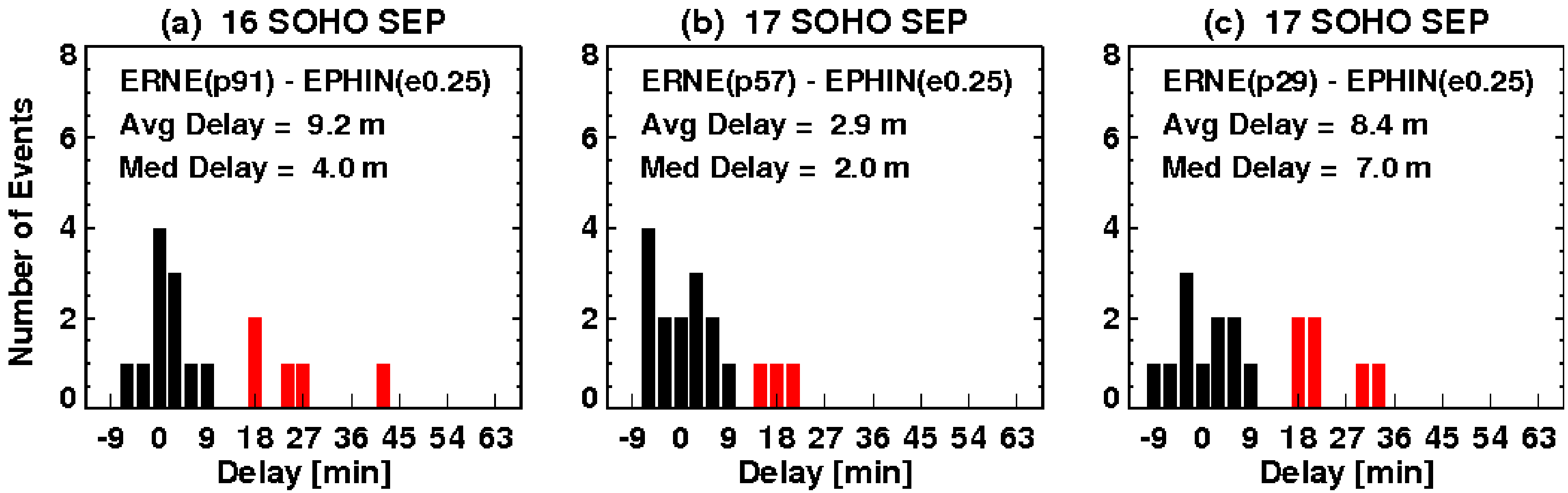
  in proton (80 – 101, 51 – 67, 26 – 32, 6 – 8) MeV
- STEREO High and Low Energy Telescope (HET and LET)

  in proton (60– 100, 40 – 60, 10 – 12, 4.5 – 5) MeV
- STEREO Solar Electron Proton Telescope (SEPT)

  in electron (0.335 - 0.375 MeV)

1. Assuming a scattering –free propagation with a path length of 1.25 AU , we compute the delay of proton onset times relative to electron onset times.
2. Assuming delayed proton onsets are due to particle trapping near the Sun.
3. Since 0.25-0.7 MeV electrons move at near relativistic speeds, assuming the electrons and first-arriving protons travel scattering –free is a good approximation.

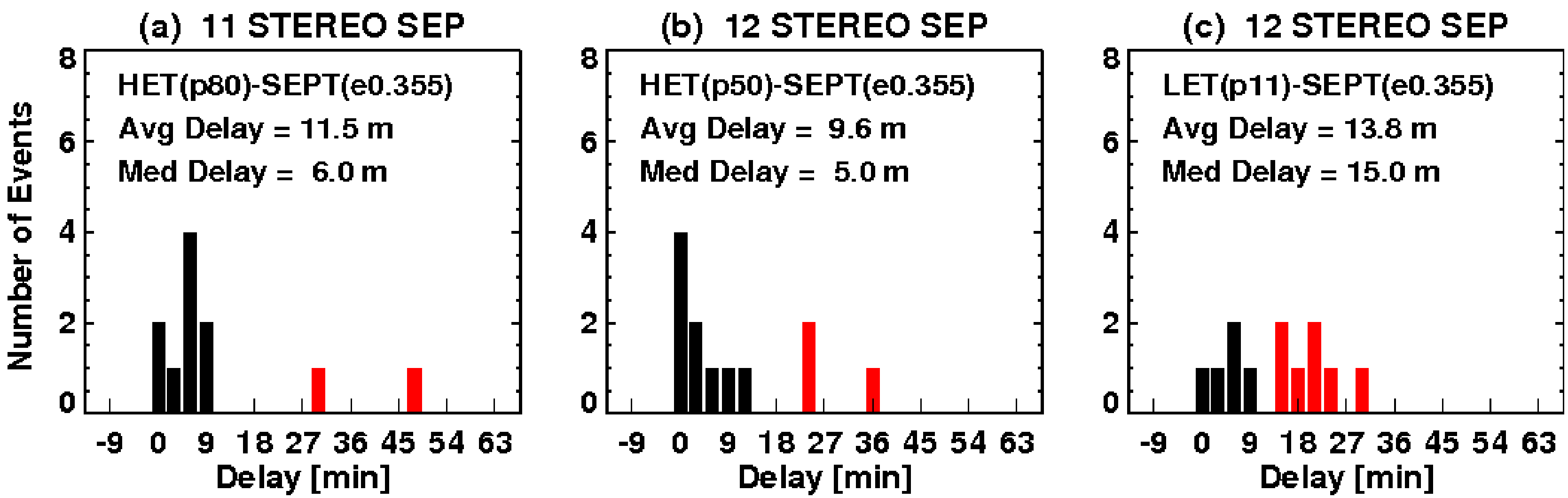
Results for 17 SOHO SEPs



Average proton onset delays :

- 80-101 MeV p delayed 9.2 ± 5 min than 0.25-.7 MeV e-.
- 51-67 MeV p onset is similar to 0.25-.7 MeV e-.
- 26-32 MeV p delayed 8.4 ± 5 min than 0.25-.7 MeV e-.

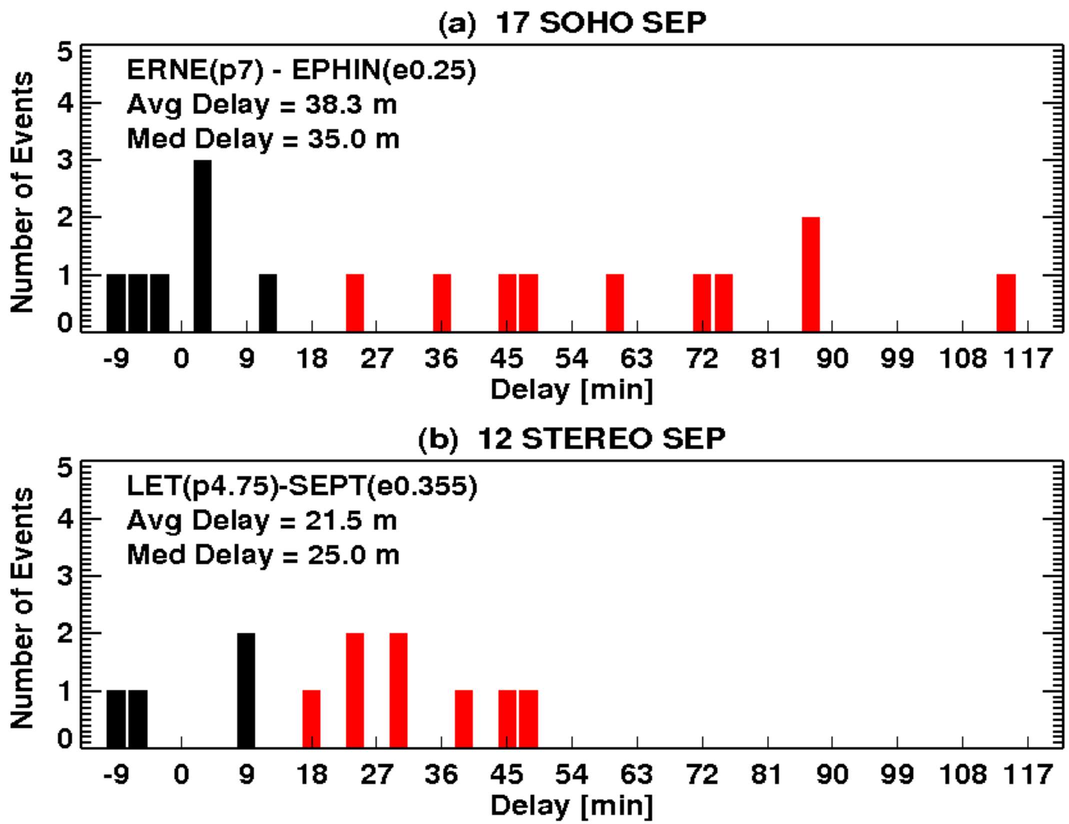
Results for 12 STEREO SEPs



Average proton onset delays:

- 60-100 MeV p delayed 11.5 ± 10 min than .335-.375 MeV e-.
- 40-60 MeV p delayed 9.6 ± 10 min than .335-.375 MeV e-.
- 10-12 MeV p delayed 13.8 ± 10 min than .335-.375 MeV e-.

Low-Energy Proton Onset Delay



Average delays:

Two groups

Group 1 : 11 out of 29

(Black bar) :

-10 min ~ 10 min

Group 2: 18 out of 29

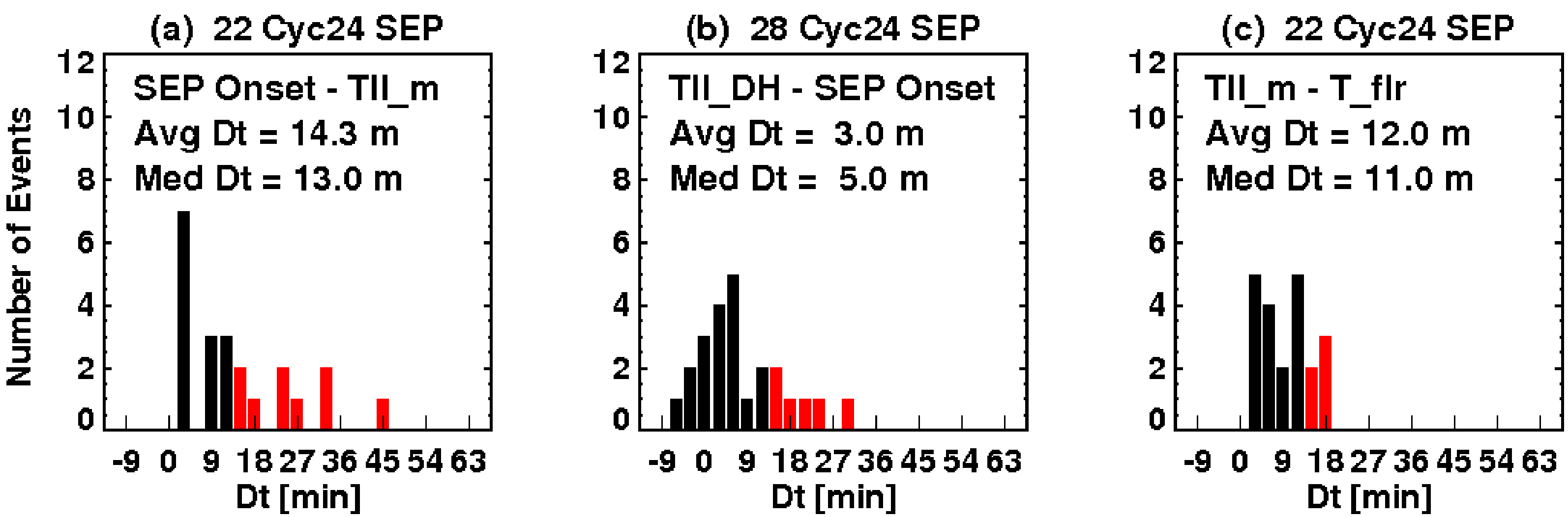
(Red bar):

18 min ~ 2 hr

Average proton onset delays:

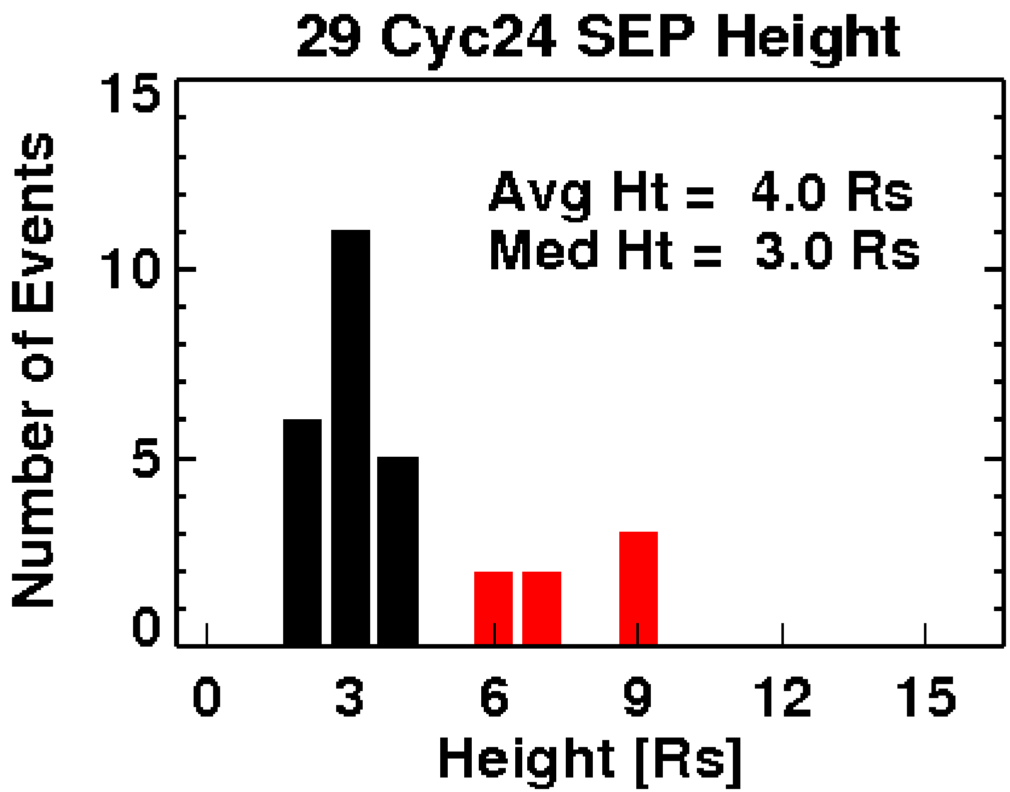
- 6-8 MeV p delayed 38.3 ± 5 min than 0.25-.7 MeV e-.
- 4.5-5 MeV p delayed 21.5 ±10 min than 0.335-.375 MeV e-.

Comparison between SEP Onset and Metric and DH Type II



- Avg delay between .25 -.7 MeV e- onset and metric type II : 14.3 min.
- Avg delay between DH type II and .25 -.7 MeV e- onset: 3.0 min.
- .25 -.7 MeV e- onset agrees with DH type II better than metric type II onset, indicating that high-energy e- acceleration is shock-related.

CME Height at .25 -.7 MeV e- onset

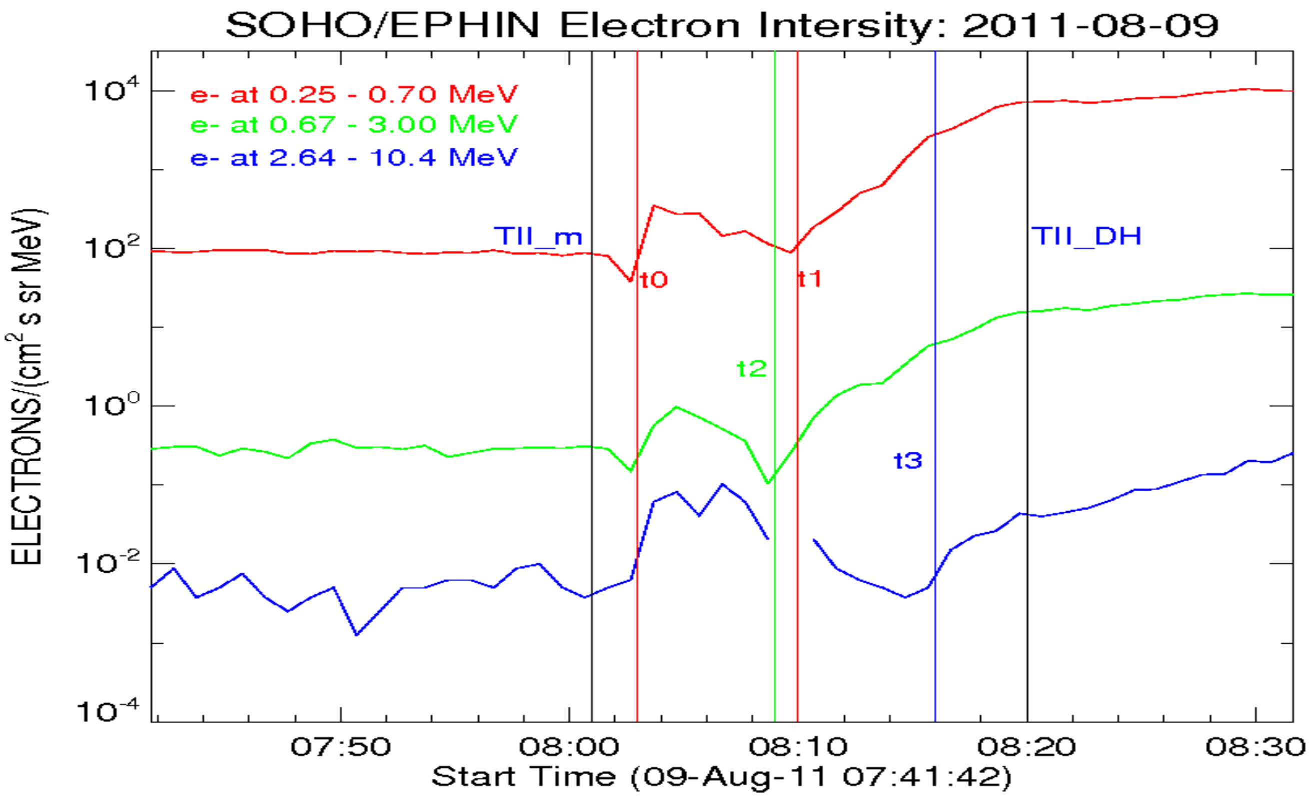


3.84 Rs for 15 CMEs at GLE onset

Gopalswamy et al. SSRv 171, 23, 2012

Avg CME height at .25 -.7 MeV e- onset (4.0 Rs) is similar to Avg CME height at GLE onset (3.84 Rs).

Double-peak Electron Intensity



The 1st onset t0 = 08:03 is close to TII_m = 08:01 UT (flare onset = 07:59 UT)

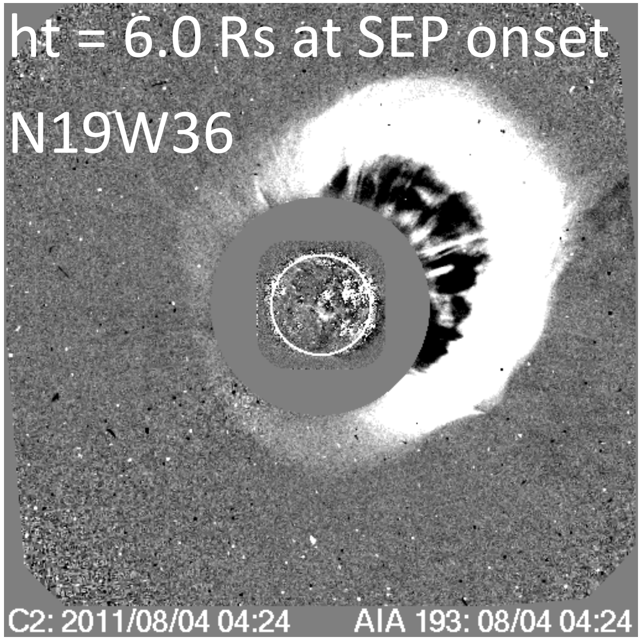
The 2.64-10.4 2nd onset t3 = 08:16 is near TII_DH (08:20 UT).

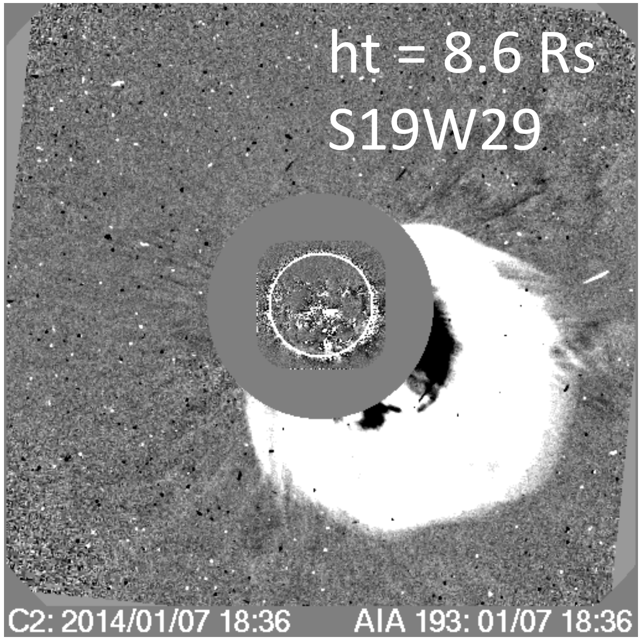
(Note: t0 and t1,t2,t3 are e- onsets for the 1st and 2nd peaks in 3-e channels)

Conclusions:

- SEP onset times estimated using high-energy electron and proton channels agree well with each other; they serve as a better indicator of shock formation than low-energy proton release times.
- Two types of low-energy protons are found: 1) 11 out of 29 release together with electrons and 2) and 18 out of 29 have large delayed release times (18 min – 2 hr) relative to electrons.
- Average CME height at .25 -.7 MeV e- onset (4.0 Rs) is similar to average CME height at GLE onset (3.84 Rs).
- High-energy (0.25-0.7 MeV) electron onset times agree well with DH type II onsets, supporting their shock acceleration origin.
- Some observed EPHIN electron intensity have double-peak profiles and peak 1 and 2 onsets correspond well to metric Type II and DH Type II onsets respectively.

Discussion: Likely explanations for large CME heights at SEP onset :





1. Latitudinal effect: similar to longitudinal effect, high latitude may also cause poor magnetic connectivity to the observer (*Gopalswamy et al. ApJL 765, 5, 2013: poor magnetic connectivity to Earth caused some large SEPs non-GLE.)*.
2. Width effect: narrow CMEs are less energetic and become only more energetic in the high corona.