Double-whammy Space Weather Events in the SOHO Era

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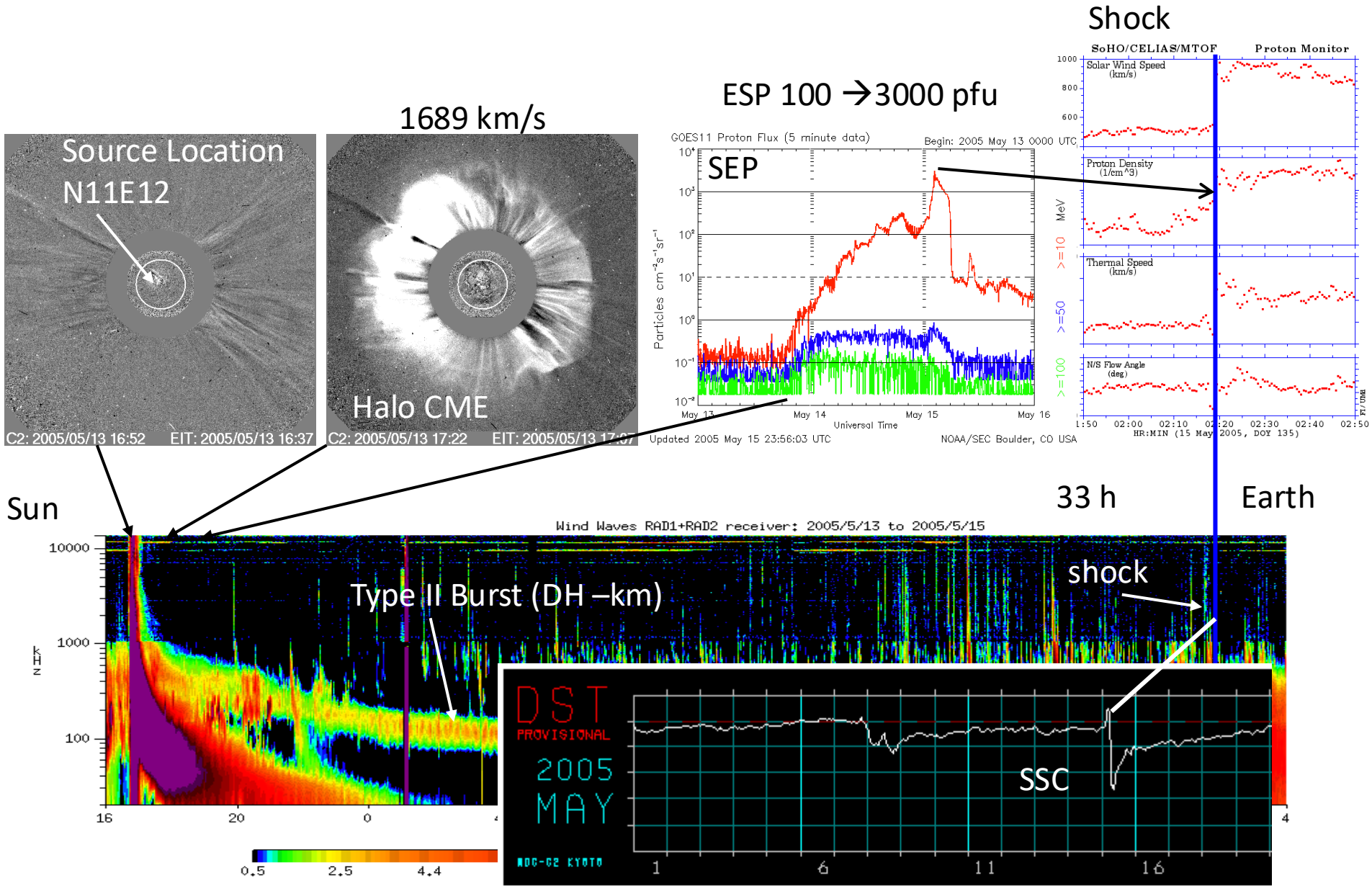
Introduction

- Double-Whammy events (DWE) are CMEs that simultaneously produce a large (≥ 10 pfu @>10 MeV) solar energetic particle (SEP) event and an intense geomagnetic storm (Dst ≤ - 100 nT).
- Some well known DWE are 2003 Halloweens CMEs (October 28 & 29), the 2004 Bastille Day CME, and the 2005 May 13 CME
- In the SOHO era (1996 -) more than 3 dozen DWEs have been observed.
- In this paper we provide some statistical properties of these CMEs and the SWx events

A Double-Whammy CME with SEP event & Geomagnetic Storm

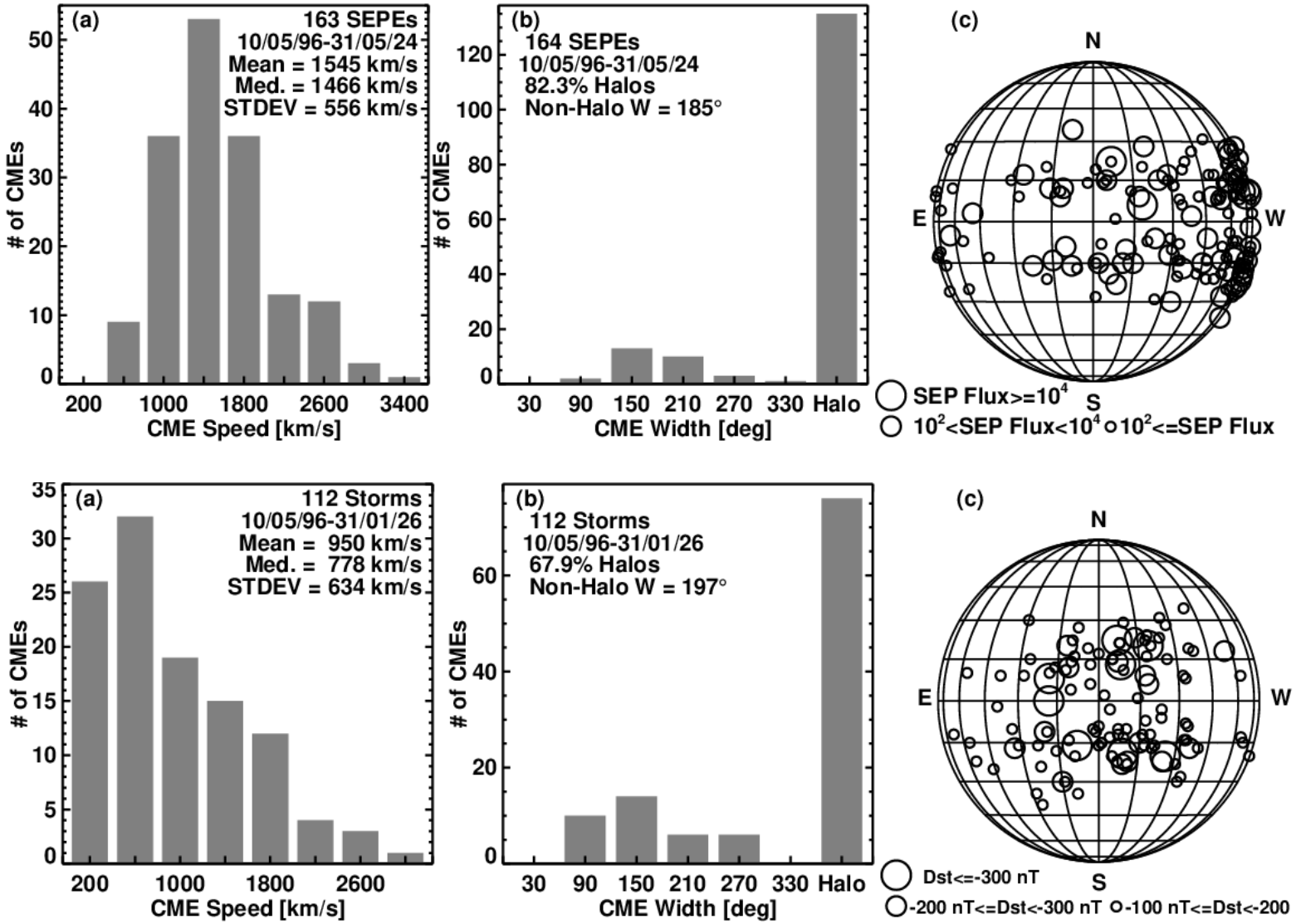


CMEs associated with both SEPs and Magnetic Storms

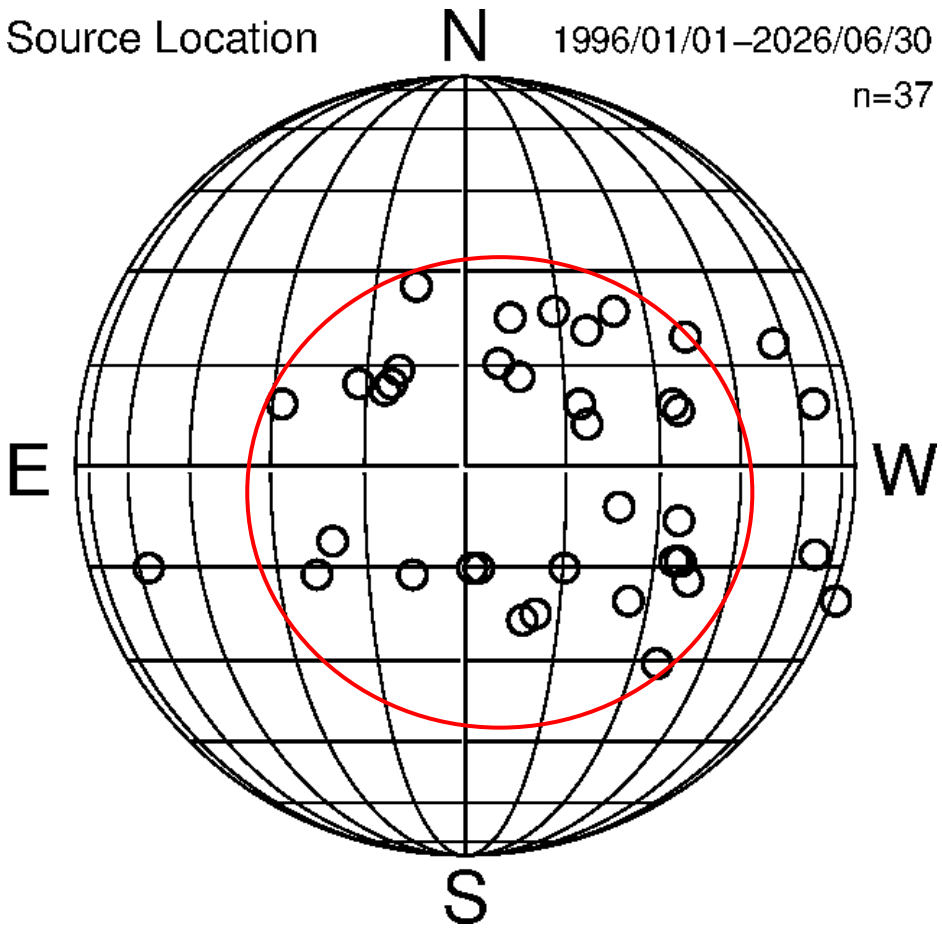
CMEs associated with large SEP events and intense geomagnetic storms are generally very energetic.

Large Halo fractions: 82% (SEPs) and 68% (mag storms)

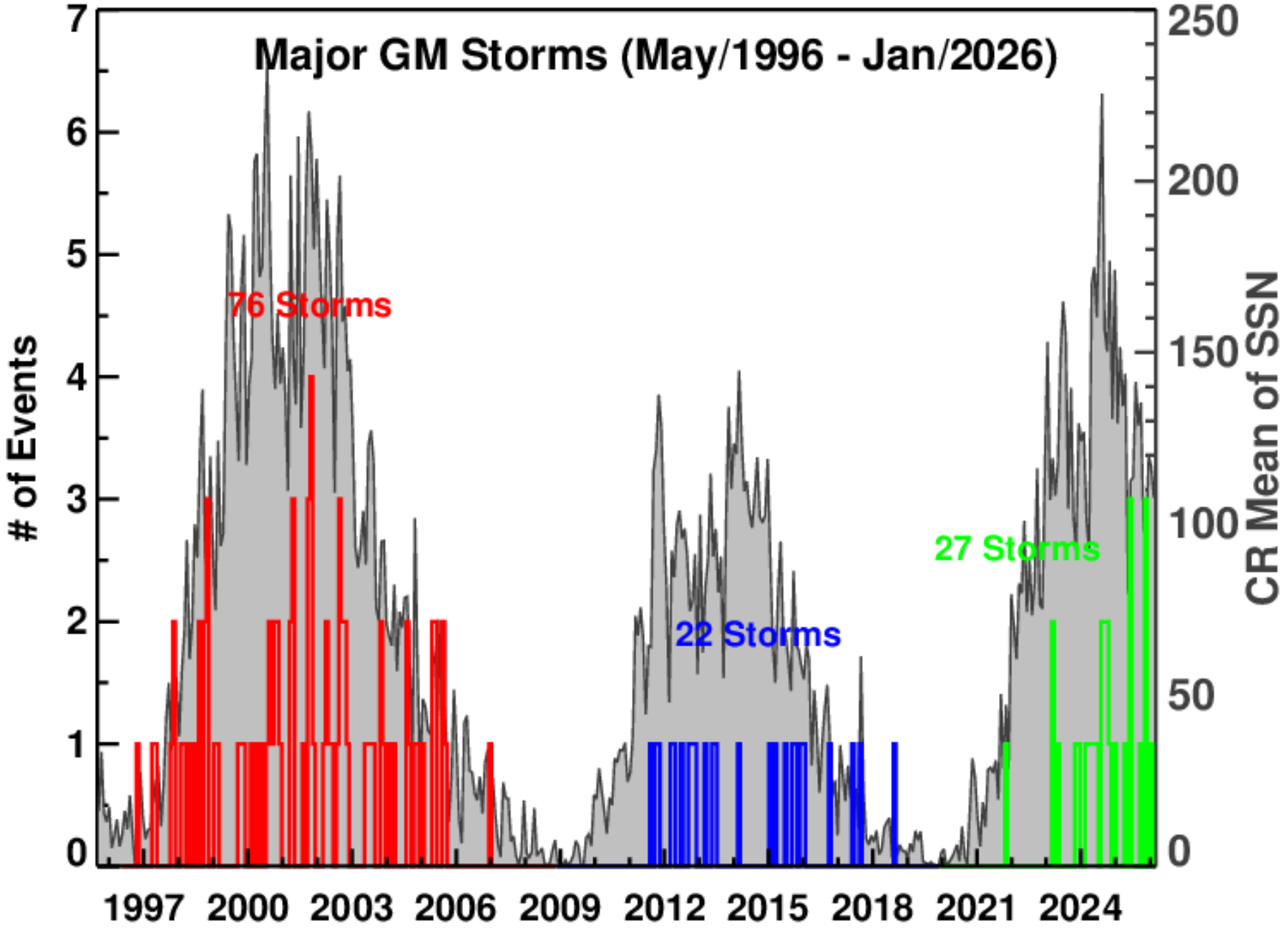
Double-whammy events are the intersection between SEP-associated storm-associated CMEs

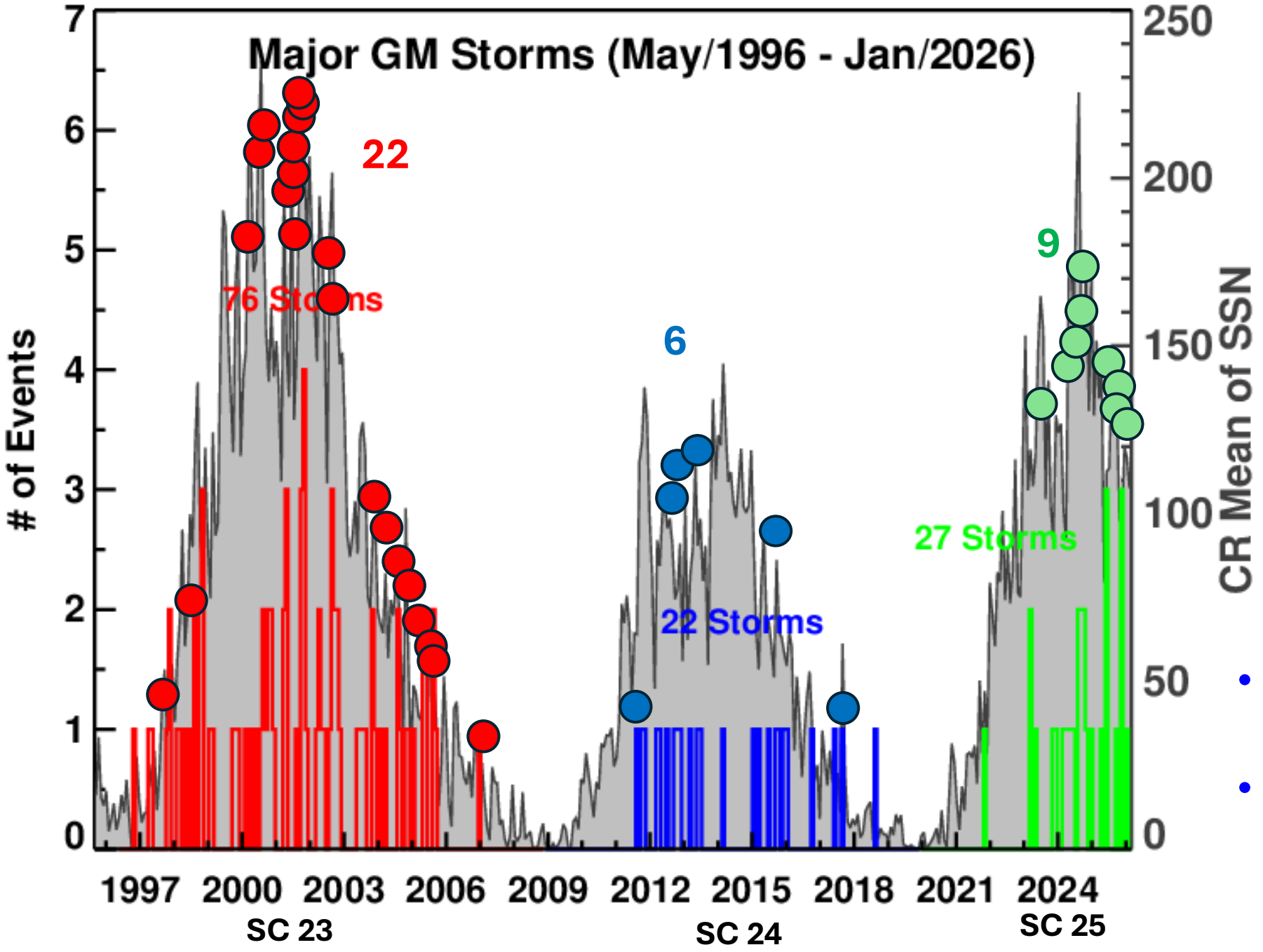


Source locations of DW CMEs



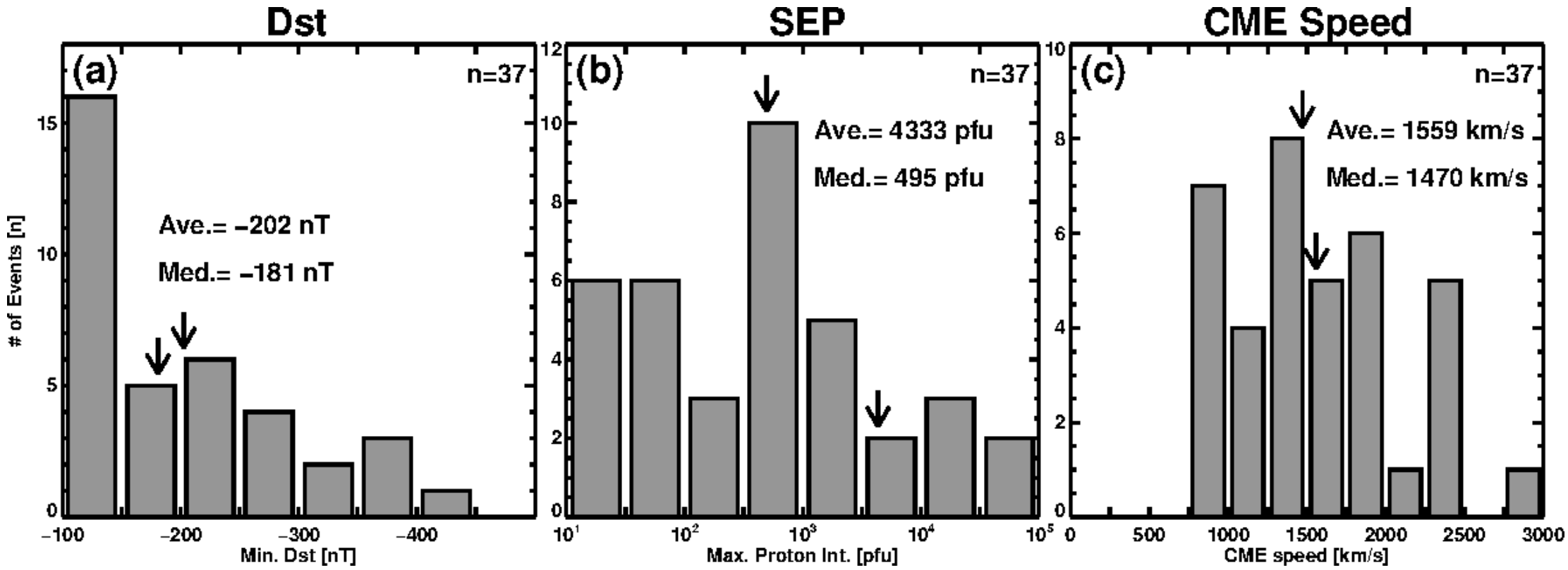
- 37 DW events
- E30 to W40
- East-west asymmetry: 10 eastern, 17 western
- Four Outliers in the western hemisphere
- One outlier in the eastern hemisphere


Major GM Storms (May/1996 - Jan/2026)
# of Events
CR Mean of SSN
76 Storms
22 Storms
27 Storms
0
1
2
3
4
5
6
7
0
50
100
150
200
250
1997
2000
2003
2006
2009
2012
2015
2018
2021
2024



- Clustered around solar maximum
- Some in rise and declining phases

Double-whammy events are more intense

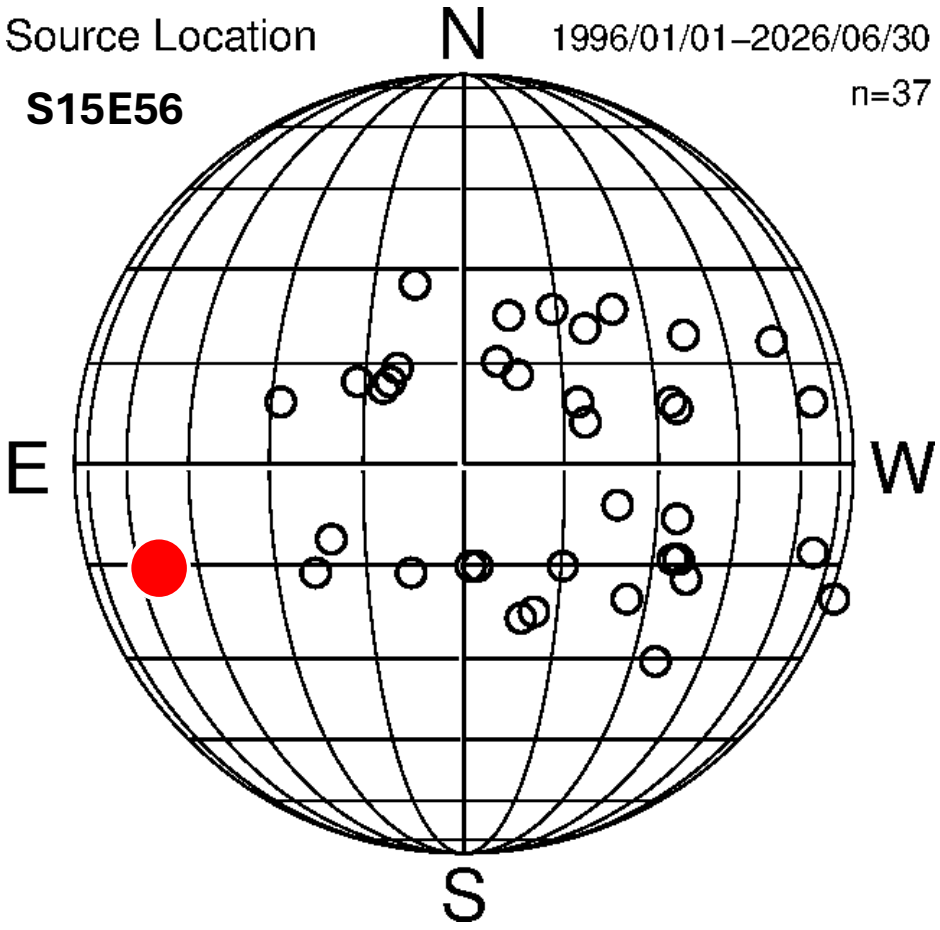


SC 23: -167/-142 nT
SC 24: -135/-124 nT
SC 25: -165/-138 nT

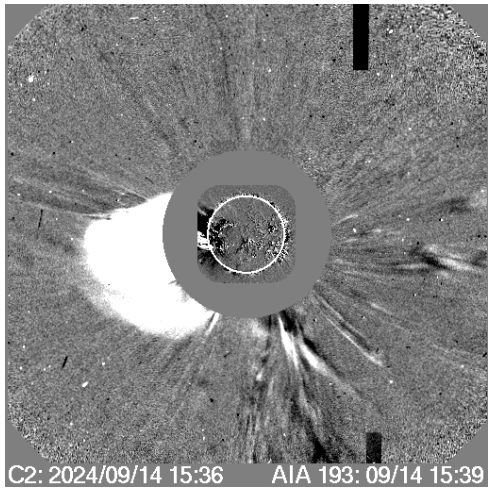
SC 23: 1520/83 pfu
SC 24: 485/46 pfu
SC 25: 204/34 pfu

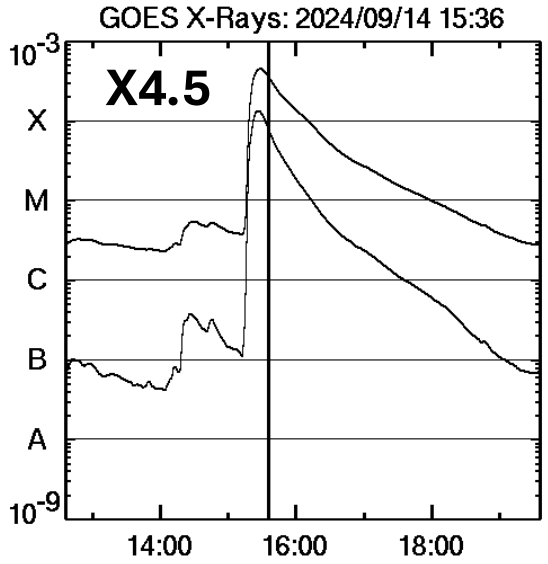
SC 23: 1393/1430
SC 24: 1510/1430
SC 25: 1481/1435

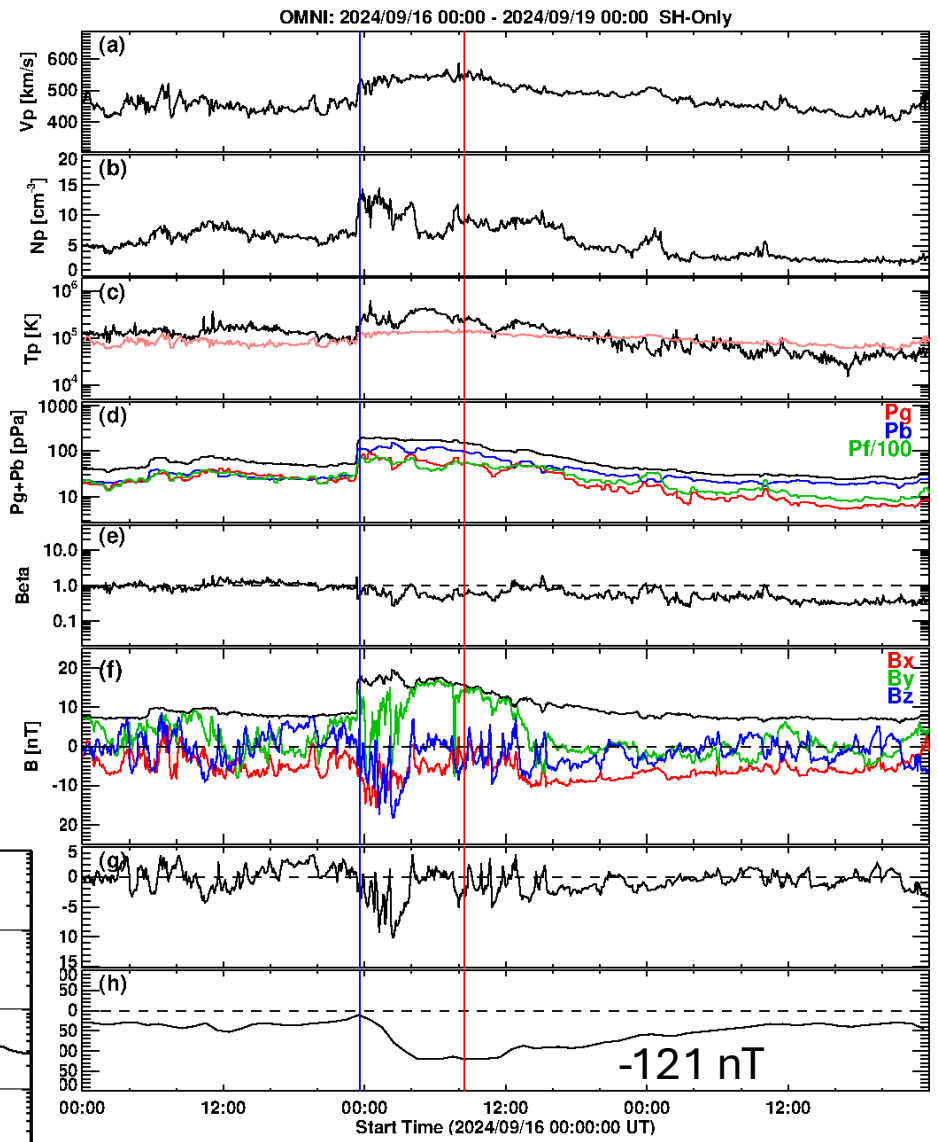
Large CMD event: 2024/09/14



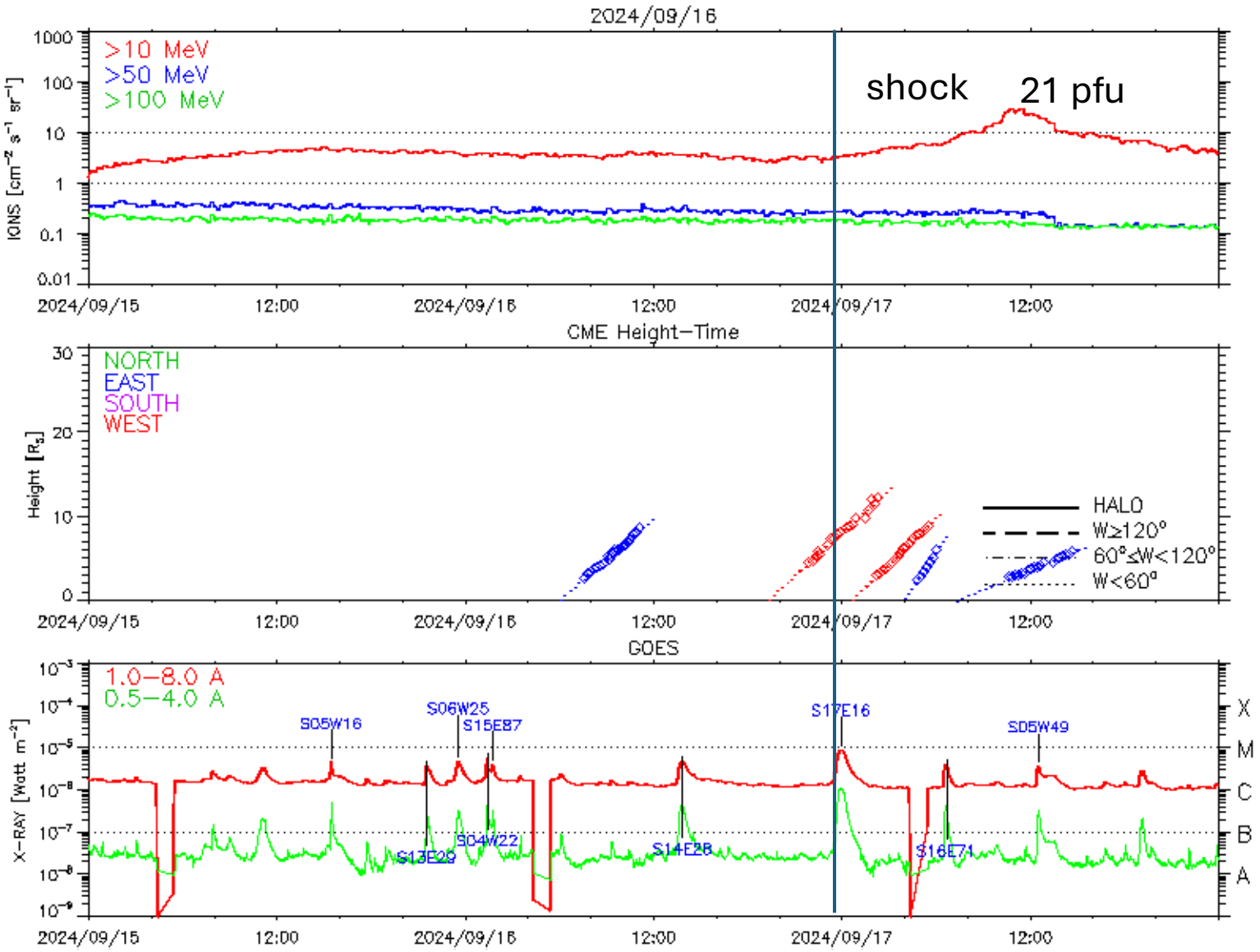
2366 km/s







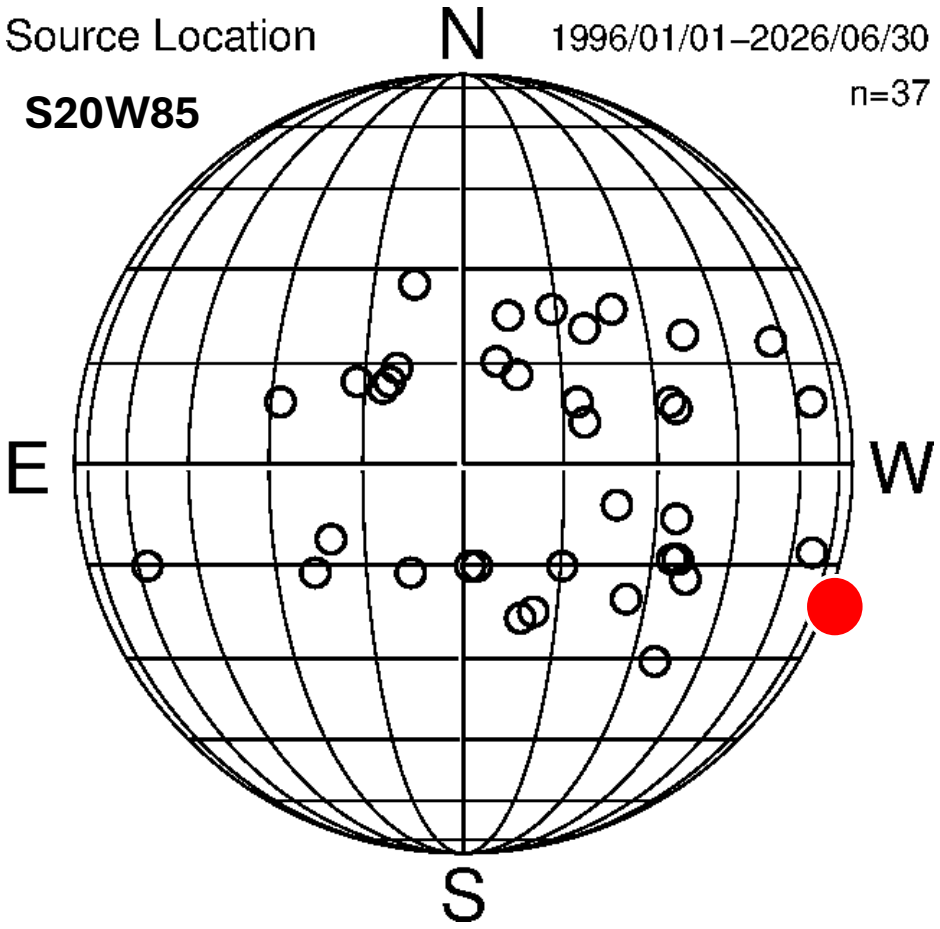
Sheath storm



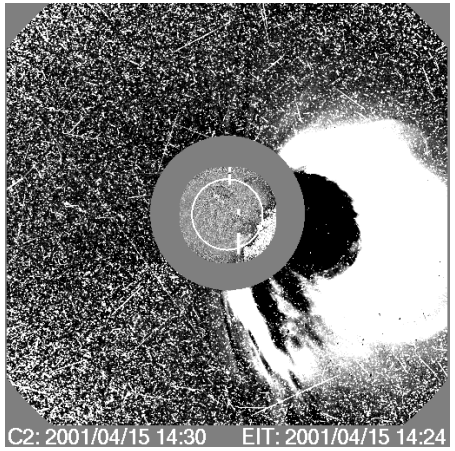
SEP

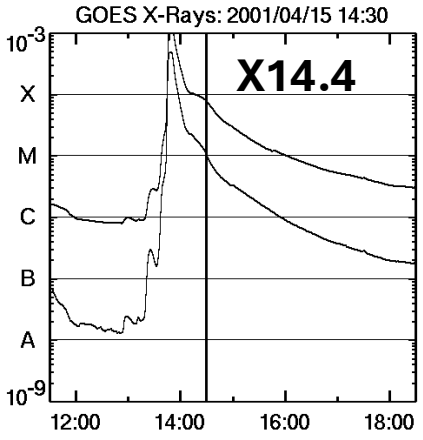
- The SEP part is a minor event
- Intensity >10 pfu when the shock arrives
  – ESP event (21 pfu)

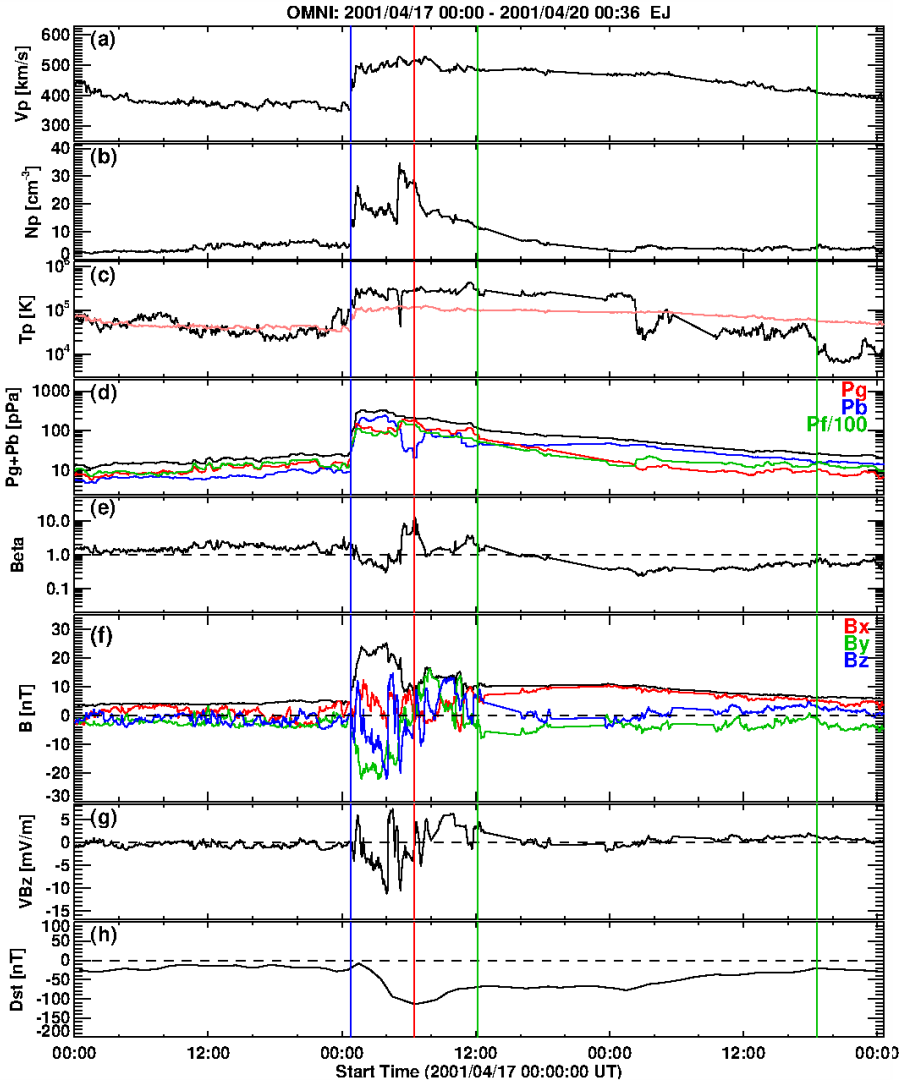
Large CMD event: 2001/04/15



1199 km/s



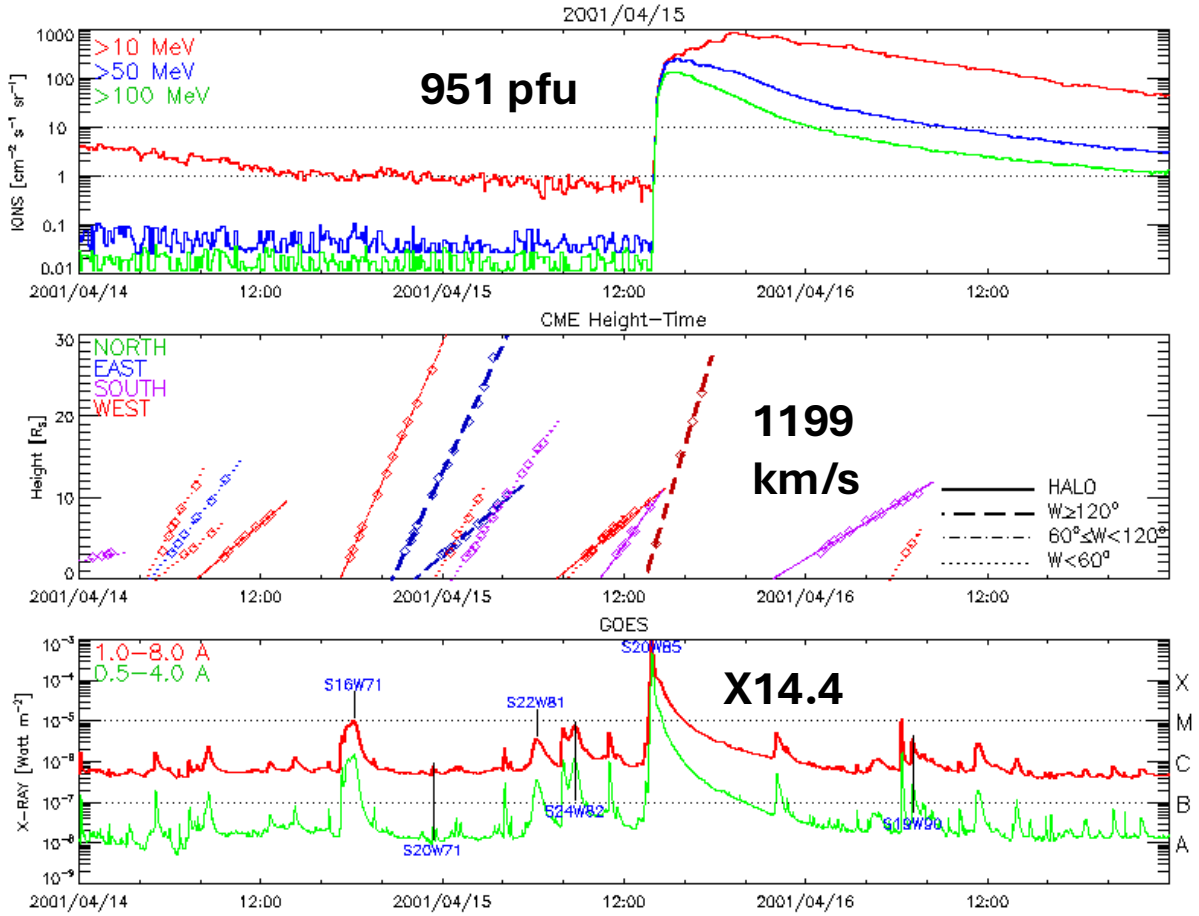




Also a sheath storm

Hard Spectrum SEP

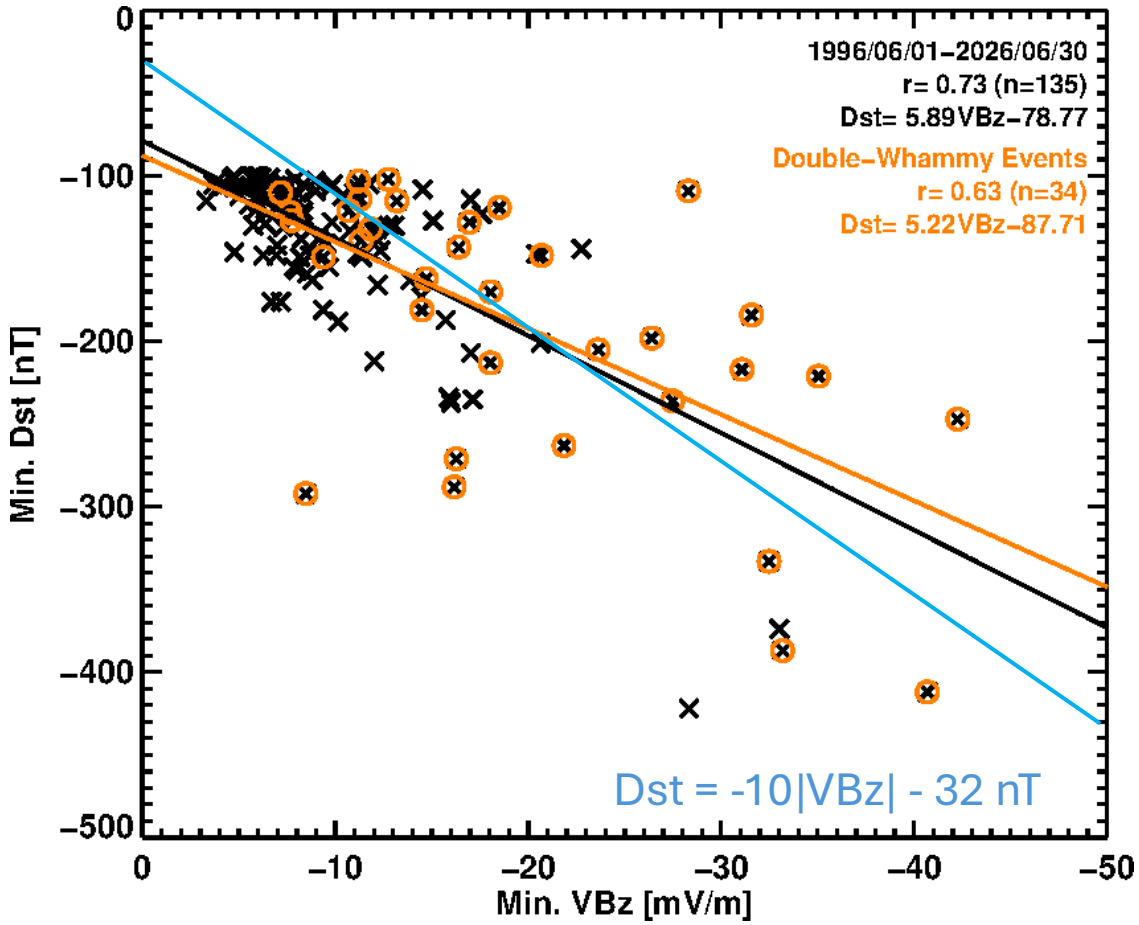
- Intense SEP event
- Ground Level Enhancement (GLE)
- Fluence spectral index: γ = 2.33
- $N(E) = EoE^{-\gamma}$



Other three Large CMD Events

Date	Source Loc.	Dst	Bz in	SEP	γ	CME Speed	Flare Size
2000/04/04	N18W61	- 288 nT	Sheath	55	5.56	1188	C9.7
2000/10/25	N09W63	- 127 nT	SN-MC	15	4.51	770	C4.0
2005/08/22	S13W65	- 184 nT	Sheath	337	5.28	2378	M5.6

Dst vs. VBz

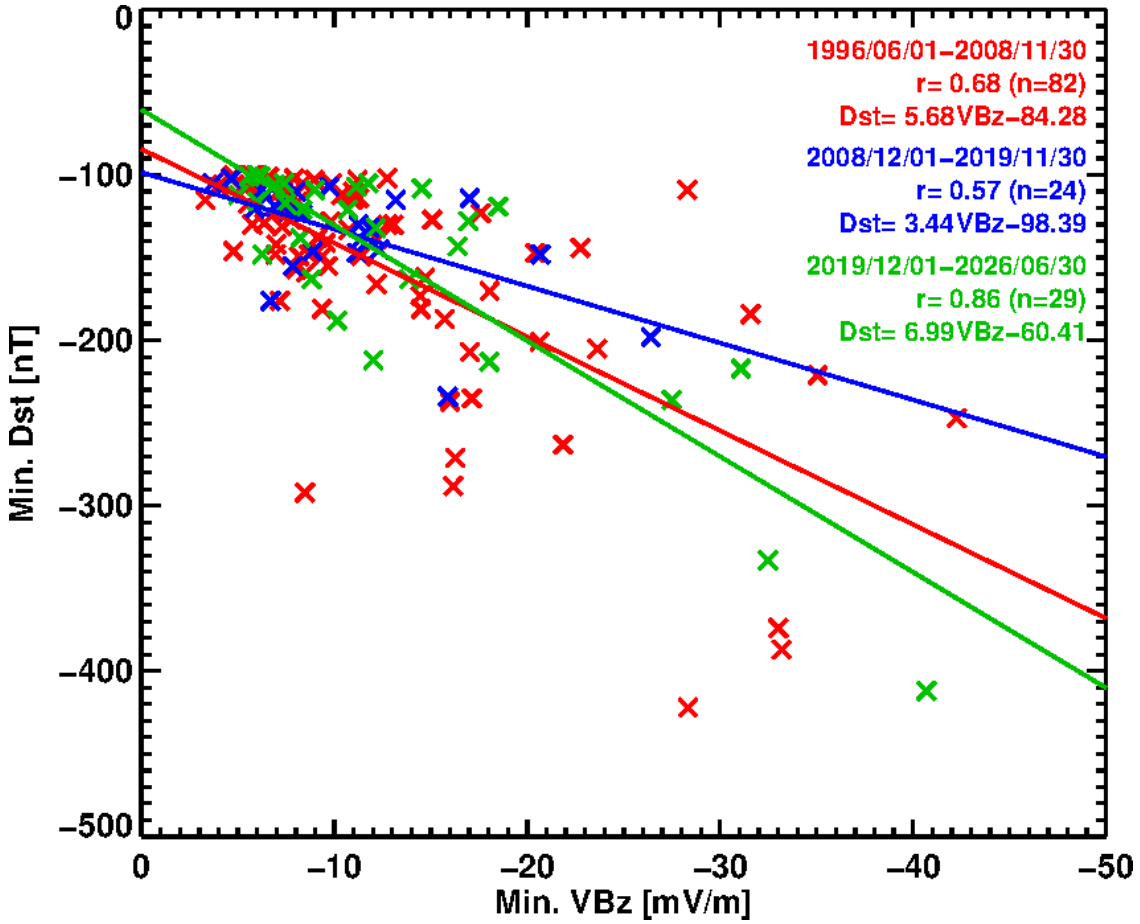


Dst is highly correlated with VBz SCs 23-25
The DW show essentially the same relation.
The slope DW slope is smaller by only 11%

Early SC 23 events (Gopalswamy+2008):
Dst = -10|VBz| - 32 nT
The slope was much higher.

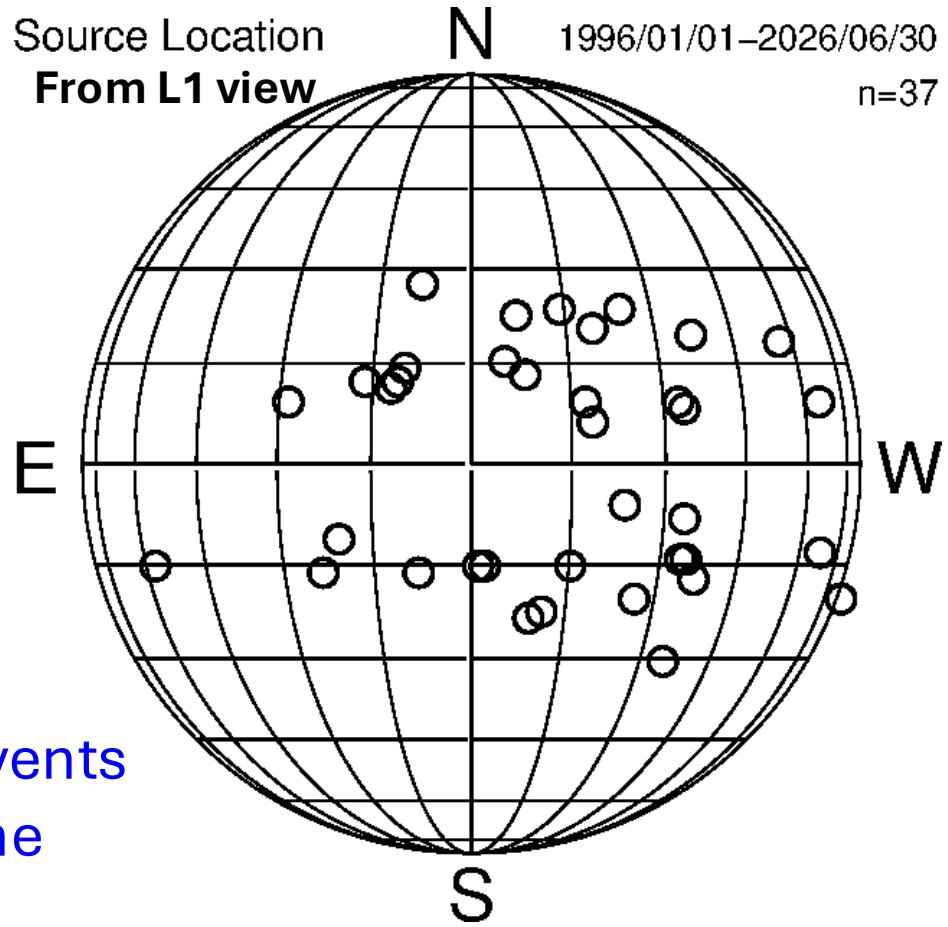
Different slopes likely indicate different heliospheric pressures → needs confirmation

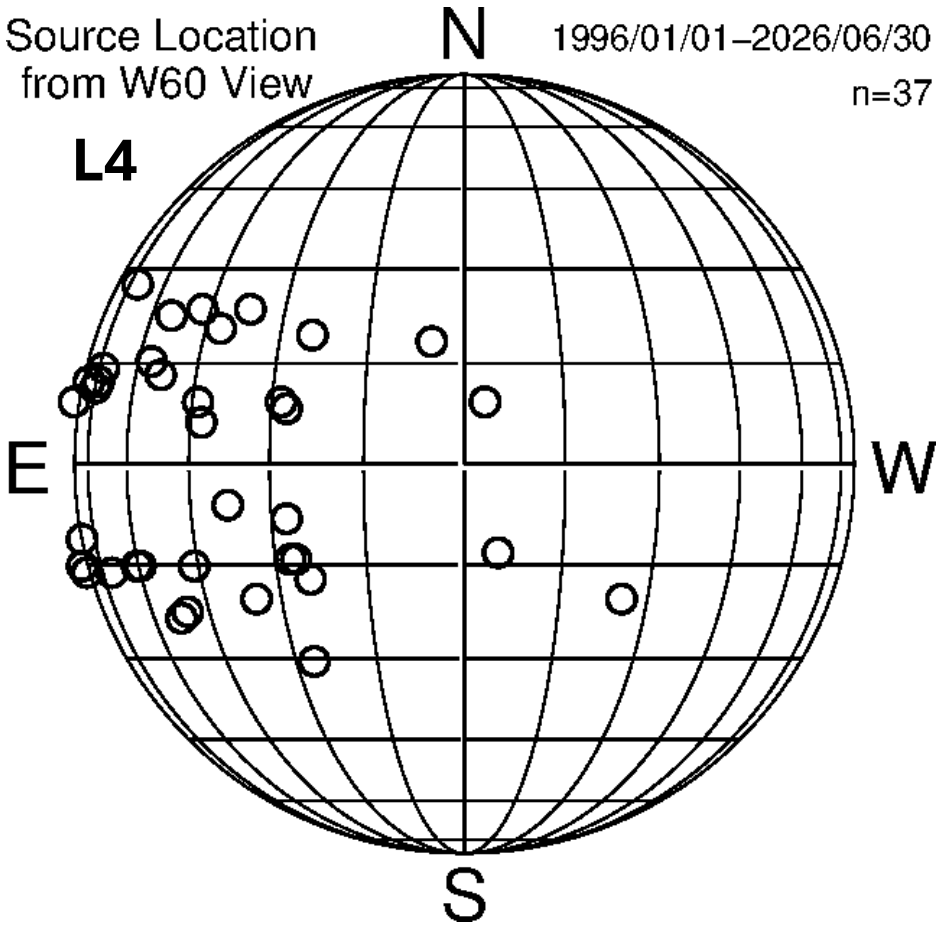
Dst vs. VBz in three SCs



- SC 23 and 24 Full cycle
- SC 25 partial cycle (up to early declining phase_
- Weak solar cycle (SC 23) has a smaller slope
- Likely due to low flow pressure in SC 24

All these CMEs can be better measured from Sun-Earth L4



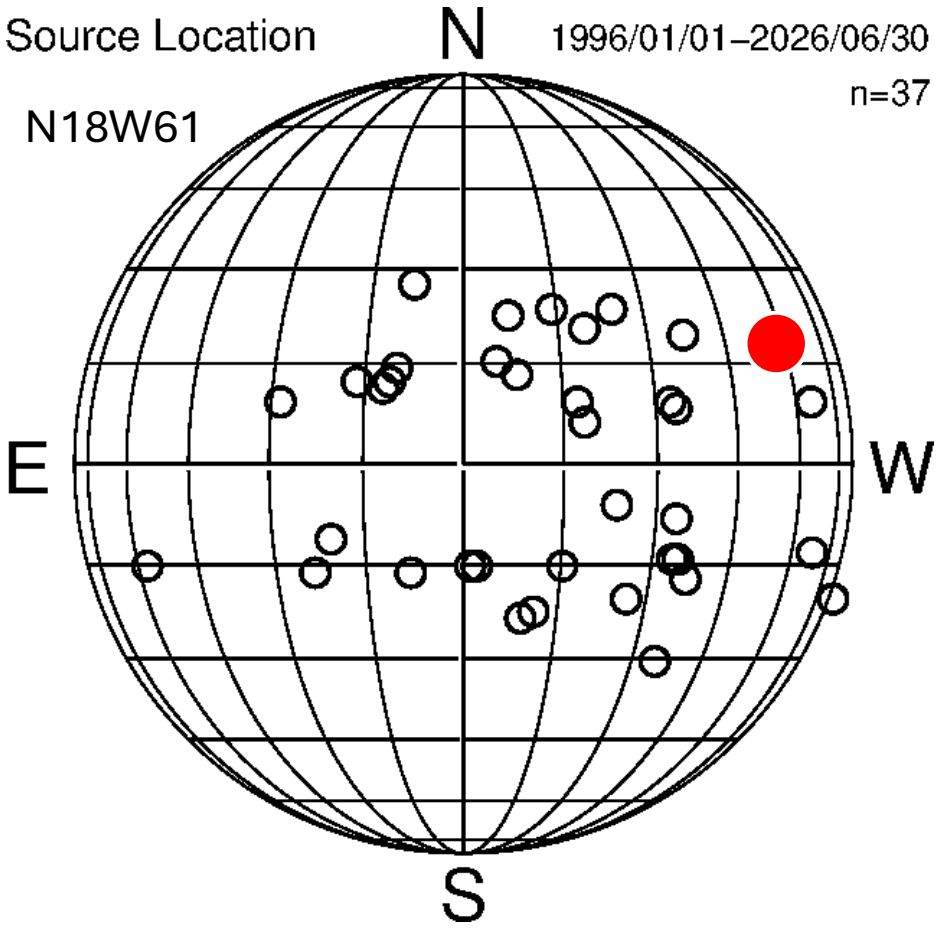


From L5, ~10 events will go behind the west limb

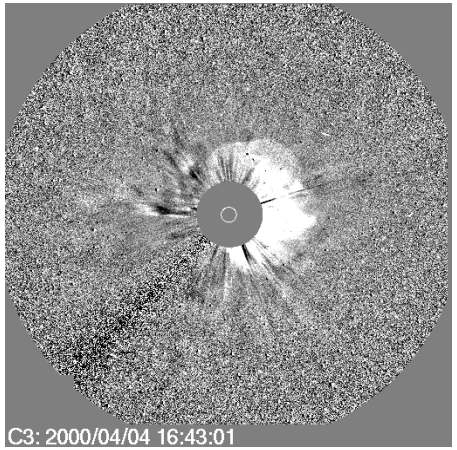
Summary

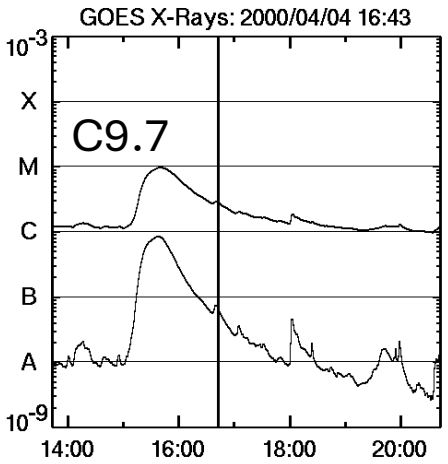
- We investigated double-whammy events in the SOHO era (since 1996)
- Criterion: Both an intense storm (Dst ≤ -100 nT) and a large SEP event (Ip ≥10 pfu @>10 MeV) should be present → 37 events
- These are special space weather events because they have both particle- and geomagnetic storm effects
- Double-whammy events are generally more intense than the general population (Dst, Ip, V_{CME})
- DW CMEs from large CMD produced geomagnetic storms mainly due to the sheath regions (glancing blow)
- The Dst vs. VBz correlation is similar to the general population
- DW can be readily observed from Sun-Earth L4 as Eastern events

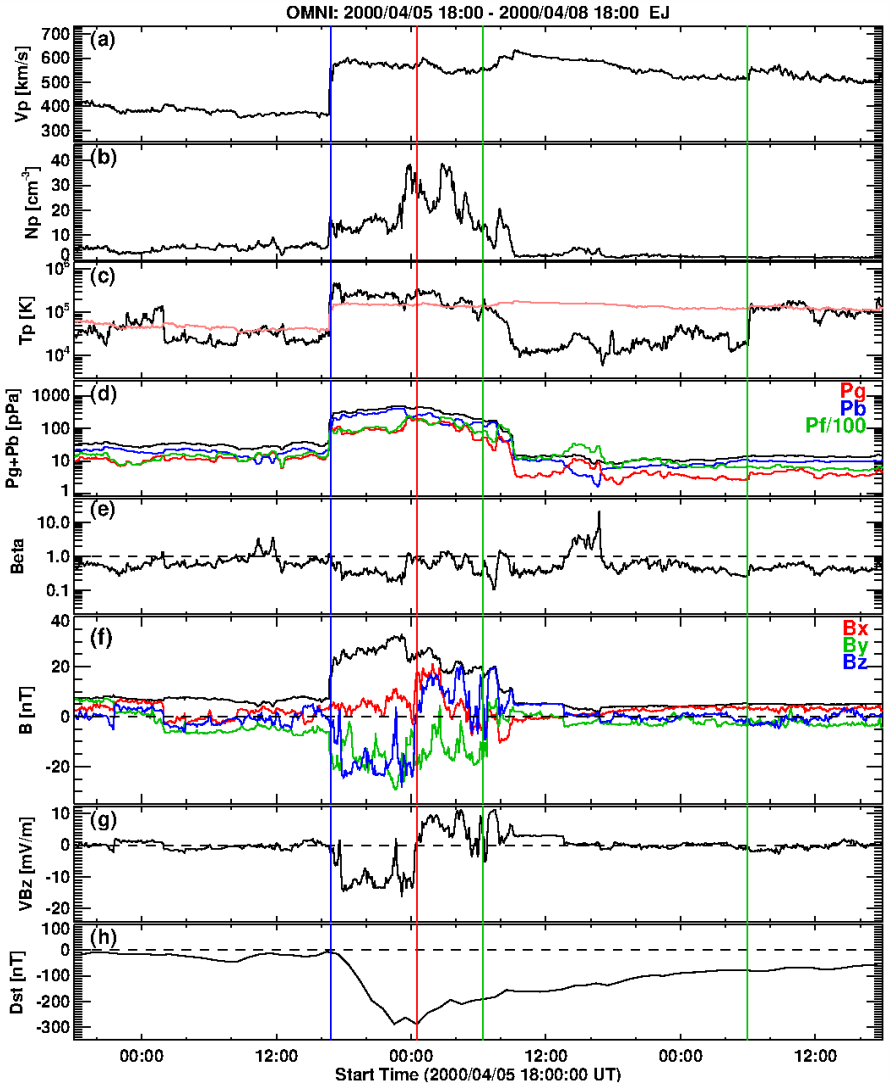
Large CMD event: 2000/04/04



1188 km/s





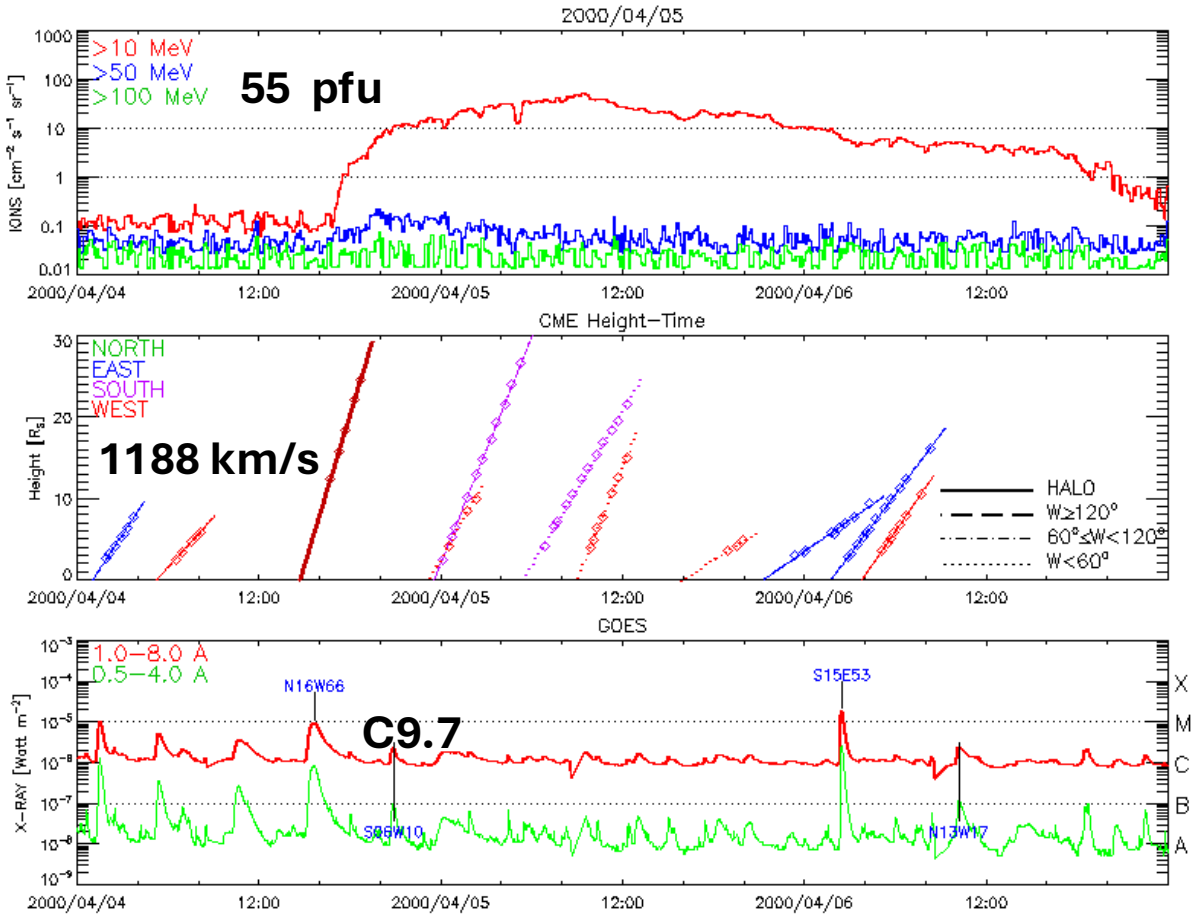


Also a sheath storm

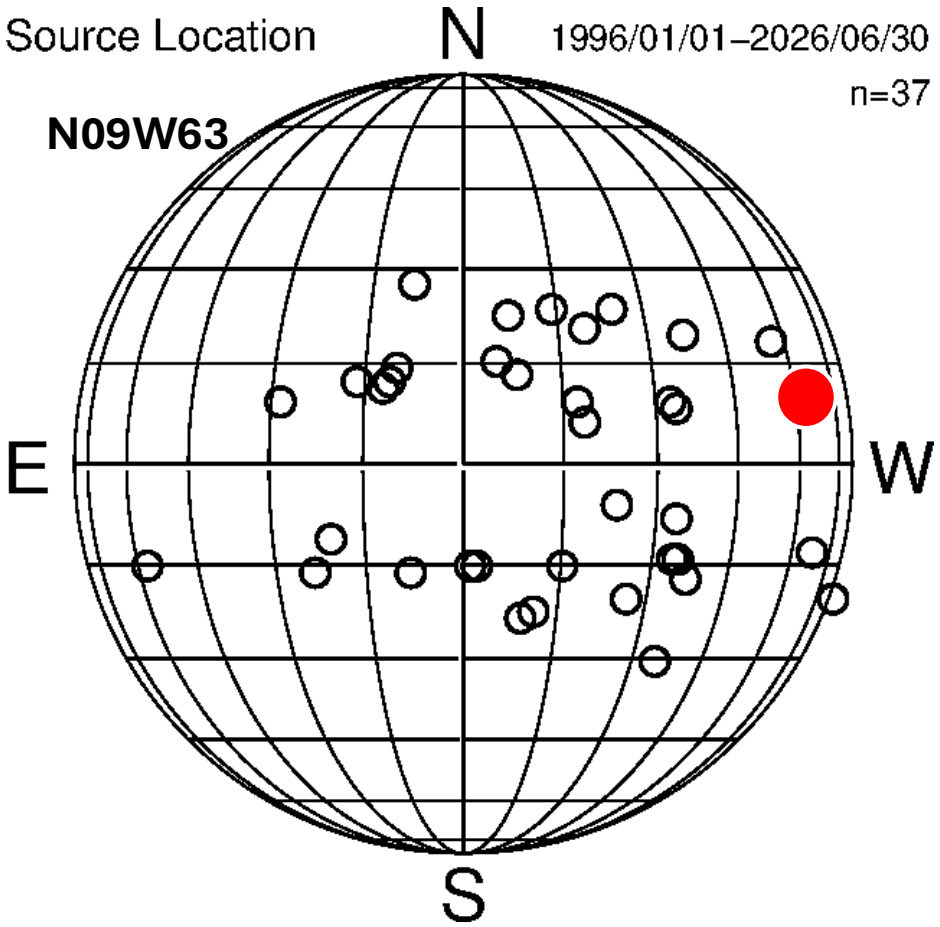
Gopalswamy+2008

SEP

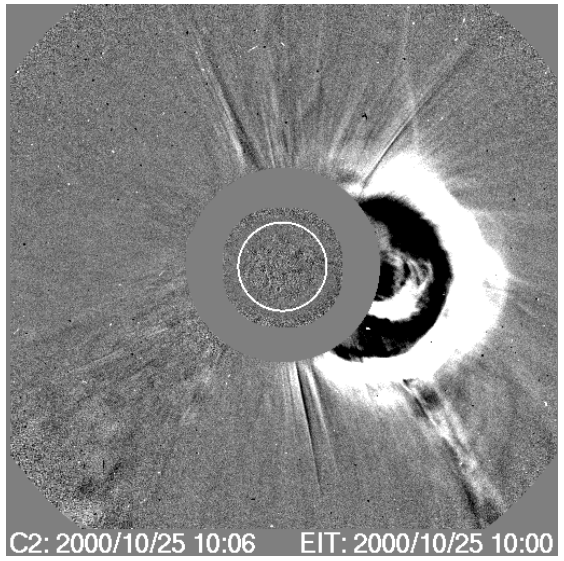
Soft Spectrum Event γ = 5.56
Filament eruption associated

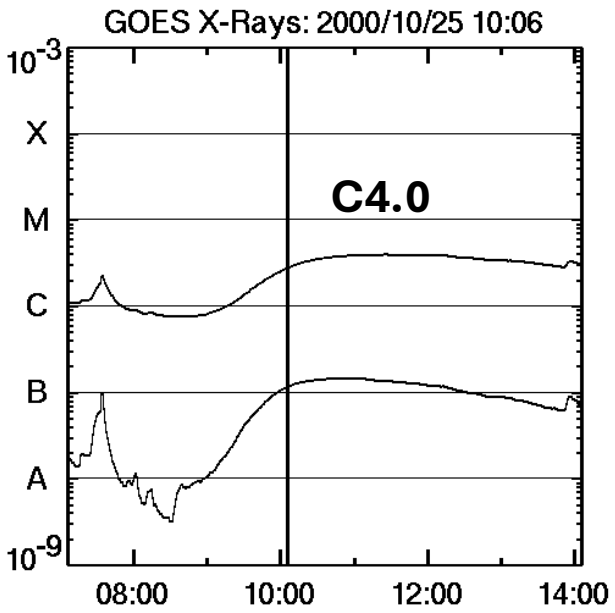


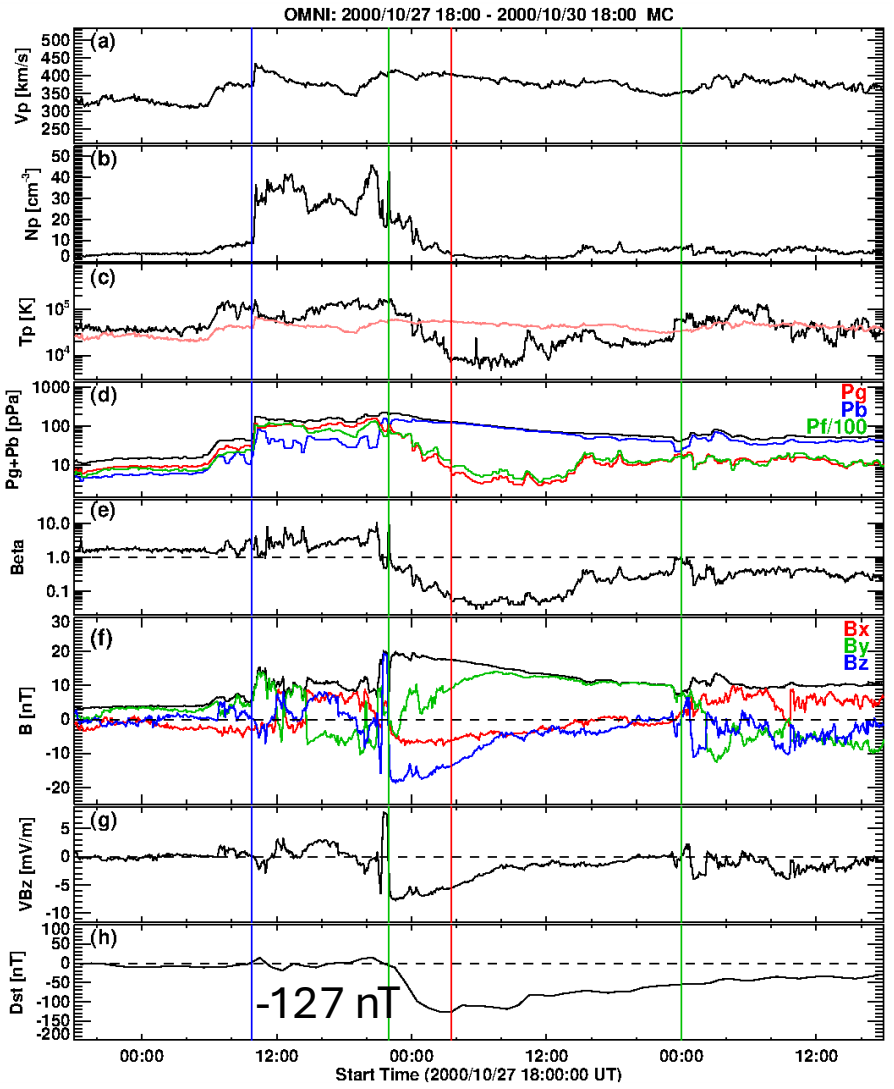
Large CMD Event: 2000/10/25



770 km/s

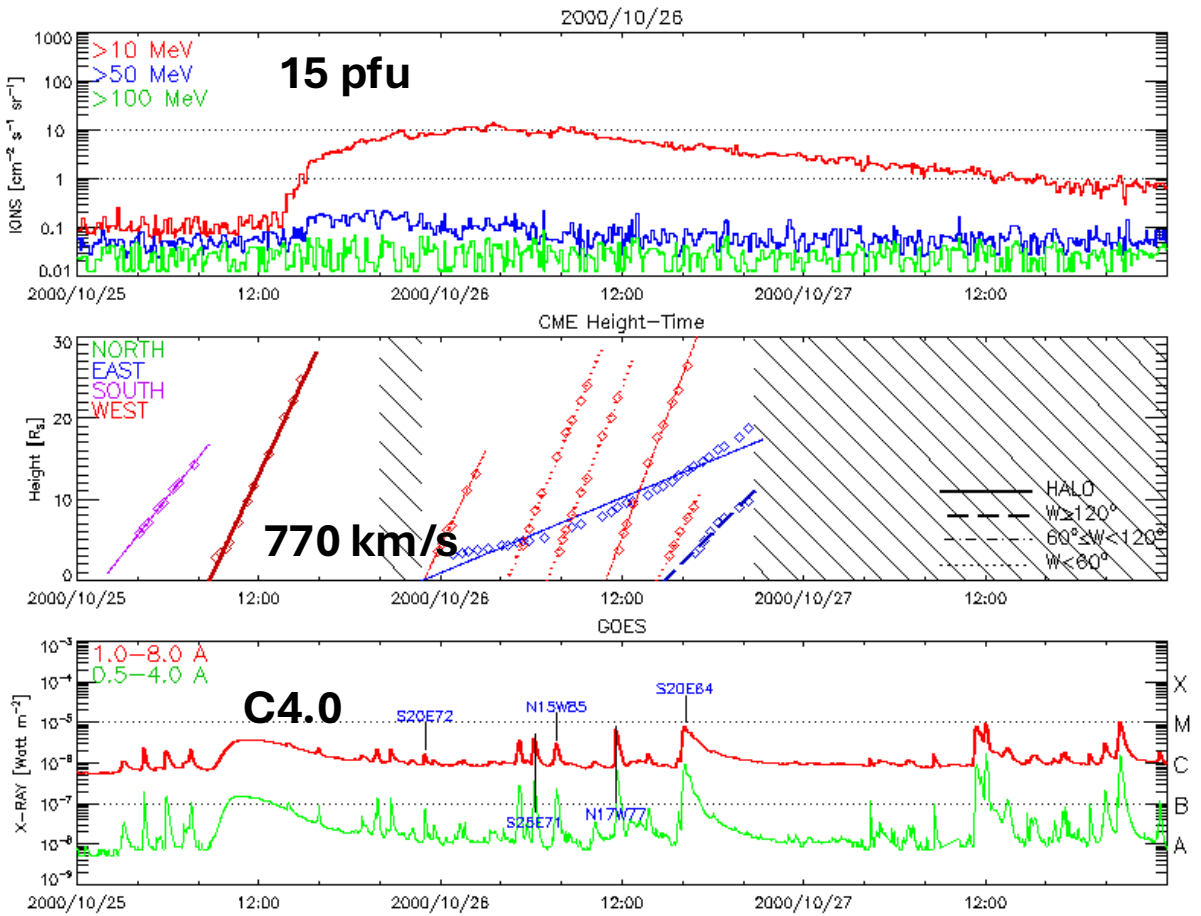




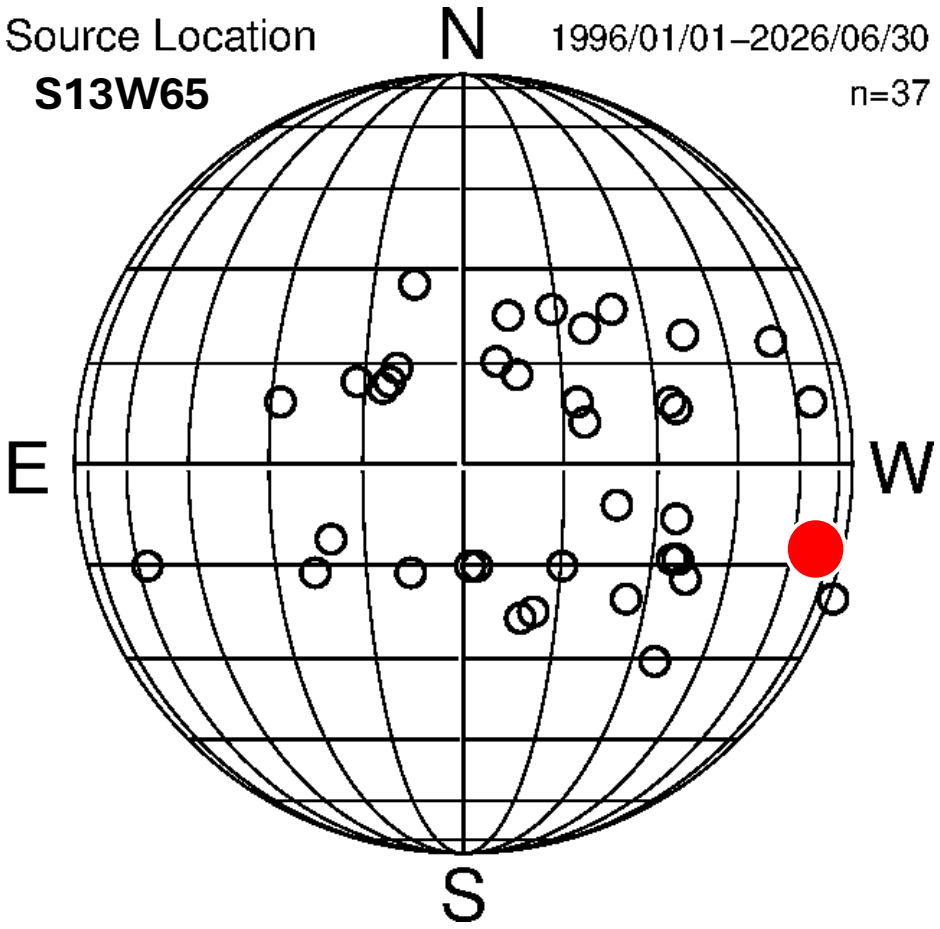


SEP

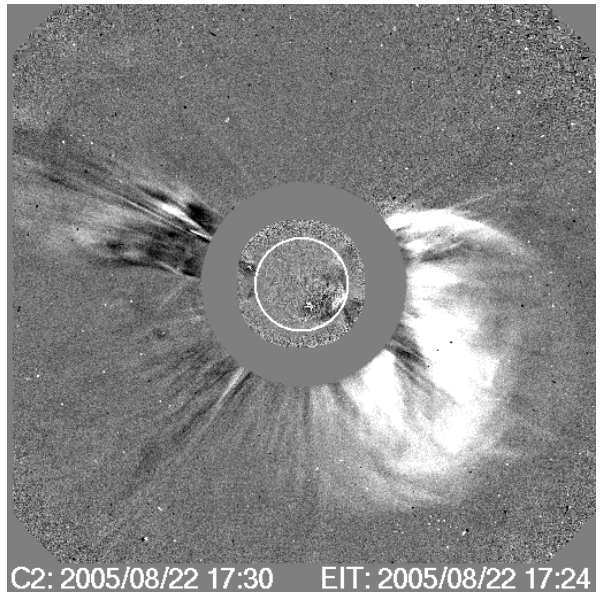
Soft Spectrum Event γ = 4.51
Filament eruption associated

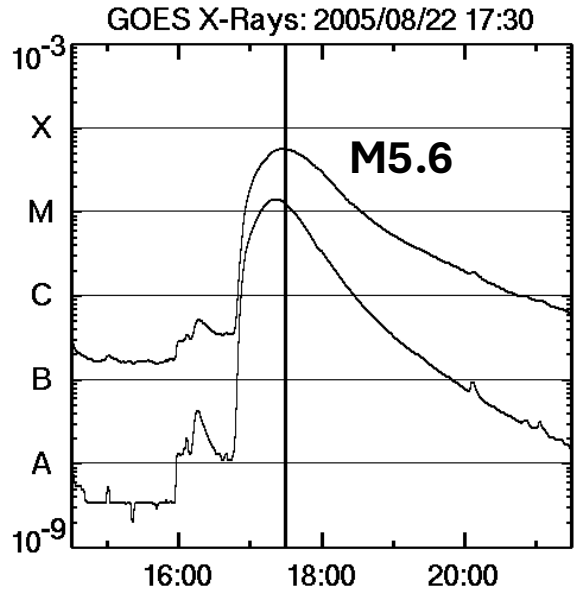


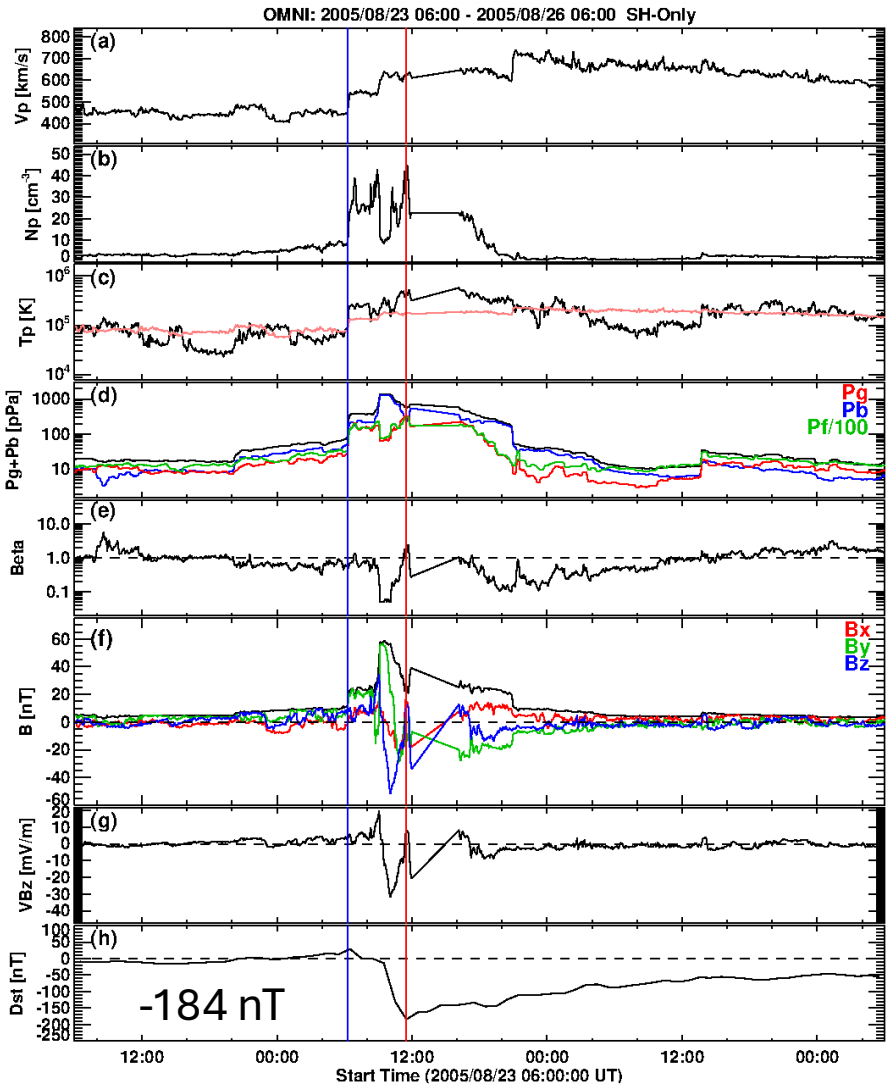
Large CMD 2005/08/22



2378 km/s



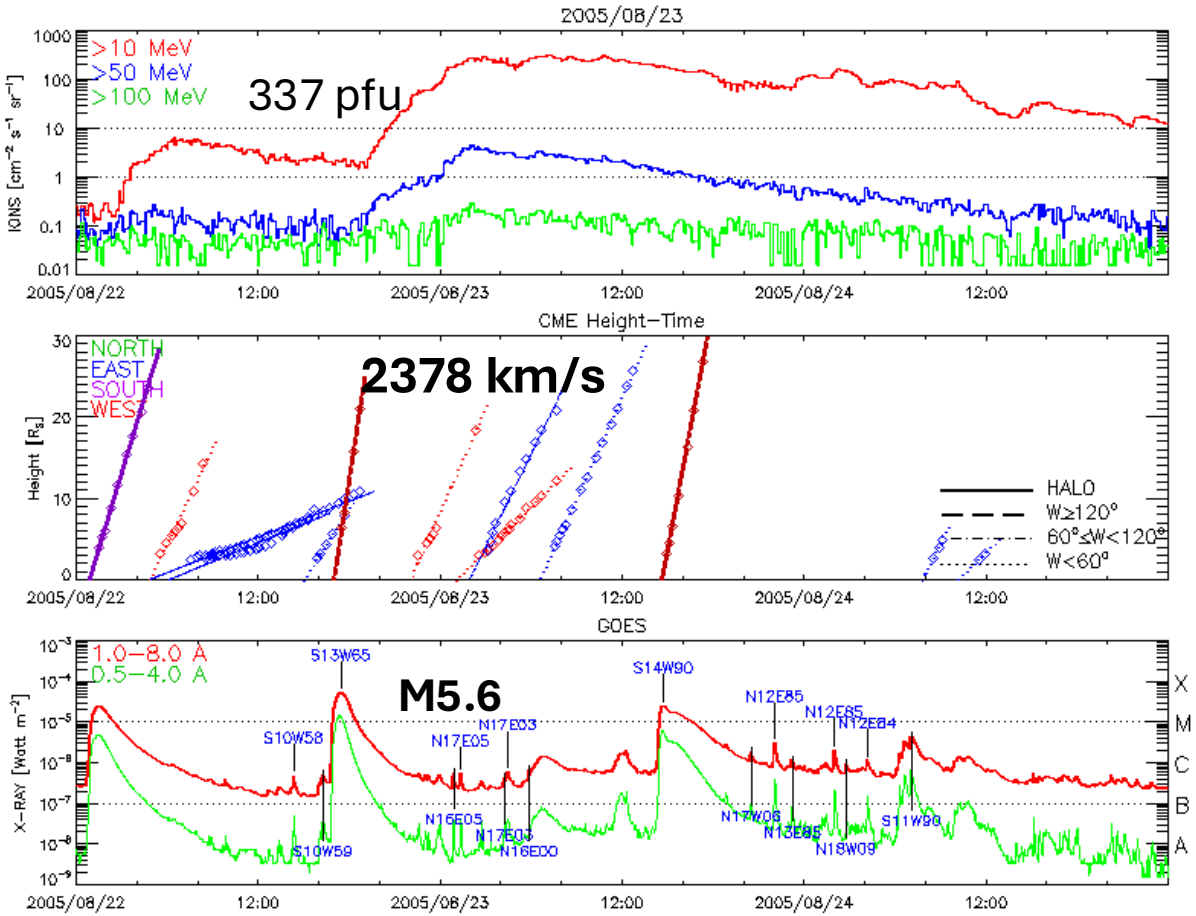


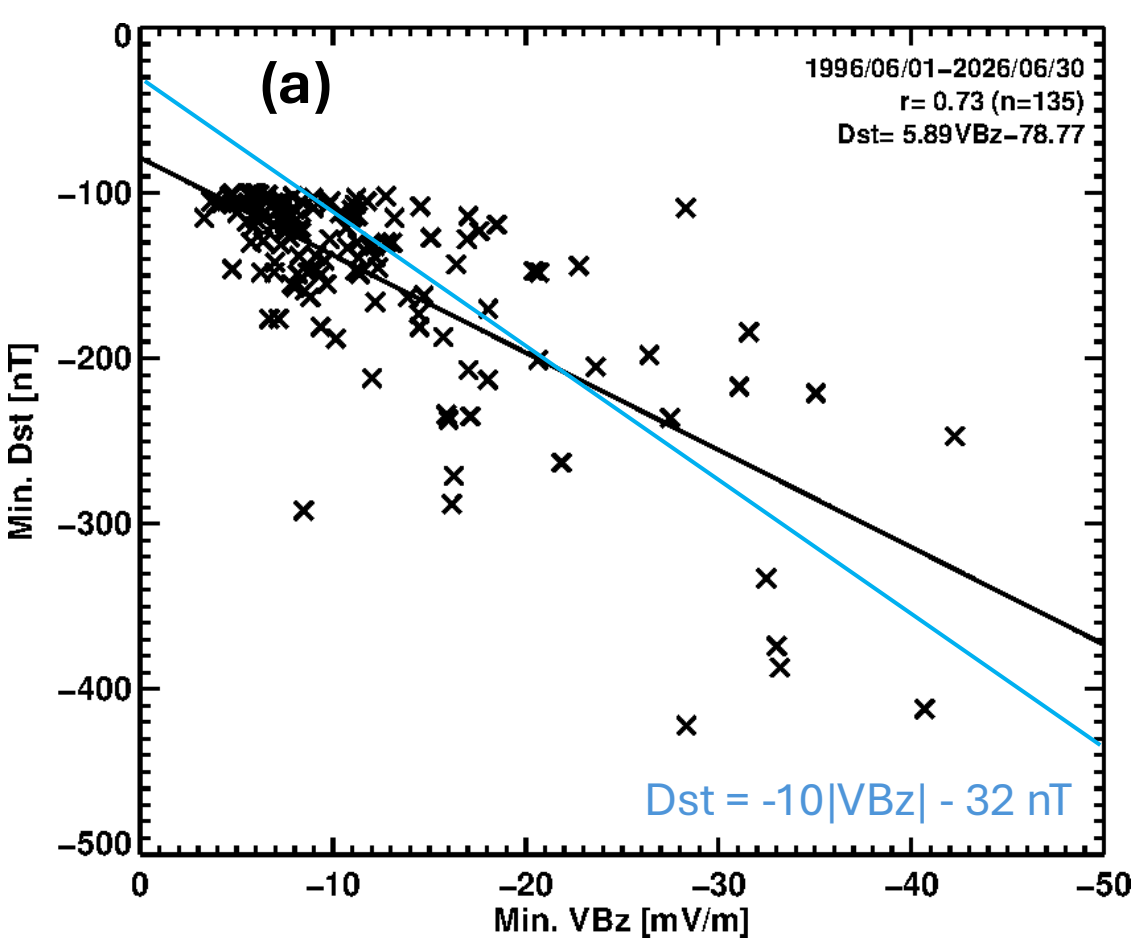


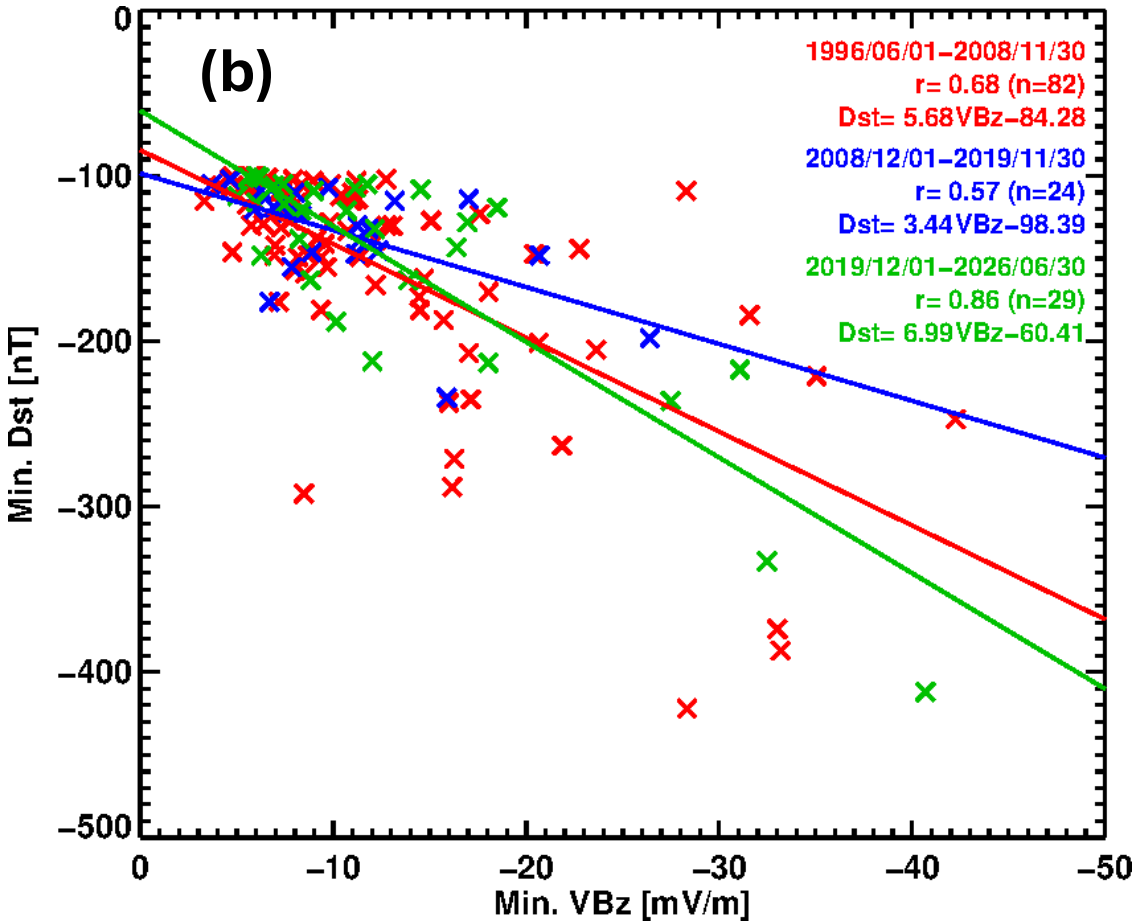
Sheath storm

SEP

Soft Spectrum Event γ = 5.28
From active region




(a)
1996/06/01–2026/06/30
r= 0.73 (n=135)
Dst= 5.89VBz–78.77
Dst = -10|VBz| - 32 nT
Min. Dst [nT]
Min. VBz [mV/m]
0
–100
–200
–300
–400
–500
–10
–20
–30
–40
–50


(b)
1996/06/01–2008/11/30
r= 0.68 (n=82)
Dst= 5.68VBz–84.28
2008/12/01–2019/11/30
r= 0.57 (n=24)
Dst= 3.44VBz–98.39
2019/12/01–2026/06/30
r= 0.86 (n=29)
Dst= 6.99VBz–60.41
Min. Dst [nT]
Min. VBz [mV/m]
0
–100
–200
–300
–400
–500
–10
–20
–30
–40
–50