# Colliding CMEs and their Consequences in the Inner Heliosphere

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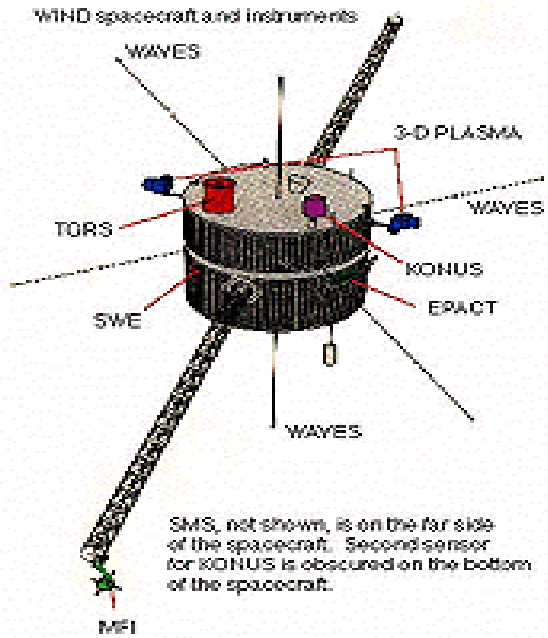
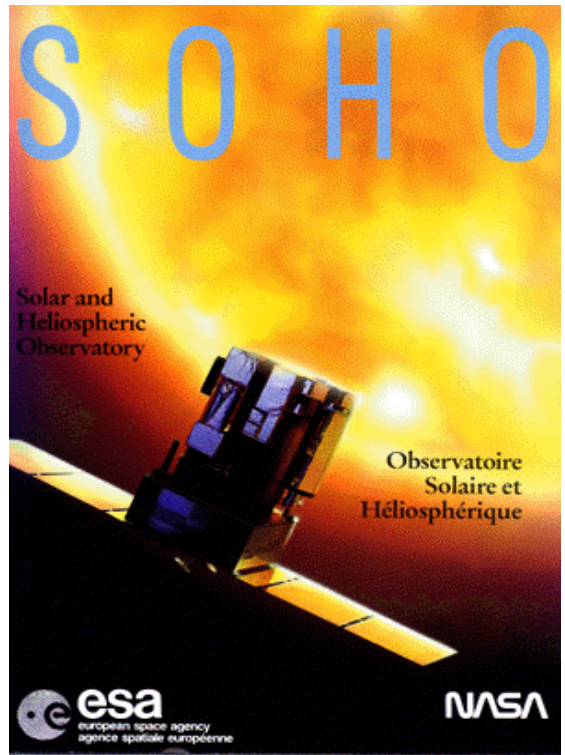
# Plan of the Talk

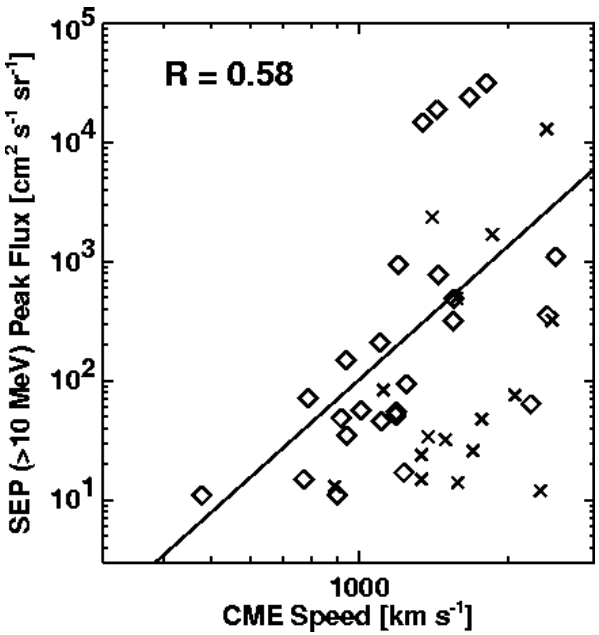
- CMEs and Radio Bursts
- CME interaction & intensity of proton/electron events
- Properties of primary & preceding CMEs
- CME speed – SEP intensity relationship
- Conclusions



# Motivation

- Interacting CMEs results in enhanced radio emission in the IP medium → additional electrons accelerated (Gopalswamy et al., 2001ApJL; 2002GRL)
- What happens to protons & electrons detected in situ? SEP-related CMEs seem to be launched into a medium distorted and disturbed by preceding CMEs. Can this affect the CME speed vs SEP intensity correlation?




If large SEP events are due to CME-driven shocks, why is th
orders of magnitude variation in SEP intensity for a given CI
→ Presence of SEPs in the ambient, spectral variation amor
events (Kahler, 2001)
→ Coronal & IP environment: of SEP events may be an addi
candidate to account for the scattering ?

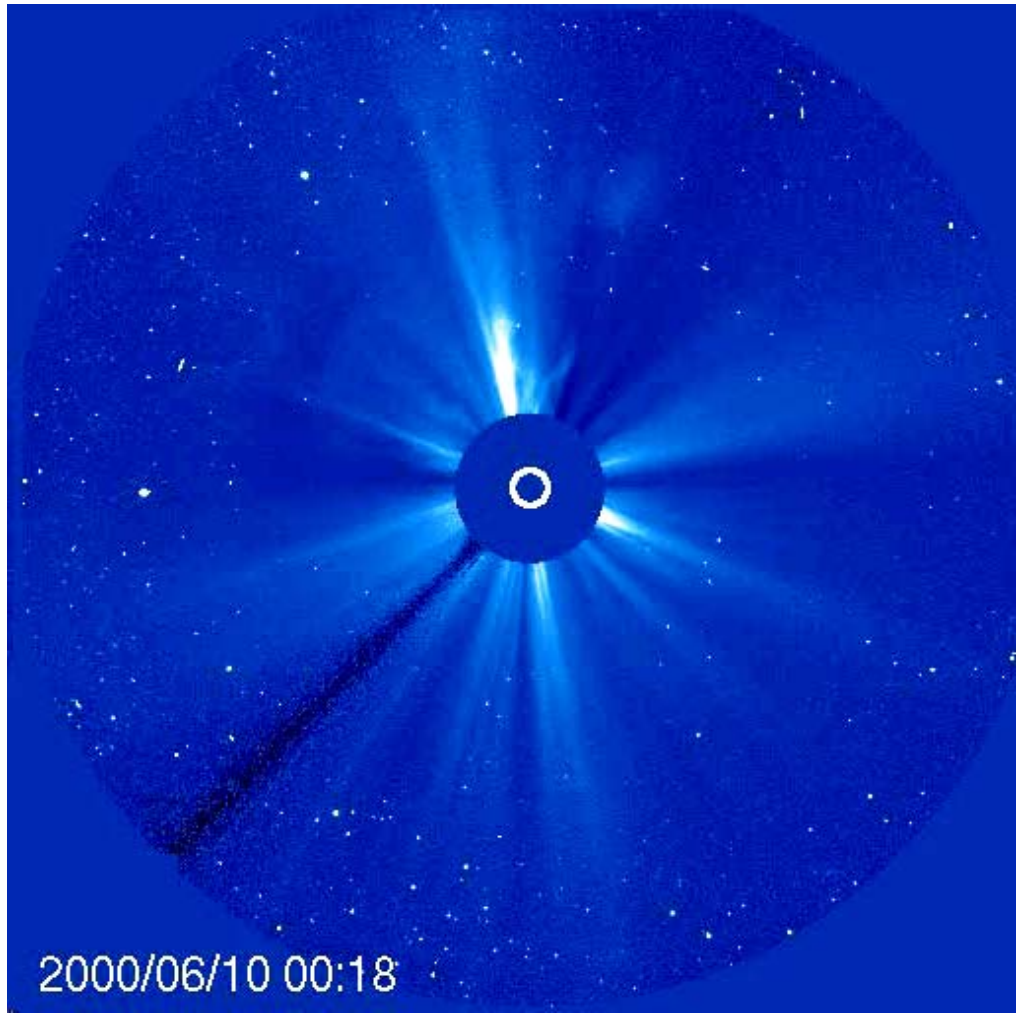
From Gopalswamy et al., 2003 GRL

# SEP events with Preceding by wide CMEs are more likely to have high Intensity (Summay of the Paper)

- Considered 68 Large (>10 pfu) GOES SEP events (1996-2002) that had overlap with SOHO/LASCO data
- Looked for preceding wide (>60$^{o}$) CMEs from the same source region as the primary CME.
- 23 CMEs with preceding wide CMEs (group-P)
- 20 CMEs with no preceding wide CMEs (group-NP)
- 18/23 (78%) of P events had high intensity (Ip > 50 pfu)
- Only 5/20 (25%) of NP events had high

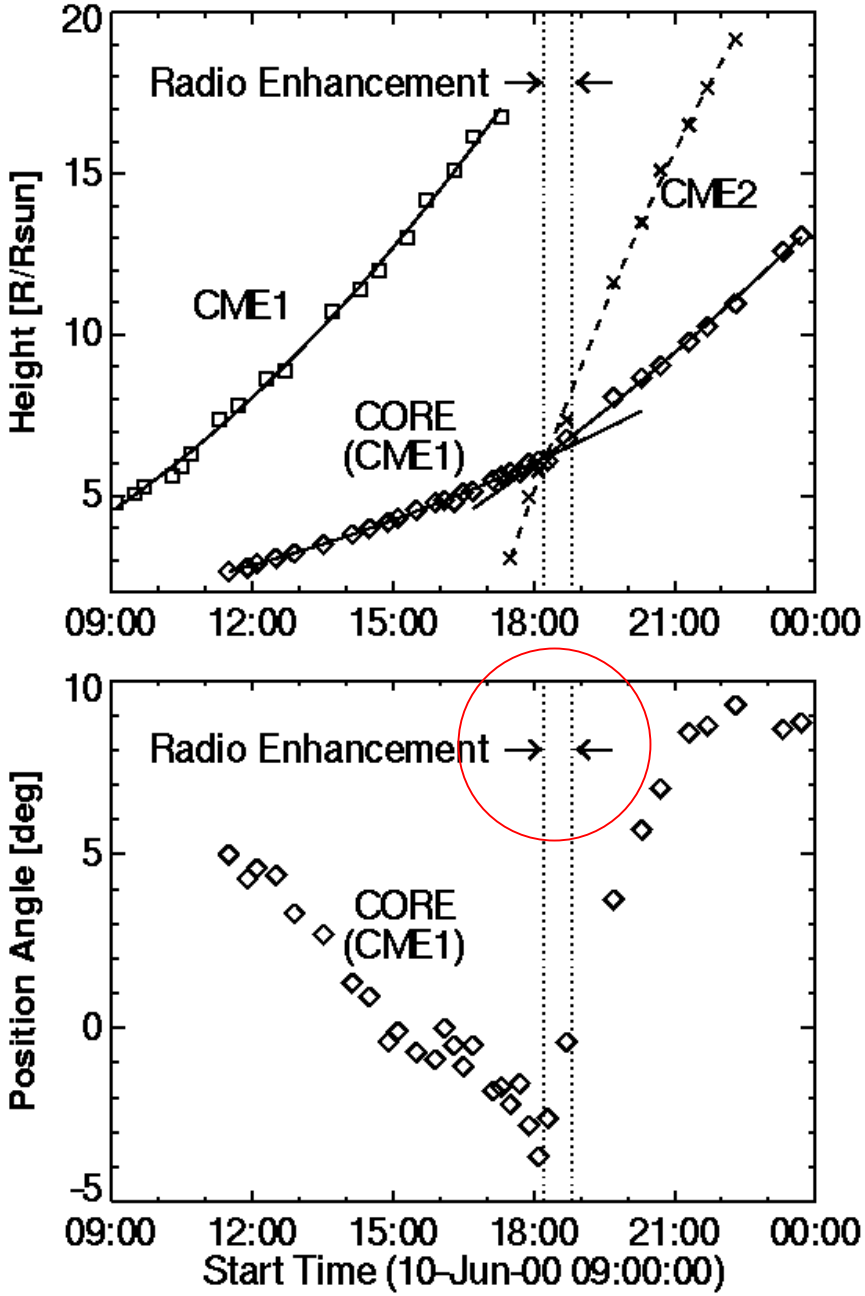
# CME Collision: A slow CME is Deflected by a Fast one

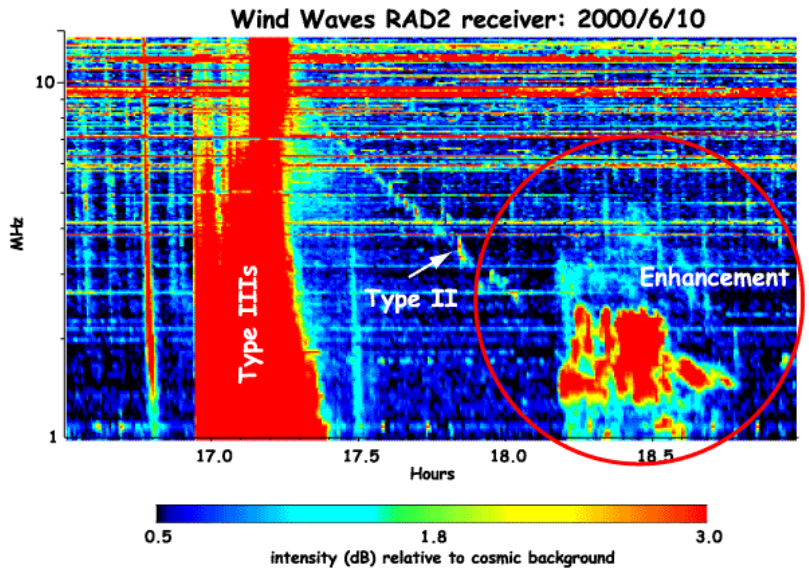
- Slow CME (290 km/s) overtaken by a fast CME (660 km/s)
- The slow CME core deflected to the left from its trajectory




LASCO C3 movie

# CMEs on 2000/06/10

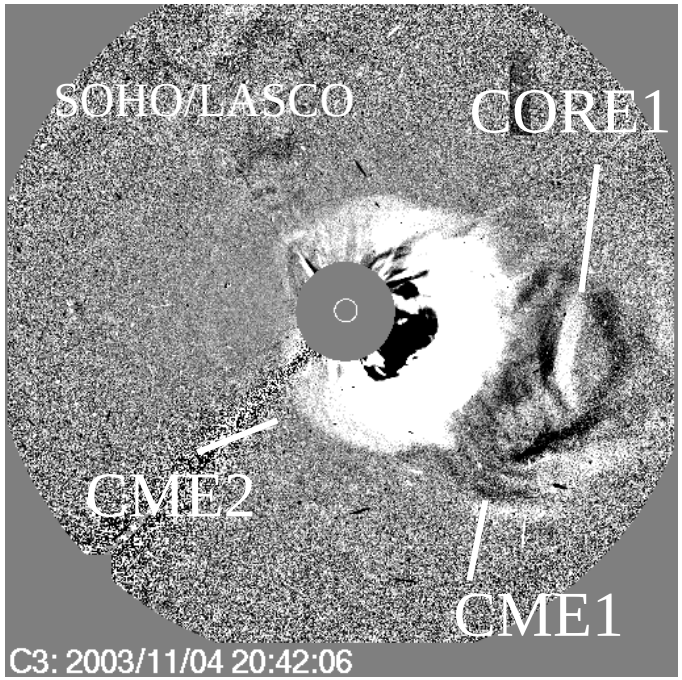


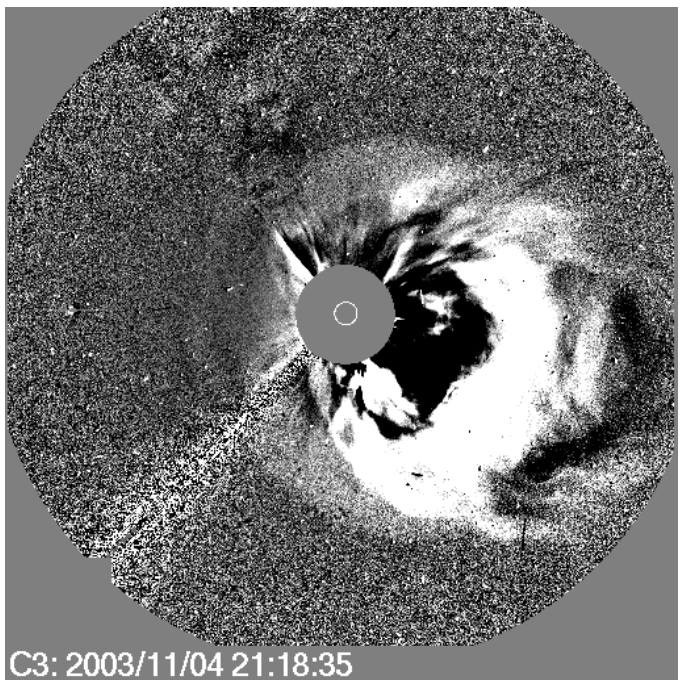




Broad-band radio emission at the time of collision.

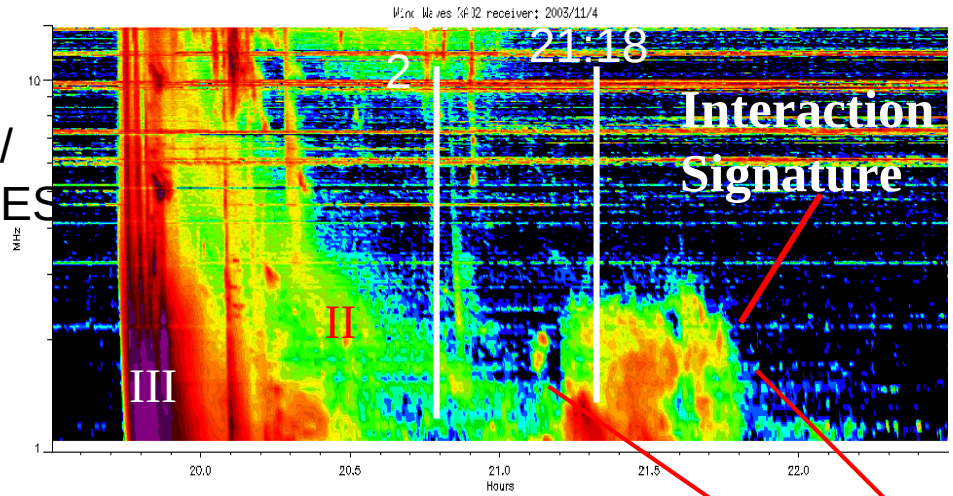
Gopalswamy et al. 2001
ApJ Lett. 548, L91, 2001

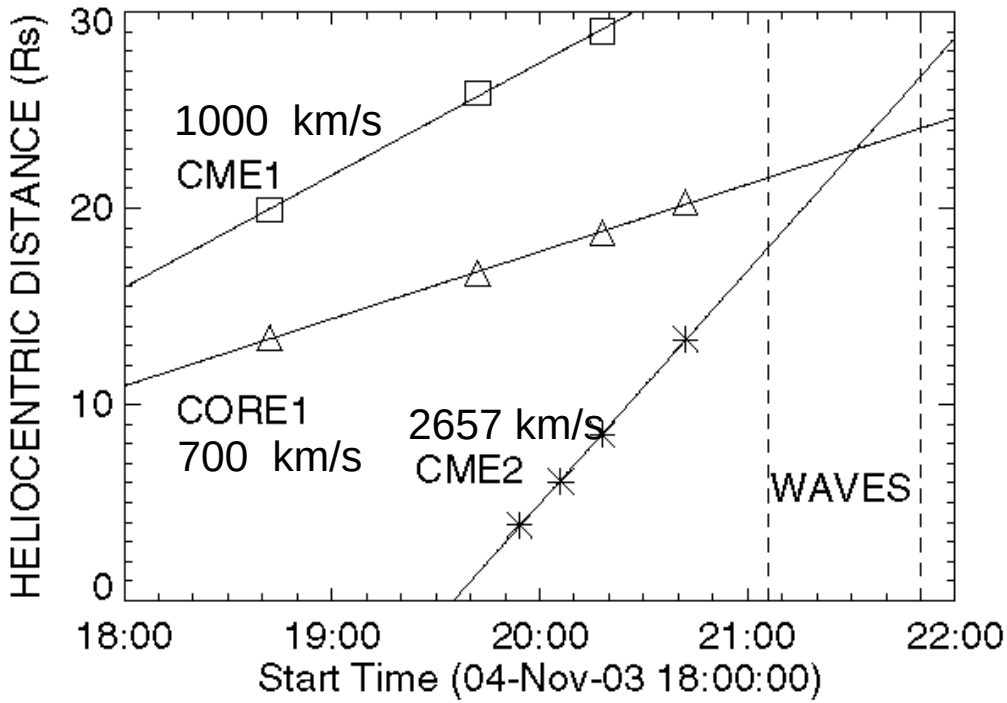
# A Recent Example (2003/11/04) During the Oct-Nov Storms



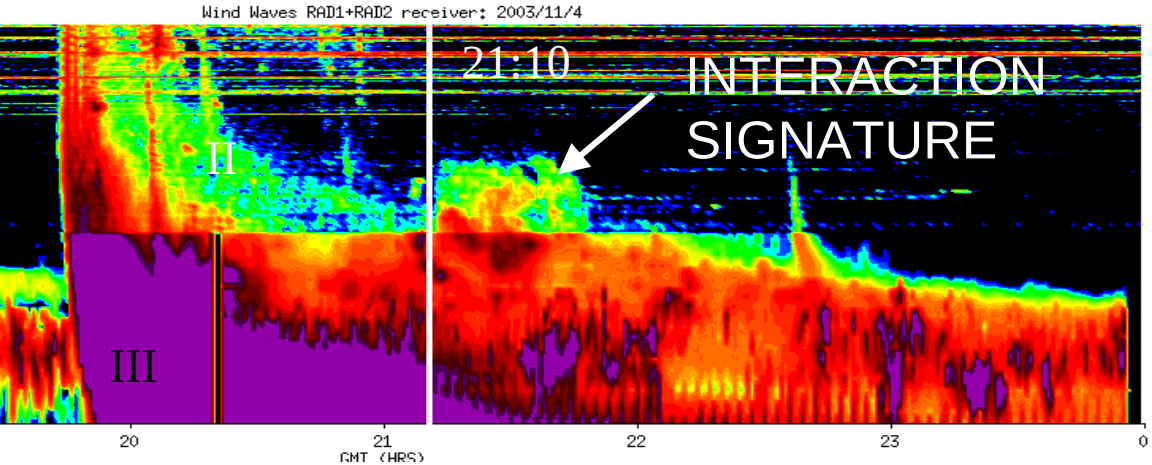



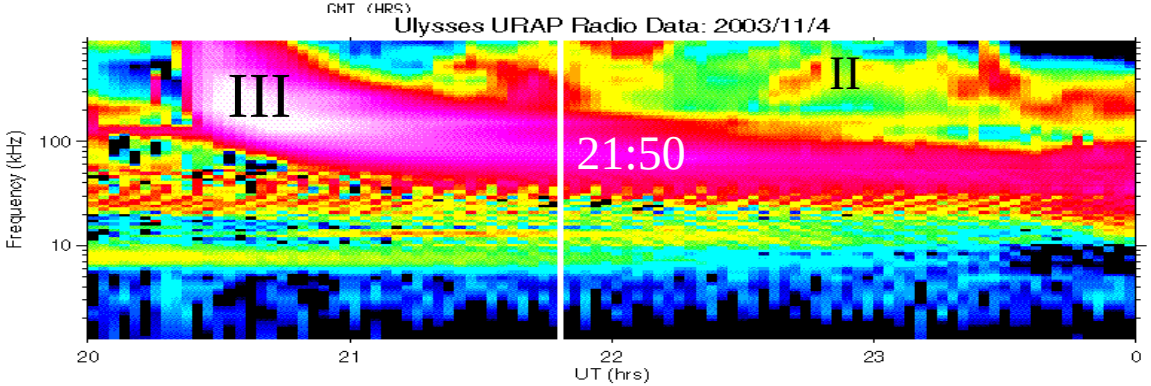

Wind/ WAVES

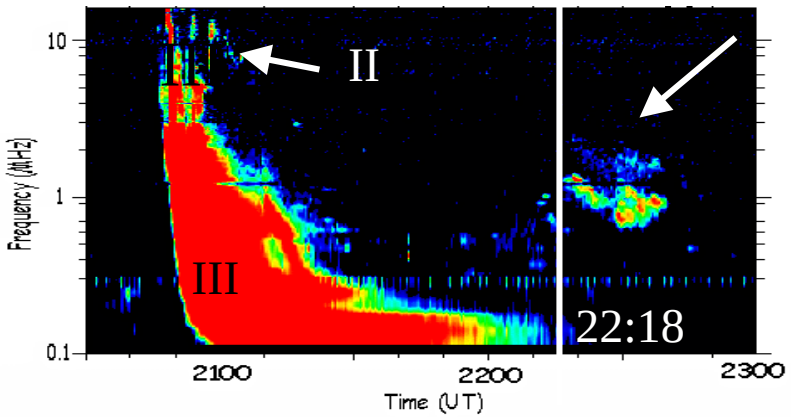


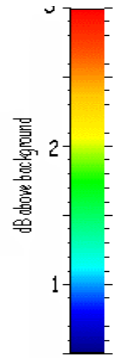



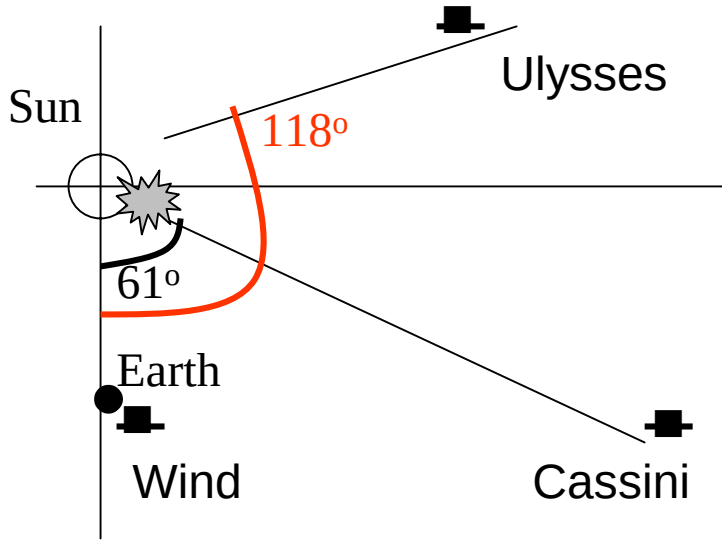
# 2003/11/04 Interaction Signature at Wind, Ulysses & Cassini



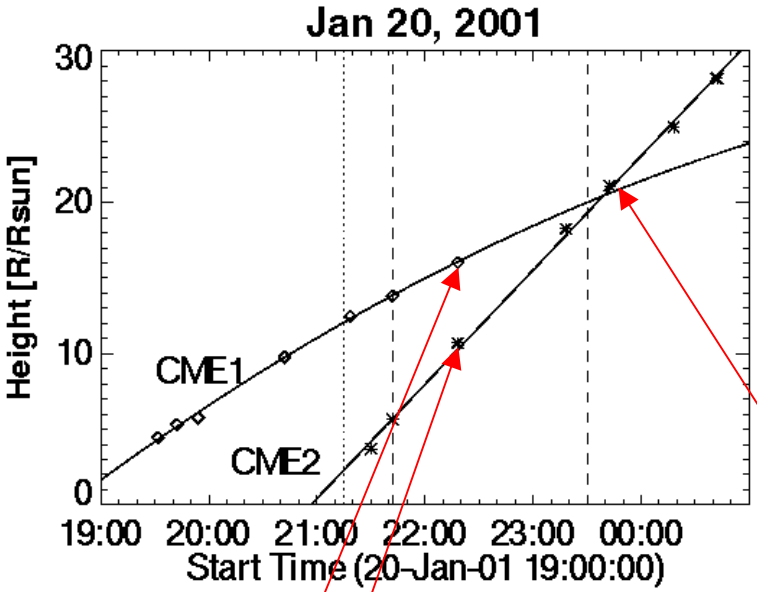




Ulysses: 5 AU
<900 kHz

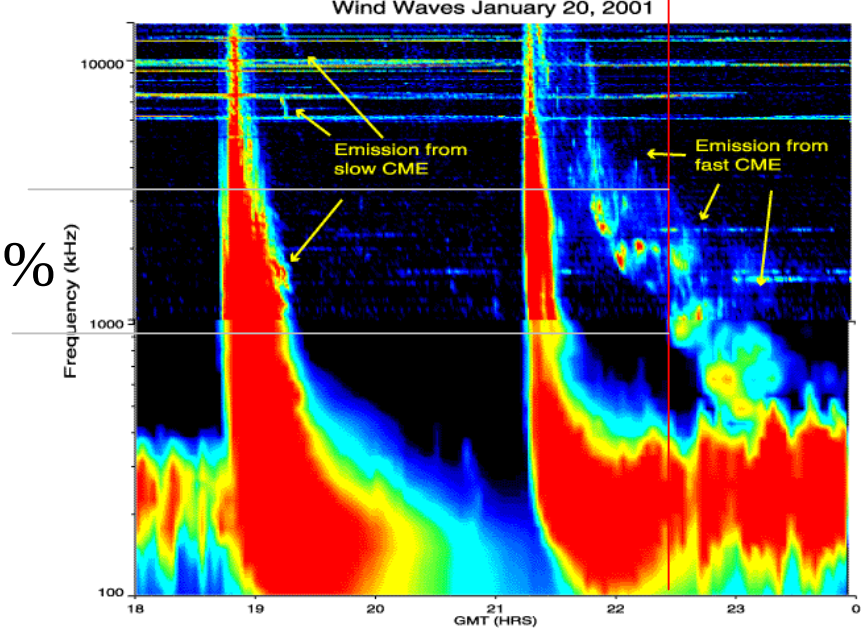
Ecliptic Plane
2003/11/04

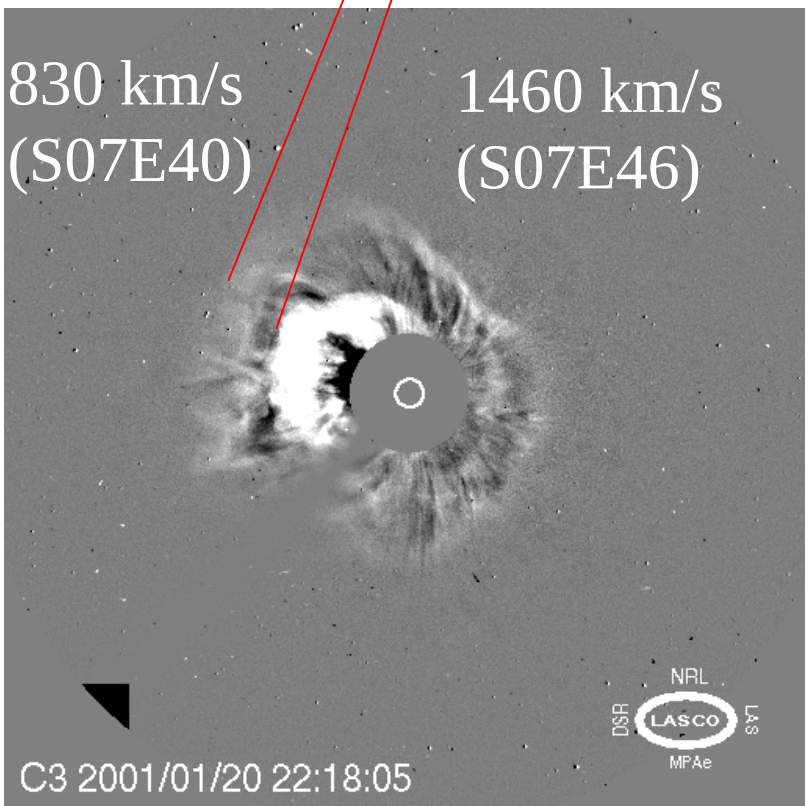
Cassini: 8.7 AU

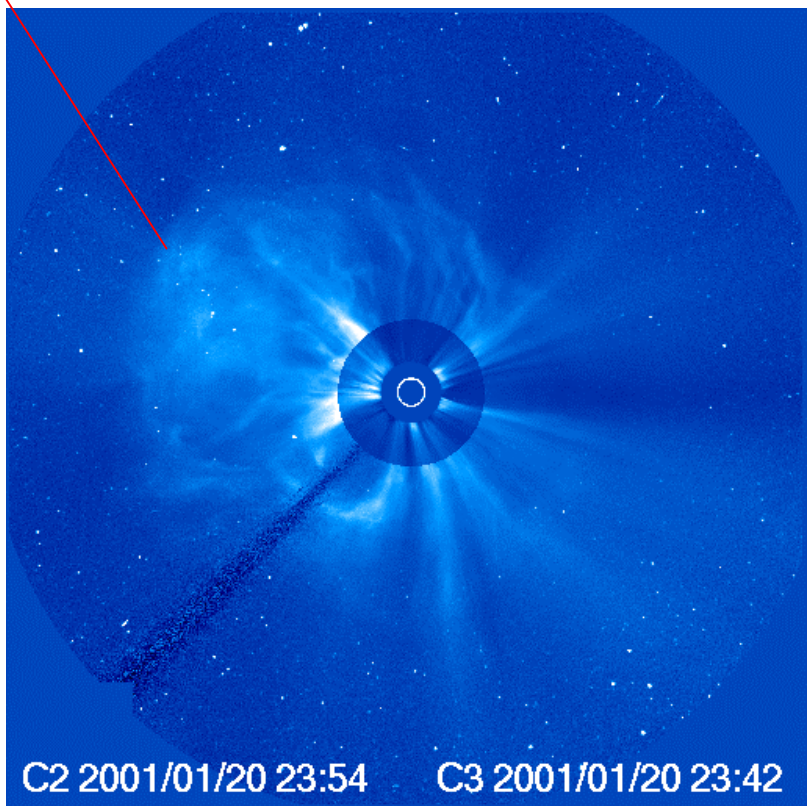
The Wind/WAVES signature starts at 21:18 was seen by Ulysses at 21:50 and Cassini at 22:18 UT (white lines). Cassini data confirms that the interaction signature is very


Jan 20, 2001
Height [R/Rsun]
30
20
10
0
CME1
CME2
19:00
20:00
21:00
22:00
23:00
00:00
Start Time (20-Jan-01 19:00:00)

~100%


Wind Waves January 20, 2001
10000
1000
100
Frequency (kHz)
Emission from slow CME
Emission from fast CME
18
19
20
21
22
23
0
GMT (HRS)

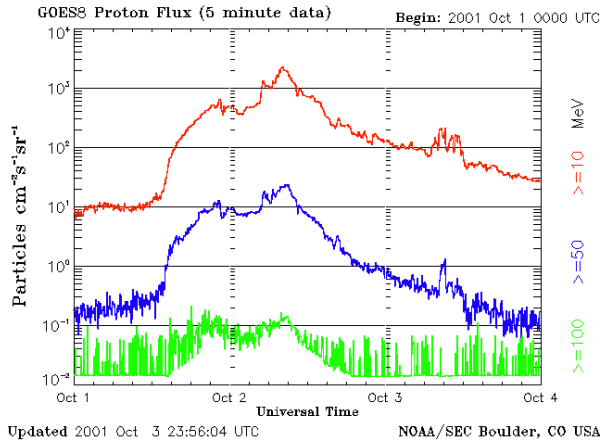

830 km/s
(S07E40)
1460 km/s
(S07E46)
NRL
LASCO
DSR
LAS
MPAe
C3 2001/01/20 22:18:05

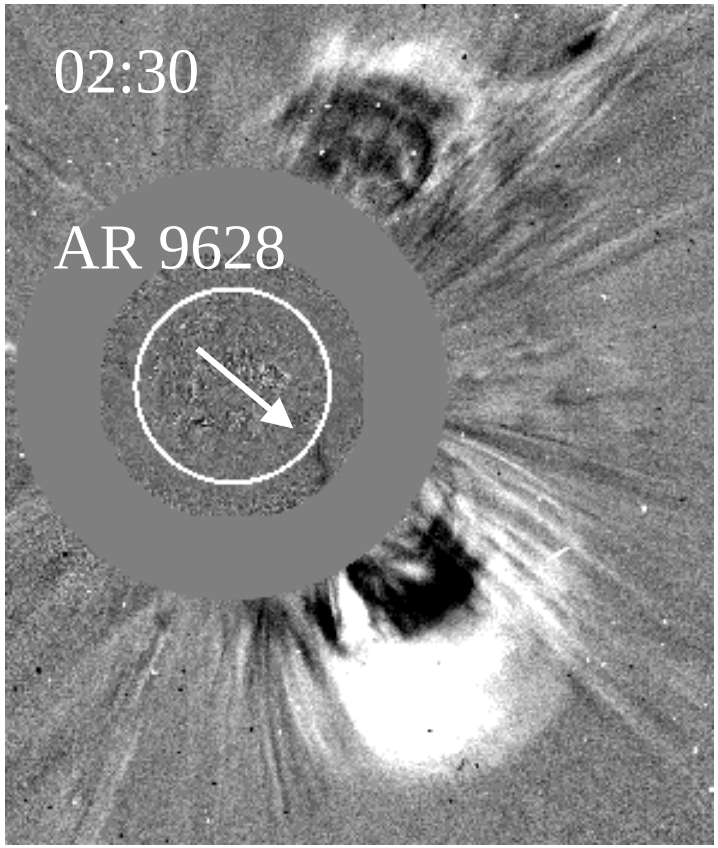

C2 2001/01/20 23:54
C3 2001/01/20 23:42

# SEPs

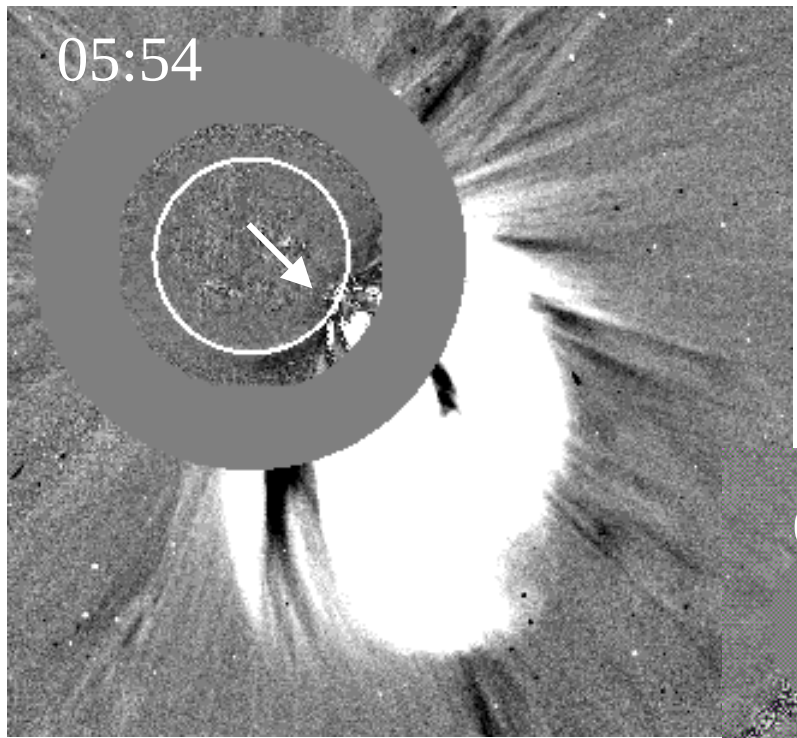
- Identify the Primary CME of each SEP event
- Identify the source using EIT images or others
- Look for preceding wide (>60$^{o}$) CMEs from the same source within 1 day ahead
- If there is a preceding CME, it is a P event
- If there is no preceding wide CME, it s an NP event

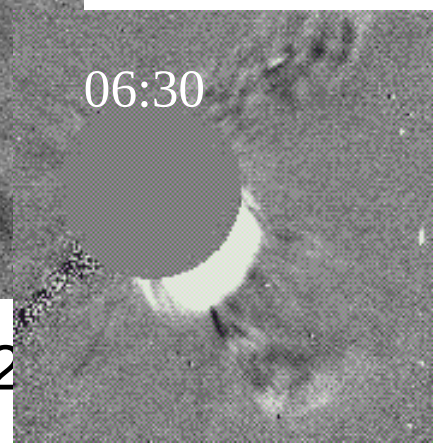
# EIT & LASCO C2 diff Images:
# Two CMEs from AR 9628 Oct 1, 2001




DT = 4.5 h



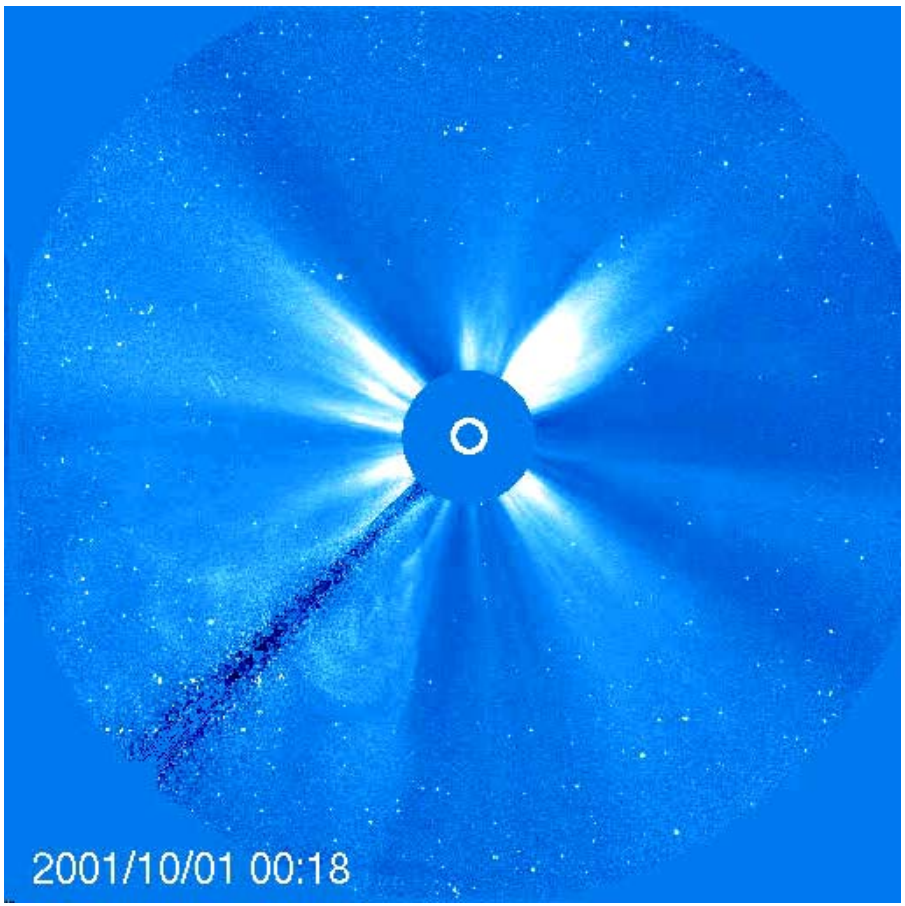




Preceding CME
CPA=226 W=68 V=478km/s

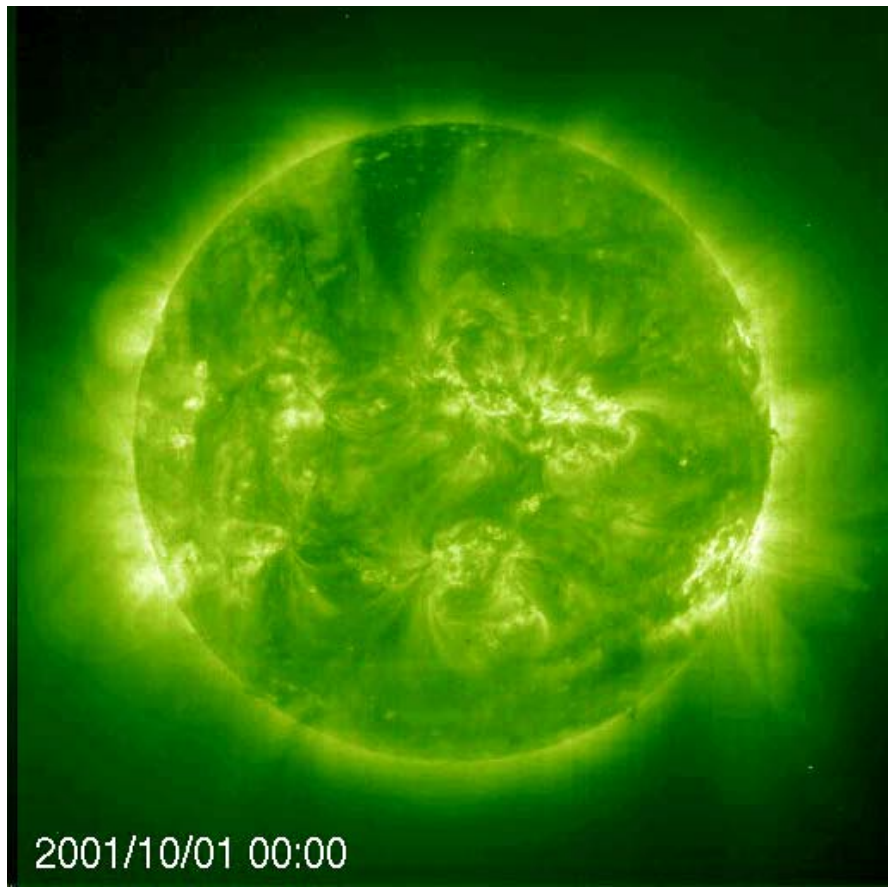
Primary CME CPA=22
W=360 V=1405 km/s

# Primary & Preceding CMEs from AR 9628

"Snow storm" SEPs hitting the SOHO detectors



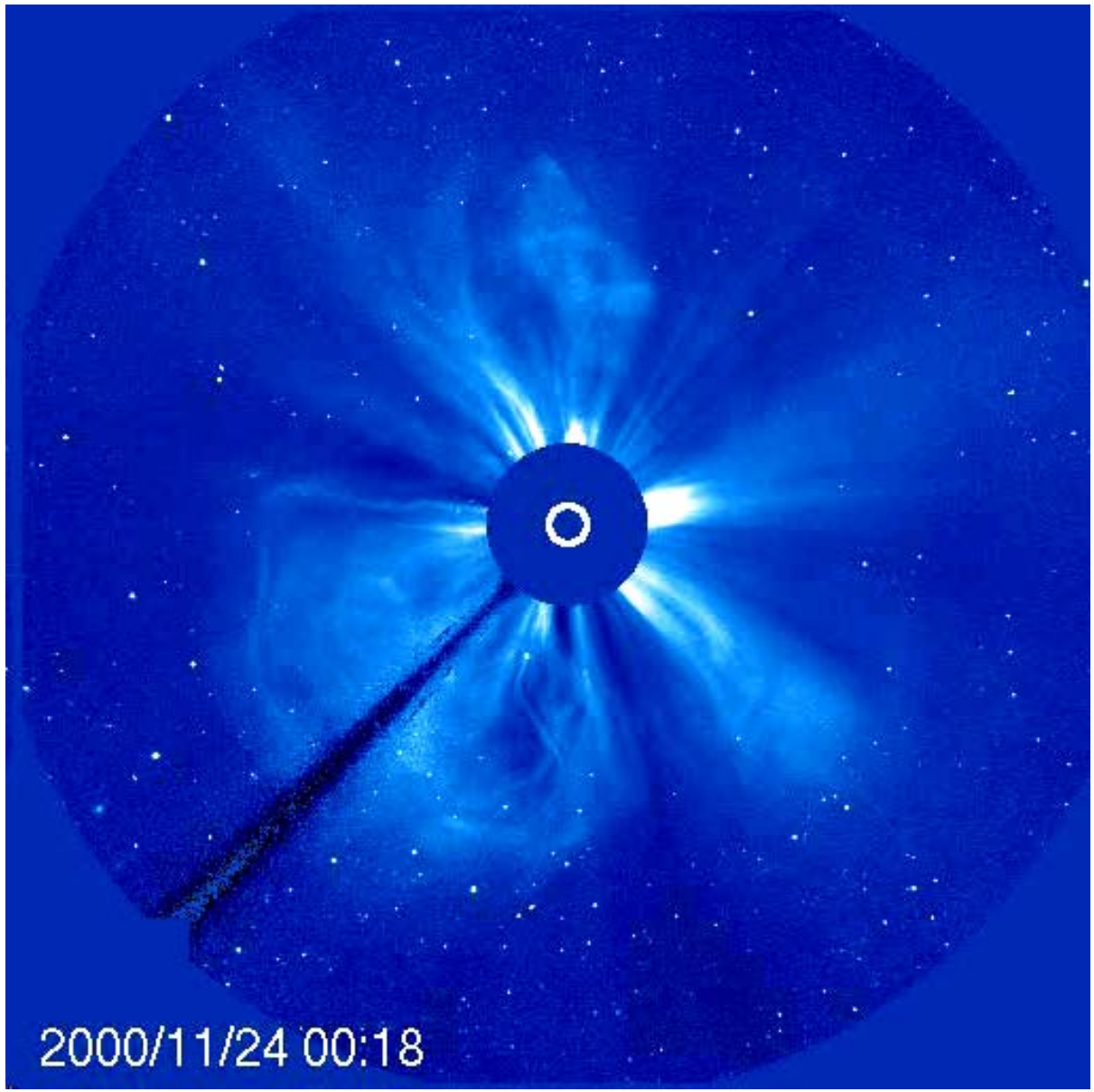

EIT movie shows that solar source is the same for the primary and preceding CMEs



# Multiple Halo CMEs 11/24/00

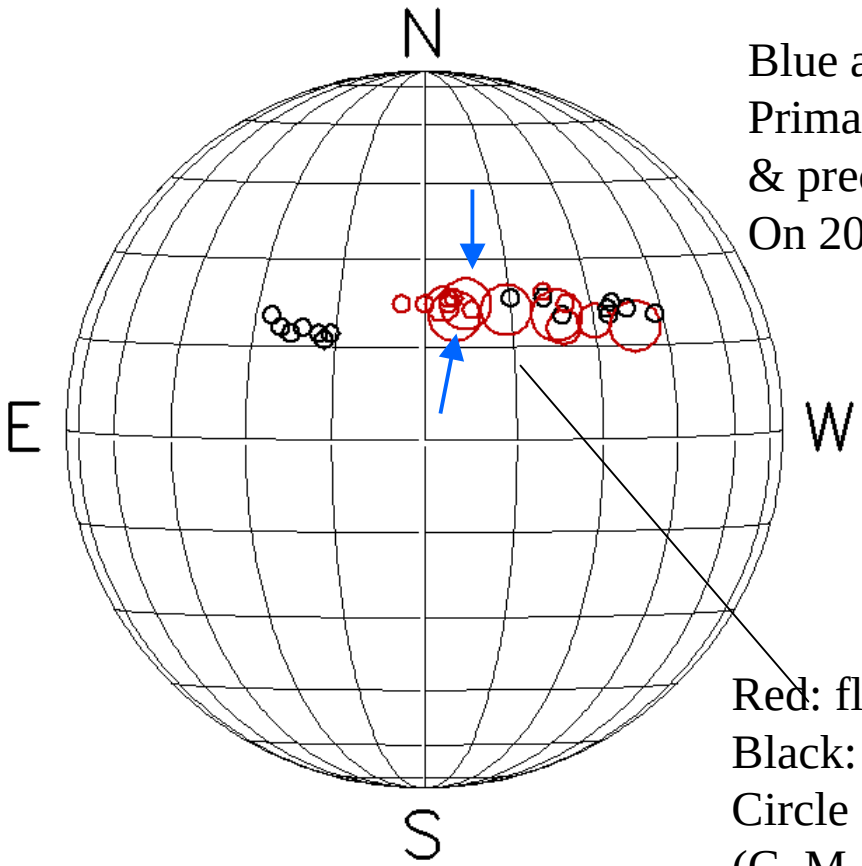
→ The Halo CME at 15:30 UT is one of SEP associated CMEs studied

→ It was preceded by Another halo at 05:30 From the same region DT = 10 h



# AR 9236
# 11/22 – 11/27 2000

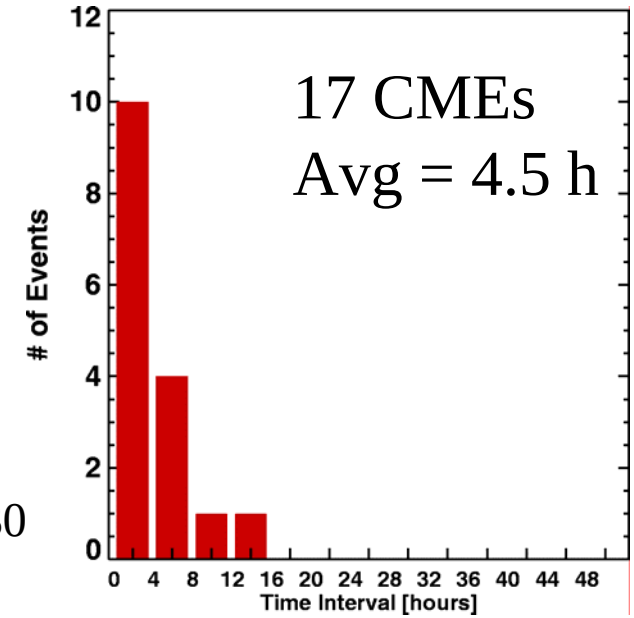
→ Most activity over 3 days
→ Flare and CME recurrence similar
→ Complex ejecta at 1 AU (Burlaga et al 2001)

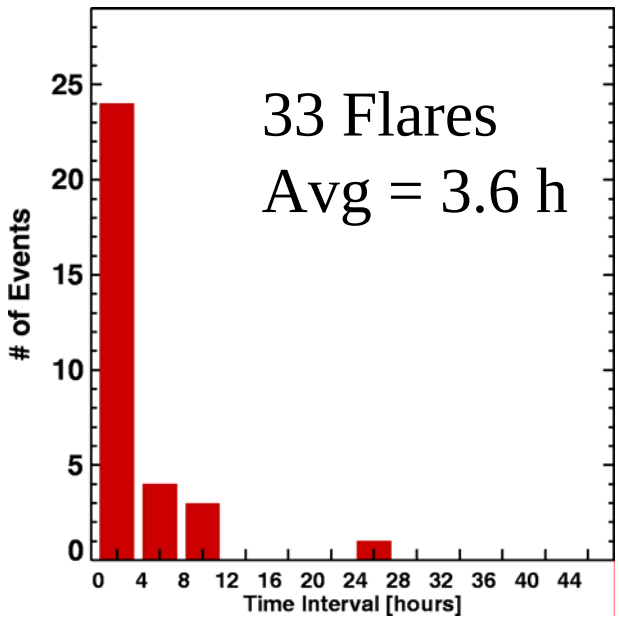



Blue arrows indicate
Primary CME at 15:30
& preceding CME at 5:30
On 2000/11/24

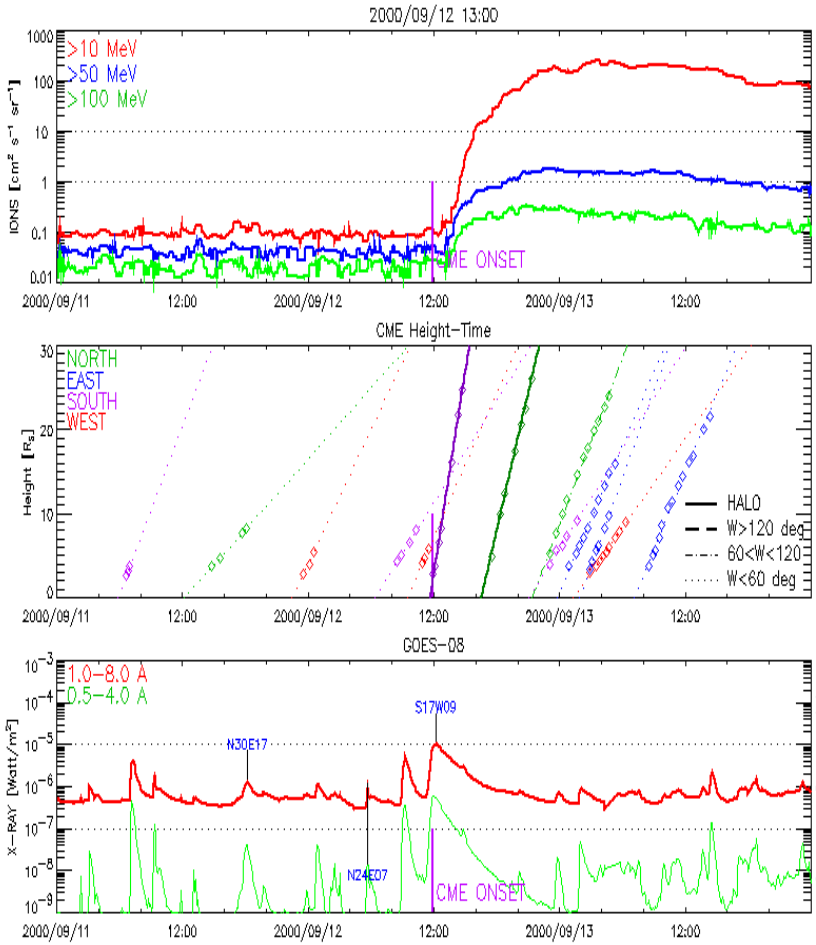
Red: flares with CMEs
Black: flares w/o CMEs
Circle size → flare size
(C, M, X)

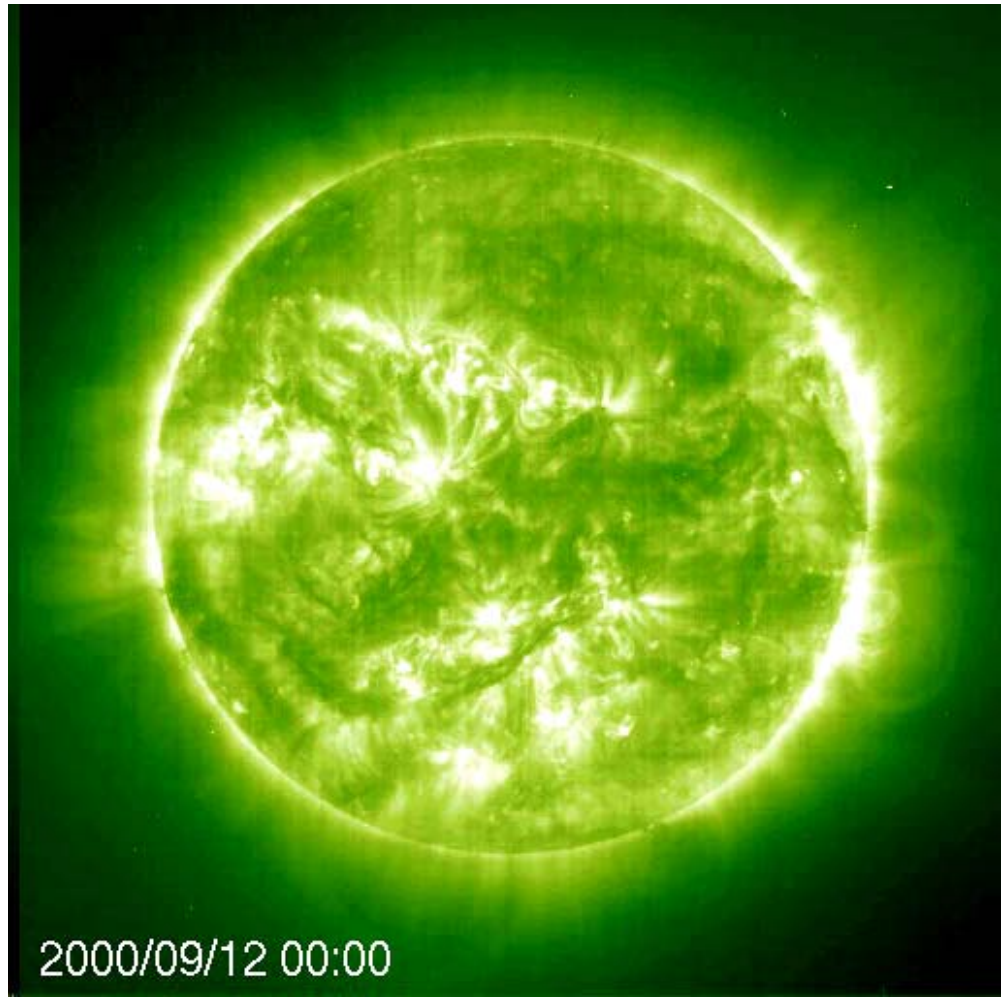
CME recurrence



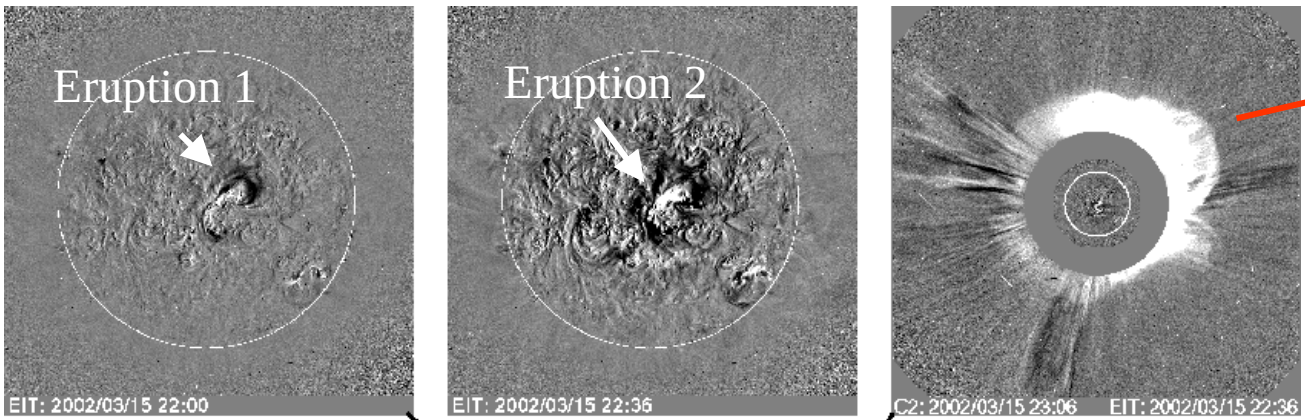
# Event with No Preceding Wide CMEs



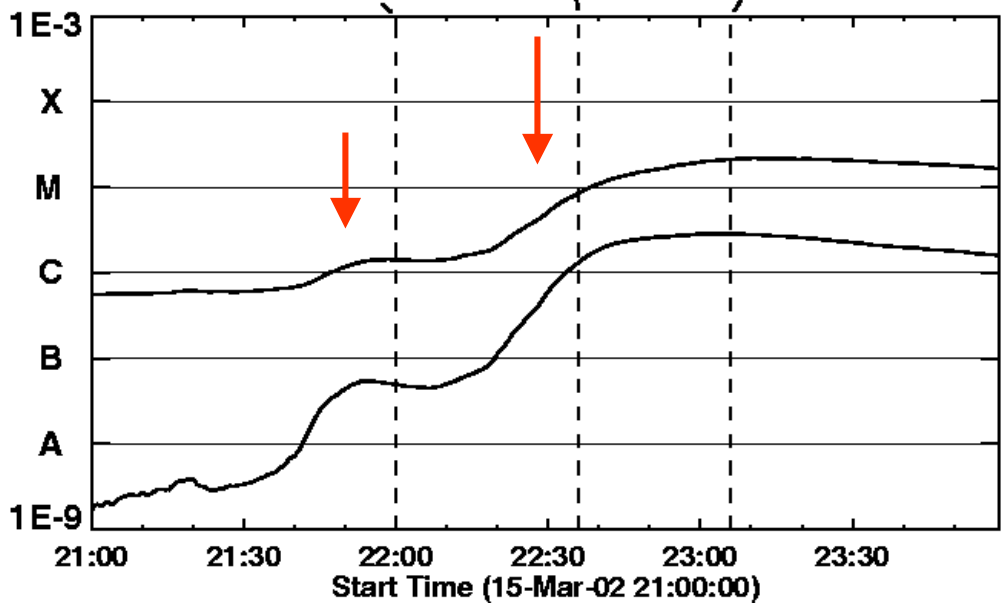




Primary CME from S17W09, V = 1550 km/s
Filament Eruption

# Closely-spaced eruptions

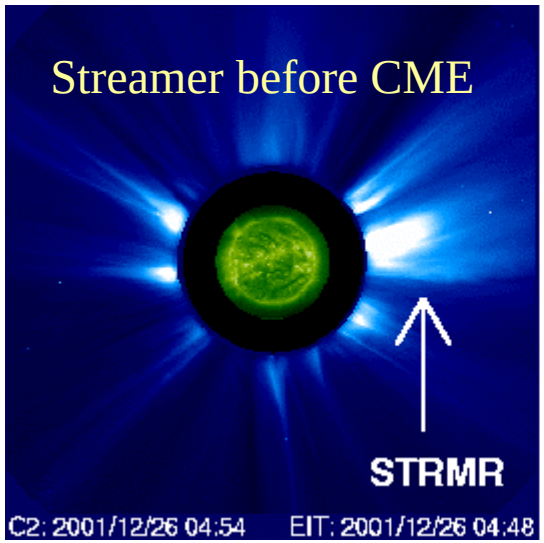


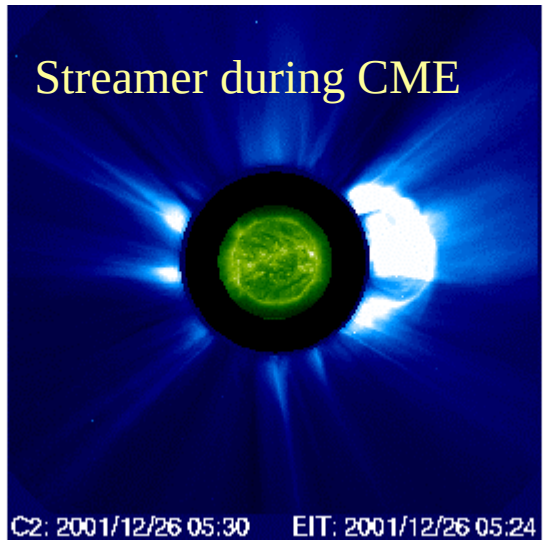

Two CMEs
or just one?

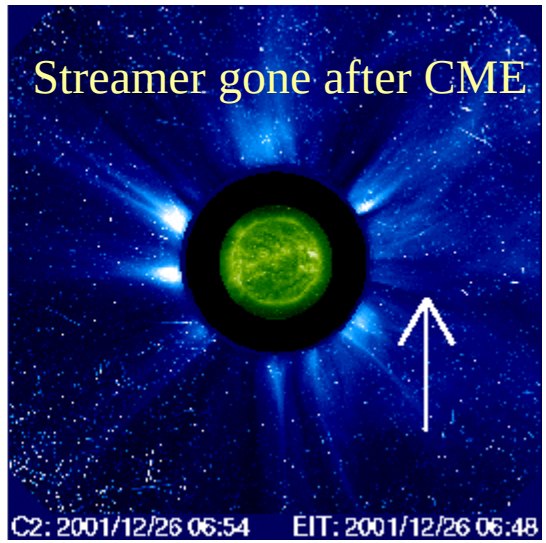



- With current LASCO cadence it is difficult to say whether there were two CMEs
- Interaction below the occulting disk
- 6 events like this

# Interaction with Streamer



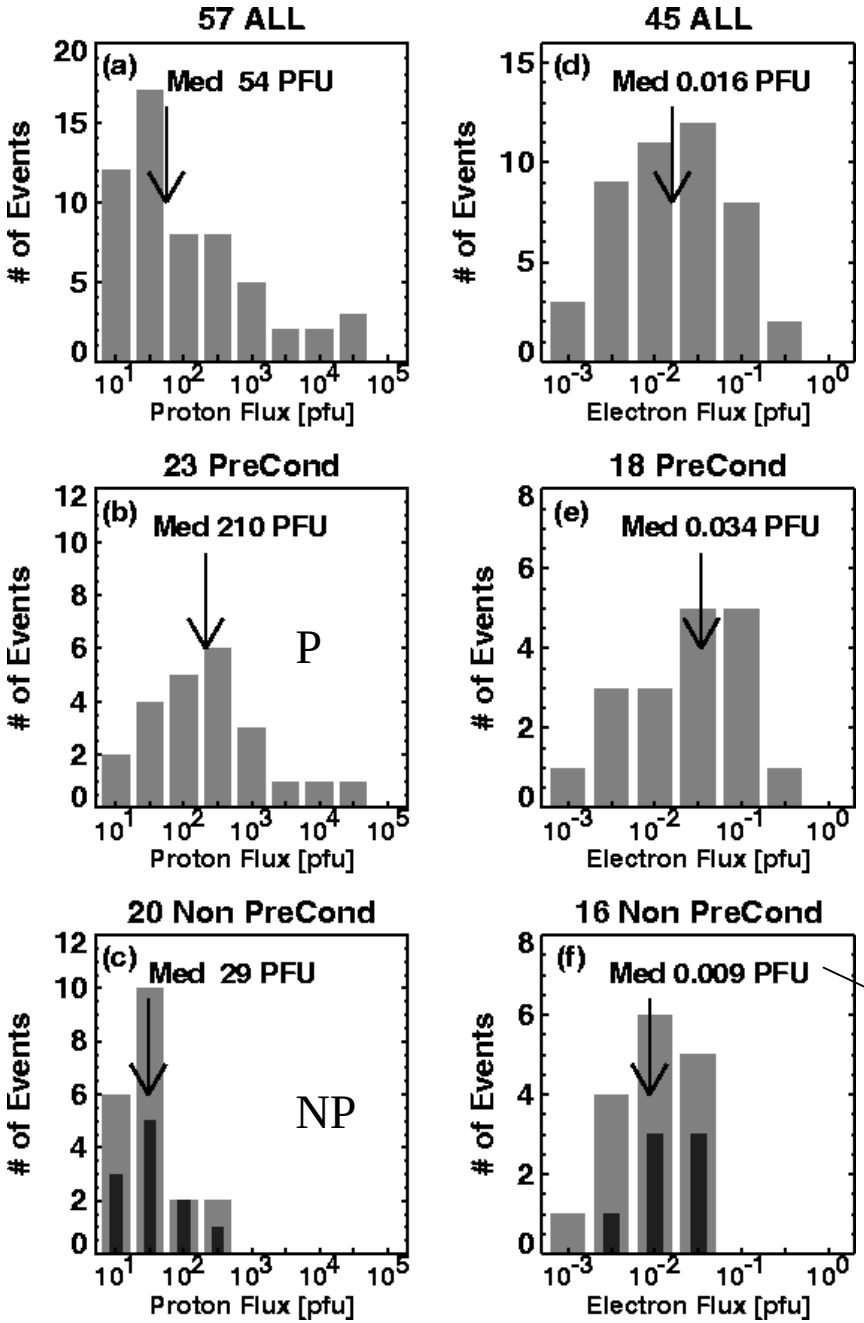




- The streamer is completely destroyed by the CME.
- Streamers are “CMEs with zero speed”
- There were 7 such events

# Compare P and NP events

- Look for difference in CME properties:

  speed, width, longitude, mass, kinetic energy, flare size
- Electron flux (from Wind/3DP)
- Effect on CME speed vs proton/electron intensity

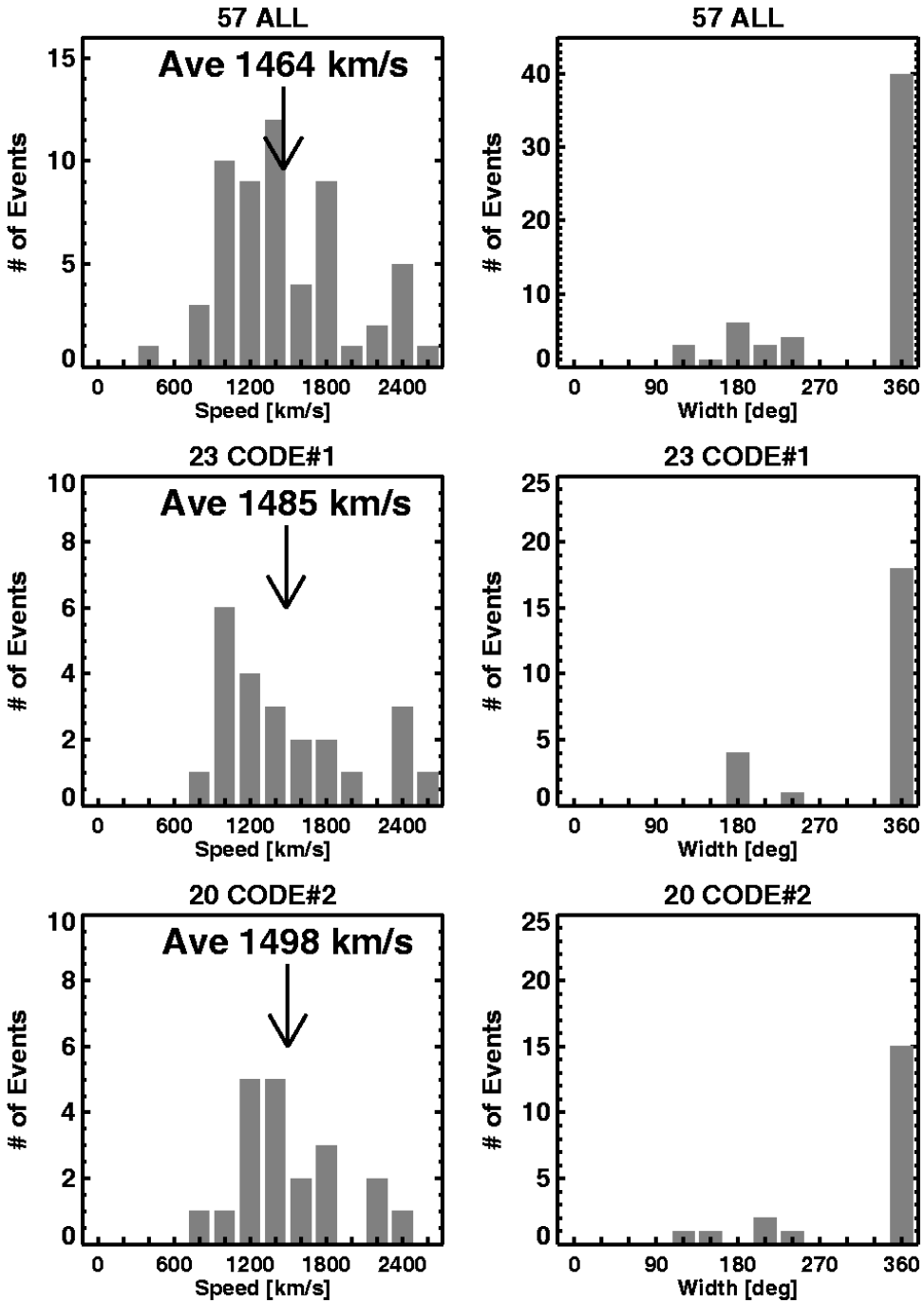



# Proton & Electron Intensities

- Higher for events with preceding CMEs by an order of magnitude
- True even if frontside events alone are considered

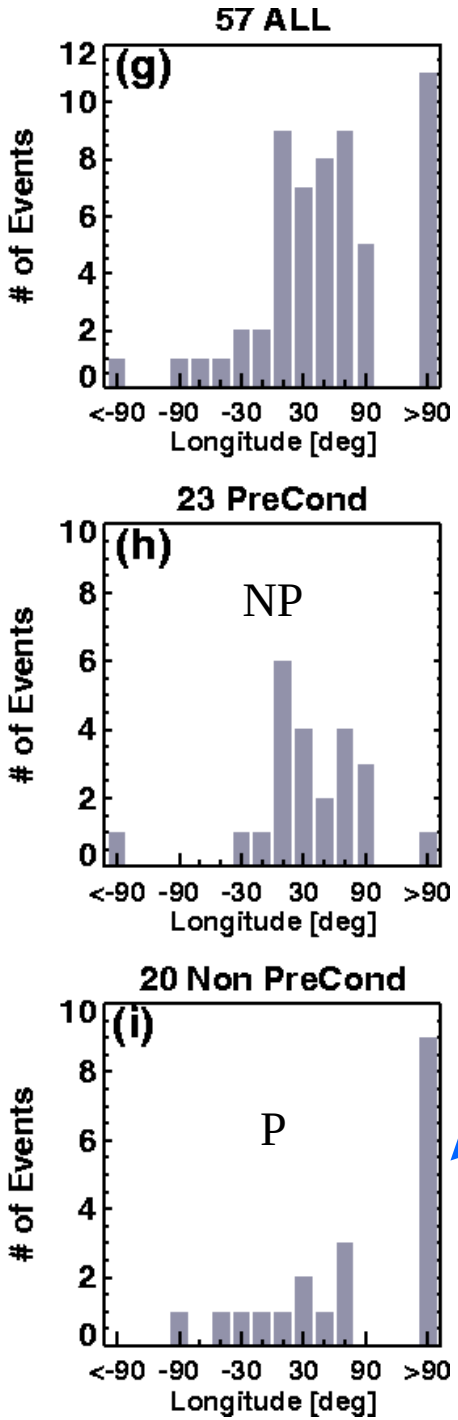
Electrons/cm$^2$/s/sr/eV

Dark → Frontside Events




# Speed & Width

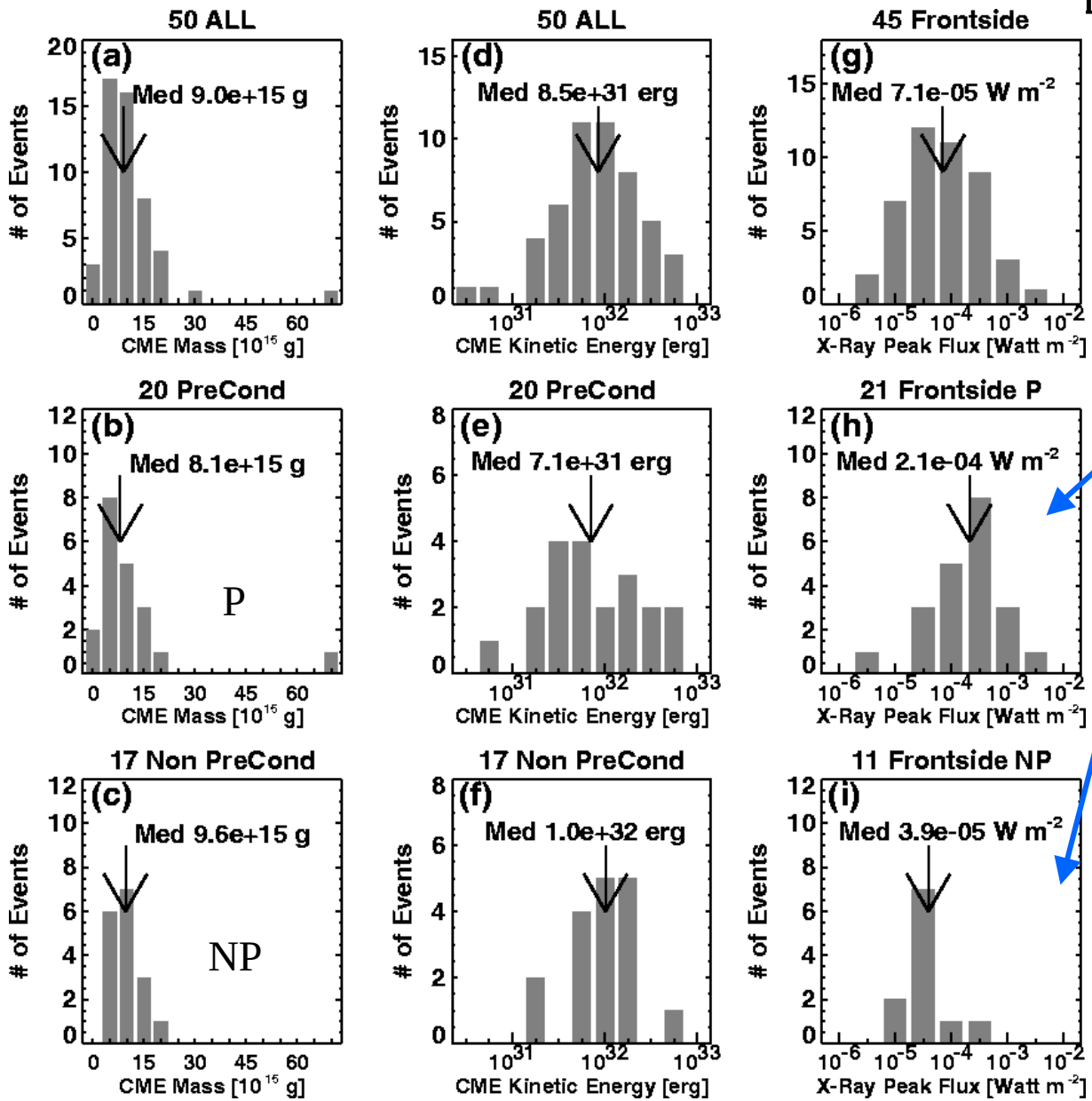
- CMEs are fast and wide for both groups
- Many halos
- Neither CME speed nor width is a distinguishing characteristic




# Source Longitudes

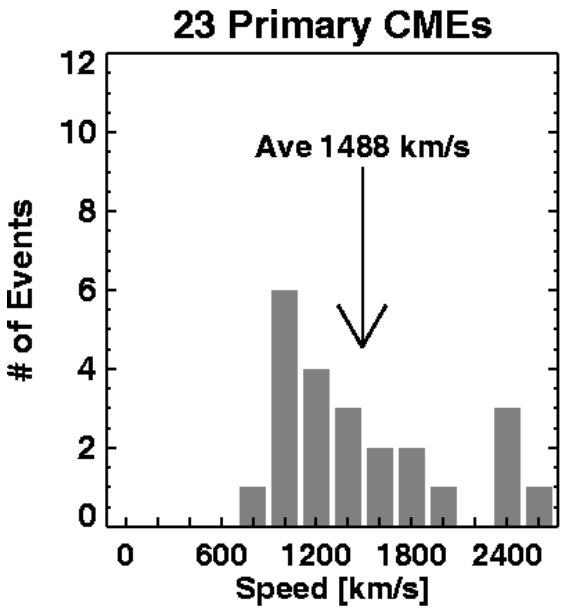
- Source longitudes are generally western for both groups
- More behind the limb events for group NP
- When frontside NP events alone are considered, they again have low intensity

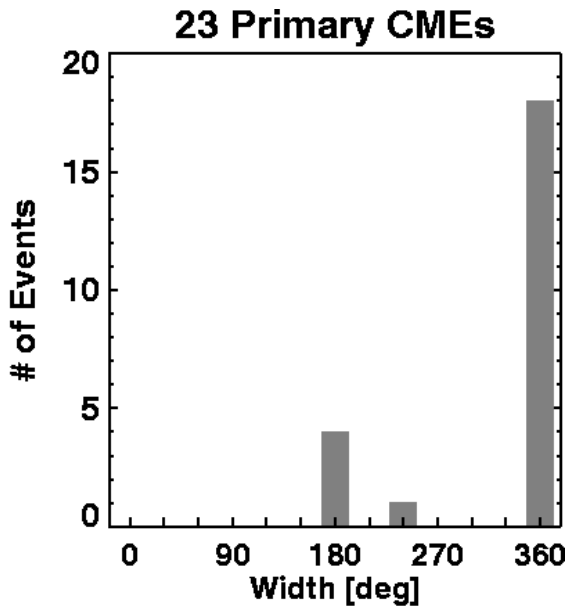
# Mass & Energy

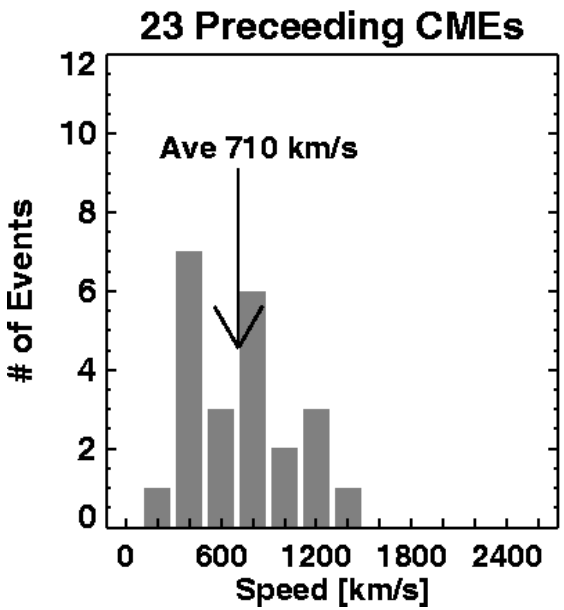


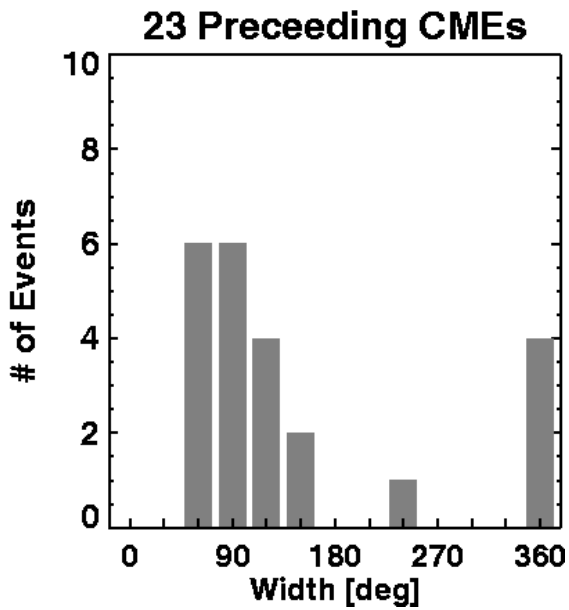

- Similar mass
- Similar KE
- Peak X-ray flux different
- Flares make a difference?

# Primary & Preceding CMEs



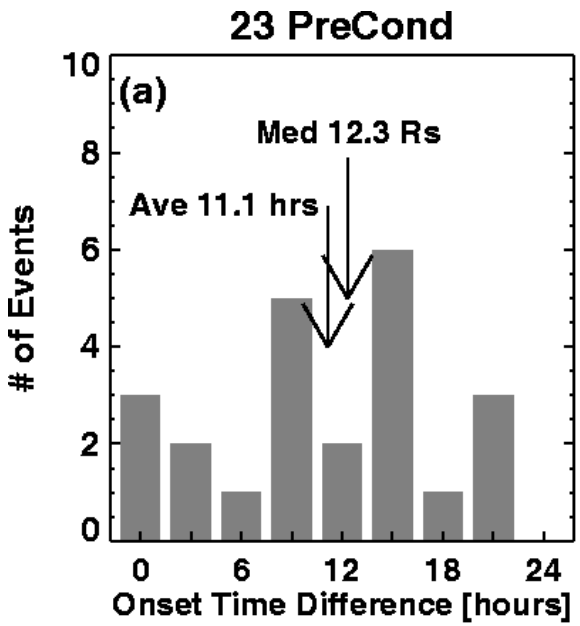



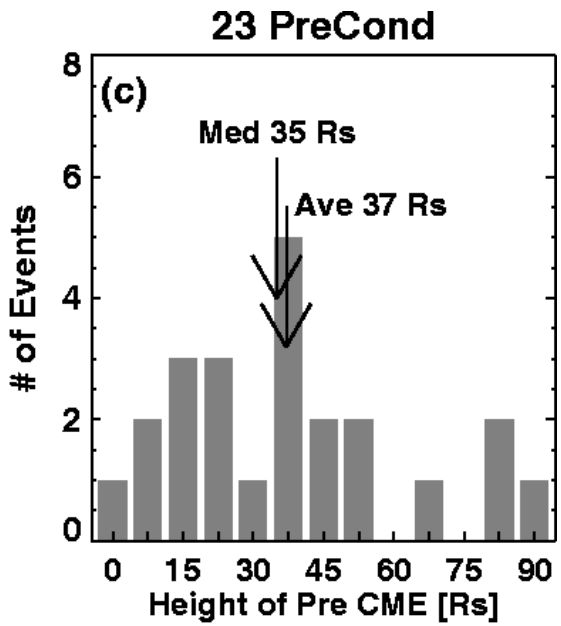

Primary CMEs are much faster than preceding CMEs

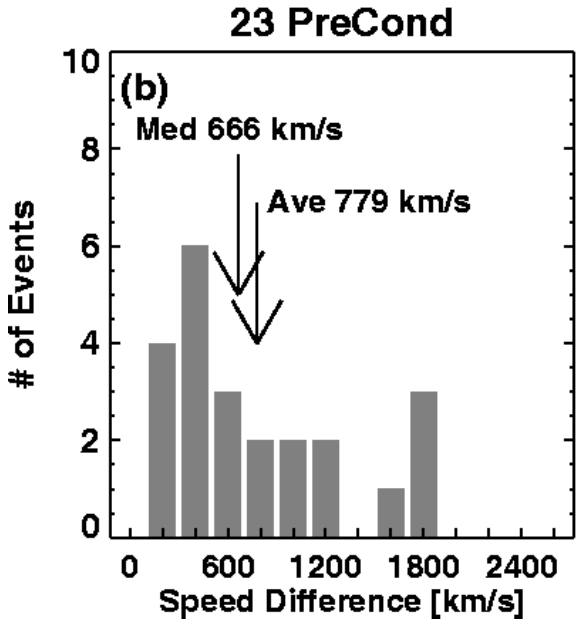
But preceding CMEs have speeds much larger compared to the general population (482 km/s)

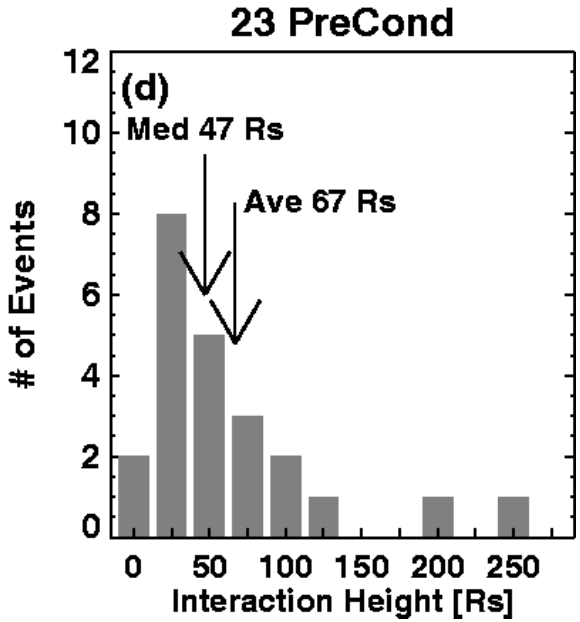
They also have above-average width (only a few at 60 deg -selection criterion). Average with of non-halo CMEs is 47 deg)

Possibility of seed particles



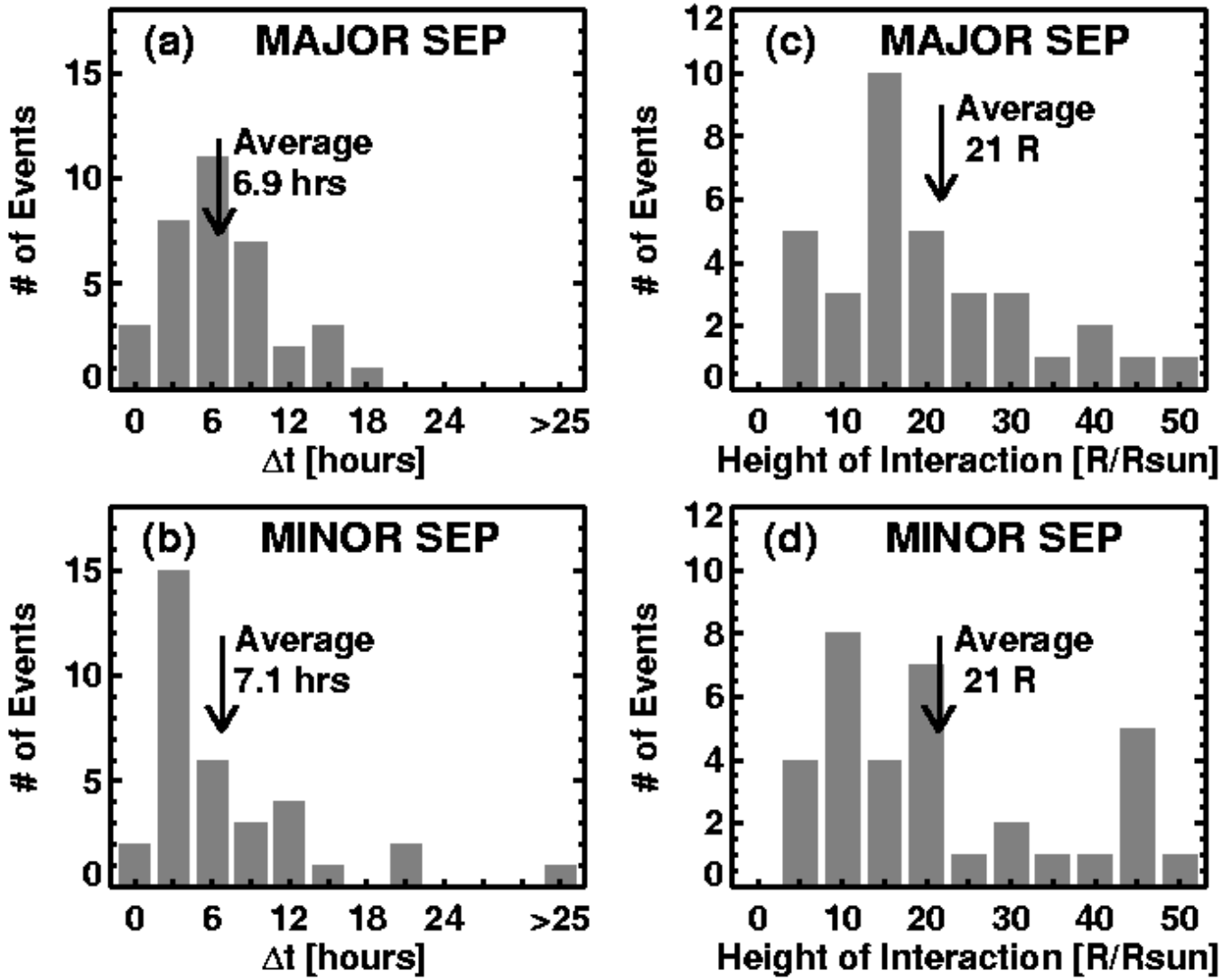




# Spatio-Temporal Separation

- Preceding CMEs typically 0.5 days ahead
- Preceding CMEs at ~ 35 Rs when Primary CMEs lift off
- Approaching speed ~ 700 km/s
- Catch up within ~67 Rs
- Interaction in the near-Sun IP medium

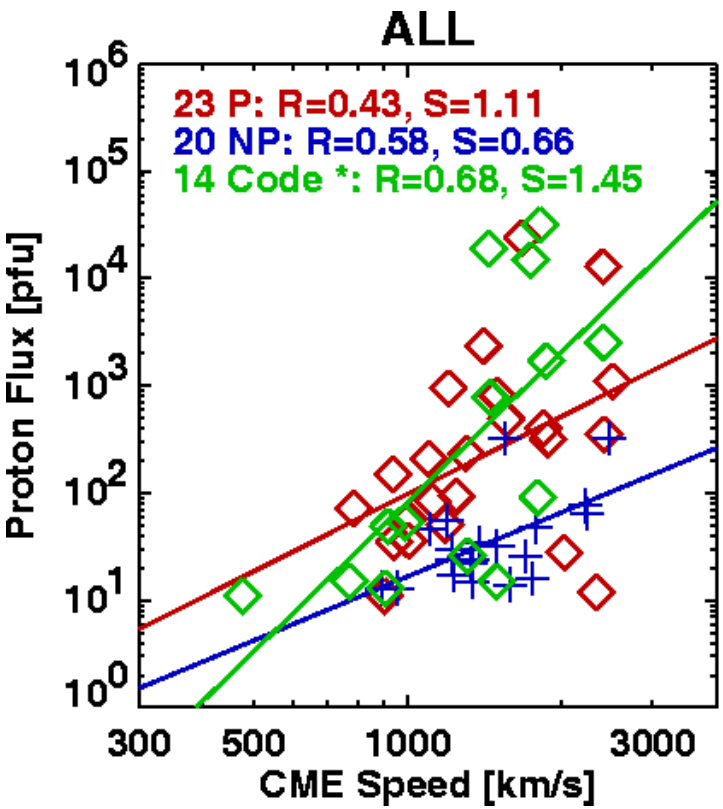
# Not too different from the results with relaxed conditions (Preceding CMEs need only PA overlap)

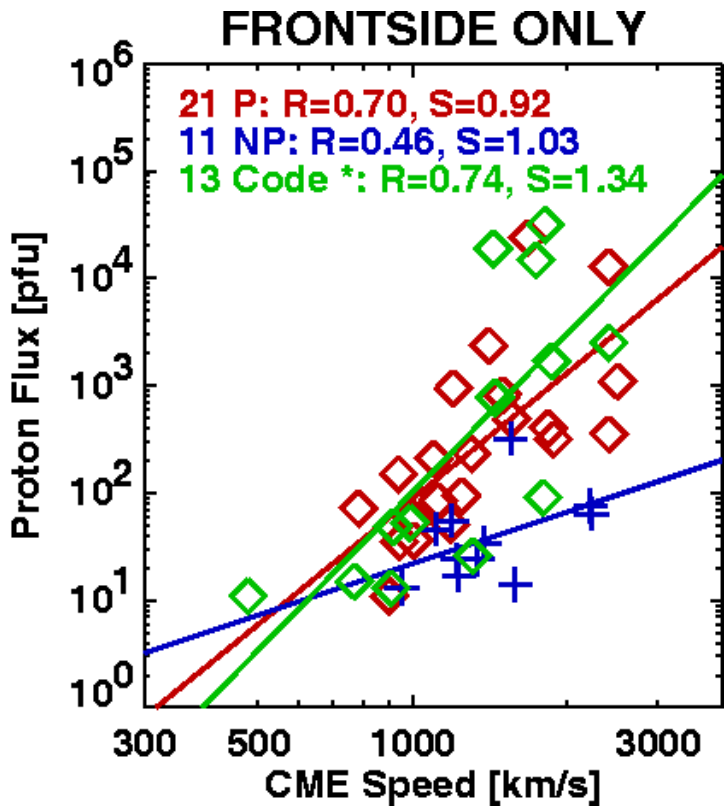



Gopalswamy et al. 2002
ApJL

# CME Speed vs Proton Intensity

- Better correlation for SEP events with preceding CMEs or Other interactions, when frontside events alone are considered.

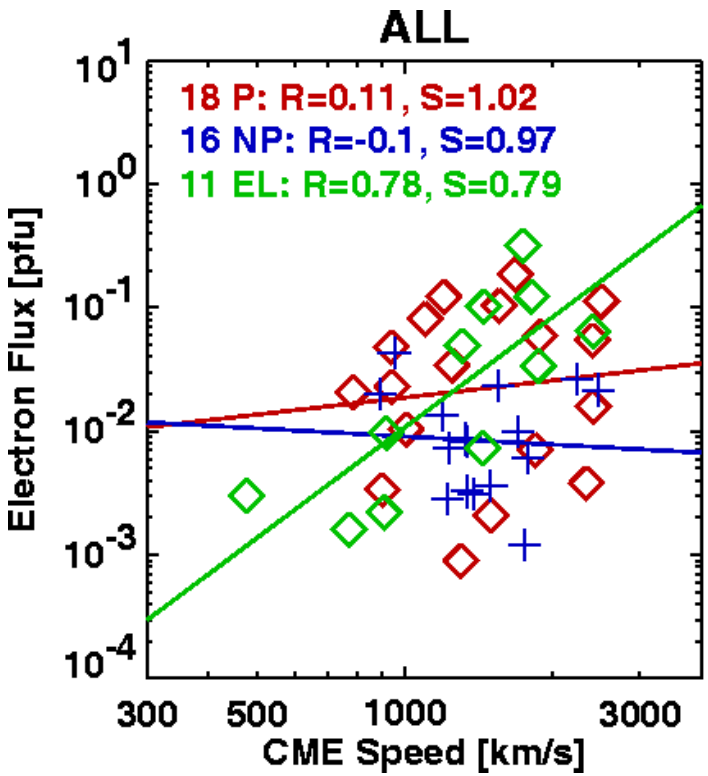


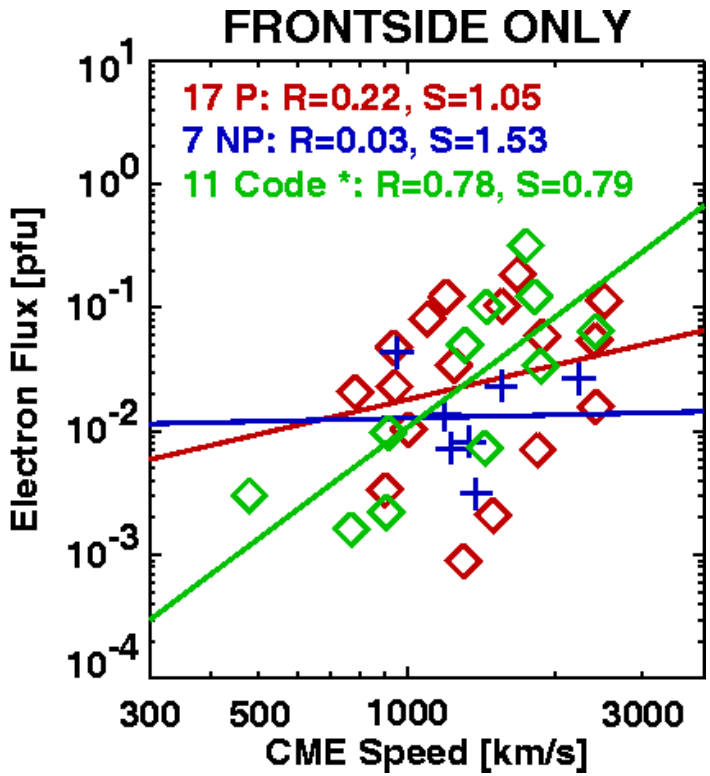




Red: SEP events
With pre-CMEs
Blue: SEP events
W/o pre-CMEs
Green: Other
Interactions
(streamer interactio
Below occulting dis

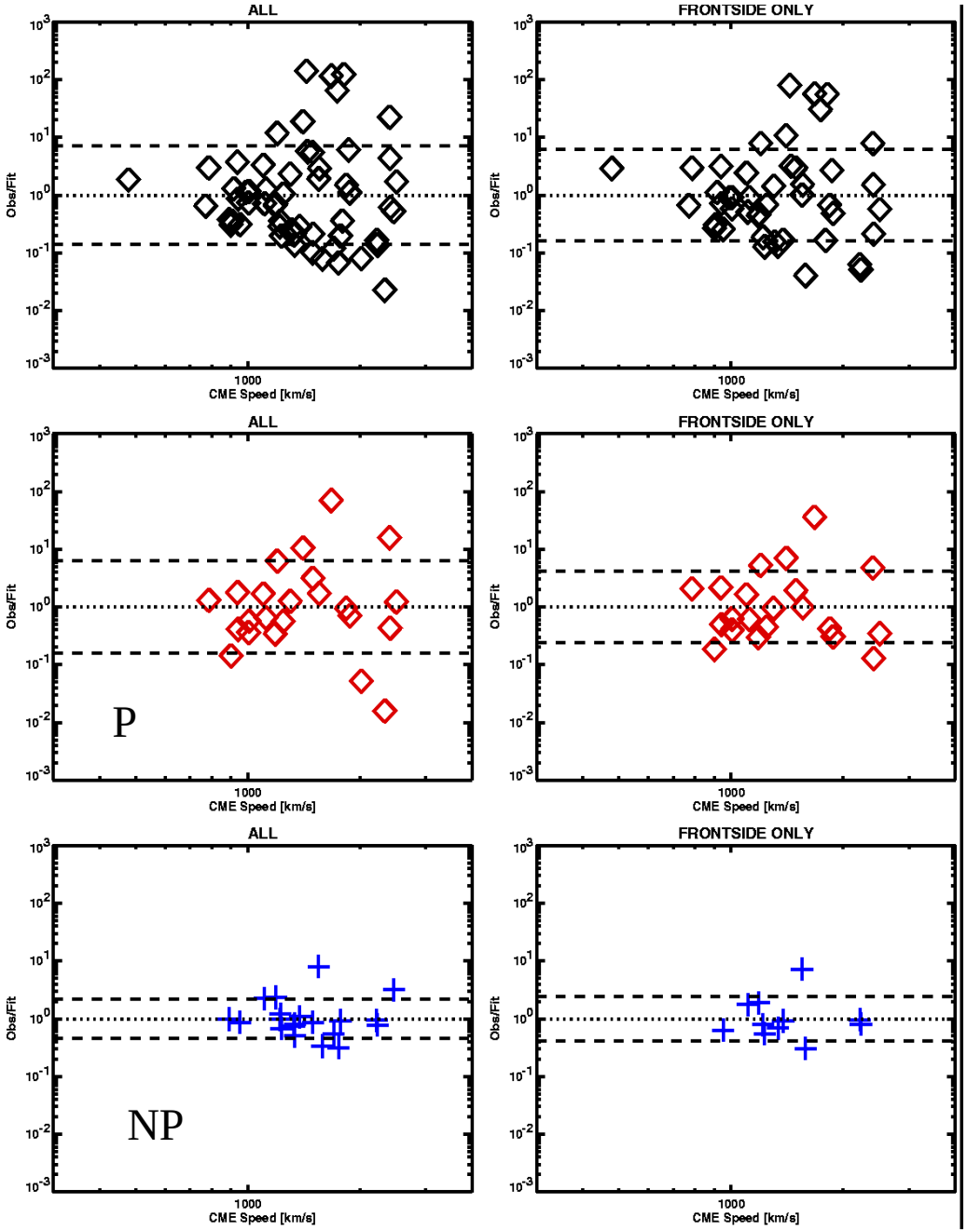
# CME Speed vs Proton Intensity

- Questionable correlation for electron events with preceding CMEs. “Other interaction” cases have a good correlation.




Red: electron event with pre-CMEs
Blue: electron even without pre-CMEs
Green: Other Interactions (streamer interactio <2 Rs interaction)




# Scatter Reduced

- Ip to Ip-fit ratio
- < 1 Data points below regression line
- >1 Data points above regression line
- 0 Data points on regression line
- Scatter reduced when frontside events are considered

# Conclusions

| Group | High Ip (>50pfu) | Low Ip (<50pfu) |
|---|---|---|
| P (with Pre CME) | 18 (78%) | 5 (22%) |
| NP (No Pre CME) | 5 (25%) | 15 (75%) |

- High intensity events are 3 times more likely to be preceded by wide CMEs within a day
- Preceding CMEs are faster and wider than average CMEs → source of seed particles
- Shock may be modified because dVa/Va = dB/B –1/2 dn/n
- Preceding CMEs likely to be cannibalized before reaching 1 AU
- Preceding CMEs – candidate source of scatter in the Ip – Vcme plot.
- "Other interaction" cases similar to those with preceding CMEs