SEP EVENTS AND THE ROLE OF FLARES AND SHOCKS

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PROPOSED STUDIES

- 1 Event Profiles
- 2 Interplanetary Shock Evolution
- 3 Early Component of SEP Events
- 4 Particle Characteristics at In Situ Shocks

From Cane and Lario (2006)

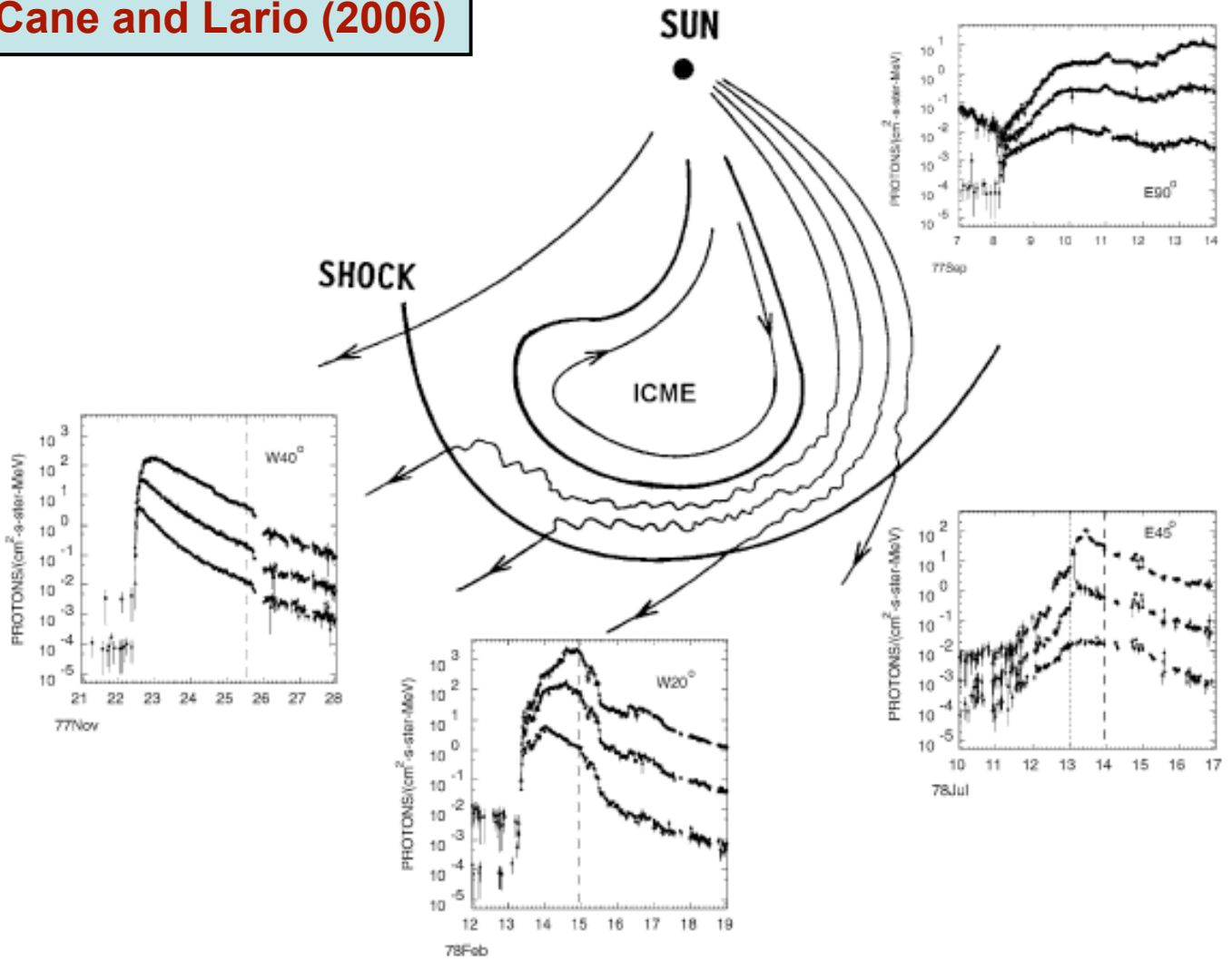
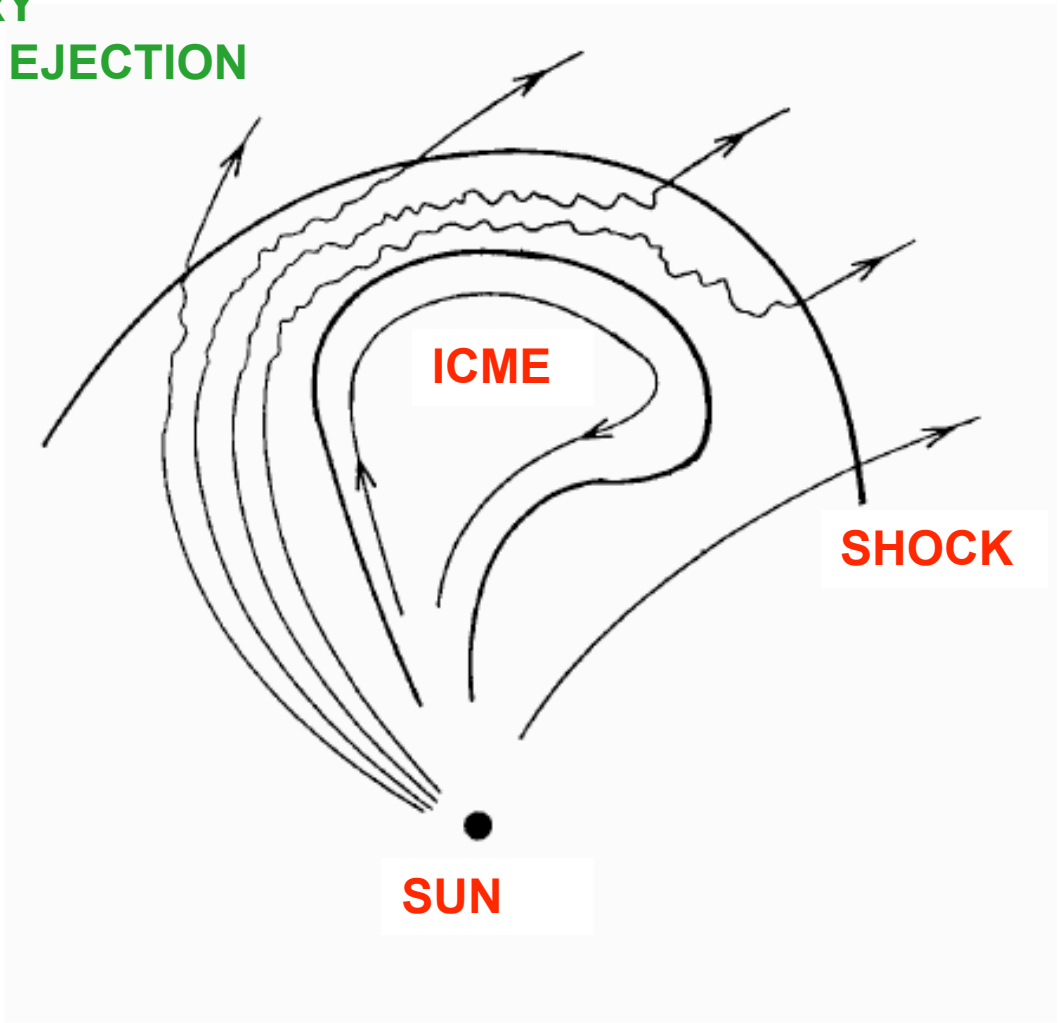


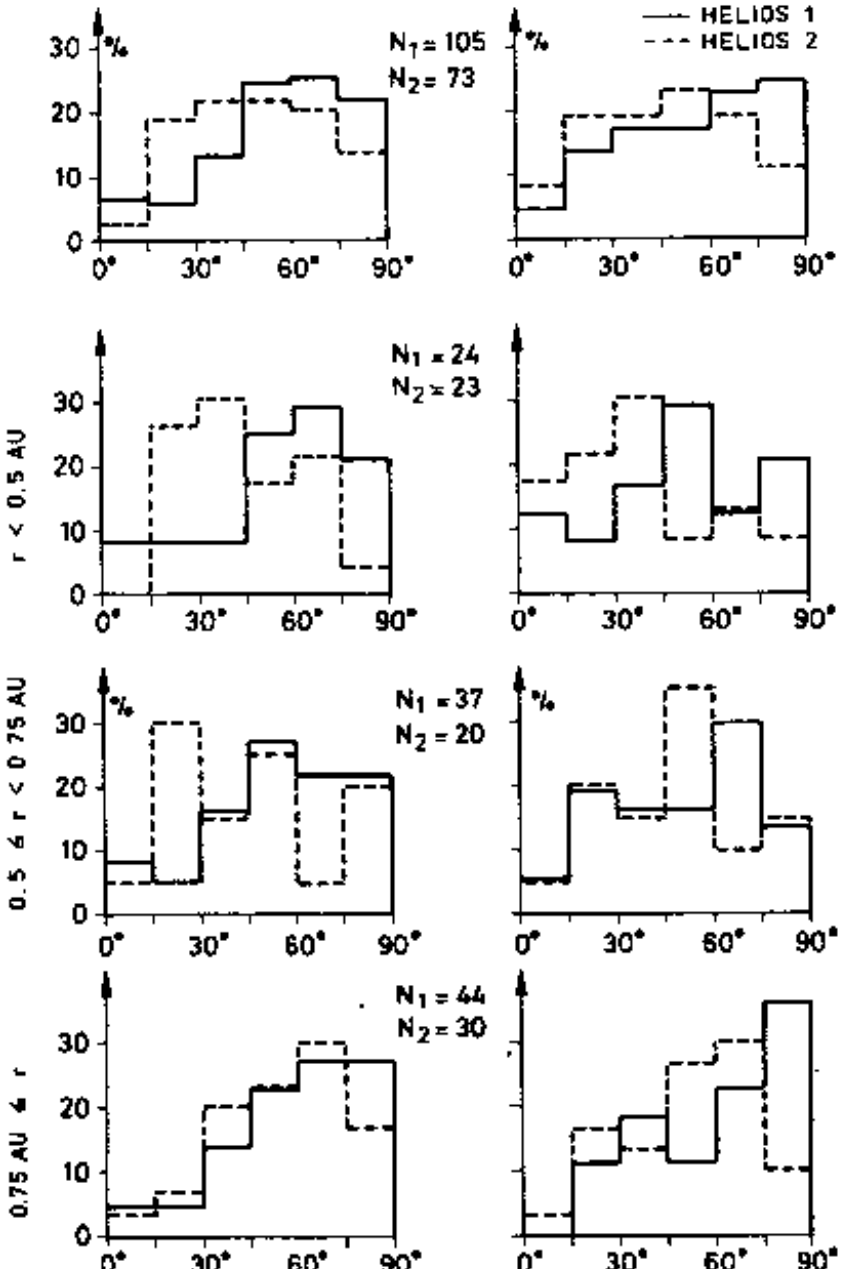
Figure 2. Cartoon showing the shape of an ICME and surrounding IP field structure including the presence of a shock. A strong shock will accelerate particles to an extent dependent on energy and the location of the observer. Thus particle intensity profiles are organised by the longitude of the associated solar event. Proton intensities in three energy ranges (~5, ~15 and ~30 MeV) are shown. Dashed lines indicate the passage of shocks. Figure adapted from Cane *et al.* (1988).

INTERPLANETARY CORONAL MASS EJECTION

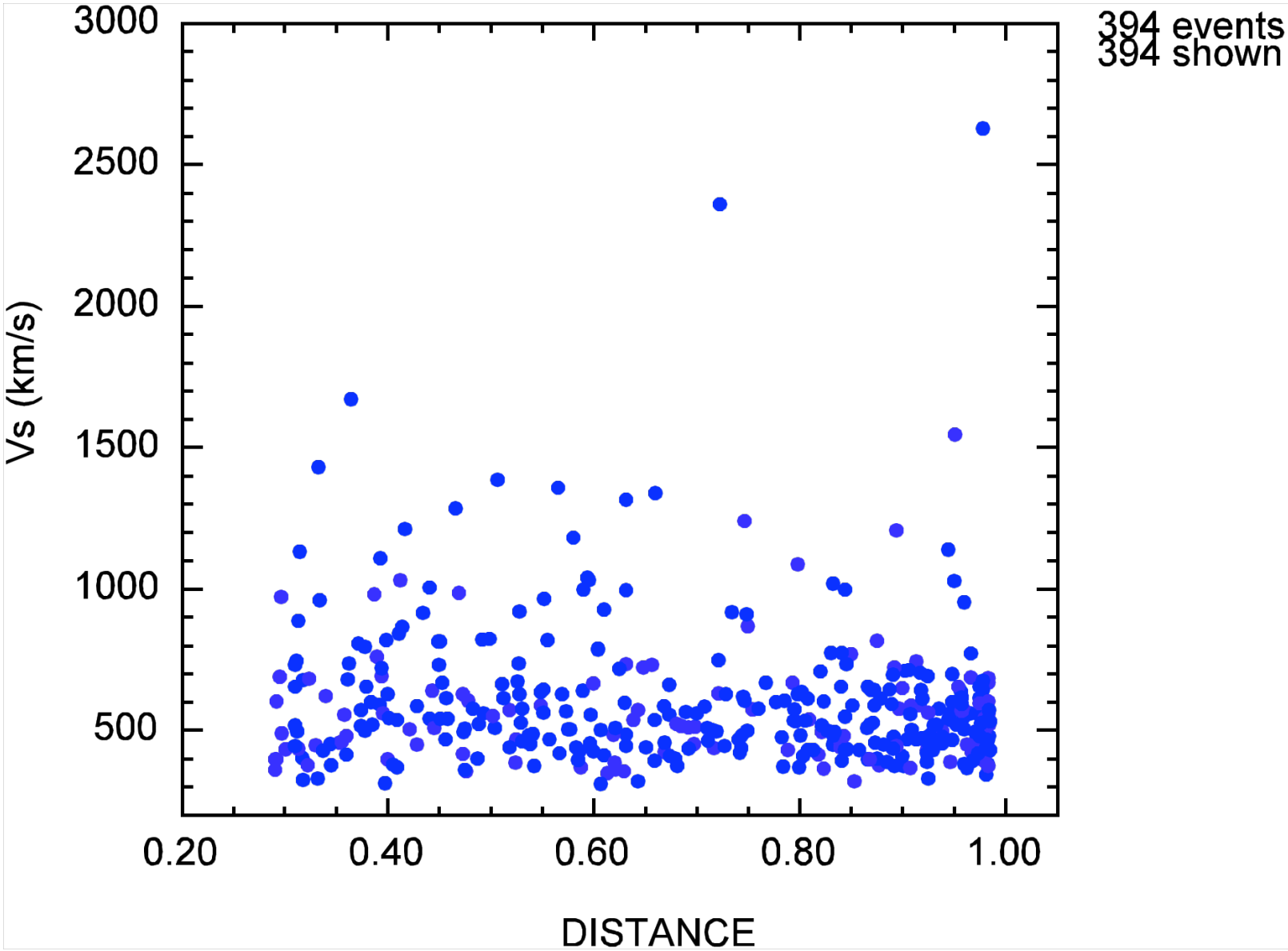


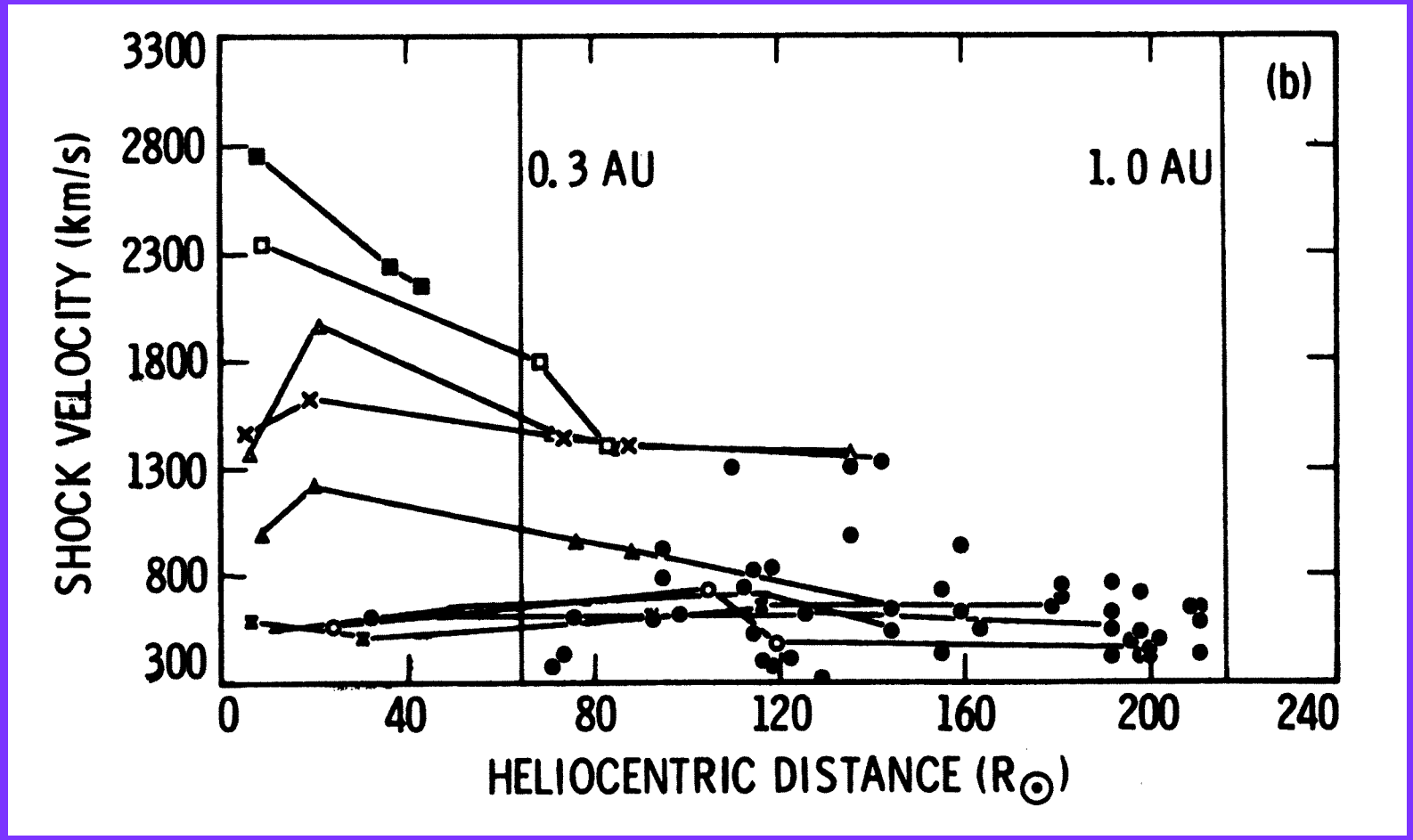
CANE and RICHARDSON

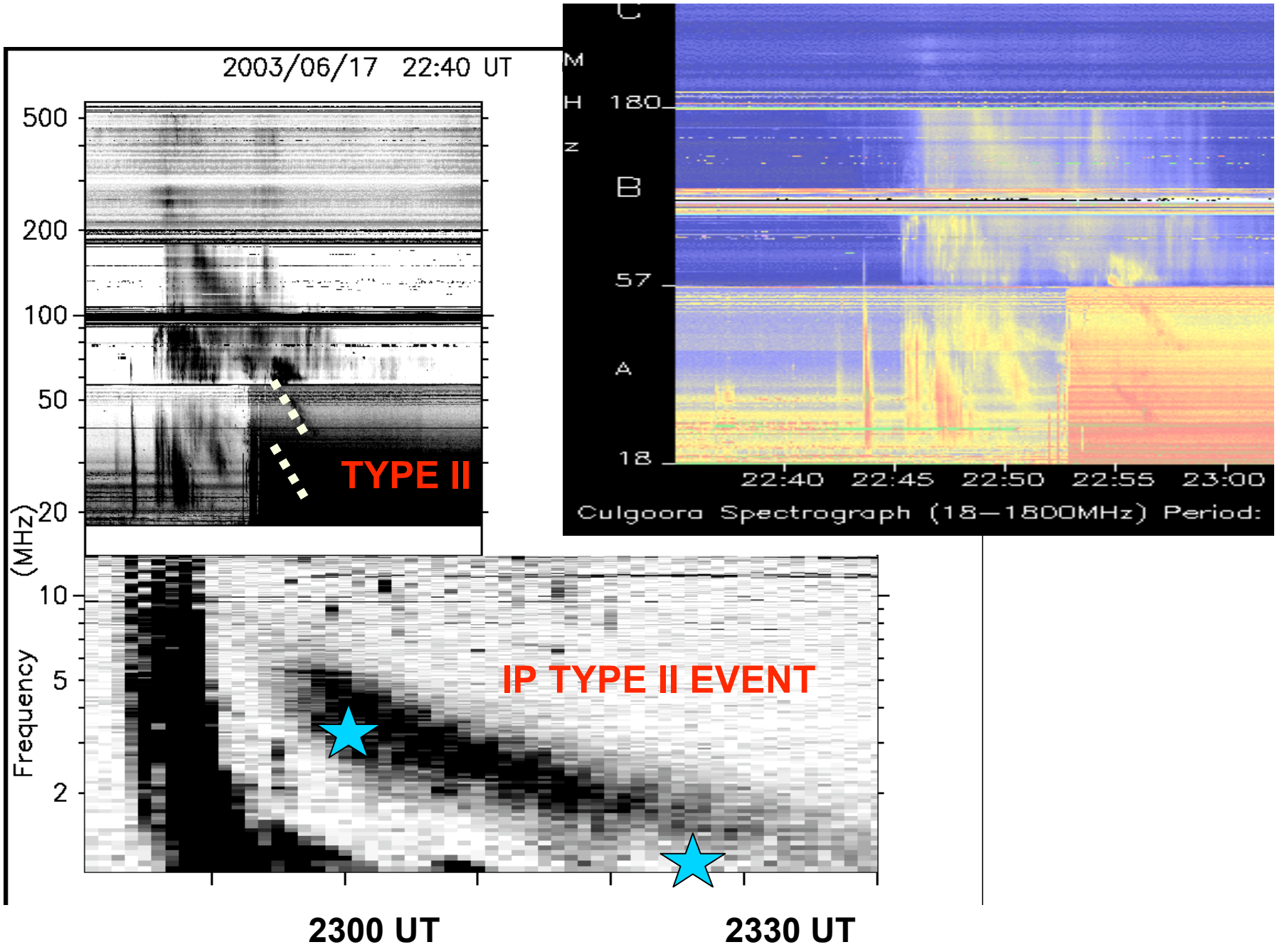
SHOCK NORMALS IMF

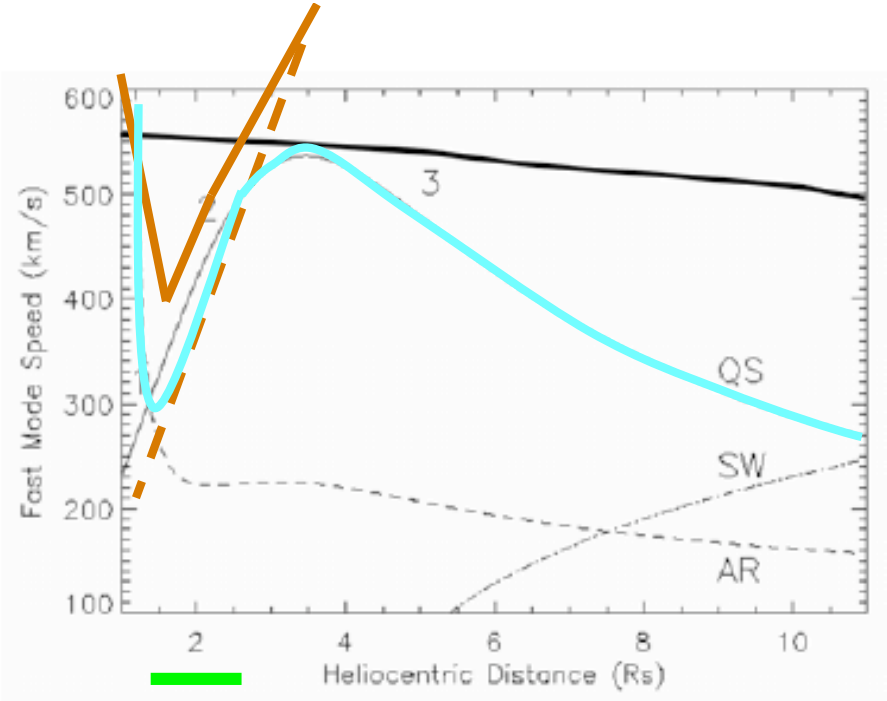


Volkmer and Neubauer 1984


394 events
394 shown
3000
2500
2000
1500
1000
500
Vs (km/s)
0.20
0.40
0.60
0.80
1.00
DISTANCE


(b)
0.3 AU
1.0 AU
SHOCK VELOCITY (km/s)
3300
2800
2300
1800
1300
800
300
0
40
80
120
160
200
240
HELIOCENTRIC DISTANCE (R⊙)

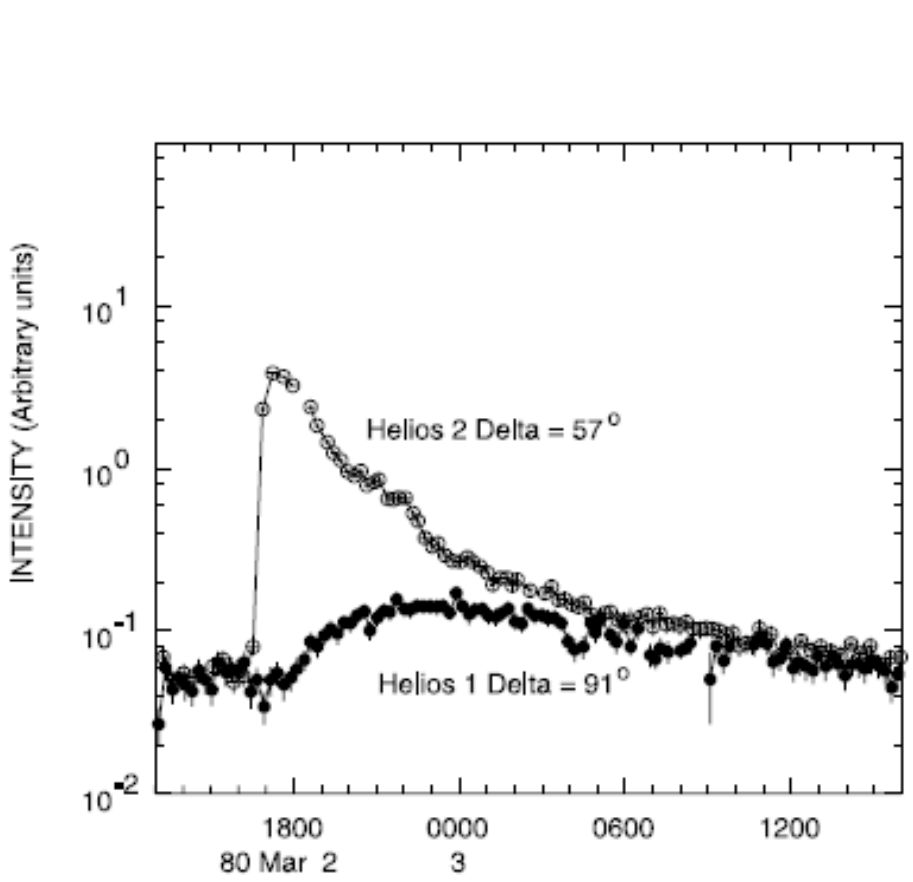

2003/06/17 22:40 UT
500
200
100
50
20
10
5
2
(MHz)
Frequency
TYPE II
IP TYPE II EVENT
2300 UT
2330 UT
C
M
H
z
180
B
57
A
18
22:40
22:45
22:50
22:55
23:00
Culgoora Spectrograph (18—1800MHz) Period:



m-λ type II

Figure 6. Fast mode speed in the quiet (QS, thin solid curve) and active region corona (AR, dashed line) compared with the solar wind speed (marked SW) adapted from Gopalswamy et al. (2001a). The thick solid curve is a sketch of the Alfven speed profile from Bougeret (1985). Region 1 corresponds to active region core where the fast-mode speed is high, so it is difficult to form shocks in this region. Metric type II bursts occur in region 2. IP type IIs occur in region 3. The Alfven speed is close to the fast mode speed since the sound speed is very small, so we use fast mode and Alfven speeds interchangeably.

Gopalswamy 2006



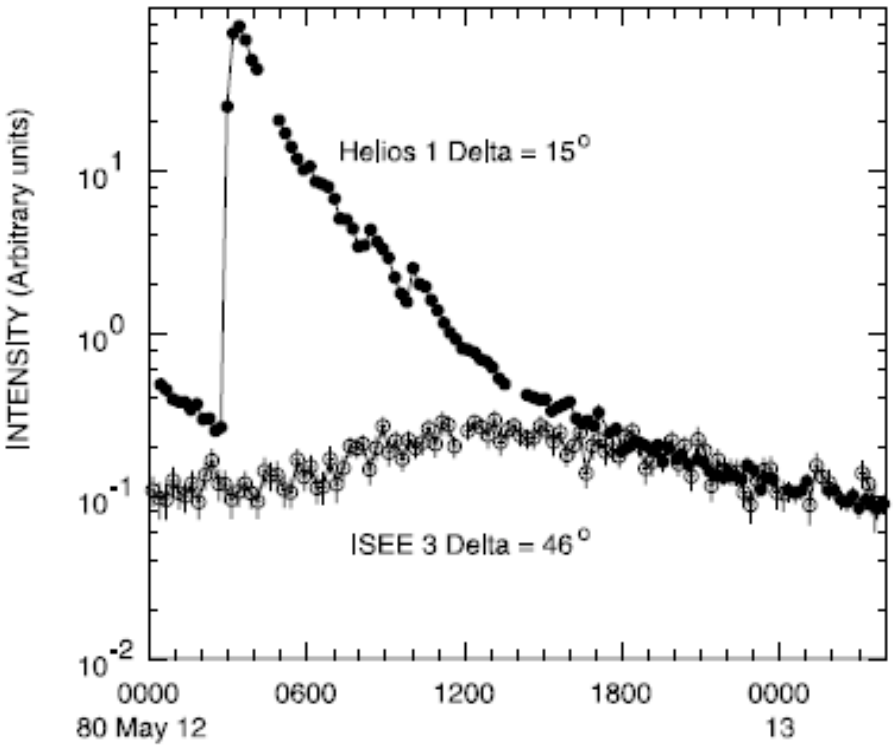


FIG. 8.—Electron time profiles for two flare events with unusually broad time profiles at one position. *Top:* Case a. For the event of 1980 March 2, *Helios 1* is at $r = 0.98$ AU and a connection angle of 91°. *Bottom:* Case b. For the event of 1980 May 12, *ISEE 3* is at a connection angle of 46°. The values of the radial mean free path estimated from the broad profiles would have been $\lambda_0 = 0.013$ AU (case a) and $\lambda_0 = 0.011$ AU (case b) for the case of radial diffusion, below the range that was previously assigned to scattering along the average IMF. We tentatively interpret this result in terms of transport processes perpendicular to the IMF direction.

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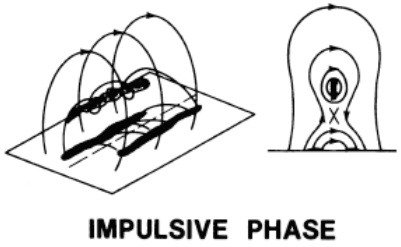
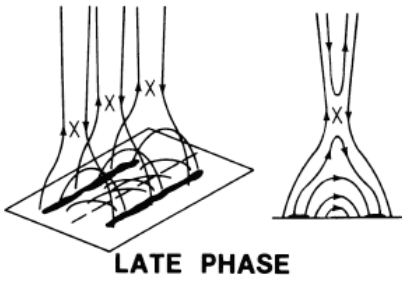
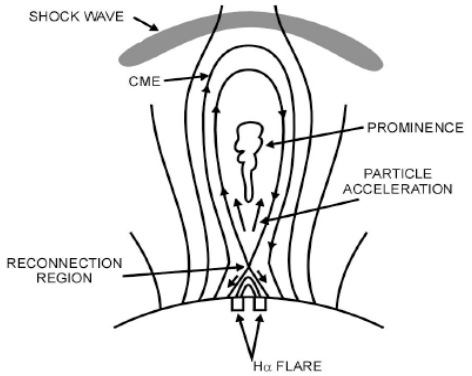
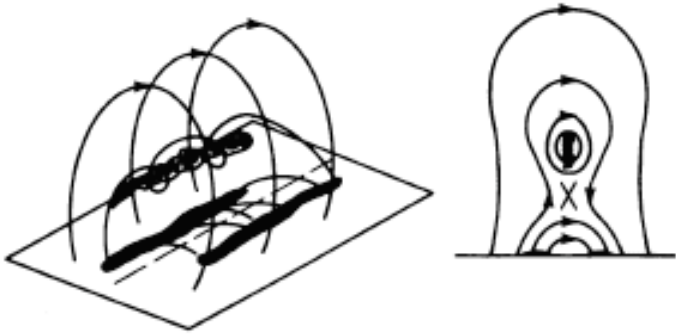


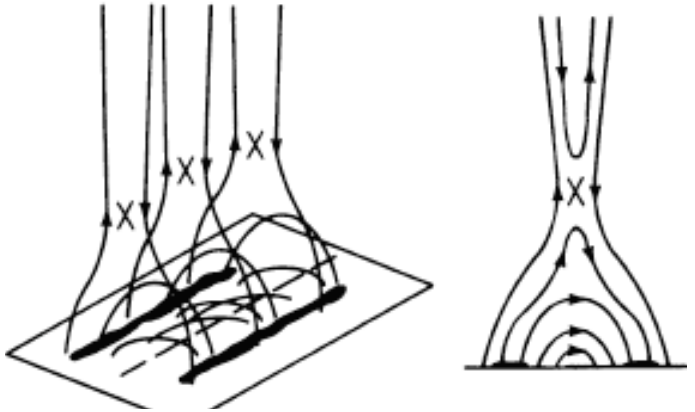




THREE PHASES OF PARTICLE ACCELERATION



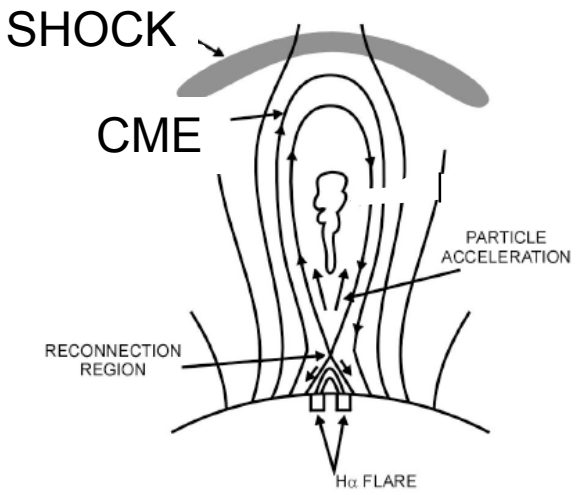
FLARE IMPULSIVE PHASE (FIRST)



FLARE LATE PHASE (SECOND)

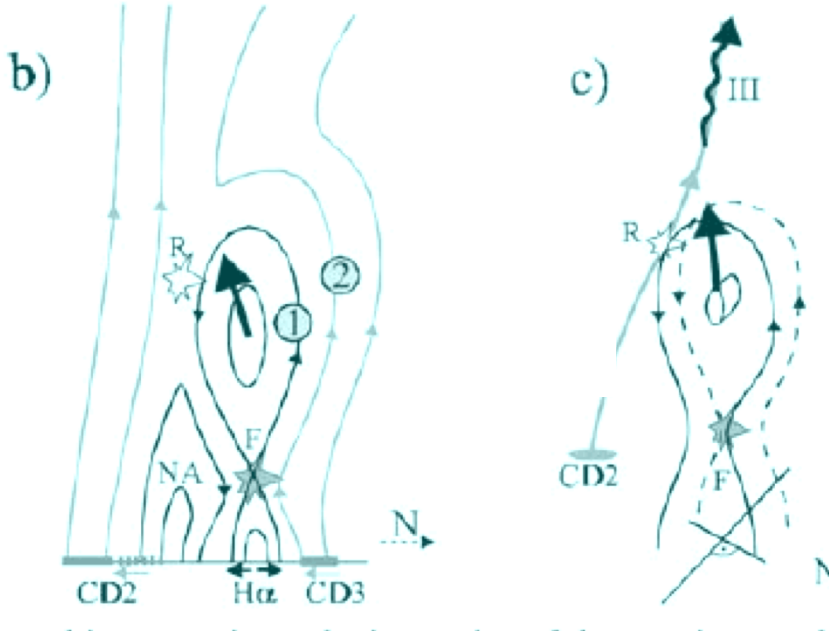
SHOCK ACCELERATION

THIRD PHASE

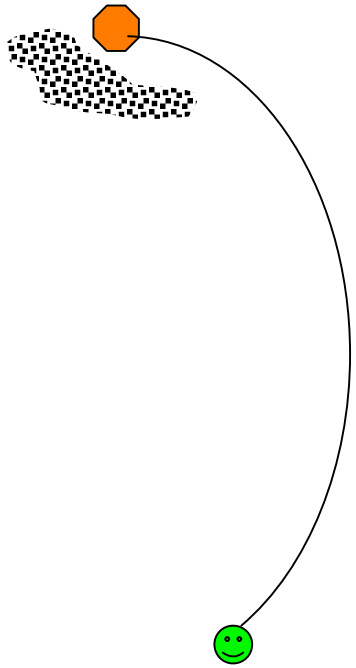


TWO CONDITIONS for detecting particles in IP space

(1) OPEN FIELD LINES



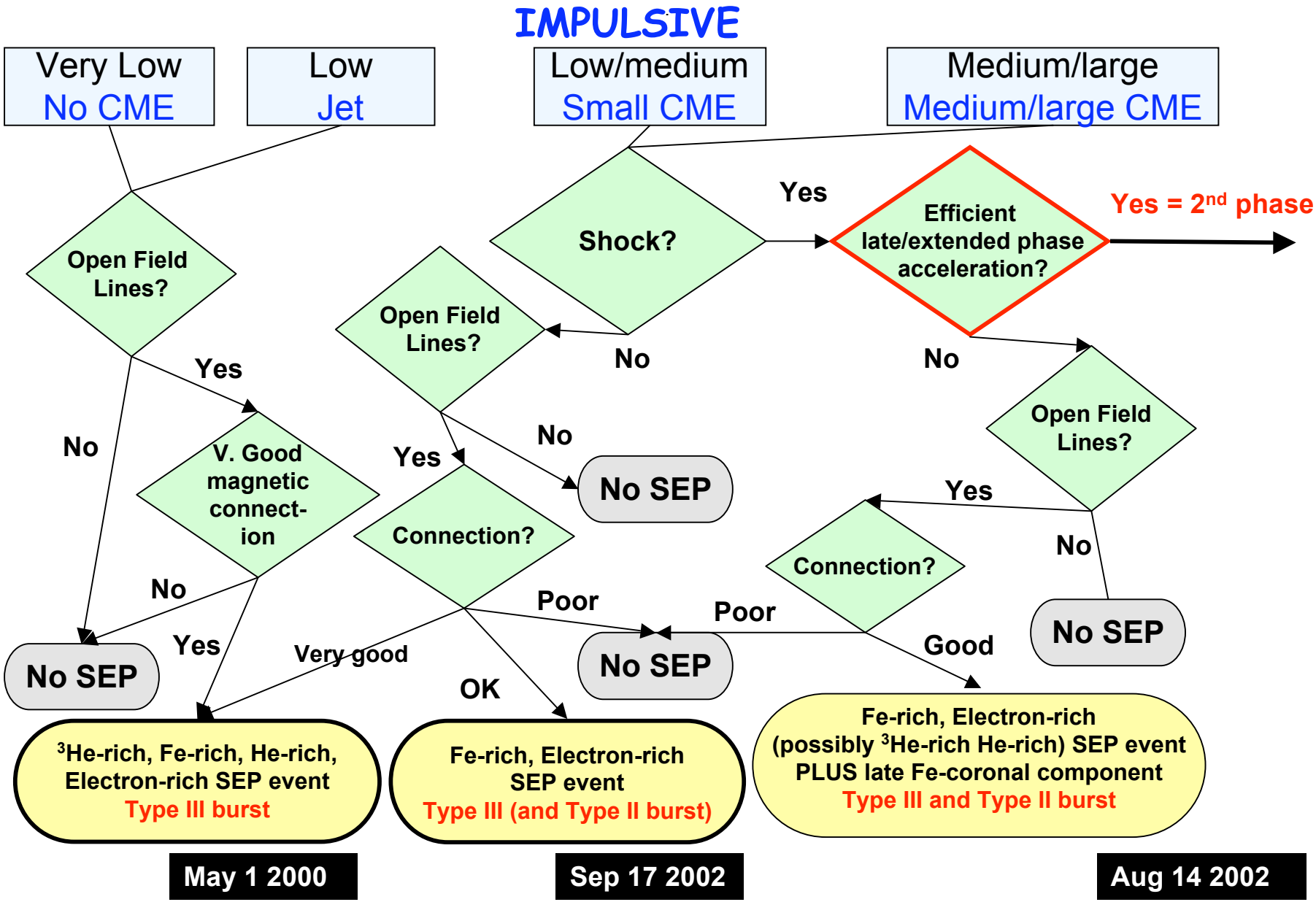
(2) MAGNETIC CONNECTION

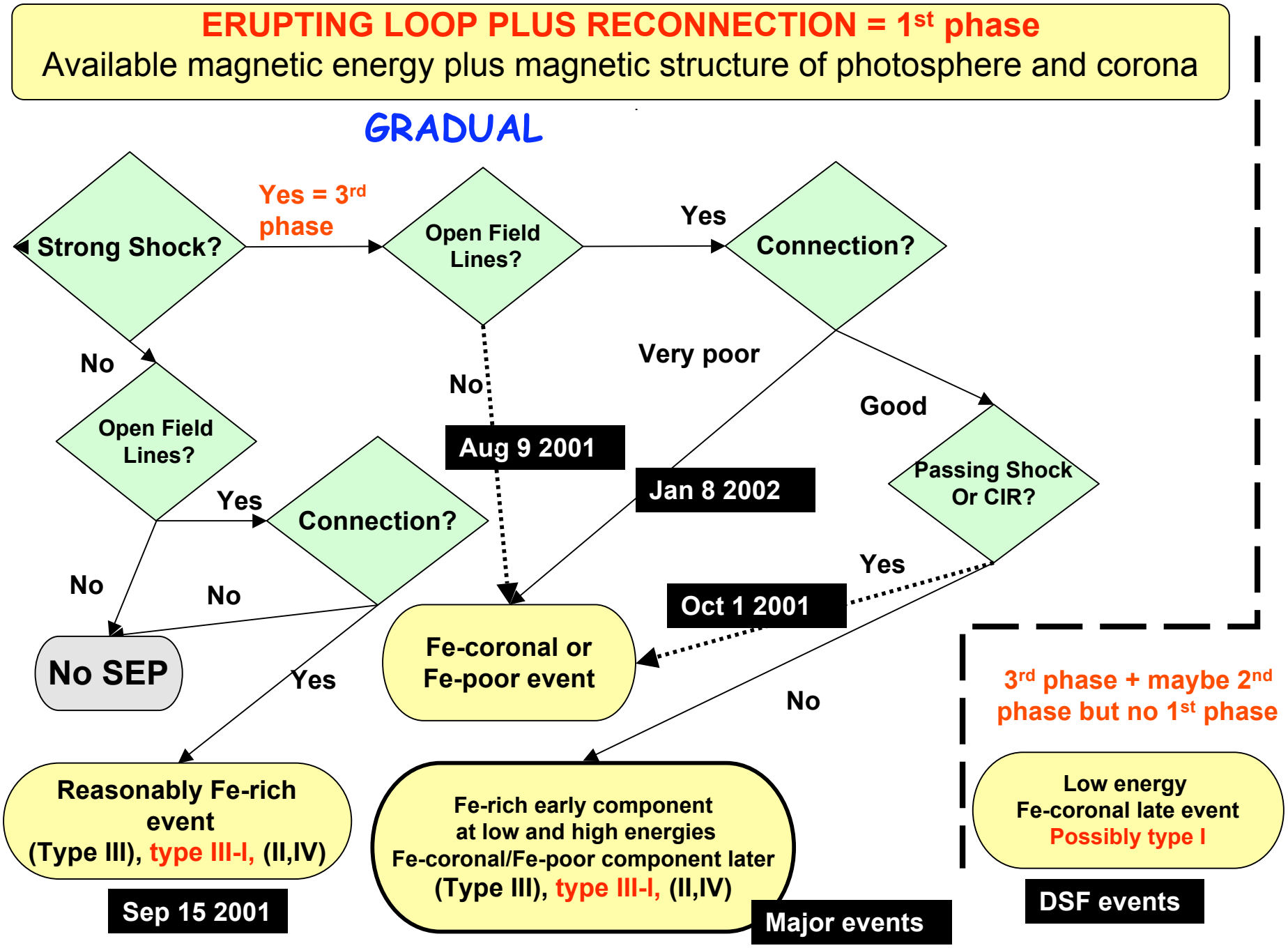


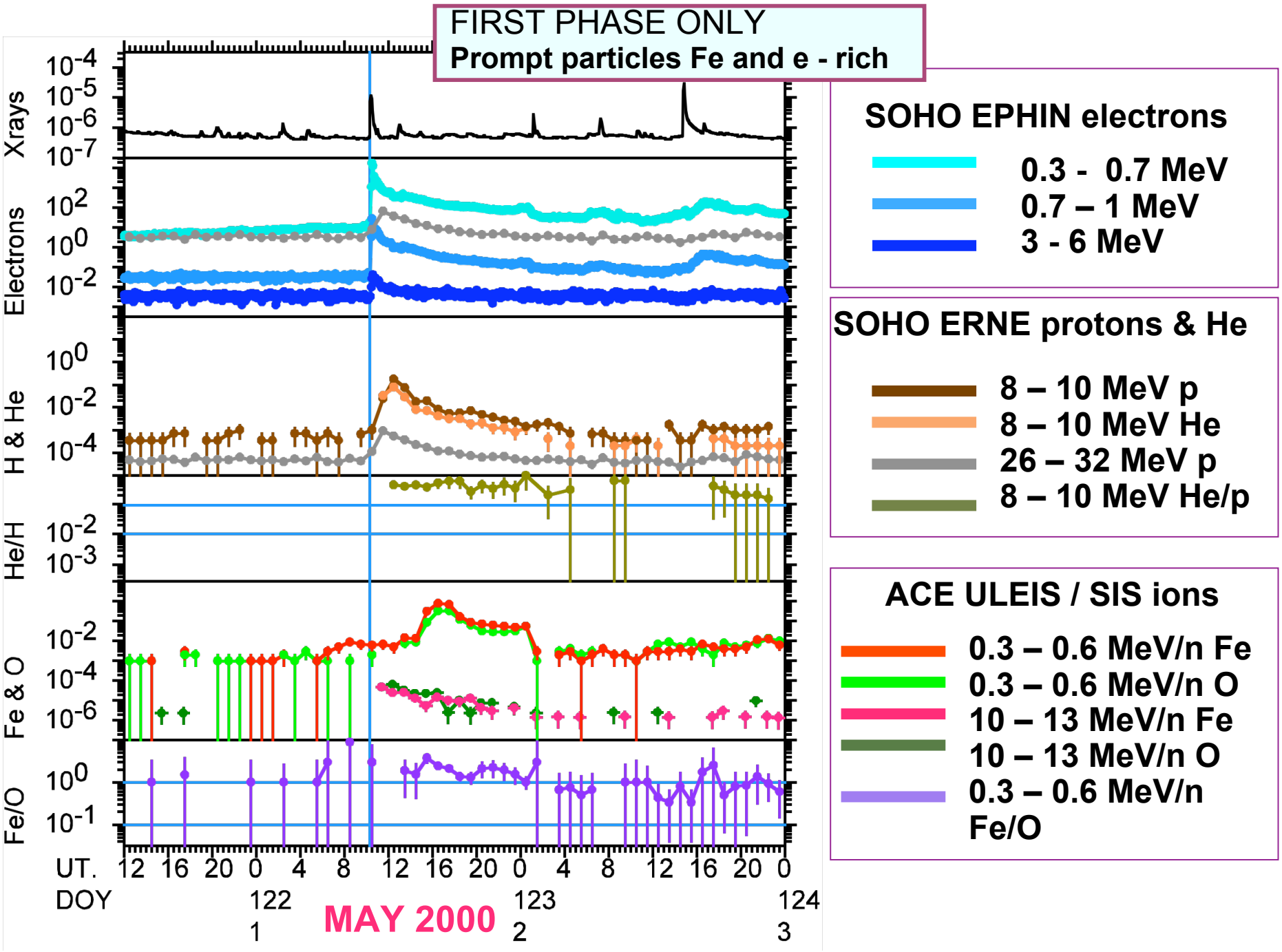
LOW FREQUENCY RADIO OBSERVATIONS PROVIDE THE ANSWERS!

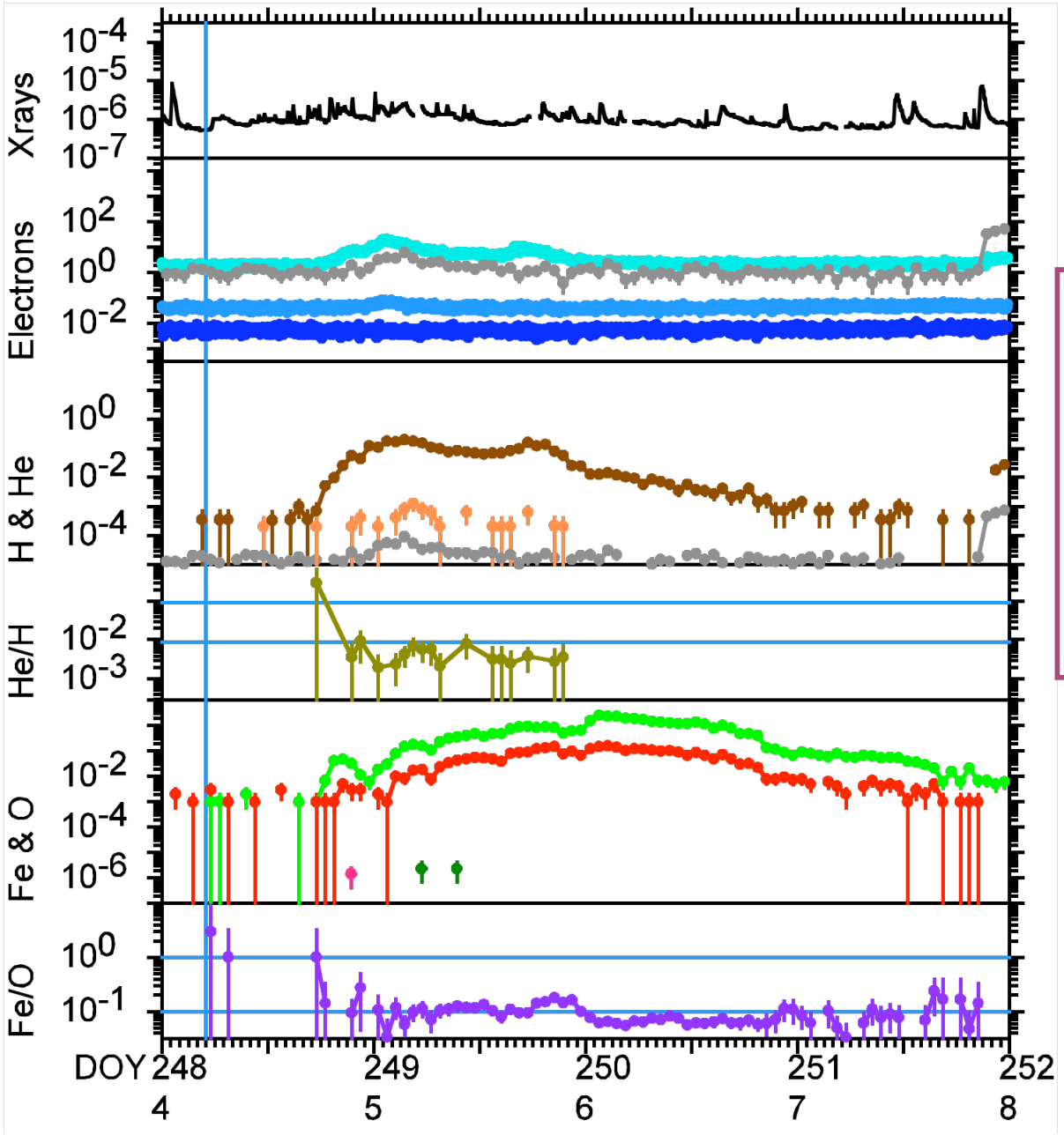
ERUPTING LOOP PLUS RECONNECTION = 1st phase

Available magnetic energy plus magnetic structure of photosphere and corona




ERUPTING LOOP PLUS RECONNECTION = 1st phase
Available magnetic energy plus magnetic structure of photosphere and corona
GRADUAL
Strong Shock?
Yes = 3rd phase
Open Field Lines?
Yes
Connection?
No
Open Field Lines?
No
Aug 9 2001
Very poor
Good
Jan 8 2002
Passing Shock Or CIR?
Yes
Connection?
No
No
Yes
Oct 1 2001
No SEP
Fe-coronal or Fe-poor event
Yes
No
3rd phase + maybe 2nd phase but no 1st phase
Reasonably Fe-rich event
(Type III), type III-I, (II,IV)
Sep 15 2001
Fe-rich early component
at low and high energies
Fe-coronal/Fe-poor component later
(Type III), type III-I, (II,IV)
Major events
Low energy
Fe-coronal late event
Possibly type I
DSF events


FIRST PHASE ONLY
Prompt particles Fe and e - rich
Xrays
Electrons
H & He
He/H
Fe & O
Fe/O
UT.
DOY
MAY 2000
SOHO EPHIN electrons
0.3 - 0.7 MeV
0.7 – 1 MeV
3 - 6 MeV
SOHO ERNE protons & He
8 – 10 MeV p
8 – 10 MeV He
26 – 32 MeV p
8 – 10 MeV He/p
ACE ULEIS / SIS ions
0.3 – 0.6 MeV/n Fe
0.3 – 0.6 MeV/n O
10 – 13 MeV/n Fe
10 – 13 MeV/n O
0.3 – 0.6 MeV/n Fe/O

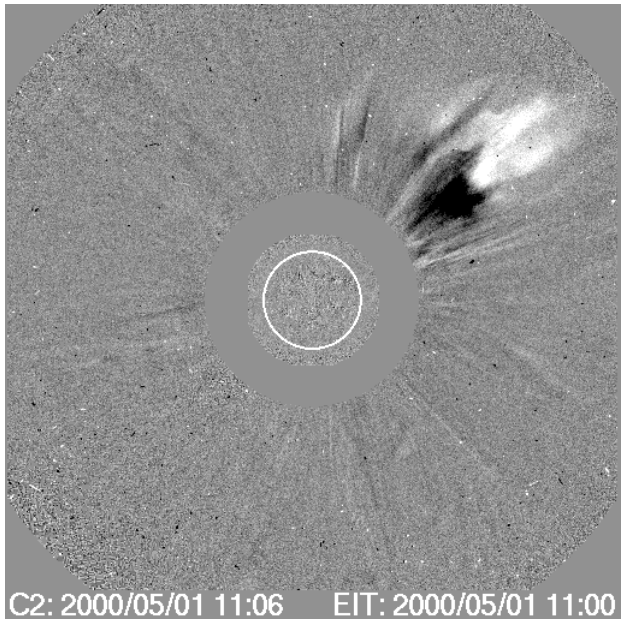


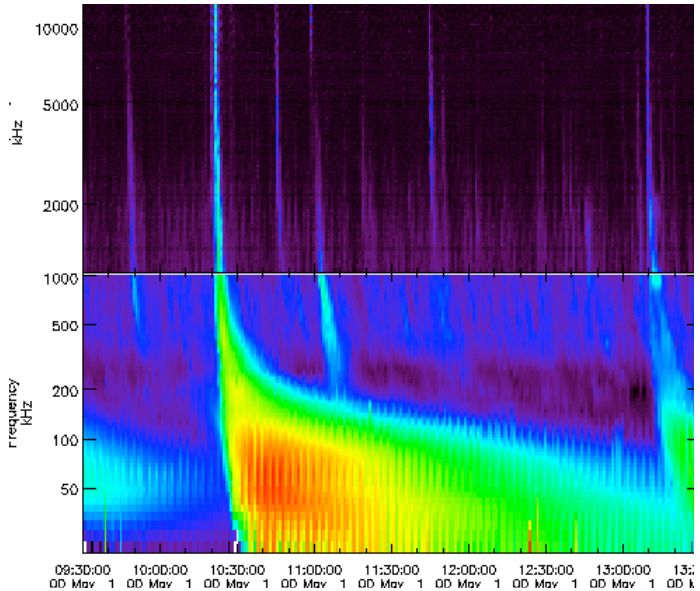
THIRD PHASE ONLY

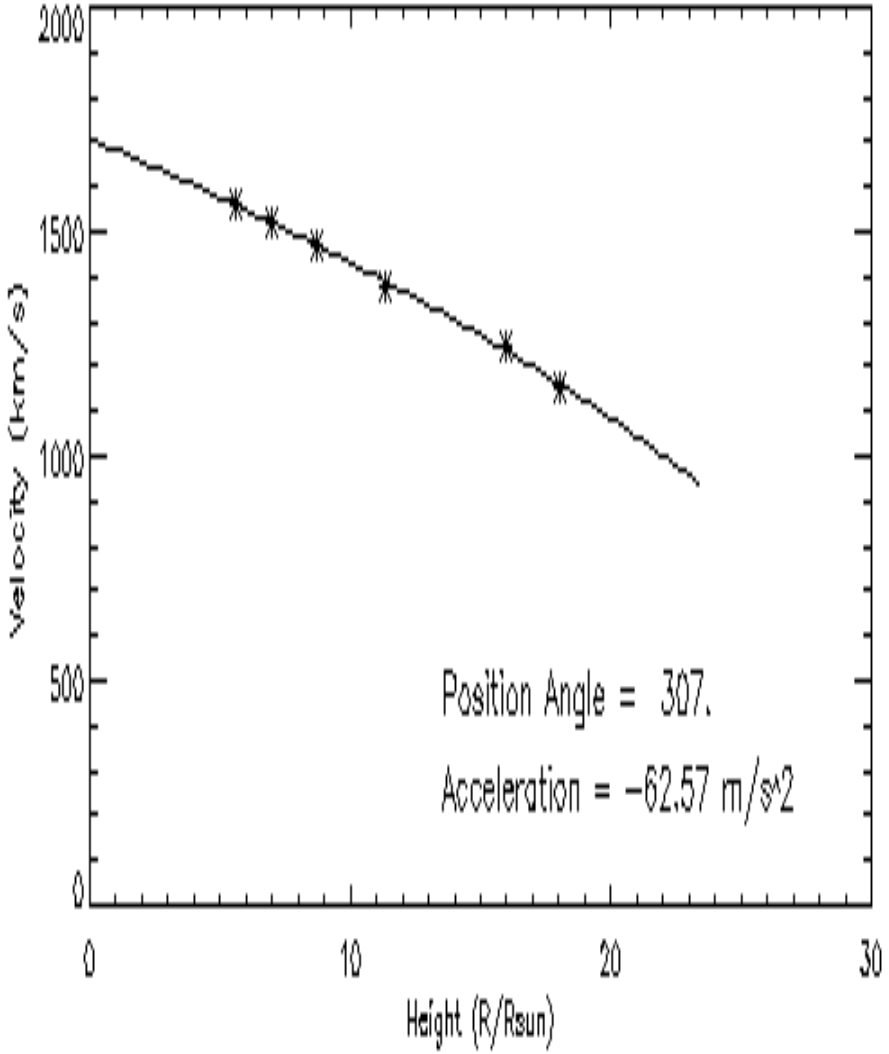
"DISAPPEARING FILAMENT EVENT"

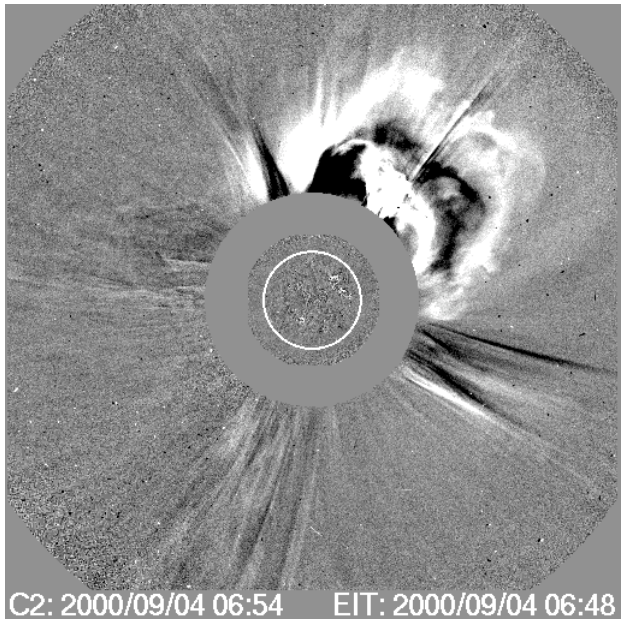
No prompt particles but W33 location

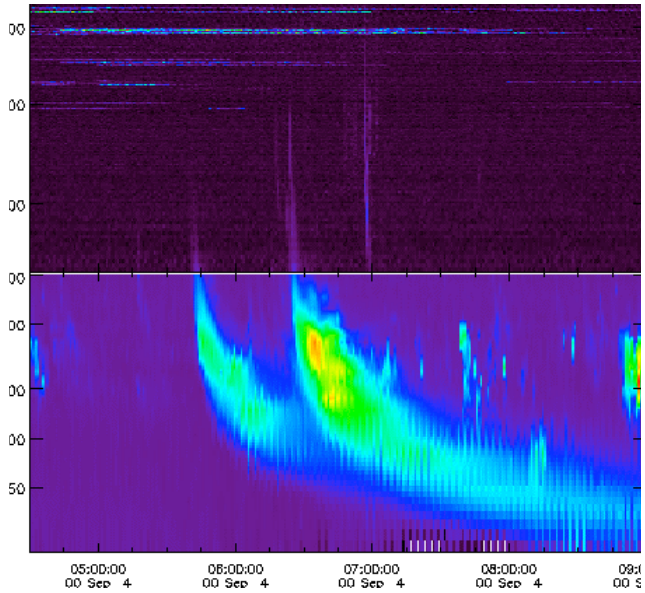
Delayed Fe-poor increase

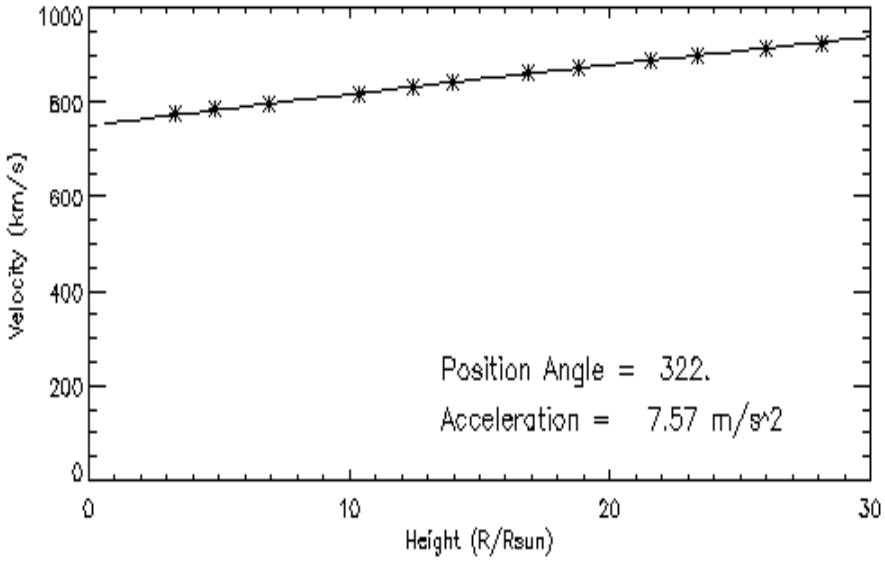

C2: 2000/05/01 11:06
EIT: 2000/05/01 11:00


10000
5000
2000
1000
500
200
100
50
kHz
Frequency
kHz
08:30:00
10:00:00
10:30:00
11:00:00
11:30:00
12:00:00
12:30:00
13:00:00


2000
1500
1000
500
0
Velocity (km/s)
Position Angle = 307.
Acceleration = -62.57 m/s^2
0
10
20
30
Height (R/Rsun)


C2: 2000/09/04 06:54
EIT: 2000/09/04 06:48


05:00:00
00 Sep 4
06:00:00
00 Sep 4
07:00:00
00 Sep 4
08:00:00
00 Sep 4


Velocity (km/s)
Height (R/Rsun)
Position Angle = 322.
Acceleration = 7.57 m/s^2

CONCLUSIONS

- THREE PHASES OF PARTICLE ACCELERATION

- ALL COMBINATIONS ARE POSSIBLE AND LEAD TO A “ZOO” OF SOLAR ENERGETIC PARTICLE EVENTS