Interplanetary Consequences of the SHINE'03 Campaign Events

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Campaign Events:

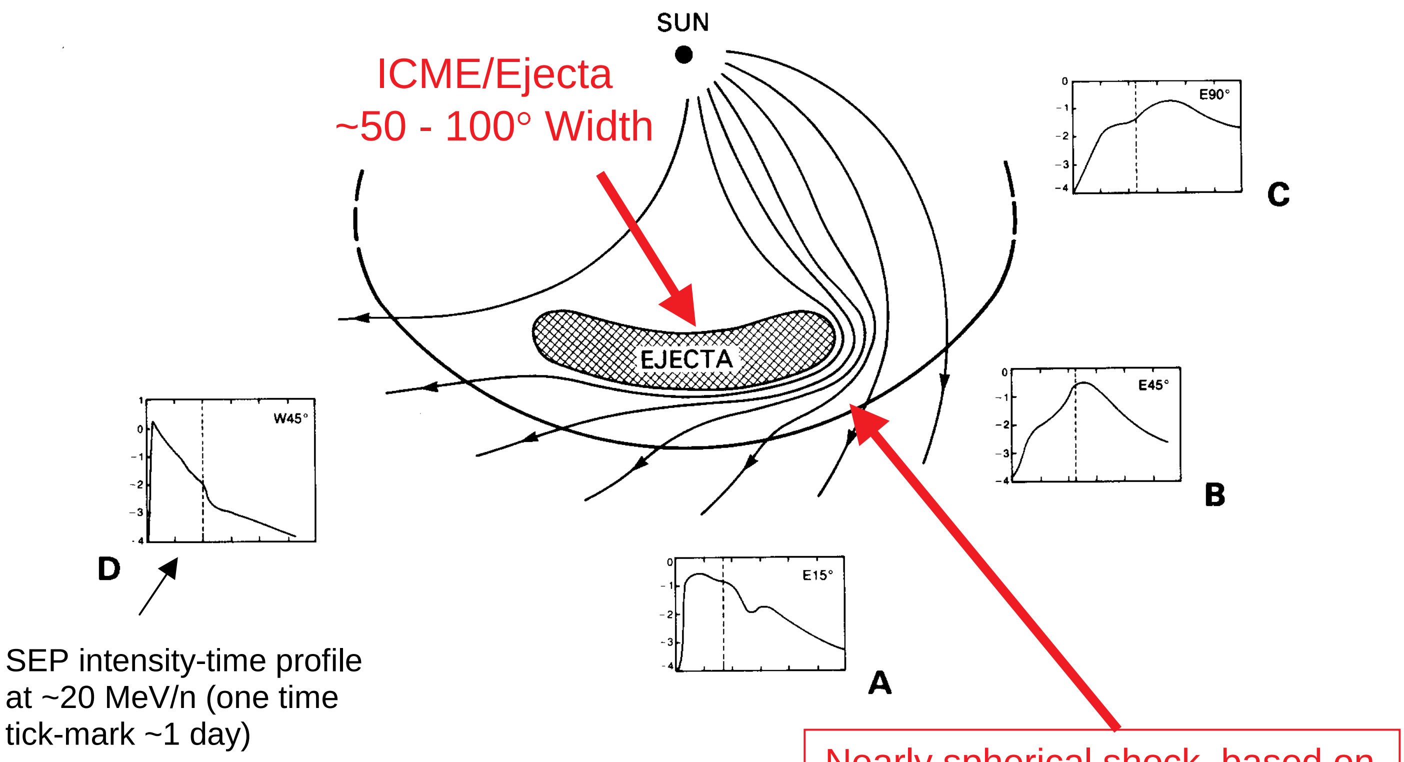
- **May 12, 1997 (N21° W07°);**
- **May 1998 group of events;**

Well studied IP events!

- **April 21, 2002 (W56-84°);**
- **August 24, 2002 (S02°W81°) (SEPs observed by neutron monitors; ground-level event, GeV particles)**

Second session will focus on aspects of the April and August 2002 SEP events. However, earlier solar events occurring in the same active regions when they are near central meridian do have some consequences near the Earth, as will be discussed.

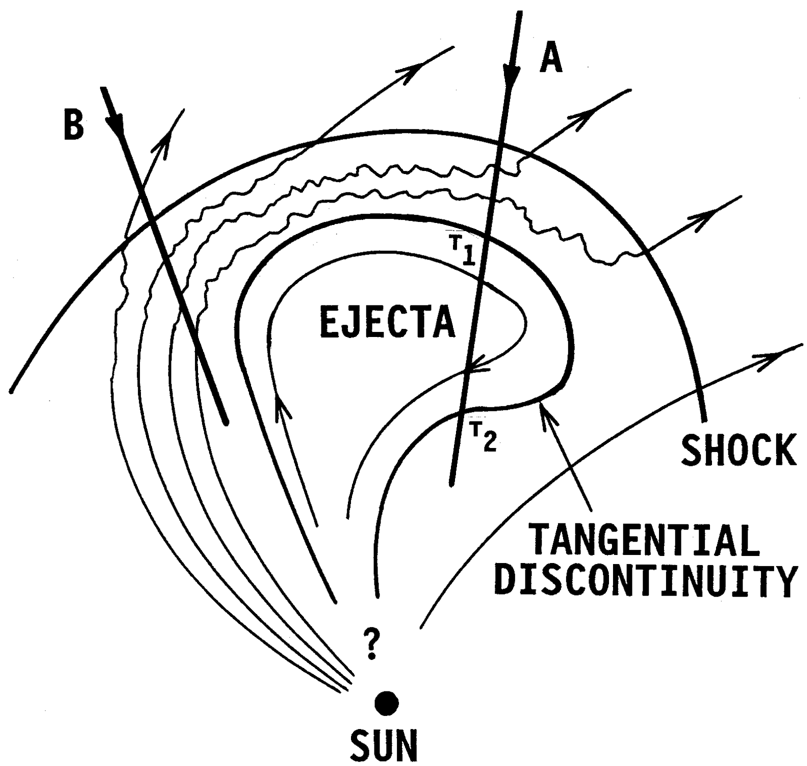
The interplanetary consequences of the campaign events are consistent with the following type of scenario (e.g., Cane et al., JGR, 1988):



<u>Western events relative to the observer (D):</u> **Are well-connected to Earth; SEP intensities rise rapidly. The weak flank of the shock may be encountered.**

<u>Central events (A):</u> **The nose (strongest region) of the shock and ejecta/interplanetary coronal mass ejection (ICME) are likely to be encountered. SEP intensities rise fairly rapidly. There may be a local depression as the ejecta/ICME passes the s/c.**

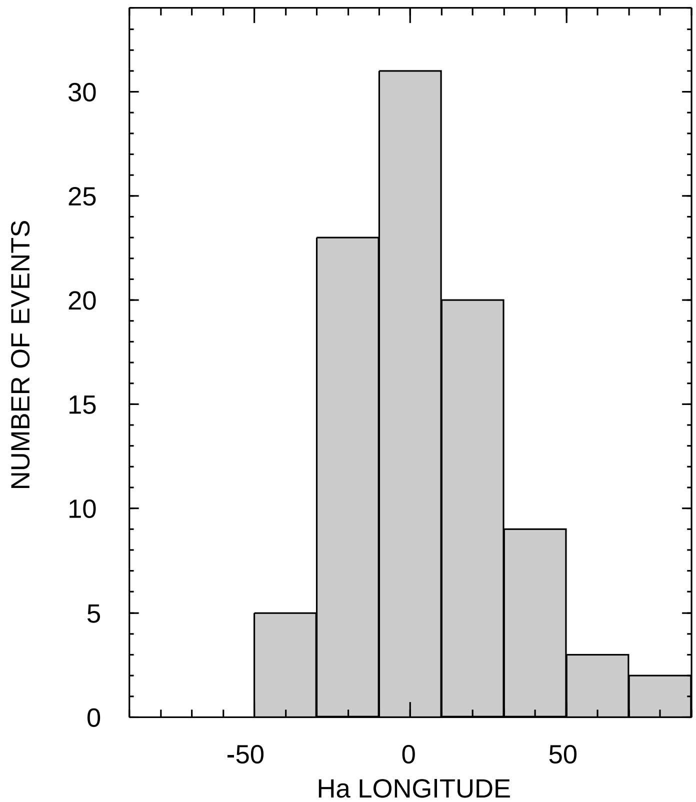
<u>Eastern events (B):</u> **Are initially poorly connected to Earth but particles accelerated by the expanding shock eventually populate field lines passing Earth, producing a gradual rise in intensity, peaking in the vicinity of shock passage. For <u>far-eastern events (C)</u>, the intensity may peak after shock passage, on field lines that connect to stronger regions of the shock nearer the nose.**



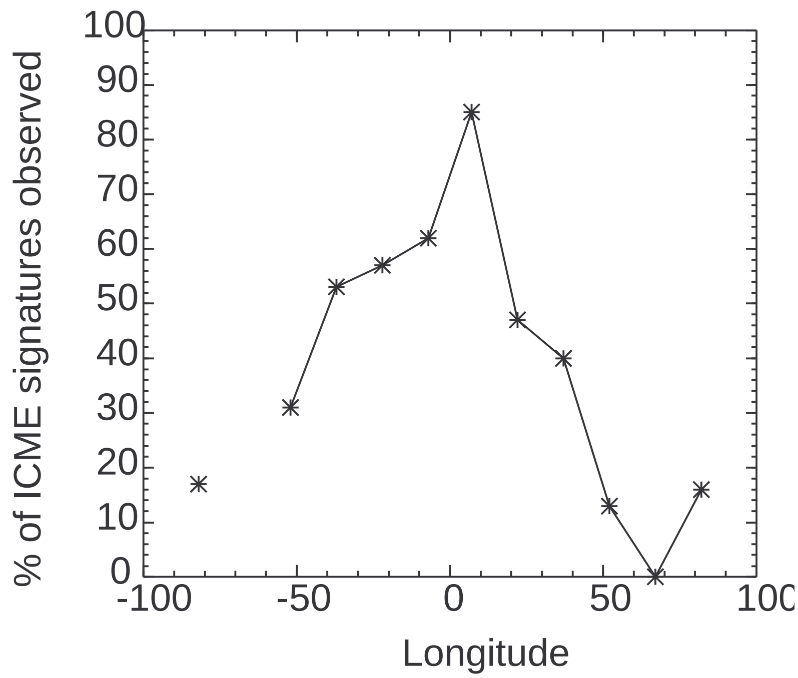
Another schematic of the shock/ICME("ejecta") configuration (Richardson, Cane and Wibberenz, Solar Wind 8, 1996, after Hundhausen, "Coronal Expansion and Solar Wind", 1972). This may be more realistic in that it suggests that the ICME may remain connected to the Sun. Note that along trajectory A relative to these structures, the shock and ICME/"ejecta" are encountered, whereas only the shock is observed along trajectory B. Multiple, widely-spaced spacecraft observations of a single ICME, or cuts through many shocks/ICMEs at various longitudes relative to that of the related solar event, allow ICME longitudinal extents to be inferred.

Estimating ICME Longitudinal Widths

Longitudes of solar events giving rise to ICMEs at Earth (Cane and Richardson, JGR, 2003).

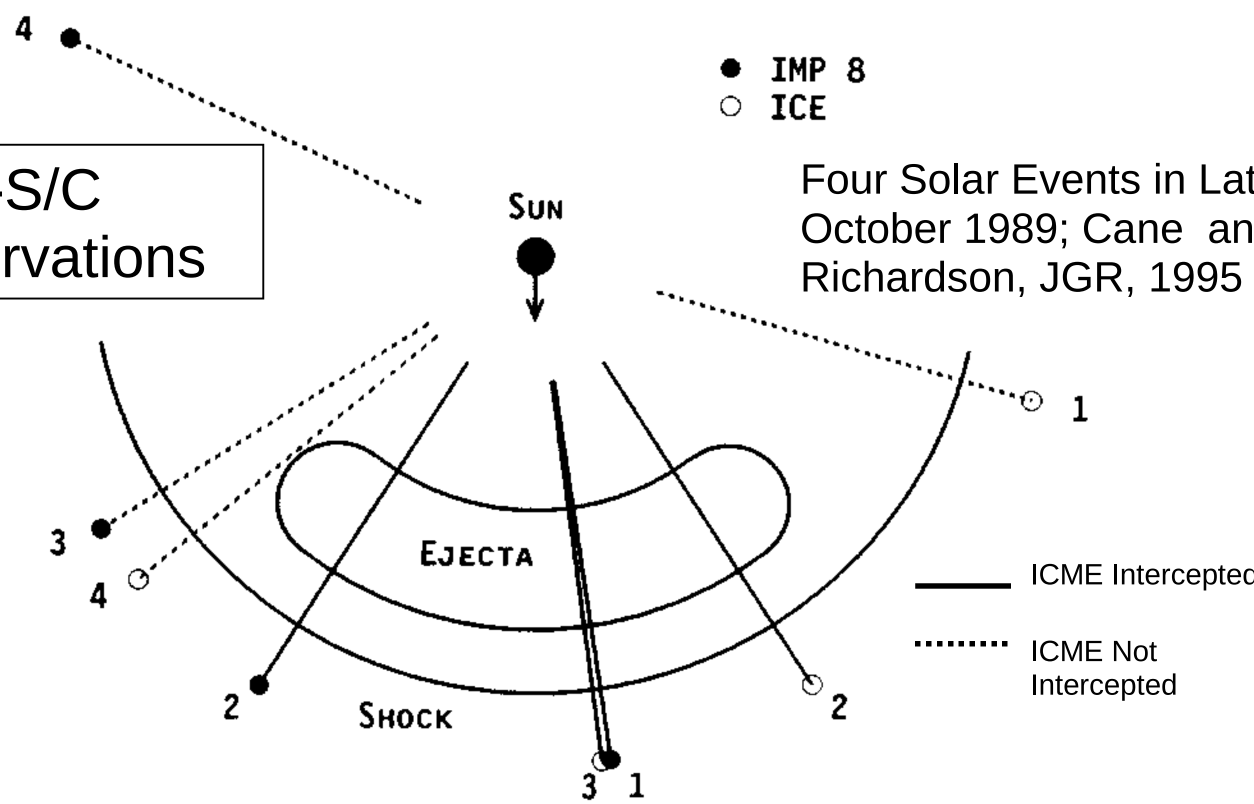


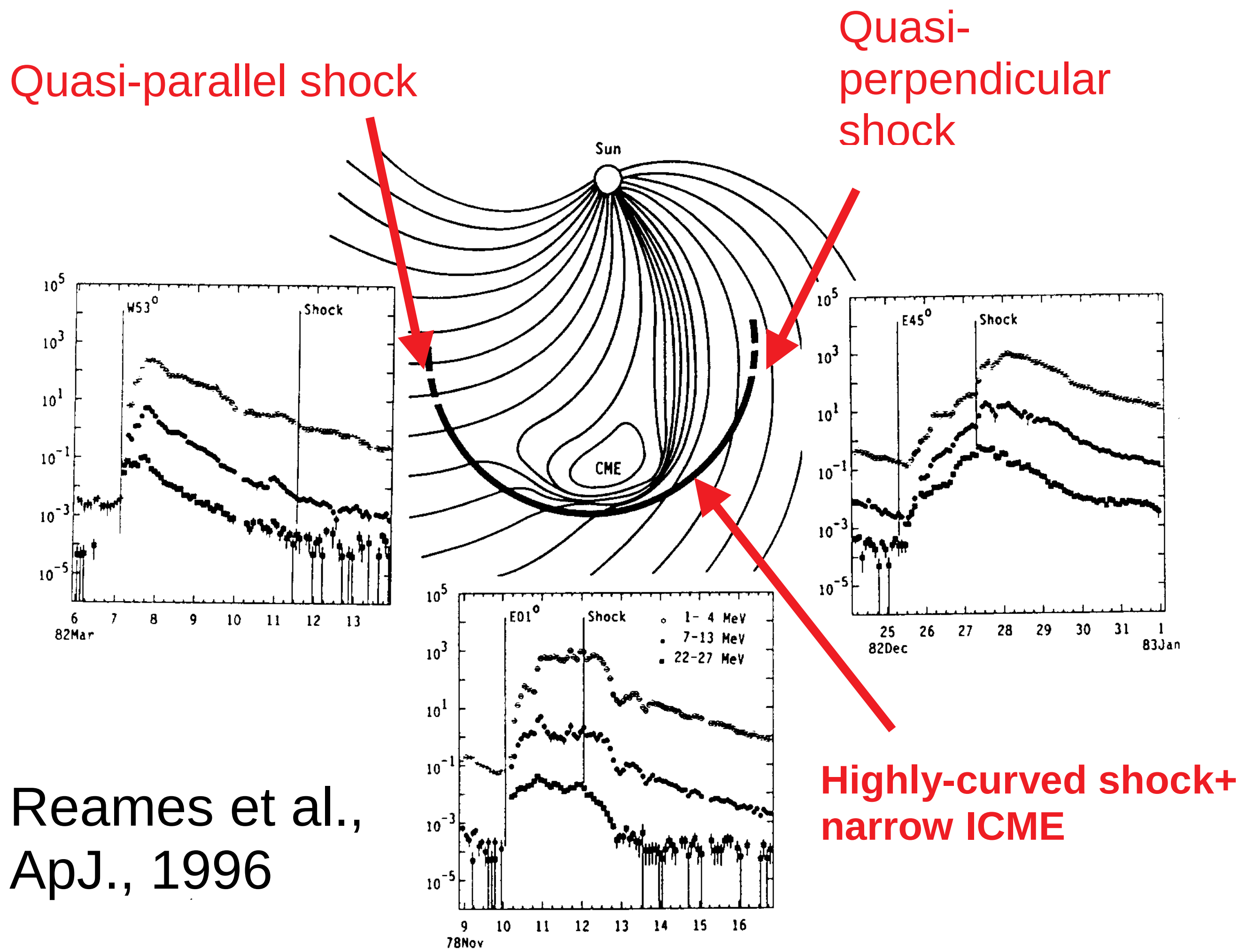
Occurrence of ICME signatures following strong shocks associated with IP type II radio events (Richardson and Cane, JGR, 1993)



Multi-S/C Observations

Four Solar Events in Late October 1989; Cane and Richardson, JGR, 1995





<u>A cautionary note about "cartoons"</u>: **Here is another illustration of an ICME - driven shock (Reames et al., ApJ., 1996) in relation to SEP event profiles. Note that the ICME is extremely narrow (~30º) whereas observations suggest that ICMEs in major events may extend to ~100º in longitude (e.g., Richardson and Cane, JGR. 1993). In addition, the shock illustrated is strongly curved and non-spherical, and suggests that the shock configuration may vary with longitude from ~quasi-perpendicular on the western flank (i.e., the shock normal is ~perpendicular to the magnetic field, θ_{Bn}~90°) to ~quasi-parallel on the eastern flank (θ_{Bn}~0°). Such a variation would not occur for a more realistic, near-spherical shock. Around 20 years ago, the longitudinal ordering of SEP event intensity-time profiles was frequently interpreted in terms of a longitudinal variation in the properties of the shock (e.g., Sarris et al. Sol. Phys. 1984; JGR. 1985), suggested in particular by the cartoon of Hundhausen (1972) which has a strongly-curved shock. Note also that temporal and spatial variations in the IMF and shock surface shape will influence local values of θ_{Bn} along the shock and may destroy any simple organization of θ_{Bn} with longitude.**

May 12, 1997 references include:

Thompson, B. J. et al., SOHO/EIT observations of an Earth-directed coronal mass ejection on May 12, 1997, Geophys. Res. Lett. Vol. 25 , No. 14 , p. 2465, 1998.

Plunkett, S. P. et al., LASCO observations of an Earth-directed coronal mass ejection on May 12, 1997 Geophys. Res. Lett. Vol. 25 , No. 14 , p. 2477, 1998.

Cane, H. V. et al., The interplanetary events of January-May, 1997, as inferred from energetic particle data, and their relationship with solar events Geophys. Res. Lett. Vol. 25 , No. 14 , p. 2517, 1998.

Torsti, J. et al., Energetic (~1 to 50 MeV) protons associated with Earth-directed coronal mass ejections, Geophys. Res. Lett. Vol. 25 , No. 14 , p. 2525, 1998

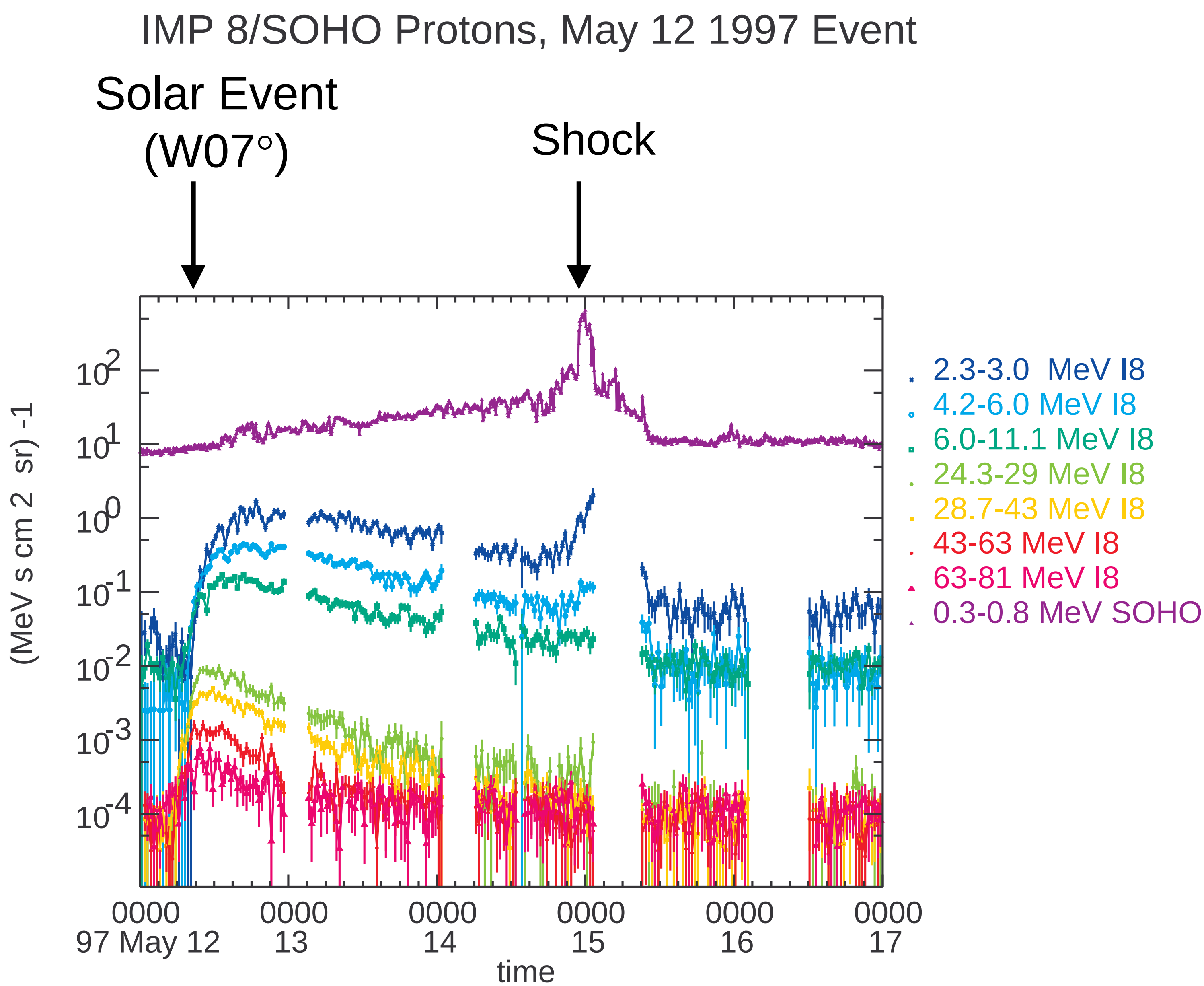
Baker, D. N. et al., A strong CME-related magnetic cloud interaction with the Earth's magnetosphere: ISTP observation of rapid relativistic electron acceleration on May 15, 1997, Geophys. Res. Lett. Vol. 25 , No. 15 , p. 2975, 1998

Brueckner, G. E. et al., Geomagnetic storms caused by coronal mass ejections (CMEs): March 1996 through June 1997, Geophys. Res. Lett. Vol. 25 , No. 15 , p. 3019, 1998

ETC, ETC……

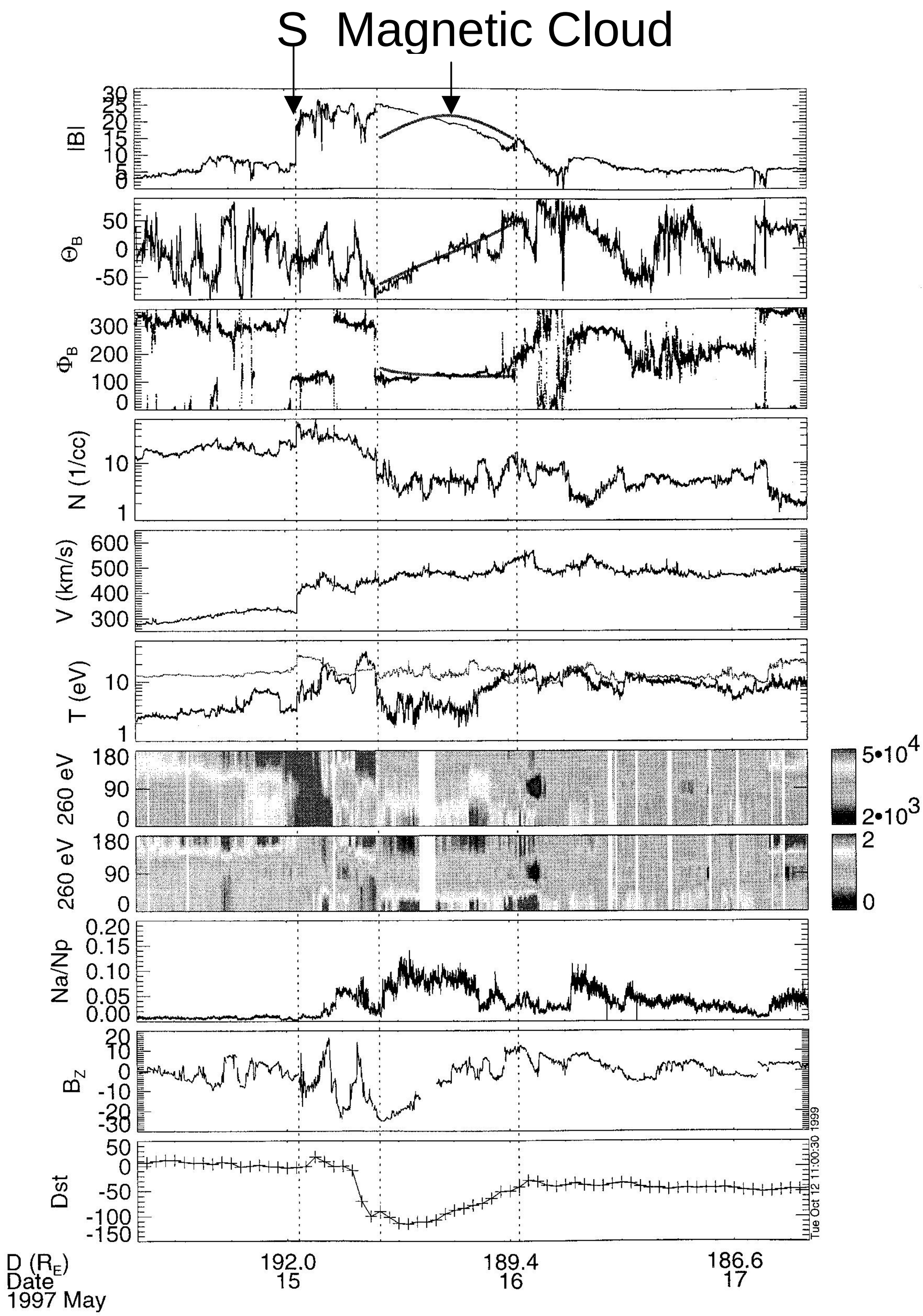
Particularly useful (comprehensive) reference:

Webb, D. F. et al., The origin and development of the May 1997 magnetic cloud, Journal of Geophysical Research, Volume 105, pp.27251-27260, 2000.



May 12 SEP event extends to ~100 MeV.

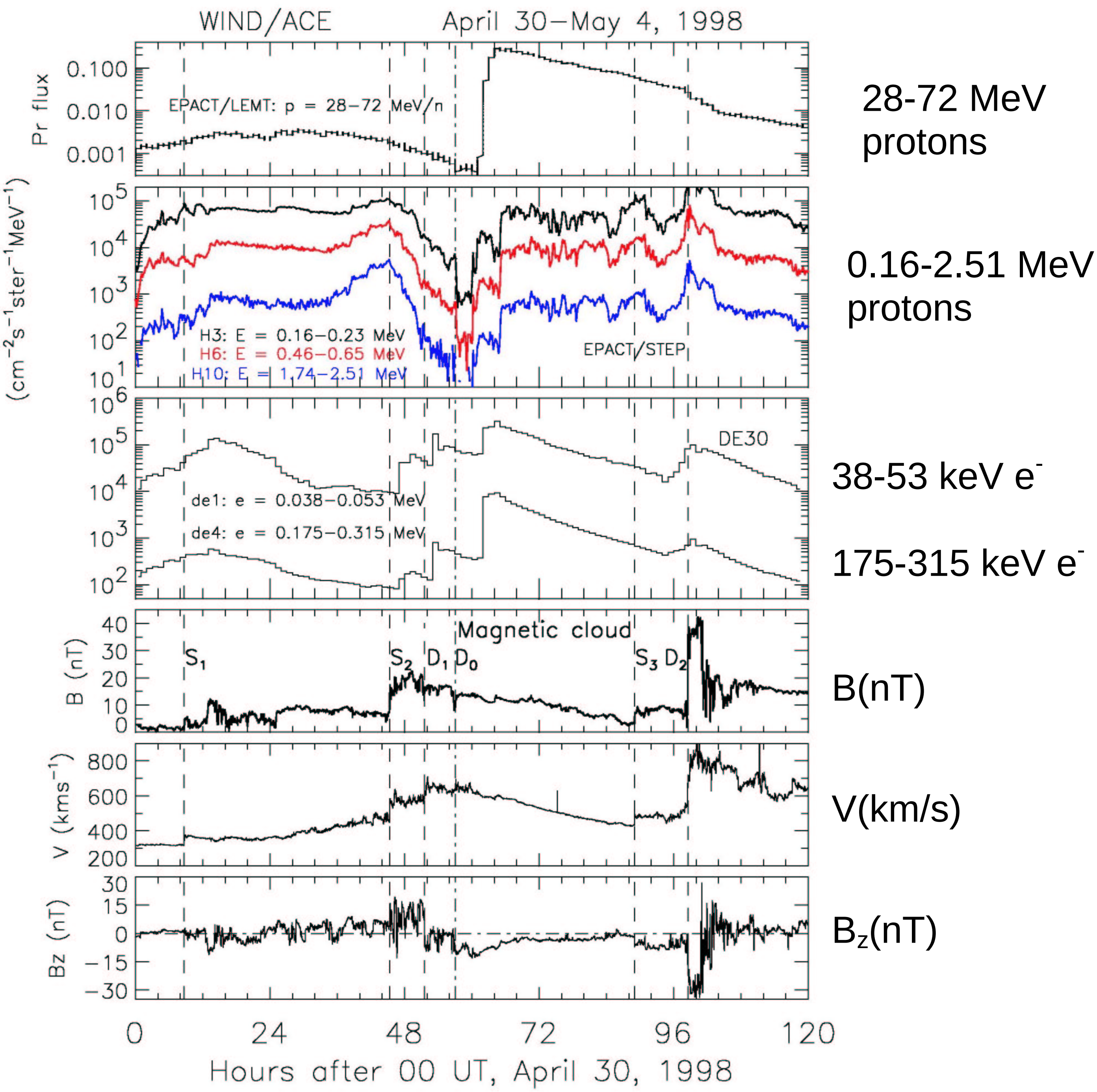
May 15 Interplanetary Event (Webb et al., 2000)



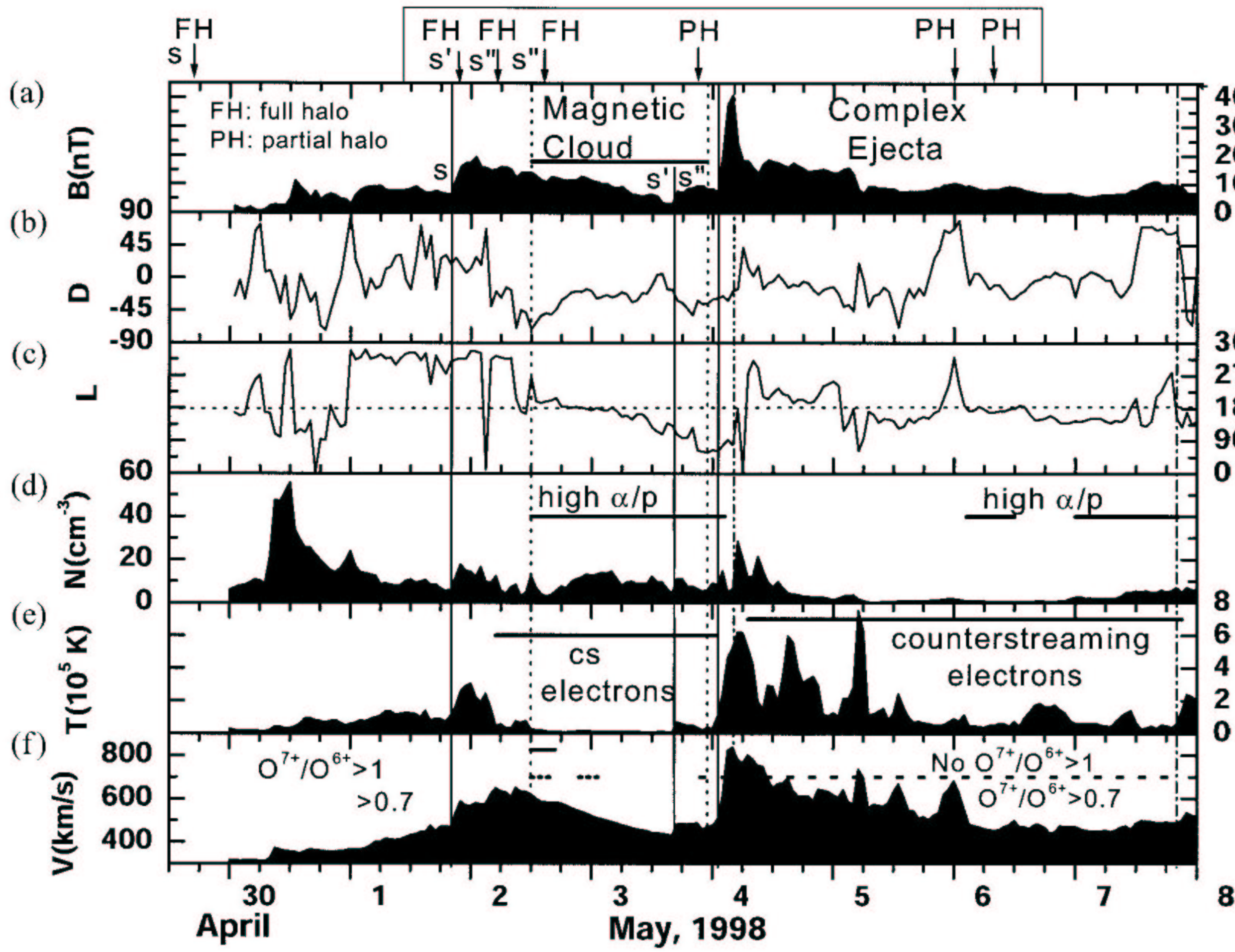
May 12 solar event gives rise to shock and magnetic cloud at Earth on May 15. Geomagnetic storm (Dst~-115 nT) caused by strong southward magnetic fields in post-shock sheath and MC.

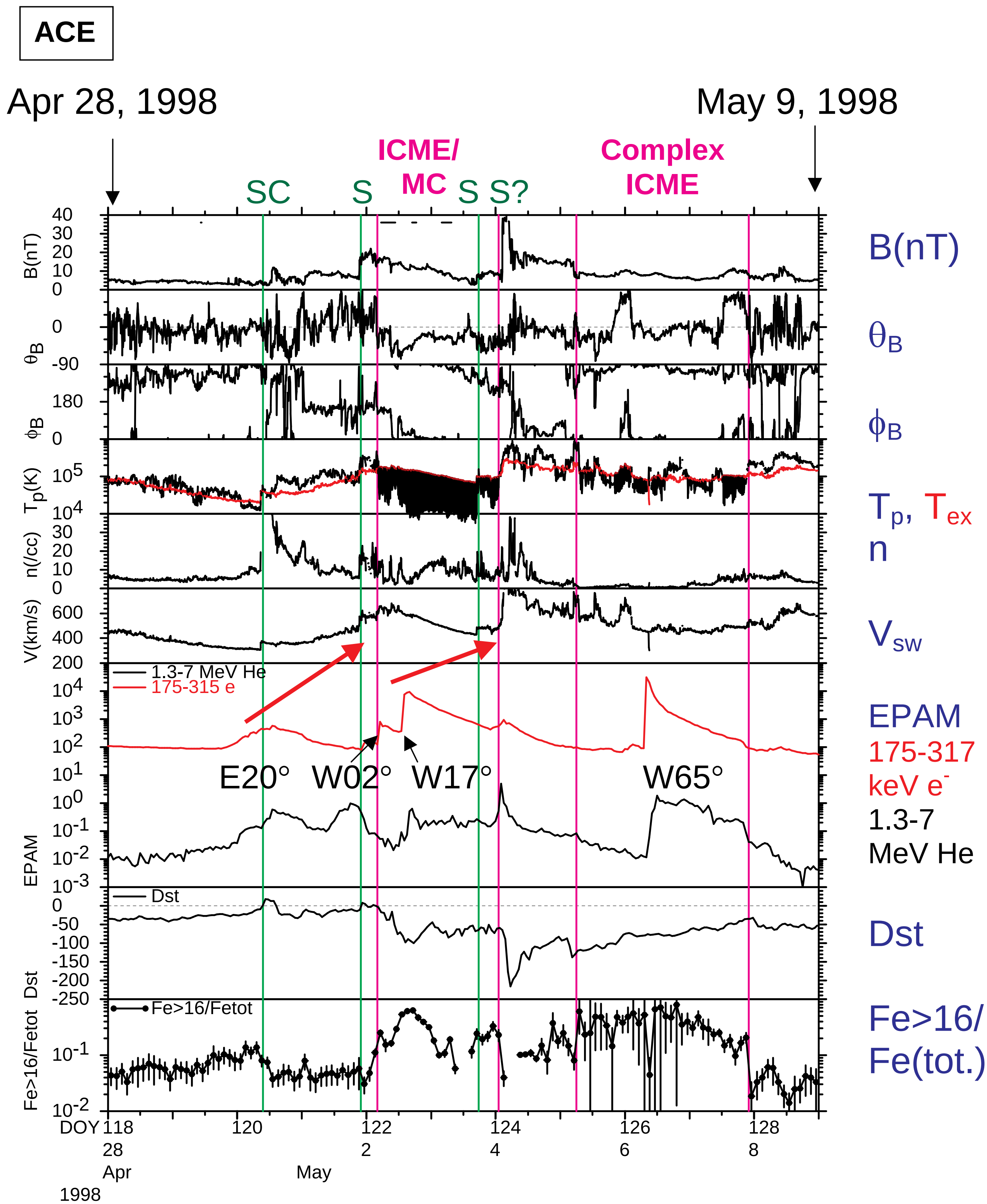
May 1998 Events

(Farrugia et al., JGR, 2002):



May 1998 Interplanetary Events
(Burlaga et al., JGR, 2001)



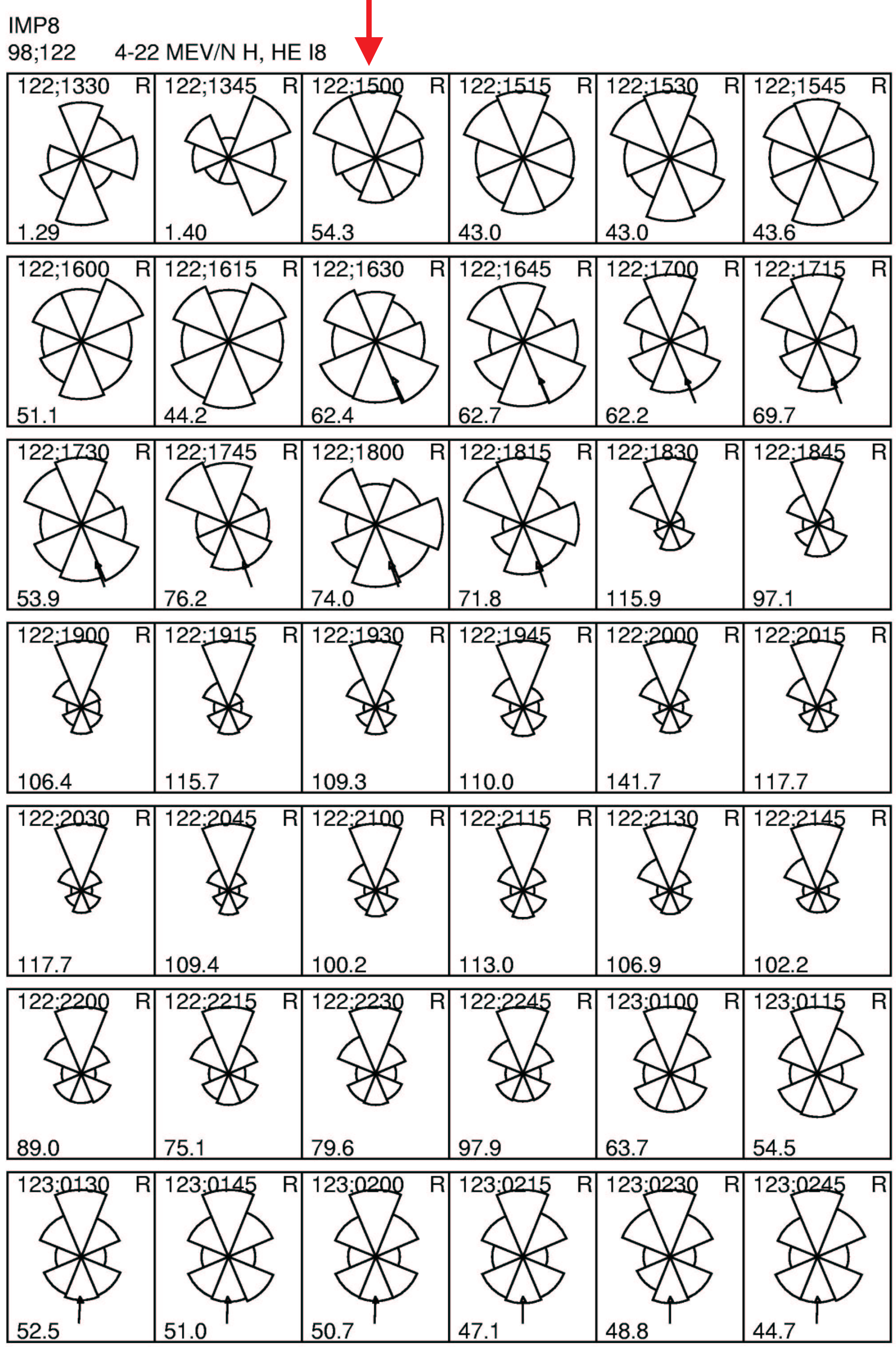


ACE
Apr 28, 1998
May 9, 1998
ICME/
MC
Complex
ICME
SC
S
S
S?
B(nT)
θ_B
ϕ_B
T_p, T_{ex}
n
V_{sw}
1.3-7 MeV He
175-315 e
E20°
W02°
W17°
W65°
EPAM
175-317
keV e^-
1.3-7
MeV He
Dst
Dst
Fe>16/Fetot
Fe>16/
Fe(tot.)
DOY 118
120
122
124
126
128
28
2
4
6
8
Apr
May
1998

IMP 8 4-22 MeV/n H, He Azimuthal Sectored Count Rates, May 2 1998, 1330 - May 3, 0300 UT

SEP Event Onset Inside Magnetic cloud

Flow from Sun along Parker Spiral



NOTE BI-DIRECTIONAL PARTICLE FLOWS

Count rates plotted vs. *viewing* direction with the Sun at top of page; arrow = B azimuth at IMP 8.

Notes on April, 2002 Events

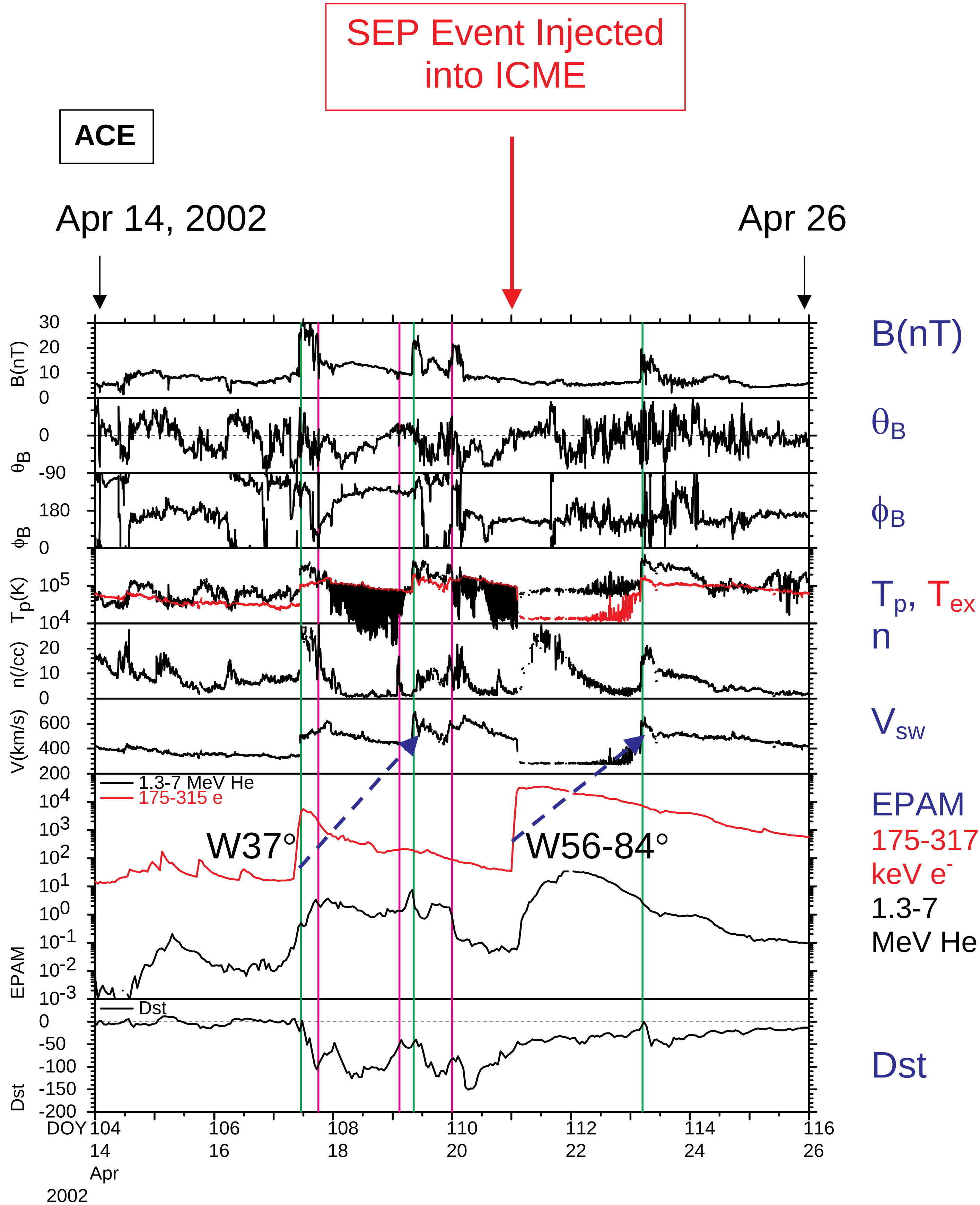
- **SEP event on April 21 (campaign event) was observed at Earth. An ICME was passing Earth at this time, probably originating in the same active region on April 17. Hence, SEPs were guided to Earth via ICME field lines (note that ACE plasma data are affected by SEP event, so the ICME trailing edge is difficult to identify).**
- **A shock flank, but no ICME, was observed on April 23 following April 21 event, consistent with the far-western location. Modest geomagnetic storm followed shock passage (brief intervals of compressed B_{south}).**
- **Shocks on April 17 and 19 were followed by ICMEs. Originated in same active region as April 21 event when closer to central meridian.**
- **April 17 and April 19 shock/ICMEs both produced 2-component geomagnetic storms, caused by strong southward fields in the post-shock sheath and subsequently in the ICME. The result was a ~4 day interval of continuously enhanced geomagnetic activity with 4 distinct activity maxima.**

Notes on August, 2002 Events

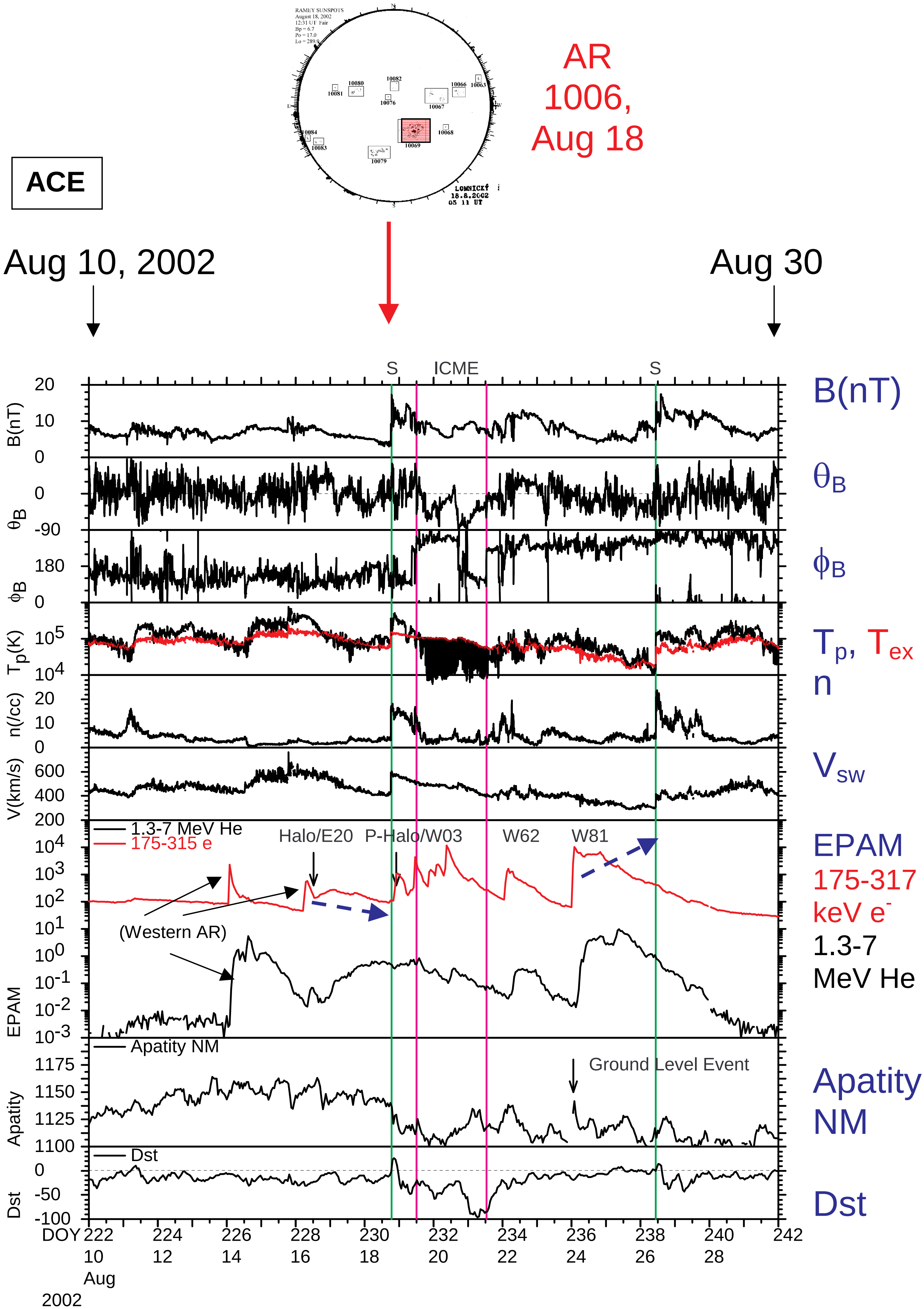
- August 24 SEP event was observed at Earth (ground level event (GeV particles) detected by neutron monitors).
- The shock flank, but no ICME was observed at Earth following this event, consistent with far western location (W81°). Minor geomagnetic storm produced by brief intervals of southward field in compressed, fluctuating IMF.
- Earlier (from April 16), a sequence of particle events was observed as the active region producing the August 24 event (1006) rotated in longitude relative to the Earth. (Note that there were additional events on April 14-16 from an unrelated active region on the western hemisphere.)
- A shock on August 18 was followed by an ICME. These structures were probably associated with the halo CME on August 16 that originated in AR1006, then at E20°. The location of the active region on August 18 is shown.
- The shock and ICME produced a 2-step cosmic ray depression (Forbush decrease), with steps at shock passage and the ICME leading edge.
- They also produced a complicated geomagnetic storm with 3 distinct maxima caused by (1) brief periods of strong southward field in the sheath; (2) a period of southward field inside the leading edge of the ICME; (3) southward fields inside the trailing edge of the ICME (the strongest phase of the storm). Note that activity temporarily declined as the center of the

ICME, where southward fields were weaker, passed the Earth.

- **A sequence of solar energetic electron injections were observed during ICME passage.**



SEP Event Injected
into ICME
ACE
Apr 14, 2002
Apr 26
B(nT)
θB
φB
Tp(K)
n(/cc)
V(km/s)
1.3-7 MeV He
175-315 e
W37°
W56-84°
EPAM
Dst
DOY 104
106
108
110
112
114
116
14
16
18
20
22
24
26
Apr
2002
B(nT)
θB
φB
Tp, Tex
n
Vsw
EPAM
175-317
keV e-
1.3-7
MeV He
Dst



AR
1006,
Aug 18
ACE
Aug 10, 2002
Aug 30
S
ICME
S
B(nT)
θB
φB
Tp, Tex
n
Vsw
Tp(K)
n(/cc)
V(km/s)
1.3-7 MeV He
175-315 e
Halo/E20
P-Halo/W03
W62
W81
(Western AR)
EPAM
175-317
keV e-
1.3-7
MeV He
Apatity NM
Ground Level Event
Apatity
NM
Dst
DOY 222
224
226
228
230
232
234
236
238
240
242
10
12
14
16
18
20
22
24
26
28
Aug
2002

Summary:

Interplanetary consequences depend strongly on location (e.g., longitude) of observer with respect to solar event, e.g.:

<~50°: shock +ICME typically observed;

>~50°: shock occasionally observed; ICME very rarely.

Campaign events follow this pattern inferred from previous studies.

Geomagnetic storms result if enhanced Bs in ICME and/or in post-shock "sheath";

Several examples of SEP events injected into ICMEs, e.g., May 2 (GLE) and 6, 1998; April 21, 2002.