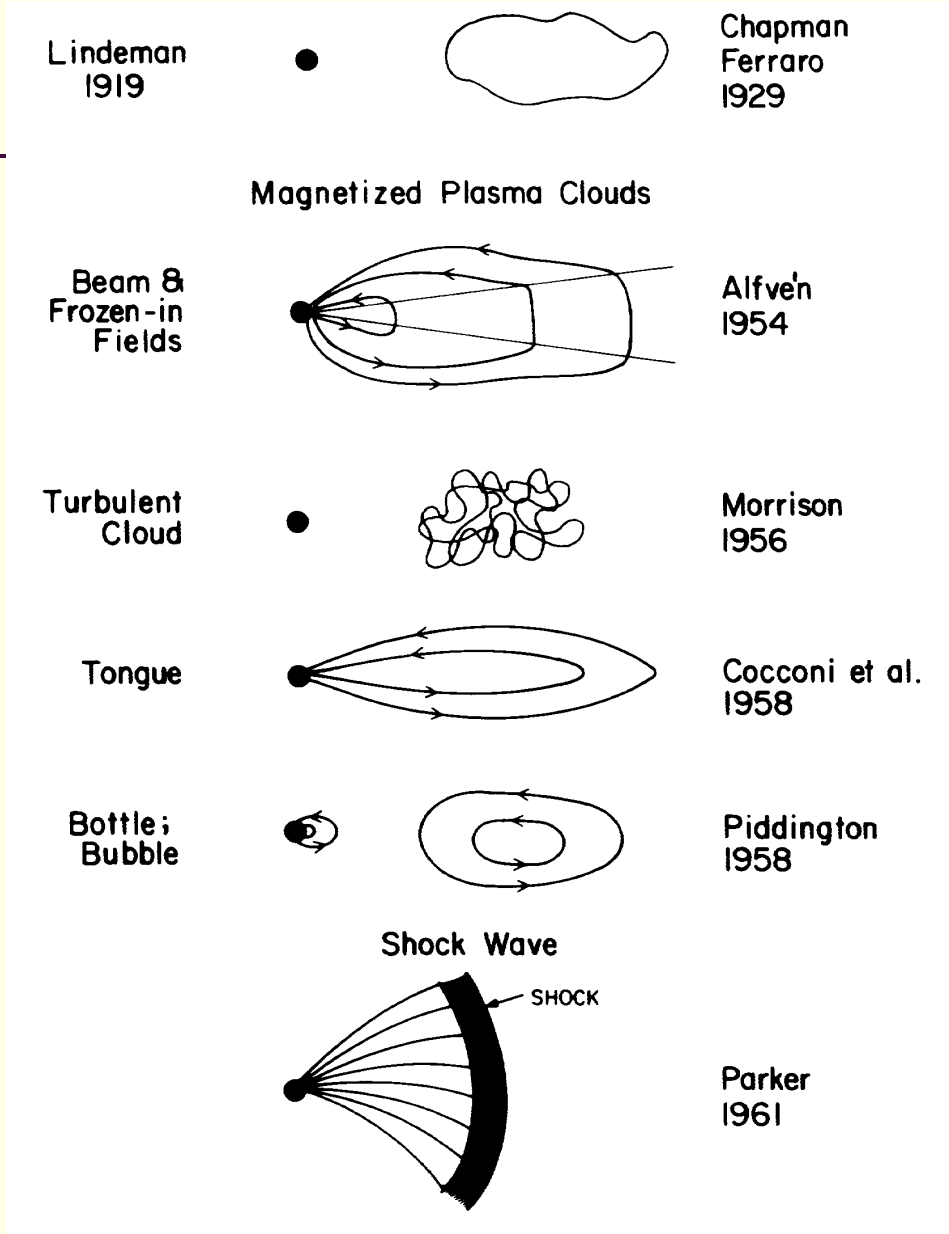
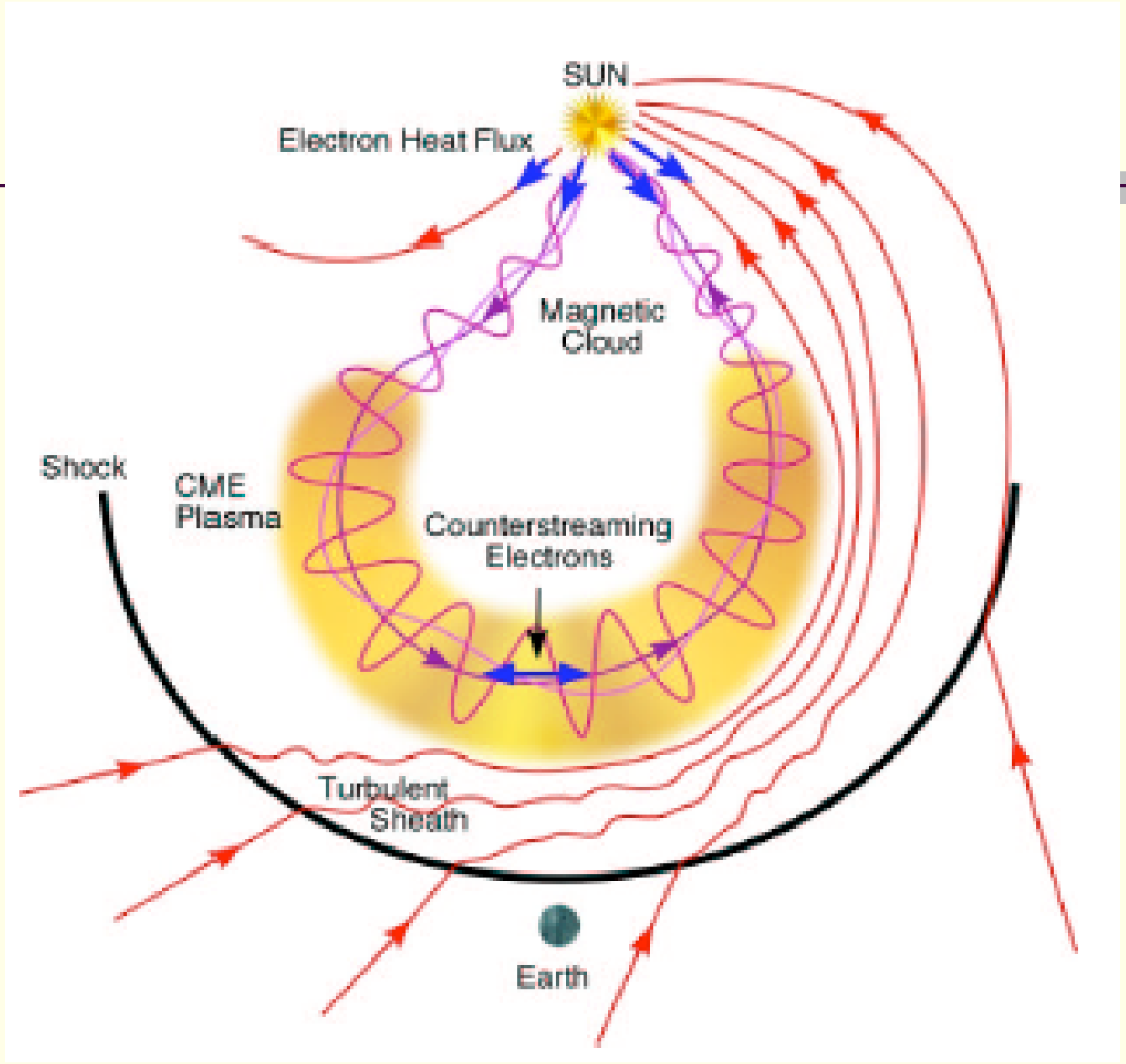
Compositional signatures in the mix..

Thomas H. Zurbuchen, Susan Lepri, and Ian Richardson

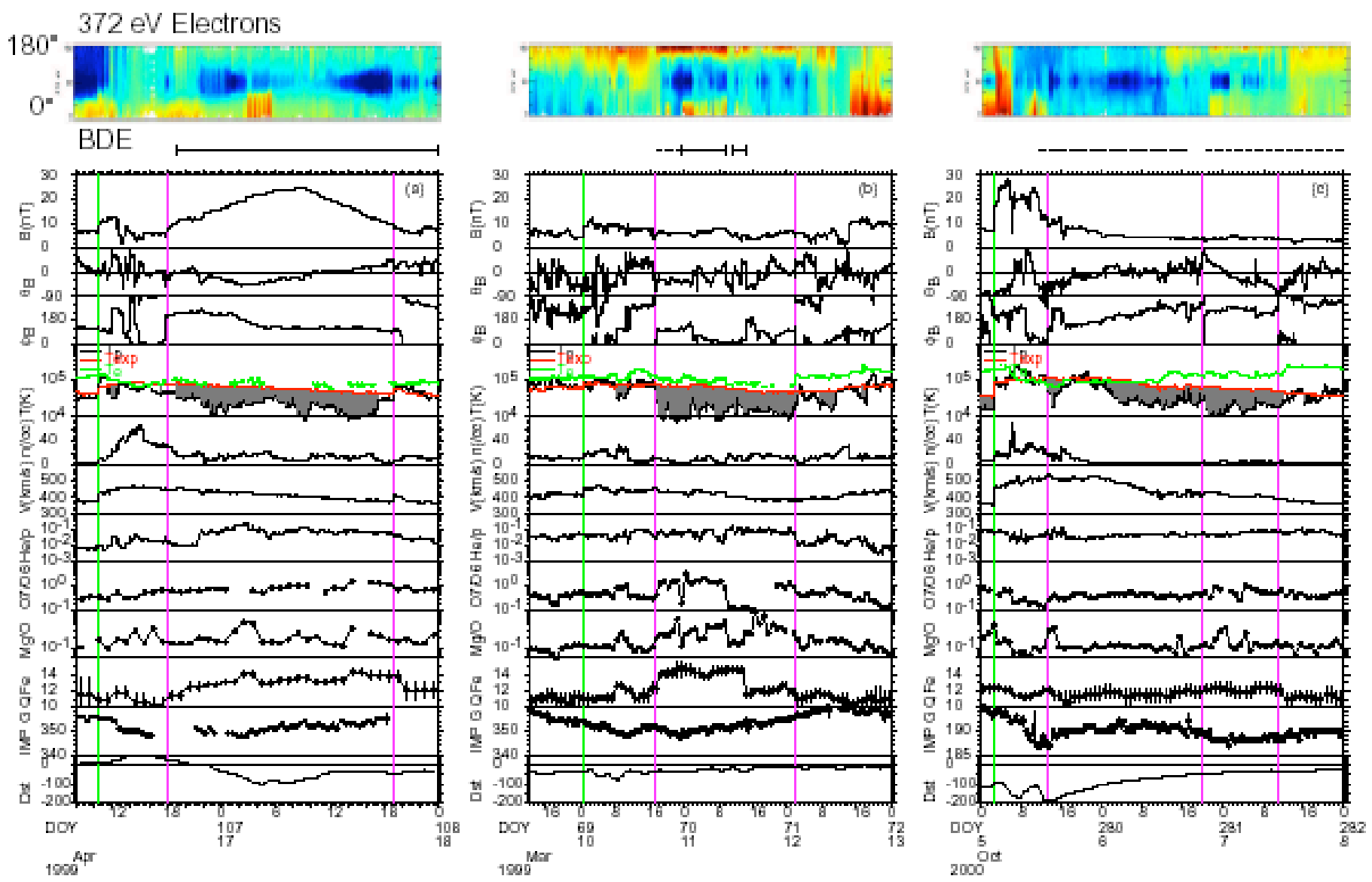
History

- Summary of views of CMEs in the early age of space exploration.
- Bottom line – most concepts were there from the beginning.

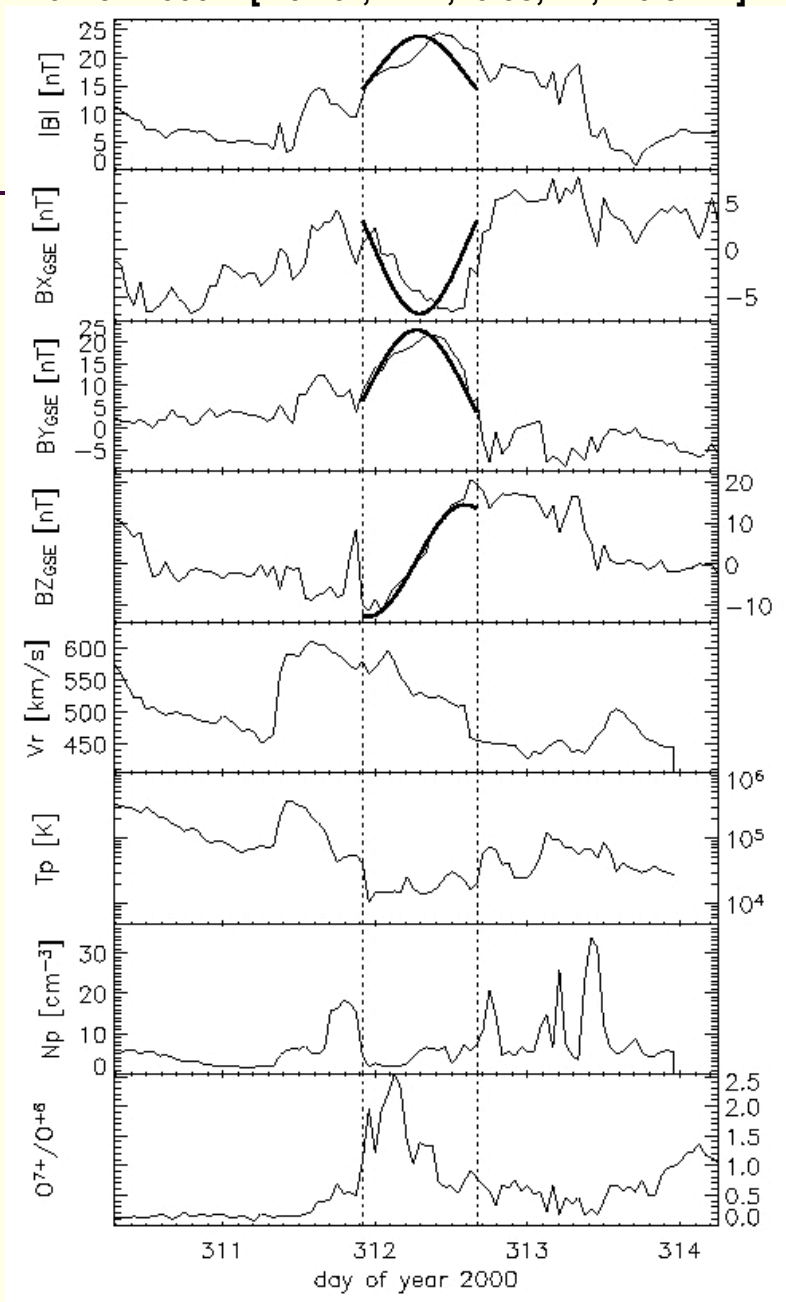


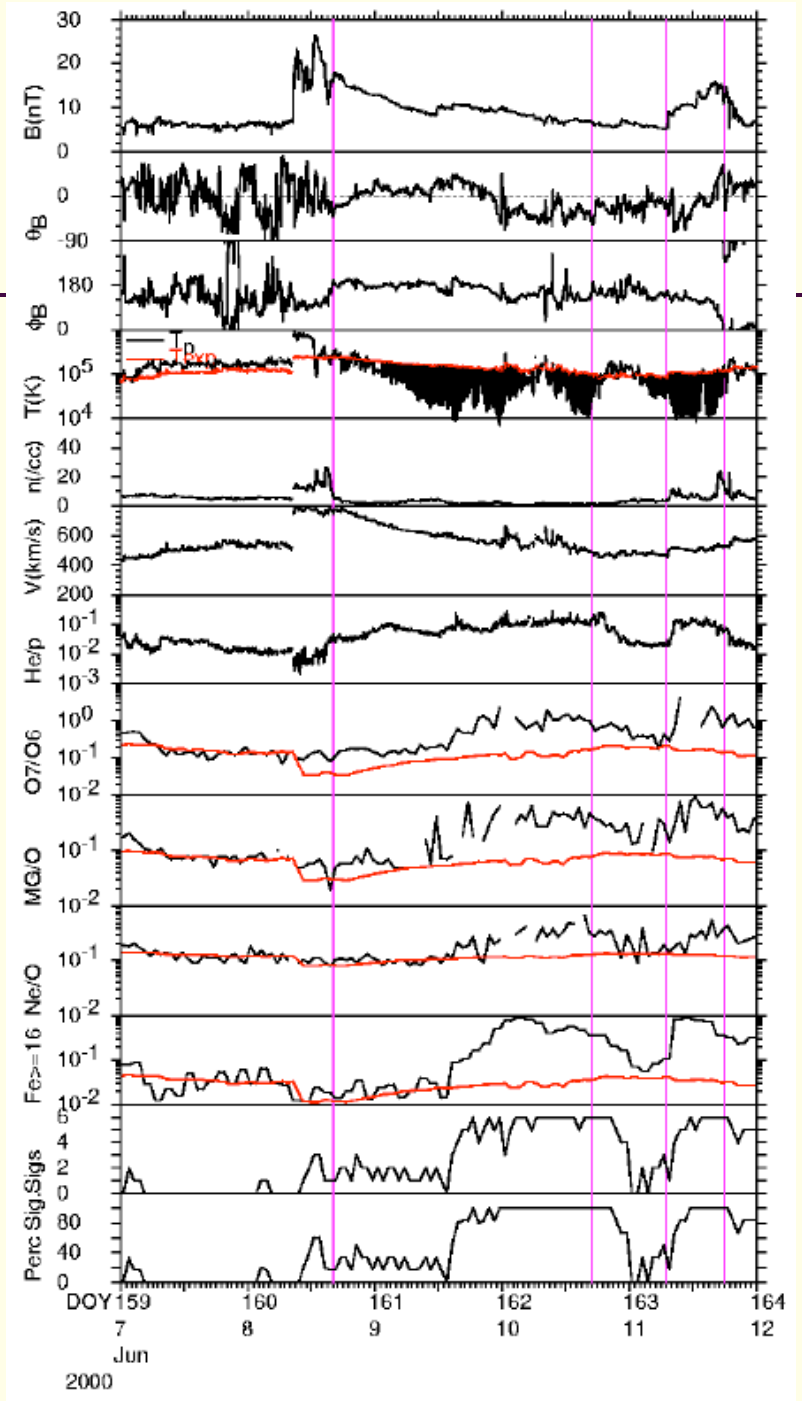

SUN
Electron Heat Flux
Magnetic Cloud
Shock
CME Plasma
Counterstreaming Electrons
Turbulent Sheath
Earth

Signature	Description	Selected References
Magnetic Field		
B1: B Rotation	$>> 30^o$, Smooth	Klein and Burlaga (1982)
B2: B Enhancement	> 10 nT	Hirshberg and Colburn (1969); Klein and Burlaga (1982)
B3: B Variance Decrease		Pudovkin et al. (1979); Klein and Burlaga (1982)
B4: Discontinuity at ICME boundaries		Janoo et al. (1998)
B5: Field line draping around ICME		Gosling and McComas (1987); McComas et al. (1989)
B6: Magnetic clouds	(B1, B2 and $\beta = \frac{\sum nkT}{B^2/(2\mu_0)} < 1$)	Klein and Burlaga (1982); Lepping et al. (1990)
Plasma Dynamics		
P1: Declining Velocity Profile/Expansion	Monotonic Decrease	Klein and Burlaga (1982); Russell and Shinde (2003)
P2: Extreme Density Decrease	≤ 1 cm-3	Richardson et al. (2000a)
P3: Proton Temperature Decrease	$T_p < 0.5 T_{exp}$ [1]	Gosling et al. (1973); Richardson and Cane (1995)
P4: Electron Temperature Decrease	$T_e < 6 \times 10^4$ K	Montgomery et al. (1974)
P5: Electron Temperature Increase	$T_e >> T_p$	Sittler and Burlaga (1998); Richardson et al. (1997)
P6: Upstream Forward Shock/"Bow Wave"	Rankine-Hugoniot Relations	Parker (1961);
Plasma Composition		
C1: Enhanced α/Proton Ratio	$He^{2+}/H^+ > 8\%$	Hirshberg et al. (1972); Borrini et al. (1982a)
C2: Elevated Oxygen Charge States	$O^{7+}/O^{6+} > 1$	Henke et al. (2001); Zurbuchen et al. (2003)
C3: Unusually high Fe Charge States	$< Q >_{Fe} > 12$; $Q_{Fe}^{>15+} > 0.01$	Lepri et al. (2001); Lepri and Zurbuchen (2004)
C4: Occurrence of He^+	$He^+/He^{2+} > 0.01$	Zwickl et al. (1982); Gloeckler et al. (1999)
C5: Enhancements of Fe/O	$\frac{(Fe/O)_{CME}}{(Fe/O)_{ph}} > 5$ [2]	Ipavich et al. (1986)
C6: Unusually High ^{3}He/^{4}He	$\frac{(^3He/^4He)_{CME}}{(^3He/^4He)_{ph}} > 2$	Ho et al. (2000)
Plasma Waves		
W1: Ion Acoustic Waves		Fainberg et al. (1996); Lin et al. (1999)
Suprathermal Particles		
S1: Bidirectional Strahl Electrons		Gosling et al. (1987)
S2: Bidirectional $\sim$MeV Ions	$A_2/A_1 > 1$ [3]	Palmer et al. (1978); Marsden et al. (1987)
S3: Cosmic Ray Depletions	Few % at~ 1 GeV	Forbush (1937); Cane (2000)
S4: Bidirectional Cosmic Rays	$A_2/A_1 > 1$ [3]	Richardson et al. (2000b)

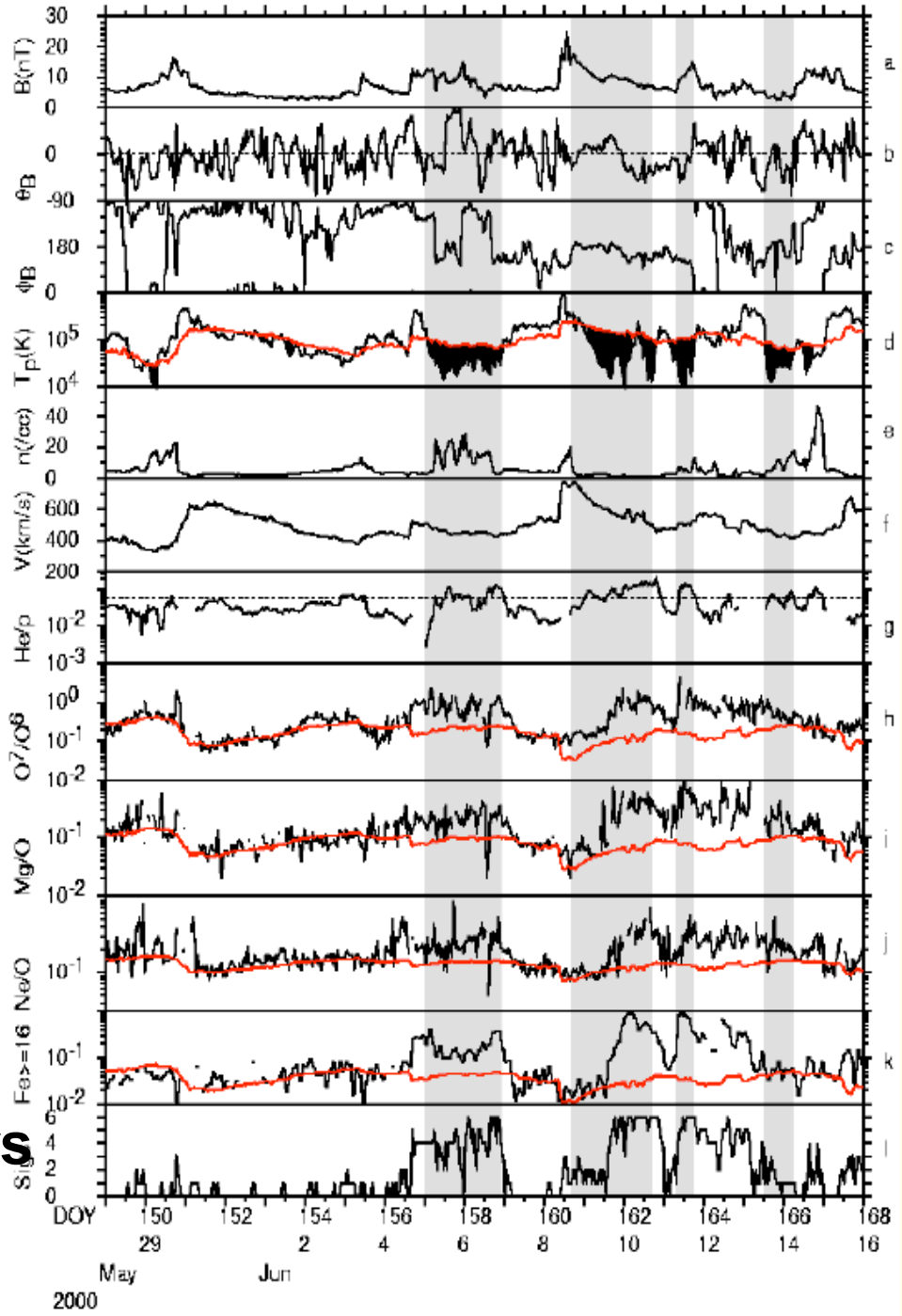

372 eV Electrons
180°
0°
BDE
(a)
(b)
(c)
B(nT)
θB
φB
T(K)
n(/cc)
V(km/s)
He/p
O7/O6
Mg/O
Fe/O
IMP 8 Q Fe
Dst
DOY
Apr
1998
Mar
1999
Oct
2000

6 Nov 2000 : [134.0º, 4.1º, 0.38, -1, 26.5 nT]




B(nT)
θB
φB
T(K)
Tp
Texp
n(/cc)
V(km/s)
He/p
O7/O6
MG/O
Ne/O
Fe>=16
Perc Sig,Sigs
DOY
159
160
161
162
163
164
7
8
9
10
11
12
Jun
2000

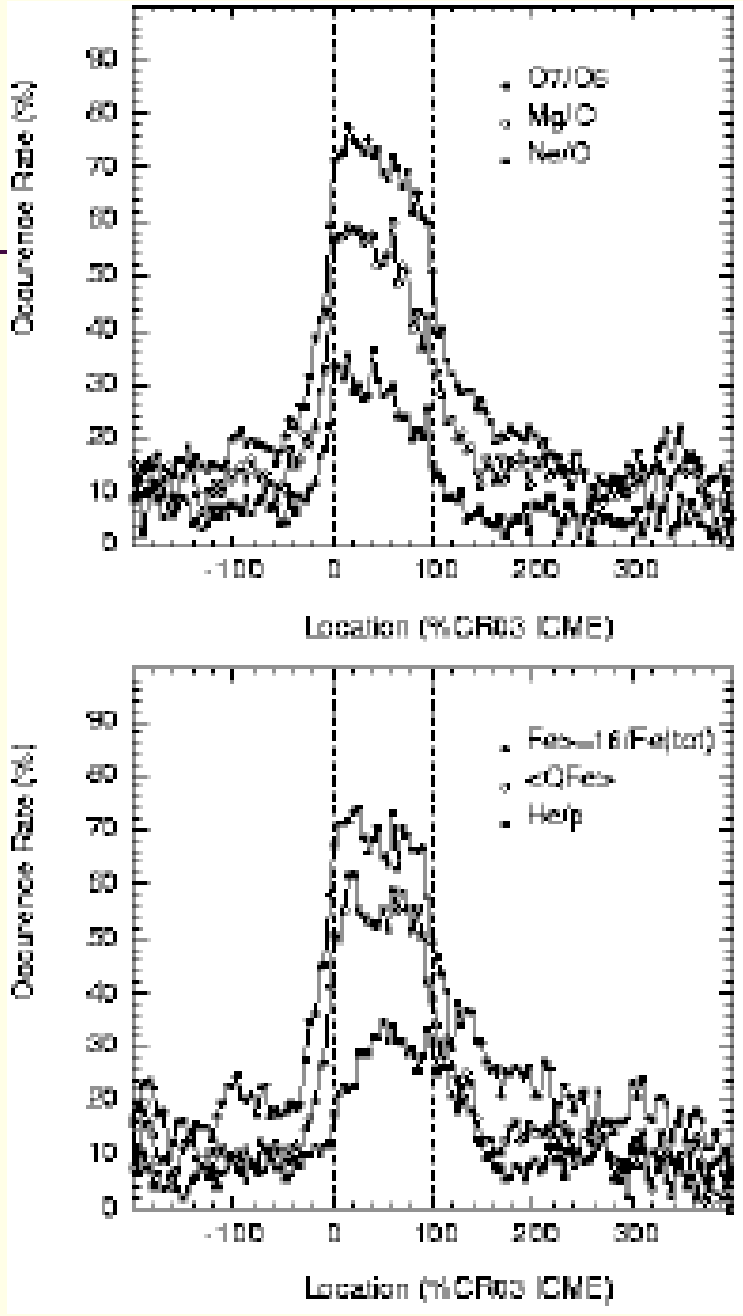
Richardson and Cane, 2004:
Use compositional parameters
Like temperature signature



Occurrence Rate

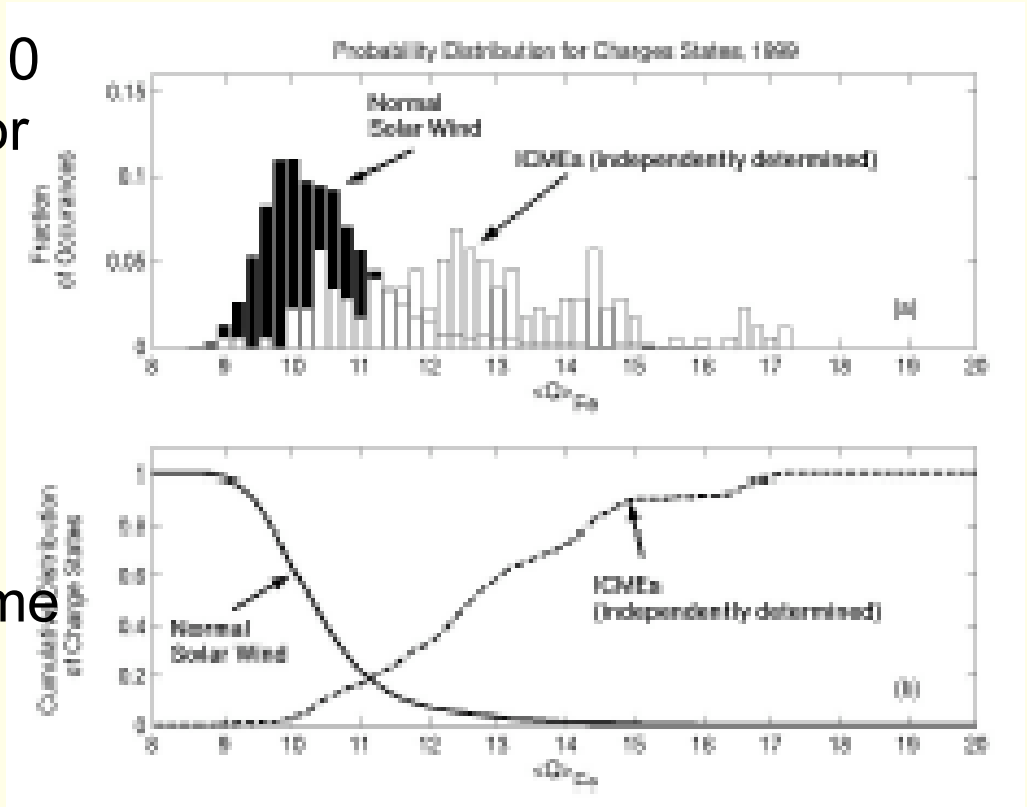
- Charge compositional signatures are very sensitive.
- Best signature are O and Fe charge states.

Richardson and Cane, 2004.



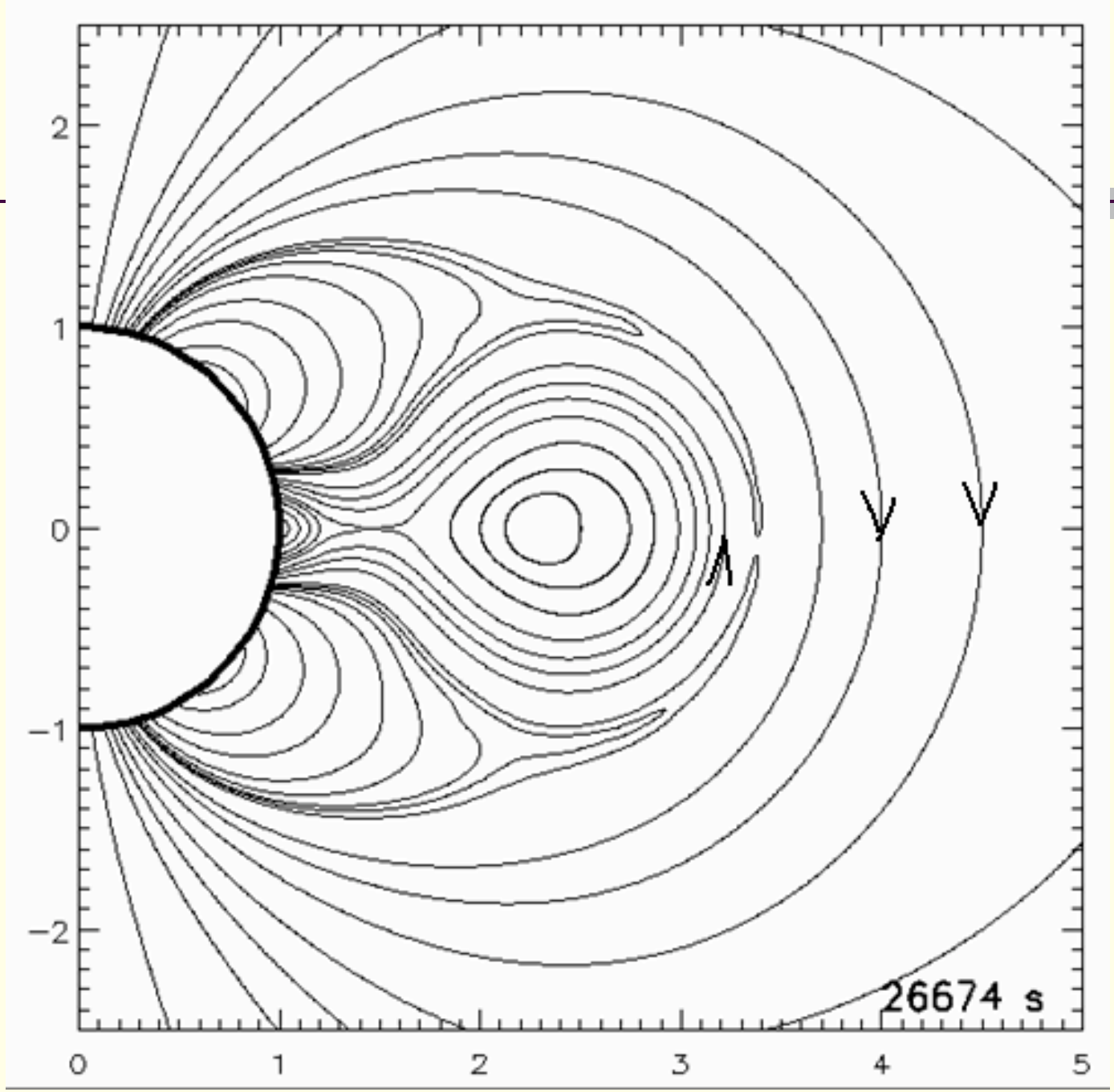
Observations

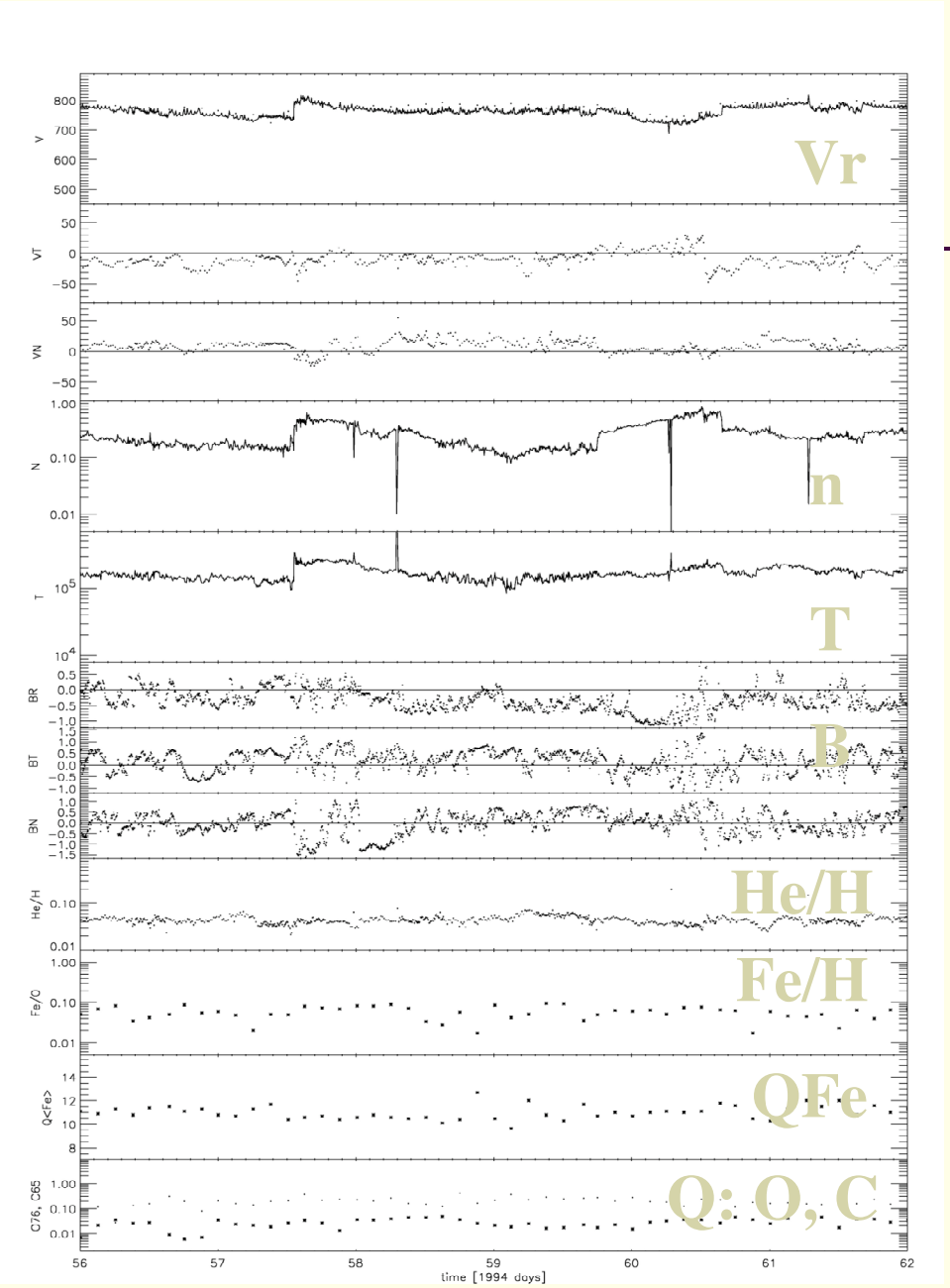
- Lepri et al., 2003
  - 50% of ICMEs have 10 hour enhancements or more.
  - Almost no false identifiers
- But
  - More than 85% of all C&H ICMEs have some heated plasma.
  - But, there are 10% false identifiers



Interpretation: Flare association

- Lepri et al, 2004:
  - There is a strong latitude dependence of Fe charge state enhancements.
  - Also, the probability of enhancement depends of distance from flare.
- Reinard, 2004:
  - Enhancements scale with flare size.
- Also
  - Inverse correlation between freeze-in temperature and local temperature


2
1
0
−1
−2
0
1
2
3
4
5
26674 s


V
VT
VN
N
T
BR
BT
BN
He/H
Fe/O
Q<Fe>
C76, C65
Vr
n
T
B
He/H
Fe/H
QFe
Q: O, C
time [1994 days]

How about these BDEs?

- Reinard et al., 2002
  - There is no notable change of BDE flux from ACE (1 AU) to Ulysses (4 AU)
- Where is all this flux? Estimate
  - Around 15% of time, observe ICMEs at 1 AU, within ~3 days of Sun.
  - If that's not disconnected, we add 4 times that till Ulysses solar wind is there, within, within 12 days
  - If CMEs have, on the average, add the same flux that was already there -> increase of >50% in flux
  - If CMEs have, on the average, add twice the flux that was already there -> Increase of >factor of 2.
- Also, why do we observe BDEs at Jupiter, but no Jupiter electrons at 1 AU.

Challenges

- What is the nature of the observed flare association?
- Thermodynamic state of CMEs and ICMEs?
- Theoretical framework for compositional data. Need quantitative interpretation.