A slow mode transition region adjoining the front boundary of a magnetic cloud as a relic of a convected solar wind feature: Observations and MHD simulations

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STEREO SWG Novmber, 2007 CALTECH

1. AIMS OF THE STUDY

- **Focus: The Ansatz of Siscoe et al.** (2007):

The radial expansion of ICMEs/MCs gives rise to basic differences between ICME sheaths and planetary magnetosheaths.

In particular: Lateral deflection of solar wind in ICME sheaths < lateral expansion of ICME...leading to a pile-up of solar wind structures in front of the ICME. Lead to the **insight** that the ICME-sheath retains of memory of its past encounters and appears as a layered structure.

- Here we give an example corroborating these ideas

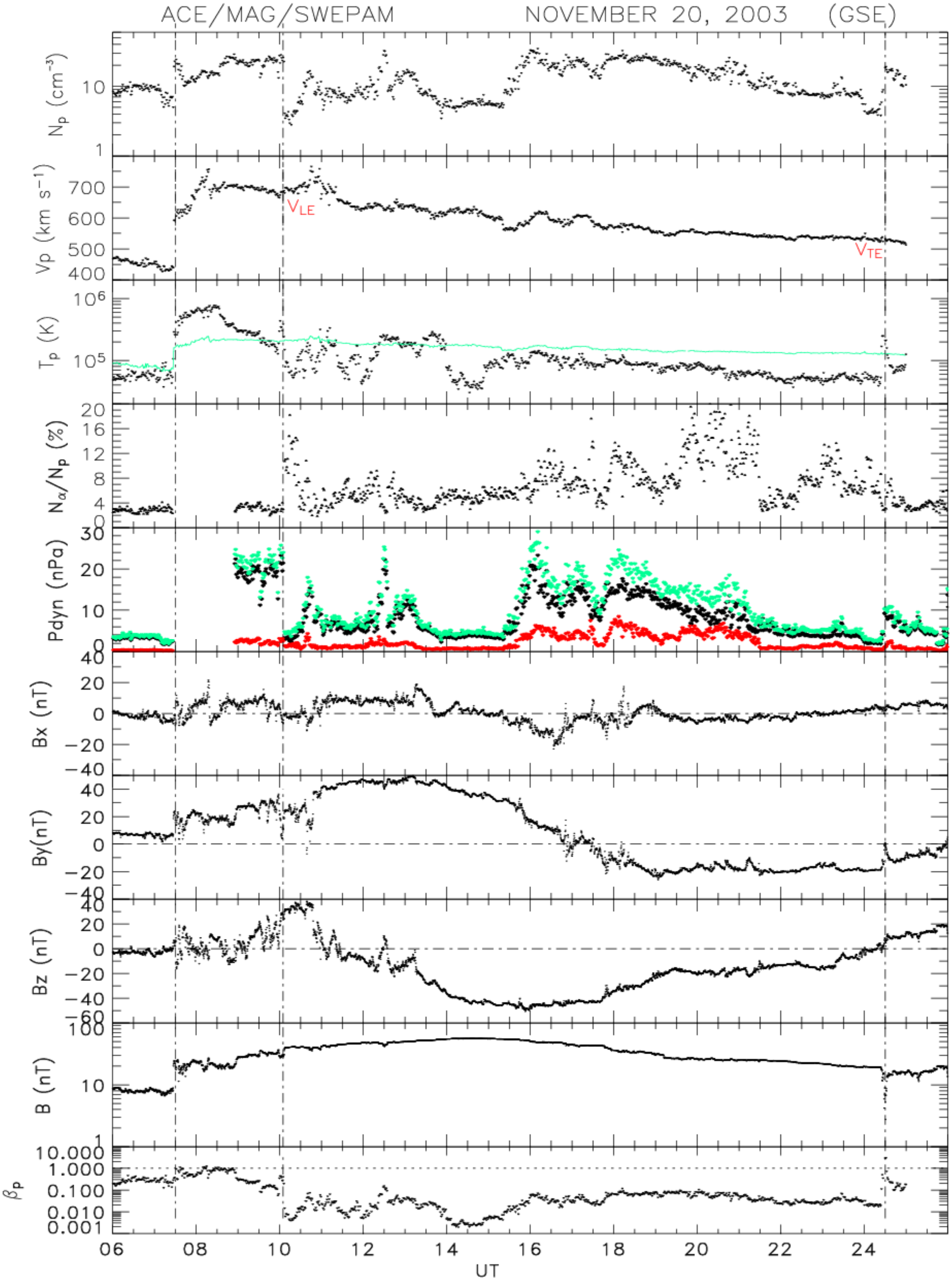
- The structure is planar, tangent to the front boundary of the cloud, and plastered against it.

- Its passage through the ICME-shock and evolution in the sheath is simulated by a 2-D MHD code.

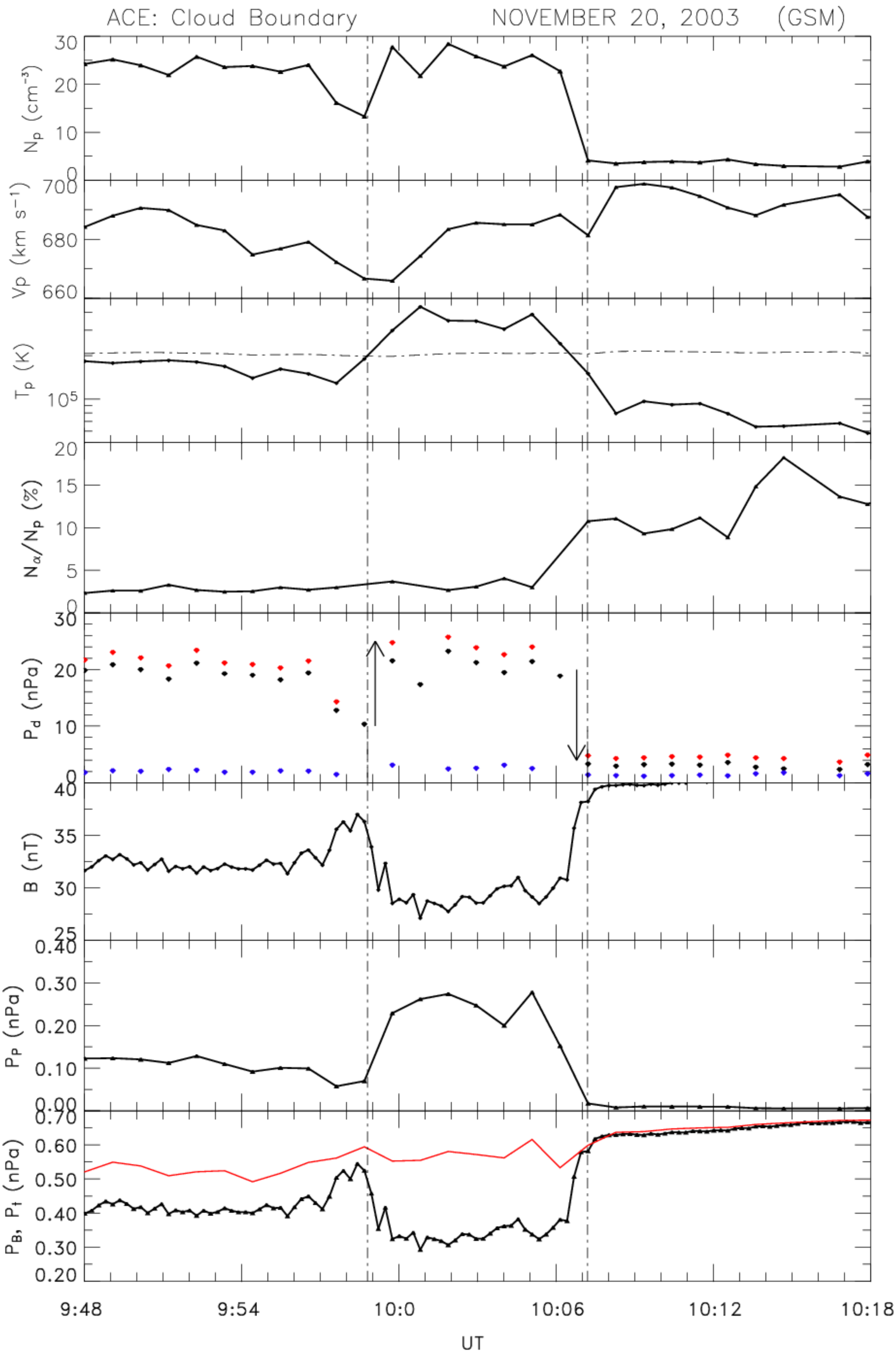
- Under reasonable assumptions, an estimate is obtained of the distance when it was it first crossed the shock.

- The structure we discuss has similarities with so-called ”slow mode transition” in the Earth’ magnetosheath, whose nature (”endogenous”/exogenous”) has been a hotly debated issue.

- Hence an appropriate topic in comparative magnetosheath studies.



ACE/MAG/SWEPAM
NOVEMBER 20, 2003
(GSE)
Np (cm⁻³)
Vp (km s⁻¹)
VLE
VTE
Tp (K)
Nα/Np (%)
Pdyn (nPa)
Bx (nT)
By(nT)
Bz (nT)
B (nT)
βp
UT



ACE: Cloud Boundary
NOVEMBER 20, 2003 (GSM)
N_p (cm^{-3})
Vp (km s^{-1})
T_p (K)
N_α/N_p (%)
P_d (nPa)
B (nT)
P_P (nPa)
P_B, P_f (nPa)
9:48
9:54
10:0
10:06
10:12
10:18
UT

Orientations of Cloud Axis and Normal to Structure

Magnetic Cloud

B. J. Lynch et al., JGR, 2005, "auxiliary material" at ftp://ftp.agu.org/apend/ja/2005JA01137:

Linear least-squares fit to a constant α, force-free magnetic flux rope of circular cross–section: (For **same** interval):

$$\theta \text{ (latitude)} = \text{-86.8}^\circ;\ \phi \text{ (longitude)} = \text{-172}^\circ$$

i.e. axis direction: (-0.055, 0.008, 0.998).

Cloud axis approximately along GSE -Z

(agrees with monopolar variation in B_z [axial field] and bipolar variation in B_y [azimuthal field])

Impact parameter: 0.00 AU

i.e. ACE passes close to the axis of the cloud.

Pressure-balanced Structure

- Our structure is also Planar.

Minimum Variance Analysis:

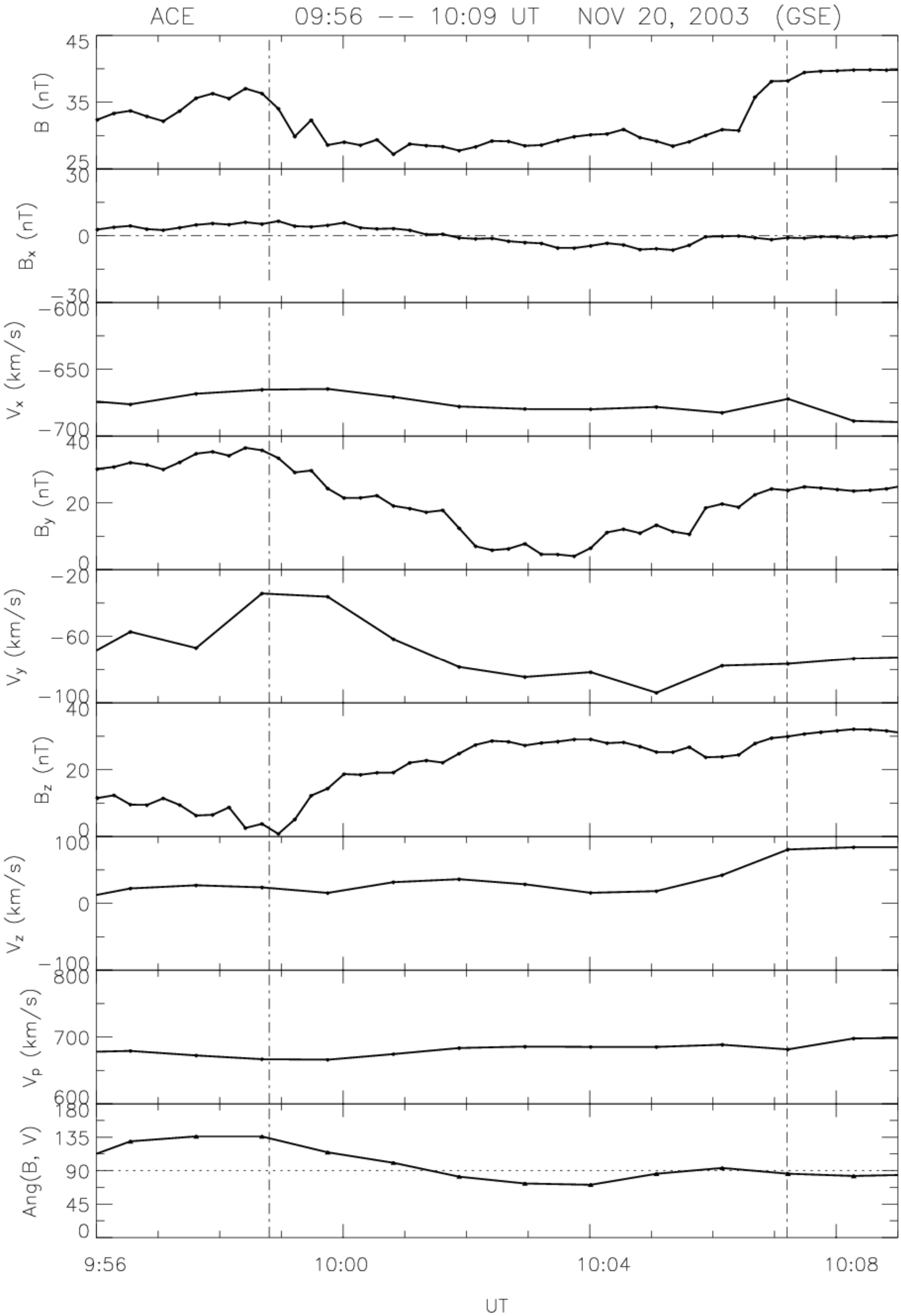
$R = 8.8, \quad \mathbf{n} = (0.97, \text{-}0.20, 0.16)$

(within 15° of GSE X-axis).

Inclination to Parker Spiral direction: $\sim 34^\circ$

Normal points approximately along GSE X.

– – – – – –– >>> Simplified Geometry <<< – – – – – ––



ACE 09:56 -- 10:09 UT NOV 20, 2003 (GSE)
B (nT)
Bx (nT)
Vx (km/s)
By (nT)
Vy (km/s)
Bz (nT)
Vz (km/s)
Vp (km/s)
Ang(B, V)
9:56
10:00
10:04
10:08
UT

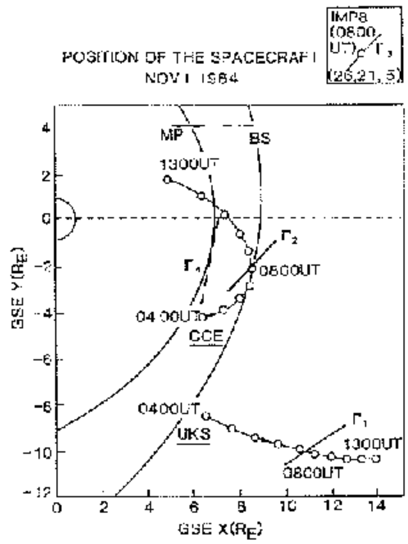


Fig. 2. The GSE-XY plane indicating the locations of the spacecraft in our study (IMP 8 shown in the inset). The positions of the bow shock (BS) and magnetopause (MP) are also shown.

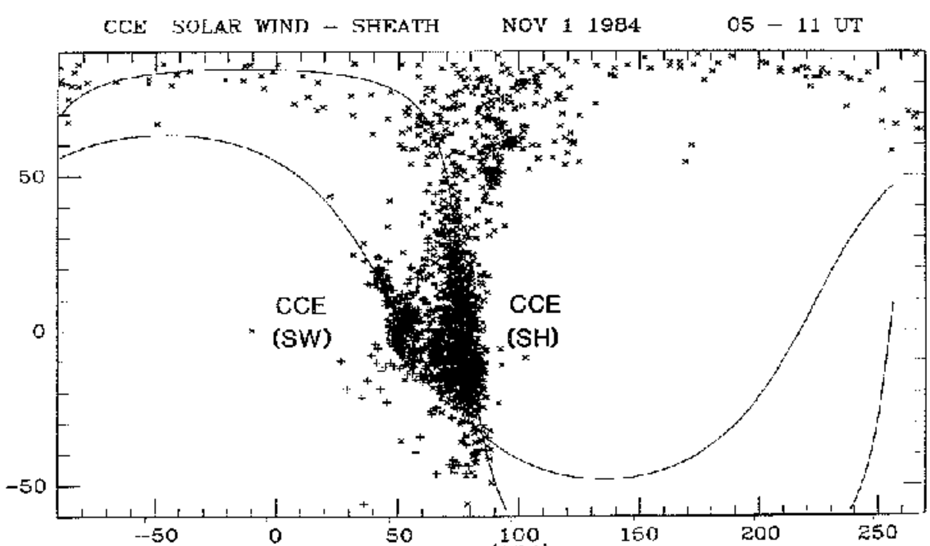


Fig. 5. Scatter plots of the field latitude vs the field longitude. The '+' symbols refer to the UKS and the '×' symbols refer to the CCE. The curves are model curves and are obtained using the coordinates of the respective normals in Table 1.

From Farrugia et al., J. Atmos. Terr. Phys., 1991

2. **Interim Summary 1**

• We identify a planar, pressure-balanced structure bounded by sharp changes in the dynamic pressure contiguous to the front boundary of the magnetic cloud which passed Earth on November 20, 2003.

• The front boundary of the magnetic cloud (MC) is particularly well-defined in this case, being located where the He^{++}/H^{+} number density ratio jumps from ~4 to ~10 % for the first time and the proton plasma beta decreases sharply from ~1 to ~0.001.

• The feature, estimated to have a length scale ~50 R_E in the Sun-Earth direction, bears close resemblance to a slow mode transition region in that P_B decreases, P_p increases, and the temporal variations of these quantities are anti-correlated.

• Simple geometry suggested by the observations and modeling:

Lateral flow deflection speed $\approx$ 70 km s^{-1}.

Lateral expansion speed of the magnetic cloud $\equiv 1/2(V_{LE} - V_{TE}) \approx$ 85 km s^{-1}.

MHD Simulations

• Track the progress though MC-sheath of a plausible solar wind structure. How “old” is the structure (lower limit)?

• Field and plasma assumed to satisfy ideal MHD equations.

• Geometry: That of a circular cylinder. At the boundary of the cloud the normal components of magnetic field and of the plasma velocity assumed to vanish.

• Use a finite-difference scheme.

• Work in a coordinate system comoving with the cloud.

• Initially, shock position and flow parameters initially obtained from a preliminary calculation of the flow around a straight circular cylinder for Mach numbers determined from using the speed of the cloud w.r.t upstream solar wind as seen at 1 AU.

• Initial perturbation: A pressure - balanced structure with very smooth variations in pressures. **Figure**

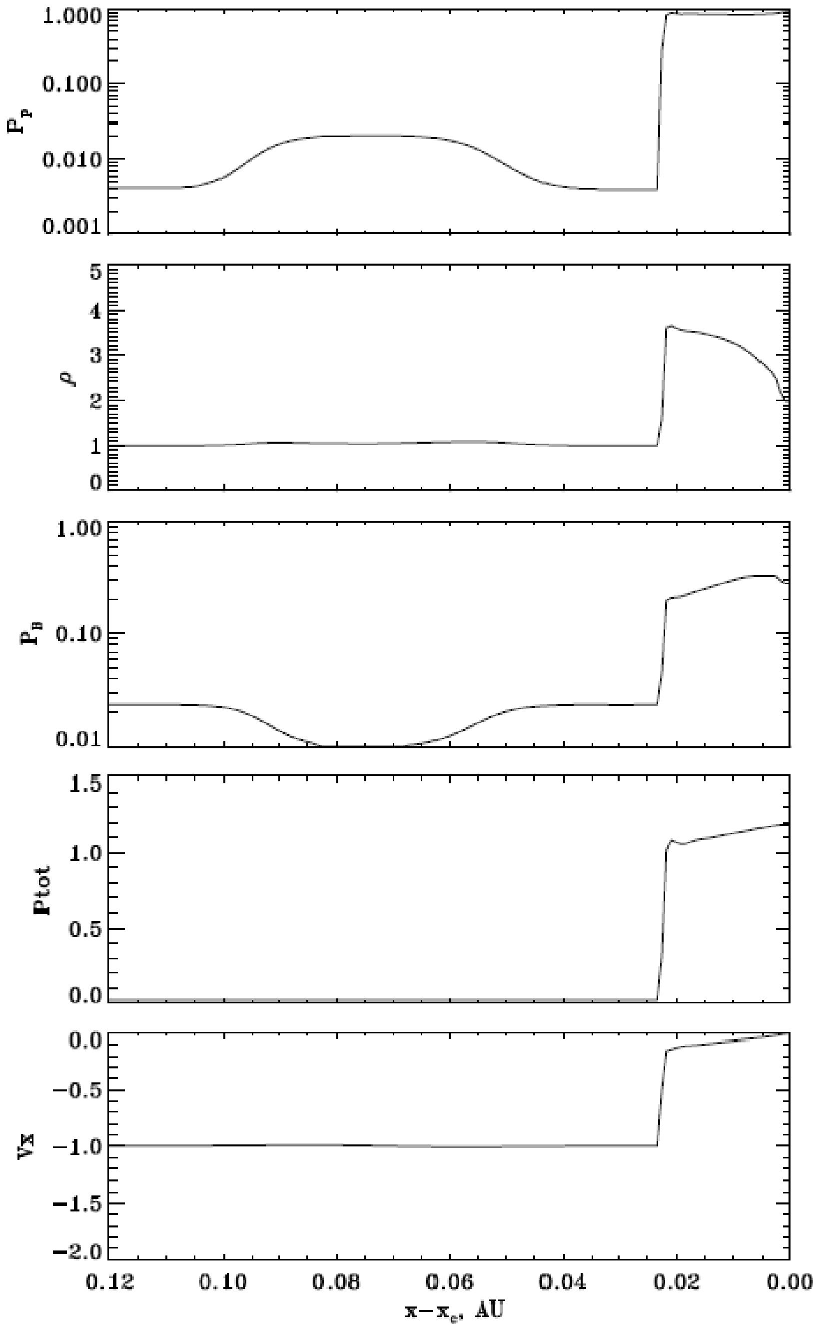
• Perturbation steepens as it proceeds and stays in approximate pressure balance.

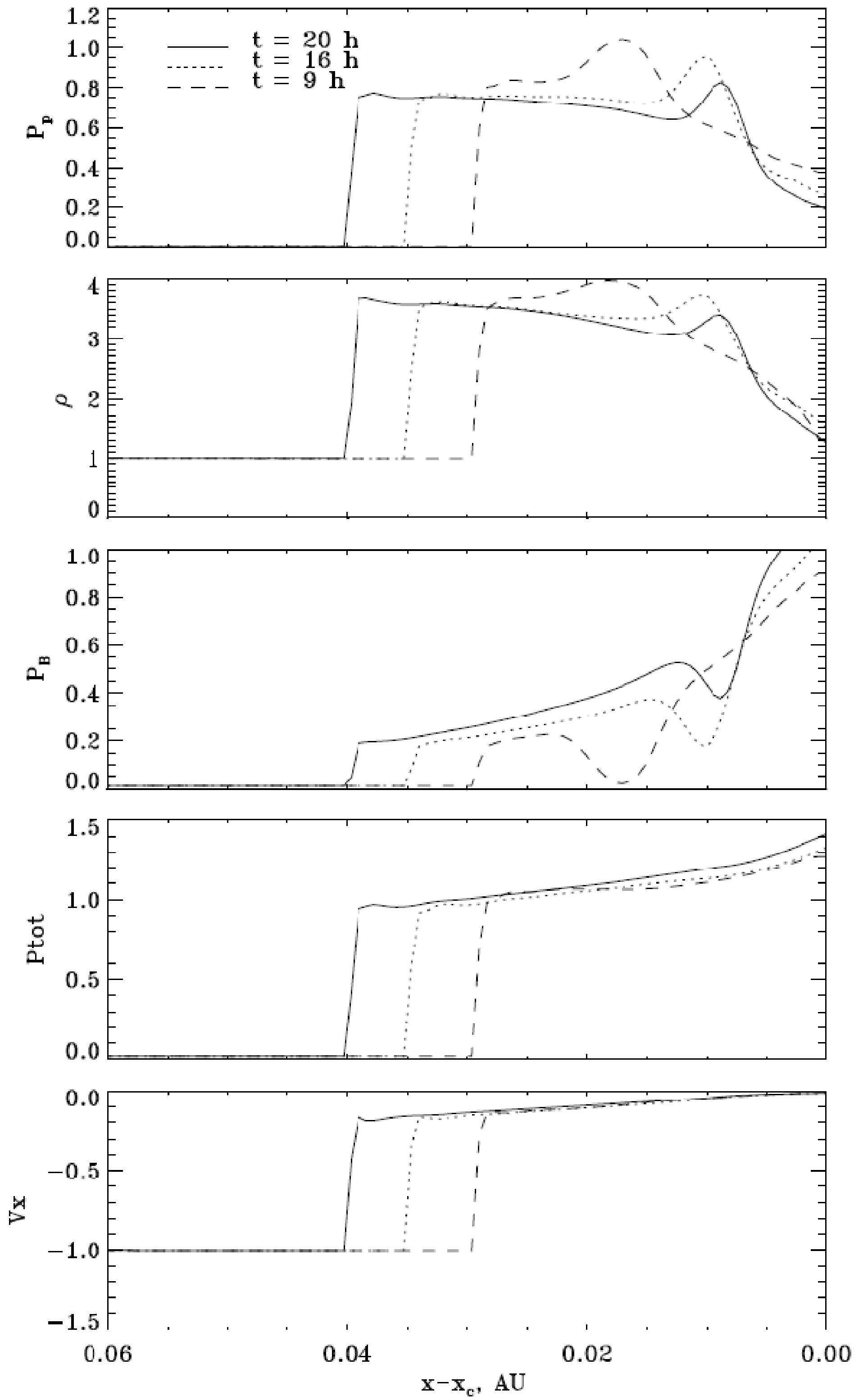
• Slow evolution near cloud boundary.

There is outward motion of shock (expansion of sheath)

Qualitative agreement with the observations

“**AGE**”: Calculations show that perturbation about <u>20 hours</u> to reach front boundary of cloud, i.e. it crossed the shock **at least** 20 hours prior to observation at 1 AU (in a 47-hour total passage of cloud from Sun to Earth).


1.000
0.100
0.010
0.001
P_p
5
4
3
2
1
0
ρ
1.00
0.10
0.01
P_B
1.5
1.0
0.5
0.0
Ptot
0.0
−0.5
−1.0
−1.5
−2.0
Vx
0.12
0.10
0.08
0.06
0.04
0.02
0.00
x−x_c, AU


t = 20 h
t = 16 h
t = 9 h
P_p
ρ
P_B
Ptot
Vx
1.2
1.0
0.8
0.6
0.4
0.2
0.0
4
3
2
1
0
1.5
0.5
−0.5
−1.0
−1.5
0.06
0.04
0.02
0.00
x−x_c, AU

Interim Summary 2

• Investigated a pressure-balanced structure/entropy wave as a plausible interplanetary source of this structure.

• Used a 2-D MHD simulation and reasonable assumptions to follow its passage and evolution in the MC-sheath

• Our calculations reproduce qualitatively the major features of the observations.

• We infer that this encounter occurred at a heliospheric distance of about 0.6-0.7 AU.

• The finding is consistent with the recent paradigm according to which solar wind plasma and field tend to pile up in front of the ejecta because the radial expansion of the ICME hinders the shocked solar wind plasma from deflecting effectively around the object.

• There are other features of the observations we could include, such as the temporal change in the IMF.

(see also *Erkaev, Farrugia, Biernat*, Plan. Space Sci., 51, 745-755, 2003.)

3. CONCLUSIONS

• Elaborated a data example corroborating the Ansatz of Siscoe et al. (2007):

• We investigated a well-defined, planar structure in approximate pressure balance plastered against the front boundary of a MC.

• Simple geomtry. We find: Indeed, lateral deflection speed < lateral expansion speed of ICME.

• Evidence of draping: (1) structure tangent to the ICME front boundary; (2) angle with Parker spiral = 57°; Also departures from draping.

• Structure had slow mode characteristics.

• 2-D MHD simulation where we input a smooth pressure-balanced structure (common in the solar wind)....model its passage and evolution in the sheath ... estimate it was convected into the ICME sheath at ~0.6 –0.7 AU.

• Interesting Point in comparative magnetosheath studies:

In magnetosheath of Earth and Jupiter: SMT (*Song et al.*, 1990, 1992) standing in the flow. Average size = 0.4 R_E. **Much contested**: Endogenous or exogenous ?

A body of evidence in favor of exogeneous (i.e. a convected feature). So here we **establish a juncture** with this line of research.

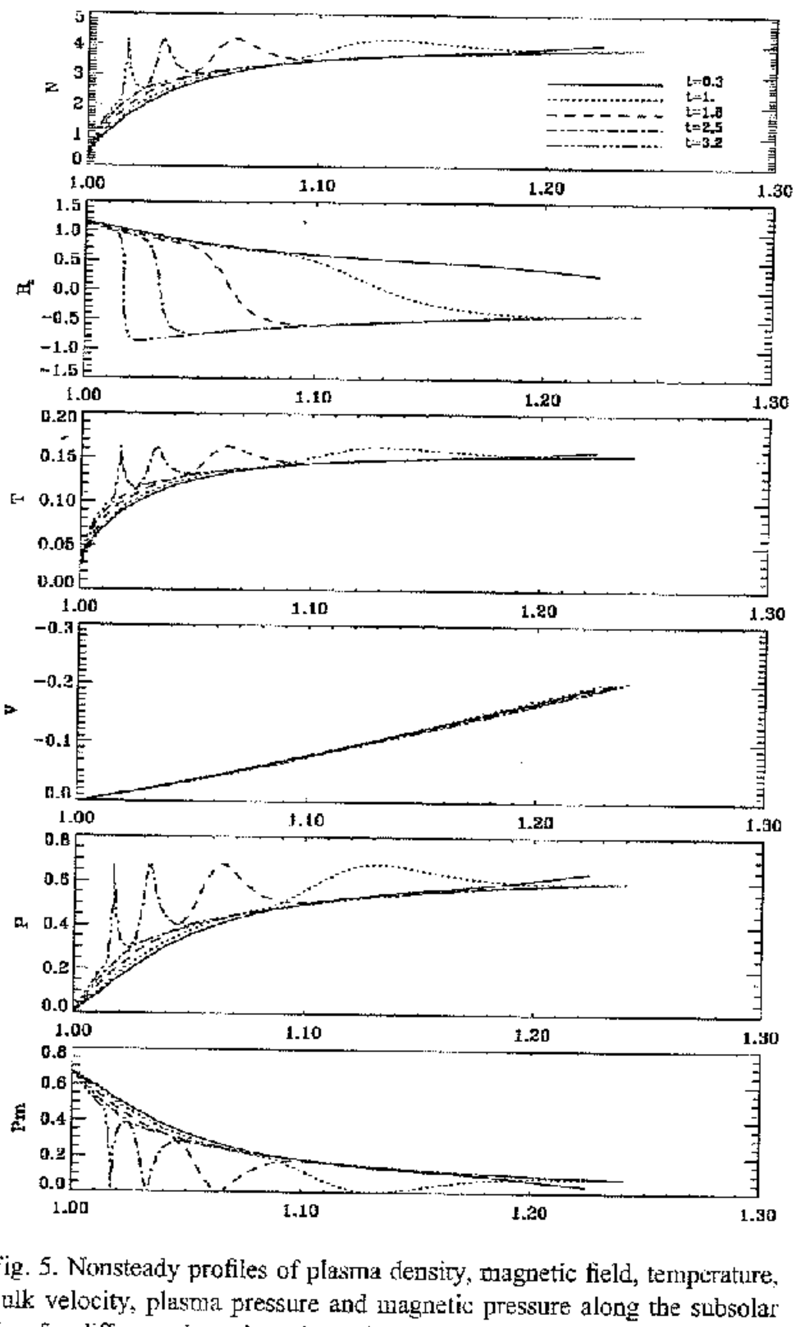


Fig. 5. Nonsteady profiles of plasma density, magnetic field, temperature, bulk velocity, plasma pressure and magnetic pressure along the subsolar line for different times in units L_0/u_∞ in a case of IMF variations from north to south.