Deep Solar Activity Minimum 2007-2009: Solar Wind Properties and Major Effects on the Terrestrial Magnetosphere

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Outline

- Temporal variations and frequency distributions of solar wind and IMF parameters in 2007-2009
  (*STEREO-A*)
- Which parameters changed most vis à vis last minimum ?
- Two aspects of their effects on magnetospheric dynamics:

(A) Estimate of cross-polar cap potential (CPCP) in its dependence on interplanetary parameters, i.e. dayside source of plasma convection in the magnetosphere.

(B) Shapes and location of Magnetopause and Bow Shock
(*Geotail*, *Cluster 1*, *THEMIS B* and *C*)

- Compare with *Fairfield's* classic results and two other Models (*Sibeck et al*., 1991; *Shue et al*., 1998)

It was 20 years ago today !

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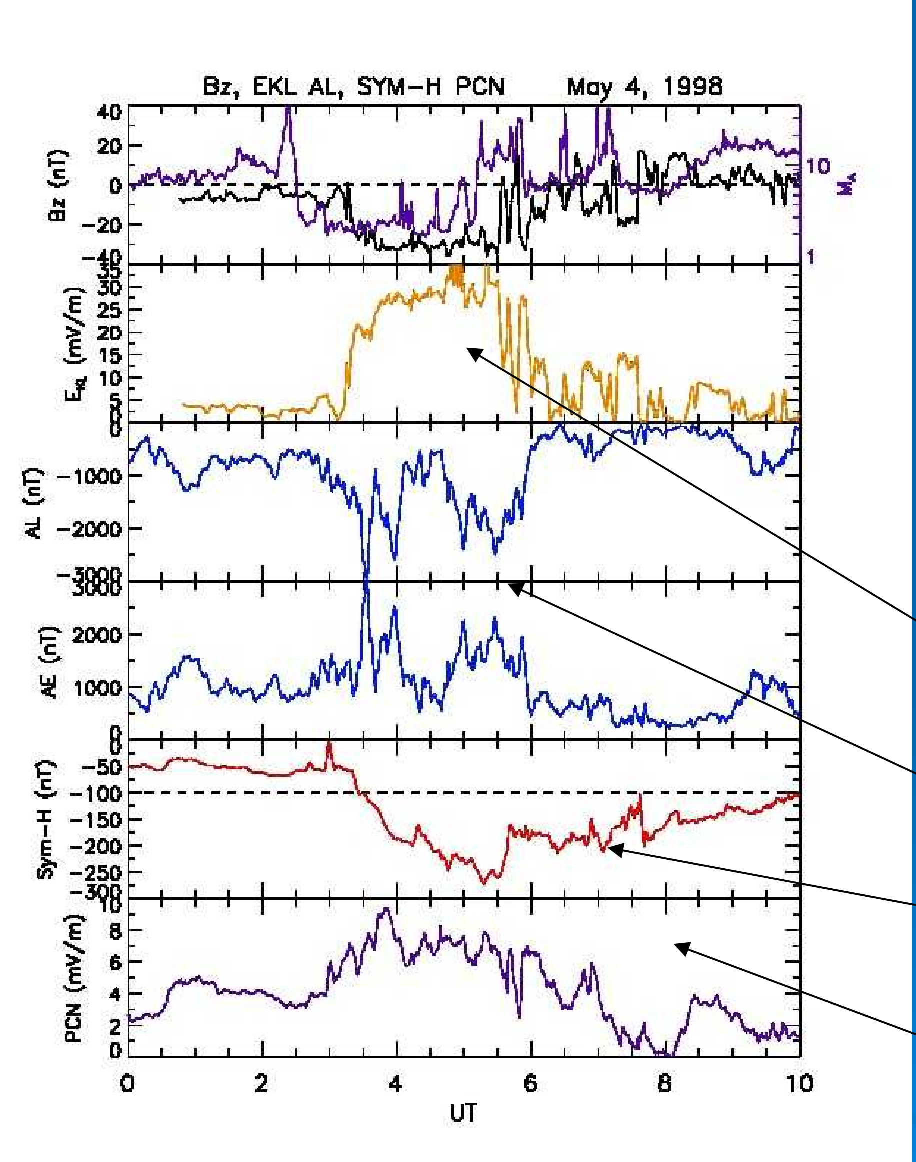
May 4, 1998



MASSIVE

Power to the Magnetosphere !

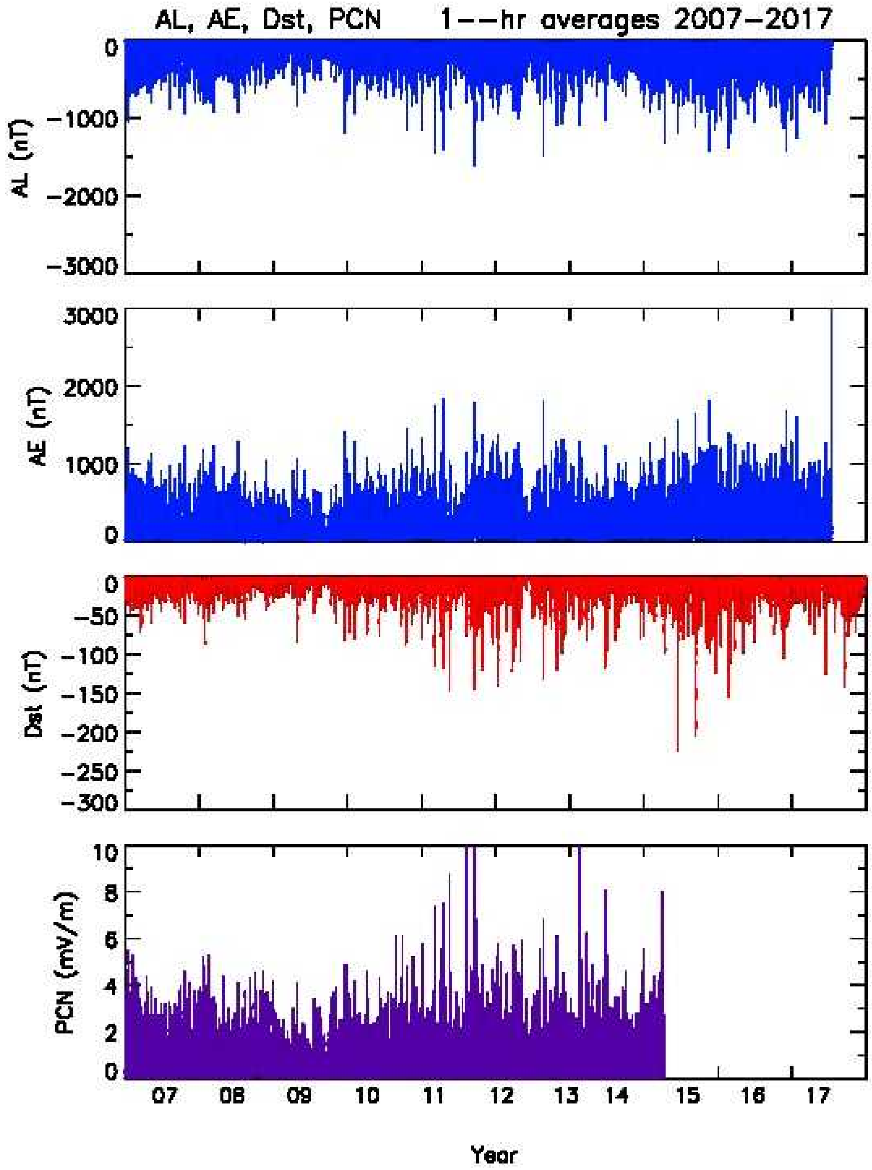
1. **Bz** reaches almost -40 nT
2. **MA** ~2-3
3. **Ekl** reaches 35 mV/m
4. **AL** index reaches -3000 nT
5. **SymH** goes to -250 nT
6. **PCN** index ...reaches 10.

Reconnection E-field (*expect saturation of CPCP*)

Auroral Electrojet Indices

Great Storm

Strength of ionsospheric convection



11-year Period: 2007--2017

Same scales !

Levels of May 4, 1998

not reached !! …

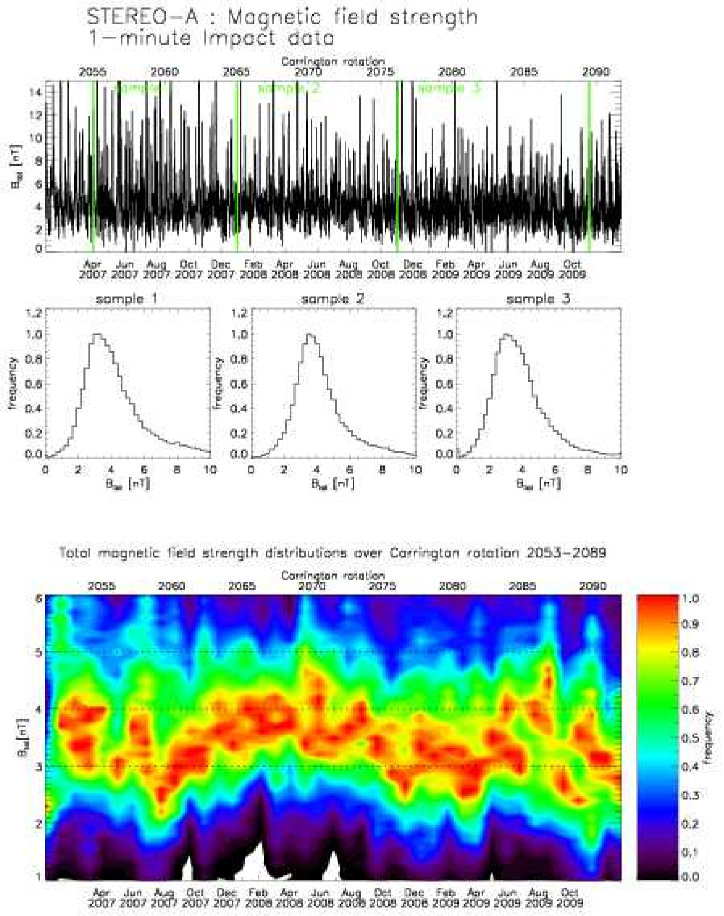
Not even remotely !

Temporal variations and frequency distributions of solar wind and IMF parameters in 2007-2009

(viewpoint: STEREO-A IMPACT/PLASTIC)

Some Key Parameters

B



Temporal profile

(1 min res.)

Frequency Distribution

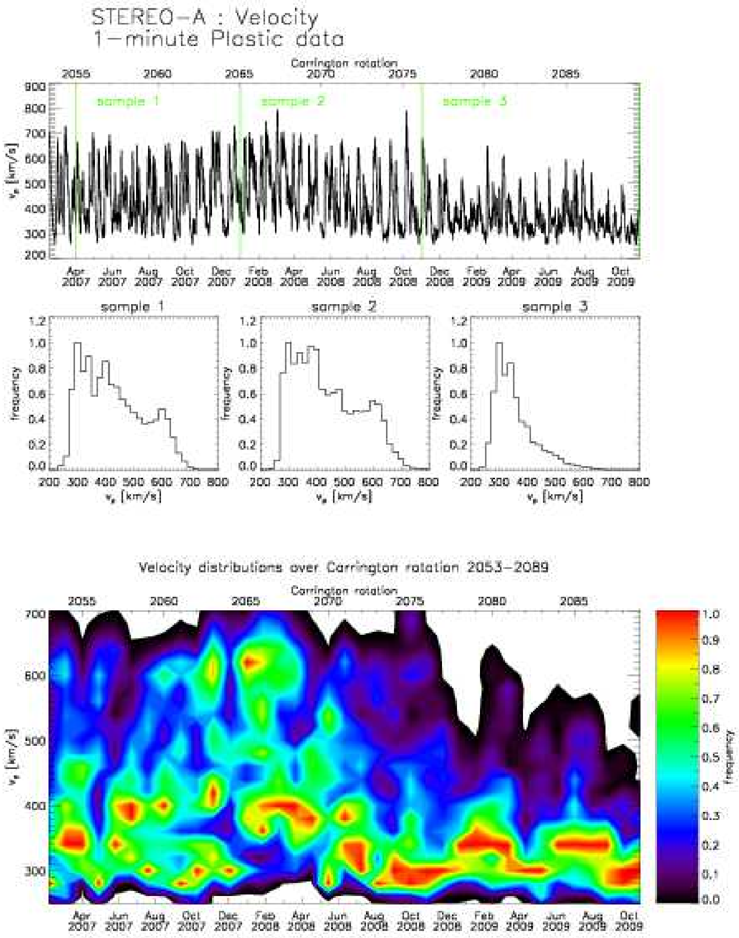
Spectrogram of the distribution arranged by Carrington rotation and month/year

Subdivision into 3 time samples: arbitrary but helps follow evolutionary trends

--<u>Distributions</u>:
Skewed to left and exhibit long tails.
-- Not Gaussian: log-normal
--Most probable values ~2.5--~4.5 nT

LOW !

V



-- Multiple peaks in S1 and S2

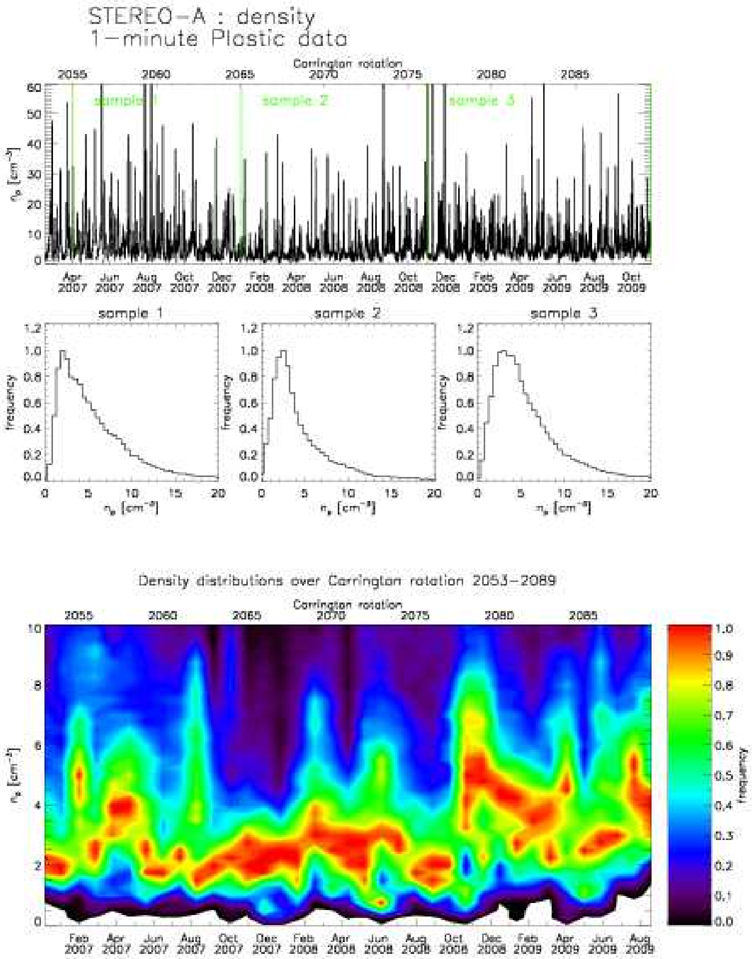
--Time profiles in S1 and S2 indicative of a succession of alternating slow and fast streams with associated CIR/SIRs.

-- *Au contraire*, *V*-profile in S3 more spiky and over a restricted range.

--- Two-peak structure in S3 centered in slow solar wind.

--- These two V-peaks at low V seem to persist throughout the whole period.

--- Expect: *Stream-stream interactions where slow stream overtakes an even slower stream.*



N

-- Distributions strongly skewed to left and have long tails.

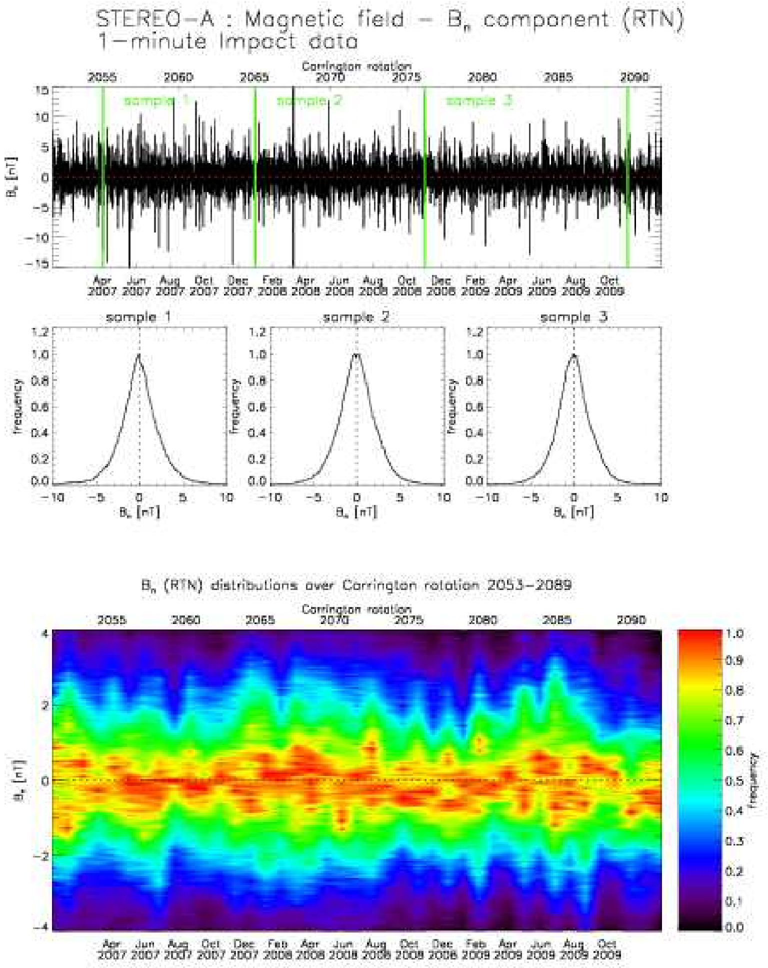
-- Maxima are reached at very low values.

-- Most probable values:

S1: 1-5; S2: 1-4; S3: 2-6 cm^{-3}

LOW !

B_N



-- Distributions are similar and each may be modeled by a Gaussian distribution clustered around 0 nT.

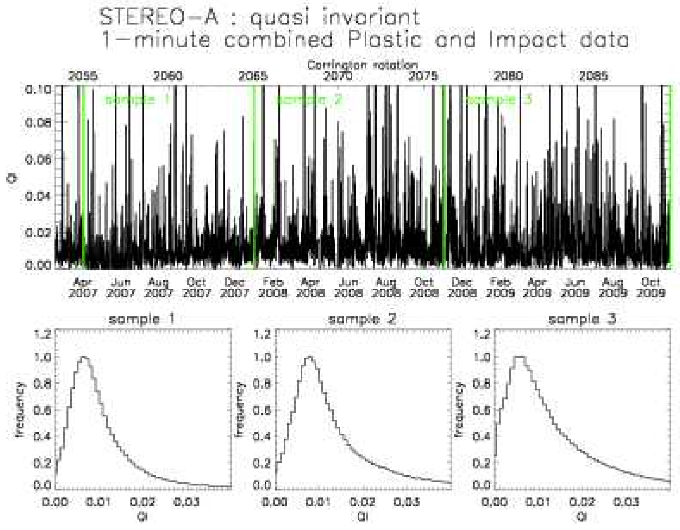
-- Narrow profiles…

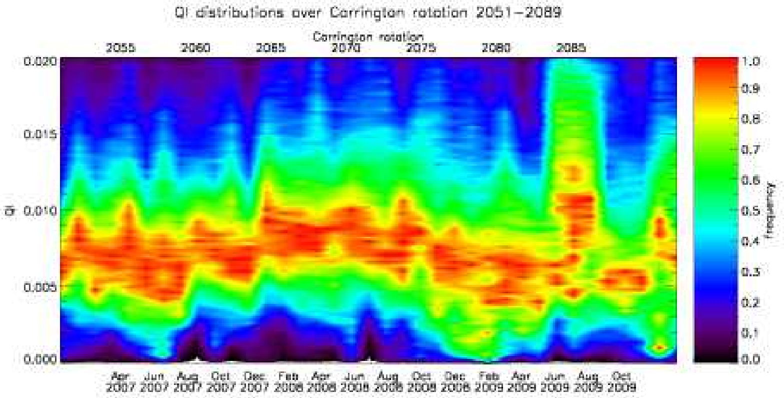
~ (-1.5 nT to 1.5 nT)

-- E_{KL} reconnection electric field !
= 0.28 mV/m < ½ value in
2001-2003

--- Suggest: *Reconnection processes were not a dominant aspect of SW-Msphere interactions.*

Solar Wind Quasi-Invariant





QI

Ratio of magnetic-to-kinetic energy densities.

Correlates very well with solar activity as given by the sunspot number…*Osherovich et al*. (1999), *Fainberg and Osherovich* (2002), *Leitner et al*. (2005)

$QI = 1/M_A^2$

Here: [0.004, 0.010]   i.e
M_A range: [15.8, 10]….

(higher than typical values in the solar wind at 1 AU).

Interim Conclusions

- *N* and *B* significantly weaker than in the previous minimum

- The Alfvén Mach number was higher than typical.

This reflects the weakness of MHD forces and has a direct bearing on the solar wind—magnetosphere interactions

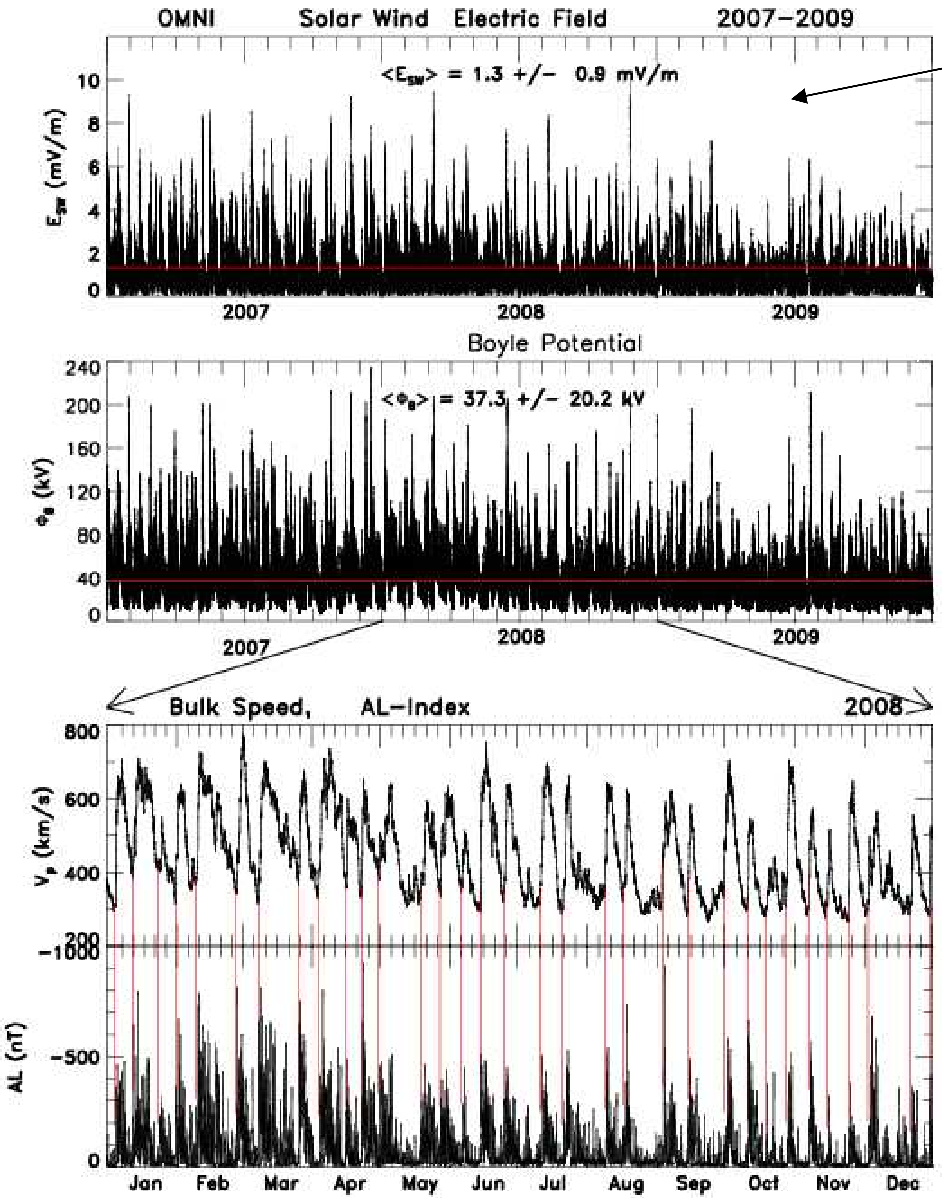
NOW:

(A) The dayside contribution to the cross-polar cap potential (CPCP)

(B) The shapes of the magnetopause and bow shock.

Cross-Polar Cap Potential: Dependence on interplanetary parameters

(Dayside source of plasma convection in the magnetosphere)



Solar wind electric field:

LOW ! (no saturation..typically
At 6-8 mV/m)
Justifies use of empirical (DMSP)
formula for CPCP (*Boyle et al*. 1997

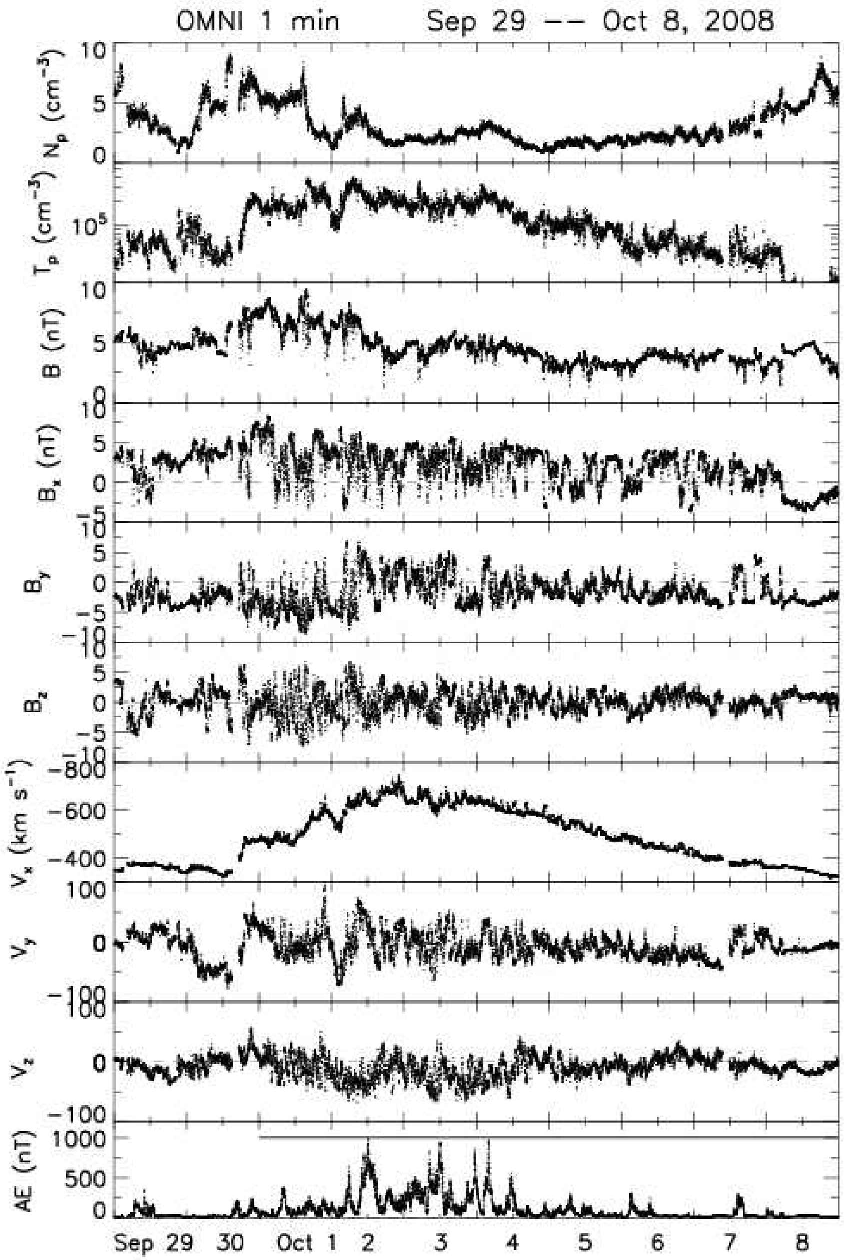
Gives the contribution to CPCP
which is dependent on solar wind
parameters…i.e. the dayside source

Typical CPCP: [40, ~80] kV....**LOW**

--Practically a 1-1 correspondence
between AL intensifications and
CIRs/SIRs

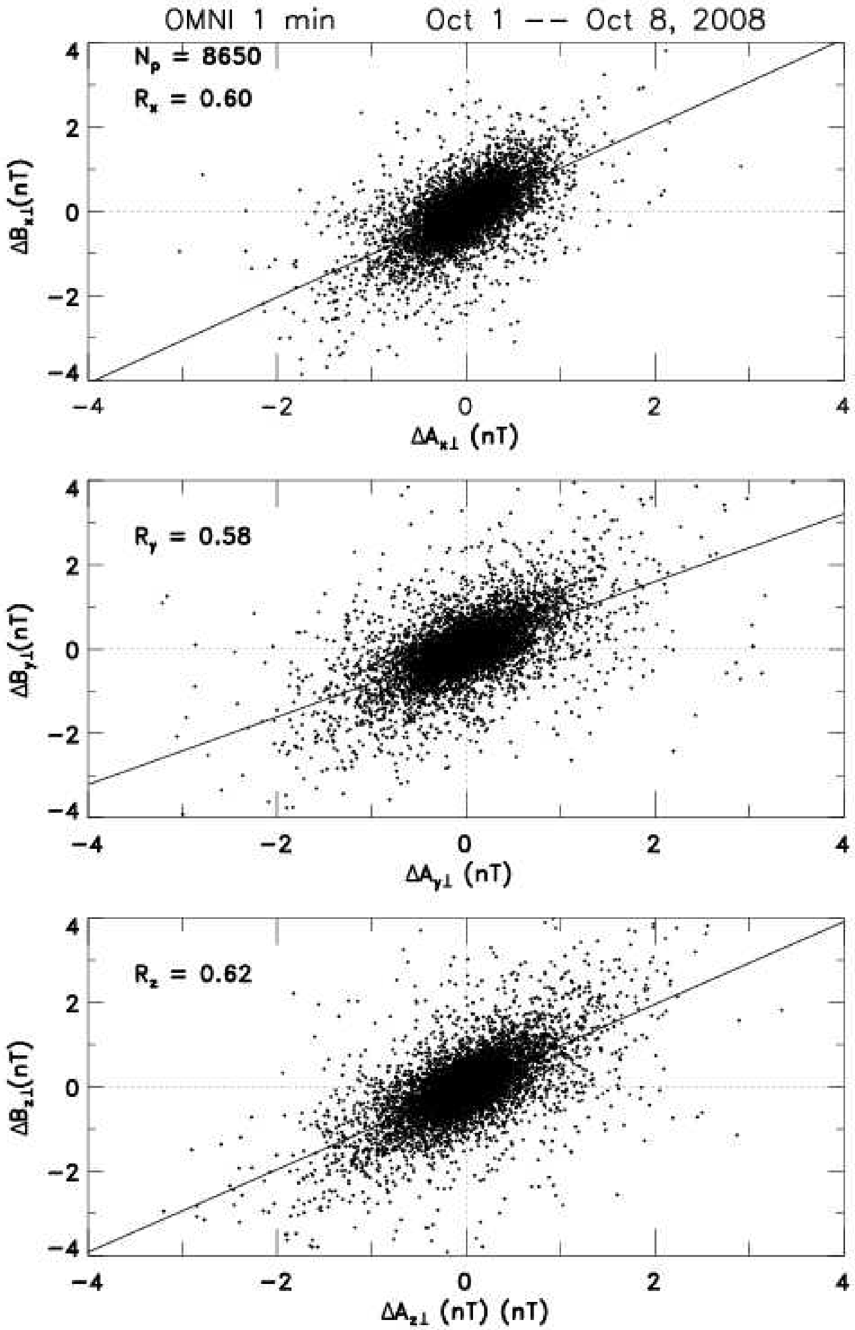
<u>Suggests:</u>
That part of msphere driving due to reconnection comes from <u>Alfvénic fluctuations</u> in fast streams.

Two examples of Alfvénic fluctuations, each lasting for several days



Average Bx > 0:
sunward

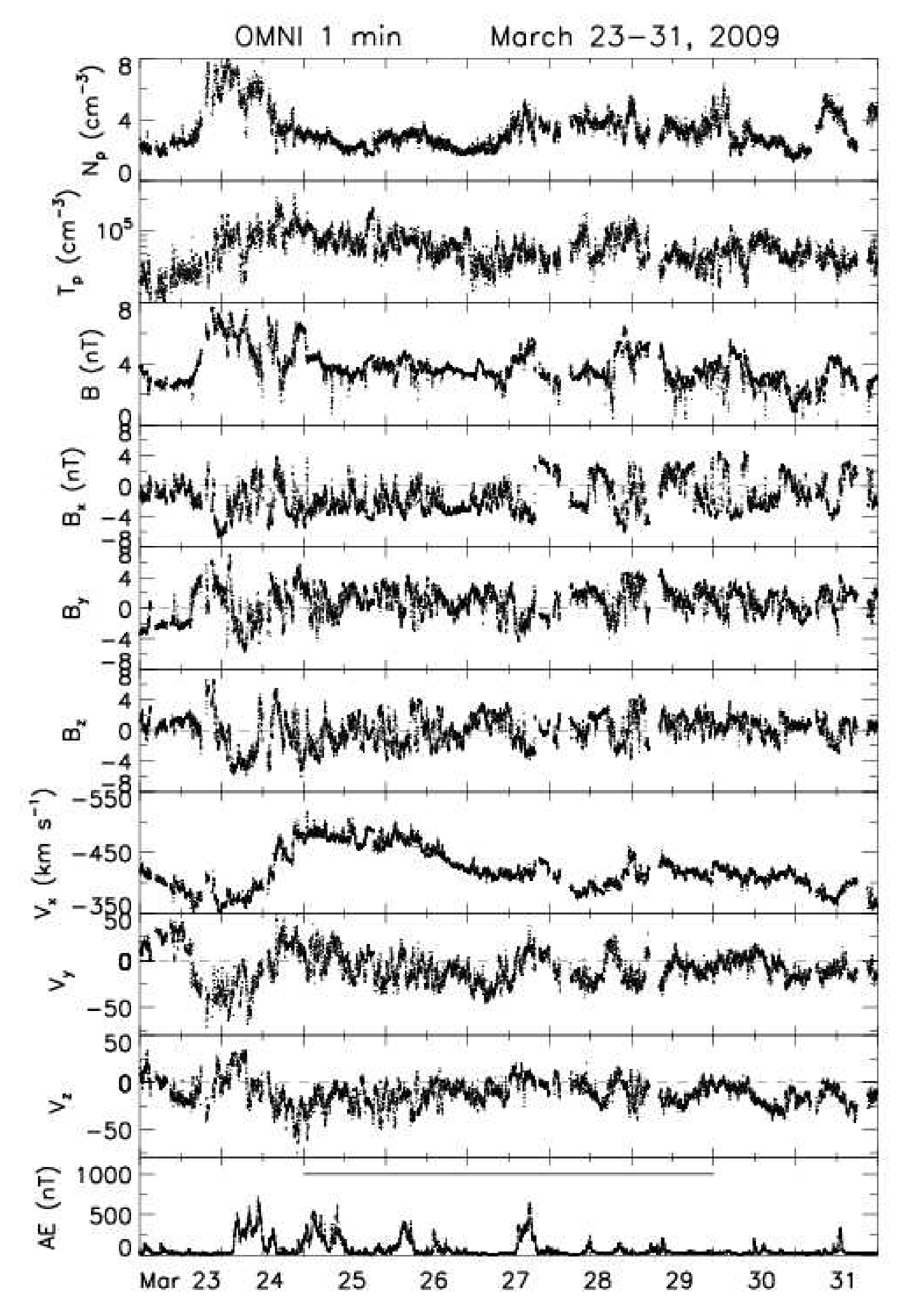
Expect positive correlation if the waves are traveling anti-sunward !



$$\Delta \mathbf{B}_\perp = (\sqrt{\mu_0 \rho})\, \Delta \mathbf{V}_\perp$$

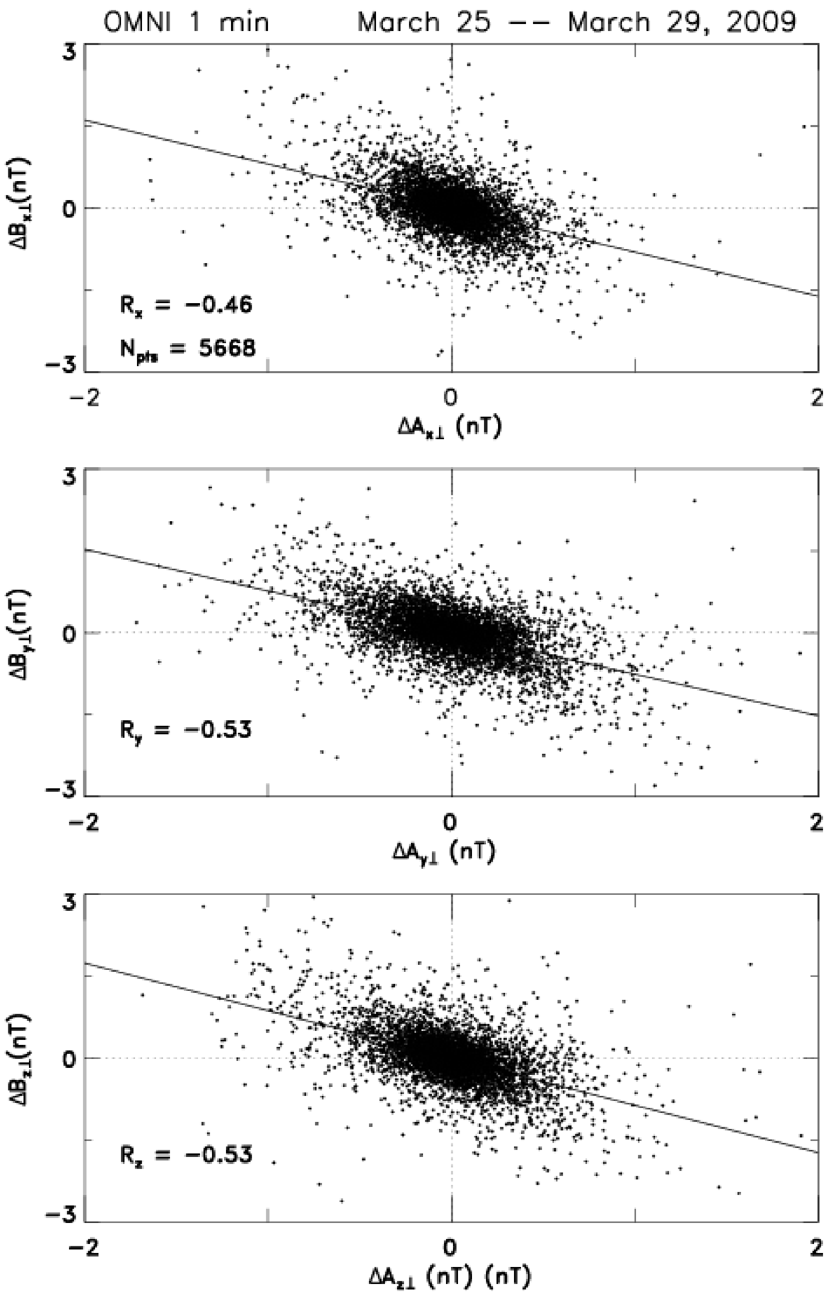
Average background Bx > 0

Waves traveling anti-sunward



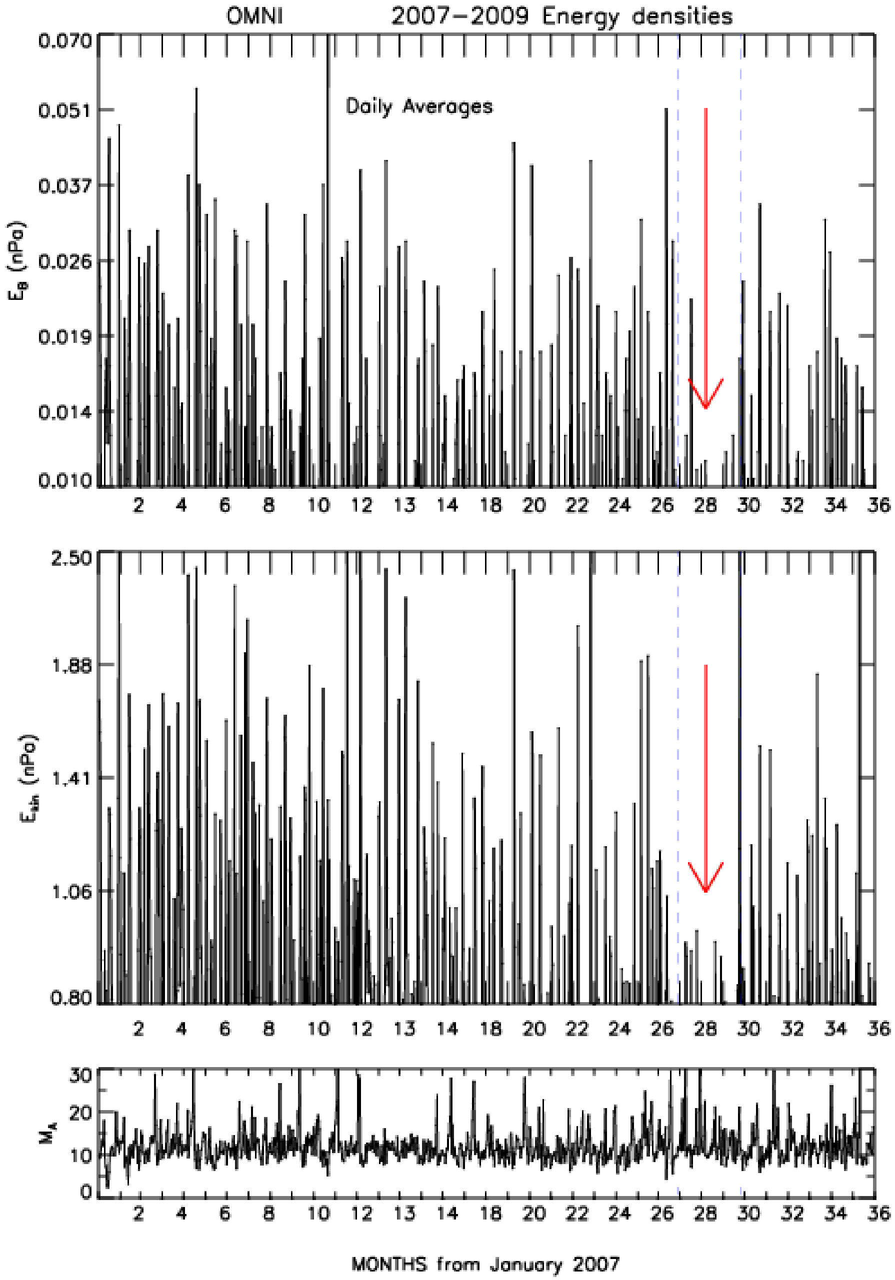
Average Bx < 0 nT
(antisunward)

Expect negative correlation
for anti-sunward propagating
waves.



Waves travelling antisunward

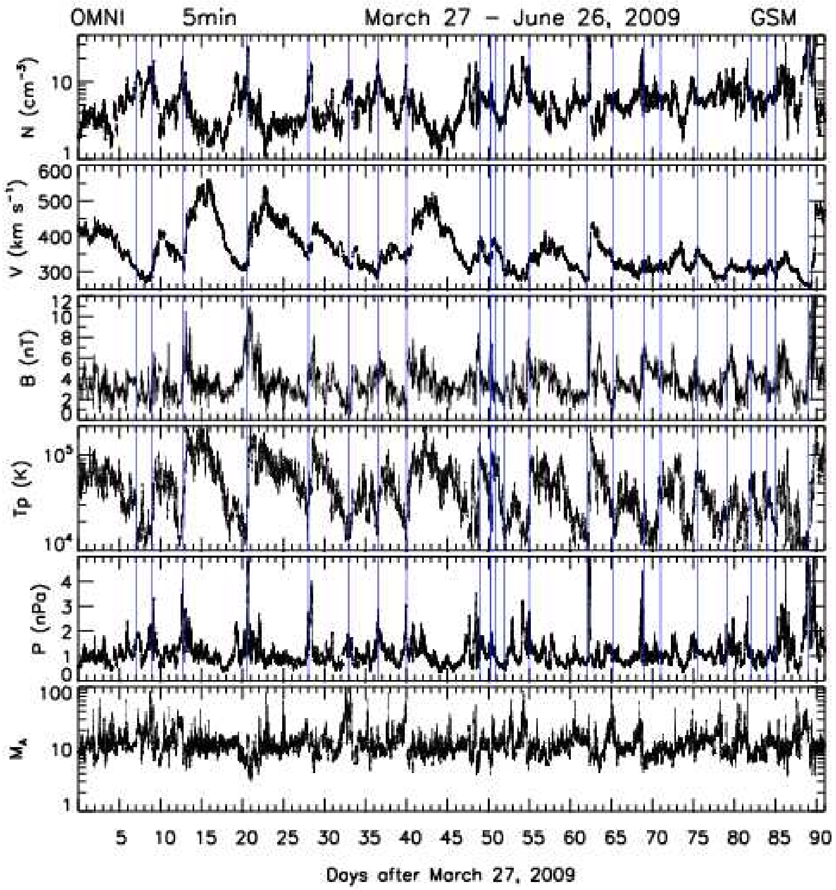
Shape and Location of the Magnetopause and Bow Shock



NOT for all three years !

Rather, for a ~ 3-month period in 2009 (red arrows)

Interplanetary parameters
From *Wind* for this period



Fast streams are hot and tenuous !

Needed to:

(1) Correct the crossings data for aberration due to motion of Earth around the Sun.

(2) Construct two model magnetopauses.

•--- compiled 328 magnetopause and 271 bow shock crossings

•--- crossings on both sides of noon

•--- in X ε [-20, 15] R_E

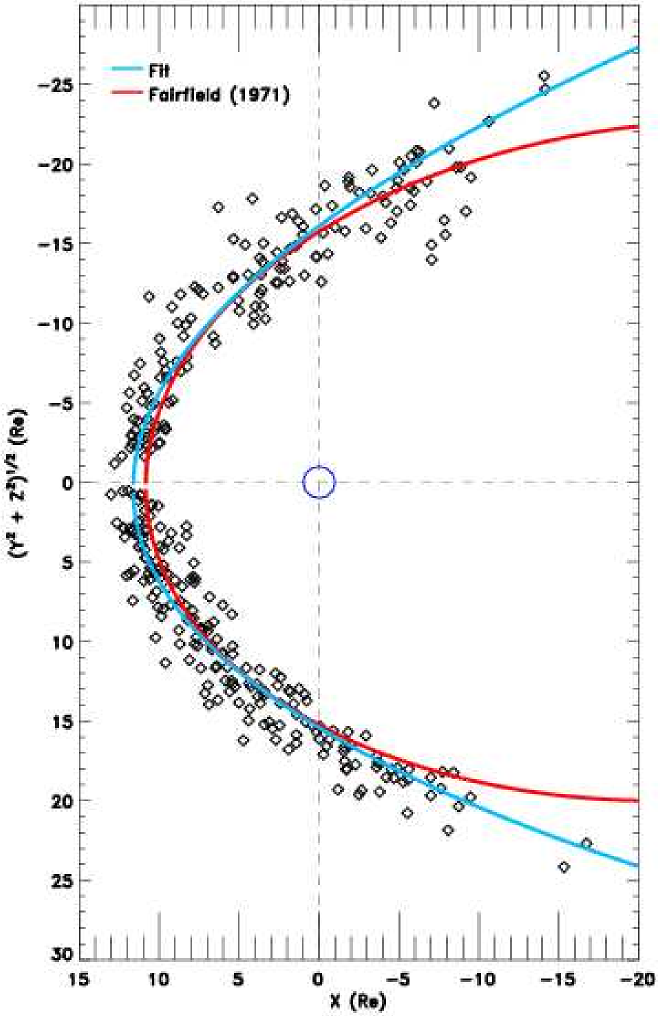
•--- Spacecraft: Geotail, Cluster 1, THEMIS B and C

• -- Each data point corrected for aberration due to motion of Earth around the Sun.

• ---Same approach as *Fairfield* (1971): Minimize function

$$0 = y^2 + Axy + Bx^2 + Cy + Dx + E$$

The Magnetopause



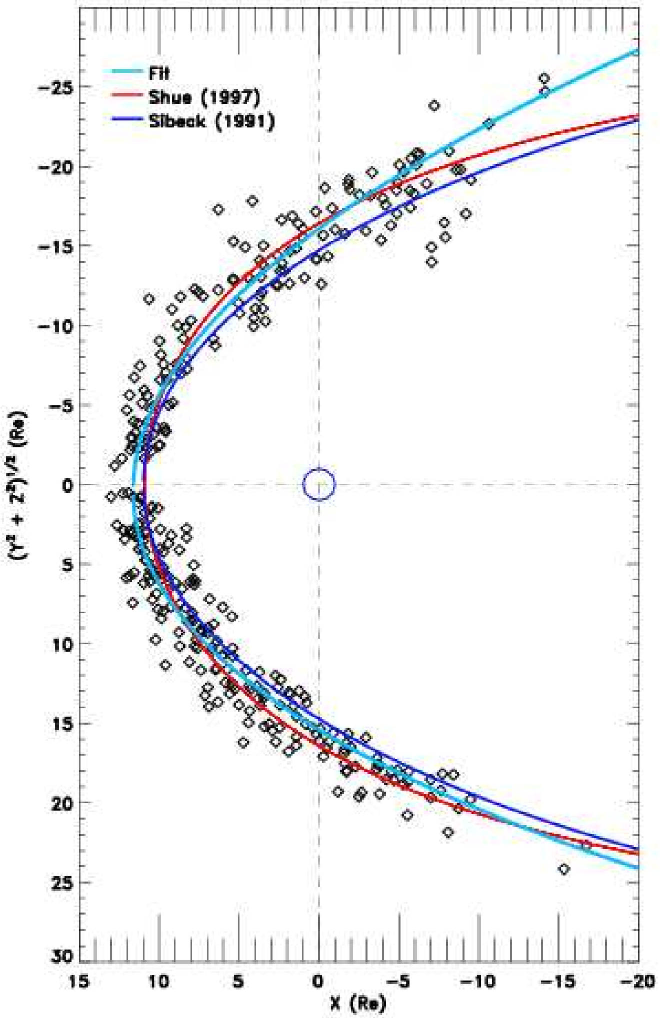
Magnetopause *flares out more* than Fairfield's

The stand-off distance = 11.8 RE, *noticeably larger* than Fairfield's

Likely due to lower dynamic pressure.

Fairfield: Data in rising phase of Solar cycle 20.

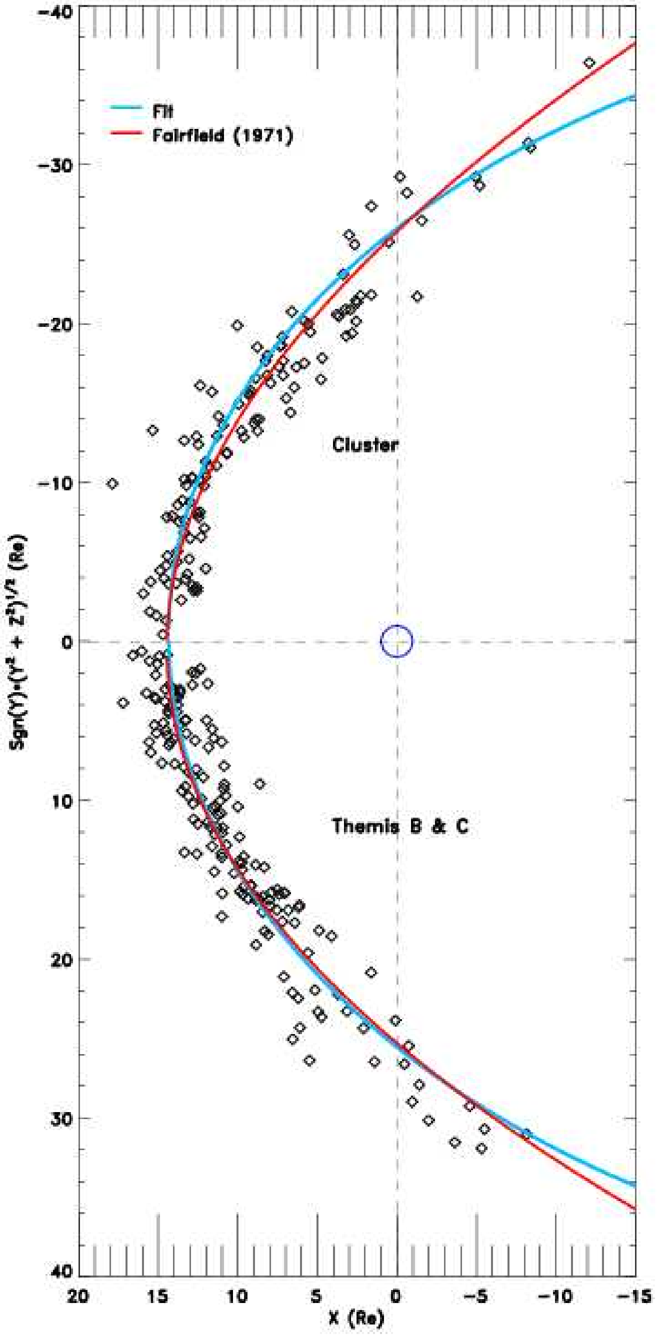
Comparison with 2 model magnetopauses: *Sibeck* (1991) and *Shue et al.* (1997)



- Both model magnetopauses underestimate the flaring of the magnetopause in our period.

- Of the two, *Sibeck et al.*'s (1991) model comes closer to reproducing the observed flaring.

- Both models underestimate the stand-off distance by ~ 1 R_E



The Bow Shock

The solar minimum BS
less flared than Fairfield’s

(Weaker MHD effects reduce flaring.)

Interestingly, the subsolar location is practically the same

Two competing trends !

---When M_A increases, BS shifts *earthward*

---When P_{DYN} decreases, MP moves sunward and flares out. The stand-off distance of BS is proportional to object size, so for lower P_{DYN} (more flaring) the BS shifts *sunward*.

Conclusions (1)

Discussed: 1. Solar wind properties during 2007-2009 and 2. Two major aspects of the magnetospheric response.

On 1. Data from STA: *N* and *B*, compared to other solar activity minima. significantly weaker. M_A untypically high.

On 2. Magnetosphere response remained <u>linear</u>.

-- Hence, used empirical formula to obtain CPCP ~ 37 kV (reliable under linear response).....drives convection.

-- Auroral activity closely correlated with the prevalent stream-stream interactions…IP medium …. a continued stream-stream interaction process

-- Comparing with Fairfield's classic result: a more flared out MP whose subsolar stand-off distance (at 11.8 R_E) was ~ larger by 1 R_E.

-- The empirically determined BS was less flared than Fairfield's.. Reflecting relative weakness of MHD forces

Conclusions (2)

--The subsolar magnetosheath was ~ 1R_E narrower (~ 25%).

--High M_A reflects the weakness of MHD forces and has a direct effect on solar wind-magnetosphere interaction processes.

More in:

***Farrugia, Harris, Leitner, Möstl, Galvin, Simunac , Torbert, et al*. Solar Phys. 281, 461-489, doi:10.1007/s11207-012-0119-1 2012.**

EOS Space Science Center   UNH

THE END

Thank You for Your Attention !