Solar wind pressure and the position of the magnetopause – Cluster

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Position of the magnetopause

- Traditionally, the MP position has been determined by identifying discrete points in time at which a spacecraft is traversing it.
- This set of positions has been correlated statistically with prevailing solar wind conditions, leading e.g. to paraboloid fits of MP (and BS) position [e.g. Sibeck et al.]
- Such models are routinely used for predicting MP shape as a function of time-varying solar wind conditions, although, in principle, this is not a correct use of the statistical information.
- The main parameter seems to be solar wind total pressure, essentially the ram pressure.
- The idea that short-term variations in MP position depend on solar wind parameters alone may be flawed: e.g. when the K-H instability is active, MP position is a result of internal magnetospheric dynamics.

Continuous monitoring of MP position

- Cluster data are a rich source for studying the magnetopause and boundary layer (MP/BL).
- In particular, multi-spacecraft methods are available that can determine the position, motion, and orientation of a boundary layer better than ever before.
- Moreover, empirical reconstruction methods are able to monitor the position of the MP continuously, for as long as at least one of the Cluster spacecraft is in the vicinity of the MP/BL, that is: usually for the whole duration of a pass through the boundary (typically hours).
- We can therefore try to do a continuous correlation between solar wind dynamic pressure and MP position.

Empirical reconstruction

- We will assume that
  - there is no intrinsic time variability of MP/BL structure,
  - the observed time variability is only due to spatial structure that is convected across the spacecraft.

- Reconstruction = identify location at which each observation is made in a reference frame that moves together with the MP/BL

- The first result of reconstruction is the position of the MP/BL as it changes with time.

- The second result is the spatial structure of the MP/BL.

Moving reference frame

- Orient the frame such that x is the average normal, y points along the boundary, z is the direction of least curvature/invariant direction (using variance analysis of n).

- Let the frame move with the MP/BL velocity v_{mpbl} in the x direction. Taking v_x, the plasma velocity measured in the vicinity of the MP/BL, as a proxy for v_{mpbl}, one finds

$$x_{mpbl}(t) = x_{mpbl}(t_o) + \int_{\tau \in [t_o,t]} v_x(\tau)\, d\tau$$

- This idea goes back to Paschmann et al., 1990.

Problems

- This procedure works only for short time intervals because of
  - measurement errors on v_x
  - limited time resolution, gaps in the v_x data
  - v_x may not always represent v_{mpbl} well

- Aggravated by all these errors:
  because x_{mpbl} is obtained by integrating the oscillatory integrand v_x, the relative error on x_{mpbl} grows rapidly with integration time.

Solution

- Determine boundary position $x_{mpbl}(t)$ and 1-D spatial profiles $f^{l}(x)$ of a set of "guiding variables" by simultaneously minimizing a weighted sum of
  - the deviation between measured proxy $v_x(t_i)$ and model $v_{mpbl}(t_i)$
  - the deviation between the measurements $f^{l}(t_i)$ and the spatial model profiles evaluated at the distance of the spacecraft from the MP/BL : $f^{l}(x_{sc}(t_i) - x_{mpbl}(t_i))$

  ⇨ nonlinear least-squares optimization

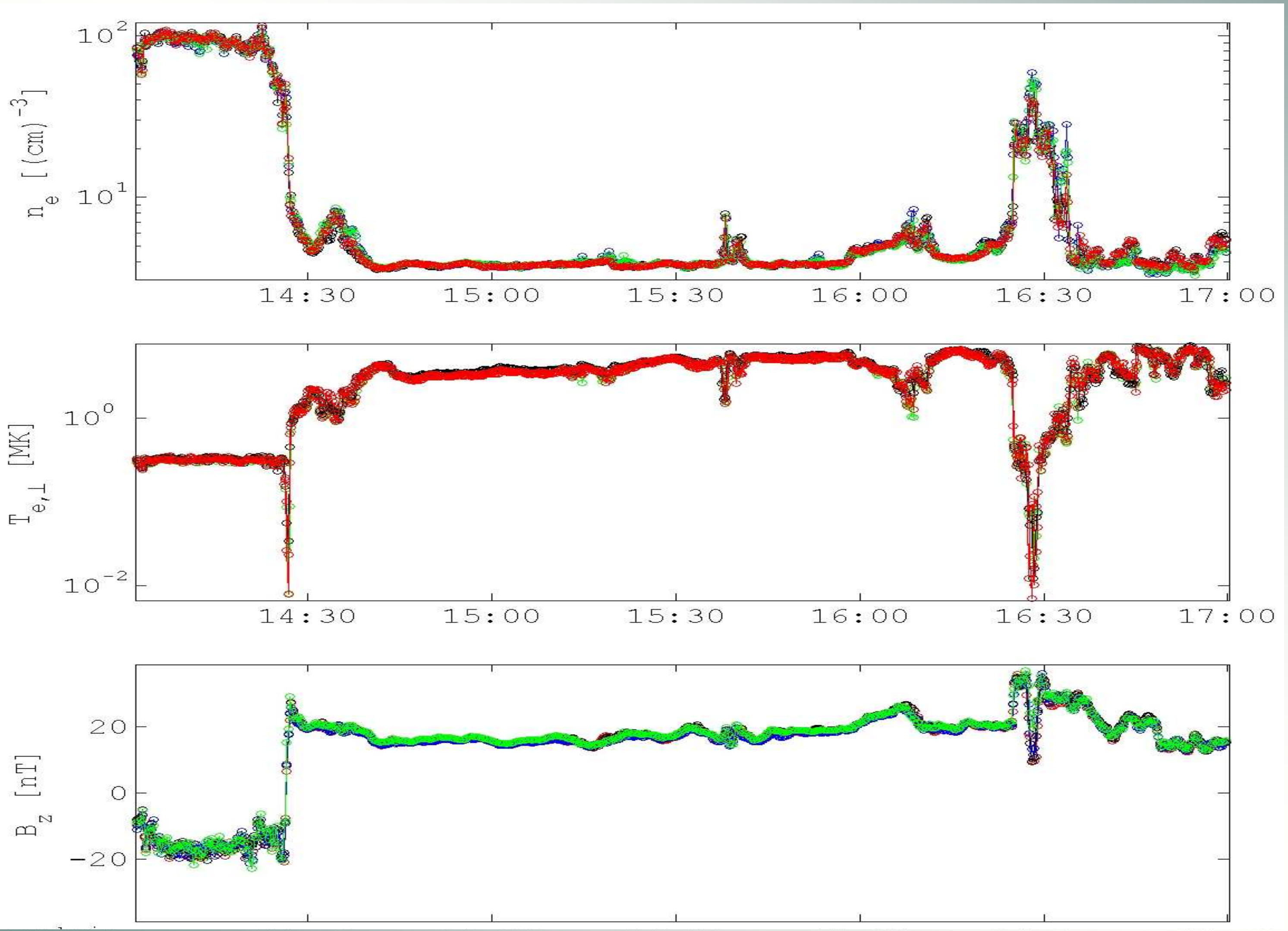
  [De Keyser et al., *Ann. Geophys.* 23, 1355-1369, 2005]

- Result:
  - boundary position and speed over the whole time interval
  - spatial profiles of all measured variables

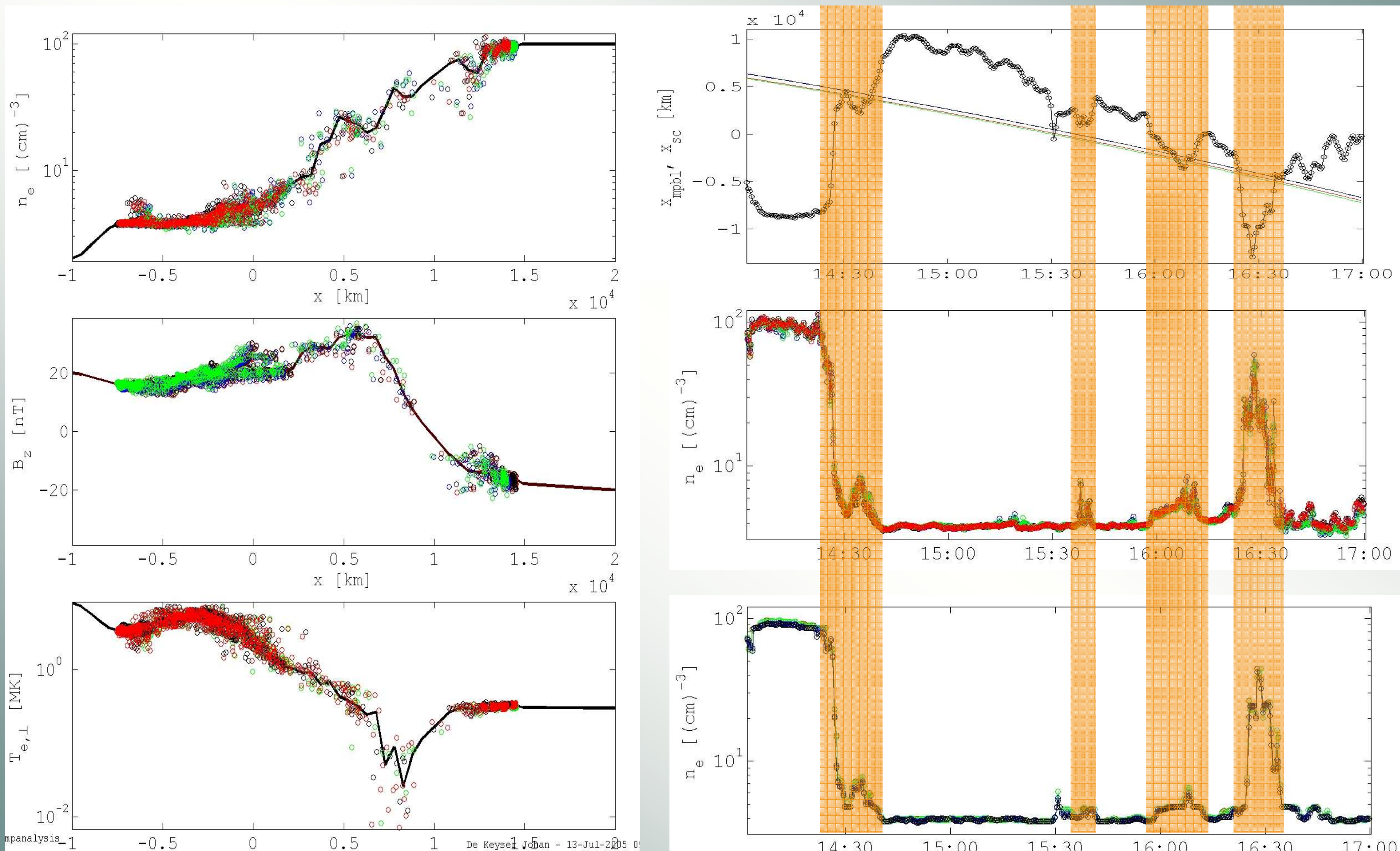
  ⇨ track MP/BL position continuously during *hours*.

Example: direct solar wind control

April 23, 2001 : Inbound MP/BL pass, 15 s resolution data; all sc see essentially the same thing (standard Cluster color coding is used)



Reconstruction with $\Delta t = 30$ s, using v_x from CIS/HIA on C1 and C3, with n_e, $T_{e\perp}$ (PEACE) and B_z (FGM) as guiding variables, giving rather little weight to v_x

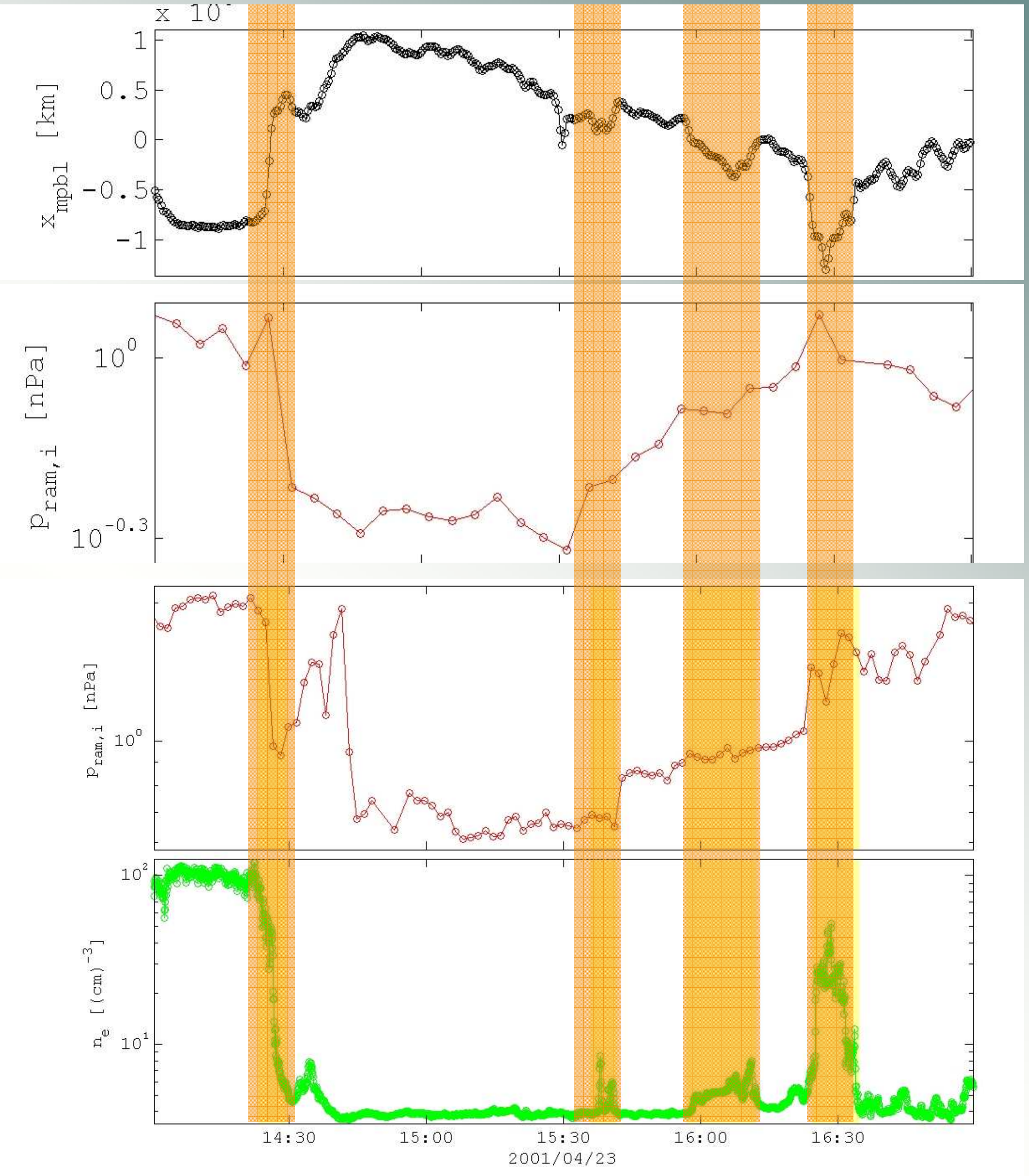


Cluster x_{mpbl}

ACE p_{ram} – 5 min averages
(D. McComas, SWEPAM)
time delay = 5200 s

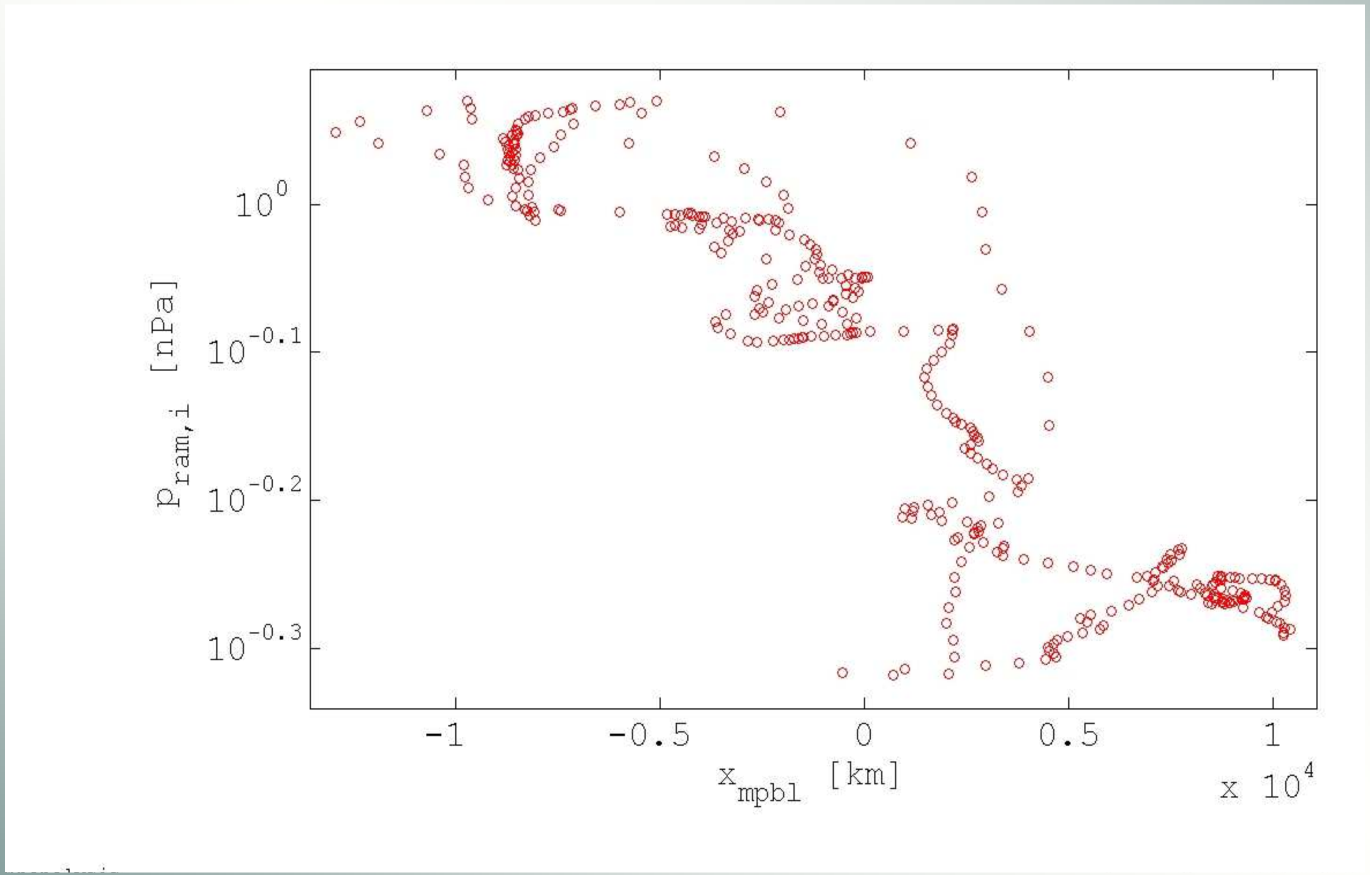
WIND p_{ram} – 92 s
(K. Ogilvie, SWE)
time delay = -2500 s

Cluster n_e



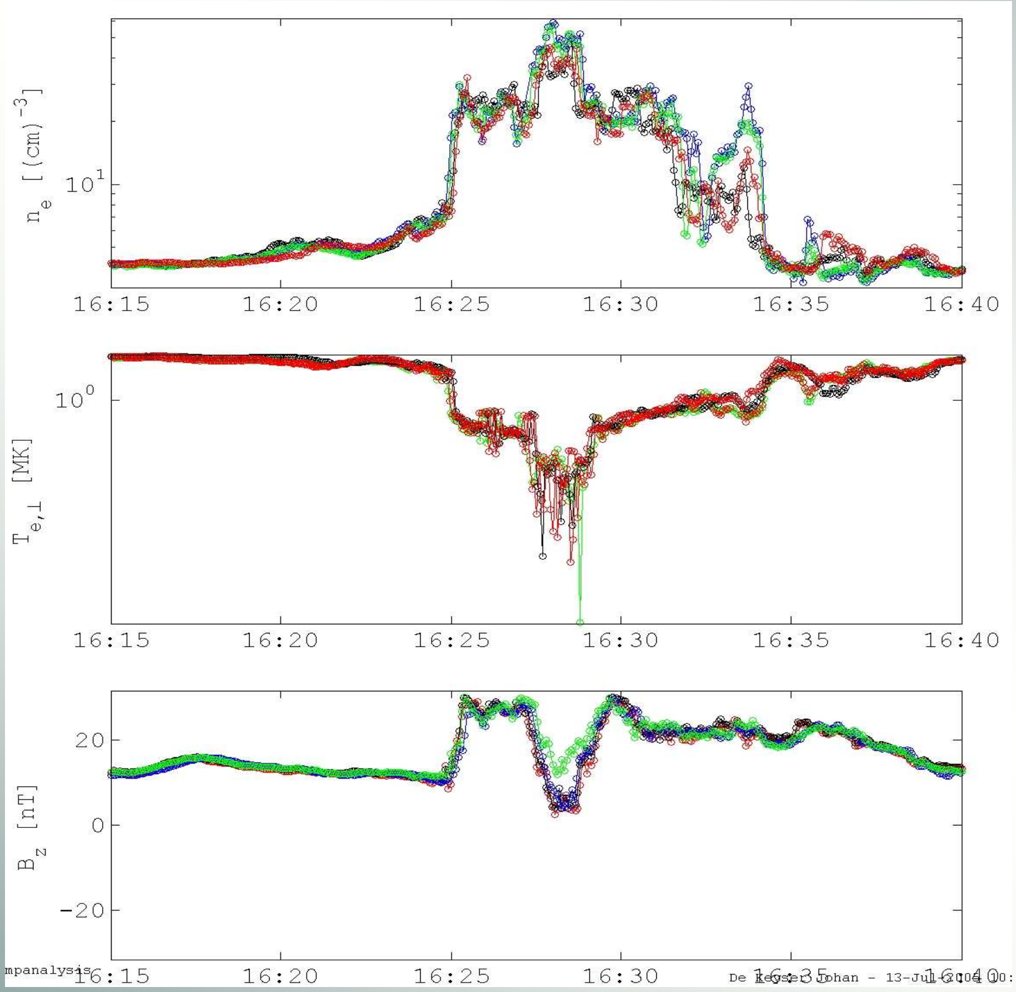
We find a clear anti-correlation between MP/BL position and ram pressure on the timescale of a few minutes.

Such a comparison is conceptually different from a statistical long-term correlation of individual MP crossings with solar wind conditions:

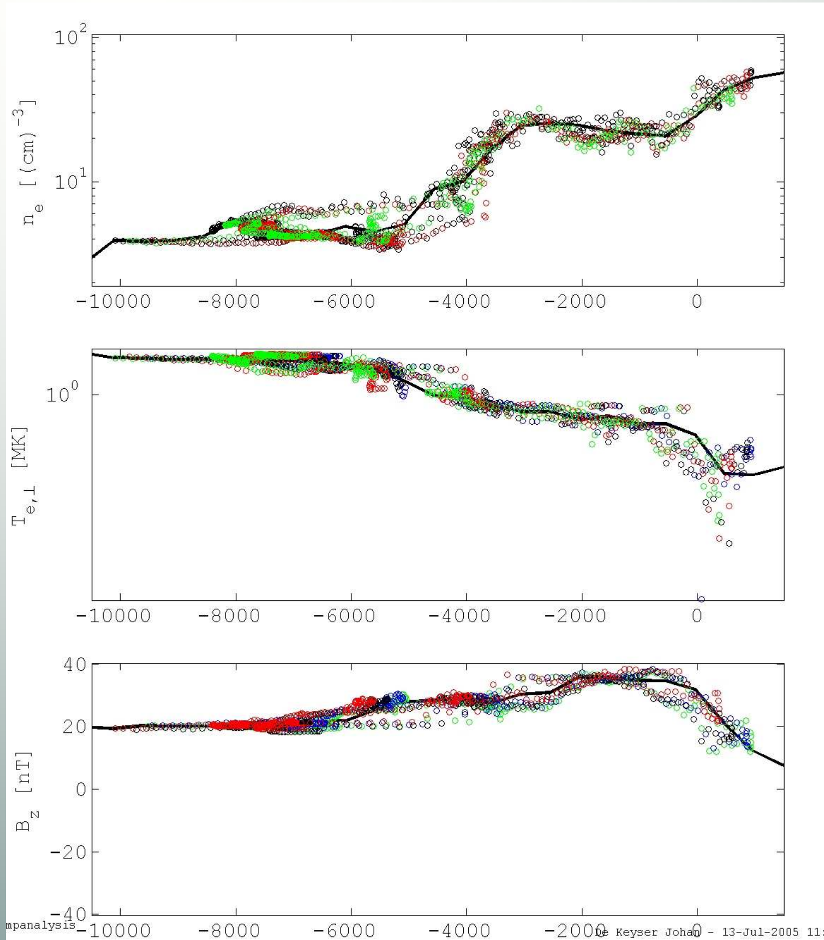


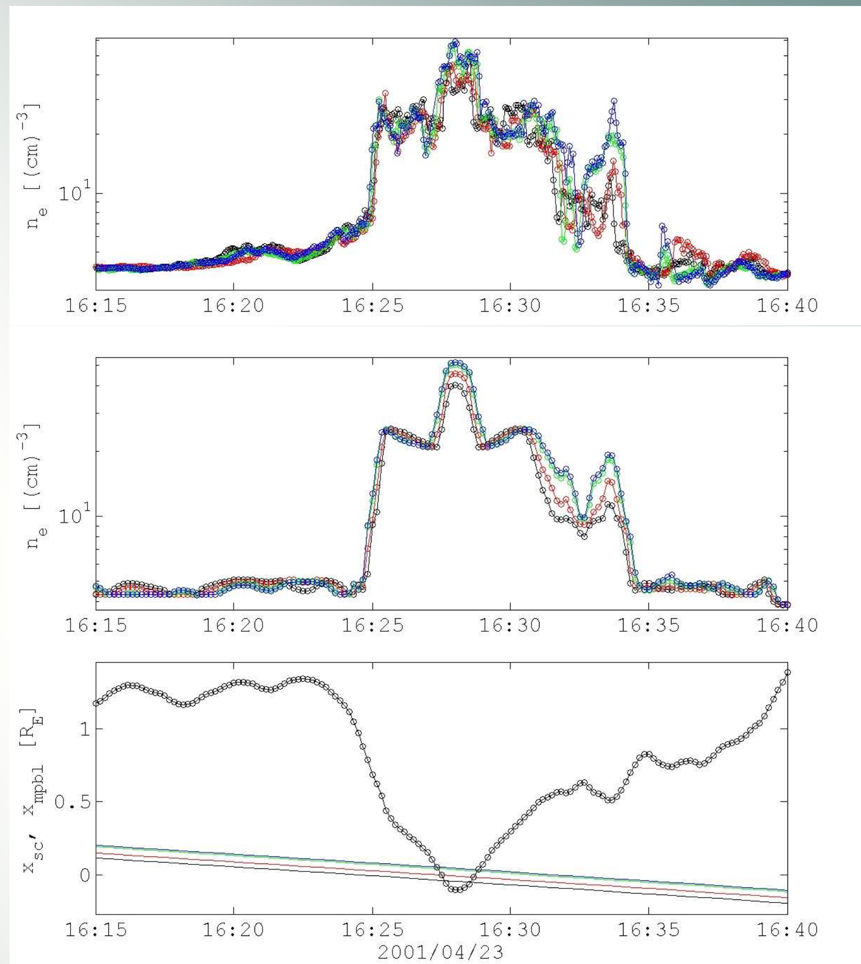
Example: substructure

Same event : last part of the inbound MP/BL pass, 4 s resolution data : some differences between the sc start to show up



Reconstruction with $\Delta t = 10$ s, using v_x from CIS/HIA on C1 and C3, with n_e, $T_{e\perp}$, and B_z as guiding variables, more confidence in the v_x





The spatial profiles are definitely non-monotonic! The same profile is traced by each sc, on both their in- and outward passes.

Note: the relative order of the curves is indeed due only to the different position of the sc in the normal direction.

Conclusions

- Empirical reconstruction allows continuous monitoring of the MP/BL position.
- In doing so, we can do a detailed continuous correlation between MP/BL position and solar wind p_{ram} in a deterministic (rather than statistical) sense, showing direct solar wind pressure control of the magnetopause position, for some events at least.
- Rapid pressure pulse response can lead to MP/BL substructure. This remains to be investigated in more detail.

Example: long-duration tracking

June 11, 2001 : Outbound MP/BL pass, Δt = 20 s, using v_x from C1 and C3, with n_e and B_z as guiding variables; C1, C2, C4 close together, C3 inward, which explains the relative ordering, the partial crossings through the MP, …