Studying the Earth's Magnetopause at High Latitudes With Cluster

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1. Motivation:

- The **magnetopause (MP)** is an important boundary
- MP location and dynamic mostly **influenced by solar wind (SW)** pressure and IMF
- Response of the MP to the SW **not yet fully understood**
- Under special circumstances **observation and prediction of MP locations can deviate** drastically
- Multi-spacecraft constellation are providing insights in the MP dynamics
- Many **studies are focused on equatorial plane**
- **Full picture** of the response only **when higher latitudes are included**
- The Cluster mission (*Escoubet et al., 2001*) with spacecraft in polar orbits can be used for such studies

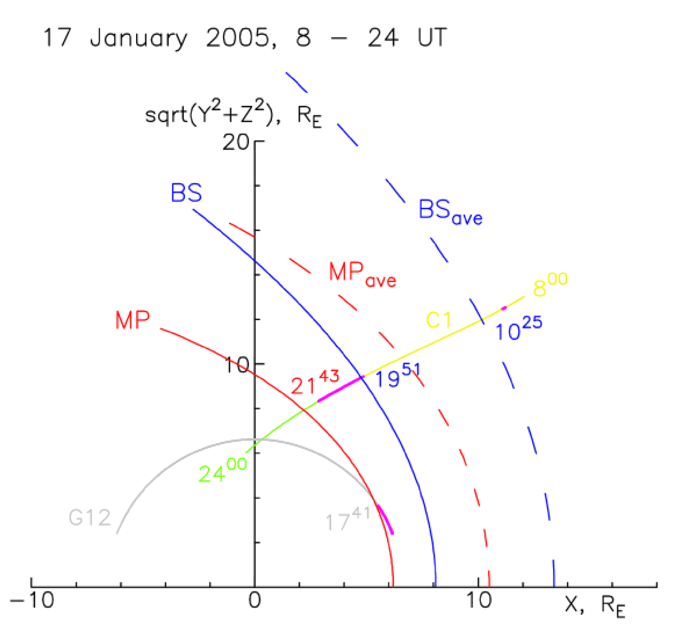

Fig. 1: Cluster and GOES orbit in cylindrical coordinates. Different observation regions are marked (yellow: IMF, purple: magnetosheath; grey (GOES) and green (Cluster): magnetosphere). Observed and predicted MP (red) and BS (blue) positions are indicated by solid and dashed lines, respectively. Adapted from Fig. 2 of *Tátrallyay et al. (2012)*.

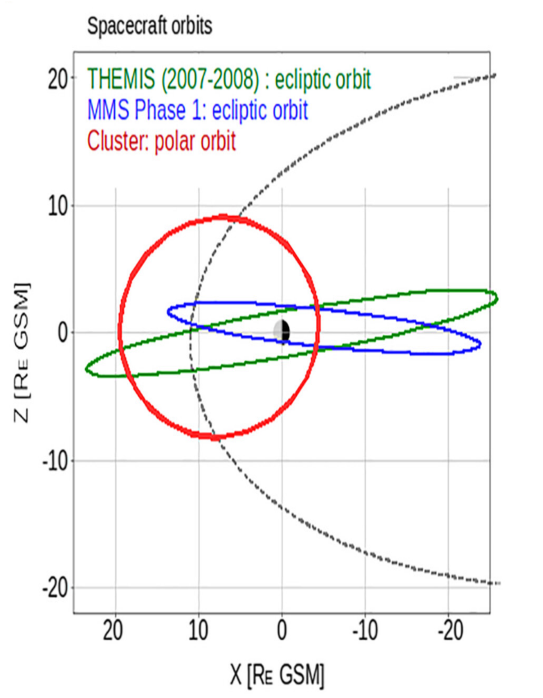

Fig. 2: Cluster polar orbit (red colour) compared with orbits of other multi-spacecraft missions in ecliptic orbits (THEMIS in green colour and MMS in blue colour). Adapted from Fig. 5 of *Haaland et al. (2021)*.

2. Data and Methods:

- **Cluster data** (*Escoubet et al., 2001*) between 2001 and 2020
  - **FGM and CIS-HIA for C1 and C3** resampled to 1 min
- Primarily **Multi-spacecraft timing method** for MP normal estimation on 5VPS FGM data
- 1 min **OMNI data for SW monitoring** and input to *Shue et al. (1998)* model prediction
- Use **MP stand-off distance for comparison** between observation and model

3. Magnetopause Dataset:

Machine Learning method adapted from *Grimmich et al. (2023)*

All identified (proper) MPCs: C1 22,357 (12,021); C3 15,965 (8,692)

Proper dayside **MPCs in high latitudes: 6,183** (57 expanded MPCs, 1,642 compressed MPCs)

High-latitude MPCs with large deviations from *Shue et al. (1998)* model: **57 expanded MPCs** (positive deviation) and **1,482 compressed MPCs** (negative deviation)

Validated with Geospace Region and Magnetospheric Boundary (GRMB) dataset (*ST2.1 Poster X3.39*) → up to **77 % agreement**

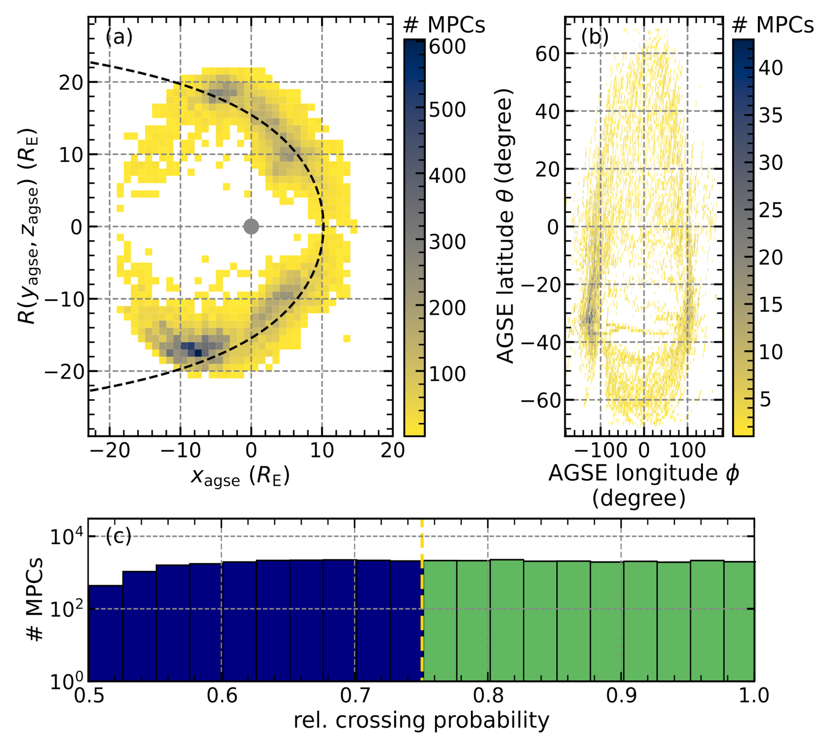

Fig. 3: Panel a) shows the 2D spatial distribution of the identified MPCs in a (x, R) plane. The dashed black line shows the MP model of *Shue et al. (1998)*. Panel b) shows the distribution of spacecraft positions during the MPCs in latitude over longitude. Panel c) shows the histogram of the crossing probability/quality value for all MPCs (high probability > 0.75 in green and low probability ≤ 0.75 in dark blue).

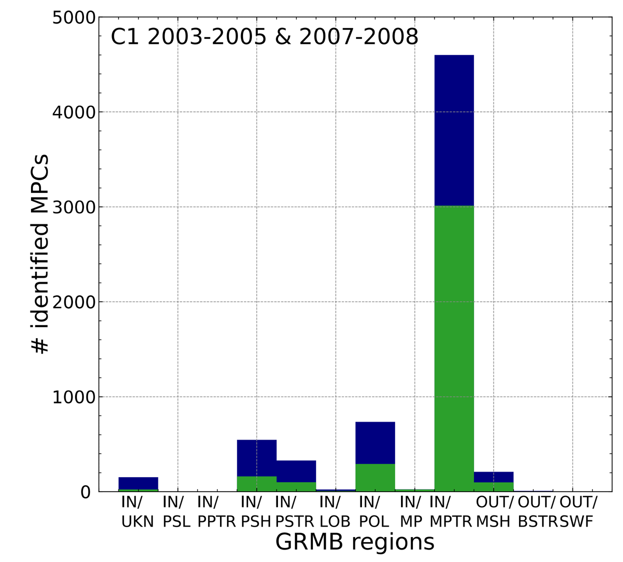

Fig. 4: Distribution of our identified MPCs in the different regions indicated by the GRMB dataset (*ST2.1 Poster X3.39*).

4. Solar Wind Influences:

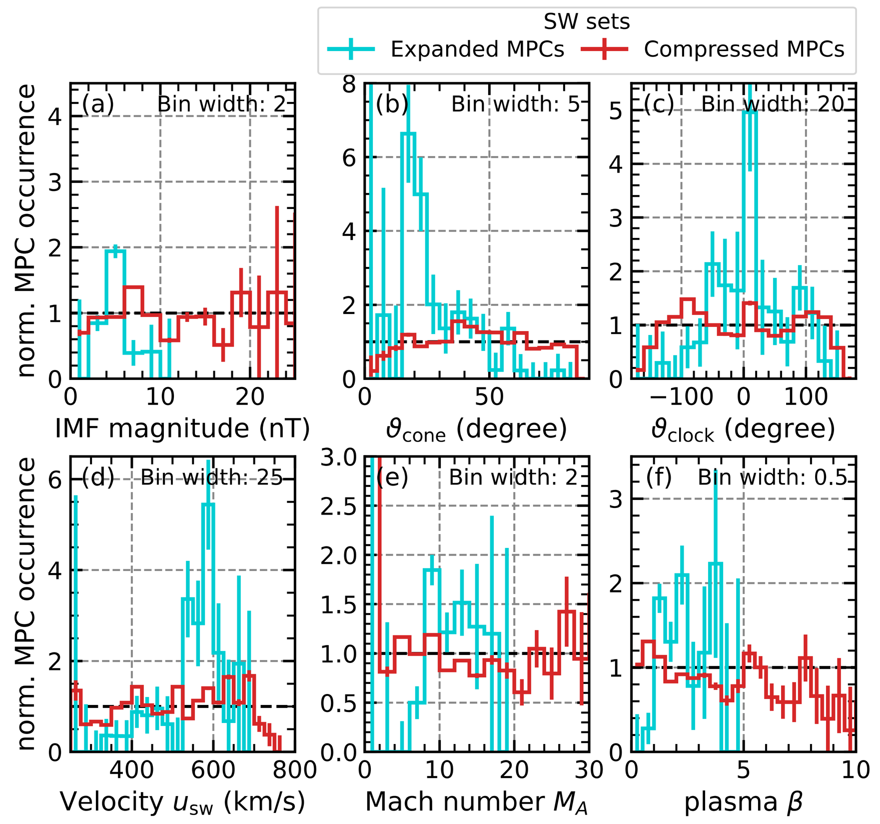

Fig. 5: Comparison of the distributions of different solar wind parameters associated with the observation of MPCs. Each panel shows the distributions associated with the unusually extended MPCs (cyan), and the unusually compressed MPCs (red). These distributions are normalised by division by the normal solar wind occurrence distribution of the corresponding parameter, revealing favourable conditions for the occurrence of unusual MPCs.

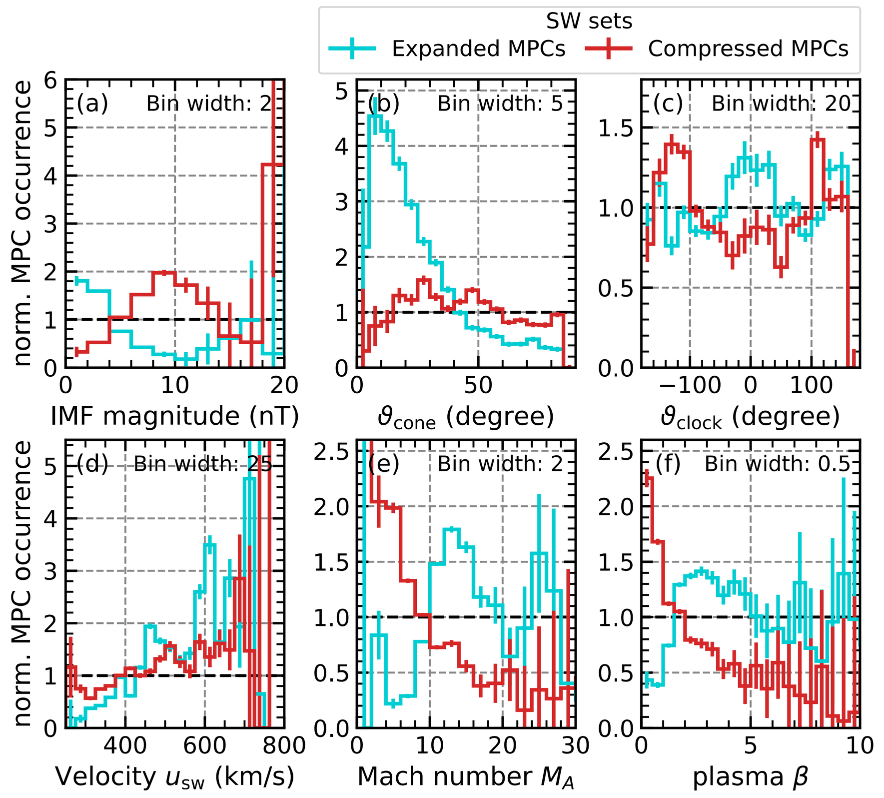

Fig. 6: Comparison of the distributions of different solar wind parameters associated with the observation of MPCs in the THEMIS dataset, identical to Fig. 5. Modified from Fig. 9 of *Grimmich et al. (2023)*.

Details on THEMIS MPCs:
Paper: Dataset:

5. High Latitude Magnetopause Analysis:

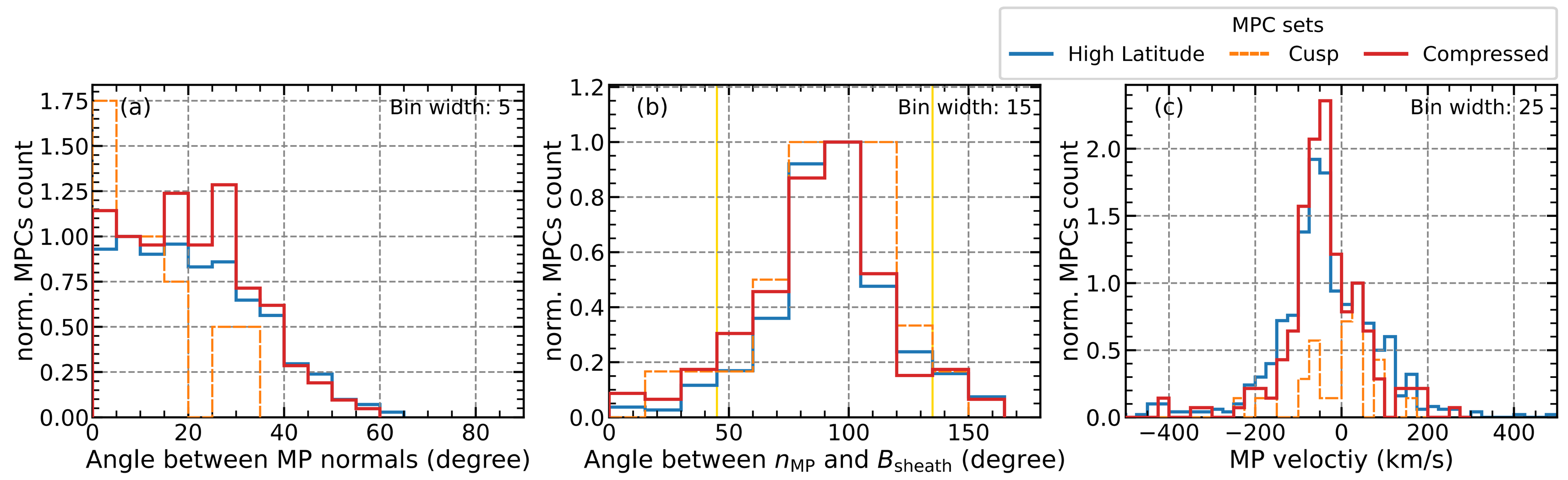

Fig. 7: Normalised distributions of different MPC subsets showing results derived from the multi-spacecraft timing method: (a) shows the total angular deviations between the estimated and the *Shue et al. (1998)* model predicted MP normals; (b) shows the angle between the estimated MP normals and the magnetic field vectors in the magnetosheath; (c) shows the MP velocity distributions.

6. Conclusions:

- High-latitude **MP motion** ...
  - … is, on average, **faster earthward than sunward**
  - … seems to be more often **associated with a closed MP boundary** (66 % of cases)
- Unusually **compressed MPCs** are more likely to have **distorted high-latitude MP surfaces**
- Occurrence rates of **unusual MP locations** beyond the *Shue et al. (1998)* model **similar at high and equatorial latitudes**
  - Expanded MPCs occur more frequent under quasi-radial IMF, higher Alfvén Mach numbers and SW velocities
  - Compressed MPCs occur more frequent under southward IMF and higher SW velocities

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