Magnetopause Speed vs the Ion Motion Inside the Boundary Layer

Mrittika Ghosh[1], Gilbert Pi[1], J. Šafránková[1], and Z. Němeček[1]

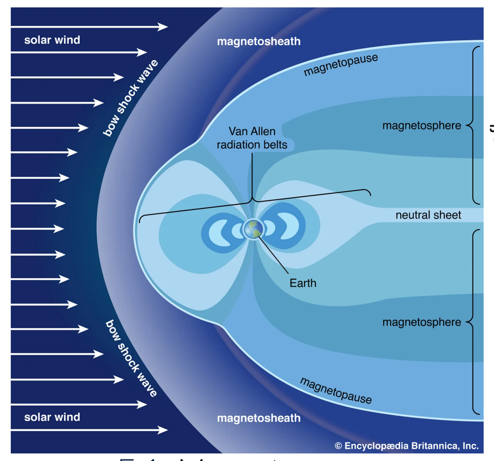
[1]Charles University, Faculty of Mathematics and Physics, Prague, CZ

FACULTY OF MATHEMATICS AND PHYSICS
Charles University

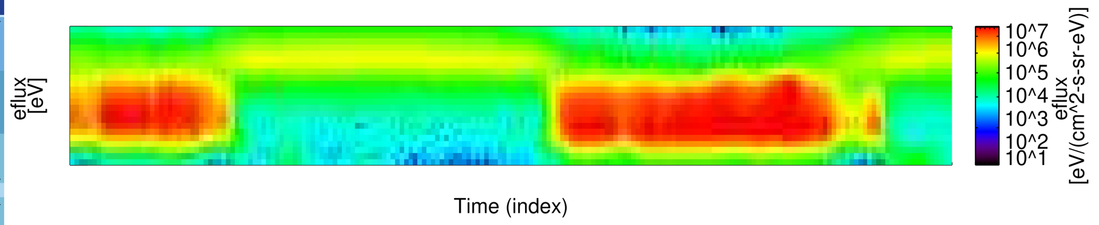
Magnetopause Motion

Magnetopause is the boundary region between the shocked solar wind from the Sun and the magnetic field from the magnetosphere. Once the upstream solar wind conditions are altered, the magnetopause's shape, location, and motion change.

Since the late 70s, researchers have been studying the position and shape of the magnetopause. Russell and Elphic [1978] state that the magnetopause is constantly in motion. Traditional methods of tracking the magnetopause motion often rely on the separation and time difference of crossings between the two spacecraft [Dunlop et al. 1995].



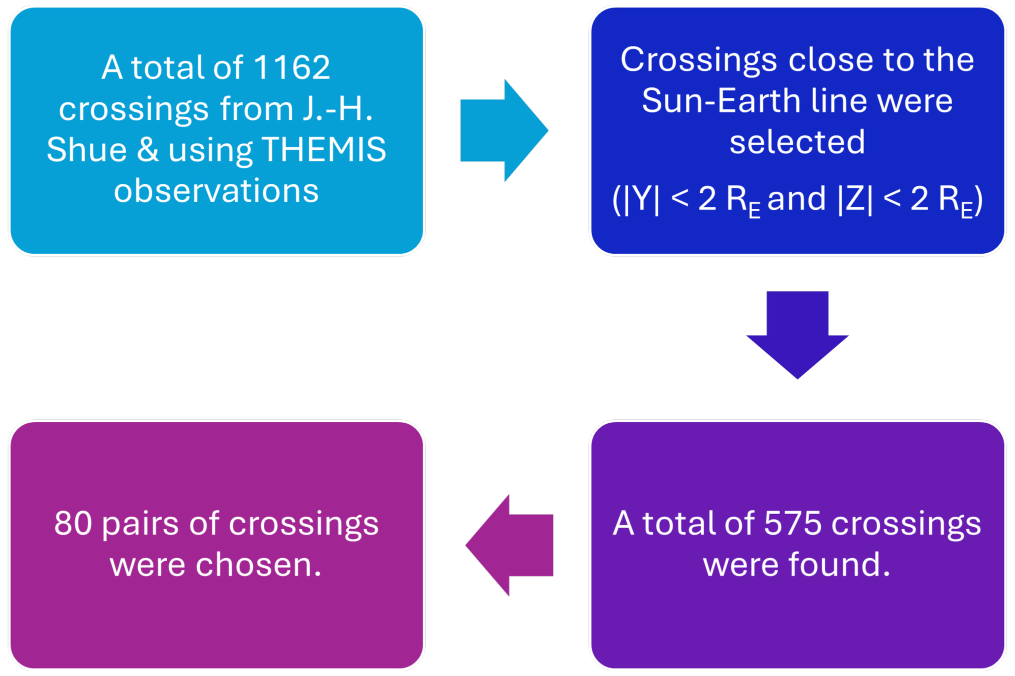
F 1. Magnetopause



F 2. Eflux

- **Energy flux** (eflux) is an important diagnostic tool for understanding the plasma environment, particle population, and dynamics in the magnetopause crossings.
- Sharp changes in the **eflux patterns** are key indicators of the transition from the magnetosheath to the magnetosphere or vice versa.

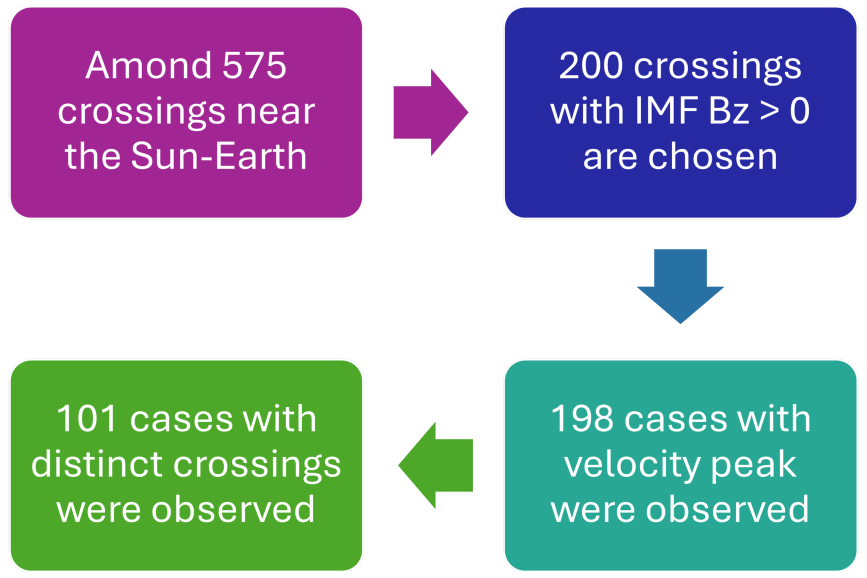
Data Chosen



F 3. Data Chosen

- **Magnetopause crossings** from 1st May 2007 to 14th December 2010 from THEMIS Mission.
- **Manual identification** of crossings and the boundary region of the magnetopause was performed.
- **Subsolar region** of the magnetopause was chosen to confine to a small region.
- **Traditional method** of calculating magnetopause motion requires a pair of data, thus 80 pairs of crossings were chosen.

- **Re-choice** of data was required as pair consideration was no longer important.
- **IMF Bz** To avoid reconnection effects, only IMF B_z components were chosen.
- A sudden **peak** in the velocity component of the magnetopause was noticeable.
- **Distinct crossings** - the region where magnetosheath and magnetosphere are understandable without any multiple crossings.

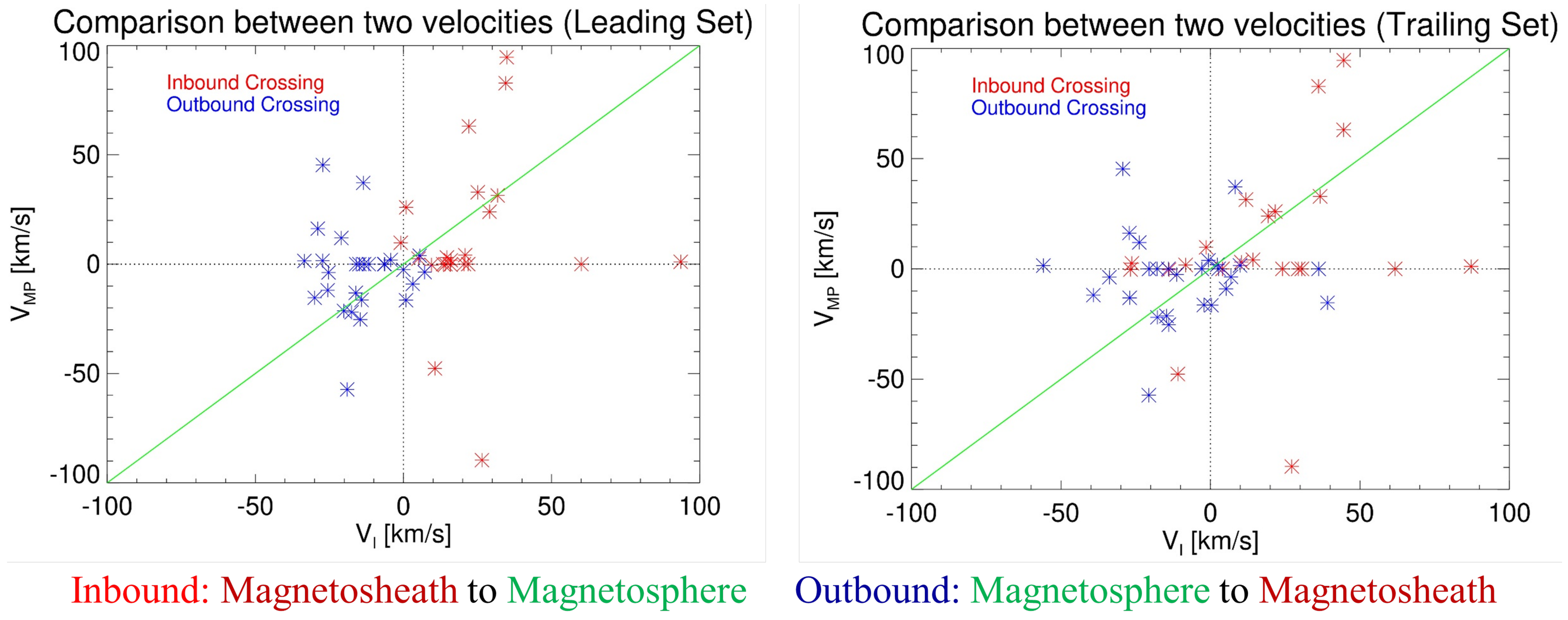


F 4. Data Rechosen

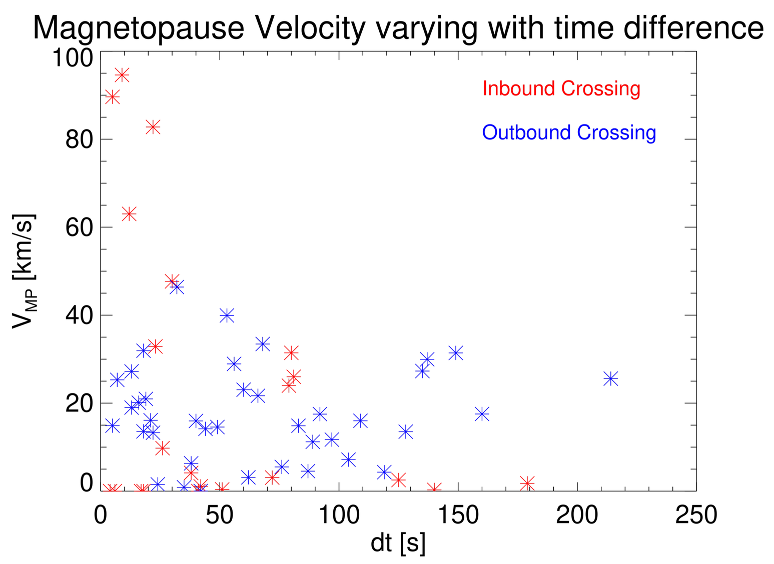
Dynamic Motion of Magnetopause

The preliminary studies show that the traditional method to estimate the magnetopause speed may not be suitable. We can easily see that in F6, a huge error occurred when the time difference was small, even though we used the Shue et al. [1997] model to calculate the subsolar point first. It might be due to local deformations. Furthermore, the Shue model describes the statistical situation of the magnetopause location. Therefore, we are searching for a new method to estimate the moving speed of the magnetopause. Guo et al. [2024] and LLera et al. [2023] denoted the cold-ion motions on the magnetospheric side, which can address the magnetopause motion. However, it can be used in a limited situation when a cold-ion flow exists. Therefore, we comprehensively analyze the velocity in the magnetopause boundary layer to find a quantity that can represent the magnetopause velocity.

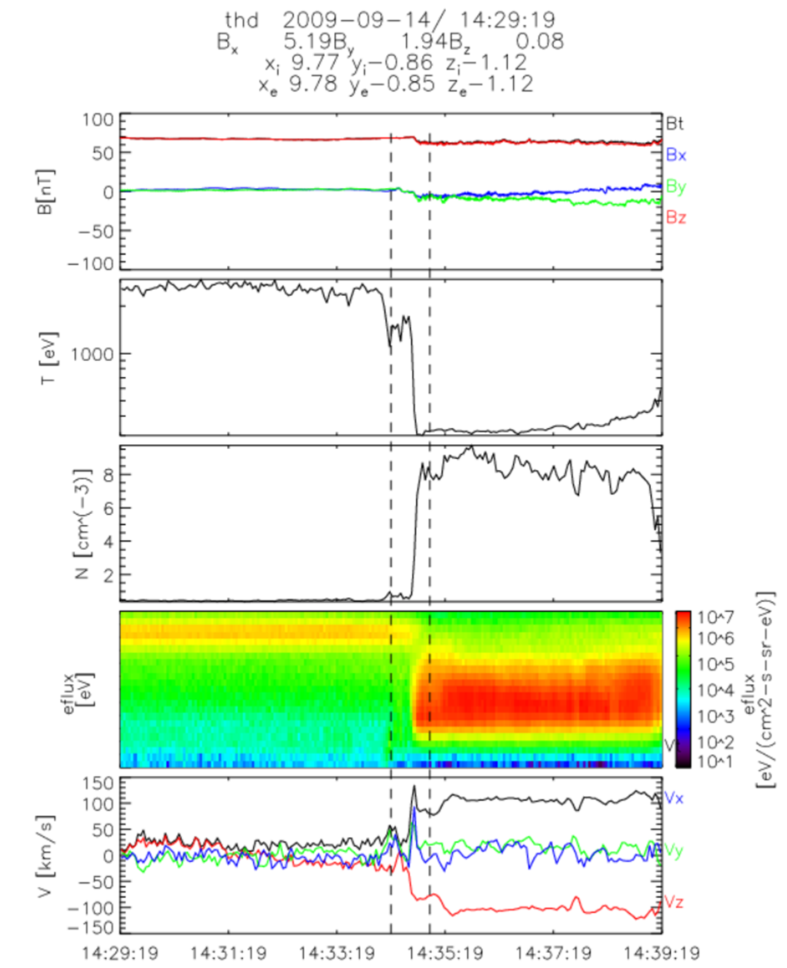
Analytical Study



F 5. Comparison of Magnetopause Velocities for 78 pairs of chosen cases



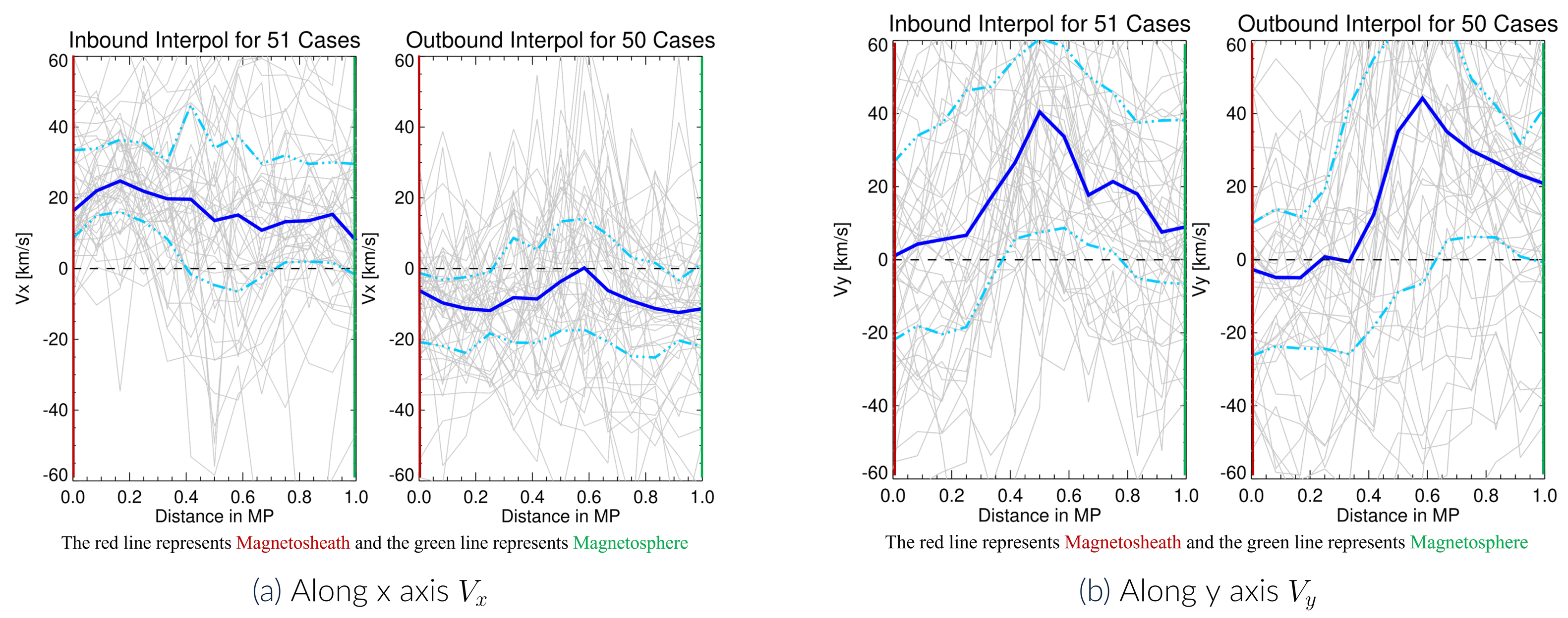
F 6. The absolute value of magnetopause velocity as a function of time difference between two spacecraft.



F 7. Example of measurements THD from top to bottom: The magnetic field components (B_x, B_y, B_z and B_t), the temperature (T), density (N), eflux and the velocity components (V_x, V_y, V_z and V_t)

- Comparison between magnetopause velocities between the traditional method and our method was performed.
- The velocity inside the magnetopause boundary layer is quite **high** in some cases.
- Traditional Calculation of magnetopause velocity shows that for short time difference, there is **more fluctuation** in velocity. This might be related to the fact that the magnetopause is not a smooth curve.
- The velocity along the x-axis has a sudden peak. The origin of this peak is unknown.

Superposed analysis

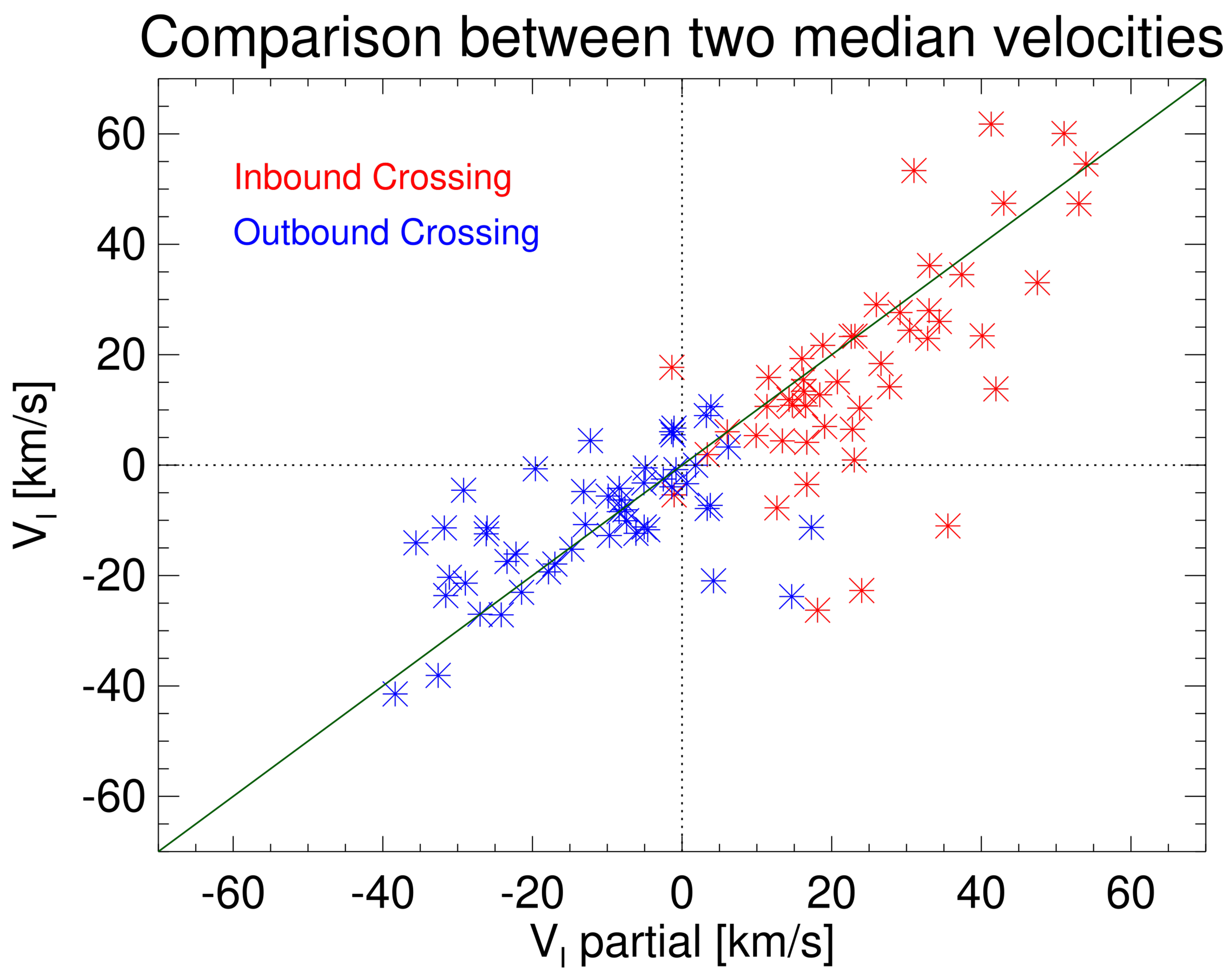


(a) Along x axis V_x

(b) Along y axis V_y

F 8. Superposed Velocity epoch analysis for B_z positive cases

Velocity Comparison



F 9. Comparison of median velocities using our calculation within the magnetopause boundary layer vs the magnetospheric side of the boundary layer for all B_z positive cases

The unknown peak in the V_x direction of the magnetopause, as shown in **F7**, affects the velocity calculation. To avoid this peak, we use the magnetospheric side of the magnetopause boundary layer for our calculation termed as V_I partial. The comparison of the median velocities shows that the partial velocity calculated from the magnetospheric side of the boundary layer has less error than the total velocity calculated from the whole boundary layer.

Discussion

- **F5** and **F6**: Show that the traditional method of calculation is not accurate. The magnetopause surface may not be smooth. Němeček et al. [2023] explains that the magnetosheath jet can hit the magnetopause, create an indentation, and change the magnetopause's local structure.
- **F7** A distinct velocity peak along the x-axis is observed inside the boundary layer of the magnetopause. The origin of this sudden peak is unknown.
- **F8a** and **F8b**: The superposed velocity epoch analysis for V_x shows that it is sometimes positive and sometimes negative, while the velocity along the y-axis V_y is always positive. This can be due to the velocity of the Earth.
- **Overall**, we suggest that the magnetopause velocity calculated from the magnetopause boundary layer is a better approach as shown in **F9**.

Key Points and Future Steps

- Discrepancy in the magnetopause velocity calculation in the traditional method.
- The velocity calculated inside the magnetopause boundary layer gives a more accurate result.
- Minimum Faraday Residue will be performed to study the normal velocity.
- Apply this method to all the regions of the magnetopause.

References

Guo, W., Tang, B., Zhang, Q., Li, W., Yang, Z., Sun, T., Ma, J., Zhang, X., Liu, Z., Guo, X., et al. (2024). The magnetopause deformation indicated by fast cold ion motion. *Journal of Geophysical Research: Space Physics*, 129(2):e2023JA032121.

LLera, K., Fuselier, S., Petrinec, S., Rice, R., Burch, J., Giles, B., Trattner, K., and Strangeway, R. (2023). Tracking magnetopause motion using cold plasmaspheric ions. *Journal of Geophysical Research: Space Physics*, 128(11):e2023JA031338.

Němeček, Z., Šafránková, J., Grygorov, K., Mokrý, A., Pi, G., Aghabozorgi Nafchi, M., Němec, F., Xirogiannopoulou, N., and Šimůnek, J. (2023). Extremely distant magnetopause locations caused by magnetosheath jets. *Geophysical Research Letters*, 50(24):e2023GL106131.

Shue, J.-H., Chao, J., Fu, H., Russell, C., Song, P., Khurana, K., and Singer, H. (1997). A new functional form to study the solar wind control of the magnetopause size and shape. *Journal of Geophysical Research: Space Physics*, 102(A5):9497–9511.

Correspondence: mrittika.ghosh@matfyz.cuni.cz