Tracing Solar Wind Plasma Transport to the Plasma Sheet Using He^{++}/H^{+} Composition

Md. Nayem Mia[1], Lynn M Kistler[1], Christopher Mouikis[1], Jing Liao[1], Michael Stevens[2]

University of New Hampshire[1], Harvard-Smithsonian CFA [2]

1. Sources of Plasma in the Plasma Sheet (PS)

Solar Wind (SW) Entry

Southward IMF	**Northward IMF (Proposed)**
Dayside magnetic reconnection	Double-lobe magnetic reconnection
Plasma convects over the polar cap	Kelvin–Helmholtz flank transport
Entry through the plasma mantle	Kinetic Alfvén wave transport

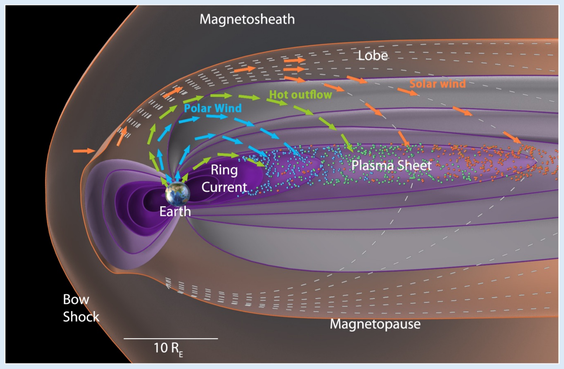


Figure 1. Major plasma sources of the plasma sheet. Solar wind plasma (orange) enters through the magnetopause and is transported into the plasma sheet. Ionospheric sources include hot auroral/cusp outflow (green) and polar wind (blue). The relative contribution of these sources varies with solar wind and geomagnetic conditions. *Kistler et al. (2023).*

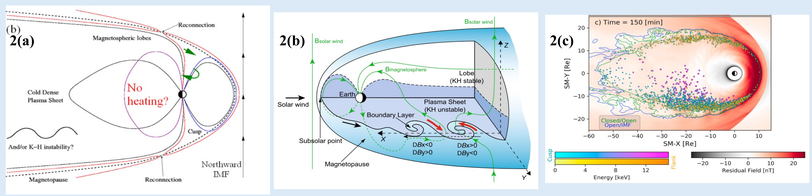


Figure 2(a): Schematic of SW transport pathways during northward IMF including double-lobe reconnection and flank transport. **Figure 2(b):** Kelvin–Helmholtz instability-driven SW entry through the magnetopause flanks. *Wing et al. (2014).* **Figure 2(c):** Simulation snapshot at 150 min showing the spatial distribution of simulated solar wind ions in the equatorial plane. *Sorathia et al. (2014).*

Science Questions

1. How much does the solar wind contribute to the plasma sheet?
2. What transport pathways deliver SW plasma to the PS?
3. How does the transport time vary with magnetic local time (MLT)?

2. He^{++}/H^{+} as a Solar Wind Tracer

- SW is dominated by H^{+} with ~ 4% He^{++}, whereas He^{++} rare in the ionosphere.
- H^{+} is abundant in both sources, cannot distinguish plasma origin.
- He^{++}/H^{+} serves as a tracer of solar wind plasma.

Measuring He^{++}/H^{+}	WIND / SWE	MMS / HPCA
	• Upstream SW composition at L1. • Bow shock propagation time delay to earth is considered.	• He^{++} and H^{+} plasma sheet densities • Computed He^{++}/H^{+} ratio at PS • Spin- averaged ion moments used.
	• 10 min time averaging → 30 min smoothing (Box-car averaging)	

Plasma Sheet Selection → Plasma Beta > 0.1 → Proton Density < 2 cm^{3} → Proton velocity Vx > -200 km/s

Time Lag Correlation Analysis

- Shift propagated WIND He^{++}/H^{+} time series by 0- 1800 min (30 min intervals)
- Calculate the **Pearson correlation coefficient (R)** with the MMS He^{++}/H^{+}
- The lag with maximum correlation is taken as the **transport time**.
- Estimate delta (Δ) delay (transport time uncertainty) from the width of the peak.

3. Representative Example Event Month

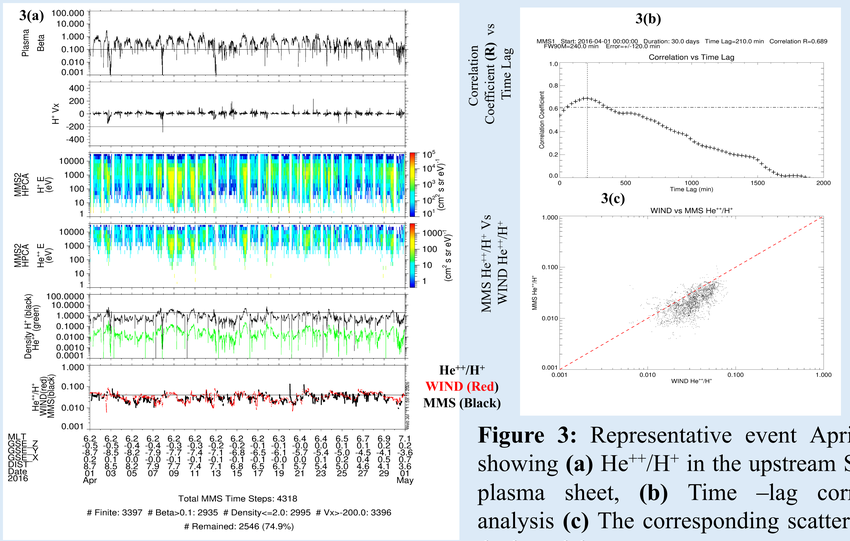
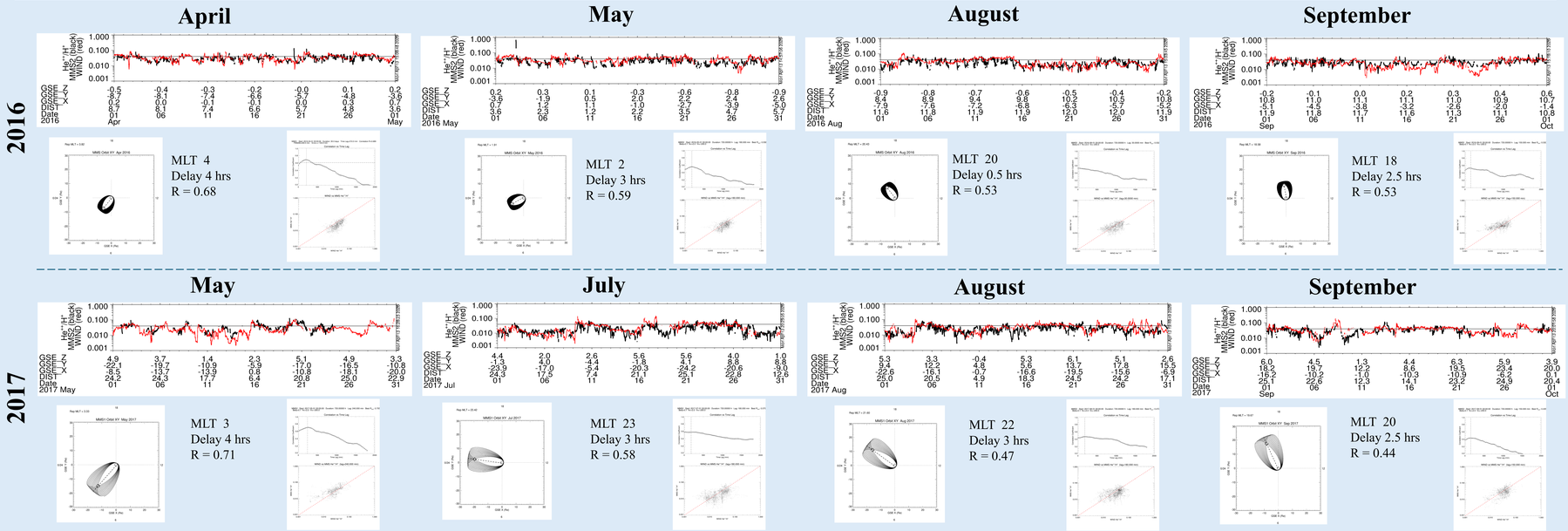


Figure 3: Representative event April 2016 showing **(a)** He^{++}/H^{+} in the upstream SW and plasma sheet, **(b)** Time –lag correlation analysis **(c)** The corresponding scatter plot at the best delay

- The Plasma sheet criteria meets most of the measurements at this month
- The PS He^{++}/H^{+} closely follow observed ratio in the upstream solar wind.
- The maximum **R** determines the transport delay of 210 min (3.5 hr)
- The scatter plot confirms the correspondence between the PS and SW.

4. Monthly Orbit and He^{++}/H^{+} Comparisons (2016, 2017)



5. MLT Dependence of Solar Wind Transport

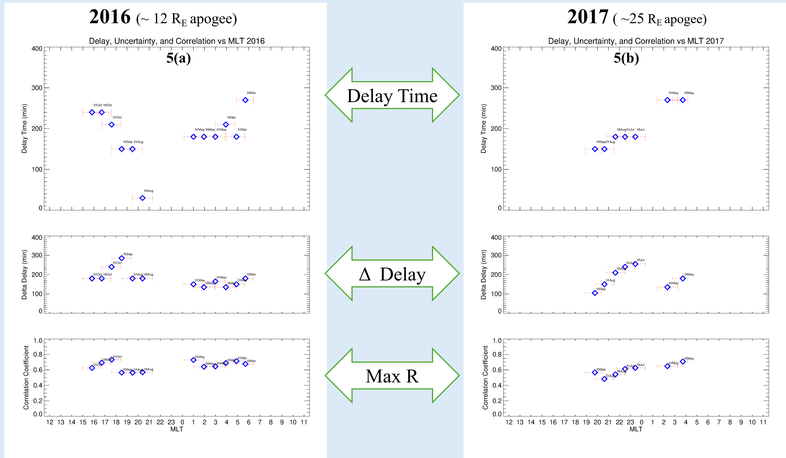


Figure 5: Statistical summary of transport time, uncertainty (Δ Delta delay), and correlation coefficient as a function of magnetic local time (MLT) **(a)** 2016 and **(b)** 2017.

Key Observations

- The 2016 MMS orbit sampled the near- Earth PS (~12 R_E apogee), whereas 2017 orbit extended farther down tail (~25 R_E apogee).
- In 2016, transport delay is relatively uniform across the nightside and increases toward the dayside MLTs.
- In 2017, transport delay increases with MLT, with shorter delays near dusk and longer delays toward dawn.

6. Conclusion

1. The He^{++}/H^{+} ratio measured in the PS closely follows the He^{++}/H^{+} ratio observed in the upstream SW, indicating that the SW is an important source of plasma sheet ions.
2. The increase in transport delay toward the dayside observed in 2016 is consistent with sunward plasma drift from the nightside PS.
3. The increase in delay with MLT observed in 2017 suggests that the solar wind source may preferentially enter on the dusk side.

7. Future Works

1. Extend the statistical analysis to all available MMS years (2016-2025).
2. Investigate transport under different IMF orientations and solar wind conditions.
3. Quantify regional variations in transport time and correlation using the 11 spatial magnetotail regions.

References

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2. Wing, S., *et al.* (2014). *Review of Solar Wind Entry into and Transport Within the Plasma Sheet.* **Space Sci. Rev.**, **184**, 33–86
3. Sorathia, K. A., *et al.* (2019). *Solar Wind Ion Entry Into the Magnetosphere During Northward IMF.* **J. Geophys. Res. Space Physics**, **124**, 5461–5481.

Acknowledgments

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