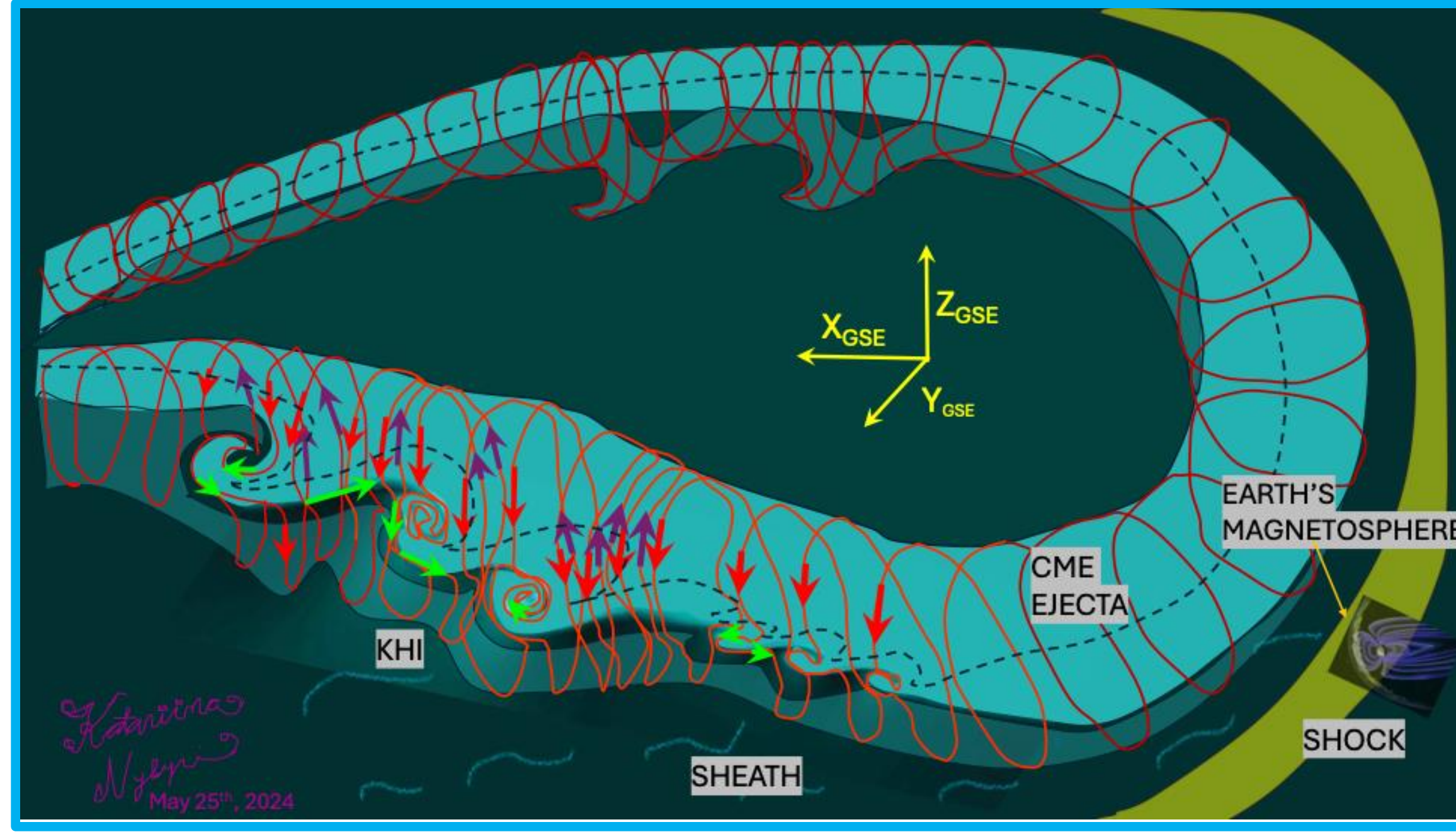


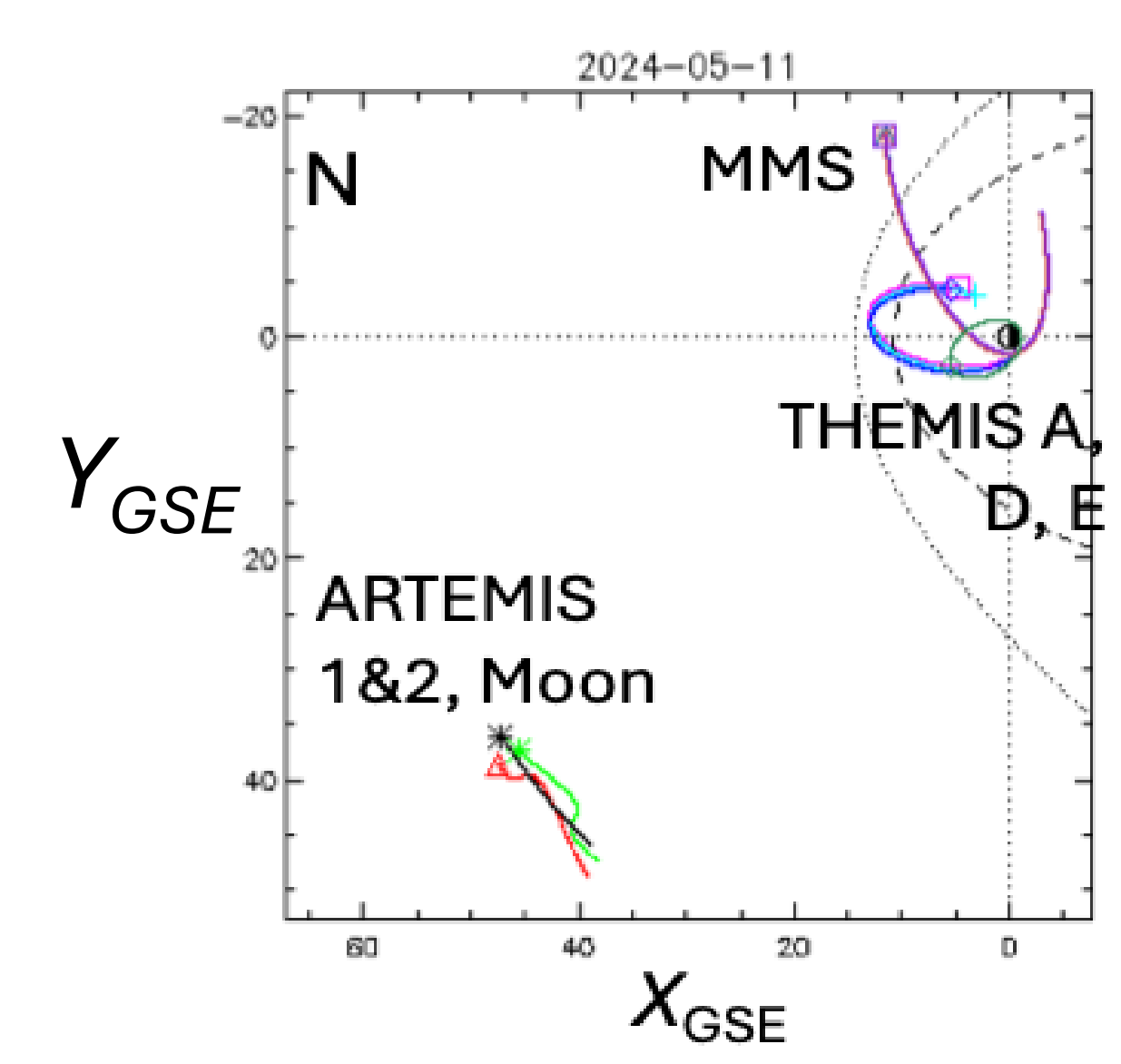
Abstract

- Starting in the evening of 10 May 2024 the Earth's magnetosphere was hit by the coronal mass ejections (CMEs) creating the largest geomagnetic storm in 20 years.
- Aurora was detected in Florida, Mexico and Southern France!
- Farmers lost ~500 million USD due to errors in GPS due to electron pockets in the ionosphere caused by this space storm.
- Storm's severity stemmed from IMF Bz variability of -60 to +40 nT with ~45-60-minute periodicity created by Kelvin-Helmholtz (KH) instability initiated ~7 million km upstream of Earth-Sun L1 point, (*Nykyri, GRL, 2024b*).

CME Structure



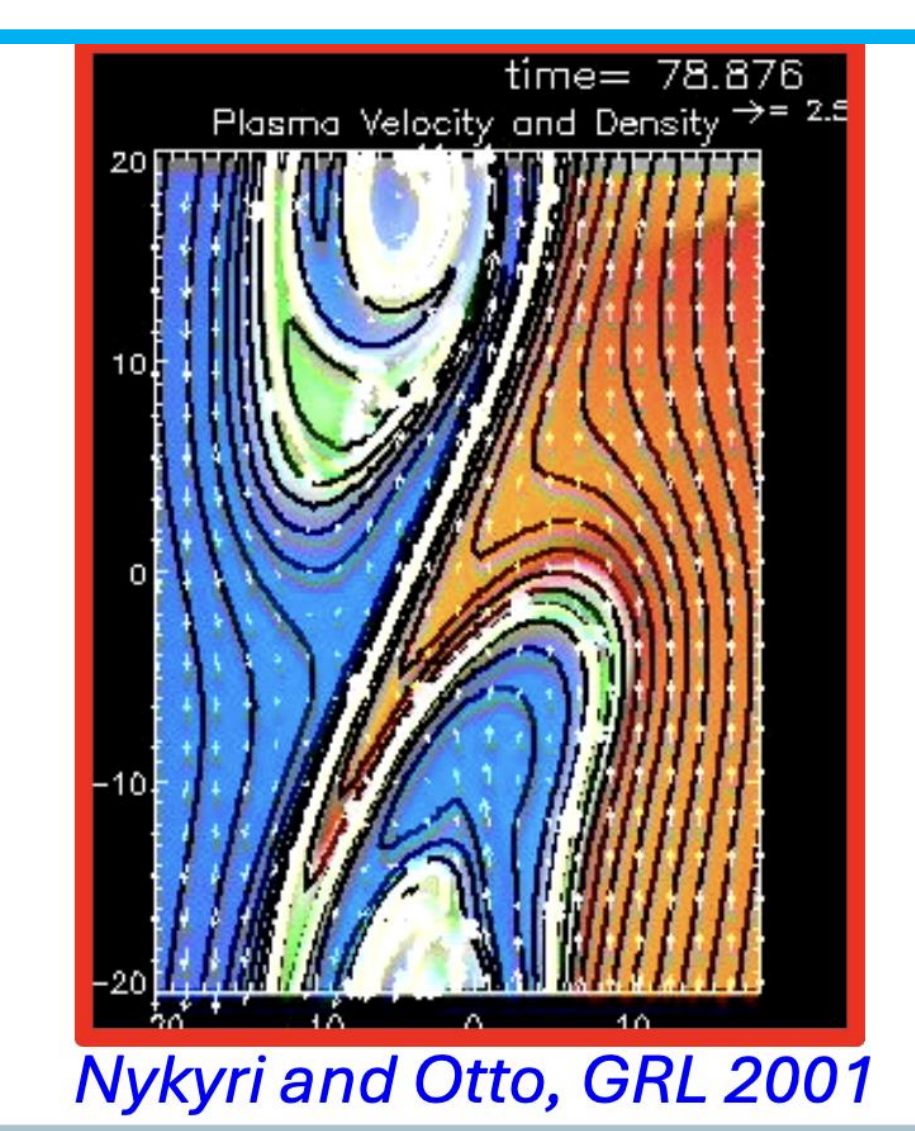
Spacecraft Locations



Main Physical Mechanisms at the Magnetopause (periodically repeated on 05/10-05/11/2024 => strong Ring Current and Aurora)

Kelvin-Helmholtz Instability (KHI)

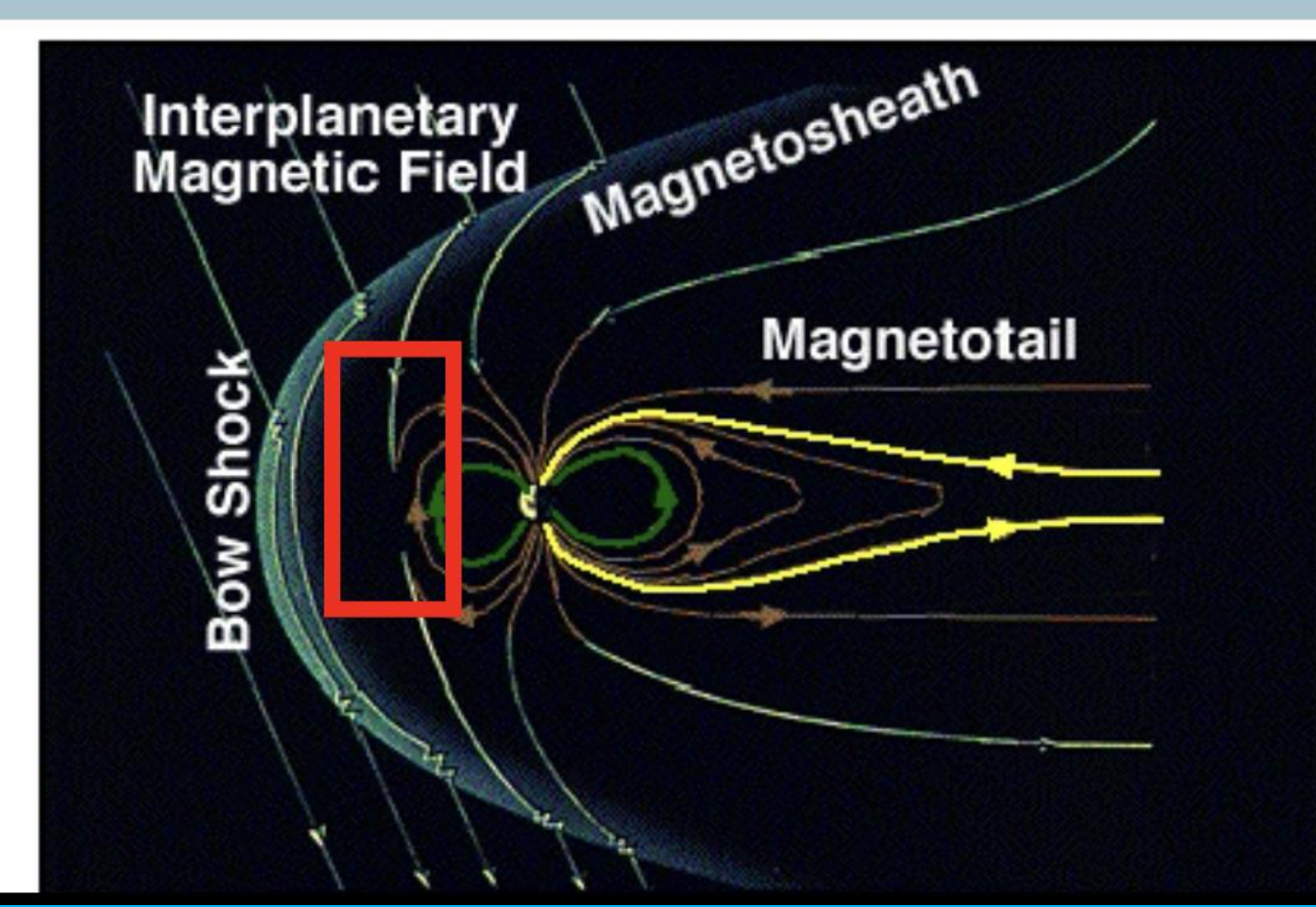
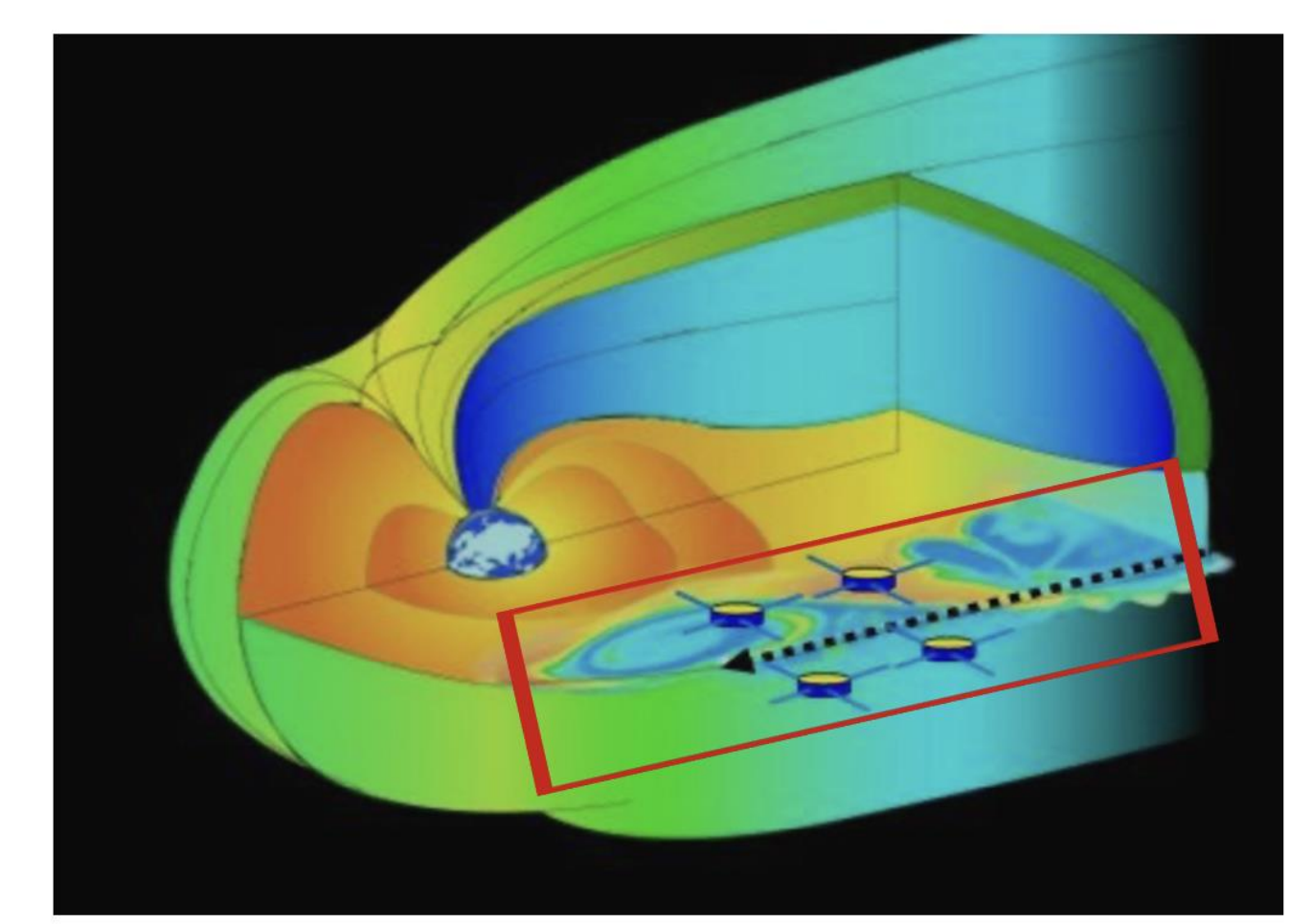
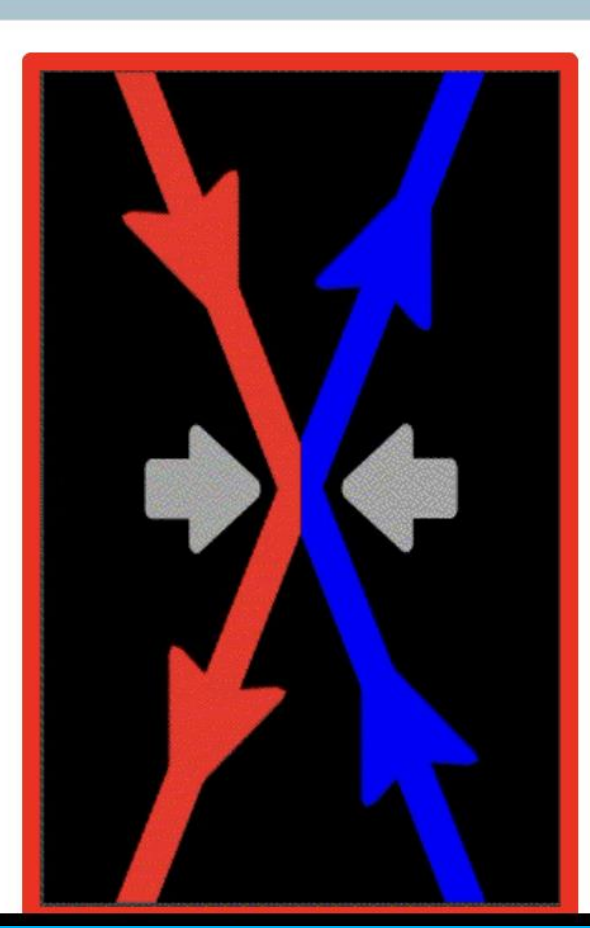
- Transport of dense solar wind plasma into the magnetotail **during northward IMF**



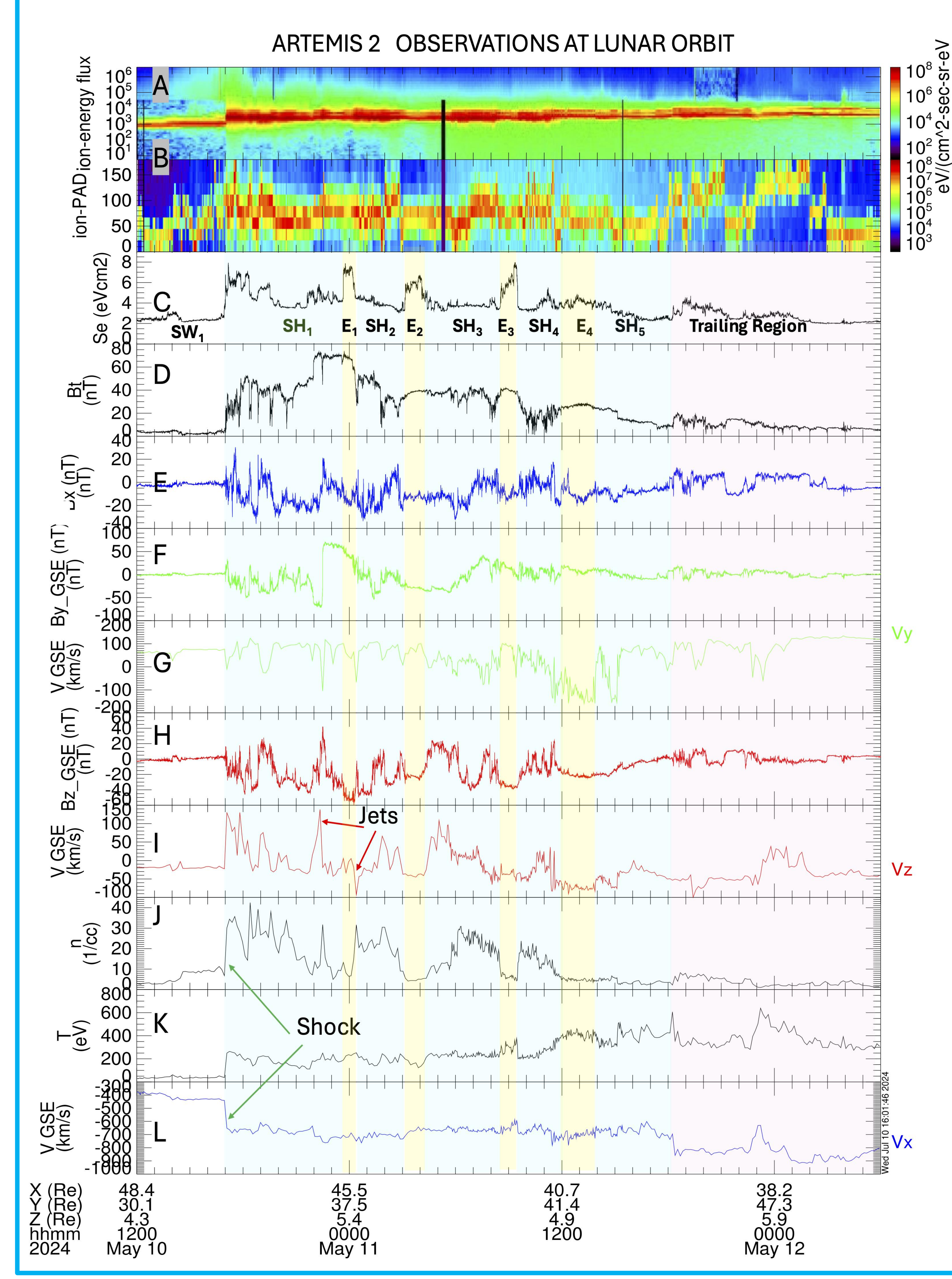
Nykyri and Otto, GRL 2001

Magnetic Reconnection

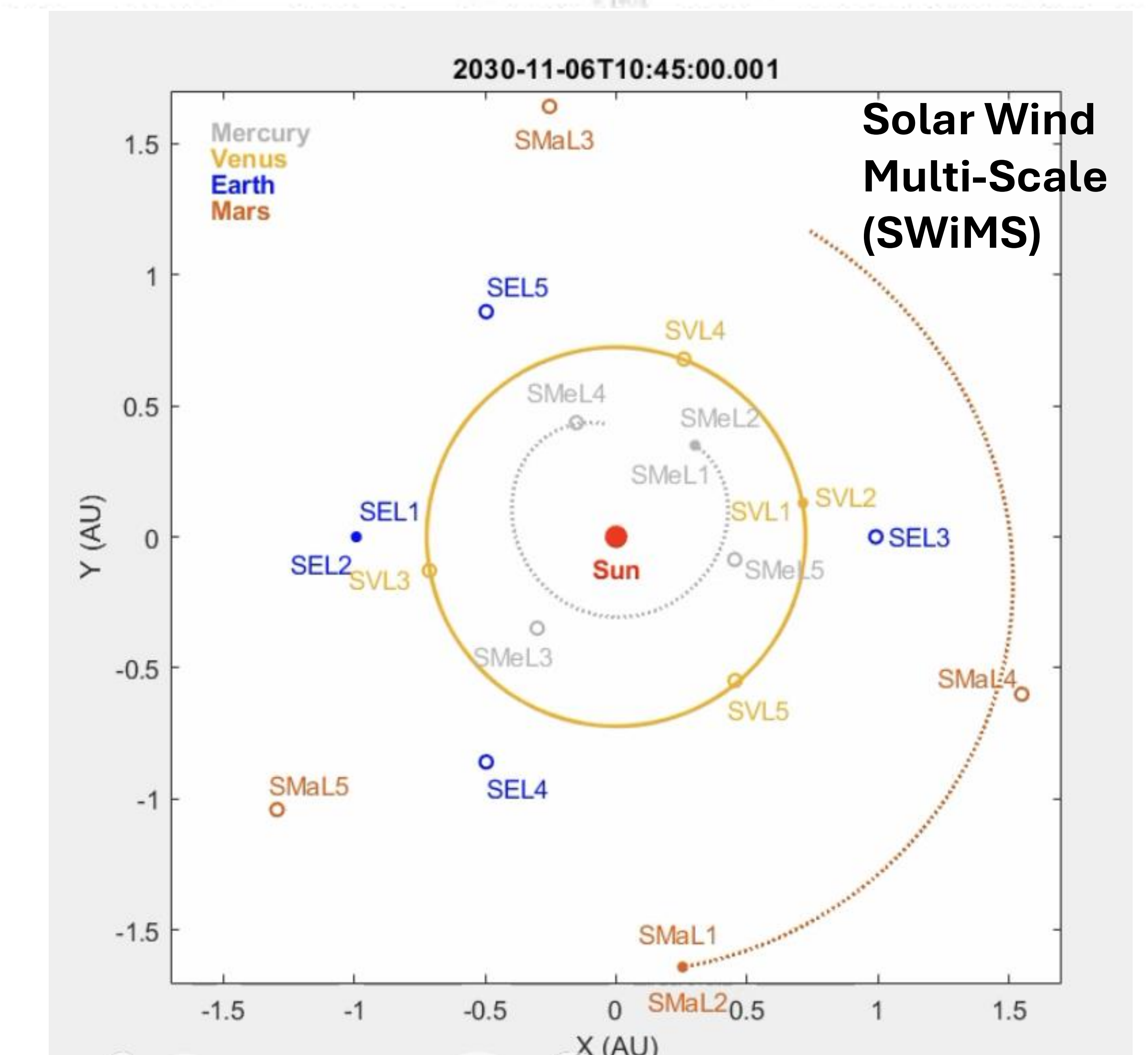
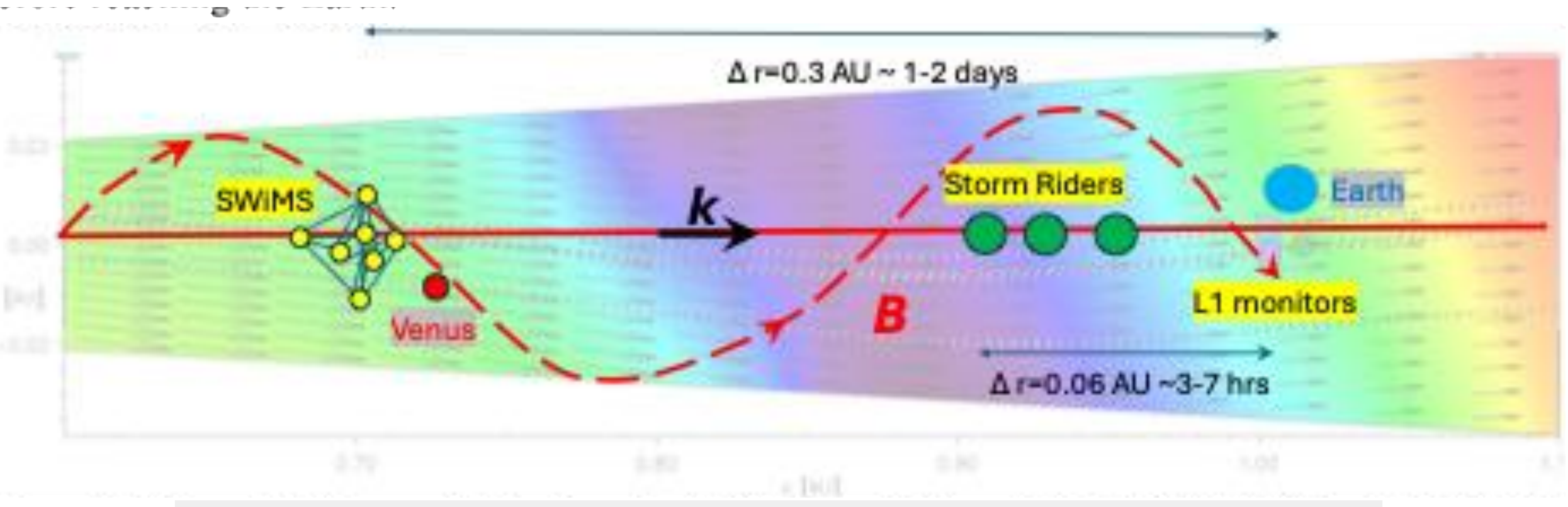
- Magnetic flux transport into the magnetotail **during southward IMF**
=> plasma acceleration and heating



ARTEMIS Spacecraft Observations



For 3-5 hr, Advanced, Warning of IMF Bz variability we need sub-L1 missions 2.5-8.5 million km from Earth and beyond!



Conclusions

- The CME boundary was twisted by giant KH waves with wavelengths ~60 to 270 R_E, initiated 7-40 M km upstream of Earth-Sun L1 point, this exposed Earth's Magnetosphere to successive intervals of strongly northward and southward IMF leading to enhanced mass and magnetic flux loading => **strong Ring Current and Aurora**
- To Prepare for the Eventual Carrington Scale Event we need Multi-scale, multi-point sub-L1 missions with automation and agility utilizing Trigger data and inter-spacecraft communication.

References: Nykyri, K. (2024). Giant Kelvin-Helmholtz (KH) waves at the boundary layer of the coronal mass ejections (CMEs) responsible for the largest geomagnetic storm in 20 years. *Geophysical Research Letters*, 51, e2024GL110477. <https://doi.org/10.1029/2024GL110477>

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Perturbation of the Earth's Magnetic field caused by the CME ejecta-sheath boundary Modulated by the Giant KH waves

