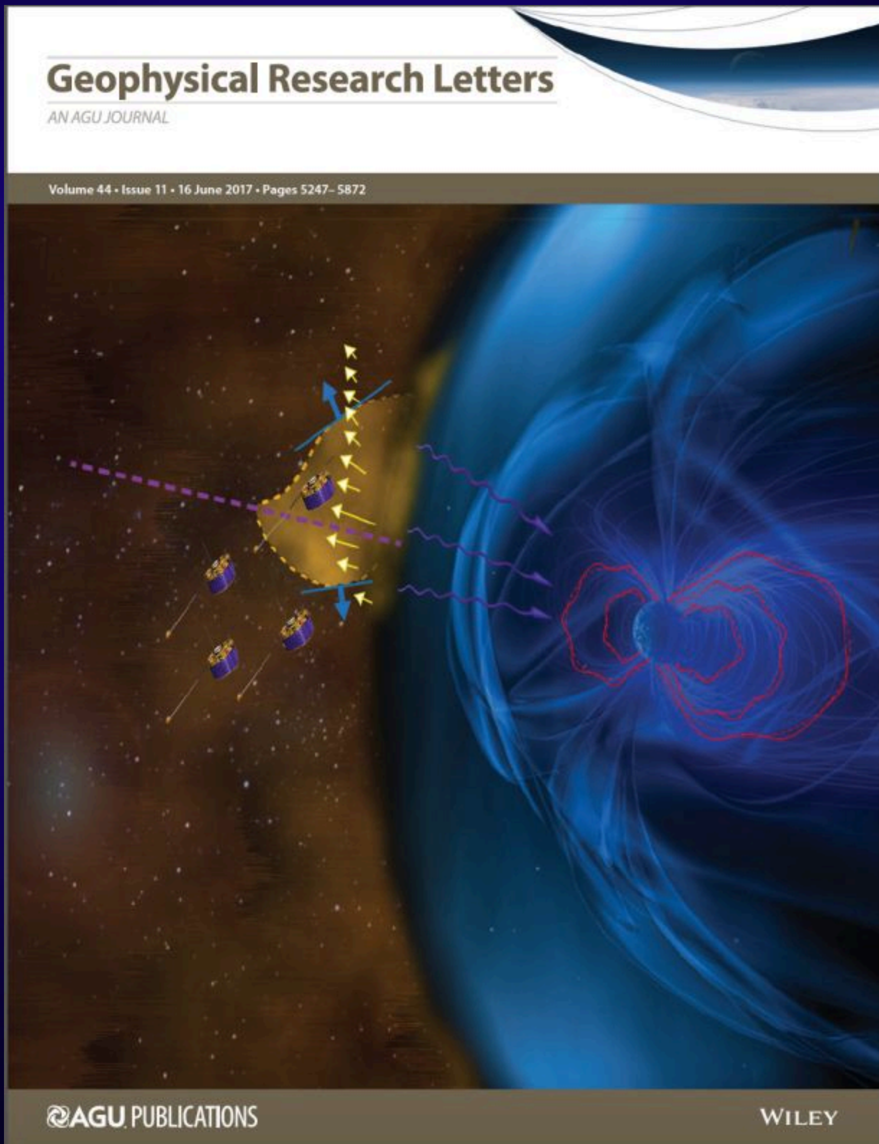
EGU2020-4367

Foreshock Transients and Their Geoeffects



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1. What are the physical differences and relationships between different transient phenomena at the bow shock?

Comparison of Transient Phenomena at the Bow Shock

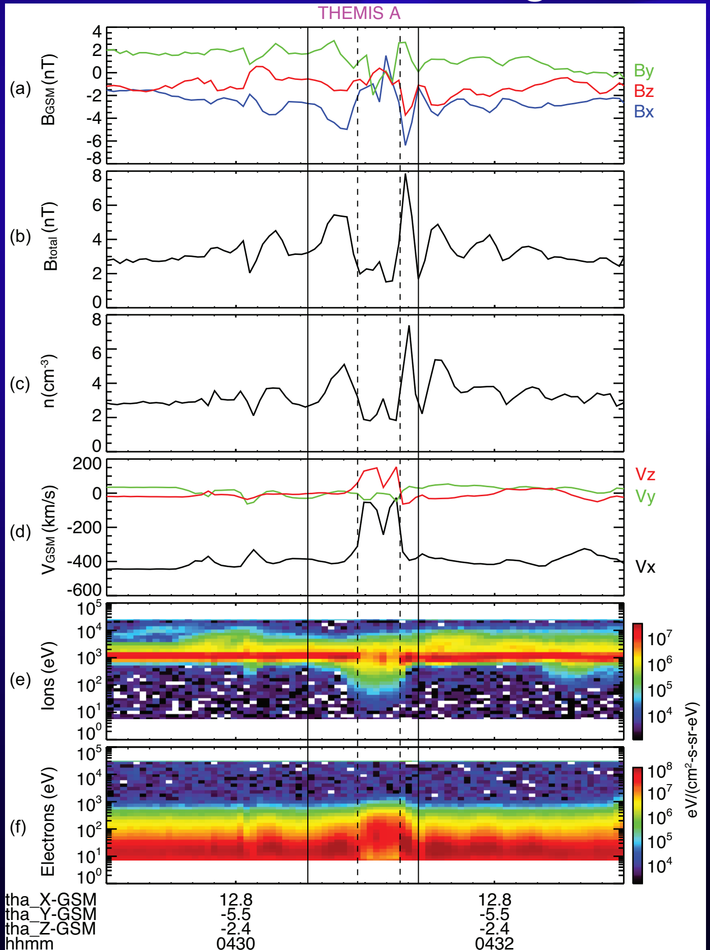
	HFAs	SHFAs	Foreshock Bubbles	Foreshock Cavities	Foreshock Cavitons	Foreshock compressional boundary	Density Holes	SLAMs
Depletion in the density and magnetic field strength	Yes	Yes	Yes	Yes	Yes	Yes on the turbulent side	Yes	Yes
Compressions at edges	Yes	Yes	Only on the upstream edge	Yes	Yes	Yes	Yes	Yes
Presence of energetic (>30 keV) particles	Yes	Yes	Yes	Yes	Yes	No	Yes	No
Significant flow deflection	Yes	Yes	Yes	No	No	No	Yes	No
Significant plasma heating	Yes	Yes	Yes	Modest	No	No	Yes	Yes
Associated with an IMF discontinuity	Yes	No	Yes	Sometimes	No	No	Yes	No
Duration	Minutes	Minutes	Minutes	Minutes	Minutes	Minutes	Seconds	~10 s
Scale size	A few R_E	A few R_E	Up to 10 R_E	A few R_E	~ R_E	~ R_E	Ion gyroradius	Ion gyroradius
Generation Mechanisms	Interaction of IMF discontinuities with the bow shock	Interaction of foreshock cavitons with the bowshock	Kinetic interactions between suprathermal, backstreaming ions and incident solar wind plasma with embedded IMF discontinuities that move through and alter the ion foreshock.	Antisunward-moving slabs of magnetic field lines connected to the bow shock that are sandwiched between broader regions of magnetic field lines that remain unconnected to	Nonlinear evolution of ULF waves	Backstreaming ions result in increased pressure within the foreshock region leading to its expansion against the pristine solar wind and the generation of FCB.	Possibly due to backstreaming particles interacting with the original solar wind	Nonlinear wave steepening

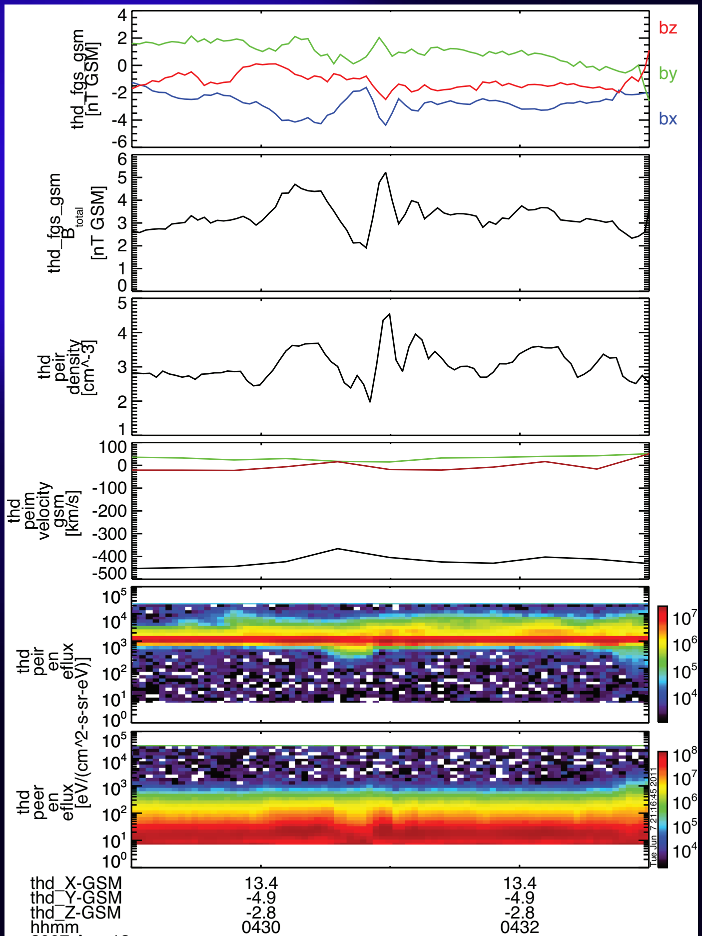
HFA and Foreshock Bubbles

- Hybrid simulations show that both tangential discontinuities and rotational discontinuities can generate HFAs by interaction with the bow shock although it is easier for tangential discontinuities to generate HFAs [personal communication with Yu Lin].
- Hybrid simulations show that rotational discontinuities can drive foreshock bubbles [Omidi et al., 2010]. Observations show that tangential discontinuities can also drive foreshock bubbles [Liu et al., 2015].
- The major observational feature to distinguish foreshock bubbles and HFAs is whether the structures have two compressional boundaries (HFAs) or only one shock on the trailing edge (foreshock bubbles) [Turner et al., 2013].
- However, sometimes a compressional boundary can also be observed on the leading edge of rotational discontinuity-driven foreshock bubbles [Liu et al., 2016a] and HFAs can also have only one compressional boundary on the trailing edge [Thomsen et al., 1988]. Therefore, it is not easy to distinguish HFAs and foreshock bubbles.

SHFA and Foreshock Caviton

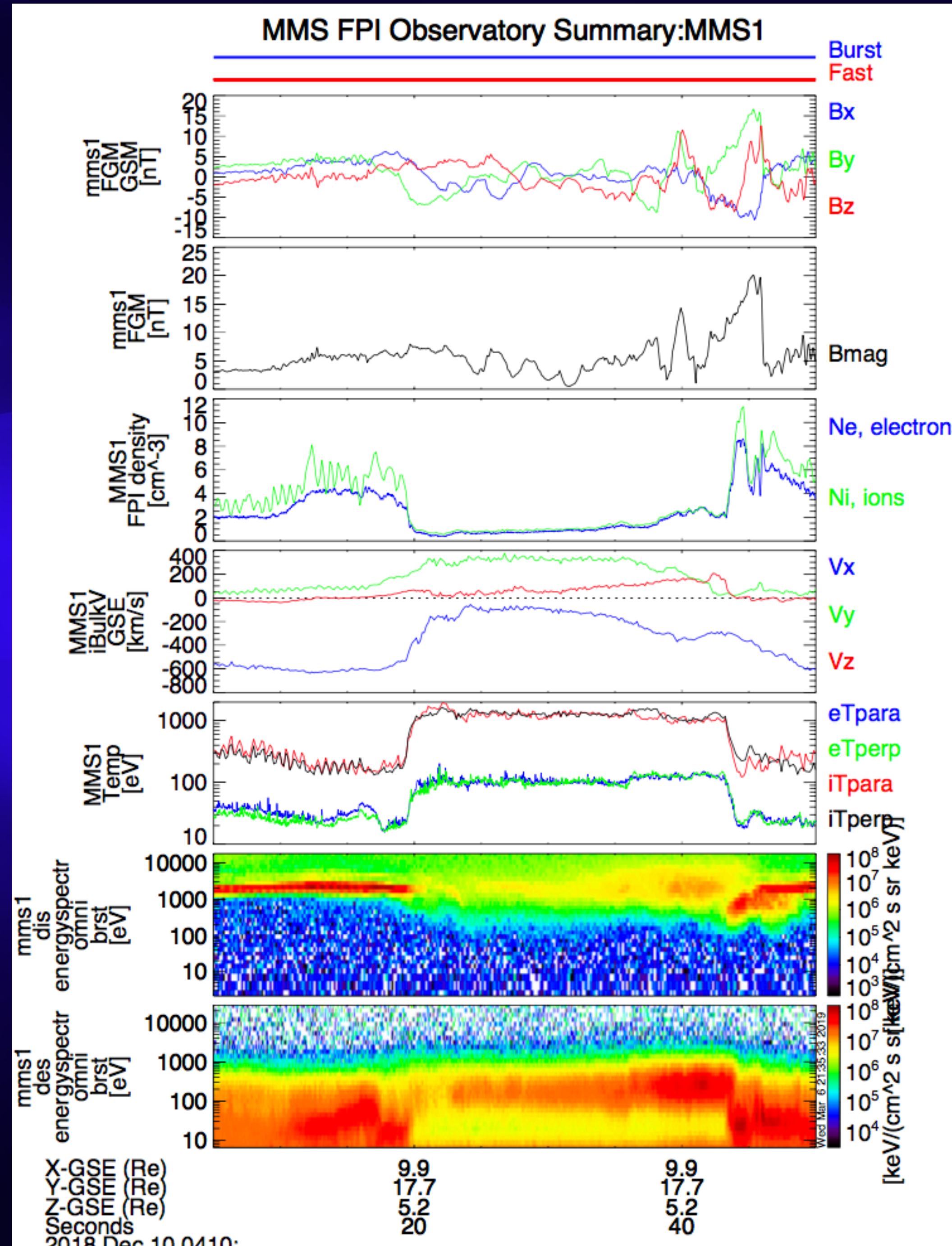
- Hybrid simulations show that SHFAs form as a result of the interaction of the foreshock cavitons with the bow shock [Omidi et al., 2013].
- The observed proto-SHFA is very similar to foreshock cavitons [Zhang et al., 2013]. These results suggest that foreshock cavitons and SHFAs could be different evolution stages of the same phenomena.





HFA and Density Hole

- Density holes [Parks et al., 2006] show similar characteristics as HFAs except that the typical duration of density holes is about 18s which is shorter than that of HFAs.
- Are density holes small scale HFAs? (Ongoing study of a graduate student Xi Lu)



2. What are the formation conditions for the transient phenomena at the bow shock and magnetopause?

- Statistical studies [Zhao et al., 2017a; Chu et al. [2017] showed that HFAs prefer to occur under the following conditions: high solar wind speed, radial IMF, Mach number greater than 5, discontinuities with large magnetic shear angles, magnetic field on at least one side of the interplanetary discontinuities has to be connected to the bow shock, the reflected flow from the bow shock is along the discontinuity, current sheets with thickness from 1000 km to about 3162 km.
- Liu et al. [2016a] suggested that if the thickness of the discontinuity is thicker (thinner) than the foreshock ion gyroradius, it is more likely to form an HFA (foreshock bubble).

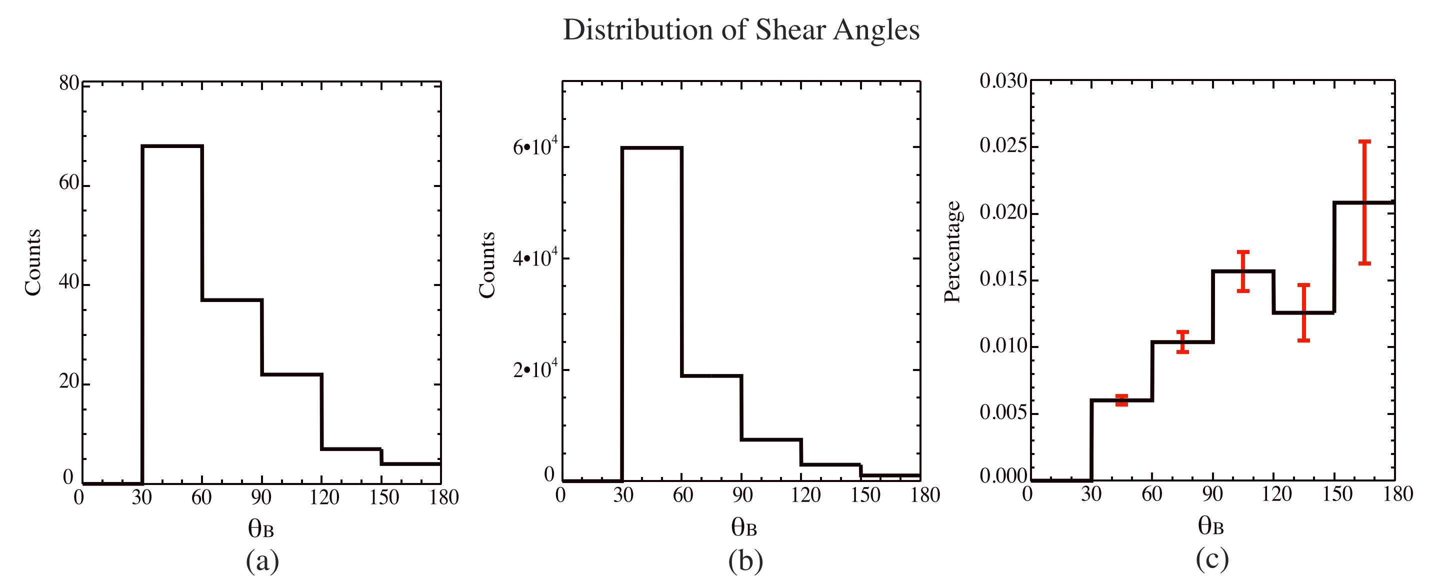


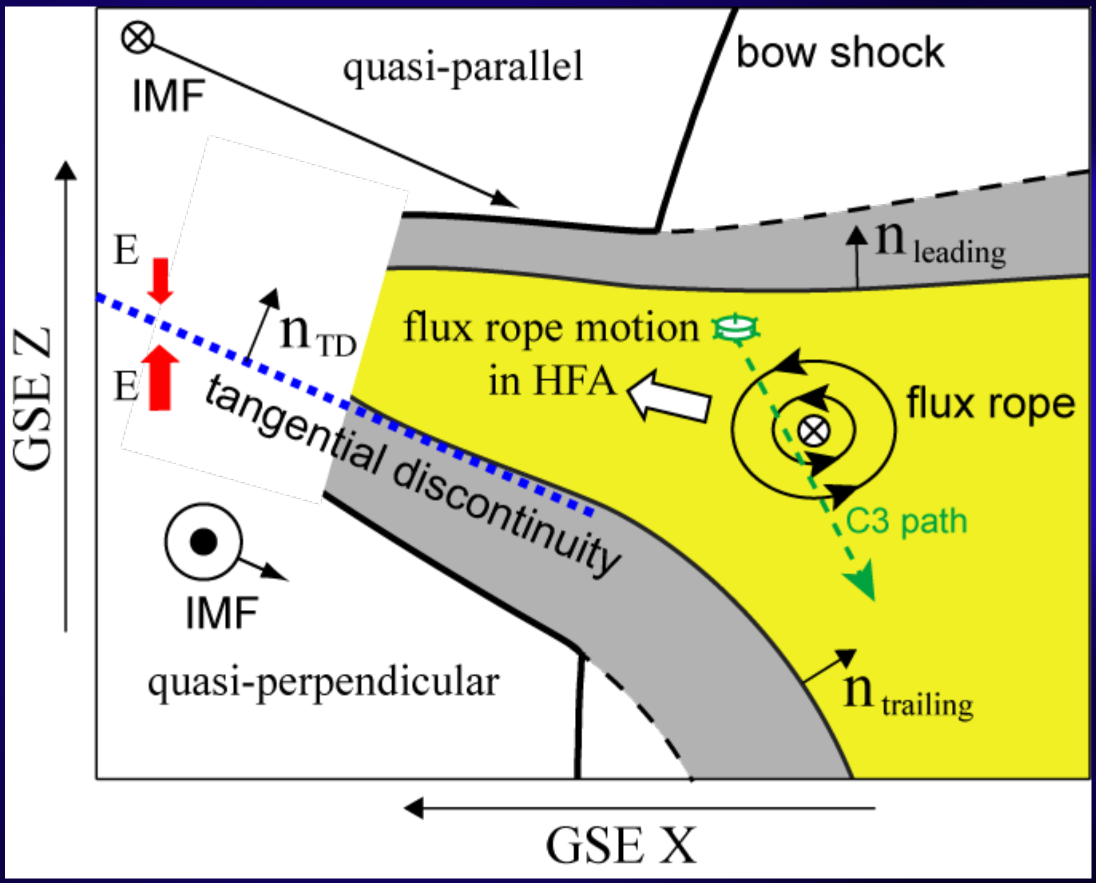
Figure 6. Statistical analysis of shear angles distribution. (a) Shear angles distribution of 138 HFA events. (b) Shear angles distribution of 90,135 discontinuities in the solar wind. (c) Normalized shear angles distribution of HFAs.

- However, HFAs have also been observed under “unreferred” conditions.
- For example, Thomsen et al. [1993] suggested that HFAs should be associated with current sheets exhibiting the predicted inward electric field orientation on at least one side.
- However, Wang et al. [2013c] found that electric field on neither leading nor trailing edge points toward the discontinuity for 19 out of 144 (13%) HFAs.
- This result implies that the convective electric field pointing toward the discontinuity may help an HFA growing but its presence is not a necessary condition to generate an HFA.
- Simulations and observations show completely different results on whether HFAs occur at quasi-perpendicular or quasi-parallel shocks [Zhang et al. 2010 and references therein]. Wang et al. [2013b] showed that HFAs can be formed at both quasi-parallel and quasiperpendicular shocks.

3. How do the magnetosphere and ionosphere respond to transient phenomena generated at bow shock?

- Trigger magnetic reconnection
- Drive magnetopause boundary waves
- Generate FACs, TCVs/MIEs
- Excite ULF waves
- Auroral response

Flux Rope Generation, i.e., Reconnection Initiation, within HFA

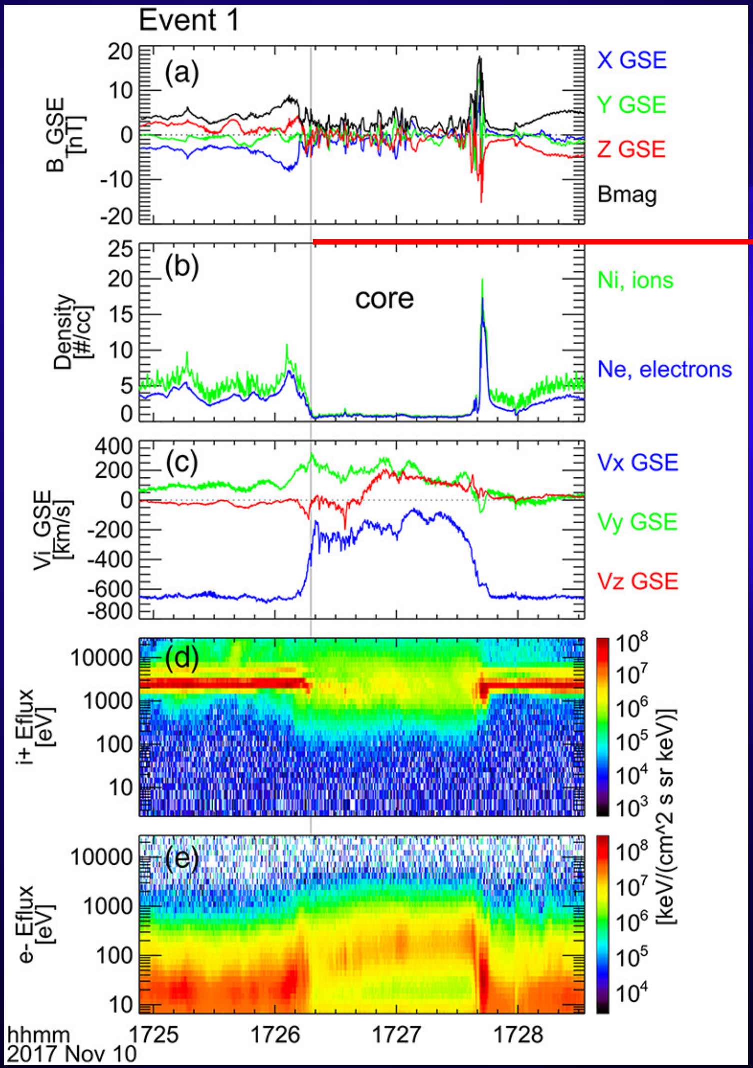


- Low N & high T_i in HFA make ion gyro-radius & inertia length longer, favorable for fast reconnection.
- Moreover, sheath current sheets may be compressed against the magnetopause & become thin (*Phan et al.*, GRL, 2011).

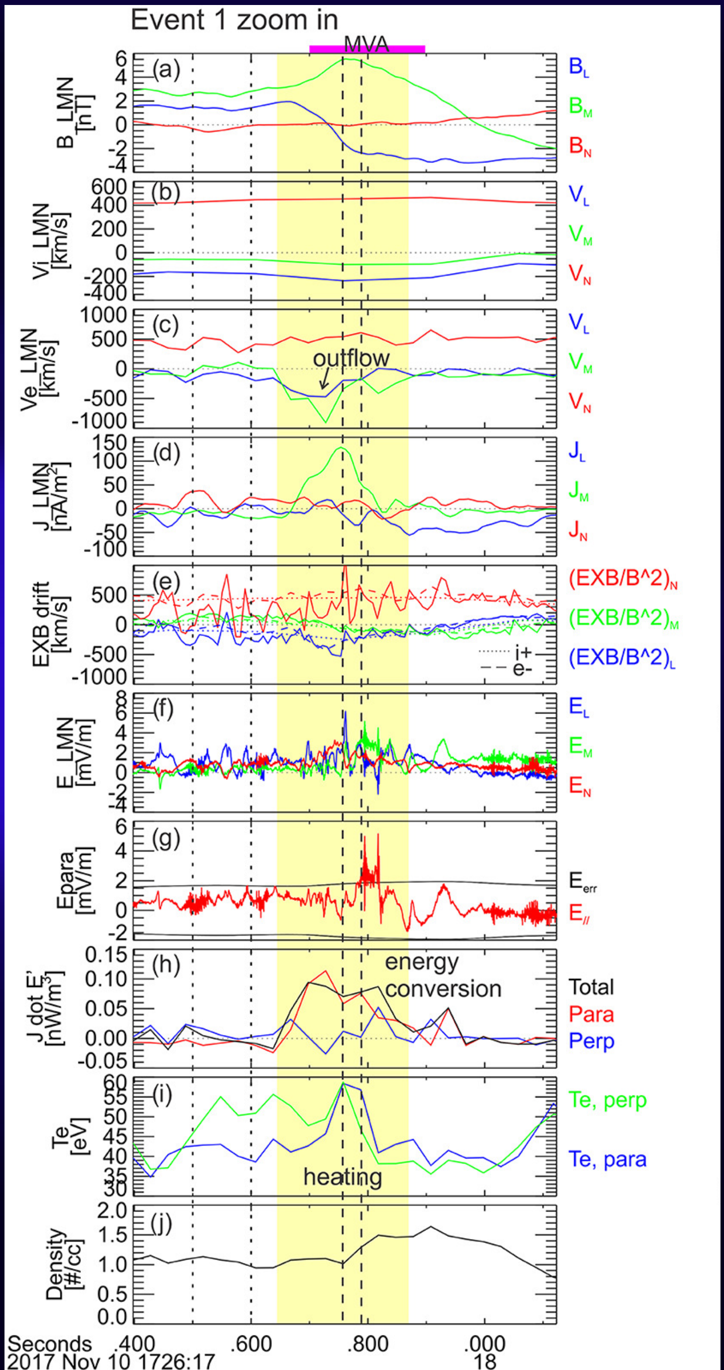
Hasegawa et al., 2012

- Reconnection probably occurred on the side with quasi-|| shock configuration.

MMS Observations of Magnetic Reconnection in Foreshock Transients



Zoomed in



T. Z. Liu et al., 2020

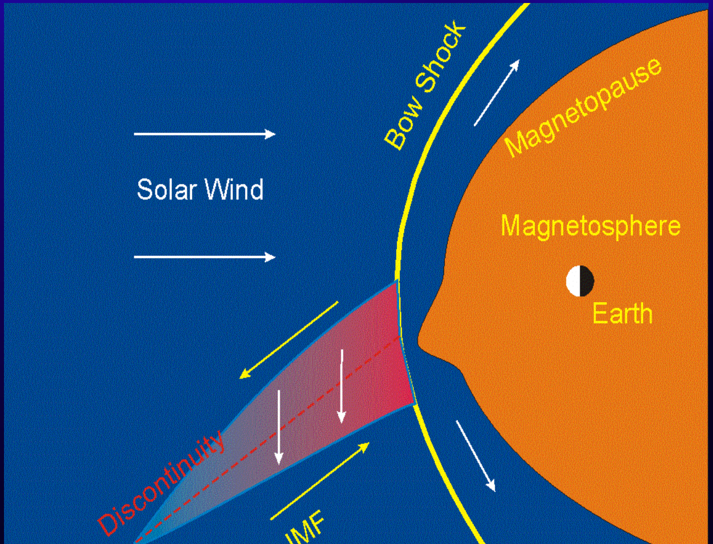
Drive Magnetopause Boundary Waves

Pressure Balance at the Magnetopause

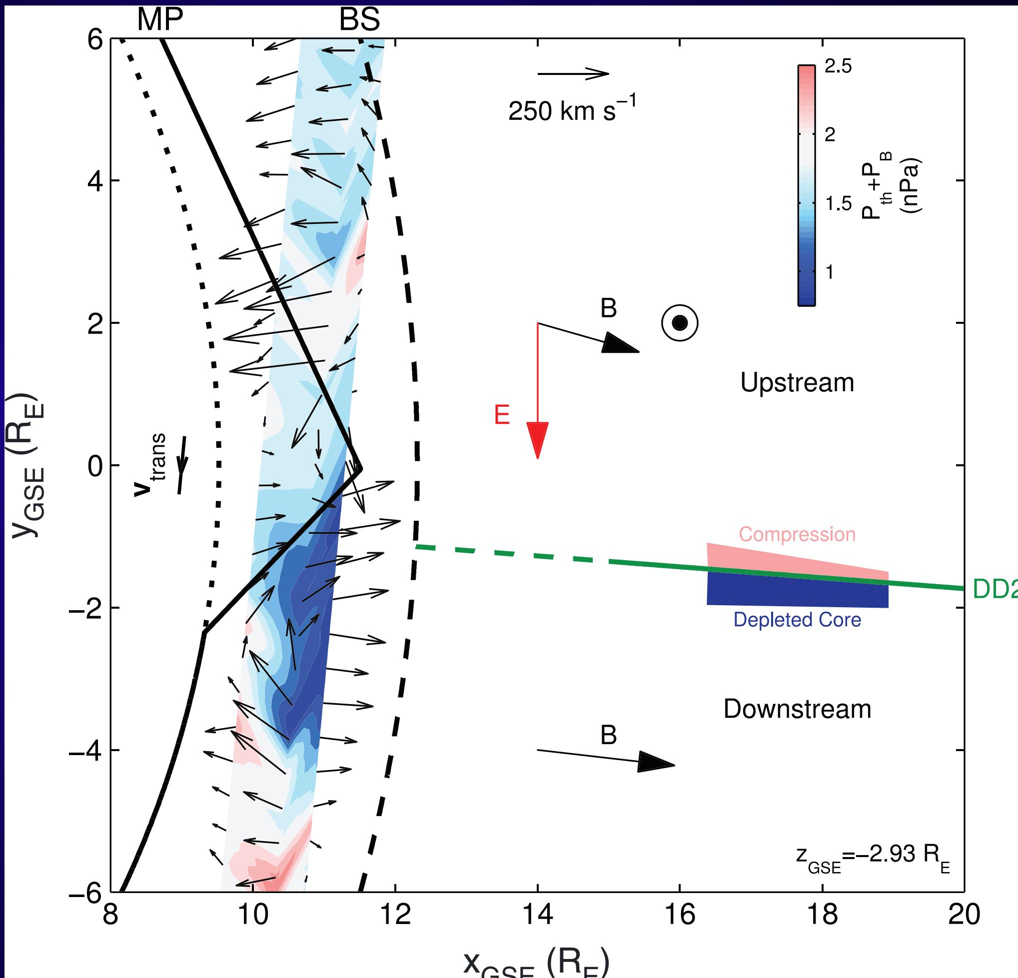
	Solar Wind		Magnetosphere	
dynamic pressure	thermal pressure	magnetic pressure	thermal pressure	magnetic pressure

$$n_{sw} m v^2 \cos^2\theta + \cancel{p_{th\_sw}} + \frac{B_{sw}^2}{2\mu_0} = \cancel{p_{th\_sphere}} + \frac{B_{sphere}^2}{2\mu_0}$$

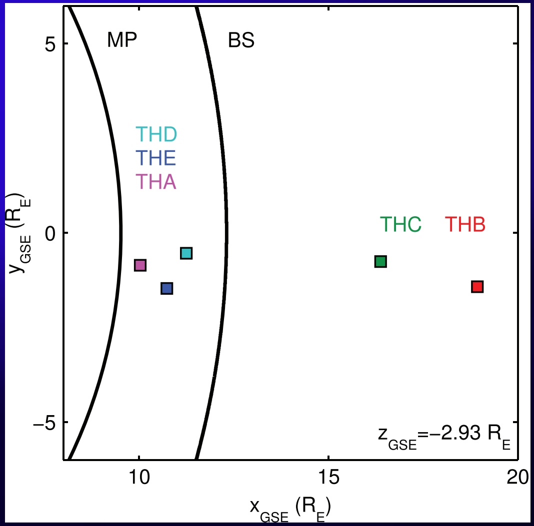
small small



Magnetopause Deformation due to an HFA

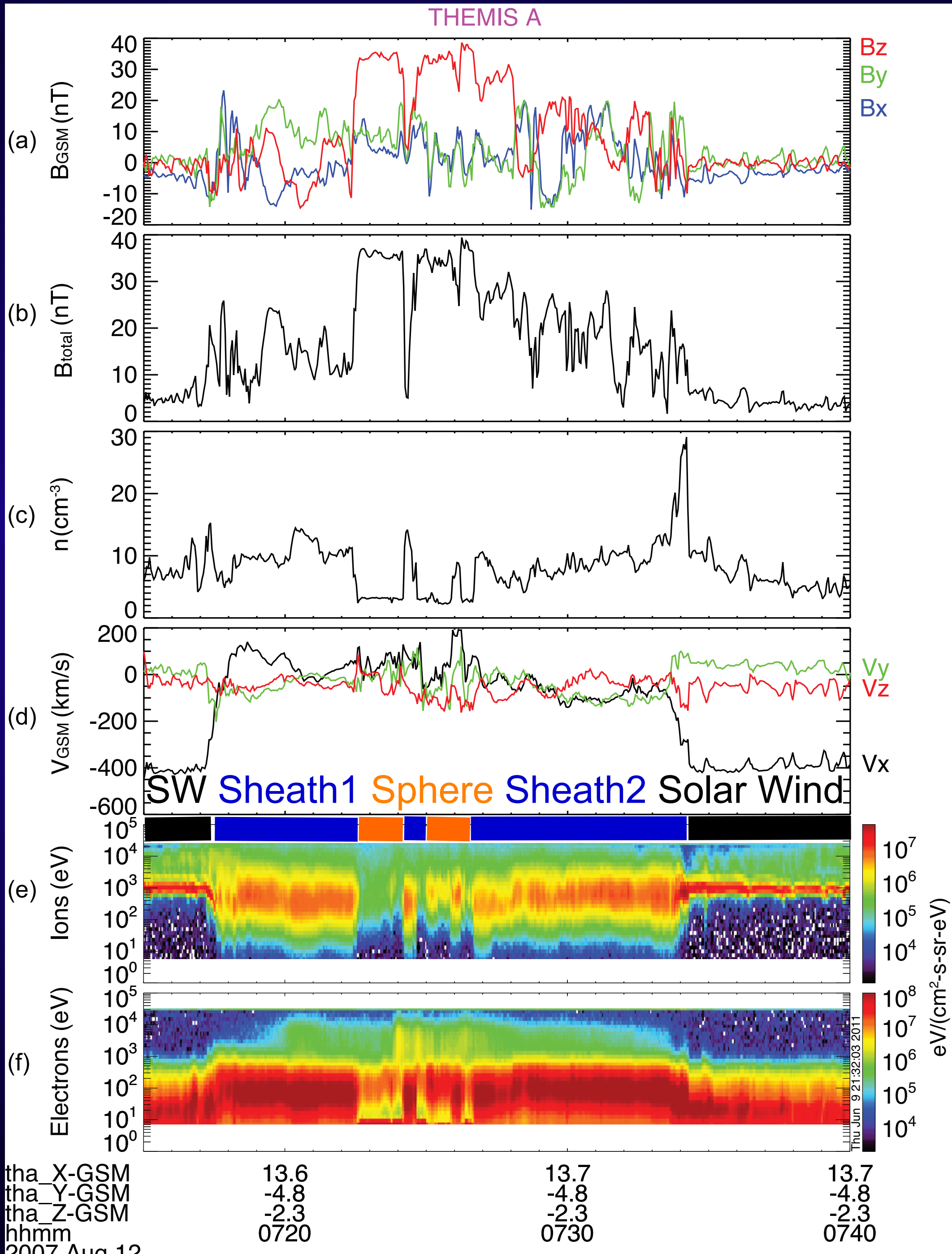


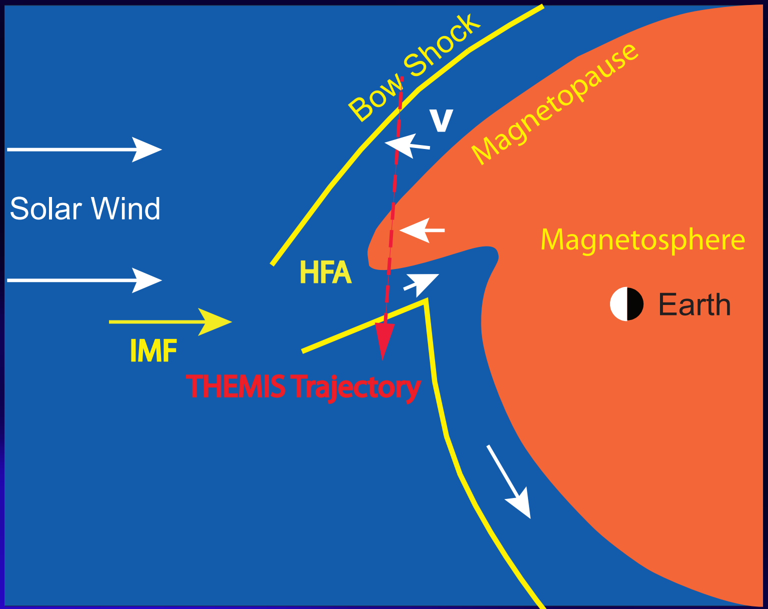
- Black solid line: The observed magnetopause deformation
- Black arrow: flow pattern
- Color scale: the contours of the thermal + magnetic pressure.
- Sunward magnetosheath flow



Archer et al., GRL 2014

Jacobsen et al.[2009] reported THEMIS observations of the extreme motion of the magnetopause, with flow speeds 800 km/s. Magnetopause was displaced outward by at least 4.8 R_E in 59 s. A bulge was moving tailward at 355 km/s.

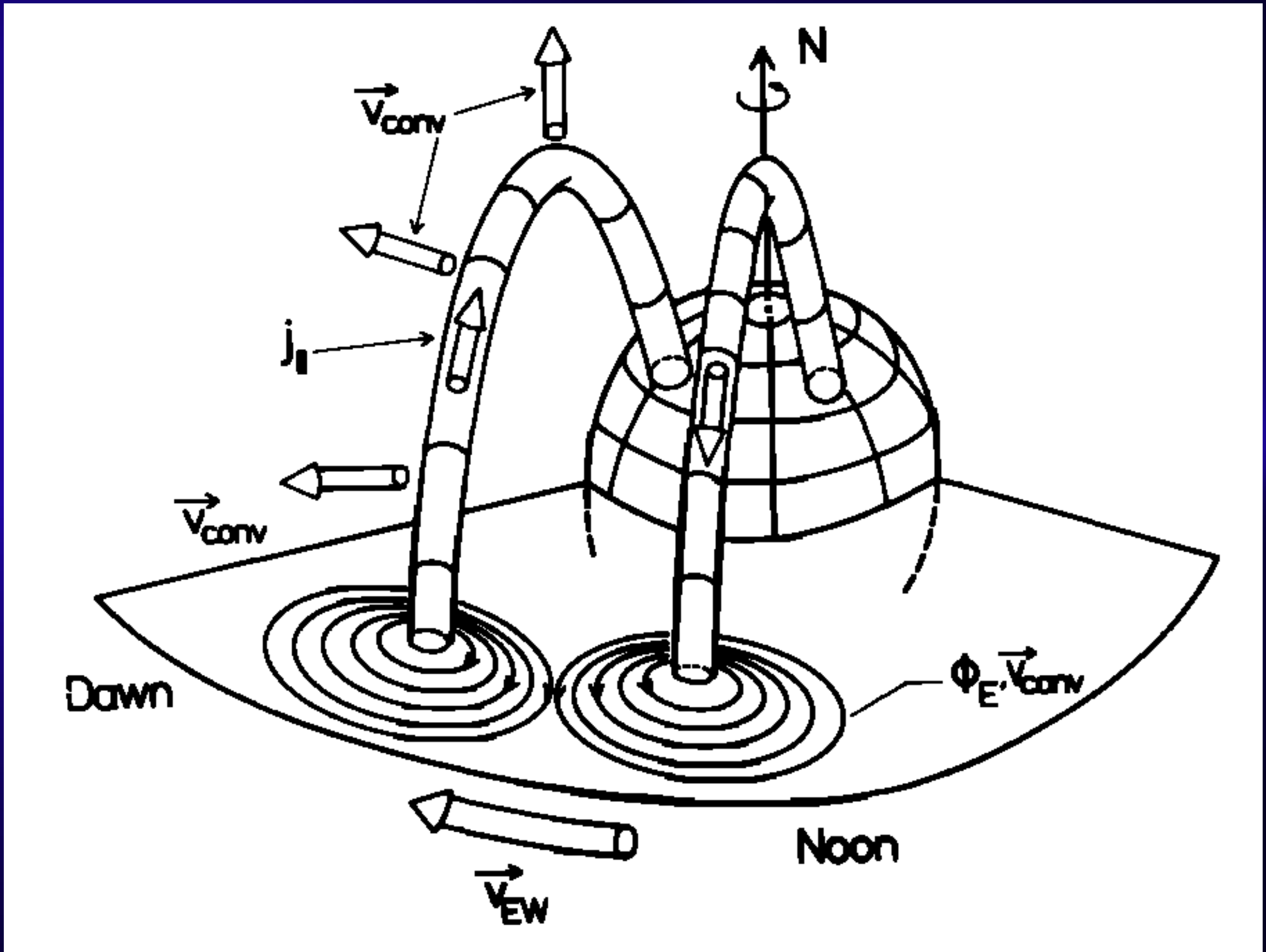




- The magnetopause bulged out by at least 4 R_E.
- The event lasted 17 minutes => scale size in y direction > 10 R_E
- The bulge is convecting tailward with the magnetosheath flow at ~100 km/s.

courtesy of H. Zhang

- Deformation of the magnetopause generates field-aligned currents (FACs) into the auroral ionosphere – FAC signatures are measured on the ground as magnetic impulse events (MIEs) or traveling convection vortices (TCVs) [*Glassmeier et al.,* 1989; *Sitar et al.,* 1998]



Glassmeier et al., 1989

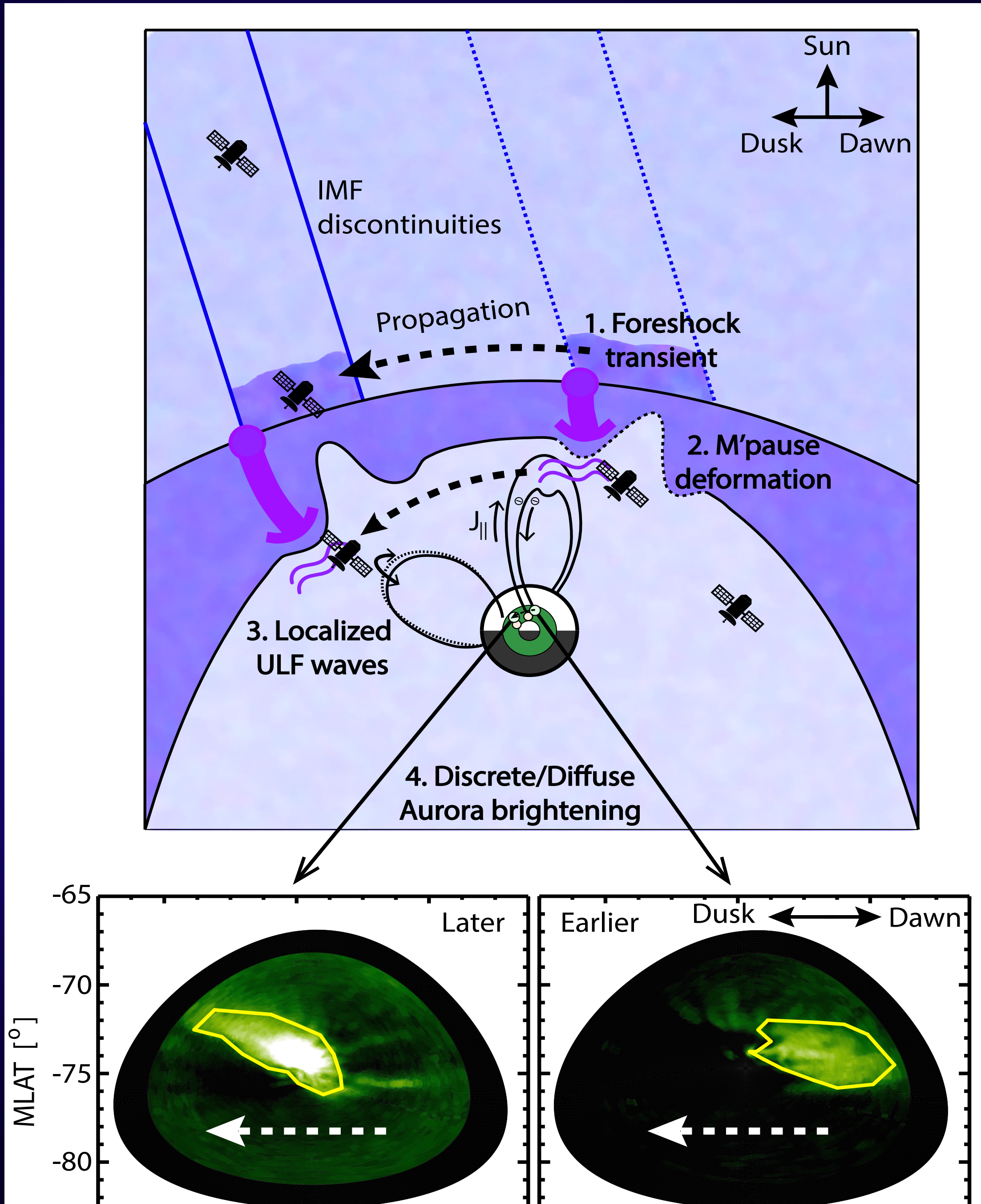
Foreshock Transients Generate ULF Waves

- Several studies have demonstrated that transient phenomena near the bow shock (such as HFAs) can generate ULF waves in the Earth's magnetosphere. (This is different from the low-latitude Pc3 waves that are driven by upstream waves in the ion foreshock.)

- The ULF waves generated by transient phenomena near the bow shock in both Pc3 [Eastwood et al., 2011, Zhao et al., 2017] and Pc5 [Fairfield et al., 1990; Hartinger et al., 2013, Shen et al., 2018] ranges have been reported.

- There may be considerable variation between ULF waves resulting from different transient features. e.g., Hartinger et al. [2013] showed mostly compressional waves whereas Eastwood et al. [2011] and Zhao et al. [2017] showed standing Alfvén waves, and Shen et al. [2018] showed both compressional and Alfvén waves.

- The magnetospheric response could be global [Zhao et al., 2017] or localized [Shen et al., 2018]. The different effects might be caused by the different pressure variation profiles associated with the transients, size of the transients, and the location where the waves were observed in the magnetosphere.



A schematic plot of **magnetospheric and ionospheric response to a foreshock transient,** from magnetopause deformation to field line resonance inside the magnetosphere and the aurora response in the ionosphere.

A localized magnetopause compression propagated from pre-noon to post-noon and induced auroral brightening.

See Shen et al. [2018] and Wang et al. [2018] for details.

Courtesy of B. Y. Wang, X. C. Shen, Q. Q. Shi, H. Zhang, and T. Nishimura