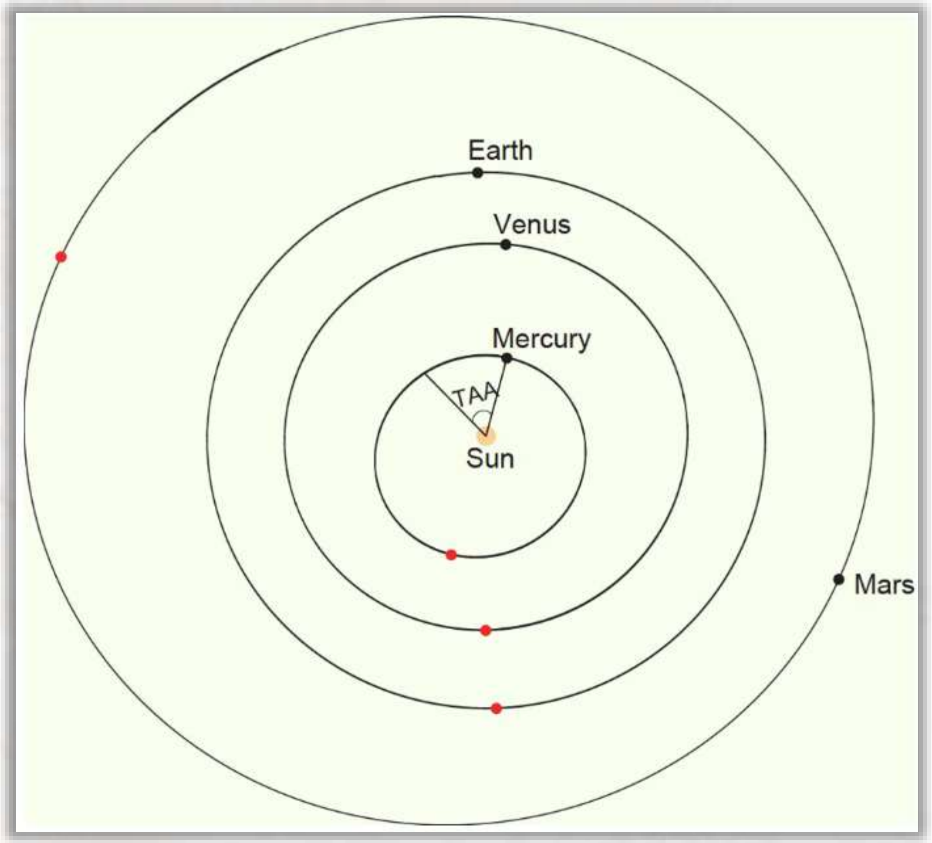
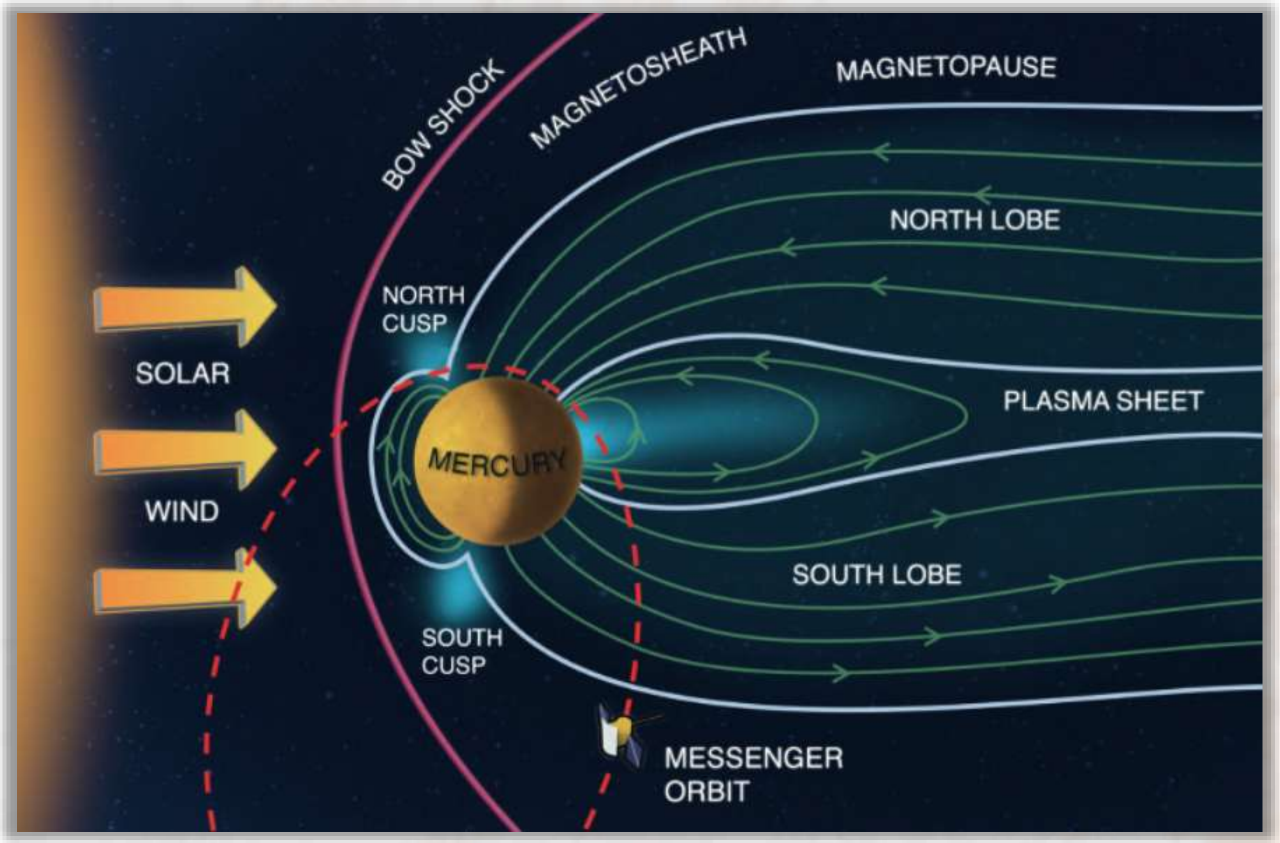
0 Dynamic Environment of Mercury's Magnetosphere

Position & Magnetosphere Structure



[Sun W et al., 2022]



[Zurbuchen et al., 2011]

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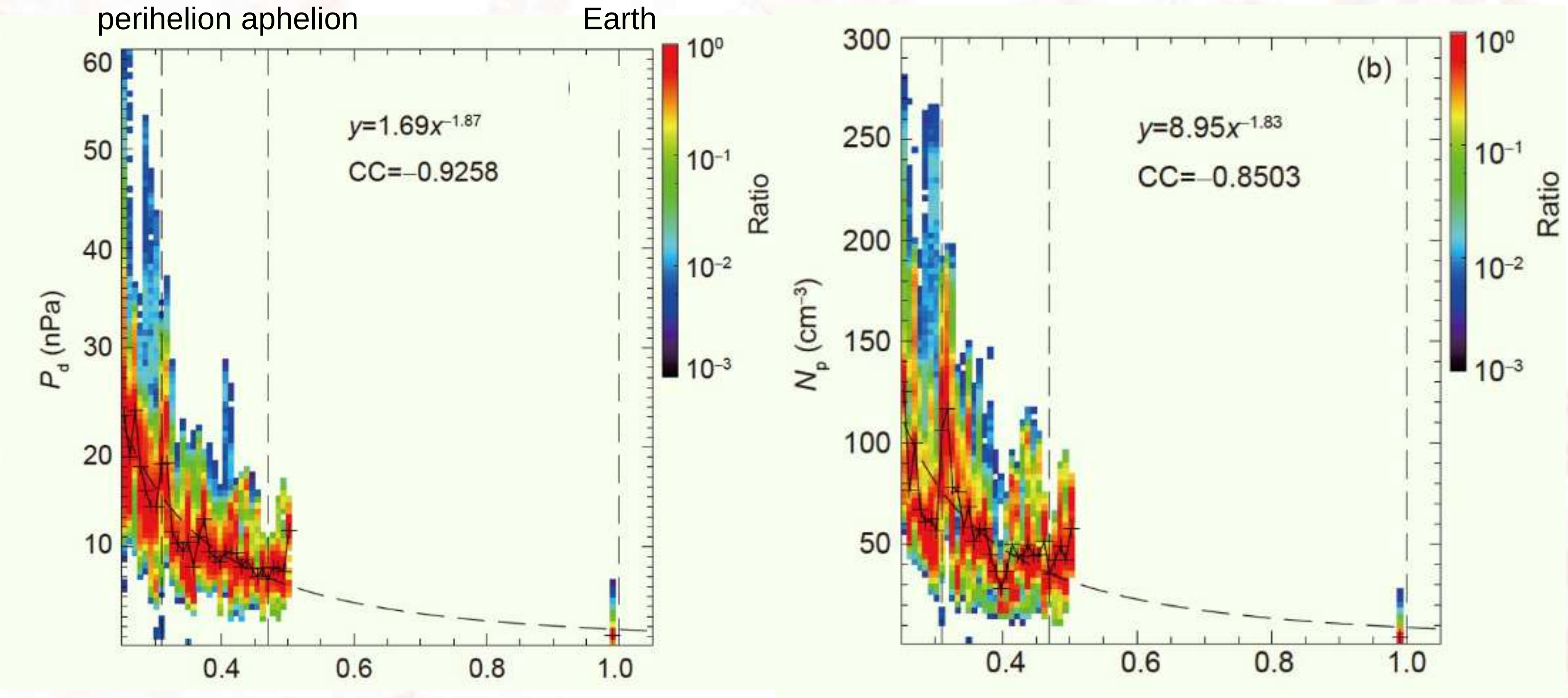
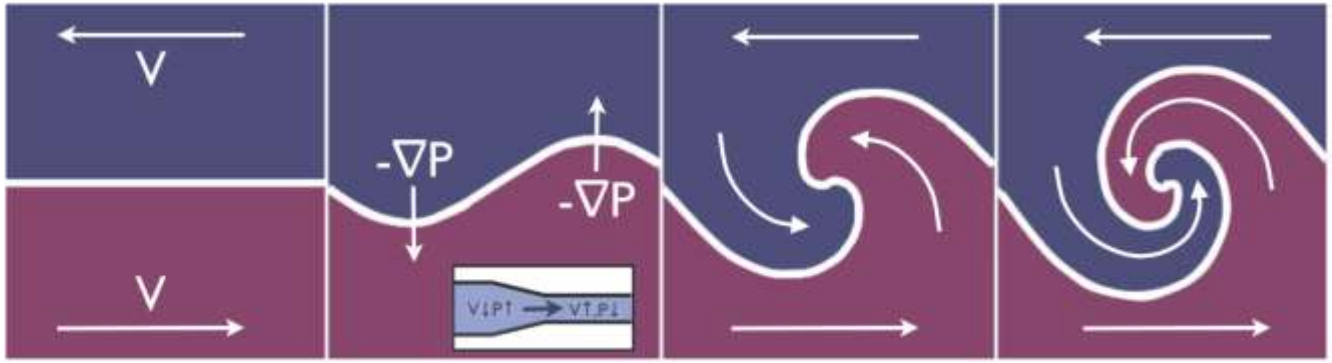


[Sun W et al., 2022]

- **Solar wind dynamic pressure:** ~3.5 to 9.0 nPa, **six to 10 times of Earth’s** (~0.55 nPa)
- **Solar wind density:** ~30 to 120 cm^{-3}, **six to 30 times of Earth’s** (~4.5 cm^{-3})

1 Kelvin–Helmholtz Instability



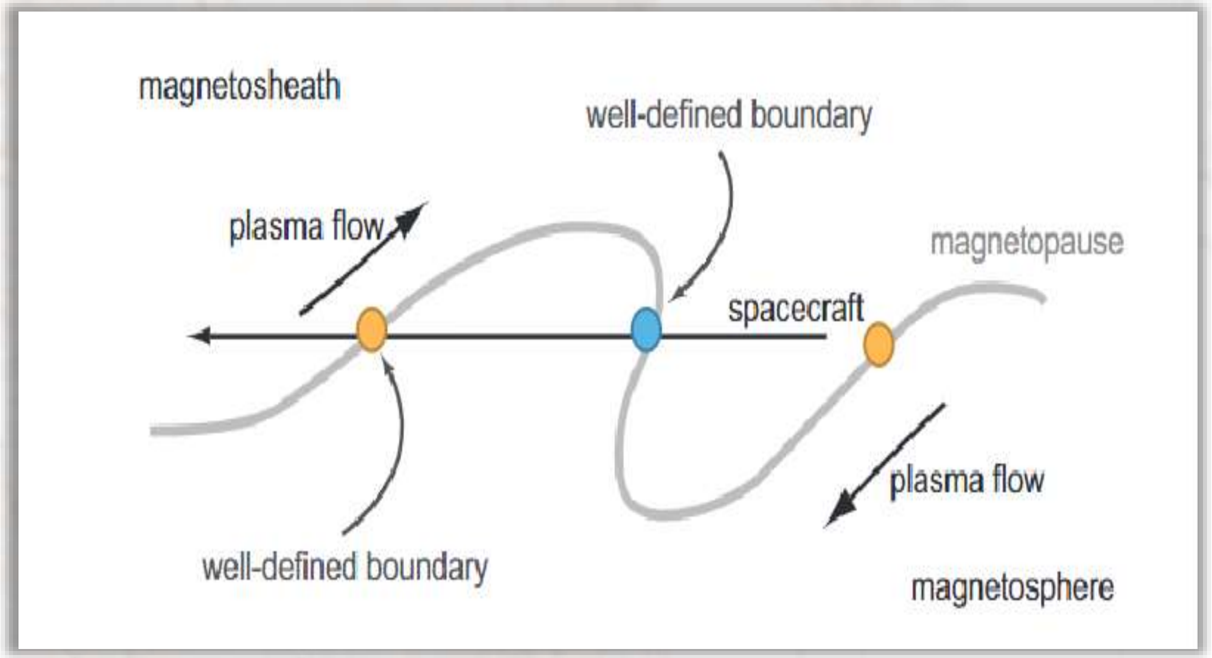
[J.R.Johnson et al., 2014]

- **A velocity shear exists either within a single fluid or between two distinct fluids.**
- Kelvin-Helmholtz (K-H) waves at the magnetopause are driven by velocity shear between magnetospheric and magnetosheath plasma flows

$$\omega = \frac{\mathbf{k}\cdot(\rho_{msh}\mathbf{V}_{\mathbf{msh}} + \rho_{msp}\mathbf{V}_{\mathbf{msp}})}{\rho_{msh}+\rho_{msp}} \pm i\sqrt{\left(\frac{\rho^*}{\rho_{msh}+\rho_{msp}}\right)\left(\left[\mathbf{k}\cdot(\mathbf{V}_{\mathbf{msh}}-\mathbf{V}_{\mathbf{msp}})\right]^2 - \frac{(\mathbf{k}\cdot\mathbf{B}_{msh})^2+(\mathbf{k}\cdot\mathbf{B}_{msp})^2}{4\pi\rho^*}\right)} \quad (1)$$

where ρ^* is a mean mass $\rho^* = \rho_{msh}\rho_{msp}/(\rho_{msh}+\rho_{msp})$ (msp/msh = magnetosphere/sheath). K–H waves are unstable when $(\mathbf{k}\cdot(\mathbf{V}_{\mathbf{msh}}-\mathbf{V}_{\mathbf{msp}}))^2 > ((\mathbf{k}\cdot\mathbf{B}_{msh})^2+(\mathbf{k}\cdot\mathbf{B}_{msp})^2)/4\pi\rho^*$.

2 How to pick up Kelvin–Helmholtz waves?

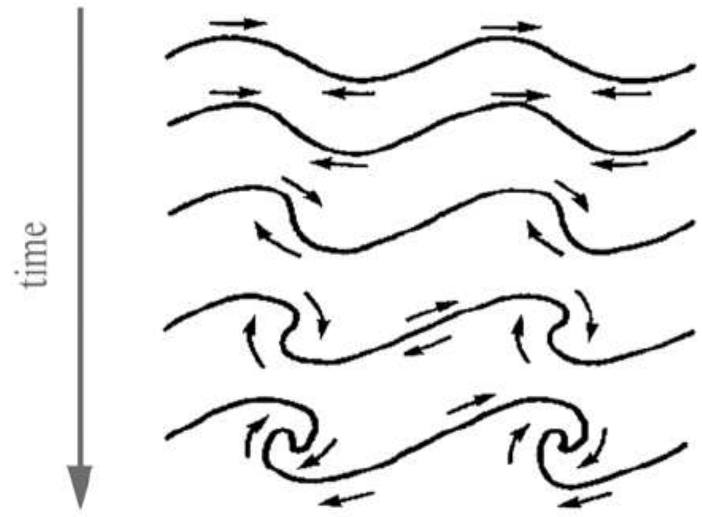


[T. Sundberg et al., 2010]

Due to the lack of direct flow measurements from MESSENGER, we identified Kelvin-Helmholtz (K-H) waves through variations in the **magnetic field, plasma density, and plasma temperature**.

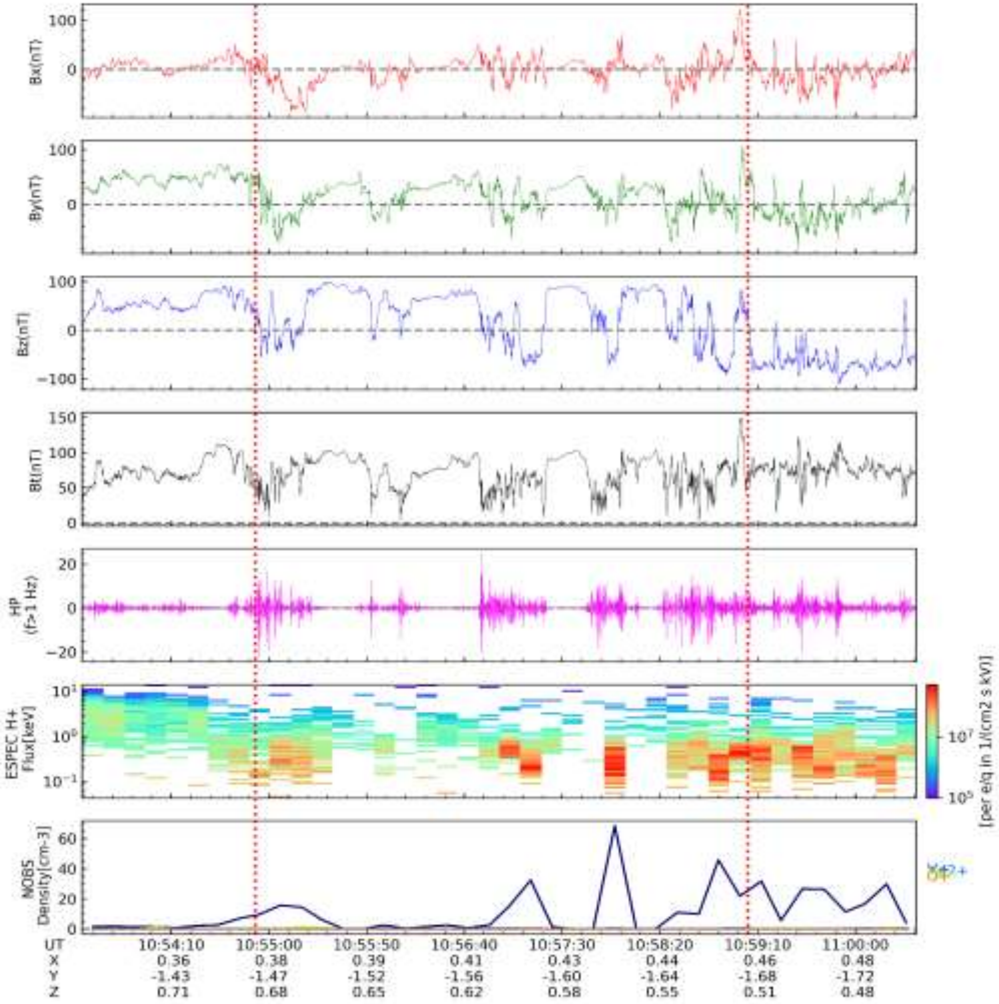
Characteristics	Comparison
Magnetic field	Magnetosheath < Magnetosphere
Plasma density	Magnetosheath > Magnetosphere
Plasma temperature	Magnetosheath < Magnetosphere

Linear magnetopause waves



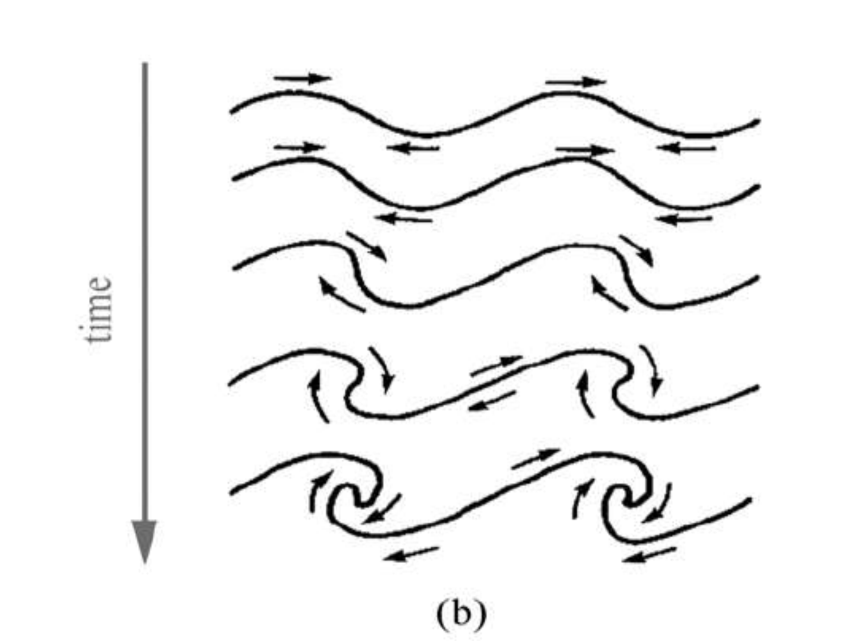
(b)

[Cushman-Roisin and Becker 2007]

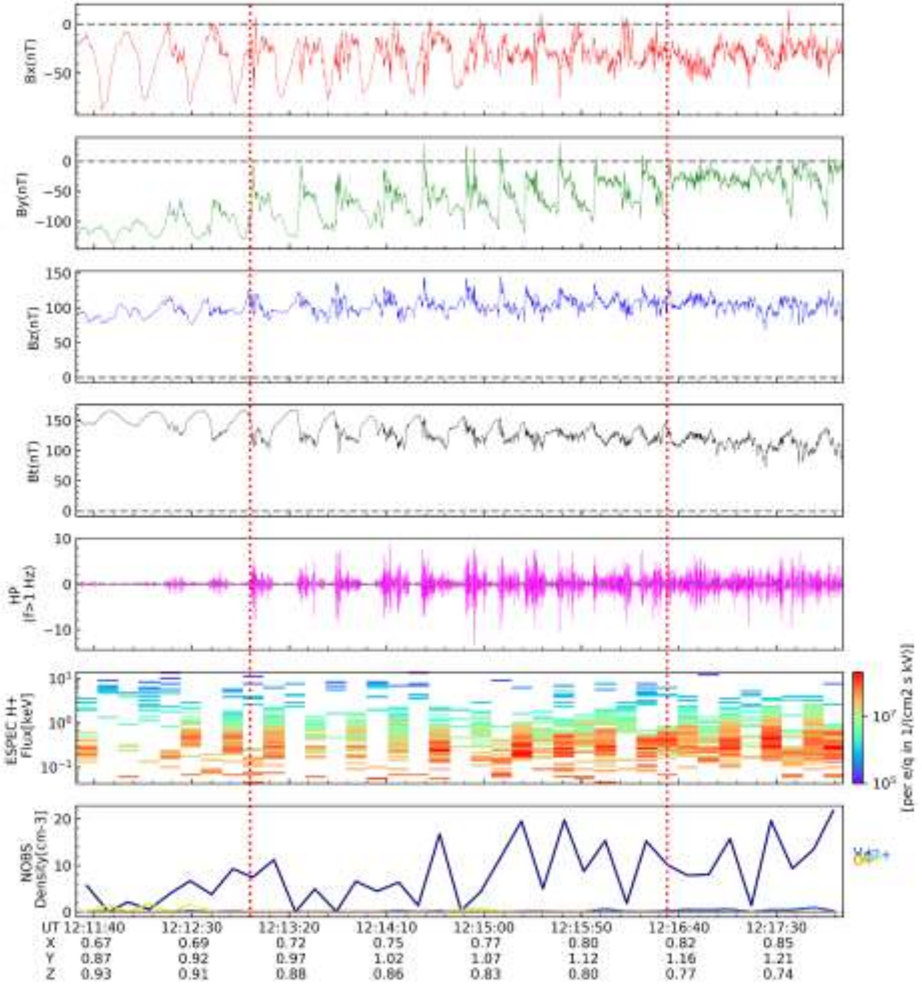


Box-like signature

Nonlinear magnetopause waves



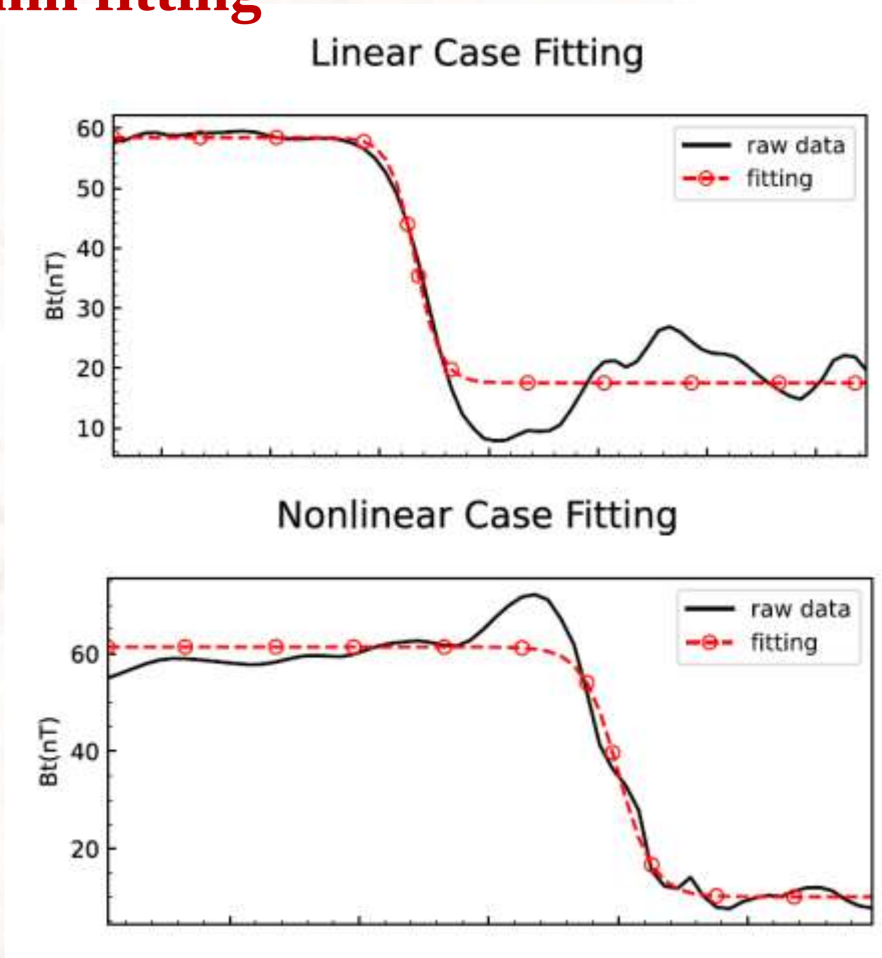
[Cushman-Roisin and Becker 2007]



Sawtooth signature

3 Quantitative methods to identify linear vs. nonlinear K–H waves

3.1 tanh fitting



$$\boxed{B(z) = B_0 \tanh\left(\frac{z}{L}\right)}$$

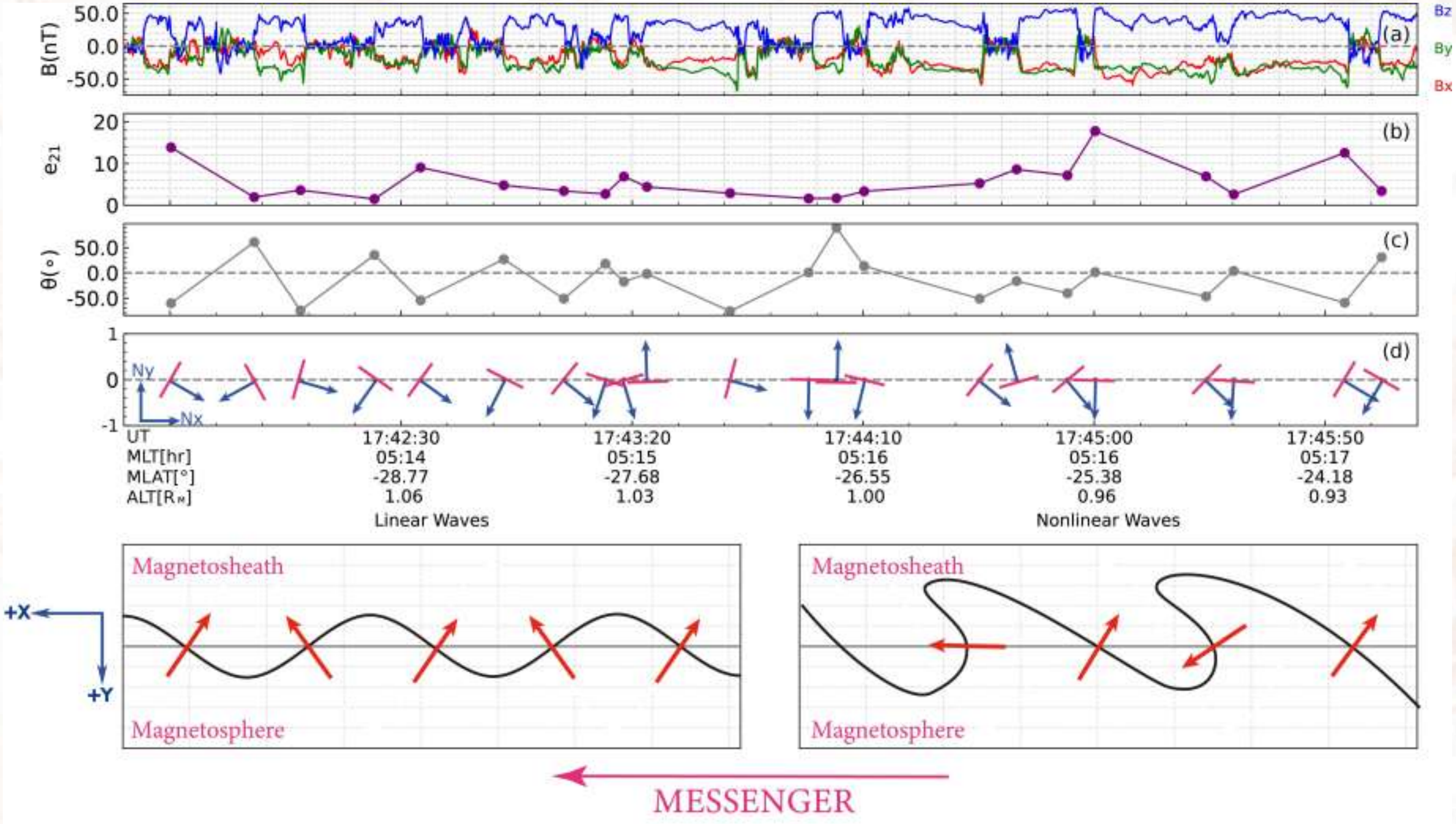
L: the half-thickness of the current sheet

B_0**:** the ambient magnetic field strength at the edge of the magnetopause current sheet

Bump: at least 15% above the modeled B_0

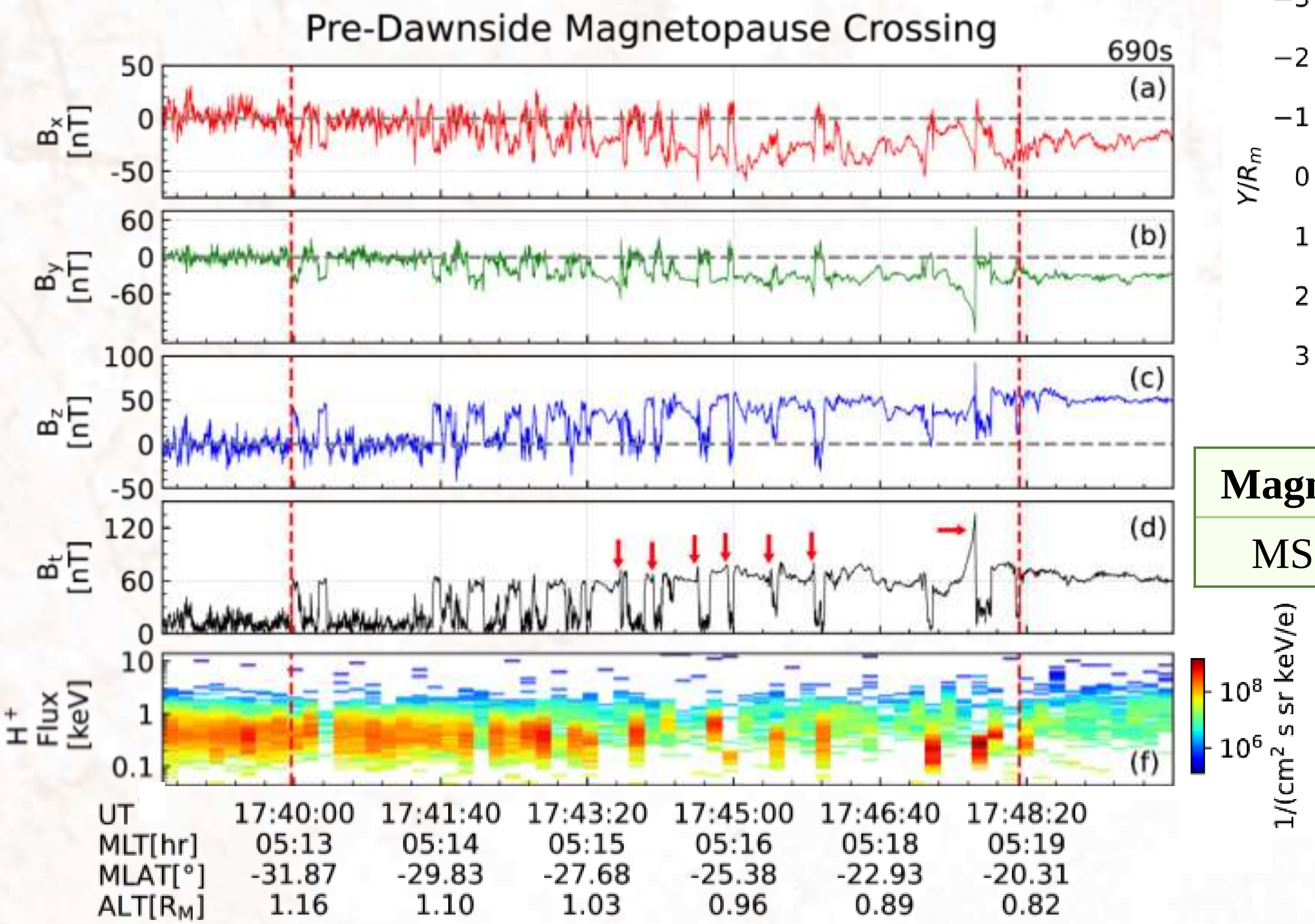
Bump: a deviation from the configuration of the magnetopause current sheet

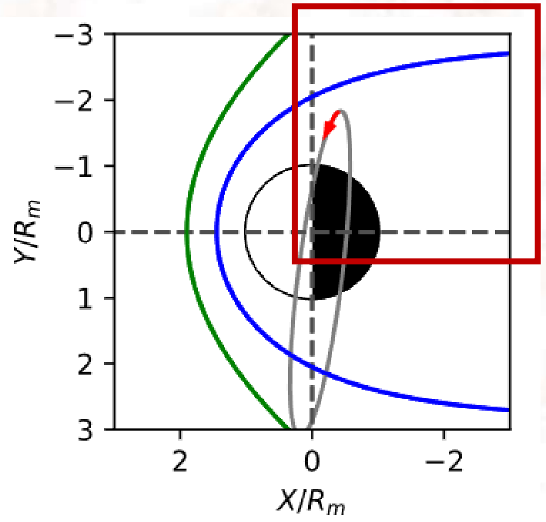
3.2 Variations in the magnetopause normal direction



For linear-stage Kelvin-Helmholtz (K-H) waves, Ny maintains a consistent direction, while during the **nonlinear stage**, **Ny exhibits sign reversals (positive/negative alternations).**

4 Case Study・Pre–dawnside Magnetopause





K-H waves have not been observed in this area before.

Magnetic field	High-pass filter of Bt	Plasma Density
MSP>MSH	MSH>MSP	MSH>MSP

- Magnetic field intensity changes at least 40 nT
- Magnetopause crossing interval is at least 5s

Total: 17 KH waveforms
Period : ~40s

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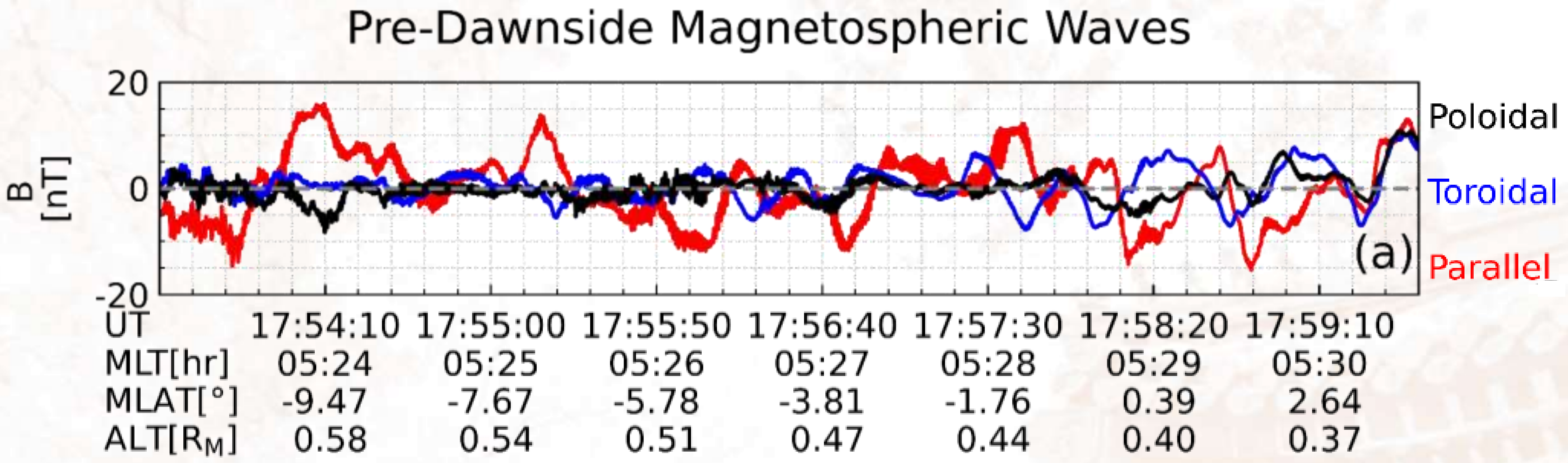
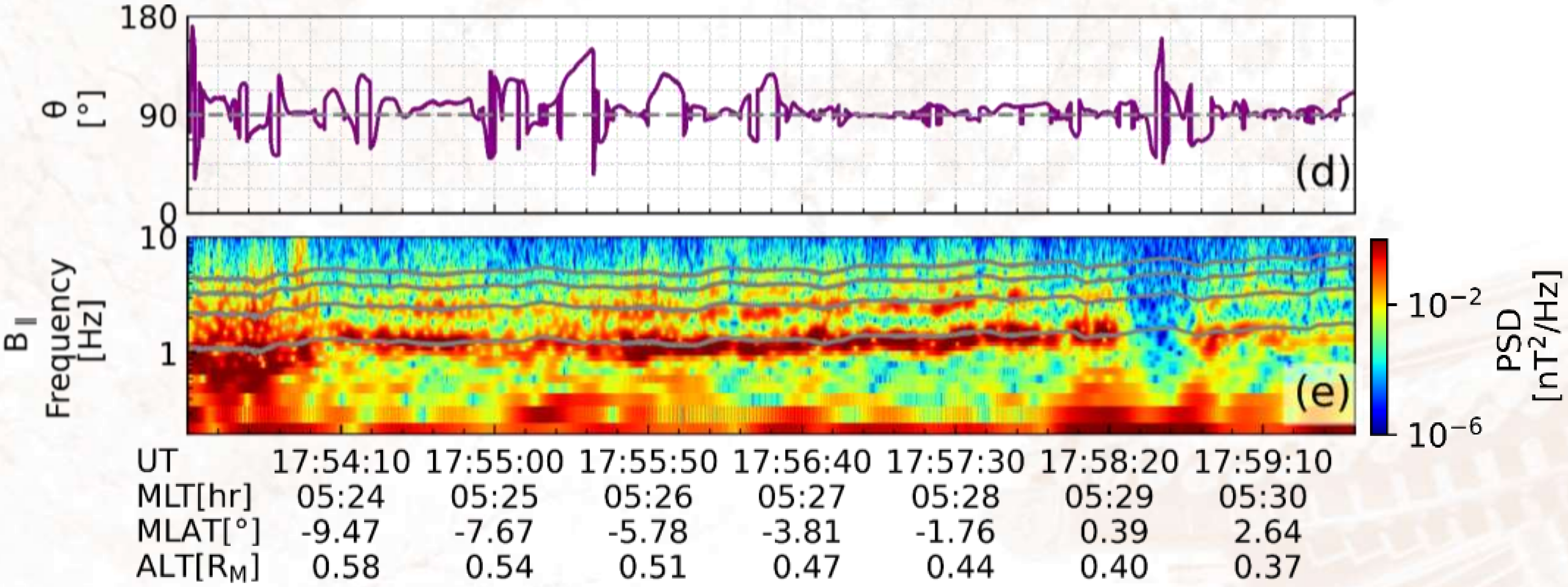
Energy Transport: 30mHz Compressional ULF waves



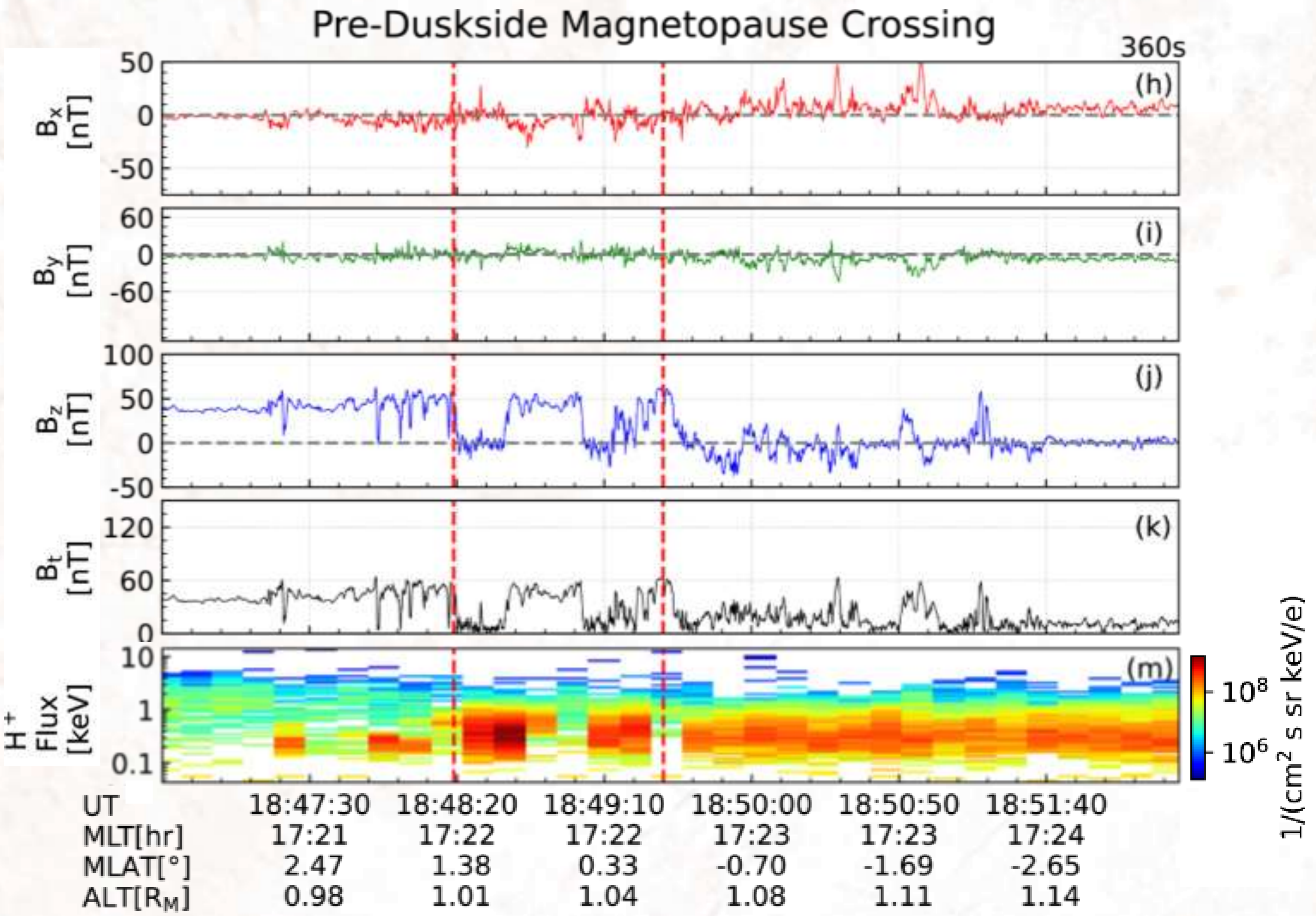
- 8 compressional waveforms
- **Period: ~35s** (similar to KH waves' period)

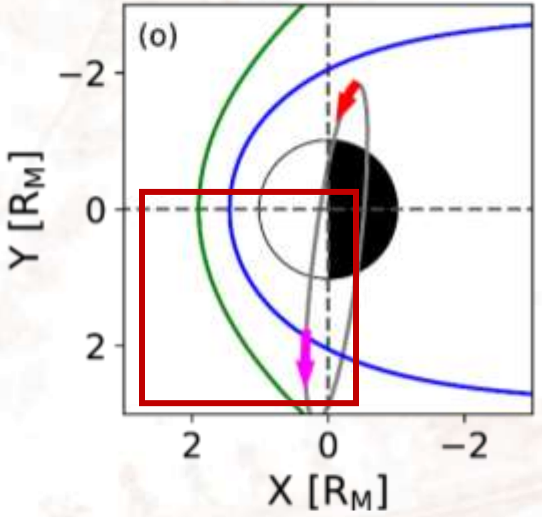
Particle Transport: Ion-Bernstein Modes



- Wave vectors are perpendicular to the background magnetic field
- Waves near **proton cyclotron and its harmonics**

4 Case Study・Pre–duskside Magnetosphere





- 5 magnetopause crossings
- **No** compressional ULF waves
- **No** ion-Bernstein modes

5 Why K–H waves in our case are clearer on the pre–dawnside?

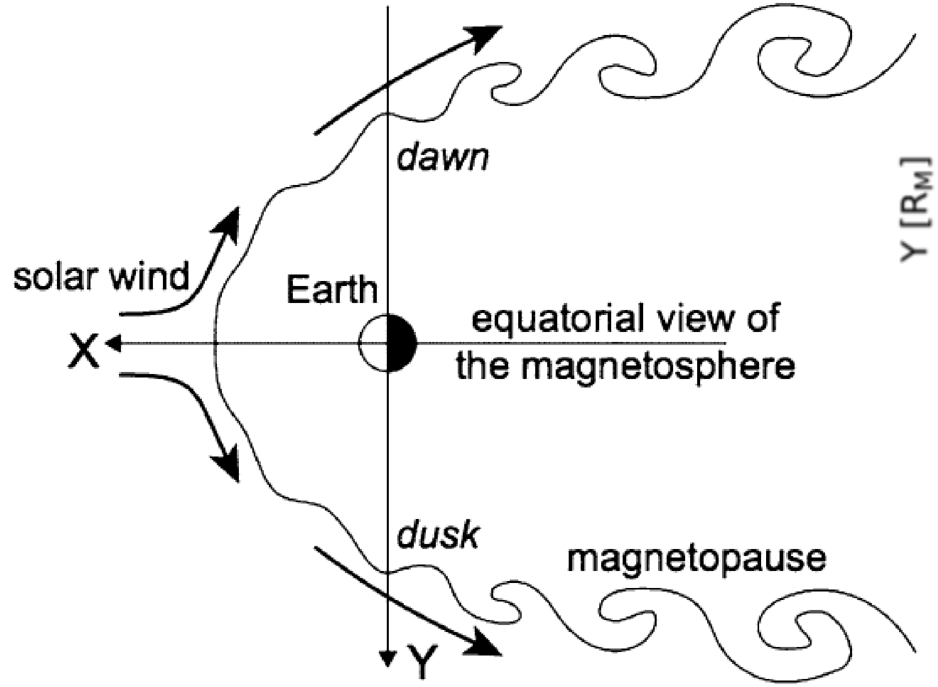
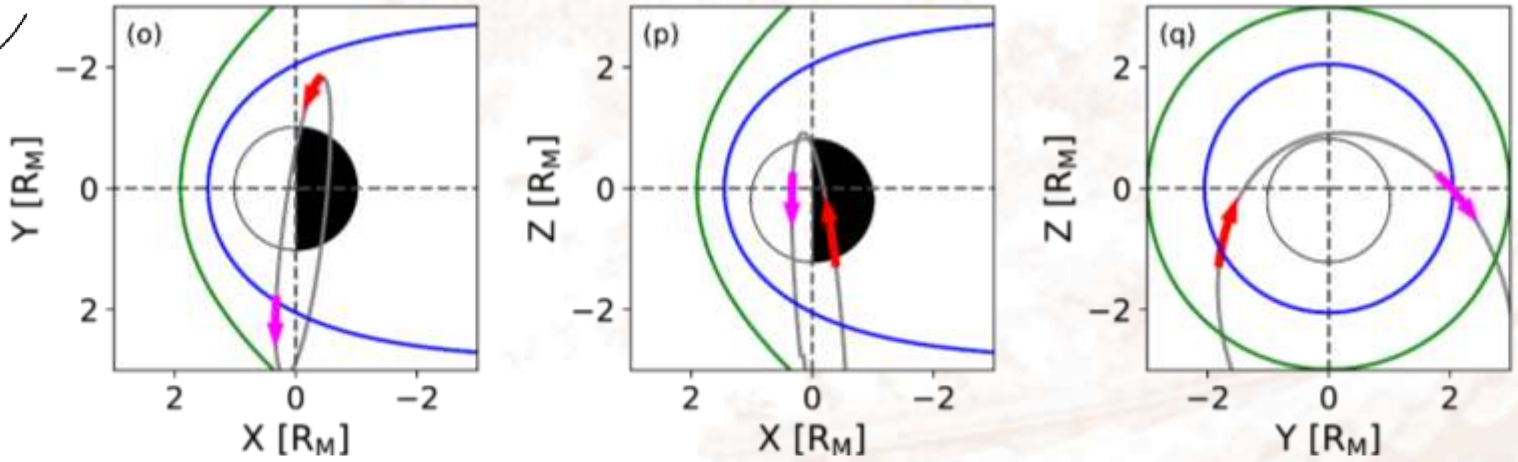


Fig. 10 Illustrating the expected evolution of the Kelvin-Helmholtz instability from a linear stage on the dayside magnetopause to a nonlinear stage on the flanks of the distant magnetotail

[D.G. Sibeck et al., 2011]



Reason1 : Pre-duskside waves may not have fully developed

Reason2: a quasi-parallel shock on the dawnside and a quasi-perpendicular shock on the duskside

K-H waves are unstable when:

$$\frac{m_0 n_1 n_2}{n_1 + n_2}[\mathbf{k}\cdot\Delta\mathbf{V}]^2 > \frac{1}{\mu_0}[(\mathbf{k}\cdot\mathbf{B_1})^2 + (\mathbf{k}\cdot\mathbf{B_2})^2]$$

Upstream solar wind variability drives observed discrepancies.

	$\theta_{B_n}(\circ)$	Bow shock	B_k^* (nT)
Dawnside	23	Quasi-parallel	10.8
Duskside	55	Quasi-perpendicular	23.26

Consistent with Parker Spiral

6 Why is Liljeblad's statistic lacking cases on the pre-dawnside?

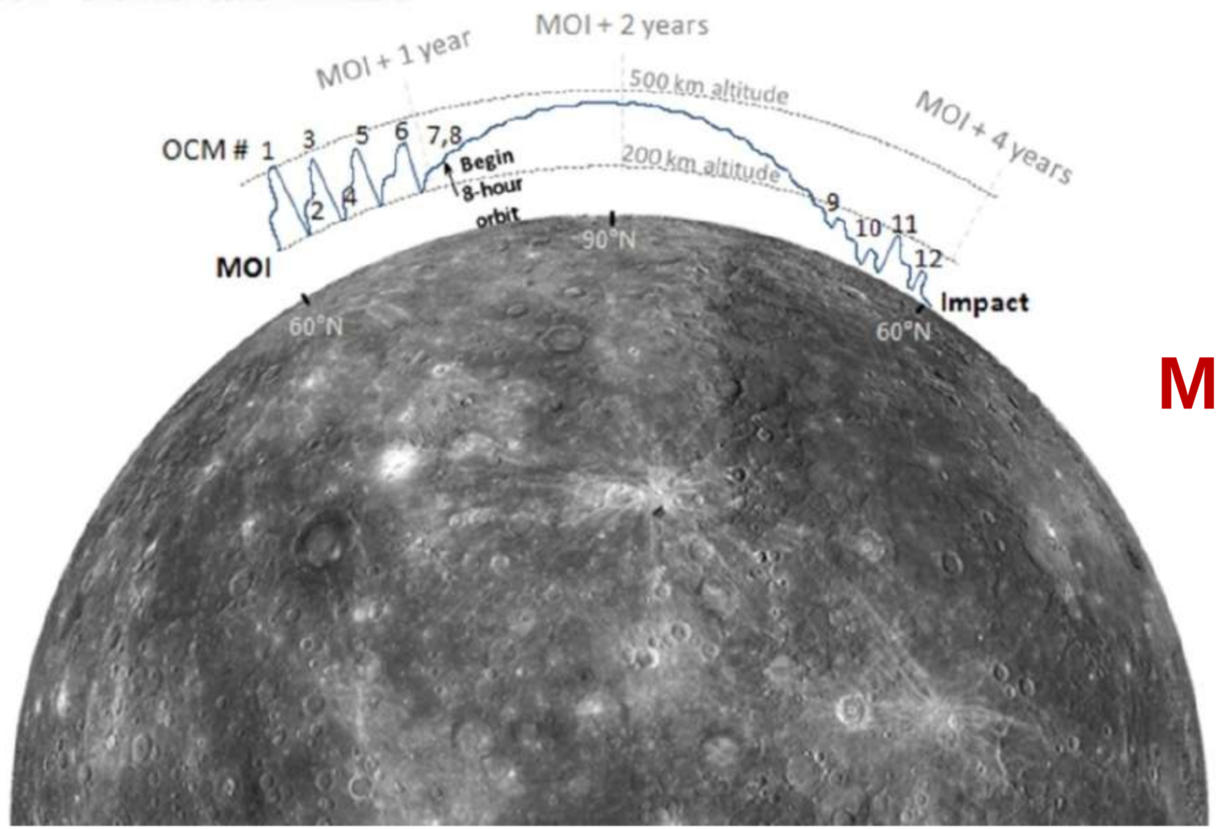
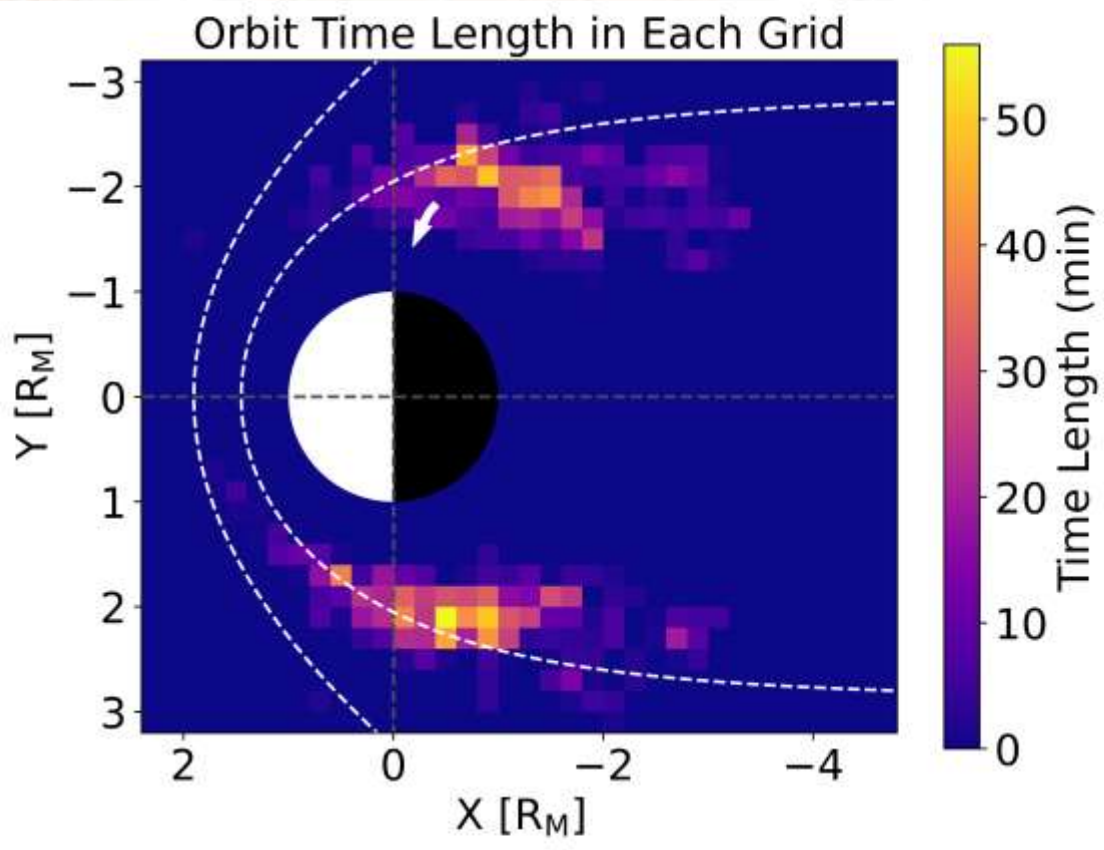


Figure 2. MESSENGER Periapsis Altitude during the Primary, XM1, and XM2 Orbital Phases. Periapsis Latitude Started at 60.0°N, Moved Northward to Peak at 84.1°N, and Then Moves Southward to 58.1°N at Mission End.

MOI=Mercury Orbit Insertion

(2011.3.18)

Maybe because of the orbit



- MESSENGER orbit:
  changed continuously after 2013.03.18

  Liljeblad's statistic:
  2011.3.24 - 2013.9.18

  Our case:
  2014.03.23

MESSENGER's orbits changed continuously after 18 March 2013. Liljeblad et al. (2014) primarily analyzed data collected before the orbital change.

6 Why K-H distribution in Liljeblad's statistical work is different from us?

- Orbit change
- Changes of IMF condition
- Maybe the criteria?