Kinetic Scale Magnetic Structure in Geospace

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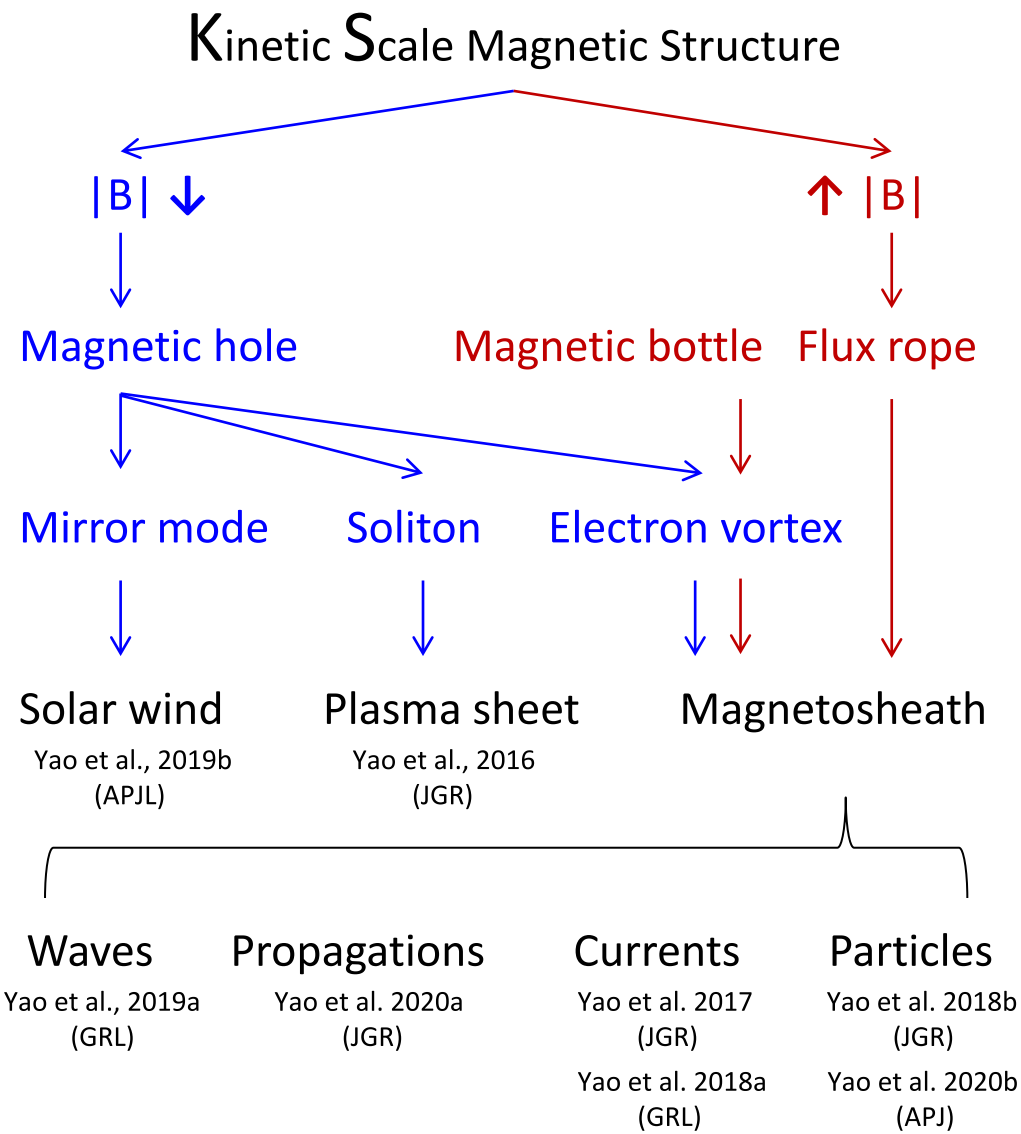
Since I learned that materials can be uploaded online, I hope to introduce more about my recent works in this field through this opportunity, so my topic expanded from the electron mirror mode to the kinetic scale or small scale magnetic structures in geospace.

1. Kinetic scale magnetic holes
    1.1. KSMHs in the magnetosheath
    1.2. Waves in the KSMHs
    1.3. Propagation and dynamic of MHs
    1.4. Electron scale and electrons in mirror mode
2. Kinetic scale magnetic peaks
    2.1. Kinetic scale magnetic bottle
    2.2. Kinetic scale flux rope

Layout



1: Kinetic scale magnetic holes

Introduction: magnetic hole

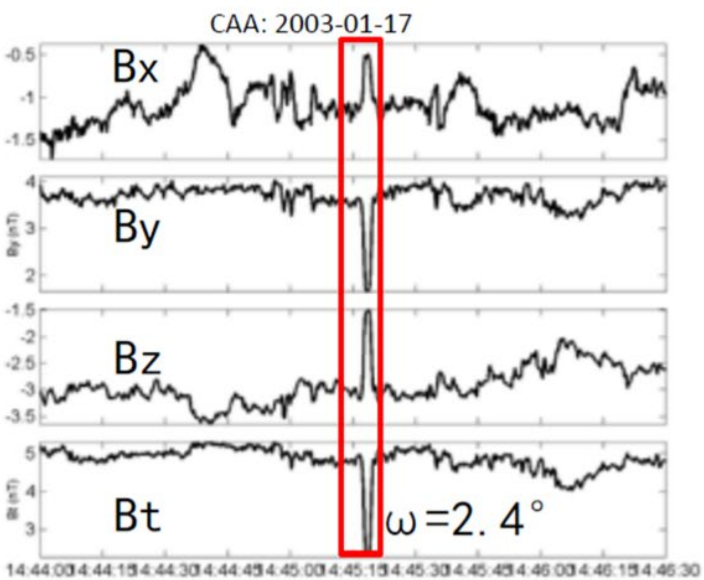
- What is magnetic hole (MH)?

A structure with observable magnetic field depression.

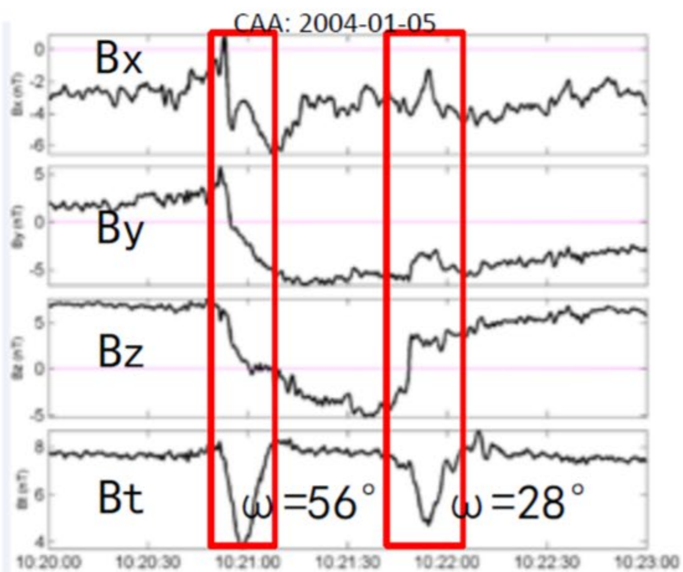
Widely observed in the solar wind, planetary magnetosheath and plasma sheet.

LMH (linear MH): has little or no change in the field direction.

NMH (nonlinear MH) has large angle change in the field direction.



LMD



NMD

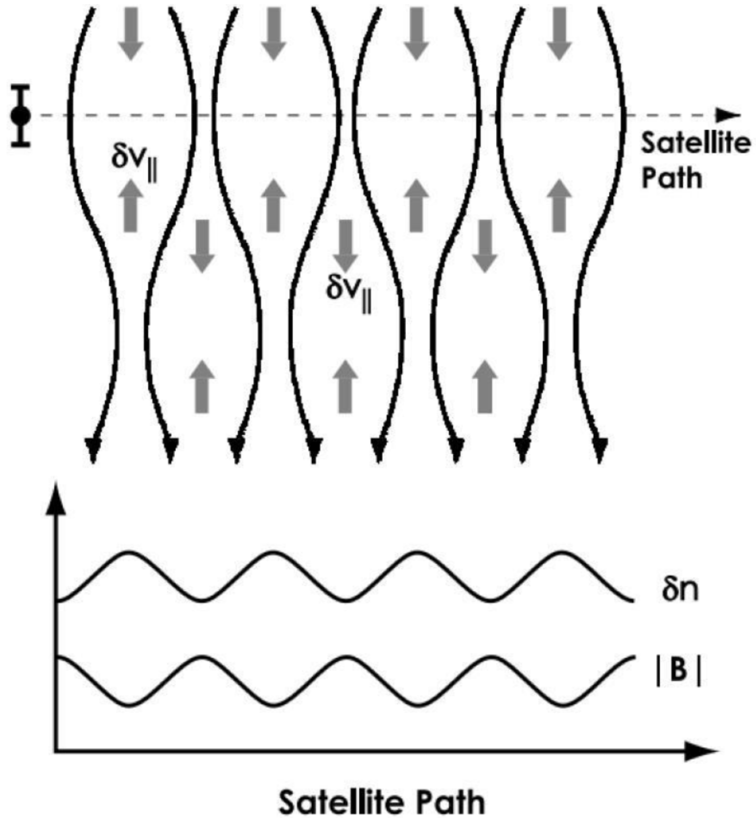
Introduction: possible generation mechanism

- Mirror instability

  high β, ($T_{\perp} > T_{//}$)

  $$(T_{\perp}/T_{//})/(1+1/\beta_{\perp}) > 1$$

  (Hasegawa, 1969; Southwood and Kivelson, 1993)



- Slow mode soliton

  lack of observational data

  [e.g. Stasiewicz, K. 2004a, 2004b]

Introduction: kinetic scale magnetic holes

Ge et al. 2011 (Themis, Plasma sheet)

1). Temperature inside: isotropy

Temperature outside: $T_{e\parallel} > T_{e\perp}$

Ion temperature: stable

2). Bipolar B_y

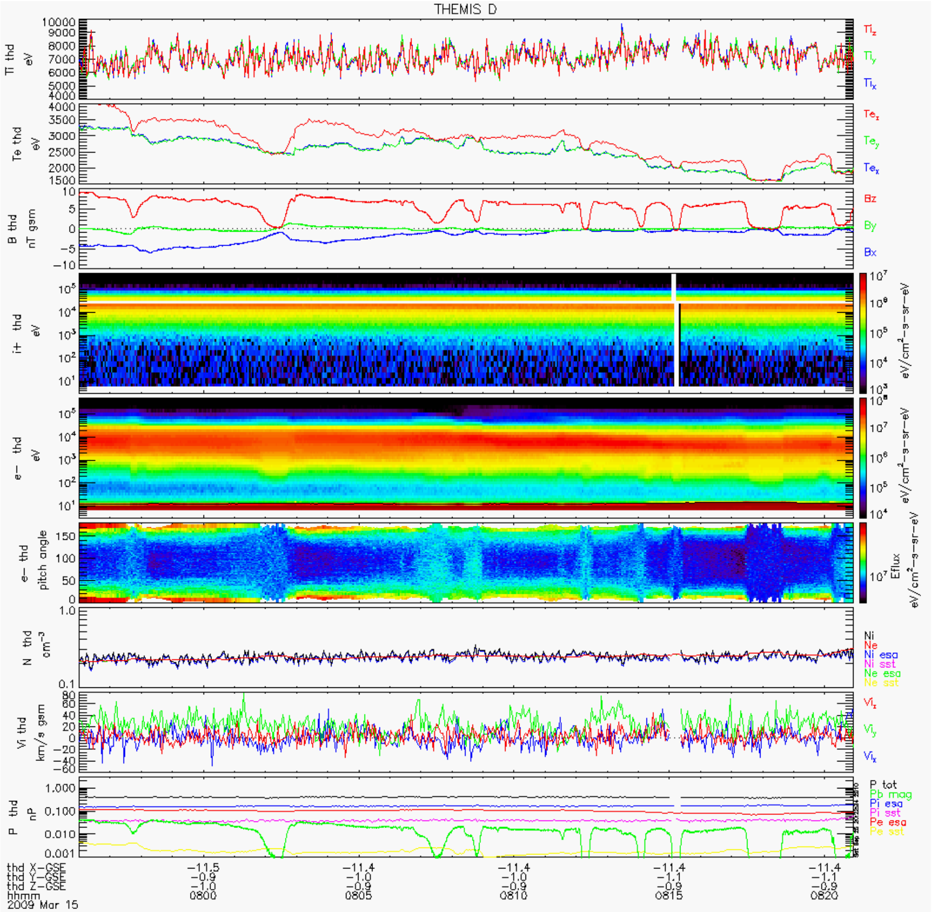
3). |B|~0 (strong-nonlinear)

4). Pressure balance

5). Observed between two DFs

6). L~ρ_i

possible mechanism: electrons play important role in mirror instability



Introduction: kinetic scale magnetic holes

Sun et al. 2012 (Cluster+TC1, Plasma sheet)

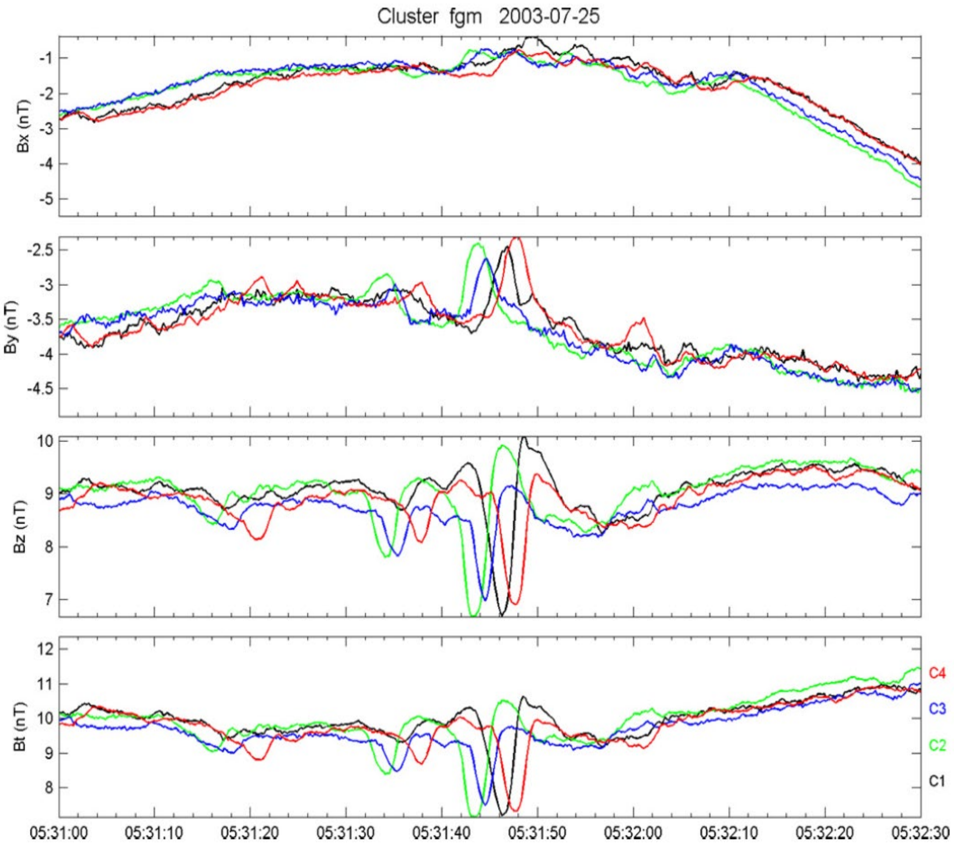
1). Temperature inside: $T_{e\perp} > T_{e\parallel}$

Ion temperature: stable

2). L~ρ_i

3). $\delta B/B_0 \sim 30\%$ (weak-nonlinear)

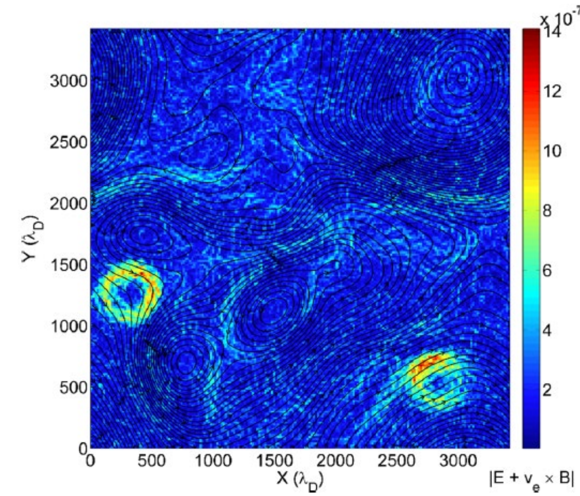
4). $B_z > B_x$: a close relationship with the depolarization process. Results of energy release of reconnection?



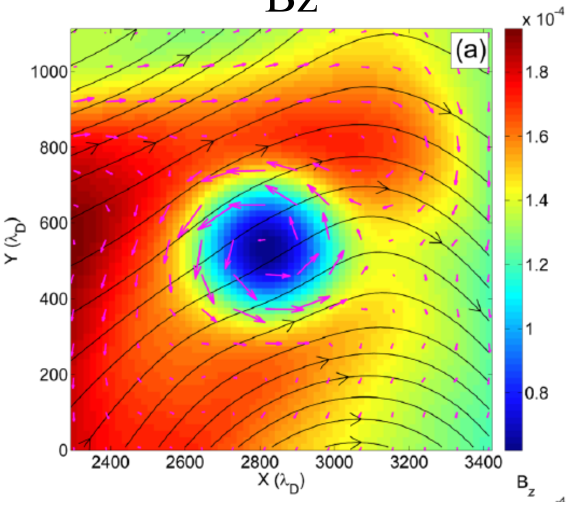
1: Kinetic scale magnetic holes

Introduction: simulations

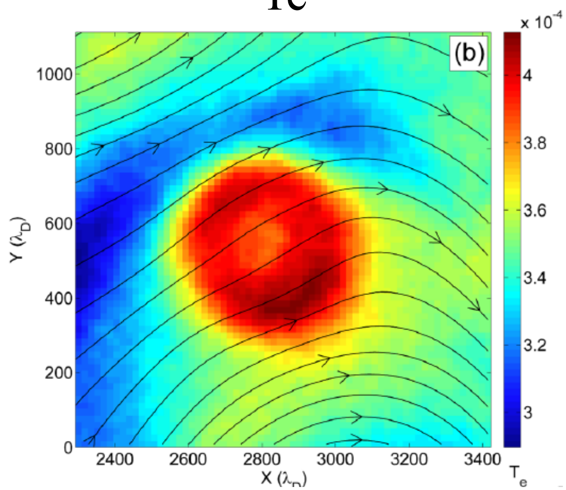
Electron vortex magnetic holes in two dimensional particle-in-cell simulations of decaying turbulence. [Haynes et al., 2015]



Bz



Te



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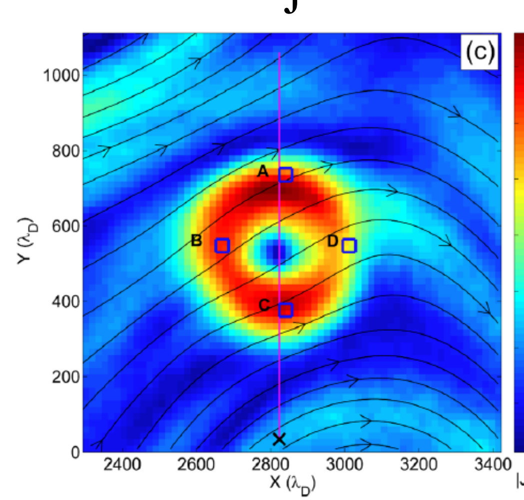
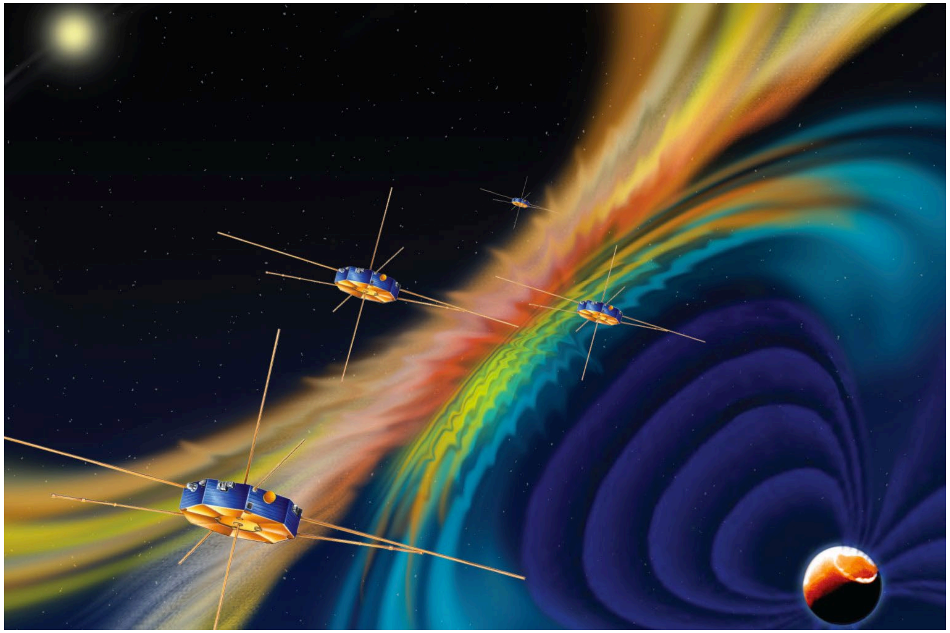
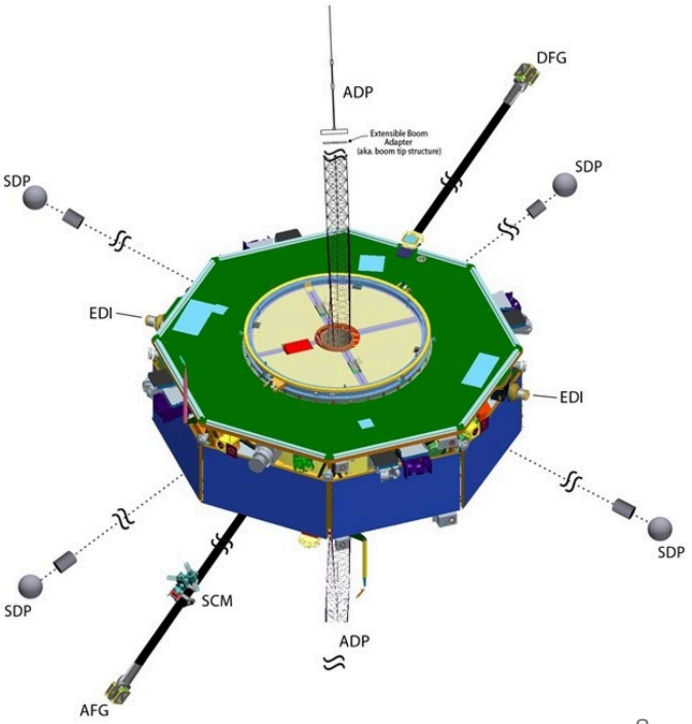


New MMS Observations

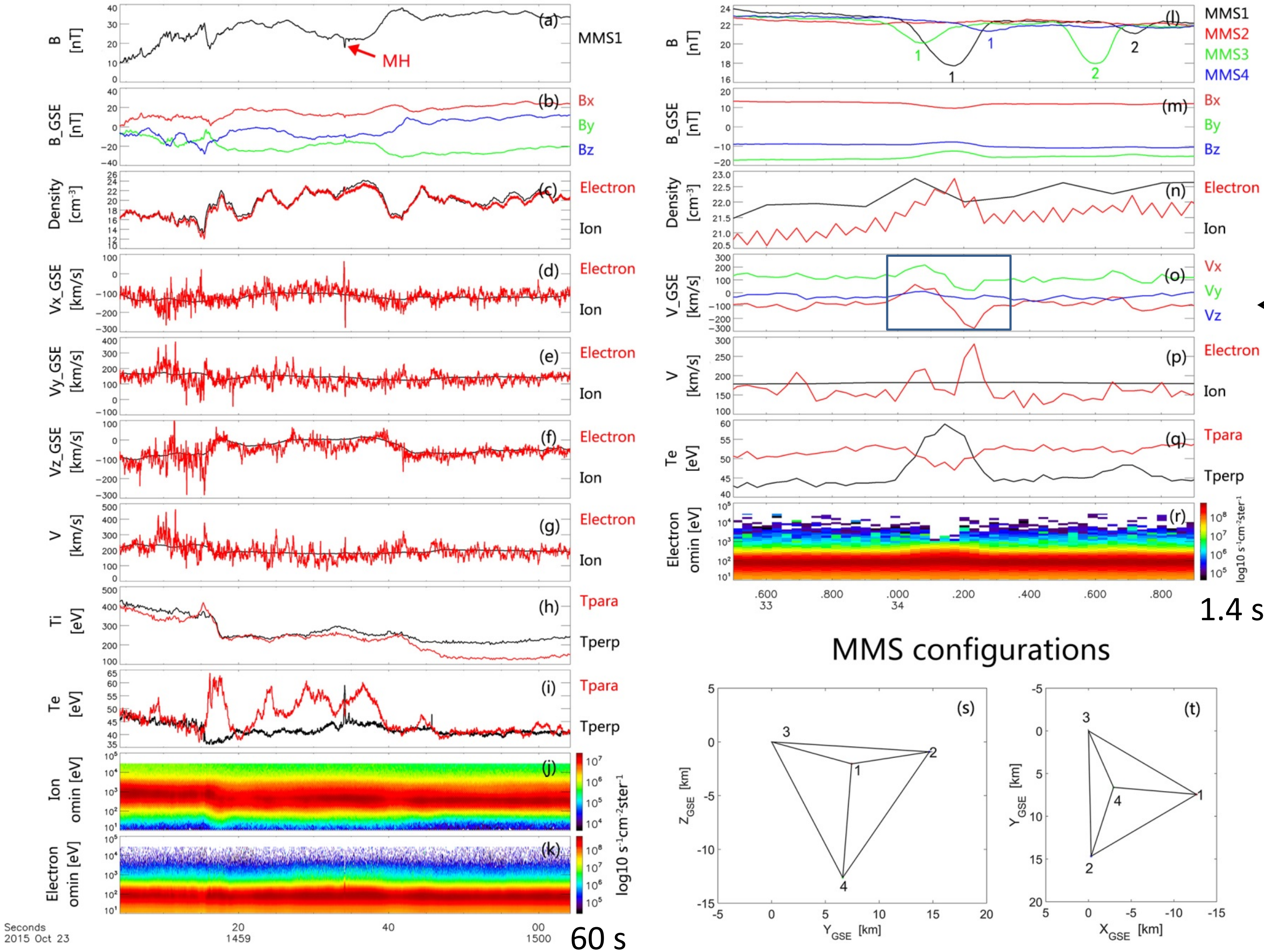
KSMHs, electron vortex and electron acceleration

Yao et al., 2017, JGR





1.1: KSMHs in the magnetosheath



Decreased |B|

Scale size **~20 ρe**

Bipolar Velocity ←

↓

Electron **Vortex**

↓

Diamagnetic Current?

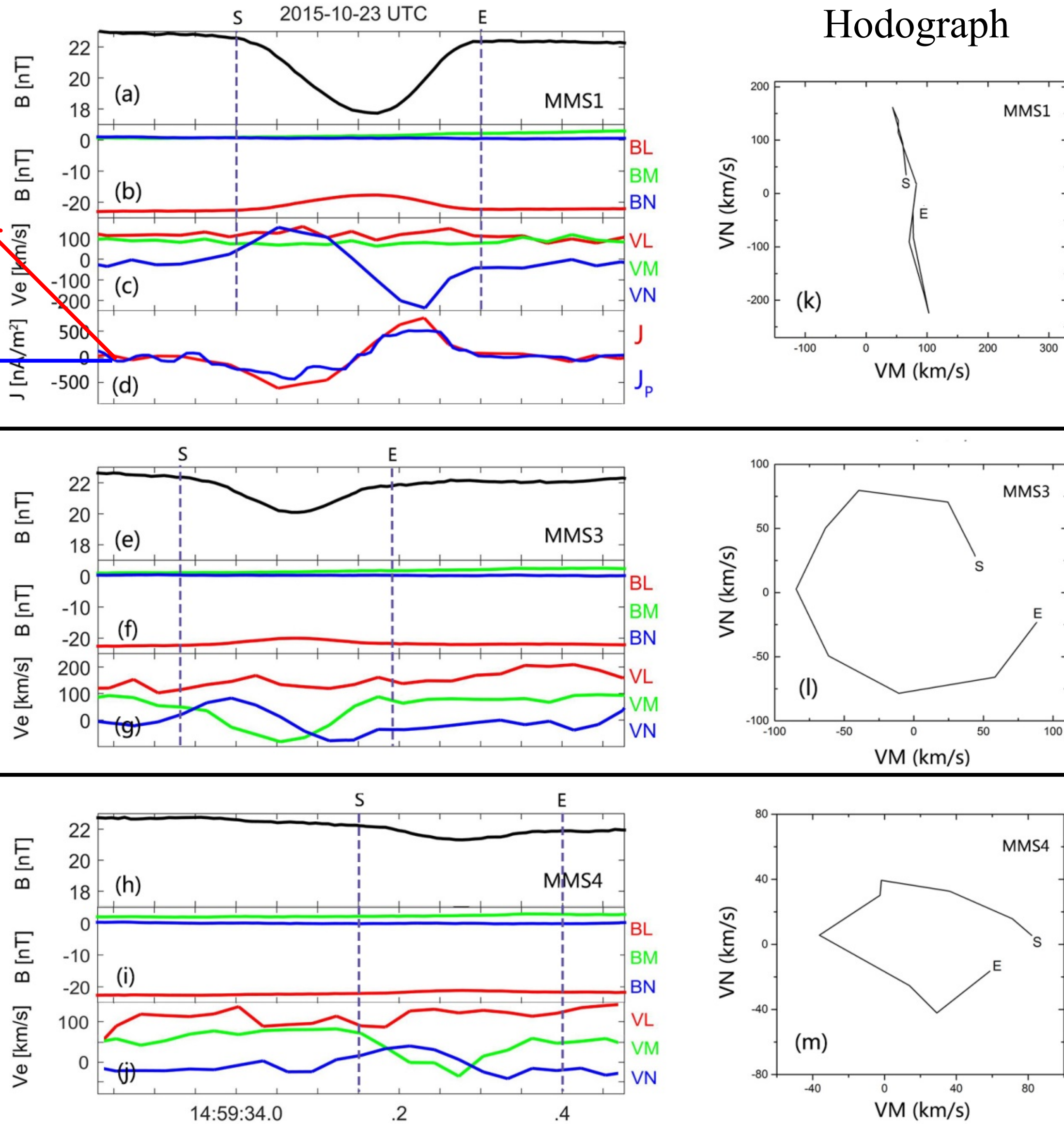
1.1: KSMHs in the magnetosheath

Diamagnetic Current

$J = n_e e(v_i - v_e)$

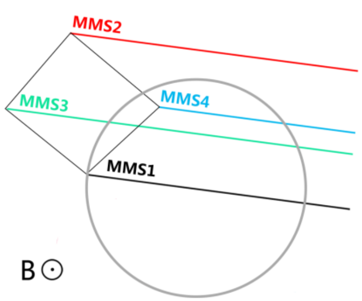
$\overrightarrow{J_P} = -\frac{(\nabla_\perp P_\perp) \times \vec{B}}{B^2}$

Hodograph



Cross
the center

Cross
one side

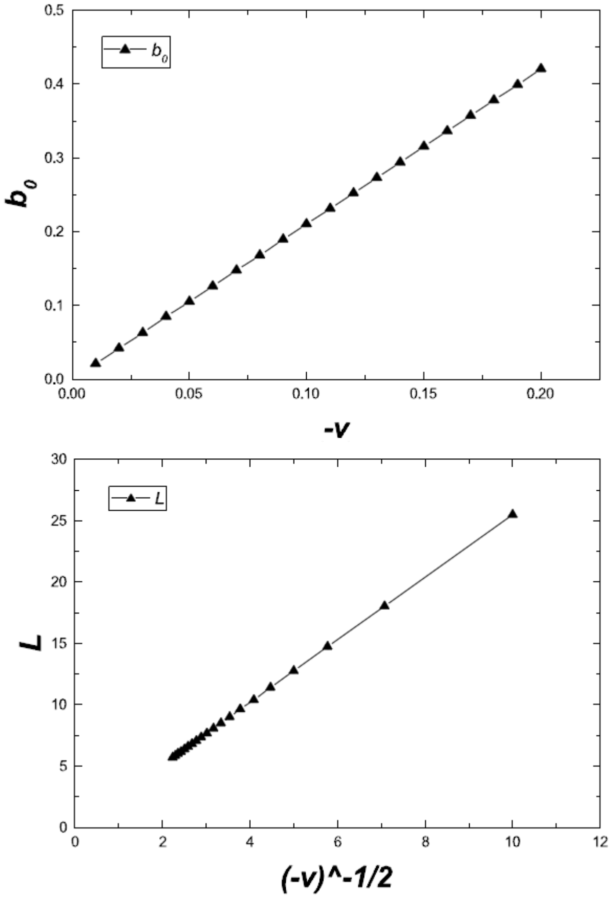


Cross
the edge

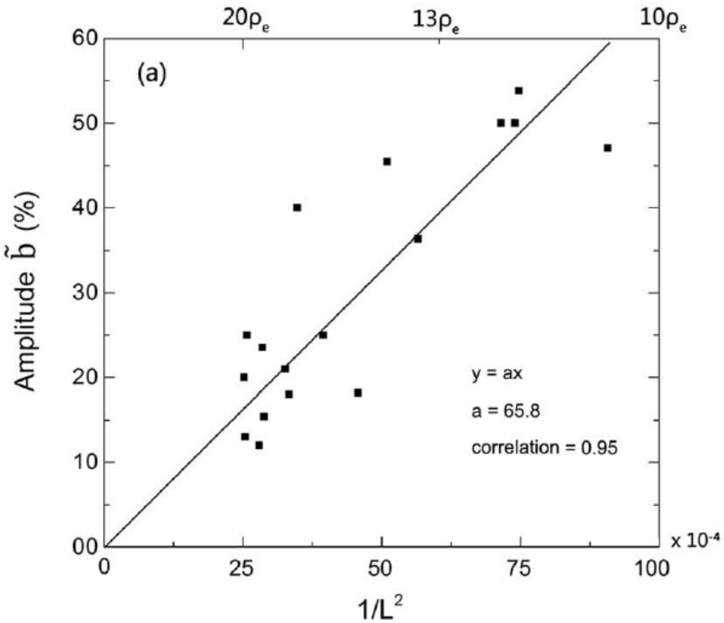
Compare with theoretical 2-D EMHD soliton

EMHD soliton

[Ji et al ., 2014; Li et al., 2016]

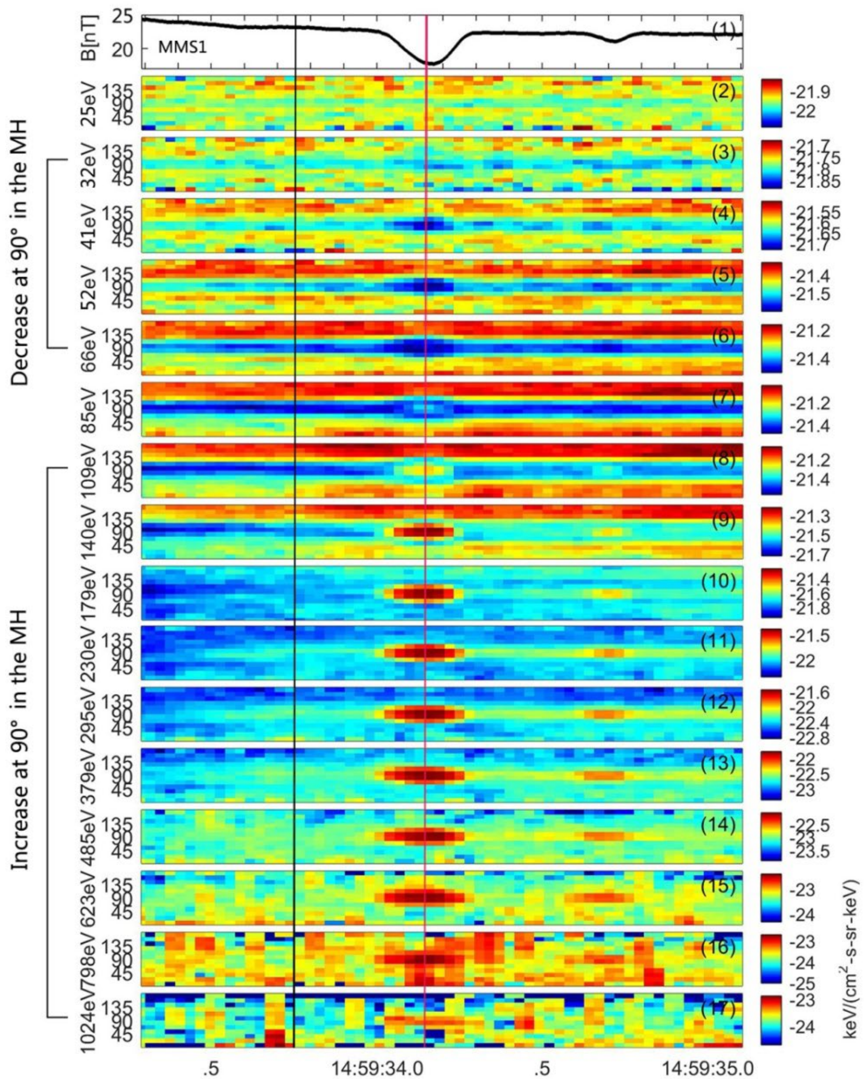


Observations



We find that $\tilde{b}$ is highly correlated with $\frac{1}{L^2}$, suggesting that the amplitude and the width of KSMHs fit well with the **2D electron soliton (vortex)** theory.

1.1: KSMHs in the magnetosheath

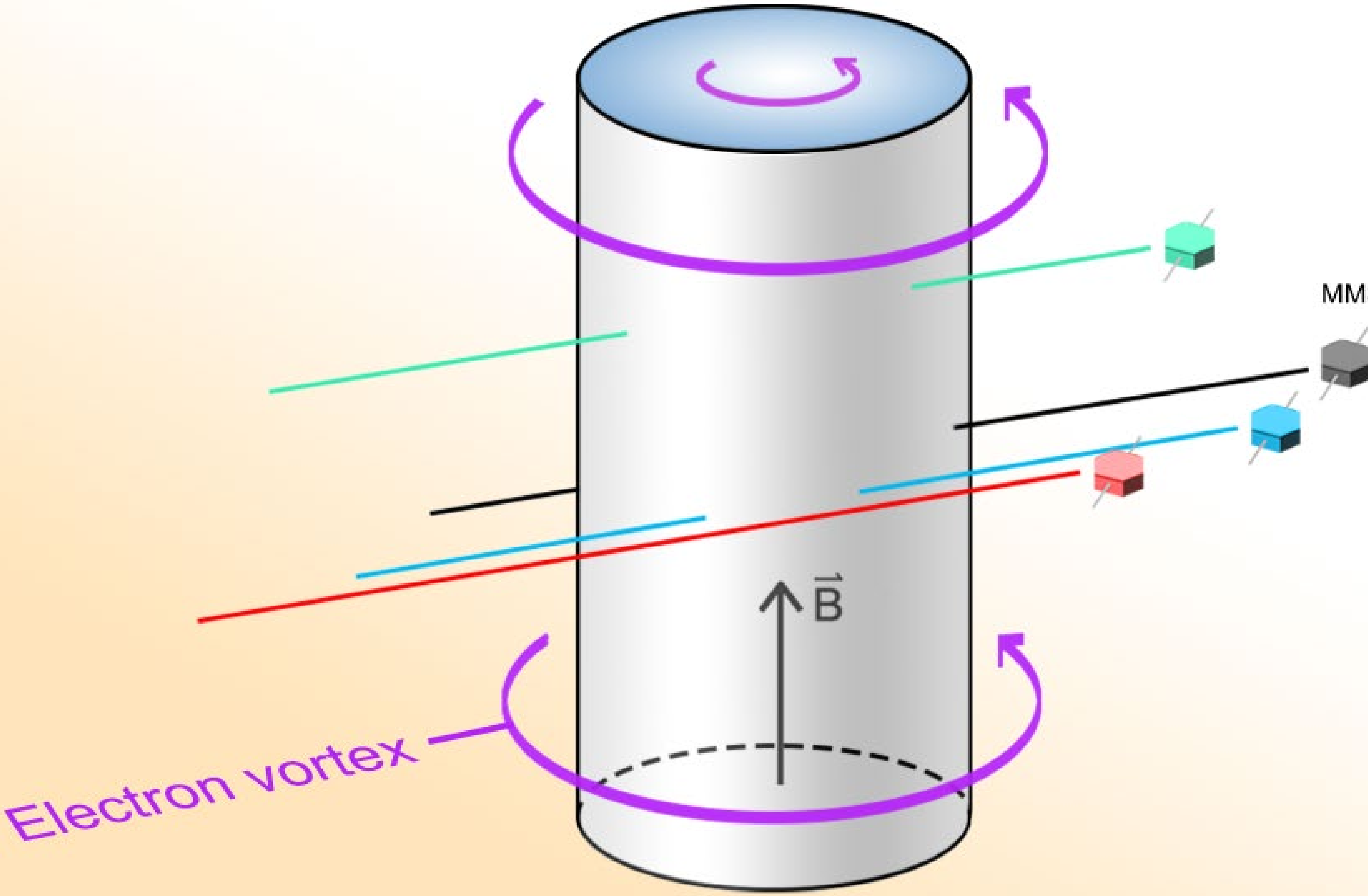


Electron **acceleration**?

Brief summary

1. Magnetosheath kinetic size magnetic holes are found with electron flow vortex caused by diamagnetic drift
2. At the 90° pitch angle, the 34-66 eV electron flux decreased while 109-1024 eV electron flux increased inside the MHs
3. Quasi-2-D EMHD soliton theory is applicable to the observations

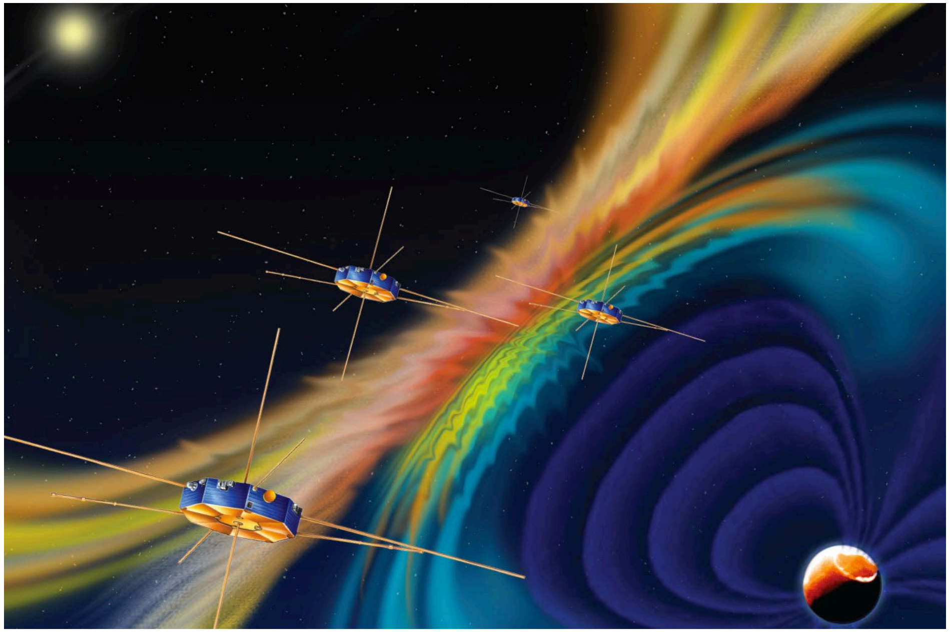
Kinetic Size Magnetic Hole

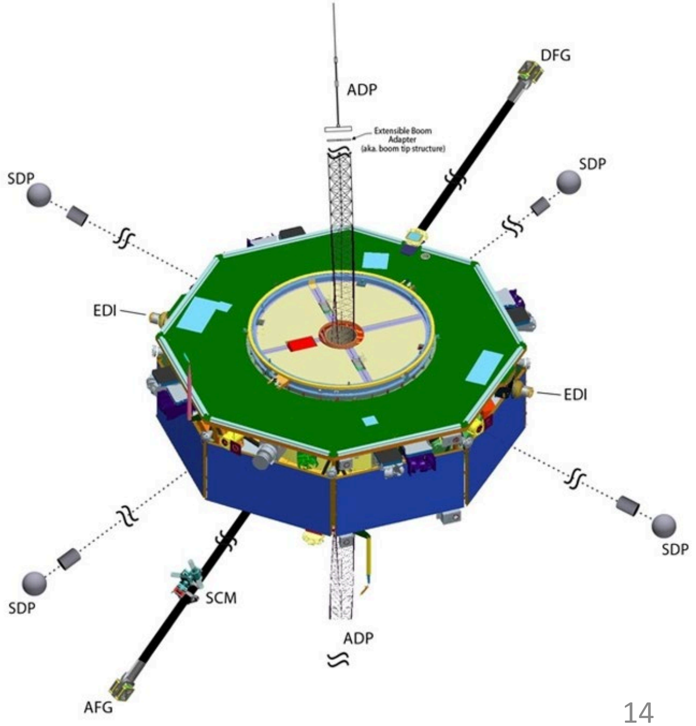


New MMS Observations

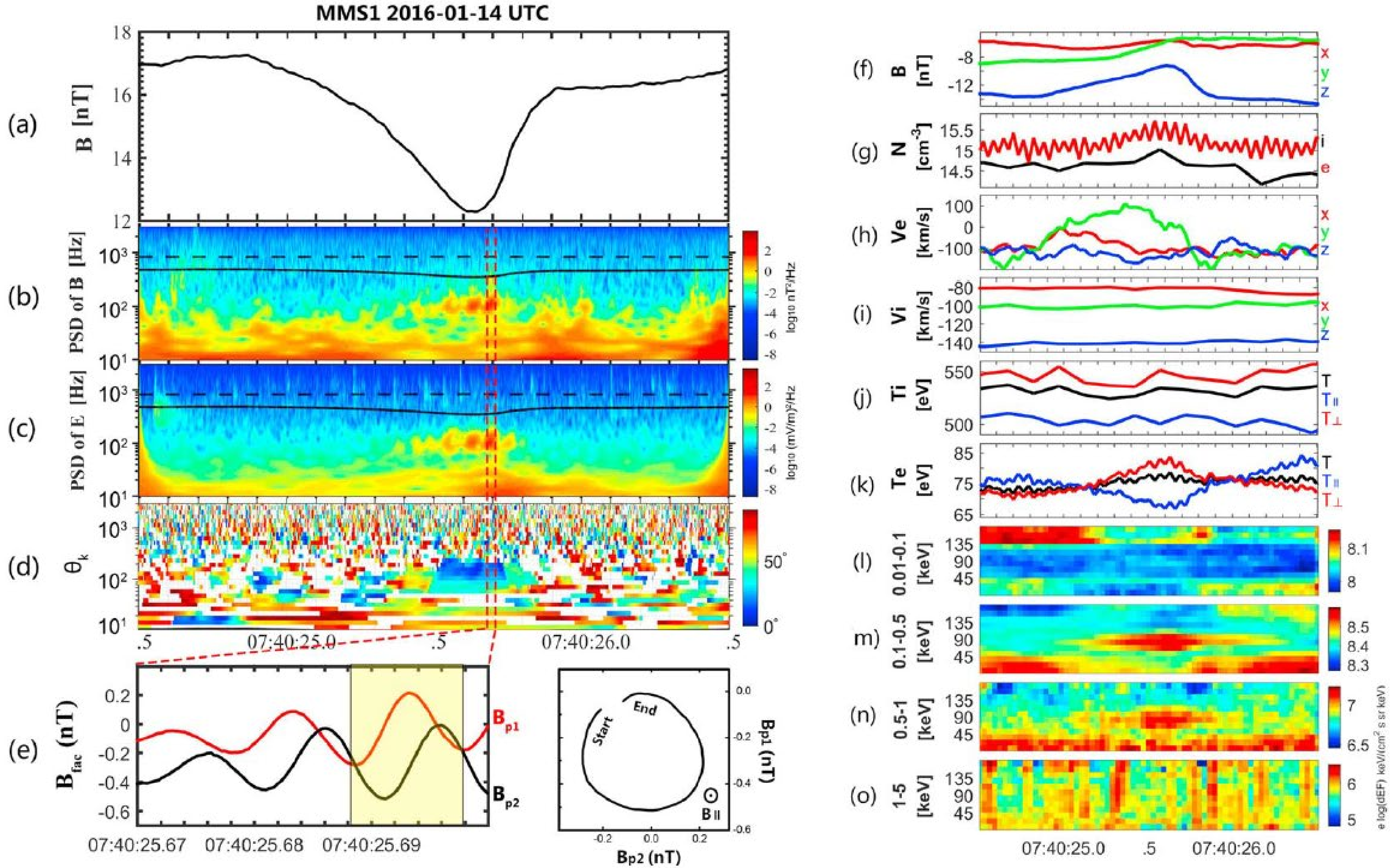
Whistler mode, electrostatic solitary and electron cyclotron waves within KSMHs

Yao et al., 2019a, GRL



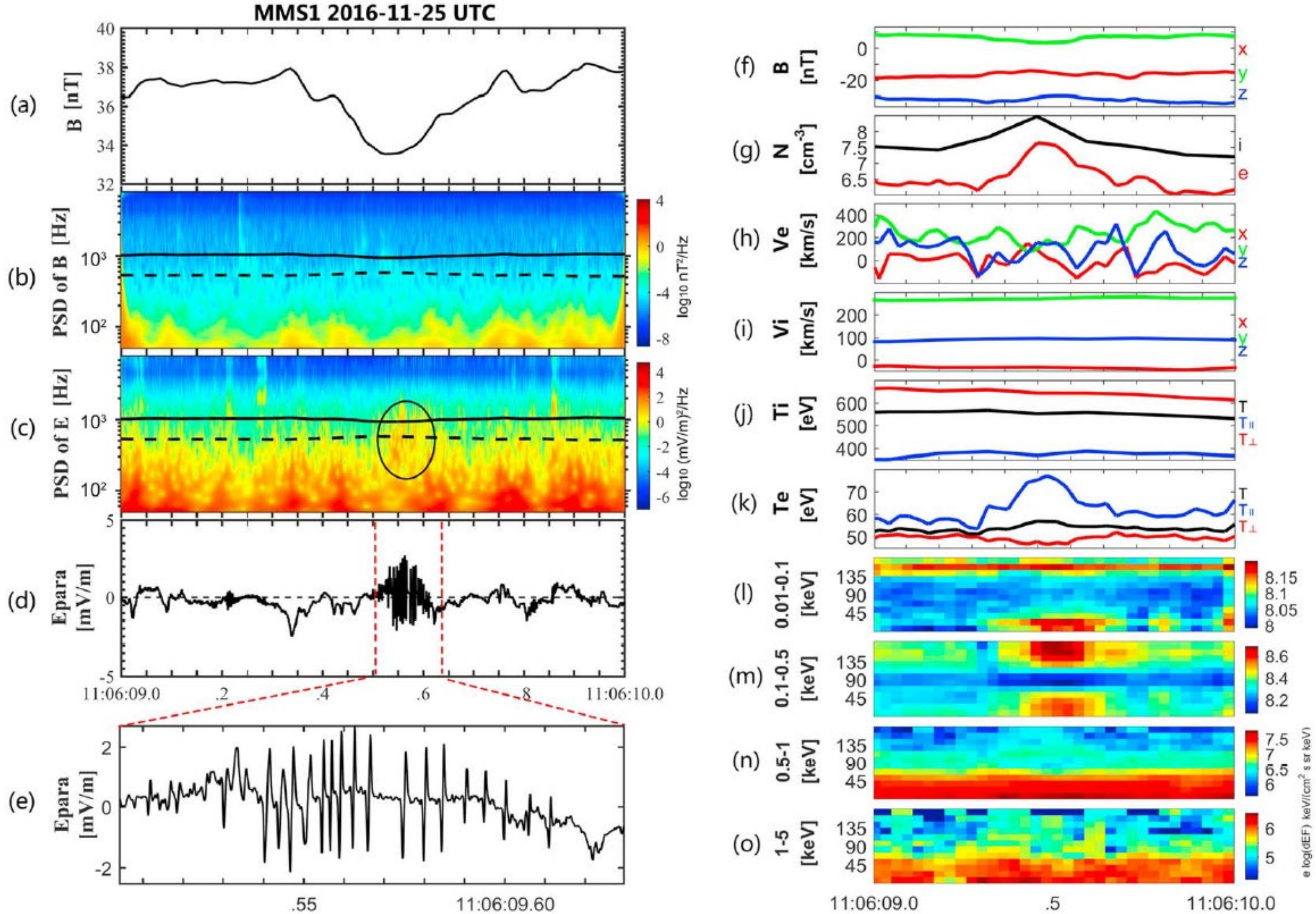


1.2: Waves in the KSMHs



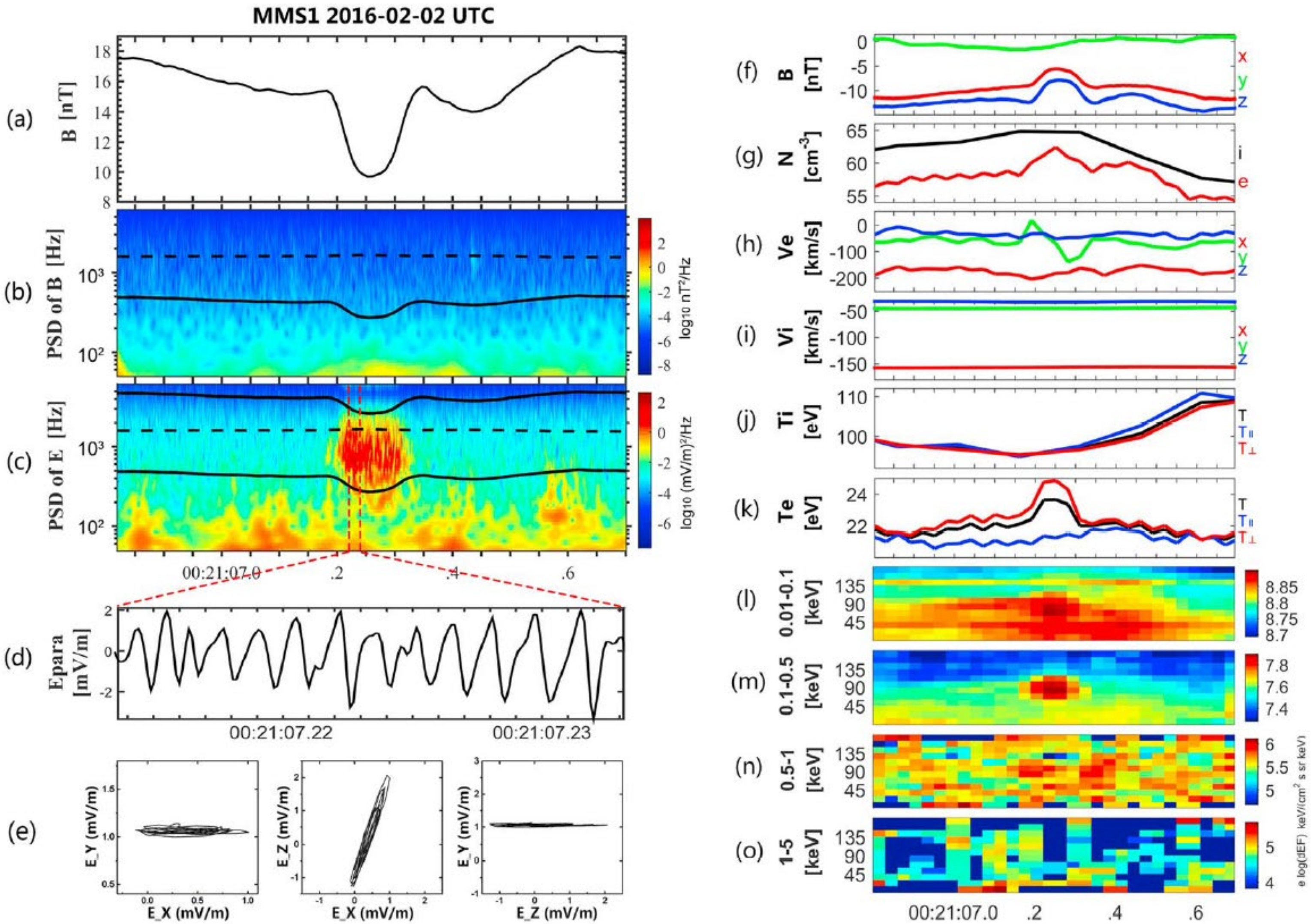
Whistler mode waves (WHs) observed in the KSMHs.

1.2: Waves in the KSMHs



Electrostatic solitary waves (ESWs) observed in the KSMHs.

1.2: Waves in the KSMHs



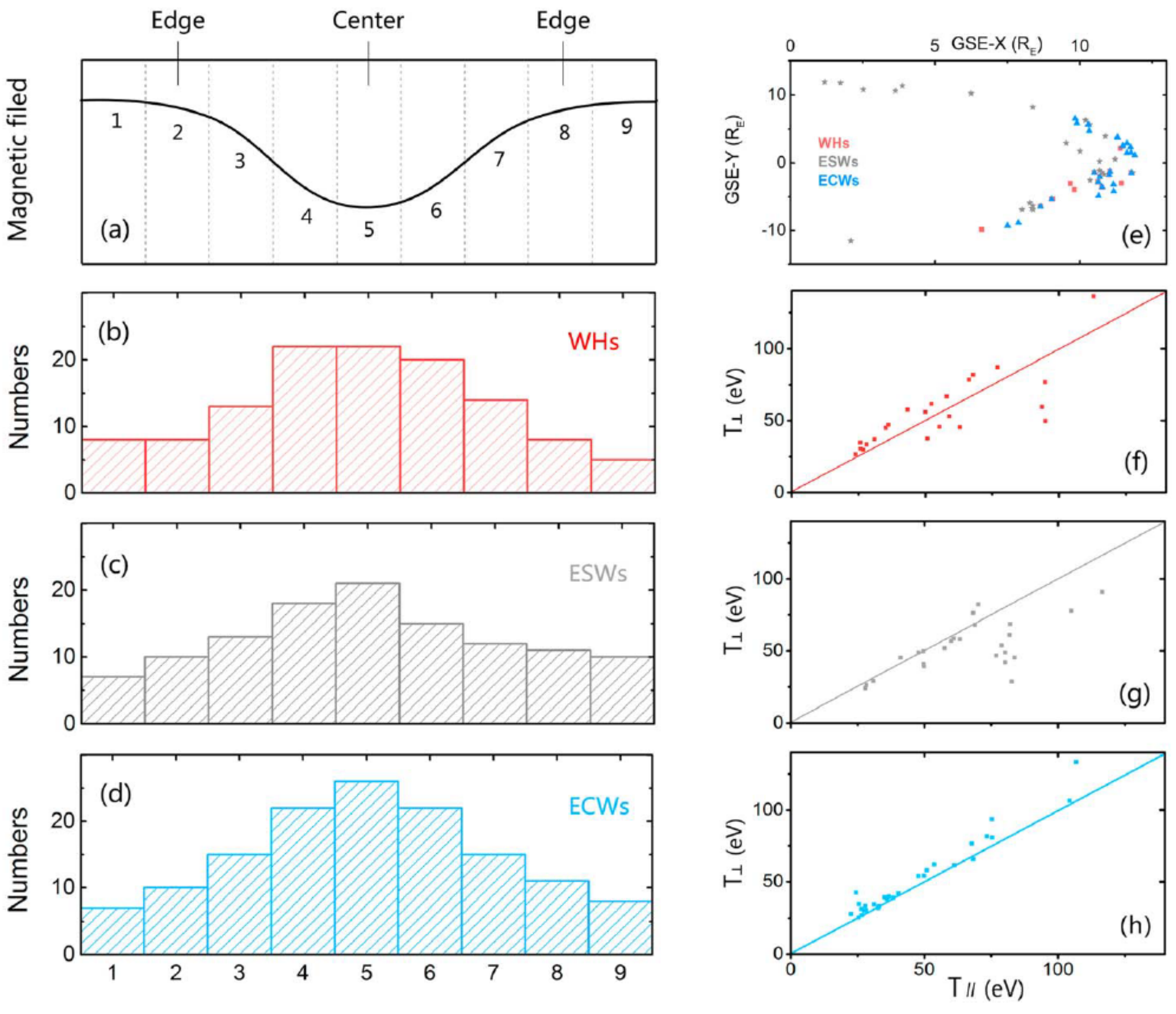
Electron cyclotron waves (ECWs) observed in the KSMHs.

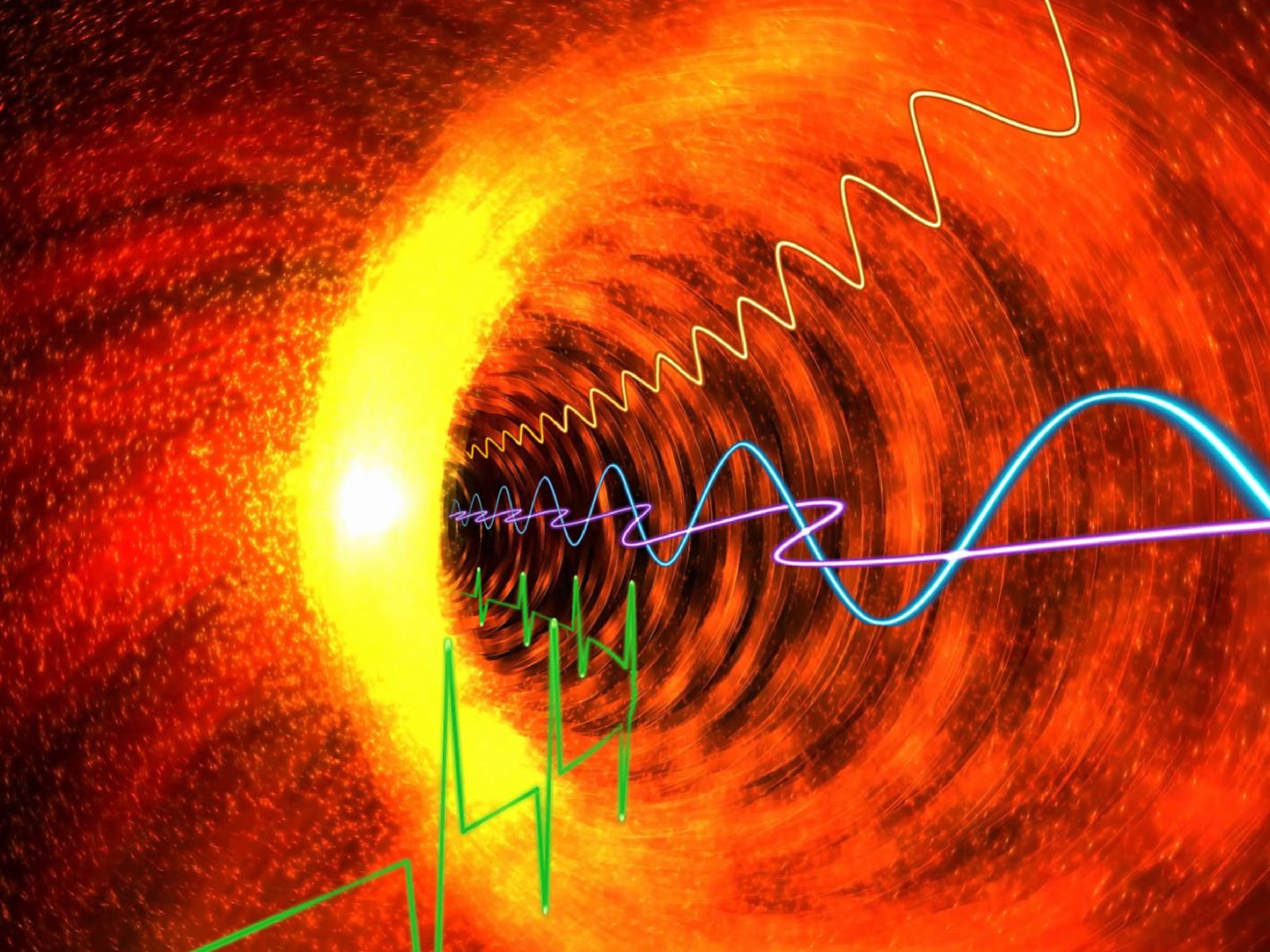
1.2: Waves in the KSMHs

Statistical analysis results of the waves.

Could be excited by electron temperature **anisotropy or beams**.

Plasma waves are important processes in converting energy, accelerating and scattering electrons and ions, and modifying the distributions of charged particles**. If plasma instabilities develop within the KSMDs, the resulting waves could absorb free energy from plasma particles and may propagate out of the KSMDs.** Our discoveries could significantly advance the understanding of energy conversion and dissipation for kinetic-scale turbulence.

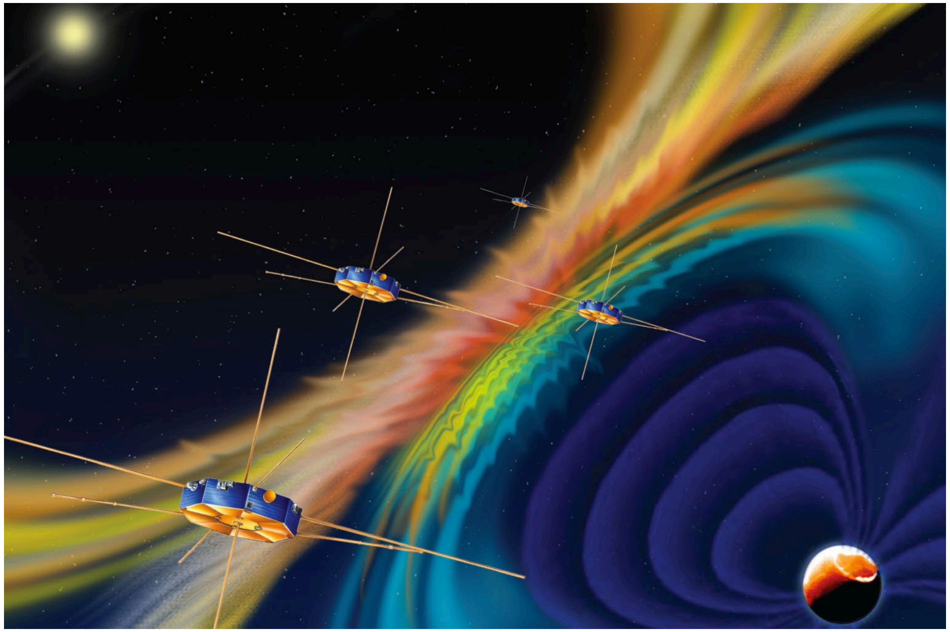


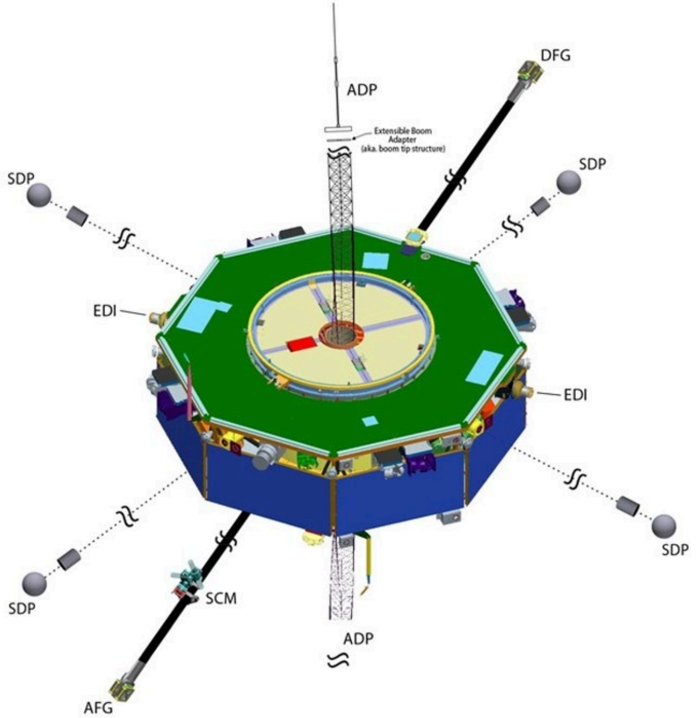


New MMS Observations

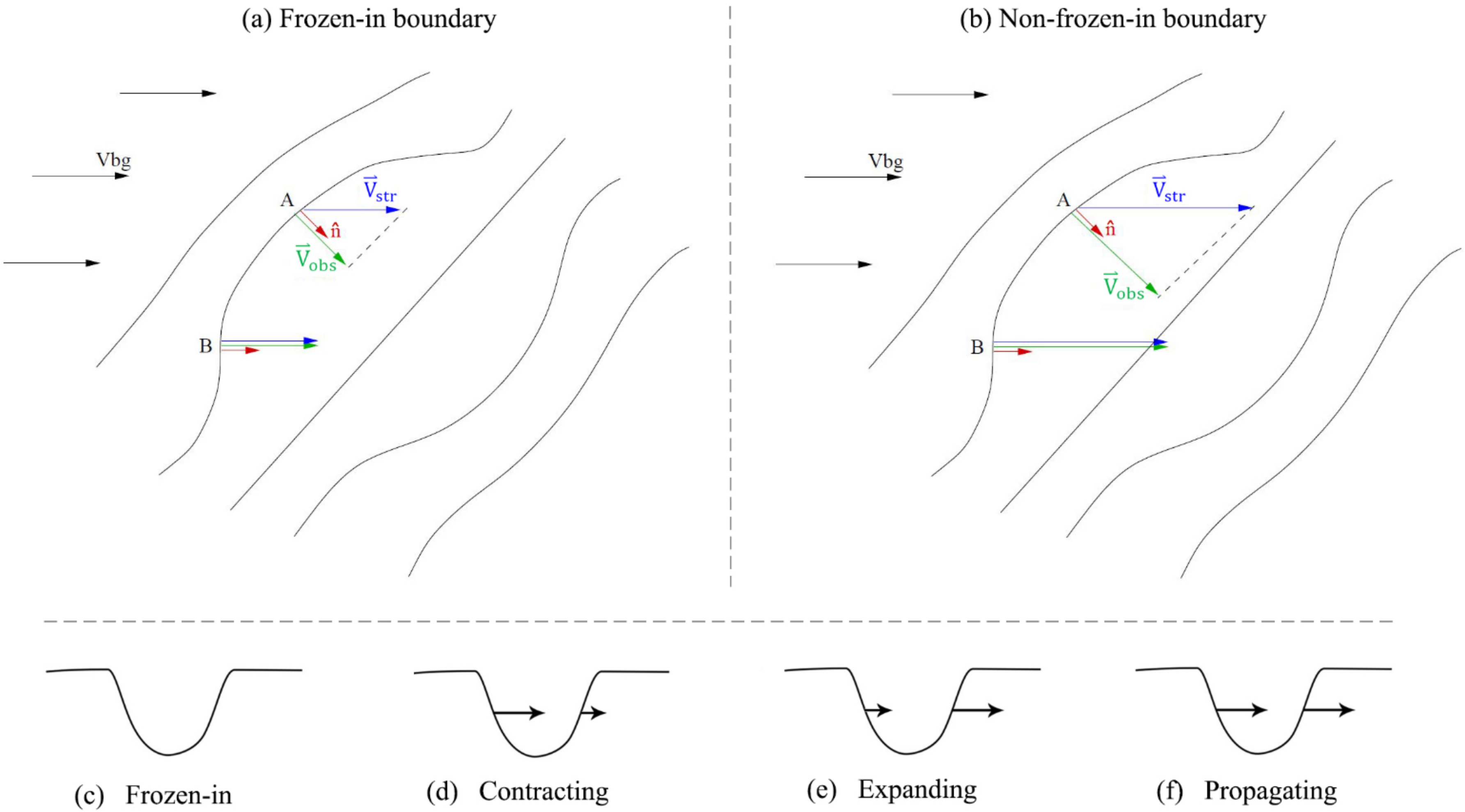
Contraction, expansion and propagation of magnetic holes

Yao et al., 2020a, JGR; 2016, JGR

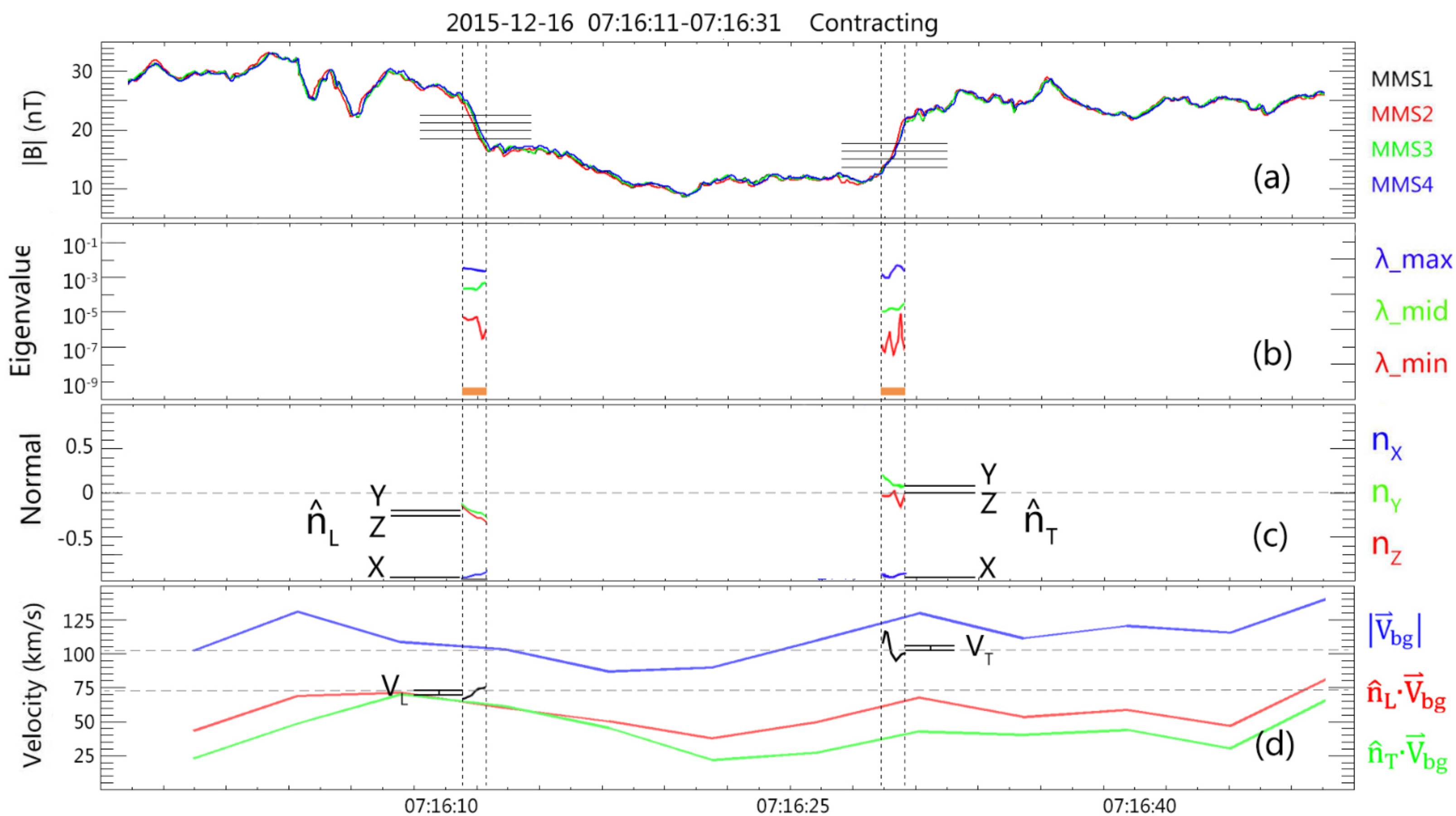




1.3: Propagation and dynamic of magnetic holes

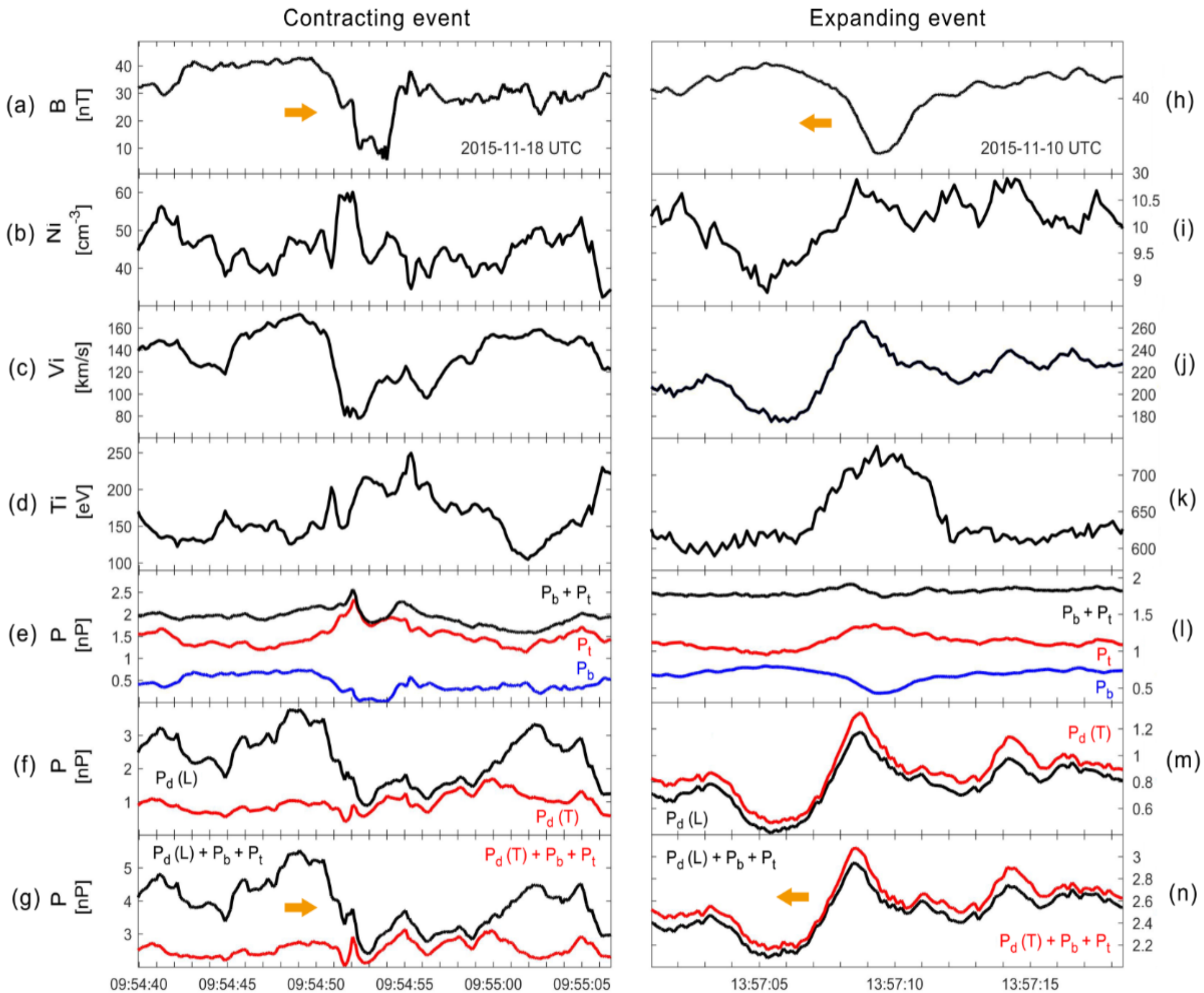


1.4: Electron scale and electrons in mirror mode



Example of a contracting event. Plasma velocity $|\vec{V}_{bg}|$ (blue) and along the leading and trailing normal (red, green) in spacecraft frame. One can compare $V_{L(T)}$ with $\hat{n} \cdot \vec{V}_{bg}$ to determine the propagation property.

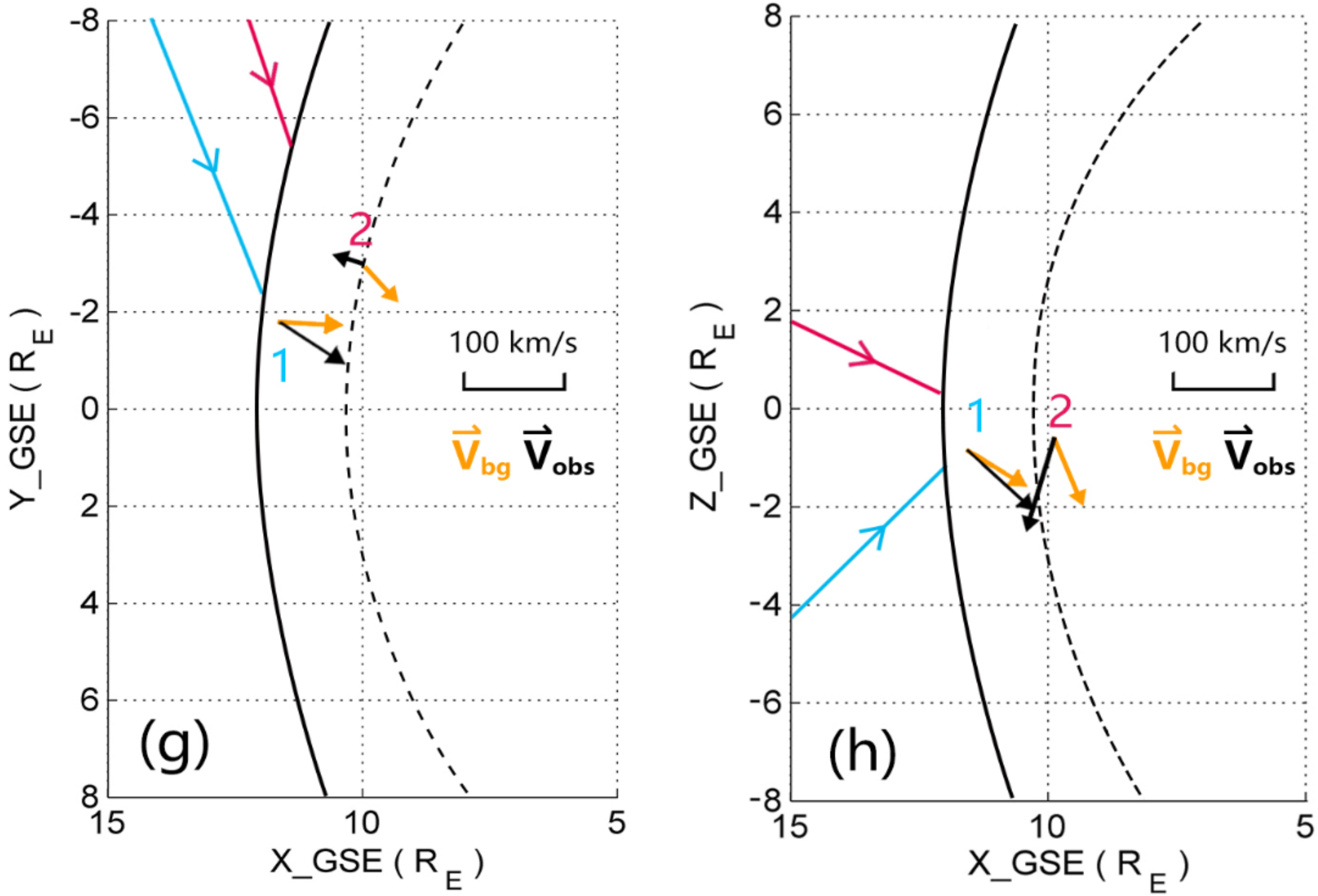
1.4: Electron scale and electrons in mirror mode



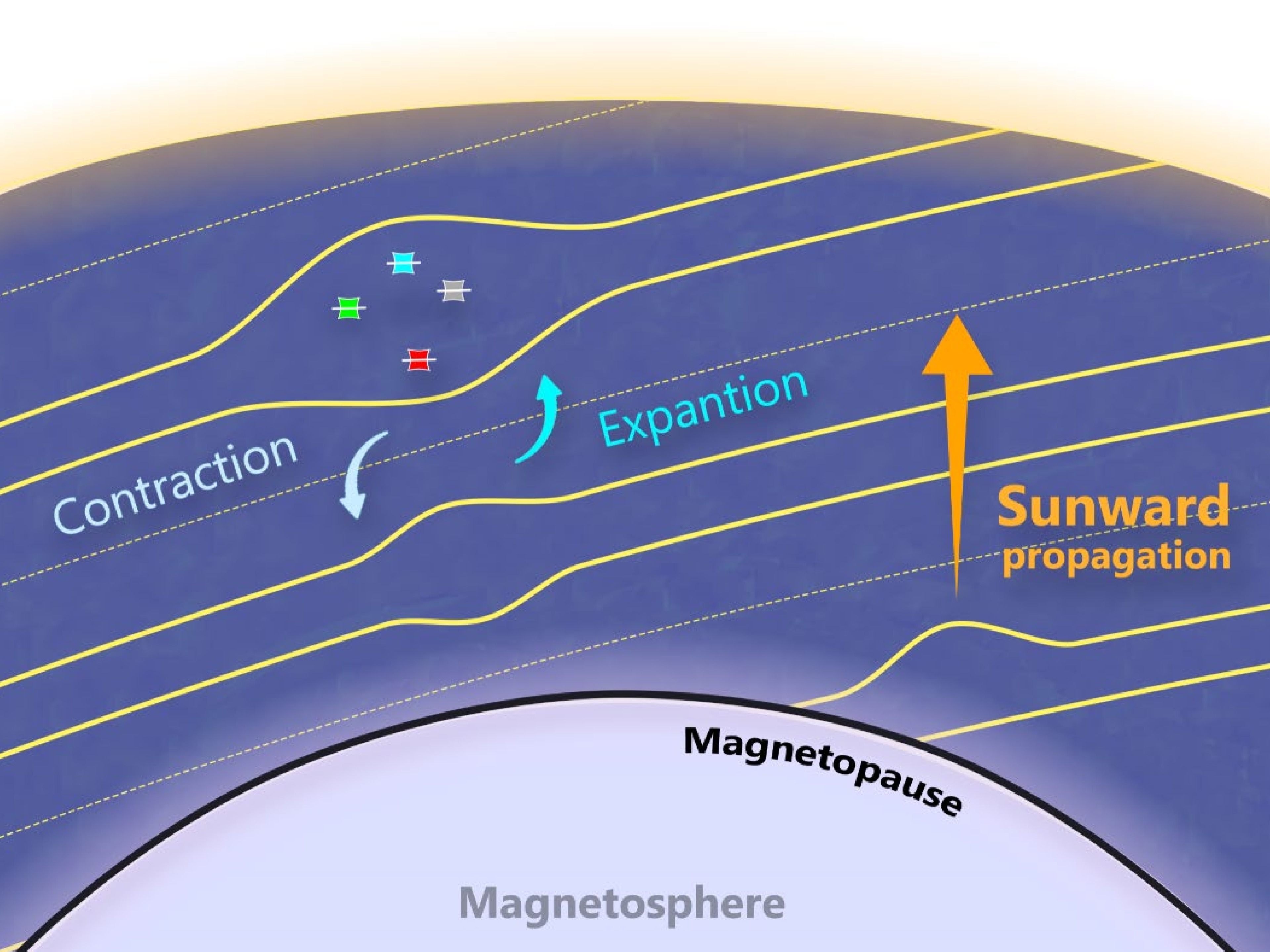
Four different propagation properties of magnetosheath magnetic dips are identified by using Several multi-spacecraft analysis methods

Pressure imbalance plays an important role in the evolution (contracting and expanding)

1.4: Electron scale and electrons in mirror mode



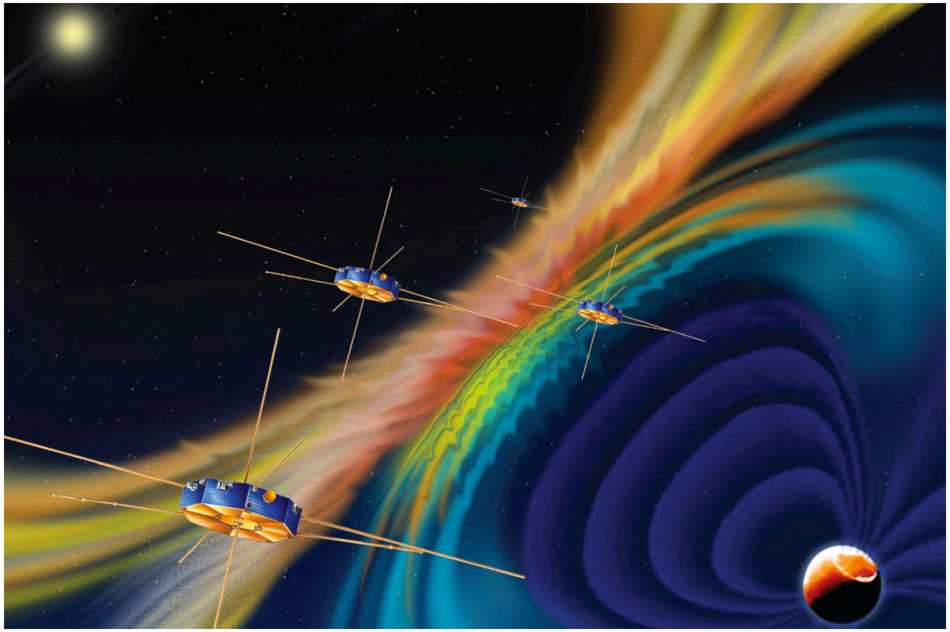
Two propagation events. A sunward propagating magnetic dip (2) indicates that the structure source is closely associated with the magnetopause

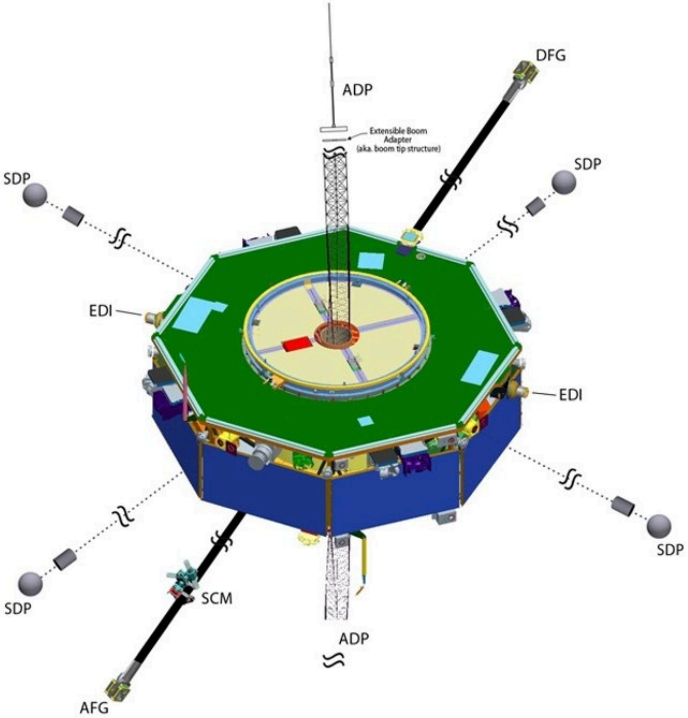

Contraction
Expantion
Sunward
propagation
Magnetopause
Magnetosphere

New MMS Observations

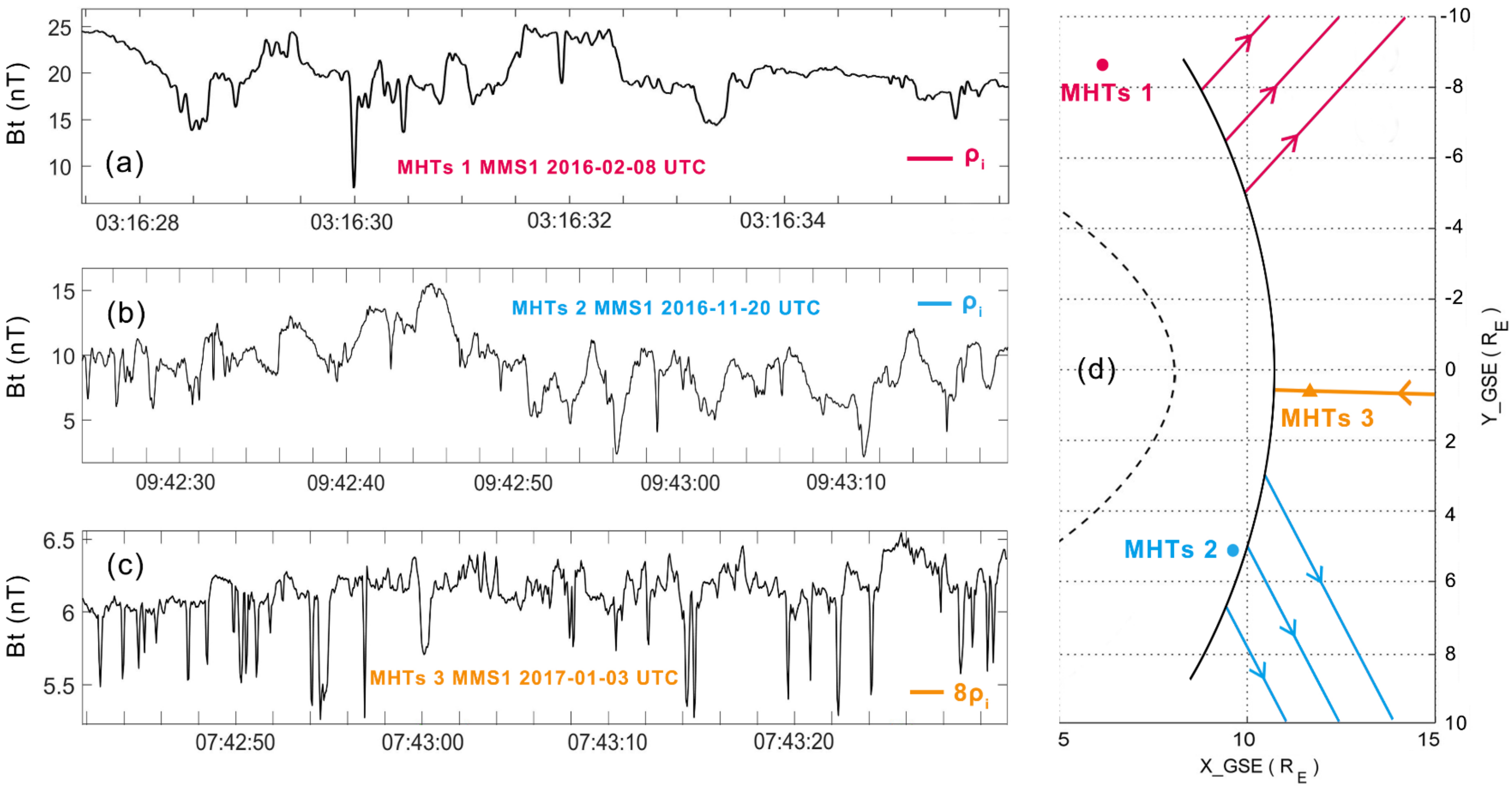
Electron scale and electrons in mirror mode

Yao et al., 2018b, JGR; 2019b, APJL



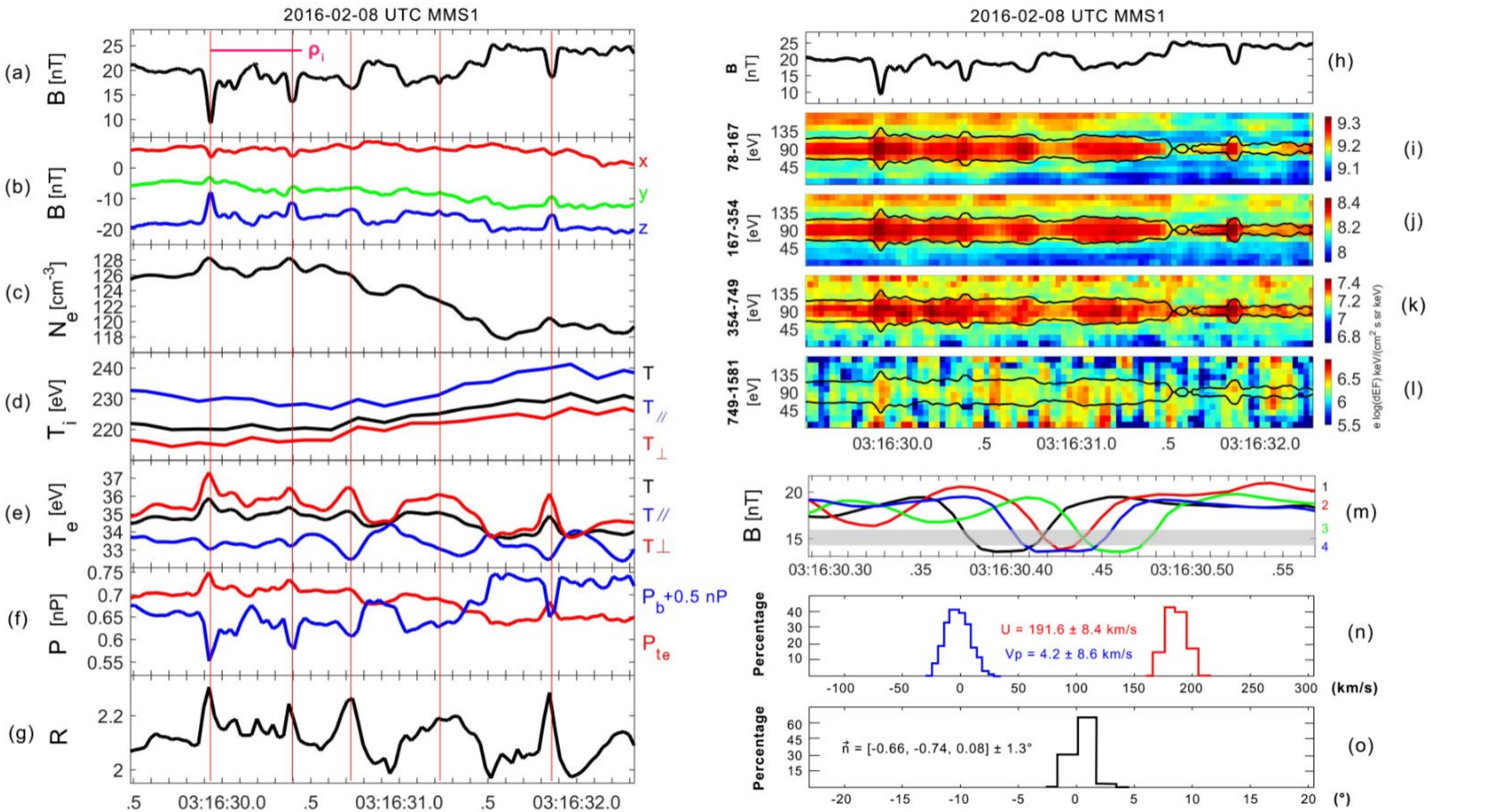


1.41: Electron scale mirror mode



Kinetic scale magnetic hole **trains** (MHTs) are observed near the Earth foreshock and its downstream turbulence during the Corotating Interaction Regions (CIRs)

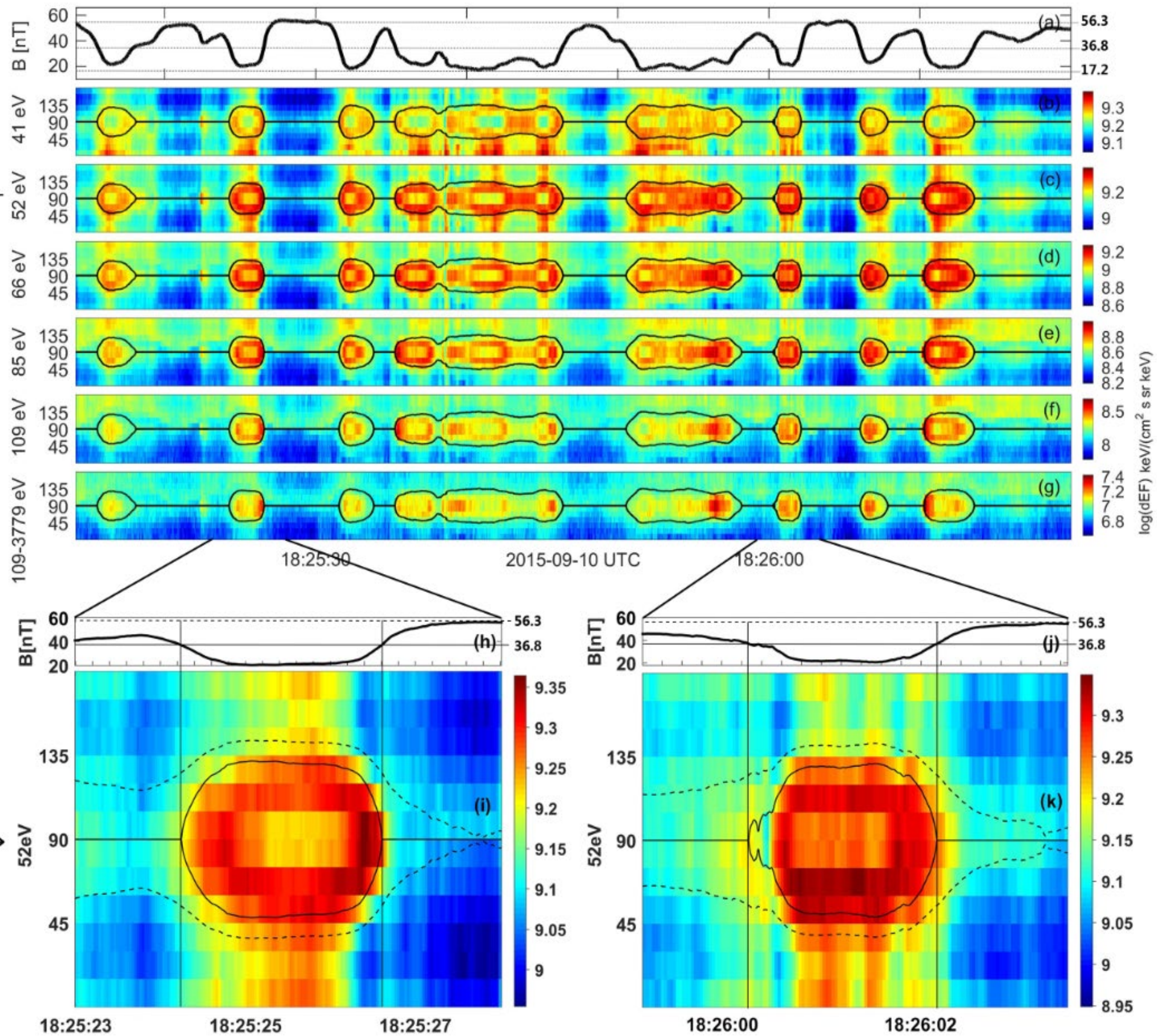
1.41: Electron scale mirror mode



They are electron scale mirror mode! **EVIDENCE**:

1. train-like (a-b); 2. compressible (f); 3. satisfy theoretical excitation (g); 4. satisfy trapped conditions (i-k); 5. non-propagation (n);

1.42: Electrons in MHD scale mirror mode

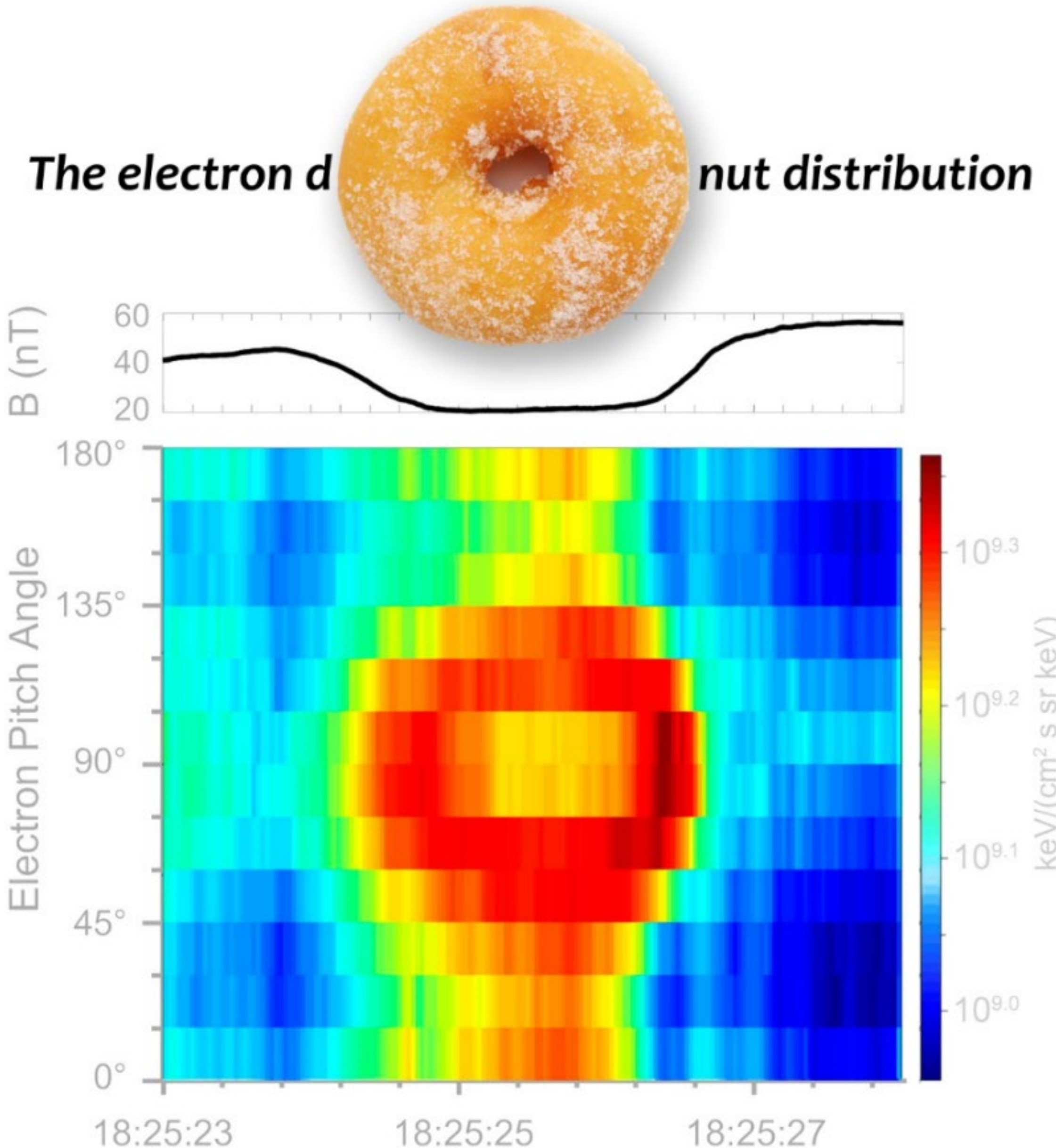


Electron pitch angle distributions of magnetosheath mirror modes are observed by MMS

The PADs display a characteristic donut-like configuration

Betatron cooling and spatial dependence of electron pitch angle are able to produce such a distribution

The electron d nut distribution



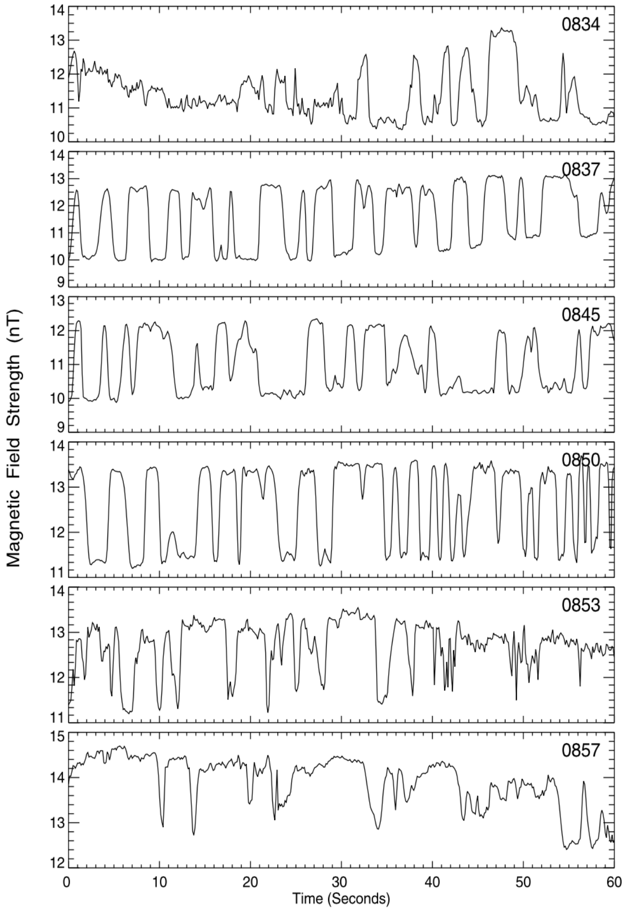
When I was doing this slide, I felt very **hungry**. However, since it was late at night and the shops outside were closed due to the developing coronavirus outbreak, I could not go outside to buy something to eat.

I am very glad to hear that the all of you are well. Wishing everyone and their families continued health and safety!

2: Kinetic Scale Magnetic Peaks

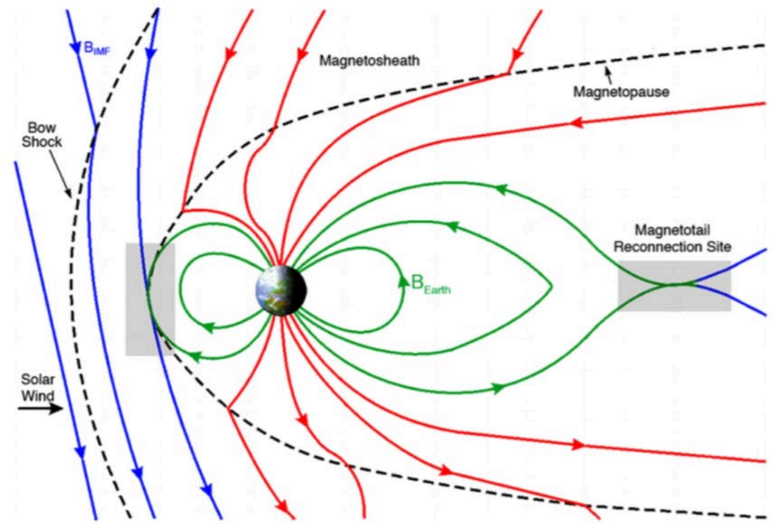
Introduction: magnetic peaks in the magnetosheath

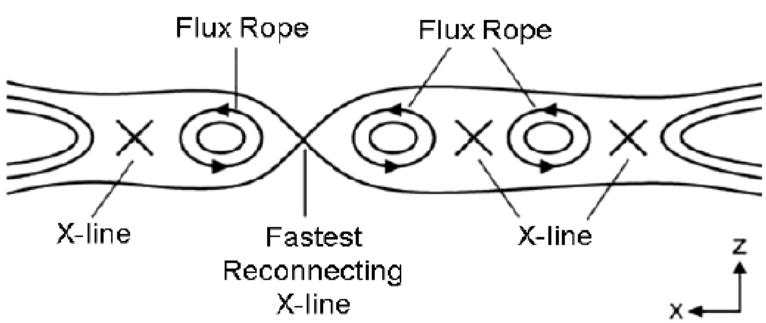
Mirror mode



Tang et al., 2012

Flux rope

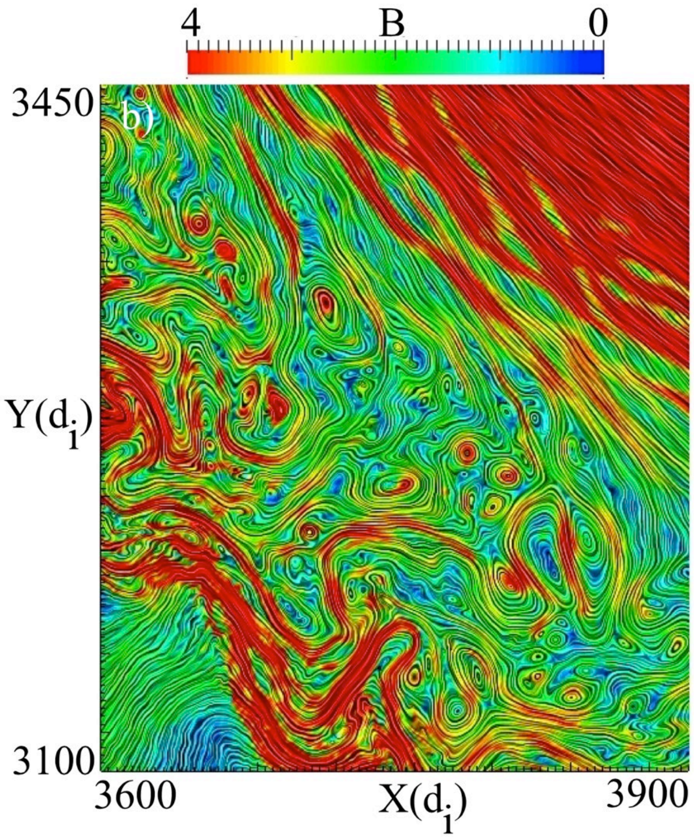




Slavin et al., 2003

2. Kinetic Scale Magnetic Peaks

Previous global hybrid simulations



Full of magnetic islands with the size of tens of ion inertial length.

Karimabadi et al., 2014

Recent MMS observations

In recent MMS studies, ion-scale FRs were observed during the reconnection at the magnetopause [Eastwood et al., 2016]. Non-ideal ion behavior and filamentary currents were exhibited.

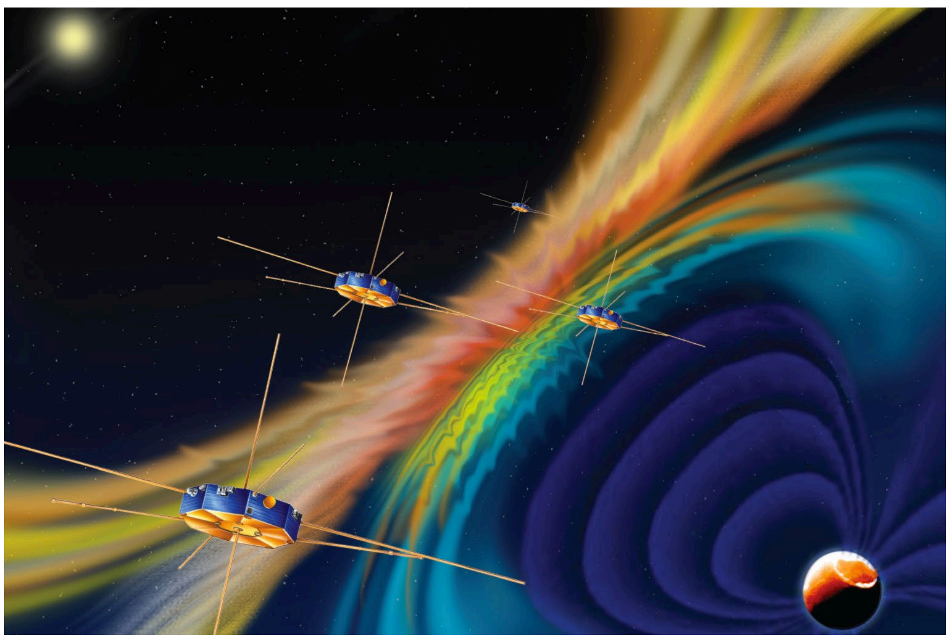
Huang et al. [2016] identified this kind of ion-scale structure in the turbulent magnetosheath as a magnetic island. Intense wave activities and electron beams were found near the structure.

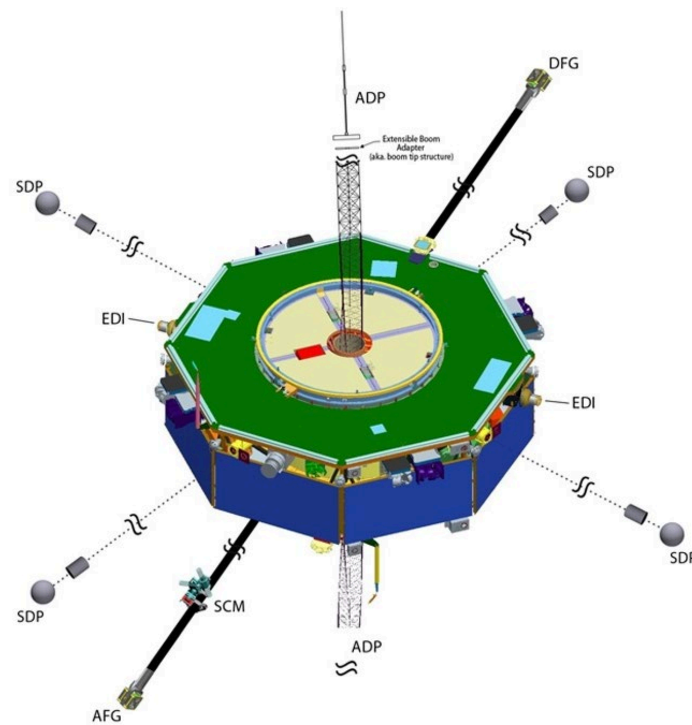
Akhavan-Tafti et al. [2018, 2019] investigated 55 flux ropes observed at the magnetopause, and found that their average scale was ~1700 km (~30 times of local ion inertial length.

New MMS Observations

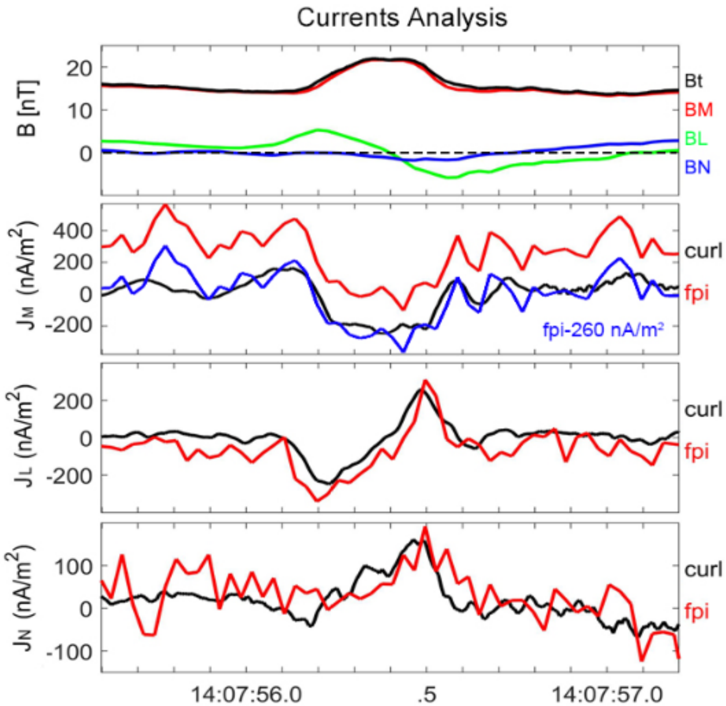
KSFR intercept magnetosheath electrons to the magnetosphere

Yao et al., 2020b, APJ

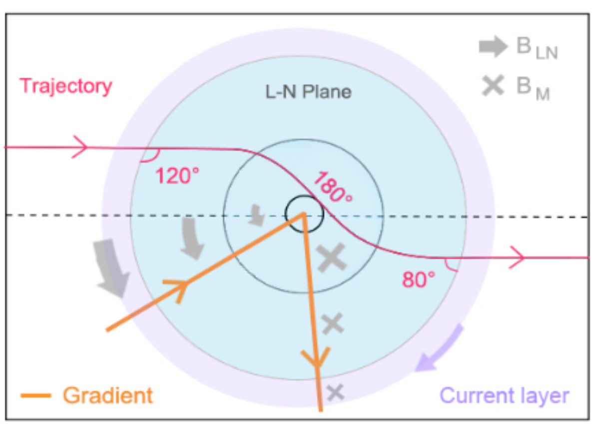




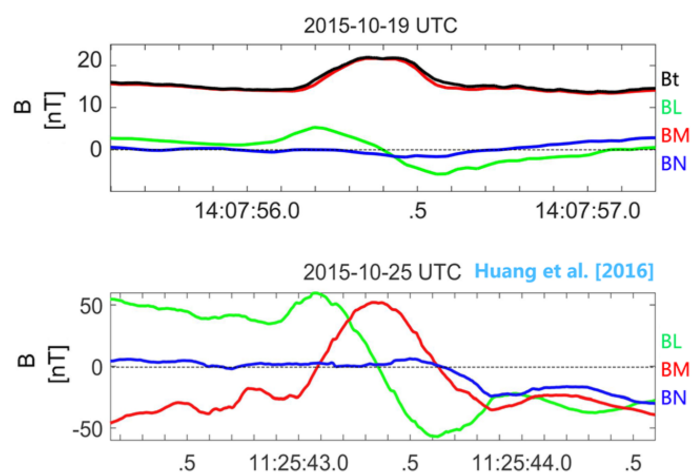
2.1: Kinetic Scale Flux Rope



A simplified equation derived from Biot-Savart law: $B = \mu_0 J \pi r^2 / 2\pi r$ is used to estimate the twist of the magnetic field generated by the field-aligned current J ~200 nA/m^{-2}, where r ~42.5 km is the radius of the KFR. The calculated magnetic field is ~5.3 nT, which fits well with the magnetic component in the L-direction. This implies that the KFR is possibly generated by the **field-aligned current**.

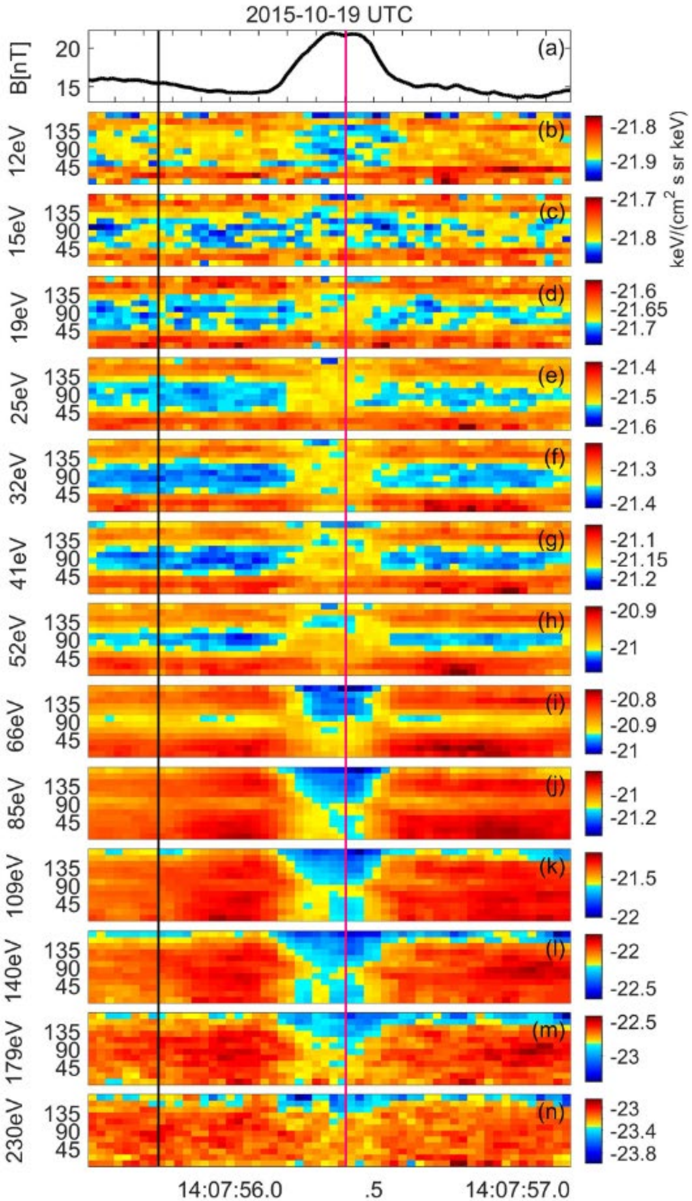


Sketch of the flux rope

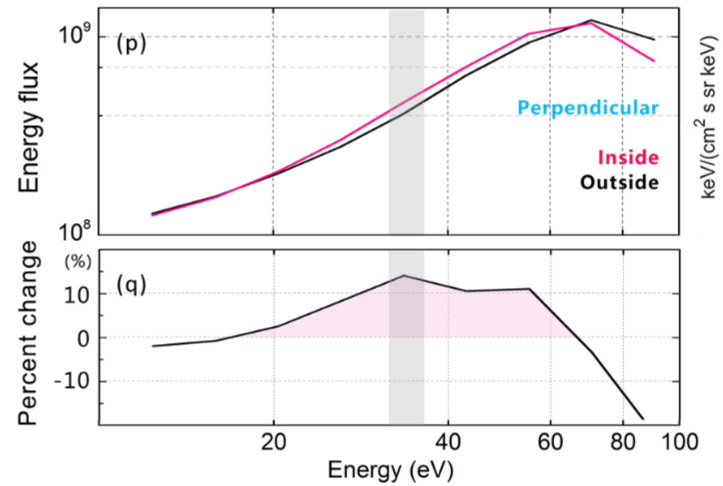


Differs from typical flux ropes usually observed within the current sheet where magnetic reconnection can occur.

2.1: Kinetic Scale Flux Rope



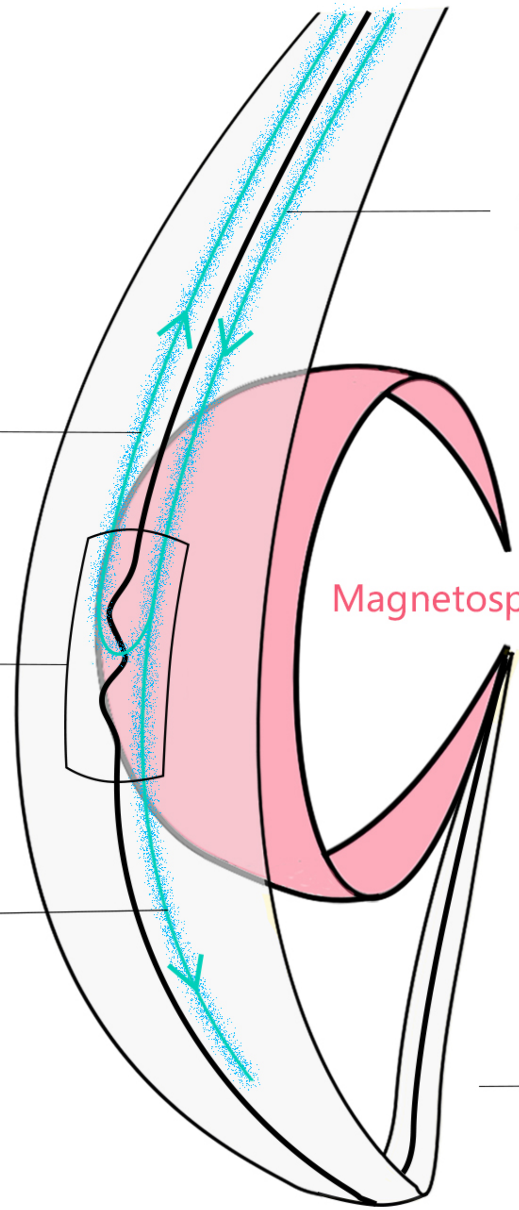
90°↑ ?
Where are they come from?

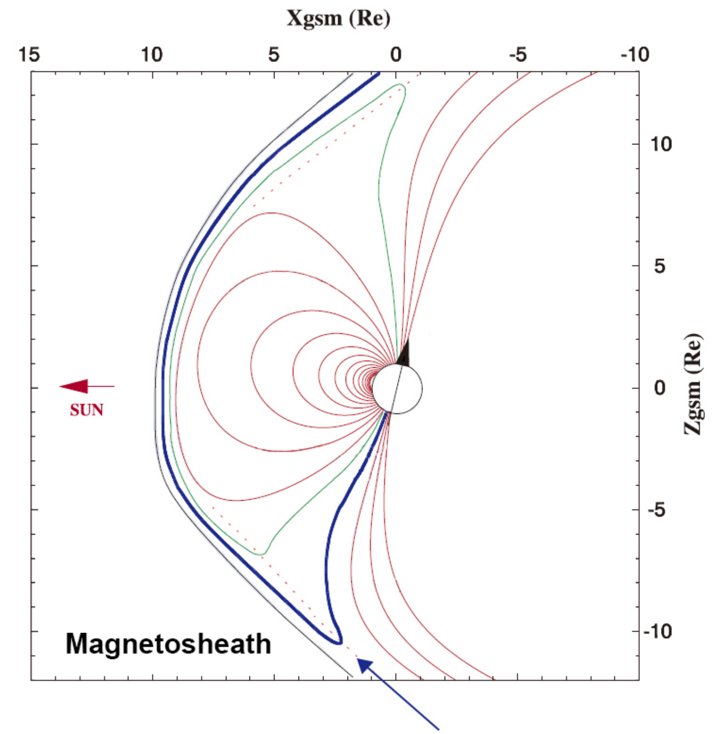


Temperature of magnetosheath electrons

Magnetosheath electrons may encounter their mirror point when traveling from the magnetosheath toward the ionosphere, and be reflected.

This KFR is **different** from previous flux ropes that transfer electron flux to the magnetosphere, but could **intercept** magnetosheath large pitch angle electron flux to the magnetosphere.

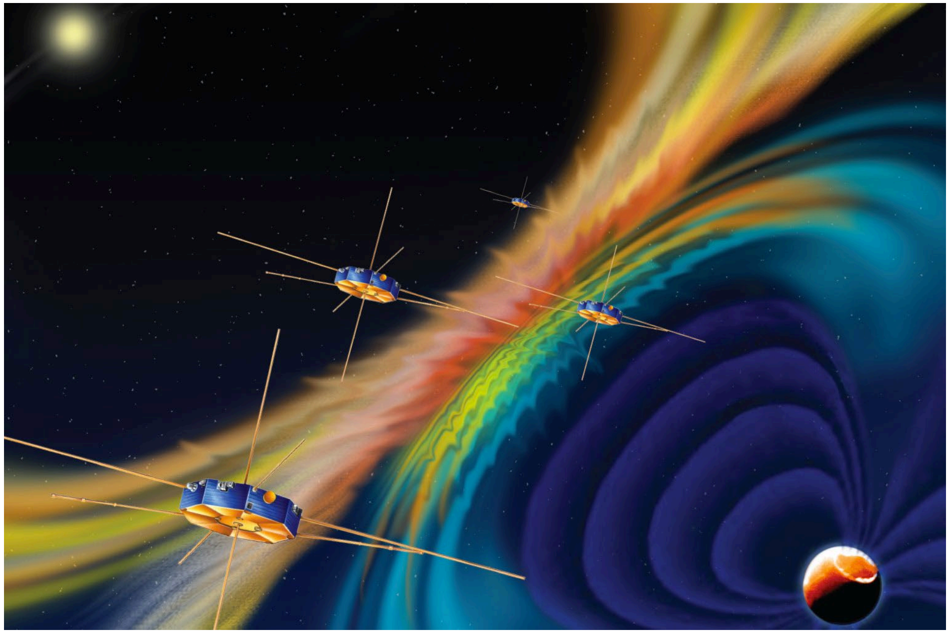

Magnetosheath electrons
Large pitch angle electrons
Flux rope
(mirror point, strong |B|)
Small pitch angle electrons
Magnetosphere
Magnetosheath boundary layer

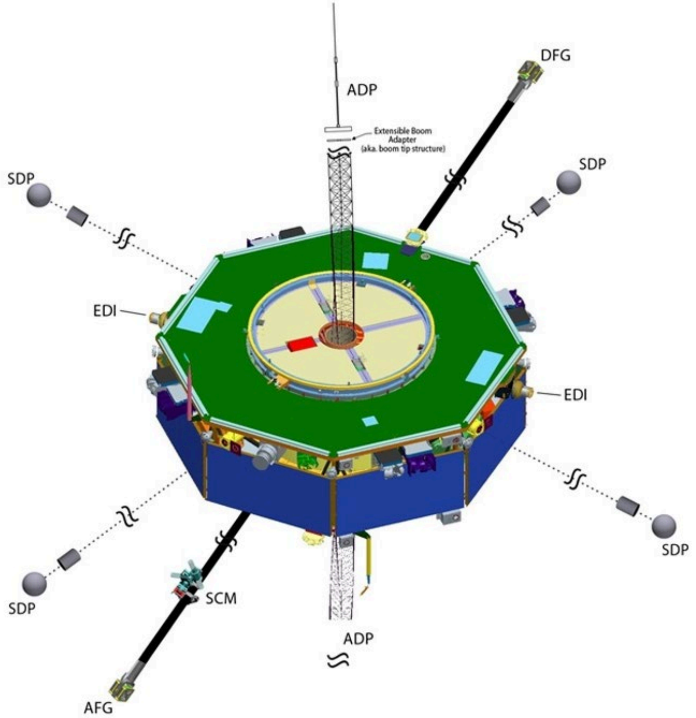

Xgsm (Re)
15
10
5
0
-5
-10
Zgsm (Re)
SUN
Magnetosheath

New MMS Observations

Kinetic scale ($7\rho_e$) magnetic peak with electron vortex

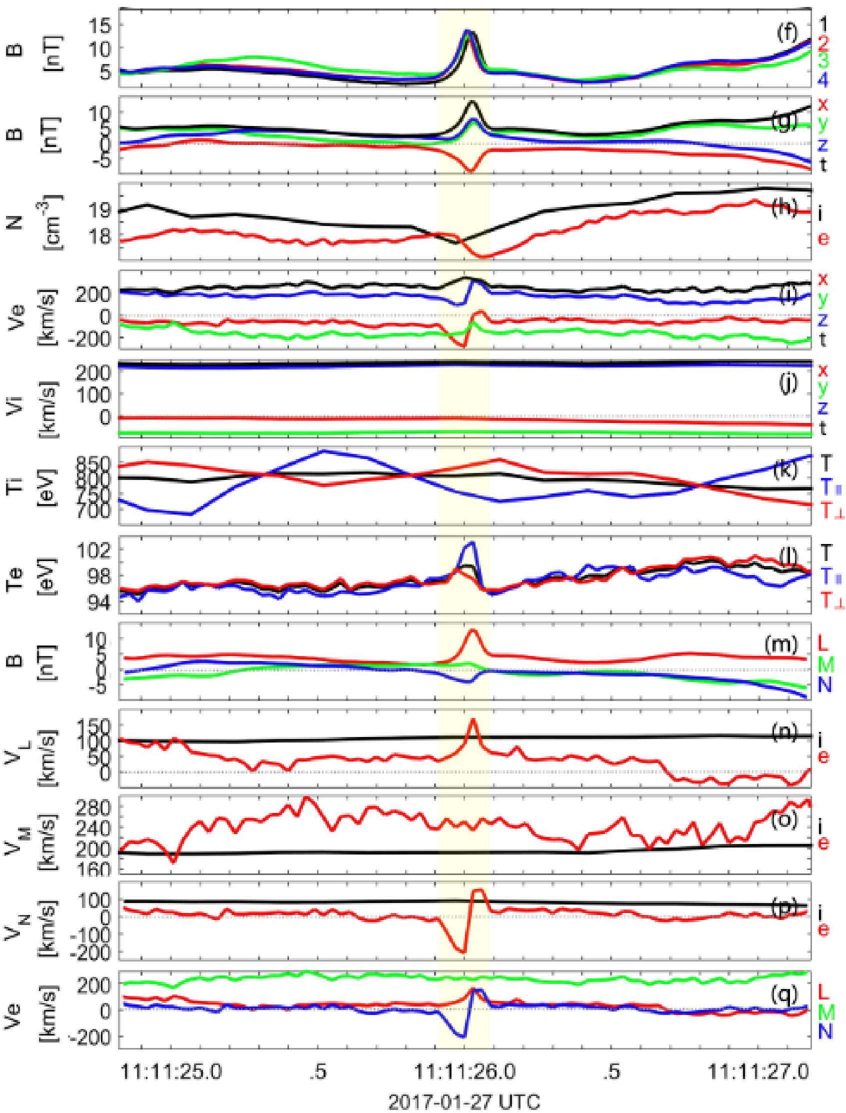
Yao et al., 2018a, GRL

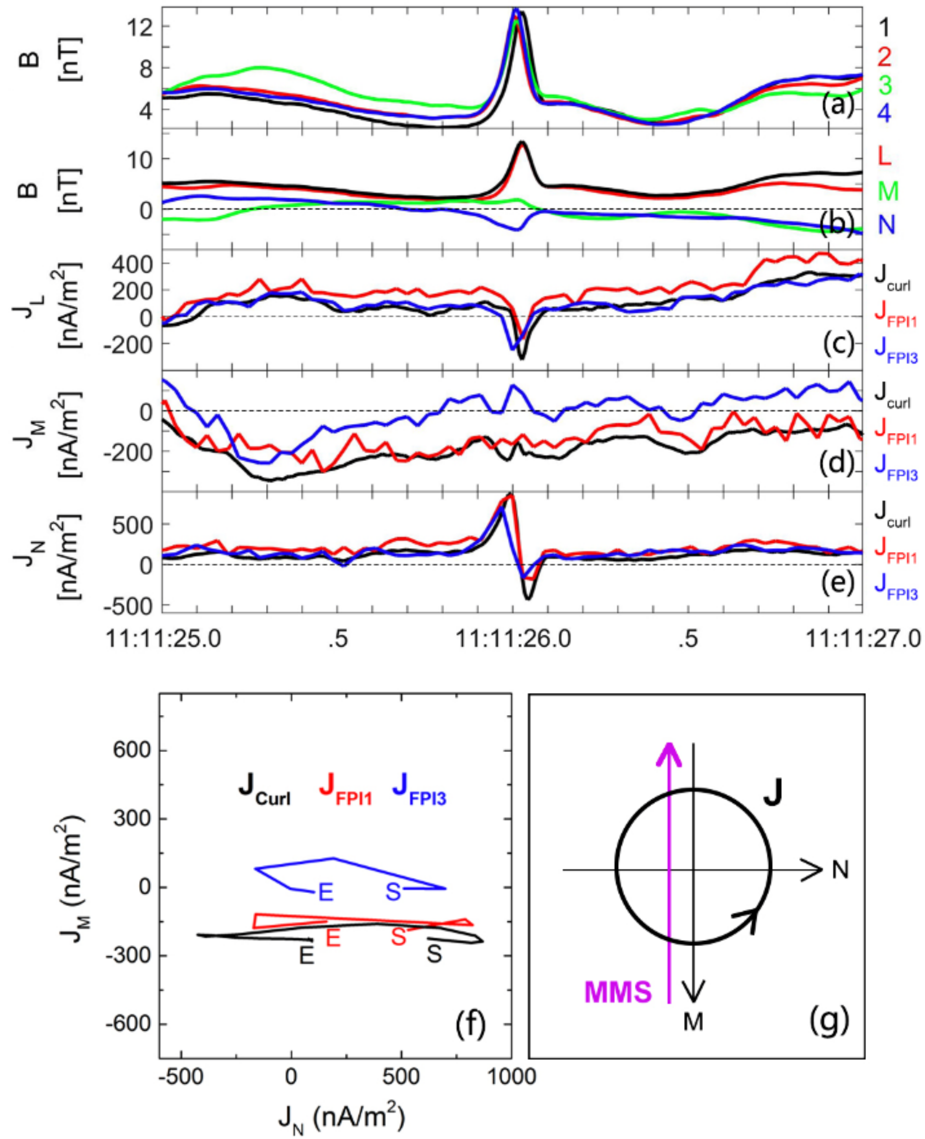




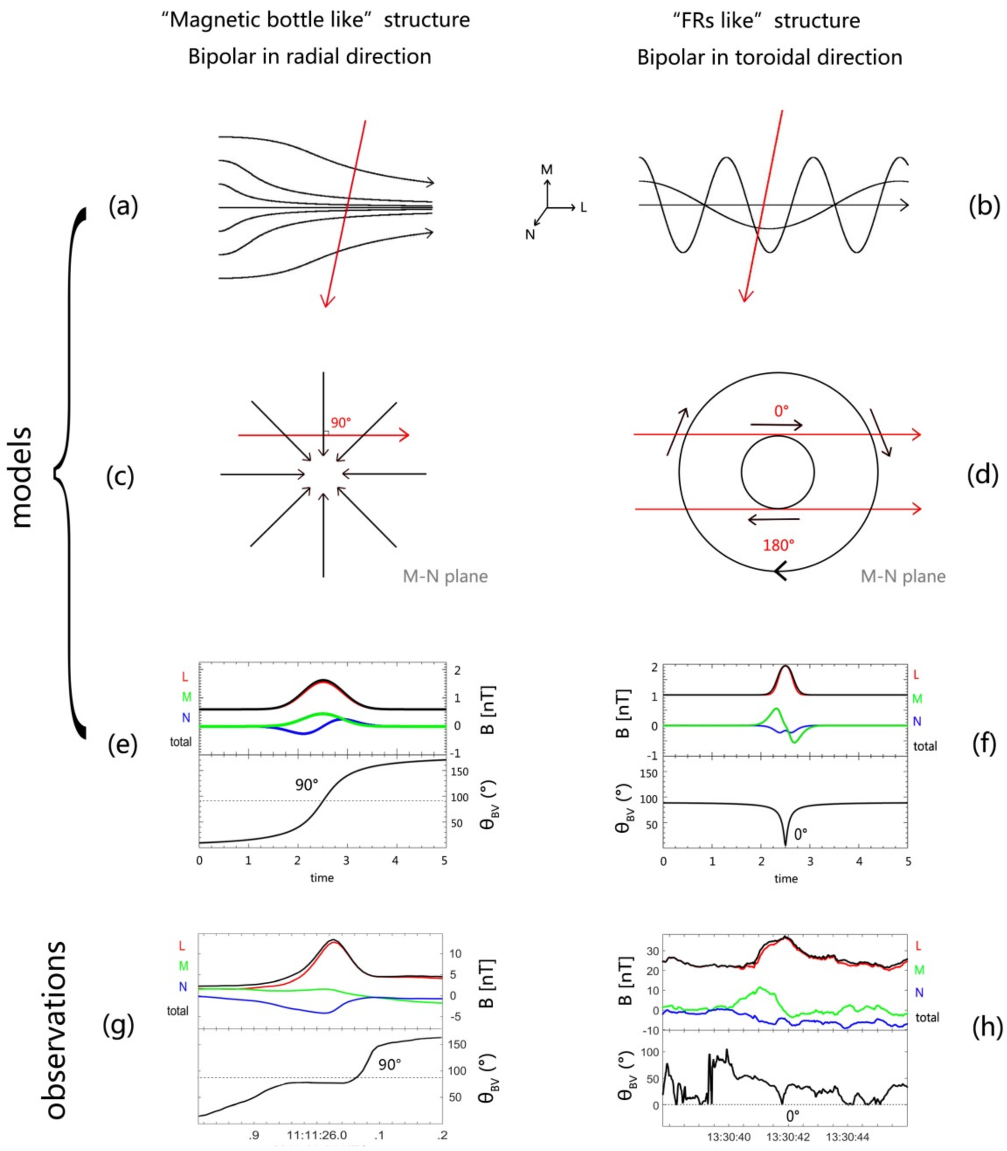
2.2: Kinetic Scale Magnetic Bottle

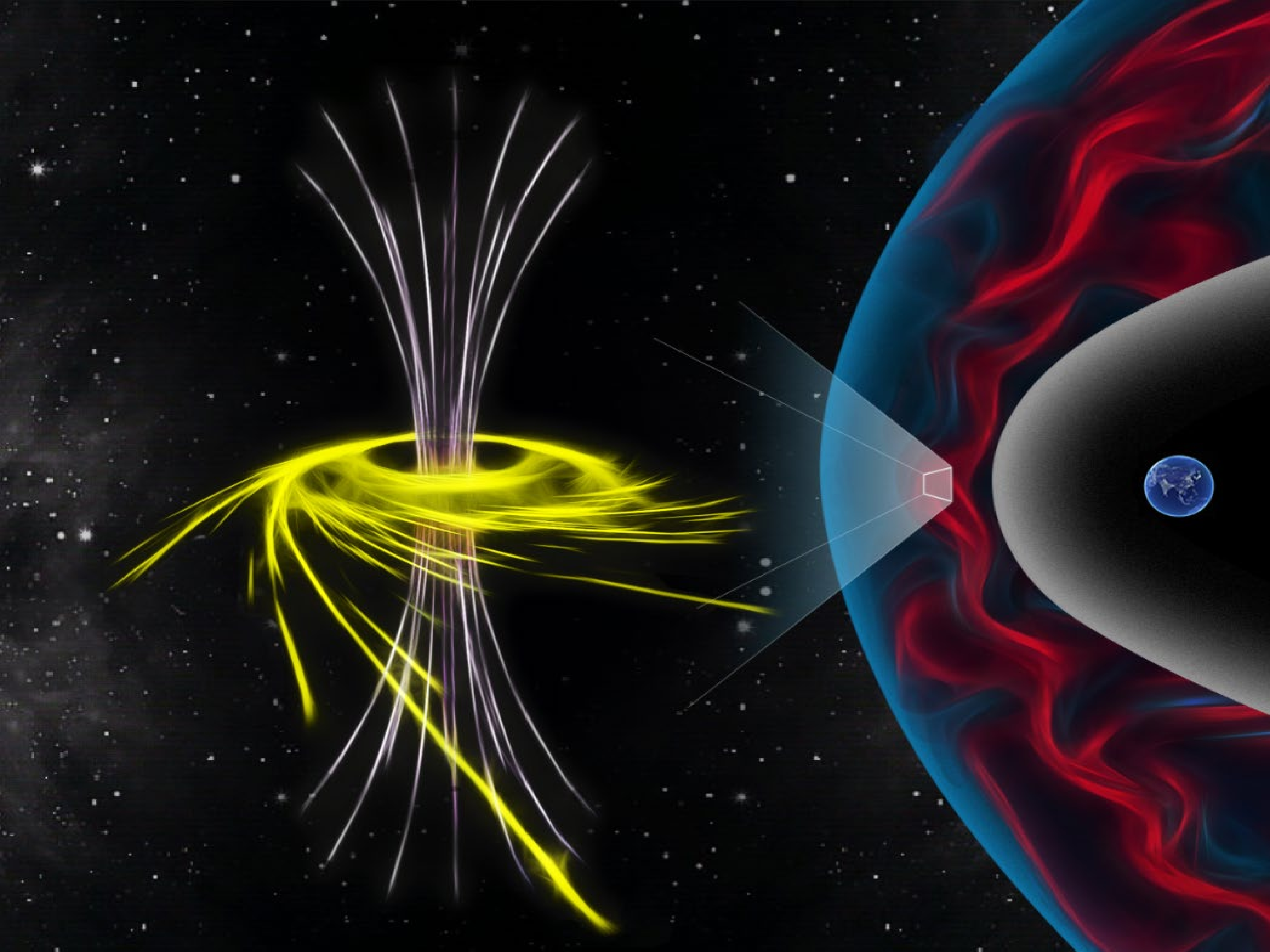
Overview plot 0.18s, 7ρe





2.2: Kinetic Scale Magnetic Bottle





3. Summary & Discussions

- **1st type: kinetic scale magnetic holes**

    1.1. In the magnetosheath

    1.2. Relation with waves

    1.3. Propagation and dynamic

    1.4. Electron scale and electrons in mirror mode

- **2nd type: kinetic scale magnetic peaks**

    2.1. Flux rope

    2.2. Magnetic bottle

3. Discussions and Questions

1. Relationship of sheath MHs and bottles with turbulence?
2. Kinetic scale flux ropes: always related to magnetic reconnection?
3. Energy transportation and electron acceleration in MHs?
4. Difference between train and isolated MHs, mirror mode or soliton?
5. Geometry and distributions in space?
6. Generation mechanism, the relation with CIR and CME?
7. MHs near dipolorization fronts: energy release in the tail through magnetic reconnection?
8. …

A lot of work to be done, and I look forward to work with you!!

Self-introduction

Hi, I am **Shutao Yao** (first from the right). I am **very glad** to share works with you. We sadly cannot meet at EGU in person, so I would like to introduce myself here.

I am a 3-year PhD student from Shandong University in China, and now looking for postdoctoral position. My supervisor is Quanqi Shi, and you can easily find him in this session.

My PhD research studies the physics in kinetic scale. I found some new types of kinetic scale structures in space; investigated the properties of waves, propagations, current systems, dynamics, particle distributions and acceleration, electromagnetic and plasmas features. During my doctoral study, I went to Zhongshan Station in Antarctica for a year's space physics observation. During this period, I did observation works of geomagnetic field, ionosphere, aurora, SuperDRAN radar and cosmic rays. I would very like to share some Antarctic aurora photograph with you **at the end of this report**.

Publication

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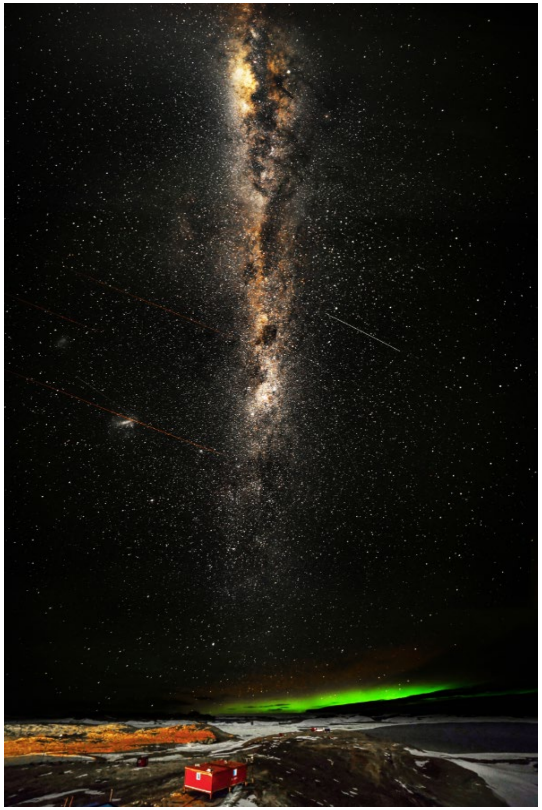













THANKS

All the photos were taken by me. If you like one, some or all of them, please contact me and leave your address. I will send you a postcard. Of course, if we meet later in some meeting, I can send it to you directly!

yaoshutao2008@163.com