

A new theory for energetic electron generation behind dipolarization front

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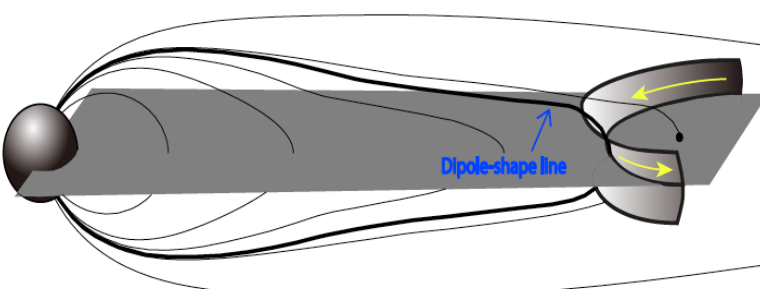
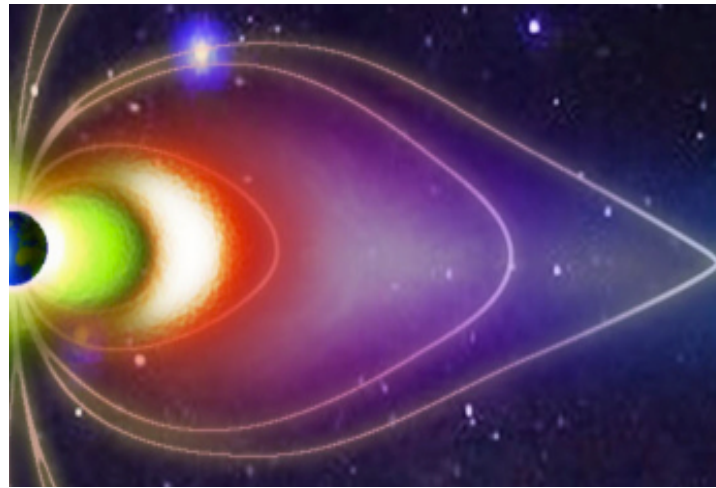
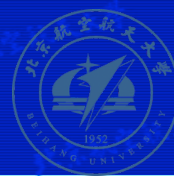
Co-authors: Mingjie Zhao, Yue Yu, Zhe Wang



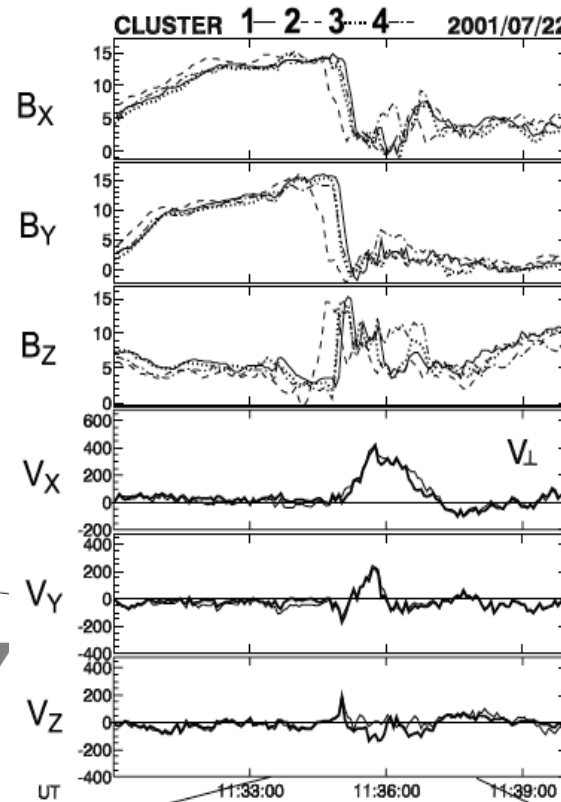
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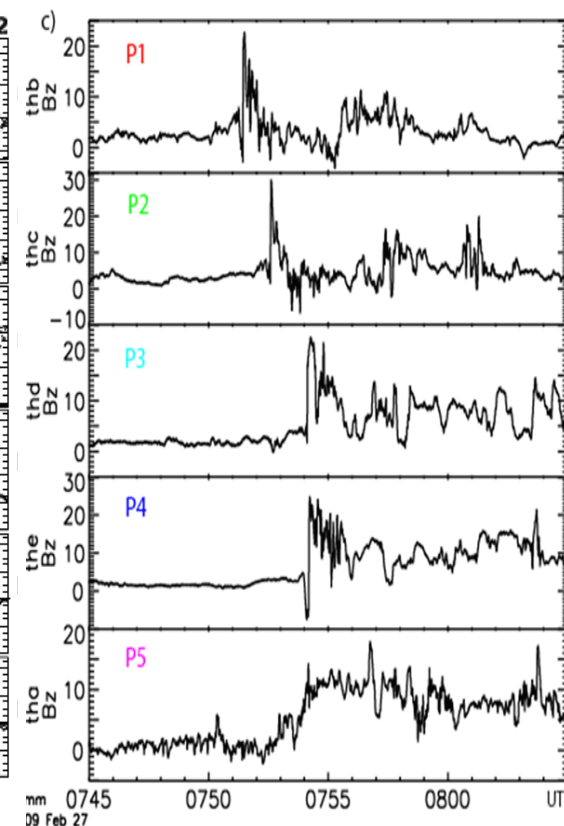
Dipolarization front



Fu+, 2012GRL



Nakamura+, 2002GRL



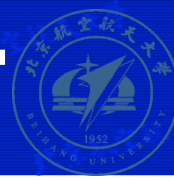
Runov+, 2009GRL

Magnetotail dipolarization fronts and particle acceleration:

A review

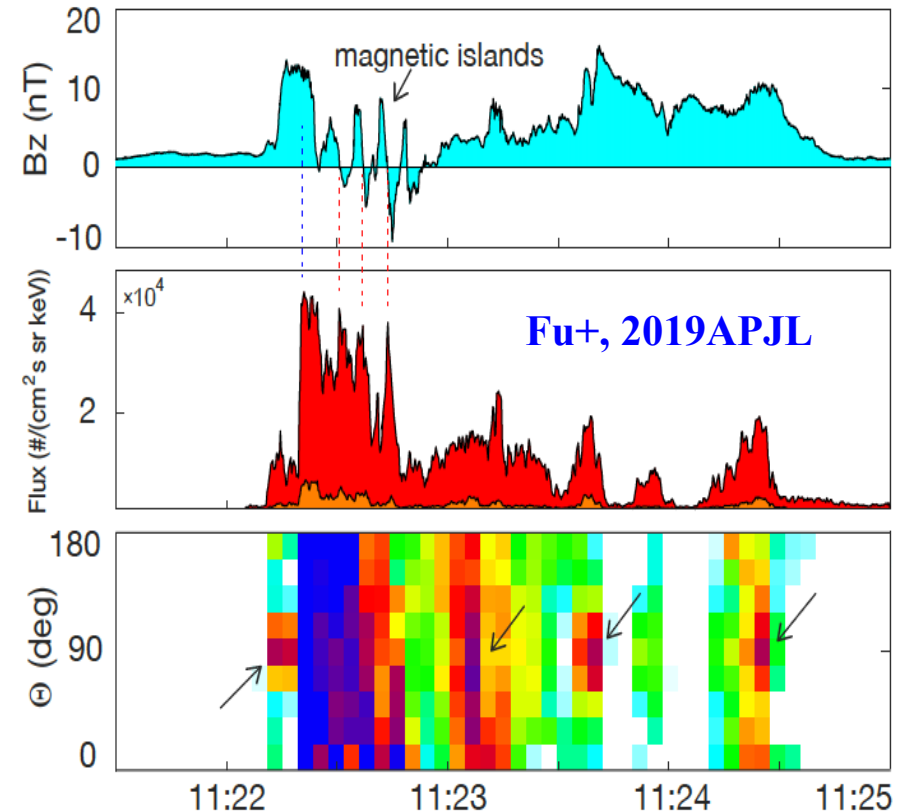
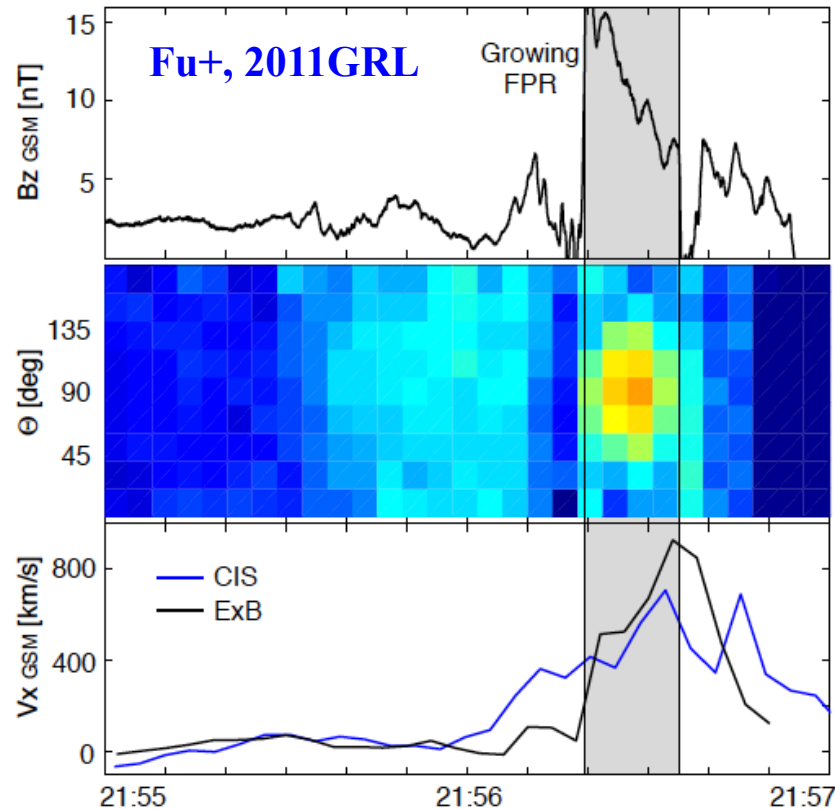
Fu+, 2020, Sci. China Earth Sci.

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K. J. HWANG⁴, Xuzhi ZHOU⁵, Zhe WANG¹ & Fang CHEN¹



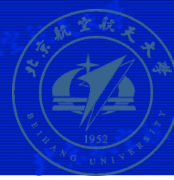
Electron acceleration at DF

Classical theory:



- Betatron acceleration
- Conservation of 1st adiabatic invariant

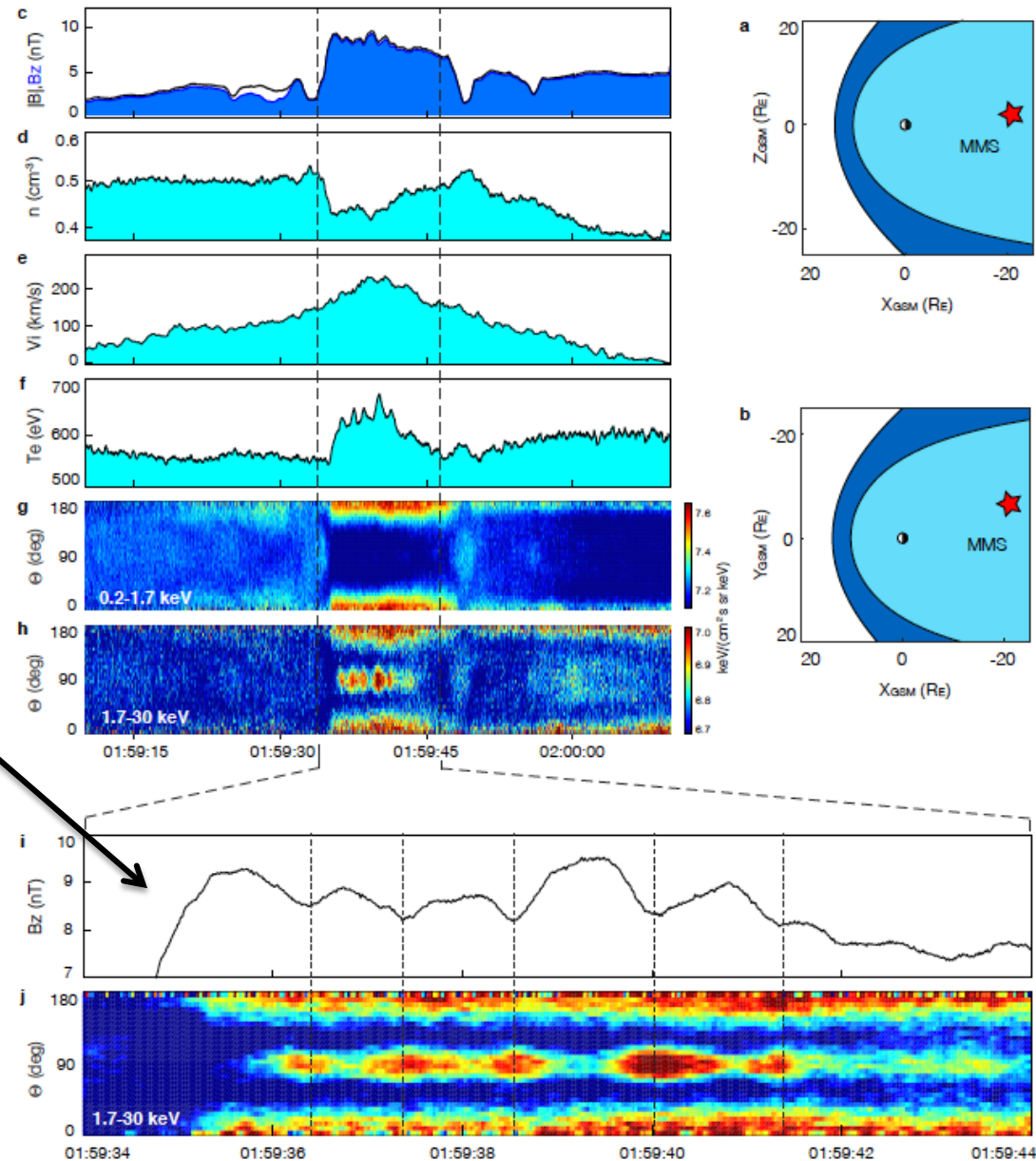
- B increase $\rightarrow$ Flux increase
- B decrease $\rightarrow$ Flux decrease



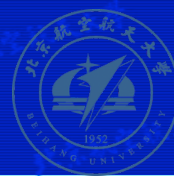
Novel observation by MMS

DF event

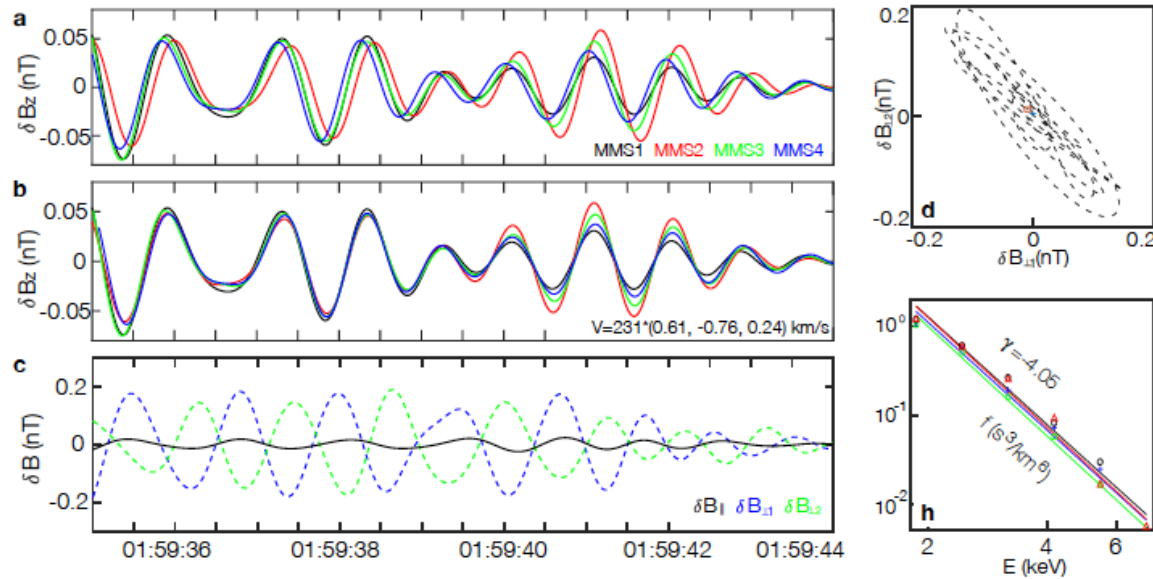
- B increase $\rightarrow$ Flux decrease
- B decrease $\rightarrow$ Flux increase



Challenge the
classical theory of
betatron mechanism

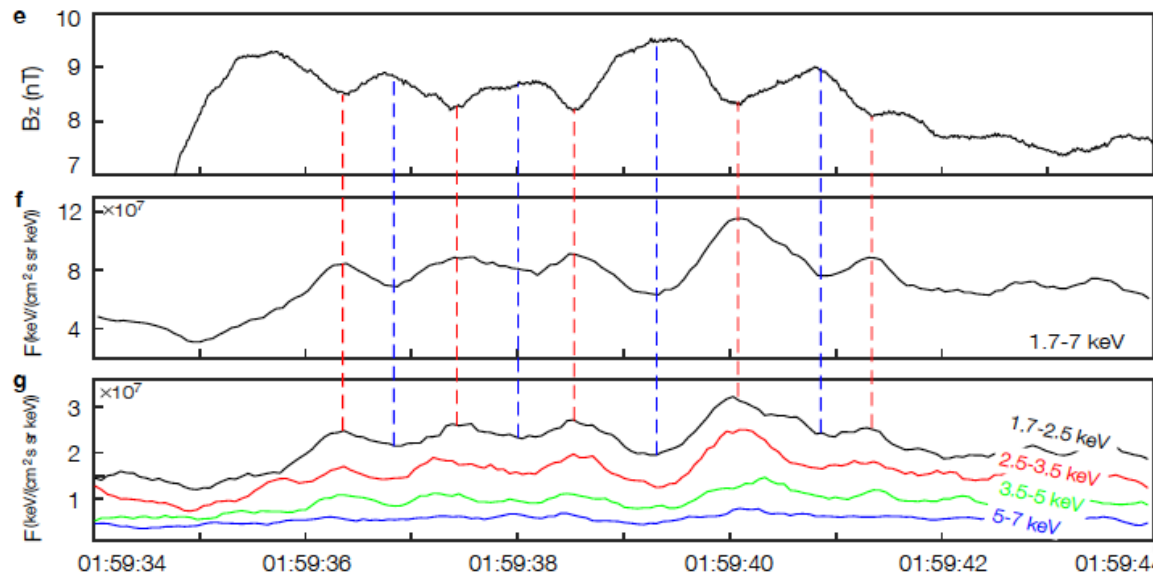


Novel observation by MMS



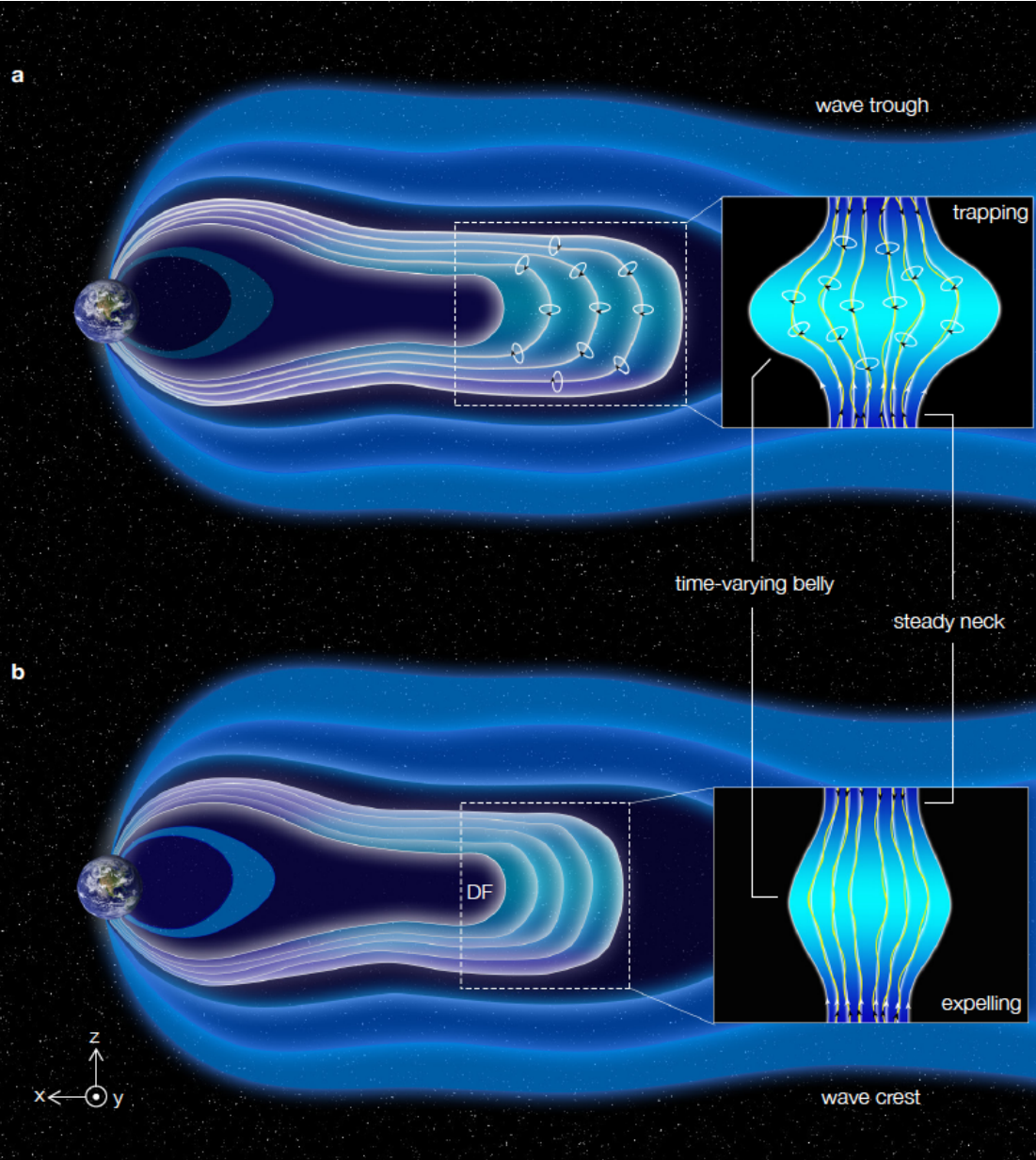
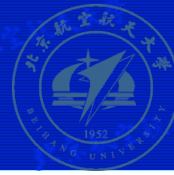
Magnetosonic wave

- $f < f_{LH}$
- Linear polarization
- Compressibility



- B increase $\rightarrow$ Flux decrease
- B decrease $\rightarrow$ Flux increase

New theory



Magnetic bottle

- Time-varying belly
- Steady neck

$$\mu = \frac{mV_{\perp}^2}{2B} \text{ remains constant}$$

$$\frac{V_{\perp b}^2}{B_b} = \frac{V_{\perp n}^2}{B_n}$$

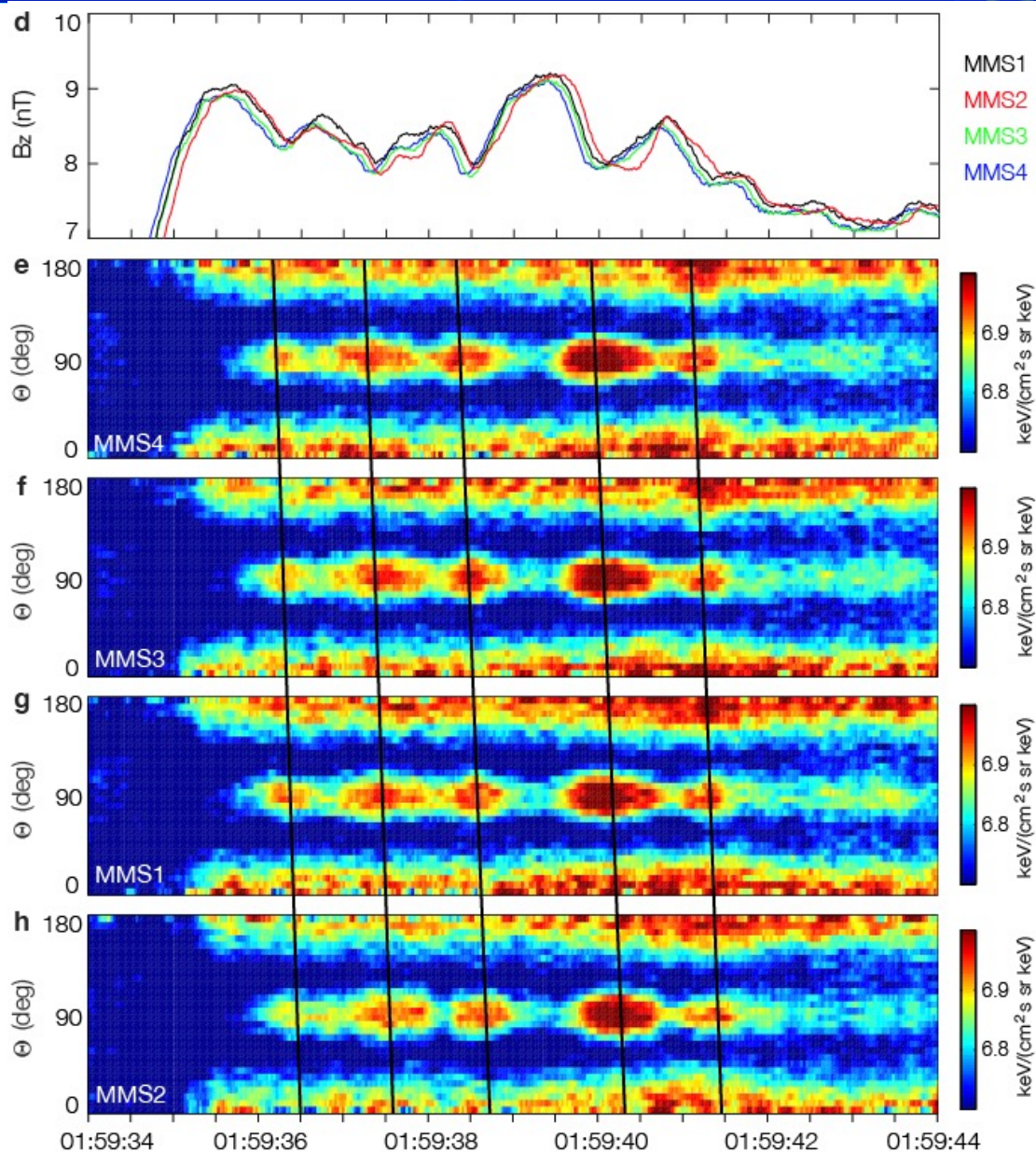
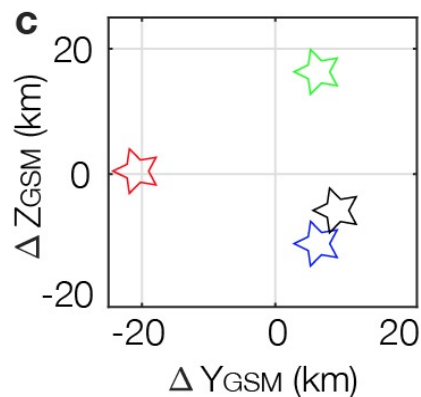
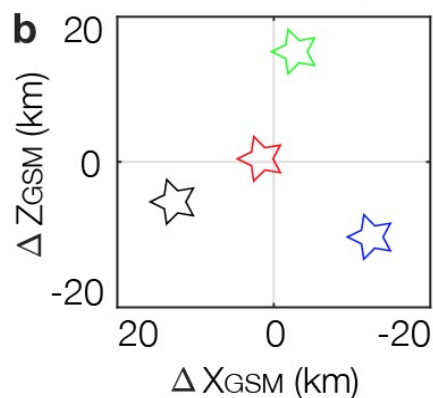
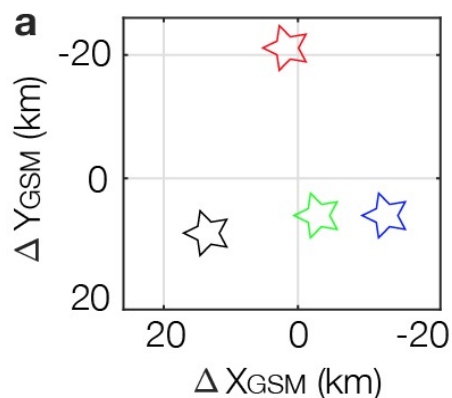
$$\frac{V_{\perp b}^2}{V_b^2} = \frac{B_b}{B_n}$$

Loss cone: $\sin \alpha \propto \sqrt{B_b}$

- B increase $\rightarrow$ Large loss cone $\rightarrow$ Flux decrease
- B decrease $\rightarrow$ Small loss cone $\rightarrow$ Flux increase

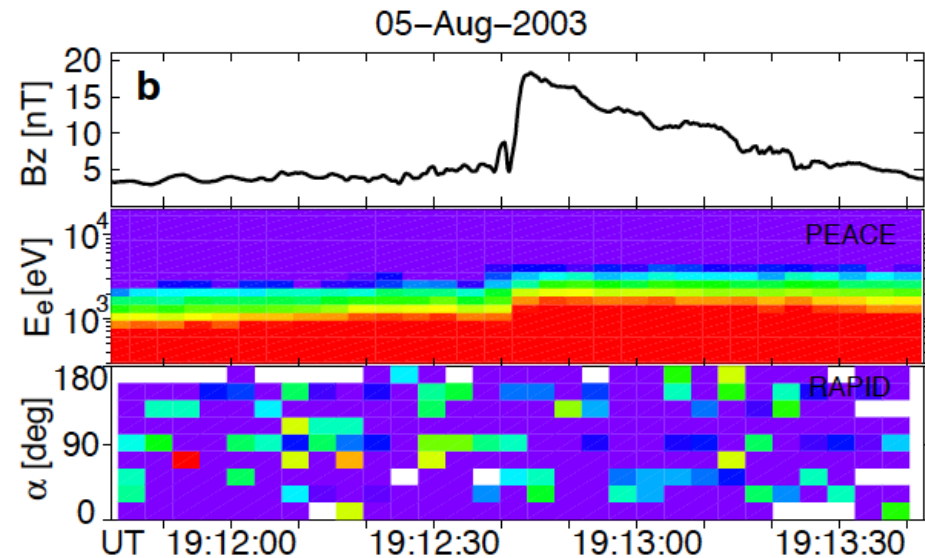
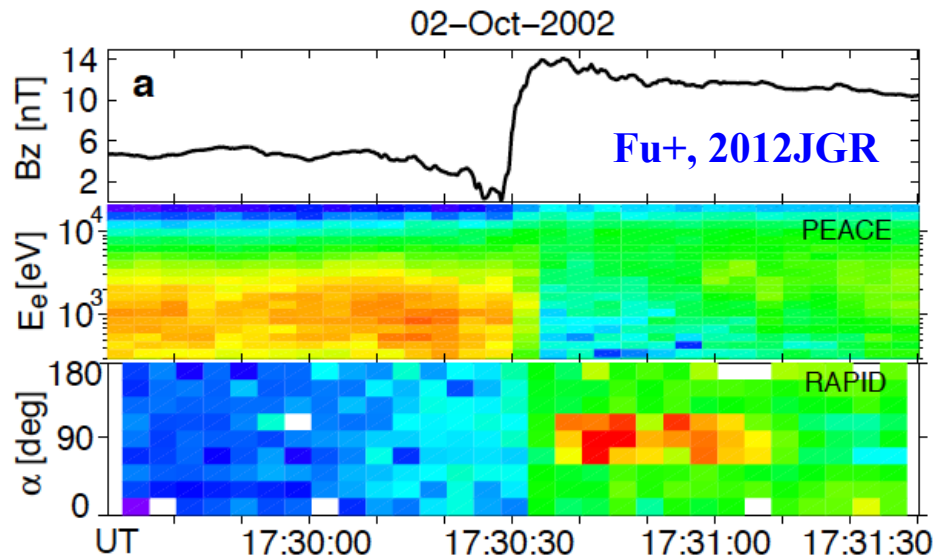
Size: $L=2-3 \text{ RE}$

Confirmation by four MMS



Implication

Why energetic electrons only appear in half the DF events?



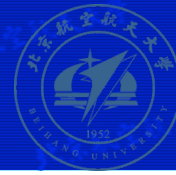
Fu+, 2012JGR; Runov+, 2013JGR

Implication:

- DF events with energetic electrons → fat DFB
- DF events without energetic electrons → slim DFB

Conclusions

1. Electron fluxes increase at B-minimum but decrease at B-maximum
2. This challenges the classical theory and thus requires new explanation
3. Our new theory includes a magnetic bottle with time-varying belly



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Key Points:

- Energetic-electron fluxes increase at B-minimum but decrease at B-maximum
- This phenomenon challenges the classical theory and thus requires new explanation
- Our new theory includes a magnetic bottle with time-varying belly but steady neck

Supporting Information S1

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A New Theory for Energetic Electron Generation Behind Dipolarization Front

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Abstract A long-standing problem concerning dipolarization front (DF) is why energetic electrons only appear in half the DF events? By analyzing MMS measurements, here we answer this question. We find a DF structure, behind which energetic-electron fluxes are modulated by magnetosonic waves: At wave troughs (B-minimum) electron fluxes are high; at wave crests (B-maximum) electron fluxes are low. This phenomenon challenges the classical theory of betatron mechanism, so we need to propose a new theory to explain it. In our theory, there exists a magnetic bottle with time-varying belly but steady neck behind the DF. When the belly expands, a magnetic bottle is formed, and electrons are trapped; when the belly contracts, the magnetic bottle disappears, and electrons are expelled. Quantitatively, we validate the existence of this bottle and estimate its size as 2–3 R_E . Our theory can explain both the presence and absence of energetic electrons behind DFs.