Electron drift echoes induced by negative solar wind dynamic pressure impulses

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outlines

Introduction

Solar wind dynamic pressure:

- The sudden increase/decrease of the solar wind dynamic pressure, denoted as a positive or negative pulse, will cause the compression/inflation of the magnetosphere.

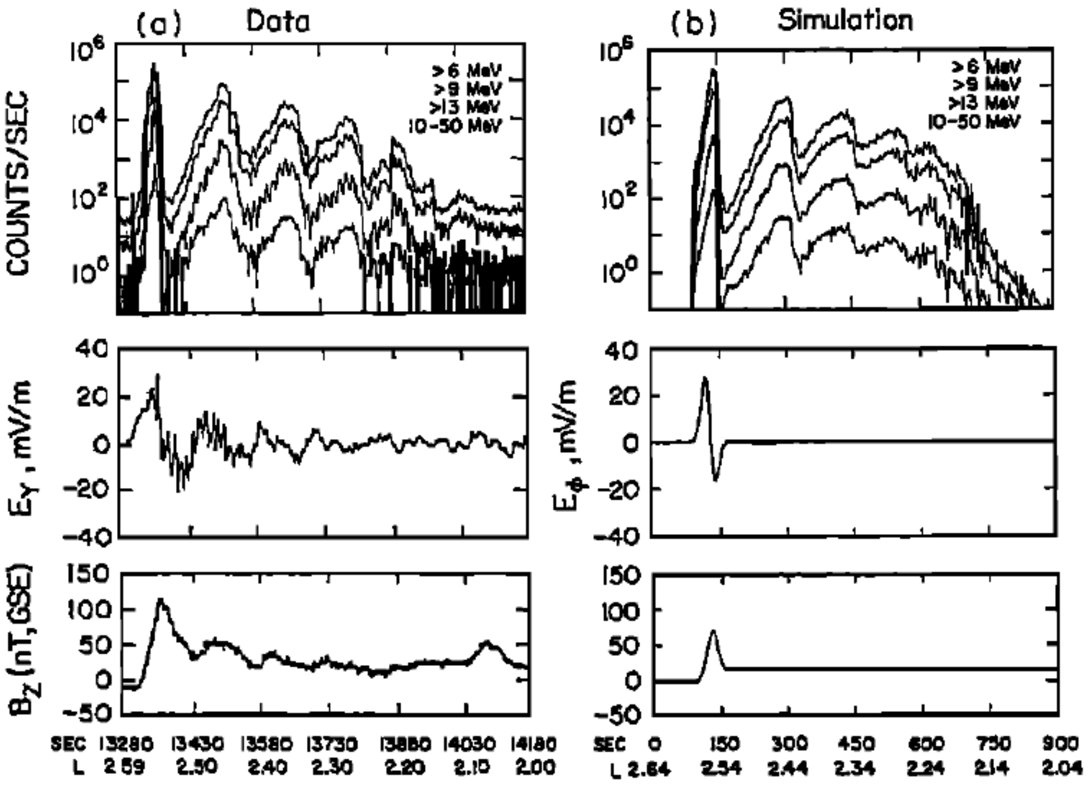
- Positive pulses are often excited by interplanetary (IP) shocks
    - The impingement of an IP shock can further lead to acceleration and transportation of energetic electrons.
    - IP shocks have been reported to cause rapid injections of relativistic electrons in the outer radiation belt and even deep into the inner radiation belt.

Introduction

Drift Echo:

☐ Injection Drift Echo:

- The particles are first injected into a longitudinally limited region called ‘injection region’ and then drift with speeds dependent on energies and species.
- The enhancement in particle flux is suggested to depend on magnetic and electric field changes associated with IP shock impact and with an isolated substorm onset.



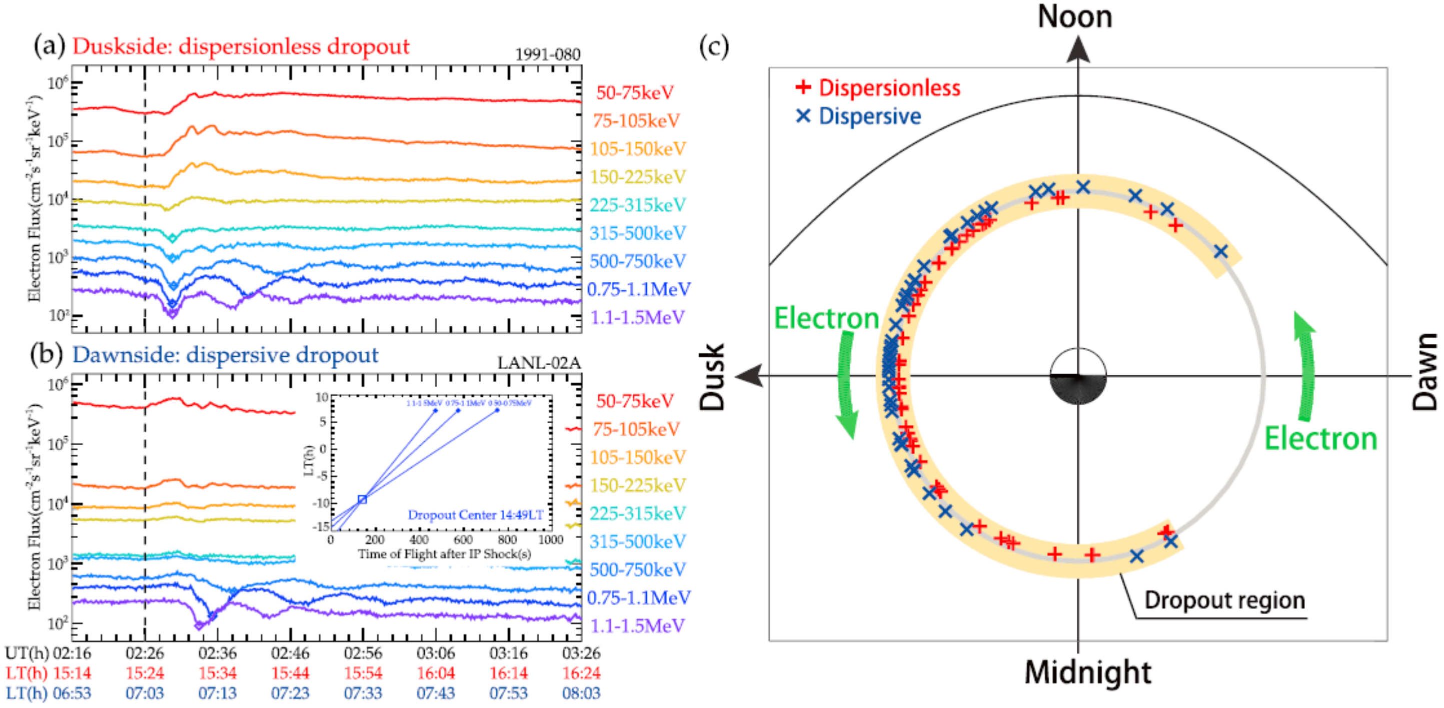
[*Li et al.*, 1993]

Introduction

Drift Echo:

☐ Dropout Drift Echo:

- The sudden dropout of electron fluxes can also be observed again as subsequent drift echoes, just like "injection drift echo"
- Dropout echo signatures caused by IP shocks are only shown in high-energy (>300 keV) channels.
- The locations of initial dropout regions are mainly located at the dusk-side.



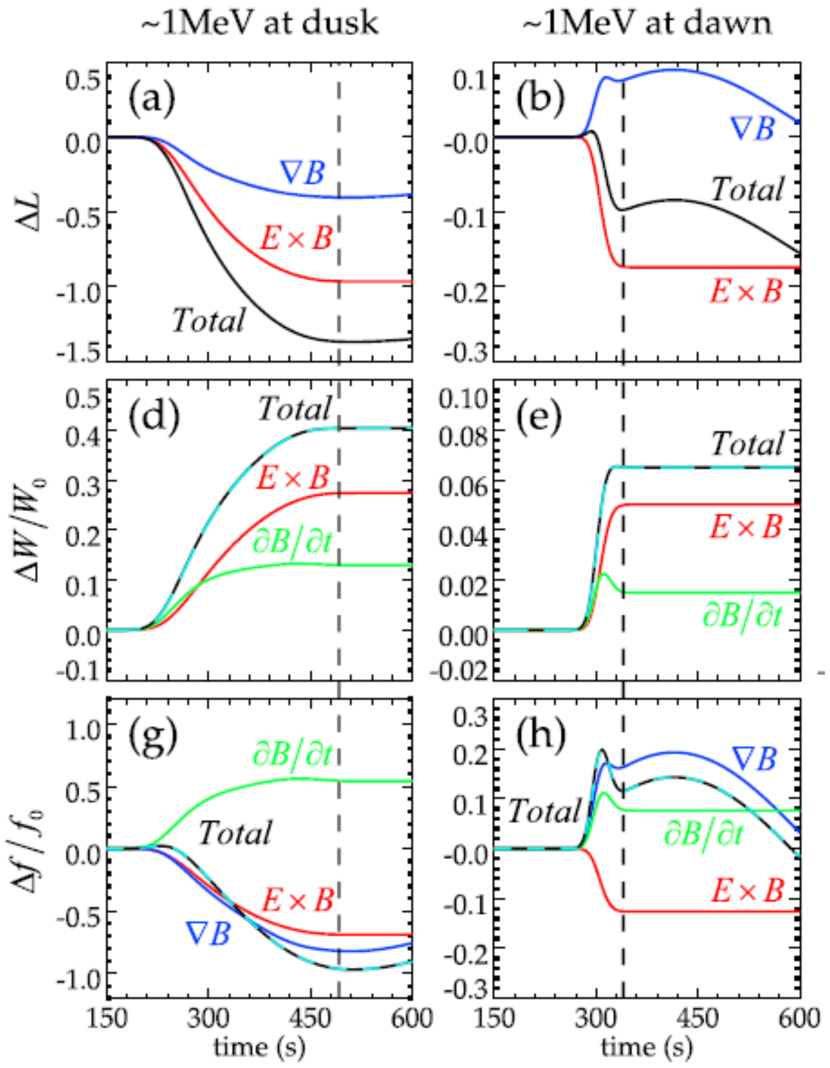
[Liu *et al.*, 2017]

Introduction

Drift Echo:

☐ Dropout Drift Echo:

- the effect of IP shock parameters were **insignificant** to the locations of dropout regions.
- electron dropouts and consequent echoes were caused by the interaction between electrons and the shock-induced propagating magnetosonic pulse
- the dawn-dusk asymmetric response arises from radial magnetic gradient drift and interaction time with the pulse of electrons.



[Liu *et al.*, 2019]

Introduction

Negative Solar Wind Dynamic Pressure Pluse:

- Unlike the abundant studies of positive solar wind dynamic pressure effects, the knowledge of the Earth's magnetosphere's response to the negative solar wind dynamic pressure pulse is relatively limited.
- We use case study to investigate the effect of negative solar wind dynamic pressure pulse on the energetic electrons in the inner magnetosphere.

Data Sets

☐ **Data Sets:**

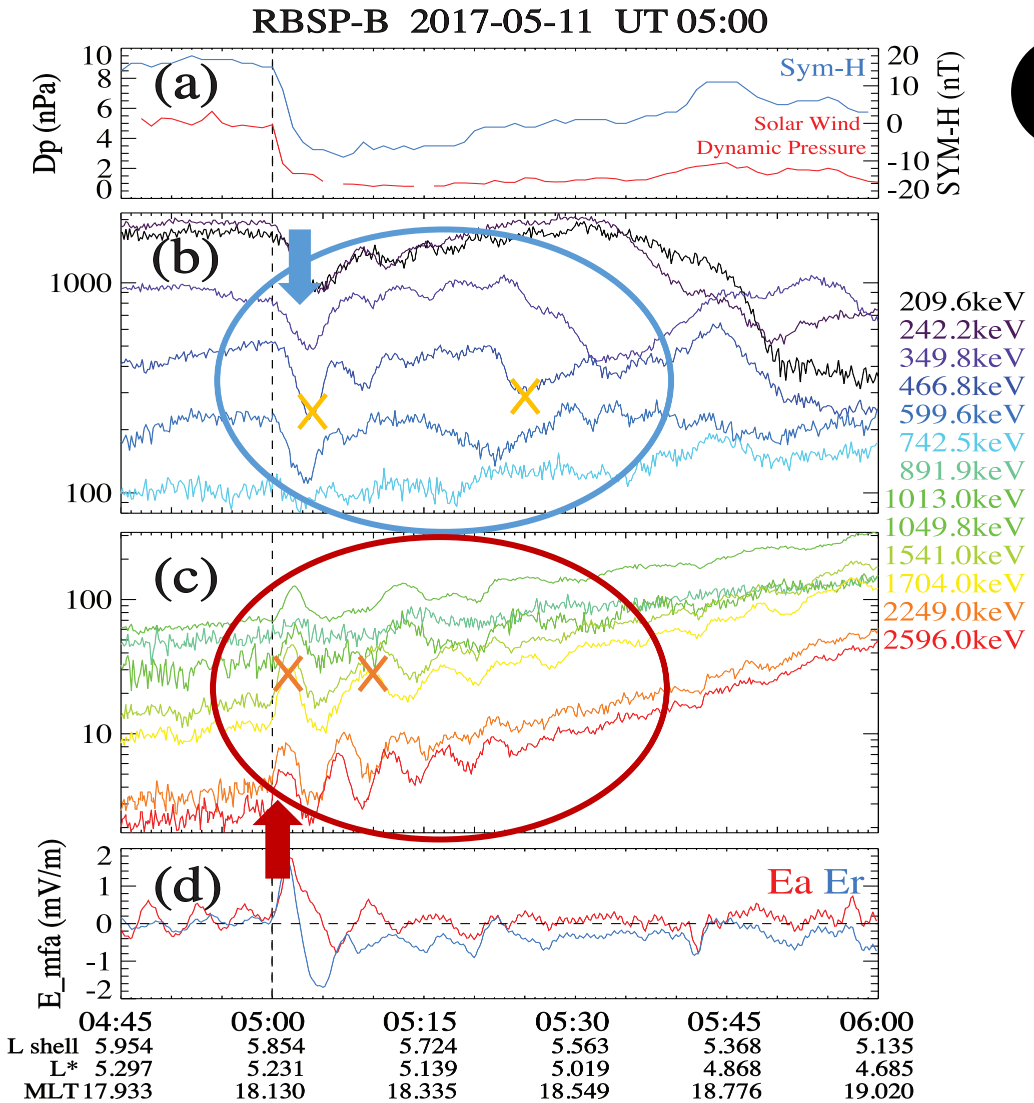
- Solar wind and geomagnetic index data: OMNI
- Electron flux, electric field and magnetic field data: Van Allen detector (RBSP)

☐ **Identification of negative solar wind dynamic pressure pulse events (2012-2017)**

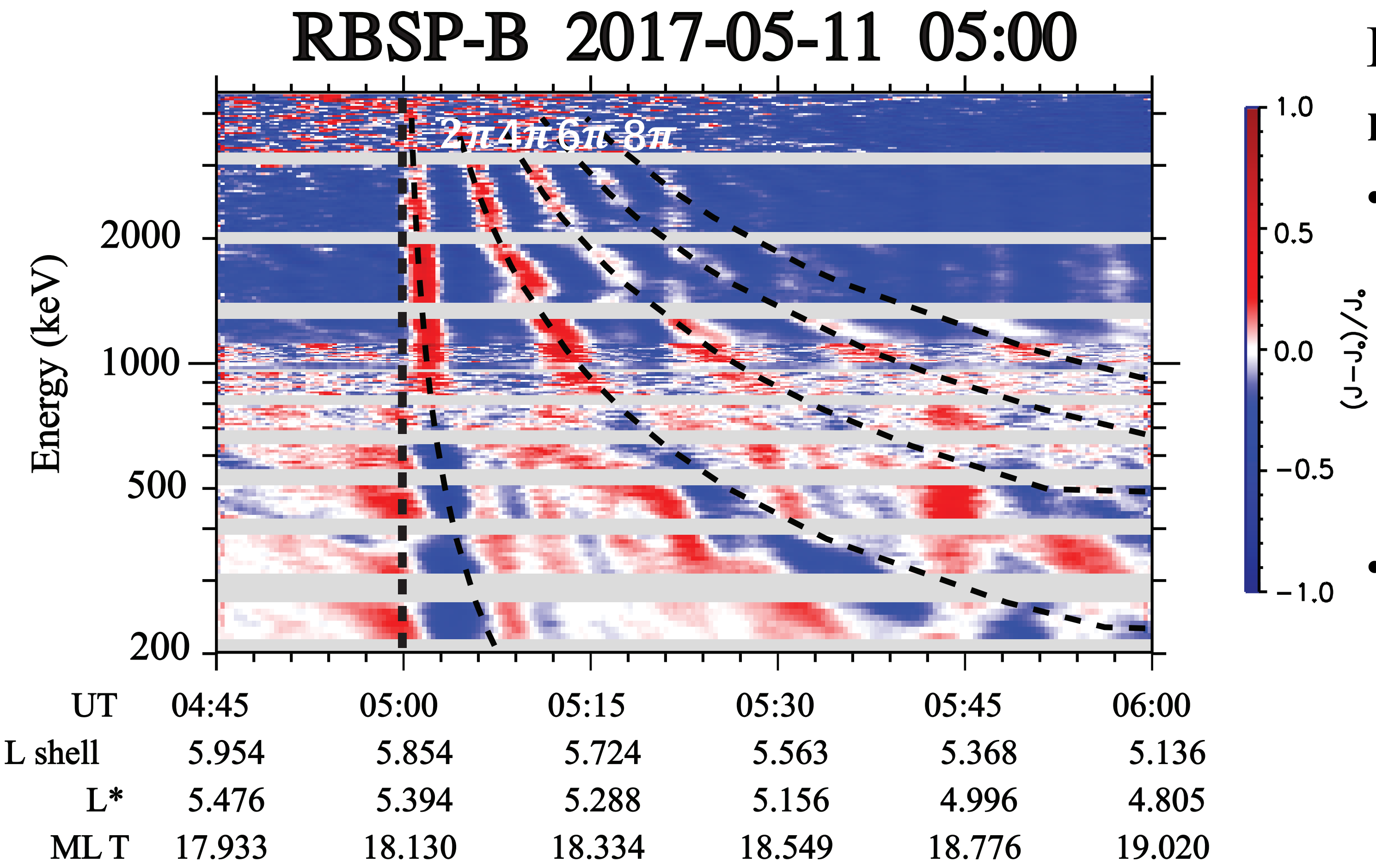
- The Sym-H index at this moment is compared to the average value of the Sym-H index in the previous 10 to 40 minutes.
- If it falls more than 5 nT and exceeds 3 times the standard deviation of the Sym-H index in the previous 10-40 minutes, it's identified as an event.

Observation results

- **Event #1 2017-5-11 5:00**
  - **High-energy (0.85~2.7 MeV)** electron fluxes **increase**
  - **Low-energy (200keV~750 KeV)** electron fluxes **decrease**
  - The flux dropout/enhancement-recovery signals repeat after a period of time, and the periods show significant **energy dependence**



Observation results



Higher energy and time resolution MagEIS data

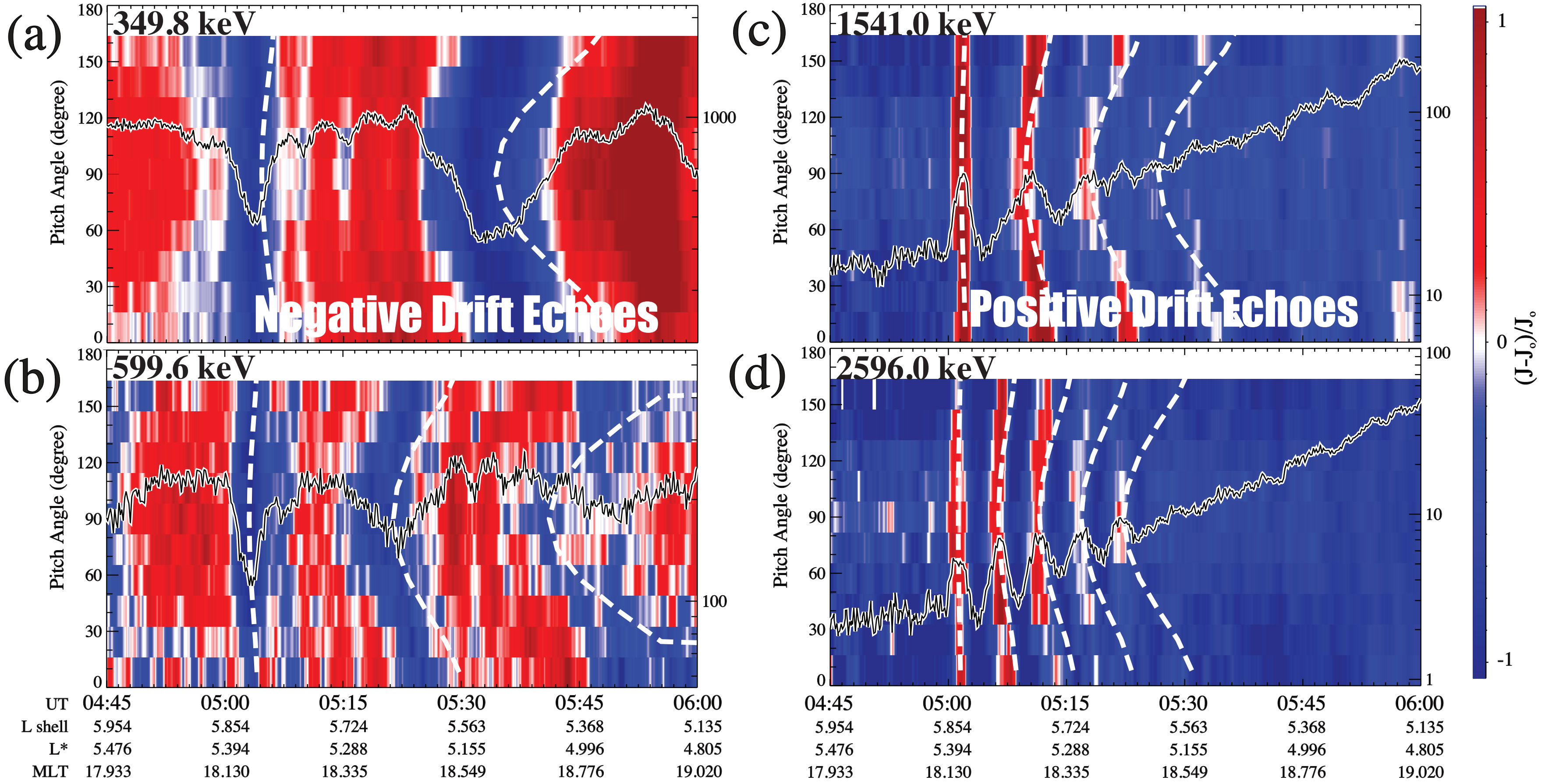
- The drift velocity is calculated in terrestrial dipole field with relativistic effect included.

$$T_d = \frac{2\pi}{\omega_d} = \frac{4\pi R_E^2 e B_E}{3 m_0 c^2 \beta^2 \gamma L}$$

- The reoccurrence periods of enhancement/dropout-recovery signals are **consistent with electron drift periods**.

Observation results

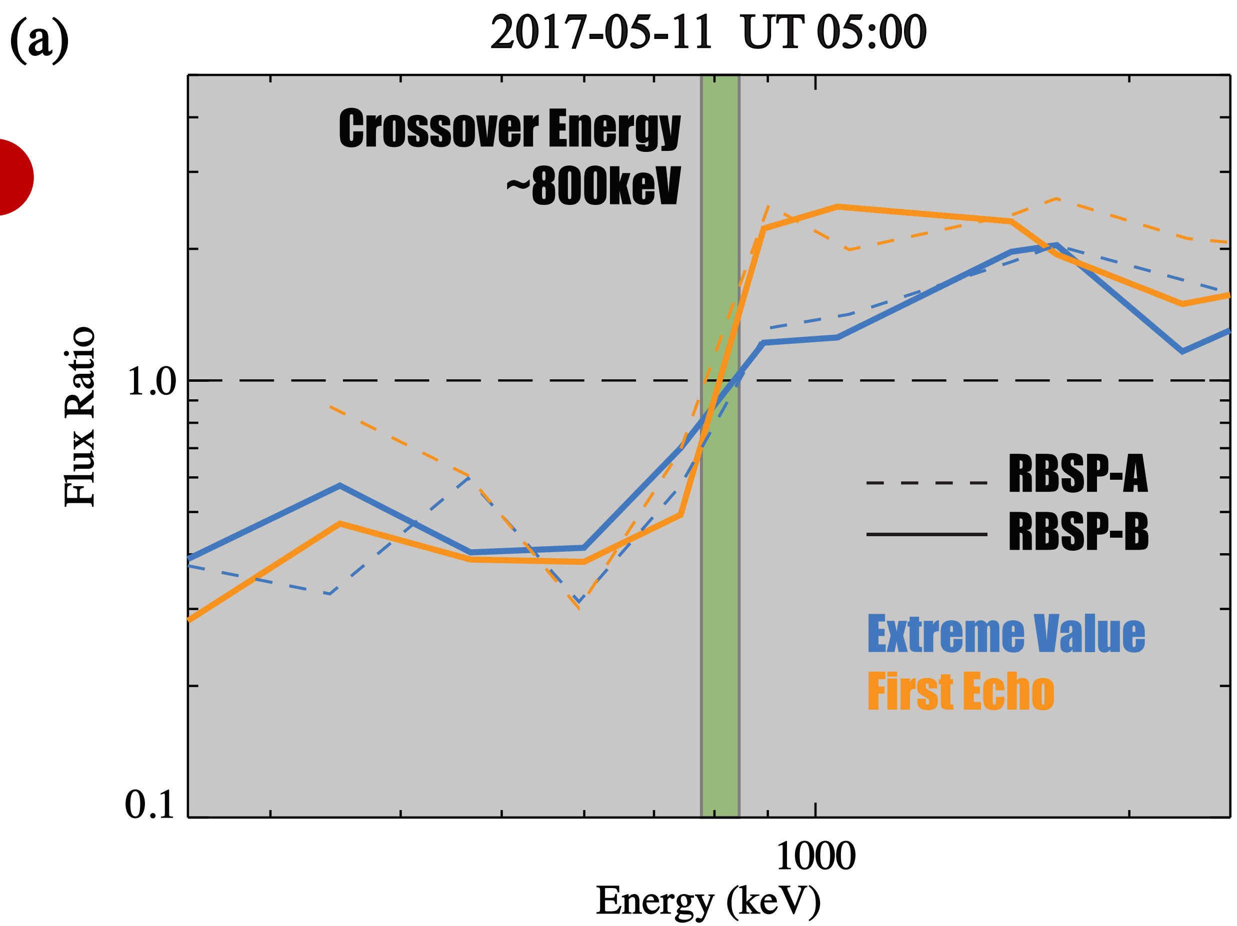
RBSP-B 2017-05-11 05:00



$$\omega_d = \frac{3m_0c^2\beta^2\gamma L}{R_E^2 eB_E}(0.35 + 0.15\sin\alpha\ )$$

- The flux variation occurs at all pitch angles, although for each energy channel the variation appear slightly earlier at **90° pitch angle** than at other pitch angles.

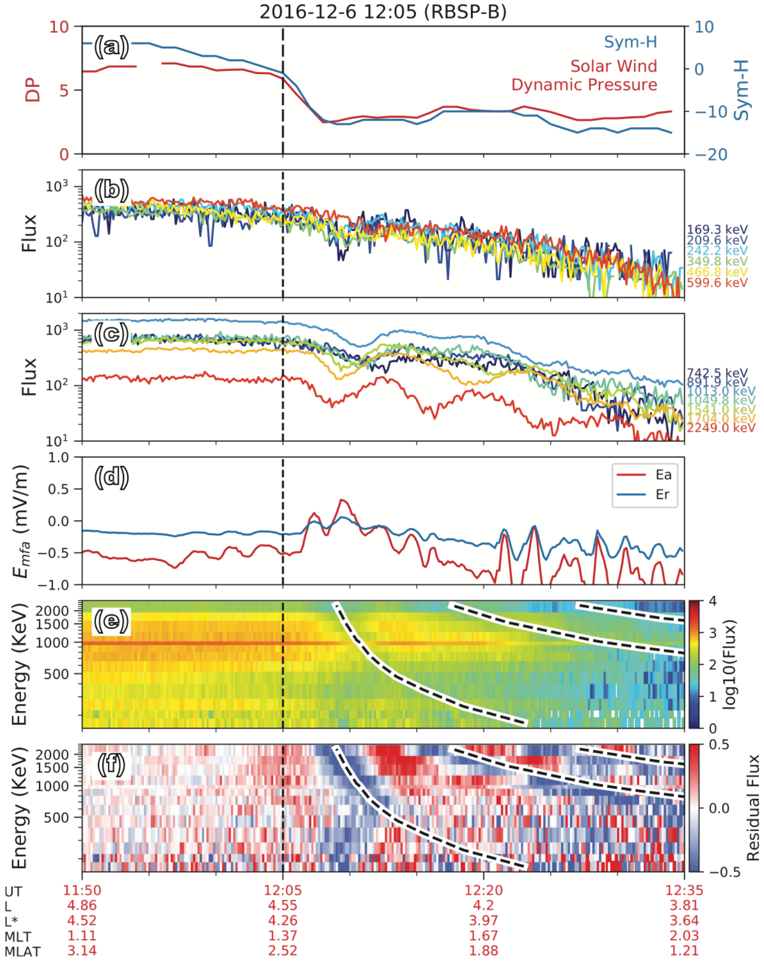
Observation results

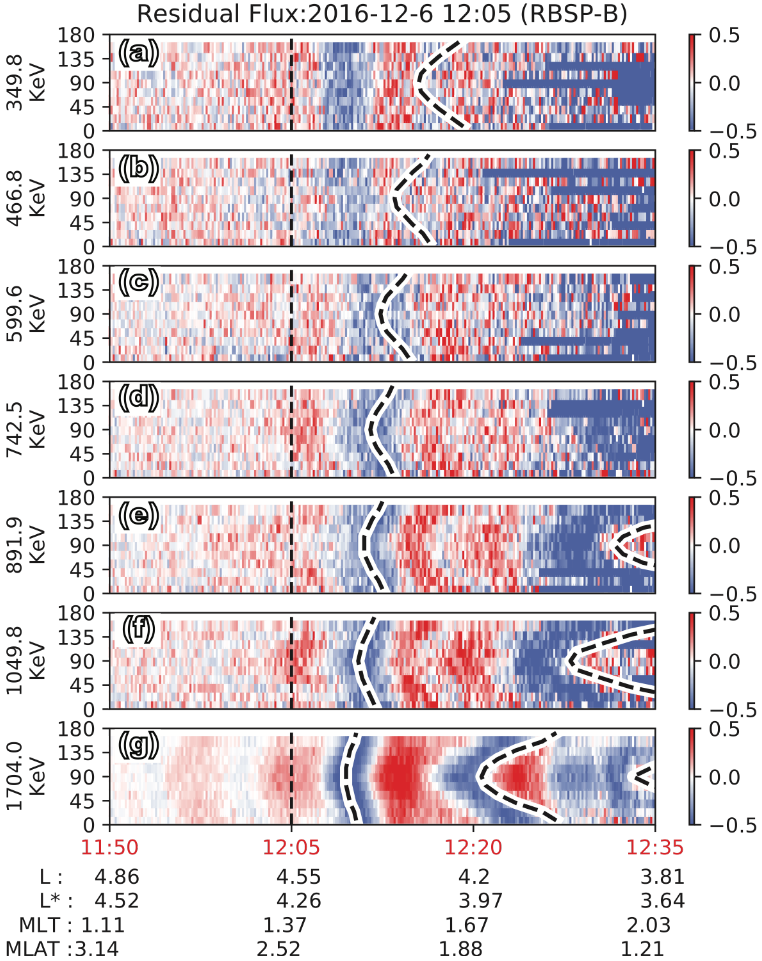


The ratio of the electron flux:

- the initial flux, mean flux over ten minutes before dynamic pressure change
- **The blue line:** the ratio of the initial extreme value, which is the extreme value of the electron flux within five minutes after the dynamic pressure drop, when the electrons have not drifted for a period.
- **The orange line:** that of the first drift echo, which is the next extreme value, when the electrons have already drifted for a period
- **A crossover energy channel at ~800 keV.**
- At 1500 keV energy channel, the ratio is the highest.

Observation results



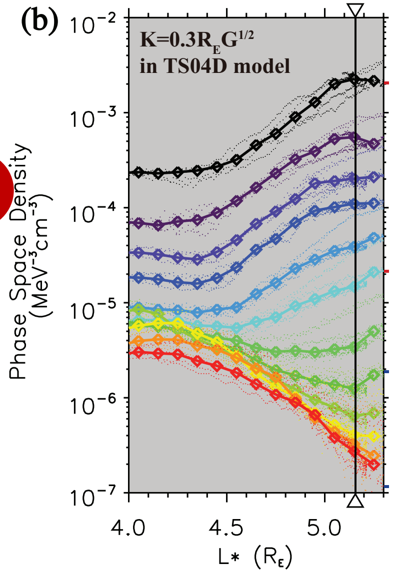


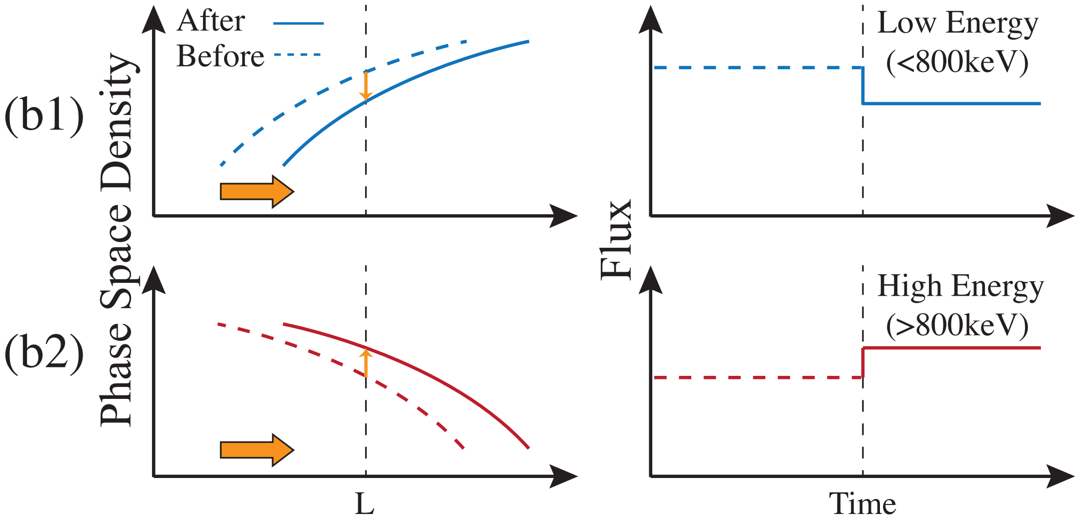
- **Event #2 2016-12-6 12:05**
  - **All energy** electron fluxes **decrease**
  - The reoccurrence periods of dropout-recovery signals are consistent with electron drift periods.

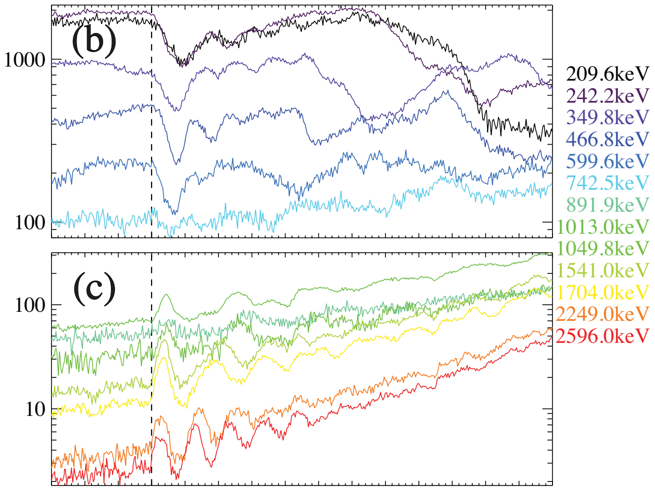
$$\omega_d = \frac{3m_0c^2\beta^2\gamma L}{R_E^2 eB_E}(0.35 + 0.15\sin\alpha)$$

Interpretation

Introduction
Data Sets
Results
Summary







☐ For low energy electron (<800 keV):

$$\frac{\partial f}{\partial L}|_{M_r,J} > 0$$

☐ For high energy electron (>800 keV):

$$\frac{\partial f}{\partial L}|_{M_r,J} < 0$$

☐ Phase Space Density (PSD) changes:

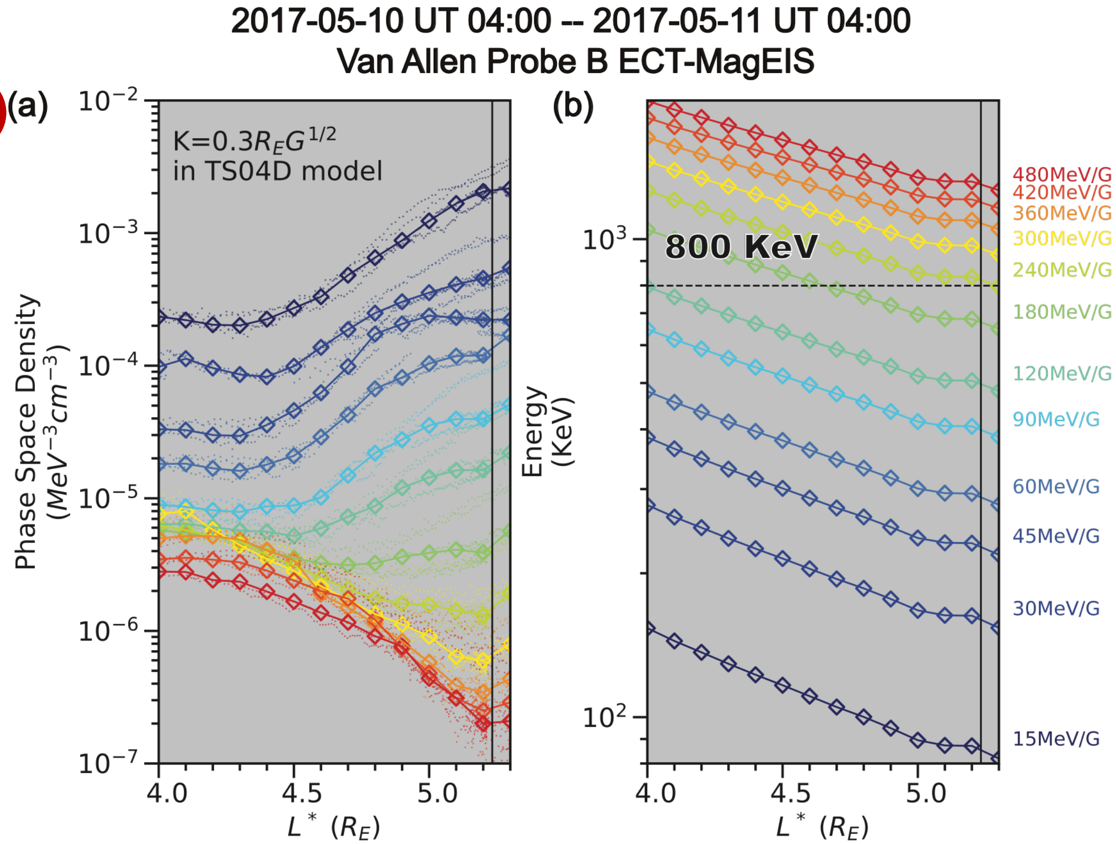
$$\Delta f = -\frac{\partial f}{\partial L}|_{M_r,J}\,\Delta L$$

☐ When $\boldsymbol{\Delta L > 0}$:

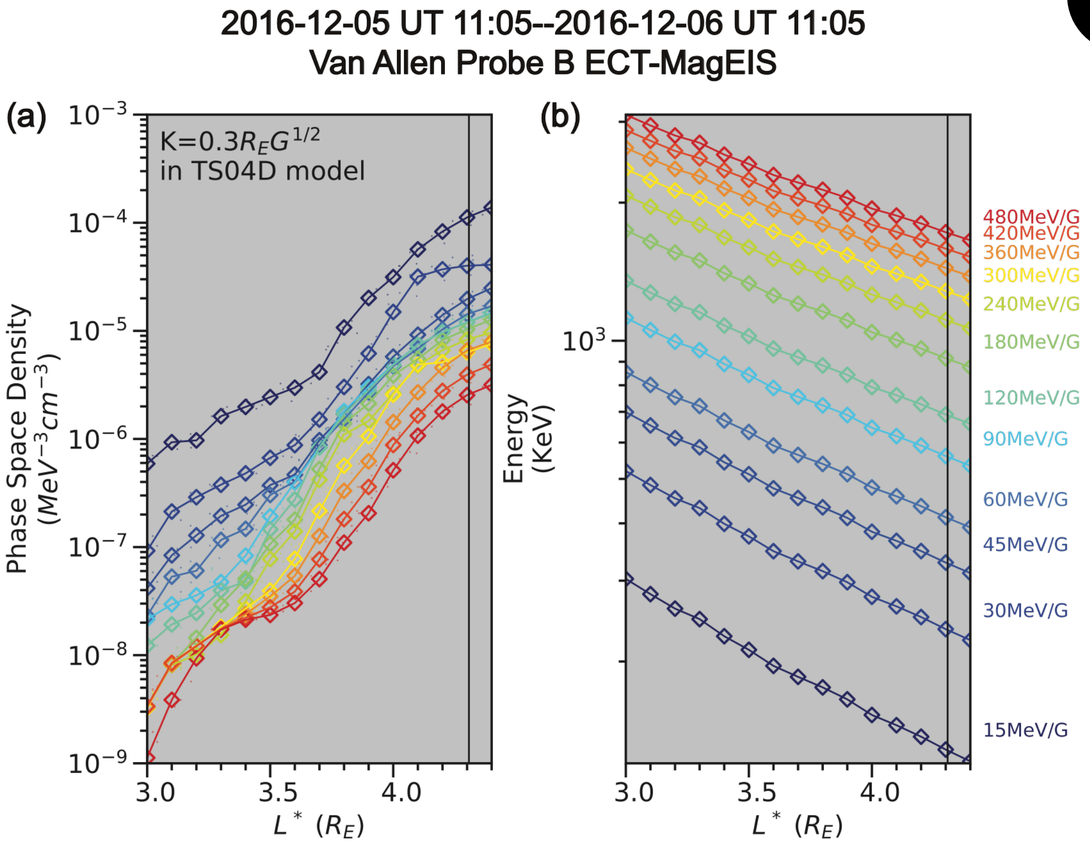
- For low energy electron (<800 keV): $\Delta f < 0$
- For high energy electron (>800 keV): $\Delta f > 0$

Interpretation

- **Event #1 2017-5-11 5:00**



- **Event #2 2016-12-6 12:05**



☐ For low energy electron:

$$\frac{\partial f}{\partial L}|_{M_r,J} > 0 \quad \boldsymbol{\Delta f < 0}$$

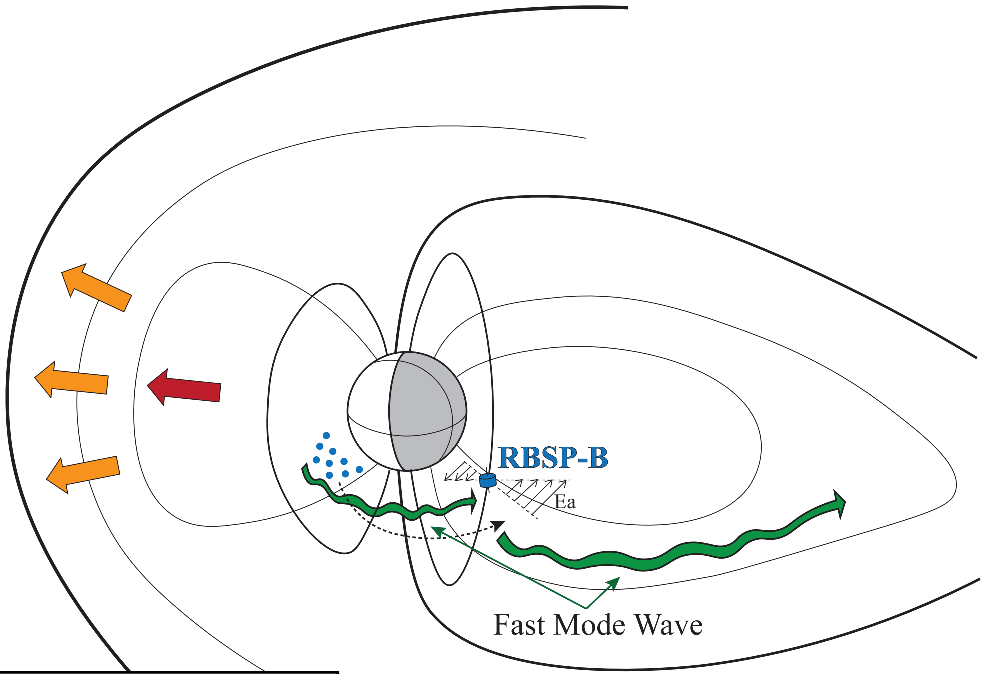
☐ For high energy electron:

$$\frac{\partial f}{\partial L}|_{M_r,J} < 0 \quad \boldsymbol{\Delta f > 0}$$

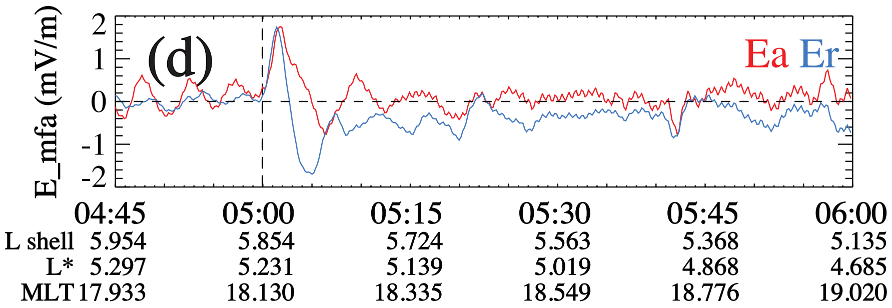
☐ For all energy electron:

$$\frac{\partial f}{\partial L}|_{M_r,J} > 0 \quad \boldsymbol{\Delta f < 0}$$

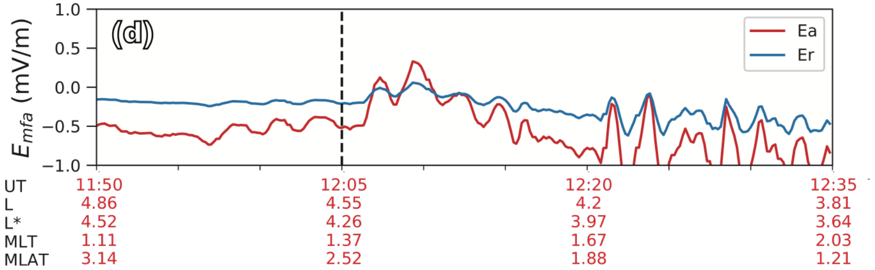
Observation results



- **Event #1 2017-5-11 5:00**



- **Event #2 2016-12-6 12:05**



The magnetosphere inflation

Fast Mode Wave: **E_a negative**

E×B Drift

Negative Dynamic Pressure Pulse

Electron Decelerate

Outward Transportation

Summary

- There are both electron flux **decrease** and **increase** in 200-2700 KeV energy channels after the negative dynamic pressure pulse on 2017-5-11 5:00 UT event. However, there are only electron flux **decrease** in 150-2500 KeV energy channels on 2016-12-6 12:05 UT event.

- There are sequential repeating flux dropout/enhancement-recovery signals. These signals match well with the estimation of electron drift behavior. Therefore, the sequentially repeated flux decrease/enhancement-recovery signal can be interpreted as a "drift echo" caused by the longitudinal drift of the initial perturbation.

- There is a positive pulse of electric field in azimuth direction after the solar wind dynamic pressure decreases, it could **decelerate electrons,** leading the electrons to **move outward** under the first adiabatic invariant conservation and cause the cause the **outward transportation** in radial direction by the $\boldsymbol{E}\times\boldsymbol{B}$ **drift**.

Summary

- ☐ There is a **crossover energy channel at ~800 KeV** on 2017-5-11 5:00 UT event, above/below which there are positive/negative drift echoes.
  - ➢ Before the sudden drop of solar wind dynamic pressure, **the PSD gradient** is positive for electrons <800 keV and negative for electrons >800 KeV.
  - ➢ Since there is outward motion of electrons in radial direction, the electron fluxes at constant energy measured by satellite are actually from a lower L shell
  - ➢ The fluxes of electrons <800 keV will decrease and those of electrons >800 keV will increase.

- ☐ There is no crossover energy channel on 2016-12-6 12:05 UT event
  - ➢ Before the sudden drop of solar wind dynamic pressure, **the PSD gradient** is positive for all energy electrons.
  - ➢ The fluxes of electrons will decrease.

- ☐ The **Phase Space Density profile in L^* direction** play an important role in the transportation of energetic electrons.