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Electron betatron acceleration in a dipolarization front driven by magnetic reconnection

Quanming Lu

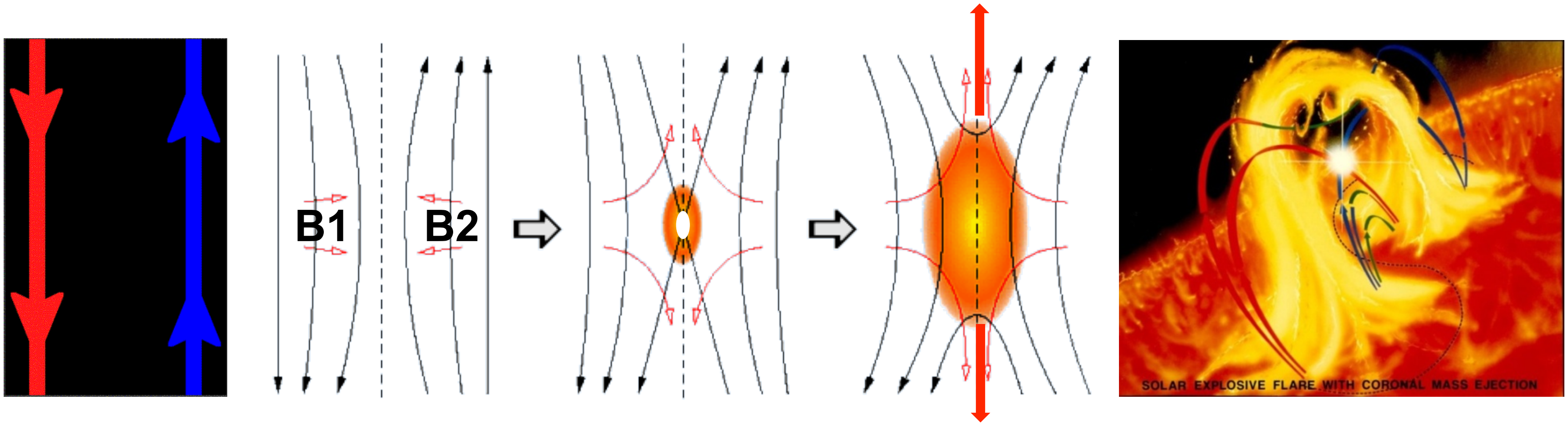
University of Science & Technology of China, Hefei, China

Collaborators: Can Huang, Mingyu Wu, Rongsheng Wang, San Lu

Outline

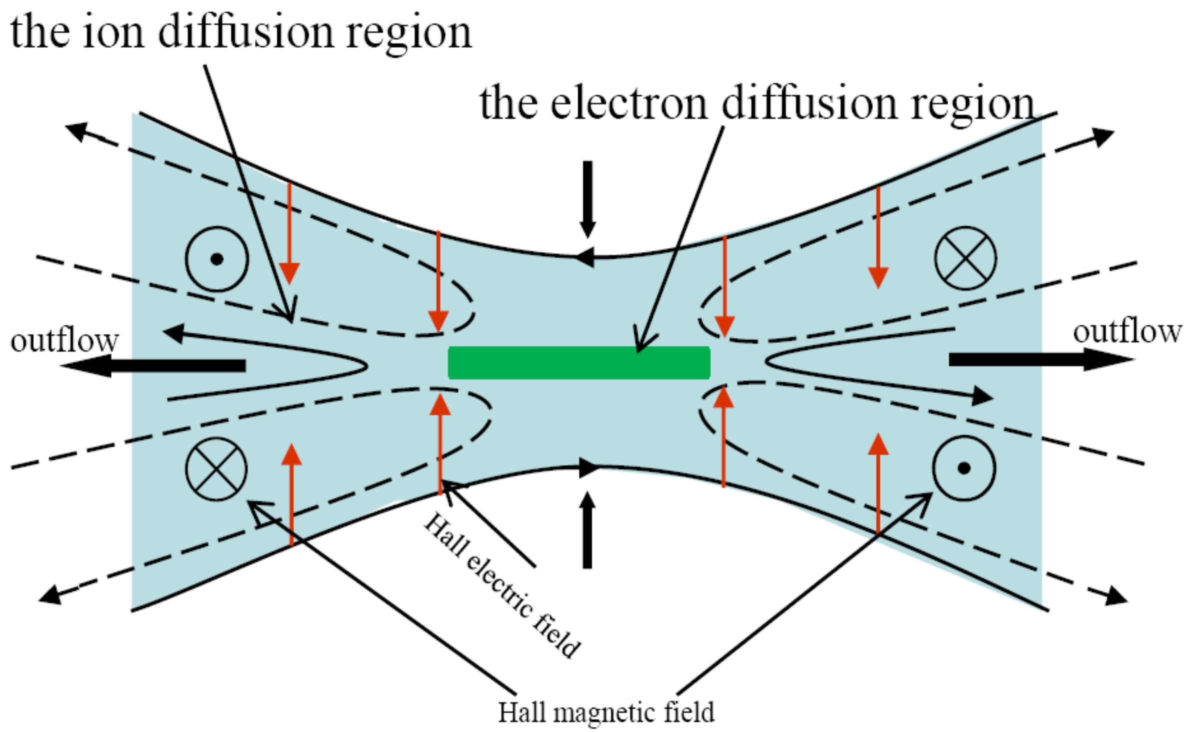
- Electron Acceleration in Magnetic Reconnection
- Dipolarization Front(DF)/Jet Front
- Microphysics of Electron Betatron Acceleration in DF
- Summary and Discussion

Magnetic Reconnection



Magnetic reconnection converts magnetic energy into plasma kinetic energy, and it is accompanied with topological change of magnetic field lines.

Collisionless Magnetic Reconnection



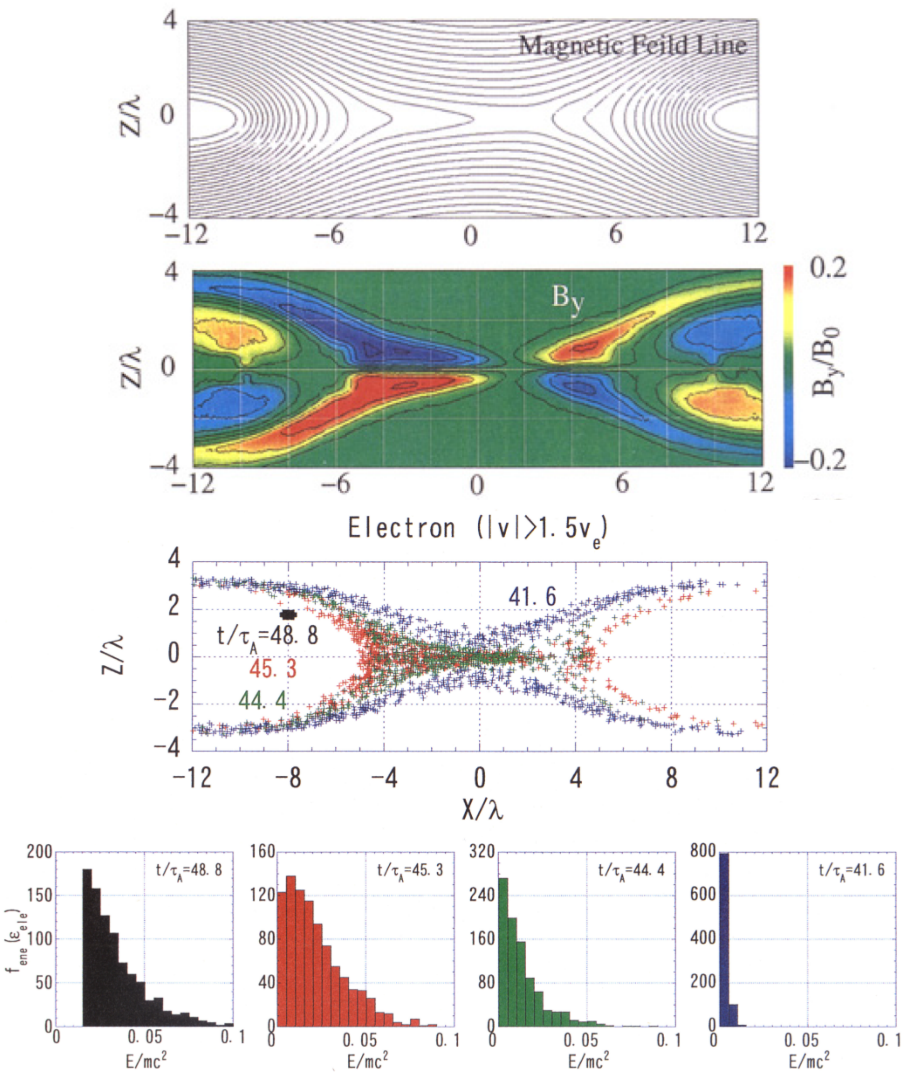
Ion diffusion region: Ions are unmagnetized, electrons are magnetized

Electron diffusion region: both ions and electrons are unmagnetized

Electron Acceleration in Reconnection

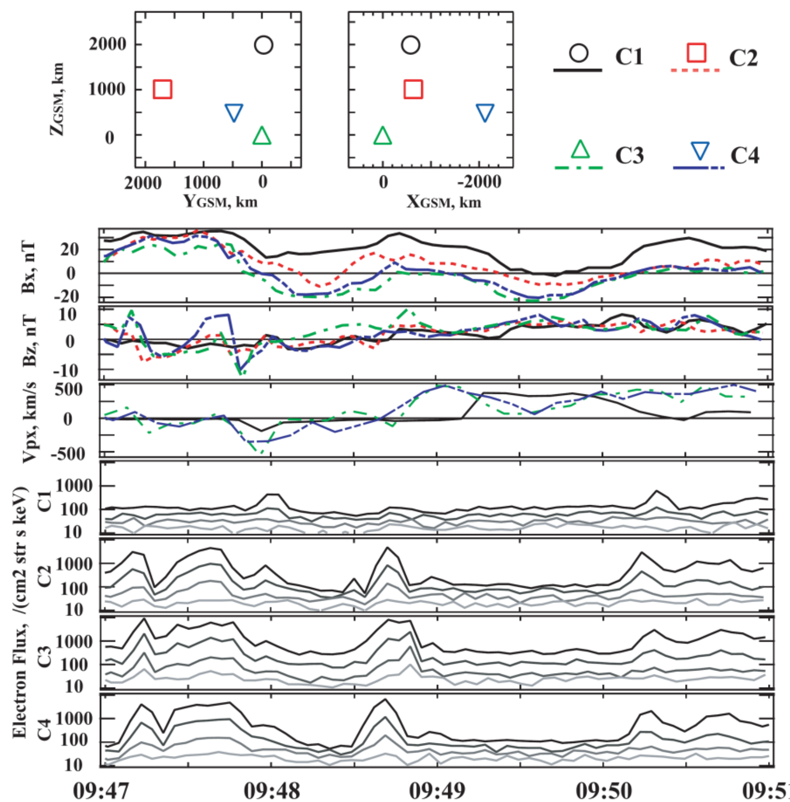
Two step acceleration

First at X-line region
Secondly in Pile-up region



Time

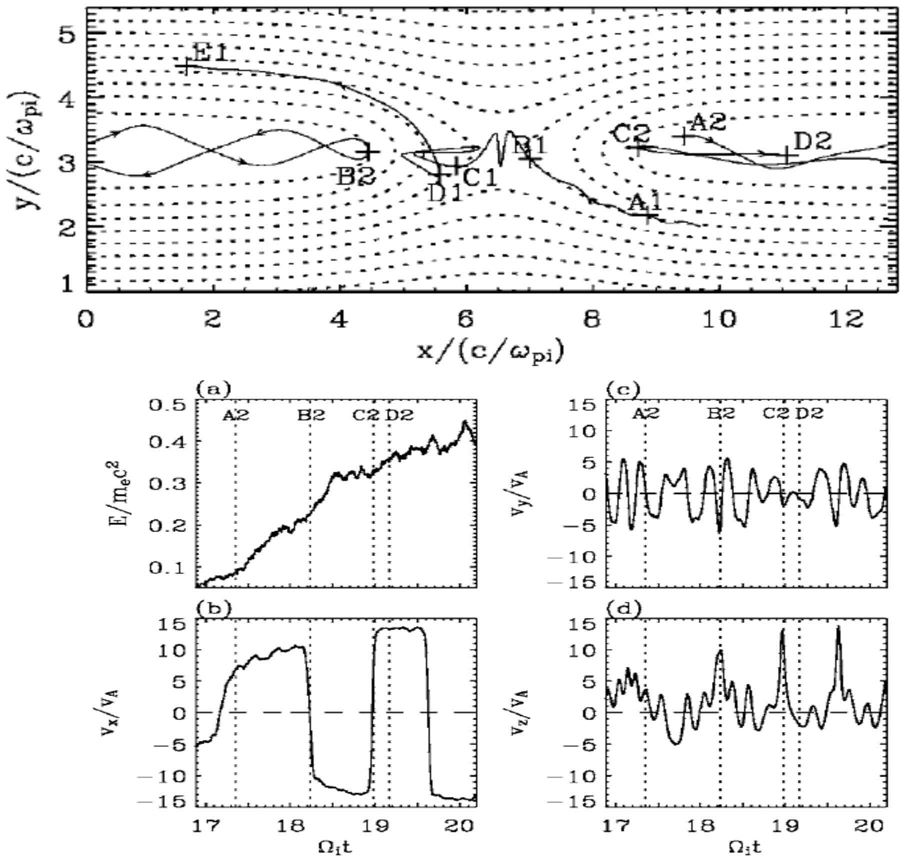
Hoshino et al., 2001



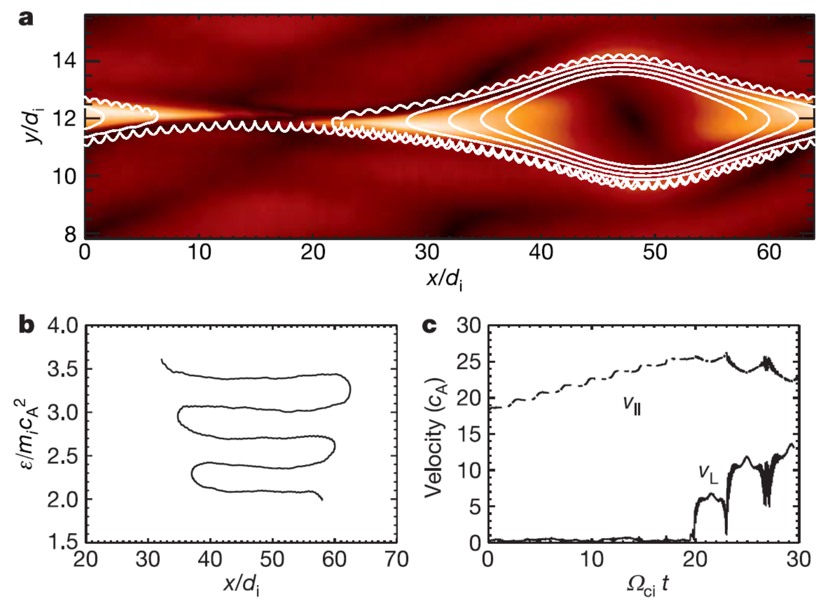
Imada et al., 2007

Electron acceleration in magnetic island

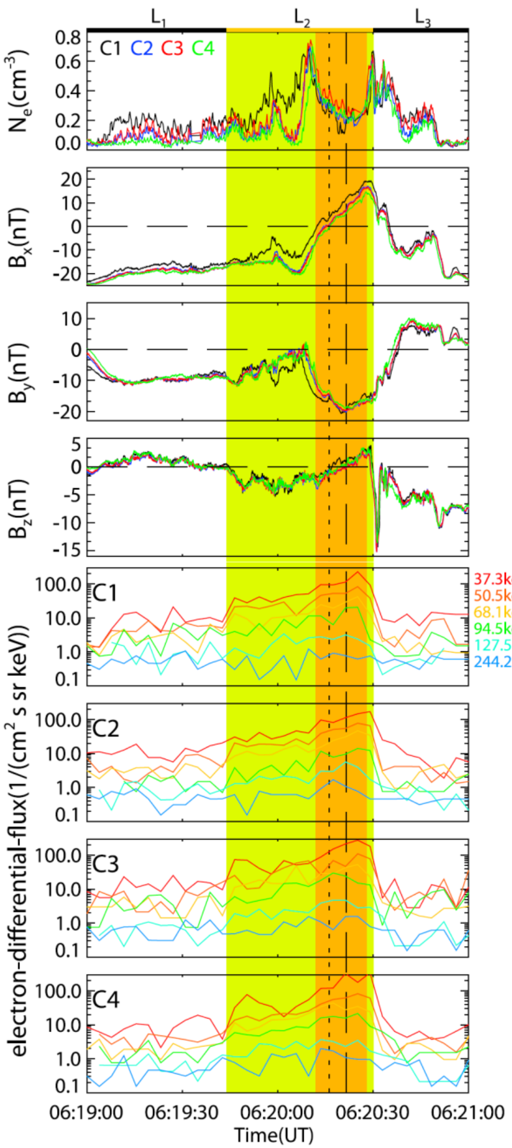
Electrons are accelerated by reflecting from the two ends of a contracting magnetic island



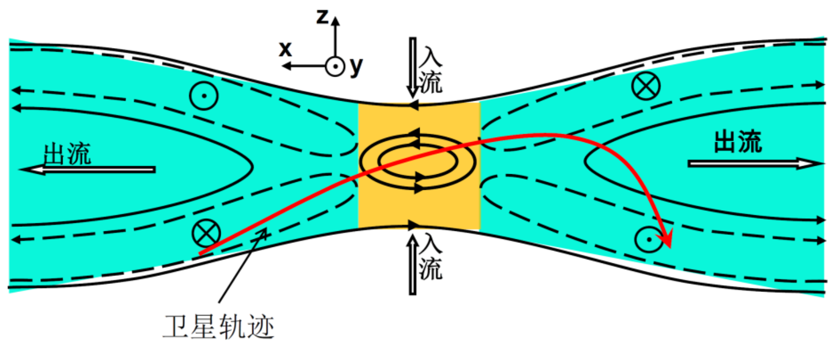
Fu et al., 2006



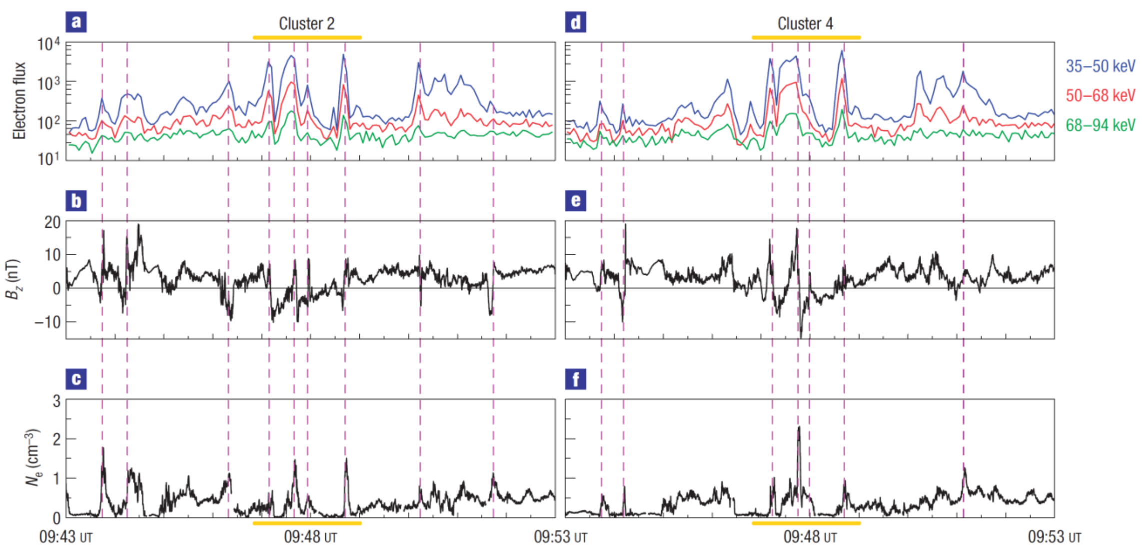
Drake et al., 2006



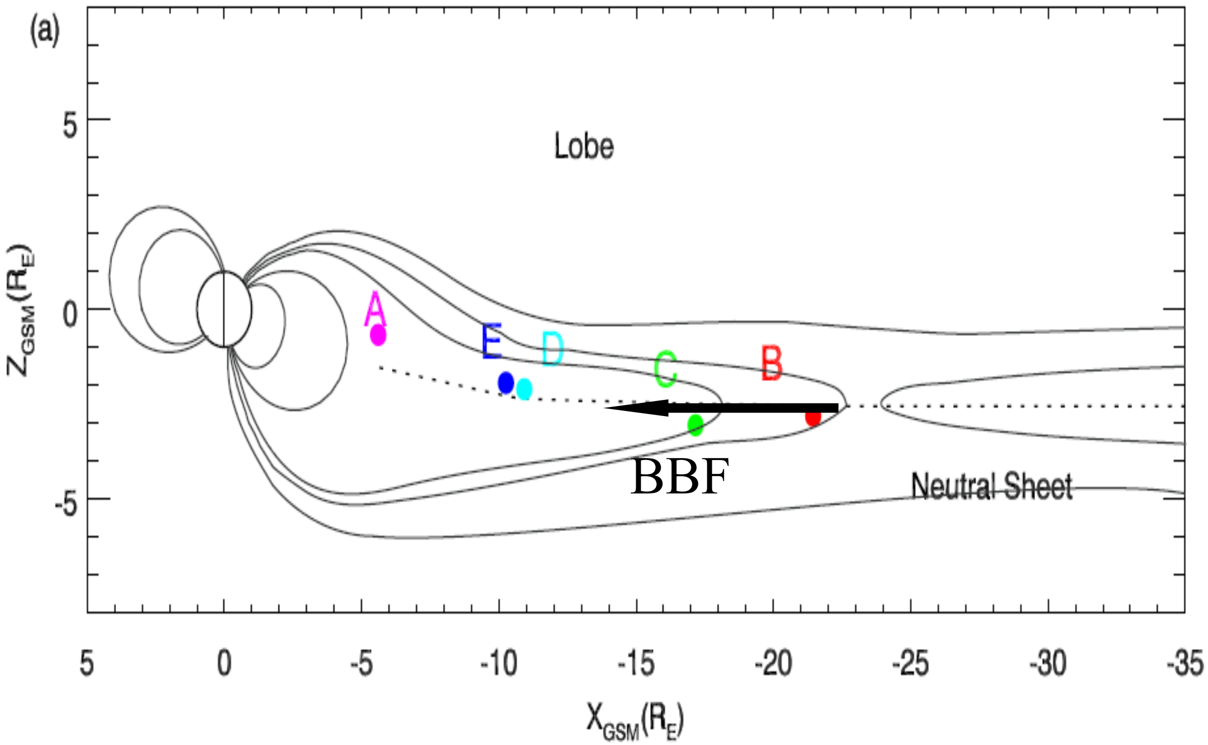
Wang et al., 2010



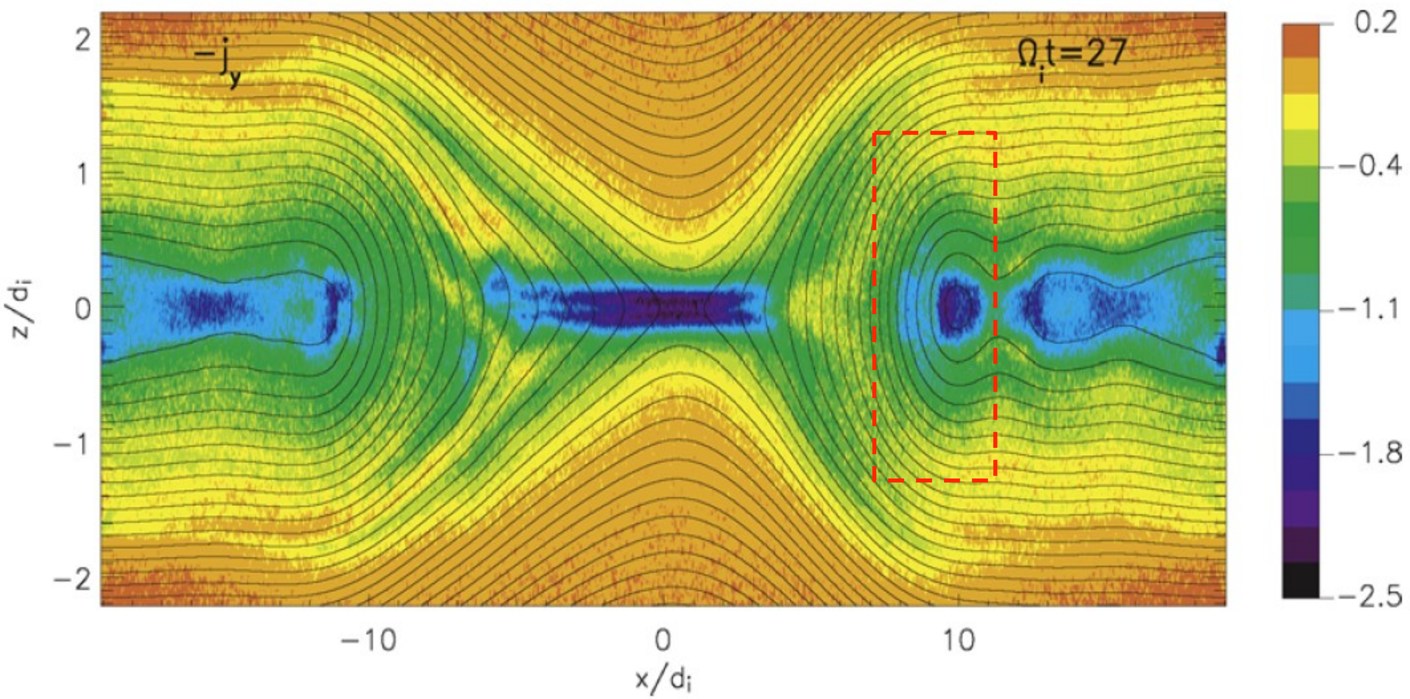
Fluxes of high energy electrons peak within magnetic island



Chen et al., 2008

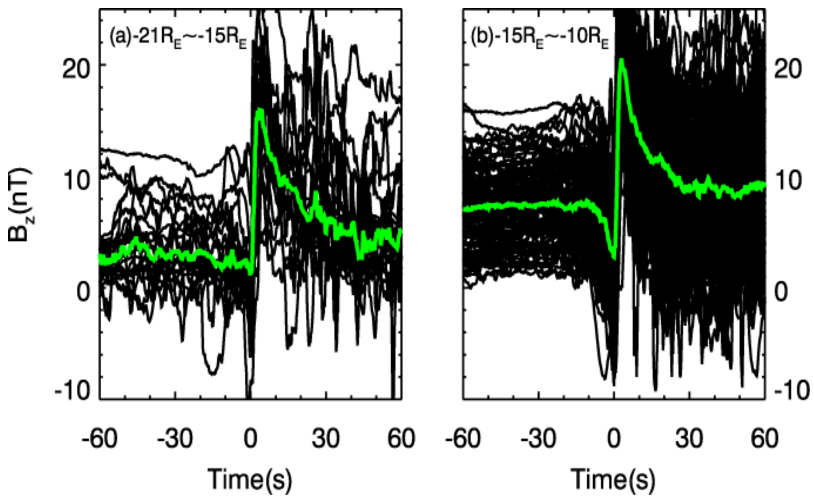


Jet front is also called as Dipolarization Front(DF)

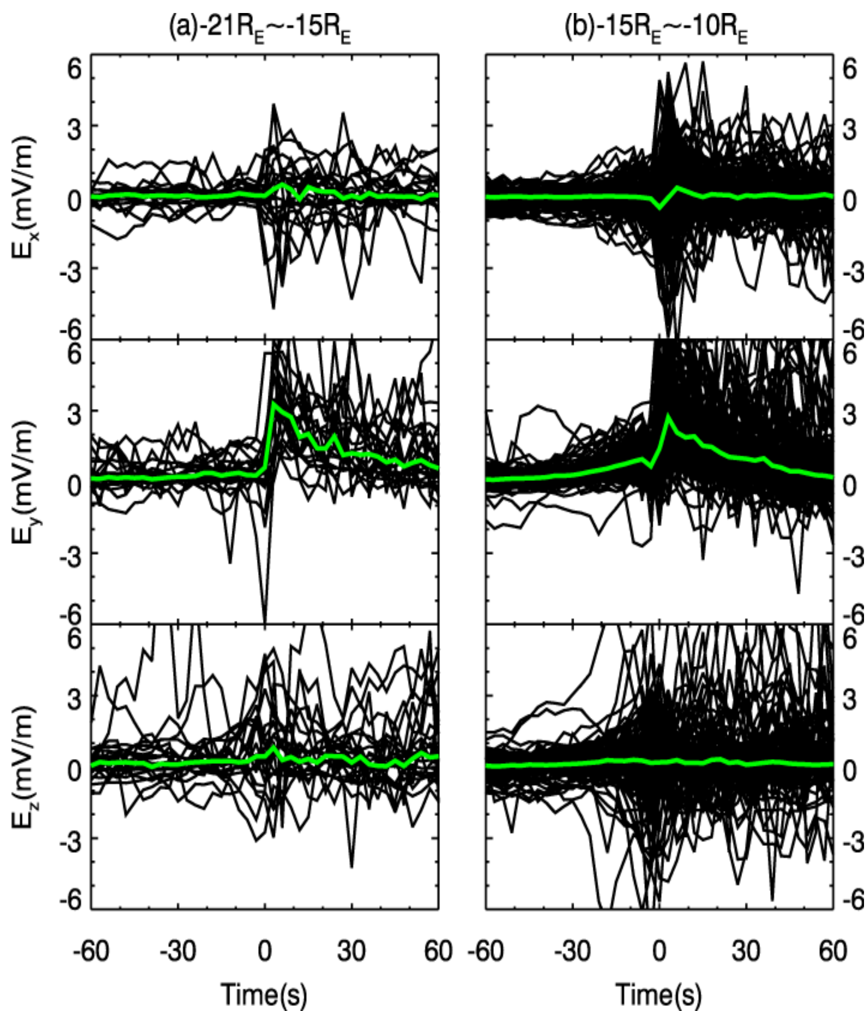


DF can be generated in the magnetic reconnection (Sitnov et al., 2009)

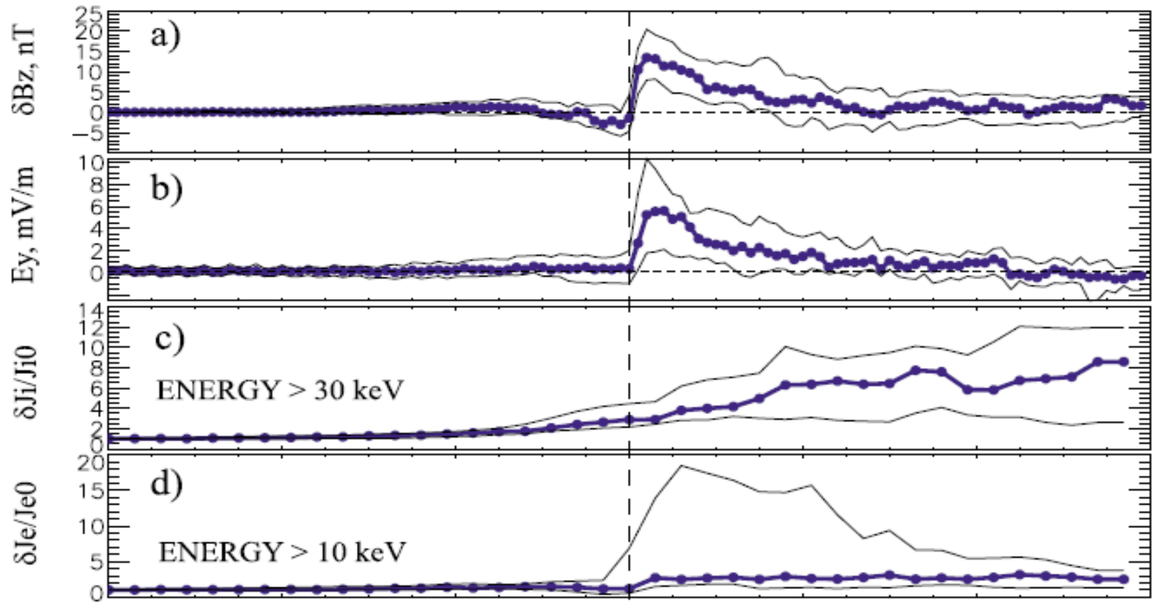
Superposed epoch analysis of DFs in different region of the magnetotail.



$$\mathbf{E} = -\mathbf{V}_i \times \mathbf{B}$$



DFs are always accompanied with large variations of the energetic electron flux(THEMIS observations).

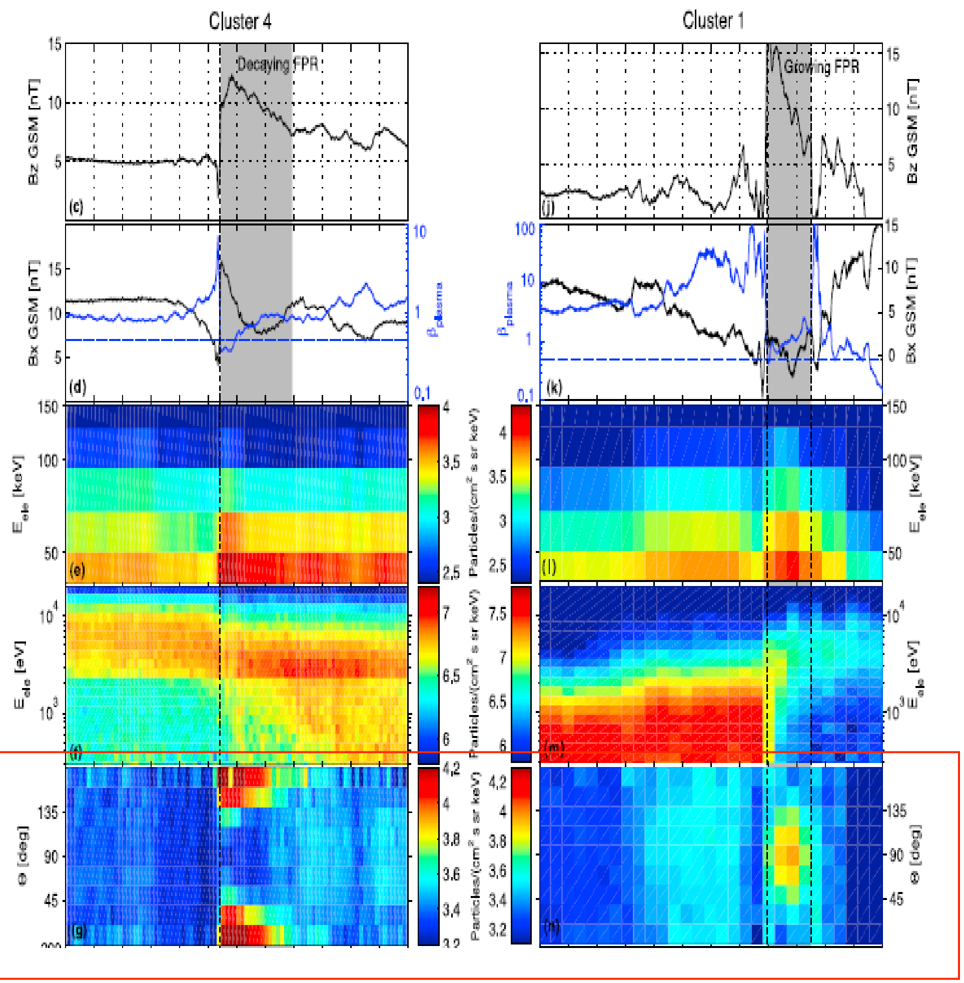


Runov et al., 2011

Betatron Acceleration: Magnetic momentum $\mu = P_{\perp}^{2}/B$ is conserved. Pancake distribution

Fermi acceleration: Parallel momentum integral $J = \int P_{//} ds$ is conserved. Cigar distribution

Electron Acceleration Behind the DFs



Fermi Acceleration

Betatron Acceleration

(1)The enhancements of the energetic electron flux at small pitch angles (around 0°or 180°) are caused by Fermi acceleration.

(2)The enhancements of the energetic electron flux at large pitch angles (around 90°) are caused by betatron acceleration.

Fu et al., 2011

With a large-scale 2-D PIC simulation, we study the microphysics of betatron acceleration associated with a DF.

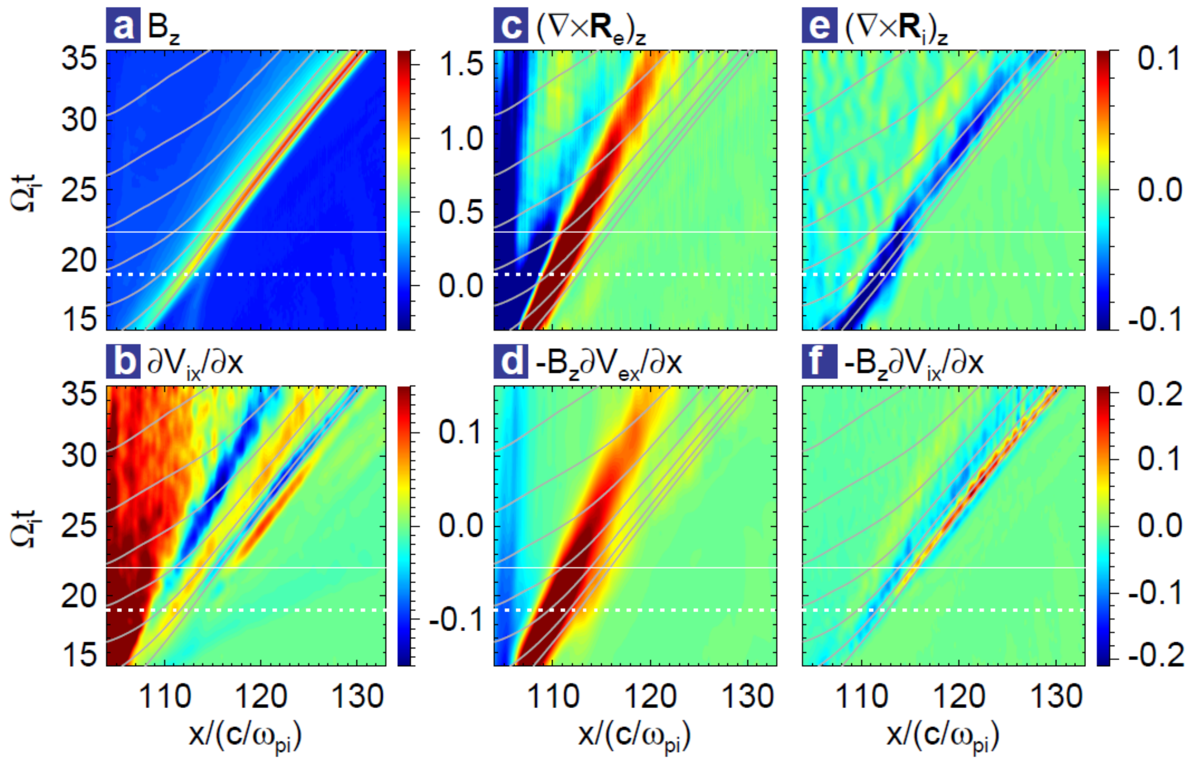
[Huang, Wu, and Lu et al., JGR, 2015]

Simulation Model

- 2D PIC simulation

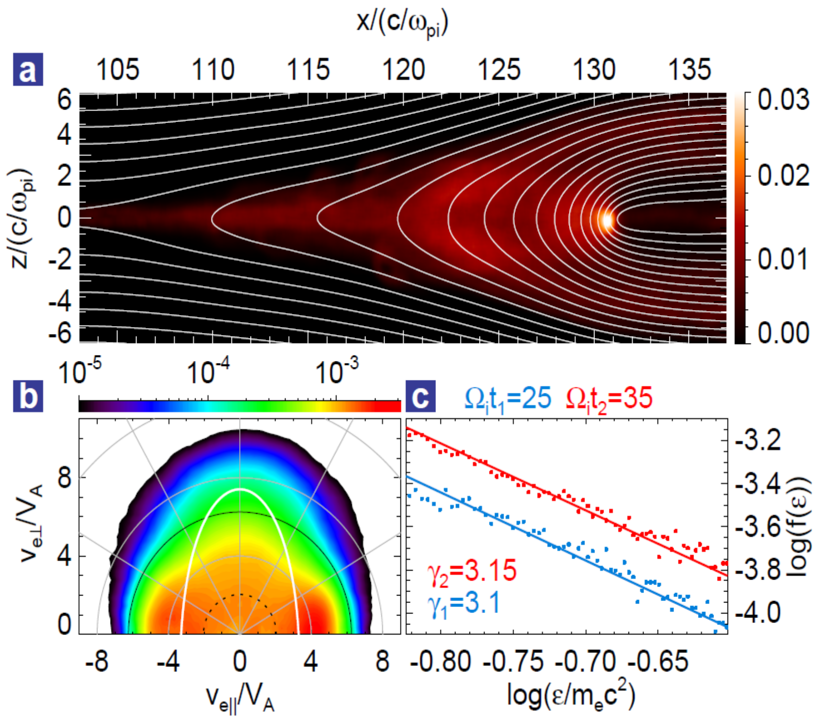
- Initial Harris current sheet equilibrium
- n_b/n_0=0.1, δ=0.5d_i, T_i/T_e=5
- m_i/m_e=25, c/V_A=15
- $L_x \times L_z$=204.8$d_i \times$25.6d_i, $\triangle x=\triangle z$=0.05d_i, $\triangle t$=0.001Ω^{-1}
- The system is initiated by a small local flux perturbation.

The evolution of the DF



- B_z increase at about $\Omega_i t=15$, and a DF is formed.
- The DF propagates away from the X line with a constant speed about V_A.
- The pileup of the magnetic field is driven firstly by the electron flow, and by then the ion flow from about $\Omega_i t=22$.

The energetic electrons



- Electrons shows a pancake distribution in the higher energy range.

- The electron spectrum in the DF region has a power law distribution at higher energy range, and the index of the spectrum is almost kept as a constant during its propagation.

Tracing energetic electrons in DF

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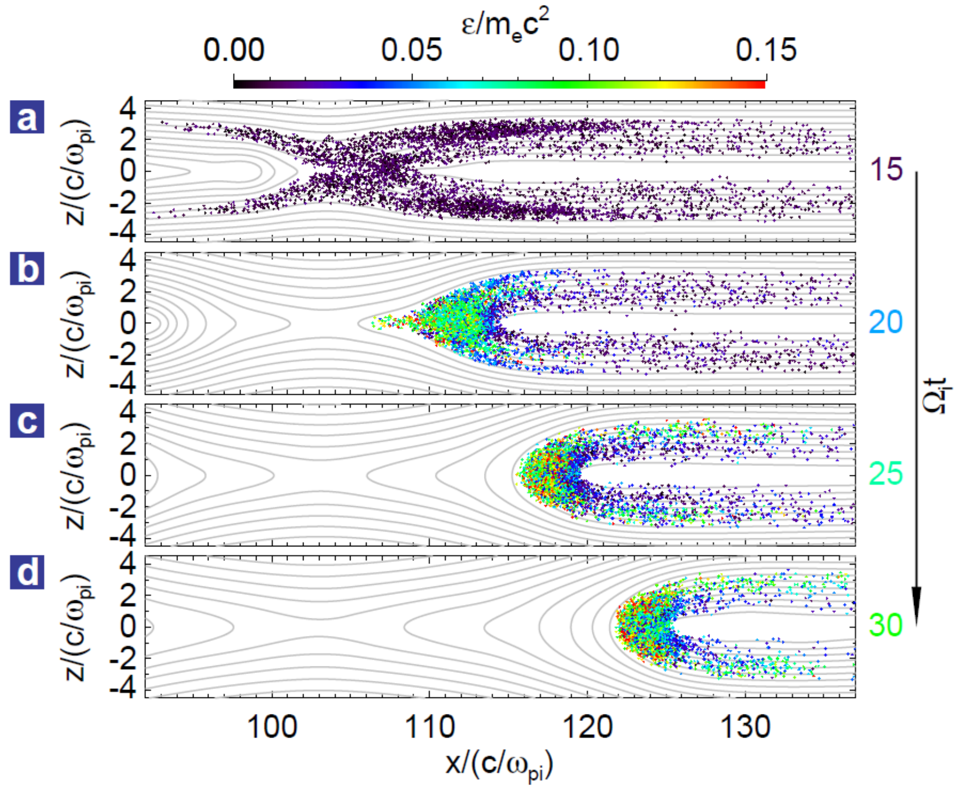

Most energetic electrons are trapped near the DF.

The trajectory of a typical energetic electron

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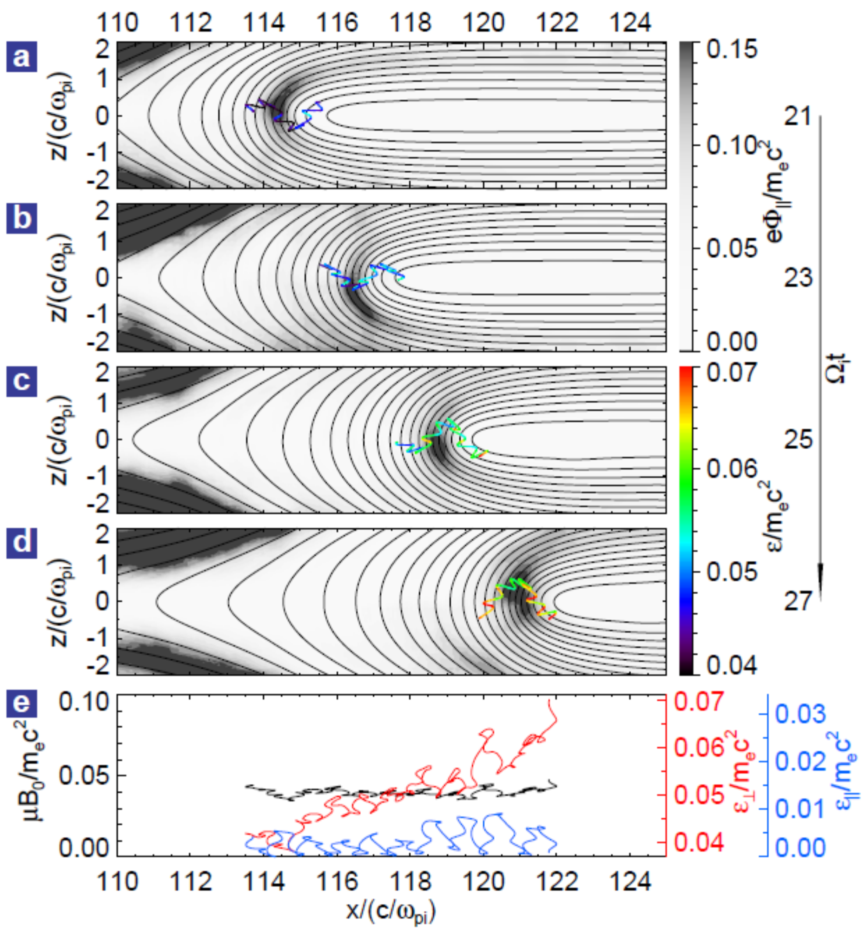
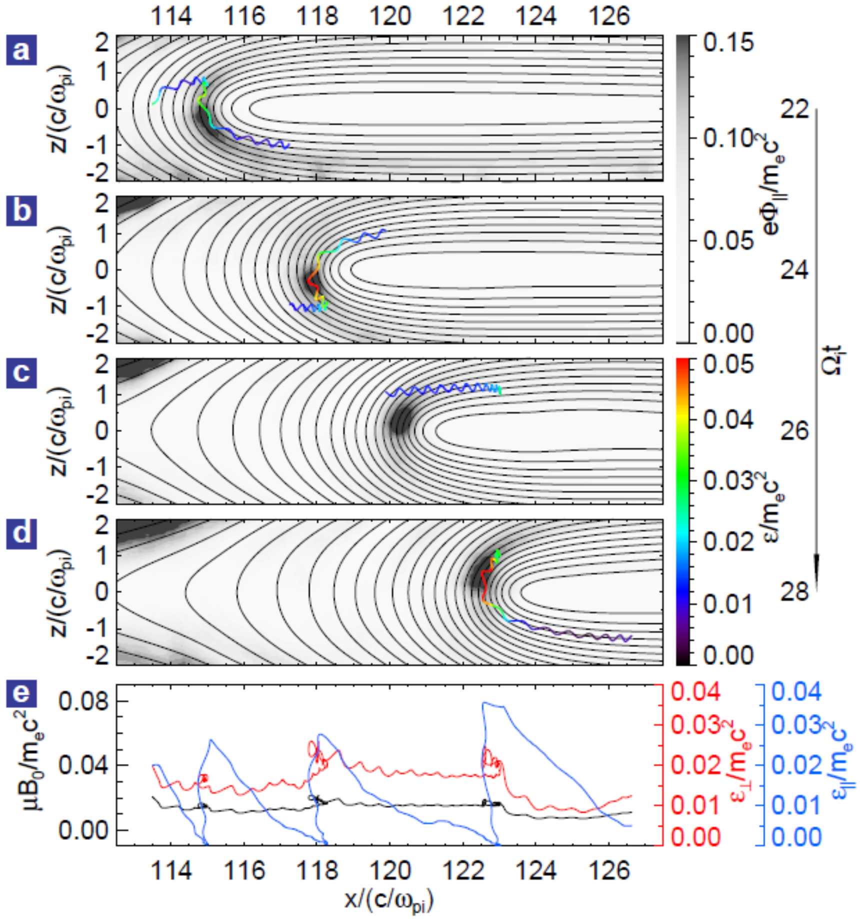


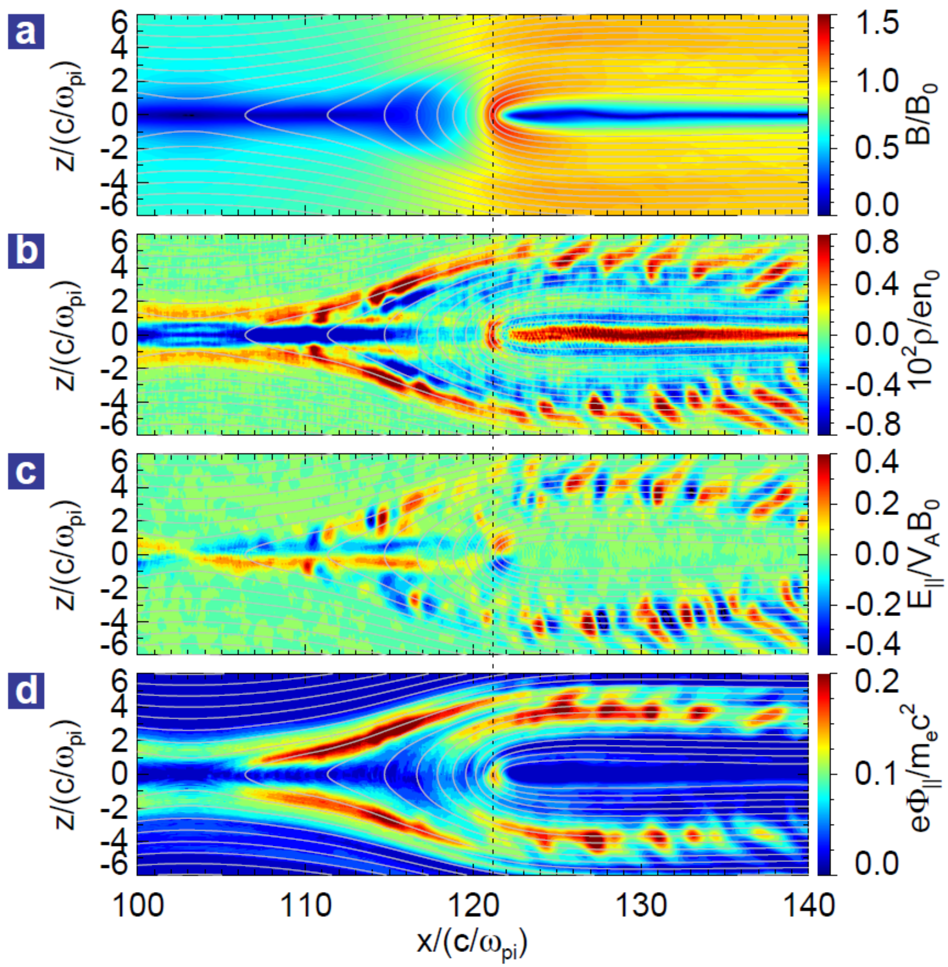
- For the most energetic electron, its parallel velocity is small.
- Theses electrons are trapped for longer time and accelerated to the higher energy in the perpendicular direction, and forms a pancake distribution.

The trajectories of an electron suffered insignificant acceleration



The electron has a larger parallel velocity, it moves through the DF region quickly, and cannot be accelerated to a high energy.

The structure of the electric field



- The ion bulk flow is decelerated in DF region, which leads to the accumulation of the ions and a positive charge density. Then, a parallel electric field with a positive parallel electric potential is generated in the DF region.

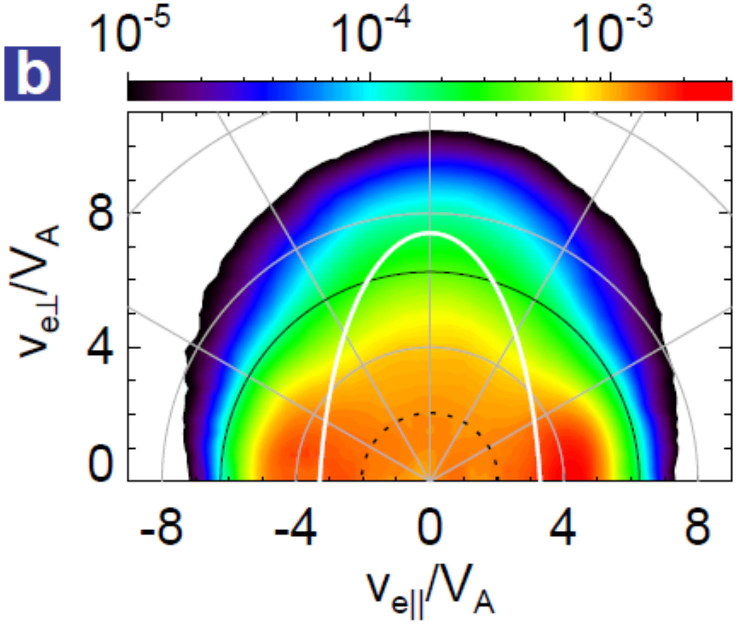
Discussion

$$\mathbf{F}_{mirror} = -\mu\,\partial B/\partial \mathbf{s} \qquad \mathbf{F}_{E_{\|}} = -e\mathbf{E}_{\|}$$

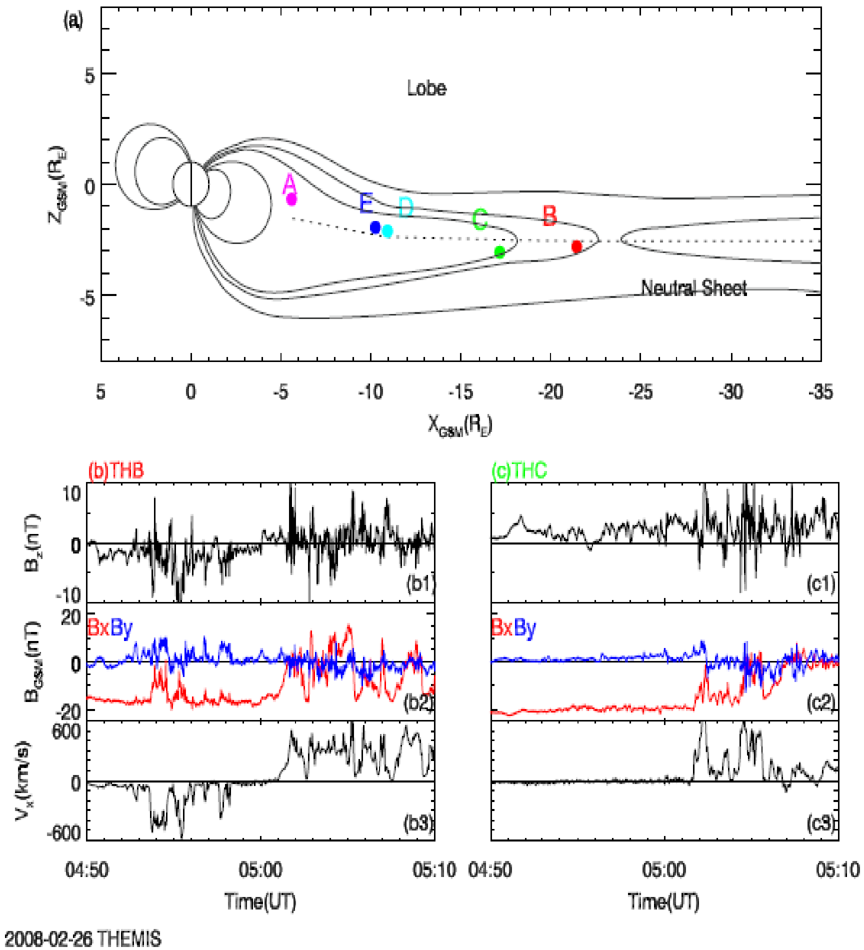
$$\varepsilon_{\|}(\mathbf{r}_2) = \varepsilon_{\|}(\mathbf{r}_1) - \int_{\mathbf{r}_1}^{\mathbf{r}_2} \left(\mu\,\partial B/\partial s + eE_{\|}\right) ds$$

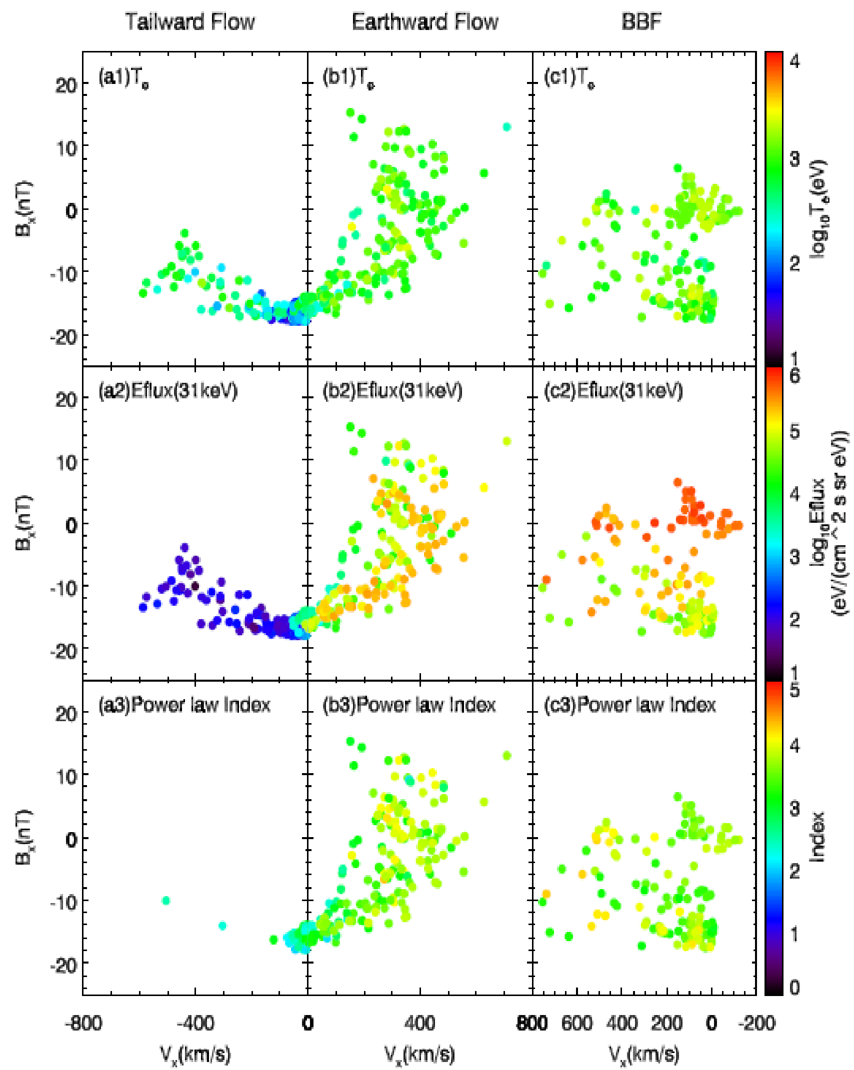
$$\frac{\gamma^2}{\gamma+1}\left[\left(\frac{v_{\|}}{c}\right)^2 + \left(1-\frac{B_{\mathrm{Edge}}}{B_{\mathrm{DF}}}\right)\left(\frac{v_{\perp}}{c}\right)^2\right] = \frac{\mathrm{e}\left(\Phi_{\|\mathrm{DF}} - \Phi_{\|\mathrm{Edge}}\right)}{m_e c^2}$$

➢**The electron behavior in the DF region is determined by two force: the “pushing” force (mirror force) and the “pulling” force (electric field force).**



Multiple stages of electron acceleration





[Wu, Huang, and Lu et al., 2015]

Summary

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- The DF is driven firstly by an electron outflow, and then by an ion flow.
- For the first time, by PIC simulation, we find that electrons can be accelerated by a betatron acceleration process in DF.
- There existence of a velocity threshold, which is related to the trapping mechanism due to the parallel electric potential in DF. The threshold categorizes the electrons into two types. Only the electrons below the threshold can be accelerated in the perpendicular direction by betatron acceleration.

Thank you!