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Magnetic Islands in Collisonless Magnetic Reconnection

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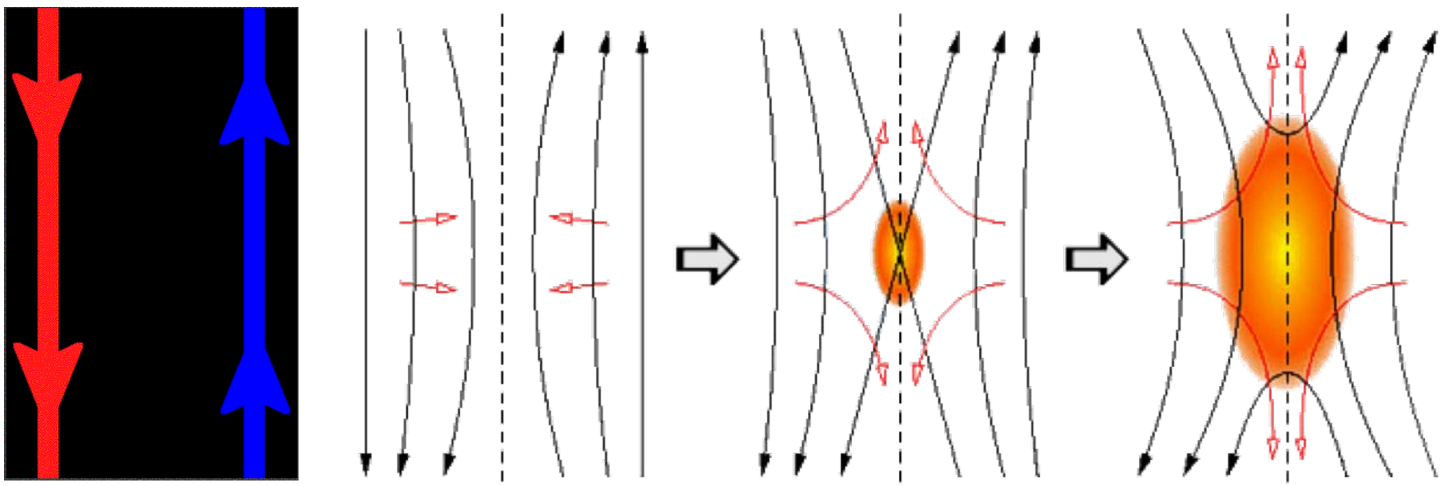
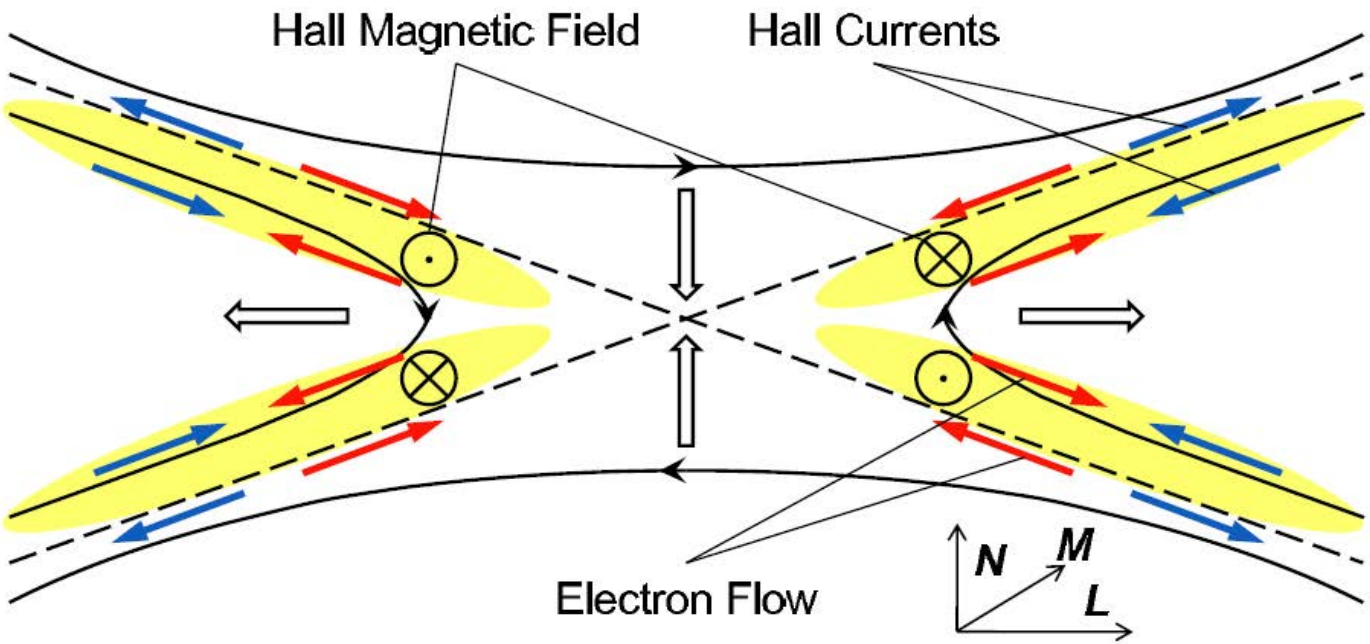
Magnetic Reconnection(MR)

Magnetic reconnection, where magnetic field lines are topologically rearranged, provides a conversion from magnetic energy into plasma kinetic energy.



Collisionless magnetic reconnection



Ion diffusion region: Ions are not frozen in the magnetic field, and electrons are magnetized. It leads to the quadrupole structure of the out-of-plane magnetic field.

Electron diffusion region(EDR): Electrons are unmagnetized.

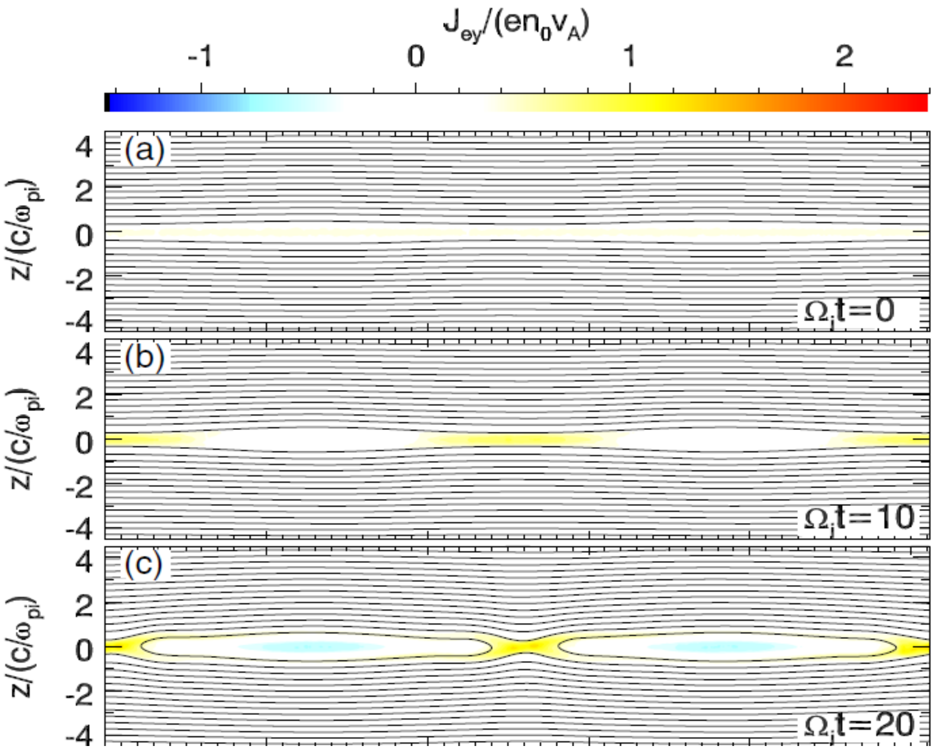
[Birn et al., JGR, 2001]

$$\frac{V_i}{V_A} \sim 0.1$$

Multiple X line reconnection

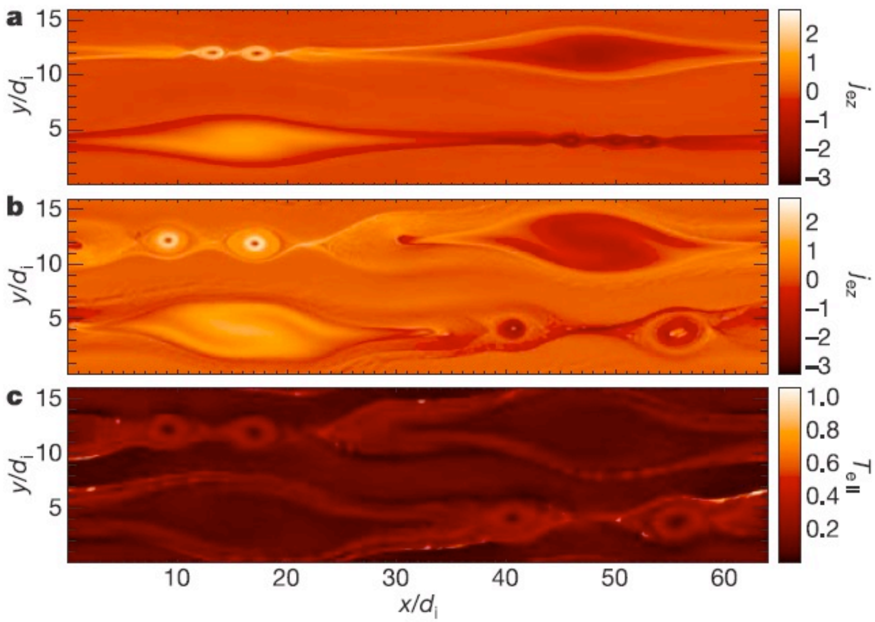
Magnetic islands can be usually generated in the topologic changes of the magnetic field lines, which is associated with magnetic reconnection.

The generation of magnetic island in multiple X line reconnection.

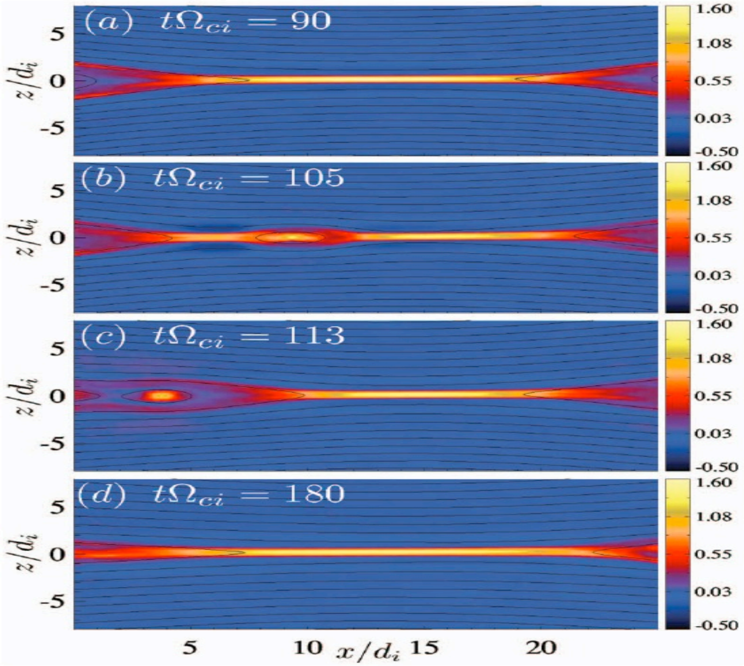


Secondary magnetic islands in extended electron diffusion region

- Generation of secondary island in extended electron diffusion region, and it can enhance reconnection rate.

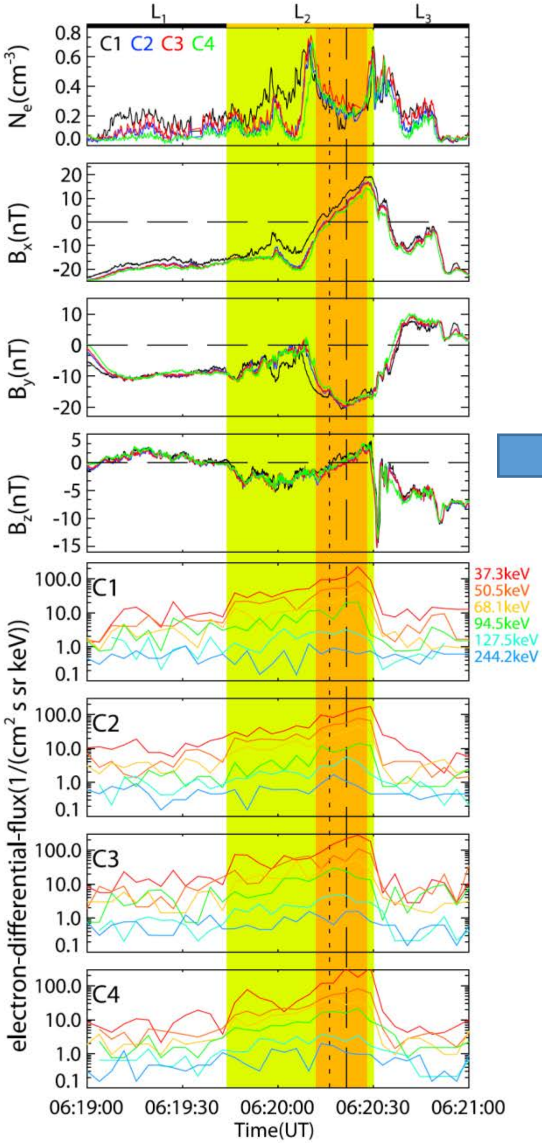


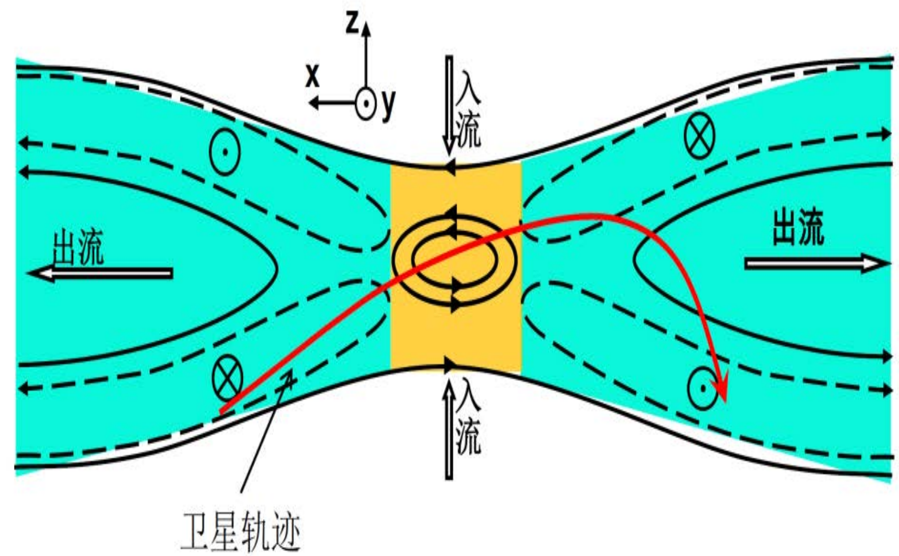
Drake et al., GRL, 2006



Daughton et al., PoP, 2006

Observation of secondary island

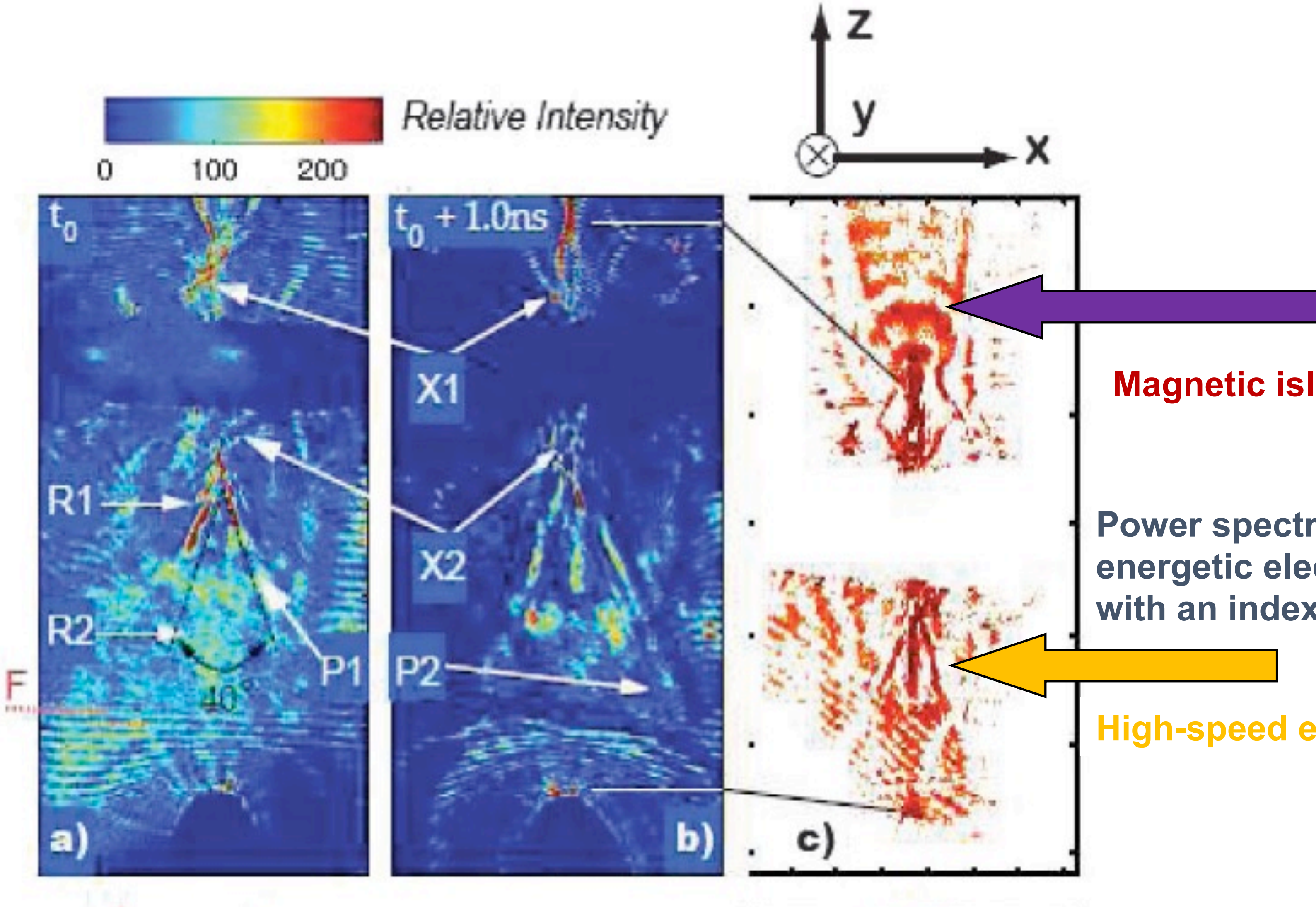




Wang et al., PRL，2010

The length of the secondary island is about 3d_i.

Magnetic island and electron jets in laser plasma reconnection



Magnetic island

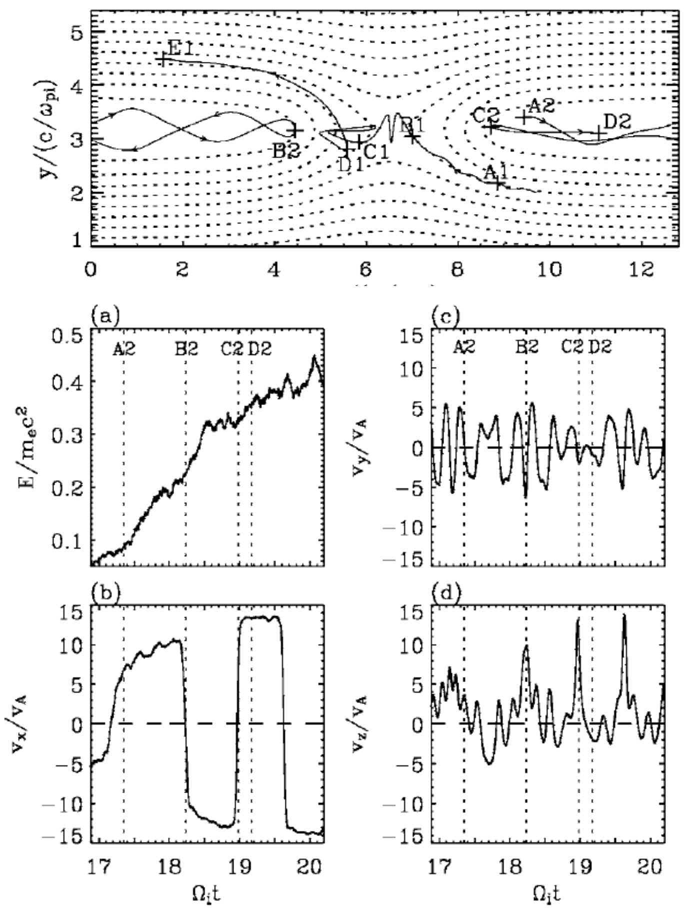
Power spectrum of energetic electrons with an index 6.5

High-speed electron jets

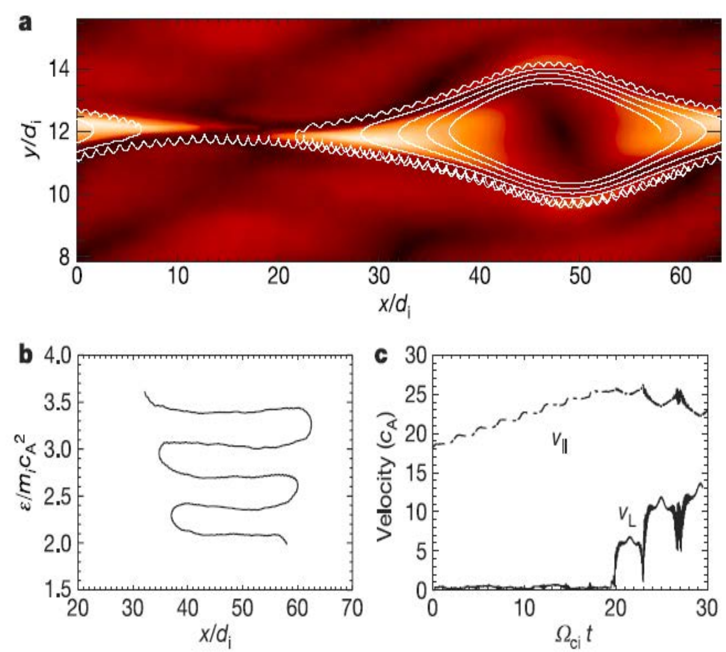
Magnetic reconnection at Shenguang-II facility [Dong et al., PRL, 2012]

Electron acceleration in magnetic island

Electrons are accelerated when reflected at the two ends of a magnetic island.



Fu et al., PoP, 2006



Drake et al., Nature, 2006

Electron acceleration during island coalescence

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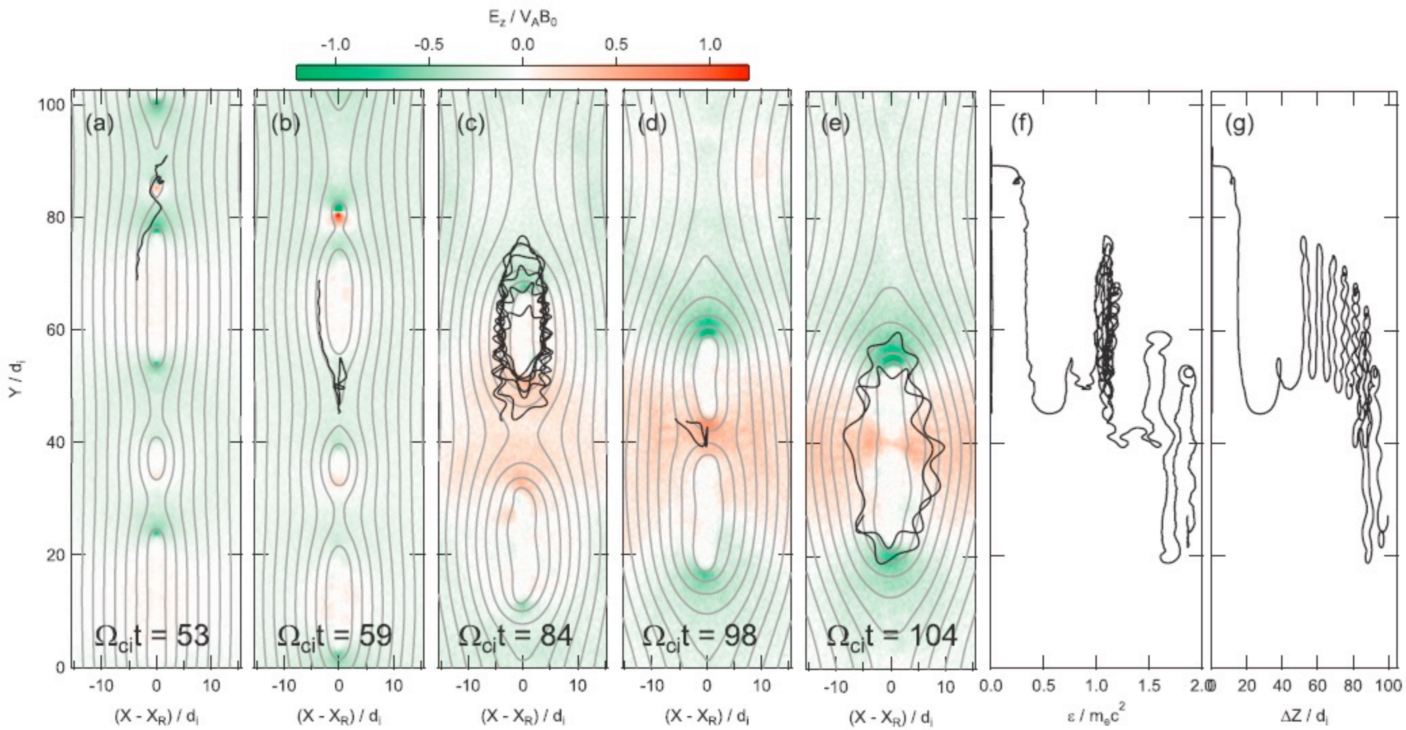
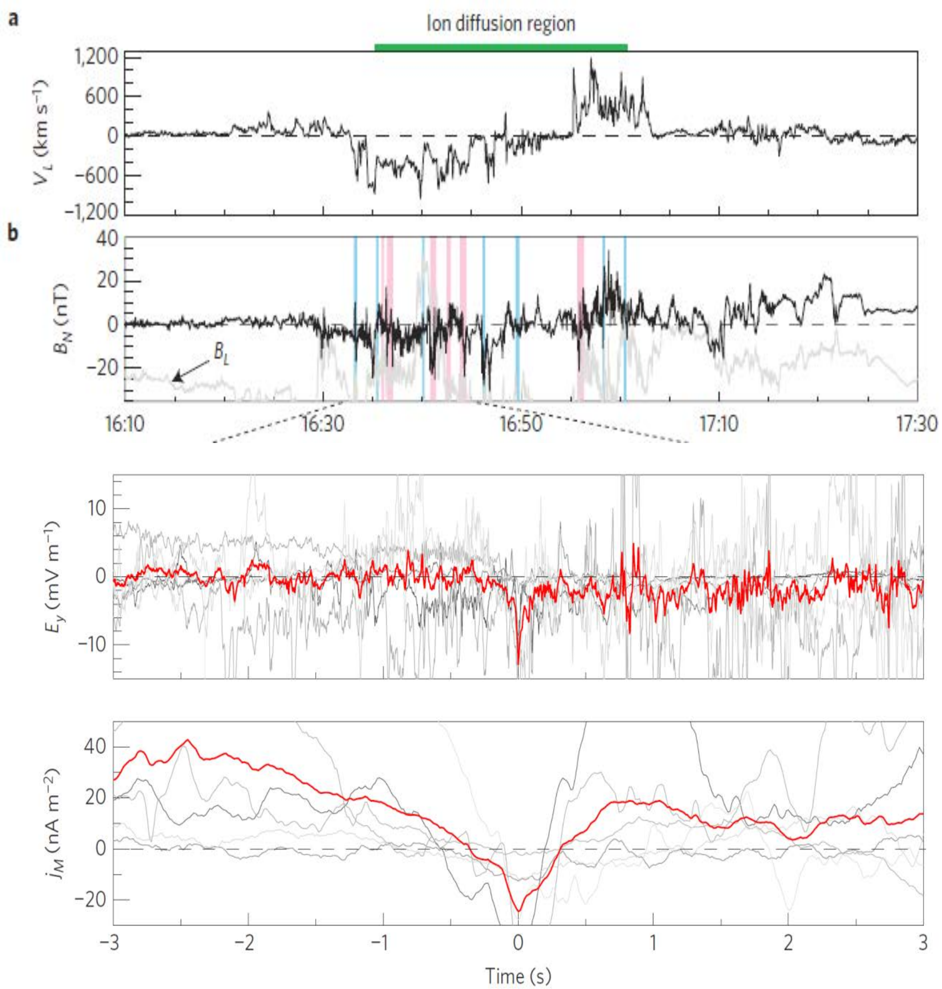
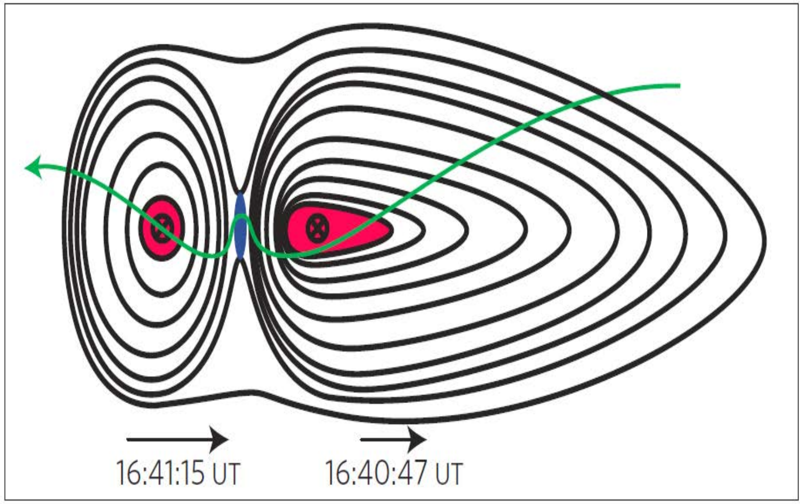
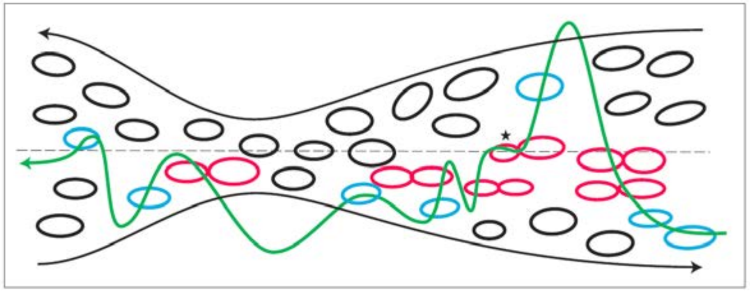


Electrons are accelerated during the coalescence of magnetic islands[Oka et al., ApJ., 2010].

Observation of coalescence of magnetic islands







Wang et al., Nature Phys., 2016

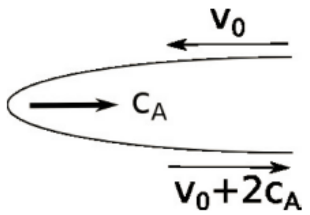
Basic mechanisms for particle gain during magnetic reconnection

- In the guiding center limit

$$\frac{d\varepsilon}{dt} = qv_{\parallel}E_{\parallel} + q\vec{v}_c \bullet \vec{E} + \mu\frac{\partial B}{\partial t} + q\vec{v}_B \bullet \vec{E}$$

- Curvature drift (Fermi reflection): increase the parallel energy

$$v_c = \frac{v_{\parallel}^2}{\Omega}\vec{b} \times (\vec{b} \bullet \vec{\nabla}\vec{b})$$



- Grad B drift-Betatron acceleration increase perpendicular energy- μ conservation

$$v_B = \frac{v_{\perp}^2}{2\Omega}\vec{b} \times \frac{\vec{\nabla}B}{B}$$

$$\mu = \frac{mv_{\perp}^2}{2B}$$

Dahlin et al., PoP, 2014

Electron acceleration mechanisms during island coalescence

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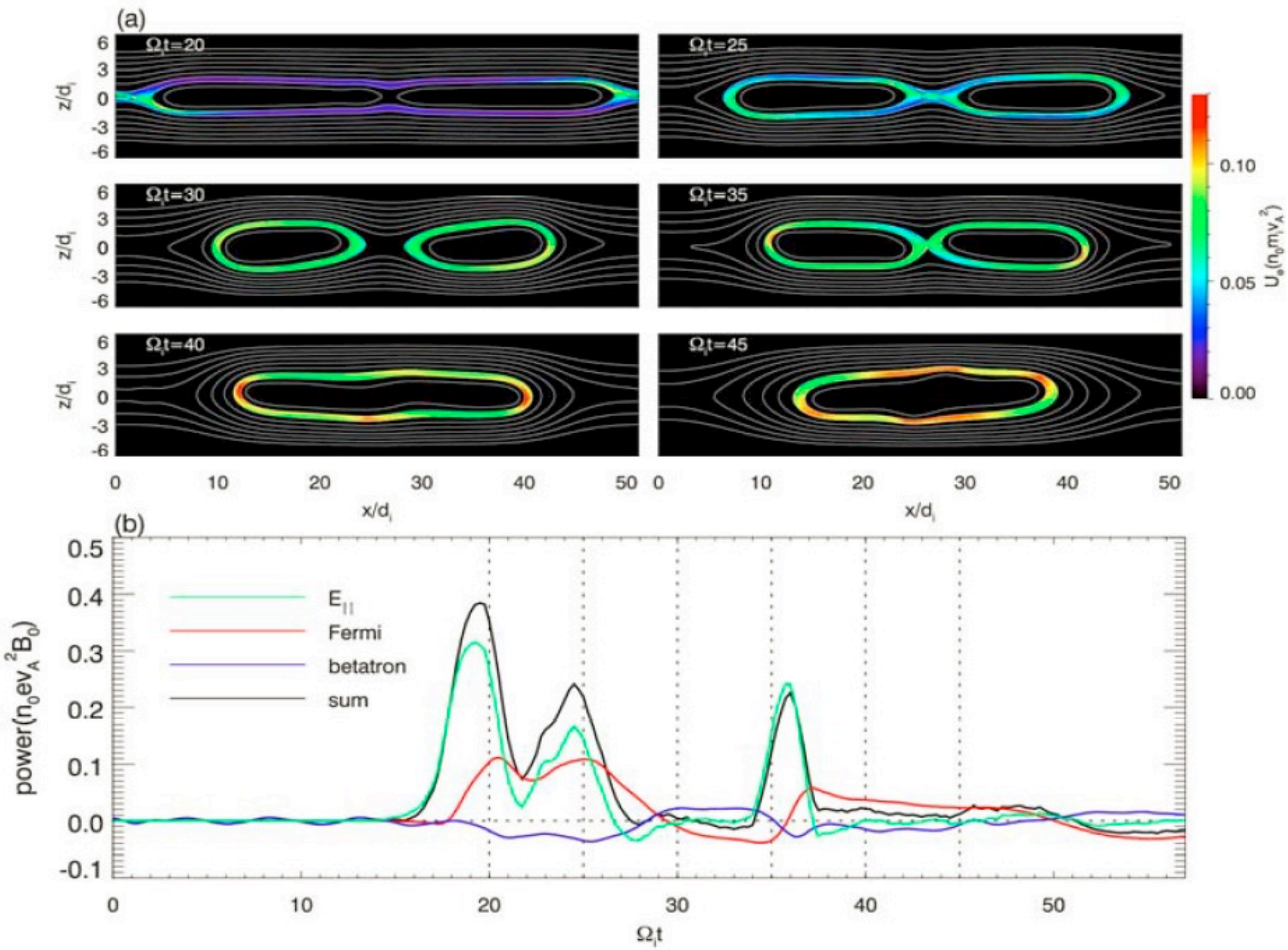
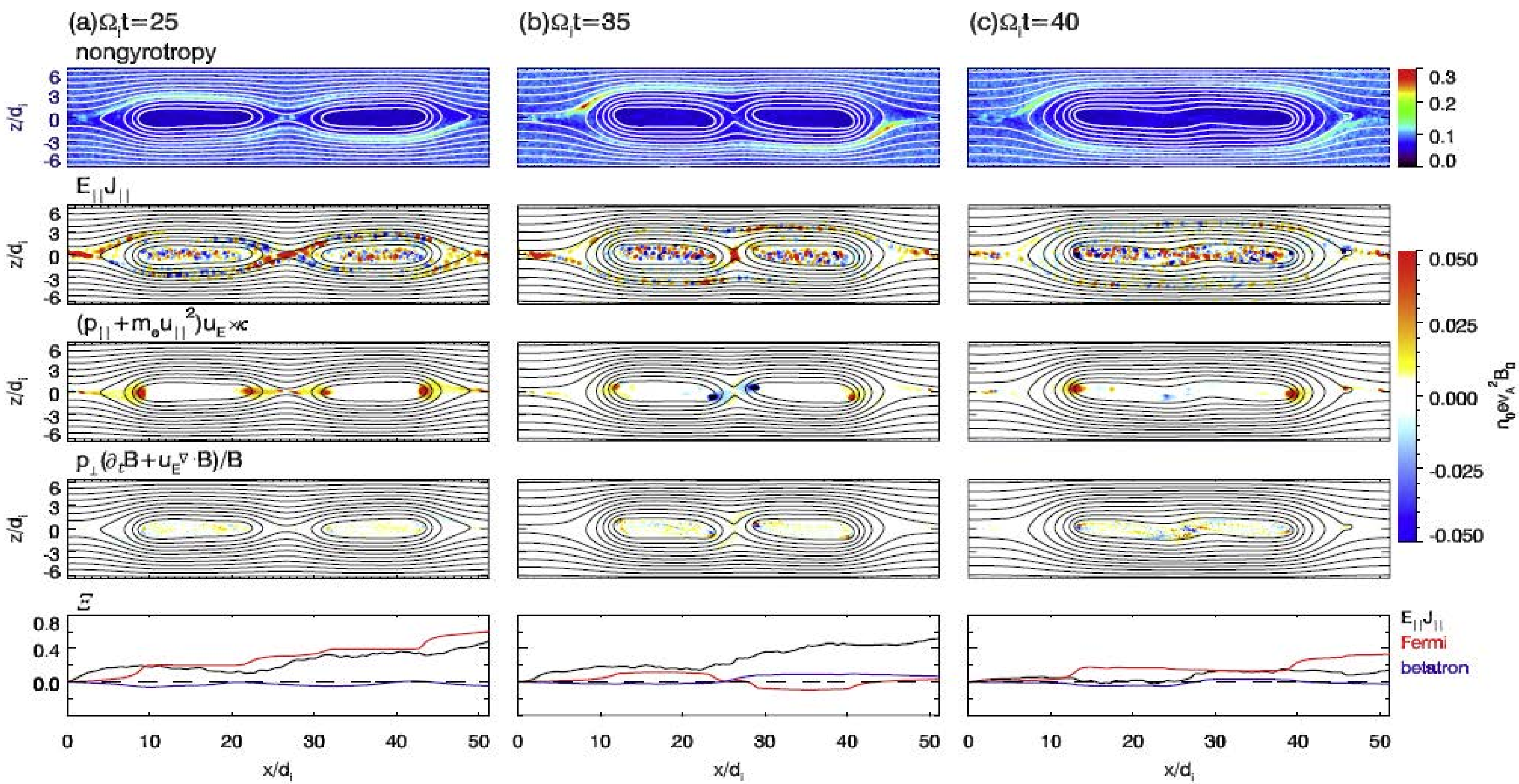
Coalesence of magnetic islands can also lead to the production of energetic electrons.



The electron acceleration by parallel electric field, Fermi and betatron mechanisms in magnetic reconnection with a guide field.

[Wang et al., ApJ, 2016]

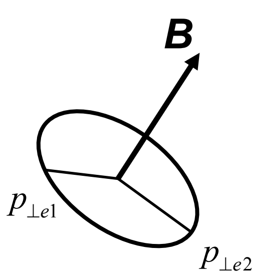
Distributions of electron acceleration mechanisms during island coalescence



Nongyrotropy

$$D_{ng} = \frac{2\sqrt{\sum_{i,j} N_{ij}^2}}{Tr(\mathbf{P}_e)}$$

(Aunai et al., 2013)



$$\Xi(x) = \int_0^x dx' \int P(x', z, t)\, dz$$

（Dahlin et al, 2014）

The dependence of electron acceleration mechanisms on the guide field

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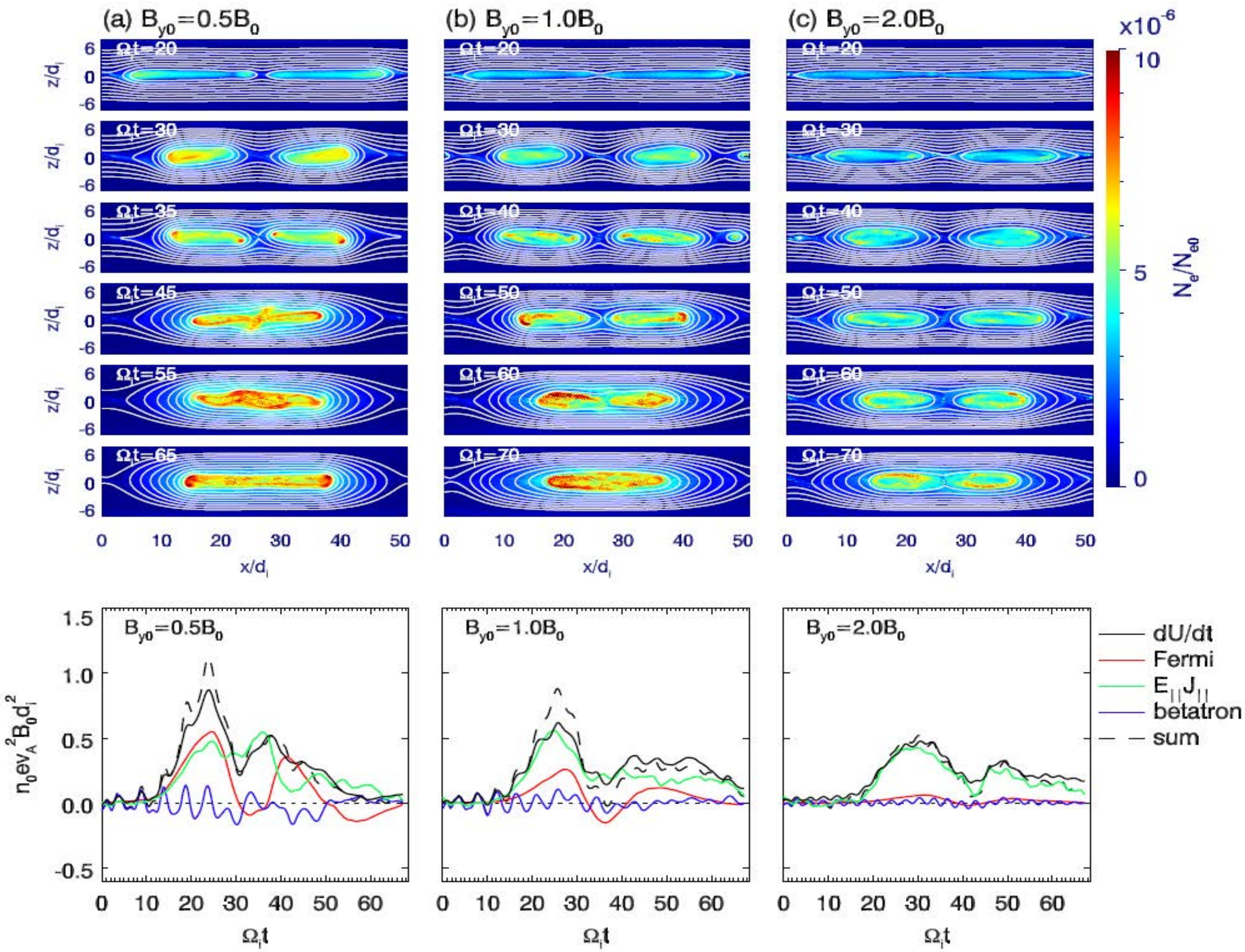
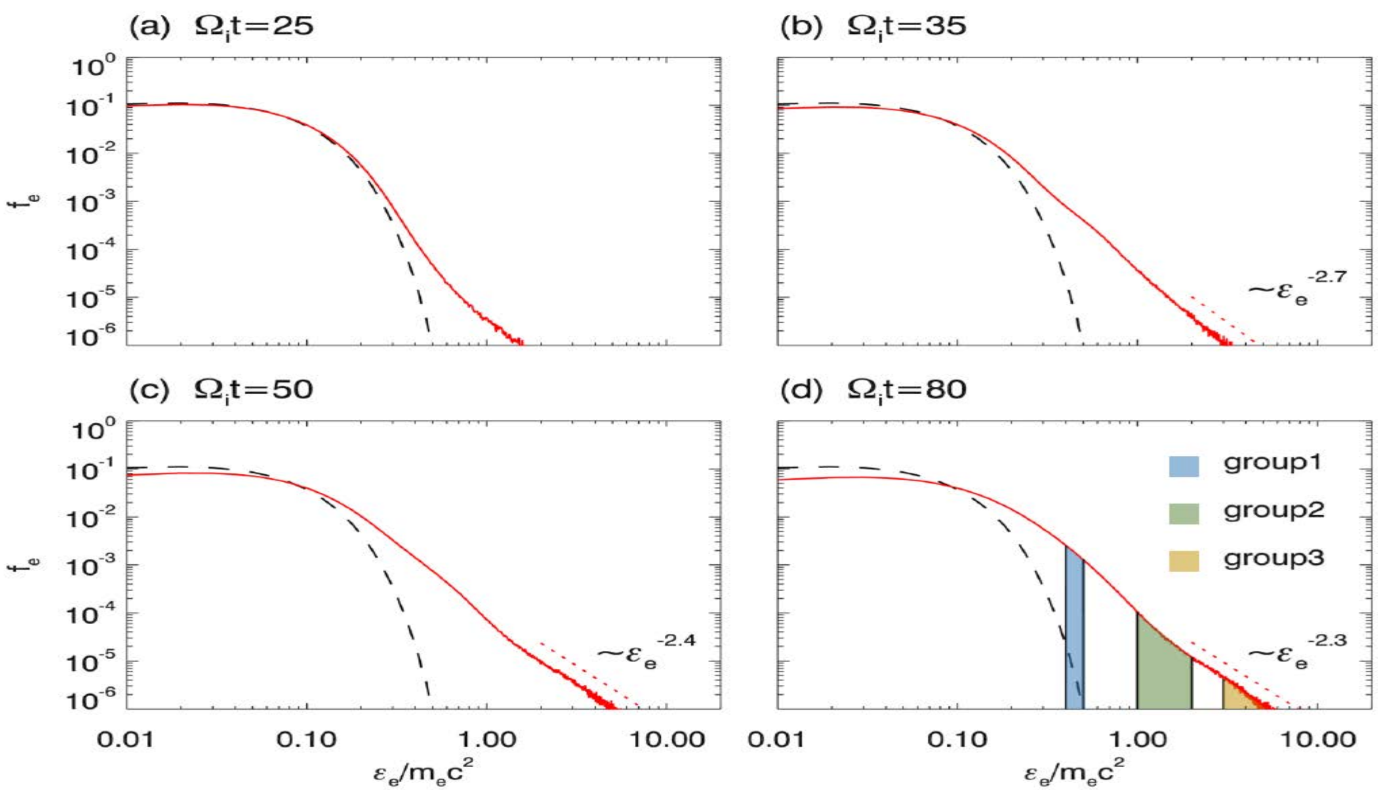


The number of electrons with energy

$$\varepsilon_e > 0.1 m_e c^2$$



The electron energy spectra at different times for the case with $B_{y0} = 2.0B_0$

A power-law distribution of energetic electrons are formed.

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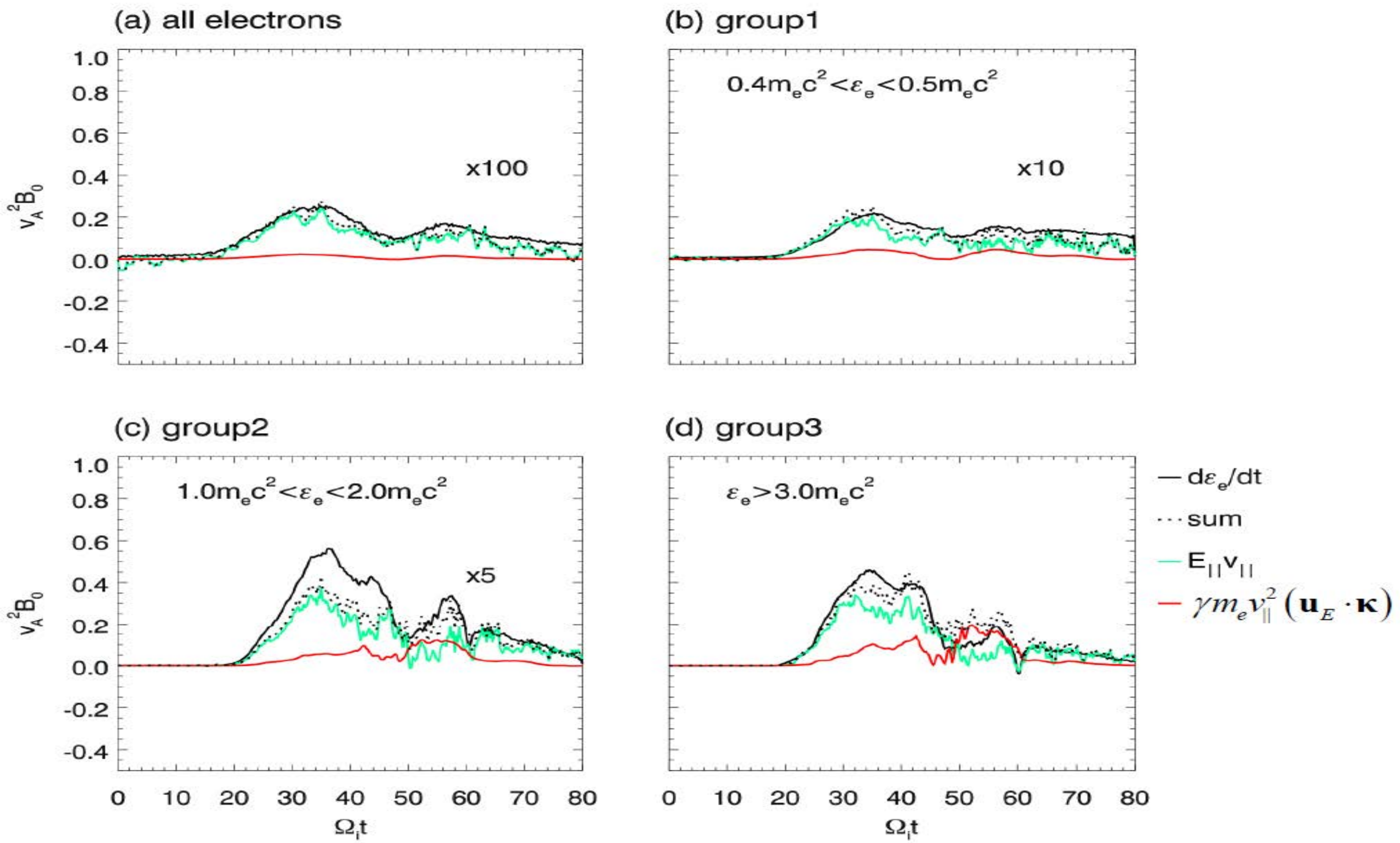

The time evolution of contributions of parallel electric fields ($\sim \varepsilon_e^{1/2}$) and Fermi mechanism ($\sim \varepsilon_e$) with energies for the case $B_{y0} = 2.0B_0$. With the increase of electron energy, the contribution of Fermi mechanism becomes more and more important.

Summary

1. Electrons can be trapped and accelerated in magnetic island by Fermi mechanism.

2. Electron acceleration during island merging may be more important, and electrons can be accelerated by the parallel electric field (with a guide field), Fermi and betatron mechanisms.

3. Power law distribution of energetic electrons can be formed during island merging.

Thanks!