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Structures of magnetic island in collisionless magnetic reconnection

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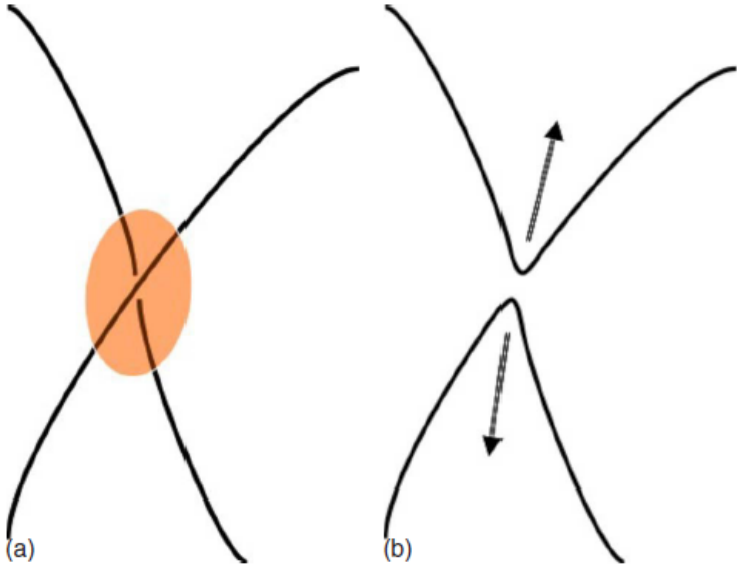
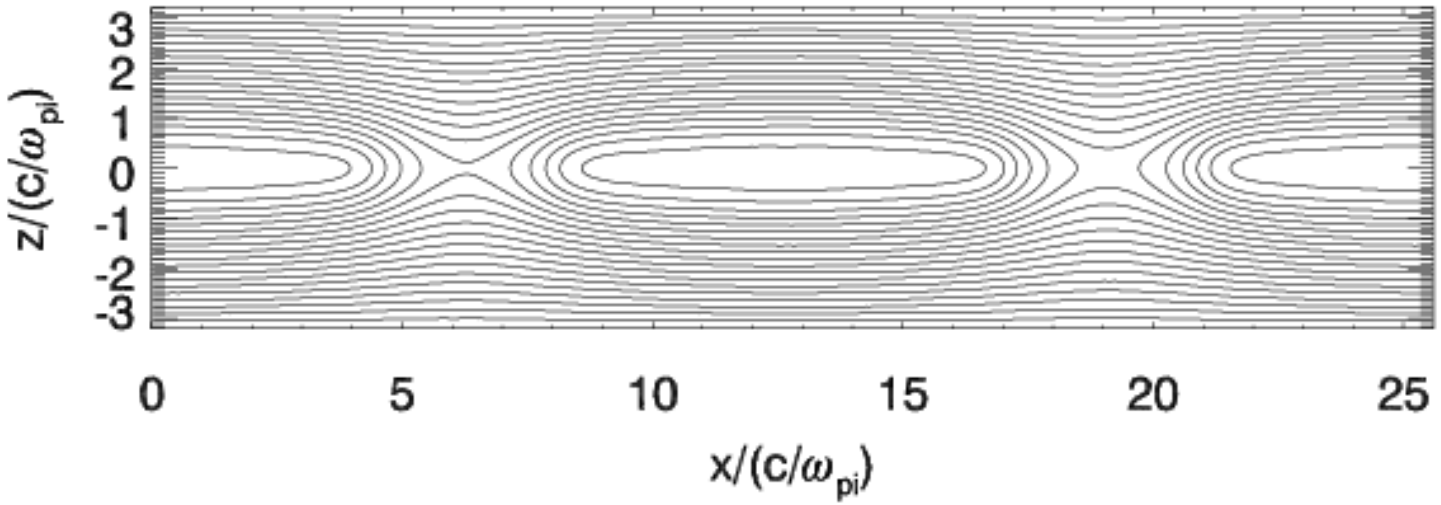
Magnetic reconnection

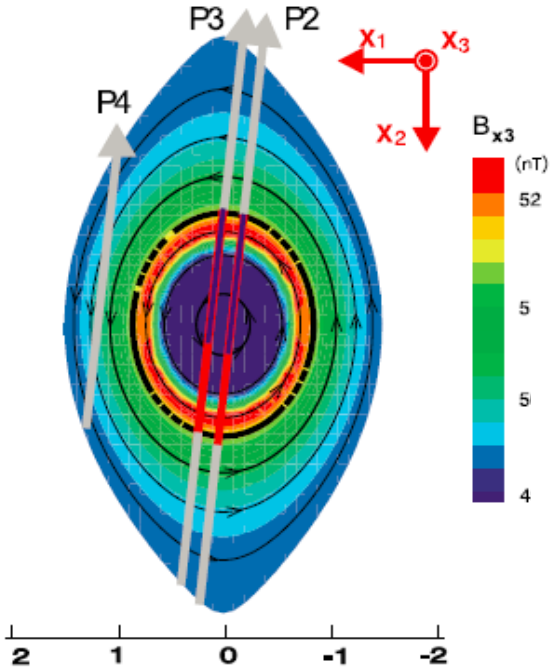
- Fast energy conversion: magnetic energy→kinetic energy
- Topological changes of magnetic field lines



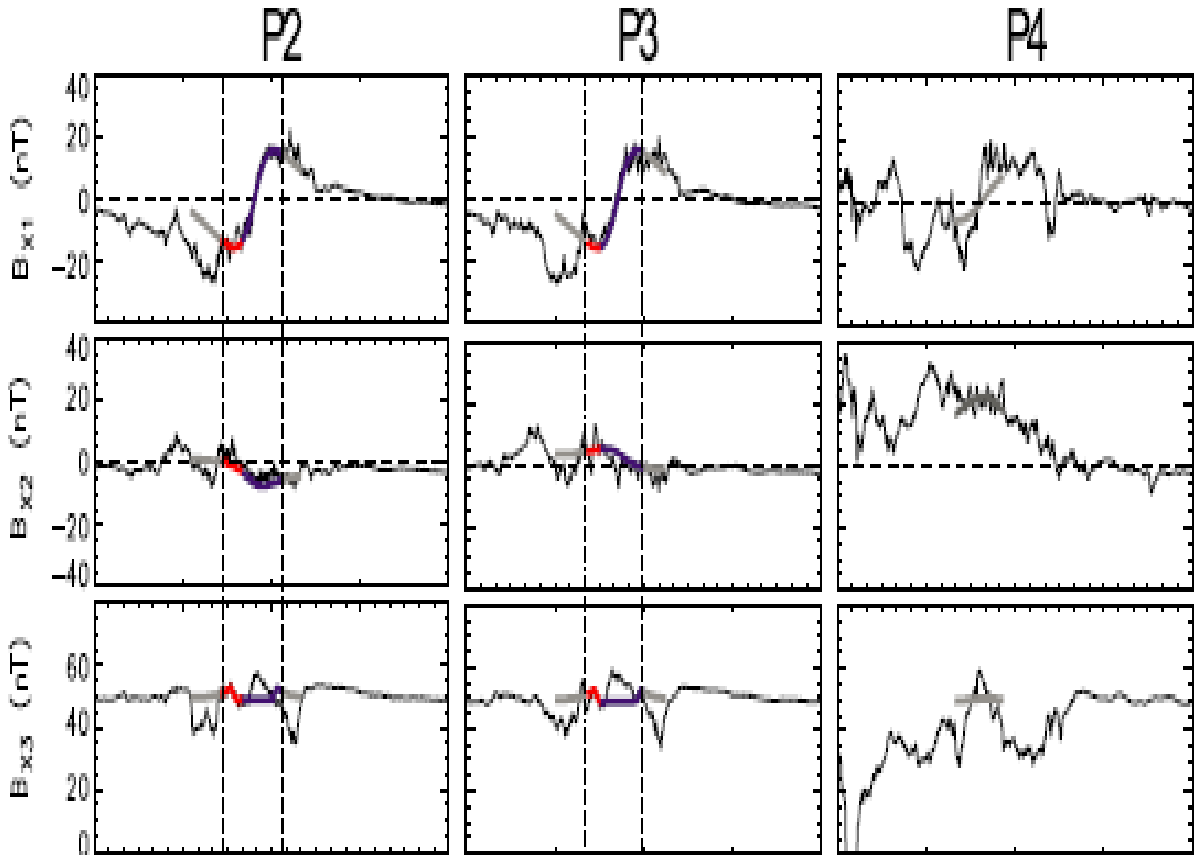
Magnetic island

- In current sheet, two X lines→magnetic island
- Observation: bipolar signature in B_z & Energetic electron flux enhancement (inside magnetic island)





Crater Flux transfer events(FTE) observed by Zhang et al. [JGR, 2010]



Base on 2D PIC simulations, we investigate the structure of magnetic island in multiple X line reconnection.

$$\mathbf{B}_0(z) = B_0 \tanh\left(z/\delta\right)\mathbf{e}_x + B_y\mathbf{e}_y$$

$$n(z) = n_b + n_0 \operatorname{sech}^2\left(z/\delta\right)$$

$$n_b = 0.2n_0 \qquad \delta = 0.5c/\omega_{pi}$$

$$T_{i0}/T_{e0} = 4$$

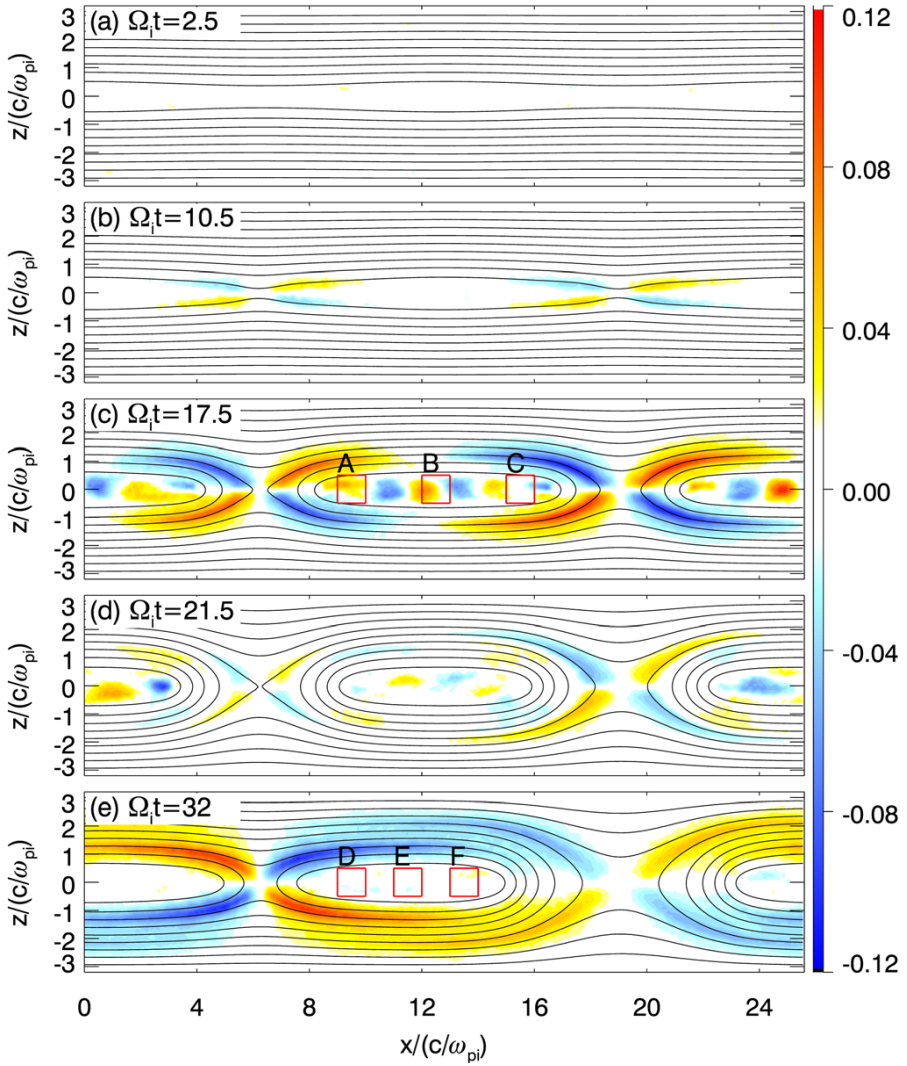
$$m_i/m_e = 100$$

$$c = 15v_A$$

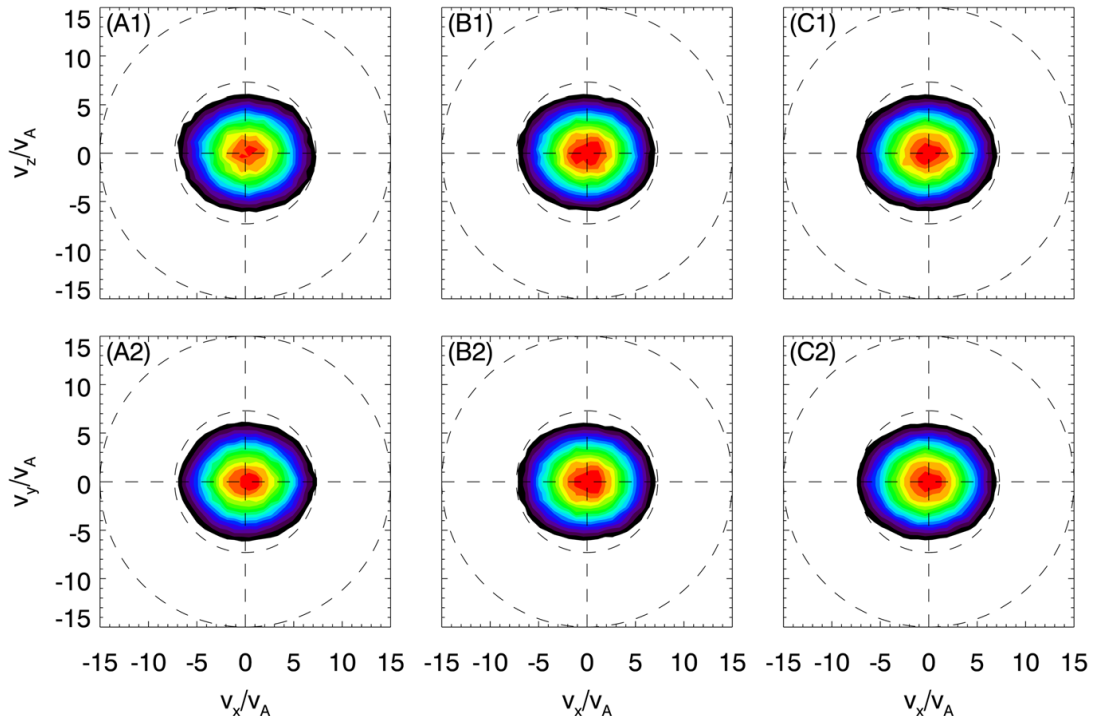
Anti-parallel reconnection

- Quadrupole structures of B_y (in the vicinity of the X line)

- B_y structures with alternative values along the x direction (inside magnetic islands)



$\Omega_{0i}t = 17.5$



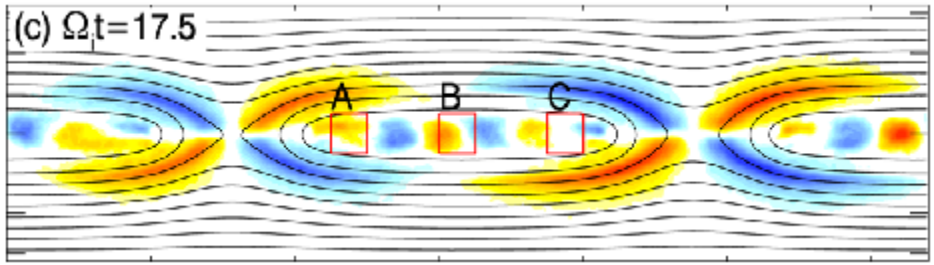
Electron velocity distributions (anisotropic)

Electron parallel and perpendicular temperature and the anisotropy

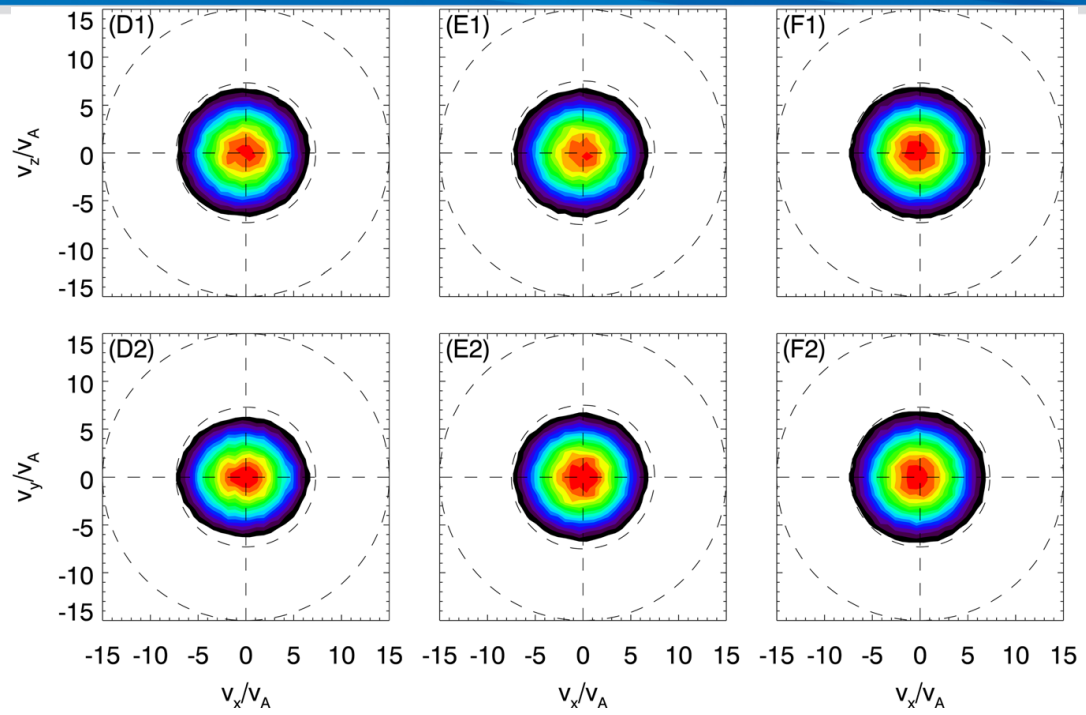
$$A_e = T_{e//}/T_{e\perp} - 1$$

Anisotropy reason: electrons move along the magnetic field lines after they are accelerated by the reconnection electric field [Fu et al., PoP, 2006]

Now, the B_y structures with alternative values along the x direction in the magnetic island is apparent

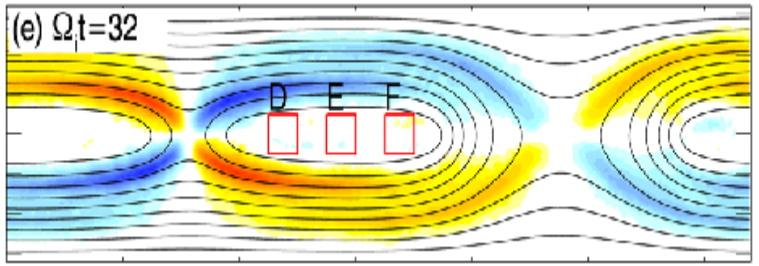


$\Omega_{0i}t=32$



Now, the B_y structures with alternative values along the *x* direction in the magnetic island disappear

Electron velocity distributions (isotropic)



$$A_{e0} = T_{//e0}/T_{\perp e0} - 1 = 0.8$$

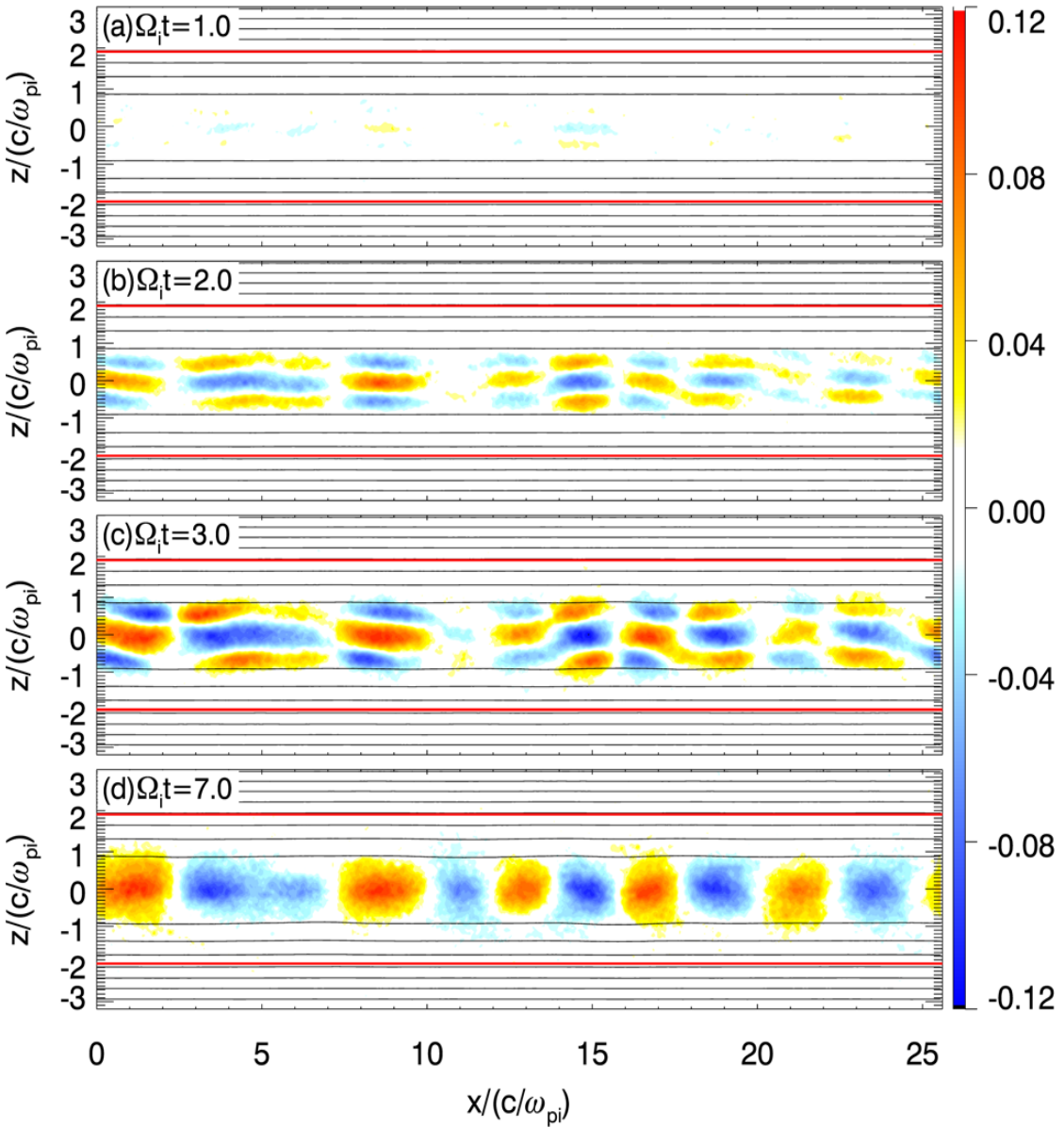
$$\delta = 2.0\, c/\omega_{pi}$$

Weibel instability in the center of the current sheet

At first, wave vector is almost along the z direction, the wave-length is $1.1d_i$
Linear theory, wavelength correspond to the maximum growth rate is $1.2d_i$

GOOD CONSISTANCY

At last, it forms the B_y structures along the x direction as observed in the magnetic islands

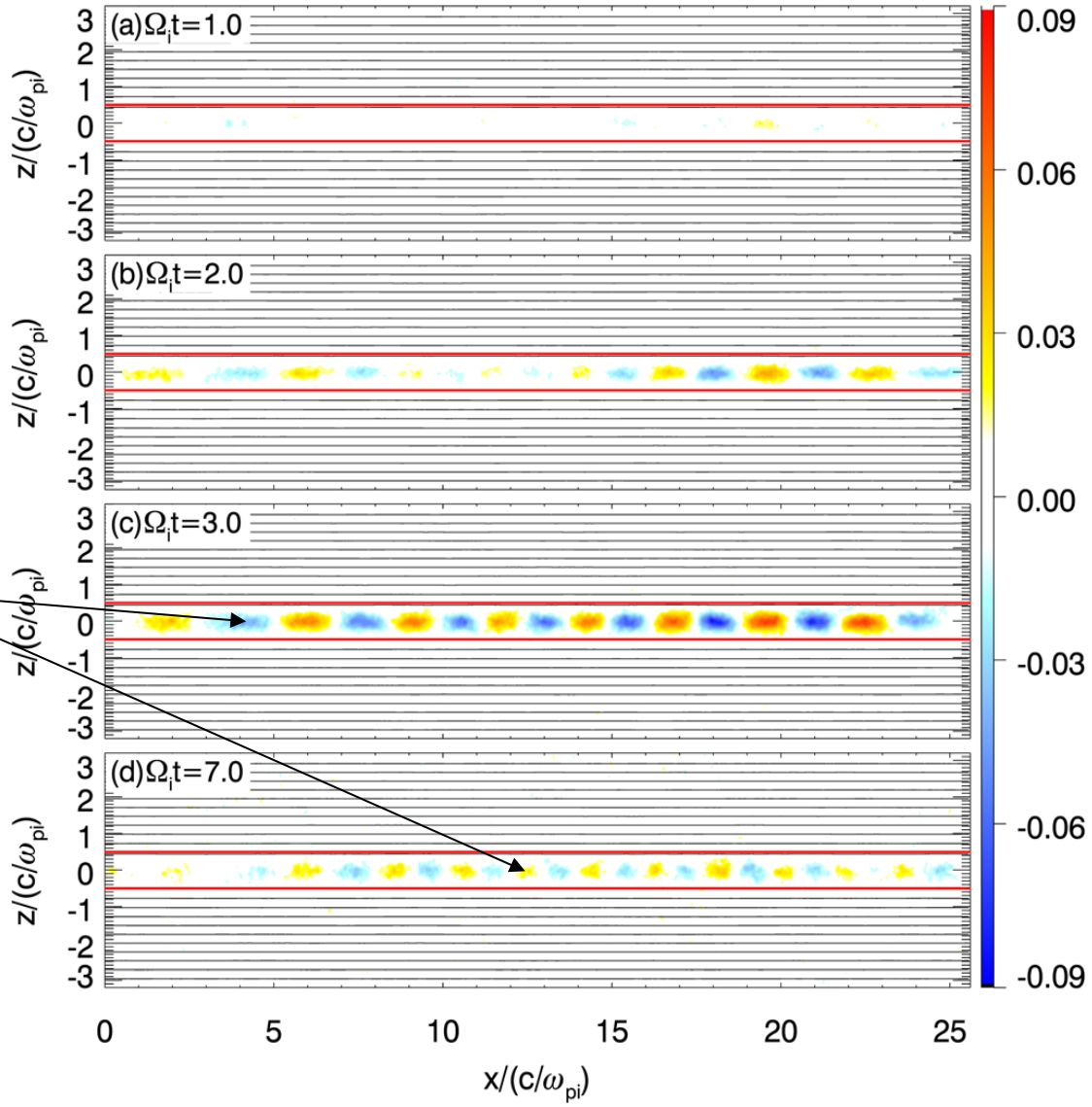


$$A_{e0} = T_{//e0}/T_{\perp e0} - 1 = 0.8$$

$$\delta = 0.5\, c/\omega_{pi}$$

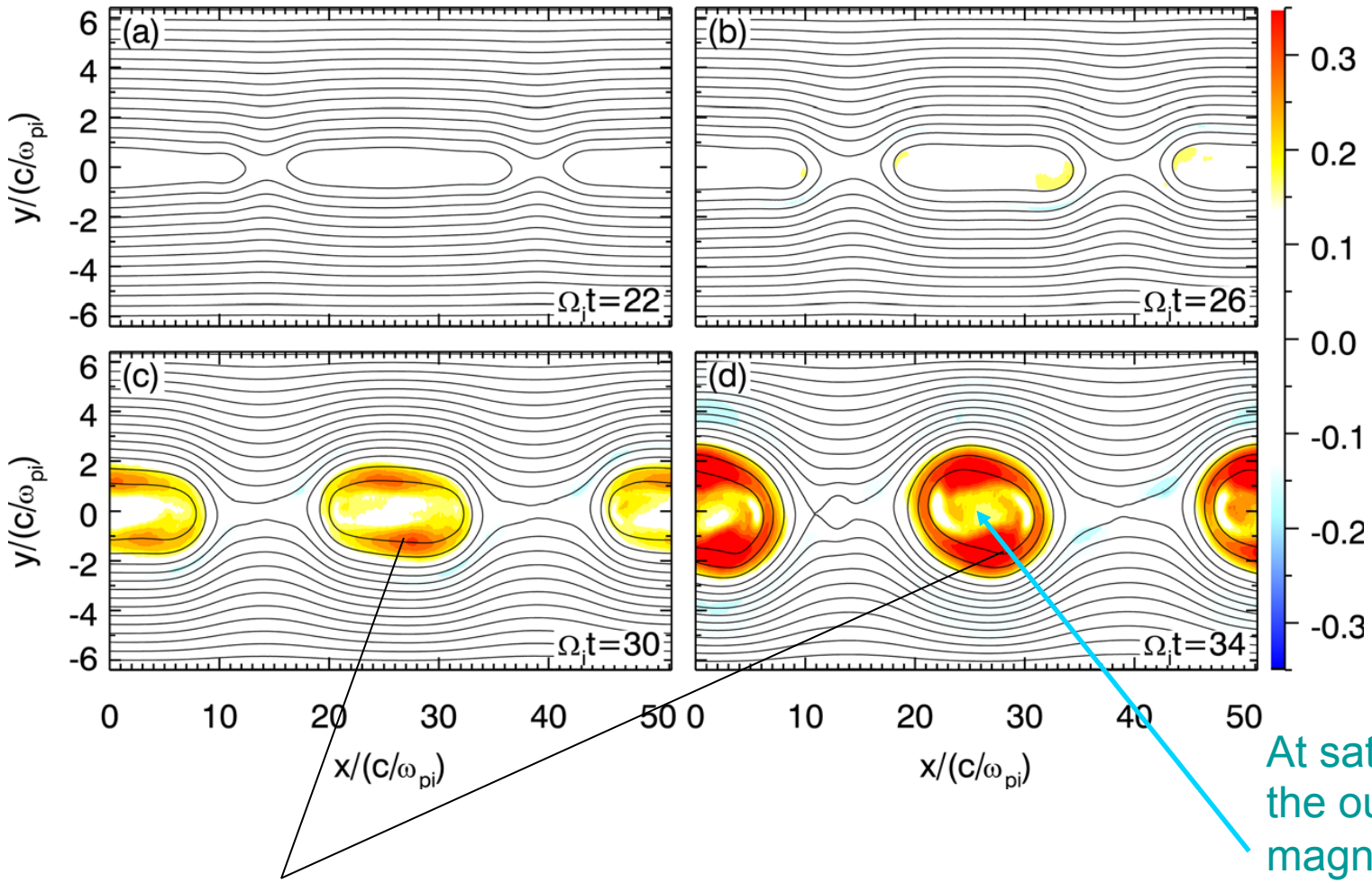
The wavelength of the excited Webel instability ($1.1d_i$) is comparable to the width of the current sheet ($1.0d_i$)

The B_y structures along the x direction will be formed



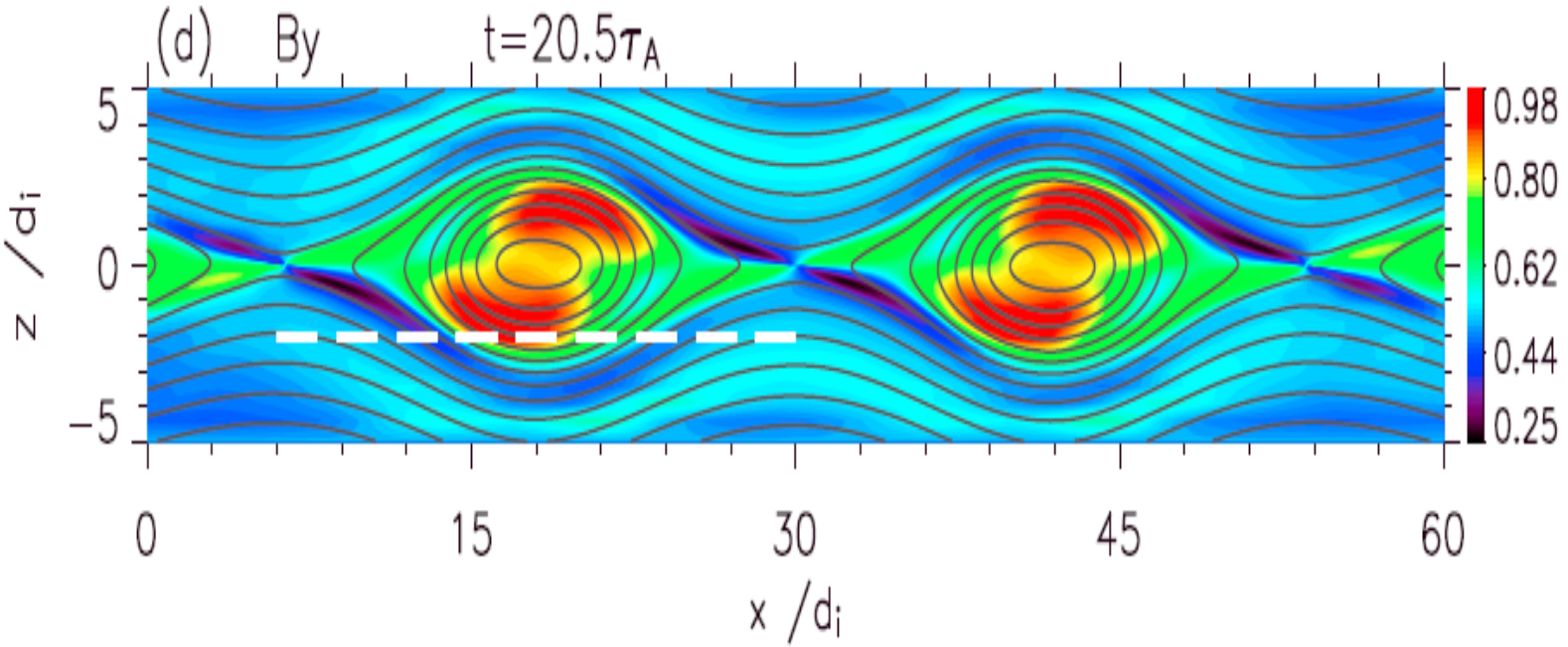
Guide field reconnection

($B_{z0}=B_0$)



Out-of-plane magnetic field enhancement

At saturate stage, the out-of-plane magnetic field shows a dip in the center of the magnetic island



Similar results can be found in Hall-MHD simulations.
[Liu et al., JGR, 2009]

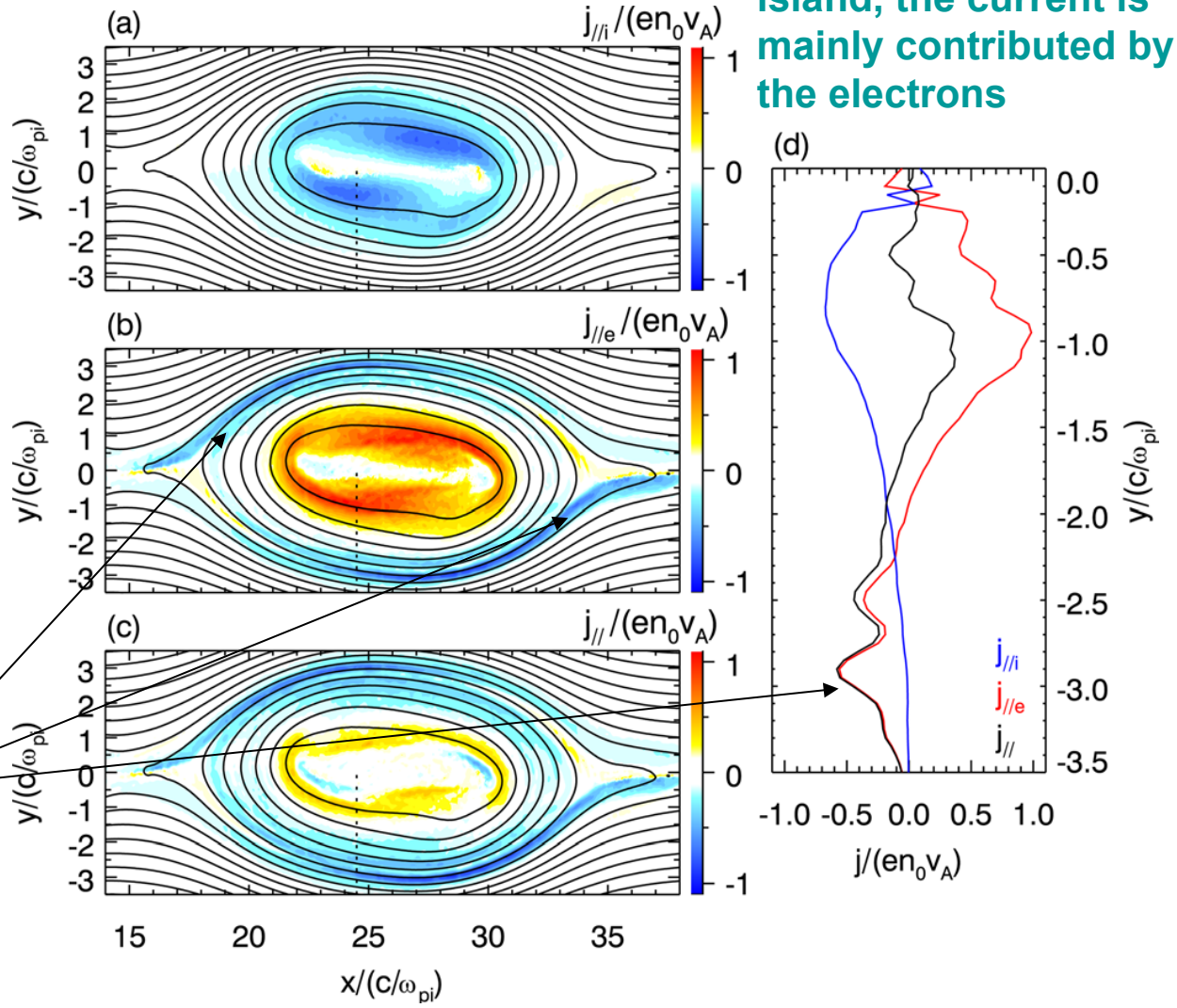
Current system→ out-of-plane magnetic field structures

$$j_{//i}=\mathbf{J}_i\cdot\mathbf{B}'/B'$$
$$j_{//e}=\mathbf{J}_e\cdot\mathbf{B}'/B'$$
$$j_{//}=j_{//i}+j_{//e}$$

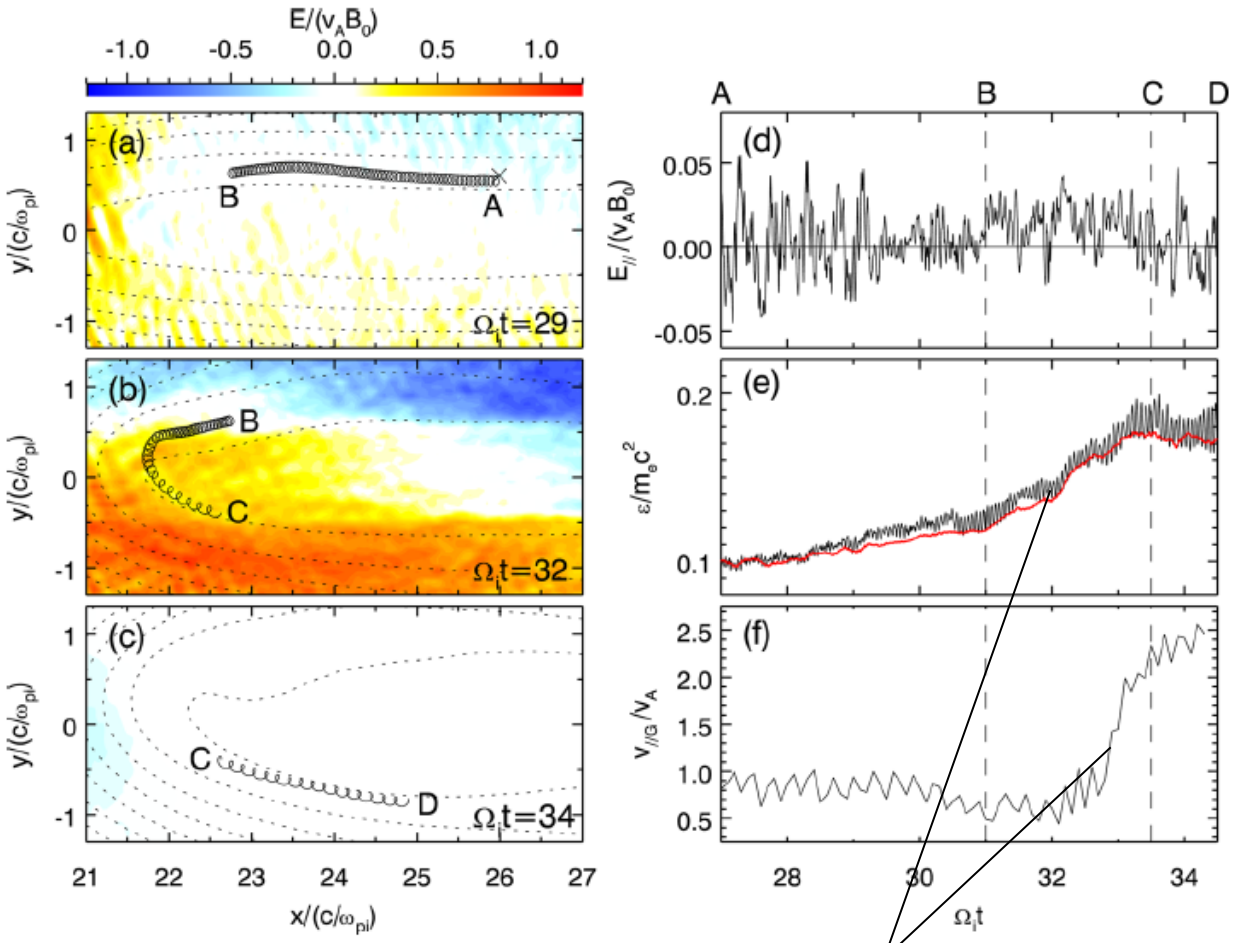
$$\mathbf{B}'=B_x\mathbf{e}_x+B_y\mathbf{e}_y$$

The electron current anti-parallel to the in-plane magnetic field
~electron acceleration in the vicinity of the X line and directed away from the X line

Inside the magnetic island, the current is mainly contributed by the electrons



Inner electron current mechanism (a typical electron trajectory)



Parallel electric field suffered by the electron

The electron kinetic energy

Velocity of the gyrocenter

Electrons are accelerated during B→C due to the parallel electric field

Ions cannot because of the large mass

So **Inside the magnetic island, the current is mainly contributed by the electrons**

Conclusions

Anti-parallel reconnection:

- The Weibel instability may be unstable in magnetic island, which forms regular structures with alternate positive and negative values of the out-of-plane magnetic field.

Guide field reconnection

- **Enhancement of out-of-plane magnetic field in magnetic island, a dip in the center of the magnetic island.**

THANK YOU!