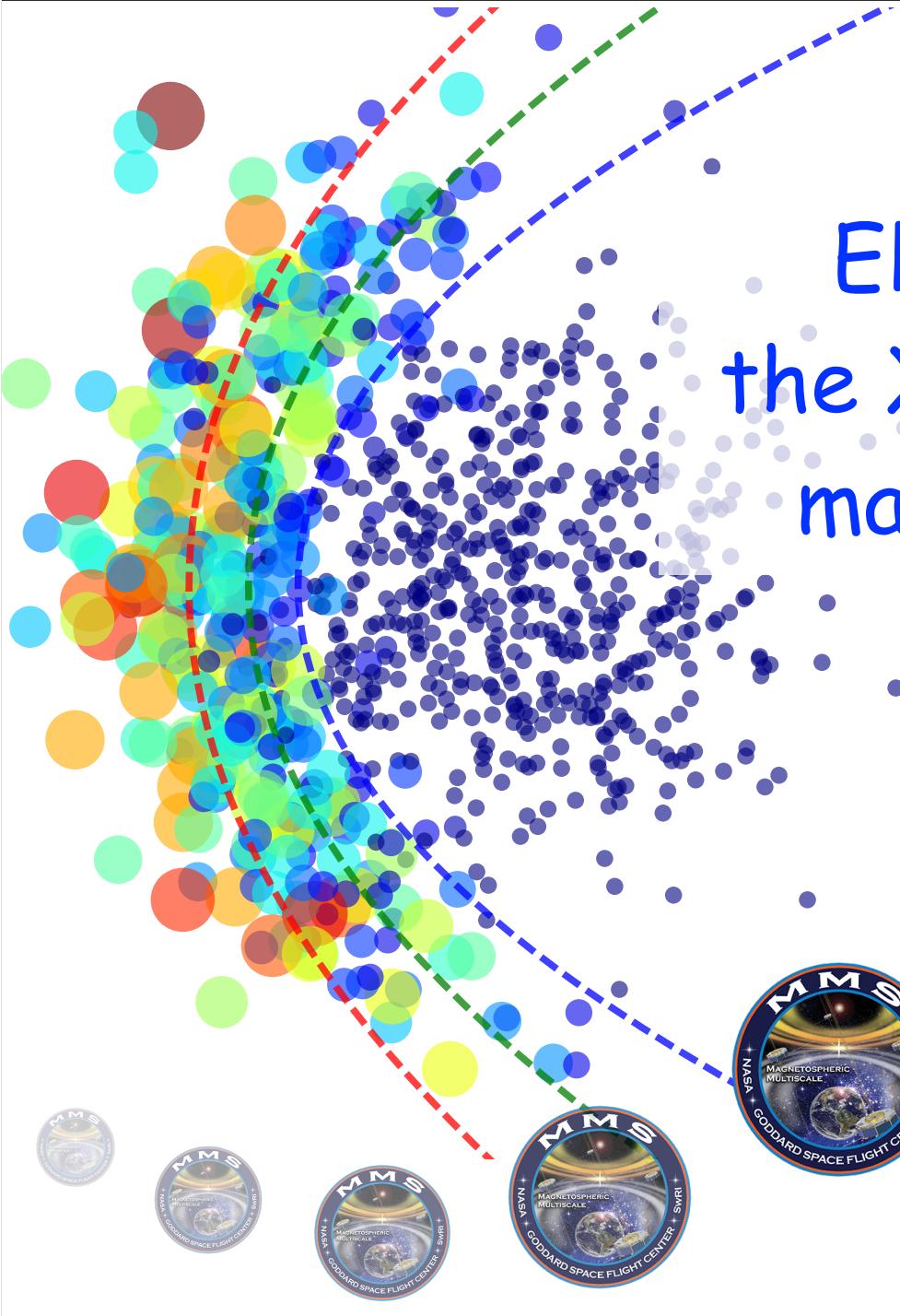


07-8



# Electron physics near the X line in asymmetric magnetic reconnection

Seiji ZENITANI

Kobe University

Hiroshi HASEGAWA  
Tsugunobu NAGAI

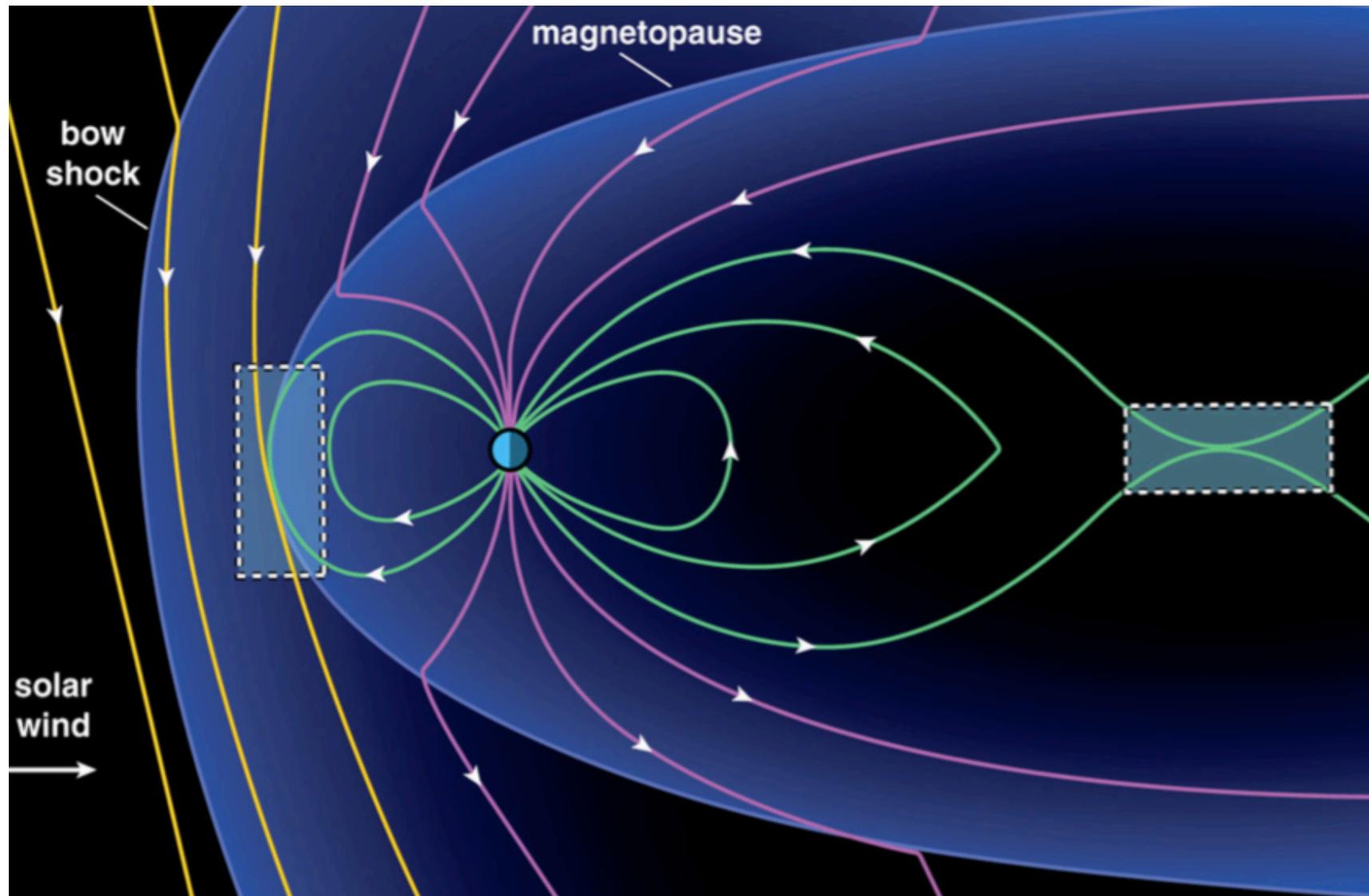
JAXA/ISAS



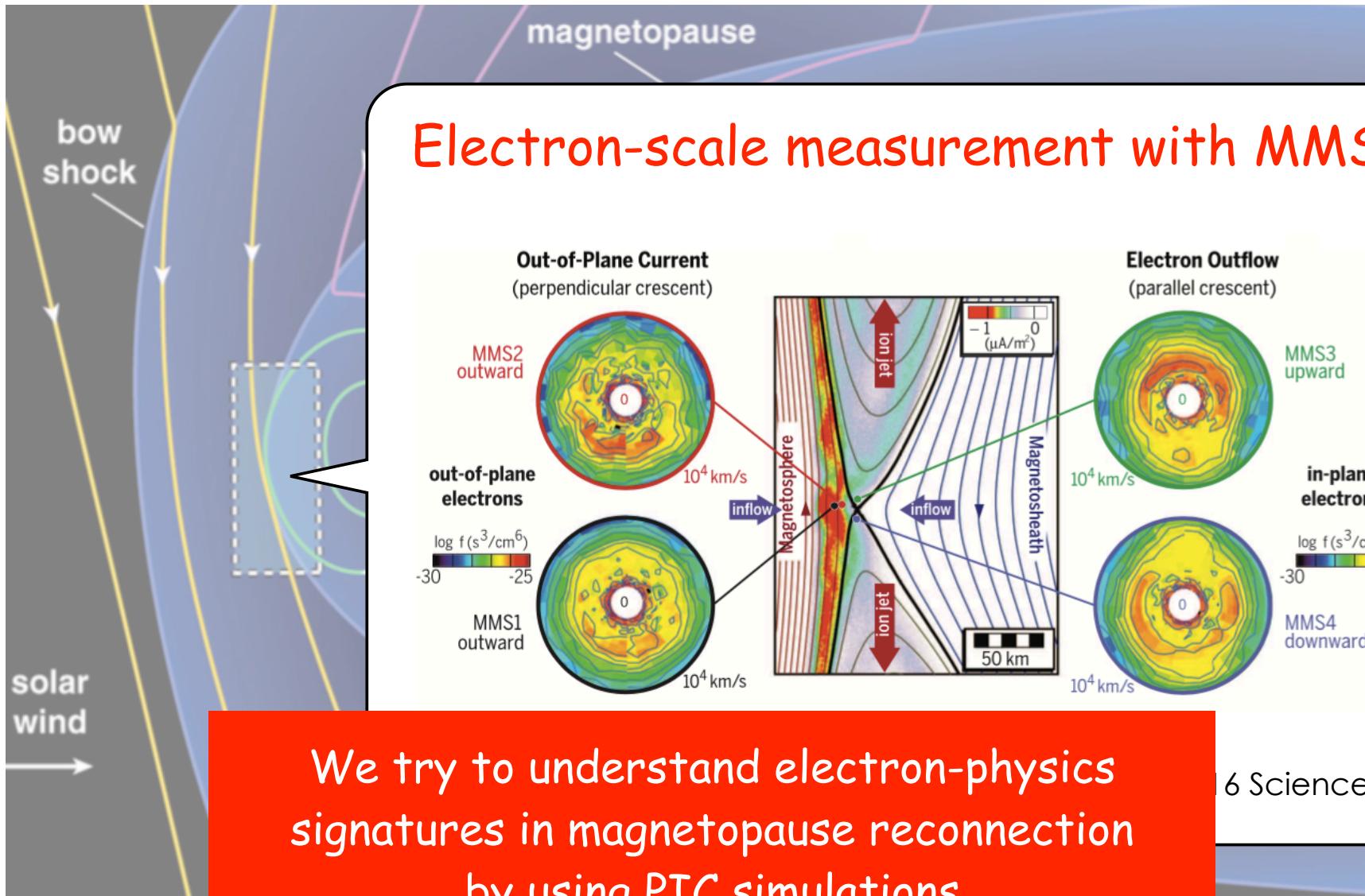
# Outline

- Introduction
- Asymmetric reconnection (2-D PIC simulation)
  - 1. Crescent-shaped electron velocity distribution functions (VDFs)
  - 2. Sheath-side anomaly
  - 3. Outflow anomaly
- Asymmetric reconnection with a guide-field
  - 4. Shannon entropy for the sheath-side boundary layer
- Summary

# Magnetic reconnection in near-Earth space

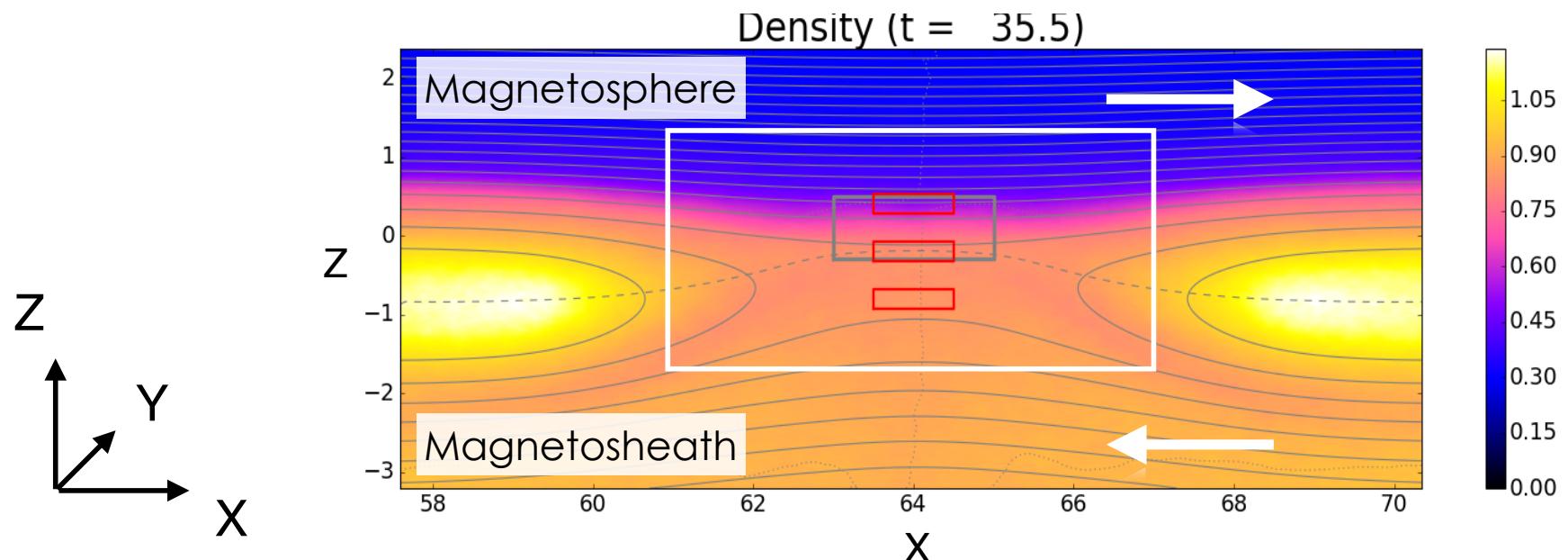


# Magnetic reconnection in near-Earth space



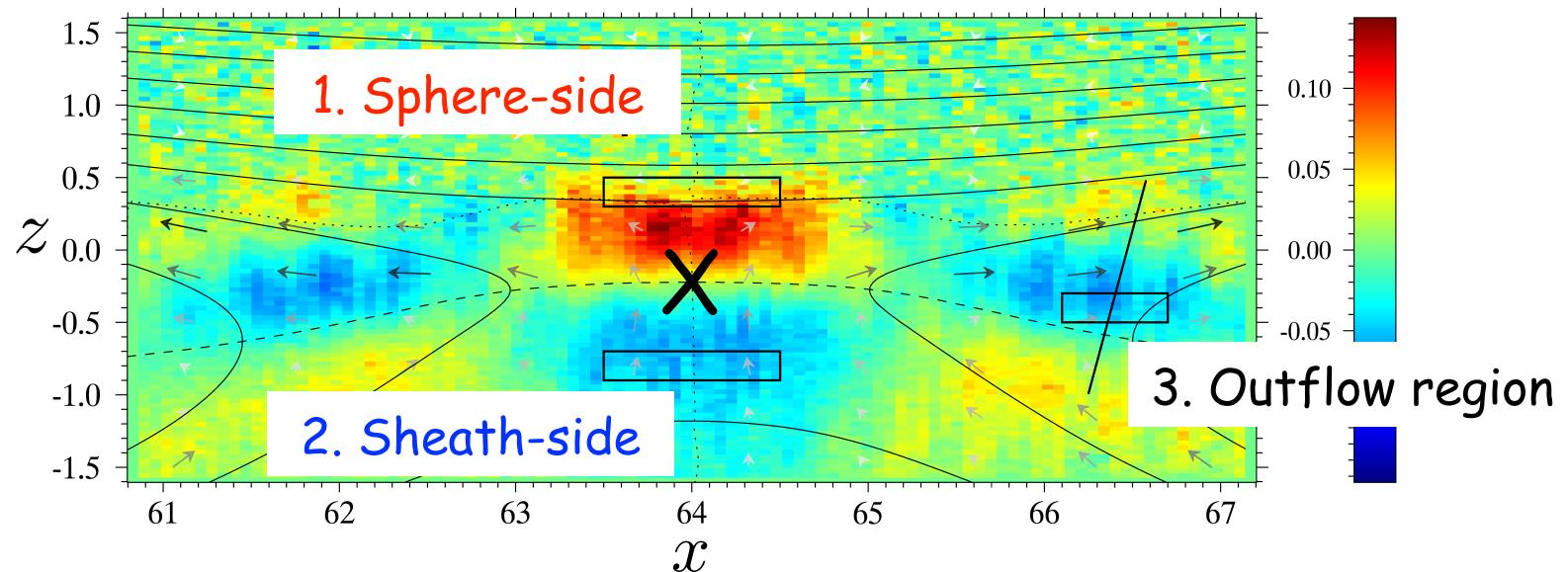
# 2-D particle-in-cell (PIC) simulation

- Asymmetry in plasma properties
  - Density variation  $n_1 : n_2 = 3 : 1$
  - Magnetic variation  $B_1 : B_2 = 1 : 3$
- Simulation parameters
  - $m_i : m_e = 25 : 1$
  - Domain size:  $128.0 \times 25.6 [d_i]$



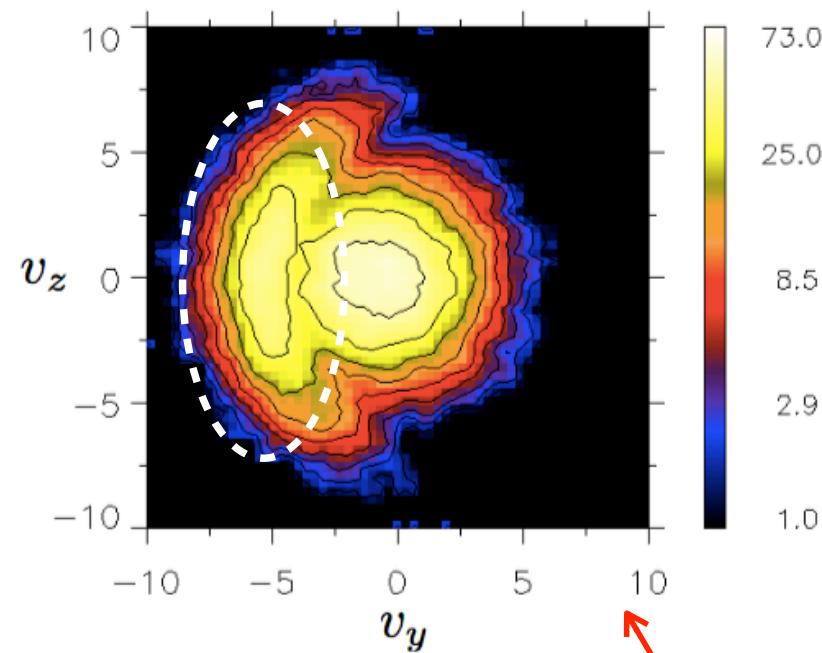
# Three features near the X line (electron diffusion region; EDR)

(c)  $E'_y = [\mathbf{E} + \mathbf{V}_e \times \mathbf{B}]_y$

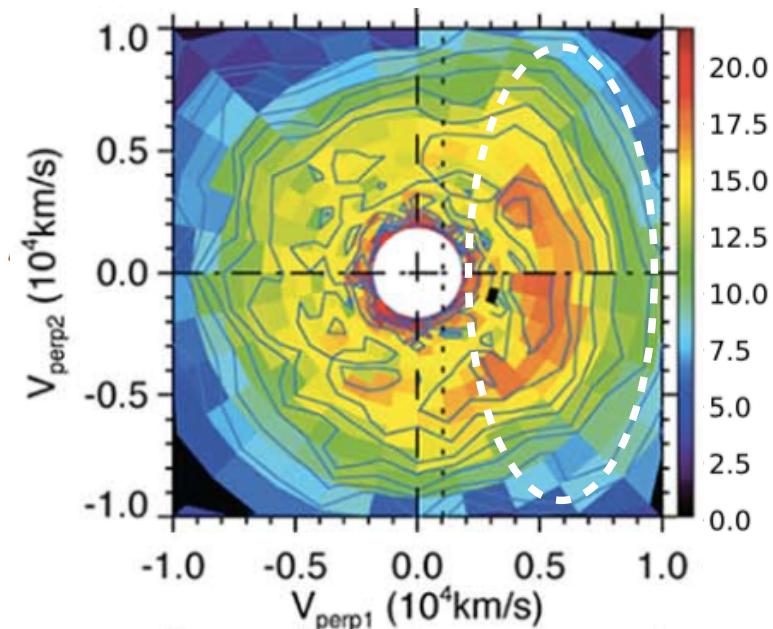


# 1. Sphere-side: Crescent-shaped VDFs

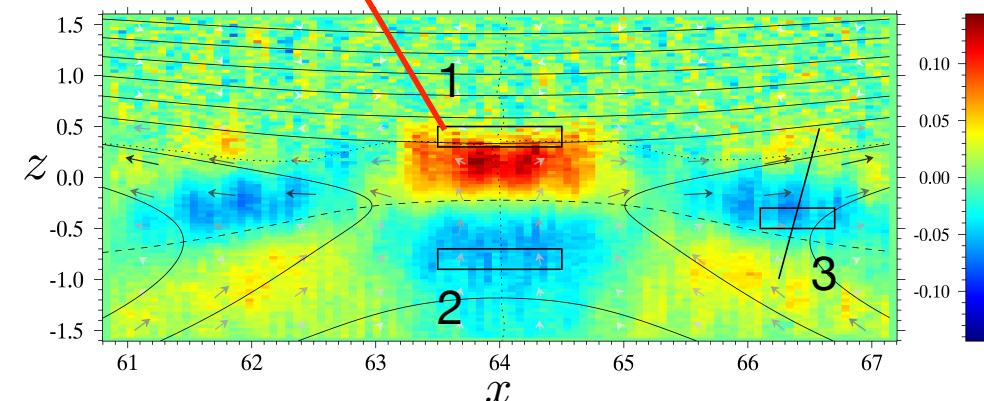
Our PIC simulation



MMS observation (Burch et al. 2016)



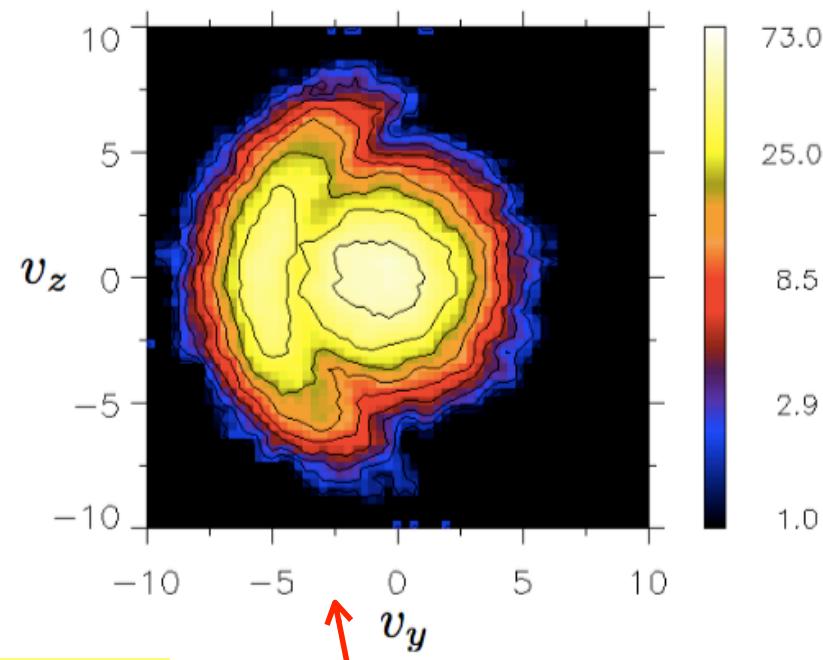
(c)  $E'_y$



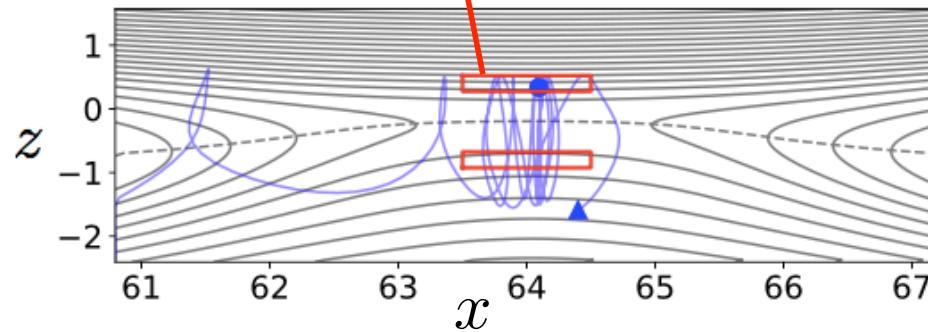
See also  
Hesse et al. 2014 GRL  
Bessho et al. 2016 GRL  
Shay et al. 2016 GRL

# Crescent-shaped VDFs = meandering electrons

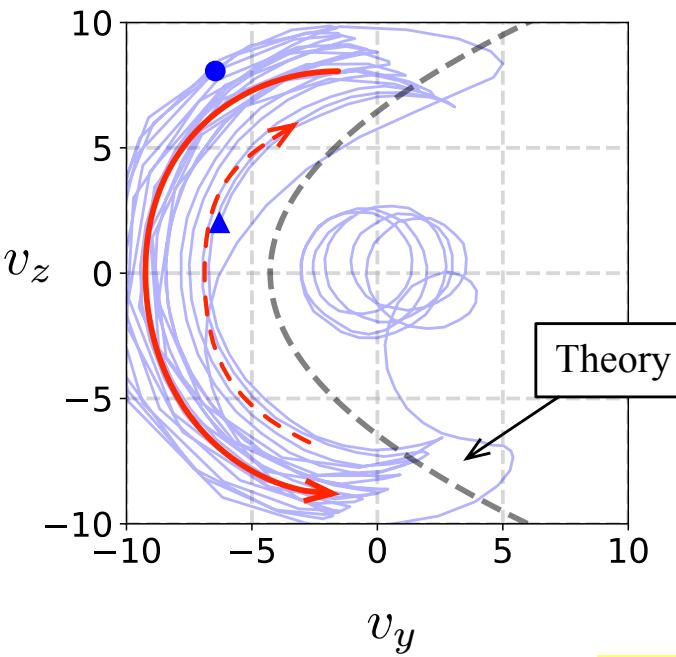
VDF: ensemble of particles



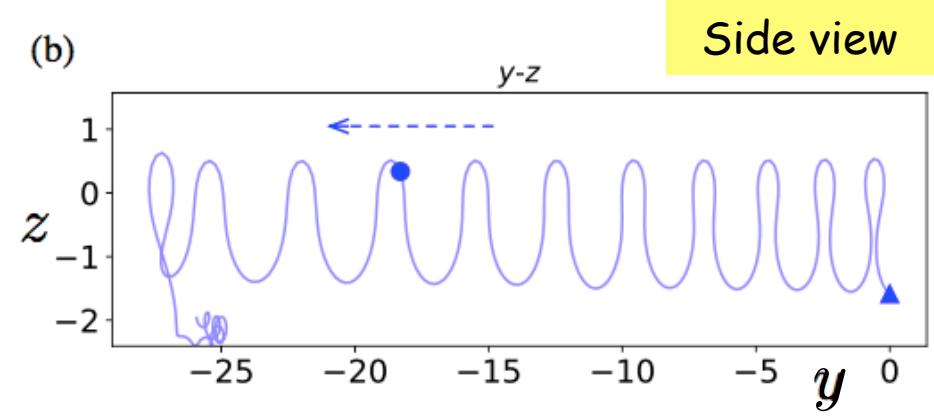
Front view



Orbit in the velocity space

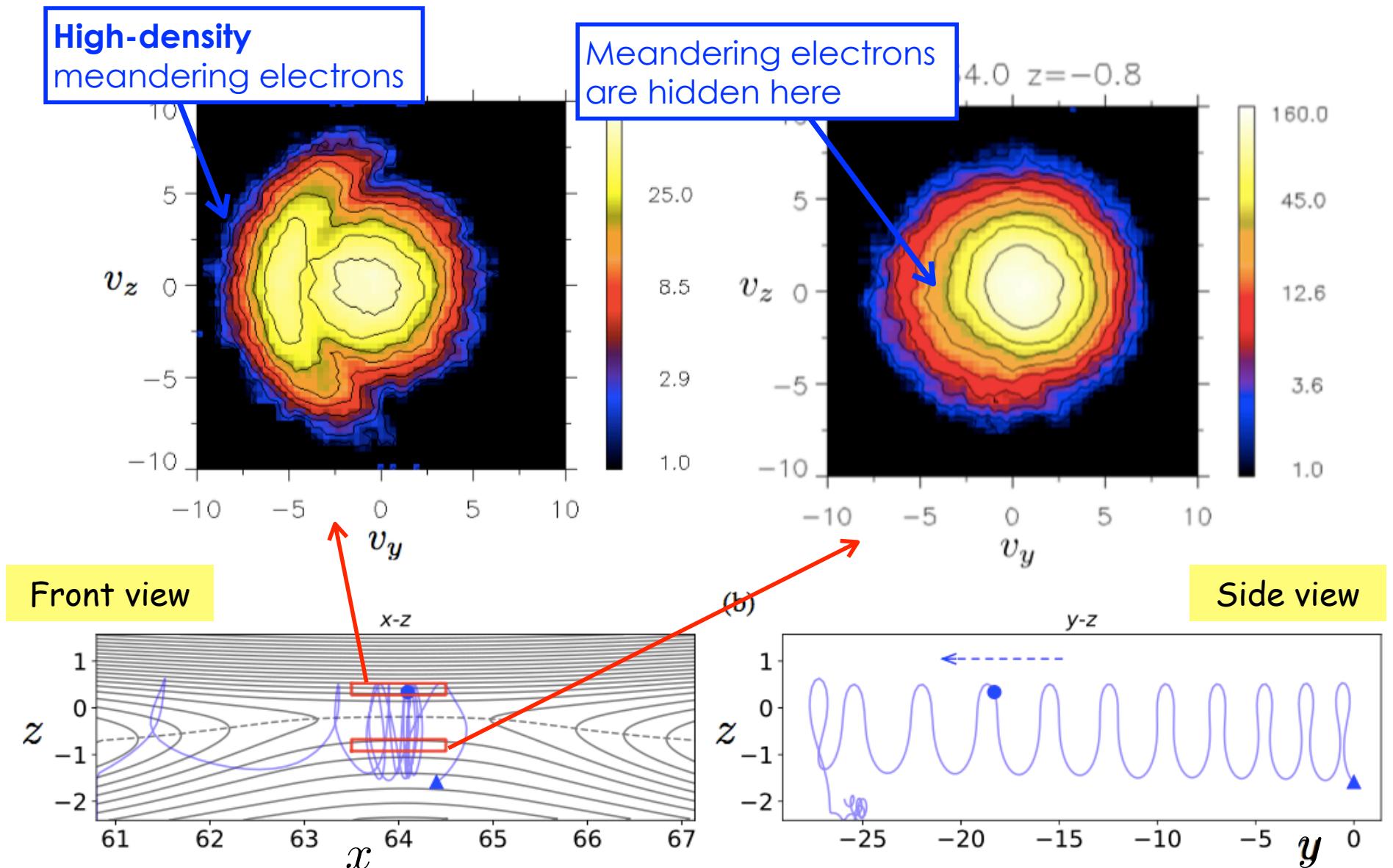


(b)

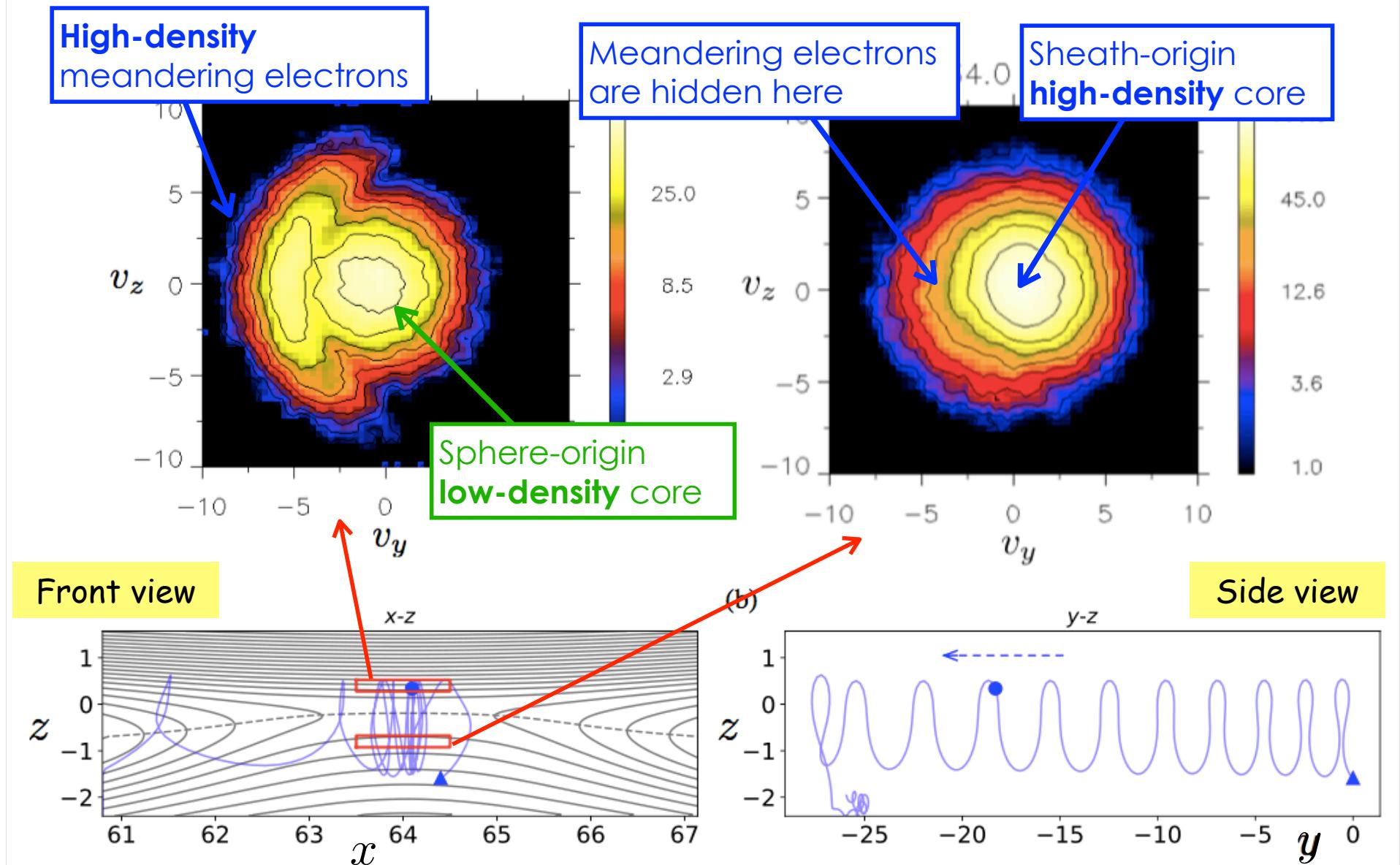


Side view

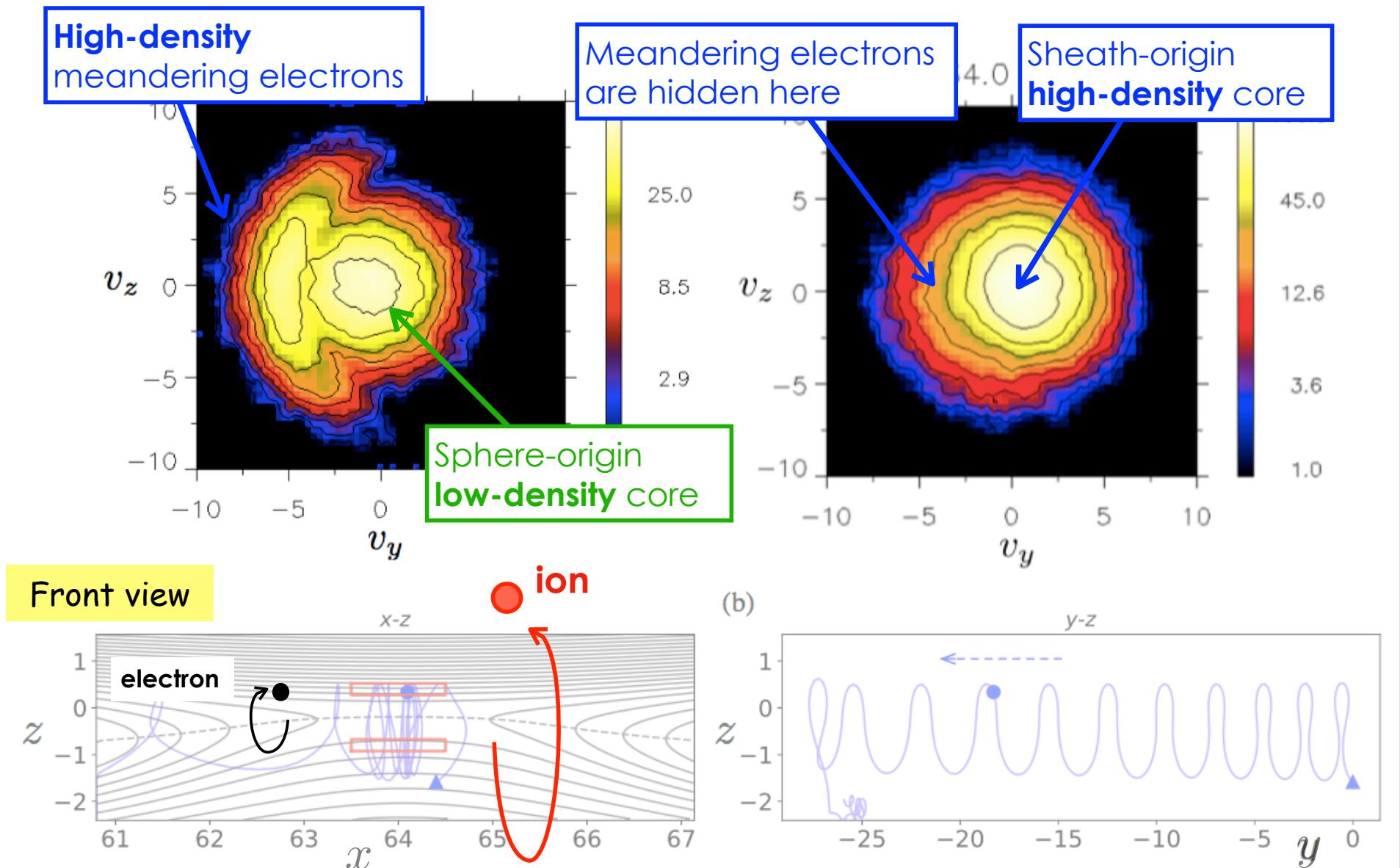
# Why is “crescent” clear in asymmetric RX? (1/2)



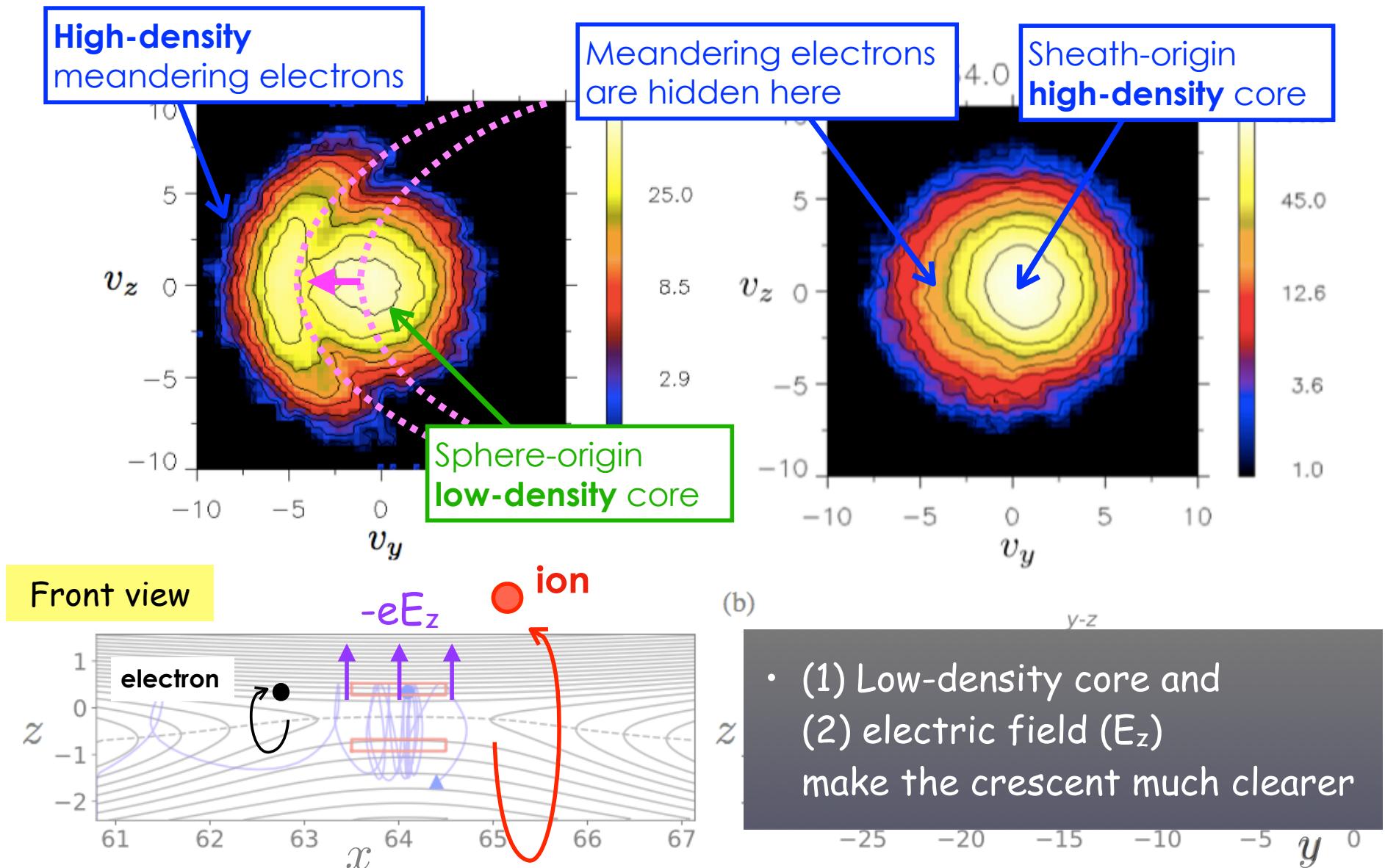
# Why is "crescent" clear in asymmetric RX? (1/2)



## Why is “crescent” clear in asymmetric RX? (2/2)

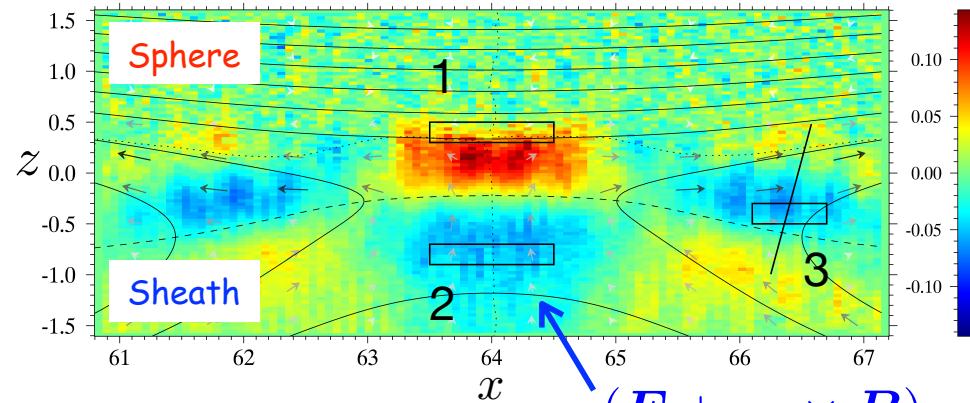


## Why is “crescent” clear in asymmetric RX? (2/2)



## 2. Sheath-side anomaly

$$(c) E'_y = [E + \mathbf{V}_e \times \mathbf{B}]_y$$

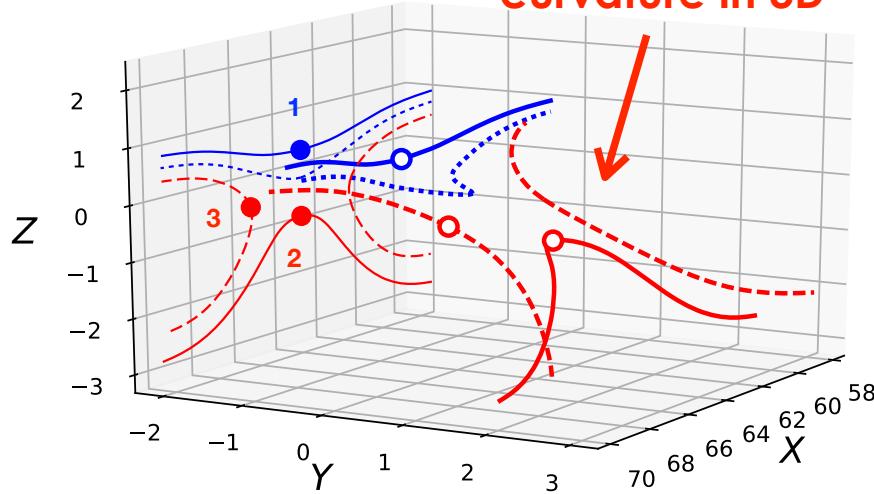


- In a well magnetized plasma, we expect an electron condition of

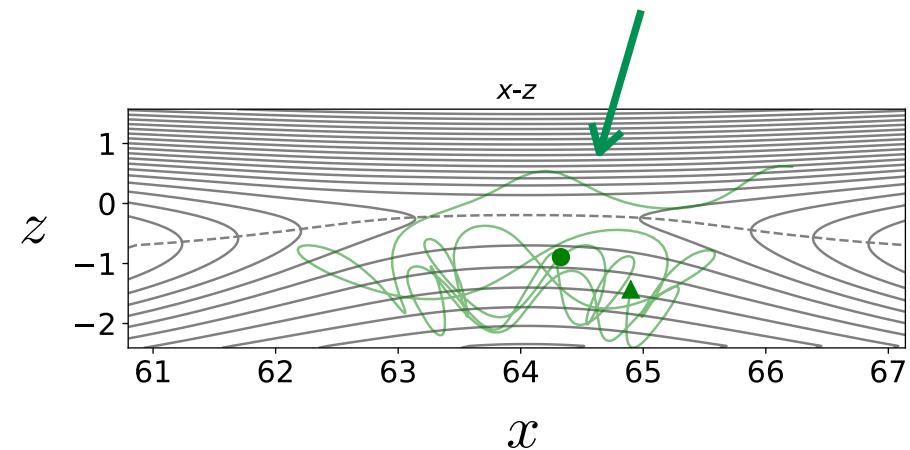
$$\mathbf{E} + \mathbf{v}_e \times \mathbf{B} \simeq 0$$

$$(\mathbf{E} + \mathbf{v}_e \times \mathbf{B})_y < 0$$

**Sharp magnetic curvature in 3D**

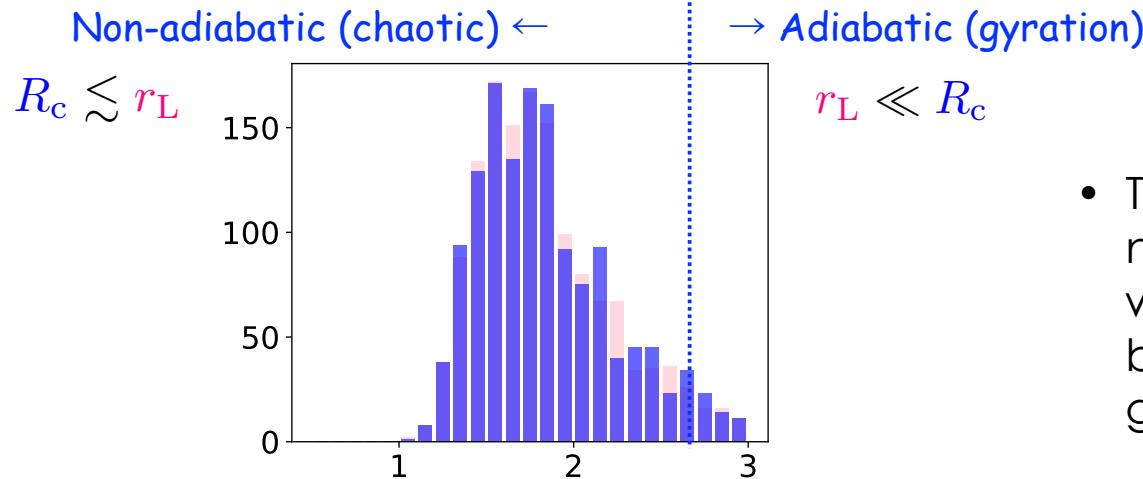
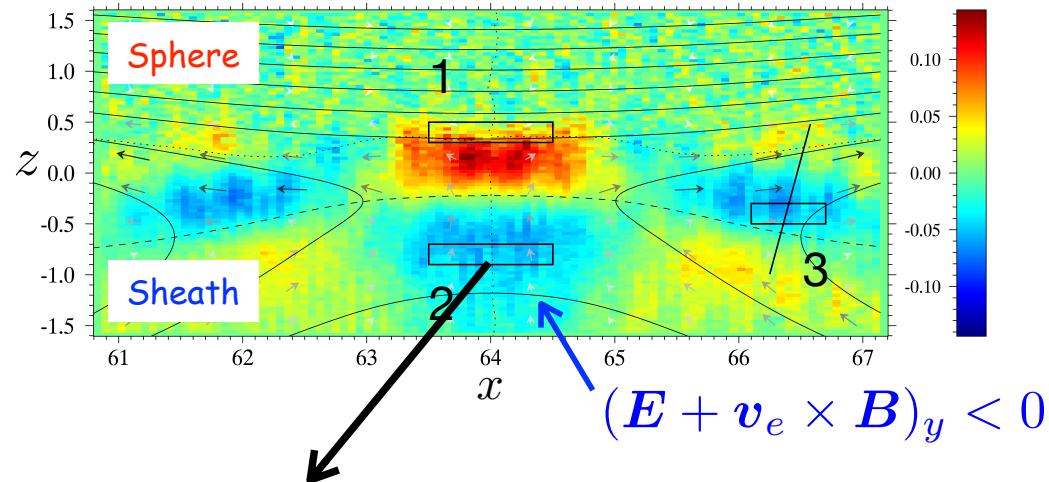


**Larger gyro radius due to weaker magnetic field**



# Sheath-side anomaly: curvature parameter

$$(c) E'_y = [E + \mathbf{v}_e \times \mathbf{B}]_y$$



- The region is largely filled with non-adiabatic electrons, whose chaotic motion is beyond the scope of the guiding-center approximation.

$$\mathbf{E} + \mathbf{v}_e \times \mathbf{B} \neq 0$$

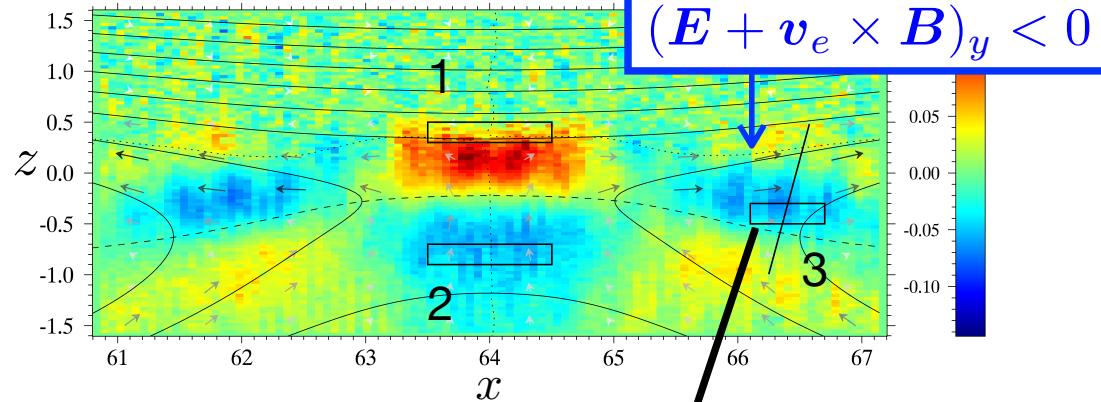
Buchner & Zelenyi  
1989, 1991

$$\kappa \equiv \sqrt{\frac{R_c}{r_L}}$$

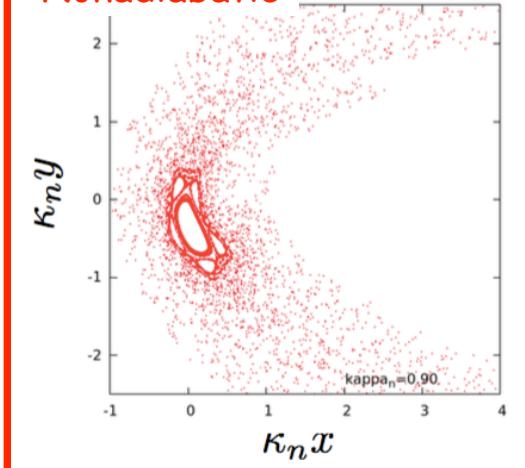
Magnetic curvature radius  
Larmor radius

### 3. Outflow anomaly

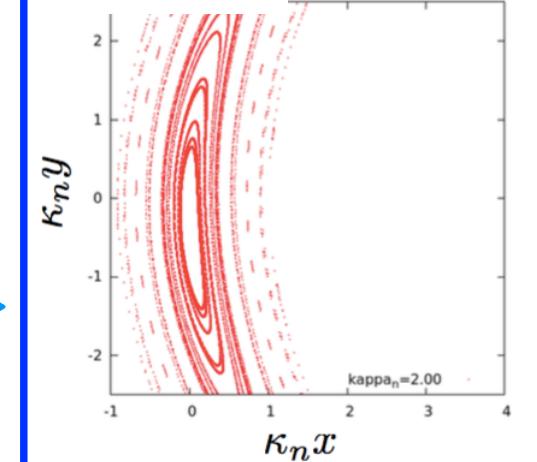
(c)  $E'_y = [\mathbf{E} + \mathbf{V}_e \times \mathbf{B}]_y$



Nonadiabatic



Adiabatic

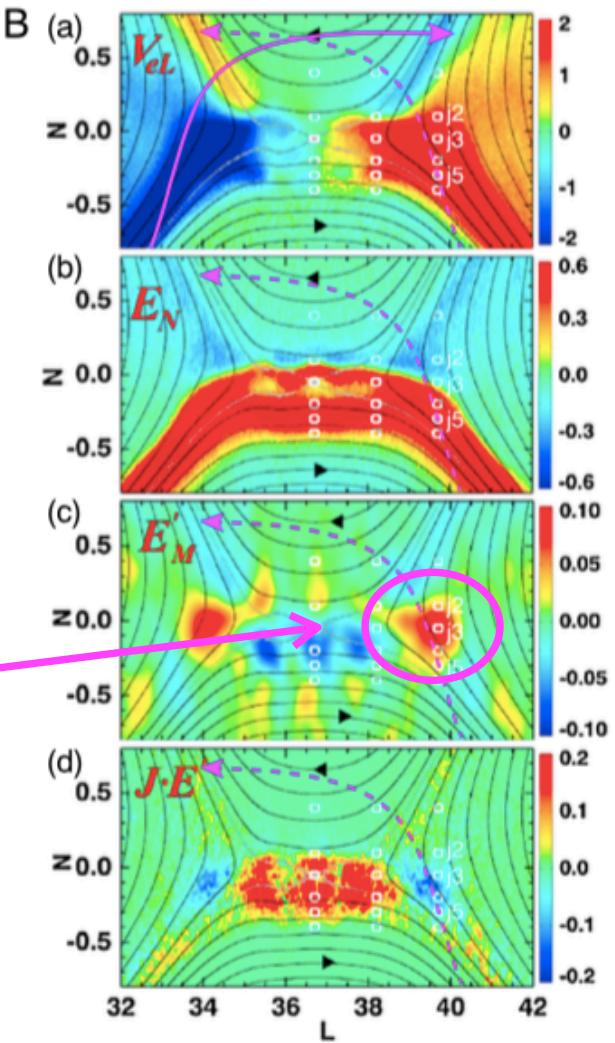
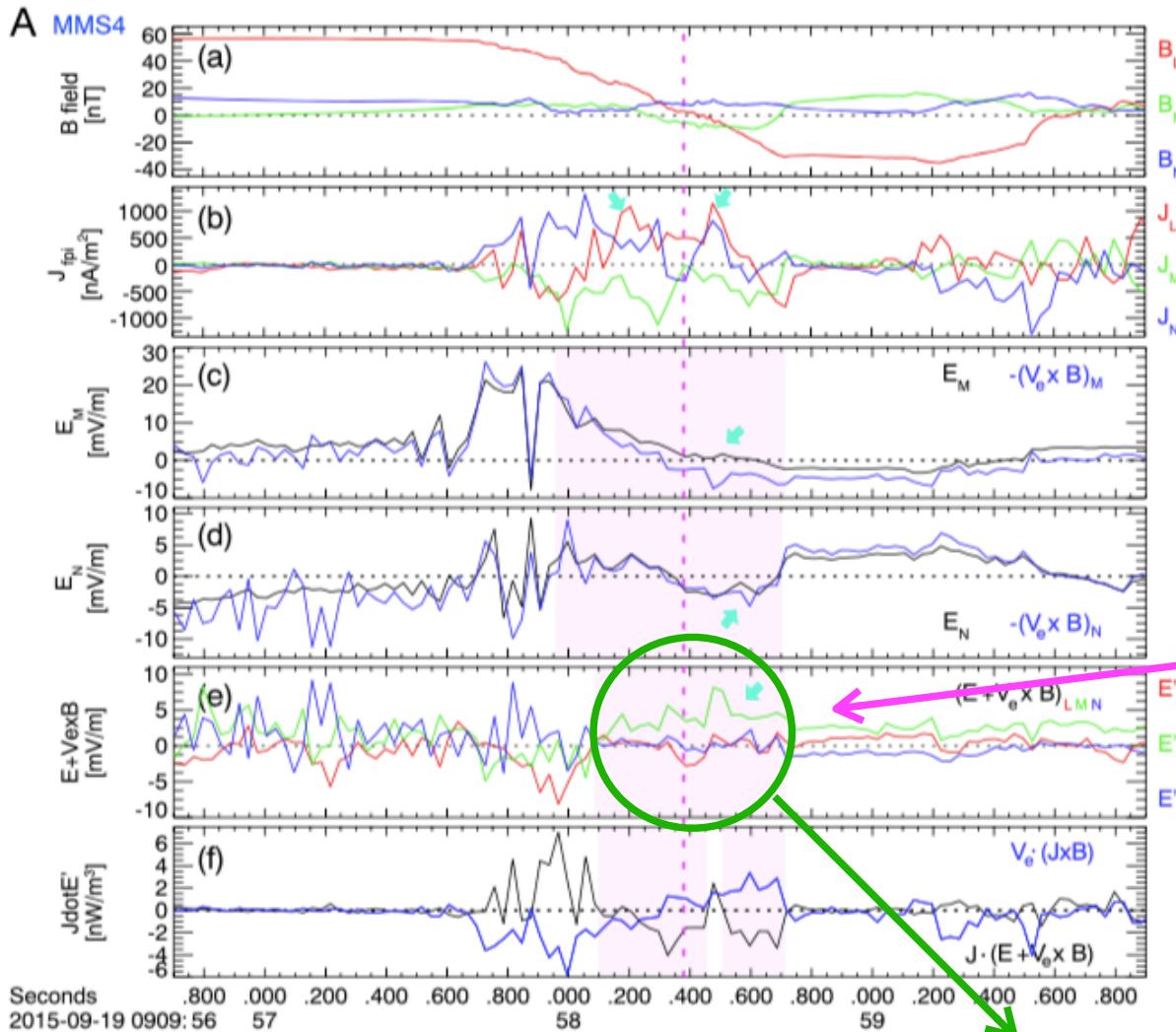


$$\kappa \equiv \sqrt{\frac{R_c}{r_L}}$$

Magnetic curvature radius  
Larmor radius

Chaotic electron motion no longer guarantees  $(\mathbf{E} + \mathbf{V}_e \times \mathbf{B}) = 0$

# Outflow anomaly: MMS4 observation



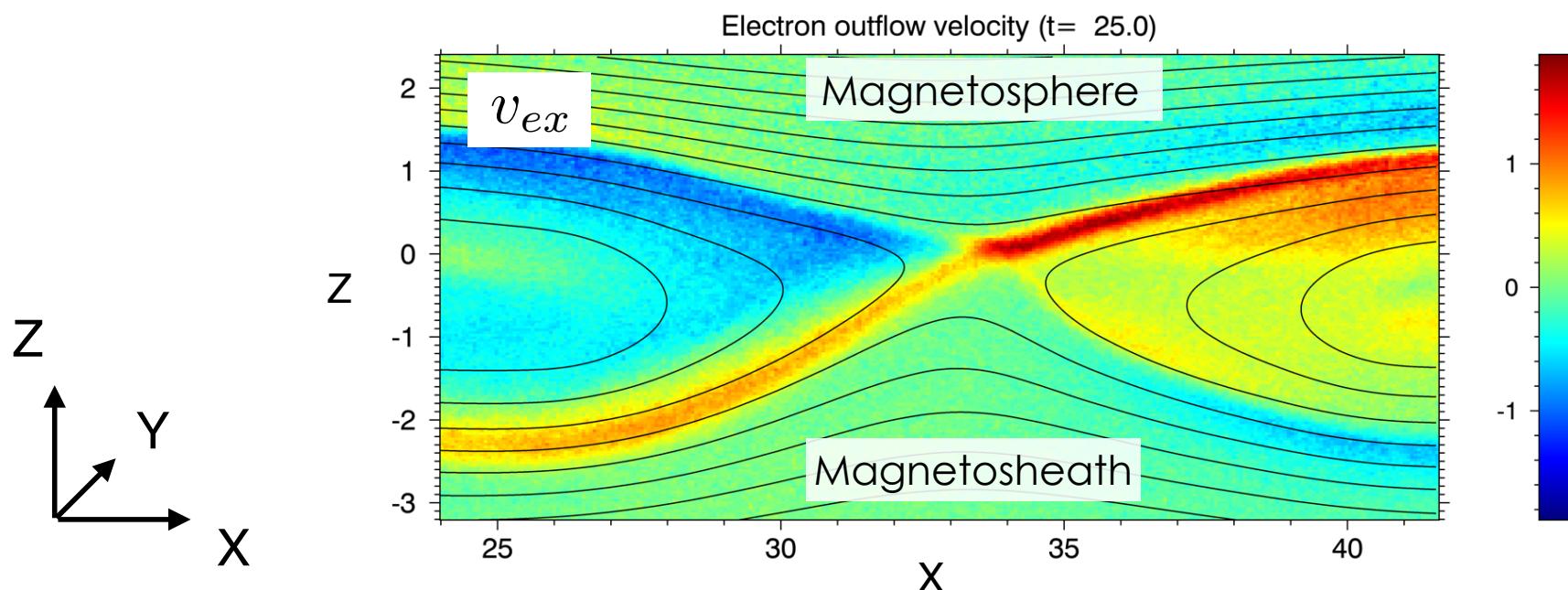
$$E + v_e \times B \neq 0$$

Hwang+ 2017 GRL

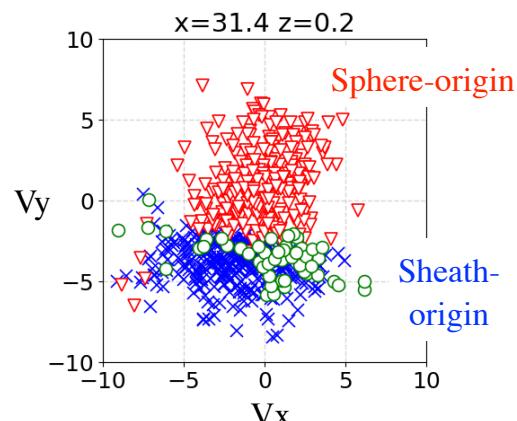
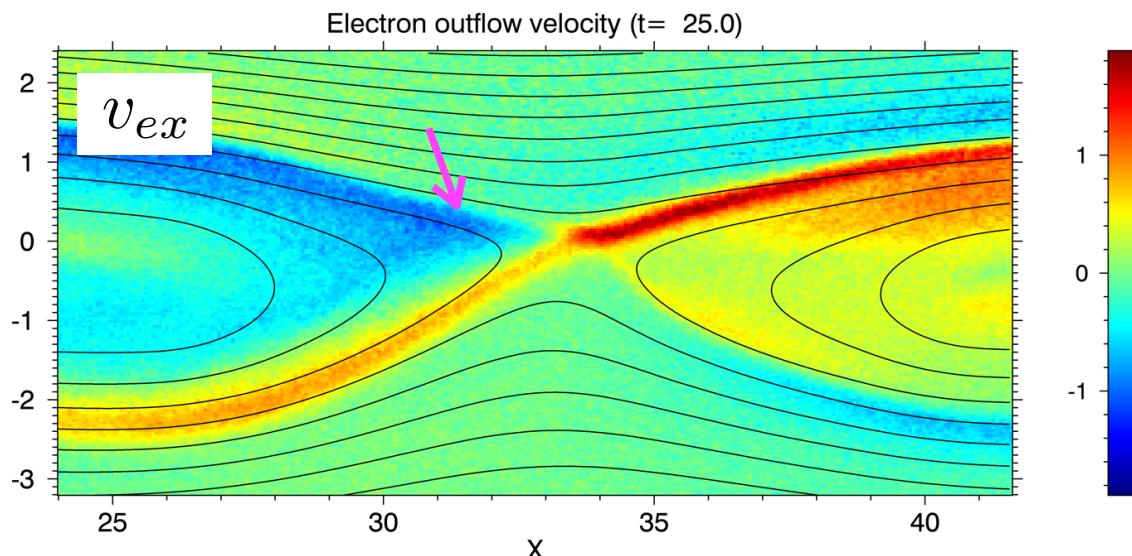
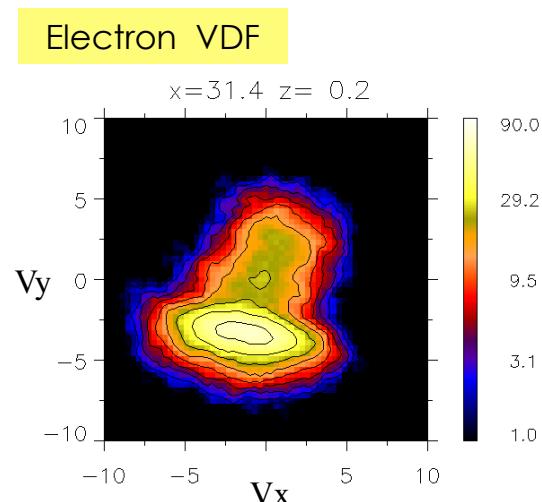
# Asymmetric reconnection with a guide-field

- Asymmetry in plasma properties
  - Density variation  $n_1 : n_2 = 3 : 1$
  - Magnetic variation  $B_1 : B_2 = 1 : 3$
- Simulation parameters
  - $m_i : m_e = 25 : 1$

$\otimes B_y$  Guide field



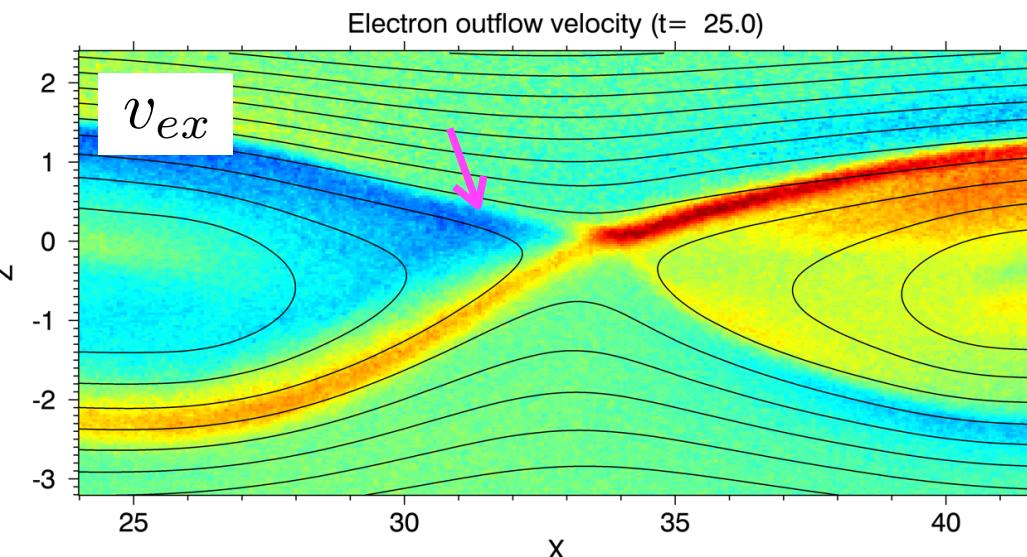
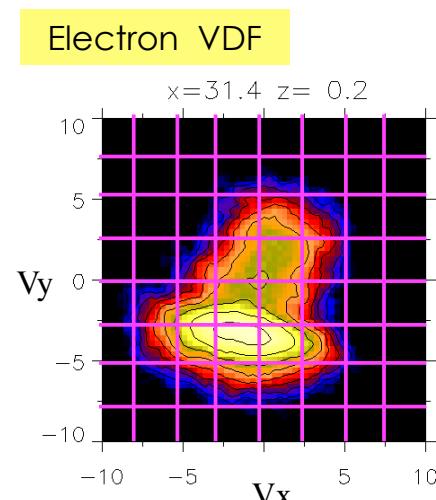
# Unmixed electron VDF



PIC data

- On the magnetosheath-side boundary, sphere/sheath-origin electrons are separate in the velocity space (Hesse+ 2017 PRL)

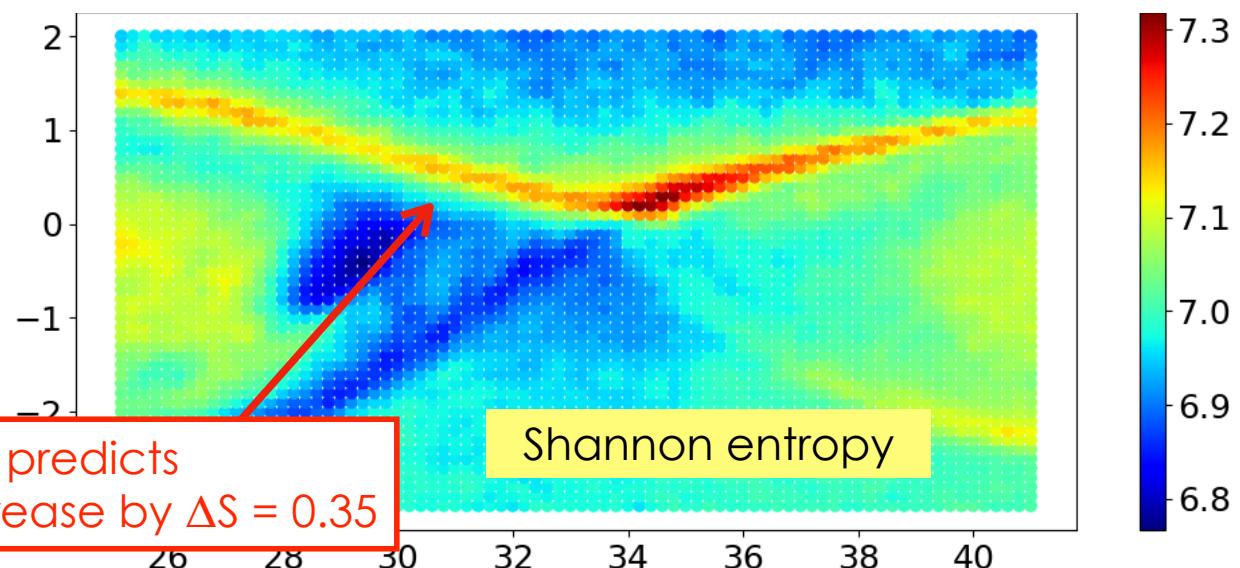
# Shannon entropy of electron VDF



$$-\sum_i p_i \log p_i$$

$p_i$ : probability in the 3D velocity space

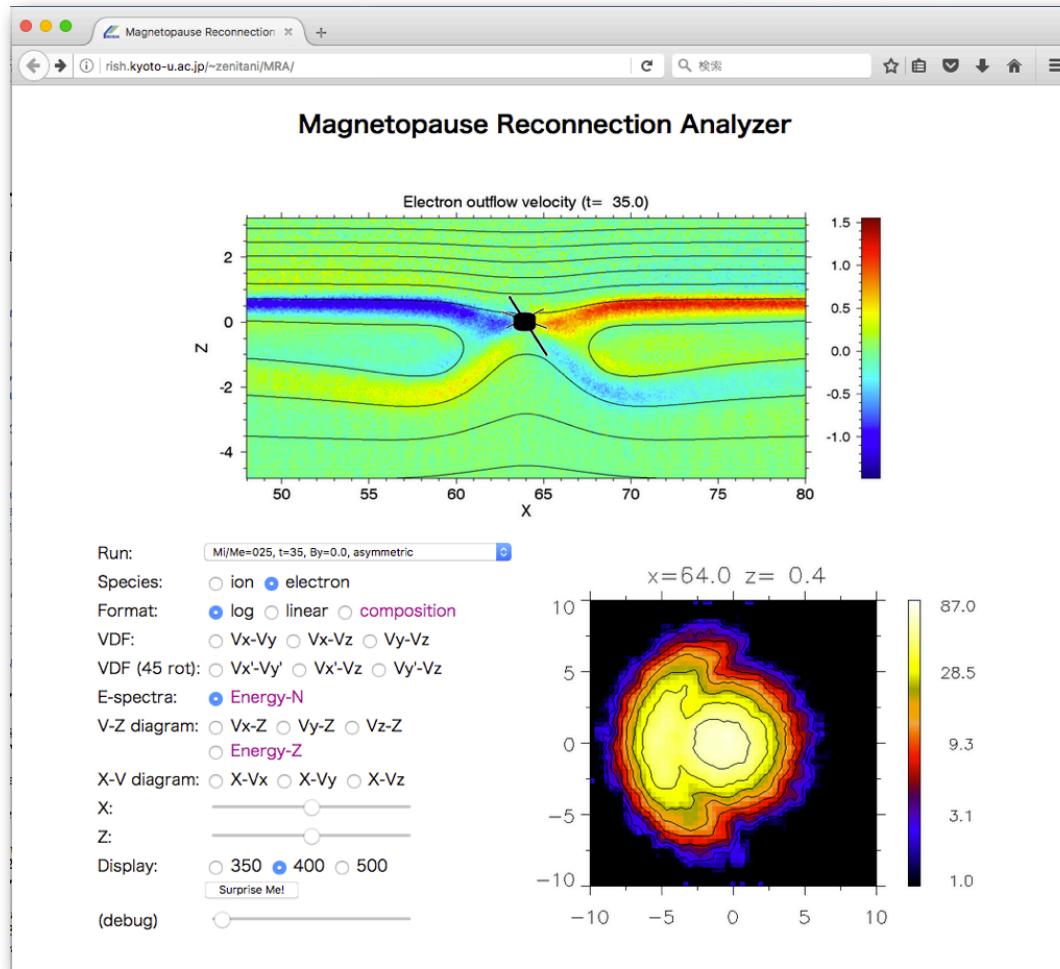
Theory predicts  
an increase by  $\Delta S = 0.35$



# Summary

- Asymmetric reconnection (2-D PIC simulation)
  - 1. Crescent-shaped electron VDFs, due to meandering electrons
  - 2. Sheath-side anomaly
  - 3. Outflow anomaly
- Asymmetric reconnection with a guide-field
  - 4. Shannon entropy for the sheath-side boundary layer with unmixed electron populations
- Reference:
  - Zenitani, Hasegawa, & Nagai (2017), *J. Geophys. Res. Space Physics*, **122**, 7396-7413, doi:10.1063/1.4963008

# Electron VDFs in our PIC simulation



- We have uploaded 70,000 ion/electron VDFs
- Click a link in our abstract: <http://rish.kyoto-u.ac.jp/~zenitani/MRA/>