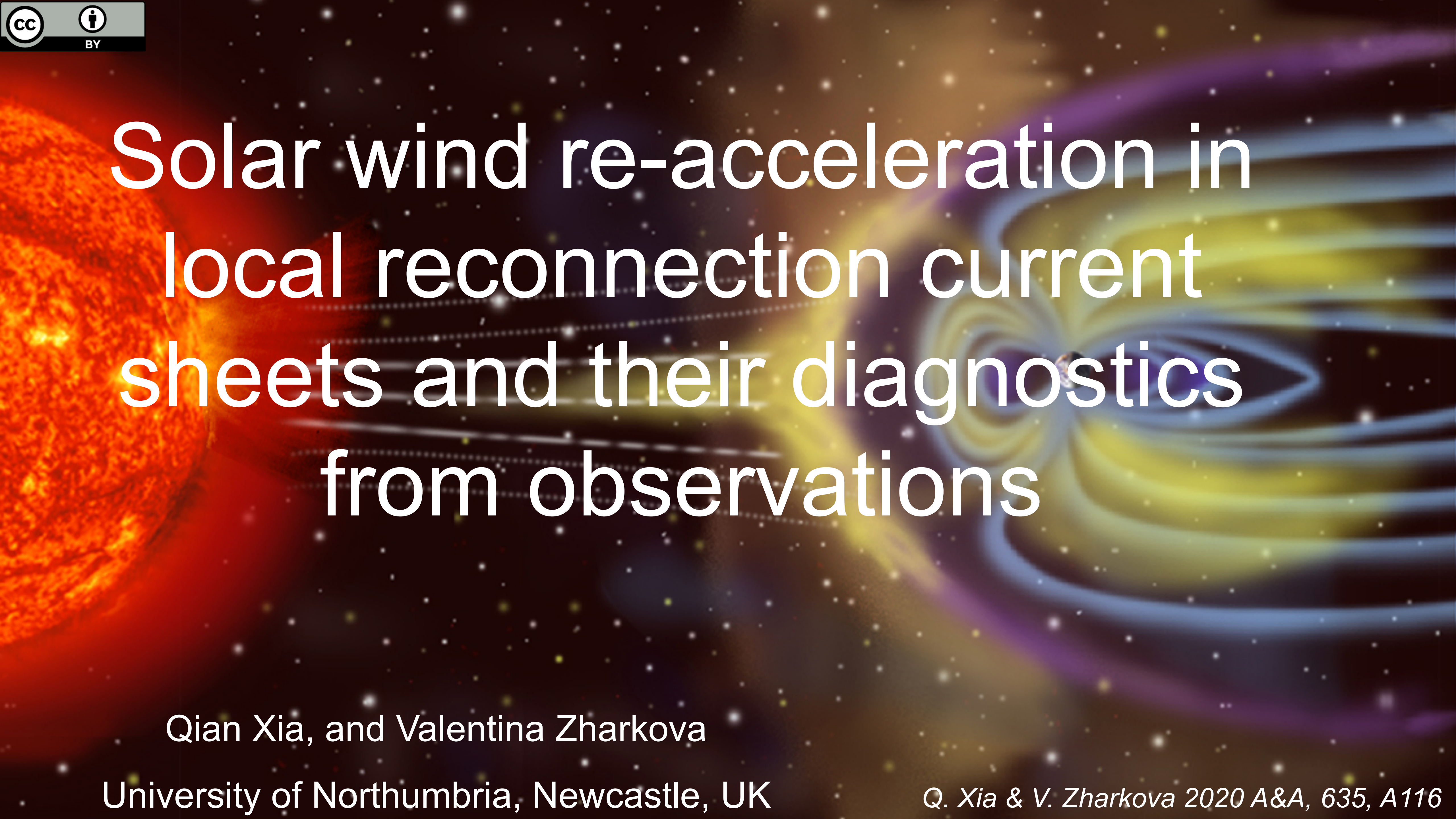
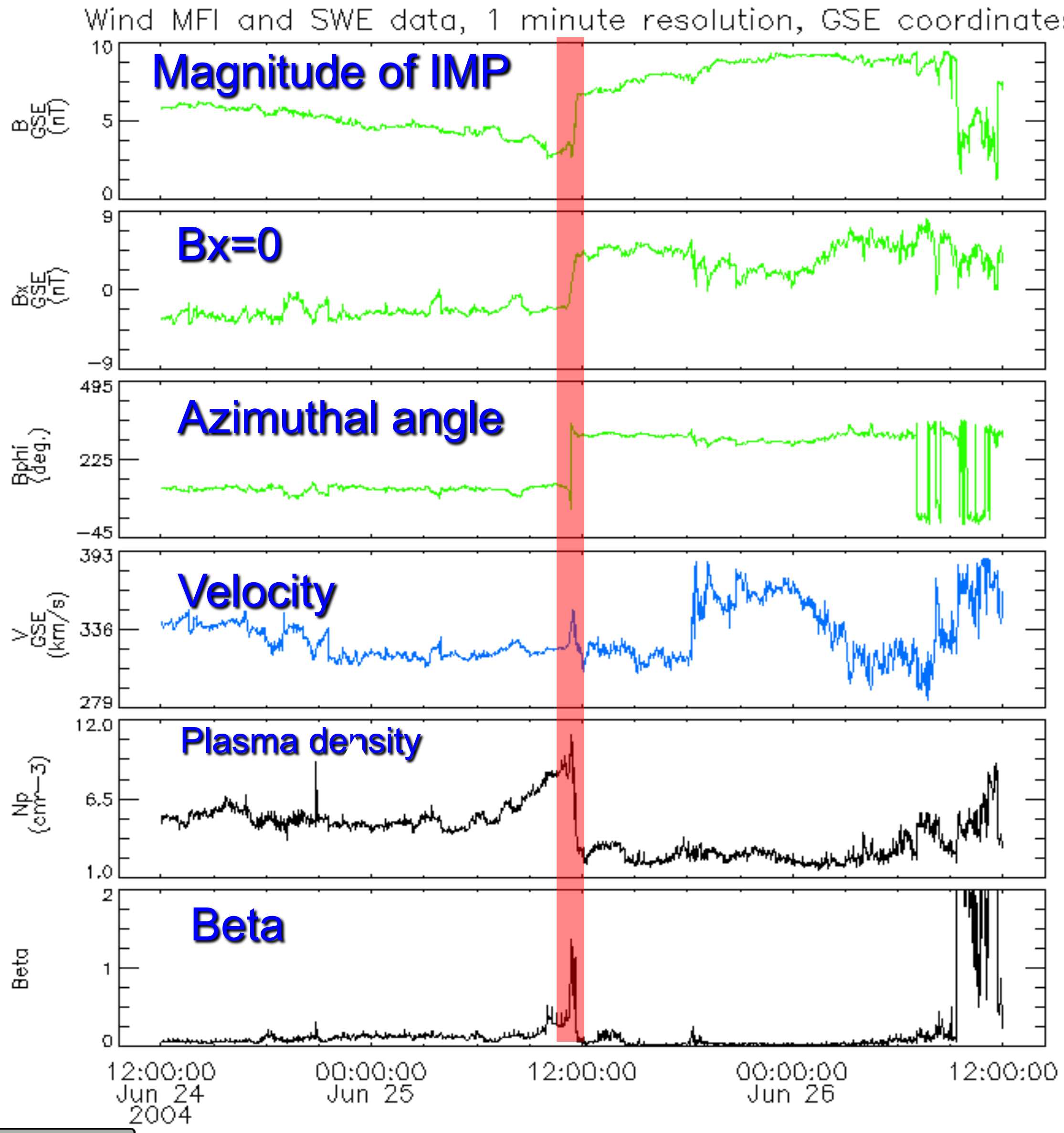


Solar wind re-acceleration in local reconnection current sheets and their diagnostics from observations

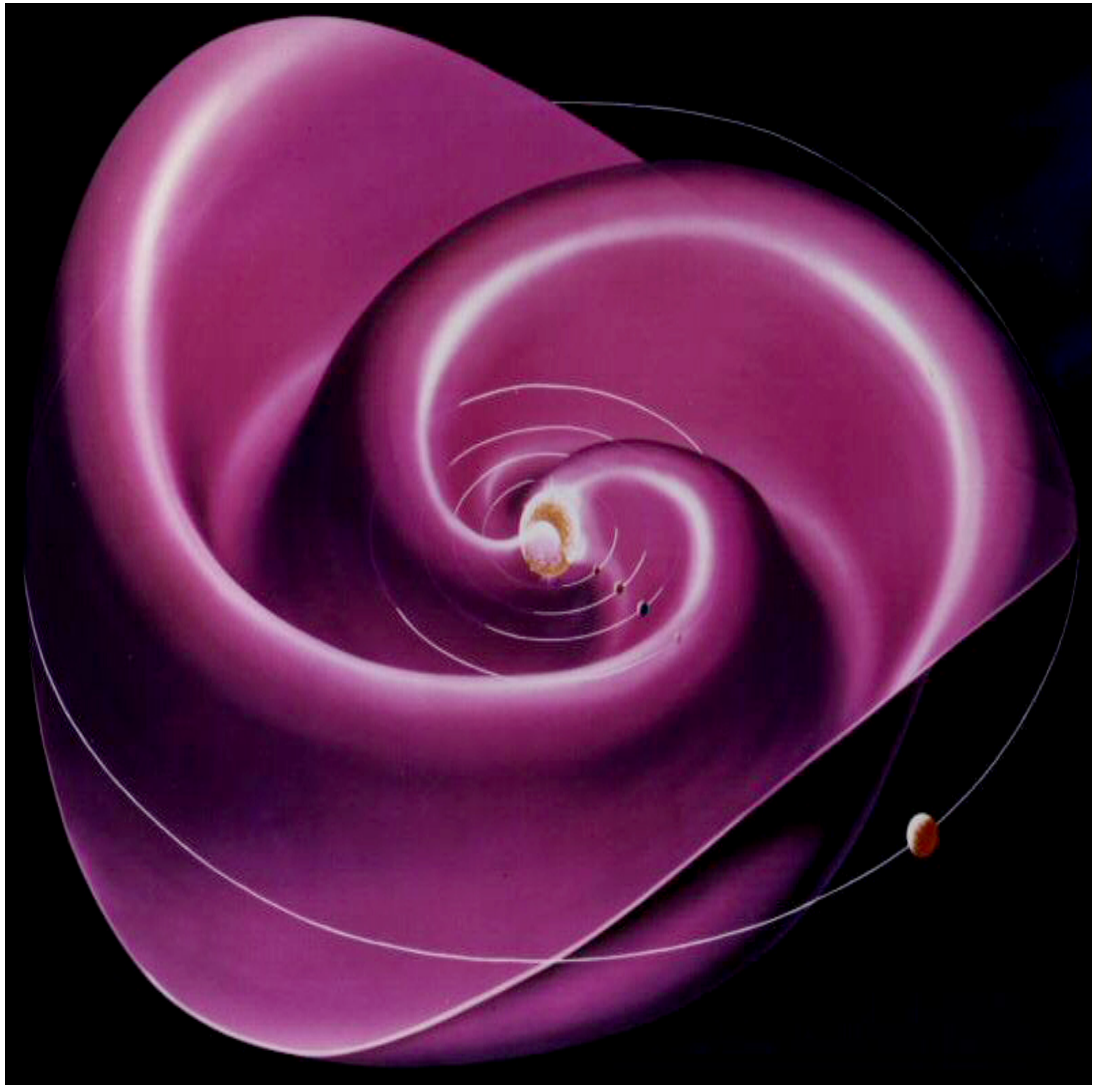
Qian Xia, and Valentina Zharkova

University of Northumbria, Newcastle, UK

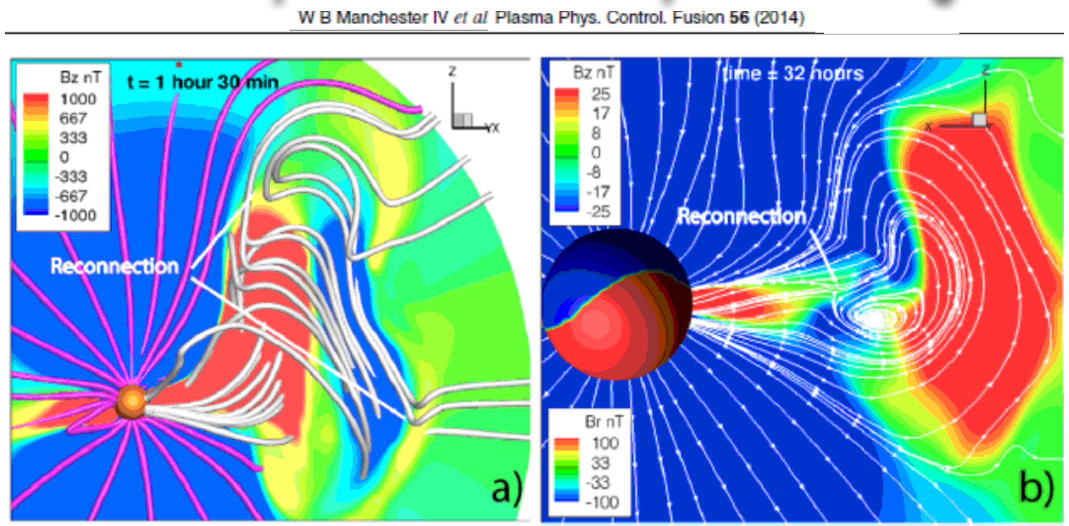
Q. Xia & V. Zharkova 2020 A&A, 635, A116

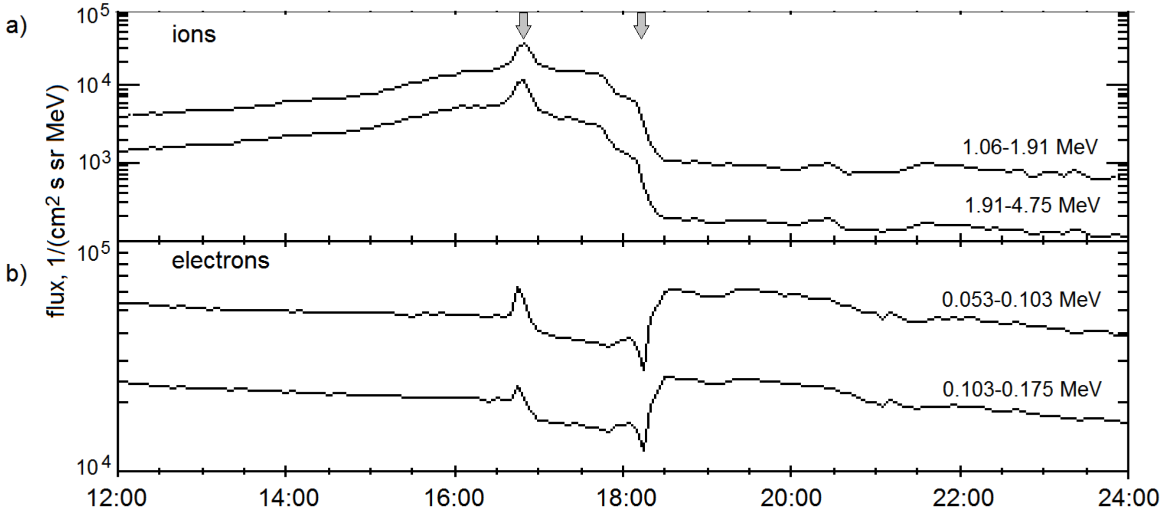


Zharkova & Khabarova, 2012



Solar wind particles passing ICME





Flux of energetic particles of different energies from ACE EPAM

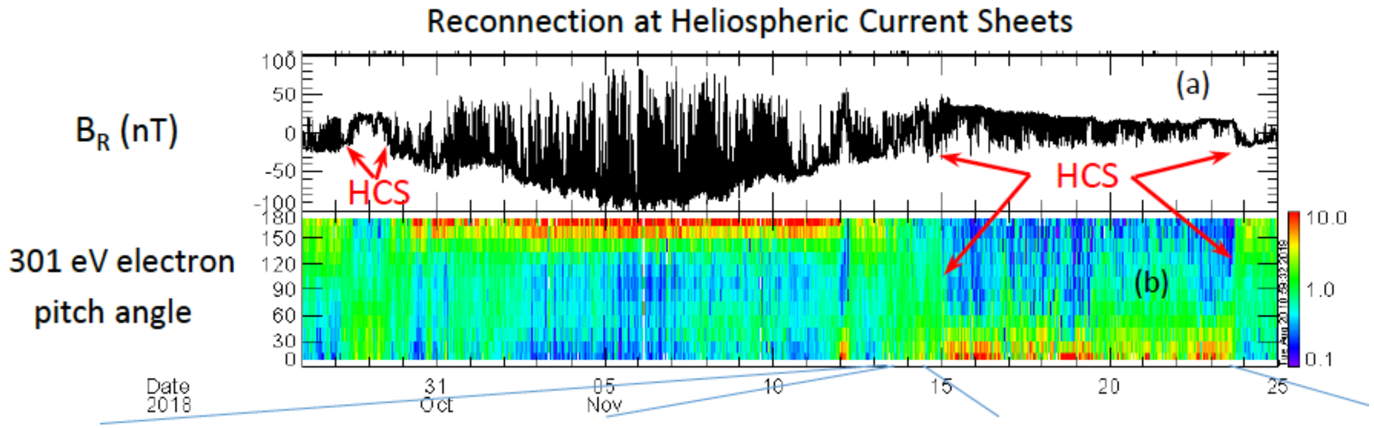
at the leading edge of an ICME;

- Sometimes
- Energetic particles stream perpendicular to IMF
- Electrons travels towards the Sun

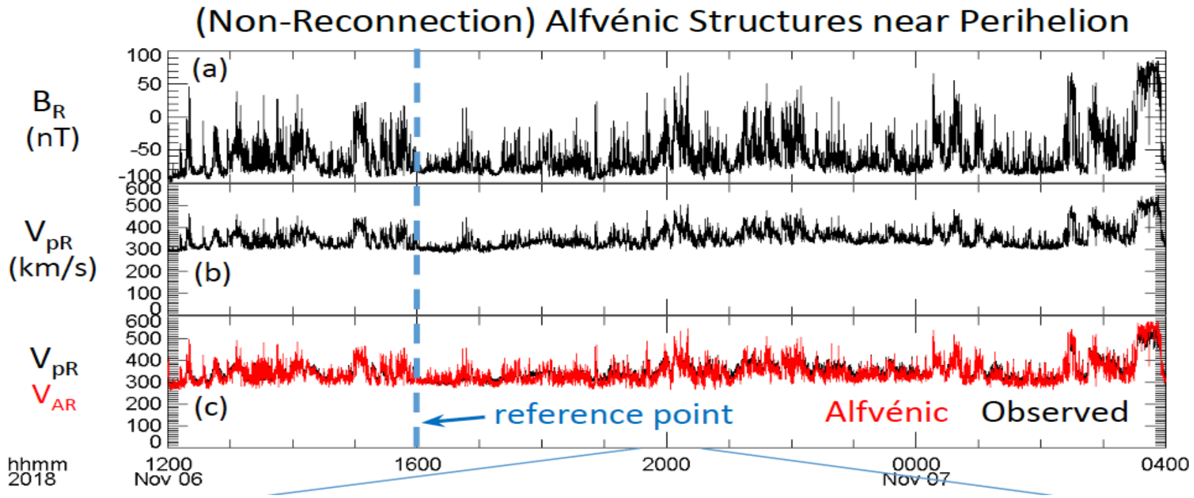
behind the ICME

Parker Solar Probe

Reconnection

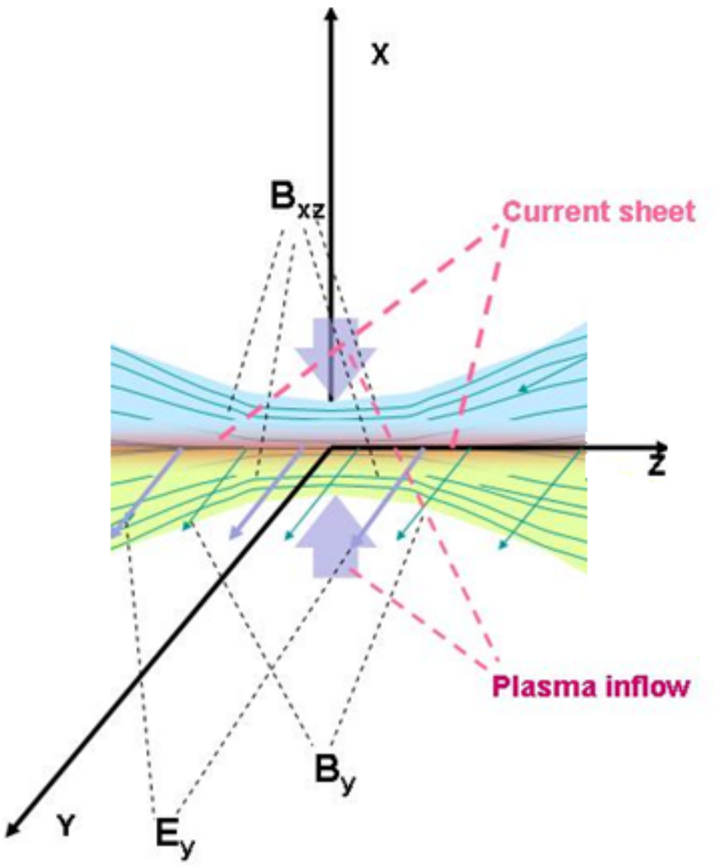


Alfvenic



T.D. Phan, et al, ApJS 2019

Physical model of current sheet



Zharkova and Khabarova, 2012, ApJ, 752, 35; 2015, Ann Geo, 33, 457

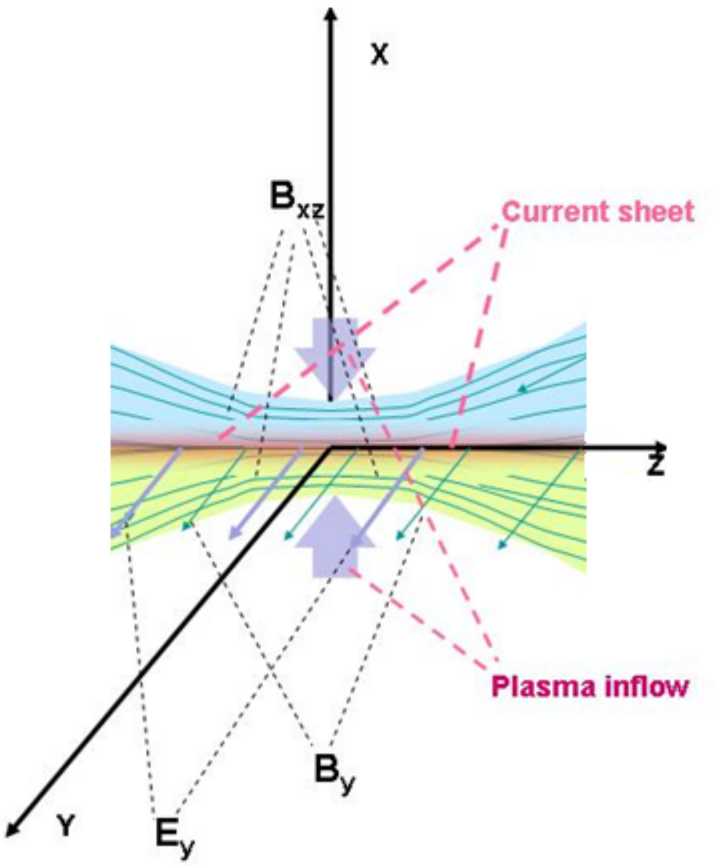
- Consider the RCS with ongoing a magnetic reconnection, which creates a reconnection electric field

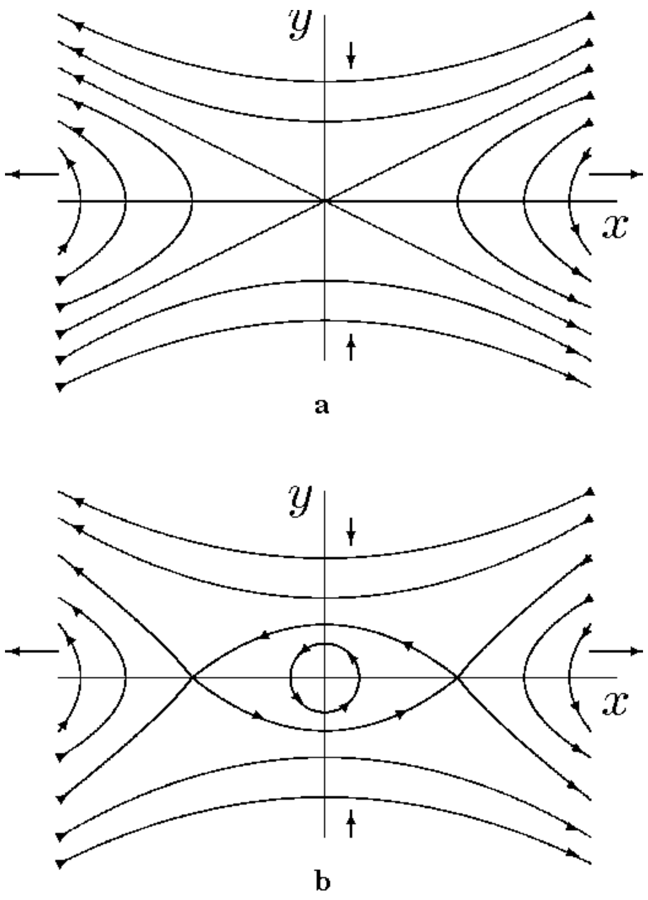
- current sheet thickness ~ proton gyroradius (10^4 km for HCS, as B_0 is reduced to from 10^{-2} to 10^{-9} T)

- Model region - 10-100 proton gyroradii from the both sides of the HCS

- Consider plasma feedback to presence of accelerated particles – induced electric and magnetic fields

Physical model of current sheet



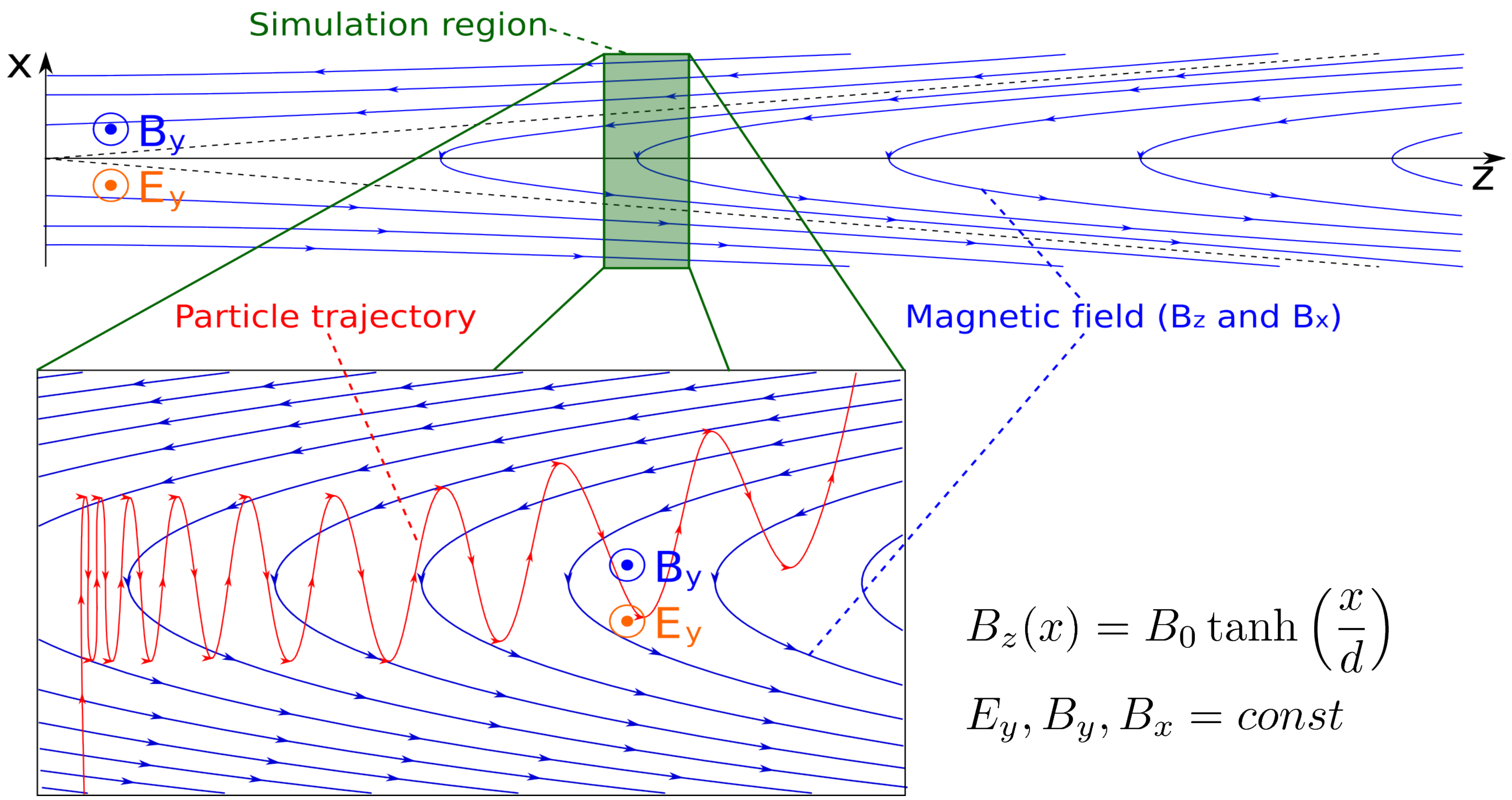


A single X-nullpoint

O-type (magnetic island)

Zharkova and Khabarova, 2012,
ApJ, 752, 35; 2015, Ann Geo, 33, 457

Particle trajectories near X-nullpoint

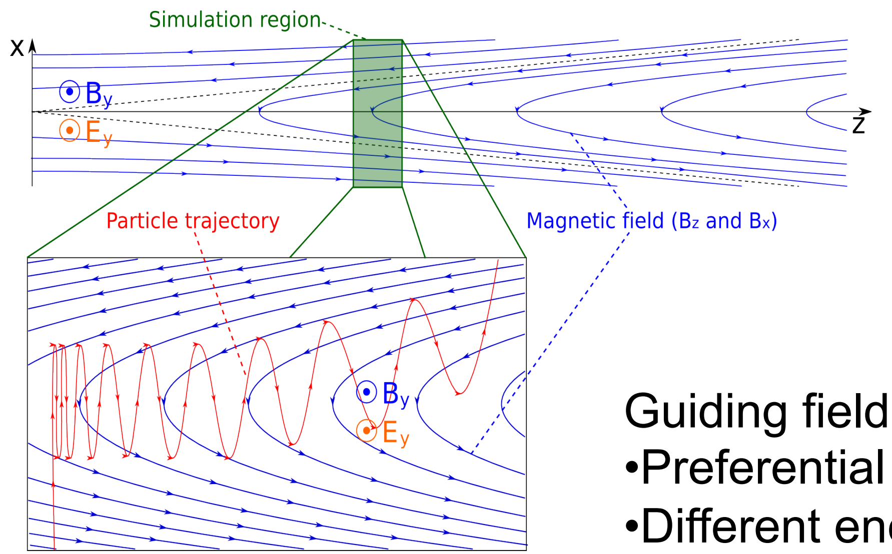


$$B_z(x) = B_0 \tanh\left(\frac{x}{d}\right)$$

$$E_y, B_y, B_x = const$$

Zharkova, et al., 2004

The role of the guiding field



Analytic electric and magnetic field model

$$B_z(x) = B_0 \tanh\left(\frac{x}{d}\right)$$

$$E_y, B_y, B_x = const$$

$$\frac{d\vec{p}}{dt} = q(\mathbf{E} + \mathbf{V} \times \mathbf{B}),$$
$$\frac{d\vec{r}}{dt} = \frac{\vec{p}}{m\gamma},$$

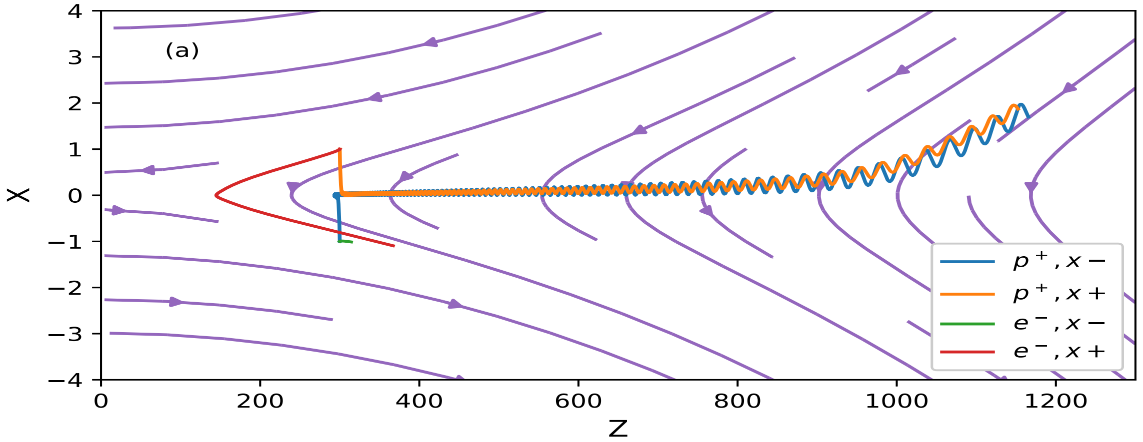
Guiding field:

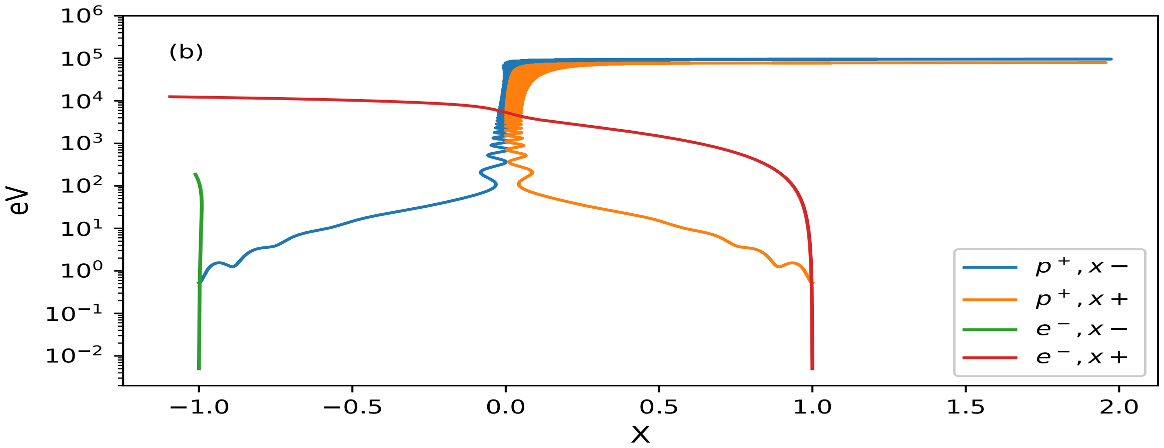
•Preferential ejection of oppositely charged particles

•Different energy gains for `transit' and `bounced' particles

$$B_X = B_{z0}(z/a)$$

Test particles



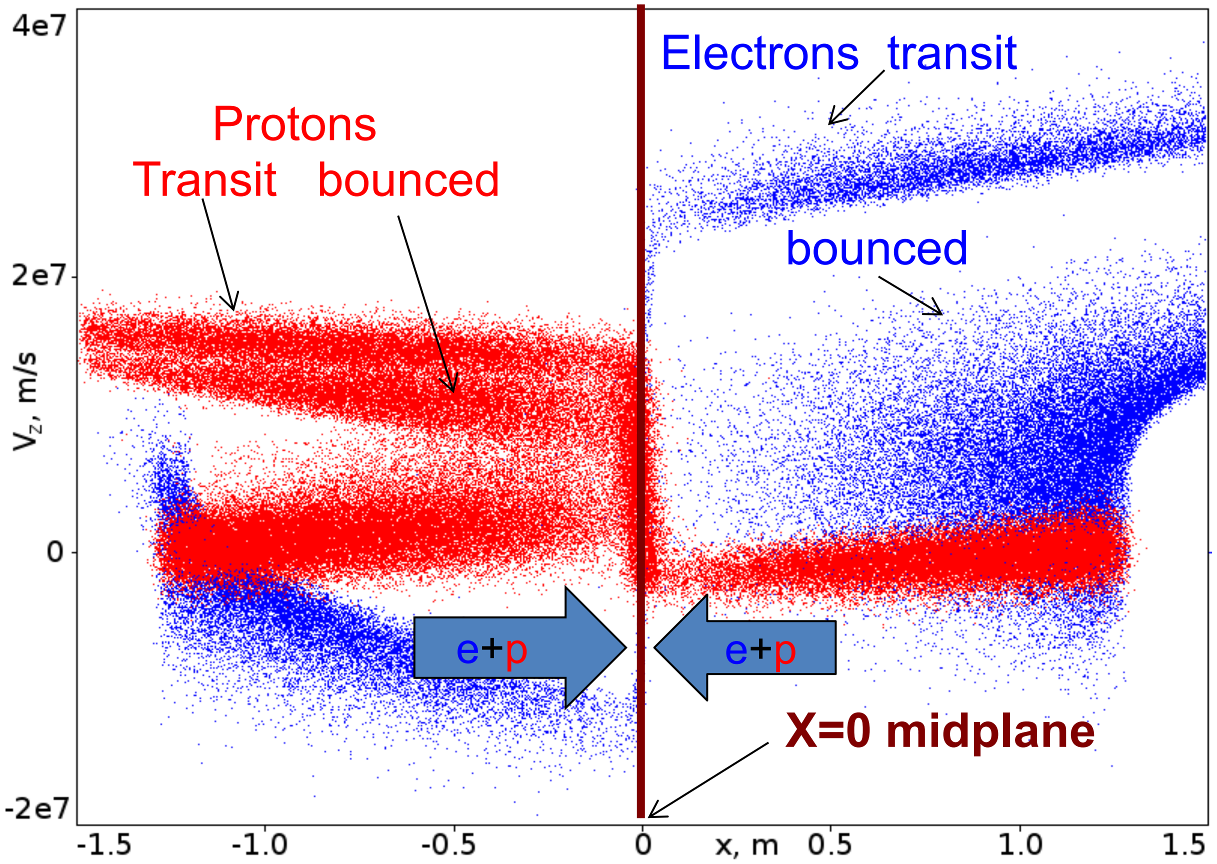


The role of the guiding field

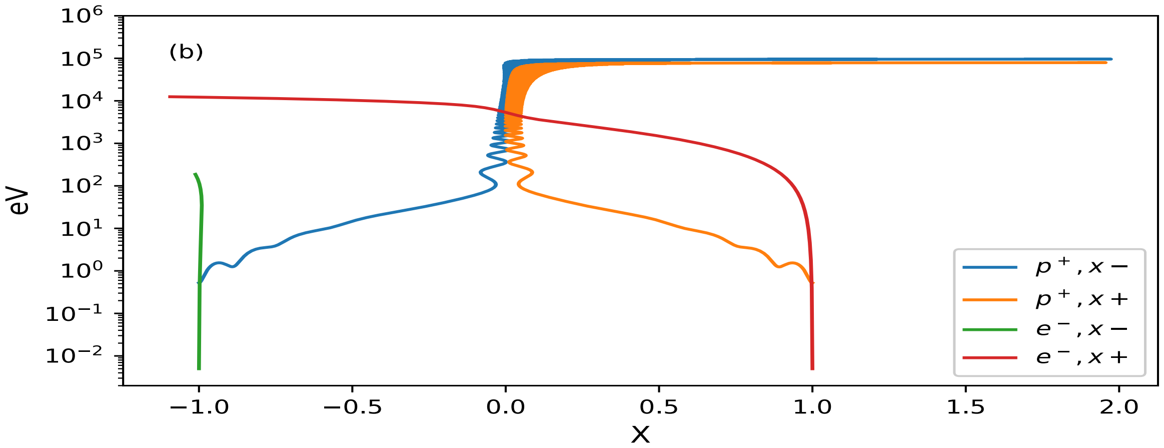
Guiding field:

- Preferential ejection of oppositely charged particles
- Different energy gains for `transit' and `bounced' particles

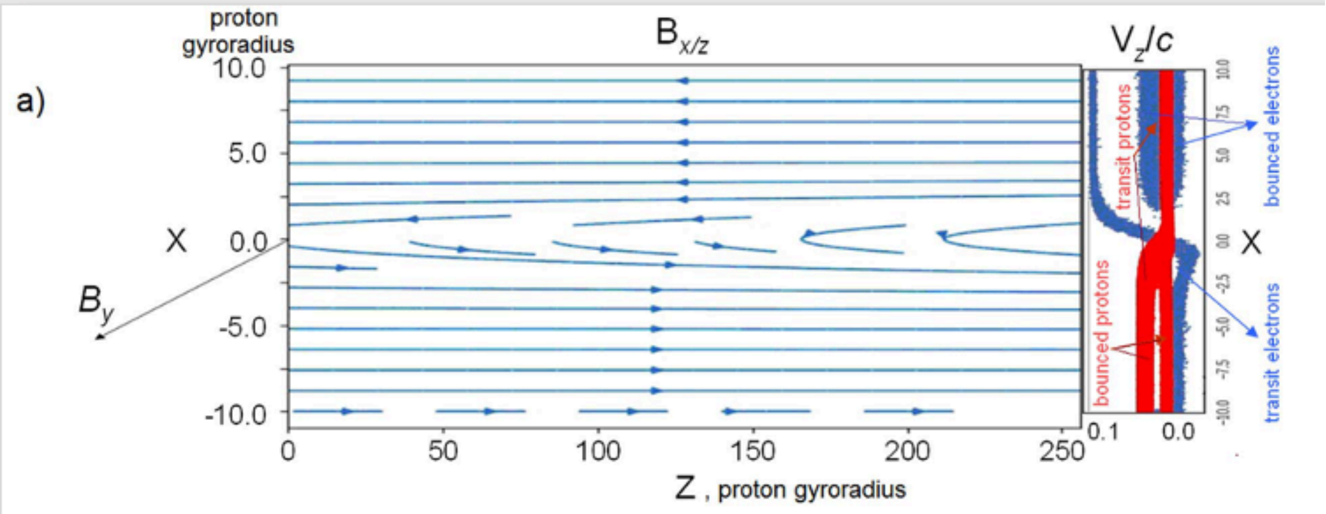
PIC simulation:

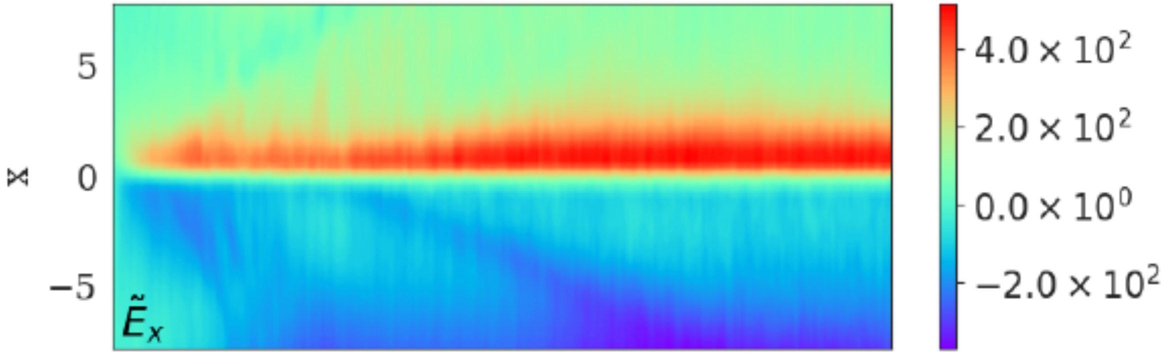


Test particles



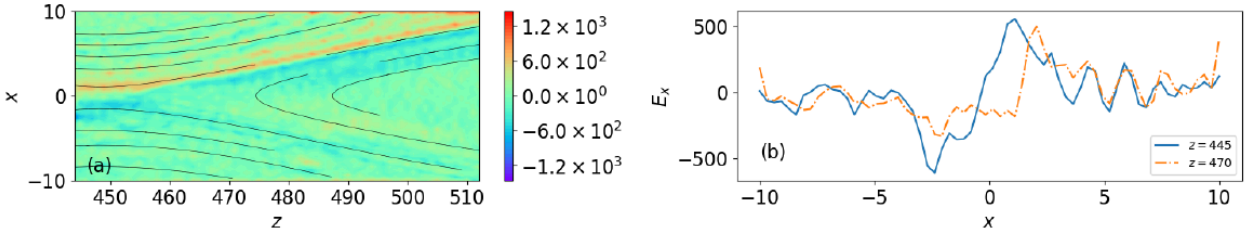
The role of the guiding field



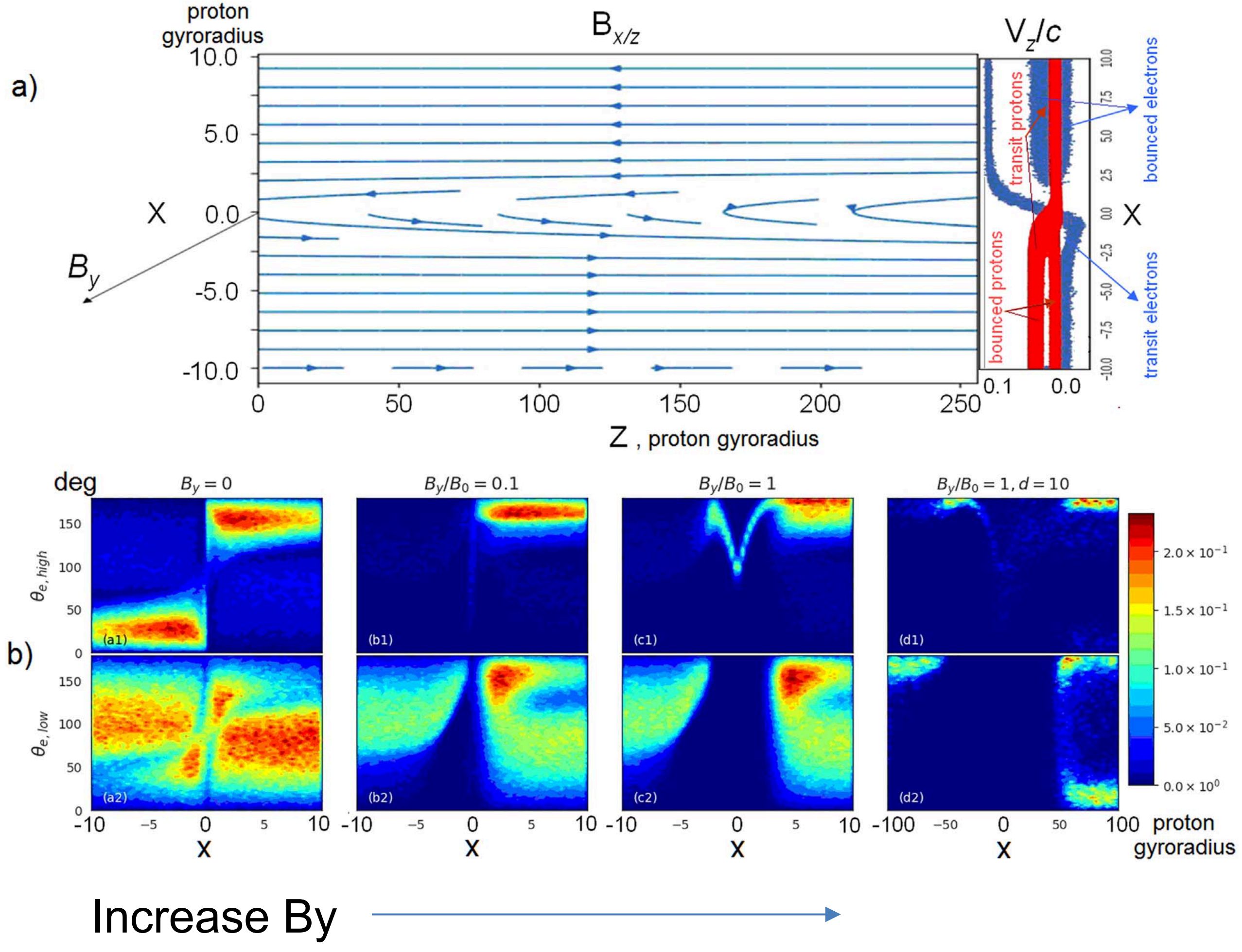


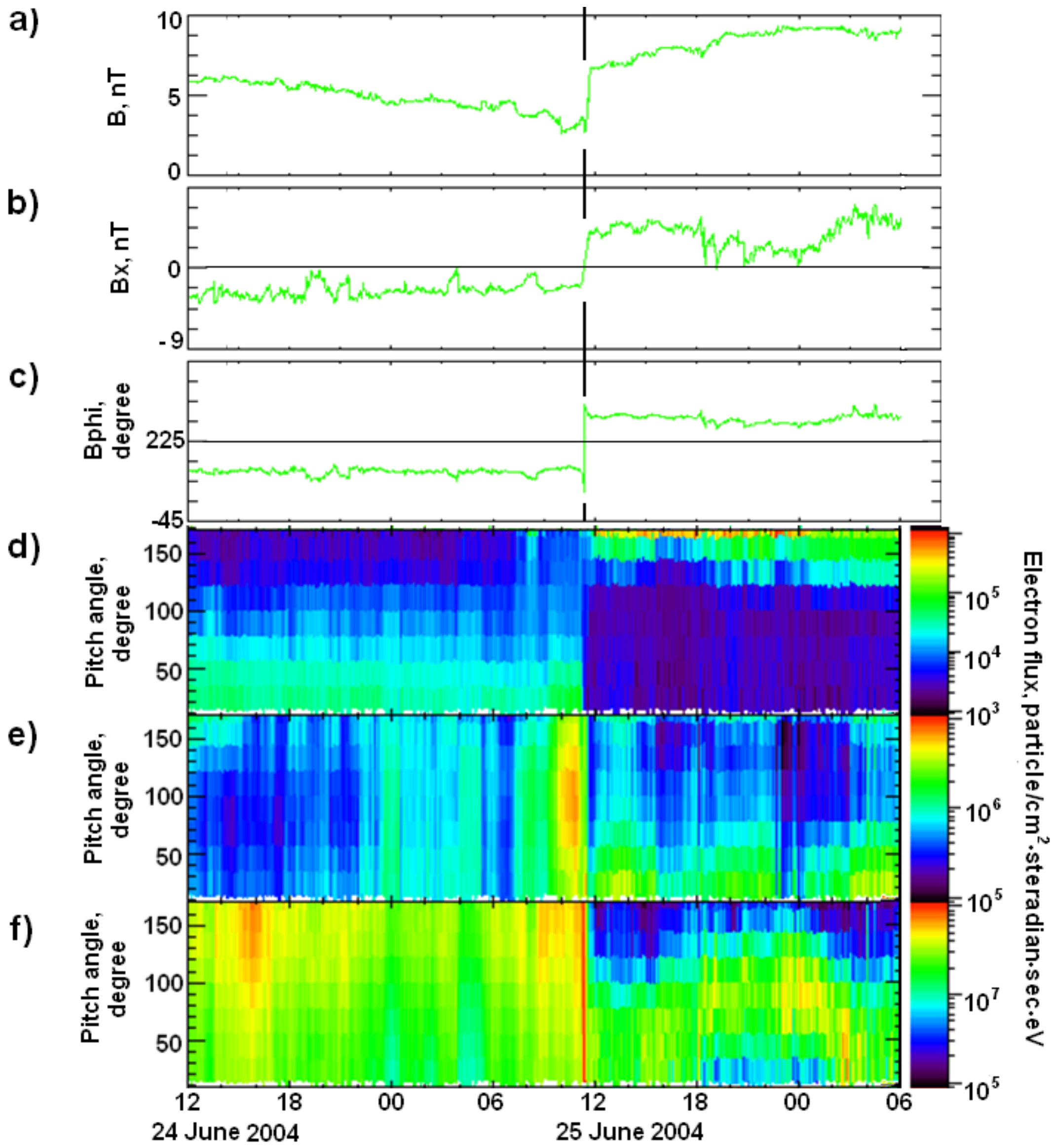
- Polarization electric field

Also presented in magnetic islands



Pitch-angle distributions

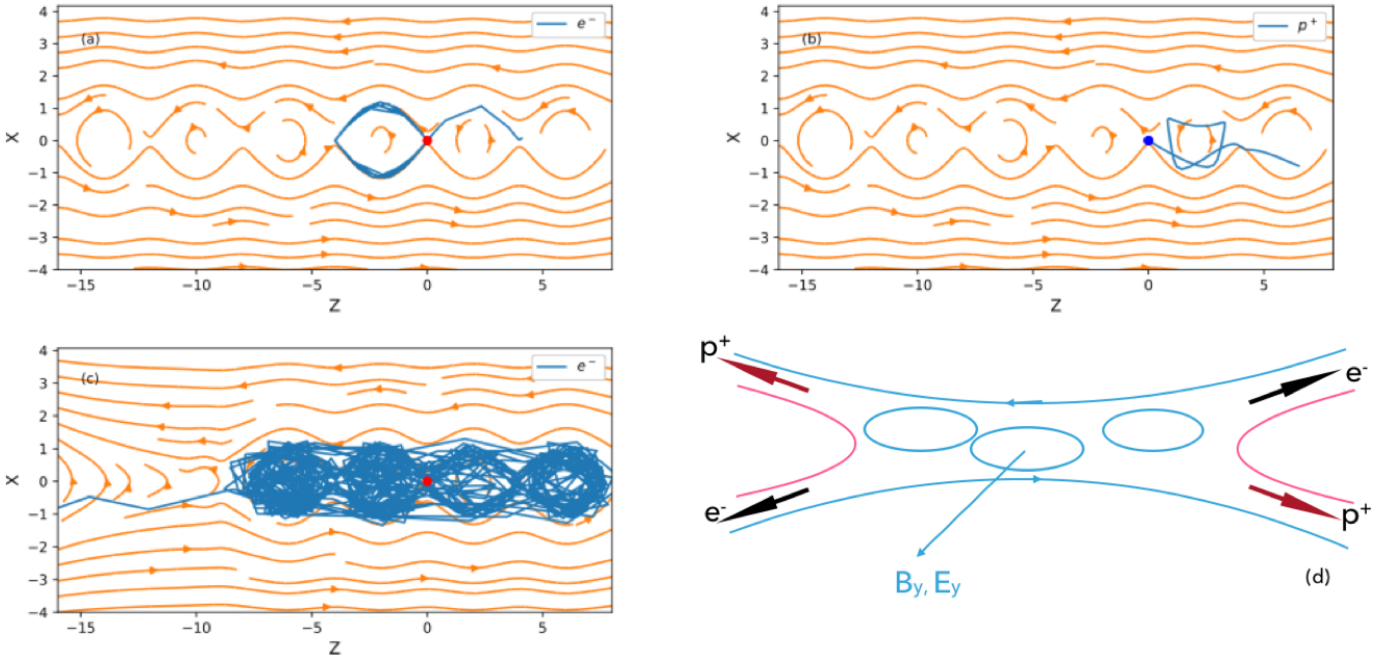


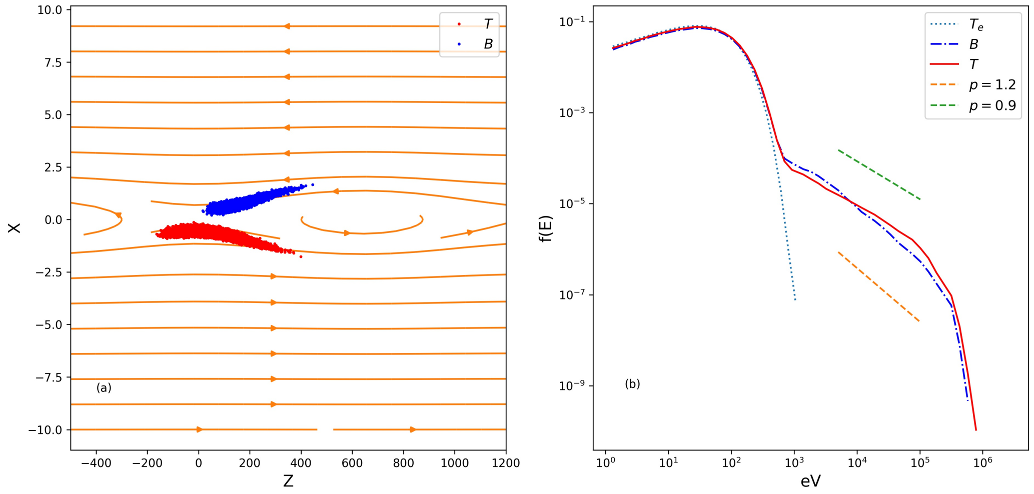


See more discussions in the talks from Olga Khabarova and Olga Malandraki, this afternoon.

Magnetic islands

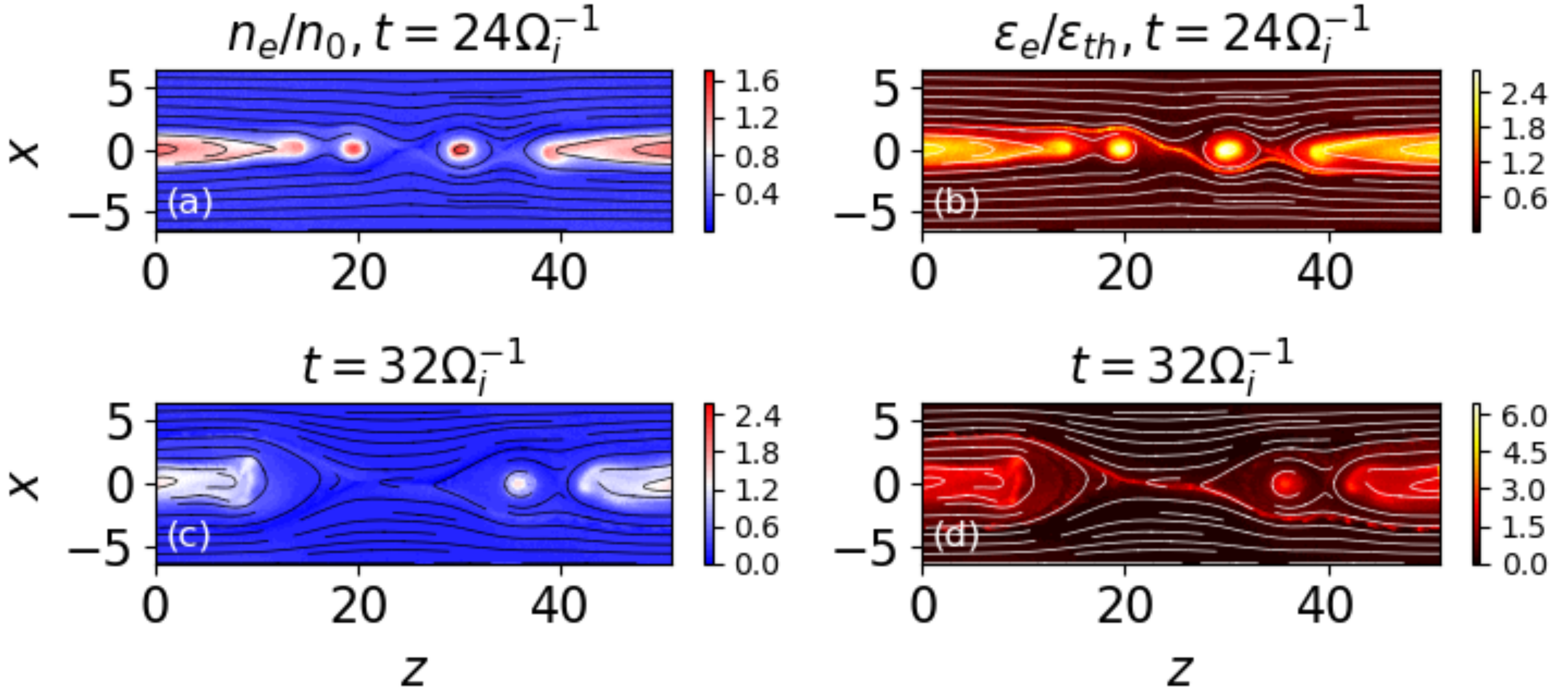
- Preferential ejection evidences:





Q. Xia, & V. Zharkova, 2018, A&A, 620, A121

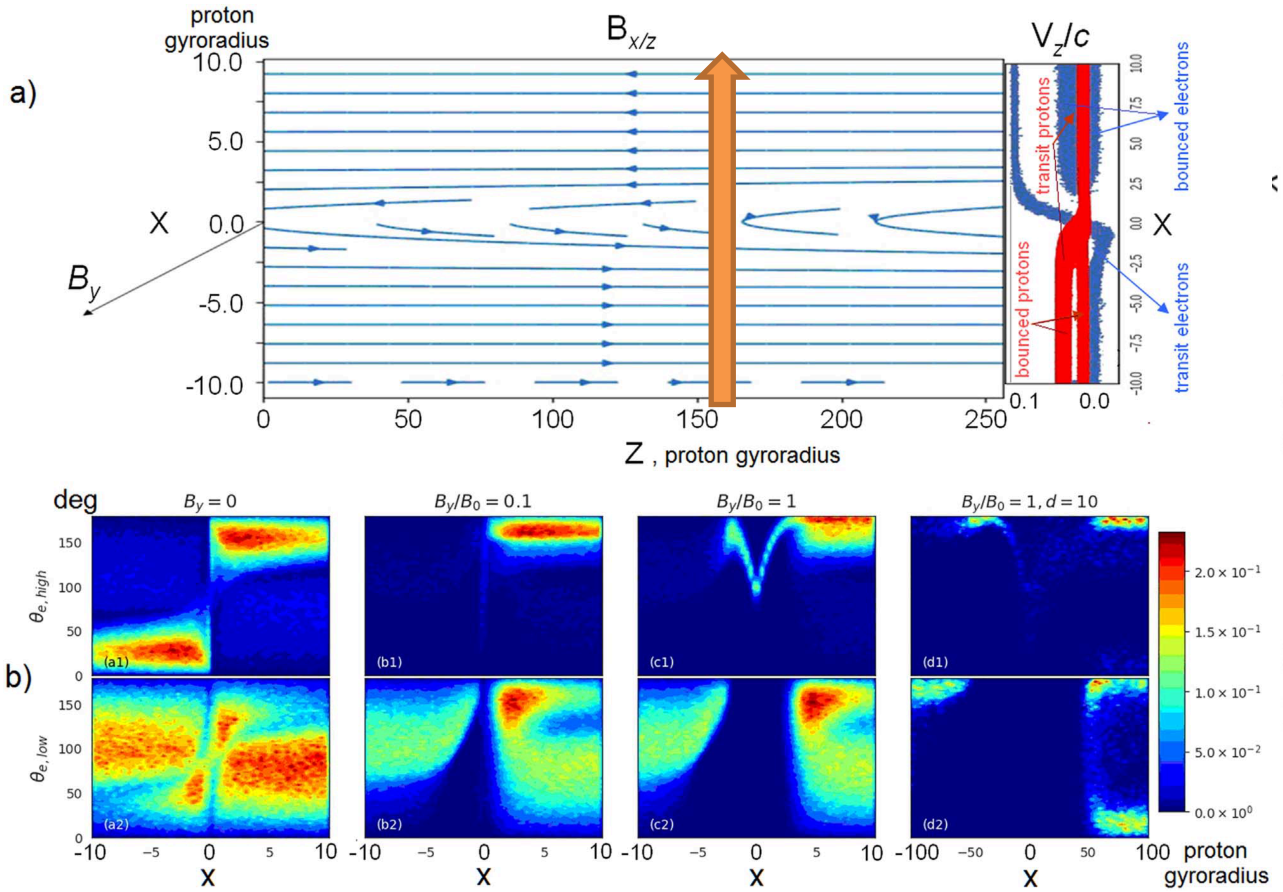
PIC simulations

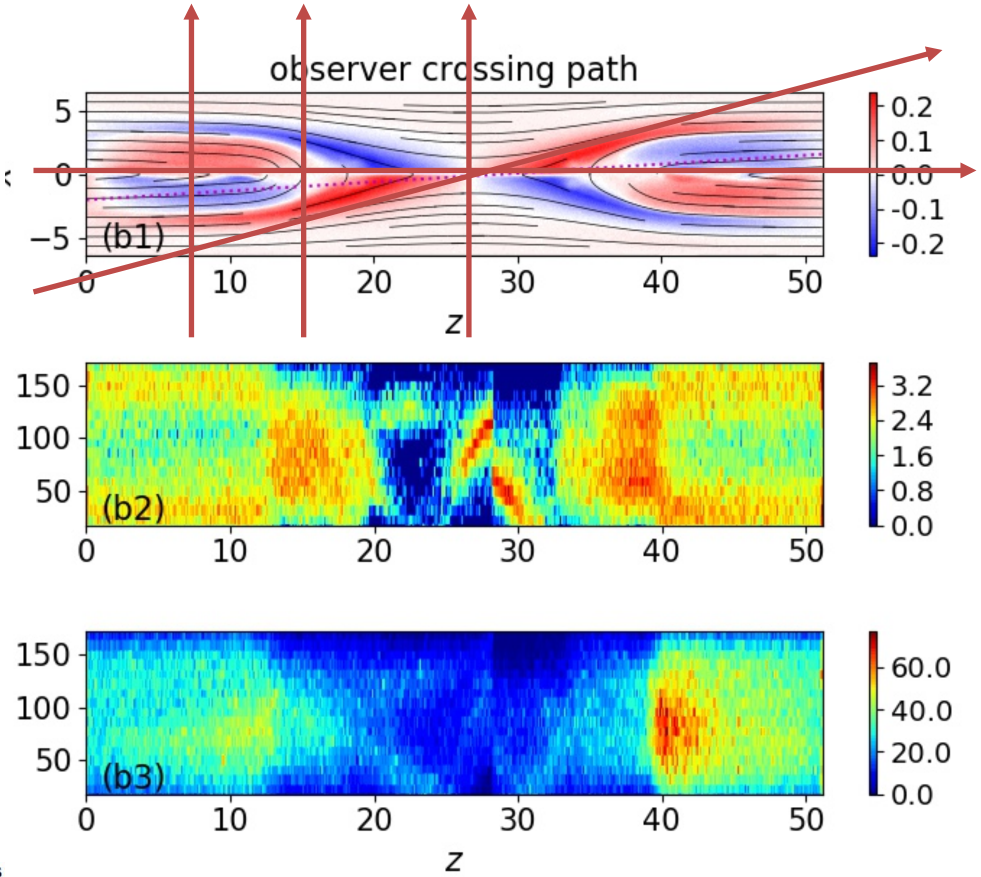


Codes:

- VPIC from LANL
- Epoch from U. Warwick

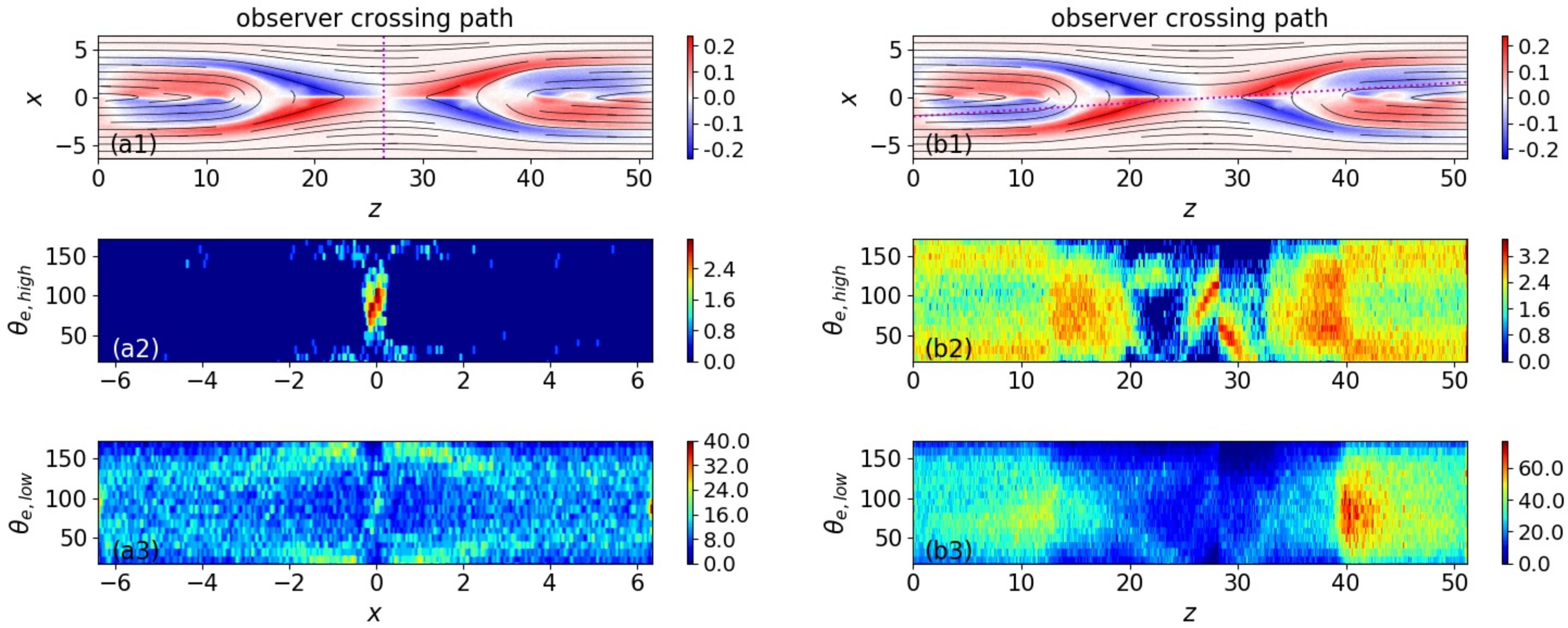
- Parametric study:





Virtual spacecraft paths

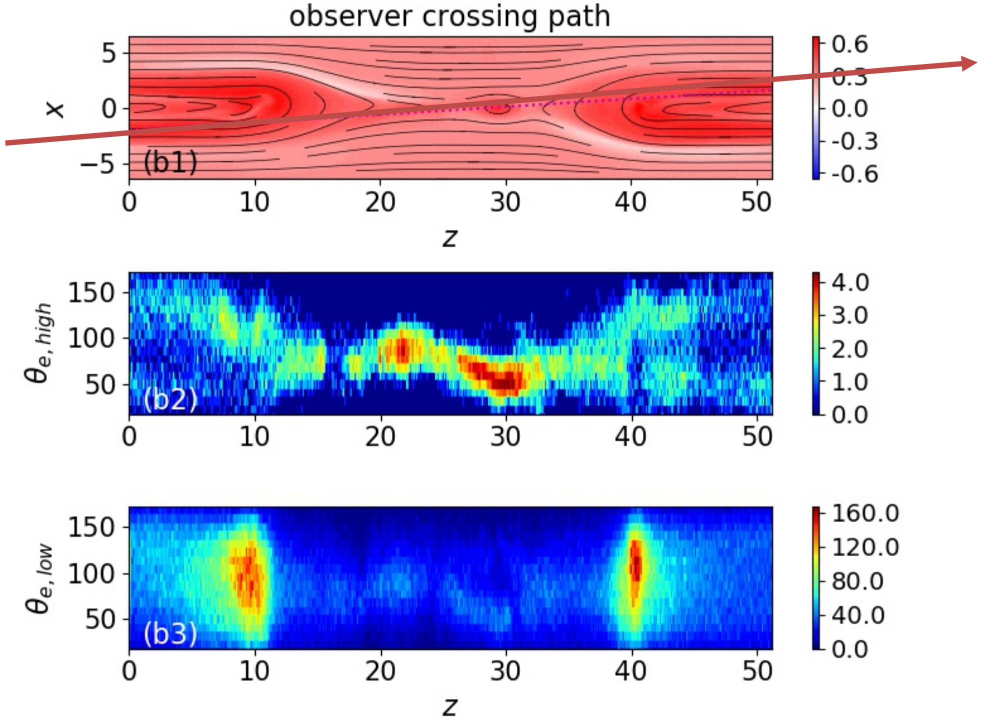
- Parametric study:



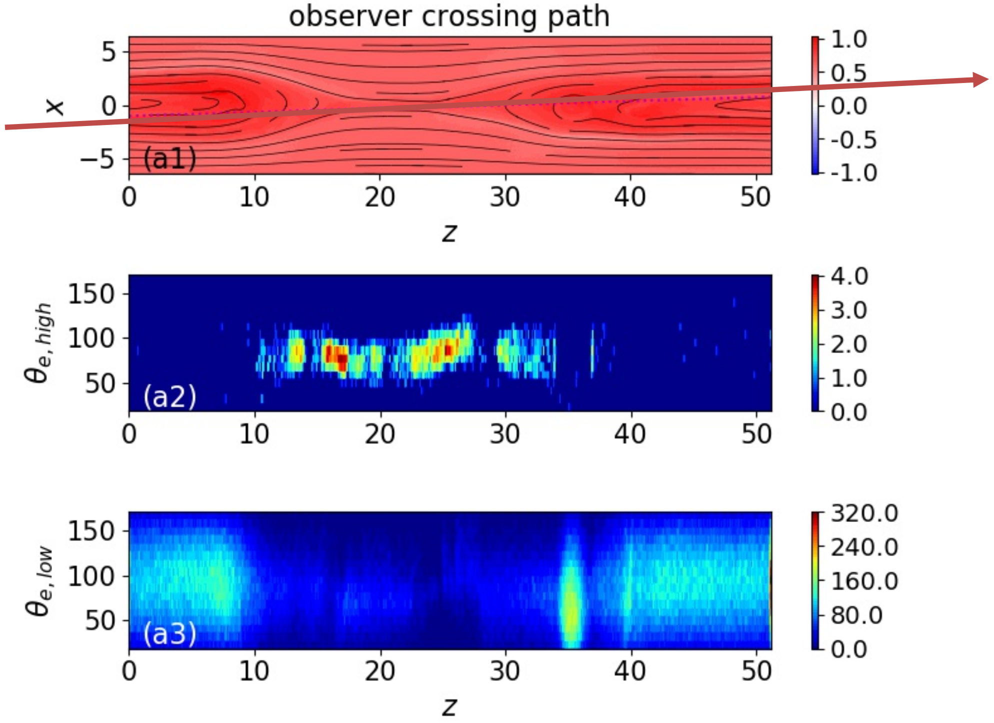
By (t=0) = 0 : bi-directional strahls

- Parametric study:

$B_{y0} = 0.5$:



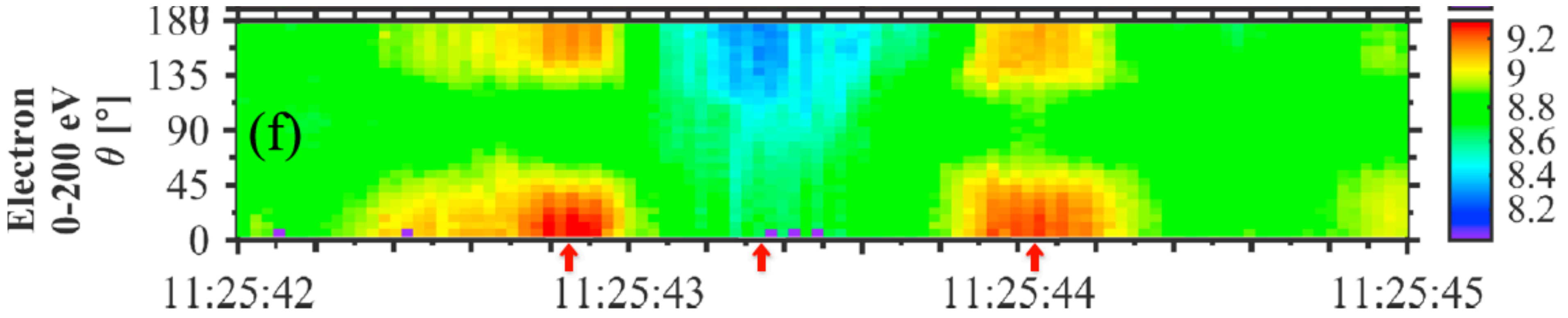
$B_{y0} = 1$:



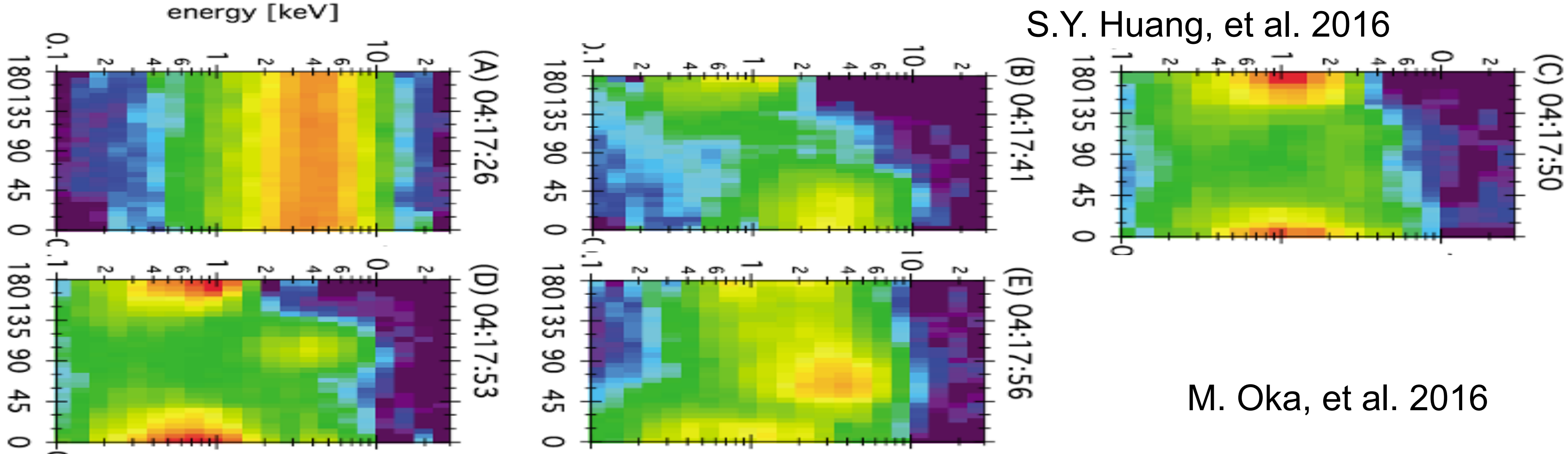
By (t=0) = 0.5, 1 : change to quasi-perpendicular direction

- Pitch-angle distributions:

Previous studies in magnetosphere (MMS):



S.Y. Huang, et al. 2016

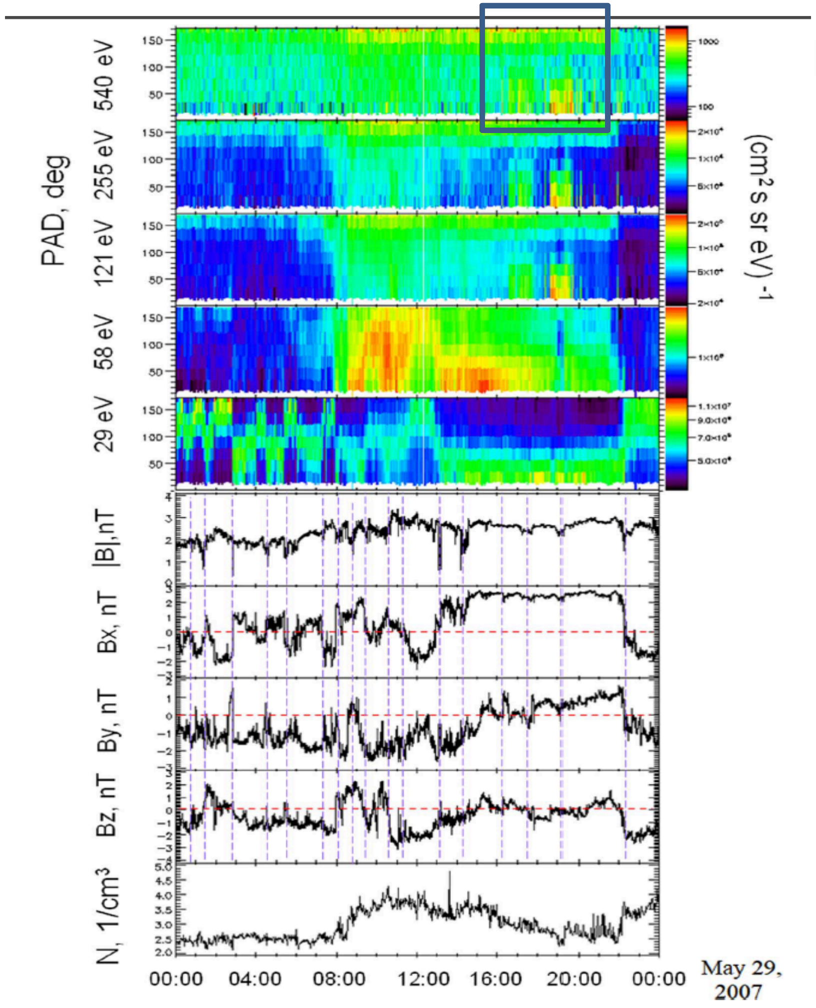


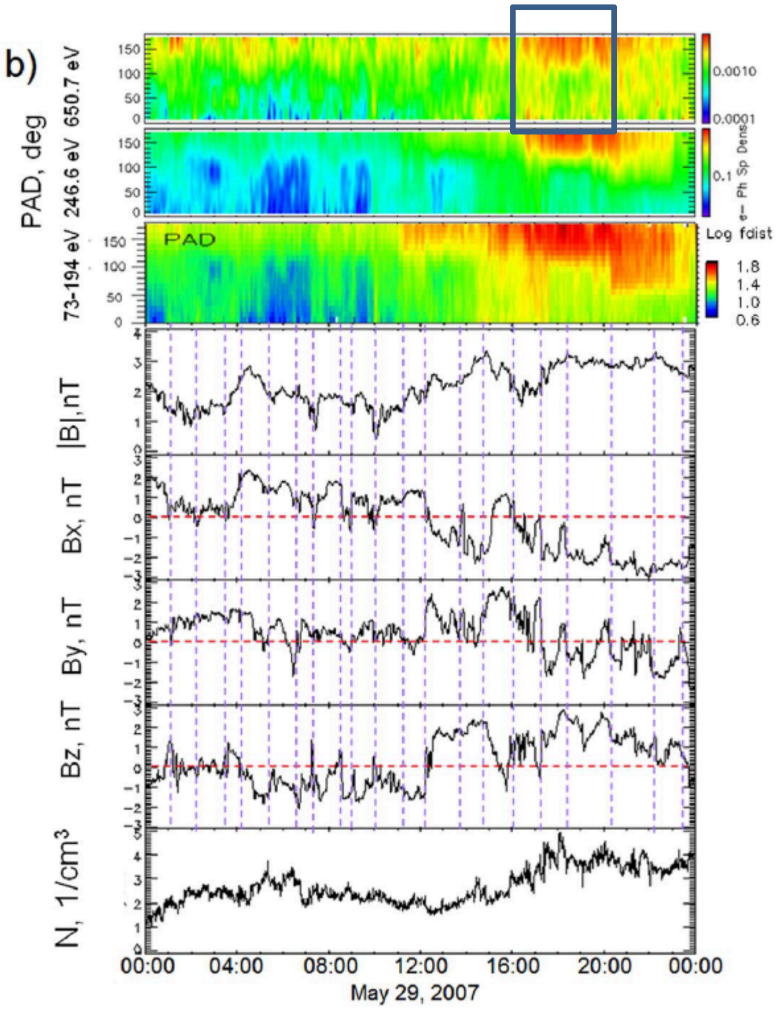
M. Oka, et al. 2016

- Pitch-angle distributions:

More observations in solar wind by O. Khabarova, O. Malandraki:

WIND

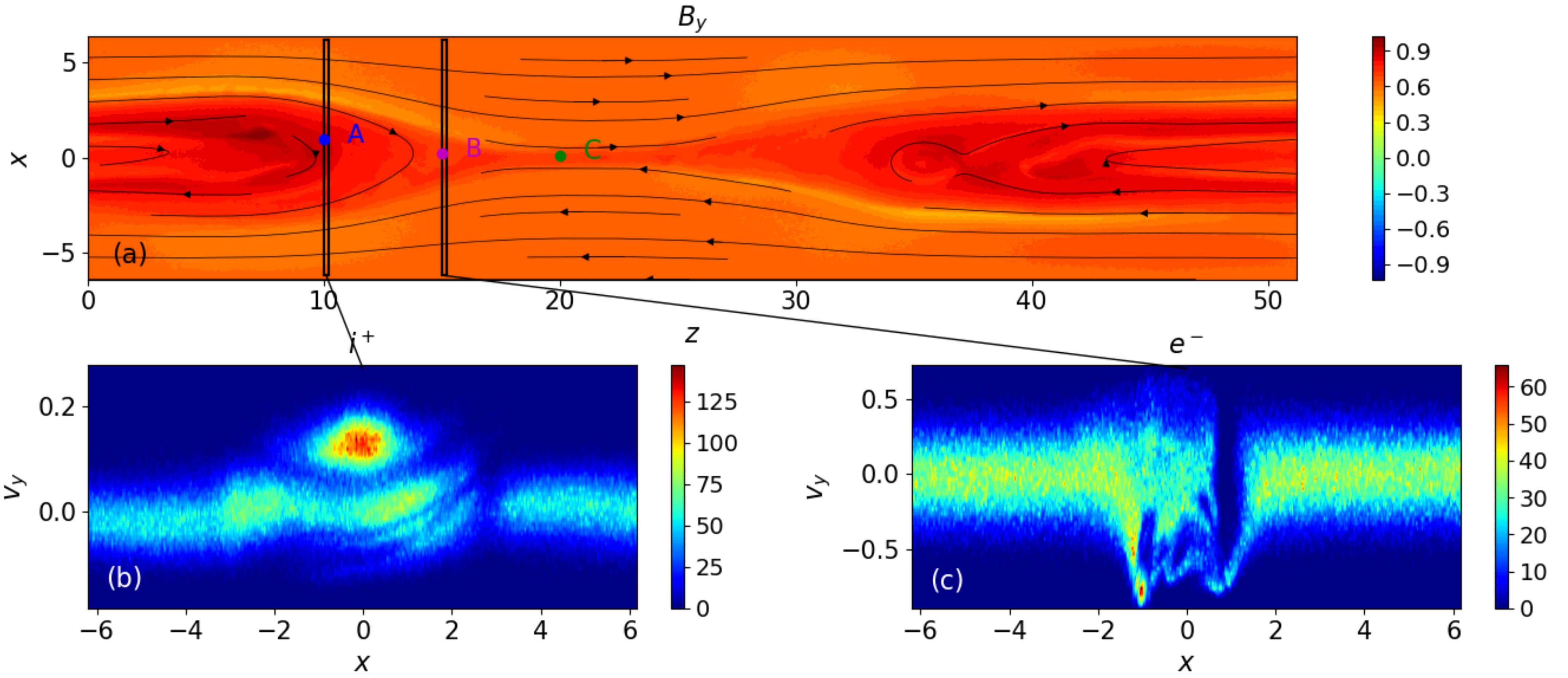




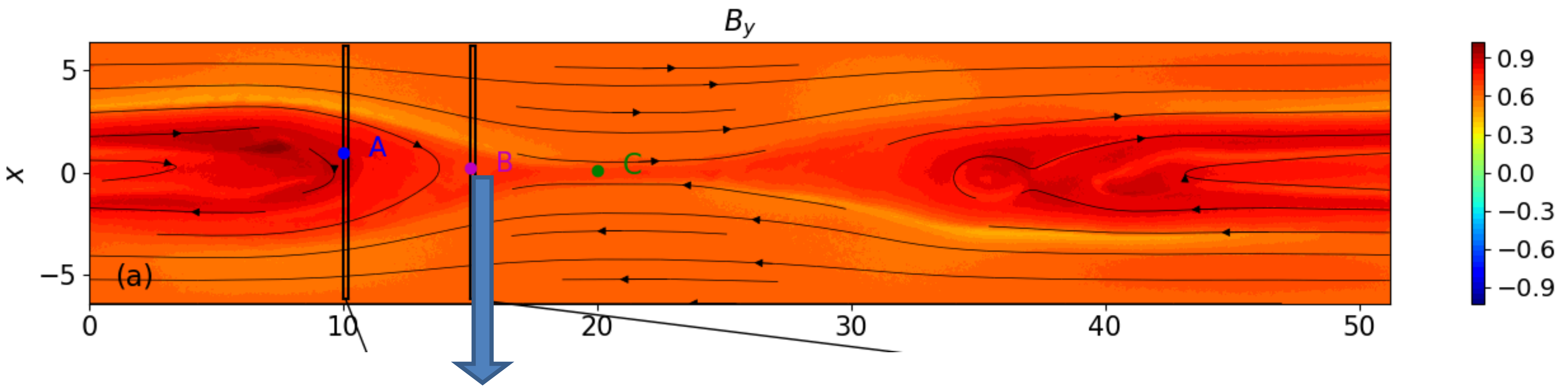
STEREO B

O. Khabarova, et al, 2020

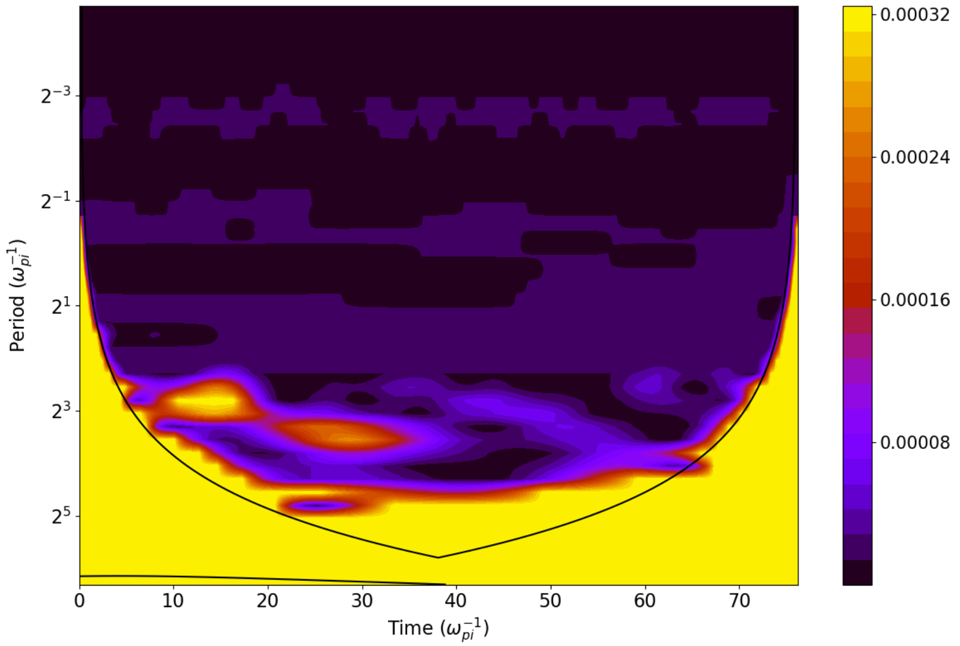
Phase space in the case with strong By



E, B fluctuations

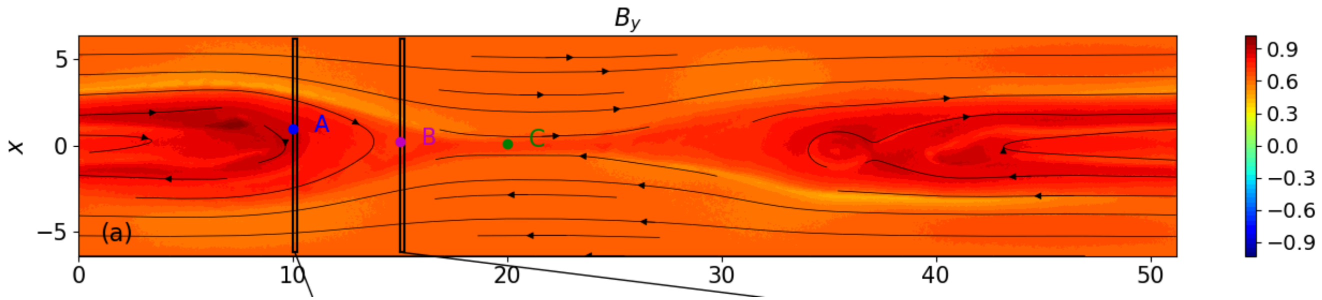


Wavelet power spectrum:



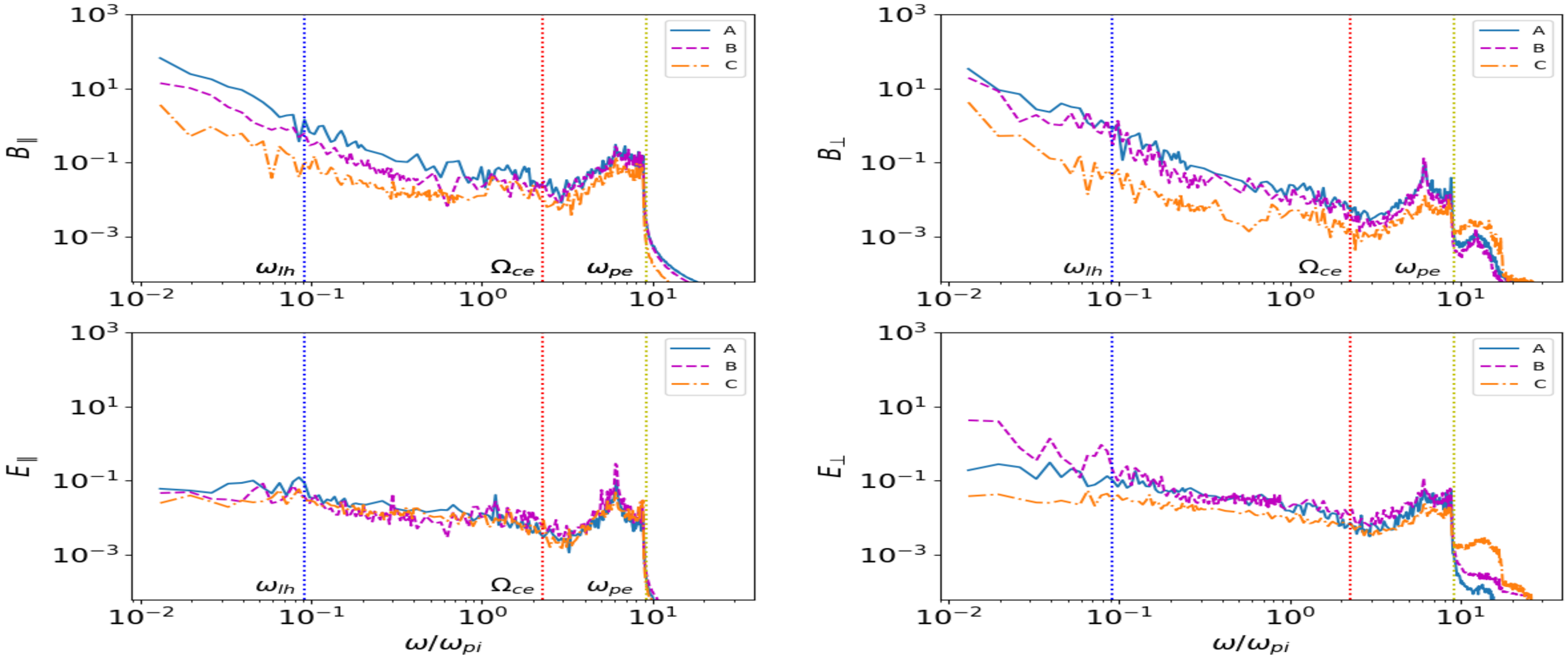
- Dominated by low-frequency
- High-frequency stripes

Fluctuations

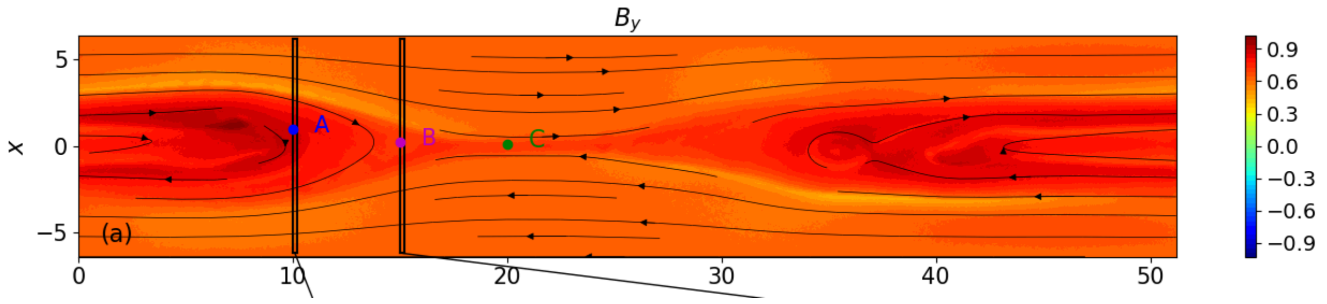


Anisotropic fluctuations :

- $E_\parallel,\ E_\perp$
- $B_\parallel,\ B_\perp$



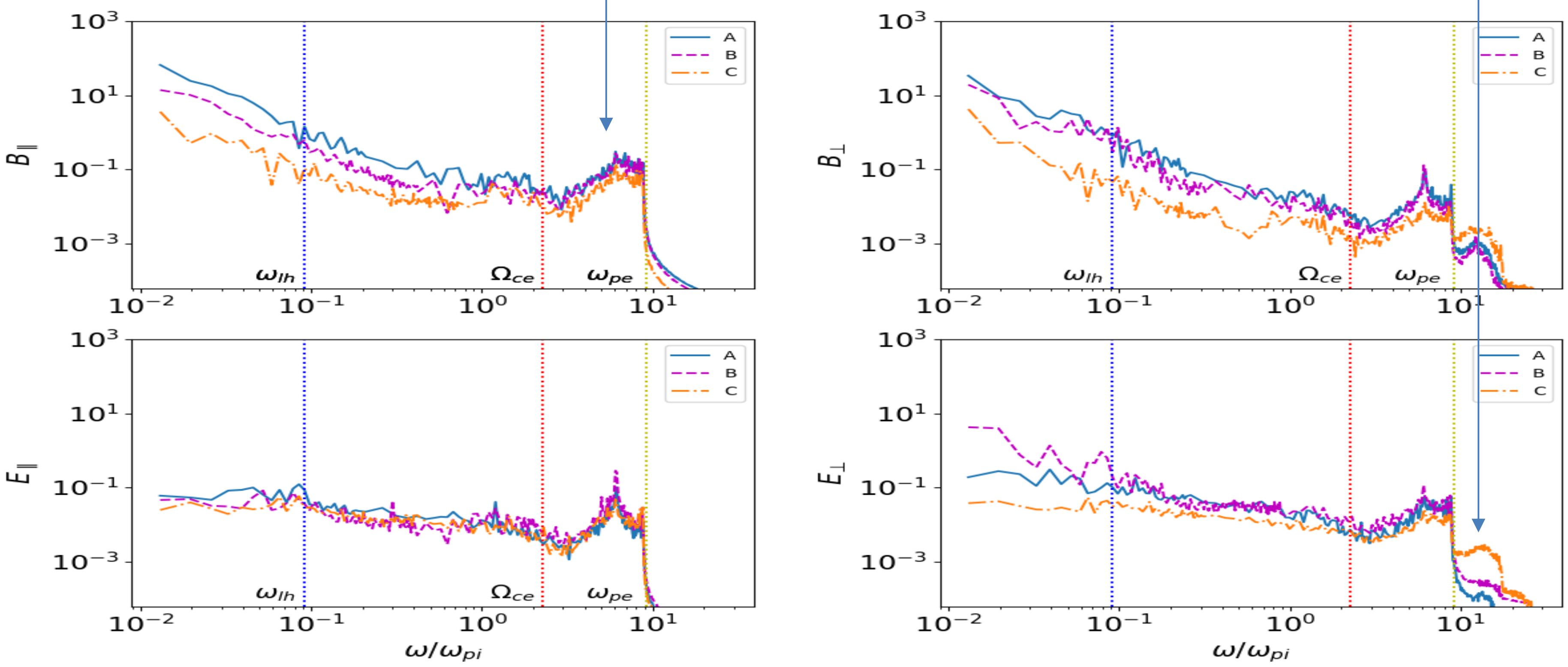
Fluctuations



- Above Ω_{ce} :

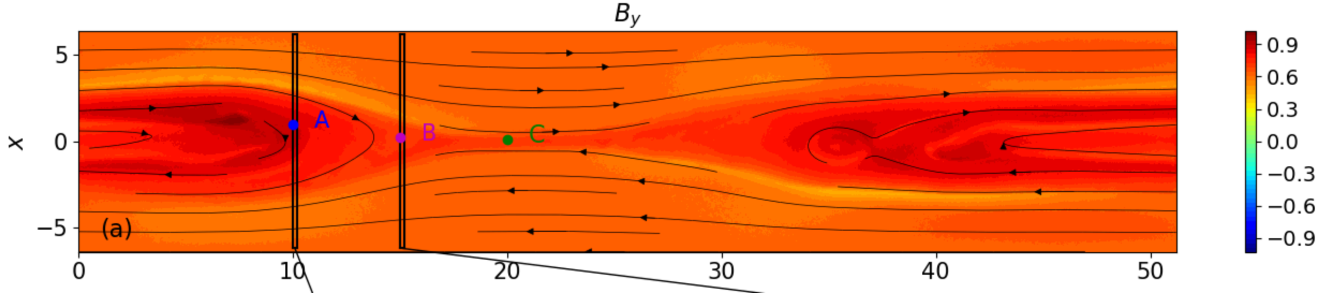
nonlinear harmonics @ $n\ f_{ce}$, etc.

electron Bernstein waves / Upper-hybrid (UH) waves ?



Near X-nullpoint, C: $f > \omega_{pe}$, $\perp$ fluctuations

Fluctuations

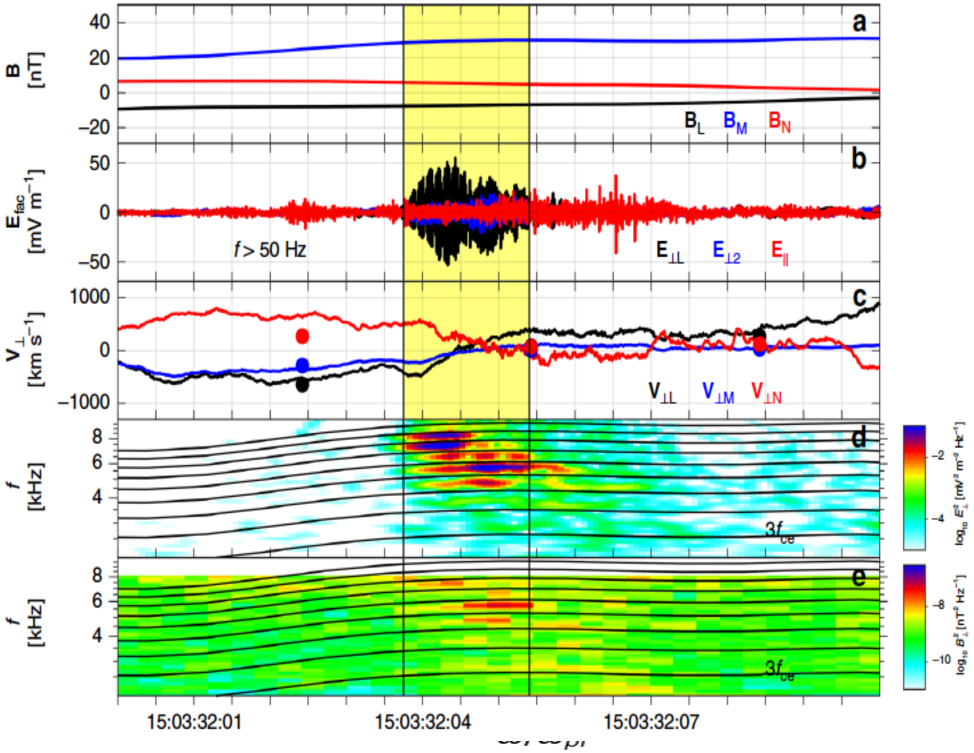


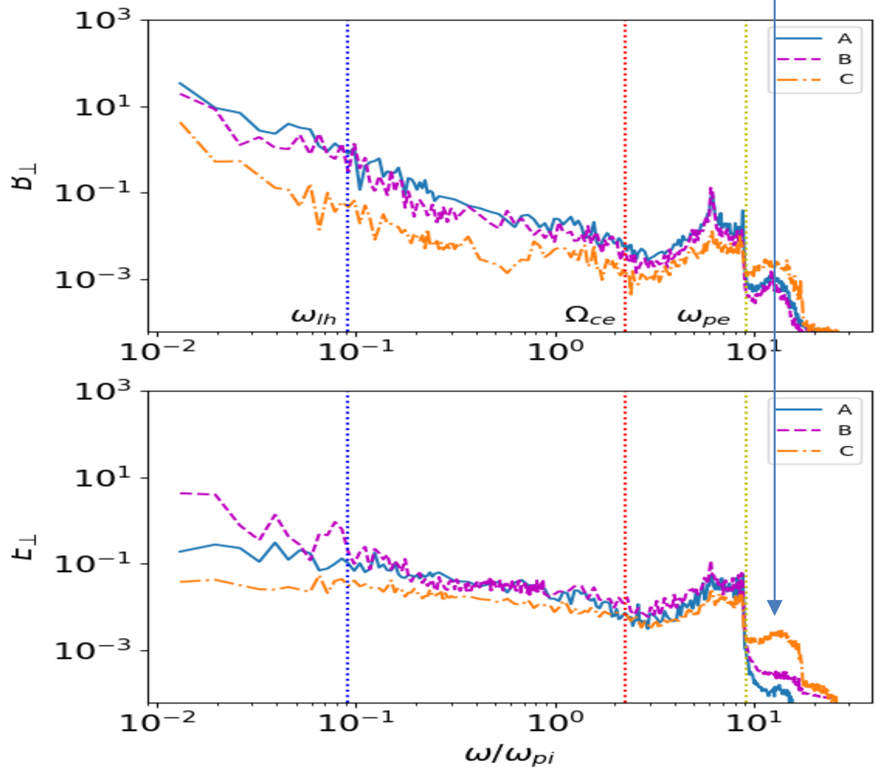
- Above Ω_{ce} :

nonlinear harmonics @ $n\ f_{ce}$, etc.

electron Bernstein waves / Upper-hybrid (UH) waves ?

Magnetotail

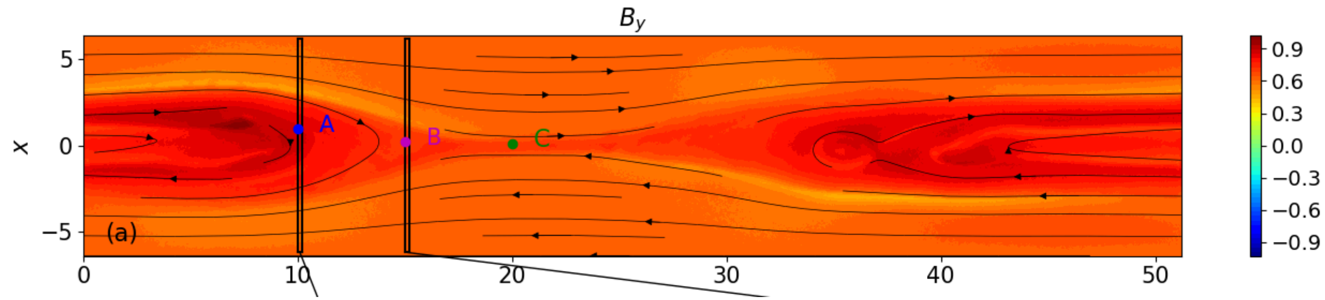




W.Y. Li, et al, 2020

Near X-nullpoint, C: $f > \omega_{pe}$, ⊥ fluctuations

Fluctuations

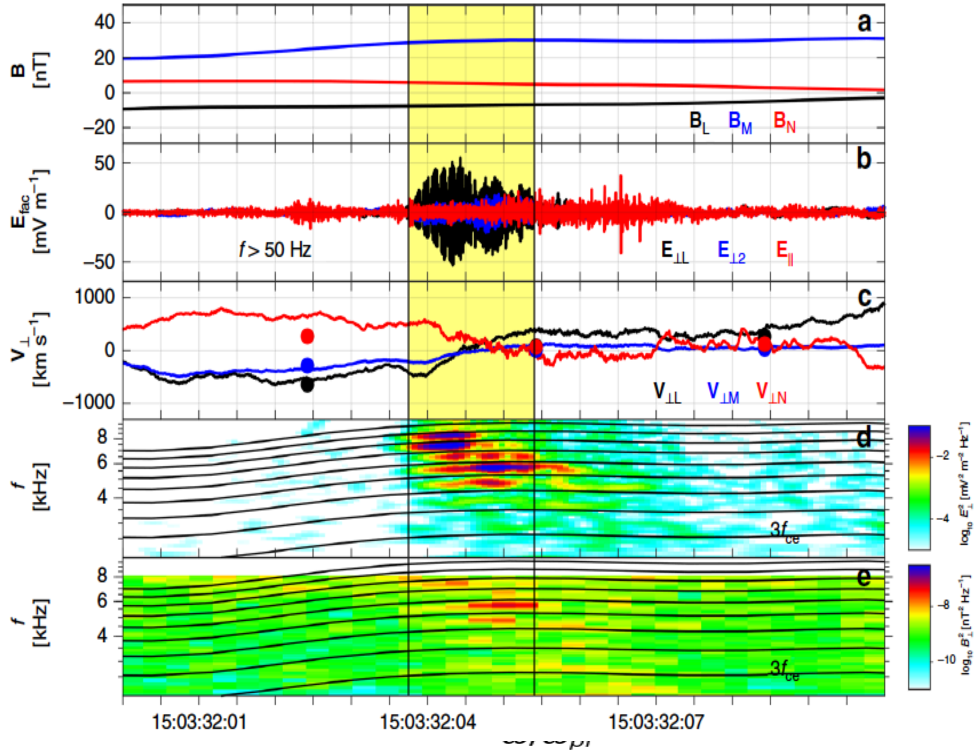


- Above Ω_{ce} :

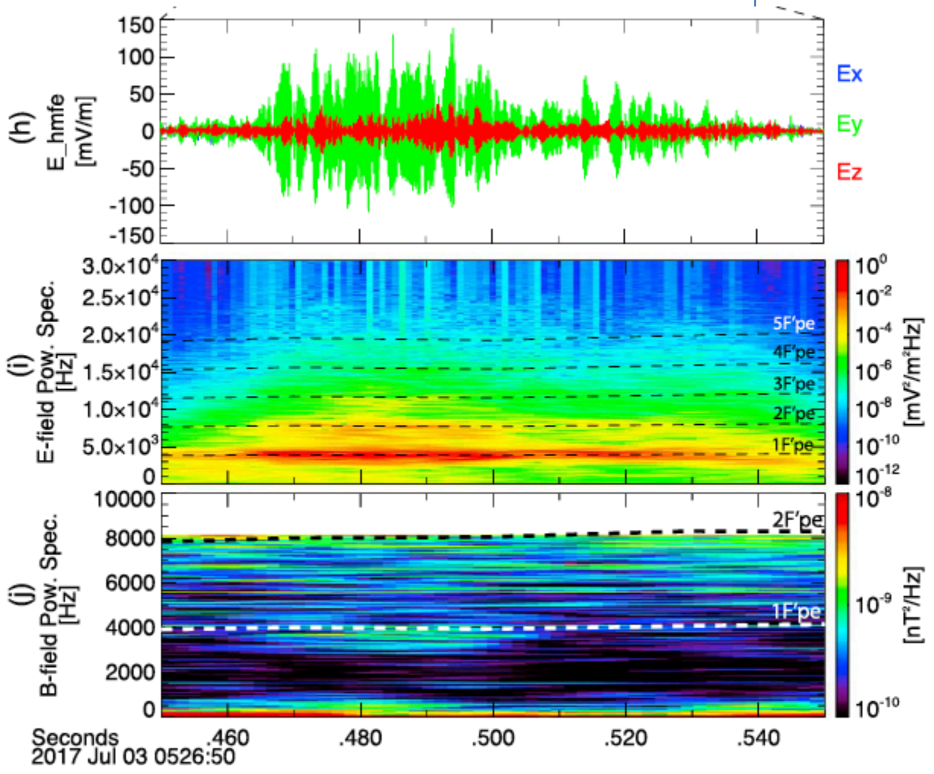
  nonlinear harmonics @ $n\ f_{ce}$, etc.

electron Bernstein waves / Upper-hybrid (UH) waves ?

Magnetotail



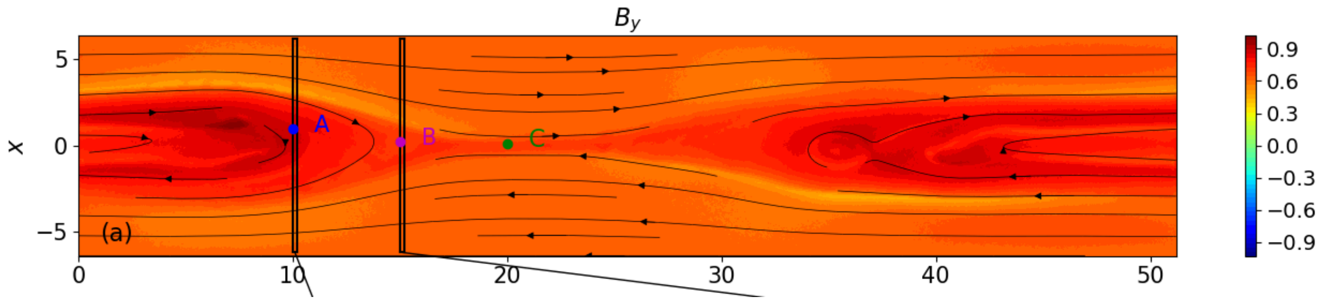
Magnetopause



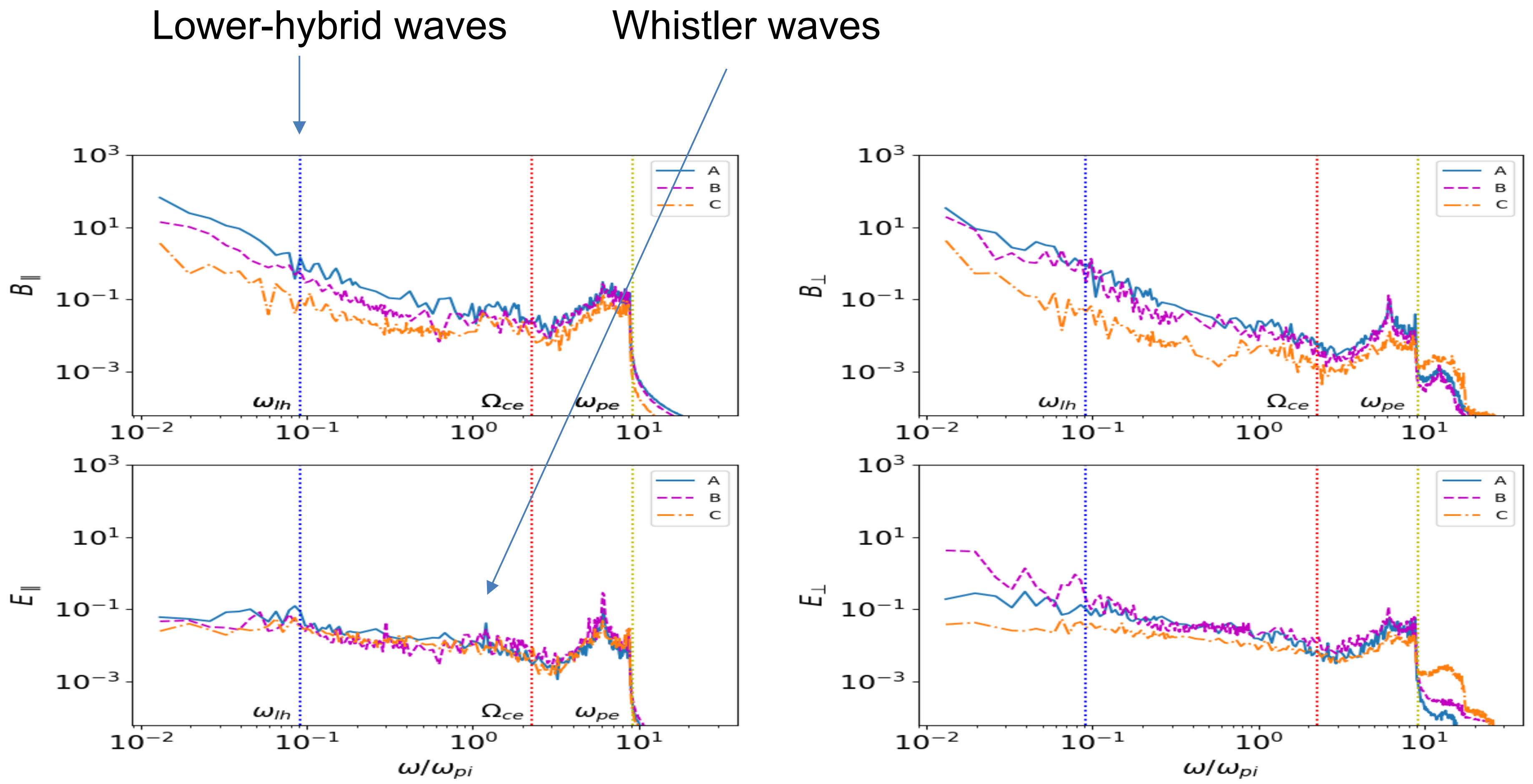
W.Y. Li, et al, 2020

K. Dokgo, et al, 2019

Fluctuations



- Below Ω_{ce} :



Conclusions:

Near an X-nullpoint or in magnetic islands, except the observations of accelerated plasma, paired rotational discontinuities*, other features include :

- Pitch-angle distributions
  - bi-directional strahls,
  - heat flux dropouts,
- Polarization electric field
- Waves, in presence of strong Bg
  - Near X-nullpoint: high-frequency ⊥ fluctuations
  - Reconnection current sheets with magnetic islands: harmonics of Bernstein, UH waves**
  - Extends into magnetic islands: whistler, LH waves

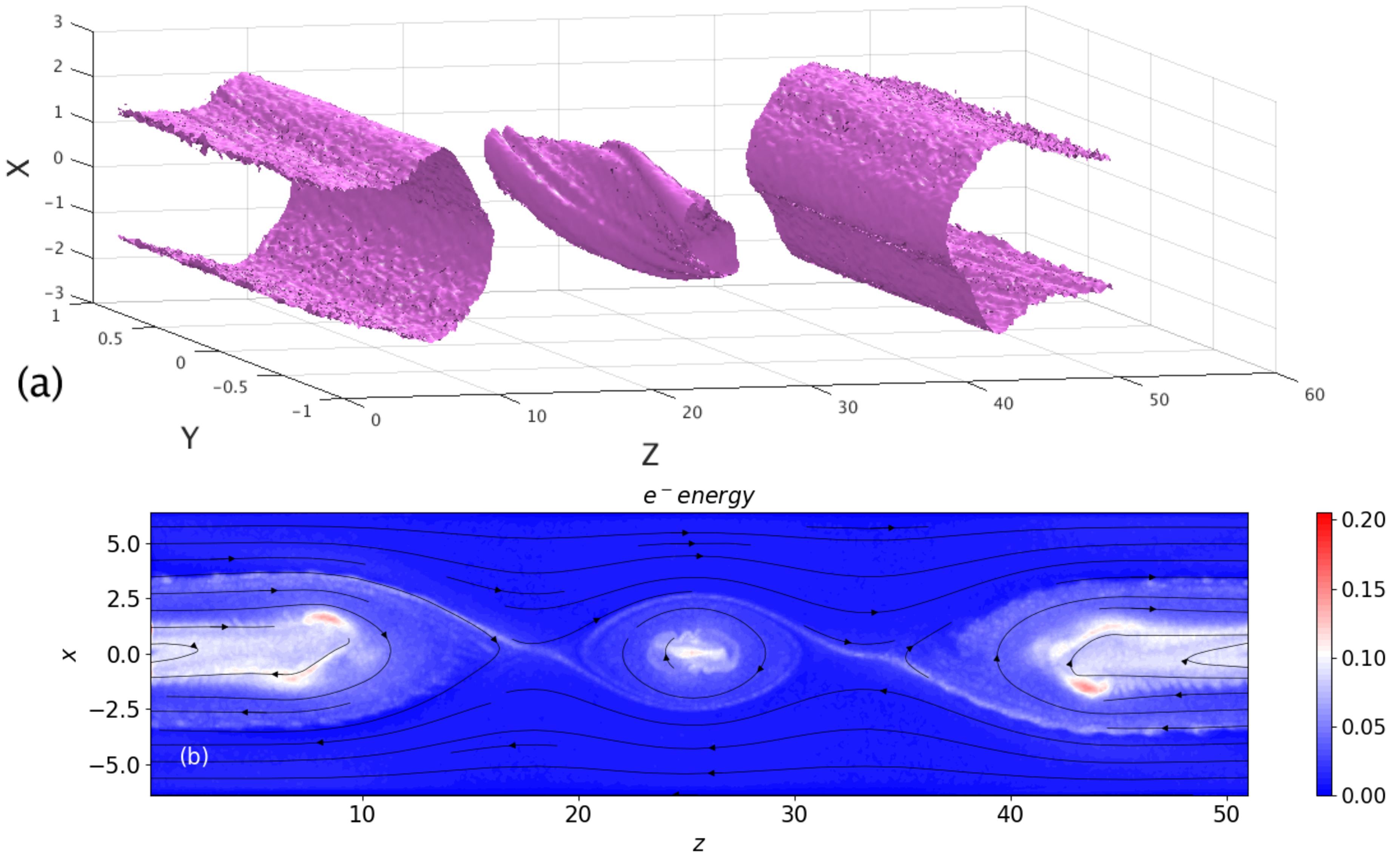
* T.D. Phan, et al. 2020
** G. Lapenta, et al. 2020

THANK YOU FOR YOUR ATTENTION!

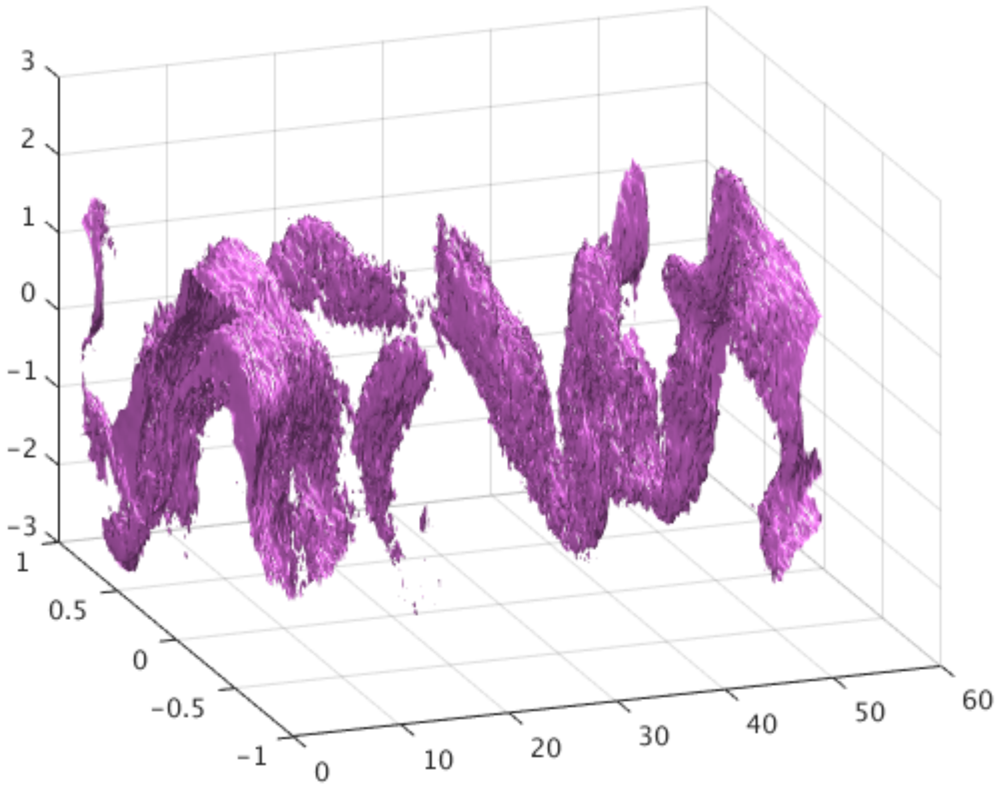
Questions …

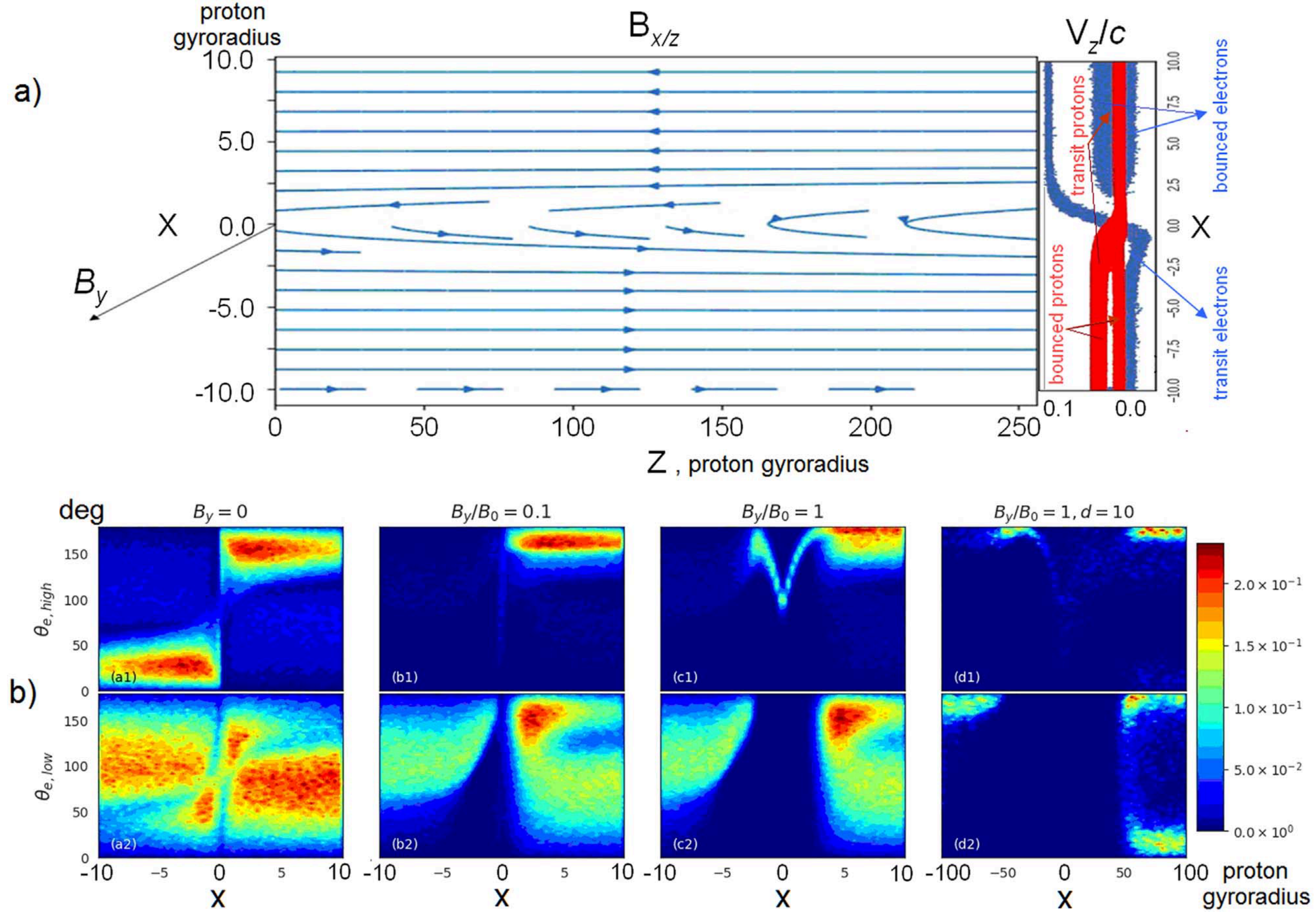
Extra slides

3D for turbulence study:

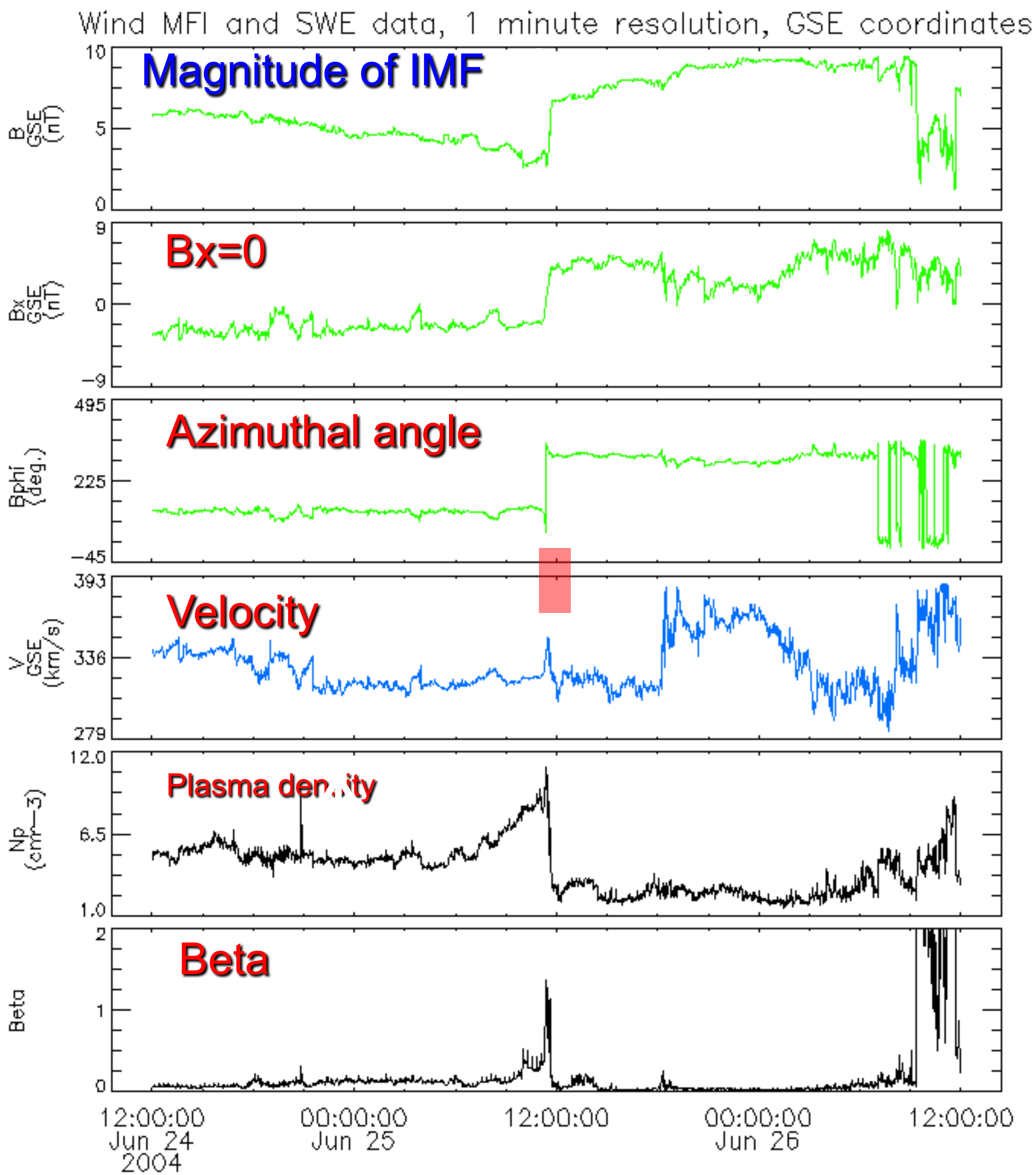


3D, By=0: kink





a)
proton gyroradius
$B_{x/z}$
V_z/c
10.0
5.0
0.0
-5.0
-10.0
X
B_y
0
50
100
150
200
250
Z , proton gyroradius
transit protons
bounced protons
bounced electrons
transit electrons
0.1
0.0
b)
deg
$B_y = 0$
$B_y/B_0 = 0.1$
$B_y/B_0 = 1$
$B_y/B_0 = 1, d = 10$
$\theta_{e,high}$
$\theta_{e,low}$
(a1)
(b1)
(c1)
(d1)
(a2)
(b2)
(c2)
(d2)
2.0×10^{-1}
1.5×10^{-1}
1.0×10^{-1}
5.0×10^{-2}
0.0×10^{0}
x
proton gyroradius



In the heliosphere

IMF magnitude sharply drops or increases

Horizontal component(Bx, GSE) = 0 nT;

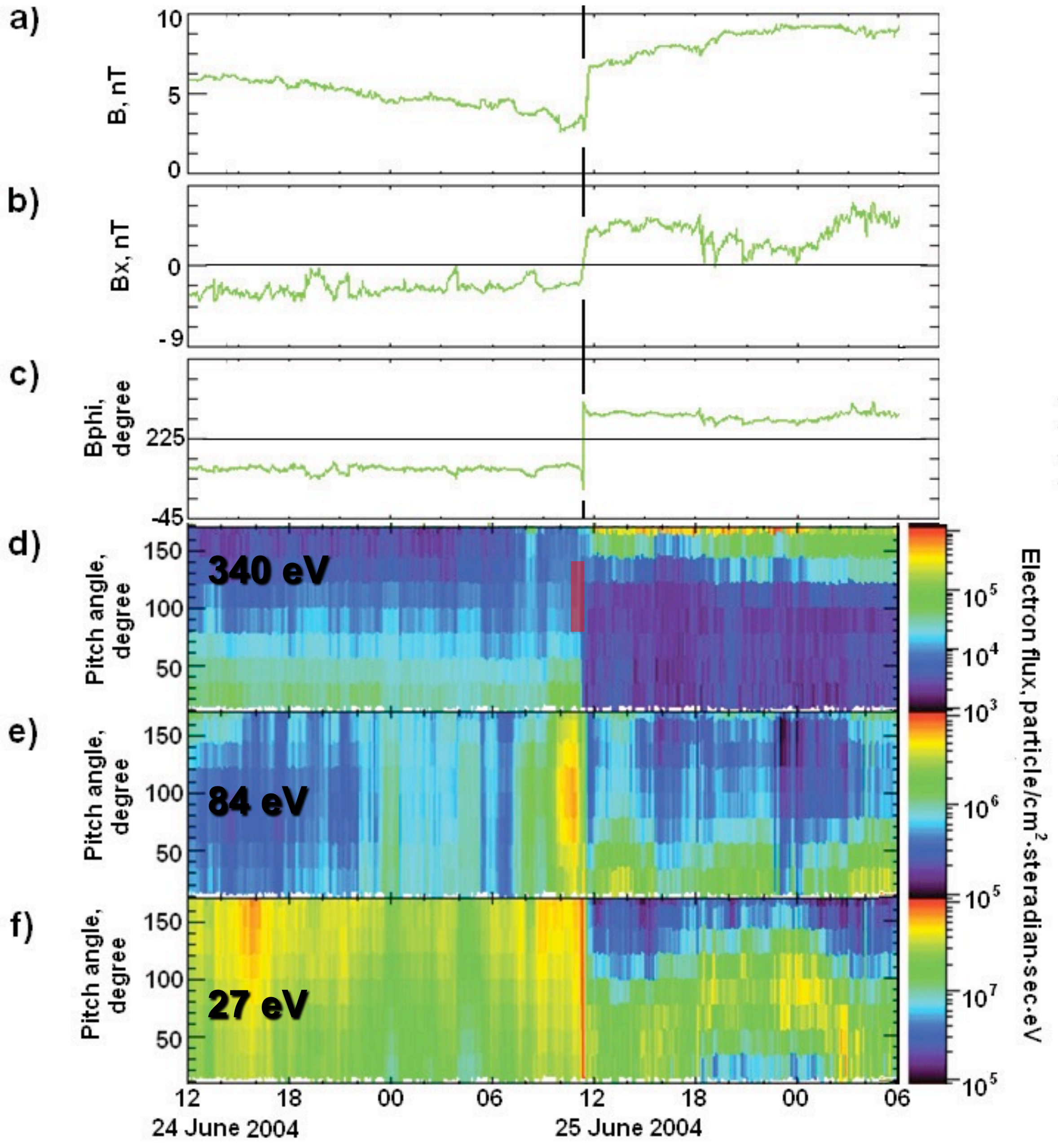
Azimuthal angle (φ_B) changes by180°;

Velocity is slightly increased

Density is sharply increased

Beta is also sharply increased

Problems in identification of sector boundaries



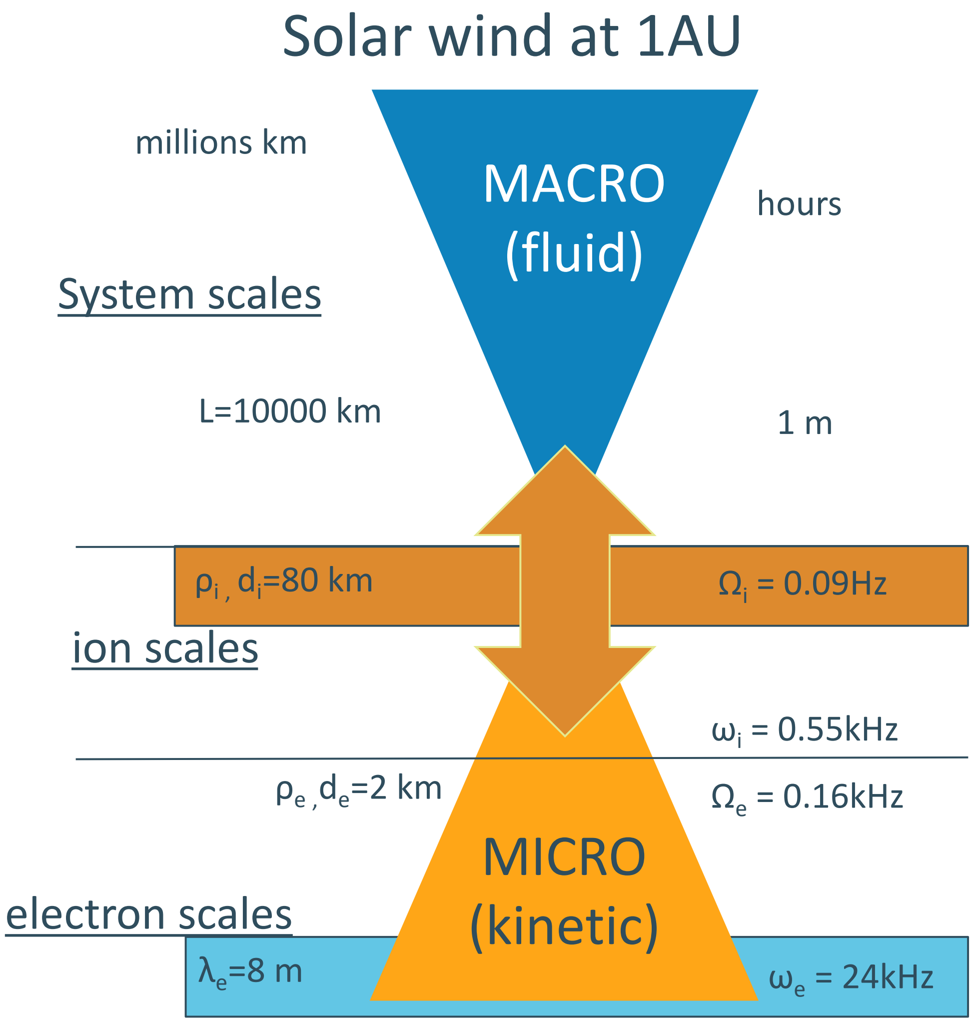
Crossing of a thin SB:
a) IMF magnitude;
b) IMF horizontal component (Bx, GSE);
c) IMP azimuthal angle (φ_B);

d-f) Spectrograms of electron distribution in pitch angles
(in 3 energy channels)

Kahler, S., and R. P. Lin (1994),, Geophys. Res. Lett., 21, 1575– 1578.
Crooker, N. U., S. W. Kahler, D. E. Larson, and R. P. Lin (2004), J. Geophys. Res., 109, A03108.

The computational challenge: an enormous separation of scales in most astrophysical systems

- Macro-scale systems: MHD model
- Micro-scale: The exploration of energetic particle production during reconnection requires a kinetic treatment
- Coupling scales



From G. Lapenta