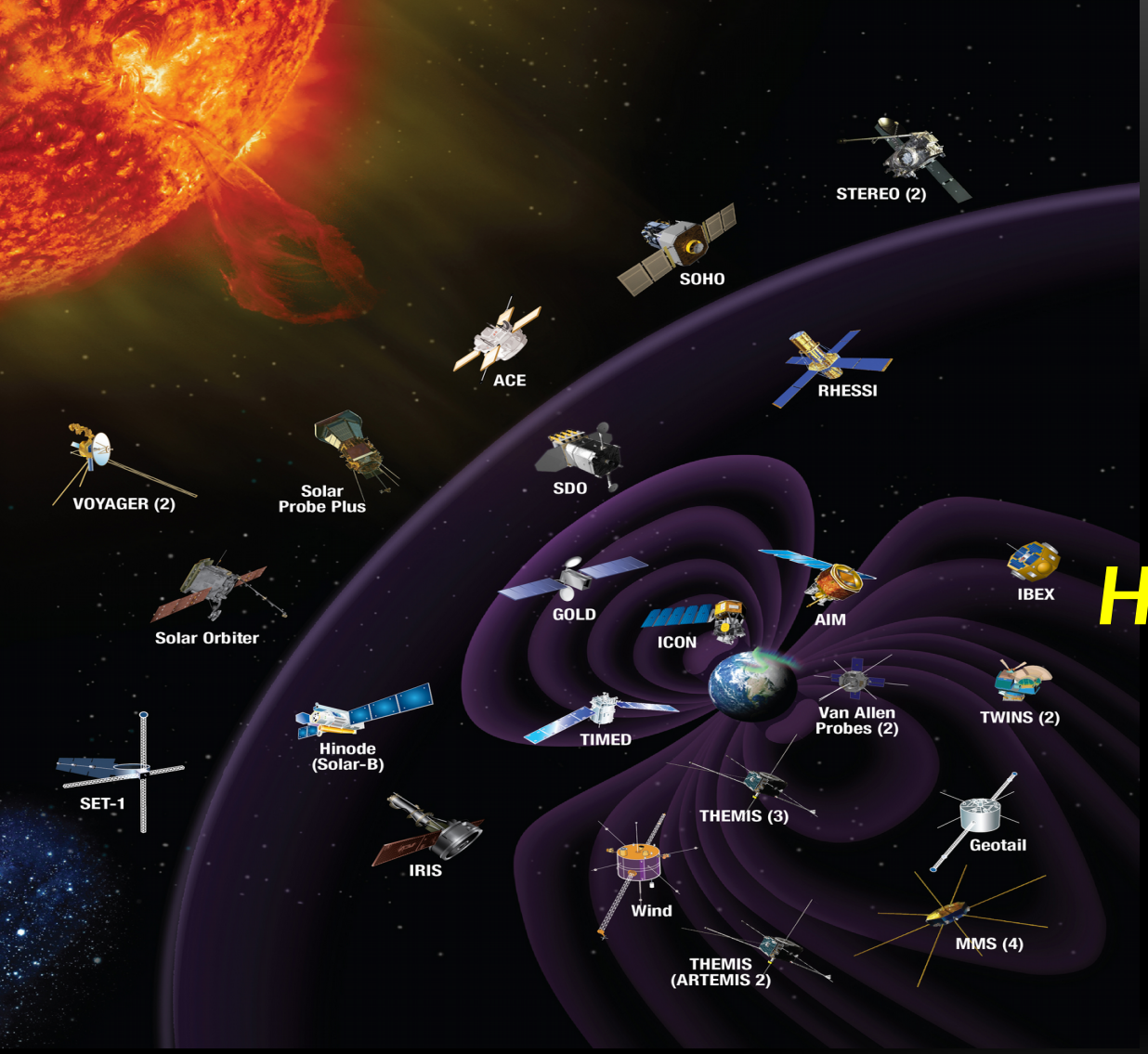

Tutorial

Magnetic reconnection in the age of the Heliophysics System Observatory

Li-Jen Chen
GSFC/UMD

Thank you for your contribution, Collaborators!

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Matt Argall
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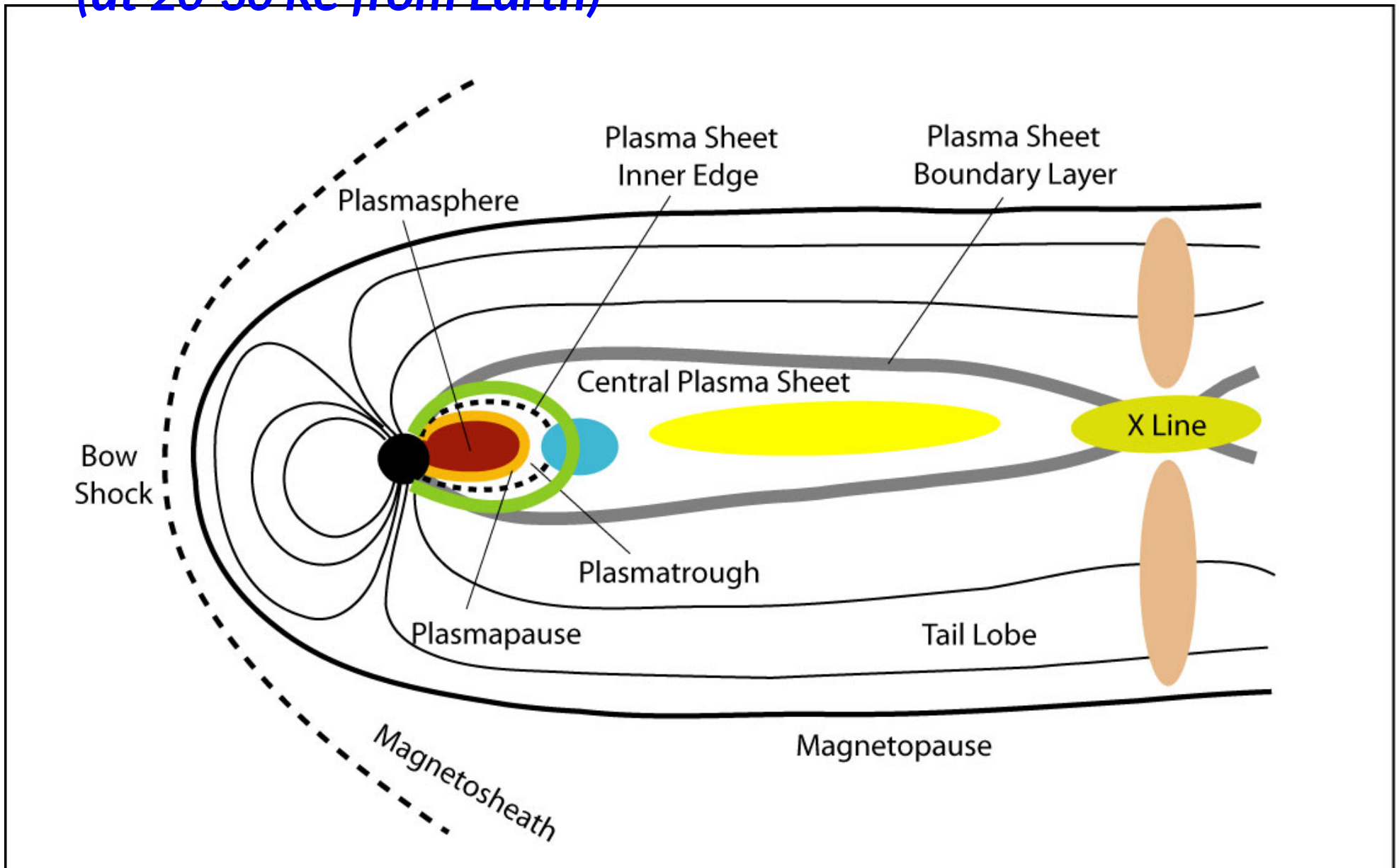
Guanlai Li
Ruilong Guo
Chris Mouikis
Ian Cohen
Barry Mauk

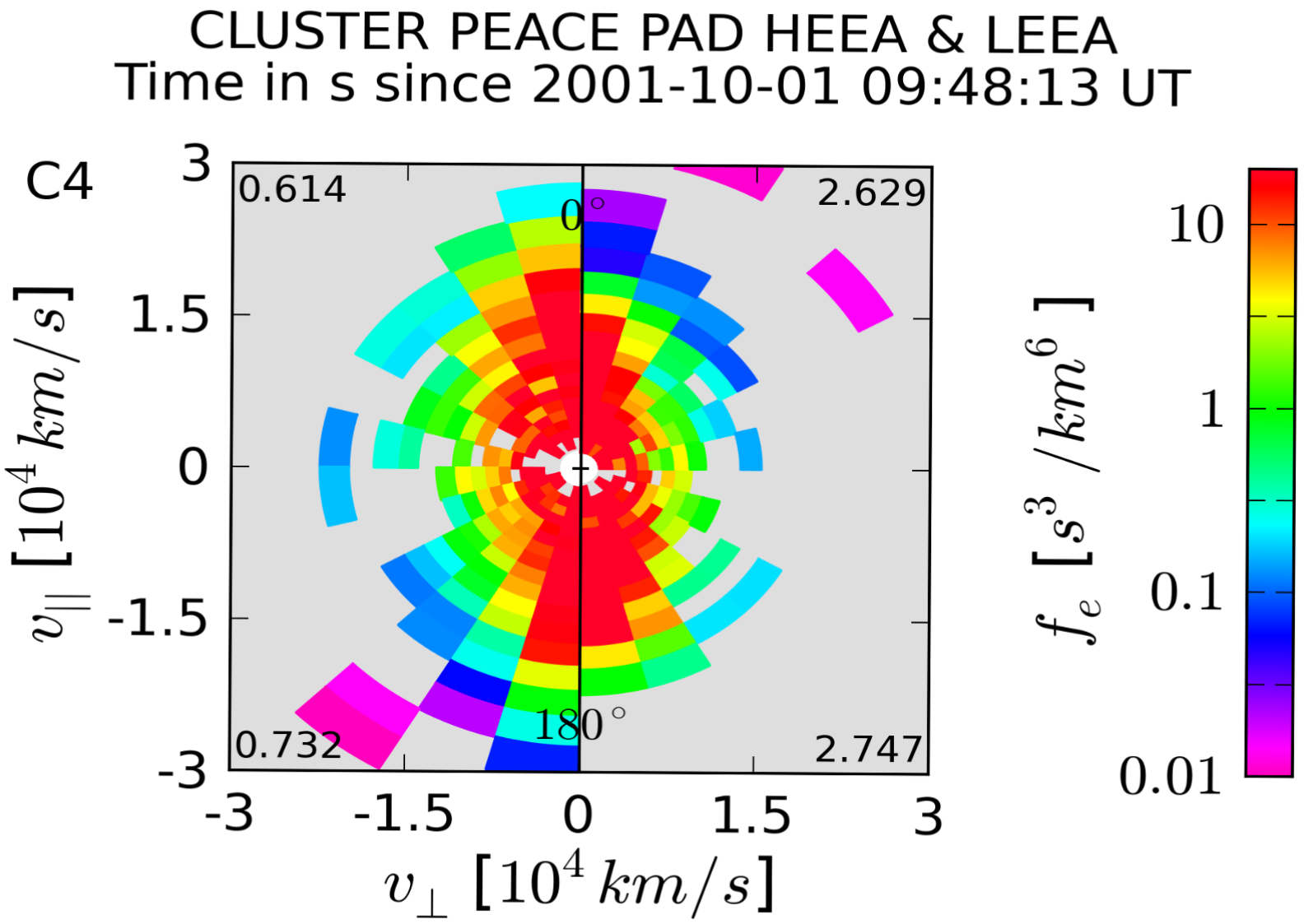
+

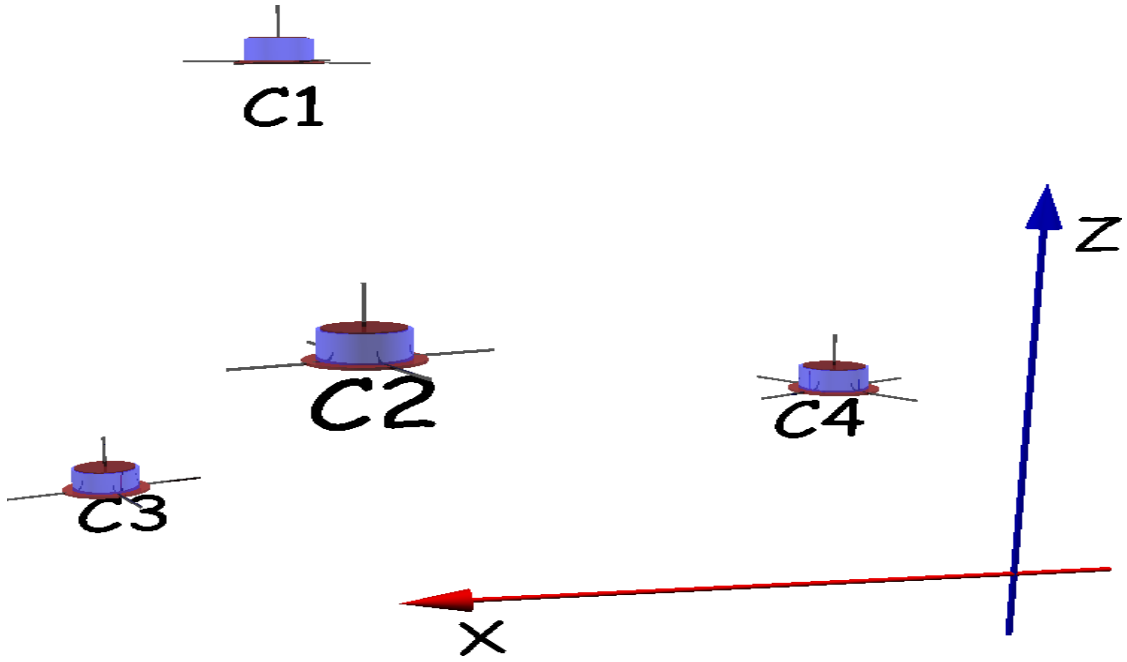
other MMS & CLUSTER team members

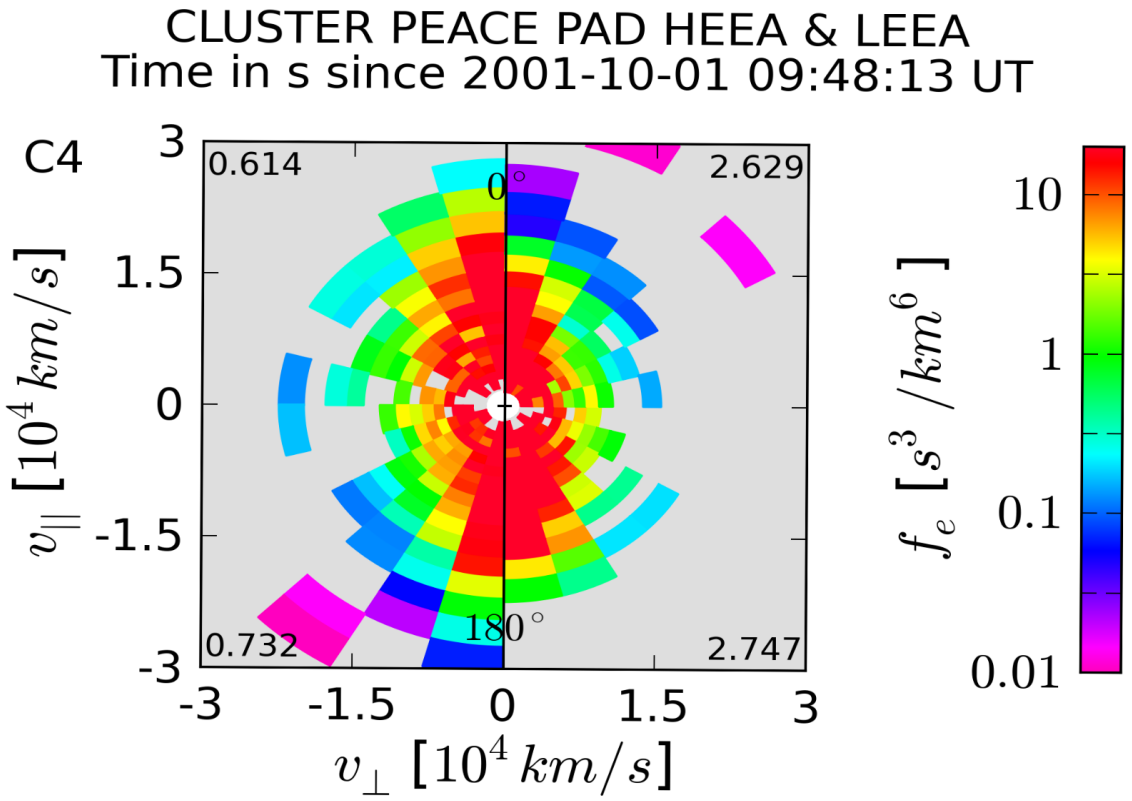
Quiet current sheet: Width ~ 1-3 Re (at 20-30 Re from Earth)

[Kaymaz et al., 2003; Petrukovich et al., 2007]




CLUSTER PEACE PAD HEEA & LEEA
Time in s since 2001-10-01 09:48:13 UT
C4
0.614
2.629
0.732
2.747
0°
180°
3
1.5
0
-1.5
-3
-3
-1.5
0
1.5
3
$v_{\parallel}$ $[10^4\,km/s]$
$v_{\perp}$ $[10^4\,km/s]$
10
1
0.1
0.01
f_e $[s^3/km^6]$


C1
C2
C3
C4
Z
X


CLUSTER PEACE PAD HEEA & LEEA
Time in s since 2001-10-01 09:48:13 UT
C4
0.614
2.629
0°
180°
0.732
2.747
3
1.5
0
-1.5
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-1.5
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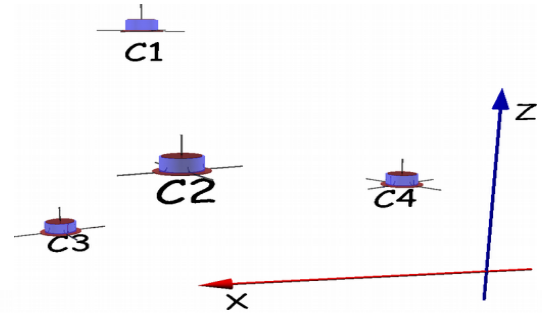
$v_{\parallel}$ $[10^4\, km/s]$
$v_{\perp}$ $[10^4\, km/s]$
f_e $[s^3/km^6]$
10
1
0.1
0.01



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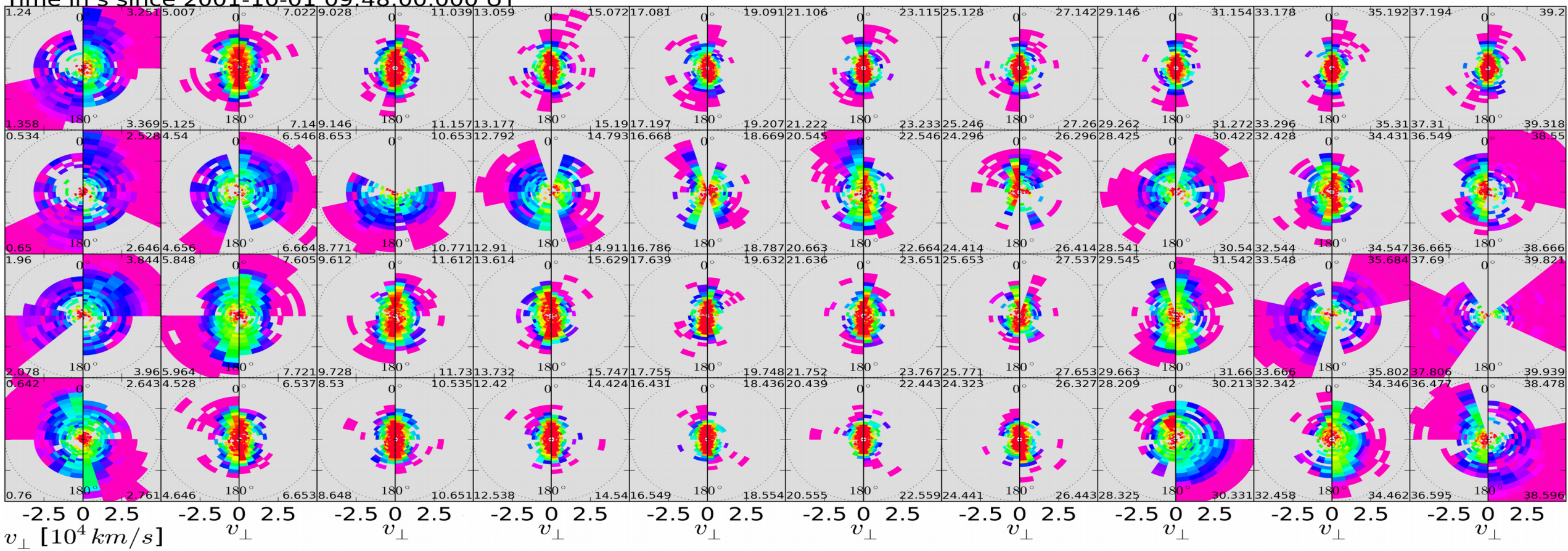
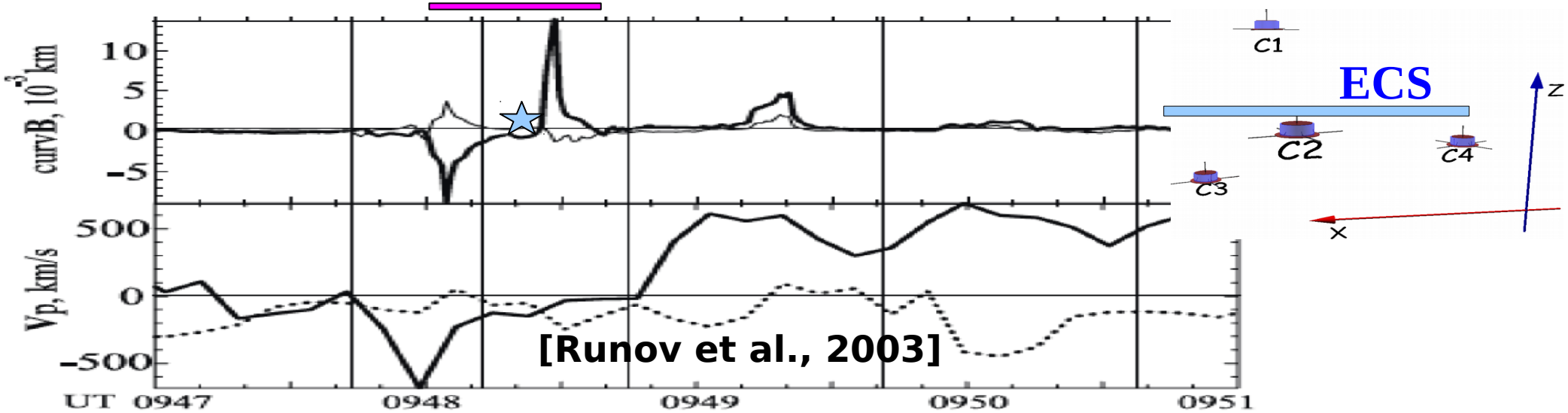
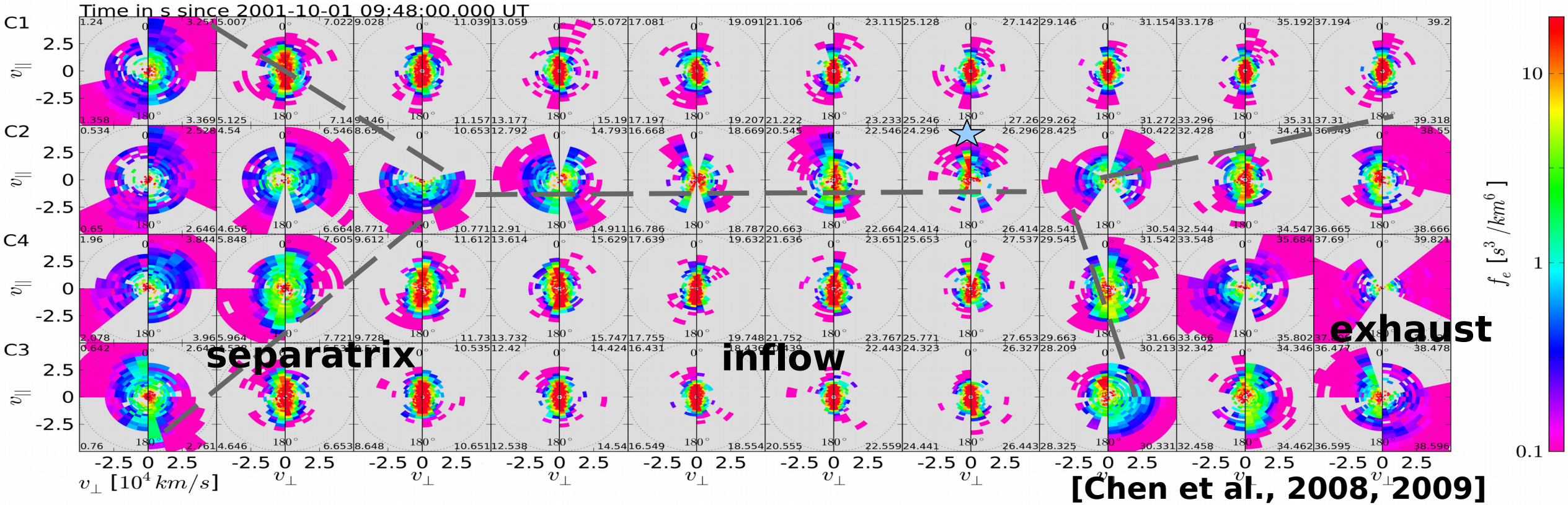


Cluster ECS crossing

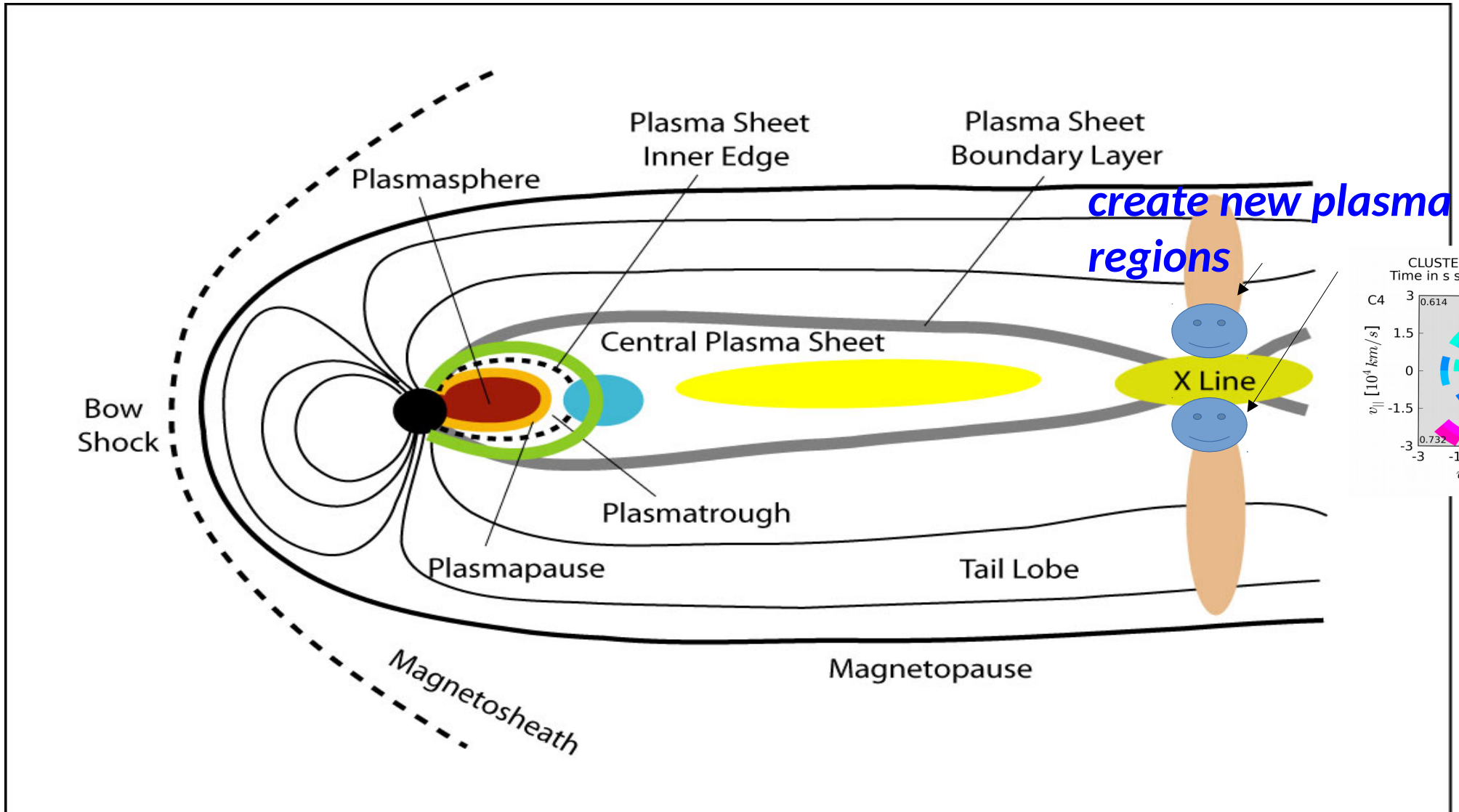


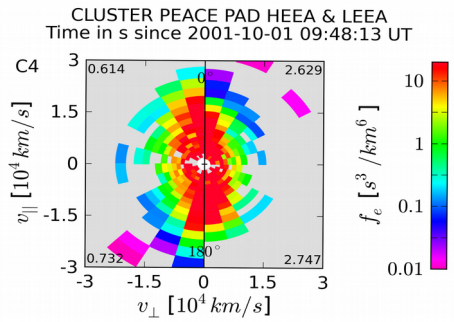
[Runov et al., 2003]



[Chen et al., 2008, 2009]

Quiet time and growth phase: Wcs ~ 1-3 Re (@20-30 Re from Earth)
During reconnection: Wcs < 160 km

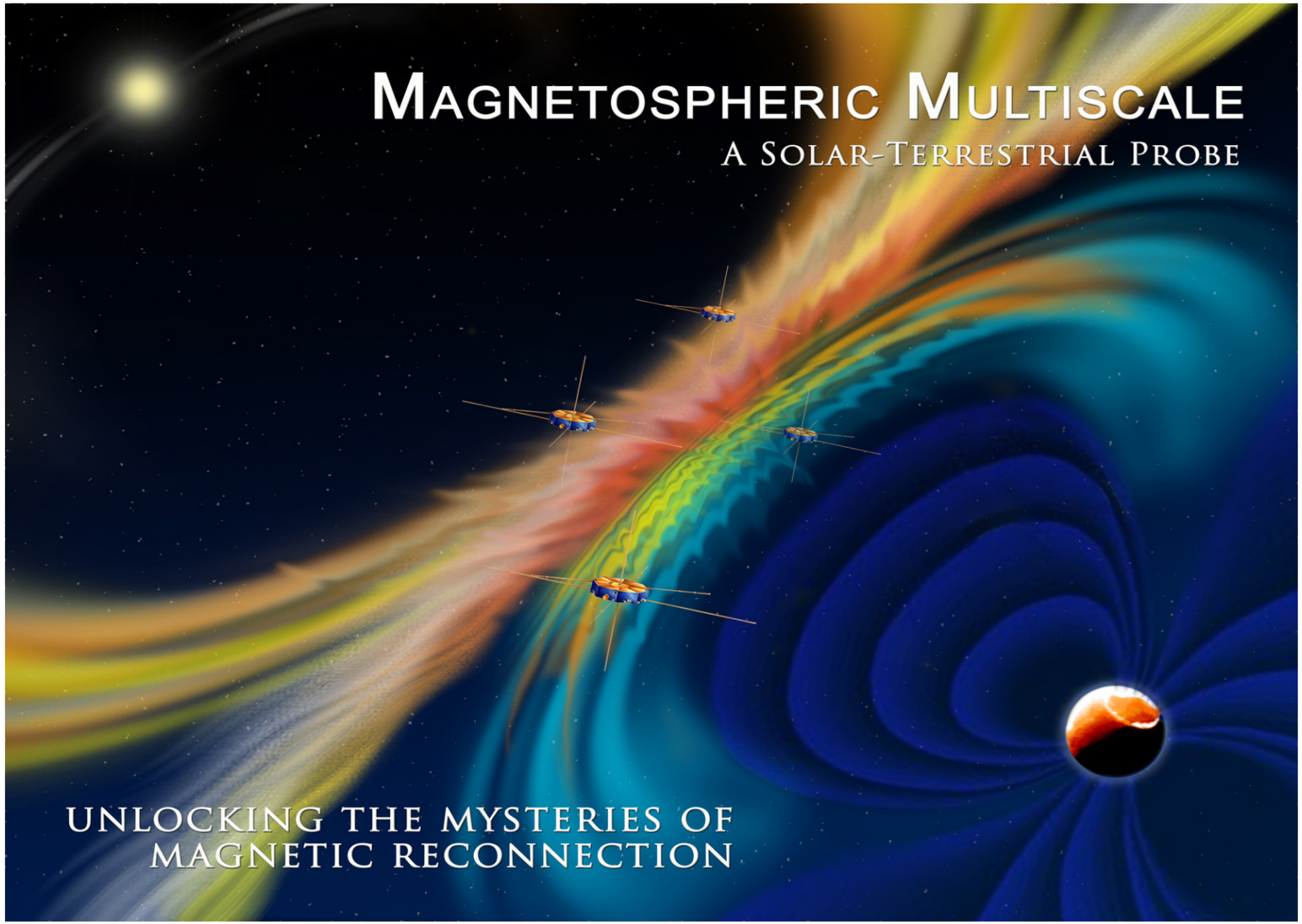


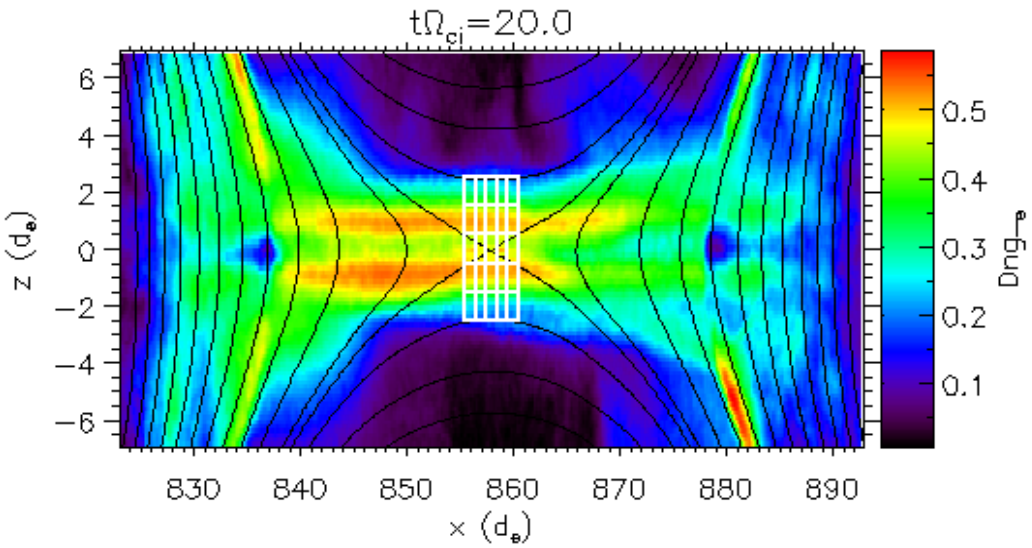


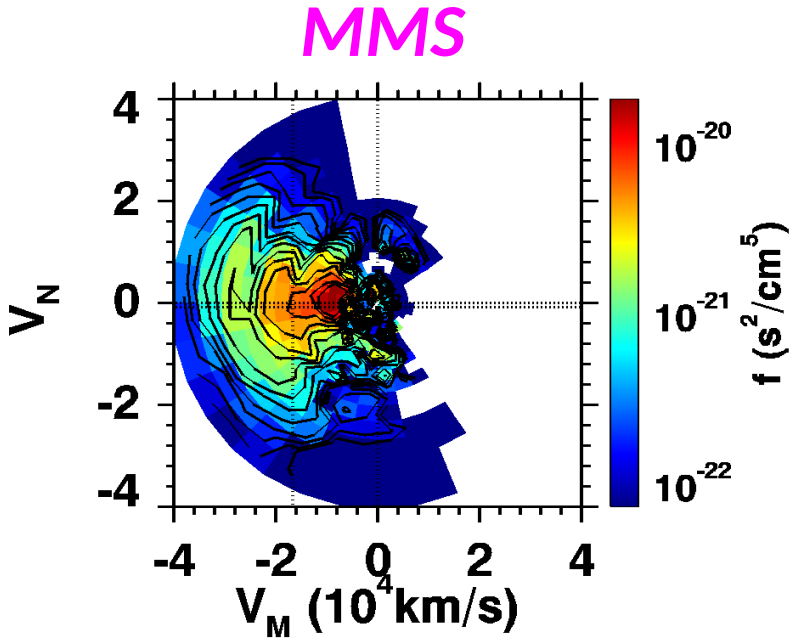
MMS: a fleet of 4 SC to unveil reconnection kinetic physics

- **3D eDFs:**
  30 ms (2 orders of magnitude higher cadence than ever)
- **3D iDFs:**
  150 ms

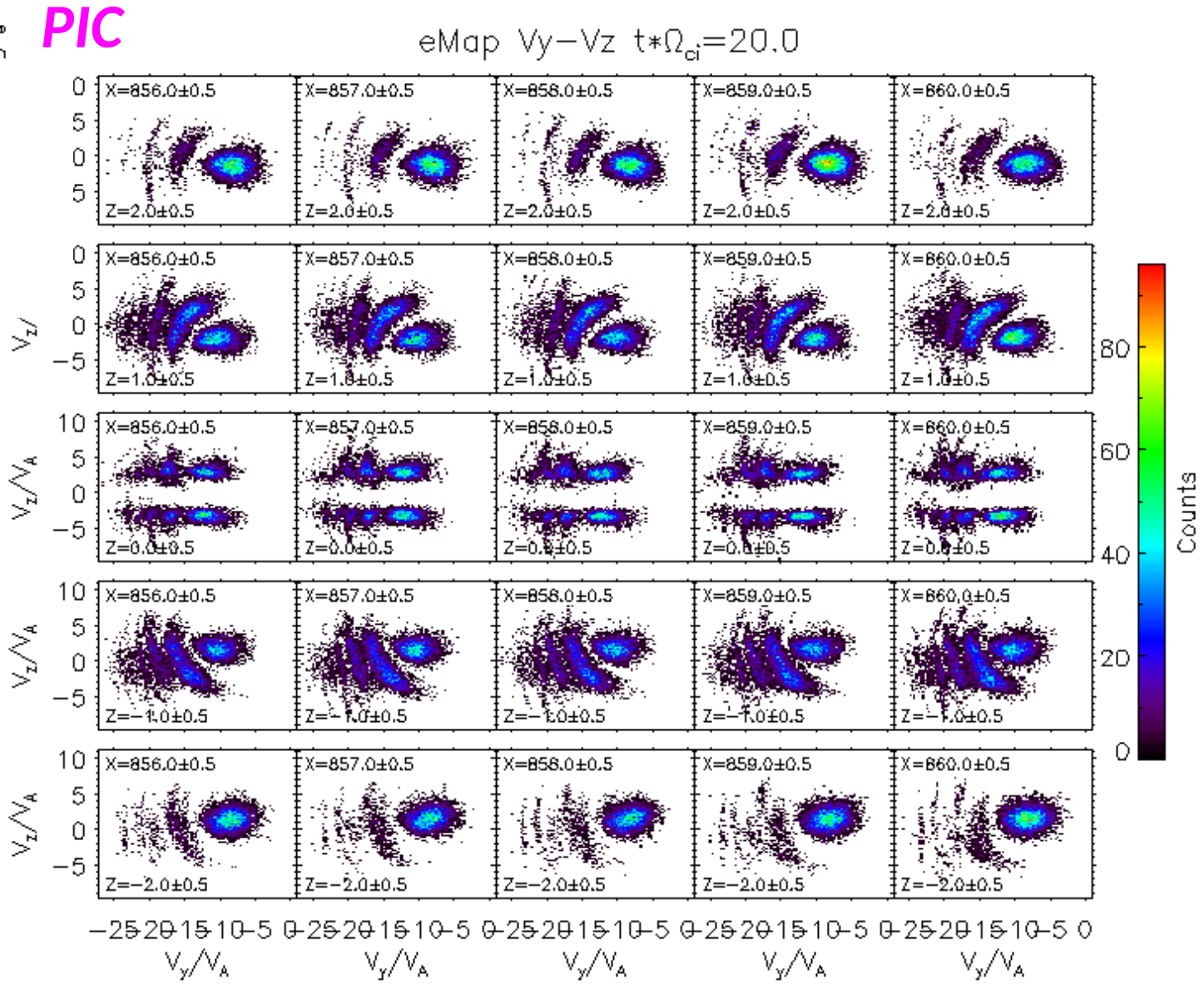
Continuous w/o data gaps!

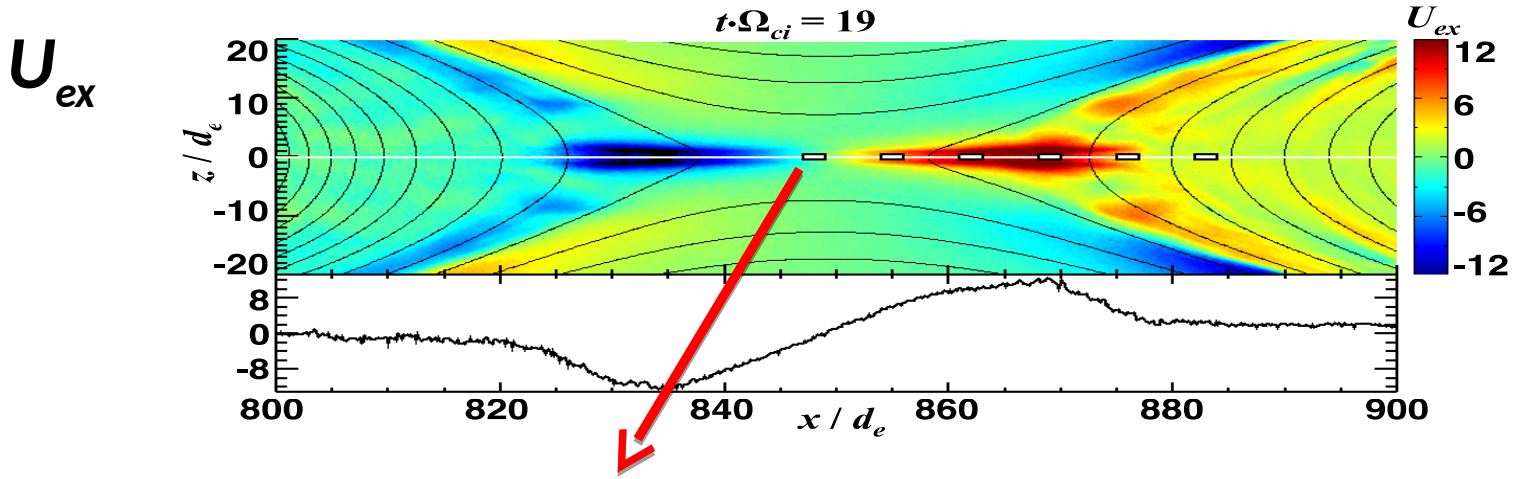


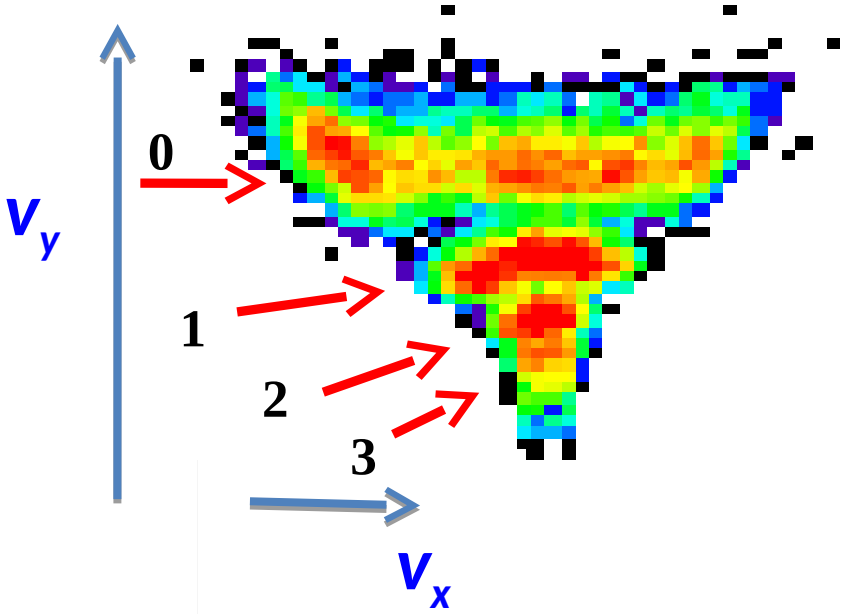




[Torbert et al., 2018]







X-line distribution → these accelerated e's will be ejected from the reconnection layer...and precipitate into the ionosphere?

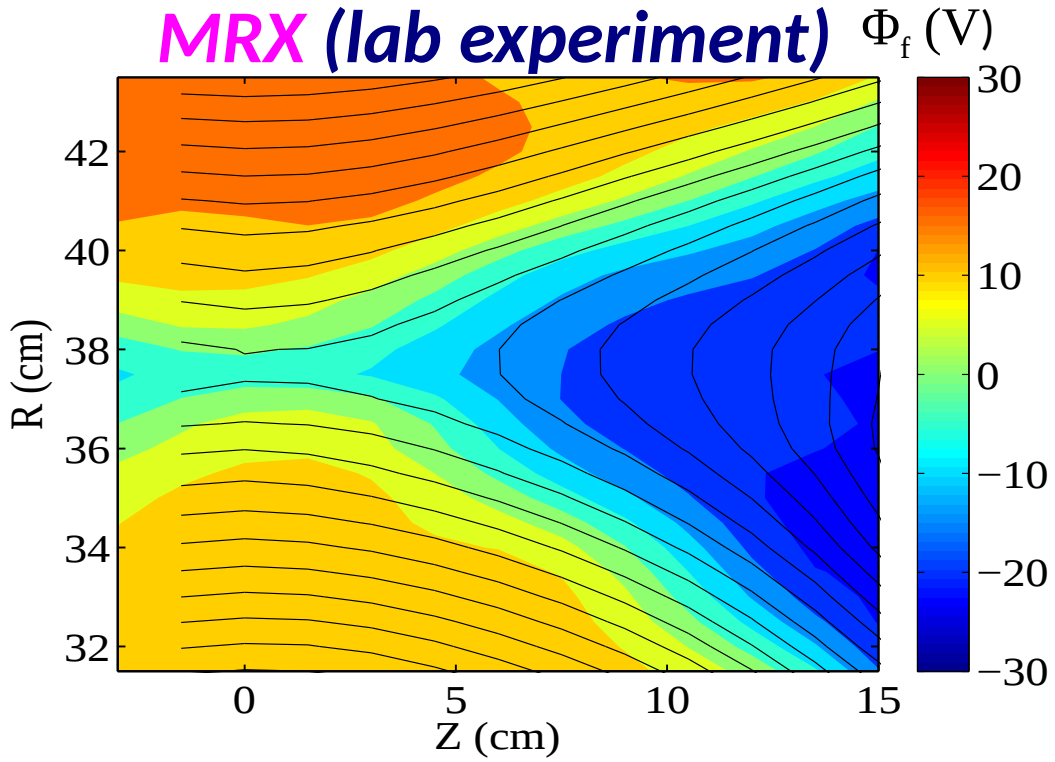
discrete populations with different # of bounces and amount of acc

[Shuster et al., 2015; Bessho et al., 2014]

In-plane electrostatic potential observed by CLUSTER and in PIC and MRX

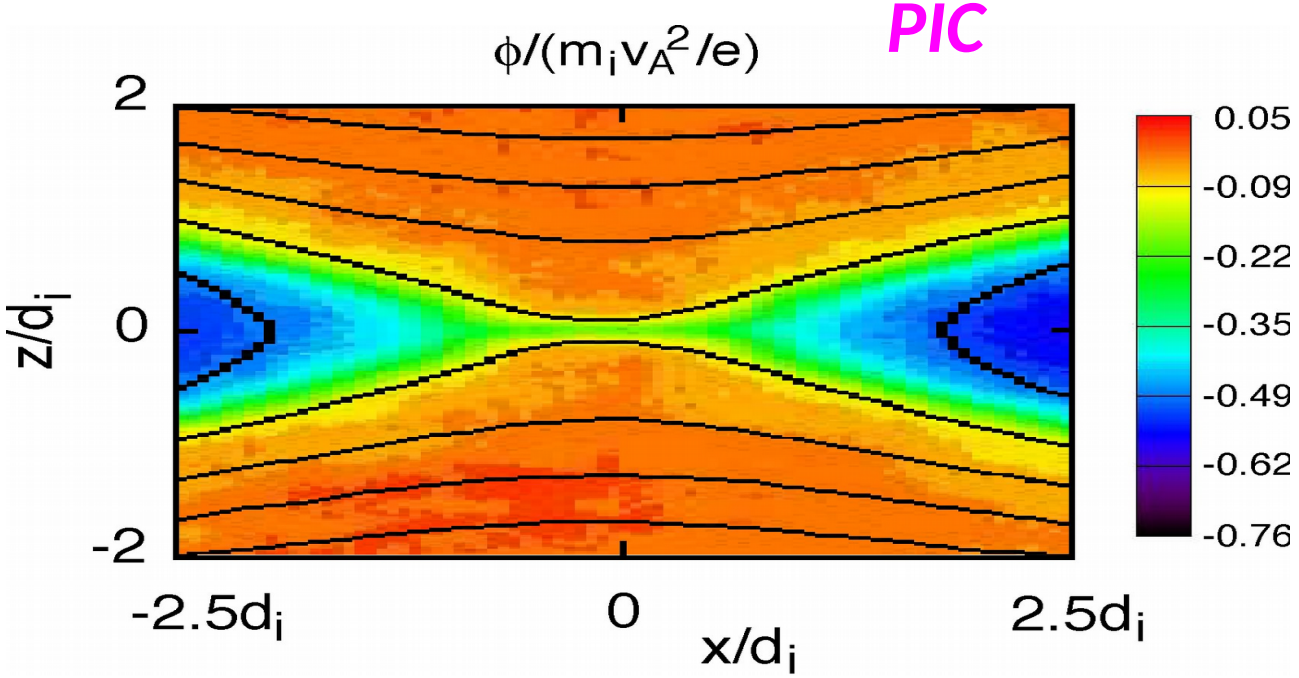
[Wygant *et al*, 2008]

MRX (lab experiment)



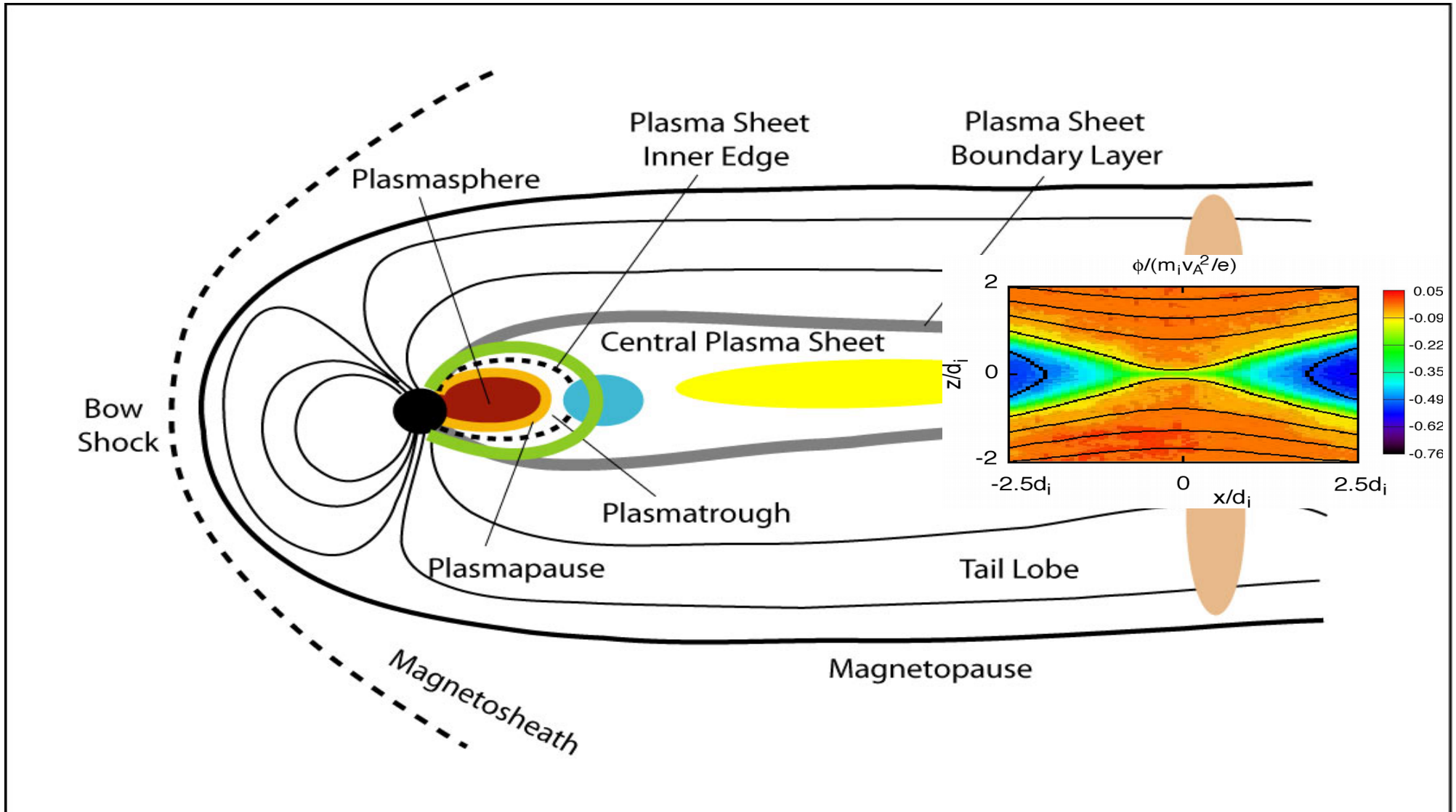
[Yamada *et al*, 2014]

PIC



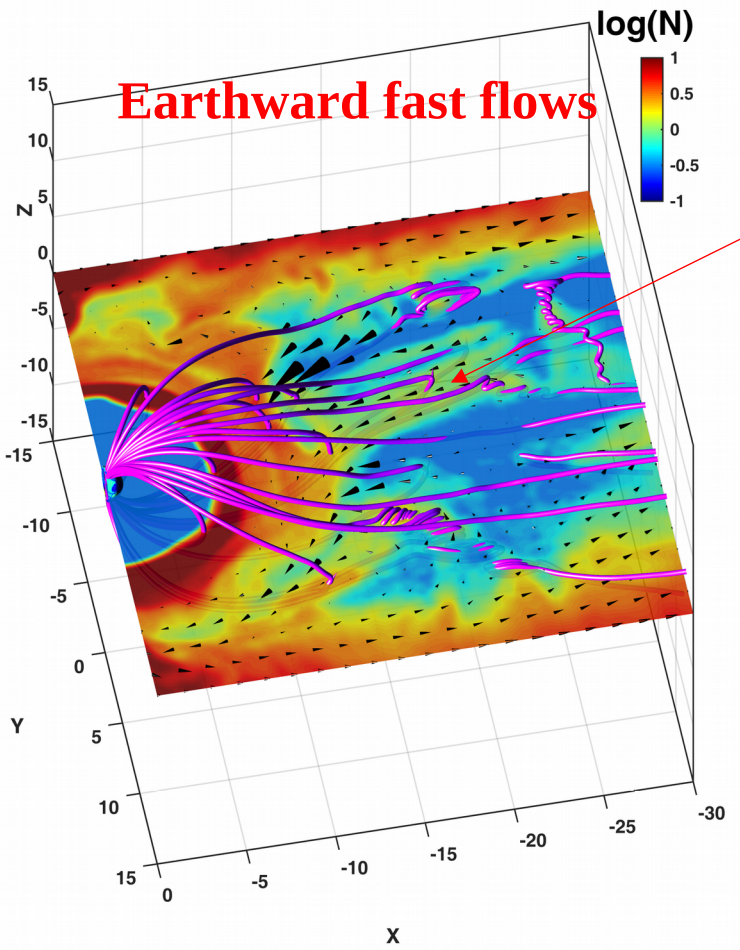
[Chen *et al*, 2008]

How does the electrostatic potential (and fields) set up by reconnection 'globalize'?



Impact of earthward fast flows on the ring current

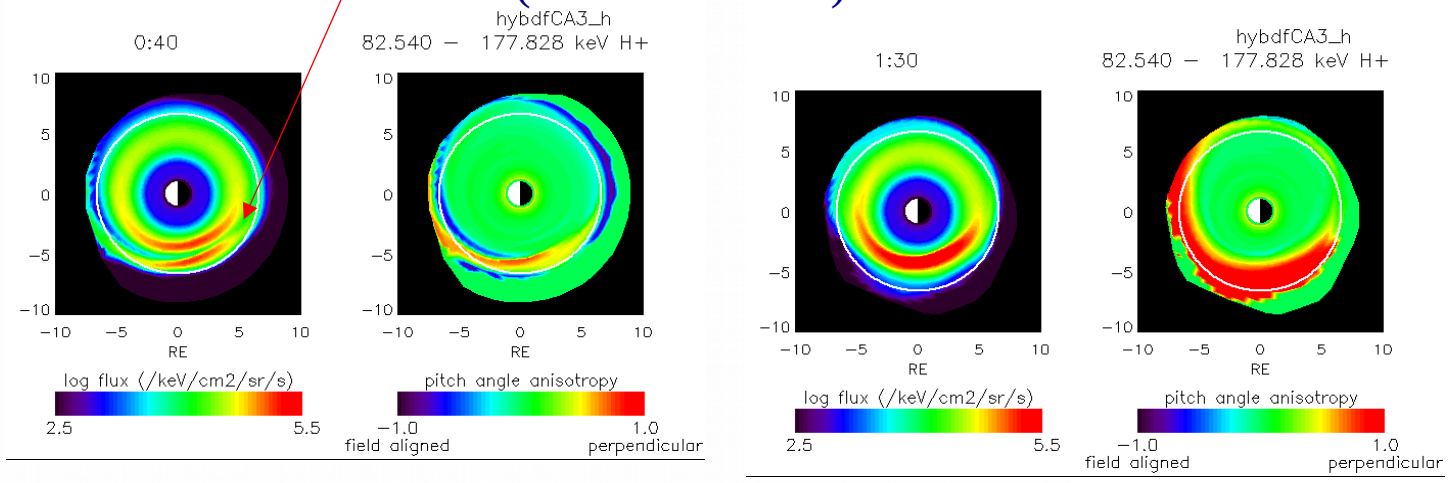
Global Hybrid Model → CIMI equatorial H^+ flux



t = 0:40 min
Injection from the tail

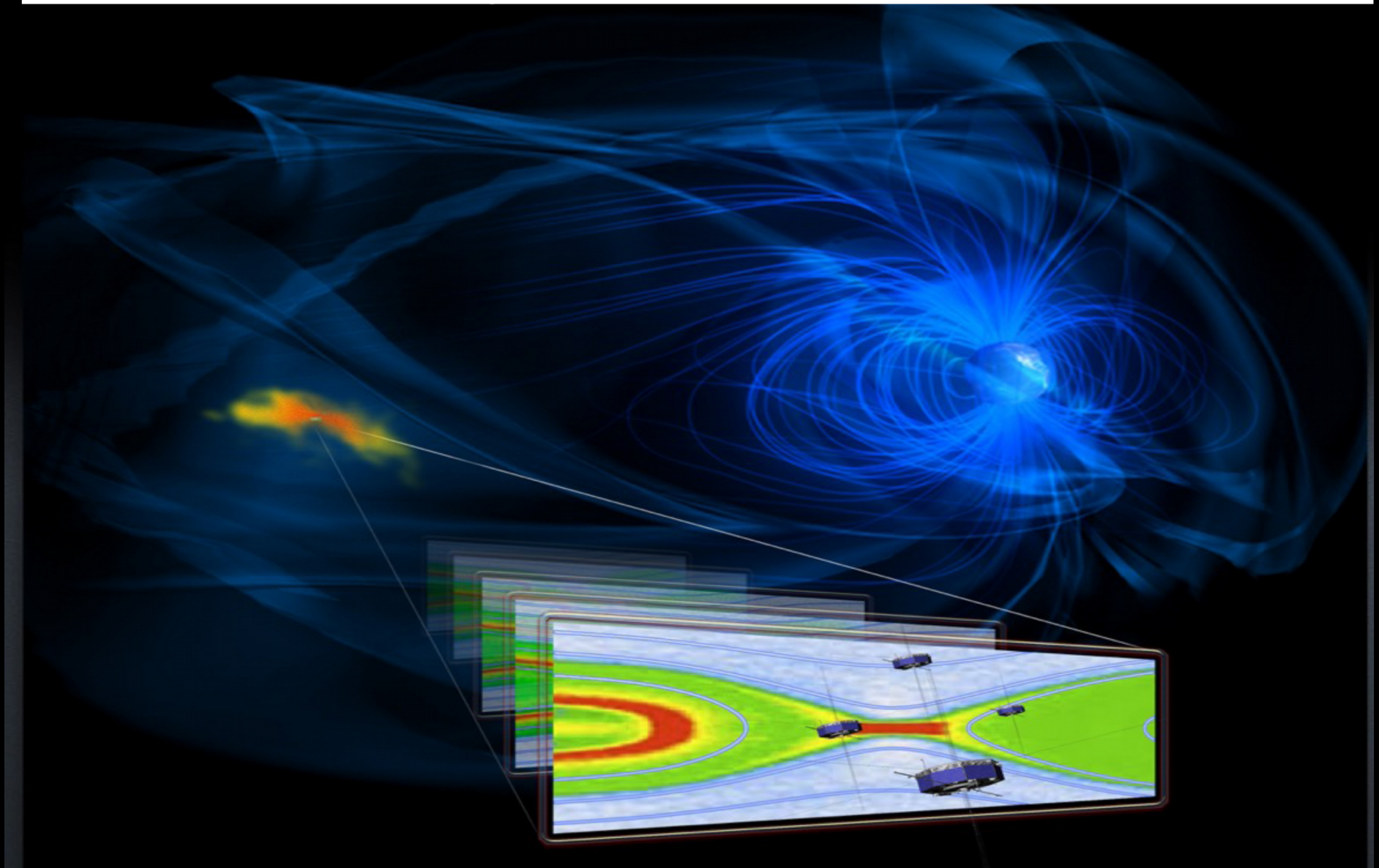
t = 1:30 min
Penetration to L~3

(82.5-177.8 keV)



Yu Lin, Xueyi Wang, Mei-Ching Fok, Natalia Buzulukova, J. D. Perez, Li-Jen Chen, and Lei Cheng

Connecting local processes and global dynamics



Relation between local reconnection and global dynamics

Global polar cap potential derived from data and simulation; reconnection rate along the 3D X-line [Cassak et al., 2017]

whether the global reconnection rate is determined only by solar wind parameters or affected by ionosphere/magnetosphere condition, [e.g., Borovsky et al., 2008, 2014; Zhang et al.2016]

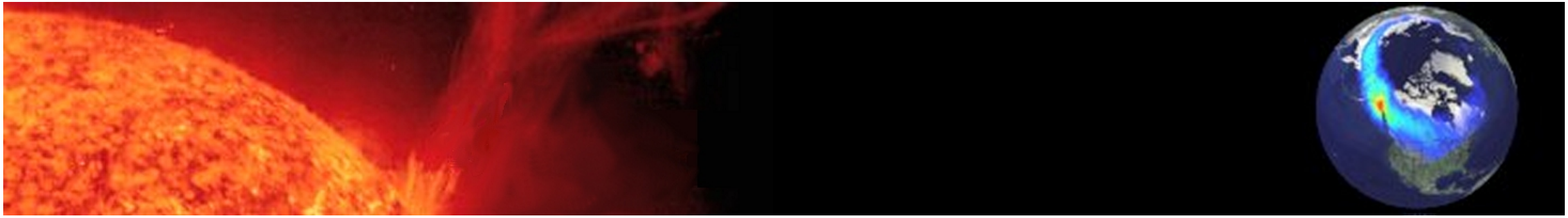
Comparison of X-line location inferred by MMS observation with global model predictions [Trattner et al., 2016]

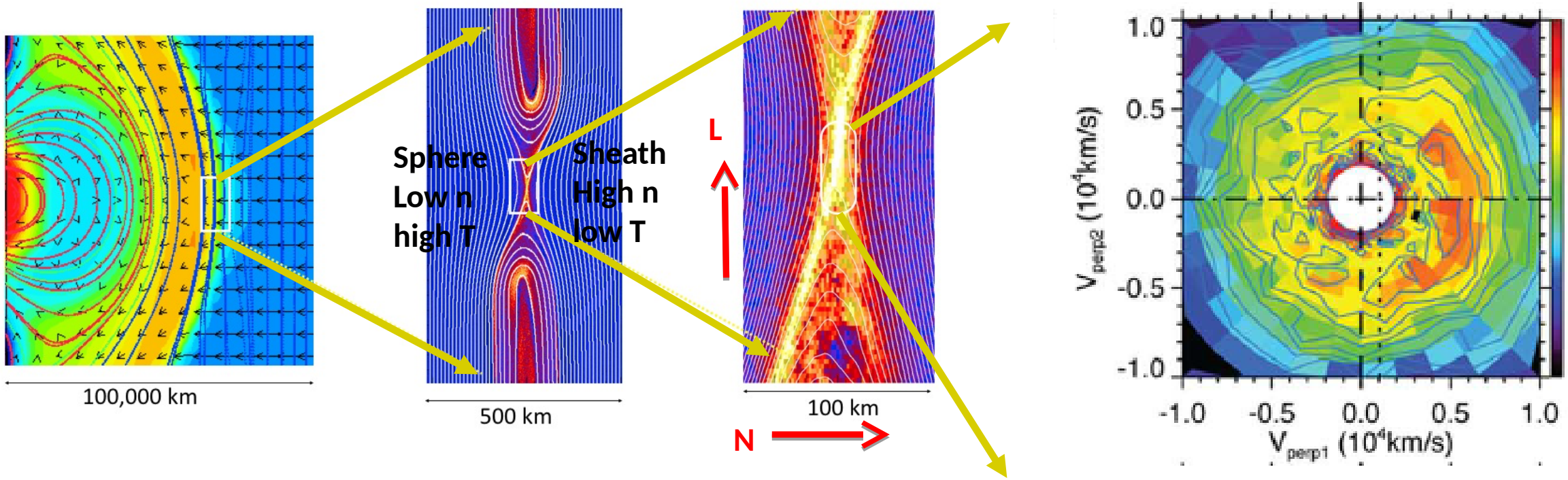
Nightside reconnection affects field-aligned currents that map to the ionosphere [e.g., Birn and Hesse 1991]

3D behaviors of reconnection

Where does 2D fail?

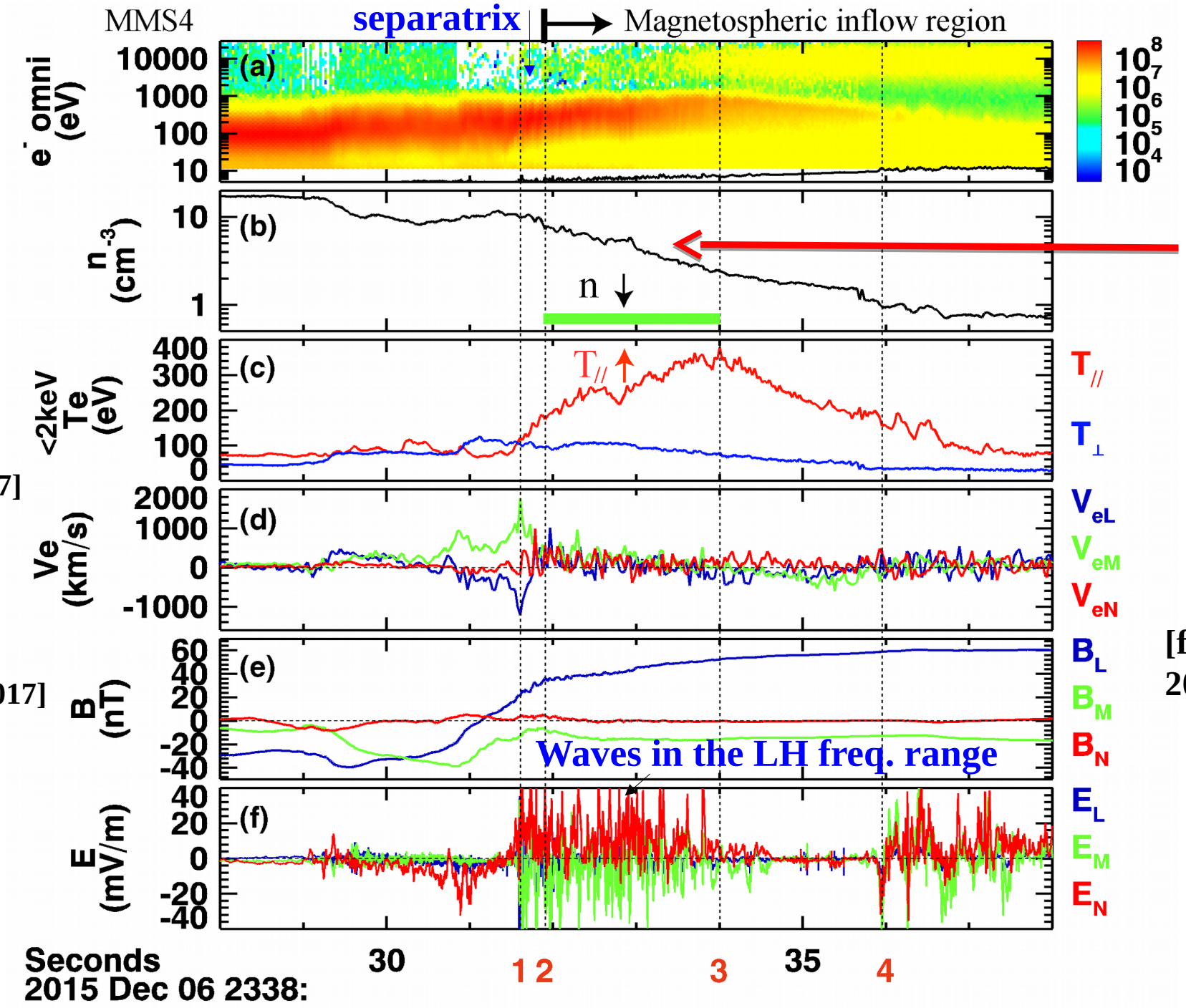
- **An example: A new electron region populated by Msheath-like e's in the magnetosphere inflow region...**





[Burch et al., 2016]

Electron velocity distributions from MMS reveal e dynamics in the diffusion region



2D fails here!

Violating the scaling law,

$$T_{e||} \propto n^2/B^2$$

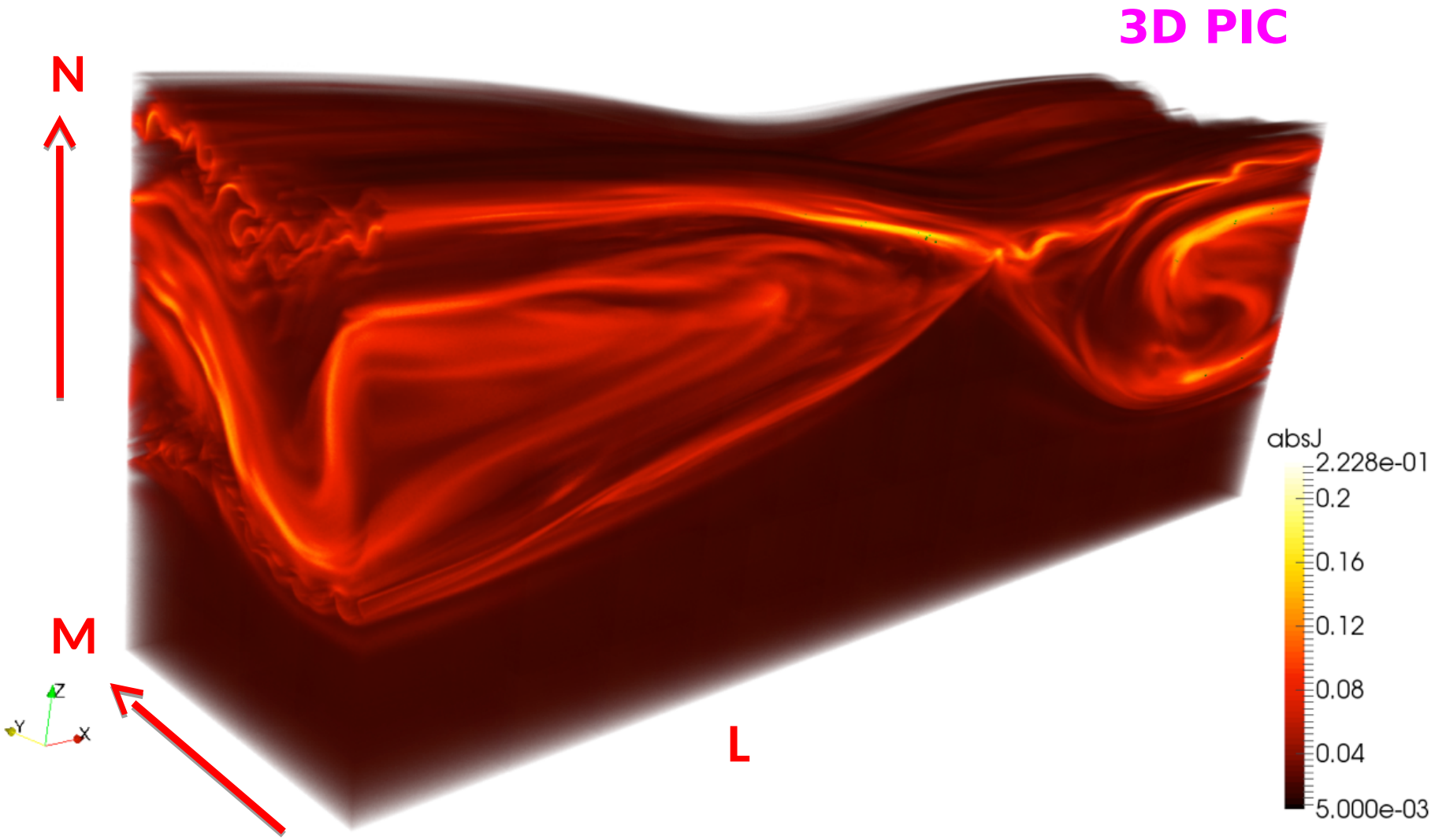
[from Le et al., 2009, 2017]

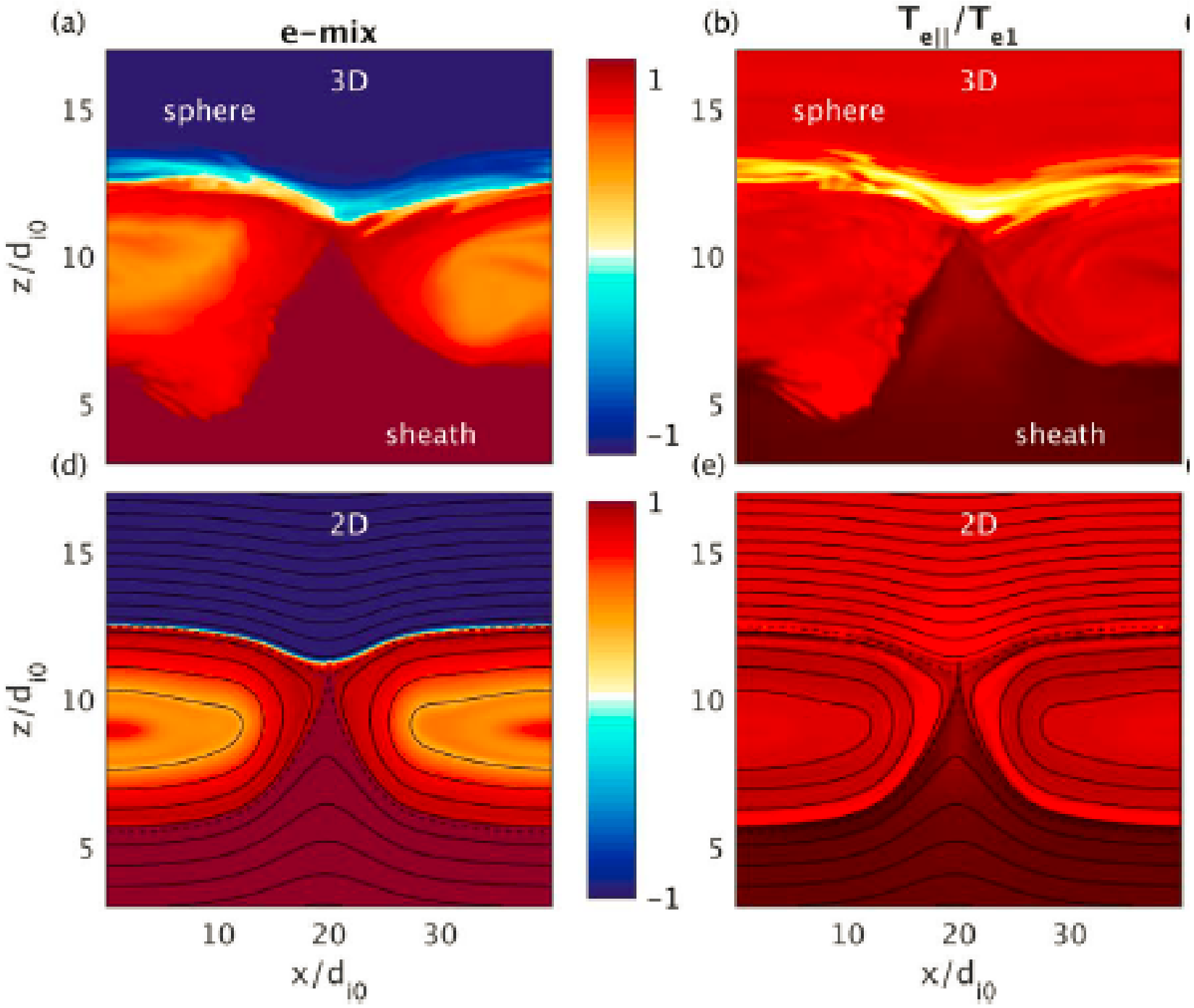
[Wang et al., 2017]

[Khotyaintsev et al., 2016; Graham et al., 2017]

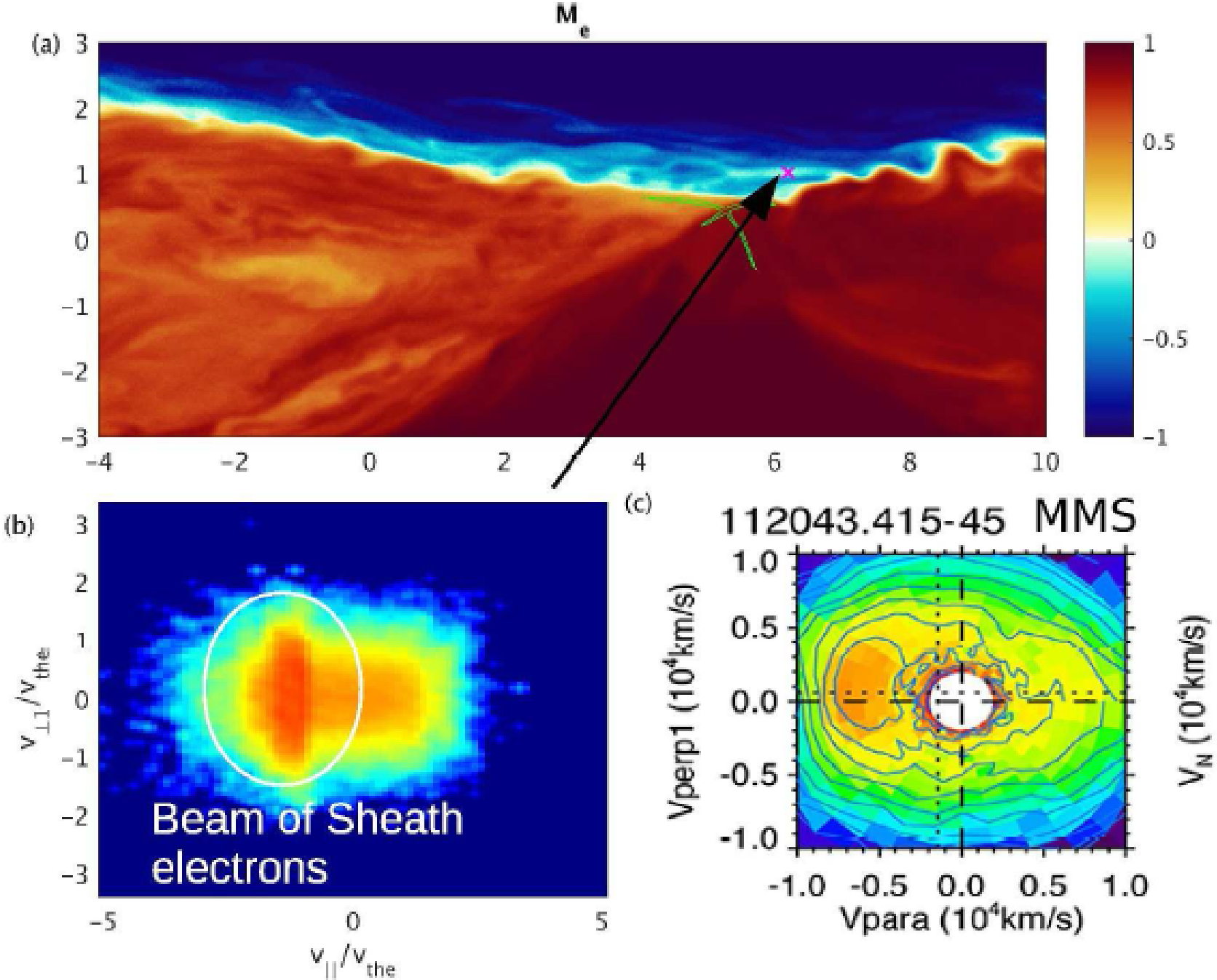
Enhanced transport of sheath e's due to LH turbulence

[Le et al., 2017]



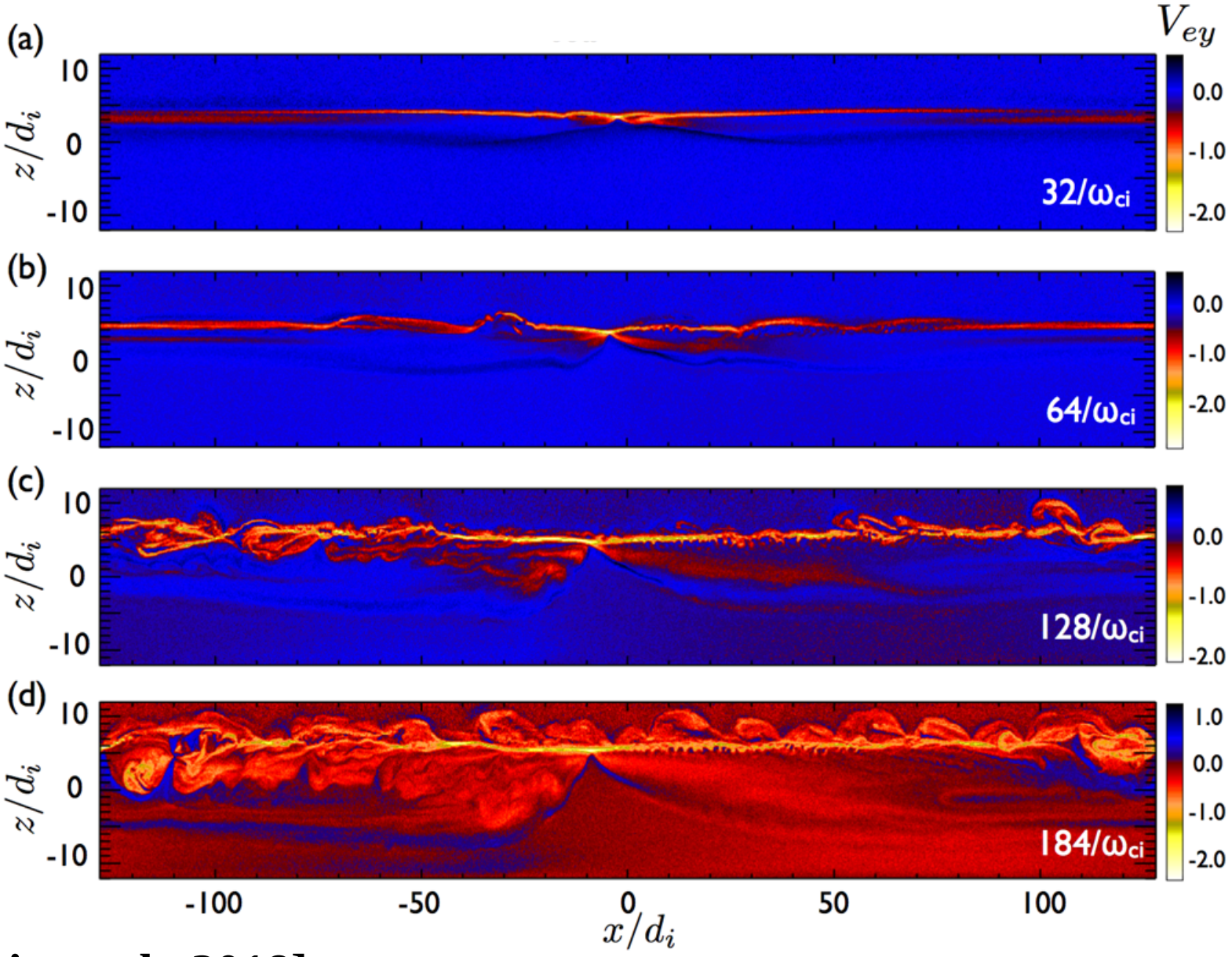

(a)
e−mix
3D
sphere
sheath
(b)
$T_{e||}/T_{e1}$
3D
sphere
sheath
(d)
2D
(e)
2D
z/d_{i0}
x/d_{i0}
15
10
5
10
20
30
1
−1

[Le et al., 2017]


(a)
M_e
(b)
$v_{\perp 1}/v_{the}$
$v_{||}/v_{the}$
Beam of Sheath electrons
(c)
112043.415-45 MMS
Vperp1 (10^4km/s)
Vpara (10^4km/s)
V_N (10^4km/s)

[Le et al., 2018]

Reconnection and turbulence in 3D

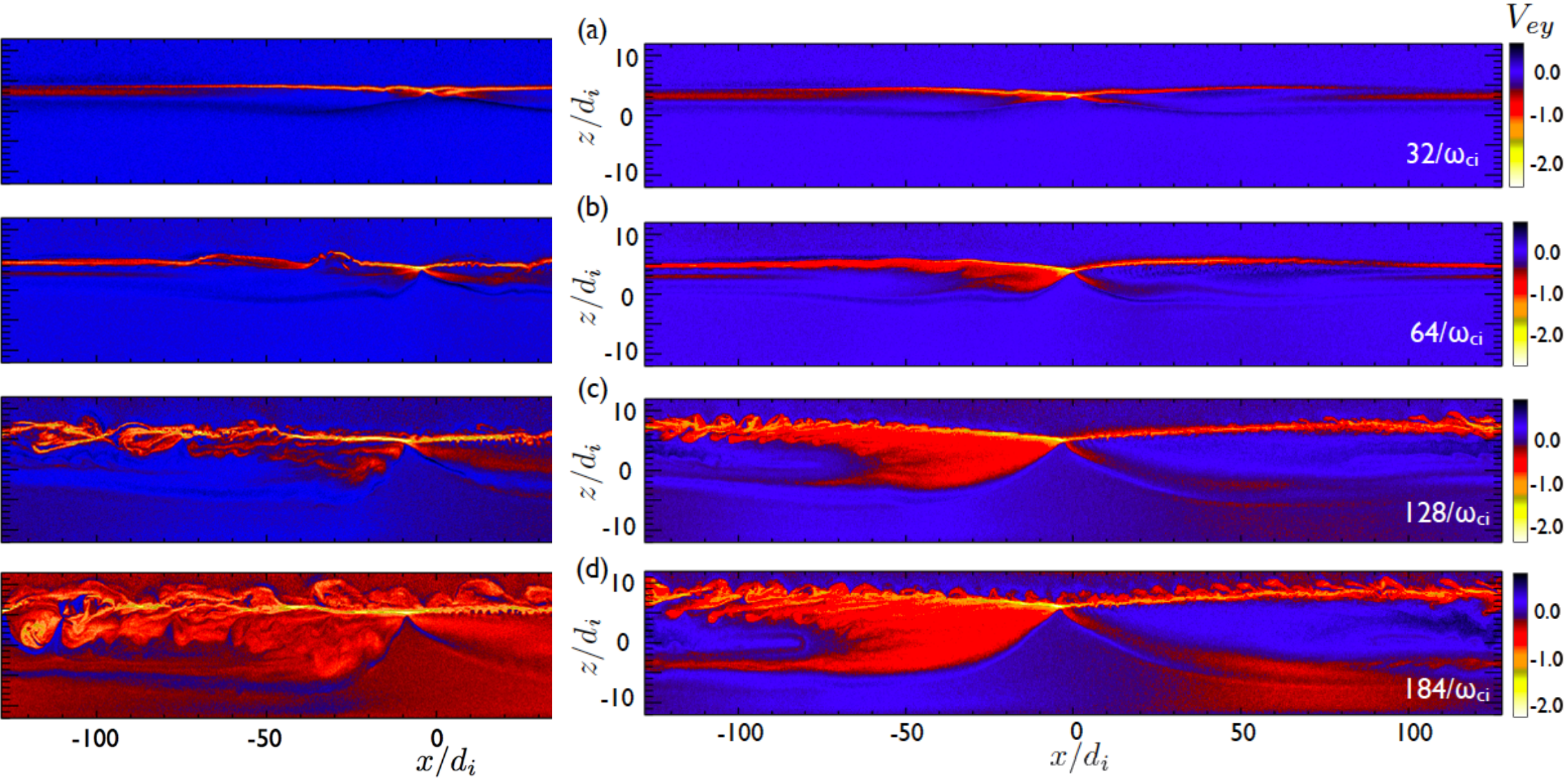


'Frustrated' X-line generates more turbulence

[Liu et al., 2018]

Reconnection and turbulence in 3D

'Realized' X-line, more stable



[Liu et al., 2018]

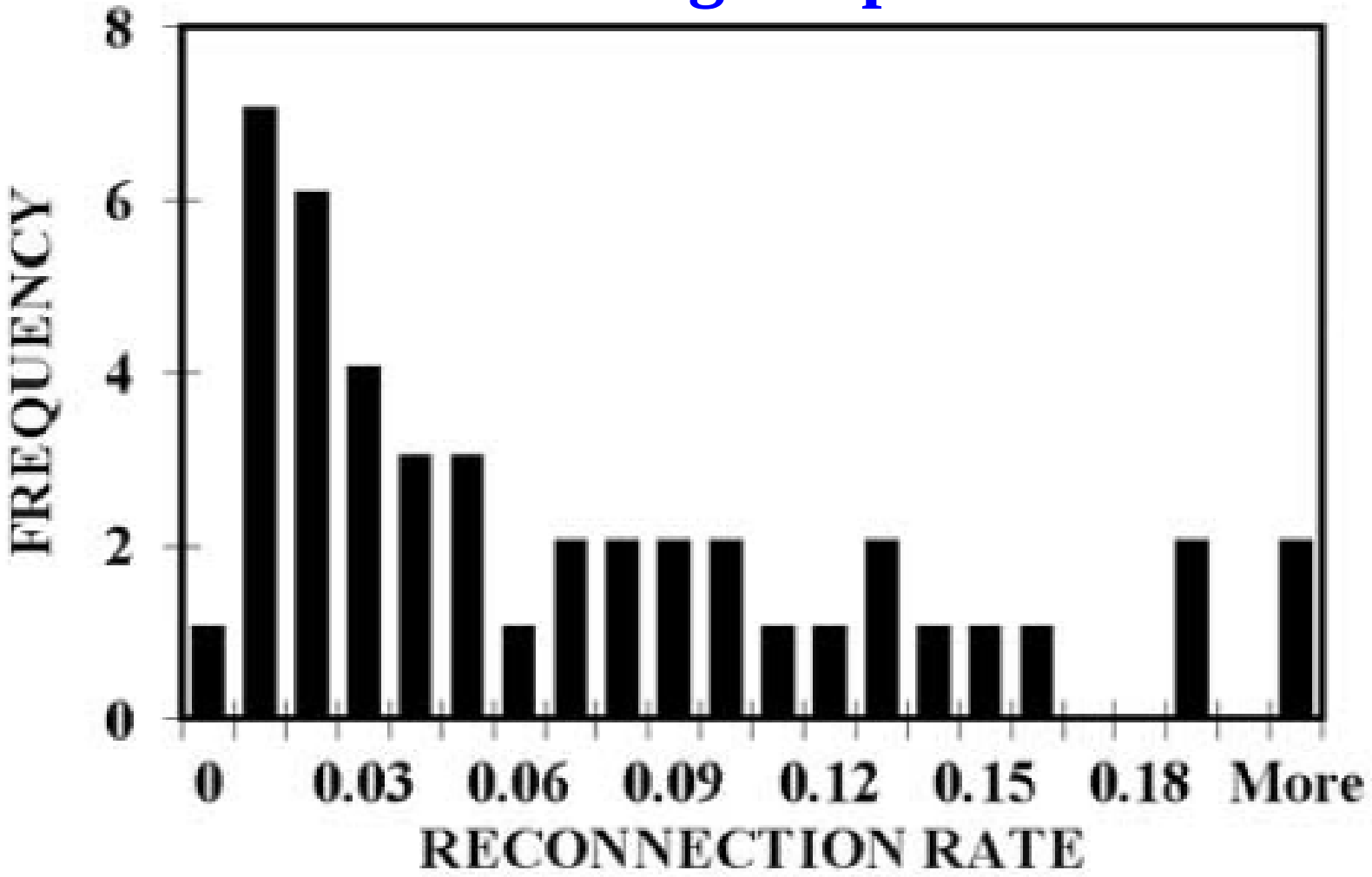
Other 3D behaviors of reconnection

Kink-mode in magnetotail
[Sergeev et al., 2003; Karamabadi et al., 2003]
Lower-hybrid waves at magnetopause
[Le et al., 2017, 2018; Price et al., 2016, 2017; Wang et al., 2017; Graham et al., 2016, 2017]
Out-of-plane variations
[Genestreti et al., 2018; Chen et al., 2016; Zhou et al., 2018]

X-line expansion speed:
Simulation and theory: no guide field, speed of the current carrier, [e.g., Lapenta et al, 2016]; **with guide fields, VA based on guide field,** [e.g., Shepherd and Cassak, 2012]
THEMIS and SuperDarn dayside observation: weak guide field, either VA or current carrier speed; strong guide field, current carrier speed [Zou et al., 2017]

Determining the reconnection rate

Magnetopause

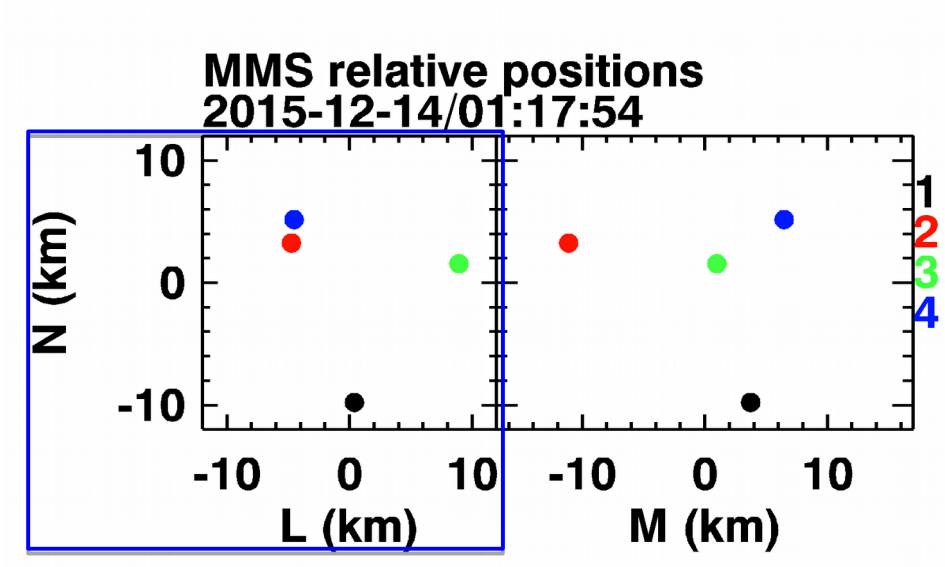


[Mozer et al., 2007]

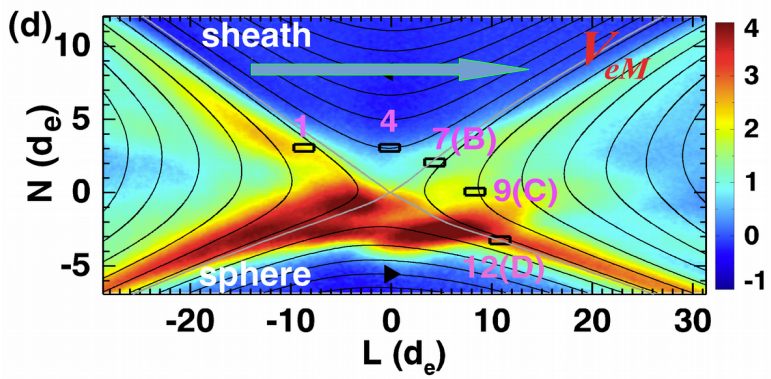
Other measurements of the reconnection rate

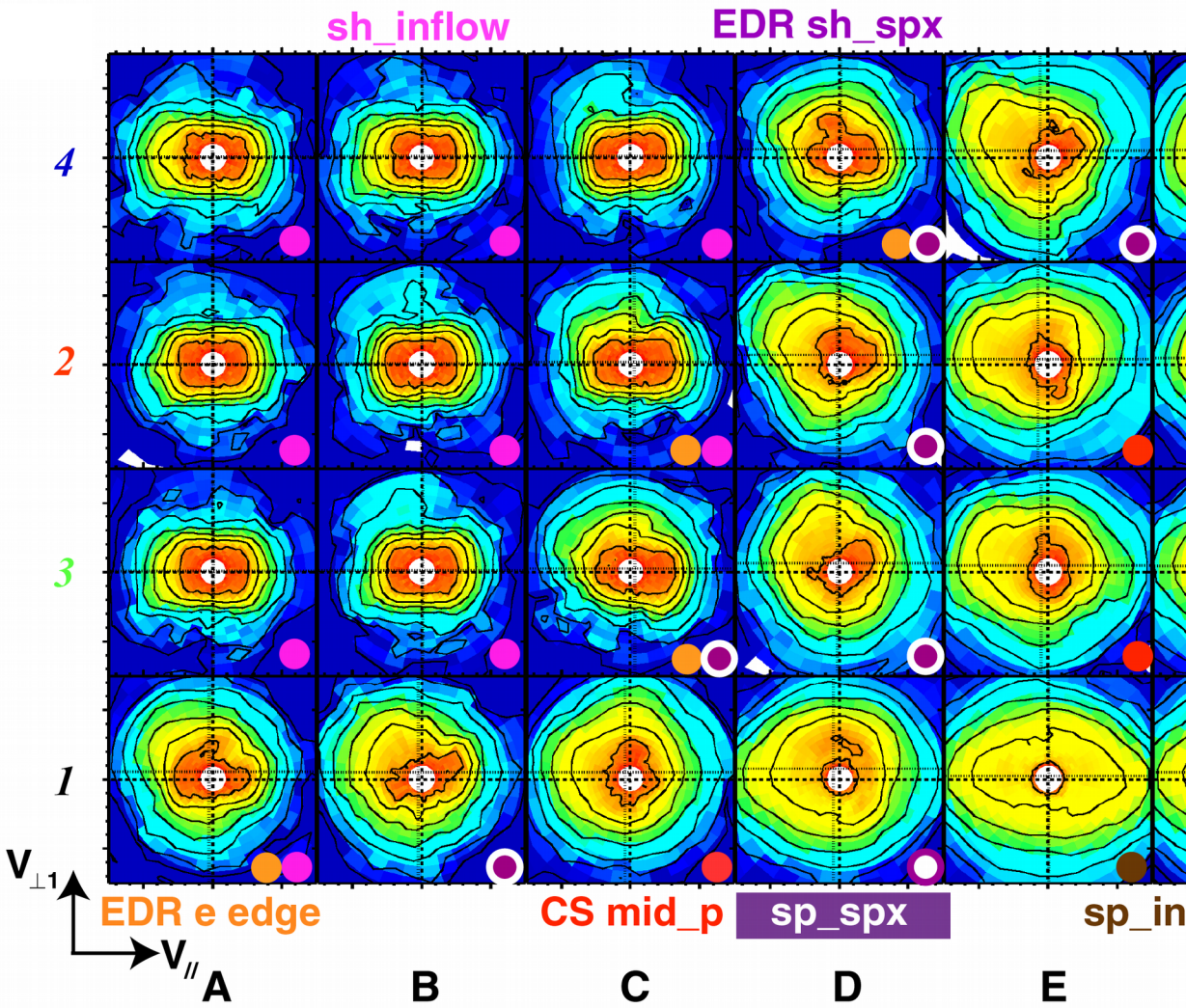
e.g. Phan et al., 2001; Mozer and Retino, 2007; Wang et al., 2015; Chen et al., 2017

"Photo" the reconnection region with eDFs



1de~2km

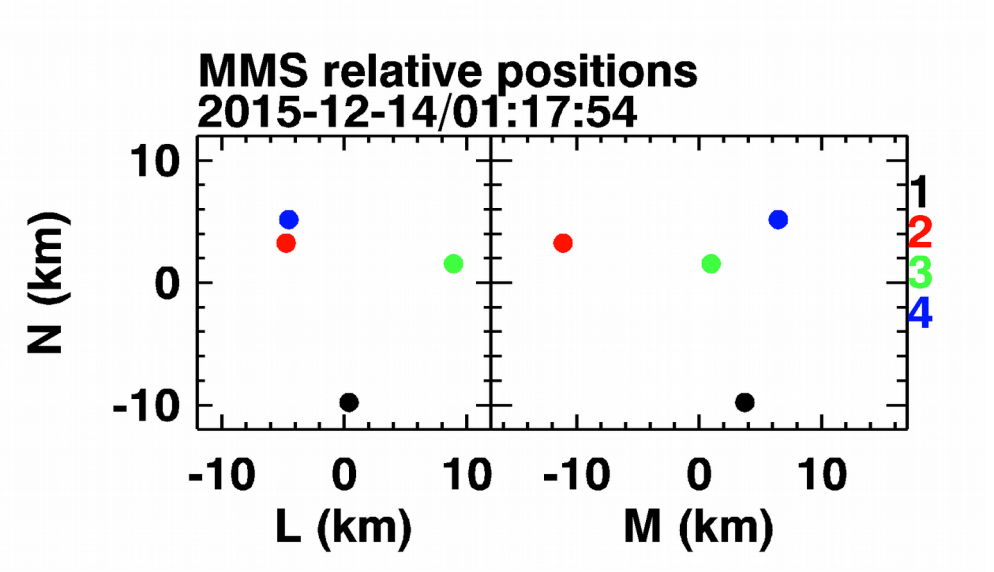


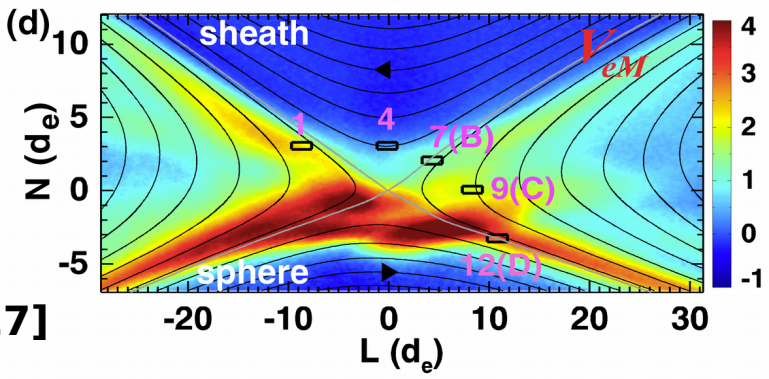


Bg~0.2 Br

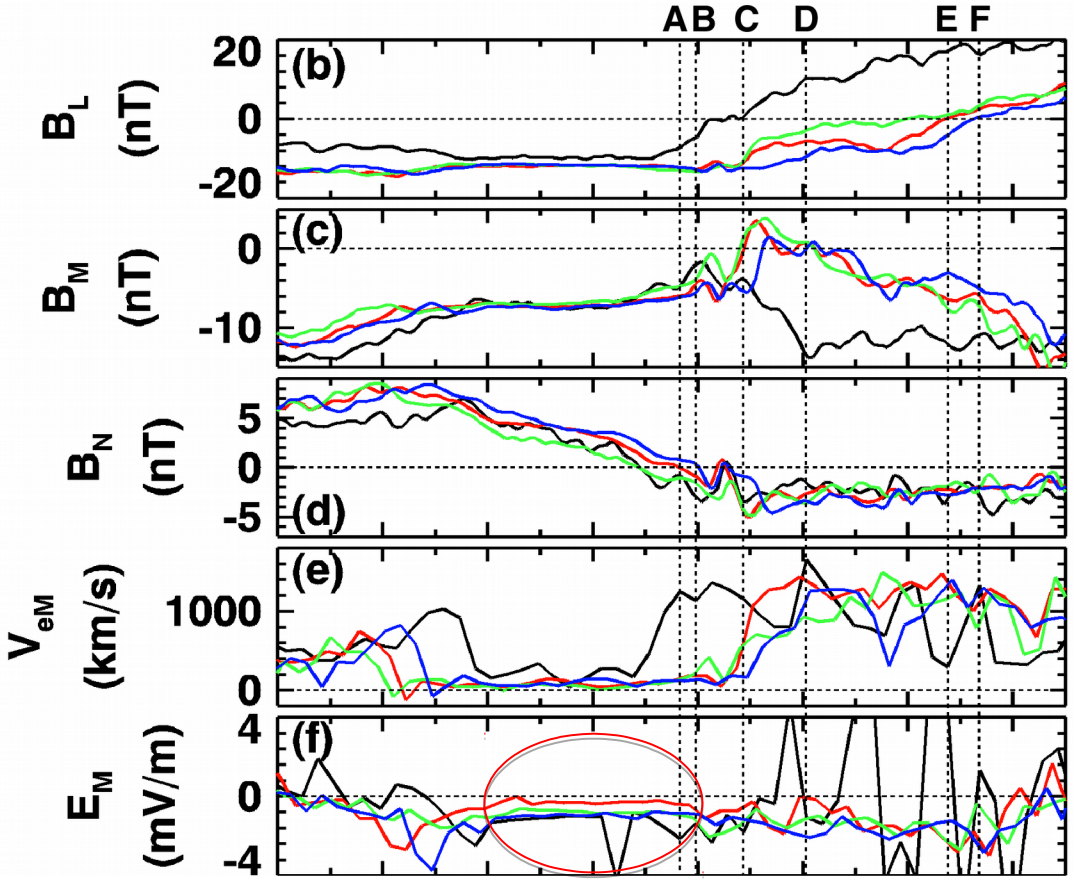
Direct measurement of the Reconnection

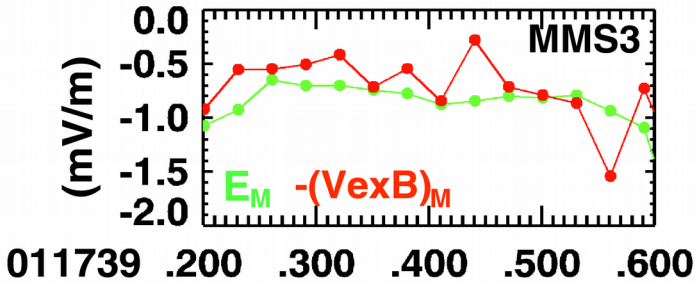
EM ~ 0.1[B0VA]



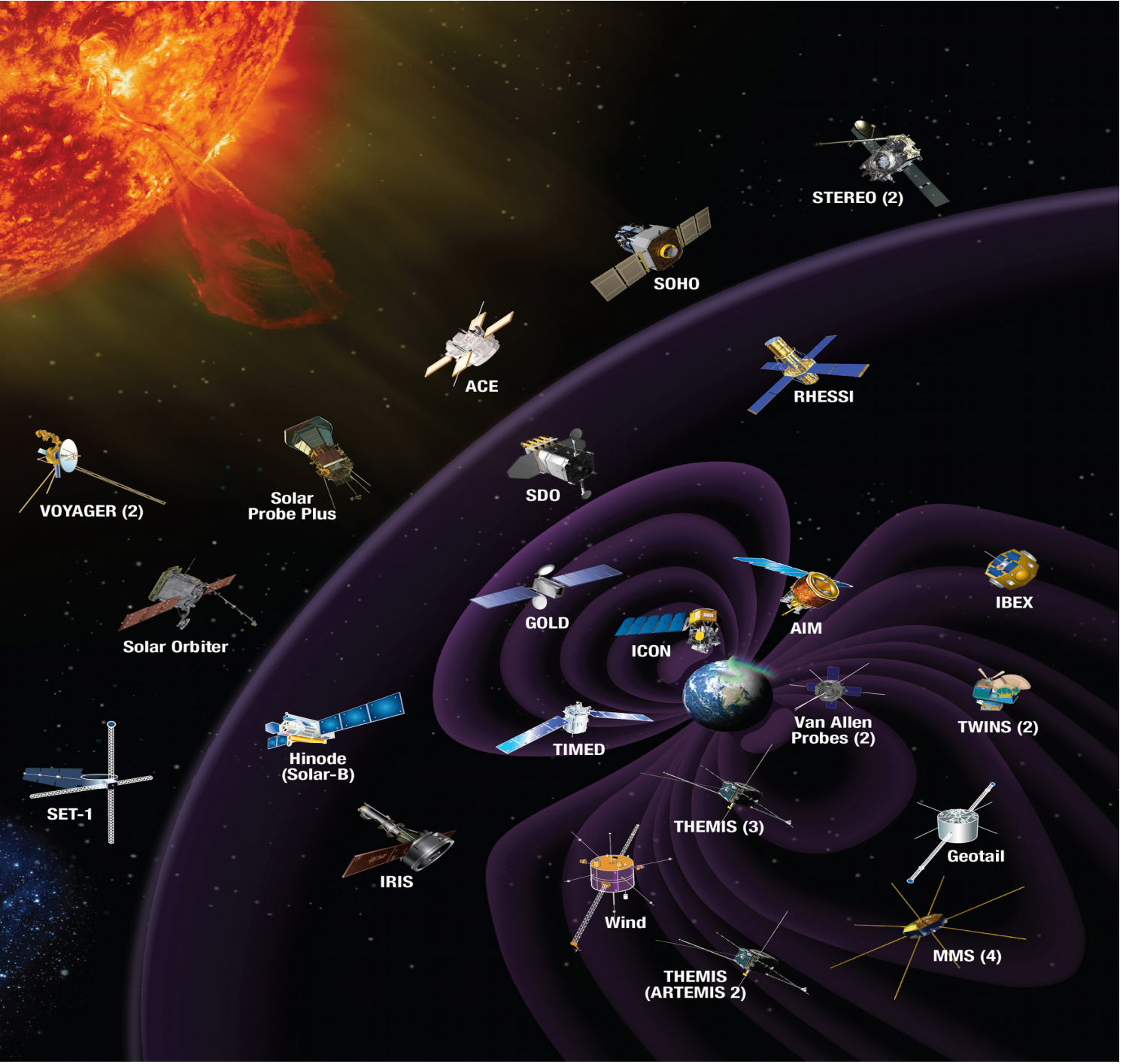


[Chen et al., 2017]





Sheath EDR *Bg~0.2 Br*



Conjunctions:

MMS, THEMIS, RBSP , CLUSTER, …

MMS orbits