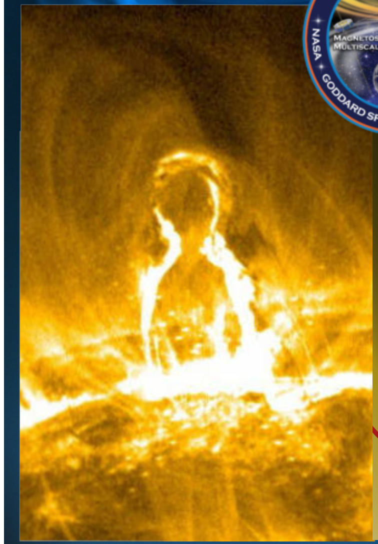
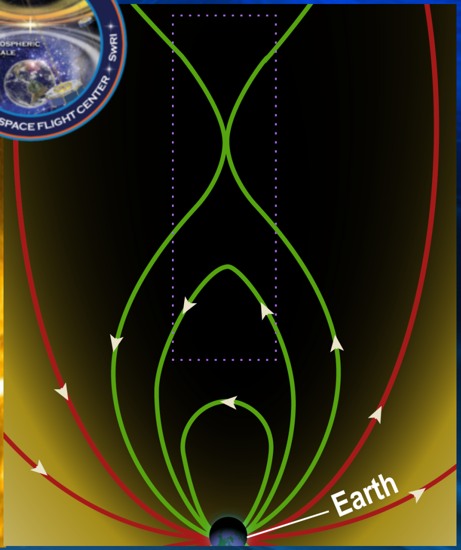
# Suprathermal electrons in Earth's magnetotail: What can they teach us about flare electron energization?



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# Acknowledgment


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**Levon Avanov**

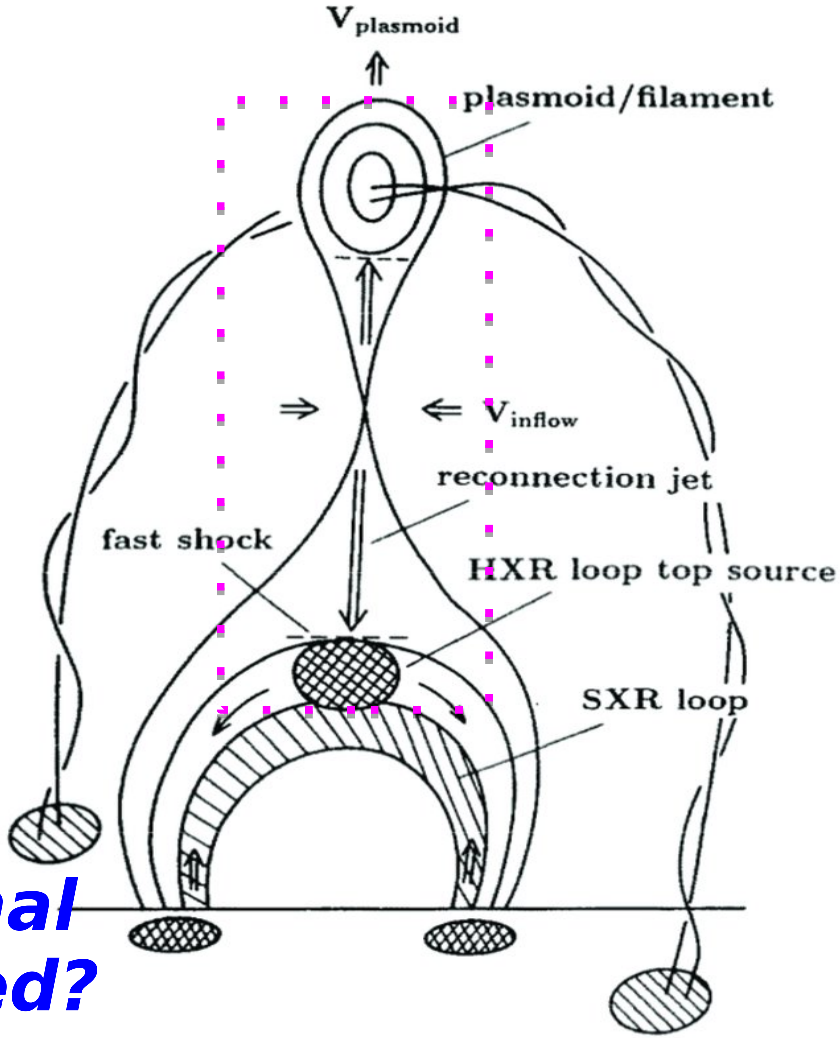
+

**other MMS & CLUSTER team members**

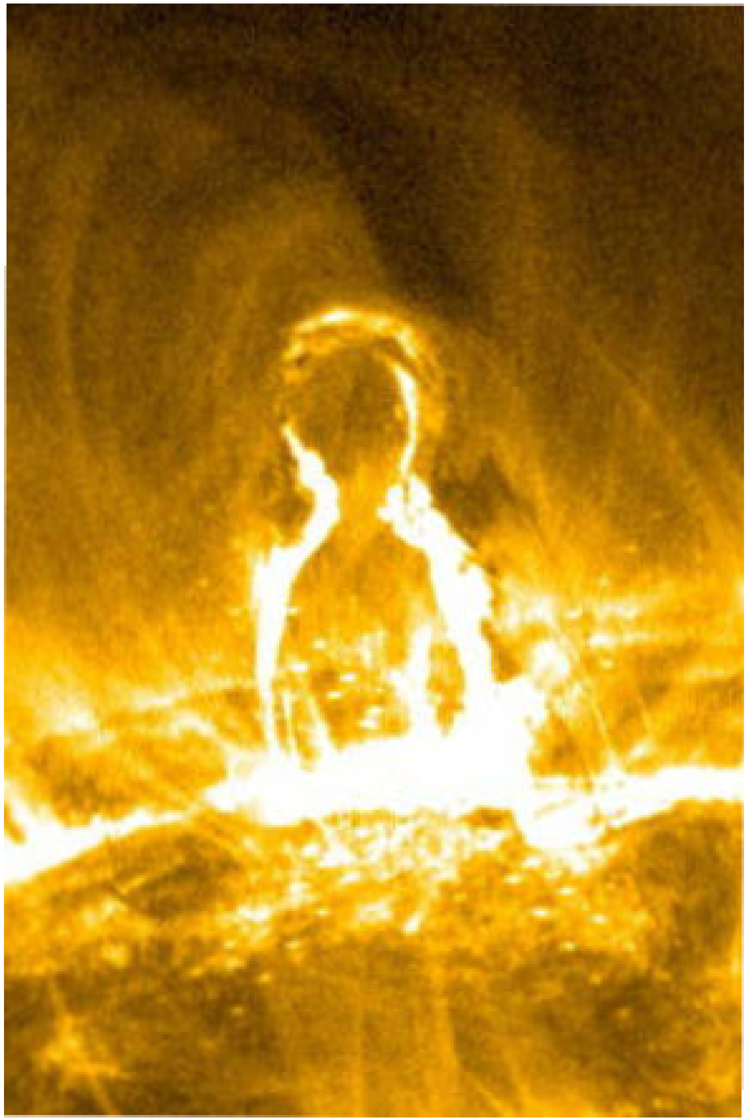
***Up to 50% of flare released energy goes to suprathermal electrons***

***[e.g., Lin+, 2003 Holman+, 2003; Krucker+, 2010; Krucker & Battaglia, 2014]***

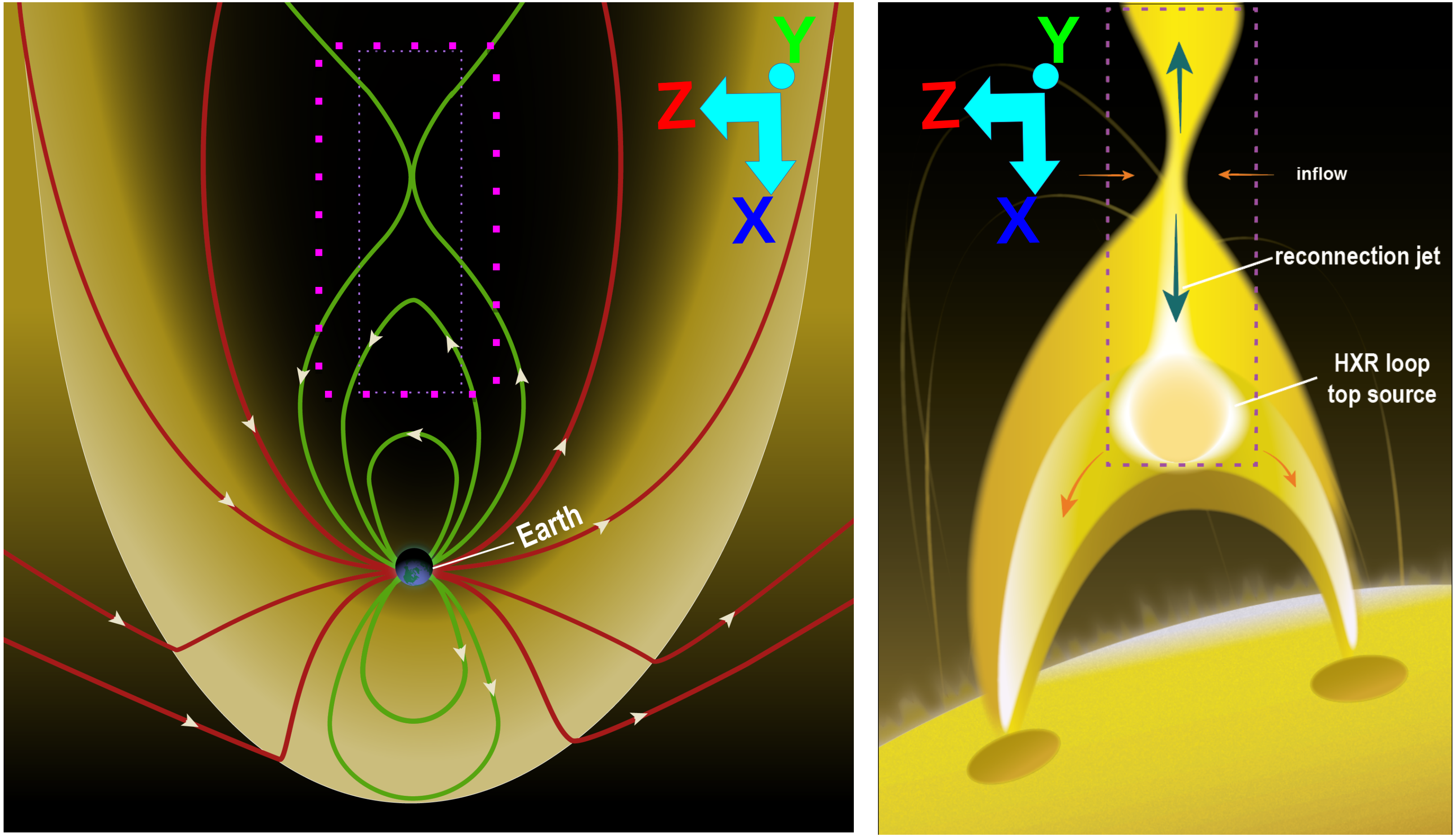
***How are suprathermal e’s produced?***



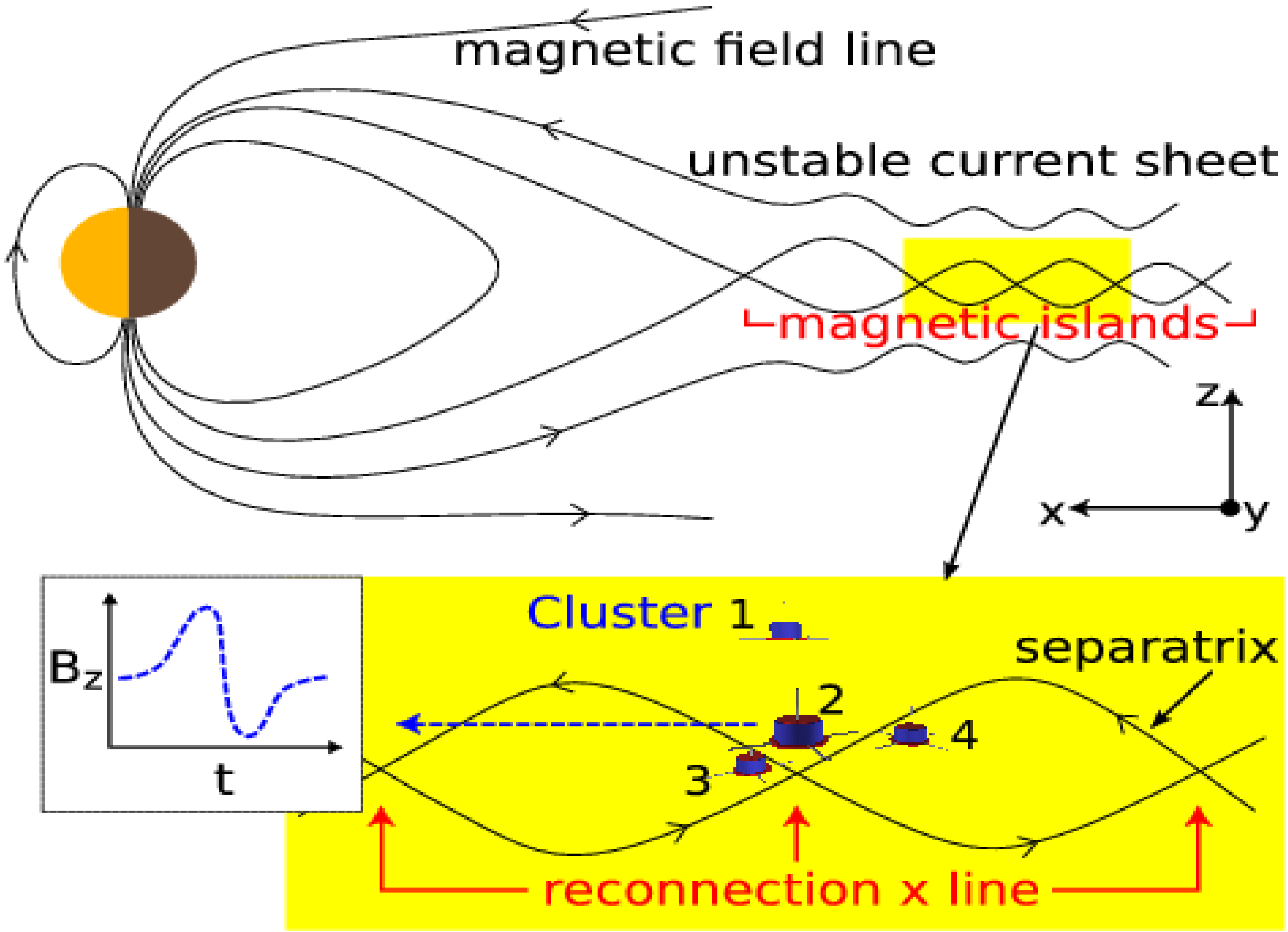

**[Shibata et al., 1995]**



# Magnetic configuration & beta in solar flares are similar to those in the magnetotail



# Volume-filling magnetic islands?

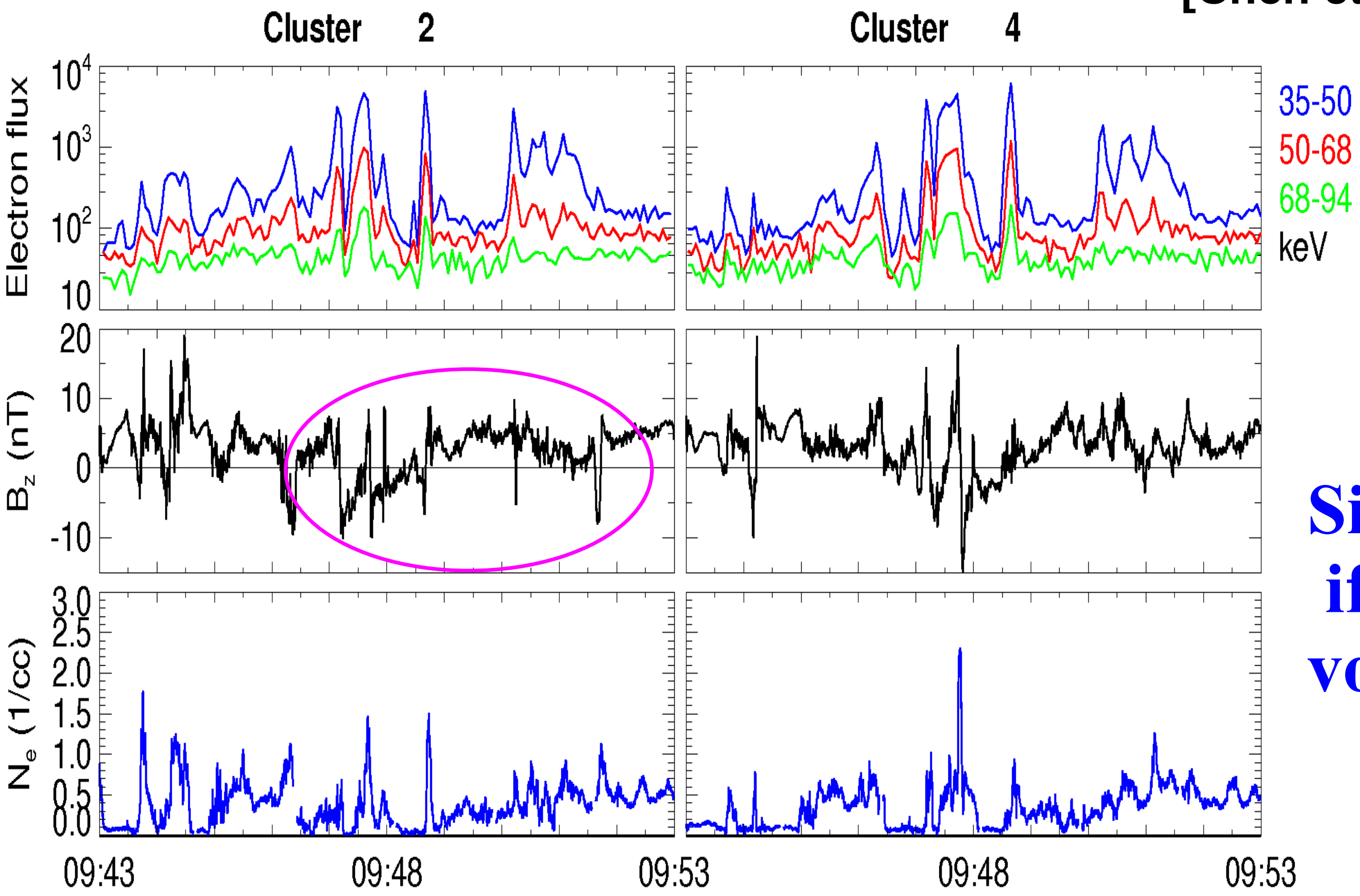



**Motivated by [Drake et al., Nature, 2006]**

**Later work: [Dahlin et al., PP, 2014, 2015; Arnold et al., PRL, 2021]**

# Energetic electrons in magnetic islands: magnetotail

[Chen et al., Nature Phys., 2008]




**Islands are di scale, grew out of the electron current layer**
[Chen et al., PP, 2012]

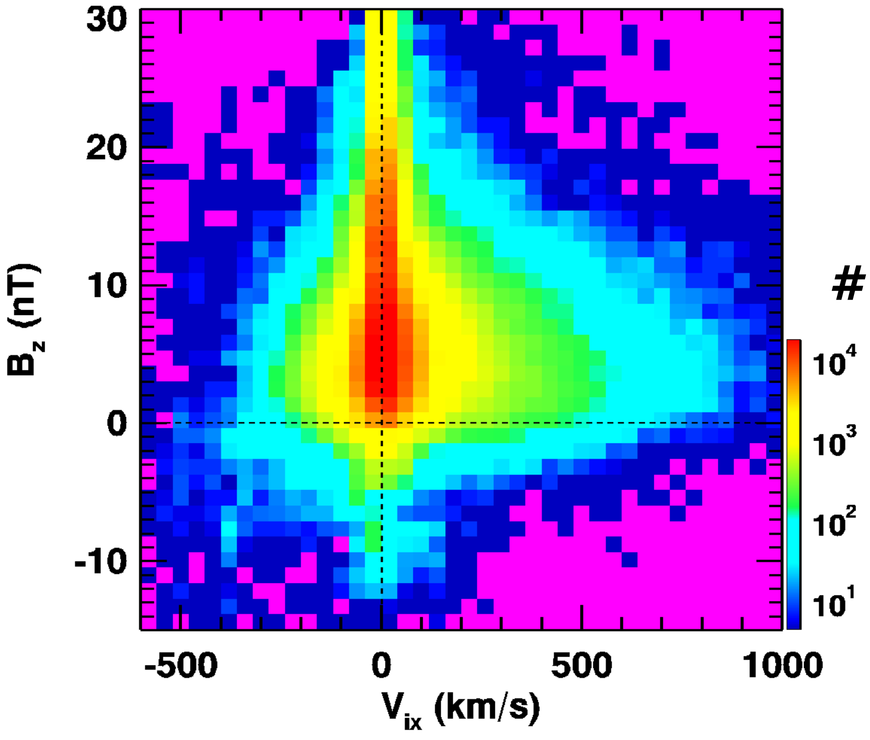
**Signatures =? if islands are volume-filling**

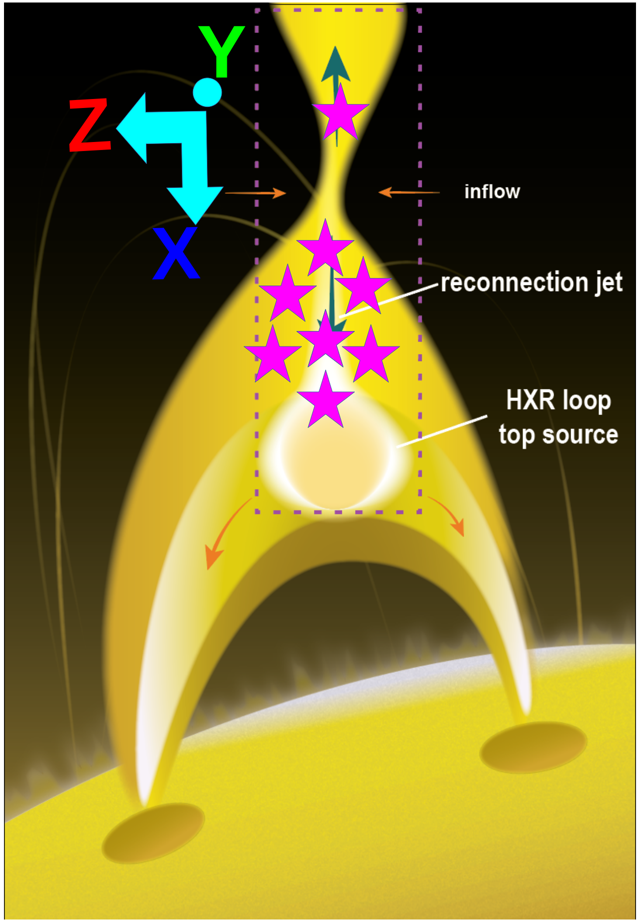
# *Use all MMS magnetotail passes (127 orbits in 4 years) to test out*

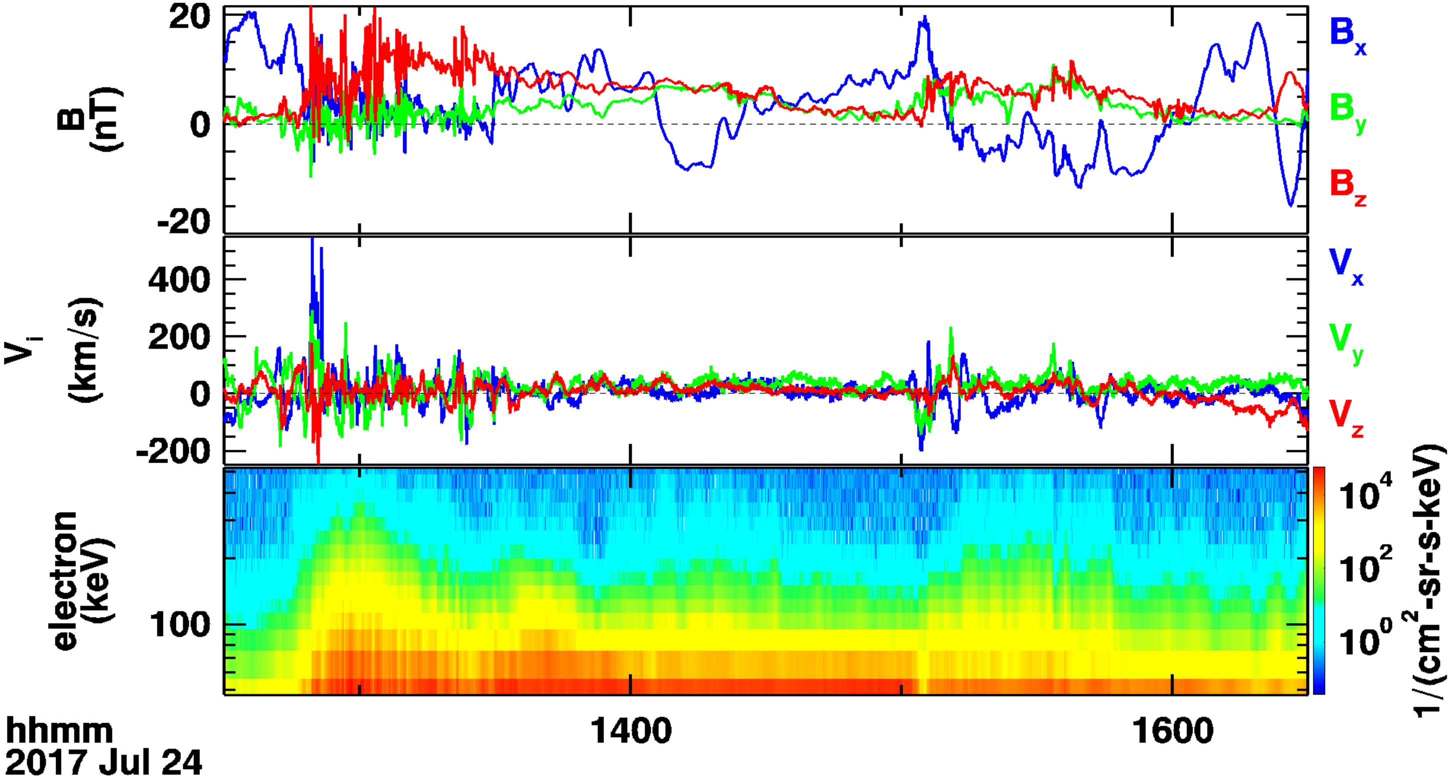
- Whether volume-filling islands are dominant accelerators
- If primary energization occurs at the X line or downstream

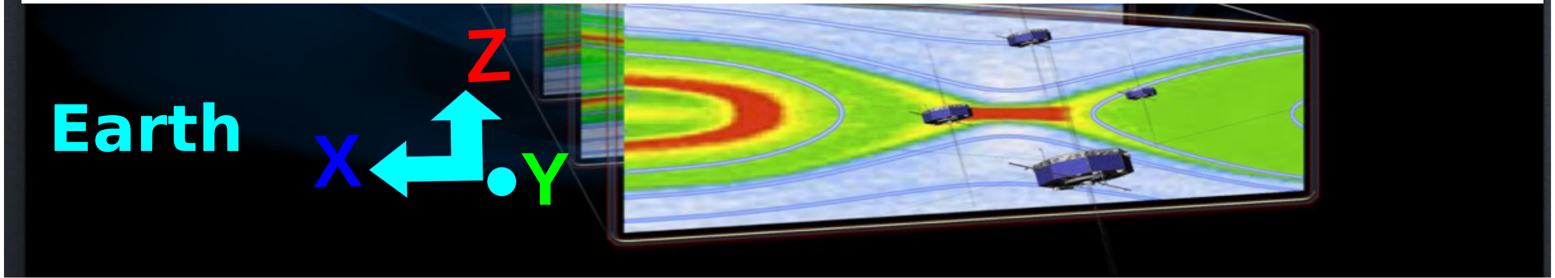
# 90 keV e's tend to be detected in regions with $B_z>0$ and $V_{ix}\sim0$

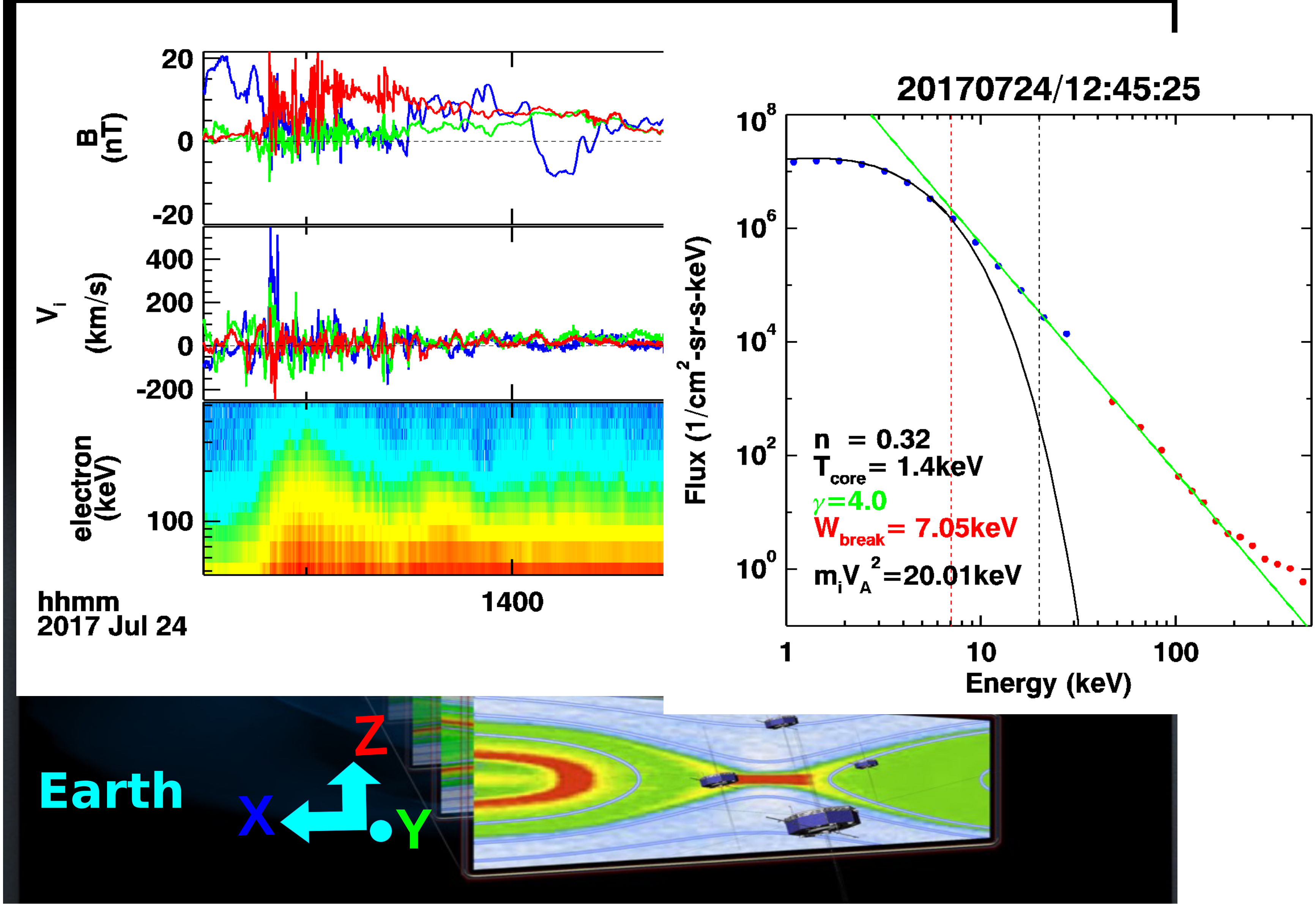
## Events: flux > threshold



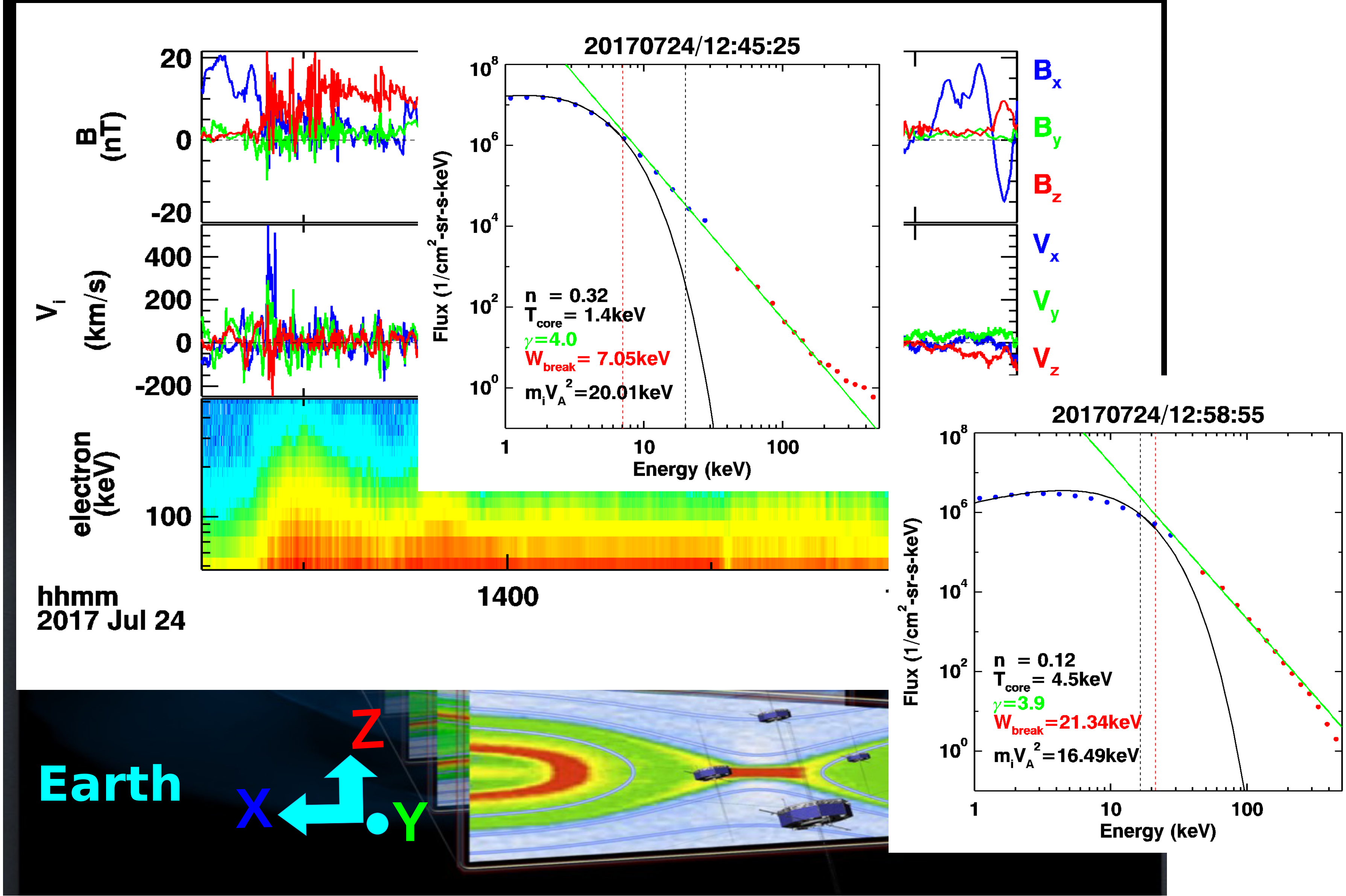




B (nT)
20
0
-20
Bx
By
Bz
Vi (km/s)
400
200
0
-200
Vx
Vy
Vz
electron (keV)
100
10^4
10^2
10^0
1/(cm^2-sr-s-keV)
hhmm
2017 Jul 24
1400
1600


Earth
Z
X
Y

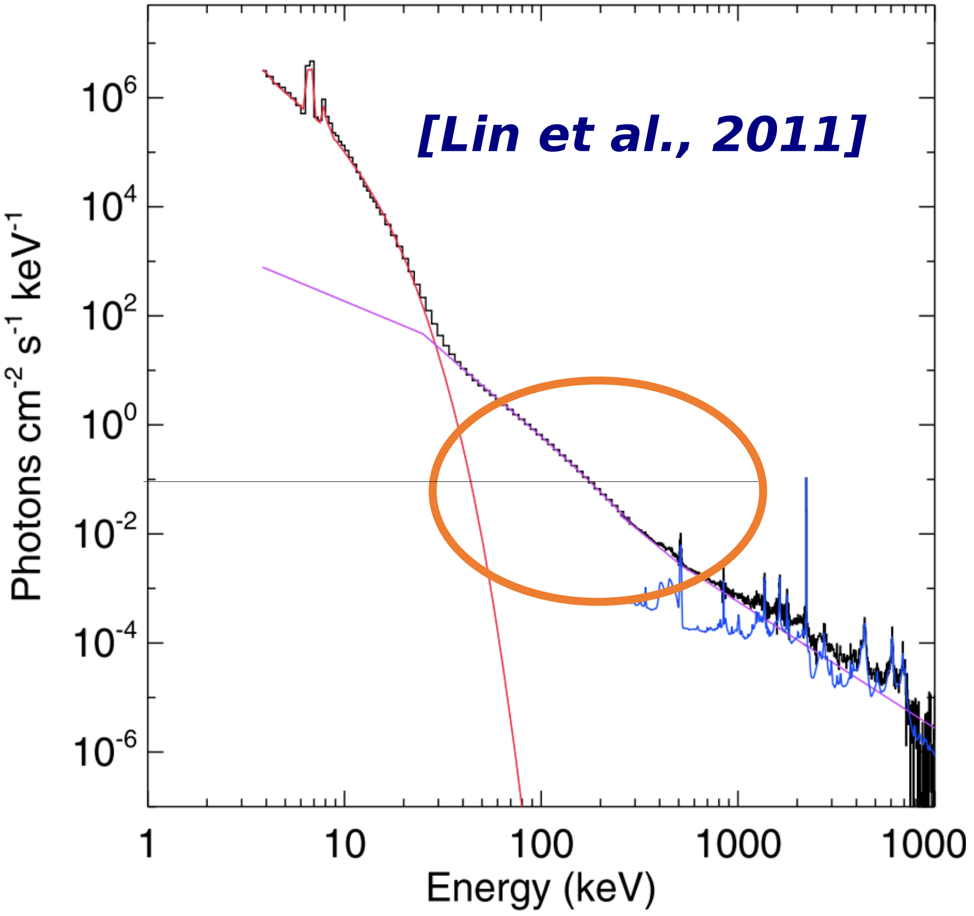


B (nT)
20
0
-20
V_i (km/s)
400
200
0
-200
electron (keV)
100
hhmm
2017 Jul 24
1400
20170724/12:45:25
Flux (1/cm^2-sr-s-keV)
10^8
10^6
10^4
10^2
10^0
n = 0.32
T_core= 1.4keV
γ=4.0
W_break= 7.05keV
m_iV_A^2=20.01keV
1
10
100
Energy (keV)
Earth
Z
X
Y

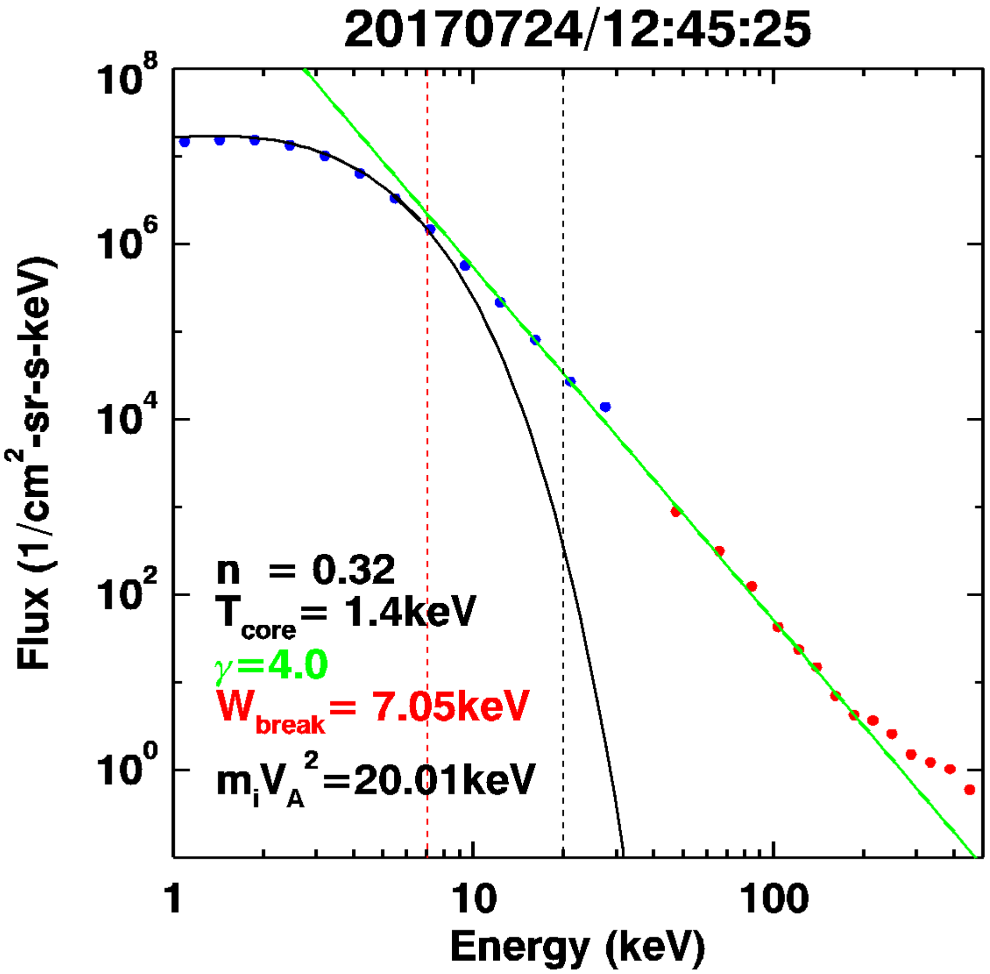


20170724/12:45:25
n = 0.32
T_core = 1.4keV
γ=4.0
W_break = 7.05keV
m_iV_A^2=20.01keV
Flux (1/cm^2-sr-s-keV)
Energy (keV)
B (nT)
V_i (km/s)
electron (keV)
hhmm
2017 Jul 24
1400
B_x
B_y
B_z
V_x
V_y
V_z
20170724/12:58:55
n = 0.12
T_core = 4.5keV
γ=3.9
W_break =21.34keV
m_iV_A^2=16.49keV
Earth
Z
X
Y

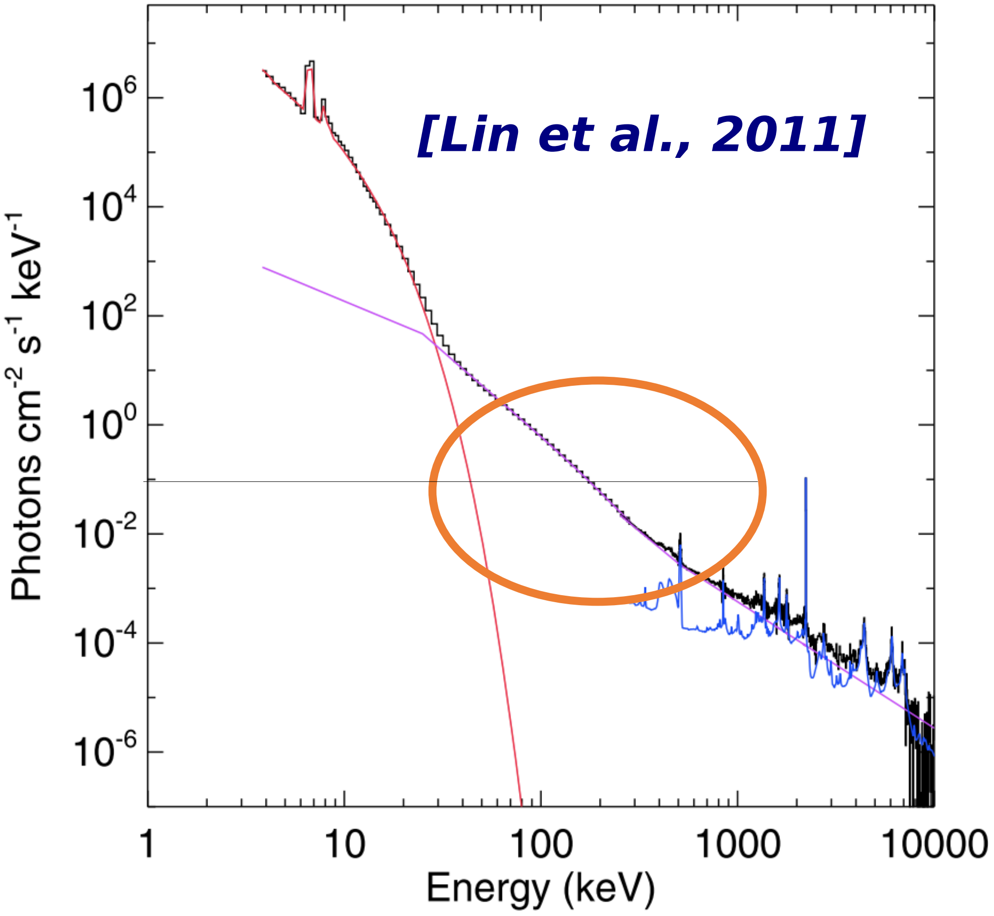
## *Solar flare*



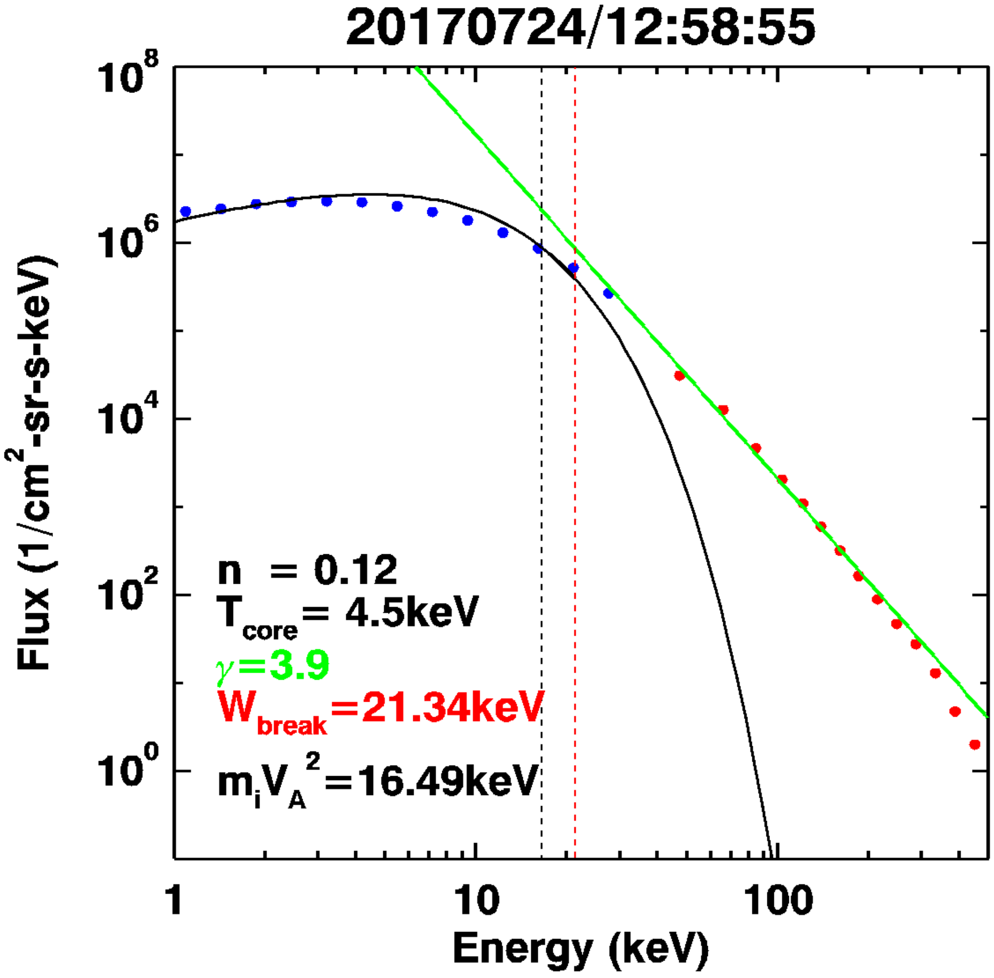

## *Magnetotail*

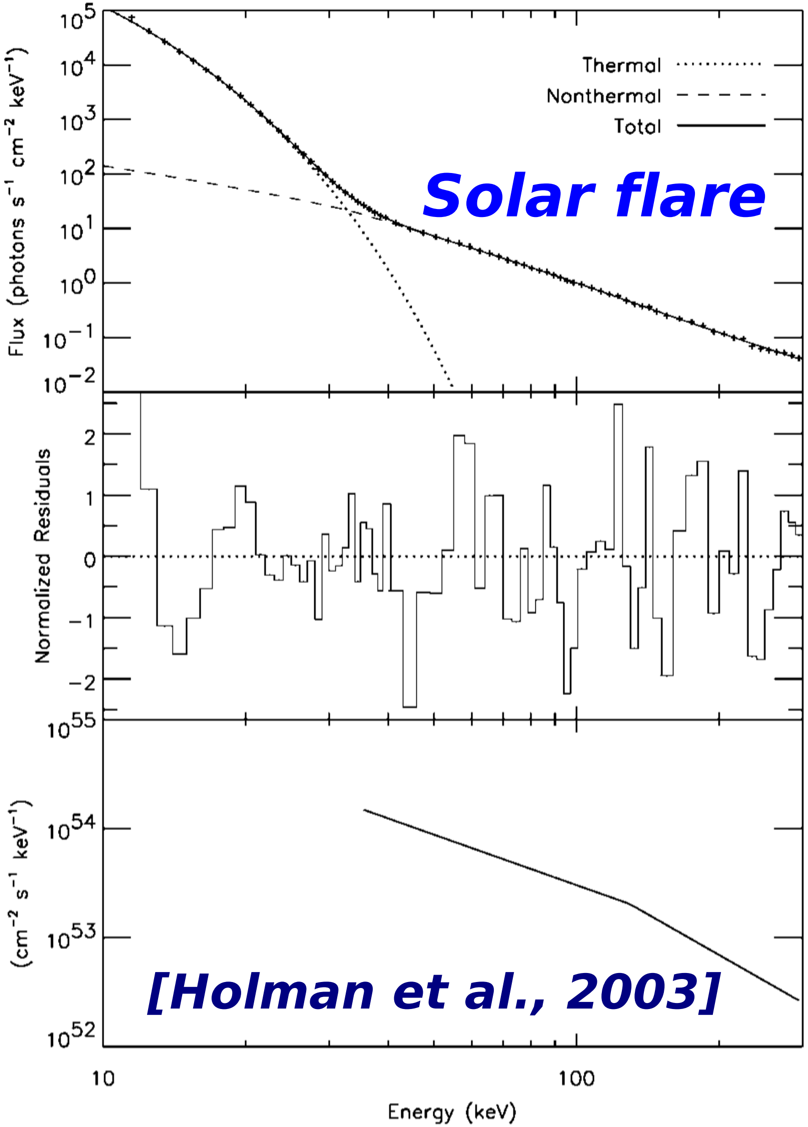


## Solar flare

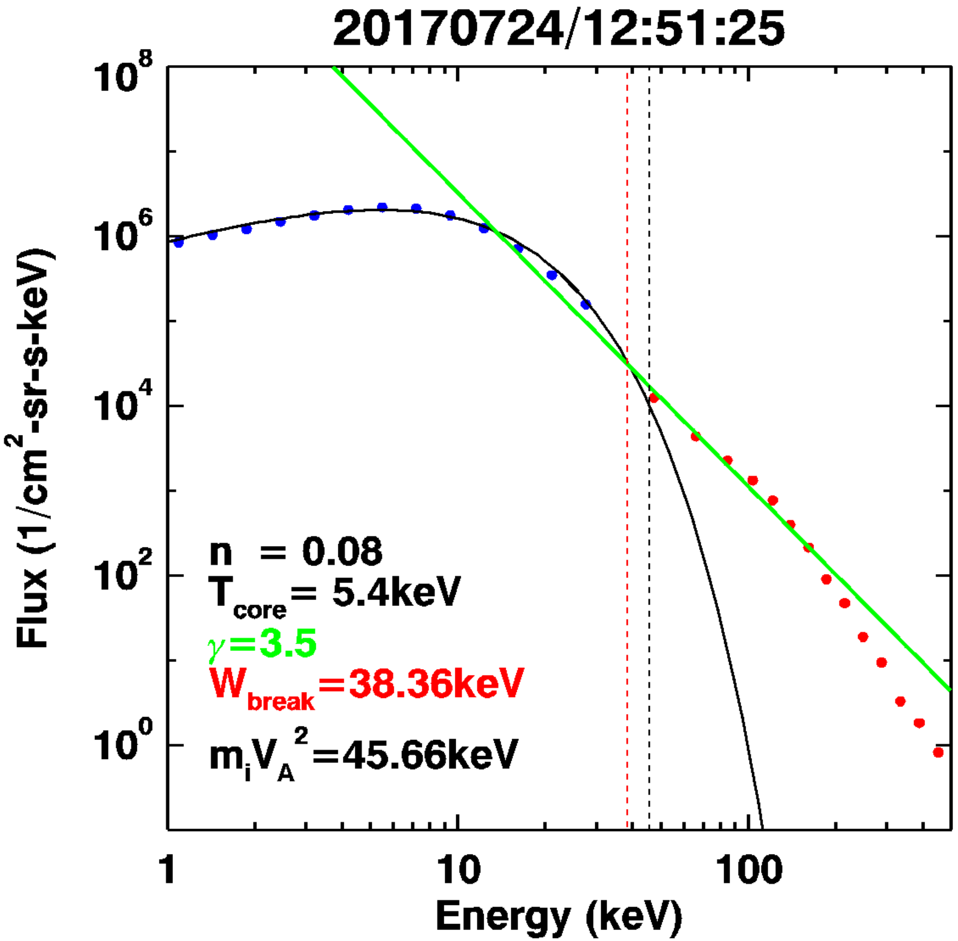


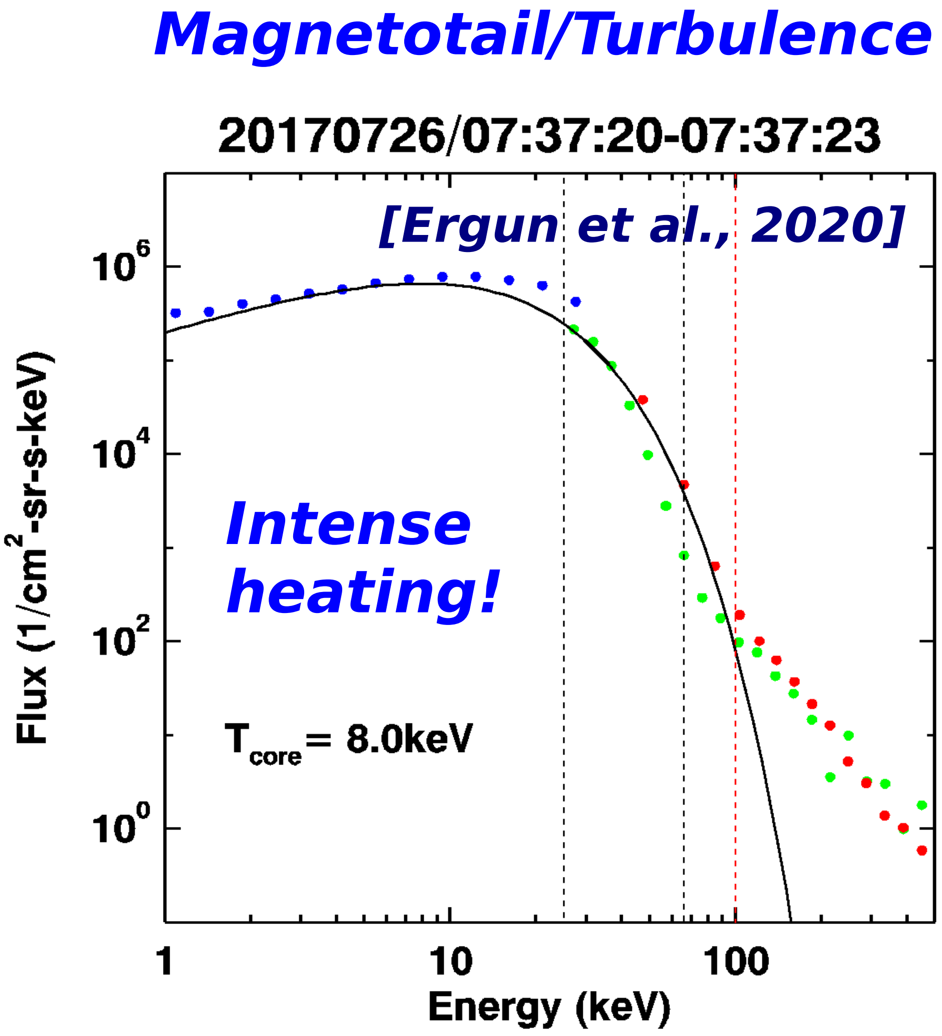

## Magnetotail



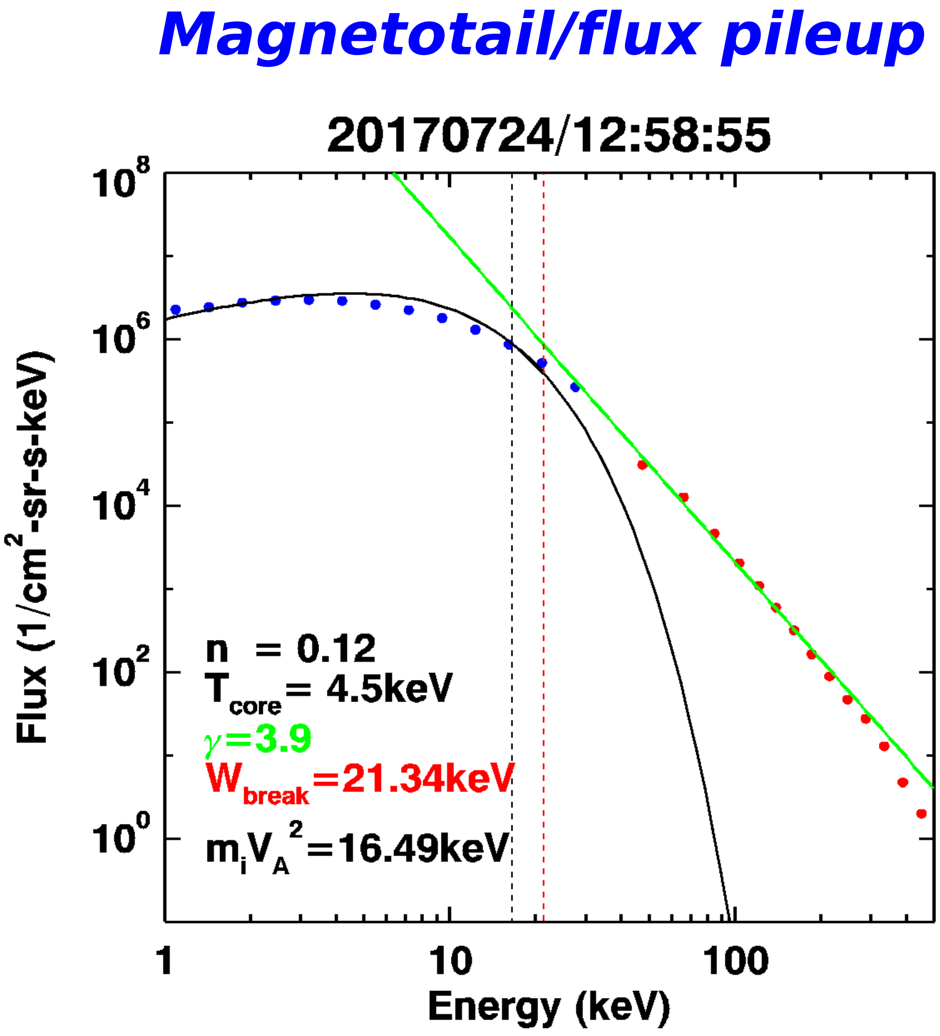



## Magnetotail (in earthward jet)

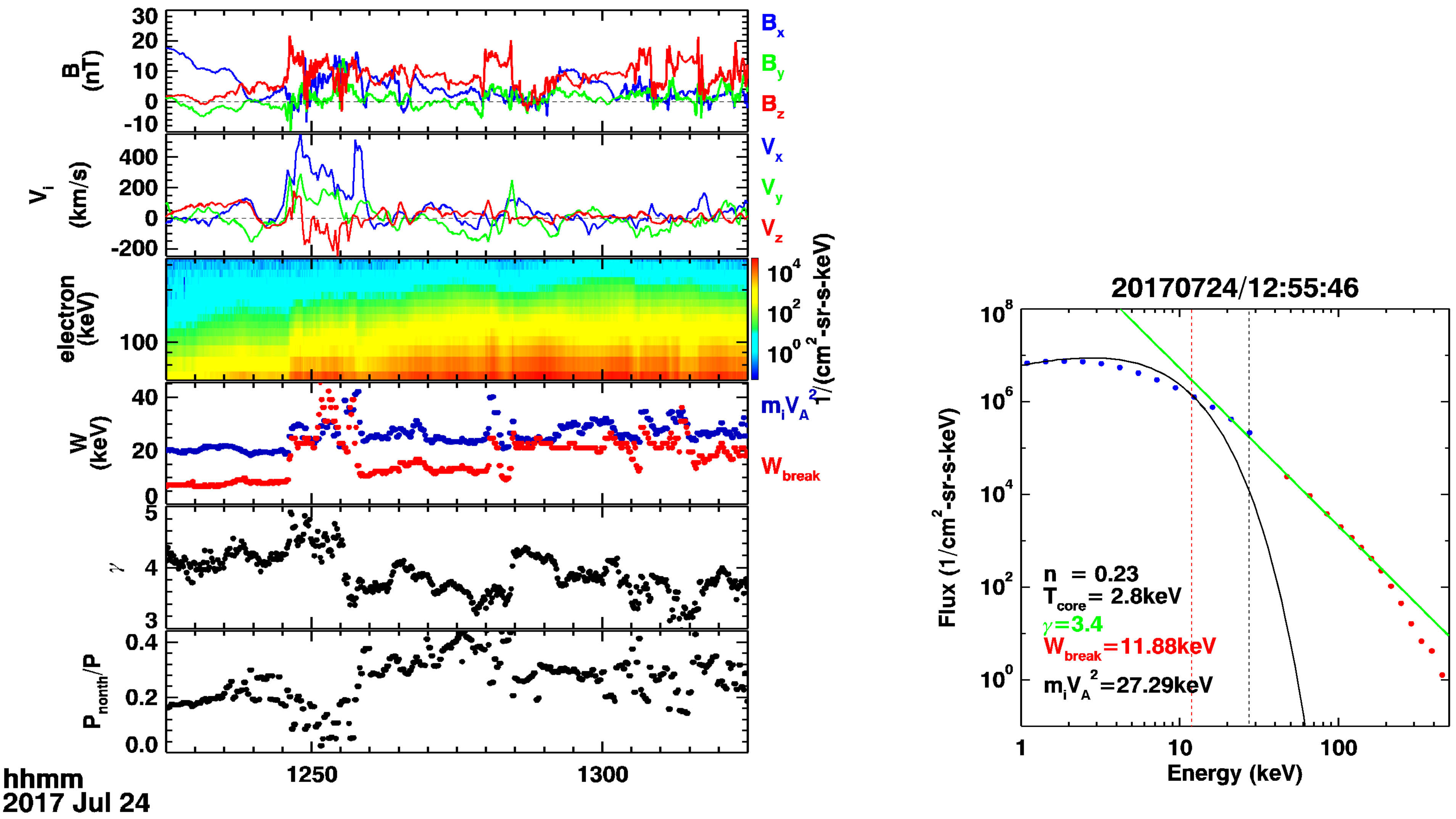




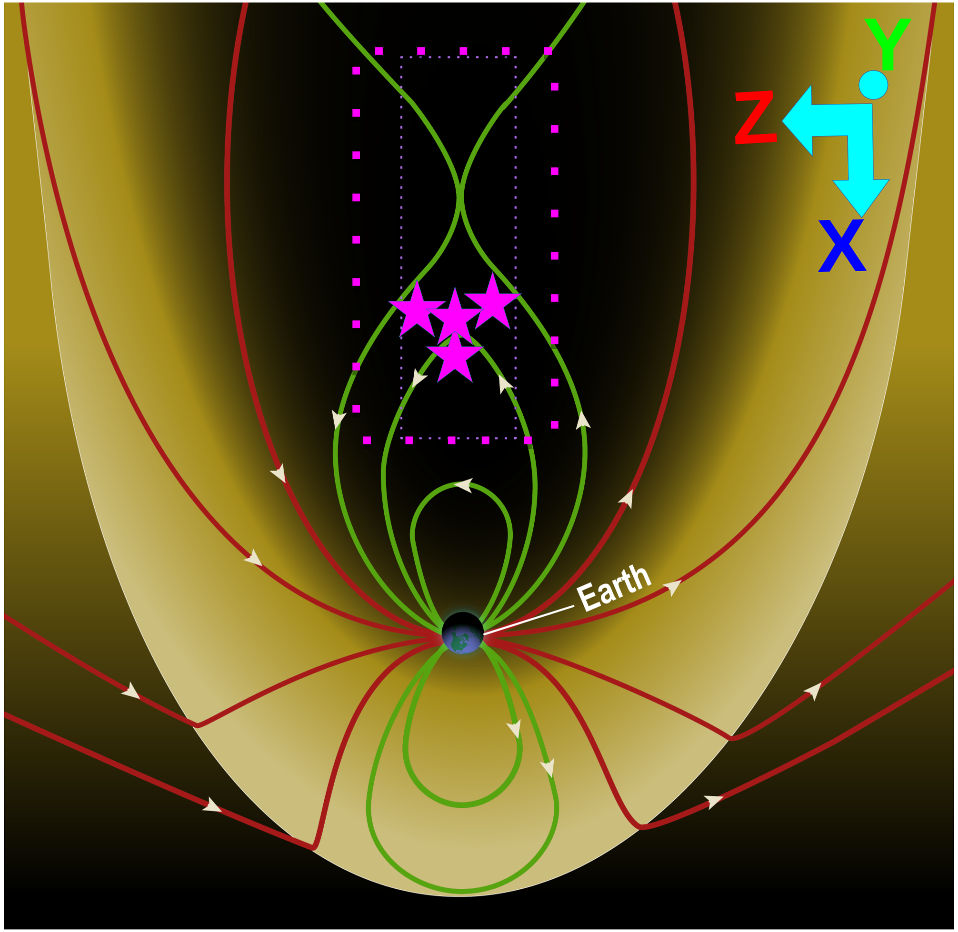
Magnetotail/Turbulence
20170726/07:37:20-07:37:23
[Ergun et al., 2020]
Intense heating!
T_core= 8.0keV
Flux (1/cm2-sr-s-keV)
Energy (keV)

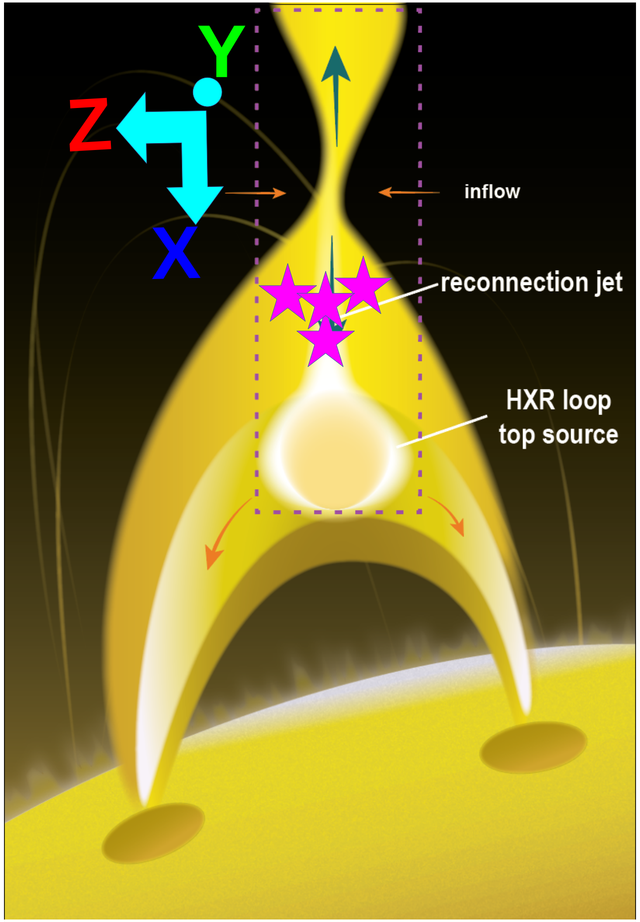



Magnetotail/flux pileup
20170724/12:58:55
n = 0.12
T_core= 4.5keV
γ=3.9
W_break=21.34keV
m_iV_A^2=16.49keV
Flux (1/cm2-sr-s-keV)
Energy (keV)

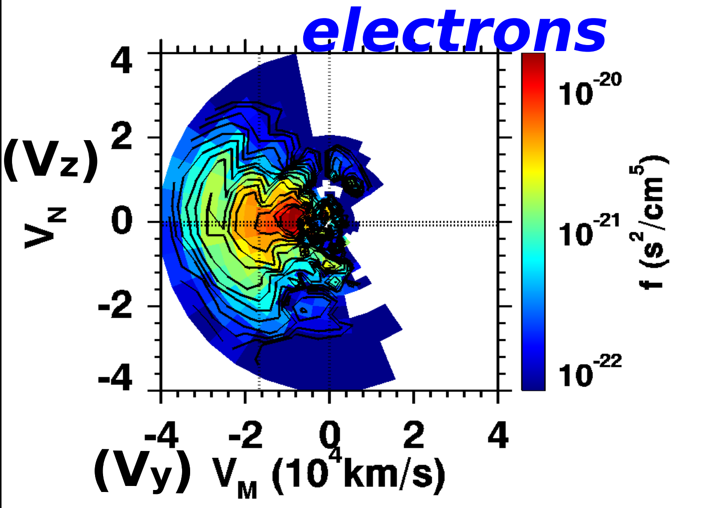


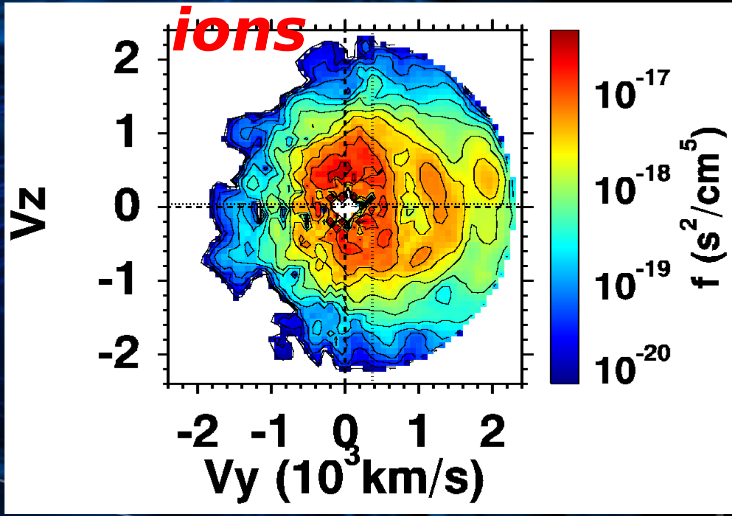
B (nT)
30
20
10
0
-10
Bx
By
Bz
Vi (km/s)
400
200
0
-200
Vx
Vy
Vz
electron (keV)
100
10^4
10^2
10^0
1/(cm^2-sr-s-keV)
W (keV)
40
20
0
miVA^2
Wbreak
γ
5
4
3
Pnonth/P
0.4
0.2
0.0
1250
1300
hhmm
2017 Jul 24
20170724/12:55:46
Flux (1/cm^2-sr-s-keV)
10^8
10^6
10^4
10^2
10^0
n = 0.23
Tcore = 2.8keV
γ=3.4
Wbreak=11.88keV
miVA^2=27.29keV
1
10
100
Energy (keV)


Y
Z
X
Earth


Y
Z
X
inflow
reconnection jet
HXR loop
top source

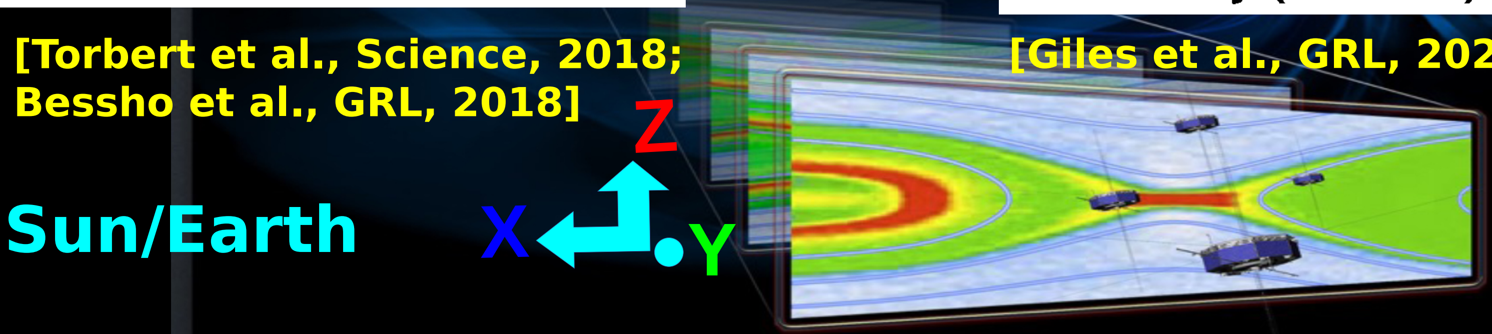
# In the diffusion region, acceleration by $E_{rec}$ can achieve: a few keV for e's ; a few tens of keV for ions

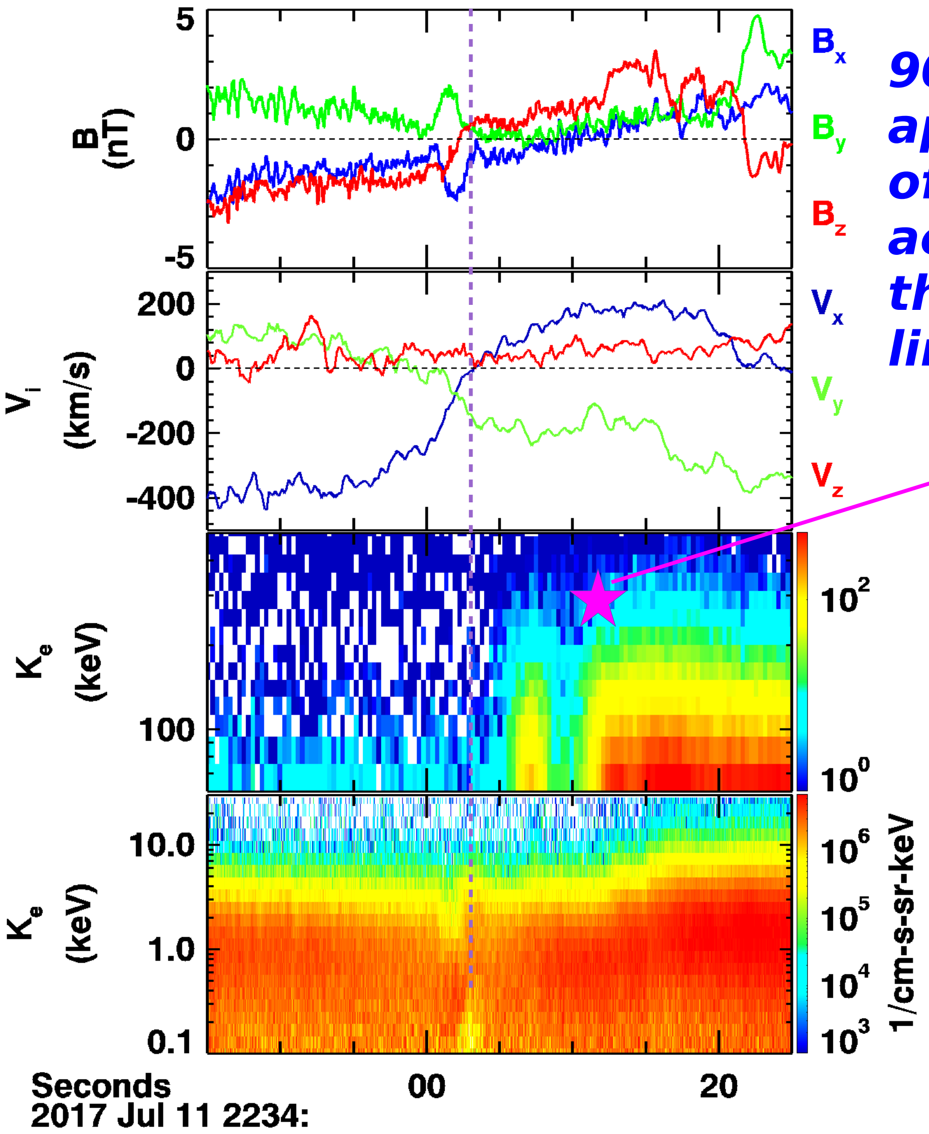


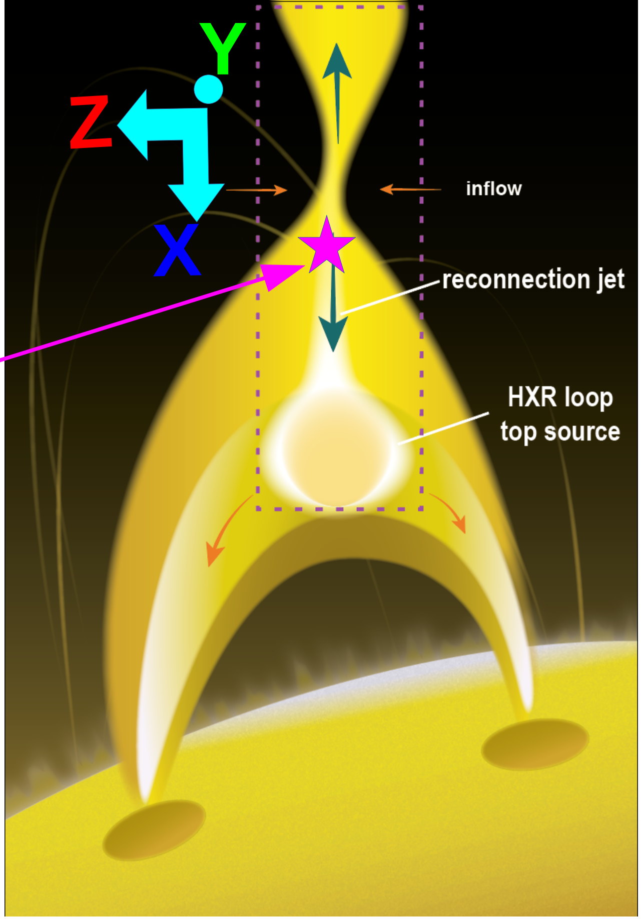

[Torbert et al., Science, 2018; Bessho et al., GRL, 2018]

[Giles et al., GRL, 2021]

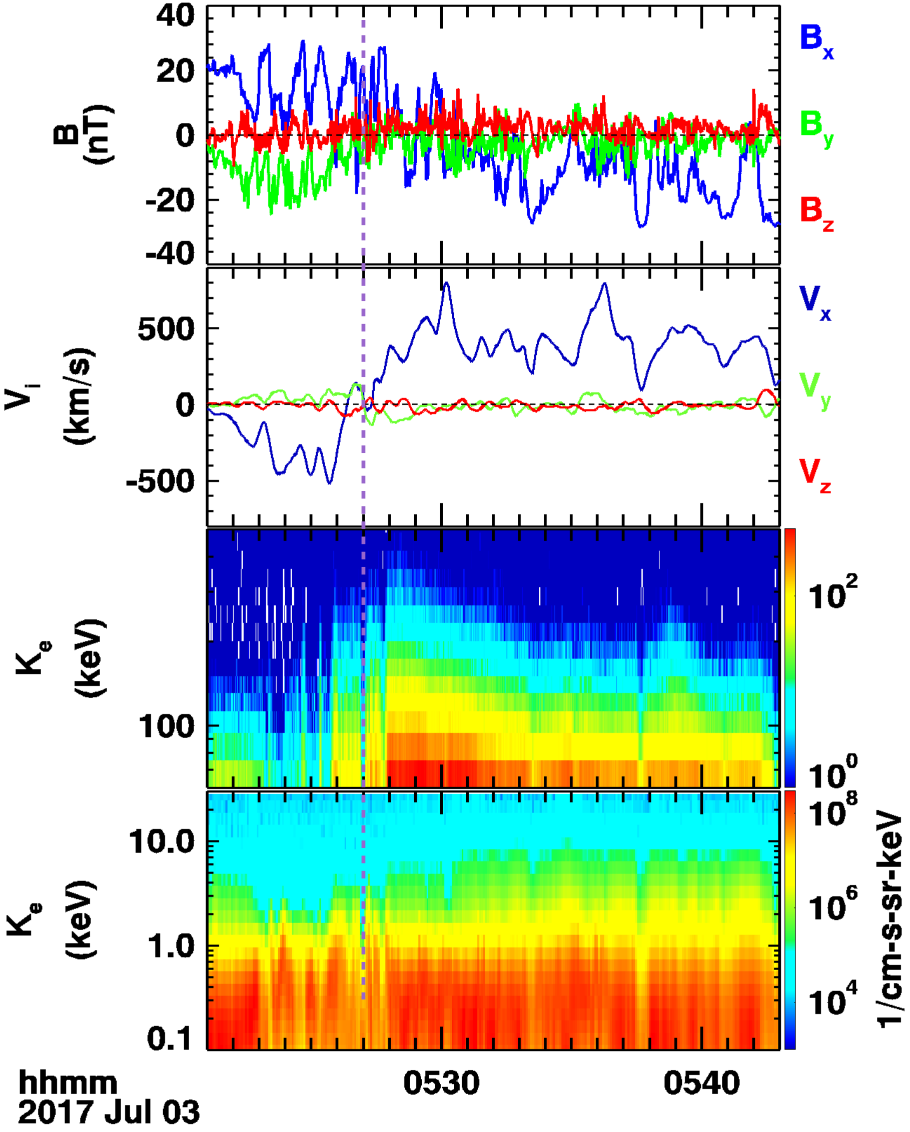




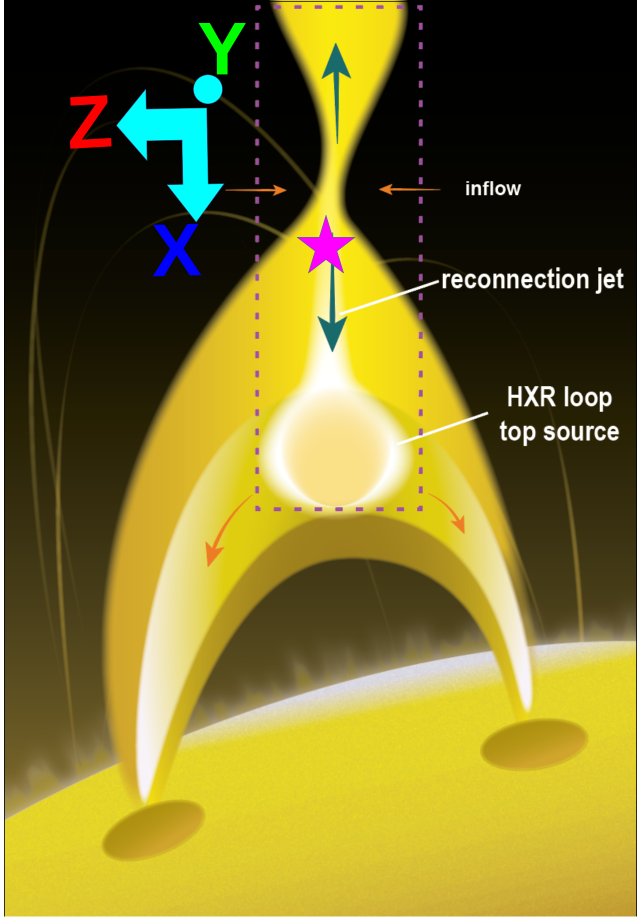

***90 keV e's only appear Earthward of the X-line: key acc. physics is in the closed field line region***



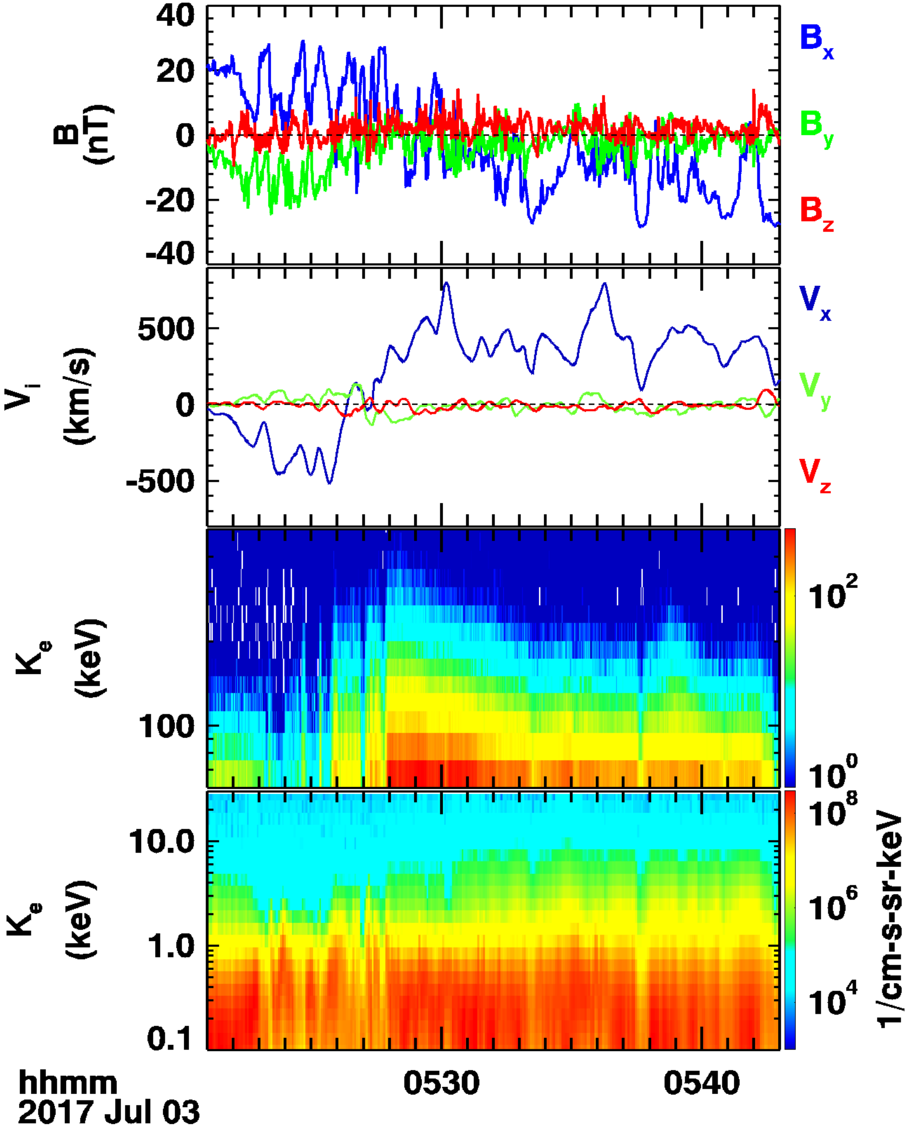

X-line (EDR) crossing in
[Torbert et al., Science, 2018]



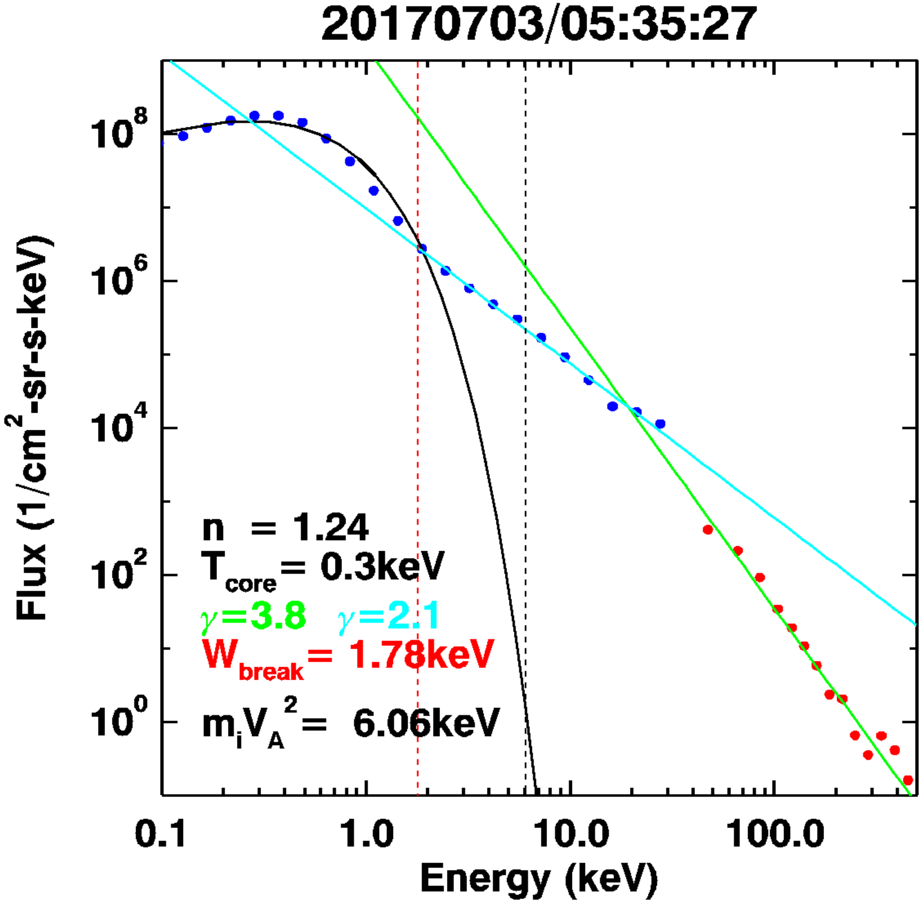

***90 keV e Flux more intense Earthward of the X-line: a higher density case for spectra analysis***



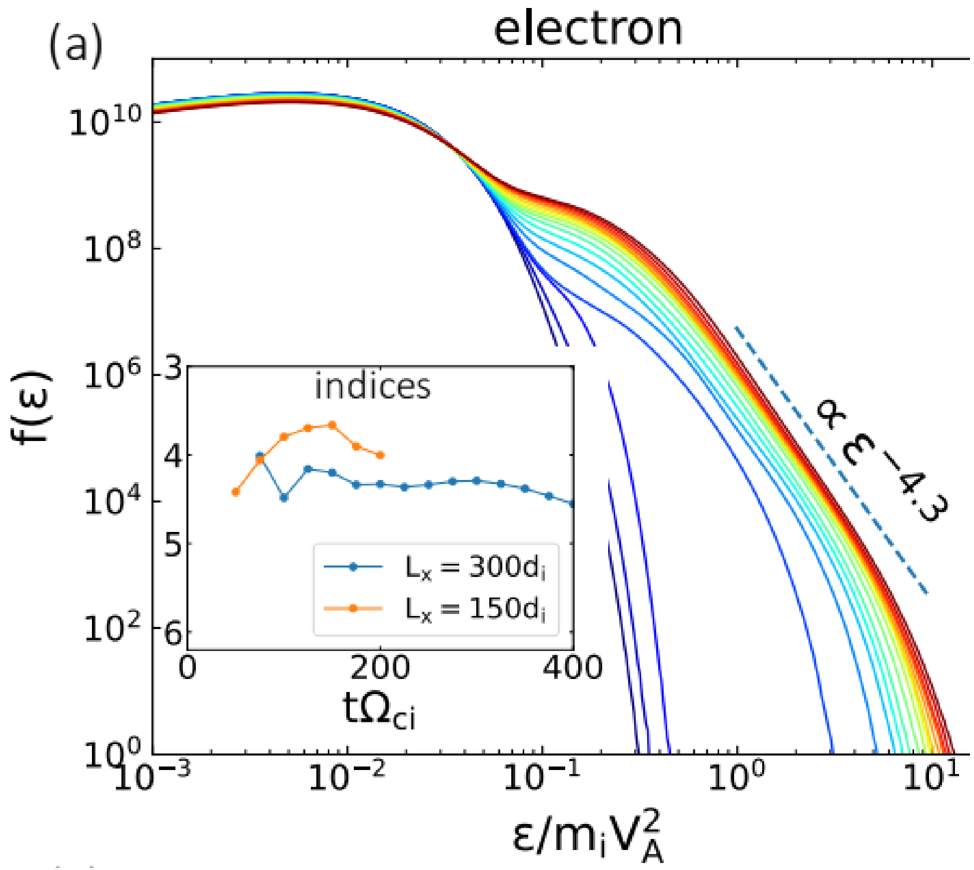

X-line (3 EDRs) crossing in [Chen et al., GRL, 2019]




## *thermal+double power laws*

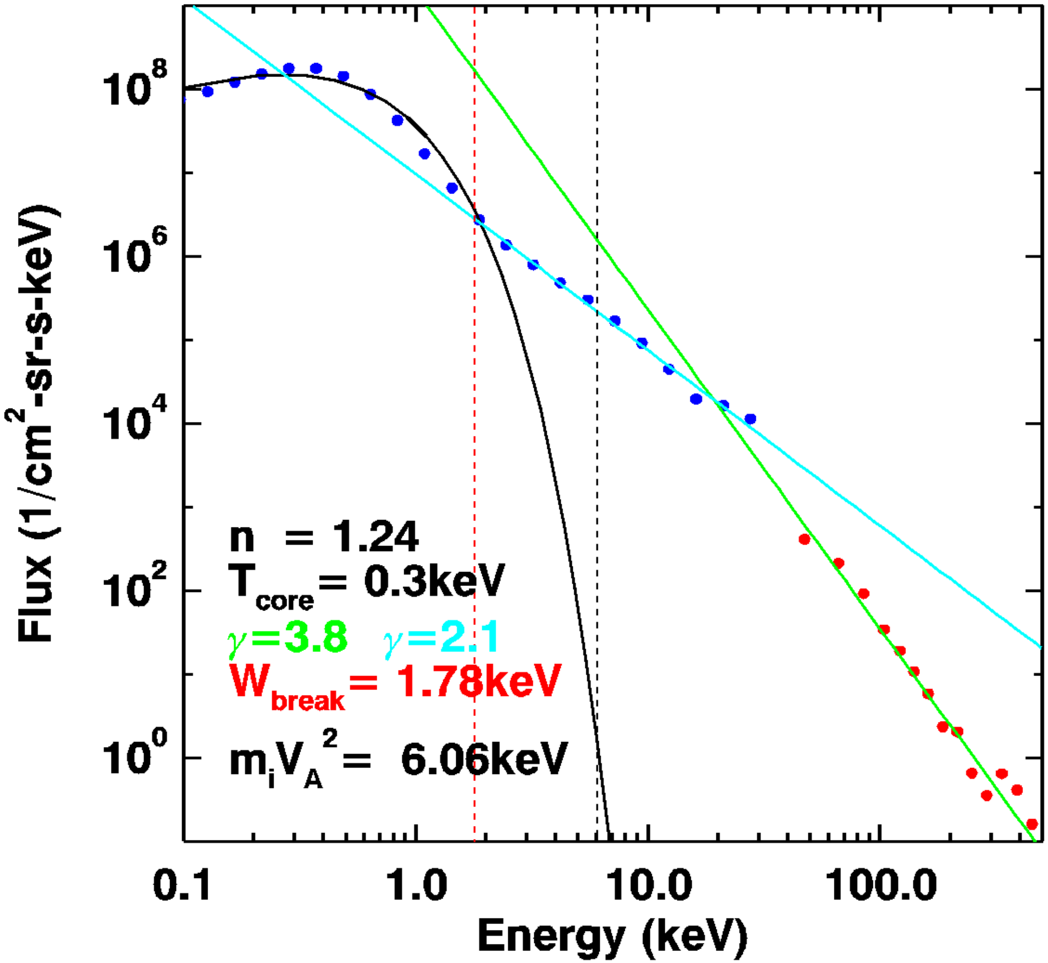


***PIC with flux rope kinks***
***[Qile Zhang, 2021]***




***Magnetotail reconnection outflow***

**20170703/05:35:27**



# Summary

- Suprathermal e's are primarily found in the earthward B pileup regions.
- Across the X line, earthward exhaust is favored.
- Statistical results do not support volume-filling islands as the dominant accelerators in the magnetotail.

## If...