Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

A statistical study of particle energization associated with field turbulence in the magnetotail plasma sheet

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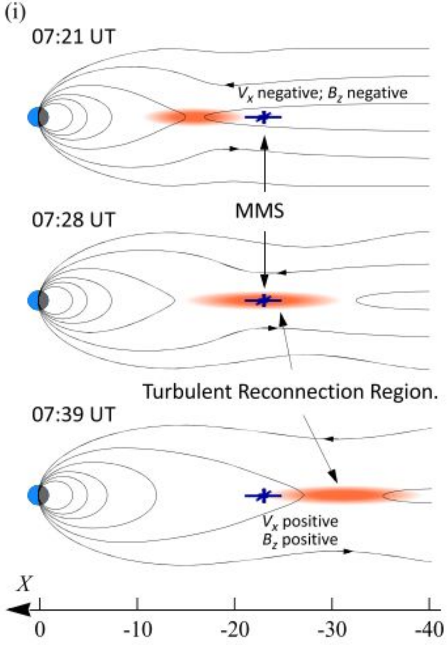
Vo et al. (2022), *in prep*

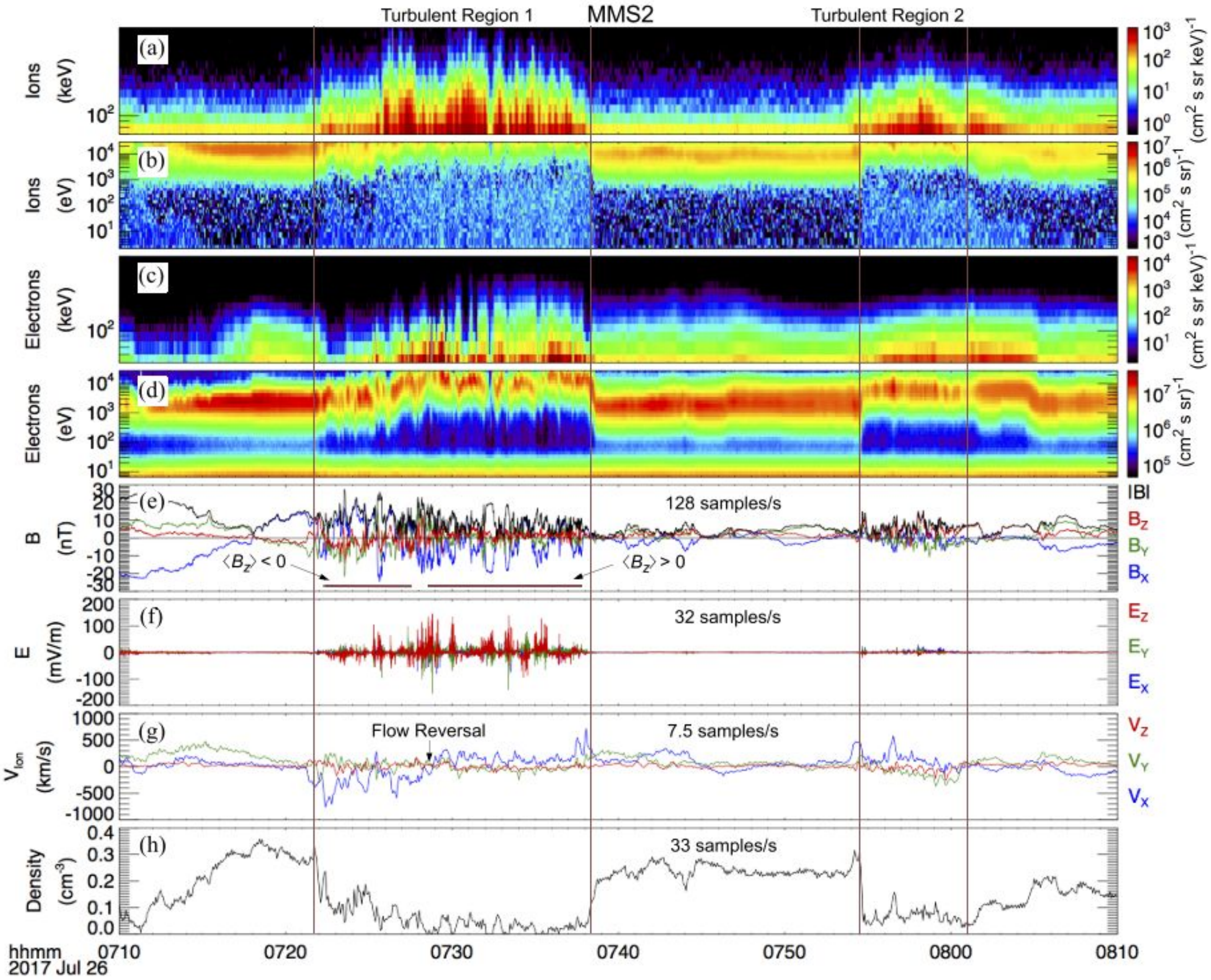
Outline

1. Precursor study: plasma sheet identification
   a. FPI+FEEPS combined moments
   b. Background plasma spatial profile

2. Statistics of field turbulence
   a. Occurrence rate
   b. Correlation with energy density & J.E

Motivations: Event studies



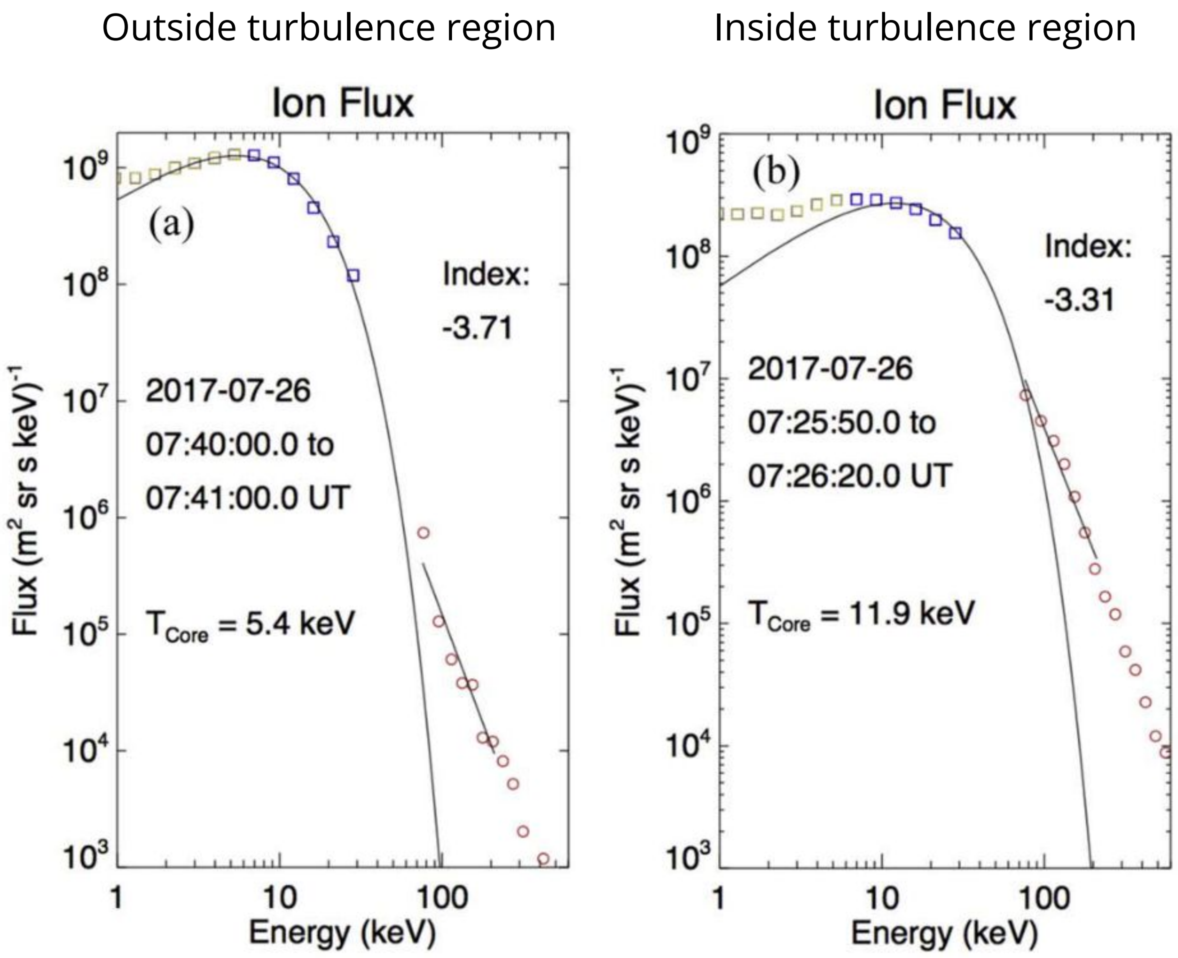


Ergun+14,Stawarz+15,Ergun+18, Ergun+20

Motivations: Event studies

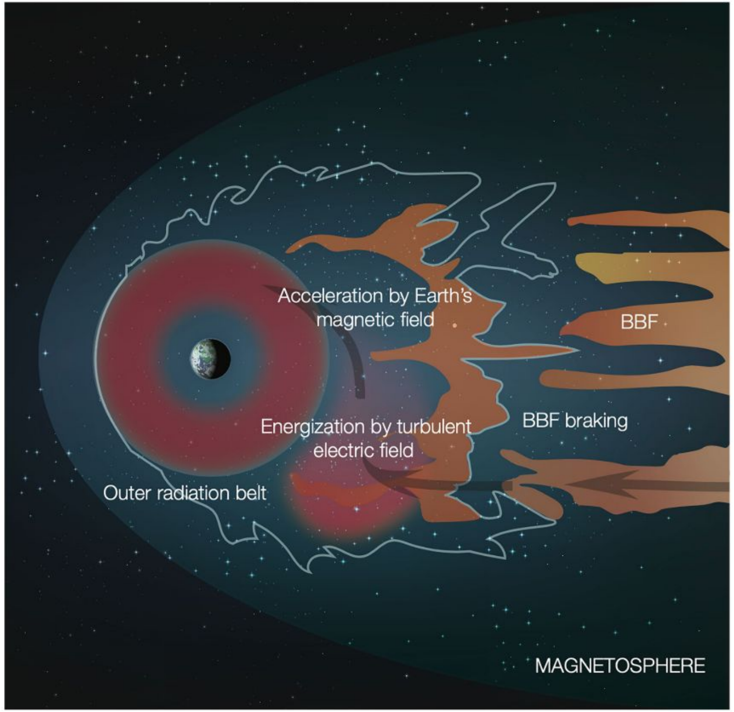
Particle heating: increase in the thermal temperature

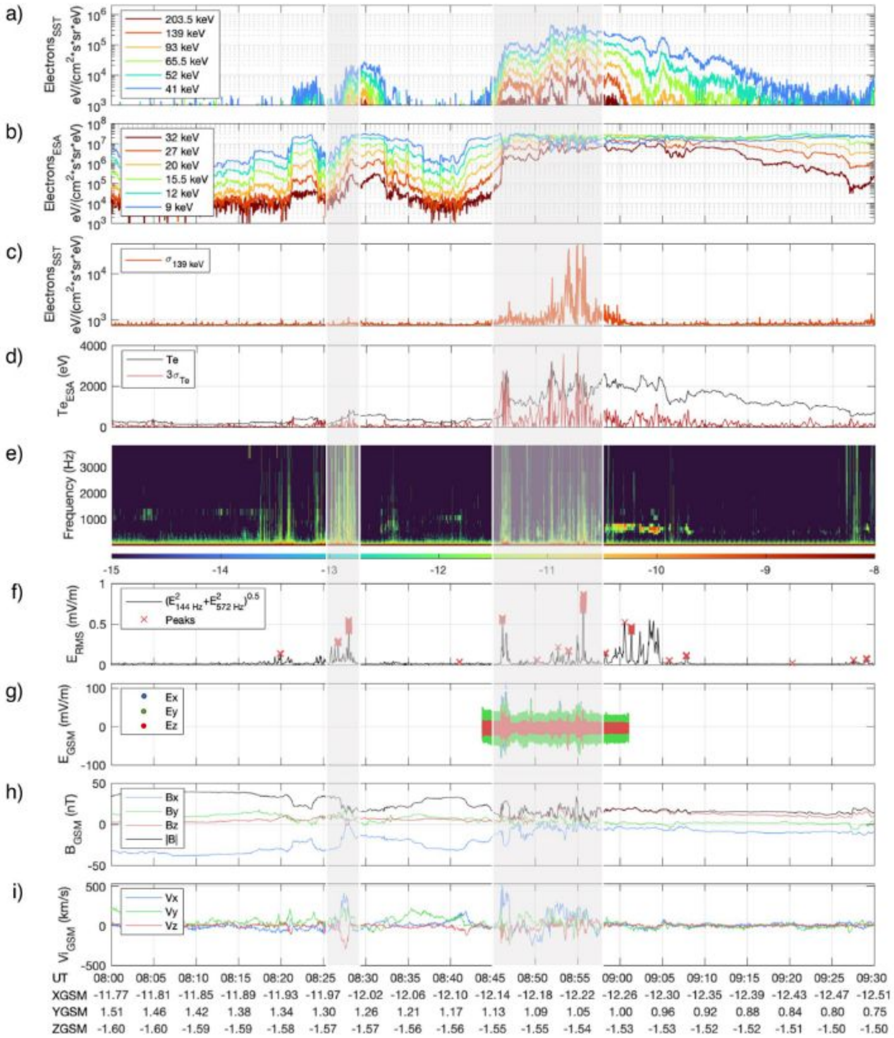
Particle acceleration: increase in the tail flux



Ergun+14,Stawarz+15,Ergun+18, Ergun+20

Motivations: role of electric field turbulence and electron energization established in BBF braking region





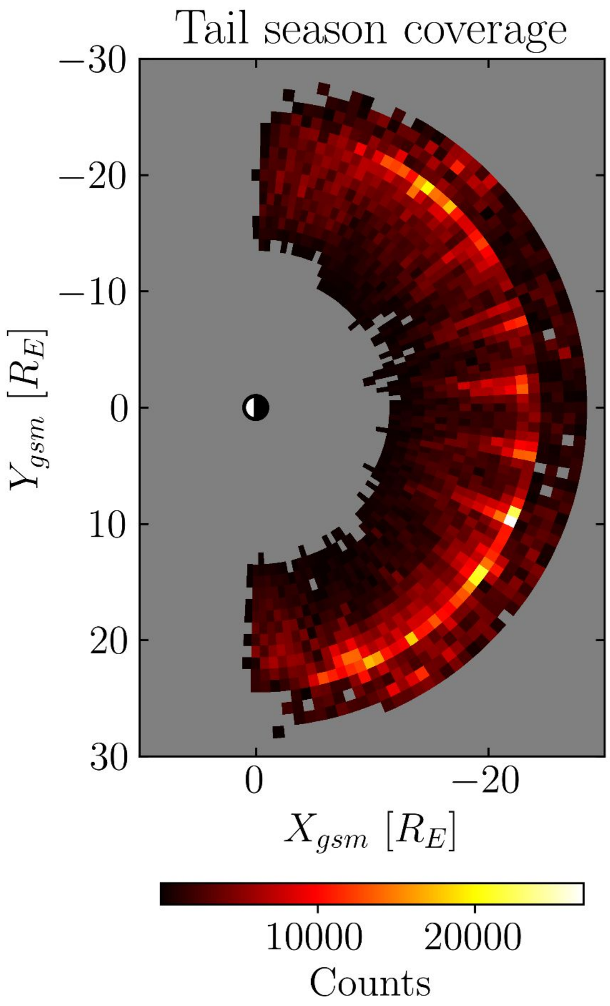
Usanova+Ergun22

MMS data availability 2017-2020

I. FGM (MMS1-4) (***T1 = 510.2 days***)
1. |R_gsm| >= 12 Re
2. Tetrahedron quality factor >= 0.5 (for curlometer)

II. FPI (MMS1) (***T2 = 347.2 days ~ 0.68 T1***)

III. EDP (MMS1-4) (***T3 = 302.3 days ~ 0.6 T1***)
1. Quality flag >= 2



FPI+FEEPS characteristic energy density as a proxy for particle energization

FPI $P_{ij} \equiv 10^8 (n\, k_B T_{1eV}) T_{ij}$ ** pressure has unit of energy density keV/cm3*

Potential issue: this term scales as 1/n for pressure calculation

This term doesn't involve density in pressure calculation

$$T_{xx} \equiv \left(\frac{2\times 10^{-5}}{m^{\frac{3}{2}} (n\, k_B T_{1eV})} (E_0 E_{1eV})^{\frac{5}{2}} \int_0^1 dU \frac{U^{\frac{3}{2}}}{(1-U)^{\frac{7}{2}}} \int_0^{\pi} d\theta \sin^3\theta \int_0^{2\pi} d\varphi \cos^2\varphi\, f(U,\theta,\varphi) \right) - \frac{10^{10} m}{k_B T_{1eV}} V_x^2$$

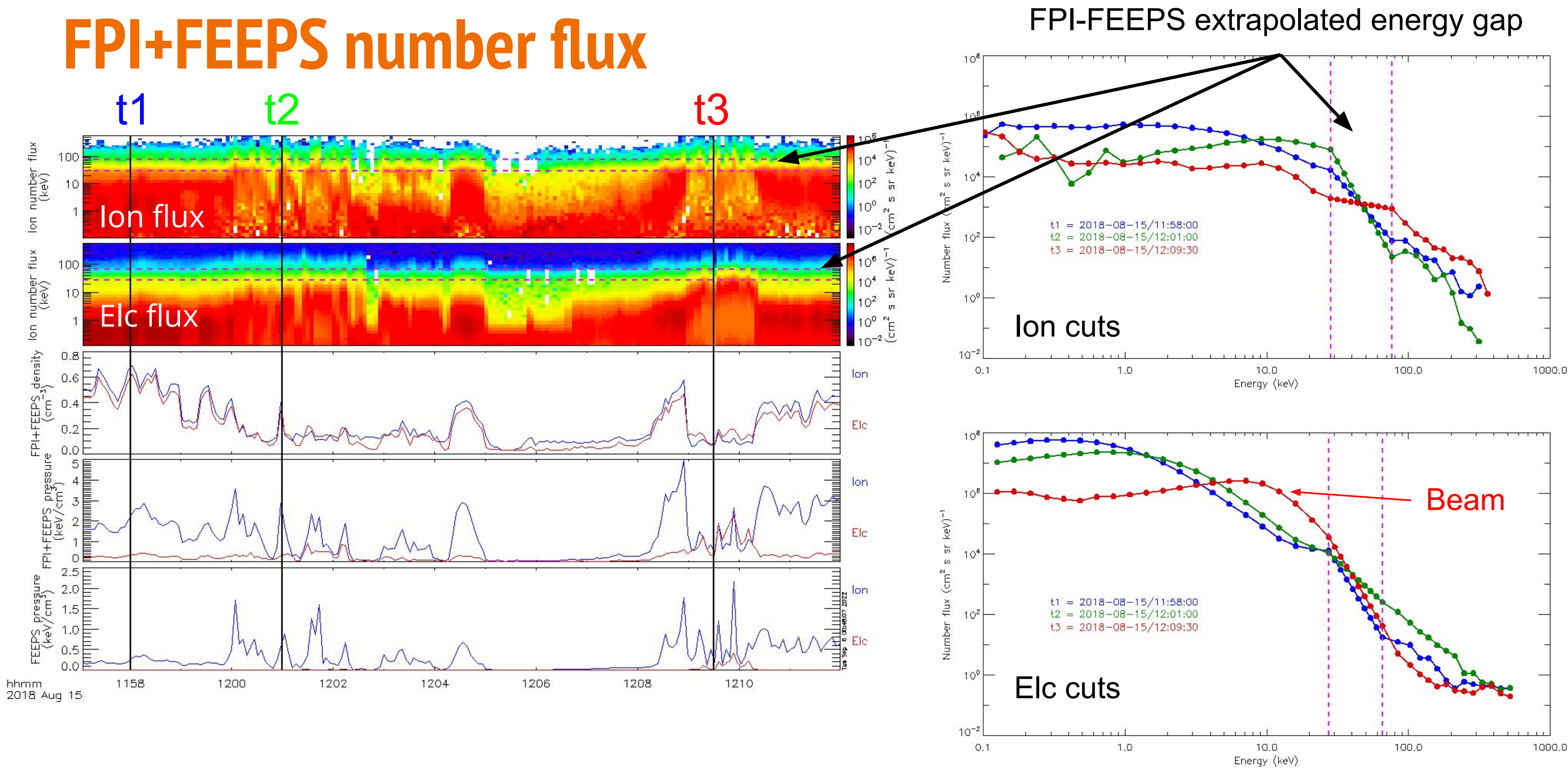
FEEPS

I ~ j = (2E/m) f(r, v)

1. Convert FPI energy flux (J) to number flux* (j)
2. Extrapolate between FPI-FEEPS gap (28 keV - 45 keV) and integrate for pressure above 28 keV

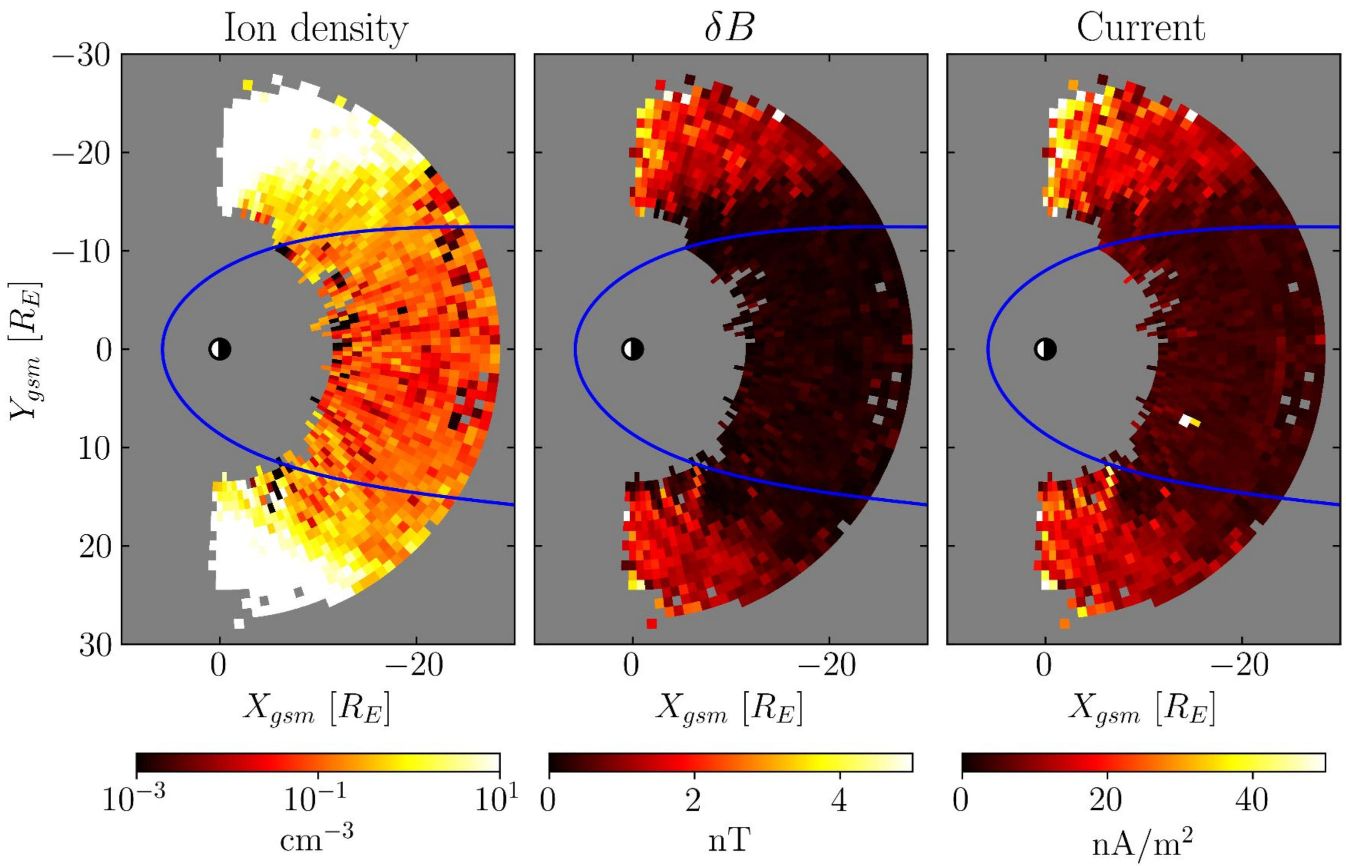
$$n(\text{cm}^{-3}) = A \int \left(E^{1/2}\right)^0 (I/E) \left(E^{1/2} dE\right) \qquad P(\text{dynes cm}^{-2}) = A \int \left(E^{1/2}\right)^2 (I/E) \left(E^{1/2} dE\right)$$

FPI+FEEPS number flux



* FEEPS provides omni-directional ***number flux*** j; FPI provides omni-directional ***energy flux*** J = E j (c.f. **Wuest+07**)

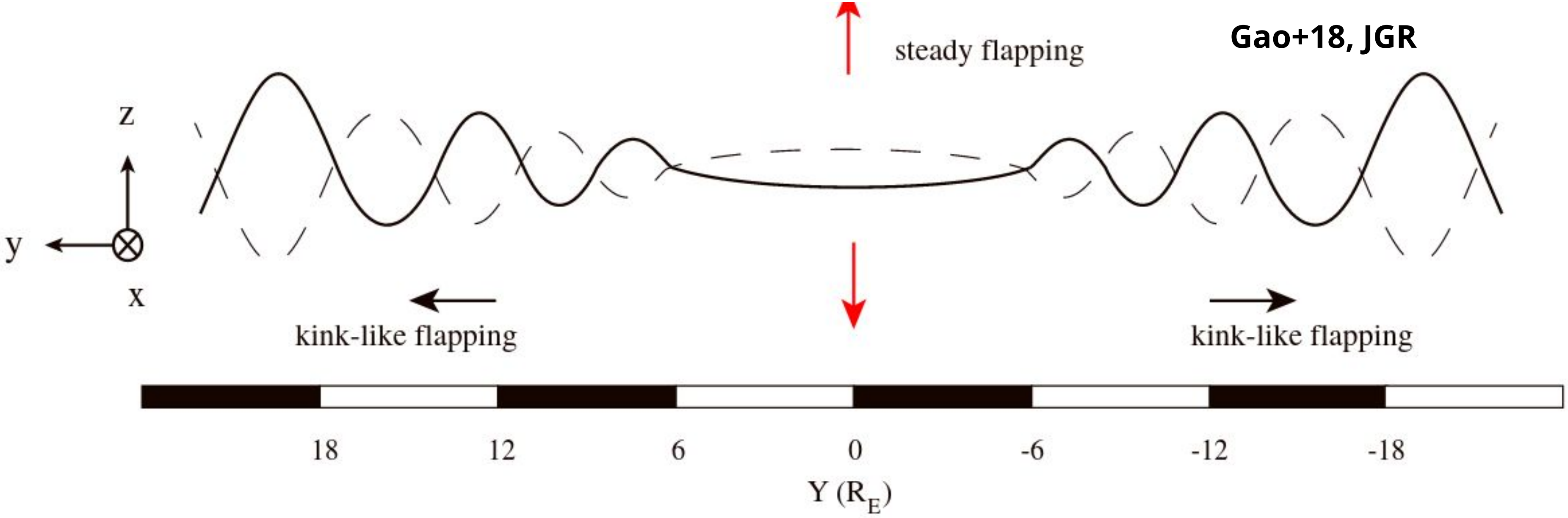
Plasma sheet ID: Eliminating solar wind from dataset



Rotated **Lin+10** magnetopause model

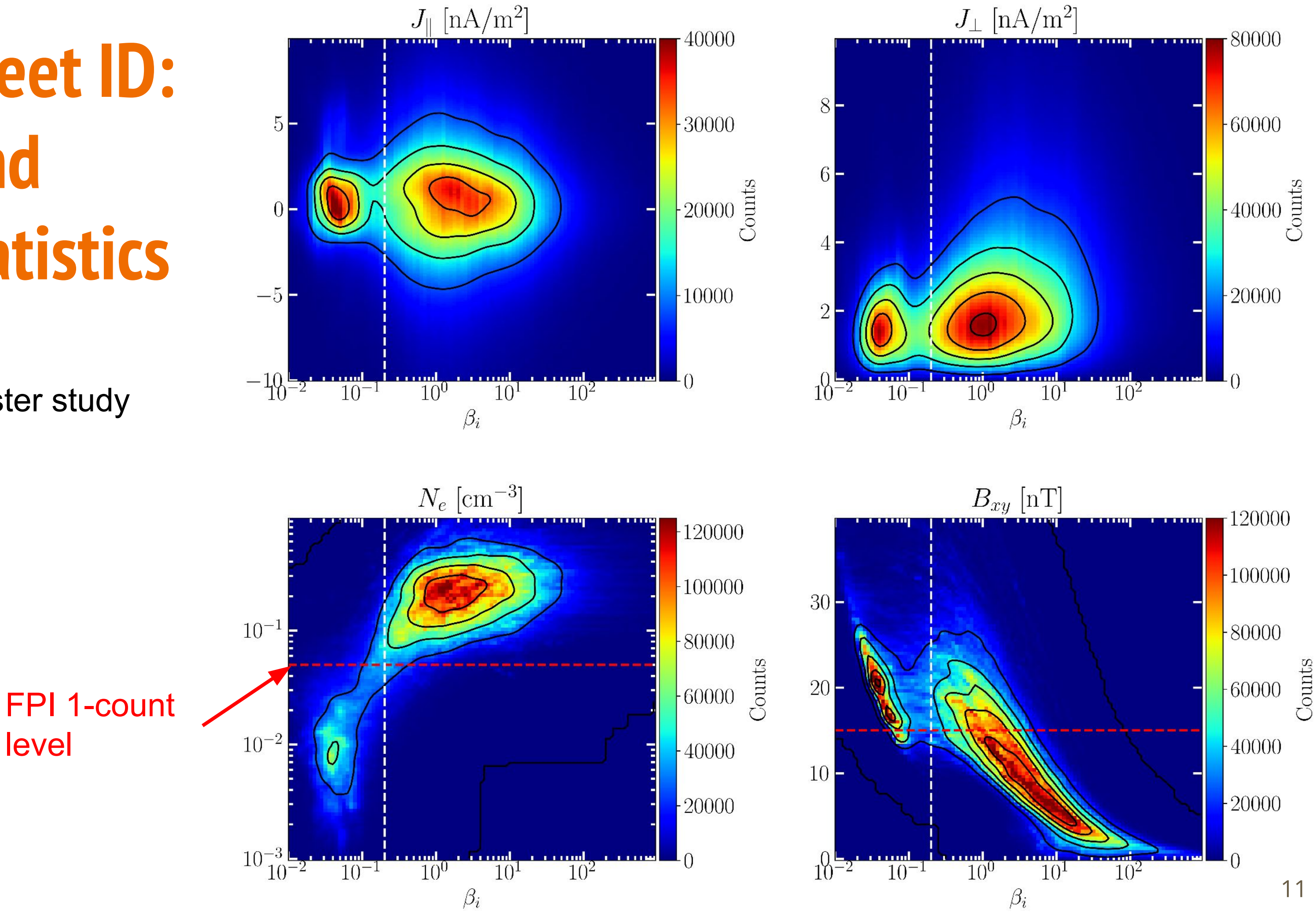
Plasma sheet ID: Eliminating solar wind from dataset

Gao+18, JGR



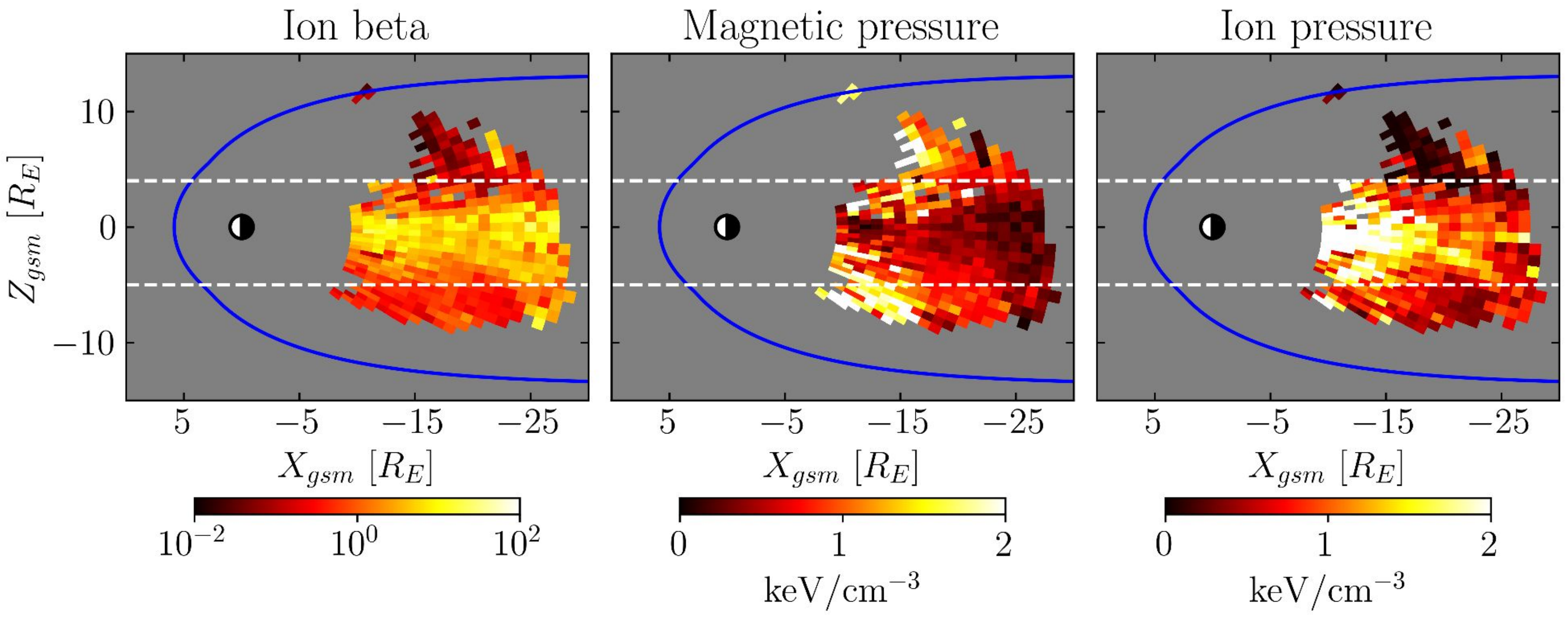
Plasma sheet ID: Background plasma statistics

Consistent with Cluster study (**Boakes+14**)



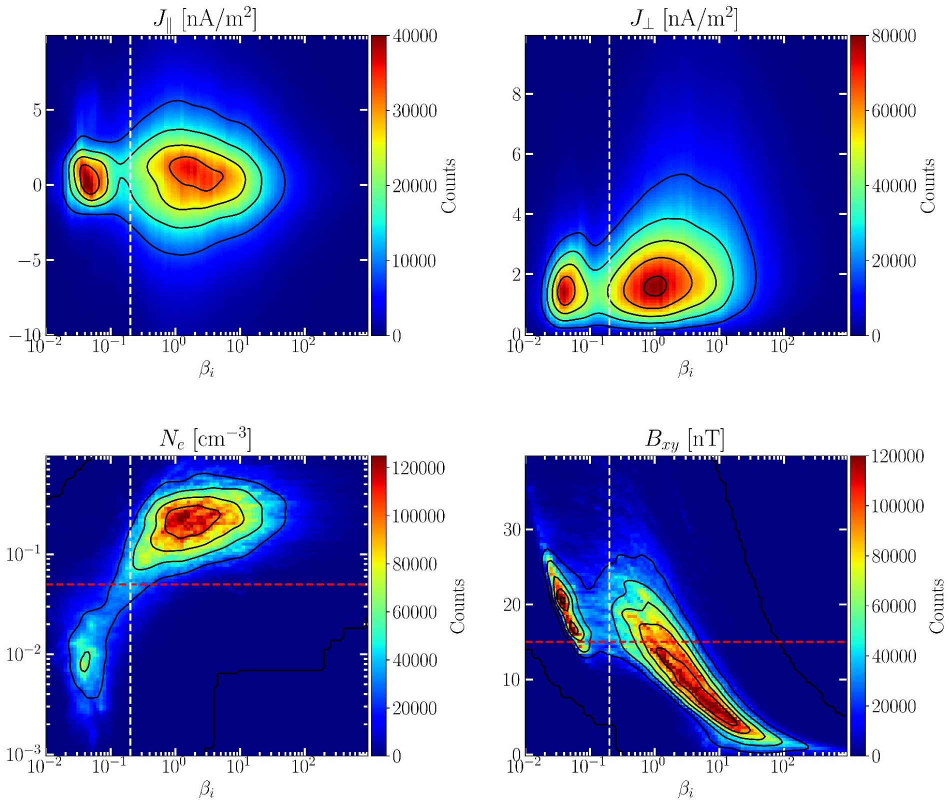
Plasma sheet ID: Background plasma statistics

Sheet condition: -5 Re <= Z <= 4 Re

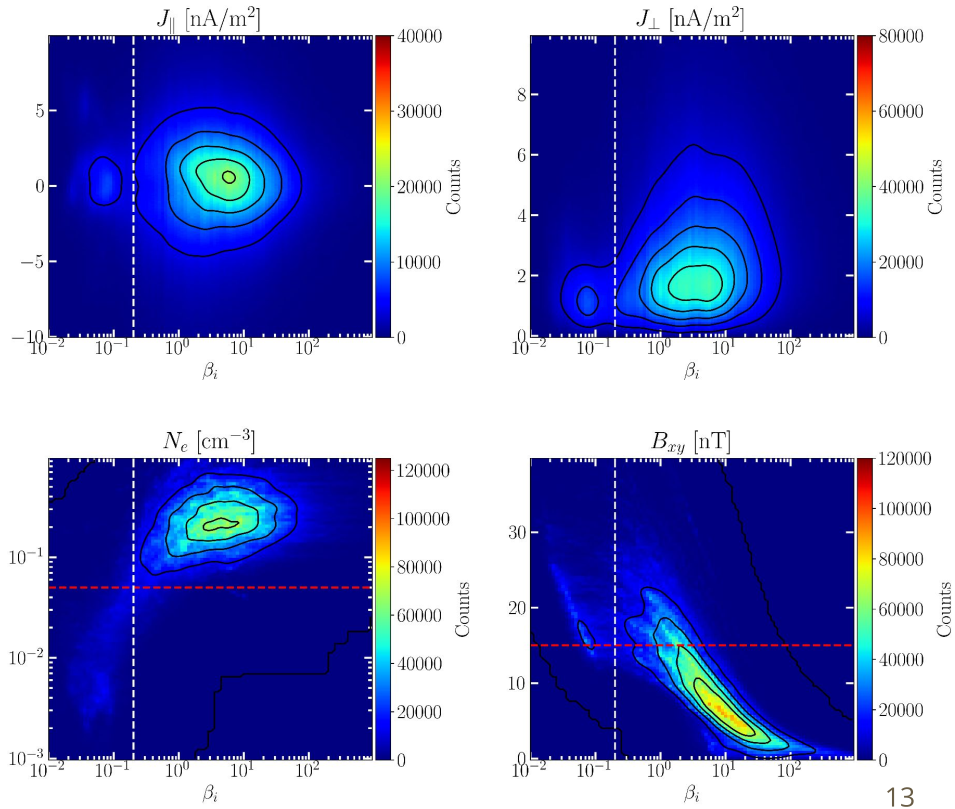


Plasma sheet ID: All Z vs. Restricted Z

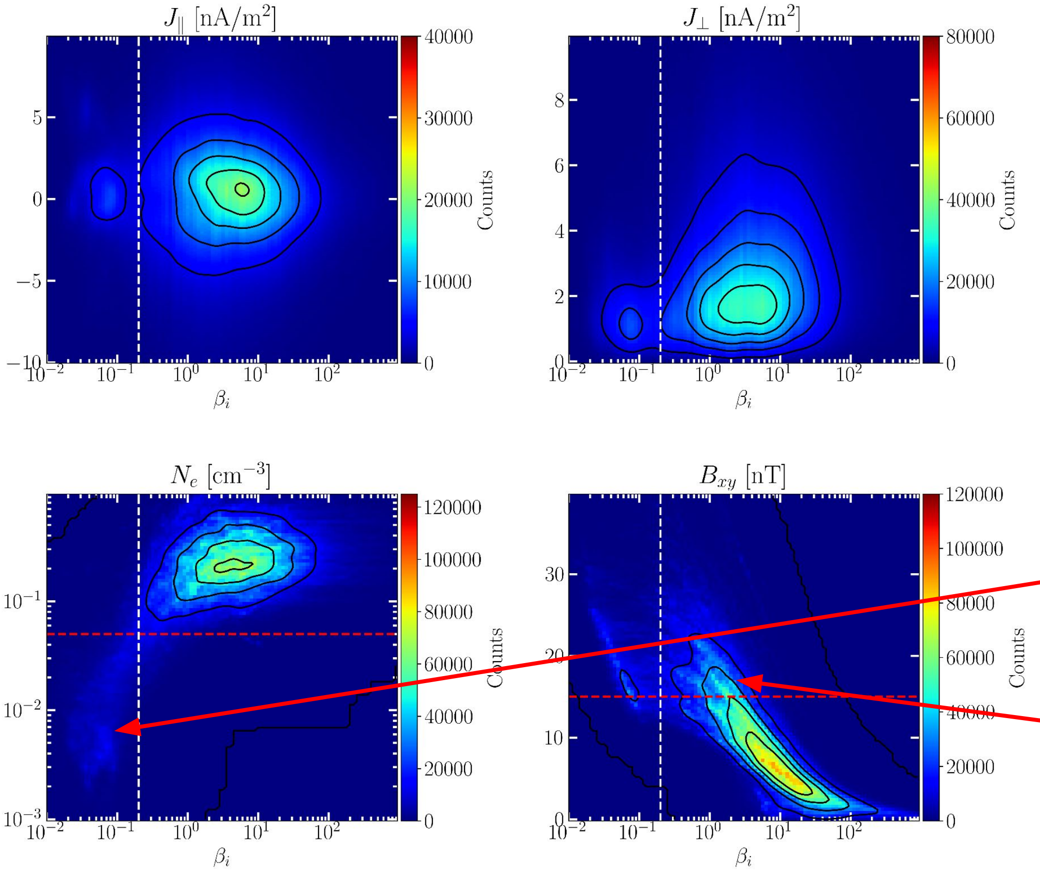
All Z



-5 <= Z <= 4



Plasma sheet ID: Recap



Define sheet conditions:

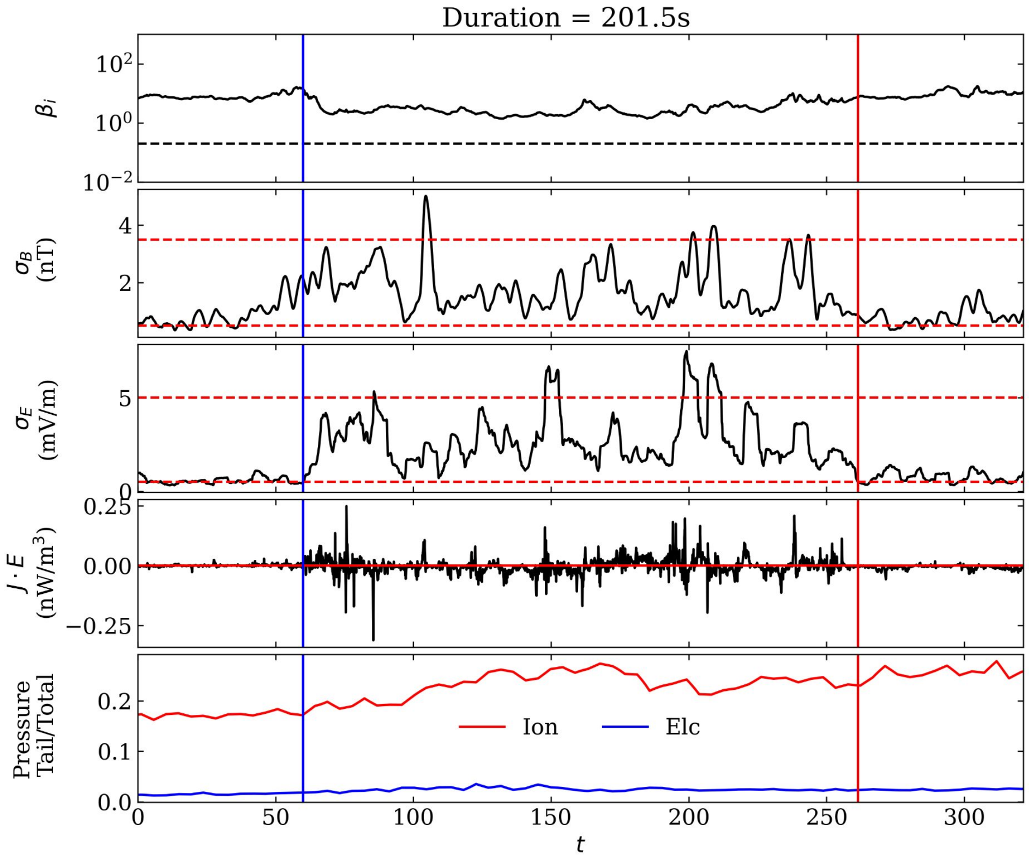
1. **Ion beta >= 0.2**
2. **Bxy <= 15 nT**
3. **-5 <= Z <= 4**

Majority of high-beta data points are above FPI low density threshold => No low density issue

Most of the "***definitely lobe***" events are eliminated

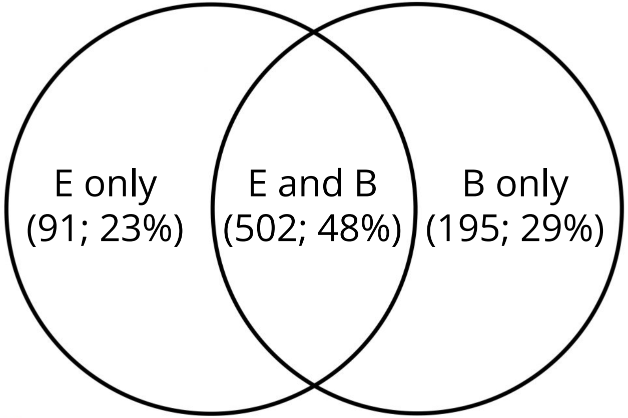
This region contains the "***probably boundary layer***" events

High turbulence events criteria

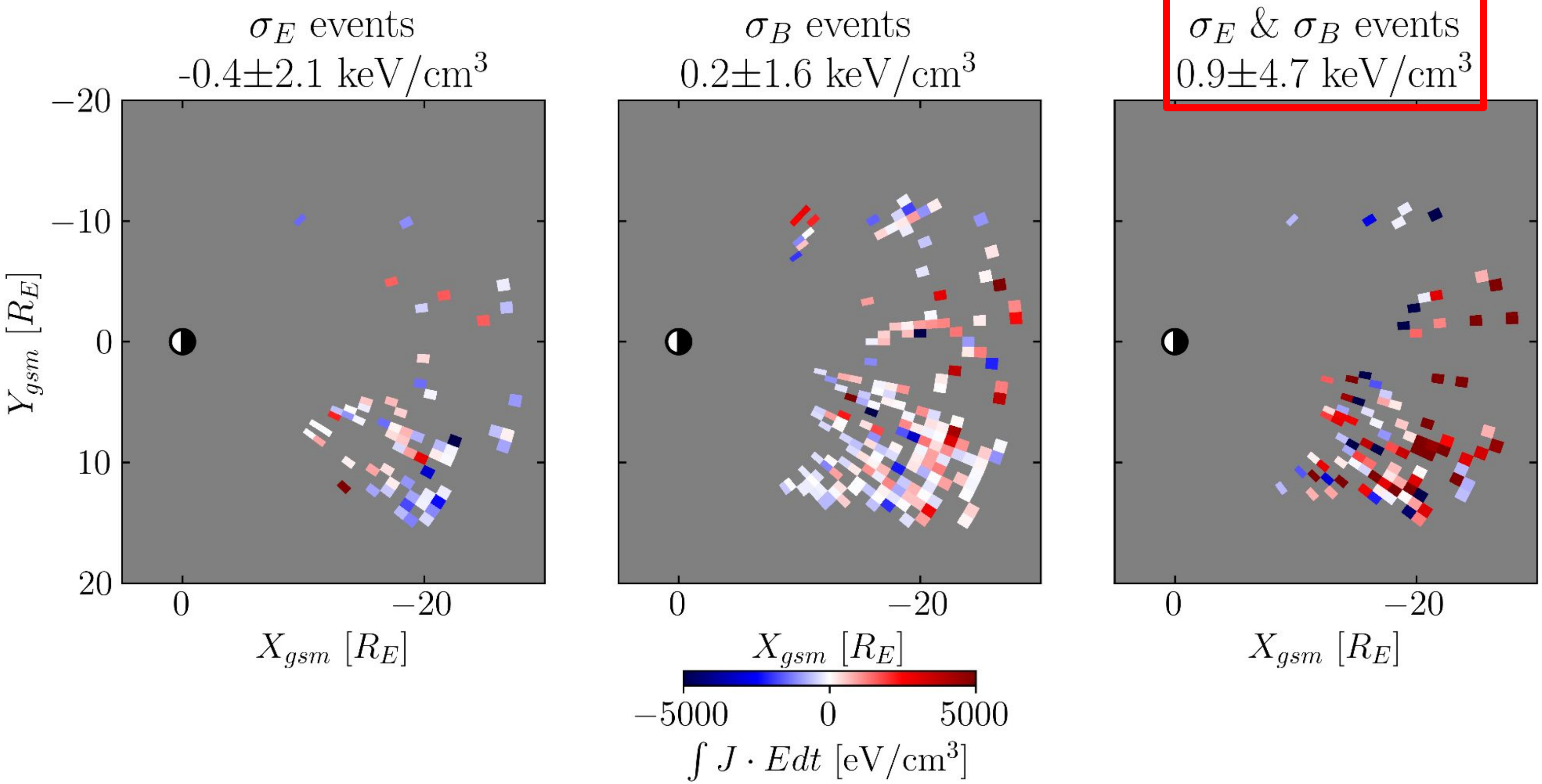


High fluctuations (5-s moving std):

a. Only electric field: trigger at 5 mV/m, stop at 0.5 mV/m
b. Only magnetic field: trigger at 3.5 nT, stop at 0.5 nT
c. Both: trigger at 5 mV/m / 3.5 nT, stop at 0.5 mV/m / 0.5 mV/m

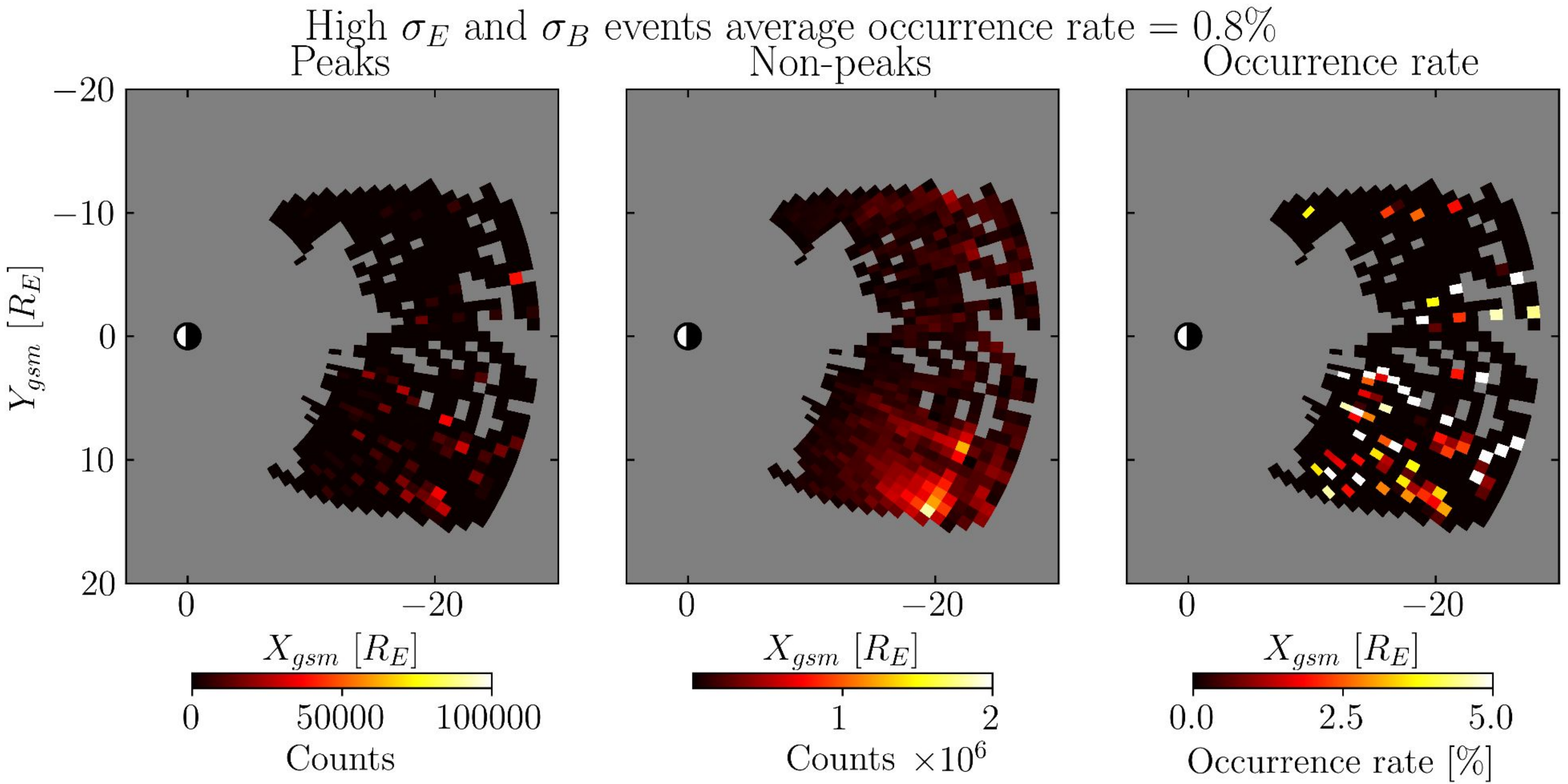


Integrated J.E



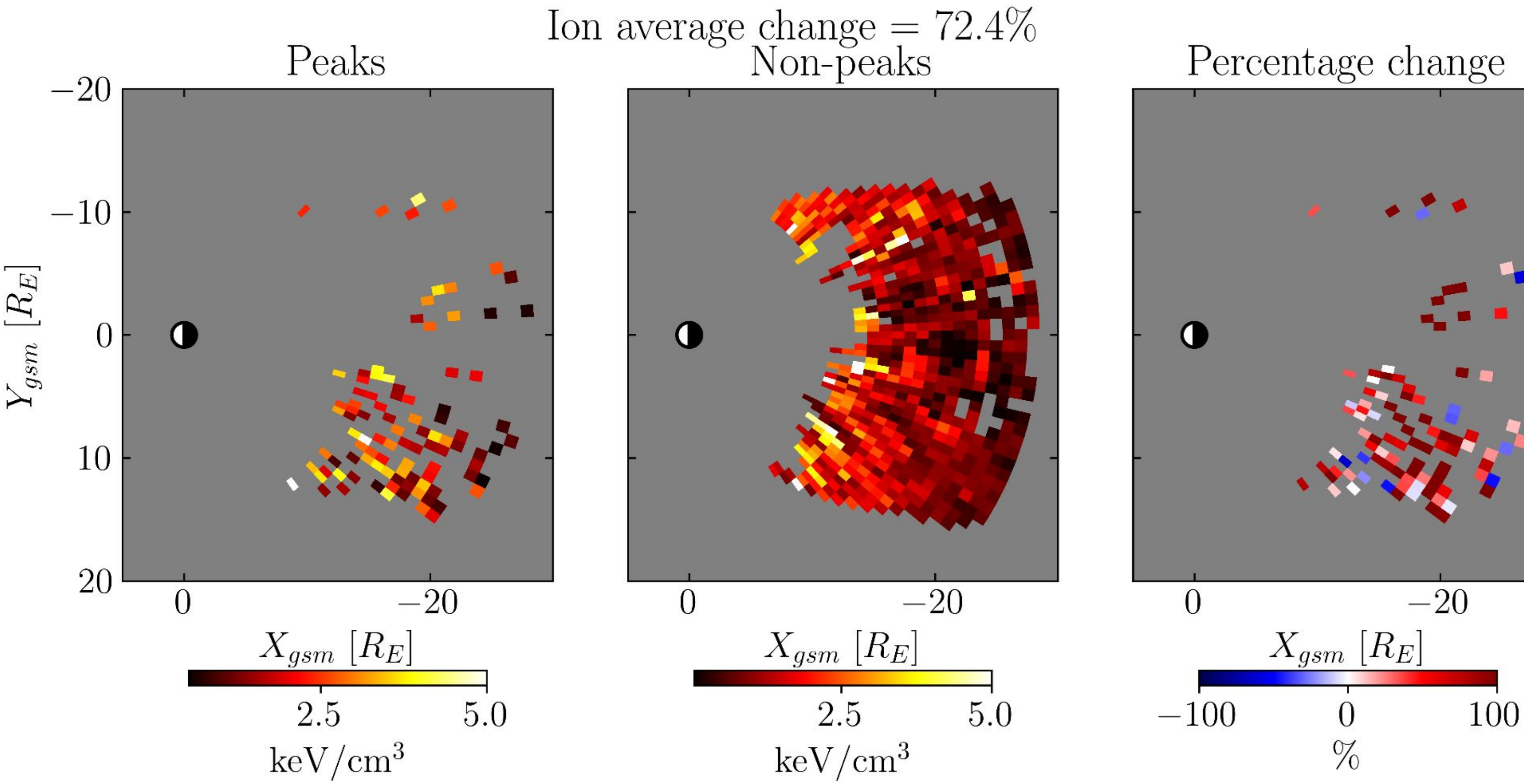
Occurrence rates

Average rate consistent with Usanova+Ergun22



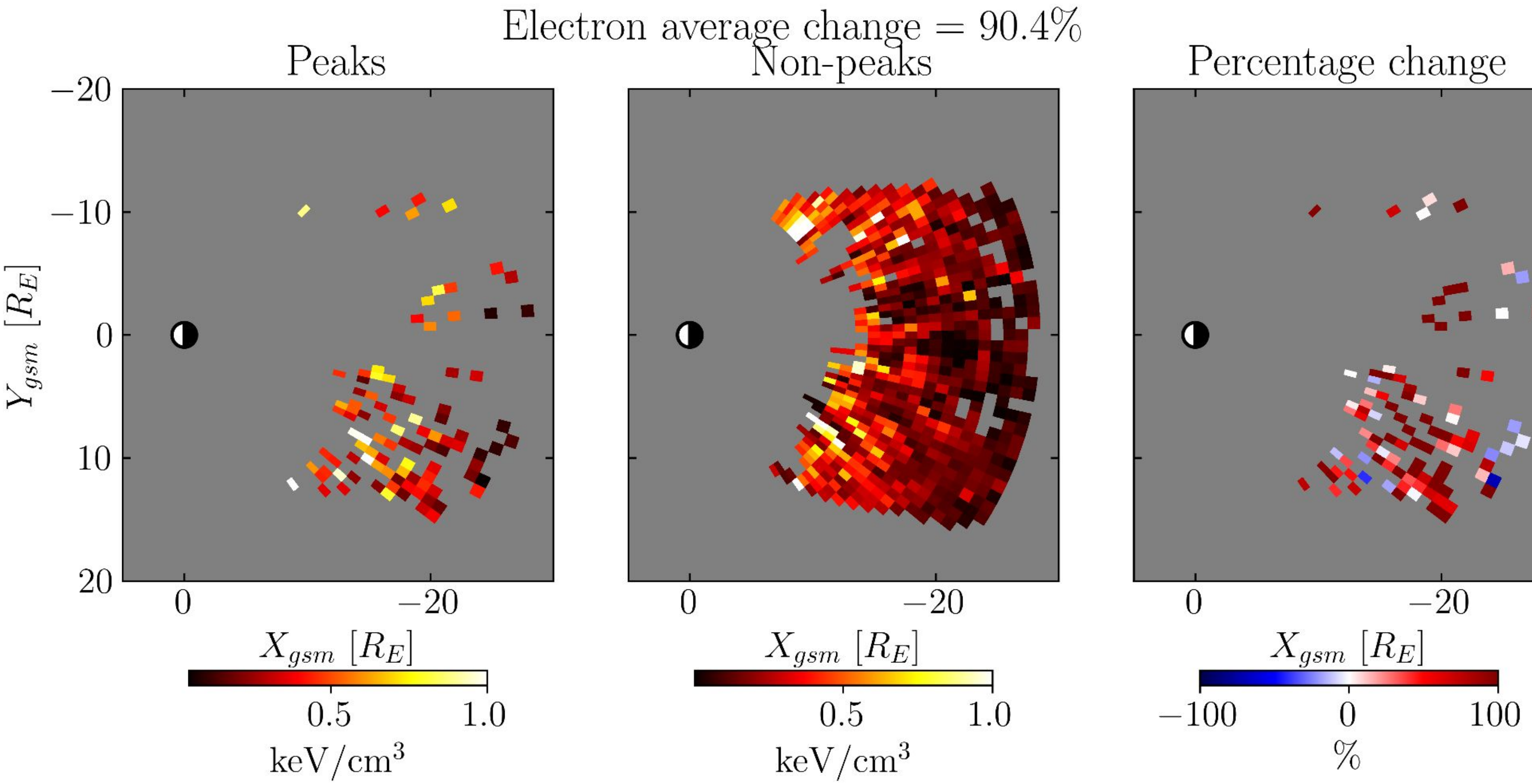
Ion pressure

Corresponding to ~ +1.3 keV/cm3

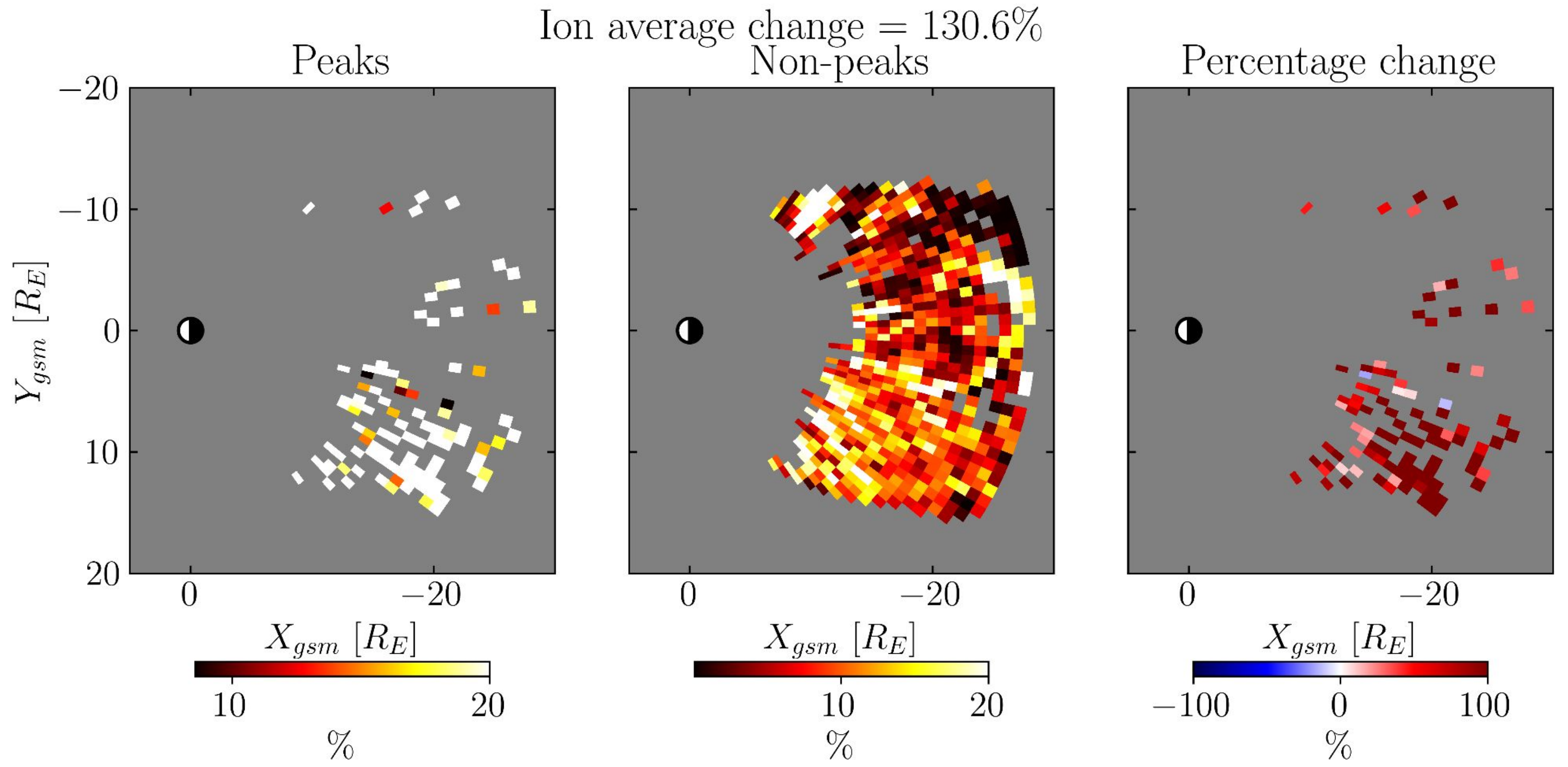


Electron pressure

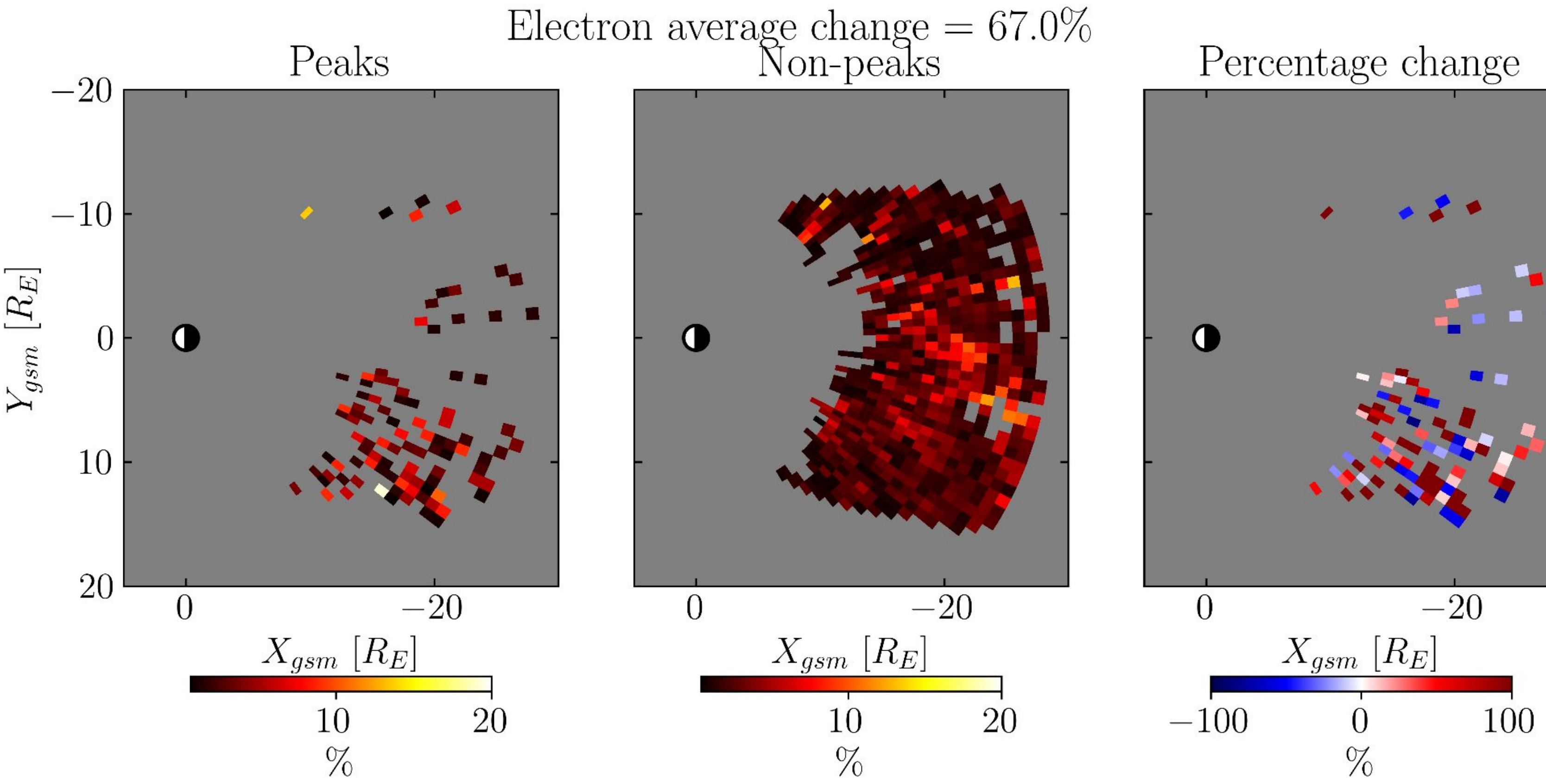
Corresponding to ~ +0.4 keV/cm3



Percentage of tail pressure (ion)



Percentage of tail pressure (electron)

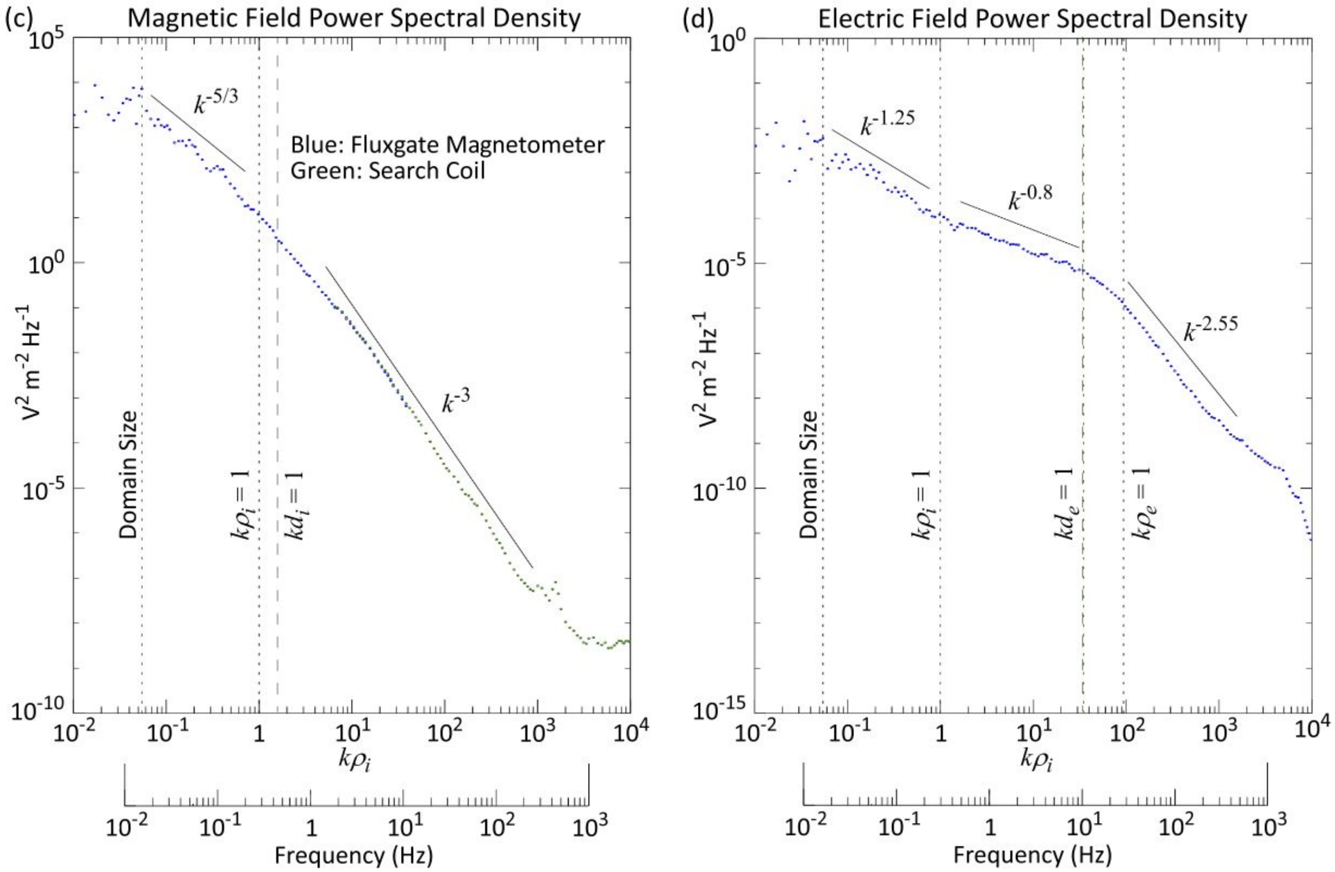


Comparison between 3 categories of events

	E only	B only	E and B
$\int \mathbf{J} \cdot \mathbf{E} dt$	-0.4 +/- 2.1 keV/cc	0.2 +/- 1.6 keV/cc	0.9 +/- 4.7 keV/cc
Pion change	+0.6 keV/cc (+49%)	+1.4 keV/cc (+65%)	+1.3 keV/cc (+72%)
Pelc change	+0.2 keV/cc (+90%)	+0.2 keV/cc (+64%)	+0.3 keV/cc (+90%)
Pion tail change	+136%	+83%	+130%
Pelc tail change	+59%	+7%	+90%

- Ions are ***heated*** more by ***B fluctuations***, but ***accelerated*** more by ***E fluctuations***.
- Electrons are both ***heated and accelerated*** more by ***E fluctuations.***

Frequency spectrum of field turbulence



Ergun+22

In summary

- Rate of electromagnetic field energy transport (J.E) most significant for high electromagnetic field turbulence.
- Increase in particle pressure is consistent with J.E => Particle energization is associated with field turbulence.
- 10-100 keV ions constitute a significant amount (~20%) of the total pressure in the vicinity of field turbulence.

Future works

- Statistical properties of field turbulences.
- Relationship with reconnection