Classifying Magnetosheath Jets Using MMS: Quasi – parallel & Quasi – perpendicular Jets

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Introduction

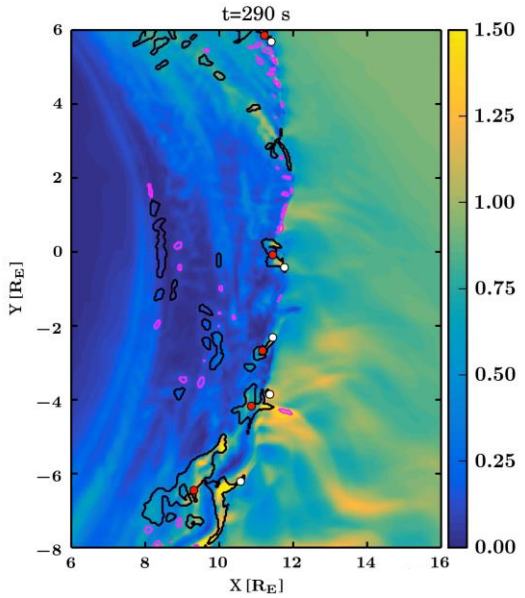
Magnetosheath Jets

What: Enhancements of dynamic pressure above the general fluctuations level

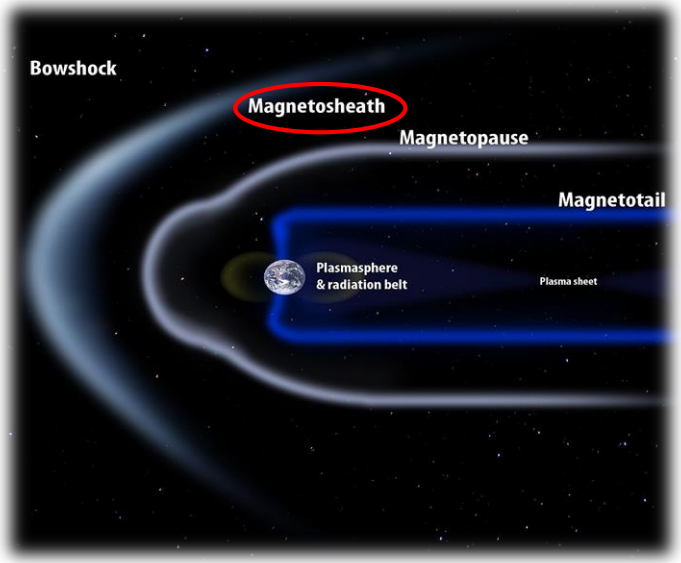
Where: Magnetosheath

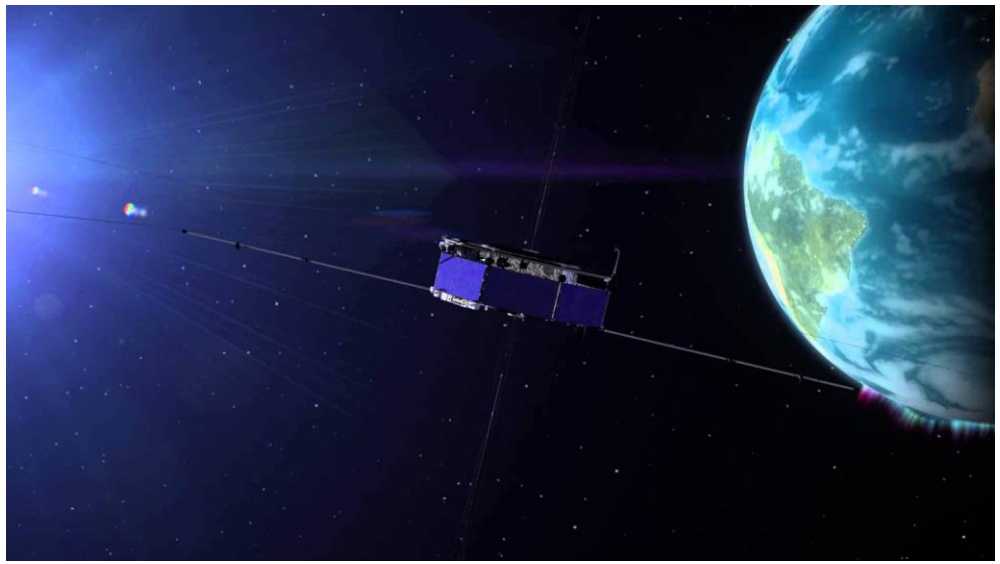
Data: MMS (Magnetospheric Multiscale Mission)

Why: Interaction of SW & Magnetosphere, magnetopause reconnection, radiation belts, auroral features…



Palmroth Minna et al. (2018)



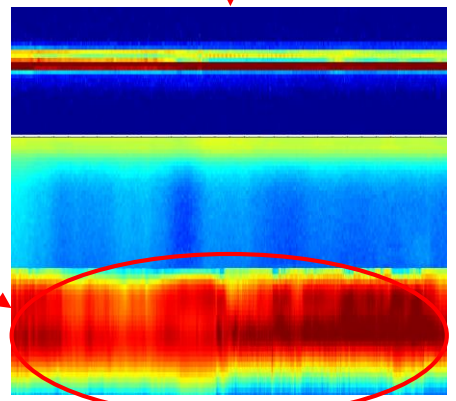


Searching for Jets

Loading MMS data

Classify regions (MS/SW/PSH)

Search for Magnetosheath Jets on MS



SW

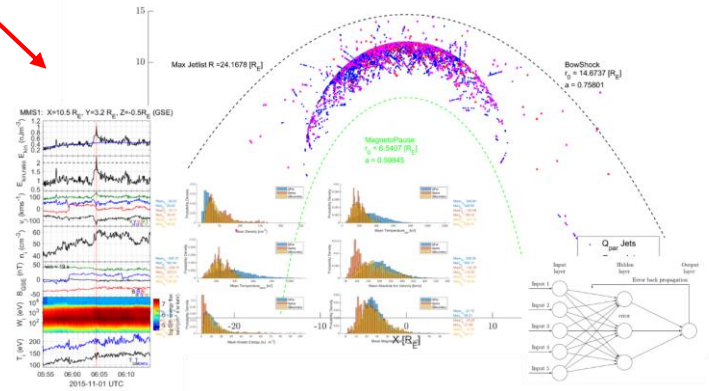
PSH

MS

Save Area and Jet Values $(\mathrm{v}, P_{dyn}, \rho, P, \mathrm{B}, \mathrm{E}, \mathrm{T}, \theta \ldots)$

Jet Classification

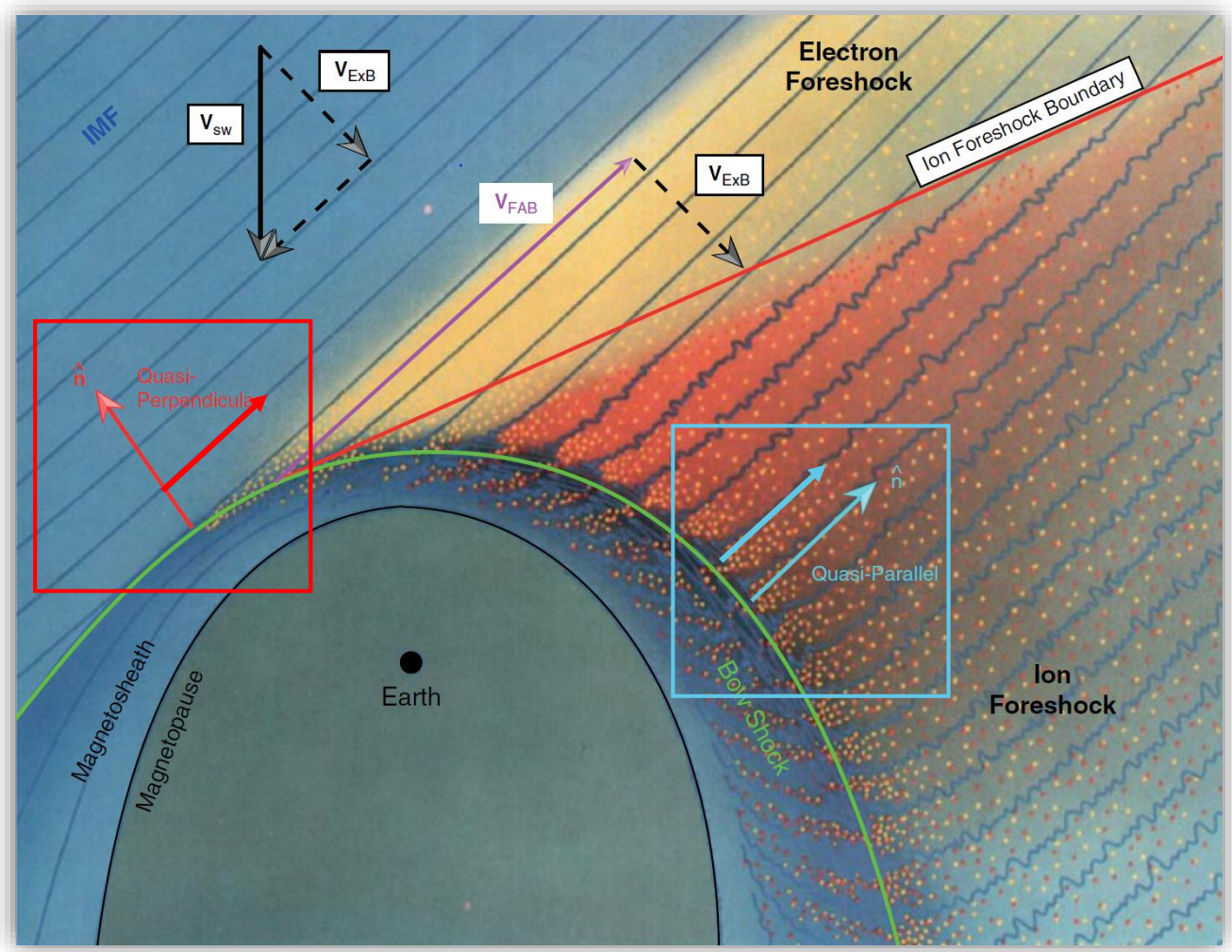
Statistics – Jet Comparison



Find patterns & Possible origin and generation mechanism

TBD …

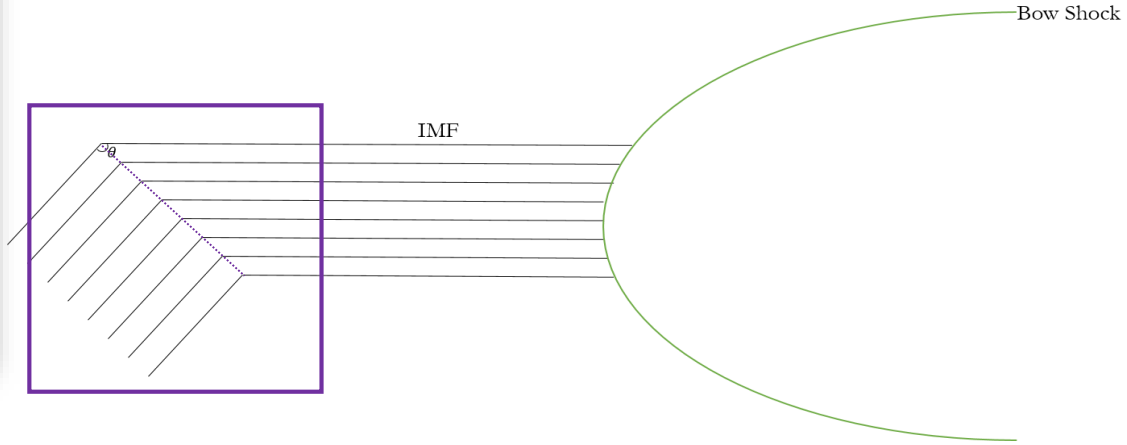
Motivation – Main Subcategories



L. B. Wilson (2016)

Jets are found mainly in Quasi-parallel shock ($\theta_n < 45°$). However, fluctuations also found in Quasi Perpendicular regions.

Q_{par}	Q_{per}	$Boundary$



How Jet look like – Quasi Parallel

High B Variance, High Energetic Particles, Low Anisotropy

Kinetic Energy Density

Kinetic Energy Density Ratio

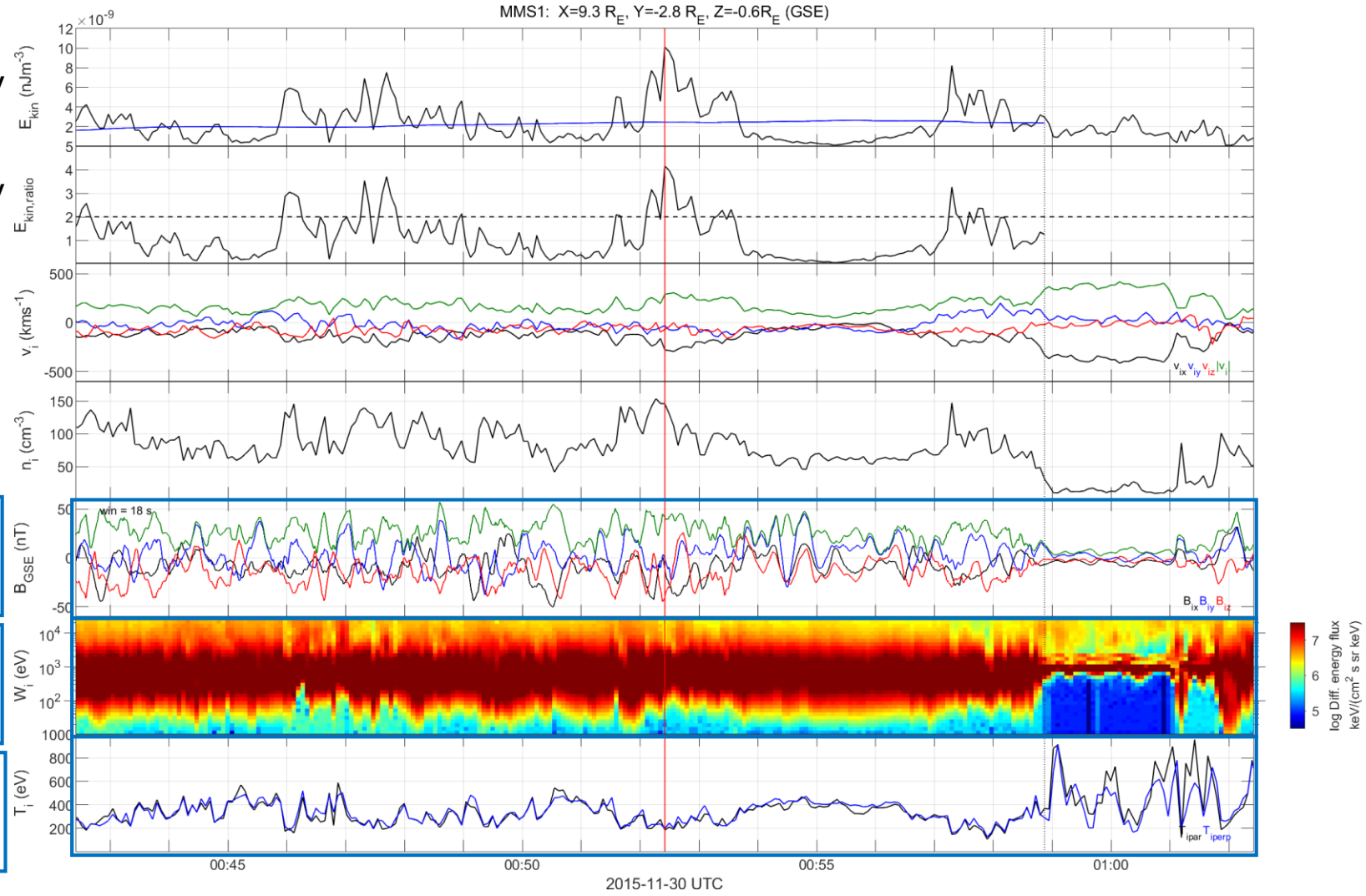
Velocity

Density

Magnetic Field

Ion Energy Spectrum

Temperature



How Jet look like – Quasi Perpendicular

Low B Variance, Low Energetic Particles, High Anisotropy

Kinetic Energy Density

Kinetic Energy Density Ratio

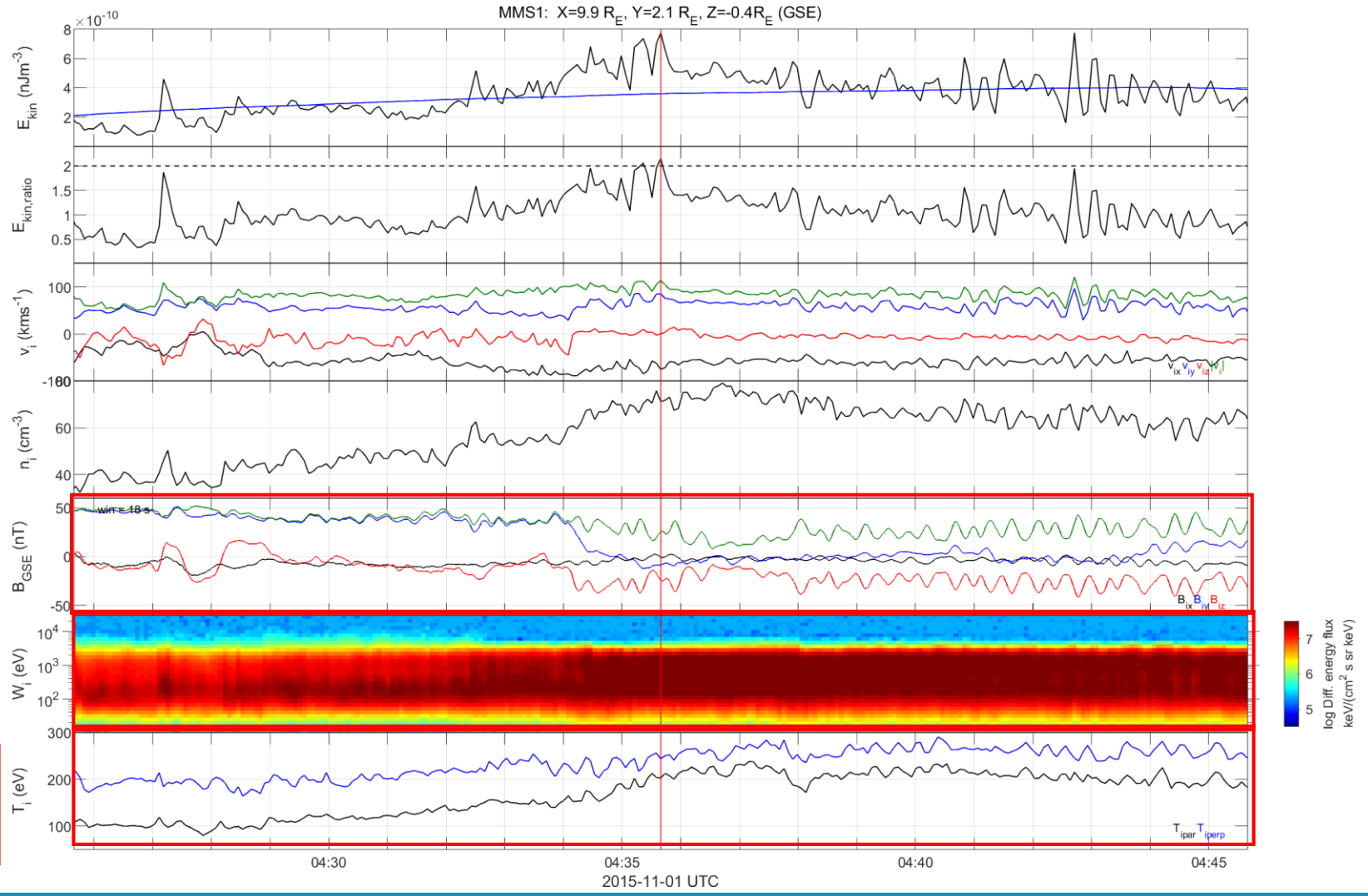
Velocity

Density

Magnetic Field

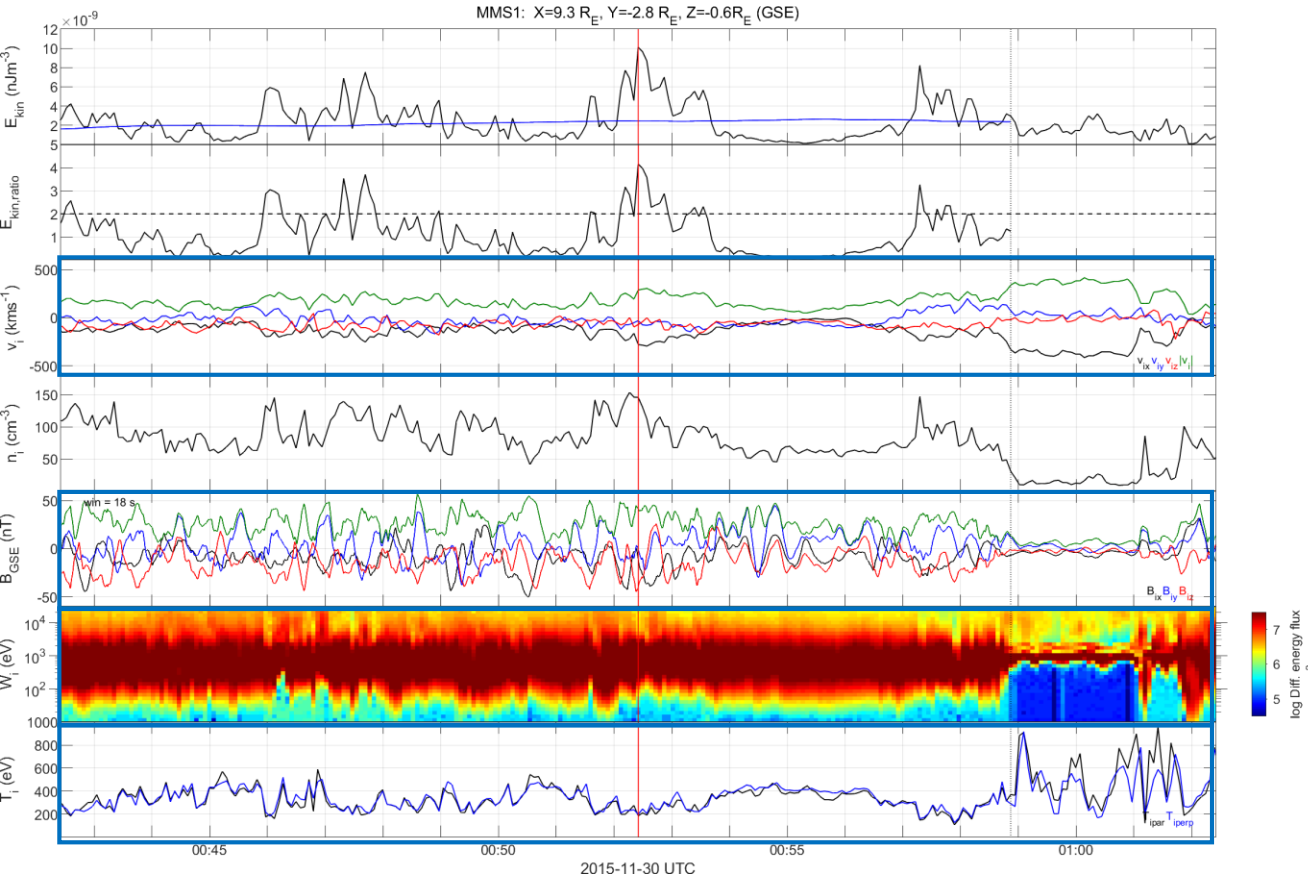
Ion Energy Spectrum

Temperature



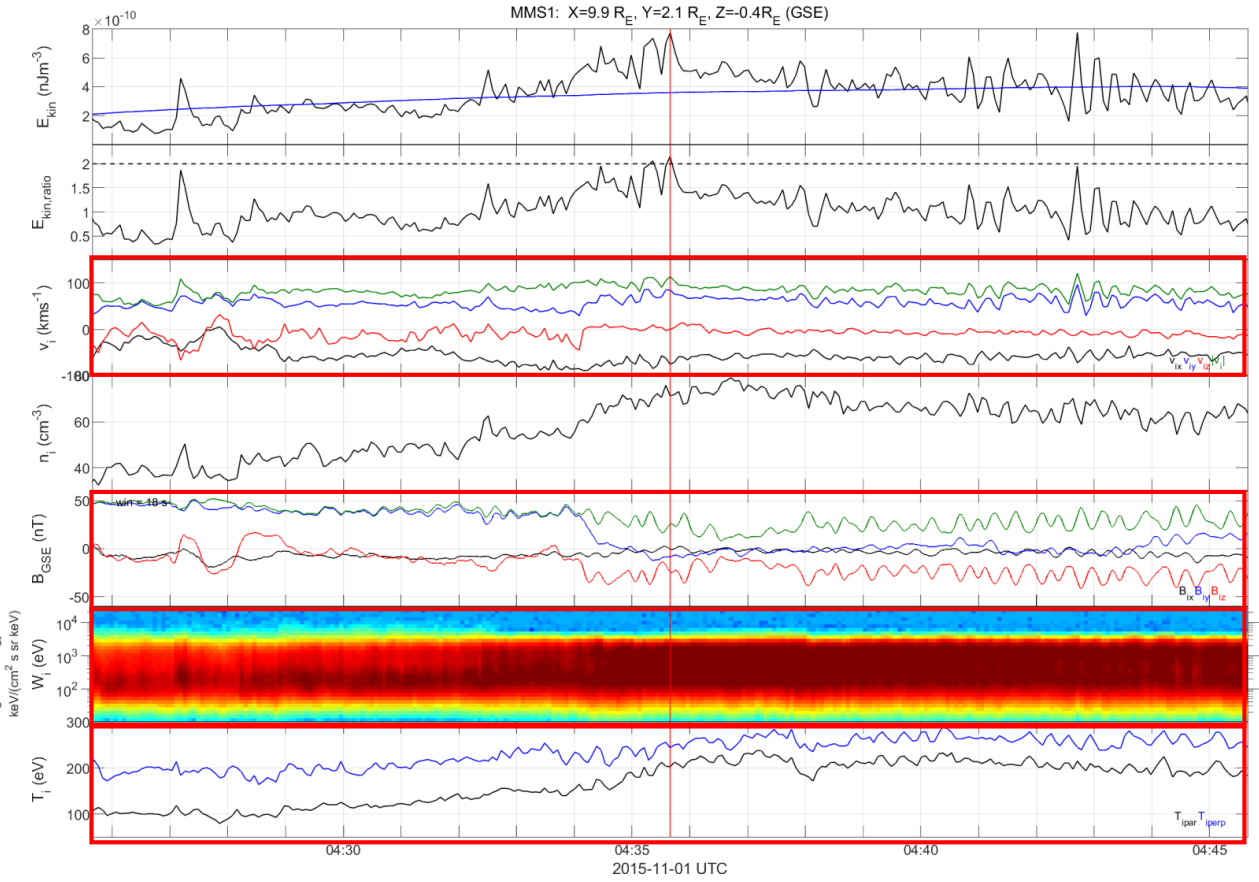
See the differences?

High Variance, High Energetic Particles, Low Anisotropy



Quasi – Parallel Jet

Low Variance, No Energetic Particles, High Anisotropy

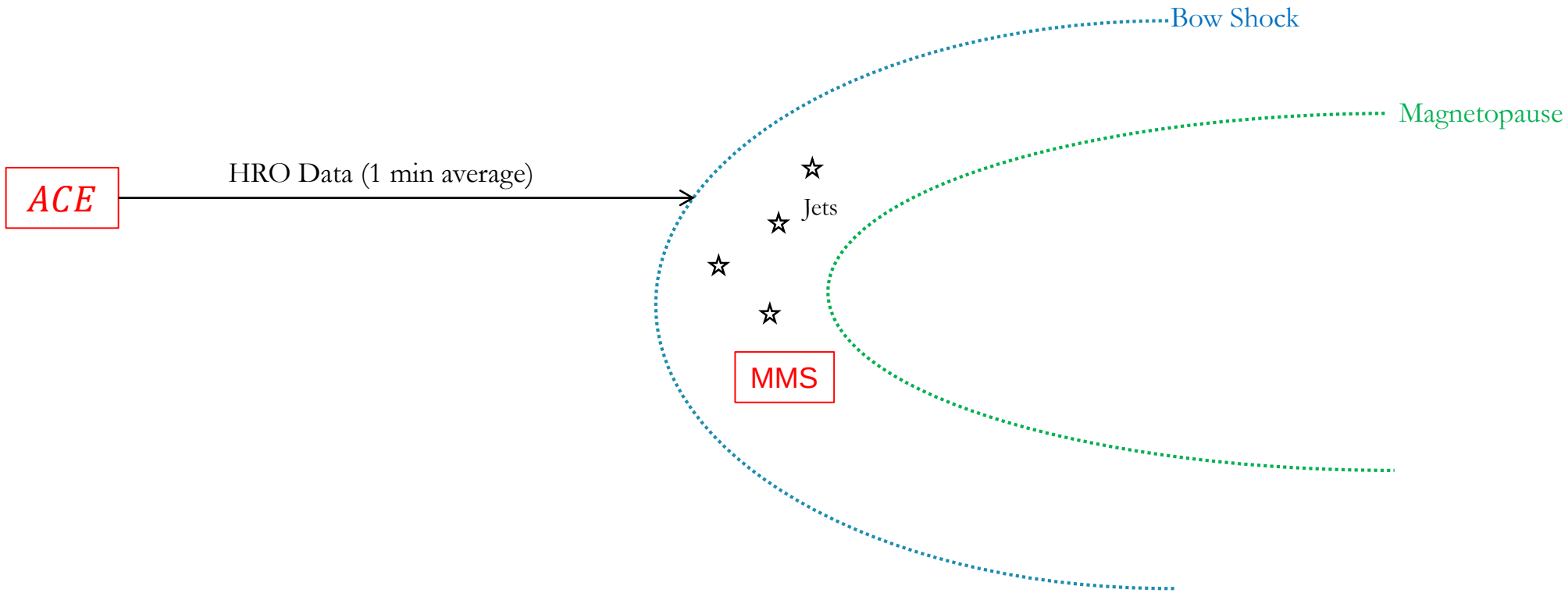


Quasi – Perpendicular

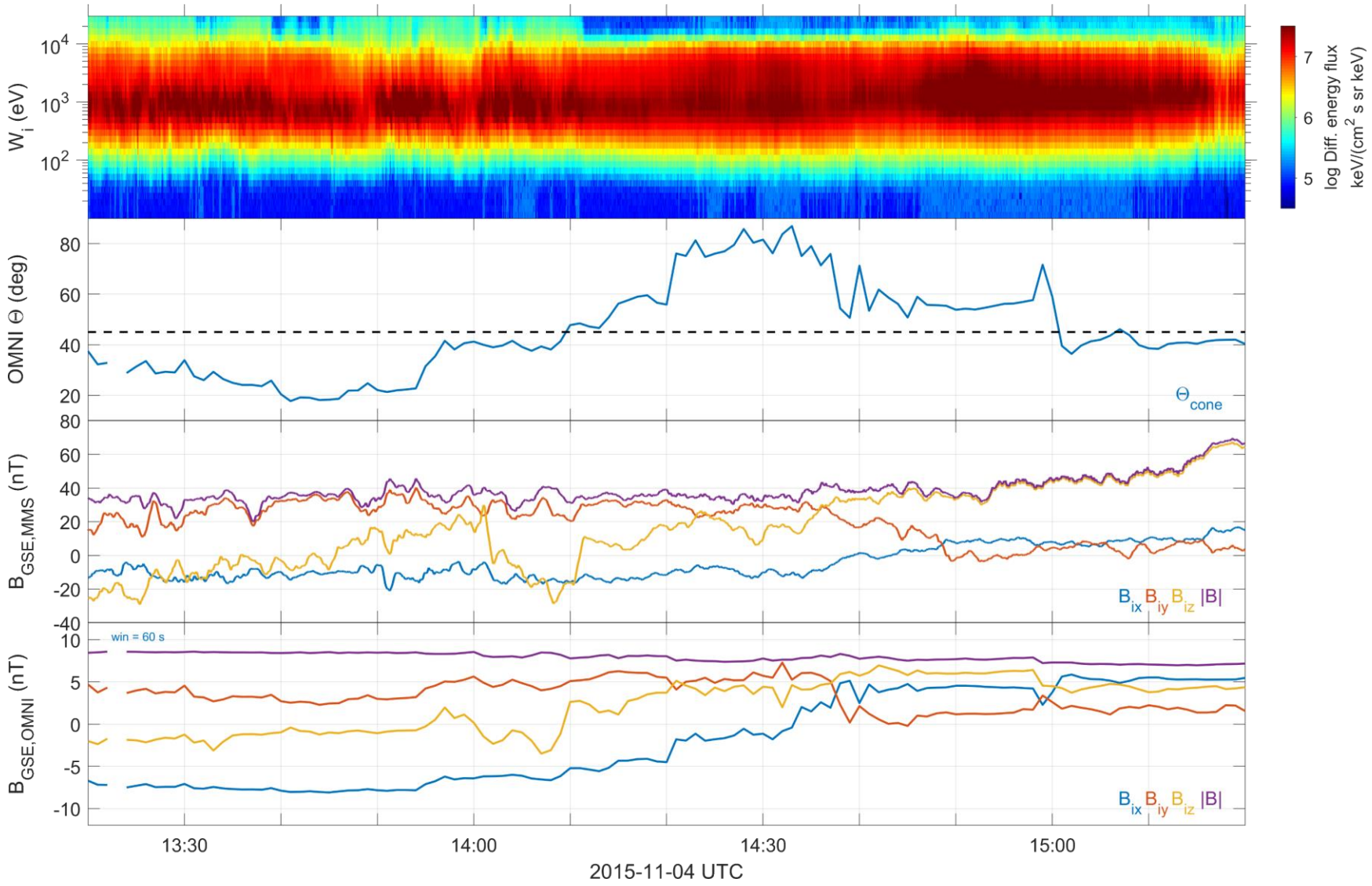
Angle & Bow shock configuration

Why not directly θ_n from Solar wind data ?

- Worse availability
- Error in propagating to Bow shock



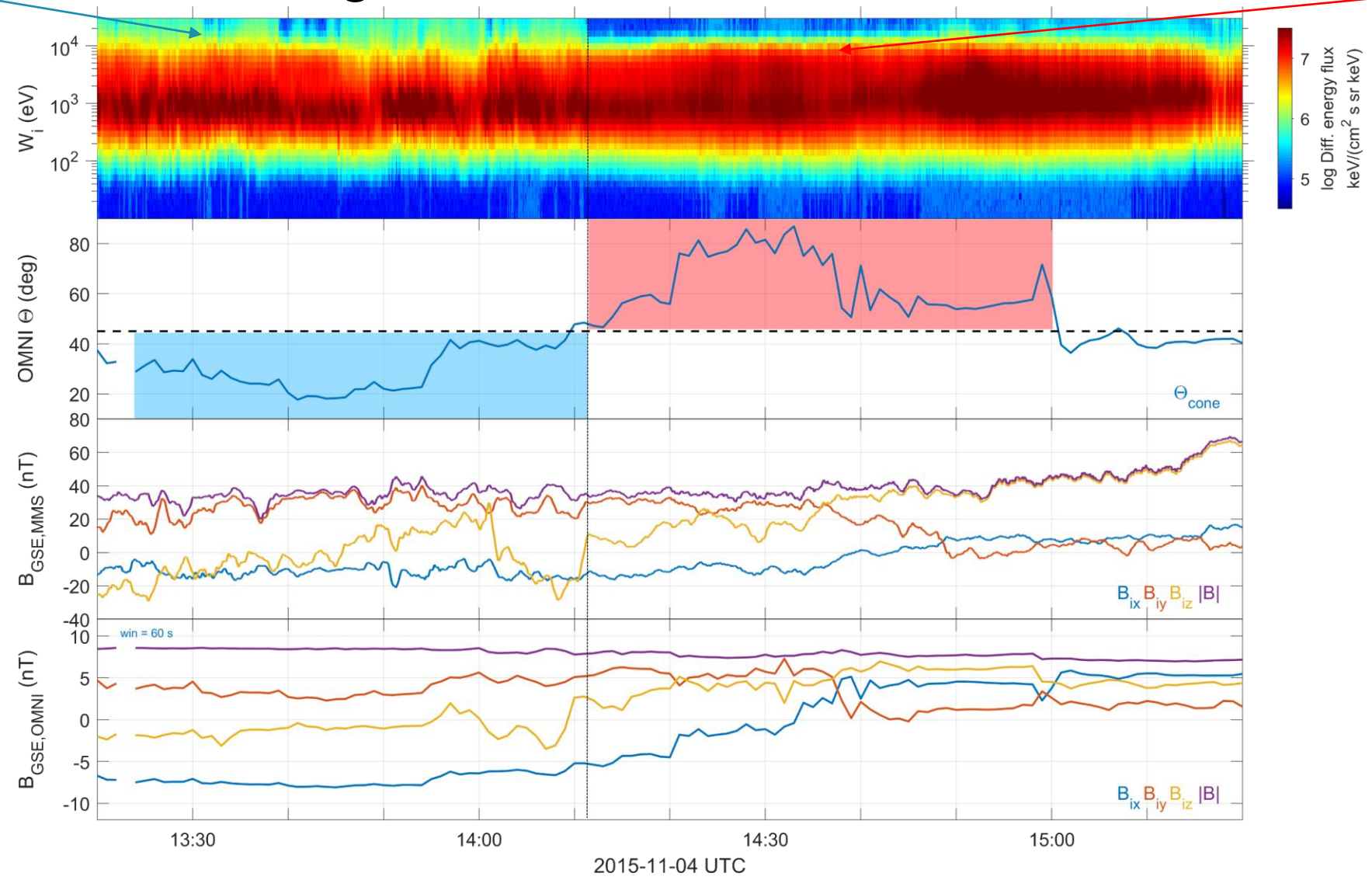
Angle & Bow shock Verification



Angle & Bow shock Verification

Q-par region

Q-perp region



More Verification

Ion Spectrum (1:32)

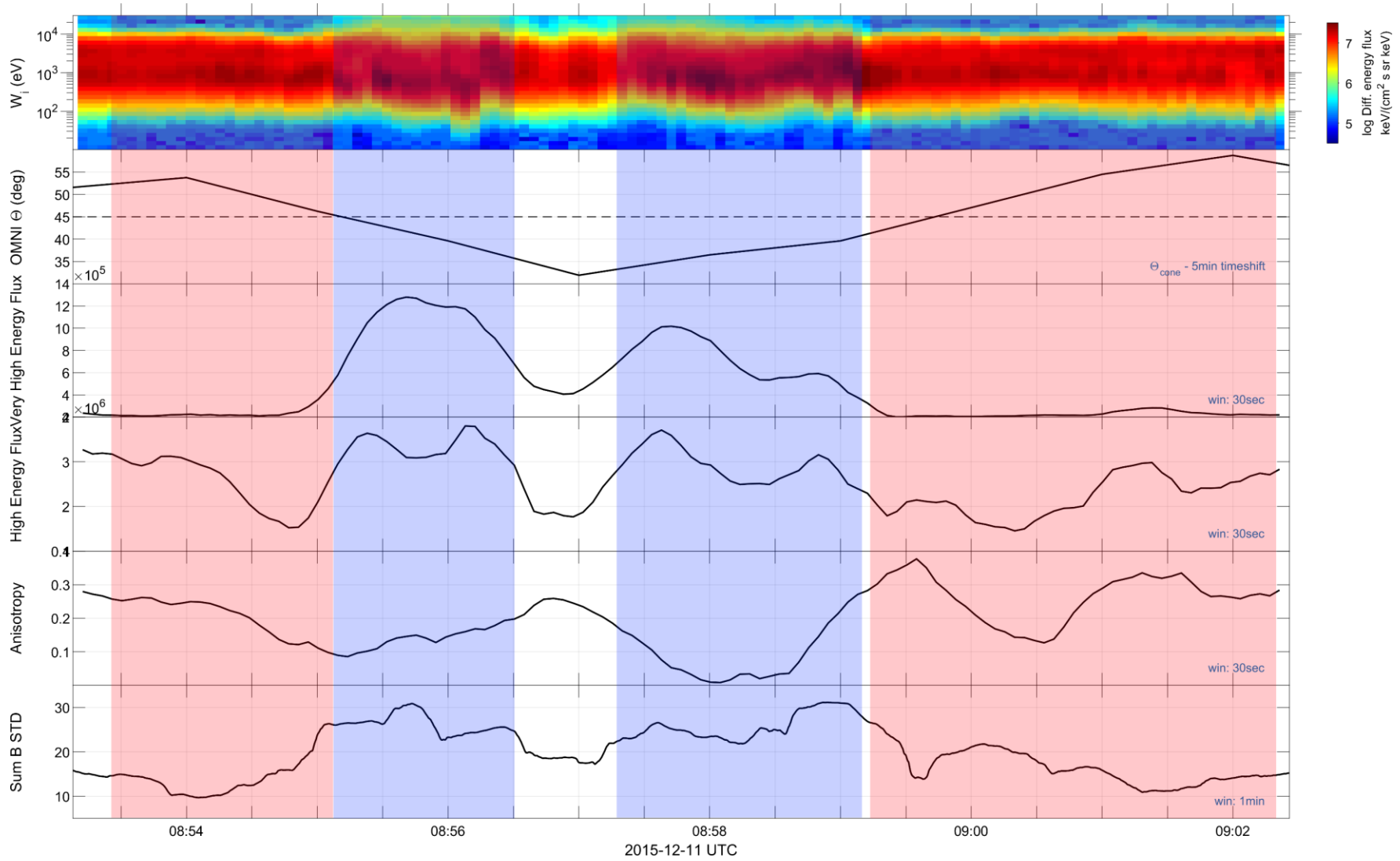
Cone Angle (SW)

Very High Flux (30:32)

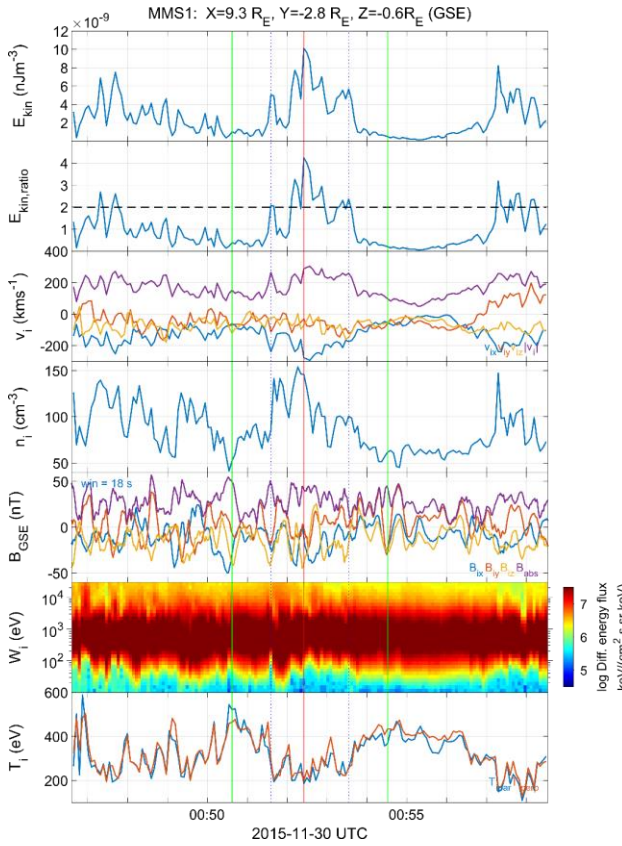
High Flux (27:29)

Temperature Anisotropy

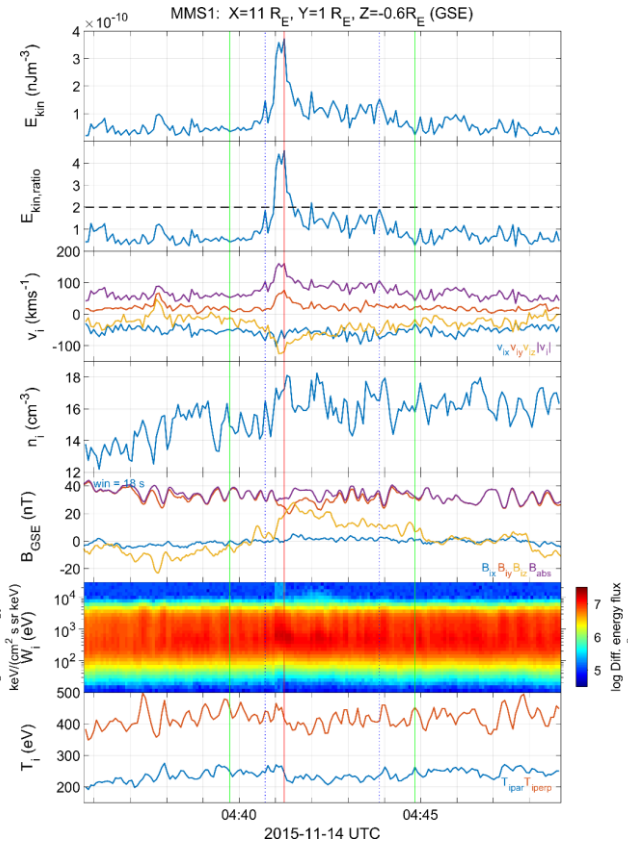
$$\sum_i \sigma(B_i)$$



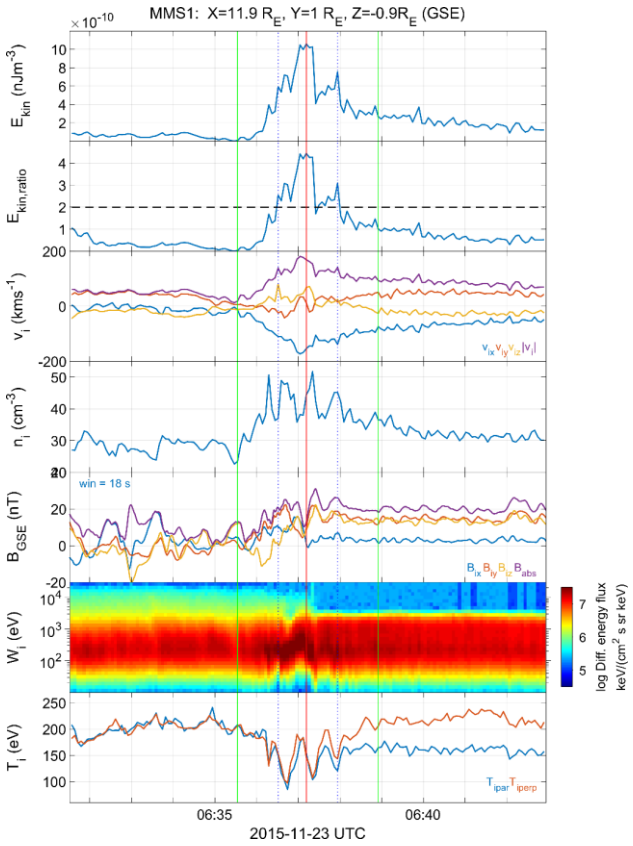
Main Categories



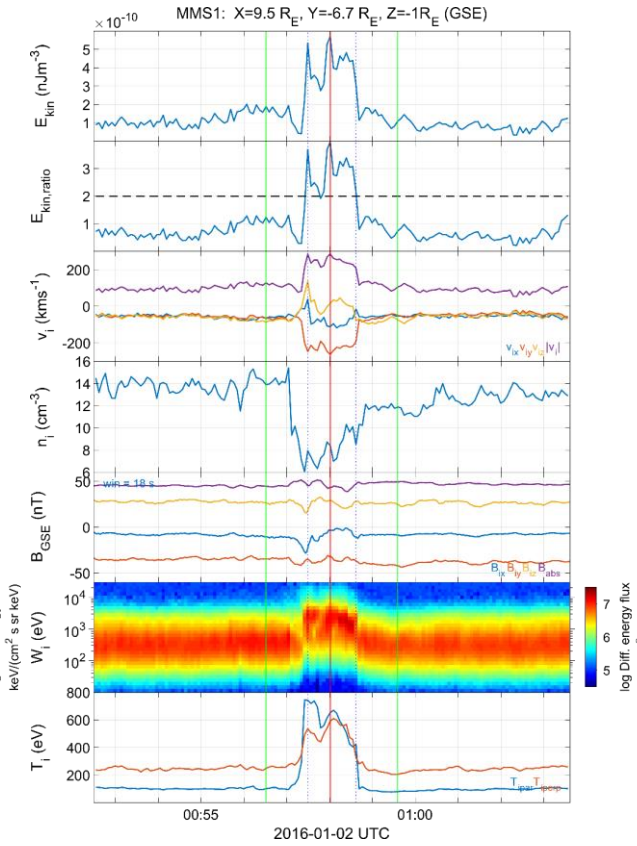
Qpar Jet



Qperp Jet



Boundary Jet



Encapsulated Jet

Results

Classification in progress!

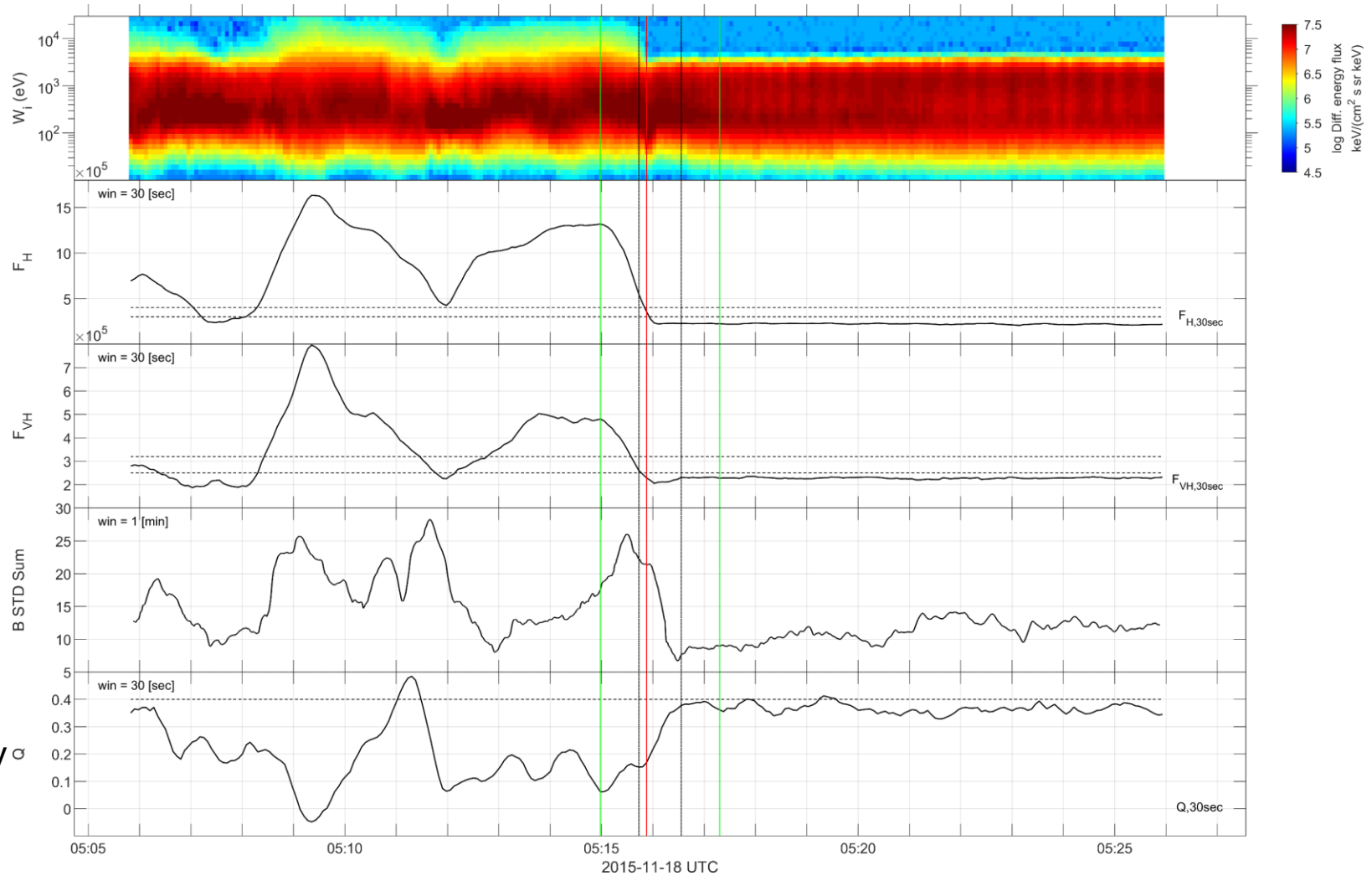
Ion Spectrum (1:32)

High Flux (27:29)

Very High Flux (30:32)

$$\sum_i \sigma(B_i)$$

Temperature Anisotropy



Classification in progress!

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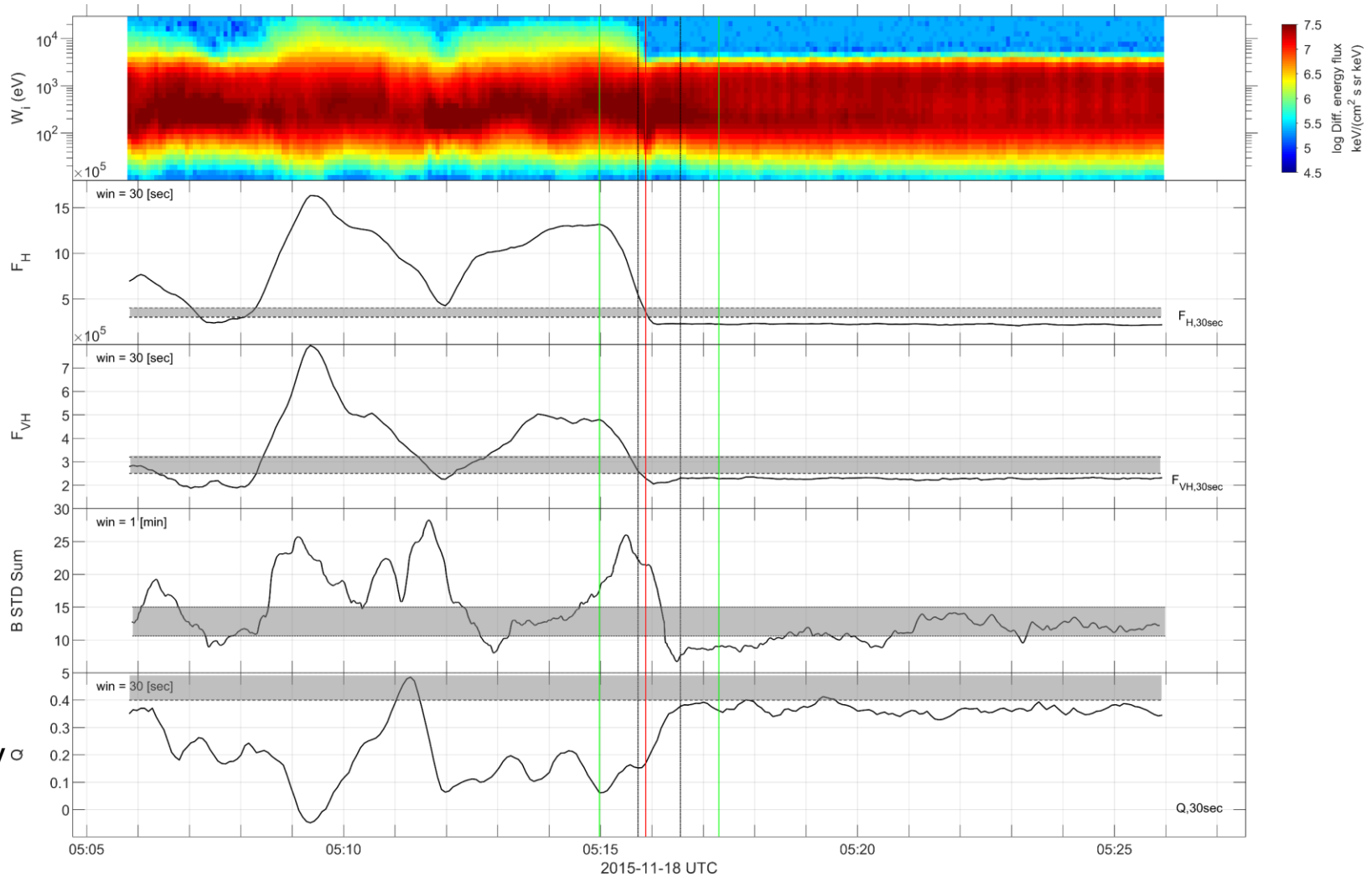
$$\sum_i \sigma(B_i)$$

Temperature Anisotropy



Classification in progress!

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High Flux (27:29)

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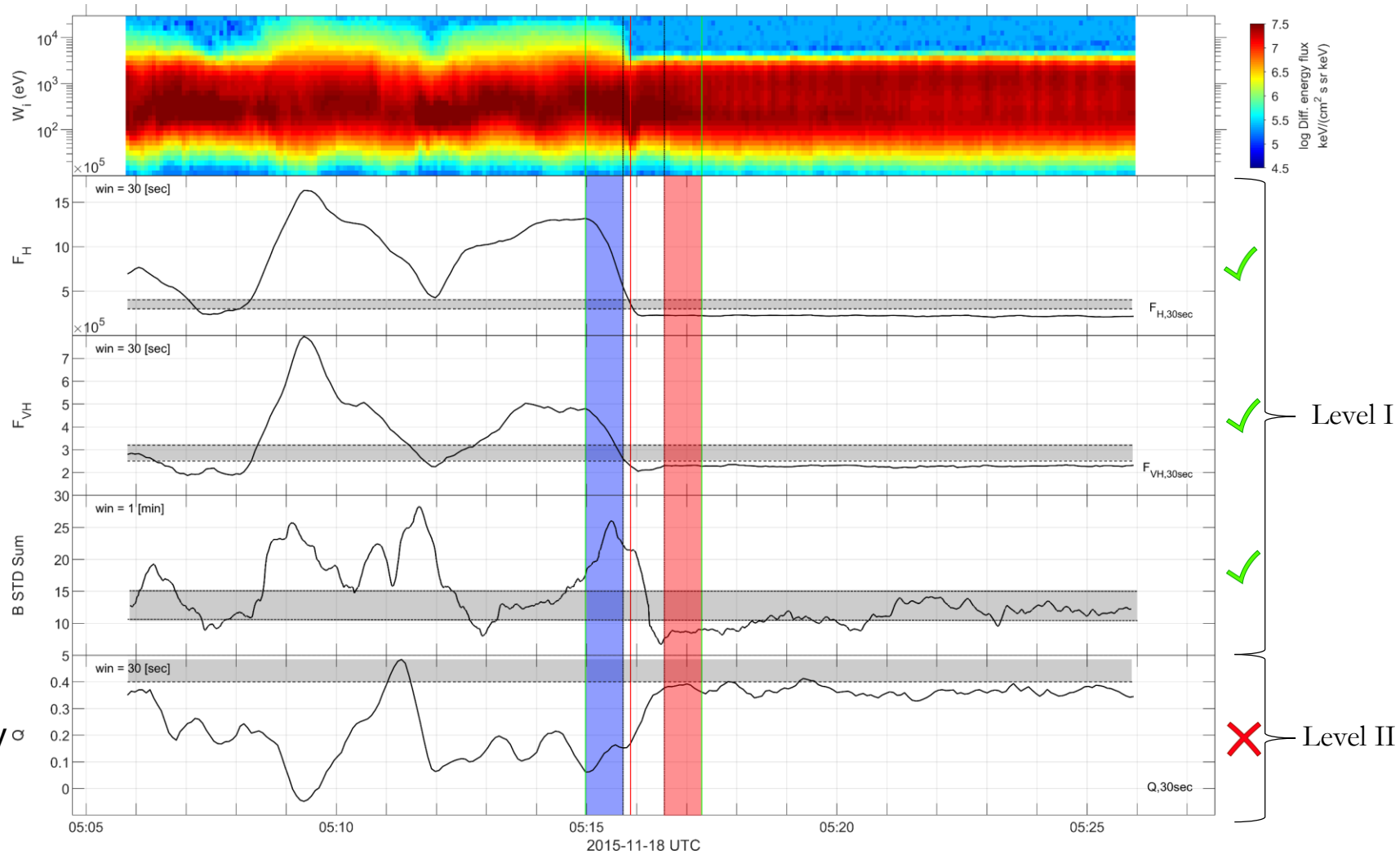
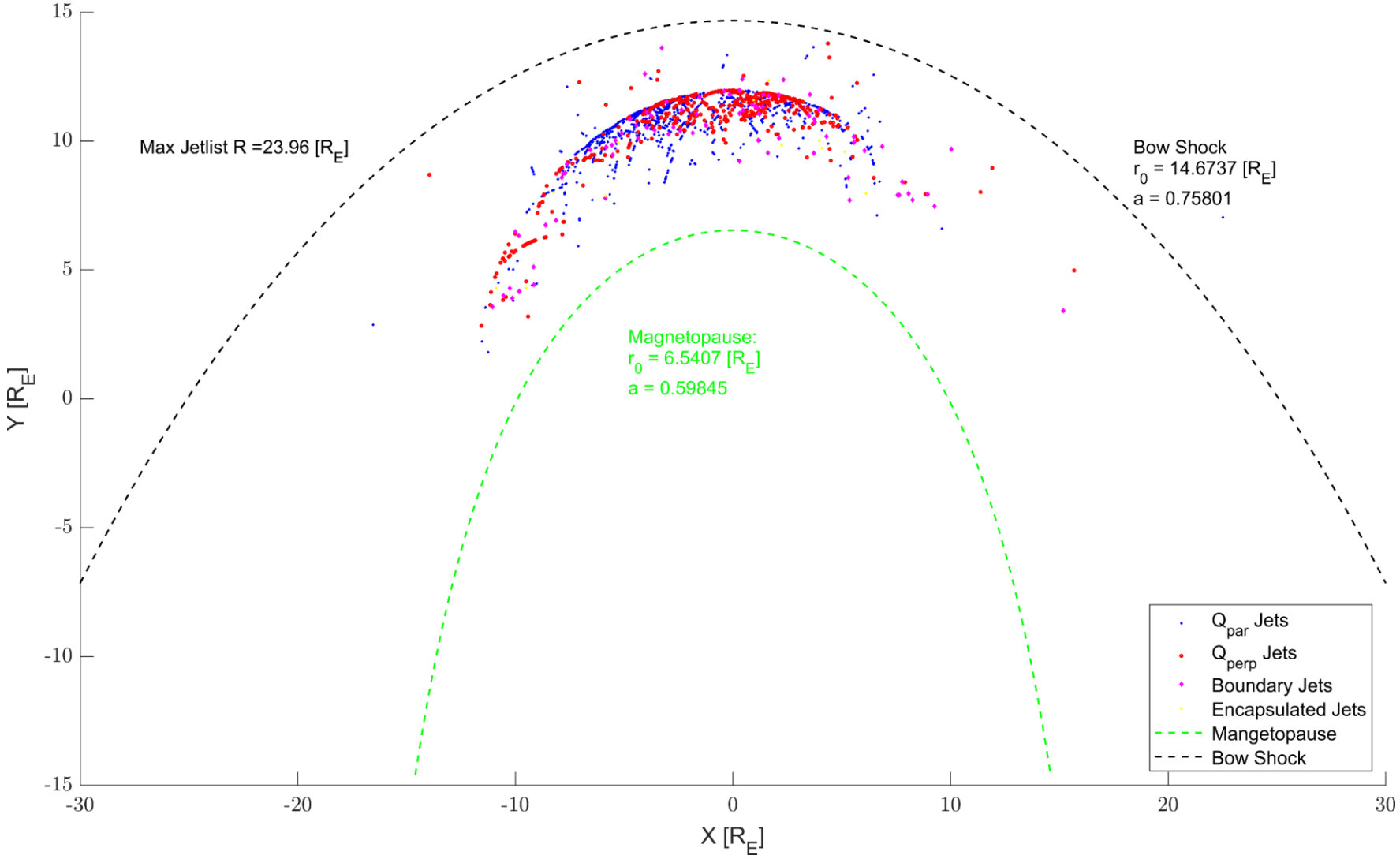
$$\sum_i \sigma(B_i)$$

Temperature Anisotropy



Where are they?



Jets criteria & database

Table 1. Initial dataset of the magnetosheath jets for the period 10/2015 - 04/2019.

Subset	Number (n)	Percentage (%)	Criteria
Basic	16034	100	Eq. (1)
Down-sampled	8499	53	Eqs. (1), (3)
High-Energetic	4369	27	Eqs. (1), (3), (4)

$$P_{msh} \geq 2\langle P_{msh} \rangle_{10\,\mathrm{min}} \quad (1)$$

$$t_{start,i+1} - t_{end,i} = dt \geq 60s \quad (3)$$

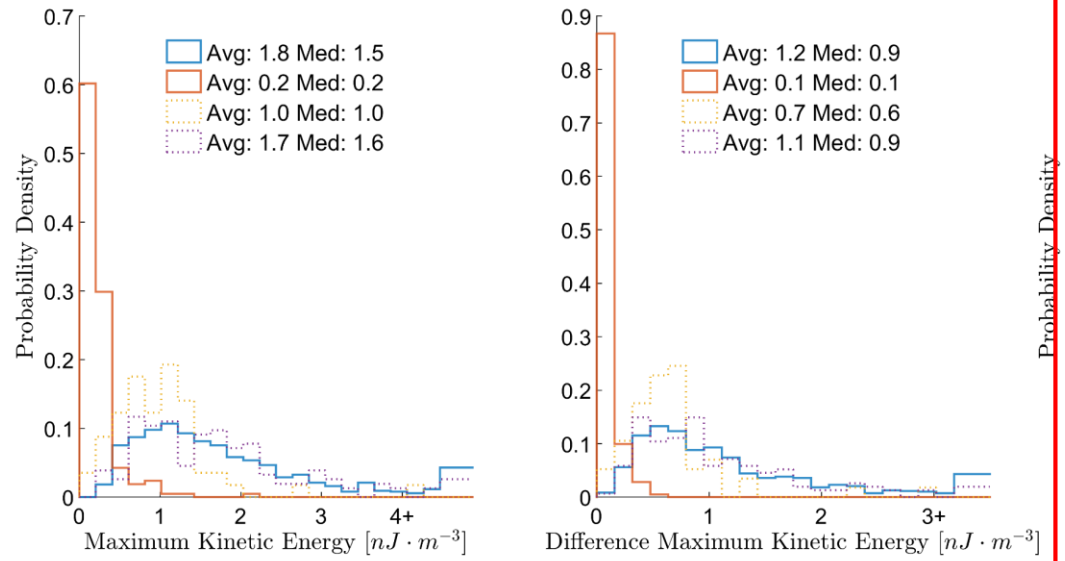
$$E_{kin,max} \geq 1\ nJ/m^{-3} \quad (4)$$

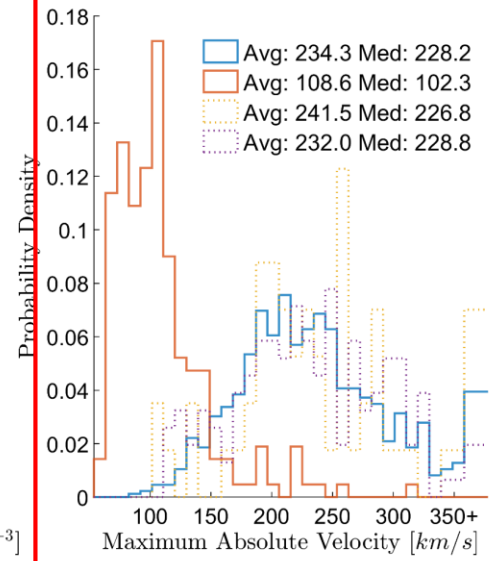
Database Jet - Classified

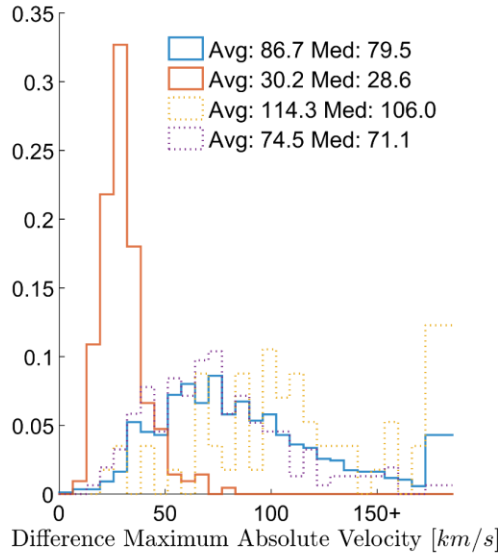
Table 3. Classified dataset of the magnetosheath jets for the period 10/2015 - 04/2019. Using as initial dataset the "down-sampled" jets of Table 1. The properties of each class is shown in Table 2.

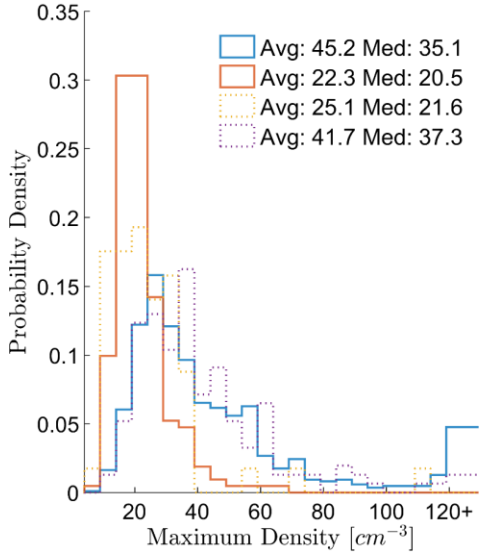
Subset	Number	Percentage (%)
Quasi - Parallel	2284	26.9
Best Cases	860	10.1
Quasi - Perpendicular	504	5.9
Best Cases	211	2.5
Boundary	744	8.8
Best Cases	154	1.8
Encapsulated	77	0.9
Best Cases	57	0.7
Other	4890	57.5
Uncertain	3499	41.2
Border	1346	15.8
Data Gap	45	0.5

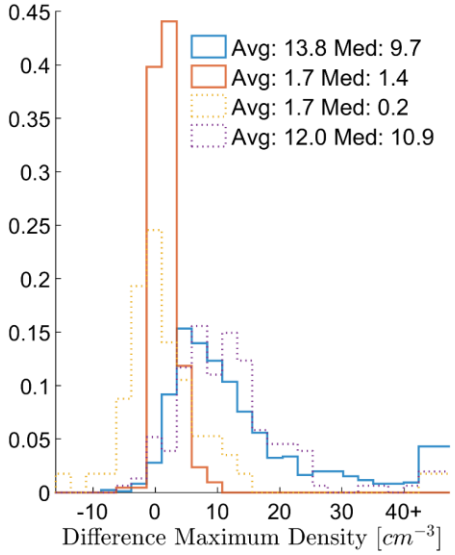
Quasi-Parallel VS Quasi-Perpendicular VS Encapsulated VS Boundary

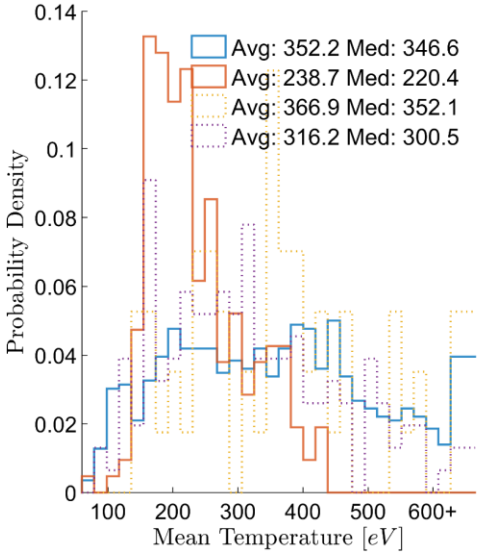


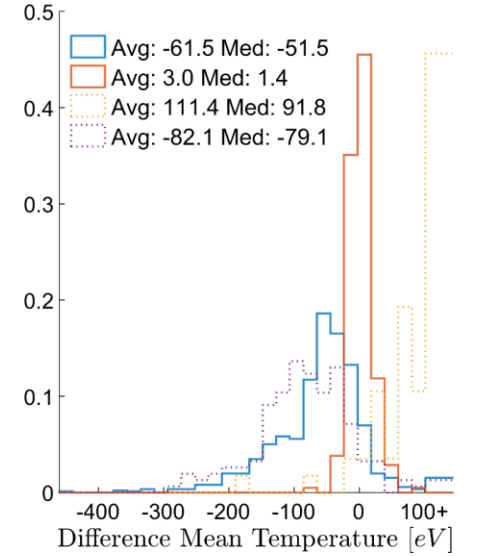




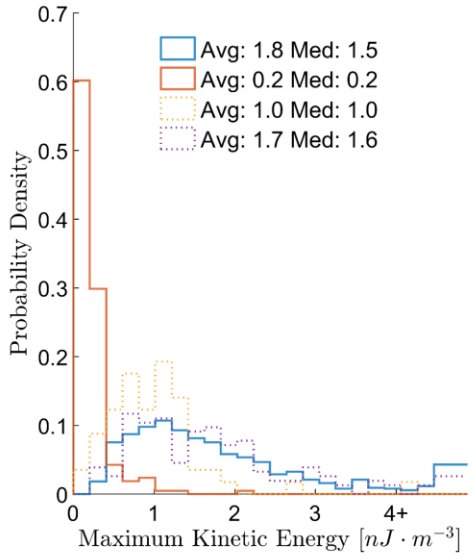


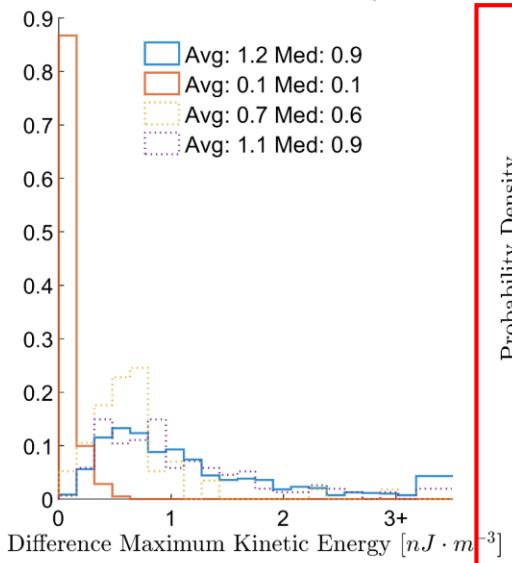


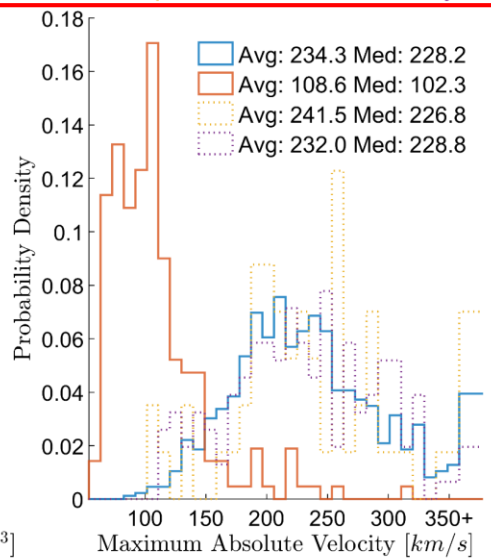


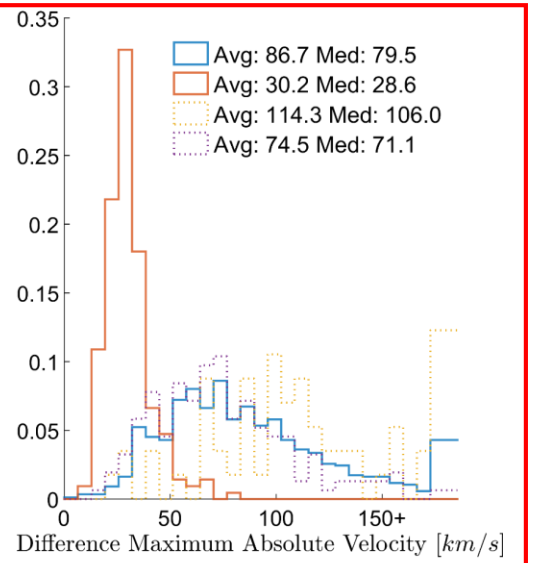


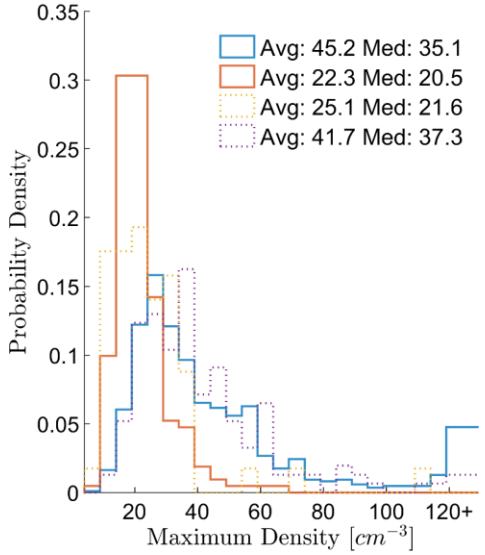
Quasi-Parallel VS Quasi-Perpendicular VS Encapsulated VS Boundary

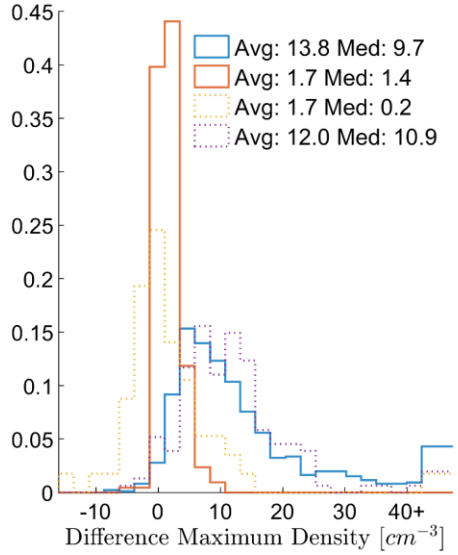


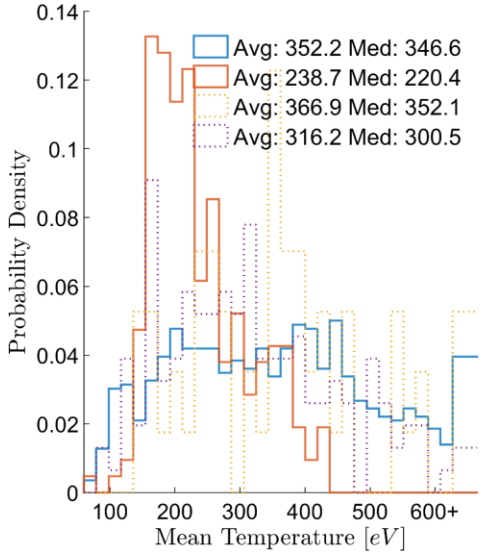


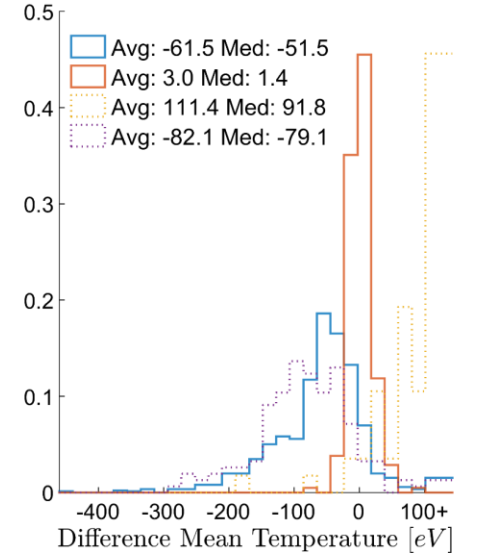




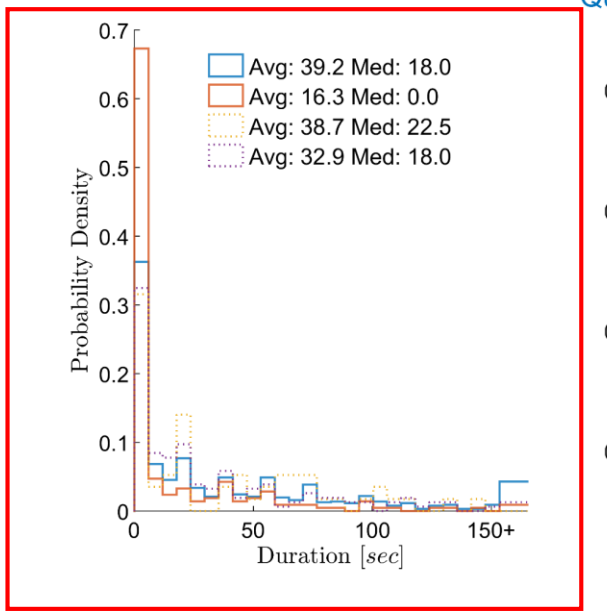


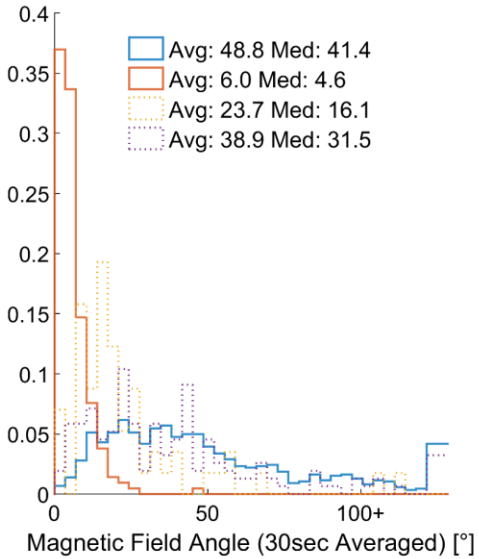


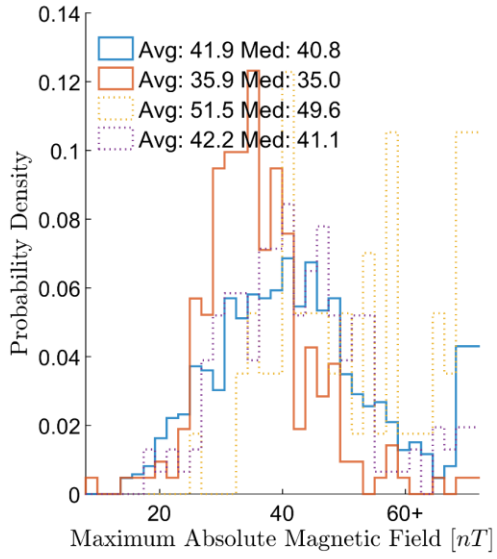


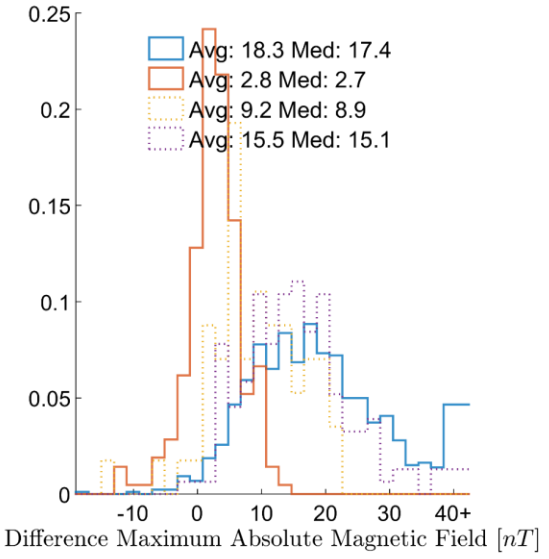


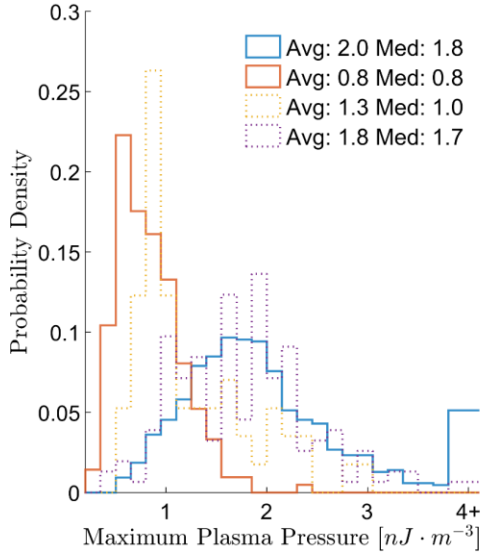
Quasi-Parallel VS Quasi-Perpendicular VS Encapsulated VS Boundary

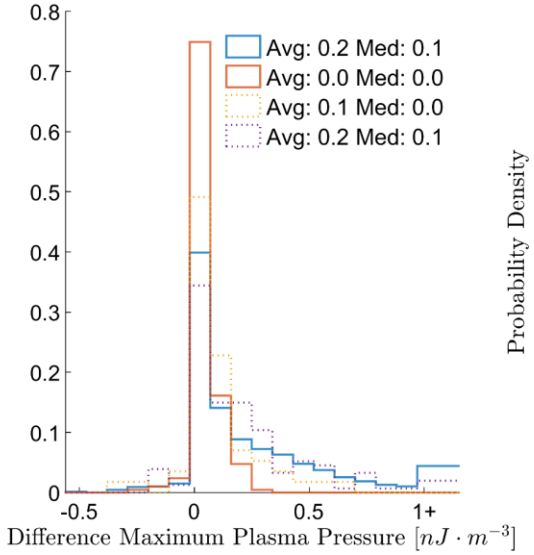


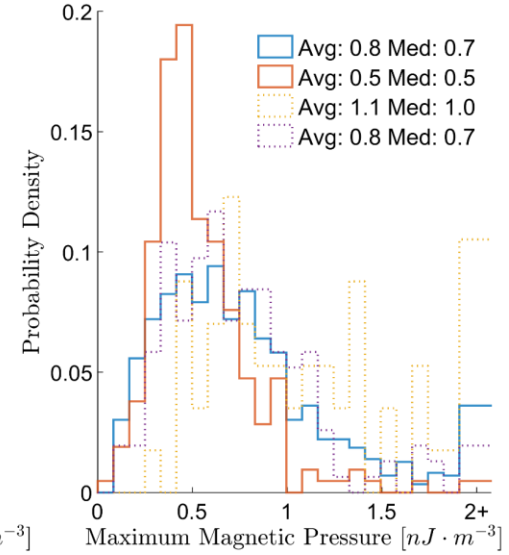


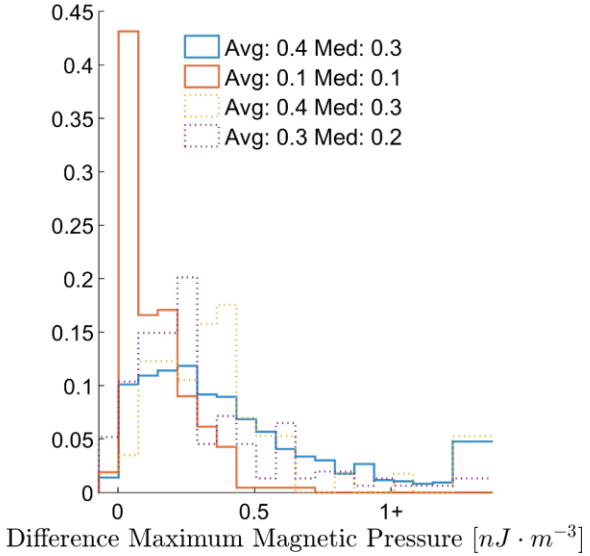


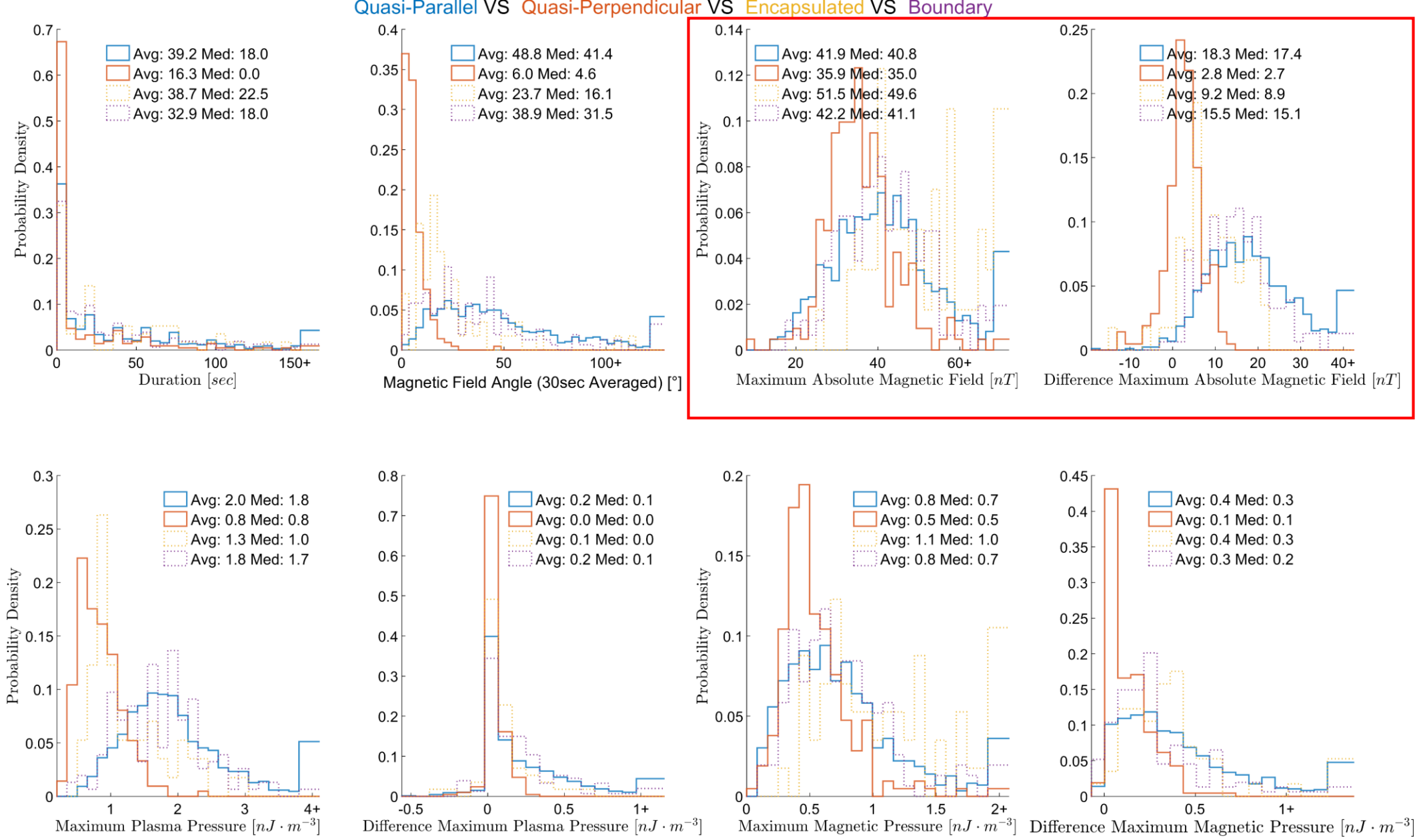




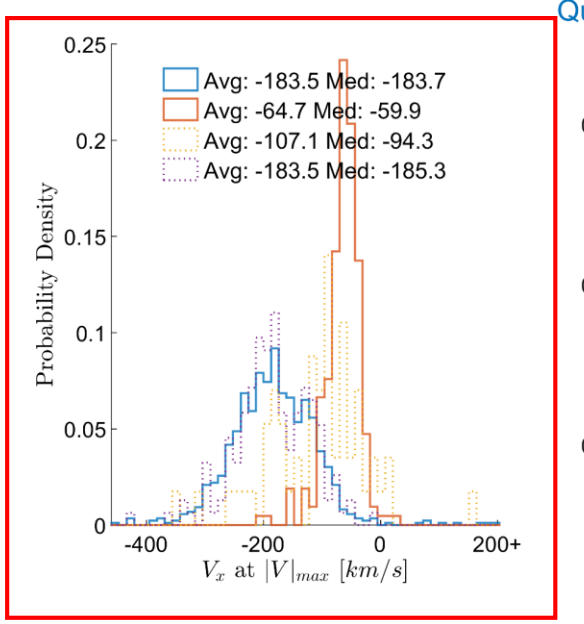


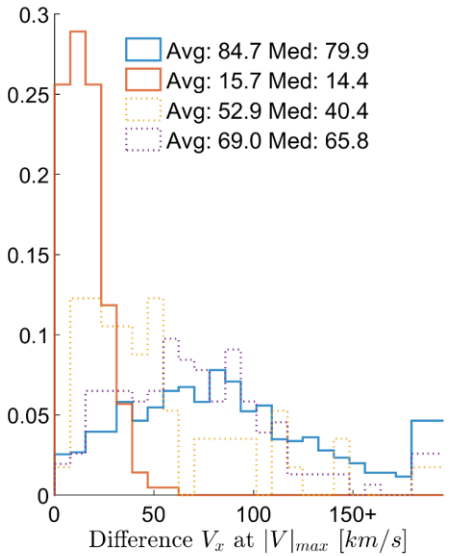


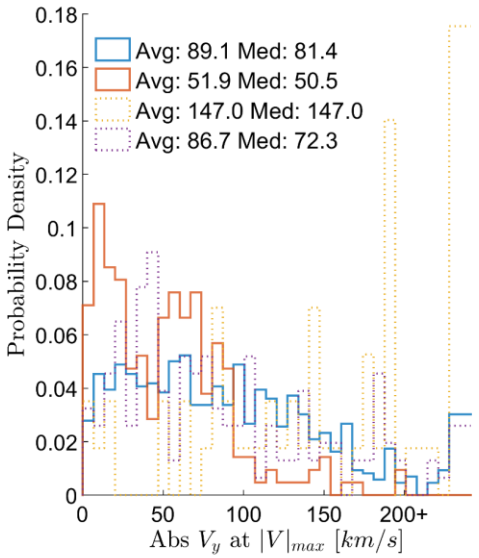


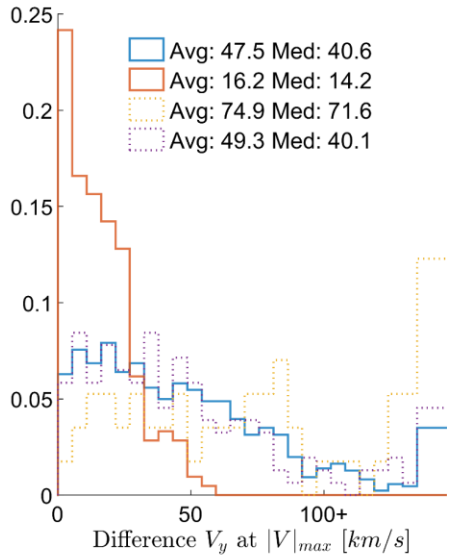

Quasi-Parallel VS Quasi-Perpendicular VS Encapsulated VS Boundary
Probability Density
Avg: 39.2 Med: 18.0
Avg: 16.3 Med: 0.0
Avg: 38.7 Med: 22.5
Avg: 32.9 Med: 18.0
Duration [sec]
Avg: 48.8 Med: 41.4
Avg: 6.0 Med: 4.6
Avg: 23.7 Med: 16.1
Avg: 38.9 Med: 31.5
Magnetic Field Angle (30sec Averaged) [°]
Avg: 41.9 Med: 40.8
Avg: 35.9 Med: 35.0
Avg: 51.5 Med: 49.6
Avg: 42.2 Med: 41.1
Maximum Absolute Magnetic Field [nT]
Avg: 18.3 Med: 17.4
Avg: 2.8 Med: 2.7
Avg: 9.2 Med: 8.9
Avg: 15.5 Med: 15.1
Difference Maximum Absolute Magnetic Field [nT]
Avg: 2.0 Med: 1.8
Avg: 0.8 Med: 0.8
Avg: 1.3 Med: 1.0
Avg: 1.8 Med: 1.7
Maximum Plasma Pressure [nJ · m^-3]
Avg: 0.2 Med: 0.1
Avg: 0.0 Med: 0.0
Avg: 0.1 Med: 0.0
Avg: 0.2 Med: 0.1
Difference Maximum Plasma Pressure [nJ · m^-3]
Avg: 0.8 Med: 0.7
Avg: 0.5 Med: 0.5
Avg: 1.1 Med: 1.0
Avg: 0.8 Med: 0.7
Maximum Magnetic Pressure [nJ · m^-3]
Avg: 0.4 Med: 0.3
Avg: 0.1 Med: 0.1
Avg: 0.4 Med: 0.3
Avg: 0.3 Med: 0.2
Difference Maximum Magnetic Pressure [nJ · m^-3]

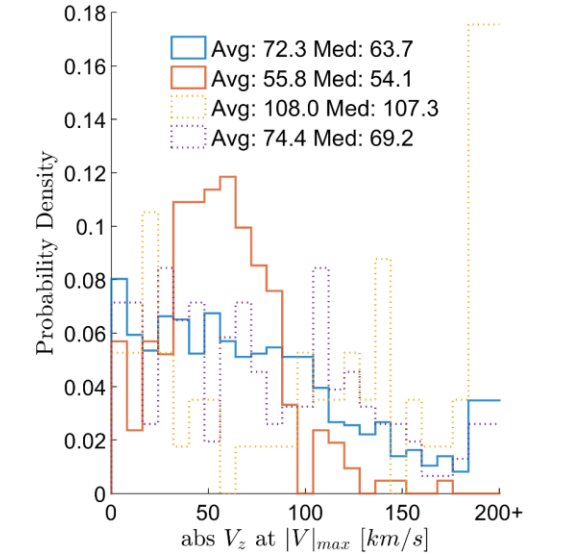
Quasi-Parallel VS Quasi-Perpendicular VS Encapsulated VS Boundary

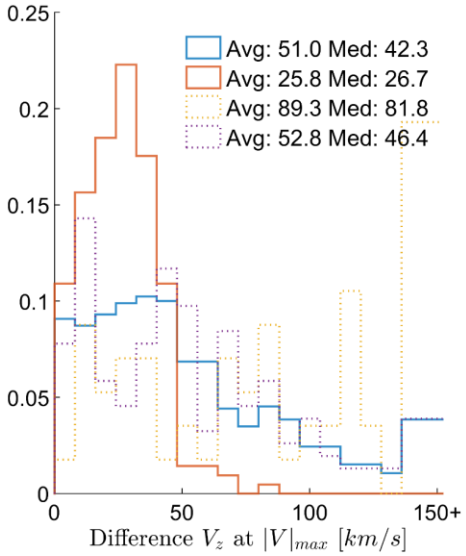


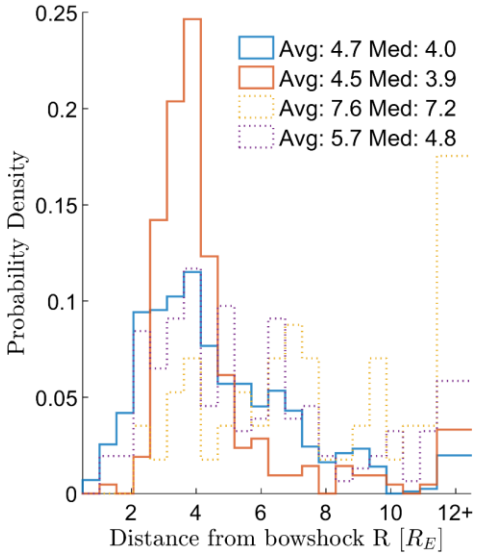


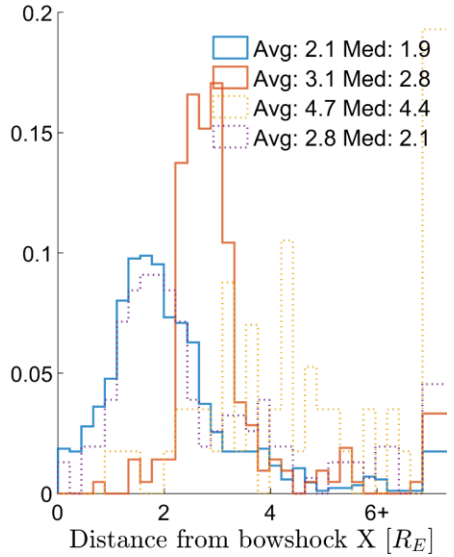




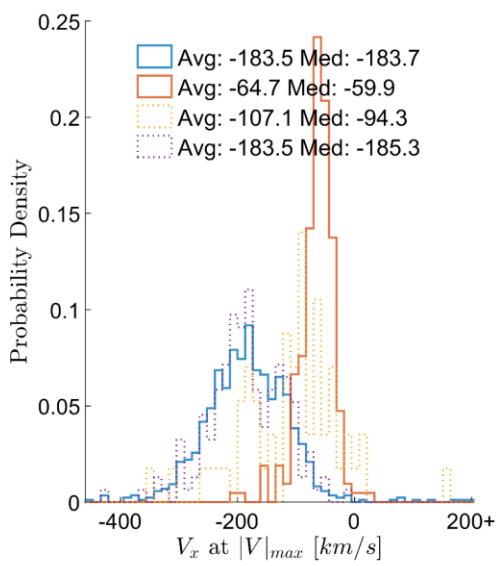


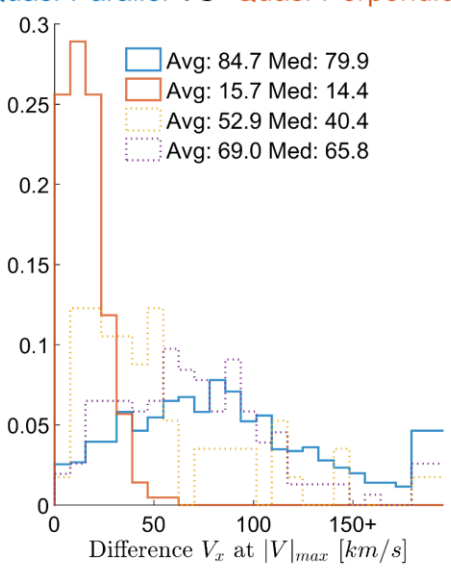


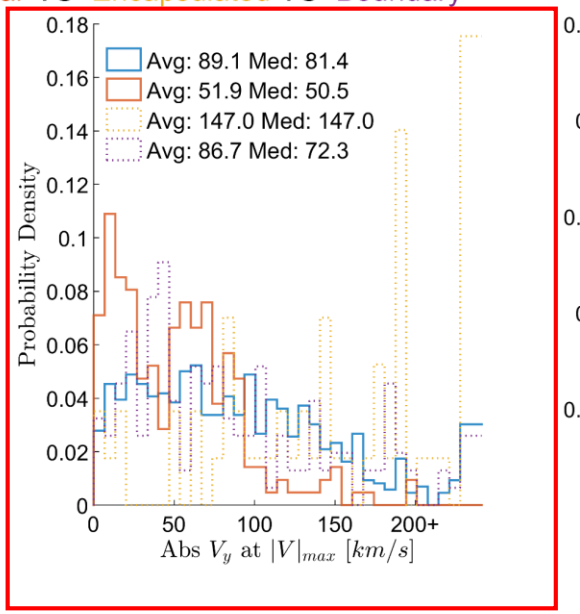


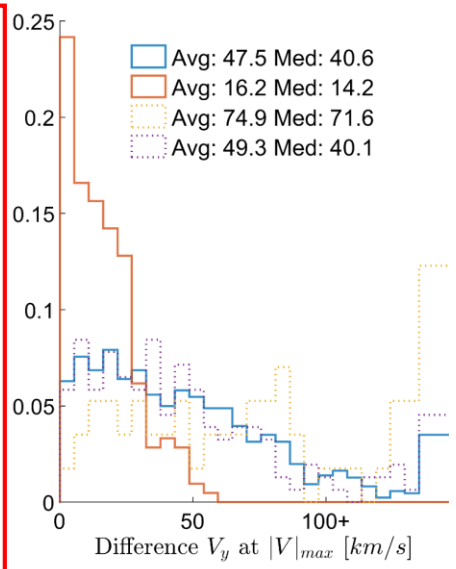


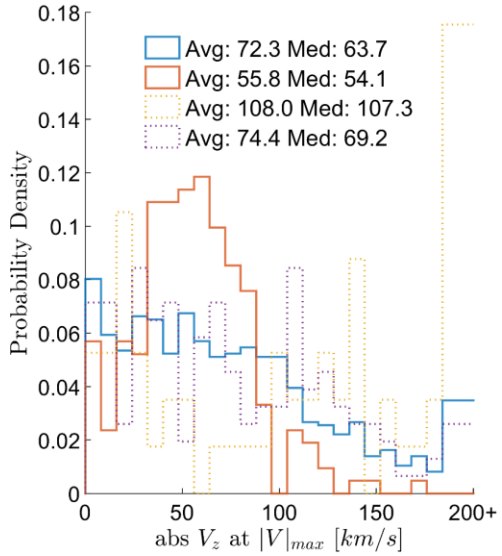
Quasi-Parallel VS Quasi-Perpendicular VS Encapsulated VS Boundary

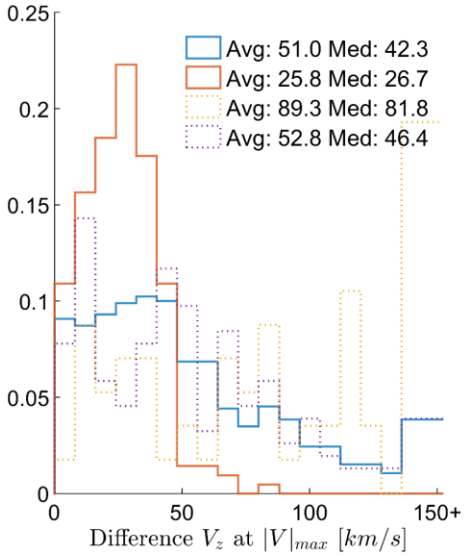


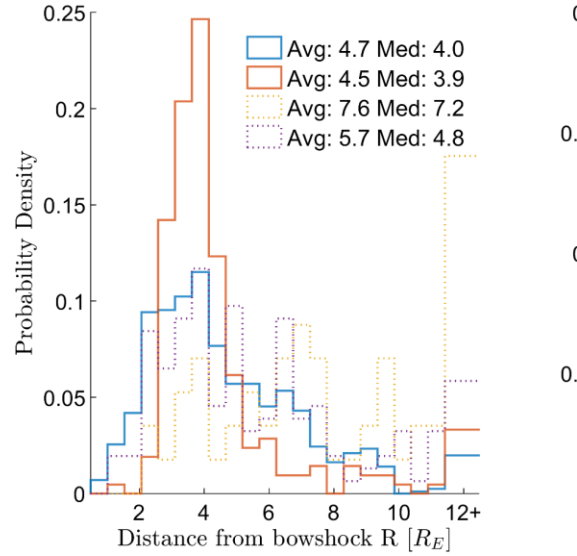


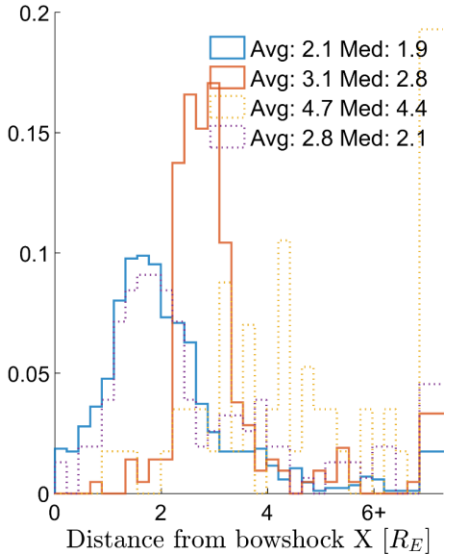


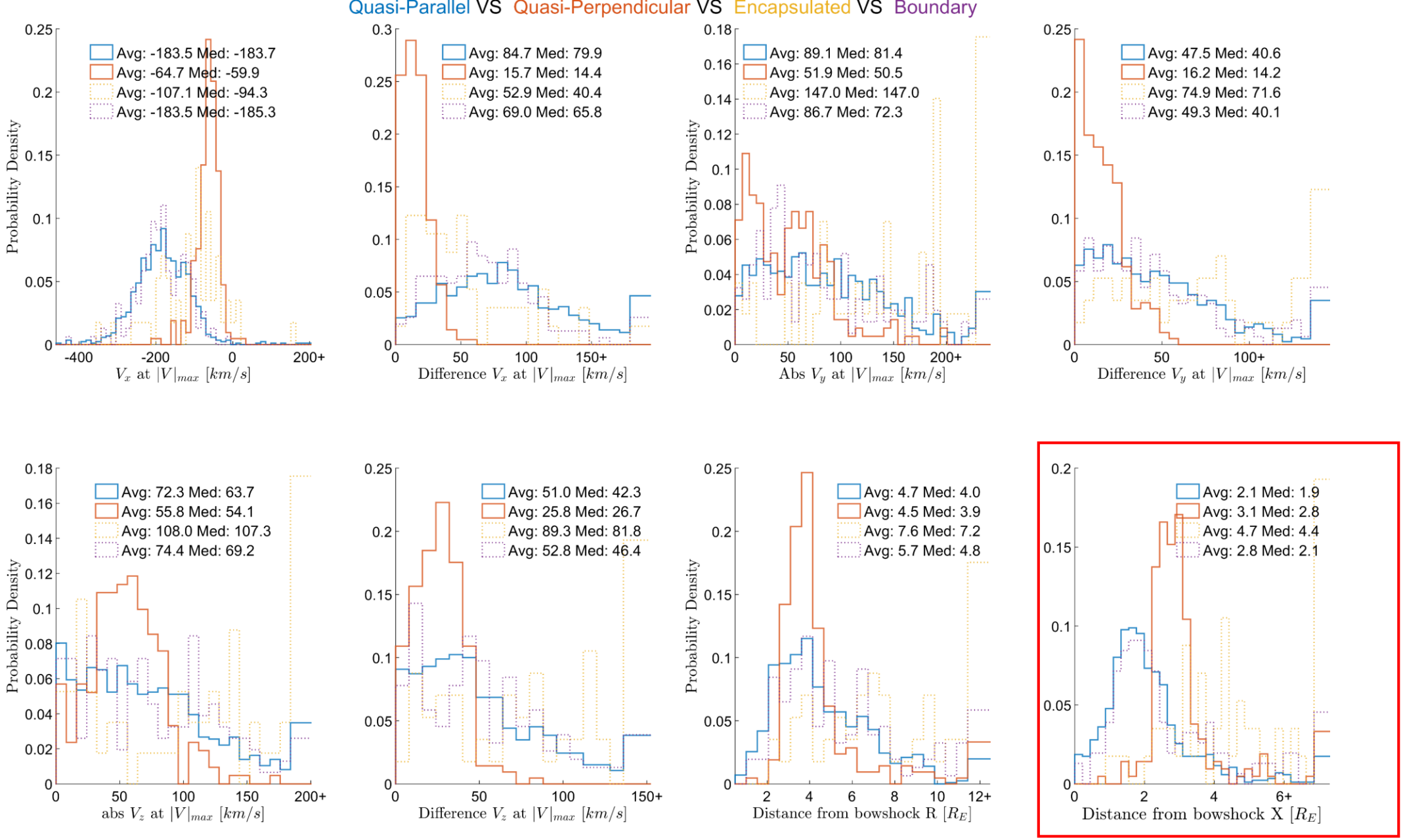


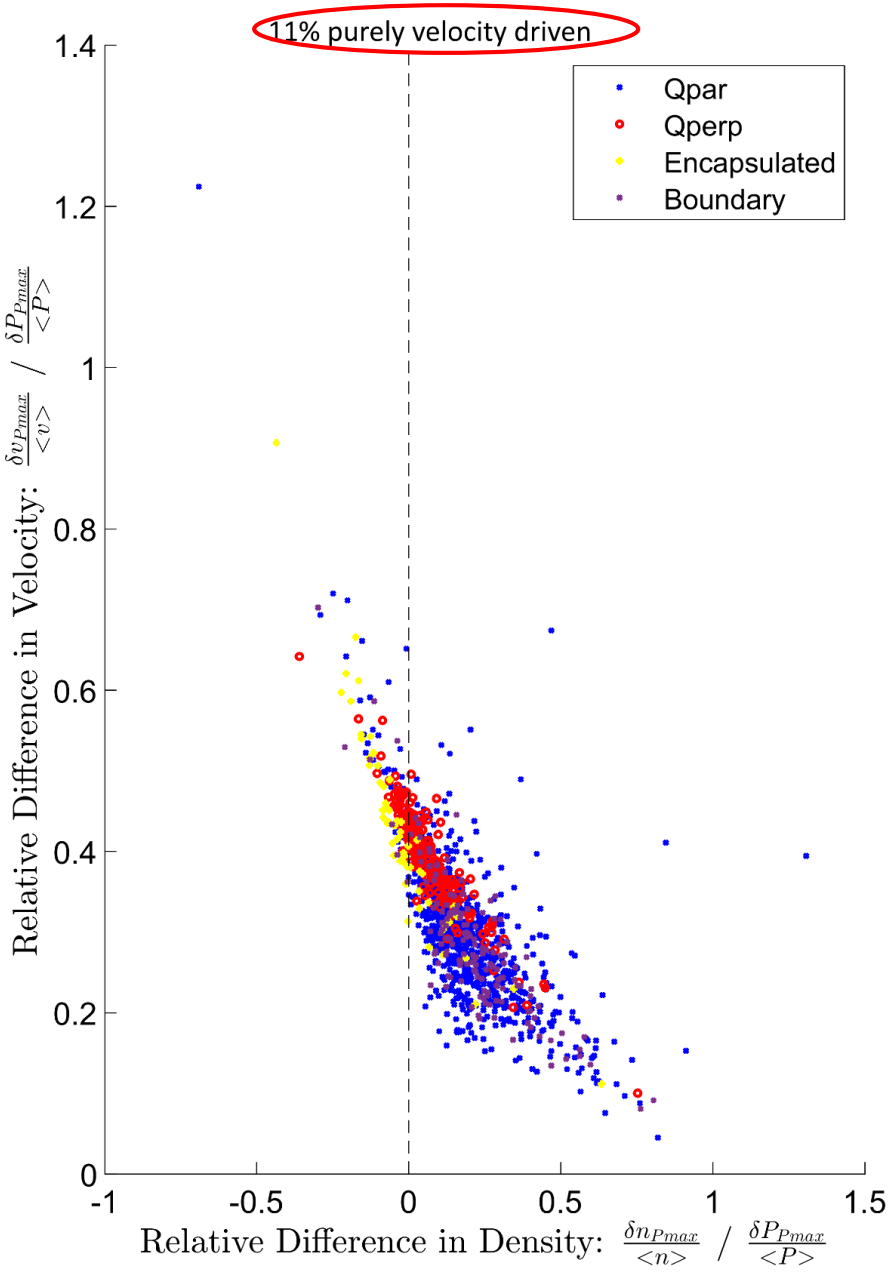


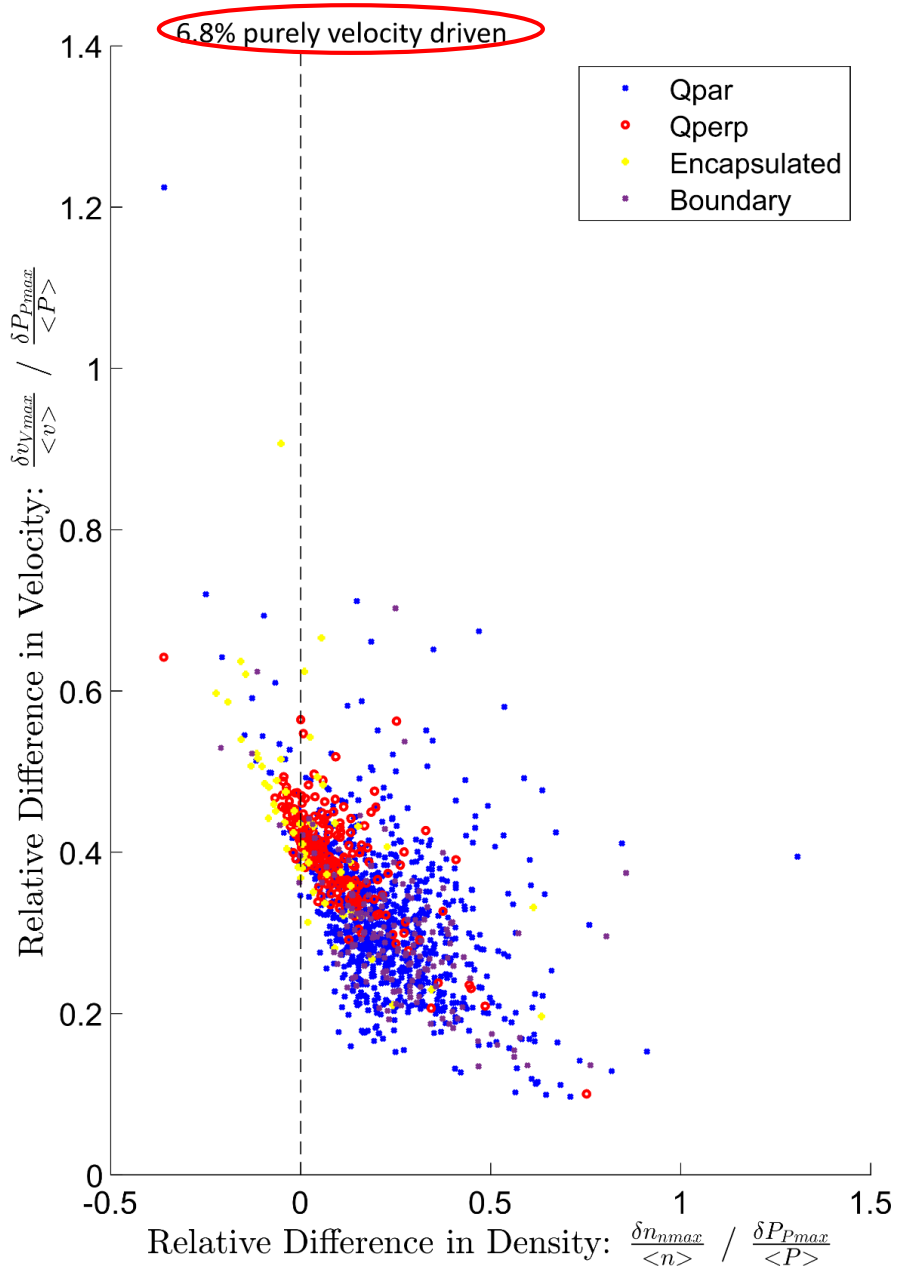


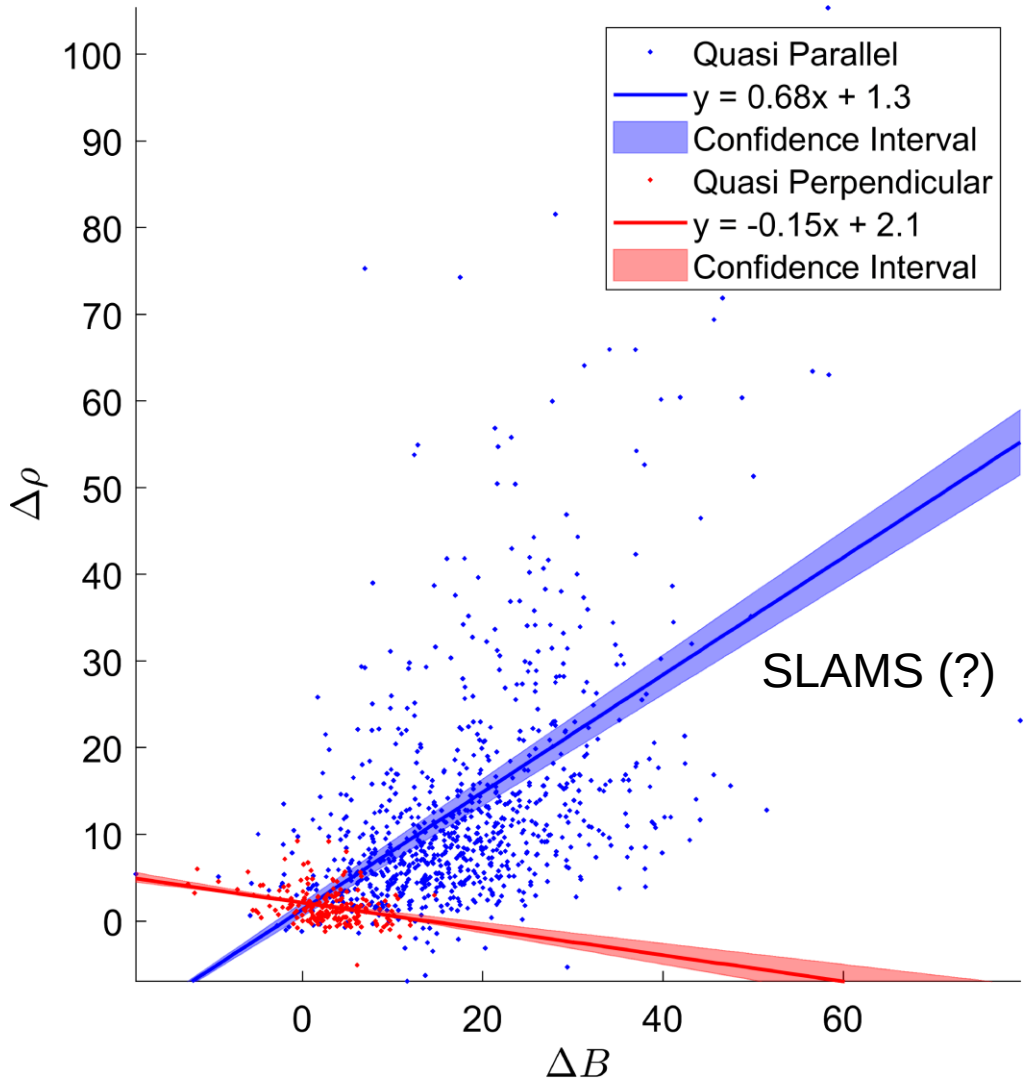


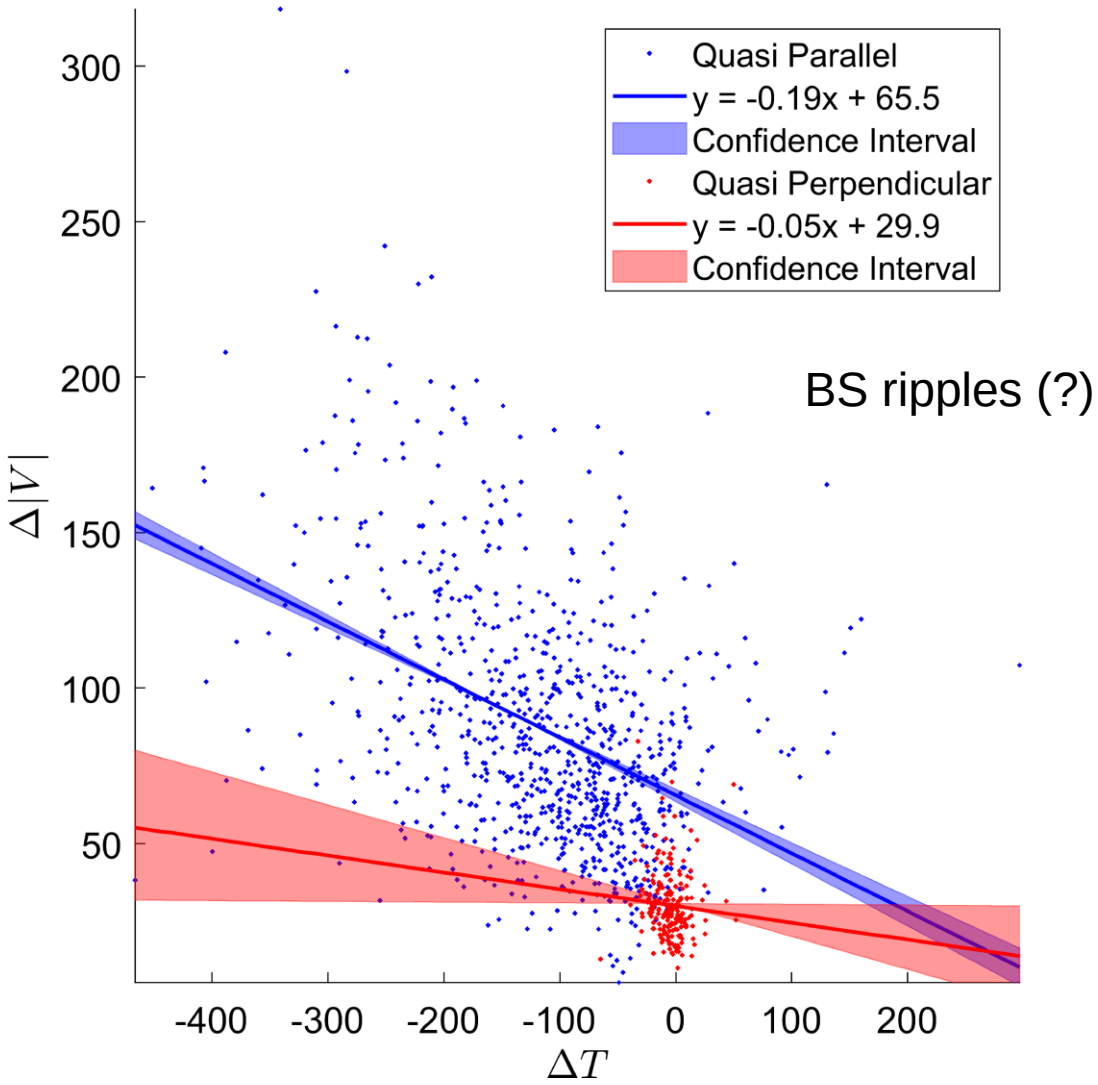



Quasi-Parallel VS Quasi-Perpendicular VS Encapsulated VS Boundary
Probability Density
Avg: -183.5 Med: -183.7
Avg: -64.7 Med: -59.9
Avg: -107.1 Med: -94.3
Avg: -183.5 Med: -185.3
V_x at $|V|_{max}$ $[km/s]$
Avg: 84.7 Med: 79.9
Avg: 15.7 Med: 14.4
Avg: 52.9 Med: 40.4
Avg: 69.0 Med: 65.8
Difference V_x at $|V|_{max}$ $[km/s]$
Avg: 89.1 Med: 81.4
Avg: 51.9 Med: 50.5
Avg: 147.0 Med: 147.0
Avg: 86.7 Med: 72.3
Abs V_y at $|V|_{max}$ $[km/s]$
Avg: 47.5 Med: 40.6
Avg: 16.2 Med: 14.2
Avg: 74.9 Med: 71.6
Avg: 49.3 Med: 40.1
Difference V_y at $|V|_{max}$ $[km/s]$
Avg: 72.3 Med: 63.7
Avg: 55.8 Med: 54.1
Avg: 108.0 Med: 107.3
Avg: 74.4 Med: 69.2
abs V_z at $|V|_{max}$ $[km/s]$
Avg: 51.0 Med: 42.3
Avg: 25.8 Med: 26.7
Avg: 89.3 Med: 81.8
Avg: 52.8 Med: 46.4
Difference V_z at $|V|_{max}$ $[km/s]$
Avg: 4.7 Med: 4.0
Avg: 4.5 Med: 3.9
Avg: 7.6 Med: 7.2
Avg: 5.7 Med: 4.8
Distance from bowshock R $[R_E]$
Avg: 2.1 Med: 1.9
Avg: 3.1 Med: 2.8
Avg: 4.7 Med: 4.4
Avg: 2.8 Med: 2.1
Distance from bowshock X $[R_E]$


11% purely velocity driven
Qpar
Qperp
Encapsulated
Boundary
Relative Difference in Velocity: $\frac{\delta v_{Pmax}}{<v>}$ / $\frac{\delta P_{Pmax}}{<P>}$
Relative Difference in Density: $\frac{\delta n_{Pmax}}{<n>}$ / $\frac{\delta P_{Pmax}}{<P>}$
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-1
-0.5
0
0.5
1
1.5


6.8% purely velocity driven
Qpar
Qperp
Encapsulated
Boundary
Relative Difference in Velocity: $\frac{\delta v_{Vmax}}{<v>}$ / $\frac{\delta P_{Pmax}}{<P>}$
Relative Difference in Density: $\frac{\delta n_{nmax}}{<n>}$ / $\frac{\delta P_{Pmax}}{<P>}$
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.5
0
0.5
1
1.5





$$\Delta \mathrm{x} = \mathrm{x}_{\mathrm{Jet}} - \langle x \rangle_{\pm 5\, min}$$

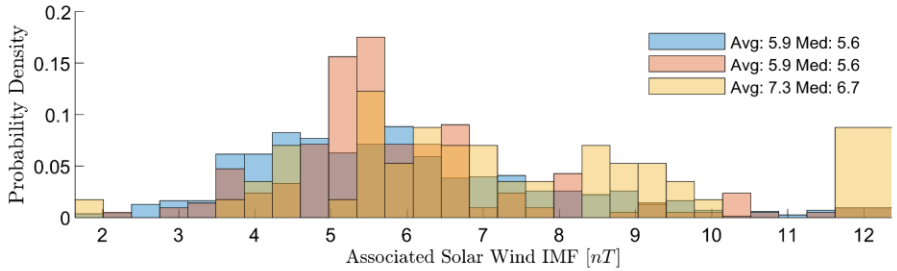
Conclusion

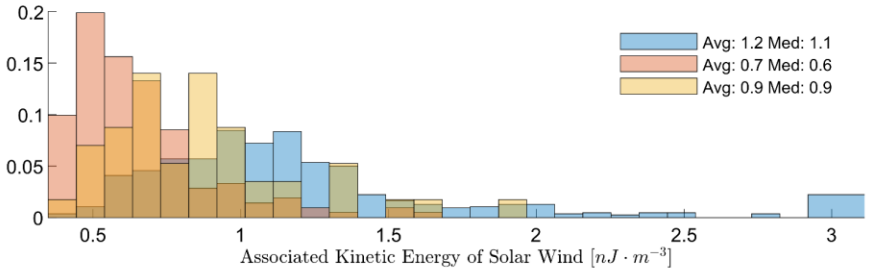
Summary

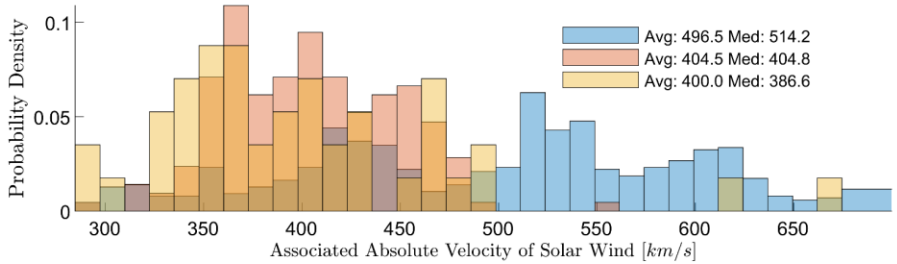
- Obtained a vast database of Magnetosheath Jets (~10.000) using all available MMS data.
- Successfully classified jets into several different categories showing different attributes.
- Analyzed their characteristics and found interesting similarities & differences compared to earlier results.
- Possible connections to other associated mechanisms such as SLAMS & Bow shock ripples.

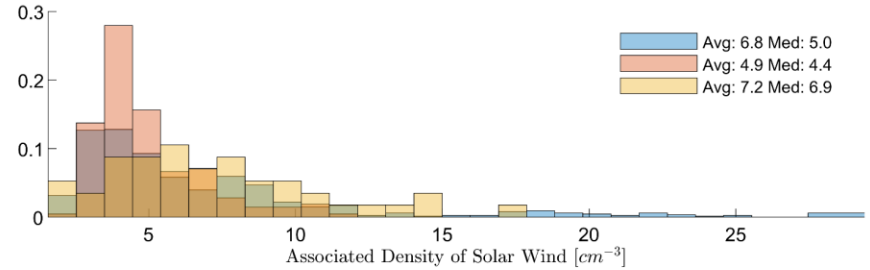
Extras

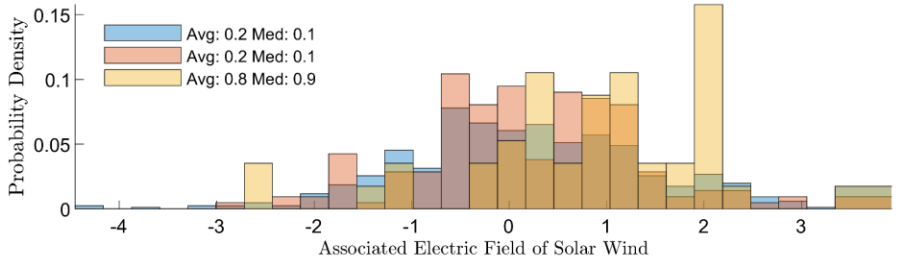
Quasi-Parallel VS Quasi-Perpendicular VS Encapsulated Magnetosheath Jets - Omniweb Solar Wind Plots

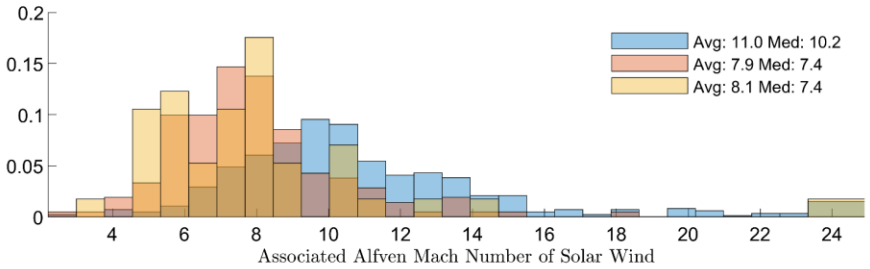


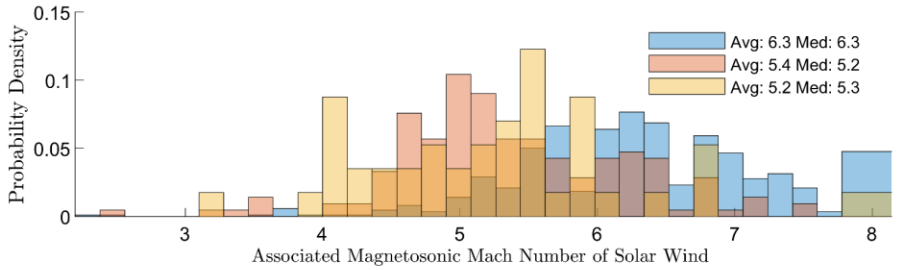


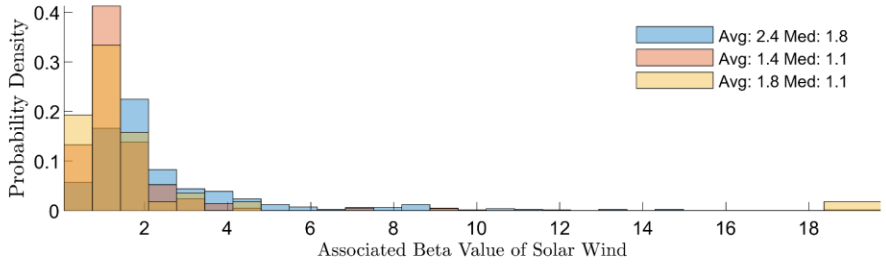


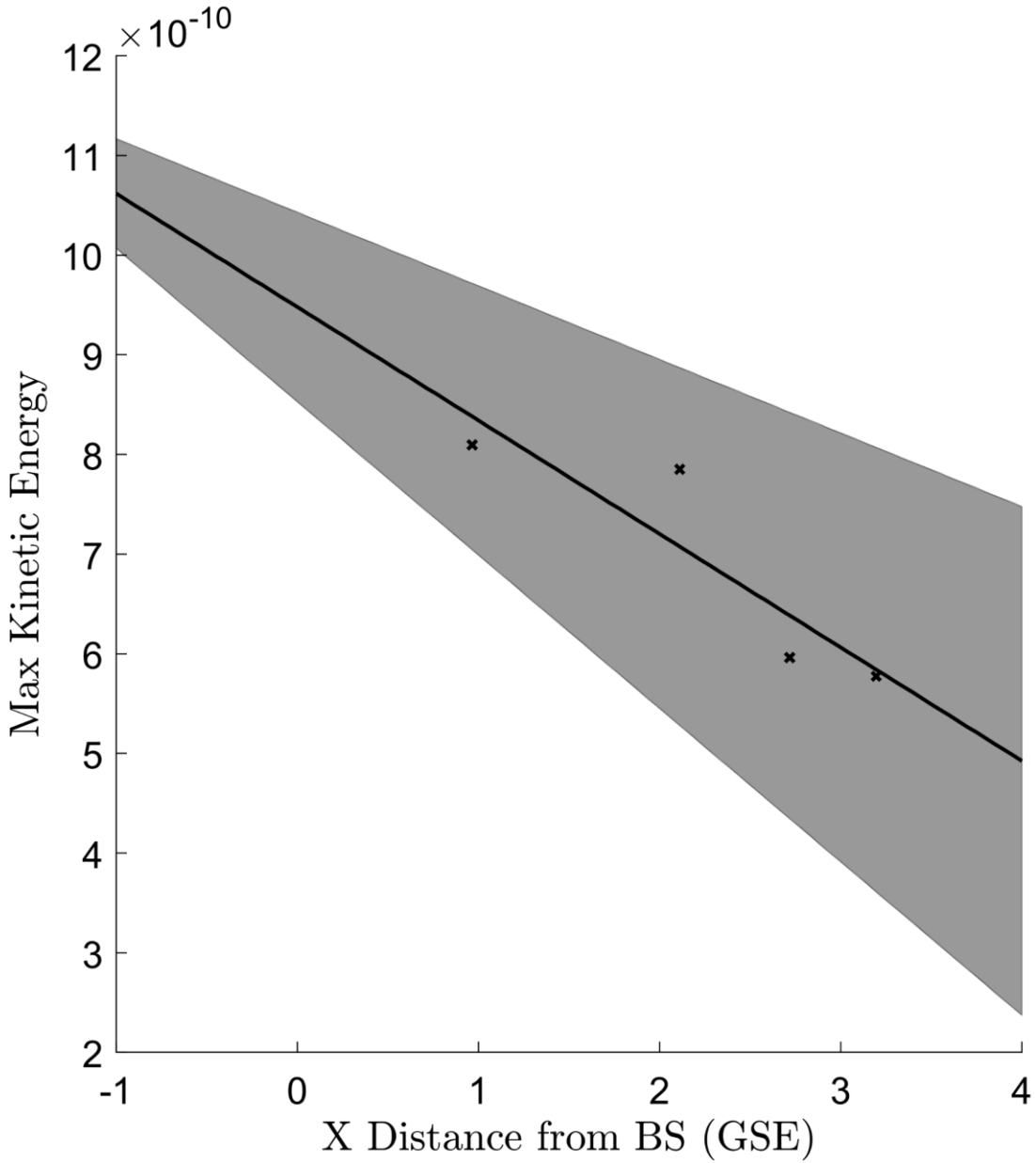




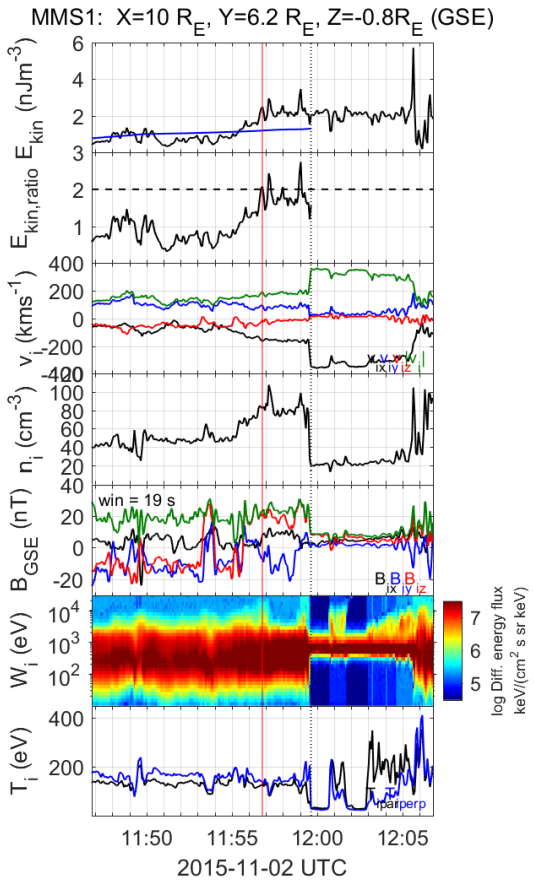




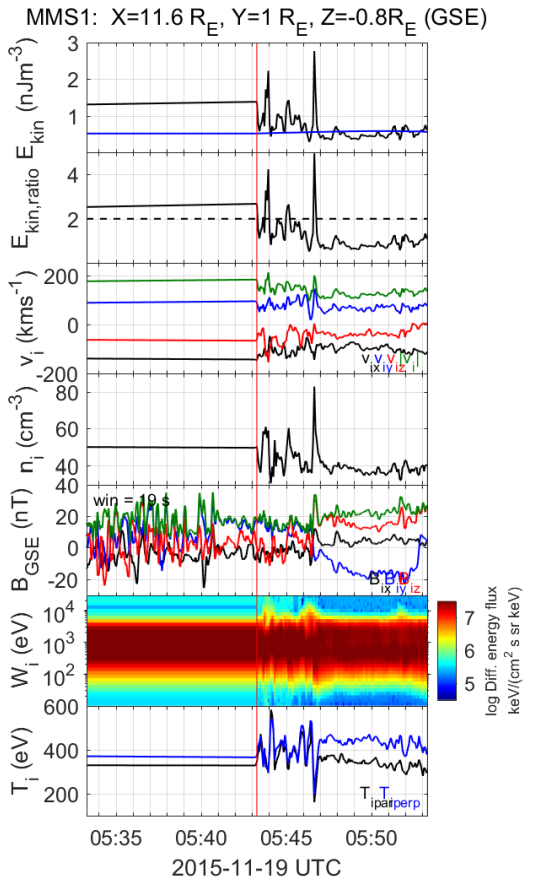



×10-10
12
11
10
9
8
7
6
5
4
3
2
Max Kinetic Energy
-1
0
1
2
3
4
X Distance from BS (GSE)

“Extra” Categories



Border Jets



Unclassified Jets

Multistage Classification – Simplified Scheme

Stages	Categories	Quality Check
(1) Pre-jet-post	1. Quasi – Par. 2. Quasi – Perp. 3. Boundary 4. Encapsulated 5. Unknown	• Criteria Number Level I – III

Multistage Classification – Simplified Scheme

Stages

(1) Pre-jet-post

(2) Adjust times & Values

(a) Jet Period

(b) Pre/post Period

Categories

1. Quasi – Par.
2. Quasi – Perp.
3. Boundary
4. Encapsulated
5. Unknown

Quality Check

- Criteria Number

Level I – III

- Tries Required

1 – 5 / stage

Multistage Classification – Simplified Scheme

Stages

(1) Pre-jet-post

(2) Adjust times & Values

(a) Jet Period

(b) Pre/post Period

Categories

1. Quasi – Par.
2. Quasi – Perp.
3. Boundary
4. Encapsulated
5. Unknown

Quality Check

- Criteria Number

Level I – III

- Tries Required

1 – 5 / stage

Multistage Classification – Simplified Scheme

Stages

(1) Pre-jet-post

(2) Adjust times & Values

(a) Jet Period

(b) Pre/post Period

(3) Normalizing

Categories

1. Quasi – Par.
2. Quasi – Perp.
3. Boundary
4. Encapsulated
5. Unknown

Quality Check

- Criteria Number

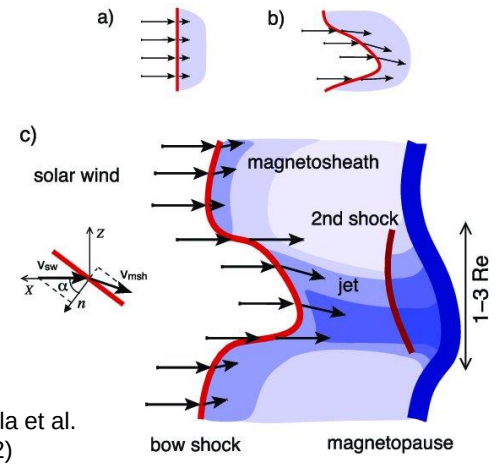
Level I – III

- Tries Required

1 – 5 / stage

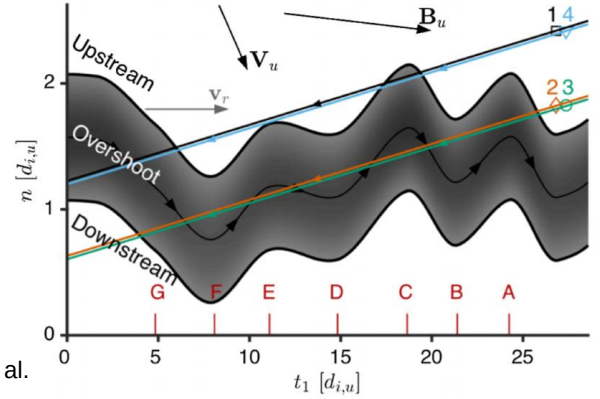
Mechanisms ideas for each jets

Quasi – Parallel



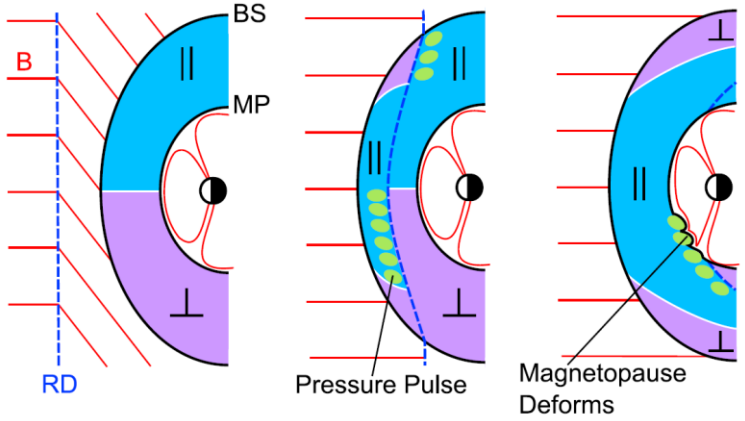
Hietala et al. (2012)

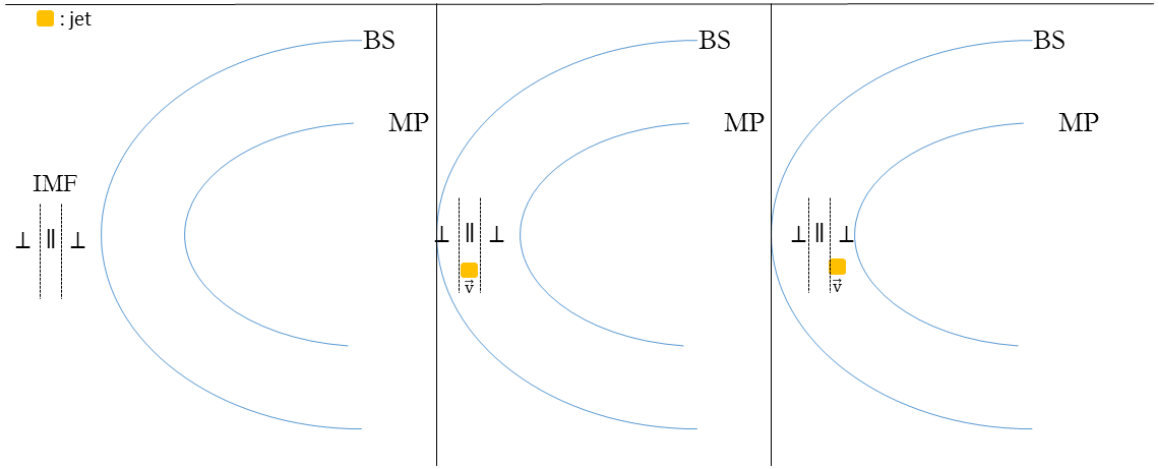
Quasi – Perpendicular



Johlander et al. (2016)

Boundary



Archer et al. (2012)

Encapsulated