The Spatial Distribution and Evolution of Dipolarization Propagation Normals, Structure Velocities, and Dimensionality with MMS

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Introduction

With NASA's Magnetospheric Multiscale (MMS) mission, we have developed a list of dipolarization events, collected between 2018 and 2023 with our detection algorithm (from R ~ 6 R_E to 30 R_E in the nightside magnetosphere). The minimum directional derivative (MDD) and spatial temporal difference (STD) methods are applied to hundreds of dipolarization events.

A large amount of variability within and between different cases is seen (see Figure 1). While DFs are often largely one-dimensional structures, we find they also often deviate from this assumption - potentially due to the presence of flux ropes, waves, or reconnection-related structures.

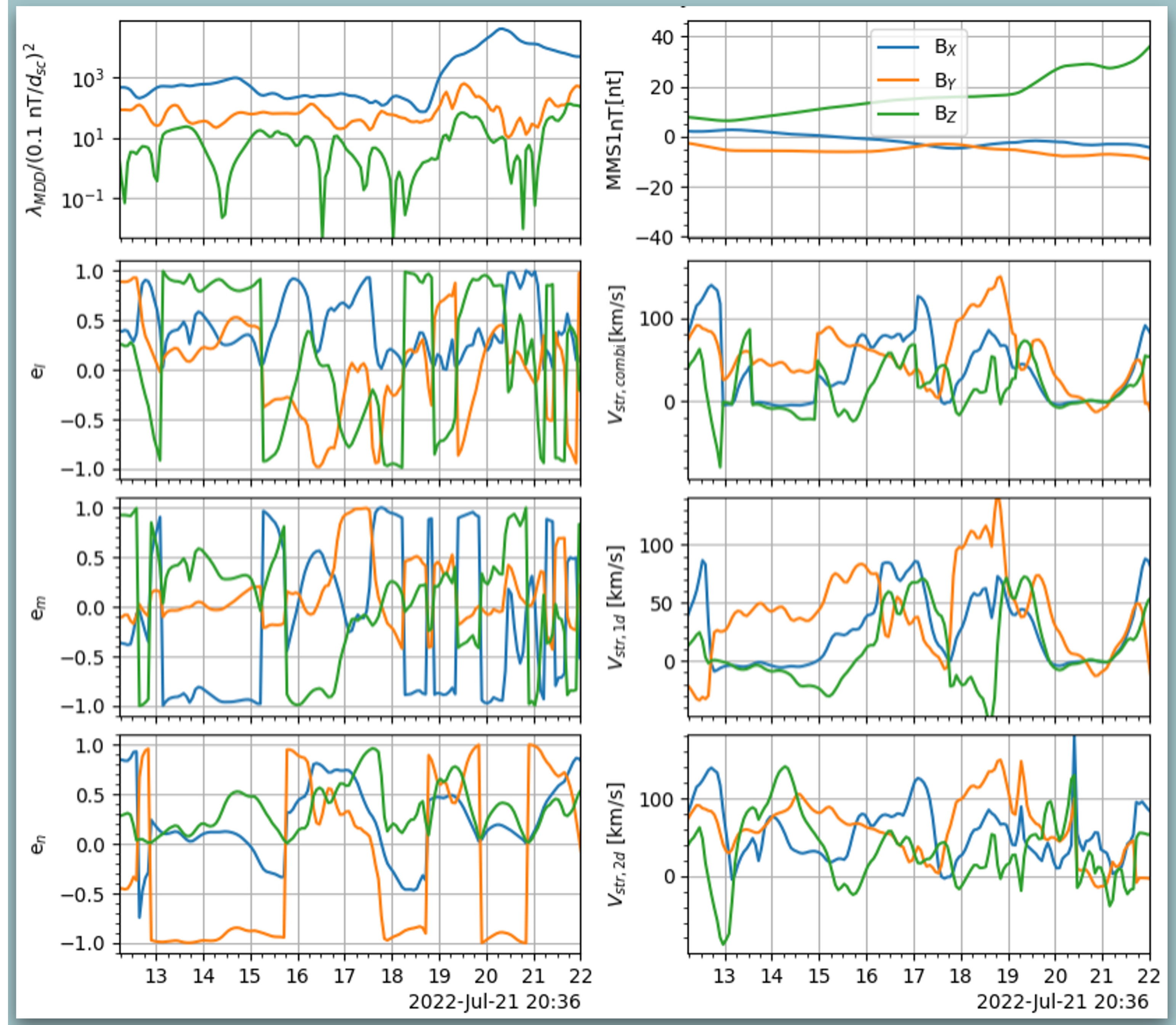

Figure 1: MDD and STD analysis results for a dipolarization event. The left column contains the eigenvalues and eigenvectors obtained from the MDD method. The right column shows the B field, the combined structure velocity, and the 1-D and 2-D solutions to the structure velocity from STD analysis. The primary and secondary eigenvalues are at least 8x the error threshold for the entire duration of this event. This dipolarization event is located in the inner magnetosphere transition region (R ~ 9 R_E).

Propagation Normals and Structure Velocities

As seen in Figure 1, MDD and STD analysis can provide multidimensional solutions for both the normal vector and the structure velocity. To eliminate erroneous solutions, we restrict our analyses to regions where the eigenvalues λ_1 and λ_2 are greater than 8x (or 10x) the error threshold - $(0.1\ nT/d_{sc})^2$. STD analysis provides different solutions based on the dimensionality of the structure - in order to infer whether or not to use 1-D or 2-D solutions, we use the following logic:

- If $\lambda_1/\lambda_2 > 10$ ⟶ structure is mostly 1-D
- If $\lambda_1/\lambda_2 < 10$ ⟶ structure is quasi-2-D

Statistically, we find most DFs possess some quasi-2-D characteristics. Other methods of determining structure velocity and propagation normals, like timing analysis, often employ the assumption that the DF structure is a 1-D tangential discontinuity – which is different from MDD and STD analysis.

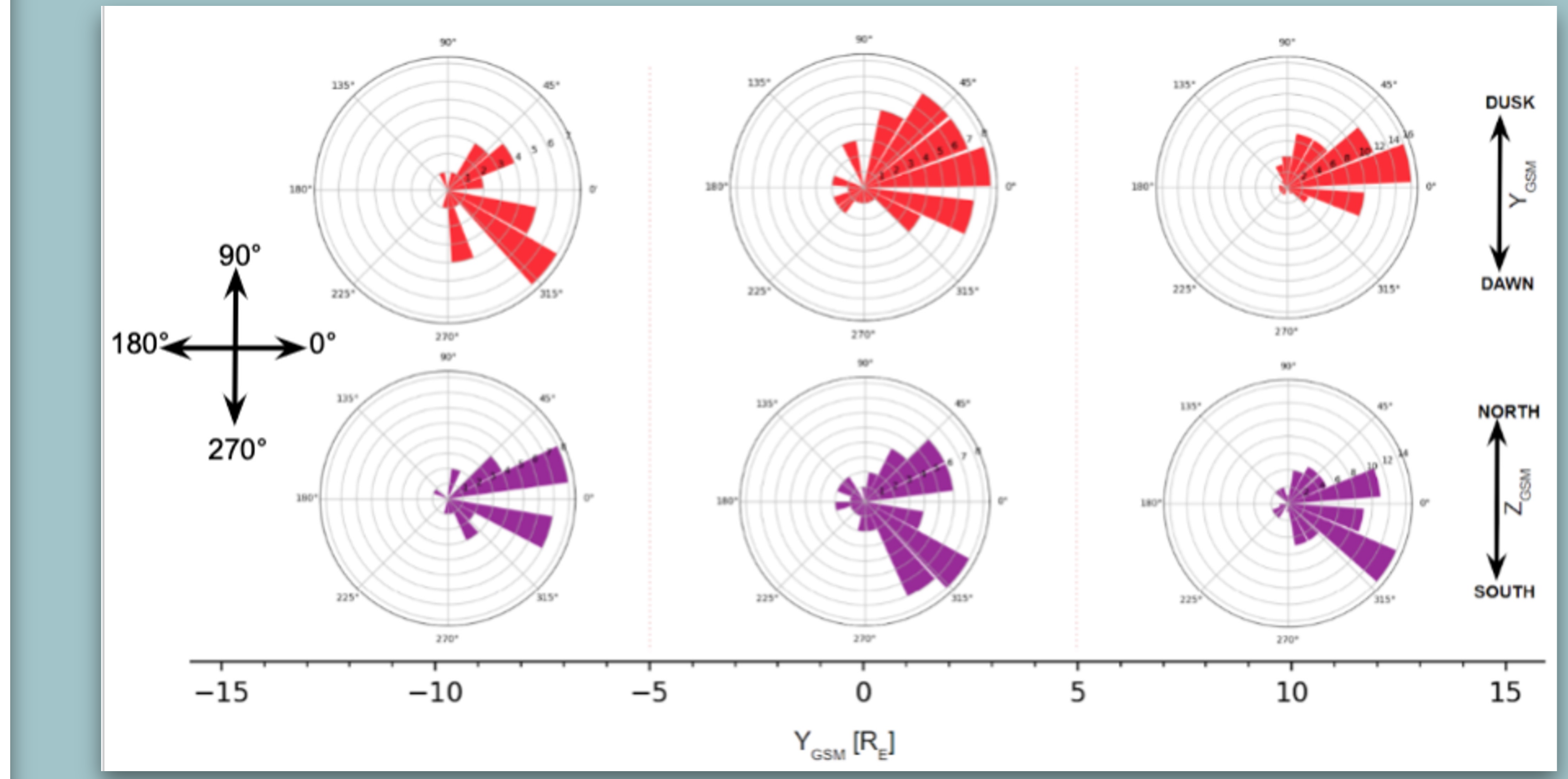

Figure 2: Polar histograms, organized by Y_{GSM}-position. The histograms on the top show the normal vectors in the X-Y plane and the bottom show the X-Z plane. 0 degrees corresponds to a vector pointing earthward and 180 degrees is tailward.

Figure 2 shows that separating cases into three groups by Y-position reveals that the N_{MDD} solutions are actually statistically different, generally with directions that point in the same direction as the side they were detected on the dusk or dawnside. This potentially reflects that reconnection and dipolarization are typically detected on the duskside, meaning that the normal direction obtained is reflecting the curvature of the DF (and that the total DF structure is much, much larger than the spacecraft separation of the order of tens of km).

Plasma Kinematics

When comparing the perpendicular ion bulk velocities to $\mathbf{V}_{str}$, we see they are often comparable. Correlation is often seen between the structure velocity, **E**x**B** drift, and the perpendicular plasma velocities. In general, the electrons almost always follow **E**x**B** drift. We note the electron velocities may contain some offset or error. Plasma motion in the inner magnetosphere transition region also seem to be dominated by **E**x**B** drift, but less consistently than those in the tail.

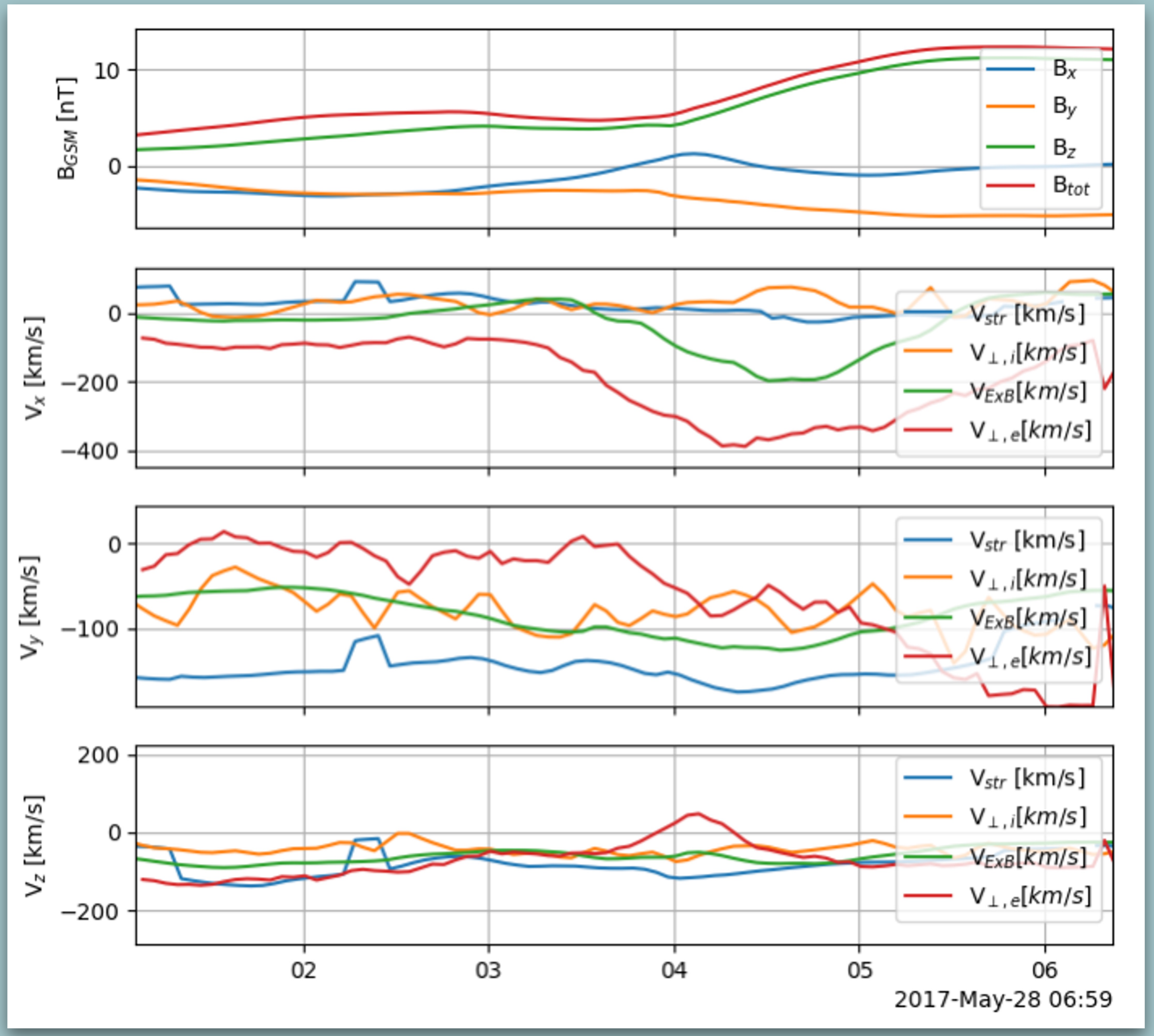

Figure 3: B-field and three velocity components (x,y,z) are shown. The bottom three panels contain the structure velocity from STD (blue), the perpendicular bulk ion velocity (orange), the perpendicular bulk electron velocity (red), and the ExB drift (green). The structure velocity used here has a higher error threshold (10x).

Discussion and Conclusion

We find that DFs are typically earthward propagating, quasi-1-D structures with occasional 2-D properties. Plasma motion is typically dominated by **E**x**B** drift, particularly the electrons. We assume in some cases the ions are not frozen-in. MDD normal vectors also suggest an expanding, curved front structure. As this is a work in progress, we intend to perform a larger statistical study and better characterize plasma kinematics as DFs evolve.

This work was supported by NASA's MMS Contract NNG04EB99C and NASA Grant 80NSSC22K0526.