# Contrasting Dipolarization Front Structure and Dynamics for Various Solar Wind Conditions: The MMS 2018 Tail Season

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## Abstract

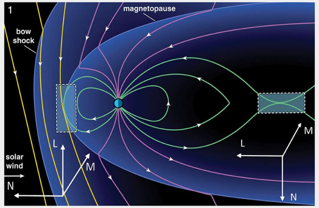

Figure 1: Tail reconnection (LMN coordinates), from Dai et al. (2020)

Dipolarization fronts (DF) are localized structures that separate the downstream energetic particles from the ambient plasma through which they travel. They are characterized by a sharp, positive gradient in the northward magnetic field component and play an important role in energy transfer and conversion in the nightside magnetosphere. The Magnetospheric Multiscale mission (MMS) 2018 tail season is a time period that covers a wide range of magnetospheric conditions during which DFs occur. These conditions include: quiet periods of slow solar wind, fast solar wind with large Alfvénic fluctuations, and magnetospheric storm events. We ask, how does this variability in conditions reflect in the properties of the observed DFs?

## Introduction

With certain geomagnetic activity, magnetic reconnection can occur in the magnetotail. Associated with this reconnection is an Earthward traveling plasma and magnetic structure. The boundary of this structure is referred to as a "dipolarization front" - as this front carries an enhanced northward magnetic field component (the Z-direction in GSM or SM coordinates).

In the magnetotail, DFs occur on the timescale of seconds (such as the one shown in Fig. 2a). As DFs propagate Earthward, they seem to decelerate, making the timescale longer. In the inner magnetosphere ($X_{SM} \geq -9\ R_E$), the sharp "spike" seen in outer DFs becomes more gradual (as seen in Fig. 2b).

Much is still unknown regarding the properties of DFs, such as: the frequency of occurrence, how they evolve as they propagate, and under what kind of geomagnetic conditions are they favored. In the next section, we show how we selected these DFs across the nightside magnetosphere and tail. We also show the frequency of these events in relation to interplanetary conditions.

This is a preliminary study on associations between DFs in the near-Earth tail with interplanetary structures.

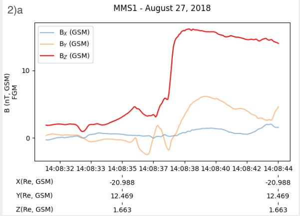

Figure 2a: Example of dipolarization front in the magnetotail. Note the sharp structure seen in the $B_Z$ direction.

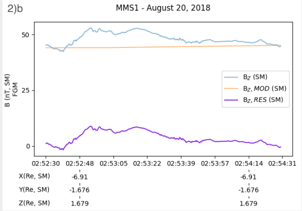

Figure 2b: Example of inner dipolarization event. Note the longer timescale than the one in Figure 1b

## Methodology

Due to MMS's high time resolution, we search for DFs beyond $X_{GSM} = -9\ R_E$ in 30 s sliding windows with 15 s increments. If multiple DFs are detected within a 3 minute window, only the largest DF is taken. We define DFs based on the criteria detailed in Schmid et al. (2014) with some modifications: (1a) $dB_z > 8$ nT, (2a) $\arctan(B_z/B_{xy}) > 45°$ for at least one data point, (3a) time at $B_z$ maximum > time at $B_z$ minimum, and (4a) location of spacecraft restricted to $X_{GSM} \leq -9\ R_E$, $|Y_{GSM}| \leq 15\ R_E$, & $|Z_{GSM}| \leq 5\ R_E$. These criteria ensure that MMS is located in the plasma sheet and eliminate false positives.

For the inner magnetosphere ($-4.5\ R_E \geq X_{SM} \geq -9\ R_E$), we use SM coordinates and model the field using the Tsyganenko-89 (T89) and the International Geomagnetic Reference Field (IGRF) models[3,4]. We then subtract the model from the data in order to find $dB_z$ and eliminate the quickly increasing or decreasing dipolar field. We use 120 s sliding windows with slightly different criteria from before: (1b) $dB_z > 8$ nT, (2b) time at $B_z$ maximum > time at $B_z$ minimum, (3b) location of spacecraft restricted to $X_{SM} \geq -9\ R_E$. In the inner magnetosphere, criteria regarding the plasma sheet becomes unnecessary (such as (2a)).

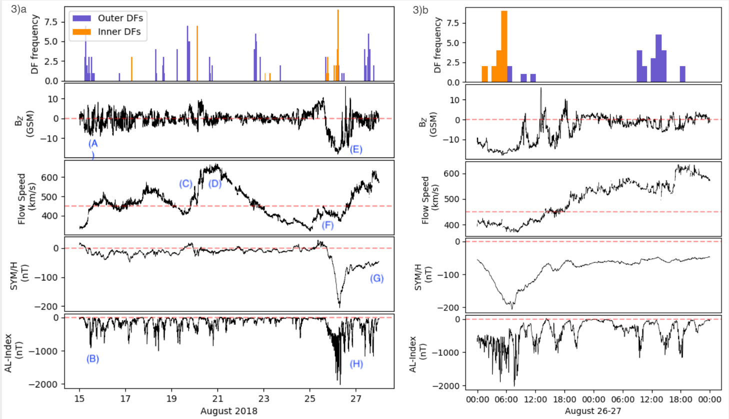

Figure 3a: Frequency of DFs from Aug 15-28 2018, shown next to OMNI data of the interplanetary $B_z$, flow speed, SYM/H, and AL-index. Features shown include: A) High-amplitude Alfvén waves, B) several moderate substorms without associated storm, C) stream interaction region (SIR), D) low-amplitude Alfvén waves, E) strong, negative $B_z$ associated with ICME, F) slow wind (during main phase of storm), G) recovery phase of super-storm associated with ICME, H) repeated substorms. Red, dotted-lines in flow speed at 450 km/s show our main threshold for active/calm conditions. There is also a red, dotted-line at $B_z$, SYM/H, and AL-index = 0. When interplanetary $B_z$ is negative, it is an indicator of magnetospheric forcing.

Figure 3b: A zoomed-in look at August 26 and 27. Note the interval of a strong storm, repeated substorms, intermittent forcing in $B_Z$, and high solar wind speeds with a stream-interaction region.

## Methodology (cont.)

For both inner and outer DFs, we require that each event is separated by 3 minutes. If two or more DFs occur within a 3 minute interval, we choose only the largest one. Based on these criteria, we run the code from 8/15/2018 to 8/28/2018, as this time period exhibits a variety of interplanetary and geomagnetic conditions. These conditions range from calm, quiet periods to strong storms associated with an interplanetary coronal mass ejection (ICME). We anticipate gaps in DF detections due to when MMS is outside of the plasma sheet or on the dayside.

All events, from both the inner and outer magnetosphere, were found using the Flux Gate Magnetometer (FGM) onboard the MMS1 probe with survey mode data. Probe locations were examined through Magnetic Ephemeris and Coordinates (MEC) data.

## Results

We wrote an automated algorithm to find DFs after determining robust criteria to detect and define them. Using the aforementioned criteria, we managed to find many dipolarization events across the magnetotail.

We are beginning to understand the relationship between forms of magnetosphere forcing and the prevalence of various types of DFs[2] in the tail plasma sheet and inner magnetosphere.

When conditions are "active" (fast wind or negative $B_z$) there are more DFs. We have also found that intermittent forcing from Alfvénic fluctuations are conducive to producing DFs. We will work towards identifying any differences in DFs in the tail with the type of solar wind-magnetosphere forcing which gave rise to them (and the region they tend to occur).

## Conclusion

In order to refine the sample, we plan on doing minimum variance analysis (MVA) and timing analysis on all DF events. This way, the trajectory of the DFs can be determined while removing any borderline events that aren't suitable for a statistical study. We also plan to run our code for the entire MMS tail season in 2018 (from ~May 2018 - October 2018) to capture even more variations in the interplanetary conditions and relate them to varieties of DFs.

## References/Acknowledgements

[1] Dai (2020), AME: A Cross-Scale Constellation of CubeSats to Explore Magnetic Reconnection in the Solar-Terrestrial Region, Frontiers in Physics
[2] D. Schmid, R. Nakamura, F. Plaschke, M. Volwerk, W. Baumjohann (2014), Two states of magnetotail dipolarization fronts: A statistical study, J. Geophys. Res., 120(2)
[3] Tsyganenko, N. A., A magnetospheric magnetic field model with a warped tail current sheet (Planet. Space Sci., v.37(1), pp.5-20, 1989
[4] Alken, P., Thébault, E., Beggan, C.D. et al. International Geomagnetic Reference Field: the thirteenth generation. Earth Planets Space 73, 49 (2021).

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