



A Preliminary Statistical Analysis of Flux Transfer Events along the Flanks of the Earth's Magnetopause



David Dyer¹, Stefan Eriksson², Wai-Leong Teh², Laila Andersson²

¹ University of Colorado, Boulder, ² Laboratory for Atmospheric and Space Physics, Colorado, USA
david.dyer@colorado.edu

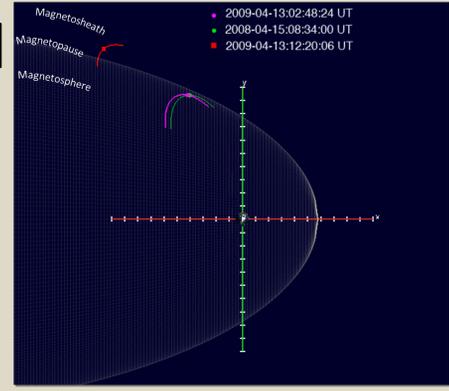
Abstract:

This work consisted of a statistical survey of flux ropes (also called Flux Transfer Events, or FTEs) along the flanks of the Earth's magnetopause. THEMIS spacecraft data were used for this survey due to their proximity to the equatorial plane, where Kelvin-Helmholtz (KH) surface wave amplitudes are the largest. FTEs are believed to be generated locally by magnetic reconnection when the nonlinear KH waves are developed.³ The objectives of the study were to identify bipolar magnetic events which indicate either an FTE or a KH surface wave and develop statistical results that would illuminate the nature of the FTEs.

The importance of this study is twofold: First, it helps satisfy basic human curiosity and an understanding of the world around us, which is an essential pursuit. Second, FTE generation contributes to plasma transport across the normally impassable magnetopause and directly affects space weather, which has numerous tangible applications. During this study, we found that trailing-edge FTEs dominate (see trailing-edge diagram). We also performed MHD reconstruction⁴ for two ideal FTE events to verify that they were, indeed, FTEs. These results are preliminary since we performed statistical analysis on 11 of 123 dates.

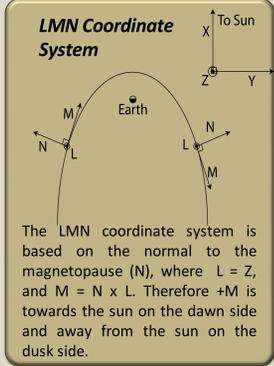
Background

The Magnetopause is defined as the boundary between the low density, low velocity magnetosphere where the magnetic field is controlled by the earth's dipole, and the high density, high velocity magnetosheath where the field is highly variable due to the sun's magnetic field. As illustrated to the right, the THEMIS spacecraft pass regularly through the magnetopause taking readings on magnetic field, electronic flux, and plasma density and velocity.

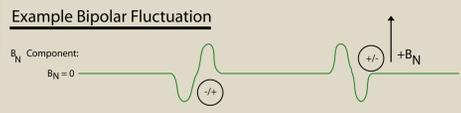
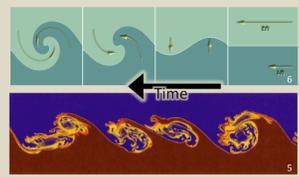


The variations associated with the magnetopause boundary and cross the THEMIS probes' locations often, and we used the data from these crossings to identify KH vortices and FTEs. The GSM and LMN coordinate systems were used, where GSM is based on +Z = Magnetic Earth North, +X = Earth Center to Sun Center and +Y = +X x +Z (see above).

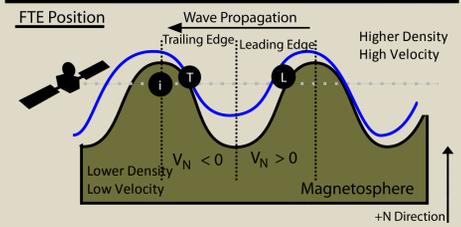
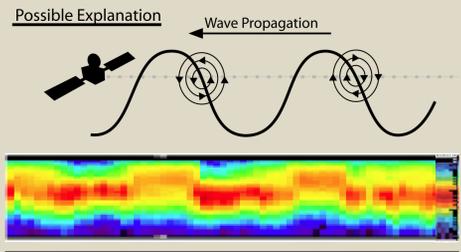
For our purposes, it is more convenient to measure most changes with respect to the magnetopause, so the LMN coordinate system was used. Therefore V_N and B_N represent the Velocity and Magnetic field strength orthogonal to the magnetopause, respectively. (see below)



The LMN coordinate system is based on the normal to the magnetopause (N), where $L = Z$, and $M = N \times L$. Therefore +M is towards the sun on the dawn side and away from the sun on the dusk side.



While the magnetopause expands and contracts constantly due to pressure differences, KH instability is caused by shear flows of different velocities. As shown above, the magnetopause boundary is quite clear during a KH surface wave. However, it becomes much less clear in a KH vortex, which leads to a higher likelihood of magnetic reconnection and thus FTEs. FTEs originate from the decoupling of a flux rope which can move to another region and then dissolve, allowing for plasma transport. THEMIS spacecraft register these fluctuations as spikes in energy flux, velocity, temperature, energy and density. Magnetic field reaction is variable.



Polarity: The diagram to the left illustrates the different polarities that were found in the B_N field for FTEs. The different polarities were possible because of opposite current directions in FTEs.

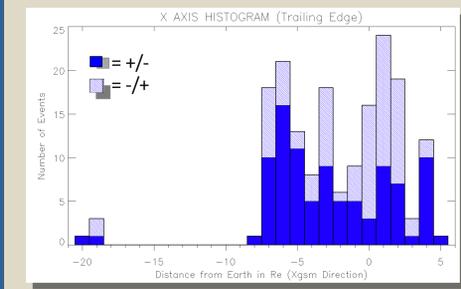
Location: As the diagram to the left illustrates, FTEs were found on the leading edge (L) or trailing edge (T) of a KH wave. A few also were designated as internal (i) to the magnetosphere.

Statistical Results

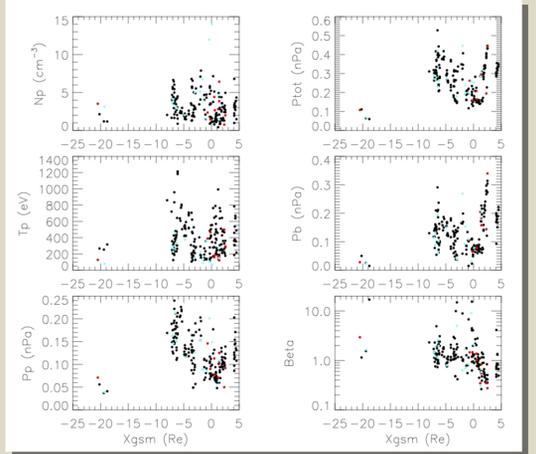
Flux Rope Phase	Trailing FTE's	Leading Edge FTE's	Internal FTE's	Total Events
All	173	10	17	200
+/- Events	95	7	10	112
-/+ Events	78	3	7	88

This study focused on dates that were selected due to their abundance of KH vortex activity, indicated by many high frequency magnetopause crossings. 11 dates, in particular, were identified due to their KH activity. Out of these 11 dates, 200 events were found with a relatively equal polarity distribution. This is the first statistical study that has focused on FTEs due to magnetic reconnection on the flanks of the Earth's magnetopause. Preliminary statistical results reveal a few possible trends.

There is a definite trend toward trailing-edge, or sunward, FTEs vs. internal or leading edge FTEs. We believe this is due to a thinning of the current sheet on the trailing edge and more occurrences of magnetic reconnection. Also, the scatter plots indicate a trend toward larger FTEs with distance down tail, as well as an average negative V_N value. However, there are too few points for any conclusive results, particularly without data in the -9 to -20 X_{GSM} region.

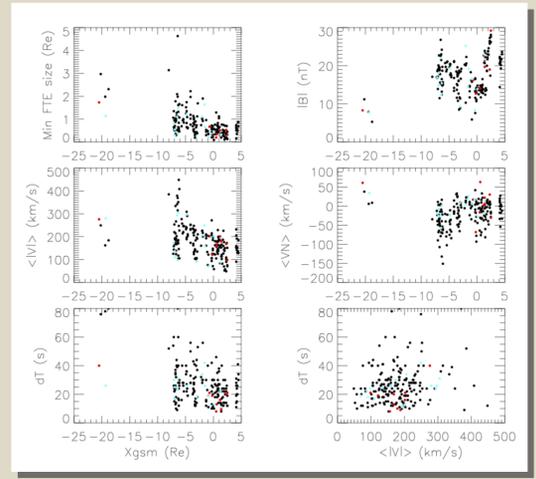


The above histogram shows the number of recorded, trailing-edge FTEs, grouped by polarity. The polarities appear to be evenly distributed, but the only conclusive result that can be drawn from this histogram is that there is not a significant, dominating polarity.



- Trailing Edge FTE
- Leading Edge FTE
- Internal FTE

These scatter plots show the distance down tail in R_E (in the X_{GSM} direction) against ion density, temperature, pressure, pressure ratio, size, average velocity and period to look for any visible trends. The 12th plot, in the bottom right corner plots average velocity against period of the bipolar fluctuation and shows a pretty wide scatter. However, once that result (Min FTE size) is plotted against distance down tail, we see a relatively regular trend towards larger FTEs down tail.

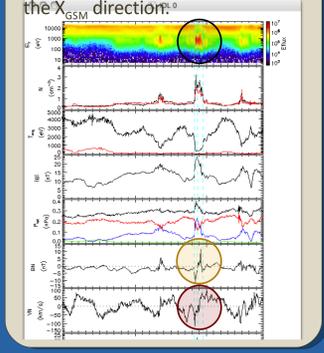


Surface Wave

While the surface wave still has a prominent bipolar B_N feature, it is not a FTE. The following features identify a surface wave:

- Bipolar B_N fluctuation
- The Magnetopause fluctuates over the spacecraft resulting in a bipolar magnetic feature
- The bipolar B_N fluctuation correlates with a bipolar V_N fluctuation

This is an ideal example of a surface wave and occurred at approximately -6.6 R_E down tail in the X_{GSM} direction.



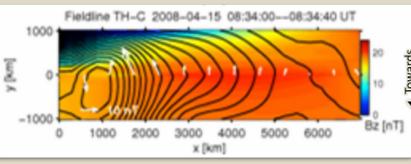
Near Tail FTE

The best example of a near tail FTE was captured on 2008-04-15 at approximately -6.8 R_E in the X_{GSM} direction. A typical FTE has the following features:

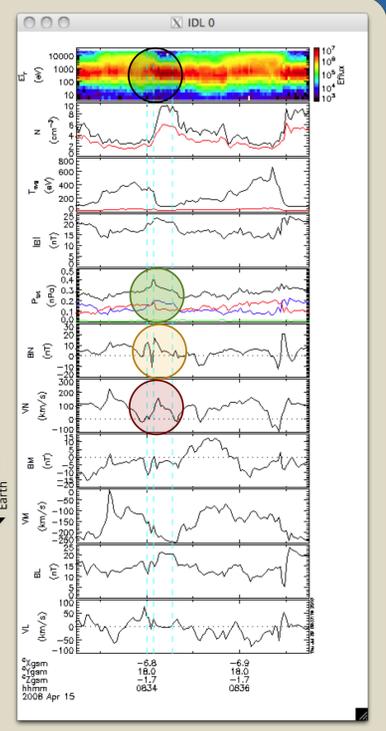
- Occurs along the Magnetopause
- There is a spike in pressure and/or density near the middle of the event.
- The characteristic bipolar B_N fluctuation
- The lack of a bipolar V_N correlation

All of these features were observed for this event.

MHD Reconstruction⁴ - Near Tail



The MHD reconstruction above was performed to validate that the bipolar B_N feature was a flux rope. The island in the field line plot is indicative of an FTE and would not exist in a surface wave.



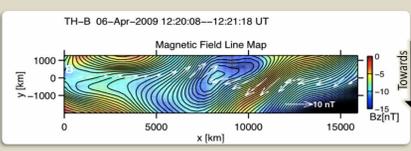
Far Tail FTE

The farthest down-tail FTE captured occurred on 2009-04-06 at approximately -20.2 Earth Radius (R_E) in the X_{GSM} direction. Again, the ideal features of an FTE are the following:

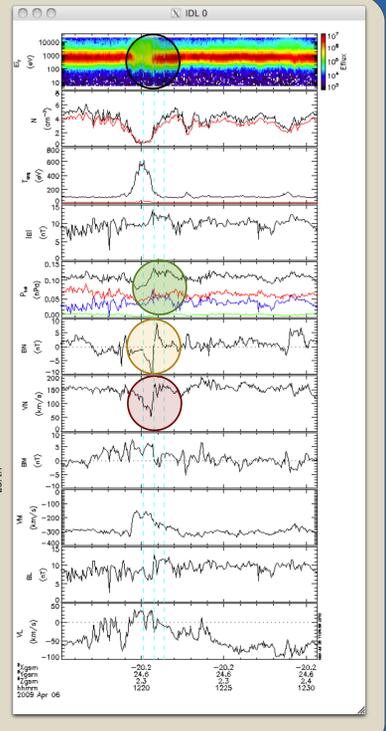
- Occurs along the Magnetopause
- There is a spike in pressure and/or density near the middle of the event.
- The characteristic bipolar B_N fluctuation
- The lack of a bipolar V_N correlation

All of these features were observed for this event.

MHD Reconstruction⁴ - Far Tail



Further down tail, FTEs are more difficult to identify than nearer the dawn/dusk terminator. The MHD reconstruction above shows that this event was an FTE. The obvious island in the Magnetic Field Line and Streamline Maps is indicative of a FTE and would not exist in a surface wave.



- Conclusion:**
- Out of 11 dates, we found 200 FTE's
 - Trailing-Edge FTEs dominate
 - We reconstructed two likely FTEs using MHD models -- One at (-20.2, 24.6, 2.3) R_E and the other at (-6.8, 18.0, -1.7) R_E in $(X, Y, Z)_{GSM}$ coordinates.
 - The average velocity in the N direction is negative, which is consistent with finding FTEs on the trailing edges.
 - There appears to be a trend where ion plasma pressure and the ion beta (ion to B-field pressure ratio) increase linearly with distance down tail. More data are needed to confirm this trend.

- Future Work:**
- In particular, data are needed for the region between -8 and -20 R_E in the X_{GSM} direction to confirm some of these initial results.
 - Additionally, all THEMIS data along the flanks will provide much greater capability for statistical analysis.

References

¹ T. K. M. Nakamura, M. Fujimoto, and A. Otto, Structure of an MHD-scale Kelvin-Helmholtz vortex: Two-dimensional two-fluid simulations including finite electron inertial effects, JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 113, A09204, 16 PP., 2008 doi:10.1029/2007JA012803

² Bengt Sonnerup and W-L Teh, Reconstruction of two-dimensional coherent MHD structures in a space plasma: The theory, Journal of Geophysical Research, 113, A05202, doi:10.1029/2007JA012718, 2008

³ J. N. Gosli, D. F. Richards, K. J. Caspersen, R. E. Rudd, J. A. Gunnels, and F. H. Stretz, Extending stability beyond CPU millennium: a micron scale atomistic simulation of Kelvin-Helmholtz instability, SC '07 Proceedings of the 2007 ACM/IEEE conference on Supercomputing, pages 1-11, 2007. Taken from: <http://www.aps.org/units/afid/pressroom/gallery/richards.cfm>

⁴ <http://www.brockmann-consult.de/CloudStructures/kelvin-helmholtz-instability-description.htm>