Dipolarization fronts associated with near-Earth dissipated flux ropes

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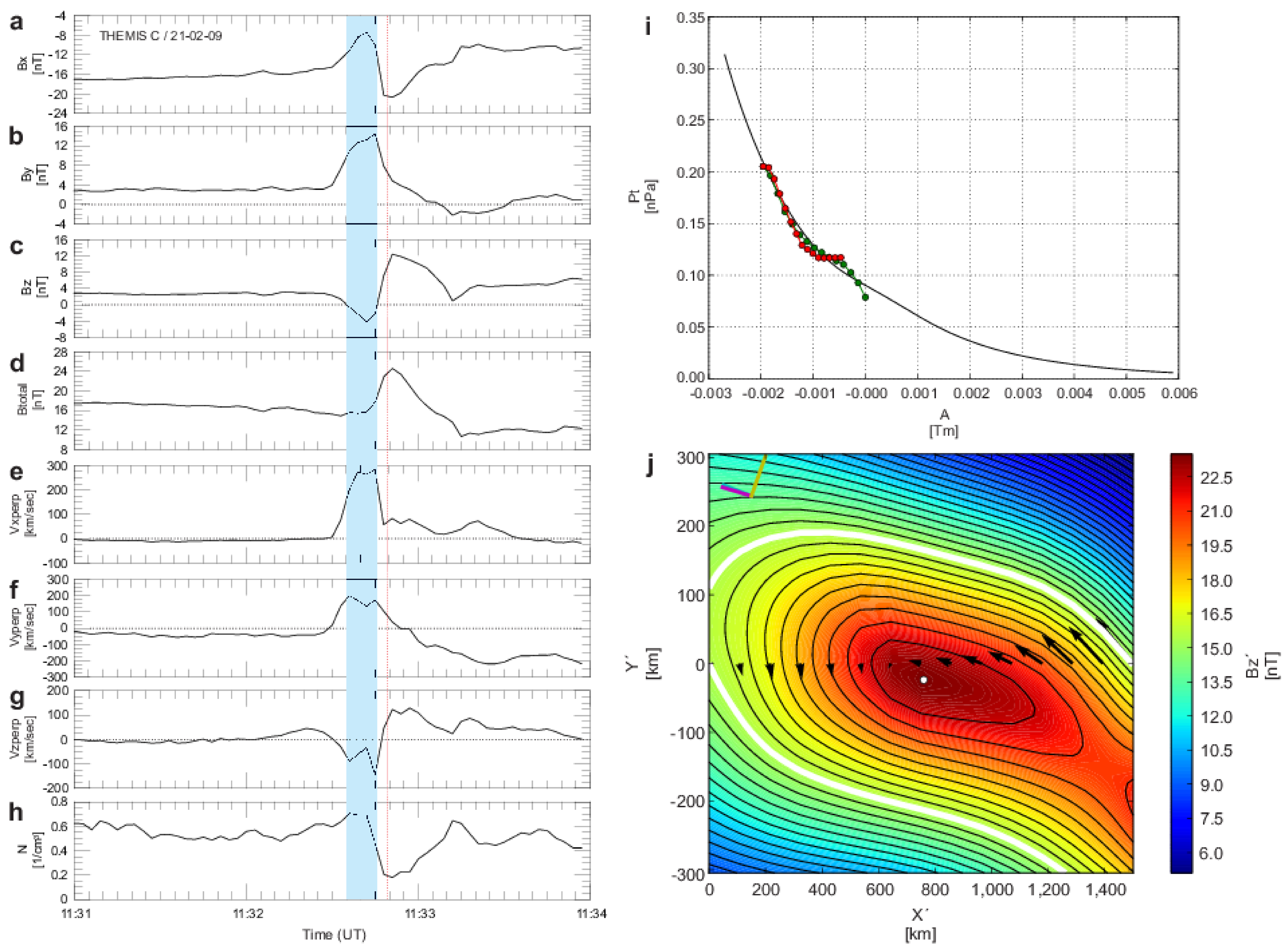
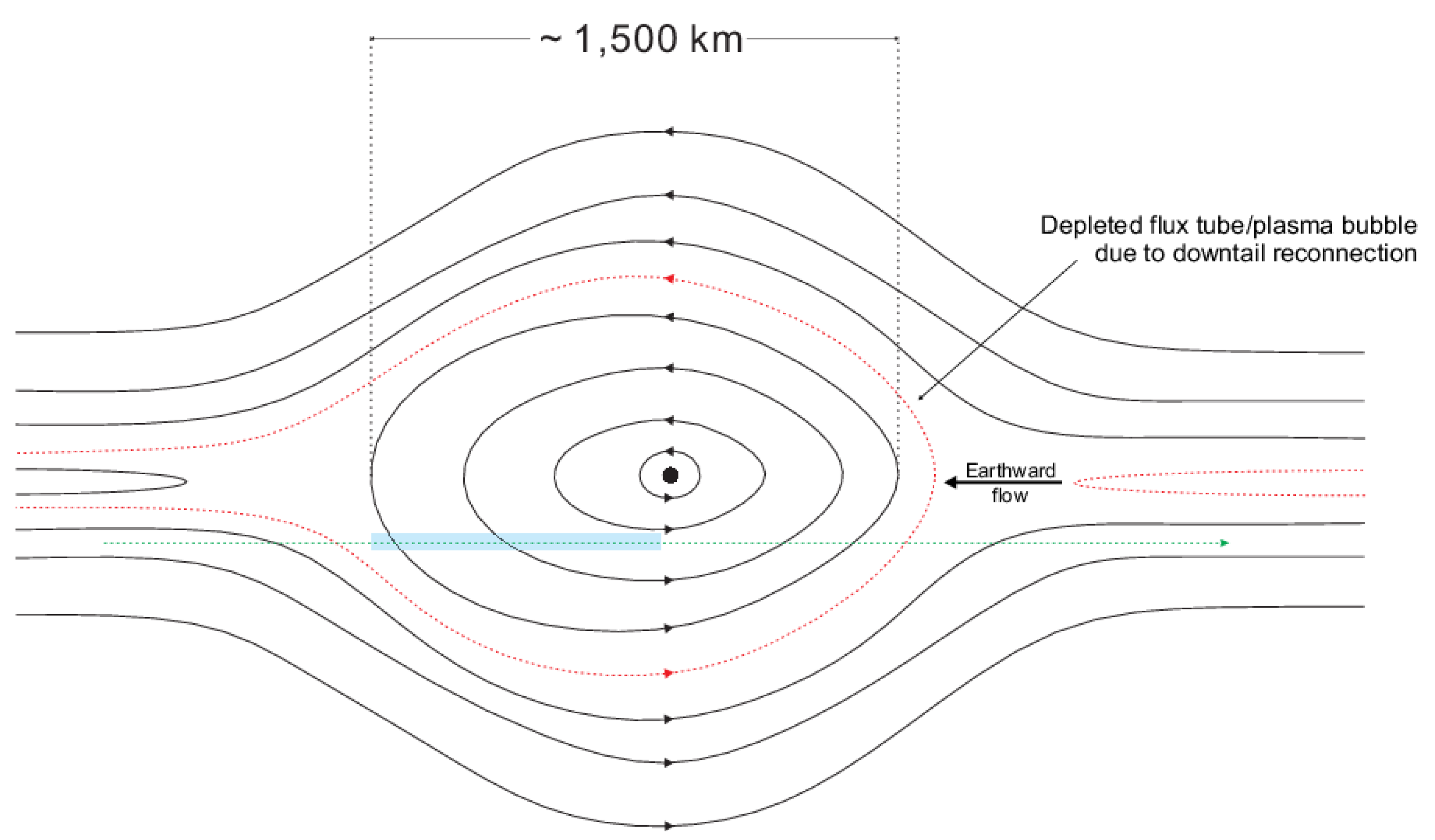
Introduction

We investigate a number of THEMIS dipolarization fronts during quiet and active periods in magnetotail at radial distance around -10Re. From a previous work we have shown evidence that dipolarization fronts originate from earthward propagating magnetic structures which resemble to flux ropes. To further support this conclusion and validate our model we analyze the events by applying magnetohydrostatic Grad-Shafranov reconstruction and estimate the orientation (invariant axis) and cross section of magnetic flux ropes. Reconstruction results show that these flux ropes in the late stage of their evolution are highly perturbed, subjected to a continuous magnetic deterioration due to anti-reconnection process. Comparison is made with unperturbed flux rope events down the tail registered early in their evolution where Grad-Shafranov reconstruction is able to estimate their invariant axis orientation with no ambiguity.

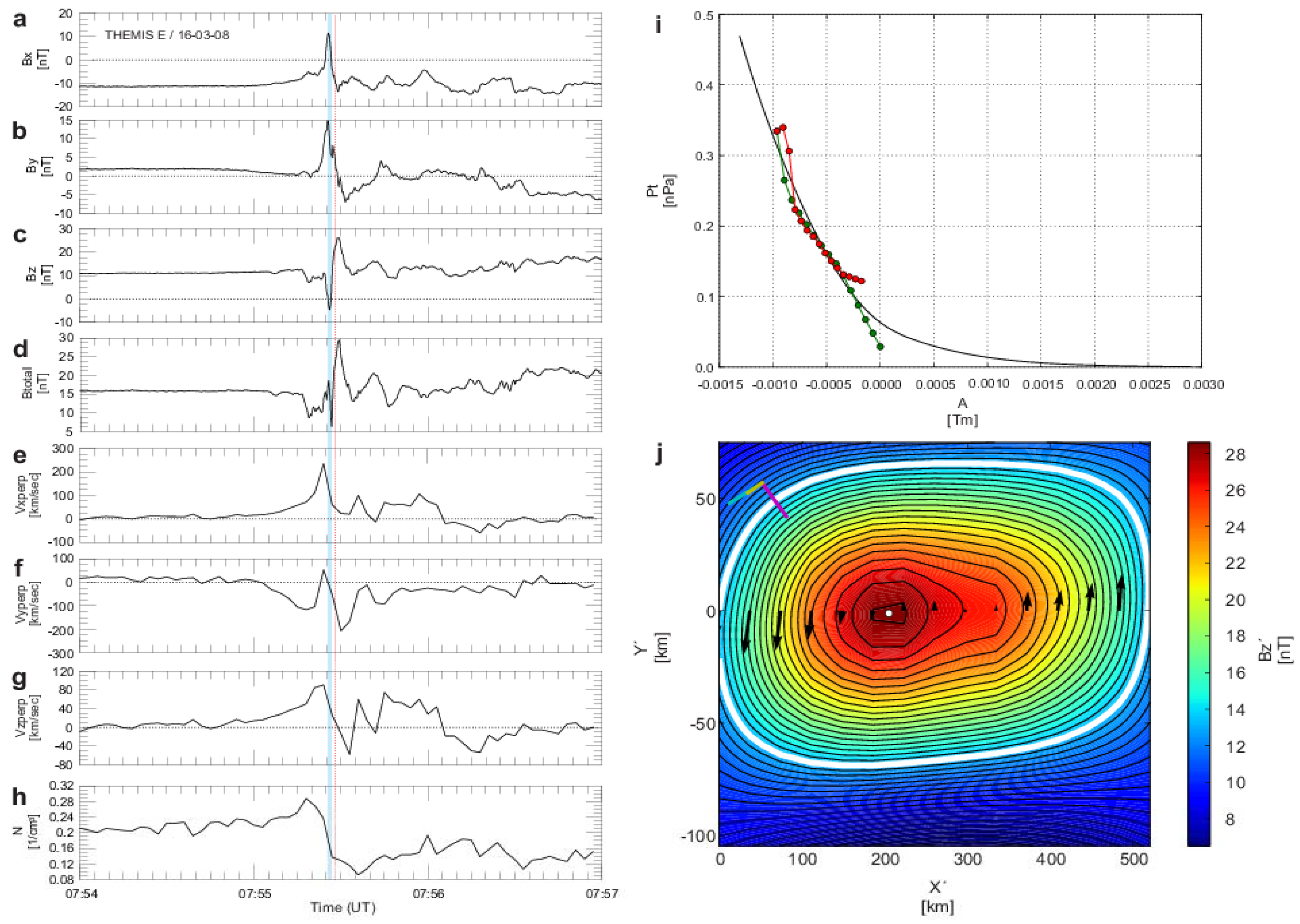
Events analyzed with Grad-Shafranov method. Here we show 2 representative cases (red letters).

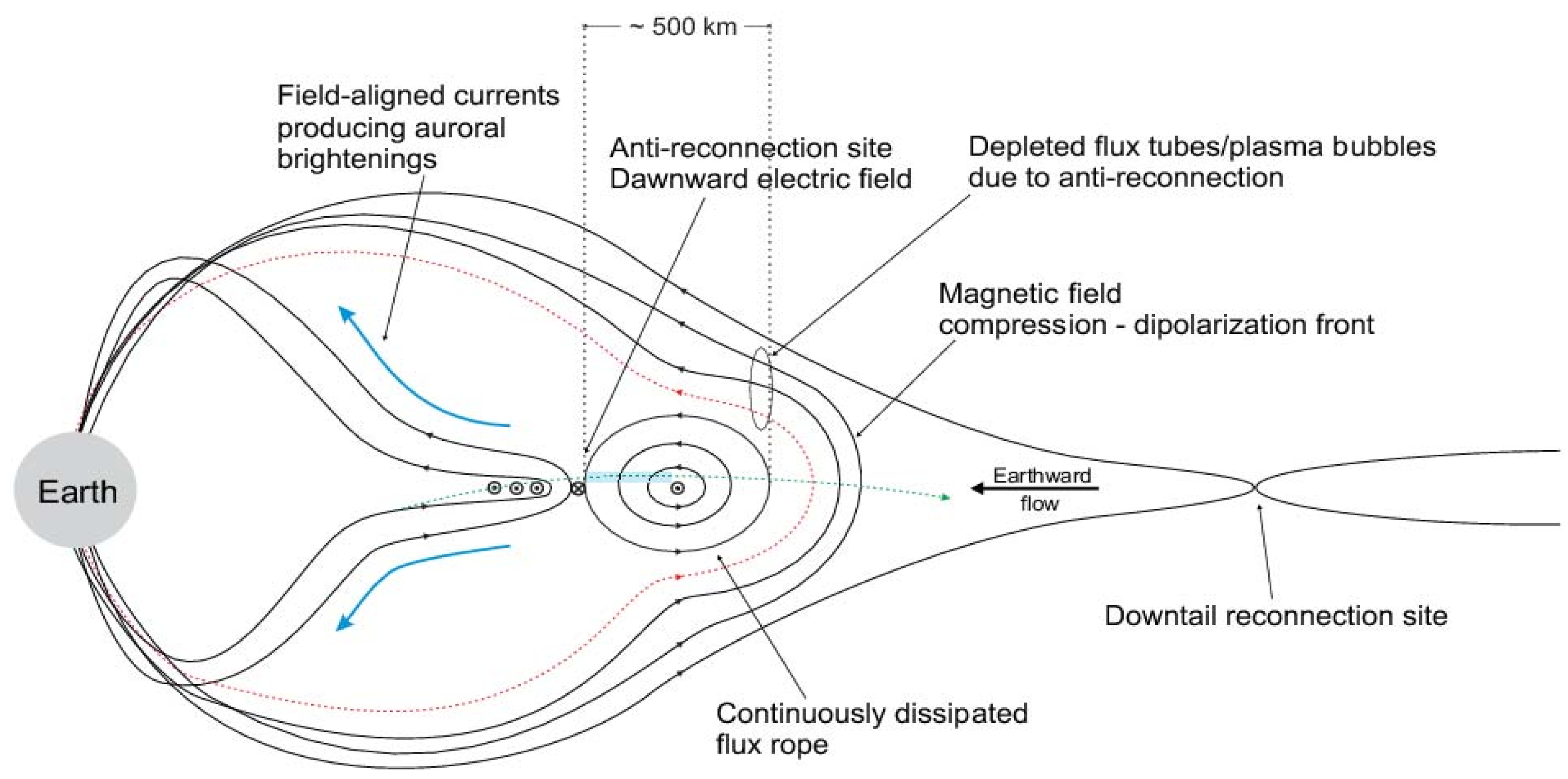
Date	Time	S/C	Location in GSM (Re)	Conventional Classification	Flux Rope Axis in GSM
09/01/2008	~03:37 UT	P3 (D)	(−9.8, −0.5, −3.7)	Dipolarization Front	(−0.867, 0.341, 0.362)
16/03/2008	~07:55 UT	P4 (E)	(−10.5, 4.9, −1.6)	Dipolarization Front	(−0.412, −0.022, 0.911)
17/06/2011	~13:39 UT	P4 (E)	(−8.6, 1.7, 3.7)	Dipolarization Front	(0.448, 0.850, 0.279)
23/07/2012	~11:37 UT	P5 (A)	(−9.8, 3.2, 2.8)	Dipolarization Front	(0.983, 0.140, −0.121)
09/03/2008	~07:52 UT	P1 (B)	(−17.1, 4.4, −1.2)	Flux Rope	(−0.929, −0.369, 0.008)
05/02/2009	~11:02 UT	P2 (C)	(−17.5, −6.1, −3.3)	Flux Rope	(−0.745, 0.632, −0.211)
21/02/2009	~11:32 UT	P2 (C)	(−15.7, −3.6, −2.3)	Flux Rope	(−0.709, 0.704, 0.042)
13/03/2009	~05:54 UT	P2 (C)	(−16.0, 1.4, −1.0)	Flux Rope	(−0.888, −0.459, 0.004)





- Panels a-h give an overview of the magnetic field components in GSM coordinates, the magnetic field intensity, the calculated Vx, Vy, Vz convective plasma velocities (plasma velocities perpendicular to magnetic field) also in GSM coordinates and ion density.
- The clear signatures shown are those of an ordinary earthward propagating flux rope which is depicted schematically in the lower part of the Figure.
- The THEMIS C relative trajectory is denoted by the dashed green arrow.
- The main observational feature here corresponds to the time interval indicated by the vertical blue bar. During this interval Bz magnetic field component turns southward obtaining negative values signifying the satellite's entrance into the "leading" portion of the flux rope structure. This trajectory portion is denoted in the schematic illustration by the horizontal blue bar.
- The flux rope is embedded in a highly earthward convective plasma flow (panel e) which is also deflected duskward and southward forming flow vortices (panels f and g) due to the flux rope structure pile-up with the "upstream" magnetic flux tubes.
- The dashed "oval-shape" red line in the schematic illustration denotes the depleted flux tube/plasma bubble that is traversed by THEMIS satellite right at the time indicated by the dashed vertical red line shown in the panels where its formation can be understood in terms of a downtail reconnection process.





- An event that is "traditionally" characterized as dipolarization front.
- The event demonstrates exceptionally similar characteristics to those of the downtail flux rope event .
- Bz shows a clear polarity reversal from northward to southward and then again to northward (vertical blue bar).
- Simultaneously, we have a clear temporally limited enhancement of By which resembles the strong flux rope core.
- Abrupt "ejection" of Btotal coincident with an abrupt increase in Bz indicating that magnetic field is dipolarized and compressed, similarly to downtail flux rope observations.
- The structure is embedded in a high speed earthward convective plasma flow with flow vortices present (panels f and g) due to the structure's pile-up with the "upstream" geomagnetic field.
- Grad-Shafranov reconstruction analysis (panels i and j) provides an unambiguous argument that the structure under investigation, commonly classified as dipolarization front, actually originates from a magnetically deteriorated flux rope.
- The limited spatial extent compared to the downtail flux rope, estimated to be around 500 km, implies that it is continuously dissipated due to some kind of mechanism responsible for constantly eroding its outer magnetic shell.
- Anti-reconnection mechanism is proposed as the responsible mechanism for flux rope deterioration.
- The dashed green arrow denotes the THEMIS E relative trajectory through the flux rope which also explains the abrupt brief excursion of Bx to positive values.

Conclusions

The present study contains significant results and useful insights concerning dipolarization fronts and substorm dynamics. The whole essence is the following: If we do observe earthward moving flux ropes at ~15-18 Re, why we tend to avoid their existence at smaller radial distances? Is it because flux ropes tend to penetrate and finally get dissipated in the inner magnetosphere, thus obtaining a different form than the usual; the form of dipolarization fronts? We definitely support the idea that flux ropes will get dissipated on their way to the Earth and eventually converted to simple compression regions. Whether we observe a bipolar Bz or not depends on the degree of flux rope dissipation and where it was initially formed. Hence, dipolarization fronts can be observed at a wide range of radial distances in the Earth's magnetotail depending on the dissipation degree of the associated flux ropes. In summary, earthward convected flux ropes can be initially formed far from or very close to the Earth, as indicated in the above Table, depending on where multiple X-lines are formed.

Moreover, our substorm model provides a simple explanation to overcome the so-called "pressure balance inconsistency" or "pressure crisis" problem, since it does not involve arrival of flux tubes from the distant tail to the near-Earth region. This inconsistency stems from the fact that the ratio of particle pressure to magnetic pressure obtains absurdly high values in the near-Earth equatorial plane when a flux tube shortens considerably as it convects earthward from e.g. -60 to -10 Re, assuming adiabatic compression of plasma during the earthward magnetoplasma transport.

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