Supra Arcade Downflows with XRT Informed by Dipolarization Fronts with THEMIS

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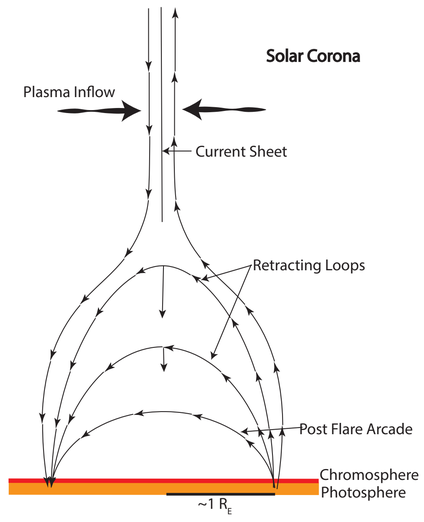
Abstract:

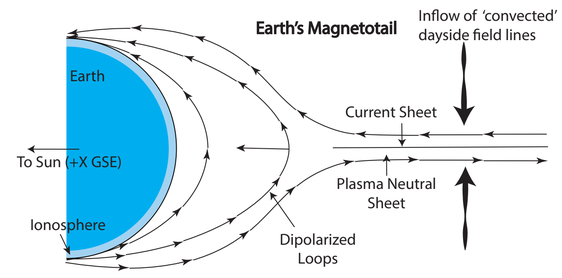
Magnetic reconnection can rapidly reconfigure the magnetic field of the corona, accelerating plasma through the site of reconnection. Ambiguities due to the nature of remote sensing have complicated the interpretation of observations of the inflowing and outflowing plasma in reconnecting regions. In particular, the interpretation of sunward moving density depletions above flare arcades (known as Supra Arcade Downflows — SADs) is still debated. Hinode/XRT has provided a wealth of observations for SADs and helped inform our current understanding of these structures. SADs have been interpreted as wakes behind newly reconnected and outflowing loops (Supra Arcade Downflowing Loops — SADLs). Models have shown the plausibility of this interpretation, though this interpretation has not yet been fully accepted. We present here observations of newly reconnected outflowing loops observed via in situ instruments in the magnetosphere. These observations, provided by five THEMIS spacecraft, show that around retracting loops (dipolarization fronts in this context) similar dynamic temperature and density structures are found as seen in SADs. We compare data from multiple SADs and dipolarization fronts to show that the observational signatures implied in the corona can be directly observed in similar plasma regimes in the magnetosphere, strongly favoring the interpretation of SADs as wakes behind retracting loops.

Comparison of Reconnection in the Regimes (Lin et al 2008):

	B	n_e (cm^{-3})	v_A (km s^{-1})	β
Corona	10^2 G	10^{10}	10^3	$3.5x10^{-3}$
Magnetotail	$2x10^{-4}$ G	0.01	$4.4x10^3$	$8.6x10^{-3}$

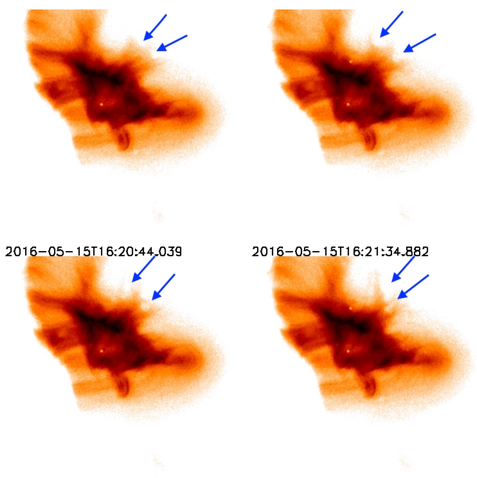
Basic plasma parameters in the Corona and Magnetotail. Numbers taken from Lin et al 2008. While the densities and magnetic fields are drastically different, the Alfvén speeds are similar as are their plasma βs suggesting notable overlap between reconnection occurring in both regimes.



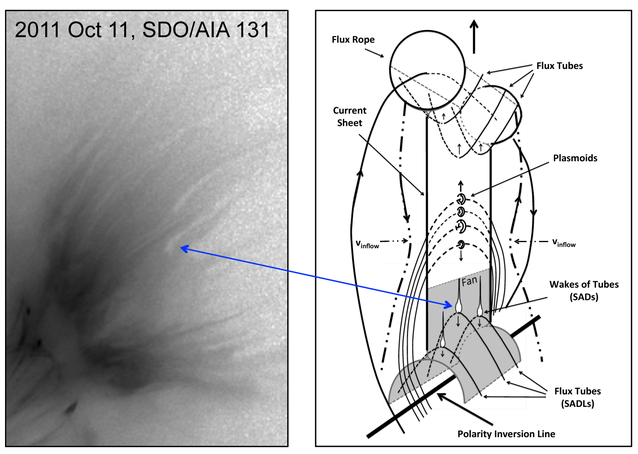


Simplified cartoons comparing the basic 2D geometry in the corona (left) and magnetosphere (above). While the language is different, the systems are notably similar.

Supra Arcade Downflows (SADs) and the Fan:

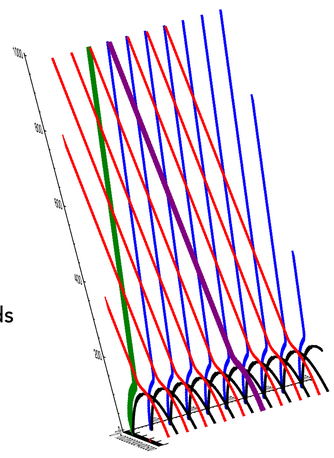


Processed XRT Be_thin images showing density depletions (Supra Arcade Downflows — SADs) descending towards an arcade after a C3.2 flare above the west limb.



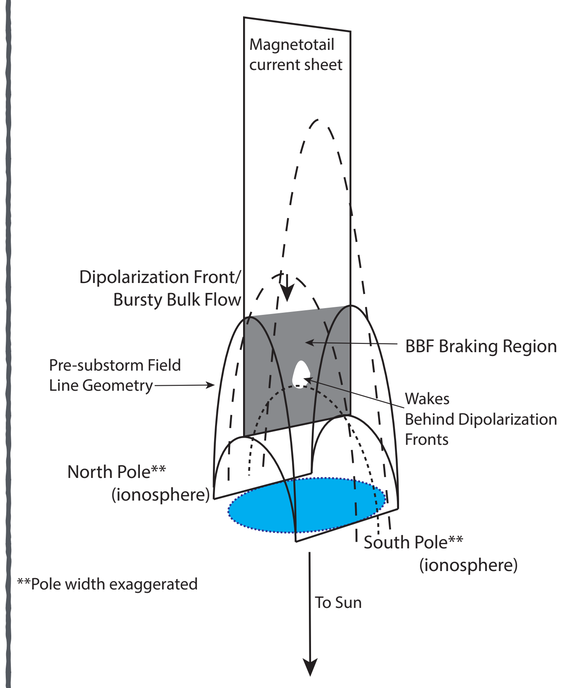
On the left is a reverse-color image of the Supra Arcade Fan, showing the density enhancements around the expected current sheet location, with SADs descending towards the post-flare arcade. On the right is the model from Savage et al. 2012 explaining the SADs as wakes behind retracting reconnection loops. There is still some debate as to whether this interpretation is correct.

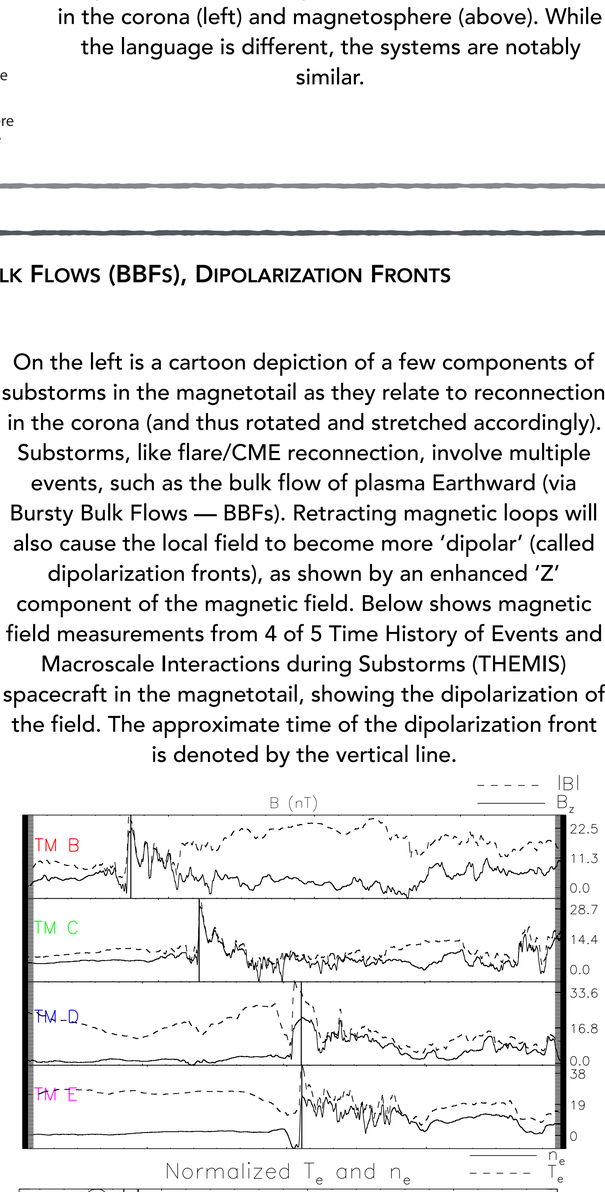
A simple illustration of a supra arcade fan around a current sheet, through which the retracting loops descend. The red indicates field lines of outward directed magnetic field, and the blue lines indicate sunward magnetic field. The fan exists as enhanced plasma density between these two domains. In this particular scheme, the green field line will reconnect with the green field line and retract downwards towards the black arcade, with wakes traveling behind the descending loops.

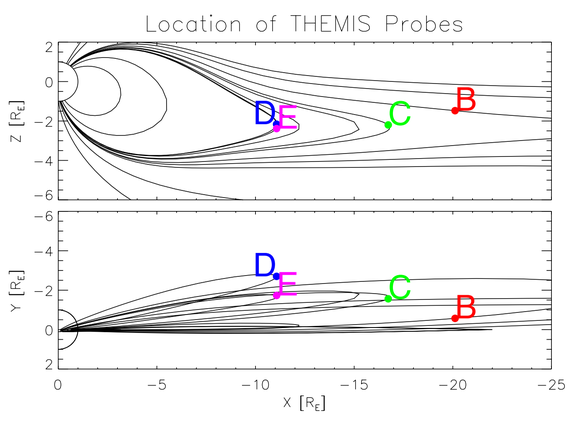


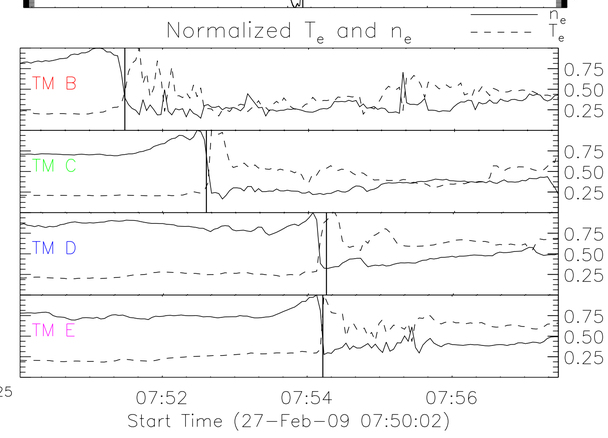
Magnetospheric Substorms, Bursty Bulk Flows (BBFs), Dipolarization Fronts

On the left is a cartoon depiction of a few components of substorms in the magnetotail as they relate to reconnection in the corona (and thus rotated and stretched accordingly). Substorms, like flare/CME reconnection, involve multiple events, such as the bulk flow of plasma Earthward (via Bursty Bulk Flows — BBFs). Retracting magnetic loops will also cause the local field to become more 'dipolar' (called dipolarization fronts), as shown by an enhanced 'Z' component of the magnetic field. Below shows magnetic field measurements from 4 of 5 Time History of Events and Macroscale Interactions during Substorms (THEMIS) spacecraft in the magnetotail, showing the dipolarization of the field. The approximate time of the dipolarization front is denoted by the vertical line.









The above left illustrates the positions of THEMIS probes B, C, D, and E within the magnetotail from the XZ and XY planes (GSM coordinates), with magnetic field lines drawn using the semi-empirical Tsyganenko (1995) model. The right shows the normalized electron temperature and densities for each spacecraft, with the time of the passing dipolarization front noted by the vertical lines. The drop in density behind the retracting field line is similar to the density depletion seen in SADs, though the analysis and comparison is ongoing. Multiple dipolarization events (including the one used here) are noted in Runov et al 2011, with empirical scalings for the plasma surround dipolarizations noted in Runov et al 2015.

Conclusions:

In the Earth's magnetosphere, wakes appear behind dipolarization fronts which are outflowing post reconnection loops retracting through the plasma neutral sheet in the magnetotail (as shown by Runov et al 2011). In simplistic terms, similar wakes should appear behind retracting coronal loops in the Supra Arcade Fan. We conclude that in the corona these wakes are SADs, as described in Savage et al 201X.

We can now inform studies of SADs and retracting loops in the corona with in situ details of retracting loops in the magnetosphere. In particular, we can now better understand the timescales for the density recovery in after the loop retraction, how the temperature recovers, and how these compare to the recovery of the Fan magnetic field. These magnetospheric data can also provide insight into the turbulent scales in reconnection. Further analysis of these data are ongoing, and will also provide a better observational footing for the cross-interpretation of SADs and dipolarization fronts when MMS begins providing data from the magnetotail.

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