Contact info:

Adam Kobelski
adam.kobelski@mail.wvu.edu
To Discuss this here and/or to view movies:
+1 406 624-9858

Supra Arcade Downflows in the Earth's Magnetotail

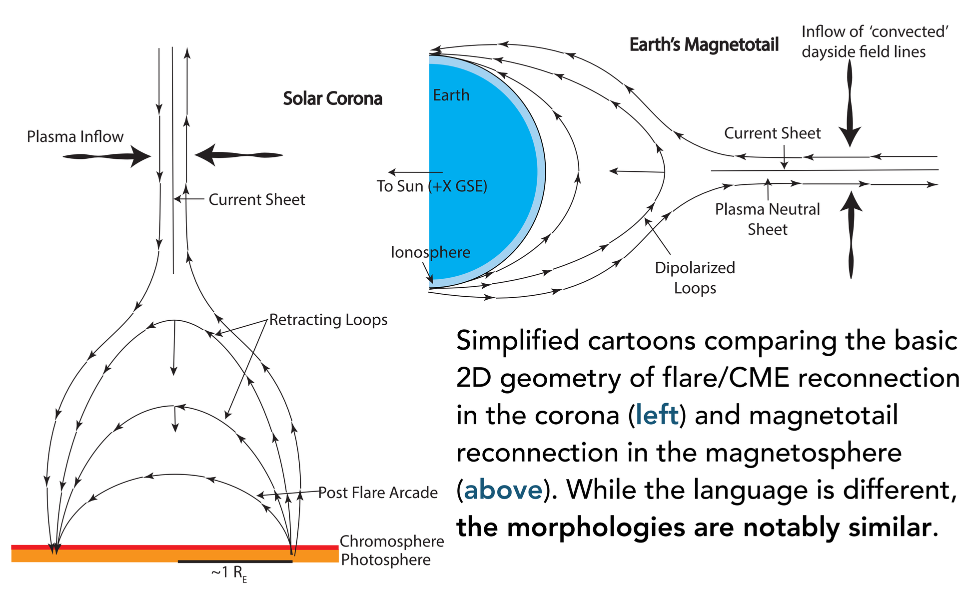
Adam Kobelski[1,2], Sabrina L Savage[3], David M. Malaspina[4]

[1]Department of Physics and Astronomy, West Virginia University, Morgantown, WV, USA
[2]Center for Space Plasma and Aeronomic Research, University of Alabama in Huntsville, Huntsville, AL, USA
[3]Marshall Space Flight Center, Huntsville, AL, USA
[4]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO, USA

Abstract:

Pinpointing the location of a single reconnection event in the corona is difficult due to observational constraints, although features directly resulting from this rapid reconfiguration of the field lines can be observed beyond the reconnection site. One set of such features are outflows in the form of post-reconnection loops, which have been linked to observations of supra-arcade downflows (SADs). SADs appear as sunward-traveling, density-depleted regions above flare arcades that develop during long duration eruptions. The limitations of remote sensing methods inherently results in ambiguities regarding the interpretation of SAD formation. Of particular interest is how these features are related to post-reconnection retracting magnetic field lines. In planetary magnetospheres, similar events to solar flares occur in the form of substorms, where reconnection in the anti-sunward tail of the magnetosphere causes field lines to retract toward the planet. Using data from the Time History of Events and Macroscopic Interactions during Substorms (THEMIS), we compare one particular aspect of substorms, dipolarization fronts, to SADs. Dipolarization fronts are observed as rapid but temporary changes in the magnetic field of the magnetotail plasma sheet into a more potential-like dipolar shape. These dipolarization fronts are believed to be retracting post-reconnection field lines. We combine data sets to show that the while the densities and magnetic fields involved vary greatly between the regimes, the plasma βs and Alfvén speeds are similar. These initial results allow direct comparison between the retracting field lines and their accompanying wakes of rarified plasma observed with THEMIS around the Earth to the observed morphological density depletions visible with XRT and AIA on the Sun. These results are an important source of feedback for models of coronal current sheets.

Comparing The Coronal and Magnetotail Current Sheets:

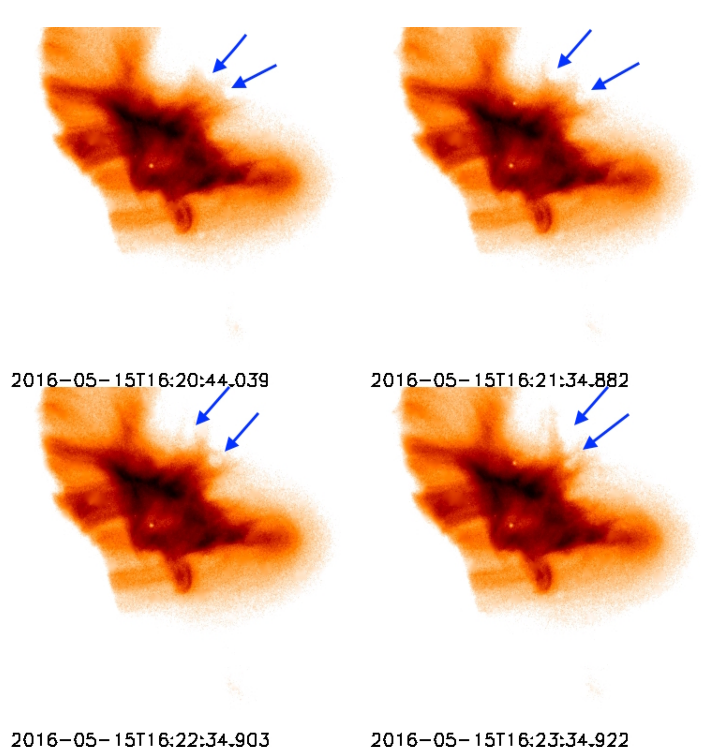


Simplified cartoons comparing the basic 2D geometry of flare/CME reconnection in the corona (left) and magnetotail reconnection in the magnetosphere (above). While the language is different, **the morphologies are notably similar.**

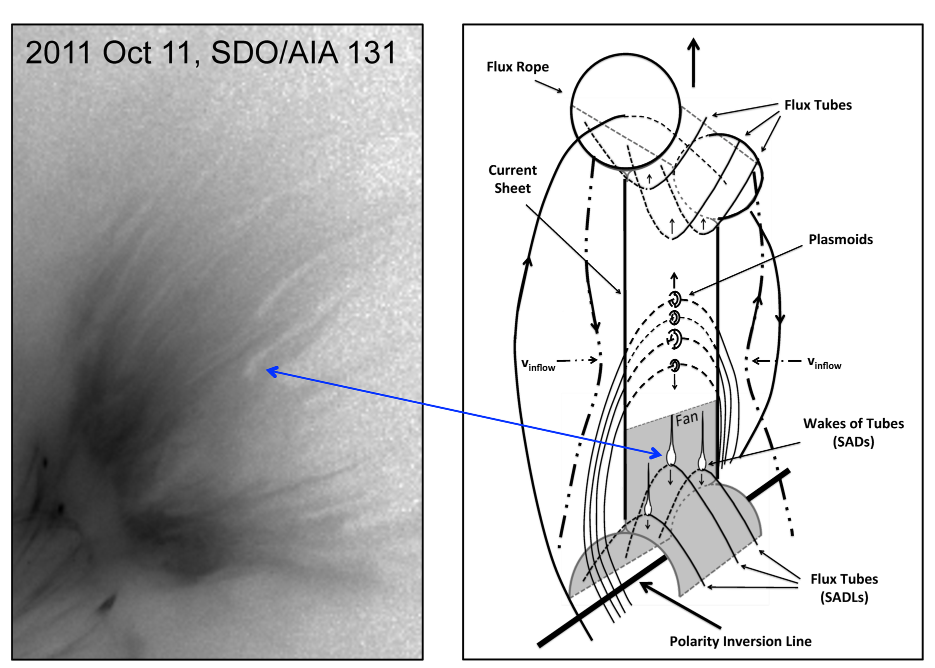
	B (G)	n_e (cm^{-3})	T (MK)	v_A (km s^{-1})	β
Corona	6-10	3×10^9	13	200	8
Magnetotail	10^{-4}	1	12	200	8

Above are basic plasma parameters in the corona and magnetotail. The magnetospheric temperature, densities and magnetic field strengths are from the THEMIS data shown here, the coronal estimates are from McKenzie 2013 and Savage et al 2010. While the densities and magnetic fields are drastically different, the Alfvén speeds and plasma βs are similar **suggesting notable overlap and similarities between the reconnection outflow dynamics in both regimes.**

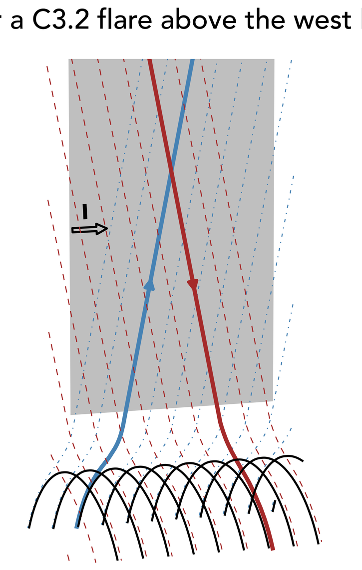
Supra Arcade Downflows (SADs) and the Fan:



Above is a sequence of processed XRT Be_thin reverse-color images showing density depletions (**Supra Arcade Downflows — SADs**) descending towards an arcade after a C3.2 flare above the west limb.

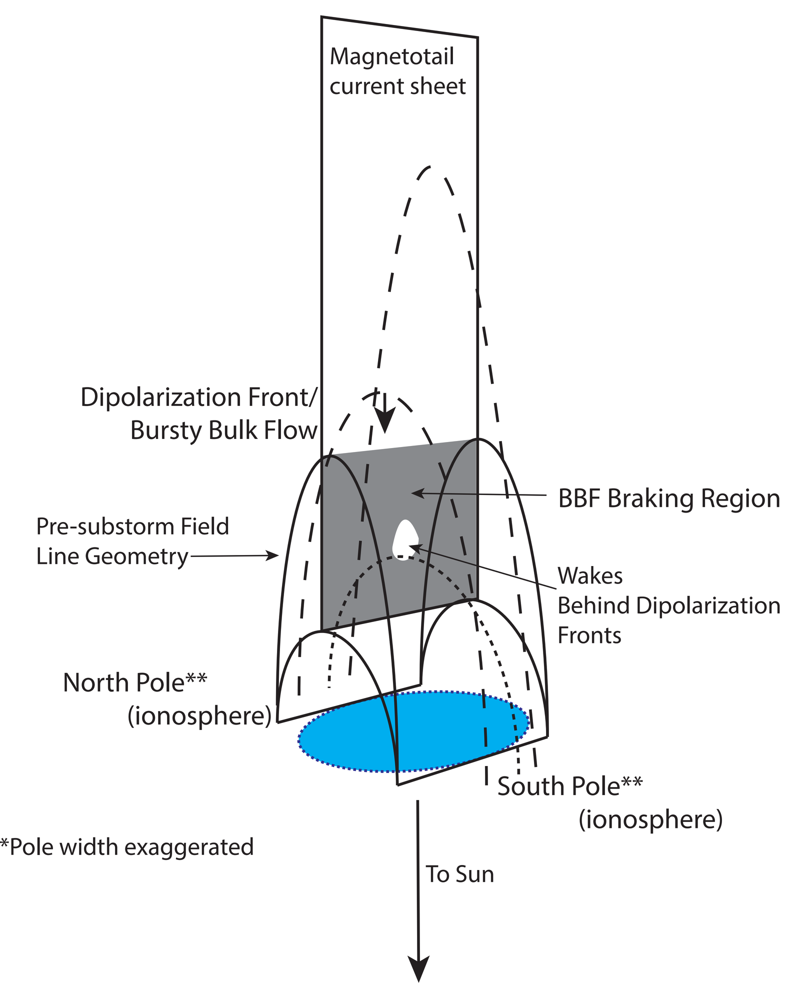


On the above left is a reverse-color image of the Supra Arcade Fan, showing the density enhancements around the expected current sheet location, with SADs descending towards the post-flare arcade. On the above right is the model from Savage et al. 2012 illustrating the **SADs as wakes behind retracting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

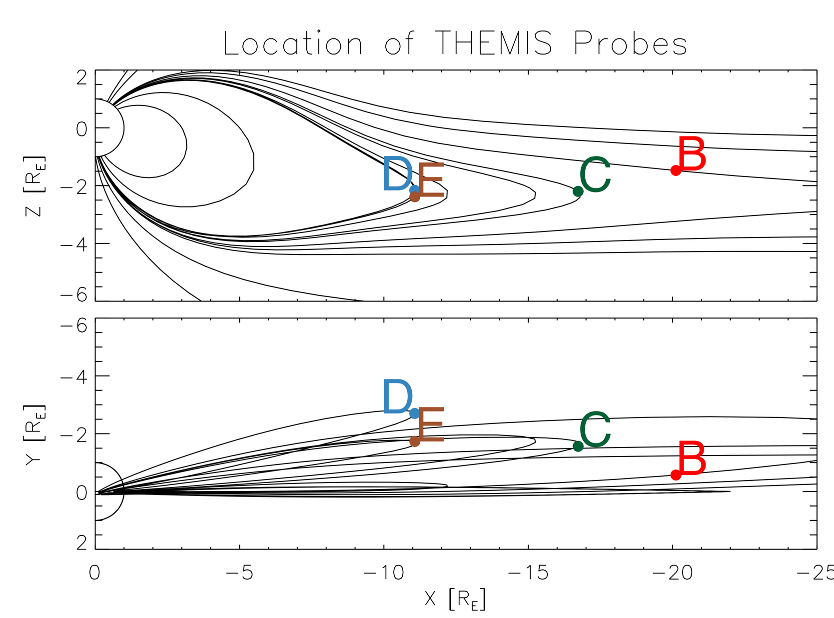


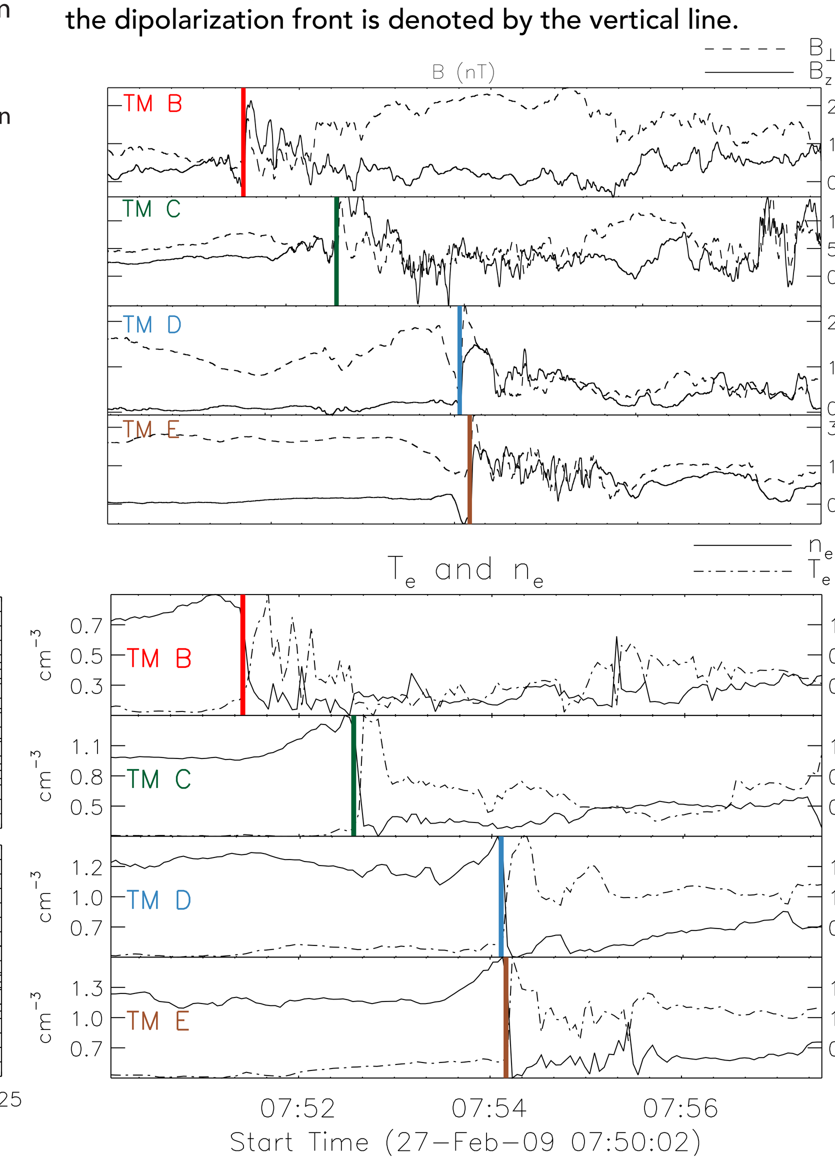
A simple illustration (left) of a supra arcade fan around a current sheet, through which the retracting loops descend. The blue indicates field lines of outward directed magnetic field, and the red lines indicate sunward magnetic field. **The fan exists as the region of enhanced plasma density surrounding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

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



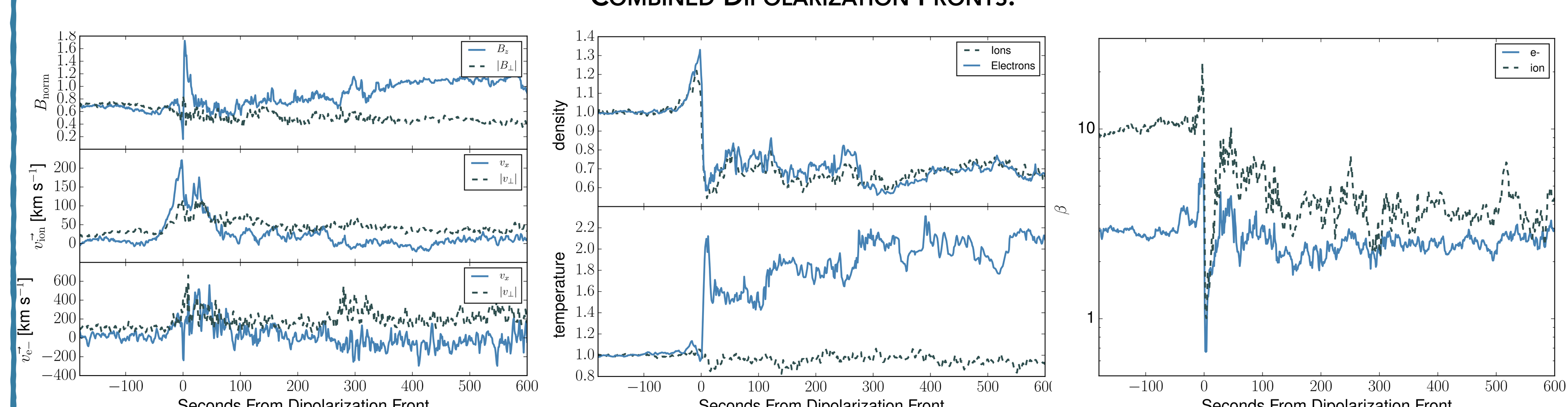
On the left is a cartoon depiction of a few components of substorms in the magnetotail as they relate to reconnection in the corona (and thus rotated and stretched accordingly). Substorms, like flare/CME reconnection, involve multiple events, such as the bulk flow of plasma Earthward (via Bursty Bulk Flows — BBFs). **The retracting magnetic loops cause the local field to become more 'dipolar' (dipolarization fronts)**, which is observed as an enhanced 'Z' component of the magnetic field. Below shows magnetic field measurements (boxcar smoothed) from 4 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 projected onto the XZ and XY planes (GSM coordinates), with magnetic field lines drawn using the semi-empirical Tsyganenko (1995) model. The above right shows the electron temperature and densities for each spacecraft, with the time of the passing dipolarization front noted by the vertical lines. **Behind the retracting field lines are pockets of rarified plasma similar to the density depletions seen in SADs.** 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. As shown in Runov et al 2011, these events can be combined via superposed epoch analysis.

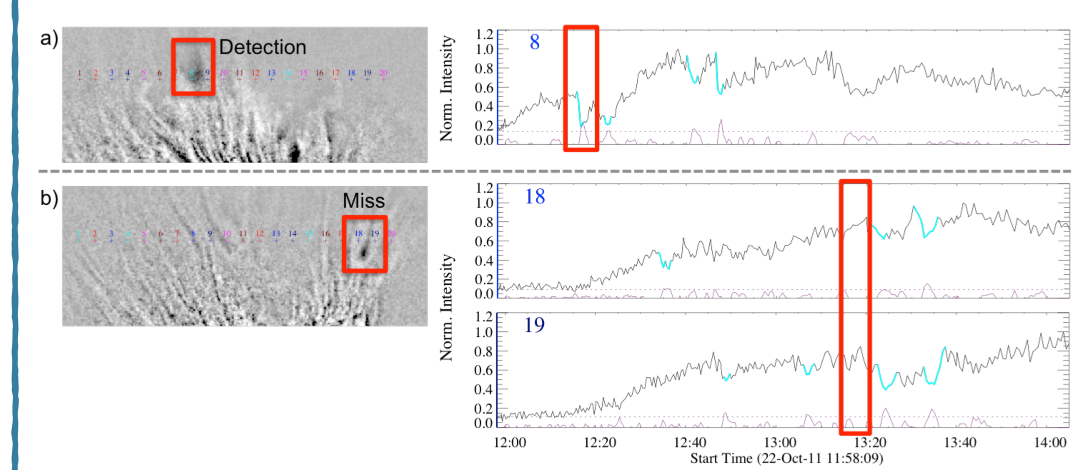
Combined Dipolarization Fronts:



Left shows the median normalized magnetic field (top), ion velocity (middle) and electron (bottom) velocities obtained from superposing 24 dipolarization front observations outlined in Runov et al 2011. The data are aligned to beginning sharp rise in B_Z. The magnetic field (velocity) vectors are split into Z (X) and perpendicular components. The velocity plots show the bulk motion of plasma towards the Earth (+X) ahead of the dipolarization front, followed by a null and a return to pre-front flow. This is suggestive a plow like motion of the plasma around the magnetic field line. The central plot shows the median normalized ion and electron temperatures and densities around the dipolarization front. The density plot clearly shows the bulk removal of plasma from the region after the passing of the dipolarization front. The dipolarization front is accompanied by a large electron temperature enhancement. The right shows the impact of the event on the plasma β for both the electrons and ions, which follow similar trends. The plasma β shows general plasma pressure dominance, except for a period directly around the collapsing field line.

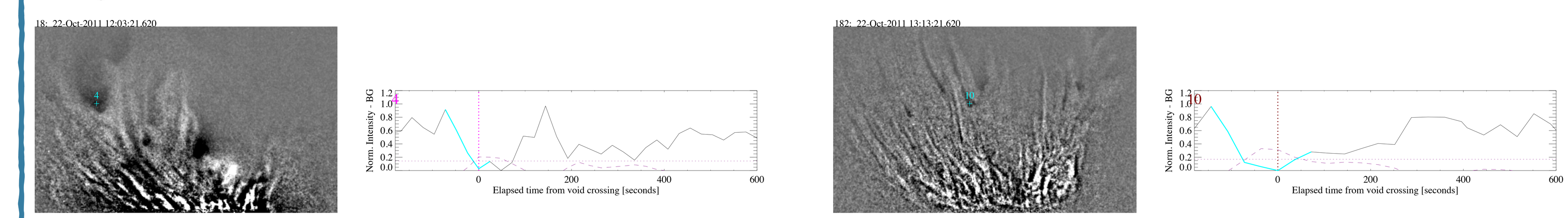
In-Situ SADs:

In order to compare SADs to dipolarization fronts, the remote sensing images are treated as *in situ* data by placing pseudo-sattelites in the path of the downflows. In the case of the 2011 Oct 11 event, ightcurves were derived for 20 distinct locations in the supra-arcade region. The passage of downflows through these "detectors" was automatically detected using a convolution routine. This detection algorithm works well for instances when the detector is hit head on, but has a tendency to miss flows that pass between detector locations, which is a natural consequence of point *in situ* data collection.

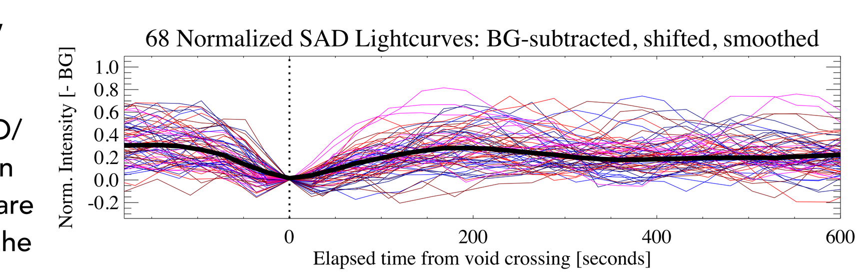


Three of these lightcurves (normalized) are show at left. The top panels (a) provide an example of a well detected downflow through "satellite" no. 8. The bottom panels (b) show an example of a missed detection as the downflow passed directly between two detector locations (nos. 18 & 19). The red boxes overlayed onto the lightcurves indicate the passage times of the flows.

Two example detections are shown below with an extracted lightcurve corresponding to 3 minutes prior to and 10 minutes following the trough crossing. The cyan portion of the lightcurve indicates when the trough was detected. The dashed purple line indicates how well the lightcurve matched the convolution kernel. The dotted horizontal line indicates the detection threshold of the convolution.



Preliminary results from 68 detections are combined in the figure at right. The lightcurves have been normalized, background-subtracted, shifted so that the minimum value within the detected trough corresponds to zero intensity, and smoothed to reduce noise in the signal. These initial results are based on a low-cadence subset of SDO/AIA 131 images. Work is being done to increase the time resolution in order to fully compare to the dipolarization results. Lightcurves that are aligned fully with the downflows are also being processed to reduce the effects from averaging over neighboring plasma sheet dynamics.



Conclusions:

In the Earth's magnetosphere, wakes of rarified plasma 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, McKenzie, and Reeves (2012). In analyzing SAD observations using methods which emulate in-situ observations, similar features are observed between SAD light curves and dipolarization front densities. Notable differences between the light curves exist, some of which are assumed to be due to instrumental differences and differences in the plasma environments, though the exact cause of these discrepancies is not fully understood or characterized.

We now plan to 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 recovery of the temperature, density, and magnetic field after the loop retraction. 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, especially when MMS begins providing data from within the magnetotail. Additionally with the in situ data, we can distinguish between ion and electron effects providing much more insight into the plasma process involved in reconnection.

References:

- Lin, J., S. R. Cranmer, and C. J. Farrugia (2008), Plasmoids in reconnecting current sheets: Solar and terrestrial contexts compared, J. Geophys. Res., 113, A11107, doi:10.1029/2008JA013409.
- McKenzie, D.E. (2013), Turbulent Dynamics in Solar Flare Sheet Structures Measured with Local Correlation Tracking, ApJ, 766, 39M,
- Runov, A., V. Angelopoulos, X.–Z. Zhou, X.–J. Zhang, S. Li, F. Plaschke, and J. Bonnell (2011), A THEMIS multicase study of dipolarization fronts in the magnetotail plasma sheet, J. Geophys. Res., 116, A05216, doi:10.1029/2010JA016316.
- Runov, A., V. Angelopoulos, C. Gabrielse, J. Liu, D. L. Turner, and X.-Z. Zhou (2015), Average thermodynamic and spectral properties of plasma in and around dipolarizing flux bundles, J. Geophys. Res. Space Physics, 120, 4369–4383, doi:10.1002/2015JA021166, DOI: 10.1088/0004-637X/766/1/39
- Savage, S. L., D. E. McKenzie, K.K. Reeves, Re-interpretation of Supra-Arcade Downflows in Solar Flares, ApJL, 747, L40, doi: 10.1088/2041-8205/747/2/L40
- Savage, S. L., G. Holman, K.K. Reeves, D. B. Seaton, D. E. McKenzie, Y. Su (2012), Low-Altitude Reconnection Inflow-Outflow Observations During a 2010 November 3 Solar Eruption, ApJ, 754, 13, doi:10.1088/0004-637X/754/1/13
- Tsyganenko, N. A. (1995), Modeling the Earth's magnetospheric magnetic field confined within a realistic magnetopause, J. Geophys. Res., 100, 5599, 94JA03193, doi: 10.1029/94JA03193