

Supra-Arcade Downflows: Results from Observational Analysis

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Abstract.

Downward motions above post-CME flare arcades are an exciting discovery of the *Yohkoh* mission, and have subsequently been detected with TRACE, SOHO/LASCO, SOHO/SUMER, and GOES/SXI. These “supra-arcade downflows” have been interpreted as outflows from flux tube reconnection, consistent with a 3D generalization of the standard reconnection model of solar flares. We will present results from our observational analyses of downflows, including measured speeds and other aspects related to 3D patchy reconnection. We will also indicate the limitations of present observations, and motivations for utilizing the Solar-B instruments for measurements of these reconnection signatures.

1. Introduction

Supra-arcade downflows (SADs), as the name implies, are downward-moving features observed in the hot, low-density region above post-eruption flare arcades. Initially detected with *Yohkoh* SXT as X-ray-dark, blob-shaped features (Figure 1; see McKenzie and Hudson, 1999), downflows have since been observed with TRACE (e.g., Innes et al., 2003; Asai et al., 2004), SOHO/SUMER (Innes et al., 2003), and SOHO/LASCO (Sheeley and Wang, 2002). The darkness in X-ray and EUV images is due to very low plasma densities, i.e., plasma voids (Innes et al., 2003). [We note additionally that McKenzie (2000) reports faint X-ray-emitting shrinking features in several flares; in our catalog of 40 SAD flares observed by SXT and TRACE, approximately half display such bright shrinking features alongside dark SADs.]

The downflows are traced by discrete X-ray and EUV features with a characteristic size. When interpreted as the outflow of magnetic flux from a reconnection site (see Figure 2, from McKenzie, 2002; see also Sheeley et al., 2004), these tracers strongly suggest that the reconnection takes place between discrete collections of magnetic flux, e.g., flux tubes. Such a conclusion indicates “patchy” 3D reconnection. While the observed speeds of tens-to-hundreds of km/s are slower than initially expected, recent models of 3D patchy reconnection suggest that these low speeds are not insurmountably problematic (Linton & Longcope, 2005; see also Linton’s article in these Proceedings).



Figure 1. Late stages of the 20 January 1999 flare in which supra-arcade downflows were first discovered. The white arrow is fixed at the location of a plasma void at 11:48:11 UT. The black arrow follows the same feature to its location at later times.

Much can be learned from quantitative measurements of downflows. Knowing the characteristic size may help to estimate the magnetic flux in individual flux tubes, and therefore the amount of flux that participates in a typical magnetic reconnection episode. And as we show below, determining the path of the downward motion yields an estimate of the energy released in the shrinkage.

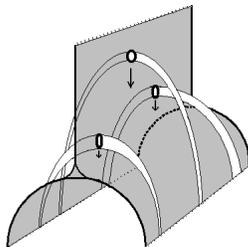


Figure 2. Cartoon depiction of supra-arcade downflows resulting from patchy reconnection. Discrete flux tubes are created, which then individually shrink, dipolarizing to form the post-eruption arcade.

Nearly 40 observations of downflows have been catalogued with SXT, dating back to 1991. Since the end of the *Yohkoh* mission, TRACE has detected SADs in several flares, LASCO sees very similar flows much higher in the corona, and SXI frequently detects motions which resemble downflows. It is certain that Solar-B XRT will also observe downflows in eruptive flares. To the extent that these flows can help us to understand the circumstances of reconnection, the capabilities of XRT will provide an avenue to information about conditions in the magnetic diffusion region.

2. Analysis of Solar Flare Data

At Montana State University, we are developing automated software for objective detection and measurement of SADs. Testing of the software will be described in a future paper; in these Proceedings we describe only the applica-

tion of the software to image sequences from two of the best-known SAD flares. The 21 April 2002 flare was observed by TRACE (Figure 3a), RHESSI, SOHO, and numerous other observatories (e.g., Wang et al., 2002; Innes et al., 2003). The 20 January 1999 flare was observed by *Yohkoh* SXT, and was the discovery event for downflows (Figure 1).

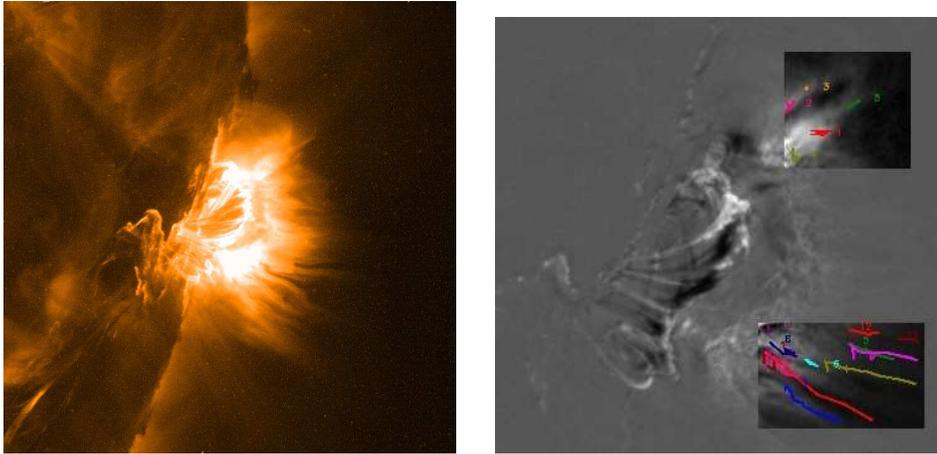


Figure 3. (a) The famous 21 April 2002 flare revealed SADs in TRACE images for the first time, and represents one of the sharpest observations of downflows. (b) Downflows detected in the 21-Apr TRACE data, as tracked by the automated routine.

2.1. TRACE, 21 April 2002

In the TRACE data from 21 April 2002, the detection routine successfully tracked 15 downflowing voids, though several more are visible in the raw data. Adjustment of the detection thresholds may allow tracking of some voids that were missed. The trajectories of the detected downflows are plotted in Figure 3b, for two regions above the northern and southern ends of the arcade. Speeds of the downward motions range from 12 to 470 km/sec; the distribution peaks near 100 km/sec.

2.2. SXT, 20 January 1999

In the SXT data from 20 January 1999, the detection routine tracked 13 downflowing voids, though again an additional few are visible in the raw data. In this case, the most likely explanations for non-detection are related to the faintness of the features amid the very noisy background, or to the fact that several downflows only appear in three successive frames (the program requires 5 for reliability in excluding false positives and for fitting the trajectory polynomial). Speeds ranging from 19 to 180 km/s were found.

3. Discussion

The supra-arcade downflows are important signatures of reconnection in flares (McKenzie, 2002; Asai et al., 2004). As tracers of outflow, they carry infor-

mation about the parameters of 3D patchy reconnection, including the size of participating flux tubes, and therefore the size of the localized diffusion region. This work demonstrates that quantitative information can be derived via the application of objective, automated algorithms to movies of these velocity fields.

As a simple example, we consider that as a flux tube undergoes shrinkage by an amount δL , the energy lost is given by $\delta W = B^2 A \delta L / 8\pi$, where A is the cross-sectional area of the flux tube. From our measurements, we estimate some typical values as $\delta L \sim 1 - 5 \times 10^9$ cm; $A \sim 2 \times 10^{17}$ cm². With B on the order of 10 G, the energy liberated is on the order of 10^{27} ergs per shrinkage event. In the two flares analyzed here, these shrinkages would correspond to energies of 10^{28} ergs. Or if $B = 50$ G, the total energy would be 10^{29-30} ergs for each flare.

To date, SADs have been observed with SXT more often than in the TRACE data. This is no doubt due to the full-Sun field of view of SXT as well as its sensitivity to hotter plasmas—the supra-arcade region is typically very hot, and the dark SADs are easier to see against a bright background. However, most of the SADs were observed with SXT’s half-resolution (5 arcseconds per pixel), so that the smallest features could never be detected. While TRACE offers much higher angular resolution, the cadence of TRACE images is slow enough to allow some fraction of flows—particularly the faster ones—to go undetected. In some cases, the cadence of SXT images was even too slow, so that motions faster than 700 km/s would have been unobservable (McKenzie, 2000). The sharper angular resolution of Solar-B XRT (compared to SXT), the range of XRT’s temperature sensitivity, and the large field of view, will extend our knowledge of the characteristics of SADs beyond the capabilities of SXT and TRACE. Sensitivity to the faint, hot plasmas in the supra-arcade region will allow more precise determination of the height of the reconnection region above the Sun’s limb, thus enabling better estimates of δL , while it is likely that XRT’s cadence and sensitivity will also make it possible to observe faster motions more reliably.

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