Exploring the Nature of Small-scale Eruptions that Make Coronal Jets in the Sun's Atmosphere

THE COLLEGE OF WOOSTER

Allison M. Knott[1]; Alphonse C. Sterling[2]; Ronald L. Moore[2,3]; Navdeep K. Panesar[4,5]; David Falconer[2,3]

[1]The College of Wooster, Wooster, OH 44691, USA, [2]NASA/Marshall Space Flight Center, Huntsville, AL 35812, USA, [3]Center for Space Plasma and Aeronomic Research, University of Alabama in Huntsville, Huntsville, AL 35805, USA, [4]Lockheed Martin Solar and Astrophysics Laboratory, 3251 Hanover Street, Building 252, Palo Alto, CA 94304, USA,[5] Bay Area Environmental Research Institute, NASA Research Park, Moffett Field, CA 94035, USA

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

Center for Space Plasma and Aeronautics Research

Overview and Chief Findings

Solar coronal jets are transient (~10--20 min), narrowly collimated (~10,000 km wide and reaching ~50,000 km length) plasma outflows, frequently observed in X-rays and extreme ultraviolet (EUV), that originate in a bright jet-base location, called a jet bright point (JBP), near the photosphere and extend in the form of a spire into the corona (Shibata et al. 1992, Raouafi et al. 2016). Jet spires tend either to remain much narrower than the extent of the base, or to grow to be comparable to the size of that base. Moore et al. (2010) called the X-ray-observed narrow and wide spire jets "standard" (Figure 1b) and "blowout" (Figure 1a) jets, respectively. Many, if not most or all, coronal jets result from miniflament eruptions (MFEs), which are a smaller-scale version of the filament eruptions that produce solar flares and initiate coronal mass ejections (Sterling et al. 2015). Analogous to the large-scale eruptions, MFEs can be either confined or ejective, based on whether the erupting minifilament stays largely confined to the base or erupts outward into the far corona.

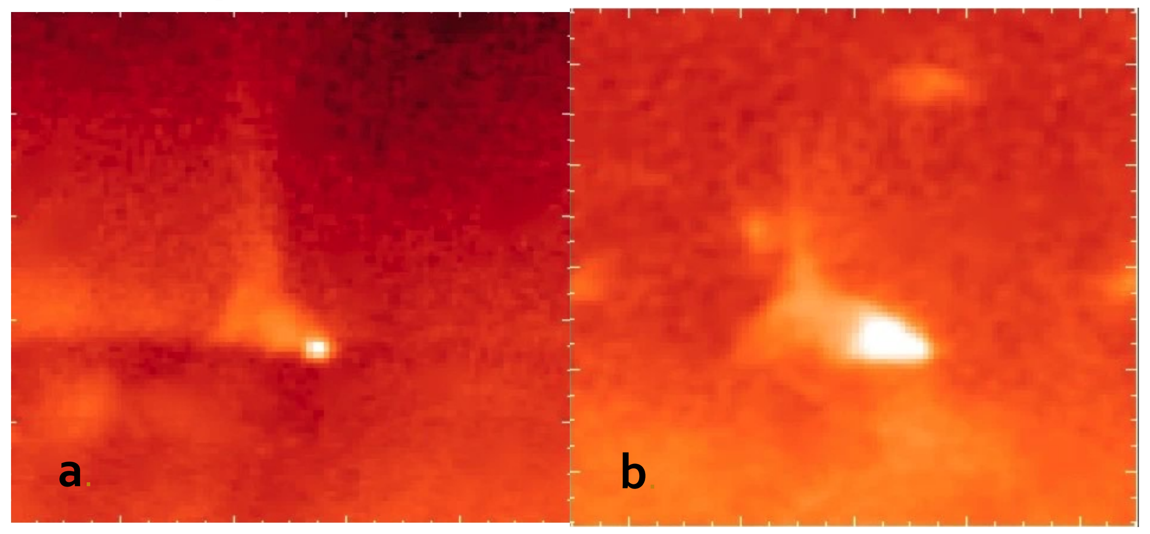

Figure 1. Jets #18 (a) and #7 (b) from Table 1. These are X-ray images from HINODE XRT, with each panel 100X100 arcseconds. Jet #18 is centered at (30,950), and jet #7 is centered at (-80,840). Jet #18 was identified as blowout because compared to its base width its spire is relatively wide (~50%). Jet #7 is identified as "standard" because its spire narrow compared to its base's width (~10%).

An early hypothesis was that standard jets result mainly from confined MFEs and blowout jets from ejective MFEs (Sterling et al. 2015). To test this idea, using Solar Dynamics Observatory's (SDO) Atmospheric Imaging Assembly (AIA) 171, 193, 211, and 304 Å images we looked at the 20 jets from 2010 studied by Sterling et. al. (2015), consisting of 14 blowout and 5 standard jets (one jet was uncertain). We found for blowout jets, 8 originate from ejective MFEs, 2 from confined MFEs, and for the remaining 4 blowout jets it was unclear whether the MFE was confined or ejective. For the standard jets, we found one to originate from a confined MFE and 4 to be unclear. We concluded that there is not a strong correlation between wide/narrow X-ray-jet spires and whether the MFE is confined or ejective, and thus the dynamics of how spires are formed from MFEs may be more complex than originally presumed. Sterling et al. (2022) reached a similar conclusion with a different set of jets.

Methods

The jets used in this research were originally discovered in X-ray and AIA 304 wavelengths by Moore et al. (2013). Sterling et al. (2015) looked at these jets in additional AIA channels and found that they resulted from MFEs. The X-ray movies were used to determine the coordinates, time range, and spire type of each jet. A jet was determined to be blowout if its spire, visible in x-ray, was at least half as wide as the base, like jet #18 (Figure 1a). A jet was determined to be standard if its x-ray visible was less than about half its base width, like jet #(Figure 1b). Data were taken from SDO AIA in 171, 193, 211, and 304 Å, with cadence of 12 s over the course of 60 minutes around the time that the JBP appeared in X-rays, with a field of view of at least '100X100 arcseconds. The data were processed into movies which were analyzed by-frame to look for the filaments and track their movement within or out of the jet base. Using the AIA data, we determined the MFE to be in one of 3 categories similar to Sterling et al. (2022): Confined, ejective, and ambiguous.

We defined **confined** as: having a majority of the filament remaining confined to the base during the eruption**;** **ejective** as: having a majority of the filament ejected from the base; and **ambiguous** as: any MFE that was too unclear to determine or showed traits of both confined and ejective

Data Set and Examples

Of the 20 jets, 8 of them were found to have minifilament eruptions that didn't fit the criteria of ejective or confined. These ambiguous MFEs often heat up the filament before it visibly leaves the arcade or appears to "evaporate" or fade shortly after it erupts. The large number of these ambiguous MFEs leads us to suspect that the eruption process may be more complicated than we initially imagined, especially in relation to how jet spires form. Despite this overwhelming evidence of a more complex relationship, it is still worth evaluating the original question: Do blowout jets result from ejective MFEs and standard jets result from confined MFEs? The blowout jet sample was found to have 7 clearly ejective MFEs, 2 confined, and 5 unclear. The set of standard jets had no clearly ejective MFEs, 1 confined, and 4 ambiguous.

#	Spire Type	EMF Type	Date	Start; End
1	Blowout	Ambiguous	Jul 24	15:56; 16:15
2	Blowout	Ambiguous	Jul 25	12:29; 12:46
3	Blowout	Ejective	Aug 26	14:13; 14:16
4	Standard	Ambiguous	Aug 27	11:35; 12:17
5	Standard	Ambiguous	Aug 27	11:40; 12:20
6	Standard	Ambiguous	Aug28	11:40; 12:03
7	Standard	Confined	Aug 28	13:41; 13:48
8	Blowout	Confined	Sep 05	21:14; 21:35
9	Blowout	Ejective	Sep 08	01:29; 01:44
10	Blowout	Confined	Sep 09	20:14; 20:33
11	Ambiguous	Ejective	Sep 09	20:21; 20:40
12	Blowout	Ambiguous	Sep 09	22:05; 22:31
13	Blowout	Ejective	Sep 09	23:52; 00:06
14	Blowout	Ejective	Sep10	00:01; 00:09
15	Blowout	Ejective	Sep 11	00:39; 00:50
16	Blowout	Ejective	Sep 11	01:08; 01;27
17	Blowout	Ambiguous	Sep 17	20:39; 21:08
18	Blowout	Ejective	Sep 17	22:08; 22:18
19	Standard	Ambiguous	Sep 19	19:47; 20:23
20	Blowout	Ejective	Sep 27	00:29; 00:43

Table 1. Jet spire and EMF Type of all 20 jets. All jets occurred in 2010

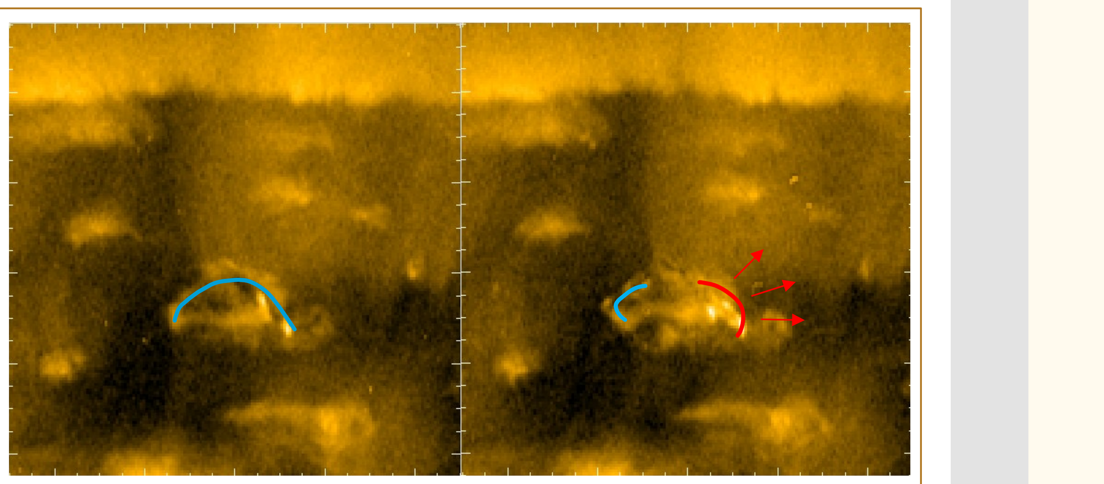

Figure 2. Jet #12 18 in 171 Å at 2 timestamps. Scale is 100 by 100 arcseconds centered around (0,+925). Timestamps are 22:06 (left) and 22:09 (right). The minifilament is clear and visible at the first timestamp (blue), however its right limb appears to "evaporate" after it erupts (red).

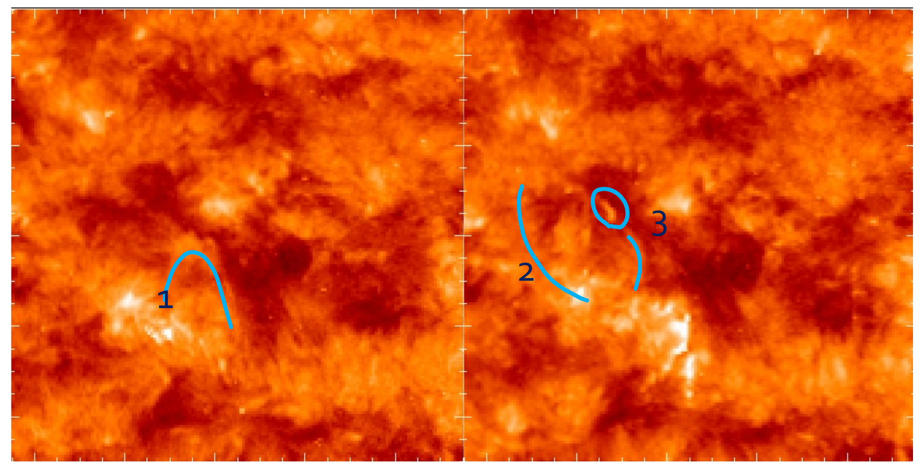

Figure 3. Jet #10 in 304 Å at 2 timestamps. Scale is 100 by 100 arcseconds centered at (+25,+800). Timestamps are 20:15 (left) and 20:19 (right). The minifilament arch is shown in blue (1) as it erupts into 2 distinct limbs. The larger left limb collapses downwards remaining within the jet base (2), while the right limb is flung possibly out of the base (3), though it does not leave the arcade until after 20:20.

Summary and Discussion

Both confined and ejective MFEs can make either narrow- or wide-spire jets, depending on circumstances (likely the magnetic environment).The fundamental point is that essentially all jets in our study apparently result from an MFE. An erupting minifilament could be clearly identified in 19 of our 20 cases. In one case, Jet #5, the identification was, but the event was still consistent with the jet resulting from a small-scale eruption, but perhaps one lacking enough cool material to appear as a clear erupting minifilament (cf. Kumar et al. 2019).

However, it is clear that many jets had MFEs that were either too hazy to define or had traits of both ejective and confined. A brilliant example of such blending is jet #12 (Figure 2) which shows, as the filament erupts, the left limb of the filament stays confined to the base, however the right limb almost seems to dissipate making it hard to determine how to classify such an MFE.

While some MFEs were classified as confined or ejective, most had features that may indicate a more complicated "evolution" of the eruption. Jet #10 was classified as confined due to the filament staying confined throughout the period of time that the jet spire was visible; however, the filament is ejected after the spire formation and dissipation (Figure 3). Its filament, visible most easily in 304 Å, clearly matches the confined MFE definition until 20:22 when the filament seems to be ejected after the spires brightest period at 20:20. These jets' complex structure and evolution point towards there being more elaborate dynamics of how spires are formed from MFEs and indicate that the confined/ejective classification of MFEs may be overly simplistic.

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Acknowledgements

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