Another Look at Erupting Minifilaments at the Base of Solar X-Ray Polar Coronal “Standard” and “Blowout” Jets

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Abstract

We examine 21 solar polar coronal jets that we identify in soft X-ray images obtained from the Hinode/X-ray telescope (XRT). We identify 11 of these jets as blowout jets and four as standard jets (with six uncertain), based on their X-ray-spire widths being respectively wide or narrow (compared to the jet's base) in the XRT images. From corresponding Extreme Ultraviolet (EUV) images from the Solar Dynamics Observatory's (SDO) Atmospheric Imaging Assembly (AIA), essentially all (at least 20 of 21) of the jets are made by minifilament eruptions, consistent with other recent studies. Here, we examine the detailed nature of the erupting minifilaments (EMFs) in the jet bases. Wide-spire ("blowout") jets often have ejective EMFs, but sometimes they instead have an EMF that is mostly confined to the jet's base rather than ejected. We also demonstrate that narrow-spire ("standard") jets can have either a confined EMF, or a partially confined EMF where some of the cool minifilament leaks into the jet's spire. Regarding EMF visibility: we find that in some cases the minifilament is apparent in as few as one of the four EUV channels we examined, being essentially invisible in the other channels; thus it is necessary to examine images from multiple EUV channels before concluding that a jet does not have an EMF at its base. The size of the EMFs, measured projected against the sky and early in their eruption, is $14'' \pm 7''$, which is within a factor of two of other measured sizes of coronal-jet EMFs. A full report on these results are available in Sterling et al. (2022, ApJ, 927, 127).

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Solar Coronal Jets

Solar coronal jets are geyser-like columns of plasma that shoot out from near the Sun's surface into the corona, mainly observed in soft X-ray (SXRs) and EUV images (e.g., Shibata et al. 1992, Yokoyama & Shibata 1995, Nisticò et al. 2009, Cirtain et al. 2007).

A jet is composed of a base region, and a spire that extends from that base into the corona. Typically the base is brighter than the spire, and often one side of the base is much brighter than the rest of the base (Shibata et al. 1992). From Savcheva et al. (2007), typical polar coronal hole SXR jets have lifetimes of around 10 min, lengths of 50,000 km, widths of 8000 km, outward velocities of 160 km/s, lateral velocities ranging over 0—35 km/s, and they have an occurrence rate of about 60/day in the two polar coronal holes.

Some reviews of coronal jets: Raouafi et al. (2016), Hinode Review Team et al. (2019), Shen (2021), Schmieder (2022).

The Cause of Solar Coronal Jets

Several studies show that jets form in response to the eruption of a small-scale filament, or minifilament; this was shown in several early case studies (e.g. Shen et al 2012, Adams et al. 2014). Sterling et al. (2015) argued that most (if not all) jets result from from minifilament eruptions; they found the length of the erupting minifilament to be about 10,000 km, and so substantially smaller than typical filament lengths of ~30,000—100,000 km.

The cause of the minifilament eruption is, at least in many cases, magnetic flux cancelation, likely leading to magnetic reconnection: E.g., Panesar et al. (2016), McGlasson et al. (2019), Muglach (2021) (Kumar et al. 2019, however, argue that shearing and/or field rotation may be more important than cancelation in many jets.)

A series of numerical simulations supports the basic concept of the minifilament-eruption model (e.g., Wyper et al. 2017).

Coronal Jet in X-rays (Hinode/XRT) and in EUV (SDO/AIA)

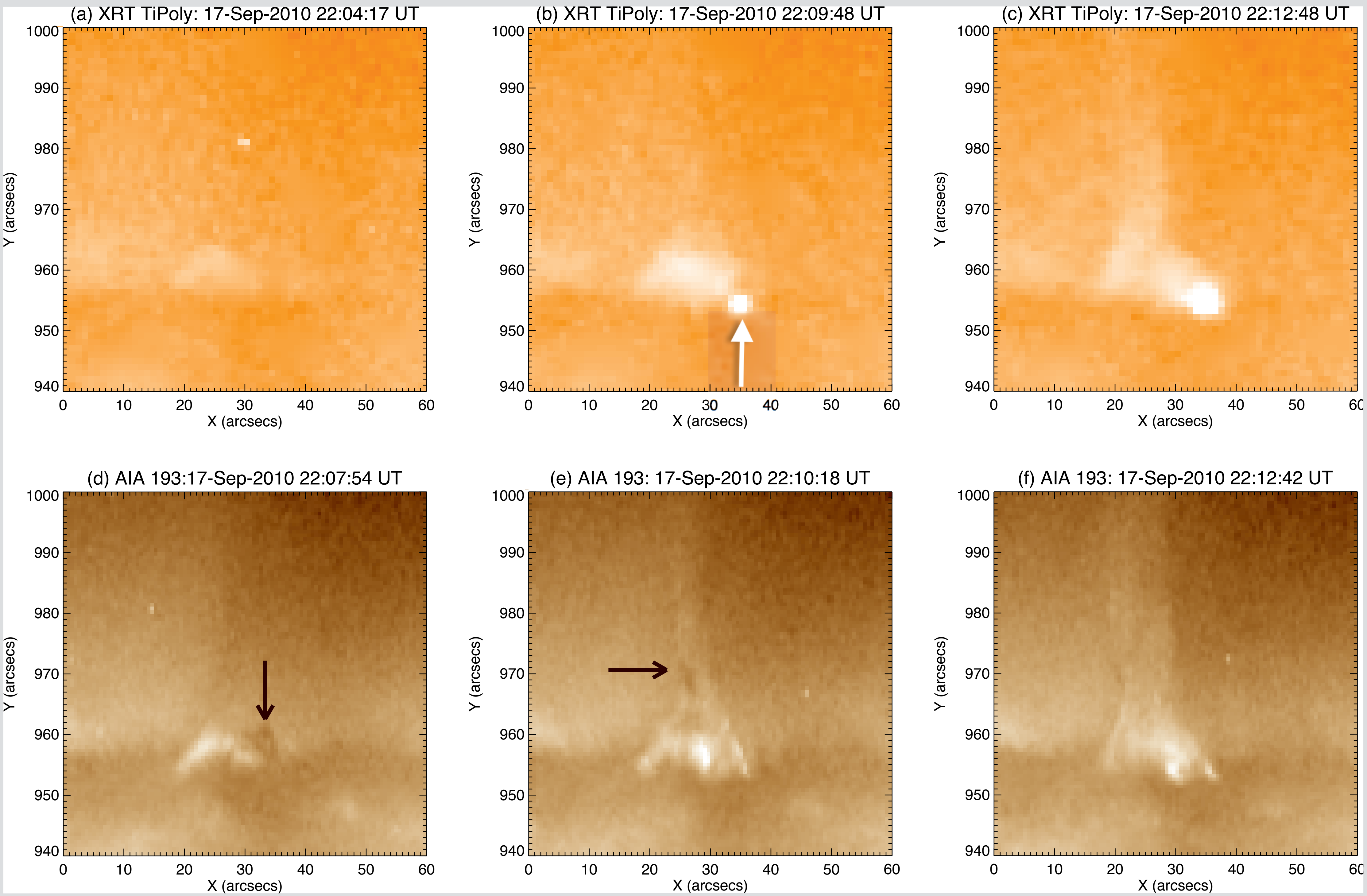

Figure 1. Coronal jet in X-rays from Hinode XRT (top three panels), and the same jet from SDO/AIA (bottom three panels). The arrow in (b) shows the jet bright point (JBP), that often appears off to one side of the jet-spire's base. The arrows in (d) and (e) show that a minifilament erupts from the location where the JBP occurs. (From Sterling et al. 2015.)

Minifilament-Eruption Model for Coronal Jets

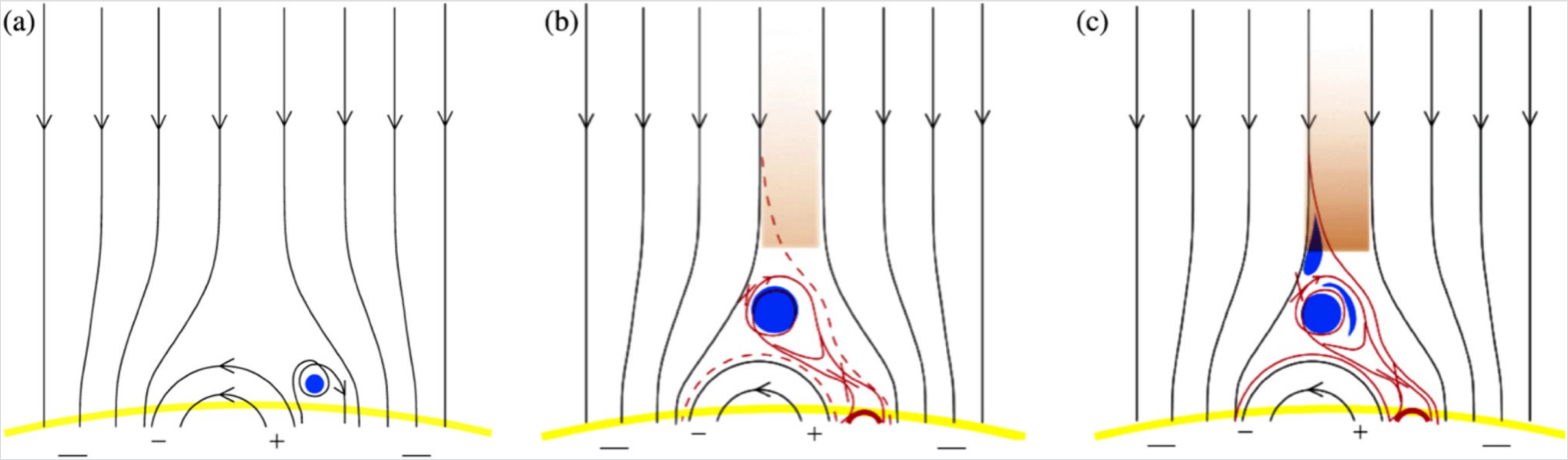

Figure 2. Schematic showing jet generation via a "minifilament eruption model," as proposed in Sterling et al. (2015). This version of the schematic appeared in Sterling et al. (2018), and includes an adjustment due to Moore et al. (2018). (a) Cross-sectional view of a 3D positive-polarity anemone-type field inside of a majority negative-polarity ambient field (which we assume to open into the heliosphere). One side of the anemone is highly sheared and contains a minifilament (blue circle). (b) Here the minifilament is erupting and undergoing reconnection in two locations: (1) internal ("tether-cutting" type) reconnection (larger red cross), with the solid red lines showing the resulting reconnected fields; the thick red semicircle represents the "jet bright point" (JBP) at the jet's base; and (2) external (a.k.a. "interchange" or "breakout" reconnection) occurs at the site of the smaller red cross, with the dashed lines indicating its two reconnection products. (c) If the external reconnection proceeds far enough, then the minifilament material can leak out onto the open field. Shaded areas represent heated jet material visible in X-rays and some SDO/AIA EUV channels as the jet's spire. See, e.g., Sterling et al. (2015) or Moore et al. (2018) for a more detailed description. Wyper et al. (2017) simulate this process.

Coronal Jets and Spire Widths: “blowout” and “standard” jets

From observations of polar coronal hole X-ray jets, using Hinode/XRT images, Moore et al. (2010, 2013) found that jets generally fall into one of two categories, based on the width of their spires compared to the jet-base width. Narrow-spire jets have spires that remain narrow compared to the base size for the duration of the jet; these are called “standard jets.” Wide-spire jets have spires that grow to be about as wide as the base; these are called “blowout jets.”

The origin of the names “standard jet” and “blowout jet” are historical, and depend on subtleties on how the jets were believed to be formed at the time of the Moore et al. (2010, 2013) papers. This history is detailed in Sterling et al. (2022). For this poster however, we will just define the two varieties in this way: when observed in SXRs, **“standard jets” are those where the spire remains narrow** compared to the base base’s size, and **“blowout jets” are those where the spire grows to be wide** compared to the jet base’s size.

Standard (left) and Blowout (right) Coronal X-ray Jets

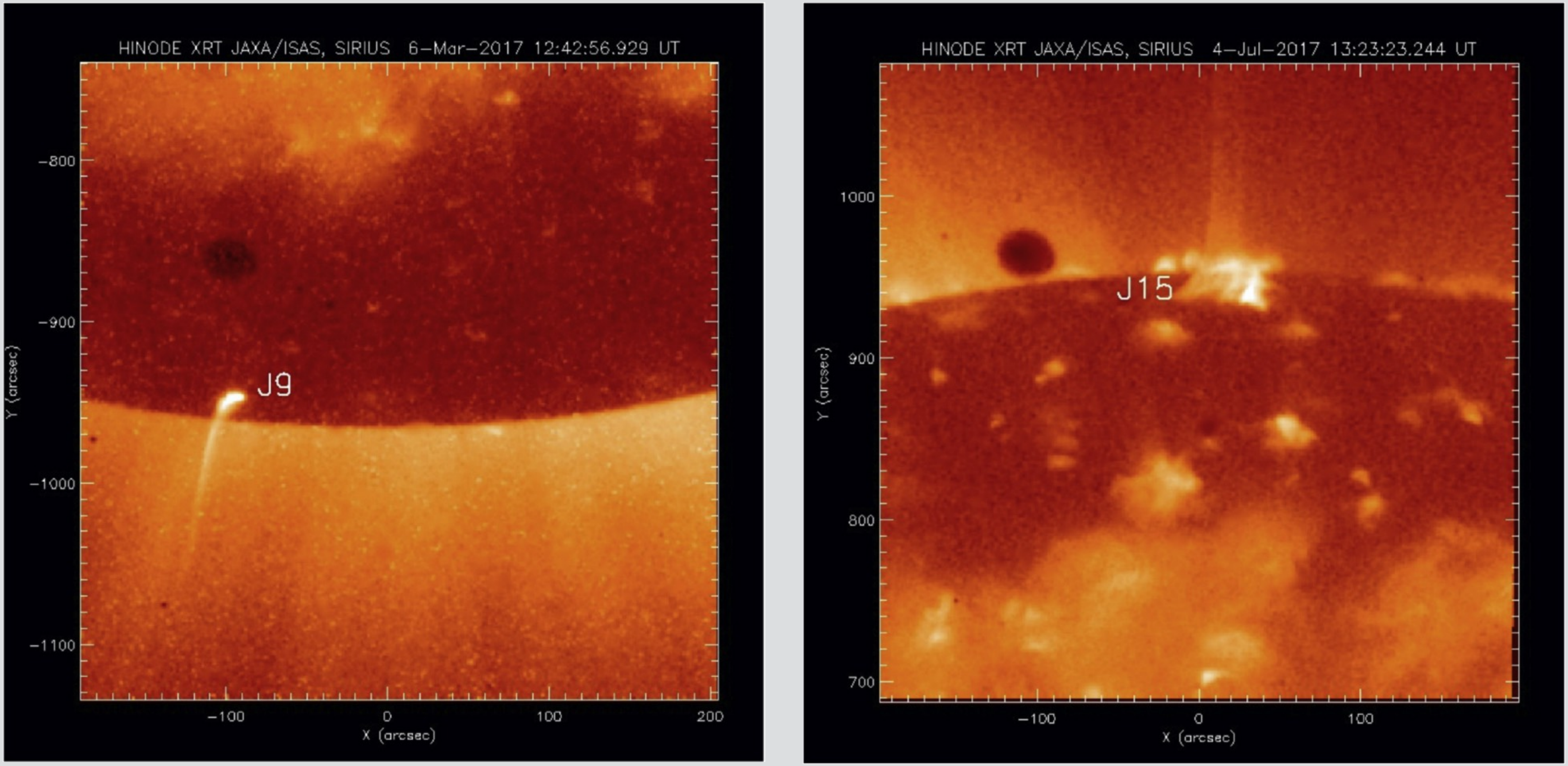

Figure 3. Examples of a standard (left) and blowout (right) coronal X-ray jet, from Hinode/XRT. These are from a study of Sterling et al. (2022). (The dark ovals and similar smaller dark spots are image artifacts.)

Data Set and Procedure

We examined Hinode XRT 21 jets for X-ray jets in the polar coronal hole regions. All of our events are from 2017 and 2018, which was a period during solar cycle 24 when the polar holes were comparatively large. We concentrated on periods when Hinode was running Hinode Operations Program (HOP) 81, where the observations are focused on the polar regions.

From the XRT images, we identified jets as either blowout (wide spire) or standard (narrow spire). We selected 21 jets that were distinct, obvious jets. We avoided jets very near the limb, because we wanted to have a clear view of the base of the jets, and if they are too close to the limb the base might be on the limb's far side.

We identified the jets as blowout or standard. We found 11 blowout jets and four standard jets, with six jets uncertain.

We then examined the events with AIA data, using the 171, 193, 211, and 304 Angstrom channels. (Sterling et al. 2015 found that the remaining AIA channels did not add additional substantial insight into understanding polar coronal jets). At least 20 of the 21 jets showed clear erupting minifilaments at the jets' bases, with the remaining case uncertain. (Consistent with the Sterling et al. 2015 findings, these erupting minifilaments are only visible in the AIA images, and are not obvious in the SXR images.)

We then examined the nature of the minifilament eruptions, and compared them with the blowout/standard nature of the jets.

Results

Our set of 21 jets consists of 11 blowout jets and four standard jets (with six uncertain).

These are the key results regarding the nature of the minifilament eruptions that made wide-spire and narrow-spire jets:

- Of the eleven blowout jets, only three came from clearly ejective minifilament eruptions. Two of them appear to be from mainly confined eruptions, and another five are from either partially confined eruptions or from eruptions that were uncertain regarding whether the cool minifilament material was ejected outward along the spire's open coronal field.
- The four jets that we classify as standard, on the other hand, all originate from eruptions of minifilaments that are either confined, partially confined, or uncertain. That is, no clearly ejective EMF occurred in the four standard jets, which, however, is a small sample of cases.
- The jets that were classified as "uncertain" regarding being standard or blowout had various spire appearances, as described in the table. These uncertain cases included both confined and ejective minifilament eruptions.

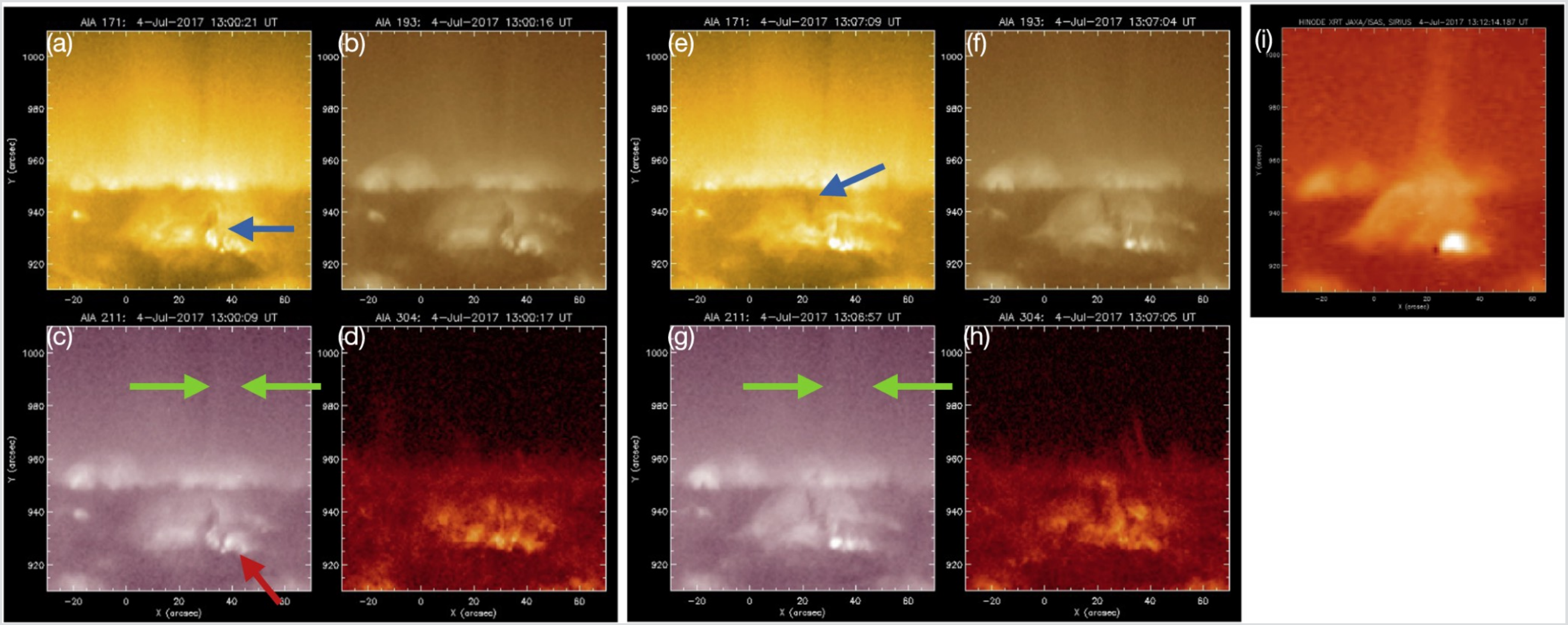

Figure 4. Blowout (right) coronal jet of Fig. 3. The rightmost panel (i) shows a closeup of the XRT image. The two left-side blocks show SDO/AIA images at two different times. Panels (a) and (e) are 171, (b) and (f) 193, (c) and (g) 211, and (d) and (h) 304 Angstrom images. In this case, the blowout jet (panel i) is due to a minifilament eruption that is largely confined to the jet's base region. In other words, this "blowout jet" does not result from an ejective minifilament eruption.

Summary

- We examined 21 polar X-ray coronal jets, selected from Hinode XRT movies.
- Among the 21 jets, 11 were blowout (wide spire), four were standard (narrow spire), and six were uncertain.
- The four standard jets all resulted from confined or nearly confined minifilament eruptions (but the sample was small).
- For the 11 blowout jets: three were from clearly ejective minifilament eruptions. Two were from mainly confined eruptions, and five were from minifilament eruptions where the ejective nature was more ambiguous.

Conclusion: Both ejective and confined minifilament eruptions can make "blowout" (=wide-spire) jets.

- For more details of this idea, see Sterling et al. (2022).

Image: Alphonse Sterling,
21 August 2017, Lewisville, Idaho

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