Revised View of Solar X-Ray Jets

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Introduction: Solar X-Ray Jets

- Observed since the Yohkoh days (Shibata et al. 1992; also Shimojo et al. 1996, etc.)
- Yohkoh (SXT) saw them mainly in active regions.
- Hinode/XRT found them to be plentiful in polar coronal holes (Cirtain et al. 2007; also Savcheva et al. 2007, etc.)
- In polar coronal holes: size~50,000 km x 8000 km; rate ~60/day (Savcheva et al. 2007).
- Often have a “hot loop” at the jet’s base.
Often-discussed mechanism is based on emerging flux ("emerging-flux model"). (Shibata et al. 1992; see also Moore et al. 2010.)

Many of the above observations and mechanism ideas were largely deduced from SXRs, and specifically from pre-SDO AIA observations.

Next: An overview of the emerging flux idea.

Later: Observations of (X-ray) jets using AIA, and resulting implications for the emerging-flux mechanism.
Emerging-Flux Model for (X-Ray) Jets

Supported by numerical simulations: Yokoyama & Shibata (1995), Nishizuka et al. (2008), Archontis et al. (2013), Moreno-Insertis et al. (2013), Fang et al. (2014), etc.
Fig. 9. Simulation results of the typical model (model 7) for the oblique-coronal-field case, $\theta_{\text{cor}} = 3\pi/4$. The figure shows the region near to the central loops (lower half of the computation box), whose range is $0 \leq x \leq 80$ and $-5 \leq z \leq 50$. Panels (a) and (b) show the time evolution of the temperature $T$, and the density $\log_{10} \rho$, respectively. Panel (c) shows the current density $J_y$ distribution at $t = 105.0$. The remaining notation is the same as in figure 3. (See Plate 9 for figure 9a.)
Standard Jets and Blowout Jets

- X-ray Jets, from the time of Yohkoh: E.g., Shibata et al. (1992); Shimojo et al. (1996); and Hinode, e.g., Cirtain et al. (2007).

- Jet model, later known as “standard jets”:
  - Shibata et al.
  - Moreno-Insertis et al. (2008)
  - Archontis & Hood (2013)….

- Dichotomy: Standard and Blowout Jets
  - Moore et al. (2010)
  - Moore et al. (2013)
  - Blowout jets seen by several workers (Liu et al. 2011, Standard to Blowout; Hong et al. 2011, Shen et al. 2012, CMEs with blowout jets; Moreton et al. 2012; etc.)
Standard vs. Blowout
(Moore et al. 2010, 2013)

- **Standard:**
  - Simple ("single") spire
  - Little X-ray brightening at base, cf. bright point
  - Little or no emission in cooler lines.

- **Blowout:**
  - Complex, broad spire
  - Strong X-ray base brightening at base
  - Substantial cool ejective jet

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“Standard Jet” Examples
“Blowout Jet” Examples
Moore et al. (2010)
Moore et al. (2010)
Jets with AIA (mainly our work)
On-Disk Macrospicule
(Mitzi Adams, Sterling, Moore, & Gary 2014)

- AIA and HMI observations.
- In on-disk Coronal Hole.
- No obvious AIA hot-channel jet; therefore might be a "macrospicule," but not certain (X-rays??).
- On-disk, so look for Shibata/Moore EFR source for the jet.
Variation $\sim 20\%$; trend $\sim 2 \times 10^{15} \text{ Mx/s}$

$\Rightarrow$ EF probably not driving the jet

(cf. Chandrashekar et al. 2014)
Also, no strong bipole under jet:

Instead, probably have filament material from neutral line:
In this case, instead of emerging flux, have *canceling* flux!
With this background in mind, look at more events with AIA data

- Studied 20 Hinode/XRT X-ray jets polar coronal holes during SDO period.

- These jets were randomly selected during a previous investigation (Moore et al. 2013).

- For first several jets, examined all seven SDO/AIA EUV channels.

- For remaining jets, only examined AIA 304, 171, 193, and 211Å channels (~0.05, 0.6, 1.6, and 2.0 MK, respectively).
Event 12
Event 3

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“Normal” Filament Eruption (TRACE)
“Normal” Filament Confined Eruption (AIA 304)
- All 20 events show filament material ejected from location that brightens.

- “Standard” ejections (based on morphology) are sometimes fainter and harder to see than in “blowout” cases. Seem to be confined or near-confined eruptions.

- Average (over 18 cases) miniature-filament properties:
  - Length $\sim (8 \pm 3) \times 10^3$ km.
    (cf. “normal” filaments: $3 \times 10^4 \sim 1.1 \times 10^5$ km; Bernasconi et al. 2005)
  - Pre-ejection $<\text{velocity}> = 31 \pm 15$ km/s.
Revised View of X-Ray Jet Formation

(a) XRT TiPoly: 17-Sep-2010 22:04:17 UT
(b) XRT TiPoly: 17-Sep-2010 22:09:48 UT
(c) XRT TiPoly: 17-Sep-2010 22:12:48 UT
(d) AIA 193: 17-Sep-2010 22:07:54 UT
(e) AIA 193: 17-Sep-2010 22:10:18 UT
(f) AIA 193: 17-Sep-2010 22:12:42 UT
How About On-Disk Jets?

- Not done in this study, but...
- Adams et al. (2014); above. Basic picture consistent with miniature filament eruption, with “flare” as the jet base brightening.
- Miniature filaments also seen by others, including Shen et al. (2012), Hong et al. (2014). (Also, Wang et al. 2000.)
- Other indications of eruptions making jets, e.g., Nisticò et al. (2009), Raouafi et al. (2010).
On-Disk Jet

Shen et al. (2012)
What Causes Miniature-Filament Eruptions?

- Did not look on-disk in this study, due to polar view. But....

- Adams et al. (2014) found no emerging flux in the jet region. Filament erupted from location where flux canceled.

- Huang et al. (2012) and Young & Muglach (2014) found jet from location where flux canceled.

- Some others, e.g., Liu et al. (2011), Shen et al. (2012), and Hong et al. (2012) found jets from location of emerging flux+flux cancelation.
Reconnection and Spire Drift in Coronal Jets

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Main Points

There are two kinds of X-ray jets in coronal holes: standard jets and blowout jets.

In most jets of either kind, as the spire grows:
- A bright point grows at the edge of the base of the jet, and
- The spire drifts away from the bright point. [Cf. Savecheva et al. 2009.]

The conventional emerging-flux model for jets implies: the spire should drift toward the bright point.

Alphonse’s minifilament-eruption model for jets implies: the spire should drift away from the bright point.

The observed drift direction is explained by most coronal-hole X-ray jets being driven by a minifilament eruption instead of emerging flux.
Standard Jet
Hinode/XRT Thin Al Poly, 2008 Oct 5

20,000 km

Bright Point
Blowout Jet
Hinode/XRT Thin Al Poly, 2008 Sept 20

20,000 km

Bright Point
Emerging-Flux Model for Standard Jets

- Spire
- Interchange Reconnection
- Bright Point
- Spire Drift
Emerging-Flux Model for Blowout Jets

Internal Reconnection
Minifilament-Eruption Model for Standard Jets

- Minifilament at Eruption Onset
- Erupting Minifilament
- Internal Reconnection
- Bright Point
- Interchange Reconnection
- Spire Drift
- Arrested Minifilament
Minifilament-Eruption Model for Blowout Jets
Conclusion

For most X-ray jets in coronal holes, the spire drift says:

- Alphonse’s minifilament-eruption model is right.
- The conventional emerging-flux model is wrong.
Summary

- We observed 20 polar coronal hole X-ray jets with Hinode/XRT and SDO/AIA.
- Jets **due to eruptions of miniature filaments**: \( \langle \text{length} \rangle \sim (8 \pm 3) \times 10^3 \text{ km}; \) pre-ejection \( \langle \text{velocity} \rangle = 31 \pm 15 \text{ km/s} \). Consistent with on-disk observations.
- Look like scaled-down larger-scale filament eruptions, where the jet-base hot-loop brightening corresponds to the flare.
- Spire drift with time is consistent with mini-filament idea, but not with emerging flux.
- Roughly speaking, blowout jets correspond to ejective eruptions, and standard jets correspond to confined eruptions.
- For some on-disk EUV jets, the miniature-filament eruptions result from flux cancelation, but cannot rule out other causes (flux emergences?).
- Finally: The jet base hot loop is due to internal reconnection, not external reconnection; reconnection at null might not be “sticky.” (\( \Rightarrow \) Astrophysical consequences?)