Update on Solar Coronal 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. Reviewed by Raouafi et al. 2016.)
- 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.
- Previously 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 ideas deduced from SXRs, and pre-SDO AIA observations.
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. (Cf. Heyvaerts, Priest, & Rust 1977.)
Coronal Hole Jets: “Minifilament eruptions”

“Normal” Filament Eruption (TRACE)
Minifilament-Eruption Model for (X-Ray) Jets


Quite Sun jets work the same way (Panesar et al. 2016b)

Recently modeled by Wyper, Antiochos, & Devore (Nature, 2017)
Quiet Sun Jets — Similar to PCH jets

(Panesar et al. 2016b)

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Same for QS jets: Occur at cancelation sites.

Ave. Cancelation rate: $\sim 10^{18} \text{ Mx/hr.}$

Panesar, Sterling, & Moore (2016b) — 10 jets.
Active Region Coronal Jets

- Yohkoh studies (Shibata et al., Shimojo et al., many others).
- Raouafi et al. (2016).
- Panesar et al. (2016a).
An Example: AR Jets

- 14 Jan 2015 (NOAA AR 12259).
- AIA, HMI, Hinode, IRIS
- Sterling et al. (2017)
Coronal Jets in Active Regions

Sterling et al. (2017)
Sterling et al. (2017)
HMI of jetting region

Jets occur at flux cancellation locations!
AR jets (Sterling et al. 2017)
Jets and CMEs: History (sampling)

- Wang et al. (1998) - EIT and LASCO white-light jets.
  - Gilbert et al. (2001), Dobrzycka et al. (2003); “narrow CMEs” (angular width $\lesssim 15^\circ$).
- Several single-event studies:
  - Hong et al. (2011) - Single-event study of a micro-CME originating from a blowout jet triggered by flux cancelation.
  - Shen et al. (2012) - Bubble-like CME from a blowout jet (SDO, STEREO, H$\alpha$).
- See Raouafi et al. (2016) review for more.
Jets and CMEs: Some recent investigations

• Moore et al. (2015): Polar coronal hole jets that extend into outer corona.

• Sterling et al. (2016): “CMEs” from AR jets.

• Panesar et al. (2016a): A “different type” of CME from AR jets. (Bemporad et al. 2005.)

• (Narrow CMEs = white-light jets.)
Moore et al. (2015)

• Selected 14 polar CH jets, that extended into LASCO/C2 FOV.

• Looked for narrow (width \( \lesssim 10^\circ \)) LASCO features.

• AIA/EUV jet.

• Found that narrow-CME-producing jets tended to have large twist.
AIA 304

9-Apr-2011 05:30:20

AIA 193

9-Apr-2011 05:30:19
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Twist in Jets

Random twisting PCH jets with cool component: Moore et al. (2013)

Narrow-CME-Producing Jets: (Moore et al. 2015)

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This suggests that: “polar jets having more axial rotation usually extend to greater heights than polar jets having less axial rotation.”

Moore et al. (2015). (Shibata & Uchida 1986-type mechanism; Patsouraos et al. 2008; Pike & Mason 1998.)
CMEs from AR Jets:

Sterling et al. (2016)
AIA 171

Most of AR jets made/likely made narrow CMEs/WLJs (width $\lesssim 10^\circ$).
(NB. Event 3 is a large-scale eruption; Event 4 is a surge/jet.)
(Wide) CMEs from AR Jets

Panesar et al. (2016a)
“Weak” CMEs from AR 12192
### Table 1
Date and Time for the Observed Jets and Their Measured Parameters

<table>
<thead>
<tr>
<th>Jet No</th>
<th>Date (UT)</th>
<th>Time (UT)</th>
<th>Flare Class</th>
<th>CME Speed (km s&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>CME Angular Width (°)</th>
<th>Jet Speed (km s&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>Jet Rise Dur. (±5 minute)</th>
<th>Jet Width (±1500 km)</th>
<th>Remote Bri. and Dim.</th>
</tr>
</thead>
<tbody>
<tr>
<td>J1</td>
<td>20 Oct 14</td>
<td>18:43</td>
<td>C6.2</td>
<td>187</td>
<td>40</td>
<td>190 ± 10</td>
<td>20</td>
<td>34000</td>
<td>Yes</td>
</tr>
<tr>
<td>J2</td>
<td>22 Oct 14</td>
<td>16:52</td>
<td>C5.8</td>
<td>281</td>
<td>20</td>
<td>310 ± 20</td>
<td>30</td>
<td>38000</td>
<td>Yes</td>
</tr>
<tr>
<td>J3</td>
<td>23 Oct 14</td>
<td>19:11</td>
<td>C3.3</td>
<td>239</td>
<td>35</td>
<td>330 ± 20</td>
<td>50</td>
<td>26000</td>
<td>No</td>
</tr>
<tr>
<td>J4</td>
<td>24 Oct 14</td>
<td>03:56</td>
<td>C3.6</td>
<td>250</td>
<td>30</td>
<td>300 ± 20</td>
<td>45</td>
<td>34000</td>
<td>Yes</td>
</tr>
<tr>
<td>J5</td>
<td>24 Oct 14</td>
<td>07:37</td>
<td>M4.0</td>
<td>677</td>
<td>50</td>
<td>400 ± 40</td>
<td>35</td>
<td>86000</td>
<td>Yes</td>
</tr>
<tr>
<td>J6</td>
<td>27 Oct 14</td>
<td>17:33</td>
<td>M1.4</td>
<td>186</td>
<td>25</td>
<td>ambiguous</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

#### Notes:
- Uncertainty in the CMEs speed measurement is less than 10% (Yashiro et al. 2004).
- Uncertainties are estimated from the time–distance plots.
- Measured at a projected height of ~72,000 km from jet base.
- This jet shows up well in the AIA 94 Å images, but not in 304 Å images. Due to its poor visibility in 304 Å images, we were unable to follow the jet plasma well enough to measure its speed.
- AR was close to the west limb, obscuring any remote brightening/dimming.
- Slower velocity (250 km s<sup>-1</sup>) in the beginning, but faster (>650 km s<sup>-1</sup>) later when a plug of plasma separates.
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(Update to Bemporad et al. 2005 picture of “streamer puff” CMEs.)
Do Jets Exist on Smaller Size Scales?
Filament-Like Feature Eruptions on Smaller Scales??

Large-scale filaments (flares+CMEs)

“Microfilaments” (spicules)??

Minifilaments (coronal jets)

Log "Filament" Size

Sterling & Moore (2016)
Sterling & Moore (2016)
**Summary**

- Jets are common, and occur all over the Sun (CHs, QS, and ARs).
- At least many, if not all, jets result from minifilament eruptions; smaller-scale version of large eruptions.
- Many (virtually all?) minifilament eruptions triggered by flux cancelation.
- At least two types of CMEs from jets:
  - Extensions of jets (narrow CMEs/white light jets).
  - Broader CMEs can be triggered by jets (streamer puff CMEs).
- Smallest-scale jets might make up some percentage of the spicule population.