Update on Solar Coronal Jets

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Sterling et al. (2017)
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 \(\sim 50,000 \text{ km} \times 8000 \text{ km}\); rate \(\sim 60/\text{day}\) (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: $\sim 10^{18} \text{ Mx/hr.}$
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)

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Coronal Jets in Active Regions

Sterling et al. (2017)
HMI of jetting region

Jets occur at *flux cancelation* 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, Hα).
- See Raouafi et al. (2016) review for more.
• 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.
Twist in Jetss

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

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

(a) CME-producing Jets

<table>
<thead>
<tr>
<th>Jet No</th>
<th>Date (UT)</th>
<th>Time</th>
<th>Flare Class</th>
<th>CME Speed&lt;sup&gt;b,c&lt;/sup&gt; (km s&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>CME Angular Width&lt;sup&gt;a&lt;/sup&gt; (°)</th>
<th>Jet Speed&lt;sup&gt;d&lt;/sup&gt; (km s&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>Jet Rise Dur. (&lt;sup&gt;±&lt;/sup&gt;5 minute)</th>
<th>Jet Width&lt;sup&gt;e&lt;/sup&gt; (&lt;sup&gt;±&lt;/sup&gt;1500 km)</th>
<th>Remote Bri. and Dim.</th>
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</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>
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<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>
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<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&lt;sup&gt;f&lt;/sup&gt;</td>
<td>...</td>
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</tr>
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</table>

(b) Non-CME-producing Jets:

<table>
<thead>
<tr>
<th>Jet No</th>
<th>Date (UT)</th>
<th>Time</th>
<th></th>
<th></th>
<th></th>
<th>Jet Speed&lt;sup&gt;d&lt;/sup&gt; (km s&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>Jet Rise Dur. (&lt;sup&gt;±&lt;/sup&gt;5 minute)</th>
<th>Jet Width&lt;sup&gt;e&lt;/sup&gt; (&lt;sup&gt;±&lt;/sup&gt;1500 km)</th>
<th>Remote Bri. and Dim.</th>
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</thead>
<tbody>
<tr>
<td>J8</td>
<td>22 Oct 14</td>
<td>02:31</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>75 ± 10</td>
<td>35</td>
<td>19000</td>
<td>...</td>
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<tr>
<td>J9</td>
<td>22 Oct 14</td>
<td>05:51</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>120 ± 20</td>
<td>10</td>
<td>15000</td>
<td>...</td>
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<tr>
<td>J10</td>
<td>22 Oct 14</td>
<td>10:46</td>
<td>C1.9</td>
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<td>...</td>
<td>140 ± 20</td>
<td>15</td>
<td>11000</td>
<td>...</td>
</tr>
<tr>
<td>J11</td>
<td>22 Oct 14</td>
<td>12:56</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>50 ± 10</td>
<td>20</td>
<td>16500</td>
<td>...</td>
</tr>
<tr>
<td>J12</td>
<td>22 Oct 14</td>
<td>17:30</td>
<td>C3.0</td>
<td>...</td>
<td>...</td>
<td>ambiguous&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10</td>
<td>13000</td>
<td>...</td>
</tr>
<tr>
<td>J13</td>
<td>22 Oct 14</td>
<td>20:11</td>
<td>C3.0</td>
<td>...</td>
<td>...</td>
<td>150 ± 20</td>
<td>10</td>
<td>16000</td>
<td>...</td>
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<td>J14</td>
<td>22 Oct 14</td>
<td>23:15</td>
<td>C1.1</td>
<td>...</td>
<td>...</td>
<td>110 ± 10</td>
<td>25</td>
<td>13000</td>
<td>...</td>
</tr>
</tbody>
</table>

Notes:

<sup>b</sup> http://cdaw.gsfc.nasa.gov/CME_list
<sup>c</sup> Uncertainty in the CMEs speed measurement is less than 10% (Yashiro et al. 2004).
<sup>d</sup> Uncertainties are estimated from the time-distance plots.
<sup>e</sup> Measured at a projected height of ~72,000 km from jet base.
<sup>f</sup> 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.
<sup>g</sup> AR was close to the west limb, obscuring any remote brightening/dimming.
<sup>h</sup> 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.
(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??

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Log "Filament" Size

Sterling & Moore (2016)
Hinode SOT/WB JAXA/ISAS, SIRIUS 15-Sep-2011 10:14:47.248 UT

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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.