Magnetic Flux Cancellation as the Trigger Mechanism of Solar Coronal Jets

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Abstract
Coronal jets are narrow eruptions in the solar corona, and are often observed in extreme ultraviolet (EUV) and X-ray images. They occur everywhere on the solar disk: in active regions, quiet regions, and coronal holes (Raouafi et al. 2016). We confirm this picture for a large sample of jets in quiet regions and coronal holes using multithermal extreme ultraviolet (EUV) images from the Solar Dynamics Observatory (SDO)/Atmospheric Imaging Assembly (AIA) and line-of-sight magnetograms from the SDO/Helioseismic and Magnetic Imager (HMI). We report observations of 60 randomly selected jet eruptions. We have analyzed the magnetic cause of these eruptions and measured the base size and the duration of each jet using routines in SolarSoft IDL. By examining the evolutionary changes in the magnetic field before, during, and after jet eruption, we found that each of these jets resulted from filament eruption triggered by flux cancellation at the neutral line. In agreement with the above studies, we found our jets to have an average base diameter of 7600 ± 2700 km and an average jet-growth duration of 9.0 ± 3.6 minutes. These observations confirm that filament eruption is the driver and that magnetic flux cancellation is the primary trigger mechanism for nearly all coronal hole and quiet region coronal jet eruptions.

Background
Solar coronal jets are narrow, short-lived eruptions that occur frequently throughout the entire solar disk (Raouafi et al. 2016); quiet regions, coronal holes, and on the edge of active regions. These eruptions are often observed in extreme ultraviolet (EUV) and X-ray emission (Raouafi et al. 2016). Previous EUV observations by Panesar et al. (2016) have observed an average base size of 17,000 ± 600 km and an average jet duration of 12 minutes. Recent studies indicate that most coronal jets in quiet regions (Panesar et al. 2016) and coronal holes are driven by the eruption of a filament (Sterling et al. 2015). Because Sterling et al. (2015) only looked at jets near the limb, they had no conclusive results regarding the magnetic origin of these eruptions. This study by Panesar et al. (2016) followed this by investigating the magnetic origin of 10 coronal jets and observed a pattern of flux cancellation at the magnetic neutral line prior to the origin of these minifilaments. The study by Panesar et al. (2016) followed this by investigating the magnetic field evolution, we used line-of-sight magnetograms from SDO/HMI (Scherrer et al. 2012). This study produced high-resolution (0.6° pixel⁻¹) line-of-sight magnetograms which allows us to closely examine the photospheric magnetic field around the jet-base regions. We use magnetogram data to track the evolution of the photospheric magnetic field in the jet-base region from approximately 5 hours prior to until 1 hour after jet eruption. For this study, we randomly selected 60 coronal jets in quiet regions and coronal holes using SDO/AIA images. We found 30 jets in quiet regions and 30 in coronal holes.

Results
We have examined the evolution of 60 on-disk quiet-region and coronal hole jets using EUV images from SDO/AIA to track the structure of the jets as well as using line-of-sight magnetograms from SDO/HMI to analyze the magnetic field evolution of the jet base region. In this paper, we show two detailed examples of coronal jets in figure 1 (quiet region jet) and figure 4 (coronal hole jet). Both jets exhibit a clear minifilament at the neutral line (figure 1a and figure 4a) prior to onset. The white boxes in figure 1c and figure 4h show the area in which we quantitatively measured the magnetic flux density through time. We were careful to use the area measured by the coronal hole jet observed on January 2, 2017. This study was carried out using multithermal (304 Å, 171 Å, 193 Å, and 211 Å) EUV images from SDO/AIA to study the evolution of the minifilament and jet spire. SOHO/MDI produces high-resolution (0.6° pixel⁻¹) full-sun images in seven EUV wavelengths (Lemen et al. 2012). We used 26 jets in quiet regions and 5, which display this flux through time, we find a clear pattern of flux cancellation and jet eruption in both the quiet region and coronal hole jets. These observations confirm that the existence of the 60 jet sample.

As the opposite polarity magnetic flux patches are cancelling at the neutral line (see figure 1e-h and 4e-h), the field enveloping the minifilament (minifilament field) destabilizes and begins to erupt (see figure 3(i)). This minifilament eruption takes place at the neutral line and results in internal reconnection within the minifilament field (represented by the lower star in figure 3b,c). This reconnection then produces the jet bright point (white arrow in figure 1c and figure 4c) at the neutral line. As the eruption continues, the minifilament field goes through external reconnection with the surrounding magnetic field (represented by the upper star in figure 3b,c), allowing the minifilament plasma to flow along that field line and become a part of the resulting jet spire (figure 3c). We find that the triggering mechanism for all 60 jets is flux cancellation, here shown by the two examples in figures 1 and 3. This observation is consistent with the findings of Panesar et al. (2016), who observed flux cancellation in a sample of 10 quiet-region coronal jets. Additionally, we present measurements of base width and duration for all 60 jets. Jet base width was measured by taking the average of three distinct measurements across the base of each jet in base of jet A at approximately 1 minute prior to jet eruption. By doing so, we found the average jet base to be 7600 ± 2700 km. Jet duration was measured in 171 Å from 1.6 hours before the brightening of the jet base until the spire was at a maximum height. The jets in this sample all had an average duration of 9.0 ± 3.6 minutes.

Conclusion
We report the trigger mechanism of 60 randomly selected, on-disk solar coronal jets in quiet regions and coronal holes, as well as the duration and base width of each jet. From our observations of the magnetic flux behavior of coronal jets in quiet regions and coronal holes, we find that prior to each jet eruption, a magnetic reconnection is present at the neutral line. This reconnection eruption due to the internal flux reconnection at the neutral line. Additionally, we find an average base width of 7600 ± 2700 km for our jets. We also find the 60 jets to have an average duration of 9.0 ± 3.6 minutes.

Acknowledgements
Special thanks to Dr. Navdeep Panesar for his guidance and mentorship throughout the research process, NASA Marshall Space Flight Center, the Center for Space Plasma and Aeronomic Research at the University of Alabama in Huntsville, and the National Science Foundation for supporting this study. This Research Experience for Undergraduates program is funded by the National Science Foundation under grant AGS-1407927.

References

Figure 1: Quiet region jet observed on 2016 November 25. Panels (a)-(d) show 171 Å intensity images. The red arrow in panel (a) points to the minifilament. The white arrow in panel (b) shows the jet bright point (JBP). The blue arrow in panel (c) indicates the jet spire next to the erupting filament. The white arrow in panel (d) shows HMI magnetogram images of the same region. The white boxes in panels (a)-(d) enclose the measured flux plotted in figure 2. The green dashed line in panel (d) roughly outlines the magnetic neutral line where the field lines end.

Figure 2: Flux cancellation plot for 30 November 2016. Upper panel shows the minority (negative) flux within the box in figure 1c(d) as a function of time. The lower panel displays the time of jet onset (16:09 UT).