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Hinode EIS and XRT Observations of Hot Jets in Coronal Holes - Does the Plasma Escape?

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Abstract. X-ray jets have been detected in the extreme ultraviolet (EUV) and soft X-ray observations of *Hinode*'s EIS and XRT instruments. Both instruments were used to observe the jets in polar and on-disk coronal holes (CHs). Here, we present a multi-wavelength study of an X-ray jet and its associated bright point found in an equatorial CH on 19 June 2007. Light curves (LCs) in 22 different emission lines were compared to that of *Hinode*/XRT. As we found in a previous study of two polar X-ray jets, this jet shows a post-jet increase in its EUV LCs. The post-jet enhancement appears cooler than the jet. We suggest this feature arises because the hot plasma of the jet, having failed to reach escape speeds, cools and falls back along the near vertical paths expected to be created by reconnection with open field lines of CHs. In addition to the increase in post-jet EUV intensity, we found tentative evidence of impact heating possibly caused by the fall-back of plasma.

1. Introduction

In a previous study of X-ray jets observed in the southern polar coronal hole (CH) on 20 January 2007, we found post-jet enhancement in EUV intensity in light curves (LCs) of two jets (Culhane et al. 2007b). The $40''$ slot was used to obtain images in 14 emission lines for the polar jets, however, due to line blending, spectral velocities were not available. Observation of jets in the equatorial CH using the $2''$ slit provides an opportunity to test our hypothesis for post-jet EUV enhancements in cooler lines.

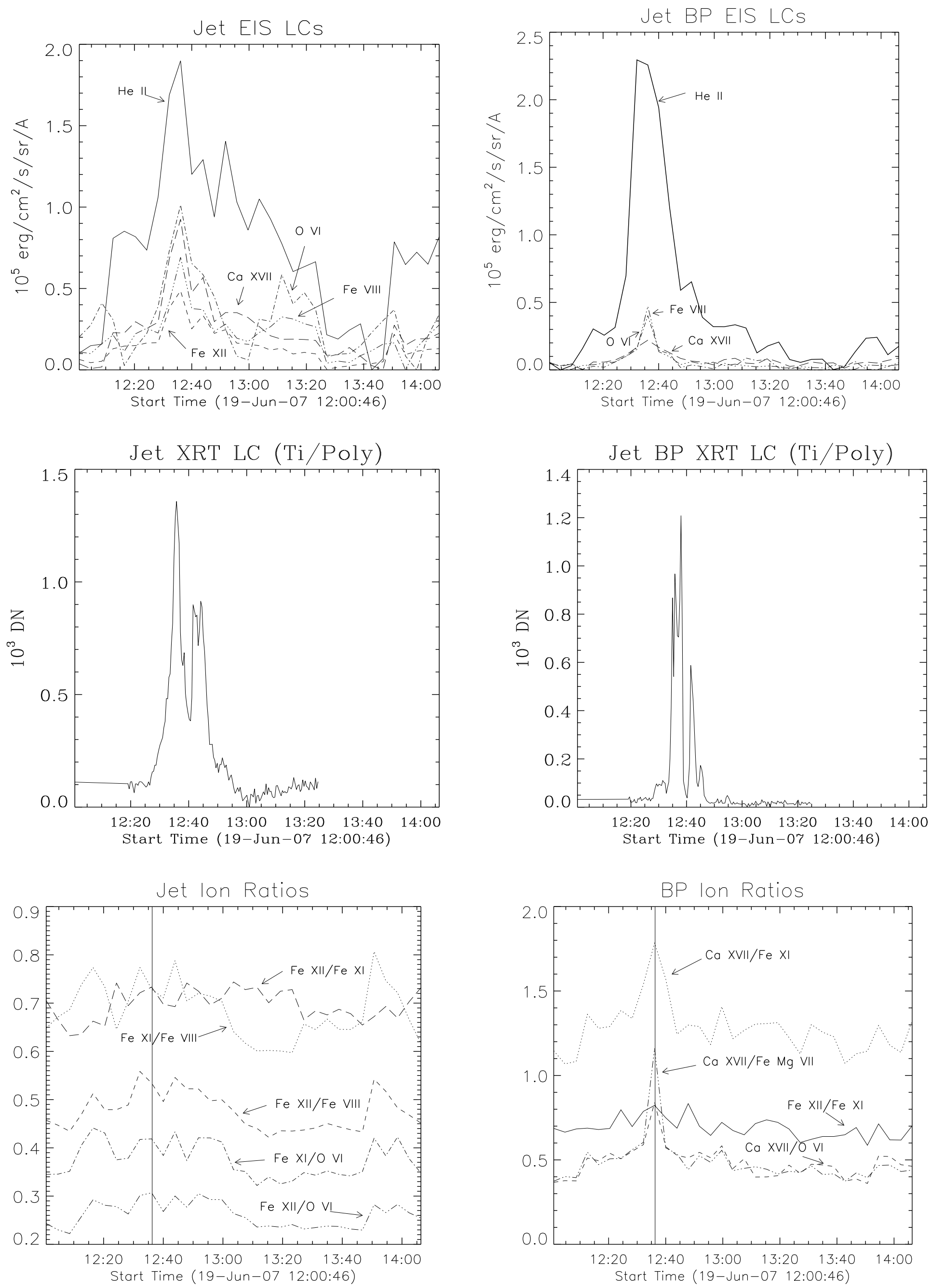

Figure 1. Top panel: EIS light curves showing EUV intensity evolution of jet (left) and bright point (right). Temperatures: Ca XVII - 5.01 MK, Fe XII - 1.26 MK, Fe VIII - 0.63 MK, O VI - 0.32 MK, He II - 0.05 MK (Young et al. 2007). Center panel: XRT light curves showing soft X-ray intensity evolution of jet and bright point. Bottom panel: Ion ratios of jet and bright point calculated from background subtracted flux. Higher temperature ion over lower temperature ion in all cases. Both plots show Fe XII/Fe XI, both of which are formed at 1.26 MK.

2. Observations

The jet was observed in an equatorial CH on 19 June 2007 by *Hinode*'s EIS and XRT instruments (Culhane et al. 2007a) employing the 2″ slit (EIS Study #173). Data were obtained with the high data rate scanning raster consisting of 20 pointing positions with exposure time of 10 sec per position. The study is composed of 22 emission lines from ions formed over a wide range of temperatures from 0.3 MK to 12 MK in addition to lower temperature emission from He II . In this coordinated campaign, XRT high cadence observations (≈ 30 sec) employed the Ti/Poly filter. XRT's large FOV (512″ × 512″) provided context images for the observing campaign.

Standard SolarSoft routines, including EIS_prep and XRT_prep, were used to create derotated map structures after correcting for instrument pointing, EIS's detector tilt, and orbital variation.

Light curves for each of the ions in EUV and soft X-ray images were constructed by fitting a contour around the jet and bright point. Flux was summed and background subtracted within the contour region for each EIS line and XRT image over the lifetime of the jet. Ion ratios were calculated from the background adjusted flux. Jet and bright point spectral velocities were obtained from EIS velocity maps.

3. Results and Discussion

EUV and soft X-ray jet and bright point LCs are displayed in Figure 1 (top and middle panels). The jet main phase extends from 12:20 UT to 13:00 UT and peaks at 12:36 UT. Jet main phase is evident in both EUV and XRT LCs with the same start and peak times. This is also the case with the bright point LCs. Simultaneous jet and bright point start and peak times provide convincing evidence for the reconnection jet model (Yokoyama & Shibata 1995).

The jet signal is characterized by hotter EUV lines such as Fe XII and Ca XVII/Fe XI, both of which form at 1.3 MK (see Culhane et al. (2007b) and Young et al. (2007) for Ca XVII/Fe XI blend discussion). Like soft X-rays, these hot ion lines rise, peak and fall back to pre-event levels during the main jet phase, whereas, cooler EUV lines fall off more gradually during the main jet phase and actually rise again to peak approximately 30 minutes after the jet. Post-jet enhancement in intensity occurs in O VI and Fe VIII ions which form at significantly lower temperatures (0.3 MK and 0.6 MK, respectively) than those of the jet.

In both soft X-ray and EUV, the bright point light curves rise and fall sharply. There is no post-jet intensity enhancement in cooler lines as seen in the jet LCs. Bright point EUV LCs are a mixture of hotter (Ca XVII T = 5 MK) and cooler lines (O VI and Mg VII with T=0.6 MK).

An obvious feature of the EUV LCs is that He II appears to form an event 'envelope' for the jet and bright point. He II is formed at 0.05 MK within the transition region. Though the interpretation of He II is complicated by significant blending (Young et al. 2007), it is likely to be a transition region response to the magnetic reconnection causing the jet and bright point formation.

The jet was found to be blue-shifted by 26 km s^{-1} while the bright point was red-shifted. This is consistent with the Kamio et al. (2007) study of the velocity structure of bright points in a north polar CH. In our previous study of polar jets, we argued that the jet plasma, having failed to reach the solar escape velocity, cools and falls back along the near vertical magnetic field lines expected to be in a CH. The measured velocity of the jet found in the on-disk CH is well below the Sun's escape velocity of 618 km s^{-1}, which is consistent with our hypothesis.

Ion ratios for the jet and bright point are shown in the bottom panel of Figure 1. In the on-disk CH, jet plasma moves approximately along the line of sight, and is therefore more likely to remain within the contour. Plasma cooling is expected to be continuous and relatively smooth from the time when the jet is at its hottest i.e. at the signal peak. The plot of the jet ion ratios illustrates the expected steady cooling of the jet plasma which lasts until ≈ 13:20, depending on the ion. This is just after the peak of the post-jet enhancement. All jet ion ratios reverse direction at 13:45, when cooler lines return to pre-event levels and hotter lines begin to rise. One possible explanation for the rise in the ion ratios after the post-jet enhancement in cooler EUV lines could be heating due to impact of the falling back plasma (private communication with K. Shibata). Evidence of impact heating is more likely to be seen in the LCs of the on-disk jet because the plasma falls back along magnetic field lines within the contour.

Bright point temperature can be inferred from looking at the Ca XVII/Fe XI ion ratio. The Ca XVII/Fe XI curve shows a distinct rise coincident with the jet signal peak which demonstrates that Ca XVII, formed at 5 MK, dominates the Fe XI blend. With the jet, Fe XI dominates the blend because the Ca XVII/Fe XI and the Fe XII/Fe XI ion ratios are relatively flat (both ions are formed at 1.3 MK). See Figure 1, bottom right panel.

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