Observations and Numerical Studies of Coronal X-Ray Jets and Hα Surges Associated with Emerging Magnetic Fields

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Abstract. Observations of the simultaneous ejections of an X-ray jet and Hα surges in NOAA7070 indicate that they are ejected in a direction almost perpendicular to the emerging loop. We extended numerical simulation of reconnection between an emerging loop and overlying oblique magnetic field (Yokoyama & Shibata, 1995, 1996) to the case where they are not in the same plane. Shear Alfvén waves generated by the twist injection associated with magnetic reconnection can accelerate cool plasma more efficiently than the shock compression.

1. Introduction

Hα surges observed as dark elongated jet-like features near sunspots on the disc are believed to be high density (n ≈ 10^{11} cm^{-3}), cool (T ≈ 10^{4} K) plasma ejected from a small Hα bright point close to a sunspot. Typical velocities of plasma motion in surges are 50–100 km s^{-1}.

On the other hand, many X-ray jet-like features, i.e., transient X-ray enhancements with an apparently collimated motion are observed with the soft X-ray telescope aboard Yohkoh (Shibata et al. 1992, Shibata et al. 1994, Shimojo et al. 1996). Many of these X-ray jets are associated with flares in X-ray bright points, emerging flux regions, or active regions. Shibata et al. (1992) reported that one of the X-ray jets in NOAA7070 was associated with a flaring bright point at the footpoint of the Hα surge. This coincidence of the X-ray jet and the Hα surge suggests that both phenomena originate from a single physical mechanism. Based on an analysis of observations of X-ray jets, Shibata et al. (1992) proposed a magnetic reconnection model of X-ray jets. Subsequently, Yokoyama & Shibata (1995, 1996) performed numerical simulations of coronal X-ray jets in the case where the emerging magnetic fields reconnect with the pre-existing oblique field.
Sunspots observed with Yohkoh Aspect Sensor

Emerging Flux Region

Footpoints of Surge

X-Ray Jet

Dark Surge

Figure 1. An overlay of Hα surge, X-ray jet, and emerging flux region in NOAA7070.

The analysis of the observations of NOAA7070 by Shibata et al. (1992), however, was limited to the morphological correlation between X-ray jets and Hα surges and was not sufficient to give a clear scheme of the embedded physics.

2. Observations

We carried out an integrated analysis of the observations of NOAA7070 by SXT, Hα (Flare Telescope in Mitaka), and vector magnetograms (SMFT in Huairou) and tried to figure out a mechanism to create both an X-ray jet and Hα surges. Figure 1 shows that the bright point of the X-ray jet is overlapped with the footpoint of the surge. The bright point also coincides with the emerging flux region. The Hα surge grows in the same direction as the X-ray jet.

3. Numerical Simulation

The results of the observation shown in Figure 1 indicate a remarkable feature that both the X-ray jet and the Hα surge are ejected in the same direction almost perpendicular to the direction of the emerging loops. In such a configuration, magnetic reconnection involves three-components of magnetic field and velocity vectors. Thus we extended the numerical simulation of coronal X-ray jets by Yokoyama & Shibata (1995, 1996) to the case where the emerging magnetic fields cross the pre-existing oblique field.
In the model by Yokoyama & Shibata (1996), the magnetic tension force of reconnected magnetic fields accelerates both the hot plasma created around the reconnection point and cool chromospheric matter brought up with the emerging loop. Although most of the cool matter falls down along the loops, some of it is accelerated by the sling-shot mechanism and forms a fast shock which heats the matter. Cool matter between the shock and the pre-existing field can be accelerated upward by compression.

We studied a case where the emerging loops have a magnetic field component perpendicular to the plane including the pre-existing field (Figure 2). In such a case, magnetic reconnection injects twists into the pre-existing field and produces shear Alfvén waves which can accelerate both the hot and cool plasma along the loop. Since Alfvén waves are not thermalized by compression, the wave energy can mostly go into the kinetic energy of the ejected plasma. Thus we expect that Alfvén wave acceleration is more efficient than shock accelerations which involves entropy generation.

The initial condition of our simulation is a magnetic flux sheet imbedded in the convection region. Since the magnetic flux sheet is unstable against the Parker instability, it generates magnetic loops which reconnect with the oblique field. The simulation region is \( (L_x, L_y) = (140H, 80H) \), where \( H \) is the photo-
spheric scale height. In Figure 3, we show the numerical results at $t = 103H/c_s$, where $C_s$ is the photospheric sound speed.

Magnetic twists injected into the overlying oblique field generate shear Alfvén wave which accelerate both cool photospheric gas brought up with the emerging loop and hot plasma heated by magnetic reconnection. Both hot and cool plasma are ejected in the direction almost parallel to the coronal oblique field, consistent with the observation. Cool plasma accelerated efficiently by the Alfvén wave can be ejected to higher height than the one without twist injection.

References

Yokoyama, T., & Shibata, K. 1995, Nature, 375, 42
Yokoyama, T., & Shibata, K. 1996, PASJ, 48, 353