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Solar coronal jets

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Abstract. The solar jets were first observed by SOHO instruments (EIT, LASCO, UVCS) during the previous solar minimum. They were small, fast ejections originating from flaring UV bright points within large polar coronal holes. The obtained data provided us with estimates of the jet plasma conditions, dynamics, evolution of the electron temperature and heating rate required to reproduce the observed ionization state. To follow the polar jets through the solar cycle a special SOHO Joint Observing Program (JOP 155) was designed. It involves a number of SOHO instruments (EIT, CDS, UVCS, LASCO) as well as *TRACE*. The coordinated observations have been carried out since April 2002. The data enabled to identify counterparts of the 1996-1998 solar minimum jets. Their frequency of several events per day appear comparable to the frequency from the previous solar minimum. The jets are believed to be triggered by field line reconnection between emerging magnetic dipole and pre-existing unipolar field. Existing models predict that the hot jet is formed together with another jet of a cool material. The particular goal of the coordinated SOHO and TRACE observations was to look for possible association of the hot and cool plasma ejections. Currently there is observational evidence that supports these models.

Key words. Stars: Sun – Stars: solar corona – Stars: magnetic reconnection in corona

1. Introduction

Jetlike phenomena in the solar corona have been known since *Skylab* data in the 1970s and observations of Soft X–ray Telescope (SXT) aboard the *Yohkoh* satellite (Shibata et al. 1992; Shimojo et al. 1996). However, first observations from *Solar and Heliospheric Observatory (SOHO)* (Domingo et al. 1995) coronal instruments showed a new type of jet propagating high in the corona. White light coronal images from the Large Angle Spectrometric Coronagraph (LASCO) have revealed polar jets occurring in LASCO's C2 coronagraph field of view (2 $R_{\odot}$ to 6 $R_{\odot}$) with a frequency of about 3–4 per day (St. Cyr et al. 1997; Wang et al. 1998). They appeared to be extensions of the structures observed by the Extreme–Ultraviolet Imaging Telescope (EIT) in the Fe XII (195Å) band originating in flaring UV bright points within polar coronal holes (Gurman et al. 1996, Moses et al. 1997; Wang et al. 1998). The jets appeared collimated (2 – 4° wide) and elongated rapidly as they traveled through the corona. Their leading edges propagated outward at speeds of 400 – 1100 km s^{-1} whereas the bulk of the jet material traveled with much lower velocities, averaging around 250 km s^{-1} at 2.9 – 3.7 $R_{\odot}$ (Wang et al. 1998; Wood et al. 1999).

As the Sun was entering the declining phase of its activity the SOHO Joint Observing Program (JOP) 155 was designed to identify

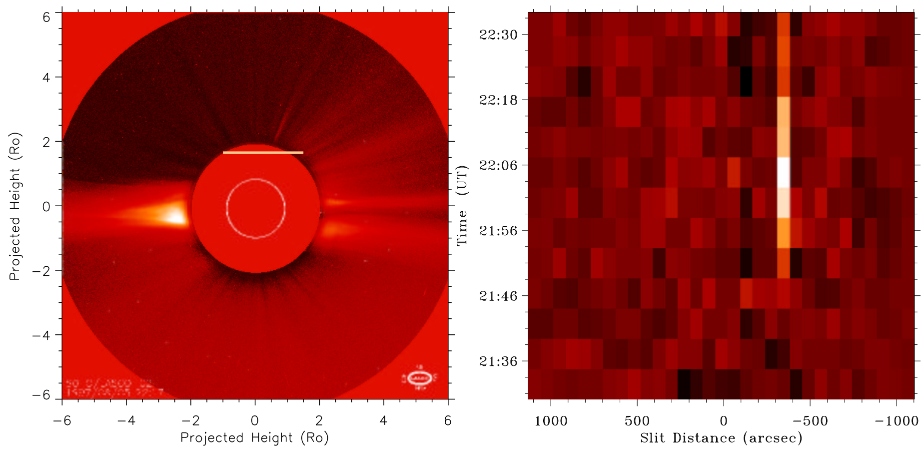

Fig. 1. The 1997 August 5 jet passing through the LASCO C2 field of view (left panel). The yellow horizontal line indicates position of the UVCS slit. The right panel shows the H I Lyα emission of the same jet along the UVCS slit. The integrated intensities were scaled by subtracting the average of the four H I Lyα intensity images before the jet became visible. The horizontal axis is the spatial coordinate along the UVCS entrance slit (in arcsec) centered at P.A.=0° around the heliocentric distance of 1.65 $R_\odot$. Adapted from Dobrzycka, Raymond & Cranmer (2002a)

and study counterparts of the last solar minimum jets. This ongoing project has been carried out since April 2002 and it involves several SOHO instruments: EIT, CDS, UVCS, LASCO as well as TRACE. So far it showed that the coronal jets are again visible within large polar coronal holes.

Here we present *SOHO* observations of the polar coronal jets. We also discuss major results and their implication for the jet models.

2. Observations

In 1996-1998 the jet observations of EIT and LASCO were accompanied with spectroscopic observations of the Ultraviolet Coronagraph Spectrometer (UVCS) at heights ranging from 1.5 Rs to 2.5 Rs. The polar coronal jets were recorded by UVCS as significant (by a factor of 1.4-3.0) enhancements with respect to the ambient corona in the integrated intensities of the strongest coronal emission lines, H I Lyα and O VI 1032,1037 Å. Also the emission line profiles appeared to be narrower during the jet events. Their $1/e$ widths were typically 20 – 50 km s^{-1} smaller than the pre-jet values, indicating that the material in the jets was cooler than the underlying corona. For details of the observational characteristic of the polar coronal jets see Dobrzycka et al. (2000, 2002a, 2002b).

Figure 1 shows example of the polar coronal jet observed by UVCS in H I Lyα on August 5, 1997. The same event was later followed in LASCO C2 field of view.

Study of the temporal evolution of the enhancements implied that jets typically undergo two phases: at the first phase the O VI lines show a brief intensity enhancement and narrowing, while the H I Lyα line is not enhanced, and the second phase, about 25 minutes later, when the H I Lyα line shows maximum intensity enhancement and narrowing, while the O VI line is relatively unchanged. Models allowed to interpret the first phase as the fast, dense centroid of the jet passing by the slit, and the second phase as a passage of cooler, lower density material following the centroid. The model runs that were able to reproduce the temperature, density, and ionization state estimated from the UVCS, EIT, and LASCO observations implied that the jet plasma most likely left the Sun at a temperature below 2.5×10^6 K and that a heating rate of the same order as the average coronal hole heating is required to match observed conditions at 1.71 $R_\odot$.

The JOP 155: *Polar Coronal Jets at the Declining Phase of the Solar Cycle* was implemented as the Sun was approaching minimum and the polar holes formed again and became permanent structures. The primary goal of this JOP was to study the jet phenomena that would be counterparts of the 1996–1998 solar minimum polar jets and to look for their possible association with cool plasma ejections. The jets are believed to be triggered by field line reconnection between emerging magnetic dipole and pre-existing unipolar field. Yokoyama & Shibata (1996) performed magnetohydrodynamic simulations of such reconnection processes and found that the hot jet is ejected together with another jet of a cool material. This would explain the observed coexistence of the *Yohkoh*/SXT X-ray jets and the H α surges. Also on 1996 July 13 EIT observed ejection of the polar jet in Fe XII 195 Å band. The jet was immediately followed by a dark surge of macrospicule at what had been the location of the base of the jet.

So far JOP 155 has provided us with a number of polar jet detections observed by different instruments. Their frequency, several events per day, is comparable with that observed at last solar maximum.

TRACE observed a polar coronal jet at 195Å within the north polar coronal hole on September 10, 2002. The same event was later recorded passing by the UVCS slit centered at P.A.= 345° on the heliocentric distance of 1.63 $R_\odot$. Simultaneous observations with EIT clearly showed brightening of the the footpoints of the jet in the 304Å and 171Å frames. On February 27, 2005 a jet became visible in UVCS spectra in form of enhanced brightening of H I Lyα emission right from the first exposure at 1.81 $R_\odot$ on 15:50 UT. It has lasted for about 30 minutes. The very same jet was observed on the disk by *TRACE* in 1216Å and 1600Å on 14:40 UT. The *TRACE* observations suggest origin of the jet at both low and higher temperatures which may indicate co–existence of cool and hot jets.

3. Summary and Results

Polar coronal jets form a new type of coronal ejections. They were first observed by SOHO at the very beginning of it's mission. Data from EIT, LASCO, and UVCS obtained during the 1996–1998 solar minimum enabled us to study temporal evolution of the jet plasma conditions and of the jet dynamics. Further observations have been carried out within JOP 155 since April 2002. So far they showed that the coronal jets are again visible within large polar coronal holes. Their frequency, several events per day, is comparable with that observed at last solar maximum.

Simultaneous EIT and TRACE observations suggest that polar jet ejections may be accompanied by ejection of cooler material. It agrees with prediction of the magnetohydrodynamic simulations of reconnection between emerging magnetic dipole and pre-existing unipolar field by Yokoyama & Shibata (1996).

Recent study by Mason (2006) appear to link the polar coronal jets to the potential field sources of the 3He–Rich solar magnetic particle events.

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