MAGNETIC EVOLUTION AND TEMPERATURE VARIATION IN A CORONAL HOLE

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ABSTRACT

We have explored the magnetic flux evolution and temperature variation in a coronal hole region, using Big Bear Solar Observatory deep magnetograms and SOHO EIT images observed from 2005 October 10 to 14. For comparison, we also investigated a neighboring quiet region of the Sun. The coronal hole evolved from its mature stage to its disappearance during the observing period. We have obtained the following results: (1) When the coronal hole was well developed on October 10, about 60% of the magnetic flux was positive. The EUV brightness was 420 counts pixel−1, and the coronal temperature, estimated from the line ratio of the EIT 195 and 171 Å images, was 1.07 MK. (2) On October 14, when the coronal hole had almost disappeared, 51% of the magnetic flux was positive, the EUV radiance was 530 counts pixel−1, and the temperature was 1.10 MK. (3) In the neighboring quiet region, the fraction of positive flux varied between 0.49 and 0.47. The EUV brightness displayed an irregular variation, with a mean value of 870 counts pixel−1. The temperature was almost constant at 1.11 MK during the 5 day observation. Our results demonstrate that in a coronal hole less imbalance of the magnetic flux in opposite polarities leads to stronger EUV brightness and higher coronal temperatures.

Subject headings: Sun: corona — Sun: magnetic fields — Sun: UV radiation

1. INTRODUCTION

Coronal holes are cool, low-density regions observed at both low latitudes and the polar regions of the Sun (Chiuderi Drago et al. 1999). They were first observed in white light by Waldmeier (1951), on X-ray plates by Underwood & Muney (1967), and on EUV line spectroheliograms by Reeves & Parkinson (1970). Their predominantly unipolar magnetic fields are open to the interplanetary space (Bohlin 1977), giving rise to high-speed solar-wind streams that can lead to geomagnetic storms (Krieger & Timothy 1973). There are three broad categories of coronal holes: polar, nonpolar, and transient ones (Harvey & Recely 2002). It has been suggested that magnetic reconnection must occur continuously at the boundary of coronal holes in order to maintain the coronal hole integrity (Kahler & Hudson 2002). The fast solar wind starts flowing out in magnetic funnels at heights between 5000 and 20,000 km above the photosphere (Tu et al. 2005).

The electron temperature is clearly an important parameter in the corona. A detailed assessment of observations in coronal holes and the deduced temperatures was published by Habbal et al. (1993). Electron temperatures in the corona can be measured with the help of a magnesium line ratio of a temperature-sensitive pair (see Wilhelm 2006), with the assumption that the density and temperature of the gas from which spectral lines are emitted are constant along the line of sight (Habbal et al. 1993). It should be mentioned that temperatures in the inner corona cannot be accurately derived as there are many sources of uncertainty such as instrument calibration, line-of-sight effects, departure from ionization balance, and inaccuracies of the atomic data.

In recent years, the coronal temperatures have been intensively studied since space observations are ascertained from the Yohkoh and Solar and Heliospheric Observatory (SOHO) missions (Hara et al. 1992, 1994; Moses et al. 1997). Using the two SOHO spectrometers, CDS and SUMER, electron temperatures were measured as a function of height above the limb in a polar coronal hole (David et al. 1998; Wilhelm et al. 1998). Doschek & Laming (2000) concluded that the emission-line ratio increase in a polar coronal hole was primarily due to an increase of the electron temperature with height. Marsch et al. (2000) found that the hydrogen temperature increased only slightly from 1 × 105 to 2 × 105 K in the height range from 12,000 to 18,000 km, and Stucki et al. (2000) presented that with increasing formation temperature, spectral lines displayed, on average, an increasingly stronger blueshift in coronal holes relative to the quiet Sun at equal heliospheric angle. Furthermore, Xia et al. (2004) reported that the bases of coronal holes seen in chromospheric spectral lines with relatively low formation temperatures displayed similar properties as normal quiet-Sun regions. More recently, Wilhelm (2006) reported that, in a polar coronal hole region, the electron temperatures in plumes are 7.5 × 105 and 1.13 × 106 K in interplume regions, in the height of 45 Mm above the limb.

In this Letter, we study the magnetic evolution, the EUV brightness changes, and the coronal temperature variations in a coronal hole and an adjacent quiet region from 2005 October 10 to 14. Initially, the coronal hole was well developed. At the end, the coronal hole had almost disappeared. Combining deep magnetograms (with a noise level of 2 G) from Big Bear Solar Observatory (BBSO) with SOHO EUV Imaging Telescope (EIT) observations, we unravel the nature of the different magnetic properties and temperature variations in this coronal hole and the quiet region.

2. OBSERVATIONS

From 2005 October 10 to 14, the observational target of BBSO was a coronal hole and a neighboring quiet region. The target was very close to the equator, centered at S3°E28° on the 10th, and at S5°W25° on the 14th. The magnetoGram was obtained using the digital vector magnetograph (DVMG) system mounted on the 25 cm refractor. The DVMG system uses liquid crystal, a Zeiss filter, and a 12 bit digital camera so that one can accurately measure small intranetwork magnetic elements on the order of 2 G. The temporal resolution is 90 s, and the field of view is 300″ × 300″ (0.6″ pixel−1). The EUV
Fig. 1.—Full-disk magnetogram from SOHO MDI (top left), an EIT 195 Å image from SOHO EIT (middle left), and a temperature map (bottom left) of the ratio from the EIT 195 and 171 Å channels. Three windows in the three full-disk images outline the field of view of BBSO magnetograms. The small windows in the right column denote a subarea where ephemeral regions appear (see Fig. 2).

 observations were obtained by EIT on board SOHO. The instrument generally observes full-disk EUV images in the coronal 171 Å (Fe ix/x, ≈1 MK), 195 Å (Fe xii, ≈1.5 MK), or 284 Å (Fe xiv, ≈2 MK) passbands. A detailed description of the instrument is provided by Delaboudinière et al. (1995).

Figure 1 shows a full-disk Michelson Doppler Imager (MDI; Scherrer et al. 1995) magnetogram (top left), an EIT 195 Å image (middle left), and a temperature map (bottom left) derived from the ratio of the 195 and 171 Å images. High values of this ratio generally outline magnetically closed field regions. The coronal holes are clearly defined as dark, i.e., cool regions in the ratio image both on and off the disk (Moses et al. 1997). Three windows on the full-disk images outline the field of view of BBSO magnetograms. Half of the area is a coronal hole and the other half a quiet region. Dashed lines in the three frames of the right column separate the coronal hole from the quiet region.

3. MAGNETIC FIELD EVOLUTION AND TEMPERATURE VARIATION

Figure 2 shows BBSO magnetograms (left column) in the region marked by the small windows in Figure 1. An ephemeral region (ER1) appeared near 17:49 UTC, October 11. As ER1 is growing, another smaller ER2 appeared between the two elements of ER1 (see the magnetogram at 19:29 UTC). The negative element of the smaller ER2 merged into the larger negative element of ER1, and the positive element of ER2 canceled with the opposite polarity element of the ER1. Three hours later, ER2 disappeared. The interaction of the two ERs is associated with the increased EUV emission in the right column of Figure 2. Figure 3 presents the evolution of magnetic flux density versus time in the upper panel, and in the middle panel the evolution of EUV emission. By tracking ER1, we find that it went through four phases (“P1,” “P2,” “P3,” and “P4”) in its evolution. Firstly, ER1 continuously emerged for 15 hr; meanwhile its positive flux canceled with the preexisting negative flux. At this stage, the flux emergence was dominant. In the second phase, the flux was almost stable, as seen from MDI magnetograms. The third phase began at 04:24 UTC on October 12. A new ER appeared in the area and interacted with ER1. Eight hours later, the new ER could not be tracked any longer. At this time, the mean flux density in this area reached the highest value. Finally, low-level emergence and cancellation intermittently persisted for about 1 day, before ER1 faded away. There was quite a close relationship between the evolution of magnetic flux density and the variation of the EUV brightness. The coronal temperature, shown in the bottom panel of Figure 3, deduced from the ratio of the Fe xii and Fe ix/x channels, also increased in the first three phases. However, in
the last phase, the temperature variation did not follow that of magnetic flux density.

It is well known that coronal holes lie within a predominantly unipolar magnetic region, but the solar magnetic field is never strictly unipolar. Wang et al. (1992) found that the minority polarity flux occupied 15%–30% of the total magnetic flux in a coronal hole. However, we have little knowledge about the magnetic flux evolution in coronal holes. Here we study the evolution of the magnetic flux and the variation of the flux imbalance in a coronal hole during its decaying stage and compare them with those in a quiet region. The top panel of Figure 4 displays the evolution of the total unsigned flux, measured from BBSO magnetic field data, in the coronal hole and the quiet region. We note that during the 5 day observations, the total fluxes in both regions were almost stable within the standard uncertainty margin. This result is confirmed by seeing-free MDI magnetic field data. The fraction of the positive flux to the total flux in the two regions is presented in the next panel. About 58% of the magnetic fields was positive in the coronal hole on October 10, the day when it was well developed. During the period in which the coronal hole gradually disappeared, the fraction of the positive flux decreased accordingly. The fraction decreased to 51% at the end, indicating that the fluxes of the positive and negative polarities were nearly balanced. In contrast to the coronal hole region, we found that the ratio between positive and negative fluxes in the quiet region did not change significantly. During the 5 day observing period, the fraction of positive flux varied between 49% and 47%, indicating that the fluxes of the two polarities are approximately balanced all the time.

The EUV brightness and temperature variations of the two regions are presented in the lower panels of Figure 4. In the quiet region, the EUV radiation fluctuates without a trend. The mean value is 870 counts pixel$^{-1}$. The coronal temperature is almost stable at a level of 1.11 MK during the 5 days. In the coronal hole, although the brightness also fluctuates, there is a clear ascending trend. From October 11 to 14, the mean EUV brightness increased from 420 to 530 counts pixel$^{-1}$, i.e., a relative increase of $\sim 26\%$. The derived temperature also increased. On October 10 and 11, the temperature was about 1.07 MK, and on October 14 it reached 1.10 MK.

4. CONCLUSIONS AND DISCUSSIONS

In this Letter, we probe the relationship between the magnetic field evolution, the EUV brightness changes, and the coronal temperature variations in a coronal hole, and compare it with...
that of a neighboring quiet region. In the coronal hole, 58% of the magnetic field was positive, while the hole was well developed. When it almost disappeared, the fraction of the positive flux decreased to 51%. This means that one of the signatures of decay of a coronal hole is the disappearance of the flux imbalance. Although the EUV emission fluctuated when the coronal hole was decaying, it clearly had an increasing trend. From October 11 to 14, the EUV increased from 420 to 530 counts pixel$^{-1}$, a relative increase of about 26%. The coronal temperature, deduced from the Fe ix/x and Fe xii line ratio, also increased. When the hole was well developed, the temperature was about 1.07 MK, and when the coronal hole almost disappeared, the temperature reached 1.10 MK. In the quiet region, the magnetic fluxes in both polarities were always approximately balanced. The EUV radiation fluctuates slightly with a mean of 870 counts pixel$^{-1}$, and the temperature was stable at a level of 1.11 MK. By using a similar line-ratio method, Moses et al. (1997) presented a full-disk temperature map. From the map, we deduced a coronal temperature range was from 1.00 to 1.10 MK in coronal holes, and from 1.10 to 1.20 MK in quiet regions. Our coronal temperatures are basically consistent with those of Moses et al. (1997).

By checking the flux transport across the coronal hole boundary for this region with MDI data, we do not see a significant migration of positive or negative fluxes. The only explanation of the magnetic field evolution then is that positive network flux canceled with “hidden” negative intranetwork (IN) flux, i.e., the magnetic flux that was too weak to be detected. Zhang et al. (2006) found that the net IN flux is opposite that of the network flux. The ephemeral regions, in turn, refurbished the missing flux. If we assume that at the mature stage of a coronal hole, there are 10 units of total flux, about six units are positive and four negative. When it evolved to the decayed stage, two positive units disappeared due to cancellation with invisible IN flux. Meanwhile, ephemeral regions provide one additional unit of flux for each of the two polarities. Consequently, five units each for the positive and negative fluxes would be detected.

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