Magnetic Fields Surrounding Coronal Holes

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Abstract: During July and August 1992 we succeeded in measuring photoelectrically longitudinal magnetic fields in areas surrounding four coronal holes, estimated from λ 10830 Å spectroheliograms. We were able to estimate values of the longitudinal magnetic flux in these areas and in their active regions, as well as in parts of coronal holes, covered by our measurements.

1 Introduction

Our knowledge of the concrete relations between coronal holes and solar magnetic fields, measured inside and around individual coronal holes, is not very comprehensive. Papers like the one published recently by Wang et al. (1992), which reported the amount of magnetic flux estimated in a coronal hole, are not very frequent.

Recently, McIntosh (1992) directly correlated formation of coronal holes not only with the global distribution of magnetic fields on the solar sphere, but also with the occurrence of large and very active (super) regions, claiming that the connection between such active centers and coronal holes can be described as "intimate". There are also many papers published earlier, during the seventies, which deal with the mutual relations of the large-scale distribution of solar magnetic fields and of solar activity, including that of the emission of the solar corona (see for example, Svalgaard and Wilcox, 1976). But all these studies were only very general.

This is the reason why we undertook the following, although still very preliminary study.

2 Observational Data

During July and August 1992 we succeeded in measuring, relatively systematically, longitudinal magnetic and Doppler velocity fields, as well as the continuum and spectral line intensity distribution in areas surrounding four low-latitude coronal holes photoelectrically with our reconstructed Magnetograph II (Klvaňa and Bumba, 1993) . We also studied the evolution of magnetic and velocity fields of active regions related somehow to coronal holes. We took the outlines of coronal holes from the Preliminary Report and Forecast of Solar Geophysical Data, and from the Solar-Geophysical Data prompt reports.

As we have already mentioned, we measure the longitudinal component of magnetic field only. Thus, the same applies to the values of magnetic flux obtained. But as regards the areas from which the flux is calculated, our program corrects these areas for their geometrical shortening.

The sizes of the areas in which we made the measurements vary, but the size of most of the measured areas oscillate around 300" $\times$ 200" ($5' \times 3.3'$). This means that we usually cover a relatively large neighborhood of the active region. We have estimated the flux values for the whole area measured, as well as for the rectangle bordering the active region.

3 Coronal Holes under Consideration

During the summer months of July and August 1992 we used practically all clear days, suitable for magnetographic observations, which were relatively frequent that year. We measured in the Fe I 5253.47 Å line, usually in all active regions on the solar disk. In most interesting active regions or areas on the solar disk our measurements were more frequent. But during this time we knew nothing of the existence of a coronal hole on the disk.

Comparing the measured areas with the distribution of active regions and other events on Hα Synoptic Charts, we found that some of our measurements were displaced very favorably around four coronal holes, covering parts of their areas several times, and in one case most of the hole itself. All this concerns the following four coronal holes:

No 43 C. M. P. around July 9, 1992, extending between latitudes -10^o and $+20^o$, of positive polarity;

No 44 C. M. P. around July 19, 1992; extending between latitudes 0^o and $+30^o$, again of positive polarity;

No 47 C. M. P. around August 5, 1992; latitudes: -10^o and $+10^o$ and

No 48 C. M. P. around August 15, 1992; latitudes: $+10^o$ and $+30^o$, both of positive polarity too.

4 Long–Term Development of the Studied Corona Holes

If we study the global distribution of the background magnetic fields and the related distribution of coronal holes during the recent two years (Carrington's rotations Nos 1837 – 1859), we see not only the close relation of coronal holes to the regular patterns in the longitudinal magnetic field distribution, but above all, the fact that their existence and development is a long–lasting process, we can follow during the whole studied time interval. We also see that a coronal hole requires a specific magnetic situation to be able to form. It develops in a certain configuration of the large-scale distribution of solar magnetic fields.

In this way we see that coronal holes Nos 44 and 48 are not only the same subjects, recurring in Carrington's rotations No 1858 and 1859, but also that this hole had developed over many rotations before. During the period of our studies it was only going through the last phases of its existence.

The other two coronal holes Nos 43 and 47, representing also the same recurrent coronal area, seem to be on the opposite side of their development process. The coronal hole they represent, is just at the beginning of its existence. During Carrington's rotation No 1958 it even slowed down its formation, to be in full strength again in the next rotation No 1859.

5 Results of our Magnetic Flux Measurements

Wang et al. (1992) estimated the value of the total flux in a field of view with the dimensions of $5' \times 4'$ in a coronal hole as high as 3.1×10^{21} Mx, claiming that about 8 % of that value came from the flux contained in ephemeral active regions (EARs).

As regards our estimates of the longitudinal component of magnetic flux (corrected for the area geometrical shortening), we first have to say that we did not observe EAR magnetic fields in our measurements, with the exception of the largest ones, and we thus studied active regions with clearly visible magnetic fields only.

We present our estimates of the longitudinal magnetic flux around coronal holes following the concrete situation on the solar disk during the day of our measurements. We took the day with sufficient number of magnetic field measurements and with the coronal hole close enough to its central meridian passage (C. M. P.). We had at our disposal the values of areas of all measured regions in 10^{-6} of the visible solar hemisphere, the total positive and negative fluxes and their differences in 10^{21} Mx (10 TWb), as well as the same quantities for rectangular regions bounding only the active region closely in each measured area. As concerns the flux, we took the positive and negative flux difference as the resulting flux emerging out from the measured or bounded area. We also give the total area of sunspots in the studied regions.

In this way we found that during the day of the C. M. P. of coronal hole No 43 (July 9, 1992), the total area of all measured regions , but one (NOAA 7225, being too close to the east limb), was 0.0787 of the visible hemisphere only. Its total positive flux $F\Sigma^+$ was $\approx 33.61 \times 10^{21}$ Mx, total negative flux $F\Sigma^- \approx -51.12 \times 10^{21}$ Mx, the difference of both fluxes being $F\Sigma \approx -17.51 \times 10^{21}$ Mx. Flux F^+ of all active regions (but the mentioned one) is $\approx 30.68 \times 10^{21}$ Mx, their negative flux

$F^- \approx -41.17 \times 10^{21}$ Mx and the difference of both fluxes $F \approx -10.54 \times 10^{21}$ Mx. The area containing NOAA 7219 covered by ≈ 11 % of its size also a very small portion of the coronal hole. There we found $F^+ \approx 0.59 \times 10^{21}$ Mx, $F^- \approx -0.30 \times 10^{21}$ Mx and $F \approx +0.29 \times 10^{21}$ Mx. The area of all sunspots A was $\approx 3284 \times 10^{-6}$ of the visible hemisphere.

During the next passage of this coronal hole under number 47, about one day after its C. M. P. (on August 7, 1992), we again measured the surroundings of all active regions visible on the disk, including a part of the coronal hole itself. The total measured area represents 0.053828 of the visible hemisphere, with $F\Sigma^+ \approx 54.59 \times 10^{21}$ Mx, $F\Sigma^- \approx -51.04 \times 10^{21}$ Mx, $F\Sigma \approx +3.54 \times 10^{21}$ Mx. The fluxes in all active regions were as follows: $F^+ \approx 30.72 \times 10^{21}$ Mx, $F^- \approx -17.91 \times 10^{21}$ Mx, $F \approx +12.81 \times 10^{21}$ Mx, A $\approx 1776 \times 10^{-6}$ of the visible hemisphere. This time we covered more than 30 % of the coronal hole with the measured area around NOAA 7245, the magnetic field of which strongly influenced the magnetic field of the coronal hole. The characteristics of the magnetic field of this portion of the coronal hole were: $F^+ \approx 8.82 \times 10^{21}$ Mx, $F^- \approx -5.33 \times 10^{21}$ Mx and $F \approx +3.49 \times 10^{21}$ Mx.

We studied the second coronal hole No 44 for the first time on July 20, 1992, about 1–2 days after its C. M. P.; it occupied a very large part of the visible solar hemisphere. Maybe, it was so large because of the very weak activity around it, with relatively small active regions. The total measured area was ≈ 0.088596 of the visible hemisphere, its $F\Sigma^+ \approx 26.95 \times 10^{21}$ Mx, $F\Sigma^- \approx -46.99 \times 10^{21}$ Mx, $F\Sigma \approx -22.78 \times 10^{21}$ Mx. The values related to the active regions only were as follows: $F^+ \approx 15.82 \times 10^{21}$ Mx, $F^- \approx -25.01 \times 10^{21}$ Mx, $F \approx -9.18 \times 10^{21}$ Mx, and the area of all spots A $\approx 609 \times 10^{-6}$ of the visible hemisphere. This time three of the measured regions also partially covered the coronal hole, i. e. about one quarter of its whole area. The fluxes of this part of the coronal hole were: $F^+ \approx 7.06 \times 10^{21}$ Mx, $F^- \approx -4.51 \times 10^{21}$ Mx, $F \approx +2.55 \times 10^{21}$ Mx.

This coronal hole recurred under number 48 considerably diminished in size. We observed it on August 16, 1992 when its center of mass was about two days past its C. M. P.. Again we measured all active regions on the disk. Two of them (NOAA 7262 and 7263) occupied a considerable part of this coronal hole. The whole measured area covered ≈ 0.058793 of the visible hemisphere with $F\Sigma^+ \approx 39.25 \times 10^{21}$ Mx, $F\Sigma^- \approx -63.94 \times 10^{21}$ Mx and $F\Sigma \approx -24.70 \times 10^{21}$ Mx. In the active regions we obtained $F^+ \approx 26.48 \times 10^{21}$ Mx, $F^- \approx -38.30 \times 10^{21}$ Mx, $F \approx -11.82 \times 10^{21}$ Mx and A $\approx 2011 \times 10^{-6}$ of the visible hemisphere.

We monitored the fluxes in both active regions covering this part of the coronal hole for three subsequent days (August 16, 17, 18, when they were too close to the west limb to be corrected for geometrical shortening). On August 16 we obtained $F^+ \approx 4.37 \times 10^{21}$ Mx, $F^- \approx -3.63 \times 10^{21}$ Mx and $F \approx +0.74 \times 10^{21}$ Mx, on August 17 $F^+ \approx 7.42 \times 10^{21}$ Mx, $F^- \approx -6.28 \times 10^{21}$ Mx and $F \approx +1.13 \times 10^{21}$ Mx.

As regards the flux in the measured areas, active regions and parts of coronal holes, we see that although the maximal values of positive and negative longitudinal fluxes in large active regions may be as high as a few tens of 10^{21} Mx, the resulting flux (the difference between the positive and negative flux for the studied area) relatively rarely exceeds the value of 10×10^{21} Mx. Usually, it amount to a few units of 10^{21} Mx, or even less.

As concerns the coronal holes, all four studied were estimated as positive coronal holes. This is in agreement with our measurements for all cases, but one, in which we covered a part of a coronal hole with a part the area we scanned. The obtained values of fluxes vary from a few tenths to a few units of 10^{21} Mx.

6 Relations of Coronal Holes with Active Regions

What seems to be meaningful is the fact that coronal holes No 47, 44 and 48 are connected with magnetic fields of older active regions, or rather with their parts of mainly positive polarity, with relatively high flux values (about 10×10^{21} Mx). In the case of coronal hole No 47, the active region (NOAA 7245) in its base changed its magnetic flux relatively rapidly from one day to the next. The same is true as in the case of coronal hole No 44 and region NOAA 7229 which developed on the disk several days before July 20), as well as in the case of coronal hole No 48. As we will demonstrate elsewhere, it seems that every coronal hole has its attached active region.

With the exception of the largest coronal hole of the ones studied (No 44), we can also clearly see the close relation of coronal holes with largest active regions preceding and following each coronal hole at a distance of about $40^o - 50^o$, as mentioned by McIntosh (1992), and as can clearly be seen on the large-scale distibution of solar magnetic fields. Again it seems that this behaviour of coronal holes to alternate regularly with strong magnetic fields of the large-scale background field network is very important for their existence.

The fact that we do not see coronal hole No 44 accompanied by large active regions may be related to the process of redistribution of coronal holes on the solar surface taking place on a global scale.

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