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THE CORRESPONDENCE BETWEEN SMALL-SCALE CORONAL STRUCTURES AND THE EVOLVING SOLAR MAGNETIC FIELD

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ABSTRACT

Solar coronal bright points, first identified in soft X-rays as X-ray Bright Points (XBPs), are compact, short-lived and associated with small bipolar magnetic flux. Contradictory studies have suggested that XBPs are either a primary signature of the emerging flux spectrum of the quiet Sun, or that they are representative of the disappearance of pre-existing flux. We present results using coordinated data obtained during recent X-ray sounding rocket flights on 15 August and 11 December 1987 to determine the correspondence of XBPs with time-series, ground-based observations of evolving bipolar magnetic structures, He-I dark points, and the network. Our results are consistent with the view that coronal bright points are more likely to be associated with the annihilation of pre-existing flux than with emerging flux.

INTRODUCTION

In the coronae of the sun and many stars, magnetic fields permeate and constrain the hot plasma such that the radiation traces, at least in a general sense, the field lines. At the visible surface of the Sun, the quiescent field consists of brighter knots of emission and stronger magnetic field that make up the "network." This network is related to supergranulation cells, which are a surface manifestation of the deeper seated convective activity of the Sun. Recent high temporal and spatial resolution imagery has shown that the network magnetic fields consist of the merging and cancellation of "ephemeral" or emerging regions, intranetwork fields, and the remnants of active region fields. Ephemeral regions are small magnetic bipoles of equal strength which appear at the surface and steadily move apart. Such regions are the most common form of flux emergence in the quiet Sun. Flux is observed to disappear from the surface at a rate which, over the short term, results in a steady-state balance of flux. Observationally, this disappearance takes the form of either cancellation of opposite-polarity elements or the gradual fading of flux. These processes involve magnetic energy conversion that have been interpreted as the reconnection and/or submergence below the surface of field lines.

In the solar corona the brightest quiet Sun structures are called bright points, because of their compact, circular form. The X-ray characteristics of coronal bright points were analyzed in detail during Skylab (see /1,2/ for reviews). These X-ray Bright Points (XBPs) are compact (typically 20-30 arc sec) and short-lived (average about 8 hours), and are associated with small photospheric magnetic bipoles. XBPs likely are small loops that connect the opposite polarity poles. A key question is how these coronal structures are related to the evolving network fields: are they the coronal manifestation of the emergence of new flux, the disappearance of older, pre-existing flux, or a combination of both? Similar bright points are also observed at other coronal wavelengths and in the transition region and chromosphere, but at lower contrast with a confusing background which consists of bright network elements.

Prior to the work presented in this paper, two approaches -- producing contradictory results -- have been taken in determining the evolution of the magnetic structure of XBPs. The approach of Golub and coworkers /1,3/ is primarily based on Skylab high resolution X-ray observations and concludes that XBPs are a consequence of emerging magnetic flux. The approach of Martin and Harvey /4,5,6/ is primarily based on high resolution magnetograms, utilizing compact absorption features in He-I 10830A images as XBP indicators, and concludes that XBPs are a consequence of cancelling or submerging magnetic flux.

The strength of the Skylab based approach was the unique time series of high spatial resolution soft X-ray data obtained during the Skylab era. From this work the fundamental characterization of XBPs was made in terms of spatial distribution, lifetime, and, in conjunction with subsequent sounding rocket flights, the solar cycle variation in XBP population /1,2,3/. The weakness of this approach was that it lacked simultaneous high time resolution, high quality magnetograms. The association of XBPs with ephemeral regions was based on study of only two simultaneous Skylab X-ray and Kitt Peak magnetogram image sets, and the correspondence between XBPs and dipoles going in either direction was only

about 50%. With the assumption that all "new" bipoles associated with XBPs were ephemeral regions, Golub and coworkers concluded that XBPs are the primary coronal signature of emerging flux in the quiet Sun.

The strength of the more recent ground-based approach is the high time and spatial resolution of the magnetogram data as well as the superior coverage of solar cycle variations. From this work Martin and Harvey /4/ found that the spatial distribution and the solar cycle variation of ephemeral regions did not match that of XBPs. The weakness of this approach was the lack of high spatial resolution soft X-ray observations. Because of this Harvey /6/ suggested that ground-based He dark point (DP) observations be used as a proxy for XBP observations. The association of XBPs and DPs is based on a single comparative study by Harvey et al. /7/ using Skylab X-ray and HeI-D3 images. That study was qualitative and did not reveal a one-to-one correspondence between XBPs and DPs. DPs exhibit the same solar cycle variation as XBPs but are more typically associated with cancelling flux regions than with ephemeral regions. Utilizing the assumption that DPs are a good proxy for XBPs, Martin and Harvey argue that XBPs are not a reliable signature of emerging flux.

The difficulty with both of the above approaches is the lack of simultaneous high spatial and high temporal resolution X-ray and ground-based observations. Partly in an attempt to correct this difficulty, two rocket flights of the AS&E high resolution, soft X-ray imaging payload were conducted in 1987. These flights were carefully orchestrated in an unprecedented campaign to coordinate key rocket and ground-based observations of small-scale solar features. Here we report on preliminary results which address primarily the problem of the correspondence of XBPs to evolving magnetic bipoles.

CORRESPONDENCE OF XBPS TO MAGNETIC BIPOLES

Three components of the XBP Observing Campaign are useful in the study of XBP-associated bipole evolution. Full-disk soft X-ray images of the solar corona were obtained from AS&E rocket flights on 15 August and 11 December 1987. Full-disk magnetogram and He-I 10830A images were obtained by J. Harvey and K. Dere at the National Solar Observatory (NSO), Kitt Peak before and after each flight, and narrow-field video magnetograms (VMGs) were acquired by H. Zirin, S. Martin and J. Cook at Big Bear Solar Observatory (BBSO) starting about 2.5 hours before and continuing through and after each flight. The NSO and BBSO magnetogram data are of comparable spatial resolution, but the VMGs have better sensitivity and a temporal resolution of about 10 min.

The figures show examples of these data on 11 December 1987. Figure 1 is a comparison of a full-disk NSO magnetogram with the longest exposure soft X-ray rocket image. The images are to the same scale. Superimposed on each is a rectangle outlining the area of 6 of the 8 VMG fields that were observed (two of the fields covered the west limb and were not used in this study). The area of each of the fields was about 300 x 400 arc-sec; one example is shown in Figure 2.

Several steps were necessary to compare the locations of the XBPs with bipoles on the VMGs. We first coaligned the full-disk X-ray and NSO magnetogram images using common bright emission features. The VMGs were easily related to the full-disk magnetograms. In an independent, double-blind manner, the authors identified XBPs on X-ray images for each flight, and S. Martin of Caltech-BBSO identified and classified the evolving bipoles within the VMG fields. Viewing each of the fields as a movie, Martin classified the bipoles as either emerging (strengthening and moving apart) or cancelling (moving together and disappearing) (see Martin et al. /5/). All other bipoles were considered static during the several hour interval of the BBSO observations. We confirmed previous results that nearly all the XBPs corresponded to bipoles on the full-disk images. We then compared the locations of the XBPs with the bipoles within the VMG areas. As an example, Figure 2 shows one of the VMG fields shortly after the 11 December rocket flight, with the evolving bipoles and locations of four XBPs marked.

The important new results are summarized in Table 1. Because of the small number of XBPs, we summed the data from both periods. However, the majority of both of the X-ray and magnetic field structures were observed in the 11 December data. The reasons for this are: (1) The global number of XBPs, and also He DPs, was about a factor of 3 higher on 11 December. (2) The nonuniformity of the XBP spatial distributions further limited the sample within the narrow VMG field of view. (3) The VMG area we used on 11 December was well onto the disk, whereas the area on 15 August was displaced toward the northwest limb where foreshortening effects compromised the magnetic field data. (4) Computer problems compromised the motion study of the bipoles on 15 August.

The second column of the table gives the total number of each class of feature observed. From the table, several points are clearly evident: (1) Within the VMG areas there were only 15 XBPs but hundreds of bipoles. Consequently, very few bipoles have associated coronal emission. (2) Most of the bipoles were not obviously evolving during these periods

of observation. This is due to two factors: The interval of observation is short compared to the mean lifetime of an ephemeral region (approximately 1 day) and many of the apparent bipoles in the VMG images are probably unrelated, i.e., not connected by the same loop. (3) Of the evolving bipoles, twice as many were classified as cancelling as emerging.

TABLE 1 Correspondence of X-ray Bright Points and Bipolar Magnetic Features

Feature	Total No. Observed*	Observed XBP Assoc.*	Expected XBP Assoc.	Standard Deviation
XBPs	16	--	--	--
Cancelling Bipoles	97	11	3.6	3.4
Emerging Bipoles	41	1	1.5	< 1
Static Bipoles	262	4	9.8	2
Total Bipoles	400			

* Sum from both 1987 observations on 15 August and 11 December.

The third column of the table shows how the XBPs were apportioned among the three classes of bipoles. (One XBP could be associated with both a cancelling and an emerging bipole, hence the total number of associations as 16.) Eleven of the 15 XBPs (approximately 2/3) were associated with cancelling bipoles. The significance of this result can be checked by apportioning the 15 XBPs according to the ratios of the observed bipole distributions to yield the expected XBP associations, assuming the XBPs are randomly distributed among the three classes of bipoles (Column 4). The last column gives the standard deviation of the observed vs. expected distributions. Despite the small number of XBPs, we see that both the higher number of XBPs associated with cancelling regions and the lower number associated with static bipoles are significant at the 2-3 sigma level. On the contrary, the single association with an emerging bipole is about as expected by chance.

CORRESPONDENCE OF XBPs TO He-I DARK POINTS

As discussed in the Introduction in the context of the debate between the association of XBP with emerging or cancelling bipoles, it is important to confirm whether or not He dark points, which can be observed from the ground, can be used as proxy for the X-ray bright points. Briefly we report on a collaborative study in progress with L. Golub of the Center for Astrophysics (CFA) and K. Harvey and J. Harvey of NSO to address this question. Routine high-quality He-I 10830A images were not available until after the Skylab mission. Therefore, we have collected 5 data sets, each consisting of AS&E full-disk, soft X-ray rocket images and near-simultaneous ground-based NSO 10830A images. These include three older data sets in 1974, 1976 and 1979 and the two sets from 1987.

Independently the XBPs on each X-ray image were identified by the authors and L. Golub and the He DPs were identified by K. and J. Harvey. These identification processes are fairly subjective, but particularly so for the He DPs. This is because He images have lower contrast and He absorption features consist of both coronal and lower temperature components.

Initial DP identifications using the older method yielded the following result, which is consistent for all 5 data sets. More XBPs than DPs were always identified, and the fraction of XBPs associated with DPs was always low, typically 1/4 or 1/3. This suggests that, using the previous subjective method, most XBPs will not be identified on a He image and, further, that with these data we cannot confirm the assumption that He DPs are a good proxy for XBPs.

However, it is clear from comparison of the images that nearly all the XBPs are associated with some compact He absorption. We are presently developing a more objective method for identifying DPs from the He data. In addition, since the He features tend to evolve in brightness and size on short time scales /6/, we need to examine the temporal evolution of individual DPs and the He emission features at the XBP sites. The 1987 data is best suited for this purpose, because full-disk and narrow-field, time-series He images were obtained in the observing campaign with the X-ray data.

SUMMARY AND CONCLUSIONS

We have used coordinated coronal images obtained from X-ray rocket flights, especially in 1987 and ground-based magnetogram and helium images to address important questions on the nature of the bright, small-scale components of the quiet-Sun magnetic field. Our main goal was to address the question of whether coronal bright points as evidenced by XBPs are a primary signature of the solar emerging flux spectrum, or representative of the annihilation of pre-existing flux. Our results with this limited data set are consistent with the latter picture. This contradicts the original Skylab result suggesting that all XBPs signified ephemeral regions, and therefore emerging flux /1,3/. A recent result using

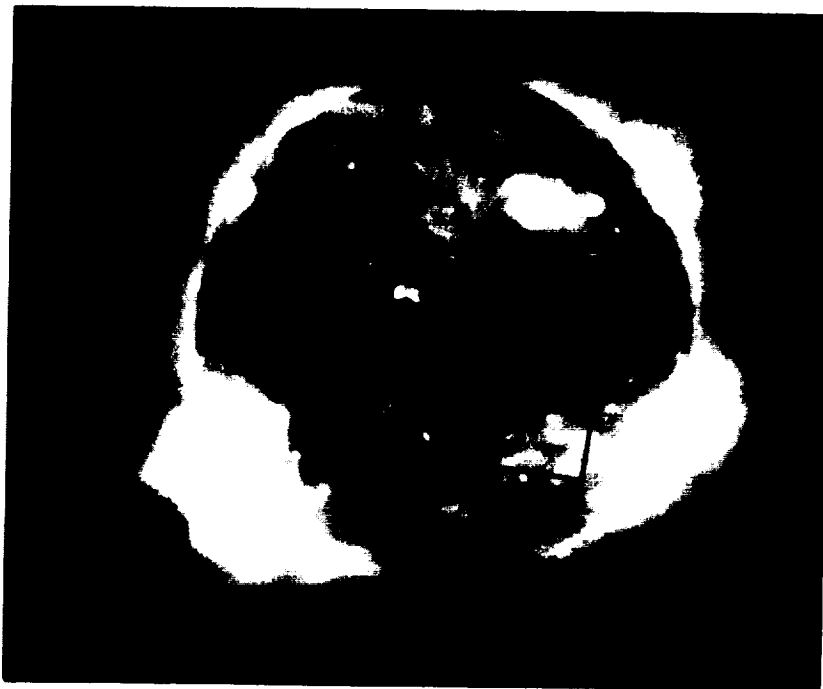
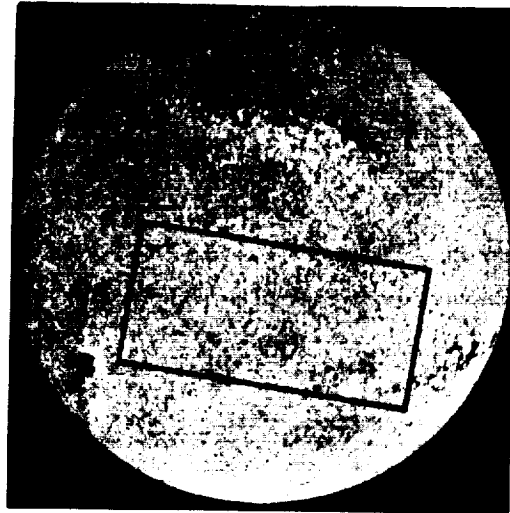


Fig. 1. Comparison of full-disk, near-simultaneous images of a photospheric magnetogram (NSO) and a soft X-ray image (AS&E). Acquisition time for the magnetogram was 40 min. The X-ray image was a 60 sec. exposure with a passband of $\sim 8-60\text{\AA}$. Solar north is at the top and east to the left. The total area covered by the six BBSO VMGs is denoted on each image by the rectangle.

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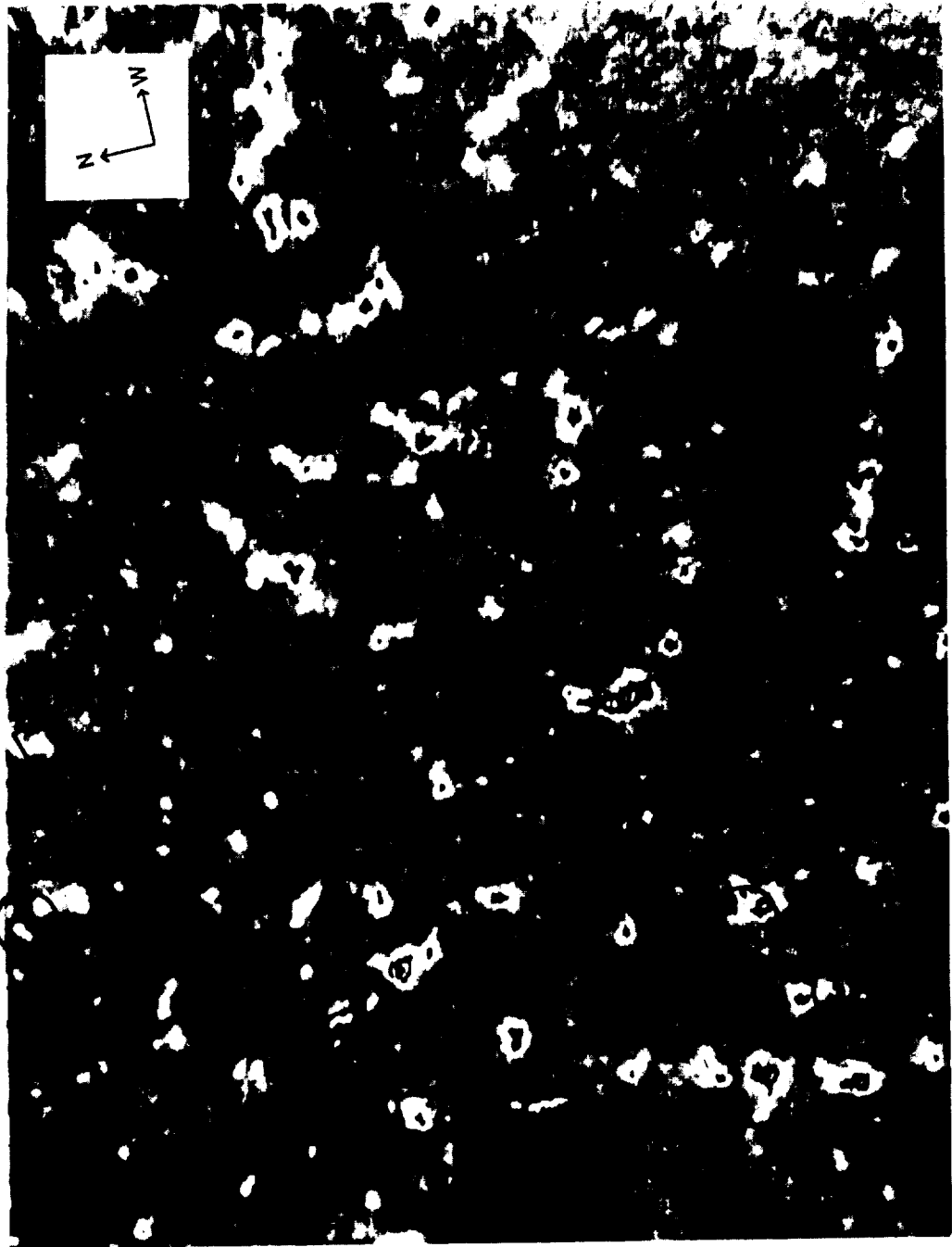


Fig. 2. An example of our comparison of the correspondence of magnetic bipoles to XBPs within one of the six VMG fields outlined by the rectangle shown in Figure 1. Square symbols identify cancelling magnetic bipoles and oval symbols identify emerging magnetic bipoles. If the evolution of the bipole occurred within one hour of the X-ray rocket flight, the symbol is marked with a solid outline, while if the evolution occurred later, the symbol is marked with a dashed outline. XBP locations are marked by the solid circles which are 20 arc sec in diameter.

older X-ray rocket images and daily NSO magnetograms falls in between these two studies, indicating that XBPs are slightly more likely to be associated with emerging than with cancelling flux /8/

Our result is consistent with Martin and Harvey's suggestion that XBPs are more likely to be associated with chance encounters of pre-existing flux than the emerging flux. This despite the fact that we have been unable to confirm one of their basic assumptions, namely that He DPs are a good proxy for coronal bright points (XBPs). We emphasize in this study, as with previous VMG studies, no distinction can be made among various mechanisms of flux disappearance.

It is possible that there are several physical classes of bright points/magnetic bipoles, and that these classes may have different solar cycle dependencies. It remains unclear where the XBPs occur with respect to the visible supergranular network. In our data most of the XBPs within the VMG fields were at sites of convergence of magnetic elements. Such convergence tends to occur at network boundaries, as do cancelling magnetic features /5/. Thus, our data provide some evidence that at least one class of XBPs occurs at network boundaries.

Finally, despite our acquisition of excellent time-series magnetic field and helium data, our comparisons were essentially static because of the short duration X-ray rocket flights. A definitive test of these correspondences and, therefore, an improved understanding of the solar small-scale magnetic flux spectrum must await the acquisition of simultaneous high spatial and high temporal resolution data at both coronal and optical wavelengths.

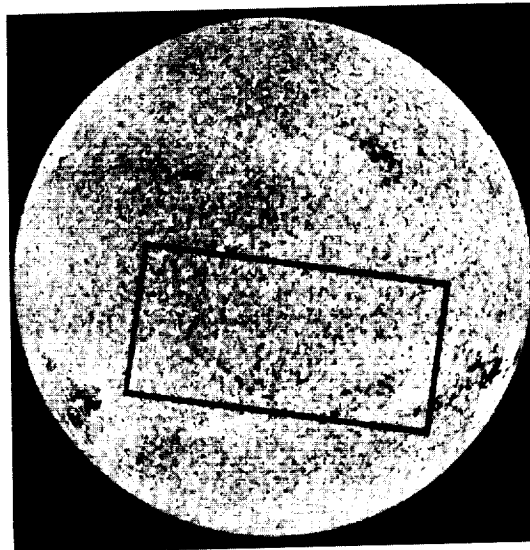
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11 DECEMBER 1987



NSO MAGNETOGRAM
1504-1544 UT



AS&E X-RAYS
1815 UT

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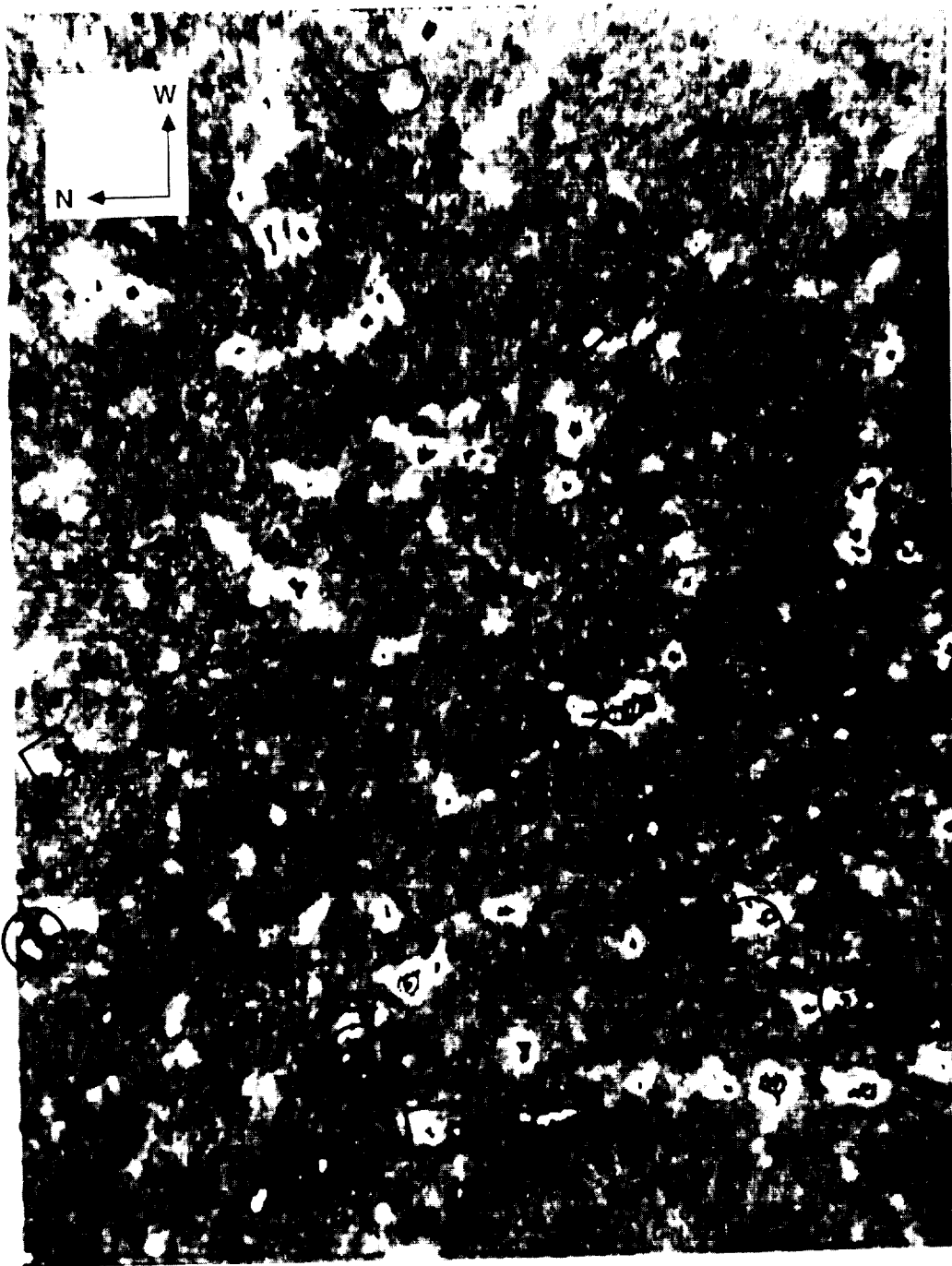


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4.20 The Observation of Possible Reconnection Events in the Boundary Changes
of Solar Coronal Holes

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