Rapid Changes in the Fine Structure of a Coronal ‘Bright Point’ and a Small Coronal ‘Active Region’

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Abstract. A coronal ‘bright point’ is resolved into a pattern of emission which, at any given time, consists of 2 or 3 miniature loops (each ~2500 km in diameter and ~12 000 km long). During the half-day lifetime of the ‘bright point’ individual loops evolved on a time scale ~6 min. A small ‘active region’ seemed to evolve in this way, but the occasional blurring together of several loops made it difficult to follow individual changes.

1. Introduction

A unique sequence of high-quality NRL Skylab/ATM spectroheliograms was obtained during a 1.5-day interval on January 19–20, 1974. This sequence was probably our best effort to observe the detailed structure and evolution of small-scale coronal features. First, it was obtained during the final Skylab mission by which time the photographic image quality had been optimized. The spatial resolution approached 2 arc sec. Second, despite a limited film budget, this sequence contained enough frames to follow coronal evolution on time scales ranging from 30 s to 3 hr.

The difficulty of obtaining the required spatial and temporal resolution has limited most studies of coronal ‘bright points’ to statistical analyses of their global surface distribution (Golub et al., 1975, 1976b), their average lifetime (Golub et al., 1976a), and their associated photospheric magnetic field (Golub et al., 1977). This paper is apparently the first attempt to describe the detailed evolution of the fine structure of individual ‘bright points’. Here, Fe xv 284 Å spectroheliograms resolve a ‘bright point’ and a small ‘active region’ into miniature loops whose histories can be followed from frame to frame. Although the temporal changes are definite, they are sometimes subtle and can only be seen with difficulty. Nevertheless, they are shown here to indicate the present limit of our observational knowledge of the structure and evolution of these small-scale coronal features.

2. The Observations

Figure 1 compares an Fe xv 284 Å spectroheliogram with a soft X-ray heliogram and a photospheric magnetogram. The Fe xv image and the X-ray image were obtained...
JANUARY 19, 1974

Fig. 1. A comparison of an NRL Fe xv 284 Å spectroheliogram, an AS&E soft X-ray heliogram, and a KPNO photospheric magnetogram on January 19, 1974. On these negative prints, A and B indicate the location of a coronal 'bright point' and a small coronal active region, respectively.

with the NRL slitless spectrograph and the AS&E soft X-ray telescope, respectively, in the Skylab Apollo Telescope Mount. The X-ray image is flawed by faint linear features that pass through the disk center from the lower left to the upper right. These flaws are characteristic of only the X-ray images that were obtained during
January 1974 when a misaligned shutter blade obscured part of the field of view. The magnetogram was obtained at the Kitt Peak National Observatory. Each image shows an equatorial swath of the solar disk with north up and east to the left. The Skylab images are negative prints. In the magnetogram, locally-bright features are areas of positive magnetic field (line-of-sight component toward the observer) and locally-dark features are areas of negative field.

The Fe \textsuperscript{XV} image is one frame of a special sequence of spectroheliograms that was obtained during the 1.5-day interval 11:43 UT January 19–01:07 UT January 21, 1974. This sequence was designed to observe the Sun with a variety of temporal resolutions ranging from 30 s to approximately 1.5 hr. The coarser resolution was achieved by exposing one frame every spacecraft orbit (~1.5 hr), or every other orbit on some occasions. The finer resolution was achieved during a single, 46-min portion of an orbit on January 19. In this case, 25 frames were exposed beginning at 6-min intervals and then progressing to 4-min, 2-min, 1-min, and finally 30-s intervals. The exposure time for each frame was 20 s.

In Figure 1, a coronal ‘bright point’ and a small coronal ‘active region’ are indicated by the letters \textit{A} and \textit{B}, respectively. The Fe \textsuperscript{XV} image resolves these features, but the X-ray image does not resolve them even when one allows for the obvious vignetting effects of the misaligned shutter blade. In the Fe \textsuperscript{XV} image, the ‘bright point’ consists of 2 features elongated nearly parallel to each other in the north-south direction. (This fine structure will be shown more clearly in Figure 2.) In the magnetogram, a small bipolar magnetic region is visible in this location. The north–south orientation of the bipolar axis is consistent with the assumption that the Fe \textsuperscript{XV} features outline coronal magnetic field lines. This assumption is strengthened by a similar examination of the small ‘active region’ (\textit{B}). In this case, an arcade of Fe \textsuperscript{XV} loops spans an east–west neutral line in a small bipolar magnetic region.

Figure 2 shows the evolution of the Fe \textsuperscript{XV} coronal ‘bright point’ on three different time scales during January 19–20, 1974. The upper strip shows the entire half-day lifetime of this feature at intervals that range from roughly 1.5 to 3 hr. At first one might tend to regard this strip simply as a sequence of blurred images whose differing fine structure is not of solar origin. Indeed, if such images had been obtained from the ground, one would tend to dismiss the differences as distortions produced by atmospheric seeing. However, an essential point of this paper is that these differences are real and indicate definite, temporal changes of the small-scale coronal structure. Perhaps the strongest evidence for this conclusion is the fact that the detailed small-scale differences vanish on frames taken less than two minutes apart (see below).

The middle strip shows a 24-min sequence at 6-min intervals. Even at this rate, successive frames differ significantly in their fine structure. The lower strip extends this sequence by an additional 18-min. However, in this lower strip, the 2-min temporal resolution clarifies the detailed way in which one pattern of emission evolves into another pattern 6 min later. Finally, the last four frames of this lower
Fig. 2. A sequence of Fe xv 284 Å negative images showing the evolution of the coronal 'bright point' on 3 different time scales during January 19–20, 1974.

strip are part of another sequence of frames that were obtained at 30-s intervals. We have not shown this sequence because the differences between consecutive frames are too subtle to reproduce.

These rapid, small-scale changes are particularly evident when they are observed in a time-lapse movie. We constructed a 16 mm movie from all 25 Fe xv images that were obtained during 19:41–20:27 UT. At a projection rate of 16 frames s⁻¹, this movie gave the impression that the 'bright point' remained essentially unchanged during the 46-min interval. However, at a rate of ~4 frames s⁻¹, the movie showed clearly and dramatically that the temporal variation consisted of the sequential, rapid formation and disappearance of several, spatially-different, small-scale coronal loops.

Figure 3 shows the evolution of the small Fe xv coronal 'active region' (B in Figure 1) during January 19–20, 1974 on the same three time scales that were used in Figure 2. Unlike the 'bright point', this small active region lived beyond the duration of the 1.5-day sequence of observations. (More than one day later, early on the morning of January 22, it was last visible as a structure having only one or two loops.) The upper strip shows the evolution of this region with a time resolution of 1.5–3 hr during the first 1.5-days of its 2.5-day lifetime. On this time scale, there are obvious detailed differences between consecutive frames.

The middle strip shows a 24-min sequence at 6-min intervals. Although detailed differences are present, they are not as pronounced as the differences on the time
Fig. 3. A sequence of Fe XV 284 A negative images showing the evolution of the small coronal 'active region' on 3 different time scales during January 19–20, 1974.
scale of 1.5–3 hr. The lower strip shows an 18-min sequence at 2-min intervals. The occasional blurring together of adjacent loops makes it difficult to follow detailed changes in coronal fine structure. This difficulty is even greater for larger active regions because individual loops are usually blurred together with many other closely-spaced and overlying (along the line of sight) coronal loops. We emphasize that this blurring is not caused by occasional image motion because other features on these full-disk images remained sharply-defined at the same times that the closely-spaced loops were blurred. (An exception occurred at 01:56 UT on January 20 when image motion did smear the spatial resolution of all features to 5–10 arc sec.)

Finally, there are two additional aspects of this study which we have considered, but which we have not attempted to demonstrate here. First, we have examined other ‘bright points’ in the January 19 images and found that they have essentially the same spatial and temporal characteristics as the ‘bright point’ that we illustrated here. This fact supports our assumption that these properties apply to virtually all coronal ‘bright points’.

Second, we have examined these images to see whether the rapid brightness changes are periodic as, for example, they might be if they were somehow associated with the 5-min oscillation of the photospheric velocity field. We found that if such coronal oscillations do exist, they are too subtle to detect from a simple inspection of the photographs. However, we did find cases in which widely-separated frames had very similar (but not identical) patterns of intensity (cf. the frames at 19:41 UT and 20:23 UT in Figure 2.) Such observations suggest that individual loops may sometimes brighten more than once. However, the relatively small size and frequent intervening changes of these features make it very difficult to determine whether or not these apparently recurrent structures are in fact the same loops.

3. Discussion

The fact that coronal ‘bright points’ consist of miniature loops is not surprising because they are associated with small bipolar magnetic regions (Krieger et al., 1971; Tousey et al., 1973; Harvey et al., 1975; Golub et al., 1977) and because larger coronal active regions seem to consist of loops. Indeed, coronal images often show elongated emission features joining the widely-separated magnetic poles of well-developed ephemeral active regions. However, it is interesting that a single ‘bright point’ may consist of more than one loop at any given time, and that the life history of the ‘bright point’ is a continuous sequence of rapidly-evolving and independently-evolving miniature loops.

The observed six-minute ‘lifetime’ of the individual loops is comparable to the cooling time that one would expect for such plasmas. We have estimated the radiative and conductive cooling times for these small loops using a temperature of $1.8 \times 10^6$ K (Little and Krieger, 1977) and an electron density of $8 \times 10^9$ cm$^{-3}$. (We derived this density from Nolte et al.'s (1979) emission measure analysis using the fact that our miniature loops were much smaller than their spatially unresolved bright
RAPID CHANGES IN THE FINE STRUCTURE OF A CORONAL

125

points.) Then, following the method used by Krieger (1978), we obtained a radiative cooling time on the order of 14 min. Similarly, using Krall’s (1977) extension of Culhane et al.’s (1970) technique, we obtained a conductive cooling time on the order of 10 min. Working together, these processes would have a combined cooling time of roughly 6 min.

It is interesting to compare our observations with Nolte et al.’s (1979) analysis of spatially unresolved X-ray bright points in a 25-min sequence of soft X-ray images obtained at 1.5 min intervals. They found that the intensities of most bright points remained significantly greater than one would expect for plasmas that were cooling from the estimated initial conditions of temperature, electron density, and size. They concluded that continual heating must occur on the time scale of the radiative energy loss. Although they did not specify this time scale explicitly, they implied that it must be comparable to the 5-min decay time of one of their bright points. Not only are our results consistent with Nolte et al.’s (1979) conclusion, but also our observations show the continual heating explicitly as the rapid formation and decay of individual miniature loops.

When Nolte et al. (1979) concluded that ‘bright points’ must be heated continually, they noted that they had obtained this same result in their study of larger-scale active region loops (Gerassimenko et al., 1978). In fact, Gerassimenko et al. (1978) stated that “if heating is due to discrete events, the time interval between events is . . . less than 10 min, which is short relative to the radiative cooling time of the loops”. We have not yet performed a similar analysis of the larger coronal structures in our sequence of high-resolution observations. As we have mentioned earlier, it is difficult to trace the detailed evolution of individual loops in large active regions because these loops are usually blurred together with numerous other such loops even with high spatial resolution. Consequently, we do not yet know if the continual heating of larger-scale coronal active regions is an intermittent process similar to the one that we observed for ‘bright points’ or (for example) whether it occurs at a much faster rate that is essentially continuous on a time scale of minutes.

In this regard, we note that there is an important difference between these very small active regions and the much larger ones. In a very small active region, photospheric magnetic flux is distributed in relatively few elements that are closely-spaced both to each other and to the often equally strong elements of the background field. Any small-scale fluctuations in the size and location of these elements would produce a relatively great effect on the average flux distribution and the associated coronal field line pattern of such a small active region. (Fluctuations of \( \sim 10^3 \) km during \( \sim 10^3 \) s occur continually in both quiet and active regions (cf. Sheeley, 1969, 1971; Vrabec, 1971, 1974; Harvey, 1977, and references contained therein). On the other hand, in a large active region the flux is concentrated in many such elements that are distributed over an area whose dimensions are large compared to the size and separation of the individual flux elements. Small-scale fluctuations in the size and location of these individual elements would have relatively little effect on the average field configuration of a large active region. Thus, one would not expect to obtain the
properties of a large coronal active region simply by scaling-up the properties of a very small one, or vice versa.

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