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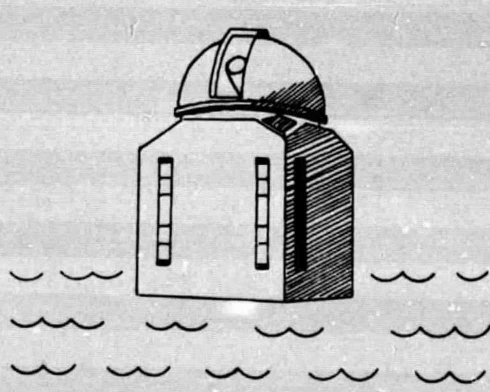

Hα OBSERVATIONS OF THE AUGUST 12, 1975 TYPE III-RS BURSTS

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ABSTRACT

We present Hα filtergram observations of a number of the Type III-RS (reverse slope) bursts that occurred on August 12, 1975. Solar radio emission was peculiar on that date in that a large number, and proportion, of the usually rare reverse slope bursts were observed (Tarnstrom and Zehntner, 1975). We show that the radio bursts coincide in time with a homologous set of Hα flares located at the limbward edge of spot group Mt. Wilson 19598. We propose a model in which the reverse slope bursts are the downward branches of U bursts, whose upward branches are hidden behind the coronal density enhancement over the spot group.

I. INTRODUCTION

Tarnstrom and Zehntner (1975), hereafter TZ, have called attention to the peculiar solar radio emission on August 12, 1975. In particular, they observed a large number and proportion of Type III-RS (reverse slope) bursts. We have studied the Hα filtergram movies taken at Big Bear Solar Observatory on August 12 and believe the combination of the Hα and radio data indicates a simple explanation for the preponderance of reverse slope bursts that day. Our argument is as follows: We consider each Type III-RS burst as the downward branch of a U burst whose upward branch is for some reason unobservable. From the Hα films we identify the sources of the Type III bursts as a series of flares at a satellite magnetic pole on the preceding edge of sunspot group Mt. Wilson 19598. We also identify a magnetic arch connecting the site of these flares with the following part of the group, which demonstrates a closed field structure necessary for a U burst. This spot group was at $\sim 45°$ W longitude on August 12, so our line of sight to the source of the Type III's lay through the coronal density enhancement over the group. Therefore the radio ray paths were reflected higher in the solar atmosphere on the preceding side of the group than on the following. The bursts were thus seen only with reverse slope because at a given frequency the plasma level, which is the site of the emission at that frequency, was observable only on the following side of the group, where the electron stream was moving down in the atmosphere.

II. OBSERVATIONS

The first point is the identification of the reverse slope bursts as the downward branches of U bursts. TZ show that at least two of their events, 1102 and 1507 UT, were downward branches, unusual in being more intense than their corresponding upward branches. Three additional events, 1220, 1651, and 1713 UT, were identified as U bursts by the groups at Harvard and at Weissenau (Solar-Geophys. Data, 1975). Since TZ see those as purely reverse slope, they must also have more intense downward branches. We will demonstrate below that at least one reverse burst, 1508 UT, was produced by activity identical to that of the U bursts at 1507, 1651 and 1713. By extension we will consider that all the reverse slope bursts on August 12 were in fact downward branches of U bursts. Our problem is then to determine why the upward branches were weak or unobservable.

Observations at Big Bear on August 12 covered 1420 - 0020 UT. The data used for this study were taken with the 22 and 25 cm vacuum refractors. Numerous small flares and surges occurred in Mt. Wilson 19598 throughout the day, with most of the activity taking place at the locations marked in Figure 1. A was a satellite magnetic pole near the preceding spots which produced a series of flares and surges, and is the site we identify as the source of the electron streams that produce the Type III bursts. Although present on August 11 and 13, A did not flare on those dates. B was an emerging flux region that appeared overnight and produced flares at 1445, 1625 and 2204 UT. C was a site among the following spots that produced nearly continuous slow surging.

Two series of events occurred at A. Events slightly to the north were at 1525, 1825, 2030, 2052, and 2310 UT. These were principally surge events, with flare brightening either absent or having a slow onset. The second series, slightly to the south, was at 1425, 1435, 1457, 1507, 1651 and 1713 UT. These events were flares in the chromosphere above the satellite pole, with surges following after, if at all. The 1425 and and 1435 events were relatively slow, but the others had one or more (at 1507 and 1713) impulsive flashes. It is this set of impulsive events that we can associate with the radio bursts. We now show the detailed correspondence.

The 1507 event had two flashes (Fig. 2). The initial brightening, from 1506:43 to 1507:15 matches the 1506.9 - 1507.2 radio event. This was followed by emission surges and then a second brightening at 1508:03 to 1508:23 that matches the 1508.2 - 1508.4 radio event. This second brightening was evident in its extension onto the penumbra of the large preceding spot.

The 1651 event (Fig. 3) was the simplest. It consisted of a bright flash in two points at the satellite pole at 1605:50 - 1651:01, which matches the radio event of 1650.9 - 1651.1. No surge appeared at any time.

The 1713 event (Fig. 4) was the largest of the day at Location A. Initial brightening occurred at 1712:57. Brightening extended onto the penumbra of the large spot at 1713:41. Peak brilliance occurred at 1714:00. Emission surging followed this flare. The radio event covers 1713.0 - 1715.6; the part shown by TZ in Figure 1a of their paper corresponds to the time of the peak brilliance.

The correspondence of radio and $H\alpha$ activity is not perfect. First, we observed an $H\alpha$ event at 1457 with a location and character similar to those which produced bursts, yet no radio event was seen. This is not a serious problem since previous studies (Kuiper and Pasachoff, 1973; Kuiper, 1973) have shown that the high resolution of the Big Bear data permits detection of $H\alpha$ activity which has no radio counterpart. Second, there was a radio burst at 1452.7 - 1452.9 for which there was no $H\alpha$ activity at A. Figure 5 shows that at the time of the burst the only $H\alpha$ activity is a rapid motion of emission material in an arch away from B. This was a part of the 1445 flare. If this activity did produce the 1453 burst, it is not clear why that burst should be similar to those produced at A, i.e. reverse slope. This one burst thus is a serious problem to our model.

One requirement for a U burst is a closed magnetic field, so that the electron stream is returned to a region of higher density. Figure 6 shows a closed magnetic arch connecting the preceding field which surrounds A with the following spots. Shortly after the onset of the 2310 emission surge at A, a portion of an arch appeared at the following spots. As the event continued, a two-pronged absorption surge was produced, reaching maximum height at 2320. At 2323 an extension of the arch from the following spots suddenly appeared, and in projection reached nearly to the preceding spots. This long arch was also two-stranded, and the material in it was downflowing, toward the following spots. We interpret this event as bulk motion of the surge material from A along a pair of closed field lines to the following part of the group. This is probably not the exact path followed by the burst electrons, since from Figure 1 of TZ the half travel time is $\gtrsim 2.3$ sec and at a velocity of c/3, the path length $\gtrsim 460{,}000$ km. The observed arch appears to lie too low to be that long. It should be noted that we do not observe any Hα brightening in the following part of the group at the times of the radio bursts, which would correspond to the impact of the electron stream at the footpoint of the closed field line.

III. THE MODEL

From our full disk photographs at ~ 1700 UT we measure positions of the large preceding spot to be 9°N, 49°W, and the centroid of the following spots to be 11°N, 38°W. Our line of sight to A lies directly over the center of the group, through the coronal density enhancement produced by the region. Newkirk (1961) has shown that the radio ray paths over an active region are reflected higher on the limbward side of the active region than on the side nearer disk center. Since reflection occurs at the point of maximum electron density along the ray path, this implies that at a given frequency we cannot observe plasma level on the limbward side of the group. Using the radio data as a probe of the coronal density structure in Mt. Wilson 19598, we can demonstrate the effect for this particular active region.

From TZ we take the following properties of the bursts: high frequency cutoff $\sim$ 500 MHz; low frequency turnover $\lesssim$ 130 MHz; and half travel time $\gtrsim$ 2.3 sec, implying a total path length of $\gtrsim$ 460,000 km. We assume that the high frequency cutoff is caused by the collisional destruction of the electron stream at the corona-chromosphere transition zone. Thus 500 MHz corresponds to the plasma frequency at the base of the corona at the ends of the closed field line. This is a minimum assumption on the density since the stream may degrade by some other mechanism before reaching the transition zone. The observation by TZ of Y bursts, which appear to show mirroring of the stream, indicates observationally that the stream may not always reach the transition zone. If we assume that the electron path has a roughly circular shape, we can use the total path length and the surface separation of the base points, $\sim$ 132,000 km, to solve for the height of the top of the path. Setting the plasma frequency at the top of the path to 130 MHz, we can then derive a density scale height which is $\sim$ 40,000 km. Using the base density and scale height we model the density structure over the region as

$$N_e(R,\theta) = \mathrm{EXP}\left(\frac{1.003-R}{.0571}\right) \times \left[5.0\times10^{8} + 8.0\times10^{9}\ \mathrm{EXP}\left(-\left(\frac{\theta-43.5}{5.5}\right)^2\right)\right] \qquad (1)$$

where R is in units of a solar radius. The spherically symmetric term represents the quiet corona. Use of a Baumbach density law for the quiet corona term gives nearly identical results for the ray reflection over the active region.

Figure 7 shows the result of ray tracing calculations using the density model of Equation 1, ignoring magnetic fields. The ray reflection levels were determined for 100 and 300 MHz. Each level represents the deepest layer in the solar atmosphere from which radiation at the given frequency can propagate to earth. Because of the finite step size of the ray tracing program, the levels plotted are systematically too deep by ~1/2 a step or ~ 7,000 km. It is easily seen that the ray paths penetrate to the plasma level on the following side of the group, but not on the preceding side. Type III bursts produced by activity on the preceding side of the group therefore should not be observable as the electrons rise in the corona. The bursts will only be seen on the following side of the group, as the electrons move downward, producing a reverse slope burst.

There are several constraints which must be met for this model to apply. The observed bursts must be emitted at the fundamental frequency, not the second harmonic. Emission at the harmonic would not be blocked by the coronal density, and the upward branch of the U burst would be observed. Another condition is that the line of sight lay in the plane of the arch along which the burst electrons travel. Soft X-ray observations, for example Vaiana et al., (1973), show that in active regions the coronal density is larger in individual magnetic arches, with lower densities elsewhere. We are concerned with such a high density arch since the repeated flare and surge activity at location A must have deposited an excess of material into a few closed field lines. If the arch was at an angle to the line of sight, the emission from the upward branch could be observed through the regions of lower density. The 2320 UT event indicated that we probably were in the plane of the arch. A related condition is that the corona above the spot group not be too inhomogeneous, lest scattering off the inhomogeneities direct some of the upward branch emission to Earth. The isolation and simple bipolar nature of the group, with activity limited to scales much smaller than the group, suggest that this condition was also met.

IV. DISCUSSION

The basic idea of our model is that an RS burst is emitted as a U burst but a region of higher density between the ends of the magnetic arch prevents observation of the upward branch. Since this model appears to explain the bursts of August 12, 1975, perhaps it can explain other RS bursts. The alternative model is that the bursts are emitted only with reverse slope, either because the electron stream is produced at high altitude and travels only downward, or some peculiar configuration of the fields or density inhibits emission during the upward passage. This last mechanism would be difficult to confirm

TABLE 1

Type III-RS Bursts with Hα Data

	Date	Time(UT)	Description
1	8/1/72	0146	Flash in arch at neutral line
2	"	2118	Similar to 1
3	10/25/72	1136	Large filament activation, X-rays
4	10/26/72	0957	Flare-surge at satellite pole
5	"	1254	Similar to 3
6	8/9/74	0850	Flare-surge at satellite pole
7	"	1003	Flare at satellite pole
8	"	1018	Small filament activation, surge
9	9/11/74	1148	Flare points at satellite pole

observationally; if the electrons cannot excite plasma oscillations they probably cannot produce any other observable phenomena. If the electrons are produced at high altitude, there are observational consequences. There should be some weak RS bursts with no Hα event. There should be some bursts in which the radio travel time between the near and far sides of an arch is large; these bursts would look like the inverse of a merging front event. Bursts associated with Hα flares will have one of two possible characteristics. If the flare is produced by the impact of the electrons on the chromosphere, there should be X-rays from thick target emission. If the flare is produced by a thermal mechanism, there should be two Hα ribbons separated by a distance comparable to the altitude, $\sim$ 100,000 km.

To further test these models observationally, we searched Solar Geophysical Data for the years of 1970 through 1974, and found 11 days with more than two Type III-RS bursts. Among these days and adjacent ones with bursts from the same spot groups, we have Hα data on 9 bursts, listed in Table 1. Four (4,6,7,9) are identical in character with the August 12 activity. Only two (3,5) have the scale or the X-ray emission predicted by the high altitude model. Thus we have seven more events which cannot be explained by alternative models. Although none of these events has as simple a geometry as those on August 12, it is not impossible to construct coronal models which produce similar blocking of upward branch emission.

V. SUMMARY

We believe that the unusual number and proportion of Type III-RS bursts observed on August 12, 1975 can be explained by a simple geometric configuration. We find that 4 of the 5 bursts for which there is Hα data coincide in time with impulsive flare brightenings at a satellite magnetic polarity on the preceding edge of Mt. Wilson 19598. We show that the preceding field surrounding the satellite pole is connected by closed field lines to the following field of the group, providing a necessary configuration for U bursts. Finally we show that the preceding side of these closed field lines was unobservable at meter wavelengths due to the coronal density enhancement over the group. Thus a radio burst would only be seen on the following side, as the electron stream moves downward in the corona travelling from the flare site, producing a reverse slope. We do note however that at least one RS burst, at 1453 UT, does not fit this model.

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REFERENCES

Kuiper, T.: 1973, Solar Phys. 33, 461.

Kuiper, T. and Pasachoff, J.: 1973, Solar Phys. 28, 187.

Newkirk, G.: 1961, Ap.J. 133, 983.

Solar Geophysical Data, 374 Part I, p. 102, August 1975, U.S. Dept. of Commerce, Boulder, Colorado 80302.

Tarnstrom, G.L. and Zehntner, C.: 1975, Nature 258, 693.

Vaiana, G.J., Davis, J.M., Giaconni, R., Krieger, A.S., Silk, J.K., Timothy, A.F., Zombeck, M.: 1973, Ap.J. 185, L47.

FIGURE CAPTIONS

FIGURE 1:

Mt. Wilson 19598 on August 12, 1975. West is left, south is up. Times given in UT. At the top the cross marks disk center. Note the basically bipolar nature of the spot group and its isolation on the disk. Locations marked in the bottom photograph are the sites of activity on August 12. Flares associated with the radio bursts occurred at A.

FIGURE 2:

Hα activity at 1507 and 1508 UT. Top sequence is Hα + .6 Å, lower sequence Hα line center. West is up. The 1507 radio event corresponds to the initial brightening at the flare site. The 1508 event matches a second brightening, which also extends onto the penumbra of the largest p spot.

FIGURE 3:

Hα activity at 1651 UT. At the time of the radio event there is an impulsive brightening at the satellite pole. No surge is produced.

FIGURE 4:

Hα activity at 1713 UT. Top sequence is Hα line center, lower sequence Hα + .6 Å. The radio event begins at the time of initial Hα brightening. As in the 1508 event, emission extends onto the penumbra of the largest p spot (1713:41). The portion of the radio event shown by Tarnstrom and Zehntner (1975) corresponds to the time of peak Hα intensity, 1714:00.

FIGURE 5:

Hα activity at 1453 UT. Arrow marks the arch of moving emission material. This is a part of the 1445 flare in the EFR at location B. Location A shows no rapid change at this time; only the slow decay of the 1435 event is in progress.

FIGURE 6:

Surge and arch structure at 2320 UT. West is up. The surge maximum is followed by the appearance of long arch connecting to the following spots. Note that both structures are double stranded.

FIGURE 7:

Coronal model of Mt. Wilson 19598. Density structure is given by Equation 1. Dotted lines are density contours; heavy dashed lines are radio reflection levels; light dashed lines schematically represents the closed field line along which the burst electrons travel.

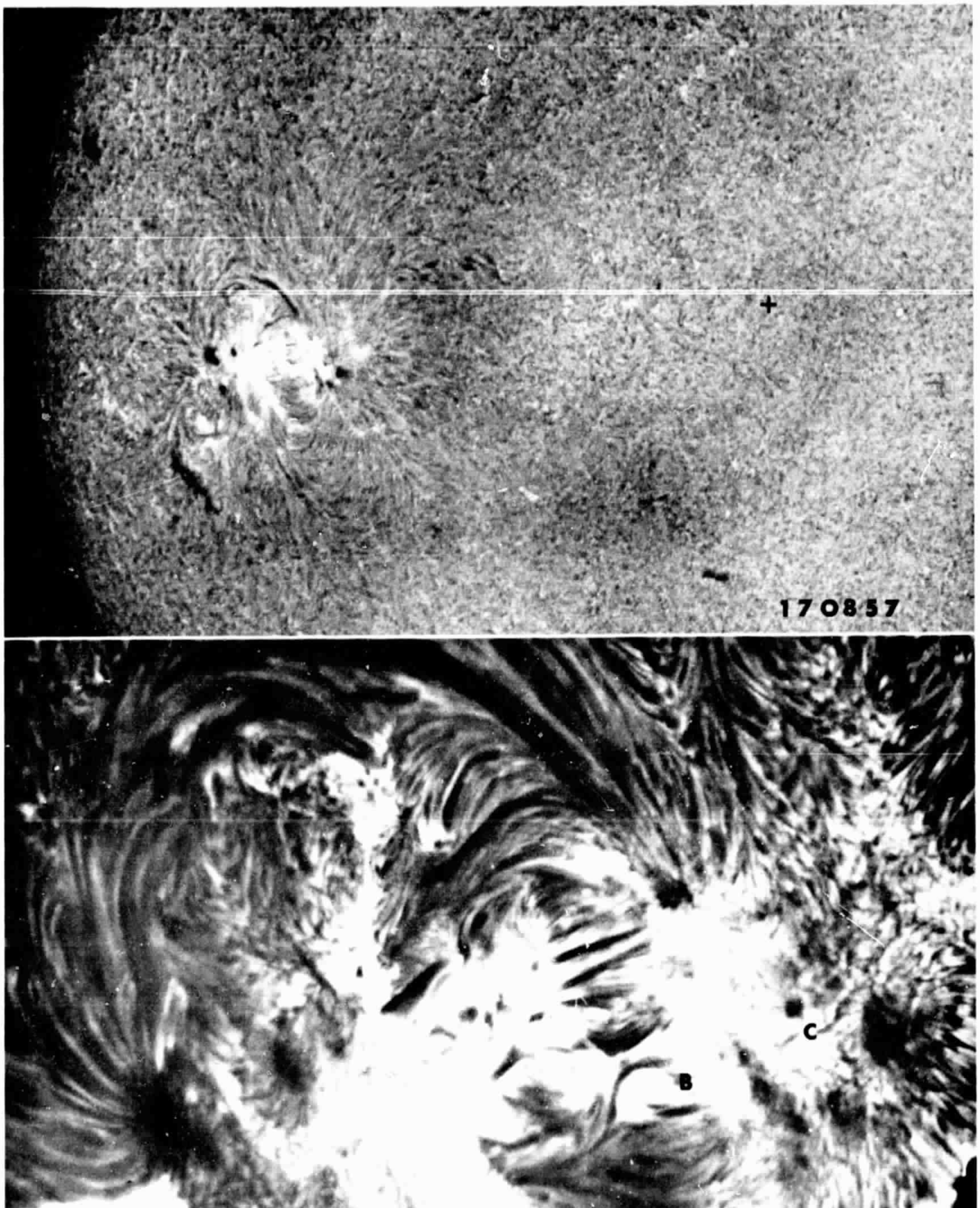


Figure 1

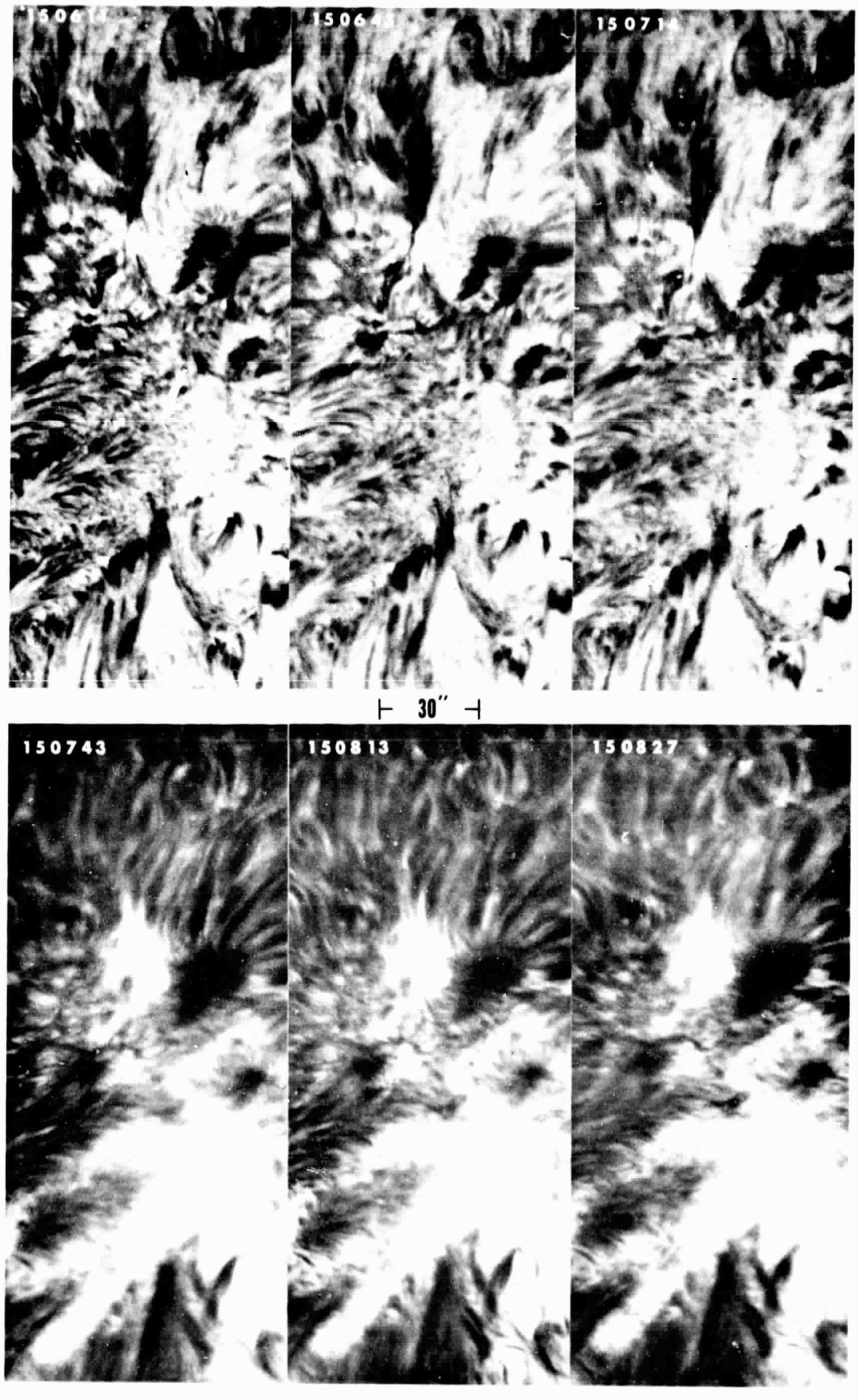
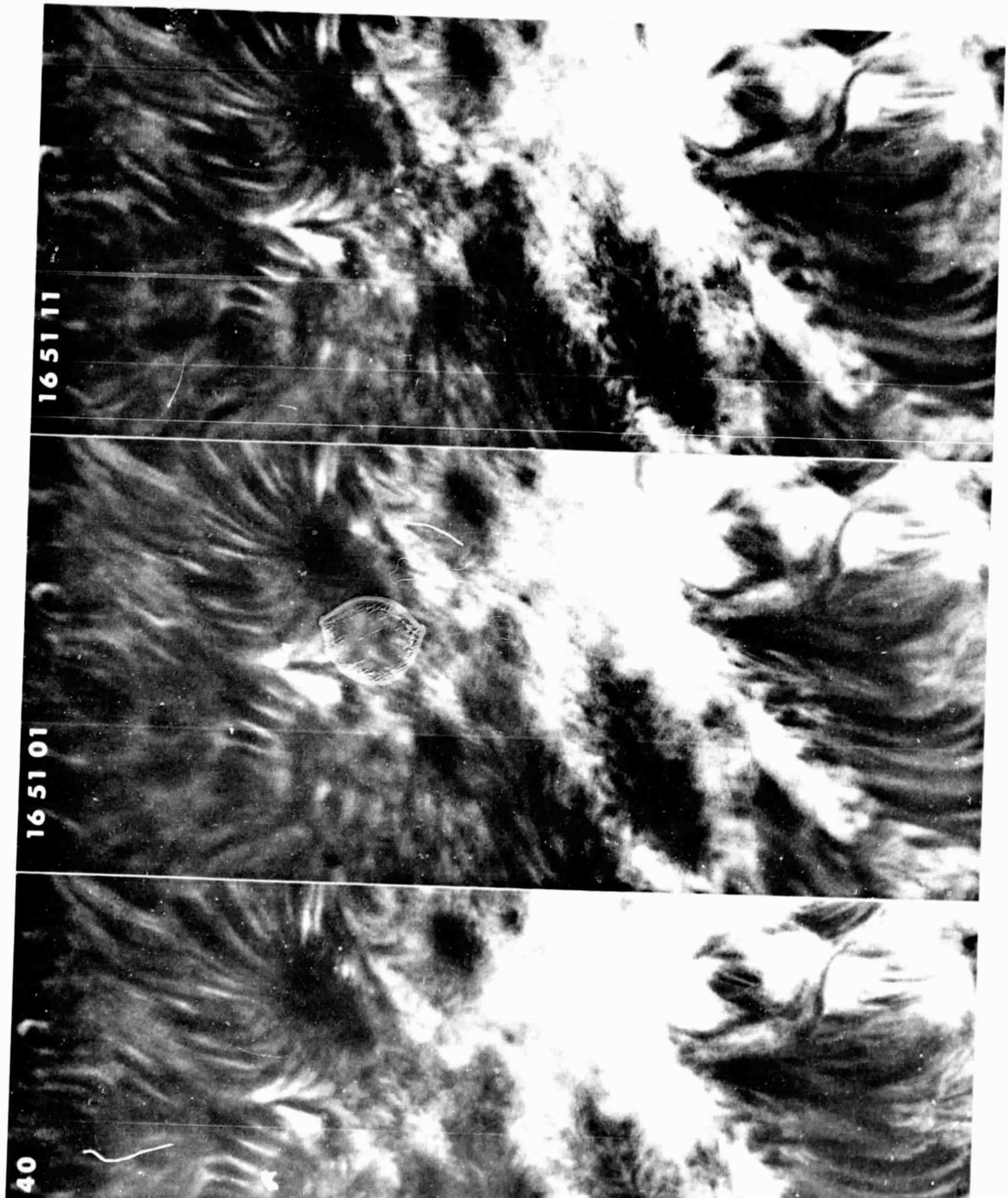


Figure 2



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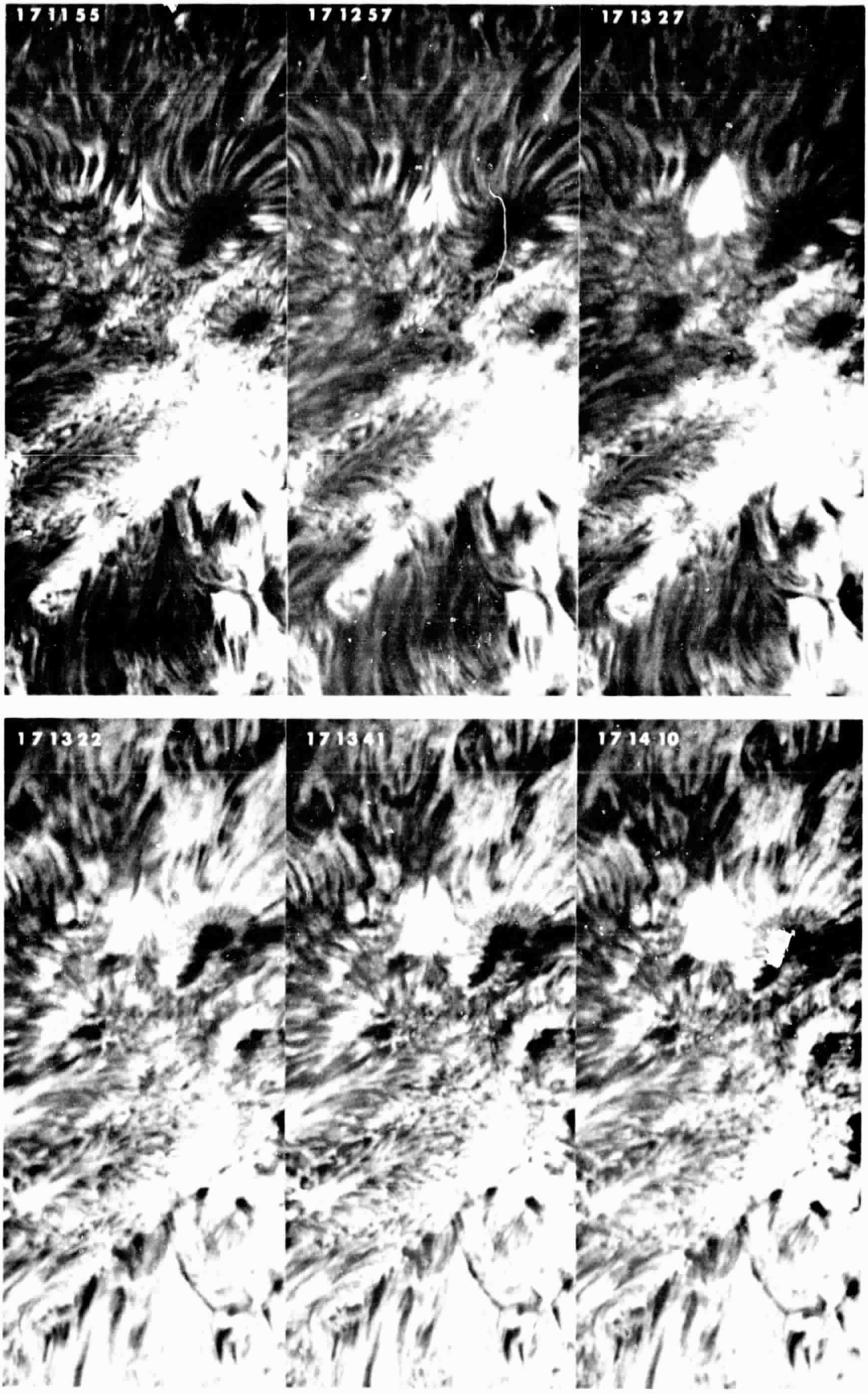

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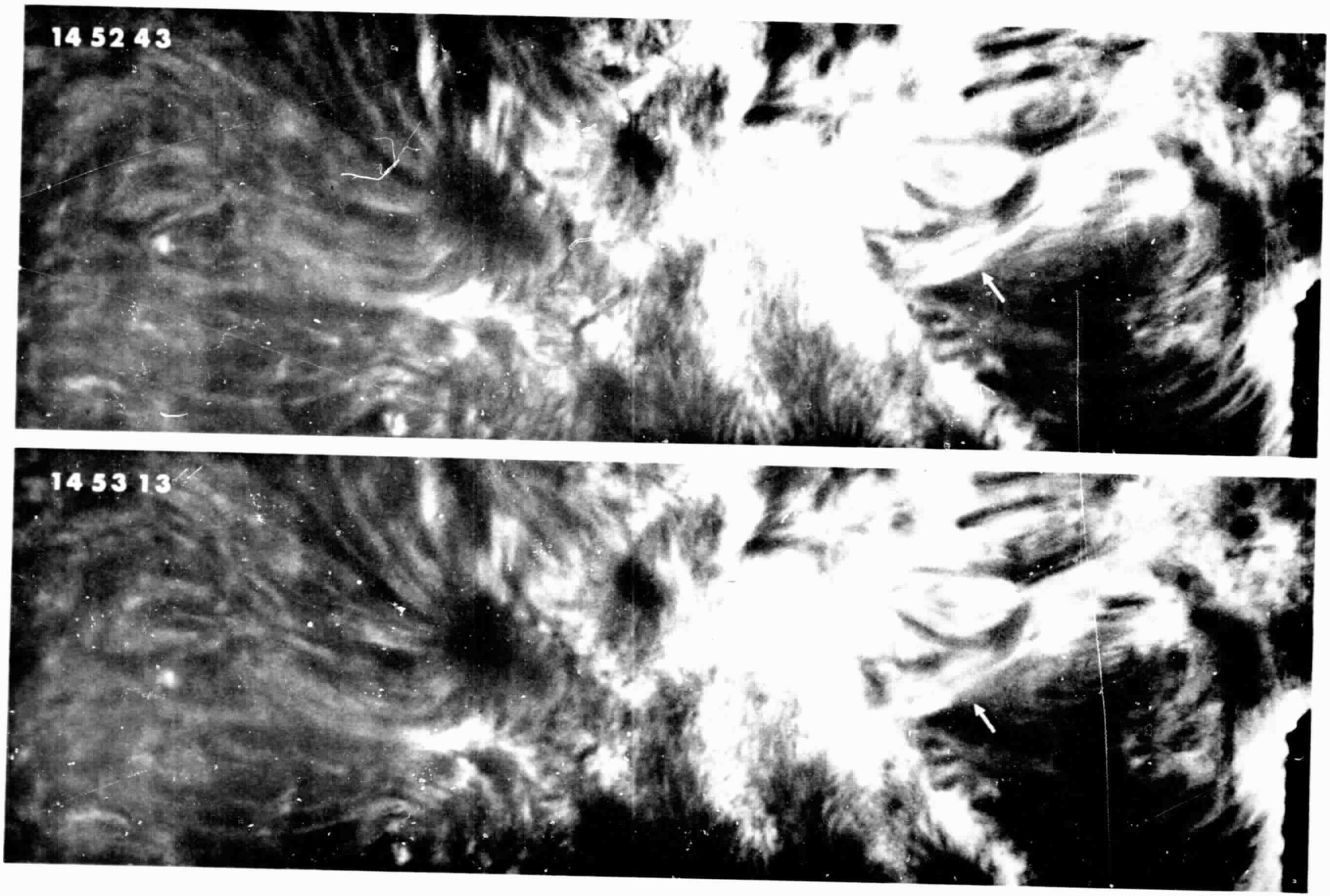

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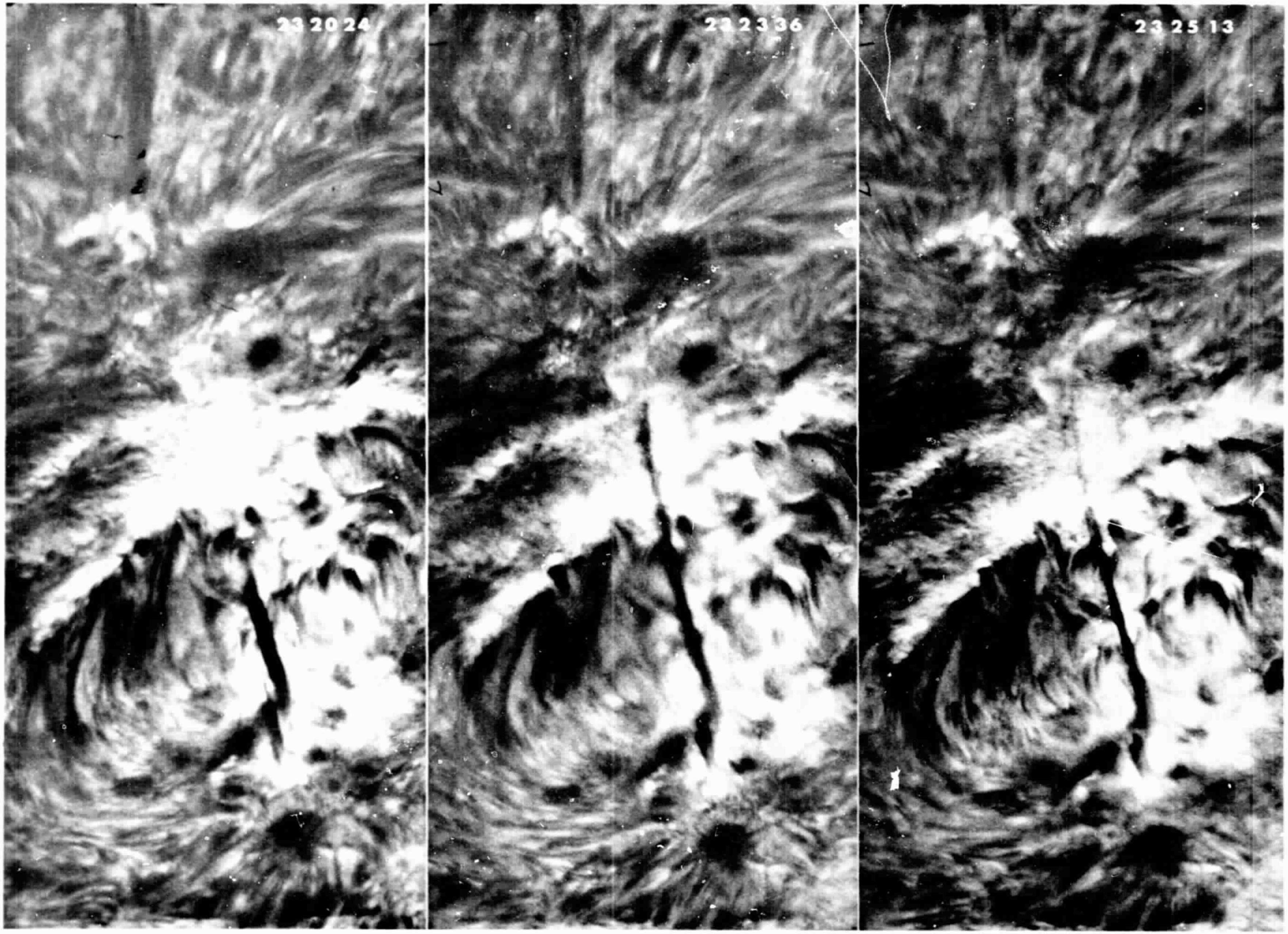

Figure 6

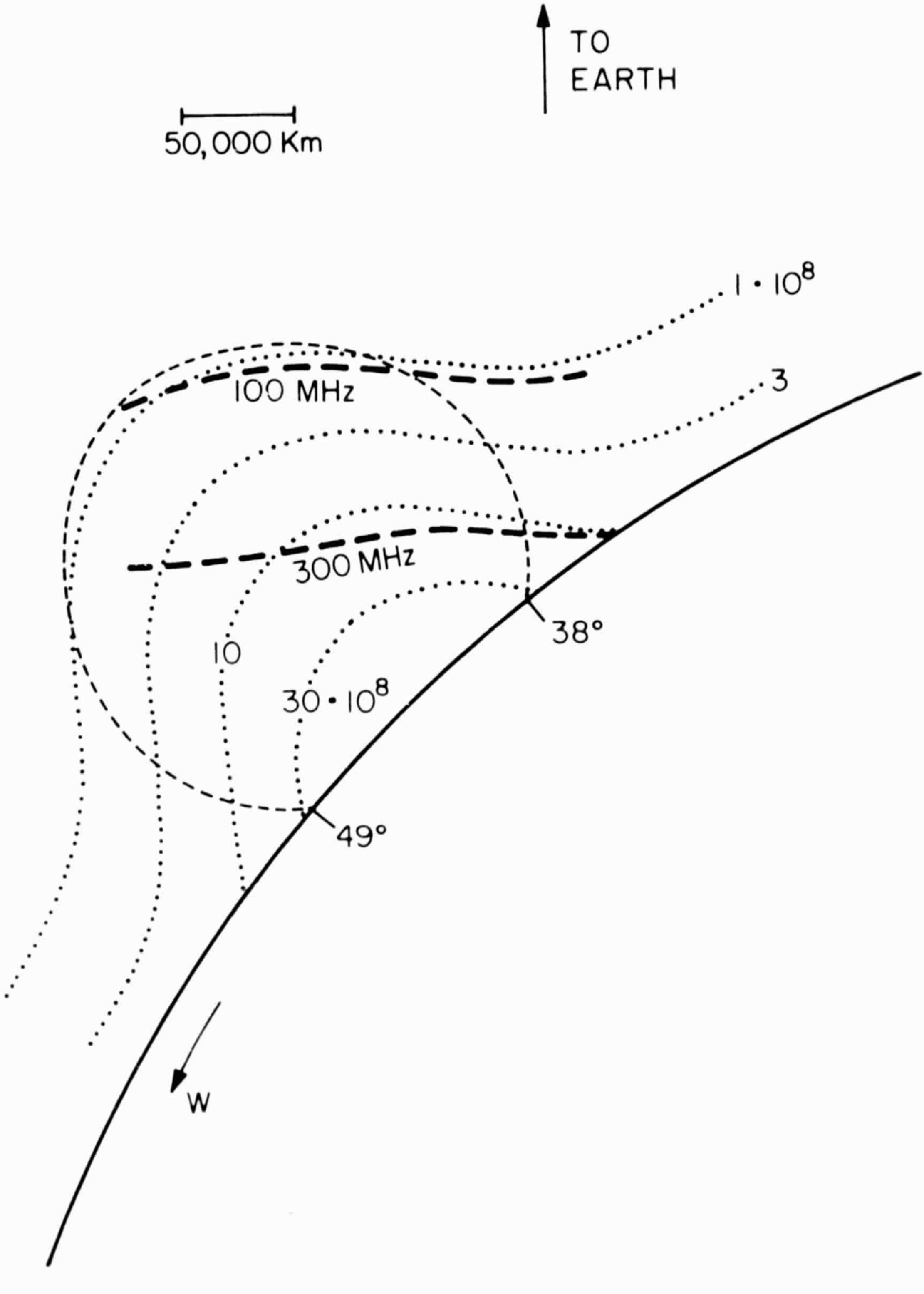
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Figure 7