NGR-05-002-034

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(NASA-CR-147103) THE LIFETIME AND EVOLUTION OF FIBRILS (Carnegie Institution of Washington) 32 p HC $4.00 CSCL 03B

N76-23137

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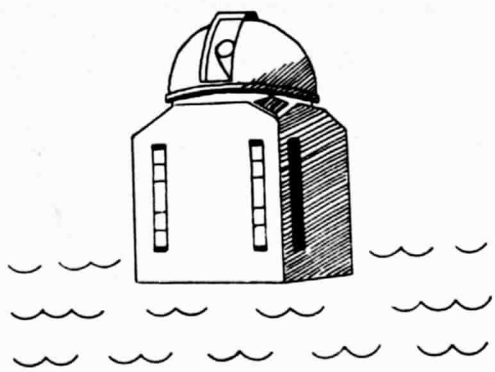

THE LIFETIME AND EVOLUTION OF FIBRILS

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CALIFORNIA INSTITUTE OF TECHNOLOGY

March, 1976

BBSO #0156

ABSTRACT

A detailed study has been made of the lifetimes and evolution of fibrils in McMath 12417, using high resolution filtergrams in Hα and CaII K made at Big Bear Solar Observatory. It was found that the lifetime of a fibril increases monotonically with its length. This relationship, together with the form of the variation of fibril lengths as a function of time, suggests that fibrils result from material being impulsively injected into magnetic field lines at approximately 30 km/sec, and returning under gravity. The lifetimes and apparent lengths of fibrils are then a function of the inclination of the field lines only. A study of wavelength scans through the Hα line confirms that the apparent expansion and contraction of fibrils represents true mass motion.

1. INTRODUCTION

One of the most prominent characteristics of an active region as viewed in a chromospheric spectral line such as Hα or CaII K, is the appearance of numerous elongated features known as fibrils. These features are generally believed to follow magnetic field lines, and as a result, the fibril pattern is widely used to obtain information on magnetic field structure. However, despite the usefulness of the fibril pattern as a tool for the study of active regions, very little effort has been made to study the properties of the individual fibrils themselves. What little information exists is best summarized by Bray and Loughhead (1974). Briefly, it has been found that the lengths of fibrils depend on the longitudinal magnetic field strength (Smith 1968), and their lifetimes vary with length, ranging from 1 minute for the shortest, up to 20 minutes for the longest (Foukal 1971). Superpenumbral fibrils undergo gradual changes with time, an individual fibril being recognizable for typically 17 minutes (Loughhead 1968). Zirin (1974) showed that there exist both bright and dark fibrils, and both occur simultaneously, bright fibrils being more prominent in CaII K, and dark fibrils being more prominent in Hα. The relationship between fibrils and other disk features has been discussed by Foukal (1971), who suggested that fibrils are simply the active-region analogues of spicules, the difference being merely one of field geometry.

The purpose of this paper is to present the results of a systematic study of the lifetimes, lengths, and evolution of fibrils in an active region, in the hope of obtaining a better understanding of their physical nature. Before beginning such a study, however, it is necessary to define what is meant by "lifetime". As an operating definition we will define the lifetime of a feature as the period during which its appearance (as characterized by shape and contrast) is recognizable by eye as belonging to the same entity. Such a definition is obviously subjective, but as will be seen later, this presents no problem since most fibrils execute a fairly well defined evolution, which is often a simple up-and-down motion. Even in cases of merging and fading, the visibility of the fibril changes sufficiently drastically in a short time interval that there is little difficulty in assigning a lifetime.

2. THE DATA

The data used in this study consists of a series of high-resolution Hα and CaII K filtergrams of the active region McMath 12417, made using a pair of 10 inch refractors at Big Bear Solar Observatory during the period July 4 - 11, 1973. A fully-tunable Zeiss filter of 0.25A bandpass was used for Hα, and a Halle filter of 0.3A bandpass was used for CaII K (see Zirin 1974 for a more complete description of the K-line filter). Frames were taken at 10 second intervals throughout most of the observation period, thus facilitating a cinematographic study with good time resolution.

The evolution of over 200 individual fibrils was followed in Hα centre-line, and in each case the lifetime and maximum length were recorded as a function of location within the active region. A number of fibrils were studied in detail, and their lengths plotted as a function of time. The evolution of 26 bright fibrils in CaII K was similarly studied, and in some cases, a direct comparison was made with the corresponding event in Hα . Figure 1 shows an Hα and a CaII K picture of the region as it appeared on July 5, together with a definition of the various sub-regions used to group the fibrils for later discussion.

Wavelength scans through the Hα line (-1, -0.5, 0, +0.5, +1 Angstroms) had been made frequently during the course of the observations, and these were used to obtain velocity information.

3. RESULTS

3.1 Qualitative description of evolution

In order to put the quantitative results of this investigation into perspective, a brief qualitative description of the evolution of fibrils will first be given.

A. General remarks

Fibrils evolve in a number of ways, for example expansion and contraction, merging, and fading. Most dark fibrils in Hα co-evolve with a parallel bright strand, which often undergoes conspicuous increases in intensity. Many fibrils are double, a fact noted by Tanaka (1972). In some cases a pair of fibrils (from the same plagette) will evolve together, while in other cases a single fibril will fade and then split during the late stages of its lifetime. More will be said about double fibrils and bright fibrils in sections 5 and 6 respectively.

The evolution of a typical fibril is shown in a sequence of frames in figure 2.

B. Comparison of evolution in different regions

Plage and enhanced network: All fibrils clearly evolve by an upwards expansion followed by a downwards contraction.

Superpenumbra: Many fibrils exhibit a clear expansion away from spot, followed by an inwards contraction, although more often a fibril will become visible by darkening along its length and then fall into the spot. The general impression in the superpenumbra is that of an overall inflow of material.

Arch region: Arches often evolve by expanding and contracting, for example an arch can be formed by a fibril emerging from a plage and extending into a sunspot, and then retreating again. In other cases, an arch will exhibit a more-or-less continuous flow of material during its lifetime, and then fade away.

Filament region: Fibrils in the neutral-line region adjacent to a filamer are in some cases born by expanding out of a plagette, and in other cases by the merging of several shorter fibrils. Many fibrils end their existence by merging with other fibrils.

3.2 Statistics of fibril lifetimes

Figure 3 shows a series of histograms of Hα fibril lifetimes for various ranges of apparent lengths, measured on July 4 and 5, when the region was near disk centre. It can be seen that for short fibrils (ℓ < 5 arcsec) the lifetime distribution is more-or-less symmetrical, with a well-defined maximum. For longer fibrils, the peak in the distribution is shifted towards longer lifetimes, and becomes broader and more asymmetric with a progressively larger tail extending to long lifetimes. The implications of these results will be discussed later.

The most probable lifetime has been plotted as a function of length, and the results are given in figure 4. This figure shows that the lifetime of a fibril increases monotonically with its length, and this confirms the tendency noted by Foukal (1971). These results will be discussed in terms of a simple evolutionary model in section 4.

Finally, the mean lifetimes and lengths have been determined for both Hα dark fibrils and CaII K bright fibrils as a function of location within the active region, and the results are presented in table 1. This table shows that fibrils in regions of predominantly horizontal magnetic field (filament region, superpenumbra) have much longer lifetimes than those in vertical field regions (plage, enhanced network), a fact which finds a logical explanation in terms of the model described in section 4. The table also shows that the properties of bright CaII K fibrils are similar to those of dark Hα fibrils, and in fact fit closely on the Hα lifetime v. length relation.

3.3 Motion of individual fibrils

As discussed in section 3.1, the greater proportion of fibrils appear to be born in the form of jet-like streams of material expanding out of plagettes. In the plage and enhanced network regions, they exhibit a clean up-and-down motion, while in the filament region and superpenumbra they often oscillate in length over an extended period of time, and sometimes end their existence by merging with other fibrils. Representative plots of the variation of length as function of time are given in figure 5, for various locations within the active region. These curves are characterized by deceleration during the rise portion and acceleration during the decay portion. Such behavior is consistent with a model in which material is rising and falling under gravity, a possibility which will be dealt with quantitatively in section 4. However, before we consider a model of this nature, we must first determine whether or not the apparent expansion and contraction of fibrils represents real material motion. This has been accomplished by studying a series of wavelength scans through the Hα line, and the results are presented below.

A. Vertical features on disk

The Doppler shifts and expansion motions of fibrils in plage and enhanced network regions (i.e. regions in which there is an appreciable line-of-sight velocity component when viewed on disk) have been studied on the disk using a wavelength scan made on July 6 at 2100 UT, together with the Hα movie.

Firstly, a list was made of 23 fibrils which were visible in one wing of the Hα line only, i.e. Hα-0.5A or Hα+0.5A (see figure 6). The Hα movie was then examined to determine in each case whether the fibril was expanding or contracting. The results were as follows:

(i) Out of 10 fibrils visible in Hα-0.5A only, 8 were expanding and 2 showed no clear motion.

(ii) Out of 13 fibrils visible in Hα+0.5A only, 9 were contracting, 3 showed no clear motion, and 1 (a superpenumbral fibril) showed a continuous flow into the sunspot.

Secondly, the converse process was carried out, i.e. from the movie, a list was made of 10 fibrils which showed clear expansion or contraction motion. A comparison was then made with the wavelength scan to see whether the observed motions corresponded to Doppler shifts (see figure 6). The results were as follows:

(i) Out of 7 fibrils which were expanding, 4 were most visible in Hα-0.5A, and 3 were equally visible in either wing.

(ii) Out of 3 fibrils which were contracting, all 3 were most visible in Hα+0.5A.

The above results clearly show that the apparent expansion and contraction of fibrils in near-vertical field regions corresponds to real upward and downward motion of material. In some cases, the fibril was totally invisible in one wing of the line, indicating that velocities of the order of 20 km/sec (or greater) are involved.

B. Superpenumbral fibrils near limb

In order to study the Doppler shifts of the horizontal fibrils in the superpenumbra, it is necessary to observe these fibrils near the limb, where there is an appreciable line-of-sight velocity component. To this end, a total of 7 wavelength scans were examined, corresponding to the period July 8 - 11 during which the active region was near the west limb, in order to determine the direction of motion of material in the fibrils on the limbward side of the spot, and to estimate the velocities involved. It was found that of 58 fibrils whose Doppler shifts could be detected from their relative contrasts in Hα-0.5A and Hα+0.5A, 47 corresponded to motion towards the spot, and 11 corresponded to motion away from the spot. This confirms the existence of the well-known inward chromospheric Evershed flow (Bray 1974), but also shows that in about 20% of the superpenumbral fibrils, material is flowing outwards, thus confirming the apparent outward motion of many superpenumbral fibrils observed on Hα movies. Relatively large velocities are involved (a few tens of km/sec), as evidenced by the fact that some fibrils were quite prominent in Hα $\pm$ 1 A.

4. A SIMPLE MODEL FOR FIBRIL EVOLUTION

It was shown in the previous section that the greater proportion of fibrils evolve by expansion and subsequent contraction, and that this motion corresponds to material flowing at velocities of the order of tens of km/sec. It was also shown that the lifetime of a fibril increases monotomically with its length, as in figure 4. We now consider a simple model in an attempt to explain these observations.

Suppose we assume that fibrils result from impulsive ejection of material into magnetic field lines, at a constant velocity v_0, and that gravity is the only decelerating force. The lifetime then represents the time taken for the material to travel upwards and return to the surface, and hence both the lifetime and maximum apparent length are functions of the inclination of the magnetic field lines only (assumed to be straight).

If g is the surface gravity of the sun, then it is easy to show that the lifetime T of a fibril will be related to its maximum projected length, ℓ, by:

$$T = \frac{2v_0}{g}\sqrt{1 + \left(\frac{2g\ell}{v_0^2}\right)^2} \tag{4.1}$$

In order to apply this equation it is necessary to know v_0. One way of determining its value is to measure the expansion velocity of fibrils in the filament region of the neutral corridor (assumed to be parallel to the sun's surface). Taking an average for 16 such fibrils yields the value $v_0 = 34 \pm 4$ km/sec, which is entirely consistent with the Doppler shifts measured in the previous section. Substitution for v_o and g in equation (4.1) then yields the theoretical lifetime v. length curve plotted in figure 4.

It can be seen that the theoretical curve fits the observations entirely within the error bars. The agreement is remarkable considering that the theoretical curve was not normalized to the observations - it depends only on g (which is well known) and v_o (which could have been determined quite independently using the Doppler shifts). This result argues strongly in favor of the simple model outlined above.

The model is obviously a simplification of the true situation, however, since many fibrils do not execute a simple expansion/contraction motion (see section 3.1). For example, the longest fibrils in the filament region and superpenumbra often oscillate in length, with "periods" of typically 20-60 minutes. Such behavior might be explained as a result of repeated injection of material into field lines. If we interpret the figure of 20-60 minutes as the interval between successive ejections of material, then for the near-vertical fibrils in plage and enhanced network regions, equation (4.1) shows that the ejected material would have no trouble in returning to the surface before the next ejection, resulting in a clean up-and-down motion, as observed. However, for the near-horizontal fibrils in the filament region and superpenumbra, the material takes much longer to return to the surface, and in many cases would not make it back in time for the next ejection. The resulting fibril would then fluctuate in length for an indefinite period of time. Such an effect may be an important contributor to the extended tails of the lifetime histograms of figure 3. The origin of these tails will, however, be discussed more fully in section 7.

5. THE PHENOMENON OF DOUBLE FIBRILS

A detailed study of dark mottles in quiet regions of the disk, as viewed in Hα , shows many such features to be double (Tanaka 1972). Tanaka found that the double phase of quiet-sun mottles lasts 40-80 seconds and repeats at intervals of 4-14 minutes, with evolution occurring by merging, splitting, and the formation of adjacent double structures. The present study has shown that double-structure is a common property of active-region fibrils also, and that such structure can arise in two distinct ways, namely:

(i) Splitting: A single dark fibril will often split at some stage during its lifetime. This typically occurs in the late stages of its evolution, and is usually preceded by fading.

(ii) Adjacent events: Quite often a pair of adjacent fibrils (either bright or dark) will reach exactly the same length, but show distinct differences in evolution.

Double structure of type (ii) is easily explained by material moving along adjacent flux tubes. More interesting, perhaps, is type (ii) double structure, which has been attributed to the existence of a hot central core surrounded by a cool outer sheath (Tanaka 1974). However, there exist many cases in which a dark fibril has a bright fibril on either side, and the combination co-evolves (see figure 7 for an example). Such a configuration would correspond to a cool core and hot outer sheath, which would be difficult to produce physically. Regardless of whether or not the "outer sheath" model is correct, it does appear that the double-structure phenomenon is related in some way to the nature of bright and dark contrast features, which will be discussed in the next section.

6. THE RELATIONSHIP BETWEEN BRIGHT AND DARK FIBRILS

A careful examination of filtergrams in Hα and CaII K shows that both bright and dark fibrils are present in both lines, the dark features being more prominent in Hα and the bright features more prominent in CaII K (Zirin, 1974). The bright fibrils are intimately associated with the dark fibrils, and in fact it appears that all or most dark fibrils have a parallel bright strand on one side (or in some cases on both sides). During the present study it was found that the bright and dark components evolve together, with the bright component frequently showing conspicuous increases in intensity. The bright components (like the dark components) appear to be associated with surging material.

The physical reason for the existence of bright and dark contrast features is not clear. In principle, the bright component of a fibril could be produced by motion transverse to the fibril axis (for example by rotation), such that the absorption profile of the transversely-moving material is shifted out ot the pass-band of the filter. However, this is unlikely since the relative configuration of the bright and dark components remains unchanged throughout a wavelength scan.

From a study of the Hα contrast profiles of mottles in the quiet chromosphere, Bray (1973) found that the source function of bright mottles is substantially greater than that of the dark mottles. To the author's knowledge, a similar comparison for bright and dark fibrils of the active chromosphere has not yet been carried out. Such a study would shed much light on the nature of the observed contrast features, and will hopefully be done in the near future. However, if the suspected analogy between quiet-chromospheric mottles and active-region fibrils is correct (Foukal 1971) then one would expect that the bright components of fibrils represent material with a greater source function (possibly due to higher temperature) than for the dark components.

7. DISCUSSION

It has been suggested (Foukal 1971) that fibrils are a result of shock waves guided along magnetic flux tubes. However the data obtained in the present study argues strongly in favor of a model in which fibrils represent material expelled impulsively into magnetic field lines, the subsequent motion being governed by gravity. The nature of the injection mechanism is uncertain, although we can exclude models which involve a prolonged acceleration of material, since the measurements of length as a function of time indicate that in all cases the material is decelerating from the moment the fibril becomes visible.

The impulsive ejection model is obviously a simplification of the true situation, since many fibrils are observed to evolve in other ways, for example merging and fading. However, such phenomena are mainly confined to the horizontal field regions of the superpenumbra and neutral line and indicate that other processes besides gravity are capable of modifying the fibril's appearance. The superpenumbra represents a particularly interesting situation, since the general impression is one of a continuous inflow of material rather than discrete expansion/contraction events (although such events often occur). It may be that the inward-flowing superpenumbral fibrils represent material which has been impulsively ejected into the sunspot by plage of opposite polarity, in which case the arguments of section 4 suggest that the apparent continuity of flow could be understood as a result of repeated ejection. The predominance of inflow (i.e.the chromospheric Evershed effect) would then imply that plages are more fervent producers of such ejections than sunspots.

An interesting effect which remains to be explained is that of the skew-symmetry of the lifetime histograms of figure 3. It is possible that the extended tails of these histograms are largly an instrumental effect caused by the pattern-persistence of the eye, such that after a structure has disappeared, the eye continues to see traces of it in what remains. Also, the death of one fibril may be confused with the birth of another in its proximity. In either case, the apparent lifetime of the fibril would be arbitrarily lengthened.

There are, however, several physical effects which could also contribute to the extended histogram tails, an example being repeated ejection (discussed in section 4). Another possibility is that the ejection velocity v_o is not the same for all fibrils. Although in section 4 it was assumed that v_o was constant at 34 km/sec, there is no proof that this is actually the case. A dispersion in velocity would be reflected in a corresponding dispersion in lifetimes, and it may be that the extended tails of the histograms are a consequence of a substantial number of fibrils having velocities less than 34 km/sec.

Finally it is of interest to compare the lifetimes of fibrils in active regions, with those of spicules in quiet regions. The mean lifetime of a spicule is 5 minutes (Beckers 1972), and when viewed on the disk, spicules have small projected lengths ($\sim$1 arcsec). Spicules thus fit closely on the short-length end of the lifetime v. length relation for fibrils, thus supporting Foukal's (1971) view that spicules and fibrils represent similar physical phenomena. The mean lifetime of spicules is, in fact, remarkably close to that predicted on the basis of the impulsive-ejection model in the limit as the projected length tends to zero (see figure 4).

8. CONCLUSION

The lengths, lifetimes, and motions of fibrils in the active region McMath 12417 suggest a model in which fibrils represent material being impulsively injected into magnetic field lines with a velocity of the order of 30 km/sec, and returning under gravity.

ACKNOWLEDGEMENTS

I wish to thank Dr. H. Zirin for his helpful comments, and for initially suggesting this project. I have benefitted greatly from discussions with Dr.'s R. Moore, G. Hurford, and A. Patterson. This work was supported by NASA grant NGR 05 002 034 and NSF grant ATM74-13489.

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TABLE 1

Mean lifetimes and lengths of fibrils at various locations in the active region.

Wavelength:	Region:	Maximum length: (arcsec)	Lifetime: (minutes)
Hα	plage	1.4 ± 0.1	6.2 ± 0.3
	enhanced network	2.2 ± 0.1	7.8 ± 0.5
	cell interior	12 ± 1	19 ± 2
	superpenumbra	14 ± 1	28 ± 4
	arch region	11 ± 1	24 ± 3
	filament region	14 ± 1	42 ± 9
CaII K	plage/enhanced network boundary	10 ± 1	18 ± 1
	superpenumbra	11 ± 2	27 ± 6

Note: The uncertainties quoted above represent standard deviations.

FIGURE CAPTIONS

Figure 1a: McMath 12417 in Hα at 1702 UT on July 5, indicating the various regions into which the fibrils were grouped for discussion in the text.

Figure 1b: The corresponding picture in CaII K.

Figure 2: The evolution of a typical fibril, viewed in Hα line centre. At 1630 UT a dark fibril (indicated by arrow) expanded outwards from a plagette, reaching maximum extension at around 1640 UT. At 1637 UT a parallel bright strand became visible along lower edge of fibril, and this bright strand intensified at 1644 UT. The fibril receded back into the plagette at 1651 UT.

Figure 3: Histograms of fibril lifetimes for various ranges of maximum length, ℓ.

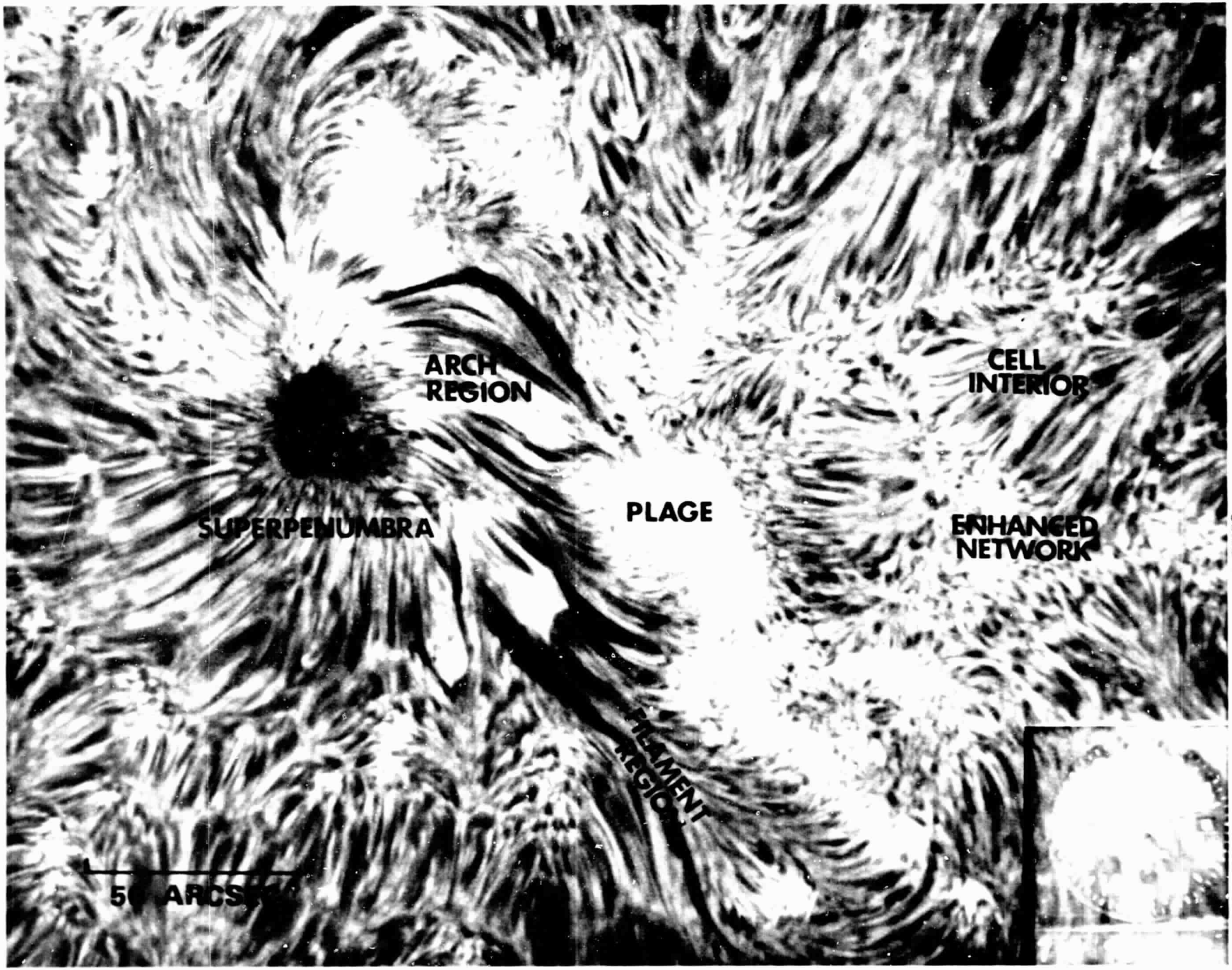
Figure 4: The lifetime of fibrils as a function of maximum length, plotted in logarithmic form. The points represent the observed values (the most probable lifetimes determined from the histograms, with error bars corresponding to the range in which 68% of the fibrils lie). The solid line represents the theoretical curve assuming a model in which fibrils result from impulsive ejection of material into

magnetic field lines at velocity of 34 km/sec, the only decelerating force being gravity.

Figure 5: Representative plots of the variation of apparent length as a function of time, for fibrils in various locations in the active region. A dashed line indicates breakup into two fragments.

Figure 6: A wavelength scan made at 2100UT, July 6.(a) Hα-0.5A, (b) Hα line centre, (c) Hα+0.5A. Fibrils whose Doppler shifts and motions were studied are indicated by loops on the centre frame. In each case, "E" means that the fibril was expanding at the time of the filtergram, "C" means that it was contracting, "I" denotes a continuous inward motion towards spot, and "U" indicates that the motion was uncertain.

Figure 7: The co-evolution of bright and dark fibrils. The dark fibril expanded outwards (to right) from point X, with a bright fibril on either side. The combination evolved together.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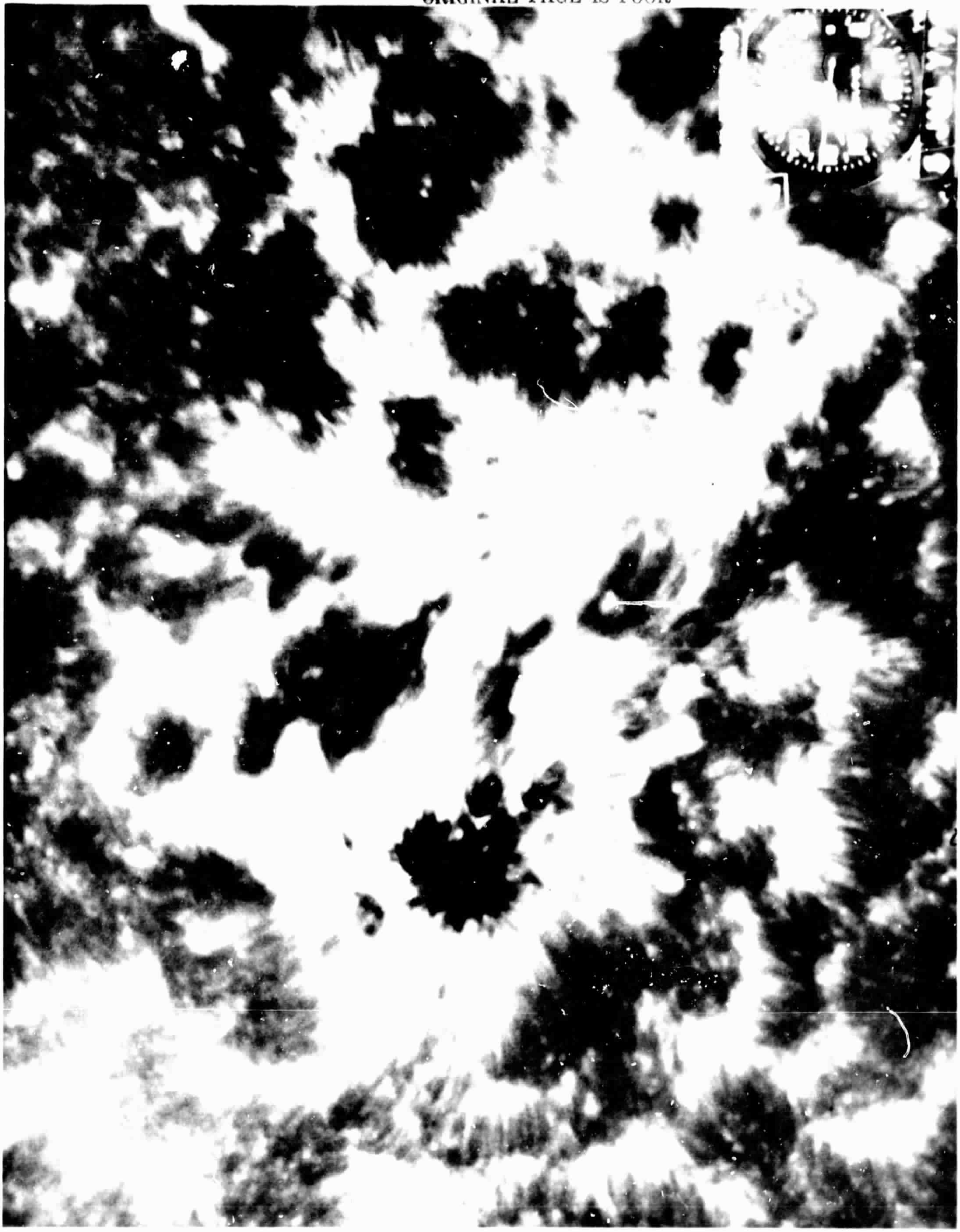
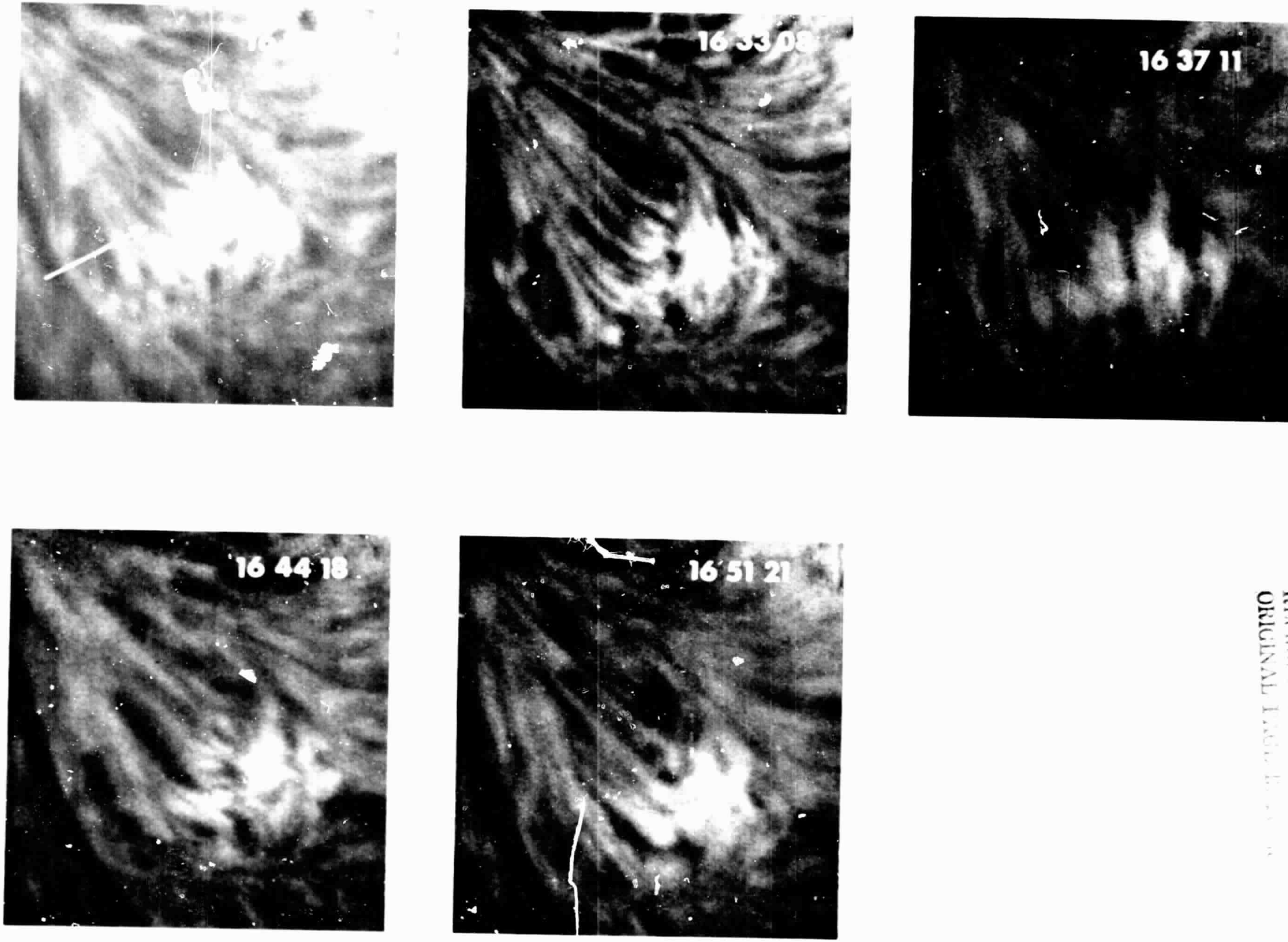
PLAGE
SUPERPENUMBRA
ENHANCED NETWORK
FILAMENT REGION
ARCSEC

Figure 1a





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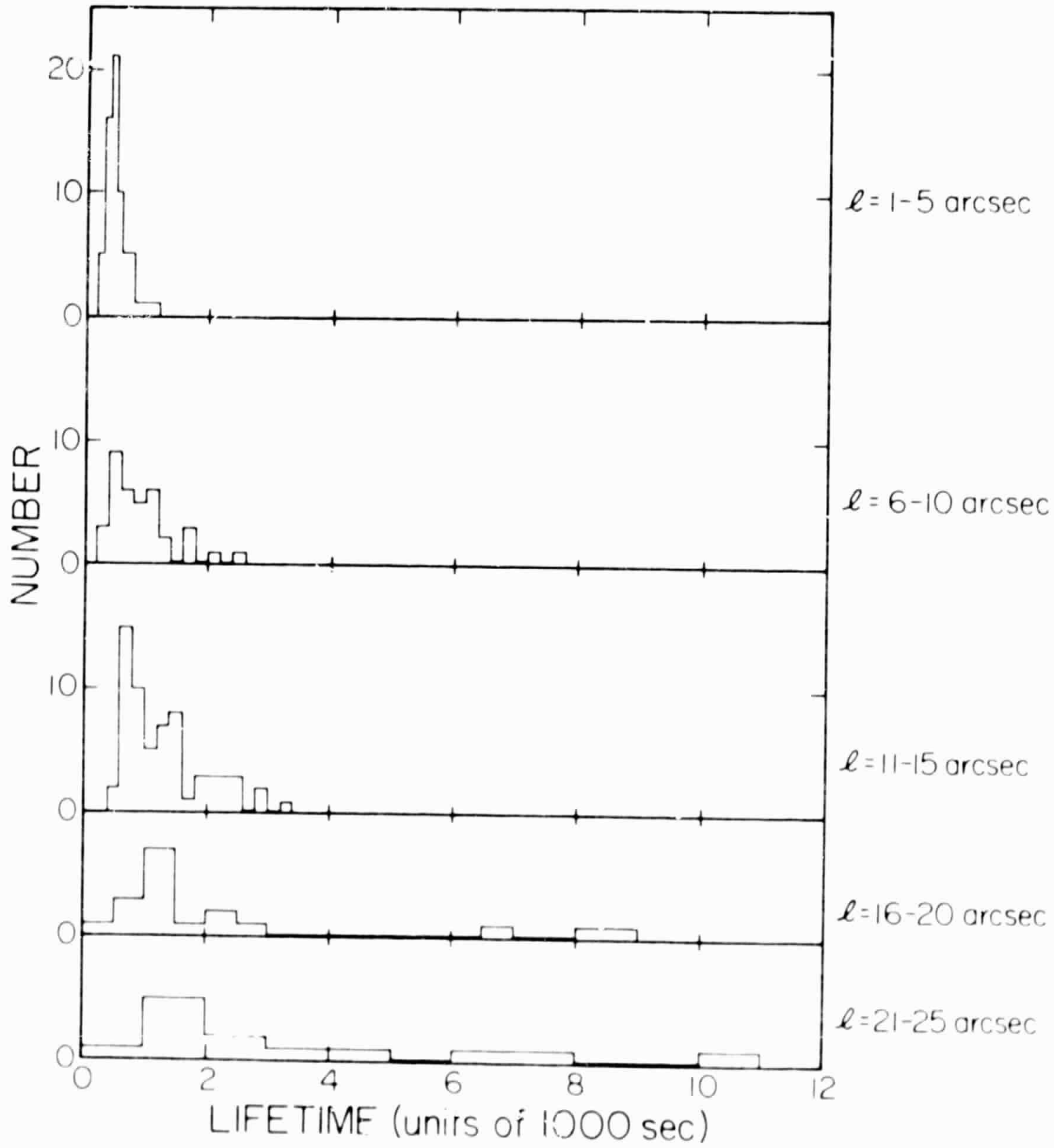

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Figure 3

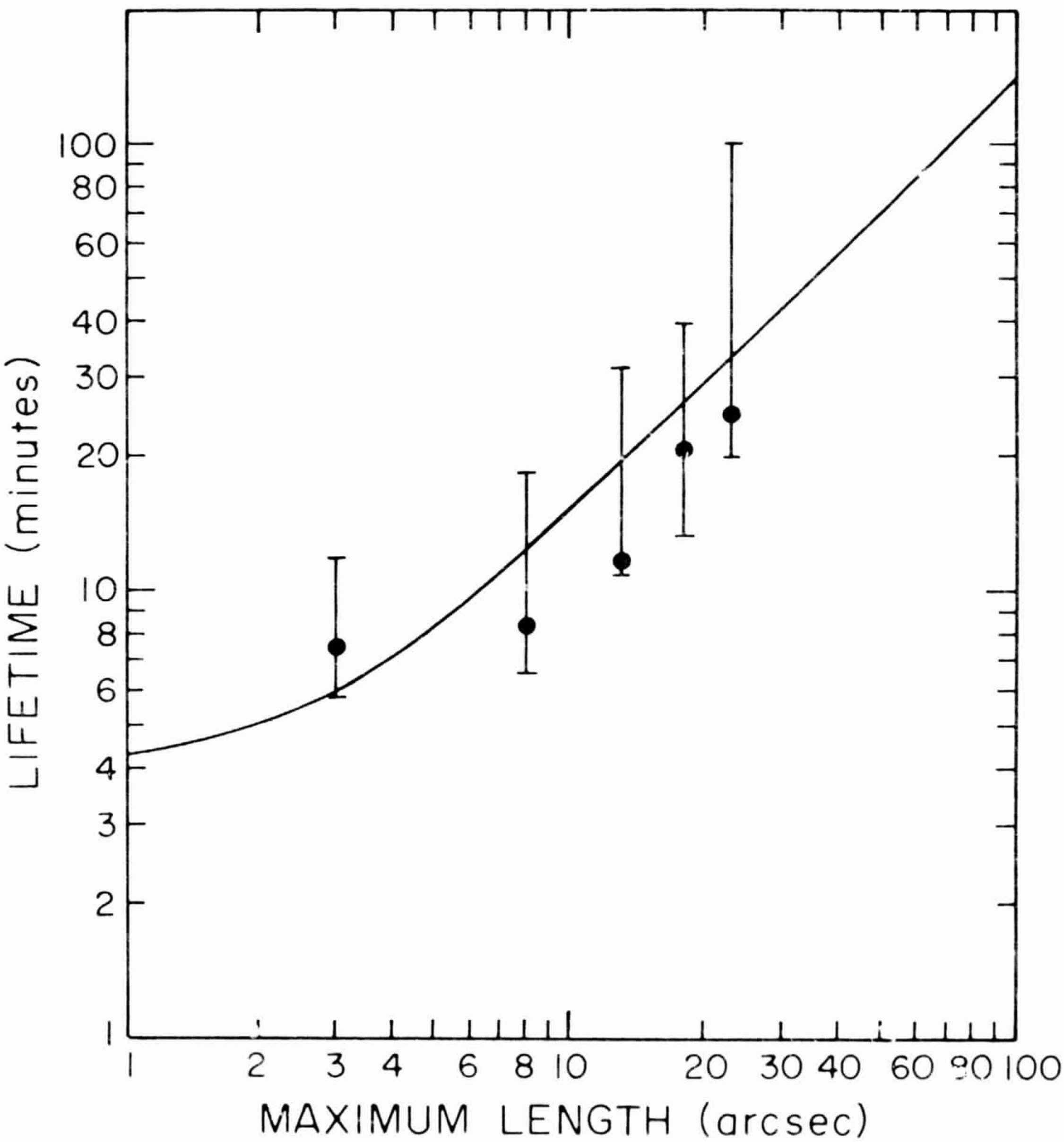
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Figure 4

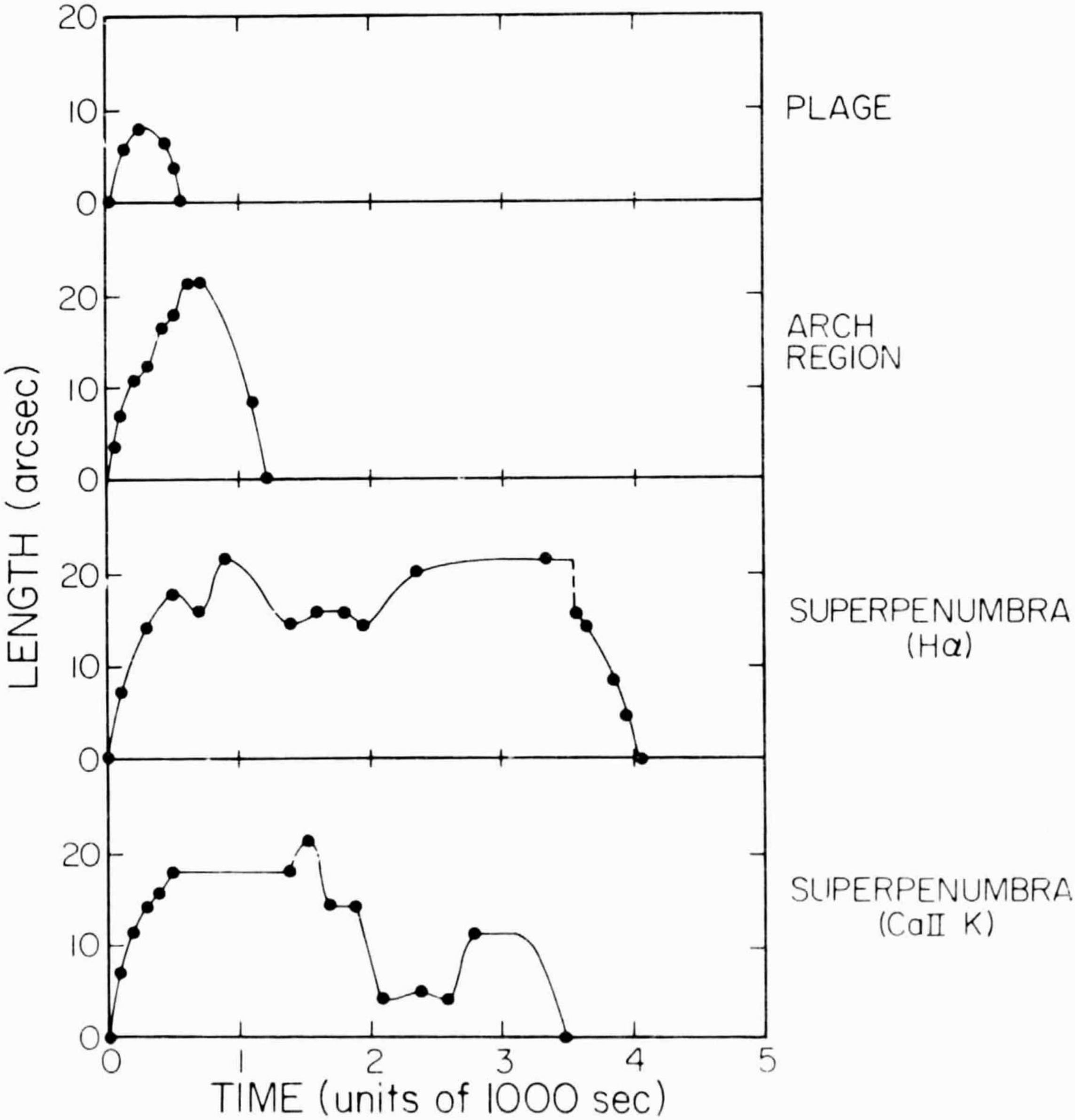
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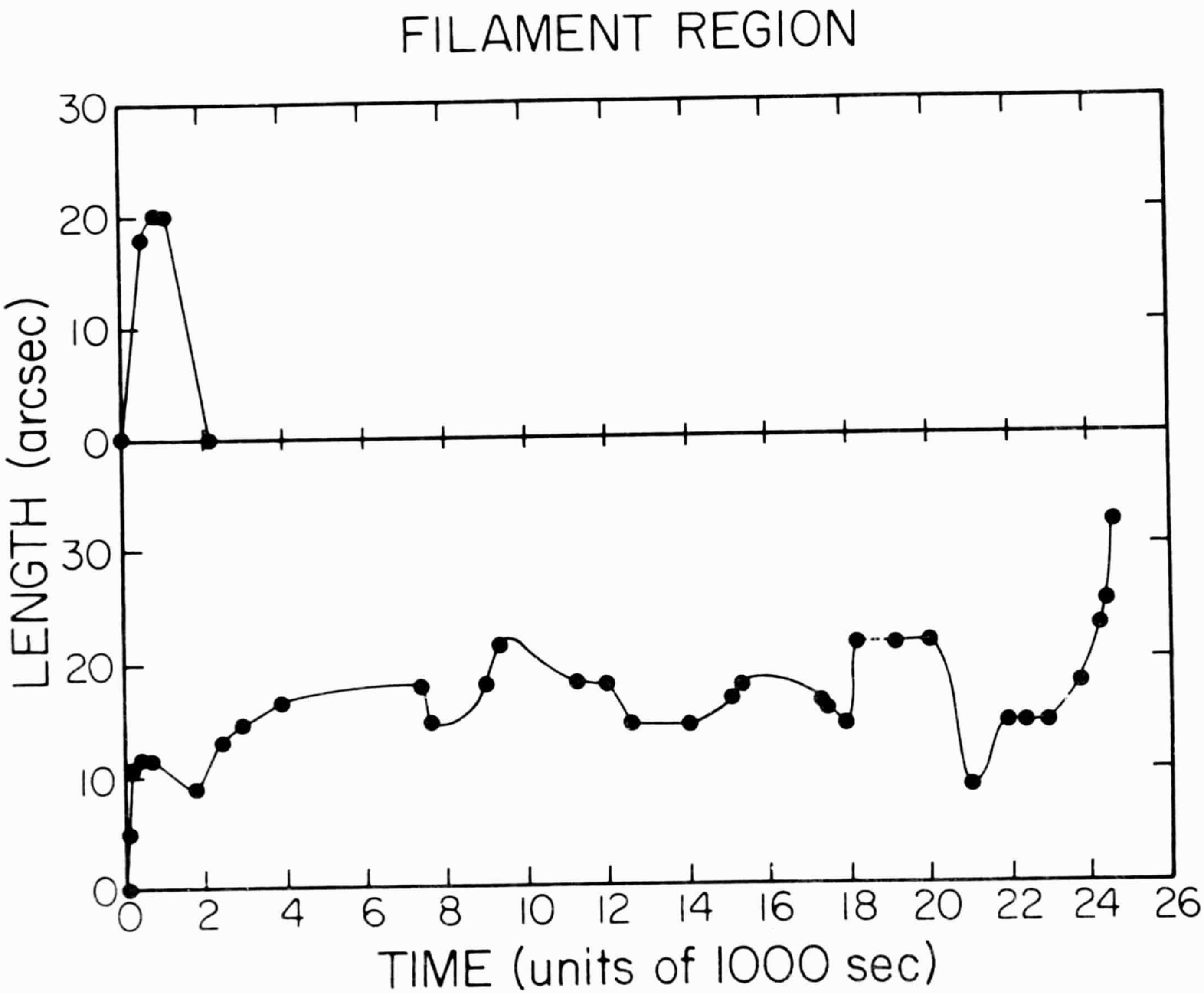
Figure 5



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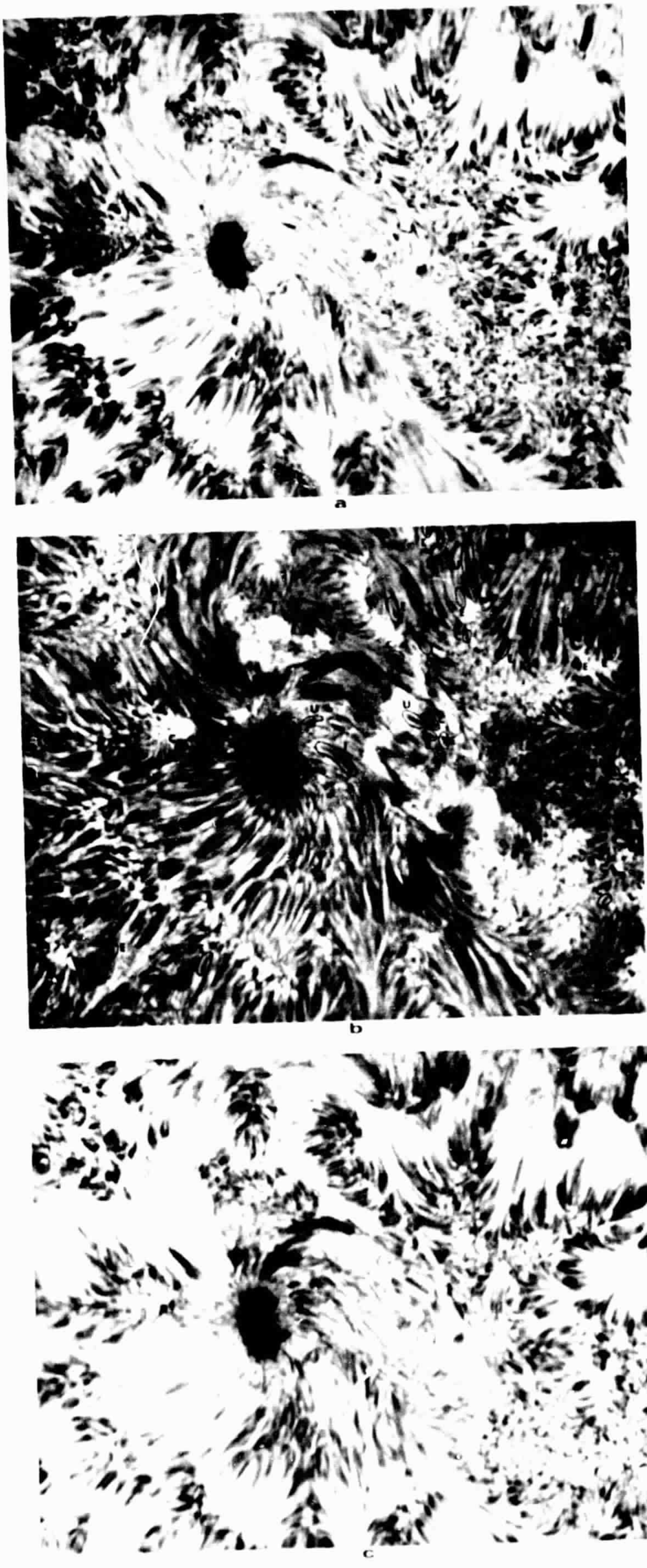

Figure 6

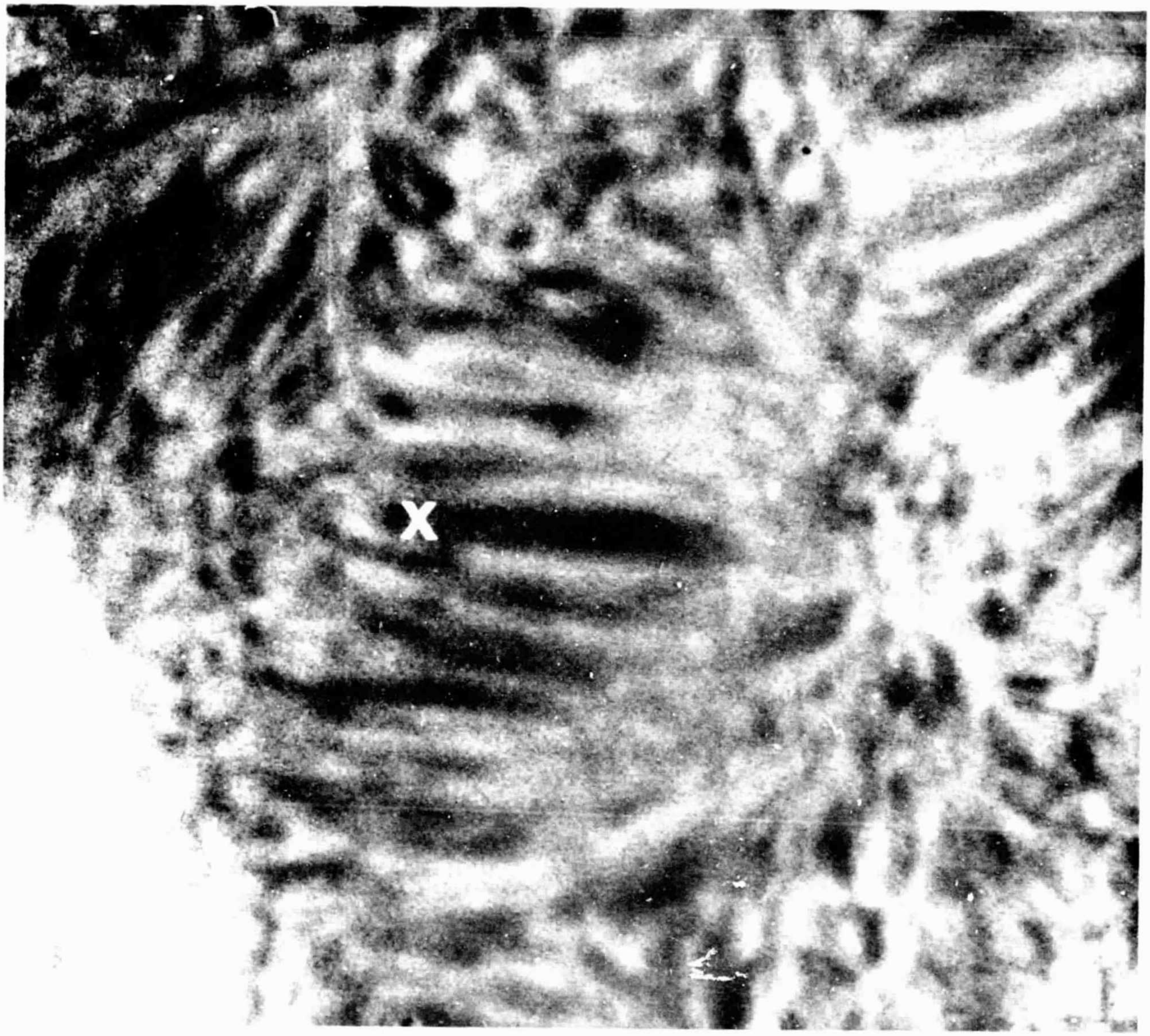

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Figure 7