ON ARCH-FILAMENT SYSTEMS IN SPOTGROUPS

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Abstract. Systems of arch-shaped filaments (AFS) occurring in the interspot region of young bipolar groups are studied. Their main characteristics are: Average length: 30000 km, average width 20000 km, width of individual filaments 1000–3000 km, height of arches 4–15000 km. A typical lifetime of the filaments 30 min; appreciable changes of the system occur within several hours; the lifetime of a system is about three days. – The arch-filament systems bridge the 'neutral' line and connect the regions of the innermost spots of opposite polarity. Material moves along the filaments ($v \sim 25$–50 km/sec) following the direction of the magnetic field, and sometimes arches are observed rising at a rate of ~ 20 km/sec. They are very dark on the inner disk and appear either in emission or in absorption close to the solar limb. – The occurrence of 'bright points' (moustaches) is found to be closely associated with AFS in young spotgroups. – The possible nature of AFS and their relation to other types of filamentary structures is discussed.

1. Introduction

In and around spotgroups various types of dark, filamentary structures are visible in the Hα chromosphere (STEPANOV, 1958; HOWARD and HARVEY, 1964; KIEPENHEUER, 1967), such as: the long, proper *filaments* which correspond to limb prominences and which are orientated across the magnetic field; the long *threads* which – apparently following magnetic-field lines in the chromosphere – connect the leader and follower part of the spotgroup; and the thin, short *fibrils* which end in bright mottles or plages.

One of the most conspicuous filamentary features observed on the solar disk are relatively short, very dark filaments occurring in young spotgroups. WALDMEIER (1937) reported on spectrohelioscopic observations of such small, single, dark filaments associated with new-born spotgroups having opposite radial velocities at their opposite ends. Short filaments of the same kind were also studied by ELLISON (1944), who made an attempt to identify the corresponding type of limb prominence. The present paper will be concerned with groups or *systems* of such dark filaments, which occur in the interspot region of small and medium bipolar spotgroups. The filaments studied by Waldmeier and Ellison probably are the initial stage or precursors of these systems. Waldmeier mentioned already that the small filaments were followed by more complex features in larger groups. This type of dark filaments was referred to also by BUMBA and HOWARD (1965) and MARTRES, MICHARD, and SORU-ISCOVICI (1966).

The interspot filament systems may play an important part in the early evolution of active regions and provide important information on the configuration and development of the magnetic field. In order to learn more about their characteristics filament systems were observed and photographed in some 15 spotgroups with the domeless Coudé refractor at the Anacapri Observatory in summer 1966. A Halle Hα

filter with a passband 0.5 Å was used. Filtergrams were taken on Eastman Kodak 4 E 35-mm film with exposure times 1/8–1/15 sec. The sun's diameter on the negative is 150 mm. Several hundred photographs were secured in the center of Hα and at different distances from the line center under good seeing conditions. The observations are analysed in the following Section A. Some interpretations and conclusions are given in Section B.

2. Analysis

A. RESULTS

1. *Occurrence and Position*

Filament systems were found in almost all young and medium, still developing bipolar spotgroups (Zurich type B, C, and D). They are most frequent and most conspicuous in well-developed young groups of type B and C, less frequent in D groups, and probably absent in large, complex groups. None were observed in old, inactive, strictly unipolar groups of type H and J.

The filament systems occur only in the interspot region of the developing bipolar spotgroup. If they are observed in the center of the Hα line the filaments end in a bright plage, which may or may not be the lowest part of the filaments themselves. Observations outside the line center show the spots – frequently covered by the plage in the line-center observation – and their association with the (dopplershifted) ends of the filaments (Figures 1 and 2). In some cases, the filaments were found to originate in or close to one of the main spots (the leader or the follower); in a few of the youngest groups they even connected leader and follower. In general, however, they extended only between the region of the innermost spots of opposite polarity (Figure 2), sometimes not ending in a visible spot at all. The filaments bridge, anyhow, the dividing line between the opposite polarities of the spotgroup.

2. *Size and Structure*

Typical overall length of the filament systems in well-developed B and C groups is 30000 km; in larger spotgroups they rather become smaller. Extreme values are about 20000 and 40000 km. The width of large systems was found to be 15000 up to 25000 km. They include 5 to 15 individual dark filaments each 1000 to 3000 km thick. Under best conditions compact filaments are seen to be split into a number of very fine components (Figure 1).

Observations show that the filaments are arch-shaped as they are expected to be if they follow magnetic-field lines between regions of opposite polarity. I therefore propose to call them 'arch filaments' and the systems 'arch-filament systems' (AFS). The arch-filament systems must not be confused with the loop-prominence systems (LPS), with which they have a number of characteristics in common. The differences between these two systems will be discussed in Section B.

In favorable positions, especially near the solar limb and in higher latitudes, the arch structure of the filaments may be clearly recognized (Figures 3 and 4). In front

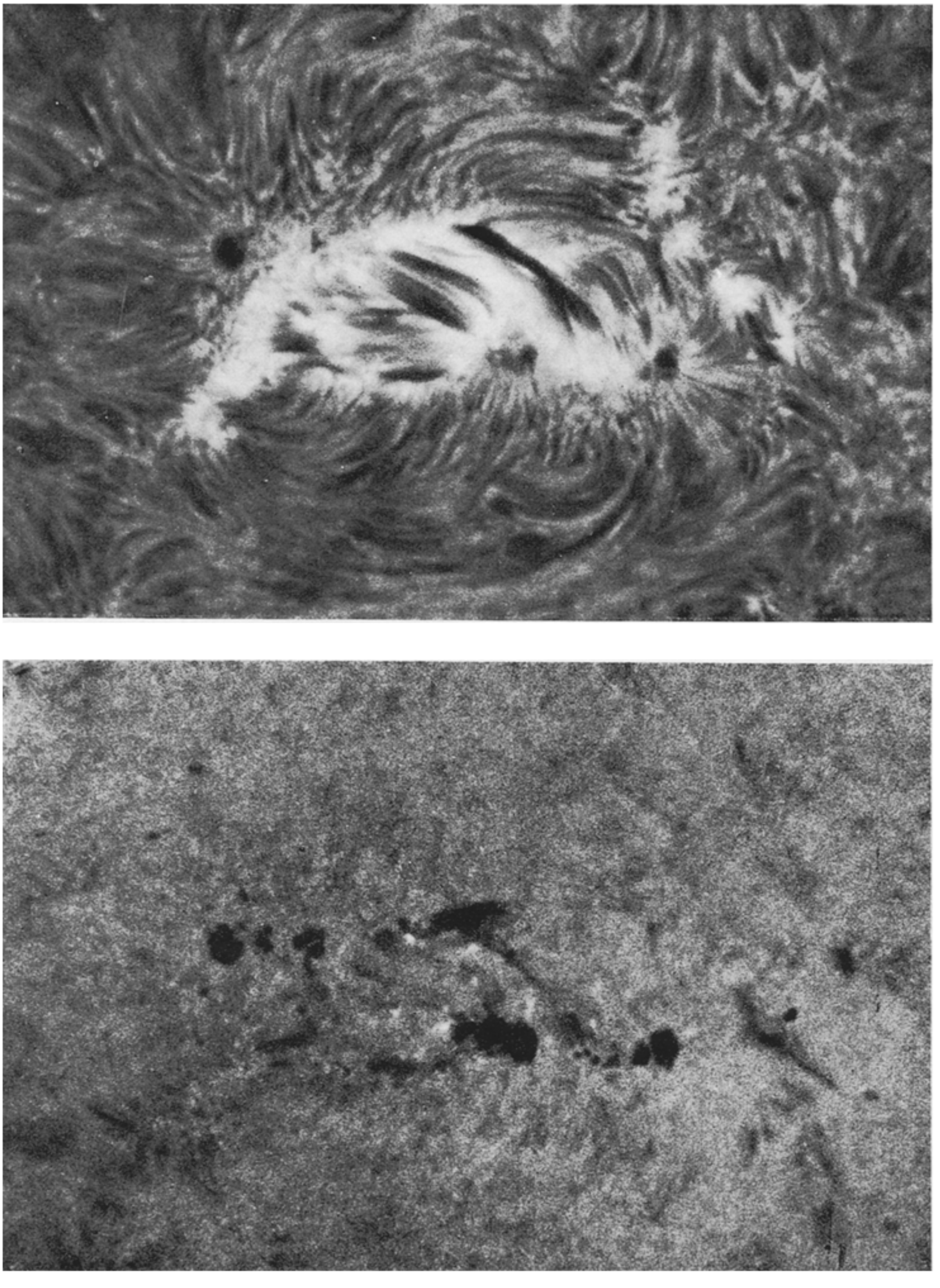
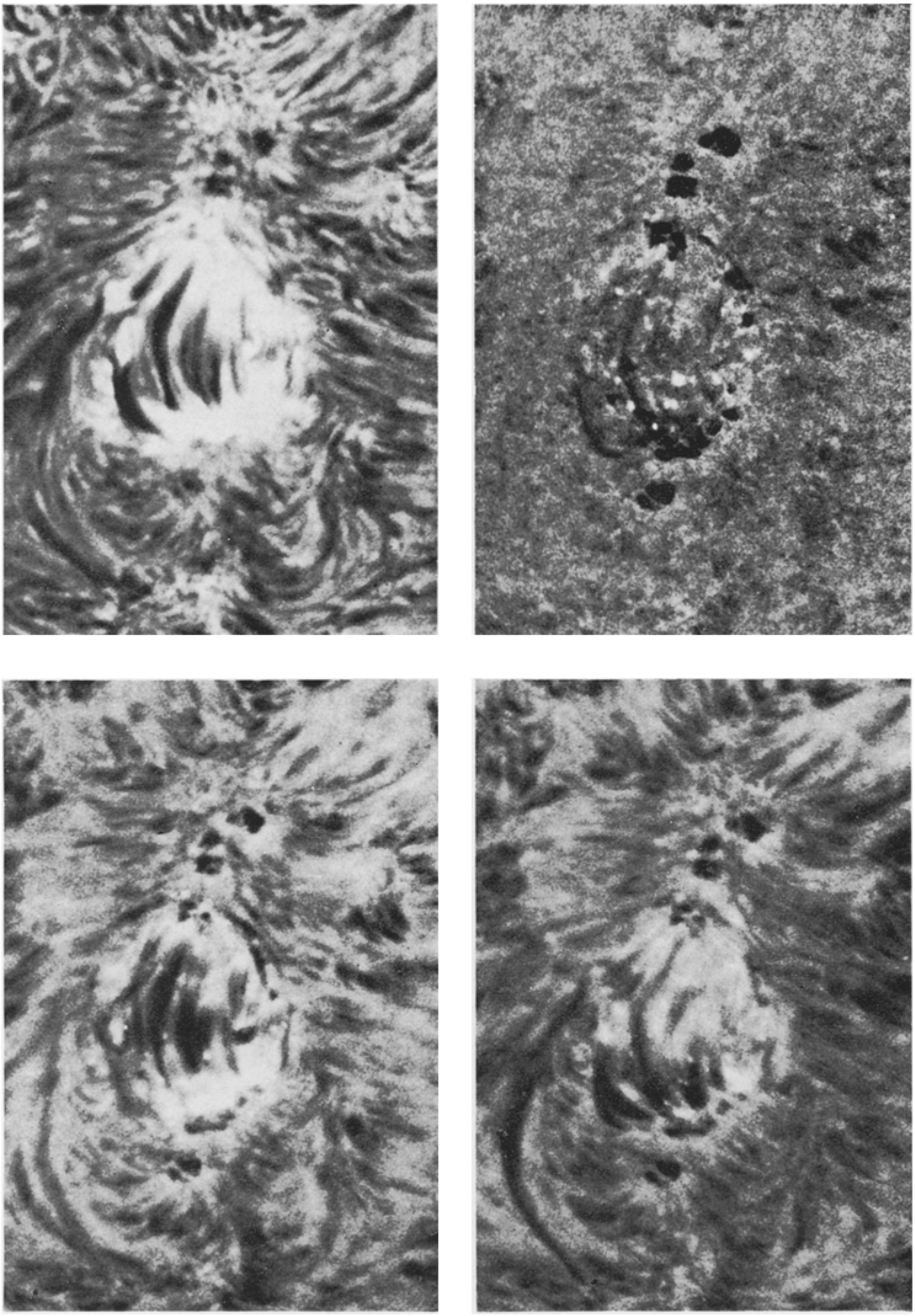


Fig. 1. Arch-filament system seen from the top in a small bipolar spotgroup, Aug. 24, 1966, 0708 UT, position 7N 3W. – Filtergrams taken in Hα and at H$\alpha \pm 1$ Å. In the line center dark filaments, plages and leader and follower spot are seen; note the fine structure of the filaments. The ± 1 Å frame shows all spots, bright points and strongly doppler shifted parts of the filaments. Scale: 1 mm = 1000 km.



(a) (c)

(b) (d)

Fig. 2. AFS seen at different wavelengths, Aug. 12, 1966, position 33N 34 E; (a) Hα 0823 UT; (b) Hα − 0.5 Å 0827 UT; (c) Hα + 0.5 Å 0828 UT; (d) Hα ± 1.0 Å 0825 UT. – Note the differences between (b) and (c), and the bright points confined to the AFS region. Scale: 1 mm = 1000 km.

of the disk the AFS – as a rule – appear dark (in absorption). Only in a few cases, several filaments or even the whole system were seen in emission near the solar limb (Figure 3). On the inner disk the AFS are seen more or less from the top and seem to consist of straight or slightly curvilinear filaments (Figures 1 and 2). The arrangement of the filaments in projection suggests that their planes diverge at the top and converge in the chromosphere. In general, however, the filaments do not meet in one point. The heights of the arches apparently vary appreciably in different systems and even within one system (Figures 3 and 4). Maximum heights of the vertices from 4000 up to about 15000 km were measured in AFS near and at the solar limb where the foreshortening was almost negligible. The majority of systems is rather low and heights

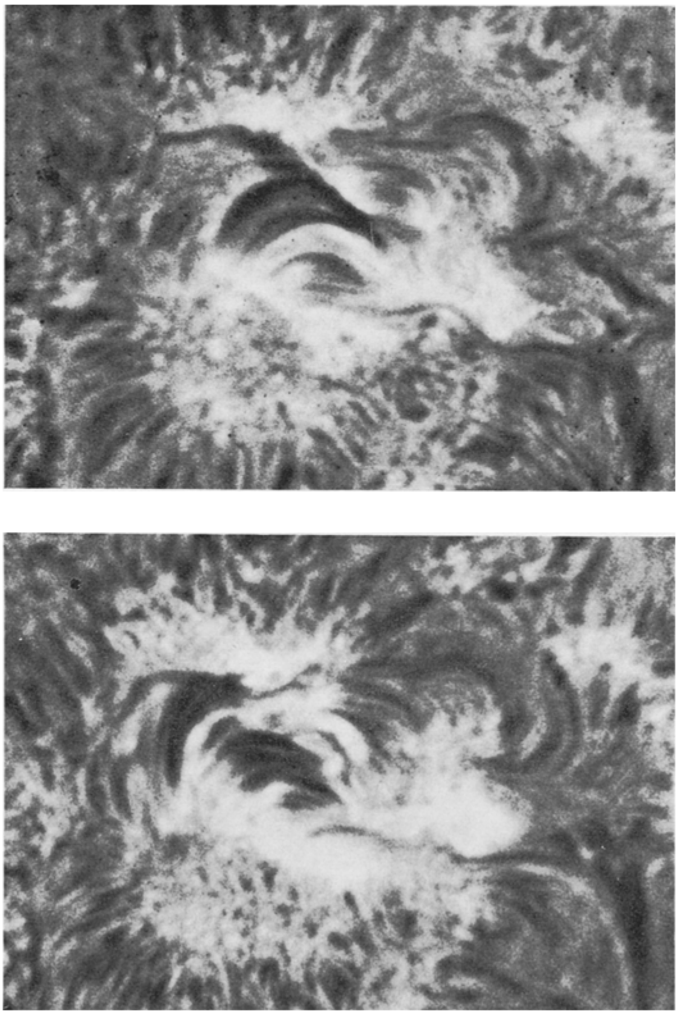


Fig. 3. AFS consisting of low and high arches seen strongly foreshortened, Aug. 4, 1007 and 1308 UT, position 19N 17E; type B spotgroup, spots not visible in Hα. Scale: 1 mm = 1000 km.

Fig. 4. Low and high AFS near the East limb (25N 76E) both seen in emission; July 28, 1966, 1207, 1208, 1209 UT. Note the bright knot ascending in the right-leg of the largest arch and the knot descending in the left-leg of the second largest arch. The tops of both arches rose between 1207 and 1212 UT at a rate of 25 and 16 km/sec respectively. Scale: 1 mm = 1000 km.

larger than 10000 km probably are exceptional. The inclination of the plane of the arch filaments relative to the vertical – and therefore the true heights – cannot be determined for AFS far from the limb.

3. *Lifetime*

The intensity (darkness) of individual filaments of an AFS varies appreciably already within 10 min. The average lifetime of the arch filaments was estimated to approximately 30 min only, while the general configuration of an AFS remains unchanged for several hours. Large-scale changes of the AFS are apparently related to changes in the spot configuration, such as appearance or disappearance or growth of spots, i.e. to a change in the magnetic-field strength and configuration. The AFS are completely changed after one day (over night) due to the development of the spotgroup. Normally developing spotgroups have conspicuous AFS for about 3 days only. Less conspicuous and more complex filamentary features may, however, still be present in large bipolar groups for several more days.

4. *Dynamics*

Two types of motion are observed in the AFS:

(a) A *mass flow along* the filament is indicated by dopplershifts changing from positive values at one end to negative values at the other end of the filaments (Figure 2). The corresponding sight-line velocities range from 20 to 50 km/sec. Material having higher radial velocities was unobservable with the Halle filter, which is tunable only between $H\alpha \pm 1$ Å. The sight-line velocities are, on the other hand, in general smaller than the actual velocities along the filament. We may therefore conclude, that the true velocities can even exceed 50 km/sec. The direction of massflow – as indicated by the dopplershifts at the ends of the filaments – was from the leader to the follower region in one part of the cases and in the opposite direction in the other – somewhat larger – part. Within the same AFS the direction is the same for all filaments (perhaps with a few exceptions).

(b) An *expansion* of the arch filaments was observed directly or indirectly in a few AFS. Figure 2 shows that the major part of each dark filament had negative (ascending) sight-line velocities and only a small part had positive (descending) velocities (frames b and c). This conspicuous asymmetry can be produced only by the expansion of the arch filaments with their vertices rising at a rate of about 20 km/sec.

On the other hand, large arch filaments seen from the side were found growing appreciably within 5–10 min. In one case (Figure 3) the vertices of the arches rose with velocities between 16 and 25 km/sec until they faded after having attained 15000 km. Low arches ($\leqslant$7000 km) of the same AFS, on the contrary, did not grow by a measurable amount within their observable lifetime, i.e. they did not grow more than 0.7 km/sec. In another case the highest arch filament of a closely packed and probably strongly foreshortened system was shifted in projection by 3000 km in 11 min, i.e. more than 5 km/sec. Again no measurable growth was found in lower arches of the same system. These observations suggest that the AFS expand faster in high levels than in their lower parts. It is hardly possible to follow shifts of 1000 km or less in the closely packed low filaments by comparing single-frame photographs. Hα-spectra taken along the filaments, and cinematography at different wavelengths during periods of excellent seeing, will be needed for a thorough study of the dynamics of the AFS.

5. *Relation to other features of the active region*

(a) *Spots.* It was found in paragraphs 2a and 2d that AFS as a whole are closely related to spots and their changes. The individual arch filaments and their development are not strictly associated with individual spots: they are not in all cases connected with spots and in the majority of cases they appear and disappear without related observable changes in the spots at all.

(b) *Flares.* A few, minor flares only were observed in spotgroups with AFS. There is some – however uncertain – indication that arch filaments change faster during flares which occur somewhere else in the spotgroup, and that flares perhaps tend to avoid the AFS region. More observations will be needed to study the AFS-flare relationship.

(c) *'Bright points' (moustaches).* There is a surprising, strong association between the occurrence of bright points and AFS. In young bipolar spotgroups bright points were found only in the interspot region occupied by the AFS. Very conspicuous bright points were seen frequently at the roots of the filaments and between the filaments (Figures 1 and 2). Bright points appeared neither in type B and C groups, which had no AFS, nor outside an existing AFS. In one case the spotgroup neither had a conspicuous AFS nor any bright point the one day, but both features were present on the following day! Apparently AFS and bright points are closely linked together and are produced by the same kind of basic activity.

B. DISCUSSION

The observations have shown that the AFS are an essential part of young, developing Active Regions. They occupy their central parts and obviously penetrate into the inner region of the relatively dense permanent coronal condensation. It seems therefore likely that arch filaments are formed by condensation out of or at the base of the coronal condensation, such as other types of filaments and prominences are condensed in the corona.

The corona is permeated by the spot fields, and these are, of course, responsible for the arch shape of the filaments because the highly conductive material necessarily moves in the direction of the field. The arch filaments apparently are a materialization of the magnetic-field lines (or tubes) and may be considered tracers for the field and its changes. For instance, the growth of arch filaments observed in a few cases indicates the expansion of the magnetic field. So far it is not known whether the expansion of the individual arches – and of the whole AFS – is a continuous process (occurring during the whole life of the AFS) or an eruptive phenomenon like the eruption of an ordinary prominence – however occurring intermittently. Available observations seem to support the second possibility. If that is true, it would indicate that the magnetic field also expands discontinuously, i.e. in single waves or pulses.

On the other hand, occurrence of AFS apparently is associated with the formation of spots, generally speaking with the evolution of the bipolar spotgroup, which is accompanied by an enhancement of the magnetic field and its propagation into the corona. The origin of the AFS therefore will somehow depend on these modifications of the magnetic field. Certainly, the AFS will require a certain field configuration for its stability (existence), and probably it is the changing magnetic field which creates, modifies and finally destroys the favorable conditions. The confinement of the AFS to the region between the last spots of opposite polarity suggests that interpretation.

The condensation of the arch filaments out of the corona, as suggested above, obviously does not account for the observed mass flow between the opposite spot regions. Material condensed out of a medium at rest would follow gravity and descend in both legs of the arches, as it does for instance in loop prominences. If we accept condensation as the origin of the AFS we have to assume in addition that the original (not yet condensed) material is already in motion from one spot region to the opposite one. There is, however, so far no observational evidence supporting this assumption.

That inconsistency is avoided if we consider another mechanism: the filament material could be injected at one root – for instance like a surge – and would then return into the chromosphere in the opposite spot region following the magnetic field and gravity. The field changes as deduced from observations may then be responsible for the ejection (acceleration).

Special consideration ought to be given to the very close association between bright points and AFS (see Section A, 5c) because it might provide some indication about the origin of both phenomena. It seems, however, premature to give a conclusive interpretation. We may suspect that bright points – as well as AFS – originate at places where magnetic fields pass the chromosphere propagating into the corona. The coincidence of bright points with other types of active filaments, especially with the ends of small surgelike features and ejections (McMath, Mohler, and Dodson, 1960; Severny and Koval, 1957, 1958; Koval, 1965; Bruzek, 1967), also provides evidence that varying fields (which are needed to accelerate the material) may play a role in the production of bright points.

The last item left to be discussed is the relationship of the arch filaments to other types of dark, filamentary and arch-shaped chromospheric features by a comparison of their respective characteristics.

(a) Normal *filaments* obviously are quite different even from single arch filaments by size, shape, and internal structure. Young filaments only are similar in appearance; they are, however, different in orientation relative to the magnetic field. Nevertheless, there may exist a relationship between normal, quiet filaments and the arch-filament systems of young spotgroups in the following way. AFS connect opposite magnetic polarities and bridge the dividing line of magnetic polarities. Quiet filaments, on the other hand, occupy this dividing line which is perpendicular to the field, while, according to Kiepenheuer (1967) "its individual structures connect the regions of opposite magnetic polarity and obviously run along the magnetic field". This observation suggests that the AFS are precursors of the quiet filaments, in the sense that the place of the AFS within the magnetic field configuration is occupied after some shearing and stretching by the individual structures of the filament.

(b) Long *threads* (KIEPENHEUER, 1967) connect spots of opposite polarity including the main spots. They run apparently within the chromosphere and outside the interspot region reproducing the field lines of the spotfields. The arch filament may be considered their counterpart in the central part of the spotgroup and its magnetic field.

(c) The *fibrils* are similar to AFS in many respects: they also occur as systems of many individuals, follow magnetic-field lines and are visible on the blue side of Hα (HOWARD and HARVEY, 1964) i.e. they are rising such as some of the AFS are. Photographs taken near the solar limb show them as flat arches descending into plages and bright mottles. There seem to exist intermediate stages between fibriles and AFS, especially as successors of AFS in larger spotgroups which no more produce the conspicuous type of AFS. Arch filaments possibly have to be considered extremely dark and large fibriles extended between strong magnetic fields.

(d) *Loop prominence systems* and AFS have a number of characteristics in common and might at first sight be considered identical or related features. Indeed, ELLISON (1944) identified the small arch filaments with type IIIb prominences (PETTIT, 1943), which are the loop prominence systems.

The characteristics similar in both types are as follows: The systems of arch filaments as well as of loop prominences are regular groups of arches or loops following magnetic-field lines and crossing the dividing line of polarities. The maximum velocity of mass flow is of the same order (50–100 km/sec) in both cases; the rate of growth is also of the same order for high arch filaments and low loop prominences; the typical lifetime of individual filaments and loops is the same (20 min), while the systems exist for many hours in both cases.

If, however, the details of the characteristics of LPS (cf. e.g. BRUZEK, 1964) are compared with those of the AFS, as stated above, we note that there are many and important differences (see Table I) which indicate that the two features are of quite a different nature and origin. LPS are closely related to flares, they are produced by a flare process propagating into the corona. AFS are independent of flares but depend

TABLE I

Differences between loop prominence systems and arch-filament systems

	LPS	AFS
origin	late flare process, condensation at the loop tops	ejection or condensation of moving material
mass flow	from top to bottom only	from spot to spot
growth of system	formation of larger loops, roots separating	growth of arches, roots fixed
max. height	$6\text{–}13 \cdot 10^4$ km	$7\text{–}15 \cdot 10^3$ km

on spotgroup evolution. LPS expand in all directions in that larger and wider loops are formed to replace fading lower loops and they are rooted in flare strands slowly separating. Arch filaments, on the contrary, expand – if at all – really and in height only, and are rooted firmly in the two opposite spot regions. LPS grow much higher than AFS ever do. Finally, motion in loops is always descending, in arches ascending and descending. It is likely that both types of filament (prominence) systems are related to special conditions in the magnetic field which are, however, different in both cases.

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