MOTIONS IN ARCH FILAMENT SYSTEMS*

A. BRUZEK
Fraunhofer Institut, Freiburg/Br., Germany

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Abstract. A new analysis of Hα filtergrams and Hα spectra of arch filament systems (AFS) shows that material flows downwards in *both* branches of the arch filaments ($v \approx 50$ km/sec) while the top of the arches ascends ($v \lesssim 10$ km/sec). It is suggested that AFS are produced by the magnetic field which expands, between growing spots, into higher levels carrying material with it that subsequently slides down along the magnetic field following gravity.

AFS are also visible in the K line of Ca II; however, there they appear less pronounced than in Hα and they are less conspicuous than the K-line quiescent filaments. There is some indication that AFS just cover a supergranulum (Ca network cell) with material streaming down at the border of the cell.

No indication was found for a close relationship between AFS and flares.

1. Introduction

Following a first exploratory study of arch filament systems (BRUZEK, 1967, hereafter referred to as Paper I) additional observations were carried out on some 40 more systems in 1967 and 1968. The observing material now available includes: (1) Hα filtergrams, i.e. λ-series taken between Hα + 1.0 Å and Hα − 1.0 Å in 0.5 or 0.25 Å steps with the Halle 0.5 Å Hα filter at the domeless coudé on Eastman Kodak SO 375 emulsion; (2) Hα spectra taken with the spectrograph of the domeless coudé on Eastman Kodak IVE and 103aE emulsions; (3) a number of λ 5250 magnetograms of regions containing AFS taken with the magnetograph of the domeless coudé; (4) a number of K-line filtergrams taken with a Halle K filter with a passband of 0.6 Å at the K heliograph (100/1650 mm); the diameter of the sun's image on the negative is 50 mm, the film used was Agfa Agepe rapid.

As a result of the analysis of the extended observing material some of the suggestions and interpretations given in Paper I – especially those dealing with the motions in AFS – have to be modified. The present paper presents the new results and a corrected qualitative interpretation of the dynamics of the AFS. As for the general characteristics, which have been largely confirmed by the new analysis, the reader is referred to Paper I.

2. Occurrence of AFS

It was stated in Paper I that AFS occur in a conspicuous form in young and medium bipolar spotgroups only. Well developed systems have now also been found in mature complex groups. In these cases, the AFS were also rather complex multiple systems obviously corresponding to the complex magnetic configuration. Furthermore, AFS were also found with a few large old regular spots that had one or more newly formed

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small companions (satellites), probably of opposite polarity. The AFS connected the region of the young spots and the inner part of the penumbra of the old spot (Figure 1). This observation is additional evidence that AFS are associated with young spots and with their growing, expanding magnetic field.

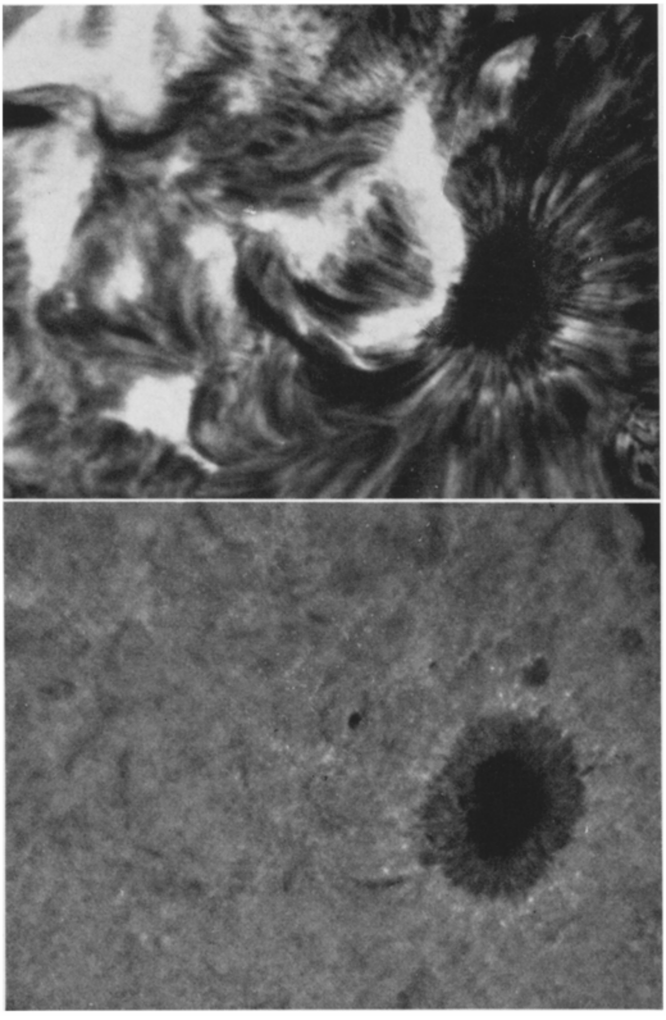

Fig. 1. Old regular spot and a young satellite spot to its left (bottom frame, H$\alpha \pm 1.0$ Å); AFS between the spot penumbra and the surroundings of the young spot (top frame, Hα line centre); flare at the feet of the AFS and in the other parts of the active region (28 Sep. 1967, height of printed frame on the sun 100000 km).

3. Dynamics

In λ-series of filtergrams different parts of the arch filaments are best visible at different wavelengths (Figure 2). That is, of course, evidence for Doppler shifts resulting from

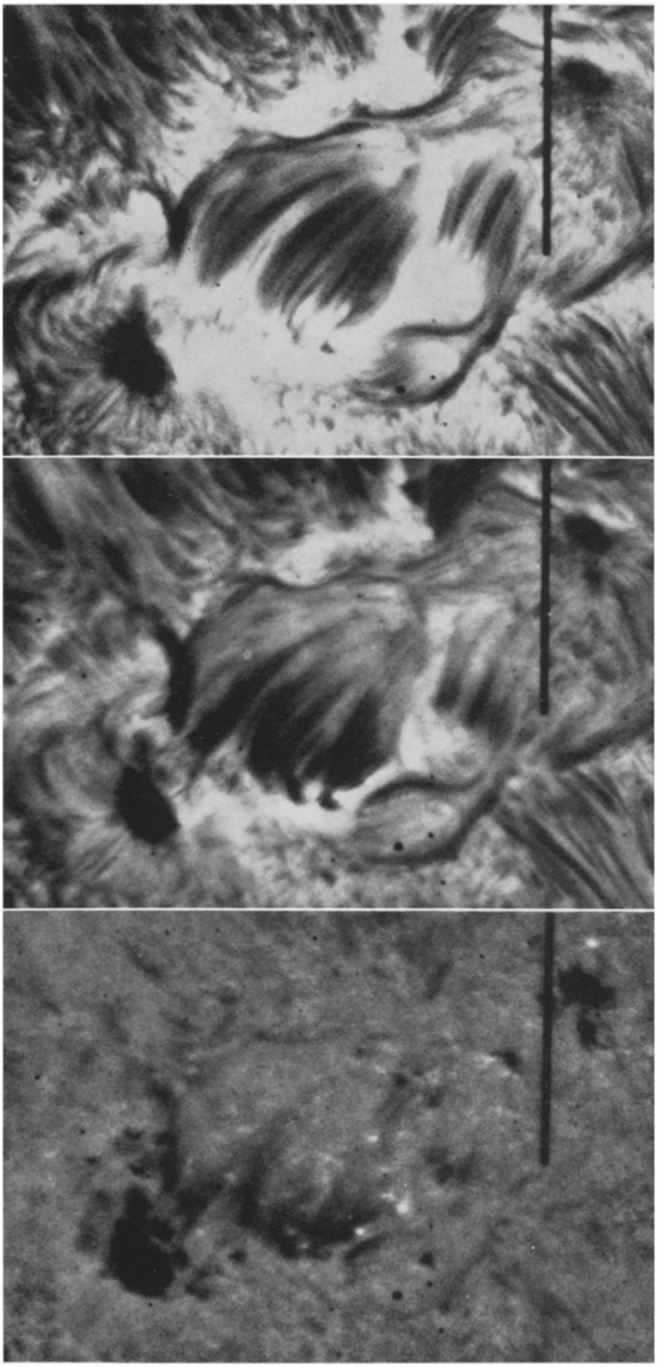

Fig. 2. AFS in a small B-type spot group (26 July 1968, 8 °N 37 °W) taken in Hα, Hα + 0.5 Å and Hα ± 1.0 Å respectively. The length of the black bar near the top right-hand corner corresponds to 30000 km on the sun. Note the fine structure of the filaments in the line centre filtergram.

mass motions inside and along the filaments. An extended study using all photographic observations (of some 40 AFS) as well as a large number of additional visual observations with the domeless coudé and with the small Hα heliograph (150/2250 mm) equipped with the 0.25/16A Zeiss filter gave the result that the Doppler shifts vary systematically along the filaments and vary with the position on the solar disk in the following way (Figure 3).

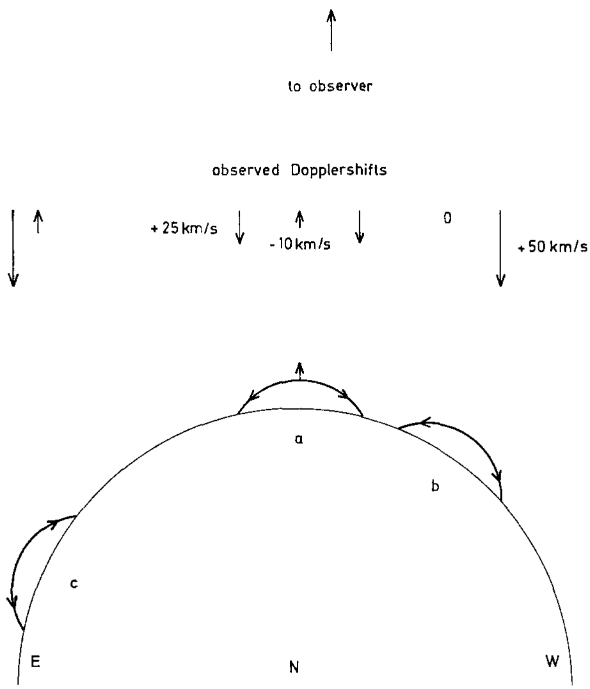

Fig. 3. Motions in AFS and Doppler shifts observed at different positions on the sun. AFS are represented by a single arch at 3 different positions. – (a) in the centre of the disk (the sun is seen from above the North pole); (b) at about 30°W, and (c) near the E-limb. The direction of mass motion is indicated by arrow heads. Direction and amount of the corresponding observed Doppler shifts are indicated by arrows at top of the figure.

In a 'central' region of the disk (central meridian distance <30°) a *positive* Doppler shift of 0.25 – <0.5 Å is found on *both* ends of the filaments. Their middle parts are seen best in the line centre; sometimes, they appear slightly shifted to the blue (<0.25 Å). Larger negative Doppler shifts (as shown in Paper I, Figure 2) turned out to be exceptional. Approaching the solar limb (either East or West) the ends of the filaments pointing to the limb become more and more strongly Doppler-shifted (0.5 – 1.0 Å, Figure 2 and 3), while the middle parts and the opposite ends are visible best in the line centre. Again, sometimes, slight negative shifts are found there.

As may be realized from Figure 3 this pattern of positive Doppler shifts is evidence that the filaments are arches with a mass flow along the filaments with a velocity of about 50 km/sec directed *downwards in both branches* of the arches. The negative

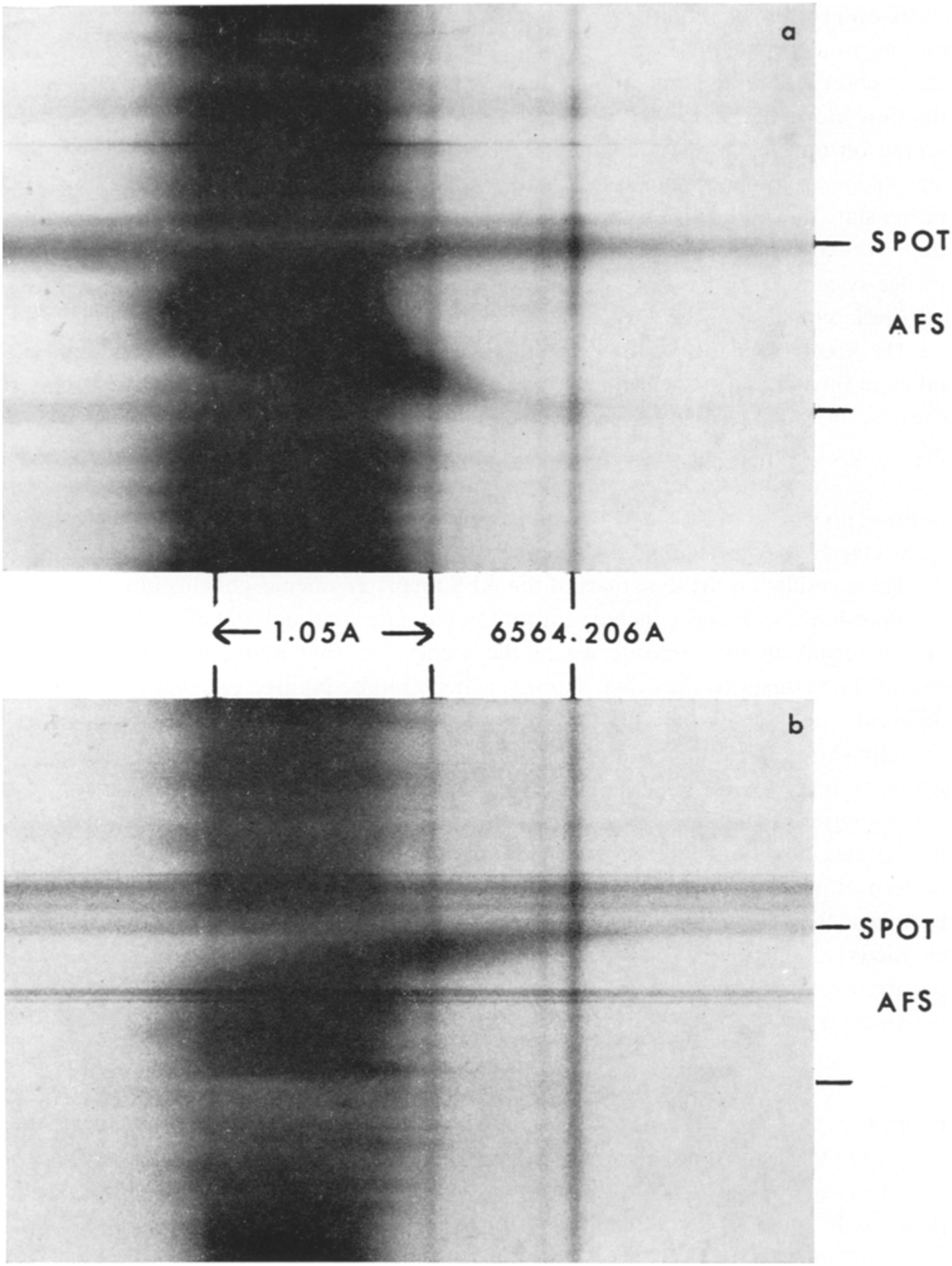

Fig. 4. Hα spectra taken along arch filaments. – (a) near the centre of the disk: the spectrum of the arch filament is approximately in the centre of the frame; the middle part shows a slight negative shift while the ends of the filament form two positively shifted 'horns' each ending in a spot; (b) in the limb zone with a strong Doppler shift at one end of the filament ending in a spot. Height of the frames is 100000 km on the sun.

shifts observed in the middle parts of the filaments in the central region of the disk, on the other hand, indicate a slow rising motion of $v \lesssim 10$ km/sec. The negative shifts observed in the limb zones of the solar disk may result – at least in part – from the flow along the filament (see Figure 3). From the fact that positive shifts are observed on both ends of the filaments inside the 30° zone only we conclude that the legs of the arches are inclined less than 30° to the horizontal, i.e. that the arches are rather flat. This agrees with the statement (Paper I) that the arches are rarely higher than 10000 km thus being definitely 1 order of magnitude smaller than loop prominence systems.

These conclusions on the dynamics of the arch filaments are neatly confirmed by Hα spectra taken with the spectrograph slit oriented along a filament. Spectra taken in this way, near the centre of the solar disk, show clearly the positive Doppler shifts at both ends of the filament and in many cases a slight negative shift in the middle part (Figure 4a). In the limb zone of the solar disk a stronger positive shift occurs at the limb end of the filament corresponding to the full downward velocity of flow; no shift is observed at the opposite end (Figure 4b). Furthermore, the spectra show clearly that the filaments descend into the umbra of spots.

These results on the dynamics of the AFS rectify erroneous conclusions presented in Paper I; there, it was concluded from limited data that material ascends in one leg and descends in the opposite leg of the arches, i.e. that material flows from one end of the filament to the other. However, it should be pointed out that sometimes a different type of *single* arch filament (prominence) is observed in active regions which actually shows ascending and descending motions, i.e. a continuous flow along the whole arch.

Comparing the motions in arch filament systems and in loop prominence systems it becomes obvious that the mass flow in both systems follows the same general pattern: downflow of material into the chromosphere along the magnetic field lines in both branches of the arches or loops. Thus, AFS and LPS are similar in one or more characteristics. However, they are still different in so many others as, for instance, occurrence, development, size (see Paper I) that no relationship whatsoever can exist between them.

4. Relation to the Magnetic Field

From the mass motion along the magnetic field as well as from the position of the feet of the filaments quite close to, or even in, spots of opposite magnetic polarity we have to conclude that AFS follow magnetic field lines connecting regions of opposite polarity. In order to check this conclusion by independent observations a number of λ 5250-magnetograms were recorded of a few small bipolar regions, with AFS, near the centre of the solar disk. A comparison with Hα filtergrams taken during the recording of the magnetograms confirms in fact that AFS connect regions of opposite polarity. The same was found by SMITH (1966, 1968) using Mount Wilson magnetograms for an "organized pattern of fibril structures" which is a feature resembling an arch filament system.

5. K-Line Observations of AFS

AFS taken in the K line of Ca II with a 0.6 Å filter have about the same general appearance as in Hα. In K, however, the plage around and in between the filaments clearly dominates the region while the K-arch filaments have not the sharp outline and the conspicuous darkness of the Hα filaments. K-line AFS are even less dark than K-line quiescent filaments.

There is a striking coincidence between the size (length) of the AFS and the cells of the Ca II network (about 20000–30000 km). This suggests that an AFS might cover just one supergranulum. Unfortunately, the network cannot be identified easily and unambiguously inside active regions because of the bright and extended plage. There are, however, some indications that in quite young spotgroups the arch filament systems actually extend between the borders of network cells thus covering one or two neighbouring cells.

If we compare the 'undisturbed' network of the day before spot appearance with the network configuration on the day of the first appearance of the spotgroup and the AFS we find that the new AFS occupies just one of the cells of the preceding day. The plage of the new active region may already cover two cells. Such a comparison and identification was possible only because the general pattern and the majority of the individual cells did not change very much in the cases under study and therefore could easily be identified on the two consecutive days.

The association between AFS and the network indicates that chromospheric material descends at the borders of supergranular cells.

6. AFS and Flares

In Paper I some doubts were expressed about a possible relationship between AFS and flares. In the new observing material several flares appeared to be associated with AFS insofar as they brightened along the feet of the arch filaments (Figure 1). However the majority of these AFS-connected flares were only parts of larger flares that also occurred in other parts of the same active region. Moreover, in the cases under study, the 'AFS-flare' was not an important or very bright part of the whole flare. Thus, it seems that although flares may appear close to AFS (i.e. at their feet) the AFS are not the favourite place for a flare to occur.

On the other hand, arch filament systems apparently are not strongly affected by flares. Smith (1966) and Tandberg-Hanssen (1967) reported on changes preceding and accompanying a flare in chromospheric fibril structures that were apparently AFS; these changes were described as 'fluttering' motions (repeated disappearance and reappearance) and brightening of individual filaments. No distinct flare-associated or flare-specific changes were found in AFS in our data. All changes observed during flares e.g. filament fading and disappearance, and appearance of one or two strong dark filaments are quite common to normal AFS development. No change in the general configuration of the AFS (i.e. no radical change of the gross magnetic field configuration) was associated with flare occurrence. It should be mentioned here that our data include only flares of importance $\leqslant 2$.

We may conclude, therefore, that in general AFS have no direct active or passive relationship to flares (importance $\leqslant 2$).

7. Discussion

A possible qualitative interpretation of the dynamics of the AFS could be as follows: In young bipolar spotgroups – where AFS mainly occur – the magnetic field increases in the region between the spots of opposite magnetic polarity. It will expand into the chromosphere and into the corona and necessarily carry material with it. Matter will be raised between growing spots. Other mechanisms may also contribute to an expanding and rising motion. As the expanding field lines become increasingly steep the lifted material will soon start to follow gravitation and return to the chromosphere along magnetic field lines thus forming the arch filaments. The filaments will fade when their material is exhausted by the downflow; the magnetic field may continue to expand into the corona.

The observations show that the AFS do not consist of a single layer or shell of arch filaments but rather form a complex multilayer system of tightly packed filaments (Paper I). Thus, if a filament fades there is already another one below it ascending to replace it. If we assume an ascending velocity of 5–10 km/sec it takes 1000 sec to attain a height of 5000 to 10000 km; it will take another 1000 sec for the material to slide down along the magnetic field returning into the chromosphere. The time scale of this ascending-descending motion agrees well with the observation (Paper I) that individual filaments change appreciably within 10 min and that their lifetime is about 30 min.

Acknowledgement

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