EVOLUTION IN SPACE AND TIME OF SUPERPENUMBRAL CHROMOSPHERIC FIBRILS

G. TSIROPOULA and D. DIALETIS
Institute of Space Research, National Observatory of Athens, Lofos Koufos, 15236 Palea Penteli, Greece

C. E. ALISSANDRAKIS
University of Ioannina, Section of Astrogeophysics, GR-45110 Ioannina, Greece

P. MEIN
Observatoire de Paris, DASOP, F-92195 Meudon Principal Cedex, France

N. MEIN
Observatoire de Paris, DASOP, F-92195 Meudon Principal Cedex, France

(Received 22 July 1996; in revised form 12 December 1996)

Abstract. We have studied the spatial structure and temporal evolution of the intensity and Doppler velocity of dark fibrils forming the superpenumbra of an isolated regular sunspot. The observations were obtained with the Multichannel Subtractive Double Pass (MSDP) spectrograph which operates in Hα and is installed at the focus of the Vacuum Tower Telescope (VTT) at Tenerife (Canary Islands). The fibril pattern shows a remarkable stability during the period of our observations (64 min). Moreover, almost all individual fibrils are identifiable in all frames, but they undergo continual changes in contrast, shape and size. Investigating the temporal evolution of intensity and velocity of individual fibrils, fluctuations were found which have a quasi periodic behavior. As mechanisms for these changes we may suggest (a) change of the Doppler shift due to a wave, (b) periodic changes of the density of the Hα absorbing material, (c) disappearance and reappearance of fibrils, in more or less the same magnetic flux tube, at regular intervals.

1. Introduction

The solar chromosphere, when seen in strong lines such as Hα and Ca II K, is covered with many dark and bright elongated features. Foukal (1971a, b) discriminated these fine structures (e.g., mottles, threads, fibrils) by their apparent character. He suggested that the differences observed between the fine structures of quiet and active regions must reflect differences in the strength and direction of the magnetic field related to them. Magnetic fields associated with mottles are weaker and appear to have an open configuration, while magnetic fields associated with fibrils and threads are strong and appear to have a closed configuration connecting opposite polarities of the longitudinal field component and forming low-lying horizontal structures.

Despite the effort that has been devoted in the study of active regions and the associated fibril pattern as a whole, little attention has been paid to the study of the properties of individual fibrils and their changes with space and time. Foukal (1971b) stated that their lifetimes vary with length, ranging from 1 min for the shortest, up to 20 min for the longest; during this interval, the visibility of the fibril

Solar Physics **172:** 139–149, 1997.

changes, but it oscillates about a ‘mean appearance’ defined by the characteristic alignment, mean darkness and mean length, which is preserved for several hours. Bray and Loughhead (1974) gave a summary of the properties of individual fibrils. Marsh (1976) suggested that the apparent extension and retraction of fibrils represent true mass motion and proposed a ballistic model.

The aim of this work is to present the results of a systematic study of the space and time evolution of dark fibrils forming part of the penumbra and the superpenumbra of a regular sunspot. Spectra in a two-dimensional field of view, such as those obtained with the MSDP (Mein, 1977, 1991), are necessary to derive properties of chromospheric structures and understand the physical mechanisms responsible for the transport of mass and energy in the outer solar layers.

2. Observations and Data Reduction

The present observations were obtained on 3 October 1994. They were performed with the MSDP operating in Hα at the Vacuum Tower Telescope (VTT) in Tenerife (Canary Islands). A sunspot which was located near the center of the solar disk (NOOA/AR 7783 at S07 W12) was observed. This instrument records a two-dimensional field of view on the solar surface with good spatial and temporal resolution. The observations were made simultaneously in 9 wavelengths, 0.3 Å apart in the Hα profile. At every pixel of the 2D field of view the line profile can be restored from the measured values of the intensity in the 9 channels using a third-degree spline interpolation. An average profile was obtained by averaging the profile over quiet regions. Thus these profiles can be used for the computation of two-dimensional intensity and Doppler velocity maps at several depths in the Hα line.

The total duration of the present observations was 64 min (from 10:10:53 UT to 11:14:53 UT) under very good seeing conditions for most of the time. By displacing the field stop, a map covering a large region is built up every 4 min from 20 elementary images, which were combined by two-dimensional cross-correlation techniques to form a single field of view.

Maps of intensities and Doppler velocities at H$\alpha \pm 0.3$ Å and at H$\alpha \pm 0.6$ Å, as well as monochromatic images at H$\alpha + 0.3$ Å, H$\alpha - 0.3$ Å, H$\alpha + 0.6$ Å and H$\alpha - 0.6$ Å were computed. In Figure 1 we show the first and last image of the time sequence at H$\alpha \pm 0.3$ Å of the entire region observed. In Figure 2 some frames of computed intensities and Doppler velocities at H$\alpha \pm 0.3$ Å and H$\alpha \pm 0.6$ Å from the time series containing the sunspot under study are shown.

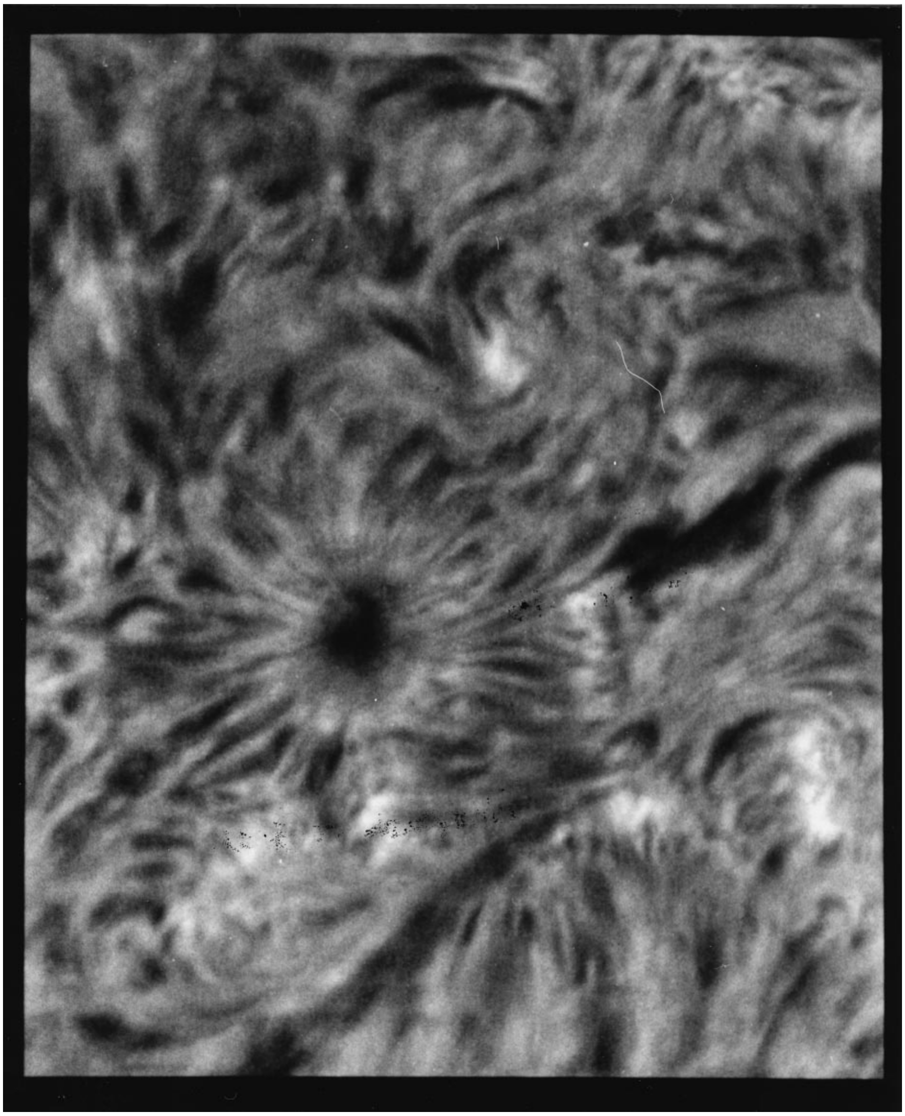

Figure 1(a).

3. Results

3.1. Large-scale pattern

The penumbra and superpenumbra are made up of an apparently well-ordered pattern of elongated dark fibrils. Individual fibrils take the form of long, thin, dark streaks having widths sometimes less than 1″ and variable lengths. The alignment of the fibril structure is roughly radial. Some of them begin at the border of the umbra,

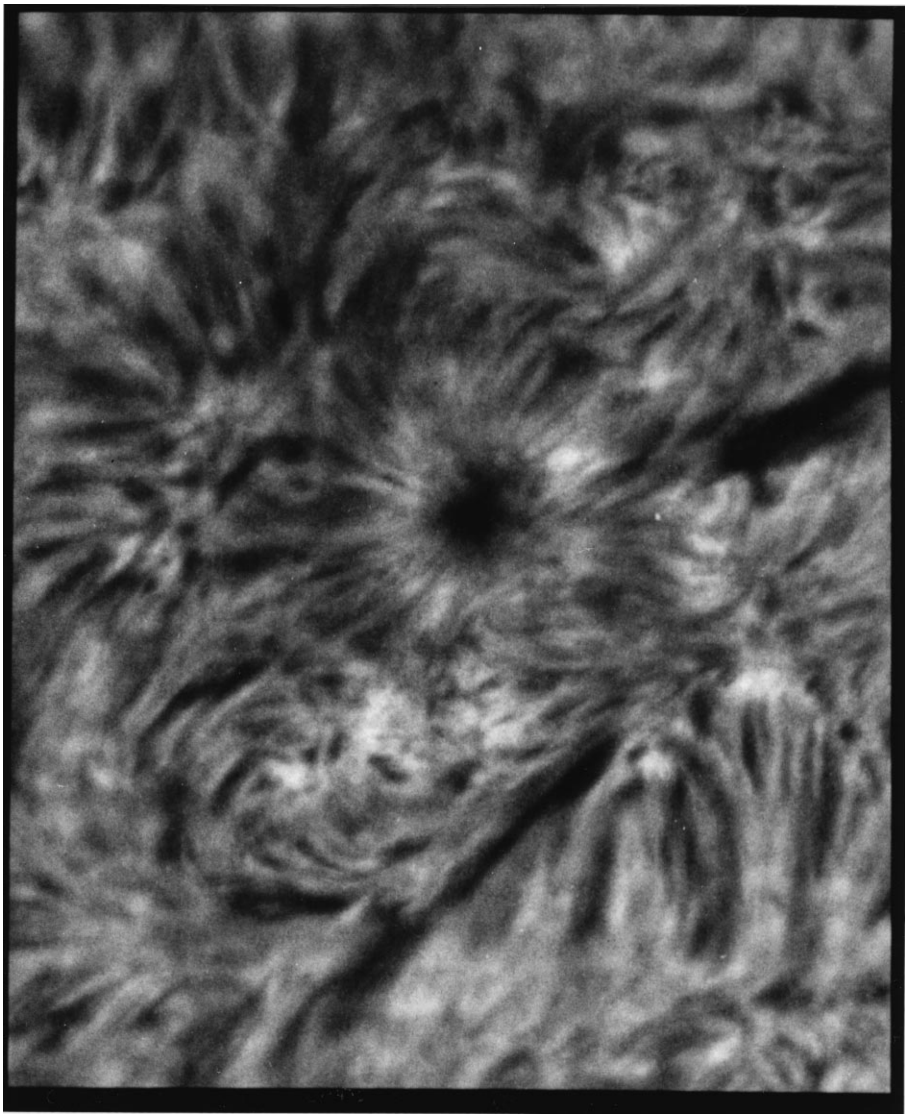

Figure 1(b).

Figure 1. Images of the isolated regular sunspot at Hα $\pm$ 0.3 Å taken 64 min apart ((a) 10:10:53 UT and (b) 11:14:53 UT).

while a few lie entirely outside the penumbra. The pattern of fibrils around the sunspot suggests magnetic ordering. For the comparison of the configuration of the fibrils with the underlying photospheric magnetic field photospheric magnetograms of high resolution are needed and also assumptions on the components of this field

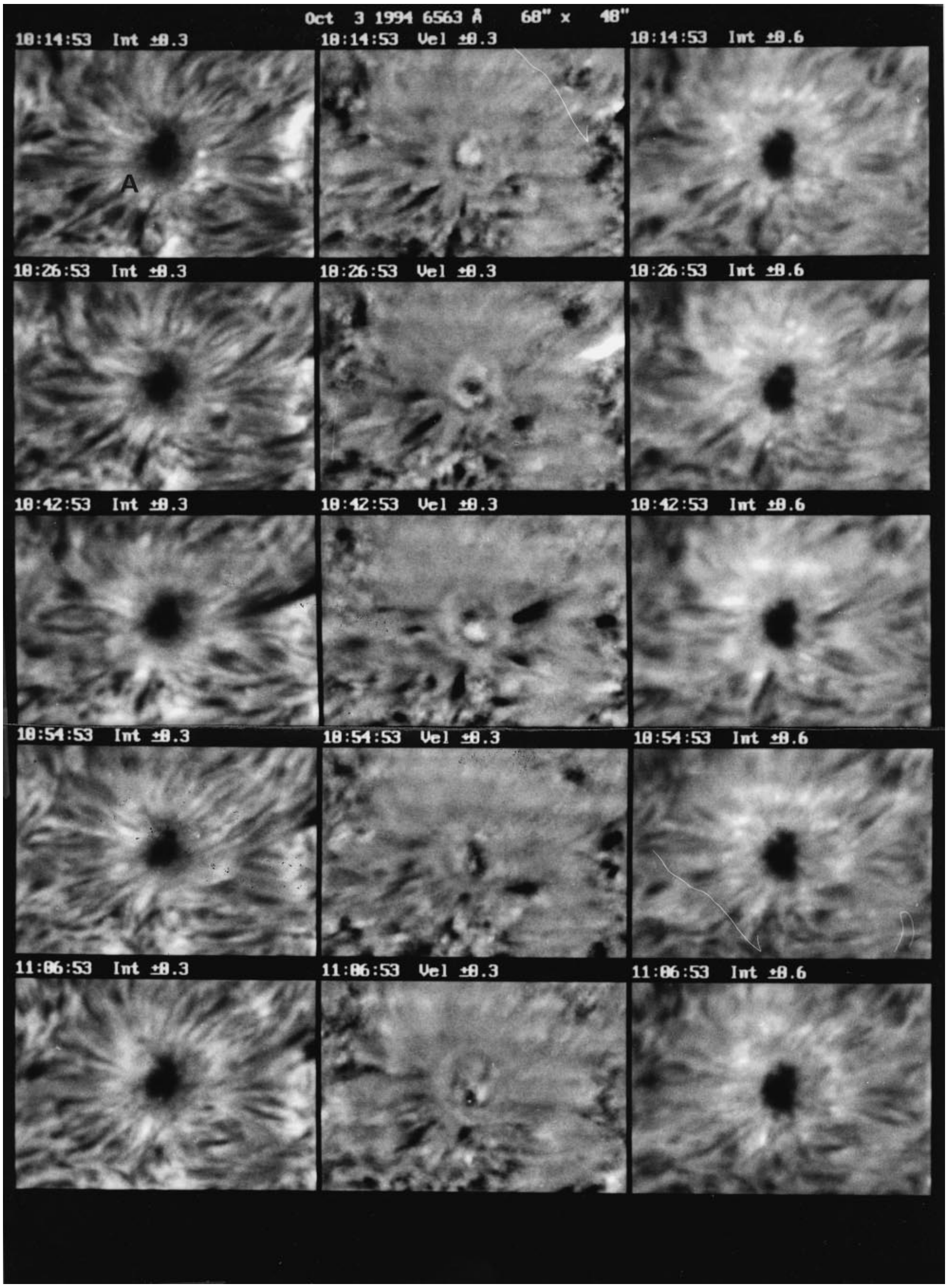

Figure 2. Computed intensities and Doppler velocities at H$\alpha \pm 0.3$ Å and intensities at H$\alpha \pm 0.6$ Å at 10:14:53 UT, 10:26:53 UT, 10:42:53 UT, 10:54:53 UT, and 11:06:53 UT. Dark regions in the velocity maps correspond to downflows.

in order to specify, after an extrapolation, the exact direction of the field within any individual fibril. No magnetograms of the date and time of our observations are available in order to make such a study.

The large-scale pattern of the superpenumbra shows a remarkable stability. This is well illustrated in Figure 1, where two images of the same region taken 64 min apart are shown. During this time the general appearance is very much the same and even the curvature of some fibrils is retained. Shortly after the beginning of the observations (at 10:26:53 UT) a dark filamentary structure appeared at the right side of the spot. It began with strong positive velocities and took the form of a bright compact patch, which was particularly prominent (Figure 2).

Umbral oscillations and running penumbral waves (Alissandrakis *et al.*, 1992; Tsiropoula *et al.*, 1996) are very obvious in the velocity images. The observed large-scale velocity pattern in the vicinity of the sunspot is stable and conforms to the typical Evershed flow pattern of radial inflows at the chromospheric levels. Thus a crescent shaped region of redshifts (dark in Figure 2) at the side of the sunspot toward the disk center and a region of blueshifts (bright in Figure 2) at the opposite side are observed. The fine structures of the velocity pattern are elongated and their orientations with respect to the spot are roughly radial; their widths are as small as $2''$ and they are as long as $11''$.

3.2. Morphology at different wavelengths

The superpenumbra as a whole is more prominent at the centre of Hα and loses contrast as one moves away from the line centre. Fibrils show most of the time their greatest contrast at the blue wing of the Hα line profile. Generally the 'roots' of the fibrils (parts closer to the spot center) are more readily seen in the red wing. This behavior is consistent with the downflows observed towards the umbra of the spot. There are fibrils which during part of their lifetime are visible only in the blue wing, while others appear only in the red wing.

3.3. Temporal evolution of intensity and velocity along the axes of fibrils

The large-scale stability does not mean, however, that individual mottles remain unchanged in intensity, shape and size.

After a careful superposition of frames, the temporal and spatial variations of the intensity and the Doppler velocity were deduced along the axes of several fibrils in order to derive their intensity and flow pattern as a function of time. It must be noted here that, following the axes of the fibrils in consecutive frames, we found some indication that most of them have transverse motions, an effect that has previously been described as flagellant motion. Having good seeing conditions, we suggest that this kind of motion is of solar origin.

In order to follow the fibrils in all frames, the intensity and the velocity were averaged over a strip extending $0.8''$ on either side of a fibril axis traced on the

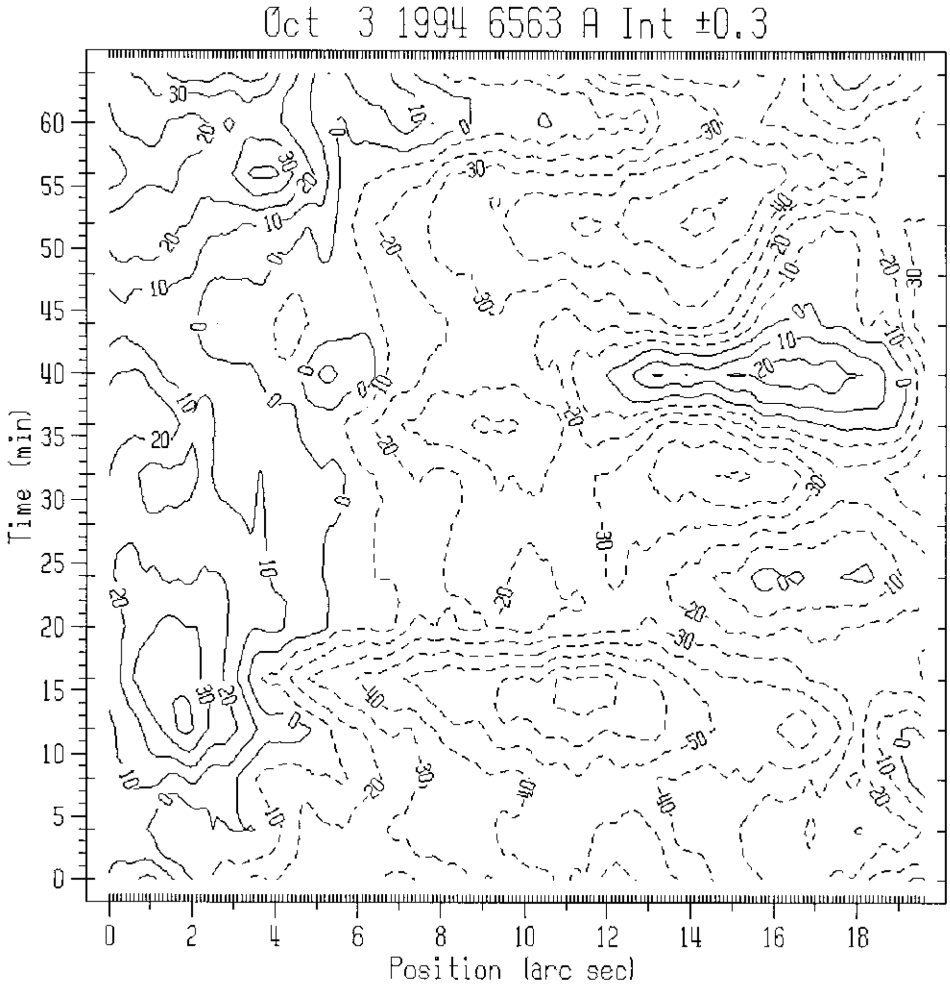

Figure 3(a).

first filtergram and then followed in all filtergrams of the time series. An example of the temporal evolution of the intensity and the Doppler velocity along the fibril A marked in Figure 2 is shown in Figures 3(a) and 3(b). This fibril is elongated and clearly visible at the same place in almost all frames. At 10:50:53 UT it loses contrast at the two ends and becomes shorter. At 10:54:53 UT is again large and elongated, while at 11:02:53 UT becomes curved. This curvature is less obvious at 11:14:53 UT.

The intensity pattern shows continuous changes, which have a quasi-periodic character, as does the length of the fibril. Changes of the flow structure over time are also evident, but here the periodic character is not apparent. This periodicity is more clearly shown in Figures 4(a) and 4(b), where the values of the intensity and

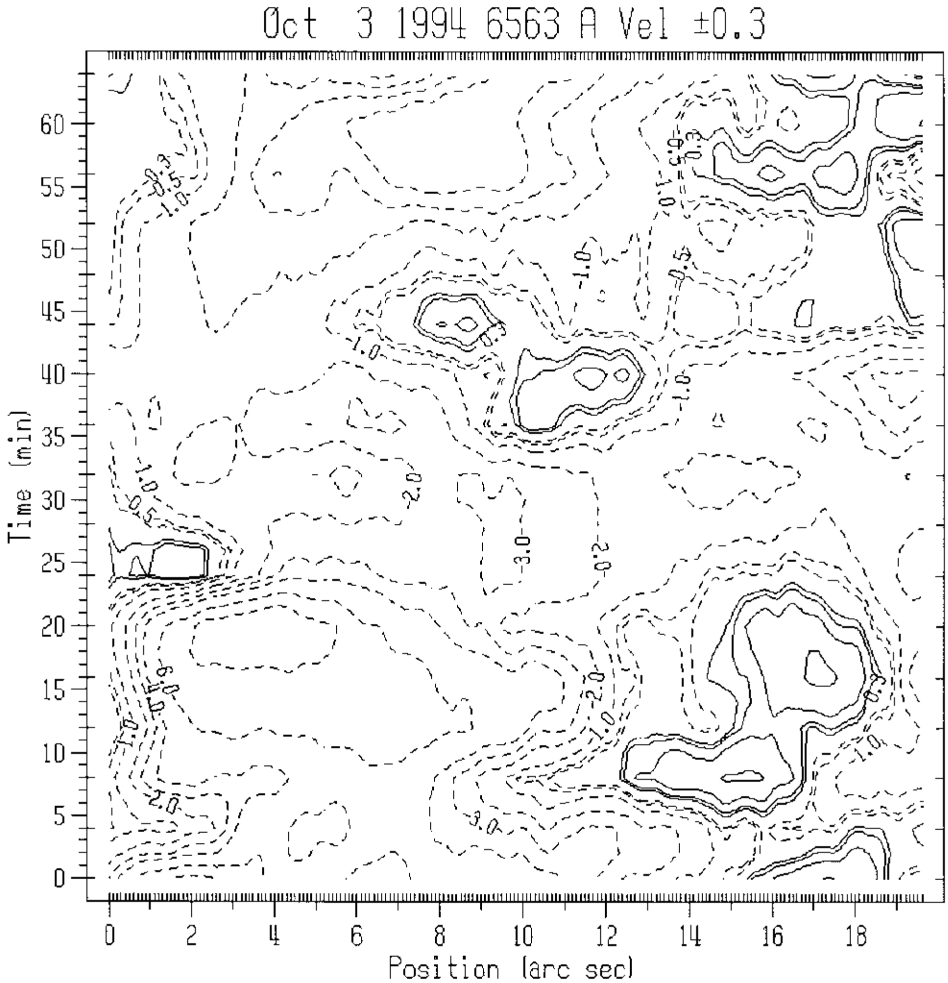

Figure 3(b).

Figure 3. (a) Intensity and (b) Doppler velocity as a function of position and time along the axis of the fibril marked A in Figure 2. The zero level in the intensity is the average intensity of the entire region, while negative velocities correspond to downflows. Position 0 $''$ corresponds to the 'root' of the fibril.

the velocity at 4 different positions along the axis of the fibril are plotted for the entire sequence. The period of the changes is of the order of $\sim$12 min (one must remember, however, that the time resolution of our observations is 4 min), and it is more or less the same for the 10 fibrils studied.

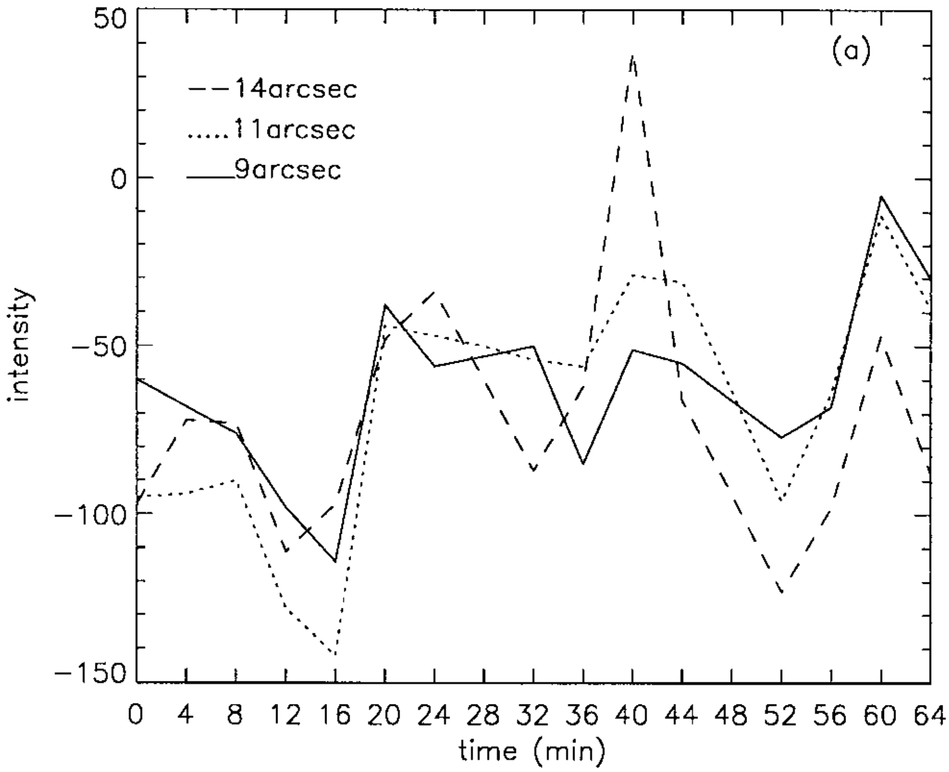

Figure 4(a).

4. Discussion

After a systematic study of the evolution of fibrils, changes in their intensity and Doppler velocity were found, which have a quasi periodic character. The period of these changes is $\sim$ 12 min, with our temporal sampling of 4 min. This quasi-periodic behavior is consistent with the one observed recently by Rimmele (1994) at photospheric levels. As the temporal resolution of our data set is 4 min one should suggest that the 12 min period of structure changes could be the modulation of the 3 min chromospheric oscillations. However, the velocity amplitude of these oscillations is of the order of 1 km s^{-1}, which is much less than the oscillatory velocity amplitude observed in fibrils. We conclude, therefore, that the quasi periodic behavior in these structures is not due to the chromospheric oscillations.

As mechanisms of the observed changes we may suggest: (a) change of the Doppler shift due to a wave, (b) periodic changes of the density of the Hα absorbing material, (c) disappearance and reappearance of fibrils, in more or less the same magnetic flux tube, at regular intervals. No direct measurements of the density and temperature of dark fibrils have been made. However, models of the contrast of structures on the disk (Giovanelli, 1967) show: (a) for $T > 25000$ K an increase of

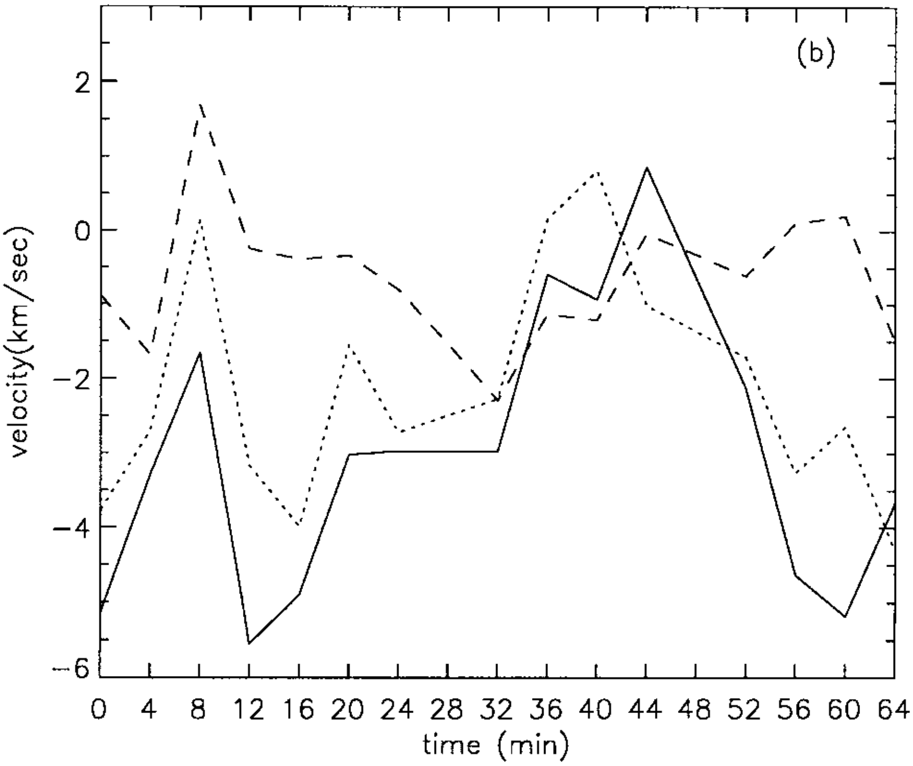

Figure 4(b).

Figure 4. Variations of (a) intensity and (b) Doppler velocity at some positions along the axes of the fibril A as a function of time.

density will result in an increase of brightness if $N_e > 10^{10}$ cm^{-3}, that is over the full range of density expected for such structures. (b) for $N_e > 10^{11}$ cm^{-3} and $T <$ 25000 K an increase of density will likewise result in an increase in brightness. Thus quasi periodic changes of density could lead to the observed periodic variation in the absorption produced by the contained material. Foukal (1971b) suggested that the observed properties of fibrils are consistent with the hypothesis that they are produced by a shock wave mechanism similar to that advanced by Parker to explain spicules. This mechanism could explain the disappearance and reappearance of fibrils. But this suggestion would certainly warrant further study.

Furthermore, with a better temporal resolution, it would be interesting to examine if there is a relation between these quasi oscillations and the oscillations or the running penumbral waves observed in the umbra and the penumbra of a spot.

Acknowledgements

We thank C. Coutard and R. Hellier for participation in the MSDP observations. We would also like to thank our colleagues from the KIS who welcomed us at the VTT and provided excellent technical assistance. This project has received observing time under International Time Programme offered by the CCI of the Canary Observatories and supported by the European Commission through the Access to Large-Scale Facility 'Activity of the Human Capital and Mobility Programme'. Travel funds for this work were provided through the bilateral scientific exchange program between France and Greece.

References

Alissandrakis, C. E., Georgakilas, A. A., and Dialetis, D.: 1992, *Solar Phys.* **138**, 93.
Bray, R. J. and Loughhead, R. E.: 1974, *The Solar Chromosphere*, Chapman and Hall, London.
Giovanelli, R. G.: 1967, in J. N. Xanthakis (ed.), *Solar Physics*, Interscience, London.
Foukal, P.: 1971a, *Solar Phys.* **19**, 59.
Foukal, P.: 1971b, *Solar Phys.* **20**, 298.
Marsh, K. A.: 1976, *Solar Phys.* **50**, 37.
Mein, P.: 1977, *Solar Phys.* **54**, 379.
Mein, P.: 1991, *Astron. Astrophys.* **248**, 669.
Rimmele, T. R.: 1994, *Astron. Astrophys.* **290**, 972.
Tsiropoula, G., Alissandrakis, C., Dialetis, D., and Mein, P.: 1996, *Solar Phys.* **167**, 79.