STRUCTURE AND EVOLUTION OF VELOCITIES IN QUIESCENT FILAMENTS

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Abstract. Simultaneous observations of radial velocities in a 'quiescent' prominence seen in Hα on the disk and in the underlaying photosphere have been obtained in the Meudon Observatory: Doppler shifts in photospheric lines are weaker than in the surrounding regions (<0.3 km s⁻¹); the scale of velocity structures is smaller (<10⁴ km). The vertical component of velocities cannot be neglected. Hα Doppler shifts show that: (a) Highest velocities are often correlated with high brightness horizontal gradients, which suggests that filament and surrounding bright regions belong to the same geometrical and dynamical structure. (b) Fast motions (7 km s⁻¹) have short lifetime (a few minutes). (c) Slow motions in dark regions (<3 km s⁻¹) are associated with blue shifts and may last several hours. This behaviour was confirmed in many other cases by filament observations with the 3-wavelength Hα patrol. This is consistent with EUV observations of the transition zone around prominences, but disagrees with 'downward motions' as seen at the limb, unless these motions do not refer to material velocities.

1. Introduction

Velocity fields in prominences have been very often investigated from emission line profiles observed at the solar limb. Doppler velocity fields have been analysed (Engvold, 1978) as well as 'motions' perpendicular to the line of sight (Dunn, 1960; Engvold, 1976).

Very few filament observations of the disk have been analysed. Although the interpretation of Doppler shifts in terms of radial velocities is sometimes difficult for absorption lines, especially when the source function is unknown, we think that this complementary approach can give new interesting results. This is the only way to measure the velocity component perpendicular to the solar surface (we shall see some discrepancies with 'motions' observed at the limb). The line of sight integration is generally less important than for limb observations, and shorter exposure times allows better image quality. Finally, the location of filaments with respect to active centers and magnetic field is straightforward. A detailed classification can be established, whereas limb observations can only allow a distinction between active and quiescent prominences according to the amplitude and life-time of velocity structures (Tandberg-Hanssen, 1977).

The present paper reports some results about quiescent filaments derived from disk observations at the Meudon Observatory.

2. Observations

Three complementary instruments of the Meudon Observatory have been used:

(1) The multichannel subtractive double pass spectrograph (MSDP) operating on
the Hα line at the solar tower; 7 wavelengths were recorded simultaneously on a 8′ × 1′ field (for data reductions, see Mein, 1977).

(2) The ‘Grand Sidérostat’ spectrograph allowing Doppler and Zeeman analysis of 5250 and 5576 Fe i lines (Rayrole, 1967).

(3) The 3-wavelength patrol (Hα ± 0.75 Å) giving every minute pictures of a major part of the disk (14′ × 19′).

Two sets of data have been analysed in this paper:

(a) Coordinated observations of a quiescent filament at 17° N near the central meridian, 25° E on the 11th of October 1977 and 4° W on the 13th. Perspective effects can be neglected between photosphere and chromosphere. A 4 min time sequence at the rate of one view every 20 s on 11 October, and some pictures on 13 October, were available from instrument (1). Two simultaneous scannings of the field lasting less than 5 min were available on 11 and 13 October from instrument (2). The instrument (3) observed the filament from 6 October to 20 October. The analysis is restricted to the densest part of the filament, outside the spot regions.

(b) ~20 different Hα patrols from instrument (3) giving long time scale evolutions of velocity fields in quiescent filaments.

3. Magnetic Field and Photospheric Velocities in the Filament Region

3.1. Location of the Photospheric Maps with Respect to the Hα Pictures

It is known that filaments take place in a ‘corridor’ between two regions where magnetic polarities have opposite directions. This ‘corridor’ is narrow and very well defined near active centers, where the magnetic field is not too weak (> 20 G). In the case of the studied filament – approximately parallel to the solar parallels – the location was clearly given, not only by the ‘corridor’, but also by the presence of active centers at both ends of the filament, as seen in Figure 1. The accuracy of location is better than 3 arc sec.

On Figure 1, we have represented the rectangular part of the field observed with the MSDP. Inside this frame we have plotted an isophote of the Hα intensity to locate filament features with respect to photospheric ones. The same isophotes is used in Figure 2a, where photospheric velocities are plotted.

3.2. Radial Velocity Amplitudes

As it was pointed out in a previous paper (Martres et al., 1976), Hα filaments are associated with regions where radial photospheric velocities (Vr) are weak. In the present case, radial velocities do not exceed 250 m s⁻¹, with very few exceptions (350 m s⁻¹ in two peculiar structures). Positive and negative values are always present below the filament, and the ‘corridor’ avoids regions with higher velocities. It must be noted that, in spite of weak line Doppler shifts, the measured velocity field is significant. The noise of data is about 60 m s⁻¹.
Fig. 1. 11 October 1977; Map of the magnetic field — in the part of the field observed with the MSDP. — an isophote of the Hα intensity.
Fig. 2. — Isochrones of the Hα intensity, —— inversion lines of radial velocity. (a) Photospheric line; (b) He line.
The average value of velocity amplitudes does not seem to depend very much on the angle between the line of sight and the local vertical direction. This can be deduced from a comparison between the present measurements (near the center of the disk) and other filament observations (Martres et al., 1976). We conclude that the photospheric velocities are not horizontal.

3.3. Direction of the $V_\parallel = 0$ lines in the photosphere.

On Figure 2a, we have represented the lines defined by zero radial velocities ($V_\parallel = 0$) for the observations of 11 October. We remark that, inside the outline of the filament, all these lines have a preferential direction, perpendicular to the general direction of the filament. A similar remark could be done on 13 October, although the direction filament – disk center has been rotating by 90° approximately. This excludes the possibility of a perspective effect, and suggests again that the velocity field under the filament is not horizontal, as it is usually assumed in active centers.

3.4. Dimensions of velocity structures

An average size of velocity structures can be deduced from the number of inversion lines intersecting a straight line of a given length. Within the filament ‘corridor’, we count 26 inversion lines of radial velocity over 275 arc sec ($A' B'$ on Figure 2a), which corresponds to a mean scale around 10 arc sec. Outside this region, and over the same length ($A B$ and $A'' B''$) we count 9 and 11 inversion lines respectively, which corresponds to a mean scale two times larger.

4. Hα Velocity Field

4.1. Correlation between intensity fluctuations and radial velocities

Figure 3a shows intensity fluctuations and Doppler shifts from MSDP observations in Hα line. Velocity computations $V$ simulate a ‘lambdameter’ technique corresponding to the wavelength distance $\pm 0.27 \text{ Å}$. The intensity map $I$ is deduced from line center fluctuation, that is fluctuation of the darkest point of the profile, whatever is the wavelength of this point. In order to locate high velocity regions with respect to the filament, we have plotted on Figure 4a the horizontal variation of radial velocity $V_\parallel$ and intensity fluctuations $I$ along the line $DE$ (Figure 3).

High velocities (V1, V2, V3) occur at the edges of bright regions (B1, B2) and seem to be correlated with brightness horizontal gradients. Another high velocity region (V4) lies between a bright region (B1) and the dark filament (F). Brightest or darkest points do not correspond to high velocities. In the case of dark points, this had already been noticed for a filament associated with an active region (Mein, 1977). In the case of bright regions, this is similar to velocity field structures in photospheric unstable regions below arch filament systems (AFS) or flares along quiescent filaments.
Fig. 3. Maps of Hα intensity fluctuations (black lines – absorbing regions; white lines – bright regions) and Doppler shifts at $\Delta \lambda = \pm 0.27$ Å (black lines – blue shift, white lines – red shift).

Since the velocity and brightness features do not coincide it can be suggested that filament and surrounding bright regions refer to the same geometrical structure above the chromosphere. Moreover, magnetic field observations (Figure 1) show that these bright regions are different from faculae.
Fig. 4a–c. Horizontal variations of radial velocity $V_r$ and intensity fluctuations $I$ along the line $DE$ (Figure 3). Positive velocities correspond to red shift. (a) $t = 0$, (b) $t = 2$ min, (c) $t = 4$ min.

4.2. FAST DISTURBANCES

On Figure 3a, high velocity structures ($\pm 7$ km s$^{-1}$) can be localized within elongated cells (typically $10 \times 50$ arc sec), almost parallel to the general direction of the filament. The lines defined by $V_{\parallel} = 0$ are parallel to this direction (Figure 2b). Such a configuration is quite different from photospheric configuration, as it was seen before.

The evolution of these high velocity structures are apparently fast if we compare the Figures 3a, b, c which represent the intensity fluctuations and the Doppler shifts in the H$\alpha$ line measured respectively at $t = 0$, 2, and 4 min. Figure 4a, b, c shows the velocity field evolution along the straight line $DE$. Many changes occur in the value and location of maxima. Time-scale of such high velocity structures can be less than 2 min.

4.3. SLOW DISTURBANCES

Except in the regions of fast disturbances, absorbing features of the filament are moving generally upwards with small velocities ($< 4$ km s$^{-1}$) during the whole time sequence. This can be seen in the lower part of Figure 3, corresponding to the 11 October observations. A similar situation occurred on 13 October for the same
regions, as it could be derived also from MSDP observations. Since the filament was near the disk center, the radial velocity is close to the vertical component.

Observations with the H\(\alpha\) patrol were available from 6 October to 20 October. They show that this same part of the filament is very stable. Slow perturbations can be detected only with time-scales around several hours.

5. Slow Vertical Motions in Quiescent Filaments

Many other filaments have been observed with the 3-wavelength H\(\alpha\) patrol. Although velocity calculations cannot be performed from these observations, good statistics can be derived with respect to time-scales, velocity direction and longitude distribution.

H\(\alpha\) patrol observations have been analysed over 170 hr; this analysis provides 34 cases of quiescent filament at different locations on the Sun. They concern 13 quiescent filaments which have been selected by their extensions (>20°) and their distances from nearest active regions. They correspond to various latitudes, orientation and dates during the solar cycle.

Long living disturbances fall into 4 kinds of motions, according to the visibility of the filament in the H\(\alpha\) blue and red wings: blue shift, red shift, coexisting blue and red shifts, no shift at all. Figure 5 shows the ratios of total observing times corresponding to the 4 kinds of motions, according to the center-limb location of the filaments (\(\theta < 30^\circ\); 30° < \(\theta < 60^\circ\); 60° < \(\theta\)).

We can do the following remarks:

(1) Red shifts are not usually observed without blue shifts in other parts of filaments. If they are, they correspond to localized and short-living structures.

(2) Blue shifts are very frequent. They have large extensions and long life-times.

(3) Coexisting blue and red shifts are also frequent, especially in the parts of filaments which are near active centers (for example motions at the end of filaments). Reciprocally, if active centers are far from the filaments, blue and red shifts never coexist in our sample.

(4) Not any radial velocity was detected during the 10 observing hours corresponding to 3 high longitude filaments (\(\theta > 60^\circ\)). Although many other cases would be needed to check this result, this indicates that material velocities in filaments should be mainly vertical.

(5) Relative weight of cases 1 and 3 (blue shifts and mixed blue and red shifts) should be modified if MSDP observations are taken into account. Velocity amplitudes in case 1 are smaller than in case 3, which implies that detection by H\(\alpha\) patrol is more difficult and that the weight of case 1 should be underestimated.

As a conclusion, quiescent filaments seem to move very often upwards. Stable velocities around 3 km s\(^{-1}\) (as indicated by MSDP observations) seem to be inconsistent with the limb observation of downward moving prominences (Dunn, 1960; Engvold, 1976). The interpretation of Doppler shifts in terms of radial velocities is not straightforward. In the case of constant source function – and velocity
Fig. 5. Ratios of total observing times corresponding to 3 kinds of motions: blue shift //, red shift \|\|, coexisting blue and red shifts \$$\otimes$$, according to the center limb location of the filaments. This histogram is provided by: 11 cases at $0 < \theta < 30^\circ$, 19 cases at $30^\circ < \theta < 60^\circ$, and 4 cases at $60^\circ < \theta < 90^\circ$.

Inside the filament, it can be shown that Doppler shift and velocity have the same sign in so far as this source function $S$ is smaller than the intensity level $I'_\lambda$ at which Doppler shifts are measured (‘cloud’ model, Beckers, 1968). If $I_\lambda$ is the chromospheric radiation without filament, and $\tau_\lambda$ the optical depth of the filament, the equation

$$I'_\lambda = I_\lambda e^{-\tau_\lambda} + S(1 - e^{-\tau_\lambda})$$

shows that a dark feature ($I'_\lambda < I_\lambda$) corresponds to $S < I'_\lambda < I_\lambda$, whatever is $\lambda$. So, the Doppler shift is expected to be of the same sign as the velocity, in the parts of the filament where the line profile is darker than in the undisturbed chromosphere. In the case of bright features, the sign is questionable. It is obvious that we must know more about variation with height of opacity and source function, before any definite assertion.
A possible explanation for inconsistency with prominence observations could be that motions at the limb represent only fluctuations in the ionization degree of material at different levels in the corona. Perhaps this could be tested by motions in some fine prominence structures, which are maybe disconnected with the ionization conditions (density or magnetic field inhomogeneities). For the present, upward velocities could reconcile the velocity amplitude with the long life time of quiescent prominences. They could be consistent also with upward vertical motions which have been found by EUV observations of the transition zone around filaments (Lites et al., 1976).

Dynamical models of prominences (Priest and Smith, 1979; Unno and Ribes, 1980) could be investigated again in case of ascending material in the filament core.

6. Conclusion

Coordinated observations have been performed at the Meudon Observatory with the MSDP of the solar tower, the magnetograph and the 3 wavelength Hα patrol. Several features of a prominence as seen on the disk have been pointed out. Table I summarized typical values observed in photospheric and chromospheric layers.

<table>
<thead>
<tr>
<th>TABLE I</th>
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<tbody>
<tr>
<td>Velocity field associated with quiescent filaments</td>
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<table>
<thead>
<tr>
<th>Lifetime</th>
<th>Size of velocity cells</th>
<th>max. radial velocity (km s⁻¹)</th>
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<tbody>
<tr>
<td>Photosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>under the filament</td>
<td>&lt; 15°</td>
<td>0.350</td>
</tr>
<tr>
<td>outside the filament</td>
<td>&lt; 30°</td>
<td>0.550</td>
</tr>
<tr>
<td>Chromosphere</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow perturbation</td>
<td>Several hours</td>
<td>whole filament</td>
</tr>
<tr>
<td>Fast perturbation</td>
<td>~ 10 min</td>
<td>~ 10°×50°</td>
</tr>
</tbody>
</table>

Velocity field under the filament in photospheric layers is quite peculiar. The amplitude is small and the velocity vector is probably not horizontal. Zero velocity lines (Vₚ = 0) are roughly perpendicular to the direction of the filament, that is to the zero magnetic field line (Bₛ = 0). The size of velocity cells is smaller than elsewhere.

Hα Doppler shifts and Hα intensity fluctuations have different geometrical structures. High velocities occur frequently at the edges of dark features, which could corroborate Doppler shift observations of prominences at the limb (Engvold, 1978). Bright regions surrounding the filament cannot be mistaken for faculae, since they correspond to low magnetic fields. They cannot be disconnected from the dark filamentary material, and surely difficult transfer problems arise in order to account for line formation in corona outside the coolest regions of the filament.
Some regions of the filament are fastly moving and the life time of velocity structures can be very short (<2 min). The other ones are more stable, and no change occurs during many hours. However, as it was also observed in many other cases by the 3 wavelength patrol, they are generally moving upwards and the velocity amplitude is too high (~3 km s⁻¹) to be consistent with the time-scale of the prominence itself. Nevertheless, apparent motions at the limb are generally downwards (Engvold, 1976). It can be suggested that material is slowly moving up, across the filament which is almost stationary.

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References