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# Some regularities of velocity oscillations in prominences

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**Abstract.** At present three types of velocity oscillations in quiescent prominences are distinguished: (1) long-period oscillations (with oscillation periods of 40–80 min), (2) oscillations with periods of 10–40 min, and (3) short-period oscillations (3–10 min).

By analyzing our observational data obtained at the Sayan Observatory during 1981–1989, we have detected: (1) a dependence of the period of long-period velocity oscillations in prominences on the heliolatitude, and (2) velocity oscillations with periods of 10–40 min (amplitudes of 30–300 m s$^{-1}$) which are interpreted as the eigenmodes of prominences.

**Key words:** the Sun: prominences – oscillations

## 1. Introduction

The study of oscillatory phenomena in prominences was initiated over half a century ago. The first type of oscillations, the so-called "Winking Filaments", whose "winking" is attributable to flares, was discovered by Greaves, Newton and Jackson [presented by Dyson (1930), a Royal astronomer]. Later, this phenomenon was confirmed and described by various authors (a fairly exhaustive list of references may be found in a paper of Bashkirtsev & Mashnich 1984). Ramsey & Smith (1965, 1966) found that oscillation periods of winking filaments (prominences) lie within 6–40 min. After Leighton et al. (1962) had discovered the 5-min oscillations in the solar photosphere, the search for such oscillations started everywhere, including in prominences, and such oscillations in prominences were, indeed, detected (Harvey 1969; Shpitalnaya & Tifrea 1971; Zhugzhda et al. 1979). As opposed to this, Malherbe et al. (1981, 1987) have not detected any oscillations in filaments. Our attempts to record short-period oscillations (with periods of about 5 min), by applying for that purpose the highly-sensitive method of Kobanov (1983), led to the detection of a new type of oscillations, the long-period oscillations of mass velocity in prominences (Bashkirtsev et al. 1983; Bashkirtsev & Mashnich 1984). Periods and amplitudes of such oscillations lie largely within 40–80 min and 200–800 m s$^{-1}$, respectively. The discovery of the long-period oscillations stimulated a renewed upsurge of interest to the study of oscillatory processes in prominences, and the past several years have witnessed the emergence of a series of relevant publications (Wiehr et al. 1984; Balthasar et al. 1986, 1988; Tsubaki & Takeuchi 1986; Tsubaki 1987; Tsubaki et al. 1987, 1988; Suematsu et al. 1990).

In this paper we shall present the results obtained by analyzing our observational data for the period 1981–1989.

## 2. Observations and results

The results to be discussed here are based on velocity oscillation observations in prominences (filaments). The observations have been made at the horizontal solar telescope of the Sayan Observatory (the solar image diameter on the spectrograph slit is 185 mm, and the spectrograph dispersion is 3.12 mm Å$^{-1}$) using the magnetograph with one photomultiplier and automatic compensation of brightness fluctuations. The spatial-differential method of Kobanov (1983) was applied for investigating quasi-periodic motions in prominences. The principle of the method as applied to prominences was outlined in a paper by Bashkirtsev & Mashnich (1984). At this point we wish to note briefly that this method measures, for the same spectral line, the H$\beta$-line in our case, the difference of Doppler shifts between its two profiles from two spatially-separated prominence areas. An H$\alpha$-filter was used for setting and checking the prominence or filament position on the spectrograph mirror slit. H$\alpha$-filtergrams of the prominence (filament) under investigation were normally taken at the beginning and at the end of the observations. During the observations the image was maintained on the spectrograph slit using the photoelectric guider. Our observations were carried out under conditions of high mountains (the observatory is located at over 2000 m above sea level), clear sky and little straylight. We have not observed any marked signal distortion in our records caused by the straylight effect.

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1993A&A...279..610B

Figure 1 gives an example of a registrogram, and Fig. 2 shows the result of its spectral processing for one of the prominences. The oscillation records were processed using the method of correloperiodogram analysis (Kopecky & Kuklin 1971). Long-period variations are well traceable in all of our non-processed prominence registrograms. For some objects at some moments of time, the records show irregular short-period oscillations.

The observational and processing results are listed in Table 1 which sequentially indicates: the observing date, the coordinates of limb prominences and filaments, time intervals of the observations, the spectroscopy entrance aperture, the distance between the centers of the two observed areas (r is the spatial separation of the areas observed with respect to the solar limb radially, t – tangentially, ⊥ and ∥ – perpendicular and parallel to the

**Table 1.** Results of the observations and processing of prominence oscillations

| Date | Position | Time (UT) | Aperture (arcsec) | Separation (arcsec) | Period (min) | A ($\mathrm{m\,s^{-1}}$) | $\theta$ (°) |
|---|---|---|---|---|---|---|---|
| 30.03.81 | −75 W | 0254–0600 | 5 × 4 | 4 r | 81, 50 | 760 | 45 |
| 31.03.81 | −18 W | 0208–0406 | 5 × 4 | 4 r | 77, 39 | 5660 | 60 |
| 31.03.81 | −38 W | 0535–0640 | 5 × 4 | 4 r | 45, 20, 70 | 750 | 60 |
| 03.05.81 | −23 E | 0056–0255 | 5 × 5 | 6 r | 74, 16, 13, 11 | 560 | 90 |
| 24.03.82 | −54 E | 0706–0848 | 9 × 12 | 6 r | 50 | 400 | 0 |
| 25.03.82 | −54 E | 0314–0412 | 9 × 12 | 6 r | 50, 25 | 1030 | 0 |
| 27.03.82 | −17 E | 0435–0543 | 9 × 9 | 12 t | 47 | 490 | 55 |
| 27.03.82 | −17 E | 0629–0747 | 9 × 9 | 12 r | 49, 25 | 260 | 55 |
| 01.04.82 | −50 E | 0152–0324 | 9 × 9 | 12 t | 47, 26 | 750 | 10 |
| 01.04.82 | −50 E | 0406–0509 | 9 × 9 | 12 r | 42 | 240 | 10 |
| 02.04.82 | +15 E | 0132–0312 | 9 × 9 | 12 t | 42, 26 | 1530 | 0 |
| 28.06.82 | −7 W | 0027–0134 | 8 × 8 | 12 t | 53, 17 | 850 | 90 |
| 28.06.82 | −7 W | 0157–0255 | 8 × 8 | 12 t | 51, 25 | 650 | 90 |
| 29.06.82 | +22 E | 2343–0131 | 8 × 8 | 12 t | 67, 26, 15 | 710 | 25 |
| 29.06.82 | +22 E | 0206–0333 | 8 × 8 | 12 r | 65, 12, 32 | 270 | 25 |
| 19.08.83 | −18 E | 0000–0320 | 7 × 9 | 12 t | 81, 40, 27 | 770 | 40 |
| 25.08.83 | $\lambda=+18$,<br>$\varphi=-27$ | 0221–0404 | 2 × 9 | 8 ⊥ | 65, 9 | 280 | — |
| 30.08.83 | $\lambda=-66$,<br>$\varphi=+23$ | 0033–0253 | 2 × 9 | 8 ⊥ | 86, 42 | 370 | — |
| 20.05.84 | −37 E | 0135–0310 | 7 × 9 | 12 t | 58, 27, 36, 16 | 550 | 30 |
| 25.05.84 | −30 E | 0112–0346 | 7 × 9 | 12 t | 72 | 690 | 30 |
| 25.05.84 | $\lambda=-25$,<br>$\varphi=-48$ | 0713–0839 | 2 × 9 | 12 t | 72, 15 | 120 | — |
| 30.05.84 | $\lambda=+15$,<br>$\varphi=-20$ | 0635–0819 | 2 × 9 | 12 ∥ | 76, 20, 15, 5 | 580 | — |
| 21.07.86 | $\lambda=-13$,<br>$\varphi=-40$ | 0011–0107 | 1 × 8 | 12 ∥ | 5, 41 | 230 | — |
| 23.07.86 | $\lambda=+50$,<br>$\varphi=-40$ | 0014–0217 | 1 × 8 | 12 ∥ | 86, 20, 16, 14 | 370 | — |
| 24.07.86 | +36 E | 0034–0320 | 7 × 8 | 12 r | 29, 44, 23, 19 | 180 | 0 |
| 24.07.86 | +36 E | 0403–0535 | 7 × 8 | 12 r | 27, 42, 19 | 115 | 0 |
| 28.07.86 | −35 W | 0134–0500 | 7 × 8 | 12 t | 53, 38, 27, 23 | 280 | 10 |
| 30.07.86 | −35 W | 0022–0217 | 7 × 8 | — | 59, 30, 14, 22 | 390 | 10 |
| 31.07.86 | −35 W | 0150–0655 | 7 × 8 | — | 54, 114, 39, 28, 20 | 217 | 10 |
| 27.06.89 | +65 W | 0310–0435 | 5 × 8 | 12 t | 49, 25 | 50 | 0 |
| 27.06.89 | +65 W | 0653–1000 | 5 × 8 | 12 t | 76, 37, 31, 24 | 110 | 0 |
| 28.06.89 | +66 W | 0038–0256 | 5 × 8 | 12 t | 32, 40, 80, 5 | 80 | 0 |
| 28.06.89 | +66 W | 0335–0539 | 5 × 8 | 12 r | 80, 29, 20, 16, 23 | 240 | 0 |
| 28.06.89 | +66 W | 0719–0901 | 5 × 8 | 12 t | 60, 31, 23, 14 | 90 | 0 |
| 29.06.89 | +66 W | 0500–0639 | 5 × 8 | 12 r | 48, 17, 11, 14, 25 | 200 | 0 |
| 13.07.89 | −10 W | 0356–0703 | 7 × 8 | — | 58, 114, 22, 29 | 730 | 85 |
| 14.07.89 | −10 W | 0151–0307 | 7 × 8 | — | 39, 15 | — | 85 |
| 14.07.89 | −10 W | 0351–0502 | 7 × 8 | — | 44, 25, 17 | 140 | 85 |

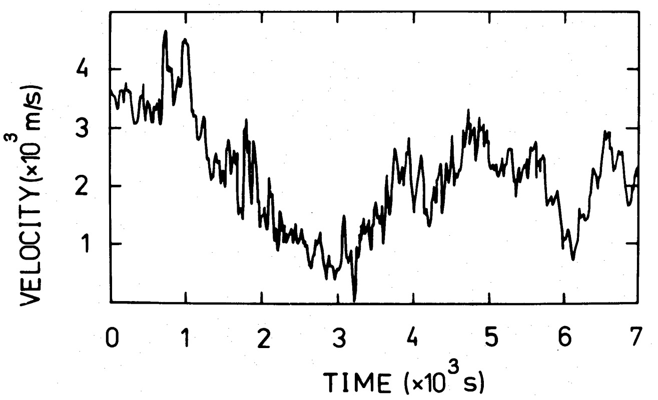

**Fig. 1.** A copy of the Doppler velocity oscillation registrogram for the prominence of 29 June 1982, 2343–0131 (see Table 1)

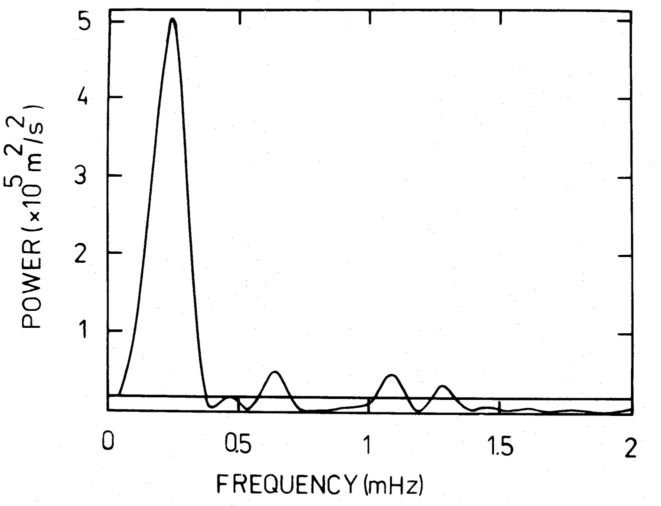

**Fig. 2.** Power spectrum of Doppler velocity oscillations presented in Fig. 1. The horizontal line gives the 99% – significance level

longitudinal filament axis, and the gap means that the observation was made in one area in the non-differential mode), observed significant oscillation periods in decreasing order of the peak amplitudes in the power spectrum, the amplitude of the largest peak (corresponding to the period indicated as the first in the preceding column of periods), and $\theta$ is the angle between the prominence (filament) longitudinal axis and the line of sight. The orientation of the filament with respect to the line of sight was determined from its solar disk passage.

## 3. Discussion

Our observations show that the main power of the prominence oscillations is contained in quasi-hour oscillations (see Fig.2). The occurrence frequency of periods of these predominant oscillations (for each prominence, this is only the first numeral in the column of periods of Table 1) is presented in Fig. 3a, and that of periods of lower power (all the other numerals following the first) is given in Fig. 3b. While in Fig. 3a the values of periods are mainly within 40–80 min, in Fig. 3b they are in the range 10–40 min, with a maximum of about 25 min. Quasi-hour prominence oscillations are caused – as we believe – by horizontal oscillations of the lower-lying solar atmosphere and are forced ones (Bashkirtsev et al. 1987). Oscillations with periods 10–40 min (1.7–0.4 mHz) coincide with the variation range of "winking filaments". Kleczek & Kuperus (1969), by invesstigating the problem of "winking filaments" and interpreting the prominence as an oscillator on a magnetic suspension, obtained the expression for the oscillation eigenperiod $P=4\pi LB^{-1}\sqrt{\pi\rho}$. By taking for the prominence the typical values: length $2L=10^{10}$ cm, mean magnetic field strength $B=9$ G (Bashkirtsev & Mashnich 1987, 1989) and the mass density of $1.67\,10^{-14}$ g cm$^{-3}$, we obtain for a mean oscillation period $P=27$ min. There are prominence oscillations at the eigenfrequency. Unlike "winking filaments", whose oscillations reach amplitudes of tens of kilometers per second and are damped rapidly, the amplitudes of the eigen-oscillations in prominences which we observed are relatively small: 30–300 m s$^{-1}$, and the oscillations are not damped. Thus, we arrive at the conclusion that the phenomenon of prominence (filament) "winking" is always present; however, it manifests itself in a most pronounced form during their activation.

Recently Balthasar et al. (1988) found indications of eigenmodes of prominences. They believe that their main frequency close to 0.7 mHz is the ratio of Alfvén speed and twice the typical length.

Apart from the above two types of velocity oscillations, there exists the third kind of oscillations (with periods of 3–10 min and amplitudes of 200–3000 m s$^{-1}$) which was observed by a number of authors (Wiehr et al. 1984; Balthasar et al. 1986, 1988; Suematsu et al. 1990; Thompson & Schmieder 1991; Yi Zhang et al. 1991) but was almost unobserved at the Sayan Observatory. In our

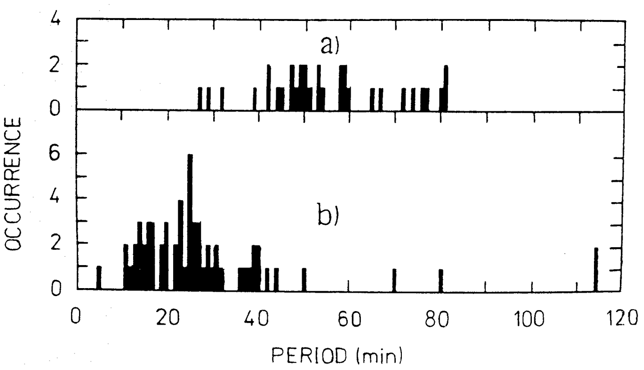

**Fig. 3.** The occurrence frequency in prominences of: (a) Periods of predominant Doppler velocity oscillations; (b) all other periods of small-power oscillations

recent paper (Mashnich & Bashkirtsev 1990) we supposed that the absence of short-period oscillations on our registrograms was, most probably, attributable to the low spatial resolution ($8'' \times 8''$). If this is the case, then the short-period oscillations are small-scale ones. They are caused by photospheric and chromospheric oscillations, and this view seems to be supported by all researchers (Harvey 1969; Balthasar et al. 1988; Tsubaki et al. 1988; Mashnich & Bashkirtsev 1990; Suematsu et al. 1990).

Thus, prominences exhibit three types of velocity oscillations (the three types of oscillations were also pointed out previously by Tsubaki & Takeuchi 1986):

(1) Long-period oscillations in the range of periods 40–80 min (0.4–0.2 mHz), usually with an amplitude of 200–800 m s$^{-1}$. These are forces large-scale oscillations of the entire prominence caused by horizontal oscillations of the lower lying solar atmosphere.

(2) Prominence oscillations at the eigenfrequency. They have periods of 10–40 min (1.7–0.4 mHz) and amplitudes of 30–300 m s$^{-1}$.

(3) Short-period oscillations with periods of 3–10 min (5.5–1.7 mHz), with amplitudes of 200–3000 m s$^{-1}$. These are forced and, most probably, small-scale oscillations caused by vertical oscillations in the photosphere and the chromosphere.

Some investigators report on prominence oscillations with a period of about 13 min which is observed in chromospheric network oscillations. As is evident, the value 13 min falls outside the limits of the range of 3–10 min periods. In this connection, it should be noted that the above-mentioned ranges of periods and amplitudes of the three types of oscillations are not strictly limited.

By analyzing the data from our Table 1, we obtained a certain dependence of the period of long-period oscillations on the heliolatitude of prominences (Fig. 4). Although the data sample still is small, a quasi-periodic variation of oscillation periods with heliiolatitude is, nevertheless, well traceable, which may be satisfactorily approximated, for example, by the expression $P = 60 - 20 \cos 8\varphi$. We believe that further observational data are needed in this case, and it is still premature to furnish any interpretation, although it seems likely that the increase in periods is associated with areas of increased solar activity. As far as the long-period oscillation amplitudes are concerned, they do not show any clear dependence on the heliolatitude.

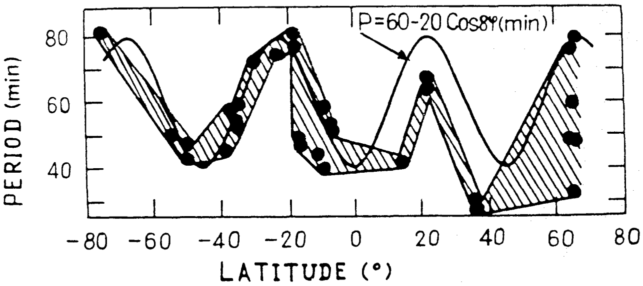

**Fig. 4.** The dependence of the period of long-period velocity oscillations in prominences on the heliolatitude

The variation in values of quasi-hour periods of velocity oscillations in prominences with heliolatitude determined in this paper gives evidence for the existence of a similar variation in the lower solar atmosphere.

*Remark.* At the stage of revising our paper, there appeared publications by Joarder & Roberts (1992a, b), who – by theoretical modelling – try to explain the entire observed spectrum of the oscillations in quiescent prominences.

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