OSCILLATORY PROCESSES IN PROMINENCES

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Abstract. A new type of oscillations, being long-period oscillations of line-of-sight velocities, with periods ranging from 42 to 82 min and amplitudes in excess of 200 m s^{-1} has been discovered in prominences. These oscillations may be interpreted as a combination of torsional and longitudinal ones.

1. Introduction

It has been apparent for some time that oscillatory motions in the solar atmosphere are a common phenomenon. Although the oscillations have been found to occur throughout the solar atmosphere, those occurring in its upper layers, in prominences, and in the corona, are very poorly understood.

The oscillatory processes in prominences have been investigated episodically by a number of authors (Dyson, 1930; Newton, 1935; Dodson, 1949; Bruzek, 1951, 1957; Ramsey and Smith, 1965, 1966; Hyder, 1966; Kleczek, 1968; Kleczek and Kuperus, 1969; Harvey, 1969; Shpitalnaya and Tifrea, 1971; Gallegos *et al.*, 1971; Zhugzhda *et al.*, 1979; Malville and Schindler, 1981; Malherbe *et al.*, 1981) and generally in studying the activation of prominences by flares.

Using an Hα-filter Ramsey and Smith (1965, 1966) observed the winking of filaments, produced by a periodic Doppler shift of the spectral line with respect to the filter's transmission band. In this case the frequency of oscillations was 1.5–10 cycles per hour. The winking phenomenon is observed as being caused by a disturbance, originating in the flare region and is interpreted as vertical oscillations, damped by the viscosity of the surrounding coronal plasma (Hyder, 1966). Contrary to this, Kleczek and Kuperus (1968) believe that prominence oscillations must probably occur horizontally and the winking phenomenon is due to the line-of-sight component of the oscillations. On the other hand, Brown (1958) in his study of the stability of magnetohydrostatic models to horizontal displacements arrived at the conclusion that no frequency of less than 10^{-3} Hz is to be expected in a stable prominence.

The most extensive observations of line-of-sight velocity oscillations have been made by Harvey (1969) using the Doppler servo recorder of the High-Altitude Observatory. Periodic oscillations of the velocity were found approximately in one-third of all the measurements (over 100). The average periods of oscillations were 318 and 354 s for prominences of non-active and active regions, respectively. The largest period measured was 16 min. It is supposed that the oscillations are caused by Alfvén waves. However, Harvey does not exclude the possibility that the observed oscillations have an instrumental origin. Similar results were obtained by Zhugzhda *et al.* (1979) by studying the

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time variations of the apparent area of a loop-type prominence, as observed with an Hα-filter. The period of oscillations was 340 s, while the detected oscillations seemed to be also of the Alfvén type.

Using the spectrograms of an active prominence in the D_3 He I line, Shpitalnaya and Tifrea (1971) found oscillatory variations of the central intensity, line-of-sight velocities, and sizes of individual knots of the prominence with a period of about 5 min. The amplitude of velocity oscillations was a high as 60 km s^{-1}. An analysis of long-term observations of D_3 He I profiles made by Landman *et al.* (1977) at a given point of a quiescent prominence, showed only low-amplitude oscillations in the line width and intensity, with a period of 25 min, but none in the line shift.

Malherbe *et al.* (1981) have obtained, using an MSDP spectrograph operating on the Meudon Solar Tower, a time sequence of a quiescent filament of a 720 s duration and with a time step of 30 s. The Fourier analysis of the radial velocities measured in the Hα-line showed that short-period oscillations are almost lacking in the filament (there is only a small peak around 190 s) while the power spectrum in the quiet chromosphere around it shows a sharp maximum at about 240 s.

Malville and Schindler (1981) observed in a *loop* prominence simultaneous radial and torsional oscillations with a period of about 75 min, a wavelength of 37 000 km and an amplitude of 1–2 km s^{-1} 90 min before the onset of a limb flare. These oscillations are believed to be associated with the kink instability of a current carrying flux tube.

Long-period oscillations of the line-of-sight velocities with a period around 80 min in *quiescent* prominences were discovered by Bashkirtsev *et al.* (1983).

The detection of long-period oscillations has stimulated the undertaking of further observations of oscillatory processes in prominences.

2. Observations and Data Processing

The prominence observations were made at the Sayan Observatory in 1981–1982 with a horizontal solar telescope (the telescope is guided photoelectrically, the diameter of the solar image on the spectrograph slit is 185 mm, and the spectrograph dispersion is 3.12 mm $Å^{-1}$) with the aid of a magnetograph with a one-photomultiplier tube and automatic compensation of brightness fluctuations and information output on a strip-chart recorder. For the study of line-of-sight velocity oscillations in prominences we have applied the differential method, developed to study local quasi-periodical motions of solar material (Kobanov, 1983). The principle of this method is easily seen in Figure 1. Directly before the spectrograph slit is placed an Iceland spar plate and a $\lambda/4$ plate. The scheme shows only the prominence areas and the light beams coming from them into the spectrograph. Upon passage through the spar plate, the light from the two prominence areas becomes orthogonally linearly polarized. At the output of the electro-optical crystal placed following the spectrograph slit, the light again becomes linearly polarized; it passes through the second spar plate and arrives at the photometer slit in the form of two spectral lines, spaced along the dispersion by a halfwidth line. Figure 1 shows

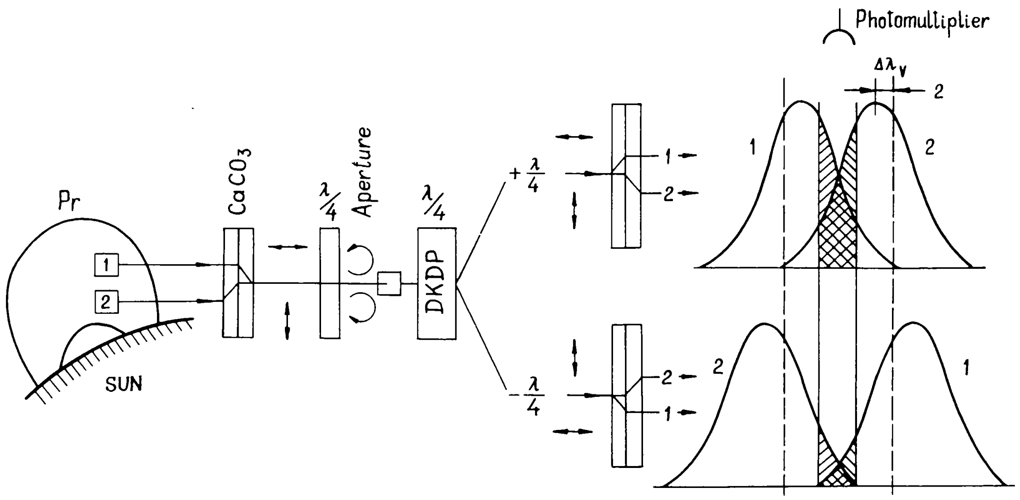

Fig. 1. The optical system of the magnetograph for recording line-of-sight velocity oscillations with the differential method.

separately the schemes of light passage and the position of line contours on the photometer slit.

Thus, for the same spectral line, in our case, the Hβ emission line, measurements are made of the *difference* of the Doppler shifts of the two line profiles from two prominence areas, each being equal to the spectrograph aperture. Light reflected from the polished entrance aperture passes through an optical system which includes an Hα filter of 0.5 Å bandpass and a 35 mm camera. With the aid of this optical system we placed on the aperture the prominence region we were interested in and took the photographic records before and after the observations. All the observed prominences did not reveal for the time of observation any substantial changes of the shape and considerable Doppler

TABLE I

Results of the observations and processing of prominence oscillations

Date	Prominence (φ)	Time (UT)	Aperture (arc sec)	Separation (arc sec)	T (min)	A (m s^{-1})	θ (deg.)	ρ
30 March, 1981	−75° W	02:54–06:00	5 × 4.4	3.9*r*	82	760	45	0.83
31 March, 1981	−18° W	02:08–04:06	5 × 4.4	3.9*r*	77	5660	60	0.97
31 March, 1981	−38° W	05:35–06:40	5 × 4.4	3.9*r*	70	750	30	0.91
3 May, 1981	−23° E	00:56–02:55	5 × 5.5	5.5*r*	74	560	90	0.50
24 March, 1982	−54° E	07:06–08:48	9 × 12	5.5*r*	50	400	0	0.92
25 March, 1982	−54° E	03:14–04:12	9 × 12	5.5*t*	53	1030	0	0.89
27 March, 1982	−17° E	04:35–05:43	9 × 9	12 *t*	47	490	55	0.90
	−17° E	06:29–07:47	9 × 9	12 *r*	49	260	55	0.71
1 April, 1982	−50° E	01:52–03:24	9 × 9	12 *t*	47	750	10	0.76
	−50° E	04:06–05:09	9 × 9	12 *r*	50	240	10	0.84
2 April, 1982	+15° E	01:32–03:12	9 × 9	12 *t*	42	1530	0	0.69
28 June, 1982	−7° W	00:27–01:34	8 × 8	12 *r*	53	850	90	0.93
	−7° W	01:57–02:55	8 × 8	12 *t*	51	650	90	0.91
29 June, 1982	+22° E	22:43–01:31	8 × 8	12 *t*	67	710	25	0.81
	+22° E	02:06–03:33	8 × 8	12 *r*	65	270	25	0.65

shifts. That is why we have regarded them as quiescent prominences. Moreover, all the objects were outside the active regions and, of ten prominences, three pertained to the polar crown.

The results of the observations and processing are listed in Table I.

Sequentially in Table I are listed: observing date, coordinates of limb prominences, time intervals of observations, entrance aperture of spectrograph, distance between the centers of two observed areas (*r* – separation of the areas with respect to solar limb radially, *t* – tangentially), observed periods of oscillations and their amplitude, θ – angle between the prominence (filament) axis and the line of sight. The filament orientation with respect to the line of sight was determined at its passage on the disk.

The recordings of oscillations have been processed by the method of correloperiodogram analysis (Kopecky and Kuklin, 1971). Figure 2 shows an example of a copy of a recording (a) and the processing results (b) for the prominence of 24 March, 1982. Other

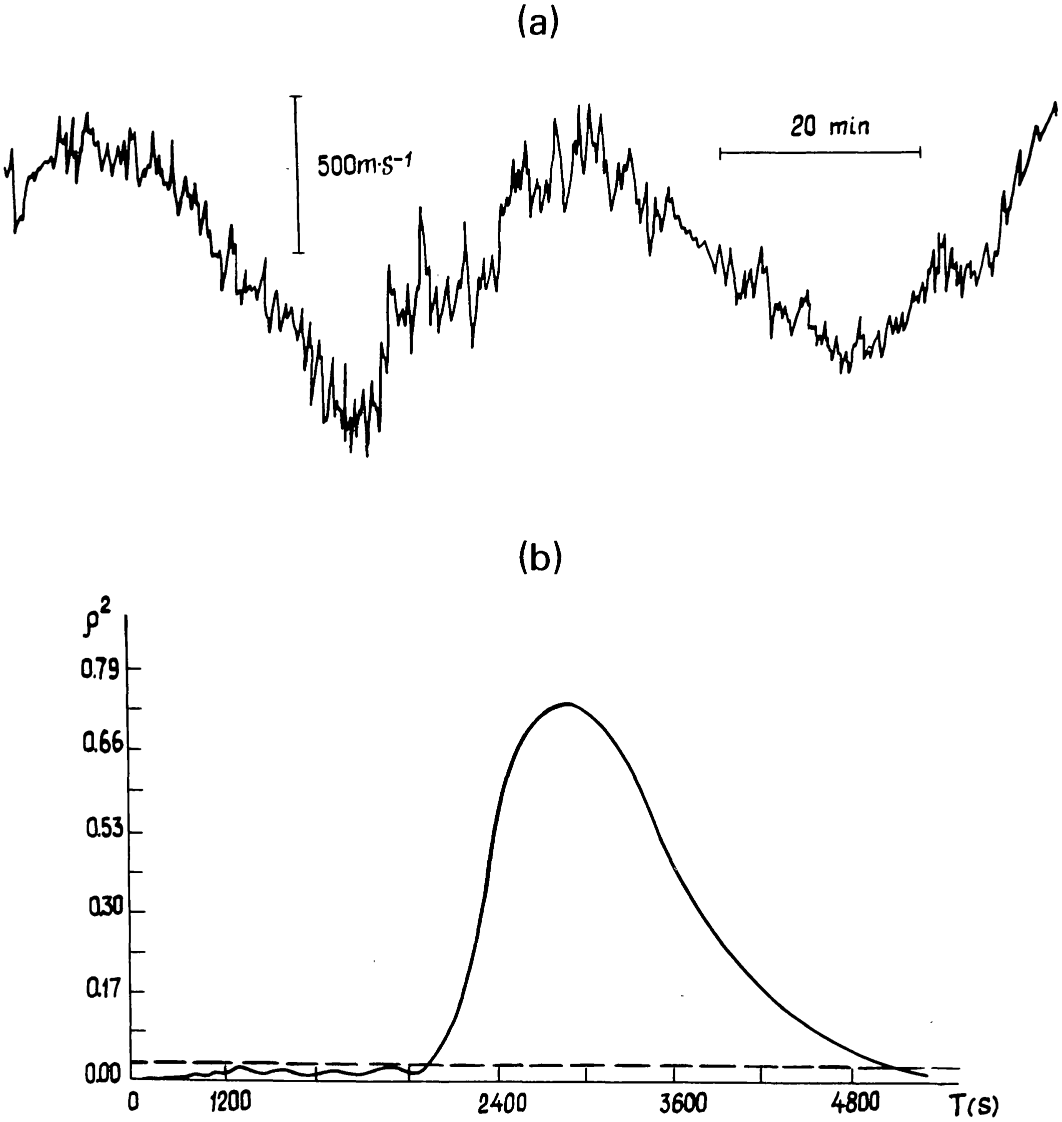

Fig. 2. Observations of line-of-sight velocity oscillations (a) and a correlation periodogram (b) for the prominence of 24 March, 1982.

samples of observations are reported by Bashkirtsev *et al.* (1983). The abscissa axis indicates time, and the axis of ordinates indicates the square of the correlation coefficient ρ, as determined by comparing our recordings with harmonic oscillations. The values of ρ are listed in the last column of Table I. A dotted line in Figure 2b shows the 99.99% significance level.

The analysis of the processed data has yielded the following conclusions:

(1) The entire set of prominences displays periodic oscillations (for the observed ten prominences the periods vary from 42 *to* 82 min), never observed before, except for the only one observation of Malville and Schindler (1981).

(2) The oscillations are *mono-harmonic*: one fixed frequency of oscillations is characteristic for each of the prominences.

(3) The amplitudes of oscillations generally lie within 200–800 m s^{-1}, for more active prominences the amplitudes can exceed 1000 m s^{-1} and the largest recorded amplitude makes up 5660 m s^{-1}. There is a tendency of the oscillation amplitudes at tangential separation of the areas to exceed those at radial separation.

(4) Not one of the prominences showed 5-min periods (or close to them), reported in the literature for different types of prominences. At the same time, the observations that we have carried out in the chromosphere on the solar disk in the Hβ-line reveal powerful short-period oscillations ranging from 3 to 6 min and one period of 800 s. In order to check upon the results obtained by Malherbe *et al.* (1981), on 29 June, 1981 we made observations of oscillations in a filament (during 23 min) at 07 S 30 W and outside the filament (during 44 min). The processing showed that while outside the filament there occur oscillations with a period around 300 s, such oscillations in the filament are damped and a period of 186 s is found. The obtained results are in good agreement with those of French investigators.

3. Discussion

As mentioned above, the differential method is used to measure the difference in Doppler shifts between two-line profiles. However, in fact the magnetograph records the difference of line intensities in two phases of modulation: $+\lambda/4$ and $-\lambda/4$. Since the recorded differential signal may be due not only to differential velocity but also to differential intensity variations, we have therefore made a detailed analysis of the influence of the latter upon the recording of magnetograph signals. Not going into details, we will highlight the analysis results.

(1) *Instrumental polarization effect.* This can only introduce a trend in the recordings.

(2) *Guiding error, image motion, spectrograph noise.* The influence of these effects can be important for the analysis of only high-frequency oscillations. In all observations of ours the prominence image on the spectrograph slit was held with the aid of a photoelectric guider with an accuracy of not less than 1 arc sec.

(3) *Displacement or departure of prominence knots from observed areas* 1 *and* 2 (Figure 1) *due to nonoscillatory proper motions in prominences or to solar rotation, actual changes of area intensities.* A simple displacement or departure of the prominence knots from the

spectrograph aperture can result only in the appearance of a trend in our records and not in the obtained recordings of sinusoidal form. As far as the solar rotation effect in limb prominence observations is concerned, straightforward calculations indicate that the observed structures practically remain in a fixed position on the spectrograph aperture: for 3 hr of observations (the event of 30 March, 1981) the departure of prominence structures due to solar rotation does not exceed 1 arc sec, i.e. the guiding error. For all the observed prominences this value is well below the size of the apertures used. The occasionally-observed intermittent intensity variations at fixed points of a prominence (see, i.e., Landman *et al.*, 1977) may, in principle, give a periodic signal but its amplitude would be too small in comparison with the observed ones. Thus, we arrive at the unambiguous conclusion that the measured magnetograph signals can be interpreted only in terms of velocity oscillations.

With the purpose of ascertaining the nature of the oscillations, relationships between such quantities as period, amplitudes and angle θ were considered. We found only a slight correlation between oscillation amplitudes A_r and A_t at different separations of prominence areas (respectively radial and tangential) and angle θ (Figure 3).

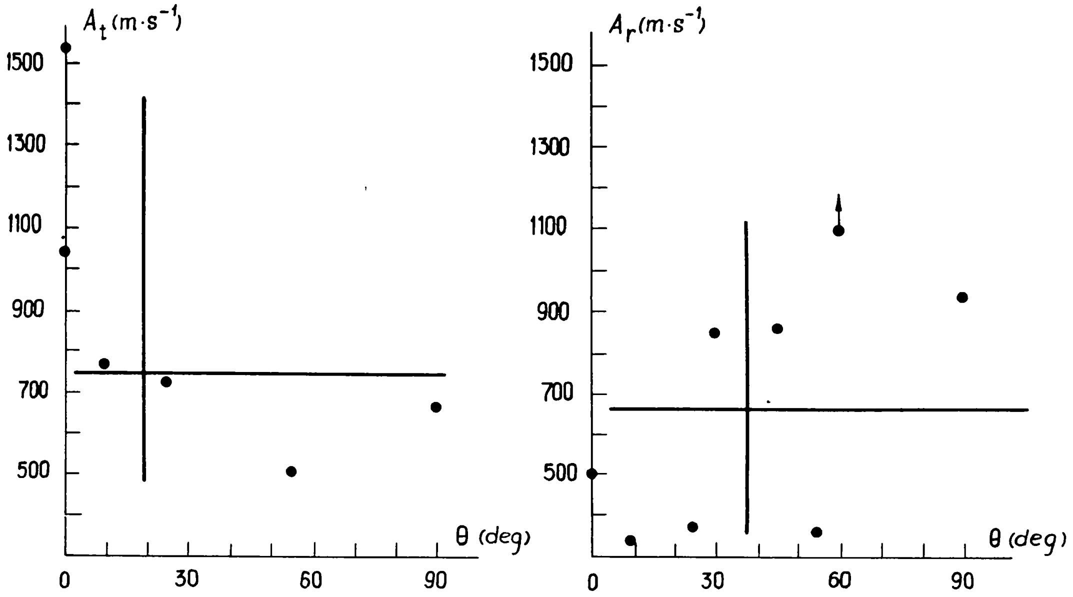

Fig. 3. Oscillation amplitudes versus angle θ at radial, A_r, and tangential, A_t, separation of the areas. The straight lines are medians of values A_t, A_r, and θ.

Using the method of quadrant correlation (Sachs, 1972), we find, according to Fisher's criterion, that with a 0.9 probability there is negative linear correlation between the quantities A_t and θ, and with a 0.8 probability, between A_r and θ, there is positive linear correlation. These correlation dependences are easily understood if we resort to rotational motions of the material in prominences (for observational evidence of such motions see e.g. Rompolt, 1975). In the case when *the magnetic field of a quiescent prominence has an arch-like helical structure* (Piddington, 1981; but the prominence does not necessarily need to appear as a loop, it may assume forms of typical quiescent prominences) and the material shows rotational translation along the magnetic field (Bashkirtsev and Mashnich, 1980), the picture of line-of-sight velocities in limb prominences at $\theta = 90°$ and $\theta = 0°$ can be represented diagramatically, as shown in Figure 4. Squares label the position of areas (spectrograph apertures) at their radial and tangential separations. As seen in Figure 4, the following relationships are found: $A_t(\theta = 0°) > A_t(\theta = 90°)$ and $A_r(\theta = 0°) < A_r(\theta = 90°)$. Indeed, the observations show that with increasing angle the oscillation amplitude A_t decreases while A_r increases. A slight excess of mean oscillation amplitudes A_t over A_r may be accounted for by some elongation of the arch (prominence) cross-section in the radial direction due to solar attraction. The large spread in experimental data in Figure 3 is chiefly associated, not with the error in amplitude measurements, which in all cases does not exceed 20 m s^{-1}, but with individual differences of prominences and inaccuracies in the determination of the angle θ.

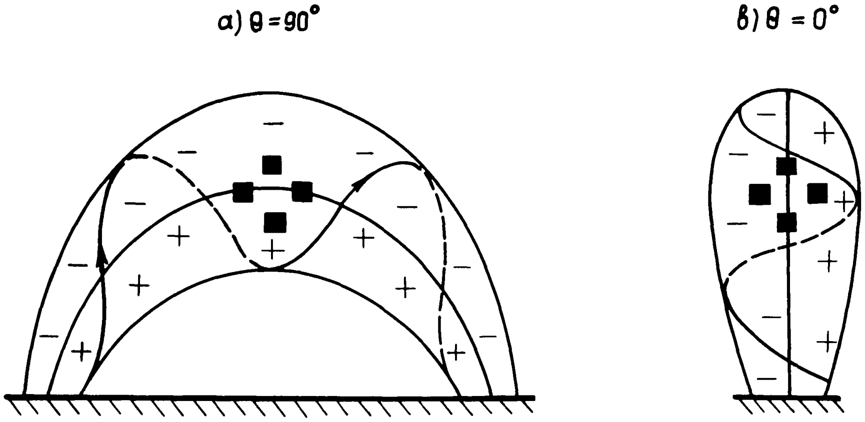

Fig. 4. The idealized representation of the quiescent prominence magnetic field structure and the picture of line-of-sight velocities in it at $\theta = 90°$ (a) and $\theta = 0°$ (b).

The precision of the derived oscillation periods can be evaluated on the basis of the dissimilar values of periods for the same prominences at different temporal realizations. According to Table I, these discrepancies do not exceed 3 min.

In order to determine the oscillation wavelength, the angular distance L between two areas is assumed $3''.9$, $5''.5$, and $12''$. In the differential method the measured signal is $A \sim \sin \pi L/\lambda$ where λ is the wavelength of oscillations. The mean values of amplitudes at $L = 3''.9$, $5''.5$, and $12''$ are, respectively, 755 (neglecting the very large amplitude of 5660 m s^{-1}), 663, and 638 m s^{-1}. Comparison of these observed amplitudes with predicted ones for the given L and different λ values shows that the best agreement of the recorded amplitudes with the computed ones is attained at $\lambda \approx 15''$ or $\lambda = 11\,000$ km. This value is in reasonable agreement with the results of Rompolt (1975) who found that the material of two active prominences spiraled at a pitch of about 13 000 km.

4. Conclusion

(1) In *quiescent* prominences we have detected a new class of oscillations, the *long-period* oscillations of line-of-sight velocities with periods from 42 to 82 min (the mean period for 10 prominences being 61 min) and amplitudes from 200 m s^{-1} and higher (see Table I).

(2) The oscillations in prominences are *mono-harmonic* and are interpretable as *a combination of torsional and longitudinal ones*. This imposes constraints on prominence models. The fact that, in our 15 observations (without exception) of ten prominences, *long-period oscillations* were recorded, enables us to assert that such oscillations are *characteristic*, at least, for quiescent prominences, and physically differ from the well-known sporadic and damped oscillations of the prominence body as a whole produced by disturbances originated in solar flares. Our observational results certainly indicate that the oscillation amplitudes are not stationary in time but undergo periodical decreases or increases in magnitude. However, to check upon this evidence requires long-time observations. The generation mechanism for oscillations is somewhat obscure, though we can surely say that such prominence oscillations are generated by the underlying layers of the solar atmosphere.

(3) The wavelength of oscillations is $\lambda = 11000$ km.

(4) *No one of the prominences revealed short-period oscillations*: there are neither 5-min nor close to that period oscillations. The absence of 5-min oscillations in our records leads us to question the reality of such oscillations, detected by other authors (see Introduction). In this connection it should be noted that, also in the corona, in which prominences reside, one should search for long-period oscillations, but it is doubtful that short-period oscillations can be detected. The hitherto collected evidence of short-period oscillations of the corona is ambiguous. Thus, Egan and Schneeberger (1979) revealed in the corona oscillations in the λ5303 Å line intensity with periods of 6 min but not in Doppler shifts of the line. At the same time Koutchmy (1981), on the contrary, revealed periodical (43 s, 80 s, 300 s) Doppler shifts of the λ5303 Å line but failed to find oscillations in the coronal emission.

We believe that the use of the highly sensitive differential method is very promising in the study of coronal oscillations.

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