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Flows and oscillations in sunspot penumbra(*)

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Summary. — In observations of penumbra oscillations there is the challenging problem of separating the oscillations associated with Evershed flows from those of a different nature. The authors used the differential method which is best suited to this problem as it can be used to filter out the wave motions in the direction and wavelength already at the stage of observation. Our findings indicate that, in addition to the 10–12 min periods, periods near 30–35 minutes are present in the velocity variations of Evershed flows. Furthermore, the possible candidates for this role are the 8 min oscillations, which we have also observed at two height levels of sunspot penumbra.

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1. – Introduction

Two types of regular motion of solar plasma are most often observed in sunspot penumbra. One of them is represented by the Evershed effect [1, 2] implying a radial outflow of material to the outside at the photospheric level and to the inside in the chromosphere. The other type of regular motion includes waves and oscillations [3]. Oscillatory processes in sunspot penumbra have been extensively investigated in recent years. But in what interrelationship are the observed oscillations with Evershed flows? Do the flows themselves undergo periodic variations? Rimmele [4] and Shine [5] found that Evershed flows experience quasi-periodic variations with a period of 12–15 min. The complexity of such observations implies that in line-of-sight velocity observations using conventional methods, a total set of motions are recorded, in which the area of the solar surface under investigation (of all possible spatial scales and directions) participates. If, however, oscillations propagating only in a radial direction are recorded, then there

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TABLE I. – *Oscillation periods in the observed sunspots.*

NOAA	Coord.	Part	Chromosphere T (min)	Photosphere T (min)	Duration (min)	Fig.
8585	N38:W19	N	≈ 10–14, 7	21, 6	54	1a, b
8585	N38:W19	W	≈ 30*, 17, 8.5, 7, 6*	≈ 40*, 17, 6*	70	2a, b
8602	N18:E22	W	28, 14, 6–5*	≈ 28, 6*	85	3a, b
8602	N18:E22	E	14, 7	≈ 14	43	3c, d
8602	N18:E08	N	42*, 14, 8.5*, ≈ 6*	42*, 21, 8.5*, 6*	75	4a, b
8602	N18:E08	N	21, 10.7, ≈ 7–5.3	≈ 6–5.3	43	4c, d
8636	N20:E61	N	≈ 30*, ≈ 7–5.3	≈ 30*, 10.7, 7	43	5a, b

will appear more chances to establish a connection of such oscillations with Evershed flows. Differential methods [6, 7] make it possible to separate from a noisy mixture the oscillations of our interest by filtering the waves in the propagation length and direction. Taking into account these properties as well as the fact that in differential measurements the instability influence of the spectrograph is reduced to a minimum, these methods are best suited for investigating the oscillations in sunspot penumbra. In simultaneous observations at two altitude levels (photosphere + chromosphere) the Sent-John effect can be used as an additional means to establish the possible connection of measured oscillations with Evershed flows. Generally, the Sent-John effect leads to a different sign of measured line-of-sight signals in the photosphere and chromosphere because of the opposite direction of the motion.

2. – Observations and results

Large round sunspots with well-developed umbra and penumbra, as a rule, were selected for the observation. The observations reported here were carried out in June, 1999 at the telescope AST of the Sayan Observatory with differential method [6]. We have investigated the line-of-sight velocity oscillations in penumbrae of several sunspots. When investigating the line-of-sight velocity oscillations in sunspot penumbra, the dis-

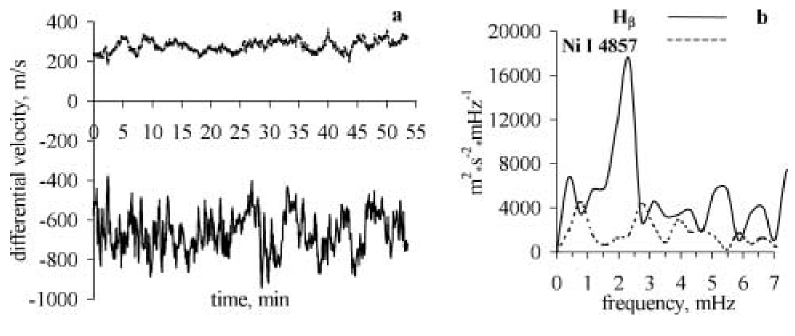

Fig. 1. – The northern penumbra of NOAA 8585 (21.06.1999). a) Value of differential velocity (the thin lines show the smoothed signals); b) power spectrum.

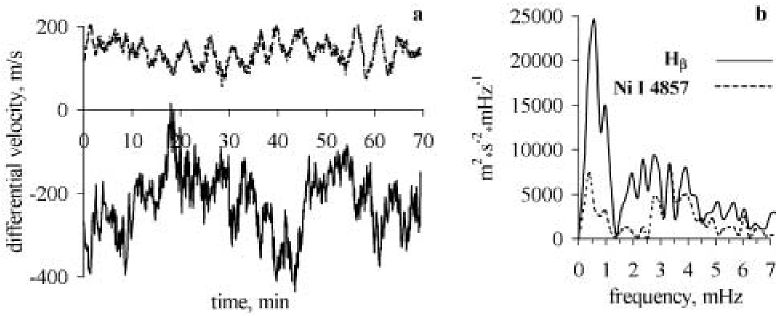

Fig. 2. – The western penumbra of NOAA 8585 (21.06.1999). a) Value of differential velocity; b) power spectrum.

tance between the elements observed was taken to be 5.5″. Simultaneously at two height levels, Ni I 4857 and Hβ, measurements were made of the line-of-sight velocity difference in the radial direction of penumbra. The polarization optics parameters of the electronic slits positions are specified such that the measurements are made in the wings of spectral lines at a distance of ± 40 mÅ away from the core. This corresponds to at least 1500–2000 km altitude for Hβ and to about 100–200 km for Ni I. The areas under observation lay radially along the direction of filaments of penumbra, in its middle part, and the height of the entrance slit was taken to be 4″ to 8″ and wide 2″. Such spatial resolution was especially chosen by these authors, although atmospheric conditions provided higher resolution. By this means the observations can be got rid of the fine-structure influence, and more general properties of oscillatory processes in penumbra can be considered. Time intervals with minimum image motion and minimum scatter light were used. Therefore, the length of the temporal series varied from 40 to 80 min. Such a duration is nearly ideally. On the one hand, it is clear that as long observational series as possible should be used to obtain power spectra with high resolution in frequency. On the other, observational practice indicates that physical conditions in sunspots are sufficiently dynamic and the spectrum of a long series will be smeared by this dynamics. Furthermore, in differential measurements of the line-of-sight velocity in sunspots the contribution to the signal is made by short-wavelength spatial harmonics, which in this case are formally equivalent to acoustic p-modes. The original temporal series were processed following the standard procedure of removing the linear trend, applying cosine spectral window, and of performing a fast Fourier transform. We have used the height inversion of Evershed effect to identify the oscillations associated with Evershed flows, and to separate them from oscillations of a different origin [8, 9]. When analyzing the spectral composition, the range 0.2–3 mHz was considered.

Table I contains a list of results of observations presented in this paper. The first column (NOAA) contains the active region number in accordance with a classification generally accepted in modern solar physics; the second column includes the approximate location of this region, the third column shows the part of the sunspot penumbra in which the observations were made, the fourth and fifth columns contain a list of periods observed, respectively, in the chromosphere and photosphere of a given sunspot, the data in the sixth column indicate the length of the time series, and, finally, the seventh column refers to the figure reflecting this observation. The symbol (*) marks those periods which are observed in the chromosphere and the photosphere simultaneously.

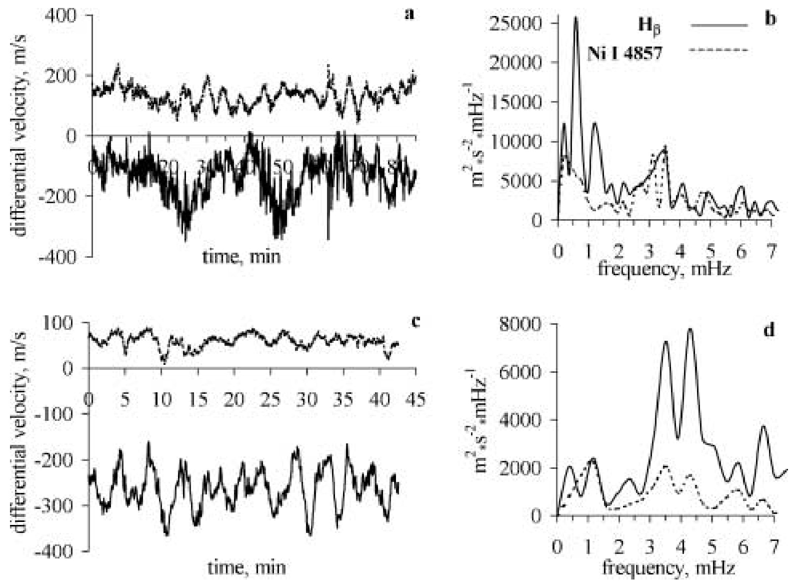

Fig. 3. – The western (a, b) and the eastern (c, d) penumbra of NOAA 8602 (28.06.1999). a), c) Value of differential velocity; b), d) power spectrum.

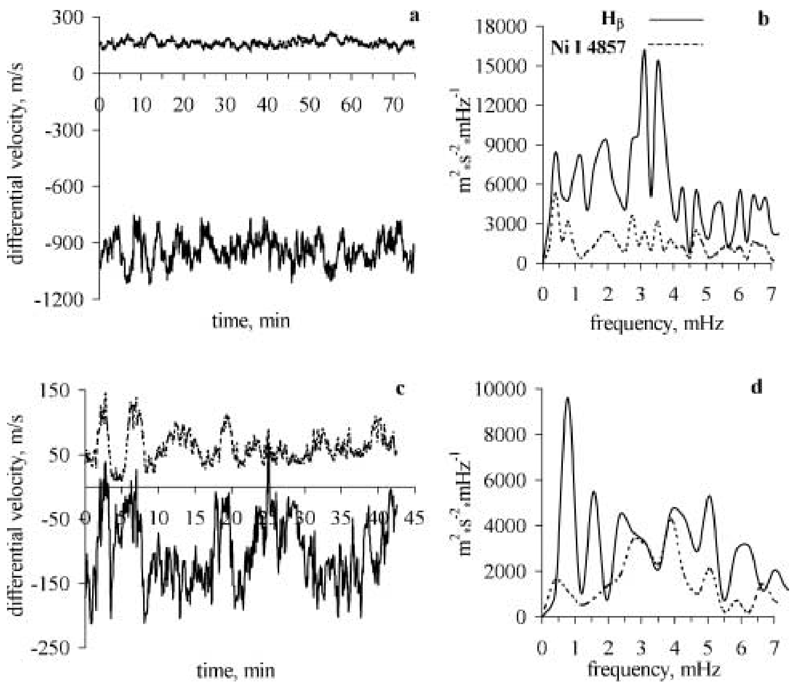

Fig. 4. – Two temporary sequences carried out in the north part of penumbra of NOAA 8602 (29.06.1999, the second at two hours after the first). a), c) Value of differential velocity; b), d) power spectrum.

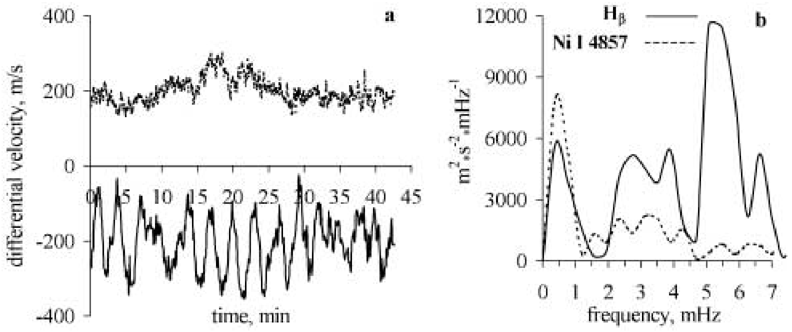

Fig. 5. – The north part of penumbra of NOAA 8636 (19.07.1999). a) Value of differential velocity; b) power spectrum.

Figures 1 and 2 show temporary series received at the NOAA 8585, 21.06.1999. In the first case 7 min fluctuations of chromosphere obviously dominate. In the photosphere the oscillations with the periods 4, 6 and 20 minutes are observed. In the second case we can see an obvious prevalence of two periods in oscillations of the chromosphere: 28 and 17 minutes, therewith a wide band from 9 to 4 minutes is present. In the photosphere level, the 43 min oscillations are clearly expressed along with the 5 min band oscillations. The signals of differential velocity at different levels of heights shown in fig. 2 demonstrate an opposite behaviour in fluctuations (on the photosphere their frequency is more than 40 minutes, on the chromosphere about 30 minutes). For establishing a connection with low-frequency oscillations, of special interest are the data shown in figs. 2, 4a, and 5. In these spectra both levels of atmospheric altitudes show oscillations within 30–40 min, and these oscillations have a synchronized character, which can be seen even without analyzing the spectra. Of the examples mentioned above, in two cases (2 and 4a) and in the case portrayed in fig. 3a there is a similar behavior for the oscillations with periods on the order of 6–7 min. Sometimes (for instance, in figs. 3a-e) oscillations with periods of 30–40 min are present in both spectra, but it is difficult to estimate their behavior. Specifically in this first case (fig. 1a) this is because the photospheric level does not show any well-defined peak but shows a "plateau" with periods from 40 min or longer to 20 min. Besides, the amplitude of these oscillations is also small. In the second case (1c), however, oscillations with periods of 40–30 min are weakly pronounced in both the photosphere and the chromosphere. We were unable to find instrumental effects that were responsible for the periods observed. Therefore, there is a reason to consider them real and to attribute their synchronous character to the Evershed and Sent-John effects. On the other hand, the proper motion of sunspots (such as rotational) can also have similar periods. In this case, however, it will be difficult to explain the consistency of the spatial structures of the velocity field in the photosphere and the chromosphere.

3. – Conclusions

In our opinion, the above observations indicate that, in addition to the 10–12 min periods, a period of 30–35 minutes is present in the velocity variations of Evershed flows. What kind of waves are these variations? To ascertain this, it will require further investigations using dopplerograms and magnetograms of the entire active region. Furthermore, we are going to investigate the possible connection with Evershed flows of the 8 min oscillations, which we have also observed sometime at two height levels of sunspot penumbra. At the present moment there is no sufficient information to make an unequivocal conclusion of this period.

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