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TEMPORAL CHANGES OF THE PHOTOSPHERIC VELOCITY FIELDS

M. KLVAŇA[1], M. ŠVANDA[1,2] and V. BUMBA[1]

[1]*Astronomical Institute, Academy of Sciences, Ondřejov, Czech Republic*
[2]*Astronomical Institute, Charles University in Prague, Czech Republic*

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Abstract. We analyse influence of the planets Mercury, Venus, Earth and Jupiter on the Doppler velocity field in the solar photosphere, using the theory of the tidal forces. We compare the measured Doppler velocity fields estimated in a zonal area along the solar equator with the results of the dynamical calculations. From this comparison it follows that we do not succeed to demonstrate presence of a velocity field, caused by the tidal forces, in the measured data. If the tidal waves in the solar photosphere do exist, they are lost in the noise and their horizontal velocity field probably will be under the limit of $\pm 20\ \mathrm{m\,s^{-1}}$.

Key words: Solar photosphere – velocity fields – tidal waves

1. Introduction

Many experienced observers are convinced that a relationship between the solar activity events and position of planets really exists. But this subjective feeling we have to take still as a hypotheses.

On the graphs published by Bumba and Hejna (1991) for the time interval 1935–1987 we can clearly follow the development of solar activity, synchronized with the motion of some planets. If the published curves of solar activity are not influenced by an effect of selectivity, the published graphs would serve as an evidence for the existence of a mutual relation between the solar activity and motion of at least some planets. This fact led us to search possible relations between both phenomena. Also papers published by Charvátová (1990) and Landscheidt (1999) bring some evidence concerning the relationships between the solar activity and the gravitational

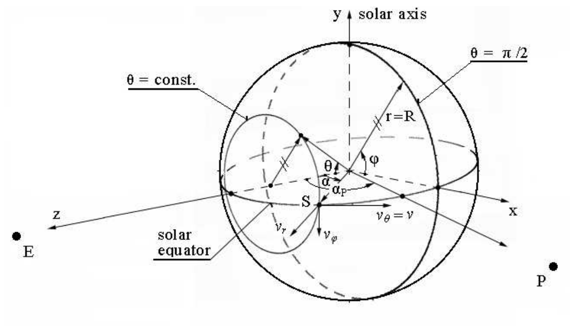

Figure 1: Orientation of angles in the plane of equator. P represents the planet under consideration, E the Earth and S is the point on the solar equator, for which we estimate the velocity vector.

field of planets. These authors investigate the movements of the solar system barycentrum around the centre of the solar body, and came to a conclusion that certain relations there really exist. We take the gravitational forces as a most distinct agent among the possible relations between the planets and the Sun. For this reason we decided to investigate an effect very narrowly connected with the gravitational forces – the generation of tidal waves in the solar photosphere.

2. Theory of Tidal Forces

The statical theory of tidal forces (Kočin *et al.*, 1955) bring as a result of the tidal forces action on the solar body its very small deformation, with the maximal height of the tidal wave caused by one planet of the order of 1 mm only (Krivtsov *et al.*, 2002). Generally, it leads to a conclusion that the planetary positions should not influence the solar activity. But we can note that also the change of the height for 1 mm only, if it concerns such a large body like the Sun, should represent a non neglectible volume change. This change could due to the large mass shifting express in its proper velocity field.

The dynamical theory of tidal forces takes into account the physical properties of plasma. Following this theory, as a consequence of the moving tidal wave a practically horizontal velocity field develops. It can be described by the following equations (Krivtsov *et al.*, 2003):

$$v_\vartheta = A\cos 2\vartheta\cos\varphi, \quad v_\varphi = A\cos\vartheta\sin\varphi, \quad A = \varepsilon\omega R/3 \qquad (1)-(3)$$

Equations (1)–(3) are derived for the system of coordinates brought in Fig. 1, where v_ϑ, v_φ are the components of the velocity vector and ϑ, φ represent the spherical coordinates on the Sun, R is the solar radius, ω the mutual angular velocity of a planet and the Carrington system of coordinates, and ε is a parameter proportional to the height of the tidal wave.

To get an approximate estimation of the velocity field characteristics, observable on the solar disk from the Earth, we neglect the actual distance of the planets from the plane of the solar equator. For the further considerations we will anticipate that all planets, including the Earth, revolve on circles in the plane of the solar equator. On the equator $\varphi = 0$ and after substitution into (2), we obtain $v_\varphi = 0$. Following the theory we can obtain horizontal velocities when $v_R = 0$. Due to this conditions we can rewrite equation (1) in the form:

$$v = -A \cos 2\alpha, \tag{4}$$

where α is the angle between the radius vector of the point S on the equator and the direction Sun-Earth, and v is the whole velocity of the tidal wave in the point S on the equator (positive in the direction of the Solar rotation), observed from the Earth (Klvaňa *et al.*, 2004).

Let us further assume that due to the small changes in heights of waves, induced by the gravitational forces of individual planets, their velocities can be superimposed:

$$v(\alpha) = -\sum_p A_p \cos 2(\alpha - \alpha_p), \tag{5}$$

p is an index differentiating individual planets, α_p represents the angle giving the planetary position against the Earth, angle α estimates position of the point S on the solar equator (Fig. 1). In analogy to equation (3), equation (6) describes the velocity amplitude generated by the gravitational field of planet p.

$$A_p = \varepsilon_p \omega_p R/3 \tag{6}$$

Let us assume that parameter ε_p of every planet is proportional to the height h_p of its tidal wave, known from the statical theory of tidal forces: $\varepsilon_p = \varepsilon_z h_p/h_z$. Introducing this assuption into equation (6), we get $A_p = \varepsilon_z B_p$. The value B_p is constant for the given planet and it is equal to $B_p = \omega_p R h_p/(3h_z)$, where ω_p represents the planet's angular velocity against the Carrington's system of coordinates $\omega_p = \omega_{sd} - \omega_{pd}$, ω_{sd} is the sidereal angular velocity of the Carrington's system of coordinates and ω_{pd} represents the sidereal angular velocity of planet p. Equation (5) can be adjusted into the form:

$$v(\alpha) = -\varepsilon_z \sum_p B_p \cos 2(\alpha - \alpha_p) \tag{7}$$

The Doppler velocity component $v_{los}(\alpha)$ which could be measured on the solar equator, we obtain by the projection of this velocity in the longitudinal direction following equation:

$$v_{los}(\alpha) = v(\alpha)\sin\alpha \tag{8}$$

3. Simulation of the Velocity Fields

For the searching for the tidal waves in the real measurements, it is useful to know their expected characteristic behaviour. Following equations (7) and (8) we made an approximate calculation of the horizontal and Doppler velocities on the solar equator. We made the calculation for the planets Mercury, Venus, Earth, and Jupiter, due to the fact that following the statical theory these planets induce the largest tidal waves. The results of this simulation of the horizontal and Doppler velocity fields on the solar equator we bring in Figs 2 and 3.

Looking on temporal development of the calculated velocities, we see striking regular alternation of expressive segments of the velocity fields every approximately 120 days. The individual segments are mostly separated by short-term sections, during that the amplitude of the horizontal velocity induced by the tidal waves is close to zero along the whole visible equator. During these time intervals, the matter flows on the solar equator would change their directions, if the Sun would not rotate. But due to the solar rotation, the influence of the tidal forces is manifested by the acceleration or retardation of the rotation. If the velocity field generated by the tidal waves would be measurable, we should find similar character of the velocity field changes also by the processing of the real Doppler measurements.

As it follows from equations (7) and (8), the scale of Doppler velocities in Fig. 3 is defined by the parameter ε_z. In this parameter the physical conditions of the solar photosphere are hidden. Therefore, it would be interesting to know the magnitude of this parameter ε_z. Then, we would be able to estimate the magnitude of the velocity field caused by tidal waves, to determine the height of the tidal wave calculated following the dynamical theory, and then to compare it with the already known results of the statical theory. Under the assumption of demonstrable correlation of modeled and observable effects, it would be possible to get the value of the parameter ε_z.

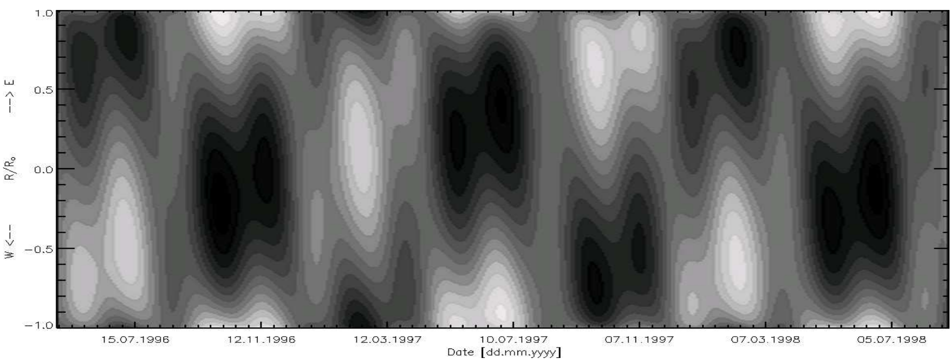

Figure 2: Simulation of the temporal development of the horizontal velocity field on the solar equator. On the horizontal axis the time scale is given in days for 852 days since 2. 5. 1996, vertically the points of the solar equator projected on the solar disk are shown. The velocities in the direction of equator rotation are positive (white).

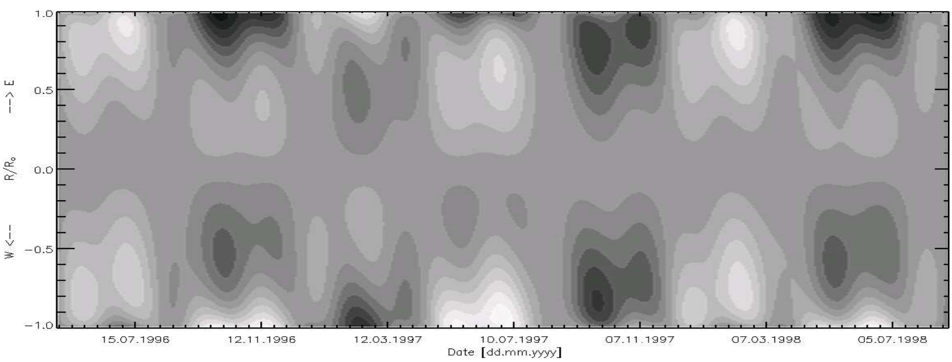

Figure 3: Simulation of the Doppler projection of the horizontal velocity field from Fig. 2. In the middle part of the figure we see a continuous gray area of zero velocities along its whole horizontal axis. The velocities from the observer are positive (white), velocities towards the observer are negative (dark).

4. Measured Velocity Fields

We got the Doppler velocities on the solar equator we got from the measurements made by the instrument MDI onboard the SoHO observatory. We used for this purpose the whole disk dopplergrams obtained every six hours. In the data, only the satellite motion in the libration point and the Carrington's rotation were compensated.

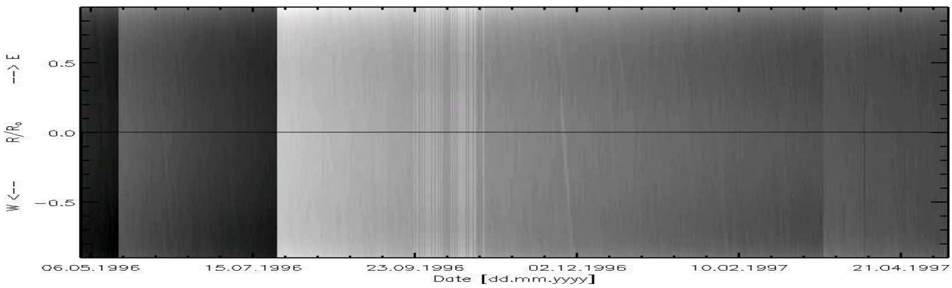

Figure 4: Temporal development of Doppler velocities measured by the MDI/SoHO in the area of the solar equator in the time interval 2. 5. 1996 till 11. 5. 1997.

To take away the influence of the local Doppler velocities, it was necessary to smooth the measured values by filtering (boxcar 40×40 px in the rectangular coordinate system). Afterwards, we integrated the velocities in a strip of $\pm 5^{\circ}$ along the solar equator into the points of the solar diameter. The main purpose of this method was to take away the local velocities and the oscillations. The obtained individual diameters we drew, in the same way as in Figs 2 and 3, side by side. And here we met with the problem concerning the measured data.

In the Doppler velocities in Fig. 4 we see vertical segments differing expressively. The segment boundaries are connected with the shift and scale change of the velocity measurements. This effect is caused by the retunning of the Michelson interferometer. The error in calibration of the MDI (Hathaway *et al.*, 2002) was not improved, because it would be necessary to adjust it together with another parameters for each segment, differing by degree of gray. We used an assumption of the zero velocity in the disk centre to remove the undesirable changes in the Doppler data: From the dynamical theory of the tidal waves it follows that the perpendicular component of the tidal wave velocity vector is equal to zero. If we succeeded by filtering in the measured velocities to take away the greatest part of the vertical velocities, then the velocity in the disk centre should be only horizontal. This assumption we used for the compensation of jumps in Fig. 4. The result of such a correction we see in Fig. 5. From the figure it follows that probably the main effects are connected to the measurement instabilities due to periodical scale shift of the interferometer.

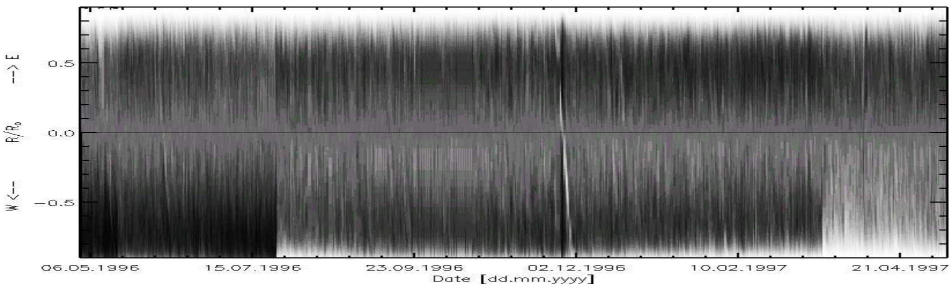

Figure 5: The development of the Doppler velocity fields from Fig. 4 in time, improved for the undesirable zero shifts.

5. Analysis of the Measured and Modeled Values

To compare the measured values with the results of the dynamical theory, we used the Doppler velocity field calculated following the dynamical theory of the tidal forces (Fig. 7), and the measured velocity field (Fig. 6 – obtained by smoothing Fig. 5 by the Gaussian window).

Comparing Fig. 6 and Fig. 7, we did not succeed to find any reliable similarity among the individual topological structures of both pictures. On the contrary, the results of processing the measured data show to a certain degree chaotic distribution of observed structures in Fig. 6, rather connected with the consequences of the interferometer retunning, than with the regular changes of structures of the Doppler velocity field. It means that if the regular structures generated by the tidal waves exist, their amplitudes are so small that they are overlapped by the error effects accumulated during the measurements.

In Fig. 8 we plot the cut through the velocity field in Fig. 5, led horizontally in the distance of $-0.6R_{\odot}$ from the horizontal axis, and its smoothed version. Oscillations of this cut are smaller than ± 20 m s^{-1}. From the point of view of the quoted sensitivity of the MDI instrument it means that we are coming into the region of noise. Due to the fact that this smoothed run of the Doppler velocity field does not correspond with modelled run, it seems to be probable, that if the tidal waves on the solar surface do exist, their Doppler component is smaller than ± 20 m s^{-1}. Principally due to the projection the maximal Doppler velocity is approximately equal to the maximal velocity of the tidal wave (this velocity is horizontal, parallel to the solar surface). Thus, the maximal amplitudes of the velocity of the

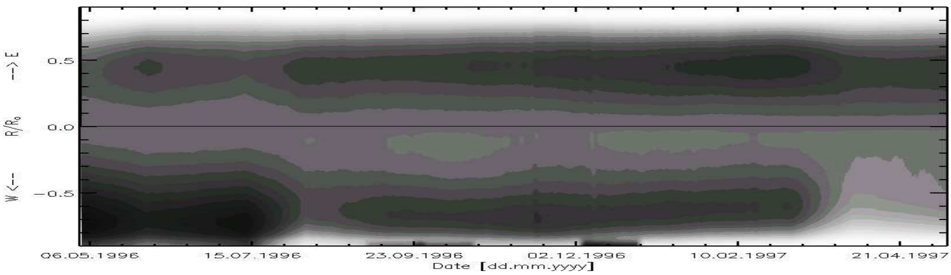

Figure 6: Topological structures of the Doppler velocity fields as a result, obtained by smoothing of structures in Fig. 5.

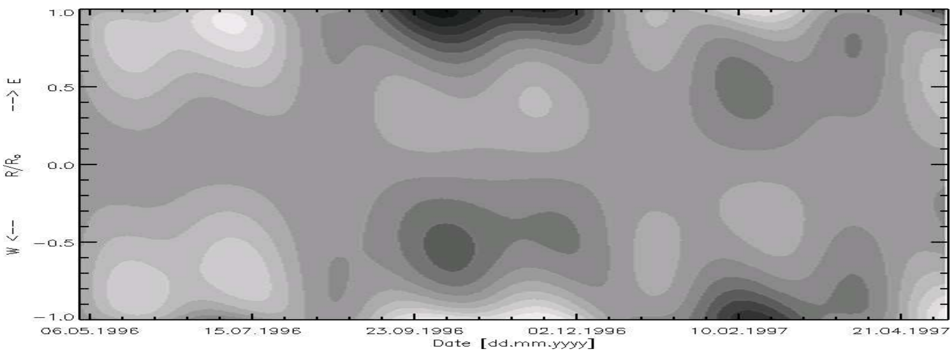

Figure 7: Topological structures of the Doppler velocity fields, calculated following the dynamical theory of the tidal forces.

tidal waves will be probably smaller than $\pm 20\ \mathrm{m\,s^{-1}}$.

6. Conclusion

Under the comparison of the observed Doppler velocity fields obtained by the MDI instrument onboard SoHO observatory with the Doppler velocity fields modelled on the basis of the dynamical theory of the tidal waves, does not lead to the confirmation of existence of the tidal waves in the solar atmosphere.

If the tidal waves in the solar atmosphere really exist, amplitudes of their Doppler velocities lie under the noise level, contained in the measured data.

On the basis of this estimation we assume that the maximal velocities of

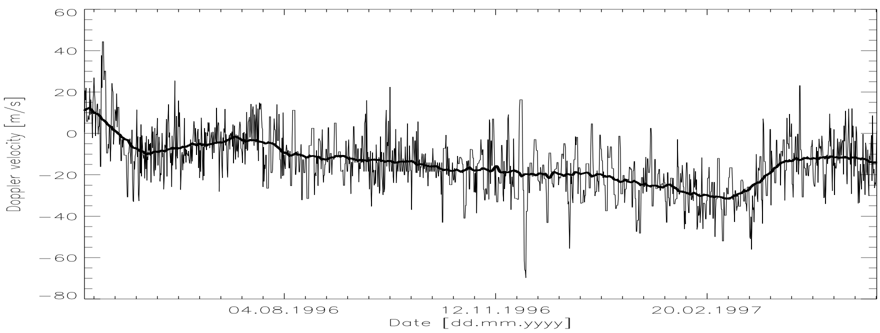

Figure 8: Horizontal cut through the velocity field of Fig. 5. Smoothed velocity is overplotted by the thick line.

the tidal waves velocity field are smaller than $\pm 20\ \mathrm{m\,s^{-1}}$.

7. Acknowledgements

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PROMJENE FOTOSFERSKIH POLJA BRZINA

M. KLVAŇA[1], M. ŠVANDA[1,2] i V. BUMBA[1]

[1]*Astronomical Institute, Academy of Sciences, Ondřejov, Czech republic*
[2]*Astronomical Institute, Charles University in Prague, Czech republic*

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Izlaganje sa znanstvenog skupa

Sažetak. Istražuje se utjecaj planeta Merkura, Venere, Zemlje i Jupitera na dopplerovo polje brzina u Sunčevoj fotosferi koristeći teoriju plimnih sila. Izmjerena dopplerova brzina polja procjenjena u pojasu uzduž Sunčevog ekvatora usporeduje se s rezultatima dinamičkih proračuna. Iz usporedbe slijedi da se ne uspijeva demonstriratu nazočnost polja brzine urokovanog plimnim silama na temelju podataka mjerenja. Ukoliko i postoje, plimni valovi u Sunčevoj fotosferi su prekriveni šumom opažanja i njihove maksimalne amplitude brzina će biti ispod ± 20 m s^{-1}.

Ključne riječi: Sunčeva fotosfera – polja brzina – plimni valovi