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DO TIDAL WAVES EXIST IN THE SOLAR PHOTOSPHERE?

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Abstract. The temporal coincidences between solar activity regularities and the motion of some planets show that there could exist a mutual physical relationship between both processes. One of the possible causal agents could be the action of the gravitational field. Although the altitude of planetary tidal waves on the Sun, following many authors, is of the order of only one millimetre, in the case of resonance it could be enlarged appreciably. Therefore, we decided to verify the possibility of detection of such waves in the solar atmosphere using the earlier developed dynamical theory of tidal waves. In this paper we present and discuss the preliminary results, obtained from the comparison of the velocity fields measured with the MDI instrument of the SOHO satellite and of the velocity fields of a tidal wave calculated on the basis of the dynamical theory.

Key words: Solar photosphere - tidal waves - planets

1. Introduction

The influence of the planetary gravitational field on the Sun has been investigated by many authors (e.g. Charvátová, 1990, Landscheidt, 1999). The results, demonstrating that the maximal vertical deformation of the solar body is of the order of only 1 millimetre, led to the conclusion that such an influence of the planetary tidal forces can be neglected. Nevertheless, the observers of the Sun often meet the situation in which the actual development of the solar activity and its repeated regularities indicate that there could possibly exist a hypothetical relation between the constellation of planets and the solar activity.

2. Solar activity

Many authors studied the temporal variations of different solar activity phenomena and their distribution over the solar surface. From such results and from their own studies, Bumba and Hejna (1991) compiled a graph of longitudinal distribution of solar activity in the Carrington's system of coordinates for a time interval longer than 50 years (Figure 1).

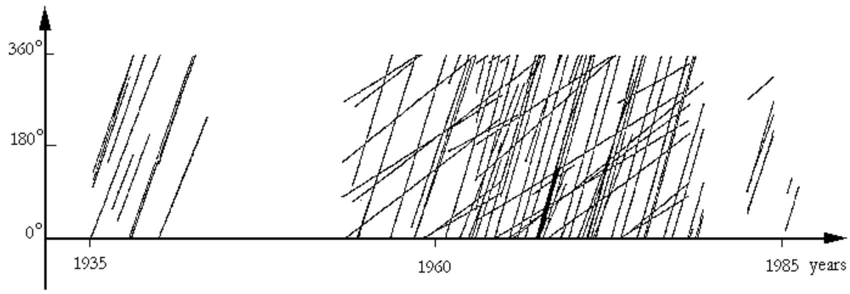

Figure 1: Diagram of the longitudinal distribution of solar activity. Horizontal axis – time since the year 1935 till 1987. Vertical axis – heliographic longitude (0 to 360 degrees) of centre of activity in Carrington's coordinates.

The individual straight lines, corresponding to different solar activity phenomena reported by different authors, were drawn by connecting the longitudes of the maxima of the given phenomenon in the consecutive Carrington's rotations.

In Figure 2, the diagram of the solar activity longitudinal distribution is plotted together with points representing the heliocentric projection of the position of conjunctions of Mercury and Earth into the same Carrington's system of coordinates. During a time interval longer than 50 years the directions of lines connecting the main active longitudes and of the lines connecting the conjunctions are almost parallel. It means that the longitudinal shifts of active longitudes from one rotation to the next and the shifts of projections of the conjunctions are nearly the same. But they are not completely equal, as we can see from the changing distances between the

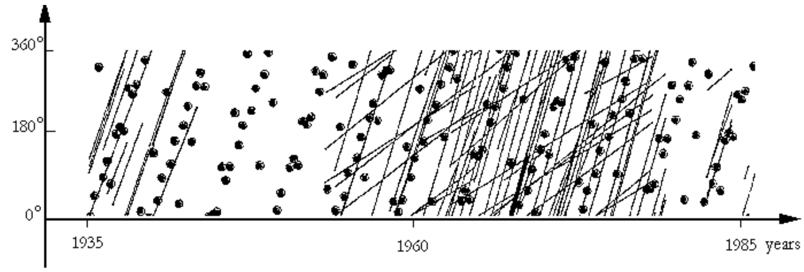

Figure 2: Heliocentric projection of the Mercury-Earth conjunctions on the solar surface plotted over the longitudinal distribution of solar activity.

lines representing the activity and the dots representing the conjunctions. In spite of that, a certain relation does exist.

A very important problem is caused by the fact that the whole investigated time interval is not covered homogeneously by observations. This could be connected with the choice of authors, with the degree of activity, etc. Further, we cannot exclude that during certain time intervals there was much less activity. This could mean that the direct relation between the planetary positions and the solar activity is influenced by some other effects. This is confirmed by the strong decrease of activity during the Maunder minimum. In fact, during the Maunder minimum the occurrence of planetary conjunctions was equally dense as during the investigated time interval.

Also conjunctions of some other planetary pairs demonstrate similar behaviour. In Figure 3 we plot points demonstrating the projections of conjunctions of Venus and Earth. Their directions are nearly parallel with the second important direction of the solar activity longitudes. And in Figure 4 conjunctions of Mercury and Venus are plotted. In this case, the possible relation with the solar activity is much less distinguishable.

The demonstrated observational data raise the question how we could explain physically the shown parallelism of displacements of both processes in time. The only physical relation known enough, with sufficiently large strength, existing between the planets and the Sun, is the gravitational field. In the past, the influence of the position of the solar system barycenter on solar activity was investigated several times (Charvátová, 1990, Landscheidt, 1999). Certain connections between both phenomena were discov-

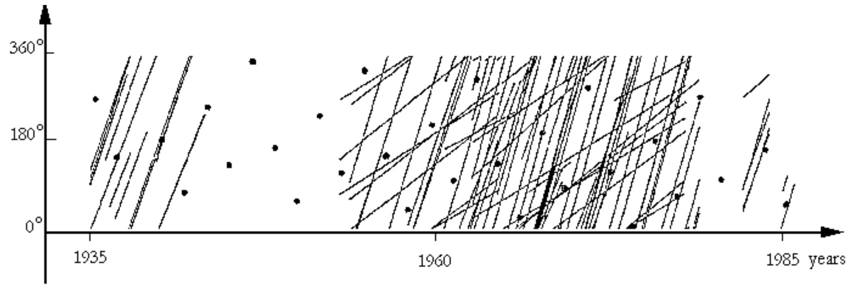

Figure 3: Heliocentric projection of the Venus-Earth conjunctions on the solar surface plotted over the longitudinal distribution of solar activity.

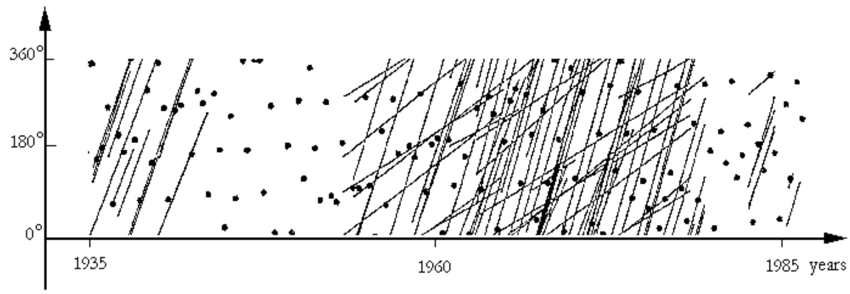

Figure 4: Heliocentric projection of the Mercury-Venus conjunctions on the solar surface plotted over the longitudinal distribution of solar activity.

ered, but until now a deeper physical interpretation has not been undertaken. For this reason we decided to direct our attention to tidal forces. They can produce a deformation of the solar body connected with transfers of material, which are accompanied by the generation of velocity fields. Static theory of tidal forces (Kočin et al., 1955) demonstrates a very small deformation of the solar body, with the height of the tidal wave caused by one planet to 1 mm as a maximum (Krivtsov et al., 2002). In this case, the planetary positions could not influence the solar activity. The dynamical theory of tidal forces takes into account the physical behaviour of the plasma. Following the theory, a nearly horizontal velocity field develops due to a moving tidal wave. The velocity field of the tidal wave can be described by the following equations (Krivtsov et all, 2003):

$$\nu_\vartheta = -A\cos 2\vartheta\cos\varphi \quad (1)$$
$$\nu_\varphi = A\cos\vartheta\sin\varphi \quad (2)$$
$$\nu_R = 0 \quad (3)$$
$$A = \varepsilon\omega R/3 \quad (4)$$

These equations are derived for the Sun-Earth system at the instant when the Earth passes the plane of the solar equator. We use here the spherical coordinate system (Figure 5). The z-axis is directed toward the Earth (perpendicular to the solar disk), the y-axis is coincident with the axis of solar rotation and the x-axis is coincident with the solar equator. In our special case, the x and y-axes lie in the plane of the solar disc The angle ϑ is measured from the z-axis, φ is the positional angle of a point on the solar surface, measured from the x-axis, R the photospheric radius of the Sun, ω the relative angular velocity of a planet with respect to the Carrington system of coordinates, ε a dimensionless parameter, proportional to the height of the tidal wave. Parameters ν_ϑ, ν_φ, ν_r are components of the velocity vector ν of plasma motion in the point $S(\vartheta, \varphi, r = R)$ on the solar surface. We will attempt to find the parameter ε, needed for the calibration of the velocity ν, by comparing the calculated and measured curves of the Doppler velocity.

For an approximate estimation of the character of the velocity fields observable on the solar disk from the Earth, we neglect the actual angular distance of the planets from the plane of the solar equator. For the next considerations we will accept that all planets have circular orbits lying in that plane. Because on the equator, due to our simplifications, $\vartheta = 0$ or $\vartheta = \pi$, we will have $\nu_\varphi = 0$ and the velocity vector on the solar equator will contain only the component ν_ϑ. It means that the velocity ν vector will lie in the plane of the solar equator, and it will have a direction tangential to the equatorial circle. Then, equation (1) can be rewritten in the following form:

$$\nu_\vartheta = \nu = -A\cos 2\alpha, \quad (5)$$

where α represents the angle formed by the radius vector of the point S on the solar equator with the direction Sun-Earth, and ν represents the velocity vector of the Earth's tidal wave on the solar equator in the point S, defined by the angle α (Figure 5).

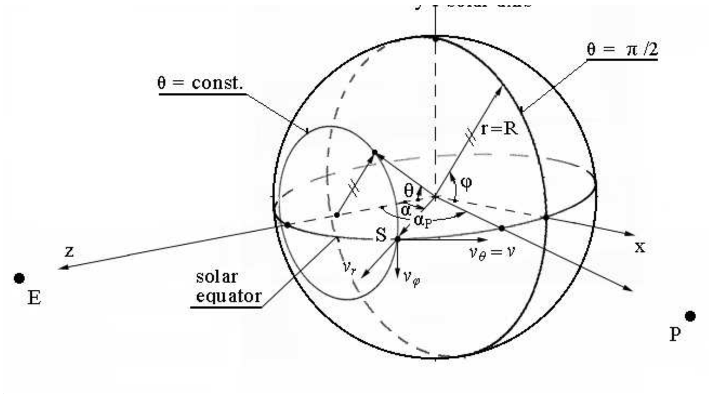

Figure 5: Orientation of angles in the plane of the solar equator. P indicates the planet under consideration, E the Earth, and S represents a point on the solar equator, in which we determine the velocity vector.

Further, let us assume that due to the small changes in height, caused by the gravitational forces of planets, the velocities induced by individual planets are additive. Then, in the point S on the solar equator the resulting velocity vector from all planets under consideration will be the sum of all local velocities from individual planets:

$$\nu_{eq} = \sum_p \left(-A_p \cos 2(\alpha - \alpha_p)\right), \tag{6}$$

where $A_p = \varepsilon_p \omega_p R/3$ is the velocity amplitude, generated by planet p, α_p is the angle determining the position of a planet with respect to the Earth, and α gives the position of the point S in the plane of the solar equator (Figure 5).

The velocity field obtained in this way for the equinox on March 20th, 1998, is shown in Figure 6. The planets with the largest gravitational influence were taken into account: Mercury, Venus, Earth and Jupiter.

It was necessary to smooth the velocity values measured by the SOHO/MDI instrument by filtering, to eliminate the influence of local Doppler velocities. In Figure 7 we present both filtered and unfiltered curves. We see that the curve we are interested in lies in the region of a strong noise, caused by supergranular motion. We did not compensate any further disturbing effects with the exception of the Carrington rotation. Analysis of the values

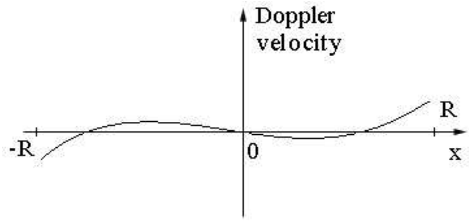

Figure 6: Character of the Doppler velocity field along the solar equator induced by the planets Mercury, Venus, Earth, and Jupiter, calculated using formula (5), for the vernal equinox on March 20, 1998.

in Figure 7 shows, that the left maximum of the curve is somewhat higher, and this is in accordance with the shape of the curve in Figure 6. However, we have to take into account that the difference between the values of maxima is small (5–10 $\mathrm{m\,s^{-1}}$). We will be able to decide if it is possible to measure the velocity fields induced by the tidal forces only in the case when it will be possible to eliminate all undesirable effects, such as the zero shift and calibration problems (Wöhl and Schmidt, 2000).

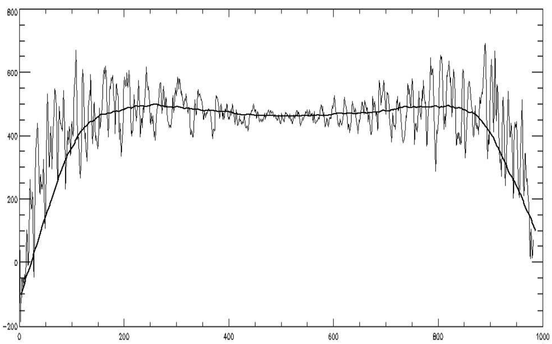

Figure 7: The Doppler velocity field along the solar equator with and without filtering, obtained by the solar laboratory SOHO for the vernal equinox on March 20, 1998. Horizontal axis – equatorial points projected on the solar disk, vertical axis – velocities in $\mathrm{m\,s^{-1}}$.

3. Conclusion

As present, our preliminary results are strongly influenced by various effects, which are very difficult to compensate. The comparison of the computed and measured velocity curves shown in Figures 6 and 7 does not provide enough information to decide if tidal effects on the horizontal velocity field are measurable.

4. Acknowledgements

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DA LI POSTOJE PLIMNI VALOVI U SUNČEVOJ FOTOSFERI?

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Izlaganje sa znanstvenog skupa

Sažetak. Podudaranje u vremenu između nekih pravilnosti Sunčeve aktivnosti i gibanja nekih planeta ukazuju na mogućnost fizikalne povezanosti tih procesa. Djelovanje gravitacijskog polja moglo bi biti jedno od mogućih uzročnika. Iako mnogi autori predviđaju visinu planetarnih plimnih valova na Suncu reda veličine samo jednog milimetra, ta visina bi se u slučaju rezonancije mogla znatno povećati. U ovom radu se provjerava mogućnost detekcije plimnih valova u Sunčevoj atmosferi koristeći dinamičku teoriju plimnih valova. Prikazuju se i diskutiraju preliminarni rezultati dobiveni usporedbom polja brzina mjerenih instrumentom MDI na sondi SOHO i brzina polja plimnog vala proračunatog u okviru dinamičke teorije.

Ključne riječi: Sunčeva fotosfera - plimni valovi - planeti