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The prominent 1.6-year periodicity in solar motion due to the inner planets

I. Charvátová

Geophysical Institute AS CR, Boční II, 141 31 Praha 4, Czech Republic

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Abstract. The solar motion due to the inner (terrestrial) planets (Mercury, Me; Venus, V; Earth, E; Mars, Ma) has been calculated (here for the years 1868–2030). The author found these basic properties of this motion: the toroidal volume in which the Sun moves has the inner radius of 101.3 km and the outer radius of 808.2 km. The solar orbit due to the inner (terrestrial) planets is "heart-shaped". The orbital points which are the closest to the centre lie at the time distance of 1.6 years (584 days), on the average, and approximately coincide with the moments of the oppositions of V and E. The spectrum of periods shows the dominant period of 1.6 years (V-E) and further periods of 2.13 years (E-Ma) (25.6 months, QBO), 0.91 years (V-Ma), 0.8 years ((V-E)/2) and 6.4 years. All the periods are above the 99% confidence level. A possible connection of this solar motion with the mid-term quasi-periodicities (MTQP, i.e. 1.5–1.7 years) in solar and solar-terrestrial indices can be proposed.

Keywords. History of geophysics (Solar-planetary relationships) – Solar physics, astrophysics, and astronomy (Celestial mechanics; Photosphere and chromosphere)

1 Introduction

One of the basic questions of solar physics still remains: What is an origin of solar variability? It seems (see Sect. 3) that an origin of a long-term solar variability (solar cycles and their modulation) is likely the solar motion due to the giant planets (SIMGP).

During the latest decades, a shorter stable periodicity of 1.5–1.7 years (so-called mid-term quasi-periodicity (MTQP, e.g. McIntosh et al., 1992; Mursula and Zieger, 2002; ..., in various solar (e.g. in solar magnetic field, solar wind speed, ...) and solar-terrestrial (e.g. in cosmic rays, geomagnetic indices, ...) phenomena has been detected. Its origin has so far been unknown. In this article, the basic properties of the solar motion due to the inner planets (SIMIP) found by the author are shown (Sect. 2). Section 3 describes the previous results concerning the SIMGP in comparison with these SIMIP results. Section 4 reviews the papers which detected MTQP in a series of solar and solar-terrestrial phenomena. SIMIP as a possible origin of MTQP can be taken under consideration if connections between the individual mentioned phenomena and SIMIP are found. Predictive assessments for solar and solar-terrestrial phenomena could be established even if a proper physical mechanism has not yet been established (Sect. 5).

Correspondence to: I. Charvátová
(ich@ig.cas.cz)

2 Basic properties found in the solar motion due to the inner planets

The SIMGP was computed by our own program created by means of the standard methods of celestial mechanics and it was checked by the program sent to me kindly by J. H. Shirley (Jet Propulsion Laboratory, Pasadena) in 1992. Now, the computations are made according to the basis: http://ssd.jpl.nasa.gov/. The SIMIP was computed separately.

In comparison with the SIMGP, which occurrs in units of 10^{-3} AU (Astronomical Unit) or 10^{6} km, the SIMIP is in minutes but not negligible. The new results of this article that are the centre of the Sun moves inside the toroidal volume with the inner radius of 101.3 km and the outer radius of 808.2 km; see Fig. 1. (A cinquefoil is created in the middle of the motion area.) The maximum radius was reached in the year 1905.311, the minimum radius will be reached in the year 2026.025 (see Fig. 3). Moreover, on the contrary to the solar orbit, due to the giant planets which consist of loops, the pattern of the solar orbit due to the inner (terrestrial) planets is similar to a curve called a cardioid; it is "heart-shaped". Figure 2 shows two examples of this orbit:

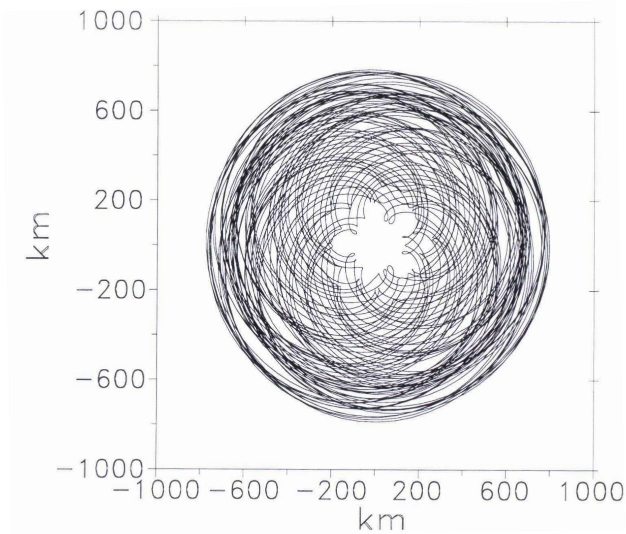

Fig. 1. The solar orbit due to the inner (terrestrial) planets in the time interval 1920–2010 in units of km.

the solar orbits in the interval a) 1934–1944 and in the interval b) 1995–2010. The first example is plotted in steps of 20 days, in order to show and understand better this motion, while the second curve is smooth. One can see in Fig. 2a that the fastest motion (notice the lengths of the 20-day abscissas) occurs in the circumference of the toroidal motion area. Then the Sun is forced to go towards the centre and its velocity decreases. The velocity again increases after the Sun reaches the closest points. The time distance between the two consecutive nearest points has been found to be very close to 1.6 years (584 days). The time positions of the noted closest points approximately coincide in time with the moments of the oppositions of V and E. In this moment, the Sun reaches the smallest distances and the smallest velocities. The solar velocity varies between 16.37 km/day and 0.64 km/day.

In Fig. 3, the distance of the centre of the Sun is depicted. The main feature of this curve is its harmony, its stable modulation by the periods of 1.6 years and 6.4 years. It is possible to see there that every fourth value of the distance is the deepest (smallest) (1.6 years (V-E)$\times$4=6.4 years or 2.13 (E-Ma)$\times$3=6.4 years).

Figure 4 shows the spectrum of periods (the power spectrum (Blackman and Tuckey, 1958) again in the distance. Besides the dominant period of 1.6 years (584 days) (V-E) the significant period of 2.13 years (25.6 months) (E-Ma) and further periods of 6.4 years, 1.0 years (E), 0.91 years (V-Ma), 0.8 years ((V-E)/2), ... have also been detected. All of these periods are above the 99% confidence level. The period of 1.3 years reaches up to the 99% confidence level. Bucha et al. (1985) also detected the period of 6.4 years (JN/2) in the SIMGP which turns our attention to a harmony of the solar system as a whole. It is interesting and important that the detected period of 2.13 years (25.6 month) (E-Ma) corresponds to a mean period of QBO.

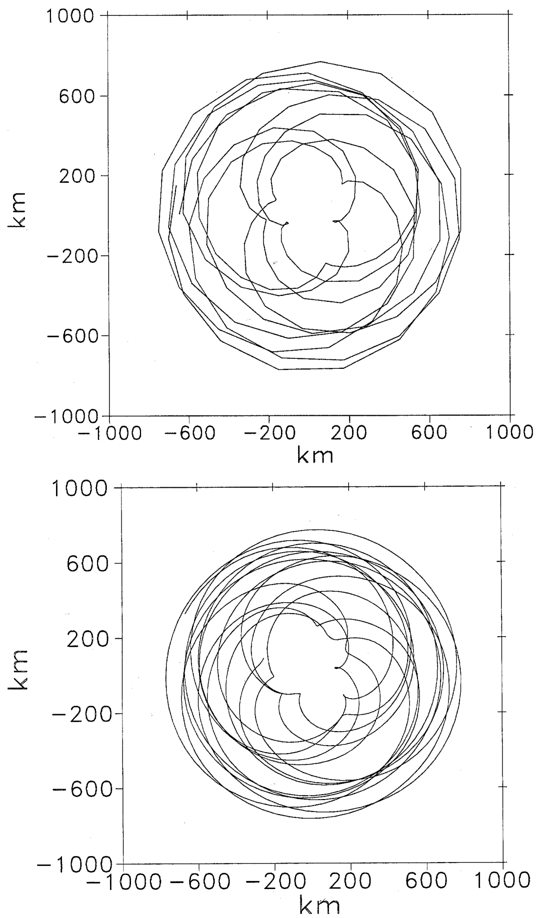

Fig. 2. The two examples of the solar orbit due to the inner (terrestrial) planets: **(a)** The solar orbit in the years 1934–1944 plotted in steps of 20 days. The times of the nearest points are: 1934.94, 1936.52, 1938.11, 1939.69, 1941.33, 1942.92. One can see here that the fastest solar motion (notice the lengths of the 20 days abscissas) occurrs in the circumference of the motion area. **(b)** The solar orbit in the years 1995–2010. The times of the nearest points are: 1995.61, 1997.22, 1998.84, 2000.41, 2001.99, 2003.62, 2005.25, 2006.81, 2008.42. The future value can serve for establishing of predictive assessments.

3 Discussion of results

The most substantial part of the solar motion is caused by the giant planets (Jupiter, J; Saturn, S; Uranus, U; Neptune, N). The circular area in which the Sun moves has the diameter of 4.34 R_S (or 0.02 AU (Astronomical Unit) or 3.02×10^6 km), where R_S is the solar radius (Jose, 1965). The basic period of SIMGP being 178.7 years was found by Jose (1965) and comfirmed by Fairbridge and Shirley (1987), Jakubcová and Pick (1987) or Juckett (2000).

Charvátová (1988, 1990a, b) divided the SIMGP into two basic types, the one ordered in the trefoils (according to JS motion order: 117.3°, 19.86 years) and the other disordered.

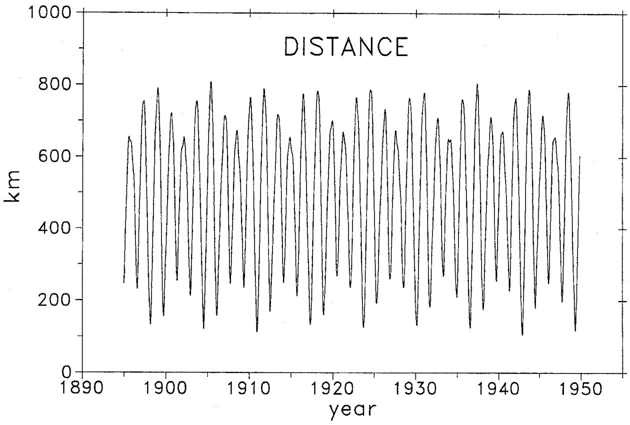

Fig. 3. The distance of the centre of the Sun created by the motion of the inner (terrestrial) planets in the years 1895–1950. The peaks occur after 1.6 years (584 days) (close to the moments of the opposition of V and E), on the average. Notice that the each fourth minimum (4×1.6 years (V-E)=6.4 years and 3×2.13 years (E-Ma)=6.4 years) is the deepest (see Fig. 4).

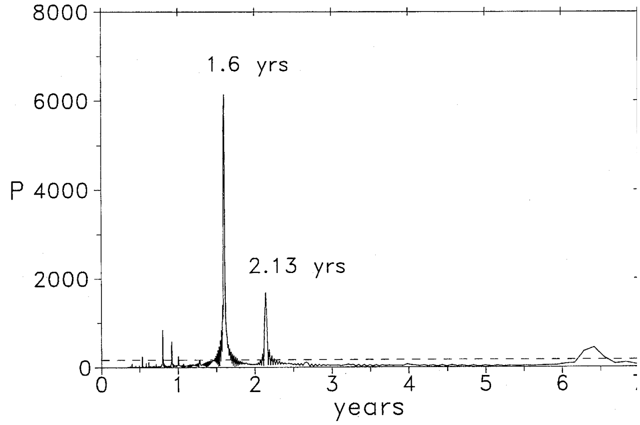

Fig. 4. The power spectrum of the periods in the distance of the centre of the Sun (computed for the time interval 1868–2030). Besides the dominant period of 1.6 years (584 days) (V-E), also the significant periods of 2.13 years (25.6 months) (E-Ma)), 1.0 years, of 0.91 years (332 days) (V-Ma), of 0.8 years (292 days) ((V-E)/2)) and 6.4 years, … have been detected. All these periods are above 99% confidence level which is represented by the dashed horizontal line. The period of 1.3 years reaches up to 99% confidence level. The period of 2.13 years corresponds to a mean value of QBO.

The most disordered intervals of SIMGP coincide with the prolonged minima of solar activity, such as in the last millennium, the Wolf, Spörer, Maunder and Dalton minima (Charvátová, 1990a, b). The Sun returns to the trefoil part of its orbit after 178.7 years (Charvátová and Střeštík, 1991), on the average. When the Sun moves along the trefoil orbit, the diameter of the motion area was always reduced up to 3.5 R_S. The trefoil intervals last about 50 years (Charvátová, 1995, 1997a, b), and the cycle lengths are equal to about 10 years (JS/2) there (Charvátová, 1990b, 1997, a, b, 2000). The series of sunspot cycles coresponding to the trefoil intervals (to the same solar orbit) repeats itself, i.e. the cycles −1 to 3 and 15 to 19 (Charvátová, 1990b). All mentioned results show that solar variability is probably caused by the solar inertial motion.

The Sun moving along the nearly identical orbits in the trefoils created nearly the same series of sunspot cycles −1 to 3 and 15 to 19. Small differences can be ascribed to a lower quality of data in the 18th century. Not only the trefoils, but also other motion (orbital) configurations are sometimes repeated: (after a rotation), e.g. (158.0 BC to 208.5 AD) and (2560.8 BC to 2193.2 BC), … (Charvátová, 2000). The solar orbits (motions) in the years 1980–2045 and 1840–1905 are nearly identical (see Charvátová, 1997, Fig. 1b). A repetition of solar variability from the years 1840–1905 can be expected after 1980. The comparison of the first 26 years of data in the both intervals is hopeful (Charvátová, in print, 2007).

The predictive assessment for cycle 23 was made in Charvátová (1995, 1997) when only data series of 15–17 years were at our disposal: maximum sunspot cycle height between 65–140 W and cycle lengths between 9.6–12.3 years could occur (Charvátová, 1990b, 1995, 1997). Our prediction of the cycle No. 23 height was successful: its height was 120 W, so that it was really between 65–140 W. All the other predictions were unsuccessful; they were too high – between 140 and even 225 W (e.g. Wilson, 1992; Shatten et al., 1996; Kane, 1997). The periods found in the SIMGP are described in Bucha et al. (1985). In Paluš et al. (2000), the quantitative relation between the solar activity and the SIMGP (here its radius of curvature) was shown, for the first time, by the method of synchronization,

The distance of the Sun's centre due to the inner (terrestrial) planets varies between 101.3 km and 808.2 km (Fig. 3), i.e. the difference is about 700 km. This is more, for example, than the depth of the solar photosphere, which is considered to be about 300–500 km. The distance of the Sun's centre due to the giant planets reaches up to 1.51×10^6 km, so that a contribution of the inner planets, which goes up to 808.2 km only, is not visible in the total (common) curve.

The individual solar spheres likely respond to the SIMGP and also to the SIMIP, provoking physical echoes on the boundary layers. The thin layer known as the tachocline lying between the radiative and convective zones, where a shear flow was found by SOHO-MDI ",is likely to be the place where the solar dynamo operates" (Kosowitchev et al., 1997). Is it possible to assume an influence of the SIMIP on the upper spheres of the Sun, on the tachocline or especially on the photosphere? The physical properties of the solar photosphere differ significantly from those of the convective zone. The layered Sun is forced to move here along the "heart-shaped" solar orbit. Could its motion, especially in the vicinity of the closest (turning) points, produce some solar changes close to MTQP? The motions of the Sun close to the nearest points (close to a turning parts of its orbit) can serve as the intervals (moments) where their possible connections with solar and solar-terrestrial phenomena can be, above all, searched for.

Wood and Wood (1965) showed that the inner planets are the most important in determining the jerk of the Sun. Shirley et al. (1990) have shown that the influence of the inner planets is greater for the higher derivatives of the position. We will deal with their results, with this problem, in comparison with our findings in the future.

4 Survey of phenomena where MTQP have been found

Ambrož (1992) found the periods of stable behaviour of solar magnetic field in steps of 20-25 rotations of the Sun, i.e. in steps of 1.67 years, on the average. A periodicity close to 1.6 years (about 600 days) was reported for the coronal hole area changes in cycle No. 21 (McIntosh et al., 1992). MTQP has also been examined in connection with large-scale photospheric motions (Valdés-Galicia and Mendoza, 1998) and it was identified in the occurrence of the sudden storm commencements (Mendoza et al., 1999): "A long-life stability of this phenomenon implies a non-random generation of the solar magnetic flux". Mursula and Zieger (1999) described a simultaneous occurrence of MTQP in solar wind speed, geomagnetic activity and cosmic rays (CR). Fraser-Smith (1972) detected the significant period of 1.47 years in the geomagnetic index A_p (1932–1969). Ambrož (1973) found that the structure of the distribution of Ca II flocculae on the whole Sun is repeated regularly after 20–25 rotations of the Sun (the mean period is 1.67 years) during cycle No. 19. He wrote: "It is clear that the fundamental pattern must be simple and must be repeated in time."

Delouis and Mayaud (1975) detected the significant period of 1.47 years in the geomagnetic index *aa* (1868–1970). Kudela et al. (1991) pointed out an abrupt change in both the level and shape of the power spectrum of the CR series at about 20 months (1.66 years). They wrote that this indicates that the CR time variations with periods longer than about 20 months are caused by another physical mechanism other than that of the shorter period variations.

From our point of view, the first mechanism can be connected with the solar motion due to the giant planets (see Sect. 3 and Charvátová, 1990a, b, 2000) and the second mechanism can be connected with the solar motion due to the inner (terrestrial) planets (see Sect. 2).

Valdés-Galicia et al. (1996) detected the prominent periods of 1.68 and 1.6 years in the CR intensity variations measured at the Deep River station during the years 1947–1990, if the mean 11-year period was eliminated. They concluded that one of the characteristic modes of the solar magnetic activity has been found there. Kudela et al. (2002) detected the most remarkable quasi-period of 1.67 years in the period range from 60 to 1000 days in CR intensity in the interval 1951–2000. Mursula and Zieger (2002) have found MTQP in the solar wind speed from 1964 onward and in the K_p index of geomagnetic activity from 1932 onward. They found the periods of 1.5–1.7 years during the odd cycles. Mursula et al. (2003) found MTQP in the geomagnetic index *aa* in the years 1844–2000. Kato et al. (2003) applied the wavelet transform technique and found the presence of the 1.68-year variation in the Voyagers' (spacecraft) CR data on their way to the outer Heliosphere. Rouillard and Lockwood (2004) have shown that the 1.68-year variation in galactic CR fluxes is a persistent feature that is linked to a similar variation in the open solar magnetic flux estimated from the IMF strength at the Earth.. Mursula and Vilppola (2004) found the period of 1.7 years in satellite data at 1 AU and probes data (Pionier 10, 11 and Voyager 1, 2) in the outer Heliosphere during cycles 21 and 22.

Figure 4 shows the prominent period of 1.6 years and the second significant period of 2.13 years. The second period corresponds to a mean value of QBO. Shapiro and Ward (1962) detected the period of 25 months (2.06 years) in the Wolf sunspot numbers in the interval 1756–1955. Westcott (1964) connected this solar period with stratospheric oscillations. Baldwin et al. (2001) have summarized the results concerning QBO and its connections with solar, terrestrial and climatic phenomena.

Starodubtzev et al. (2004) detected, by means of wavelet dynamic spectrum, a strong MTQP in the CR fluctuation index since 1980. Their power spectrum (Fig. 5, right) shows nearly the same prominent periods (1.7 years and 2.2 years) as seen in our power spectrum in Fig. 4. This represents a further, closer evidence about a possible connection between the SIMIP and solar-terrestrial phenomena.

5 Conclusions

This wide survey of MTQP (1.5–1.7 years) presence in many solar and solar-terrestrial phenomena calls for investigations on whether the SIMIP, with the dominant period of 1.6 years and with the second significant period of 2.13 years, could be the origin of MTQP (and may be an origin of QBO). The solar motion can be computed in advance (see the Figs. 1, 2b). If mutual connections (and consequently, a viable mechanism to explain these correlations) is found, predictive assessments for solar and solar-terrestrial phenomena can be done.

Connections seem to be hopeful: Foukal and Lean (1988) studied the total solar irradiance from ACRIM (active cavity radiometer irradiance monitor) on the Solar Maximum Mission spacecraft and from ERB (Earth radiation budget radiometer) on the Nimbus 7 satellite in the interval 1978–1984. Their Figs. 6, 8, 9 show maxima of He 10 830 index and CaK plage index in the moments of the turning points (see here Figs. 2, 3) of the SIMIP. The author of this article partially studied the mutual connections between the SIMIP and the geomagnetic index *aa*. The results obtained are hopeful.

Besides the period of 1.5–1.7 years, the shorter period of 1.3–1.4 years has also sometimes been detected in some phenomena (e.g. Richardson et al., 1994; Toomre et al., 2003). We will study this shorter periodicity in detail in the future. Jakubcová and Pick (1987b) detected the period of 1.3 years as significant in the solar distance by the method of logarithmic spectrum analysis. The power spectrum plotted in Fig. 4 also shows the period of 1.3 years (the fifth harmonic of the period of 6.4 years). This period reaches the 99% confidence level.

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