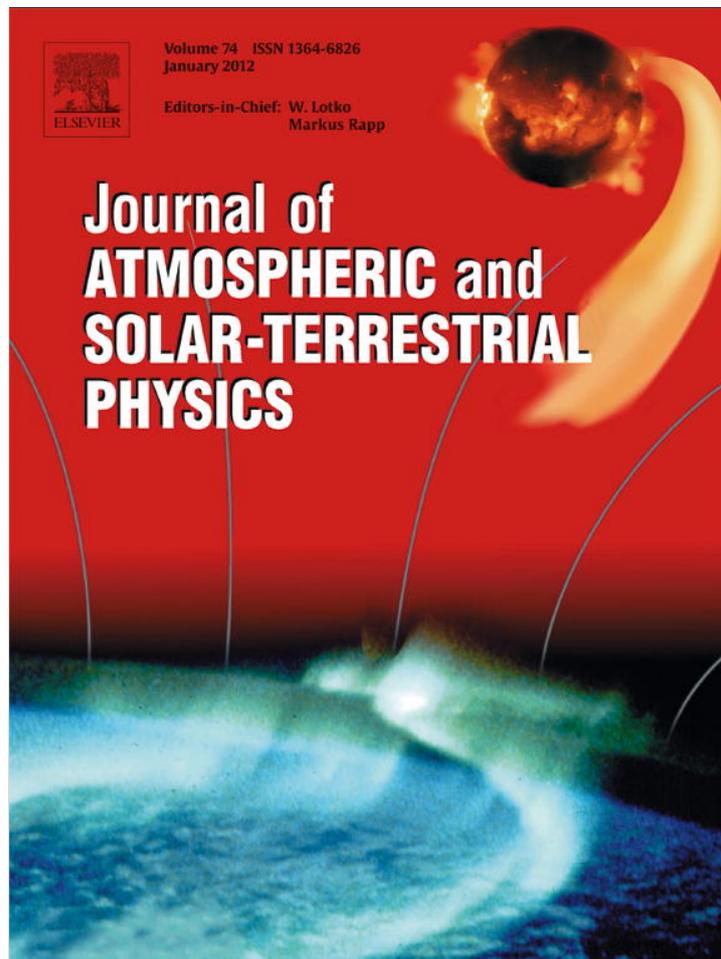


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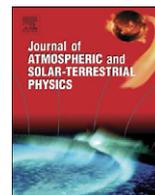
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The influence of planetary attractions on the solar tachocline

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ABSTRACT

We present a physical analysis of the occasionally forwarded hypothesis that solar variability, as shown in the various photospheric and outer solar layer activities, might be due to the Newtonian attraction by the planets. We calculate the planetary forces exerted on the tachocline and thereby not only include the immediate forces but we also take into account that these planetary or dynamo actions occur during some time, which demands integration. As an improvement to earlier research on this topic we reconsider the internal convective velocities and we examine several other effects, in particular those due to magnetic buoyancy and to the Coriolis force. The main conclusion is that in its essence: planetary influences are too small to be more than a small modulation of the solar cycle. We do not exclude the possibility that the long term combined action of the planets may induce small internal motions in the sun, which may have indirectly an effect on the solar dynamo after a long time.

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1. Introduction

Various authors have dealt with the problem of the possible planetary influence on solar activity. The first, primitive proposition that such might be the case arose, down in the 19th century, from the similarity between the 12-years orbital motion of Jupiter and the 11-years Schwabe cycle in the sunspot numbers. It was soon realized that this assumption was too simple and actually incorrect (De Jager, 1959), but these ideas were refined during the past century, also in view of the renewed interest in the problem of the possible solar influence on terrestrial climate. One of the often quoted papers on the suggested influence on the solar dynamo (Jose, 1965) is related to the 178.7 years period around the centre of mass of the solar system, due to Jupiter, Saturn, Uranus and Neptune. More papers on the same theme (cf. e.g. Wood and Wood, 1965; Landscheidt, 1999; Charvátová, 2007; Callebaut et al., 2008; Fairbridge and Shirley, 1987; Milan et al., 2007; Wolff and Patrone, 2010; Georgieva et al., 2009; Tan, 2011, with many references to earlier work) are all aiming at finding periodicities in planetary motions that are equal to or can be related to the known solar periodicities.

So far the study of solar variability has identified five solar periodicities with a sufficient degree of significance (cf. the review by De Jager, 2005, Chapter 11). These periods are:

- The 11 years Schwabe cycle in the sunspot numbers. We note that this period is far from constant and varies with time, e.g. during the last century the period was closer to 10.6 years.
- The Hale cycles of solar magnetism encompasses two Schwabe cycles and shows the same variation over the centuries.
- The 88 years Gleissberg cycle (cf. Peritykh and Damon, 2003). Its length varies strongly over the centuries, with peaks of about 55 and 100 years (Raspopov et al., 2004). The longer period prevailed between 1725 and 1850.
- The De Vries (Suess) period of 203–208 years, with a fairly sharply defined cycle length.
- The Hallstatt cycle of about 2300 years. An interesting new development (Nussbaumer et al., 2011) is the finding that Grand Minima of solar activity seem to occasionally cluster together and that there is a periodicity in that clustering. An example of such a cluster is the series of Grand Minima that occurred in the past millennium (viz. the sequence consisting of the Oort, Wolf, Spörer, Maunder and Dalton minima). This kind of clustering seems to repeat itself with the Hallstatt period.

It should be remarked in this connection that virtually none of the papers on planetary influences on solar variability succeeded in identifying these five periodicities in the planetary attractions.

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Another approach to this problem is the study of climate variations in attempts to search for planetary influences. As an example we mention a paper by Scafetta (2010), who found that climate variations of 0.1–0.25 K with periods of 20–60 years seem to be correlated with orbital motions of Jupiter and Saturn. This was, however, not confirmed in another paper on a similar topic (Humkin et al., 2011). This is another reason for a more fundamental look at the problem: can we identify planetary influences by looking at the physics of the problem?

The challenge we face here is twofold: planetary influences should be able to reproduce at least the most fundamental of the five periodicities in solar variability, and secondly the planetary accelerations in the level of the solar dynamo should be strong enough to at least equalize or more desirably, to surpass the forces related to the working of the solar dynamo. In this paper we discuss the second aspect, realizing that the attempts to cover the first aspect have been dealt with sufficiently in literature while the second aspect was grossly neglected so far. A first attempt to discuss it appeared in an earlier paper (De Jager and Versteegh, 2005; henceforth: paper I). They calculated three accelerations:

- 1) One by tidal forces from Jupiter. They found $a_{Jup} = 2.8 \times 10^{-10} \text{ m/s}^2$.
- 2) One due to the motion of the sun around the centre of mass of the solar system due to the sum of planetary attractions (a_{inert}).
- 3) The accelerations (a_{dyn}) by convective motions in the tachocline and above it.

It was shown in their work that the third one is larger by several orders of magnitude than the first and second mentioned accelerations. Soon after its publication it was realized that some of the forces are effective for a long time, which demands an integration of the forces over the time of action. That might change the results. It was also realized that more forces may be operational than the two mentioned in paper I. Therefore, in the present paper, we improve and expand these calculations; we investigate a few more possible effects; moreover, we study the effect of the duration of these actions as well.

2. Planetary influences

2.1. Planetary accelerations: some numbers

We calculate the planetary effects at the tachocline level, because it is there that the essential aspects of solar activity originate (cf. Parker, 1955a, 1955b; Steenbeck and Krause, 1967, and later authors). There are many reviews on the solar dynamo; discussing its physical mechanisms (cf. reviews by Fisher et al., 2000; Ossendrijver, 2003; De Jager and Duhau, 2011; see also research papers by Seehafer and Pepin, 2009; Ruediger and Kitchatinov, 2007; Kopyla, 2011; Georgieva and Kirov, 2011). The tachocline is the layer where solar variability finds its origins. It has a thickness of about 30,000 km and is situated at a depth of about 200,000 km below the solar photosphere. Hence, our problem is: what is the influence of planetary Newtonian attractions on the tachocline.

In our Table 1 we list the tidal accelerations in the tachocline due to the planets up to Saturn. The latter is more than 20 times smaller than a_{Jup} ; hence the farther planets are irrelevant in this respect. Note that the tidal accelerations of the Earth and of Mercury are each nearly half the one by Jupiter, while the one of Venus is nearly equal to that of Jupiter. If the latter were important for the solar cycle then there should be several short cyclic variations superposed to the solar cycle.

Table 1

Tidal accelerations due to the first six planets at the tachocline and with respect to the solar centre. At the solar surface they have to be increased by 40%. With respect to the centre of the solar system they may increase by a factor of up to 4.

Planet	Tidal accelerations at tachocline in 10^{-10} m/s^2
Mercury	1.1
Venus	2.6
Earth	1.2
Mars	0.036
Jupiter	2.8
Saturn	0.13

The combined acceleration (at the tachocline level) due to Mercury, Venus, Earth and Jupiter can occasionally amount to $7.8 \times 10^{-10} \text{ m/s}^2$. With respect to the centre of the solar system this may amount to $\sim 31 \times 10^{-10} \text{ m/s}^2$. Indeed, according to Jose (1965) the distance between the centre of the sun and the centre of mass of the solar system varies from 0.01 to 2.19 solar radii. Jose studied this over a complete “system period” (178.7 years), extending from 1834 to 2013. The maximal elongation between both centres is therefore $1.533 \times 10^6 \text{ km}$, which is 3 times the distance from the centre of the sun to the tachocline (as used in Table 1). The part of the tachocline, which is at the side of the centre of mass, is then about 10^6 km away from the centre of mass. Hence, the figures in Table 1 may then occasionally be doubled. For the part of the tachocline on the opposite side of the sun’s centre we have $2 \times 10^6 \text{ km}$ and the values in Table 1 may occasionally be multiplied by ~ 4 . (For comparison: the acceleration on the Earth due to the moon is $3.5 \times 210^{-5} \text{ m/s}^2$ and the moon’s tidal acceleration at the surface of the Earth is about $1.2 \times 10^{-6} \text{ m/s}^2$.)

Periods: the sidereal period of Jupiter is 11.86 years while during the rather active Grand Maximum of the 20th century we obtained 10.6 years for the average solar cycle. Jupiter should be out of phase in a few cycles. Moreover, the activity due to Jupiter should go on all the time with barely pronounced maxima and minima unless one particular place (orientation) of the tachocline is more suited than the rest for generating sunspots. Then the effect of Jupiter e.g. might reveal itself in a strong azimuthal asymmetry of the sunspot distribution with the rotation period of the sun (about 27 day at the tachocline). Moreover, the tidal effect acts on both sides of the centre with about the same strength, which means that in the considered asymmetric case the spots should show half the period of sun’s revolution. However, Mercury, Venus and the Earth would complicate (blur out to some extent) this asymmetric appearance. Hence, the monthly rotation of the sun hampers for an important part a reconciliation of the orbital period of Jupiter and the period of the solar cycle.

Finally, the polarity changes of the solar cycle can hardly be understood or even not at all, as stated in paper I, since Jupiter (like all the planets) is practically in the equatorial plane of the sun (3° deviation for Jupiter). Of course, the main mechanism of the solar cycle may be one inherent to the sun (e.g. the dynamo) while Jupiter might only be the cause of some extra effect, which adds itself to the result of the inherent mechanism during the odd cycles and which counteracts it during the even cycles. This would represent an explanation of the Gnevychev–Ohl rule (1948): an even cycle is in many cases – though not always; it is not a strict rule – a bit weaker than the odd one following it. (Cycles 22 and 23 form a notable exception to this rule and are an indication of the coming deep Grand Minimum (De Jager and Duhau, 2009; Makarov et al., in preparation; Duhau and De Jager, 2010).)

Hence, the planets can hardly be an important agent in the solar cycle. To see that they can at most contribute a small

secondary effect we investigate various accelerations (tidal and other) located at the tachocline. Nevertheless, we cannot fully exclude that the tidal actions may have some very small effect on the solar layers and thus indirectly on the meridional motion, which may affect the generation of sunspots. Let us just mention a possibility: all the planets circulate in the same sense around the sun, which is the sense of the solar rotation as well. The latter is much faster than the planetary revolutions, but the accumulated action of all the planets may have an effect. We remind the reader of the relations between the sunspot cycle and the poleward motion of the surface layers on one hand and the meridional motion on the other hand (Makarov and Makarova, 1996; Makarov et al., 2001; Callebaut and de Jager, 2007; Georgieva et al., 2009).

2.2. New determination of a_{inert}

The motion of the sun around the centre of mass of the solar system was studied by Jose (1965). His figure 1 shows the motion of the sun's centre around the centre of mass of the solar system from 1833 to 2013. The average distance of the solar centre to the mass centre is on the order of one solar radius and the maximum distance is about two solar radii. His figure 2 gives the time variation of various quantities, among which that of the radius of curvature $R_{curv}(t)$ and that of the momentum of the whole solar body, dJ/dt . The consequent acceleration for the whole solar body is $d(dJ/dt)/dr$. An estimated value for it is obtained by dividing dJ/dt by the average radius of curvature R_{curv} and for obtaining a_{inert} , the planetary acceleration per kg of matter, that quantity must be divided by the solar mass. Hence

$$a_{inert} = (d(dJ/dt)/dr)/M_o = (dJ/dt)/(R_{curv}M_o) \quad (1)$$

From Jose's figure 2 we read the average value of $R_{curv} = 5 \times 10^{-3}$ AU, while that of $|dJ/dt|$ is $2 \times 10^{-8} M_o (AU/40d)^2$. By dividing this quantity by $(R_{curv}M_o)$ and introducing MKS values for AU and 40 days, one obtains $a_{inert} = 5 \times 10^{-8} \text{ m/s}^2$. This value is about 10 times larger than that in paper I. The difference is due to a numerical error in paper I.

Calculation of centripetal acceleration: Let us deduce a_{inert} alternatively as the centripetal acceleration. The period of motion of the sun around the centre of mass is 178.7 yr (Jose, 1965), which is composed of nine Jupiter–Saturn periods, combined in groups of three. The Jupiter–Saturn period is 19.9 yr. (This does not differ much from a Hale period, but is not sufficiently close to it for avoiding large phase differences in a few cycles. Moreover, the polarity reversal is again hard to explain in this way.) The circumference of a quasi-circle described in 19.9 yr is $2\pi R_{curv}$. The corresponding velocity is $v = 2\pi R_{curv}/19.9 \times 3.15 \times 10^7$ (about 7 m/s). The centripetal acceleration is then (say up to a factor 2)

$$a_{cp} = \frac{v^2}{R_{curv}} = \frac{4\pi^2 R_{curv}}{(19.9 \times 3.15 \times 10^7)^2} \cong 7 \times 10^{-8} \text{ m/s}^2.$$

This confirms our estimation a_{inert} as being much smaller than a_{dyn} (see further). Moreover, a_{inert} and a_{cp} , act on the whole sun and are thus relatively irrelevant. In fact, the sun is in free fall around the centre of mass of the solar system (Shirley, 2006) except for spin–orbit coupling (see e.g. para vi in Section 4) and for tidal effects of the planets.

The inertial acceleration of the sun around the centre of mass of the solar system, as estimated by Wood and Wood (1965) is on the order of $1-3 \times 10^{-7} \text{ m/s}^2$; this is at most a factor 4 larger than our estimation. Their value is (only) a factor 20–60 times smaller than a_{dyn} , but much closer to it than a_{Jup} . However, in view of the free fall of the sun this is irrelevant for our purpose.

The actually existing acceleration a_{dyn} at the tachocline level (which is supposed to be responsible for the solar dynamo) was

derived in paper I as $a_{dyn} = 6 \times 10^{-6} \text{ m/s}^2$ which is about 4 orders of magnitude larger than a_{Jup} and still much larger than a_{inert} as well. De Jager and Versteegh (2005) concluded that the accelerations caused by the planets are simply too small as compared with the accelerations that occur in the tachocline. Moreover, they stressed rightfully that the planetary actions do not give an explanation for the polarity changes in the solar cycle, but as explained before this may give a supplementary modulation (cf. the Gnevyshev–Ohl, 1948 rule).

In the next section we re-estimate the convective velocities, calculate some other effects which were not considered in paper I, and take into account the duration of the various actions. Indeed, a small acceleration acting during several years might amount to a significant effect.

3. Duration and effects of tidal and convective accelerations.

3.1. Tidal acceleration

Fixing a blob in the tachocline shows that the tidal acceleration varies with the solar rotation, for which we assume here a value of 27 days (this being an average value for the sunspot belt). Moreover, the tidal acceleration is directed alternatively towards and away from the centre of the sun with in between a perpendicular orientation. Hence, its final effect will still be negligible as compared to the one due to the motion around the centre of mass. Calculating crudely (i.e. without taking into account friction, effect of other layers, etc.) for 6 days yields $1.5 \times 10^{-4} \text{ m/s}$ as the maximum resulting velocity which a blob or a layer of solar matter located in the tachocline may obtain from Jupiter in this manner. Correspondingly the distance (displacement) covered during that period would be less than 100 m (even neglecting the variation in direction), which is negligible for an object like the sun.

3.2. Acceleration around the centre of mass of the solar system due to the enduring combined action of planets

Actually, Jupiter moves about $30^\circ/\text{yr}$ and Saturn about $12^\circ/\text{year}$. (We consider Jupiter and Saturn as an example; in fact Saturn is rather unimportant according to Table 1; however, Saturn matters for the centre of mass.) This makes a difference of $18^\circ/\text{yr}$; hence, they combine perfectly their attraction every 19.6 years. If we count from 54° before to 54° after the opposition, then they combine their actions roughly during 6 yr. Of course, this varies too with the rotation of the sun (towards and away from the centre), however with different amplitudes; hence some net effect may result. In $18 \times 10^7 \text{ s}$, a_{Jup} results in a velocity of 0.05 m/s and a displacement of 4500 km. This is a measurable and not insignificant magnitude, but small as compared with the solar radius. It may be noted that the neighbouring layers experience a similar effect. In the next part of our paper we show that the effect of planetary motions is negligible as compared to some other effects.

3.3. Acceleration due to convective cell motions

At the depth of the tachocline the temperature $T = 2.27 \times 10^6 \text{ K}$ and the density $\rho = 230 \text{ kg/m}^3$. (This is about a quarter of that of water.)

The convective velocities are some 10 m/s (Robinson et al., 2004). We adhere to the usual assumption that convective elements rise over one or two scale heights h before dissolving. We assume also that they rise with constant acceleration a ; hence

$v=at$. Then, after some algebra: $a=v^2/yh$ where y is 2–4. With $h=38\,000$ km, we obtain $a=(0.65\text{--}1.3)\times 10^{-6}$ m/s².

The data obtained here confirm the statement in paper I that the planetary attractions discussed so far are negligible as compared to the acceleration due to convective motions, even when we take into account the duration of their actions, although the ratios turn out somewhat different from those in paper I.

4. Other possible effects

We may further extend the mechanisms by the following ones.

4.1. Acceleration due to buoyancy force on magnetic flux tube near tachocline

The thermal buoyancy contribution seems to be the main driving acceleration for the rising of the flux tubes. A rough estimation of the relative density change yielded 5×10^{-3} , which is comparable with the situation in Bénard cells (Chandrasekhar, 1961).

Using the usual conventions we have

$$p_{in} + \mu H^2/2 = p_{ex}, \quad (2)$$

as the relation between the pressure in the flux tube and the pressure outside it (for the same gravitational potential). Clearly, p_{in} is smaller than p_{ex} . Using $p=nk_B T$ inside and outside the tube yields

$$n_{ex} - n_{in} \frac{T_{in}}{T_{ex}} = \frac{\mu H^2}{2k_B T_{ex}},$$

with obvious notations. As $T_{in}/T_{ex} \leq 1$, but very close to 1, we have to a good approximation for the difference in density (Callebaut and de Jager, 2007)

$$dn = \frac{(\mu H)^2}{2\mu k_B T_{ex}}, \quad (3)$$

which yields $dn \sim 1.4 \times 10^{24}$ m⁻³ in the tachocline when taking $H=100,000$ G (10 T). T at the tachocline is 2×10^6 K and the mass density in the tachocline is 0.15 g/cm³ (Lang, 1991) and thus the number density n is about $0.15/0.75 \times 1.67 \times 10^{-24} = 1.3 \times 10^{23}$ cm⁻³ or $n = 1.3 \times 10^{29}$ m⁻³, taking the molecular weight in the tachocline to be 0.7. Hence the relative difference in density is $(dn/n)_m \sim 10^{-5}$ between a flux tube and a neighbouring layer without magnetic field. This may be translated to a difference in acceleration with respect to neighbouring material of $10^{-5} g_{sun}$. Now $g_{tachocline}$ in the tachocline is close to 500 m/s² (note: it may seem surprising that at this level g_{sun} is larger than at the solar surface (274 m/s²) but that is simply due to the fact that virtually the whole solar mass is situated below the tachocline level, as can be read in solar model calculations). For the difference under consideration we find a change in acceleration (buoyancy–magnetic) of $a_{bm} \sim 0.005$ m/s². This one is acting continuously and specifically on the flux tube and not on the neighbouring material, which constitutes a great difference with the items discussed in Sections 2 and 3. Anyway, this is 3 orders of magnitude more than the a_{dyn} . However, now the inertia and friction with surrounding layers will strongly reduce the rising velocity, whose maximum is probably some 40 m/s so that the distance of $200\,000$ km may be covered in $5\text{--}8 \times 10^6$ s (a few months).

Note on the equipartition of the energies: We first determine the equipartition value for which the magnetic energy equals the kinetic one of the rising convective elements. With a density of 230 kg/m³ and a convective velocity of 10 m/s (as assumed above) equipartition is reached for a field of 10^4 G, a value that is generally mentioned in literature (D'Silva and Choudhuri, 1993; Caligari et al., 1995; Ruzmaikin, 1998). For larger field strengths,

on the order of 10^5 G, tachocline models show that the fields are expected to break and disintegrate into smaller filaments, causing flux ropes to rise (Hughes, Rosner and Weiss, 2007; De Jager and Duhau, 2011). Subsequently they show themselves at the surface as sunspots. One may also compare with the gravitational energy (Callebaut et al., 2002).

By way of comparison – though realizing that the physical implications do not apply to our present problem – we next compare the equipartition between the thermal energy (say in one direction) and the magnetic energy: $(nk_B T/2) = (\mu H^2/2)$, with $k_B = 1.38 \times 10^{-23}$ J K⁻¹, $\mu = \mu_0 = 4\pi \times 10^{-7}$ H/m, $n = 1.3 \times 10^{29}$ m⁻³, $T = 2.3 \times 10^6$ K. This results in $B = 2000$ T (2×10^7 G!). The equipartition, however, is by far not yet reached when blobs start to rise: in fact, the motion and the magnetic energy should first roughly equalize their energies (taking a long time!) and later (taking much more time) the magnetic energy and the thermal energy may equalize. In the actual case even the first step is prevented because when the field reaches about 10 T ($100\,000$ G), the flux tubes start to rise and most of their energy is dissipated at the solar surface, either in heat or as fields in the solar atmosphere.

4.2. Deceleration due to centrifugal force of a magnetic flux tube near the tachocline

The centrifugal acceleration is given by $a_c = \omega^2 r \sin \vartheta$ with ϑ the co-latitude. As we are mainly thinking of sunspots, we approximate the sine by 0.9 or even 1. Taking 27 days for the rotation period at the tachocline we find $\omega = 2.7 \times 10^{-6}$ s⁻¹ and $a_c = 3.6 \times 10^{-3}$ m/s². For $(dn/n)_m = 10^{-5}$ we find a deceleration (centrifugal-magnetic) $a_{cm} \sim 3 \times 10^{-8}$ m/s², opposing the motion towards the solar surface caused by the buoyancy force as it has a centripetal effect. This a_{cm} is negligible compared to the buoyancy contribution a_{bm} caused by the same $(dn/n)_m$. For other latitudes the effect is even smaller.

4.3. Coriolis force

The Coriolis force acts on matter moving in a rotating system. There are two places where it can be of importance in the context of the present paper: (a) the ascending (convective) motions in the rotating solar body and (b) the motion of the sun around the centre of gravity of the solar system. We calculate the corresponding accelerations for both cases, to begin with the effect on convective elements.

- (a) The Coriolis acceleration (Feynman et al., 1966) is given as $a_{cor} = 2\omega_S v_{rise}$ with the angular frequency of the rotating sun $\omega_S = 2\pi/(27 \times 86\,400)$ s⁻¹ and $v_{rise} = 20$ m/s (say). This yields $a_{cor} = 10^{-4}$ m/s². This would result in a maximum velocity of 500 m/s in 2 months and a displacement of 1.2×10^9 m, which is nearly a solar diameter! However, the Coriolis force is perpendicular to the rising velocity; hence it produces some rotational motion, not an ascending one. Moreover, the neighbouring regions may strongly damp this motion. However, this motion may be relevant for the solar dynamo, but its relation to the (individual) planets will be blurred out.
- (b) Effect of Coriolis force due to the motion around the centre of gravity. Here the angular frequency ω_C is about 2 orders of magnitude smaller than ω_S as now the period is about 20 yr (essentially the period for Jupiter and Saturn, which seems more reasonable than 178.7 yr) instead of a month. However, our situation is more complicated than the one considered by Feynman (1966). Our sun is rotating with ω_S and revolving around the centre of mass with ω_C . If we suppose that matter is moving with velocity v , then the associated Coriolis acceleration (perpendicular to v) due to the revolution is

$a_{Cor}=2v\omega_C$, neglecting the solar rotation for a moment. With $v=20$ m/s and $\omega_C=10^{-8}$ s $^{-1}$ we obtain $a_{Cor}=4 \times 10^{-7}$ m/s 2 , an order of magnitude less than a_{inert} or a_{cp} given above, but comparable to the acceleration given by Wood and Wood (1965). However, v changes its orientation due to ω_S , say $v=v_0 \cos \omega_S t$. This goes much faster than the revolution due to ω_C . Hence, after one rotation of the sun, the corresponding velocity is about $\int 2v_0\omega_C \cos(\omega_S t) dt$, and it practically vanishes.

5. Conclusions

We calculated various accelerations near or in the tachocline area and compared them with those due to the attraction by the planets. We found that the former are larger than the latter by four orders of magnitude. Moreover, the duration of the various causes may change a bit the ratio of their effects, but they are still very small as compared to accelerations occurring at the tachocline. Hence, planetary influences should be ruled out as a possible cause of solar variability. Specifically, we improved the calculation of a_{inert} in paper I and gave an alternative estimation. If the tidal acceleration of Jupiter were important for the solar cycle then the tidal accelerations of Mercury, Venus and the Earth would be important too. The time evolution of the sunspots would then be totally different and the difference between the solar maximum and its minimum would be much less pronounced.

Taking into account the duration of the acceleration a_{Jup} does not really change the conclusions of paper I: the planetary effects are too small by several orders of magnitude to be a main cause of the solar cycle (they can be at most a small modulation); moreover, they fail to give an explanation for the polarity changes in the solar cycle. In addition, the periods of revolution of the planets (in particular Jupiter) do not seem compatible with the solar cycle over long times. In fact, a planetary explanation of the solar cycle is hardly possible.

Besides, we estimated various other effects, including the ones due to the magnetic field (buoyancy effect and centripetal consequence) and those due to the Coriolis force; their relation to the tidal effects can be indirect at its utmost best (by influencing motions which might affect the solar dynamo).

As all planets rotate in the same sense around the sun their combined action over times of years may induce a small motion e.g. at the solar surface. This may have an influence on the meridional motion or on the poleward motions of the solar surface (Makarov et al., 2000), having in turn an influence on the solar dynamo (maybe leading to an effect like the Gnevyshev–Ohl rule). Again, this will be very indirect and the effect of one planet or one orbital period will be masked.

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