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DO PLANETARY MOTIONS DRIVE SOLAR VARIABILITY?

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Abstract. We examine the occasionally forwarded hypothesis that solar activity originates by planetary Newtonian attraction on the Sun. We do this by comparing three accelerations working on solar matter at the tachocline level: Those due to planetary tidal forces, to the motion of the Sun around the planetary system's centre of gravity, and the observed accelerations at that level. We find that the latter are by a factor of about 1000 larger than the former two and therefore cannot be caused by planetary attractions. We conclude that the cause of the dynamo is purely solar.

1. Approaches in Explaining Sun-Induced Climate Change and Solar Variability

The role of the Sun in climate change is a matter of ongoing debate (e.g. Reimer, 2004). A fundamental issue in this respect is the solar variability, its predictability with respect to amplitude, and timing of the changes.

In dealing with Sun–climate relationships there are two complementing mechanisms. First, climate may change due to varying insolation of the Earth by changes in the Earth's orbital parameters, such as the distance to the Sun, the axial inclination, and the precessional motion. We call this the Milankovich approach. It has been successful in explaining the ice-ages (Milankovich, 1941). For shorter time scales it was applied by Loutre *et al.* (1992). The second mechanism is based on the assumption that climate may change as a consequence of solar variability and the consequently varying emissions of radiation and of magnetized plasma. In the present note we only deal with the second mechanism, that of solar variability and particularly with the question of what mechanism causes solar variability. In that respect there are two opposing hypotheses.

Currently the most popular hypothesis is that the variability is driven by the solar dynamo (recent reviews by Weiss and Tobias, 2000; Ossendrijver, 2003; Bushby and Mason, 2004). The dynamo finds its origin in the tachocline. This is the level that separates the inner rigidly rotating part of the Sun from the upper convective layer. It is situated at $r/R_0 = 0.693$ (Kosovichev, 1996; Charbonneau *et al.*, 1999), which is about 500 000 km from the solar centre. The thickness of the tachocline is

0.039 R_0 (Charbonneau *et al.*, 1999). At that level strong shearing motions occur in the solar plasma. These motions can store and deform magnetic fields that are initially poloidal but that are subsequently stretched in solar longitudinal directions by differential rotation, to eventually become toroidal. The sunspots and the active regions surrounding the spots originate from these toroidal fields and the changing solar irradiation is emitted from these active regions.

Slightly delayed upwelling and emerging magnetic fields eventually arrive at the surface. The combination of uprising motions and Coriolis forces transforms them into poloidal fields. These are basic to the ejection of solar magnetized plasma that eventually fills the heliosphere, with possible consequences for climate. Equatorward motion of the spot zone and poleward motion of the polar prominence zone are ascribed to meridional circulation inside the convection zone.

The other approach seeks the origin of solar variability in the attraction of the planets. The relatively close equality of the average solar cycle length (10–12 years) and the orbital period of Jupiter (12 years) was for several authors a reason for suggesting a causal relationship. One of the first to develop this idea with mathematically elaborated details was Jose (1936, 1965). He found, confirmed by Landscheidt (1999), that the Sun's motion around the centre of mass of the solar system has a periodicity of 178.7 years and these authors claim that the same period seems to appear in the sunspot cycle. We note in passing that recent extensive researches did not verify that claim (Ogurtsov *et al.*, 2002; Le and Wang, 2003). A comparison of the time dependence of the sunspot numbers with various variables, notably the time derivate $\mathrm{d}J/\mathrm{d}t$ of the angular momentum around the instantaneous centre of curvature of the solar motion, shows a remarkable similarity. But this similarity is obtained by plotting sunspot number curves for successive Schwabe cycles alternating positive and negative. No physical reason is given for that choice. More recent papers elaborating on this hypothesis are from Fairbridge and Shirley (1987), who forecasted an immanent new deep and prolonged minimum of activity on the basis of the 178.7 years period, and from Charvátová (1997, 2000) who suggests that a (so far not confirmed) periodicity of 2400 years would be due to heliocentric/barycentric alignments of Jupiter. Other papers on the same and related topics are by Landscheidt (1999, and references therein). The importance of this approach is that if confirmed, it would be a solid basis for forecasting solar variability and possibly climate. For example, Landscheidt (2000) and Tomasino, Zanchettin and Traverso (2004) use such data, particularly those on the angular momentum of solar motion around the planetary system's barycenter, to forecast discharges of river Po.

The hypothesis of planetary influences is solely based on arguments of qualitative similarity of the sunspot cycle and aspects of the solar motion around the centre-of-gravity of the solar system. No physical support has yet been given. Therefore, it is important that in the past decade solar seismology has yielded sufficient data on internal motions to verify which of the two suggestions is most likely.

2. Numerical Comparison of Accelerations

The motion of a body moving around a centre of gravity contributes to its instability when the centrifugal forces are a significant fraction of other forces that regulate the body's motion and structure. What matters are the differential forces, i.e., the difference between gravitational and centrifugal forces, in other words, the tidal forces.

We compare three accelerations acting on the solar body. One is the planetary tidal forces. We calculated them, using the classical expression, for which reference is made to elementary astronomy or geophysics textbooks. The tidal acceleration due to the largest planet, Jupiter, is:

$$a_{\mathrm{Jup}} = g\frac{2\,M}{r^3},$$

where g is the acceleration of gravity at the level concerned, M is the ratio between the mass of the attracting body and that of the Sun. We took the solar mass inside the tachocline, which is essentially equal to the whole solar mass. Further, r is the distance between Jupiter and the Sun. We found $a_{\mathrm{Jup}} = 2.8 \times 10^{-8}\,\mathrm{cm\,s^{-2}}$.

Next we derived the acceleration resulting from the motion of the solar body (as calculated by Jose), due to the sum of the planetary attractions. The Sun's motion can be described as a succession of quasi-circular motions, with different radii of curvature around a variable series of instantaneous centers of attraction. Calling J the angular momentum about the instantaneous centre of curvature and ρ the instantaneous radius of curvature, Jose gives graphs for the variation of ρ and $\mathrm{d}J/\mathrm{d}t$. The force acting on the whole Sun is then $\mathrm{d}(\mathrm{d}J/\mathrm{d}t)/\mathrm{d}r$, where r is the distance along the sun's path. From this expression the acceleration, i.e. the force per unit mass, is derived. From Jose's graphs we read the average value for $|\mathrm{d}J/\mathrm{d}t|$, which is about 2×10^{-8} (Sun's mass)(AU^2)/(40 days) while the average value for the derivative over r is approximated by dividing this quantity by the average radius of curvature, which is 5×10^{-3} (AU). The acceleration, i.e. the force per gram of matter is then found to be $a_{\mathrm{inert}} = 5 \times 10^{-7}\,\mathrm{cm\,s^{-2}}$, which is nearly 20 times the tidal acceleration. This result by itself justifies Jose's approach, but it does not quantitatively address the mechanism of solar variability, nor the polarity reversals. We should add that the above calculated average value is valid for the centre of the Sun. For the tachocline, which can be situated farther or nearer to the centre of curvature of the Sun's path, these distances can be larger or smaller by *at most* a factor 2. This means that the actual average acceleration a_{inert} can be as large as 10^{-6} and as small as $2.5 \times 10^{-7}\mathrm{cms^{-2}}$.

We next consider the actually existing accelerations a_{dyn} at the tachocline level. These are assumed to be responsible for the solar dynamo. To calculate a_{dyn} we derived $\langle v_{\mathrm{conv}}\rangle\,(\mathrm{d}v_{\mathrm{rot}}/\mathrm{d}r)$ where $\langle v_{\mathrm{conv}}\rangle$ is the average convective velocity at the basis of the solar convection zone and $\mathrm{d}v_{\mathrm{rot}}/\mathrm{d}r$ the derivative of the solar internal rotational velocity along the solar radius. The rotational velocity above the tachocline is latitude-dependent. We took the value for a solar latitude of 30° being a level representative for the early part of the solar cycle, because the first sunspots of a cycle appear at that latitude (assuming values for other latitudes would not significantly change the result). For the average convective velocity at the bottom of the convection zone we took a conservative value of 10 m/s (Robinson *et al.*, 2004) and thus we found for the actual acceleration near the tachocline level a value $a_{\mathrm{dyn}} = 6 \times 10^{-4}\,\mathrm{cm\,s^{-2}}$, which is of the order of 600–2000 times the larger of the two other accelerations.

3. Discussion and Conclusion

We note that the above results have been derived for the physical conditions valid at the tachocline level. They would qualitatively also be valid for other layers in the solar convective region. The conclusion is therefore that accelerations caused by the planets simply completely disappear in the accelerations actually observed inside the solar body. They are too small by a very large factor to be able to cause the observed accelerations. Therefore they cannot significantly influence the solar dynamo unless a completely different hypothesis is forwarded that would, first, invalidate the present dynamo theory, and, secondly, at the same time explain solar activity, its polarity reversals and sunspots by planetary gravitational attractions. A strong point of criticism to the planetary hypothesis is that no physical mechanism has yet been forwarded for explaining polarity reversal by planetary motions.

Conversely, it must be noted that the present dynamo theories, although well describing the periodicities and the polarity reversal of solar activity, are not yet able to quantitatively explain the 11- and 22-year cycles, nor the other observed quasi-cycles. Therefore quantitative explanations need to be found for the quasi-cyclic behavior of solar activity.

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