Comparative Magnetic Minima:
Characterizing quiet times in the Sun and Stars
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A new imminent grand minimum?

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Abstract. The planetary hypothesis of solar cycle is an old idea by which the planetary gravity acting on the Sun might have a non-negligible effect on the solar magnetic cycle. The advance of this hypothesis is based on phenomenological correlations between dynamical parameters of the Sun's movement around the barycenter of the Solar System and sunspots time series. In addition, several authors have proposed, using different methodologies that the first Grand Minima (GM) event of the new millennium is coming or has already begun. We present new fully three dimensional N-body simulations of the solar inertial motion (SIM) around the barycentre of the solar system in order to perform a phenomenological comparison between relevant SIM dynamical parameters and the occurrences of the last GM events (i.e., Maunder and Dalton). Our fundamental result is that the Sun acceleration decomposed in a co-orbital reference system shows a very particular behaviour that is common to Maunder minimum, Dalton minimum and the maximum of cycle 22 (around 1990), before the present prolonged minimum. We discuss our results in terms of a dynamical characterization of GM with relation to Sun dynamics and possible implications for a new GM event.

Keywords. Sun: activity - Sun: interior, sunspots.

1. Introduction

The planetary hypothesis of the solar cycle is an old idea in which the gravitational influence of the planets has a non-negligible effect on the causes of the solar magnetic cycle (Perrymann & Schulze-Hartung 2011, and references therein). The advance of this hypothesis is based on phenomenological correlations between dynamical parameters of the Sun's movement around the barycenter of the Solar System and sunspots time series. However, at present there is no clear forcing mechanism between these phenomena. In addition, the current exceptionally long minimum of solar activity has attracted the attention with respect to the possibility of developing a new grand minimum in the next decades (see e.g., Feulner & Rahmstorf 2010).

The aim of this work, was to find some distinctive dynamics in planetary forcing related to solar barycentric movement and its possible relationship with Grand Minima (GM) events. Our fundamental result is that the solar acceleration had a unique geometry with respect to the Solar System barycentre before the Maunder Minimum, in the Dalton Minimum and also, at the maximum of cycle 22, around 1990, before the present prolonged minima. These dynamical events are unique at these epochs and never occurred before at least in the past millennium. We discuss our results in terms of a possible dynamical characterization of GM with relation to Sun dynamics. In the light of the planetary hipothesis, these dynamical similarities support the idea of an imminent important minimum.

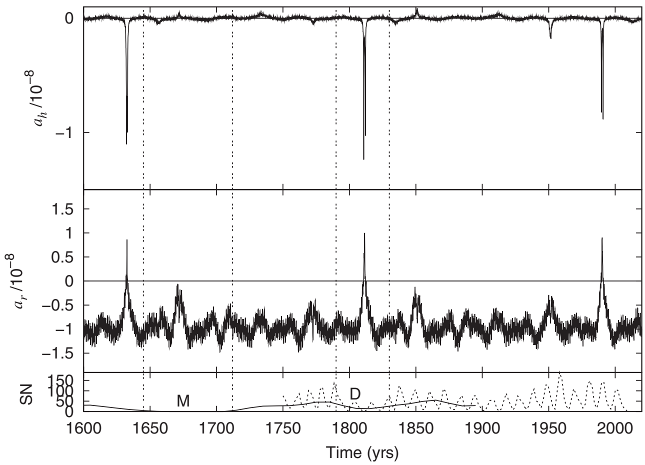

Figure 1. Normal (a_h) and radial (a_r) accelerations; sunspot number SN (solid line:^{14}C reconstruction Solanki *et al.* (2004), dashed: observed-smoothed). The Maunder (M) and Dalton (D) Minima are marked with vertical dashed lines. The impulses are clearly visible starting-during Munder Minimum, Dalton Minimum and at maximum of cycle 22. Physical units: astronomical unit, solar masses and days.

2. Methods

The 3D equations of motion of the solar system planets are integrated using a Bullirsch-Stoer scheme. Then, we obtain position, velocity and acceleration of the Sun in the ecliptical-barycentric system (the 'inertial system'), we also obtain angular momentum L and planetary 'torque' dL/dt. In order to observe the solar acceleration in a reference system more related to solar dynamics, we transformed from the inertial system to a barycentric orbital rotating system. This new system is defined by the *osculating solar orbit* (OSO) and the directions radial ($\breve{r}$), normal ($\breve{h}$) and transversal ($\breve{t}$). Therefore, the Sun's acceleration in this system is (a_r, a_t, a_h).

3. Results

Whereas the Sun acceleration's components show a monotonic harmonic behavior in the inertial system (not showed), their representation in the orbital system (a_r, a_t, a_h), show clearly gravitational impulses (Fig. 1) at the epochs of retrograde solar motion (OSO inclination $i > 90$ deg; $L_z < 0$) around the barycentre. The radial component a_r that is always negative, becomes positive. This is due to the barycentre being left outside the solar orbit, i.e., the Sun fails to loop the barycentre. This is a gravitational impulse due to giant planets quasi-alignments. The normal component a_h also has an exceptional increase at these epochs, which is explained as follows. When the OSO becomes retrograde, the angular momentum is inverted and this inversion aligns the L vector towards the planetary acceleration direction. Therefore, a_h is not an impulsive change in planetary acceleration normal to the solar orbit. This must be seen as the maximum projection of L in the solar acceleration direction, but in a contrary sense. Obviously, changes in this component are due to orbital libration, not to an important increase in z-component of acceleration in the inertial system, because planetary acceleration is always near the ecliptical plane. But these features in a_h are not trivial, they mean that at the times of angular momentum inversions, L is almost anti- parallel to the acceleration vector for a while.

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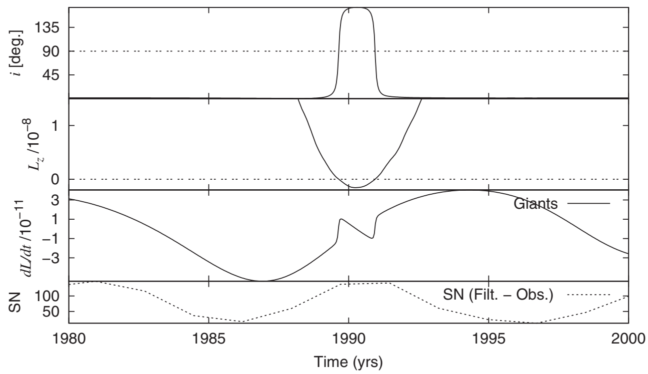

Figure 2. OSO inclination (i); L_z component and dL/dt (only giant planets) of SIM; Sunspot Number (SN) observed-filtered about 1990. When i becomes greater than 90 deg the OSO is retrograde. Note the correlation-anticorrelation between dL/dt and SN and the duration of the maximum of cycle 22. Physical units: astronomical unit, solar masses and days

It is very suggestive that the first detected impulse occurs at the very beginning of the Maunder Minimum, the second one occurs in the middle of the Dalton Minimum; and taking into account these facts, it is straightforward to think about the possibility of a new GM after 1990. This last impulsive event occurred in 1990 and was coincident with the maximum of the cycle 22. We plot in Fig. 2, the OSO inclination, dL/dt, L_z and the monthly observed/smoothed numbered sunspots series (SN). We can see an apparent phase synchronization (correlated, anti-correlated) between SN and dL/dt. The correlation between both quantities taking into account a Schwabe cycler before the radial impulse is 0.76, and after the impulse is -0.52. Notably, the duration of the maximum of the smoothed cycle is coincident with the retrograde motion interval.

It is interesting to note that in 1990 there was another Gnevyshev-Ohl (G-O) rule violation (like during Maunder and Dalton minimum) involving cycle 22 and 23 (Javaraiah 2005; Kane 2008)), i. e., before the radial impulse at the maximum of the cycle 22. Nielsen and Kjeldsen (2011) analysed the spotless days of solar cycle and conclude that the ongoing accumulation of spotless days is comparable to that of cycle 6 near the Dalton Minimum, among other cycles. These facts and our findings strongly suggest that particular epochs with impulsive manifestations in radial acceleration have associated GM events, therefore, support the claims that we are at the onset of a new prolonged minimum.

4. Conclusions and hypothesis

We have shown for the first time the existence of a unique forcing nexus between the Sun and the planets in 1632, 1811 and 1990; that is, at times of retrograde barycentric motion. Although giant planets quasi-alignments repeat every 179 yr, only at epochs of Maunder Minimum, Dalton Minimum and the maximum of cycle 22, is this particular barycentric dynamic shared. Our findings make a global support to planetary hypothesis on a physical basis. Thus, we argue for a classification or dynamical characterization of GM events and also for a possible new imminent prolonged minimum. The general dynamo theory cannot naturally reproduce the cyclicality occurrence of GM-like events; for that, some prescribed changes in the dynamo parameters or external parameterizations are also required (Chouduri & Karak 2011; Chouduri 1992). Then it is important to investigate this forcing in relation to dynamo activity and possibly Sun-planet interactions (see Cionco, this volume).

Acknowledgments

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