Tidally Synchronized Solar Dynamo: A Rebuttal

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Abstract
The idea of a planetary origin for the solar cycle dates back to the nineteenth century. Despite unsurmounted problems, it is still advocated by some. Stefani, Giesecke, and Weier (Solar Phys. 294, 60, 2019) thus recently proposed a scenario based on this idea. A key argument they put forward is evidence that the \( \approx 11 \) years solar cycle is “clocked”, as if it were paced by an accurate clock inside the Sun. Their demonstration rests upon the computation of a ratio proposed by Dicke (Nature 276, 676, 1978) applied to the solar-cycle time series of Schove (J. Geophys. Res. 60, 127, 1955). I show that their demonstration is invalid, because the assumptions used by Schove to build his time series force a clocked behavior. I also show that instabilities in a magnetized fluid can produce fluctuation time series that are close to being clocked.

Keywords Solar cycle, models · Solar cycle, observations

1. Introduction

The recent opening and publication by Courtillot, Le Mouël and Lopes (Malburet, 2019) of a pli cacheté (sealed letter), entrusted to the French Academy of Science by Jean Malburet in 1918 (Malburet, 1918), highlights the early interest in the search for a link between solar cycles and tides. In fact, the work of Malburet was already known from a detailed and thoughtful report he wrote for the journal L’Astronomie in 1925 (Malburet, 1925). In that report, he correctly estimates the tidal accelerations exerted by planets on the Sun as being proportional to \( m_p/d_p^3 \) where \( m_p \) and \( d_p \) are the mass of a planet and its distance from the Sun, respectively. This scaling yields tidal accelerations proportional to \( \approx 4.0, \approx 3.8, \approx 1.8 \), and \( \approx 1.7 \) for Jupiter, Venus, Earth, and Mercury, respectively (the contributions of the other planets are at least ten times smaller). With this in mind, Malburet shows a good correspondence between the dates of solar maxima and the dates of “weak deviations from Jupiter–Venus–Earth syzygies” (alignment of all these planets with the Sun). Malburet’s idea was later taken up and extended by Wood (1972) and Okhlopkov (2016).

There are, however, two serious problems with this idea:

i) The amplitude of the tidal acceleration on the Sun is extremely small \( (\approx 10^{-9} \text{ m s}^{-2}) \), one thousand times smaller than accelerations observed in the convective zone of the
Sun (De Jager and Versteegh, 2005). It is 10,000 times smaller than the tidal accelerations exerted by the four Galilean satellites on Jupiter (and about 1000 smaller than the tidal acceleration from the Moon on Earth).

ii) The \( \approx 11.2 \) years period inferred from the “weak deviations from the Jupiter–Venus–Earth syzygies” is an artificial construction that has no signature in the complete tidal signal, as demonstrated by Okal and Anderson (1975), and illustrated in Appendix A.

It is therefore surprising that this idea has received a renewed attention (Scafetta, 2012; Okhlopkov, 2016; Baidolda, 2017; Courtillot, Lopes, and Le Mouël, 2021; Charbonneau, 2022). In particular, Stefani and colleagues have published no less than seven articles exploiting this idea (see Stefani, Stepanov, and Weier (2021) and references therein). It seems that the main reasons that give confidence in these authors is their demonstration that the solar cycle is clocked, as if it were paced by an accurate clock inside the Sun, and probably the belief that this property requires a clocked forcing that only planetary motions can provide. Their demonstration, presented by Stefani, Giesecke, and Weier (2019), rests upon the computation of “Dicke’s ratio” of a 1000-year time series of solar minima, which favors a clocked origin over a random-walk type origin.

The main objective of the present article is to show that the demonstration of Stefani, Giesecke, and Weier (2019) is invalid. I also show examples of fluid instabilities that naturally produce clocked-looking time series.

2. The Demonstration of Stefani, Giesecke, and Weier (2019)

Stefani, Giesecke, and Weier (2019) picked up an idea that Dicke (1978) proposed for testing whether there is a “chronometer hidden deep in the Sun”. The aim of Dicke was to distinguish a clocked behavior from an “eruption hypothesis”, in which solar cycles would appear with a random phase. While Dicke restricted his analysis to the post-1705 time series of the 25 solar maxima, Stefani, Giesecke, and Weier (2019) extend it to 92 solar cycles starting at 1000 CE, in an attempt to obtain a better statistical significance.

2.1. Dicke’s Ratio

Dicke (1978) noticed that a succession of three very short cycles starting in 1755 was followed by a very long cycle, as if the Sun were trying to keep up with some internal clock. He proposed several statistical tools to assess the existence of such a clock.

Consider a time series \( \{ t(i) \} \) of \( N \) events \( i \). In a perfectly clocked time series, all event dates \( t(i) \) are evenly spaced. When Gaussian distributed noise is added, each event date is displaced from the regular grid by some random time, yielding a corresponding distribution of cycle durations: \( d(i) = t(i) - t(i - 1) \). In contrast, when events occur with a random phase, cycle durations \( \{ d(i) \} \) have a Gaussian distribution, and event dates are obtained as \( t(i) = t(i - 1) + d(i) \). Clocked and random-walk time series can yield the same mean cycle duration \( \bar{d} \) and standard deviation \( \sigma \), but their statistical properties are not all identical.

Dicke (1978) introduced a ratio that measures this difference, which Stefani, Giesecke, and Weier (2019) refer to as “Dicke’s ratio”. Dicke’s ratio \( \{ Di(n) \} \), computed for subsets of \( n \leq N \) consecutive events, is defined by

\[
Di(n) = \frac{\sum_{i=2}^{n} \delta_n^2(i)}{\sum_{i=2}^{n} (\delta_n(i) - \delta_n(i - 1))^2},
\]
Figure 1  The two assumptions made by Schove (1955) to construct his series of solar maxima, as displayed in his article p. 131.

where \( \delta_n(i) = t(i) - f_n(i) \) is the deviation of event date \([t(i)]\) from a best linear fit \([f_n(i) = a_n i + b_n]\) of the \(n\) dates.

According to Dicke (1978), the expectation of Dicke’s ratio is

\[
E(D_{\text{clock}}(n)) = \frac{n^2 - 1}{2(n^2 + 2n + 3)} \xrightarrow{n \to \infty} \frac{1}{2}
\]

for a clocked time series, while it is

\[
E(D_{\text{rand}}(n)) = \frac{(n + 2)(n^2 - 1)}{3(5n^2 + 6n - 3)} \xrightarrow{n \to \infty} \frac{1}{15}n
\]

for a random-walk time series.

The expectation of \( Di(n) \) is independent of \( \bar{d} \) and \( \sigma \) for both families, but the spread around the expectation does depend upon \( \sigma \). Dicke (1978) applied this statistical tool to the time series of sunspot numbers starting in 1705. Due to the limited number of cycles, he could not reach a very definitive conclusion.

2.2. Schove’s Solar Cycle Time Series

To reach a firmer conclusion, Stefani, Giesecke, and Weier (2019) complemented the post-1705 solar minima series by solar minima dates as far back as 1000 CE, following Schove (1955). Indeed, Schove published in 1955 the outcome of a very ambitious venture: the dating of maxima and minima of the solar cycle from 653 BCE to 2025 CE. Pre-1705 observations of sunspots being very rare, he mostly relied on reports of the observation of polar aurorae. In order to make up for the limited amount of reliable data, Schove (1955) explicitly mentions (p. 131) that he made use of two assumptions to build his 26-century-long table. These assumptions are reproduced in Figure 1.

3. Arguments for a Rebuttal

Schove’s assumption (b), as listed in Figure 1, clearly suggests that his time series of solar maxima is clocked by construction. In order to be more specific, I have built synthetic solar cycles to test the impact of Schove’s assumptions on the character of the resulting time series.

3.1. Synthetic Solar Cycles

The well documented 24 solar cycles from 1755 yield a cycle duration (time between maxima) of \(11.0 \pm 2.0\) years. Extending backwards to 1000 CE with Schove’s dates yields 92 maxima separated by \(11.1 \pm 2.2\) years. I have built two different families of synthetic cycles: a random-walk family and a clocked family. Both retain the post-1755 dates of solar maxima, as distributed by WDC-SILSO, Royal Observatory of Belgium, Brussels (SILSO World Data Center, 2021).
Figure 2  Probability density function of the duration of synthetic solar cycles. (a) Random-walk synthetics: Gaussian distribution of all 10,000 realizations (teal), and pdf of the three realizations that comply with Schove’s assumptions (magenta). (b) Clocked synthetics: nearly Gaussian distribution of the 10,000 realizations (teal), pdf of the 42 Schove-compliant realizations (magenta), and pdf of Schove cycle durations (red).

- The random-walk series are built by drawing at random normally distributed cycle durations with a mean of 11.1 years and a standard deviation of 2.0 years. The dates of the maxima are then constructed by the cumulative difference from the date of the oldest post-1755 maximum.
- The clocked series are built by extending the post-1755 dates of the maxima backwards in time with a constant duration of 11.1 years, and then adding to the obtained dates a normal random noise with zero mean and a standard deviation of 1.5 years, this value providing the desired standard deviation of 2.1 years for the cycle durations.

Figure 2 displays the probability density function (pdf) obtained with 10,000 realizations, for the random-walk series (Figure 2a) and the clocked series (Figure 2b). The pdf of Schove series is also drawn in Figure 2b.

3.2. The Impact of Schove’s Assumptions

The assumptions recalled in Figure 1 appear to strongly constrain the time series. Indeed, I find that only 42 out of my 10,000 synthetic clocked realizations comply with the two assumptions of Schove (1955), and only three random-walk realizations out of 10,000 obey these constraints. In other words, the assumptions used by Schove (1955) practically exclude random variations of the duration between solar maxima.

The cycle-duration pdf of Schove-compliant realizations are shown in Figure 2, while their time series and deviations from a linear fit are displayed in Appendix B together with those of Schove’s series.

Figure 3 shows Dicke’s ratios for a random selection of 100 realizations of both families (note that all Dicke’s ratios are calculated backwards in time, as by Stefani, Giesecke, and Weier (2019), since more recent dates are considered more reliable.) The thick black line shows the mean of Dicke’s ratio for all realizations, while the thick red line shows the mean of the Schove-compliant realizations. Note that Dicke’s ratio of the rare Schove-compliant random-walk series is much lower than the mean of all realizations and that individual realizations can lie far from the mean.
Figure 3  Dicke’s ratios of (a) random-walk and (b) clocked synthetic solar cycles. Random selection of 100 realizations (gray), mean of all 10,000 realizations (thick black), Schove-compliant realizations (red) and their mean (thick red), Schove time series (blue squares). The thick green and magenta lines show the expectation of Dicke’s ratio for a random-walk (Equation 3) and for a clocked law (Equation 2), respectively. Note that all synthetics share the same post-1755 reliable time series.

4. Quasi-Clocked Magneto-hydrodynamic Instabilities

The original goal of Dicke (1978) was to test the compatibility of solar-cycle time series with an “eruption hypothesis” expressed by Kiepenheuer (1959) as “each cycle represents an independent eruption of the Sun which takes about 11 years to die down”. Fluid dynamic and magneto-hydrodynamic instabilities do not necessarily behave that way, even when strong turbulence is present. For example, quasi-periodic magnetic oscillations were reported in the VKS dynamo experiment (Berhanu et al., 2009) at Reynolds numbers above $10^7$. Nonetheless, we have seen that Dicke’s ratio yields a more stringent measure of the clocked behavior of a time series than provided by visual inspection or pdf.

The Grenoble DTSΩ liquid-sodium experiment exhibits magnetic fluctuations that are often quite regular (Schmitt et al., 2008). From one such experiment, I extracted time series of the maximum induced magnetic intensity (see Appendix C for details) and computed Dicke’s ratio of several sequences of 100 consecutive maxima. Figure 4 shows that the behavior of these magnetic fluctuations is quasi-clocked, even though the Reynolds number is $\approx 8 \times 10^6$, and the standard deviation of the fluctuations is about 30%.
Figure 4  Dicke’s ratio of magnetic fluctuations in the DTSΩ liquid-sodium experiment (see Appendix C for details). Three consecutive series of 100 maxima are plotted (peaks 101 to 200, 201 to 300, and 301 to 400). The green and magenta lines show the expectation of Dicke’s ratio for a random-walk (Equation 3) and for a clocked law (Equation 2), respectively.

5. Conclusion

The demonstration by Stefani, Giesecke, and Weier (2019) of clocked behavior for solar cycles is invalid because the 1000-year time series they use (Schove, 1955) is clocked by construction. The astrological quest for a link between solar cycles and planetary tides remains as unfounded as ever. Magnetohydrodynamic instabilities can produce quasi-periodic fluctuations that appear almost clocked.

Appendix A: Frequency Spectra of Synthetic Tidal Forcings

I have built synthetic tidal forcings to illustrate the lack of evidence for a ≈ 11.2 years periodicity, as demonstrated by Okal and Anderson (1975). I model the tidal accelerations exerted by Jupiter, Venus, Earth, and Mercury, assuming circular orbits and starting at a time when all the planets are aligned. Mass, distances and orbital periods are taken from nssdc.gsfc.nasa.gov/planetary/factsheet/.

The tidal signal of this simplified planetary system at a given meridian on the Sun can be expressed as:

\[ Tide(t) = \sum_p \frac{m_p}{d_p^3} \left[ \cos^2 \left( 2\pi \frac{t}{T_S} - 2\pi \frac{t}{T_p} \right) - \frac{1}{3} \right], \]

where \( m_p \) and \( d_p \) are the mass and distance from the Sun of planet \( p \), respectively. \( T_p \) is its orbital period, while \( T_S \) is the duration of a solar day, taken as 27 days.

Figure 5a shows the predicted tidal signal over a period of 10,000 days (27.4 years). The orbital period of Jupiter (11.86 years) is indicated by vertical red bars. The maximum tidal forcing achieved at \( t = 0 \) is marked by a horizontal dashed line. It can be seen that forcings almost as large occur many times during one orbital period of Jupiter, typically each time Jupiter and Venus are aligned with the Sun.

The tidal minima are better seen in Figure 5b, which displays the envelope of the tidal signal. The minimum of the series (at \( t = 1245 \) days) is marked by a blue triangle, while the second maximum (at \( t = 8174 \) days) is shown by a red triangle. The corresponding positions of the four planets are given in Figures 5c and 5d, respectively. As expected, all
Figure 5  Time series and envelope of tidal forcing as a function of time in a realistic synthetic solar system. (a) Tidal signal at a given meridian on the Sun, calculated from Equation 4 over 10,000 days (27.4 years). The periods of the four planets are marked by vertical lines of different colors. The maximum tide (achieved at \( t = 0 \)) is shown by a horizontal dashed black line. (b) envelope of the tidal signal. The minimum and the (second) maximum are marked by a red triangle and a blue triangle, respectively. The periods of Jupiter and Venus are shown by vertical lines. (c) Positions of the four planets at the minimum tide (\( t = 1245 \) days). (d) Positions of the four planets at the (second) maximum tide (\( t = 8174 \) days).

Figure 6 presents the spectra of a 360-year synthetic tidal signal (blue) and of its envelope (orange). The four peaks of the former simply correspond to half a solar day as seen from each planet (see Equation 4). The spectrum of the envelope is dominated by peaks at the periods of the syzygies of pairs of planets with the Sun and their overtones. The spectrum is almost flat for periods beyond 300 days. This plot mimics Figure 3 of Okal and Anderson (1975), which shows the full tidal spectrum, “taking into account the complete orbital elements [of the four planets], including eccentricity, inclination and their variation with time” over a period of 1800 years. Orbital eccentricity adds up small tidal peaks at the orbital periods of Jupiter (11.86 years) and Mercury (0.241 years), but nothing shows up at 11.2 years (4088 days), as emphasized by Okal and Anderson (1975).

Appendix B: Time Series and Deviations of Synthetic Solar Maxima

Figures 7 and 8 display the time series and deviations of the synthetic solar cycles that comply with Schove’s assumptions, for comparison with Figure 1 of Stefani, Giesecke, and Weier (2019). Deviations of each realization are the difference between dates of the maxima and a linear fit of these dates.
Figure 6  Power spectra of the tidal signal (blue) and of its envelope (orange), as a function of period. The tidal peaks of the envelope spectrum appear at syzygies of pairs of planets with the Sun. Following Okal and Anderson (1975), I label them with the initials of the two planets. The largest tide is “VJ” at 118.5 days when Venus and Jupiter are aligned with the Sun.

Figure 7  (a) Time series and (b) deviations of Schove-compliant random-walk synthetic solar cycles (three lines of different colors). The blue squares are for Schove’s maxima before 1755 and from SILSO World Data Center (2021) after 1755.

Appendix C: Dicke’s Ratio of Magnetic Fluctuations in the DTSΩ Experiment

The DTSΩ experiment was built to study magnetohydrodynamics in the magnetostrophic regime, in which Lorentz and Coriolis forces are dominant. Fifty liters of liquid sodium are enclosed in a spherical container that can rotate around a vertical axis. An inner central sphere can rotate independently around the same axis and hosts a strong permanent magnet producing an axial dipolar magnetic field. The three components of the induced magnetic field are measured at the surface of the outer sphere at 20 equally spaced latitudes from $-57^\circ$ to $57^\circ$ (see Schmitt et al. (2013) for more details). The frequency spectra of the electric and magnetic fluctuations reveal a quasi-periodic behavior that can be linked to the presence of magneto-Coriolis waves (Schmitt et al., 2008, 2013) or instabilities (Figueroa et al., 2013; Kaplan, Nataf, and Schaeffer, 2018).

An example of such quasi-periodic magnetic fluctuations is given in Figure 9. The spin rate of the outer sphere is $f_o \approx 10$ Hz, while the differential rotation of the inner sphere is $\Delta f \approx -20$ Hz, yielding fluid velocities $U \approx 25$ m s$^{-1}$. With an outer radius $r_o = 0.21$ m, the Reynolds number $Re = \frac{U r_o}{\nu} \approx 8 \times 10^6$ and the magnetic Reynolds number $Rm = \frac{U r_o}{\eta} \approx 60$. 

(Springer)
Figure 8  (a) Time series and (b) deviations of Schove-compliant clocked synthetic solar cycles (*42 lines of different colors*). The blue squares are for Schove’s maxima before 1755 and from SILSO World Data Center (2021) after 1755.

Figure 9  Magnetic fluctuations in the DTSΩ experiment. (a) Color-coded image of the square of the azimuthal magnetic-field fluctuations normalized by the square of the imposed magnetic field [%] at the surface of the outer sphere. The magnetic field is measured at the 20 latitudes which form the y-axis. The x-axis is time given in number of turns of the inner sphere with respect to the outer sphere. The records are averaged over one such differential turn. (b) Extraction of the same signals at a latitude of 9°, showing a succession of peaks labelled by magenta triangles.

where $\nu$ is the kinematic viscosity, and $\eta$ is the magnetic diffusivity. Figure 9a displays a latitude-versus-time color-coded image of the squared azimuthal magnetic fluctuations averaged over one turn of the inner sphere, in a time-window of some 250 rotations of the inner sphere. Latitudinally coherent quasi-periodic fluctuations of variable intensity dominate. Figure 9b is the time record of the same fluctuations at a latitude of 9°. I have extracted the 100 maxima from this record, plotted as triangles in Figure 9b. The duration between maxima is $0.11 \pm 0.03$ seconds. Dicke’s ratio of the resulting time series is plotted in Figure 4, together with Dicke’s ratio of the previous and next series of 100 maxima. All three series appear to be closer to clocked behavior than to random-walk behavior.
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Materials Availability  All matlab scripts and data used to produce the figures of this article are available as supplementary material.

Declarations

Conflict of Interest  The author declares that he has no conflicts of interest.

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