Is Solar Activity Modulated by Astronomical Cycles?

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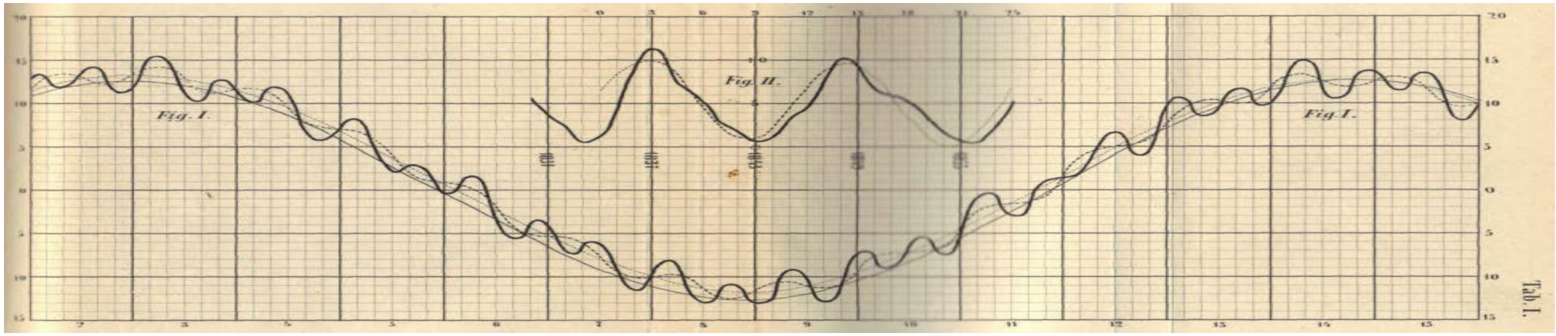
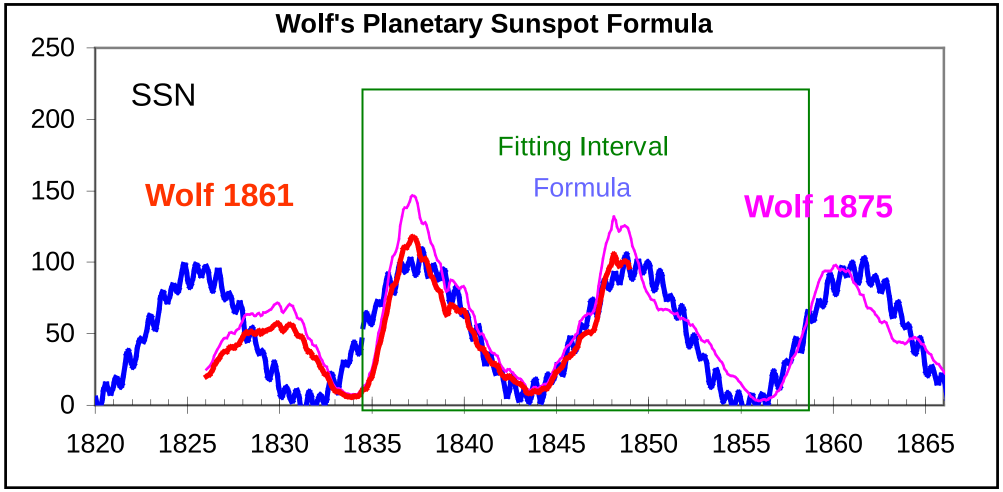
‘External’ Control of Solar Activity?

- When Rudolf Wolf devised the sunspot number he noted [1859] that the length of the cycle was close to the orbital period of Jupiter.
- From time to time since then, the idea that the planets create/control/modulate the solar cycle has been put forward
- Even galactic ‘influence’ is sometimes called for (not discussed here)

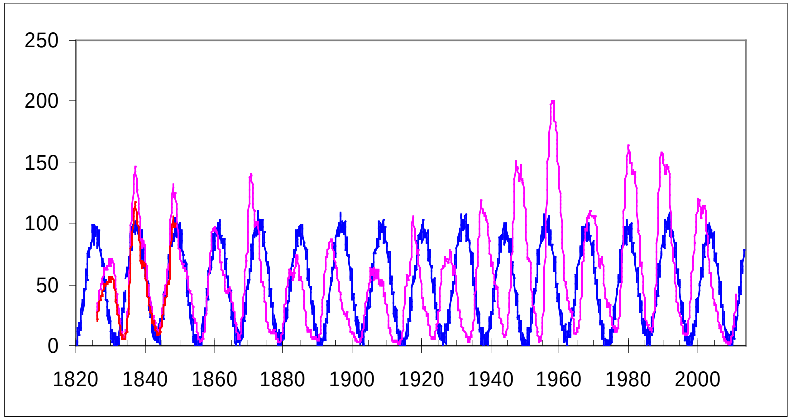
Rudolf Wolf's Attempt in 1859

R = 50.31 + 3.73 [1.68 sin(586.26°*t*){Venus} + 1.00 sin(360.00°*t*){Earth} + 12.53 sin(30.35°*t*){Jupiter} + 1.12 sin(12.22°*t*){Saturn}], where *t* is years from 1834.50. The angles are degrees per Earth year. The coefficients are *mass/distance-squared*.





The fit eventually broke down:



At the end of his life [1893] Wolf remarked that this research (by him and others) never produced any really satisfactory results

The Tidal Bulges Raised by Planets

Tidal effects depends on *mass / distance-cubed*:

$$T = 3/2\, r_c\, (M_o/M_c)\, (r_c/d)^3$$

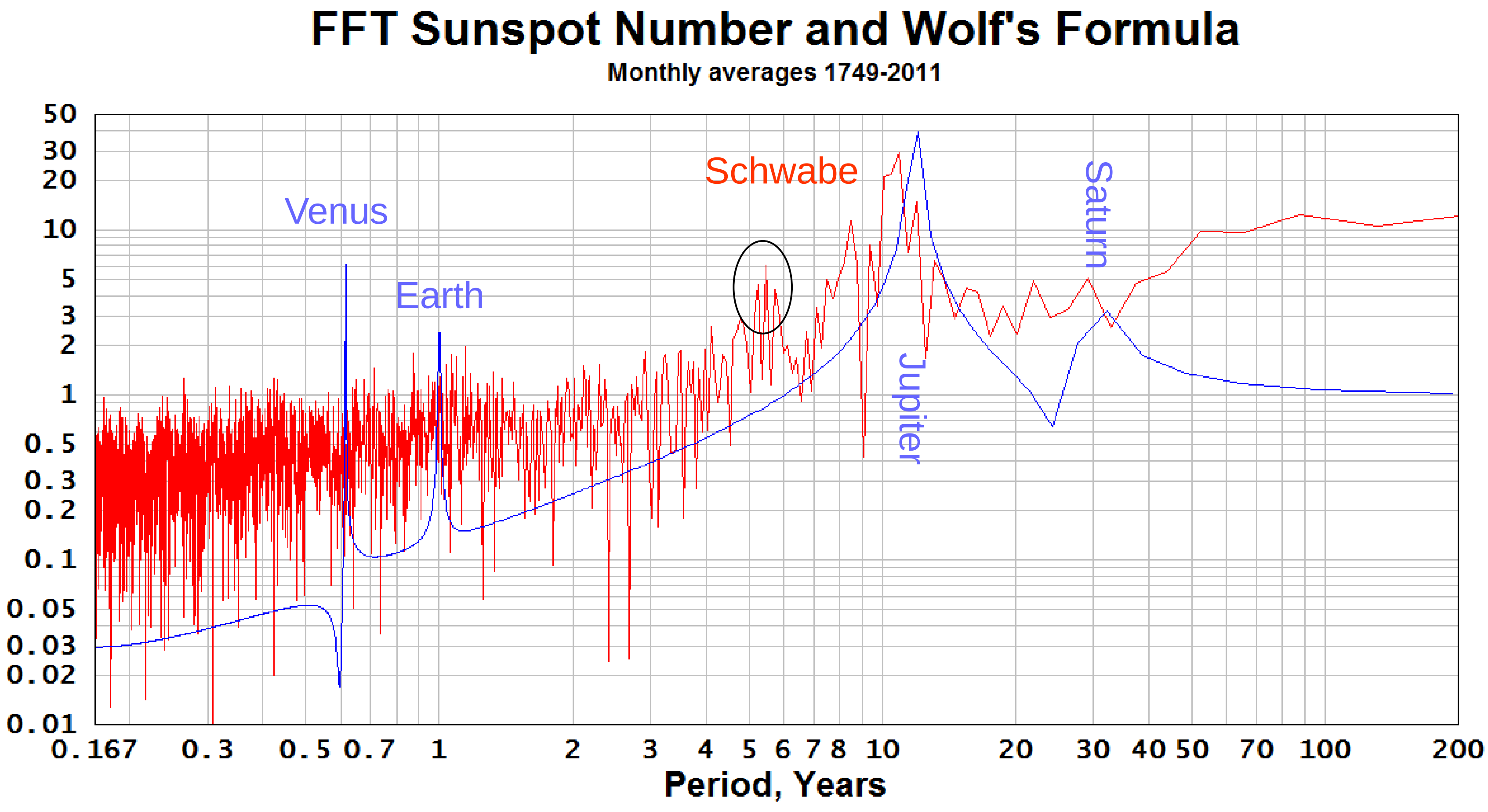
Planet	M_o	M_c	r_c m	d m	d AU	T mm
Mercury	0.0553	332946	496248000	5.7909E+10	0.3871	0.07776
Venus	0.8150	332946	496248000	1.0820E+11	0.7233	0.17577
Earth+Moon	1.0123	332946	496248000	1.4960E+11	1.0000	0.08261
Mars	0.1074	332946	496248000	2.2794E+11	1.5237	0.00248
Jupiter	317.8281	332946	496248000	7.7828E+11	5.2025	0.**18420**
Saturn	95.1609	332946	496248000	1.4274E+12	9.5415	0.00894
Uranus	14.5358	332946	496248000	2.8705E+12	19.1880	0.00017
Neptune	17.1478	332946	496248000	4.4983E+12	30.0695	0.00005

For comparison, The tidal bulge that the *Sun* raises on Jupiter is 87 mm and on Earth 248 mm

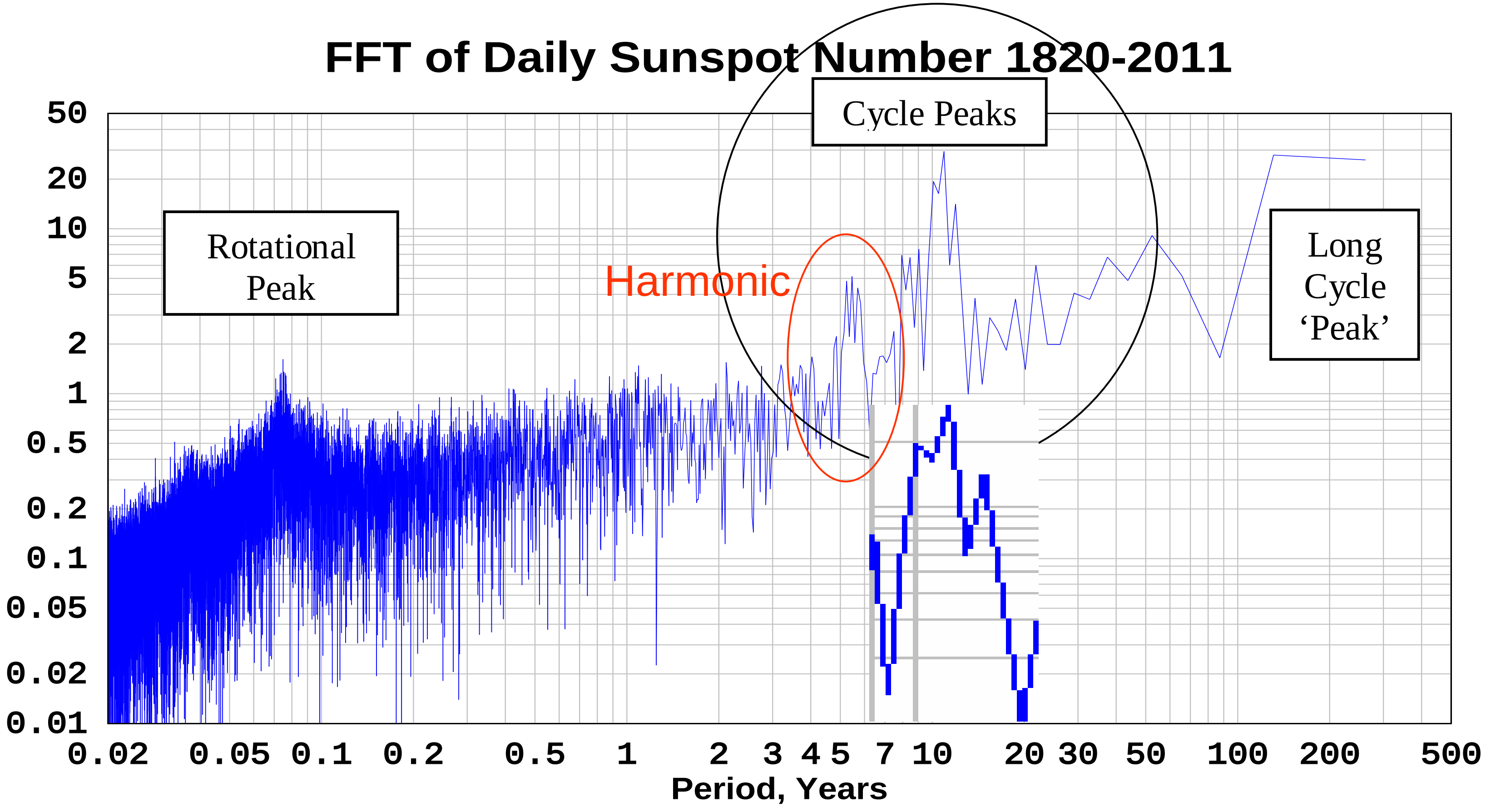
The extreme smallness of the tidal bulges at the tachocline (r_c) (≤ 0.2 millimeter) is usually taken as a strong argument against the hypothesis that solar activity is generated or significantly modulated by tidal forces.

Smallness of the forces is a general problem with all proposed mechanisms

Straightforward FFT will show a peak if there is a real, strong one



Splitting of the 11-year Peak



People have noticed that the '11-yr' solar cycle peak seems to have 'side peaks'. These show up much better with more sophisticated tools than FFT.

Splitting of the 11-year Peak

"Saturn in its motion around the Sun raises a tidal bulge, too. Whenever that wave crosses the main Jupiter wave, the latter will have its height increased. As the tide-raising force produces equal waves on opposite sides of the Sun, the intervals between coincidences will be half of the time between conjunctions." (Brown, MNRAS, *60*, 599, 1900; also Loomis, 1870)

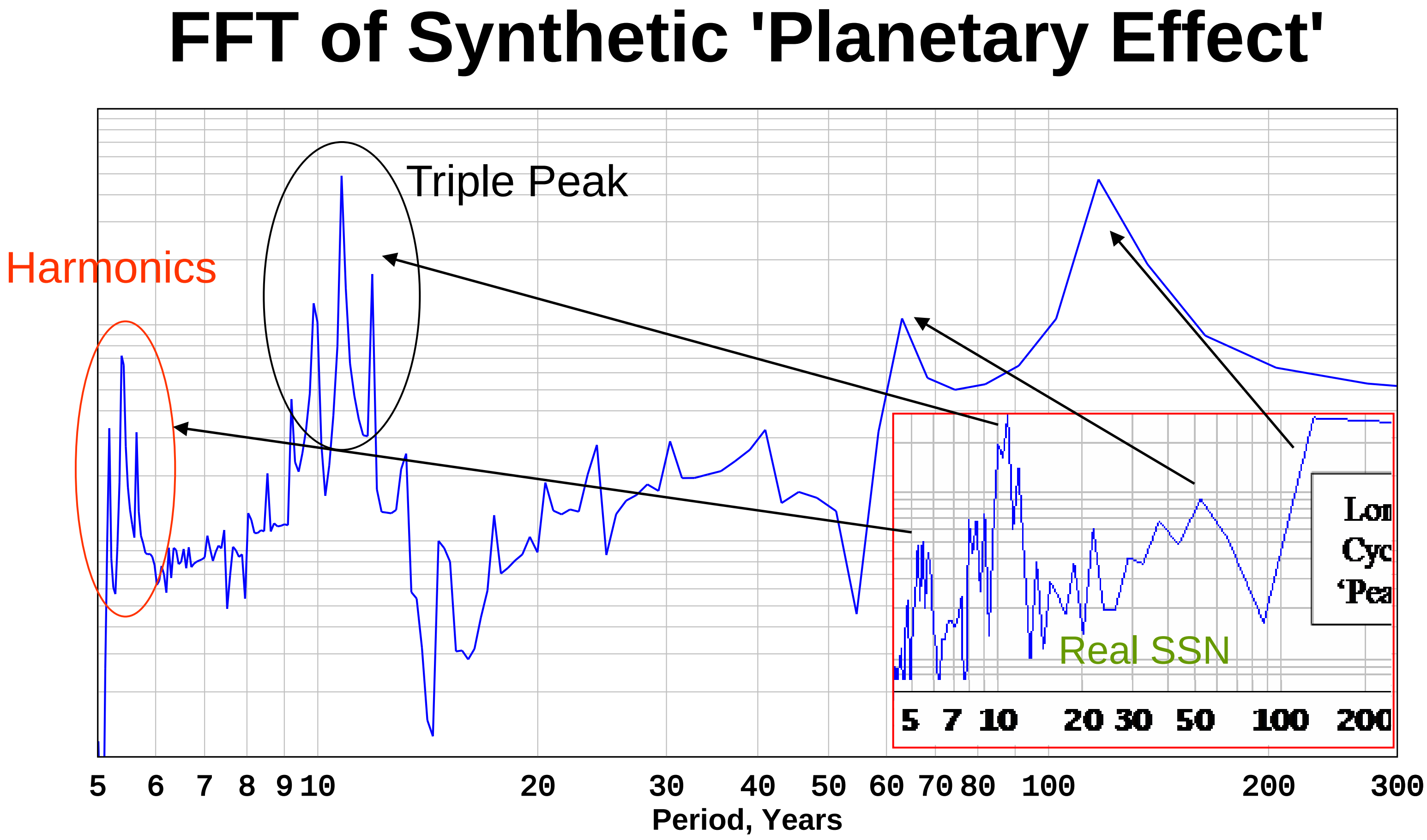
A toy-model illustrates the approach:

'Sunspot Number' =SQRT(ABS[k cos(π/J*t) + cos(π/C*t)])

Where J = 11.86199 yr is the period of Jupiter and C = ½ (S*J)/(S-J) = 9.92945 yr is half the time between conjunctions of Jupiter and Saturn (S = 29.45713 yr].

The SQRT approximates that the influence may not be linear. The ABS ensures that the sunspot numbers are positive. Because of the ABS operator, a full cycle is just π and not 2π. We first set the coefficient k = 1, although the Saturn wave ought to be much smaller than the Jupiter wave [i.e. k >> 1]

Support for the Planetary Effect?



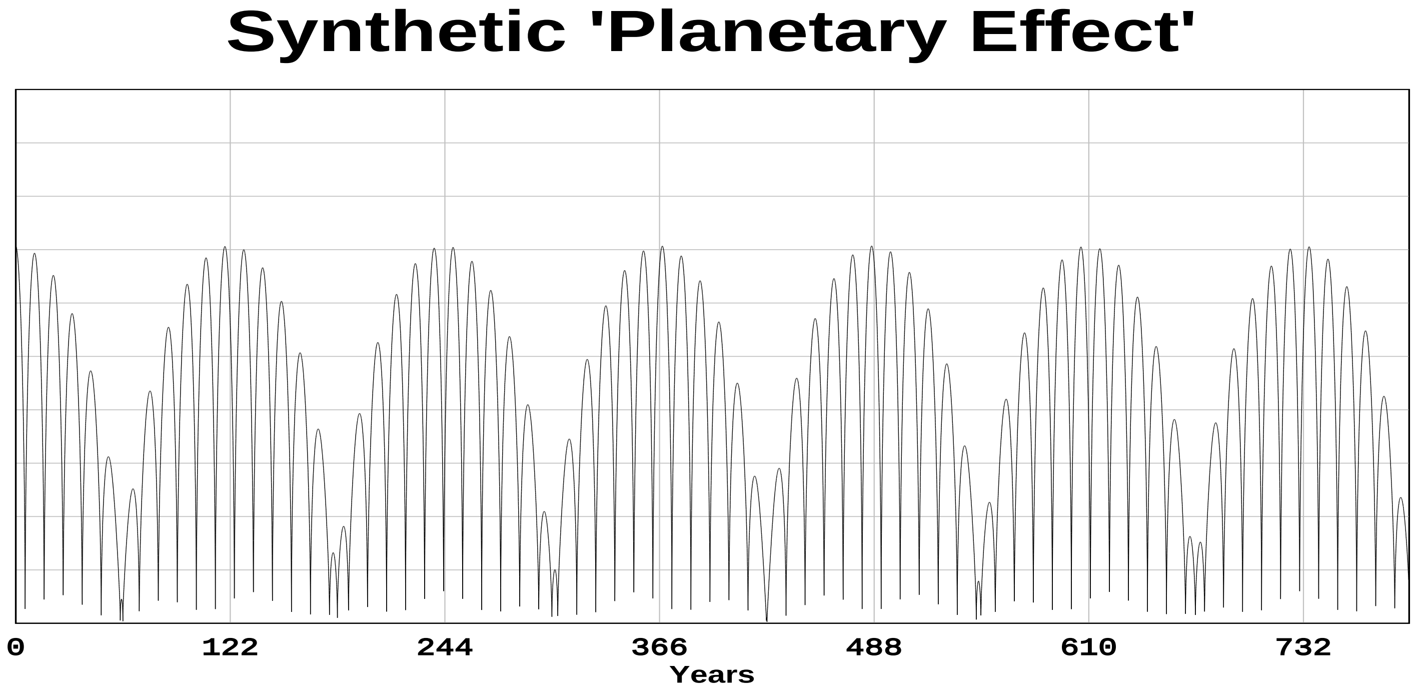
Triple Peak Periods of 9.91 yr [C], 10.78 yr, and 11.87 yr [J]

The real sunspot number power spectrum has those very same peaks…

Not So Fast, Perhaps

At first blush, the previous slides seem to suggest that astronomical factors may be important. But if you look at the resulting 'sunspot curve' it is also clear that just a long-term modulation of the amplitude of the solar cycle is also a good description of the data. This is, of course, not so strange, because in general we have:

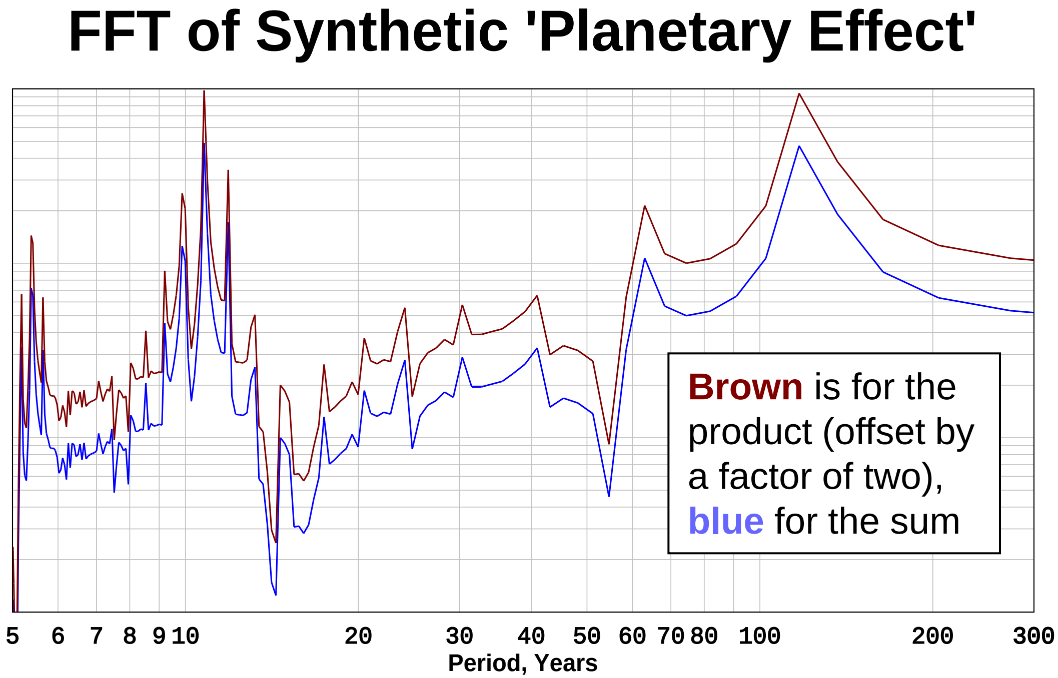
$$\cos\alpha + \cos\beta = 2\cos[(\alpha+\beta)/2]\cos[(\alpha-\beta)/2]$$



Amplitude Modulation rather than Two Beating Bulges

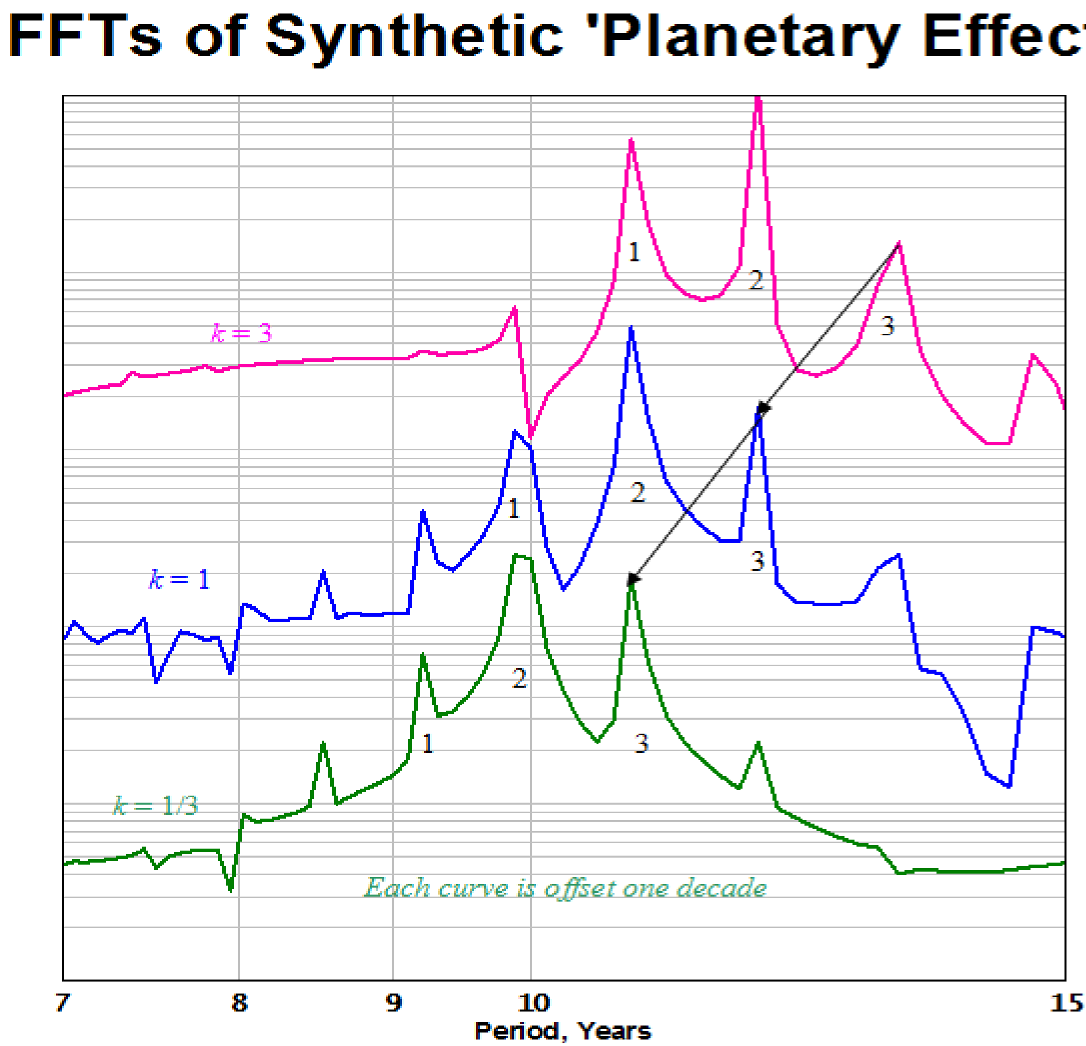
In fact, ‘Sunspot Number’ =SQRT(ABS[cos(π/*P***t*)*cos(π/*M***t*)]) produces exactly the same curve when *P* = 10.810 yr and *M* = 121.8944 yr as the previous formula which was a sum of two cosines.

And, of course, exactly the same FFT power spectrum:



So, the sum of two cosines can be written as the product of two cosines [‘amplitude modulation’]. The astronomical cycles mimic a basic solar dynamo with period 10.81 yr which is amplitude modulated by a ~120 yr ‘grand’ cycle

The Effect of Varying *k*

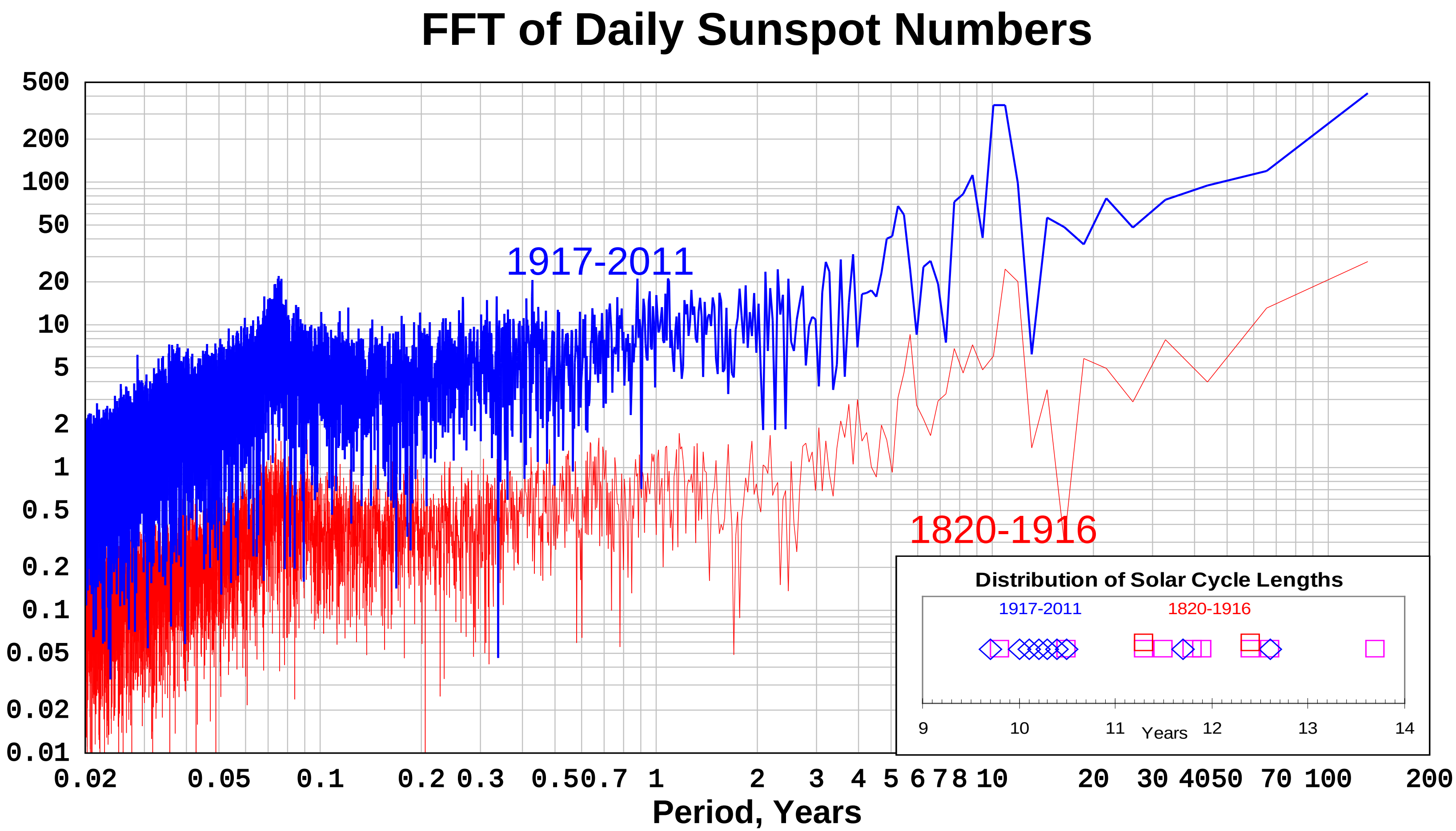


The close correspondence between observed peaks and ‘toy peaks’ is only for *k* = 1. Other [significantly different] values of *k* move the peaks out of correspondence:

Peak#	*k* = 1/3	***k* = 1**	*k* = 3
1	9.20	**9.91**	10.78
2	9.92	**10.78**	11.87
3	10.78	**11.87**	13.21

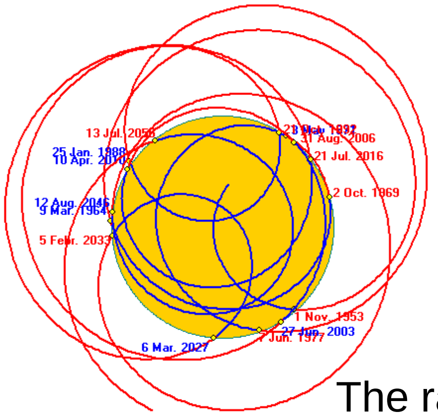
It seems unlikely that *k* ≈ 1

The Splitting is not Stationary



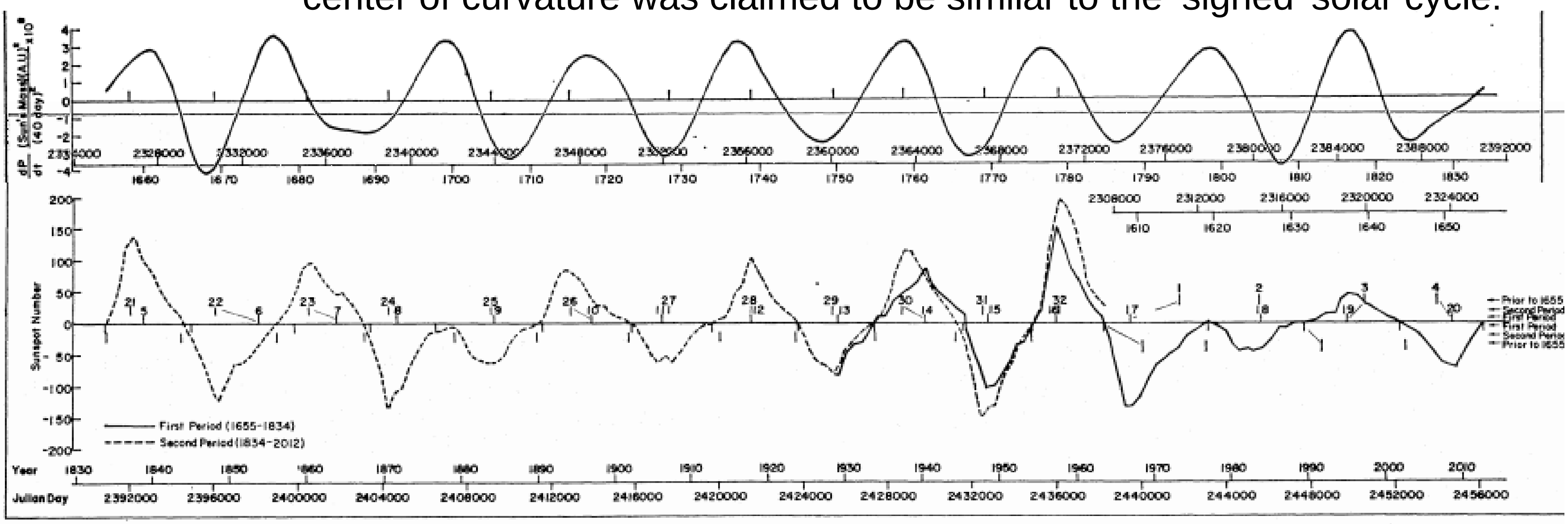
So the idea of combined Jupiter-Saturn tides does not seem fruitful

‘Center of Mass’ Approach



P. D. Jose (ApJ, *70*, 1965) noted that the Sun’s motion about the Center of Mass of the solar system [the Barycenter] has a period of 178.7 yr and suggested that the sunspot cycles repeat with a similar period. Many later researchers have published variations of this idea.

The rate of change of the angular momentum about the instantaneous center of curvature was claimed to be similar to the ‘signed’ solar cycle:



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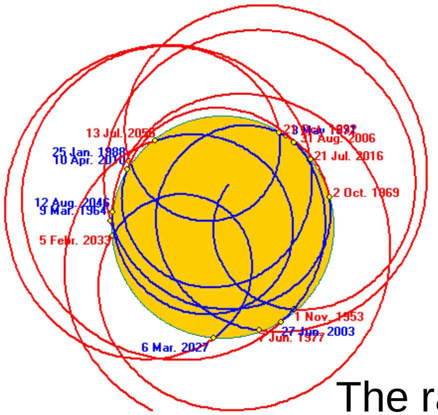

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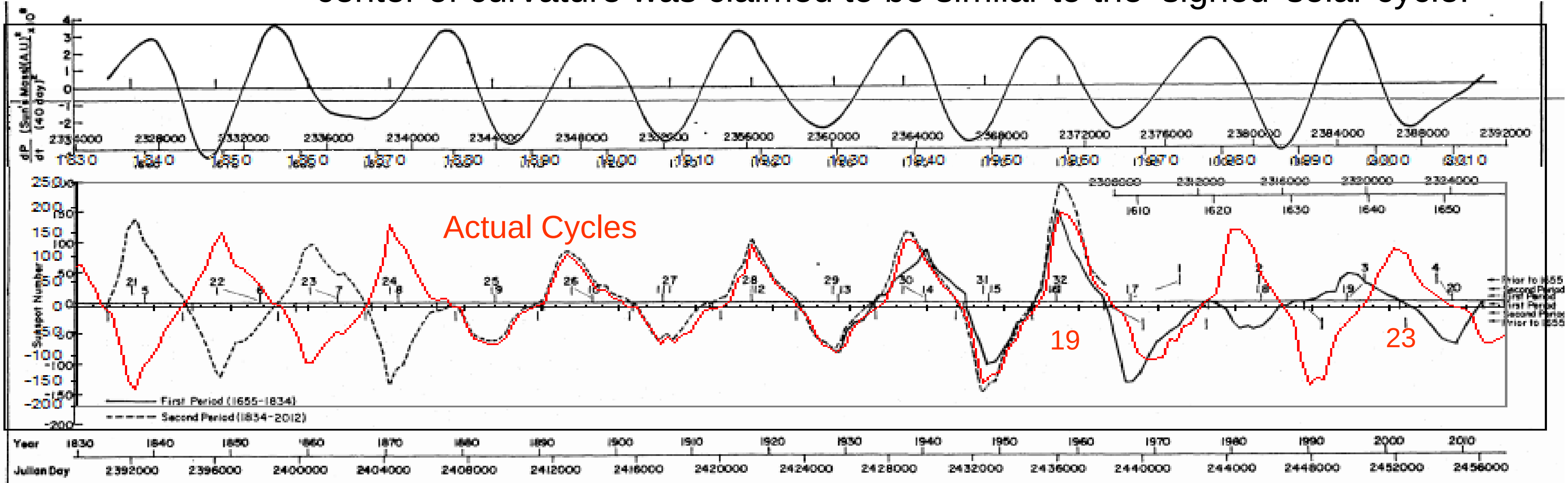
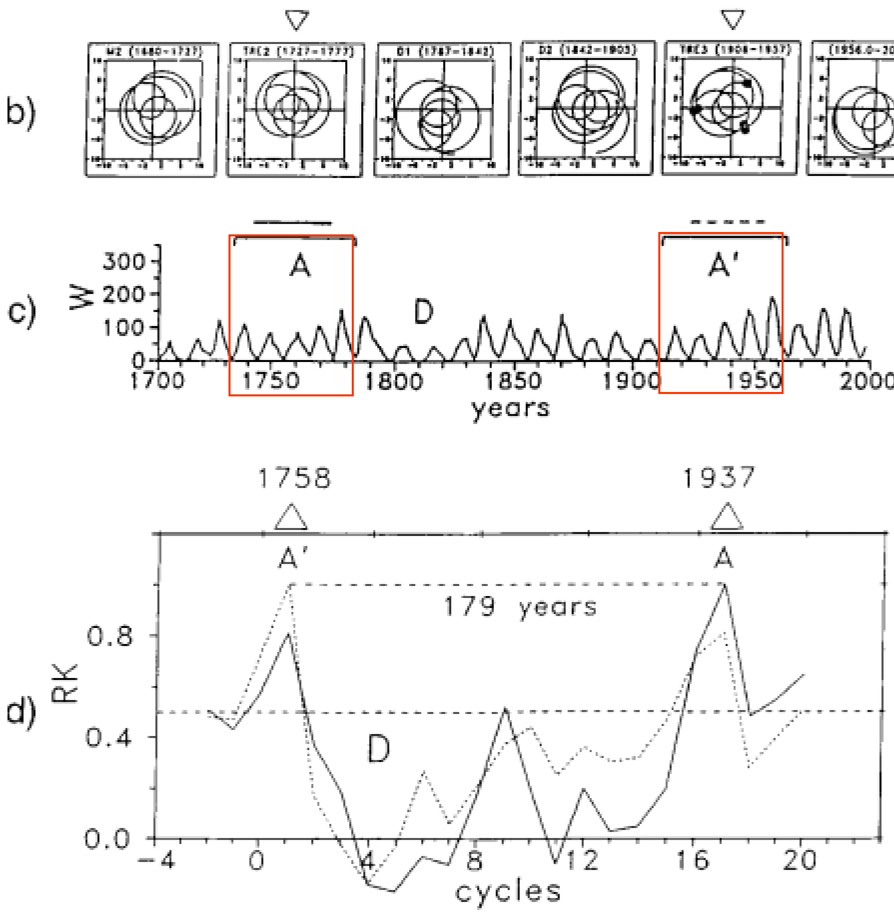
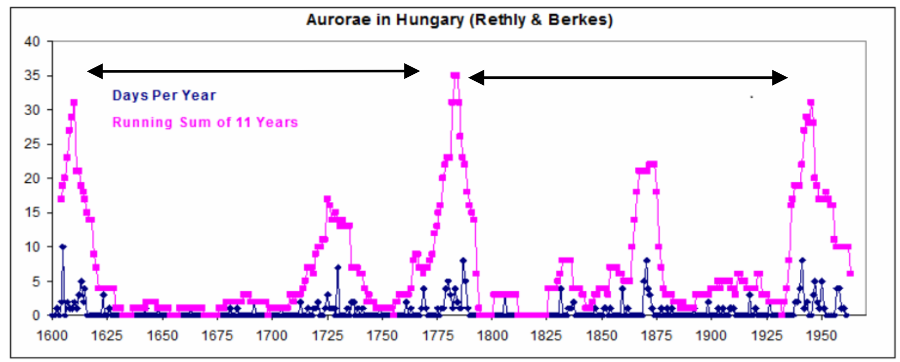


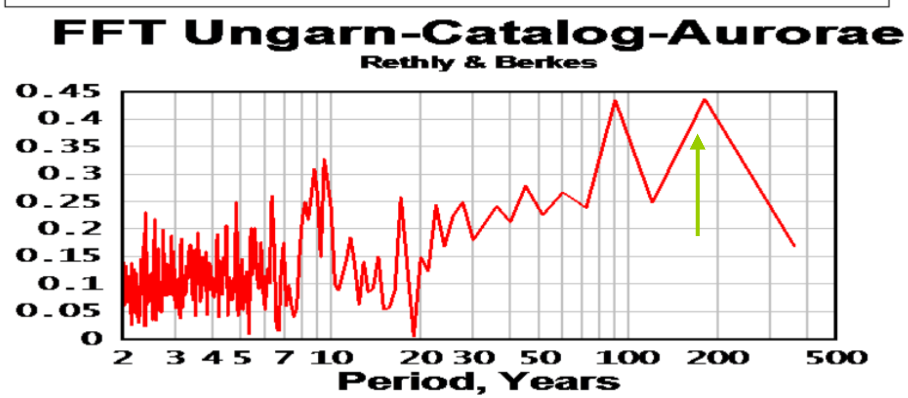
Unfortunately a ‘phase catastrophe’ is needed every ~8 solar cycles (Uranus)

The 179-yr ‘cycle’ is seen as similar occurrences of solar cycles

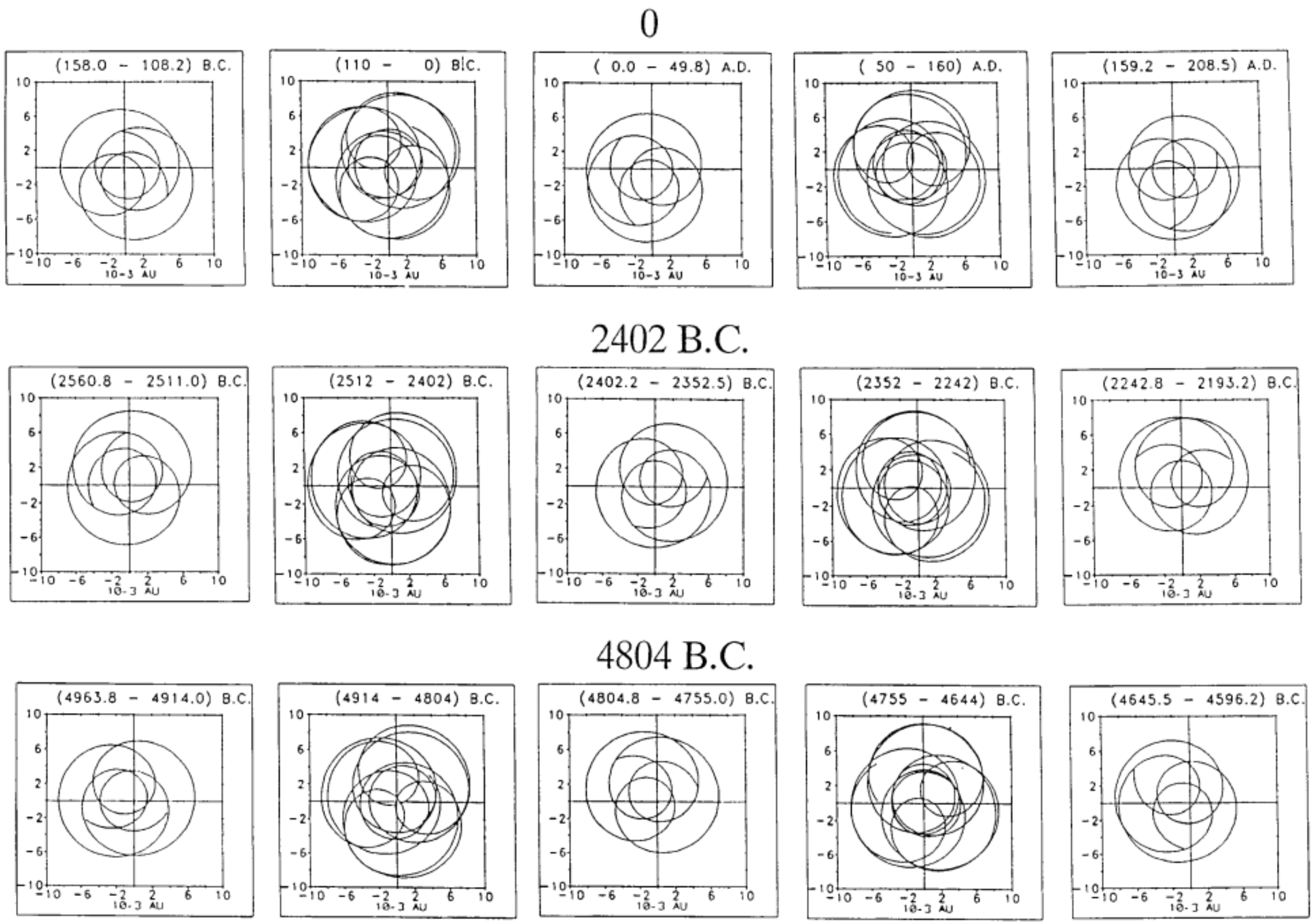


‘trefoils’ repeat every 179 years





Has also been used to ‘explain’ the longer cycles, e.g. 2402 yr



The ‘mechanism’ has been called ‘spin-orbit’ coupling where angular momentum is transferred between the Sun’s rotation and its revolution around the barycenter

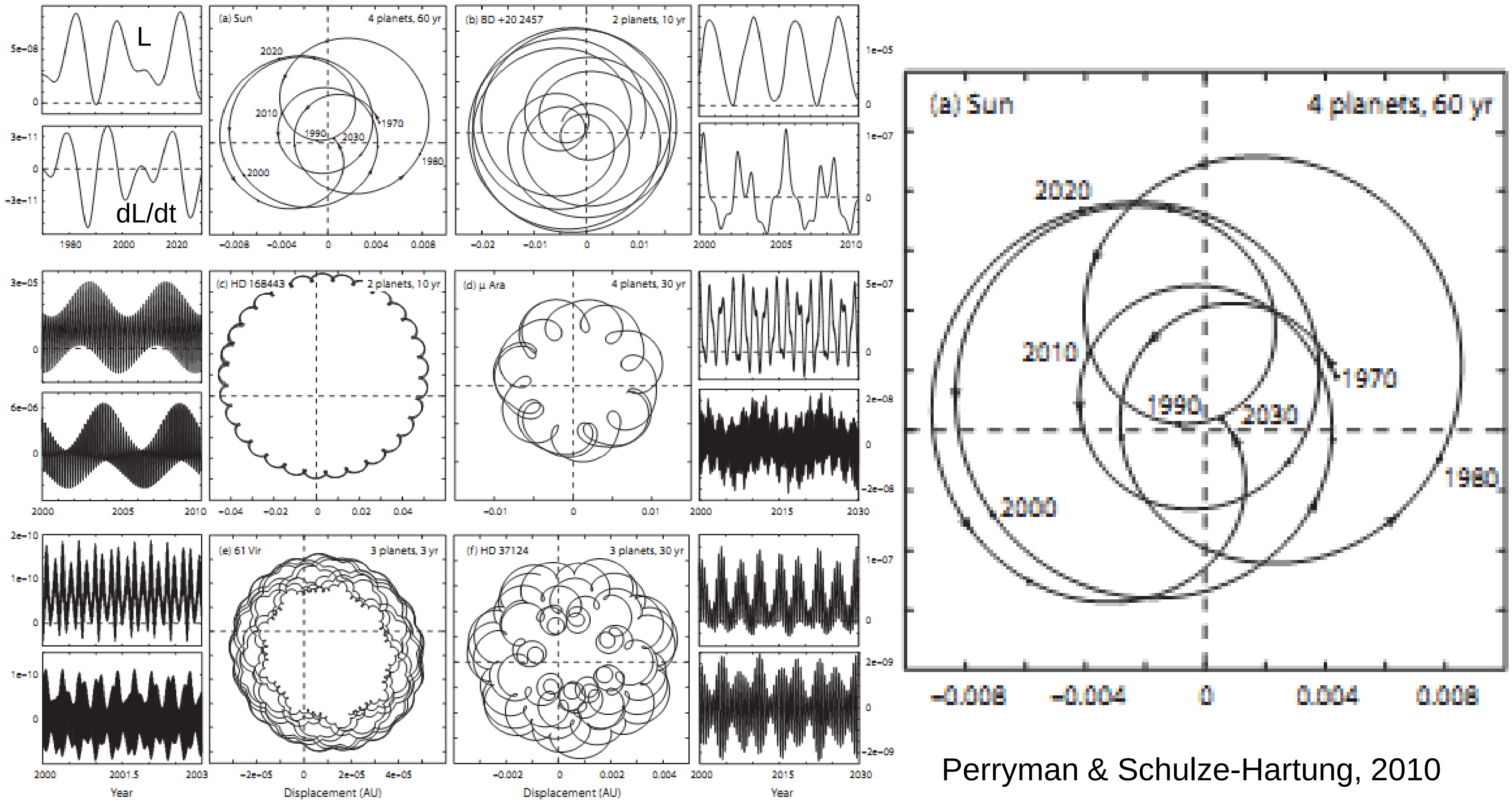
Charvatová, I. 2000, Annales Geophysicae, 18, 399

Fundamental difference between Rotation and Revolution

In rotation, the constituent particles of a body move in concentric trajectories with velocities that depend upon their position in relation to the axis of rotation

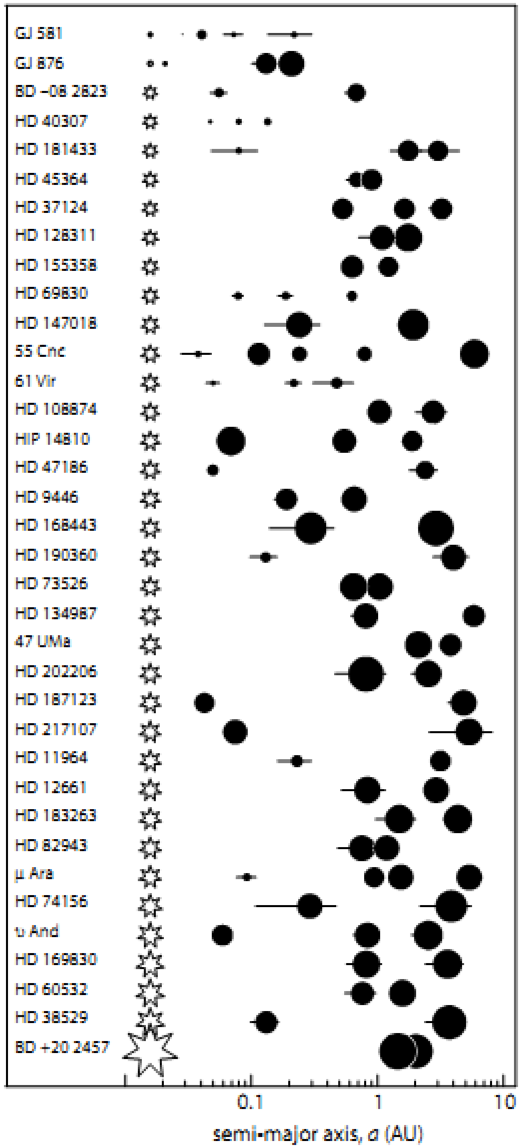
In revolution, the particles of the body move in parallel trajectories with identical velocities (aside from small differences produced by the gradients that give rise to the tides). This motion is a state of free fall

Exoplanets may provide observational proof or disproof



Perryman & Schulze-Hartung, 2010

Barycentric motion of the host star for a selection of representative multiple exoplanet systems.



Large planets very close to their host star are expected to exert a much larger effect than the far-flung smaller planets in our solar system. A ‘Mega Jupiter’ with mass $3M_J$ and at 0.052 AU would have a tidal effect $4*100^3$ = 4,000,000 times larger than our Jupiter’s [τ Boo].

HD 168443, with the innermost planet at 0.3 AU, has a *dL/dt*, with a periodicity of 58 d, that exceeds by more than five orders of magnitude that of the Sun. If orbital angular momentum variation plays a role, its effects should be visible in this system

Magnetic cycles might be visible in XUV or X-ray emission, or even total brightness for large star spots

“We conclude that there is no detectable influence of planets on their host stars, which might cause a lower floor for X-ray activity of these stars” (Poppenhäger & Schmitt, ApJ, 2011)

So far, no star cycles synchronized with any exoplanets have been found

The End

Abstract

When Rudolf Wolf devised the sunspot number he noted [1859] that the length of the cycle was close to the orbital period of Jupiter. He even constructed a formula involving the periods of Jupiter, Saturn, Venus, and Earth that reproduced the sunspot numbers 1834-1858. Unfortunately the formula failed for both earlier and subsequent cycles and Wolf concluded at the end of his life that the attempts by himself and others to 'explain' solar activity by planetary influences had really never yielded any satisfactory result. Nevertheless, the hypothesis rears it head from time to time, even today. I review several recent attempts, both proposed correlations and mechanisms. The recent discovery of exoplanets and the possibility of detecting magnetic cycles on their host stars offers a near future test of the hypothesis, based on more than the one exemplar, the solar system, we have had until now.

Calculating the Magnitude of Tides is Easy

The gravitational potential Φ at distance r around a central body with mass M_c modified by a body of mass M_o, orbiting at a distance d, is to good approximation given by:

$$\Phi(r) = -GM_c/r - GM_o r^2/d^3\ [3 \sin^2\theta \cos^2\varphi - 1]/2 \qquad (1)$$

where θ is the polar angle and φ is the azimuthal angle. Since the potential on an equipotential surface can be set equal to any constant, we may set it equal to $-GM_c/r_c$, where r_c is the radius of the (undistorted) central body, giving

$$-GM_c/r_c = -GM_c/r - GM_o r^2/d^3\ [3 \sin^2\theta \cos^2\varphi - 1]/2 \qquad (2)$$

Let $h(\theta, \varphi) = r - r_c$ be the height of the displacement due to the tide, then rearrangement of eq.(2) gives (after division through by $-GM_c$):

$$h(\theta, \varphi) = (M_o/M_c)\ (r_c^4/d^3)\ [3 \sin^2\theta \cos^2\varphi - 1]/2 \qquad (3)$$

where we approximate $r_c r^3$ by r_c^4, since, by definition, $r = r_c + h$ and h is very small compared to r_c.

For simplicity [and still to good approximation as most planetary orbits are close to a common plane] we consider the 2D case where $\theta = 90°$ (looking ‘down’ on the orbital plane). The tidal height as a function of longitude (φ) is then

$$h(\varphi) = (M_o/M_c)\ (r_c^4/d^3)\ [3 \cos^2\varphi - 1]/2 \qquad (4)$$

We can define the tidal range to be the difference between high tide ($h>0$) where $\varphi = 0°$ or $180°$ and low tide ($h<0$) perpendicular to the line connecting the centers of the two bodies, at $\varphi = 90°$ or $270°$. The tidal range is thus

$$T = h(0°) - h(90°) = 3/2\ r_c\ (M_o/M_c)\ (r_c/d)^3 \qquad (5)$$

If we take the region in the Sun where solar magnetic fields are thought to originate to be the radius of the tachocline: $r_c = 0.713\ R_☼ = 496{,}248{,}000$ m and express masses in units of the Earth, we get for the maximal tidal range (‘bulge’) generated by each planet: