On the astronomical origin of the Hallstatt oscillation found in radiocarbon and climate records throughout the Holocene

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ABSTRACT

An oscillation with a period of about 2100–2500 years, the Hallstatt cycle, is found in cosmogenic radioisotopes (^{14}C and ^{10}Be) and in paleoclimate records throughout the Holocene. This oscillation is typically associated with solar variations, but its primary physical origin remains uncertain. Herein we show strong evidences for an astronomical origin of this cycle. Namely, this oscillation is coherent to a repeating pattern in the periodic revolution of the planets around the Sun: the major stable resonance involving the four Jovian planets - Jupiter, Saturn, Uranus and Neptune - which has a period of about p = 2318 years. Inspired by the Milankovic's theory of an astronomical origin of the glacial cycles, we test whether the Hallstatt cycle could derive from the rhythmic variation of the circularity of the solar system assuming that this dynamics could eventually modulate the solar wind and, consequently, the incoming cosmic ray flux and/or the interplanetary/cosmic dust concentration around the Earth-Moon system. The orbit of the planetary mass center (PMC) relative to the Sun was used as a proxy. We analyzed how the instantaneous eccentricity vector of this virtual orbit varies from 13,000 BCE to 17,000 CE. We found that it undergoes a kind of pulsations as it clearly presents rhythmic contraction and expansion patterns with a 2318 year period together with a number of already known faster oscillations associated to the planetary orbital stable resonances, which are theoretically calculated. These periods include a quasi 20-year oscillation, a quasi 60-year oscillation, the 82-97 year Gleissberg oscillation and the 159-185 year Jose oscillation. There exists a quasi $\pi/2$ phase shift between the 2100–2500 year oscillation found in the ^{14}C record and that of the calculated eccentricity function. Namely, at the Hallstatt-cycle time scale, a larger production of radionucleotide particles occurs while the Sun-PMC orbit evolves from more elliptical shapes (e ≈ 0.598) to more circular ones (e ≈ 0.590), that is while the orbital system is slowly imploding or bursting inward; a smaller production of radionucleotide particles occurs while the Sun-PMC orbit evolves from more circular shapes (e ≈ 0.590) to a more elliptical ones (e ≈ 0.598), that is while the orbital system is slowly exploding or bursting outward. Since at this timescale the PMC eccentricity variation is relatively small (e = 0.594 ± 0.004), the physical origin of the astronomical 2318 year cycle is better identified and distinguished from faster orbital oscillations by the times it takes the PMC to make pericycles and apocycles around the Sun and the times it takes to move from minimum to maximum distance from the Sun within those arcs. These particular proxies reveal a macroscopic 2318 year period oscillation, together with other three stable outer planets orbital resonances with periods of 159, 171 and 185 years. This 2318 year oscillation is found to be spectrally coherent with the ^{14}C Holocene record with a statistical confidence above 95%, as determined by spectral analysis and cross wavelet and wavelet coherence analysis. At the Hallstatt time scale, maxima of the radionucleotide production occurred when, within each pericycle-apocycle orbital arc, the time required by the PMC to move from the minimum to the maximum distance from the Sun varies from about 8 to 16 years while the time required by the same to move from the maximum to the minimum distance from the Sun varies from about 7 to 14 years, and vice versa. Thus, we found that a fast expansion of the Sun-PMC orbit followed by a slow contraction appears to prevent cosmic rays to enter within the system inner region while a slow expansion followed by a fast contraction favors it. Similarly, the same dynamics could modulate the amount of interplanetary/cosmic dust falling on Earth. Indeed, many other stable orbital resonance frequencies (e.g. at periods of 20 years, 45 years, 60 years, 85 years, 159–171–185 years) are found in radionucleotide, solar, aurora and climate records, as determined in the scientific literature. Thus, the result supports a planetary theory of solar and/or climate variation that has recently received a renewed attention. In our particular case, the rhythmic contraction and expansion of the solar system driven by a major resonance involving the movements of the four Jovian planets appear to work as a gravitational/electromagnetic pump that increases and decreases the cosmic ray and dust densities inside the inner region of the solar system, which then modulate both the radionucleotide production and climate change by means of a cloud/albedo modulation.

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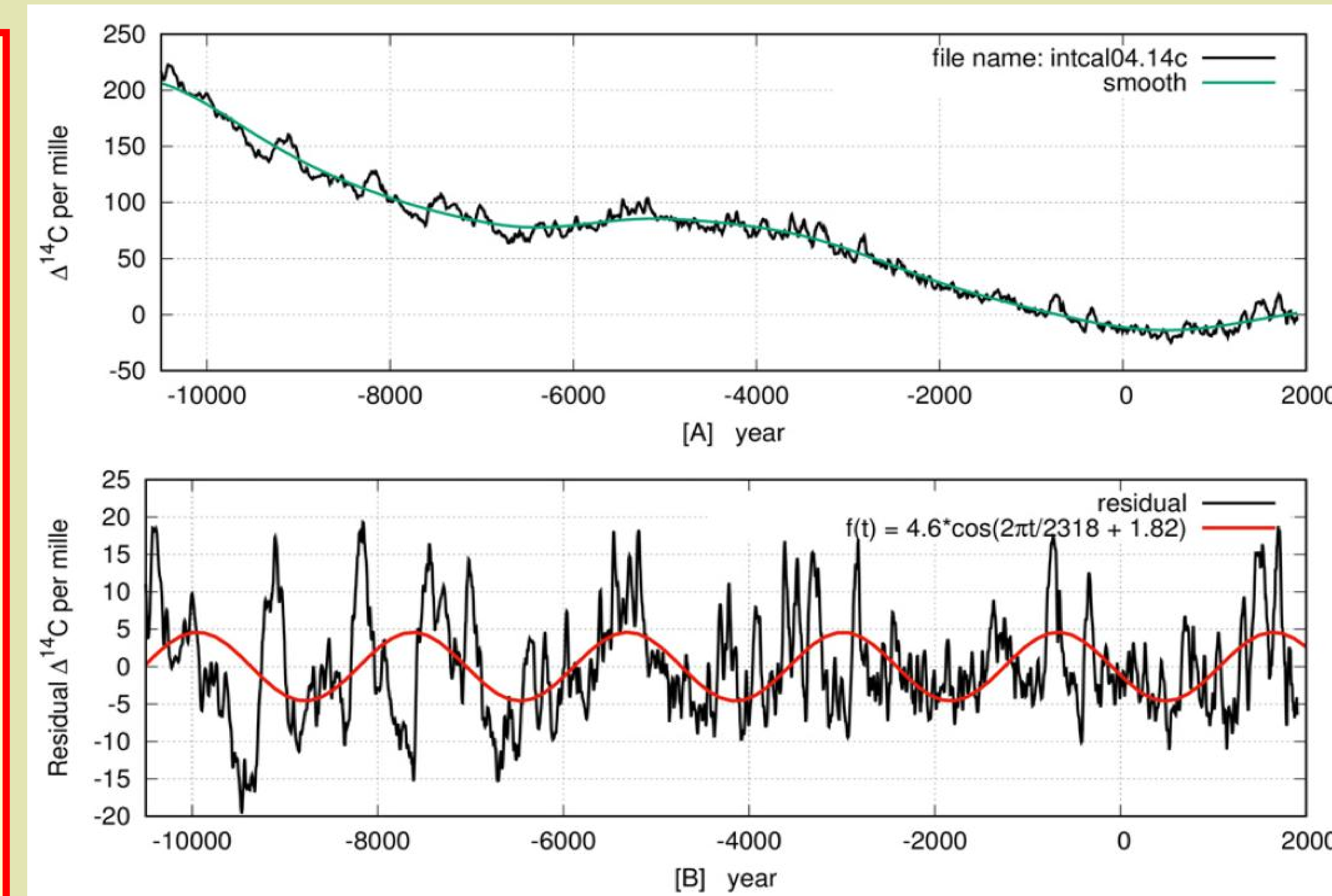
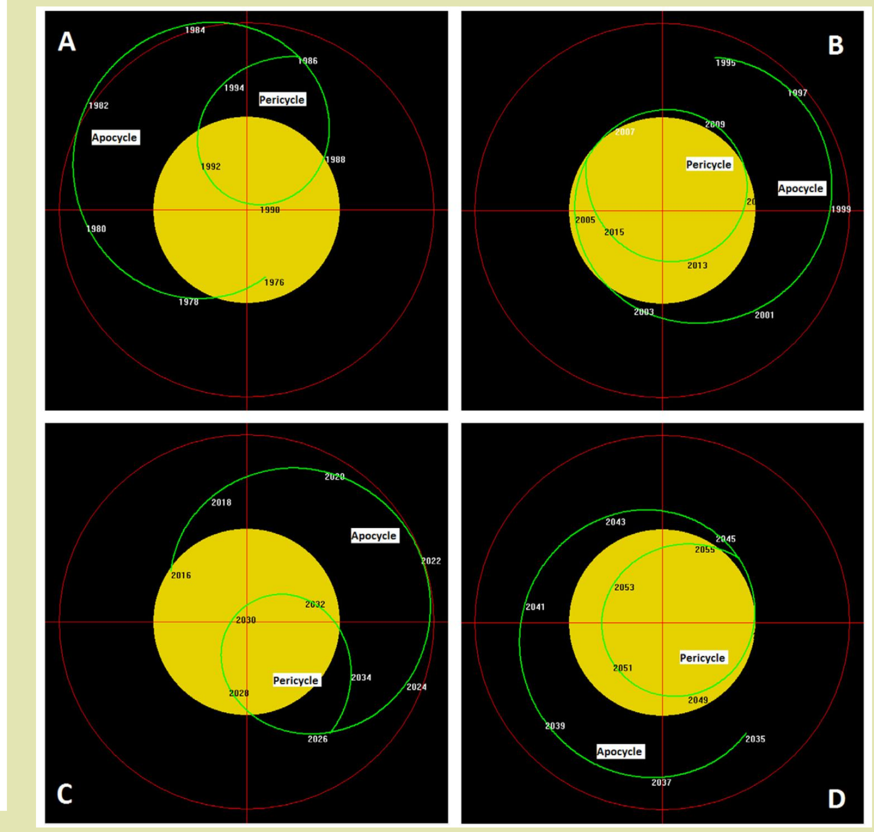
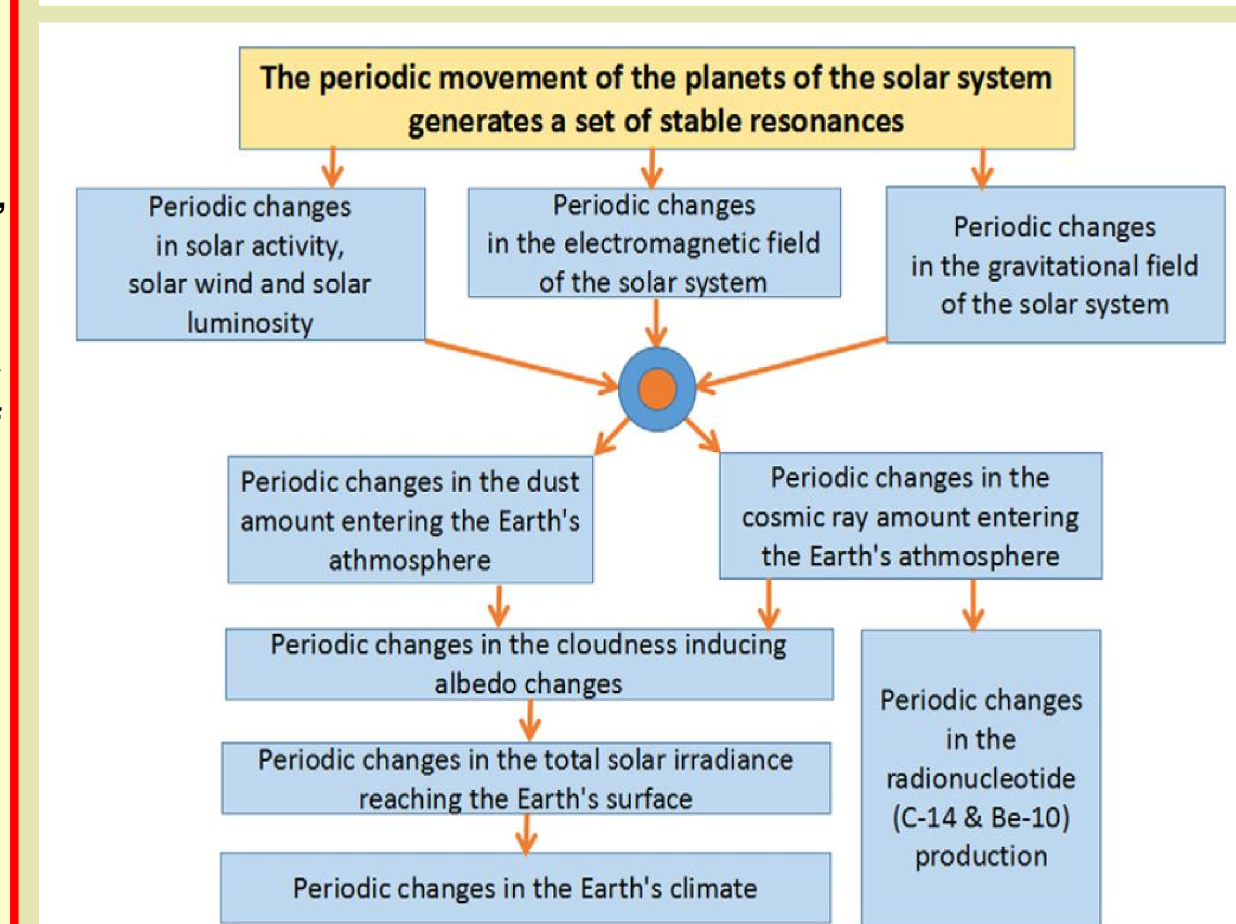


Fig. 1. [A] D14C record (black) throughout the Holocene from 10,500 BCE to 1900 CE and its multi-millennial smooth curve (green). [B] A residual signal obtained by detrending the smooth curve from the data. The latter is a fit with a sinusoidal function (red).





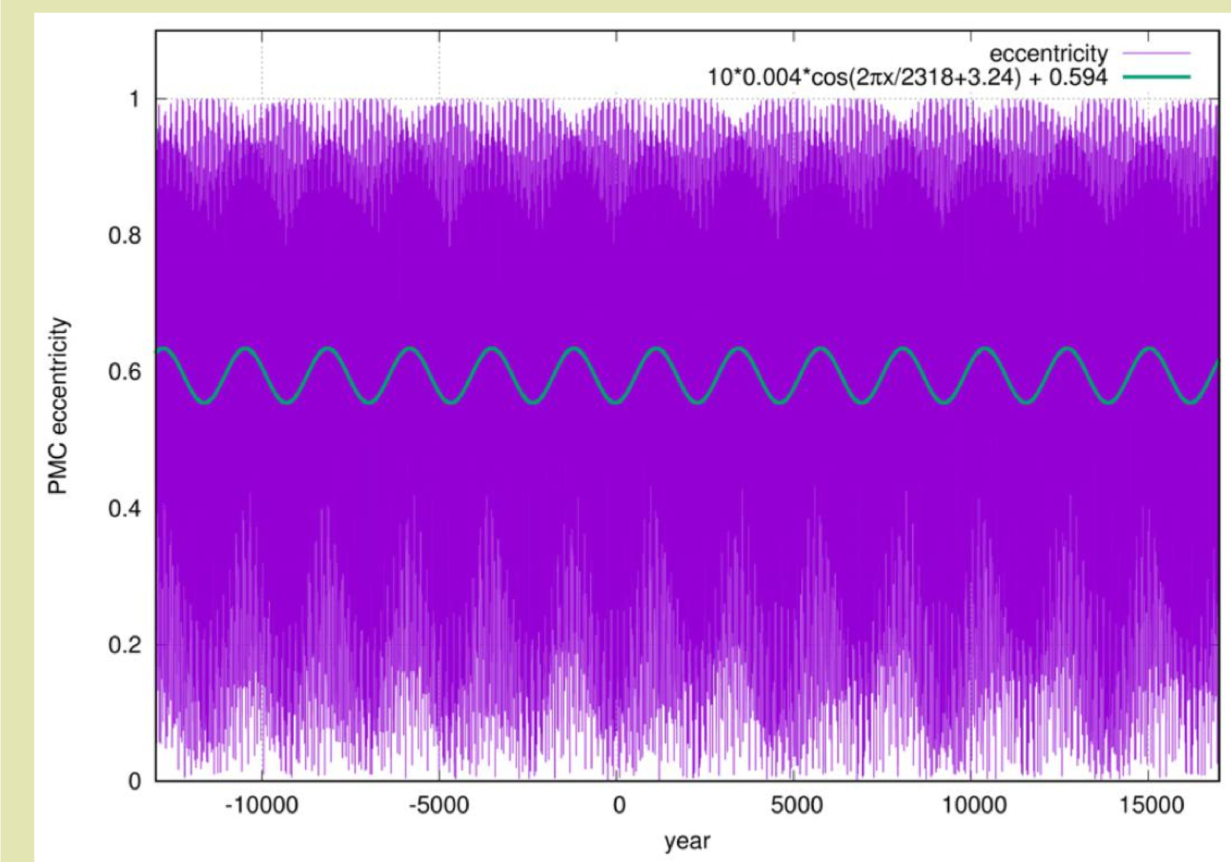


Fig. 3. Variation of the eccentricity (Eq. (14)) of the PMC relative to the Sun.

Table 1
Stable resonances associated to the Jupiter-Saturn-Uranus-Neptune system. The coefficients a_i of Eq. (2) are made to vary between −3 and 3. See also Fig. 4B.

a_{Jup}	a_{Sat}	a_{Ura}	a_{Nep}	T (year)	a_{Jup}	a_{Sat}	a_{Ura}	a_{Nep}	T (year)
3	−1	−2	0	5.12	2	−2	−2	2	11.23
2	2	−3	−1	5.14	1	1	−3	1	11.29
3	−2	2	−3	5.25	2	−3	2	−1	11.83
3	−1	−3	1	5.28	1	0	1	−2	11.90
3	−2	1	−2	5.41	0	3	0	−3	11.96
2	1	0	−3	5.42	2	−2	−3	3	12.02
3	−2	0	−1	5.59	2	−3	1	0	12.71
2	1	−1	−2	5.60	1	0	0	−1	12.78
3	−2	−1	0	5.78	0	3	−1	−2	12.85
2	1	−2	−1	5.79	2	−3	0	1	13.73
3	−3	3	−3	5.93	1	0	−1	0	13.81
3	−2	−2	1	5.98	0	3	−2	−1	13.90
2	1	−3	0	5.99	1	−1	3	−3	14.74
3	−3	2	−2	6.15	2	−3	−1	2	14.93
2	0	1	−3	6.16	1	0	−2	1	15.02
3	−2	−3	2	6.19	0	3	−3	0	15.12
3	−3	1	−1	6.37	1	−1	2	−2	16.12
2	0	0	−2	6.39	0	2	1	−3	16.24
1	3	−1	−3	6.41	2	−3	−2	3	16.35
3	−3	0	0	6.62	1	0	−3	2	16.47
2	0	−1	−1	6.64	1	−1	1	−1	17.80
1	3	−2	−2	6.66	0	2	0	−2	17.93
3	−3	−1	1	6.89	1	−1	0	0	19.86
2	0	−2	0	6.91	0	2	−1	−1	20.03
1	3	−3	−1	6.93	1	−1	−1	1	22.46
2	−1	2	−3	7.13	0	2	−2	0	22.68
3	−3	−2	2	7.17	1	−2	3	−2	25.01
2	0	−3	1	7.20	0	1	2	−3	25.29
2	−1	1	−2	7.44	1	−1	−2	2	25.85
1	2	0	−3	7.46	0	2	−3	1	26.14
3	−3	−3	3	7.49	1	−2	2	−1	29.29
2	−1	0	−1	7.78	0	1	1	−2	29.66
1	2	−1	−2	7.80	1	−1	−3	3	30.44
2	−1	−1	0	8.15	1	−2	1	0	35.32
1	2	−2	−1	8.18	0	1	0	−1	35.87
2	−2	3	−3	8.46	1	−2	0	1	44.49
2	−1	−2	1	8.55	0	1	−1	0	45.36
1	2	−3	0	8.58	0	0	3	−3	57.13
2	−2	2	−2	8.90	1	−2	−1	2	60.09
1	1	1	−3	8.93	0	1	−2	1	61.69
2	−1	−3	2	9.00	1	−3	3	−1	82.64
2	−2	1	−1	9.39	0	0	2	−2	85.70
1	1	0	−2	9.42	−1	3	1	−3	88.99
2	−2	0	0	9.93	1	−2	−2	3	92.54
1	1	−1	−1	9.97	0	1	−3	2	96.39
2	−2	−1	1	10.54	1	−3	2	0	159.59
1	1	−2	0	10.59	0	0	1	−1	171.39
2	−3	3	−2	11.07	−1	3	0	−2	185.08
1	0	2	−3	11.12	1	−3	1	1	2317.56

A system of periods T_i is said to be in linear resonant state if there exists a set of small integer numbers a_i such that:

$$\frac{1}{T} = \left|\sum \frac{a_i}{T_i}\right| < \gamma, \qquad (2)$$

where $i = 1, \ldots, N$. N is the number of orbiting objects, γ a very small number and T the resonance period. The simplest case of resonance is when two orbital periods (e.g. P_1 and P_2) have an integer ratio: $P_1/P_2 = n$, where n is the integer 1, 2 or 3 etc.

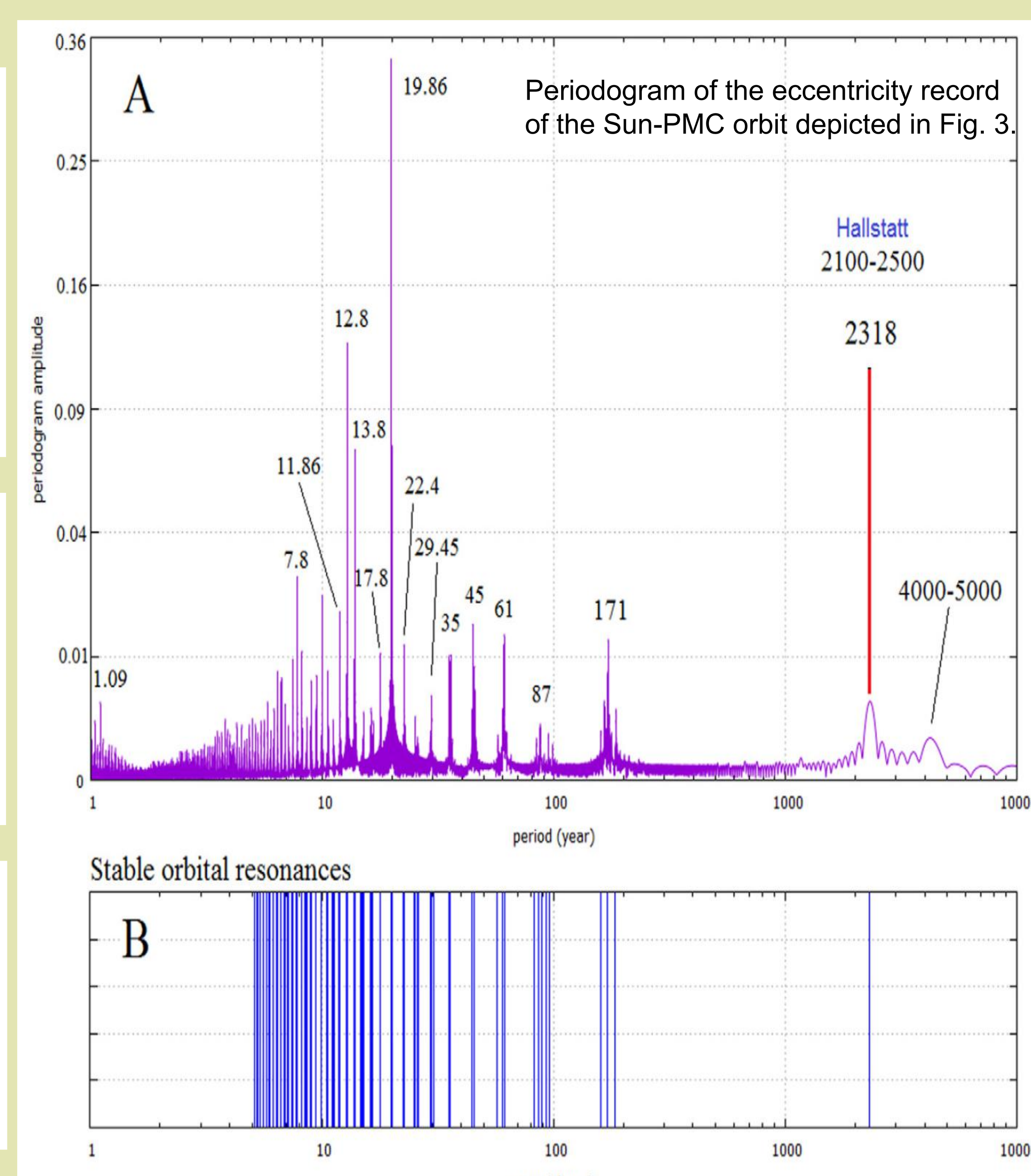
$$f_{JSUN} = \frac{1}{P_J} - \frac{3}{P_S} + \frac{1}{P_U} + \frac{1}{P_N}. \qquad (3)$$

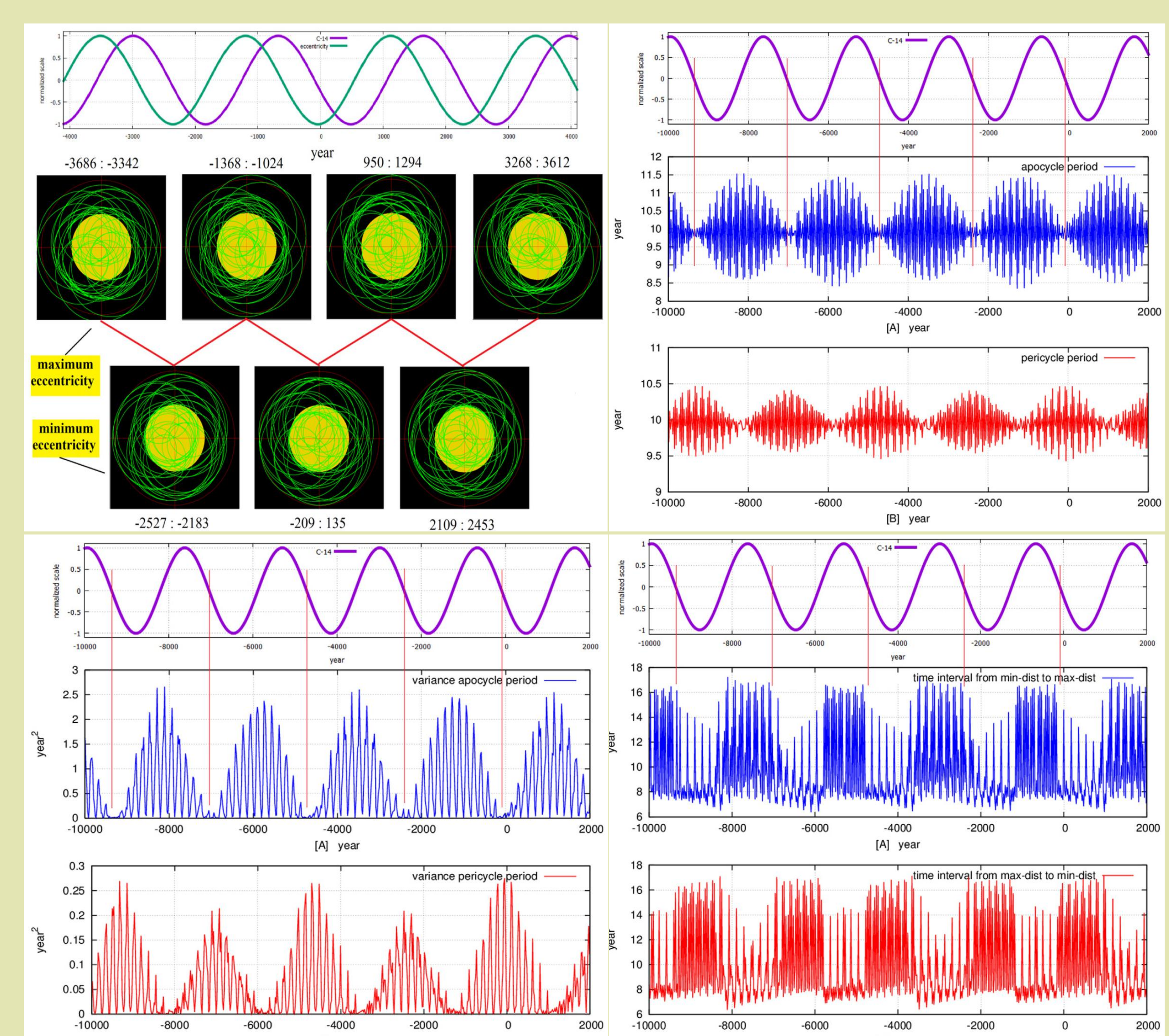
The period of such a resonance is

$$P_{JSUN} = \frac{1}{f_{JSUN}} = 846471.447\ d = 2317.56\ year. \qquad (4)$$

Using simple vector algebra, $\boldsymbol{v} \times (\boldsymbol{r} \times \boldsymbol{v}) = (\boldsymbol{v} \cdot \boldsymbol{v})\boldsymbol{r} - (\boldsymbol{r} \cdot \boldsymbol{v})\boldsymbol{v}$, Eq. (10) can be rewritten in a more friendly way, and the instantaneous eccentricity of the trajectory of each planet of the solar system can be defined as

$$e = \left|\left(\frac{v^2}{\mu} - \frac{1}{r}\right)\boldsymbol{r} - \frac{\boldsymbol{r} \cdot \boldsymbol{v}}{\mu}\boldsymbol{v}\right|, \qquad (14)$$





2300–2400 year harmonics referring to the ^{14}C record depicted in Fig. 1 and varius orbital indices related to the eccentricity, apocycles and pericycles.