Cosmology, Oscillating Physics, and Oscillating Biology

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According to recent reports there is an excess correlation and an apparent regularity in the galaxy one-dimensional polar distribution with a characteristic scale of $128h^{-1}$ Mpc. This apparent spatial periodicity can be naturally explained by a time oscillation of the gravitational constant G. On the other hand, periodic growth features of bivalve and coral fossils appear to show a periodic component in the time dependence of the number of days per year. We show that a time oscillating gravitational constant with similar period and amplitude can explain such a feature.

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Our theoretical description of nature presents a set of parameters, the so-called fundamental constants, that have to be determined from experience. It is generally thought that this is so because we lack a unified theory of all interactions and the time variation of any fundamental constant might be one of the few low energy phenomena which could manifest this "new physics." The time evolution of these parameters is supposed to be governed by dynamics of cosmological origin, so its variation rate is likely to be of the same order (or less) than the Hubble rate. We should seek then for low energy and long term (millions of years) phenomena [1–3] or else for high precision measurements (ten or more places in the decimal expansion) of some "constant" parameter, separated by a few years [4, 5]. Actually, superstring theories [6] and Kaluza-Klein theories [7] have cosmological solutions in which the low-energy fundamental constants vary with time [8–12].

Broadhurst, Ellis, Koo, and Szalay [13] (hereafter BEKS) combined data from four distinct deep pencil-beam surveys at the north and south Galactic poles to produce a well sampled distribution of galaxies by redshift on a linear scale extending to $2000h^{-1}$ Mpc. They reported a periodicity in the galaxy distribution of $128h^{-1}$ Mpc. Soon afterwards Morikawa [14] noted that this apparent spatial periodicity could be naturally explained by a time oscillation of the Hubble parameter. In his model the oscillation was produced by a massive scalar field nonminimally coupled to gravity, inducing also the time oscillation of the gravitational constant G. Hill, Steinhardt, and Turner [15] proposed different scenarios, including a time oscillating Hubble parameter, and also the oscillation of atomic lines as alternative explanations of the redshift galaxy distribution. An oscillation in the Rydberg constant due to the variation of the fine structure constant α or the electron mass m_e requires a modification of the standard model in which α or m_e become dependent on a scalar field. Thus, an oscillating α introduces a Yukawa potential between samples with nonzero electrostatic energy contribution, while an oscillating m_e induces a similar interaction proportional to the lepton numbers of the samples [16]. In this context both possibilities were shown to be ruled out [16] by the experiment of Braginskii and Panov [17], leaving the Hubble oscillating scenario as the only likely candidate. An oscillation in the Hubble parameter modulates the observed redshift. Let z_0 denote the redshift in the absence of oscillations. If the Universe is spatially homogeneous, with a uniform galaxy density per comoving volume n_0, the number of galaxies dN in a solid angle $d\Omega$ with redshift between z and $z+dz$ is modulated compared to the distribution in the absence of oscillations in the following way:

$$\frac{dN}{z^2dzd\Omega} = \left(\frac{dN}{z_0^2dz_0d\Omega}\right)\frac{dz_0}{dz}, \tag{1}$$

where to lowest order $z^2 \simeq z_0^2$. The modulation due to the oscillation changes the distribution by a factor of $dz_0/dz = \bar{H}/H$, where $\bar{H}$ is the Hubble parameter in the absence of oscillations. We have then an apparent variation in the density of galaxies which is isotropic and has peaks lying on concentric spherical shells at periodically spaced radii.

In this context Crittenden and Steinhardt [18] analyzed the G oscillating mechanism for an oscillating H, using the generic action for a scalar field ϕ nonminimally coupled to gravity,

$$S = \int d^4x\sqrt{-g}[-f(\phi)\mathcal{R} - \tfrac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)] + S_{\text{matter}}\,, \tag{2}$$

where $f(\phi)$ is the coupling function whose inverse is the effective gravitational constant G and $\mathcal{R}$ is the curvature scalar. If $V = m^2\phi^2$, $\phi \simeq \cos(mt+\psi)$, then $m \simeq 10^{-31}$ eV in order to account for a period of 4×10^8 y. If $f(\phi) = M_{\rm Pl}^2 + \xi M_{\rm Pl}\phi + \cdots$ then the galaxy redshift count is modulated by the factor $dz_0/dz = \bar{H}/H \simeq 1/[1+\alpha\cos(mt+\psi)]$, where $\alpha = f'm\phi_0/2\bar{H}f$. From the calculation of Hill *et al.*, an amplitude $\alpha \geq 0.5$ could match the sharp peaks observed by BEKS. On the other hand the strong limits on the time variation of G, mainly due to Viking radar ranging experiments, constrain the value of the phase ψ through the expression $\dot{G}/(GH) = 2\alpha\cos(mt+\psi) \leq 0.3h^{-1}$, which implies that

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$\cos(mt+\psi) \leq 0.4$. Moreover, the same authors pointed out that planetary Eötvös experiments provide a much more severe constraint, since the modification of the gravitational force for a massive ϕ field is virtually identical to the original massless Brans-Dicke case on length scales much smaller than the Compton wavelength of ϕ, m^{-1}. One can define the effective Brans-Dicke parameter ω as $\omega = f/(2f'^2)$, and reexpress the amplitude α in terms of it as $\alpha^2 = 1/(4\omega)[m^2\phi_0^2/(2f\bar{H}^2)]$ and the constraint on α implies $\omega \leq 3$, in conflict with fifth force tests, $\omega \geq 500$. However, if $f(\phi)$ grows quadratically with small perturbations in ϕ, $f(\phi) = M_{\rm Pl}2 + \xi\phi^2 + \cdots$ the modulation is $dz_0/dz = \bar{H}/H \simeq 1/[1+\alpha\cos(2mt+\psi)]$, where $\alpha = \xi m\phi_0^2/\bar{H}f$. Now $\omega \propto 1/\phi^2$, becoming oscillatory too, so the amplitude constraint becomes $\omega \leq 3/\cos^2(mt+\psi)$ which again can be made arbitrarily large while making $\dot{G}/G$ arbitrarily small for a convenient phase ψ (there are some other problems concerning the decreasing amplitude of ϕ since nucleosynthesis which can also be avoided and which we will not discuss here). In what follows we will show that there is some evidence of similar time scales (periodicities) in paleontological records.

It is well known that several taxons record growth rhythms in their skeletons; i.e., periodic markings locked to the astronomical cycles of day, month, and year [19]. From these growth rhythms, the number of days per year, days per month, and months per year have been obtained as functions of geological time [19–21]. These parameters can be simply expressed in terms of the Earth's rotation Ω, the mean motion of the Sun $n_\odot$, and the mean motion of the Moon $n_{\rangle}$, as $N_{d/y} = \Omega/n_\odot - 1$, $N_{d/m} = (\Omega - n_\odot)/(n_{\rangle} - n_\odot)$, and $N_{m/y} = (n_{\rangle} - n_\odot)/n_\odot$. The effect of a varying G on the Earth-Moon system can be studied under the adiabatic hypothesis, as stated in Refs. [22, 23], so the Keplerian equations of motion mantain their form, and G is replaced by the appropriate time function. Morover, in a reference system where G depends only on time but not on space, angular momentum is still conserved [22]. According to Lambeck [21], present day growth rhythms suggest that there may be significant systematic errors in the counts, and it is convenient to introduce parameters $\Delta n_\odot$, $\Delta n_{\rangle}$, and $\Delta\Omega$ accounting for such errors in the estimation of the planetary angular velocities. Then, for a time oscillating G the final expressions for the observables are

$$\frac{N_{d/y}}{N^0_{d/y}} - 1 = \beta\frac{G_1}{G_0}[\sin(\omega\tilde{t}-\phi) - \sin(\phi)] - \left.\frac{\dot{\Omega}}{\Omega}\right|_t \tilde{t} - \frac{\Delta\Omega}{\Omega} + \frac{\Delta n_\odot}{n_\odot}, \quad (3)$$

$$\frac{N_{m/y}}{N^0_{m/y}} - 1 = \beta\frac{G_1}{G_0}[\sin(\omega\tilde{t}-\phi) - \sin(\phi)] + \left(\left.\frac{\dot{n}_{\rangle}}{n_{\rangle}}\right|_t - \left.\frac{\dot{\Omega}}{\Omega}\right|_t\right)\tilde{t} - \frac{\Delta\Omega}{\Omega} + \frac{\Delta n_{\rangle}}{n_{\rangle}}, \quad (4)$$

$$\frac{N_{d/m}}{N^0_{d/m}} - 1 = -\left.\frac{\dot{n}_{\rangle}}{n_{\rangle}}\right|_t \tilde{t} + \frac{\Delta n_{\rangle}}{n_{\rangle}} + \frac{\Delta n_\odot}{n_\odot}, \quad (5)$$

where $\beta \simeq 1.83$ depends on the mass and pressure distribution in the Earth's interior [22], $\gamma \simeq 1.84$ is related to the tidal couple of the Earth-Moon system [20], $\dot{n}_{\rangle}|_t$ is the tidal acceleration of the lunar longitude, $-(2-\beta)\dot{G}/G$ is the change of the moment of inertia due to the change of G [22], $\tilde{t}$ is minus the geological (not ephemeris) time [22], and $\phi = \frac{\pi}{2} - \psi$.

We used the Lambeck data set [21], which has been carefully filtered according to biological reliability criteria [20]. We have taken 37 values from Refs. [20,21]. Lambeck has adjusted the data assuming that only (constant) dissipation mechanisms are responsible for $\dot{\Omega}$ and $\dot{n}_{\rangle}$. The estimated values of $\dot{\Omega}$ and $\dot{n}_{\rangle}$ were in good agreement with the modern astronomical values and the residuals showed no obvious systematic trends, indicating that the growth rhythms present a high degree of confidence. We have adjusted simultaneously the three equations, both with and without the oscillatory parameters (i.e., with and without an oscillatory G), using the Levenberg-Marquardt least-squares method. The χ^2 significances of the adjustments are shown in Table I. There is still a debate on the correct values for standard deviations of the palaeontological number counts, so the absolute value of the χ^2 significance is not important. What is really important is the *change* of the significance when the oscillatory parameters are included. We see that there is a conspicuous increase of significance level when the oscillatory parameters are introduced. For the latter adjustment, the best fit values are shown in Table II, together with 95% confidence limits. The upper confidence limit on G_1/G_0 is about 0.009, which is the necessary amplitude to account for the redshift survey, i.e., we have marginal consistency with the oscillating G hypothesis. The best fit value of the period of oscillation remarkably coincides with the galaxy distribution period, although the confidence limits weaken its relevance. The values for (tidal) $\dot{n}_{\rangle}/n_{\rangle}$, $\dot{\Omega}/\Omega$, and $\dot{n}_\odot/n_\odot$ agree with other estimates [21]. The phase ψ is consistent with the zero value proposed in [15], which implies a zero value for the present rate of change of G. Our fit is then consistent with the current upper bounds on the time variation of G based upon the Viking radar-echo experiments [5] [note that only upper bounds based on present observations are valid if G oscillates, so

TABLE I. Significance of the χ^2 test for all adjustments.

Data source	Number of adjusted parameters	χ^2 significance
Original	5	below 10%
Original	8	below 10%
Lambeck	5	17%
Lambeck	8	85%

TABLE II. Adjusted parameters of the curves fitting Lambeck data, together with 95% confidence limits.

Parameter	Best fit value	Confidence limits Lower	Upper
$\Delta n_\odot$	-1.3×10^{-2}	-2.5×10^{-2}	1.6×10^{-3}
$\Delta n_☽$	9.3×10^{-3}	-4.1×10^{-2}	5.9×10^{-2}
$\Delta\Omega$	1.9×10^{-3}	-4.1×10^{-3}	7.9×10^{-3}
$\dot{n}/n$ [10^{-11} yr^{-1}]	16.4	12	20
$\dot{\Omega}/\Omega$ [10^{-11} yr^{-1}]	32.0	29	35
G_1/G_0	6.5×10^{-3}	3.8×10^{-3}	9.2×10^{-3}
Period [10^6 yr]	486	370	680
ψ	0.27	-0.53	0.83

the much more stringent upper bounds of [22, 23] do not apply because they are also based in long-term (several oscillation periods) phenomena], and with Eötvös experiments, as in the model based on the nonlinear $f(\phi)$ dependence proposed by Crittenden and Steinhardt.

In order to test the sensibility of the solution, we have repeated the adjustments using unfiltered data from several sources, as shown in Table III, including bivalves, corals, cephalopods, brachiopods, and estromatolites and totalizing 61 points. As shown in Table I in this case both significances are small, showing that the filtering of data as made by Lambeck introduces a bias towards the oscillatory hypothesis.

We conclude that our results do not exclude an oscillating gravitational constant inducing a periodic galaxy distribution. Indeed the significance of the Lambeck data adjustment suggests that there is an oscillatory component in the time evolution of planetary orbit ratios. However, there are several uncertainties in our model that forbid a definite conclusion. In the first place, biological growth rhythms are subject to large uncertainties, and should be handled with care [24–26]. Second, it should be noted that the changes in the resonance structure of the oceans due to continental drift provoke considerable variations of the Earth-Moon tidal torque within 100 million years time scales [27]. This fact could account as well for the time oscillation of the number of days per year. As a result we can only state that an upper bound for the oscillation amplitude of the gravitational constant is $G_1/G_0 < 0.01$ (taken from the upper confidence limit of Table II).

It has been stated that the Hubble oscillating hypothesis is strongly testable because it predicts the same periodic patterns in all directions, but the uncertainties introduced by the statistical nature of the large scale structure preclude such a test. Indeed, as stated by Morikawa [14] both the density contrast and the distance to the nearest peak is not clear from the survey; and there is an asymmetry in the BEKS North-South survey, which could be addressed by introducing an anharmonic potential for the oscillating field ϕ. The growth rhythm periodicity, if existent, would be a different test of the hypothesis,

TABLE III. Original counting and geological data (dy=days per year; dm=days per month; my=months per year).

Geologic time [M.Y.]	Data type	Value	Adopted S.D.	Organisms	Ref.
−300	dy	385	4.3	corals	[29]
−330	dy	398	6.1	corals	[29]
−390	dy	397.6	1.8	corals	[29]
−425	dy	400	6.1	corals	[29]
−465	dy	412	6.1	corals	[29]
0	dy	360	3.1	corals	[29]
−390	dy	401	6.1	corals	[30]
−395	dy	410	4.5	corals	[31]
−440	dy	421	6.4	corals	[31]
−390	dm	30.63	0.11	corals	[30]
−335	dm	30.2	0.15	corals	[32]
−480	dm	30.7	0.23	corals	[33]
−395	dm	31.5	0.45	corals	[31]
−440	dm	32.4	0.64	corals	[31]
−390	my	13	0.29	corals	[30]
−395	my	13	0.2	corals	[31]
−440	my	13	0.29	corals	[31]
0	dy	359.3	1.6	bivalves	[33]
−70	dy	375	2.6	bivalves	[33]
−220	dy	371.6	3.6	bivalves	[33]
−290	dy	383	2.3	bivalves	[33]
−350	dy	398	1.8	bivalves	[33]
−390	dy	405.5	6.0	bivalves	[33]
0	dm	29.22	0.08	bivalves	[33]
−10	dm	29.52	0.08	bivalves	[33]
−22	dm	29.42	0.15	bivalves	[33]
−51	dm	29.7	0.09	bivalves	[33]
−70	dm	29.85	0.10	bivalves	[33]
−220	dm	29.66	0.15	bivalves	[33]
−290	dm	30.16	0.09	bivalves	[33]
−350	dm	30.37	0.11	bivalves	[33]
−390	dm	30.35	0.17	bivalves	[33]
0	my	12.35	0.07	bivalves	[33]
−70	my	12.64	0.11	bivalves	[33]
−220	my	12.56	0.08	bivalves	[33]
−1	dm	29.5	0.08	bivalves	[34]
−5	dm	29.66	0.15	bivalves	[34]
−30	dm	29.52	0.08	bivalves	[34]
−45	dm	29.72	0.28	bivalves	[34]
−60	dm	29.7	0.16	bivalves	[34]
−100	dm	29.72	0.05	bivalves	[34]
−170	dm	29.84	0.3	bivalves	[34]
−220	dm	29.76	0.3	bivalves	[34]
−325	dm	30.13	0.13	bivalves	[34]
−400	dm	30.5	0.4	bivalves	[34]
−70	dm	29.65	0.18	bivalves	[35]
−70	my	12.49	0.02	bivalves	[35]
−320	dm	30.22	0.40	cephalopods	[33]
−410	dm	29.84	0.23	cephalopods	[33]
−310	dm	30.11	0.35	cephalopods	[37]
−395	dy	407.75	3.2	brachiopods	[31]
−425	dy	419	4.5	brachiopods	[31]
−395	dm	31.38	0.32	brachiopods	[31]
−425	dm	31.5	0.45	brachiopods	[31]
−395	my	13	0.15	brachiopods	[31]
−425	my	13	0.2	brachiopods	[31]
−540	dy	424	6.4	estromatolites	[36]
−150	dm	30	0.64	estromatolites	[33]
−510	dm	31.56	0.75	estromatolites	[33]
−510	dm	33	0.64	estromatolites	[33]
−510	my	13	0.29	estromatolites	[33]

if the ambiguities related to biological and geophysical phenomena could be kept under control. Then, besides making further deep-pencil surveys in the same and other directions in the sky, it would be very important to perform new studies on growth rhythms, both on fossil and present day taxons; on the paleorotation of the Earth and on the theoretical models. Summarizing, the coincidences which we observe in this work (coincidences may become consequences [28]) are significant enough so as to become a subject of further theoretical and observational research.

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[1] M. W. Mc.Elhinny, S. R. Taylor, and D. J. Stevenson, Nature (London) **271**, 316 (1978).
[2] A. M. Wolfe, R. L. Brown, and M. S. Roberts, Phys. Rev. Lett. **37**, 179 (1976).
[3] A. I. Shlyakhter, Atomki Report No. A/I, 1983 (unpublished); Nature (London) **264** , 340 (1976).
[4] T. Damour, G. W. Gibbons, and J. H. Taylor, Phys. Rev. Lett. **61**, 1151 (1988).
[5] R. H. Hellings, P. J. Adams, J. D. Anderson, M. S. Keesey, E. L. Lau, E. M. Standish, V. M. Canuto, and I. Goldman, Phys. Rev. Lett. **51**, 1609 (1983).
[6] J. H. Schwartz, Phys. Rep. **89**, 223 (1982); M. B. Green and J. H. Schwartz, Phys. Lett. B **199**, 117 (1984).
[7] T. Kaluza, Sitz. Preuss. Akad. Wiss. Phys. Math. **K1**, 966 (1921); O. Z. Klein, Physica (Utrecht) **37**, 895
[8] Y. Wu and Z. Wang, Phys. Rev. Lett. **57**, 1978 (1986).
[9] K. Maeda, Mod. Phys. Lett. A **3**, 243 (1988);
[10] S. M. Barr and P. K. Mohapatra, Phys. Rev. D **38**, 3011 (1988).
[11] A. Chodos and S. Detweiler, Phys. Rev. D **21**, 2167 (1980); M. Gleiser and J. G. Taylor, Phys. Rev. D **31**, 1904 (1985).
[12] W. J. Marciano, Phys. Rev. Lett. **52**, 489 (1984).
[13] T. J. Broadhurst, R. S. Ellis, D. C. Koo, and A. S. Szalay, Nature (London) **343**, 726 (1990).
[14] M. Morikawa, Astrophys. J. **369**, 20 (1991).
[15] C. T. Hill, P. J. Steinhardt, and M. S. Turner, Fermi National Accelerator Laboratory Report No. 90/129-T, 1990 (unpublished).
[16] D. Sudarsky, Fermi Institute report, 1992 (to be published).
[17] V. B. Braginskii and V. I. Panov, Zh. Eksp. Teor. Fiz. **61**, 873 (1971) [Sov. Phys. JETP **61**, 463 (1972)].
[18] R. G. Crittenden and P. J. Steinhardt, University of Pennsylvania Report No. UPR-0479T, 1992 (to be published).
[19] C. T. Scrutton, in *Tidal Friction and the Earth's Rotation*, edited by P. Brosche and J. Sundermann (Springer, New York, 1978), pp. 154–196.
[20] K. Lambeck, *The Earth's Variable Rotation* (Cambridge University Press, New York, 1980).
[21] K. Lambeck, in *Tidal Friction and the Earth's Rotation*, edited by P. Brosche and J. Sundermann (Springer-Verlag, Berlin, 1978).
[22] P. D. Sisterna and H. Vucetich, Phys. Rev. D **41**, 1034 (1990).
[23] P. D. Sisterna and H. Vucetich, Phys. Rev. D **44**, 3096 (1991).
[24] R. A. Lutz and D. C. Rhoads, Science **198**, 1222 (1977).
[25] W. W. Hughes, Geophysical Surveys **7**, 169 (1985).
[26] G. D. Rosenberg, Geophysical Surveys **7**, 185 (1985).
[27] P. Brosche, in *Sun and Planetary System*, edited by W. Fricke and G. Teleki (Reidel, Dordrecht, 1982).
[28] J. D. Barrow and F. J. Tipler, *The Anthropic Cosmological Principle* (Oxford University Press, Oxford, 1988).
[29] J. W. Wells, Nature (London) **197**, 948 (1963); in *Palaeogeophysics*, edited by S. K. Runcorn (Academic Press, London, 1970).
[30] C. T. Scrutton, Palaeontology **7**, 552 (1965).
[31] S. J. Mazzulo, Bull. Geol. Soc. Am. **82**, 1085 (1971).
[32] G. A. L. Johnson and J. R. Nudds, in *Growth Rhythms and the History of the Earth's Rotation*, edited by G. D. Rosenberg and S. K. Runcorn (Wiley, London, 1975).
[33] G. Panella, Astrophys. Space Sci. **16**, 212 (1972).
[34] W. B. N. Berry and R. M. Baker, in *Growth Rhythms and the History of the Earth's Rotation* (Ref. [32]).
[35] W. B. N. Berry and R. M. Baker, Nature (London) **217**, 938 (1968).
[36] A. McGuhan, Abstr. Mtg. Geol. Soc. Am. **1967**, 145 (1967).
[37] S. M. Pompea, P. G. K. Kahn and R. B. Culver, Vistas Astronomy **23**, 185 (1979).