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 $128 \ h^{-1} \ Mpc$. 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. In this letter we show that a time oscillating gravitational constant with similar period and amplitude can explain such a feature.

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. 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 or else for high precision measurements (ten or more places in the decimal expansion) of some “constant” parameter, separated by a few years. Actually, superstring theories and Kaluza-Klein theories have cosmological solutions in which the low-energy fundamental constants vary with time.

Broadhurst, Ellis, Koo and Szalay 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 $2000 \ h^{-1} \ Mpc$. They reported a periodicity in the galaxy distribution of $128 \ h^{-1} \ Mpc$. Soon afterwards Morikawa 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 non-minimally coupled to gravity, inducing also the time oscillation of the gravitational constant $G$. Hill, Steinhardt and Turner proposed different scenarios, including a time oscillating Hubble parameter, but also the oscillation of atomic lines as an alternative explanation of the red-shift galaxy distribution. An oscillation in the Rydberg constant due to the variation of the fine structure constant $\alpha$ or the electron mass $m_e$ requires a modification of the standard model in which $\alpha$ or $m_e$ become dependent on a scalar field. Thus an oscillating $\alpha$ introduces a Yukawa potential between samples with non-zero electrostatic energy contribution, while an oscillating $m_e$ induces a similar interaction now proportional to the lepton numbers of the samples. In this context both possibilities were shown to be ruled out by the experiment of Braginsky and Panov, leaving the Hubble oscillating scenario as a solely candidate to analyze.

Even if the periodicity reported by Broadhurst et al. were an artifact of small angle sampling of galaxy distribution, the problem of an oscillating gravitational constant is interesting enough to deserve a different observational analysis. There are indeed superstring models that predict oscillating fundamental constants. These are functions of massive dilaton fields associated with the size of extra dimensions. To account a period $c\tau \simeq 128 h^{-1} \ Mpc$ the dilaton mass $m$ must be $O(10^{-31} eV)$. In Ref. the time dependence proposed for the gravitational constant is

$$G = G_0 + G_1 \cos[2m(t-t_0)+\psi],$$

and the equation for the cosmological scale factor is

$$H^2 = \frac{\dot{G}}{G}H + \frac{8\pi G \rho}{3},$$

where $H$ is the Hubble parameter. From Eq. it is easy to see that the leading correction to the Hubble parameter is $H \simeq \dot{H}[1 - \frac{1}{2}(G/GH)]$. Then, since $H \equiv \dot{a}/a$ and $1 + z \propto a^{-1}$, one finds that

$$\frac{dz}{dz_0} = 1 - \frac{\dot{G}}{2GH} = 1 + A \cos[2m(t-t_0)+\psi],$$
where we have defined the amplitude $A = -mG_1/\bar{H}G_0$. Following Ref. [15], 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 red shift between $z$ and $z + dz$ is modulated compared to the distribution in the absence of oscillations in the following way:

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

where to lowest order $z^2 \simeq z_0^2$. 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. An amplitude $A \simeq 0.5$ (or equivalently about 1% for $G_1/G_0$), a phase $\psi \simeq 0$ and a period $\tau \simeq L = 128h^{-1}$ Mpc approximately reproduces the result of Ref. [13]. Such a period is similar to the time scales involved in the paleontological record.

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 [18]. 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 [18–20]. This parameters can be simply expressed in terms of the Earth’s rotation $\Omega$, the mean motion of the Sun $n_\odot$ and the mean motion of the moon $n_j$ as follows:

$$N_{d/y} = \frac{\Omega}{n_\odot} - 1,$$

$$N_{d/m} = \frac{\Omega - n_\odot}{n_j - n_\odot},$$

$$N_{m/y} = \frac{n_j - n_\odot}{n_\odot}.$$

The effect of a varying $G$ on the Earth-Moon system can be studied under the adiabatic hypothesis, as stated in references [21,22], so the Keplerian equations of motion maintain their form, and $G$ is replaced by the appropriate time function. Moreover, in a reference system where $G$ depends only on time but not on space, angular momentum is still conserved [21]. Then we obtain

$$\frac{\dot{n}_\odot}{n_\odot} = 2\frac{\dot{G}}{G},$$

$$\frac{\dot{n}_j}{n_j} = 2\frac{\dot{G}}{G} + \frac{\dot{\Omega}}{\Omega}|_{t},$$

$$\frac{\dot{\Omega}}{\Omega} = -\gamma \frac{\dot{n}_\odot}{n_\odot}|_{t} + (2 - \beta)\frac{\dot{G}}{G},$$

where $\beta \simeq 1.83$ depends on the mass and pressure distribution in the Earth’s interior [21]. $\gamma \simeq 1.84$ is related to the tidal couple of the Earth-Moon system [19]. $\frac{\dot{n}_\odot}{n_\odot}|_{t}$ is the tidal acceleration of the lunar longitude and $-(2 - \beta)\frac{\dot{G}}{G}$ is the change of the moment of inertia due to the change of $G$ [21]. According to Lambeck [20] the paleontological data suggest that there may be significant systematic errors in the counts, and it is convenient to introduce parameters $\Delta n_\odot, \Delta n_j$, 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

$$\frac{N_{d/y}}{N_{d/y}^0} - 1 = \beta \frac{G_1}{G_0} [\sin(\phi) - \sin(\phi)] - \frac{\dot{\Omega}}{\Omega}|_{t} \frac{\Delta \Omega}{\Omega} + \frac{\Delta n_\odot}{n_\odot},$$

$$\frac{N_{m/y}}{N_{m/y}^0} - 1 = \beta \frac{G_1}{G_0} [\sin(\phi) - \sin(\phi)] + \left(\frac{\dot{n}_j}{n_j}|_{t} - \frac{\dot{\Omega}}{\Omega}|_{t}\right) \frac{\Delta \Omega}{\Omega} + \frac{\Delta n_j}{n_j}.$$
\[
\frac{N_{d/m}}{N_{o/d/m}} - 1 = - \frac{n_i}{n_{\circ}} \tilde{\Omega} + \frac{\Delta n_i}{n_{\circ}} + \frac{\Delta n_{\circ}}{n_{\circ}},
\]

(13)

where \( \tilde{\Omega} \) is minus the geological (not ephemeris) time \([21]\) and \( \phi = \frac{\pi}{2} - \psi \).

We used the data carefully filtered by Lambeck \([20]\) according to biological reliability criteria \([19]\). These data (37 points) are shown in Table II. Originally Lambeck adjusted the data assuming that only (constant) dissipation mechanisms are the responsible for \( \Omega \) and \( n_i \). The adjusted values of \( \Omega \) and \( n_i \) were in good agreement with the modern astronomical values. The residuals showed no obvious systematic trends, indicating that the growth rings present a high degree of confidence. In our case we adjusted simultaneously the three curves with and without the oscillatory parameters (i.e. with and without an oscillatory \( G \)), using the Levenberg-Marquardt least-squares method. The \( \chi^2 \) significances of the adjustments are shown in Table III. There is still a debate on the correct values for standard deviations of the paleontological number counts, so the absolute value of the \( \chi^2 \) significance is not important. What it is really important is the change of the significance when we include the oscillatory parameters. We see that there is a conspicuous increase of significance when we include the oscillatory parameters. For this last adjustment the best fit values are shown in Table IV together with independent 95\% confidence limits. The upper confidence limit of \( G_{\odot}/G_0 \) is about 0.009, which is the desired amplitude accounting for the red-shift 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) \( \dot{n}_i/n_{\circ}, \dot{\Omega}/\Omega \) and \( n_{\odot}/n_{\odot} \) agree with other estimates \([4]\). The phase \( \psi \) is consistent with the zero value proposed in \([5]\), 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 \([6]\) note that only upper bounds based on present observations are valid if \( G \) oscillates, so the much more stringent upper bounds of \([22,23]\) do not apply because they are also based in long-term (several oscillation periods) phenomena. In order to test the sensibility of the solution, we made the same adjustments using original data from several sources, as shown in Table II, including bivalves, corals, cephalopods, brachiopods and estromatolites and totalizing 61 points. As shown in Table II 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, paleontological growth rhythms are subject to large variations, and should be handled with care \([22,23]\). Secondly, 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 \([20]\). 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 \( G_{\odot}/G_0 < 0.01 \) (taken from the upper confidence limit of Table IV). The Hubble oscillating hypothesis is strongly testable because it predicts the same periodic patterns in all directions. Also, as stated by Morikawa \([4]\) both the density contrast and the distance to the nearest peak is not clear from the survey. Then it is worth making further deep-pencil surveys in the same and other directions in the sky. Summarizing, the coincidences which we observe in this work (coincidences may become

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TABLE I. Lambeck selection of counting and geological data.

| Geologic time [M.Y.] | Counting | Adopted S.D. | Organisms | Data type |
|-----------------------|----------|--------------|-----------|-----------|
| -300                  | 385      | 4.2          | corals    | da        |
| -320                  | 398      | 6            | corals    | da        |
| -370                  | 398      | 1.7          | corals    | da        |
| -420                  | 400      | 6            | corals    | da        |
| -440                  | 412      | 6            | corals    | da        |
| 0                     | 360      | 4            | corals    | da        |
| -370                  | 401      | 6            | corals    | da        |
| -370                  | 30.66    | 0.5          | corals    | dm        |
| -330                  | 30.2     | 0.4          | corals    | dm        |
| 0                     | 359      | 2.1          | bivalves  | da        |
| -70                   | 375      | 3.5          | bivalves  | da        |
| -220                  | 372      | 3.5          | bivalves  | da        |
| -290                  | 383      | 3.5          | bivalves  | da        |
| -340                  | 398      | 4.2          | bivalves  | da        |
| -360                  | 406      | 6            | bivalves  | da        |
| 0                     | 29.2     | 0.4          | bivalves  | dm        |
| -14                   | 29.4     | 0.5          | bivalves  | dm        |
| -38                   | 29.8     | 0.8          | bivalves  | dm        |
| -54                   | 29.6     | 0.6          | bivalves  | dm        |
| -70                   | 29.9     | 0.4          | bivalves  | dm        |
| -220                  | 29.7     | 0.6          | bivalves  | dm        |
| -300                  | 30.2     | 0.6          | bivalves  | dm        |
| -350                  | 30.4     | 0.6          | bivalves  | dm        |
| -445                  | 30.3     | 0.8          | bivalves  | dm        |
| -1                    | 14.75    | 0.14         | bivalves  | dm/2      |
| -4                    | 14.83    | 0.16         | bivalves  | dm/2      |
| -30                   | 14.82    | 0.09         | bivalves  | dm/2      |
| -48                   | 14.87    | 0.27         | bivalves  | dm/2      |
| -60                   | 14.82    | 0.17         | bivalves  | dm/2      |
| -100                  | 14.88    | 0.12         | bivalves  | dm/2      |
| -160                  | 14.90    | 0.18         | bivalves  | dm/2      |
| -230                  | 14.91    | 0.07         | bivalves  | dm/2      |
| -310                  | 15.09    | 0.17         | bivalves  | dm/2      |
| -370                  | 15.25    | 0.60         | bivalves  | dm/2      |
| 0                     | 12.3     | 0.17         | bivalves  | ma        |
| -70                   | 12.6     | 0.26         | bivalves  | ma        |
| -220                  | 12.6     | 0.26         | bivalves  | ma        |
| Geologic time [M.Y.] | Counting | Adopted S.D. | Organisms | Data type | Reference |
|----------------------|----------|--------------|-----------|-----------|-----------|
| -300                 | 385      | 4.3          | corals    | dy        | [28]      |
| -330                 | 398      | 6.1          | corals    | dy        | [28]      |
| -390                 | 397.6    | 1.8          | corals    | dy        | [28]      |
| -425                 | 400      | 6.1          | corals    | dy        | [28]      |
| -465                 | 412      | 6.1          | corals    | dy        | [28]      |
| 0                    | 360      | 3.1          | corals    | dy        | [28]      |
| -390                 | 401      | 6.1          | corals    | dy        | [28]      |
| -395                 | 410      | 4.5          | corals    | dy        | [28]      |
| -440                 | 421      | 6.4          | corals    | dy        | [33]      |
| -390                 | 30.63    | 0.11         | corals    | dm        | [29]      |
| -335                 | 30.2     | 0.15         | corals    | dm        | [31]      |
| -480                 | 30.7     | 0.23         | corals    | dm        | [32]      |
| -395                 | 31.5     | 0.45         | corals    | dm        | [32]      |
| -440                 | 32.4     | 0.64         | corals    | dm        | [32]      |
| -390                 | 13       | 0.29         | corals    | ma        | [32]      |
| -395                 | 13       | 0.2          | corals    | ma        | [32]      |
| -440                 | 13       | 0.29         | corals    | ma        | [32]      |
| 0                    | 359.3    | 1.6          | bivalves  | da        | [32]      |
| -70                  | 375      | 2.6          | bivalves  | da        | [32]      |
| -220                 | 371.6    | 3.6          | bivalves  | da        | [32]      |
| -290                 | 383      | 2.3          | bivalves  | da        | [32]      |
| -350                 | 398      | 1.8          | bivalves  | da        | [32]      |
| -390                 | 405.5    | 6.0          | bivalves  | da        | [32]      |
| 0                    | 29.22    | 0.08         | bivalves  | dm        | [32]      |
| -10                  | 29.52    | 0.08         | bivalves  | dm        | [32]      |
| -22                  | 29.42    | 0.15         | bivalves  | dm        | [32]      |
| -51                  | 29.7     | 0.09         | bivalves  | dm        | [32]      |
| -70                  | 29.85    | 0.10         | bivalves  | dm        | [32]      |
| -220                 | 29.66    | 0.15         | bivalves  | md        | [32]      |
| -290                 | 30.16    | 0.09         | bivalves  | dm        | [32]      |
| -350                 | 30.37    | 0.11         | bivalves  | dm        | [32]      |
| -390                 | 30.35    | 0.17         | bivalves  | dm        | [32]      |
| 0                    | 12.35    | 0.07         | bivalves  | ma        | [32]      |
| -70                  | 12.64    | 0.11         | bivalves  | ma        | [32]      |
| -220                 | 12.56    | 0.08         | bivalves  | ma        | [32]      |
| -1                   | 29.5     | 0.08         | bivalves  | dm        | [32]      |
| -5                   | 29.66    | 0.15         | bivalves  | dm        | [32]      |
| -30                  | 29.52    | 0.08         | bivalves  | dm        | [32]      |
| -45                  | 29.72    | 0.28         | bivalves  | dm        | [32]      |
| -60                  | 29.7     | 0.16         | bivalves  | dm        | [32]      |
| -100                 | 29.72    | 0.05         | bivalves  | dm        | [32]      |
| -170                 | 29.84    | 0.3          | bivalves  | dm        | [32]      |
| -220                 | 29.76    | 0.3          | bivalves  | dm        | [32]      |
| -325                 | 30.13    | 0.13         | bivalves  | dm        | [32]      |
| -400                 | 30.5     | 0.4          | bivalves  | dm        | [32]      |
| -70                  | 29.65    | 0.18         | bivalves  | dm        | [32]      |
| -70                  | 12.49    | 0.02         | bivalves  | ma        | [32]      |
| -320                 | 30.22    | 0.40         | cephalopods | dm      | [32]      |
| -410                 | 29.84    | 0.23         | cephalopods | dm      | [32]      |
| -310                 | 30.11    | 0.35         | cephalopods | dm      | [32]      |
| -395                 | 407.75   | 3.2          | brachiopods | da     | [32]      |
| -425                 | 419      | 4.5          | brachiopods | da     | [32]      |
| -395                 | 31.38    | 0.32         | brachiopods | dm     | [32]      |
| -425                 | 31.5     | 0.45         | brachiopods | dm     | [32]      |
| -395                 | 13       | 0.15         | brachiopods | ma     | [32]      |
| -425                 | 13       | 0.2          | brachiopods | ma     | [32]      |
| -540                 | 424      | 6.4          | estromatolites | da  | [32]      |
| -150                 | 30       | 0.64         | estromatolites | dm  | [32]      |
| Data source | number of adjusted parameters | $\chi^2$ significance |
|-------------|-------------------------------|-----------------------|
| Original    | 5                             | below 10%             |
| Original    | 8                             | below 10%             |
| Lambeck     | 5                             | 17%                   |
| Lambeck     | 8                             | 85%                   |

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

| Parameter | best fit value | confidence limits |
|-----------|----------------|-------------------|
| $\Delta n_0$ | $-1.3 \times 10^{-2}$ | $-2.5 \times 10^{-2}$ to $1.6 \times 10^{-3}$ |
| $\Delta n_1$ | $9.3 \times 10^{-3}$ | $-4.1 \times 10^{-2}$ to $5.9 \times 10^{-2}$ |
| $\Delta \Omega$ | $1.9 \times 10^{-3}$ | $-4.1 \times 10^{-3}$ to $7.9 \times 10^{-3}$ |
| $\dot{\Omega}$ ($10^{-11}$ yr$^{-1}$) | 16.4 | 12 to 20 |
| $\dot{\Omega}$ ($10^{-11}$ yr$^{-1}$) | 32.0 | 29 to 35 |
| $\psi$ | $6.5 \times 10^{-3}$ | $3.8 \times 10^{-3}$ to $9.2 \times 10^{-3}$ |
| period [10$^6$ yr] | 486 | 370 to 680 |
| $\psi$ | 0.27 | -0.53 to 0.83 |