

Cosmological dark matter and galactic periodicity

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ABSTRACT. We present an introductory review of the standard cosmological model in the framework of Einstein's theory of gravitation. We show that the standard model while succeeding in predicting many features of the evolution of the Universe, cannot, however, explain some other recent observations. In particular, some inconsistencies arise between the present values of the cosmological parameters, the age of the Universe, the nature of the so-called dark matter, and the standard inflationary prediction $\Omega = 1$. Neither can the standard cosmology explain the recent discovery of a galactic periodicity in pencil beam surveys. In this paper we review the alternative oscillating G model proposed as an explanation of this phenomena, and also as a candidate to reconcile the cosmological parameters with the cosmological dark matter problem.

RESUMEN. En este artículo presentamos un resumen introductorio del modelo cosmológico estándar en el contexto de la teoría de la gravitación de Einstein. Mientras que este modelo ha tenido éxito en predecir varios aspectos de la evolución del Universo, sin embargo, no logra explicar algunas observaciones recientes. Han surgido, particularmente, inconsistencias entre los valores actuales de ciertos parámetros cosmológicos, la edad del Universo, la naturaleza de la así llamada materia oscura y la predicción estándar del modelo inflacionario de $\Omega = 1$. La cosmología estándar tampoco puede explicar el reciente descubrimiento de la periodicidad galáctica. En este artículo presentamos un resumen del modelo alternativo con G oscilante que ha sido propuesto para explicar este fenómeno y también como un candidato para reconciliar las discrepancias entre los parámetros cosmológicos y el problema de la materia oscura cosmológica.

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1. INTRODUCTION

The way we study our Universe depends very closely on the scales of our observations. While observations of the distribution of galaxies show galaxy clustering on a wide range of distance scales, on the largest scales the galaxy distribution appears to be homogeneous and isotropic. These important properties mean that there are no preferred points or preferred directions in our Universe. Moreover, at the largest scale of observations, galaxy clusters have to be considered as "points" in our Universe without any internal

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structure. Homogeneity and isotropy are the starting properties used in the construction of modern cosmological models. The assumption of these properties has come to be known as the *Cosmological Principle*. As far as present-day observations are concerned, there are no compelling indications to abandon this principle. It should be emphasized that homogeneity and isotropy are properties of our Universe at a fixed time, *i.e.* they are characteristics of the spatial sections of the spacetime.

One important implication of our global consideration of the Universe is that at large scales the interaction that governs the dynamical behavior of the components (galaxy clusters, galaxies, etc.) of the Universe is gravitation. Of course, there exist also local effects in which the electromagnetic field plays an important role, but at the largest scales of observations all such effects other than the gravitational ones are negligible. Thus, in order to describe the dynamics of the Universe we need a theory of gravitation which allows us to take into account its main properties. The most viable candidate for a such theory is Einstein's theory of relativity since it has shown in all experiments that it describes the gravitational interaction with the best accuracy.

In Einstein's theory, the spacetime is a 4-dimensional pseudo-Riemannian manifold described by the metric tensor $g_{\mu\nu}$ ($\mu, \nu = 0, 1, 2, 3$), and the mathematical structure of the main field equations follows by applying a variational principle to the Einstein-Hilbert Lagrangian $\mathcal{L}_{EH} = \sqrt{-g} R/16\pi G_0$, where g is the determinant of the metric tensor and R is the curvature scalar associated with spacetime (for more detailed descriptions of the mathematical and physical aspects of general relativity see, for instance, Ref. 1). Einstein's field equations can be written as

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R = 8\pi G_0 T_{\mu\nu}, \quad (1)$$

where $R_{\mu\nu}$ is the Ricci curvature tensor, $T_{\mu\nu}$ is the energy-momentum tensor associated with the source of the gravitational field, and G_0 is the Newtonian gravitational constant. Here we use geometrical units in which $c = 1$. As we can see, the left-hand side of Einstein's equations is completely related to the geometrical structure of spacetime, while the right-hand side contains the information about the structure and behavior of the matter which acts as the source of gravity.

As we mentioned above, in the case of our Universe the source of gravity are the "massive points" (clusters, galaxies, etc.) observed at large scales. Since in the approximation considered here, there is no interaction between those "points" other than the gravitational one and collisions between them are extremely rare, we can consider our Universe as a perfect fluid which is described by its energy density e and pressure p . The corresponding energy-momentum tensor is then given by

$$T_{\mu\nu} = (p + e)U_\mu U_\nu + p g_{\mu\nu}, \quad (2)$$

where U_μ represents the 4-velocity of the fluid particles.

Under the assumption of the Cosmological Principle, the solution of Einstein's equations (1) with a perfect fluid (2) as source is the foundation of the so-called standard cosmological model, which we will briefly describe in Sect. 2. In the following Sects. 3 and 4,

we present the results of recent observations of our Universe which seem to imply the existence of a new type of matter (dark matter) and to contradict the Cosmological Principle, respectively. Finally, in Sect. 5 we analyze a model in which an additional scalar field contributes to the total energy of the Universe and therefore generates the missing (cosmological) dark matter, needed to reconcile the observational value ($\Omega_{\text{bar}} \approx 0.01$) and the inflation prediction ($\Omega = 1$) without violating the Cosmological Principle.

2. THE STANDARD COSMOLOGICAL MODEL

The metric for a spacetime with homogeneous and isotropic spatial sections is the Friedman-Robertson-Walker (FRW) line element, which can be written in the form

$$ds^2 = -dt^2 + a^2(t) \left[\frac{dr^2}{1 - kr^2} + r^2 (d\theta^2 + \sin^2 \theta d\varphi^2) \right], \quad (3)$$

where t , r , θ , and φ are the comoving coordinates of spacetime, $a(t)$ is the so-called cosmic scale factor, and k is a constant which, with an appropriate rescaling of the coordinates, can be chosen to be $+1$, 0 , or -1 for spaces of constant, zero or negative spatial curvature, respectively.

Under the assumption that the perfect fluid preserves the symmetries of spacetime (homogeneity and isotropy), Einstein's field equations lead to

$$H^2 + \frac{k}{a^2} = \frac{8\pi}{3} G_0 e, \quad \frac{2\ddot{a}}{a} + H^2 + \frac{k}{a^2} = -8\pi G_0 p, \quad (4)$$

where a dot represents differentiation with respect to the cosmic time t , and $H = \dot{a}/a$ is the Hubble parameter which determines the expansion rate of the Universe. From Eqs. (4) it follows an expression for the acceleration, namely $\ddot{a} = -4\pi G_0(p + e/3)a$. Observations show that today $a > 0$, and if in the past $p + e/3$ was always positive, then $\ddot{a} < 0$. This means that at some moment in the past the cosmic scale factor $a(t)$ must have vanished. This event is usually referred to as the *Big Bang*, and it corresponds to a singularity (divergence) of the curvature of spacetime. Since an extrapolation to events occurring before the singularity is impossible in the framework of Einstein's theory, it is convenient to identify the Big Bang as an event at $t = 0$.

The conservation law $T^{\mu\nu}_{;\nu} = 0$ for the perfect fluid gives an additional equation $(ea^3) + p(a^3) = 0$ which implies a relationship between the two Eqs. (4). A further equation is needed in order to close this system of differential equations, namely the equation of state which relates the energy density e and the pressure p of the fluid. One of the simplest examples is that of a barotropic equation of state for which $p = (\gamma - 1)e$, where γ is a constant. Once it is given, the Einstein equations may be integrated yielding different expressions which depend on the specific values of the constants k and γ . For reasons we will explain below, we will consider here only the case of a conformally flat

Universe ($k = 0$). In this case we obtain the following dependence

$$e = 3p, \quad e \propto a^{-4}, \quad a \propto t^{1/2}, \quad \text{radiation} \quad (5)$$

$$p = 0, \quad e \propto a^{-3}, \quad a \propto t^{2/3}, \quad \text{collisionless matter} \quad (6)$$

$$e = -p, \quad e \propto \text{const.}, \quad a \propto e^t, \quad \text{vacuum.} \quad (7)$$

Equations (5) and (6) indicate that the early Universe was dominated by radiation, and we know from observations that today matter plays the most important role in the cosmological evolution. The epoch (if any) during which the evolution was dominated by the vacuum energy is known as the inflation era.

The nature of the early Universe can be understood qualitatively from the fact that the decrease of the scale factor $a(t)$ as one goes back into the past leads to a contraction of the matter so that the contribution of radiation compared with ordinary matter increases in the past. The energy density of the cosmic microwave radiation today is about 10^4 times smaller than the ordinary matter density. If we assume that this radiation continues to exist in the past and consider a scale factor 10^4 times smaller than its value today, then, according to Eqs. (5) and (6) the radiation should have been the dominant part of the total energy density of the Universe. As the scale factor becomes smaller, the matter and radiation in the Universe gets hotter and, finally, they become infinitely hot as $a(t)$ approaches zero. This simple observation turns out to be the basis for the formulation of the thermal history of the Universe. It is even possible to predict the density of several light elements in the Universe (for more details see, for instance, Ref. 3).

The standard cosmological model provides a reliable and tested account of the history of the Universe from at least as early as the time of the synthesis of light elements (nucleosynthesis era), corresponding to $t \approx 10^{-2}$ to 10^2 sec, until today, $t \approx 11.5$ Gyr. Nevertheless, the model leaves among others the important question open: why is our Universe so isotropic and homogeneous? The observation of the cosmic microwave radiation shows a high degree of isotropy. If one considers the two most distant observable points in the Universe, and goes back into the past, it turns out that those points could not be causally connected when the light we see today was emitted from there. The question emerges: how is it then possible that those points have the same temperature (associated with the microwave radiation) if they were never causally connected? The solution to this problem comes from the so-called inflationary model according to which our Universe has gone through an inflationary era, making causally connected all observable points in the Universe.

An important prediction of the inflationary model is that the total energy density of the Universe equals the critical value $e_c = 3H^2/8\pi G$, which corresponds to a flat space ($k = 0$). Usually, the densities are expressed in terms of e_c and denoted by Ω , *i.e.*, $\Omega_{\text{bar}} = e_{\text{bar}}/e_c$, etc. In this work, we assume the predictions of the inflationary model and, therefore, we will deal only with the flat case of the FRW metric as mentioned above.

In the following Sections we will discuss the results of recent observations which have no explanation in the context of the standard cosmological model described above.

3. THE DARK MATTER PROBLEM

There are strong indications from different observations for the existence of a large amounts of dark matter in the Universe: that is, matter whose existence has been inferred only through its gravitational effects. There exist also several indications that at least a part of this dark matter has a nonbaryonic nature, *i.e.*, its components are other than electrons, protons, and neutrons.

The strongest evidence for the existence of dark matter in the Universe comes from the analysis of the dynamics of stars in spiral galaxies. In these observations, the circular velocity v_c of hydrogen clouds surrounding the galaxy is measured in terms of the radius r to the center of the galaxy. According to the gravitational laws, if there were no dark matter, at large r we would measure $v_c^2 \approx G_0 M_{\text{vis}}/r$, because the visible mass M_{vis} of a galaxy is concentrated at its center. Nevertheless, observations of a large number of spiral galaxies show at large r a rotational velocity which is independent of the radius, leading to the well-known flat rotation curves. This result implies that the total mass within a given radius grows linearly with r . The measurements of rotation curves imply a total mass within this radius which is typically about ten times the visible mass. Other indications of the presence of dark matter come from the observations of the motion of galaxies and hot gas in clusters of galaxies [2].

The most dramatic indication of the insignificance of ordinary matter, relative to the total matter content of the Universe, comes from the inflationary scenarios which predicts that the sum of all contributions to the average energy density of the Universe exactly equals the critical value e_c . Since the observed ordinary matter is of the order of 1% of the critical value, there must be a large amount of dark matter. Moreover, this dark matter must be mostly exotic since it cannot consist of radiation or baryonic matter. This conclusion results from the dependence on the baryonic energy density of the predicted values of the relative primordial abundances of light elements (${}^7\text{Li}$, ${}^3\text{He}$, D, etc.) in Big Bang nucleosynthesis. This restricts the value of the baryonic energy density to lie in the range $(1.5 \pm 0.5)h^{-2}\%$ of the critical value, where h is the Hubble parameter in units of $100 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

Cosmologists and particle physicists have long been puzzled about what this exotic matter might be [4]. The main models can be divided in two categories. The first one is called hot dark matter which consists of light neutrinos or a similar species, *i.e.* massive particles whose number density was determined during an epoch in which they still may be considered as relativistic particles. The cold dark matter models consist of all the remaining weakly interacting massive particles like axions, neutralinos, superheavy monopoles, primordial black holes, etc. These particles were already non relativistic when their number density reached a state of equilibrium in which annihilations freezes out. No independent evidence for the existence of these new types of matter has so far been found.

In Sect. 5 we present evidence supporting a model in which the missing cosmological energy density corresponds to a scalar field.

4. GALACTIC PERIODICITY

The recent observations, in deep pencil beam surveys [6], showing that the galaxy number distribution exhibits a remarkable periodicity of $128h^{-1}$ Mpc comes as a shocking development, since, if taken at face value it would imply that we live in the middle of a pattern consisting of concentric two-spheres that mark the maxima of the galaxy number density. This, of course, would be catastrophic for our cosmological conceptions based on the standard cosmological model. While it is true that such periodicity has been observed only in the few directions that have been explored so far, it would be a striking coincidence if it turns out that it is absent in other directions and we just happen to have chosen to explore the only directions in which that phenomenon occurs. Therefore it seems reasonable to assume that the periodicity is also present in the deep pencil beam surveys in other directions, thus taking us to the concentric spheres scenario.

The only known way out of this type of scenario, is to assume that there is only an apparent spatial periodicity that is the result of a true temporal periodicity which shows up in our observations of distant points in the Universe and that is mistakenly interpreted as a spatial periodicity [16]. The specific models that have been proposed involve the oscillation of the effective electric charge, electron mass, galaxy luminosity or gravitational constant [16, 18, 15, 19]. From these the first two have been shown to conflict with bounds arising from the test of the *Equivalence Principle* [8]. As for the third scenario, it would seem to involve a large number of hypothesis since the galactic luminosity is fixed by the number and type of stars present in the galaxy and their respective luminosities, and the later are themselves, functions of the standard physics coupling constants that control nuclear reaction rates, and of the transport mechanisms.

In light of the complicated nature of the alternative scenarios, it seems worthwhile to carry out a careful analysis of the viability of the oscillating gravitational constant model, despite the difficulties that seem to appear when confronting the predictions of the model with other experimental data. We will address these difficulties below.

5. THE OSCILLATING G MODEL

We will consider a model in which the effective gravitational constant becomes dependent on cosmic time due to a contribution to it coming from the expectation value of a scalar field. This can be achieved by considering a scalar field ϕ non-minimally coupled to gravity. One of the simplest models of this kind is obtained by taking a Lagrangian as follows

$$\mathcal{L} = \left(\frac{1}{16\pi G_0} + \xi\phi^2 \right) \sqrt{-g} R - \sqrt{-g} \left[\frac{1}{2} (\nabla\phi)^2 + m^2\phi^2 \right] + \mathcal{L}_{\text{mat}}. \quad (8)$$

Here ξ is the non-minimally coupling constant, and m is the mass associated with the scalar field ϕ . In this model we are also including an schematic matter Lagrangian \mathcal{L}_{mat} . Equation (8) shows that the introduction of the coupling term is equivalent to considering an effective gravitational constant which explicitly depends on the scalar field:

$$G_{\text{eff}} = \frac{G_0}{1 + 16\pi G_0 \xi \phi^2}. \tag{9}$$

The gravitational field equations following from the Lagrangian (8) can be written as

$$R^{\mu\nu} - \frac{1}{2}g^{\mu\nu}R = 8\pi T_{\text{eff}}^{\mu\nu}, \tag{10}$$

where

$$T_{\text{eff}}^{\mu\nu} = G_{\text{eff}} \left(4\xi T_{\xi}^{\mu\nu} + T_{\text{sf}}^{\mu\nu} + T_{\text{mat}}^{\mu\nu} \right), \tag{11}$$

$$T_{\xi}^{\mu\nu} = \nabla^{\mu}(\phi \nabla^{\nu} \phi) - g^{\mu\nu} \nabla_{\lambda}(\phi \nabla^{\lambda} \phi), \tag{12}$$

$$T_{\text{sf}}^{\mu\nu} = \nabla^{\mu} \phi \nabla^{\nu} \phi - g^{\mu\nu} \left[\frac{1}{2}(\nabla \phi)^2 + m^2 \phi^2 \right]. \tag{13}$$

The energy-momentum tensor of “matter” $T_{\text{mat}}^{\mu\nu}$ will be composed of a combination of two non-interacting perfect fluids, one corresponding to pure baryonic matter ($i = 1$) and the other one representing a pure radiation field ($i = 2$):

$$T_{\text{mat}}^{\mu\nu} = T_{\text{bar}}^{\mu\nu} + T_{\text{rad}}^{\mu\nu} = \sum_{i=1,2} [(p_i + e_i)U^{\mu}U^{\nu} + p_i g^{\mu\nu}], \tag{14}$$

which possesses the symmetries of the spacetime. The scalar field will also be assumed to posses these symmetries.

Finally, the equation of motion for the scalar field becomes

$$\square \phi + 2\xi \phi R = 2m^2 \phi. \tag{15}$$

Our purpose is to study the behavior of the solutions of the gravitational, matter and scalar field equations for the FRW line element (3). Since these equations are highly non linear, it is a difficult task to find analytic solutions; therefore, we will approach the problem via a numerical analysis.

We will moreover assume that the two-perfect fluid components (baryons and photons) do not interact among themselves, thus each of their corresponding energy-momentum tensors is separetely conserved leading to $\dot{e}_i + 3(e_i + p_i)\dot{a}/a = 0$. This equation integrates immediately with respect the scale factor like in the standard cosmology case. We find then

$$e = e_{\text{bar}} + e_{\text{rad}} = \Omega_{\text{bar}} \left(\frac{a_0}{a} \right)^3 + \Omega_{\text{rad}} \left(\frac{a_0}{a} \right)^4, \tag{16}$$

$$p = p_{\text{bar}} + p_{\text{rad}} = \frac{c_2}{3} \left(\frac{a_0}{a} \right)^4, \quad \text{with } a_0 := a(t = t_0). \tag{17}$$

Here we have assumed an equation of state $p_{\text{rad}} = e_{\text{rad}}/3$ for the radiation part, whereas $p_{\text{bar}} = 0$ for the corresponding baryonic component.

Our analysis consists in evolving the scale factor, the scalar field and the ordinary matter densities backwards and forwards in cosmic time using the field equations, and starting from the model parameters ξ and m , and data corresponding to today's values of H_0 , Ω_{bar} , Ω_{rad} , ϕ_0 and $\dot{\phi}_0$. With these initial conditions it is then possible to integrate the field equations numerically.

The constants Ω_{bar} and Ω_{rad} are fixed by the "initial" conditions which we choose as their value at present time (t_0). In particular, Ω_{rad} will be chosen to correspond to the 2.73°K cosmic background radiation. The total energy density of the Universe will be then given by the sum of all components, *i.e.*, $\Omega = \Omega_{\text{bar}} + \Omega_{\text{rad}} + \Omega_\phi$. Since we will work within the standard inflationary model, so $\Omega = 1$ for the total energy density of the Universe, and Ω_{rad} is several orders of magnitude smaller than Ω_{bar} , the fixing of Ω_{bar} is equivalent to the fixing of Ω_ϕ .

The initial condition (today) for the time derivative of the scalar field $\dot{\phi}_0 = 0$ was fixed so that it satisfies the Viking radar echo experiments [14, 9]. The initial condition ϕ_0 as well as the value of the coupling constant ξ turn out to be expressible in terms of the values of the amplitude \mathcal{A}_0 , the oscillation frequency ω of the scalar field and the parameter Ω_ϕ . The parameter \mathcal{A}_0 corresponds to the modulation factor which relates the red shift in presence of oscillations with that in absence of oscillations. Observations yield a value of \mathcal{A}_0 of about 0.5 (in fact, it has been argued that $\mathcal{A}_0 \geq \mathcal{O}(0.5)$ [9]), while the observed galactic periodicity of $128 h^{-1}$ translates into the value $m \sim 10^{-31} \text{eV}$ for the scalar-field mass [9, 15].

A potential problem for the model arises from the bound imposed by nucleosynthesis. The standard cosmological model predicts the abundance of several light elements that we can observe today. In fact, there exists a very narrow range for which the expansion rate of the Universe and the transition rate of the weak interaction, which converts neutrons to protons, lead to a freeze-out temperature that reproduces the observed abundance of ${}^4\text{He}$. Therefore, the nucleosynthesis bound translates itself into a limit on the deviation of the expansion rate of the Universe from the value imposed by the standard model.

We have seen in Ref. 11 that when we numerically integrate the field equations backwards in time, the scalar field goes to $\pm\infty$ depending on the initial data (Fig. 1). This suggested that there must exist a specific initial data for which the scalar field ϕ will remain steady and close to zero during an early epoch of the history of the Universe. This "steady state" is represented by a kind of plateau during which $G_{\text{eff}} \rightarrow G_0$ [11]. It was possible to correlate the length of this plateau with the recovery of the precise freeze-out temperature which determines the primordial abundance of the light element ${}^4\text{He}$. The larger the plateau the closer the freeze-out temperature predicted by the oscillating model approached the value 0.7 MeV.

The search for that specific initial data is what we call "*fine-tuning*" and it turns out that this can be done by adjusting only the parameters \mathcal{A}_0 and Ω_{bar} . In principle it is possible to extend the plateau of ϕ to the nucleosynthesis era or even to earlier eras by improving the fine tuning of the values of Ω_{bar} or \mathcal{A}_0 . While this fine tuning is completely unnatural when approached, as we have approached to it, from the present to the past, when looked from the opposite, and more natural direction, the situation

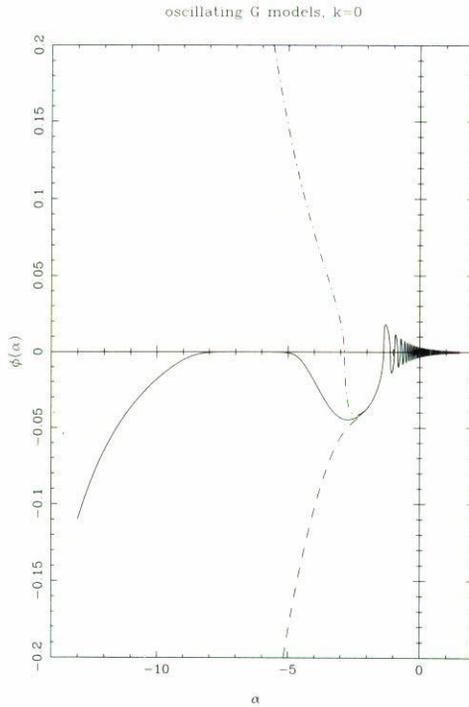


FIGURE 1. Behavior of the scalar field for three different values of Ω_{bar} and $\Omega = 1$ (inflationary scenario). Here we use the time coordinate $\alpha = \ln[a(t)/a_0]$. The solid line represents the best adjustment with $\Omega_{\text{bar}} = 0.021\,012\,641$; the dashed line corresponds $\Omega_{\text{bar}} = 0.022$ (upper line) $\Omega_{\text{bar}} = 0.020$ (lower line).

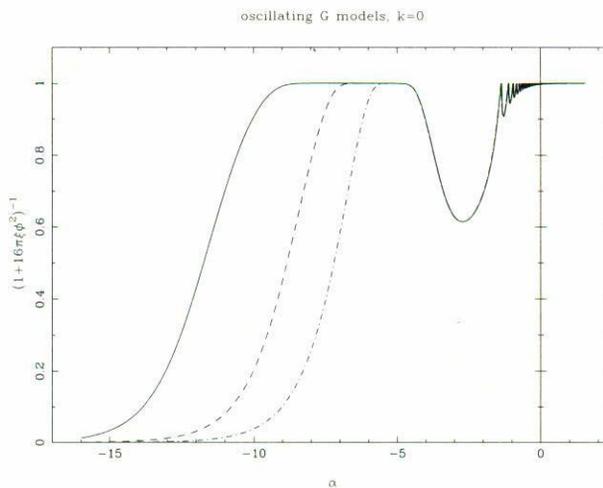


FIGURE 2. Behavior of the effective gravitational constant (G_{eff}/G_0) for three different values of Ω_{bar} which are very closed to the best adjustment of Fig. 1.

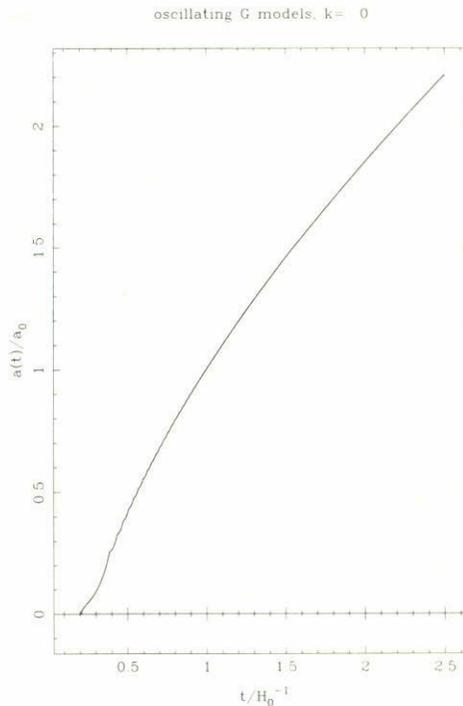


FIGURE 3. Behavior of the scale factor of the oscillating G model, corresponding to the data of previous figures, in terms of cosmic time (t/H_0) and in units of its value today.

is quite different. In fact all that seems to be required is for some mechanism to drive the scalar field to an extremely low value before the era of nucleosynthesis. Then, as our calculations show, the field will remain at that value up to and beyond that era so that we will have $G_{\text{eff}} \approx G_0$ and then the success of “Big Bang Nucleosynthesis” will be recovered naturally. The value of the field ϕ will later be amplified by the curvature coupling just before the onset of oscillatory behavior (see Fig. 1). As we argued in Refs. 11 and 12 this fine tuning is then just a procedure that becomes necessary in order to recover the observational data extracted from our Universe today.

If we use Ω_{bar} as a “shooting parameter”, the model will describe the periodicity in the galactic number distribution if the emerging value of \mathcal{A}_0 coincides with the value following from observations. In fact, in Ref. 11 we fixed the value $\mathcal{A}_0 = 0.5$ and then used different values of Ω_{bar} in order to obtain the desired behavior of the scalar field which corresponds to the plateau behavior. We obtained the value of $\Omega_{\text{bar}} \approx 0.021$ (see Fig. 1) which turns out to lay for $h = 1$ in the very narrow range $0.016 \leq \Omega_{\text{bar}} \leq 0.026$ that results in a succesful nucleosynthesis of the light elements other than ${}^4\text{He}$. The age of the Universe corresponding to this case turns out to be $\approx 0.8H_0^{-1}$ (see Fig. 3), a value which lies under the lower limit allowed by observations. However, a more detailed analysis shows that the parameters entering the oscillating G model can be chosen such that the predicted age of the Universe is within the observational range [13].

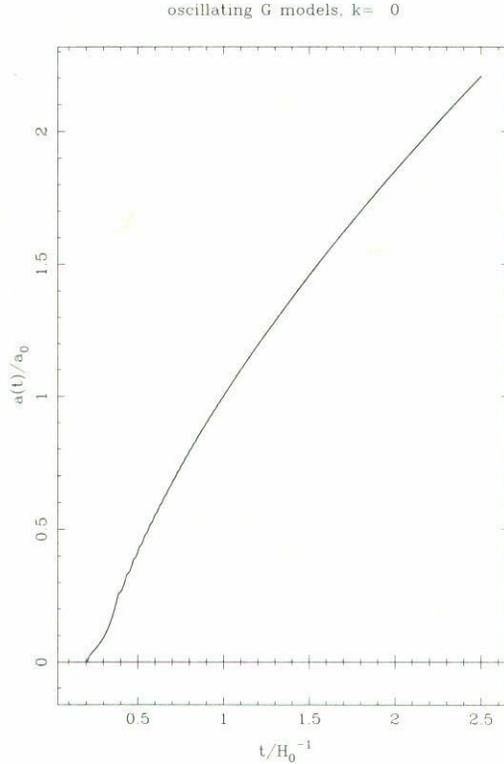


FIGURE 4. The Hubble parameter as a function of red-shift $z(t)$. The initial value H/H_0 corresponds to $z_0 = z(t_0)$.

In Fig. 4 we show the typical behavior of the Hubble parameter in terms of the redshift $z(t)$. This implies that the oscillating G model is compatible with some of the most important cosmological bounds and at the same time is able to explain the observed galactic periodicity.

Specifically, the model assigns approximately 98% of the energy density of the Universe to the scalar field Ω_ϕ which can consequently be interpreted as the energy density of the missing cosmological dark matter.

Summarizing our results, we have shown that the central feature of the oscillating G model is a cosmological massive scalar field non-minimally coupled to gravity, which oscillates in cosmic time. The behavior of the effective gravitational “constant” G_{eff} is determined by the expectation value of ϕ and, therefore, oscillations of ϕ induce oscillations in G_{eff} [11] (see Fig. 2). In this way the spatial periodicity reported in [6] is explained as just an illusion that results from a true temporal periodicity induced by the oscillation in cosmic time of the effective gravitational constant. In other words, this temporal periodicity influences our observations of distant points in the Universe and is mistakenly interpreted as spatial periodicity.

In the context of this model, the cosmological dark matter is represented by the energy density of the scalar field Ω_ϕ , and we have argued that the observed periodicity

in the distribution of galaxies can be considered as an indication of the existence of that scalar field.

Finally, let us mention that it is necessary to perform a more detailed analysis of the model in order to see if it satisfies simultaneously the most important cosmological tests: i) the constraints imposed by nucleosynthesis; ii) the present energy density of baryonic matter Ω_{bar} and iii) the age of the Universe. This is a highly non trivial task which has been considered elsewhere [12, 13].

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