A Steady Flow Cosmological Model from a Minimal Large Numbers Hypothesis

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Assuming a minimal version of the Large Number Hypothesis, we explore the possibility that the cosmological constant has decayed with time and define a cosmological parameter, depending of the vacuum energy and the universe scale, which should be presently ca. 10^{122} times smaller than at the Planck epoch. From it, a short version of the Friedmann equation for a flat and spatially infinite universe is obtained, which allows the estimation of the Hubble parameter at any epoch. The obtained result is a linear expansion dynamics in concurrence with a number of previous works, including a Steady Flow model, whose main features are compared with the Concordance model. The resultant model is devoid of the horizon, flatness, cosmological constant, coincidence and age problems without the need of either inflation or initial fine-tuning. It agrees with the main features of observational cosmology including the supernovae results, cosmic background radiation anisotropy, angular size–redshift relation, gravitational lensing, X-Ray and gamma ray bursts data, and accommodates old high redshift objects. On the other hand, it agrees with the standard model as regards to primordial nucleosynthesis, cosmic recombination, expansion time and temperature evolution with the scale factor.

Keywords: cosmological parameters; cosmology: observations; cosmology: theory; distance scale; early Universe.

1. Introduction

In 1917 Einstein introduced a cosmological constant (Λ) in the field equations of general relativity (GR) in order to allow for a static universe incorporating Mach's principle. When Hubble discovered his fundamental law describing the universal expansion, Λ was not needed anymore, and Einstein discarded it. The classical Big Bang model postulates the creation of space, time, matter and energy from a singularity. During decades the expansion of the universe was assumed to be decelerated by gravitation and the Einstein–de Sitter model without Λ was favoured as the standard cosmology (see e.g. curve Ω_M=0.3 in Figure 1). However, measurements of type Ia supernovae (SNe Ia) show that they look fainter than expected by such a model (Perlmutter et al.1998; Riess et al. 1998 2001; Tonry et al. 2003; Wang et al. 2003). In order to fit these observations within a new standard model, Λ has been reintroduced in the Friedmann equations and a repulsive dark energy, derived from the concept of cosmological constant, has been postulated to fuel an accelerated expansion of the universe in our epoch. This energy has been identified with the vacuum energy on theoretical grounds, but both energies are 122 orders of magnitude apart and the true nature of dark energy is one of the major challenges of modern cosmology.

In the meantime, the Inflationary model (Guth and Lightman 1997) was constructed, in order to solve old issues of the Big Bang

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such as the horizon, flatness and initial fine-tuning problems (Hu et al. 1994, Ellis 2000), by means of a scalar field whose vacuum energy essentially plays the role of a time-varying Λ. Inflation proposes that an extremely fast exponential acceleration of the expansion took place for a very small fraction of a second after the Big Bang. Very shortly after, the expansion decayed to a decelerated Hubble flow.

So, the current standard model gives a quite intricate picture for the dynamics of the universe: an inflationary period right after the initial creation event, with a extremely fast acceleration, followed by a long lasting deceleration era (including 2 different expansion regimes depending on radiation or matter dominance) and, since redshift $z \sim 1$, a new acceleration era, much slower (see upper curve of Fig. 1). In this description the role of Λ, in its different versions, is still unclear since it appears and disappears as required, not only in cosmic history but also in the history of physics. Nevertheless, the important number of works on the subject (Sahni and Starobinsky 2000), along with a possible relationship between a small cosmological constant today and a large cosmological term driving inflation at an early epoch, advise taking seriously the case for a $\Lambda > 0$.

1.1. The Large Numbers Hypothesis

The history of the so-called large numbers hypothesis (LNH) begins about eight decades ago, when Eddington noted that two large dimensionless numbers that characterise our universe are approximately equal, namely:

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$$\alpha' = \frac{e^2}{Gm_e m_n} \approx 10^{40} \qquad (1)$$

$$\beta = \frac{ct_0}{e^2 / m_e c^2} \approx 10^{40}, \qquad (2)$$

where e and m_e are the electron charge and mass, t_0 is the present age of the universe and m_n refers to the mass of a nucleon. The first of these numbers is the ratio between the electromagnetic force by which a proton attracts an electron and their respective gravitational attraction force, whereas the second number is the ratio between the size of the observable universe and the classical radius of an electron. This coincidence was regarded by most researchers as fortuitous, while a few others, leaded by Dirac, attributed a relevant paper to it, up to the point of proposing a cosmological theory based on this LNH and postulating a varying $G \propto t^{-1}$ (Singh 1974). In spite of its elegant features, Dirac's LNH turns out to be incompatible with the tight experimental constraints that exist on the time variation of G (Williams 1996; Uzan 2003).

However the original LNH is not the subject of the present work. Different authors have introduced new sets of dimensionless numbers in a similar way to the original coincidence considered by Dirac and his contemporaries. Various numbers of the order of 10^{60} have been obtained by Shemi-Zadeh (2002) through measuring cosmological parameters in Planck units. The relevance of the Planck scale to LNH was also shown by Marugan and Carneiro (2002), who claimed that the relations between large numbers can be explained by the holographic principle assuming that the present energy density is dominated by Λ. Other authors have discussed the significance of yet a bigger number, ca. 10^{120}, which is clearly related to 10^{60}. Weizsaecker obtained both big numbers from his interpretation of

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quantum theory in terms of information and identified 10^{120} with the sum of elementary bits of information in the universe (Lyre 2003). Görnitz (1986), building on Weizsaecker's work, proposed an interpretation for large numbers coincidences in the context of Bekenstein-Hawking entropy, which allowed the theoretical estimation of the number of nucleons within the observable universe (ca. 10^{80}). Furthermore, the ratio of the mass-energy in the observable universe to the energy of a photon with a wavelength ct_0 can be easily calculated to be about 10^{121}.

This large number is also the ratio of the estimates of the energy density of the vacuum and the current value of Λ obtained from cosmological data, which corresponds in round numbers to 10^{-9} Jm^{-3}. At a theoretical level, a cosmological constant is expected to arise out of zero-point quantum vacuum fluctuations of several fundamental fields. In Quantum Field (QF) theory, these fluctuations would have Planck energy density, i.e. about 10^{113} Jm^{-3}. So, the discrepancy between theoretical expectations and empirical observations is, again, of 122 orders of magnitude. Such a huge gap constitutes the cosmological constant problem, a fundamental difficulty at interface of astrophysics, cosmology and quantum physics (Weinberg 1989, Sahni and Starobinsky 2000). Remarkably, Matthews (1997), while reviewing Dirac's LNH, associated 10^{120} with a scaling law for the cosmological constant, but to date this has not been accepted as a definitive solution.

As a related issue, the cosmic coincidence problem wonders why the density of matter, which decreases as the universe expands, and Λ, assumed to be constant, are comparable particularly at present times. The radiation energy density and the Λ energy density should be fine-tuned to an accuracy of better than one part in 10^{120} at the Planck time in order to ensure this coincidence (Padmanabhan 2003, Peebles and Ratra 2003). This problem also remains unsolved.

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The purpose of this paper is showing that the assumption of a scaling law for the cosmological constant, derived from a minimal LNH, leads to an important simplification of the expansion dynamics of the universe in agreement with a Steady Flow model, which was already introduced in a previous paper (Casado 2009). Though this postulate could be seen as artificial, the introduction of a cosmological constant was not less artificial. Thus, it would be not legitimate to set aside this possibility without a previous analysis of it. Anyway, the aim of this paper is to study the consequences of the postulate rather than to justify it a priori. This work does not try to explain a new LNH, but to extract some relevant cosmological information from it. Therefore, we will briefly study how our hypothesis influences some of the most salient features of cosmological interest. In section 2 we justify such a minimal LNH and define a cosmological parameter depending of the universe scale. In section 3 the Friedmann equation is simplified for the case of a flat and spatially infinite universe and the value of the Hubble parameter is obtained from it. In section 4 the main features of the Steady Flow model are recapitulated and compared with the Concordance model and with some non-standard models, and in Section 5 we check the models against actual observational results. Finally, section 6 summarizes the conclusions of this work.

2. A minimal LNH and a cosmological parameter Λ_R

In a previous paper (Casado 2004) the author obtained 3 pure numbers of order 10^{61} and 5 additional numbers of order 10^{122}, all of them derived from relations between the cosmic scales, set by the radius, R_0, the mass, M_0, and the age, t_0, of the observable universe at

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present, and the quantum scales given by natural Planck units, namely:

$$\frac{R_0}{l_p} \approx \frac{t_0}{t_p} \approx \frac{M_0}{m_p} \approx 10^{61}, \tag{3}$$

and showed that these order-of-magnitude ratios can be valid for both the standard model and a model postulating a decreasing speed of light. Although the cited big numbers were discussed in the framework of this naive model, two conclusions stay on:

(i) The entropy of the universe is, once again, 10^{122} in units of Boltzmann constant, as calculated using the Bekenstein-Hawking formalism and the holographic principle.

(ii) So many coincidences allow an interpretation of them as a natural connection of quantum and cosmic scales, i.e. quantum microphysics could also determine some properties of the whole cosmos.

Later on, Sidharth (2005) interpreted the universe as a collection of ca. 10^{120} Planck oscillators. The fact that the number 10^{122} can be represented in such a variety of ways has been considered as a new LNH by Funkhouser (2008), who claimed to have resolved these coincidences without departing from the standard cosmology.

It is indeed tempting to attribute to this unique number, probably the largest dimensionless constant with a physical meaning, a relevant significance in cosmology. For instance, it coincides with the maximum number of elementary quantum logic operations that the universe can have performed, as independently calculated by Lloyd (2002) using the Margolus-Levitin theorem.

Although some of these large numbers of order 122 are not independent, they all do resemble each other to an extent which allows us to conjecture a deeper underlying principle or connection. If we assume that the pure numbers coincidence above described is a

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result of some fundamental physics rather than mere chance alone, it seems judicious to explore if these numbers are providing some significant information on the nature of our universe. This LNH only assumes a direct connection between quantum physics, related to Planck units, and cosmology. At present, this cannot be shown a priori from any existing theory, but its formal elegance invites to pay some attention to its possible consequences. Notice that the present discussion is self-restricted to cosmological parameters and Planck units, disregarding particle masses, charges, radius or the fine structure constant, which have been frequently involved in previous works on other LNH. That's why the present conjecture can be considered as a *minimal* LNH.

Particularly, the possibility that Λ could be a scale dependent quantity is analysed in here in the light of such a LNH. In fact, some QF and quantum gravity theorists have been treating Λ as a dynamical quantity for decades (e.g. Bergmann 1968, Bertolami 1986). According to eq. (3), 10^{61} is the order-of-magnitude ratio between the radius of the universe R_0 -both the apparent and the Hubble horizons coincide for flat FRW models (Marugan and Carneiro 2002)- and the Planck length l_p, usually identified with the size of the observable universe at the Planck epoch. It seems natural that $10^{122} = (10^{61})^2 = (R_0 lp^{-1})^2$ could be a scaling factor of the vacuum energy density, specially taking into account the dimensions of Λ, which is the inverse of the square of a length. Thus, assuming that the cosmological constant is decreasing as universe expands, we will refer to it as the cosmological parameter Λ_R:

$$\Lambda_R = \frac{\Lambda l_p^2}{R^2} \tag{4}$$

The possibility that Λ varies as a^{-2} (a is the scale factor. As we will see, $R \propto a$ in our model) has been discussed by different authors

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(Abdel-Rahman 1992, Abdussattar and Vishwakarma 1997, Chen and Wu 1990, Calvao et al. 1992, Méndez and Pavón 1996). Pavón (1991) performed a thermodynamic analysis of non-equilibrium fluctuations of different possible Λ decays, concluding that if Λ diminishes with cosmic expansion its dependence on scale factor should take the form $\Lambda \propto a^{-2}$ to avoid conflict with the high degree of isotropy of the cosmic background radiation (CBR). Ozer and Taha (1986) developed a model of this class assuming that the energy density of the universe equals its critical value. Their model has $k = 1$, is singularity-free, initially cold and does not possess the horizon, monopole or cosmological constant problems. Chen and Wu (1990) developed another of these models on the grounds of some dimensional considerations in line with quantum cosmology. It assumes inflation, but implies creation of matter with a rate comparable to that in the Steady-State cosmology and yields a value for the deceleration parameter that appears to be incompatible with observations.

There are also studies in which the value of the exponent in general models following the law $\Lambda_R \propto a^{-n}$ is not fixed a priori. Ages of these universes have been calculated and agree with observation if $n < 3$ (Olson and Jordan 1987). The power spectrum of matter density perturbations does not appear to be greatly modified by a decaying Λ_R, at least for $0 \leq n \leq 2$ (Silveira and Waga 1994). Lensing statistics combined with other tests involving CBR anisotropies and the magnitude redshift relation for SNe Ia, favour models with $n \geq 1.6$ (Silveira and Waga 1997). Therefore, n=2 is the only natural exponent also favoured by all these observations and this is the case we will analyse in here.

This kind of dependence suggests that the holographic principle could be applicable not only to the entropy but also to the energy density in the observable universe and, in particular, to the evolution

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of Λ_R (Horvat 2004). If $M \propto R$, as equation (3) suggests, and thus the density of matter follows the same scale law, $\rho_M \propto R^{-2}$, by any reason (following either the holographic principle or the standard model, or even by apparition of new mass at very low rate), the coincidence problem could also be explained. In such a case, one straightforward consequence is that the present coincidence of mass and energy densities is not a mere chance of a special epoch in the universe history. It could be barely the natural result of a long lasting equilibrium (or coupling) between matter and dark energy since both show the same dependence on the universe scale, and the problem reduces to explain why the amounts of matter and dark energy have been of comparable magnitude since both coexist. In fact, other works have shown that the coupling between dark matter and dark energy can alleviate the coincidence problem (Zimdahl et al 2001, Amendola 2000, Amendola and Tocchini-Valentini 2001). This intimate relationship could even suggest the possibility of matter being the result of vacuum energy condensation, which would be not so surprising considering that vacuum energy is just a particular form of energy (the predominant one) and that matter (and antimatter) was produced from energy in the early universe.

3. A reduced Friedman equation

Accurate measurements of the angular power spectrum of anisotropies in the CBR have shown that the universe curvature is very close to flatness (e.g. Bernardis et al. 2001). In a recent publication (Casado 2009) a simple model for the expansion of the universe, assumed to be flat and spatially infinite was introduced. It was justified in there that in such a case gravitation should not decelerate the expansion. As a result from classical physics and the Mach principle, the expansion would be inertial (among realistic

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models, only flat models can be considered Machian in the sense that the inertia be determined by the gravitational field of the whole universe), i.e. at a constant rate for each pair of remote, unbounded galaxies. In other words, the universal expansion should be acting as if the universe had 0 matter density and the resulting expansion would be linear (see line $\Omega_M = 0$ in Fig. 1). Here we show how this Steady Flow model can be also derived from quantum physics and our minimal LNH in the framework of FRW metrics.

If we recall FRW metrics, it is immediate that from the above hypothesis the first Friedmann equation is greatly simplified since the matter density and the curvature terms disappear, leading to the short version:

$$H^2 = \frac{\Lambda_R c^2}{3} \tag{5}$$

It is possible to get the approximate value of the cosmological parameter at Planck epoch (Λ_p) from first principles taking into account that from QF theory the density of energy of vacuum was of the order of the Planck density, which in the appropriate natural units reads:

$$\Lambda_p \approx \frac{G\rho_p}{c^2} = \frac{c^3}{\hbar G} = \frac{1}{l_p^2} = 10^{70}\, m^{-2} \tag{6}$$

Then, from the scaling law above mentioned and eq. (5), it is easy to obtain an approximate solution for the present value of the Hubble parameter:

$$H_0 = \sqrt{\frac{\Lambda_p c^2}{3 \times 10^{122}}} = 2 \times 10^{-18}\, s^{-1}, \tag{7}$$

which corresponds, in the usual units, to ca. 62 km s^{-1} Mpc^{-1}, in remarkable agreement with the observational consensus of ca. 70 km

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s^{-1} Mpc^{-1} (Spergel et al. 1997, Jarosik et al. 2011)). Obviously the value of the Hubble parameter at any universe scale could be obtained in a similar way. For instance, when the universe was 10 times smaller, H was 10 times larger. The key result is that the Hubble parameter is determined simply by the vacuum energy and the size of the observable universe. This is not trivial, since if Λ_p was either smaller or larger a different value for H_0 would be obtained. We could equally well live in an epoch where the universe was smaller or bigger, with the same consequence. After all, both Λ_p (a constant) and R_0 are properties that should not depend on the rate at which the universe expands. Or, in more general terms, the instant size of any system is independent of its expansion or contraction rate.

On the other hand, if Λ was really constant, as stated by classical GR, H itself would also be constant and thus, as the universe expands the recession velocity would also increase, certainly leading to an accelerated expansion. Furthermore, if the value of Λ was constant since the Planck era (Λ_p), then the universe would have suffered a runaway exponential expansion, so amazingly fast that no structure could ever be formed. Instead, a "Big Rip" of the universe (Caldwell 2003) would have happened and we would never be here to discuss these intriguing questions.

Luckily for us, nature seems to have been working as if it liked life. This is a way to estate the anthropic principle (Dicke 1961, Misner et al 1973, Barrow and Tipler 1986). Following this principle, there are restrictions on the magnitude of any cosmological constant. If it is too large it will either precipitate premature collapse back to high density (if Λ is negative) or prevent the gravitational condensation of any stars and galaxies (if Λ is positive). Likewise, it was pointed out that life-supporting universes need to be close to flatness. This ensures that the universe cannot collapse back to high density or expand too fast before galaxies, stars, and biochemical

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elements can form by gravitational instability. In this way, for instance, the lower curve in figure 1 could be ruled out as incompatible with our own existence.

4. Retrieving the Steady Flow model

Since the cosmological parameter scales with R^{-2} as the universe expands and, from equation (5), H^2 scales accordingly, H should decrease with time in such a way that the recession velocity of any two distant galaxies, unbounded by local gravitation, keeps constant. In other words, the only natural solution of equation (5) implies that the time derivative of the scale factor is constant. Thus we see that starting from a different hypothesis, we reach the same result: a linear expansion model with $R \propto a \propto t$.

I will not repeat in here the details of the Steady Flow model since they have been already described (Casado 2009), but let's summarize its main features. In this scenario the time of expansion exactly fulfils at any epoch the well known relationship $t=H^{-1}$. This time should be ca. 13.8 10^9 years at present. Surprisingly, this value coincides with the intricate determinations of the universe age obtained from the Concordance model (Turner 2007), as can be observed for the time axis interceptions of the two upper curves in Figure 1. Note that, in contrast to the standard cosmology, our model avoids the use of free parameters or free functions to fit the observations. Note also that the present time is the only time in the Concordance scenario when $t_0=H_0^{-1}$. Is this just another fortuitous coincidence? Or perhaps one more hint indicating that the plain expression $t=H^{-1}$ could be right at any expansion epoch?

The horizon problem vanishes in the Steady Flow model since the universe should have been always spatially infinite and homogeneous. In fact, particle horizons only occur in models with $a(t) \propto t^{\alpha}$ for $\alpha < 1$.

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A linear evolution of the expansion is also clean of the flatness or the fine-tuning problems (Ford 1987, Dolgov 1997, Batra et al. 2000, Dev et al. 2002). The scale factor in power-law models with $\alpha \geq 1$ does not constrain the density parameter and consequently, they are free from the flatness problem. In our specific case, with $\alpha = 1$, the flatness problem is conceptually avoided because of the lack of any spatial curvature (except at local scale) due to the overall cancellation of the gravitational field. Although our model does not rule it out, inflation is not needed to solve the classical problems that motivated its introduction. Nevertheless, a still uncertain mechanism is obviously required to trigger the expansion (Casado 2009).

The Steady Flow model does not prescribe any initial singularity and thus the problem of the cosmic origin could also be avoided. Note, by the way, that the Hubble expansion, CBR and nucleosynthesis imply that the universe was hotter and denser in the past, but do not require that it began with zero size (Dabrowski 1996). Concomitantly, it has been shown that a variable cosmological parameter can avoid in some cases the initial singularity with current values of Λ_R well within experimental limits (Overduin and Cooperstock 1998). In fact, some explicitly nonsingular solutions have been constructed, all of them with $\Lambda_R \propto a^{-2}$ (Ozer and Taha 1986, Abdel-Rahman 1992, Abdussattar and Vishwakarma 1997).

The time evolution of the scale factor after the Planck epoch, $a \propto t$, is an explicit feature of the Steady Flow model and does not depend on either radiation or matter dominance in the universe. Our model allows for the smooth formation of first galaxies, clusters and voids during a longer time than expected from the Concordance model. For similar reasons, we obtain longer times for the development of structure seeds observed in CBR. Recombination occurred at an expansion time of ca. 1.3 10^7 years (Casado 2009) as opposed to 3.8 10^5 years in the Concordance model. The Hubble radius at

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recombination (decoupling) is therefore almost two orders of magnitude greater for the present model. This fact, coupled with the absence of any horizon, could well have falsified the model. Any concordance with observations, as we will see in next section, is therefore very significant. On the other hand, some other features of Big Bang cosmology, such as the evolution of temperature with the scale factor (but not with time), the cosmic recombination or the primordial nucleosynthesis, remain essentially unchanged.

A number of models pioneered by the well-known Milne universe and developed on different theoretical grounds and assumptions have also arrived at linear expansion laws (e.g. Dev et al. 2002, Gehlaut et al. 2003). In fact, a linear expanding cosmology, independent of the equation of state of matter, is a generic feature in a class of models that attempt to dynamically solve the cosmological constant problem (Ford 1987, Weinberg 1989, Dolgov 1997).

Particularly, John and Joseph (2000) generalized the Chen-Wu ansatz mentioned in section 2 to the total energy density of the universe. The resulting model has a linear expansion and is devoid of most of the cosmological problems. However, this model also predicts the continuous creation of mass at low rates and a mass density well above the observational limits to avoid serious contradictions with big bang nucleosynthesis.

Applying the holographic principle to the observable universe, Petri (2007) has described an isotropic expansion with a nearly homogeneous matter-distribution within the Hubble volume. Due to an overall string equation of state, the active gravitational mass-density is zero, resulting also in a linear expansion.

Sethi et al. (2005) have considered a generic empirical model where the scale factor depends on time with a power law ($a(t) \propto t^{\alpha}$, α being a free parameter), concluding that cosmological observations point to $\alpha = 1$ as the best-fit solution.

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Here we have only mentioned some of the models related to our proposal, but let's notice, in passing, that the fact that so many alternatives have been recently presented suggests that the Concordance model seems not to be fully satisfactory for an increasing number of researchers, due not only to the cited theoretical problems but also to some observational constraints that we briefly review in section 5.

5. Observational constraints

Although measurements of WMAP agree with the standard cold dark matter model including Λ (Komatsu et al. 2009), so far the main direct evidence favouring an apparent acceleration of the expansion in recent times comes from distant supernovae observations (Blanchard et al. 2003).

However, as already reported (Casado 2009), the SNe Ia data are also compatible with a Steady Flow model, i.e. an universe that expands linearly without either deceleration or acceleration of the Hubble flow (q=0). It has been independently shown that a linear expansion cosmology presents a good fit to these supernovae results (Sethi *et al.* 2005, see also Fig.1 in Gehlaut et al. 2003). In connection to this, Schwarz and Weinhorst (2007) have found an unexpected anisotropy of the Hubble diagram between both galactic hemispheres, which suggests a systematic error in the SNe Ia reduced data. Their model independent test failed to detect acceleration of the universe at high statistical significance (see Fig.2 therein), and concluded that it is too early to take accelerated expansion for granted, as the evidence relies on the *a priori* assumption of the Concordance model.

In fact the measurements of peak brightness of these remote supernovae explosions are extremely difficult and require several corrections. Moreover, there are systematic differences in the

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corrections made for the same objects by different groups of observers (Leibundgut 2000). Considering this, the self-consistency of the data is remarkable. However, especially the decelerated expansion at $z > 1$ is still based in too few observations to be considered as conclusively demonstrated. The Steady Flow model can be falsified through further SNe Ia data at different redshifts, and explicitly predicts that supernovae of $z > 1$ should not show any deceleration in the past expansion of the universe.

On the other hand, the present model does not modify the main results of Big Bang nucleosynthesis (Casado 2009) and thus is in agreement with the observed H/He ratio. Previously, it has been demonstrated that a linear expansion model is also consistent with the primordial nucleosynthesis (Batra *et al.* 2000), although the observed abundance of deuterium would require a subsidiary production of it by spallation. The abundances predicted by Big Bang nucleosynthesis are certainly sensitive to the expansion history in the early universe, but both papers show that the resulting H/He ratio would be significantly changed only for a *faster* expansion of the early universe, which is not the case of Steady Flow model.

Linear expansion surprisingly clears preliminary constraints on structure formation and CBR anisotropy (Gehault *et al.* 2003). In spite of a significantly different evolution, the recombination history of a linearly expanding cosmology gives the location of the primary acoustic peaks in the same range of angles as that given in Standard cosmology.

It is widely accepted that Baryon Acoustic Oscillations (BAO) are consistent with cosmic acceleration in recent times, so that BAO are considered as evidence for the Standard model. However, Shafieloo and col. (2009) have recently found that, allowing dark energy to vary, a linear expansion model (q_0=0) fits the data of SN Ia + BAO + CBR at practically the same level of confidence as the Standard

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model. In fact their model provides an excellent fit to the assembly of data and also leads to a decay of dark energy.

Jain et al. (2003) have studied the angular size–redshift relation in power-law cosmologies by using measurements for a large sample of compact radio sources. They found as a best-fit exponent $\alpha=1 \pm 0.3$ at 68% confidence level. The agreement of this kind of data with a linear expansion has been recently confirmed (Abdel-Rahman and Riad 2007). Besides, the X-ray mass fraction data of galaxy clusters agree with a flat universe following a power-law expansion of exponent very close to 1 (Zhu *et al*. 2008). What's more, a linear expansion is also consistent with gamma ray burst data (Petri 2007).

Recent high quality observations of radio sources gravitational lensing and SNe Ia favour a time-evolving dark energy instead of a cosmological *constant* (Jain et al. 2006). Moreover, a linear expansion model is also consistent with gravitational lensing statistics within 1σ (Dev et al. 2002, Sethi et al. 2005). In contrast, the observed quasar lensing fraction appears to be lower than expected in a Standard flat cosmology with $\Omega_\Lambda= 0.7$ (Maoz 2005).

The Steady Flow model has not any age problem. Its estimated expansion time of 14 Gyr accommodates the ages of the oldest stars and globular clusters, including the age of the oldest known star: 13.2 Gyr (Frebel *et al*. 2007). Note that only the Concordance and the Steady Flow models in Figure 1 (two upper curves) avoid the age problem, so that the rest of expansion curves can be ruled out. Moreover, a linear expansion model can easily accommodate old high-redshift galaxies and quasars (e.g. Sethi *et al.* 2005) and can help to understand the observations of high redshift galaxies, which appear to be more fully formed and mature than Concordance model would expect (e.g. Krauss 1997, Cimatti et al. 2004). This so-called high redshift "age crisis" appears to be more restrictive than the total age as a cosmological test. The most striking case up to now corresponds to

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the old, high-redshift quasar APM 08279+5255 (z=3.91, t=2.1 Gyr) (G. Hasinger *et al.* 2002, Friaca *et al.* 2005), which Standard flat FRW models with cosmological constant fail to accommodate. In contrast, according to the Steady Flow model such a redshift would correspond to an expansion time >3 Gyr, which can accommodate the age of this old object without difficulty.

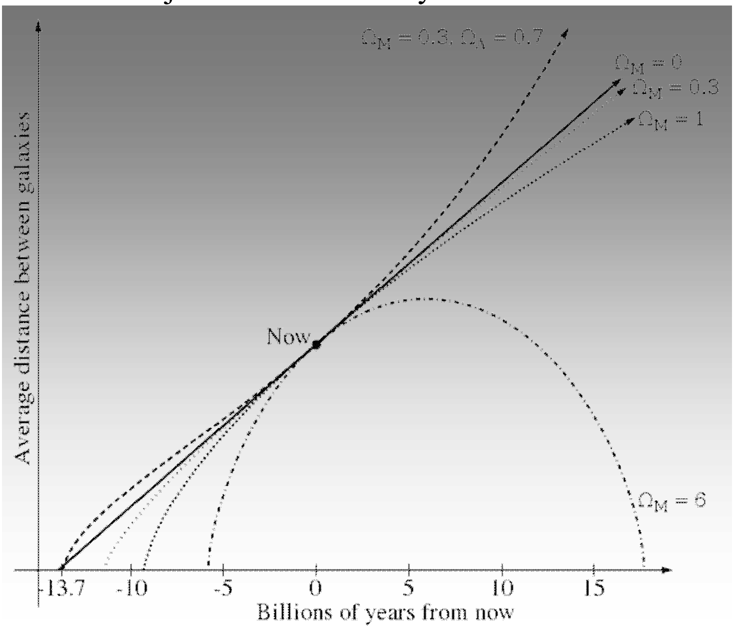

Figure 1. Time evolution of the scale factor in arbitrary units for different cosmological models as function of the Ω_M and Ω_Λ contributions. Ω refers, as usual, to the ratios between the assumed densities, of mass and Λ respectively, and the critical density.

Conclusions

From the present investigation we can conclude that the breakthrough revealed by SNe Ia data could be purely that the universe is not

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decelerating, which does not mean an accelerated expansion. In any case, the discovery is not less important since these data ruled out the previously favoured Einstein-de Sitter model. The introduced cosmological parameter Λ_R is compatible with a steady expansion flow; in other words, the possible existence of a dark energy, derived from the vacuum energy, does not necessarily imply an accelerated expansion. Λ_R allows the derivation of H at any time or vice versa. If this is correct, it implies that vacuum energy is driving the space expansion and, concurrently, is *diluted* by this expansion. Perhaps this is not as surprising as it might seem at first glance. Given that the vacuum energy affects the large scale structure and the expansion of the universe, but should originate from effective local vacuum fluctuations, it may well provide a natural connection between macro and microphysics. Thus, the results of this work point to a deep connection between micro and macro-cosmos, as suggested by our minimal LNH. In particular, the dimensionless number 10^{122} provides an explanation to the vast difference between vacuum energy and dark energy. This hypothesis gives further support to the Steady Flow model from the grounds of QF theory. Additionally, in the present scenario the cosmological constant problem and the coincidence problem can be solved. The first one disappears because Λ_R is not constant anymore, and the second one vanishes if both mass and dark energy densities evolve with the universal expansion following the same scaling law, namely $\rho_M \propto \Lambda_R \propto R^{-2}$.

Furthermore, since the Steady Flow model can be derived either from classical or quantum principles, without the need of gravitation, the conflict between GR and Quantum Mechanics at the Planck era disappears since gravitation does not control the overall expansion dynamics.

The Steady Flow model is only one among the plethora of alternatives proposed so far to the Standard cosmology and, as most

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of them, it is probably flawed and yet incomplete, but it has the elegance of simplicity (neither free parameters nor free functions are needed to obtain a linear expansion rate that essentially depends on vacuum energy) and, above and beyond, it works (avoids the main cosmological problems, agrees so far with the available observational data and is predictive, and thus falsifiable). In any case, the growing evidence here reported indicates that perhaps this linear expansion paradigm deserves some attention as a feasible alternative to the Concordance model.

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