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Conceptual Problems in Cosmology

F. J. Amaral Vieira
Departamento de Física, Universidade Estadual Vale do Acaraú (UVA)
Avenida Dr. Guarani 317, CEP 62040-730, Sobral, Ceará, Brazil
e-mail: amaralvieira@wirelink.com.br

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In this essay a critical review of present conceptual problems in current cosmology is provided from a more philosophical point of view. In essence, a digression on how could philosophy help cosmologists in what is strictly their fundamental endeavor is presented. We start by recalling some examples of enduring confrontations among philosophers and physicists on what could be contributed by the formers to the day-time striving of the second ones. Then, a short review of the standard model Friedmann-Lemaître-Robertson-Walter (FLRW) of cosmology is given, since Einsteins days throughout the Hubble discover of the expansion of the universe, the Gamow, Alpher and Herman primordial nucleo-synthesis calculations and prediction of the cosmic microwave background (CMB) radiation; as detected by Penzias and Wilson, to Guth-Linde inflationary scenarios and the controversial multiverse and landscape ideas as prospective way outs to most cosmic conceptual conundrums. It seems apparent that cosmology is living a golden age with the advent of observations of high precision. Nonetheless, a critical revisiting of the direction in which it should go on appears also needed, for misconcepts like "quantum backgrounds for cosmological classical settings" and "quantum gravity unification" have not been properly constructed up-to-date. Thus, knowledge-building in cosmology, more than in any other field, should begin with visions of the reality, then taking technical form whenever concepts and relations inbetween are translated into a mathematical structure. It is mandatory, therefore, that the meaning of such concepts be the same for all cosmologists, and that any relationship among all them be tested both logically as well as mathematically. In other words, the notorius feature of improbability of our universe, as is well-known, assures to cosmologists a priviledged degree of freedom for formulating interpretations and theories. However, at the same time, it demands for their formulations and conclusions to be considered in the light of data taken from astrophysical observations.

Keywords: Cosmology: standard model :: open issues: cosmological constant, singularity — cosmology: conceptual — science: philosophy — science: interdisciplinarity

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I. INTRODUCTION

The fact that cosmology was able to describe the evolution of the universe starting from a time 10^{-43} seconds after the creation, *i.e.* the Big Bang, to the present time, answering some of the most challenging questions proposed by the human mind, has raised the question of finding out what contribution philosophers could offer, in our time, to this fascinating field of research.

In an approach to the issue, McMullin [1] quoted Weinberg's answer to this question which would become emblematic of the position of a large number of physicists: "When physicists make discoveries in areas that have been the object of philosophy, they not only confirm or refute the speculations of philosophers but show that philosophers were out of their jurisdiction when speculating such problems"

Weinberg, in the chapter "Against Philosophy" of his celebrated book *Dreams of a Final Theory* [2], bases his disenchantment with philosophy on the conviction assumed during the days of his undergraduate studies "that the insights of the philosophers he studied 'seemed murky and inconsequential' compared with the dazzling successes of physics and mathematics," adding: "From time to time, since then, I have tried to read current work on the philosophy of science. Some of it I found to be written in a jargon so impenetrable that I can only think that it aimed at impressing those who confound obscurity with profundity." His conviction is that "(...) we should not expect it (philosophy) to provide today's scientists with any useful guidance about how to go about their work or about what they are likely to find."

Hawking, on his turn [3], points out that philosophy has been depleted in as much as "in the nineteenth and twentieth centuries, when science became too technical and mathematical for the philosophers, or anyone else except a few specialists." To this realistic view of the facts, he opposes an idealistic reasoning: "If we do discover a complete theory, it should in time be understandable in broad principle by everyone, not just by a few scientists. Then we shall all, philosophers, scientists, and just ordinary people, be able to take part in the discussion of the question on why it is that we and the universe exist." And through the confrontation between the view of "how, that is typical of science, and the view of why, proper of philosophy", Hawking comes to a synthesis that may be interpreted both as metaphysical and as a product of the most audacious reductionism: "If we find the answer to that, it would be the ultimate triumph of human reason – for then we should know the mind of God."

Meanwhile, that is not exactly the question, for since the first decades of the past century the work of the cosmologist, starting with Einstein, has been that of systematically transforming their views of reality in idealizations called models and of describing such models by means of a logical discourse, a procedure that, in essence, corresponds to the method of philosophy. The second and irrefutable step is to base such discourse on the laws of physics and to demonstrate it through a mathematical language capable of endowing it with the precision and sustainability that characterizes the physicist's work method.

However, how could philosophy help cosmologists in what is strictly their business? The most evident and delicate problems of cosmology nowadays are not found solely in the elegance and fineness of its mathematical formalisms nor in the technical content of the constructs, but rather in the difficulty to handle concepts. And contemporary philosophy, as pointed out by Araújo [4], does not have the task of creating foundations for the sciences, since this would be a return to the medieval philosophy, while its characteristic today is its critical attitude, strict reasoning, ability to handle concepts and integrate them, thus having become an articulator of different fields of knowledge.

II. THE STANDARD MODEL OF COSMOLOGY

A. The beginning

Modern cosmology was born in the context of Einstein's General Relativity, in 1915, built around the revolutionary idea that gravitation stems directly from the space-time curvature (geometry) and the linear momentum of the interacting bodies. In this context, the geometry is described by the metric, *i.e.* the gravitational field itself. In it, space-time geometry, *i.e.*, the spatial configuration of the universe as a whole, is described through the so-called gravitational field equations, whose form reads

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \, , \tag{1}$$

where $R_{\mu\nu}$ is Ricci tensor, R is the scalar curvature of space-time, $g_{\mu\nu}$ is the metric which determines distances in that geometry, G is the gravitational constant, c the speed of light in a vacuum and $T_{\mu\nu}$ is the energy momentum tensor of the matter-energy distribution.

Einstein noticed that the solution to those equations led to a dynamic universe which is curved by matter and energy, and that could collapse on itself under the effect of gravity. To avert this, for reasons that we will discuss later, he amended the field equation in 1917, so as to introduce a new term on the left side, which he called the "cosmological term", the product of a parameter of dimension $(1/L^2)$ times the metric. It is designated by the Greek letter Λ (Lambda). It would represent an intrinsic property of space. Then, the equation were written as:

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + g_{\mu\nu}\Lambda = \frac{8\pi G}{c^4} T_{\mu\nu} \ . \tag{2}$$

Einstein admitted that a positive Λ would offset gravity, providing a solution for a static universe, *i.e.*, one that does not contract nor expand. The result, in summary, is a model of universe having a spatially positive curvature, being finite, static, and four-dimensional, since it houses space-time as described by the special relativity theory. Nonetheless, Alexander Friedmann, until then an obscure Russian physics teacher, between the years 1922 and 1924, derived new solutions starting from Einstein's equations which describe three dynamic models of universes simply connected, with evolution and destiny related to the specific geometry of each one, namely: (i) a universe with Euclidean geometry destined to expand forever; (ii) a universe with spherical geometry, destined to contract under gravitational collapse and (iii) a universe with hyperbolic geometry that would expand in an accelerated way. Its original form reads

$$\frac{2R\ddot{R} + \dot{R}^2 - kc^2}{R^2} - \Lambda = 8\pi\rho G \tag{3}$$

in which R represents the size of the universe, c the speed of light, ρ the initial density, G the gravitational constant, Λ the cosmological constant and k the constant of curvature. Thus, $k > 0$ defines a curved and closed universe, $k < 0$ defines a hyperbolic universe and $k = 0$ defines a spatially flat universe, precisely the one we inhabit, according to the most recent data from the WMAP satellite.

In 1924, the Belgian astronomer George Lemaître, working independently, arrived at similar results. A propos, he had already warned that gravity, as established in the general relativity theory, would create a large concentration of matter in the concavities of space-time caused by the mass of large astronomical bodies, which contradicted the scenario of visible galaxies uniformly spread around. The evolution of Friedmann models follows local physics and the principle postulated by Milne, in 1930, according to which the universe is statistically homogeneous, *viz.*, the same for different observers, placed at different observation points. For the majority of authors working in the field, this is a generalization of Copernicus' principle, according to which there are no privileged positions in the universe. However, it is necessary to recall that what we call Copernicus principle was referred to our solar system, while the homogeneity of the universe, as considered today, appears to occur at a very large cosmic scale, *i.e.*, beyond 30 Mpc. Even after recognizing the accuracy of Friedmann calculations, which demanded time and debates, Einstein only admitted that he had committed an error (his great blunder) when he introduced the cosmological constant, after Hubble findings in 1929, when he presented at the Solvay Congress the measurements of the spectrum of the galaxies (distant nebulae), showing that they were moving away from us at a speed proportional to distance. Such relation, known afterwards as Hubble's Law, is expressed by the equation

$$V = H_0 D \ , \tag{4}$$

in which H_0 is the constant of proportionality between the velocity V and the distance D, known as the Hubble constant today. The linearity of that law showed that the universe was expanding [5] and made it implicit that going over its history back to the past we would arrive at a point of density and curvature tending to the infinite [6]. This idea of a singular beginning was implicit in all of the Friedmann models and had been assumed by Lemaître, who was known to express in a letter to the editor of Nature magazine, in 1934, that the universe "began in a state of maximum density on a day without yesterday." Hubble's Law, which defines the rate of expansion of the universe, can be cast in the simplest form (which is the first Friedmann equation):

$$H^2 = \frac{8\pi G}{3}\rho - \frac{k}{a} \ , \tag{5}$$

in which the Hubble parameter is a function of time; ρ the density of matter in the universe, a the factor of the scale relative to the size of universe and k defines the curvature of space.

B. Einstein's Great Blunder

Einstein's mistake in not accepting the dynamic universe revealed by his own equations, changing them to make it static, has been the subject of hundreds of articles, essays and debates. Stephen Hawking said that such mistake would be understandable if made by Newton who lived two centuries before, but thought that Einstein should have been able to see further. However, a judgment is not easy. Lee Smolin [7] admits that even, in those days, Einstein hardly could have imagined a universe that were neither eternal nor immutable, simply because that was the view of all scientists since Aristotle. He adds, however, that if Einstein were really a genius, he would believe more in his own theory than in the prejudice and would have predicted the expansion of the universe. Nonetheless, Smolin admits that in his decision Einstein was influenced by the thought that predicting an expanding universe may be based on a defect of his theory plus the fact that, at the time, there was no evidence in favor of a dynamic universe evolving with time. The last argument makes sense. By the time when Einstein introduced General Relativity there was the idea that the universe was limited to the Milky Way, (Kapteyn's universe, 1910) where the stars seem to move slowly, a view then of serene stability.

In such conditions, it would be inevitable to admit that gravitational attraction would lead galaxies to come increasingly closer to one another what would inevitably result in a contraction of the universe sometime in the future. It is evident that Einstein took up this scenario as an objective fact. Hence, to admit that the expansion foreseen in his equations could be based in some drawback or defect of the theory may have been just a small step.

It is undeniable that Einstein was influenced by the ideas of the Austrian physicist and philosopher Ernst Mach, who many authors retain might have been the inspiration for the relation between mass density and the positively curved geometry established by him, as well as the creation of the cosmological constant itself. Physicist Norbert Straumann [8] agrees that Einstein believed that the universe was globally closed because by this time he believed that such a view was the only way to satisfy Mach's principle on inertia. He recalls, however, that in a letter to physicist F. Pirani, in 1954, Einstein argued that the positive curvature of space would have been established by his own results, which would have prevailed even if the cosmological constant had not been introduced. And he added that it would be necessary only to enable a distribution of nearly static matter as required by the speed of stars. Taking into account that Mach was a radical positivist, we should admit that his influence must have been a guidance for Einstein to take as reference the data of the observation relative to the speed of stars and not to influence him toward a vision of a pure philosophical nature. But there were many circumstances conspiring in favor of the introduction of the cosmological constant, among them the fact that Lambda Λ gave to the equations symmetry and elegance, something of which Einstein was a devotee.

For Mario Novello [9], Einstein amended the field equations to make the gravitational theory to fit his mental scenario of the universe, a decision for which there would be no explanation in terms of physics. The cosmological constant would be a feature typical of the totality, a characteristic of the universe's global structure. Novello adds that this daring step by Einstein, without support from any other part of science, must be accepted as the first strategy to free cosmology from physics, *i.e.*, to allow scientists to be prepared to accept the properties that do not have a counterpart in our surroundings.

As pointed out by Weinberg, in inspired and very succinct words, "Einstein's mistake was that he thought it was a mistake." [10] To me, it was clearly a conceptual fault as verified 90 years later with the discovery of the accelerated expansion of the universe.

C. A long intermezzo

In the late 1940's, when the idea of a static universe – despite all that had been established on the contrary – still dominated the preferences of the scientific community, George Gamow entered the stage. Although he had been a disciple of Friedmann, he was not directly interested in the geometry of the universe, but in the possibility of explaining the creation of the atoms in the initial instants of the universe.

The first step was to describe nucleo-synthesis, which required finding a solution to the problem of the abundance of some atoms as compared to others, and more precisely the synthesis of the nuclei of light elements. Gamow and collaborators Ralph Apher and R.C. Herman demonstrated not the synthesis of all the elements, but the synthesis of $^2H_1$, ^3He, ^4He and ^7Li, in a very brief and unique moment, at a time of 10^{-4} seconds of the existence of the universe. At the same time, Gamow's team added to the scenario of creation described by Lemaître the inconceivably high temperature that would have made possible all the nuclear reactions necessary for creation, for the beginning of everything. [11] The moment of creation is then understood as the cosmological singularity at which the universe's density, temperature and curvature were infinite, and at which – in Barrow's word – "everything collided with everything." [12] That turbulent beginning became known as the Big Bang. With Gamow's contribution emerges the standard model of the hot Big Bang or simply the standard model of cosmology (SMC) which is described by the metric of Friedmann-Lemaître-Robertson-Walter (FLRW):

$$\mathrm{d}r^2 = \mathrm{d}t^2 - R^2(t)\left[\frac{\mathrm{d}r^2}{1-kr^2} + r^2(\mathrm{d}\theta 2 + \sin^2\theta \mathrm{d}\phi^2)\right] , \tag{6}$$

where k, as indicated above defines the type of curvature and $R(t)$ is the factor of scale of the expansion [13]. The dynamics of the expanding universe, and consequently $R(t_{\mathrm{rec}})$, obeys Einstein's equations through which the expansion rate is related to the content of matter, or more precisely to the density of energy ρ and to the pressure p. Gamow and his associates foresaw the existence of a thermal radiation created in the heat of the Big Bang and that had become visible in the recombination phase (t_{rec}) when electrons broke away from photons to form the first electrically neutral atoms. Free to take the flight of light, the photons would have dislocated since that time to the present, in a spatial distribution typical of a black body. Nowadays, the radiation predicted by Gamow should be isotropic and fill in the universe in a homogeneous manner. Some 20 years later, it would be discovered, at the microwave band, by the engineers (today said radio-astronomers) Arno Penzias e Robert Wilson. The Cosmic Microwave Background Radiation (CMBR), as it became known, uniformly spreads to all directions in space, with the same intensity, showing that it was isotropic and homogeneous, had the spectrum of a black body and a temperature of 2.73K (Gamow had predicted a temperature of 5.0K). We can count on by now three strong evidences of the Standard Model of Cosmology: (i) the redshift of the light coming from receding galaxies which indicated the expansion; (ii) the explanation of the abundance of light elements and their synthesis during the initial moments of the universe and (iii) the CMBR discovery. And all that was sufficient to bury the stationary model of the universe and the cosmological constant.

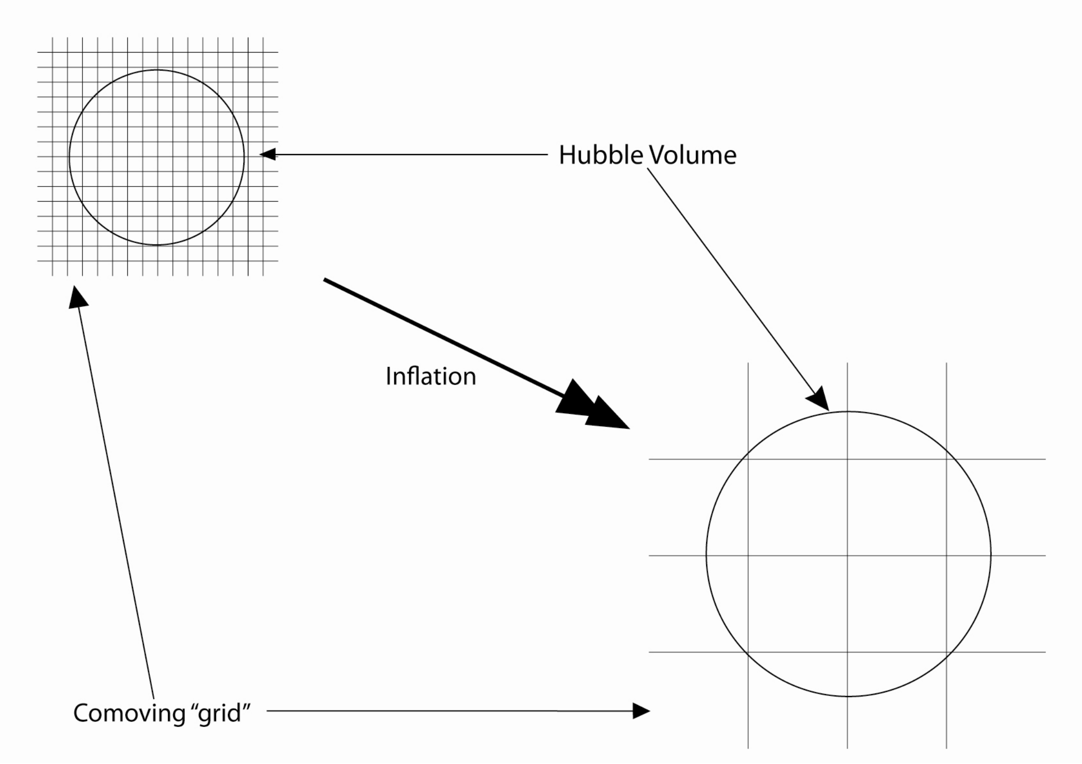

FIG. 1. The Universe before and after inflation. The gridlines represent the commoving coordinate system, and the circle the Hubble volume 1/H, which has shrunk with respect to the commoving coordinates after inflation, (From A.H. Jaffe - Cosmology 2010: Lectures Notes - Imperial College). (By courtesy of the author).

D. The Inflationary Expansion

So much success masked questions for which the Big Bang theory did not have answers as we shall see next:

(i) Why is matter distributed homogeneously in large scale just as postulated by SCM? Subsequently, the maps of the background radiation obtained from the data collected by satellites COBE and WMAP showed that the temperature of the regions symmetrically separated by large distances were homogeneous in more than one part in 10^5 despite not being in causal contact. This difficulty has become known as the horizon problem. As pointed out by Brandenberger [14] it was the fact that regions symmetrically separated by large distances from the commoving region $\ell p(t_{\rm rec})$, over which the CMBR is observed to be homogeneous to better than one part in 10^4, is much larger than the commoving forward light cone $\ell_f(t_{\rm rec})$ at the time $(t_{\rm rec})$, which is the maximal distance over which microphysical forces could have caused the homogeneity.

(ii) Why is it spatially flat? This peculiarity stems from the coincidence of the value of the total density today (ρ_0) with the value of the critical density (ρ_c), which defines the tenuous limit between a negatively curved geometry (open universe) and a positively curved geometry (closed universe). The relationship between ρ_0 and ρ_c is given by the density parameter Ω such that $\Omega = 1$ defines a flat universe, $\Omega > 1$ defines a universe positively curved and $\Omega < 1$ defines a universe negatively curved. These relations may be expressed in the form below:

$$\Omega \equiv \frac{\rho}{\rho_{\rm crit}} = \left(\frac{8\pi G}{3H^2}\right)\rho \ , \tag{7}$$

where ρ is the density of the universe today and $\rho_{\rm crit}$ is the critical density. Two consequences emerge from what we have just seen: (a) $\Omega = 1$ reflects a condition very unstable, since a minimal change in their value could change the geometry and the fate of the universe; and (b) its value should have been finely tuned in the initial moments of the universe and, since then, it has been spatially flat. The theory of the Big Bang had no way to explain one thing nor the other.

(iii) Whence could have come the disturbances of density that allowed the formation of agglomerates of galaxies? The apparently absolute homogeneity of CMBR, as detected by Penzias and Wilson, did not offer any leads as to the existence of minor non-homogeneities of temperature so as to allow that matter were deposited by gravity in warmer regions from which galaxies could have been formed, while the colder regions responded for the space amid them, the voids.

In summary, the cosmology of the Big Bang assumed the homogeneity and flatness, as well as the immense size of the universe as determined by initial conditions, of which the most representative is the fine tuning required by the value of Ω. But it did not develop a physical mechanism to explain them. Big Bang cosmologists faced yet another problem: the high energies of the primeval universe would have created super massive magnetic particles that had only one pole, for which reason they were called magnetic monopoles, which should exist today in great abundance because they are very stable. However, neither were they observed nor physicists envisioned a justification for their non-existence today within the standard model of the Big Bang.

It was precisely the interest in magnetic monopoles that led Alan Guth to describe, in 1981 [15], a physical mechanism capable of solving the problems left by the theory of the Big Bang, which established an indissoluble link between relativistic cosmology and quantum theory. The hypothesis underpinning Guth's model is that during the infinitesimal interval of time of 10^{-34} seconds the scale factor $R(t)$ had grown exponentially, sustaining this up to 10^{-32} seconds, allowing for the size of the universe to rise from $\sim 10^{-26}$ m to something around 1 meter, this way growing proportionally to the distance scale it reached over all of its existence hitherto. This brief and violent period of inflationary expansion, as named by Guth, brought an elegant and convincing explanation to the problems that we have just discussed. [16]

As pointed out by Jaffe [17], during inflation the Hubble scale remains constant, but commoving scales increase much more rapidly, that is, the true horizon scale is now much larger than in Hubble length. (See Fig. 1). Thus, all scales that were compressed within the horizon before the inflationary expansion have remained outside the horizon at $t_{\rm rec}$ when CMBR became visible. In other words, inflation has placed in causal contact all regions of the universe before they were separated by distances beyond the cosmic horizon. As it can easily be deduced, during inflation the cone of light for the future increased exponentially, while the same did not happen in relation to the past light cone. As we see, inflation cancelled the horizon problem, too.

The solution to the problem of flatness seemed more obvious and is a natural consequence of an exponential increase of $R(t)$. The effect of gravity, as pointed out by Guth [18] is reversed during the inflation, changing all the equations that describe the evolution of the universe so that, instead of moving away from 1, Ω is brought to 1 at incredible speed, adding that in 100 times of duplicating the difference between Ω and 1 decreases by a factor of 10^{60}. If we can expand a curved surface, continuously and for sufficient time, there will come the time when it will appear to be flat in relation to the coordinates in which it is defined. This is precisely what we see as the surface of our planet and as we imagine should occur with the three dimensional "surface" of the universe. On the other hand, all scales that were compressed within the horizon before the inflationary expansion have remained outside the horizon by the trec when CMBR became visible. In other words, inflation has placed in causal contact all regions of the universe before they

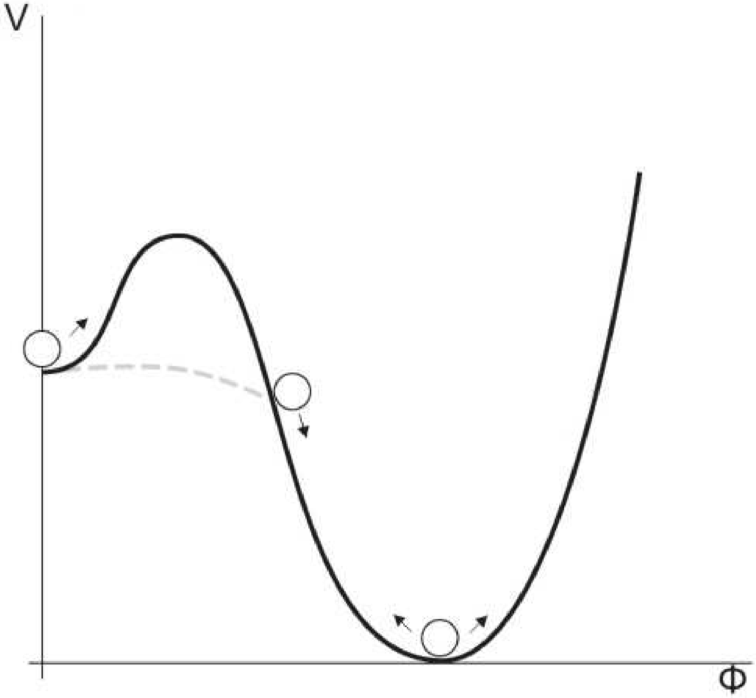

FIG. 2. Evolution of Scalar Field in Old Inflation. The field tunnels a barrier of energy and “rolls”down toward the minimum where it oscillates.

were separated by distances beyond the event horizon. Villela, Wuensche and Leonardi [19] showed that one may reach such a conclusion, through a mathematical procedure, by comparing the distance that light can travel at the beginning of inflation t_{inf}, during an interval Δt, with the distance that it could have traveled after recombination. As is ease to deduce, during inflation the cone of light for the future increased exponentially, while the same did not happen in relation to the past light cone. As we see, inflation has removed the horizon problem too. This same homogeneizing power of inflation would dilute the magnetic monopoles making its present number irrelevant.

To build his model of inflationary expansion, Guth admitted that the primeval universe, at the time of creation, would have been dominated by a type of energy predicted in high energy physics capable of exerting a negative pressure and, therefore, to offset gravity. That energy, different from all that cosmologists had encountered, Guth ended up finding it in the quantum vacuum emerging as a scalar field (Higgs field) in the form of a density potential $V(\phi)$. This potential, namely false vacuum, was defined as a peculiar form of matter, a metastable state, produced by a phase transition of super-cooling. It decays through bubbles nucleation until it reaches its minimum value and start to oscillate, the point at which the universe is being reheated. The electrical barrier is part of the characteristics of the diagram of energy employed. (See Graphic 2).

For what matters to us, it has a negative pressure $\rho = V(\phi)$, which, being opposed to gravity, creates a rapid exponential expansion state while it is sustained. Guth found the technical bases and mathematical formalisms for its model in the Grand Unified Theories (GUTs).

Guth had the merit of introducing a phase of exponential expansion in the initial moments of the universe, with technical bases and conceptually comprehensible, establishing its technical foundations and defining its role in the universe’s evolution. His inflationary scenario would be of a statuesque beauty were it not for two difficulties: (i) the first of a conceptual nature, which is summed up in that it does not solve the fine tuning problem; (ii) the second of a technical nature, which lies in the fact that inflation did not end in the direction predicted by his model. Guth explained that when inflation comes to an end, bubbles of matter are formed and grow, while the energy is released. But, rather than distributing itself uniformly through space, that energy increasingly concentrated within the walls of the bubbles as they expanded. Thus, it is only when the bubbles collide that energy may spread uniformly throughout the universe in the form of squirts of particles in all directions. At that point, however, a complication appeared: as the walls of bubbles move apart at the speed of light – and nothing can move more quickly – the effects may not pass from its own wall while the space continues to expand exponentially. In short, the expansion itself avoids collision between the bubbles and this detail prevents the formation of the soup of hot particles from which everything would be made. The inflationary model was elegant, simple and, in general lines, conceptually correct, but it did not work properly as a result of a technical problem whose solution was called "graceful exit." That solution was first found by Andrei Linde [20] of Stanford University and, soon afterward, by Paul Steinhardt and Andreas Albrecht of the University of Pennsylvania. [21] Summarizing, they introduced changes in the equations so that the energy of the false vacuum did not decay so rapidly, as it was the case in Guth's model, but slowly, which means, in practice, altering the original energy diagram to attain a smooth transition of phase. (See Fig. 3). With such change, when the energy oscillates as it reaches true vacuum, it gets converted into the hot and uniform soup of electrons, gluons and quarks from which everything was to be made.

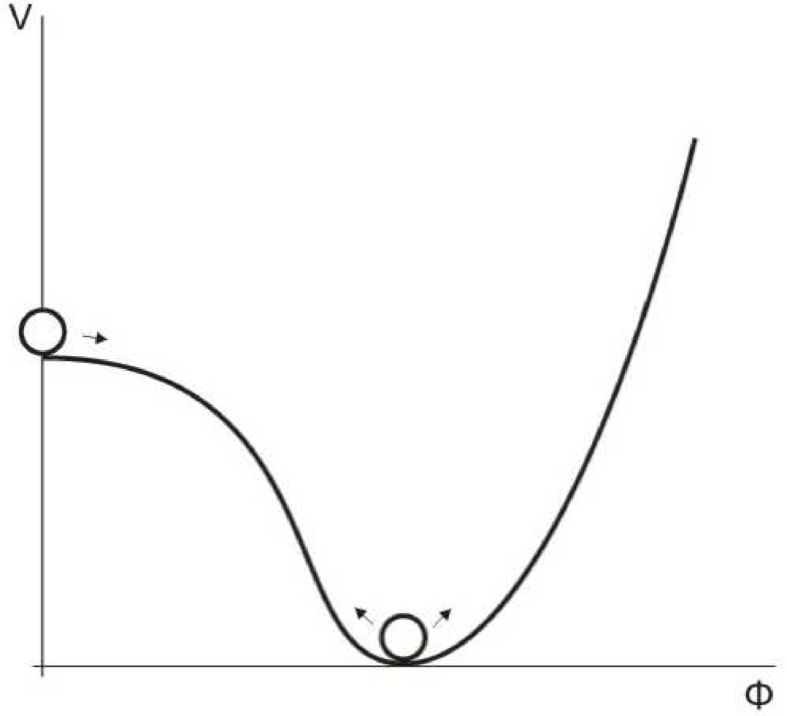

FIG. 3. Evolution of Scalar Field in New Inflation. The field "rolls" down slowly toward the minimum where it oscillates.

E. From Eternal Inflation to Multiverse

In 1983, Linde invented "the Chaotic Inflation". The new model, according to him, does not require an initial state of thermal equilibrium, super-cooling and tunneling from the false vacuum and it appears in theories that can be as simple as that of the harmonic oscillator [22]. Its descriptive paradigm invokes a scalar field ϕ, with mass m and potential energy density $V(\phi) = 1/2m^2\phi^2$ that rolls from the high value in region A (see Fig. 4) toward a minimum of $V(\phi)$ in region C, when it oscillates creating pairs of elementary particles and drives the universe heating.

It should be recalled that the large quantum fluctuations that fed inflation occurred not at a specific point, but at different parts of the universe, in jumps of a scalar field. Those particularities lead to the eternal process of self-reproduction of the universe. As Linde states, if the Hubble constant during inflation is sufficiently large, quantum fluctuations of the scalar fields may lead not only to the formation of galaxies but also to the division of the universe into exponentially large domains with different properties. The consequence is that our universe is no longer everything that exists, but a finite part of a huge and eternal universe, that is, the multiverse. And this is the more important issue of Linde's model. In Figure 5, created by Linde, one can see a collection of bubbles interconnected by isthmuses. As this might suggest a permanent connection between them, I asked Linde if we should not consider the possibility that a baby universe might detach itself from the original universe in microseconds following its creation. Linde explained that in his approach different "universes" are simply very large separate parts of the same universe and

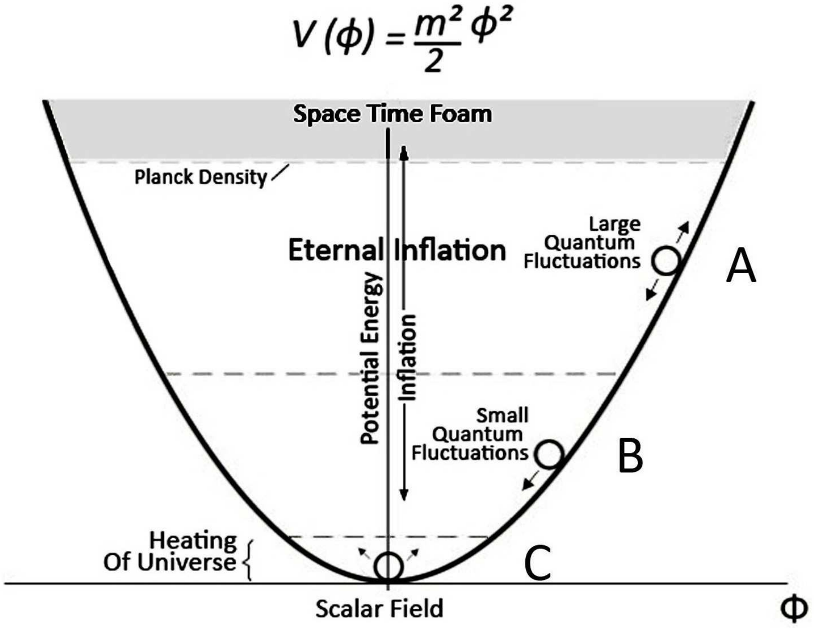

FIG. 4. Evolution of the scalar field in the theory with $V(\phi) = m^2\phi^2/2$ (According to Linde and by his courtesy.)

they are so far from each other that inhabitants of one of them do not know anything about the other part of the universe. In this sense, one can approximately consider them separate and independent, but in fact they are a part of the same manifold and they cannot separate from it.

Linde added that "the figures illustrating this concept are very imperfect because they are an attempt to show curved space, which is very hard to do without creating some confusion." He further asserted that "At the level of quantum cosmology, one can talk about many totally separate universes. However, this possibility is much more difficult to study, so most people now concentrate on investigating the simpler picture when huge universes (or multiverses) consist of many smaller but still huge "universes"."

Based on Linde's explanation, we should avoid the idea that our universe is an "island universe" inside huge archipelagos of connected worlds, since this could lead to the conceptual problem of knowing if there is an external space for each particular universe that was not yet studied in technical terms.

The biggest problem of the post-Big Bang Theory has been the fine tuning of constants, parameters and numbers associated to the initial conditions of the universe precisely because all of them are directly related to the evolution of life and, particularly, of intelligent life, which were studied in detail by John Barrow [23]. Physicists and cosmologists broke up into those who preferred to admit that they were dealing with a fine tuning that was only in part apparent and those convinced that the problem was already solved by classical inflation. Linde was among those who tackled the problem head on. [24] In his book published in 1990 [25], he offered an idea of the problem with some examples: "by increasing the mass of the electron by a factor of two and one-half would make it impossible for atoms to exist; multiplying α_e by one and one-half would cause protons and nuclei to become unstable; and more than a ten percent increase in α_s would lead to a universe devoided of hydrogen. Adding or subtracting even a single spatial dimension would make planetary systems impossible, since in space-time with dimensionality $d > 4$, gravitational forces between distant bodies fall off faster than r^{-2}, and in space-time with $d < 4$, the general theory of relativity tells that such forces are absent altogether". He concludes by recalling that to shelter life such as we know it, "it is necessary that the universe be sufficiently large, isotropic and homogeneous." Such a large number of delicately tuned figures that are directly related to life cannot be attributed to mere coincidences, especially as we have already stressed, as they are unequivocally related to the emergence of intelligent life. This conviction leads directly to the anthropic principle introduced by Brandon Carter [26], which is essentially a way out envisaged for limiting the principle of Copernicus. "En passant, let us mention that Carter defended that idea at a conference in Krakow, Poland, in 1974, as part of the celebration of the 500 years of Copernicus, which is rather ironical. The (Copernicus) principle became a matter of mandatory consideration by cosmologists following the publication of the book by John Barrow and Frank Tipler [27] (indeed, not just a book, but a *vademecum* on the initial conditions of the universe and its future from the view of

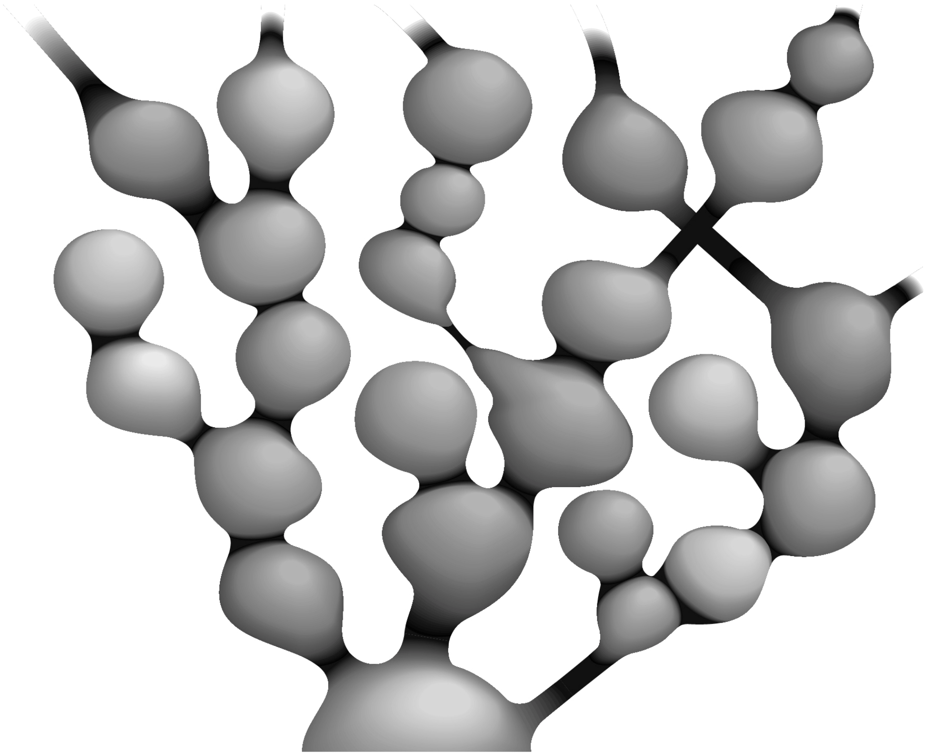

FIG. 5. The multiverse scenario - A surrealistic tree of inflationary bubbles illustrate different domains with different initial conditions and properties. (According to Andrei Linde and by his courtesy.)

the anthropic principle.)

In the present case it is not a question of rejecting a theory, but simply of knowing if the explanation contained in it yields an answer that is adequate to the problem that it intends to eliminate.

The solution of the problems of homogeneity and flatness is easily accepted because a set of reliable observations shows that the universe went through a phase of exponential expansion. But there is a great discrepancy between, on the one hand, the deliberate fine tuning of the values of a large number of parameters, as well as their linear relation with the existence of life, and on the other hand an extremely complex solution that is not subject to observation. One must remember that, in the vicinity of a universe, including ours, there must coexist regions of space that are inflating at the speed of light, which eliminates any possibility of an expedition to another particular universe governed by physical laws that in all probability are different from ours.

And the problem is not only conceptual – although this is a very important aspect – but also technical, as recognized by Stoeger, Ellis and Kischner [28]. They argue that “one way one might make a reasonable claim for the existence of a multiverse would be if one could show that its existence was a more or less inevitable consequence of well-established physical laws and processes. Indeed, this is essentially the claim that is made in the case of chaotic inflation. However, the problem is that the proposed underlying physics has not been tested, and indeed may be untestable. There is no evidence that the postulated physics is true even in this universe, much less in some pre-existing metaspace that might generate a multiverse”.

Jim Hartle and Stephen Hawking [29] tried to describe a wave function of the universe, considering all of its possible histories, which is similar to considering that all universes are possible. And the wave function they found is concentrated in our universe, assuming infinitesimal values for all other universes. Thus, Linde’s model, despite its elegance, reasoning and a certain air of completeness, and the Hawking model, despite its daring endeavor, seem to bring into reality only one universe, precisely that in which we live in and whose existence cannot be put into question.

F. From the Big Bang to the Big Bouncing

General relativity (GTR) equations converge to a point when the history of the universe is followed backwards to the beginning wherein the space-time metric becomes singular and the universe temperature and density become infinite. At this point, the so-called "initial singularity“, the equations of GTR collapse and space-time disappears. Such singular origin of the universe is considered by plenty of cosmologists a very serious embarrasing and unsuspected drawback, which may justify to reject the standard model of cosmology despite the recognized success and observational verification of its predictions. This led to look for building alternative models in which the singularity would be eliminated or somehow avoided, as is the case of the so-called cyclic universe models in which each phase of contraction is followed by another one of accelerate expansion, being this phase reversal determined by a quantum mechanism, that is as energetic as the Big Bang itself, generically named as "bouncing". It is stressed that the bouncing is one of the plenty of mechanisms figured out to overcome the intial singularity problem (string theory, M-theory, Smolin's cosmological natural selection -bouncing black holes-), varying speed of light, etc.), and all of them are admitted by the most general theory unifying gravity and quantum physics.

Regarding this field of research, there is a fact: part of the community of cosmologists working in this branch makes use of a combination of fundamentally different concepts in formulating most of the quantum effects-inspired bouncing theories. Indeed, Hawking created his model of unbound universe in which the initial singularity is avoided based on a quantum theory of gravitation that has not been formaly developed, as himself admits in his book [30]:

"We dont yet have a complete and consistent theory that combines quantum mechanics and gravity -*Note of the author: vis-a-vis general relativity*-. However, we are fairly certain of some features that such a unified theory should have. One is that it should incorporate Feynmans proposal to formulate quantum theory in terms of a sum over histories. In this approach, a particle does not have just a single history, as it would in a classical theory. Instead, it is supposed to follow every possible path in space-time, and with each of these histories there are associated a couple of numbers, one represent-ing the size of a wave and the other representing its position in the cycle (its phase). The probability that the particle, say, passes through some particular point is found by adding up the waves associated with every possible history that passes through that point. When one actually tries to perform these sums, however, one runs into severe technical problems. The only way around these is the following peculiar prescription: one must add up the waves for particle histories that are not in the real time that you and I experience but take place in what is called imaginary time. Imaginary time may sound like science fiction but it is in fact a well-defined mathematical concept. If we take any ordinary (or real) number and multiply it by itself, the result is a positive number. (For example, 2 times 2 is 4, but so is -2 times -2.) There are, however, special numbers (called imaginary numbers) that give negative numbers when multiplied by themselves. (The one called "i", when multiplied by itself, gives -1, 2i multiplied by itself gives -4, and so on.) ... "

The current status on the search for such a theory can be illustrated, as a matter of example, by quoting arguments extracted from the review article by Pinto-Neto [31]:

"Any mechanism which eliminates the initial singularity yields at most two possible scenarios: either there is a quantum creation of a small but finite universe and hence a beginning of time, or the universe is eternal, with no beginning of time. This last possibility can be divided in two other cathegories: the universe has always expanded, with a long accelerated phase before the usual decelerated expansion of the standard model from either an asymptotically zero volume flat space-time or from a finite but small compact region; the universe had a contracting phase before the usual expanding phase, hence performing a bounce. The transition from accelerated to decelerated expansion or from contraction to expansion demands non standard or non classical physics (modifications of general relativity through nonminimal couplings, non-linear curvature in the lagrangian, quantum effects in matter fields and/or gravitational fields, etc., and/or non-standard matter (N-of-the-A: i. e., matter violating GTR energy conditions) in order to avoid the singularity in between".

It becomes apparent that if one critically analyzes the set of fashions proposed to overcome the singularity problem, one realizes immediately that three of them no needs fundamental changes to the physical role of the gravitational field if understood as a pure space-time curvature phenomenon. Meanwhile, invocation of quantum effects in matter and/or gravitational fields implies, in the first case, to superpose to the classical gravitational field a number of quantum effects. However, such method clearly means to attempt to fuse together physical theories that are fundamentally different from the conceptual point of view, as depicted by Eq.(8)

$$S = \int d^4\mathrm{x}(\mathrm{R} + \mathrm{L}^{\mathrm{Matter}}_{\mathrm{Quantum-Effects}}) \ . \tag{8}$$

Whilst for the second proposed procedure, such way out implies to have in hands a quantum theory of gravity. Unfortunately, to overrun this conceptual dicothomy such a construct till to date has not been unveiled, if indeed there exists such a thing, as many workers in the field have questioned.

From an alternative perspective, and returning to the bouncing black holes singularity quoted above, lots of authoritative authors, including the reverencied book on *Gravitation* by Misner, Thorne and Wheeler [32] who have suggested that perhaps we may be inhabitating a universe which resembles (is) in most respects a classical (Schwarzschild-like) black hole. They have also demonstrated that the coordinate system used to describe the dynamics of an expanding universe can also be used to describe univoquely the gravitational collapse of a mass leading to the formation of a black hole, and its forever "censured" singularity, after simply reverting the direction of evolution of the time coordinate in the system being used. Hence, it seems that if such a view is correct, then the singularity issue gains a new dimension as regarding the transition from a contraction to an accelerate expansion phase, since it appears to be implicit that everything that exists inside this universe had come out from such singularity. Such a conclusion by itself conveys once again conceptual problems.

Summarizing, the recent revision by Novello and Pérez Bergliaffa in "Bouncing Cosmologies" [33] shows that the bouncing models took new impetus after the discovery of the acceleration of the universe and should have a room in the cosmological debate.

Hence, the expectation proceeds: whether the value of Lambda has changed over the cosmic time so as to allow for a phase of exponential expansion, followed by phase of deceleration that drove the acceleration phase we are undergoing by now, then, it appears reasonable to imagine that the same mechanism of cancellation might produce a deceleration phase able to drive the universe to a contraction stage. Within this line of reasoning, the reversal of the contraction phase to a phase of exponential expansion is fairly similar to the inflationary expansion which constituted by itself the central event of the standard model Lambda-CDM. A model exhibiting such characteristics, which properly could be denominated the *Lambda-Bouncing Cosmology*, should accommodate the inflationary expansion phase, and thus fully describe the mechanism for the reversal of the contraction stage, in a time scale able to drive the universe throughout the stages that are current proved to show consistency with most of current astrophysical observations.

G. The resurrection of the Cosmological Constant

In 1998, two research groups working independently - the Supernova Cosmology Projetct, led by Saul Permutter [34] and the High-Z Supernova Search Team, headed by Adam Riess [35] announced that the expansion of the universe had undergone an acceleration at a recent cosmic time. The method that these group employed consisted in locating supernovae of type IA (SNIA), the light curve of which appear to evolve as standard candles, and are situated billions of light years away. From their intense brightness astronomers can calculate the distante and the time the SNIA light took to arrive to Earth from its location. As soon as SNIA event is detected, astronomers look for the measurement of the redshift of the (host) galaxy found at each field of view around a SNIA. Basically, it was observed that the distance increased with the redshift much more rapidly than was expected in the context of the standard cosmological model. The discovery has been widely confirmed by data obtained from the CMBR collected by the Wilkinson Microwave Background Probe (WMAP), whose maps show that dark energy represents around 74% of the energy density of the entire universe (dark matter represents 22 % and the intergalatic gas and dust 3.6%.

Nikcholas Suntzet, astronomer of the group of Adam Riess, once said that: "What we have found is that there is a 'dark force' that permeates the universe and that has overcome the force of gravity. This result is so strange and unexpected, that it perhaps is only believable because two independent international groups have found the same effect in their data." Soon, it was perceived that the dark energy had all the characteristics of the vacuum energy, and that it was mathematically equivalent to it. This led directly to the so-called Problem of the Cosmological Constant summed up in the fact that the attempts to establish the value of the energy of the vacuum – the energy of point zero – lead to divergent values.

Robert R. Caldwell pointed that if the vacuum energy density really is so enormous as predicted by quantum physics it would cause an exponentially rapid expansion of the universe that would rip apart all the electrostatic and nuclear bonds that hold atoms and molecules together, and so there would be no galaxies, stars or life [36]. So that we must admit the existence of a miraculous cancellation mechanism that instead of making Lambda exactly zero, only cancels it to 120 decimal places. Those requirements, says Caldwell, seem bizarre. And he explains why: "Some constant that is naturally enormous must be cut down by 120 orders of magnitude, but with such precision that today it has just the right value to account for the missing energy". But, this is precisely what was required when the time came for the formation of galaxies, stars and planets, such as Earth, capable of harboring life and observers.

The solution to this impasse was proposed by Weinberg in 1987 [37] with the introduction of the Anthropic Principle, in its weak version, understood by him as an explanation "of which of the various possible eras or parts of the universe we could inhabit, by calculating which eras or parts of the universe we could inhabit". "Desesperate situations require desesperate measures, and in 1987 Steven Weinberg, one of the most eminent scientists in the world, acted in desesperation, " said Leonard Susskind [38]. He is right because, at the time, the anthropic principle was a forbidden expression for most physicists.

The discovery of the cosmic acceleration not only resuscitated the Cosmological Constant Problem, but made it even more challenging since it showed that the value of the energy of the vacuum increase over a time that coincides with our presence at this point of the universe. This is also namely the problem on the cosmic coincidence.

In summary, the high value of the cosmological constant that we will find at inflation was drastically reduced to the time it took for the formation of the large structures, and then varied again, this time increasing over a time that coincides with the emergence of life and consciousness.

Yakob Zeldovich, in 1967 [39] and in 1968 [40], was the first to relate, so convincingly, the cosmological constant and the energy of the vacuum, so that $\Lambda = 8\pi G\rho$vac. This idea though well founded was not easily assimilated for reasons that Zeldovich and I. D. Novikov would explain in a book of great importance to cosmology published in 1983 [41] in the following terms:

> "Give the tendency toward objectivity and completeness, this practice would already have been a reason enough for the theory with a zero Λ to be located – at least in small type – in an appendix. But sensible, calm decisions are often made only under the pressure of extraordinary circumstances, in a situation of fire and/or flood and panic."

That is so much so that Guth, in his inspired book, to which we have referred to early, published in 1998, admits that the gravitational effect of the false vacuum during inflation is identical to the effect of the cosmological constant. Nonetheless, he recalls the existence of an important difference between the two: "While the cosmological constant is a permanent term in the universal equations of gravity, the false vacuum is an ephemeral state that exercised its influence but for a rather brief moment at start of history in the past."

Notwithstanding, time has shown that the cosmological constant is the value we attribute to the energy of the vacuum that has varied in time apparently in order to support life. In this context it is opportune to quote from a comment by Jayant V. Narlikar and Geoffrey Burbidge [42]:

> "This is ironical, since the one reason for invoking inflation was to avoid fine tuning of precisely this nature. Now it appears that inflation brought its own fine tuning to an even greater degree!"

The solution to what I will call the Expanded Problem of the Cosmological Constant was the same proposed by Weinberg in 1987, the anthropic principle, today widely employed in different cosmological models, as Linde's Multiverse and the Susskind's Landscape, created in the context of the string theories. This model fits the consideration and test of a variety of hypotheses since it is not a real place, but a space of possibilities, a mathematical construction, as defined by Susskind. In it all properties and environments and a number of dimensions that could reach hundreds and thousands are present. The landscape is undoubtedly a field of tests of the anthropic principle.

There are other scenarios and models for dark energy (in addition to the energy of the vacuum) within which we could tackle the expanded problem of the cosmological constant, as that of the Quintessence and Modified Gravity. (See Frieman, Turner and Huterer [43]). The energy of the vacuum, however, is the most plausible and the simplest to solve the problem. But without the anthropic principle it becomes a most complicated puzzle.

III. DISCUSSION AND FINAL REMARKS

L. Krauss and M. Turner [44], commenting what they called "a cosmic connundrum", recall that the term cosmological, today called cosmological constant, resuscitated thanks to the evidence of the expansion of the universe and directly from the principles of quantum physics, the branch of physics that Einstein so famously abhorred. Indeed, the mysterious form of energy that the cosmological constant represents emerges in the quantum vacuum through the continuous generation of the so-called virtual particles, admitted by the uncertainty principle, which come into reality in pairs, but which eliminate each other mutually before they are detected. The most current version of the standard model of cosmology, nowadays named Λ-CDM, accommodates all of the results gathered from the CMB radiation and those from the observations of SNIa, specillay dark energy is interpreted as vacuum energy, that is Λ. Such priviledged status of the standard model Λ-CDM is emphasized by Mike Turner [45]: "The case is simple": there is no compelling theoretical argument against a cosmological constant, and Λ-CDM is the only CDM model that is consistent with all present observations. Λ-CDM has two noteworthy features: it can be falsified in the near future (the prediction $q_0 \sim -0.5$ is an especially good test), and, if correct, it has important implications for fundamental physics". Notwithstanding, the standard model has yet to solve both the fundamental and very serious shortcomings it is facing presently: the cosmological constant problem (a Λ value today at least 10^{56} times larger than observations allowed) and the coincidence problem (one among several of the so-called *fine tuning* problems).

The first step is to consider that the Anthropic Principle constitutes the unique available instrument that we have to provide an explanation of the fine tuning of the parameters associated to the initial conditions of the universe, including the value of Λ, and leading to identify their attractors. Nonetheless, over decades the Anthropic Principle was treated as something anti-scientific, what restricted its usage to the creation of probabilistic stratagemas in the context of the multiverse proposal. The anthropic principle, the models of multiverse, the cyclical universe and many other ideas have faced this type of restriction in the last decades at the same time that the use of increasingly sophisticated mathematical techniques seemed to make unnecessary the logical discourse and the systematic conceptual criticism. This represents one of the most serious conceptual errors in the approach to the problems of cosmology in our days, namely, the mistake of establishing what must or musn't be accepted as explanation and even as working hypothesis, which amounts, in essence, to choosing which properties can the universe have or not have in the realm of a model. In this very respect, just this year, Barrow and Shaw in [46] pointed out that: "Attempts to explain the coincidence that $\Lambda \sim 1/t_U^2$ (t_U is the age of the universe) have relied upon ensembles of possible universes, in which all possible values of Λ are found. Anthropic selection is combined with some prior probability distribution for Λ over the ensemble to find the most probable value (*N-of-the-A: These authors seem to refer to the attractors quoted in the precedent discussion*) that allows galaxies to form. Clearly, it would be much more attractive to predict Λ directly using a testable theory without appeal to a multiverse of possibilities ...". Hence, it is not negligible the possibility that the Anthropic Principle may lead to the formulation of a theory with such purpose.

Times seem to be changing. This is what emanates from the book *Universe or Multiverse?* published by Bernard J. Carr in 2007 [47]. It brings together eminent cosmologists, physicists, and philosophers who are all doing good philosophy. In the remissive index of the book the word "Anthropic" appears at least 78 times, many more than any other. The delicate, complex and not yet fully assimilated theme of the multiverse is discussed in all its versions. And the focus in most of the texts is predominantly conceptual.

Summarizing, it seems apparent that cosmology is living a golden age with the advent of observations of high precision. Nonetheless, a critical revisiting of the direction in which it should go on appears also needed, for misconcepts like "quantum backgrounds for classical cosmological settings" and "quantum gravity unification" have not been decidedly achieved up-to-date. Thus, knowledge-building in cosmology, more than in any other field, should begin with visions of the reality, and passing to have a technical form whenever concepts and relations inbetween are translated into a mathematical structure. It is mandatory, therefore, that the meaning of such concepts be the same for all cosmologists, and that any relationship among all of them be tested both logically as well as mathematically. In other words, the notorius character of improbability of our universe, as is well-kown, assures to cosmologists a priviledged degree of freedom for formulating interpretations and theories. However, at the same time, it demands that their formulations and conclusions be considered in the light of data from astrophysical observations.

To the last, but not to end point, cosmology is living a moment in which open forums featured by authoritative scientists are inviting to admit that most current observations demand to revisit the pillars of the standard model. As a matter of examples, some years ago in "The large-scale smoothness of the Universe" by Wu, Lahav and Rees [48] have put into question the validity of the *Cosmological Principle*, (which states that the universe is homogeneous and isotropic over cosmic distance scales), under the argument that such pillar was put by hand by the founders of modern cosmology in an epoch where there were no conclusive astronomical observations that would provide the due support it had required. Besides, a few years ago by Fuzfa and Alimi [49] showed that a self-consistent way to accommodate the SNIa observations goes through by admitting that the *Equivalence Principle*, another pillar of the standard model, should be forsaken. And even more, many years ago the Lemaître-Tolman-Bondi (LTB) cosmological models were brought in into play as one can verify in the article by Hellaby [50] who reviewed those models which also give up at least the *radial homogeneity* in cosmological scenarios. And to the last, several cosmological models recently idealized as an explanation of the alignments found in the observations by WMAP of the CMB radiation also invoke LTB models Caldwell and Stebbins [51], or something of the like, and even a non scale invariant gravitational interaction [52], besides of calling also for cosmological models *a lá* Gödel. This moment of effervescence in cosmology invites to the reflexion and debate.

Perhaps we are already are in a position to successfully battle the "cosmic conundrum" and enter the golden age of cosmology. This is a moment to reflect on the advice given by Einstein [53]:

> "It has often been said, and certainly not without justification, that the man of science is a poor philosopher. Why then should it not be the right thing for the physicist to let the philosopher do the philosophizing? Such might indeed be the right thing at a time when the physicist believes he has at his disposal a rigid system of fundamental concepts and fundamental laws which are so well established that waves of doubt cannot reach them; but, it cannot be right at a time when the very foundations of physics itself have become problematic as they are now. At a time like the present, when experience forces us to seek a newer and more solid foundation, the physicist cannot simply surrender to the philosopher the critical contemplation of the theoretical foundations; for he himself knows best, and feels more surely where the shoe pinches. In looking for a new foundation, he must try to make clear in his own mind just how far the concepts which he uses are justified, and are necessities."

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