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COSMOLOGICAL MODEL OF BUBBLE MULTIVERSE

Alexander Yosifov

e-mail: alexander_yosifov@abv.bg

Abstract

The conventional singular hot Big Bang scenario is questioned. A new model which does not include an initial singularity (g_{00}=∞ at $t = 0$), neither a brief period of exponential expansion $a(t)\sim e^{Ht}$ is considered. The main parameters T and ρ are kept finite. The proposed cosmological picture represents our Universe as part of a multiverse. The beginning of the Universe we occupy is revisited in the framework of quantum field theory in curved spacetime. However, a straightforward alternative mechanism for not only solving the most fundamental problems in modern cosmology – flatness problem, horizon problem and magnetic monopole problem, but even suppressing their number is provided. In the particular paper I discuss the very nature of the spacetime and the apparent contradiction between quantum mechanics and general relativity in terms of a classical field theory in 3+1 dimensions.

Introduction

For the past decades the prevailing view, regarding the beginning of the universe and its evolution in the first fraction of a second, has been a combination of the big bang theory and the theory of cosmic inflation [1]. However, recently this paradigm has been challenged. According to The Big Bang Theory (TBBT), if we extrapolate the current picture of the Universe backwards in time, temperature T and density ρ start increasing until we reach the initial singularity $g_{00}= \infty$ at the beginning of time $t = 0$. At that moment the whole Universe is compressed to a single point of zero size, $t \to 0$ and $a(t) \to 0$ while $T \to \infty$ and $\rho \to \infty$. At this point our laws of physics break down. The central problem of TBBT is namely the singularity. Furthermore, the theory does not provide any explanation regarding the initial conditions. The model is completely ignorant about the events prior to the expansion phase as neither space, nor time existed.

The theory of cosmic inflation states that right after the Big Bang the universe went through a brief period, 10^{-36}s, of superluminal exponential expansion $a(t)\sim e^{Ht}$. The concept was originally pioneered to smooth and flatten the Universe, starting from random initial conditions, and thus solve the horizon, flatness and magnetic monopole problems with a straightforward mechanism. The conventional theory dictates that in order for inflation to be triggered, a scalar field ϕ, *inflaton*, satisfying the property $V(\phi) >> E_k$ has to be present. Because of the small kinetic energy E_k, the inflaton ϕ settles down to a state of potential well adiabatically. Once the scalar field ϕ is settled, the potential energy $V(\phi)$ starts dominating. When the potential takes over, the Lagrangian $L = E_k - V(\phi)$, becomes negative and the universe starts expanding. The measure of the expansion, *e-folds*, is given by $\frac{a(t_f)}{a(t_i)}=e^N$, where $a(t_f)$ and $a(t_i)$ is the scale factor after and prior to inflation, respectively. The number of *e-folds*, N, is defined as $N \equiv (t_f - t_i)H$, where $H = \dot{a}/a$, is the Hubble parameter. Large kinetic energy value would prevent inflation from initiating. I am not going to provide a detailed description of inflation; neither will I examine its different models, as this is not of interest to the particular paper. Great effort in this direction has been devoted in the past [2-4]. However, this view has to be abandoned. Recent data, gathered by the Planck satellite [5], seriously questions the paradigm. A subsequent paper, based on the obtained results, [6], shows problems with inflation that until now were not present. According to the data, for inflation to start smoothing and flattening the Universe, it has to have extremely low initial anisotropy prior to the exponential expansion phase. Moreover, *Planck*2013 rules out most of the inflationary models and favors only the simple ones [7-9]. It shows we live in an amazingly elegant Universe; the spatial curvature is negligible and the fluctuations are Gaussian. The overall data, collected by *Planck* satellite, calls for a new and simple description of the Universe. The contemporary cosmological model suffers from many problems which force us to rethink our understanding concerning the early history of the Universe. I discuss an alternative non-singular and inflation-free model which predicts finite values for both space and time. The proposed picture is simple in a sense that it does not require the addition of n compacted extra dimensions. The model eliminates the flatness of the spacetime geometry as a problem, and solves both of the remaining ones, horizon and monopoles problems, with a straightforward mechanism motivated by certain string theory models.

Bubble multiverse

I will describe a scenario which provides a non-inflationary solution to the horizon and magnetic monopoles problems. The Bubble Multiverse (BM) suggests our Universe is part of an Multiverse. The model represents each Universe as a separate 3+1 dimensional bubble, described by the Friedmann-Robertson-Walker (FRW) metric

(1) $$ds^2=-dt^2+a^2(t)\left[\frac{dr^2}{1-kr^2}+r^2 d\Omega^2\right]\equiv g_{\mu\nu}dx^\mu dx^\nu,$$

where $\Omega^2 = d\Theta^2 + sin^2\Theta d\phi^2, k = +1$, in which case the scale factor $a(t)$ becomes the radius curvature of space, denoted as $R(t)$. Einstein's equation for the particular metric reads

(2) $$G_\mu^\nu = \frac{8\pi G}{3} T_\mu^\nu,$$

where T_μ^ν is the energy-momentum tensor. The Friedmann equation for the evolution of the FRW universe is provided by (3):

(3) $$(\frac{\dot{a}}{a})^2 = H(t)^2 = \frac{8\pi G}{3c^2}\varepsilon(t) - \frac{kc^2}{R_0^2 a(t)},$$

where $k = +1$, $\varepsilon(t)$ is the energy density and $a(t)$ is the FRW scale factor. Initial homogeneity and isotropy of the Universe on large scales (>100 Mpc) is assumed. The bubbles are taken to propagate in a quantum vacuum background and interact only via gravity. Hence, we suppose different bubbles can approach each other. This is a semi-classical theory, matter fields are quantized and gravity is treated classically. In the presence of a gravitational source, the spacetime geometry becomes non-Euclidean, thus allowing for trivial description of the dynamics using Einstein's field equation

(4) $$G_{\mu\nu} = 8\pi\langle T_{\mu\nu}\rangle$$

Given the metric of the spacetime, depending on the matter and radiation density one might expect the universe to reach a maximum size R_{max} and then start contracting or keep expanding forever *a(t)* -> ∞ as *t->0*. In the framework we describe, it is more convenient to assume finite size of the different universes. It is therefore plausible, I believe, to assume every single bubble has a boundary layer exhibiting superfluid properties. Numerous experiments with superfluids have been done in the last couple of decades [10-12]. Of particular interest is He-3, a type of Fermi superfluid. It has proved to be extremely useful medium for studying the effects of quantum field theory and high-energy physics. Furthermore, superfluid He-3 is a good environment for mimicking event horizons of black holes [13-15]. As a result, when two "parent" universes come close together, due to the superfluid properties of their shells, a force of repulsion, that overcomes the force of gravity, occurs. Hence, the bubbles repel each other. Because of the strong gravitational field, generated by the two universes, the quantum vacuum *in-between* gets polarized. The idea of vacuum polarization in the presence of a strong gravitational field was presented by Stephen Hawking [16]. He proved mathematically that at the vicinity of its horizon, $g_{00} = 0$, a black hole polarizes the quantum vacuum under the influence of its own gravitational field, which leads to an increase of the local energy density of the quantum fluctuations $\delta\phi$, hence pairs of positive frequency oscillations are produced. The expectation value of the field fluctuations in curved spacetime is given by $\langle\phi^2\rangle$. The change of the area of the event horizon due to the particle absorption, is non-negative. Consequently, high frequency outgoing modes of the quantum field, Hawking radiation, are emitted to infinity and the black hole evaporates. A static black hole emits Hawking quanta with a black body thermal spectrum of temperature T=$\frac{\hbar c^3}{8\pi GM}$, where $\hbar$ is the reduced Planck constant. Because of the quantum nature of the environment, Quantum Field Theory in Curved Spacetime (QFTCS) is the framework behind the mechanism for creating a new Universe in the particular paradigm. The no-hair theorem [17-18] implies black holes are indistinguishable from one another. It posits they are entirely described by three classical parameters – angular momentum *J*, charge *Q*, and mass *M*. The theorem states that all of the information regarding the matter that has collapsed to form the black hole is trapped behind the event horizon and is inaccessible to the external observers. Similarly, bubble universes can be described by the same parameters. This line of reasoning allows us to assume the boundary surface of an individual bubble is a flat surface. This was first proposed by G.‘t Hooft in the context of the holographic principle. I have come to the same conclusion based on completely different arguments from black hole physics which suggests the proposed view might have deep implications. Furthermore, since both the boundary layer of an Universe and the event horizon of a black hole are flat surfaces and polarize the vacuum in their vicinity, an analogy between them could be made. Describing the quantum vacuum polarization in the spacetime region *between* two bubble universes, we apply the Hermitian operators $\Psi^\dagger$(x) and Ψ(x) to the scalar field ϕ. They are defined as follows (5):

(5) $$\Psi^\dagger(x) = \sum_i \Psi_i^*(x)\, a_i^+, \qquad \Psi(\mathrm{x}) = \sum_i \Psi_i(x)\, a_i,$$

where $a_i^\dagger$ and a_i are the creation and annihilation operators, respectively. When we apply a creation operator on the lowest possible energy state, the vacuum $|0>$, we get (6)

(6) $$a_i^+|0>=|x>.$$

We find that a positive frequency oscillation is produced at point x. This is due to the instability of the quantum vacuum in the presence of a strong gravitational field. The initial vacuum will not appear entirely particle-free to all observers. An annihilation operator, acting on the vacuum yields

(7) $$a_i|0>=|0> \text{ for } \forall \text{ states.}$$

The number of particles in this case is not globally determined but rather observer-dependent. The expectation value of the particle production is given by

(8) $$\langle N_i\rangle=\langle 0|a_i^{\dagger}a_i|0\rangle,$$

where N_i is the number operator and it is defined as $N_i=a_i^{\dagger}a_i$. We expand the creation and annihilation operators by a Bogoliubov transformation

(9) $$a_i=\sum_j(\alpha_{ij}^{*}a_j-\beta_{ij}^{*}a_j^{\dagger}),$$

where α_{ij} and β_{ij} are the Bogoliubov coefficients. The scalar fields are time-independent; they solely depend on position. Therefore, we assign a Hermitian operator to every point in space

(10) $$\Psi^{\dagger}(x)=\sum_i\Psi_i^{*}(x)a_i^{+}.$$

We can calculate the density by applying the operators $\Psi^{\dagger}(x)$ and $\Psi(x)$. Integrating over a particular region allows us to find the approximate number of particles in the given volume of space

(11) $$\int dx\,\Psi^{\dagger}(x)\Psi(x)$$

(11.1) $$\int dx\sum_{ij}a_i^{\dagger}\Psi_i^{*}(x)a_j\Psi_j(x)$$

(11.2) $$\sum_{ij}a_i^{\dagger}a_j\delta_{ij}\ .$$

Due to the quantum nature of the process, the number varies. The Dirac delta function shows continued distribution. We can now proceed and calculate the energy density in the present region. I will start by first considering the more familiar example with only one particle. The energy of each produced quanta is given by the time-independent one-particle $Schrödinger$ equation

(12) $$\Psi_i H = \Psi_i \omega,$$

where H is the Hamiltonian. Substituting H in equation [(8)] gives us

(12.1) $$\Psi_i \left[\frac{-\hbar^2}{2m}\boldsymbol{\nabla}^2 + V(\phi)\right] = \Psi_i \omega_i,$$

where $\boldsymbol{\nabla}^2$ is the Laplace operator and in 3D Cartesian coordinates yields the form

(13) $$\boldsymbol{\nabla}^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} .$$

Hence, by applying Hermitian operators to the Hamiltonian of each one-particle state we find the total amount of energy in a given region of space to be

(14) $$E = \int dx\, \Psi^+(x) \left[\frac{-\hbar^2}{2m}\boldsymbol{\nabla}^2 + V(\phi)\right] \Psi(x).$$

Let me now consider the many-particles case. Despite we are now dealing with a more complex system, consisting of N number of particles, and one might expect it to be more complicated, we do, however, apply the same formalism as in equation [(12.1)]

(15) $$H = -\frac{\hbar^2}{2}\sum_i^N \frac{\boldsymbol{\nabla}^2{}_i}{m_i} + V(\phi),$$

where the dot product of the del operator denotes the kinetic energy of the N-particle system. The above-developed concept creates the initial causally connected patch of matter which will later expand to become our Universe. We initially begin with a non-zero value of the scale factor $a(t)$, thus we avoid the formation of a cosmic singularity and keep the parameters ρ and T finite. The matter patch is in low entropy state and must satisfy the extremely low initial anisotropy condition in order for expansion to be initiated. Considering an inflation-free model, depending chiefly on the initial expansion rate Λ, leads to two extreme possible scenarios in the early universe: (i) adiabatic expansion and (ii) very rapid initial expansion, corresponding to $\Lambda << 1$ and $\Lambda >> 1$, respectively. In the first case, the critical value of the density ρ_{crit} will be exceeded quickly, thus gravitational attraction will take over, resulting in an immediate collapse. Whereas in the second case, numerous Planckian-size low entropy state horizons will form, each of which containing several bits of information. In both cases the lifespan of the Universe will be incredibly short; thus being, for all practical purposes, meaningless. Aside from the extreme scenarios, for the Universe to grow and form large-scale structures, the initial expansion Λ, has to take an arbitrary value somewhere between the extreme velocities (16)

(16) $$\Lambda << 1 < \Lambda_{right} < \Lambda >> 1 .$$

Cosmological problems

A period of chaotic exponential expansion is not required in order for the main cosmological problems to be solved. Alternative solutions are presented in the present section. I argue the apparent flatness of the spacetime geometry, at least on the scales we observe, should not be considered a problem but rather a consequence. The metric of the Universe depends chiefly on two parameters, ρ and H. A stable closed model, however, can be constructed. A non-singular patch with extremely low degree of initial anisotropy in low entropy state, going through a non-exponential expansion phase, can result in an apparent flatness. The 4D spacetime within the Bubble Universe we live in might appear flat on smaller scales. Although one can set local coordinates that exhibit Minkowski metric, they do not represent the complete manifold. It is possible, however, for the Universe to exhibit flat geometry on fairly large scales (>H^{-1}). Based on the requirements for expansion to be initiated, the flatness of the spacetime, observed today, is simply a natural consequence of the initial conditions.

Let us now consider the horizon problem. A non-inflationary solution, which was inspired by some string theory models, is proposed. Let us suppose the existence of a tachyon field in the low entropy state of the Universe. The tachyon field coupled to 4D gravity has a non-canonical action, which can be written as

(17) $$S_T = -\int d^4 x\sqrt{-g}\left[V(T)\sqrt{1+\partial_\mu T\partial^\mu T}\right],$$

where $V(T)$ is the positive effective potential of the field with maximum value at $\phi = 0$ and g is the coupling constant. The Lagrangian of the scalar field in curved spacetime is written as

(18) $$\mathcal{L}(x) = \frac{1}{2}[-g(x)]\hat{}1/2\left[g^{\mu\nu}(x)\partial_\mu\phi(x)\partial_\nu\phi(x) - [m^2 + \varepsilon R(x)]\phi^2(x)\right],$$

where m is the mass of the field, R is the Ricci scalar and ε is the coupling constant. The tachyon field is in a state of unstable equilibrium at the top of its potential energy $V(\phi)$. Due to quantum fluctuations the field is taken out of its present state, consequently, it rapidly decays, converting all of its effective potential into *metastable* spin-0 electrically neutral particles, *tachyons*, which obey the following energy-momentum relation $E^2 = p^2 + m^2$, where $c = 1$. Because the tachyons are metastable, they dilute before their energy reaches zero, as this would imply infinite propagation velocity, $v_T \to \infty$ as $E \to 0$. As the field rolls down, it relaxes to a stable configuration, corresponding to the minimum of its potential. Once the field is settled, no more particles are produced. The particles propagate superluminally for an extremely brief period of time. When the tachyons dilute, they release the remaining of their energy. Therefore they can even the temperature of the universe and produce the near-isotropy of the cosmic microwave background (CMB) radiation. The apparent lack of monopoles in the Universe today is one of the central puzzles in modern cosmology. We do, however, strongly believe in their existence. Contemporary particle models, like Grand Unified Theories (GUTs) and Superstring Theory predict the existence of magnetic monopoles. Furthermore, experiments for artificially creating monopoles bolster our view even more [19]. Most of the GUTs suggest that when the temperature of the early Universe dropped below the GUT threshold $T < T_{GUT}$, the Universe went through a phase transition, associated with spontaneous symmetry breaking, and hence the creation of topological defects, like domain walls, cosmic strings, and magnetic monopoles, for example. The rest energy of the magnetic monopoles at the time of the GUT phase transition, based on most particle models, is estimated to be $m_M c^2 = 10^{12}\, TeV$, which yields an approximate energy density of $\rho_M \sim 10^{94}\, TeV\, m^{-3}$. The same, string-theory-borrowed mechanism, used to resolve the horizon problem, is applied. We emphasize here on the inversed proportionality between the energy of the particles and their velocity. As we have explained, when the field decays, it produces tachyon condensate. The condensate is highly energetic at first, and then its energy E_T exponentially decreases as the velocity v_T increases, in accordance the following relation $E_T = \frac{1}{v_T}$. As a result, a fraction of the magnetic monopoles is annihilated.

Discussions and Conclusions

In the present section, I will first discuss the apparent contradiction between quantum mechanics and general relativity by conducting a simple *gedanken* experiment. I will then present an early-Universe phenomena which reinterprets the nature of the spacetime. The scenario occurs naturally as we approach Planck energy scale and addresses the cosmological principle which we have been taken for granted. The phenomena show the crucial role quantum mechanics plays in the early history of the Universe. A lot of work towards unifying quantum mechanics and relativity has been done in the past. However, developing a comprehensive theory of quantum gravity has proven to be extremely difficult. The conclusions, which I draw, are based on a *gedanken* experiment which I will now put forward. For the purposes of the current experiment I will consider the fundamental building blocks of nature to be tiny constructor pieces which behave quantum mechanically. Imagine Charlie starts playing with the constructor pieces by adding the individual blocks together. We assume he has created a bigger structure. Although the new construction is somewhat bigger, suppose it still behaves probabilistically. If he keeps playing though, a point will be reached, at which the whole system (consisting of N number of pieces), will start exhibiting deterministic properties. However, consider Charlie decides to take a piece away from his toy, so that the new structure now consists of $N - 1$ pieces. As a result, we assume his actions would bring back the random nature of the system. The difference in the behavior between the *N number* configuration and the *N-1 number* configuration is believed to be discrete. Following the *gedanken* experiment described above, we narrow it down to two possibilities. The first possibility relies on the well-bounded difference between the intuitive laws in the macroscopic world and the seemingly chaotic laws in the quantum realm. That is why it is plausible to assume that at particular scale a *transition* between quantum mechanics and general relativity occurs. Building on that, it is then feasible for us to speculate that every $N\text{-}particle$ quantum system will change its nature to general relativistic one in the $N + 1 - particle$ case when the transition point, corresponding to a certain number of particles, is passed. However, it is still unknown at what scale exactly does the transition between stochastic and deterministic behavior occur. The second interpretation of the *gedanken* experiment includes the naive conclusion that since the fundamental building blocks of nature act quantum mechanically, then the large-scale structures they make should act in the same manner. In this case the reason why we tend to experience our macro world as deterministic could be attributed to our ability to perceive the physical reality. It should be noted that I have covered the second possibility despite my skepticism towards it.

Based on the provided interpretations of the thought experiment, I argue *general relativity is nothing more than a macroscopic manifestation of quantum mechanics*. A contradiction is present because we are trying to unify a manifestation of a theory with the theory itself. The homogeneity and isotropy of the Universe on large scales (> 100 Mpc) is formulated as the cosmological principle. A satisfactory explanation about which has not yet been provided, and the very notion has been so far taken for granted. As we go backwards in time both the temperature and the density of the Universe increase. If we go as far back as $10^{-36}s$ the temperature of the Universe is approximately $10^{28}\ K$, corresponding to energy levels of $10^{12}\ TeV$. At that energy scale the electromagnetic, weak and strong forces unify in GUT. We expect if we go even further back in time to $10^{-43}s$ the temperature of the universe to be $10^{33}K$, corresponding to Planck energy, $E_p{\sim}10^{16}\ TeV$. This is believed to be the so-called Theory of Everything scale, at which gravity unifies with the other gauge forces. I claim *quantum* *mechanics acts differently* in a certain way when $T >> T_{GUT}$. Therefore, I argue the *monogamy of entanglement is violated* at Planck energy scale and what I call "global entanglement" or "polygamy of entanglement" is present. The notion of global entanglement in the very early Universe can naturally explain the cosmological principle we observe today. In that sense, objects separated by distance greater than the Hubble radii never lose causal contact, as one might expect. On a deeper quantum mechanical level, the different regions of the Universe are always in causal contact, regardless of the physical distance. Because of the fundamental implications of quantum mechanics, it is plausible for us to assume the polygamy of entanglement played an essential role in the early history of the Universe. Recent developments in theoretical physics opened the possibility for a different approach to the nature of the spacetime. Work by Mark Raamsdonk [20] and others point out that we might have to reconsider our understanding of the spacetime. A proposal was made that the classical spacetime geometry emerges from quantum entanglement. In a sense, quantum entanglement holds space together and the structure of the spacetime is combinatorial rather than continues. The contemporary, and somewhat radical views, fit elegantly with the idea of polygamy of entanglement at Planck energy scale. In this picture the "spooky action at a distance" becomes a feature of the combinatorial structure of the Universe. The naïve interpretation would be that in a combinatorial structure, held together by quantum entanglement, any two points in space should be able to communicate instantaneously. We observe this not to be the case. From what we know if two particles have not interacted in the past they should not be able to communicate. The reason points to the ER=EPR relation. As it has been suggested by Susskind and Maldacena [21] any pair of entangled particles should have a tiny wormhole connecting them. The new view regarding the structure of the spacetime strongly advocates this proposal. An integral feature of the combinatorial structure of the spacetime should be namely the possibility for creating tiny wormholes between any pair of entangled particles.

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КОСМОЛОГИЧЕН МОДЕЛ НА МЕХУРНА МУЛТИВСЕЛЕНА

А. Йосифов

Резюме

Поставя се под съмнение конвенционалната сингулярна теория за Големия взрив. Представя се нов модел, който не включва нито първоначална сингулярност $g_{00} = \infty$ при $t = 0$, нито кратък период на експоненциално разширение $a(t) \sim e^{Ht}$. Основните параметри, T и ρ, са с крайни стойности. Предлаганият космологичен модел представя Вселената, като част от мултивселена. Зараждането на нашата Вселена се описва в контекста на квантова теория на полетата в нагънато пространство. Също така се представя алтернативен механизъм не само за решаване на основните фундаментални проблеми в съвременната космология – плоскостта на Вселената, проблемът с хоризонта, както и магнитните монополи, но и за редуциране на техния брой. В конкретния труд се описва фундаменталната структура на пространство-времето, както и привидното несъответствие между квантовата механика и теорията за гравитацията на Айнщайн от гледна точка на класическа теория на полетата в 3+1 измерения.