Virtual gravitational dipoles as the cause of cosmic inflation in the beginning of each cycle of the universe

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Abstract. The hypothetical cosmic inflation, driven by a fundamental scalar field of unknown nature, is widely acclaimed as the cause of the primordial gravitational waves revealed by BICEP2 Collaboration. We challenge this opinion and suggest that the quantum vacuum enriched with the virtual gravitational dipoles (i.e. particle-antiparticle pairs with the opposite gravitational charge) might lead to a cyclic Universe, with cycles alternatively dominated by matter and antimatter and with each cycle beginning with the accelerated expansion. This scenario might have four significant advantages. First, there is no need for a mysterious scalar field. Second, there is an elegant explanation of the matter-antimatter asymmetry in the Universe: our Universe is dominated by matter because the previous cycle of the Universe was dominated by antimatter. Third, singularity and microscopic size of the universe are prevented; the new cycle of the universe is always born with a macroscopic size. Fourth, as recently argued, the virtual gravitational dipoles might also be an alternative to dark matter and dark energy.

1. Introduction

According to astronomical observations we live in an expanding Universe; hence, the size of the Universe was smaller in the past. How much smaller? Was it smaller than our Galaxy, smaller than our Solar System, smaller than our planet, smaller than an electron, or even smaller than the Planck length ($10^{-35}\,m$)? At what size would an imagined trip backward in time end? We do not know.

The old Big-Bang model without inflation and the current Standard Big-Bang model *improved* by inflation have a common conjecture: the whole universe emerges from an ultra-microscopic domain, comparable with a single Planck size domain.

Let us start with a simple definition of cosmic inflation: *Inflation is a stage of accelerated expansion of the primordial universe when gravity acts as a repulsive force* [1].

The key difference between the model without inflation and the model with inflation is schematically presented in Fig.1, with t, R and $\dot{R}$ denoting respectively the cosmic time, the scale factor of the Universe and the speed of the expansion of the universe. The old picture of a decelerated Friedmann universe is modified by inserting a stage of cosmic acceleration. Of course, in order to preserve the successful predictions of the standard Friedmann model, inflation must end sufficiently early and must possess a smooth graceful exit (roughly speaking in less than $10^{-30}\,s$) into the decelerated Friedmann stage.

The ad hoc assumption of cosmic inflation was motivated by the fact that the old Big-Bang theory contains both, theoretical predictions well confirmed by observations and predictions in sharp conflict with observations. For instance, the old theory predicts the existence of the cosmic microwave background (CMB) but contradicts its major characteristics: high level of homogeneity and isotropy.

The theory of cosmic inflation was born from the mathematical understanding that the decreasing functions $\dot{R}$ cannot be reconciled with the homogeneity and isotropy revealed by the study of the CMB, while some mathematical functions with $\dot{R}$ initially increasing and after that decreasing are in good agreement with the observed homogeneity and isotropy. This *mathematical* success can be considered as indication that the initial accelerated expansion of the Universe really existed; however the cause of such a phenomenon remains a total mystery and we can only speculate about it.

The inflationary cosmology is based on speculation that the primordial accelerated expansion of the universe is driven by a fundamental scalar field of unknown nature (in fact in the absence of any empirical evidence, cosmologists still play with different mathematical forms of the scalar field). According to the prevailing scenario (chaotic inflation) the creation of matter of our Universe has happened *after* inflation [1, 2] when the energy concentrated in the inflation field was converted into particle-antiparticle pairs. From this time on, the universe can be described by the usual Big-Bang theory. Let us underline how this is radically different from the theory without inflation. In the Big Bang model without inflation, the *totality* of mass of the Universe emerges from a single Planck size domain. In the theory with inflation, the *only* content of the universe during inflation is the fundamental scalar field; the mass of the universe emerges at the *end* of inflation when universe already has a *macroscopic* size. Hence the microscopic universe doesn't contain matter; matter appears only in a macroscopic universe!

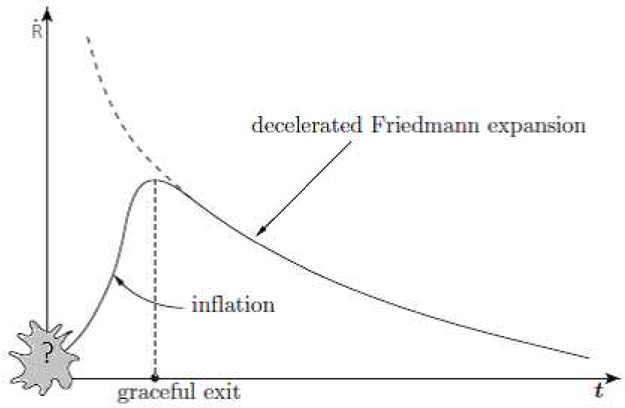

Figure 1

In March 2014, astronomers working on the Background Imaging of Cosmic Extragalactic Polarisation 2 (BICEP2) telescope have reported results [3] which are apparently the discovery of the primordial gravitational waves. In fact, the primordial B-mode polarisation of the cosmic microwave background has been observed; the key point is that B-mode polarisation can be created only by very strong primordial gravitational waves. Hence, a background of strong gravitational waves existed in the Universe at the moment of the "birth" of CMB (by the way at that moment the Universe was already much bigger than our Galaxy). The existence of strong primordial gravitational waves proves that a mysterious cataclysmic event happened before the birth of CMB. Of course, inflation caused by a scalar inflation field is a cataclysmic event inevitably accompanied with creation of the primordial gravitational waves [1, 2]. However it is premature to conclude that the current inflation theory is confirmed by the discovery of the primordial gravitational waves; the existence of the waves and the physical source of the waves are two different things. The BICEP2 results tell us *only* that much before the birth of the CMB there was a cataclysmic event as the source of the primordial gravitational waves; what the event was, the scalar inflation field or something else, remains an open question. In fact, it seems that current versions of inflation contradict [4] the observed characteristics of the primordial waves; it is reminiscent of the old Big-Bang theory successfully predicting CMB but with wrong characteristics.

While it is never stated clearly, the theory of cosmic inflation has two parts. The first part is apparently very robust: for some unknown reasons the speed $\dot{R}$ of the expansion of the universe firstly increases, i.e. gravity acts as a repulsive force in the primordial universe. In the present Letter we do not challenge this hypothesis; to the contrary we consider it as a great revelation and the major scientific contribution. The second part, the attempt to explain the phenomenon of the accelerated expansion by invoking the fundamental scalar (inflation) field of unknown nature, is less robust and more questionable. It is important to note that in addition to the hypothetical inflation field there are two other hypotheses: the inflation field emerges from a single domain of the Planck size, while the repulsive effect is achieved by modeling the scalar field with a cosmological fluid having a negative pressure (it is the only possibility within the framework of General Relativity, mathematically expressed by Eq. (1)).

In the present Letter we challenge: (1) the hypothesis of the fundamental scalar field as the cause of the primordial inflation, (2) the need for expansion speed many orders of magnitude larger than the speed of light, (3) the negative pressure as the mechanism for the initial gravitational repulsion and (4) the microscopic birth size of the universe. As an alternative we suggest quantum vacuum enriched with the virtual gravitational dipoles.

2. The cosmological equation for acceleration

In contemporary cosmology (See for instance [4]) the "mass-energy content" of the Universe is successfully modelled as a perfect "cosmological fluid", which consists of a mixture of several distinct components (hereafter denoted by the subscript n) having density ρ_n and pressure p_n in the instantaneous rest frame.

The cosmological principle leads to the Friedman-Robertson-Walker metric [4]. The dynamics of that metric (i.e. the space-time geometry) is entirely characterized by the scale factor $R(t)$ which depends on the content of the Universe. For the purpose of the present paper it is important that the scale factor satisfies [4] the following cosmological field equation

$$\ddot{R} = -\frac{4\pi G}{3} R \sum_n \left(\rho_n + \frac{3 p_n}{c^2} \right) \tag{1}$$

Within the Standard Cosmological Model, densities ρ_n follow the power-law

$$\rho_n = \rho_{n0} \left(\frac{R_0}{R} \right)^n \tag{2}$$

where index 0 denotes the present-day values.

Each component of the cosmological fluid obeys an equation of state of the form $p_n = w_n \rho_n c^2$ with constant equation-of-state parameter $w_n = (n-3)/3$. The cases $n = 4, 3, 0$ (with $w = 1/3, 0, -1$) correspond respectively to relativistic particles, pressureless matter (including both ordinary matter and dark matter) and a cosmological constant Λ (as one plausible candidate for dark energy).

Today $\ddot{R}$ has a small value of the order of $10^{-9}\, m/s^2$. However (and it is crucial for our arguments), in the primordial Universe soon after inflation acceleration $\ddot{R}$ was extremely big. For instance, if we limit only to the effects of the pressureless matter, equations (1) and (2) lead to the following *lower bound* $\ddot{R}_{lb}$ for acceleration

$$\ddot{R}_{lb} = -\frac{4\pi G \rho_{m0}}{3} \frac{R_0^3}{R^2} = -\frac{4\pi G \rho_{m0}}{3} \left(\frac{c}{H_0} \right)^3 \frac{1}{(\Omega_{0tot} - 1)^{3/2}} \frac{1}{R^2} \tag{3}$$

The second equality in (3) is a consequence of well-known relation [3] $c^2 / H^2 R^2 = \Omega_{tot} - 1$ where the usual dimensionless parameter Ω_{tot} (with the present-day value $\Omega_{0tot} \approx 1.002$) denotes the total energy density of the Universe. For example, if $R = 1m$, $\ddot{R}_{lb}$ has tremendous value of the order of $10^{45}\, m/s^2$.

Now when we know how strong the gravitational field in the primordial universe might be we need to remember the important mechanism coming from quantum electrodynamics.

3. The Schwinger mechanism in quantum electrodynamics

A virtual electron–positron pair (and in principle any charged particle-antiparticle pair) from the quantum vacuum, might be *converted* into a real one by a sufficiently strong external electric field which accelerates electrons and positrons in *opposite* directions. For a constant acceleration a (which corresponds to a constant electric field), the particle creation rate per unit volume and time, can be written [6, 7] as:

$$\frac{dN_{m\bar{m}}}{dt dV} = \frac{c}{\lambda\!\!\!^{-}{}_m^4} \left(\frac{a}{a_{cr}} \right)^2 \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(-n \frac{a_{cr}}{a} \right), \quad a_{cr} \equiv \frac{\pi c^2}{\lambda\!\!\!^{-}{}_m} \tag{4}$$

which is the famous Schwinger formula [6 , 7], with λ_m being the reduced Compton wavelength of a particle with mass m . In simple words, a virtual pair can be converted to a real one (i.e. real particle–antiparticle pairs can be created from the quantum vacuum!), by an external field which, during their short lifetime, can separate particle and antiparticle to a distance of about one reduced Compton wavelength. Let us note that according to (4) the critical accelerations for creation of electron-positron and proton-antiproton pairs are respectively $7.4\times10^{29}\ m/s^2$ and $1.4\times10^{33}\ m/s^2$. These accelerations are much smaller than the gravitational accelerations which might exist in the primordial Universe!

It is important to understand, the Schwinger mechanism is valid *only* for an external field that has the tendency to *separate* particles and antiparticles. Hence, Eq. (4) can be used for the gravitational field, *only if*, particles and antiparticles have *gravitational charge of the opposite sign*, implying both the gravitational repulsion between matter and antimatter and the existence of virtual gravitational dipoles in the quantum vacuum.. Well, why not? The existing experimental evidence does not and cannot preclude the hypothesis that the quantum vacuum contains virtual gravitational dipoles. The hypothesis can be confirmed or dismissed only by forthcoming experiments at CERN [8, 9, 10 and 11] and astronomical observations [12, 13]. So, we continue our considerations assuming that virtual gravitational dipoles exist, and consequently that there is the gravitational version of the Schwinger's mechanism.

4. Big Crunch and virtual gravitational dipoles

In the framework of contemporary physics there is no known mechanism to stop the gravitational collapse; hence, our imagined trip backward in time must end with a *singularity* as is the case in the Old Big Bang theory. As noted there is no singularity in chaotic inflation but the initial quantum vacuum fluctuation is roughly within a single Planck size domain.

However, assuming the quantum vacuum contains virtual gravitational dipoles, there is a physical mechanism preventing gravitational collapse to microscopic size. Through the gravitational version of the Schwinger mechanism *at a macroscopic size* the matter of our Universe would be converted to antimatter leading to a new cycle of the Universe dominated by antimatter.

The qualitative picture of the expected phenomena is very simple and beautiful. An extremely strong gravitational field (estimated by Eq. 3) would create a huge number of particle-antiparticle pairs from the physical vacuum; with the additional feature that matter tends to reach toward singularity while antimatter is violently ejected farther and farther from singularity. The amount of created antimatter is equal to the decrease in the mass of the collapsing matter Universe. Hence, the quantity of matter decreases while the quantity of antimatter increases for the same amount; the final result might be conversion of nearly all matter into antimatter. If the process of conversion is very fast, it may look like a Big Bang starting with a macroscopic initial size many orders of magnitude greater than the Planck length.

The particle-antiparticle creation rate per unit volume and time can be estimated using Eq. (4). For instance, if the scale factor of the Universe is $R = 1\,m$, Eq. (4) gives the following order of the magnitude for neutron-antineutron pairs

$$\frac{dN_{n\bar{n}}}{dtdV} \sim 10^{96}\ \frac{pairs}{sm^3} \tag{5}$$

which corresponds to a mass of $10^{69}\,kg$ per second and cubic meter. With such an enormous conversion rate the matter of our Universe can be transformed into antimatter in a tiny fraction of second.

It is evident that during the process of conversion, the antimatter (matter) of the new cycle of the universe is subject to the *gravitational repulsion* by the matter (antimatter) of the previous cycle of the universe, which is in fact the definition of cosmic inflation. Hence there is a kind of cosmic inflation but without need for a mysterious scalar field. In addition, as the mass of the previous cycle decreases and the mass of the new cycle increases there is a natural transition from repulsion to attraction (i.e. there is no problem with the graceful exit). Everything happens as sketched in Figure 1, but at a macroscopic size, eliminating the need for an exponential expansion with more than billions of billions times faster than the speed of light.

In the current inflation scenario at a macroscopic size the energy of the hypothetical scalar field converts to an initial matter-antimatter mixture, from which somehow only matter will survive. In our scenario, instead of the energy of the scalar field, the existing matter of the Universe converts to antimatter; there is no need for fundamental scalar field and for any additional mechanism to explain the matter-antimatter asymmetry of the Universe. Of course conversion of matter to antimatter is a cataclysmic event comparable with the supposed conversion of scalar field to matter; hence the strong primordial gravitational waves (revealed by results of BICEP2 Collaboration) are inherent part of both theories.

5. Concluding comments

Inflation is a mature theory more than 30 years old and developed by the work of many top theorists. It is a theory which proposes elegant mathematical solutions (but questionable physical solutions) to the problems of the Old Big Bang theory. However, in spite of mathematical success based on the conjecture about an inflation field, we must stay open to alternatives.

It would be wrong to confront this initial paper with the already well-developed inflation theory. It would be more reasonable to compare this paper with the initial rudimentary papers proposing the idea of inflation (just imagine that both proposals have appeared at the same time, one paper proposing inflation and the other proposing virtual gravitational dipoles). Hopefully our short paper would stimulate detailed theoretical study of the proposed mechanism; only after a fair development must it be confronted with inflation and both of them with the future more accurate observations.

Within the framework of virtual gravitational dipoles the most urgent tasks are the appropriate simulations and theoretical study of the gravitational waves in the case of the simplest toy model: a massive body made from matter that suddenly converts to a body made from antimatter.

In this paper the virtual gravitational dipoles were considered as an eventual alternative to inflation but it is worth noting that as recently suggested [14, 15, 16, 17] they also have the potential to explain phenomena usually attributed to dark matter and dark energy.

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