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Research Article

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The universe generated by the explosion of the primordial cosmic vacuum!

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Abstract

Over all its epochs mankind always has put the fundamental question: When and why at all did the universe start its existence? Most cosmologists univocally do answer this question with the standard dogmatic answer: By the Big-Bang! - namely by the initial explosion of an extremely concentrated world matter system! This standard paradigm of a general and global explosion creating this world obviously appears to be highly suggestive, though such an explosive event unexpectedly turns out to be extremely hard to understand on purely physical grounds. This is because it is extremely hard to explain which pressures might be responsible to drive the initially highly compacted cosmic matter apart. The somewhat naive idea that the required explosion forces in view of the extremely high temperatures and the extreme highly compacted primordial cosmic matter, are due to extreme initial pressure forces does not solve the problem, because relativistically hot matter will be just an additional source of gravity, hence just contrary to the expectations impedes matter to fly apart. It can, however, be shown that the expected explosive BB- event can only physically occur, if the required pressure is not established by the temperature of gravitating matter, but by the cosmic vacuum. In fact we show that without this cosmic vacuuum pressure, the so-called Big-Bang never could have happened, even though vacuum pressure up to the present days of cosmology, still may be a rather speculative subject. In the following article we shall demonstrate that with a revised understanding of this highly speculative quantity one can explain the present universe as an explosion of the primordial cosmic vacuum followed by a succesive materialisation of this vacuum into cosmic matter at the ongoing cosmic expansion.

Keywords: Big-Bang Cosmogony, Relativistic Pressure, Vacuum Energy

1. Introduction

A critical look onto the standard cosmological Big-Bang paradigm

The standard cosmologic paradigm starts from the assumption that the origin of the universe consists in the initial event of the cosmic Big-Bang. The general belief hereby is that about 13.7 Gigayears ahead of our present time an initial explosive matter event happened from which all cosmic structures and all cosmic dynamics ultimately emerged. This cosmic genesis up to now is naively well believed up to the present epoch and astonishingly has not been critically questioned till now, though this standard answer is not at all satisfying in itself, as we shall show further below.

The so-called Big-Bang may have presented the prime physical condition for the cosmic matter to explosively fly apart. It thereby may also have initiated the early Hubble expansion of the universe. But should one not ask for the responsible physical terms and forces which caused this initial explosion? Matter, if assumed to be highly condensed at this BB-begin, evidently organizes a strong gravitational field which effectively opposes the explosive fly-off of cosmic matter. One evidently needs something in addition to overcome the gravitational forces by overcompensating "antigravitational", explosive forces, similar to the explosive forces at a bomb explosion.

The required force in this cosmic game was immediately identified as a pressure force, since the Big-Bang-matter has to be imagined as infinitely dense and hot, and therefore it also must be highly pressurized. This made it evident in a first view that this necessarily creates an explosive scenario! This, however, is astonishingly enough, not true, because the pressure connected with the relativistic Big-Bang matter also contributes to strengthen the internal gravitational field, due to the presence of countable proportions of equivalent relativistic masses, as descibed by the theory of general relativity.

This must be concluded, since energy in all its mass-equivalent forms, - evidently including kinetic energy -, acts as source of gravity. The relativistic thermal kinetic energy of the Big-Bang matter can, however, not at all be neglected relative to its rest mass energy. If the mass energy $\varepsilon_M = \varrho_M . c^2$, seen from its order of magnitude, competes with the energy equivalent of the material pressure p_M, then immediately its pressure-induced effects are showing up in the field-relevant energy-momentum tensor Π_{ik} of the GR-field equations.

When introducing them here first without consideration of the vacuum energy Λ, then these equations attain the following form (see e.g. Goenner, 1969):

$$\Psi_{ik} - \frac{\Psi \cdot g_{ik}}{2} = 8\pi G \cdot \frac{\Pi_{ik}}{c^4}$$

where ψ_{ik} denotes the Riemannian curvature tensor, ψ is the curvature scalar, g_{ik} is the metric tensor, Π_{ik} is the energy-momentum tensor, and G is Newton‘s constant of gravitation.

The specific action of the thermal material pressure p_M becomes more evident, when one procedes from the above tensor equations to the Friedmann-Lemaître differential equations (Friedman, 1922, 1924) which are given in the following form:

$$(\dot{R}/R)^2 = \frac{8\pi G}{3}\varrho_M(t) - \frac{kc^2}{3}$$

And:

$$\frac{\ddot{R}}{R} = -\frac{4\pi G}{3}[\varrho_M(t) + \frac{3p_M(t)}{c^2}]$$

where $R = R(t)$ is the time-dependent spatial scale of the homogeneous Robertson-Walker universe (Robertson, 1929, 1933), ϱ_M and p_M denote mass density and pressure of the cosmic matter, k is the curvature parameter which in this approach can only attain values of $k = +1$, $k = 0$, $k = -1$. Interestingly enough, from the second of the above differential equations one will learn that the material pressure $p_M(t)$, as also the material density $\varrho_M(t)$, both do contribute just in identical sense to the acting gravitational field, namely to decelerate the scale expansion, and with $\ddot{R} < 0$ to determine a collapsing!, rather than an explosively expanding universe, unless additional cosmic forces had to be taken into account. This then opens up the question, how under such cosmic conditions the early universe can at all have exploded? This only seems possible, if in addition to the upper material pressure $p_M(t)$ an additional cosmic pressure $\tilde{p}(t)$ becomes active which is not of normal thermodynamic nature, i.e. is not coupled to massive matter, but is of an unusual, different , say “immaterial” form, such that it does not simultaneously contribute to gravity.

Such an unusual pressure $\tilde{p}(t)$ could probably be connected with cosmic vacuum energy which anyway nowadays is sincereously discussed in cosmology. The first who introduced vacuum energy, however, as a pressure-less vacuum energy into the theory of cosmology was Einstein (1917) with his cosmologic constant Λ. This term helped at least for the value $\Lambda = -8\pi G\varrho/c^2$ to enable a static Euclidean (uncurved $k = 0$!) universe that Einstein was looking for. Later then Friedman (1922, 1924) introduced this term, given by the cosmologic constant Λ, into the field equations, and with the use of the so-called Robertson-Walker geometry (Robertson, 1929,1933), then obtained the following set of equations:

$$\text{(F1)} \quad (\dot{R}/R)^2 + c^2k/R^2 - c^2\Lambda/3 = \frac{8\pi G\varrho}{3}$$

And:

$$\text{(F2)} \quad 2\ddot{R}/R + (\dot{R}/R)^2 + c^2k/R^2 - c^2\Lambda = -\frac{8\pi G}{c^2} \cdot (p + \tilde{p})$$

When being only interested in the uncurved Euklidean universe with k = 0!, then from the above one obtains the following two differential equations:

$$\text{(F1)} \quad (\dot{R}/R)^2 = \frac{c^2\Lambda + 8\pi G\varrho}{3}$$

And:

$$\text{(F2)} \quad 2\ddot{R}/R + (\dot{R}/R)^2 - c^2\Lambda = -\frac{8\pi G}{c^2} \cdot (p + \tilde{p})$$

Replacing here the term $(\dot{R}/R)^2$ in (F2) by (F1) delivers:

$$\ddot{R}/R = \frac{c^2\Lambda}{3} - \frac{4\pi G}{c^2}[\frac{1}{3}\varrho c^2 + (p + \tilde{p})]$$

The above equation, however, now clearly indicates the possibility of getting an explosive Big-Bang event - namely for the case:

$$\frac{c^2\Lambda}{3} > \frac{4\pi G}{c^2}[\frac{1}{3}\varrho c^2 + (p + \tilde{p})]$$

For a further analysis we have to study the unusual form of the vacuum pressure $\tilde{p}$ which is connected with the vacuum energy density ϵ_{vac} and anyway, in these days, is strongly instrumentalized for cosmological purposes, but its physical nature and its relation to other physical quantities, even nowadays, is strongly obscure and under discussion. Nevertheless as has been shown by Fahr and Sokaliwska (2011) and Fahr (2022), vacuum energy density only is a conserved quantity of cosmic spacetime, when it is introduced like Einstein (1917) did it with Λ = *const*, - namely only -, if the proper energy of the comoving space time volume is conserved. This invariance, however, can only be expected when this vacuum proper energy or its energy density does not perform work at the expansion of the universe or upon the dynamics of cosmic space time. If to the contrary such a work is in fact performed by the vacuum energy, then as an unavoidable thermodynamical consequence it cannot be constant, because in that case the following thermodynamic relations between the cosmic vacuum energy density ϵ_{vac} and the associated vacuum pressure $\tilde{p} = p_{vac}$ must be respected (Fahr, 2022):

$$\frac{d}{dR}(\epsilon_{vac}R^3) = -p_{vac}\frac{d}{dR}R^3$$

This relation can mathematically only be satisfied, when the following functional relation between these two quantities holds:

$$p_{vac} = -\frac{3 - \xi}{3}\epsilon_{vac}$$

where ξ is the polytropic vacuum index, i.e. a pure number which for the specific case $\xi = 3$ describes the case of a pressure-less vacuum which in fact Friedman (1924) did consider. In all other cases $\xi \lessgtr 3$ vacuum energy ϵ_{vac} is associated with a pressurized vacuum and evidently then does unavoidably perform work at the expansion of space.

Under these latter conditions, however, vacuum energy density ϵ_{vac} as shown by the upper equation, cannot be constant, which, however, in contrast once was formulated by Einstein (1917) with his $\Lambda = 8\pi G\epsilon_{vac}/c^4 = 8\pi G\varrho_E/c^2 = \text{const.}$, where ϱ_E is equivalent of the Einstein´ían mass density stabilizing the universe against a gravitational collapse. Looking back upon the earlier problem raised in this article, that the thermal pressure p_M of relativistic matter cannot help to let the Big-Bang matter explode, we therefore for a Big-Bang genesis would need a vacuum with a non-vanishing, but positive pressure p_{vac}, i.e.given for the cases $\xi > 3$, with the consequence, however, that this kind of pressure then unavoidably performs thermodynamic work at the expansion of the universe (i.e. with growing scale R = R(t)). This unavoidably also would mean that ϵ_{vac} in that case cannot be constant, but, also, and even in the interest of a Big-Bang genesis of the universe, has to fall off with the scale R of the universe! But independent of that, let us remind here, that the only essential condition for an "explosive" BB- event is fulfilled, if the following relation holds:

$$\frac{8\pi G\varrho_{vac}}{3} > \frac{4\pi G}{c^2}\left[\frac{1}{3}\varrho c^2 + (p + p_{vac})\right]$$

which with $p_{vac} = -\frac{3-\xi}{3}\epsilon_{vac} = \frac{\xi-3}{3}\varrho_{vac}c^2$ leads to the following form of the second Friedman equation F2:

$$\ddot{R}/R = \frac{8\pi G\varrho_{vac}}{3} - \frac{4\pi G}{c^2}\left[\frac{1}{3}\varrho c^2 + (p + \frac{\xi-3}{3}\varrho_{vac}c^2)\right]$$

Taking this equation serious, we then may think positively in favour of the Big-Bang infact to happen: To have the vacuum pressure dominant at small scales of the universe, i.e. in the young universe $R < R_0$!, and thus to have the Big-Bang happening in this early cosmologic epoch, one needs to have the vacuum mass energy density ϱ_{vac} dominant over the cosmic mass density ϱ, for instance a relation given in the form:

$$\varrho_{vac}/\varrho = (\varrho_{vac,0}/\varrho_0) \cdot (R_0/R)^{\gamma}$$

with γ denoting a positive number and meaning that the vacuum energy density is given by:

$$\varrho_{vac}(R) = (\varrho_{vac,0}) \cdot (R_0/R)^{3+\gamma}$$

With this information one could reduce the upper differential equation for scales $R < R_0$ by neglecting the term containing the mass density ϱ into the following simplified form:

$$\ddot{R}/R = \frac{8\pi G\varrho_{vac}}{3} - \frac{4\pi G}{c^2}\left[\frac{\xi-3}{3}\varrho_{vac}c^2)\right]$$

$$= \frac{4\pi G}{3}\varrho_{vac} \cdot [2 - (\xi - 3)]$$

Taking now for instance from the allowed range of values (i.e.$\xi > 3$!) for instance a polytropic index $\xi = 4$, one would then be led to the following relation:

$$\ddot{R}/R = \frac{4\pi G}{3}\varrho_{vac} \cdot [2 - (\xi - 3)] = \frac{4\pi G}{3}\varrho_{vac}$$

$$= \frac{4\pi G}{3}\varrho_{vac,c}(R_c/R)^{3+\gamma}$$

or find the Big-Bang acceleration $\ddot{R}$ for the range $R < R_c$ with a positive scale acceleration given by:

$$\ddot{R} = \frac{4\pi G}{3}\varrho_{vac,c}R_c \cdot (R_c/R)^{2+\gamma}$$

The above equation does not allow to exactly calculate the course of the Big-Bang scale explosion due to the missing knowledge on the three relevant cosmologic quantities $\varrho_{vac,c}$, ξ, and γ, but it nevertheless allows to show that under the above conditions of a pressurized cosmic vacuum the event of a cosmic Big-Bang appears as a possibility.

2. The explosion of the cosmic vacuum

According to general Bible knowledge in the book "genesis" the world at the beginning was an empty desert and vastness, i.e. it originally was "empty, structureless, and chaotic". This scenario can in fact well be taken serious by modern cosmologists by declaring that this universe had its origin, - not as usually thought in the Big-Bang of highly concentrated, cosmic matter -, but in the explosion of the primordial cosmic vacuum.

Here we shall start from the assumption that in the beginning the universe does not consist of any real matter, but only contains "emptiness" in the form of a primordial cosmic vacuum with an energy density of $\epsilon_{vac} = \epsilon_{vac}(R)$ with R denoting the scale of a homogeneous universe. If this cosmic vacuum in addition to its energy density $\epsilon_{vac} = \epsilon_{vac}(R)$ also is physically connected with a vacuum pressure $p_{vac} = p_{vac}(R)$ (see Fahr, 2023, Fahr and Heyl, 2006), then the work that this pressure performs at the expansion of the universe with growing scale R is reflected in the reduction of vacuum energy density ϵ_{vac} according to the following equation:

$$\frac{d}{dR}(\epsilon_{vac}R^3) = -p_{vac}\frac{d}{dR}R^3$$

From thermodynamic relations one can derive (Fahr and Heyl, 2006) that the pressure of the vacuum hereby is given through:

$$p_{vac} = -\frac{3-\xi}{3}\epsilon_{vac}$$

with ξ denoting the polytropic vacuum index, a pure and constant number. This transforms the upper differential equation into the following form:

$$\frac{d}{dR}(\epsilon_{vac}R^3) = -\frac{3-\xi}{3}\epsilon_{vac}\frac{d}{dR}R^3 = -(3-\xi)\epsilon_{vac}R^2$$

The above equation describes how vacuum energy density ϵ_{vac} would have to change with the expansion of the universe, if it would only perform thermodynamic work due to its acting pressure. This process, indeed, would explain an explosion of the universe, it, however, would explain only the blow-up of an empty universe, opposite to the actual material universe that we obviously and evidently see these days with a present mass density of $\rho_0 = \rho(R_0)$, R_0 denoting the present scale of the universe.

In order to in fact achieve a material universe from the sheer explosion of the cosmic vacuum one would need a vacuum which not only performs thermodynamic work at the expansion of its volume, but also produces matter in an adequate rate so that at present time, i.e. $t = t_0$; $R = R_0$, the cosmic matter density now would amount to $\rho_0 = \rho(R_0)$, i.e. the actually found mass density of the present universe. This matter generation should of course occur under energy conservation restrictions and thus must be physically connected with a corresponding loss of vacuum energy density. Thus taking this form of mass generation and thermodynamics together one hence must have the following net request fulfilled:

$$\frac{d}{dR}(\epsilon_{vac}R^3) = -(3-\xi)\epsilon_{vac}R^2 - \frac{d}{dR}(\rho(R)c^2R^3)$$

or expressed in the following form:

$$\frac{d}{dR}[(\epsilon_{vac}+\rho(R)c^2)R^3] = -(3-\xi)\epsilon_{vac}R^2$$

Let us first study here the action of a pressure-less vacuuum: For the pressure-less vacuum, i.e. for ξ = 3, this then means that the following equation must be fulfilled;

$$\frac{d}{dR}[(\epsilon_{vac} + \rho(R)c^2)R^3] = 0$$

or meaning:

$$(\epsilon_{vac}(R) + \rho(R)c^2) * 3R^2 + R^3\frac{d}{dR}[\epsilon_{vac}(R) + \rho(R)c^2] = 0$$

Taking into account that for all scales R the quantity $(\epsilon_{vac}(R) + \rho(R)c^2) > 0$, this is expressed by the expression:

$$-\frac{3}{R} = \frac{1}{(\epsilon_{vac}(R) + \rho(R)c^2)}\frac{d}{dR}(\epsilon_{vac}(R) + \rho(R)c^2)$$

which leads to:

$$-\frac{3}{R} = \frac{d}{dR}\ln(\epsilon_{vac}(R) + \rho(R)c^2)$$

and thus finally expresses the fact:

$$(\epsilon_{vac}(R) + \rho(R)c^2) = \exp[-\int_0^{R_0}\frac{3dR}{R}] = C[R_0^3/R^3]$$

This equation thus simply requires that the sum of the volume energies of cosmic vacuum and cosmic matter remains a constant C, not prescribing so far anything specific about the magnitude of the mass energy density $\rho(R)c^2$ as function of the scale R.

Also that term which has been dropped up to now $d\epsilon_{vac}/dp_{vac} = -(3-\xi)\epsilon_{vac}R^2$, i.e. the change of the vacuum energy density $\epsilon_{vac}(R)$ due to the thermodynamic action of the vacuum pressure (ξ >3) will most probably not improve on this situation. This means, in order to tie things together, one needs to additionally prescribe a specific vacuum materialisation process. But how does a cosmic vacuum materialize?

Reminding the fact that the particular change of the vacuum energy density which is only due to the work done by the vacuum pressure p_{vac} would have led us to the following equation:

$$\frac{d\epsilon_{vac}}{dR} = -\frac{\epsilon_{vac}}{R}(2 + (3-\xi))$$

which furthermore leads us to:

$$\frac{1}{\epsilon_{vac}}\frac{d\epsilon_{vac}}{dR} = -\frac{5-\xi}{R}$$

or to:

$$\epsilon_{vac}(R) = \exp[-(5-\xi)\int_0^R\frac{dR}{R}] = C[\frac{R_0}{R}]^{5-\xi}$$

demonstrates that the decay of the vacuum energy depends on the polytropic vacuum index ξ. Requiring now that the vacuum universe begins with a finite vacuum energy density requires that $\epsilon_{vac}(0 \sim R < R_c)$ at small scales R must be inversely proportional to R^3, so that by this it is guaranteed that

$$lim_{R\to 0}[\epsilon_{vac}R^3] = finite = \epsilon_{vac,a}R_a^3$$

But that does not yet allow to prescribe how this vacuum energy density behaves with large values of R. Requiring, however, that the universe today at $t = t_0$; $R = R_0$ is practically characterized by a material universe with its matter content generated by total conversion of the volume energy of the cosmic vacuum into cosmic matter requires that:

$$\epsilon_{vac,a}R_a^3 = C[\frac{R_0}{R_a}]^{5-\xi}R_a^3 = \varrho_0c^2 * R_0^3$$

allowing to fix the value C by:

$$C = \varrho_0c^2*(R_0^3/R_a^3) * (R_a/R_0)^{5-\xi} = \varrho_0c^2*(\frac{R_0}{R_a})^{\xi-2}$$

And there we are: Herewith we are able to offer the reader a universe that starts with the explosion of a primordial cosmic vacuum and, continuously converting vacuum energy into matter, finally merges into an expanding material universe of our present days. !

3. Conclusions

As we have shown in the article ahead, vacuum energy density ϵ_{vac}, *even* though it is till today a mysterious quantity, for the case of a vacuum polytropic index $\xi \geq 3$ is connected with a positive vacuum pressure $p_{vac} = [(\xi-3)/3]\epsilon_{vac}$ and thus induces a kind of a Hubble- expansion of the cosmic scale R. This may demonstrate the enormous potential of the vacuum concerning the determination of the whole dynamics of the universe, beginning, however, with an explosive, initial cosmic event without a mass singularity.

In a view, alternative to ours here, it was recognized by Farnes (2018) that a kind of vacuum pressure of just that form, as requested here in this article, would also arise, if the cosmic masses are partly due to negative masses $m\_$ and partly due to positive masses m_+, with the evident property that positive and negative mass particles would reject each other by gravitational forces between them according to forces $dp_{vac}/d_R = -G * m+ * m\_/r^2$. As Farnes (2018) demonstrates this opens up a situation similar to the one under positive cosmic vacuum pressure. In this sense a mass-less cosmology with $\rho+ = \rho-$ (i.e. full compensation of negative by positive cosmic masses!) would also represent at the same time a gravity-free cosmology like given in a mass-less case $\rho = 0$, when only vacuum forces are active. In this respect Farnes (2018) derives an equivalence of the cosmological constant Λ and the neglected negative cosmic masses given by the relation:

$$\Lambda = 8\pi G\rho\_/c^2$$

A similar relation is connected with Hoyle's "steady state universe" requiring that the expansion of the universe be connected with a well adjusted mass generation rate $\dot{\rho}_m$ to guarantee that the state of the expanding universe characterized by its instantaneous mass density $\rho_m = \rho_H = const$ does not change with time. As we have shown (Fahr and Heyl, 2006) in the sense of the Einstein - de Sitter universe (Einstein and de Sitter, 1932) this would lead to the following identity:

$$\Lambda_H = [\frac{8\pi G\sqrt{3}}{c^2}\rho_H]$$

Thus we can draw the following conclusion: On one hand it seems as if vacuum energy is definitely needed to have an initial cosmic explosive event which later leads into an expanding universe according to a Hubble expansion, on the other hand , however, this vacuum energy has to manifest a positive pressure and while doing thermodynamic work at the expansion reduces its vacuum energy density. It thus seems from the above, as if there are only two options to understand the universe as we wish to understand it at these days: Either one accepts a variable vacuum energy density decreasing at ongoing expansion of the cosmic scale $R(t)$. This would imply that cosmic vacuum energy density becomes less and less important in the cosmic future, and the SN1a-redshift fits presented by Perlmutter et al. (1999), Schmidt et al.(1998), Riess et al. (1998), built on the assumption of a constant vacuum energy according to Einstein's Λ, hence cannot tell us the cosmic truth. Or alternatively when one assumes, that cosmic vacuum energy density is a constant quantity, however, with a permanently vanishing pressure, - then one cannot explain the initial explosive Big-Bang event and the ongoing Hubble expansion of the universe due to an evident lack of cosmic pressure.

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