Review Article

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The big-bang started from nothing: Not the initially hot cosmic matter, but a positive vacuum pressure made the universe explode!

Abstract

Mankind all over its past epochs did ask the question, how this huge and materially impressive universe could ever have started its existence. The standard dogmatic answer presently given by the majority of modern cosmologists is: By the Big-Bang! - i.e. that initial explosion of the central highly condensed world matter system! But why - it could be asked - should this system have exploded at all? Perhaps this popular BB-hypothesis of a general and global cosmic explosion creating the world is especially suggestive just in these days of wars and weapons all around. Nevertheless to declare such an initial event as the begin of the universe unexpectedly turns out to be extremely hard to explain when based on purely physical grounds. Though it is easy to envisage a granate explosion causing matter to fly apart in all directions from the center of the explosion, but as a total surprise it is extremely hard to explain which physically operating forces or pressures might be responsible to drive the initially highly compacted cosmic matter agglomeration apart of each other. If the explosion forces are imagined as due to acting thermal pressure forces of normal massive matter, then the needed pressures cannot be due to the extremely high temperatures of the condensed matter, because the thermal energy of relativistically hot matter, as relativity theory tells us, will act as an additional source of gravity, i.e. making matter even "heavier"! Hence this just impedes the initial mass agglomeration to explode and fly apart. As we shall show in the following article the explosive BB- event can only physically be explained, if the necessary pressure is not conventionally realized by the temperature of the gravitating matter, but to the contrary by the immaterial cosmic vacuum. In fact - as we shall demonstrate here - without a cosmic vacuum pressure, the so-called Big-Bang never at all could have happened. Certainly vacuum pressure up to the present days of cosmology still is a fully speculative subject, but it will become evident in the following article, that without this highly speculative, physically handable quantity a primordial Big-Bang would not have happened at all.

Volume 7 Issue 4 - 2023

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Received: November 29, 2023 | **Published:** December 08, 2023

Introduction: Doubts on the big-bang hypothesis

Surprisingly enough just this initial explosive event of the universe represents a genuine physical secret and deep mystery. This is true because relativistic material pressure namely not acts explosively, but to the contrary does effectively support gravity, i.e. produces additional centripetal gravitation forces. This just impedes an explosion by helping to keep concentrated the matter at its small volume or even initiating an implosion. This problem, however, as we shall show here, might have an astonishing, completely unexpected solution: Namely the initial explosion only could happen by a pressure of a completely unusual type - namely an immaterial pressure that is not connected with hot matter, but with a pressurized, cosmic vacuum.

The always cited Big-Bang is generally seen as the prime physical, causal condition for the cosmic matter to explosively fly apart into ever growing cosmic volumes. This initial explosion may also have initiated the early Hubble expansion of the universe. But should scientists of these days not ask on the basis of modern physics for the responsible physical terms and forces which could have provocated this initial explosive event? Matter, when it is 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 in addition an overcompensating "antigravitational", "centrifugally directed" force. As the needed force cosmologists have of course identified pressure forces at this cosmic evolution. Evidently the B-B-matter not only is infinitely dense and hot - it also evidently is highly pressurized by thermal pressure. And hence in a first glance this makes evident that this necessarily creates an explosive scenario!

But this is simply not true, - because the thermal pressure connected with the relativistically hot BB- matter namely also contributes to a strengthening of the internal centripetal gravitational field. This is due to the presence of countable portions of increased equivalent relativistic masses, as it is well described by the theory of General Relativity.[1–4]

This has to be concluded, because energy in all its mass-equivalent forms, evidently including all forms of kinetic energy, also acts as source of gravity. And the relativistic thermal kinetic energy of the Big-Bang matter can not at all be neglected relative to its rest mass energy. As soon as the mass energy density $\varepsilon_M = \varrho_M \cdot c^2$, 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. We first give them here without taking into account vacuum energy. Then these equations take the form:[1]

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

where ψ_{ik} denotes the Riemann´ian 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 evident, when one procedes from the above tensor equations to the Friedmann-Lemaître differential equations[2,3] which are given in the form

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

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,[4,5] $\overset{\circ}{R}$ and $\ddot{R}$ denote its first and second derivatives with respect to cosmic time t, ϱ_M and p_M denote mass density and pressure of the cosmic matter, and k is the curvature parameter which in this normalized approach can only attain values of $k = +1, k = 0, k = -1$.

One can see in the second of these two above differential equations, that as well the material pressure $p_M(t)$, as also the material energy density $\varrho_M(t)c^2$, both do contribute in the same sense to the acting gravitational field. They namely do decelerate the scale expansion, and with $\ddot{R} < 0$ do determine a collapsing!,- rather than an explosively - expanding universe, in case no other cosmic forces in addition had to be taken into account. This is especially true in case when the cosmic matter has relativistic temperatures, i.e. when $\varrho_M(t)c^2$ and $p_M(t)$ turn out to be of the same order of magnitude. How then the early universe with a relativistically hot matter can at all have exploded? This according to present-day views is only possible, if in addition to the upper material pressure $p_M(t)$ an additional cosmic pressure $\tilde{p}(t)$ of a completely different nature becomes active; namely a pressure is needed of a nonthermal nature and thus is not coupled to "massive" matter. It rather must be a pressure of an unusual, i.e. an "immaterial" form, which does not simultaneously contribute to a centripetal gravity field.

Such an "immaterial" pressure $\tilde{p}(t)$, as it is suggested in these present days, could perhaps be connected with cosmic vacuum energy, whose role nowadays is seriously discussed all around in cosmology. The first who introduced vacuum energy, however , a pressure-less vacuum energy ,into the theory of cosmology was Einstein[6] with his cosmologic constant Λ which helped at least for the value $\Lambda_E = -8\pi G\varrho_E / c^2$ to enable a static Euclidean (uncurved $k = 0$!) universe which Einstein at these days was looking for. Later then Friedman,[3,4] introduced this term, given by the cosmologic constant Λ, into the field equations. Together with the use of the so-called Robertson-Walker geometry,[4,5] (Robertson), he obtained the following set of equations:

$$\left(\dot{R}/R\right)^2 = c^2k/R^2 - c^2\Lambda/3 = \frac{8\pi G\varrho}{3}$$

And:

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

If now one only is interested in the uncurved Euclidean universe with a constant but vanishing curvature $k = 0$!, one then obtains the following two differential equations, but now containing the influence of vacuum energy in the form:

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

and:

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

Replacing here the term $\left(\dot{R}/R\right)^2$ in the second equation by the first equation leads to

$$2\ddot{R}/R + \frac{-2c^2\Lambda + 8\pi G_\varrho}{3} = -\frac{8\pi G}{c^2}\cdot(p+\tilde{p})$$

Expressing the following, interesting relation:

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

This equation, however, for the first time here and now, shows the possibility of getting an explosive Big-Bang event for the specific, but realistic case:

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

How to describe vacuum pressure?

To further continue this analysis we now 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. Of course, its physical nature and its relation to other physical quantities, even today, is strongly obscure and under permanently new discussions. Nevertheless as has been shown by Fahr and Sokaliwska[7] and Fahr,[8] vacuum energy density only is a conserved quantity of cosmic spacetime, when it is introduced like Einstein[6] did it with his $\Lambda = const$, - namely only -, if the proper energy of the comoving space time volume is conserved. This invariance, however, can only be expected, if this vacuum proper energy or its energy density does not perform work at the expansion or upon the dynamics of cosmic space time. If to the contrary such a work is in fact performed by the vacuum energy, i.e. in case the vacuum does perform work at the expansion of the cosmic scale R,[9] then - as an unavoidable thermodynamical consequence of the omni-valid energy conservation law - it cannot be constant!

This is because in that case the thermodynamic relations between the cosmic vacuum energy density ϵ_{vac} and the associated vacuum pressure $\tilde{p} = p_{vac}$ do require that the following thermodynamical relation is fulfilled:

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

This relation can, however, 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 only for the specific case $\xi = 3$ describes the case of a "pressure-less" vacuum which in fact Einstein[6] and Friedman[2] did consider. In all other cases $\xi \lesseqgtr 3$ vacuum energy ϵ_{vac} is associated with a pressurized vacuum and evidently also then does unavoidably perform work at the scale-expansion of space. Under these latter conditions, however, vacuum energy density ϵ_{vac} as shown by the upper equation, cannot be constant, which in contrast once was formulated by Einstein[7] with his $\Lambda = 8\pi G\epsilon_{vac}/c^4 = 8\pi G\varrho_E / c^2 = const$ .for a static universe (i.e for $R = const$!), where ϱ_E is equivalent of the Einstein´ían mass density just stabilizing the universe against a gravitational collapse.

Looking here again back to the earlier problem raised in this article, that the thermal pressure p_M of relativistic cosmic matter cannot help to let the Big-Bang matter explode, we therefore, in order to nevertheless have a Big-Bang genesis of our universe, would need a type of vacuum with a non-vanishing, positive pressure p_{vac} , given for the cases $\xi > 3$, however, with the evident consequence, that this kind of pressure unavoidably performs thermodynamic work at the expansion of the universe (i.e. with growing scale $R = (R(t))$. This necessarily means that ϵ_{vac} in that case cannot be constant, but, also, and even in favour of a Big-Bang genesis of the universe, has to fall off with the scale R of the universe! This in no case would be a dramatic or desastrous solution for a Big-Bang universe. One only has to see the consequence that this result were contrary to what was thought by many cosmologists of these days, especially by Perlmutter et al.,[10] Schmidt et al.,[11] or Riess et al.[12] namely that this actual universe, in view of its observed redshift-luminosity relations, can well and best! be explained by a constant vacuum energy density with $\Lambda = 8\pi G\varrho_{vac} / c^2 = const$ according just to the idea once created by Einstein,[7] however, by him for different reasons.

How does the cosmic vacuum cause a big-bang?

Let us remind here, that the only essential condition for an "explosive" BB- event is fulfilled, if the following relation holds:

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

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:

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

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

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

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

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

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

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

and would find the Big-Bang acceleration $\ddot{R}$ for the range $R < R_0$ with a positive scale acceleration given by:

$$\ddot{R} = \frac{4\pi G}{3}\varrho_{vac,0}R_0 \cdot (R_0 / R)^{4+\gamma}$$

The above equation does not allow to calculate the exact course of the Big-Bang scale explosion due to the missing knowledge on the relevant cosmologic quantities $\varrho_{vac,0}$, ξ , and γ but it nevertheless allows to at least prove that under conditions of a pressurized cosmic vacuum the event of a cosmic Big-Bang at least seems physically representable.

A universe with vanishing energy

For many cosmologists it would establish a usefull basis to start from the principle, that this universe in terms of energy consists of "nothing". Because then it would also be easy to understand that this world could have originated from "nothing", and the plagueing question, how the world could originate at all, would have an easy and evident answer: This universe came from nothing, it is nothing, and will be nothing forever! But how such an idea could be put on rational physical grounds?

Physically spoken, - "nothing" is absense of energy. But can the assumption of a complete absense of energy be a rational approach towards the real nature of our universe where evidently the energies of stars and galaxies, added up from all over the universe, represent a huge positive amount of energy? The answer can astonishingly enough be : "YES"! - Namely, if all positively valued energies E are completely balanced by negatively valued energies U , e.g. like binding energies , with the result: $E+U=0$!

Whether or not such a cosmic condition can at all be expected as realized, must be further investigated in detail, but it definitely requires a universe different from that which we presently believe in or have in mind.

Ideas that the total energy of the universe might be zero, already appeared in the scientific literature very early in the last century[13,14] Cosmic mass energies can be calculated by[15] (Rosen and Cooperstock, the expression derived for perfect fluids in the form:

$$E = \int\sqrt{-g}(\rho c^2 + 3p_m)dV$$

where g is the determinant of the cosmic metric tensor, and ρ and p_m denote the mass density and the material pressure. When additionally including the pressure of the vacuum here with $p_{vac} = -\rho_{vac}c^2$ and integrating the above integral one obtains:

$$E = Mc^2 - \frac{\Lambda c^4 R^3}{3G}$$

where $M = 4\pi R^3\rho / 3$ is the cosmic mass inside a spherical region of $V = 4\pi R^3 / 3$, and $\Lambda = 3GM / c^2R^3$ denotes the vacuum energy density according to Einstein and De Sitter.[16]

As shown by Overduin and Fahr[17] the total binding energy under such conditions can be determined to

$$U = \frac{\Lambda c^2 MR^2}{10} - \frac{3GM^2}{10R}$$

and thus leads to the following condition for the "zero"-energy universe:

$$E+U = 0 = (1 - \frac{\Lambda c^2R^2}{3GM})(Mc^2 - \frac{3GM^2}{10R})$$

This means one would have two conditions under which the total energy of the universe vanishes, namely

1: $1 = \frac{\Lambda c^2R^2}{3GM}$

And

2: $1 = \frac{3GM}{10c^2R}$

This second condition is in fact, and to some surprise for theoreticians, identical with the well known "perfect cosmic dragging" - condition formulated already very early in the last century by Thirring,[18] but for completely different reasons.

To stress this result a little more let us construct an expression for the total energy of the universe. Hereby not only those energies have to be added up over the total cosmic space, which serve as energy equivalents of deposited masses with densities ϱ , but also the thermal and kinetic energies of these masses have to be added up in this balance. This can be done by accounting for their pressures and bulk velocities. For a total balance one thereby has to count for baryonic mass densities ρ_b , dark matter densities ρ_d , and of course also the mass equivalent density of the vacuum ρ_{vac} . The same procedure has to be carried out for the respective pressures in the form $p = p_b + p_d + p_{vac}$. The resulting expression of the sum E in a homogeneous universe reveals as proportional to the cube of the cosmic scale, i.e. R^3 .

Along a similar procedure the gravitational binding energy of the mass-and energy-carrying cosmic matter can be define by adding up scale-per-scale of the gravitating mass and energy in their gravitational binding strength to the rest of the world. Hereby one finds for the total binding energy U an expresssion which is proportional to the fivth power of the scale R, i.e. R^5 (Fahr and Heyl, 2007a/b). When requiring again now that E and U just compensate, this then leads to the interesting requirement:

$$\frac{3c^2}{2\pi GR^2} = (\rho_b + \rho_d + (\xi - 2)\rho_{vac})$$

where ξ again is the polytrope of the relation between vacuum pressure and vacuum energy density as given in the form:

$$p_{vac} = -\frac{(3-\xi)}{3}\rho_{vac}c^2$$

As can be recognized from the above, the requirement $E+U=0$ can only be fulfilled, if all mass densities in the universe are scaling with $\varrho \sim R^{-2}$. That implies that the mass densities ρ_b and ρ_d scale like $\varrho \sim R^{-2}$, different from the generally expected form $\rho \sim R^{-3}$, and clearly meaning that here a cosmic mass generation according to

$$\dot{\rho}_{b,d} = \frac{\rho}{R}\dot{R} = \rho H$$

has to happen in this universe which otherwise would remain massless forever. It is very interesting to notice that this is exactly identical to the mass generation rate which was required for bound mass systems in the universe as expression of the work of the vacuum pressure at the expansion of the universe[8]

This may also answer easily the question how the required mass generation can be explained; Now the cosmic vacuum energy density is not anymore taken to be constant as in the standard cosmology (e.g. see Perlmutter et al.,[8] but it is reduced in an expanding universe like $\rho_{vac} \sim R^{-2}$, from where one can easily draw the solution $\dot{\rho}_{vac} = -\dot{\rho}$.

This interestingly enough means, that in a "zero-energy universe" the cosmic vacuum energy has to convert into cosmic matter energy with the exciting consequence, that at very small cosmic scales, i.e. towards the begin of the universe, the energy of the universe becomes more and more vacuum energy, while the matter energy seen back towards the Big-Bang event dissolves, i.e. vanishes completely. This fits perfectly into the view developed recently by Fahr[12] speculating that the Big-Bang only could happen as an explosion of the initial cosmic vacuum.

An other question, however, also not yet solved here is whether or not such a matter generation as a consequence of the decay of the cosmic vacuum energy could also then at its decay deliver the elementary abundances of the originating cosmic matter (i.e.H-, D-, He-, Li- abundances etc!).[19] To decide this question one, however, first had to study the thermodynamics of the cosmic vacuum and the condensation and temperature of the generated cosmic matter as function of the scale R and the cosmic time t. We shall, however, look into this problem in a forthcoming paper.

Conclusions with a view on cosmic mass generation and negative masses:

In the article above we have argued that vacuum energy density ϱ_{vac}, even though it is till today a mysterious and hardly handable quantity, for the case of a vacuum polytropic index $\xi \geq 3$ at least must be connected with a positive vacuum pressure $p_{vac} = \left[(\xi-3)/3\right]\varrho_{vac}$. Thanks to this vacuum pressure it induces at the absence of other cosmic forces a kind of a Hubble- expansion of the whole universe with a growing cosmic scale $R(t)$. This may demonstrate the enormous potential of the vacuum concerning an alternative determination of the whole dynamics of the universe, beginning with an explosive, initial cosmic event, however, at the absence of matter, without a mass singularity at its begin.

Our ideas here can be seen as running a little bit in parallel to the so-called "Cold Genesis Theory" (CGT) propagated by Arghirescu.[15,20] In this latter theory the possibility was discussed to explain all fundamental fields and particles by a simple, composite chiral soliton model of fermions like a kind of condensation from the primordial vacuum. Hereby it is conceived that leptons and anti-leptons are generated as "gravistars" from a strong vortex of primordial dark energy. This possibility of the generation of dark particles condensating out of the primordial vacuum energy as dark chiral solitons is supported by several accompanying CGT theories.[20]

Perhaps it may be furthermore interesting to compare this idea with an other view, alternative to ours here and the above, namely presented by Farnes:[21] It was recognized by Farnes[21] that a kind of vacuum pressure of just that same form, as requested in our article here, would as well arise, if the total of cosmic masses were partly due to negative masses m_- and partly due to positive masses m_+ (n.b.: not electrically positively and negatively charged masses, - but with negative and positive mass qualities). This would have the evident property that positive and negative mass particles would reject eachother by repulsive gravitational forces between them according to forces $dp_{vac}/dR = -G{*}m_+{*}m_-/r^2 \geq 0$. As Farnes[21] this opens up a situation similar to the one under positive cosmic vacuum pressure as we have discussed it here in this article. 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[21] derives an equivalence of the cosmologic 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 $\dot{\rho}$ to guarantee that the state of the expanding universe characterized by its instantaneous mass density $\rho = \rho_H = const$ does not change with time. As we have shown[18] in the sense of the Einstein - de Sitter universe[16] this would lead to the following identity:

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

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 which is shown here to do thermodynamic work at the cosmic scale expansion and thus has to unavoidably reduce 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.,[10] Schmidt et al.,[11] Riess et al.,[12] built on the assumption of a constant vacuum energy according to Einstein's Λ, hence cannot tell us the final cosmic truth.

Or alternatively when one assumes, that cosmic vacuum energy density is a constant universal 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! The reader may make his own choice!

Acknowledgments

None.

Conflicts of interest

The author declares there is no conflict of interest.

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