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Research Article

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The Cosmic Vacuum Pressure Polytrope: What Causes the Big-Bang?

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Abstract

In preceding papers we have shown that an initial Big-Bang explosion of the universe can not have happened as caused by a singularity of extremely hot cosmic matter due to the centripetal gravity field enhanced by relativistic mass [1,2]. Instead it must have started from a pressurized cosmic vacuum. In this article here we shall analyse how to adequately describe this cosmic vacuum pressure and how to formulate the initial scale expansion of the universe as reaction to its action. We find that for a needed positive vacuum pressure the thermodynamic polytrope relation between vacuum energy density and vacuum pressure only allows for a range of the vacuum polytrope indices ξ of $3 < \xi_{vac} < 5$. Furthermore we find that for the preferred value $\xi_{vac} = 4$ one can derive a complete description of the cosmic vacuum energy as function of the cosmic scale and the cosmic time with inclusion of a process of cosmic matter generation by a specific vacuum condensation process producing quantized matter. As result one obtains a matter universe well aquainted to all present day astronomers, however, without the need for an initial, material Big-Bang.

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

1. Pure Cosmic Matter Can Not Explode

As we have shown in recently preceeding publications an initial explosion of the virgin universe can at least not happen purely because of an extremely strong centripetal gravitational field in connection with a highly concentrated central mass singularity [1,2]. This is even true when one in addition considers the natural centripetal material pressures which under these conditions certainly are enormous. But since the extremely hot cosmic matter has relativistic temperatures, this leads to relativistically increased mass energies and thus to even stronger centripetal gravitational fields. This at first glance may appear controvisionary, but as can clearly be shown by the two cosmologic Friedman equations describing the cosmic scale as function of the cosmic time, it becomes evident that the relativistically hot cosmic matter in fact increases the centripetal gravity field so much that no explosive cosmic motion, but an implosion is caused [3,4]. As shown by Fahr (2023) only a medium that can realize a cosmic pressure without an initial singularity of relativistically hot matter can cause an initial explosion of the universe; this namely is the cosmic vacuum energy connected with a specific vacuum pressure as we are demonstrating and specifying further down here.

2. Starting from a Pressurized Cosmic Vacuum

If one aims at the introduction of a pressurized cosmic vacuum, one has to take care of a thermodynamic condition by which it is taken account of the fact that the action of the cosmic vacuum pressure p_{vac}, i.e the positive work that has been expended in changing the volume of a spherically symmetric universe, leads to a corresponding request for the loss of the vacuum energy ϵ_{vac} which causes this change. This condition is expressed by the following, in gas dynamics well known thermodynamic relation (see e.g. Fahr, 2022) [1]:

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

where R is the scale function of the universe. As shown by Fahr (2023) this relation is mathematically satisfied, if the following polytropic relation is valid between the energy density ϵ_{vac} and the pressure p_{vac} of the cosmic vacuum:

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

Here ξ is a pure number, namely the so-called, at present unknown vacuum polytrope index $\xi = \xi_{vac}$. For normal, mono-atomic gases for example this index is given by the number $\xi_m = 5/3$. In case of a vacuum pressure the exact value of the corresponding number here, i.e. $\xi = \xi_{vac}$, is, however, not yet known or physically prescribed at this moment, though the range of permitted values can drastically be reduced. So for a nonvanishing, positive cosmic vacuum pressure, needed to explain the initial expansion of the universe, it is at least required that the following relation holds:

$$p_{vac} = -\frac{3-\xi}{3}\epsilon_{vac} > 0$$

i.e. for a positive vacuum energy and a positive vacuum pressure it is required that $\xi_{vac} \geq 3$. A positive vacuum pressure hereby must be requested in analogy to the thermodynamic pressure expressing the quantity "pressure" as the mean kinetic energy, i.e. a positive moment of the distribution function $f(v)$ as function of the particle velocity v, - if symmetric and isotropic - given by $\int f(v) < mv^2/2 > v^2 dv = \frac{4\pi m}{3}\int f(v)v^4 dv > 0$ (see e.g. Chapman, 1952, Cercignani, 1988).

Furthermore one can derive in addition from the second Friedman equation for an initially expanding universe with R as its radial scale and $\ddot{R} > 0$ (see e.g. Fahr, 2023) the result:

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

which for $\ddot{R} > 0$ leads to the request $\xi_{vac} < 5$. This then permits the following range of polytrope values for ξ_{vac}:

$$\xi_{vac} \in]3,5[$$

where the open brackets hereby mean that the border values $\xi = 3$ and $\xi = 5$ must be excluded for an expanding universe with positive vacuum pressure, when causing an initial scale expansion. Hence the permitted range of values for the vacuum polytrope index is given by:

$$3 < \xi_{vac} < 5$$

This result would perhaps strongly suggest a value of $\xi = 4$, which is interesting as such and also is perhaps way-paving, since for different reasons Fahr (2024) had derived from a different context the following relation for the vacuum energy as function of the cosmic scale:

$$\epsilon_{vac}(R) = \epsilon_{vac,o} \cdot [\frac{R_0}{R}]^{\xi}$$

which now with the upper suggestion for ξ_{vac} would thus yield a consistent solution with;

$$\epsilon_{vac}(R) = \epsilon_{vac,o} \cdot [\frac{R_0}{R}]^4$$

where $\epsilon_{vac,o} = \epsilon_{vac,o}(R_0(t))$ is the vacuum energy density at the reference scale $R_0 = R_0(t)$.

This however nicely fits together with a derivation of the matter density $\rho_m = \rho_{mo}(R(t)/R_0)^{-4}$ which was derived by Fahr (2024) for the plausible case that matter in the universe is generated from the energy decay of the initial vacuum energy by a quantized matter condensation process. So things seem nicely to support each other. Nevertheless it would, however, be wrongly concluded on this basis that as result one would obtain from the above equations the outcome that the ratio of ϵ_m and ϵ_{vac} would be constant, even though the result perhaps first seems to indicate this by:

$$\frac{\epsilon_m}{\epsilon_{vac}} = \frac{\rho_m c^2}{\epsilon_{vac}} = \frac{\rho_{m0}c^2}{\epsilon_{vac,0}}$$

but one has to pay attention to the important point that

$$\frac{\rho_{m0}c^2}{\epsilon_{vac,0}} = \frac{\rho_{m0}(t)c^2}{\epsilon_{vac,0}(t)} \neq const$$

but it has to be clearly realized that a universe which at its expansion converts vacuum energy into matter, needs to have the quantities ρ_{m0} and $\epsilon_{vac,0}$ not as prefixed cosmic constants, but as cosmically variable quantities, variable with cosmic time t in any forms like:

$$\rho_{m0} = \rho_{m0}(t)$$

and

$$\epsilon_{vac,0} = \epsilon_{vac,0}(t)$$

The above functions of cosmic time t have been studied in more detail in an earlier paper by Fahr and Heyl (2024), and it becomes evident there that a variety of possible solutions does exist, alltogether making it a highly nontrivial problem to answer the question concerning the total mass M_U or the total energy E_U of the whole universe. One may rather have to live with the puzzling fact that these quantities are not - as often thought: "cosmic constants", - but quantities variable with cosmic time t, in line with the earlier Machìan ideas concerning a scale-related behaviour of inertial cosmic masses [5].

In order to fullfill for instance the above mentioned request for an initially explosive Big-Bang- universe one had to have at the beginning of cosmic time $t \to 0$ no or nearly no cosmic matter at all compressed compressed by its gravitational pull in a singularity, but only a dominating cosmic vacuum energy. This means one should rather have as initial conditions: $\rho_{m0} = \rho_{m0}(t \to 0) \simeq 0$ and $\epsilon_{vac,0}(t \to 0)/\rho_{m0}(t \to 0)c^2 \simeq \infty$!

To fullfill these latter requests we have shown that perhaps the following relations could be helpfull:

$$\rho_m(R,t) = \rho_{m,0} \cdot (R/R_0)^{-4} \cdot \exp[\alpha(\frac{t}{t_0}-1)]$$

and:

$$\rho_{vac}(R,t) = \rho_{vac,0} \cdot (R/R_0)^{-4} \cdot \exp[\alpha(1-\frac{t}{t_0})]$$

where the coefficient α implies something like the cosmic time period of a conversion of vacuum energy into matter energy. This then shows that under these conditions in fact the ratio

$$\frac{\rho_m(R,T)}{\rho_{vac}(R,T)} = \frac{\rho_{m,0}}{\rho_{vac,0}}[\exp[\alpha(\frac{t}{t_0}-1)-\alpha(1-\frac{t}{t_0})]$$

$$= \frac{\rho_{m,0}}{\rho_{vac,0}}\exp[-2a(\frac{t}{t_0}-1)]$$

is not a cosmic constant, but a time-variable cosmic quantity, all the more, if this conversion period α itself is time-dependent !

3. Conclusions

We have shown in this paper above that the initial explosion of the universe cannot be caused by a singularity of overdense, hot cosmic matter, because the overdense matter would have to be extremely hot and highly relativistic. This would, however, just strengthen the centripetal gravity field such that an expansion of the universe this way would be impeded which is also clearly reflected in the two Friedman differerential equations [1]. As we show here, an initial centrifugal, explosive event of the universe can only cosmically and physically be caused by a pressurized cosmic vacuum with properties that we derive as function of the scale R and time t of the universe in this article. We can show that a conversion process converting vacuum energy into quantized massive matter can be discussed which explains why at present times we find a partially materialized universe with stars, galaxies and clusters of galaxies in it as consequence of the ongoing vacuum energy decay at the ongoing expansion of the universe [6-14].

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