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Research Article

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Non-Adiabatic Behaviour of the Early Cosmic Baryons Due to Vacuum Pressure Action: What Causes the Structure Formation in the Post-Recombination Era?

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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 simply caused by a singularity of extremely hot, highly condensed cosmic matter due to the enhanced centripetal gravity field, enhanced by relativistic cosmic masses [1-3]. Instead, as we argue here, the initial "Bang" must have started from a pressurized cosmic vacuum. We analyse how to adequately describe this cosmic vacuum pressure and how to formulate the initial scale expansion of the universe as a reaction to it. 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 acquainted to all present day astronomers, however, without the need for an initial, material Big-Bang of a mass singularity. As a surprise, however, the Hubble expansion of the post-recombination universe under the action of cosmic vacuum pressure drives the baryonic distribution function into a more and more non-equilibrium shape with over-Maxwellian-ized populations of the high velocity wings demonstrating surprisingly enough that the cosmic matter temperatures in this expansion phase are in fact increasing, opposite to classical expectations which properly speaking would clearly predict adiabatic temperature decreases.*

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

1. Even the Hottest Cosmic Matter would not Explode!

We have shown in recent publications that 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 and extremely heated central mass singularity [1-3]. This is true even though one has to consider the natural centripetal material pressures which under these conditions certainly are enormous and somehow would enter definitely the cosmic game. But since the extremely hot cosmic matter has relativistic temperatures, this also leads to relativistically enhanced mass sources, and thus to even stronger centripetal gravitational fields connected with them. That may at first glance appear contra-visionary, but as can clearly be shown by the two cosmological Friedmann equations describing the cosmic scale R as function of the cosmic time t, it becomes evident, perhaps as a surprise, that the relativistically hot, enhanced cosmic matter increases the centripetal gravity field such that no explosive cosmic motion, but just the opposite - an implosion - would be caused [4,5]. The hotter the matter is in the mass singularity, the more the situation resembles that of a singular "black hole". As shown by Fahr, 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, positive vacuum pressure as we are demonstrating and specifying further down now.

2. The Big-Bang Starts from A Pressurized Cosmic Vacuum

Perhaps the best explanation of the problematic begin of our universe would be to assume that this universe does not at all start from a matter singularity, but rather from a vacuum singularity with no initial matter involved. The latter first is systematically generated when the metric of the universe is expanded connected with the conversion of vacuum energy into matter energy. The concept of a pressurized cosmic vacuum doing this job at this physical event has to start from the unavoidable thermodynamic condition that energy needs to be consumed in order to cause a blow-up of the universe. This means the fact has to be respected that the action of the cosmic vacuum pressure p_{vac}, i.e the positive work that has been carried out in blowing up the volume of a spherically symmetric universe, requests a loss of vacuum energy ϵ_{vac} causing this change. This prerequisite is fulfilled, if the following, well known thermodynamic relation holds [8]:

$$\frac{d}{dR}(\epsilon_{vac}R^3) = -p_{vac}\frac{d}{dR}R^3 \quad [1]$$

where R is the radial scale of the universe. As shown by Fahr this relation can be mathematically satisfied e.g. by [1]

$$\epsilon_{vac} = \epsilon_{vac,0} \cdot [\frac{R_0}{R}]^{\xi} \quad [2]$$

which leads to the relation

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

Here ξ is a pure number, namely the so-called, yet at present unknown vacuum polytrope index $\xi = \xi_{vac}$. For normal, mono-atomic gases for example this index is given by the number $\xi = 5/3$. 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 non-vanishing, positive cosmic vacuum pressure, needed to explain the initial expansion of the universe, it is at least required that the following relation $\xi_{vac} > 3$ holds for a positive vacuum energy and a positive vacuum pressure. 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 [9,10]

$$\int f(v) < mv^2/2 > v^2 dv = \frac{4\pi m}{3}\int f(v)v^4 dv > 0. \quad [4]$$

Furthermore one can derive in addition from the second Friedmann equation for an initially expanding universe with vacuum energy only at the very beginning, R as its radial scale and $\ddot{R} > 0$the result [1]:

$$\ddot{R}/R = \frac{8\pi G\rho_{vac}}{3} - \frac{4\pi G}{c^2}[\frac{\xi-3}{3}\rho_{vac}c^2] = \frac{4\pi G}{3}\rho_{vac} \cdot [2-(\xi-3)] \quad [5]$$

Which for $\ddot{R} > 0$ leads to the request $\xi_{vac} < 5$. This then 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:

$$\xi_{vac} \epsilon]3,5[\quad [6]$$

where the 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:

$$3 < \xi_{vac} < 5 \quad [7]$$

This result strongly suggests a value of $\xi = 4$ which then yields a vacuum energy (see Eq. (2))

$$\epsilon_{vac}(R) = \epsilon_{vac,o} \cdot [\frac{R_0}{R}]^4 \quad [8]$$

Where $\epsilon_{vac,\,0} = \epsilon_{vac,0}\,(R_0)$ is the vacuum energy density at the reference scale $R_0 = R_0$.

In order to fulfill the request for an initially explosive Big-Bang-universe one had to have at the beginning of cosmic time $t \rightarrow 0$ no cosmic matter at all compressed by its gravitational pull in a singularity, but only a dominating cosmic vacuum energy. This means that we start with the initial vacuum energy density $\epsilon_{vac} = \epsilon_{vac,0}\,(R_0)$ and the cosmic matter energy density $\epsilon_m\,(R_0) = 0$.

The conversion from vacuum energy into matter, (Aghirescu, 2015) could then for instance be described by the following relations [11,12]:

$$\epsilon_{vac}(R,t) = \epsilon_{vac,0}\frac{R_0^4}{R^4}exp(-\alpha(t-t_0)) \quad [9]$$

and

$$\epsilon_m(R,t) = \epsilon_{vac,0} - \epsilon_{vac}(R,t) = \epsilon_{vac,0}\frac{R_0^4}{R^4}(1 - exp(-\alpha(t-t_0))) \quad [10]$$

with $R(t = t_0) = R_0$ and the coefficient α implying something like the cosmic time period of a conversion of vacuum energy into matter energy. The ratio

$$\frac{\epsilon_m(R,t)}{\epsilon_{vac}(R,t)} = \frac{1 - exp(-\alpha(t-t_0))}{exp(-\alpha(t-t_0))} = exp(\alpha(t-t_0)) - 1 \quad [11]$$

is not a cosmic constant but grows exponentially with cosmic time t.

With the above equations for ϵ_{vac} and ϵ_m the time dependence of $R(t)$ can be simply calculated with the 1st Friedmann equation:

$$(\frac{\dot{R}}{R})^2 = \frac{8\pi G}{3c^2}(\epsilon_{vac}(R,t) + \epsilon_m(R,t)) = \frac{8\pi G}{3c^2}\epsilon_{vac,0}\frac{R_0^4}{R^4} \quad [12]$$

This leads us to:

$$\frac{\dot{R}}{R} = H = \sqrt{\frac{8\pi G}{3c^2}\epsilon_{vac,0}} \cdot (R_0/R)^2 \quad [13]$$

Which then results in the following relation:

$$\int_{R_0}^{R}\frac{dR}{R}\frac{1}{\sqrt{\frac{8\pi G}{3c^2}\epsilon_{vac,0}} \cdot (R_0/R)^2} = \int_{t_0}^{t} dt \quad [14]$$

After integration of the above expression one finds:

$$\frac{1}{\sqrt{\frac{8\pi G}{3}\rho_{vac,0}} \cdot {R_0}^2} \cdot \frac{1}{2}[R^2 - R_0^2] = [t - t_0] \quad [15]$$

or finally for the normalized scale $X = R/R_0$:

$$\frac{1}{2}[X^2 - 1] = \sqrt{\frac{8\pi G}{3}\rho_{vac,0}}\,[t - t_0] \quad [16]$$

Introducing the Hubble time τ_0 and roughly identifying it with the recombination time $\tau_0 = 1/\sqrt{\frac{8\pi G}{3}\rho_{vac,0}} = t_0$, and setting $Y = t/\tau_0$ one finds as a condensed relation between Cosmic scale and cosmic time:

$$X^2 = 2Y - 1 \quad [17]$$

This relation defines for the given conditions after the recombination of baryonic Matter, how the scale R and the time t of the universe are further on related to each other.

3. Thermodynamics under Vacuum-Driven Cosmic Expansion

In a full gas kinetic study of the cosmic baryon gas behaviour in a vacuum-driven, expanding Hubble universe after the time of recombination by Fahr it had been shown (see Figure 3 there) that the gas temperature during the expansion of the gas over 1, 2, 3, 4 Gigayears - instead of adiabatically decreasing - in fact does increase by a total factor of 1. 8, due to occurence of the conversion of the initial Maxwell-Boltzmann distribution into a more and more non-Maxwellian NLTE- distribution with over Maxwellian-ized high velocity wing populations under the vacuum-driven Hubble expansion of the cosmic gas [13]. This latter phenomenon is due to expansion of the universe by the action of the vacuum pressure, instead of by the action of the thermal pressure!

One may want to see this result compared with the normal case, when the thermal pressure would be responsible and would drive instead an adiabatic expansion, then temperatures instead should have decreased, namely according to the following Poissonian relation:

$$pV^{\lambda} = pR^{3\lambda} = const \quad [18]$$

If we start from an age of the universe of τ_0 = 14 Gigayears at recombination time t_0, then we obtain from the upper equation (17):

$$X^2 = (R/R_0)^2 = 2(t/\tau_0) - 1 \quad [19]$$

for times t_1, t_2, t_3, t_4 = 1, 2, 3, 4 Gigayears after the recombination time $t_0 = \tau_0$ that the following relations then should be fulfilled:

$$(R_1/R_0)^2 = 2(t_1/\tau_0) - 1 = 2 * 15/14 - 1 = 1.14 \quad [20]$$

$$(R_2/R_0)^2 = 2(t_2/\tau_0) - 1 = 2 * 16/14 - 1 = 1.28 \quad [21]$$

$$(R_3/R_0)^2 = 2(t_3/\tau_0) - 1 = 2 * 17/14 - 1 = 1.43 \quad [22]$$

$$(R_4/R_0)^2 = 2(t_4/\tau_0) - 1 = 2 * 18/14 - 1 = 1.57 \quad [23]$$

yielding the following results for the scale growth during this time:

$$R_1 = R_0\sqrt{1.14} \quad [24]$$

$$R_2 = R_0\sqrt{1.28} \quad [25]$$

$$R_3 = R_0\sqrt{1.43} \quad [26]$$

$$R_4 = R_0\sqrt{1.57} \quad [27]$$

According to Figure 3 in Fahr this scale growth $R_1 \rightarrow R_4$, however, has the effect of increasing under vacuum-induced NLTE conditions the baryonic temperatures by a factor 1, 8 [13]. It would be interesting here to compare now this result with what should happen under pure LTE gas dynamic adiabatic conditions, i.e. under an adiabatic Poissonìan expansion of the Maxwellian baryonic gas, leading via [14]:

$$\frac{1}{T}\frac{dT}{dR} = -\frac{4}{3}R^2 \qquad \# \quad [28]$$

to :

$$T_i/T_0 = \exp[-4[(R_i^3/R_0^3) - 1)]] \qquad \# \quad [29]$$

which expresses the following "classical Poissonian" thermodynamic expectations for decreasing temperatures:

$$T_1 = T_0 \exp[-4(1.14^{3/2} - 1)] \quad [30]$$

$$T_2 = T_0 \exp[-4(1.28^{3/2} - 1)] \quad [31]$$

$$T_3 = T_0 \exp[-4(1.43^{3/2} - 1)] \quad [32]$$

$$T_4 = T_0 \exp[-4(1.57^{3/2} - 1)] \quad [33]$$

The above result would mean that instead of $T_4 = 1.8T_0$ one would via classic thermodynamics expect to find a baryonic temperature of only:

$$T_4 = T_0 * \exp[-4 * 1,89] = 5.1 * 10^{-4} T_0 \quad [34]$$

If in fact one had to agree to these vacuum-induced increased temperatures, then it would for sure need a thourough further investigation in order to study whether after the recombination of baryonic matter - with afterwards increasing temperatures – the collapse of cosmic matter to structured stellar and galactic clusters could have happened at all. But since it is nowadays well known that even on the basis of classic Jeans structure formation theories it turns out, that stars like our Sun with masses of about 1 solar mass on the basis of these classic theories only can evolve from pre-structured cosmic matter of densities of $\rho_H \geq 10^6$ atoms/cm^3, while under normal galactic conditions of $\rho_H \approx 10^2$cm^{-3} only Jeans masses of M > 100 solar masses could have fragmented [15,16]. This clearly shows that even structure formation theory under normal, i.e. classic thermodynamic conditions, is not yet settled to convincing results. Thus, the question posed above we, however, shall first be focused to in a forthcoming paper.

4. 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 Friedmann differential 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 derived above as function of the scale R and time t of the universe. However, for that to become true, one first had to clarify how the structure formation in the universe in the post-recombination period can be caused under increasing NLTE matter temperatures. 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, however, why this universe contains stars, galaxies and clusters of galaxies and the final consequence of the ongoing vacuum energy decay at the ongoing expansion of the universe must be clarified at first.

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