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Research Article

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Creation of Cosmic Matter Through the Action of the Primordial Cosmic Vacuum Energy

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Abstract

We have shown in recent papers (see Fahr, 2023, Fahr and Heyl, 2023) that the original explosion of the universe cannot have had its origin in a mass singularity of relativistically superhot cosmic matter, since the associated extremely strong centripetal gravitational field would clearly have impeded the Big-Bang to happen. As we suggest instead, the so called paradigmatic "Big-Bang", if it at all ever happened, must rather be caused by something like a positively pressurized primordial cosmic vacuum, but not by a singularity-condensed cosmic matter. The question, however, then is, how a cosmic vacuum in physical terms has to be constituted that drives the initial explosion of the universe as expected into a Hubble – expansion, and, while doing so, in addition generates that amount of cosmic matter which in the present days of our universe evidently is all around us and thus needs to have its non-singular origin later in the evolution of the universe? As we do show here in this article, this requires a positively pressurized vacuum with $p_{vac} = p_{vac}(\varepsilon_{vac}) \geq 0$ and a vacuum energy density ε_{vac} that, while performing thermodynamic work at the expansion of the universe, decreases with the increase of the scale R of the universe. This, however, is different to the well known ΛCDM -model with a constant vacuum energy density which is presently in favour. On the basis of the general energy conservation law we do formulate a relation here, that describes the condensation of quantized energy structures in form of elementary masses out of the energized vacuum. While the relative energy density of vacuum-condensed masses ρ_m/ρ_{vac} is permanently increasing with world time t, the energy density of the vacuum itself permanently decreases. In this paper we look for solutions which on the basis of these procedures just lead to the structures which evidently appear in our present-day universe. Not yet solved, though touched by us in this paper here, is the question whether or not the elementary abundances of the condensed cosmic matter under these conditions also would match the astrophysical observations.

1. Conditions at the earliest expansion of the universe

Concerning the worldtime-evolution of the cosmic scale function $R = R(t)$ one can start from the work by Friedman (1922, 1924) and obtain as a start from there the following differential equation (see also Fahr, 2023):

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

with $R = R(t)$ denoting the scale of the universe at world time t, and $p = p_m$ and $\tilde{p} = p_{vac}$ being the pressures of cosmic matter and of the cosmic vacuum, the latter given for thermodynamic reasons by Fahr and Heyl (2023) in the specific form:

$$\tilde{p} = p_{vac} = -\frac{3-\xi}{3}\epsilon_{vac} \qquad \#$$

with ξ denoting the polytropic constant of the cosmic vacuum, converting p_{vac} into the associated energy density ε_{vac} of the cosmic vacuum. Hence with Friedman (1922,1924) one then obtains:

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

Since we have shown in Fahr (2023) and Fahr and Heyl (2023) that the initial explosion of the universe cannot be caused by the initial thermal explosive pressure of relativistically hot, cosmic matter, since the latter primarily increases, i.e. strengthens, the centripetal gravity field, since energy at the same time constitutes a source of gravity (i.e.: $kT_m \sim mc^2$), we here have instead to consider as the suggested alternative, that – not the gravitationally active thermal pressure p_m of cosmic matter -, but the pressure p_{vac} of the cosmic vacuum is primarilly responsible for the earliest primordial expansion of the universe.

However, to have the vacuum pressure p_{vac} and energy density ρ_{vac} dominant at the begin (i.e. at the start of existence of the universe (i.e. $R, t \to 0$), i.e. meaning $\rho_{vac} \gg \rho_m$ at scales $R \leq R_0$, one might assume, since there is a lack of any better information, to have at this earliest cosmic period a relation for the vacuum energy density valid in the form:

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

Also from the paper by Fahr and Heyl (2023), taking into account the decrease of ρ_{vac} at the scale expansion due to work solely performed by the positive vacuum pressure p_{vac} with nearly no cooperative action by the cosmic matter, one would independently derive the following relation:

$$\varrho_{vac}(R) = \varrho_{vac,0} \cdot (R_0/R)^{5-\xi} \qquad \#$$

Thus it appears, as if one in fact had to respect the identity $3 + \gamma = 5 - \xi$, or $\gamma = 2 - \xi$, which for $\xi = 4$ (i.e. positively pressurized vacuum!, different from ΛCDM with its pressure-less vacuum with $\xi = 3$!) , would lead to $\gamma = -2$, or simply meaning the following scale-behaviour of the vacuum energy density:

$$\varrho_{vac}(R) = \varrho_{vac,0} \cdot (R_0/R) \qquad \#$$

This has to be taken together with the assumption $\varrho_{m,0} \ll \varrho_{vac,0}$, in order to thereby guarantee that the energy density of the gravitating cosmic matter at the begin of the universe (i.e. $R \leq R_0$) is negligible and the centripetal gravity field, instead of growing to infinite strength towards a matter singularity, stays moderate, finite - and in fact unimportant!

If the exponent γ - characterizing the exact scale distribution of the vacuum energy density $\varrho_{vac}(R)$ had to be selected with $\gamma = -1$, one would then regain the result of a special R^{-2}- dependence of $\varrho_{vac}(R)$, which could be expected for a corresponding steady-state universe with the analogue to Hoyle‘s steady-state-request for a matter universe with matter generation at the expansion by quantized condensation out of the vacuum (Jordan, 1968, Hönl and Dehnen, 1968, Schäfer and Dehnen, 1977), but now with an new aspect in the form: $\dot{\rho}_{vac} \sim \rho_{vac}$ (see Fahr and Heyl, 2007, Fahr, 2023, or Arghirescu, 2015a/b).

With this information one could then reduce the upper differential equation for scales $R < R_0(t_0)$, i.e. under conditions of dominating vacuum energy density, by neglecting the term containing the matter density ϱ_m, despite its later growing importance ($R \geq R_0$) with time, into the following simplified form:

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

Selecting now for instance from the allowed range of values that constitute a positive vacuum pressure necessary for a cosmic expansion (i.e. $\xi > 3$!), for instance the polytropic index $\xi = 4$, one would then be led to the following relation for the earliest "vacuum-dominated, matter-less" - primordial Hubble expansion:

$$\ddot{R}/R = \frac{4\pi G}{3}\varrho_{vac} \cdot [2 - (\xi - 3)] = \frac{4\pi G}{3}\varrho_{vac} = \frac{4\pi G}{3}\varrho_{vac,0}(R_0/R)^{3+\gamma} \qquad \#$$

or meaning

$$\ddot{R} = \frac{4\pi G}{3}\varrho_{vac,0}R_0 \cdot (R_0/R)^{2+\gamma} \qquad \#$$

which would describe the earliest expansion dynamics $R = R(t)$ of the universe up to scales $R \simeq R_0$. Beyond that evolutionary state the continuation of the expansion is also additionally influenced by the growing matter density ρ_m - a situation which has already adequately been described by the complete set of the two Friedman equations in the form presented by Fahr and Heyl (2023).

Hence anyway one can nevertheless say that the earliest cosmic expansion dynamics is characterized by the following integrated Friedman equation:

$$\dot{R}(t) - \dot{R}(0) = \frac{4\pi G}{3}\varrho_{vac,0}R_0 \cdot \int_0^t (R_0/R)^{2+\gamma} dt = \frac{4\pi G}{3}\varrho_{vac,0}R_0 \cdot \int_0^t (R_0/R)^{2+\gamma} \frac{dR}{\dot{R}} \quad \#$$

What concerns the adequate relation for $\dot{R}(t)$, we have already obtained from the first Friedman equation for $k = 0$ (i.e. uncurved universe):

$$(\dot{R}/R)^2 - c^2\Lambda/3 = \frac{8\pi G\rho_m}{3} \quad \#$$

and remembering that for $R \leq R_0$ the vacuum energy density is assumed to strongly dominate over the mass energy we simply at this phase then would have:

$$\dot{R} = cR\sqrt{\Lambda/3} = R\sqrt{8\pi G\rho_{vac}} \quad \#$$

which leads one to:

$$\dot{R}(t) - \dot{R}(0) = \frac{4\pi G}{3}\varrho_{vac,0}R_0 \cdot \int_0^t (R_0/R)^{2+\gamma} \frac{dR}{\dot{R}} \quad \#$$

If we now use the favoured upper dependence of the vacuum energy on R, i.e $\rho_{vac} = \rho_{vac,0} * (R_0/R)^2$, then we arrive at the surprisingly simple relation:

$$\dot{R} = R\sqrt{8\pi G\rho_{vac}} = \sqrt{8\pi G\rho_{vac,0}R_0^2} = const. \quad \#$$

meaning that the initial scale expansion speed $\dot{R}$ for scales $R \leq R_0$ is const. and given by $\dot{R} = \sqrt{8\pi G\rho_{vac,0}R_0^2}$. Consequently the initial scale expansion is described by the simple formula:

$$R(t) = \dot{R}\int_0^t dt = \sqrt{8\pi G\rho_{vac,0}R_0^2} * (t - t_0) \quad \#$$

with $t_0 = 0$! as the actual "Big-Bang"- event time, i.e. the beginning of the universal or cosmic time. The initial Hubble parameter for the earliest epoch of the cosmic expansion is therefore given by:

$$H(R \leq R_0) = \frac{\sqrt{8\pi G\rho_{vac,0}R_0^2}}{\sqrt{8\pi G\rho_{vac,0}R_0^2} * (t - t_0)} = \frac{1}{(t - t_0)} \quad \#$$

which means that one finds the usual, well known relation valid also in this earliest phase, saying that the inverse of the Hubble parameter, i.e. $1/H = R/\dot{R} = \tau$, even in this earliest cosmic epoch, equals the actual age of this young universe, which in this case simply is $\tau = t$.

Since for all our further derivations we consider the case of a pressurized vacuum which, as we have shown (Fahr and Heyl, 2023), automatically does perform thermodynamic work at the ongoing cosmic scale expansion, the energy density ρ_{vac} of the vacuum in the universe has to diminish at the cosmic expansion, while to the contrast the relative energy density ρ_m/ρ_{vac} of massive cosmic matter has to correspondingly increase in such a way as not to violate the energy conservation law of the whole cosmic "matter - vacuum" - system. Thus, as we have shown before, the following relation (at least in case of subrelativistic matter generation, i.e. $kT_m \ll mc^2$!) has to be fulfilled:

$$-\dot{\rho}_{vac} = \dot{\rho}_m \quad \#$$

and also perhaps in the interest of Hoyle 's steady state request - namely to keep the "face of the universe" always unchanged - not to disadvantage any sooner or later cosmic spectator - with Hoyle's relation:

$$\dot{\rho}_{b,d} = \frac{\rho_{b,d}}{R}\dot{R} = \rho_m H = \dot{\rho}_m \quad \#$$

As soon as matter generation in fact in Hoyle's style prevails in the universe, one then obtains a corresponding scale-behaviour of the matter density given by (Fahr and Heyl, 2023)

$$\rho_m(R) = \rho_{m0} * (R_0/R)^2 \quad \#$$

and hence for massive cosmic matter densities ρ_m (baryonic ρ_b and dark ρ_d as well) this should mean:

$$\rho_m = \rho_m(t, R_0) \cdot (R_o/R)^2 \qquad \#$$

and furthermore:

$$-\dot{\rho}_{vac} = \dot{\rho}_{m,0} \cdot (R_o/R)^2 - 2\rho_{m,0} \cdot (R_0^2/R^3)\dot{R} = (R_o/R)^2 \cdot [\dot{\rho}_{m,0} - 2\rho_{m,0} \cdot H] \qquad \#$$

The energy conservation law for subrelativistic matter thus consequently would require:

$$4\pi R^3 \rho_m/3 + 4\pi R^3 \rho_{vac}/3 = E = const. \qquad \#$$

leading to:

$$[\rho_m(R_0(t)) \ + \rho_{vac}(R_0(t)]R_0^2 = \frac{3}{4\pi R} \cdot const. \qquad \#$$

or:

$$\rho_m(R_0(t))R_0^2 = \frac{3}{4\pi R} \cdot const. - \rho_{vac}(R_0(t))R_0^2 \qquad \#$$

For the begin of the universe we had already (Fahr and Heyl, 2023) derived a vacuum energy density behaviour according to:

$$\varrho_{vac}(R) = \varrho_{vac,0} \cdot (R_0/R)^{5-\xi} \qquad \#$$

which with the further above proposed index $\xi = 4$ (i.e. positively pressurized vacuum!) then finally leads to:

$$\rho_m(R_0, t)R_0^2 = \frac{3}{4\pi R} const - \rho_{vac}(R_0, t) \cdot (R_0/R) \qquad \#$$

2. How to conciliate these above relations?

Forgetting at the moment thermal energy parts of condensed matter, the total energy in the universe, taking vacuum energy and matter energy together, should be given by:

$$E = (4\pi c^2/3) \cdot [\rho_{vac} + \rho_m] \cdot R^3$$

which would then lead us - including a matter-generation process (material fall-out from the vacuum!), like a particle production out of a free quantized Dirac field in a static spherical Einstein universe (discussed by Schäfer and Dehnen, 1977) or a subrelativistic matter condensation out of the cosmic vacuum (see e.g. Arghirescu, 2015a/b), - to something like:

$$E = (4\pi c^2/3) \cdot [\rho_{vac,0} \cdot \exp[\alpha(1 - \frac{t}{t_0})] \ + \rho_{m,0} \cdot \exp[\alpha(\frac{t}{t_0} - 1)]] \ \cdot (R_0/R)^2 \cdot R^3 \qquad \#$$

with α denoting the actual matter-condensation rate at present, here given by a constant $(\rho_{vac,0}/\rho_{m,0}) = \exp[\alpha]$, regulating the ratio of vacuum over mass energy density at the world reference scale R_0.

At the world time $t = t_0$ with the cosmic scale $R = R_0$ one would thus with the above regulation have the following mass/energy densities:

$$\rho_0(R_0) = \rho_{vac,0} \cdot \exp[\alpha(1 - \frac{t}{t_0}) + \rho_{m,0} \cdot \exp[\alpha(\frac{t}{t_0} - 1)] \ = \rho_{vac,0} + \rho_{m,0} \qquad \#$$

At scales $R \ll R_0$, i.e. $t \rightarrow 0$, one would instead have connected with the early scale-relation at that early time:

$$R(t) = \sqrt{8\pi G \rho_{vac,0} R_0^2} \, * (t - t_0)$$

the following relations given for the matter density $\rho_m(R)$ and for the vacuum density $\rho_{vac}(R)$ at times $t \rightarrow 0$:

$$\rho_m(R) = \rho_{m,0} \cdot \exp[\alpha(\frac{t}{t_0} - 1)] \ \rightarrow \rho_{m,0} \cdot \exp[-\alpha] \qquad \#$$

$$\rho_{vac}(R) = \rho_{vac,0} \cdot \exp[\alpha(1 - \frac{t}{t_0}) \rightarrow \rho_{vac,0} \cdot \exp[\alpha] \qquad \#$$

i.e. both these densities do at these earliest cosmic times $t \ll t_0$ neither depend on t nor R, but are constant, while at scales $R \gg R_0$, i.e. $t \rightarrow \infty$, one should instead have time-dependent densities given by:

$$\rho_m(R) = \rho_{m,0} \cdot \exp[\alpha(\frac{t}{t_0} - 1)] \rightarrow \rho_{m,0} \cdot \exp[\alpha \frac{t}{t_0}] \quad \#$$

$$\rho_{vac}(R) = \rho_{vac,0} \cdot \exp[\alpha(1 - \frac{t}{t_0}) \rightarrow \rho_{vac,0} \cdot \exp[-\alpha \frac{t}{t_0}] \quad \#$$

making it evident that at some later time $t \gg t_0$ the universe finally will become a pure -matter dominated universe.

Looking now at those cosmic phases with $R \leq R_0$, when, due to the meanwhile increased matter densities - and probably also increased matter temperatures T_m -, at least under the assumption of pressure-equivalent, - i.e. "isobaric" mass condensations with $d_p = dp_{vac} + dp_m = 0$! -, fusion reactions between different condensed matter components m_i, m_j might have arranged or rearranged scale-dependent elemental abundances $X_{i,j} = X_{i,j}(R)$ (*H, D, Tr*, He^3, He^4, *Li* etc., see e.g. Kolb and Turner, 1990), then for this expansion phase ($t \rightarrow 0$) one can start from the following cosmic conditions:

$$\rho_m(R) = \rho_{m,0} \cdot \exp[\alpha(\frac{t}{t_0} - 1)] \rightarrow \rho_{m,0} \cdot \exp[-\alpha] \quad \#$$

$$\rho_{vac}(R) = \rho_{vac,0} \cdot \exp[\alpha(1 - \frac{t}{t_0}) \rightarrow \rho_{vac,0} \cdot \exp[\alpha] \quad \#$$

with matter densities at $R \leq R_0$ given by:

$$\rho_m(R) = \rho_{vac}(R) \cdot (\rho_{m,0}/\rho_{vac,0}) \cdot \exp[-2\alpha] \quad \#$$

Furthermore one had perhaps to pay attention to an energy-conserving matter-generation process which would probably require the validity of both of the following two relations:

$$d(R^3 \rho_{vac}) = -d(R^3 \rho_m)$$

and for a pressure-equivalent materialisation:

$$d(R^3 p_{vac}) = -d(R^3 \rho_m kT_m/m) = -(kT_m/m) d(R^3 \rho_m) - R^3(\rho_m/m) d(kT_m)$$

which makes evident that for a complete description of this cosmic period one would need a physical basis for the change of the matter temperature T_m with the scale of the universe, associated with the process of matter condensation out of the cosmic vacuum.

3. Aspects of cosmic nucleosynthesis

Looking now specifically at the inherent nucleosynthetic processes (Meyer, 1988, Goenner, 1994 , Kolb and Turner, 1990) during the earliest expansion phase of the universe ($t < t_0$) under conditions of a vacuum energy dominance, we can use the following thermodynamic relation (see Fahr and Heyl, 2023):

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

Where p_m is the thermal pressure of the cosmic matter condensed out of the vacuum, i.e. given by (total energy density ϵ_m of matter reduced by the rest-mass energy density $\rho_m c^2$):

$$p_m = nkT_m = \frac{\rho_m}{m}(\frac{\epsilon_m}{\rho_m}m - mc^2) = \epsilon_m - \rho_m c^2 \quad \#$$

which allows to write the temperature of the "isobarically-condensed" cosmic matter in the following form:

$$T_m = \frac{\rho_m}{m}(\frac{\epsilon_m}{\rho_m}m - mc^2) = \frac{m}{\rho_m k}[\epsilon_m - \rho_m c^2] \quad \#$$

This then leads us back to the upper thermodynamic relation, now given in the following combined form:

$$\frac{d}{dR}((\epsilon_{vac} + \epsilon_m)R^3) = -(-\frac{3-\xi}{3}\epsilon_{vac} + \epsilon_m - \rho_m c^2)\frac{d}{dR}R^3 \quad \#$$

where the following findings could perhaps be used for the region $R \leq R_0$:

perhaps connected with the relation already used by us earlier (Fahr and Heyl, 2023), but now extended to the case of matter condensation out of the vacuum:

$$dp_{vac} = -\frac{3-\xi_m}{3} d\epsilon_{vac}$$

in order to correctly take account of the thermodynamic change of the vacuum pressure connected with a corresponding change of the vacuum energy density ϵ_{vac}. However, dependend on the form of the materialisation of vacuum energy density, it could be recommended to allow hereby for a vacuum-polytrope ξ_m which is different from $\xi = 4$ due to the non-thermodynamical influence at the matter condensation out of the vacuum. Perhaps in case of an "isobaric" matter condensation one could require that the associated change of vacuum pressure is compensated by the associated change of the material pressure in the form:

$$-dp_{vac} = \frac{3-\xi}{3} d\epsilon_{vac} = +dp_m$$

Since up to now in our knowledge in none of the available papers treating the problem of matter condensation from cosmic vacuum energy (Jordan, 1968, Schaefer and Dehnen, 1977, Prigogine et al., 1988, Overduin and Fahr, 2001, Fahr and Heyl, 2007, Arghirescu, 2015) it has been discussed in detail, how exactly the thermodynamic status of the newly appearing condensed matter has to be described, for entropy reasons we could at this moment simply assume that the condensed matter is produced out of the vacuum as pressurized matter with the actual pressure $p_m = p_{vac}$ of the vacuum from which it condensed. This at least will guarantee that the cosmic matter creation process is entropy-irrelevant with $dh/dt = 0$ as e.g. Prigogine et al. (1988) require, since otherwise the unified system of "matter and vacuum" taken as a joint natural system would not fullfill the second law of thermodynamics, but would decrease the system‘s entropy by following the natural occurences. We shall leave this problem for consecutive publications and thus finish our investigations here.

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