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# Evolution of cosmic structures in the expanding universe: Could not one have known it all before?

Hans J.Fahr[1*] and M. Heyl[2]

[1]Argelander Institute for Astronomy, University of Bonn, Auf dem Huegel 71, 53121 Bonn Germany

[2]Deutsches Zentrum f¨ur Luft- und Raumfahrt (DLR), K¨onigswinterer Strasse 522-524, 53227 Bonn (Germany)

*Corresponding author
Hans J.Fahr, Argelander Institute for Astronomy, University of Bonn, Auf dem Huegel 71, 53121 Bonn Germany.

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***Abstract***

*Most recent observations from the James Webb space telescope (JWST) have shown by highly resolved infrared observations of highest sensitivity that structure formation in the universe into the forms of early galaxies has already taken place at cosmic times less than 0.6 Gigayears after the Big-Bang. This is taken up with a big surprise in the whole astronomic community, though, as it seems, it could have been predicted from simple theoretical considerations. In this article, we are demonstrating that this result already would have clearly come out from theoretical considerations of gravitational structure formation processes in the early expanding universe just after the cosmic matter recombination period. While, however, it can be easily understood how matter structures of the order of $10^8$ solar masses could evolve in the cosmic meantime, it nevertheless remains obscure, how galaxies of the type of the Milky way or more massive structures with $10^{11}$ or more solar masses can have evolved up to the present cosmic days without some not yet specified collapse-accelerating processes.*

## Collapse in Expanding Universes

In principle it is a problem hard to understand that matter may be able to collapse into large local mass units, though in an expanding universe the initially widely and uniformly distributed cosmic matter must be subject to the expansion into a permanently growing cosmic space with permanently decreasing cosmic mass densities. This only can be possible, if the structuring collapse velocity is larger than the general expansion velocity. The problem thus evidently is and must be connected with the specific form of the actual expansion dynamics of the whole universe.

Therefore this study certainly is and must be based on the specific form of the cosmic expansion of the universe. In a static universe structure formation runs along the lines that astronomers have developed since long ago for the static space [1, 2]. Processes of structure formation of course are very much different in the expanding universe, because then structure formation definitely will depend on the specific form of the prevailing cosmic expansion (e.g. decelerated, accelerated or coasting expansion etc.). To best explain the SN 1a luminosities Perlmutter et al. (1998), Schmidt et al.(1998), or Riess et al. (1998) have preferred the accelerated expansion of the universe connected with action of a constant vacuum energy density [3-10], however, there are attempts by Casado (2011) and Casado and Jou (2013) showing that a ”coasting non-accelerated universe” can equally well explain these supernovae luminosities [11-12]. In our following con- siderations we shall consider first here - mainly for mathematical reasons - the case of a “coasting expansion” [13-16], which in fact can be expected to prevail, if the universe expands under the form of thermodynamic and gravidynamic action of vacuum pressure [17]. Alternative forms of a cosmic expansion may be discussed at the end of this paper and lead to very interesting conclusions.

If then as our working basis such a ”coasting universe” can be assumed to prevail, like given in the case when $\rho_\Lambda \sim R^{-2}$ ($\varrho_\Lambda$ denoting the mass density equivalent of the vacuum energy, R denoting the scale of the universe, see e.g. Fahr, 2022) and when vacuum energy is the dominant ingredient to the cosmic mass density $\rho_\Lambda \gg \rho_b, \rho_d, \rho_\nu$, (indices *b, d, v* standing for baryons, dark matter, and photons, respectively) and to the relativistic energy-momentum tensor, then one unavoidably finds:

$$\dot{R} = \frac{dR}{dt} = const \tag{1}$$

which in fact means and necessarily implies: a ”coasting expansion” of the universe! Then consequently, a Hubble parameter must be expected falling off with the scale R like:

$$H(R) = \frac{\dot{R}}{R} = H_0 \cdot (\frac{R_0}{R}) \tag{2}$$

This means that the Hubble parameter in course of the coasting cosmic expansion decreases like $H \sim R^{-1}$!

Under these cosmic auspices one finds that the local free-fall time $\tau_{ff} = (4\pi G\varrho)^{-1/2}$ of baryonic, cosmic matter (see Jeans, 1929) is smaller than the expansion time $\tau_{ex} = 1/H$ of that matter (i.e. so that mass structures can grow even in the expanding universe!), as soon as:

$$\frac{1}{\sqrt{4\pi G\varrho}} \leq \frac{1}{H_0}(\frac{R}{R_0}) \tag{3}$$

i,e, if actual free fall times are shorter than expansion times of material structures. This means one would need to have the following relation fulfilled:

$$\frac{1}{\sqrt{4\pi G\varrho_0}}(\frac{R}{R_0})^{3/2} \leq \frac{1}{H_0}(\frac{R}{R_0}) \tag{4}$$

or:

$$\tau_{ff,0}/\tau_{ex,0} \leq (R_0/R)^{1/2} \tag{5}$$

This implies that the critical scale Rc from which upwards a progress of structuring despite of cosmic expansion can and will occur is given by:

$$R_c = R_0\frac{\tau_{ex,0}^2}{\tau_{ff,0}^2} \tag{6}$$

That means for world times with $R(t) \geq R_c$ one thus cannot expect to have any more a homogeneous cosmic matter distribution, but a hierarchical mass structure in the universe like described by Fahr and Heyl (2019) [18].

On the other hand - since matter can anyway not gravitationally condense, before it has recombined to neutral atoms due to the strong interactions of free electrons with the strongly coupling el-mag. radiation fields (photon fields), one can therefore start this consideration here with the time $t_0 = t_r$ of matter recombination, since before that time no irreversible condensations are possible in the form of enduring, persisting structures. Hence along this argumentation one might find this critical scale by:

$$R_c = R_r\frac{\tau_{ex,r}^2}{\tau_{ff,r}^2} = R_r\frac{4\pi G\varrho_r}{H_r^2} = R_r \cdot [8.38 \cdot 10^{29}/1.677 \cdot 10^{29}] = R_r\frac{8.38}{1.67} = 5.02 \cdot R_r \tag{7}$$

This obviously says that structuring of cosmic matter can only start when the scale of the world has increased to at least $R_c = 5.02 \cdot R_r$, i.e. to about five times the recombination scale $R_r$!

The question now may pose itself concerning the critical mass $M_c$ that is connected with such a selfstructuring mass unit $M_c(R_c)$. The answer must come from the usual knowledge of the collapse-critical mass unit $M_c$ given by a comparison of the free-fall time $\tau_{ff}$ and the sound time (pressure counterreaction time) given by $\tau_s = D/c_s$ (D being the radial dimension of the collaps-critical mass unit Mc) and thus leading to the following request:

$$\frac{1}{\sqrt{4\pi G\varrho}} = \frac{D}{\sqrt{\frac{\gamma P}{\varrho}}} \tag{8}$$

with $P$ and $\gamma$ denoting the baryonic gas pressure and the polytropic index of the gas. This then with Fahr and Heyl (2021) leads to the following expression for $M_c = M_c(R)$:

$$M_c(R) = \frac{4\pi}{3}D^3\varrho = \frac{4\pi}{3} \cdot [\frac{\gamma P/\varrho}{4\pi G\varrho}]^{3/2}\varrho = \frac{(\gamma/G)^{3/2}}{3\sqrt{4\pi}}(\frac{P(R)}{\varrho^2(R)})^{3/2} = 10^5 M_\circ\frac{P(R)\varrho^2(R_r)}{\varrho^2(R)P(R_r)} \tag{9}$$

Assuming that pressure and density during the cosmic expansion conserve the gas entropy, i.e.$P/\varrho^\gamma$ = const, then leads to the result:

$$M_c(R) = 10^5 M_\circ\frac{P(R)\varrho^2(R_r)}{\varrho^2(R)P(R_r)} = 10^5 M_\circ \cdot (\frac{\varrho_r}{\varrho})^{1/3} = 10^5 M_\circ \cdot (R/R_r)! \tag{10}$$

where hereby the typical collapse mass $M_c(R_r)$ at the recombination scale has been calculated by Fahr and Heyl [19] to be $M_c(R_r) = 10^5 M_o$.

It is interesting now to ask at what cosmic times $t \geq t_r$ the first gravitationally bound mass structures of galactic type according to the above considerations can be expected as existing in the universe? This now can be answered with the following calculation:

$$(5-1)R_r \leq \dot{R}_r \cdot (t - t_r) \tag{11}$$

Under the prerequisites which we have discussed before this leads to the following result:

$$(t - t_r) \simeq 4 \cdot (\frac{R_r}{R_0}) \cdot \tau_0 = 4 \cdot 10^{-3} \cdot \tau_0 \tag{12}$$

where $\tau_0 = 1/H_0$ denotes the present age of the universe (say 13.7 Gi- gayears!). The recombination scale Rr hereby was estimated with the redshift $z_r \simeq 10^3$ of the CMB (Cosmic Microwave Background, see Bennet et al., 2003) [20] through $R_0/R_r = 1 + z_r \simeq 1000$. That implies that already at a time of $\Delta t = 4 \cdot 10^{-3} \cdot \tau_0$ after the recombination point matter could start creating gravitationally bound, selfsustained, collapsed structures! So far this result at least seems to be out of any conflict with the most recent James-Webb ST observations stating that already at times of 13.1 Giga years before our present time galaxies and stellar structures appear to have been present in the early universe which were very much similar to our present day galaxies.

The only remaining problem from our theoretical explanations presented here in this paper are the predicted typical masses of present day galaxies com- pared to their realistic values which are about a factor of 1000 larger. While present day galaxies - like typically the one of our Milky way - have typical masses of about $10^{11}$ solar masses, our above theoretical predictions for the present-day collaps masses would rather give us

$$M_c(R_0) = 10^5 M_\circ \cdot (R_0/R_r) \simeq 10^8 M_\circ! \tag{13}$$

Obviously a further mass growth of more than three orders of magnitude would still be left over for an upcoming better explanation. One idea for an ongoing mass growth is connected with the process of a cumulative mass growth of mass units collapsed before that time. This idea we shall briefly sketch here below.

## The Idea of a Cumulative Mass Growth

Let us start from a homogeneous universe under Hubble expansion that has, as discussed above, started to produce the first generation of massive collapse centers with masses of the order of $M_c \simeq 10^5 M_o$. Assuming furthermore a symmetric production of collapse centers in this homogeneous universe one could then assume that these collapse centers conserve the general Hubble expansion dynamics. This would allow to assume that two of such neighboring centers of masses $M_{c,A}$ and $M_{c,B}$ in a radial distance of twice the collapse radius $D = D(M_c)$ of such objects A and B would have a mutual, relative Hubble migration velocity of:

$$V_{AB} = H \cdot 2D \tag{14}$$

One can now compare the relative Hubble energy $E_{kin} = (1/2) M_c V_{AB}^2$ of these two objects A and B with the gravitational binding energy $E_{bind} = GM_c^2/2D$ between these two mass centers and can study their absolute magnitudes investigating:

$$(1/2)M_c V_{AB}^2 \lessgtr GM_c^2/2D \tag{15}$$

or leading to:

$$H^2 \lessgtr \frac{GM_c}{4D^3} \tag{16}$$

Studying then the situation when first in the universe collapse structures can be expected, i.e. at $R = R_c = 5R_r$, will lead to:

$$H^2 = H_0^2 \cdot (\frac{R_0}{R_c})^2 \lessgtr \frac{G(\frac{4\pi}{3}D^3 \varrho_c)}{4D^3} = G(\frac{\pi}{3}\varrho_c) \tag{17}$$

In view of Rc = 5Rr and $\varrho_c = (1/125)\rho_r = 8 \cdot 10^{-25} g/cm^3$ we then obtain:

$$H^2 = H_0^2 \cdot (\frac{R_0}{R_c})^2 \lessgtr \frac{G(\frac{4\pi}{3}D^3 \varrho_c)}{4D^3} = \frac{\pi}{3} G\varrho_c = 1.05 \cdot 6.67 \cdot 10^{-8} \cdot 8 \cdot 10^{-25} [\frac{cm^3 g}{g \cdot s^2 cm^3}] = 5.6 \cdot 10^{-32} [s^{-2}] \tag{18}$$

which finally with $\tau_0 = 1/H_0 = 13.7$ Gigayears means:

$$\frac{1}{\tau_0^2}(200)^2 \gtreqless 5.6 \cdot 10^{-32} [s^{-2}] \tag{19}$$

or:

$$2.15 \cdot 10^{-29} \gtreqless 5.6 \cdot 10^{-32} \tag{20}$$

That finally expresses the fact that the left side (i.e. kinetic energy $E_{kin,AB}$) is much greater than the right side (i.e. binding energy $E_{bind,AB}$). This indicates that the two centers A and B of collapsed masses would be essentially free to continue their Hubble dynamics, - i.e. **no!** further accumulation of collapsed materials would occur. The latter to the contrast would, however, occur, if the binding energy would turn out to be larger than the kinetic energy, because in this case the two mass clusters would produce one new gravitationally bound system decoupling from the free Hubble expansion, and, in view of the other equivalent systems in the neighborhood, would induce a multi-cluster collaps system.

As it looks so far, however, accumulation of cosmic masses beyond a cluster mass of $M_c \simeq 10^5 M_o$ until the present age of the universe remains unexplained by our present theory. When JWST in its highly resolving infrared observations can really find indications for the existence of systems of clustered masses with $10^{11} M_o$ with an age of 13.1 Gigayears, - then **this!** is really an exciting message.

On the other hand perhaps, taking serious what Perlmutter et al. (1999), Schmidt et al. (1999), and Riess et al. (1999) are claiming, namely that they are seeing in the SN1a luminosities of the most distant galaxies already clear indications of an accelerated expansion of the universe would express the fact that already at that early times [21-24], all the more at all later cosmic times, the Hubble constant would have been given by:

$$H = \frac{\dot{R}}{R} = \sqrt{\frac{8\pi G}{3}[\varrho_B + \varrho_D + \varrho_\nu + \varrho_\Lambda]} \simeq \sqrt{\frac{8\pi G}{3}[\varrho_\Lambda]} = H_\Lambda = const \tag{21}$$

meaning that the expansion times $\tau_{ex} = 1/H_\Lambda$ would have stayed constant all the way since that time till today and later, while the free-fall times $\tau_{ff} = 1/\sqrt{4\pi G\varrho}$ are increasing permanently since that time like

$$\tau_{ff} = 1/\sqrt{4\pi G\varrho} = \frac{1}{\sqrt{4\pi G\varrho_0}}(\frac{R}{R_0})^{3/2} \tag{22}$$

which would mean that since that early time no collapse could have happened anymore, and especially young galaxies could not at all be understood in this context of the universe. Does that mean: $H = H_\Lambda = const$ can be ruled out?, while $H = H_{coast} = H_r \circ (R_r/R)$ might appear as the better, since more valid approach?

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