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Research Article

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Structure Formation After the Era of Cosmic Matter Recombination

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Abstract

In an aforegoing paper (Fahr and Heyl, 2021) we have studied in physical details the event of cosmic matter recombination expected at about 400000 years after the Big Bang at cosmic photon redshifts of about zr =1000. It turned out there, that photons taken as surely cooling by permanent increase of their cosmic redshifts, while electrons and protons partly are cooled by Thomson scatter processes with photons, but partly are heated due to the Hubble expansion of the universe. It can be shown, however, that in this cosmic epoch the cooling of electrons and protons is much more effective than the heating, and that a recombination of cosmic matter to neutral H-atoms thus is unavoidable. We then show, however, that the neutral gas atoms do not couple anymore to the cosmic CMB photon field, but instead are subject only to the Hubble migration in velocity space and thus become heated again. The question then poses itself, how cosmic structure formation in a gas with decreasing density and increasing temperature should have been able to take place. Where did the galaxies and clusters of galaxies come from? Looking into the unstable, self-gravitating acoustic oscillation modes we find the answer at what cosmic times which magnitudes of self gravitating critical masses can have been produced that could have sustained till the present times.

Keywords: Recombination, Heated Hydrogen Gas, Structure Formation

Introduction

Standard cosmology generally assumes that cosmic matter in the earliest phases of cosmic evolution was at high temperatures and hence in a fully ionized state. At this time cosmic photons in their number density n_ν were strongly dominant by a factor of 10^9 compared to particle number densities, like electron or proton densities n_e or n_p (see e.g. Rees, 1978). Due to the strong thermodynamic coupling between photons, electrons and protons at these pre-recombination phase, the temperatures of all these species were thought to be identical, i.e. $T_\nu = T_e = T_p$. But in an expanding universe matter densities will systematically decrease with time, and consequently the thermodynamic coupling strengths, i.e. energy exchanges between electrons, protons and photons, become systematically weaker, and temperatures consequently decouple from each other (see studies e.g. by Burbidge, Gould and Pottasch, 1963, or Gould,1968, or Fahr and Loch, 1991).

In case thermodynamic equilibrium could be assumed at this phase, then the degree ξ of ionisation could be calculated with the help of the Saha-Eggert equation (see M.Saha, 1920, or Rybicki and Lightman, 1979). In principle the actual degree of ionization $\xi(T)$ is then obtained from the minimum of the Gibbs potential $G=G(\xi)$ by the request: $dG/d\xi=0$!. The whole of that classic Saha-Eggert theorem is, however, based on the fundamental assumption: Thermodynamic equilibrium! - If the latter is not guaranteed, and if temperatures T_ν; T_e; T_p are different, then this theorem is not applicable.

In a precedent paper (Fahr and Heyl, 2021) we have, however, demonstrated that the equilibrium state during this phase is perturbed, as soon as the energetic coupling between photons, electrons and protons becomes too weak, as it unavoidably occurs during the ongoing cosmic expansion due to permanent density decreases. After the recombination phase, when electrons and protons should have recombined to H-atoms, and photons start propagating through cosmic space practically without further interaction with matter, establishing the cosmic radiation background *CMB,* the thermodynamic contact between matter and radiation for the following cosmic time is stopped. Both behave in principle independent of each other, primarily only reacting to the cosmic scale expansion. For this reason, the initial Maxwellian atom distribution function does not persist in an expanding universe over times of the ongoing collision-free expansion (Fahr, 2021b).

The kinetic situation at the recombination border

What type of a kinetic distribution function $f(v, t > tr)$, and what change of it with respect to time t, should be expected in times after recombination time t_r? In Fahr and Heyl (2021) we have approached this problem by use of a kinetic transport equation slightly different from that used by Fahr (2021a), however, treating the identical cosmophysical situation as already envisioned earlier. Starting from a kinetic transport equation used by Fahr (2007) one can describe a plasma physical scenario analogous to the one we are confronted with here. With the two terms a) for a temporal derivative $\partial f(v,t)/\partial t$, and b) for the particle redistribution in velocity space under collision-free conditions, due to the Hubble-induced

velocity space drift $\dot{v}_{eH} = \dot{v}_{pH}(v) = -v \cdot H$ of electrons or protons, are adequately represented. However, we raised the point there that energetic coupling processes between electrons and photons and electrons and protons need to be installed into this kinetic transport equation in order to take into account important interactions during the recombination phase. These latter processes count for the cosmic era of interest here and cannot be excluded. For them one needs additional terms a) for the energetic coupling between protons and electrons and b) for the coupling between electrons and photons, in relevant transport equations which do lead to the following enlarged system of equations (Fahr and Heyl, 2021):

$$\frac{\partial f_e(v,t)}{\partial t} = \frac{1}{v^2}\frac{\partial}{\partial v}\left[v^2 \dot{v}_H f_e(v,t)\right] + \frac{f_e - f_p}{\tau_{e,p}} + \frac{f_e}{\tau_{e,v}}\frac{[(m_e v^2/2) - KT_e(t)]}{K[T_e(t) - T_v(t)]}$$

and

$$\frac{\partial f_p(v,t)}{\partial t} = \frac{1}{v^2}\frac{\partial}{\partial v}[v^2 \dot{v}_H f_p(v,t)] - \frac{f_e - f_p}{\tau_{e,p}}$$

Hereby the quantities $T_e = T_e(t)$ and $T_v = T_v(t)$ represent the actual, time-dependent electron and photon temperatures, $\tau_{e,p}$ and $\tau_{e,v}$ denote typical electron-proton and electron-photon energy exchange periods which are given by:

$$\tau_{e,v} = \frac{T_v - T_e}{\left\langle \frac{\partial T_e}{\partial t} \right\rangle} = \frac{3m_e c}{8\sigma_{Th}\alpha T_v^4}$$

with $\sigma_{Th} = (8\pi/3)(e^2/m_e c^2)^2 = 0.66.10^{-24} cm^2$ denoting the Thomson photon-electron scattering cross section and α being the Stefan-Boltzmann constant, and furthermore according to Spitzer (1956):

$$\tau_{e,p} = 11.4\sqrt{\frac{m_p}{m_e}}\frac{(KT_e)^{3/2}}{\delta_{ee} n_e \ln\Lambda}$$

where ∧ is the Coulomb logarithm, and δ_{ee} denotes the mean energy transfer rate in electron-electron collisions.

If photons, electrons and protons are solely affected by, without mutual interactions, then the cosmic photons are redshifted with time, and their temperature T_v is permanently reduced according t_o $T_v = T_{v0}(R_o/R)$ (see e.g. Fahr and Zoennchen, 2009), while, to the contrary, proton and electron temperatures purely reflecting the effect of the Hubble migration, as shown in Fahr (2021b), both are increasing, thus creating evidently a strange NLTE-situation with $T_v << T_{p,e}$ which would probably not allow at all the recombination of electrons and protons to neutral H-atoms, suggesting that the recombination should not take place at all.

This strongly depends on the strengths of the energetic couplings between photons and electrons, and as we could show in Fahr and Heyl (2021) taking these interaction effects quantitatively into account, the cooling of electrons and protons due to energetic coupling to the redshifted and cooled photons cannot be compensated or even overcompensated by the Hubble migration-induced heating, unless the Hubble parameter H_r at the recombination time is larger than the present-day Hubble parameter H_0 by a factor of 10^{15}. Otherwise one would in all cases have the electrons systematically cooled by the photons. But when the latter are cooled, and Coulomb collision are effective enough, these electrons cannot be impeded from recombining with protons, leaving as products neutral H-atoms for the coming period of the cosmic evolution. However, drastically different now from earlier approaches, these collision-less neutral atoms are solely subject to the effect of the Hubble-migration which slowly leads to a gas temperature increase again (see Fahr, 2021b). Whether or not this heated cosmic gas will then later be able to form larger massive structures or complex, elementary cosmic cornerstones like stellar clusters and galaxies hence needs to be answered along quite a new baseline in the argumentation.

If the Hubble parameter has a sub-critical value

How much larger than the present-day Hubble parameter H_0 could the actual one H_r at the time of recombination have been? What does one in fact know about the value of the Hubble parameter at earlier times in the cosmic past, especially near the point of recombination of cosmic matter? - To frankly confess the truth: Not very much! - and for sure - nothing safe yet. All depends on the main cosmic view that cosmologists share concerning the universe near recombination times. Therefore, one can only speculate on this point, - if it existed at all in the history of the universe, i.e. if cosmic matter at times in the past was at all in a fully ionized phase. The present day value of the Hubble parameter with H_{today} = 70km/s/Mpc is obtained from redshift observations of the more or less nearby galaxies with redshifts $z \leq 1$, and not very much can be speculated with this poor observational basis on the specific value of H_r valid for the time of recombination $t = t_r$. If some theoretical conditions or prerequisites are fulfilled, then things for estimations would be better. For example:

If the Hubble parameter H is predetermined at all cosmic times, for instance by a constant vacuum energy density, i.e. only by the vacuum energy density ∧, at present time as well as back all the time till the recombination time $t = t_r$, then it can be shown (see Fahr, 2021a), that the Hubble parameter would have been constant all over this time period from the recombination period till now, i.e. $H = H_0 = H_r$. That would mean concerning the above relation that $H_r = H_{today}$!, and with the result of the section ahead, that the electrons are effectively cooled by the cosmic photons, since otherwise one would need $H_r = 10^{15} H_{today}$ (see the discussion above).

If the Hubble parameter at present times, as well as at the recombination time t_r, is purely determined by baryonic matter, i.e. by the rest-mass density of baryonic matter $\rho = \rho_r$, then one could use the following relation taken from the first of the Friedman equations (see e.g. Goenner, 1996)

$$H^2 = \frac{8\pi G}{3}\rho_B$$

which then would lead to the relation:

$$H_r = H_{today} \cdot \left(\frac{R_{today}}{R_r}\right)^{3/2} = H_{today} \cdot \left(\frac{10^3 R_r}{R_r}\right)^{3/2} = 10^{4.5} H_{today}$$

meaning that the Hubble parameter at the recombination era could certainly have been much larger than H_{today}, but by far not large enough to get the cosmic electrons effectively heated competing with the cooling by CMB photons.

This seems to show that electron cooling in this cosmic phase is unavoidable, and that consequently also a recombination of the cooling electrons with ambient protons to neutral *H*-atoms, as soon as $KT_e(t) \leq E_B$, with $E_B = 13.6\ eV$ denoting the hydrogen ionization energy, also appears unavoidable. But then one automatically enters into the consecutive problem that the recombination product, i.e. the resonance-free baryon gas (H -gas), when it is now decoupled from the CMB photon field, does not continue to cool further down, but to the contrary, when solely being subject to the Hubble drift connected with the cosmic expansion, will again start increasing its temperature (see relations given further above and in Fahr, 2021b).

The historic evolution of the Hubble parameter $H = H(t)$ can be even put on a broader, more analytic basis by again looking back to the first of the Friedman equations (see e.g. Goenner, 1996) expressing the fact that the Hubble parameter is given by:.

$$H^2 = \frac{\dot{R}^2}{R^2} = \frac{8\pi G}{3}[\rho_B + \rho_D + \rho_\nu + \rho_\Lambda]$$

where all quantities like the mass densities $\rho_B, \rho_D, \rho_\nu, \rho_\wedge$ of baryonic matter, of dark matter, of photons, and of the vacuum energy are thought to be known functions of time *t*, or equivalently, of the scale of the universe $R = R(t)$.

Introduction of $\Omega_0 = 3H_0^2/8\pi G$ with H_0 denoting the present-day Hubble parameter, then allows to write the upper equation in the form:

$$1 = \frac{1}{\Omega_0}[\rho_B + \rho_D + \rho_\nu + \rho_\Lambda] = [\Omega_B + \Omega_D + \Omega_\nu + \Omega_\Lambda]$$

For the present epoch one has, however, obtained observational best-fit values for the above quantities Ω_B, Ω_D, Ω_ν, $\Omega_\wedge$ given by (Perlmutter et al., 1999, Bennet et al., 2003) by the following values:

$\Omega_B = 0.04$
$\Omega_D = 0.23$
$\Omega_\nu = 0.01$
$\Omega_\wedge = 0.72$

Inserting now the expected dependences of ρ_B; ρ_D; ρ_ν; $\rho\wedge$ on the scale R of the universe leads us to:

$$H^2 = \frac{\dot{R}^2}{R^2} = \frac{8\pi G}{3}[\rho_{B0}(R_0/R)^3 + \rho_{D0}(R_0/R)^3 + \rho_{\nu 0}(R_0/R)^4 + \rho_\Lambda]$$

Hereby the equivalent mass energy density ρ_ν of the cosmic photons has been taken into account by its value corresponding to a cosmologically redshifted Planck radiation (see e.g. Fahr and Zoennchen, 2009). When introducing the present-day Ω- values into the upper equation, one then obtains:

$$H^2 = \frac{\dot{R}^2}{R^2} = H_0^2 \cdot [\Omega_B(R_0/R)^3 + \Omega_D(R_0/R)^3 + \Omega_\nu(R_0/R)^4 + \Omega_\Lambda]$$

or expressing the fact that the R - dependence of the Hubble parameter is given by:

$$\frac{H^2}{H_0^2} = [0.04(R_0/R)^3 + 0.23(R_0/R)^3 + 0.01(R_0/R)^4 + 0.72]$$

or expressed by the relation:

$$H = H_0 \cdot \sqrt{[0.27(R_0/R)^3 + 0.01(R_0/R)^4 + 0.72]}$$

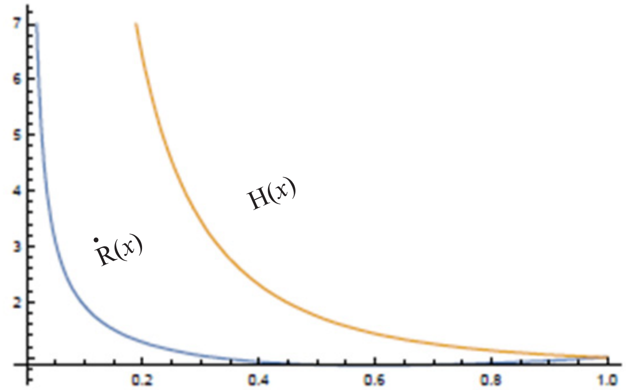

Figure 1: Hubble parameter $H(x)$ (yellow curve) and the expansion velocity $\dot{R}(x)$ (blue curve) as functions of the normalized Hubble scale $x = R/R_0$

Going back to the expected recombination point at $R_r = R_0/1000$ we thus obtain a Hubble parameter given by:

$$H_r = H_0 \cdot \sqrt{[0.27(R_0/R)^3 + 0.01(R_0/R)^4 + 0.72]} \simeq 10^5 H_0$$

or expressing the surprising fact that at the expected recombination time $t = t_r$ the photon field does contribute the most to the Hubble parameter which itself amounts at that time $t = t_r$ to: $H_r \simeq 10^5 H_0$.

Recapitulating, however, our earlier request that, to really have an effective heating of the electron gas occurring, one would need a Hubble parameter of $H_r \geq 10^{13} H_0$. This then tells us that an electron cooling at this period seems unavoidable.

Evolution of the cosmic scale

From the result obtained in the section above we use the expression that gives the actual Hubble parameter as a function of the scale of the universe in the form:

$$H = \frac{\dot{R}}{R} = H_0 \cdot \sqrt{[0.27(R_0/R)^3 + 0.01(R_0/R)^4 + 0.72]}$$

This relation also allows to write the scale velocity $\dot{R}$ as function of the scale R in the form:

$$\dot{R} = H_0 R \cdot \sqrt{[0.27(R_0/R)^3 + 0.01(R_0/R)^4 + 0.72]}$$

By means of this upper expression, separating variables *R* and *t*, one can then find a solution for the scale *R* as function of the cosmic time *t* in the form:

$$\frac{dR}{RH_0 \cdot \sqrt{[0.27(R_0/R)^3 + 0.01(R_0/R)^4 + 0.72]}} = dt$$

which can be integrated to yield the following relation:

$$t - t_r = \int_{R_r}^{R} \frac{dR}{RH_0 \cdot \sqrt{[0.27(R_0/R)^3 + 0.01(R_0/R)^4 + 0.72]}}$$

Introducing the new variable $x = R/R_0$ we then find:

$$H_0 \cdot (t - t_r) = \int_{x_r}^{x} \frac{dx}{\sqrt{[0.27/x + 0.017/x^2 + 0.72x^2]}}$$

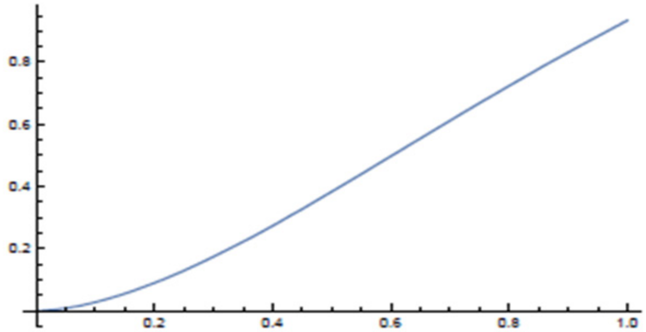

Figure 2: Hubble time $(t - t_r)H_0$ as function of the Hubble scale $x = R/R_0$:

Structure formation in a heated cosmic gas

As discussed in Fahr and Zönnchen (2009) in a homogeneous expanding cosmic gas cosmic matter structures can form due to self-gravitational interactions in density perturbations of this cosmic gas. These self-generating structures are persistent phenomena of cosmic sound waves, however, when self-gravity of the oscillatory matter is included. The typical dispersion relation for such self-gravitating, acoustic waves is given in the following form (see Jeans, 1929, Chandrasekhar, 1961):

$$\omega^2(k) = v_s^2 k^2 - 4\pi G \rho_r$$

with ω as the wave frequency, $k = 2\pi/\lambda$ as the wave vector and wave length λ, and v_s as the effective, local sound velocity at recombination era. G is Newton's gravitational constant ,and ρ_r is the actual local matter density at the recombination time $t = t_r$.

As evident from the above dispersion relation, there exists a critical wave number k_c with

$$k_c = \sqrt{\frac{4\pi G \rho_r}{v_s^2}}$$

and the property that all waves with wavenumbers $k \leq k_c$ lead to unstable, standing waves with imaginary values for associated frequencies ω, i.e. with growing wave amplitudes and hence ongoing of structure formation.

From that fact one can conclude that the characteristic wavelengths of standing wave structures at the recombination epoch are given by:

$$\lambda_c = \frac{2\pi}{k_c} = \frac{2\pi}{\sqrt{\frac{4\pi G \rho r}{v_s^2}}} = \sqrt{\frac{\pi v_s^2}{G \rho_r}}$$

Calculating the value of λ_c one obtains with $v_s = P_r/\rho_r$ and $\gamma = 5/3$, $P_r = n_r K T_r$ and T_r denoting pressure and temperature of the cosmic H-gas:

$$\lambda_c = \sqrt{\frac{\pi \gamma P_r}{G \rho_r^2}} = \sqrt{\frac{\pi \gamma (n_r K T_r)}{G \rho_r^2}} = \sqrt{\frac{\pi \gamma (K T_r)}{m G \rho_r}} = 2.3 \sqrt{\frac{K T_r}{m G \rho_r}}$$

The temperature at the recombination era is expected to be about $3000K$, and due to the redshift cooling of the present CMB ($3K$-radiation) one obtains the redshift relation: $(1 + z) = (R_0/R_r) \simeq 1000$. This means that the present cosmic density of the universe $\rho_0 = 10^{-31}$g/cm^3 should have been larger at the recombination era by a factor $(1000)^3$ yielding an actual value at $t = t_r$ of $\rho_r = 10^{-22}$g/cm^3. This argumentation is based on the assumption that cosmic photons are subject to redshifts which are due to the expansion of the universe. If this cosmic mainstream basis is questioned, then, as we shall show at the end, this would change all of our conclusions.

The baryon gas temperature T_r, solely due to the influence of the Hubble drift at the recombination era, should develop according to a linear approach for $0.\,1 \geq H_r(t - t_r)$ by (Fahr, 2021b):

$$T_H(t) = \frac{T_{Hr}}{(1 - H_r(t - t_r))^2}$$

and the density is given by:

$$\rho_H(t) = \rho_r \cdot (\frac{R(t_r)}{R(t)})^3$$

Covering a time period Δt after the recombination point $t = t_r$, over which the Hubble parameter $H = H_r$ can be considered as constant, permits then to write

$$R(t) = R(t_r) \exp[H_r(t - t_r)]$$

and consequently yielding the following density as function of time:

$$\rho_H(t) = \rho_r \cdot (\frac{R(t_r)}{R(t_r)\exp[H_r(t - t_r)]})^3 = \rho_r \exp[-3H_r(t - t_r)]$$

The critical mass M_c of a collapse-critical gas package is then given by

$$M_c = \frac{4\pi}{3} \lambda_c^3 \rho_H = \frac{4\pi}{3} 2.3^3 (\frac{K T_H}{m G \rho_H})^{3/2} \rho_H = 51.3 \cdot (\frac{K T_H}{m G})^{3/2} \rho_H^{-1/2}$$

If now one introduces the above expressions for $T_H(t)$ and $\rho_H(t)$ as functions of t, one then can see the critically possible, self-gravitational collapse mass $M_c = M_c(t)$ as function of the cosmic time t after the recombination point as given by:

$$M_c(t) = \frac{4\pi}{3} \lambda_c^3(t) \rho_H(t) = 51.3 \cdot (\frac{kT_H}{mG})^{3/2} \rho_H^{-1/2} = [51.3 \cdot (\frac{kT_{H,r}}{mG})^{3/2} \rho_{H,r}^{-1/2}] \frac{\exp[(3/2)H_r(t - t_r)]}{(1 - H_r(t - t_r))^3} =$$

$$[2.3 \cdot 10^5 M_\odot] \cdot \frac{\exp[(3/2)H_r(t - t_r)]}{(1 - H_r(t - t_r))^3} = M_{c0} \cdot \mu(t)$$

The above expression $\mu(t)$ describing the growth factor of the mass condensate in time is shown in Figure 3. The three curves represent solutions for three Hubble parameters namely $H_0 = H_{today} = 70km/s/Mpc$; $H_1 = 2H_0$; and $H_2 = 4H_0$. One can see that the critical mass substantially increases and also reaches the expected magnitude of 10^6, meaning that masses of the order of $Mc > 10^{11}\ M_\odot$, i.e. solar masses, within a time of several Billions of years are possible, however, it must be realized that the results of Figure 3 are based on the assumption that within the considered time the actual Hubble parameter is not varying, but keeps a value of $H = H_{1,2,3}$.

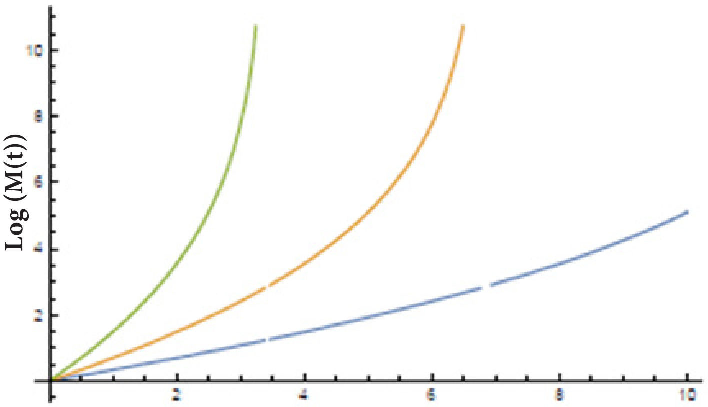

Figure 3: The mass growth factor $\mu(t)$ as function of cosmic time in Billion years in a linear approach with $H = 1, 2, 4\ H_0$

The above expression shows that possible critical masses $M_c(t)$ are growing with cosmic time t, however, one should keep in mind, to produce elementary cosmic cornerstones like galaxies, one would need a growth factor of about 10^6. Furthermore, there exists a severe limitation for this mass growth given through a comparison between gravitational free-fall times τ_{ff} and expansion times τ_{ex}. The time τ_{ff} is the time it takes to condense the gravitationally unstable mass $M_c(t)$ to a stable structure by its free-fall in the genuine gravitational field, without the pressure action taken into account, and is given by:

$$\tau_{ff} = \frac{1}{\sqrt{4\pi G\rho_r}}$$

The expansion time τ_{ex} is the typical time needed to expand the mass $M_c(t)$ with the ongoing Hubble expansion to infinity or say: back to the whole universe!, and it is simply given by:

$$\tau_{ex} = \frac{R}{\dot{R}} = \frac{1}{H_r}$$

The critical mass can only survive as a cosmic structure, as long as τ_{ff} is smaller than τ_{ex}, meaning that one should numerically have the following relation fulfilled:

$$\frac{1}{\sqrt{4\pi G\rho_r}} \leq \frac{1}{H_r}$$

At considerations of gravitational instabilities on smaller scales, say in galactic gas clouds, there is usually also an other characteristic time τ_s that counts, namely the pressure reaction time (sound time!). i.e. the time it takes to communicate a pressure increase in the center of the condensation back to its border. If the cloud diameter is given by D then this time τ_s is estimated by:

$$\tau_S = \frac{D}{v_s} = \frac{D}{\sqrt{\frac{\gamma}{\rho_r}P_{H,r}}}$$

Usually this allows to conclude that the dimension of the gas condensation in order to fulfil the above relation should not be larger than:

$$D \leq \frac{\sqrt{\frac{\gamma}{\rho_r}P_{H,r}}}{\sqrt{4\pi G\rho_r}} = \sqrt{\frac{\gamma P_{H,r}}{4\pi G\rho_r^2}}$$

Hence a limitation on the mass of such a gas condensation is again given by:

$$M_c = \frac{4\pi}{3}D^3\rho_r = \frac{1}{3\sqrt{\pi}}\left(\frac{\gamma P_{H,r}}{G}\right)^{3/2}\rho_r^{-2} \simeq 10^5 M_\odot$$

Conclusions

In an aforegoing paper (Fahr, 2021b) it had been shown that after a recombination of cosmic matter, the remaining hydrogen atoms are without interactions with the CMB photon field and can be taken as a collision-free gas. They will be solely subject to the cosmic scale expansion of the universe, and, astonishingly, due to the kinetic action of the Hubble drift on the whole gas population in velocity space, the thermal spread, i.e. the temperature of this population, will increase, though embedded in an expanding universe. This latter effect, however, only takes place in this form after the recombination of electrons and protons to neutral gas atoms, since before this occurs, electrons, instead of being heated, are much more effectively cooled via Thomson scatter processes with the cooling cosmic photon radiation field, which is permanently redshifted in time and, according to standard expectations, is unavoidably cooled by the expansion of the universe. This would be completely different, if freely propagating photons without any material interactions are not redshifted, al least as long as they are not locally interacting or registered (see Fahr and Heyl, 2017, 2018). The latter circumstance, if taken serious in this context, would have tremendous consequences, because based on our earlier theoretical derivations cosmic photons at free flights along their light-geodetics will not change their characteristic properties, i.e. their frequencies or wavelengths. That would imply that their original spectral distribution would not change with cosmic time, only their spectral photon densities would change with cosmic time, meaning that the actual cosmic photon spectrum in fact is not anymore a true Planck spectrum with its typical characteristics.

Otherwise the electrons cooled by redshifted photons on their side are then also effectively cooling the protons by Coulomb collisions, since it turns out that in the first collision-dominated phase this cooling by the cooled electrons is dominant over the Hubble-heating in the expanding universe. As we could show in this paper the electron cooling by Thomson scatter processes with the cooling CMB radiation field is much more effective compared to the Hubble induced heating. Hence one can conclude that the recombination of electrons and protons is not impeded by the electron heating. However, when finally, the recombination is finished and only neutral gases are left, then these neutral gases, when exclusively being subject to the Hubble expansion, will again start being heated despite the expansion of the scale of the universe. The question then remains whether or not this heated cosmic gas would, or would not, have impeded the evolution of larger structures of cosmic matter in form of stars and galaxies. As we do show at the end of this article here the evolution of typical cosmic mass elements of about 10^{11} solar masses appears, however, as likely along the process of self gravitational formations of gas density fluctuations.

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