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REQUIREMENT OF NEUTRAL HYDROGEN PERIOD IN THE EVOLUTION OF THE UNIVERSE

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SUMMARY

The hot model Universe is considered, discussing successively the energy losses by the hot plasma, radioemission in the galactic medium, determining z_{max}, examining the heating of gas and the background of the radiowave band. It is shown that hydrogen is neutral for $z < 1300$ but > 300, and that the formation of various objects took place for $z < 300$.

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In the hot model Universe, corroborated by recent radio observations (see review [1]), it is assumed that during the earlier stage of expansion, the fully ionized plasma is in equilibrium with the emission. Cooling at expansion leads to hydrogen recombination for $T \sim 4000°K$ and $z \sim 1300$ **. As hydrogen expands further, it must remain neutral. Observation in the 21 cm line and measurements of absorption in the Ly-α line in spectra of remote quasars point to the absence of neutral intergalactic hydrogen. The total gas condensation in the galaxy is difficult to figure out and this is why it is considered that the absence of neutral hydrogen points to a high degree of ionization, and, as a consequence of this, to a high electron temperature of the intergalactic gas. Moreover, contemporary theories of galaxy formation point indirectly to the necessity of preliminary gas heating. It is assumed in [2] that gas was heated for $z \sim 10 - 20$, but the author of reference [3] considers that gas heating took place for $z \sim 100$, while in [4] it is ascribed to $z \gtrsim 10$. Taking into account the uncertainty of the choice, it makes sense to provide if only a rough, but maximum estimate of $\underline{z}$, at which heating took place. Analysis of the energy balance of intergalactic gas and of the available experimental data on its radioemission shows that heating could not have taken place earlier than $z \sim 300$, i. e. for $300 < z < 1300$ gas was neutral. The significant energy

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(*) NEOBKHODIMOST' PERIODA NEYTRAL'NOGO VODORODA V EVOLYUTSII VSELENNOY

(**) see Note at the end of the paper

losses by the plasma lead to the necessaity of reworking into helium more than 30% of all the matter in order to sustain for z > 300 a high temperature, and this is in contradiction with the observation data. As to temperature decrease, it leads to contradiction with the observed background emission in the radiowave band.

1. ENERGY LOSSES BY HOT PLASMA. When z > 6, the principal role in cooling of intergalactic gas is played by energy losses of electrons at inverse Compton-effect in relict radiation [5, 6]

$$L_{-} = 4\sigma_0 \frac{kT}{m_e m_p c} \varepsilon_\gamma = 4{,}95\cdot 10^{-12} (1+z)^4 T(z) g \cdot \mathrm{sec} \tag{1}$$

where σ_0 is the Thomson scattering cross-section; ε_γ is the energy density of relict radiation. It is evident that if W is the total possible energy liberation per gram of matter, we have

$$\int L_{-} dt = H_0^{-1} \int_0^{z_{max}} L_{-}(z) \frac{dz}{(1+z)^2 \sqrt{1+\Omega z}} < \overline{W}, \tag{2}$$

where z_{max} characterizes the beginning of heating.

2. RADIOEMISSION OF INTERGALACTIC MEDIUM. The volumetric radiation factor of helium-hydrogen plasma (30% He, 70% H is the chemical composition forecast by the hot model) for free-free transitions is

$$\varepsilon_{ff}(\nu, z) = 6\cdot 10^{-39} g T^{-1/2}(z) e^{-h\nu(1+z)/kT(z)} n_0^2 (1+z)^6 \ \mathrm{erg/cm^3 \cdot sec \cdot ster \cdot hz.} \tag{3}$$

We shall assume the Gaunt factor to be 10: for $h\nu \ll kT$ $g = \frac{\sqrt{3}}{\pi}\left(\ln\frac{4kT}{h\nu} - 0{,}577\right)$.

Since $h\nu \ll kT$, the radioemission spectrum of intergalactic plasma must be plane, which must facilitate its identification:

$$\varepsilon_{ff}(z) = 6\cdot 10^{-48} \Omega^2 T^{-1/2}(z)(1+z)^6 \quad \mathrm{erg/cm^3 \cdot sec \cdot ster \cdot hz} \tag{4}$$

The radioemission flux of intergalactic gas is [7]

$$\int \frac{\varepsilon_{ff}(z)\, dl}{(1+z)^3} = cH_0^{-1} \int_0^{z_{max}} \varepsilon_{ff}(z) \frac{dz}{(1+z)^5 \sqrt{1+\Omega z}} < \frac{2kT_b(\nu)}{\lambda_0^2}, \tag{5}$$

where T_b is the brightness temperature of background emission.

3. DETERMINATION OF z_{max}. We have a system of two functionals:

$$\int_0^{z_{max}} \frac{(1+z)^2}{\sqrt{1+\Omega z}} T(z)\,dz < A, \quad A = 6{,}7\cdot 10^{-7} W; \tag{6}$$

$$\Omega^2 \int_0^{z_{max}} \frac{1+z}{\sqrt{1+\Omega z}} T^{-1/2}(z)\,dz < B, \quad B = 4\cdot 10^3\, T_b(\nu)/\lambda_0^2, \tag{7}$$

which provides the possibility of determining z_{max} for the extreme T(z) (i.e. such that for any other function T(z), z_{max} will be smaller than the that found). The extreme of the functional

$$\int_0^{z_{max}} \left(K\frac{(1+z)^2}{\sqrt{1+\Omega z}} T(z) + \Omega^2 \frac{(1+z)}{\sqrt{1+\Omega z}} T^{-1/2}(z)\right) dz < AK + B, \tag{8}$$

where K is an undetermined Lagrange multiplier, is the function

$$T(z) = (\Omega^2 / 2K(1+z))^{2/3}.$$

It is evident that that the main contribution to integrals (6) and (7) at such a form of function T(z) is made by great z, and this is why

$$\sqrt{1+\Omega z} \approx \Omega^{1/2} z^{1/2}.$$

Resolving the system (6) and (7), we find that the maximum z_{max} is attained at K = B/2A and $T(z) = (A/B)^{2/3}\Omega^{4/3} z^{-2/3}$, while the very $z_{max} = 1{,}39(A^2B^4/\Omega^5)^{1/11}$.

4. HEATING OF GAS. The actual helium content ($\sim$ 30% by mass) in various objects, such as the interstellar medium, most of stars, other galaxies, cosmic rays etc, shows that during intergalacting gas heating the liberation of energy did not exceed $W_1 = 2\cdot 10^{18}$ ergs/g. During the formation of heavy elements ($W < 3\cdot 10^{16}$ ergs/g) the energy liberated can be neglected: their abundance is low ($\sim$ 2% by mass). The gravitational energy, having been liberated during the condensation of galaxies and galactic clusters, provides a contribution of no more than $W = GM/R = 3\cdot 10^{14}$ ergs/g (the radius of the galaxy being $R \sim 1$ kps. and the mass $M = 10^{10}\, M_{\odot}$); the energy liberation of our contemporary powerful objects (quasars, quasi- and radiogalaxies) is possibly of not nuclear origin, but it is insignificant by comparison with the above figures; moreover, the counting of weak radiosources points to the presence of a boundary z ($\sim$ 2 - 4), beyond which there are no sources [8]. Sub-cosmic rays might have appeared only as a result of explosion of various objects, i. e. their energy has already been accounted for.

The hot model Universe forecasts in the matter not having passed through the stellar stage the presence of 28 to 30% of helium [1], i. e. no more than $W_2 = 3\cdot 10^{17}$ ergs/g could have gone to gas heating, which corresponds to reprocessing into helium of $\sim$ 5% of the matter. But if we take into account the contribution to chemical composition of galaxies by stars of first generation and if we recall the efficiency, the estimates of energy expended on intergalactic plasma heating, may be lowered at least to $W_3 = 3\cdot 10^{16}$ erg/g.

5. BACKGROUND IN THE RADIOWAVE BAND. Measurements by Howell and Shakeshaft [9] ($\alpha = 13h.00$ min, $\delta = 52°$) have shown that in the frequency of 610 Mc $T_b(610 = 7.6 \pm 0.8°K$. The results of work [10] give for the same coordinates $T_b(404) = 19.4 \pm 2.0°K$ in the frequency of 404 Mc. Taking into account the relict radiation T_R and the great inclination of the spectrum of galactic and isotropic metagalactic compontnt of the radiobackground T_1 [11], we shall find the upper limit of gas' thermal radioemission T_2:

$$T_1(610) + T_2(610) = T_b(610) - T_R, \quad (9)$$
$$T_1(404) + T_2(404) = T_b(404) - T_R. \quad (10)$$

The spectrum inclination of the galactic and isotropic background of radiosources ($T_1 \sim \nu^{-\alpha}$ in the considered frequency band is $\alpha = 2.7 \pm 0.2$ [11]); for the thermal component $\alpha = 2$. This is why

$$aT_1(610) + bT_2(610) = T_b(404) - T_R, \quad (10')$$

where $a = (610 / 404)^{2.7 \pm 0.2}$ and $b = (610 / 404)^2$

TABLE 1

Ω	W. ergs/g		
	$2\cdot10^{16}$	$3\cdot10^{17}$	$3\cdot10^{18}$
3	160	115	75
1	270	190	125
0,3	465	310	205
0,1	765	540	300 *
0,035	1200	630 *	250 *

* For $\Omega < 0.1$ the plasma emission is small and z_{max} may be found from the condition $z_{max} < 1{,}2\times10^{-1}\Omega^{1/5} W^{2/5}$, which is easy to obtain from (6) by assigning $T = 10^4 °K$ (for lower temperatures hydrogen is neutral).

From (9) and (10') we obtain that $T_2(610) < 1°K$, i. e. that radioemission flux of the intergalactic plasma can not exceed

$$I_\nu = 2kT_2(\nu) / \lambda_0^2 \approx 10^{-19} \text{erg/cm}^2\text{.sec·hz.sterad.}$$

A somewhat rougher estimate can be obtained by comparing the data on measurements of relict radiation in 0.254 and 20.7 cm, and also at analysis of contribution by various sources to the minimum brightness temperature of radiosky in 178 and 404 Mc/sec.

6. RESULTS. Compiled in Table 1 are the values of z_{max} for various Ω and W ($\Omega = 0.035$ corresponds to the observed matter in the galaxies).

Since z of hydrogen recombination does not practically depend on Ω, it follows from the data of Table 1 that the period of neutral hydrogen is required even at maximum possible energy liberation for matter density in the Universe, so long as it is not in contradiction with observations. The energy liberation W could not exceed $3 \cdot 10^{16}$ ergs/g (see section 4), and this is why at $z < 1300$ but > 300, hydrogen was neutral and the formation of various objects began for $z < 300$.

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*** THE END ***

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NOTE : (**) from page 1.

Let us introduce parameters Ω and z: $\Omega = 2q_0 = \rho/\rho_{crit}$ where $\rho_{crit} = 2 \cdot 10^{-29}$ g/cm^3. $n_{crit} = 10^{-5}$ cm^{-3}; at Universe expansion the density varies according to the law $n = n_0(1 + z)^3$; the wavelength $\lambda_0 = \lambda(1 + z)$; the temperature of equilibrium radiation is $T = T_0(1 + z)$; the time from the beginning of expansion is $t \approx t_0(1+z)^{-3/2}$, where $n_0 = \Omega_{crit}$ is the contemporary mean density of matter in the Universe; $T_0 = 3^{\circ}K$ is the temperature of relict radiation; $t_0 \sim H_0^{-1} = 3 \cdot 10^{17}$ sec ($H_0 = 100$ km/sec Mps is the Habble @ constant) and λ_0 is the wavelength of the received emission.

@ the right spelling could not be ascertained