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BUDAPEST

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ABSTRACT

The abundances of ^{4}He and ^{2}H are calculated in terms of the baryon density and neutrino degeneration, under the assumption, that the present dynamical properties of the Universe are determined by neutrinos, as it is suggested by recent measurements. It is shown, that only a limited range of these parameters gives the abundances in agreement with observations. This provides a limit on both ρ_B, the baryon density of the Universe, and ξ, the neutrino degeneration parameter. These limits are

$$2.10^{-31}\ g/cm^3 < \rho_B < 3.10^{-30}\ g/cm^3;\ -0.2 < \xi < 0.05$$

which are in agreement with the observed amount of visible matter, $\rho* = 3.10^{-31}$ g/cm^3, and the value $\xi = 10^{-9}$, expected from SU(5) Grand Unification.

АННОТАЦИЯ

Предполагая, что современные динамические свойства Вселенной определяются нейтрино, как на то указывают недавние эксперименты, мы даем расчет распространенности ^{4}He и ^{2}H в зависимости от плотности барионов ρ_B и параметра вырождения нейтрино ξ. Согласие с данными наблюдений относительно ^{4}He и ^{2}H возможно при

$$2.10^{-31}\ г/см^3 < \rho_B < 3.10^{-30}\ г/см^3;\ -0.2 < \xi < 0.05$$

Пределы плотности не противоречат данным о распределении видимой материи, а ограничения величины ξ согласуются с теорией SU(5) /"Великое Объединение/.

KIVONAT

Kiszámitottuk a nukleoszintézis során keletkező ^{4}He és ^{2}H mennyiségét az Univerzum barion-sürüsége és neutrino-aszimmetriája függvényében, feltételezve, hogy az Univerzum tágulásának dinamikai jellemzőit a neutrinók határozzák meg. A fenti paramétereknek csupán egy szük tartománya szolgáltat helyes eredményt. Ez korlátokat ad az Univerzum barionsürüségére és neutrino--aszimmetriájára.

$$2.10^{-31}\ g/cm^3 < \rho_B < 3.10^{-30}\ g/cm^3;\ -0.2 < \xi < 0.05$$

Ezek az értékek összhangban vannak a látható anyag megfigyelt mennyiségével, és az SU(5) egyesitett térelméletekből várható 10^{-9}-es aszimmetriával.

As it was noted by Stecker[1], there seem to be some basic inconsistencies between the abundances produced in the early nucleosynthesis, and the dynamics of the Universe. The recent measurement of neutrino rest masses by Lyubimov et al.[2]gives 16 eV$<$ m_ν $<$45 eV. This discovery has serious cosmological implications, as it has been already noted by several authors.[3].

This mass range for the neutrinos suggests, that the mass density of the Universe today is entirely dominated by the neutrinos, so all dynamical properties(H_o, q_o, t_o) depend essentially on the neutrino masses.

In this case these dynamical parameters contain no information about the baryon density, and they do not give any constraints on it, either. There remains one epoch in the history of the Universe, when the baryon density had an important role: the early nucleosynthesis.

In the early nucleosynthesis all the produced abundances depend on the following parameters:

i/ baryon number density
ii/ expansion rate of the Universe
iii/ ν - degeneracy.

Other effects, like small changes in reaction cross-sections, or modification of the neutron lifetime also effect the calculations, but the three parameters above are the least known ones.

We assumed six neutrino degrees of freedom $(\nu_{eL}, \bar{\nu}_{eR}, \nu_{\mu L}, \bar{\nu}_{\mu R}, \nu_{\tau L}, \bar{\nu}_{\tau R})$ The possible effects of having also the opposite helicity states filled up are discussed later.

Due to the experiment of Reines et al[4], we assume, that neutrino oscillations do exist, and for symmetry reasons among all three types of neutrinos, so the degeneracy parameter $\xi = \frac{\mu}{kT}$ is equal for all neutrinos. The ξ_μ and ξ_τ effect only the expansion rate, of course[5], so deviations from this symmetry cause only a different expansion rate.

The effect of the existence of the τ neutrino, as compared with earlier calculations is just cancelled by the new value for the neutron lifetime $t_{1/2}$ = 10.1$\div$10.8 min.[8]

The calculations in this paper are the same as Wagoner, Fowler and Hoyle[6], Wagoner[7], who considered all cases: they calculated the dependence of the abundances in terms of the baryon density, and in terms of $\xi = \xi_\mu = \xi_\tau$, respectively. Schramm and Wagoner[9]used the X(^{2}H) abundances to give limits on ρ_B .
Here the philosophy is different: for a given expansion rate the

allowed regions for the possible ^4He and ^2H abundances are calculated in terms of ϱ_B and ξ . It is shown, that these limits are not very sensitive on the expansion rate.

A series expansion of log $X(^4He)$ and log $X(^2H)$ was made, using [6] and [7] around the point $\xi = 0$ and $h_o = 10^{-4}$, where h_o is the Wagoner parameter. ($\varrho_B = 1.97 \times 10^{-26} \times h_o$ g/cm^3, assuming $T_\gamma = 2.7^oK$.)

The expansions were made up to second order, in the variables ξ , and $\Delta = \log (h_o/10^{-4})$, but the effects of the second order terms were negligible in the interesting region. All abundances were normalized to the values at $\xi = 0$, $\Delta = 0$, taken from [7].

$$X(^4He)_{o,o} = 0.246$$

$$X(^2H)_{o,o} = 1.3 \times 10^{-5}$$

The expanded functions were

$$y = \log \frac{X(^4He)_{\xi,\Delta}}{0.246} \quad \text{and} \quad d = \log \frac{X(^2H)_{\xi,\Delta}}{1.3 \times 10^{-5}}$$

The shape of y is simple

$$y = 0.0344\Delta \quad - 0.560\xi \quad - 0.110\,\xi^2$$

$$d_\xi = \begin{cases} -0.842\xi - 0.099\,\xi^2 & \text{, if } \xi < 0 \\ 0 & \text{if } \xi > 0 \end{cases}$$

$$d_\Delta = \begin{cases} -0.716\,\Delta & \text{if } \Delta < 0 \\ -0.764\,\Delta \quad - 1.11\Delta^2 & \text{if } \Delta > 0 \end{cases}$$

We will plot the iso-abundance curves in the (ξ,Δ) plane corresponding to reasonable lower and upper limits of the abundances.

The value of $X(^2H) = 2.5 \times 10^{-5} \times (1 \pm 0.25)$ of Rogerson and York [10] has been used as an approximate value.

$$0.23 < X(^4He) < 0.29 \qquad 1.0 \times 10^{-5} < X(^2H) < 5.0 \times 10^{-5}$$

$$y_1 = \log \frac{0.23}{0.246} = -0.03 \qquad d_1 = \log \frac{1.0 \times 10^{-5}}{1.3 \times 10^{-5}} = -0.11$$

$$y_2 = \log \frac{0.29}{0.246} = 0.07 \qquad d_2 = \log \frac{5.0 \times 10^{-5}}{1.3 \times 10^{-5}} = 0.59$$

The results are shown on Fig 1. It can be well seen, that only a limited range of the (ξ, Δ) values is allowed.

$$-0.2 < \xi < 0.05$$

$$2 \times 10^{-31}\ g/cm^3 < \varrho_B < 3 \times 10^{-30}\ g/cm^3$$

$$10^{-9.5} < \frac{n_B}{n_\gamma} < 10^{-8.3}$$

If right handed neutrinos exist, their decoupling occured at much higher temperatures, when still many particles were present. The annihilation of these particles is causing a much smaller number density for the right handed neutrinos, compared with the left handed ones. However, all such effects e.g. new neutrino flavors are increasing the expansion rate, so in order to see the sensitivity of our results, we increase the expansion rate by a factor of 2, as in [9], corresponding to a 4-fold increase in ϱ.

In this case for the same ξ and Δ, more helium is produced, so for a fixed ξ we need a smaller Δ to obtain the same amount. The helium-isoabundance curves are shifted towards smaller baryon densities with $\Delta_{He} = -1.64$. The deuterium abundance is also increased with the larger expansion rate, but it requires a larger ϱ_B to produce the same abundance, so the shift in Δ is positive: $\Delta_{^2H} = 0.68$.

This is causing a minor change in the limits on the chemical potential, and somewhat larger one for the baryonic density, as seen on Fig 2.

$$-0.05 < \xi < 0.22$$

$$1.2 \times 10^{-30}\ g/cm^3 < \varrho_B < 1.6 \times 10^{-29}\ g/cm^3$$

$$10^{-8.6} < \frac{n_B}{n_\gamma} < 10^{-7.6}$$

Using the conservative $\xi = 0$ assumption and the standard expansion rate the limits on ς_B are rather strong, coming from the deuterium abundance, in agreement with previous calculations /6,7/ and observation of luminous matter. This calculation gives another hint, that baryonic matter cannot be responsible for the deceleration of the Universe, but some other mechanism, possibly massive neutrinos may provide the answer.

The limits on the degeneracy of neutrinos are important in this respect as well, since degeneracy would increase the total number density of the neutrinos. The best observational limit on neutrino degeneracy was given by Cowsik, Pal and Tandon /11/ to be $\mu < 2$eV, corresponding to $\xi < 11000$. Weinberg /12/ considered zero rest mass neutrinos. From limits on the total energy density of the Universe he concluded $\xi < 46$. Baudet and Yahil, using the ^{4}He abundance gave the limits

$$-0.25 < \xi < 1.8$$

Our conclusion is that for any reasonable value of the expansion rate using conservative upper and lower bounds on the abundances of ^{4}He and ^{2}H a new limit on the neutrino degeneracy parameter can be obtained, giving

$$|\xi| < 0.2$$

It should be pointed out, that any further measurement leading to better experimental values on $X/^4$He/ and $X/^2$H/ of cosmological origin, or on the baryon density of the Universe can help to reduce these limits. All three free parameters $/n_B/n_\gamma/$, ς_B, expansion rate/ are essentially determined by the GUT of elementary particles. The limits obtained can be used to reduce the number of possible GUT schemes and parameters. The limits on ξ are in good agreement with the SU/5/ expectations $\xi \sim 10^{-9}$.

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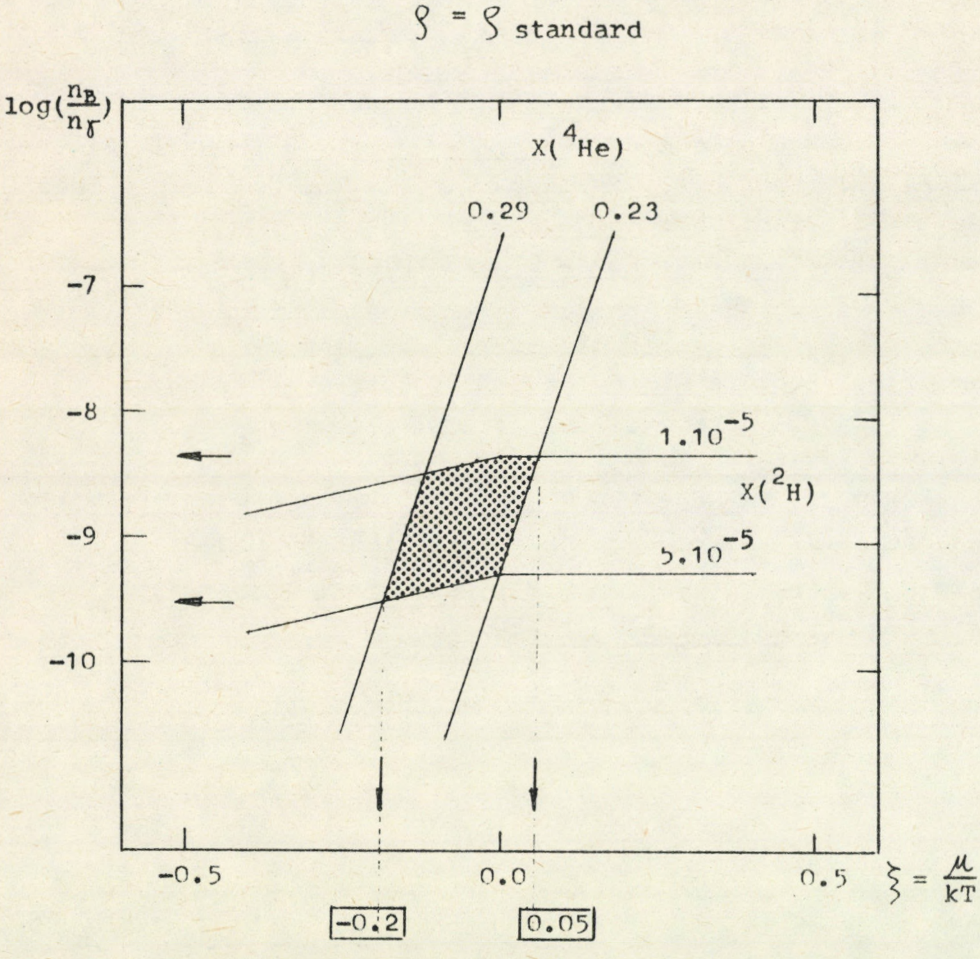

Fig 1. The dependence of $X(^4He)$ and $X(^2H)$ on $\log \frac{n_B}{n_\gamma}$ and ξ, the neutrino degeneracy parameter, in case of $\varrho = \varrho$ standard

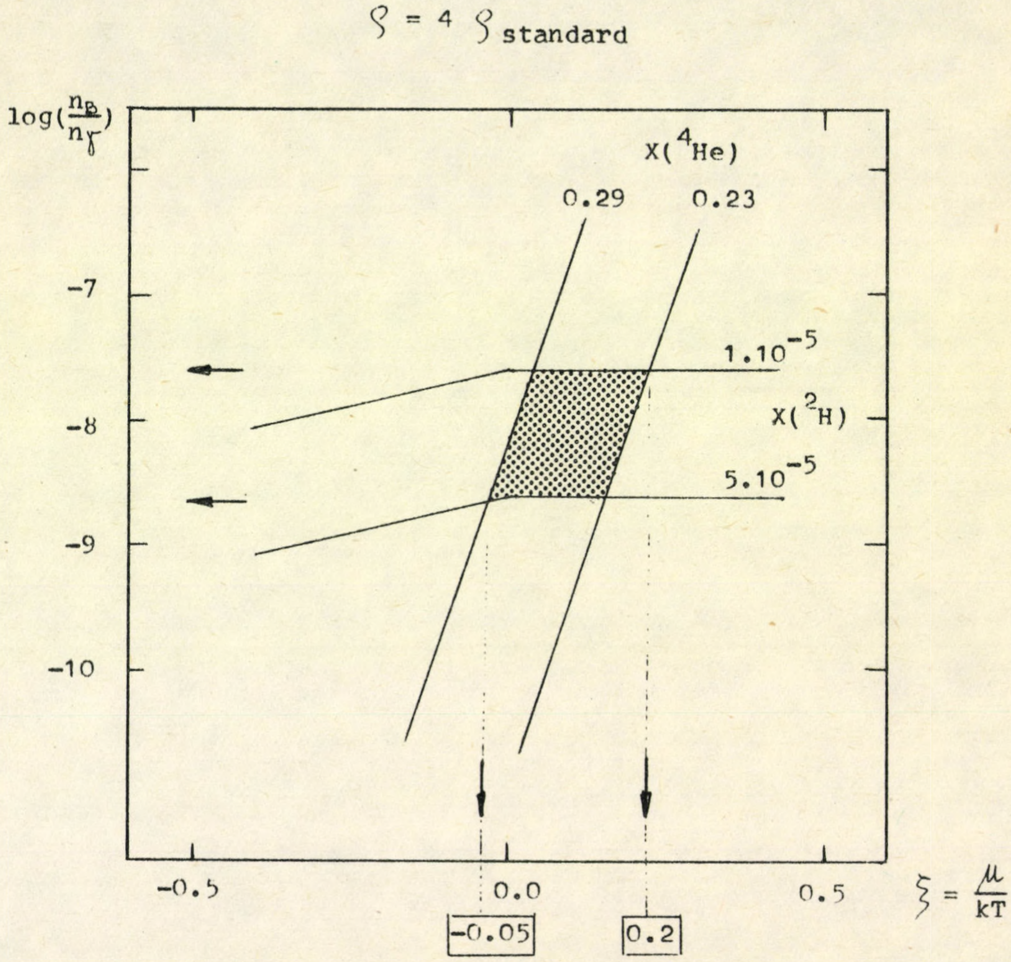

Fig 2. The dependence of $X(^4He)$ and $X(^2H)$ on $\log \frac{n_B}{n_\gamma}$ and ξ, the neutrino degeneracy parameter, in case of $\varrho = 4\ \varrho$ standard

63.035

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