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CBPF-NF-025/80

PRIMORDIAL NUCLEOSYNTHESIS AND THE COSMICAL DEPENDENCE OF WEAK INTERACTION

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ABSTRACT: Primordial Nucleosynthesis is investigated in order to set limits on the possible cosmical dependence of weak interaction.

In a recent paper, Stecker[1] has argued that astronomical observations sets an upper limit on the helium abundance in the Universe wich seems in disagreement with the standard model based on Friedmann (Big Bang) geometry plus the V-A theory of weak process. In order to quote with this result we have to face either a modification on the cosmological metric (e.g, introducing an anisotropic era in the history of our universe) or in the basic properties of the weak interactions.

We favour, in this paper, a modification of the weak process, due to the expansion of the Universe. The idea goes back to some years ago, when Novello and Rotelli[2] proposed a model in which the cosmological dependence of weak process should be manifested through a time dependence weighting of the axial vector current relative to the vector current. The weak current thus modified takes the form

$$J^{\mu} = \bar{\psi}\gamma^{\mu}\left[1+\varepsilon(t)\gamma^{5}\right]\psi$$

in which, due to the homogeneity of the standard cosmological model, the function ε depends only on the global time t.

The idea that interactions in nature change with the cosmological expansion stems, in the recent tradition , from Dirac's 1937 paper[3] on the dependence of the gravitational constant with time.

Recently, Canuto et al[4] have investigated the observational aspects of such dependence, throwing a new light on such a hypothesis.

In the case of weak interaction, however, we face a different situation because, unlike the gravitational force, here there is room for two possible distinct cosmological dependence. We follow the 1972 Novello-Rotelli proposal and assume that the weak coupling does not change (g_F = constant) but that the parity violating term is time dependent.

The purpose of the present letter is to try to restrict the possible range of dependende of the value of $\varepsilon(t)$. Such limits can be obtained by an examination on the effects of a non-constant ε in the evaluation of the abundance of low elements (essentially Helium and Deuterium) originated from primordial nucleosynthesis.[5]

After the almost chaotic era in which the temperature of the Universe was too high ($T>10^{10}$ °k) it suceeds an epoch of thermal equilibrium between nucleons (neutrons, protons). After the temperature drops to about $1.3\mathrm{x}10^9$ °k the ratio of neutron to proton abundance depends almost uniquely on the decay process $n \rightarrow p\ e\ \bar{\nu}_e$. The effect of a non-trivial ε(e.g., $\varepsilon \neq 1$) is to modify the time scale of the neutron decay by a factor which is essencially given by

$$\frac{\tilde{\lambda}}{\lambda} = \frac{1 + 3(1.25)^2\ \varepsilon^2}{1 + 3(1.25)^2} \simeq 0.176 + 0.824\ \varepsilon^2$$

in which λ is the transition rate of the process, and we have used the standard value[6] 1.25 for the laboratory measurement of the ratio $\frac{g_a}{g_v}$.

If nucleosynthesis start at the temperature $T_0 = 0.9 \times 10^9\ {}^0k$ (corresponding to a period of time from the Big-Bang given by $t_0 = 226sec$), then the abundance of Helium which equals the double of the value of the neutron abundance at the beginning of nucleosynthesis, can be evaluated at any time t, by the expression (see, for instance , Peebles[7])

$$(1) \qquad Y_{He}\ (t) = 2\ X_n\ (t) = 0.164 \exp\ (-\frac{t}{917})$$

The value 917 is obtained from the decay of the neutron through the weak process $n \to p\ e\ \bar{\nu}_e$.

In order to proceed we have to assume a model for the time dependence of the weak current. At the early times , near the cosmical singularities, it seems reasonable to consider a power low dependence of the ε - function with time , by setting

$$\varepsilon(t) = \left(\frac{t}{t_0}\right)^\alpha = \left(\frac{3}{T}\right)^\alpha$$

in which we have normalized ε to its present value (t_0 = age of the Universe and T = temperature corresponding to the cosmological time t_0).

Thus, the abundance of neutron just before nucleosynthesis, instead of expression (1) is given by

$$X_n\ (t{=}226sec) = 0.157 \exp -\left[0.203 \times (2.28)^\alpha \times 10^{46\alpha}\right]$$

or, in case nucleosynthesis start at t = 146sec:

$$X_n(t = 146\text{sec}) = 0.157 \exp - \left[0.312 \times (0.96)^{\alpha} \times 10^{46\alpha}\right]$$

In table I we give some values of the helium abundance by weight for different values of the constant α.

Value of $\alpha \times 10^{-3}$	Helium abundance (% by weight) for $t_c = 226$ sec	Helium abundance (% by weight) for $t_c = 146$ sec
3	23.8	——
4	23.0	26.0
5	22.2	25.6
6	21.4	24.8
7	20.4	24.2
8	——	23.4
9	——	22.8

Table I - Helium abundance by weight for the case nucleo - synthesis start at temperature 0.9×10^9 ^{0}k (t = 216sec) or at 1.1×10^9 ^{0}k (t = 146sec)

What information can we extract from these tables? First of all, we see that the best value of α compatible with the maximum value issued from recent estimatives of the Helium abundance in the Universe sets $\alpha > 8\times10^{-3}$ (for $t_c = 146$sec). Such a small value precludes the possibility of a laboratory direct measure of the time variation of weak process. Indeed, the ratio of the mean life time of the neutron, for instance, to the present cosmological age is roughly 10^{-18}. Thus, any local variation of the weak decay should be almost completely undetectable.

We remark that Helium abundance is very sensitive to the value of α. Indeed, a small value, let us say $\alpha < 2\times10^{-3}$ enlarges the rate of transition of the neutron , allowing fewer neutrons to be converted into proton until the start of nucleosynthesis, making thus more neutrons to be available and so increasing almost drastically the abundance of Helium[8].

If we accept the value $Y_{He} \approx 23.0$ for the Helium abundance, we conclude that $\alpha \simeq 4 \times 10^{-3}$ or twice this value depending on t_c (see table I). In the other way round, such small variation of the weak interaction can explain the low value of the Helium abundance in a standard homogeneous and isotropic Universe.

Although our present arguments are not conclusive it allows the dependence of maximal parity violating process on the expansion rate of the Universe, to be contemplated in a quantitative manner. In the same vein , others effects could be analysed, for instance, the possible variation of the luminosity of stars which are born in different cosmical times[9] This seems to us to transform the speculation of a global time dependence of weak interaction in a model which can be submitted to observational tests.

ACKNOWLEDGEMENTS - One of us (MN) would like to thank Dr V. Canuto for some interesting discussions.

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