JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
29: S15 ~ S16, 1996

ELECTRON-NEUTRINO DEGENERACY AND PRIMORDIAL NUCLEOSYNTHESIS

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ABSTRACT

We discuss the possible ranges of electron neutrino degeneracy which is consistent with the inferred primordial abundances of the light elements. It is found that the electron neutrino degeneracy, $|\xi_e|$, up to order of 10^{-1} is consistent with the present data.

Key Words : cosmology, nucleosynthesis, neutrino

The big bang nucleosynthesis(BBN) has been considered as one of the important cosmological processes which provides the valuable limits on the number of cosmological and particle physics parameters, for example, the number of species of light neutrinos, and the baryon number density of our Universe.

However, given the uncertainties of the inferred abundances, the possibility of variations from the standard BBN(SBBN) has been studied in various contexts(Maleney93). Moreover, recent measurements of deuterium (Rugers95, Tytler96) abundance, new estimations of ^4He (Izotov96) together with the recent statistical assesment of the SBBN(Hata95, Copi95) encourage the detailed study of the possible variations. In SBBN the neutrinos are assumed to be very simple object although only little of neutrino properties are known. For example, mass, magnetic moment, oscillation, and neutrino degeneracy are among them , which should be studied in deatil to see how the BBN constraints them and how those properties affect the primordial nucleosynthesis.

The concordance between the predictions and the observations of the light element abundances seems to be remarkable with $\eta \sim 3$, which lead to the nonbaryonic-matter dominated Universe. By introducing the neutrino degeneracy it is possible to reduce nonbaryonic matter considerably(Kang92) since it allows more baryonic matter which participate into nucleosynthesis. It is also suggested(Kim95) that if primordial abundance of ^{11}B can be measured it might be a possible test, since it depends quite sensitively on the baryon number density.

In this work, we estimate the possible ranges of electron neutrino degenercay using the sets of recently observed(inferred) abundance data of light elements .

The evolution of the Universe is described by the expansion rate H, $H^2 = \frac{8\pi}{3}G\rho_{rad}$,where G is the gravitational constant. ρ_{rad} is the energy density of the light particles which includes the contribution from the possible nonzero neutrino degeneracies. While the contribution of neutrino degeneracy($\xi_e = \mu_\nu/T$ for the degenarate neutrino with chemical potential μ_ν) speeds up the expansion rate of the Universe, the degeneracy of electron neutrino, ξ_e also affects the weak interaction rates, which together with the expansion rate determine the weak interaction freezing temperature, T_f, and it controles the neutron to proton ratio at the beginning of nucleosynthesis. The effects of muon- and tau- neutrino degeneracy are only on the expansion rate which can be possibly accommodated by modifying the gravitational constant G(Kim95). In this work, we take G as the present observed value of gravitational constant and assume no degeneracy of muon- and tau-neutrinos to see more transparently the role of the electron neutrino degeneracy. The three light neutrinos are considered to be effectively massless during the nuclear synthesis and no neutrino oscillation is assumed.

Using the extended reaction network(Kim95) with neutron mean life time taken to be 887.0±2.0 sec, we calculate the abundances as a function of ξ_e and the baryon to photon ratio η to find out the possible ranges which are consistent with the inferred abundances of light elements.

For deuterium abundance, we take both high and low values from QSO observations. The low abundance of deuterium, $[D/H] = (1.7 - 3.5) \times 10^{-5}$ which is similar to the ISM value , has been estimated by (Tytler96), while higher abundance, $[D/H] = (1.5 - 2.3) \times 10^{-4}$by (Rugers95). We use $0.226 \leq Y_p \leq 0.242$ for ^4He and for ^7Li, $0.7 \leq [^7Li/H] \times 10^{-10} \leq 3.8$(Olive95).
The allowed regions for ξ_e and η are serched in ξ_e - η plane which are consistent with these data.

With low value of $[D/H]$, the case is similar to the anaysis which leads to the recent 'crisis' (Hata95) where the possible variations of SBBN , for example , smaller number of of light neutrino species, nuetrino degeneracy or underestimation of ^4He abundance have been suggested. By allowing the neutrino asymmetry , we can have good fits to the inferred abundances. The allowed ranges for ξ_e and η are $-0.01 \leq \xi_e \leq 0.08$ and $4 \leq \eta \leq 6$, respectively . Replacing the deuterium abundance with higher value , the permitted range for the η becomes smaller $1.4 \leq \eta \leq 2.0$. The permitted range for positive electron neutrino degeneracy is very limited because the adopted deuterium abundance prefer the lower ^4He abundance. The permitted range is found to be $-0.07 \leq \xi_e \leq 0.02$. In connection with the two distinct deutrerium abundance estimations, it is observed that the positive electron neutrino degeneracy is preferred for lower value of deuterium abundance while the larger range of negative ξ_e is possible for the higher deuterium abundance.

If we adopt the high abundance of ^4He by Izotov et al.(Izotov96), $0.240 \leq Y_p \leq 0.246$ up to 1-σ statistical error, the permitted ranges of ξ_e and η are changed only slightly. For example, we can observe the permitted range of ξ_e is a little bit enlarged in negative direction, up to -0.09.

¿From this analysis, we can observe that the nonvanishing electron neutrino degeneracy is allowed up to $|\xi_e| \sim 0.1$. It is interesting to note that this value is not inconsistent with the recently proposed limit from the neutrino oscillation consideration(Foot95) and the large scale stucture analysis(Madsen95).

For the case of low value of D/H, we can see that the permitted ranges of η with nonvanishing ξ_e are higher than SBBN case. Then the observation of the heavier elements ^9Be and ^{11}B might be a good test(Kim95) of nonvanishing electron neutrino degeneracy aginst SBBN, since they are very sensitive on η in the range of our interest. However if the estimation by Izotov et al.(Izotov96) can be adopted then there is essentially no differences in the permitted ranges of η and the abundances of ^9Be and ^{11}B,it might not be a best way of testing the neutrino degeneracy. Also for the larger deuterium abundances the permitted range of η is not sensitive to the neutrino degeneracy. However, since ^9Be and ^{11}B are sensitive on η in the range of our interst, the measurements of those abundances themselves are still needed in connection with the current issues in deuterium abundances which is also very sensitive on η.

In summary, while the issue whether the implication of the nonvanishing electron neutrino degeneracy can be quite different from SBBN so as to be tested, for example in the primordial abundances of heavier element like ^9Be and ^{11}B, needs more observational data and more detailed analysis of the data, we observe that the nonvanishing electron degeneracy, up to $|\xi_e| \sim 0.1$, can be a possible variation of SBBN.

ACKNOWLEDGEMENTS

HKL thanks Institute of Nuclear Theory at the University of Washington for its hospitality where a part of this work is done while he is participating INT 96-2 workshop. He also thanks George Fuller and Gary Steigman for useful discussions. This work was supported by the Ministry of Education(BSRI-95-2441) and in part by the Korean Science and Engineering Foundation and also in part by the Hanyang University Research Grant(1996).

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