Big bang nucleosynthesis with new data of the neutron lifetime

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Recent astronomical observations provide a unique opportunity to test cosmological theories with high precision. Measurements of the anisotropies of the cosmic microwave background (CMB) radiation such as the *WMAP* observation determined the primordial baryon-to-photon ratio η_{10} in units of 10^{-10} to be 6.13±0.25 [1]. η_{10} can be independently determined from the theory of the big bang nucleosynthesis (BBN) with use of the abundance data of primordial light elements. However, it has been claimed that there is no region of η_{10} which gives simultaneous agreements with the recent observations on ^{4}He, D, ^{3}He and ^{7}Li, and a compromise value of η_{10} is critically smaller than the value from the CMB observations [2]. One of the possible source of this discrepancy might be inaccuracy in the nuclear data used in the BBN calculations. Recently a new experimental value of the lifetime of the neutron β-decay has been reported by the PNPI-ILL collaboration [3]. They used the storage method of ultra-cold neutron (UCN), and obtained the most precise lifetime of 878.5±0.7(stat)±0.3(syst) sec, which is significantly shorter than the previous world average 885.7±0.8 sec [4]. This new value is important because it meets the unitarity condition of the Cabbibo-Kobayashi-Maskawa matrix, and also it may affect the primordial nucleosynthetic yields of light elements. To study the influence of the neutron lifetime τ_n on BBN, we made a new evaluation of τ_n using the above new value in addition to the data set used for the previous world average. In order to take account of the inconsistency among those data, we employed a chi-squared minimization method instead of a simple weighted-mean method used in Ref. [4]. The present evaluation gives τ_n =881.9±1.6 sec, to be compared with a weighted-mean value τ_n =881.9±0.6 sec. The effect of the new neutron lifetime was studied based on the standard homogeneous BBN. As shown in Fig. 1, concordance between ^{4}He and D is realized with the new value of τ_n = 878.5±0.7±0.3 sec [3]. This is because a shorter lifetime corresponds to a smaller coupling constant of the weak interaction, and that leads to the reduction of the primordial ^{4}He production by shifting the equilibrium between proton and neutron to the proton-dominant side. In Table 1 the allowed regions of η_{10} in BBN with evaluated values τ_n are compared with the *WMAP* result.

In summary, the standard homogeneous BBN calculation with new data of the neutron lifetime predicts primordial abundances of ^{4}He and D consistently, and the determined value of the baryon-to-photon ratio is consistent with the one from the CMB observations within experimental uncertainties. As for the abundance of ^{7}Li, further studies about possible ^{7}Li destructions either in BBN or stellar evolutions.

Table 1: Allowed regions of η_{10} from BBN vs neutron lifetime τ_n.

τ_n [sec]	η_{10}
885.7±0.8 (previous world average [4])	4.8±0.8
878.5±0.7±0.3 (PNPI-ILL [3])	5.5±0.9
881.9±1.6 (present work)	5.1±1.1
WMAP [1]	6.13±0.25

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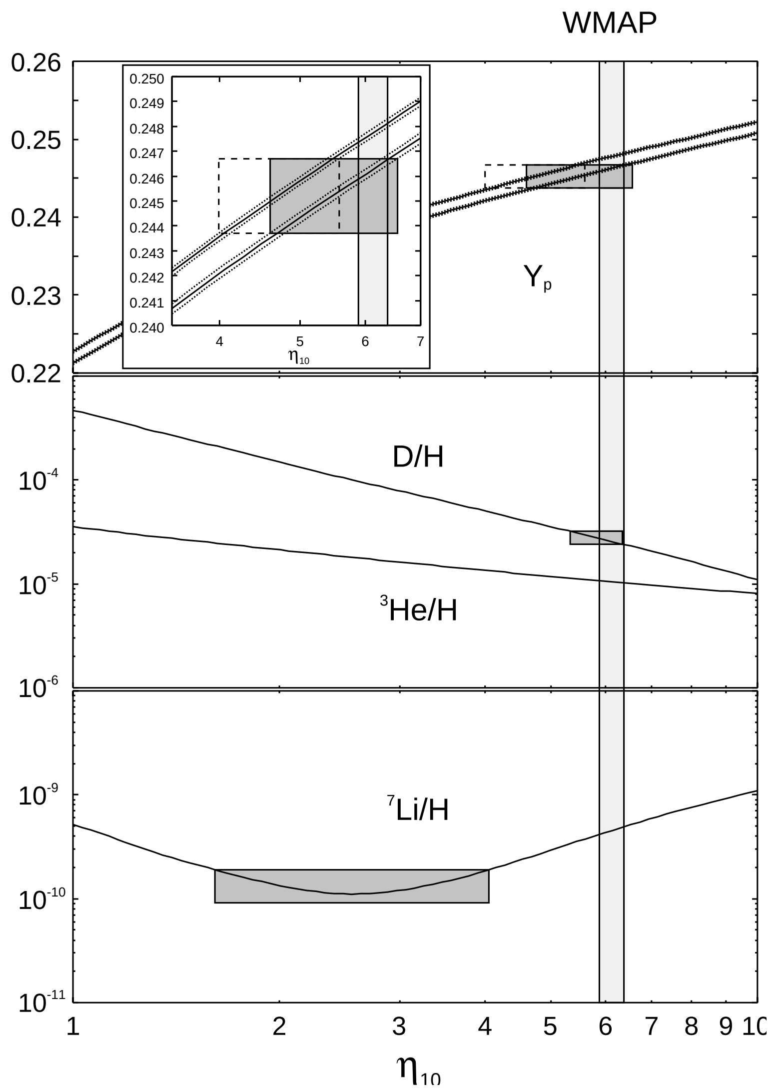

Figure 1: Predicted BBN light element abundances vs the baryon-to-photon ratio η_{10} in units of 10^{-10}. These are compared with the observationally inferred primordial abundances (horizontal lines) and the independent determination of η_{10} from the *WMAP* result (light shaded region). The top box shows the primordial helium abundances Y_p. The inset shows an expanded view of Y_p near the allowed region. The banded regions indicate the range of predicted Y_p due to the uncertainty of τ_n. The upper lines are based upon the previous world average $\tau_n = 885.7 \pm 0.8$ sec. The lower lines are based upon the new measured value of $\tau_n = 878.5 \pm$ 0.8 sec. The previously allowed region of η_{10} (dashed open box) shifts to the dark shaded box if the new neutron lifetime is adopted.