New results on catalyzed BBN with a long-lived negatively-charged massive particle

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It has been proposed that the apparent discrepancies between the inferred primordial abundances of ^{6}Li and ^{7}Li and the predictions of big bang nucleosynthesis (BBN) can be resolved by the existence of a negatively-charged massive unstable supersymmetric particle (X^-) during the BBN epoch. Here, we present new BBN calculations with an X^- particle utilizing an improved nuclear reaction network including captures of nuclei by the particle, nuclear reactions and β-decays of normal nuclei and nuclei bound to the X^- particles (X-nuclei), and new reaction rates derived from recent rigorous quantum many-body dynamical calculations. We find that this is still a viable model to explain the observed ^{6}Li and ^{7}Li abundances. However, contrary to previous results, neutral X-nuclei cannot significantly affect the BBN light-element abundances. We also show that with the new rates the production of heavier nuclei is suppressed and there is no signature on abundances of nuclei heavier than Be in the X^--particle catalyzed BBN model as has been previously proposed. We also consider the version of this model whereby the X^- particle decays into the present cold dark matter. We analyze the this paradigm in light of the recent constraints on the dark-matter mass deduced from the possible detected events in the CDMS-II experiment. We conclude that based upon the inferred range for the dark-matter mass, only X^- decay via the weak interaction can achieve the desired ^{7}Li destruction while also reproducing the observed ^{6}Li abundance.

The nucleosynthesis of light elements in the big bang is a unique probe of new physics which may have occurred during the first few minutes of cosmic expansion in the big bang. Of particular interest in this work is the apparent discrepancy between the inferred primordial abundances of ^{6}Li and ^{7}Li and the predictions of standard BBN. A popular model to resolve this discrepancy is the existence of an unstable negatively charged supersymmetric particle during the nucleosynthesis epoch [1–13]. Depending upon their abundance and lifetime [7], such particles can catalyze the nuclear reactions leading to enhanced ^{6}Li [1] and depleted ^{7}Li [5, 6] as required by observations. Here we present new calculations based upon a substantially improved nuclear reaction network for this X^--catalyzed BBN. We solve numerically the nonequilibrium nuclear and chemical reaction network associated to the X^- particle [7] with improved reaction rates derived from recent rigorous quantum many-body dynamical calculations [9]. We show that both the ^{6}Li and ^{7}Li problems can still be solved. However, contrary to earlier speculation [10], there is no signature in the primordial abundances of heavier nuclides produced by this mechanism.

Also in this work we examine the version of this model in which the X^- particles decay into the present dark matter. In such models the allowed lifetimes and abundances can be sensitive to the mass of the dark-matter particle. In this regard the recent results of the Cryogenic Dark Matter Search experiment (CDMS II) are of interest. Possible detected events imply an upper limit on the elastic scattering spin-independent cross section between the weakly interacting massive particle (WIMP) and the nucleon [14]. Based upon this, they have identified an allowed parameter region of the WIMP mass of 40 GeV $< m_{\rm DM} <$ 200 GeV which is consistent with both the CDMS II experiment and the DAMA/LIBRA data. We discuss the implication of this mass constraint and show that the ^{7}Li problem can still be resolved together with the ^{6}Li abundance, but only if the negatively charged particles decay into a lighter dark-matter particle via a weak charged boson exchange.

The primordial lithium abundances can be inferred from measurements of absorption line profiles in metal-poor stars (MPSs). These stars exhibit roughly constant values of the abundance ratio, ^{7}Li/H, as a function of metallicity [15–21] implying a primordial abundance of ^{7}Li/H$= (1-2)\times 10^{-10}$. The standard BBN model, however, predicts a value that is a factor of $2-4$ higher (e.g., ^{7}Li/H$=(5.24^{+0.71}_{-0.67})\times 10^{-10}$ [22]) when one uses the baryon-to-photon ratio determined from an analysis [23] of data from the Wilkinson Microwave Anisotropy Probe (WMAP) of the cosmic microwave background (CMB) radiation. This discrepancy requires a mechanism to reduce the ^{7}Li abundance inferred from BBN. The combination of atomic and turbulent diffusion [24, 25] might have reduced the ^{7}Li abundance in stellar atmospheres, but this possibility has not yet been established [26].

An even more intriguing result concerns the ^{6}Li/^{7}Li

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