Big-Bang Lithium Problem, and Effects of Long-Lived Negatively Charged Massive Particles on Primordial Nucleosynthesis

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We reviewed the big bang nucleosynthesis (BBN) model including a long-lived negatively charged massive particle, i.e., X^- [1]. The mass of the X^-, m_X, is assumed to be much larger than the nucleon mass. This model provides a reason why observed ^{7}Li abundances of metal-poor stars are smaller than that predicted in the standard BBN (SBBN) model [2]. Since the primordial ^{9}Be abundance can be larger than that of the SBBN model, the existence of the X^- particle can be tested by future observations of ^{9}Be in metal-poor stars [3].

The ^{7}Be nuclei are destroyed via a recombination with the X^- followed by a radiative proton capture, i.e., ^{7}Be(X^-, γ)^{7}Be$_X$(p, γ)^{8}B$_X$ [2]. Since the primordial ^{7}Li nuclei predominantly originate from ^{7}Be nuclei produced during BBN, this ^{7}Be destruction reduces the primordial ^{7}Li abundance. Rates for recombination of ^{7}Be and X^- were calculated accurately, and the dominant transition is the d-wave → 2P for $m_X \gtrsim 100$ GeV [3].

Figure 1 shows the energy level diagram of ^{7}Be$_X$ for $m_X = 1$ TeV [1]. Red and blue arrows show the three important transitions in the nonresonant recombination reaction, while purple and green arrows show decays of the two main resonances into bound states of ^{7}Be$^*_X$ (of the nuclear excited state) in the resonant reaction.

Based on the detailed reaction network calculations of BBN, the most realistic constraints on the X^- particle were derived [3]. Parameter regions for the solution to the ^{7}Li problem were identified: the X^- to baryon ratio is $Y_X \gtrsim 0.04$ and the lifetime is $\tau_X \sim (0.6\text{–}3) \times 10^3$ s. Using this result, possible candidates of X^- particle are considered [1]. One candidate is a slepton, i.e., a supersymmetric partner of lepton, and the other is a Kaluza-Klein (KK) leptons, i.e., excited states of leptons realized in extra-dimensional models [4]. We focus on the situation that the slepton can only decay into the gravitino, and the KK leptons can only decay into the KK graviton.

The thermal relic abundance of the long-lived stau [5] can be consistent with the parameter region for the ^{7}Li reduction if the stau mass is $\mathcal{O}(1)$ TeV. In addition, the lifetime of the sleptons [4] can be close to $\sim 10^3$ s if the masses of sleptons and the gravitino are of order TeV.

The slepton decay induces nonthermal nucleosynthesis and gravitino production. Constraints from electromagnetic energy injection at the decay and the gravitino energy density [5] lead to a very narrow parameter region. This region for the ^{7}Li problem is available for a selectron and a smuon. However, the stau has a certain hadronic branching ratio at the decay [4]. Hadronic energy injection is heavily constrained [6], and the interesting parameter region is excluded in the stau scenario.

Similarly, a solution to the Li problem exists for the cases of KK electron and muon, while it does not exists for the case of the KK tau [1].

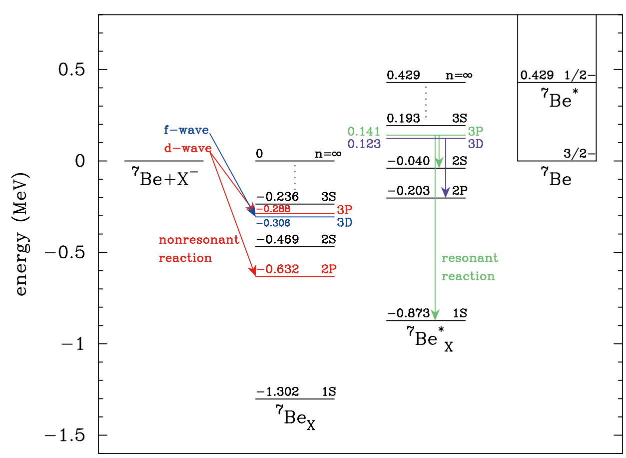

Figure 1: The energy level diagram of the exotic atom ^{7}Be$_X$ for m_X= 1 TeV [1]. Red and blue arrows show the three important transitions in the nonresonant recombination reaction. Purple and green arrows show decays of the two main resonances into atomic bound states of ^{7}Be$^*_X$ (of the nuclear excited state ^{7}Be*) in the resonant reaction.

References

[1] Kusakabe, M., et al.: 2017, *Int. J. Mod. Phys. E*, **26**, 1741004.
[2] Bird, C., et al.: 2008, *Phys. Rev. D*, **78**, 083010.
[3] Kusakabe, M., et al.: 2014, *ApJS*, **214**, 5.
[4] Feng, J. L., et al.: 2003, *Phys. Rev. D*, **68**, 063504.
[5] Asaka, T., et al.: 2000, *Phys. Lett. B*, **490**, 136.
[6] Kawasaki, M., et al.: 2005, *Phys. Rev. D*, **71**, 083502.