Cosmological Solutions to the Big-Bang Lithium Problem: Big-Bang Nucleosynthesis with Photon Cooling, X-Particle Decay and a Primordial Magnetic Field

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The ^{7}Li abundance calculated in BBN with the baryon-to-photon ratio fixed from fits to the CMB power spectrum is inconsistent with the observed lithium abundances on the surface of metal-poor halo stars. Previous cosmological solutions proposed to resolve this ^{7}Li problem include photon cooling (possibly via the Bose-Einstein condensation of a scalar particle) or the decay of a long-lived X-particle (possibly the next-to-lightest supersymmetric particle). In this paper we reanalyze these solutions, both separately and in concert. We also introduce the possibility of a primordial magnetic field (PMF) into these models. We constrain the X-particles and the PMF parameters by the observed light element abundances using a likelihood analysis to show that the inclusion of all three possibilities leads to an optimum solution to the lithium problem. We deduce allowed ranges for the X-particle parameters and energy density in the PMF that can solve ^{7}Li problem.

We have calculated BBN taking into account three possible cosmological extensions of the standard BBN. These include photon cooling, the radiative decay of X particles, and the possible existence of a PMF. In particular, we consider the possible combination of all three paradigms simultaneously in a new hybrid model. We then utilized a maximum likelihood analysis to deduce constraints on the parameters characterizing the X particles (τ_X[s], ζ_X[GeV]) and the energy density of the PMF ($\rho_B = B^2/8\pi$) from the observed abundances of light elements up to Li.

From Fig. 1, as a result, we obtained ranges for the X-particle parameters given by

$$4.06 < \log(\tau_X[\mathrm{s}]) < 6.10 \ (95\,\%\ \mathrm{C.L.}),$$
$$-9.70 < \log(\zeta_X[\mathrm{GeV}]) < -6.23 \ (95\,\%\ \mathrm{C.L.}),$$

also find that the hybrid model with a PMF gives the better likelihood than that without a PMF, and the best fit and 2σ upper bound on the energy density of the PMF are

$$B = 1.89\ \mathrm{nG}\ \text{at}\ a = 1.0\ \text{(the best fit)},$$
$$B < 3.05\ \mathrm{nG}\ \text{at}\ a = 1.0\ (95\,\%\ \mathrm{C.L.}),$$

We discussed the degeneracy between the parameters of the X particle and the PMF. Since the parameters of X particle are mainly constrained by the D and ^{7}Li abundances, while the energy density of the PMF is constrained by the ^{4}He abundance, we found there are no significant degeneracies between parameters of the PMF and the X particle.

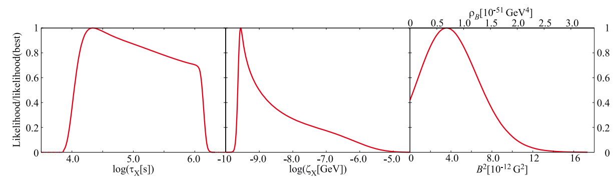

Figure 1: Constraint on the X particle parameters and the PMF strength and energy density.

Reference

[1] Yamazaki, D. G., et al.: 2014, *Phys. Rev. D*, **90**, 023001.