Effects of Power Law Primordial Magnetic Field on Big Bang Nucleosynthesis

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Big bang nucleosynthesis (BBN) is affected by the energy density of a primordial magnetic field (PMF) [1,2]. For an easy derivation of constraints on models for PMF generations, we assume a PMF with a power law (PL) distribution in wave number defined with a field strength, a PL index, and maximum and minimum scales at a generation epoch. We then show a relation between PL-PMF parameters and the scale invariant (SI) strength of PMF for the first time. We perform a BBN calculation including PMF effects, and show abundances as a function of baryon to photon ratio η. The SI-PMF strength is constrained from observational constraints on ^{4}He and D. The minimum abundance of ^{7}Li/H as a function of η slightly moves to a higher ^{7}Li/H value at a larger η value when a PMF exists during BBN. We then discuss degeneracies between the PL-PMF parameters in the PMF effect. We also assume a general case in which both the existence and the dissipation of PMF are possible. It is then found that an upper limit on the SI-PMF strength can be derived from a constraint on ^{4}He abundance, and that a lower limit on the allowed ^{7}Li abundance is significantly higher than those observed in metal-poor stars.

We investigated constraints on parameters of the PL-PMF from the light elements abundance up to Li produced in BBN [3]. We showed respective and combined constraints on the parameters. As a result, we obtained upper limits on the SI-PMF strength, i.e., $B_{\rm SI}^{Y_{\rm p}+D} \leq 1.45 - 1.95\,\mu$G from abundances of ^{4}He and D for the 2σ region of η values by the WMAP 7yr data (Fig. 1).

We assume a PMF characterized by the power spectrum of a PL in wave number. Parameters of this PL-PMF are a field amplitude B_λ, a PL index $n_{\rm B}$, and maximum and minimum scales at a generation epoch $k_{[\rm max]}$ and $k_{[\rm min]}$, respectively. We then show a relation between PL-PMF parameters and the scale invariant (SI) strength of PMF for the first time as follows:

$$B_\lambda = B_{\rm SI}\sqrt{\frac{\Gamma\left(\frac{n_{\rm B}+5}{2}\right)}{\left(k_{[\rm max]}^{n_{\rm B}+3}-k_{[\rm min]}^{n_{\rm B}+3}\right)\lambda^{n_{\rm B}+3}}}. \qquad (1)$$

Using this relation, we discuss the degeneracy of the PL-PMF parameters in effects on BBN and showed some possibility of constraining models of PMF generations by combining constraints on the SI field strength from light element abundances to the relation between PL-PMF parameters and the SI field strength.

In addition, we consider a general case in which the existence and energy dissipation of the PMF are allowed. Based on our result of the BBN calculation (Fig. 1), it was found that an upper limit on the strength of the PMF can be derived from a constraint on ^{4}He abundance. A lower limit on ^{7}Li abundance is also derived, and it is significantly higher than those observed in metal-poor stars. We then conclude that it is impossible to solve the ^{7}Li problem by the PMF energy density, even if we consider that part of the PMF energy is dissipated and transferred to the radiation energies.

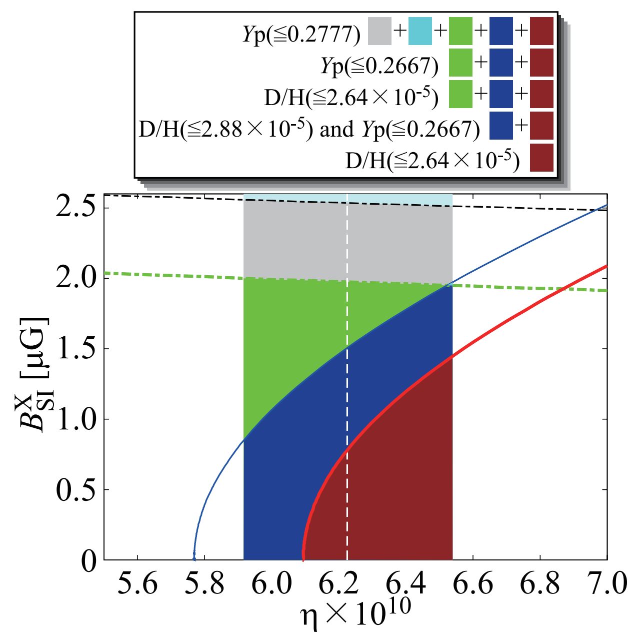

Figure 1: Constraints on the field strength $B_{\rm SI}^{\rm X}$ We use the following upper limits on the abundances: $Y_{\rm p} = 0.2667$ (thick solid line) and 0.2777 (thin solid line), D/H $= 2.88\times10^{-5}$ (thick dot-dashed line) and 2.64×10^{-5} (thin dot-dashed line), and ^{7}Li/H $= 2.35\times10^{-5}$ (dotted line). The vertical painted band is the limit on the baryon to photon ratio from WMAP 7yr data [4]. The white dashed line indicates the best value. Painted regions in this figure are as indicated in the legend box at the top.

References

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