Effects of Magnetic Fields with Log-Normal Distribution on the CMB

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We research effects of a primordial magnetic field (PMF) on the temperature fluctuations and polarization anisotropies of the cosmic microwave background (CMB) [1]. We assume that spectra of a primordial magnetic field (PMF) are described by log-normal distributions (LND) to research the PMF which has a characteristic scale on the temperature fluctuations and polarization anisotropies of the CMB and constrain the parameters of the LND-PMF by the CMB observations.

Theoretical models of PMF generations on cosmological scales have been proposed by many researchers. Since such generation models are based on causal physical processes, PMFs are expected to have the model-dependent scale. If PMFs have been generated from inflation the power law model would be a good representation of the magnetic field power spectrum. On the other hand, if the PMFs was created through other mechanisms than inflation the spectrum would have a characteristic scale and may not be described as a simple power law. Furthermore, we need to understand how such PMFs cascade from smaller to larger scales to study effects of the PMFs created in the early universe on the large scale structures. Actually, we can learn behaviors of PMF cascading or inverse-cascading by simulations [2], which results, however, generally depend on cosmological parameters and models. Since such simulations generally spend too long time and have the limited dynamical range, it is not efficient to estimate distributions of the PMF by some simulations when we study cosmology and astrophysics with the PMF quantitatively.

To avoid these problems, we use a log-normal distribution (LND) in place of the power law defined as,

$$f_{\mathrm{LND}}(k; k_{\mathrm{M}}, \sigma_{\mathrm{M}}) = \frac{1}{k\sigma_{\mathrm{M}}\sqrt{2\pi}} \exp\left\{-\frac{[\ln(k) - \ln(k_{\mathrm{M}})]^2}{2\sigma_{\mathrm{M}}^2}\right\}, \quad (1)$$

where k_{M} is the characteristic scale depending on the PMF generation model, and σM is the variance. The variance σ_{M} in Eq.(1) expresses how this distribution is expanded (or concentrated) around the characteristic scale k_{M}. Therefore, the variance σ_{M} may be related to the cascading of the PMFs.

We have revealed the features of the LND-PMF effects on the CMB as follows: (1) For larger k_{M} or/and σ_{M}, the CMB spectra of TT, TE and EE from the LND-PMF are dominated by the vector mode. Meanwhile, in the opposite case, these spectra are dominated by the scalar mode. (2) The CMB spectrum of the BB polarization anisotropy for all scales and other polarization anisotropies and temperature fluctuations of the CMB for smaller scale is dominated by the vector modes. Because three parameters which characterize the LND-PMF affect the CMB power spectra differently at small and large scales we expect that tight constraints can be placed on these parameters without degeneracy. We found that the LND-PMF which generates CMB anisotropies among $1000 < \ell < 2000$ is most effectively constrainted by the current CMB data sets. For example, B_{LND} for $10^{-3}\,\mathrm{Mpc}^{-1} \leq k/h \leq 10^{-2}\,\mathrm{Mpc}^{-1}$ and $\sigma_{\mathrm{M}} = 1.0$ is limited most strongly as shown in Fig. 1.

In the near future, the tigher constraints on B_{LND} at $k_{\mathrm{M}}/h > 10^{-2}\,\mathrm{Mpc}^{-1}$ will be expected from the observations, such as *Planck*, *QUIET*, and *PolarBear* missions.

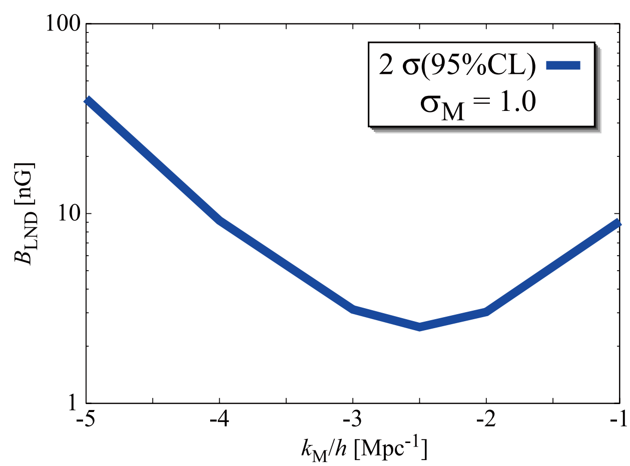

Figure 1: Constraint on the strengths of LND-PMF for $10^{-5} < k_{\mathrm{M}} < 10^{-1}$. Blue curve is the 2σ (95 % CL) upper limits of B_{LND} [nG]. We fix the standard cosmological parameters and use the best-fitted value from WMAP 7th + tensor mode [2].

References

[1] Yamazaki, D. G., Ichiki K., Takahashi, K: 2011, *Phys. Rev. D*, **84**, 123006.
[2] Larson D., et al.: 2011, *ApJS*, **192**, 16.