

Large-scale magnetic fields in inflationary cosmology

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It is well established that magnetic fields with the field strength about micro G, ordered on 1-10 kpc scale, exist in our galaxy and other galaxies. Furthermore, in recent years magnetic fields in clusters of galaxies have been observed by means of the Faraday rotation measurements (RMs) of polarized electromagnetic radiation passing through an ionized medium. In general, the strength and the scale are estimated on 0.1-1 micro G and 10kpc-1Mpc, respectively. It is very interesting and mysterious that magnetic fields in clusters of galaxies are as strong as galactic ones and that the coherence scale may be as large as about Mpc.

Inflation in the early Universe provides a mechanism to generate primordial density perturbations out of the quantum fluctuations of the inflation-driving scalar field, namely, inflaton, which produce gravitationally bound objects (galaxies, quasars, etc.) and the large-scale structure of the Universe, in addition to account for the observed degree of homogeneity, isotropy, and flatness of the present Universe. Hence, the most natural origin of such a large-scale magnetic field would be electromagnetic quantum fluctuations generated in the inflationary stage. Inflation naturally produces effects on very large scales, larger than Hubble horizon, starting from microphysical processes operating on a causally connected volume. However, there is a serious obstacle on the way of this nice scenario as argued below.

The Friedmann-Robertson-Walker (FRW) metric usually considered is conformally flat. Moreover, the electrodynamics is conformally invariant. Hence large-scale electromagnetic fluctuations could not be generated quantum mechanically in cosmological background. In other words, if the origin of large-scale magnetic fields in clusters of galaxies is electromagnetic quantum fluctuations generated and amplified in the inflationary stage, the conformal invariance must have been broken at that time. Several breaking mechanisms therefore have been proposed.

In the present study [1,2], in addition to the inflaton field we assume the existence of the dilaton field and introduce the coupling of it to electromagnetic fields. Such coupling is reasonable in the light of indications in higher-dimensional theories, e.g., string theories. In particular, we consider the case in which the dilaton continues its evolution with the exponential potential after inflation until it is stabilized after oscillating around its potential minimum and then decays into radiation with or without entropy production. It is shown that large-scale magnetic fields with observationally interesting strength at the present time could be generated if the conformal invariance of the Maxwell theory is broken through the coupling between the dilaton and electromagnetic fields in such a way that the resultant quantum fluctuations in the magnetic field have a nearly scale-invariant spectrum. If this condition is met, the amplitude of the generated magnetic field could be sufficiently large even in the case huge amount of entropy is produced as the dilaton decays.

References

[1] K. Bamba and J. Yokoyama, Phys. Rev. D 69, 043507 (2004).

[2] K. Bamba and J. Yokoyama, Phys. Rev. D 70, 083508 (2004).