Primordial Magnetic Fields and Triangle Anomaly

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Abstract

A possible relationship between primordial hypermagnetic fields, fermion number asymmetry and baryon number fluctuations is discussed.

The existence of large scale magnetic fields observed in our and other galaxies is still a puzzle. If the galactic magnetic field is naively blue-shifted to earlier epochs, one finds that the Universe was always filled by a magnetic field of a considerable amplitude, with energy density comparable with that of cosmic microwave background radiation. Of course, this consideration does not take into account different physical processes operating at the galactic scale, such as the dynamo mechanism, which change considerably the naive scaling law $|\vec{H}| \sim T^2$ (here $\vec{H}$ is the magnetic field, and T is the temperature). In any case, it is widely believed that some seed fields of primordial origin are necessary for the successful generation of the galactic magnetic fields.

There are neither compelling theoretical arguments nor motivated phenomenological constraints that could exclude the existence of magnetic fields at temperatures as high as that of the electroweak phase transition, $T_c \sim 100$ GeV. At T_c the SU(2)$\times$U(1) group "breaks" down to U(1)$_{EM}$, and a transition from hypermagnetic $U(1)$ fields to ordinary magnetic fields takes place. This talk addresses the question of a possible existence of any cosmological implications associated with this transition. Since this analysis has already been published in [1, 2, 3], I just make some qualitative remarks and formulate the results.

The main observation is that there is an essential difference between interaction of magnetic fields and that of hypermagnetic fields with matter. An ordinary electromagnetic field has a vector-like coupling to fermions, while the coupling of hypercharge fields is chiral. Thus, if hyperelectric ($\vec{\mathcal{E}}_Y$) and hypermagnetic ($\vec{\mathcal{H}}_Y$) fields are present simultaneously, they cause a variation of the fermionic number according to the anomaly equation,

$$\partial_\mu j_\mu \sim \frac{g'^2}{4\pi^2}\vec{\mathcal{H}}_Y \cdot \vec{\mathcal{E}}_Y \ , \tag{1}$$

where g' is the hypercharge gauge coupling constant. So, the anomalous coupling of a hypercharge magnetic field to fermions induces a transformation of the hypermagnetic energy density into fermionic number and vice versa.

In [2, 3] we assumed that primordial hypermagnetic fields were generated by some mechanism before the electroweak epoch and studied their influence on the fermion content of the Universe. We showed that, depending on the particle physics model and on the initial spectrum of the primordial magnetic fields, quite large fluctuations of the baryon and lepton numbers may be generated. These fluctuations can survive until the onset of Big Bang Nucleosynthesis (BBN) and create unusual initial conditions for the calculation of the light element abundances. In particular, a natural outcome of our considerations is a non-uniform distribution of baryon number, not necessarily positive-definite. Matter–antimatter domains are then possible. The requirement that these fluctuations be small enough not to conflict with the predictions of the standard homogeneous BBN allowed us to put quite a strong constraint on the spectrum of the primordial magnetic fields. Moreover, we argued that the primordial magnetic field may change the nature of the electroweak phase transition. Finally, the existence of primordial fields with some specific topological structure may result in the production of the net baryon number at the electroweak scale.

In ref. [1] we studied a possible hypermagnetic field generation from right-handed electron asymmetry, which may have existed before the electroweak phase transition as a result of GUT baryogenesis. We showed that quite large magnetic fields ($\sim 10^{22}$ gauss at $T \sim 100$ GeV with typical inhomogeneity scale $\sim \frac{10^6}{T}$) can be generated. These fields may be of cosmological interest, potentially acting as seeds for amplification to larger scale magnetic fields through non-linear mechanisms [4].

References

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