NEW PRIMORDIAL MAGNETIC FIELD EVOLUTION AND SIGNATURE ON THE CMB SPECTRUM

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Abstract

A new scenario for a primordial magnetic field is proposed and its evolution is presented. Signatures on the cosmic microwave background spectrum are also discussed.

Keywords: *cosmology, redshift, cosmic microwave background, magnetic fields.*

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I. INTRODUCTION

The existence of magnetic fields takes more evidence from recent observations. The Faraday rotation measurements indicate dynamically significant magnetic fields in galaxies, clusters and even in inter-clusters voids that their strength rang from 10^{-6}-10^{-9}G (1). The origin of these magnetic fields has different proposed magnetogenesis processes (2). The strength of magnetic fields predicted by these processes is many orders of magnitude lower than present-day observed fields, they must been amplified during cosmic history.

The measurable characteristics of the observed magnetic fields differentiate the astrophysical or cosmological origin of these fields. The primordial magnetic fields give seed fields to complete the scenario of dynamo amplification as an origin of galactic magnetic fields. The primordial nature of these seed fields is supported by observations of strong magnetic fields in high redshift galaxies and in inter-cluster voids that is proposed to explain the low flux of GeV photons from distant Blazars (3). The discovery of the proposed primordial magnetic fields would have profound insights into the fundamental problems of the early universe such as matter-antimatter asymmetry.

A recent paper (8) support that the magnetic fields can generate a non cosmological redshift through the photon radiation of high frequency gravitational waves. The primordial magnetic fields will leave a new signature on the cosmic microwave background (CMB) anisotropies through this new non cosmological redshift. The aim of this present paper is to make insights in such a proposal and take into account the nature and the evolution of these primordial magnetic fields in the cosmic history.

II. NEW COSMIC MAGNETIC FIELD EVOLUTION SCENARIO

II-1-Approach and methodology:

The Maxwell's equations in a curved space time will take an appropriate form [1, 2] to be covariant under coordinate transformations. The differential derivations (**Erreur ! Signet non défini.** ∂_μ) of the flat spacetime equations will be converted to covariant derivatives (D_μ).

$$D_\mu F^{\mu\nu} = J^\nu \quad (1)$$

$$D_\alpha F_{\mu\nu} + D_\mu F_{\nu\alpha} + D_\nu F_{\alpha\mu} = 0 \quad (2)$$

The Maxwell's equations in curved space time take into account the electric ($\vec{E}$) and magnetic ($\vec{B}$) components forming the electromagnetic tensor ($F^{\mu\nu}$) and reveal the propagation and generation of these fields from the electric current (J^μ).

Several analyses of this case have been made considering the interaction of the electromagnetic radiation with the curvature of spacetime (4). The new scenario considers the cosmic magnetic fields in the curved expanding spacetime of the Friedmann-Robertson-Walker (FRW) universe. The new admitted physical interpretation of Maxwell's equations in curved spacetime is that the curvature preserves the magnetic fields after the magnetogenesis processes ends and affects the field configuration evolution. Terms of the form ($\Gamma^\mu_{\alpha\beta} F^{\beta\nu}$) will acts like a pseudo-currents, where $\Gamma^\mu_{\alpha\beta}$ are the Christofell symbols. To investigate Maxwell's equations, the electromagnetic tensor is defined in an appropriate form. Initially, the electromagnetic tensor ($F_{\mu\nu}$) of flat space time is given in the spherical coordinates in term of the field components by considering the coordinate transformation [3].

$$F^{spherical}_{\mu\nu} = \frac{\partial x^\alpha}{\partial x'^\mu} \frac{\partial x^\beta}{\partial x'^\nu} F^{Cartesian}_{\alpha\beta} \quad (3)$$

Where (x^{α}) is the Cartesian coordinates, (x'^{μ}) is the spherical coordinates. After that, the scale factor $a(t)$ is inserted to provide the expansion in the space time of the homogeneous and isotropic FRW universe. Ultimately for a flat or curved space time, the field strength will be defined as the scalar ($F_{\alpha\beta}F^{\alpha\beta}$) given the physical measurable strength.

II-2-Results:

The admitted approach to investigate the cosmic magnetic fields in the expanding curved FRW universe will result in seven non vanishing Maxwell's equations, after neglecting the electric fields and currents. These equations can be solved in an interesting situation related to the longitudinal component, to the line of sight or a fixed direction in the sky, of the magnetic field. The total contribution to the magnetic fields strength come from the transverse components (B_2, B_3) and the longitudinal component (B_1) is neglected; ($B_1(t,r,\theta,\phi)=0$). The final configuration of the non vanishing cosmic magnetic field components will be [4, 5]:

$$B_2(x^{\mu}) = \frac{(-1)^m \sin^{-1}(\theta)}{a(t)r\sqrt{1-hr^2}}\left[\begin{array}{l} a\left(\frac{\cos(\theta)+1}{\sin(\theta)}\right)^{2m}\cos(2m\phi) \\ +b\left(\frac{\sin(\theta)}{\cos(\theta)+1}\right)^{2m}\sin(2m\phi)\end{array}\right] \quad (4)$$

$$B_3(x^{\mu}) = \frac{(-1)^m \sin^{-1}(\theta)}{a(t)r\sqrt{1-hr^2}}\left[\begin{array}{l} a\left(\frac{\cos(\theta)+1}{\sin(\theta)}\right)^{2m}\sin(2m\phi)+ \\ b\left(\frac{\sin(\theta)}{\cos(\theta)+1}\right)^{2m}\cos(2m\phi)\end{array}\right] \quad (5)$$

Where (h) is the curvature constant defining the open, flat or closed type of the FRW universe, (m) is an imposed constant of the method, ($a(t)$) is the scale factor and (a, b) are the magnitude of the two possible configurations.

III. DISCUSSION OF THE NEW PRIMORDIAL FIELDS:

The attempt to apply these results to the primordial magnetic fields has to take with care. The cosmological magnetogenesis of primordial magnetic fields is usually assumed to be in the pre-recombination epoch and their evolution is ruled by the Magneto-Hydrodynamics equations. The high conductivity of the universe in the ideal limit make that the electric field vanishes; providing an explanation that only the magnetic fields are observed (5). The strength of the frozen-in primordial large-scale magnetic field is proportional to an inverse square of the scale factor provided by the conservation of the magnetic flux and energy density in an adiabatic expansion of the universe. The cosmic magnetic fields introduced in this new approach seem to hold with these characteristics of the primordial magnetic fields. This magnetic flux conservation that is not preserved in some analysis of the electromagnetic radiation propagation in curved space time. An important other characteristic of this scenario is that the cosmic magnetic fields revealed from the primordial ones has a spatial configuration unlike the stochastic nature assumed for the primordial fields. The assumed primordial nature will preserve the global isotropy of the CMB temperature spectrum. What distinguish between the new scenario and the others is the observations in the both the CMB temperature anisotropies and B-mode polarizations.

IV. NEW PRIMORDIAL MAGNETIC FIELD SIGNATURE ON THE CMB SPECTRUM

The primordial magnetic fields have different proposals on their signatures in the CMB temperature and polarization anisotropies. These primordial magnetic fields will leave a new signature on the CMB anisotropies through our non cosmological redshift (8). The new effect predicts a redshift for each photon propagating in a magnetic field. This new non cosmological redshift z_{NC} [6] will be exponentially proportional to the transverse, to the photon propagation direction, external magnetic field strength $B_{\perp}$ and coherent length L.

$$1+z_{NC} = e^{\frac{1}{12}B_{\perp}{}^2 L^3} \quad (6)$$

If the magnetic field is assumed to be truly stochastic (6, 7), the numerical solver will give the new contribution in CMB temperature anisotropies. If the Maxwell's equations solutions for the FRW universes give the magnetic field evolution in the post-recombination era, two proposals are made. The CMB temperature anisotropies depend on the transverse, to the line of sight, part of the analytically given magnetic field (B_{θ}, B_{ϕ}). The CMB B mode polarization depends on the longitudinal, to the line of sight, part of the magnetic field (B_r). The two proposals have to take a numerical solver for quantitative results. For redshift independent of (ϕ), we have ($m=0$). The relation of the temperature anisotropies as an expansion of Legendre Series [7, 8, 9]:

$$\left(\frac{\Delta T}{T}\right)_{CMB} = (1+z_{NC}) \quad (7)$$

$$\left(\frac{\Delta T}{T}\right)_{CMB} = exp\left[c\kappa\frac{\left(a^2+b^2\right)}{sin^2(\theta)}\int_{t_{recomb}}^{t_0}\frac{dt}{a^2(t)}\right] \quad (8)$$

$$\left(\frac{\Delta T}{T}\right)_{CMB} = \sum_{l=0}^{\infty} a_l P_l(cos(\theta)) \quad (9)$$

The final CMB temperature anisotropy is a model dependent through the temporal evolution of the scale factor ($a(t)$), the time of recombination (t_{recomb}) and the age of the universe (t_0).

CONCLUSION

The new primordial magnetic field evolution scheme, ruled by Maxwell's equations in curved spacetime, is characterized by a configuration different from the stochastic description. The primordial magnetic field in this case is conserved by the spacetime curvature and is not cancelled by the high neutrality of the cosmic staff after the recombination. The signature of these fields on the Cosmic Microwave Background spectrum can be predicted in the insight of the contribution generated by non cosmological redshift and the well established b modes signatures in the CMB photons polarizations. It is worth to mention that our preliminary results are qualitative and not quantitative (more studies are under investigations).

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