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# Magnetic fields:their influence on the Reionization epoch

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We are investigating the influence of primordial magnetic fields on CMB anisotropies and present some preliminary results on the Reionization epoch. We introduce magnetic fields as a source of anisotropies, having a contribution to the energy-momentum tensor. The last scattering surface (LSS) could be transversed by large radiation energy density filaments inheritors of primordial magnetic flux tubes. We make an estimation about the redshift of Reionization of the Universe.

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## 1. Introduction

Many works have been presented to explain the early reionization found by WMAP. The last 3-year results show a more accurate value but far from the early accepted optical depth of the Reionization epoch.

In this work we propose an alternative outline in which we obtain an approximated value for the Reionization epoch taking into account primordial magnetic fields as an additional effect producing the seed of large-scale structure.

We present a theoretical framework in which we obtain a set of perturbed equations in real space which enable us to estimate the redshift of Reionization epoch.

## 2. Magnetic fields at Radiation Era

We follow the obtained results in previous papers by Battaner, Florido, Jimenez-Vicente (1996) and Florido and Battaner (1997), now extended to include CDM and dark energy.

Our first hypothesis is that primordial magnetic fields were created at Inflation. We consider the Universe as a relativistic multicomponent fluid composed by photons, CDM particles, dark energy and magnetic fields.

To obtain a set of linear perturbed equations in the synchronous gauge we consider a fluctuation of $g_{\mu\nu}$ and of all other thermodynamics parameters of all components. In particular p, the radiation pressure, $\varepsilon$ , the energy density of radiation, $U_\mu$, the velocity of the photonic fluid, $U'_\mu$, the velocity of the CDM fluid and $\rho$, the density of CDM particles.

Let us write every component of the energy-momentum tensor for each component:

- Photons:

$$\tau_{\mu\nu} = pg_{\mu\nu} + 4pU_\mu U_\nu$$

- CDM:

$$\tau_{\mu\nu} = \rho_{CDM} U'_\mu U'_\nu$$

- Dark Energy:

$$\tau_{\mu\nu} = \frac{\Lambda}{8\pi} g_{\mu\nu}$$

- Magnetic Fields:

$$\tau_{\mu\nu} = diag\{\frac{B^2}{8\pi}, (\frac{\langle B^2\rangle}{24\pi}R^{-2}), (\frac{\langle B^2\rangle}{24\pi}R^{-2}), (\frac{\langle B^2\rangle}{24\pi}R^{-2})\}$$

*Set of equations (in real space):*

We obtain perturbed motion and energy equations using $\tau^{\mu\nu}{}_{;\mu} = 0$

- Equation of energy balance for photons, dark energy and magnetic fields:

$$\frac{\Lambda}{4\pi}\frac{\dot{a}}{a^3}h+3\frac{\partial\delta p}{\partial t}+4p\nabla\cdot\vec{u}+\frac{2p}{a^2}\frac{\partial h}{\partial t}+12(\delta p)\frac{\dot{a}}{a}-4p\frac{\dot{a}}{a^3}h+\frac{\partial}{\partial t}(\frac{B^2}{8\pi})+4\frac{\dot{a}}{a}(\frac{B^2}{8\pi})=0$$

- Equation of energy balance for dark matter:

$$\frac{\partial\delta\rho}{\partial t}+\rho\nabla\cdot\vec{u}'+\frac{\rho}{2a^2}\frac{\partial h}{\partial t}+3(\delta\rho)\frac{\dot{a}}{a}-\rho\frac{\dot{a}}{a^3}h=0$$

- Equation of motion for photons, dark energy and magnetic fields:

$$\frac{\partial}{\partial t}(4pa^5\vec{u}_i)+a^3\left[\nabla\left(\delta p+\left(\frac{B^2}{8\pi}\right)\right)-\frac{1}{4\pi}\vec{B}\cdot\nabla\vec{B}\right]=0$$

- Equation of motion for dark matter:

$$\frac{\partial}{\partial t}4\rho^5\vec{u'}_i=0$$

- Einstein's equations: component $\delta R_{0i}$:

$$\frac{\partial}{\partial t}\left(\frac{h_{ij}}{a^2}\right)+64\pi a^2pu_i+16\pi\rho u_i'=0$$

- Einstein's equations: component $\delta R_{00}$:

$$\frac{\partial^2 h_{ii}}{\partial t^2}-2\frac{\dot{a}}{a}\frac{\partial h_{ii}}{\partial t}+2(\frac{\dot{a}^2}{a^2}-\frac{\ddot{a}}{a})h_{ii}+16\pi a^2\delta\rho+48\pi a^2\delta p+2a^2B_iB_i=0$$

  where a is the cosmological scale factor and h is $h_{ii}$ the "trace" of the perturbed metric ($h_{\mu\nu}=g_{\mu\nu}-\eta_{\mu\nu}$) and $u_i$ and $u_i'$ are the perturbed velocities of photon fluid and CDM particles respectively.

## 3. Redshift of Reionization and Primordial Magnetic Fields

The influence of magnetic fields on the Reionization epoch has been considered by Sethi and Subramanian (2004) taking the effects of ambipolar diffusion and generating decaying MHD turbulence into account. We have considered here another complementary approach: Primordial magnetic fields produce a higher energy density in superhorizon filaments, thus enhancing galaxy formation. We assume that when the density in these huge filaments reaches a critical value the formation of galaxies takes place in the way explained by current CDM models.

In the Radiation era we can neglect the contribution of dark energy and CDM.

Introducing linear perturbations, we obtain the following equation for the evolution of the density perturbation:



PoS(CMB2006)057

$$\ddot{\delta} - \delta - X + \frac{1}{3}e^{-\tau}\nabla'^2\delta + 2e^{-\tau}m = 0$$

where:

$\delta$ is the relative energy density contrast, defined as $\delta\varepsilon/\varepsilon$, where $\varepsilon$ is the energy density and $\delta\varepsilon$ is the difference between its value within the filamentary inhomogeneity and its mean value in the Universe.

$\tau$ is defined as $\tau = ln\frac{t_{equality}}{t}$

$\nabla'$ is the nabla operator in spatial comoving coordinates

$X = \frac{B_0^2}{24\pi p}$

$m = -\frac{1}{2}\nabla' \cdot \left(\frac{2}{3}\vec{n} - \nabla' X\right)$

where $\vec{n} = -\frac{\vec{B}_0 \cdot \nabla' \vec{B}_0}{4\pi p_0} + 3\nabla' X$

$B_0$ is the comoving field strenght

***Assumptions and approximations:***

Just for huge filaments larger than the horizon along the Radiation Era, initial value and homogeneity boundary conditions give for the density perturbations a very simplified expression:

$\delta = -X + \frac{1}{2}\frac{X+\delta_i}{t_i}t$

where the subindex i means values at some unespecified magnetogenesis time $t_i$. This solution is valid up to the Recombination epoch. After recombination, the evolution of $\delta$ is considered to be proportional to $t^{2/3}$.

## 4. Conclusions

It is found that **the Reionization time in presence of primordial magnetic fields $t_M$ is shorter than the classical Reionization time $t_c$ in absence of them**, as given by the approximated formula:

(1)

$$t_M = \left(\frac{1}{1+x}\right)^{2/3} t_c$$

where the parameter $x = \frac{X}{\delta_i}$ gives the relative importance of magnetic fields compared with energy density perturbation at $t_i$. We also show in figure 1 that this simplified model predicts a linear relation between the reionization redshift when magnetic fiedls are included in the calculation, $z_M$ and the parameter x indicating the relative importance of primordial magnetic fields initially. This relation is:

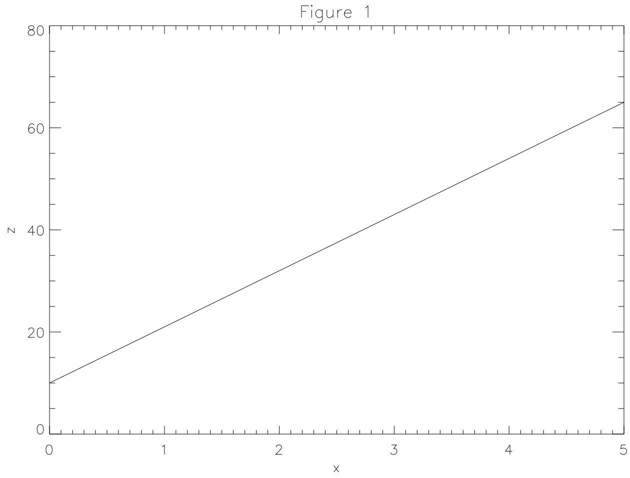
(2)

$$z_M = (1+z_c)x + z_c$$

where $z_c$ is the Reionization redshift without including magnetic fields. See figure.

Then, we obtain an estimation of the order of magnitude of the Reionizaion redshift for a comoving magnetic field strenght $B_0 = 10^{-8}$ Gauss. Using (2) and assuming that $z_c \approx 10$ and $\delta \approx 3.3 \cdot 10^{-5}$ we obtain a $z_M \approx 13.7$.

We conclude that in the presence of primoridal magnetic fields the Reionization of the Universe could take place before.

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