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Excitation of MHD waves in magnetized anisotropic cosmologies

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ABSTRACT

The excitation of cosmological perturbations in an anisotropic cosmological model and in the presence of a homogeneous magnetic field was studied, using the resistive magnetohydrodynamic (MHD) equations. We have shown that fast-magnetosonic modes, propagating normal to the magnetic field, grow exponentially and *saturate* at high values, due to the resistivity. We also demonstrate that Jeans-like instabilities can be enhanced inside a resistive fluid and that the formation of condensations influence the growing magnetosonic waves.

Key words. magnetic fields – magnetohydrodynamics (MHD) – instabilities – waves – cosmology: early Universe – relativity

1. Introduction

Magnetic fields are known to have a widespread presence in our Universe, being a common property of the intergalactic medium in galaxy clusters (Kronberg 1994). Reports on Faraday rotation imply significant magnetic fields in condensations at high redshifts (Kronberg et al. 1992). Large-scale magnetic fields and their potential implications for the formation and the evolution of the observed structures have been the subject of theoretical investigation (see Thorne 1967; Jacobs 1968; Ruzmaikina & Ruzmaikin 1971; Wasserman 1978; Zel'dovich et al. 1983; Adams et al. 1996; Barrow et al. 1997; Tsagas & Barrow 1997; Jedamzik et al. 1998; Barrow et al. 2006, etc.). Magnetic fields observed in galaxies and galaxy clusters are in energy equipartition with the gas and cosmic rays (Wolfe et al. 1992). The origin of these fields, which can be astrophysical, cosmological or both, remains an unresolved issue.

If magnetism has a cosmological origin, as observations of μG fields in galaxy clusters and high-redshift protogalaxies seem to suggest, it could have affected the evolution of the Universe (Giovannini 2004; Barrow et al. 2006). There are several scenarios for the generation of primordial magnetic fields (e.g. see Grasso & Rubinstein 2001). Most of the early treatments were Newtonian, with relativistic studies making a recent appearance in the literature. A common factor between almost all the approaches is the use of the MHD approximation, namely the assumption that the magnetic field is frozen into an effectively infinitely conductive cosmic medium (i.e. a fluid of zero resistivity). With a few exceptions (e.g. see Fennelly 1980; Jedamzik et al. 2000; Vlahos et al. 2005), the role of kinetic viscosity and the possibility of non-zero resistivity have been ignored. Nevertheless, these aspects are essential for putting together a comprehensive picture of the magnetic behavior, particularly as regards the non-linear regime. The electric fields associated with the resistivity can become a source of particle acceleration, while the induced non-linear currents may react back on the magnetic field (Vlahos et al. 2005).

Many recent studies have used a Newtonian or a Friedmann–Robertson–Walker (FRW) model to represent the evolving Universe and super-imposed a large-scale ordered magnetic field. The magnetic field is assumed to be too weak to destroy the FRW isotropy and the anisotropy, induced by it, is treated as a perturbation (Ruzmaikina & Ruzmaikin 1971; Tsagas & Barrow 1997; Durrer et al. 1998). Current observations give a strong motivation for the adoption of a FRW model but the uncertainties on the cosmological *Standard Model* are several. Therefore, the limits of the approximations and the effects one may lose by neglecting the anisotropy of the background magnetic field should be investigated. The formation of small-scale structures and the excitation of resistive instabilities in Bianchi-Type models have been explored (Fennelly 1980). Nevertheless, the excitation of MHD-waves in curved spacetime and their subsequent temporal evolution is far from being clearly understood (Papadopoulos et al. 2001).

In the present article we explore the evolution of a magnetized resistive plasma in an anisotropic cosmological model. We begin with a uniform plasma driving the dynamics of the curved spacetime (the so-called *zeroth-order solution*). This dynamical system is subsequently perturbed by small-scale fluctuations and we study their interaction with the anisotropic background, searching for imprints on the temporal evolution of the perturbations' amplitude.

In Sect. 2, we present the system of the field equations appropriate to describe the model under consideration. In Sect. 3, we solve this system analytically, to derive the zeroth-order solution. In Sect. 4, we extract the first-order perturbed equations. In Sect. 5, we derive the dispersion relation for the magnetized cosmological perturbations and in Sect. 6, we perform a numerical study of their evolution, using a fifth-order Runge–Kutta–Fehlberg temporal integration scheme. In Sect. 7, a perturbation

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