

Cosmic Magnetic Fields

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Abstract. Most of the visible matter in the Universe is in a plasma state, or more specifically is composed of ionized or partially ionized gas permeated by magnetic fields. Thanks to recent advances on the theory and detection of cosmic magnetic fields there has been a worldwide growing interest in the study of their role on the formation of astrophysical sources and the structuring of the Universe. In this lecture, I will briefly review the importance of the cosmic magnetic fields both from a theoretical and from an observational perspective, particularly focusing on stellar and compact objects, the interstellar medium and star formation regions, and on galaxies, clusters of galaxies, and the primordial Universe.

Keywords: Magnetic fields in: stars, interstellar medium, jets and accretion disks, galaxies, clusters of galaxies, intracluster and intergalactic medium, and in the early universe.

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INTRODUCTION

Few decades ago cosmic magnetic fields were generally regarded as unimportant. Only a few scientists, like Alfvén, Biermann, Chandrasekhar, and Parker, realized the potential role of the magnetism in the Universe. Since then, our view has changed considerably. We know now that most of the visible matter in the Universe is in a plasma state, or more specifically is composed of ionized or partially ionized gas permeated by magnetic fields. There seems to be now no doubts that magnetic fields play a crucial role in: star formation, solar and stellar activity, pulsars, accretion disks, formation and stability of jets, formation and propagation of cosmic rays, and stability of galactic disks. They are also probably crucial in: the interstellar medium (ISM) dynamical evolution, in molecular clouds, supernova remnants, proto-planetary disks, and planetary nebulae, but its importance is still not well understood in: stellar evolution, halos of galaxies, galaxy evolution, and structure formation in the early Universe (e.g., [1]). In this lecture, I will very *briefly* review the importance of the cosmic magnetic fields, particularly focusing on compact objects, the ISM and star formation regions, and on galaxies, clusters, and the early Universe. I will also briefly discuss the potential origin of the cosmic magnetic fields.

Before starting this review, let me consider the magnetic induction equation that describes the magnetic field evolution in a fluid:

$$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B}) + \frac{1}{4\pi\sigma} \nabla^2 \mathbf{B} \quad (1)$$

Where σ is the electric conductivity. The first term of the RHS accounts for the flux freezing between the ionized gas and the magnetic field lines and the second one accounts for the magnetic diffusion. The comparison of the second term with the one of the LHS gives the diffusion time scale for the magnetic field configuration decay, $t_{\text{diff}}(L) = 4\pi\sigma L^2$, where L is the characteristic length scale of the spatial variation of $\mathbf{B}$. In most astrophysical systems and environments, the gas is a good conductor and since the typical length scales L are very large, one finds that $t_{\text{diff}}(L)$ is generally much longer than the typical dynamical time scales of the systems. This implies that the first term on the RHS (the frozen-in term) generally dominates and the magnetic flux is conserved in most astrophysical plasmas, with the possible exception of magnetic boundary layers or surface discontinuities, like magnetic reconnection regions, where the condition above may be violated. Therefore, as a *golden rule* in Astrophysics, one may say that once magnetic fields are created in cosmic environments it is very difficult to get rid of them!

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David Baud



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