Viscoresistive MHD configurations of plasma in accretion disks

Giovanni Montani · Riccardo Benini

Abstract We present a discussion of two-dimensional magneto-hydrodynamics (MHD) configurations, concerning the equilibria of accretion disks of a strongly magnetized astrophysical object. We set up a viscoresistive scenario which generalizes previous two-dimensional analyses by reconciling the ideal MHD coupling of the vertical and the radial equilibria within the disk with the standard mechanism of the angular momentum transport, relying on dissipative properties of the plasma configuration. The linear features of the considered model are analytically developed and the non-linear configuration problem is addressed, by fixing the entire disk profile at the same order of approximation. Indeed, the azimuthal and electron force balance equations are no longer automatically satisfied when poloidal currents and matter fluxes are included in the problem. These additional components of the equilibrium configuration induce a different morphology of the magnetic flux surface, with respect to the ideal and simply rotating disk.
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1 Preliminaries

Understanding the mechanism of accretion that compact objects show in the presence of lower dense companions, is a long standing problem in astrophysics [3]. In fact, while in absence of a significant magnetic field of the massive body the disk configuration is properly described by the fluidodynamical approach [13], the situation becomes a bit puzzling when we deal with a strongly magnetized source. Since over the last three decades, increasing interest raised about the mechanism of the angular momentum transport across the disk profile. The solution of this problem stands as settled down in the form of a standard model, at least in the case of small (intrinsic) magnetic fields. This context prevents the formation of high magnetic back-reactions inside the plasma disk and the gas-like approximation is predictive. We remark how it is known from the observations [16] that the accretion profile takes place often with the morphology of a thin disk configuration. In this limit of a thin gaseous disk, the hydrodynamical equilibria underlying the accretion process are cast into a one-dimensional paradigm (see among the first analyses of the problem [8,11,13]). In such a fluidodynamical scenario, the accretion mechanism relies on the angular momentum transfer as allowed by the shear viscosity properties of the disk material. The differential angular rotation of the radial layers is associated with a non-zero viscosity coefficient, accounting for diffusion and turbulence phenomena. Indeed, microscopic estimations of the viscosity parameter indicate that the friction of different disk layers would be unable to maintain a sufficiently high accretion rate, and therefore non-linear turbulent features of the equilibrium are inferred.

However, when the magnetic field $B$ of the central object is strong enough, the electromagnetic back-reaction of the disk plasma becomes relevant [12]. As shown in Coppi [4], the Lorentz force induces a coupling between the radial and the vertical equilibria, which deeply alters the local morphology of the system. In particular, the radial dependence of the disk profile acquires an oscillating character, modulating the background structure too. The existence of such a coupling breaks down the one-dimensional nature of the problem and suggests a revision of the original point of view of the standard model.

Furthermore, in Coppi and Rousseau [5] it is discussed how the plasmas, characterised by a $\beta$-parameter (i.e. the ratio of the thermostatic pressure $p$ to the magnetic one $B^2/8\pi$) close to unity, exhibit an oscillating-like mass density and the disk is decomposed in a ring profile. Thus, the analyses in Coppi [4] and Coppi and Rousseau [5] demonstrate that the details of the disk equilibria are relevant in establishing a crystalline local structure inside the disk. This ideal MHD result constitutes an opposite point of view with respect to the idea of a diffusive magnetic field within the disk, as discussed in Bisnovatyi-Kogan and Lovelace [3]. The striking interest in the details of this local disk morphology relies on the idea that jets of matter and radiation are emitted by virtue of the strong magnetic field and of the axial symmetry of the accretion profiles (see for instance [7]).