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Heating mechanisms in accretion disks around young stellar objects

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Abstract. Accretion disks are observed around young stellar objects such as T Tauri stars. In order to complete the star formation, particles in the disk need to loose angular momentum in order to be accreted into the central object. The magneto-rotational instability (MRI) is probably the mechanism responsible for a magneto-hydrodynamic (MHD) turbulence that leads to disk accretion, which implies the disk particles to be coupled with the magnetic filed lines. As the temperature in the disk is low, we considered, besides the viscous heating mechanism often included in the models by means of the α - prescription, the damping of Alfvén waves as an additional heating source. In particular, we show that the mechanism derived that couples the turbulent and non-linear damping mechanisms of Alfvén waves proved to be very efficient, generating temperatures almost one order of magnitude higher than those mechanisms considered independently.

Keywords. stars: pre–main-sequence, stars:formation, MHD, plasma

1. Introduction

Accretion disks are commonly associated with young stellar objects (YSOs) and are strongly related with the evolution process of such protostars. Those structures can be defined as rotationally supported and are known to be formed of both gas and dust (Armitage 2011). Those circumstellar structures are responsible for accreting mass onto the central object, until the star is massive enough to propitiate its entry in the Main Sequence (MS). This mass transference towards the central star is accompanied by a net transference of angular momentum outwards. The most promising mechanism of angular momentum transference in accretion disks is the Magneto-Rotational Instability (MRI), proposed by Balbus & Hawley (1991). This instability, responsible for promoving the turbulence and angular momentum transport in disks, requires high levels of ionization in order to be effective, since the particles need to be coupled with the magnetic field lines. It is known that the T Tauri accretion disks exhibit very low temperatures and ionization degrees. Therefore, an extra heating mechanism, besides the viscous dissipation proposed by Shakura & Sunyaev (1973), must be present in those structures. The effects of the damping of Alfvén waves as heating sources in T Tauri accretion disks were previously studied by different authors (e.g. Vasconcelos *et al.* 2000). In the present work, we consider the coupling of two of the mechanisms proposed by Vasconcelos *et al.* (2000), the turbulent and non-linear damping, whereas the first transfer energy from large to small scales due to the interaction of an Alfvén wave with a turbulent cell (Hollweg 1987), the latter consists of the interaction between two Alfvén waves of opposite directions, originating a sound wave, which will be rapidly dissipated, releasing energy (Lagage & Cesarsky 1983).

Table 1. We show the temperatures, for three radial distances of the disk, generated by the damping mechanisms of Alfvén waves: non-linear, turbulent and both coupled, for a disk of $M_* = 0.5\, M_\odot$, $\dot{M} = 10^{-8}\, M_\odot/yr$, $\alpha = 0.01$, $\mu = 2.33$ and $f = 0.002$.

Damping mechanism	**T(K)** r = 0.1 (UA)	**T (K)** r = 10 (UA)	**T (K)** r = 99.95 (UA)
non-linear	274.34	15.47	3.79
turbulent	1016.14	56.79	10.89
coupled	2827.85	194.87	30.39

2. The model

In the present work, we have adopted the α-prescription, as proposed by Shakura & Sunyaev (1973), in the definition of viscosity. We have also assumed that the disk is optically thick, geometrically thin, and that it can be divided in layers, in agreement with the model suggested by Gammie (1996).

Additionally, since the disk is optically thick, it is reasonable to assume that the temperature generated is given by the black-body law, $T = (D/\sigma)^{1/4}$, with D representing the energy dissipated, $D = \int_0^H \Phi\, \Gamma / v_A$, where σ is the Stefan-Boltzmann constant, H is the disk scale height, Φ is the wave energy flux, Γ is the damping rate and v_A is the Alfvén velocity.

By the maximization of both turbulent and non-linear damping mechanisms, we found the following prescription for the damping rate of the coupled mechanism:

$$\Gamma = \frac{(c_s/v_A)\rho < \delta v^2 > + B^{3/2} < \delta v^2 >^{1/2}}{B}, \tag{2.1}$$

where c_s is the sound velocity, v_A is the Alfvén velocity, ρ is the volumetric density, $< \delta v^2 >$ is the quadratic velocity dispersion and B is the magnetic field strenght.

3. Results

From Table 1, we show that even for small wave fluxes, denoted by the magnitude of the f parameter, the coupled mechanism, significantly, heats the disk to temperatures necessary for the IMR to be effective.

4. Conclusions

In this work, we show that the coupled mechanism proposed is quite efficient in heating the disk, when compared to the turbulent and non-linear damping mechanisms, yeilding to high temperatures even for small wave flux (see Table 1).

In the sequence, we intend to consider the damping of magneto-acoustic waves as an extra source for the disk heating.

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