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A study of the heating sources of protostellar accretion disks under the MRI instability

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Abstract. Accretion disks are commonly found around young stars, such as T Tauri stars, and are responsible for transporting matter to the central object in low-mass stars, as the Sun. However, this transportation requires a mechanism for angular momentum transport. So far, the most promising mechanism is the magneto-rotational instability, MRI, which demands the particles to be coupled with the magnetic field lines. As the temperatures of the particles throughout the disk, considering only the viscous dissipation, as proposed by the standard model, are too low, the ionization rates are also very small. In that sense, in order to increase the temperature of the disk, we simulated the disk considering the coupling of three extra damping mechanisms of Alfvén waves, the turbulent, non linear and dust-cyclotron damping, along with the viscous dissipation, that could maximize the energy dissipation, heating the accretion disk. We considered two cases, a dusty and non-dusty accretion disk. For the dusty disk, we obtained that the dust-cyclotron damping generates very low temperatures when compared to those from the turbulent and non-linear mechanisms. For the non-dusty disk, the mechanism derived that couples the turbulent and non linear damping mechanisms proved to be very efficient, generating temperatures almost one order of magnitude higher than those mechanisms considered independently.

Resumo. Discos de acreção são, comumente, observados ao redor de estrelas jovens, como as estrelas T Tauri, e são responsáveis por transferir matéria em direção ao objeto central em estrelas de baixa massa, i.e., estrelas de tipo solar. Entretanto, este transporte requer a atuação de um mecanismo de transporte de momento angular. Atualmente, o mecanismo mais aceito é a Instabilidade Magneto-Rotacional, a IMR, a qual exige que as partículas estejam congeladas às linhas de campo magnético. Como as partículas do disco, considerando apenas a dissipação viscosa, conforme proposto pelo modelo padrão, são muito baixas, os níveis de ionização também são muito pequenos. Dessa forma, para aquecer o disco, nós o simulamos considerando o acoplamento de 3 mecanismos de amortecimento de ondas Alfvén, o turbulento, o não linear e o amortecimento cíclotron da poeira, além da dissipação viscosa, de forma a maximizar a energia dissipada, aquecendo o disco. Foi considerado dois casos, um disco empoeirado e outro sem poeira. Para o disco empoeirado, obtemos que o amortecimento cíclotron da poeira gera temperaturas muito baixas, quando comparado àquelas geradas pelos mecanismos turbulento e não linear. Já para o disco não empoeirado, o mecanismo obtido que acopla os amortecimentos não turbulento e linear provou-se muito eficiente, gerando temperaturas quase uma ordem de magnitude maiores do que quando estes mecanismos foram considerados independentemente.

Keywords. Stars: pre-main sequence — Stars: formation — Magnetohydrodynamics (MHD) — Plasmas

1. Introduction

Accretion disks are common structures in astrophysics, being present around pre-main sequence (PMS) stars, active galactic nuclei, black holes and other astrophysical objects. Specially, for low-mass PMS stars - the T Tauri stars- those disks play an important role in transporting matter towards the central objects: a net inward transference is responsible for the matter transport, at the same time that an outward angular momentum transference takes place. Moreover, the presence of turbulence in these structures are also of exterme importance in models of disk evolution, having a key part in the growth and evolution of solids in the first phases of planet formation Armitage (2011).

Throughout the years, multiple mechanism responsible for the angular momentum transport in accretion disks have been proposed, such as the baroclinic instability (Klahr & Bodenheimer 2003), a hydrodinamical instability associated with the thermal structure of the disk and the self-gravity, (e.g. Lin & Pringle (1987)). However, nowadays, the most accepted mechanism is a MHD instability, proposed by Balbus & Hawley (1991), the Magneto-Rotational Instability (MRI), which, besides promoving the angular momentum transportation, also is responsible for invoking the turbulence in the disk. However, in order to arise, the MRI demands the particles to be coupled with the magnetic field lines. Thus, the temperatures must be high in the regions affected by the MRI, which do not occur in the T Tauri disks when only the viscous dissipation of the standard model, proposed by Shakura & Sunyaev (1973), is acting. Thereby, extra heating mechanisms acting in the disk are required to guarantee the occurrence of the MRI.

The damping of Alfvén waves was considered in multiple works in the literature as a possible extra heating source in disks associated with low-mass PMS stars (e.g. Vasconcelos, Jatenco-Pereira & Opher (2000), Jatenco-Pereira (2013) and Jatenco-Pereira (2015)). In the present work, we consider the coupling of two of the mechanisms considered by Vasconcelos, Jatenco-Pereira & Opher (2000): the turbulent and non-linear dampings, as an extra hating mechanism of T Tauri accretion disks.

2. The model

It was considered a disk that follows both the α-parametrization proposed by Shakura & Sunyaev (1973) and the layered model of Gammie (1996). Furthermore, if we assume that we are treating a geometrically thin and optically thick disk, we get that the released energy for each of the heating mechanims is related to the temperature accordingly to the black-body law:

$$T^4 = \frac{D}{\sigma}, \tag{1}$$

where D corresponds to the released energy and σ is the Stefan-Boltzmann constant.

It was also assumed that the quadractic velocity dispersion is given by:

$$< \delta v^2 >= f\left(\frac{1}{4}\frac{v_A^2 B^3}{A^2 c_s^2 \rho^2}\right), \tag{2}$$

where f is a free parameter related to the flux of Alfvén waves in the medium, v_A is the Alfvén velocity, B is the magnetic field strenght, c_s is the sound velocity, ρ is the volumetric density and A is a numerical constant, yielding to a damping rate of

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

for the mechanism that couples both the turbulent and non-linear dampings.

3. Results and discussion

Using the damping rate given in Equation 3, it was obtained the amount of energy dissipated by the coupled mechanim, through

$$D = \int_0^H \frac{\Phi}{v_A}\Gamma dz, \tag{4}$$

where Φ is the Alfvén wave flux, $\Phi = < \delta v^2 > /\rho$ and H is the scale height of the disk.

In Figure 1, we show one of our results, consisting of a disk with $M_* = 0.5\, M_\odot$, $\dot{M} = 10^{-8}\, M_\odot/yr$, $\alpha = 0.02$ and $f = 0.002$.

4. Conclusions

In order to achieve the coupling of the non-linear and turbulent damping and maximize the heating, it was necessary to abandon the equipartition proposed by Vasconcelos, Jatenco-Pereira & Opher (2000), which made the models constant with the disk parameters except for the free parameter, f. From Figure 1, we can conclude that the new damping mechanism of Alfvén wave proposed by us, generate higher temperatures that when the turbulent and non-linear mechanisms are considered independently. Thus, this new mechanism, although quite simple in its definition, proved itself to be of good importance in heating the disk, and, consequently, diminishing the size of the quiescent zone Gammie (1996), improving, significantly, the area in which the MRI can occur.

In the future, we intend to improve this coupling mechanism, through the consideration of new heating sources, such as the resonant damping of surface Alfven waves.

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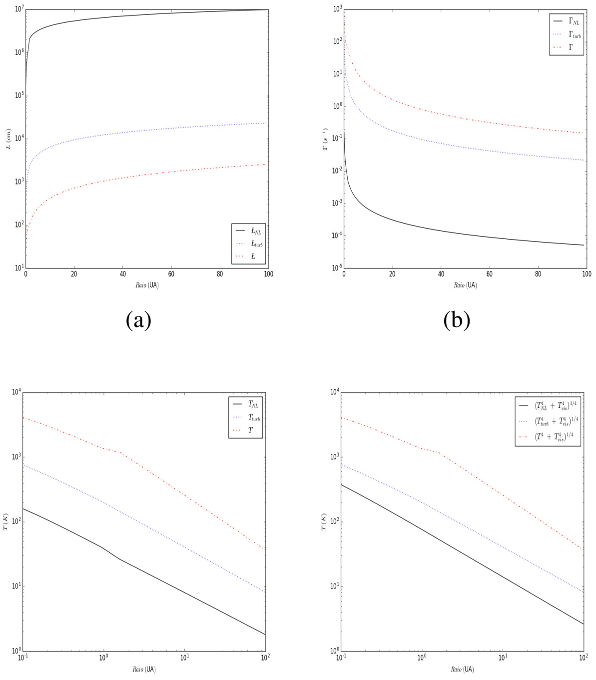

(a) (b)

(c) (d)

Figure 1. In the plot, it is shown the behaviour of some properties of the damping mechanisms, as a function of the radial distance. For comparison purposes, we show the evolution of the parameters for the three mechanisms considered: the non-linear, turbulent and coupled mechanism. In (a), we show the profiles for the damping length, in (b) the profiles for the damping rate and in (c) and (d), the temperatures without and with the viscous dissipation, as proposed by Shakura & Sunyaev (1973), respectively.

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