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# ALFVÉNIC HEATING OF ACCRETION DISKS

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RESUMEN

Investigamos los efectos del calentamiento generado por la disipación turbulenta y nolineal de ondas de Alfvén. Nuestros resultados dependen de dos parámetros: $f = \delta v/v_A$, que es una medida del nivel de turbulencia y $F = \varpi/\Omega_i$ que es la frecuencia promedio de las ondas ($\delta v$, $v_A$ y $\varpi$ son la amplitud, velocidad y frequencia de las ondas de Alfvén y $\Omega_i$ es la frecuencia ciclotrón de los iones). Sólo se estudia una fracción pequeña del disco, de 0.1 AU a 1.4 AU. Comparado con el calentamiento de la disipación viscosa, encontramos que el calentamiento Alfvénico es importante para $R > 0.5$ AU. La temperatura aumenta, aumentando el grado de ionización del sistema. El incremento de temperatura es mayor cuando se incluye la radiación de la estrella central. La influencia de la inestabilidad magnetorotacional se extiende a una mayor parte del disco debido al calentamiento Alfvénico.

ABSTRACT

In this work, we investigate the effects of heating generated by nonlinear and turbulent damping of Alfvén waves. Our results are a function of two parameters: $f = \delta v/v_A$, which is a measure of the degree of turbulence, and $F = \varpi/\Omega_i$, which is the average frequency of the waves ($\delta v$, $v_A$ and $\varpi$ are the amplitude, velocity and frequency of the Alfvén waves, respectively, and $\Omega_i$ is the ion cyclotron frequency). Only a small portion of the disk is studied, ranging from 0.1 AU to 1.4 AU. We find that, when compared with the heating generated by viscous dissipation, the Alfvénic heating is important for $R > 0.5$ AU. An increase in temperature occurs, which causes an increase in the degree of ionization of the system. When irradiation from the central star is taken into account the increase in temperature is much more significant. Due to Alfvénic heating, the influence of the magnetorotational instability extends to a greater part of the protostellar accretion disk.

*Key Words:* **ACCRETION DISKS — MHD — STARS: PRE-MAIN SEQUENCE — WAVES**

## 1. ALFVÉNIC HEATING

In this work, we study two damping mechanisms of Alfvén waves, both nonlinear and turbulent. In nonlinear damping, waves of great amplitude interact to create magnetosonic waves, which are easily damped. Energy from the waves is thus transfered to the medium as thermal energy. The turbulent damping proceeds as a cascade of energy from large to small scale, where microscopic processes dissipate the energy of the wave.

We assume that Alfvénic heating is an additional source of energy, acting together with viscous dissipation. In order to evaluate the energy transfered by the damping process, we need to know the damping length or the rate of damping. A more comprehensive derivation of the following equations can be found in Vasconcelos, Jatenco-Pereira, & Opher (2000). The energy dissipated by the nonlinear and turbulent damping of Alfvén waves is given by

$$D_{NL} = \frac{\sqrt{2}}{4} f^4 F \frac{e\xi}{m_i c} \left(\frac{\gamma \Re}{\mu}\right)^{1/2} \int_0^H (\rho T)^{1/2} B^2 dz \quad , \tag{1}$$

$$D_T = \left(\frac{f}{\sqrt{4\pi}}\right)^3 2\int_0^H B^{7/2}\rho^{-1/2}dz \quad , \tag{2}$$

where $e$ is the electric charge, $\xi$ is a constant, $m_i$ is the ion mass, $c$ is the velocity of light, $\gamma$ is the adiabatic coefficient, $\Re$ is the gas constant, $\mu$ is the mean molecular weight, $\rho$ is the density, $T$ is temperature and $B$ is the magnetic field, assumed to be vertical and uniform.

We study three different situations in two disk models: 1) the standard, optically thick, geometrically thin, stationary accretion disk, and 2) the layered model disk of Gammie (1996). The different profiles considered are: i) constant density and temperature, ii) varying density ($\rho = \rho_0 \exp(-z/H)$) and constant temperature, iii) varying density ($\rho = \rho_0 \exp(-z/H)$) and temperature ($T = T_0 \exp(-z/H)$).

## 2. RESULTS AND DISCUSSION

Nonlinear Alfvénic heating is found to be more important than viscous dissipation in the outer part of the disk region considered ($R > 0.5$ AU). For all profiles the Alfvénic energy dissipation is greater than viscous dissipation. Irradiation by the central star is very important for all radii and if we have nonlinear Alfvénic heating and irradiation acting at the same time in the disk, the increase in temperature is significant. Temperatures obtained with Alfvénic dissipation in the model of the layered disk are the highest, for $R > 0.2$ AU. The energies deposited by turbulent damping of Alfvén waves are very high, as compared with viscous energy. Dissipation of turbulent energy is important for all radii considered, even when irradiation is taken into account.

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