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MHD WAVES IN STELLAR WINDS AND ACCRETION DISKS

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RESUMEN

Las ondas de Alfvén han sido usadas para explicar el calentamiento de las coronas estelares y de la producción de vientos estelares en varias zonas del diagrama Hertzsprung-Russell (HR). Las ondas fueron usadas como un mecanismo importante en la aceleración del viento de protoestrellas, de estrellas de tipos tempranos y tardíos y del viento solar. También son importantes en la creación de inhomogeneidades, vía las inestabilidades térmicas, en vientos de estrellas de tipo temprano. Por otro lado, el calentamiento generado por la disipación no lineal y turbulenta de las ondas puede ser una fuente importante de energía para ionizar discos protoestelares, permitiendo el transporte de momento angular mediante la inestabilidad de Balbus-Hawly (BHI). Analizamos el papel de la disipación de ondas de Alfvén en las regiones medias e internas de los discos protoestelares ($0.1 < R(\mathrm{AU}) < 1.4$). Demostramos que cuando la disipación viscosa es insuficiente para mantener la ionización requerida por la BHI, el amortiguamiento de las ondas de Alfvén puede ser una fuente alternativa de energía para la ionización.

ABSTRACT

Alfvén waves have been used to explain the heating of stellar coronae and the production of stellar winds in many regions of the Hertzsprung-Russell (HR) diagram. The waves were used as a major acceleration mechanism in the wind of protostars, late-type stars, early-type stars and in the solar wind. They are also very important in the creation of inhomogeneities in the wind of early-types stars via thermal instability. On the other hand, Alfvénic heating generated by nonlinear and turbulent damping can be an important source of energy for ionizing protostellar disks, enabling angular momentum transport to occur through the Balbus-Hawley instability (BHI). We analysed the role of the damping of Alfvén waves in the inner and intermediate regions of protostellar disks ($0.1 < R(\mathrm{AU}) < 1.4$). We show that when viscous dissipation is insufficient to ensure the necessary degree of ionization for BHI to occur, the damping of Alfvén waves can be an alternative source of energy for ionization.

Key Words: **ACCRETION DISKS — MHD — STARS: EARLY-TYPE — STARS: LATE-TYPE — STARS: PRE-MAIN SEQUENCE**

1. ALFVÉN WAVES IN STELLAR WINDS

We suggested that Alfvén waves are created above the steep density gradients present near the photosphere of the stars and studied the momentum deposition in the wind.

We used a flux of Alfvén waves as a major acceleration mechanism to explain the winds of: the Sun, hot stars, protostars and late-type stars (Jatenco-Pereira & Opher 1989a, 1989b, 1989c; Dos Santos, Jatenco-Pereira, & Opher 1993; Jatenco-Pereira, Opher, & Yamamoto 1994). We applied the following damping mechanisms for the waves: 1) nonlinear damping, 2) resonace surface damping, and 3) turbulent damping. The model is based on our knowledge of the magnetic structure of the Sun. We used a diverging geometry for the magnetic field lines and, in particular, we showed that to a obtain large terminal wind velocity, u_∞, we need a combination of both a slow divergence up to a height r_t and a rapid divergence thereafter. On the other hand, a terminal wind velocity, u_∞, less than the escape velocity, v_{e0}, can be obtained with an initially diverging geometry.

Our results showed that, taking into account Alfvén wave momentum deposition in the wind, we can explain the observational data with reasonable Alfvén wave fluxes damping lengths and periods.

We have also investigated the possible importance of Alfvén waves in the creation of inhomogeneities in the winds of Wolf-Rayet stars via thermal instability. This study is based on the wind acceleration model for Wolf-Rayet stars developed by Dos Santos et al. (1993), in which Alfvén waves act jointly with radiation pressure. The heat-loss function includes: thermal bremsstrahlung, radiative losses via resonant transitions, heating from recombination and photoionization, Compton heating-cooling, and heating by Alfvén waves with damping due to nonlinear and turbulent mechanisms (Gonçalves, Jatenco-Pereira, & Opher 1998).

We found solutions that show three equilibrium regions: 1) one stable region representing the diffuse medium, 2) one unstable region, and 3) another stable region representing the condensations. We showed that the two stable equilibrium regions can exist over the range of pressures that describe the diffuse medium and the clumps.

2. ALFVÉN WAVES IN PROTOSTELLAR ACCRETION DISKS

The presence of the magnetorotational instability (Balbus & Hawley 1991, 1998) in protostellar accretion disks is uncertain because of the low temperatures. If only viscous dissipation is taken into account, only small regions near the star can reach the necessary degree of ionization to ensure the development of this instability. If we consider irradiation from the central star, the temperature increases. However, if we assume that the disk has a magnetic field (Tamura et al. 1999), another mechanism can be considered: the damping of Alfvén waves. These waves are produced in a turbulent medium, as is expected for an accretion disk, and can be damped by several mechanisms (Kulsrud & Pearce 1969; Melrose 1980; Holzer, Flá, & Leer 1983). The damping of these waves loses their energy and ultimately transfers it to the medium as thermal energy.

In this work, we study two damping mechanisms: nonlinear and turbulent. In order to evaluate the energy transfered by the damping process we need to know the rate of damping or the damping length. The derivation of the equations for the energy dissipated by the nonlinear and turbulent damping of Alfvén waves can be found in Vasconcelos, Jatenco-Pereira, & Opher (2000).

We assume three different situations in two disk models: the standard, optically thick, geometrically thin, stationary accretion disk and 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 ($T = T_0 \exp(-z/H)$).

Our results show that nonlinear Alfvénic heating is more important than viscous dissipation in the outer part of the disk region considered ($R > 0.5$ AU). For all profiles adopted, the Alfvénic energies are greater than viscous dissipation. Irradiation is very important for all radii and if we can have nonlinear Alfvénic heating and irradiation acting at the same time in the disk, the increase in temperature is very significant. The energies obtained from turbulent damping of Alfvén waves are very high, when compared with viscous energy. The dissipation of turbulent energy is very efficient for all radii considered, even when irradiation is taken into account. We must note, however, that the damping mechanisms depend themselves on the ionization degree that they help to increase. We can not have this mechanism working in a region where the magnetic field is totally separated from the neutral part of the gas.

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