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GLOBAL ALFVEN WAVES IN SOLAR PHYSICS: CORONAL HEATING

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RESUMEN. Se ha demostrado que la onda discreta de Alfvén puede generar por lo menos un 20% de la energía coronal requerida con densidad de flujo de $\cong 10^{-3}$ erg cm^{-3} s^{-1}. Las ondas discretas de Alfvén son una nueva clase de ondas de Alfvén las cuales pueden describirse por el modelo con que incluye un ión finito, con frecuencia ciclotrónica ($\omega/\omega ci \neq \theta$) y los efectos del equilibrio de plasma mostrados por Appert, Vaclavik and Villar 1984.

ABSTRACT. It has been shown that the Discrete Alfvén wave can power at least 20% of the required coronal energy flux density $\cong 10^{-3}$erg cm^{-3} s^{-1}.
Discrete Alfvén waves are a new class of Alfvén waves wich can be described by the model with the inclusion of finite ion cyclotron frequency ($\omega/\omega ci \neq \theta$) and the equilibrium plasma current effects as shown by Appert, Vaclavik and Villar 1984.

Key words: HYDROMAGNETICS — SUN-CORONA

I. INTRODUTION

The mechanism wich converts the kinetic energy of the solar photosphere and convection zone into the termal energy of the corona has been investigated for some decades Hollweg 1982. However, no completely convincing coronal heating theory has yet arised (e.g., Gordon and Hollweg 1983). MHD surface waves has been considered as one of the best candidate for coronal heating, for these waves can propagate energy along the magnetic field, and in this respect they are very similar to the usual WKB MHD shear Alfvén wave mode ($\omega = k_{..} v_A$) widely investigated in this context (e.g. Gordon and Hollweg 1983). Hollweg (1982) has pointed out that surface wave can be dissipated by viscosity, heat conduction, radiation or by Cherenkov damping (Landau damping and (or) transit-time magnetic pouping) in a collisioness plasma. However, none of these mechanisms can explain the coronal heating.

In this paper we first propose the discrete Alfvén wave as a candidate for coronal heating because these waves can propagate energy almost along the magnetic field, and in this respect they are also very similar to the usual WKB MHD shear Alfvén wave. Furthemore, since in Tokamak plasmas their propagation disturbs all plasma column. The term discrete is just because these nodes lie below the Alfvén continuum that occurs in inhomogeneous plasmas (see Appert et all. 1984). The C G S sistem of units is used throughout this paper.

II. DISPERSION RELATION FOR THE ALFVÉN WAVE IN A COLD CURRENTELESS HOMOGENEOUS PLASMA

In our paper, we are interested in exploring the potential of the discrete Alfvén wave to propagate in the solar atmosfere as well as to dissipate their energy via collisional and collisionless damping there. Therefore, rather than complicated geometric details wich are out of the scope of this paper, we adopt a very simple model in wich the underlying physics can be brought out. This means that the basic information in the dispersion relation is kept that is $:\omega = k_{..} v_A$ - first order corrections (due to the equilibrium current and (or) $\omega/\omega_{ci} \neq \theta$) .Our simple model has to include a correction in the dispersion relation wich is of first order for tomak plasmas. This model is discribed as following : we consider a homogeneous infinite plasma in wich the ambient magnetic field lies in the z-direction. In this formulation no equilibrium magnetic field geometrical effects are taken into account in the dispersion relation. The dispersion relation for MHD waves in this approximations and in the range $\omega << (\omega_{ce}\ \omega_{ci})^{1/2}$ is given as follows (Akhiezer 1975)

$$N^2 \cos^2\theta - \varepsilon_{xx}(1 + \cos^2\theta)N^2 + \varepsilon_{xx}^2 - \varepsilon_{xy}^2 = \theta \qquad (1)$$

where N is the refractive index, θ is the angle between the total wave vector $\vec{K}$ and the ambient magnetic field, ε_{xx} is the xx-component of the dieletric tensor $\overleftrightarrow{\varepsilon}$ and ε_{xy} is the xy-component of the dieletric tensor ε

Equation (i) represents the dispersion relation for the fast magnetosonic and whistler waves if we assume the + sign, using the - sign we obtain the dispersion relation for the WKB MHD shear Alfvén wave, and for our modeled discrete Alfvén wave. Note that, if we assume $\omega << \omega_{ci}$ eq. (2) becomes the previous dispersion relation for the WKB MHD shear Alfvén wave ($\omega = K_{..} V_A$).

III. COLLISIONAL AND COLLISIONLESS DAMPING OF THE DISCRETE ALFVÉN WAVES

Since the discrete Alfvén waves have much of the physical properties of the usual WKB MHD shear Alfvén wave, it is reasonable to assume that their non-resonant collisional damping coefficient is almost the same. Therefore, we can get these coefficients from Braginskii 1965, pgs. 302 to 303.

The discrete Alfvén wave can also be collisionless dissipated via Cherenkov damping (Cd) Landau damping (Ld) and transit-time magnetic pumping (ttmp)] and the cyclotron damping (c). The Cherenkov damping occurs via the E_z (Ld) and B_z (ttmp) wave fields, and the cyclotron damping occurs via the $E_\perp$ field. E_z , B_z and $E_\perp$ are the waveelectric field parallel to the ambient magnetic field, the wave magnetic field parallel to the ambient magnetic field, and the wave electric field perpendicular to the ambient magnetic field, respectively. The Cherenkov damping coefficient for the discrete Alfvén wave can be obtained following Assis and Busnardo-Neto 1987.

The result is:

$$\frac{I^c_m\,\omega}{\omega} \cong \left[\frac{\pi}{8}\right]^{1/2} \cdot \left\{\frac{m_e\, v_{the}}{m_i\, v_A}\right\} \cdot$$

$$\left\{\left[\frac{\omega^2}{\omega_{ci}^2\,(1-\omega^2/\omega_{ci}^2} \cdot \frac{K^2}{K_z^2}\right] + \right.$$

$$\left.\left[\frac{\omega^2\,[1-\omega^2/\omega_{ci}^2]}{K^2} \cdot \frac{K^2\,K_z^2}{(K^2\,\omega_{ci}^2 + K_z^2\,\omega^2)}\right]\right\} \qquad (3)$$

The cyclotron damping coefficient is given by Akhiezer 1975.

IV. CORONAL HEATING

At that point it is necessary to compare the spectral energy flux density of the discrete Alfvén wave with the required 10^{-3} ergs $cm^{-3}\,s^{-1}$ (see Hollweg 1985) to power the coronal loop.

The spectral energy density for the discrete Alfvén wave is given by Azevedo and de Assis 1988 and the spectral energy flux density is given as follows

$$p_{\vec{k}} = 2\, I_m\, \omega \,.\, U_{\vec{k}} \qquad (6)$$

To obtain a numerical value for $P_{\vec{k}}$, we use the following data (see Hollweg 1985) equilibrium magnetic field: 50 gauss, density: 3×10^9 cm^{-3} , temperature:2.5×10^6 , coronal loop lenght: 10^{10} cm, coronal loop radius: $.5 \times 10^8$ cm. Using these values to calculate the damping coefficients, collisional and collisionless,described in previus sections, we conclude that:

$$\frac{I_m^v \omega}{\omega} \cong 0{,}56 \times 10^{-6}$$

and

$$\frac{I_m^j \omega}{\omega} \cong \frac{I_m^d \omega}{\omega} \cong \frac{I_m^f \omega}{\omega} \cong \frac{I_m^{cd} \omega}{\omega} \cong \frac{I_m^c \omega}{\omega} << \frac{I_m^v \omega}{\omega} .$$

Note that we have used the dispersion relation of the modeled discrete Alfvén wave given by Eq. (2). We see that the only relevant collisional mechanism is the viscosity. To obtain $U_{\vec{k}}$ we have assumed δv_{rms} =30km/s (Hollweg 1984), δv_{rms} is related to the wave magnetic field by the expression below:

$$\delta v_{rms} = \frac{\delta_B}{(4\pi\rho)^{1/2}}$$

where

$$\delta_B = \frac{K_z \cdot c}{\omega} \delta E .$$

The spectral energy density is:

$$U_{\vec{k}} = \frac{1}{8\pi} \left[\frac{c}{v_A}\right]^2 |\delta E|^2 .$$

Using now the coronal data we find: $U_{\vec{K}} = 10^2$ erg cm^{-3} s^{-1}.

The better result for $P_{\vec{k}}$ is given by the viscosity:

$$P_{\vec{k}} = 2\, I_m^v \omega \quad U_{\vec{k}} = 1.6 \times 10^{-4} \text{ erg cm}^{-3} \text{ s}^{-1}$$

Comparing with the powe density to mantain the coronal flux $\cong 10^{-3}$ erg cm^{-3} s^{-1}, we conclude that the viscosity can be responsable for at least 0.2×10^{-3} erg cm^{-3} s^{-1},it means that discrete Alfvén mode can power at least 20% of the required coronal energy flux density via collisional (viscosity) damping.

In short, we have studied the coronal heating by the collisional and collisionless damped discrete Alfvén wave. We have shown that the relevant collisional mechanism to account for the heating is the viscosity, and also that its contribuition is at least 20% of the required energy flux density to power an active coronal loop. The collisonless mechanisms (Landau Damping, transit-time magnetic pumping and cyclotron dampind) are not very important since in coronal plasmas $\omega << \omega_{ci}$ and $v_A >> v_s$.

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