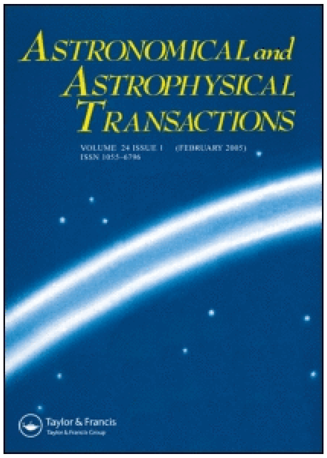

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TRANSVERSE MAGNETOHYDRODYNAMIC WAVES IN A STRATIFIED PLASMA

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Waves in an isentropic and stratified stellar atmosphere with an embedded uniform magnetic field are considered in one-dimensional nonlinear analytical approach. A corrected source function and a wave equation are obtained for the case of vertical transverse magnetohydrodynamic propagation.

Keywords: Magnetohydrodynamics; Magnetoacoustic waves; Stratified atmosphere

1 INRODUCTION

It is generally believed that the heating of the stellar corona is caused by magnetohydrodynamic (MHD) waves originating from the photosphere (Ferrarro and Plumpton, 1958). Stellar atmospheres are in general case permeated by magnetic fields, which complicates the behaviour of wave propagation (Kalkofen, 1989). The heating mechanism of stellar atmospheres has to satisfy observational facts summarized by Ulmschneider and Stein (1982). Based on the work done by Musielak and Rosner (MR) (1987), in this paper a theoretical study of transverse vertical wave propagation in an isentropic, stratified and magnetized stellar atmosphere is performed.

2 THE INHOMOGENEOUS WAVE EQUATION

To describe an isentropic plasma in a constant gravity field, we shall use the fundamental MHD equations coupled with the isentropic equation of state. The standard MHD notation is used; the vector $\boldsymbol{B}$ describes the magnetic field, $\boldsymbol{g}$ represents the gravitational acceleration vector and $\boldsymbol{v}$, ρ and p are the velocity vector, mass density and pressure of plasma, respectively. μ_0 is magnetic permeability constant and γ is the ratio of the specific heats.

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We set the Cartesian coordinate system such that the atmosphere is assumed to be a stratified plane with constant gravity acceleration $\boldsymbol{g} = -g\boldsymbol{e}_z$ and suffused by a uniform magnetic field $\boldsymbol{B}_0 = B_{0x}\boldsymbol{e}_x + B_{0z}\boldsymbol{e}_z$. The y component B_{0y} of the magnetic field can be set to zero, without any loss of generality, by simple rotation of the coordinate system around the z axis.

In the equilibrium state, variations in the mass density and pressure with height z are exponential with the scale height $H = a^2/g\rho$, where $a = (\gamma p_0/\rho_0)^{1/2}$ is the speed of sound.

The fundamental MHD equations can be perturbed in such a way that $\boldsymbol{B} = \boldsymbol{B}_0 + \boldsymbol{B}'$, $\rho = \rho_0 + \rho'$, $p = p_0 + p'$ and $\boldsymbol{v} = \boldsymbol{v}'$. All perturbed quantities are assumed to depend only on z and t. Following the same approach as in equations (2.2a)–(2.2g) of the paper by MR, we isolated all perturbation quadratic terms on the right-hand side.

Because of the symmetry in a stratified system, transverse and longitudinal modes must exist. To solve the nonlinear system (the MR equations (2.2a)–(2.2g)), we assume that all nonlinear terms are known. The expression for the longitudinal mode has been given by MR. To obtain the wave equation for the transverse mode, the continuity equation can be substituted into a combination of the MR equations (2.2b) and (2.2e). After combining those with the MR equations (2.2c) and (2.2f) we obtain the wave equation

$$\left[\hat{W}_{\mathrm{T}}\left(\hat{D}_{\mathrm{A}z} - \frac{v_{\mathrm{A}z}^2}{H}\frac{\partial}{\partial z}\right) - \hat{D}_{\mathrm{T}}\right]B'_x = S_{\mathrm{T}}(z, t), \tag{1}$$

where the operators $\hat{W}_{\mathrm{T}}$, $\hat{D}_{\mathrm{A}z}$ and $\hat{D}_{\mathrm{T}}$ are defined as

$$\hat{W}_{\mathrm{T}} = \frac{\partial^2}{\partial t^2} - a^2\frac{\partial^2}{\partial z^2} + \frac{a^2}{H}\frac{\partial}{\partial z},$$
$$\hat{D}_{\mathrm{A}z} = \left(\frac{\partial^2}{\partial t^2} - v_{\mathrm{A}z}^2\frac{\partial^2}{\partial z^2}\right)$$

and

$$\hat{D}_{\mathrm{T}} = v_{\mathrm{A}x}^2\left(\frac{\partial}{\partial t}\right)^2\left(\frac{\partial^2}{\partial z^2} + \frac{1}{H}\frac{\partial}{\partial z}\right).$$

The components of the Alfvén velocity are determined from $v_{\mathrm{A}[x,y]}^2 = B_{0[x,y]}^2/(\mu_0\rho_0)$. In the MR equation (3.14) the term $-(v_{\mathrm{A}z}^2/H)(\partial B'_x/\partial z)$ has been neglected. However, that term can be neglected only when $H \to \infty$. The source function $S_{\mathrm{T}}(z, t)$ is

$$S_{\mathrm{T}}(z, t) = \hat{W}_{\mathrm{T}}\left[B_{0z}\frac{\partial}{\partial z}\left(\frac{n_3}{\rho_0}\right) + \frac{\partial n_6}{\partial t}\right] - B_{0x}\frac{\partial}{\partial t}\left[\frac{\partial^2}{\partial t\,\partial z}\left(\frac{n_5}{\rho_0}\right) - \left(\frac{1}{H} + \frac{\partial}{\partial z}\right)\left(\frac{\partial n_2}{\partial z} + n_1 g\right)\right].$$

In the MR equation (3.15), the third term has the wrong partial derivative, the fourth term has the incorrect signum, and the last term must contain g. The last error arises from the MR equation (3.12).

3 CONCLUSIONS

We have found the transverse inhomogeneous wave equation and the source function for a vertical propagation of magnetoacoustic waves in a stratified stellar atmosphere suffused by a uniform magnetic field. The same problem has already been studied by MR; however, their conclusions are incomplete in the light of the results presented here.

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