Rev. Mexicana Astron. Astrof., **21**, 538-540 (1990)

NONLINEAR PROPAGATION OF MAG WAVES THROUGH THE TRANSITION REGION[1]

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RESUMEN. Una onda de gravitación magneto acústica (GMA), se inicia en el regimen de alta beta cerca de la basa de fotósfera solar y es seguida, usando simulaciones numéricas, mientras viaja radialmente a través de la cromosfera, la región de transición y dentro de la corona. Se han seleccionado parámetros iniciales de manera que la beta resulte menor que uno cerca de la parte alta de la región de transición. Nuestro interés máximo se concentra en la cantidad y forma del flujo de energía que puede ser llevada por la onda hasta la corona dados una atmósfera inicial y amplitud de onda específicas. Según los estudios a la fecha, el flujo de energía térmico domina, aumentando linealmente con la amplitud deonda y resulta de aproximadamente 10^5 ergs/cm^2-s en una amplitud de 0.5. El flujo de energía cinética siempre permanece despreciable, mientras que el flujo de energía magnética depende de la orientación inicial del campo. Un modo GMA rápido y casi paralelo, el cual es esencialmente un modo MHD en la corona se convierte a un modo rápido modificado y a uno lento, cuando la beta atmosférica disminuye a uno.

ABSTRACT: A magneto-acoustic-gravity (MAG) wave is initiated in the high-beta regime near the base of the solar photosphere and followed, using numerical simulations, as it travels radially through the chromosphere, the transition region, and into the corona. Initial parameters are selected such that beta becomes less than one near the top of the transition region. Our primary interest is in the amount and form of energy flux that can be carried by the wave train into the corona for a specified initial atmosphere and wave amplitude. For the studies conducted to date, the thermal energy flux dominates, it increases about linearly with wave amplitude and becomes approximately 10^5 ergs/cm^2 - s at an amplitude of 0.5. The kinetic energy flux always remains negligible, while the magnetic energy flux depends on the initial field orientation. A nearly parallel fast MAG mode, which is essentially an MHD mode in the corona, converts to a modified fast and a slow mode, when the atmospheric beta decreases to one.

Key words: HYDROMAGNETICS — SUN-CORONA

I. INTRODUCTION

Some form of nonradiative energy input to the solar chromosphere and corona is necessary, since their temperatures are higher than they would be in a radiative equilibrium (Stein and Leibacher, 1974). In this sense, the propagation of waves and the possibility that

1. Research supported by NASA and NSF. Computations performed at Center for High Performance Computing at University of Texas at Austin.

the energy flux carried by the waves can contribute to the energy balance of the solar atmosphere has been investigated for years (e.g. Leroy and Schwartz, 1982; Schwartz and Leroy, 1982).

In the present study, we supplement previous work by extending the theory of magneto-acoustic-gravity (MAG) waves to the nonlinear regime and consider their propagation through the chromosphere, transition region, and corona. In particular, we are interested in determining the amount and form of energy flux thatcan be carried by the wave train from the chromosphere to the corona for a specified initial atmosphere and wave amplitude.

The magnetic field influences the plasma structure when the plasma beta (β), the ratio of plasma to magnetic pressure, is less than or on the order of unity. In this sense, we also study potential mode conversion of waves by allowing them to propagate from a high beta regime into an atmosphere with beta less than one.

II. ASSUMPTIONS AND GENERAL PROCEDURE

It is assumed that the solar atmosphere is initially in hydrostatic equilibrium and can be represented as a single fluid with negligible dissipation. The waves propagate radially, and the wave fluctuations are confined to the equatorial plane. The time-dependent, one-dimensional MHD equations can be written in MKS units in the equatorial plane of the spherical coordinate system (r, θ, ϕ) (e.g. Steinolfson, 1981), which are solved numerically using an explicit method.

In simulating the evolution of MAG waves through the solar atmosphere, we first obtain the solution of the steady state form of the MHD equations. This solution represents the ambient atmosphere through which the waves propagate.

To simulate the propagation of waves through the transition region, we assume the following temperature structure as a function of distance:

$$T(r) = T_t - (T_t - 1)\,\frac{\tanh[\delta(r-r_t)]}{\tanh[\delta(1-r_t)]}$$

where $T_t = (1/2)(T_{cor} + T_{chr})$, T_{cor} and T_{chr} are the coronal and chromospheric temperatures, respectively, and δ is a measure of transition region thickness. This temperature structure is shown schematically in Figure 1.

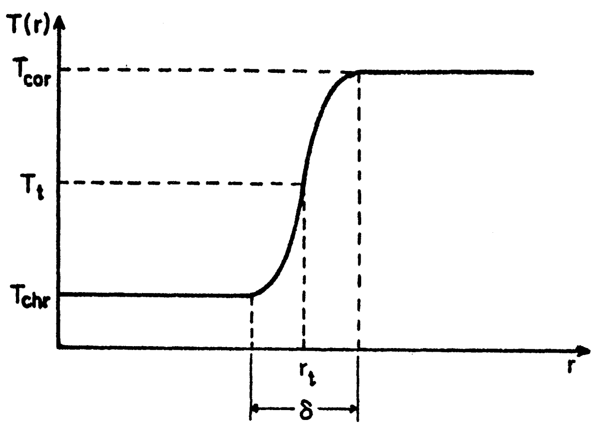

Figure 1. Structure of the temperature as a function of radial distance.

Once the steady state has been established, the next step is to introduce a perturbation representing the waves at the inner boundary in the simulation. We have conducted two different simulations:

a) to simulate the propagation of waves through the transition region, the inner boundary condition was taken at $T = T_{chr}$ (see Figure 1). For this case, we have evaluated the amount and form (kinetic, magnetic and thermal) of energy flux that can be carried by the wave train into the corona, for a specified atmosphere, as function of wave amplitude, as well as, the influence of the thickness of the transition region (δ) on the amount of energy flux that can be transmitted through it;

b) to study the potential mode conversion of the waves, we started the calculations at the coronal base where $T = T_{cor}$ (see Figure 1), and we selected the initial parameters such that the plasma beta in greater than one. The wave is initiated and followed as it propagates outward into an atmosphere in which beta becomes less than one.

In both cases (a and b), we specified the wave period τ and the pressure amplitude δp for the input wave at the lower boundary.

III. RESULTS

a) ENERGY FLUX TO THE CORONA

Our results show that the thermal energy flux dominates and increases about linearly with wave amplitude (for amplitudes larger than 0.05) and becomes approximately 10^5 ergs/cm^2-s at an amplitude of 0.5. The kinetic energy flux always remains negligible compared with the thermal and magnetic energy fluxes. The magnetic energy flux depends on the initial field orientation. For approximately radial fields, the magnetic energy flux is negligible, but it increases to about one-half the thermal energy flux when the initial radial and azimuthal fields are equal. The wave energy flux becomes substantially less than the input value and tends to asymptote to a constante value, of $\sim$ 30% of the initial value, after it enters well into the corona. Our analysis indicates that the total energy flux decreases with distance because some of the energy is used to move the material upward against gravity and to increase the internal energy of the system.

Our study of the influence of the thickness of the transition region (δ) on the amount of energy flux that can go through it, show that there is a tendency for thinner transition regions to allow larger energy flux and thereby provide more potential wave energy to heat the corona.

b) MODE CONVERSION

The results of this study show that a nearly parallel fast MAG mode, which is essentially an MHD mode in the corona, converts to a modified fast mode and a slow mode, which now carries the compression, when the atmospheric beta decreases to one. Similar mode conversion does not occur when the radially propagating wave is at a large angle to the initial magnetic field.

ACKNOWLEDGEMENTS

V. Jatenco-Pereira would like to thank the Institute for Fusion Studies, University of Texas at Austin, for its kind hospitality. R.S. Steinolfson was supported in part by NASA Grant NAGW-1324 and by NSF Grant ATM-8814443.

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