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Wave reflection in roAp stars

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Abstract. Our main goal with this work is to understand the role of the magnetic field in the process responsible for reflecting the waves in the surface layers of roAp stars. We argue that the magnetoacoustic solution decouples into two almost independent solutions in the outer atmospheric layers of the magnetic star. Moreover we describe how this fact can be used to calculate the amount of pulsating energy that is lost over each pulsation period when the frequency of the oscillation is above the acoustic cut-off frequency.

Key words. Stars: Chemically Peculiar – Stars: variables – Stars: Magnetic

1. Introduction

To study the energy properties of the oscillations observed in roAp stars we consider a very simple three layer model in a plane parallel geometry. The outer layers of the star are modeled by an isothermal atmosphere which is matched at the surface onto an index 3 polytropic interior. The three different layers of our model correspond to the interior, where $\beta \gg 1$ (β^{+}), the coupling region, where $\beta \sim 1$, and the outer layers of the star, where $\beta \ll 1$ (β^{-}) (cf. figure 1), with β defined as the ratio between the gas and the magnetic pressures. We assumed that the magnetic field is locally homogeneous and is inclined in relation to the local vertical coordinate. Different inclinations were considered (from vertical to horizontal).

2. Wave decoupling

To study the oscillations we start from the perturbed magnetohydrodynamic equations describing low amplitude, adiabatic, magnetically nondiffusive pulsations.

As known from previous works (e.g. Dziembowski & Goode 1996, Bigot et al. 2000, Cunha & Gough 2000, Saio & Gautschy 2004) in the coupling region the oscillation is an intricate magnetoacoustic wave and in the region where $\beta \gg 1$ the oscillation decouples into waves that are essentially acoustic and waves that are essentially magnetic.

Since in the region where $\beta \ll 1$ the perturbed Lorentz force is much greater than the gradient of the perturbed gas pressure, the former will dominate the restoring force for the displacement perpendicular to the magnetic field direction. Thus this displacement will be associated with a wave that is essentially magnetic in nature. Along the direction of the unperturbed magnetic field, however, the perturbed Lorentz force is zero, to first order, and we find a wave which is essentially acoustic. These two components have very different wavenumbers and are decoupled just as in the case of the interior. Since in our model the outer layers of the star are described by an

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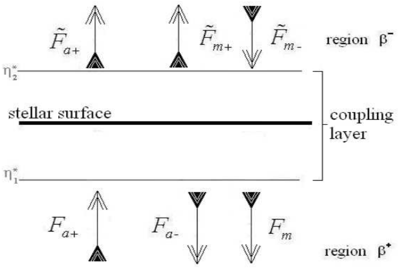

Fig. 1. Sketch of the different wave components

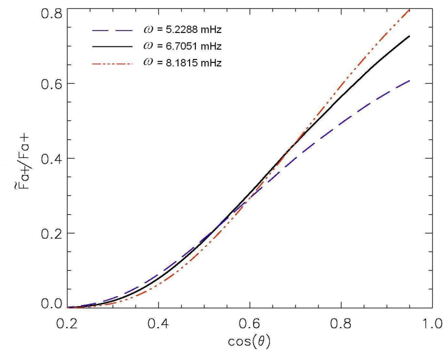

Fig. 2. The ratio $\tilde{F}_{a+}/F_{a+}$ as a function of co-latitude, θ, for a magnetic field of 6000 G. Different lines show different oscillation frequencies, all above the critical cut-off frequency.

isothermal atmosphere it is possible to find approximate analytic solutions for these two decoupled components of the displacement there.

3. Energy Fluxes

To study the energy properties of the oscillation in the different regions of the star we follow the approach used by Cunha & Gough (2000). Consider a wave that propagates upwardly from the interior of the star carrying an energy flux F_{a+}. At some point the wave is reflected, or partially reflected, and propagates downwardly again, back to the starting point (cf. Fig. 1). As a result of the magnetoacoustic coupling in the coupling region this wave transfers part of its energy to a slow Alfvénic wave which eventually dissipates in the β^+ region (Robert & Sowards 1983). Besides the energy that is lost through the downwardly propagating Alfvénic wave (which flux is represented by F_m) some energy might also be lost in the β^- region through the acoustic wave that propagates parallel to the magnetic field and which flux is defined as $\tilde{F}_{a+}$. This will happen if the oscillation frequency is above the critical cut-off frequency appropriate to that region. In Fig. 2 we show the ratio $\tilde{F}_{a+}/F_{a+}$ as a function of the inclination of the magnetic field. In practice we assumed that the magnetic field has a dipolar configuration and defined the local inclination in terms of the co-latitude θ.

As expected, the fraction of the energy flux carried by the acoustic wave is large near the pole, where the magnetic field is nearly vertical. However, as the field gets further inclined, that fraction gets relatively small.

4. Conclusion

In this work we emphasized that the problem of wave reflection in the atmosphere of roAp stars has to be analyzed in the context of magnetoacoustic waves. In this context only part of the energy is lost through the upwardly propagating acoustic wave in the atmosphere, even when the frequency of the oscillation is well above the local acoustic cut-off frequency.

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