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# Excitation of oscillations in roAp stars: the roles of He settling and winds

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## Abstract

The properties of the oscillations in rapidly oscillating Ap stars strongly depend on the chemical stratification of the star. In this paper we examine the effects of a large magnetic field and various chemical transport processes (convection, He settling, turbulence and mass loss) on the chemical composition of Ap stars and on their stability. We show that the stellar evolutionary models that best reproduce the observations are those with convection suppressed, He settling and no wind. In the region of the HR diagram where most roAp stars have been found, these models predict the excitation of high frequency p modes and the damping of low frequency p modes, as observed.

## 1. Introduction

The rapidly oscillating Ap stars are generally found in the main-sequence part of the classical instability strip, similarly to $\delta$-Scuti stars. However their oscillations show different properties. While the $\delta$-Scuti stars oscillate with periods of a few hours, the roAp stars oscillations are characterized by periods between 4 and 16 min. As one fundamental difference between the $\delta$-Scuti and roAp stars is the presence of large magnetic fields in the latter, the discrepancies observed in their oscillations are thought to be related to magnetic effects. These effects are both direct and indirect: direct because magnetic fields can change the geometry and the frequency of the oscillations (e.g. Dziembowski & Goode 1996, Cunha & Gough 2004, Saio & Gautschy 2004) and indirect because magnetic fields alter the transport of chemical species and consequently the chemical stratification, which is a key ingredient for the pulsations.

In this paper we focus on the indirect effects of the magnetic field and examine its influence on the chemical transport and stratification. In roAp stars the excitation mechanism of oscillations is thought to be strongly sensitive to the distribution of H and He, especially in their ionization regions where most of the driving and damping - through the $\kappa$-mechanism - is thought to take place. Therefore we concentrate our study on the H and He stratifications.

## 2. Stratification and magnetic field

Four chemical transport processes are thought to be determinant to the chemical stratification of Ap stars: convection, helium settling (and H levitation), stellar winds and turbulent motions. All these processes are affected by the magnetic field.

Works by Gough & Tayler (1966), Moss & Tayler (1969) and Balmforth et al. (2001) indicate that the strong vertical magnetic field present near the magnetic poles of roAp stars possibly suppresses convective motions. Near the magnetic equator, where the magnetic field is closer to horizontal, the suppression or the onset of convection is more difficult to establish. With this in mind we suppose in our computations that convection as well as turbulent motions are suppressed at all latitudes.

In a magnetic field the diffusion velocity component perpendicular to the magnetic field is reduced (Vauclair et al. 1979, Michaud et al. 1981). However this decrease is expected to be very small for helium and we neglect it in our computations.

The mechanism and the properties of stellar winds are poorly known in magnetic Ap stars and only upper limits are available for their mass loss rates (Brown et al. 1990, Lanz & Catala 1992). Besides this, in the presence of a magnetic field, a wind can freely flow only from the polar regions where the magnetic lines are open (e.g. Babel & Montmerle 1997), near the magnetic equator the wind is inhibated, what strongly breaks the spherical symmetry of the star. With this in mind, and because we are able de produce only spherical models, we compute models without wind and models with a mass loss consistent with the observed upper limits.

## 3. Stellar evolutionary models

We have computed models for 1.6, 1.8 and 2.0 $M_{\odot}$. As discussed above they include He settling with respect to hydrogen but no convection and no turbulent motions. The diffusion of metals is also neglected. For each mass, 3 models have been computed: one model without wind, one model with a small wind ($\dot{M} \simeq 4.10^{-14} M_{\odot}.yr^{-1}$) and one model with a stronger wind ($\dot{M} \simeq 12.10^{-14} M_{\odot}.yr^{-1}$). Figure 1 shows the evolutionary tracks of models without wind (the tracks for models including winds are very similar). As an example, Fig. 2 displays for the $1.8 M_{\odot}$ models the helium profiles inside the star at different evolutionary stages. When no wind is present, He simply sinks and the regions where H and He are ionized become rapidly poor in helium and rich in hydrogen. When a wind competes with He settling, an accumulation of helium takes place in the region where helium suffers its first ionization.

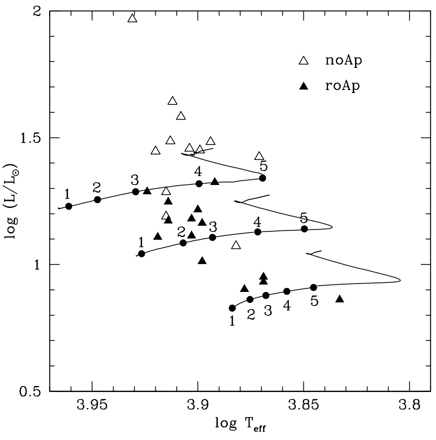

Figure 1: Evolutionary tracks of models without winds, upper track: $2.0M_{\odot}$, middle track: $1.8_{\odot}$, lower track: $1.6M_{\odot}$. Solid circles numbered from 1 to 5 correspond to different evolutionary stages. The triangles are observations by North et al. (1997)

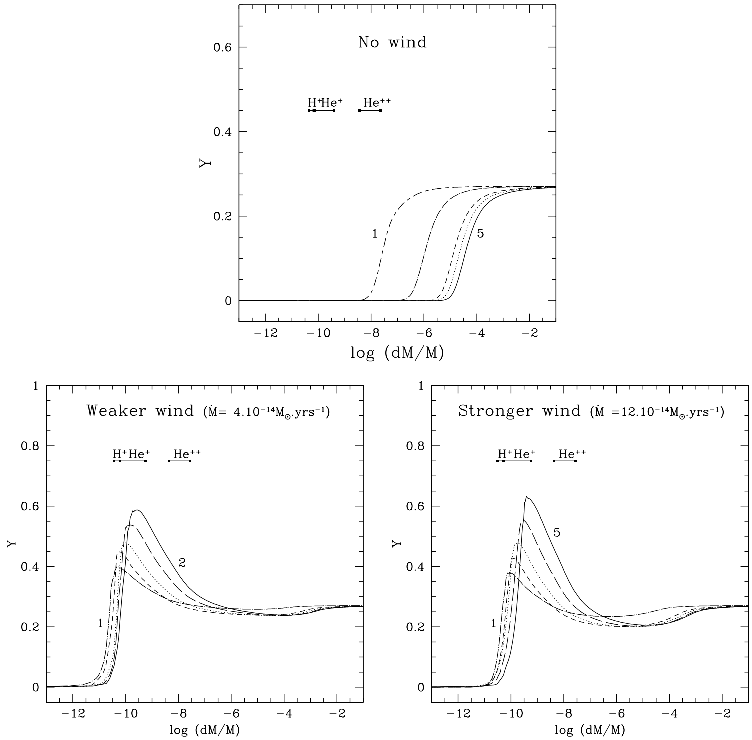

Figure 2: He profiles versus the outer mass fraction, for the 1.8 $M_\odot$ models (for stages 1 to 5 of Fig. 1). The H and He ionization regions are represented for models 5.

Figure 3 shows the results of the stability analysis of our models. As expected the frequencies of the excited modes are sensitive to the He stratification. High frequency modes are excited in all 1.8 and 2.0 $M_\odot$ models, even in models with homogenous chemical composition: it is the lack of convection which allows the excitation of high frequency modes. For these masses models with diffusion and no wind tend to show fewer unstable low order modes of the type observed in $\delta$-Scuti stars. In the 1.6$M_\odot$ model, which is located on the red edge of the instability strip, only low frequency modes are excited contrary to observations.

## 4. Conclusion

Models including He settling but no convection, no turbulent motions and no wind are those which best reproduce the observed properties of roAp star oscillations. Their chemical composition allow to excite the high frequency modes while damping the low frequency modes in the region where most roAp stars are found. However our models are not able to explain the position of the red edge of the instability strip which appears to be too hot in our computations. The fact that our best models are those without wind may be an indication that stellar wind is not a common phenomenon in roAp stars, although recent work by Saio (2005)

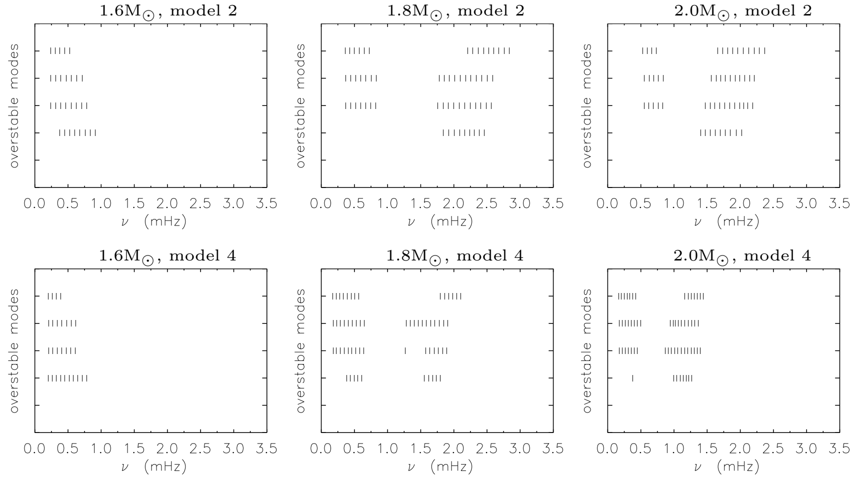

Figure 3: Stability analysis of our models. In each panel, results are given for the 4 different models: diffusion of helium only (bottom), diffusion of helium plus weaker wind (second from bottom), diffusion of helium plus stronger wind (third from bottom), for comparison, a model with homogeneous composition (but with convection suppressed) (top) is also shown. Each vertical dash corresponds to the frequency $\nu$ of an unstable mode. The convention for the models numbering is the same as in Fig. 1.

indicates that the direct effects of the magnetic field on oscillations may also contribute to damp the low frequency modes.

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