# Radiative Forces and Pulsations in $\beta$ Cephei Stars

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**Abstract:** Recently radiatively-driven diffusion in $\beta$ Cephei stars has been suggested as a possible explanation to account for excitation of the observed oscillation modes of the $\beta$ Cephei stars $\nu$ Eridani and 12 Lacertae. Preliminary results (Bourge and Alecian 2006) show that microscopic diffusion of iron could indeed occur in a region situated just above the opacity bump of the iron group elements. This diffusion has little influence on the position of the star in the HR diagram and on the spectrum of low radial order eigenfrequencies. It does however increase the number of excited frequencies. We show here that the ratio between the number of p-modes to the number of g-modes could be used as a signature of this diffusion process.

## 1 Introduction

Asteroseismologists use observed frequencies to get constraints on the internal structure of variable stars. In the case of $\beta$ Cephei stars, only a few frequencies are usually observed and they can rather easily be matched to theoretically excited frequencies. The oscillation modes can be identified and we can then get informations on the main stellar parameters of the star (i.e.: mass, metallicity, etc.), on the convective core overshoot, and on the internal rotation (in presence of multiplets), (see, e.g., 16 Lacertae (Thoul et al. 2003), HD 129929 (Aerts et al. 2003; Dupret et al. 2004)).

Recently, several authors have shown that it was not possible to reconcile the observed stellar oscillation spectrum to the theoretically calculated excited frequencies for several stars ($\nu$ Eridani and 12 Lacertae) by using 'standard' stellar parameters (Ausseloos et al. 2004, 2005; Pamyatnykh, Handler and Dziembowski 2004). Moreover the existence of $\beta$ Cephei stars in the LMC (Kołaczkowski et al. 2004) and even a few in the SMC (private discussion with A. Pigulski, paper in preparation) is also a puzzle to solve since Pamyatnykh (1999) showed that the lower part of the instability strip in the HR diagram of $\beta$ Cephei stars should almost vanish for metallicites below 0.01.

For $\nu$ Eridani, Ausseloos et al. (2004, 2005) have suggested global overabundances of iron or underabundances in hydrogen in the star to solve the problem of the mode excitation. Pamyatnykh et al. (2004) suggest an ad hoc local enhancement of iron in the driving region.

Global enhancement is hard to justify since no physical mechanism could easily explain it. For local enhancement, radiative levitation of iron is proposed as an explanation since it is shown to be already at work in other types of stars, such as in late B, A and F stars (Richard, Michaud and Richer 2001) or in sdB stars (Charpinet et al. 1996, 1997), which present the same driving mechanism for the oscillations (i.e.: $\kappa$-mechanism due to iron-group opacity bump) and the same range of effective temperature as the $\beta$ Cephei stars.

# 2 Radiatively-driven diffusion of iron in $\beta$ Cephei stellar models

We have shown through a preliminary study (Bourge and Alecian 2006, hereafter paper I) that the radiatively-driven microscopic diffusion of iron is likely to have a significant impact on the excitation of pulsation modes in $\beta$ Cephei stars. Indeed, we find that radiative accelerations on iron are much larger, by a factor of a hundred, than the local gravity (Cf. Fig. 1 of paper I), and the timescale of diffusion is smaller than the typical lifetime on the main sequence. Therefore chemical stratification can occur. The preliminary results show an enhancement of iron by more than a factor ten just above the opacity bump of the iron-group elements, i.e., the driving region of the $\kappa$-mechanism (Cf. Fig. 2 of paper I).

# 3 Effect of microscopic diffusion on the excitation of the pulsations

The detailed modus operandi we followed to investigate the effects of the microscopic diffusion of iron on the excitation of the pulsations is given in section 3 of paper I. We chose a 10 $M_\odot$ stellar model with no overshooting (Cf. table 1), we used the new solar abundances from Asplund, Grevesse and Sauval (2004), we used the stellar evolution code CLES (Scuflaire 2005), and the excitation of the pulsations were determined with the non-adiabatic code MAD (Dupret 2002).

Table 1: Stellar parameters of our reference model for the calculation of the effects of the radiatively-driven microscopic diffusion of iron.

| Mass | $X$ | $Z$ | $\alpha_{ov}$ |
|---|---|---|---|
| 10 $M_\odot$ | 0.7392 | 0.0122 | 0.0 |

In Fig. 1, we show the effect of the accumulation of iron just above the opacity bump for an abundance enhancement factor $\chi = 1, 2, 4$. $\chi$ is defined as the ratio of the abundance after diffusion to the initial abundance. This enhancement factor $\chi$ is reached after 20 Myr which is roughly the lifetime of a 10 $M_\odot$ star on the main sequence. We assumed linear evolution with time of the abundances. In Fig. 1, we show the spectrum of eigen frequencies versus the central hydrogen mass fraction $X_c$ for models having the same stellar parameters. Unstable oscillation modes are shown by filled symbols. The left panels are for a model without diffusion ($\chi = 1$). The middle and right panels correspond to models with diffusion, having respectively an enhancement factor $\chi = 2$ and 4. The top, middle and bottom panels show the spectrum of eigen frequencies respectively for oscillation modes of spherical degree $l = 0, 1, 2$.

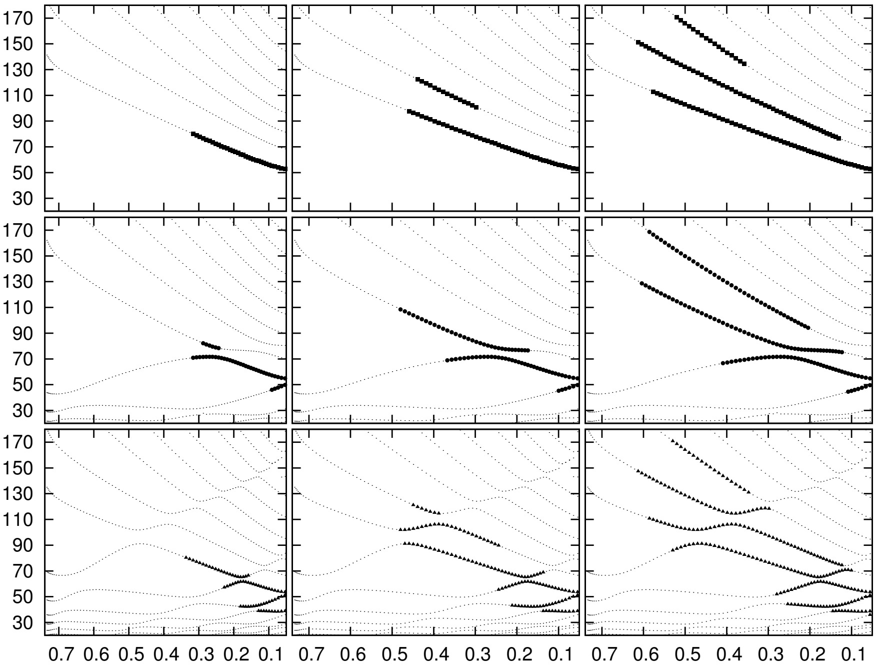


Figure 1: *Left panels:* Spectrum of eigen frequencies [$\mu$Hz] versus the central hydrogen mass fraction $X_c$ for a model without diffusion ($\chi = 1$). Unstable oscillation modes are given by filled symbols. Top, middle, bottom panels correspond respectively to oscillation modes of spherical degree $l = 0, 1, 2$. *Middle panels:* As in left panels, for a model with diffusion and $\chi = 2$. *Right panels:* As in left panels, with diffusion and $\chi = 4$.

We see from Fig. 1 that the effect of the microscopic diffusion of iron is to excite more and more overtones as the enhancement factor of iron $\chi$ increases, i.e., that more and more iron accumulates above the opacity bump of the iron-group elements. The effect is clearly visible for acoustic modes but seems inexistent for gravity modes. The presence of more excited p-modes compared to the g-modes could be a signature of non-homogeneous models, i.e., that diffusion of iron occurs in the viscinity of the driving region of $\beta$ Cephei stars. Another signature of the iron accumulation near the opacity bump is that excited modes appear earlier on the main sequence for models with diffusion.

# 4 Conclusions

We show that the signature of the diffusion of iron in the viscinity of the driving region could be found in the asteroseismic spectrum of $\beta$ Cephei stars through the presence of more numerous excited acoustic modes compared to gravity modes.

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