Comm. in Asteroseismology
Vol. 151, 2007

Analysis of $\Pi_{1/0}\,(\Omega)$ period ratios in the presence of near degeneracy

J. C. Suárez[1,2], R. Garridol[1] and A. Moya[1]

[1] Instituto de Astrofísica de Andalucía (CSIC), CP3004, Granada, Spain
[2] LESIA, Observatoire de Paris-Meudon, UMR8109, France

Abstract

In the present work we provide the preliminary results obtained when analysing the rotational Petersen diagrams when including the effects of near degeneracy. We found that near degeneracy affects significantly the fundamental-to-first overtone period ratios, $\Pi_{1/0}\,(\Omega)$, showing wriggles in the Petersen diagrams. Analysis of such wriggles reveals that they are mainly caused by the avoided-crossing phenomenon. The size of wriggles seems to increase with the rotational velocity and could, in certain cases, invalidate any accurate mass and/or metallicity determinations. Nevertheless, deep analysis of near degeneracy effects may allow us to obtain additional information on the mode identification of the radial modes and their corresponding coupled pairs, which would allow us to constrain the modelling.

Introduction

In a previous work (Suárez et al. 2006b, hereafter SGG06), we showed the importance of taking the rotation effects into account (even for relatively slow rotating stars, as double-mode pulsators) especially when accurate metallicity and/or mass determinations are required. In that paper, 1O period ratios were calculated for different rotational velocities (RPD) and metallicities and then compared with standard non-rotating Petersen diagrams (PD). The difference in period ratios was shown to increase with the rotational velocity for a given metallicity. Differences in the period ratios were found to be equivalent to differences in the metallicity.

The present work intends to complete SGG06's work by including the effects of near degeneracy in the computations of oscillations. Mode identification is essential for the correct use of PD. As shown by Soufi et al. (1998) and Suárez et al. (2006c), near degeneracy effects cannot be neglected for asteroseismic studies of slowly-to-moderately rotating stars. Near degeneracy affects the small separations since it occurs for close modes (under certain selection rules, $\Delta\ell = 0, \pm 2$, and $\Delta\, m = 0$). However, such an effect is far from being trivial and deserves special attention.

We examine in detail the effect of rotation on mass and metallicity diagnostics based on Petersen diagrams, focusing on the influence of the near degeneracy effects on the period ratios of radial modes. Indeed, important effects are expected to be found when near degeneracy is taken into account (Pamyatnykh 2003). In that work, very large and non-regular perturbations of such ratios were expected to occur. We found such perturbations under the form of wriggles in the RPD. However such wriggles seem to be regular. A short discussion on the possible origin of these wriggles is here provided.

The $\Pi^{\rm d}_{1/0}\,(\Omega)$ period ratios

In order to study the effect of near degeneracy on RPD, we construct tracks of asteroseismic models for different mass, metallicity and rotational velocity. Equilibrium models are computed with the evolutionary code CESAM (Morel 1997) for which a first-order effect of rotation is taken into account in equilibrium equations. Uniform rotation and global conservation of the total angular momentum is assumed. Such models are the so-called 'pseudo-rotating' models (see Soufi 1998, Suárez et al. 2006c). Although the non-spherical components of the centrifugal acceleration are not considered, they are included as a perturbation in the oscillation frequencies computation. Computation of the oscillation spectra is carried out using the oscillation code FILOU (Tran Minh & Lon 1995, Suárez 2002) which is based on a perturbative analysis and provides adiabatic oscillations, corrected for the effects of rotation up to the second order (centrifugal and Coriolis forces), including near degeneracy effects.

In order to determine how near degeneracy affects mass and metallicity determinations using RPD, we selected several evolutionary tracks with different metallicities and two different initial rotational velocities $\Omega_{\rm i} = 25, 50$, for a fixed mass of $1.8\,{\rm M}_{\odot}$. For each model we then computed the corresponding $\Pi^{\rm d}_{1/0}\,(\Omega)$ period ratio, i.e., the 1O period ratios including near degeneracy effects.

In Fig. 1 we show RPD displaying such period ratios, from top bottom, for tracks computed for $\Omega_{\rm i} = 25$ to $50\,{\rm km\,s^{-1}}$ respectively. As expected, near degeneracy does not modify the general behaviour of the 1O period ratios with the metallicity, i.e., $\Pi^{\rm d}_{1/0}\,(\Omega)$ increases when increasing rotational velocities. This is equivalent to decrease the metallicity in standard PD (see SGG06). However, the presence of wriggles may inverse this situation in the regions where

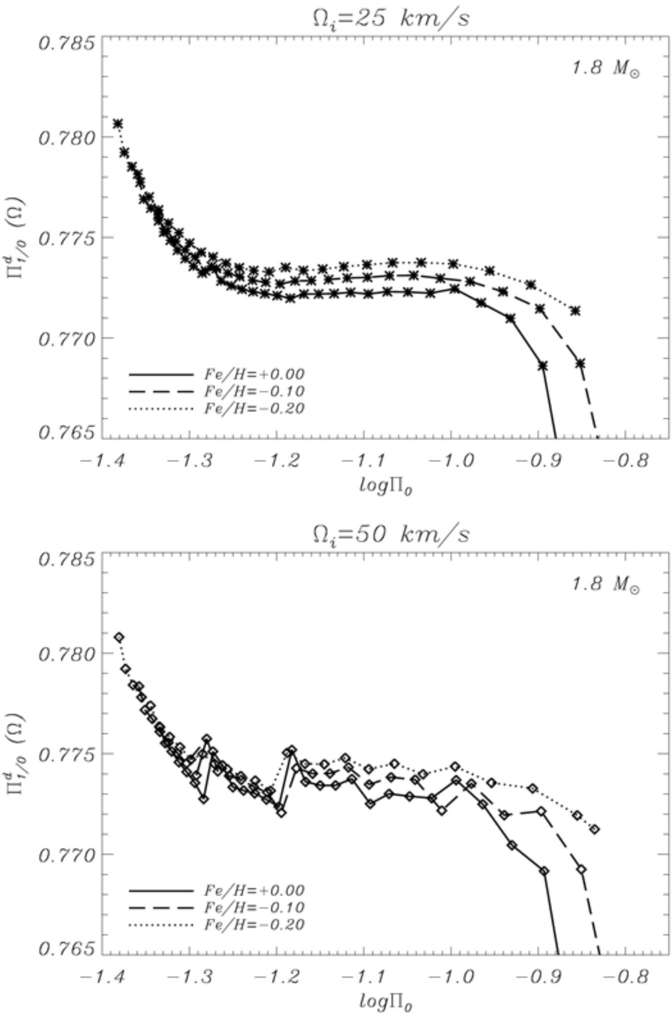

Figure 1: Theoretical RPD showing the $\Pi^{\rm d}_{1/0}\,(\Omega)$ period ratios for a set of evolutionary $1.8, \mathrm{M}_{\odot}$ tracks obtained for different metallicities. Tracks for two initial rotational velocities are considered: 25 and $50\,\mathrm{km\,s^{-1}}$ (from top to bottom). For convenience, the following symbols are used: asterisks, representing models evolved with $\Omega_{\rm i} = 25\,\mathrm{km\,s^{-1}}$; diamonds and those evolved with $\Omega_{\rm i} = 50\,\mathrm{km\,s^{-1}}$.

the curves cross each other. Wriggles are found larger for increasing rotational velocities and they become significant (in the context of RPD) degrading substantially the accuracy of period ratios $\Pi^{\mathrm{d}}_{1/0}(\Omega)$, which can reach up $3 \cdot 10^{-3}$. In terms of metallicity, this implies uncertainties reaching up to 0.50 dex (for the largest rotational velocity considered) which is critical for Pop. I HADS. This new scenario would invalidate, a priori, the PD as diagnostic diagrams. However, wriggles in period ratios do not seem to be located randomly in PD. They depend on the frequency evolution of the quadrupole modes coupled with the radial ones which are mainly dominated by the avoided-crossing phenomenon, and they seem nearly independent of the rotational velocity and metallicity. If these results are confirmed, it would be possible to provide some clues for the mode identification of the fundamental radial mode, the first overtone, and their corresponding quadrupole coupled modes, only using *white* light photometry. We will provide a complete study of the effect of near degeneracy on RPD, for different metallicities, masses and rotational velocities in a forthcoming paper (Suárez et al. 2006a), in which we show that wriggles in period ratios may imply differences of about 10^{-2} (for rotational velocities around $50\,\mathrm{km\,s^{-1}}$) when comparing with non-rotating PD. In that work we also examine certain properties of the near degeneracy effects, namely the mode contamination i.e., the weight of the original individual spherical harmonics describing the oscillation mode in the resulting coupled mode; and the coupling strength, i.e., the effect of near degeneracy on the oscillation frequencies. Analysis of these properties seem to be a promising procedure, not only to retrieve the usefulness of PD, but also to provide additional information for the complete mode identification, the rotational velocity and the inclination angle of the star.

Acknowledgments. JCS acknowledges support by the Instituto de Astrofísica de Andalucía (CSIC) by an I3P contract financed by the European Social Fund and from the Spanish "Plan Nacional del Espacio" under project ESP2004-03855-C03-01.

References

Morel, P. 1997, A&AS 124, 597
Pamyatnykh, A. A. 2003, Ap&SS 284, 97
Soufi, F., Goupil, M. J., & Dziembowski, W. A. 1998, A&A 334, 911
Suárez, J. C. 2002, Ph.D. Thesis, ISBN 84-689-3851-3, ID 02/PA07/7178
Suárez, J. C., Garrido, R., & Goupil, M. J. 2006a, A&A, submitted
Suárez, J. C., Garrido, R., & Goupil, M. J. 2006b, A&A 447, 649
Suárez, J. C., Goupil, M. J., & Morel, P. 2006c, A&A 449, 673
Tran Minh, F. & Lon, L. 1995, Physical Process in Astrophysics, 219