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Pulsation models of RR Lyrae stars: dependence on the mixing-length parameter α

M. Di Criscienzo[1], M. Marconi[1], and F. Caputo[2]

[1] Osservatorio Astronomico di Capodimonte, via Moiariello 16, 80131 Napoli, Italy
[2] Osservatorio Astronomico di Roma, via Frascati33, 00040 Monte Porzio Catone, Italy

Abstract.
In order to provide a detailed analysis of the pulsational behavior of RR Lyrae and in particular to investigate on the dependence of the models on the free mixing-lenght parameter α, we have implemented the existing set of models computed with α = 1.5 with new sequences computed adopting α = 2.0. The latter value is also adopted in recent evolutionary computations . We show the effects of this α increase on both the width of the instability strip and the morphology of light curves. In order to attempt to calibrate the α parameter we also show the comparison between model predictions and empirical data. The results of this comparison seem to suggest that the α parameter is not the same at varying the effective temperature and the pulsation mode. Further tests are needed in order to confirm this conclusion.

Key words. RR Lyrae stars– pulsation models – convection

1. Introduction

RR Lyrae are among the most popular standard candels to estimate the distance of globular clusters in the Galaxy and of the nearest galaxies in the Local Group (see Cacciari 1999; Carretta et al. 2000), also providing an indipendent test of the Cepheid distance scale, as well as a calibration of secondary distance indicators (e.g. the globular cluster luminosity function). The adoption of RR Lyrae as standard candles relies on the accurate knowledge of their mean absolute magnitude $M_V(RR)$ and its still debated dependence on the metal content [Fe/H] (see Carretta et al. 2000).

In this contest, important results have been obtained from the computation of an extensive and homogeneous set of nonlinear convective pulsation models (see Bono et al. 1997a,b, 2001 and references therein). All these models have been used to derive relevant relations between pulsational (periods and amplitude of pulsation) and evolutionary (mass, absolute luminosity and color) stellar parameters (Di Criscienzo et al. 2003). These relations, collated with sound contraints on the stellar mass (Marconi et al. 2003), as inferred from updated horizontal branch evolutionary models, provide a pulsational route to the determination of accurate distances to RR Lyrae rich globular cluster as well to perform a valuable test of the physics adopted in current stellar evolution computations.

Send offprint requests to: M. Di Criscienzo
Correspondence to: dicrisci@na.astro.it

However, the most recent evolutionary models adopt a larger value of the free mixing lenght parameter (α=1.9-2.0) than that assumed to close the equation system in the pulsational code (α=1.5). In order to perform a consistent comparison between evolutionary and pulsational predictions, as well as to investigate the dependence of theoretical pulsation properties on the adopted mixing lenght parameter, new pulsation models have been computed with α=2.0, at various stellar masses and chemical compositions.

In the following sections we show the results of this analysis (Sec. 2) and some indication on the α parameter, as inferred from the comparison with observations (Sec. 3).

2. New models with α=2

In order to investigate the dependence of the pulsation properties, namely the topology of the instability strip, the Bailey diagram and the light curve morphology, on the adopted α parameter, we have calculated additional models with α=2 and the intrinsic parameters reported in Table 1.

Table 1. Foundamental parameters of new models calculated with α=2.0

Z	Y	M/M$_\odot$	logL/L$_\odot$
0.0001	0.24	0.80	1.72, 1.81, 1.91
0.0001	0.24	0.75	1.61, 1.72, 1.81
0.0001	0.24	0.70	1.72
0.0001	0.24	0.65	1.61
0.001	0.24	0.65	1.51, 1.61, 1.72
0.001	0.24	0.75	1.61
0.006	0.255	0.58	1.75
0.02	0.28	0.53	1.51, 1.61

Different chemical compositions have been investigated and, for each abundance selection, various masses have been taken into account, in order to disentangle the effects of these input parameters on the investigated dependence on α.

When passing from α=1.5 to $\alpha = 2.0$ we obtain the following results:

- the instability strip becomes narrower because the increased efficiency of the convective transfer quenches the pulsation earlier with an effect which is larger at the red edge (~ 300-400 K) than at the blue one (~ 100 K);
- the lightcurves of computed models keep their shape but the amplitudes get smaller;
- the above effects are indipendent of metallicity and mass. Only for the models with solar metallicity (Z=0.02) the instability strip of first overtone pulsators disappears. Preliminary computations with Z=0.02 and M=0.65$M_\odot$ (see Di Criscienzo et al. 2003) seem to suggest that this occurrence is independent of the adopted mass, beeing mainly a metallicity effect. Since solar metallicity RRc are observed, we conclude that $\alpha = 2$ is too high for modeling these metallic pulsators.

3. Comparison between theory and empirical data

In Fig.1 we compare the observed distribution of RR Lyrae stars in the globular cluster M3 [1] in the $M_V(RR) - logP$ plane compared with the predicted edges of the instability strip for α=2 (solid lines) under two different assumptions on the cluster distance, matching the observed fundamental red edge (left panel) and first overtone blue edge (right panel) respectively. In fact, there is no way to reproduce the observed instability strip by adopting α=2 and a single distance value. Two different interpretations of this occurrence are that:

a) the correct α value is between 1.5 and 2.0;

b) the correct α value is smaller for first overtone pulstors than for the fundamental ones.

The latter interpretation is supported by the fit of observed light curves with pulsation models (see Bono et al. 2000). In fact, in Fig. 2 we report the fit of the light curve

[1] In this analisis we have used the extensive set of BV photometrc data provided by Corwin & Carney (2001) from which we have selected a fiducial sample of variables with well mesured period, mean magnitude and amplitude. We also have adopted E(B-V)=0.

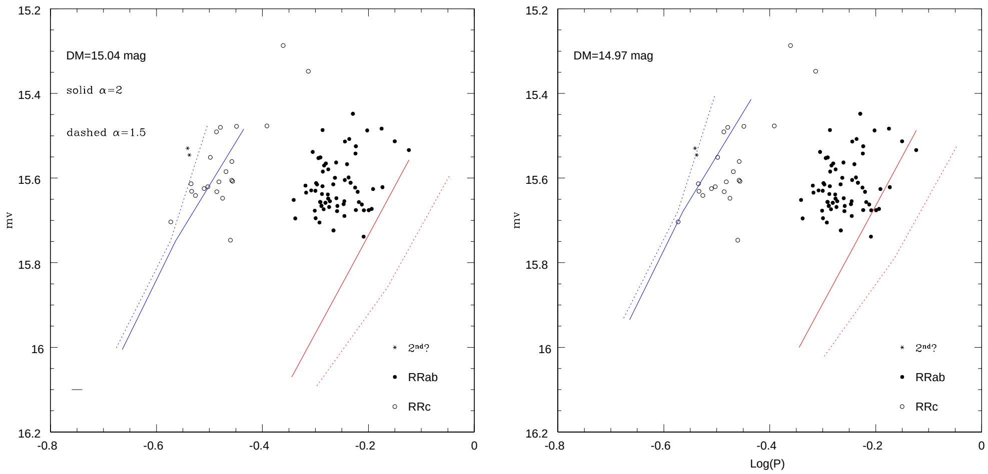

Fig. 1. The predicted edges of instability strip for M=0.65$M_{\odot}$ and Z =0.001 and α = 2 (solid lines) compared with the distribution of RR Lyrae stars in M3. Different symbols refer to c-type (open circles) ab-type (filled circles) variables. Asterisks are probably second overtone pulsators. The labelled distance moduli are obtained by contraining the observed RRab distribution to macht the predicted red limit of the pulsation region (left panel) and the observed RRc distribution to reproduce the blue limit (right panel). The theoretical boundaries for α = 1.5 are also shown (dashed lines).

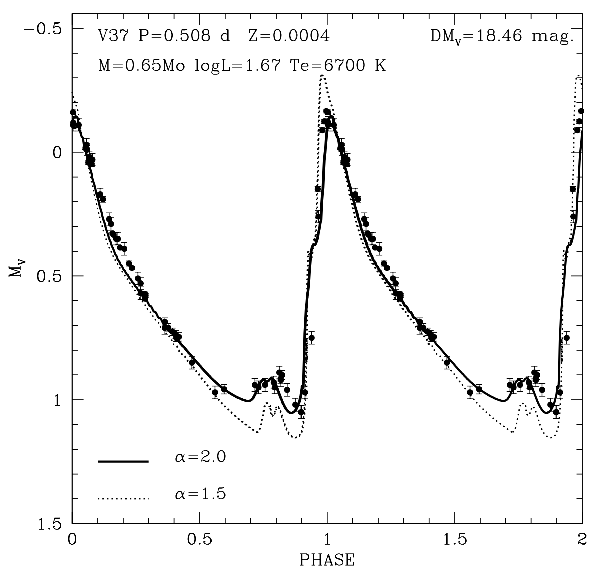

Fig. 2. Comparison between the light curve of V37 (filled circles) and two theoretical curves calculated respectively with α=2 (solid) and α=1.5 (dotted) and the labeled stellar parameters.

of the ab-type RR Lyrae V37 belonging to the Large Magellanic Cloud cluster Reticulum, by means of two theoretical curves calculated respectively with α=2 (solid) and α=1.5 (dotted) and the labeled stellar parameters. From this comparison $\alpha = 2$ seems to be preferred. However, a similar analysis performed for the galactic field c-type variables U Comae (Bono et al. 2000) and CM Leo (Di Fabrizio et al. 2002) provided best fit models with α=1.5. Moreover, the fit of Classical Cepheid lightcurves (see Bono, Castellani & Marconi 2002) suggests that a different α value should be adopted in the blue and in the red regions of the instability strip.

4. Conclusions

The main results of this study are the following:

- As the α parameter adopted in the pulsation models increases from 1.5 to 2.0 the width of instability strip gets smaller with the red edge shifting toward higher effective temperatures by $\sim$ 300-400 K and the blue edge becoming redder by only $\sim$ 100 K;
- The pulsation amplitudes decrease as α increases but the light curve morphology is unchanged;
- The comparison between theoretical results and empirical data seem to suggest that the α parameter is not the same at varying the effective temperature and the pulsation mode. Further tests are needed in order to confirm this conclusion.

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