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Helium abundance effects on RR Lyrae pulsation properties

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Abstract. A new set of nonlinear convective pulsation models of RR Lyrae stars has been computed varying both the metallicity and the helium content. To constrain the helium dependence of pulsation observables we adopted, for each metal content, at least three different helium abundances. We provide for the first time a homogeneous evolutionary and pulsation framework covering the entire range of cluster and field variables. The implications for the use of RR Lyrae as stellar population tracers and distance indicators are briefly discussed.

1. Introduction

RR Lyrae stars are important standard candles to evaluate the distance and trace the properties of population II stars (Caputo 2012; Marconi 2012; Marconi et al. 2015). They are the most popular variable stars in globular clusters and the characterization of their properties is crucial not only to date but also to constrain the chemistry and the kinematics of the host systems. In the last decade there has been a growing interest towards the study of globular clusters thanks to the observational evidence of secondary stellar populations in these systems (Piotto et al. 2015). This evidence has been widely interpreted in terms of a helium enhancement in subsequent stellar generations (Renzini 2010; Milone 2015; Nardiello et al. 2015). Helium abundances up to about Y=0.40 (abundance in mass fraction) are often invoked by stellar evolution studies on specific Galactic globular clusters (ω Cen, NGC 6441, NGC 2808, NGC 6352), thus pointing out the need to verify the presence of such an enhancement through independent methods. The RR Lyrae stars play, in this context, a crucial role, since their pulsation properties can be soundly adopted to constrain the occurrence of a helium-enhanced stellar population. We have already computed He-enhanced models for RR Lyrae in ω Cen (Marconi et al. 2011) and the comparison with observations suggested that:

1. The key parameter causing the difference between canonical and He-enhanced observables is the luminosity.
2. The period distribution of He-enhanced models moves to periods that are systematically longer than observed.

3. The fraction of He-enhanced structures in ω Cen cannot be larger than 20%.

However, these models only covered two metal abundances. The extension of the He-effect analysis to the whole metallicity range covered by Galactic and extragalactic RR Lyrae is mandatory in order to properly trace the He enhancement phenomenon through RR Lyrae stars pulsation properties (Marconi et al. in preparation). Here we present some preliminary theoretical results concerning the helium abundance effects on pulsation periods and light curves.

2. The new helium enhanced pulsation models

Starting from the canonical theoretical scenario presented in Marconi et al. (2015), for each selected metal abundance, ranging from $Z = 0.0001$ to $Z = 0.008$, we increased the helium content from the canonical value (ranging from 0.245 for $Z = 0.0001$ to 0.256 for $Z = 0.008$) to $Y = 0.30$ and $Y = 0.40$. Nonlinear convective models with the same physical and numerical assumptions as in Marconi et al. (2015) were computed for the new helium-enhanced chemical compositions. As a result, we computed an extensive and detailed grid of models including 18 chemical compositions and, for each selected Z, Y combination, two different stellar masses and three different luminosity levels. The anchor, for each given chemical composition, is given by the mass and the luminosity predicted by evolutionary models for the Zero Age Horizontal Branch (ZAHB). This set was complemented with a new sequence with the same ZAHB mass, but a luminosity level that is 0.1 dex brighter than the ZAHB luminosity level. This takes account of the off-ZAHB evolution within the instability strip. We also computed a third sequence assuming a stellar mass that is 10% smaller than the ZAHB mass and a luminosity level 0.2 dex brighter than the predicted ZAHB level. This takes account of the spread in mass inside the instability strip.

The luminosity level of the predicted ZAHB increases with the assumed helium content and, at fixed mass and effective temperature, will produce longer predicted pulsation periods, as discussed in the following section.

3. Helium abundance effect on the predicted pulsation period and light-curve morphology

The main effect on the pulsation properties when increasing Y from the canonical value to 0.30 and 0.40 is shown in Figure 1. In this plot the predicted fundamental pulsation periods are shown as a function of the corresponding effective temperatures for the three different assumptions on the helium abundance (see labels). The pulsation periods get significantly longer so that the fundamental minimum period of an RR Lyrae sample is expected to be a crucial observable to disentangle the helium abundance of the underlying stellar population.

The light-curve amplitude and morphology is also affected by the increase in helium content as disclosed in Figure 2. In this plot the bolometric light curve is shown for two fundamental models with $Z = 0.0006$, effective temperature $T_{\rm e} = 6100$ K and a luminosity level $\log L/L_{\odot} = 1.69$, but two different helium abundances (see labels).

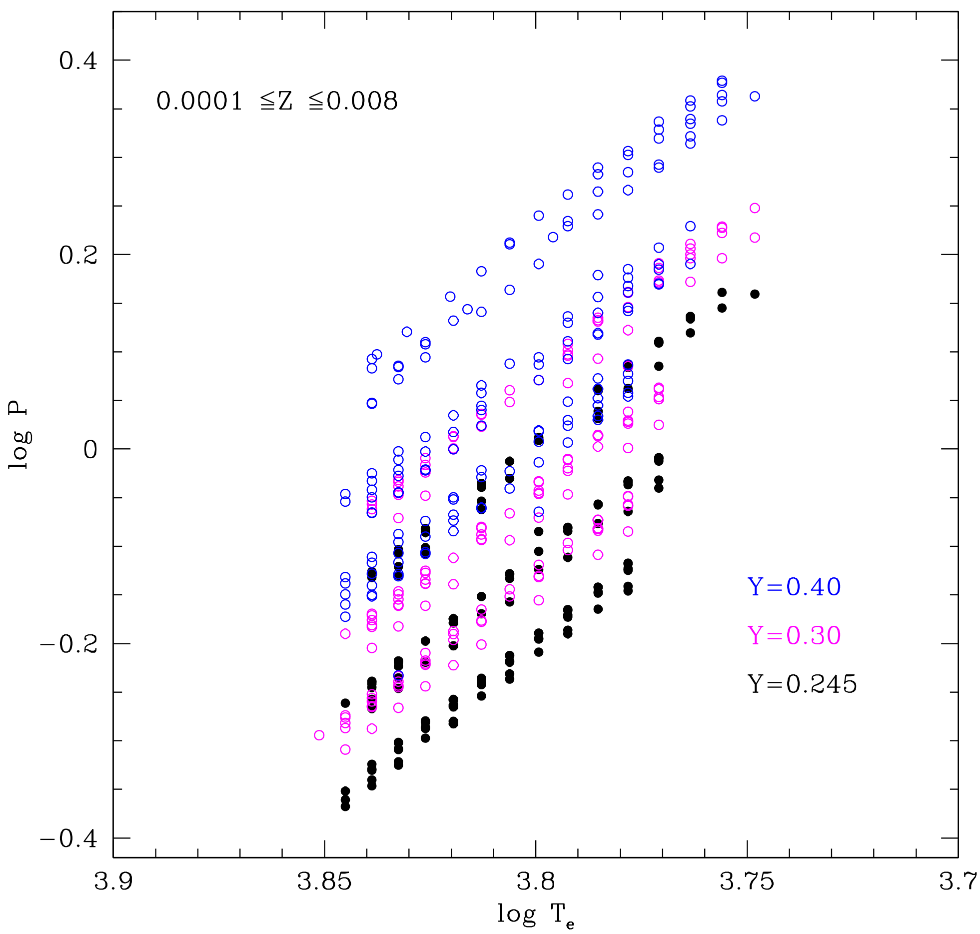

Figure 1. Computed fundamental pulsation periods as a function of the effective temperatures for the canonical helium abundance (black filled circles), $Y = 0.30$ (magenta open circles) and $Y = 0.40$ (blue open circles).

A glance at the models plotted in Figure 2 suggests that the predicted amplitude decreases (and the morphology gets smoother) as the helium content increases, as also confirmed by the fact that the corresponding model for $Y = 0.40$ shows a vanishing amplitude, as it does not pulsate. This occurrence is expected, the increase in helium content causes a decrease in the envelope opacity, and in turn in driving the pulsation.

In spite of the quoted significant effect on the pulsation period, as the evolutionary luminosity levels also increase, the slope and the zero point of the predicted period-luminosity (in the near infrared bands) and multi-filter Wesenheit relations are expected to be barely affected by helium content variations (Marconi et al. in preparation).

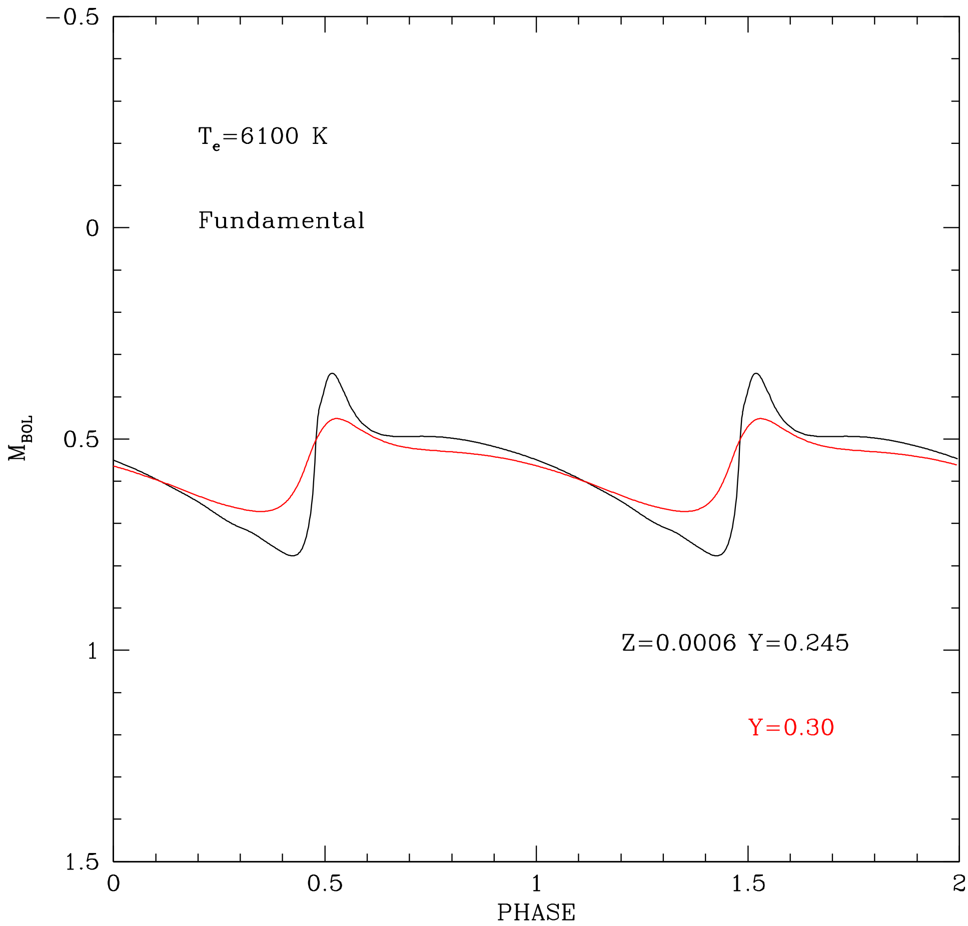

Figure 2. Predicted bolometric light curves of models with the same metallicity ($Z = 0.0006$), effective temperature ($T_e = 6100$ K) and luminosity ($\log L/L_{\odot} = 1.69$) and two different helium contents (see labels).

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