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'Anomalous' or low mass Classical Cepheids?

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Abstract. We present a theoretical investigation of the pulsation behaviour of the so-called "Anomalous" Cepheids (ACs) and its correlation with RR Lyrae stars, Classical and Population II (PII) Cepheids. Using suitable stellar evolution and pulsation models for Z=0.0004, we found that the masses in the range 0.8-1.7 $M_{\odot}$ are expected not to cross the instability strip (IS). Stars with mass larger than 1.7 $M_{\odot}$, including both Anomalous and Classical Cepheids, populate with good approximation a common M_V-logP_F IS, independently of the helium ignition type. At the same time, the less massive pulsators (M <0.8$M_{\odot}$), including RR Lyrae and PII stars, are located in a distinct IS, as a consequence of the different mass-luminosity relations, according to which the pulsation periods increase if the mass of the pulsators decreases.

Key words. Cepheids – He burning stars – stars: oscillations

1. Introduction

According to the current nomenclature, among the central helium-burning variable stars that are more luminous than RR Lyrae stars, one finds the so-called "Anomalous" Cepheids, with periods ranging from ∼ 0.3 to 2 days, and PII Cepheids, with periods from ∼ 1 to 25 days. These stars are observed in the Galactic globular cluster and in low-metallicity stellar systems. Using the predictions of stellar evolution and pulsation models, it is shown that PII Cepheids are the evolution of low-mass (high effective temperature) stars from Zero Age Horizontal Branch (ZAHB) towards the colder effective temperatures of the Asymptotic Giant Branch (AGB). The difference between the AC and PII classes of Cepheids resides in the Period Luminosity relation. In fact, at a given observed period, ACs are brigther than PII Cepheids. This property is at the origin of their supposed "anomaly" and it is usually taken into account in the study of their different evolutionary history. ACs are found in all dwarf spheroidal galaxies that have been surveyed for variable stars Mateo (1998). Recently Dolphin et al. (2002) found a large number of short-period Cepheids (log P ≤ 2 days) in the Local Group dwarf irregular galaxy Leo A. This galaxy is characterized by very low metal

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abundances ($Z \leq 0.0004$), Moreover, the evidence of an old stellar population component (age ~ 10-11 Gyr) is suggested by the detection of RR Lyrae stars, with a mean magnitude of <V>=25.10 ± 0.9 mag. About 84 variable stars with observational properties typical of AC stars have been found, and the authors suggest that rather than being indicative of the AC class, these stars may be "Classical" (i.e. metal-intermediate) short-period Cepheids with low metallicities. Using up-to-date theoretical predictions we will show that AC stars are indeed the natural extension to low mass and metallicity of Classical Cepheids.

2. Pulsation and evolution models

To discuss AC properties in Leo A we use pulsation models with Z=0.0001 and 0.0004, recently computed by Marconi, Fiorentino & Caputo (2004) implemented with a set of 4 $M_\odot$ models at Z=0.0004 and $\log(L/L_\odot)=3.5$. These pulsation theoretical models have been computed using a nonlinear, nonlocal and time-dependent convective hydrodinamical code which has been discussed in a series of previous papers (Bono & Stellingwerf 1994, Bono et al. 1997a, Bono et al. 1997b). With the mentioned code we can predict all the pulsation properties, such as the effective temperature boundaries of the Instability Strip (IS), pulsation periods and amplitudes, ligth and velocity curves. The luminosity levels ($1.82 \leq \log(L/L_\odot) \leq 2.28$) have been selected for each mass ($1.3 \leq M/M_\odot \leq 2.2$), taking into account evolutionary tracks suggested by Castellani & Degl'Innocenti (1995). For each selected metallicity, mass and luminosity level, the temperature values cover the entire IS, in steps of 100 K. Such a pulsational scenario has been combined with canonical (not overshooting) evolutionary models with Z=0.0004 from the "Pisa Evolutionary Library" set (http://gipsy.cjb.net). These tracks follow the evolution from the Main Sequence to the early AGB, covering the major phases of both H and He burnings (see Cariulo, Degl'Innocenti & Castellani (2003) for details). In the left panel of Figure 1 we compare theoretical evolutionary tracks, with no mass-loss, but defined IS boundaries, as in Bono et al. (1997a), Bono et al. (1997b). In the figure, the effective temperatures are scaled for appropriate Fundamental Red Age (FRE), for each mass and luminosity. The First Overtone Blue Edge (FOBE) is situated at log(Te) ~ 0.09, bluer than FRE. This figure shows that different evolutionary phases may or may not cross the IS. In particular, for $M < 1\ M_\odot$ no variable stars are expected at all. For $1 \leq M/M_\odot \leq 1.7$ only the stars in the short-lived hydrogen burning phase cross the IS, while for $M > 1.7\ M_\odot$ the variable stars cross the IS during the He-burning phase and we can observe them. In the right panel of Fig. 1 we consider evolutionary models with mass loss. In this case also less massive variable stars (PII Cepheids and RR Lyrae stars) are predicted to be present in the IS, with the result that only masses in the range $0.8 \leq M/M_\odot \leq 1.7$ do not give rise to variable stars.

3. Comparison with observations

To compare theoretical predictions with observations, bolometric corrections, as derived by Castelli et al. (1997), are used. In this way we transform the luminosities in visual magnitudes. Then the period, a quantity less affected by systematic errors, can be estimated for fixed physical parameters with relationships such as in Bono et al. (1997a), Bono et al. (1997b). By selecting only the models falling in the considered IS, the predicted period-magnitude diagram of pulsators with Z=0.0004 and various masses can be derived. This is shown in left panel of Fig. 2. Stars from 1.9 to 4 $M_\odot$ (a mass range that includes both Anomalous ($M < 2.2\ M_\odot$) and Classical ($M > 2.2\ M_\odot$) Cepheids) undergoing their radial pulsation phase define a nearly unique IS, independently on the occurence of a quiet ($\leq 2.1\ M_\odot$) or a flashing ($> 2.1\ M_\odot$) He ignition. The pulsators with larger mass present generally longer periods and become brighter. For these massive central He-burning pulsators a lower luminosity limit of $M_{V,LE} \sim -0.5$ mag can be predicted, as indicated by the uppermost arrow in left panel of Fig. 2. Less massive pulsators (indicative

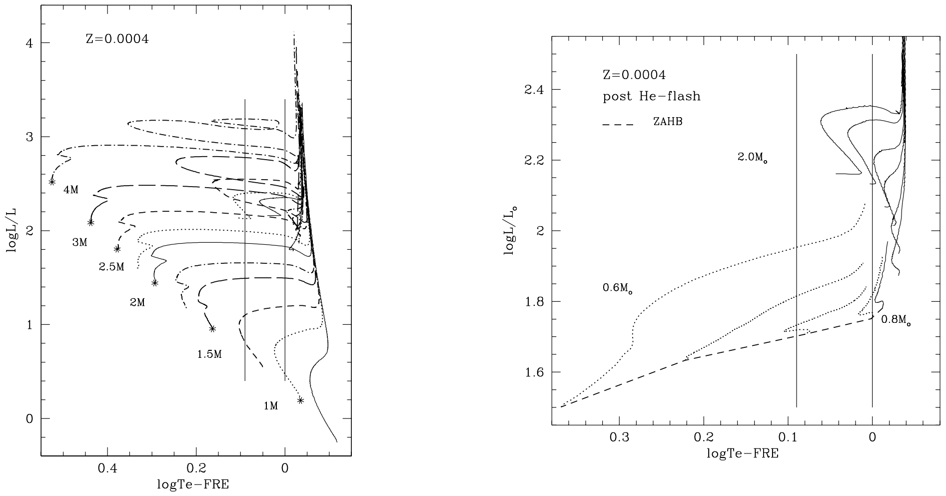

Fig. 1. Comparison between pulsation and evolutionary predictions. Left panel: Evolution models for 0.8 $\leq$M/M$_\odot$$\leq$4 scaled at the Fundamental Red Age (FRE), with no mass loss. Right panel: Zoom of a region in the left panel. Solid lines: evolutionary tracks for 0.8 $\leq$M/M$_\odot$$\leq$ 2, with no mass loss. Dotted lines: evolution from ZAHB (dashed line) of models with masses from 0.60 to 0.75 M$_\odot$, originating from 0.8 M$_\odot$.

of PII Cepheids and RR Lyrae stars) evolving off their ZAHB (M< 0.8 M$_\odot$) populate a different zone in the HR diagram. For smaller pulsator mass the crossing with the IS occurs for brighter magnitudes and for longer periods. The results plotted in Fig. 2 reveal that post-He flash structures with masses in the range $\sim$ 1.9-2.2 M/M$_\odot$ (i.e. AC candidates) are the natural extension to fainter magnitudes of the more massive central He-burning pulsators of similar metal content.

We compared theoretical predictions with a sample of variables observed in Leo A by Dolphin et al. (2002), but with periods scaled to FRE of First Overtone candidates. In Fig. 2, right panel, μ_V=24.6 mag is assumed, as derived from the observed RR Lyrae stars. Predictions and observations are in reasonable agreement, both for the IS edges and for the evidence that bright pulsators show a limiting magnitude of $\sim$ -0.5 mag. The predicted mass range is 1.9 $\leq$M/M$_\odot$ $\leq$ 3, which nicely confirms that the distribution in the M$_V$-log P diagram of massive stars which experienced the He flash is the natural extension of the distribution of more massive pulsators characterized by a quiet He ignition, at least for M $\leq$ 4 M$_\odot$. The same confirmation is obtained using observational data for the metal rich (Z=0.001) dwarf irregular galaxy Sextans A (see Caputo et al. 2004).

4. Conclusions

In the current literature the term "Anomalous" Cepheids is adopted to indicate variables brighter than RR Lyrae stars and with periods $\leq$ 2 days, generally observed in dwarf spheroidal galaxies of the Local Group. In a recent work (Dolphin et al. 2002) it has been suggest that these variables can represent the natural extension to low metallicities of the sequence of Classical Cepheids, rather then being classified as ACs.

Following these suggestions, we have analysed theoretical scenarios for Z=0.0004 to 0.008 central He-burning pulsators with mass $\leq$ 4 M$_\odot$. We conclude that variable stars more massive than RR Lyrae pulsators with periods $\leq$ 3 days populate a unique IS, independently on the occurrence of He-ignition and on the metal

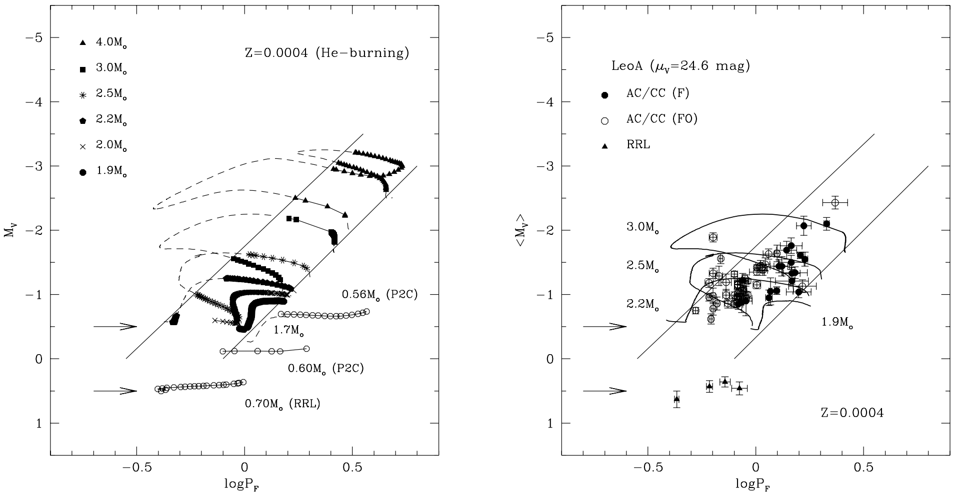

Fig. 2. Left panel: Comparison in M_V vs log P_F plane of theoretical evolution and pulsation models. The uppermost arrow marks the predicted absolute magnitude $M_{V,LE} \sim$ -0.5 mag of the lower envelope of the pulsators distribution. The lowermost arrow shows the predicted absolute magnitude of RR Lyrae stars. Right panel: Observed Cepheids (dots) and RR Lyrae stars (triangles) in Leo A compared with the predicted edges of the IS. Selected evolutionary tracks are also drawn.

content. Thus the results presented do confirm that the so-called "Anomalous" Cepheids are indeed the extension of the Classical Cepheids to lower metallicities and masses. In fact less massive stars cross the pulsation region giving rise to pulsators with fainter magnitudes and shorter periods.

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