

RR Lyrae the Stellar Beacons of the Galactic Structure

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Abstract

We present some recent findings concerning the use of RR Lyrae as distance indicators and stellar tracers. We outline pros and cons of field and cluster RR Lyrae stars and discuss recent theoretical findings concerning the use of the Bailey (amplitude vs pulsation period) diagram to constrain the possible occurrence of Helium enhanced RR Lyrae stars. Nonlinear, convective RR Lyrae models indicate that the pulsation properties of RR Lyrae stars are minimally affected by the helium content. The main difference between canonical and He enhanced models is due to the increase in luminosity predicted by evolutionary models. Moreover, we focus our attention on the near-infrared Period-Luminosity (PL) relation of RR Lyrae and summarize observational evidence concerning the slope of the K-band PL relation in a few globulars (M92, Reticulum, M5, ω Cen) covering a range in metallicity of ~ 1 dex. Current findings suggest that the slope has a mild dependence on the metal content when moving from the metal-poor to the metal-intermediate regime. Finally, we also discuss the use of RR Lyrae stars either to estimate (helium indicator: A-parameter) or to measure (absorption and emission lines) the helium content.

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1. Introduction

Even after a cursory reading of the papers published in the seminal Vatican conference on stellar populations it becomes clear the key role that RR Lyrae played in the development of what we now call stellar populations and in the shaping of Galactic structure. Their relevance is also supported by the first sentence of one the papers given by W. Baade at that conference:

Variable stars, in particular the cepheids and the cluster-type variables, have becoming increasingly important in the exploration of our own and other galaxies.

The relevance of RR Lyrae stars in stellar astrophysics is further supported by the fact that RR Lyrae are the most popular old, low-mass distance indicators. In early times it was assumed that their mean luminosity was constant, but soon after the spectroscopic investigations showed that they do obey a visual magnitude metallicity relation. Therefore, the knowledge of their metallicity was fundamental for accurate estimates of their individual distances. However, high-resolution spectroscopy in single slit mode was prohibitive for large numbers of RR Lyrae stars. The ΔS method invented by George (Preston 1959) opened a new path in the extensive use of field RR Lyrae as stellar tracers of the Galactic halo (Suntzeff et al. 1994) and of the bulge (Walker & Terndrup 1991; Blanco & Blanco 1997).

RR Lyrae are also fundamental laboratories to constrain the physical mechanisms that drive their pulsation instability. After the pioneering investigations by Christy (1966) based on nonlinear radiative models, the modelling of RR Lyrae pulsation behavior was at the cross-roads of several theoretical and observational investigations. Once again the papers by Preston & Paczynski (1964) and Preston et al. (1965) have been a benchmark for those interested in understanding the impact that the different physical mechanisms (convection) and input physics (opacity, equation of state) have on light and radial velocity curves.

The structure of this paper is the following. In §2 we briefly discuss pros and cons of cluster and field RR Lyrae. The pulsation framework developed by our group during the last few years is outlined in §3, together with the added values and the drawbacks of the Bailey Diagram (amplitude versus period). In §5 we discuss the current observational scenario of the K-band Period-Luminosity relation of cluster RR Lyrae. In §6 we discuss the diagnostics currently adopted to estimate the primordial helium content, in particular we focus our attention on RR Lyrae stars. In the last section we briefly mention the possible paths that the next generation of observing facilities will open during the next few years.

2. Pros and cons of field and cluster RR Lyrae stars

Field and cluster RR Lyrae bring forward several distinctive advantages worth discussing in detail:

i)–Distance– Cluster RR Lyrae provide accurate distance estimates of Galactic Globular Clusters (GGCs), and in turn more accurate estimates of their absolute age. Unfortunately, they are not ubiquitous, i.e. their occurrence in GGCs does depend on the morphology of the horizontal branch. They are not present in GGCs that have either a very red or a very blue HB morphology. This means that they are affected by the so-called second parameter problem (e.g., Kunder et al. 2011).

ii)–Ensemble properties– Cluster and field RR Lyrae stars do show different period distributions, i.e. they are affected by the so-called Oosterhoff dichotomy (Oosterhoff 1939; Bono et al. 1995a; Smith 1985; Catelan 2009). However, RR Lyrae in MC globulars are Oosterhoff intermediate (Bono et al. 1994a). The same outcome applies to RR Lyrae in different dwarf spheroidal galaxies in the Local Group (e.g. Carina, Dall’Ora et al. 2003). The fraction of first overtone (FO, RRc) and fundamental (F, RRab) variables is also affected by the HB morphology and changes when moving from GGCs to dwarf galaxies to the Galactic field (Petroni & Bono 2003). This indicates that pulsation properties of RR Lyrae do depend on the chemical and dynamical evolution of their stellar environment.

iii)–Evolutionary status– Empirical evidence and theoretical predictions indicate that the range in visual magnitude between the Zero-Age-Horizontal-Branch (ZAHB) and the end of central helium burning is correlated with the metallicity (Sandage 1990; Bono et al. 1995b). Together with this intrinsic evolutionary effect, we are also facing the problem that we still lack a firm photometric diagnostic to constrain the evolutionary status of individual RR Lyrae stars. This drawback applies to both cluster and field RR Lyrae and causes a series of problems not only in the distance estimate, but also in the estimate of the observed ZAHB luminosity level, and in turn on the parameters correlated with this evolutionary feature, namely the R parameter (Sandquist 2000; Troisi et al. 2011, in preparation), the ΔV_{bump}^{HB} (Di Cecco et al. 2010) and the relative ages of GGCs (Marín-Franch et al. 2009). A possible solution to overcome this problem is to estimate the individual distances using the NIR PL relations, since they are minimally affected by evolutionary effects and by a possible spread in mass inside the instability strip (Bono et al. 2001, 2003). On the basis of the true distance modulus and of their individual reddenings, the same objects can be located in the absolute CMD (M_V vs $(B - V)_0$) to constrain their evolutionary status (Bono et al. 2011, in preparation).

iv)–Evolutionary/Pulsation connection– Cluster variables are also relevant to constrain the input physics adopted in pulsation and evolutionary codes. Observables predicted by pulsation models (periods, modal stability, pulsation amplitudes) and by evolutionary models (lifetimes, mass-luminosity relation, effective temperature) do depend on the same intrinsic parameters (stellar mass, chemical composition). The comparison between theory and observations using the same objects (RR Lyrae), seen as variables and as HB stars, provide a fundamental sanity check for both the micro (opacity, equation of state, cross sections) and the macro (gravitational settling, mixing, mass-loss) physics. This is a fundamental stepping stone to improve the plausibility of

the physical assumptions adopted in pulsation and evolutionary models, since the former rely on the mass-luminosity relation predicted by evolutionary models. This is the path that has been followed to address several open problems (Oosterhoff dichotomy, Sandage period effect, hysteresis mechanism, topology of the instability strip) that are at the cross-roads between theory and observations.

iv)–Statistics and progenitors– The number of GGCs that host several tens of RR Lyrae stars is quite limited (Clement et al. 2001). The new photometric surveys are disclosing several thousands of field RR Lyrae. This means that robust comparisons can only be based on field stars. However, for cluster variables we have accurate knowledge of the absolute age and chemical composition of the progenitors. For field RR Lyrae we can either estimate (photometric indices) or measure (spectroscopy) the chemical composition, but we can barely constrain their absolute age, and in turn the mass of the progenitor.

v)–Helium abundance– More than 30 years ago it was suggested that the mass-luminosity ratio of RR Lyrae, the so-called A-parameter (Caputo et al. 1983) can be adopted, via the pulsation relation (van Albada & Baker 1973; Caputo et al. 1998), to estimate the helium content of individual variables (Sandquist 2000). The application of this diagnostic to cluster RR Lyrae is very powerful, since the precision is only limited by the size of the sample. The two main drawbacks of this approach is that the He estimates are affected by the precision of the color-temperature relation and by the evolutionary status of individual objects. A breath of fresh air on this delicate topic arrived with the discovery by Preston (2009) of both He I and He II emission and absorption lines in field RR Lyrae stars. The lines show up during the rising branch of RR Lyrae stars and appear to be the consequence of the shock propagation (Bono et al. 1994b; Chadid & Gillet 1996).

3. Theoretical Framework

The content of §2 indicates that RR Lyrae stars are the cross-roads of several open astrophysical problems. Several of these problems call for new theoretical and observational insights. In particular, the theoretical approach does require a theoretical framework dealing with both evolutionary and pulsation properties of radial variables. Our group undertook this project almost twenty years ago (Caputo 2008). In the following, we briefly mention recent findings concerning the predicted Bailey diagram and the K-band Period-luminosity relation.

We constructed new sets of RR Lyrae pulsation models by using the hydrodynamical code developed by Stellingwerf (1982) and updated by Bono et al. (1994b) [see also Smolec & Moskalik 2010 for a similar approach], Bono et al. (1999). The physical assumptions adopted to compute these models will be described in Marconi et al. (2011, in preparation). We adopted the OPAL radiative opacities released in 2005 by

Iglesias & Rogers (1996)¹ and the molecular opacities by Alexander & Ferguson (1994). To properly constrain the pulsation properties of RR Lyrae stars, we typically cover a wide range in metal abundances (scaled-solar, α -enhanced). Moreover, to constrain the dependence of the pulsation properties of RR Lyrae stars on the He abundance we also adopt different values of this crucial parameter. For each fixed chemical composition the stellar mass of RR Lyrae stars was fixed by using the evolutionary prescription for α -enhanced structures provided by Pietrinferni et al. (2006) and available on the BaSTI database². Note that for each fixed metal content the mass of the He-enhanced models was estimated assuming the same cluster age (13 Gyr). Together with the luminosity predicted by evolutionary models we often adopted a brighter luminosity level to account for the possible occurrence of evolved RR Lyrae stars. The reader interested in a more detailed discussion concerning evolutionary and pulsation ingredients is referred to Marconi et al. (2011, and references therein).

3.1. The luminosity amplitude vs period (Bailey) diagram

The period distribution and the Bailey diagram (luminosity amplitude vs pulsation period) are very robust observables, since they are independent of distance and reddening corrections. After the seminal discovery of this diagram (Oosterhoff 1939), Preston (1959) found that objects with different metal abundances display different trends. The use of the pulsation amplitude as a proxy of the metal content is still lively debated both from the observational (Kinemuchi et al. 2006; Kunder & Chaboyer 2009; Kunder et al. 2011) and the theoretical (Bono et al. 2007; Fiorentino et al. 2010) point of view. The reader interested in a detailed discussion concerning the development and the use of the Bailey diagram is referred to the detailed paper by Smith et al. (these proceedings). In the following, we focus our attention on the use of the Bailey diagram to constrain the helium content of RR Lyrae stars.

The bolometric light curves predicted by nonlinear, convective, pulsation models are typically transformed into the observational plane using the bolometric corrections and the Color-Temperature transformations provided by Castelli et al. (1997a,b). Figure 1 shows predicted B-band amplitudes for fundamental (top) and first overtone (bottom) RR Lyrae models computed at fixed metal content ($Z=0.001$) and primordial helium contents ranging from $Y=0.24$ to $Y=0.38$ (see labeled values). To constrain the dependence of the luminosity amplitude on evolutionary effects the models –for each fixed chemical composition– were constructed using two different luminosity levels.

Data plotted in this figure indicate that the He content marginally affects the pulsation behavior of RR Lyrae. The top panel shows that an increase of 30% in He content (0.24 vs 0.30) causes a systematic shift in the pulsation period. Thus, suggesting that the difference in the helium enhanced models is mainly due to the increase in the luminosity level. The different sets of models disclose that structures with a

¹ <http://opalopacity.llnl.gov/>

² <http://albione.oa-teramo.inaf.it/>

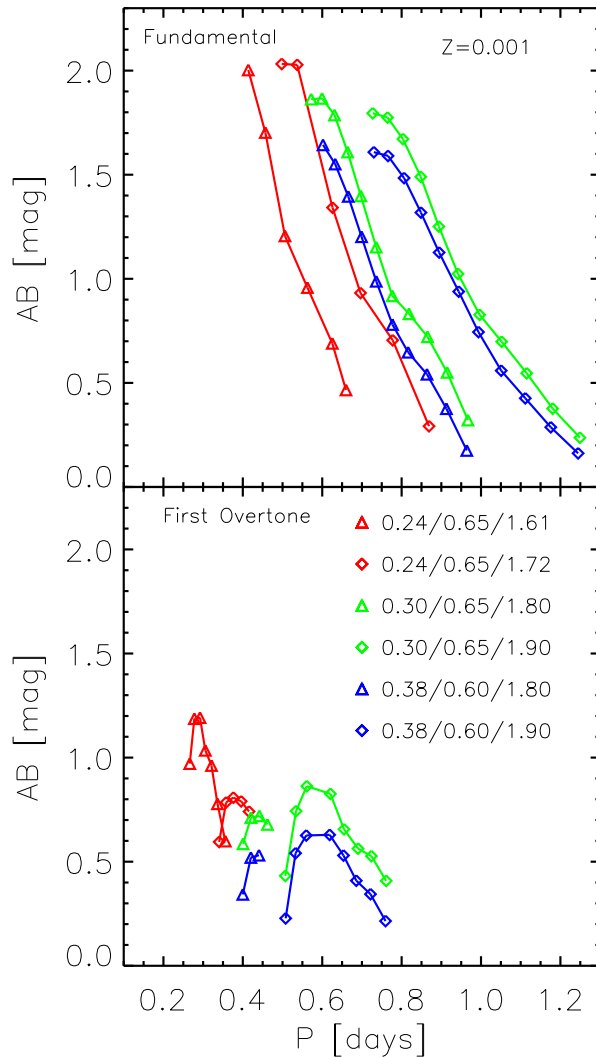


Figure 1.— Top – Predicted B-band amplitudes versus period for fundamental RR Lyrae computed at fixed metallicity ($Z=0.001$). Different symbols display different luminosity levels, while different colors show models constructed assuming different helium abundances and/or stellar masses. From left to right the labelled numbers show helium content (mass fraction), the stellar mass and the logarithmic luminosity (solar units). Bottom – Same as the top, but for first overtone pulsators.

difference in helium content of $\sim 50\%$ might have, at fixed period, similar pulsation amplitudes. The amplitudes of the He enhanced models $-Y=0.30, Y=0.38-$ display minimal changes, since the latter group was constructed assuming the same luminosity levels and slightly smaller stellar masses (0.60 vs $0.65 M_{\odot}$). The first the overtone pulsators (bottom panel) show similar trends concerning the He dependence.

This circumstantial evidence indicates that the Bailey diagram is not a good diagnostic to constrain the helium content of cluster and field RR Lyrae. Moreover, in dealing with luminosity amplitudes we need to keep in mind two relevant limits. *i)*–

The theoretical Bailey diagram is affected by uncertainties on the mixing length parameter (see e.g. Marconi et al. 2003). A decrease in the convective efficiency causes larger amplitudes, but the pulsation periods are minimally affected. This means that the mixing length affects the slopes of the predicted amplitude–period relations, but the systematic drift as a function of the He content is not affected (Marconi et al. 2011, in preparation). *ii)*– Recent space (COROT, Chadid et al. 2010) and ground-based (Kunder et al. 2010) observations indicate that the fraction of RR Lyrae stars affected by the Blazhko phenomenon is higher than previously estimated ($\approx 50\%$, Benkó et al. (2010)).

4. The NIR Period-luminosity relation of RR Lyrae stars

RR Lyrae variables are relatively bright and have been detected in several Local Group galaxies (e.g. Dall’Ora et al. 2003, 2006; Pietrzyński et al. 2008; Greco et al. 2009; Fiorentino et al. 2010; Yang et al. 2010) and can be easily identified from their characteristic light curves. The most popular methods to estimate their distances is to use either the visual magnitude–metallicity relation or the near-infrared (NIR) Period-Luminosity (PL) relation (e.g. Bono 2003; Cacciari & Clementini 2003) or parallaxes and proper motions (Feast et al. 2008). The reader interested in independent approaches based on RR Lyrae to estimate stellar distances is referred to the thorough investigations by, e.g., Marconi et al. (2003); Di Criscienzo et al. (2004); Feast et al. (2008).

The visual magnitude–metallicity relation appears to be hampered by several uncertainties affecting both the zero-point and the slope (Bono et al. 2003). On the other hand, the NIR PL relation seems very promising, since it shows several relevant advantages. Longmore et al. (1986) demonstrated, on an empirical basis, that RR Lyrae do obey to a well defined K -band PL relation. The reason why the PL relation shows up in the NIR bands is due to the fact that the BC in the NIR bands, in contrast with the optical bands, steadily decreases when moving from the hot (blue) to the cool (red) edge of the RR Lyrae instability strip. This means that they become brighter as they become redder. The pulsation periods –at fixed stellar mass and luminosity– become longer, since redder RR Lyrae have larger radii. The consequence of this intrinsic property is that periods and magnitudes are strongly correlated when moving toward longer wavelengths.

Theoretical and empirical evidence indicates that the NIR PL relations of RR Lyrae are robust methods to determine stellar distances.

i)– The NIR PL relations are minimally affected by evolutionary effects inside the RR Lyrae instability strip. The same outcome applies for the typical spread in mass inside the RR Lyrae instability strip (Bono et al. 2001, 2003). Therefore, RR Lyrae distances based on the NIR PL relations are minimally affected by systematics introduced by their evolutionary status. *ii)*– Theory and observations indicate that fundamental (F)

and first overtone (FO) RR Lyrae do obey independent NIR PL relations. *iii)*– Theory and observations indicate that the NIR PL relations are linear over the entire period range covered by F and FO pulsators.

The NIR PL relations also have three observational advantages.

i)– The NIR magnitudes are minimally affected by uncertainties on the reddening. *ii)*– The NIR amplitudes are at least a factor of 2-3 smaller than in the optical bands. Therefore, accurate estimates of the mean NIR magnitudes can be obtained with a modest number of observations. Moreover, empirical K-band light curve templates (Jones et al. 1996) can be adopted to further improve the accuracy of the mean magnitudes. *iii)*– Thanks to 2MASS, accurate samples of local NIR standard stars are available across the sky. This means that both relative and absolute NIR photometric calibrations can be easily accomplished.

The use of the NIR PL relations is also affected by two limits.

i)– Empirical estimates of the slope of NIR PL relations show a significant scatter from cluster to cluster. They range from ~ -1.7 (IC4499, Sollima et al. 2006) to ~ -2.9 (M55, Sollima et al. 2006) and it is not clear whether the difference is intrinsic or caused by possible observational biases. *ii)*– Current predictions indicate that the intrinsic spread of the NIR PL relations decreases by taking into account either the metallicity or the HB-type of the Horizontal Branch (HB) (Bono et al. 2003; Cassisi et al. 2004; Catelan et al. 2004; Del Principe et al. 2006). Therefore accurate distance estimates of field RR Lyrae do require an estimate of the metallicity. However, no general consensus has been reached yet concerning the value of the coefficient of the metallicity term in the NIR Period-Luminosity-Metallicity (PLZ) relations. The current estimates for the K-band range from 0.08 (Sollima et al. 2006) to 0.23 (Bono et al. 2003) mag/dex by using cluster and field RR Lyrae, respectively.

To address these problems our group undertook a long-term project aimed at providing homogeneous and accurate NIR photometry for several GCs hosting a good sample of RR Lyrae and covering a wide range of metal abundances. In the following, we briefly discuss the slope of the K-band³ PL relation when moving from metal-poor to metal-intermediate GCs.

M92)– This is the most metal-poor cluster in our sample (Del Principe et al. 2005). According to the metallicity scale by Kraft & Ivans (2003) based on FeII lines, the iron content is $[\text{Fe}/\text{H}]=-2.38\pm 0.07$. We observed eight fundamental and three first overtones. The latter were fundamentalized and we found a slope of -2.26 ± 0.20 , where the error only accounts for the uncertainty on the linear fit to the data. By using the K-band PL relation provided by Cassisi et al. (2004) we found a true distance modulus of $\mu=14.62\pm 0.04$ mag, that agrees quite well with similar estimates available in the literature Di Cecco et al. (2010, and references therein).

Reticulum)– This is an LMC metal-poor cluster (Dall’Ora et al. 2004). According to the metallicity scale by Suntzeff et al. (1992) based on Calcium triplet lines, the iron

³ The intensity weighted mean magnitudes of the RR Lyrae discussed in this section were calibrated to the 2MASS NIR photometric system using either local standards or the transformations provided by Carpenter (2001).

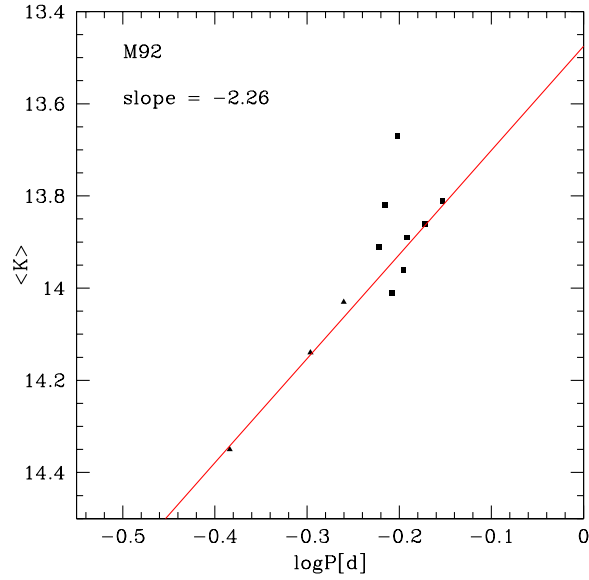


Figure 2.— K-band Period-Luminosity relation of RR Lyrae in the Galactic globular cluster M92, based on data collected by Del Principe et al. (2005). The squares display fundamental (RRab) variables, while the triangles the first overtones (RRc). The latter were fundamentalized ($\log P_F = \log P_{FO} + 0.127$). The red line shows the linear fit of the PLK relation and the slope is labeled.

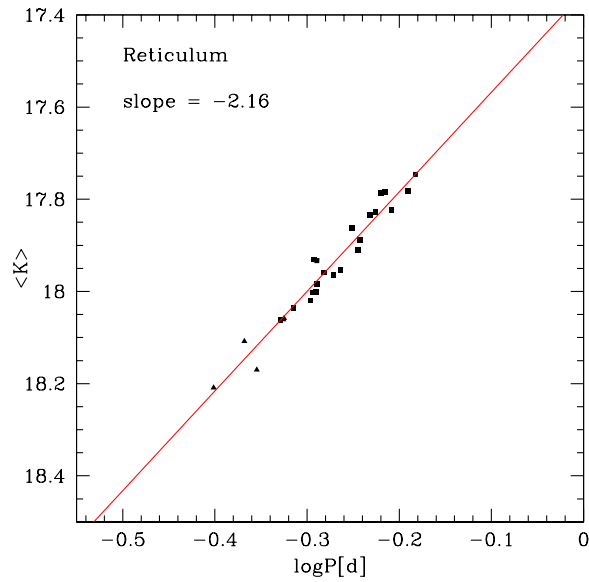


Figure 3.— Same as Fig. 2, but for RR Lyrae stars in the metal-poor LMC globular cluster Reticulum based on data collected by Dall’Ora et al. (2004).

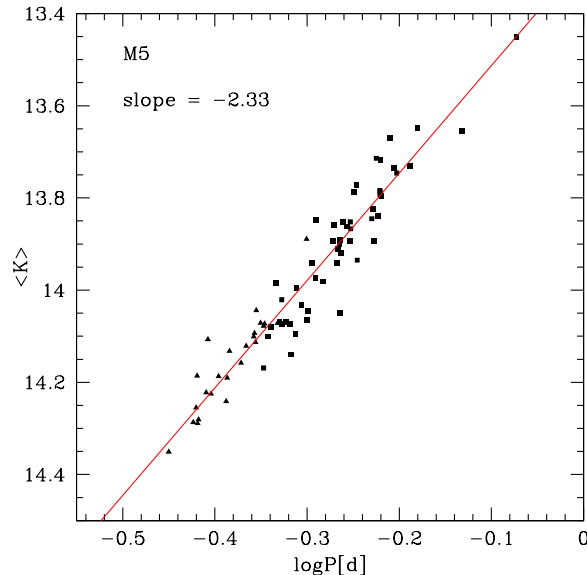


Figure 4.— Same as Fig. 2, but for RR Lyrae stars in the metal-intermediate globular cluster M5 based on data collected by Coppola et al. (2011).

content is $[Fe/H] = -1.71 \pm 0.1$. We observed 21 fundamental and five first overtones. The latter were fundamentalized and we found a slope of -2.16 ± 0.09 , where the error only accounts for the uncertainty on the linear fit to the data. By using the K-band PL relation provided by Bono et al. (2003) we found a true distance modulus to Reticulum of $\mu = 18.523 \pm 0.005$ mag, that agrees quite well with similar LMC distances available in the literature.

M5— This is the metal-intermediate ($[Fe/H] = -1.26 \pm 0.06$) cluster in our sample with the richest sample of first overtone (52) and fundamental (24) pulsators (Coppola et al. 2011). By using the entire sample we found a slope of -2.33 ± 0.08 . We also found a true distance modulus to M5 of $\mu = 14.44 \pm 0.02$ mag, that agrees quite well with distances based on different distance indicators. The good agreement also applies to the kinematic distance. This seems an important finding, since this geometrical methods provides distance that are systematically larger than the distances based on different distance indicators (Bono et al. 2008).

ω Cen— Finally, we also estimated the distance to ω Cen and observed 93 first overtones and 104 fundamentals (Del Principe et al. 2006). The nature of this massive stellar system is not well established yet (Bekki & Freeman 2003). However, there is general consensus that the stellar content of this system shows a metallicity distribution with multiple peaks (Calamida et al. 2009). The same outcome applies to the heavy element abundances (Johnson et al. 2009; Pancino et al. 2002, and references therein). To test the dependence of the slope on the iron abundance we split the sample into a metal-poor and a less metal-poor subsample. We found that the slopes, within the errors, are very similar. Therefore, we decided to perform a linear fit over the entire

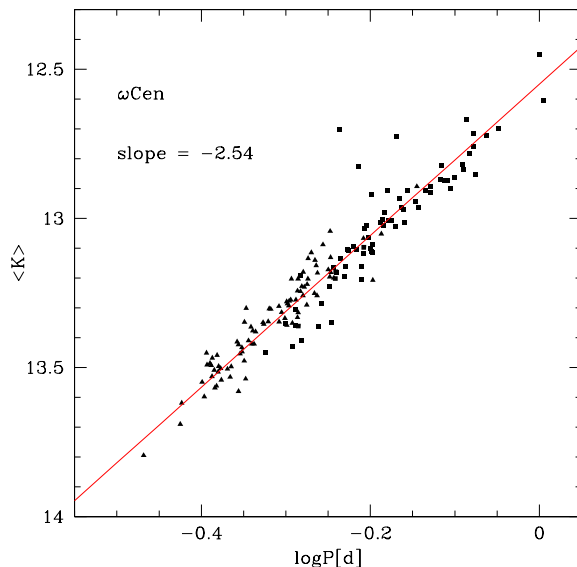


Figure 5.— Same as Fig. 2, but for RR Lyrae stars in the giant globular cluster ω Centauri based on data collected by Del Principe et al. (2006).

sample and we found a slope of -2.54 ± 0.09 . By using the calibration of the K-band PL relation provided by Cassisi et al. (2004) we found a true distance modulus to ω Cen of $\mu = 13.77 \pm 0.07$ mag, that agrees quite well with distance estimates available in the literature (Bono et al. 2008).

The iron content of the GGCs we have already investigated, neglecting ω Cen, ranges from -2.38 to -1.26 dex. The slope of the K-band PL relation should change from ~ -2.1 (Bono et al. 2003) to ~ -2.4 (Del Principe et al. 2006). The former slope is based on models that include the metallicity term, while the latter include the HB type. Current evidence indicates that the slope of the K-band PL relation is marginally affected by iron abundance, thus supporting the results by theory and by Sollima et al. (2006). However, more accurate data both in the metal-poor and in the metal-rich regime are required before we can reach firm conclusions concerning the metallicity dependence of both the slopes and the zero-points of the NIR PL relations.

5. Helium abundances of RR Lyrae: where the eagles dare

Precise abundances of primordial helium (Y_p) together with the abundances of a few other light elements can provide robust constraints on the primordial nucleosynthesis, and in particular on the baryonic density of the Universe. Unfortunately, stellar spectra display strong photospheric helium absorption lines in the visual spectral range only at high effective temperatures ($T_e > 10,000$ K). High-mass stars are useless in constraining Y_p , since their material was already polluted by previous stellar generations. Low-

mass stars only attain hot effective temperatures during central helium-burning phases. The typical evolutionary lifetime of these phases –called Hot and Extreme Horizontal-Branch phases– is of the order of 100 Myr. However, these stellar structures cannot be adopted to constrain Y_p , since their surface abundance are affected by gravitational settling and/or by radiative levitation (Behr 2003; Moehler et al. 2004).

To overcome current observational limits, accurate estimates of Y_p have been provided using He emission lines in HII region of blue compact galaxies. Current estimates agree, within the errors, with the Y_p abundance provided by WMAP (Larson et al. 2011). However, the agreement is not solid because Y_p is used as a prior in the cosmological solutions. Moreover, the spectroscopic abundances based on nebular lines might be affected by systematic errors (Bresolin et al. 2009; Bresolin 2011).

The observational scenario concerning the helium abundance has been recently enriched by the possible occurrence of a variation in the helium abundance of Globular Cluster (GC) stars. The presence of He-enriched stars in GCs has been suggested to explain not only the presence of multiple unevolved sequences, but also the presence of extended blue HB tails (D’Antona & Caloi 2008). This working hypothesis relies on the well established anti-correlations between the molecular band-strengths of CN and CH (Smith 1987; Kraft 1994) and between O–Na and Mg–Al measured in evolved (RG, Horizontal Branch [HB]), and in unevolved (Main Sequence [MS]) stars of the GCs investigated so far with high-resolution spectra (Pilachowski et al. 1983; Gratton et al. 2004). More recently, deep Hubble Space Telescope photometry disclosed the presence of multiple stellar populations in several massive GCs. Together with ω Centauri (Bedin et al. 2004) multiple stellar sequences have been detected in GCs covering a broad range of metal contents: NGC 2808 (Piotto et al. 2007), M54 (Siegel et al. 2007) and NGC 1851 (Calamida et al. 2007; Milone et al. 2008). Some of these multiple sequences (ω Cen, NGC 2808, NGC 1851) might be explained either with a He-enhanced (Norris 2004; D’Antona & Caloi 2008; Piotto et al. 2007), or with a CNO-enhanced (Calamida et al. 2007; Cassisi et al. 2008) sub-population. However, we still lack an empirical validation of the occurrence of He-enhanced sub-population(s) in GCs.

To overcome the spectroscopic problems, Iben (1968) suggested to use the R-parameter –the number ratio between HB and RGB stars brighter than the luminosity level of the HB at the RR Lyrae instability strip (IS)– to estimate the initial He abundance of cluster stars.

Two independent approaches to estimate the helium content in GCs were also suggested by Caputo et al. (1983). The Δ -parameter, –the difference in magnitude between the MS at $(B-V)_0=0.7$ and the luminosity level of the HB at the RR Lyrae IS, and the A-parameter –the mass-to-luminosity ratio of RR Lyrae stars. The pros and cons of the quoted parameters were discussed in a thorough investigation by Sandquist (2000). Theoretical and empirical limits affecting the precision of the R-parameter have been also discussed by Zoccali et al. (2000), Riello et al. (2003) and Salaris et al. (2004).

The key feature of the quoted parameters is that they are directly or indirectly connected with the HB luminosity level. In spite of the improvements in the photo-

metric precision, in the sample of known cluster HB stars, we still lack firm empirical methods to estimate the HB luminosity level in GCs. This problem is partially due to substantial changes in the HB morphology when moving from metal-poor (blue HB) to metal-rich (red HB) GCs. Moreover, we still lack a robust diagnostic to constrain the actual off-ZAHB evolution of HB stars ((Ferraro et al. 1999; Di Cecco et al. 2010; Cassisi et al. 2011). To overcome several of the above drawbacks, Troisi et al. (2011) suggested a new method based on the difference in luminosity between the RGB bump and the main sequence benchmark at the same color of the bump. The new method shows several indisputable advantages, but also a strong dependence on the metal content.

A new approach has been suggested by Dupree et al. (2011) who detected, in a few RG stars in ω Cen, the chromospheric He I line at 10830Å. The He line was detected in more metal-rich stars and it seems to be correlated with Al and Na, but no clear correlation was found with Fe abundance. However, a more detailed non-LTE analysis of the absolute abundance of He is required before firm conclusions can be drawn concerning the occurrence of a spread in helium content.

Interestingly enough, Preston (2009) discovered both He I and He II emission and absorption lines in field RR Lyrae stars. The lines show up during the rising branch of RR Lyrae stars and appear to be the consequence of the shock propagation soon after the phases of minimum radius (Bono et al. 1994b; Chadid & Gillet 1996). The first detection of helium lines in low-mass variables dates back to Wallerstein (1959), who detected helium lines in Type II Cepheids. The key advantage of RR Lyrae stars, when compared with detections of helium lines in hot and extreme HB stars (Behr 2003), is that they have an extended convective envelope. Therefore, they are minimally affected by gravitational settling and/or radiative levitation (Michaud et al. 2004). The drawback is that the measurement of the helium abundance requires hydrodynamical atmosphere models accounting for time-dependent, convective transport, radiative transfer equations, together with the formation and the propagation of sonic shocks.

Empirical evidence indicates that He absorption and emission lines in RR Lyrae stars take place along the rising branch of the light curve. Plain physical arguments suggest that they are triggered by the formation and the development of strong shocks across the phases of maximum compression. To further constrain the physical mechanism(s) driving the occurrence of these interesting phenomena, new high-resolution, high signal-to-noise spectra are required to constrain the dependence of He lines on evolutionary and pulsation properties of RR Lyrae stars and eventually to estimate the helium abundance.

6. Future remarks

Recent theoretical and observational perspectives indicate that RR Lyrae stars are heading for a new golden age. This is due to the huge amount of field RR Lyrae stars

that have already been collected by extended photometric surveys. A sample of $\sim 1,200$ field RR Lyrae were collected by the Northern Sky Variability Survey (NSVS, Wozniak et al. 2004) and analyzed by Kinemuchi et al. (2006). They cover a distance of $\sim 7-9$ Kpc in the solar neighborhood and reach a limit magnitude of $V=15$ mag. An even more ambitious project was realized by the All Sky Automated Survey (ASAS, Szczygiel et al. 2009), since they covered the southern sky up to $\delta=+28$ ($\sim 75\%$ of their sky). The survey has a limiting magnitude of $V\sim 14$ and they identified more than 1,450 RR Lyrae within 4 kpc in the solar neighborhood. Deep multiband photometric (ugriz) and spectroscopic data for almost 500 RR Lyrae have been collected by the Sloan Digital Sky Survey II (SDSS-II, Sesar et al. 2010, Sesar et al. these proceedings). They have been able to investigate the spatial distribution of halo RR Lyrae stars up to galactocentric distances of 5-100 kpc. A sizable sample of field RR Lyrae (more than 2,000) was found by (Keller et al. 2008) using V and R-band archival data collected by the Southern Edgeworth-Kuiper Belt Object (SEKBO) survey. This survey covers 1675 square degrees along the ecliptic to a mean depth of $V=19.5$, i.e. up heliocentric distances of ~ 50 kpc. However, the real quantum jump concerning the photometric precision, the depth and the sampling of current RR Lyrae surveys, is given by the Optical Gravitational Lensing Experiment III survey (OGLE III, Pietrukowicz et al. 2011). They collected V and I-band data over a time interval of almost ten years, toward the Galactic bulge and identified the richest sample ever collected of field RR Lyrae, i.e. more than 16,800 stars. The near future appears even more promising not only concerning the new optical (Pan-STARRS) and NIR (VISTA) photometric surveys, but also for the spectroscopic surveys (M2FS@Magellan, FLAMES@VLT). This means that together with pulsation properties, also the metallicity of a relevant fraction of field RR Lyrae will become available.

It is noteworthy that to attack the open problems mentioned above requires a multiwavelength, a spectroscopic, and a theoretical approach (Benkő et al. 2010; Marconi et al. 2011): a challenge that we have to deal with to further improve our knowledge of the detailed structure of the Galactic spheroid and to improve the accuracy of the RR Lyrae distance scale. The goal is not trivial: not only to further constrain the structure of the Galactic bulge and the interaction with the Galactic Bar, but also to trace the possible transition from thick to thin disc stars (Kinemuchi et al. 2006). Note that up to now, we still lack firm empirical evidence concerning the presence of old, low-mass stars –like RR Lyrae stars– in the thin disc. There are a few field stars that are good candidates (TV Lib), but their intrinsic properties might be significantly different than typical RR Lyrae (Bono et al. 1997). The RR Lyrae can be even more relevant as beacons to trace the stellar streams in the Galactic halo (Marconi et al. 2006) and to constrain the outermost radial extent of the Galactic halo.

This new spin will make a comeback to RR Lyrae and in this ongoing effort George Preston will always be a reference point for suggestions and new ideas.

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