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# RR Lyrae variables in $\omega$ Centauri (NGC 5139) ⋆

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**Abstract.** We present a new analysis for 128 RR Lyrae stars in the globular cluster $\omega$ Cen based on the most recent V and K photometry, and the metallicities derived by Rey et al. (2000). Two populations have been clearly identified, peaking at [Fe/H]$\sim -1.35 \pm 0.2$ dex and $\sim -1.75 \pm 0.2$ dex, in agreement with previous well known results both on RR Lyrae variables and on non-variable stars. The distance modulus estimated from the most numerous metal-poor sample is $(m\text{-}M)_0=13.70 \pm 0.10$, in excellent agreement with other determinations, whereas the less numerous metal-intermediate sample is ~0.2 mag too faint. No age or helium abundance difference can explain this discrepancy. Are these two populations spatially separated, the metal-intermediate one being more distant by 300-400 pc? Or is this a spurious effect of errors in the metal abundance determinations?

**Key words.** Stars: variables: RR Lyrae – Stars: abundances – Stars: evolution – Galaxy: globular clusters: general Galaxy: globular clusters: individual: NGC 5139

## 1. Introduction

RR Lyrae (RRL) stars are considered standard candles for estimating stellar distances within the Milky Way and to Local Group Galaxies, because their absolute magnitude is remarkably constant, albeit with some dependence on the metal content in the sense that metal-poorer stars are brighter (Sandage 1981a,b). The issue is further complicated by stellar evolution, since RRLs in a more advanced stage of evolution are brighter (by up to ~0.3 mag in some cases) than those closer to the zero age horizontal branch for the same value of metallicity (Sandage 1990; Cacciari et al. 2005). The exact slope of the $M_V$-[Fe/H] relation has been a subject of debate for about two decades, and only recently it seems to be converging towards a value ~0.20-0.23 (Gratton et al. 2004; Rich et al. 2005).

The globular cluster $\omega$ Cen (NGC 5139) represents the ideal laboratory for this study, since it contains a large population of RRL variables that can be regarded essentially equally far, and spanning a wide range in metallicity. For these stars accurate V magnitudes (Kaluzny et al. 2004) are available. In

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addition, we have used infrared J and K photometry obtained from SOFI at the ESO-NTT on the central ∼13'×13' region of the cluster and 2MASS data on the outer regions, for a total sample of 128 RRL stars. Metallicities were derived in the past with various methods. We show in Fig. 1 the metallicity distributions (in the Zinn & West 1984 scale) of the RRL variables (ab-type only) from three different studies, i.e. the spectroscopic ΔS results obtained by Butler, Dickens & Epps (1978, BDE78), the results obtained by Rey et al. (2000, R00) using the photometric *hk*-index, and the results we have obtained by applying Jurcsik & Kovàcs (1996, JK96) parameterization to the Fourier $\phi_{31}$ parameter derived by Olech et al. (2003). All three distributions show a wide range of metallicity, with evidence of a bimodal shape in the two most populous ones. If we consider in particular the statistically more significant sample by R00, the two distributions peak at [Fe/H]∼–1.35±0.2 dex and –1.75±0.2 dex, and might be associated with the corresponding metal-intermediate (MI) and metal-poor (MP) components of non-variable stars, in excellent agreement with the many independent results that have revealed the existence of multiple stellar populations in $\omega$ Cen (e.g. Norris et al. 1996; Lee et al 1999; Pancino et al. 2000; Ferraro et al. 2004; Bedin et al. 2004, and references therein). We note that an old more metal-rich component, that was also identified among the non-variable stars (Norris & Da Costa 1995; Pancino et al. 2002; Origlia et al. 2003), is not expected to produce RRL stars in any significant number.

*Does this mean that there have been at least two separate events of star formation in $\omega$ Cen?* If so, did the MI component form later from self-enriched material ejected by a previous generation of stars, or did it form earlier because of faster chemical evolution in the inner regions? In this latter case the MP component would be infalling from external regions with higher angular momentum (as observed by e.g. Norris et al. 1997) and should be younger. *Can RRL stars help answer these questions?*

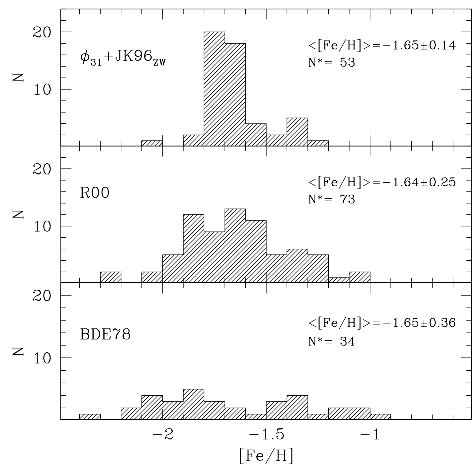


**Fig. 1.** Metallicity distributions of RRL stars (ab-type only) in $\omega$ Cen according to three different methods: the ΔS method by BDE78 (bottom panel); the photometric *hk*-index by R00 (middle panel); the Fourier $\phi_{31}$ parameter following JK96 parameterization (top panel).

## 2. Two groups of RRL stars

We show in Fig. 2 the fundamental relations of mean V & K magnitudes and V light curve amplitude with period (logP) for the RRab stars (including the Blazhko stars) of our sample. We note that: **i)** Both <K> and <V> magnitudes have a non-zero dependence on period, as indicated by the best-fit linear relations for the MP sample (shown as filled and open circles) $< K_{MP} >$=–2.55logP+12.55 and $< V_{MP} >$=–0.875logP+14.34 (see Nemec et al. 1994); **ii)** The MI stars (shown as crosses) are well represented by the same relations shifted to fainter magnitudes by 0.1 mag in K and 0.2 mag in V. However, the shift in V is a factor ∼2 larger than expected from the corresponding difference in metal abundance, according to the slope of the $M_V$(RR)-[Fe/H] relation (see Sect. 1). **iii)** We compare the logP-<V> and logP-<K> relations of the normal main MP population (with period <0.7d, see below) with the corresponding relations in the reference globular cluster M3, on the assumption that E(B–V)=0.01 mag, $[Fe/H]_{ZW}$=–1.66 and

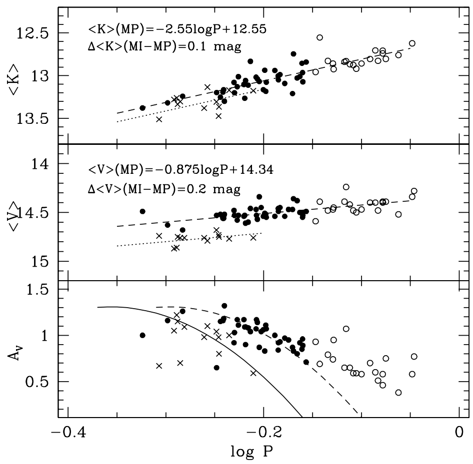


**Fig. 2.** RRab stars only: symbols indicate the MI stars (crosses), normal MP stars (filled circles) and evolved MP stars (open circles). The dashed lines in the two upper panels show the best fit relations to the MP stars indicated in the top left corner of each panel. The dotted lines show the same relations shifted by 0.1 mag in <K> and 0.2 mag in <V>, that seem to represent quite well the MI stars. In the bottom panel, the solid curve represents the relation for M3 regular stars (i.e. typical Oosterhoff I clusters), and the dashed line is the same relation shifted by ΔlogP=0.06 that represents the typical Oosterhoff II clusters.

$(m–M)_0$=15.07 for M3, and E(B–V)=0.11 mag and $[Fe/H]_{ZW}$=–1.75 for the MP RRL stars in $\omega$ Cen. From this comparison we derive $(m–M)_0$=13.70±0.10 for $\omega$ Cen, in excellent agreement with independent estimates from different methods, e.g. Thompson et al. (2001) and Kaluzny et al. (2002) using the eclipsing binary OGLE17, and Bellazzini et al. (2004) considering various methods. **iv)** Both the MI and MP normal stars fall nicely on the $A_V$-logP relations corresponding to Oosterhoff I and II clusters. However, the MP stars with period >0.7d fall off the OoII distribution and are on average brighter than the main normal population of MP stars. **v)** When compared to ZAHB models with Y=0.23 and [Fe/H]=–1.3 and –1.7 (VandenBerg et al. 2000, see Fig. 3), the main distribution of the normal MP RRL stars lies on the corresponding MP ZAHB (solid line), the long period MP stars are indeed brighter, indicating evolution off the ZAHB, and the main distribution of the MI RRL stars falls below the MI ZAHB (dashed line) by ΔlogL~0.035 i.e. ~0.1 mag.

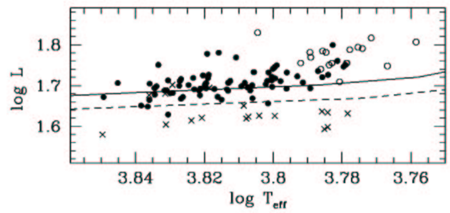


**Fig. 3.** RRab and RRc stars: symbols indicate the MI stars (crosses), normal MP stars (filled circles) and evolved MP stars (open circles). The solid and dashed lines show the ZAHB models for Y=0.23 and [Fe/H]=–1.3 and –1.7 respectively (VandenBerg et al. 2000). In this plot we show both RRab and RRc stars for better statistics, but we note that R00 metallicities for the RRc stars are less accurate.

## 3. Discussion and conclusions

We discuss some possibilities to account for the systematically fainter MI RRL stars.

*Are the MI RRL stars older than the MP ones?* According to theoretical models (Cassisi et al. 1999), $\Delta M_V$(TO)~+0.07 mag/Gyr and ΔV(TO–HB)~+0.07 mag/Gyr, therefore age is not expected to affect significantly $M_V$(HB).

*Are the MI RRL stars helium enriched?* Some helium enrichment was proposed to explain the characteristics of the MI sub-giant and main sequence stars (Norris 2004; Piotto et al. 2005), but it would produce hotter and brighter HB stars (D'Antona & Caloi 2004) contrarily to the observations.

*Are the MI RRL stars more distant, by 300-400 pc?* This was proposed by Freyhammer et al. (2005) for the MR component (–0.8>[Fe/H]>–1.1), which shows several other chemical and dynamical anomalies. However, the MI component has the same projected center, mean radial velocity (Pancino et al. 2003) and proper motion (Ferraro et al. 2002) as the MP one.

*Is the metallicity of the MI RRL stars wrong?* A slightly higher metal abundance, by ~0.2-0.3 dex, for the MI RRL stars would account for most of the observed luminosity discrepancy with the MP RRL stars. We have no specific reason to mistrust the previous metallicity determinations, however FLAMES spectra for ~ 80 RRL stars have been taken recently to test the metallicities in a further independent way (Sollima et al. 2005, in preparation).

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