Light curves and metal abundances of RR Lyrae variables in the bar of the Large Magellanic Cloud

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Abstract. The Large Magellanic Cloud (LMC) is widely considered a corner-stone of the astronomical distance scale, however a difference of 0.2–0.3 mag exists in its distance as predicted by the short and long distance scales. Distances to the LMC from Population II objects are founded on the RR Lyrae variables. We have undertaken an observational campaign devoted to the definition of the average apparent luminosity and to the study of the mass-metallicity relation for RR Lyraes in the bar of the LMC. These are compared with analogous quantities for cluster RR Lyraes. The purpose is to see whether an intrinsic difference in luminosity, possibly due to a difference in mass, might exist between field and cluster RR Lyraes, which could be responsible for the well-known dichotomy between short and long distance scales. Preliminary results are presented on the V and B−V light curves, the average apparent visual magnitude, and the pulsational properties of 102 RR Lyrae in the bar of the LMC, observed at ESO in January 1999. The photometric data are accurately tied to the Johnson photometric system. Comparison is presented with the photometry of RR Lyraes in the bar of the LMC obtained by the MACHO collaboration (Alcock et al. 1996). Our sample includes 9 double-mode RR Lyraes selected from Alcock et al. (1997) for which an estimate of the metal abundance from the ∆S method is presented.

1. Observations, data reduction and calibration

We have collected B,V CCD photometry in two 13′ x 13′ fields located close to the bar of the LMC and overlapping with fields #6 and #13 of the MACHO microlensing experiment (see http://www.macho.mcmaster.ca), using the 1.5m Danish telescope in La Silla. The photometric data set consists of 58 V and 25 B frames of each field. 118 variables were identified in the two fields (62 ab type RR Lyrae, 30 RRc, 10 RRd, 6 Cepheids, 9 eclipsing binaries and 1 δ Scuti). Photometry was accurately tied to the Johnson standard photometric system using a large number of standard stars from Landolt (1992).
Low resolution spectra (R=450, res.element=9 Å) were obtained for 7 of the RR$_d$ variables with EFOSC2 at the 3.6 m ESO telescope, and metal abundances have been derived using the ∆S technique (Preston 1959). For calibration purposes we took also spectra at minimum light of 8 field RR Lyraes of known ∆S (of which a c type followed along the pulsation cycle), and of 14 stars of the open cluster Collinder 140, which contains spectral type standard stars.

Photometric data were analyzed using the package DoPHOT (Schechter, Mateo, & Saha, 1993). Spectroscopic data were reduced using the standard IRAF packages for long slit spectra. Total numbers of 28000 and 25000, and 23000 and 19000 objects were measured in the V and B frames of the two fields, respectively. The average magnitude the LMC clump stars is $<V> = 19.202$ ($\sigma = 0.202$; 8979 stars) The comparison with the Alcock et al. (1997, hereinafter A97) $<V>$ for the clump, as can be read from their Fig. 3, shows that our value is about 0.10 mag "fainter".

2. Identification, period search and pulsational properties of the RR Lyrae variables

Variables were identified on the V and B frames independently. Periods were defined using the program GRATIS (GRaphycal Analyzer Ti me Series; Montegriffo, Clementini, & Di Fabrizio 1999, in preparation) which was run on the differential photometry of the variables with respect to a number of stable reference stars. The period search procedure was to perform a Lomb analysis (Lomb 1976) on a wide period interval first, and then use a Fourier analysis to refine periods and find the best fitting models. Average residuals from the best fitting models for single-mode pulsators with well sampled light curves are 0.02–0.03 mag in V, and 0.04–0.06 mag in B. Figure 1 shows examples of the V and B light curves of an ab, a c type RR Lyrae in our sample. The period distribution of the c type RR Lyraes in our fields peaks at $<P(\text{RR}_c)> = 0.314 \pm 0.047$ (average on 30 stars), while $<P(\text{RR}_ab)> = 0.577 \pm 0.077$ (average on 60 stars) to compare with 0.342 and 0.583 of Alcock et al. (1996, hereinafter A96). Our shortest period ab
type RR Lyrae has period 0.318 d, and there are two other RR\textsubscript{ab}’s with periods around 0.40 d. We derived \(<V>\) and \(<B>\) intensity average magnitudes as well as V and B amplitudes (A\textsubscript{V} and A\textsubscript{B}) for all variables with complete light curves. The average <V> apparent magnitude of the RR Lyraes in our sample is: <V> = 19.325 ± 0.170 (75 stars), to compare with <V> = 19.4 from A96. On the assumption that: E(B−V)=0.10 (Bessel 1991) and A\textsubscript{V}=3.1[E(B−V)] for the LMC we find:

\[
< V_0 > = 19.015 \pm 0.020 \text{ at } [\text{Fe/H}] \sim -1.5 \text{ field RR Lyraes, this paper}
\]
\[
< V_0 > = 19.09 \text{ at } [\text{Fe/H}] \sim -1.7 \text{ field RR Lyraes, A96}
\]
\[
< V_0 > = 19.06 \pm 0.06 \text{ field RR Lyraes, Kinman et al. (1991)}
\]
\[
< V_0 > = 18.94 \pm 0.040 \text{ at } [\text{Fe/H}] = -1.9 \text{ cluster RR Lyraes, Walker (1992)}
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Allowing for the 0.4 dex difference in [Fe/H] our <V> is in very good agreement with Walker (1992), thus showing that there is no clear evidence for a difference in luminosity between field and cluster RR Lyraes in the LMC.

3. Spectroscopy of the double-mode RR Lyraes

Spectra for 7 of the RR\textsubscript{d} variables falling in our fields were obtained at phases corresponding to the minimum light. Metallicities were inferred from these spectra using the ∆S index and the Clementini et al. (1995) calibration of ∆S in terms of metallicity ([Fe/H]=−0.194×∆S−0.08). Dealing with variables which pulsate both in the fundamental and first overtone, the question arises whether these stars should be treated as \textit{ab} or \textit{c} type pulsators in measuring ∆S. Following Kemper (1982) and discussions in Clement, Kinman, & Suntzeff (1991), we considered our targets as \textit{c} type variables. ∆S values were thus measured from spectra with Hydrogen spectral type later than A8, and applying phase corrections derived from the field RR\textsubscript{c} T Sex. Table 1 lists the ∆S values and corresponding metallicities we derived for our targets. Values for star #5 are rather uncertain since the spectrum of this star has very low S/N. Errors on the quoted ∆S are of the order of 0.7–1 ∆S subclasses, corresponding to an error of about 0.20–0.30 dex in [Fe/H].

| N(A97) | ∆S | [Fe/H] | M/M\textsubscript{\odot} |
|-------|-----|--------|----------------------|
| 2     | 8.6 | −1.74  | 0.60                 |
| 5     | 11.3| −2.28  | 0.61                 |
| 45    | 7.9 | −1.62  | 0.65                 |
| 48    | 5.2 | −1.09  | 0.67                 |
| 49    | 7.3 | −1.50  | 0.69                 |
| 61    | 5.9 | −1.23  | 0.71                 |
| 67    | 8.8 | −1.78  | 0.81                 |

4. The mass-metallicity relation for the RR Lyrae stars

A97 provides P\textsubscript{0}/P\textsubscript{1} ratios for the 7 double-mode variables in Table 1. These ratios can be used together with Petersen diagrams (Petersen 1973) and Bono
et al. (1996) loci of model pulsators to estimate the masses of our targets (see e.g. Figure 2 of A97). Masses obtained with this procedure are listed in the last column of Table 1 and plotted against metallicity in Figure 2. Also shown is the mass-metallicity relation defined by double-mode pulsators in the globular clusters M68 (Walker 1994), M15 (Nemec 1985) and IC 4499 (Clement et al. 1986, Walker & Nemec 1996) and two RR\textsubscript{d}’s in the Milky Way (Clement et al., 1991). Although there is some scatter, and there are only few field objects, most of the LMC RR\textsubscript{d}’s seem to follow the general mass-metallicity relation defined by the cluster RR\textsubscript{d}’s. Hence, no clear-cut evidence is found for a difference in mass between field and cluster RR Lyraes.

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