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The RR Lyrae distance scale from near-infrared photometry: current results

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Abstract. We present new observational results on the RR Lyrae *K*-band Period-Luminosity relation (*PLK*). Data on the Galactic globular clusters NGC 3201 and NGC 4590 (M68), and on the Large Magellanic Cloud cluster Reticulum are shown. We compare the observed slopes of the *PLK* relations for these three clusters with those predicted by pulsational and evolutionary models, finding a fair agreement. Trusting on this finding we decided to adopt these theoretical calibrations to estimate the distance to the target clusters, finding a good agreement with optical-based RR Lyrae distances, but with a smaller formal scatter.

Key words. Stars: variables: RR Lyr – Galaxy: globular clusters: individual: NGC 3201 – Galaxy: globular clusters: individual: NGC 4590 – Galaxies: Magellanic Clouds

1. Introduction

RR Lyrae stars are well-known Population II variable stars, widely used as distance indicators, since their mean *V*-magnitude is almost constant and they are bright enough to be detected at moderately large distances. Usually their mean *V*-magnitude is calibrated as a linear funtion of their abundance [Fe/H], but this calibration is still hampered by several theoretical and observational uncertainties (see, e.g., Cacciari & Clementini 2003 and Bono

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2003). However, in the K-band the RR Lyrae stars follow a quite tight Period-Luminosity relation (*PLK*, Longmore et al. 1990). This relation shows several advantages when compared to the optical calibration: the *PLK* relation is only moderately affected by evolutionary effects, its intrinsic spread is of the order of 0.03 mag (Bono et al. 2001 (B01); Bono et al. 2003 (B03)), K-band magnitudes are only marginally affected by reddening, and the light curves have low amplitudes, allowing the estimate of the mean magnitude even with a few observations. Moreover, empirical templates (Jones et al. 1996) can be adopted to improve the estimate of the mean magnitude when a single observation is available. However, theoretical *PLK* relations show a small dependence on the metallicity, with a slope of the order of 0.2 mag/dex. We present current results on the Galactic globular clusters NGC 3201 and NGC 4590 (M68), and on the Large Magellanic Cloud (LMC) cluster Reticulum. This work is part of a large observational project, which includes data for 17 Galactic globular clusters, 5 LMC clusters, and field RR Lyrae stars in the Baade Window, in the Sagittarius Stream, and in the main body of the LMC.

2. Observations and data reductions

All the data presented in these proceedings were collected with SOFI@NTT and pre-processed with IRAF routines following the prescriptions reported in the SOFI user's manual. Photometry was carried out with DAOPHOT/ALLFRAME packages (Stetson 1987; Stetson 1994). The photometric zero-points were computed from the standards catalogue by Persson et al. (1998), which is defined in the LCO system. For NGC 3201 and M68, a cross-check with local standards from the 2MASS catalogue showed a difference in magnitude of 0.01 mag in the K_s-band, in excellent agreement with the shift predicted by Carpenter (2001) between these two NIR systems. To properly compare empirical results and theoretical predictions, computed in the Bessell & Brett (1988) system, we finally transformed observations and theory to the 2MASS system following the equations by Carpenter (2001).

NGC 3201 is a metal-intermediate cluster ([Fe/H]= −1.53), with a large number of RR Lyrae stars (77) and characterized by a strong differential reddening (Layden & Sarajedini 2003; Piersimoni, Bono & Ripepi 2002), that makes it difficult the estimate of the distance from V-band photometry. Owing to its large extent, this cluster was observed with two different pointings, covering only the southern part. Therefore, only 30 RR Lyrae stars are present in our catalogue, for which we collected a dozen phase points. Observed light curves were fitted with cubic splines, and intensity-averaged mean magnitudes were computed. Figure 1 shows the observed *PLK* relation for this cluster. The straight line marks the empirical fit to the complete set of RRab (27) and fundamentalized ($\log P_F = \log P + 0.127$) RRc stars (3), with a slope of -2.35 ± 0.08. This slope is slightly steeper than the slope predicted by the pulsational models (-2.101, B03; -2.071, B01), but in close agreement with the slopes based on evolutionary models (~ -2.34, Catelan, Pritzl & Smith 2004; Cassisi et al. 2004). When only RRab stars are used, the observed slope is -2.13 ± 0.12. Using the fully theoretical B01 calibration, and an average reddening of $E(B-V) = 0.30$ mag (Piersimoni, Bono & Ripepi 2002), the true distance modulus is 13.38 ± 0.03 mag, in good agreement with the optical estimates (Layden & Sarajedini 2003). The semi-empirical calibration by B03 gives a longer distance of 13.47 ± 0.03 mag.

M68 is a metal-poor cluster ([Fe/H]= −2.1), characterized by a sizable sample of RR Lyrae stars (42) and by a well-known reddening ($E(B-V) = 0.07 \pm 0.01$, Walker 1994). We collected data for two different pointings, recovering 34 RR Lyrae stars. Observed light curves (12 phase points) were fitted with cubic splines (see Figure 2 for an example). M 68 contains a large number of suspected Blazhko stars and double pulsators, and for these variables the light curves show a large spread. Mean magnitudes for these variables could be improved with the use of the templates.

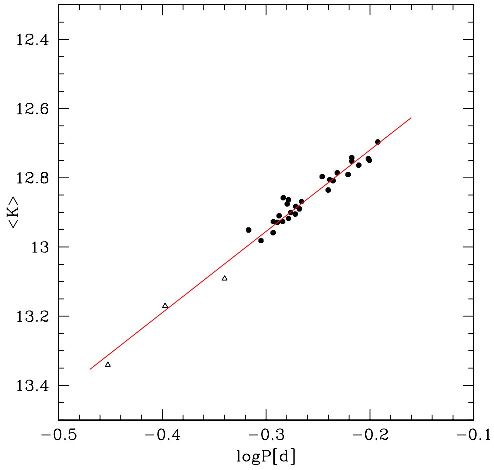

Fig. 1. Observed *PLK* relation for NGC 3201. Filled circles are fundamental pulsators, while filled triangles depict first overtone fundamentalized RR Lyrae stars. The straight line marks the empirical fit to the data.

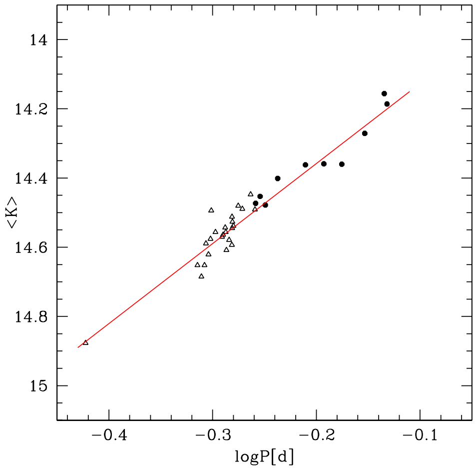

Fig. 3. Observed *PLK* relation for NGC 4590. Filled circles are fundamental pulsators, while open triangles depict first overtone "fundamentalized" RR Lyrae stars. The straight line marks the empirical fit to the data.

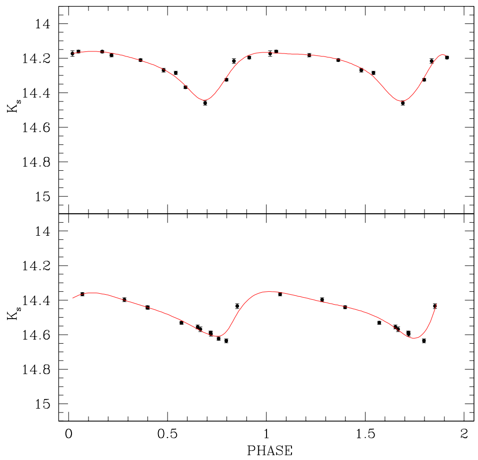

Fig. 2. Light curves for the M68 RR Lyrae stars V10 (bottom panel) and V35. Observations were fitted with a cubic spline (solid line).

Figure 3 shows the empirical *PLK* relation for M 68. Filled circles represent RRab stars, while empty triangles show the position of fundamentalized RRc stars. The straight line depicts the empirical fit to the data. The observed slope, when the whole sample (RRab + RRc stars) is considered, is -2.36 ± 0.11, in good agreement with the prediction of the evolutionary models of Cassisi et al. (2004). However, if only the fundamental pulsators are used, the observed slope is -2.19 ± 0.23. Adopting the theoretical calibration of B01, the true distance is 15.11 ± 0.04, in excellent agreement with the most recent estimates available in the literature (Di Criscienzo, Marconi & Caputo 2004). As in the case of NGC 3201, the B03 calibration yields a larger distance (μ_0 = 15.24 mag).

Data presented for Reticulum have already been discussed in Dall'Ora et al. (2004). Here we focus our attention on the estimated distance: adopting the B01 calibration, we estimate a true distance of 18.46 ± 0.03 mag, slightly smaller than the distance estimated with the B03 calibration, 18.52 ± 0.03 mag, adopted in Dall'Ora et al. (2004).

The observed slopes and the estimated distances are summarized in Tables 1 and 2, respectively.

Table 1. Observed and predicted slopes. See text for details.

Cluster	RRab + RRc	RRab	B01	B03	Catelan et al.	Cassisi et al.
NGC 3201	−2.35 ± 0.08	−2.13 ± 0.12			−2.345	−2.34
M 68	−2.36 ± 0.11	−2.19 ± 0.23	−2.071	−2.101	...	−2.30
Reticulum	−2.16 ± 0.09	−2.19 ± 0.11			−2.358	−2.34

Table 2. Distances: we list optical-based RR Lyrae distances (NGC 3201:Layden & Sarajedini 2003; M 68: Di Criscienzo, Marconi & Caputo 2004; Reticulum: Walker 1992), and the estimated true distances with the current calibrations of the *PLK*.

Cluster	[Fe/H]	Optical	B01	B03	Catelan et al.	Cassisi et al.
NGC 3201	−1.53	13.40 ± 0.05	13.38 ± 0.03	13.47 ± 0.03	13.27 ± 0.03	13.38 ± 0.02
M 68	−2.10	15.08 ± 0.07	15.11 ± 0.04	15.24 ± 0.06	...	15.15 ± 0.04
Reticulum	−1.71	18.35 ± 0.10	18.46 ± 0.03	18.52 ± 0.03	18.31 ± 0.03	18.47 ± 0.03

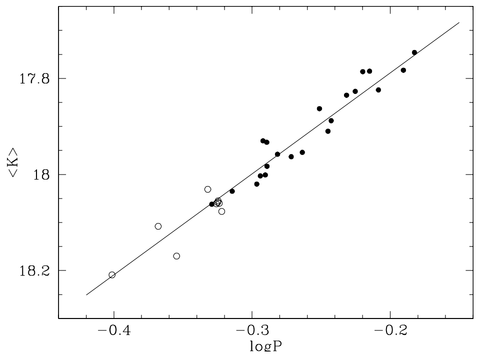

Fig. 4. Observed *PLK* relation for the LMC cluster Reticulum. Filled and open circles show fundamental and fundamentalized pulsators, respectively. The straight line marks the theoretical prediction from B03 for the derived distance modulus. Plot from Dall'Ora et al. (2004).

3. Discussion and conclusions

The observed slopes for the three targets are listed in Table 1. Current slopes have been estimated using the entire sample of variables and only for fundamental variables. The slopes predicted by pulsational and evolutionary models are also listed. In Table 2 we compare the estimated distances using the four most recent calibrations of the *PLK* available in the literature, and for comparison the optical-based distances. Values listed in this table indicate that B03 calibration gives longer distances than B01. This difference can be accounted for with the metallicity coefficient (+0.167 and +0.231 in the B01 and B03 calibrations, respectively). Finally, we note that *PLK* distances are characterized by a smaller formal error than optical distances. It is worth noting that the *PLK* relations estimated by Cassisi et al. (2004) and by Catelan, Pritzl & Smith (2004) require knowledge of the HB morphological type. This parameter is completely unknown for field RR Lyrae stars. On the other hand, pulsationally based *PLK* relations only need knowledge of the metallicity and, once calibrated, can be adopted for individual RR Lyrae stars. To this aim, we have already collected accurate near-infrared data for a large sample of globular clusters that cover a wide range of metal contents and HB morphologies, and firmer conclusions will be drawn when the photometry of this dataset is completed.

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