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Near-Infrared photometry of LMC cluster Reticulum

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Abstract. We present near-infrared (JK_s) time series data of the Large Magellanic Cloud (LMC) cluster Reticulum. The observing strategy and data reduction (DAOPHOTII/ALLFRAME) allowed us to reach a photometry accuracy of the order of 0.02 mag at limiting magnitudes typical of RR Lyrae stars. We are interested in Reticulum, since it hosts a sizable sample of RR Lyrae (32), and therefore the use of the K-band Period-Luminosity-Metallicity (PLZ_K) relation will allow us to supply an accurate LMC distance evaluation. The main advantages in using this method is that it is marginally affected by off-ZAHB evolutionary effects and by reddening corrections. As a preliminary but robust result we find a true distance in good agreement with the LMC Cepheid distance scale, i.e. $\mu = 18.47 \pm 0.07$ mag.

Key words. CM diagram: Reticulum – Variable stars: RR Lyrae stars – LMC: distance modulus

1. Introduction

RR Lyrae stars are traditionally considered good Population II distance indicators, since they approximatively share a common V magnitude, are easily detectable from their light curve and they

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are bright enough to be observable at large distances. The mean V magnitude of RR Lyrae does depend on the metallicity, i.e. $M_V = \alpha[Fe/H] + \beta$. Unfortunately, there is no general consensus on the slope of this relation, and current values range from $\alpha \approx 0.18$ to ≈ 0.30. When applied to globular clusters, these distance uncertainties imply a substantial uncertainty on the absolute age estimate as well as on the statement of a quantitative age-metallicity relation. Finally, we note that it has been suggested that the M_V vs. [Fe/H] relation might not be strictly linear when moving from metal-poor to metal-rich RR Lyrae stars (Caputo et al. 2000). Moreover, even in the same globular cluster (i.e. in a population of stars characterized by the same metallicity), evolutionary effects can produce a spread in magnitudes ranging from ≈ 0.2 to ≈ 0.5 mag (Sandage, 1990).

These problems can be overcome in the near-infrared bands, because RR Lyrae in the K-band (2.2 μm) obey a well-defined period-luminosity relation (Longmore et al. 1986, 1990). The major advantages of such a relation are that K-band magnitudes are only marginally affected by both metallicity and reddening effects. In their theoretical work, Bono et al. (2001) derived a PLZ_K relation for the K-band. They found that the relation shows only a mild dependence on the luminosity level and a small dependence on the mass. Moreover, Bono et al. (2003) showed that the residual uncertainty on the luminosity level can be further reduced by using a period-color-metallicity relation. The theory has been tested by Bono et al. (2002) on RR Lyrae itself, whose trigonometric parallax was recently measured by HST (Benedict et al., 2002). Bono et al. found a "pulsational parallax" of 3.858±0.131 mas, to compare with 3.82 ± 0.20 mas obtained by Benedict and coworkers.

In the present work we apply these theoretical relationships to RR Lyrae stars hosted in the LMC cluster Reticulum, since LMC is the cornerstone of the extragalactic distance scale.

2. Data analysis

J and K_s images were collected in three different runs with SOFI@NTT/ESO from December 1999 to February 2002, and they were pre-reduced, following the procedures outlined in the SOFI user's manual (Lidman et al., 2002), by means of standard IRAF commands. Photometric reduction on 46 J and 171 K_s useful frames was performed with DAOPHOTII/ALLFRAME packages (Stetson, 1987, 1994). Photometric zero-point was estimated on the Persson et al. (1998) 9109 standard star.

$J-(V-J)$ and $K_s-(V-K_s)$ color-magnitude diagrams were obtained by coupling infrared data with V observations collected with SUSI1 and SUSI2@NTT/ESO (Fig.1). Data plotted in Fig. 1 are ALLFRAME mean magnitudes. Note that the photometric accuracy for RR Lyrae stars is better than 0.02 mag, and the good photometric accuracy is also supported by the narrow distribution of stars along the Red Giant Branch. We reached limiting magnitudes of ≈ 21 and ≈ 19.7 mag in J and K_s bands, respectively.

3. Distance modulus

To accomplish our goal we only used RR Lyrae stars with well-sampled light curves, namely 21 stars in the J and 23 in the K_s band. First overtone pulsators were "fundamentalized", i.e. we added 0.127 to their $\log P$, to use the same PLZ_K relation for fundamental and first overtone pulsators. Fig.2 displays observed J (left panel) and K_s magnitudes vs. $\log P$, showing the well-defined correlation between these two quantities. In the following we will also put $K = K_s$, since the color term in the transformation between these two filters is negligible (Lidman et al., 2002).

For the K band we used the fundamental pulsators relation given by Bono et al. (2003)

$$M_K = 0.568 - 2.101\log P + 0.125\log Z - 0.734\log L/L_\odot \quad (1)$$

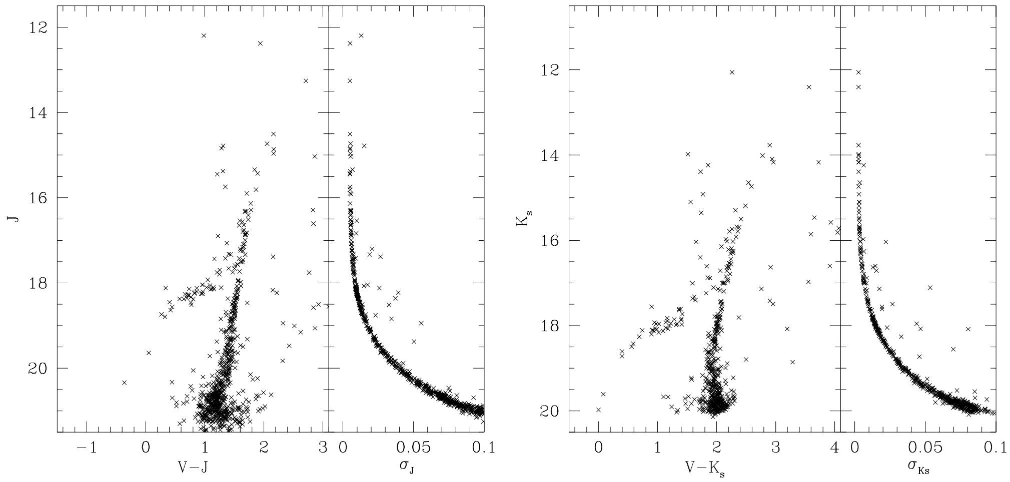

Fig. 1. $J-(V-J)$ (left) and $K_s-(V-K_s)$ color-magnitude diagrams of Reticulum. ALLFRAME mean magnitudes are plotted. We detected ≈ 900 stars. The two figures only show stars with DAOPHOT parameters *sharpness (sh)* and χ (that are diagnostics of the goodness of the photometry) in the range $-1 \leq sh \leq 1$ and $\chi < .6$, respectively.

The luminosity of each pulsator can be evaluated using the $(V-K)$ period-color relation (Bono et al., 2003)

$$(M_V - M_K) = 3.963 + 1.986 \log P + \\ +0.162 \log Z - 1.662 \log L/L_\odot \quad (2)$$

Adopting $\log Z = -3.4$ (Suntzeff et al., 1992), $E(B-V) = 0.02$ (Walker, 1992) and $A_K = 0.11 A_V$ (Cardelli et al., 1989) we obtained a true distance modulus

$$(DM)_{K,0} = 18.55 \pm 0.07$$

We also estimated the distance with a period-luminosity-metallicity relation for the J-band

$$M_J = 1.669 - 1.491 \log P + 0.048 \log Z - \\ -1.251 \log L/L_\odot \quad (3)$$

where once again we estimated the luminosity with equation (2). Adopting $A_J = 0.28 A_V$ (Cardelli et al., 1989) we obtained

$$(DM)_{J,0} = 18.51 \pm 0.06$$

Current distance estimates agree quite well, within the errors, with distance determinations available in the literature and in particular with the distance evaluation based on LMC Cepheids, i.e. ($\mu = 18.55 \pm 0.06$, Fouquè et al., 2003). Note that, if we assume a difference in distance between Reticulum and the LMC center of $\Delta\mu = 0.08$ (Walker, 1992), then the true distance to LMC becomes $(DM)_{J,0} = 18.43 \pm 0.06$ and $(DM)_{K,0} = 18.47 \pm 0.07$, respectively. Both values are in good agreement with the distance modulus of LMC evaluated by Cacciari & Clementini (2003), namely $\mu = 18.48 \pm 0.05$, obtained by averaging different absolute magnitude determinations for RR Lyrae stars.

4. Conclusions

Empirical and theoretical evidence suggest that the PLZ_K relation is a quite promising method to obtain accurate distance estimates for RR Lyrae stars. With this relation we obtained a distance modulus to the LMC cluster Reticulum that is in good agreement with the LMC Cepheid distance. The accuracy of the result could be further improved by fitting the light curves with suitable templates (Jones et al., 1996).

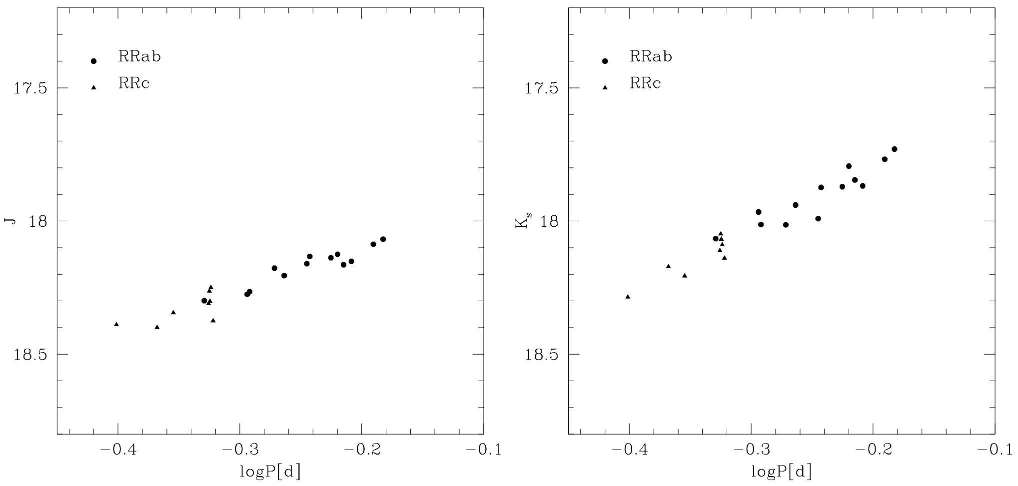

Fig. 2. Observed period-luminosity relations for J (left panel) and K_s-bands. Filled circles depict fundamental pulsators (RRab), while filled triangles are first overtone pulsators (RRc). Periods of RRc have been "fundamentalized" (see text).

Finally, as a preliminary result, we also estimated the Reticulum distance modulus with a period-luminosity-metallicity relation for the J-band, and we obtained a value in good agreement with the PLZ_K distance.

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