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Distance scale and variable stars in Local Group Galaxies: LMC and Fornax

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Abstract. We briefly review our photometric and spectroscopic study of RR Lyrae variable stars in the bar of the Large Magellanic Cloud (LMC), that allowed us to reconcile the so-called *short* and *long* distance moduli of the LMC on the value $\mu_{LMC} = 18.51 \pm 0.085$ mag. Then we present preliminary results from the photometric study of a 33'×34' area in the Fornax dwarf spheroidal galaxy containing the stellar clusters Fornax 3 (NGC 1049) and 6. We identified about 1000 candidate variables in this field of Fornax, and report the first detection and measure of about 60 RR Lyrae variable stars in the globular cluster Fornax 3.

Key words. Magellanic Clouds – Fornax – Variable stars – Distance scale

1. Introduction

Variable stars are important to set the astronomical distance scale, and to sample different stellar populations in galaxies. RR Lyrae stars, in particular, trace the oldest stellar component and are the primary Population II distance indicators in the Local Group galaxies.

2. The Large Magellanic Cloud

The distance to the LMC has for a long time remained uncertain notwithstanding its vicinity to the Milky Way. In fact, the LMC distance modulus from different indicators ranges from about 18.3 mag (e.g. Baade-Wesselink and statistical parallax methods: Fernley et al. 1998a,b) to about 18.7 mag (e.g. Cepheid trigonometric parallaxes: Feast & Catchpole 1997). In the following, we present the results of our study of variable stars in the LMC and its impact on the *short* and *long* distance scale controversy.

We obtained time series photometric data (72 V, 41 B, and 15 I frames) of two 13' × 13' fields (Field A and B) close to the bar of the LMC and derived light curves accurate to 0.02-0.03 mag, for 125 RR Lyrae stars (77 RRab's, 38 RRc's, 10 double-mode pulsators RRd's), 4 anomalous Cepheids, 11 classical Cepheids, 11 eclipsing binaries, and one δ Scuti star.

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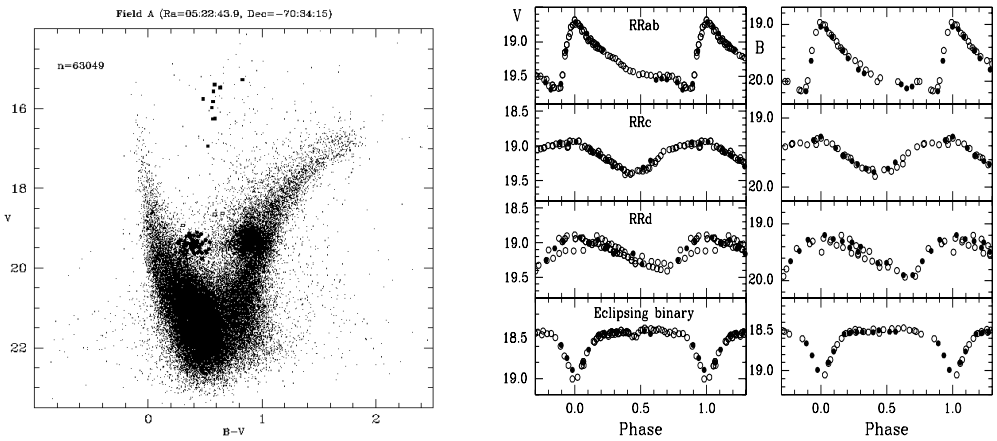

Fig. 1. Left panel: V *vs* B − V color - magnitude diagram of our LMC Field A. Larger symbols mark the variables identified in this area. Right panel: examples of our light curves.

Figure 1 shows, on the left, the location of the variable stars in the HR diagram of Field A; variables are plotted according to their intensity-average magnitudes and colors. On the right, we show the light curves for an RRab, an RRc, an RRd and an eclipsing binary in our sample.

We also derived metallicities for a total number of about 100 of the RR Lyrae stars using different methods. We applied the ΔS method (Preston 1959) to 6 RRd's (Bragaglia et al. 2001), and a revised version of this technique to spectra obtained with FORS at the VLT in 2001 for 101 RR Lyrae stars in our sample. Finally, photometric metallicities were estimated from parameters of the Fourier decomposition of the *V* light curves (Jurksic & Kovács 1996, Kovács & Walker 2001) for 29 RRab's.

All these different estimates are in very good agreement to each other, once differences in the adopted metallicity scales are properly taken into account and give an average metal abundance of [Fe/H]=−1.5.

We used the VLT spectroscopic metallicity determinations and our estimates of the average luminosities of the RR Lyrae stars and reddening, to derive the luminosity-metallicity relation followed by the LMC RR Lyrae stars:

$$< V_0\ (RR) >= (0.214 \pm 0.047)\,([\mathrm{Fe/H}] + +1.5) + 19.064 \pm 0.017 \quad (1)$$

(Clementini et al. 2003, Gratton et al. 2003, in preparation).

Our estimate of the dereddened average luminosity of the RR Lyrae stars in the LMC bar is $< V(RR) >_0 = 19.06$ mag (at [Fe/H] = −1.5 dex). This value was combined with a number of recent independent estimates for the absolute magnitude of the RR Lyrae stars (e.g. Gratton et al. 2002, Cacciari et al. 2000) to estimate the LMC distance. The distance moduli so derived where compared with the most recent and accurate LMC distance determinations from several other Population I and II distance indicators, reaching 1 σ convergence on a distance modulus of $\mu_{LMC} = 18.51 \pm 0.085$ mag, as fully described in Clementini et al. (2003).

3. The Fornax dwarf spheroidal galaxy

Located about 140 Kpc from the Milky Way, Fornax is a dwarf spheroidal galaxy (dSph) dominated by an intermediate-age stellar population (Stetson et al. 1998, Saviane et al. 2000). There is also evidence for an old stellar component, since the galaxy contains five globular

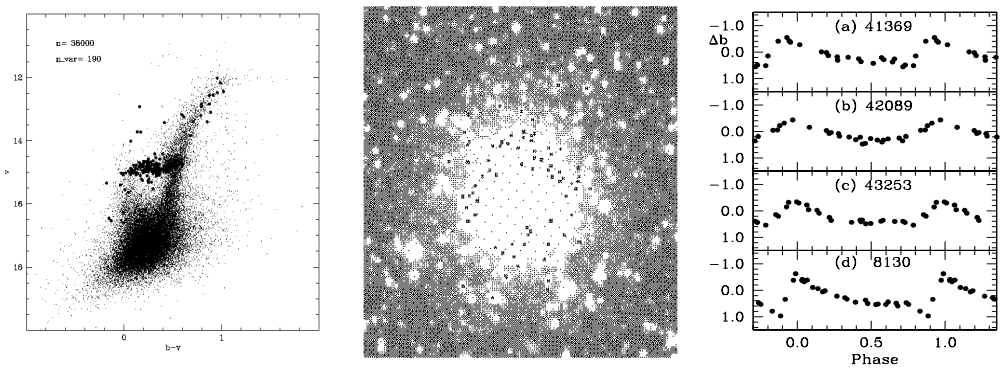

Fig. 2. On the left: Instrumental color-magnitude diagram of chip #7; candidate variables are marked as larger symbols. In the center: image 95" × 95" of the globular cluster NGC 1049, with candidate variables marked as filled squares. On the right: examples of light curves in Fornax 3, [panels (a) and (b)], and in the field, [panels (c) and (d)].

clusters and field population as old and metal-poor as that in globular clusters (Saviane et al. 2000). The field of Fornax dSph has been investigated for variability by Bersier & Wood (2002) who surveyed a half square degree covering the central region and found about 600 variables (among which 515 RR Lyrae). However, because of the small telescope size and the mediocre seeing conditions of their observations, RR Lyrae are close to the detection limit of their photometry, and their observations did not result in high quality light curves. GCs of Fornax dSph have never been adequately surveyed for variability, in spite of clear indications, from their HB morphologies, that they should indeed contain RR Lyrae variables (Buonanno et al. 1998,1999).

Fornax 3, one of the two clusters that lie in our Fornax field, is quite metal-poor ([Fe/H=−1.96 ±0.20, Buonanno et al. 1998) and has a relatively well populated Horizontal Branch (HB) characterized by a very extended HB blue tail. Buonanno et al. (1998) identified 66 candidate RR Lyrae stars in this cluster from their limited HST data.

We observed an area of 34' × 33' North to the Fornax dSph center with the Wide Field Imager (WFI) of the 2.2 m ESO-MPI telescope, with the larger part of the galaxy in chip #6 and #7 of the WFI mosaic. We obtained time series B and V photometry (18 *V* and 62 *B* frames). Photometric reductions using the packages DAOPHOT/ALLSTAR II (Stetson 1998) and ALLFRAME (Stetson 1994) are in progress. Candidate variables were identified using the package ISIS 2.1 (Alard 2000) that works with the image subtraction method. We detected 335 candidate variable stars in chip #6 and 190 candidate variables in chip #7. The globular cluster Fornax 3 falls in chip #6. We selected a box of 95" × 95" centered in the core of Fornax 3 and in this area we find about 70 candidate variables. Even if decontamination from the field variables has not been made yet, these candidate variables are very likely to belong to the cluster, and since most of them fall on the cluster HB, they are RR Lyrae stars. This is the first detection and measure of the variable stars in one of Fornax dSph galaxy globular cluster system. Figure 2 shows in the left panel the (v, v-b) instrumental color-magnitude diagram of Fornax dSph field in chip #6, and in the central panel an image of the globular cluster Fornax 3. In both panels the candidate variables are marked by filled circles. Finally, the right panel shows some preliminary light curves of RR Lyrae stars in Fornax GC3 (panels *a* and *b*) and Fornax dSph field (panels *c* and *d*). These are DAOPHOT in-

strumental differential *b* light curves and only half of the time series data has been plotted. Photometric reductions are still in progress and we expect that the photometric quality of the RR Lyrae light curves (about 0.05-0.06 mag for each data points in the DAOPHOT reductions) will improve to a few hundredths of a magnitude for the magnitude calibrated Alard fluxes. We also detected 4 candidate variables in the scarcely populated cluster Fornax 6, an object whose actual nature still needs to be investigated.

We estimate that the total number of candidate variable stars in the 8 chips of our WFI field of Fornax galaxy is of about 1000 (lower limit), to be compared to the 600 found by Bersier & Wood 2002 in an area about 1.6 times larger than ours. This should be taken into when extrapolating Bersier & Wood results to determine the total census of the variable star population in Fornax dSphs galaxy.

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