Astronomical Journal, in press

DISTANCE TO THE LARGE MAGELLANIC CLOUD: THE RR LYRAE STARS [1]

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ABSTRACT

New photometry and spectroscopy for more than a hundred RR Lyrae stars in two fields located close to the bar of the Large Magellanic Cloud (LMC) are used to derive new accurate estimates of the average magnitude, the local reddening, the luminosity-metallicity relation, and of the distance to the LMC. The average apparent luminosity of the RR Lyrae's with complete V and B light curves is $< V(RR) >= 19.412 \pm 0.019$ (σ=0.153), $< B(RR) >= 19.807 \pm 0.022$ (σ=0.172) in our field A (62 stars), and $< V(RR) >= 19.320 \pm 0.023$ (σ=0.159), $< B(RR) >= 19.680 \pm 0.024$ (σ=0.163) in our field B (46 stars). The average V apparent luminosity of the clump stars in the same areas is 0.108 and 0.029 mag brighter than the RR Lyrae level ($< V_{clump} >= 19.304 \pm 0.002$ and 19.291 $\pm$0.003, in field A: 6728 stars, and B: 3851 stars, respectively). Metallicities from low resolution spectra obtained with the Very Large Telescope have been derived for 101 RR Lyrae stars, finding an average value of [Fe/H]=-1.48 ± 0.03 (σ=0.29, on Harris 1996 metallicity scale). An estimate of the reddening within the two fields was obtained (i) from Sturch (1966) method applied to the fundamental mode pulsators (RRab's) with known metal abundance; and (ii) from the colors of the edges of the instability strip defined by the full sample of RR Lyrae variable stars. We obtained : $E(B-V)$=0.116$\pm$0.017, and 0.086$\pm$0.017 mag in field A and B, respectively, with a clearcut indication of a 0.03 mag differential reddening betweeen the two fields. We find that reddening in field A is 0.028 mag smaller than derived by OGLE-II in the same area. On average, the new reddenings are also 0.035 mag larger than derived from

Cepheids with projected distances within 2 degrees from the centers of our fields. The new metallicities were combined with the apparent average V_0 luminosities to determine the slope of the luminosity-metallicity relation for the RR Lyrae stars. We derived $\Delta M_V(RR)/\Delta[Fe/H]= 0.214\pm0.047$, with no clear evidence for the change in slope at [Fe/H]=−1.5, recently suggested by evolutionary/pulsation and Horizontal Branch models.

The dereddened apparent average luminosity of the RR Lyrae's defined by the present photometry is $< V(RR) >_0 = 19.064 \pm 0.064$ at [Fe/H]=−1.5.

When coupled with the absolute magnitude derived from the Baade-Wesselink and the statistical parallaxes methods ($M_V(RR)$=0.68±0.15 and 0.76±0.13 mag at [Fe/H]=−1.5), both methods known to favour the *short* distance scale, this value leads to distance moduli for the LMC of μ_{LMC}=18.38 ± 0.16 and μ_{LMC}=18.30 ± 0.14, respectively. If we use instead the absolute magnitude from the new Main Sequence Fitting of Galactic globular clusters ($M_V(RR)$=0.61±0.07 mag at [Fe/H]=−1.5; Gratton et al. 2002a) we derive μ_{LMC}=18.45 ± 0.09.

The average I apparent luminosity of the clump stars derived by the present photometry is $< I_{clump} >$= 18.319 ± 0.002 and 18.307 ±0.003, in field A (σ=0.190, 6728 stars) and B (σ=0.184, 3851 stars), respectively. These values once corrected for our new reddening estimates lead to $< I >_0$=18.12 ±0.06 mag and move the clump distance modulus to the LMC to 18.42±0.07 and 18.45 ±0.07, when Udalski [2000a, ApJ, 531, L25] or Popowski [2000, ApJ 528, L9] metallicity-I luminosity relations for the clump stars are adopted.

All these values are only 1 σ shorter than provided by the Population I distance indicators, and allow to **reconcile the short and long distance scale** on a common value for the distance modulus of the LMC of μ_{LMC}=18.515±0.085 mag.

Subject headings: distance scale – Magellanic Clouds – stars: oscillations – stars: variables: other (RR Lyrae) – techniques: photometry – techniques: spectroscopy

1. Introduction

The Large Magellanic Cloud (LMC) is widely considered as a benchmark in the definition of the astronomical distance scale; however no general consensus has been reached so far on its actual distance and a dichotomy at a 0.2-0.3 mag level seems to persist between *short* and *long* distances to the LMC as derived from Population I and II indicators. Population I distance indicators have a preference to cluster around a *long* distance modulus for the LMC in the range from 18.5 to 18.7 mag.

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[1]Based on observations collected at the European Southern Observatory, proposal numbers 62.N-0802, 66.A-0485, and 68.D-0466

An internal dichotomy is presented instead by the Population II indicators with most indicators based on "field stars" (Baade-Wesselink, B-W, and Statistical Parallax methods, in particular) yielding a *short* distance modulus of 18.3, while indicators based on "cluster stars" (e.g. the Main Sequence Fitting method: Gratton et al. 1997, Carretta et al. 2000b, Gratton et al. 2002a; the globular clusters dynamical models; or the pulsational properties of RR Lyrae's in globular clusters: Sandage 1993a) support a *longer* modulus in the range from 18.4 to 18.6. Indeed, the well-known discrepancy between *short* and *long* distance scales derived from old, Population II stars is still an unsolved issue (see e.g. Gratton et al. 1997), in spite of the impressive improvements in measuring distances achieved thanks to the Hipparcos mission. The average difference between the two scales (0.25-0.30 mag) translates into a difference of about 3-4$\times 10^9$ years in the corresponding age of the Galactic globular clusters and in turn in the age of the Universe.

1.1. The RR Lyrae distance scale to the LMC

The distance to the LMC from Population II objects is finally founded on the luminosity of the RR Lyrae variables: observations provide the "apparent luminosity" of the LMC RR Lyrae's: $\mathrm{m(RR_{LMC})}$. Various techniques provide the absolute luminosity of the RR Lyrae's: M(RR). Distance to the LMC simply follows from the well known relation between apparent and absolute magnitudes. The first step actually includes two issues: (a) the derivation/use of a relation between the absolute luminosity of RR Lyrae stars and metallicity; and (b) the derivation of the apparent magnitude of RR Lyrae stars at a given metal abundance. Both issues are addressed in this paper with the help of new, photometric and spectroscopic data we have obtained for more than 100 RR Lyrae stars in the bar of the LMC.

Various estimates of the **apparent luminosity** of RR Lyrae stars in the LMC existed so far, with small but significant differences. (i) Walker (1992a) published average luminosities in the Johnson system for RR Lyrae's in 7 clusters of the LMC; the mean dereddened apparent magnitude of these stars is 18.95 $\pm$ 0.04 mag (182 variables) at an average metal abundance of [Fe/H]= -1.9, and for an average reddening value of $<\mathrm{E(B-V)}>$=0.09 mag. A slightly different value of 18.98 $\pm$ 0.04 mag (160 variables) and $<\mathrm{E(B-V)}>$=0.07 mag is obtained if NGC 1841, a cluster suspected to be about 0.2 mag closer to us (Walker 1992a), is discarded. (ii) The MACHO microlensing experiment has led to the discovery of about 8,000 RR Lyrae's in the bar of the LMC (Alcock et al. 1996, hereinafter referred to as A96), among which 73 double-mode pulsators (Alcock et al. 1997, hereinafter referred to as A97). The average dereddened apparent magnitude of the RR Lyraes published by A96 for a subsample of 500 of these variables is 19.09 at [Fe/H]=-1.6 (the most frequent metallicity value in A96 spectroscopic abundances of 15 RR Lyrae's in their sample) and for an assumed reddening value of $E(B-V)$=0.1. Recently, MACHO photometry has been re-calibrated to the standard Johnson-Cousins photometric system (Alcock et al. 1999, hereinafter referred to as A99) superseding all prior calibrations. Alcock et al. (2000, hereinafter referred to as A00) present the color-magnitude diagram of 9 million stars (9M CMD) contained in 22

MACHO fields covering the LMC bar, and provide also median luminosity and metallicity of about 680 RRab's: V=19.45 mag, and [Fe/H]=−1.6, respectively, and the revised average luminosity of A97 RRd's: $< V >= 19.327 \pm 0.021$, based on the new photometric calibration. (iii) A further estimate of the apparent dereddened average luminosity of RR Lyrae's in the LMC comes from observations obtained during the second phase of the Optical Gravitational Lensing Experiment, OGLE-II (Udalski, Kubiak & Szymański 1997). Udalski (1998a) quotes an apparent dereddened average luminosity of $<V_0(RR)>$=18.86 ±0.04 mag at an average metallicity of [Fe/H]=-1.6 ± 0.2 (see Table 6 of Udalski 1998a) and for assumed reddening values in the range from $E(B-V)$=0.17 to 0.20 mag (see Table 2 of Udalski et al. 1998) based on 104 RR Lyrae's observed in OGLE-II fields LMC_SC14, 15, 19 and 20. This value was lately revised to $<V_0(RR)>$=18.94 ±0.04 mag (Udalski et al. 1999b), on the claim that extinction was slightly overestimated in Udalski (1998a). Extrapolating back from this revised $<V_0(RR)>$, the new adopted E(B–V) shoud be about 0.025 mag smaller than in Udalski (1998a). Udalski (2000b) has furtherly revised the OGLE-II apparent dereddened average luminosity of the RR Lyrae in the LMC bar to $<V_0(RR)>$=18.91 ±0.01 mag, apparently based on the total sample of Lyrae variables detected by OGLE-II in the LMC bar, at [Fe/H]=−1.6 and for E(B−V)=0.143 mag. These new $<V_0(RR)>$ and reddening are inconsistent with both Udalski (1998a) and Udalski et al. (1999b) values for these quantities; we further note that if the 0.3 dex difference in metallicity between Udalski (2000b) and Walker (1992a) samples is taken into account, Walker's RR Lyraes should be 0.06 mag brighter and not 0.04 (or 0.07) mag fainter than Udalski (2000b). Both authors claim that their photometric zero-points are good to 0.02-0.03 mag, so this could suggest that Walker's reddening is too small or Udalski's too large by E(B−V)=0.03–0.04 mag.

Estimates of the **absolute magnitude** of the RR Lyrae stars come from the B-W method (Liu & Janes 1990; Jones et al. 1992; Cacciari, Clementini & Fernley 1992; Skillen et al. 1993; Fernley 1994), and from the Hipparcos based Statistical parallaxes (Fernley et al. 1998a; Tsujimoto et al. 1998; Gould & Popowski 1998), applied to field RR Lyrae's.

Fernley et al. (1998b) provide a summary of previous B-W analyses and discuss the slope and zero-point of the RR Lyrae absolute magnitude – metallicity relation. They quote a zero-point of M_V(RR)=0.98±0.15 mag (at [Fe/H]=0.0), and a mild slope of 0.18±0.03 mag, given by the weighted average of the B-W slope (0.20±0.04) and of results for 8 globular clusters (GCs) in M31 observed with the Hubble Space Telescope (Fusi Pecci et al. 1996: 0.13± 0.07). However, analysis of an enlarged sample of 19 M31 GCs (Rich et al. 2001) now suggests a steeper slope of 0.22 mag/dex. An even steeper slope of 0.30 mag/dex was found by Sandage (1993a) from the pulsational properties of RR Lyrae stars. Finally, a shallow slope of $\sim$ 0.18-0.22 mag/dex has been obtained from evolutionary HB models (e.g. Caloi et al. 1997, Cassisi et al. 1998). Moreover, recent evolutionary/pulsation and HB models also suggest that the slope may be not unique in the metallicity range spanned by the Galactic GCs (Castellani et al. 1991, Cassisi et al. 1998, Caputo 1997, Demarque et al. 2000) with two different regimes for metallicities below and above [Fe/H]=−1.5.

Statistical parallaxes lead to M_V(RR)=0.77±0.15 mag at [Fe/H]=−1.53 (Fernley et al. 1998a), 0.69 ±0.10 mag at [Fe/H]=−1.58 (Tsujimoto et al. 1998), and 0.77±0.13 at [Fe/H]=−1.60 (Gould & Popowski 1998), but do not provide information on the slope of the M_V(RR)-[Fe/H] relation.

In the remaining part of this Section we assume a value of ΔM_V(RR)/Δ[Fe/H]=0.2 mag/dex[2] (which is supported by both the B-W and the new M31 results) to transform the above M_V(RR) values to the average metallicity of the LMC RR Lyrae stars in our sample. This is assumed to be [Fe/H]=-1.5 ± 0.2, which is the most commonly adopted average value for the RR Lyrae variables in the LMC, and it was confirmed by the ΔS metal abundances derived by Bragaglia et al. (2001) for 6 of the LMC RRd's in our sample. This metallicity is also consistent with A96, and with the average metal abundance we derived from low resolution spectroscopy of about 80% of the RR Lyrae stars considered in this paper (see Sections 3.3 and Gratton et al. 2002b).

We thus derive M_V(RR)=0.72 ± 0.15 mag as average of the B-W (0.68 mag at [Fe/H]= −1.5)[3] and of the statistical parallaxes results (0.76 at [Fe/H]=−1.5). This value, when combined with Walker's apparent luminosity for the LMC cluster RR Lyrae's leads to a distance modulus for the LMC of $\mu_{\rm LMC}$=18.32 (at [Fe/H]=−1.5 dex) in better agreement with the **short** distance scale. On the other hand, MACHO's revised value (V=19.45 mag at [Fe/H]=−1.6) leads to a **longer** modulus of 18.44 mag for the LMC, but further complicates the scenario since it also seems to suggest that an intrinsic difference of $\sim$ 0.1 mag might exist between field and cluster RR Lyrae's. In fact, if allowance is given for the 0.3 dex difference in metallicity between Walker's and A96/A00 samples and according to ΔM_V(RR)/Δ[Fe/H]=0.2, A00 apparent luminosity for the field RR Lyrae's is 0.12 mag **fainter** than Walker's apparent luminosity for the cluster variables[4]. Finally, if the bright average magnitude proposed by Udalski (2000b) is correct ($<V_0$(RR)$>$=18.91 ±0.01 mag at [Fe/H]=−1.6), the distance modulus to the LMC would be as short as $\mu_{\rm LMC}$=18.21. This shows that simply considering different recent determinations for the average magnitude of the RR Lyrae stars, the range in the distance modulus values for the LMC is larger than 0.2 mag. This situation is clearly unsatisfactory and requires further inquiry of this issue.

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[2]We will return on the value of the slope of the luminosity-metallicity relation in Sect. 5.2.

[3]The B-W determination of the absolute luminosity of the Galactic field RR Lyrae's is being revised in order to test the effects on this technique of the most recent model atmospheres (Kurucz 1995; Castelli 1999; Canuto & Mazzitelli 1992) with various approximations in the treatment of convection, different values of turbulent velocity and more complete and accurate opacity tables, as well as the use of instantaneous gravity along the pulsation cycle. Preliminary results (Cacciari et al. 2000) give M_V(RR)=0.56 mag, for one star at [Fe/H]=−1.5 (RR Cet); this is about 0.12 mag brighter than found from previous studies (e.g. Fernley et al. 1998b). A similar analysis is presently being performed on a larger sample of field RR Lyrae's at [Fe/H]=−1.5 (Cacciari, Clementini & Castelli 2003, in preparation), and on RR Lyrae stars in the globular cluster M3.

[4]Even with the steep slope of ΔM_V(RR)/Δ[Fe/H]$\sim$0.3, supported by Sandage (1993a) there is still a −0.10 mag difference between Walker's and A00, and a +0.13 mag difference between Walker's and Udalski (2000b), reddening corrected, apparent luminosities for the LMC RR Lyrae's.

1.2. What may cause these differences in <V_0(RR)>?

An intrinsic difference at $\sim 0.1-0.2$ mag level between the luminosity of HB stars in globular clusters and in the field was tentatively suggested by Gratton (1998) calibration of the absolute magnitude of field horizontal branch (HB) metal-poor stars with good parallaxes from Hipparcos. Sweigart (1997) evolutionary models, which include some extra-mixing of He and other heavy elements (C,N,O) might give some support to this hypothesis, since there is observational evidence for extra-mixing in cluster red giants but not among field stars (Gratton et al. 2000c). However, Gratton's suggestion was tested qualitatively by Catelan (1998) and, lately and in a more quantitative way, by Carretta, Gratton & Clementini (2000a) using the pulsational properties of a selected sample of field and cluster RR Lyrae's. Their results show that field and cluster variables, in our Galaxy, cannot be distinguished in the $\Delta \log \mathrm{P}_{\mathrm{field-cluster}}$ – [Fe/H] plane, so that the actual existence of a luminosity difference between field and cluster variables seems very unlikely.

Alternative explanations for the differences in the apparent luminosity of the LMC RR Lyrae's found by Walker (1992a), A00, and Udalski (2000b) should be considered. We notice that:

(i) MACHO photometry is in non standard blue and red filters, which are very different from the Johnson passbands of Walker's cluster RR Lyrae photometry (see fig. 1 of A99). A99 find that there is a systematic shift of $\Delta V \sim -0.035$ mag between MACHO and other literature data with MACHO photometry being brighter (see fig.7 of A99). Additional concern also arises from the accuracy of the MACHO photometry at the limiting magnitude typical for the LMC RR Lyrae's (19-20 mag); the problem is clearly shown in fig. 6 of A99. Comparison with MACHO is presented in Section 2.2, and the problem is considered at lenght in Di Fabrizio et al. (2002, hereinafter referred to as DF02), where we find that MACHO photometric zero-points, while apparently correct in some of their fields, appear to present a mismatch in others (see Section 2.2).

Udalski et al. (1997) provide a detailed description of the instrumental set up of OGLE-II. They briefly mention the OGLE-II filter passbands and comment that, except for the ultraviolet filter, they are very close to the standard Johnson-Cousins UBVRI photometric system. Udalski et al. (2000) compared OGLE-II apparent magnitudes and colors for a few local standard stars in the field of NGC 1835 they have in commom with Walker (1993). They found a mean difference of ΔV=–0.026±0.025 mag (based on 6 stars, Walker's magnitudes beeing slightly brighter), and Δ(B–V)=–0.026±0.028 (based on 4 star, Walker's colors being bluer), but also noted that for stars redder than (B–V)∼1.2 mag OGLE colors are redder by more than 0.1 mag. Udalski et al. (2000) attribute this discrepancy to the Walker B-band filter, that matches rather poorly the standard B-band (the color coefficient of the transformation is about 1.2, see Walker 1992b). However, given the small number of objects in common between Walker (1993) and Udalski et al. (2000), any firm conclusion on the comparison between the two photometries seems premature, particularly at red colors. This point is considered more extensively in DF02, where we conclude that OGLE-II systematically overestimates apparent luminosities for stars close to the limit of their B, V photometry, including RR Lyrae and clump stars.

(ii) It may be possible that due to projection effects combined to small number statistics, the globular clusters in Walker (1992a) sample are, on average, closer to us than the bar of the LMC. Indeed, Walker (1992a) assumed that the clusters were on the same plane as younger populations, based on similarity in kinematics (Schommer et al. 1992). However, this assumption may be questioned in view of the large scatter of the individual objects in the sky (see Figure 1), and Walker himself cautions that at least one of the clusters in his sample (NGC 1841) could actually be about 10% closer to us.

(iii) A major crucial point is the actual reddening towards and inside the LMC. Walker (1992a; see his Table 1) derives reddening values from a number of methods in each cluster of his sample, including two techniques based on the pulsational properties of RR Lyrae's, namely the color of the edges of the instability strip, and Sturch's (1966) method. These reddenings range from $E(B-V)$= 0.03 for the Reticulum cluster to $E(B-V)$= 0.18 for NGC 1841, with an average value of $E(B-V)$= 0.09 mag. However, in some clusters the adoption of such reddening values results in a too blue dereddened instability strip (NGC 1835), suggesting that in these cases the reddening may be overestimated. In other clusters (NGC 1786, NGC 1841) the strip may be not totally filled: reddening estimates are rather uncertain in these cases. A96 do not derive an independent reddening estimate, but simply assume $E(B-V)$=0.1 mag, based on Bessel (1991) re-examination of the reddening towards and inside the two Clouds.

Udalski (1998a) adopts an average reddening value of $E(B-V)$=0.185 mag for his RR Lyrae's sample, but Udalski et al. (1999b) claim that this value is too high. They do not give the revised value, but extrapolating back from the revised $< V_0(RR) >$, the new adopted $E(B-V)$ shoud be about 0.16 mag. Udalski et al. (1999a) published reddening values for all the 21 LMC fields observed by OGLE-II. They range from E(B–V)=0.105 to 0.201 mag with an average value of 0.143±0.017 mag. This average value is 0.042 and 0.017 mag smaller than the reddenings adopted for the LMC RR Lyrae stars in Udalski (1998a) and Udalski et al. (1999b) respectively.

Finally, we recall that the reddening value derived from Cepheids in the bar of the LMC is E(B−V)= 0.07 mag (Laney & Stobie 1994), i.e. $\sim$ 0.02-0.03 mag smaller than Walker's and A96, and about 0.07 mag smaller than Udalski (2000b). This would be enough to justify most of the spread observed in different distance scales. The work presented in this paper represents a step toward the solution of these inconsistencies.

2. Our new data-sets

We have undertaken a photometric and spectroscopic observational campaign of two fields close to the bar of the LMC using the 1.5 m Danish, the 3.6 m, and the VLT ESO telescopes. Within our program we have obtained (1) accurate B, V and I photometric light curves directly tied to the Johnson-Cousins photometric system for 152 variable stars in these areas, among which 125 RR Lyrae stars, and (2) low resolution spectra for 101 of the RR Lyrae stars, among which

9 of A97 LMC double-mode pulsators, and for more than 300 clump stars. The main purposes of the observing program were (a) the definition of the average luminosity, and (b) the measure of the metal abundance of RR Lyrae and clump stars in the LMC, in order to investigate the luminosity-metallicity and mass-metallicity (for double-mode pulsators) relations of the RR Lyrae's, and the metallicity distribution of the clump stars in the LMC bar. The photometric data are presented in DF02.

Metal abundances for a first sample of 6 double-mode RR Lyrae stars were derived using the ΔS method (Preston 1959), and masses of the stars were estimated from new pulsational models and the Petersen diagram (Petersen 1973). The mass-metallicity distribution of the RR Lyrae's in the LMC was found to be indistinguishable from that obtained from Galactic globular clusters, thus ruling out any intrinsic difference in mass which might induce intrinsic differences between field and cluster RR Lyrae's. The results from this first spectroscopic study are described in Bragaglia et al. (2001). New spectroscopic metal abundances for a sample comprising 80% of the RR Lyrae stars discussed in the present paper were obtained with FORS at the VLT in December 2001. The metallicity derivation technique is briefly outlined in Section 3.3 and described in detail in Gratton et al. (2002b).

The present paper is devoted to the presentation of the results obtained from the combination of the photometric and specroscopic study of the RR Lyrae stars. The new photometry has allowed us to define a very precise average apparent luminosity for the RR Lyrae stars in the bar of the LMC, which can be compared to Walker (1992a) estimate for the LMC cluster RR Lyrae's, as well as to the mean apparent luminosity of the LMC clump stars found in the same fields. These data also allow an independent estimate of the reddening in these regions of the LMC bar, with fundamental fall-backs on the derivation of the distance to the LMC. The individual metallicities are combined with the apparent V_0 luminosities to firmly establish the slope of the luminosity-metallicity relation for RR Lyrae stars.

The photometric and spectroscopic datasets used in this paper are briefly described in Sections 2.1, 2.2, and 2.3 where we also provide a summary of the results from the comparison of our, MACHO and OGLE-II photometries, based on large samples of stars in common between the three independent data-bases. The properties of the RR Lyrae variables in our sample (apparent average luminosity, period and metallicity distributions) are discussed in Section 3. Section 4 addresses the problem of measuring the reddening in the LMC, and new estimates of $E(B-V)$ from the color of the edges of the instability strip defined by our RR Lyrae sample, and from Sturch method applied to the RRab's with known metal abundances are presented. In Section 5 we summarize our results on the RR Lyrae average luminosity and on the LMC reddening, and present the luminosity-metallicity relation defined by the RR Lyrae stars in our sample, based on our new photometric and spectroscopic analyses. Comparison with Walker (1992a), MACHO and OGLE-II average luminosity of the LMC RR Lyrae stars is presented in Section 6, where we also briefly review the use of the clump as distance indicator, and compare the average luminosity of the RR Lyrae stars to the luminosity distribution of the clump stars in the same areas. Finally, in Section

7 we summarize our results and discuss the impact of the present new photometry, spectroscopy, and reddening values on the derivation of the distance to the LMC.

Photometric data, variable star identification and period search procedures, and the detailed comparison between our, MACHO, and OGLE-II photometries, are fully described in DF02, where we publish the photometric catalogue with multicolor light curves and the individual measurements for all the variable stars in our sample. Spectroscopic data, along with a detailed description of the metallicity derivation technique, and the individual spectroscopic metallicities derived for the RR Lyrae stars are presented in Gratton et al. (2002b), where we also provide details on the derivation of the RR Lyrae luminosity-metallicity relation. Discussion of the luminosity and metallicity distribution of clump stars, based on the spectroscopic database obtained with the VLT, is postponed to a following paper in preparation.

2.1. The photometric dataset

The photometric dataset used in this paper arises from observations taken with the 1.54 m Danish telescope (La Silla, Chile) in two separate observing runs in January 1999 (four nights) and January 2001 (two nights), respectively. We observed at two different positions, hereinafter called field A and B, close to the bar of the LMC and contained in fields #6 and #13 of the MACHO microlensing experiment. Field A is also about 40% overlapped with OGLE-II field LMC_SC21 (Udalsky et al. 2000). In the 1999 run, observations were done in the Johnson-Bessel B and V filters (ESO 450, and 451, see ESO web page), and we obtained 58 V and 27 B frames for field A, and 55 V and 24 B frames for field B. In the 2001 run observations were done in the Johnson-Bessel-Gunn B, V and i filters (ESO 450, 451, and 425) and we obtained 14 V, 14 B and 14 i frames for field A, and 15 V, 14 B, and 14 i frames for field B. Both nights of the 2001 run were photometric, and with good seeing conditions, while only one of the nights in 1999 was photometric.

Reduction and analysis of the 1999 photometric data were done using the package DoPHOT (Schechter, Mateo & Saha 1993). Photometric reductions of the 2001 data were done using DAOPHOT/ALLSTAR II (Stetson 1996) and ALLFRAME (Stetson 1994). A detailed description of the reduction procedures can be found in DF02.

In the 2001 run, nights were superior to the ones in the 1999 run, and a much larger number of standard stars were observed. Therefore our entire photometric dataset was tied to the standard Johnson-Cousins photometric system through the absolute photometric calibration of the 2001 run. Calibration equations are provided in DF02. They are based on 127 measurements in two separate nights of 27 standard stars selected from Landolt (1992) - Stetson (2000) standard fields PG0918+029, PG0231+051, PG1047+003, and SA98, with magnitude and colors in the ranges $12.773 < V < 17.729$, $-0.273 < B-V < 1.936$, $-0.304 < V-I < 2.142$. Photometric zero-points accuracies are of 0.02 mag in V and 0.03 mag in B and I, respectively.

Variable stars were identified on the 1999 time-series dataset using the program VARFIND, written for this purpose by P. Montegriffo. Candidate variable objects picked up interactively from the scatter diagram produced by VARFIND were checked for variability using the program GRATIS (GRaphycal Analyzer TIme Series) a private software developed at the Bologna Observatory by P. Montegriffo, G. Clementini and L. Di Fabrizio. Confirmed variable stars were then counteridentified on the 2001 frames using private software by P. Montegriffo (see DF02 for further details.)

We detected 152 variable objects in the two fields, and an additional 7 candidate variable objects of unknown type. 125 of the certain variables are of RR Lyrae type (115 single-mode and 10 double-mode RR Lyrae's, one of which not previously known from A97). Of course, the high fraction of RR Lyrae stars among the identified variable stars is due to the type of observations and variable stars search we made.

Periods for all the identified variable stars were defined using the program GRATIS on the instrumental differential photometry with respect to stable, well isolated objects used as reference stars. Thanks to the two years base line of our observations we were able to: (i) derive periods and epochs for all the 152 variables accurate to better than the fourth- fifth decimal place; the accuracy depends on the light curve data sampling, which in the best cases is 72 V, 41 B, 14 I data points for variables in field A, and 70 V, 38 B, 14 I data points for variables in field B; (ii) identify the Blazhko modulation of the light curve (Blazhko 1907) in about 15 % of our RR Lyrae stars; and finally (iii) to derive complete and well sampled B and V light curves for about 95% of the RR Lyrae stars. Typical accuracies[5] for the single-mode, non Blazhko variables are 0.02-0.03 mag in V, and 0.03-0.04 mag in B.

Apart from RR Lyrae's, we also fully covered the light curve of 4 Anomalous Cepheids, 9 eclipsing binaries with short orbital period ($P<1.^{d}4$), 6 classical Cepheids, and reasonably well sampled the light curves of the other 5 Cepheids.

Examples of the light curves of an *ab*, *c* and *d* type RR Lyrae, as well as of an anomalous Cepheid, a classical Cepheid and an eclipsing binary in our sample are shown in Figure 2 and 3. The full catalogue of individual photometric measurements and light curves is provided in DF02.

The location of the variable stars on the HR diagram of field A and B is shown in Figure 4 and 5, respectively, where they are plotted according to their intensity-average magnitudes and colors, and with different symbols corresponding to the various types.

2.2. Comparison with MACHO and OGLE-II photometries

Our fields are contained in MACHO's fields #6 and #13, and there is about 40% overlap between field A and OGLE-II field LMC_SC21. This occurrence has allowed us to make a detailed comparison between our, MACHO, and OGLE-II photometries, based on large samples of stars,

[5]Accuracies are the average residuals from the Fourier best fitting models of the light curves.

and without any assumption about reddening.

The comparison with MACHO was restricted only to the variable stars in common, since calibrated photometry of individual stars was readily available only for the variable star subsample. We found that we have about 30% and 20% more short period variables ($P < 4$ days) than MACHO in field A and B, respectively. We also found that MACHO classification of some of the variable stars in common did not match our classification (see details in DF02).

The average V difference, in the sense present photometry minus MACHO, is -0.174 mag ($\sigma = 0.092$, 58 stars) in field A, and -0.010 mag ($\sigma = 0.085$, 40 stars) in field A. The quite large systematic shift found for variable stars in field A, with MACHO luminosities being **fainter** than ours, is rather surprising and of no obvious explanation, since the different treatment of the background in the reduction package used by MACHO (SoDoPhot) is expected to produce **brighter** magnitudes than DAOPHOT+ALLFRAME photometry (A99). Moreover, we notice (i) that a shift by +0.174 mag of field A photometry would result in an average luminosity of the RR Lyrae stars in this area about 0.24 mag fainter than A00 median luminosity of the RRab's in the LMC, and (ii) given the good agreement existing in field B, it would imply a rather unlikely difference of about 0.27 mag in the average luminosity of RR Lyrae stars in the two fields.

Our field A is 42.13 % overlapped with OGLE-II field LMC_SC21. In this common area we measured 21,524 objects (in all three photometric bands), our limiting magnitude reaches about 1.5 mag fainter, and we resolved about 39, 26, and 22% more stars (in B, V and I, respectively) than OGLE-II.

There are about 13,000 objects in common between the two photometries, with V magnitude in the range from 16 to about 22.5 mag. Among these objects OGLE-II reports 114 variable stars; 96 of them have a counterpart in our database, but only 14 are identified as variable stars in our photometry. On the other hand, in the same area we have 22 further variable stars all having a counterpart, but not recognized as variable objects by OGLE-II. A more significant comparison with OGLE-II can be achieved by restricting the sample to the stars in common that have photometric errors smaller than 0.1 mag in all photometric passbands in both databases (about 5400, 6500, and 7200 stars in V, B, and I, respectively). Average residuals between the two photometries were computed dividing objects in magnitudes bins; they are provided in Table 5 of DF02. At the magnitude level of RR Lyrae and clump stars ($V \sim 19.4, B \sim 19.8, I \sim 18.8$; and $V \sim 19.3, B \sim 20.2, I \sim 18.3$, respectively) offsets are: $\Delta V = 0.06$ (σ_V=0.03), $\Delta B = 0.03$ (σ_B=0.04), $\Delta I = 0.07$ (σ_I=0.05), and $\Delta V = 0.06$ (σ_V=0.03), $\Delta B =$ 0.03-0.04 (σ_B=0.04-0.05), $\Delta I = 0.07$ (σ_I=0.04-0.05), with our photometry being systematically **fainter** than OGLE-II DoPhot photometry. This is not unexpected since DoPhot is reported to give systematically brighter magnitudes for faint stars in crowded regions than DAOPHOT, and since we resolve many more faint stars than OGLE-II in the area in common.

The interested reader is referred to DF02 for a thorough discussion of the comparison with MACHO and OGLE-II photometries.

2.3. The spectroscopic dataset

Low resolution spectra (R$\sim$450) at minimum light for 6 of the double mode pulsators in our sample were obtained in January 1999, with the Faint Object Spectrograph and Camera of the 3.6 m ESO telescope. We used the classical ΔS method (Preston 1959) to measure [Fe/H] abundances, as fully described in Bragaglia et al. (2001).

A more extended spectroscopic survey was conducted in 2001 with FORS at the VLT. We obtained low resolution spectra (R$\sim$815) for 80% of the RR Lyrae stars discussed in this paper and for about 300 clump stars. Metal abundances for the RR Lyrae stars were obtained using a revised version of the ΔS technique: we estimated metallicities for individual stars by comparing directly the strength of H lines and the K Ca II line with analogous data for RR Lyrae stars in 3 Galactic Globular clusters of known metal abundance (namely NGC 1851, M 68 and NGC 3201). An advantage of this technique is that we do not need an explicit phase correction; even if accuracy of our [Fe/H] determinations is still a function of phase (as represented by the strength of the H lines): determinations accurate to about 0.2 dex are obtained only from observations taken far from maximum light. Note however that the allowed phase range is about two times larger than that required for a safe application of the original ΔS method. A detailed description of the metallicity derivation technique can be found in Gratton et al. (2002b).

3. The RR Lyrae stars

3.1. The apparent luminosity

The average apparent luminosities of Lyrae's with full coverage of the V and B light curves are: $< V >= 19.412 \pm 0.019$ (σ=0.153, 62 stars), $< B >= 19.807 \pm 0.022$ (σ=0.172, 62 stars) in field A; and $< V >= 19.320 \pm 0.023$ (σ=0.159, 46 stars), $< B >= 19.680 \pm 0.024$ (σ=0.163, 46 stars) in field B. The I light curve coverage is inferior, being based only on the 2001 data, and we do not expand further on this band.

The double-mode RR Lyrae stars in our sample are slightly overluminous compared to the single-mode pulsators: $< V_{RRd} >= 19.394 \pm 0.066$ (σ=0.161, 6 stars), and $< V_{RRd} >= 19.239 \pm 0.085$ (σ=0.171, 4 stars), in field A and B respectively. A similar result is found also by A96/A00.

There is a difference of 0.092 and 0.127 mag, respectively, between the average V and B magnitudes of the RR Lyrae stars in the two fields, explained by a difference in the reddening towards the two areas, with field A being 0.03 mag more reddened than field B (see Section 4). A few RR Lyrae's were discarded when calculating the above average values. These were 11 objects (4 RRc and 4 RRab in field A, and 2 RRc and 1 RRab in field B), for which systematic offsets were present between the 1999 and 2001 light curves, possibly due to not resolved blends in either of the two datasets; variable stars whose light curves were not evenly covered (2 stars in field A and 3 in field B, respectively); and 1 object in field A which fell on a bad CCD column in the 1999 run.

The intrinsic dispersions of the average B and V apparent luminosities (and, in turn, of the average B and V absolute magnitudes) of the RR Lyrae's in the two fields are: $\sigma_B \sim 0.17$ and $\sigma_V \sim 0.16$ mag, respectively. A number of sources contribute to these dispersions:

- the internal photometric errors of the present photometry: 0.02 mag standard deviation of the average
- the metallicity distribution of the RR Lyrae's in our sample. The dispersion around the mean value of [Fe/H]=-1.48 found from the VLT low resolution spectroscopy of 101 RR Lyrae stars in the sample is $\sigma = 0.29$ dex (see Section 3.3 and Gratton et al. 2000b). This metallicity dispersion well compares with the $\sim$0.4 dex dispersion we would derive taking into account the total period distribution spanned by the *ab* type RR Lyrae's in our sample ($0.^{d}40$–$0.^{d}74$). According to $\Delta M_V(RR)/\Delta[Fe/H]$=0.2 mag/dex, these metallicity dispersions correspond to a magnitude dispersion of about 0.06 mag.
- the level of evolution off the Zero Age Horizontal Branch (ZAHB) of the variables in our sample. Here what matters is not the global systematic difference between ZAHB and average luminosity of the RR Lyrae's, but rather the dispersion around the average RR Lyrae luminosity due to the evolution off the ZAHB of each individual RR Lyrae. Sandage (1990) studied the vertical height of the HB of a number of globular clusters of different metallicity, and found for M3 and NGC 6981, clusters whose metallicity is close to the average value of the LMC, HB luminosities with standard dispersions of 0.064 and 0.097 mag respectively, giving an average value of 0.08 mag[6]; and, finally
- the intrinsic depth of the observed fields.

Adding up in quadrature all dispersion contributions except the latter, we obtain a total dispersion of about 0.10 mag to compare with the observed V dispersion of 0.16 mag. This gives us some hint on the actual intrinsic depth of our observed fields, for which we derive a most probable value of 0.13 and an upper limit of about 0.15 mag corresponding to a dispersion in depth of 6.5% and 7.5 % or 3.3 kpc and 3.8 kpc (for an assumed distance modulus μ_{LMC}=18.50 mag, see Section 7).

Based on the spatial density profile of the MACHO RRab stars and on data for six additional fields from Kinman et al. (1991), A00 conclude that the majority of the old and metal-poor LMC field stars are likely to lie in a disk with i=35 deg, line of nodes running North-South, and center near the optical center (Westerlund 1997), and not in a spheroid. Our results on the intrinsic depths of field A and B are not in contrast with A00 results.

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[6]This is likely to be an overestimate of the real contribution due to evolution, because the field RR Lyrae population should be dominated by stars closer to the ZAHB than variables in clusters at same metallicity (see Carney et al. 1992)

The comparison of the apparent luminosity of our RR Lyrae sample with other estimates available in the literature (Walker 1992a; Udalski et al. 2000, Udalski 2000b, and A00) is postponed to Section 6.

We have formed $< B > - < V >$ and $< V > - < I >$ colors from the intensity average B, V, and I magnitudes for all the variables with complete light curves. These intensity average magnitudes and colors ($< V >$, $< B > - < V >$, $< I >$, $< V > - < I >$) were used to place the variables on the color-magnitude diagrams of the two fields, shown in Figure 4 and 5.

3.2. The period distribution

Two peaks are clearly visible in the period distribution of the single-mode RR Lyrae's in our sample (115 objects), corresponding to the *c* (38 objects), and the *ab* (77 objects) type pulsators (see Figure 8 of DF02). The number of *c*-type pulsators divides almost equally among the two fields (20 and 18 RRc's in field A and B, respectively). On the other hand, the number of RRab's is about 50% larger in field A. This difference, although not statistically significant, may suggest that we could be missing some *c* type pulsators in field A, likely due to the smaller amplitude of the variables and the larger crowding of the field.

The mean period of the *c* and *ab* type RR Lyrae's is: $< \mathrm{P_{RR_c}} >=0.^d327$ (σ=0.047, 38 stars), and $< \mathrm{P_{RR_{ab}}} >=0.^d580$ (σ=0.064, 77 stars), respectively, to be compared with $0.^d342$ and $0.^d583$ of A96.

A96, on the basis of their $< \mathrm{P_{RR_{ab}}} >=0.^d583$, conclude that the preferred period of the *ab*-type variables of the LMC falls between the periods of the Galactic RR Lyrae stars of Oosterhoff (1939) type I (Oo I) and II (Oo II), but it is actually closer to the Oo I cluster periods (being $<\mathrm{P_{RR_{ab}}} >=0.^d55$, and $0.^d65$ in the Oo I and II clusters, respectively). This finding is confirmed and strengthened by our results.

The period-amplitude diagram of MACHO Bailey diagram sample (935 RRab's, see Section 4.2 of A00), is found to be very similar to the ridgeline defined by the RRab's in M3, from which A00 infer similarity of the mean metallicity of the Bailey sample with M3. B and V amplitudes (A_B, A_V) were calculated for all the RR Lyrae's in our sample with full coverage of the light curve as the difference between maximum and minimum of the best fitting models (see DF02), and have been used together with the newly derived periods to build period - amplitude diagrams. The overlap in the transition region between *ab* and *c* type is small (6 objects) and the transition period between *c* and *ab* type occurs in our sample at $\mathrm{P_{tr}} \sim 0.^d40$, while $\mathrm{P_{tr}} = 0.^d457$, in A96. The period - amplitude distributions of the LMC variables were compared with the relations defined by the *ab* type RR Lyrae's in the globular clusters M3, M15 and ω Cen. RR Lyrae's in field B seem to better follow the amplitude-period relations of the variables in M3 and to belong to the OoI type. Variables in field A, instead, have pulsational properties more intermediate between the two Oostheroff types (see Figure 9 of DF02).

According to A97, nine double-mode pulsators were expected to fall in the observed areas. We actually detected all of them and also found evidence for one possible additional RRd candidate not previously known from A97 : star #2249 (see Table 5 of DF02).

3.3. The metallicity distribution

Metal abundances derived by Bragaglia et al. (2001) for a first subset of 6 of the double-mode pulsators in our sample using Preston (1959) ΔS technique range from -1.09 to -1.78, with an average value of [Fe/H]=-1.49 ± 0.11 (6 stars, rms=0.28 dex), on Clementini et al. (1995) metallicity scale, quite similar to Zinn & West (1984) scale (see Section 4 of Bragaglia et al. 2001).

Metallicities obtained from the spectroscopic survey conducted in 2001 with FORS at the VLT, for 101 of the RR Lyrae stars discussed in this paper range from ~ -0.5 to ~ -2.1 with an average metal abundance of [Fe/H] = -1.48 ± 0.03 (σ=0.29, 101 stars, see Gratton et al. 2002b). These metallicities are tied to Harris (1996) metal abundances for the Galactic globular clusters NGC 1851, NGC 3201, and M 68 that we used as calibrators. The values (available at http://www.physics.mcmaster.ca/Globular.html) we have used are: [Fe/H]=-1.26, -1.48, and -2.06, respectively, to compare to -1.33, -1.56, and -2.09 of Zinn & West (1984). Thus they are on a metallicity scale that, on average, is 0.06 dex more metal rich than Zinn & West scale.

Photometric metallicities from the parameters of the Fourier decomposition of the V light curves were also derived for 29 RRab's in our sample, 6 of which do not have spectroscopic metal abundances, appling Jurcsik & Kovacs (1996) and Walker & Kovacs (2001) techniques (see DF02, for details). These metal abundances are on the metallicity scale defined by Jurcsik (1995) which is, on average, about 0.2 dex more metal rich than Harris (1996) scale. The average metallicity of this subsample of stars is: [Fe/H]=-1.27 (σ=0.35, 29 stars), in good agreement with the average values derived from the above spectroscopic analyses, once differences between metallicity scales are taken into account. The comparison between photometric and spectroscopic abundances can be found in Gratton et al. (2002b).

The spectroscopic abundances also well compare with both the range and the most frequent value of A96 spectroscopic analysis of 15 LMC RRab's, thus confirming both the similarity with M3 suggested by A00, and the existence of RRab's very metal poor which, according to A00, might trace a spheroid population.

4. The reddening of the LMC

Accurate corrections for interstellar reddening are crucial for precise distance estimates. On the other hand, there is strong evidence that the reddening within the LMC is patchy and varies from one region to the other. This originates quite a lot of confusion in the various distance determinations to the LMC.

4.1. Literature values

Bessel (1991) provides a re-examination of the reddening of the LMC obtained by several independent methods and concludes that the foreground $E(B-V)$ reddening probably lies between 0.04 and 0.09 mag, while the average reddening within the LMC is probably about 0.06 mag but with many regions with higher and lower than average reddening.

Walker (1992a) derives reddening values ranging from 0.03 to 0.18 mag for the 7 clusters he analyzes based on a combination of several independent methods and estimates: (i) Burnstein & Heiles (1982) maps; (ii) the position of the Red Giant Branch in the color magnitude diagram of the clusters (the so called $(B-V)_{0,g}$ method); (iii) the pulsational properties of the variables is his sample [namely: Sturch (1966) method applied to the *ab* type RR Lyrae at minimum light and with $E(B-V)$=0.00 mag for the reddening at the polar caps; and the colors of the edges of the instability strip defined by the RR Lyrae's in each individual cluster of his sample].

The reddening maps (based on COBE/DIRBE and IRAS data) of Schlegel, Finkbeiner, & Davis (1998) give a foreground reddening, measured from dust emission in an annulus surrounding the LMC, of $E(B-V)$=0.075. Schlegel et al. find that their reddenings are offset by $E(B-V)$= +0.02 mag with respect to those provided by Burstein & Heiles (1982), which are based on HI column densities and deep galaxy counts[7]. The same maps give upper limits of $E(B-V)$=0.218 and 0.128 for field A and B, respectively. However Schlegel et al. maps do not provide reliable reddening for extended objects like the Clouds or M31 close to their centers.

Foreground and internal reddenings have also been estimated from UBV photometry of individual early type stars by Oestreicher, Gochermann & Schmidt-Kaler (1995) and Oestreicher & Schmidt-Kaler (1996). The values for the directions of our two fields are: $E(B-V)$=0.056 and 0.062 (foreground), 0.150 and 0.140 (internal). We may then derive lower and upper limits of the reddening of $0.056 < E(B-V) < 0.206$ and $0.062 < E(B-V) < 0.202$ for field A and B, respectively. However, Zaritsky (1999) noted that reddenings derived from early type stars may be biased towards large values, likely because these stars are preferentially located near star forming regions.

Udalski et al. (1999a) published reddening values determined along 84 lines of sights for all of the 21 LMC fields observed with OGLE-II. They used the red clump stars for mapping the fluctuations of mean reddening in their fields, treating the mean I-band magnitude as the reference brightness. Differences of the observed I-band magnitudes of the red clump stars were assumed as differences of the mean A_I extiction and transformed into differences of $E(B-V)$ reddening

[7]On average, the reddenings of Schlegel et al. agree quite well with those usually adopted for the Galactic globular clusters (see data set by Harris, 1996) for reddening values smaller than 0.10 mag; for more reddened clusters, the reddenings by Schlegel et al. are systematically larger by 30%.

assuming the standard extinction curve $E(B-V)$= $A_I/1.96$ by Schlegel et al. (1998). We note that this procedure neglects possible systematic differences in the intrinsic mean I-band luminosity of the LMC red clump due to age or metallicity variations from field to field of the LMC. As discussed in Section 6.2, this may be a too crude assumption. The zero-points of OGLE-II reddening maps were based on determinations around two LMC star clusters, namely NGC 1850 [$E(B-V) = 0.15\pm$ 0.05 mag, based on UBV photometry by Lee 1995], and NGC1835 [$E(B-V) = 0.13\pm$ 0.03 mag, based on colors of RR Lyr stars, Walker 1993][8]; and on determinations based on OB-stars in the field of the eclipsing variable star HV2274 (Udalski et al. 1999a)[9]. These reddenings range from $E(B-V)$=0.105 to 0.201 mag, with an average value of 0.143±0.017 mag. This average value is respectively 0.042 and 0.017 mag lower than the reddenings adopted for the LMC RR Lyraes in Udalski (1998a) and Udalski et al (1999b).

Much smaller reddenings are obtained by considering individual Cepheids. Reddenings for a total number of 80 individual Cepheids have been published by Caldwell & Coulson (1986) and Gieren, Fouqué & Gomez (1998). These are the values used by Laney & Stobie (1994) and most other works on Cepheids. The two sets of reddenings are on the same system, and are coincident for the majority of the stars in common. These Cepheids have distances from the centers of our fields ranging from 0.66 up 7.8 degrees. In Table 1 we give identification number and reddening value in both Caldwell & Coulson (1986) and Gieren, Fouqué & Gomez (1998) systems, for a subsample of Cepheids with projected distances within two degrees from either of the centers of our fields. An average of these reddening values gives $E(B-V) = 0.067\pm0.006$ mag (7 stars) and $E(B-V) = 0.067\pm0.023$ mag (15 stars) for field A and B, respectively. A weighted average of the reddening estimates (with weights proportional to the inverse square of the projected distance from our fields) for all Cepheids whithin the two samples yields mean reddening values of $E(B-V)$=0.070 for field A and 0.063 for field B. Note also that a star-by-star comparison shows that the reddening for the Cepheids are on average ~ 0.06 mag smaller than those given by Schlegel et al.'s maps.

Which of these different reddening scales should we adopt?

Independent indications for the reddening values in our fields can be derived directly from the properties of RR Lyrae variables in our sample, i.e. i) from the colors at minimum light of the *ab* type pulsators through the so called Sturch's method (Sturch 1966); and ii) from the colors of the edges of the instability strip defined by the full sample of RR Lyrae stars.

Before applying these methods to our fields, we note that a direct comparison suggests that field A is more reddened than field B. In fact:

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[8]We recall however that the instability strip of NGC 1835 dereddened according to this $E(B-V)$ value appears too blue

[9]The value of $E(B-V) = 0.149 \pm 0.015$ used by Udalski et al. for this star has been questioned by Nelson et al. (2000), and Groenewegen & Salaris (2001), who suggested lower values of $E(B-V) = 0.088 \pm 0.025$ and 0.103 ± 0.007, respectively.

- on average, RR Lyrae's in field A are fainter by ∼0.09 mag in V, and ∼0.13 mag in B, compared to the variables in field B
- average colors of the *ab*, and *c* and *d*-type RR Lyrae's in field A are redder (by 0.036 and 0.016 mag, respectively)

We conclude that reddening is likely to be 0.03 ± 0.01 mag larger in field A than in field B. Such a difference is not unconsistent with the literature results mentioned above, and will be used in the following discussion when combining results from the two fields.

4.2. Reddening from Sturch's method

Sturch (1966) derives the reddening of *ab* type RR Lyrae's from the (magnitude-average) color at minimum light $(B-V)_{min}$ (phases 0.5-0.8), the period P, and the metal abundance [Fe/H] of the variables. The application of Sturch's method requires the knowledge of the metallicity of each individual RRab. We have used Sturch's method as described in Walker (1990, 1998), where the reddening zero-point has been adjusted to give E(B−V)=0.0 mag at the Galactic poles, and the [Fe/H] is that of Zinn & West (1984) metallicity scale, whereby

$$E(B-V) = (B-V)_{min} - 0.24P - 0.056[Fe/H]_{ZW} - 0.336$$

Metal abundances are available for 56 of the *ab*-type RR Lyrae stars from our VLT spectroscopic study. They are given in the upper portion of Table 2 (column 5), along with magnitude-average colors at minimum light (column 3) and periods (column 4) of the variables. These metallicities are on Harris (1996) scale (see Gratton et al. 2002b, and Section 3.3). Reddenings for these stars have been calculated from the above relation after having offset all metallicities by −0.06 dex, to put them on Zinn & West (1984) scale. For 6 additional objects (listed in the lower portion of Table 2), metal abundances on Jurcsik (1995) scale were derived from the Fourier decomposition of the V light curves. We have used the relation provided by Jurcsik (1995; $[\mathrm{Fe/H}]_{Yurcsik}= 1.431[\mathrm{Fe/H}]_{ZW}+0.880$) to transform metallicities to Zinn & West scale.

Derived $E(B-V)'s$ are given in column 6 of Table 2. The average reddening value for the stars in field A is $E(B-V) = 0.133 \pm 0.005$ (σ=0.031, average on 37 stars), discarding star #19711 which gives a negative reddening value, and star #26525 wich deviates more tha 2.5 σ from the average. The average value for the stars in field B is $E(B-V) = 0.115 \pm 0.007$ (σ=0.036, average on 23 stars), again suggesting the existence of differential reddening between the two areas ($\sim$ 0.02 mag).

Walker (1998) found that Sturch's method gives reddening values systematically larger by 0.02-0.03 mag when compared to other reddening determination techniques. We have verified Walker's finding applying Sturch's method to some of the RR Lyrae stars in two of the clusters used as spectroscopic calibrators, namely M68 and NGC1851. Brocato et al. (1994) have published B, V CCD photometry of RR Lyrae stars in M68. For three RRab's in their sample (namely stars V9, V10 and V12) Sturch's method gives $E(B-V)_{V9}$=0.040, $E(B-V)_{V10}$=0.039, and $E(B-V)_{V12} = -0.011$, and an average value $E(B-V)$=0.04, discarding V12 which gives a negative reddening. This average reddening is to be compared with literature values in the range from 0.02 to 0.04 mag (see Brocato et al. 1994, and reference therein), and with $E(B-V)$=0.035 from Schlegel et al. (1998) maps. For NGC1851 we have used Walker (1998) photometry for the RRab's V1, V6, V7, V11, V12, V16, V17 and V22. The average reddening from Sturch's method applied to these 8 stars is $E(B-V)$=0.055 (σ=0.012, 8 stars), to compare with $E(B-V)$=0.02 by Harris (1996), and 0.061 mag from Schlegel et al. maps. The present results confirm that Sturch's method may overestimate reddening by 0.01-0.02 mag, therefore we conclude that the reddening values for field A and B derived with Sturch's method can be considered as upper limits of the actual reddenings in these areas.

4.3. Reddening from the colors of the instability strip

Reddening in our fields may be better constrained by comparing the edges of the instability strip defined by the RR Lyrae stars with those defined by variables in globular clusters of known $E(B-V)$. This same procedure was used by Walker (1992a) to estimate the reddening value in some of the LMC globular clusters.

Walker (1998) presents dereddened (magnitude-average) $B-V$ instability-strip boundary colors from precise observations of 9 Galactic and LMC globular clusters covering a range in metallicity from –1.1 to –2.2 dex. The dereddened color of the blue edge is at $(B-V)_0 = 0.18 \pm 0.01$ mag, with no discernable dependence on metallicity, while the color of the red edge shows a shift of 0.04±0.02 mag dex^{-1} with metal abundance. On the other hand, since the RR Lyrae's in the LMC have period and amplitude distributions more similar to those of the M3 variables (see Section 3.2), we can directly compare the observed average colors of the LMC RR Lyrae's with those of the M3 ones. A further advantage of this choice is the very low reddening of M3, with $E(B-V)$ values in the range from 0.00 to 0.01 mag (Ferraro et al. 1997, Harris 1996, Schlegel et al. 1998, Cacciari et al. 2003, in preparation).

Corwin & Carney (2001) have published accurate CCD B, V light curves for more than 200 RR Lyrae variables in M3. The magnitude-average $B-V$ color of the observed blue edge defined by Corwin et al. M3 RR Lyrae's is 0.184 mag. This value compares extremely well with Walker (1998) dereddened color of the instability strip blue edge $(B-V)_0$=0.18, thus confirming the very low reddening suffered by M3. The M3 observed red edge is at $B-V = 0.402$ mag (Corwin & Carney, 2001).

In Table 3 we list (intensity and magnitude-average) $B-V$ colors for the 5 bluest and the 5 reddest LMC variables in field A and B combined sample. Colors of the variables in field A have been made bluer by 0.03 mag to put them on the same reddening system of field B.

The First Overtone Blue Edge (FOBE) of the LMC RR Lyrae strip is very well defined by the three bluest stars in the left hand portion of Table 3, namely field B star #2517 and field A stars # 2623 and #2223, giving an average color of the FOBE $< B-V >_{FOBE} = 0.245$ (σ=0.011).

The Fundamental Red Edge (FRE) of the RR Lyrae instability strip is more difficult to define. Spectroscopic metal abundances are available for 4 of the 5 stars at the FRE, namely stars: #8094, #28293 in field A; and #7468 and #5589 in field B. Colors were corrected to account for the difference in metallicity with M3 (assumed at [Fe/H]=−1.66 according to Zinn & West 1984) by applying the shift with metal abundance found by Walker (1998). Final adopted colors for the stars at the FRE are given in column 9 of Table 3. We used the 3 reddest stars in the right hand portion of Table 3, namely field A stars #8094, #28293, and #7468 in field B to obtain an average color of the FRE of $< B-V >_{FRE} = 0.507$ (σ=0.023).

Differences in color between the LMC and M3 FOBE and FRE are 0.061 and 0.105 mag, respectively. From the weighted average of these differences, with the FOBE having double weight, the reddening in field B should be 0.076 ± 0.016 larger than in M3 (i.e., larger than $E(B-V) = 0.010 \pm 0.007$ mag). The reddening estimated from the colors of the RR Lyrae instability strip edges is then $E(B-V) = 0.086 \pm 0.017$ for field B, and $E(B-V) = 0.116 \pm 0.017$ for field A. These values agree well with the estimates obtained by Sturch's method if the 0.02-0.03 mag offset suggested by Walker (1999) is considered.

We verified that RR Lyrae's in both field A and B, once corrected for the above reddening values, are very well confined within the edges of the instability strip defined by Corwin & Carney (2001) M3 variables, thus confirming the similarity of our LMC RR Lyrae sample to the OoI cluster M3, and giving support to the reddening values we determined in the two fields.

5. Our results

5.1. Reddening and luminosity

Hereinafter, we will adopt reddening values of E(B − V) = 0.116 ± 0.017 and $E(B-V) = 0.086 \pm 0.017$ for field A and B, respectively. Reddening in field A is 0.028 mag smaller than derived by Udalski et al. (1999a) in the same area, and on average these new reddenings are 0.04 mag smaller than OGLE-II average reddening for the LMC (E(B − V) = 0.143, Udalski 2000b), and 0.03 mag smaller than estimated from the UBV photometry of early type stars (Oestreicher, Gochermann & Schmidt-Kaler 1995; and Oestreicher & Schmidt-Kaler 1996). On the other hand, while reddening in field B within the quoted uncertainties agrees with the estimates based on Cepheids (0.067 ± 0.006), that in field A is clearly larger, and on average our values are 0.035 mag larger than reddenings derived from Cepheids. However, this result is not totally surprising since most of the Cepheids with measured reddening lie in regions far from the LMC bar and none of them falls in our fields. We also note that since we are using a large sample of $\sim$ 100 objects projected into the direction of the bar, we also eliminated the possibility of systematic differences in the position of the barycenter, that is well possible when considering a small number of objects like e.g. the globular clusters.

The absorption corrected intensity average magnitudes of the total sample of RR Lyrae's with full coverage of the light curves are $< V >_0 = 19.053 \pm 0.021 \pm 0.053$ and $< B >_0 = 19.329 \pm 0.023 \pm 0.070$; average values of each field were corrected for the corresponding reddening, adopting standard values for the selective absorption R_V=3.1 mag, R_B=4.1 mag (Cardelli et al. 1989). The first error bar is the internal dispersion of the average, while the second term is due to the 0.017 mag uncertainty in the reddening, still by far the largest uncertainty source. The final error should also include the contributions of the uncertainty of the photometric calibration and of the aperture corrections (0.017 mag in V and 0.032 mag in B, and 0.023 in V and 0.019 in B; see DF02).

Adding up in quadrature all error contributions we derive for 108 objects: $< V >_0 = 19.05 \pm 0.06$ and $< B >_0 = 19.33 \pm 0.08$ for the average dereddened apparent luminosities of our sample of RR Lyrae stars in the bar of the LMC. A summary of our photometric results is provided in Table 4.

5.2. The luminosity-metallicity relation

The absolute magnitude of the RR Lyrae's, M_V(RR), is known to depend on metallicity [Fe/H] according to the relation $M_V(RR) = \alpha \times$ [Fe/H] + β, but rather large uncertainties exist both on the slope α and on the zero-point β of this relation. The zero-point has been already discussed (see Section 1.1): we will now consider the slope.

The exact value of α has a large impact on several relevant astrophysical problems. For instance, when coupled with the almost constant value of ΔV^{HB}_{TO} found for globular clusters, the M_V(RR) - [Fe/H] relationship implies i) that all clusters are more or less coeval if the high value of α is chosen, or, conversely, ii) that there is a significant age-metallicity dependence in the family of the galactic GCs (see Sandage 1993b and references therein) if a shallow slope is the correct value. The whole Galactic formation scenario is thus heavily affected by the precise knowledge of α.

RR Lyrae stars in the LMC bar may play a key rôle in the definition of α, since they can be considered all at the same distance from us, are very numerous, and span more than 1.5 dex range in metallicity. They can be used to firmly constrain the value of α, independently of any model assumption, the only limiting factor being the intrinsic spread in the luminosities of the RR Lyrae stars due to their evolution off the ZAHB. To minimize this effect a fairly large number of variables is needed.

We have combined the individual metal abundances of the RR Lyrae stars derived from our spectroscopic study with the corresponding dereddened mean apparent V luminosities, and determined the slope of the luminosity-metallicity relation for RR Lyrae stars. We used 85 out of the 101

RR Lyrae stars we analyzed spectroscopically, i.e. those which have well sampled V light curves and no shifts between 1999 and 2001 photometries. They were divided into 5 metallicities bins; for each bin we computed the average metal abundance, the average dereddened apparent luminosity V_0, and their root mean square errors (see details in Gratton et al. 2002b). A least square fit of these average values weighted by the errors in both variables gives the following relation for the apparent luminosity-metallicity relation of RR Lyrae stars:

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

where the error in the slope was evaluated via Monte Carlo simulations.

This relation is shown in Figure 6, where open and filled symbols are used for single and double-mode RR Lyrae stars, respectively. The mild slope we derive is in very good agreement with recent results based on the HB luminosity of 19 globular clusters in M31: $\Delta \mathrm{M_V(RR)}/\Delta[\mathrm{Fe/H}]=$ 0.22 mag/dex (Rich et al. 2001) and it also agrees with the 0.20±0.04 slope found by the Baade-Wesselink analysis of Milky Way field RR Lyrae stars: a confirmation that the same luminosity-metallicity relation for HB stars is valid in three different environments, namely M31, the LMC and the Milky Way. Figure 6 does not show any clear evidence for the break in the slope around [Fe/H]=−1.5 suggested by recent evolutionary/pulsation and HB models.

Finally we note that in the V_0 *vs* [Fe/H] relation the LMC RRd's are systematically offset to slightly higher luminosities, thus giving support to the hypothesis that the double-mode pulsators may be more evolved than their single-mode pulsator counterparts.

That RRd's might be more evolved than single-mode RR Lyrae stars has often been suggested on both observational and theoretical grounds, however here for the first time we can test this hypothesis on a large sample of stars with known metal abundance and all at same distance from us.

6. Comparison with previous photometric results

6.1. The RR Lyrae

The average absorption corrected apparent V luminosity of the 108 RR Lyrae's with full coverage of the light curve in our sample is $< V(RR) >_0 = 19.06 \pm 0.02 \pm 0.03 \pm 0.05$ at an average metallicity of [Fe/H]=-1.5 ± 0.03, on Harris (1996) metallicity scale (see Section 3.3 and Gratton et al. 2002b), and for reddening values of 0.116±0.017 and 0.086±0.017 mag in field A and B, respectively (see Section 4). Here 0.02 mag is the standard deviation of the average, 0.03 mag is the contribution due to uncertainties of photometric calibration and aperture corrections (0.017 and 0.023 mag, respectively), and 0.05 mag is the absorption contribution due to the 0.017 mag uncertainty in the reddening.

This value can be compared with the following estimates available in the literature: (i) $< V(RR) >_0$=18.95±0.04, Walker (1992a; i.e. 19.04±0.04 at [Fe/H]=−1.5), based on 182 variables in 7 LMC globular clusters at [Fe/H]=−1.9 and for an average reddening value of $< E(B-V) >$=0.09 mag. The 0.04 mag error bar is the internal error, and Walker estimates that systematic errors due to photometric zero-points and absorption are of the order of 0.02–0.03 and 0.05 mag, respectively; (ii) $< V(RR) >_0$=19.14, derived from A00 median value of 680 RRab's observed by the MACHO microlensing experiment, at [Fe/H]=−1.6 (i.e. 19.16 at [F/H]=−1.5) and for $E(B-V)$=0.1 mag (Bessell 1991). A00 do not provide an evaluation of the error, and we have worked them out as follows: (a) we estimate a 0.073 mag photometric zero-point uncertainty based on the combination of A99: 0.021 mag internal precision of the MACHO photometry, and A96: ± 0.07 mag mean error of a single point of the RR Lyrae photometry; and (b) 0.06 absorption uncertainty based on a 0.02 uncertainty in the reddening. Finally, the 0.09 mag total error is likely to be an underestimate since it does not include the standard deviation of the average (not provided by A96 and A00). In this respect we notice that A97 quotes 0.10 mag as a conservative estimate of the photometric uncertainties of MACHO photometry for the RR Lyrae stars; and (iii) $< V(RR) >_0$=18.91 ±0.01 mag at [Fe/H]=−1.6 (i.e. 18.93 at [Fe/H]=−1.5) and for an assumed reddening value of 0.143 mag, in Udalski et al. (2000b).

In Table 5 we summarize the $< V(RR) >_0$ values from the literature transformed to [Fe/H]−1.5, and we also list the associated errors divided in internal contribution and systematic errors (photometric zero-point and absorption components).

Summarizing:

(a) The present average luminosity of the RR Lyrae stars in the LMC bar agrees well with Walker (1992a) photometry of RR Lyrae stars in the LMC globular clusters (both including or discarding NCG 1841), thus ruling out the existence of any intrinsic differences between field and cluster variables. Walker's and our V photometries are both on the same consistent Johnson photometric system, and we used both reddenings values measured with the very same procedure based on the intrinsic properties of the stars whose average luminosities are compared.

(b) Our $< V(RR) >_0$ is about 0.1 mag brighter than MACHO A00 value, contrary to A99 who found a systematic negative shift of $\Delta V = -0.035$ between MACHO and other photometric works, implying higher luminosities for MACHO. As discussed in Section 2.2 and DF02 this difference is almost interely due to the difference existing between MACHO and our photometry for field A, the results for field B being in agreement with ours. On the other hand the average luminosity of the RRd stars in our sample: $< V >= 19.331 \pm 0.055$ (σ=0.175, 10 stars) is in excellent agreement with A00 recalibration of A97 luminosity of the LMC RRd's: $< V >= 19.327 \pm 0.021$.

(c) In Table 5 the two values listed for OGLE correspond to the average luminosity of the total sample of RR Lyrae stars (Udalski 2000b), and to the luminosity of the subsample of RR Lyrae stars in OGLE field LMC_SC21 with declination within the limits of our Field A (Udalsky et al. 2000). Both OGLE values are systematically brighter by 0.14, 0.24 and 0.15 mag (or 0.12

mag if NGC1841 is included) than the present photometry, A00 and Walker (1992a), respectively. The total error bar of Udalski et al. (2000) determination only marginally allows to make their $< V(RR) >_0$ values overlap with the estimate from the present photometry. The offset between OGLE-II and our average luminosity for the RR Lyrae stars is due for about 0.06 mag to the zero-point shift existing between the 2 photometries (caused by overestimate of star brightness at the faint limit of OGLE-II photometry, likely due to the different data reduction packages, see DF02) and for the remaining 0.08 mag to OGLE-II overestimate by about 0.02-0.03 mag of the reddening in these areas of the LMC.

Using the average absolute magnitudes for RR Lyrae stars considered in Section 1.1 ($M_V = 0.72 \pm 0.15$ at [Fe/H]=-1.5, average of the values from statistical parallaxes and the B-W method), we obtain a distance modulus of μ_{LMC}=18.34±0.15. If we rather adopt the value recently obtained from the globular cluster Main Sequence Fitting by Gratton et al. (2002a, $M_V = 0.61 \pm 0.07$ at [Fe/H]=-1.5), we obtain a slightly longer distance modulus of μ_{LMC}=18.45±0.09.

6.2. The clump

We present here results on the clump, since it is relevant for the distance to the LMC. In fact, the I_0 luminosity of the clump stars by the OGLE team gives the shortest distance modulus to the LMC. Udalski et al. (1998) modulus of 18.08 ± 0.15 mag has undergone a number of revisions which have moved it towards longer values (18.18 ± 0.06: Udalski 1998b; 18.24 ± 0.08: Udalski 2000a), but even the Popowski (2000) latest increase to 18.27 ± 0.07 still provides the shortest modulus derived so far for the LMC. Somewhat short distance moduli were also provided by two LMC eclipsing binary systems (namely: HV2274, Guinan et al. 1998; and HV982: Fitzpatrick et al. 2000), however Ribas et al. (2002), in their recent analysis of a third LMC binary system (EROS 1044) conclude that the 3 binaries provide a consistent distance modulus to the barycenter of the LMC of 18.4 ± 0.1.

A lively discussion is in place among scientists arguing whether the clump method is reliable or not, and invoking or not metallicity and age effects and dependences of the absolute luminosity of the clump at various different extent (see e.g. Girardi & Salaris 2001, and reference therein). A much longer clump distance to the LMC has been published by Romaniello et al. (2000) based on HST WFC2 observations of a field around SN1987A: μ_{LMC}=18.59±0.04±0.08. More recent applications of this technique make use of the K-band luminosity of the LMC red clump stars (Sarajedini et al. 2002, Pietrzyński & Gieren 2002). The derived distance moduli are: μ_{LMC}=18.54±0.10 and μ_{LMC}=18.59±0.008 ± 0.048, respectively, and Pietrzyński & Gieren (2002) emphasize that, due to uncertainties on population corrections, actual errors of the clump method are as large as 0.12 mag.

Hipparcos measured parallaxes for clump stars in the solar neighborhood and derived for them an absolute V magnitude of about +0.8 mag, with a width of about 0.7 mag (FWHM:

Jimenez, Flynn & Kotoneva 1998), and a $B-V$ color of about 1.1 mag, with a range of about 0.86$\lesssim$ $B-V$ $\lesssim$1.34 mag (read from figure 4 of Jimenez et al. paper). This is 0.1 mag **fainter** than the absolute V magnitude of RR Lyrae stars at [Fe/H]=−1.5, the typical value for the LMC variables, if the absolute magnitude given by the statistical parallaxes and the B-W method is adopted.

A00 found that the red HB clump of the 9M CMD is 0.28 mag **brighter** than the mean brightness of the RR Lyrae stars. This difference is larger than predicted by theory for an old, coeval HB population, thus leading to the conclusion that RR Lyrae and clump stars in the LMC have different ages.

We may directly compare the mean apparent V magnitudes of the RR Lyrae and clump stars in our LMC fields. This comparison is shown in Figure 7 where we plot enlargements of the RR Lyrae and HB red clump region in the HR diagrams of our fields. In each panel of the figure, the boxes outline the clump stars of the field, chosen to lie in the region $B-V$=0.65–1.20, and V=19.70–18.9 in Field A, and $B-V$=0.62–1.17 and V=19.61–18.81 in field B, and containing 6728 and 3851 stars, respectively. Gaussian fittings of the B, V, and I luminosity functions provide the following average magnitudes and colors of the clump: $<B>=20.215$ mag, $\sigma=0.207$, $<V>=19.304$ mag, $\sigma=0.185$, $<I>=18.319$ mag, $\sigma=0.190$, $<B>-<V>=0.911$ mag, and $<V>-<I>=$ 0.985 mag in field A; and $<B>=20.194$ mag, $\sigma=0.202$, $<V>=19.291$ mag, $\sigma=0.188$, $<I>=18.307$ mag, $\sigma=0.184$, $<B>-<V>=0.903$ mag, and $<V>-<I>=0.984$ mag in field B. These values can be compared with $<I_{clump}>$=18.25 reported by OGLE-II (from $<I_0>$=17.97 by Udalski 2000b, with $E(B-V)$=0.143, and A_I=1.96$E(B-V)$ from Udalski et al. 1999a). A summary of our photometric results for the clump is provided in Table 5.

Clearly the LMC red clump has a complex structure resulting from the superposition of stellar populations with different masses and ages. Evolutionary and age effects are then present and should be properly accounted for when the HB red clump is used as a distance indicator. On the other hand, the contribution to the clump by the old horizontal branch in the LMC is very well defined by its RR Lyrae stars. Figure 7 shows that the average luminosity of RR Lyrae stars corresponds to the lowest envelope of the clump. In fact, the average V apparent luminosity of the clump stars is 0.108 and 0.029 mag **brighter** than the RR Lyrae level in field A and B, respectively. These results show that: (1) the properties of the clump population in field A and B are different, and a population gradient it is likely to exist between the two areas. (2) the properties of the clump population are quite different in the LMC and in the solar neighborhood. This is not unexpected. However the differences in M_V are not those expected based on OGLE-II results.

The fine structure of the red HB clump stars in our LMC fields will be investigated more in detail in a following paper with the help of the metallicity distribution drawn from about 300 clump stars we observed spectroscopically. Here we only outline the effects on the clump distance modulus to the LMC due to our new estimate for I_0.

According to our reddening estimates in the two fields, and adopting Schlegel et al. (1998) value for the absorption in the I band, A_I=1.94 $E(B-V)$, the dereddened average luminosity of the clump is I_0=18.12 ±0.06 mag (where the error bar includes standard deviation of the average, photometric zero-point, and absorption contribution). This value is in excellent agreement with Romaniello et al. (2000) but is 0.15 mag **fainter** than in Udalski (2000b). This difference is accounted for by the 0.07 mag offset existing between our and OGLE-II photometries at the luminosity level of the clump (see Section 2.2 and DF02), and by a 0.08 mag difference in the I band absorption, with OGLE-II reddening being about 0.04 mag larger than our average reddening (see Sections 4 and 5.1).

Using the metallicity-I luminosity calibration for the clump stars by Udalski (2000a; M_I= 0.13([Fe/H]+0.25)−0.26), and assuming a mean metallicity of [Fe/H]=−0.55 (again as in Udalski 2000a), we find a distance modulus of $(\mathrm{m}-\mathrm{M})_{0,\mathrm{LMC}}$ = 18.42 ± 0.07; while if we adopt instead the calibration by Popowski (2000; M_I = 0.19[Fe/H]−0.23) we obtain $(\mathrm{m}-\mathrm{M})_{0,\mathrm{LMC}}$ = 18.45 ± 0.07. These values are larger than those found by Udalski (2000a,b) and Popowski (2000), and in agreement with almost all other distance modulus determinations for the LMC (see Figure 7). Lacking at present precise estimates of the metallicities of the clump stars in our fields, these values have to be considered as preliminary. However, given the low sensitivity of M_I on metallicity, the assumption about the metal abundance of the clump stars has little impact on this distance derivation.

7. Summary and conclusions: the distance to the LMC

We have presented results based on new B, V, I photometry in the Johnson-Cousins system obtained for two fields close to the bar of the LMC and partially overlapping with fields #6 and #13 of the MACHO microlensing experiment. 125 RR Lyrae variables, 3 anomalous Cepheids, 11 Cepheids, 11 eclipsing binaries and 1 δ Scuti star have been identified in the two areas. The new photometry allows a very precise estimate of the average V and B apparent luminosity of the RR Lyrae variables, as well as of the V, B, I luminosity of the clump stars. The present new photometry has been accurately compared with MACHO and OGLE-II photometries. An estimate of the reddening within the two fields was also obtained from Sturch's (1966) method and from the colors of the edges of the instability strip defined by the RR Lyrae variables. This corresponds to $E(B-V)$=0.116, and 0.086 mag in field A and B, respectively. These values are on average about 0.03-0.04 mag smaller than reddening derived from the UBV photometry of early type stars, and by OGLE-II, and about 0.035 mag larger than reddening estimated from Cepheids within two degrees from either of the centers of our fields.

Spectroscopic metal abundances we derived for 80% of the RR Lyrae stars were combined with individual dereddened average luminosities to determine the luminosity-metallicity relation followed by the RR Lyrae stars: $< V_0(RR) >= 0.214([\mathrm{Fe/H}] + 1.5) + 19.064$. The slope of this relation is in very good agreement with recent results from GCs in M31 (Rich et al. 2001) and shows no evidence for a break around [Fe/H]=−1.5.

The average dereddened apparent luminosity of the RR Lyrae and clump stars in our LMC fields is $< V(RR) >_0$=19.06±0.06 (at [Fe/H]=−1.5), and $< V_{clump} >_0$=18.98±0.08, where errors include standard deviation of the average (0.02 mag and 0.06 mag for RR Lyrae and clump stars, respectively), uncertainty of the V photometric calibration and aperture corrections, and absorption contribution.

The present $< V(RR) >_0$ moves the B-W and statistical parallax determinations of the distance modulus of the LMC to 18.38±0.16[10] and 18.30±0.14, respectively. Using the most recent results from the Subdwarf Fitting Method (Gratton et al. 2000a), it is 18.45±0.09.

The present determination of the I luminosity of the clump stars corrected for our new reddening values leads to $< I >_0$=18.12±0.06 mag and moves the clump distance modulus of the LMC to 18.42±0.07 and 18.45±0.07 mag, when Udalski (2000a) or Popowski (2000) metallicity-I luminosity relations for the clump stars are adopted.

The state-of-the-art on the true distance modulus of the LMC as derived from various techniques is summarized in Figure 8, where different symbols are adopted for Population I (filled triangles) and II (filled circles) distance indicators. Far for pretending to be exhaustive (see Figure 8 and Table 10 of Benedict et al. 2002, for a more extensive listing of extant LMC distance modulus estimates), Figure 8 is meant to provide an overview of the results from the most commonly used and more robust distance indicators found in the LMC. In panel (a) distance moduli from Pop. II indicators are based on Walker (1992a) average luminosity of RR Lyrae's in the LMC Globular clusters: $< V(RR) >_0$=18.95 at [Fe/H]=−1.9 (transformed to [Fe/H]=−1.5). Panel (a) of Figure 8 well illustrates the dichotomy existing between *short* and *long* distance scales provided by the different distance indicators: with a few exceptions (the red clump and the eclipsing binaries method), the Population I distance indicators give a *long* distance modulus for the LMC in the range from 18.5 to 18.7 mag, while Population II indicators based on "field stars" (Baade-Wesselink, and Statistical Parallax methods, in particular) yield a *short* distance modulus of 18.3, and indicators based on "cluster stars", as for instance the Main Sequence Fitting method (MSF; Gratton et al. 1997, Carretta et al. 2000b) and the globular clusters dynamical models, or the pulsational properties of RR Lyrae's in globular clusters (Sandage 1993a) support a *longer* modulus in the range from 18.4 to 18.6. The solid and dashed lines in panel (a) shows the HST key project on extragalactic distances preferred value $\mu_{\rm LMC}$=18.50 and its 1σ=0.10 mag error bar (Freedman et al. 2001).

The impact on the derived distance modulus of the LMC of the present average luminosities of RR Lyrae and clump stars in the LMC bar: $< V(RR) >_0$=19.06 at [Fe/H]=−1.5, and $< I_{Clump} >_0$=18.12, and of our new reddening estimates: $E(B-V)$=0.116 and 0.086 mag (in field A and B, respectively) is shown in panel (b). Further changes with respect to Figure 8a are i) the

[10]The B-W value would further move to 18.50 mag using the new preliminary estimate of the magnitude of the Galactic field RR Lyrae star RR Cet: M_V(RR)=0.56 mag at [Fe/H]=−1.5, from Cacciari et al. (2000) revision of the B-W method.

revised estimate of the distance to the LMC from the combinations of the results for 3 LMC binary systems studied so far (namely: HV 2274, HV982 and EROS 1044; Ribas et al. 2002); ii) the clump distance based on K-luminosity (Sarajedini et al. 2002), Pietrzyński & Gieren 2002); iii) the revised HB luminosity from the new Main Sequence Fitting (MSF) distances to NGC 6397, 6752 and 47 Tuc based on ESO-VLT spectroscopy of cluster giants and turn-off stars (Gratton et al. 2002a); iv) Cacciari et al. (2000) revised estimate of $M_V(RR)$ from the Baade-Wesselink method; v) the use of A00 revised average luminosity of A97 LMC RRd's: vi) the revision of the absolute luminosity of RR Lyrae stars from the white dwarf (WD) cooling sequence: $M_V(RR)$=0.66±0.14 at [Fe/H]=−1.5 (Gratton et al. 2002a); and vii) the use of the trigonometric parallax of RR Lyr measured by HST (Benedict et al. 2002). Distance moduli shown in Figure 8b are also listed in Table 6. Errors for the Population II indicators in Figure 8b and Table 6 include the 0.06 mag contribution of the uncertainty in $< V(RR) >_0$.

A weighted average of the values in Table 6, (with weights proportional to the inverse square of the error, and after having first weight-averaged the independent estimates available for the clump, the Miras, the B-W of RR Lyrae stars, the RRd's, and the TRGB) shows that **all** distance determinations converge within 1 σ on a distance modulus of $\mu_{\rm LMC}$=18.515±0.085 mag (where the error bar is the 1 σ scatter of the average) thus allowing to **fully reconcile the long and the short distance scale to the LMC**. This value is shown by the heavy long dashed line of Figure 8b while heavy dashed lines give the 1σ=0.085 mag errorbars. A straight average of the values in Table 6, with no weights, would give $\mu_{\rm LMC}$=18.50±0.10. We caution that distance moduli from Cepheids may be overestimated by 0.06-0.09 mag due to an underestimate of the reddening adopted for Cepheids by 0.02-0.03 mag.

We thank the referee A. Walker for making constructive comments and suggestions concerning the original manuscript which have definitely helped to improve and strenghten the paper, and M. Feast for his comments on the first version of the paper circulated as astro-ph/0007471. Special thanks go to P. Montegriffo for the development of the specific software used for the detection of the variable stars and in the study of their periodicities. G.C. whishes to thank M. Marconi and C. Cacciari for very helpful discussions about the classification, according to Bailey types, of some of the RR Lyrae variables, and about the use of the Fourier decomposition parameters, and the reddening of M3.

This paper utilizes public domain data obtained by the MACHO Project, jointly funded by the US Department of Energy through the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48, by the National Science Foundation through the Center for Particle Astrophysics of the University of California under cooperative agreement AST-8809616, and by the Mount Stromlo and Siding Spring Observatory, part of the Australian National University.

This work was partially supported by MURST - Cofin98 under the project ”Stellar Evolution” , and by MURST - Cofin00 under the project ”Stellar observables of cosmological relevance”.

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Fig. 1.— Positions of the 7 LMC globular clusters studied by Walker (1992a) with respect to the LMC bar.

Fig. 2.— V, B, I light curves of RR Lyrae stars falling in our fields. From top to bottom an RRab, an RRc and an RRd variable. Filled and open symbols are used for the 1999 and 2001 data, respectively.

Fig. 3.— V, B, I light curves of an anomalous Cepheid, a classical Cepheid and an eclipsing binary falling in our fields. Different symbols are as in Figure 2.

Fig. 4.— V *vs* $B - V$, and I *vs* $V - I$ color - magnitude diagrams of field A from the ALLFRAME reduction of the 2001 data. The box outlines the clump stars of this field. Different symbols mark the variables identified in this field (RR Lyrae stars: filled circles; anomalous Cepheids: open squares; Cepheids: filled squares; binaries: filled triangles; crosses: δ Scuti) which are plotted according to their intensity average magnitudes and colors. Only the RR Lyrae stars are shown in the I *vs* $V - I$ diagram.

Fig. 5.— Same as Figure 4 for field B.

Fig. 6.— The luminosity-metallicity relation defined by our RR Lyrae stars. Filled circles mark the double-mode pulsators.

Fig. 7.— Enlargement of the regions containing the RR Lyrae and clump stars in the V *vs* $B - V$, and I *vs* $V - I$ CMDs of field A (top panels) and B (lower panels), respectively. Filled pentagons are the RR Lyraes plotted according to their intersity average magnitudes and colors. Solid lines in the left hand panels indicate the average levels of the RR Lyrae's ($< V(RR)_A >$=19.412 mag, $< V(RR)_B >$=19.320 mag) and clump stars ($< V_{ClumpA} >$=19.304 mag, $< V_{ClumpB} >$=19.291 mag) in each field. Dotted-dashed lines represent the 1 σ deviations from the averages ($\sim$0.16 and $\sim$0.19 mag for RR Lyrae's and clumps stars, respectively).

Fig. 8.— The distance modulus of the Large Magellanic Cloud as derived from various distance indicators. Triangles and circles mark the Population I and II indicators, respectively. In panel (a) distance moduli from Pop. II indicators are based on Walker (1992a) average luminosity of RR Lyrae's in the LMC Globular clusters: $< V(RR) >_0$=18.95 at [Fe/H]=$-$1.9 (transformed to [Fe/H]=$-$1.5); while in panel (b) distance moduli are based on our new average luminosities of RR Lyrae and clump stars in the bar of the LMC: $< V(RR) >_0$=19.06 at [Fe/H]=$-$1.5, and $< I_{Clump} >_0$=18.12, and on our new reddening estimates: $E(B - V)$=0.116 and 0.086 mag (in field A and B, respectively). The solid and dashed lines in panel (a) shows the HST key project on extragalactic distances preferred value $\mu_{\rm LMC}$=18.50 and its 1σ=0.10 mag errorbar (see Freedman et al. 2001, and Section 7). Data in panel (a) of the figure for the Cepheids are taken from: (a) trigonometric parallaxes, Feast & Catchpole (1997; with errorbar revised according to Carretta et al. 2000b); (b) MS Fitting, Laney & Stobie (1994 value corrected to account for Hipparcos new distance modulus for the Hyades, and with errorbar revised according to Carretta et al. 2000b); (c)

B-W, average of Gieren et al. (1998) value corrected according to Carretta et al. (2000b), and of Di Benedetto (1997) estimate; (d) P/L relation from Groenewegen (2000); for the eclipsing binaries: average from Guinan et al. (1998) and Fitzpatrick et al. (2000); for the clump from: Udalski (2000a), Popowski (2000), and Romaniello et al. (2000); for the Miras from: Van Leeuwen et al. (1997) and Feast (2000); for SN1987a from: Panagia (1998); for the MSF and the HB stars from: Carretta et al. (2000b); for the RR Lyrae Statistical parallaxes and B-W: from $M_V(RR)$=0.76 and 0.68 mag, respectively, and Walker (1992a) $< V(RR) >_0$; for the LMC RRd's from A97 and from Kovacs (2000); for the GCs dynamical models from: Carretta et al. (2000b) revision of Chaboyer et al. (1998); for the white dwarfs cooling sequence from: Carretta et al. (2000b); for the Hipparcos trigonometric parallax of RR Lyrae itself: Perryman et al. (1997); and for the RGB Tip Cioni et al. (2000), and Romaniello et al. (2000). The revision of the LMC distance moduli due to the present new photometry and reddening is shown in panel (b). Further changes with respect to panel (a) are: (i) Ribas et al. (2002) revised estimate of the distance to the LMC from the 3 eclipsing binary systems HV 2274, HV 982 and EROS 1044; (ii) the clump distances based on the K-luminosity (Sarajedeni et al. 2002, and Pietrzyński & Gieren 2002); (iii) the revised MSF distances to GCs by Gratton et al. (2002a); (iv) Cacciari et al. (2000) revised estimate of $M_V(RR)$ from the B-W method; (v) A00 revised average luminosity of A97 LMC RRd's; (vi) the revised distance from the WD cooling sequence by Gratton et al. (2002a); and (vii) Benedict et al. (2002) trigonometric parallax of RR Lyr measured by the HST. The heavy long dashed line shows the average value of all distance moduli in panel (b): $\mu_{\rm LMC}$=18.515 mag, while heavy dashed lines give the 1σ=0.085 mag errorbars (see Section 7).

Table 1: Reddening values for Cepheids within two degrees from the centers of either of our fields

HV number	$E(B-V)$ (1)	$E(B-V)$ (2)	d(A) (deg)	d(B) (deg)
12823	0.058		0.93	1.30
2549	0.058		1.13	0.99
2527	0.070		1.18	0.66
12797	0.070		1.57	1.09
2694	0.070		1.67	2.05
6065	0.070		1.82	3.11
2749	0.070		1.92	2.49
2405	0.070		2.15	1.54
909	0.058		2.66	0.88
2352	0.100	0.105	2.71	0.96
2338	0.040	0.036	2.74	0.96
902	0.070		2.82	1.02
900	0.058		3.03	1.33
914	0.070		3.17	1.95
881	0.030		3.56	1.73
2257	0.060	0.061	3.74	1.95
873	0.130		3.75	1.92
878	0.058		3.76	1.97

(1) Gieren et al. (1998); (2) Caldwell & Coulson (1986)

Table 2: Individual reddenings from Sturch's method applied to the RRab stars with known metal abundance. Metal abundances in the upper portion of the table derive from our spectroscopic study and are on Harris (1996) metallicity scale (see Section 3.3 and Gratton et al. 2002b). Metal abundances in the lower portion of the table were derived from the Fourier parameters of the light curve and are on Jurcsik (1995) metallicity scale. Reddenings were calculated using the relation given in Section 4.2, after having transformed metallicities to Zinn & West (1984) scale.

Id.	Field	$< B-V >_{min}$ mag.	P day	[Fe/H]	$E(B-V)$
2525	A	0.535	0.6161	−2.06	0.169
2767	A	0.528	0.5311	−1.37	0.144
3061	A	0.496	0.4762	−1.26	0.119
3948	A	0.564	0.6666	−1.46	0.153
4933	A	0.559	0.6135	−1.48	0.162
4974	A	0.513	0.5807	−1.35	0.116
5589	A	0.555	0.6365	−1.60	0.159
6398	A	0.532	0.5603	−1.40	0.143
6426	A	0.540	0.6622	−1.59	0.137
7247	A	0.478	0.5617	−1.41	0.088
7325	A	0.490	0.4868	−1.28	0.112
7468	A	0.584	0.6355	−1.41	0.177
7477	A	0.527	0.6564	−1.67	0.130
7609	A	0.511	0.5734	−1.58	0.129
7734	A	0.538	0.6170	−1.39	0.135
8094	A	0.595	0.7457	−1.83	0.186
8720	A	0.479	0.6577	−1.76	0.087
8788	A	0.516	0.5596	−1.55	0.135
9154	A	0.508	0.6198	−1.66	0.119
9245	A	0.448	0.5598	−1.42	0.060
9494	A	0.518	0.5786	−1.69	0.141
10214	A	0.500	0.5999	−1.48	0.106
10487	A	0.531	0.5896	−1.52	0.142
12896	A	0.574	0.5737	−1.53	0.189
15387	A	0.512	0.5598	−1.81	0.146
16249	A	0.480	0.6048	−1.86	0.106
18314	A	0.526	0.5871	−1.71	0.148
19450	A	0.537	0.3979	−0.90	0.159
19711	A	0.361	0.5530	−1.68	−0.010
25301	A	0.576	0.5606	−1.40	0.187

Table 2 continued

Id.	Field	$< B-V >_{min}$ mag.	P day	[Fe/H]	$E(B-V)$
25362	A	0.509	0.5775	−1.49	0.121
25510	A	0.525	0.6496	−1.63	0.127
26525	A	0.601	0.5229	−1.63	0.234
26821	A	0.554	0.5875	−1.37	0.157
26933	A	0.456	0.4883	−1.34	0.081
28293	A	0.483	0.6615	−1.74	0.089
1408	B	0.453	0.6260	−1.70	0.065
1575	B	0.541	0.6739	−1.61	0.136
1907	B	0.524	0.5805	−1.52	0.137
2249	B	0.526	0.6104	−1.56	0.134
2884	B	0.515	0.6194	−1.90	0.140
3400	B	0.504	0.4862	−1.45	0.136
4780	B	0.576	0.6176	−1.20	0.162
4859	B	0.486	0.5234	−1.44	0.108
5902	B	0.459	0.5698	−2.12	0.108
6440	B	0.407	0.4948	−1.19	0.032
6798	B	0.498	0.5841	−1.20	0.092
7063	B	0.516	0.6543	−1.49	0.109
7442	B	0.519	0.5780	−1.58	0.136
7620	B	0.480	0.6562	−2.05	0.104
10811	B	0.500	0.4764	−1.42	0.132
14449	B	0.523	0.5841	−1.70	0.145
19037	B	0.505	0.4113	−1.26	0.144
22917	B	0.485	0.5647	−1.34	0.092
23502	B	0.525	0.4722	−1.43	0.159
24089	B	0.474	0.5598	−1.31	0.080
5167	A	0.514	0.6302	−1.32	0.115
8220	A	0.562	0.6768	−1.03	0.140
9660	A	0.496	0.6218	−1.35	0.100
3054	B	0.433	0.5080	−0.94	0.048
3412	B	0.522	0.5302	−1.62	0.158
4540	B	0.472	0.5689	−1.40	0.091

Table 3: Instability strip edges defined by RR Lyrae variables in our LMC fields[a]

Id.	Field	< B > − < V > int.	< B > − < V > mag.	Id.	Field	< B > − < V > int.	< B > − < V > mag.	< B > − < V > adopted
		First Overtone Blue Edge				Fundamental Red Edge		
2517	B	0.230	0.237	8094	A	0.509	0.517	0.525[b]
2623	A	0.233	0.240	28293	A	0.502	0.508	0.514[b]
2223	A	0.249	0.258	7468	A	0.481	0.489	0.481[b]
4008	B	0.278	0.284	5589	A	0.475	0.480	0.480[b]
7783	B	0.285	0.298	5452	A	0.473	0.473	0.473

[a]Colors of the variables in field A have been made bluer by 0.03 mag to put them on the same reddening scale of field B.

[b]Corrected colors derived using Walker (1998) 0.04 mag dex^{-1} shift of the color of the FRE with metal abundance, and assuming [Fe/H]=−1.66 for M3 (Zinn & West, 1984).

Table 4: Summary of our photometric results. Errors in the lower portion of the table include internal dispersion of the average, contributions of the uncertainty of the photometric calibration and of the aperture corrections, and absorption contribution due to the uncertainty in the reddening

Field A		Field B
$< V(RR) >$=19.412± 0.019		$< V(RR) >$=19.320± 0.023
$< B(RR) >$=19.807± 0.022		$< B(RR) >$=19.680± 0.024
$< V(clump) >$=19.304± 0.002		$< V(clump) >$=19.291± 0.003
$< B(clump) >$=20.215± 0.003		$< B(clump) >$=20.194± 0.003
$< I(clump) >$=18.319± 0.002		$< I(clump) >$=18.307± 0.003
$E(B-V)$=0.116±0.017		$E(B-V)$=0.086±0.017
R_V=3.10	R_B=4.10	R_I=1.94
$< V(RR) >_0$=19.052		$< V(RR) >_0$=19.053
$< B(RR) >_0$=19.331		$< B(RR) >_0$=19.327
$< V(clump) >_0$=18.944		$< V(clump) >_0$=19.024
$< B(clump) >_0$=19.739		$< B(clump) >_0$=19.841
$< V(clump) >_0$=18.094		$< V(clump) >_0$=18.140
	Average values	
	$< V(RR) >_0$=19.05± 0.06	
	$< B(RR) >_0$=19.33± 0.08	
	$< I(clump) >_0$=18.12± 0.06	

Table 5: Comparison with the <V(RR)>$_0$ values in the literature transformed to a common value of [Fe/H]=−1.5

<V(RR)>$_0$	N_{stars}	Error				Reddening	Reference
		(1)	(2)	(3)	(total)		
19.06	108	0.02	0.03	0.05	0.06	0.086-0.116	This paper
19.04	182	0.04	0.025	0.05	0.07	0.09	Walker (1992a)
19.07[a]	160	0.04	0.025	0.05	0.07	0.07	Walker (1992a)
19.16[b]	680	–	0.073[c]	0.06[c]	>0.09[c]	0.1	A00–MACHO
18.92	71	–	0.015[d]	0.08[d]	>0.08	0.144[e]	Udalski et al. (2000)–OGLE-II LMC_SC21
18.93	–	0.01	0.015[d]	0.08[d]	0.08	0.143[f]	Udalski (2000b)–OGLE-II

(1) standard deviation of the average, (2) photometric zero-point, (3) absorption contribution

[a] Average value without NGC1841

[b] From A00 V=19.45 corrected for a reddening of $E(B-V)$=0.1, as in A96, and for the metallicity

[c] These errors are our guess, according to the procedure described in Section 6

[d] Sources for the photometric zero-point and absorption contributions to the total error are Udalski et al. (1998) and Udalski (1998a), respectively

[e] Reddening is the average of the values for field LMC_SC21 in Table 2 of Udalski et al. (1999a). The 18.92 is obtained subtracting 3.1×0.144=0.446 mag from $< V(RR) >$=19.37 mag quoted in Udalski et al. (2000), and withouth metallicity correction since RR Lyrae's in OGLE-II field LMC_SC21 can be expect to share the same average metallicity of our field A

[f] Reddening is average of the values for all the LMC fields in Table 2 of Udalski et al. (1999a)

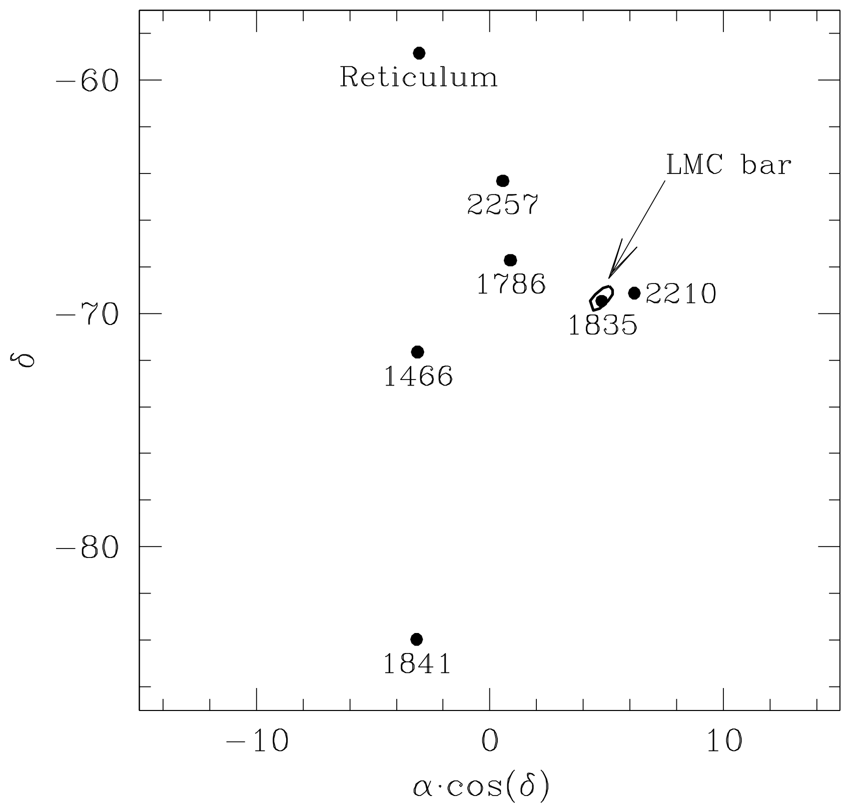
Table 6: Distance moduli to the LMC from Population I and II distance indicators

Method	μ_{LMC}	Reference
Population I distance indicators		
Cepheids: trig. paral.	18.70±0.16[a]	Feast & Catchpole (1997)
Cepheids: MS fitting	18.55±0.06[b]	Laney & Stobie (1994)
Cepheids: B-W	18.55±0.10	Gieren et al. (1998), Di Benedetto (1997)[c]
Cepheids: P/L relation	18.575±0.2	Groenewegen (2000)
Eclipsing Binaries	18.4 ±0.1	Ribas & al. (2002)
Clump	18.42±0.07	this paper, see Section 6.2
Clump	18.45±0.07	this paper, see Section 6.2
Clump	18.59±0.09	Romaniello et al. (2000)
Clump	18.471±0.12	Pietrzynsky & Gieren (2002)
Clump	18.54±0.10	Sarajedini et al. (2002)
Miras	18.54±0.18	Van Leeuwen (1997)
Miras	18.64±0.14	Feast (2000)
SN1987a	18.58±0.05	Panagia (1998)
Population II distance indicators		
GCs: MSF	18.45±0.09	Gratton et al. (2002a) & this paper
GCs: dyn. mod.	18.45±0.13	Carretta et al. (2000b) & this paper
HB: trig. paral.	18.44±0.13	Carretta et al. (2000b) & this paper
RR Lyr: stat. paral.	18.30±0.14	this paper, see Section 7
RR Lyr: BW	18.38±0.16	this paper, see Section 7
RR Lyr: BW revised	18.50±0.16	Cacciari et al. (2000) & this paper
LMC RRd's	18.55±0.19	A97 and A00
LMC RRd's	18.52±0.18	Kovacs (2000) & this paper
WD cool. seq.	18.40±0.15	Gratton et al. (2002a) & this paper
RRLyr: trig. par	18.45±0.16	Benedict et al. (2002) & this paper
TRGB	18.55±0.09	Cioni et al. (2000)
TRGB	18.69±0.26	Romaniello et al. (2000)

[a] Error bar has been revised according to Carretta et al. (2000b).

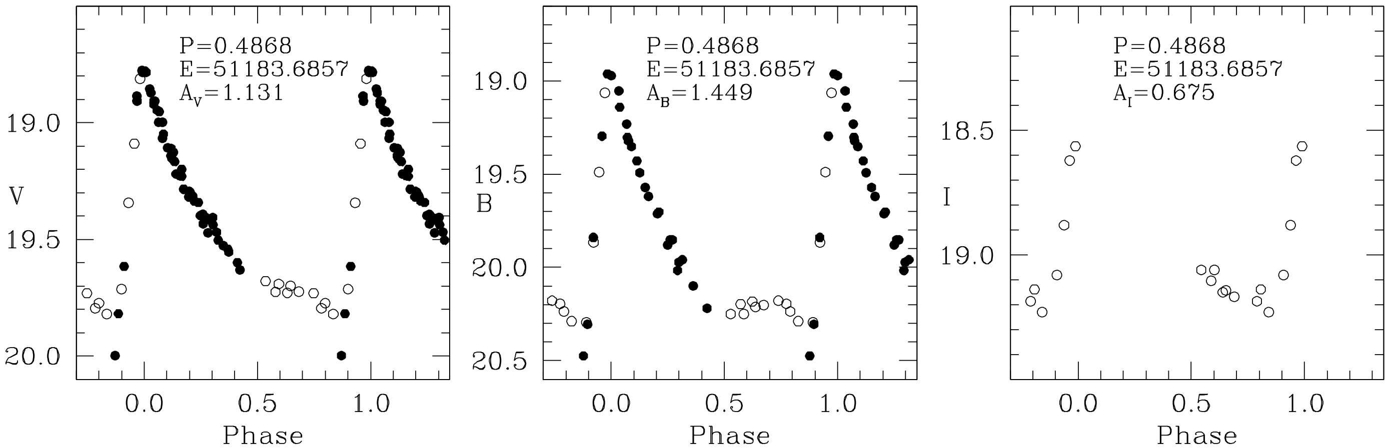
[b] Laney & Stobie (1994) original value corrected to account for Hipparcos new distance modulus for the Hyades (see Carretta et al. 2000b).

[c] Average of Gieren et al. (1998) value corrected according to Carretta et al (2000b), and of Di Benedetto (1997) estimate.

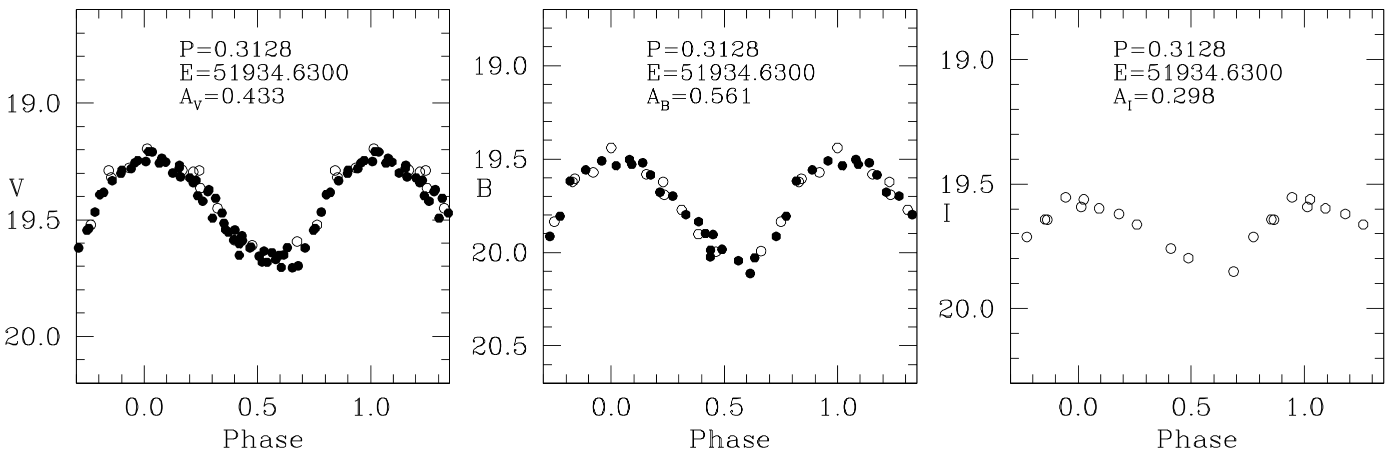


Reticulum
2257
1786
LMC bar
2210
1835
1466
1841
−60
−70
−80
δ
−10
0
10
α·cos(δ)

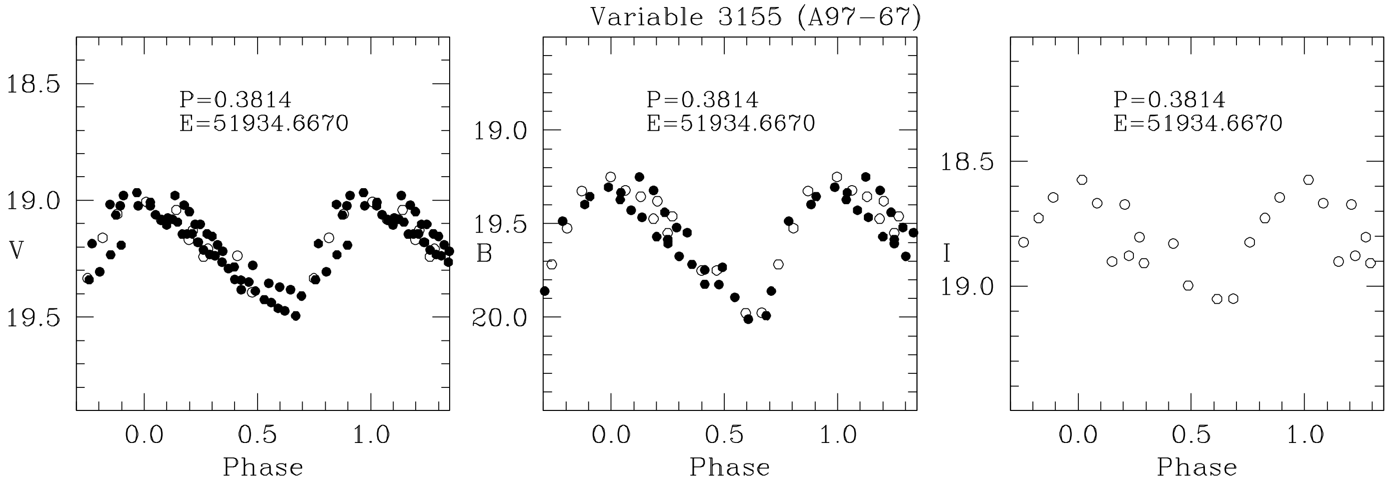
Variable 7325

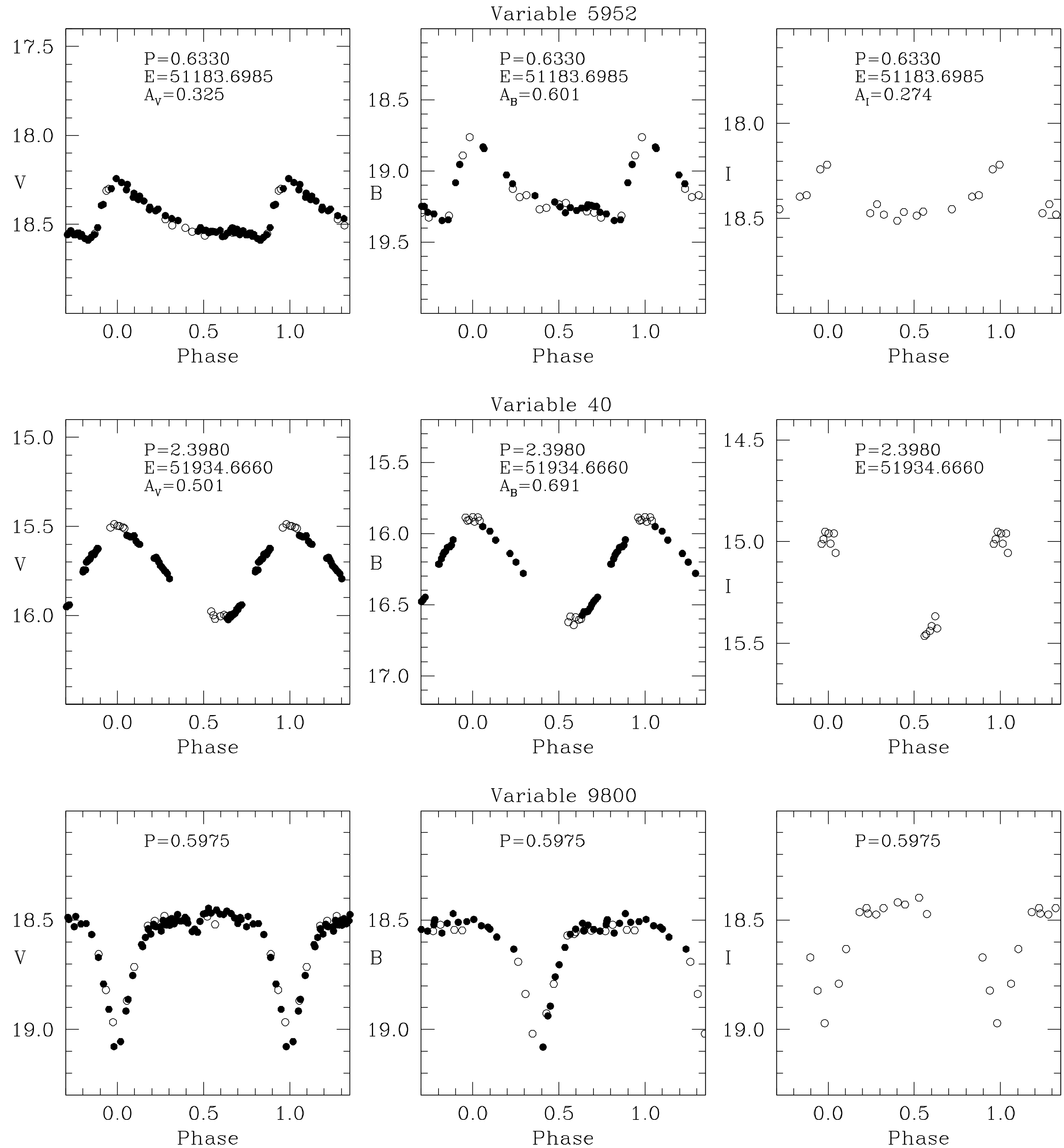


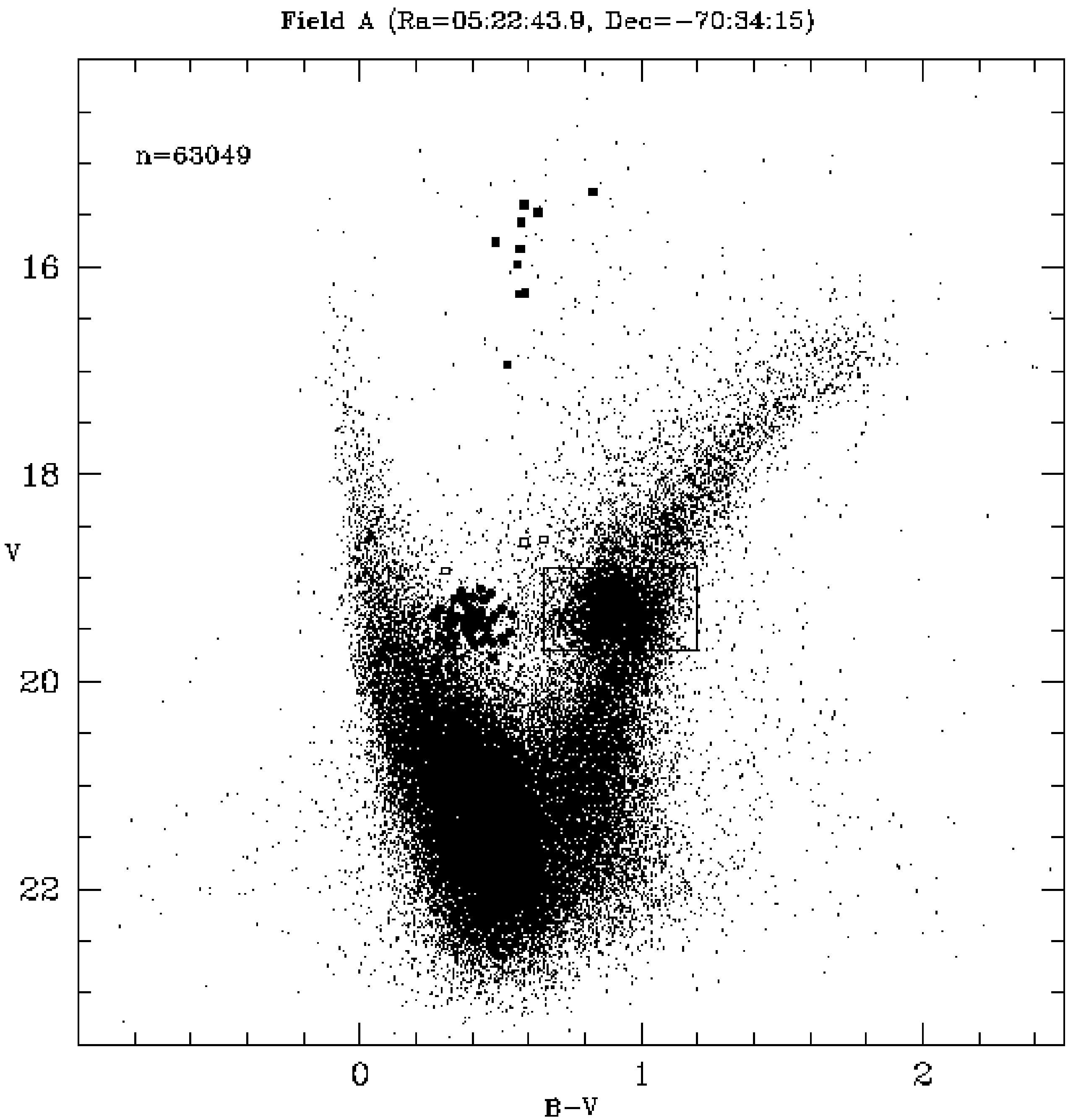
Variable 4946

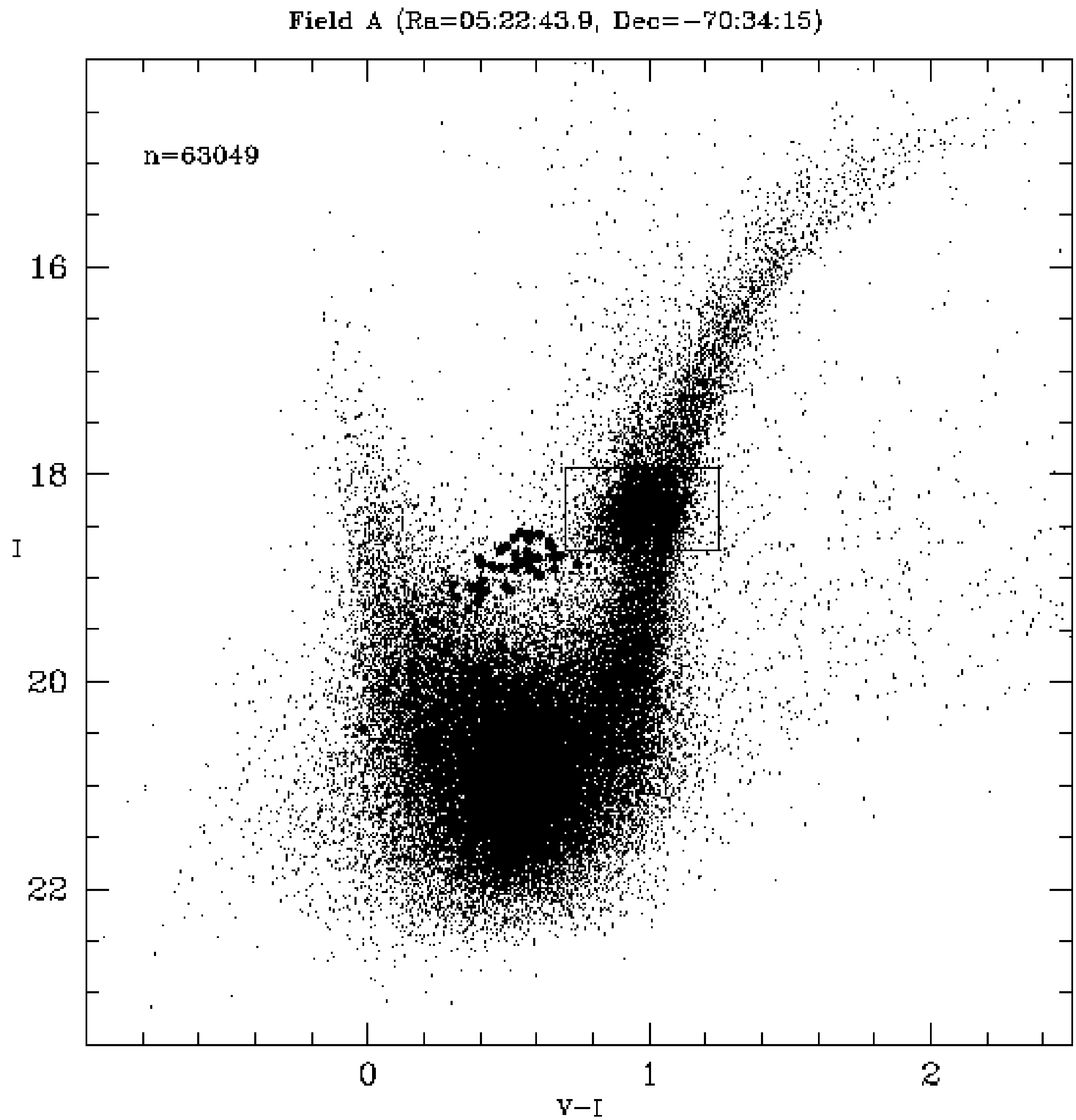


Variable 3155 (A97-67)



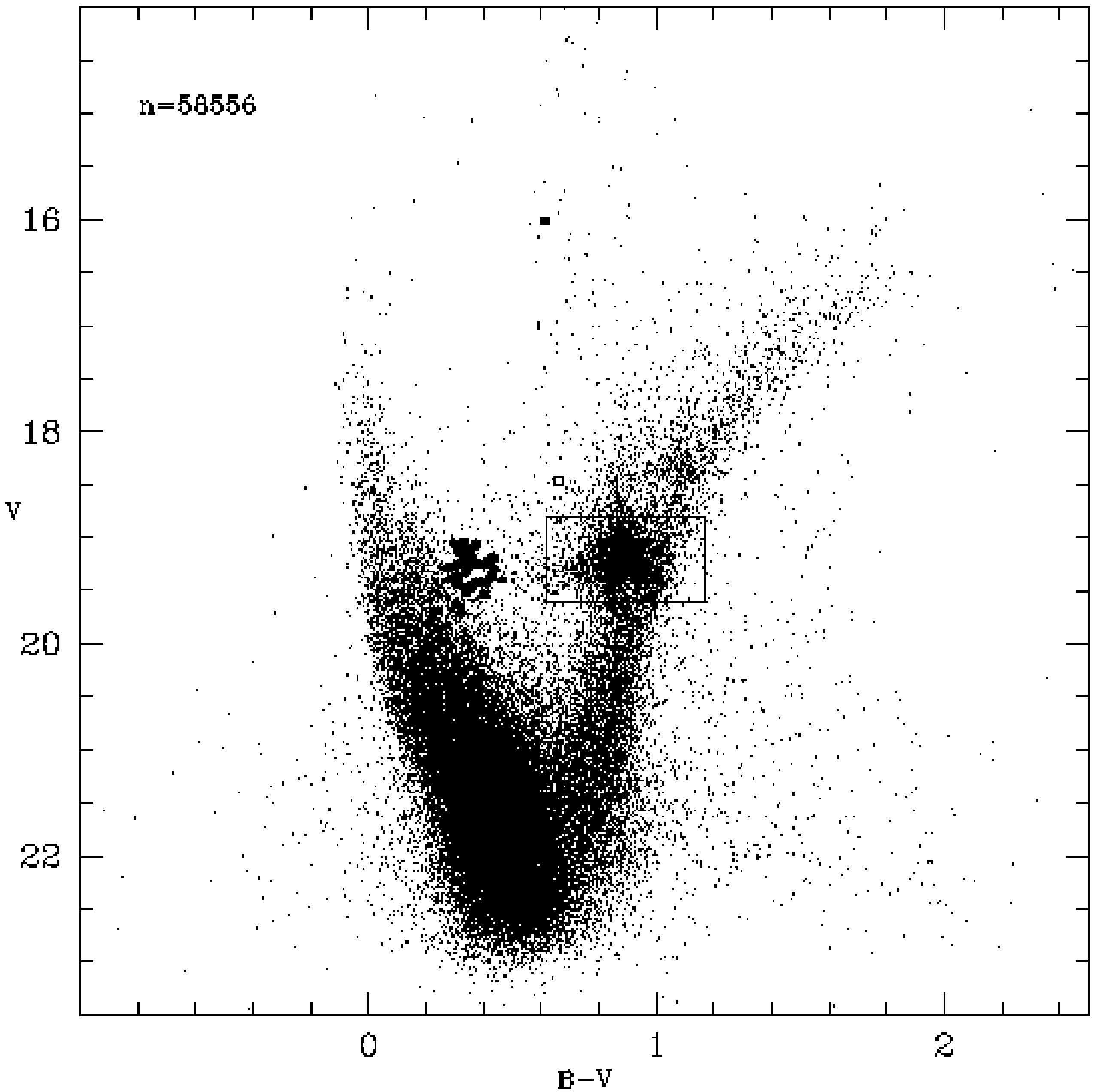

Variable 5952
P=0.6330
E=51183.6985
A_V=0.325
V
Phase
P=0.6330
E=51183.6985
A_B=0.601
B
Phase
P=0.6330
E=51183.6985
A_I=0.274
I
Phase
Variable 40
P=2.3980
E=51934.6660
A_V=0.501
V
Phase
P=2.3980
E=51934.6660
A_B=0.691
B
Phase
P=2.3980
E=51934.6660
I
Phase
Variable 9800
P=0.5975
V
Phase
P=0.5975
B
Phase
P=0.5975
I
Phase

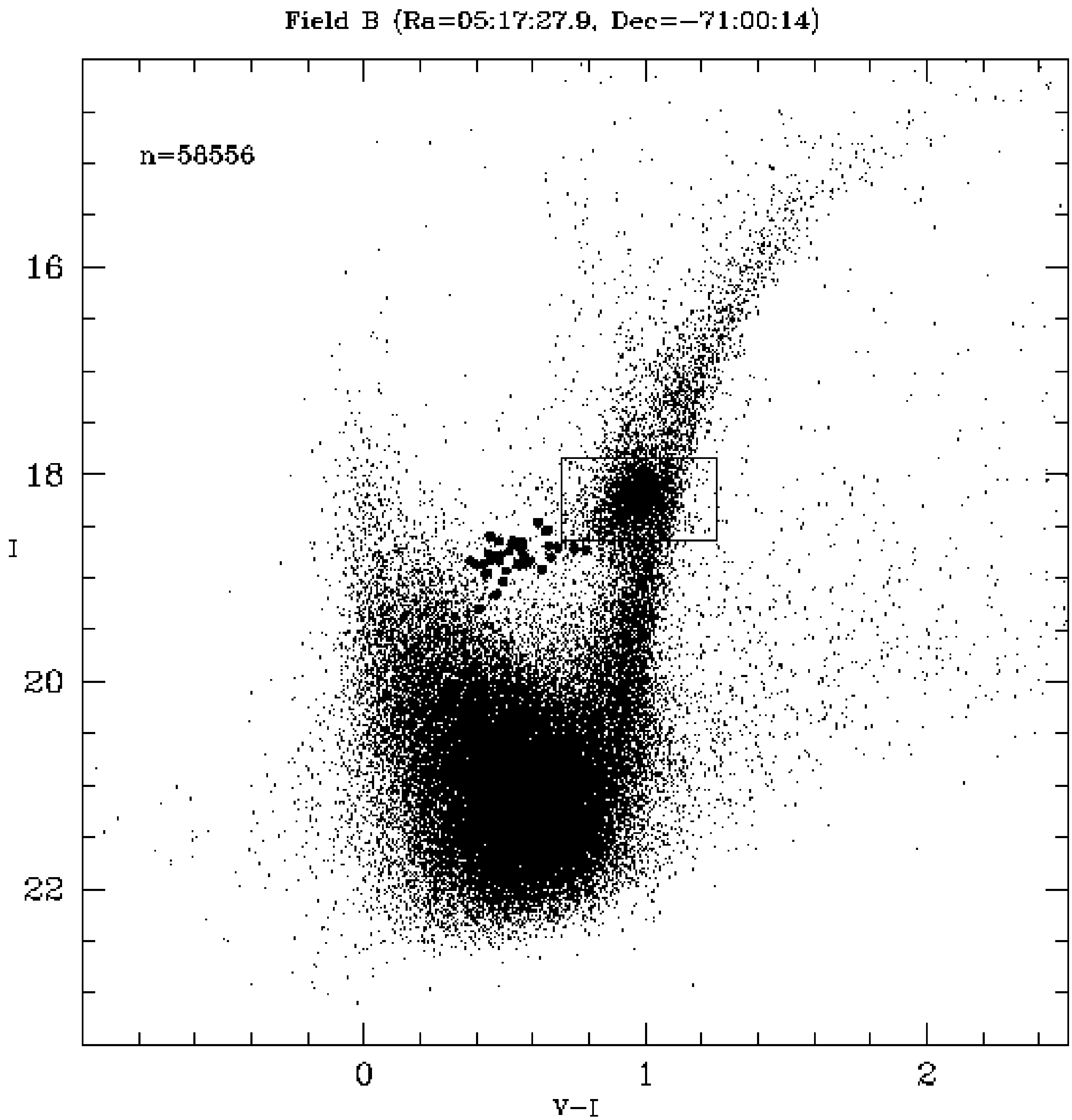

Field A (Ra=05:22:43.9, Dec=−70:34:15)
n=63049
16
18
20
22
V
0
1
2
B−V

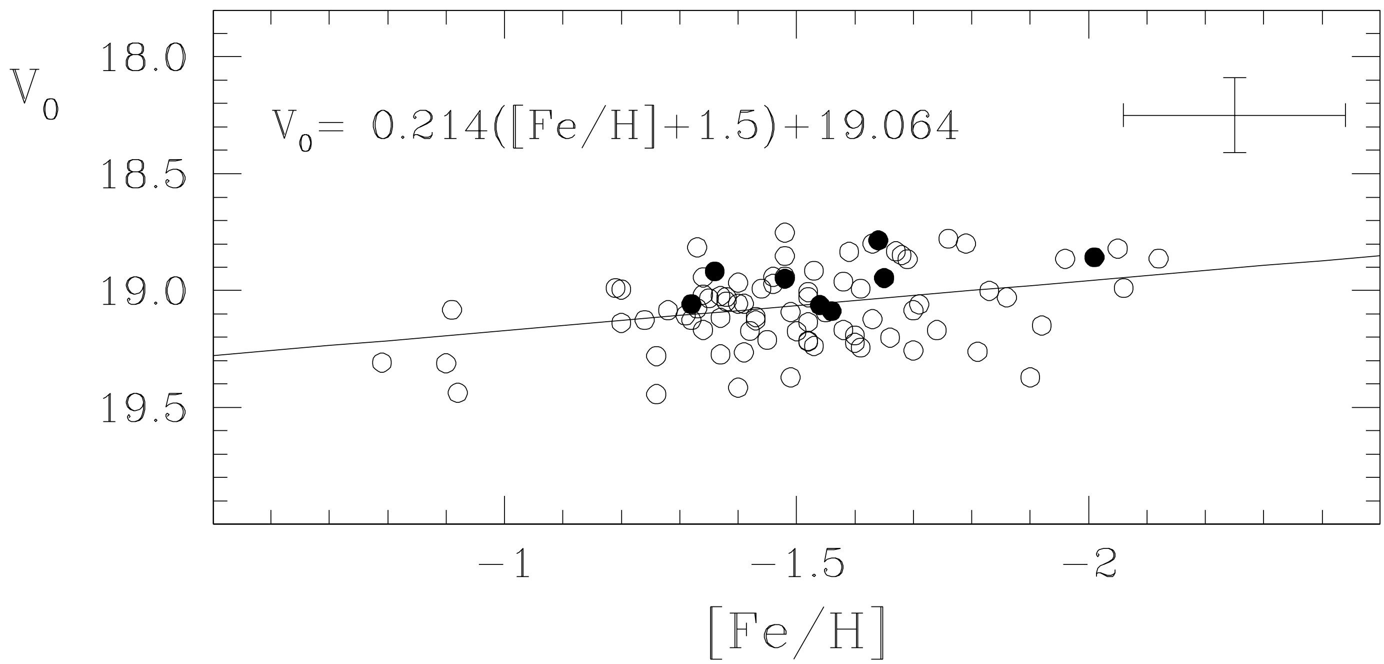


Field A (Ra=05:22:43.9, Dec=−70:34:15)
n=63049
16
18
20
22
I
0
1
2
V−I

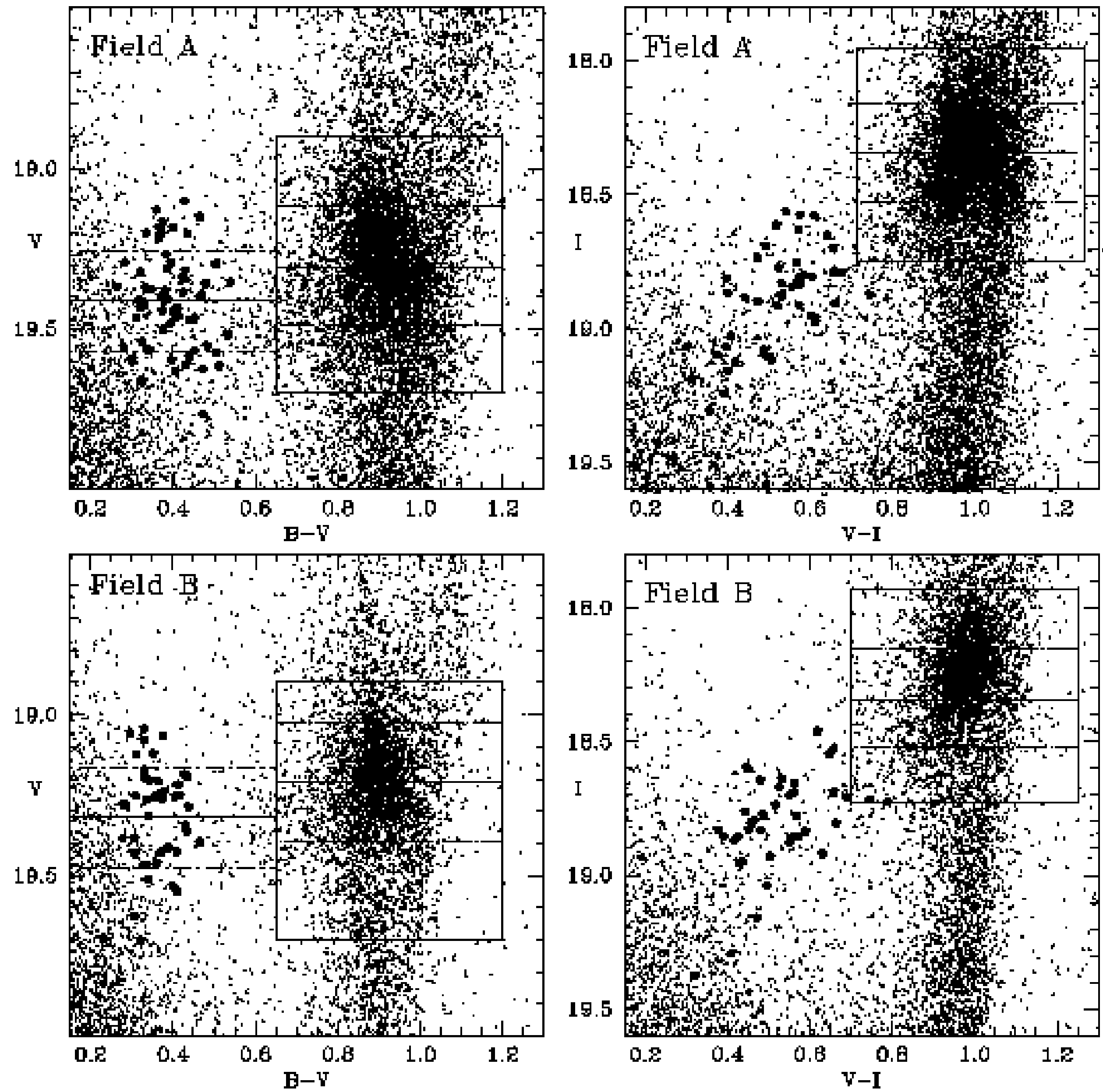
Field B (Ra=05:17:27.9, Dec=−71:00:14)



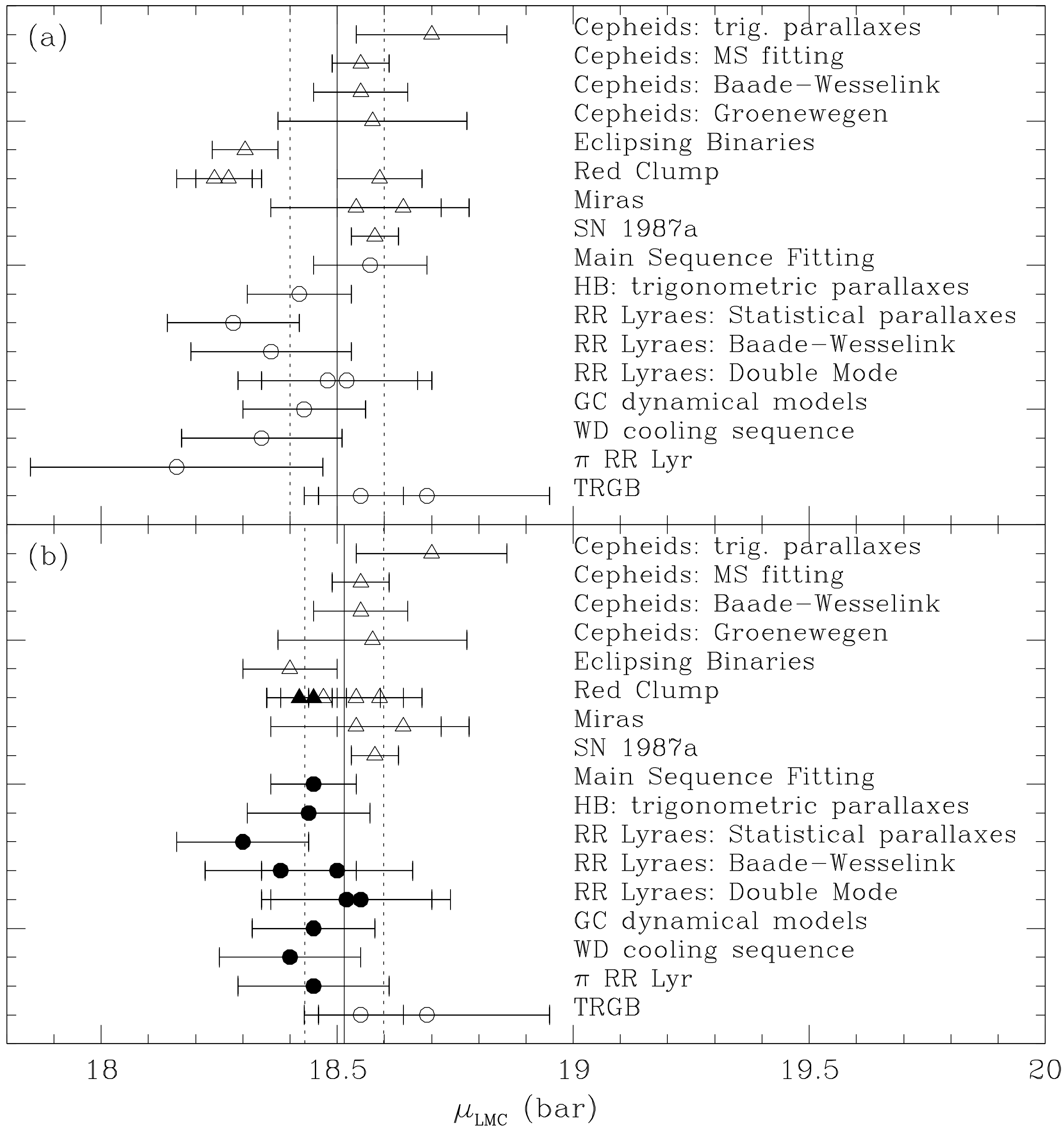

Field B (Ra=05:17:27.9, Dec=−71:00:14)
n=58556
16
18
20
22
I
0
1
2
V−I



V_0
V_0= 0.214([Fe/H]+1.5)+19.064
18.0
18.5
19.0
19.5
−1
−1.5
−2
[Fe/H]



Field A
19.0
V
19.5
0.2
0.4
0.6
0.8
1.0
1.2
B−V
Field A
18.0
18.5
I
19.0
19.5
0.2
0.4
0.6
0.8
1.0
1.2
V−I
Field B
19.0
V
19.5
0.2
0.4
0.6
0.8
1.0
1.2
B−V
Field B
18.0
18.5
I
19.0
19.5
0.2
0.4
0.6
0.8
1.0
1.2
V−I



(a)
(b)
Cepheids: trig. parallaxes
Cepheids: MS fitting
Cepheids: Baade–Wesselink
Cepheids: Groenewegen
Eclipsing Binaries
Red Clump
Miras
SN 1987a
Main Sequence Fitting
HB: trigonometric parallaxes
RR Lyraes: Statistical parallaxes
RR Lyraes: Baade–Wesselink
RR Lyraes: Double Mode
GC dynamical models
WD cooling sequence
π RR Lyr
TRGB
18
18.5
19
19.5
20
μLMC (bar)