THE ASTROPHYSICAL JOURNAL, 530:738–743, 2000 February 20

HUBBLE SPACE TELESCOPE OBSERVATIONS OF THE LARGE MAGELLANIC CLOUD FIELD AROUND SN 1987A: DISTANCE DETERMINATION WITH RED CLUMP AND TIP OF THE RED GIANT BRANCH STARS

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Received 1999 September 30; accepted 1999 October 6

ABSTRACT

We have used *Hubble Space Telescope* (*HST*) WFPC2 multiband observations of a field around SN 1987A in the Large Magellanic Cloud to measure its distance from the Sun. The observations allowed us to carefully determine the interstellar extinction along the line of sight to a large number of stars and to measure the LMC distance by using two stellar distance indicators: the red clump (RC) and the tip of the red giant branch (TRGB). From an application of the red clump method, we obtain a distance modulus of $(m-M)_{0,\mathrm{RC}}^{\mathrm{LMC}} = 18.59 \pm 0.04 \pm 0.08$ mag (statistical plus systematic error), in good agreement with the distance derived by using the TRGB stars, namely, $(m-M)_{0,\mathrm{TRGB}}^{\mathrm{LMC}} = 18.69 \pm 0.25 \pm 0.06$ mag (statistical plus systematic error). Both values agree well with the distance to SN 1987A as determined from a study of its inner ring fluorescent echo [$(m-M)_{\mathrm{SN1987A}} = 18.55 \pm 0.05$ mag], thus excluding distance moduli lower than 18.43 to a 99.7% significance level. Differences with respect to previous results obtained using the same distance indicators are discussed.

Subject headings: galaxies: distances and redshifts — galaxies: individual (Large Magellanic Cloud) — stars: evolution

1. INTRODUCTION

The distance to the Large Magellanic Cloud is a fundamental step in the cosmological distance ladder: since the Cepheid extragalactic distance scale is tied to the LMC distance, any error in the determination of the distance to the LMC propagates directly to the cosmological distances.

Recent determinations based on the light echoes of the supernova SN 1987A (Panagia 1998), on the *Hipparcos*-calibrated RR Lyrae (via a main-sequence fitting technique) and Cepheids distance scale (Gratton et al. 1997; Reid 1997; Feast & Catchpole 1997; Oudmaijer, Groenewegen, & Schrijver 1998), and on the theoretical calibration of RR Lyrae and tip of the red giant branch (TRGB) star brightnesses (Salaris & Cassisi 1998) provide distance moduli ranging approximately between $(m-M)_0^{\mathrm{LMC}} = 18.50$ and 18.70 mag (the "long" distance scale). On the other hand, the straightforward application of the red clump (RC) method (Paczynski & Stanek 1998) for distance determinations to two LMC fields by Stanek, Zaritsky, & Harris (1998) provides a much shorter distance, namely, $(m-M)_0^{\mathrm{LMC}} = 18.065 \pm 0.031 \pm 0.09$ mag (statistical plus systematic error). According to Cole (1998) and Girardi et al. (1998), when properly taking into account population effects on the RC luminosity, that distance modulus must be increased by ~ 0.2–0.3 mag, making it only marginally consistent with the "long" distance scale. It is unpleasant to notice how different independent stellar distance indicators provide different answers for such an important quantity.

In this paper we make use of multicolor *Hubble Space Telescope* (*HST*) WFPC2 observations (Romaniello 1998; M. Romaniello et al., in preparation) of a circular region with a radius of approximately 2′ centered on the SN 1987A, obtained as part of the long-term General Observer Supernova Intensive Study (SINS) project. The main aim of our investigation is to provide an accurate distance determination to this field by using two independent stellar standard candles: the TRGB and the RC. Since the observed stellar field is located around the SN 1987A, we can perform a meaningful comparison between the derived distance modulus and the distance to the supernova as independently determined by means of studies of the fluorescence echoes from the supernova circumstellar ring (Panagia 1998). Moreover, the availability of multiband observations has allowed a careful and homogeneous reddening determination by means of a newly developed technique (Romaniello 1998; M. Romaniello et al., in preparation). This constitutes an important improvement over previous works, because it permits us to carefully take into account the existing small-scale variations in the internal extinction of the observed LMC field (which is located in an area containing a large number of early-type stars interspersed with H II regions and supernova remnant shells).

In § 2 we briefly discuss the observational data and the technique employed for the reddening determination. Section 3 deals with the distance determinations, and in § 4 we discuss the main results.

2. THE DATA

Since 1994, SN 1987A has been imaged every year with the Wide Field and Planetary Camera 2 (WFPC2) on board the NASA/ESA *Hubble Space Telescope* (*HST*) in the context of the long-term SINS project (PI: Robert P. Kirshner). Here we use the observations taken on 1994 Sep-

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tember 24, 1996 February 6, and 1997 July 10. They provide full coverage of a circular portion of the LMC with a radius of roughly 2′ (∼30 pc) centered on SN 1987A in six wide-band filters covering the spectral region from the ultraviolet to the near-infrared: F255W, F336W, F439W, F555W, F675W, and F814W.

A full description of the data and of the reduction process is given elsewhere (Panagia et al. 2000; M. Romaniello et al., in preparation). In brief, the observations were processed through the standard PODPS (Post-Observation Data Processing System) pipeline for bias removal and flat-fielding. In all cases, the available images for each filter were combined to remove cosmic-ray events. The fluxes were measured by performing aperture photometry following the prescriptions by Gilmozzi (1990), as refined by Romaniello (1998), i.e., measuring the flux in a circular aperture of 2 pixels radius and the sky background value in an annulus of inner radius 3 pixels and width 2 pixels. The flux calibration is obtained using the internal calibration of the WFPC2 (Whitmore 1995), which is typically accurate to within ±5%. We use the spectrum of Vega as photometric zero point.

Both of the distance determination methods used in this paper rely solely on the luminosity of the red giant stars in the F814W filter. The WFPC2 sensitivity is extremely stable in this spectral region. The zero-point variation, as evaluated from the PHOTFLAM keyword in the image headers, is smaller than 3% over the entire time span covered by our observations. The uncertainty on the final calibrated zero points of the photometry is of the order of ±0.04 mag.

In our analysis we have taken full advantage of the wealth of information provided by the broad wavelength range (about 2300–9000 Å) covered by the observations. By means of multiband fits with the theoretical spectra by Bessel, Castelli, & Plez (1998), we have derived both the intrinsic stellar properties and the interstellar extinction along the line of sight to the individual stars (Romaniello 1998; M. Romaniello et al., in preparation). In our field, we find that the hot ($T_{\rm eff} \gtrsim 10{,}000$ K, i.e., young) and cold ($6{,}500 \lesssim T_{\rm eff} \lesssim 8{,}500$ K, i.e., presumably old) main-sequence stars are affected, on average, by the same amount of extinction. When no determination of the reddening for a given star on the red giant branch (RGB) was possible, the mean value from its neighbors belonging to the same intermediate–old stellar population was used. As recently also noted by Zaritsky (1999), one must be extremely careful that the stars from which the extinction is determined belong to the same population as the stars one is studying in order to take into account possible population-dependent effects.

The resulting dereddened $\rm F814W_0$ vs. $\rm (F555W-F814W)_0$ color-magnitude diagram (CMD) is shown in Figure 1*a*. In Figure 1*b* we show the reddening distribution[6] *individually measured for 2510 stars* in our field (one every 13 arcsec^2, on average). The peak occurs at $E(B-V) = 0.20$ mag, and the distribution displays nonnegligible scatter: $\sigma(E(B-V)) = 0.072$ mag rms, at least twice the measurement errors. It is clear that in a case like this an improper evaluation of the interstellar extinction may introduce an error/uncertainty in the subsequent distance modulus by as much as ±0.14 mag (rms). By measuring it directly for individual stars or, in the worst case, from numerous well-measured neighbors, we eliminate this uncertainty that can significantly affect the final result.

3. DISTANCE DETERMINATION

An inspection of the CMD displayed in Figure 1*a* reveals the presence of an intermediate–old stellar population in the red part of the diagram. The RC [$17 \lesssim \rm F814W_0 \lesssim 18$ mag, $1 \gtrsim \rm (F555W - F814W)_0 \gtrsim 0.8$ mag] and an extended RGB [$\rm F814W_0 \lesssim 20$ mag, $\rm (F555W - F814W)_0 \gtrsim 0.7$ mag]

[6] The extinction in the various *HST* filters has been translated into $E(B-V)$ according to the reddening law as determined by Scuderi et al. (1996).

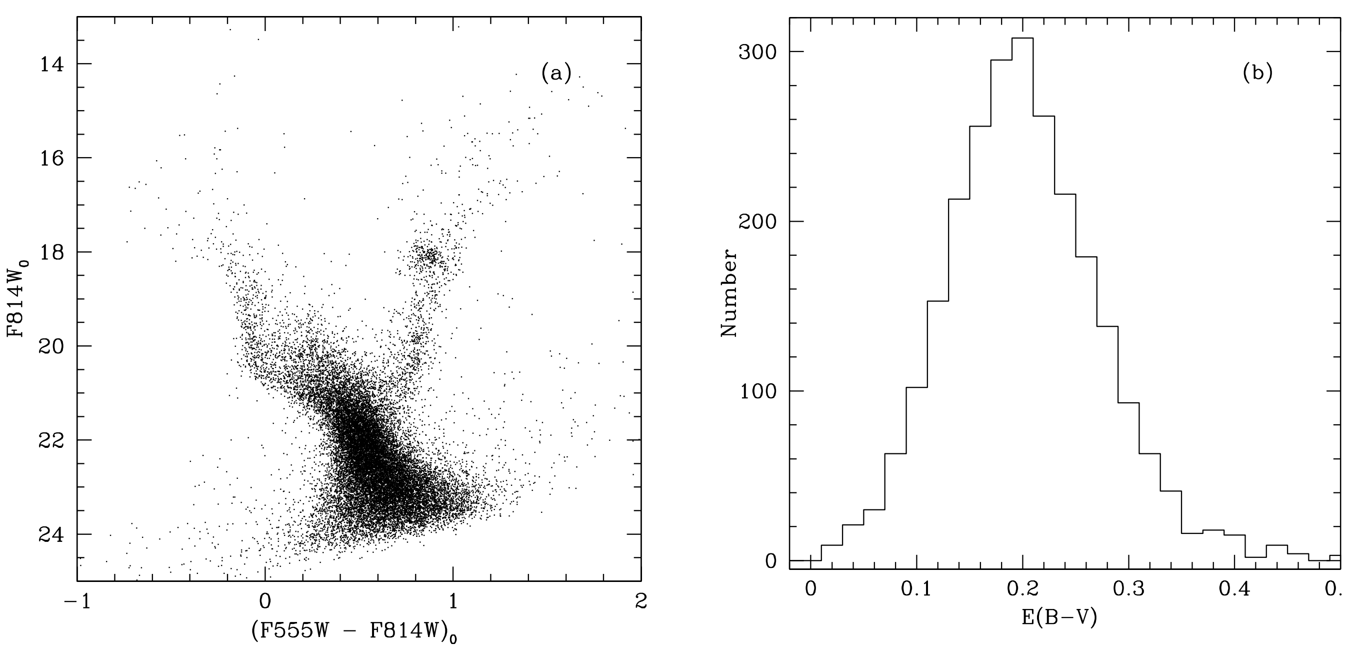

FIG. 1.—(*a*) Dereddened $\rm F814W_0$ vs. $\rm (F555W-F814W)_0$ color-magnitude diagram of the field around SN 1987A. (*b*) Reddening distribution in the observed field.

are clearly visible. Typically, our photometry for RGB stars is accurate to better than 1% in both filters.

3.1. *The Red Clump*

The RC is a common feature in many CMDs: it is populated by low-mass, metal-rich stars experiencing central He burning, and represents the intermediate-age, metal-rich counterpart of the globular clusters' horizontal branch. The $I-(V-I)$ CMD from *Hipparcos* data clearly shows the local red clump, extending horizontally in the $(V-I)_0$ interval approximately between 0.8 and 1.25 mag, with a mean absolute magnitude of $M_I^0 = -0.23 \pm 0.03$ mag and a dispersion of $\sigma_{\rm RC} = 0.20$ mag (Stanek & Garnavich 1998).

The constancy of the RC mean brightness over such a wide color range was interpreted as evidence that it can be used as a stellar standard candle, independent of the properties of the underlying stellar population, at least for $(V-I)_0$ between 0.8 and 1.25 mag (see, e.g., Paczynski & Stanek 1998). However, using evolutionary stellar models, Cole (1998) and Girardi et al. (1998) have shown that M_I^0 of the RC does depend on the properties of the stellar population. In particular, Girardi et al. (1998) have demonstrated that theoretical stellar models are able to reproduce the structure and the constancy of M_I^0 with color for the local *Hipparcos* RC, and that M_I^0 is not a constant among different populations, but depends on their metallicities. On the observational side, Twarog, Anthony-Twarog, & Bricker (1999) have found a dependence of M_I^0 on the metallicity from a determination of the distance to two Galactic open clusters with ages and metallicities typical of the LMC stellar population; they used the main-sequence fitting technique to estimate the distances by employing theoretical isochrones calibrated on *Hipparcos* subdwarfs.

In Figure 2 (*left*) we show the RC region in our CMD. The dereddened data in the F555W and F814W band have been transformed into the VI Johnson-Cousins system following Holtzman et al. (1995). These transformations are consistent with those derived by convolving the Bessel et al. (1998) synthetic spectra with the *HST* and Johnson-Cousins filters using the IRAF-STSDAS SYNPHOT package. These corrections are typically of 0.03 mag, and in all cases are smaller than 0.05 mag.

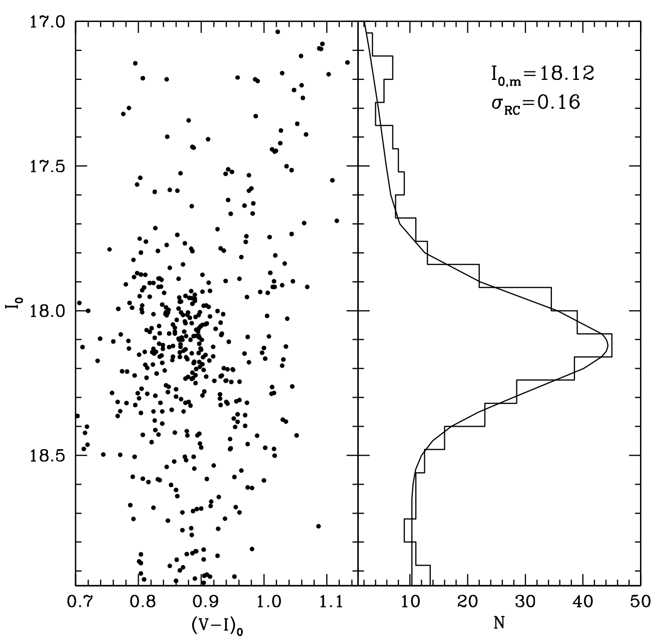

FIG. 2.—*Left*: RC region in the CMD of the observed LMC field. *Right*: Distribution of the RC stars as a function of their I_0 magnitude, along with the analytical fit as described by eq. (1).

We have applied the RC method as described, for example, in Stanek et al. (1998) by selecting the stars in the range $0.8 < (V-I)_0 < 1.25$ mag (note that the RC is almost completely contained within this color range). We have also verified that the final result does not change even if we include the bluemost part, with $(V-I)_0 < 0.8$ mag and $17.0 < I_0 < 19.0$ mag, and fitting the distribution of stars as a function of the I-band magnitude with the function (Stanek & Garnavich 1998)

$$n(I_0) = a + b(I_0 - I_{0,m}) + c(I_0 - I_{0,m})^2 + \frac{N_{\rm RC}}{\sigma_{\rm RC}\sqrt{2\pi}} \exp\left[-\frac{(I_0 - I_{0,m})^2}{2\sigma_{\rm RC}^2}\right]. \quad (1)$$

The first three terms correspond to a fit to the distribution of RGB stars, while the Gaussian term represents a fit to the RC. We find the peak magnitude of the RC population to be $I_{0,m} = 18.12 \pm 0.02$ mag, while the dispersion turns out to be $\sigma_{\rm RC} = 0.16$ mag. The result of the fit is shown in Figure 2 (*right*). By using $M_I^0 = -0.23 \pm 0.03$ mag for the local clump and without any evolutionary correction, one would get $(m-M)_{0,\rm RC}^{\rm LMC} = 18.35 \pm 0.04$ mag (statistical error only).

It is important to consider at this point the correction (ΔM_I) due to population effects. The red boundary of the RC in our CMD is located at $(V-I)_0 \approx 1.0$ mag, approximately 0.2 mag bluer than the local *Hipparcos* RC, and the color extension is of about 0.3 mag in $(V-I)$, i.e., about 0.1 mag less extended than the local RC. Using the models from Girardi et al. (1998), the position and color extension of the RC in the observed LMC field indicates a metallicity ranging between $Z \approx 0.002$ and $Z \approx 0.008$ ($[{\rm M/H}] \approx -1.0$ to -0.4). A similar result is derived by using different theoretical models, such as the ones by Cassisi, Castellani, & Straniero (1994) or Seidel, Demarque, & Weinberg (1987).

The value of ΔM_I to be applied to M_I^0 as derived by Twarog et al. (1999) for a metallicity of $[{\rm Fe/H}] = -0.8$ amounts to -0.31 mag. This figure is obtained by considering stars in a cluster, which means stars belonging to a stellar population with a single metallicity and a single age. Cole (1998) and Girardi et al. (1998) considered a composite stellar population (such as the one observed in the LMC fields) with realistic assumptions about the star formation history (SFH). Cole (1998) obtained $\Delta M_I = -0.32$ by considering a SFH as in Holtzman et al. (1997), and $\Delta M_I = -0.23$ when assuming the more "burstlike" SFH from Vallenari et al. (1996). Girardi et al. (1998) have derived $\Delta M_I = -0.23$ for a constant star formation rate in the last 3 Gyr and equally probable metallicities between $Z = 0.004$ and $Z = 0.008$, while $\Delta M_I = -0.17$ for the Vallenari et al. (1996) SFH.

Based on these results, we use an average value of $\Delta M_I = -0.24$, adding to the error budget on the final distance modulus a systematic error of ± 0.08 mag, which takes into account the uncertainties on ΔM_I coming from the adopted stellar models, the assumed SFH, and the error on the zero point of the photometry.

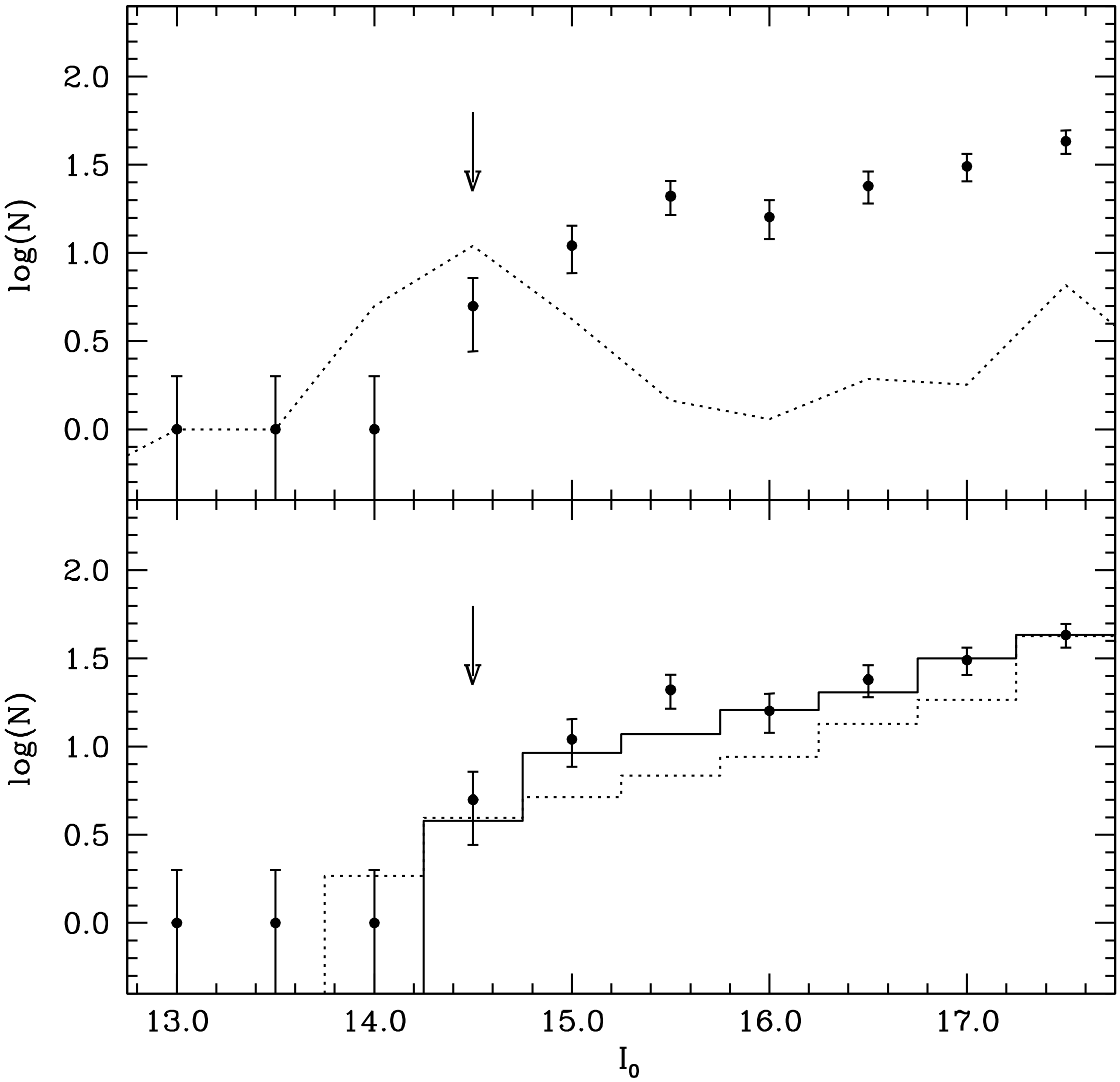

FIG. 3.—*Top*: Observational LF for the upper part of the RGB (*filled circles*) and the convolution of the LF and the edge-detector (*dotted line*). The arrow marks the position of the bin where the TRGB discontinuity is detected. *Bottom*: Same as top, but the theoretical LFs for $(m - M)_{0,\mathrm{TRGB}}^{\mathrm{LMC}} = 18.69$ (*solid line*) and $(m - M)_{0,\mathrm{TRGB}}^{\mathrm{LMC}} = 18.10$ (*dotted line*) are also plotted.

The final value for the distance to the observed LMC field is

$$(m - M)_{0,\mathrm{RC}}^{\mathrm{LMC}} = 18.59 \pm 0.04 \pm 0.08 \text{ mag}$$

(statistical plus systematic error).

3.2. *The Tip of the Red Giant Branch*

The use of the TRGB as a distance indicator is discussed at length in Lee, Freedman, & Madore (1993), Madore & Freedmann (1995), and Salaris & Cassisi (1997, 1998). Stars at the TRGB are experiencing the core Helium flash, and their luminosity is remarkably constant for a large range of masses (corresponding to ages equal to or larger than ~ 2 Gyr). Moreover, the absolute I magnitude of TRGB stars is very weakly affected by the metallicity of the underlying stellar population, at least for metallicities lower than half-solar (Salaris & Cassisi 1997, 1998). The basic idea of the TRGB method for distance determination is to derive the position of the TRGB from the observed luminosity function (LF) of the upper RGB population, and to compare it with prescriptions from theoretical stellar models. As discussed in Salaris & Cassisi (1998), all theoretical models agree quite well with each other on the predicted luminosity of the TRGB. In addition, the uncertainties on the theoretical bolometric corrections appear to be quite small.

The position of the observed TRGB has been determined according to the procedure described in Lee et al. (1993) and Madore & Freedman (1995). We have computed the differential LF for $I_0 \leq 17.5$, in order to avoid substantial contamination of RC stars. Because of the limited spatial extension of the observed field, the upper part of the RGB cannot be very populated (~ 150 stars in the selected brightness range). We have employed bins ± 0.25 mag wide in the LF, basing our choice on the results from Monte Carlo simulations performed using the theoretical models of Salaris & Cassisi (1998). According to these simulations, this bin selection ensures that we will always have a RGB population more than 2 σ different from zero in the bin centered on the TRGB brightness. The kernel $[-1, 0, +1]$ (Madore & Freedman 1995) has been convolved with the observational LF (our results do not change appreciably when using a kernel covering a wider baseline, namely, $[-1, -2, 0, +2, +1]$); the kernel response reflects the gradient detected across a three-point interval and produces a maximum at the luminosity for which the count discontinuity is the largest. We used the midpoint of the corresponding luminosity bin as the value of the TRGB brightness (see Fig. 3, *top*). The TRGB in the observed CMD is located at $I_0^{\rm TRGB} = 14.50 \pm 0.25$ mag. From the previous discussion, it is clear that an error bar of ± 0.25 mag corresponds to an estimate of the maximum error on the TRGB position. This value of $I_0^{\rm TRGB}$ is in good agreement with the value of $I_0^{\rm TRGB} = 14.53 \pm 0.05$ mag derived by Reid, Mould, & Thompson (1987) from observations of a large area of the Shapley constellation III within the LMC. This value was used in subsequent analyses (Lee et al. 1993; Salaris & Cassisi 1997, 1998) for deriving the TRGB distance to LMC.

By considering a mean metallicity of $[{\rm M/H}] = -0.7$, as for the RC stars, and the theoretical TRGB absolute I magnitude from equation (5) of Salaris & Cassisi (1998), one derives

$$(m - M)_{0,\rm TRGB}^{\rm LMC} = 18.69 \pm 0.25 \text{ mag}$$

(statistical error only). Note that the error introduced by an uncertainty (or a spread) in metallicity even as large as a factor of 2 is negligible with respect to the error on the TRGB position.

In Figure 3 (*bottom*) we show a comparison of the observational and theoretical LF for the adopted mean value of the distance modulus and metallicity. The faintest, and most populated, bin in the observational LF has been used to normalize the population of the theoretical one. It is comforting to see how well the theoretical LF reproduces the observed one over the last 3 mag below the TRGB. After performing a least-squares fit, we found that the slopes of the two LFs agree within the statistical error. This result also confirms the negligible level of contamination from different stellar populations, both in the Galaxy and in the LMC itself (asymptotic giant branch stars). In Figure 3, the LF for the "short" distance scale, namely, $(m - M)_{0,\rm TRGB}^{\rm LMC} = 18.10$ mag, is also included; it is clear that such a short distance is ruled out by our data not only because it predicts RGB stars at magnitudes brighter than the TRGB discontinuity, but also because it is clearly inconsistent with the remaining part of the observed LF.

By adding to the final value of the TRGB distance modulus a systematic uncertainty of ± 0.05 mag due to theoretical uncertainties on the calibration of the absolute TRGB luminosity and bolometric corrections (Salaris & Cassisi 1998), and the error on the zero point of the photometry, we obtain

$$(m - M)_{0,\rm TRGB}^{\rm LMC} = 18.69 \pm 0.25 \pm 0.06 \text{ mag}$$

(statistical plus systematic error).

4. DISCUSSION

The distances we obtained from the RC method and the TRGB for the stellar population around SN 1987A are in good mutual agreement. When combined, they rule out distance moduli smaller than 18.34 at a 3 σ level. They are also in good agreement with the distance to the SN 1987A as determined by Panagia (1998), namely, $(m - M)_{\rm SN1987A} = 18.55 \pm 0.05$ mag. Let us note that this value is also consistent with that derived from the fit of theoretical models to the observed zero-age main sequence (Romaniello 1998; M. Romaniello et al., in preparation). In conclusion, these results all agree on a value of around 18.57 and exclude values lower than 18.43 mag to a 99.7%, i.e. 3 σ, confidence level.

Our derived value of $I_0^{\rm TRGB}$ compares well with the results of Reid et al. (1987) from observations of a different, more extended LMC field. As a consequence, the distance modulus derived by Salaris & Cassisi (1998), who used the Reid et al. (1987) data together with the same theoretical calibration we employed, agrees well with our results. Moreover, we have found that the LF of the upper RGB agrees quite well with theoretical models, and by itself rules out distances as short as $(m - M)_{0,\rm TRGB}^{\rm LMC} = 18.10$ mag.

The distance modulus we get from the RC method is about 0.5 mag higher than the value determined by Stanek et al. (1998). About half of this discrepancy is due to the correction ΔM_I for population effects we have applied, while the other half is due to an intrinsic difference in the observed $I_{0,m}$ values. The RC position in our CMD differs substantially from the results of Stanek et al. (1998); specifically, we derive a value for $I_{0,m}$ dimmer by ≈ 0.3 mag and a $(V-I)_0$ color redder by $\simeq 0.15$ mag.

An obvious possibility for explaining the apparent discrepancy in both magnitude and color is an improper reddening correction. We are confident about our treatment of the extinction because it is based on individual determinations for a large number of stars in the sample, mostly belonging to the old population (one every 13 arcsec^2; e.g., Romaniello 1998). As we pointed out in § 2, the reddening corrections we have applied are appropriate for the old population to which the red giant stars belong. Moreover, in our field the mean reddening is in good agreement with the independent determination of the reddening toward SN 1987A as discussed in Scuderi et al. (1996), which is based on a detailed study of the *HST* FOS UV and optical spectrum of "star 2," one of the two companion stars near SN 1987A. In order to eliminate the discrepancy in the observed $I_{0,m}$ values, one should therefore invoke a $\delta E(B-V) \simeq 0.15$ systematic overestimate of the reddening by Stanek et al. (1998). This seems to be indeed the case, according to the recent analysis by Zaritsky (1999). He finds population-dependent extinction properties in the LMC, and concludes that the extinction map derived by Harris, Zaritsky, & Thompson (1997) and used by Stanek et al. (1998) is not an accurate representation of the reddening to RC stars. Moreover, the real extinction for the RC population in the regions selected by Stanek et al. (1998) turns out to be $A_I \simeq 0.06$, which increases the observed $I_{0,m}$ by $\simeq 0.25$ mag. With this correction, the level of the RC (as well as its color) in the fields considered by Stanek et al. (1998) turns out to be in excellent agreement with our value.

In order to verify our results from the RC method, we have searched for a third, independent estimate of the absolute $I_{0,m}$ of the RC in LMC field populations. To this end, we have considered the data of Brocato et al. (1996) for an LMC region around the old cluster NGC 1786. The cluster reddening, as estimated by Brocato et al. (1996) using the technique of Sarajedini (1994), turns out to be $E(B-V) = 0.09 \pm 0.05$, in agreement with the value derived by Walker & Mack (1988) for the field around the cluster. We have then corrected the data for extinction by adopting the reddening law of Cardelli, Clayton, & Mathis (1989). The resulting $(V-I)_0$ color range spanned by the RC is very much the same as in our data. We have then applied the procedure described in § 2, obtaining $I_{0,m} = 18.05 \pm 0.09$ mag (the contribution due to the reddening uncertainty is included in the error) and $\sigma_{RC} = 0.17$ mag. The results for both $I_{0,m}$ and σ_{RC} are in good agreement with the corresponding quantities we derived from our data.

A remaining matter of concern appears to be the result by Udalski (1998) regarding the RC level in six clusters of the LMC: SL 388, SL 663, SL 862, NGC 2121, NGC 2155, and ESO 121-SC03). These objects span an age range between 2 and 9 Gyr (suitable for comparisons with the field RC populations), and display an almost constant value of $I_{0,m} \simeq 17.9$ mag. The extinctions are generally small, so that even an overestimate of the reddening cannot explain (at least not completely) the discrepancy. However, a deeper analysis of these clusters reveals that their brighter RC levels are in agreement with predictions from stellar evolutionary models and the "long" distance to the LMC. We have considered five of the mentioned clusters in more detail; for these, the RC level is determined with a reasonably large number of stars. We have excluded SL 388, since the peak of its observed RC luminosity function is poorly populated and not sharply defined, but distributed over approximately 0.2 mag (only six stars in the most populated bin 0.07 mag wide, five in the adjacent less luminous one, and five again in the bin 0.14 mag brighter), thus making a statistical determination of $I_{0,m}$ not very reliable. According to Sarajedini (1998), SL 663, NGC 2121, and NGC 2155 share the same metallicity (derived from the slope of the RGB, independently of the assumed reddening), i.e., $[Fe/H] \simeq -1.0$. Bica et al. (1998) derived from Washington photometry of the RGB of SL 862 a metallicity of $[Fe/H] = -0.9$, adopting a reddening of $E(B-V) = 0.09$ for this cluster. By considering $E(B-V) = 0.12$, as used by Udalski (1998), the derived metallicity lowers to $[Fe/H] = -1.0$ (Bica et al. 1998). Finally, in the case of ESO 121-SC03, Bica et al. (1998) find $[Fe/H] = -1.05$, adopting $E(B-V) = 0.03$, which becomes $[Fe/H] = -1.1$ if one adopts the reddening used by Udalsky (1998), i.e., $E(B-V) = 0.044$.

In conclusion, all of the five clusters have approximately the same metallicity, $[Fe/H] \simeq -1.0$, which is at least a factor of 2 less than the average metallicity of the field RC stars in our sample. This fact helps in explaining the brighter RC levels found in the clusters. According to the models presented by Cole (1998) and Girardi (1999), a metallicity difference of $\Delta[Fe/H] \simeq 0.3$ causes a difference of roughly 0.1 mag in the RC level, the more metal poor one being brighter. Taking into account this correction, possible small depth effects (these clusters are mainly located in the halo of the galaxy), and the error budget, i.e., the error associated with $I_{0,m}$ (typically a contribution of 0.02 mag due to the statistical error and 0.03 mag systematic error due to reddening uncertainties as estimated by Udalski 1998), there is no serious contradiction between the LMC distances derived from field stars or intermediate-age clusters by means of the RC method.

In conclusion, we emphasize that our results based on different and independent distance indicators seem to rule out the LMC distance evaluation recently provided by Stanek et al. (1998). The recent revision by Zaritsky (1999) of the reddening for the fields analyzed by Stanek et al. (1998) further corroborates our result. The present investigation represents important evidence for the paramount importance of carefully determining the reddening (and extinction) distribution for the stellar population one is planning to study. We believe that additional work is needed in order to collect more reliable estimations of both the mean value and the fluctuations of the interstellar extinction for the various stellar populations along the different lines of sight in the direction of the LMC.

We wish to warmly thank M. Lombardi for many precious suggestions, A. Piersimoni for providing us with the data of the field around NGC 1786, M. Groenewegen for many stimulating discussions about the LMC distance, and Leo Girardi for fruitful discussions about the red clump method. We wish to thank the anonymous referee for valuable comments that helped to improve the presentation of the paper. One of us (M. S.) would like to dedicate this paper to the memory of the late Stanley Kubrick.

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