A Review of the Distance and Structure of the Large Magellanic Cloud

David R. Alves

Columbia Astrophysics Laboratory, 550 W. 120th St., New York, NY, USA;
Email: alves@astro.columbia.edu

Abstract

The average of 14 recent measurements of the distance to the Large Magellanic Cloud (LMC) implies a true modulus of 18.50 ± 0.02 mag, and demonstrates a trend in the past 2 years of convergence toward a standard value. The distance indicators reviewed are the red clump, the tip of the red giant branch, Cepheid, RR Lyrae, and Mira variable stars, cluster main-sequence fitting, supernova 1987A, and eclipsing binaries. The eclipsing binaries yield a consistent distance on average; however, the internal scatter is twice as large as the average measurement error. I discuss parameters of LMC structure that pertain to distance indicators, and speculate that warps discovered using the color of the clump are not really warps.

Key words: galaxies: Magellanic Clouds, cosmology: distance scale

1 Introduction

The debate about the distance to the LMC has an epic history full of controversial and dramatic claims (Walker 2003), and yet in recent years a standard distance modulus has emerged due primarily to the completion of the *Hubble Space Telescope* (*HST*) key project to measure the Hubble constant (Freedman et al. 2001). The standard modulus, $\mu_0 = 18.5 \pm 0.1$ mag, yields $H_0 = 71 \pm 10$ km s^{-1} Mpc^{-1} (total error) in excellent agreement with that derived from the *Wilkinson Microwave Anisotropy Probe*: $H_0 = 72 \pm 5$ (Spergel et al. 2003), which lends considerable support to its accuracy. Moreover, it is a recent trend in the literature that most new LMC distance measurements indicate $\mu_0 = 18.5$ mag, and that many systematic errors in prior studies are being found and corrected. In order to illustrate the trend, this review is restricted to mostly refereed journal papers published since January, 2002.

2 Red Clump

Alves et al. (2002) presented and analyzed the first near-infrared data for LMC red clump giants. The K-band data were obtained with the SOFI infrared imager at the New Technology Telescope. Additional V and I data were obtained with WFPC2 onboard the *HST*. A comparison of multiwavelength luminosity functions of the LMC red clump with those of the *Hipparcos* red clump yielded simultaneously the mean interstellar reddening correction and true LMC distance modulus: $\mu_0 = 18.493 \pm 0.033_r \pm 0.03_s$ (random and systematic error, respectively). Pietrzyński & Gieren (2002) also used K-band red clump data to derive $\mu_0 = 18.471 \pm 0.008_r \pm 0.045_s$, as did Sarajedini et al. (2002) who obtained $\mu_0 = 18.54 \pm 0.10$. The reddening correction accounts for the 0.02 mag discrepancy between the results of Alves et al. (2002) and Pietrzyński & Gieren (2002). Sarajedini et al. (2002) include the systematic errors associated with the red clump population correction and the geometric tilt of the LMC in their reported error bar. Despite these minor differences, the *Hipparcos*-calibrated red clump distance to the LMC has probably converged. It is encouraging that 3 independent estimates of the apparent K magnitude of the LMC red clump all agree to within an accuracy of 1–2%.

2.1 Tip of Red Giant Branch

Figure 1 shows the tip of the red giant branch (TRGB) in the LMC. These are unpublished *HST*/WFPC2 color-magnitude data for 17 different fields on lines-of-sight to LMC microlensing events. I have applied the average reddening correction derived from multiband red clump data for 6 of the fields (Alves et al. 2002). The TRGB calibration from Bellazini et al. (2001) is shown assuming $\mu_0 = 18.5$ mag. The weak metallicity dependence of the calibration is expressed in terms of color. Note that the colors of the LMC TRGB stars suggest a range of metallicities from [Fe/H] $= -2$ to -1 dex with a mode of about -1.4 dex. This comparison shows that the TRGB and red clump methods yield superb agreement with the standard LMC distance modulus.

3 Cepheid Variable Stars

Recent distance estimates based on Cepheid variable stars in the LMC have made use of the densely sampled light curves available from microlensing surveys like MACHO and OGLE. Theoretical pulsation models reproduce the detailed shapes of period-folded light curves, and best-fit models yield the fundamental parameters of each Cepheid, like luminosity and effective tem-
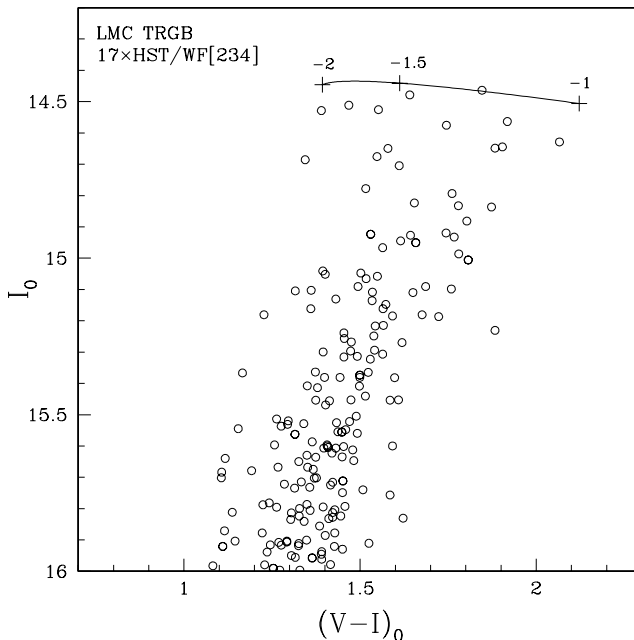
Fig. 1. Color-magnitude array of *HST*/WFPC2 data where LMC TRGB stars (circles) are compared with the Galactic TRGB calibration (line) assuming $\mu_0 = 18.5$ mag. The tick marks along the TRGB calibration label [Fe/H].

perature, and hence the distance. The Cepheids used for this analysis are those which display a secondary luminosity maximum each pulsation cycle. These so-called "bump" Cepheids collectively represent the Hertzsprung Progression because the bumps occur at earlier phases in the pulsation cycle as period increases. Bono et al. (2002) modeled the OGLE *I*-band light curves for 2 bump Cepheids and found $\mu_0 = 18.48$ mag. Keller & Wood (2002) modeled the MACHO *V* and *R* light curves for 20 bump Cepheids to derive $\mu_0 = 18.55 \pm 0.02_r$. Both studies also found a level of core overshoot in good agreement with the calibration from eclipsing binaries (Ribas et al., these proceedings).

The use of pulsational models of bump Cepheids to derive the LMC distance is a promising method. However, only a small fraction of the available data have been used so far. I have identified 183 bump Cepheids with periods of 5 to 25 days in the MACHO database[1], and out of these 117 are also found in the OGLE database[2], and 89 in the catalog of four-color light curves published by Sebo et al. (2002). Furthermore, 153 of these bump Cepheids are found in the 2MASS database[3], which provides partial light curve coverage in the near-infrared. Models will eventually be constructed for all of the LMC bump Cepheids, and parameter estimation will employ more multiwavelength data.

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[1] http://wwwmacho.mcmaster.ca/Data/MachoData.html
[2] http://bulge.princeton.edu/~ogle
[3] http://www.ipac.caltech.edu/2mass/

Table 1
Comparison of Standardized Photometry for LMC Bump Cepheids

MACHO – Other	Ave. Difference (mag)	No. Stars
$V - V_{\mathrm{OGLE}}$	-0.060	117
$V - V_{\mathrm{Sebo}}$	-0.028	89
$(V - R) - (V - R)_{\mathrm{Sebo}}$	$+0.007$	89

Table 1 lists the average differences between the (intensity-weighted) mean magnitudes published by OGLE (Udalski et al. 1999) and Sebo et al. (2002) relative to the MACHO data for bump Cepheids. The implication is a V-band offset of -0.032 mag between Sebo et al. (2002) and OGLE; however, Sebo et al. (2002) report a $+0.04$ mag offset. Hence the different comparisons of the same two datasets yield different results. I note that their average is weighted differently and their comparison is only for Cepheids with periods greater than 10 days. See Bono et al. (2002b) for analysis of LMC and theoretical period-luminosity (PL) calibrations and their metallicity dependence.

The *HST* key project calculates true distance modulus using $\mu_0 = 2.48\mu_I - 1.48\mu_V - 0.2\Delta[\mathrm{Fe/H}]$, where μ_I and μ_V are apparent moduli relative to LMC PL calibrations (Freedman et al. 2001). As a check, consider the following application of this method to the Cepheids in the Galaxy. In this case, however, the Galactic Cepheids are represented by only one star, δ Cephei. Benedict et al. (2002) recalibrated the *Hipparcos* parallax of δ Cephei using *HST*/FGS3 and found $M_V = -3.47 \pm 0.10$ and $M_I = -4.14 \pm 0.10$ mag. Adopting the Sebo et al. (2002) PL calibrations and $\Delta[\mathrm{Fe/H}] = 0.4$ dex yields $\mu_0 = 18.54 \pm 0.29$ mag. See Alves (2003) for a review of the metallicity slope.

4 RR Lyrae Variable Stars

Clementini et al. (2003; C03) presented new B and V photometry and spectroscopy of RR Lyrae variable stars in two LMC fields. They derived an average metallicity of $[\mathrm{Fe/H}] = -1.48 \pm 0.03$ dex in good agreement with other estimates, and a luminosity–metallicity slope of 0.21 ± 0.05 mag/dex (in the sense that the most metal-poor RR Lyrae stars are brightest). C03 obtained a reddening-corrected magnitude of $V_0 = 19.06 \pm 0.06$ mag. Benedict et al. (2002b) used *HST*/FGS3 to measure the parallax of RR Lyrae itself ($[\mathrm{Fe/H}]=-1.39$ dex) and derived $M_V = 0.61 \pm 0.11$ mag. Di Fabrizio et al. (2003) made a Baade-Wesselink analysis of CM Leonis ($[\mathrm{Fe/H}]=-1.91$ dex) and obtained $M_V = 0.47 \pm 0.04$ mag. Adopting C03's estimate of the metallicity slope, the weighted average calibration is $M_V = 0.56 \pm 0.04$ mag at $[\mathrm{Fe/H}] = -1.48$ dex. The C03 value for V_0 thus implies $\mu_0 = 18.50 \pm 0.07$ mag.

The most recent use of MACHO data to derive the LMC distance is based on first-overtone RR Lyrae stars (Alcock et al. 2004). Including corrections for blending and crowding bias based on artificial star tests, the MACHO data yield $\mu_0 = 18.43 \pm 0.06_r \pm 0.16_s$ mag (C. Clement & A. Muzzin, *priv. comm.*). C03 compared their RR Lyrae V data with MACHO data and found an average of difference of -0.17 and -0.01 mag in their fields A and B, respectively (their magnitudes minus MACHO). However, Alcock et al. (2004) found only 7 RR Lyrae stars in common with C03 and these stars yielded an offset of $+0.07$ mag (C03 being fainter). Applying the crowding/blending correction yields an offset of -0.03 mag, which is consistent within calibration uncertainties.

Dall'Ora et al. (2003) recently obtained the first K-band data for LMC RR Lyrae stars in the Reticulum cluster and derived $\mu_0 = 18.55 \pm 0.07$ mag. A subsequent analysis of these data yields a consistent but slightly lower distance modulus (G. Bono, *priv. comm.*). Finally, additional K-band data for field RR Lyrae stars near the LMC center yields $\mu_0 = 18.48 \pm 0.08$ mag (Borrisova et al. 2004; J. Borissova, *priv. comm.*).

5   Other Distance Indicators

5.1   Mira Variables

Recent work on Mira variables includes a revised zero-point for the PL calibration based on Galactic globular clusters (Feast et al. 2002), and a new *Hipparcos* zero-point for thin disk Miras (Knapp et al. 2003). Feast (2003) suggests a best-average PL calibration that leads to $\mu_0 = 18.48 \pm 0.10$ mag.

5.2   Cluster Main-Sequence Fitting

Kerber et al. (2002) used *HST*/WFPC2 data for the LMC cluster NGC 1831 and main-sequence models to derive $\mu_0 = 18.5$ to 18.7 mag. Salaris et al. (2003) used *HST*/WFPC2 data for the LMC cluster NGC 1866 and a *Hipparcos* subdwarf calibration to derive $\mu_0 = 18.33 \pm 0.08$ mag. However, Groenewegen & Salaris (2003) subsequently revised the main-sequence-fitted modulus of NGC 1866 to $\mu_0 = 18.58 \pm 0.08$ mag. In this revision, the reddening correction was derived from the colors of the cluster's Cepheids. The field red clump stars around NGC 1866 are apparently in front of the cluster.

5.3 Supernova 1987A

Mitchell et al. (2002) use the "Spectral-fitting Expanding Photosphere Method" to derive $\mu_0 = 18.46 \pm 0.12$ mag from observations of Supernova 1987A. They also review previous distance measurements based on this object.

5.4 Eclipsing Binaries

I refer the reader to other papers presented at this meeting for details about measuring distances with eclipsing binaries. In the past 2 years, Fitzpatrick et al. (2002) reported a modulus of $\mu_0 = 18.51 \pm 0.05$ mag for HV 982, Ribas et al. (2002) found $\mu_0 = 18.38 \pm 0.08$ mag for EROS 1044, Fitzpatrick et al. (2003) found $\mu_0 = 18.18 \pm 0.09$ mag for HV 5936, and Clausen et al. (2003) found $\mu_0 = 18.63 \pm 0.08$ mag for HV 982. The weighted average is $\mu_0 = 18.46 \pm 0.08$ mag in good agreement with the standard modulus. However, the standard deviation is about twice as large as the average reported error bar. Possibly the error bars are too optimistic. I speculate that an unknown systematic error may affect the eclipsing binary distance results.

6 Summary of LMC Distance

Table 2 summarizes the different measurements of the LMC distance published since January of 2002. It is customary to calculate an average final result in a review like this one, and in order to do this I have to make some assumptions about the error bars. Where both random and systematic errors are given, I adopt their (arithmetic) sum as the total error, and I use this to weight the average. Two of the Cepheid-based distance results have incomplete error estimates, and for these I adopt ± 0.1 mag (see notes in 3rd column). The result from Kerber et al. (2002) is excluded. The weighted average of 14 measurements is $\mu_0 = 18.50 \pm 0.02$ mag (standard deviation $= 0.04$ mag). The reduced chi-squared is less than one, which suggests that the adopted error bars may be too conservative.

A great American sports journalist once said famously, "The opera ain't over till the fat lady sings," to make a point that the outcome of a series of games was not yet determined. Regarding the convergence of published LMC distance results, I suggest to you that the fat lady has begun to sing.

Table 2 demonstrates a remarkably high level of consistency. The possibility that a consensus on the LMC distance has been reached seems much more

Table 2
LMC Distance Moduli from 2002 – Present

Method	μ_0	Reference
Red Clump	$18.493 \pm 0.033_r \pm 0.03_s$	Alves et al. (2002)
Red Clump	$18.471 \pm 0.008_r \pm 0.045_s$	Pietrzyński & Gieren (2002)
Red Clump	18.54 ± 0.10	Sarajedini et al. (2002)
Cepheid	18.48	Bono et al. (2002); ± 0.1
Cepheid	$18.55 \pm 0.02_r$	Keller & Wood (2002); ± 0.1
Cepheid	18.54 ± 0.29	Benedict et al. (2002)
RR Lyrae	18.50 ± 0.07	Clementini et al. (2003)
RR Lyrae	$18.43 \pm 0.06_r \pm 0.16_s$	Alcock et al., *preprint*
RR Lyrae	18.55 ± 0.07	Dall'Ora et al. (2003)
RR Lyrae	18.48 ± 0.08	Borissova et al., *preprint*
Mira	18.48 ± 0.08	Feast (2003)
Main Sequence	18.5 — 18.7	Kerber et al. (2002); exclude
Main Sequence	18.58 ± 0.08	Groenewegen & Salaris (2003)
SN 1987A	18.46 ± 0.12	Mitchell et al. (2002)
Eclipsing Binaries	18.46 ± 0.08	see §5.4
Weighted Ave.	$\mathbf{18.50 \pm 0.02}$	**(s.d.= 0.04)**

plausible now than it did when Freedman et al. (2001) reviewed the literature at the conclusion of the *HST* key project only two years ago. See also Walker (2003) for a recent review of distances to Local Group galaxies.

7   Structure of the LMC

In the review just presented, the corrections employed by different authors to account for the inclination of the LMC in the plane of the sky were not always self-consistent. There is no standard model for LMC structure, at least not yet. Moreover, it is not known that the Population II distance indicators like RR Lyrae variables are distributed in the same way as the young and intermediate-age stellar populations which represent the bulk of the LMC disk, and hence whether or not a correction appropriate for the disk should apply. The eclipsing binaries studied in the LMC so far have been mostly Population I stars.

In a series of recent papers (e.g., van der Marel & Cioni 2001, van der Marel et al. 2002), a new understanding of the structure of the LMC has emerged. It is now known that the photometric major axis is not the same as the line-of-nodes. The LMC is intrinsically elongated. The line-of-nodes derived from a variety of different distance indicators that uniformly cover the entire face of the LMC is $\Theta = 122.°5 \pm 8.°3$ measured East of North (van der Marel & Cioni 2001), while the radial velocity field of carbon stars implies $\Theta = 129.°6 \pm 6.°0$ in good agreement (van der Marel et al. 2002). The photometric major axis is about 50° away. The inclination is $34.°7 \pm 6.°2$. Several independent estimates for the center of the LMC are consistent with the optical center. The notable exception is the center derived from the velocity field of the HI gas, which is disturbed and probably not useful for making inferences about the LMC's structure (van der Marel et al. 2002).

The LMC disk is thick (van der Marel et al. 2002). The ratio of rotational to pressure support is $V/\sigma \sim 2.9 \pm 0.9$, where for comparison the Galactic thin and thick disks have ratios of 9.8 and 3.9, respectively. The ratio of vertical to radial disk scale heights is about 1/3 for both the LMC disk and the Galactic thick disk. The LMC disk is also flared (Alves & Nelson 2000). The vertical exponential scale height of carbon stars attains a value of about 1 kpc at locations 5-6 degrees from center, and is about 100 pc near the center (van der Marel et al. 2002). These inferences about the LMC disk are based on stellar kinematics and simple equilibrium models. High precision distance indicators like Cepheids have not yet resolved the thickness of the LMC disk. However, observations of the light echoes from Supernova 1987A are consistent with a thickness of about 1 kpc (A. Crotts, *priv. comm.*).

Minniti et al. (2003) recently obtained kinematic data for the metal-poor stellar population in the LMC using the European Southern Obervatory's *Very Large Telescope*. The radial velocities derived from the spectra of 43 RR Lyrae stars imply a line-of-sight $\sigma = 53 \pm 10$ km s^{-1}, which is larger than that of any other population in the LMC. For comparison, the carbon stars analyzed by van der Marel et al. (2002) have $\sigma = 20.2 \pm 0.5$ km s^{-1}. Minniti et al. (2003) interpret the RR Lyrae velocity data as evidence for a stellar halo. Therefore, the LMC is the nearest example of a disk galaxy that has a halo, but not a bulge, and in this way it is similar to M33 (Gebhardt et al. 2001).

Finally, 3 warps in the LMC disk have recently been detected using a reddening-free color-magnitude index $I_0 = I - 1.4 \cdot (V - I) + 1.29$ in conjunction with V & I data for the red clump (Olsen & Salyk 2002; Subramaniam 2003). The Olsen & Salyk (2002) warp in the South-West quadrant of the disk, and the more significant of the two warps found by Subramaniam (2003), specifically the warp at the East end of the bar, are both coincident with regions of higher reddening. Olsen & Salyk (2002) suggested that a foreground dust cloud was responsible in the South-West, but this does not explain a second coinciden-
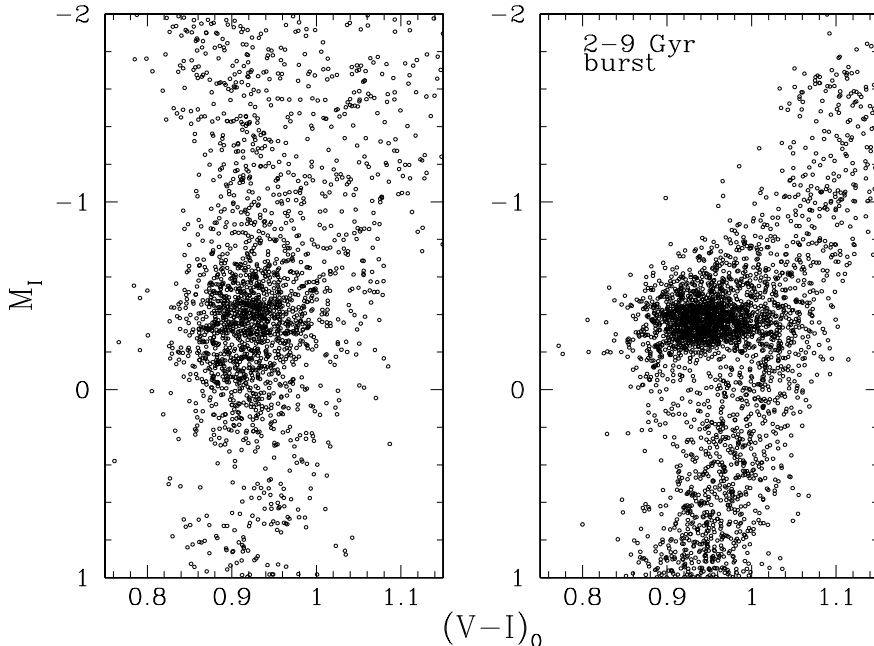
Fig. 2. *(Left)* Simulated color-magnitude diagram for the LMC red clump based on fiducial star formation history adopted by Salaris et al. (2003b). *(Right)* Another simulated color-magnitude diagram, but for a fictitious burst of field star formation between 2 and 9 Gyrs ago that produces a redder red clump.

tally reddened warp at the East end of the bar. No other distance indicator has yet confirmed the existence of these warps.

The star formation histories (SFHs) of the LMC fields with warps have not yet been derived. Therefore, it is possible that the warps are caused by a change in the mix of young and old red clump stars. Compare the two simulated color-magnitude diagrams of the LMC red clump shown in Figure 2 (M. Salaris, *priv. comm.*). The left panel corresponds to the fiducial SFH adopted by Salaris et al. (2003b), which is constrained by observations of mostly main sequence stars. The right panel shows an illustrative example of a redder red clump associated with a fictitious SFH that would be difficult to detect except for the color of its clump. A higher fraction of the stars on the right mixed in with the stars on the left in certain regions of the LMC could be misinterpreted as physical warps that are coincidentally also in regions of high reddening.

The LMC has both young and old populations with distinct properties, although the detailed nature of the latter is not yet well known. Therefore, it is possible that old clump stars could be mixed with young clump stars in unexpected ways to create complex color-magnitude variations across the LMC. New K-band data would help to test this hypothesis (Alves et al. 2002).

References

Alcock, C. et al. 2004, *preprint*

Alves, D. R. & Nelson, C. A. 2000, ApJ, 542, 789

Alves, D. R. et al. 2002, ApJ, 573, L51

Alves, D. R. 2003 in "Stellar Candles for the Extragalctic Distance Scale," astro-ph/0303035

Bellazzini, M., Ferraro, F.R. & Pancino, E. 2001, ApJ, 556, 635

Benedict, G. F. et al. 2002, AJ, 124, 1695

Benedict, G.F. et al. 2002b, AJ, 123, 473

Bono, G., Castellani, V., & Marconi, M. 2002, ApJ, 565, L83

Bono, G., et al. 2002b, ApJ, 574, L33

Borrisova, J. et al. 2004, *preprint* (A&A)

Clausen, J. V. et al. 2003, A&A, 402, 509

Clementini, G. et al. 2003, AJ, 125, 1309

Dall'Ora, M. et al. 2003, *preprint* (MmSai), astro-ph/0305276

di Fabrizio, L. et al. 2002, MNRAS, 336, 841

Feast, M., Whitelock, P., & Menzies, J. 2002, MNRAS, 329, L7

Feast, M. in "Variable Stars in the Local Group," astroph/0309369

Fitzpatick, E. L. et al. 2002, ApJ, 564, 260

Fitzpatick, E. L. et al. 2003, ApJ, 587, 685

Freedman, W. et al. 2001, ApJ, 553, 47

Gebhardt, K. et al. 2001, AJ, 122, 2469

Groenewegen, M. A. T. & Salaris, M. 2003, *preprint* astro-ph/0308529

Keller, S. C. & Wood, P.R. 2002, ApJ, 578, 144

Kerber, L. O. et al. 2002, A&A, 390, 121

Knapp, G. R. et al. 2003, A&A, 403, 993

Minniti, D. et al. 2003, Science, 301, 1508

Mitchell, R. C. et al. 2002, ApJ, 574, 293

Olsen, K. A. G. & Salyk, C. 2002, AJ, 124, 2045

Pietrzyński, G. & Gieren, W. 2002, AJ, 124, 2633

Ribas, I. et al. 2002, ApJ, 574, 771

Salaris, M. et al. 2003, ApJ, 588, 801

Salaris, M., Percival, S. & Girardi, L. 2003, *preprint* astro-ph/0307329

Sarajedini, A. et al. 2002, AJ, 124, 2625

Sebo, K. M. et al. 2002, ApJS, 142, 71

Spergel, D. N. et al. 2003, ApJS, 148, 175

Subramaniam, A. 2003, *preprint* astro-ph/0310349

Udalski, A. et al. 1999, Acta Astron. 1999, 49, 223

van der Marel, R. P. et al. 2002, ApJ, 124, 2639

van der Marel, R. P. & Cioni M.-R. L. 2001, AJ, 122, 1807

Walker, A. R. in "Stellar Candles for the Extragalctic Distance Scale," astro-ph/0303011

APPENDIX A

Long-form Abstract for "Highlights of Astronomy, Vol. 13," O. Engvold, ed.

A Review of the Distance and Structure of the Large Magellanic Cloud

The debate about the distance to the Large Magellanic Cloud (LMC) has an epic history full of controversial and dramatic claims (i.e., see review by A. Walker in "Stellar Candles for the Extragalactic Distance Scale," astro-ph/0303035), and yet in recent years a standard distance modulus has emerged due primarily to the completion of the *Hubble Space Telescope* (*HST*) key project to measure the Hubble constant (W. Freedman et al. 2001, ApJ, 553, 47). The adopted standard distance modulus, $\mu_0 = 18.5 \pm 0.1$ mag, yields $H_0 = 71 \pm 10$ km s^{-1} Mpc^{-1} (total error) in excellent agreement with that derived from the *Wilkinson Microwave Anisotropy Probe*: $H_0 = 72 \pm 5$ (D. Spergel et al. 2003, ApJS, 148, 175), which lends considerable support to its accuracy.

The average of 14 recent measurements of the distance to the LMC implies a true modulus of 18.50 ± 0.02 mag, and demonstrates a trend in the past 2 years of convergence toward a standard value. Table 1 is a summary of the distance results by method. Where both random (r) and systematic (s) errors are given, I adopt their arithmetic sum as the total error, and I use this to weight the average. I exclude one result, and two are assigned new error bars as noted. Last, I adopt the average distance modulus for the 4 eclipsing-binary estimates as one result. Note that the eclipsing binaries yield a consistent mean distance, but their scatter is twice as large as their average measurement error. The reduced chi-squared is about 0.3 for the final average, and thus the adopted error bars are probably too conservative (the average uncertainty is ± 0.08 mag).

The recent results for the LMC distance demonstrate a remarkably high level of consistency. The possibility that a consensus on the LMC distance has been reached seems much more plausible now than it did at the conclusion of the *HST* key project only two years ago. A great American sports journalist once said famously, "The opera ain't over till the fat lady sings," to make a point that the outcome of a series of games was not yet determined. *Regarding the convergence of published LMC distance results, I suggest to you that the fat lady has begun to sing.*

There is no standard model for LMC structure, at least not yet, but in a series of recent papers a new understanding has emerged (R. van der Marel et al. 2002, ApJ, 124, 2639). It has been established that the photometric major axis of the LMC disk is about 50° away from the line-of-nodes (along which the disk is at a constant distance equal to the center-of-mass distance), and thus the LMC is intrinsically elongated. Several independent estimates for the center of the LMC are consistent with the optical center; the exception is the center derived from the velocity field of HI gas. The velocity field of carbon stars and simple equilibrium models indicate that the LMC disk is thick like the Galactic thick disk and flared. The vertical exponential scale height of carbon stars attains a value of about 1 kpc at locations 5-6 degrees from center, and is only about 100 pc in the central bar region.

The LMC is the nearest example besides the Milky Way of a disk galaxy that has a stellar halo (D. Minniti et al. 2003, Science, 301, 1508). Although the LMC has a halo, it does not have a bulge, and in this way it is similar to M33. It not known whether or not the Population II distance indicators like RR Lyrae variables are distributed in the same way as the young and intermediate-age stellar populations which represent the bulk of the LMC disk, and hence whether or not geometric inclination-corrections appropriate for the disk should apply. However, the kinematics of the halo and disk stars in the LMC are distinct.

Finally, I note that the warps in the LMC disk recently discovered using the color and magnitude of the red clump (K. Olsen & C. Salyk, 2002, AJ, 124, 2045) are suspiciously found in regions of high reddening, and could be caused by a change in the mix of young and old red clump stars which would bias the reddening correction. Old and intrinsically redder red clump stars, if they exist, could be distributed in a different manner than the young (disk) clump stars, and thus it is possible for the population mix of the clump to vary in unexpected ways across the LMC.

Table 1. LMC Distance Moduli in Past 2 Years

Method	μ_0	
Red Clump	$18.493 \pm 0.033_r \pm 0.03_s$	
Red Clump	$18.471 \pm 0.008_r \pm 0.045_s$	
Red Clump	18.54 ± 0.10	
Cepheid	18.48	± 0.1
Cepheid	$18.55 \pm 0.02_r$	± 0.1
Cepheid	18.54 ± 0.29	
RR Lyrae	18.50 ± 0.07	
RR Lyrae	$18.43 \pm 0.06_r \pm 0.16_s$	
RR Lyrae	18.55 ± 0.07	
RR Lyrae	18.48 ± 0.08	
Mira	18.48 ± 0.08	
Main Sequence	$18.5 - 18.7$	excl.
Main Sequence	18.58 ± 0.08	
SN 1987A	18.46 ± 0.12	
EB (HV 982)	18.51 ± 0.05	
EB (EROS 1044)	18.38 ± 0.08	
EB (HV 5936)	18.18 ± 0.09	
EB (HV 982)	18.63 ± 0.08	
Eclipsing Binaries	18.46 ± 0.08	ave. of 4
Wtd. Ave.	$\mathbf{18.50 \pm 0.02}$	**s.d.= 0.04**