1993ApJ...417..553L

THE ASTROPHYSICAL JOURNAL, 417:553–559, 1993 November 10

THE TIP OF THE RED GIANT BRANCH AS A DISTANCE INDICATOR FOR RESOLVED GALAXIES

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Received 1993 March 4; accepted 1993 May 18

ABSTRACT

We show that the *I* magnitude of the tip of the first-ascent red giant branch (TRGB) of low-mass stars is a distance indicator for resolved galaxies with metal-poor ([Fe/H] < -0.7 dex) old populations, having a precision comparable to primary distance indicators such as Cepheids and RR Lyraes. A comparison of the distances to resolved galaxies based on the TRGB with those derived from Cepheids and RR Lyraes shows that they agree within ± 0.1 mag. Advantages of the TRGB method are discussed.

Subject headings: Cepheids — galaxies: distances and redshifts — Hertzsprung-Russell (H-R) diagram — stars: distances — stars: evolution — stars: giants

1. INTRODUCTION

In 1944 Baade resolved the central region of the Andromeda nebula (M31) and its two companion elliptical galaxies, M32 and NGC 205, using red-sensitive photographic plates (Baade 1944). He found that the brightest red stars in all three systems have the same apparent brightness and color, which he expected because the three galaxies form a triple system on the sky (suggesting that all three galaxies are at the same distance). A similarity in brightness and colors between these stars and the stars of the Galactic globular clusters led him to conclude that the stellar populations of the galaxies are divided into two distinct groups: now known as Population I (represented by the stars in our solar neighborhood) and Population II (characterized by the stars in the globular clusters). Later Sandage (1971) claimed that direct photographs of all galaxies in the Local Group reveal the presence of a background sheet of red stars similar to the resolved red stars in the three galaxies studied by Baade, and pointed out that the brightest stars of this background sheet are also at the top of the giant branch of a globular-cluster–like population. He found that the brightest red stars in the underlying sheets of M33, M31, and IC 1613 have the same absolute magnitude, $M_V \approx -3.0 \pm 0.2$ mag. Modern studies suggest that these brightest red stars in the background sheet of resolved galaxies represent either the tip of the first-ascent red giant branch (RGB) of low-mass stars or a more luminous extended asymptotic giant branch (AGB) (e.g., Mould & Kristian 1986; Freedman 1988, 1989; Lee, Freedman, & Madore 1992, 1993a, b, c).

Since Sandage's study, the tip of the RGB (called TRGB) method has been used for estimating the distances to several nearby galaxies (e.g., Graham 1982 for NGC 55 and NGC 300; Hoessel & Mould 1982 for the Pegasus dwarf; Mould, Kristian, & Da Costa 1983 for NGC 147; Mould, Kristian, & Da Costa 1984 for NGC 205; Mould & Kristian 1986 for the M31 and M33 halos; Reid & Mould 1987 for the LMC; Freedman 1988 for IC 1613; Freedman 1989 for M32; Wilson, Freedman, & Madore 1990 for M33; Davidge & Pritchet 1990 for NGC 253; Mould & Kristian 1990 for And I; van de Rydt, Demers, & Kunkel 1991 for the Phoenix dwarf; Reid & Mould 1991 and Lee et al. 1993a, b for Leo I; Lee, Freedman, & Madore 1992, 1993c for NGC 185; Lee, Freedman, & Madore 1993a for WLM; Lee, Freedman, & Madore 1993b for NGC 6822; and most recently Lee 1993 for NGC 3109). For future applications, Mould (1988) has pointed out that the TRGB may be useful as a distance indicator perhaps out to 10 Mpc once the *Hubble Space Telescope* is refurbished.

However, the reliability of the TRGB method as a distance indicator is to date not well established. In this paper we examine the TRGB as a distance indicator, present a comparative study of three distance indicators (the TRGB, Cepheids, and RR Lyraes) for resolved galaxies, and show that the TRGB is indeed an excellent distance indicator for resolved galaxies.

2. A METHOD FOR DISTANCE DETERMINATION USING THE TIP OF THE RED GIANT BRANCH

2.1. *Background*

The tip of the first-ascent red giant branch stars seen in the color-magnitude diagram of faint red giants in resolved galaxies represents the core helium flash stage of low-mass stars with $M < M_{\rm crit}$. $M_{\rm crit}$ is a characteristic mass for the core helium flash with electron-degenerate cores, which varies as a function of metallicity, ranging from $\sim 1.6\ M_\odot$ for Population I stars to $\sim 1\ M_\odot$ for Population II stars (Bertelli et al. 1986). The bolometric luminosity at the core helium flash of low-mass stars *of the same metallicity* varies only by ~ 0.1 mag for ages of 2–15 Gyr (see Fig. 7 in Iben & Renzini 1983). It is therefore expected that low-mass stars will accumulate along the RGB up to the TRGB as they evolve (the most dominant population will probably be of very old age, but note that not all stars at the TRGB are necessarily pure Population II). As a result, the bolometric luminosity functions of these stars are thus expected to show a sudden discontinuity at the magnitude of the TRGB (see also Renzini 1992).

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However, it is not always easy to identify observationally the position of the TRGB in the luminosity function because the brightest red giant stars in galaxies in the H-R diagram represent a mixture of several populations including the TRGB (e.g., young-age RGB of massive stars, intermediate-age AGB, old-age AGB, old-age merged blue straggler progeny, etc.) (Renzini 1992).

One means of avoiding the above problem is to use both an $I-(V-I)$ [or $I-(R-I)$] diagram and the I luminosity function. Empirical loci of the RGB for four Galactic globular clusters in the $M_I-(V-I)_0$ diagram given by Da Costa & Armandroff (1990 hereafter DA90) are plotted in Figures 1*a* and 1*b* to show the dependence of the I and V luminosity of the TRGB on metallicity. The metallicities of the Galactic globular clusters (M15, M2, NGC 1851, and 47 Tuc) are [Fe/H] = −2.17, −1.58, −1.29, and −0.71 dex, respectively. For distance estimates to Galactic globular clusters, DA90 adopted a relation for the metallicity$-M_V$ magnitude for RR Lyraes: $M_V(\mathrm{RR}) = 0.17[\mathrm{Fe/H}] + 0.82$, based on the theoretical horizontal branch models for $Y_{\mathrm{MS}} = 0.23$ of Lee, Demarque, & Zinn (1990). Figures 1*a* and 1*b* illustrate that the I luminosity of the TRGB changes by less than 0.1 mag for a metallicity range of $-2.2 < [\mathrm{Fe/H}] < -0.7$ dex, while the V luminosity of the TRGB varies by 1.3 mag over the same range in metallicity. To test the variation of the I luminosity of the TRGB against age, we plotted a set of the Revised Yale theoretical isochrones for $Y = 0.23$, $[\mathrm{Fe/H}] = -1.3$ dex and ages of 7–17 Gyr (Green, Demarque, & King 1987) in the $M_I-(V-I)_0$ diagram in Figure 1*c*. We adjusted the zero point at I for the isochrones by −0.15 mag to match DA90's scale. Figure 1*c* shows that the I luminosity of the TRGB changes little for ages of 7–17 Gyr.

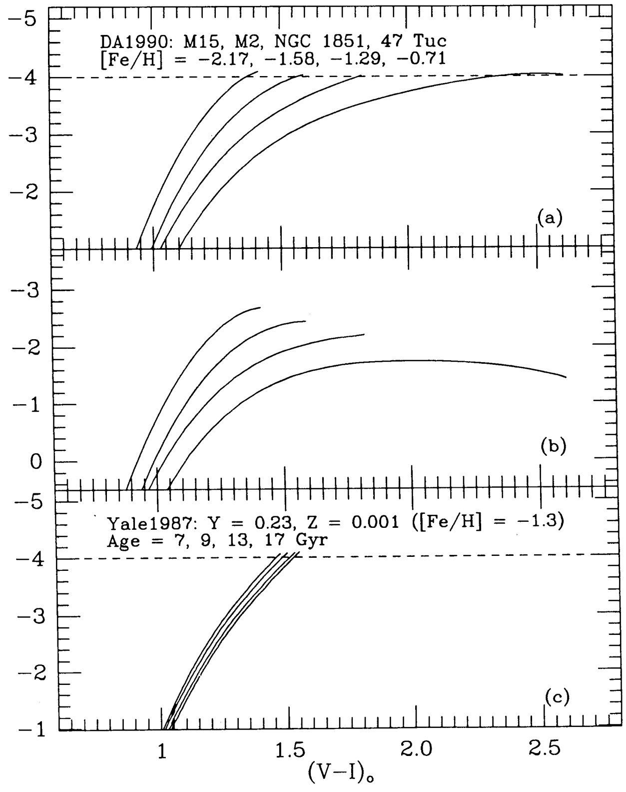

FIG. 1.—(*a*) Empirical loci in the $M_I-(V-I)_0$ diagram of the red giant branch for Galactic globular clusters: M15, M2, NGC 1851, and 47 Tuc, the metallicities of which are [Fe/H] = −2.17, −1.58, −1.29, −0.71 dex, respectively. Note that the I magnitude of the tip of the red giant branch changes little due to metallicity. (*b*) An $M_V-(V-I)_0$ diagram with the same sequence as in (*a*). Note that the V magnitude of the tip of the red giant branch changes by ~1.3 mag for the metallicity range of $-2.2 < [\mathrm{Fe/H}] < -0.7$ dex. (*c*) An $M_I-(V-I)_0$ diagram showing a set of Revised Yale theoretical isochrones for $[\mathrm{Fe/H}] = -1.3$ dex and ages of 7, 9, 13, and 17 Gyr. Note how insensitive the I magnitude of the tip of the red giant branch is to age.

In summary, the I luminosity of the TRGB appears to be a potentially good distance indicator for resolved stellar systems with wide range of metallicity, which have stellar populations older than few gigayears. We caution, however, that the calibration presented here applies to the metallicity range $-2.2 < [\mathrm{Fe/H}] < -0.7$ dex, and is unlikely to be applicable to very metal rich populations where line-blanketing effects may become significant, even at I band.

2.2. *A Method for Distance Determination Using VI Photometry*

We briefly summarize the method for determining distances using *VI* photometry of the RGB in the following (for more details see Mould, Kristian, & Da Costa 1983, 1984; Mould & Kristian 1986; DA90). The distance modulus is derived from the observed I magnitude of the TRGB, I_{TRGB}, using $(m-M)_I = I_{\mathrm{TRGB}} + BC_I - M_{\mathrm{bol,TRGB}}$, where BC_I is the bolometric correction to the I magnitude, and $M_{\mathrm{bol,TRGB}}$ is the bolometric magnitude of the TRGB.

The bolometric correction to the I magnitude is given by DA90 as a function of $(V-I)$ color of the TRGB: $BC_I = 0.881 - 0.243(V-I)_{\mathrm{TRGB}}$. DA90 also give the bolometric magnitude in terms of the metallicity: $M_{\mathrm{bol,TRGB}} = -0.19[\mathrm{Fe/H}] - 3.81$.

DA90 presented a relation for measuring the metallicity of red giant branch stars: $[\mathrm{Fe/H}] = -15.16 + 17.0(V-I)_{-3} - 4.9(V-I)^2_{-3}$ for $-2.2 < [\mathrm{Fe/H}] < -0.7$ dex, where $(V-I)_{-3}$ is the color at $M_I = -3.0$ mag. However, the photometric errors of giant stars in galaxies are considerably larger than those for Galactic globular clusters. For this reason, we derived a similar relation for half-magnitude brighter magnitude, $M_I = -3.5$ mag (which is 0.4–0.5 mag below the TRGB), using the same data for the globular clusters given in DA90: $[\mathrm{Fe/H}] - 12.64 + 12.6(V-I)_{3.5} - 3.3(V-I)^2_{-3.5}$. In principle, we have to iterate calculating the distance and the metallicity based on the $(V-I)_{-3.5}$ color of the RGB until they converge, because we need to know first the distance of the galaxies to estimate the metallicity using the $(V-I)_{-3.5}$ color. However, the $(V-I)$ color of the RGB measured at the I magnitude 0.4–0.5 mag below the TRGB in the $I-(V-I)$ diagram is close to the converged value of the $(V-I)_{-3.5}$ color for the following reasons: (*a*) $M_{I,\mathrm{TRGB}}$ changes little due to the variation of the metallicity with $M_{I,\mathrm{TRGB}} \approx -4.0 \pm 0.1$ mag for $[\mathrm{Fe/H}] < -0.7$ dex; and (*b*) the $(V-I)_{-3.5}$ color of the RGB changes little for the change of 0.1 magnitude at I in the $I-(V-I)$ diagram (see Fig. 1*a*). Note also that the resulting distance estimates are insensitive to the metallicity as shown in the previous subsection.

Estimates of the apparent magnitude of the tip of the red giant branch appearing previously in the literature have been based on eye estimates. However, it is possible to formally define the position of this feature in a reproducible and quantitative manner. We have chosen a standard image-processing edge-detection algorithm employing the zero-sum Sobel kernel [−2, 0, +2] which, when convolved with our luminosity functions, gives a maximum in its output at the luminosity where

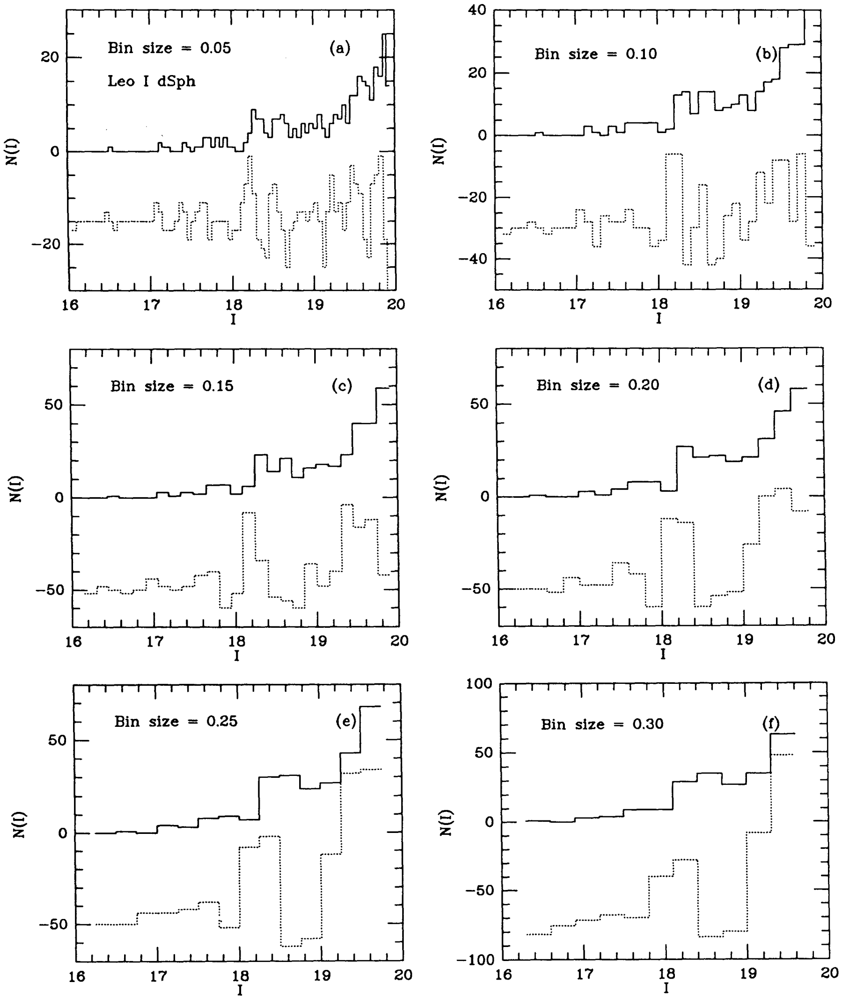

FIG. 2.—(*a*–*f*) Experiments with the edge-detector for the *I*-band luminosity function of the giant branch stars in the Leo I dwarf spherodial galaxy (Lee et al. 1993a, b). Solid lines present the luminosity functions and the dotted lines the convolution of the luminosity function and the edge-detector. Each panels are for the magnitude bin sizes used for deriving the luminosity functions of (*a*) 0.05, (*b*) 0.10, (*c*) 0.15, (*d*) 0.20, (*e*) 0.25, and (*f*) 0.30 mag. The TRGB is estimated to be at $I = 18.25 \pm 0.10$ mag.

the count discontinuity is the greatest. We used, as the value of the magnitude of the TRGB, the midpoint of the corresponding luminosity bin. Using data of high photometric precision for the TRGB in Leo I (Lee et al. 1993a, b) as a test case, we demonstrate in Figure 2 that this estimator of the discontinuity provides consistent results over a wide range of photometric precision (as reflected in the bin size chosen to represent the data, and typical of data so far acquired). The data in Figure 2 have been binned in intervals of 0.05, 0.10, 0.15, 0.20, 0.25, and 0.30 mag. The solid line represents the data and the dashed line below is the convolution. Figure 2 shows that the TRGB of Leo I is estimated to be at $I = 18.25 \pm 0.10$ mag. Figure 3 shows a montage of luminosity functions (solid lines) and their corresponding edge detection functions (dotted lines) for the galaxies with tabulated luminosity functions available to us. As can be seen the discontinuities are quite well defined by this procedure, and an error estimate is immediately available from the width of the spike centered on the apparent magnitude of the TRGB. The measuring errors for $I_{\rm TRGB}$ thus estimated are typically 0.1–0.2 mag for most of the nearby galaxies used in this study. The largest uncertainty is for NGC 185 where the half-width of the edge-detection function amounts to 0.3 mag. However, as seen below, the estimate of the distance obtained independently in this way agrees well with the RR Lyrae determination in the literature. The detection of the TRGB in this galaxy is complicated by the presence of a substantial AGB components as is the case for M32 (see Freedman 1989; Lee, Freedman, & Madore 1992, 1993c).

3. THE OBSERVATIONAL DATA FOR DISTANCES TO GALAXIES

The calibration of the absolute visual magnitudes of RR Lyrae stars remains uncertain (e.g., Sandage & Cacciari 1990; Renzini 1991; Carney, Storm, & Janes 1992). Disagreement over both the slope (*a*) and the zero point (*b*) remains in the relation $M_V = a[\mathrm{Fe/H}] + \mathrm{b}$, but for the range of observed metallicity, the uncertainty in the zero point remains the largest source of concern. For studies of extragalactic RR Lyrae stars, distances have been generally obtained adopting the conventional absolute magnitude $M_V(\mathrm{RR}) = 0.77$ mag. As discussed by Walker (1992), Saha et al. (1992), Freedman & Madore (1993), there is a discrepancy between the RR Lyrae

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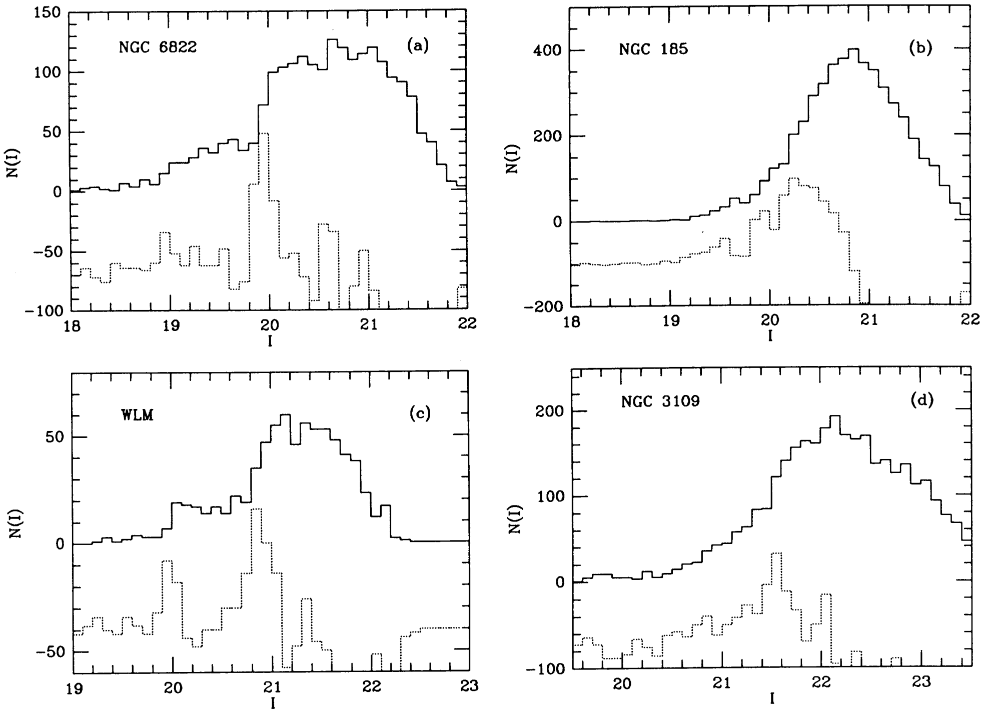

FIG. 3.—Examples of finding the TRGB with the edge-detector for four galaxies used in this study: (*a*) NGC 6822, (*b*) NGC 185, (*c*) WLM, and (*d*) NGC 3109. Solid lines represent the luminosity functions and dotted line the convolution of the luminosity function and the edge-detector.

and Cepheid distance scales at a level of ~0.2 mag [assuming M_V(RR) = 0.77 mag]. Resolution of this discrepancy is beyond the scope of this paper. Our interest is a relative comparison of the various distance scales. For the purposes of comparison in this paper, we have adopted the following distance scale calibrations: (1) the Cepheid distances given by Madore & Freedman (1991); Lee, Freedman, & Madore (1993a, b), and Capaccioli, Piotto, & Bresolin (1992); (2) the calibration of the TRGB based on the calibration of DA90 which assumes $M_V(\mathrm{RR}) = 0.17[\mathrm{Fe/H}] + 0.82$; (3) for consistency with the TRGB determinations we have used the same calibration for the RR Lyraes as above. We note that the value for the zero point, $b \approx 0.8$ mag agrees well with the zero point obtained using the same sample of Cepheid distances for three galaxies for which Cepheid and RR Lyrae distances are available (IC 1613, M31, and M33). If we use the Cepheid distances to these three galaxies to determine the zero point in the [Fe/H] − M_V relation, we obtain $M_V = 0.15[\mathrm{Fe/H}] + 0.80(\pm 0.07)$. Finally we note that the recent zero point obtained by Carney (1993) from Baade-Wesselink studies is $b \approx 0.9$.

We have collected the distance estimates for 10 resolved galaxies to which distances were measured using the TRGB, Cepheids, or RR Lyraes, as listed in Table 1. The columns of Table 1 give the following: (1) the names of galaxies; (2) their

TABLE 1

DISTANCE ESTIMATES FOR RESOLVED GALAXIES BASED ON PRIMARY DISTANCE INDICATORS

			$(m-M)_0$							
GALAXY (1)	TYPE[a] (2)	$E(B-V)$ (3)	Cepheid (4)	RR Lyrae (5)	I_{TRGB} (6)	I_{TRGB} (7)	REFERENCE[b] (8)	[Fe/H][c] (9)	M_B (10)	M_V (11)
LMC	SBmII	0.10	18.50	18.28	18.42	14.6	1, 2, 3	−1.2	−17.93	−18.36
NGC 6822	ImIV–V	0.28	23.62	...	23.46	20.05	4, 4	−1.8:	−15.13	−16.42
NGC 185	dE3pec	0.19	...	24.01	23.94	20.30	5, 6	−1.2	−14.63	−15.52
NGC 147	dE5	0.17	...	24.06	24.13	20.4	7, 8	−0.9	−14.39	−15.17
IC 1613	IMV	0.02	24.42	24.27	24.27	20.25	1, 9, 10	−1.3	−14.51	−15.16
M31	SbI–II	0.08	24.44	24.36	24.44	20.55	1, 11, 12	−0.8	−20.98	−21.74
M33	Sc(s)II–III	0.10	24.63	24.71	24.70	20.95	1, 13, 12	−2.0	−18.94	−19.40
WLM	ImIV–V	0.02	24.92	...	24.81	20.85	14, 14	−1.6:	−14.28	−14.62
NGC 205	S0/dE5pec	0.035	...	24.76	24.42	20.45	15, 16	−0.8	−15.80	−16.62
NGC 3109	SmIV	0.04	25.5	...	25.45	21.55	17, 18	−1.6	−15.95	−16.25

[a] From Sandage & Tammann 1987.

[b] References: (1) Madore & Freedman 1991, (2) Walker 1988, (3) Reid & Mould 1987, (4) Lee, Freedman, & Madore 1993, (5) Saha & Hoessel 1990, (6) Lee, Freedman, & Madore 1992, 1993c; (7) Saha, Hoessel, & Mossman 1990; (8) Mould, Kristian, & Da Costa 1983; (9) Saha et al. 1992; (10) Freedman 1988; (11) Pritchet & van den Bergh 1987, 1988; (12) Mould & Kristian 1986; (13) Pritchet 1988; (14) Lee, Freedman, & Madore 1993a; (15) Mould, Kristian, & Da Costa 1984; (16) Saha, Hoessel, & Krist 1991; (17) Capaccioli, Piotto, & Bresolin 1992; (18) Lee 1993.

[c] The metallicity [Fe/H] has been determined using the color $(V-I)_{-3.5}$.

morphological types; (3) the foreground reddening; (4) the intrinsic Cepheid distances; (5) the intrinsic RR Lyrae distances re-estimated in this study as described below; (6) the intrinsic TRGB distances estimated in this study from *VI* photometry of the RGB stars; (7) the *I* magnitude of the TRGB; (8) the references; (9) the metallicities of the RGB stars in galaxies, derived from the mean color $(V-I)_{-3.5}$ of the RGB stars; and (10) and (11) the total absolute *B* and *V* magnitudes of galaxies.

The sample of galaxies covers a wide range in the morphological type (E, S, Irr), luminosity ($-21.6 < M_B < -14.4$ mag), metallicity ($-2.0 < [\mathrm{Fe/H}] < -0.8$ dex), and distance [$18.5 < (m-M)_0 < 25.5$ mag]. All observational data are based on CCD photometry of good quality except for the LMC, for which modern photographic data are available (Reid & Mould 1987). The values for I_{TRGB}, $(V-I)_{\mathrm{TRGB}}$, and $(V-I)_{-3.5}$ were obtained from *VI* photometry in the literature and then the TRGB distances were derived consistently for all galaxies using the method described in § 2. The Cepheid distances from Madore & Freedman (1991) are based on a distance modulus of the LMC, $(m-M)_0 = 18.50$ mag for $E(B-V) = 0.10$ mag under the assumption of the extinction law, $A_V = 3.3E(B-V)$. For consistency we adopted the same extinction law in this study. RR Lyrae distance moduli were re-estimated from the photometry in the literature as follows: We used the relation for the $[\mathrm{Fe/H}] - M_V$ for RR Lyraes adopted by DA90 (see § 2) to be consistent with that used in the calibration of the TRGB. Note that most values in the literature have adopted $M_V(\mathrm{RR}) = 0.77$ mag for distance estimates for galaxies, while the *V* magnitude of RR Lyraes used in this study ranges from $M_V(\mathrm{RR}) = 0.5$–0.7 mag.

4. COMPARISON OF THREE PRIMARY DISTANCE INDICATORS

A comparison of the distance estimates to resolved galaxies based on the TRGB and those derived from Cepheids or RR Lyraes (Table 1) is displayed in Figure 4. The RR Lyrae

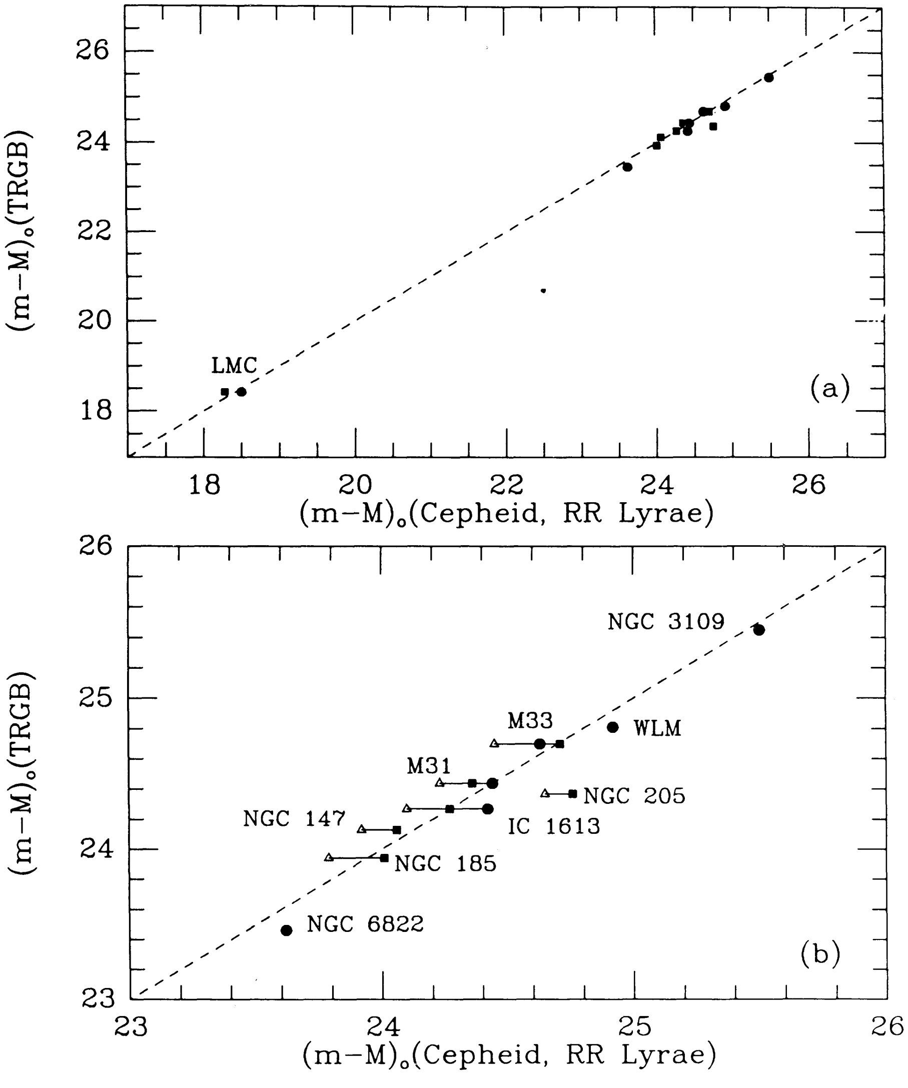

FIG. 4.—Comparison of distances to resolved galaxies estimated using the tip of the red giant branch (TRGB) with those derived from Cepheids (*filled circles*) or RR Lyraes (*open triangles and filled squares*). Open triangles represent the RR Lyrae distance moduli given in the literature [$M_V(\mathrm{RR}) = 0.77$ mag] and filled squares the RR Lyrae distance moduli reestimated in this study using the metallicity $-M_V$ magnitude relation for RR Lyraes consistent with that used for the TRGB distance moduli. Note that, with the exception of the LMC, (*a*) and (*b*) show the same data but at a different scale. The scatter about a line of unit slope (represented by the dashed line) is remarkably small, ±0.1 mag.

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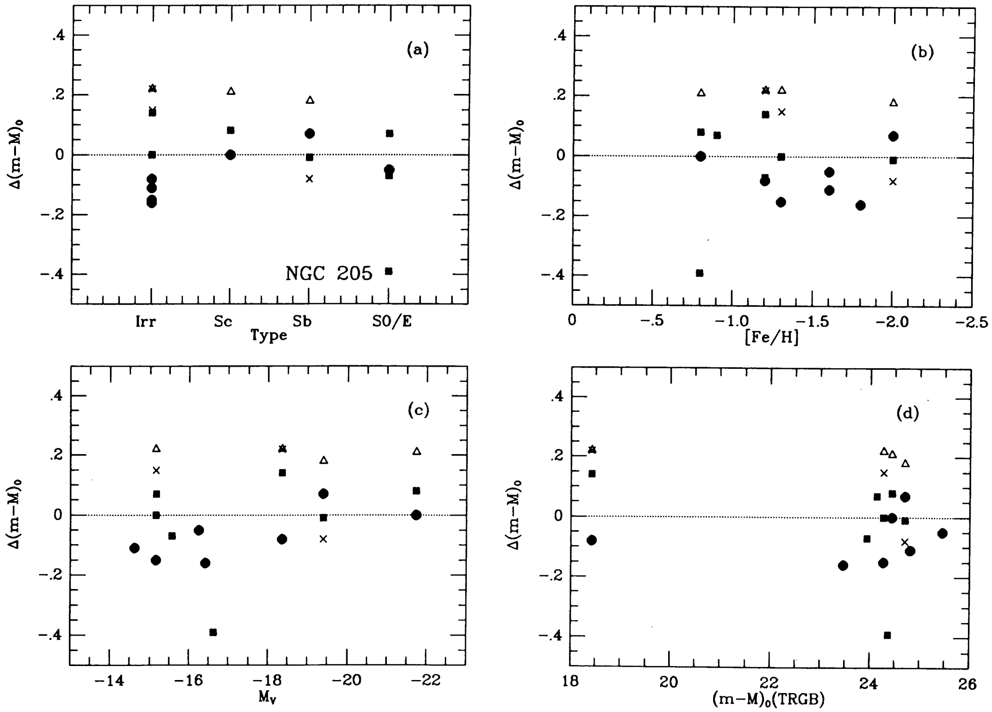

FIG. 5.—Differences among distance moduli based on the TRGB, Cepheids, and RR Lyrae vs. (*a*) morphological type, (*b*) metallicity, (*c*) total absolute V magnitude, and (*d*) the TRGB distance moduli. Filled circles for $(m-M)_0$(TRGB) − $(m-M)_0$(Cepheid); *open stars* for $(m-M)_0$(TRGB) − $(m-M)_0$(RR, this study); crosses for $(m-M)_0$(Cepheid) − $(m-M)_0$(RR, this study); triangles for $(m-M)_0$(TRGB) − $(m-M)_0$(RR, literature).

distance moduli from the literature [assuming M_V(RR) = 0.77 mag] are represented by open triangles, the RR Lyrae distance moduli reestimated in this study by filled squares, and the Cepheid distance moduli by filled circles. Figure 4 shows three interesting points: (1) the TRGB distance estimates show excellent agreement with the Cepheid and RR Lyrae distance estimates. The mean differences in distance moduli for the sample, excluding NGC 205, are remarkably small: -0.07 ± 0.08 mag for (TRGB − Cepheid) and 0.01 ± 0.09 mag for [TRGB − RR Lyrae (this study)]; (2) the RR Lyrae distance moduli given in the literature are systematically smaller (by ~0.2 mag for M31, M33, and IC 1613) than the Cepheid distance moduli; and (3) NGC 205 is the only outlier among the sample showing a significant deviation from the line of unit slope. Mould, Kristian, & Da Costa (1984) published a distance estimate based on the TRGB for a field located at 9′.5 north of NGC 205, $(m-M)_0 = 24.3 \pm 0.2$ mag. On the other hand, Saha, Hoessel, & Krist (1992) presented a study of ~30 RR Lyraes in a 8′ × 8′ field located 18′ west and 9′ north of NGC 205, using Gunn g photometry and gave a lower limit for the distance to NGC 205, $(m-M)_0 = 24.65 \pm 0.25$ mag. We do not have a clear explanation for such a large difference in the estimated distances of NGC 205. At present NGC 205 has been excluded in the estimate of the mean differences in distance moduli. We investigate potential systematic dependences of the differences in distance moduli on the morphological type, metallicity, total absolute luminosity, and distance of galaxies, as displayed in Figure 5. Figure 5 shows that there is little dependence of the differences between the TRGB distance estimates and the Cepheid or RR Lyrae distance estimates on any of the four factors described above.

5. DISCUSSION

We have shown that the tip of the first-ascent red giant branch of low-mass stars is an excellent distance indicator with an accuracy comparable to that for the primary distance indicators such as Cepheids and RR Lyraes. The obvious strengths of this method are (1) it can be used for any types of galaxies as long as the galaxies show resolved red giant branch stars of low mass stars with [Fe/H] < −0.7 dex (older than a few gigayears); (2) it is reasonably easy to detect the TRGB from the I luminosity function of red giant stars in combination with color-magnitude diagrams; (3) it can be used reliably even for edge-on galaxies (see Lee 1993); and (4) the sensitivity of commonly used CCDs is well matched with observing these red giants. In addition, this TRGB method has several advantages for distance determinations of resolved stellar systems over Cepheids or RR Lyraes: (1) the TRGB method requires much less telescope time than for variable stars; (2) the I magnitude of the TRGB, $M_I \approx -4$ mag is brighter by ~4 mag than that of RR Lyraes; (3) the I magnitude of the TRGB is insensitive to the variation of metallicity for [Fe/H] < −0.7 dex; and (4) the TRGB method suffers less from extinction problems compared with Cepheids which are in general located in star-forming regions.

A disadvantage of the method, as discussed in the case of M32 by Freedman (1989), is the potential presence of substantial intermediate-age AGB stars brighter than the TRGB, complicating the detection of the TRGB.

Since the absolute magnitude of the TRGB is as bright as $M_I \approx -4.0$ mag, we expect that this method can be applied using large ground-based telescopes under good seeing conditions (i.e., 0$''$.7) to determine the distances to galaxies out to $(m - M)_v \approx 28$ mag, to an accuracy of ± 0.2 mag. This distance modulus corresponds to the distance of the M81 Group. If a factor of 5 or 6 increased resolution can be routinely expected from the refurbished *Hubble Space Telescope*, it is reasonable to expect that this method will be useful in determining distances out to ~ 20 Mpc which would put both Virgo and the Fornax clusters within striking range.

We acknowledge helpful discussions with Y. W. Lee, M. Mateo, and B. Carney. This research is supported in part by NSF grants AST 87-13889 and AST 91-16496 to W. L. F. B. F. M. is supported in part by the NASA/IPAC Extragalactic Database and in part by the Jet Propulsion Laboratory which is operated by the California Institute of Technology under contract with NASA's Office of Space Science and Applications.

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