DETERMINATION OF THE DISTANCE TO M33 BASED ON SINGLE-EPOCH I-BAND HUBBLE SPACE TELESCOPE OBSERVATIONS OF CEPHEIDS

MYUNG FYOON LEE AND MINSUN KIM
Astronomy Program, SEES, Seoul National University, Seoul 151-742, Korea; mglee@astrog.snu.ac.kr, mskim@astro.snu.ac.kr

ATA SARAJEDINI
Department of Astronomy, University of Florida, P.O. Box 112055, Gainesville, FL 32611; ata@astro.ufl.edu

AND

DOUG GEISLER AND WOLFGANG GIEREN
Departamento de Física, Grupo de Astronomía, Universidad de Concepción, Casilla 160-C, Concepción, Chile; doug@kukita.cfm.udec.cl, wgieren@comaf.cfm.udec.cl

Received 2001 July 2; accepted 2001 October 4

ABSTRACT

We have determined the distance to M33 using single-epoch I-band observations of Cepheids based on Hubble Space Telescope (HST)/Wide Field Planetary Camera 2 (WFPC2) images of five fields in M33. Combining the HST I-band photometry and the periods determined from the ground-based observations (DIRECT) for 21 Cepheids with log P > 0.8 in the sample of 32 Cepheids, we derive a distance modulus of (m – M)_0 = 24.52 ± 0.14(random) ± 0.13(systematic) for an adopted total reddening of M33, E(B – V) = 0.20 ± 0.04 [E(V – I) = 0.27 ± 0.05] given by Freedman et al.; the reddening to the LMC, E(B – V) = 0.10; and the distance to the LMC, (m – M)_0 = 18.50. If the total reddening to M33 of E(B – V) = 0.10 ± 0.09 given by Freedman, Wilson, and Madore is used, the Cepheid distance modulus based on the I-band photometry will be increased by 0.20. Metallicity effect on the Cepheid distance to M33 is estimated to be small, δ(m – M)_0 = 0.01–0.06, which leads to (m – M)_0 = 24.53–24.58 after this metallicity effect correction. Using the Wesenheit W_i, an extinction-free parameter, we derive a similar value, (m – M)_0 = 24.52 ± 0.15(random) ± 0.11(systematic). These results are in reasonable agreement with those based on the ground-based multiepoch BVRI observations of brighter Cepheids in M33 and are ≈0.3 smaller than those based on the tip of the red giant branch and the red clump. It is needed to estimate better the reddening to Cepheids in M33.

Subject headings: Cepheids — galaxies: distances and redshifts — galaxies: individual (M33, NGC 598)

1. INTRODUCTION

The Local Group spiral galaxy M33 is one of the primary calibrators for secondary distance indicators including the Tully-Fisher relation. Although it is a nearby bright galaxy and the Cepheids in it were discovered as early as the 1920s (Hubble 1926), it was only in the 1980s that reasonable estimates for the distance to M33 became available (Sandage 1983; Sandage & Carlson 1983; Freedman, Wilson, & Madore 1991).

M33 is close enough that useful photometry of the bright Cepheids can be obtained from ground-based observations. Taking advantage of the excellent seeing at the Canada-France-Hawaii Telescope, Freedman et al. (1991) determined the distance to M33 using BVRI photometry of 10 bright Cepheids, obtaining (m – M)_0 = 24.64 ± 0.09, which is close to the median of the previous estimates using Cepheids, (m – M)_0 = 24.1–24.8 (Sandage 1983; Sandage & Carlson 1983; Madore et al. 1985; Christian & Schommer 1987; Mould 1987; see also van den Bergh 2000). Later, Freedman et al. (2001) revised the Freedman et al. (1991) value to (m – M)_0 = 24.62 ± 0.10, adopting slightly different period-luminosity relations and the metallicity effect correction of 0.06 mag based on δ(m – M)_0/BV = −0.2 ± 0.2 mag dex⁻¹. On the other hand, very recently Macri et al. (2001) discovered 251 Cepheids in M33 and presented their BV I light curves using the Fred Lawrence Whipple Observatory (FLWO) 1.2 m telescope. Crowding and blending problems for faint Cepheids, however, are severe in the ground-based data. Therefore, the periods of the Cepheids in nearby galaxies such as M33 can be determined reasonably well from the ground-based observations, but the photometry of these Cepheids is prone to errors owing to the severe crowding and blending (Mochejska et al. 2001).

In this paper, we present a determination of the distance to M33 using single-epoch I-band photometry of known M33 Cepheids, based on deep Hubble Space Telescope Wide Field Planetary Camera 2 (HST/WFPC2) images, taking advantage of the high spatial resolution of HST and the periods of the DIRECT Cepheids obtained from ground-based CCD observations.

Single-epoch I-band photometry of Cepheids with known periods is very efficient when used in determining the distances to nearby galaxies (Freedman & Madore 1988; Lee, Freedman, & Madore 1993a, 1993b). The amplitude (≈0.5 mag) of variability of Cepheids and extinction at the I-band are much smaller than at shorter wavelengths (such as B), so we can estimate the distances reasonably well even from single-epoch I-band observations of several Cepheids with known periods.

2. OBSERVATIONS AND REDUCTION

We analyzed HST/WFPC2 data for five fields in M33 obtained between 1995 November and 1997 June for the...
Sarajedini et al. (1998) Cycle 5 program (GO-5914). Each field was observed for four orbits, yielding a total exposure time of 4800 s for F555W(V) and 5200 s for F814W(I). These data were obtained originally for the study of globular clusters in M33; thus, a globular cluster is centered in each PC chip.

We have identified 32 Cepheids known from the DIRECT project in these HST images, as shown in Figure 1 (there were three more Cepheids in our fields, but two of them were saturated and one could not be identified, so we used only 32 Cepheids for this study). Table 1 lists the information for the Cepheids used in the present study. The periods of these Cepheids range from 4 to 26 days. We have classified the quality of the light curves given by Macri et al. (2001) into five classes: 0 for very good, 1 for good, 2 for fair, 3 for unusually red color, and 4 for ambiguous identification, as shown in Table 1. At the position of C49 shown in the DIRECT image, there are seen two stars separated by 0.525 in the HST image. The magnitudes and colors of both stars [V = 20.78, (V - I) = 0.59, and V = 21.93, (V - I) = 1.14] are within the range of those of known Cepheids, so we could not identify which of the two is a Cepheid. Finally, we decided not to use this object for the distance estimation.

The photometry of the stars in the images has been obtained using the multiphot routine of the HSTphot package, which was designed for photometry of HST/WFPC2 data and employs a library of Tiny Tim point-spread functions (PSFs) for the PSF fitting (Dolphin 2000a, 2000b). The multiphot routine gives the magnitudes transformed to the standard system as well as instrumental magnitudes. The standard V and (V - I) of the Cepheids as measured by the multiphot routine are listed in Table 1. Formal errors of both V and (V - I) are smaller than 0.02 mag. More details of the observations and data reduction are given in Kim et al. (2002).

After phasing our data to the DIRECT data, we have compared our photometry with the DIRECT photometry on the same phase and with the mean magnitudes of the Cepheids given by the DIRECT project (Macri et al. 2001), which are listed in Table 1. It is found that the phase distribution of our HST Cepheid data is random, showing that they can be used for reliable distance estimation. A comparison of our single-epoch photometry with both sets of the DIRECT data shows that HST magnitudes are on average ≈ 0.2 mag fainter than the DIRECT magnitudes; the differences between the two sets of photometry are ∆V(HST - DIRECT) = 0.16 with a standard deviation σ = 0.46 and ∆I(HST - DIRECT) = 0.23 with a standard deviation σ = 0.29, as shown in Figure 2. There is little difference in the standard deviation between the comparisons with the mean magnitudes and phased magnitudes of the DIRECT data. This difference between our data and the DIRECT data is most likely due to the crowding and blending effect in the ground-based data, which leads to brighter magnitudes in the DIRECT photometry (see also Mochejska et al. 2001). The crowding and blending, however, has much less effect on the period determination for Cepheids, so that the Cepheid periods given by the DIRECT project are considered to be reliable. The reason for the difference between our photometry and Mould’s photometry (see below) is not known, but note that it goes in the direction opposite to what one would expect from additional crowding in the ground-based data.

The foreground reddening values of all the regions in M33 are as low as E(B - V) = 0.04 (Schlegel, Finkbeiner, & Davis 1998). Freedman et al. (1991) estimated the mean value of the total (foreground plus internal) reddening for the M33 Cepheids from BVRI photometry of bright Cepheids to be E(B - V) = 0.10 ± 0.09. Later, Freedman et al. (2001) revised this estimate to a value 2 times larger.

![Fig. 1.—Finding chart for Cepheids in M33. The dots represent the DIRECT Cepheids, and the open circles represent the Cepheids used in Freedman et al. (1991). The squares represent the HST fields centered on the globular clusters.](image)

![Fig. 2.—Comparisons of the HST and DIRECT photometry of Cepheids in the (a) I and (b) V bands. The crosses represent the difference between the HST photometry and the DIRECT magnitudes at the same phase, and the open circles represent the difference between the HST photometry and the DIRECT mean magnitudes of the Cepheids. The solid lines represent the mean value for the differences between the HST photometry and the DIRECT mean magnitudes.](image)
but with a smaller error, \( E(V - I) = 0.27 \pm 0.05 \) \([E(B-V) = 0.20 \pm 0.04]\), by applying new period-luminosity relations of the Cepheids to the same data. We adopted the latter in this study. The extinction laws for \( R_v = 3.3, A_I = 1.956E(B-V) = 0.39\) and \( E(V - I) = 1.35E(B-V)\) (Cardelli, Clayton, & Mathis 1989) are adopted in this study.

### 3. RESULTS

#### 3.1. Color-Magnitude Diagram

Figure 3 displays the color-magnitude diagram of 32 Cepheids listed in Table 1, where the field stars in one region (H38 region) are also included to illustrate the field stellar population. In Figure 3, we also plot for comparison the field stars in one region used in the Freedman et al. (1991) study (as shown by the open squares in Fig. 3). One M33 Cepheid (C150) with the reddest color \( V - I = 1.73 \) from both the \( HST \) and DIRECT photometry shows an extremely red color even when compared with the Cepheids in other galaxies (Ferrarese et al. 2000). The range of Cepheid colors obtained in this study is similar to that of the DIRECT project, although our photometry is based only on single-epoch observations, while the DIRECT photometry represents mean values based on multiepoch data (>100 photometric points taken over about 40 nights).

In Figure 4, M33 Cepheids are compared with those in the LMC (Udalski et al. 1999a) and the \( HST \) \( H_0 \) Key Project galaxies (Ferrarese et al. 2000; Freedman et al. 2001) in the color-magnitude diagrams. In the case of the LMC for which the extinction \( E(B-V) = 0.1 \) and the distance modulus \( (m-M)_0 = 18.5 \) are adopted, first-overtone Cepheids (triangles) as well as the fundamental-mode Cepheids (open circles) are plotted. For the \( HST \) \( H_0 \) Key Project galaxies, extinction values and distance moduli given by Freedman et al. (2001) are adopted. Figure 4 shows that M33 Cepheids used in this study are located within the instability strip roughly defined by the Cepheids in other galaxies.
galaxies. M33 Cepheids go fainter than those in the HST $H_0$ Key Project galaxies and show a larger range of color compared with the LMC Cepheids.

3.2. Cepheid Distance

Figure 5 displays the $I$–$\log P$ relation of the Cepheids in M33 based on this study and other studies: mean magnitudes of bright Cepheids by Freedman et al. (1991) (open squares), mean magnitudes from the DIRECT project for the same Cepheids by Macri et al. (2001) (crosses), and single-epoch photometry of other Cepheids by Mould (1987) (open triangles). Several features of note are seen in Figure 5. First, our HST photometry of M33 Cepheids shows a tight correlation between period and luminosity, although our data are based only on single-epoch observations. Second, our photometry is on average fainter than the DIRECT photometry and brighter than the Mould (1987) photometry for a given period. Third, our photometry is on average similar to the Freedman et al. (1991) photometry for a given period. Fourth, the scatter along the period-luminosity relation is smaller in our photometry ($\sigma = 0.25$) than that of the ground-based data ($\sigma = 0.28$ for the DIRECT data, $\sigma = 0.27$ for the Freedman et al. 1991 data, and $\sigma = 0.45$ for the Mould 1987 data).

For distance estimation, we have used the calibration of the $M_I$–$\log P$ relation for Cepheids given by Freedman et al. (2001): $M_I = -2.962 \log P - 1.942$, with $\sigma = 0.11$. The zero point in this calibration is based on the LMC distance modulus of $(m - M)_L = 18.50$ and reddening of $E(B-V) = 0.1$ and the distance modulus for the LMC is adopted. $\sigma = 0.22$ for the LMC. The open circles, asterisks, and open pentagons represent, respectively, the Cepheids with class 2, 3, and 4 in this study, and the crosses represent the mean magnitudes of the same Cepheids given by the DIRECT project (Macri et al. 2001). The open squares represent the mean magnitudes of bright Cepheids given by Freedman et al. (1991), and the open triangles represent the single-epoch magnitudes of other Cepheids given by Mould (1987).
TABLE 2
ERROR BUDGET FOR THE CEPHEID DISTANCE MODULUS TO M33

| Source of Error | Error |
|-----------------|-------|
| Cepheid PL calibration: | |
| A. LMC true modulus | 0.10 |
| B. I-band PL zero point | 0.01 |
| S1. LMC PL systematic uncertainty | 0.10 |
| S2. Metallicity effect (LMC−M33) | 0.04 |

HST photometric calibration:

| Source of Error | Error |
|-----------------|-------|
| D. HST I-band zero point | 0.05 |
| DW. HST V-band zero point | 0.05 |
| R1. HST calibration uncertainty | 0.12 |
| RW1. HST calibration uncertainty | 0.14 |

M33 distance modulus:

| Source of Error | Error |
|-----------------|-------|
| F. M33 I-band PL fitting | 0.05 |
| FW. M33 W−log P PW fitting | 0.04 |
| H. Finite strip width and random phase data | 0.07 |
| R2. M33 distance modulus uncertainty | 0.07 |
| RW2. M33 distance modulus uncertainty | 0.04 |
| S3. Total I-band extinction uncertainty | 0.07 |

Total uncertainty*: 0.14, 0.15
S. Systematic errors for PL and PW 0.13, 0.11

* $R_{PL} = \sqrt{R1^2 + R2^2}$, $R_{PW} = \sqrt{RW1^2 + RW2^2}$, $S_{PL} = \sqrt{SI^2 + S2^2 + S3^2}$, and $S_{PW} = \sqrt{SI^2 + S2^2}$.

$E(B−V) = 0.10$. The slope in this calibration is based on the results of Udalski et al. (1999a) and is slightly flatter than that given by Madore & Freedman (1991), $M_I = -3.06 \log P - 1.81$, with $\sigma = 0.18$. The slope in the adopted calibration is similar to those based on newer studies (Groenewegen 2000; Groenewegen & Oudmaijer 2000).

There is a possibility that there may be included some first-overtone Cepheids as well as the fundamental-mode Cepheids at the short periods. As a matter of fact, we could classify C29 and C35, which are the brightest among the Cepheids with $log P < 0.8$, into first-overtone Cepheids from the shape of the light curves. The light curves of the first-overtone Cepheids are more sinusoidal than the fundamental-mode Cepheids (Mantegazza & Poretti 1992). The LMC Cepheid data show that the longest period of the first-overtone Cepheids is about 6 days (Udalski et al. 1999a). Therefore, we decided to use the Cepheids with $log P > 0.8$ for distance determination.

Fitting the $I-\log P$ relation to 21 Cepheids (classes 0, 1, and 2) with $log P > 0.8$ in M33, we obtain a value for the distance modulus, $(m - M)_0 = 24.91$ with $\sigma(\text{fit}) = 0.25$ mag. The uncertainty corresponding to this fitting error is $\sigma(\text{fit})/\sqrt{N} = 0.05$ mag. On the other hand, the error in the distance modulus associated with a single I-band observation of one Cepheid of known period is 0.30 mag, which leads to 0.065 mag for 21 Cepheids in this study, following the description in Freedman & Madore (1988). These two types of errors are comparable, so we adopt 0.07 as the error of the $I-\log P$ fitting. From this we derive an extinction-corrected distance modulus of $(m - M)_0 = 24.52 \pm 0.14$ (random) $\pm 0.13$ (systematic), considering extinction and other error sources as listed in Table 2 (following also Mould et al. 2000). If we use 18 good Cepheids with classes 0 and 1, we obtain very similar results, $(m - M)_0 = 24.50 \pm 0.14$ (random) $\pm 0.13$ (systematic).

In addition, we have used $W$ (the Wesenheit parameter) for distance estimation (see Freedman et al. 1991). $W$ is a representative magnitude that is defined to be extinction free: $W_I = V - R_P(B-V)$ and $W_I = I - R_I(V-I)$, where $R_P$ and $R_I$ are the ratio of total-to-selective absorption. Using $W_I = 2.45I - 1.45V$ (for $R_P = 3.3$ adopted in this study) and the calibration $M_W = -3.255 \log P - 2.644$ [based on $(m - M)_0, LMC = 18.50$] (Udalski et al. 1999a; Freedman et al. 2001), we obtain from 21 Cepheids with classes 0, 1, and 2, $(m - M)_0 = 24.52 \pm 0.15$ (random) $\pm 0.11$ (systematic). If we use 18 Cepheids with classes 0 and 1, we obtain $(m - M)_0 = 24.55 \pm 0.15$ (random) $\pm 0.11$ (systematic).

We also tried to use the DIRECT mean magnitudes of the Cepheids corrected for the difference between our the photometry and the DIRECT photometry. The last two columns in Table 1 list the differences between the DIRECT magnitudes of the Cepheids at the same phase as the $HST$ data and the mean magnitudes. Using these corrected mean magnitudes of the Cepheids, we obtain very similar results for the distance estimates to above (the difference in the distance modulus is only 0.02). Finally, we adopt $(m - M)_0 = 24.52 \pm 0.14$ (random) $\pm 0.13$ (systematic) as the Cepheid distance to M33 before the metallicity effect correction.

4. DISCUSSION AND SUMMARY

We have determined the distance to M33 using the single epoch $I$-band observations of Cepheids based on the $HST$/WFPC2 images of five fields. Combining the $HST$ $I$-band photometry and the periods determined from the ground-based observations (DIRECT) for 21 Cepheids ($log P > 0.8$) with the best data in our sample of 32 Cepheids, we derive a distance modulus of $(m - M)_0 = 24.52 \pm 0.14$ (random) $\pm 0.13$ (systematic). Using the Wesenheit $W$ quantity, an extinction-free parameter, we derive a very similar value, $(m - M)_0 = 24.52 \pm 0.15$ (random) $\pm 0.11$ (systematic). These results are in good agreement with those based on the multiepoch ground-based $BVRI$
observations of 11 bright Cepheids in M33, \((m - M)_0 = 24.56 \pm 0.10\) [and \(E(B - V) = 0.20 \pm 0.04\)] before metallicity correction by Freedman et al. (1991) and Freedman et al. (2001).

These Cepheid distances are somewhat smaller than those derived recently using the tip of the red giant branch (TRGB) and red clump (RC) of the M33 field stellar population. Using the same set of HST data for field stars as we have used for the Cepheids, Kim et al. (2002) have determined the distance to M33, obtaining \((m - M)_0 = 24.81 \pm 0.04\) (random) + 0.15 (systematic) from the TRGB and \((m - M)_0 = 24.80 \pm 0.04\) (random) + 0.05 (systematic) from the mean magnitudes of the RC. Note also that Sarajedini et al. (2000) found \((m - M)_0 = 24.84 \pm 0.16\) from the inferred location of the RR Lyrae stars in two M33 halo globulurs and 24.81 \pm 0.24 from the red clump of seven halo clusters.

These TRGB and RC distances (Sarajedini et al. 2000; Kim et al. 2001) were derived adopting a foreground reddening of only \(E(B - V) = 0.04\). The RGB and RC stars are old, so that the M33 internal reddening for these stars is considered to be negligible. On the other hand, Cepheid distances are derived adopting a total reddening of \(E(B - V) = 0.20 \pm 0.04\) given by Freedman et al. (2001).

If only the foreground reddening is adopted for the Cepheids used in this study, the differences between the Cepheid distances and the TRGB and RC distances become much smaller (by 0.3 mag). Since there is a large difference, \(dE(B - V) = 0.1\), in the reddening estimates based on the same data used by Freedman et al. (1991, 2001), the uncertainty in the reddening must be larger than the 0.04 quoted error in Freedman et al. (2001). We strongly urge better determination of the reddening of the Cepheids in M33 in the future.

Note also that the metallicity effect in the Cepheid distance determination has been controversial (see, e.g., Sasselov et al. 1997; Kochanek 1997; Kennicutt et al. 1998; Allen & Shanks 2001). In the case of M33, however, the error due to metallicity differences is estimated to be negligible because the mean metallicity of the disk components in M33 is known to be very similar to or slightly more metal-rich than that of the LMC on which the calibration of the P-L relation used in this study is based. While van den Bergh (2000) lists 12 \(\log \text{[O/H]} = 8.37 \pm 0.09\) for the LMC, \(\log \text{[O/H]} = 8.4 \pm 0.15\) for M33 (Massey 1998), Ferrarese et al. (2000) and Freedman et al. (2001) use \(12 + \log \text{[O/H]} = 8.5 \pm 0.08\) for the LMC (Pagel et al. 1978) and \(12 + \log \text{[O/H]} = 8.82 \pm 0.15\) for M33 (Zaritsky, Kenicutt, & Huchra 1994). These values lead to a metallicity correction in the distance modulus to M33, from \(\delta(m - M)_0 = 0.01\), to 0.06, if the relation between the distance modulus and metallicity adopted by Freedman et al. (2001), \(\delta(m - M)_0/\delta\text{[O/H]} = -0.2 \pm 0.2\) mag dex \(^{-1}\), is used. We stress, however, that the metallicity dependence of Cepheid luminosities is very uncertain at the present time.

In closing, it is important to reiterate that the fitting error for the I-log \(P\) relation of 21 Cepheids based on the single-epoch HST observations in this study is \(\sigma(\text{fit}) = 0.25\).

It is impressive that this fitting error is very similar to that for the mean I-band magnitudes of 11 brighter Cepheids based on multiepoch ground-based observations given by Freedman et al. (2001), \(\sigma(\text{fit}) = 0.27\). This confirms that single-epoch I-band observation of Cepheids using HST is a very efficient way to determine accurate distances if the reddening of individual Cepheids can be accurately determined. As a result, we would advocate the following strategy for determining Cepheid distances to nearby galaxies. First, search for Cepheids and determine the periods of the Cepheids using small to mid-size ground-based telescopes (e.g., the DIRECT project). Second, obtain I-band photometry of a large sample of Cepheids at a single epoch (or a few epochs) using HST. Finally, determine the distance using the I-log \(P\) relation. An excellent alternative is to obtain K-band photometry of selected Cepheids. The very low K-band amplitude and low reddening make this a very promising way to get accurate Cepheid distances to nearby galaxies, especially those where reddening effects are important.

The authors are grateful to the referee, K. Stanek, for useful comments. M. G. L. is supported in part by the MOST/KISTEP International Collaboration Research Program (1-99-009). M. G. L. is grateful to the Astronomy Group at the University of Concepcion for the warm hospitality during his stay for this work. A. S. has benefited from financial support from NSF CAREER grant AST 00-94048. D. G. and W. G. acknowledge financial support for this project received from CONICYT through Fondecyt grant 8000002.

REFERENCES

Allen, P. D., & Shanks, T. 2001, preprint (astro-ph/0102447)
Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
Christian, C. A., & Schommer, R. A. 1987, AJ, 93, 557
Dolphin, A. E. 2000, PASP, 112, 1383
——. 2000b, PASP, 112, 1397
Ferrarese, L., et al. 2000, ApJ, 529, 745
Freedman, W. L., et al. 2001, ApJ, 553, 47
Freedman, W. L., & Madore, B. F. 1993, ApJ, 332, L63
Freedman, W. L., Wilson, C. D., & Madore, B. F. 1991, ApJ, 372, 455
Hubble, E. 1926, ApJ, 63, 236
Groenewegen, M. A. T. 2000, A&A, 363, 901
Groenewegen, M. A. T., & Oudmaijer, R. D. 2000, A&A, 356, 849
Kennicutt, R. C., et al. 1998, ApJ, 498, 181
Kim, M., Kim, E., Lee, M. G., Sarajedini, A., & Geisler, D. 2002, AJ, in press
Kochanek, C. S. 1997, ApJ, 491, 13
Kurt, C. M., & Dufour, R. J. 1998, Rev. Mexicana Astron. Astrofis. Ser. Conf., 7, 202
Lee, M. G., Freedman, W. L., & Madore, B. F. 1993a, in IAU Colloq. 139, New Perspectives on Stellar Pulsation and Pulsating Variable Stars, ed. J. M. Nemec & J. M. Matthews (New York: Springer), 91
——. 1993b, in IAU Colloq. 139, New Perspectives on Stellar Pulsation and Pulsating Variable Stars, ed. G. Gilmore & D. Howell (San Francisco: ASP), 17
Mocnjak, B. J., Macri, L. M., Sasselov, D. D., & Stanek, K. Z. 2001, AJ, 121, 870
Madore, B. F., & Freedman, W. L. 1991, PASP, 103, 933
Macri, L. M., Stanek, K. Z., Sasselov, D. D., Krockenberger, M., & Kaluzny, J. 2001, AJ, 121, 870
Macri, L. M., Stanek, K. Z., Sasselov, D. D., Krockenberger, M., & Stanek, K. Z. 2001, AJ, 121, 870
Massey, P. 1998, in ASP Conf. Ser. 142, The Stellar Initial Mass Function, ed. G. Gilmore & D. Howell (San Francisco: ASP), 17
Mould, J. 1987, PASP, 99, 1127
Mould, J., et al. 2000, ApJ, 528, 655
Pagel, B. E. J., Edmunds, M. G., Fosbury, R. A. E., & Webster, B. L. 1978, MNRAS, 184, 569
Sandage, A. 1983, AJ, 88, 1108
Sandage, A., & Carlson, G. 1983, ApJ, 267, L25
Sarajedini, A., Geisler, D., Harding, P., & Schommer, R. 1998, ApJ, 508, L37
Lee, M. G., Freedman, W. L., & Madore, B. F. 1993, in IAU Colloq. 139, New Perspectives on Stellar Pulsation and Pulsating Variable Stars, ed. J. M. Nemec & J. M. Matthews (New York: Springer), 91
Sarajedini, A., Geisler, D., Schommer, R., & Harding, P. 2000, AJ, 120, 2437
Sasselov, D. D., et al. 1997, A&A, 324, 471
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Udalski, A., Soszyński, I., Szymański, M., Kubiak, M., Pietrzyński, G., Wozniak, P., & Zebrun, K. 1999b, Acta Astron., 49, 223
Udalski, A., Szymański, M., Kubiak, M., Pietrzyński, G., Soszyński, I., Wozniak, P., & Zebrun, K. 1999a, Acta Astron., 49, 201
van den Bergh, S. 2000, The Galaxies of the Local Group (Cambridge: Cambridge Univ. Press), 75
Zaritsky, D., Kennicutt, R. C., Jr., & Huchra, J. P. 1994, ApJ, 420, 87