THE EXTRAGALACTIC DISTANCE SCALE WITHOUT CEPHEIDS. III.

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ABSTRACT

The Cepheid period–luminosity relation is the basis of distances of galaxies in the Hubble Space Telescope (HST) Key Project. The tip of the red giant branch (TRGB) is an alternative basis. Using archival HST data, we check the calibration of the fundamental plane of early-type galaxies and the luminosity of type Ia supernovae. Using all four distance indicators (i.e., including the infrared Tully–Fisher relation and surface brightness fluctuations as well) we find that the TRGB and Cepheid distance scales are consistent.

Key words: distance scale – galaxies: distances and redshifts

1. INTRODUCTION

The extragalactic distance scale of the Hubble Space Telescope (HST) Key Project (Kennicutt et al. 1995) is based on the Cepheid period–luminosity (PL) relation and secondary distance indicators, such as the Tully–Fisher relation (Sakai et al. 2000), the supernova standard candle (Gibson et al. 2000), surface brightness fluctuations (Ferrarese et al. 2000), and the fundamental plane (Kelson et al. 2000). It has been criticized recently (Tamman et al. 2008; Sandage & Tamman 2006, 2008) on the grounds that the PL relation may not be unique. Indeed, the finite width of the Cepheid instability strip in the H–R diagram implies that nuisance parameters such as metallicity, helium abundance, and star formation history may play a role in determining the PL relation. Metallicity was considered as a second parameter by Freedman et al. (2001), Sakai et al. (2004), and Macri et al. (2006), and linear corrections were made based on the measured values of [O/H] from the galaxies’ H II regions.

It is of interest, therefore, to see how well the distance scale can be measured without reference to Cepheids at all. In Papers I and II (Mould & Sakai 2008, 2009), we calibrated the infrared Tully–Fisher relation and surface brightness fluctuations using the tip of the red giant branch (TRGB) and found a distance scale compatible with that of the H0 Key Project (Mould et al. 2000). In this paper, we use the TRGB distance indicator to check the calibration of the fundamental plane of early-type galaxies and type Ia supernovae. As discussed in Paper I, the TRGB is a good standard candle because it results from the helium flash on the red giant branch, which theory suggests is relatively immune to metallicity effects in old stellar populations. Rizzi et al. (2007) find hundredth of a magnitude systematics in TRGB for old metal-poor stellar populations. Salaris & Girardi (2005) show that this dispersion grows substantially for young and metal-rich populations.

However, a drawback to our consistency check is that there are relatively few early-type galaxies and supernova hosts on which to base a calibration within the 10 Mpc range of TRGB. We combine the constraints from all four distance indicators used in the H0 Key Project to derive the TRGB Hubble Constant.

2. THE FUNDAMENTAL PLANE

The scaling relationship for early-type galaxies is a plane in the volume spanned by log $r_e$, log $\sigma$, and log $I_e$, that is effective radius, velocity dispersion, and surface brightness.
Table 1
Distances of Calibrating Galaxies

| Galaxy   | TRGB Distance (mag) | Random Error | Reference       | γ   | $M_{\text{max}}^B$ |
|----------|---------------------|--------------|-----------------|-----|------------------|
| NGC 3377 | 30.59               | 0.07         | Paper II        | −0.70 |                   |
| NGC 3379 | 30.35               | 0.1          | Paper II        | −0.102 |                |
| NGC 3384 | 30.42               | 0.09         | Paper II        | 0.002 |                  |
| NGC 3368 | 29.65               | 0.28         | Paper II        | −18.95 |               |
| NGC 3627 | 29.82               | 0.1          | This paper      | −19.00 |               |
| IC 4182  | 28.25               | 0.06         | Note$^a$        | −19.45 |               |
| NGC 5253 | 27.76               | 0.04         | Paper I         | −19.54 |               |

Note.
$^a$ Sakai et al. (2004).

Table 2
Combining the Constraints

| Method                          | $H_0$ (km s$^{-1}$ Mpc$^{-1}$) | Error | Reference                      |
|--------------------------------|-------------------------------|-------|--------------------------------|
| Infrared Tully–Fisher relation | 73                            | 5     | Mould & Sakai (2008)           |
| Surface brightness fluctuations | 68                            | 7     | Mould & Sakai (2009)           |
| Fundamental plane               | 60                            | 9     | This paper                     |
| Type Ia supernovae              | 74                            | 8     | This paper                     |
| Error weighted mean            | 70                            | 4 (Random) | 5 (Systematic)                |

Figure 1. Location of Leo group galaxies in the fundamental plane. The ordinate gives surface brightness parameters, and the abscissa is velocity dispersion from Kelson et al. (2000). The points are based on distances from TRGB; the straight line is the calibration based on Cepheids by Kelson et al. (2000).

Figure 2. (Left) the $I$, $V-I$ CMD of NGC 3627. (Right, upper) the RGB luminosity function above the peak in the filtered indicator of the TRGB.

and F814W. The color–magnitude diagram and luminosity function are shown in Figure 2. The TRGB occurs at $I = 25.83 \pm 0.1$ (independent of color) and the distance modulus after correction for 0.06 mag reddening (Schlegel et al. 1998) is 29.82 mag.

Following Gibson et al. (2000) and Phillips et al. (1999), we plot $M^B_{\text{max}}$ versus the decline rate of the supernova, $\Delta m_{15}$ in Figure 3. The solid curve is Equation (1) of Gibson et al. (2000) for $H_0 = 68$ km s$^{-1}$ Mpc$^{-1}$. The mean value of $M^B_{\text{max}}$ is $-19.29 \pm 0.10$ for $\Delta m_{15} = 1.1$. This corresponds to $H_0 = 74 \pm 6 \pm 5$ km s$^{-1}$ Mpc$^{-1}$, where the error bars follow from the relevant terms of Table 7 of Gibson et al. (2000).

4. COMBINING THE CONSTRAINTS

We have obtained TRGB calibrations for all four of the distance indicators employed by the HST Key Project on the extragalactic distance scale. In Table 2, we take the weighted mean of the four. The weights are the inverse of the uncertainty squared. The mean value of the Hubble constant over these four distance indicators is 70 ± 4 (random) ± 5 (systematic)
The fundamental plane and supernova results presented in this paper would be stronger, if samples as large as the Tully–Fisher and surface brightness fluctuations were available. High signal-to-noise TRGB distances for some galaxies in the Virgo cluster would therefore be worth the investment in HST orbits required.

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