THE ARAUCARIA PROJECT: THE DISTANCE TO THE SCULPTOR GALAXY NGC 247 FROM NEAR-INFRARED PHOTOMETRY OF CEPHEID VARIABLES

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Received 2009 March 20; accepted 2009 May 1; published 2009 July 10

ABSTRACT

We have obtained deep near-infrared images in J and K filters of four fields in the Sculptor Group spiral galaxy NGC 247 with the ESO VLT and Infrared Spectrometer and Array Camera. For a sample of 10 Cepheids in these fields, previously discovered by García-Varela et al. from optical wide-field images, we have determined mean J and K magnitudes and have constructed the period–luminosity (PL) relations in these bands. Using the near-infrared PL relations together with those in the optical V and I bands, we have determined a true distance modulus for NGC 247 of 27.64 mag, with a random uncertainty of ±2% and a systematic uncertainty of ~4% which is dominated by the effect of unresolved stars on the Cepheid photometry. The mean reddening affecting the NGC 247 Cepheids of $E(B-V) = 0.18 ± 0.02$ mag is mostly produced in the host galaxy itself and is significantly higher than what was found in the previous optical Cepheid studies in NGC 247 of our own group, and Madore et al., leading to a 7% decrease in the previous optical Cepheid distance. As in other studies of our project, the distance modulus of NGC 247 we report is tied to an assumed Large Magellanic Cloud distance modulus of 18.50. Comparison with other distance measurements to NGC 247 shows that the present IR-based Cepheid distance is the most accurate among these determinations. With a distance of 3.4 Mpc, NGC 247 is about 1.5 Mpc more distant than NGC 55 and NGC 300, two other Sculptor Group spirals analyzed before with the same technique by our group.

Key words: Cepheids – distance scale – galaxies: distances and redshifts – galaxies: individual (NGC 247)

1. INTRODUCTION

In our ongoing Araucaria project (Gieren et al. 2005a), we are improving various stellar standard candles as tools for precise distance measurements. The overall goal is a very accurate calibration of the distance ladder in the local universe, out to perhaps 10 Mpc, which we hope to achieve by tracing down the age and metallicity dependences of the various standard candles we are investigating by comparative analyses of the distances to the same targets we obtain from different methods. This will lay the foundation for a truly accurate determination of the Hubble constant, reducing the uncertainty on $H_0$ achieved by the HST Key Project on the Extragalactic Distance Scale (Freeman et al. 2001). The methods we use include Cepheid variables, via period–luminosity (PL) relations in the optical and infrared spectral domains (e.g., Pietrzyński et al. 2002a; Gieren et al. 2005b), the K-band period–luminosity–metallicity relation for RR Lyrae stars (e.g., Pietrzyński et al. 2008; Szewczyk et al. 2008), near-infrared magnitudes of red clump giants (e.g., Pietrzyński & Gieren 2002; Pietrzyński et al. 2003), the flux-weighted gravity–luminosity relation (FLGR) for blue supergiant stars (e.g., Kudritzki et al. 2008), and most recently late-type eclipsing binary systems in the Large Magellanic Cloud (LMC; Pietrzyński et al. 2009) which bear the potential to determine the LMC distance, as a crucial step in the distance ladder, with an accuracy of 1%.

In this paper, we are using near-infrared observations of Cepheids in the spiral galaxy NGC 247 located in the nearby Sculptor Group, to determine an accurate distance to this galaxy which improves on the preliminary distance we had derived from optical (VI) data in a previous paper (García-Varela et al. 2008, hereafter Paper I). Infrared photometry has a number of distinct advantages over optical photometry for distance work with Cepheid variables. The most important gain is the very substantial reduction of the sensitivity of the observed Cepheid magnitudes to interstellar extinction. In addition, the intrinsic dispersion of the Cepheid PL relation becomes smaller toward the infrared region of the spectrum as compared to optical passbands, helping in obtaining more accurate distances. A further important advantage of the near-infrared domain is the fact that the mean magnitudes of Cepheid variables can be obtained with an accuracy of about 2% from just one observation obtained at an arbitrary pulsation phase with the technique developed by Soszyński et al. (2005). This technique can be applied when an optical light curve (V and/or I) of a Cepheid, and its period, are known from a previous discovery survey, which has to be conducted in the optical spectral range in which Cepheid amplitudes are significantly larger than in the infrared, making their discovery much easier. In the Araucaria Project, it has therefore been our strategy to discover the Cepheid populations in our Local and Sculptor Group target galaxies from wide-field imaging surveys in optical (BV) bands, and select subsamples of the detected Cepheid for follow-up observations in the infrared. We have shown in previous papers that a combination of the distance moduli...
derived in the optical $VI$ and near-infrared $JK$ bands leads to a very accurate determination of the true, absorption-corrected distance modulus of the host galaxy, and the mean color excess affecting its Cepheids (Gieren et al. 2005b, 2006, 2008a, 2008b; Soszyński et al. 2006; Pietrzyński et al. 2006a). Generally, we have found in these previous studies that the intrinsic reddening found in the spiral, and even the smaller irregular Local Group galaxies we have studied is larger than previously assumed by other authors, which has demonstrated that infrared work with its potential to virtually eliminate reddening as a significant source of systematic error is indeed imperative if one seeks to achieve distance accuracies in the 3%–5% range, which is the aim of our project.

The principal properties of NGC 247 have been described in Paper I. At a distance of about 4 Mpc it is possible, using 8 m class telescopes, to obtain high-quality infrared photometry for the long-period Cepheid population we have detected in this galaxy (Paper I), and high-quality low-resolution spectra for its blue supergiant population as needed for the FGLR analysis (Kudritzki et al. 2008; Pietrzyński et al. 2006). The Cepheid and blue supergiant methods of distance measurement can therefore be well compared on this galaxy.

Our paper is organized as follows. In Section 2, we describe the near-infrared observations of the Cepheids in NGC 247, the data reductions, and the calibration of our photometry. In Section 3, we derive the $J$- and $K$-band Cepheid PL relations in NGC 247 obtained from our data and determine the true distance modulus to the galaxy from a multiwavelength analysis. In Section 4, we discuss our results, and in Section 5, we summarize our conclusions.

2. OBSERVATIONS, DATA REDUCTION AND CALIBRATION

We used deep $J$- and $K$-band images recorded with the 8.2 m ESO VLT equipped with the Infrared Spectrometer and Array Camera (ISAAC). Figure 1 shows the location of the four 2.5 × 2.5 arcmin fields observed in service mode during seven nights between 2005 August 9 and November 18. The location of the fields was chosen in such a way as to maximize the number of Cepheids observed and optimize their period distribution. Fields 1, 2, and 4, were observed in both NIR bands two times, on two different nights, and therefore at different pulsation phases of the Cepheids in these fields. Field 3 was observed on a single night only.

The observations were carried out using a dithering technique, with a dithering of the frames following a random pattern characterized by typical offsets of 15 arcsec. In order to perform an accurate sky subtraction for our frames, we frequently observed random comparison fields located outside the main body of the galaxy, where the stellar density was very low, using the AutoJitterOffset template. The final frames in the $J$ and $K$ bands were obtained as a co-addition of 34 and 238 single exposures obtained with integration times of 30 and 15 s, respectively. Thus, the total exposure time for a given observation was 17 minutes in $J$ and 57 minutes in $K$. The observations were obtained under excellent seeing conditions, typically around 0.5 arcsec. Standard stars on the UKIRT system (Hawarden et al. 2001) were observed along with the science exposures to allow an accurate transformation of the instrumental magnitudes to the standard system.

The images were reduced using the program JITTER from the ECLIPSE package developed by ESO to reduce near-IR data. The point-spread function (PSF) photometry was carried out with the DAOPHOT and ALLSTAR programs. The PSF model was derived iteratively from 20 to 30 isolated bright stars following the procedure described by Pietrzyński et al. (2002b). In order to convert our profile photometry to the aperture system, aperture corrections were computed using the same stars as those used for the calculation of the PSF model. The median of the aperture corrections obtained for all these stars was finally adopted as the aperture correction for a given frame. The aperture photometry for the standard stars was performed with DAOPHOT using the same aperture as the one adopted for the calculation of the aperture corrections.

The astrometric solution for the observed fields was performed by cross-identification of the brightest stars in each field with the Infrared Digitized Sky Survey 2 (DSS2-infrared) images. We used programs developed by Udalski et al. (1998) to calculate the transformations between the pixel grid of our images and equatorial coordinates of the DSS astrometric system. The internal error of the transformation is less than 0.3 arcsec, but systematic errors of the DSS coordinates can be up to about 0.7 arcsec.

In order to perform an external check on our photometric zero points, we tried to compare the magnitudes of stars in the Two Micron All Sky Survey (2MASS) Point-Source Catalog located in our NGC 247 fields with our own photometry. Unfortunately, even the brightest stars in our data set whose photometry is not affected by nonlinearity problems are still very close to the faint magnitude limit of the 2MASS catalog and have 2MASS
magnitudes with formal errors of ~0.2 mag. Moreover, all our NGC 247 fields are located in regions of high stellar density (see Figure 1), and most of the 2MASS stars turn out to be cep023

\begin{verbatim}
| ID   | J HJD     | J    | σ_j  | K HJD     | K    | σ_K |
|------|-----------|------|------|-----------|------|------|
| cep006 | 3592.86819 | 21.216 | 0.068 | 3592.78328 | 20.753 | 0.098 |
| cep006 | 3616.62511 | 20.623 | 0.090 | 3616.60091 | 20.140 | 0.054 |
| cep008 | 3625.72588 | 20.771 | 0.054 | 3625.67282 | 20.288 | 0.075 |
| cep009 | 3657.60604 | 20.684 | 0.052 | 3657.60342 | 20.189 | 0.067 |
| cep012 | 3592.86819 | 20.433 | 0.033 | 3592.78328 | 19.969 | 0.044 |
| cep012 | 3616.62511 | 20.626 | 0.061 | 3616.60091 | 20.058 | 0.055 |
| cep015 | 3607.73856 | 20.846 | 0.036 | 3607.77029 | 20.454 | 0.058 |
| cep015 | 3639.69953 | 20.532 | 0.113 | 3639.65978 | 20.264 | 0.071 |
| cep016 | 3625.72588 | 20.671 | 0.048 | 3625.67282 | 19.839 | 0.058 |
| cep018 | 3625.72588 | 20.137 | 0.031 | 3625.67282 | 19.420 | 0.033 |
| cep019 | 3592.86819 | 20.072 | 0.038 | 3592.78328 | 19.361 | 0.062 |
| cep019 | 3616.62511 | 20.011 | 0.058 | 3616.60091 | 19.400 | 0.039 |
| cep021 | 3607.73856 | 19.861 | 0.035 | 3607.77029 | 19.164 | 0.040 |
| cep021 | 3639.69953 | 19.656 | 0.067 | 3639.65978 | 19.323 | 0.035 |
| cep023 | 3592.86819 | 18.873 | 0.020 | 3592.78328 | 18.356 | 0.034 |
| cep023 | 3616.62511 | 18.969 | 0.023 | 3616.60091 | 18.261 | 0.028 |
\end{verbatim}

Table 1

| ID   | log P (days) | (J) (mag) | σ_J (mag) | (K) (mag) | σ_K (mag) |
|------|--------------|-----------|-----------|-----------|-----------|
| cep006 | 29.585       | 20.908    | 0.064     | 20.326    | 0.063     |
| cep008 | 30.978       | 20.887    | 0.062     | 20.394    | 0.081     |
| cep009 | 32.114       | 20.781    | 0.060     | 20.314    | 0.073     |
| cep012 | 35.809       | 20.662    | 0.046     | 20.157    | 0.046     |
| cep015 | 41.393       | 20.569    | 0.066     | 20.160    | 0.055     |
| cep016 | 44.481       | 20.413    | 0.057     | 19.605    | 0.069     |
| cep018 | 63.505       | 20.194    | 0.043     | 19.487    | 0.045     |
| cep019 | 64.889       | 20.091    | 0.046     | 19.428    | 0.047     |
| cep021 | 69.969       | 19.754    | 0.048     | 19.213    | 0.040     |
| cep023 | 131.259      | 18.914    | 0.034     | 18.297    | 0.037     |

Table 2

In order to determine the relative distance moduli between NGC 247 and the LMC, we need to convert the NICMOS (LCO) photometric system used by Persson et al. (2004) to the UKIRT system used in this paper. According to Hawarden et al. (2001), there are just zero-point offsets between the UKIRT and the NICMOS systems (e.g., no color dependencies) in the J and K filters which amount to (0.034 ± 0.004) mag, and (0.015 ± 0.007) mag, respectively. Applying these offsets, and assuming a true distance modulus of 18.50 for the LMC as in our previous work in the Araucaria Project, we derive distance moduli for NGC 247 of 27.799 ± 0.038 mag in the J band, and 27.702 ± 0.007 mag in the K band.
Figure 2. Near-infrared CMD for NGC 247 obtained from our VLT-ISAAC data. Also plotted are the positions of the Cepheids in our sample (filled circles). They delineate the location of the Cepheid instability strip in its expected position. There is no evidence for any peculiarity of the Cepheids from their locations in this diagram.

Figure 3. Cepheid PL relation for NGC 247 in the $J$ band, as obtained from the mean magnitudes in Table 2. The dotted line is the best fit to the data, with the slope fixed to the LMC value of Persson et al. The mean magnitudes were determined using the technique of Soszynski et al. 0.04 mag in the $K$ band. The quoted uncertainties are those from the fits and do not include systematic uncertainties, which will be discussed in the next section.

As in our previous papers in this series, we adopt the extinction law of Schlegel et al. (1998) to find $R_\lambda$ (values given in Table 3) and fit a straight line to the relation $(m - M)_0 = (m - M)_0 + A_{\lambda} = (m - M)_0 - E(B - V) \times R_\lambda$, using the distance moduli for NGC 247 in the $V$ and $I$ photometric bands derived in Paper I, which are also given in Table 3, together with the values for the $J$ and $K$ bands derived above, we obtain from the least-squares fit shown in Figure 5 the following values for the reddening, and the absorption-corrected, true distance modulus of NGC 247:

$$E(B - V) = 0.177 \pm 0.020$$

$$m - M)_0 = 27.644 \pm 0.036$$

corresponding to a distance of NGC 247 of 3.38 ± 0.06 Mpc. The small uncertainties on both the reddening, and the true distance modulus derived from the fit in Figure 5 demonstrate...
that these quantities are indeed very well determined by our data. The agreement between the true distance moduli obtained from the different bands, which are listed in Table 3, is excellent; in $V$, $J$, and $K$ the values differ by less than $0.02$ mag from the adopted true distance modulus. Only in the $I$ band the agreement is slightly worse ($0.05$ mag), but clearly within the error bar of this determination.

4. DISCUSSION

The Cepheid distance to NGC 247 derived in this paper is in principle affected by a number of systematic uncertainties, which will now be discussed in turn. The most serious concern with Cepheid-determined distances to late-type galaxies is always with reddening. Classical Cepheids, as young stars, tend to be embedded in dusty regions in their host galaxies, which makes a precise determination of absorption corrections absolutely necessary. Since reddening is expected to be patchy and individual Cepheids can thus be expected to have widely differentreddenings, the only way to reduce this problem is to include infrared photometry in the distance analysis, as we are doing in our project. With the results derived from the data in Table 3 we believe that any remaining uncertainty on the true distance modulus due to reddening is smaller than $0.03$ mag, in agreement with the conclusions we had reached for the other target galaxies of the Araucaria Project whose distances were determined from Cepheid photometry in the $VIJK$ bands (NGC 55, NGC 300, IC 1613, NGC 6822, WLM, and NGC 3109; references as given in the Introduction of this paper). It is worthwhile mentioning that from Figure 5 there is evidence that our assumed Galactic reddening law is valid, to a very good approximation, in NGC 247 as well. This is in agreement with our findings in the other spiral and irregular galaxies we have studied so far.

Very recently, Madore et al. (2009) have published a Cepheid distance to NGC 247 based on optical (VRI) CCD images obtained at the CTIO some 25 years ago. Their distance result of $27.81 \pm 0.10$ mag is in near-perfect agreement with our distance reported in Paper I based on the same filters ($V$ and $I$). The mean reddening they derive for the Cepheids in NGC 247 from their data of $E(V - I) = 0.07 \pm 0.04$, corresponding to $E(B - V) = 0.12$, is also almost identical to our own value of $E(B - V) = 0.13$ found in Paper I. Their sample of nine Cepheids contains six objects independently discovered in our own survey, and the light curve agreement is excellent for all common variables with the exception of one object, cep020 ($P = 65.862$ days) in our catalog in Paper I. The long time difference between the Madore et al. and our own observing epochs indicates that both period and the mean brightness of this peculiar Cepheid have changed over the past $\sim 25$ years. This peculiar Cepheid is not contained in our present infrared-observed fields, and therefore not a source of systematic uncertainty in our present distance moduli derived in the $J$ and $K$ bands.

The excellent agreement of the results of Madore et al. (2009) with the results obtained in Paper I is reassuring and constitutes a valuable external check of our own previous results from optical photometry. The inclusion of infrared photometry in this paper shows again (see previous papers in this series) that this is an absolutely essential step to determine the total Cepheid reddening with a truly high accuracy. The decrease of the true distance modulus of NGC 247 found in this paper as compared to Paper I, and the Madore et al. (2009) result, is just a consequence of an underestimate of the mean Cepheid reddening in both papers based on optical data alone which provide a wavelength base which is just too small, even with very good data, to assess the reddening with reasonable accuracy. This is also seen in Figure 5; the slightly outlying distance modulus in $I$ produced the smaller reddening, and larger distance modulus we had obtained in Paper I from the $V$ and $J$ data only.

As in the previous papers in our project, we have applied utmost care to determine the zero points of our photometry as accurately as possible. From the arguments given in Section 2 and our previous experience we believe that the zero points are accurate to better than $\pm 0.03$ mag, in both $J$ and $K$ bands. An issue of concern is the crowding of stars in the images of NGC 247 which could cause significant blending for some of Cepheids, increasing their observed fluxes. To minimize this problem, we chose our observed fields in NGC 247 in the least crowded regions of the galaxy (see Figure 1). Fortunately, our VLT images are of exquisite quality and the seeing during the exposures did never exceed 0.6 arcsec (for most images it was 0.4–0.5 arcsec). For none of the 10 Cepheids in Table 2 is evidence for a photometrically significant companion star in the infrared images. This is also borne out in the PL diagrams shown in Figures 3 and 4, where no obvious outlier is observed. A significantly blended Cepheid should be too bright for its period and stand out from the mean PL relation, and this is clearly not observed in the case of our sample. The only candidate, from its location in the $K$-band PL plane, would be the variable cep016 which is $\sim 0.25$ mag brighter than the ridge line at the corresponding period, but such an offset is compatible with the combined effect of the intrinsic width of the Cepheid instability strip, which is about $\pm 0.2$ mag in the $K$ band, and the standard deviation of the mean $K$ magnitude of this star of $\pm 0.07$ mag (see Table 2). Also, this star lies almost exactly on the ridge line in the $J$-band period–luminosity plane, arguing against significant blending. As a general guide for the effect of blending on Cepheid distances we can use our previous $HST$-based study on NGC 300 which is also a member galaxy of the Sculptor Group. Comparison of $HST$ ACS photometry to ground-based photometry allowed us to set an upper limit of $\pm 0.04$ mag for the effect blending of the Cepheids in NGC 300 might have on the derived Cepheid distance modulus (Bresolin et al. 2005). NGC 300, at about 1.9 Mpc (Gieren et al. 2005a, 2005b, 2005c), is about 1.5 Mpc nearer than NGC 247 however, so we might expect a slightly larger effect of blending for NGC 247. From the arguments given, we assume that 0.06 mag, or 3% is a reasonable upper limit for the possible remaining effect of unresolved stars in the Cepheid photometry on the distance result. The effect acts to make Cepheids too bright and therefore tends to decrease the derived distance.

Another potential cause of concern is the possible non-universality of the Cepheid PL relation. Sandage & Tammann (2008) have recently put forward arguments to demonstrate that both slope and zero point of the PL relation (in any given passband) depend on the slope of the Cepheid instability strip on the H–R diagram, which in turn is metallicity-dependent. They conclude that as a consequence the coefficients of the PL relation must depend, to some degree, on the metallicity of the Cepheids. In their paper, they show a table which reports empirically determined PL relation slopes in different galaxies which indeed seem to suggest that the Cepheid PL relation is steepest for the most metal-rich galaxies, supporting their claim from theoretical arguments. However, the uncertainties on the empirical slopes of the PL relations in the different galaxies they compare are not given; from our own work in the Araucaria Project, which has generally provided the best
Cepheid samples in the different target galaxies of the project, we know that the uncertainties attached to the least-squares fits to the period–magnitude diagrams are generally large enough to hide any systematic change of slope with metallicity, should it exist. So the empirical evidence for a systematic change of the slope of the PL relation (in any band) with metallicity is very weak, at the present time. On the other hand, the Optical Gravitational Lensing Experiment (OGLE) project has found, from many hundreds of extremely well-observed Cepheids in both Magellanic Clouds, that the slopes of the Cepheid PL relations in $V$ and $I$, respectively, in both Clouds agree very well, within extremely small uncertainties (Udalski et al. 1998; Udalski 2000), in spite of the metallicity difference of ~0.4 dex between its Cepheid populations (Luck et al. 1998), arguing against a dependence of the PL relation slope on metallicity. Also, very recent and improved work using the infrared surface brightness technique (Fouqué & Gieren 1997; Gieren et al. 1997) to measure direct distances to Cepheids in the Milky Way galaxy and the LMC has led to a recalibration of the method which has produced PL relations in the LMC and Milky Way, in passbands from $B$ through $K$, whose respective slopes agree within a fraction of their respective standard deviations (Gieren et al. 2005c; Fouqué et al. 2007). It seems to us that the accumulated empirical evidence favors a universal, metallicity-independent slope over the scenario put forward by Sandage and Tammann, at the present time, but further work on this crucial question is obviously required. Until truly convincing empirical evidence becomes available demonstrating a significant metallicity effect on the slope of the PL relation, we will assume the constancy of the slope in all photometric bands, in agreement with the results we have obtained so far in the Araucaria Project.

Regarding the effect metallicity has on the zero point of the Cepheid PL relation, a recent study of Romaniello et al. (2008) indicates that there is indeed a small effect in optical bands, but only a marginal effect in the near-infrared $K$ band. In $V$, metal-rich Cepheids appear to be slightly intrinsically fainter than their more metal-poor counterparts. The smallness and sign of the metallicity effect on the Cepheid PL relation zero points found by Romaniello et al. is in agreement with most other published work (discussed in that paper). While we will re-discuss the metallicity effect from our own data on the Araucaria Project galaxies in the near future, our preliminary findings on the metallicity dependence of the PL relation are consistent with a very small, and possible vanishing effect on the zero points in optical and near-IR bands. Any systematic uncertainty on the current distance modulus of NGC 247 from the metallicity difference between its Cepheids and those of the LMC which provide the fiducial PL relation is expected to be very small, probably less than 2%. This statement rests on both the smallness of the metallicity effect as found by Romaniello et al. (2008) and other authors, and the expectation that the mean metallicity of the young stellar population in NGC 247 is quite close to that of the LMC. This second statement is in turn based on the similarity of NGC 247 to NGC 300, whose young stars (and H II regions) at mean galactocentric radii have been found to possess LMC metallicity (Kudritzki et al. 2008; Bresolin et al. 2009).

As in the previous papers in this series, the distance of our target galaxy in this paper, NGC 247, is tied to an assumed distance modulus of 18.50 mag for the LMC. In spite of the intense work of many groups over the years, this value may still be uncertain by as much as 10% (e.g., Benedict et al. 2002; Schaefer 2008). Very recently, the discovery of a number of late-type eclipsing binary systems in the LMC for which the distances can be measured very accurately has opened a new possibility to measure the distance to the LMC with an unprecedented accuracy (Pietrzyński et al. 2009). This new route might finally allow to measure the LMC distance with an accuracy close to 1%.

From the discussion in this section we conclude that the total systematic uncertainty on the new infrared-based Cepheid distance reported in this paper is in the order of ~4%. In estimating this number, we assume that future work will confirm the universality of the slope of the Cepheid PL relation. The 4% systematic error of our current distance determination does not include the current uncertainty of the adopted LMC distance.

Among the various attempts which were made in the past to determine the distance to NGC 247 (which have been listed and discussed in Paper I), the present determination is clearly the most accurate one. Probably the most accurate previous measurement with methods independent of Cepheids was made by Karachentsev et al. (2006) with the Tip of the Red Giant Branch (TRGB) method; their distance result of 27.87 ± 0.21 mag agrees with our infrared Cepheid distance within the combined 1σ error bars of both measurements. The fact that it agrees even better with our previous Cepheid distance to NGC 247 from $VI$ data is certainly fortuitous and may have its explanation in the systematic uncertainties affecting the TRGB method.

The distance of NGC 247 determined in this paper confirms that this galaxy is quite significantly more distant than the other two member galaxies of the Sculptor Group we have studied before, NGC 55 (Gieren et al. 2008a; Pietrzyński et al. 2006b) and NGC 300 (Gieren et al. 2005b). This confirms the previous conclusion of Jerjen et al. (1998) that the Sculptor Group exhibits a filament-like structure with a large depth extension in the line of sight.

5. SUMMARY AND CONCLUSIONS

We have carried out the first distance determination for the spiral galaxy NGC 247 located in the nearby Sculptor Group using deep near-infrared images, and our multiwavelength technique presented and applied in the earlier studies in this series. The distance we determine has a random uncertainty less than 2%, and a systematic uncertainty in the order of ±4%. The systematic uncertainty is likely to be dominated by the effect of unresolved stars on the Cepheid photometry while the effect of metallicity on the Cepheid PL relation, and particularly the effect of interstellar absorption are only smaller contributors to the total systematic uncertainty of our result. The full assessment of the reddening suffered by the NGC 247 Cepheids due to the use of near-infrared photometry has led to a decrease of the distance modulus reported in Paper I, and independently by Madore et al. (2009), by 7%. As in all our previous studies in the Araucaria Project, the distance to NGC 247 is tied to an assumed distance modulus of 18.50 for the LMC.

We find a mean reddening of $E(B-V) = 0.18$ mag for the Cepheids in NGC 247. Since the foreground reddening to this galaxy is only ~0.02 mag (Schlegel et al. 1998), 0.16 mag are produced inside NGC 247, which is higher than in any other galaxy we have studied so far in the Araucaria Project. This shows that it is mandatory to use deep infrared photometry to handle the absorption problems when using Cepheids for distance determinations to relatively massive spiral galaxies.

The present study adds another spiral galaxy to our sample of galaxies in the Araucaria Project for which an accurate Cepheid distance, based on deep infrared photometry, is now available.
for comparative analyses with the distances obtained from other stellar techniques, particularly the TRGB method (e.g., Rizzi et al. 2006), and the FGLR method (Kudritzki et al. 2003, 2008). Such comparative analyses will improve the determination of the environmental dependences of the different techniques of distance measurement.

We find that NGC 247 is about 1.5 Mpc more distant than the Sculptor Group spirals NGC 300 and NGC 55, and therefore not physically associated with neither of these two spirals.

W.G., G.P., and D.M. gratefully acknowledge financial support for this work from the Chilean Center for Astrophysics FONDAP 15010003, and from the BASAL Centro de Astrofisica y Tecnologias Afines (CATA) PFB-06/2007. Support from the Polish grant N203 002 31/046 and the FOCUS subsidy of the Foundation for Polish Science (FNP) is also acknowledged. I.S. was supported by the Foundation for Polish Science through the Homing Programme. It is a great pleasure to thank the support astronomers at ESO-Paranal for their expert help in the observations, and the ESO OPC for the generous amounts of observing time at the VLT allocated to our Large Programme.

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