THE DISTANCES TO NEARBY GALAXIES FROM NEAR-INFRARED PHOTOMETRY OF CEPHEIDS

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Abstract. Near-infrared photometry of Cepheid variables in the Local Group galaxies, NGC 6822, IC 1613, and M33, and in the M81 Group galaxy, NGC 2403 has been used to determine new, independent distances to these objects, which are almost unaffected by dust extinction and by differences in metallicities among the galaxies.

Introduction

The advantages inherent in using the near-infrared Period-Luminosity (P-L) relation have been discussed in some detail by McGonegal *et al*. (1982) and in various papers at this meeting. For the purpose of using the technique for more distant galaxies, it should be stressed that it is the smaller variation of surface brightness with temperature that allows near-infrared observations of Cepheids in external galaxies to be practical. The intrinsic width of the *H* band (1.65 um) P-L relation for random-phase observations has been shown to be approximately the same as that for fully phase-averaged *V* (0.55 um) measurements. Thus, single-phase near-infrared observations of Cepheids in external galaxies can lead to apparent distance moduli which have about the same intrinsic uncertainty as the best available in the optical; however, the large telescope time required for such measurements is an order of magnitude less, and it is primarily this consideration that makes the near-infrared technique so attractive. In addition, the smaller extinction in the near-infrared means that the uncertainty in the true distance modulus to a galaxy is likely to be smaller than in the optical.

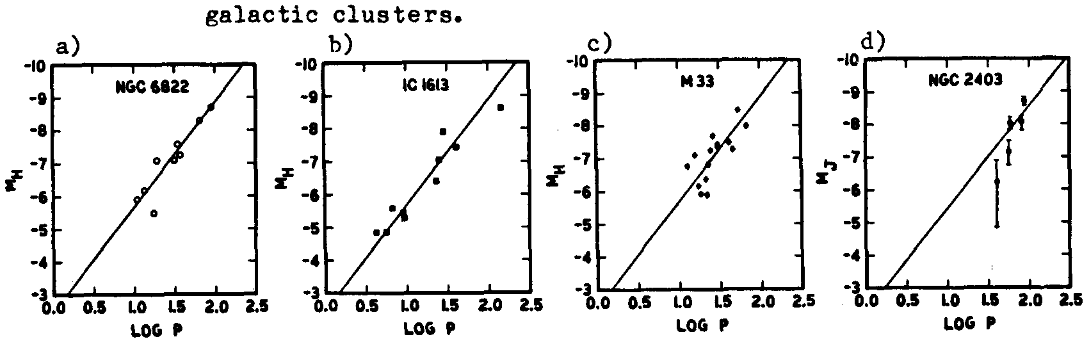
Over the past three years, observations of Cepheids in six nearby galaxies have been carried out. Welch *et al*. (1984) have already discussed the continuing program to monitor the Cepheids in the Magellanic Clouds. This paper will discuss four more distant objects observed.

Observations

More than 90% of the near-infrared observations of extragalactic Cepheids outside the Magellanic Clouds have been obtained with the Multiple Mirror Telescope (MMT), operated by the Smithsonian Institution and the University of Arizona. The telescope has a collecting area equivalent to a 4.5m conventional telescope, and the specialized near-infrared photometer built for the MMT is the most sensitive such system in the world. As an example of the sensitivity of the photometer, a signal-to-noise ratio of one can be obtained in one hour of integration for an object of $J = 22.3$. The mount for the MMT is altitude-azimuth, and chopping is performed in elevation. This provides a singular advantage when observing Cepheids in the crowded fields of external galaxies. Multiple observations of a given Cepheid, when obtained several hours apart, will be made at significantly different position angles, and the effects of field crowding can be minimized.

The four galaxies which have been observed are the Local Group members NGC 6822, IC 1613, and M33. In addition, several Cepheids in NGC 2403, which is probably a member of the M81 group, were also measured. Further descriptions of the observations can be found in McAlary et al. (1983), McAlary, Madore, and Davis (1984), McAlary and Madore (1984), and Madore et al. (1984). For the Local Group members, the Cepheids are all brighter than 19th magnitude in the near-infrared and were therefore observed in the H band so as to minimize reddening and intrinsic strip width. The extreme faintness of the Cepheids in NGC 2403 necessitated observations in the J band, where the MMT photometer is about 0.7 mag more sensitive. The observations are shown in Fig 1, where the solid line indicates the composite P-L relation determined by Welch et al. (1984).

Fig. 1 Near-infrared P-L relations for a) NGC 6822, b) IC 1613, c) M33, and d) NGC 2403. Photometric uncertainties for the Local Group galaxies are about twice the size of the symbols. The solid line is the composite P-L relation determined from Cepheids in the Magellanic Clouds and galactic clusters.



The distances to the four galaxies were determined by incorporating the observations into a multiple linear regression fit which also included the galactic cluster Cepheids (Caldwell 1983) and those in the Magellanic clouds. The distances are given in Table 1. These compare favorably with most other determinations with the exception of NGC 6822, where the extinction appears to have been underestimated in most optical studies, and for NGC 2403, where our distance is even larger than that found by Tammann and Sandage (1968). Recently, however, Sandage (1984)

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has estimated the distance modulus to be 27.9, in good agreement with our result. Our result for M33 also disagrees with that of Sandage (1983). At least part of this must be related to his low value for the foreground and internal extinction toward the Cepheids in the galaxy, but there may also be residual zero-point errors in his re-analysis of the photographic photometry of Hubble (1926).

The Red Supergiant Calibration

Beyond the realm of the Cepheids, distance moduli are not well determined. It is now generally conceded that the diameters of HII regions are not reliable indicators, and Sandage (1984a) has shown that the brightness of the blue supergiants within a galaxy is a strong function of the galaxy's intrinsic luminosity. In a series of papers on the supergiants of nearby galaxies Humphreys (1984, and references therein) has asserted that the absolute visual magnitude of the brightest red supergiants is a constant for all galaxies, with M_V=-8.0. Since we now have a consistent set of distances for 6 galaxies with detailed searches for supergiants, this hypothesis can be properly tested. Fig. 2 shows how the _V_ and _K_ magnitudes of the 3 brightest supergiants, corrected for extinction, relate to the absolute _B_ magnitude of the galaxy, corrected for foreground extinction and inclination effects. It is immediately apparent that, while the mean _V_ magnitude is approximately -8.0, there is definately a trend toward brighter supergiant magnitudes with higher luminosity galaxies. This effect is even more pronounced in the _K_ band.

This should not be viewed as discouraging for distance work. The slope of the relation is very shallow, and far removed from that of a distance degenerate case. When a least-squares solution is run on the data, it gives hope that the dispersion of the fit may not exceed 0.15 mag. Since the red supergiants can be detected out to the distance modulus of the Virgo cluster, such an uncertainty would be a great improvement over present techniques.

Table 1 Distance Moduli of Nearby Galaxies

Galaxy	No. Cepheids	$(m-M)_H$	E(B-V)	$(m-M)_o$
LMC	39	18.54 ± 0.06	0.08 ± 0.04	18.50 ± 0.07
SMC	25	18.91 ± 0.06	0.08 ± 0.04	18.89 ± 0.07
NGC 6822	9	23.49 ± 0.13	0.36 ± 0.06	23.30 ± 0.13
IC 1613	10	24.10 ± 0.14	0.03 ± 0.03	24.08 ± 0.14
M 33	15	24.28 ± 0.14	0.2: ± 0.1	24.17 ± 0.15
NGC 2403	5	28.14 ± 0.21[1]	0.06 ± 0.03	28.09 ± 0.21

[1] $(m-M)_J$

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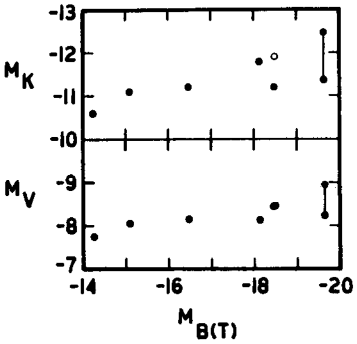
Fig. 2 Absolute magnitude of the three brightest red supergiants in a galaxy in the V and K bands as a function of the absolute B magnitude of the galaxy. The open circle is represents the local galactic neighborhood. The two points shown for NGC 2403 (connected by a line) indicate the range in absolute luminosity possible if the candidates proposed by Sandage (1984) are shown to be supergiants.



Conclusions

The advent of modern infrared techniques has allowed a significant improvement in our estimates of the distances to nearby galaxies. There are only two more objects, M31 and NGC 300, which can be observed in this manner, and observations of both are planned. The major problem with photometry of Cepheids in external galaxies is field crowding, and this accounts for more than one-half of the uncertainty in distance modulus. In the next year the infrared Astronomy group at Steward Observatory hopes to have in operation a near-infrared CCD. If the Cepheids can be detected with this device, distance moduli for galaxies out to 4 Mpc will be obtainable with 0.1 mag accuracy.

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