The Distance to M33 Based on BVRI CCD Observations of Cepheids

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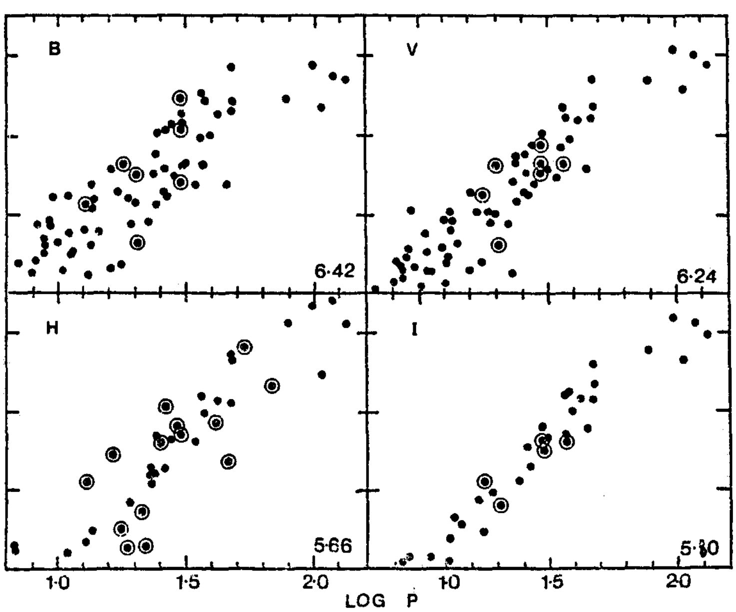
Introduction

As part of a long-term program to study the distance and stellar content of M33, CCD frames of a number of fields centered on known Cepheids in this galaxy (Hubble 1926, Sandage and Carlson 1983) have been obtained, in collaboration with Madore, McAlary, and Davis. The observations were made at the prime focus of the Kitt Peak 4m telescope, and reduced using the Kitt Peak RICHFLD profile fitting programs. These data are still preliminary, but quite sufficient to illustrate the power in the application of our method.

Figure 1. Differential (M33-LMC) P-L Relations



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The Application of I-band Photometry of Cepheids to the Determination of Distances

McGonegal et al. (1982) have illustrated the advantages of near-infrared photometry applied to the cepheid Period-Luminosity (PL) relation. The effects of reddening and metallicity are reduced at longer wavelengths, and the amplitude of the Cepheids themselves decreases toward the red, so that the scatter in the PL relation is significantly reduced compared to the optical, even for random phase observations. However, the main disadvantage of the method is the following: aperture photometry, which is presently the only readily available technique for near-infrared observations, is limited by crowding in the main beam and by background contamination in the comparison beams.

Panoramic detectors such as CCD's, however, offer the advantage of seeing-limited photometry while retaining a linear response. With these detectors the stellar magnitude, locally corrected for background light can be well-determined using profile-fitting techniques. Working with stellar profiles, rather than fixed apertures, has a distinct advantage for the more distant systems. The following study was undertaken in order to combine the advantages offered by both techniques: the CCD observations were extended as far to the red as possible (0.9μm). The R and I bands are relatively insensitive to the radiation redistribution effects due to possible metallicity variations from galaxy to galaxy (see McGonegal et al. 1982, their Figure 1). Furthermore, the effects of extinction are more than a factor of 2 lower at I with respect to B.

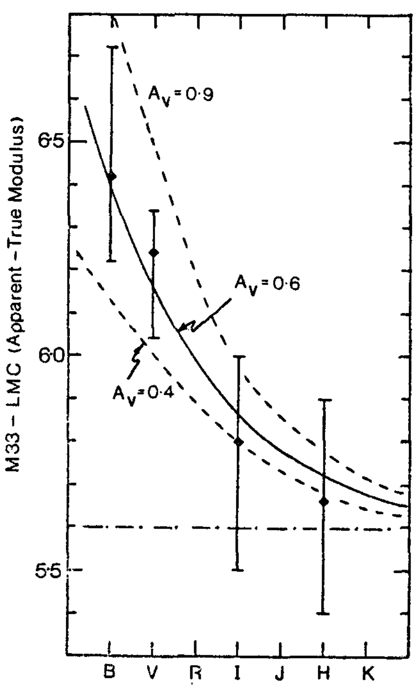

Figure 2. Differential moduli versus wavelength.

Distance to M33

The Cepheids in Field No. 1 in M33 have periods ranging from 18 to 42 days. The solid dots in Figure 1 show PL relations in BVI obtained from photoelectric photometry of Cepheids in the LMC (Martin, Warren and Feast 1979; Grieve 1983). H-band observations from the study by McGonegal et al. (1982) are also plotted (lower left panel). Differential reddening has not been corrected for in any of the plots. Superimposed on the LMC mean-light relations are the CCD data for the M33 Cepheids (circled dots), each shifted in distance modulus by an amount which gives the minimum scatter between the LMC and M33 P-L relations for BV and I. Also plotted for comparison, are the H-Band observations of Madore et al. (1984) for M33.

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The scatter in the M33 H data is appreciably larger than the scatter in the LMC H-band data. This is likely the result of contamination problems. At the increased distance of M33 relative to the LMC, crowding in the main beam and comparison fields is more severe. The scatter of the random-phase I observations on the other hand is much lower than at H indicating that the CCD method can likely be applied with success to distance determinations further than the infrared aperture photometry technique. A single CCD observation, which can be obtained at R or I, is therefore a highly competitive alternative to classical B photometry, which requires many nights of observing to follow the variation.

The shifts in magnitude which result in the minimum scatter between the LMC and M33 data at each of the various wavelength bands are: 6.42 at B, 6.24 at V, 5.80 at I and 5.66 at H. These differences in apparent moduli as a function of wavelength are plotted in Figure 2. The shape of this relation is the same as that expected for the extinction as a function of wavelength. If we assume that the true distance modulus is being approached as the wavelength increases, and choose a true differential distance modulus of 5.6, then the extinction at V and A_V = 0.6. Computing the extinction at the various other wavelengths using the recent calibration of Leitherer and Wolf (1984), the solid curve drawn in Figure 2 is obtained. Lower and upper limit extinctions which bracket the data are shown as dashed lines at values of A_V = 0.4, and 0.9 mag, respectively.

An extinction of E(B-V)=0.08 has been applied to the LMC data, and a distance modulus of 18.5 adopted (McGonegal et al. 1982). This results in a new preliminary distance modulus of 24.1 for M33, 1.2 mag closer than the recently determined apparent blue modulus of 25.3 preferred by Sandage (1983). Part of this difference may be attributed to the inclusion of E(B-V)=0.2 mag of internal absorption in M33 itself, and part to the higher LMC distance modulus adopted by Sandage.

References

Grieve, G. 1983, (Unpublished Ph.D. thesis: University of Toronto)
Hubble, E. 1926, Ap. J., 63, 236.
Leitherer, C. and Wolf, B. 1984, Astr. and Ap., 132, 151.
McGonegal, R. McLaren, R. A., McAlary, C.W. and Madore, B.F. 1982, Ap. J. (Letters), 257, L33.
Madore, B.F., McAlary, C.W., McLaren, R.A., Welch, W.L. and Neugebauer, G. 1984,(in preparation)
Madore, B.F., Freedman, W.L., Grieve, G., McAlary, C., and Davis, L. 1985, (in preparation).
Martin, W.L., Warren, P.R. and Feast, M.W., 1979, M.N.R.A.S., 188, 139.
Sandage, A.R. 1983, A.J., 88, 1108.
Sandage, A.R. and Carlson, G. 1983, Ap. J. (Letters), 267, L25.

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