The period–luminosity relation for Mira variables and the distance of the Large Magellanic Cloud

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Summary. New data by Wood, Bessell & Paltoglou are shown to provide strong confirmation of the LMC Mira P–L relation discovered by Glass & Lloyd Evans. At K, both carbon and non-carbon Miras fit the same relation. Results from Cepheids, OB stars, main-sequence fitting, RR Lyrae and Mira variables are consistent with a true LMC distance modulus of 18.50±0.10 if (M_L(RR))=+0.6 at all metallicities including the metal-rich globular clusters containing the Miras studied by Menzies & Whitelock. However the results would also be consistent with the metal-rich RR Lyrae variables being ~0.15 mag fainter than metal-poor ones. There is some suggestion of such a difference in α Cen.

1 The Mira period–luminosity relation

The first evidence that Mira variables might be rather precise distance indicators came from the work of Glass & Lloyd Evans (1981). They discovered 11 Mira variables in the LMC and obtained infrared photometry for them. This showed the existence of a relation between period and bolometric magnitude which had very little scatter (σ=0.22). Similar good relationships may be derived in J, H and K (Glass & Feast 1982). It is obviously important to confirm this work with more extensive data and the opportunity to do so has now arisen through the work of Wood, Bessell & Paltoglou (1984, WBP). These workers have discovered 33 new Mira variables with periods in the range 155–417 day in an LMC field. [An additional object of considerably brighter luminosity and longer period (526 day) probably belongs with the more luminous red variables discussed by various workers (cf. Lloyd Evans 1984 for a summary) and is omitted here.] WBP obtained single observations of their variables in JHK. They discuss their results from the point of view of stellar evolution and epochs of star formation but do not directly discuss the question of the period–luminosity relation.

For the purposes of the present analysis the data of WBP have been converted to the SAAO system (Glass 1983 and unpublished). Absorption corrections A_J=0.06, A_H=0.03, A_K=0.02 have been applied, corresponding to E(B–V)=0.074 for the LMC (Caldwell & Coulson 1984). Fig. 1(a) shows a plot of K_0 against log P. Data from Glass & Feast (1982) are included and the M or S-type Miras are distinguished from the carbon type. The line is a least-squares fit and has the form:

\[ K_0 = 19.03 - 3.291 \log P. \] (1)
Within the errors the carbon and non-carbon Miras fit the same relation. Some of the scatter about the line must result from the data of WBP being single (random phase) observations only. Nevertheless the overall scatter is remarkably small ($\sigma=0.21$).

Bolometric magnitudes have been derived from the data using the procedure outlined by Robertson & Feast (1981). A good period–luminosity relation is found but with the carbon Miras slightly separated from the rest. Least-squares solutions give:

for non-carbon Miras

$$m_{\text{bol}}=19.56-2.242\log P \quad \sigma=0.26,$$

for carbon Miras

$$m_{\text{bol}}=19.32-2.092\log P \quad \sigma=0.19.$$

These two relations differ by only 0.08 to 0.16 at a given period. Pending more precise determinations of the bolometric magnitudes, the significance of this small difference for stars of rather different energy distribution should not be over-emphasized. It may be noted that WBP attempt to make some correction of their random phase bolometric magnitudes to mean light. The method they employ is very approximate and in fact applying these corrections results in no decrease in the scatter.

2 The Mira zero point and the distance to the LMC

It is convenient to discuss the zero point of the Mira $P–L$ relation in terms of the implied distance modulus of the LMC since it may then be compared with the results from other distance indicators. Table 1 lists moduli from the more important indicators and these are discussed below. The reddening corrections given in the various references cited were retained.
Table 1. Estimates of the true modulus of the LMC.

1. Cepheids
   (a) ZAMS (Caldwell 1983) \( \Delta m = 18.64 \pm 0.15 \)
   (b) H\beta (Balona & Shobbrook 1984) \( \Delta m = 18.54 \pm 0.10 \)
   Unweighted Mean \( \Delta m = 18.59 \pm 0.10 \)

2. OB Stars (Crampton 1979) \( \Delta m = 18.68 \pm 0.2 \)

3. Main Sequence Fitting (Schommer et al. 1984) \( \Delta m = 18.32 \pm 0.2 \)

4. RR Lyrae Variables in NGC 2210 (Walker 1984)
   (a) \( \langle H_R \rangle = 0.6 \) \( \Delta m = 18.42 \pm 0.10 \)
   (b) \( \langle H_R \rangle \) (Sandage) \( \Delta m = 18.29 \pm 0.10 \)
   (c) \( \langle H_R \rangle \) (Lub) \( \Delta m = 18.79 \pm 0.10 \)

5. Mira Variables
   (i) Miras in Globular Clusters (Henzies & Whitelock 1984)
      (a) \( \langle H_R \rangle = 0.6 \) \( \Delta m = 18.50 \pm 0.06 \)
      (b) \( \langle H_R \rangle \) (Sandage) \( \Delta m = 17.90 \pm 0.04 \)
      (c) \( \langle H_R \rangle \) (Lub) \( \Delta m = 18.45 \pm 0.04 \)

   (ii) Other Individual Miras
      (Statistical Parallaxes)
      \( \Delta m = 18.46 \pm 0.3 \)
      Adopted LMC Modulus \( \Delta m = 18.50 \pm 0.10 \)

NOTE: The standard errors in brackets are internal only i.e. they do not take into account uncertainties in the adopted absolute magnitude calibration.

2.1 CEPHEIDS

(1) Caldwell’s \( P – L – C \) zero point from galactic clusters containing Cepheids uses a ZAMS from Schmidt-Kaler (1982) with a Hyades modulus of 3.28 mag and an (effective) Hyades metallicity correction of 3.03+0.1–3.28=−0.15 mag. Changing this correction to −0.22 mag (Pel 1984) and adopting Caldwell’s LMC Cepheid metallicity correction of −0.16 mag (cf. Feast 1984) with the LMC data of Martin, Warren & Feast (1979), leads to the tabulated figure.

(2) Balona & Shobbrook’s (1984) \( P – L – C \) zero point from H\beta photometry of galactic clusters containing Cepheids is based on a Pleiades distance modulus of 5.50. Their result has been adjusted to a Pleiades modulus of 5.57 (van Leeuwen 1983). This latter modulus is consistent with the Hyades modulus of (1) (cf. Pel 1984). Other details are as in (1).

The two Cepheid determinations agree well (contrary to some earlier determinations using these two methods) and a straight mean has been adopted.

2.2 OB STARS

Crampton’s modulus has been amended to take into account changes in the Hyades and Pleiades moduli noted above. These moduli are basic to his distance scale.

2.3 MAIN-SEQUENCE FITTING

Schommer, Olszewski & Aaronson (1984) obtain 18.7±0.2 from a fit of the Hyades main sequence (modulus=3.29) to LMC clusters. Adopting a metallicity of \([Fe/H]=+0.15\) for the
Hyades and $-0.15$ for the LMC clusters leads to a modulus correction of $-2 \times 0.22$ mag (cf. Pel 1984). Adopting a Hyades modulus of 3.28 [as in (1)] and a mean correction for the cluster moduli to the centre of the LMC of $+0.06$ (Schommer et al.) leads to the tabulated modulus. For consistency we consider only the fit to the Hyades and not fits to model calculations although the latter do not give significantly different moduli.

### 2.4 RR Lyraes in NGC 2210

Details are given by Walker (1984) who obtained accurate (CCD) magnitudes for RR Lyrae variables in this cluster of known metallicity ([Fe/H] = $-1.9$). Despite much work the absolute magnitudes of RR Lyrae variables remain uncertain. Results are given in Table 1 for (1) the conventional value, $\langle M_V (RR) \rangle = +0.6$; (2) the Sandage (1982) relation, $\langle M_V (RR) \rangle = 1.39 + 0.35$ [Fe/H]; (3) $\langle M_V (RR) \rangle = 0.82 + 0.31$ [Fe/H], estimated from the discussion of Pel & Lub (1978). The Lub relation is 0.5 to 0.6 mag brighter than that of Sandage.

### 2.5 Miras

For the present analysis only the $K$ magnitude result (i.e. equation 1) is used. Provided the distance scale for (metal-rich) globular clusters is known the zero point of the Mira $P-L$ relation can be obtained with high accuracy from the work of Menzies & Whitelock (1984) on Miras in globular clusters. Three possible distance scales are considered depending on the three RR Lyrae scales just discussed. Fig. 1(b) shows the results of Menzies & Whitelock adopting the Lub relation with the line from equation (1) moved to fit the points in the mean. As discovered by Menzies & Whitelock the fit is better when a dependence of $\langle M_V (RR) \rangle$ on [Fe/H] is included $[\sigma (Lub) = 0.13, \sigma (Sandage) = 0.12]$ than without ($\sigma = 0.23$). The residuals are correlated with [Fe/H] in the latter case and this is some evidence in favour of a Sandage–Lub type relation at least for the metal-rich RR Lyraes. The crosses in Fig. 1(b) are for other Miras with individual distances (members of visual binaries or moving groups). Both these and the statistical parallax results (Robertson & Feast 1981 and references there) unfortunately scatter rather widely in absolute magnitude (partly no doubt due to uncertainties in the individual distances). The six individual Miras imply an LMC modulus of $18.79 \pm 0.19$ while the statistical parallaxes give $18.17 \pm 0.12$ internal standard error). A mean of these two values (with a large standard error) is tabulated.

### 3 Conclusions

The above discussion and the results of Table 1 lead to the following conclusions:

1. Cepheids, OB stars and main-sequence fits are consistent with one another within the errors and yield an unweighted LMC modulus of 18.53.
2. The RR Lyraes and Miras agree with this modulus if $\langle M_V (RR) \rangle = +0.6$ (Table 1, 4a and 5a) yielding an overall mean for all five classes of object of 18.50.
3. If $\langle M_V (RR) \rangle$ depends on [Fe/H] then the Miras in globular clusters show that the zero point of Lub is required to bring the Miras into agreement with a mean LMC modulus of 18.5 (cf. Table 1, 5c). However if the Lub (or Sandage) relations applied to both the metal-rich RR Lyraes in globular clusters (used to calibrate the Miras) and the RR Lyraes in the LMC metal-poor cluster NGC 2210, there should be close agreement between Table 1, 4b and 5b (or between 4c and 5c). This agreement is lacking. Either a Sandage–Lub type relation does not extend over all metallicities or the RR Lyrae and/or Mira variables differ from one stellar system to another in a manner not yet understood. Some slight support for the former hypothesis is found in $\omega$ Cen.
(Butler, Dickens & Epps 1978) where \(M_V(\text{RR})\) is constant from \([\text{Fe/H}]=-2.2\) to \(-1.2\) with in addition a group of five metal-rich variables \([\text{Fe/H}]=-0.76\) which are 0.15 mag fainter. The resolution of these problems requires further data. In the meanwhile the available data for the distance indicators discussed can be made consistent with an LMC modulus of 18.50±0.10. Combining this with equation (1) yields

\[
M_K = 0.53 - 3.291 \log P
\]

as the best currently available Mira \(P-L\) relation.

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References