IRAC Band Period-Luminosity Relations from LMC Cepheids: Application to Three Nearby Galaxies

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Abstract. It is well-known in the cosmology community that an accurate determination of the Hubble constant (H_0), to within few percent, can be used to break the degeneracy between Ω_M and H_0 in CMB measurements. The current uncertainty in H_0 from the HST Key Project is about 10%. In contrast future observations by the James Webb Space Telescope (JWST) have the potential to deliver an H_0 measurement accurate to under a few percent. This is because JWST will operate in the near and mid infrared, thus significantly reducing the influence of extinction. Motivated by this, we derive Spitzer IRAC band period-luminosity (PL) relations (the Leavitt Law) from the Large Magellanic Cloud Cepheids which can be applied to future distance scale measurements with JWST. To test these PL relations, we applied the IRAC band PL relations to the three nearby galaxies (NGC 6822, IC 1613 & WLM), where the Cepheid data were found from the Spitzer Archival data, and derive the distance moduli (in IRAC bands) to these galaxies. We also compare our results to the distance moduli derived using the reddening free Wesenheit function in optical.

Keywords: Cepheids — Distance Scale

INTRODUCTION

The James Webb Space Telescope (JWST) will be operated in near and mid infrared, with a potential of measuring the Hubble constant (H_0) within few percent accuracy. An accurate measurement of H_0 will help to break the degeneracy in cosmological parameters (between matter density Ω_M and H_0) measured from CMB. It is possible that JWST will reobserve or discover a large number of extragalactic Cepheids. Therefore, there is a need of the mid infrared period-luminosity (PL) relation, also known as the Leavitt Law, in order to derive the distance to the galaxies that host these Cepheids. As a result, the mid infrared Cepheid PL relations, based on the Spitzer's IRAC band data, were derived in [1] and [2] (see the updated version of the PL relations in [3] and [4], respectively) that can be applied in the future distance scale work.

There are several advantages of using the mid-infrared band PL relations, as discussed in [1, 2, 3, 4]. These include:

- Extinction in the IRAC bands is negligible as compared to the optical bands ([1, 4]). For example, [1] suggests that the extinction in 5.8μm band can be 28 times smaller than in the *B* band.
- The amplitudes of the light curves in IRAC band is expected to be small ($\sim$ 0.4mag, see [3]), hence small number of observation or even a single epoch data may be adequate (see also [2]).
- Influence of metallicity on IRAC band photometry may be significantly reduced ([1]).

However, potential problems for using the IRAC band, or the mid infrared, data of the Cepheids may include:

- The small amplitude of the Cepheid light curves in these wavelength suggest that the detection of the Cepheid need to be done in optical prior to the observation in IRAC band or in the mid-infrared.
- Cepheid may undergo mass-loss, and could produce a circumstellar envelop around the star, which may influence the photometry in those bands ([5]).

THE IRAC BAND PL RELATIONS

Recently, the Optical Gravitational Lensing Experiment (OGLE) team released a catalog of the Cepheids in the Large Magellanic Cloud (LMC) from its third phase of observation (OGLE-III, see [6] for more details of this catalog). The $\sim$ 1800 LMC Cepheids from OGLE-III were matched to the Spitzer IRAC band archival data from the SAGE catalog (Surveying the Agents of a Galaxy's Evolution, see [7]).

The SAGE catalog contains the photometric data from two epoch of observations. We took an average of the photometric data when both epoches were present. We employed an iterative 2.5σ-clippling algorithm to remove the outliers. The derived PL relations in 3.6μm

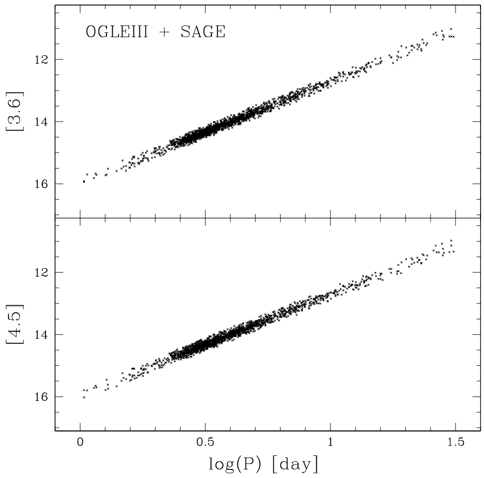

FIGURE 1. The PL relations in 3.6μm and 4.5μm band, after iteratively removing the outliers with 2.5σ-clippling algorithm, derived from matching the OGLE-III LMC Cepheids with the point sources given in SAGE catalog.

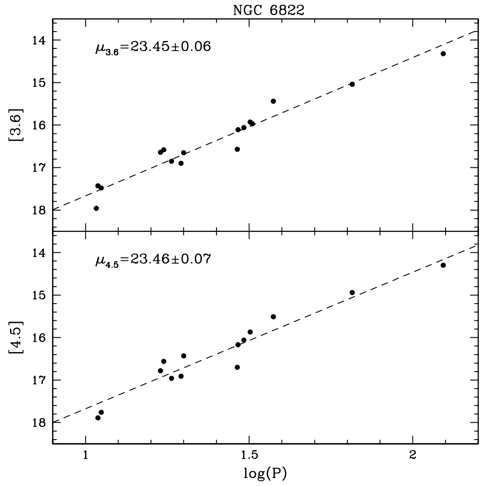

FIGURE 2. Fitted IRAC band PL relations (dashed lines) to the Cepheids data in NGC 6822, where the Cepheid photometry is adopted from [8].

and 4.5μm band are shown in Figure 1, with the following expression (assuming the LMC distance modulus is 18.50):

$$[3.6] = -3.253\log(P) - 2.533 \quad (1)$$

$$[4.5] = -3.214\log(P) - 2.570 \quad (2)$$

The 5.8μm and 8.0μm band PL relations were not included in this Proceeding, however the further details of their treatmenat and derivation can be found in [4].

DISTANCE TO THREE GALAXIES

Using the Spitzer's archival imaging data, [8] and [9] derive the (single epoch) IRAC band photometry for the known Cepheids in NGC 6822 and IC 1613, respectively. These Cepheids were fitted by the PL relations given in equation (1) & (2). The fitted results are presented in Figure 2 and 3 for NGC 6822 and IC 1613, respectively. The derived distance moduli in the 3.6μm and 4.5μm band for these two galaxies are summarized in Table 1 (the quoted errors for the 3.6μm and 4.5μm band distance moduli are random errors only).

In addition to NGC 6822 and IC 1613, we also include WLM in our sample. [12] detected 60 Cepheids in this galaxy from the optical observation. On the other hand, [13] published a stellar catalog based in the Spitzer's IRAC band observation to the WLM. Therefore, we matched the known Cepheids in WLM to the Spitzer IRAC band stellar catalog. We only found 4 and 2 possible matched sources in 3.6μm and 4.5μm band, respec-

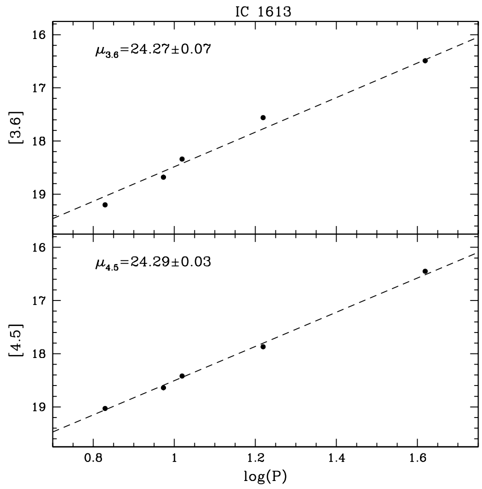

FIGURE 3. Fitted IRAC band PL relations (dashed lines) to the Cepheids data in IC 1613, where the Cepheid photometry is adopted from [9].

TABLE 1. Distance moduli to the three nearby galaxies.

	3.6μm	4.5μm	W_I
NGC 6822	23.45 ± 0.06	23.46 ± 0.07	$23.34 \pm 0.06^{*}$
IC 1613	24.27 ± 0.07	24.29 ± 0.03	$24.43 \pm 0.07^{\dagger}$
WLM	24.97 ± 0.10	24.89 ± 0.07	$25.14 \pm 0.08^{**}$

* Taken from [10].
† Taken from [11], after adjusting the distance using the LMC distance modulus of 18.50.
** Taken from [12].

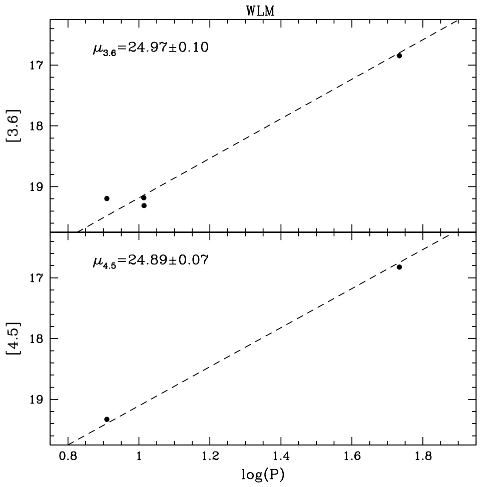

FIGURE 4. Fitted IRAC band PL relations (dashed lines) to the Cepheids data in WLM. The possible Cepheids are found by matching the Cepheid catalog from [12] to the Spitzer's IRAC band stellar catalog from [13].

tively. The fitted PL relations are presented in Figure 4 and the resulted distance moduli are shown in Table 1.

It can be seen from Table 1 that the distance moduli from the 3.6μm and 4.5μm band PL relations show a very good agreement. Even thought the difference of the distance modulus in these two bands is large for WLM, the difference is still within the 1σ of the quoted random errors. We have to remind that the results for WLM is still preliminary, a more robust selection criteria between the matching of Cepheids and IRAC band catalog may imrove the results.

Compare to the Optical Result

Table 1 also lists the distance moduli derived from the optical data, using the reddening free Wesenheit function, $W_I = I - 1.55(V - I)$. Since the effect of extinction is minimal in the IRAC band, the IRAC band distance modulus is expected to be same as the distance modulus derived from using the Wesenheit function. Except the 4.5μm band distance modulus for WLM, other IRAC band distance moduli given in Table 1 agree with the optical distance moduli within ~ 0.1 to ~ 0.2mag (or within $\sim 1.3\sigma$ to $\sim 1.8\sigma$). This difference may due to several reasons: (1) small number of Cepheids to fit the IRAC band PL relations; (2) metallicity correction may be needed for the optical Wesenheit function; and (3) Random phase correct may need to apply to the single epoch IRAC band photometry, even though the amplitude in the IRAC band is small. Further invesigation for this problem will be presented in a future paper.

CONCLUSION

In this Proceeding, we show the IRAC band PL relations derived from the LMC Cepheids, which can be used in future distance scale work based on the observation from JWST. We applied these PL relations to three nearby, low metallicity galaxies, and compare the IRAC band distance moduli to those derived from using the reddening free Wesenheit function in optical. We found that the agreement of the distance moduli is within 0.2mag.

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