Mitigating Random-Phase Errors in Cepheid Variable Star Studies: A Cross-Filter Correction Approach

Mahdi Abdollahi [1], Barry F. Madore[2,3], Atefeh Javadi[1], Wendy L. Freedman[3,4]

[1] School of Astronomy, Institute for Research in Fundamental Sciences (IPM), P. O. Box19395- 5531, Tehran, Iran

[2] The Observatories, Carnegie Institution for Science, 813 Santa Barbara St., Pasadena, CA 91101, USA

[3] Department of Astronomy & Astrophysics, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637, USA

[4] Kavli Institute for Cosmological Physics, University of Chicago, 5640 S. Ellis Ave., Chicago, IL 60637, USA

Abstract

Thanks to the multiwavelength data collected in several surveys conducted by Three-hundred MilliMeter Telescope (TMMT), Swope, duPont and Spitzer telescopes, we can consider the Period-Luminosity (PL) relation from optical to mid-IR of same 92 stars firstly selected by Persson et al. (2004).

It is evident that as we move to longer wavelengths, the dispersion of PL data decreases, indicating a reduction in statistical errors due to the diminishing effect of temperature. In detail, the amplitude of the light curves decreases as the wavelength increases, accompanied by a transition in shape from triangular to cyclical. Furthermore, the peak of the light curves shifts to a later phase (Wisniewski & Johnson 1968). Therefore, working in redder wavelengths (near- and mid-IR) provides us with more reliable results, leading to more accurate determinations of H0, which is crucial in other fields, especially cosmology.

Observations in this range of wavelengths are challenging and often impossible with ground-based telescopes, necessitating space-based telescopes such as JWST. However, these observations are constrained by time limitations due to the many observations they must conduct. This poses a challenge in requiring time-averaged data in subjects like PL relation. This idea emerged from the question: is it possible to derive time-averaged magnitudes from single-epoch observations?

In this project, we aim to discover a relationship to correct random-phase data, resulting in narrower PL data. This method tackles errors originating from the single-epoch observations by utilizing information from observations in another filter, leading to time-averaged data. The technique relies on correlations between residuals from Period-Luminosity (PL) relations and magnitude-magnitude diagrams across various bandpasses, primarily spanning different ranges of wavelengths.

Considering pair plots among all wavelengths, we chose the J and B bandpasses to calibrate and test our method, with the J bandpass representing the random-phase data component. The calibration involved conducting 1000 designed experiments to determine the slopes and intercept of the linear regression model used for correction. Given the considerable number of experiments, we employed statistical techniques to determine the slopes and intercepts by fitting a Gaussian distribution.

The findings illustrate that this correction reduces the scatter around the PL fitted line by approximately √2 in the J bandpass, from 0.24 to 0.17 magnitude, resulting in a decrease in statistical uncertainty in the apparent distance modulus by around a 30% (i.e., (0.24-0.17)/0.24 = 0.29).