

Comparing Cepheid distances: Gaia DR3 and mid-infrared

A consistency analysis using WISE and Spitzer data

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Abstract. Classical Cepheids are pulsating stars whose period-luminosity relation (PLR) makes them fundamental tools for calibrating Type Ia supernovae and determining cosmic distances. This work investigates the consistency between distances derived from Gaia DR3 parallaxes and those obtained from the mid-infrared PLR, utilizing data from the WISE and Spitzer satellites. Our initial sample of 1,589 Cepheids was refined to 245 stars after applying strict quality criteria: (1) astrometric reliability in Gaia DR3 (parallax signal-to-noise ratio > 5); (2) selection of fundamental-mode pulsators; and (3) positive parallaxes with relative errors below 5%. The distances cover a wide range (1–8 kpc), allowing for an evaluation of potential biases in the distance scale. We found good agreement between the distances derived from both methods, although slight offsets suggest a need for continued refinement in the calibration of the mid-infrared PLR.

Resumo. As Cefeidas Clássicas são estrelas pulsantes cuja relação período-luminosidade (RPL) as torna ferramentas fundamentais para calibrar supernovas do Tipo Ia e determinar distâncias cósmicas. Este trabalho investiga a consistência entre as distâncias derivadas das paralaxes do Gaia DR3 e aquelas obtidas a partir da RPL no infravermelho médio, utilizando dados dos satélites WISE e Spitzer. Nossa amostra inicial de 1.589 Cefeidas foi refinada para 245 estrelas após a aplicação de rigorosos critérios de qualidade: (1) confiabilidade astrométrica no Gaia DR3 (razão sinal-ruído da paralaxe > 5); (2) seleção de pulsadores no modo fundamental; e (3) paralaxes positivas com erros relativos abaixo de 5%. As distâncias abrangem um amplo intervalo (1–8,kpc), permitindo a avaliação de potenciais vieses na escala de distâncias. Encontramos uma boa concordância entre as distâncias derivadas por ambos os métodos, embora leves desvios sugeriram a necessidade de um refinamento contínuo na calibração da RPL no infravermelho médio.

Keywords. stars: variables: Cepheids – distance scale – astrometry

1. Introduction

Classical Cepheid variables are primary distance indicators in the cosmic distance ladder due to their tight Period-Luminosity Relation (PLR). Accurate calibration of the PLR is crucial for minimizing systematic errors in the determination of the Hubble constant. Recent data releases, such as Gaia DR3 (Gaia Collaboration et al. 2023), provide highly precise parallaxes for numerous Galactic Cepheids, offering a geometric anchor for the distance scale. However, distance measurements derived from the mid-infrared (MIR) PLR (e.g., using WISE and Spitzer data), which are less affected by interstellar extinction, are often used for comparison and cross-validation (Skowron et al. 2019). This work aims to analyze the consistency between the distances derived from Gaia DR3 parallaxes and those based on the MIR PLR, using a rigorously filtered sample of fundamental-mode Cepheids.

2. Methodology and Sample

Our initial sample comprised 1,589 Classical Cepheids. To ensure the reliability of the comparison, we applied the following stringent criteria, resulting in a final sample of 245 stars: (1) parallax signal-to-noise ratio > 5 in Gaia DR3; (2) restriction to fundamental-mode pulsators; and (3) positive parallaxes with a relative error less than 5%.

TABLE 1. Subset of the final sample of Cepheids comparing distances.

Name	P (days)	D_{Gaia} (kpc)	σ_{Gaia} (kpc)	$D_{\text{P-L}}$ (kpc)	$\sigma_{\text{P-L}}$ (kpc)
AA Mon	3.938	3.186	0.151	4.100	0.114
AD Cru	6.397	3.414	0.154	2.999	0.076
AE Vel	7.134	2.832	0.097	2.303	0.054
AG Cru	3.837	1.347	0.036	1.274	0.046
...

We calculated two distances for each star. The geometric distance via Gaia DR3 parallax (ϖ) in arcseconds:

$$d_{\text{Gaia}}(\text{pc}) = \frac{1000}{\varpi}, \quad (1)$$

and the distance via the P-L relation:

$$d_{\text{PL}}(\text{pc}) = 10^{0.2(m_{\lambda} - M_{\lambda} - A_{\lambda}) + 1}, \quad (2)$$

where m_{λ} is the apparent magnitude, M_{λ} is the absolute magnitude derived from the P-L relation, and A_{λ} is the interstellar extinction.

A detailed comparison of the two distance measurements for a subset of the final sample is presented in Table 1.

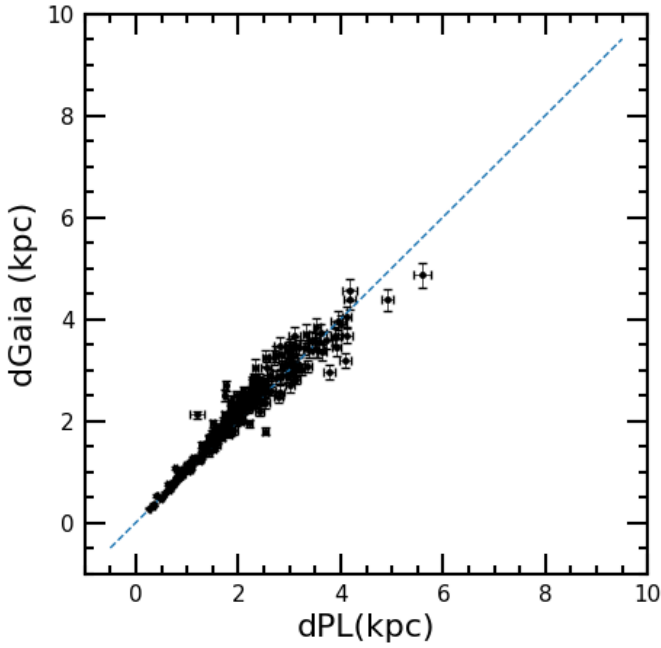


FIGURE 1. Comparison between distances obtained via parallax (d_{Gaia}) and P-L relation (d_{PL}). The solid line represents the linear fit ($m \approx 1.05$), while the dashed line is the identity.

3. Results

The primary objective was to investigate the relationship between the two distance scales. By fitting the Gaia DR3 distances against the MIR PLR distances, we derived parameters for the linear relation $d_{\text{GAIA}} = m d_{\text{PL}} + b$.

The Markov Chain Monte Carlo (MCMC) analysis was used to estimate the parameters (Foreman-Mackey et al. 2013), yielding a slope of $m = 1.0534 \pm 0.0059$ and an intercept of $b = 0.0218 \pm 0.0073$ kpc.

The value of m being close to 1.0 indicates a general agreement between the two distance methods, but the slight deviation suggests a subtle difference in scale. The non-zero intercept b may point to systematic zero-point offsets.

4. Conclusions

Our analysis confirms that the distances derived from the Gaia DR3 parallaxes and the MIR PLR (using the Skowron et al. 2019 calibration) are largely consistent. However, we detected a statistically significant systematic deviation ($m = 1.0534 \pm 0.0059$). For a sample of 245 Cepheids, it was shown that distances calculated via the PRL are systematically underestimated compared to Gaia measurements. This result highlights the need to refine the calibration of the PLR, as the discrepancy suggests the influence of secondary parameters (such as metallicity) not accounted for in current models. Improving the precision of this rung of the distance ladder is critical for calibrating Type Ia supernovae and determining the Hubble Constant.

Acknowledgements. The author thanks God for the strength and inspiration. Immense gratitude to Prof. Leonardo Andrade de Almeida for the guidance. Thanks to the Titan research group for the discussions and to my family for their unconditional support.

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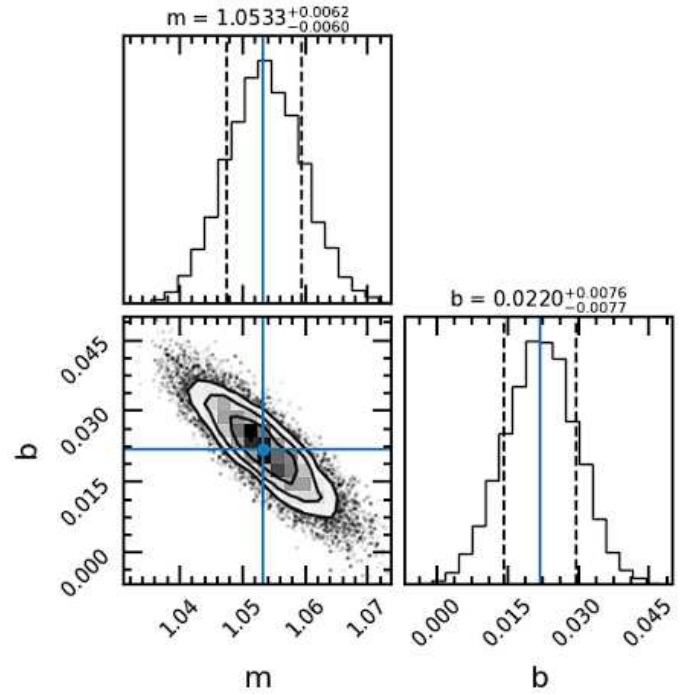


FIGURE 2. Posterior distributions for the parameters m (slope) and b (intercept) obtained via Markov Chain Monte Carlo (MCMC).

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