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A Suite of Classical Cepheids Tied to the Binary Cluster Berkeley 58 and NGC 7790

Daniel Majaess[1] and David G. Turner[2]
[1] Mount Saint Vincent University, Halifax, Canada; Daniel.Majaess@msvu.ca
[2] Saint Mary's University, Halifax, Canada; David.Turner1@smu.ca
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Abstract

The classical Cepheids CE Cas A, CE Cas B, CF Cas, and CG Cas are likely members of the binary open cluster comprising NGC 7790 and Berkeley 58. The clusters are of comparable age and in close proximity, as deduced from differentially dereddened UuB_PBVGR_P photometry, and Cepheid period-age relations. Gaia DR3 astrometric and spectroscopic solutions for the clusters are likewise consistent. Conversely, the seemingly adjacent open cluster NGC 7788 is substantially younger and nearer.

Unified Astronomy Thesaurus concepts: Star clusters (1567); Cepheid variable stars (218)

1. Introduction

The coauthor (D.G.T.) long suspected that the open clusters Berkeley 58 and NGC 7790 (Figure 1) might be associated (see also Piecka & Paunzen 2021). Turner et al. (2008) established an age for Berkeley 58 of $\log \tau = 8.0 \pm 0.1$ using Meynet et al. (1993) isochrones, and Majaess et al. (2013) concluded that NGC 7790 appears the same age according to Padova models (Girardi et al. 2002). Importantly, the classical Cepheids CE Cas A, CE Cas B, and CF Cas are members of NGC 7790 (Sandage 1958, and discussion therein regarding O. Eggen), and Turner et al. (2008) argued that Berkeley 58 hosts CG Cas as a coronal member (Figure 1, near bottom left). Reyes & Anderson (2023) included CG Cas/Berkeley 58 within their gold sample of cluster Cepheids.

The other binary open cluster that may host a Cepheid is NGC 6716 and Collinder 394 (Turner & Pedreros 1985). However, there are ambiguities concerning the membership of the classical Cepheid BB Sgr therein, and a separate effort is underway to clarify that star's status.

Here, differentially dereddened UuB_PBVGR_P photometry is employed to assess whether Berkeley 58 and NGC 7790 form a binary pair, in conjunction with Gaia DR3 astrometry and spectroscopy.

2. Analysis

Gaia DR3 data were utilized to inspect the field of view (Figure 1), and the clusters share comparable proper motions (Table 1). Yet unrelated open clusters along an adjacent sightline (e.g., NGC 7788) feature similar astrometry. Consequently, a holistic approach was pursued whereby cluster ages and potential binarity were examined via dereddened color–magnitude diagrams, along with period-age relations for the Cepheids. In addition, a debate continues regarding the Gaia zero-point (e.g., Owens et al. 2022), and a similar situation transpired for Hipparcos parallaxes (e.g., the Pleiades and Blanco 1, Majaess et al. 2011). Hence the present reliance on dereddened color–magnitude diagrams.

A color–magnitude diagram of differentially dereddened Gaia B_PGR_P photometry is plotted in Figure 2. Stars were individually dereddened using extinction estimates inferred from low-resolution Gaia spectroscopy ($\lambda \simeq 330$–1050 nm). Gaia Collaboration et al. (2023) and Andrae et al. (2023) provide preliminary estimates for $T_{\rm eff}$, $\log g$, A_G, and $E(B_P - R_P)$. Andrae et al. (2023) stress that work on refining their initial approach continues. Indeed, there are discernible offsets between DR3 spectroscopically dereddened main-sequences and unobscured clusters (e.g., NGC 2451). Nevertheless, Figure 2 confirms that Berkeley 58 and NGC 7790 are coeval, whereas NGC 7788 appears younger (see also Davidge 2012). Only the brightest turnoff stars for NGC 7788 are shown in Figure 2, since its main-sequence bisects the older and more distant binary cluster. Regarding the latter, Berkeley 58 appears marginally closer than NGC 7790. A small subset of rogue points were removed from Figure 2.

A differential extinction analysis was likewise undertaken using independent *UuBV* photometry, and the Gaia DR3 astrometric solutions (Table 1). The ultraviolet data utilized are characterized as approximating Johnson *U* and UVEX Sloan *u* (Monguió et al. 2020). Standardizing terrestrial ultraviolet photometry is a longstanding challenge (Monguió et al. 2020, their Section 8.6), and there exists the Hyades anomaly (e.g.,

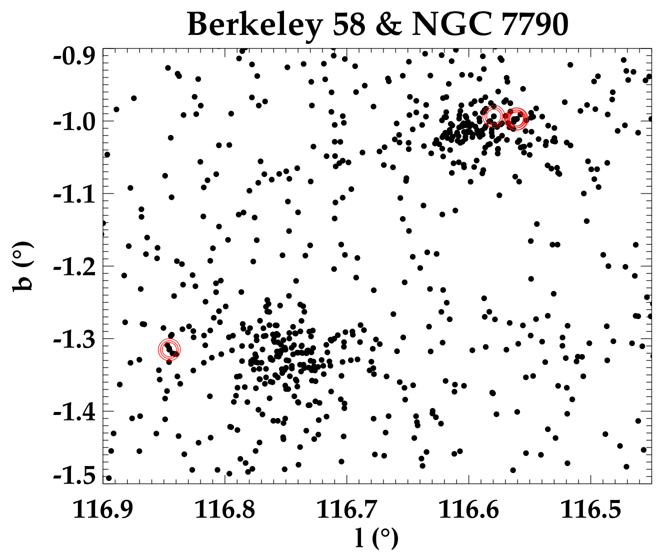

Figure 1. A subsample of stars ($\pi < 0.37$ mas) along the sightline to Berkeley 58 and NGC 7790 (right). Cepheids are encompassed by red circles.

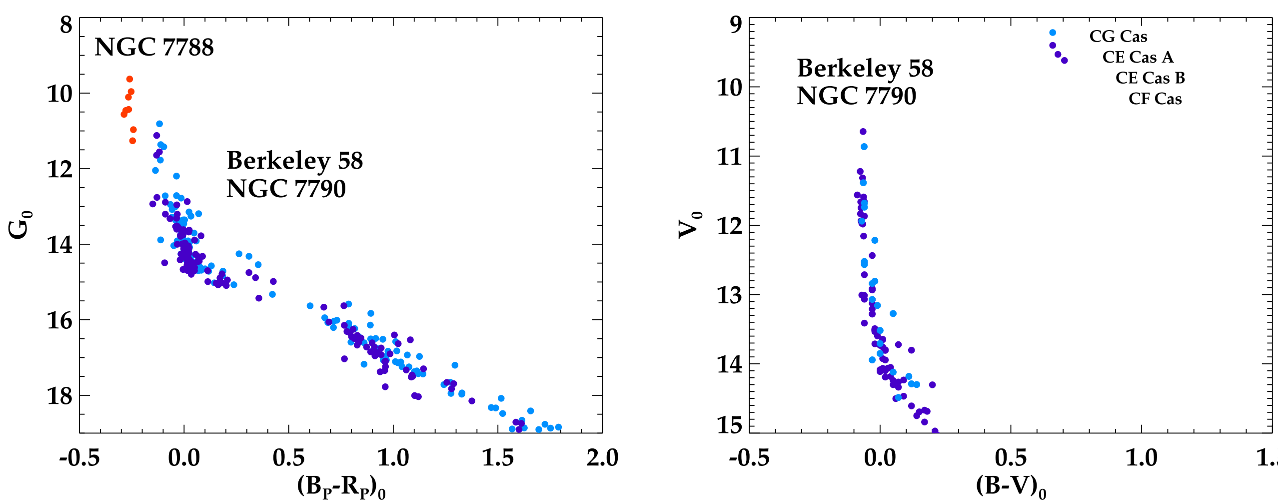

Figure 2. Differentially dereddened color–magnitude diagrams for Berkeley 58 (blue), NGC 7790 (magenta), and NGC 7788 (red, earlier turnoff). Sequences for Berkeley 58 and NGC 7790 align owing to a similar age and binarity. Left, NGC 7788 is an unassociated younger cluster in the foreground. Right, the Cepheids were dereddened using the Turner (2016) compilation.

Table 1
Gaia DR3 and Isochrone Results

	Berkeley 58	NGC 7790	CE Cas A	CE Cas B	CF Cas	CG Cas	NGC 7788
π	0.30 ± 0.04	0.29 ± 0.04	0.31 ± 0.02	0.31 ± 0.02	0.29 ± 0.01	0.27 ± 0.01	0.33 ± 0.04
μ_α	-3.49 ± 0.13	-3.24 ± 0.10	-3.30 ± 0.01	-3.30 ± 0.02	-3.24 ± 0.01	-3.24 ± 0.01	-3.16 ± 0.20
μ_δ	-1.81 ± 0.11	-1.73 ± 0.09	-1.81 ± 0.02	-1.87 ± 0.02	-1.77 ± 0.01	-1.67 ± 0.02	-1.80 ± 0.11
$\log \tau$	8.0 ± 0.1[a]	8.0 ± 0.1[b]	7.99 ± 0.07	8.03 ± 0.06	8.01 ± 0.06	8.04 ± 0.06	7.3–7.6[c]

Notes. Uncertainties for cluster astrometry and Cepheid $\log \tau$ represent the standard deviation.
[a] Turner et al. (2008).
[b] Majaess et al. (2013).
[c] Davidge (2012).

Turner 1979; Majaess et al. 2011). UVEX u advantageously samples faint stars in both fields (Berkeley 58 and NGC 7790). Therefore, UVEX u was paired with BV data from Stetson (2000)[3] and Turner et al. (2008), and standardized to the coauthor's (D.G.T.) unpublished photoelectric U observations hosted at WebDA[4] (Mermilliod & Paunzen 2003). Importantly, the independent $UuBV$ and B_PGR_P results converge upon the same conclusion (Figure 2): Berkeley 58 and NGC 7790 are two clusters of comparable age which are in close proximity, and thus form a binary cluster. Early-type stars yield mean reddenings of $E(B-V) \simeq 0.7$ and 0.5 for Berkeley 58 and NGC 7790, accordingly, which agree with a subset of published findings (Takala 1988; Turner et al. 2008; Majaess et al. 2013). Intrinsic UBV colors stemmed from Turner (1989, and references therein). The following relationship was adopted to determine the reddening trend, $E(U-B) \simeq E(B-V)X + E(B-V)^2Y + Z$, and constrain remaining photometric inhomogeneities rather than dust properties. A cutoff was imposed for faint Berkeley 58 photometry (e.g., photographic photometry possess large uncertainties, Turner et al. 2008).

The differential dereddening results were further validated by constructing a $V-BV$ color–magnitude diagram (not shown) tied to the mean extinction. Majaess et al. (2013) determined $<E(B-V)> = 0.52 \pm 0.05$ for NGC 7790 (see also Mateo & Madore 1988; Takala 1988), while Berkeley 58 is observed through increased obscuration (i.e., $<E(B-V)> \simeq 0.70$, Turner et al. 2008). The cluster sequences once again align.

Cepheid ages can be compared to the clusters using the framework of Bono et al. (2005), Turner (2012), and Anderson et al. (2016). Pulsation periods for the Cepheids CG Cas ($P \simeq 4^{\mathrm{d}}.4$), CF Cas ($P \simeq 4^{\mathrm{d}}.8$), CE Cas A ($P \simeq 5^{\mathrm{d}}.1$), and CE Cas B ($P \simeq 4^{\mathrm{d}}.5$) are comparable. The mean Cepheid ages and standard deviations are $\log \tau = 8.04 \pm 0.06$, 8.01 ± 0.06, 7.99 ± 0.07, 8.03 ± 0.06, respectively (Table 1). That matches the evolutionary age of the clusters Berkeley 58 and NGC 7790 ($\log \tau = 8.0 \pm 0.1$, Takala 1988; Turner et al. 2008; Majaess et al. 2013).

Lastly, Table 1 in Reyes & Anderson (2023) features radial velocities for numerous Cepheids, including CG Cas and CF Cas. Comparable velocities are cited of -77.52 ± 0.56 and -77.76 ± 0.15 km s^{-1}, accordingly.

3. Conclusions

A multifaceted approach indicates that Berkeley 58 and NGC 7790 are in close proximity, share a common age, and constitute a binary open cluster (Figure 2, Table 1). That finding is supported by dereddened multiband UuB_PBVGR_P photometry, and DR3 astrometry and spectroscopy. A suite of four Cepheid members have ages consistent with that for the clusters (i.e., $\log \tau \simeq 8.0$, Table 1). NGC 7788 is discernibly younger, and lies to the foreground, and is likely unrelated.

Continued research on Cepheid variables in open clusters is desirable (e.g., Chen et al. 2015; Breuval et al. 2020; Hao et al. 2022; Reyes & Anderson 2023).

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ORCID iDs

Daniel Majaess https://orcid.org/0000-0001-8803-3840
David G. Turner https://orcid.org/0000-0003-1184-1860

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3 See Pancino et al. (2022).
4 https://webda.physics.muni.cz/