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A Rare Cepheid-hosting Open Cluster Triad in Sagittarius

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ABSTRACT

The following Galactic star clusters may constitute a rare Cepheid hosting triad in Sagittarius: M25, NGC 6716, and Collinder 394. The open clusters have comparable ages ($\tau \simeq 80$ Myr) and nearly aligned main-sequences and turnoffs after accounting for differential extinction (A_G, $E_{B_P-R_P}$). Gaia DR3 astrometry confirms an association between the three clusters, and importantly, the classical Cepheid U Sgr is a member ($P \simeq 6^d.75$, $\tau \simeq 80$ Myr), while DR3 data indicate that the classical Cepheid BB Sgr ($P \simeq 6^d.64$, $\tau \simeq 80$ Myr) could possibly be an escaped member traversing the background field.

Keywords: Star clusters (1567) — Cepheid variable stars (218)

1. INTRODUCTION

Turner & Pedreros (1985) confirmed that NGC 6716 and Collinder 394 comprise a binary open cluster. Multiband $UBVRI$ photometry was analyzed, and a comparable distance and age was determined ($d \simeq 650$ pc, $\tau \sim 60 - 100$ Myr). Yet cluster membership for the classical Cepheid BB Sgr and eclipsing binary V4088 Sgr (HD 174403) remained ambiguous. Regarding BB Sgr, membership is supported by comparable ages between the Cepheid and clusters via a period-age relation (Turner 2012). However, the cluster distance implied a potentially under-luminous $6^d.64$ Cepheid, thus hinting that BB Sgr may lie in the background, or occupy the red edge of the instability strip. Regarding V4088 Sgr (Gieren 1981; Turner & Pedreros 1983), its position in the color-magnitude diagram was ideally placed (Fig. 7 in Turner & Pedreros 1985). Conversely, a prior spectroscopic parallax tied to low-resolution classifications favored a foreground location (Lloyd Evans & Stobie 1971; Turner & Pedreros 1983). Houk & Smith-Moore (1988) subsequently published a more luminous spectral type of B8III/II, which can reposition V4088 Sgr within the cluster's extent (Turner 2003). Astrometry would provide pertinent insight into the aforementioned uncertainties, and those observations are now available via Gaia DR3.

In this study Gaia DR3 data are used to elucidate the connection between the classical Cepheid BB Sgr, the eclipsing binary V4088 Sgr, and the clusters NGC 6716 and Collinder 394 (Fig. 1). Importantly, the latter pair are shown to constitute a rare open cluster triad in tandem with M25. Moreover, M25 hosts the classical Cepheid U Sgr (e.g., Sandage 1960; Majaess et al. 2013), and would make the triad complex rare as a Cepheid host. The other Cepheid host which is not a single cluster is the highly-probable pair of NGC 7790 and Berkeley 58 (Majaess & Turner 2024), whose membership includes several classical Cepheids (e.g., Pedreros et al. 1984; Turner et al. 2008). It is improbable that a triad of clusters should survive the mean 10 Myr dissolution time scale (Bonatto & Bica 2011) and remain together for a subsequent 70 Myr.

2. ANALYSIS

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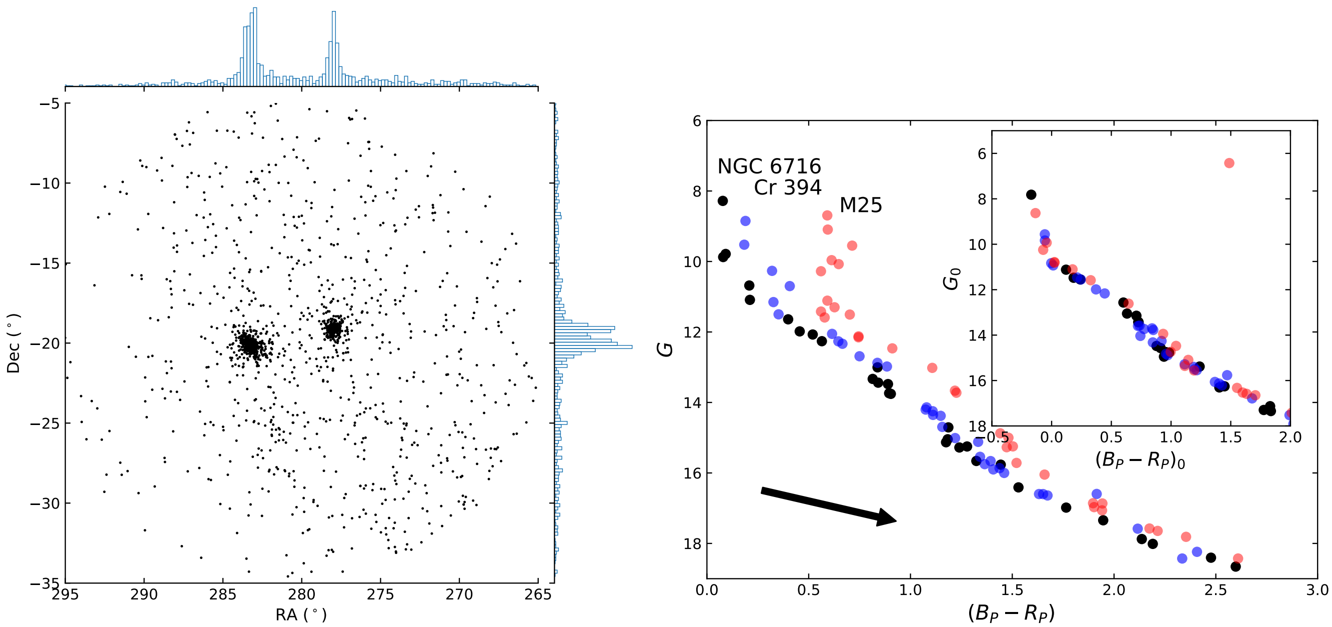

Figure 1. Left, stars in the field that exhibit DR3 astrometry comparable to V4088 Sgr (see text). Principal overdensities define M25 (center right), and NGC 6716 and Collinder 394 (center left). The latter pair (center left) are indistinguishable at the scale displayed, and their coronae overlap (Turner & Pedreros 1985). Right, $G/(B_P - R_P)$ color-magnitude diagram for M25, Collinder 394, and NGC 6716. The inset panel indicates that the differentially dereddened $G_0/(B_P - R_P)_0$ sequences align owing to similar ages, with slight vertical offsets from an expected marginal distance spread. The arrow represents the approximate reddening vector.

Critically, the differential extinction approach employed here aims to partially circumvent ongoing concerns regarding the Gaia zero-point (e.g., Lindegren et al. 2021; Owens et al. 2022). Relatively aligned differentially dereddened main-sequences and turnoffs would imply a comparable age and distance, and can be indicative of a ternary star cluster.

Color-magnitude diagrams for the clusters are shown in Fig. 1. Stars were selected such that their proper motion and parallax were within 0.3 mas yr^{-1} and 0.3 mas of astrometry for V4088 Sgr. Culling parameters were likewise employed ($RUWE < 2$, $RPlx > 3$, possess proper motion uncertainties and $B_P G R_P$ photometry), and the sampling radius was limited to within $5'$ of the cluster centers to mitigate field contamination, differential reddening, and overlapping coronae (e.g., Turner & Pedreros 1985 concluded Collinder 394 has a coronal radius of $\simeq 0.5°$). The cohort in the inset right panel of Fig. 1 concurrently possess spectroscopically determined $E(B_P - R_P)$, and were dereddened directly. The differentially dereddened diagram confirms the clusters are of similar age and proximity. The reddening analysis relied on DR3 B_P/R_P spectroscopic data (Gaia Collaboration et al. 2023). The wavelength spans $\lambda \simeq 330 - 1050$ nm, and published output includes $T_{\rm eff}$, $\log g$, A_G, and $E(B_P - R_P)$. However, efforts are ongoing to resolve concerns within that Gaia dataset (Andrae et al. 2023). For example, Majaess & Turner (2024) noted that in certain cases dereddened main-sequences did not match those of relatively unobscured clusters (inhomogeneous $T_{\rm eff} - (B_P - R_P)_0$).

Importantly, the clear discernment of main-sequences and turnoffs indicate the proper motion cut separated triad members from the field. The median and standard deviation of DR3 parallaxes for cluster members shown in Fig. 1 are: NGC 6716 ($\pi = 1.42 \pm 0.05$ mas), Collinder 394 ($\pi = 1.37 \pm 0.08$ mas), and M25 ($\pi = 1.51 \pm 0.07$ mas). Those results are comparable with published estimates by Song et al. 2022 and Angelo et al. 2022 for NGC 6716 and Collinder 394, and Hao et al. 2022 for M25. A 2MASS JHK_S (Cutri et al. 2003) color-magnitude analysis supports the *relative* DR3 cluster parallaxes, whereby M25 is nearest and Collinder 394 is furthest. However, the 2MASS results indicate the DR3 parallaxes for these clusters are too small and require an adjustment to their zero-point (e.g., Lindegren et al. 2021). Applying the Lindegren et al. (2021) correction yields the following: NGC 6716 ($\pi_{L21} = 1.46 \pm 0.06$), Collinder 394 ($\pi_{L21} = 1.41 \pm 0.08$ mas), and M25 ($\pi_{L21} = 1.55 \pm 0.07$ mas). The latter is consistent with the Majaess et al. (2013) distance for M25 ($\pi = 1.59 \pm 0.06$ mas).

Angelo et al. (2022) cited ages for NGC 6716 and Collinder 394 of $\log\tau = 7.90 \pm 0.30$ and 7.85 ± 0.20, accordingly (see also Song et al. 2022). Majaess et al. (2013) relied upon XMM-Newton X-ray, $UBVJHK_SW_{1-4}$, and spectroscopic observations to constrain a comparable age for M25 of $\log\tau = 7.88 \pm 0.10$ (see also Hao et al. 2022, who determined 8.06 ± 0.16). For both U Sgr and BB Sgr the Turner (2012) Cepheid period-age relation yields $\log\tau = 7.89$ ($\tau \simeq 80$ Myr). In sum, multiple independent determinations and lines of evidence point toward a common age.

U Sgr and V4088 Sgr feature DR3 parallaxes which are comparable with the clusters. Yet, BB Sgr has a DR3 parallax ($\pi = 1.15 \pm 0.02$ mas) placing it in the background. Furthermore, that Cepheid's proper motion in right ascension is offset from cluster members ($\Delta\mu_\alpha \simeq 2$ mas/yr). The uncertainty associated with the Hipparcos μ_α for BB Sgr is too large to validate the DR3 result. Cepheid period-Wesenheit (dereddened Leavitt Law) distances computed using published photometry (Ngeow 2012; Riess et al. 2021) position BB Sgr beyond the complex. Anderson et al. (2024) relayed radial velocities for BB Sgr (7.260 km s^{-1}) and U Sgr (3.169 km s^{-1}) that likewise favor BB Sgr being more distant, given the velocity-distance trend for this sightline (ℓ). Ultimately, forthcoming DR4 observations may help clarify the status of BB Sgr, yet in the interim, that Cepheid may potentially be a former member that escaped into the field.

3. CONCLUSIONS

A differentially dereddened color-magnitude diagram indicates that M25, NGC 6716, and Collinder 394 may represent an expansive open cluster triad in Sagittarius (Fig. 1). That is substantiated by published Gaia DR3 astrometric data. Future work may include examining potential tidal tails, bridges, and characterizing smaller stellar overdensities in the broader field possibly associated with the $\simeq 80$ Myr complex (e.g., a dedicated inspection of ASCC 87 is desirable).

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