



Discovery of an Unbound Flyby Companion of UBC 63: In the Immediate Aftermath of a Close Encounter

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Abstract

We reinvestigate the open cluster UBC 63 using the Gaia Data Release 3 and show that, rather than being a single cluster as previously classified, it is a compelling candidate for a double cluster undergoing an unbound flyby interaction. A Gaussian mixture model decomposition performed in the 5D astrometric space reveals the two statistically distinct components, namely UBC 63A (98 members; Age = 21 ± 4 Myr) and UBC 63B (148 members, Age = 562 ± 43 Myr). A significant age difference of $\Delta \text{Age} = 541 \pm 43$ Myr between the clusters, rules out coeval formation. Their 3D separation of 60 ± 29 pc at the birth-epoch of the younger cluster, hints at a possible common environment origin. At present, the system exhibits a 3D separation of 26 ± 8 pc, with a relative velocity of 3.60 ± 1.80 km s⁻¹. Orbital integrations and *N*-body simulations of the pair suggest that the systems had a close encounter, reaching a separation of 7 ± 2 pc only ~ 6 Myr ago and predict a rapid divergence to a separation of 491 ± 213 pc within the next ~ 100 Myr. The low escape velocity ($V_{\text{esc}} = 0.51 \pm 0.12$ km s⁻¹) of the system compared to the relative 3D velocity indicates that they are gravitationally unbound. Their low tidal factors, elongated structures and populations extending beyond the Jacobi radii may reflect a strong transient tidal interaction between the clusters.

Unified Astronomy Thesaurus concepts: [Star clusters \(1567\)](#); [Close encounters \(255\)](#); [Tidal interaction \(1699\)](#); [N-body simulations \(1083\)](#)

1. Introduction

Open clusters (OCs) are gravitationally bound stellar systems that form within giant molecular clouds (C. J. Lada & E. A. Lada 2003). Most of them evolve as isolated entities. However, a small fraction forms in association with other clusters, giving rise to binary clusters (BCs) and, in some cases, higher-order systems (S. Qin et al. 2025). The origin of binary and multiple cluster systems can be broadly grouped into five scenarios: simultaneous formation, sequential formation, tidal capture, resonant trapping, and optical pairing (R. de La Fuente Marcos & C. de La Fuente Marcos 2009). These systems are astrophysically crucial because, unlike isolated clusters, they preserve signatures of mutual gravitational interaction, providing us with a rare opportunity to probe dynamical processes such as mass exchange, tidal distortion, and eventual merging or disruption (J. Casado 2021; M. Piecka & E. Paunzen 2021; F. Song et al. 2022).

Before the Gaia era, limited astrometric precision made membership determination in OCs challenging, thereby complicating the identification of BCs. Despite these limitations, early studies made important contributions to this field. For example, E. D. Pavlovskaya & A. A. Filippova (1989) identified five possible cluster groups from a sample of 66 OCs with known spatial and kinematic properties. A. Subramaniam et al. (1995) adopted a separation threshold of 20 pc to identify 18 candidate pairs of BC and estimated that BCs constitute $\sim 8\%$ of the OC population in the Galaxy. Later, R. de La Fuente Marcos & C. de La Fuente Marcos (2009) found that BCs account for $\sim 12\%$ of OCs in our Galaxy.

In recent years, high-precision astrometric and multi-band photometric data from Gaia (Gaia Collaboration et al. 2018, 2021, 2023a) have substantially improved the study of BCs. C. Conrad et al. (2017) performed the first systematic search for binary clusters and cluster groups based on 6D phase-space information: R.A. (α), decl. (δ), parallax (ϖ), proper motions (μ_{α}^* , μ_{δ}), and radial velocities (RVs). They identified 19 open cluster groupings, including 14 pairs, four groups with three to five members, and one complex with 15 members. Some very recent discoveries include the tidally captured pair NGC 1605a and NGC 1605b, with ages of



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~ 2 Gyr and 600 Myr, respectively (D. Camargo 2021); the primordial binary cluster pairs: NGC 2323-a and NGC 2323-b, aged at 158 Myr (S. Qin et al. 2025) and ASCC 19 and ASCC 21, with an estimated age of only ~ 8.9 Myr (Q. Hu et al. 2025); the gravitationally unbound flyby encounter pairs: ASCC 71 and ESO 064-65, and NGC 2129 and UBC 437 (Z. Zhu et al. 2025). Several other noteworthy BC candidates spanning a wide range of ages and formation histories have been discovered and studied using combinations of spatial proximity, velocity consistency, age similarity, shared membership, signatures of tidal interaction and N -body simulations in the recent years (e.g., L. Liu & X. Pang 2019; J. Casado 2021; F. Song et al. 2022).

In this study, we present evidence that the open cluster UBC 63, previously classified as a single system (R.A. (J2000) = $05^{\text{h}}18^{\text{m}}41^{\text{s}}.6$, decl. (J2000) = $+37^{\circ}48'31''$; $l = 169.5051$, $b = 0.1540$; Gaia Collaboration et al. 2023b), is more likely a cluster pair undergoing an unbound flyby. UBC 63 has not been the subject of a dedicated, in-depth investigation in the existing literature. Nevertheless, some previous works provide constrained estimates of its fundamental parameters, including (ϖ): 0.626–0.692 mas, μ_{α}^* : 1.059–1.134 mas yr $^{-1}$, μ_{δ} : -3.516 to -3.563 mas yr $^{-1}$, $RV \sim -22.15$ km s $^{-1}$, age ~ 21.3 –60.3 Myr, metallicity (z) ~ 0.010 –0.011, distance ~ 1470 –1546 pc, extinction (A_V) ~ 0.45 –0.838 mag, Mass (M) $\sim 291 M_{\odot}$ etc. (e.g., A. Castro-Ginard et al. 2019; T. Cantat-Gaudin & F. Anders 2020; W. S. Dias et al. 2021; X. Fu et al. 2022; D. Liu et al. 2023; D. Almeida et al. 2025).

We perform a robust re-investigation of the system using the astrometric and photometric measurements from Gaia Data Release 3 (DR3; Gaia Collaboration et al. 2023a). The cluster members for UBC 63 were retrieved using the membership analysis technique provided by S. Deb et al. (2022). This sample was then decomposed using Gaussian mixture models (GMMs), into two statistically distinct stellar populations (UBC 63A and UBC 63B) with markedly different ages. We probe the dynamical evolution of the pair by means of orbital integrations and direct N -body simulations. The results strongly favor the unbound flyby scenario with the closest approach occurring merely ~ 6 Myr ago. The system also shows signatures of strong yet transient tidal interactions. We thus capture the system in a fleeting and rarely observed phase: an unbound cluster pair in the immediate aftermath of a close flyby passage.

The remaining paper is organized as follows: Section 2 describes the discovery of the cluster pair. The characterization of the two clusters is presented in Section 3. The past and future dynamical evolution are discussed in Section 4 and 5. Section 6 presents the summary of the work.

2. Discovery of the Cluster Pair

Assuming UBC 63 to be a single cluster, we performed its membership analysis using astrometric data from Gaia DR3 (Gaia Collaboration et al. 2018, 2021, 2023a). The data was extracted within a 2° radius centered at R.A. (J2000) = $05^{\text{h}}18^{\text{m}}36^{\text{s}}$ and decl. (J2000) = $+37^{\circ}37'18''$. We selected sources with $G < 18$ mag, $\varpi > 0$, $RUWE < 1.4$, astrometric excess noise < 2 , visibility periods > 10 and reliable five-parameter solutions.

The membership determination was performed using a kNN-assisted GMM approach. Approximate cluster astrometric ranges were first estimated from the central $10'$ region

and used to pre-select stars across the 2° field. The resulting 3D astrometric distribution was transformed into a 1D Mahalanobis distance (MD) distribution (P. Mahalanobis 1936; R. De Maesschalck et al. 2000) and modeled with a two-component (cluster and field) GMM. Membership probabilities were derived via an expectation-maximization algorithm, providing 246 members with $P > 0.5$. Further methodological details are available in S. Deb et al. (2022), S. Biswas et al. (2024, 2025).

Figure 1(a) presents the color–magnitude diagram (CMD) of the 246 probable members, color coded according to their membership probabilities. The CMD morphology strongly suggests that a single isochrone cannot adequately reproduce the observed stellar distribution, as two clearly separated sequences are visible. This CMD feature is strikingly similar to the case of the old binary open cluster NGC 1605a and NGC 1605b reported in D. Camargo (2021). As a preliminary inspection, we visually fitted two representative isochrones corresponding to ages of ~ 21 and ~ 562 Myr. Thus, the presence of distinct sequences prompted a detailed investigation into a possible second cluster toward UBC 63. We note, however, that the CMD shown here has not been corrected for differential reddening, which may contribute additional scatter to the observed sequences and also bias the parameter estimates. Therefore, in Section 3, we examine dereddened CMDs and derive the corresponding cluster parameters using the corrected photometry.

To investigate further and to achieve the population separation, we performed a probabilistic GMM in the scaled 5D astrometric space ($\alpha, \delta, \mu_{\alpha}^*, \mu_{\delta}, \varpi$) of the member stars. The Bayesian Information Criterion (BIC), used as the primary model-selection metric, was evaluated for models containing one to five components. The representative BIC values and their uncertainties were inferred from 100 Monte Carlo (MC) realizations, generated by sampling the astrometric parameters within their observational uncertainties. The BIC distribution showed a clear minimum for a two-component solution (See Figure 1(b)). Thus, it was inferred that the distribution comprises two statistically distinct groups. Hereafter, we designate the two populations as clusters UBC 63A and UBC 63B, respectively. Based on a membership probability threshold of > 0.5 , we assigned 98 stars to UBC 63A (with $p(A) > 0.5$) and 148 stars to UBC 63B (with $p(B) > 0.5$).¹³ Figure 1(c) shows their separation using a MD based discriminant, defined as $D = MD_A - MD_B$. The parameters MD_A and MD_B are squared MDs of each star from the 5D mean parameters of UBC 63A and UBC 63B, respectively. The negative and positive values of D represents stars preferentially associated with UBC 63A and UBC 63B, respectively. The two-component GMM (blue for UBC 63A and red for UBC 63B) shows a low overlap fraction ($f_{\text{overlap}} = 0.096$, indicating moderate but significant separation between the populations. Figure 1(d) presents the distribution of UBC 63A (blue) and UBC 63B (red) in parallax (upper left), proper motion (upper right) and α – δ space (lower left). The apparent overlap shows the similarity in the bulk kinematics of the two populations. A comparable spatial and kinematic similarity was also seen for the binary cluster pairs: NGC 1605a & NGC 1605b in D. Camargo (2021), Collinder

¹³ A parallel analysis using a stricter threshold ($p(A/B) > 0.7$ and $p(A/B) > 0.9$) provided consistent results. However, we report the more inclusive ($p(A/B) > 0.5$) sample for completeness.

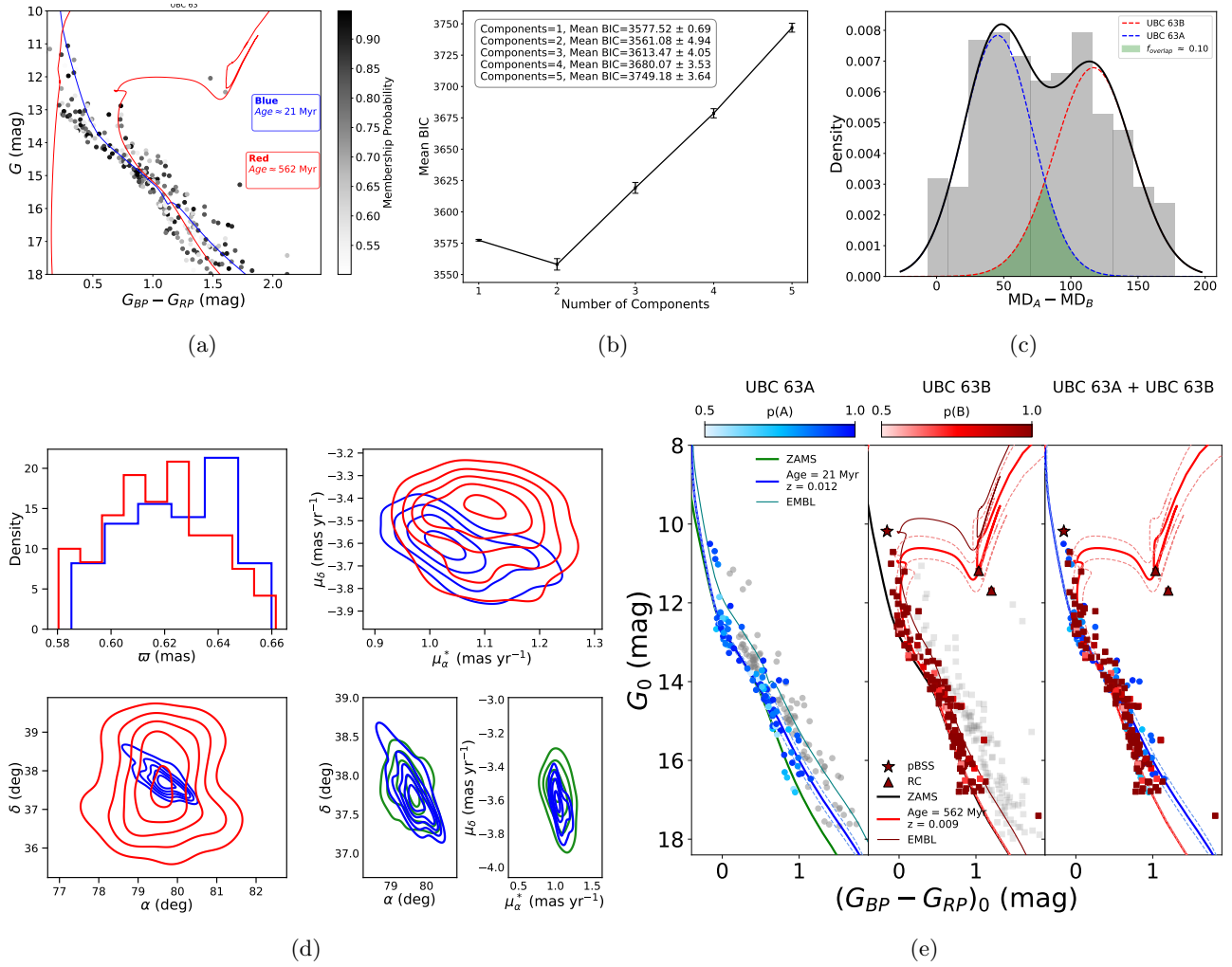


Figure 1. (a) CMD of the 246 UBC 63 members with isochrones of 21 Myr (red) and 562 Myr (blue). (b) The BIC distribution for GMM models with 1–5 components obtained from 100 MC realizations. The mean BIC values along with their standard error for different number of components are also indicated. (c) Distribution of the difference in squared MD from the mean astrometric parameters of UBC 63A and UBC 63B, fitted with a two-component GMM. Blue and red curves denote UBC 63A and UBC 63B, respectively; the black curve shows the combined model, and the green shading indicates the overlap fraction. (d) Distributions of UBC 63A (blue) and UBC 63B (red) in parallax (upper left), proper motion (upper right), and α – δ space (lower left). The lower-right panel shows the spatial and kinematic distributions of UBC 63A (blue) and classical UBC 63 (green). (e) Isochrone fits to the CMDs of UBC 63A (left), UBC 63B (middle), and the combined population (right). Points are color coded by membership probability in UBC 63A (blues) and UBC 63B (reds); gray points represent the CMD points without reddening correction. The dashed curves represent the uncertainty bounds of the respective isochrone fits. The zero-age main sequence and the equal-mass binary locus are included in the left and middle panels, as indicated in the legend. The best-fit age and metallicity (z) are listed in the upper right and lower-left corners of the left and middle panels. The red star and triangle symbols in the middle and right panels mark a probable blue straggler star (pBSS) and two red-clump (RC) stars, respectively.

135 & UBC 7 and UBC 547 & UBC 549 in F. Song et al. (2022). This kinematic similarity might be an indication that the clusters were born within the same environment, although not at the same time. However, it should be noted that clusters at similar Galactocentric radii in the same spiral arm can share similar kinematics even without a common parent molecular cloud.

In the lower-right panel of Figure 1(d), we show that the members of UBC 63A (blue) show near complete spatial/kinematic overlap with the previously reported members of the cluster UBC 63 (green) taken from M. G. J. van Groenningen et al. (2023). This shows that UBC 63A is same as the classical single cluster population of UBC 63. On the other hand, UBC 63B, although partially overlapping, exhibits systematic offsets in proper motion and parallax relative to UBC 63A. Furthermore, UBC 63B also forms a coherent kinematic structure (shown in Figure 1(d); in red) with a well-defined

CMD sequence (Figure 1(e); in red), strongly disfavoring a field-star origin. Its distinct age as compared to UBC 63A (see Section 3) further rules out an extended halo interpretation (J. Zhong et al. 2022).

3. Characterization of the Two Populations

The mean cluster positions and proper motions of UBC 63A and UBC 63B were derived by modeling their astrometric distributions with independent Gaussian profiles. The RVs were estimated by crossmatching their member stars with the survey of surveys catalog (M. Tsantaki et al. 2022). This provided measurements for 9 and 18 stars in UBC 63A and UBC 63B, respectively. Mean RVs for each system were derived using inverse-variance weighting with iterative 3σ clipping (S. Qin et al. 2025) and the uncertainty was estimated following C. Soubiran et al. (2013). The difference in RVs of the two systems is calculated as $\Delta RV = 3.46 \pm 1.70 \text{ km s}^{-1}$,

which again indicates that the two systems are kinematically distinct. The distances (d_{bayes}) to UBC 63A and UBC 63B, were derived using the photo-geometric estimates from C. A. L. Bailer-Jones et al. (2021). The mean cluster extinctions were inferred from their member star distributions in the A_V space using values from F. Anders et al. (2022). To constrain the age and metallicity (z), we constructed dereddened CMDs for each cluster (Figure 1(e)). The dereddening was performed on a star-by-star basis using the extinction values from F. Anders et al. (2022). Although this approach has some dependency on the adopted extinction estimation, it is still necessary to mitigate the differential reddening, which otherwise broadens the CMD and may bias the inferred cluster parameters (C. Reyes et al. 2024). The isochrone fitting was carried out using the `isochrones`¹⁴ package with MIST v1.2 models (J. Choi et al. 2016; A. Dotter 2016; E. B. Bauer et al. 2026; A. Dotter et al. 2026). All the estimated cluster parameters are listed in Table 1.

The age and metallicity difference between UBC 63A and UBC 63B is computed as $\Delta\text{Age} = 541 \pm 43$ Myr and $\Delta z = 0.003 \pm 0.004$. The significant age difference reinforces the interpretation that the two populations are distinct and also effectively rules out the scenario of simultaneous formation. The metallicity difference is not significant enough (considering the uncertainties) to confirm chemical distinction between the populations.

The star symbol shown in the middle and right panels of Figure 1(e) is a member of UBC 63B located above the main-sequence turnoff. It possesses a GALEX near-ultraviolet counterpart (L. Bianchi 2009) and exhibits a phase-folded double-wave pattern in its TESS light curve, characteristic of an ellipsoidal binary. The projected rotational velocity ($v \sin i \sim 79.45 \pm 8.04$ km s⁻¹) supports a rapidly rotating star (W. Sun 2025). These properties suggest that this star can be considered as a probable BSS (pBSS) in a close binary system, which are typically found in clusters older than about 300 Myr (V. V. Jadhav & A. Subramaniam 2021; A. H. Sheikh et al. 2025).

We also note that the two stars located in the red-giant-branch region of the CMD of UBC 63B, marked using triangles in Figure 1(e), have been previously reported in the literature as red-clump (RC) stars (M. Lucey et al. 2020; S. Khanna et al. 2025). These two RC stars provide an important constraint on the older age of UBC 63B. Hence, the effect of astrometric uncertainties on their population assignment must be considered. For this, we repeated the population separation analysis (as described in the previous section) for 100 MC realizations, sampling the astrometric parameters within their observational uncertainties. Across the 100 MC runs, the two RC stars had mean probabilities of 0.62 ± 0.03 and 0.59 ± 0.04 of belonging to UBC 63B. Thus, according to our adopted membership criterion of $p > 0.5$, both RC stars remain confidently assigned to UBC 63B despite the astrometric uncertainties.

Thus, it is safe to say that the presence of these core-helium-burning stars independently supports the relatively advanced age of UBC 63B.

4. Galactic Trajectories

We compute the Galactocentric positions and velocities of UBC 63A and UBC 63B using `astropy` (Astropy Collaboration et al. 2013, 2018). For the transformation, we adopt the solar position and velocity as $(X, Y, Z)_\odot = (8, 0, 0.015)$ kpc and $(U, V, W)_\odot = (10, 235, 7)$ km s⁻¹ (J. Bovy 2015). The resulting positions and velocities are listed in Table 2. The present 3D spatial separation between the two clusters is estimated as $\Delta D_{3D} = 26 \pm 8$ pc and the total space velocities are estimated as $V_{3D,A} = 208.01 \pm 0.14$ km s⁻¹ and $V_{3D,B} = 208.40 \pm 0.21$ km s⁻¹. The corresponding relative 3D velocity is $\Delta V_{3D} = 3.60 \pm 1.80$ km s⁻¹. The derived ΔD_{3D} and ΔV_{3D} are comparable to the case of the binary cluster pair ASCC 71 and ESO 064-05 in Z. Zhu et al. (2025).

To investigate the past and future trajectories of UBC 63A and UBC 63B, we integrated the orbits of the two systems both forward and backward in time using the Python package `galpy`,¹⁵ with the axisymmetric Galactic potential module `MWPOTENTIAL2014` (J. Bovy 2015). The orbits of both clusters were integrated forward in time for 100 Myr from the present epoch. The backward integrations were extended to their respective formation epochs, corresponding to -21 Myr for UBC 63A and -562 Myr for UBC 63B. In addition, we also used MC simulations to estimate the uncertainty in the trajectories. The past and future trajectories of UBC 63A (blue) and UBC 63B (red) in the Z - R_{GC} plane are shown in Figure 2(a). The dashed gray curves correspond to the 16th and 84th percentile bounds obtained from 500 MC simulations. It was found that both clusters follow low-eccentricity orbits with similar angular momenta, UBC 63A: $e = 0.084 \pm 0.025$, $L_x = -6.0 \pm 0.2$, $L_y = 13.8 \pm 0.7$, $L_z = 1940.3 \pm 1.5$ kpc km s⁻¹; UBC 63B: $e = 0.073 \pm 0.005$, $L_x = -5.6 \pm 0.4$, $L_y = 8.4 \pm 0.7$, $L_z = 1951.4 \pm 2.8$ kpc km s⁻¹. Such similar orbital eccentricity and angular momenta was also observed for the pair ASCC 71 and ESO 064-05 in Z. Zhu et al. (2025).

Figure 2(b) presents the temporal evolution of the intercluster separation from -21 to $+100$ Myr. The 3D separation between the two clusters at the formation epoch of UBC 63A (-21 Myr) is found to be $\Delta D_{3D}^{\text{birth}} = 60 \pm 29$ pc. Within uncertainties, the inferred separation is comparable to the characteristic size of giant molecular clouds (~ 100 pc; Z. Zhu et al. 2025), hinting at a possible common environment origin and potentially explaining the similar bulk kinematics of the two populations. The closest approach at ~ -6 Myr, reaching a minimum separation of $\Delta D_{3D}^{\text{min}} = 7 \pm 2$ pc, likely reflects a transient phase alignment along their orbits. After the closest approach, the clusters are now diverging. Forward integration shows a steady increase in separation, reaching $\Delta D_{3D}^{\text{future}} = 491 \pm 213$ pc at $+100$ Myr. This is consistent with a flyby-like encounter. The lack of recurrent close passages disfavors a bound configuration. We estimated the mutual escape velocity (V_{esc}) of the pair using the cluster masses from Table 2 and their present-day 3D separation, obtaining $V_{\text{esc}} = 0.51 \pm 0.12$ km s⁻¹. Accounting for the uncertainties, the relative 3D velocity (ΔV_{3D} ; Section 3) is found to substantially exceed V_{esc} . About 10,000 MC samplings of the masses, separation and relative velocity parameters, considering the uncertainties, provides a $\sim 98\%$ probability that the pair is gravitationally unbound.

¹⁴ <https://isochrones.readthedocs.io/en/latest/>

¹⁵ <https://docs.galpy.org/en/v1.11.2/>

Table 1
Fundamental Parameters of UBC 63A and UBC 63B

Population	α (deg)	δ (deg)	ϖ (mas)	μ_{α}^* (mas yr ⁻¹)	μ_{δ} (mas yr ⁻¹)	Age (Myr)	A_V (mag)	d_{bayes} (pc)	z	RV (km s ⁻¹)
UBC 63A	79.599 ± 0.042	37.800 ± 0.033	0.624 ± 0.002	1.061 ± 0.008	-3.632 ± 0.011	21 ± 4	1.148 ± 0.007	1502 ± 5	0.012 ± 0.003	-17.005 ± 0.99
UBC 63B	79.649 ± 0.076	37.666 ± 0.080	0.618 ± 0.002	1.099 ± 0.006	-3.521 ± 0.012	562 ± 43	1.025 ± 0.011	1527 ± 5	0.009 ± 0.002	-13.54 ± 1.38

Note. α : R.A.; δ : decl.; ϖ : parallax; μ_{α}^* , μ_{δ} : proper motion in R.A. and decl.; A_V : visual extinction; d_{bayes} : distance; z : metallicity; RV: radial velocity.

Table 2
Properties of UBC 63A and UBC 63B used to Generate Mock Clusters for N -body Simulations

Population	M ($M_{\odot}$)	(X, Y, Z) (kpc)	(U, V, W) (km s^{-1})	W_0	f_b	r_{hm} (pc)	Q	M_{min} ($M_{\odot}$)	α_l	M_t ($M_{\odot}$)	α_h	M_{max} ($M_{\odot}$)
UBC 63A	294 $\pm$ 58	(−9.477 $\pm$ 0.005, 0.274 $\pm$ 0.001, 0.020 $\pm$ 0.001)	(22.03 $\pm$ 0.97, 206.83 $\pm$ 0.21, −1.77 $\pm$ 0.07)	1.018	0.29	9.44 $\pm$ 1.73	0.5	0.15	2.17 $\pm$ 0.62	1.40	−2.18 $\pm$ 0.48	5.20
UBC 63B	435 $\pm$ 87	(−9.502 $\pm$ 0.005, 0.275 $\pm$ 0.002, 0.019 $\pm$ 0.002)	(18.71 $\pm$ 1.85, 207.54 $\pm$ 0.36, −1.19 $\pm$ 0.07)	1.274	0.82	23.57 $\pm$ 2.48	0.5	0.11	2.81 $\pm$ 0.45	0.89	−1.96 $\pm$ 0.36	2.48

Note. M : cluster mass; X, Y, Z : Galactocentric positions; U, V, W : Galactocentric velocity; W_0 : king concentration parameter; f_b : binary fraction; r_{hm} : half mass–radius; Q : virial ratio; $M_{\text{min/max}}$: minimum/maximum stellar mass; $\alpha_{l/h}$: low-/high-mass slope of mass function; M_t : transition mass.

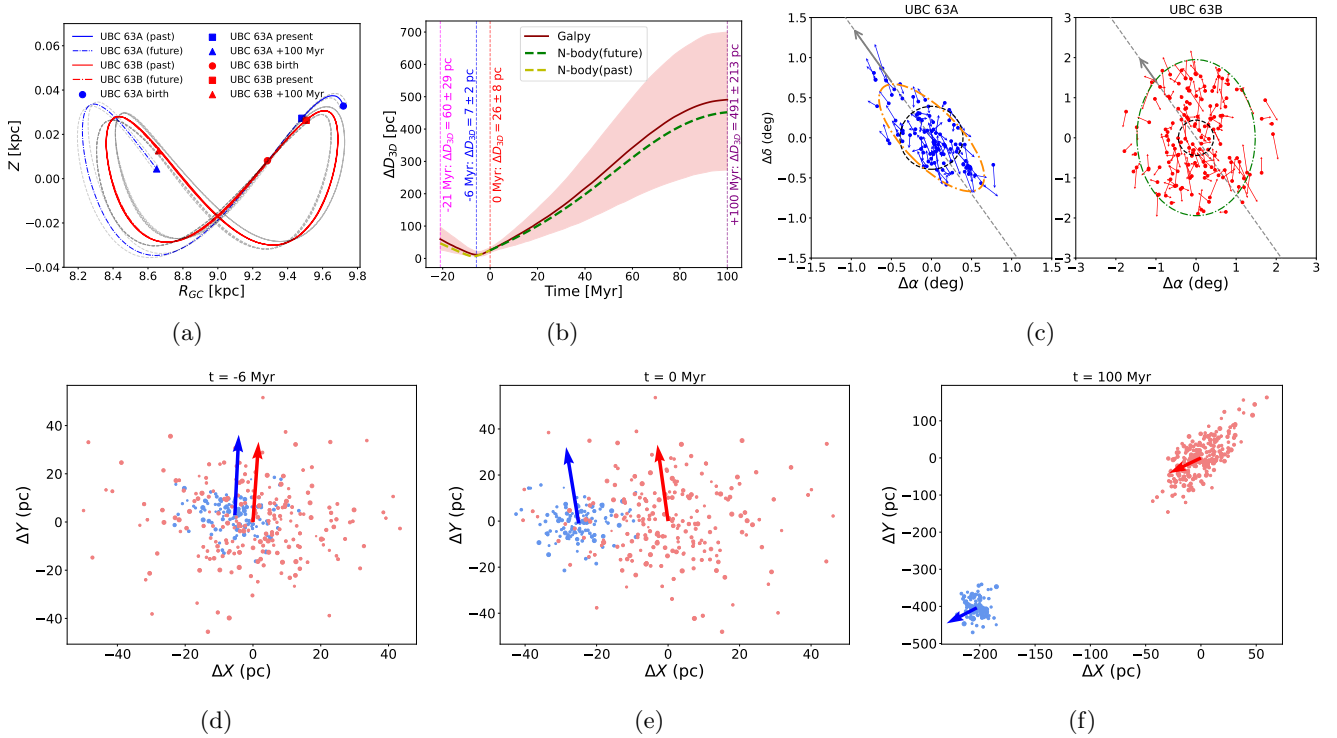


Figure 2. (a) The Galactic orbits of UBC 63A (blue) and UBC 63B (red) in the Z - R_{GC} plane. Solid and dashed-dotted curves trace the past and future evolution, respectively. Circles, squares, and triangles mark the birth, present, and future positions (at +100 Myr), respectively. The dashed gray curves denote the 16th and 84th percentile uncertainty bounds from the MC sampling. (b) Temporal evolution of the intercluster separation from -21 to +100 Myr. The solid red curve shows the mean evolution derived from *galpy*. The corresponding shaded regions indicate the 16th and 84th percentile uncertainty bounds from MC sampling. The yellow and green dashed curves correspond to the past and future evolution scenarios from the N -body simulation, respectively. The birth epoch of UBC 63A, closest approach, the present epoch and the +100 Myr epoch is marked using magenta, blue, red, and purple dashed vertical lines, respectively, with the corresponding separations annotated. (c) The spatial distributions of UBC 63A (blue) and UBC 63B (red) in a tangentially projected Cartesian plane. The arrows attached to the scatter points denote their first-order corrected proper-motion vector. The gray dashed line traces the cluster orbit and indicates the direction of motion. The black dashed circle marks the Jacobi limit of each cluster. The best-fitting ellipses are overlaid on UBC 63A and UBC 63B, in orange and green, respectively. X - Y projection of the mock cluster of UBC 63A (blue) and UBC 63B (red) at three different epochs: (d) -6 Myr, (e) 0 Myr and (f) +100 Myr as obtained from the N -body simulation. The blue and red arrows represent the space velocity projection of each cluster.

Nevertheless, such unbound close encounters can still induce transient but non-negligible tidal effects (Z. Zhu et al. 2025). To quantify this, we estimate their tidal factors in the present day, using the expression in (T. Palma et al. 2025). The resulting values for UBC 63A and UBC 63B are 4.33 and $2.01 \text{ pc}^2/M_\odot$, respectively. These low values indicate that the clusters still experience strong tidal interactions (G. Liu et al. 2025).

Figure 2(c) shows the spatial distributions of UBC 63A (blue) and UBC 63B (red) in a tangentially projected Cartesian plane (I. Sharma et al. 2025). The arrows attached to the scatter points denote their proper-motion vector corrected for projection effects (F. van Leeuwen 2009; I. Sharma et al. 2025). The gray dashed line traces the cluster orbit and indicates the direction of motion. The black dashed circle marks the Jacobi limit (E. L. Hunt & S. Reffert 2024) of each cluster. To highlight the overall morphology and degree of elongation, best-fitting ellipses are overlaid on UBC 63A and UBC 63B, shown in orange and green, respectively.

Figure 2(c) shows that both UBC 63A and UBC 63B possess a number of candidate members located beyond their respective Jacobi radii, many of which show projected motions broadly consistent with the orbital trajectories. UBC 63B appears substantially more diffuse than UBC 63A. This is expected from its older age (V. V. Jadhav et al. 2025) and consequently longer exposure to Galactic tidal perturbations, allowing escaping members to disperse over a larger volume.

Furthermore, the mutual perturbation during the close flyby encounter between UBC 63A and UBC 63B may have contributed to the stripping of stars from the young UBC 63A, while simultaneously acting as a catalyst to further scatter the already loosely bound, extended outer population of UBC 63B. A detailed investigation of the extended population is required to quantify the relative roles of the Galactic tidal field and the close flyby encounter in shaping the morphology of both clusters.

5. NBODY Simulation

The *galpy* orbital integration treats the clusters as point masses, an approximation that may sometimes oversimplify their dynamical behavior (Z. Zhu et al. 2025). Hence, to validate these result, we constructed mock clusters from the observational data using *McCluster*¹⁶ (A. H. W. Kuepper et al. 2011) and followed their evolution with the high performance N -body code *PeTar*¹⁷ (L. Wang et al. 2020).

As discussed in Section 3, the Galactocentric positions (X, Y, Z) and velocities (U, V, W) of the two clusters were derived from the observed kinematics. Their cluster masses (M), binary fractions (f_b), minimum and maximum stellar masses ($M_{\min/\max}$), transition mass (M_t), and the low- and high-mass slopes ($\alpha_{l/h}$) of their

¹⁶ <https://github.com/AlbrechtKamlah/mcluster>

¹⁷ <https://github.com/lwang-astro/PeTar>

segmented mass functions were obtained using the method of A. Almeida et al. (2023). The King concentration parameter (W_0) was derived from the c – W_0 correspondence provided in I. R. King (1966), where c (=tidal radius/core radius) was computed from (I. King 1962) fits to the radial density profiles of the clusters. The half mass–radius (r_{hm}) was computed using the expression from (I. Šabliučius et al. 2006).

We also estimated the dynamical relaxation time (t_{relax}) of the two clusters using the equation in (J. Binney & S. Tremaine 2011). It was found to be 94 ± 27 Myr for UBC 63A and 415 ± 77 Myr for UBC 63B. While the age of UBC 63B exceeds its relaxation time, the younger UBC 63A is likely not yet dynamically relaxed. Nevertheless, for simplicity, we adopted a virial ratio of $Q = 0.5$ for both systems (S. Qin et al. 2025). To assess the impact of this assumption, we additionally carried out PETAR simulations with subvirial initial conditions ($Q < 0.5$). We found that the overall results remain largely unchanged, indicating that the conclusions are not strongly sensitive to the assumed virial ratio.

All of these parameters were used as inputs to generate the mock clusters representing UBC 63A and UBC 63B. These are summarized in Table 2.

The mock clusters were then evolved with PeTar. The simulations account for mutual stellar interactions (L. Wang et al. 2020), single and binary stellar evolution (J. R. Hurley et al. 2000, 2002; S. Banerjee et al. 2020), as well as the Galactic potential (J. Bovy 2015). Each system was first integrated forward for +100 Myr with snapshots recorded at 1 Myr intervals.

To investigate the clusters' dynamical history up to the present day, we required backward integration, a capability, which is not natively supported by PeTar. To resolve this, we first derived the phase-space coordinates of both the clusters at $t = -21$ Myr, via reverse-time point-mass orbit integration in galpy. The clusters were then initialized at this epoch using these coordinates and assuming their structural properties to be same as the present day. The reconstructed system was then evolved forward to the present day. While this simplified approach is not expected to be perfectly accurate, it is sufficient for evaluating the dynamical consistency of the inferred interaction history (S. Qin et al. 2025).

Figures 2(d)–(f) presents the projected evolution of the cluster pair in the X – Y plane at -6 Myr, the birth epoch of the younger cluster; 0 Myr, the present day and +100 Myr, illustrating future evolution. The corresponding 3D spatial separations at these epochs are ~ 7.4 pc, 25 pc and 452 pc respectively. These results agree well (within the error limits) with the Galpy orbital integration. The full temporal evolution of the separation, as obtained from the N -body simulation is also presented in Figure 2(b), as yellow (for past) and green (for future) dashed curves.

Taken together, these results suggests that UBC 63A and UBC 63B are best interpreted as an unbound flyby pair, rather than a gravitationally bound binary or a tidally captured system.

6. Summary

In this study, we revisit the nature of UBC 63 and demonstrate that it is unlikely to be a single cluster, but instead a compelling candidate for a double cluster system (UBC 63A and UBC 63B) caught in the immediate aftermath of a close flyby.

The clusters exhibit distinct evolutionary phases, with ages of 21 ± 4 Myr (UBC 63A) and 562 ± 43 Myr (UBC 63B) and metallicities of 0.012 ± 0.003 (UBC 63A) and 0.009 ± 0.002 (UBC 63B). The significant age disparity ($\Delta\text{Age} = 541 \pm 43$ Myr) effectively rules out coeval formation scenario. The older cluster, UBC 63B, also exhibits advanced stellar evolution signatures, hosting a pBSS as well as two RC stars, consistent with its evolved status.

The dynamical orbit integration and direct N -body simulations show that, at the formation epoch of UBC 63A, (~ 21 Myr), the two clusters were separated by 60 ± 29 pc. This hints at a possible common environment origin for the clusters and also explains their similar kinematics. The closest approach occurred only ~ 6 Myr ago, during which the separation reduced to 7 ± 2 pc. The system's low escape velocity ($V_{\text{esc}} = 0.51 \pm 0.12 \text{ km s}^{-1}$) compared to the relative 3D velocity ($\Delta V_{3D} = 3.60 \pm 1.80 \text{ km s}^{-1}$) indicates that the pair is gravitationally unbound. At present, the system exhibits a 3D separation of 26 ± 8 pc. The future evolutionary scenarios of clusters show that they are now rapidly diverging and are expected to reach separations of 491 ± 213 pc within the next ~ 100 Myr.

The close flyby, occurring approximately 6 Myr ago, appears to have been dynamically significant and may have generated a transient but significant tidal interaction between the two clusters. This is consistent with their low tidal-factor values of $4.33 M_{\odot}^{-1} \text{ pc}^2$ (UBC 63A) and $2.01 M_{\odot}^{-1} \text{ pc}^2$ (UBC 63B). Both systems also display elongated morphologies and extended stellar populations reaching beyond their respective Jacobi radii, further suggesting ongoing tidal evolution.

Thus, the two clusters are best interpreted as an unbound tidally interacting flyby system. Thus, this system represents a rare, real-time laboratory for studying the tidal consequences of cluster-cluster interaction in the solar neighborhood. Understanding these brief but intense dynamical exchanges is crucial for refining our current models of open cluster survival, mass loss, and overall evolution in the solar neighborhood.

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