251. Binary open clusters

I LOOKED AT SOME of the most recent insights into open clusters being inferred from the Gaia data in essays 219–222, covering their numbers, ages, kinematics, and chemistry respectively. In essay 219, on their overall properties and Galactic distribution, I also mentioned some recent advances in the identification of 'binary clusters', which I will say more about here.

To give a brief historical context, around a third of the open clusters known before Gaia were catalogued by Charles Messier, and William and John Herschel, and subsequently compiled into the New General Catalogue (NGC; Dreyer, 1888). Clusters found from photographic surveys were added in the 20th century, with subsequent discoveries benefitting from large-scale ground-based proper-motion surveys, as well as from Hipparcos.

Before Gaia DR2, released in April 2018, the two largest catalogues of open clusters were those of Dias et al. (2002), with about 2000 systems, and Kharchenko et al. (2013) which listed over 3000. With Gaia, a significant fraction of these were actually found to be *apparent* 'overdensities', but at the same time also seen to be highly incomplete (Cantat-Gaudin et al., 2019).

NUMEROUS Gaia-based studies have since identified some 25 000 open clusters out to 15 kpc (including duplicates), exploiting the DR3 parallaxes, proper motions, and multi-colour photometry, and using clustering algorithms such as DBSCAN (Castro-Ginard et al., 2022), HDBSCAN (Hunt & Reffert, 2023), and others. The *Unified Cluster Catalogue* of Perren et al. (2023), online at https://ucc.ar, has compiled these into a list of nearly 18 000 unique Milky Way open clusters, with more than a million probable members in total (essay 219).

Typical clusters have around 50 members, but many of the most populated have several hundred up to several thousand. Most have half-number radii in the range 2–6 pc, somewhat independent of numerical size (e.g. Tarricq et al., 2022; Zhong et al., 2022; Hunt & Reffert, 2023). These advances in quantity and quality are allowing improved studies of membership, Galactic distribution, age, chemistry, and dynamics (essays 220–222).

THERE WERE already hints in the 1970s that open clusters are sometimes found in pairs (Rozhavskii et al., 1976). More recent simulations and observations confirm that such pairs can form together, co-orbiting before mass loss eventually leads to them separating and evolving as two independent clusters (e.g. Camargo et al., 2016; Priyatikanto et al., 2016; Casado, 2021b).

Well-studied pairs include h and χ Persei (NGC 869 and NGC 884; e.g. Slesnick et al., 2002; Currie et al., 2010), where Gaia DR2 has revealed extended halo and filamentary substructures (Zhong et al., 2019). Binary clusters have also been identified in other galaxies, including the LMC (Bhatia & Hatzidimitriou, 1988), and the SMC (Pietrzynski & Udalski, 1999).

Binary clusters provide constraints on cluster formation, with insights into star formation, as well as tidal interactions within the disk. New discoveries and detailed kinematic studies with Gaia DR3 are consolidating this picture (Casado, 2021b; Song et al., 2022; Ye et al., 2022; Ishchenko et al., 2024; Majaess & Turner, 2024; Hu et al., 2025; Li & Zhu, 2025; Qin et al., 2025).

MORE GENERALLY, binary clusters can be classified into three types (e.g. de La Fuente Marcos & de La Fuente Marcos, 2009; Liu et al., 2025a): (a) primordial binaries, with similar properties; (b) distinct systems formed through tidal capture or resonant trapping; and (c) hyperbolic ('chance' or 'flyby') encounter pairs.

The former includes sequential formation, in which stellar winds or supernova shocks generated by one cluster might trigger formation of another, of slightly different age (Brown et al., 1995; Wall et al., 2020; Karam et al., 2025), a model supported by Gaia data (Liu et al., 2025b).

In tidal capture, independent clusters could become gravitationally bound through a close encounter followed by angular momentum loss (e.g. van den Bergh, 1996; Mora et al., 2019). But evidence for such a route is limited, with ASCC 71 and ESO 064–05, and NGC 2129 and UBC 437, suggested as captured pairs by Palma et al. (2025), found to be gravitationally unbound by Zhu et al. (2025), albeit both studies being based on Gaia DR3.

A COMPILATION of binary systems previously reported in the literature, including more recent findings from Gaia, is given by Liu et al. (2025a, Table 1). The same table includes references to studies reporting triple or higher order cluster groupings (Pavlovskaya & Filippova, 1989), including cluster aggregates inferred from Gaia (e.g. Liu & Pang, 2019; Piecka & Paunzen, 2021; Casado, 2021a; Palma et al., 2025).

AMONGST RECENT Gaia DR3 studies, Ye et al. (2022) found that UPK 39 and UPK 41 (near the Aquila Rift cloud) are a primordial binary pair, likely to have formed at the same time, with PHOC 39 possibly destined to capture both clusters in the future.

Li & Zhu (2025) identified nine new close binary pairs, seven of which were classified as primordial systems. Of these, only one pair (CWNU 1024 and OCSN 82) was identified as gravitationally bound. The other eight appear to be gravitationally unbound, although the conclusions are sensitive to estimates of the tidal radii.

Starting from the Gaia DR3 based catalogue of 5647 open clusters compiled by Hunt & Reffert (2023), further restricted to pairs separated by less than 100 pc, Li et al. (2026) identified a total of six gravitationally bound 'wide binary' pairs, integrating their Galactic orbits, and estimating age differences <40 Myr in all cases.

A LARGER STUDY has been based on a sample of 4084 clusters selected from Gaia DR3. Liu et al. (2025a) targeted a rigorous identification of binary clusters using the full phase-space information from Gaia, taking account the 3D velocity difference, ΔV, as well as the age difference between each cluster and its nearest neighbour, $\Delta\tau$. They classified binary pairs as primordial ($\Delta V < 20\,\mathrm{km\,s^{-1}}$ and $\Delta\tau < 30$ Myr); tidally or resonantly captured ($\Delta V < 20\,\mathrm{km\,s^{-1}}$ and $\Delta\tau > 30$ Myr); or as hyperbolic encounters ($\Delta V > 20\,\mathrm{km\,s^{-1}}$).

They identified 400 pairs (involving 686 clusters), confirming the recovery of previously reported systems, in addition to the discovery of 268 new binary pairs.

Amongst these, they classified 60% (243 pairs) as probable primordial binaries, having similar ages and space motions, suggesting a scenario in which they formed together in the same giant molecular cloud. From a 'gold sample' of 146 pairs, they classified 88 as primordial, 47 as tidally captured, and 11 as hyperbolic encounters (their Figure 3).

In addition, they classified 278 clusters as members of 82 multi-cluster systems (of 3 or more clusters), including 27 newly reported groups. In their sample, about 16% of the star clusters are involved in some type of interaction with another cluster. The high fraction of primordial binary clusters, and their mutual tidal interaction, in turn suggests that cluster formation in pairs is a significant outcome of star formation.

Liu et al. (2025a) estimated the mutual tidal force between each cluster pair by means of the tidal factor, given by $d^3/(M_{\rm cl}\,R_{50})$, where d is the 3D separation between the pairs (pc), R_{50} is the half-member radius of the target cluster (pc), and $M_{\rm cl}$ is the mass of the companion cluster ($M_\odot$). Smaller values indicate a stronger tidal force exerted by the companion cluster, with values < 200 adopted as a threshold for identifying binary clusters by Palma et al. (2025).

The figures below, taken from their Figure 4, show a single representative example of each classified binary type (in sky coordinates) from their study: primordial, captured, or hyperbolic. Colours indicate the cluster members. Their published figure also shows the associated distributions of member stars in radial velocity as well as colour–magnitude coordinates. Arrows indicate the tangential velocities of the clusters.

Their bottom line is that 16% of open clusters are currently part of binary or higher-order group systems, with 10% having likely formed as primordial. The results will have implications for models of hierarchical star formation, stellar feedback, and dynamical evolution within the Galactic disk.