249. The Greater Pleiades Complex

The Pleiades cluster, in the constellation Taurus, has been recognised as a group of stars since antiquity. Its distance, along with other nearby open clusters, notably the Hyades, has long played an important role in establishing the astronomical distance scale through main-sequence fitting via the HR diagram.

As I described in essay 13 (March 2021), Hipparcos precipitated a new controversy: while pre-Hipparcos estimates had converged on a distance of 130–135 pc, the Hipparcos parallaxes gave a mean value of only 118 pc, 7% less than the previous consensus (van Leeuwen, 1999). But the early Gaia results, already from DR1 (Gaia Collaboration et al., 2017), and confirmed with DR2 (Abramson, 2018; Lodieu et al., 2019; Gao, 2019), 'restored' its distance to around 135–136 pc. The Hipparcos outlier is generally inferred to have resulted from positional correlations on small angular scales.

The 'big picture' today is that all stars form in clusters or associations, which disintegrate over time, and steadily merge into the field population. Two-body relaxation leads to the more massive stars sinking to the central cluster regions, while the less massive gradually escape, or 'evaporate'. Additionally, the Galactic potential perturbs clusters to form tidal tails, an effect observed pre-Gaia for both open clusters (amongst them Berkeley 17 and NGC 6791), and globular clusters (amongst them Palomar 5, Omega Cen, and NGC 5466).

In their early studies of the Pleiades using Gaia DR2 astrometry, Lodieu et al. (2019) identified 1248 candidate members inside its tidal radius, ~13 pc, resolving its depth, and further clarifying its age and stellar content. And they noted a stream of slowly escaping stars, extending up to 40 pc from its centre, and gradually merging into the field population over millions of year.

I have written more on the relationship between the Pleiades cluster and Galactic dynamical resonances in essay 115, and on the kinematics of open clusters with Gaia more generally in essay 221, touching on the new kinematic insights into the Pleiades (Alfonso & García-Varela, 2023), including evidence for a global rotation of the entire cluster (Hao et al., 2024).

Further Gaia-based studies of the Pleiades cluster have continued to probe its structure and kinematics (e.g. Danilov & Seleznev, 2020; Danilov, 2021b; Pang et al., 2022).

In their morphological and dynamical study of ten nearby (< 500 pc) young (30–300 Myr) clusters, including the Pleiades, Meingast et al. (2021) identified stellar coronae extending out to 100 pc from the cluster cores. These appear to form a network of interconnected, coeval, and co-moving extended cluster populations, each encompassing tens of thousands of cubic parsec, and stretching tens of degrees across the sky.

Using Gaia DR3, and similar to the DR2 findings of Lodieu et al. (2019), Heyl et al. (2022) found nearly 1300 cluster members, and 289 former cluster candidates, while Alfonso & García-Varela (2023) identified 958 members. Bhattacharya et al. (2022) identified 40 pc long tidal tails from its extended morphology.

The importance and difficulty of identifying binaries, and in particular the occurrence of wide binaries in the presence of stellar interactions and tidal effects, has also been the subject of several Gaia studies (Deacon & Kraus, 2020; Danilov, 2021a; Danilov, 2022; Danilov, 2023; Chulkov, 2024).

The much more rigorous membership definitions being provided by Gaia also allows the nature of certain specific stars to be re-assessed. Amongst these, Stauffer et al. (2020) 'resolved the conundrum' of the elevated lithium content of two M5 dwarfs, HHJ 339 and HHJ 430, as a result of them being much younger (25 Myr) foreground objects, kinematically associated with the 32 Ori moving group. Gaia has similarly provided further insight into the nature of the eclipsing binary brown dwarf Roque 12 (Scholz et al., 2020), as well as the detailed properties of its δ Sct stars (Bedding et al., 2023).

But the focus of the rest of this essay is a study which has combined the Gaia data with stellar rotational data from the TESS mission, to more securely identify young escaping members of the Pleiades out to much larger distances than has been possible using the Gaia astrometric and photometric data alone.

IDENTIFYING STARS which have escaped from such open clusters in the tens to hundreds of millions of years that have elapsed since their birth is important in clarifying many details of the underlying star formation process, the very origin and evolution of star clusters, and their ages and associated disruption mechanisms.

Gagné et al. (2021) already found that some nearby moving groups may be much more extended spatially than previously thought: some are possibly parts of tidal tails around the cores of known open clusters. For example, they suggested that the AB Dor moving group, as well as Theia 301, may form a tidal tail trailing behind the Pleiades cluster, with Theia 369 perhaps part of its leading tidal tail.[1]

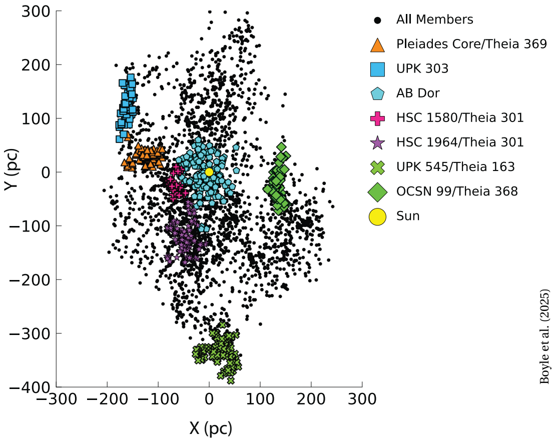
A related problem is that the physical processes which regulate the dispersal of the stars from the cluster into the field (including early gas dispersal, N-body interactions, and external tidal forces) depend on their age, mass, and their full space velocities. These properties can only be quantified by the careful identification and characterisation of all stars which have been lost from the cluster over the tens to hundreds of millions of years since its formation.

Quoting Boyle et al. (2025a): *'While recent Gaia studies have honed our view of cluster dispersal, the exact chronology of which star formation events begat which star cluster remnants remains unclear. This problem is acute after 100 Myr, when cluster remnants have spread over hundreds of parsecs, and most age estimates for main sequence stars are too imprecise to link the stars to their birth events.'*

ONCE STARS are sufficiently far from their birthplaces, and diluted by the wider and more numerous field population, they may no longer be detectable from studies of their spatial or kinematic clustering. In their recent study using Gaia DR3, Boyle et al. (2025a) exploited the properties of stellar rotation to provide an alternative means for selecting young stars amongst the more dilute background population.

The underlying technique of gyrochronology rests on the fact that stellar rotation slows down with age due to magnetic braking (e.g. Barnes, 2003; Meibom et al., 2015). This enables the use of rotation periods as a proxy for age, with rapid rotation serving as a powerful diagnostic of young stars. Cantat-Gaudin & Casamiquela (2024) have reviewed how this method has been applied to the dating of open clusters using the 3 million rotation periods derived from the Gaia DR3 BP/RP photometry and RVS spectroscopy (Frémat et al., 2023).

[1]The Theia catalogue resulted from a Gaia-based search for density structures out to a distance of 3 kpc, resulting in a compilation of 8292 separate low-density filaments or streams, comprised of hundreds to thousands of stars, and spanning hundreds of parsecs (Kounkel et al., 2020; Kounkel et al., 2022).



Boyle et al. (2025)

TAKING INTO ACCOUNT the effects of extinction (derived from independent Gaia studies, as described in essays 191 and 236), and the range of stellar mass over which magnetic braking is most relevant, $T_{\rm eff} = 3000$–6500 K, Boyle et al. (2025a) identified a starting list of more than 6 million stars. The sample was further restricted to those with Gaia-based space velocities within 5 km s^{-1} of the Pleiades core, and with TESS-derived rotation periods < 12 d (Boyle et al., 2025b).

Their clustering and membership analysis then resulted in 3091 coeval stars spanning nearly 600 pc in spatial extent. What they then refer to as the *'Greater Pleiades Complex'* includes at least seven previously known groups (including the Pleiades itself), several of which were earlier Gaia discoveries, amongst them UPK 303 from the Ulsan Pusan Korea cluster catalogue (Sim et al., 2019; Risbud et al., 2025), Theia 3015 (Kounkel et al., 2020), Theia 163/UPK 545, OSCN 99 (Qin et al., 2023), and the AB Dor moving group. Their distribution in Galactic XY coordinates is shown above.

Their validation of these inferred structural features included inspection of their colour–magnitude diagrams, analysis of their chemical abundances using the bulk metallicities derived from the Gaia BP/RP spectra (Andrae et al., 2023), and (backward) Galactic orbit integration of the present-day positions and velocities of stars in each group relative to the median positions and velocities of the Pleiades cluster core.

ON THE BASIS of their uniform ages, coherent space velocities, detailed elemental abundances, and traceback histories, Boyle et al. (2025a) concluded that most stars in this 'Greater Pleiades Complex' indeed originated from the same giant molecular cloud.

Some groups (e.g. UPK 303) may be associated with tidal tails, others (e.g. Theia 163/UPK 545) are likely to have arisen as concurrently forming clusters. They also found stellar bridges connecting the Pleiades with other young associations. Together, these highlight a particularly extensive and complex star-formation history.