257. More globular cluster stellar streams

In this and the following two essays, I will say more on stellar streams. While it is a subject that I have covered several times (Enceladus 15; more streams 71; discovery update 156; black holes 176; and the effect of sub-halos 184; as well as several on specific streams: Hercules 115; HR 1614 and Arcturus 116; GSE 197; Sagittarius 198; and Cetus 199) it is one that is at the forefront of Gaia's scientific impacts – and developing rapidly.

In this essay, I will describe a specific search for stellar streams associated with *known* globular clusters. In the following two, I will focus on a couple of unusually complex streams (essay 258), and then give an update on their use in detecting dark matter sub-halos (essay 259).

At the time of my update in 2023 (essay 156), Mateu (2023) listed 95 known streams, many found using the `Streamfinder` algorithm (Malhan & Ibata, 2018). `Streamfinder` was developed specifically for Gaia, uses the full phase-space (positions and velocities) information, and is based on the fact that stars in a (thin and dynamically cold) stream are connected through the progenitor's orbit. Starting with one or more members of a hypothesised stream, others will then be contained in a 'hypertube' defined by the progenitor's orbit and velocity dispersion. I said more on this and other search algorithms (notably the unsupervised learning `STARGO`, and the 'model agnostic' `Via Machinae`) in essay 199.

`Via Machinae` used unsupervised machine learning for anomaly detection (`ANODE`), originally developed for the Large Hadron Collider (Shih et al., 2022; Shih et al., 2024). Its most recent version, using the anomaly detection method Cathode, also developed for particle physics, Via Machinae 3.0 (or VM3–C), yields a further 10% or so in numbers (Hallin et al., 2025).

Here, the 'anomalies' sought are overdensities with respect to the background that are broadly consistent with stellar streams. Amongst their most notable discoveries are *Raritan* and *Passaic* which, they infer, may indicate the presence of larger objects, such as dwarf galaxy streams, or non-trivial orbital dynamics resulting in bifurcation or fanning. I say more on these in essay 258.

My focus for this essay is on a specific search for stellar streams associated with *known* globular clusters. But let me first expand on two points to provide some astrophysical context.

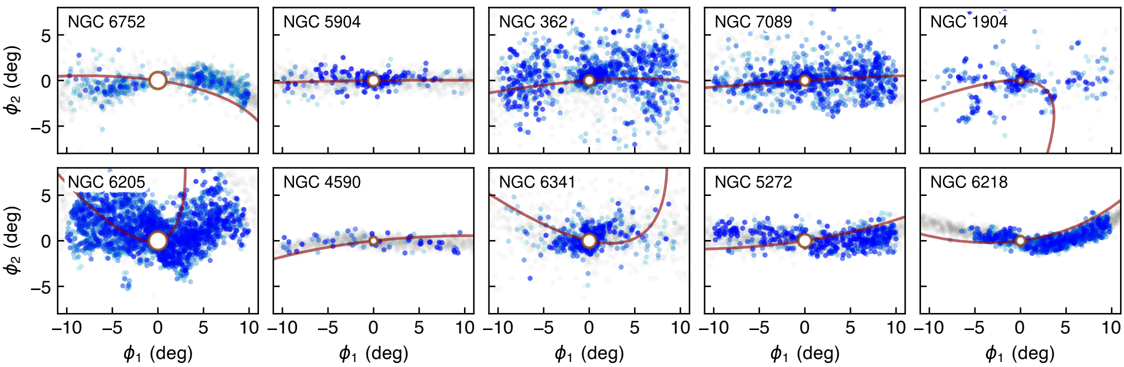
Do stellar streams originate from globular clusters, or dwarf galaxies? The current view is that amongst the 100 or more thin stellar streams now known, the majority originated from globular clusters, notable exceptions to this being the Gaia Sausage–Enceladus (GSE) and Sagittarius streams. The arguments are based on their physical, chemical, and kinematic signatures.

Specifically, globular cluster streams retain their primordial 'cold' (low velocity dispersion) dynamics, resulting in very narrow, thin, and highly coherent structures. Spectroscopically, their stars reflect a largely single stellar-generation origin, with nearly identical chemistry, and contrasting with the extended star-formation episodes and wide spread in ages and abundances of dwarf galaxies. Finally, without their own dark matter halos, globular clusters are more rapidly and cleanly disrupted by Galactic tidal forces, with dwarf galaxies resulting in a more complex disruption pattern.

In practice, the distinction is more nuanced. While individual streams are generally the remnants of disrupted globular clusters, orbital clustering studies using Gaia EDR3/DR3 have shown that many of these globular clusters (and their streams) originally belonged to dwarf galaxies. When the Milky Way devoured those dwarf galaxies, the associated globular clusters were stripped out into our Galaxy's halo, where they were subsequently shredded into the thin streams observed today.

For example, Massari et al. (2019) traced about 40% of all Milky Way globular clusters back to five major dwarf galaxy mergers, such as GSE and Sagittarius.

Bonaca et al. (2021) used orbital energies and angular momenta to show that for 20 out of their 23 halo streams investigated, the orbits can be matched to a specific, now-disrupted host dwarf galaxy that originally deposited them into the Milky Way. Only a single stream (Svöl) was found to plausibly originate from a globular cluster born locally within the Milky Way's disk.



Chen et al. (2026)

Stream members (blue circles, colour-coded by membership probability) around some of the 34 Milky Way globular clusters from Chen et al. (2026). Streams are shown in the great circle frame ($\phi_1 - \phi_2$) centred on the progenitor globular cluster (brown circles indicate tidal radii). Orbits of the progenitor clusters are shown as brown curves. The simulated streams are shown as grey symbols.

MY SECOND contextual point is to clarify the distinction and use of the terms 'stellar stream' and 'tidal tail', which is really one of spatial and temporal scale.

Tidal tails describe the leading and trailing extensions still loosely attached to an existing, surviving parent globular (or open) cluster. They are young and actively forming as a result of Galactic tidal forces, typically span just a few degrees, and are seen as two distinct leading and trailing arms. Over billions of years, the cluster disintegrates completely, the leading and trailing tails stretch out, eventually wrapping around the Galaxy to result in an old, dynamically evolved stellar stream.

NOW TO THE KEY TOPIC of this essay, which is a search for the stellar streams associated with known Galactic globular clusters. The search by Chen et al. (2026) makes use of another new stream detection algorithm, `StarStream` (Chen et al., 2025a).

`StarStream` uses a very different (physics-based) approach to stream detection, which makes no prior assumptions about a stream's morphology. The orbits of both the cluster progenitor, and tracer particles, are integrated in a model Galactic potential, while incorporating a 'particle spray model' (Chen et al., 2025c). This 'ejects' tracer particles from the model cluster, assuming some uniform but adjustable ejection rate over the past 1 Gyr. Escaping stars are drawn from a standard initial mass function, with associated magnitudes and colours estimated from MESA isochrones. Through models of mock streams, the completeness and 'purity' of the detected stream members can be estimated.

Applied to our Galaxy's known globular clusters, taken from the 156 members of the fourth edition of the catalogue of Milky Way globular clusters by Hilker et al. (2020), and making use of the astrometry and photometry from Gaia DR3, they identified 87 associated streams, including 34 high-quality cases with estimated completeness, and purity, both exceeding 50%.

EXAMPLES of their results are shown above, being just 10 out of their 34 high-quality cases (their Fig. 2).

Pre-dating this work, fewer than 20 Galactic globular clusters had been associated with streams. Specifically, although tidally stripped stars have been widely observed around globular clusters (e.g. Kuzma et al., 2025), thin, extended stream-like features remained undetected along the orbits of most. The discoveries by Chen et al. (2026) double the number of known globular cluster streams, and increase the fraction of tidal streams at high Galactic latitudes ($|b| > 30°$) to 75%.

Many of the new streams are rather wide or short, or misaligned with their progenitor's orbit. This confirms the suggestion that assuming streams to be thin features, primarily elongated along the progenitor's orbit, can miss these more irregular streams. Indeed, their findings substantiate the predictions that streams may appear more dynamically hot or spatially complex, depending on the progenitor's mass and orbit (Amorisco, 2015). And that streams can deviate from the progenitor's orbit in a non-spherical or time-evolving Galactic potential (Sanders & Binney, 2013a; Sanders & Binney, 2013b; Panithanpaisal et al., 2026). All of these effects may be amplified depending on the viewing angle.

THEY ALSO USED their membership numbers to estimate the mass-loss rate for the progenitor clusters (cf. Chen et al., 2025b). They found several large low-mass clusters with high mass-loss rates, suggesting that they are close in time to complete tidal disruption.

As one example, they estimated $\dot{M} \sim 10 M_\odot\,\mathrm{Myr}^{-1}$ for Pal 5 over the past 1 Gyr. This is some factor 3 higher than the average rate over the past 6 Gyr estimated by Chen et al. (2025b). But it is remarkably consistent with the prediction by Gieles et al. (2021), who showed that the high black hole abundance of Pal 5 could accelerate the mass-loss rate from an initial $5-10 M_\odot\,\mathrm{Myr}^{-1}$ to $10-20 M_\odot\,\mathrm{Myr}^{-1}$ towards the end of its lifetime.