134. Resolved binaries with 1000 pc

Binary stars, as well as systems of higher-order multiplicity, are important scientifically for many reasons, ranging from understanding star formation and subsequent stellar evolution, deriving fundamental astrophysical parameters related to stellar mass, and probing the Galactic tidal field through system disruption.

They occur in a bewildering variety of configurations, including unresolved short-period binaries that can only be distinguished spectroscopically (or as photometrically eclipsing), extremely wide-separation long-period systems, and higher-multiplicity systems with a host of hierarchical orbital periods and mass ratios.

This makes it impossible to identify all of even the *two*-component systems with a single instrument, resulting in the need for a range of spectroscopic, astrometric, or visual surveys for any sort of global census.

And it complicates, enormously, their measurement with Gaia: while a single star's motion can be characterised with just 5 astrometric parameters (two position and two proper motion components, and the parallax; or 6 including the radial velocity) over just 3–4 years, binary and multiple systems require many more observations, and a more extended temporal baseline, depending on their constituent orbital periods.

In previous essays, I have touched on various aspects of these binary and multiple systems in different contexts: on the identification and characterisation of non-single stars within the Gaia data processing chain (#78 and #79); on the statistics of the various categories of non-single stars in Data Release 3 (#76); on their occurrence in both the 100 pc Gaia Catalogue of Nearby Stars (#33) and the 25 pc Fifth Catalogue of Nearby Stars (#129); and some 'special' cases, including both ultra-wide binaries (#37), and ellipsoidal variables (#133).

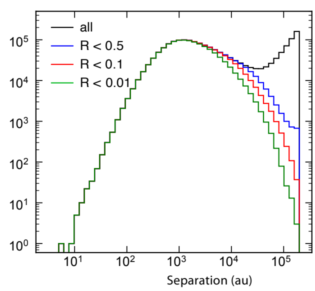
Here I will look at another important sample of binary stars derived from Early Data Release 3 (EDR3): the catalogue of resolved binaries within 1 kpc constructed by El-Badry et al. (2021). It largely supersedes similar constructions using DR2 (Brown et al., 2018; El-Badry & Rix, 2018; Tian et al., 2020; Hartman & Lépine, 2020).

In the context of this catalogue of resolved binaries, let me start by emphasising two words: 'binary' here means that their catalogue comprises systems with exactly two components – because of the complexity of identifying higher multiplicity systems with any degree of completeness, they specifically excluded them from their catalogue. 'Resolved' means that the two components have a separate source identifier in EDR3. Their catalogue therefore excludes many of the other types of non-single stars identified in EDR3 (and DR3), including orbital spectroscopic binaries and eclipsing binaries.

Their construction starts by selecting all sources with parallaxes greater than 1 mas (i.e. a nominal distance limit of 1 kpc), and $\sigma_\varpi/\varpi < 20\%$, yielding a total of $N = 64\,407\,853$ sources, corresponding to $N(N+1)/2 \approx 2\times10^{15}$ possible pairs. Of these, they consider as initial binary candidates all pairs that have a projected separation less than 1 pc (i.e. an orbital period of $\sim 10^8$ yr, beyond which the Galactic tidal field is likely to result in their disruption), parallaxes consistent within 3σ, and proper motions consistent with a Keplerian orbit.

The resulting 10^8 candidate pairs still contains many chance alignments, which they clean by further consideration of each object's neighbours in 'phase space' (position and velocity), spurious coincidences in crowded regions (Galactic bulge, LMC and SMC), 'overlapping pairs' (which also eliminates true triple-systems in the process), and spurious pairs in open clusters. All this leads to just over 1.8 million binary pairs.

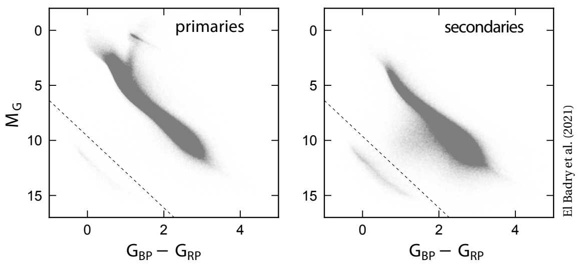
Further consideration of chance alignments, and the probability of the pairs being bound, both of which are a function of separation, Galactic coordinate, and magnitude, result in their sample of 1 256 400 binary systems with a 'high probability' of being physically bound, $N_{\mathcal{R}<0.1}$.



El Badry et al. (2021)

THE GAIA multi-colour photometry, combined with the parallax, then allows each system component to be placed in the Hertzsprung–Russell diagram. Each can then be designated as a white dwarf, or as a 'non-white dwarf' (mostly main sequence stars, but including giants, subgiants, pre-main sequence stars, and brown dwarfs) based on whether they fall below or above the dashed line in the corresponding diagram (below).

Although a quarter of the components have no colour in EDR3, the majority could be assigned to systems in which *both* components are main sequence (877 416 systems), one is a main sequence and one is a white dwarf (16 156), or both are white dwarfs (1390).



ANGULAR SEPARATIONS range from 0.2 arcsec to 1°, with 271 pairs having separations 0.2–0.4 arcsec, and the peak of the angular separation distribution being at 1.2 arcsec. The median magnitude of high-confidence primaries is $G = 15.2$, and that of secondaries is $G = 17.7$. Most white dwarfs are much fainter: the median magnitudes of primaries and secondaries in the white dwarf–white dwarf sample are 19.1 and 19.8. The median distance of the full high-confidence sample is 485 pc ($\varpi = 2.05$ mas), while the median distances for the white dwarf–white dwarf and white dwarf–main sequence binaries are 148 pc and 212 pc.

Because of their smaller distances, the white dwarf–white dwarf and white dwarf–main sequence binaries are distributed roughly uniformly on the sky. The main sequence–main sequence sample, which extends to larger distances, shows a clear imprint of the stratification of the Galaxy disk. Most of the binaries are, kinematically, part of the disk population, but a few thousand are members of the halo.

The catalogue also contains about 10 000 high-confidence binaries in which the primary is a giant star (about half of these giants are in the red clump), along with 130 giant–giant binaries, and some 13 000 binaries in which one component is a subgiant.

THEY FIND a total space density of wide binaries with $s > 30$ au of $0.006 \pm 0.001\,\mathrm{pc}^{-3}$ in the solar neighbourhood, about 1/10th of the space density of all unresolved Gaia EDR3 sources in the solar neighbourhood, at around $0.07\,\mathrm{pc}^{-3}$ (Smart et al., 2021).

IN ABSOLUTE numbers, the catalogue gives a factor of four increase in the number of high-confidence binaries compared with the DR2 (Tian et al., 2020), and by far the largest catalogue of high-confidence binaries of any type. For example, as of June 2017, the Washington Double Star Catalog (WDS) had 141 743 double star entries, inclusive of the Hipparcos discoveries.

AN INTERESTING property of binary stars is the excess population of equal-brightness (and presumably, equal-mass) 'twin' binaries (Lucy & Ricco, 1979; Tokovinin, 2000).

This had been noted in the Gaia data by El-Badry et al. (2019), who identified a sharp excess of equal-mass 'twin' binaries, statistically significant out to separations of 1000–10 000 au, depending on primary mass. This latest EDR3 sample confirms that the excess is narrow, with a steep increase between mass ratios 0.95–1, but no significant excess at lower mass ratios.

El-Badry et al. (2019) argued that the wide twin population is difficult to explain if the components of all wide binaries formed via core fragmentation. Instead, they conjectured that these wide twins formed at smaller separations ($a \lesssim 100$ au), likely via accretion from circumbinary disks (e.g. Bate, 2000; Adams et al., 2020), and were later widened by dynamical interactions in their cluster environments.

THIS ENORMOUS CATALOGUE of resolved binary systems within 1000 pc, and its updates exploiting future data releases, will find many applications. As examples, the authors draw attention to its value for:

(a) calibrating stellar ages, in which constraining the age of one component fixes the age of the other, perhaps of a different and less well-understood evolutionary state;

(b) determining the initial–final mass relation for white dwarfs, exploiting the fact that the masses and cooling ages can be well-constrained from photometry;

(c) deriving white dwarf masses from gravitational redshifts, in which the white dwarf and main sequence star in a wide binary have the same radial velocity;

(d) establishing abundances for white dwarf progenitors, including the (now well-identified) contributions from disintegrating planets;

(e) investigating the spin alignment of wide binaries, e.g. examining whether the spin vectors of 'twin' binaries are more aligned than those of non-twins;

(f) calibration of the systematic effects in spectroscopic surveys, by exploiting the generally similar abundances of stars in wide binaries;

(g) their use as dynamical probes where, at wider separations, disruption due to gravitational encounters with other stars or molecular clouds becomes important.