The 10 parsec sample in the Gaia era: first update

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Abstract

The nearest stars provide a fundamental constraint for our understanding of stellar physics and the Galaxy. The nearby sample serves as an anchor where all objects can be studied and understood with precise data. This work is an update of the 10 pc sample published by Reylé et al. (2021) that used the unprecedented high precision parallax measurements from the early third data release of the astrometric space mission Gaia. We review this census, all updates being related to close binaries, brown dwarfs and exoplanets. We provide a new catalogue of 541 stars, brown dwarfs, and exoplanets in 336 systems within 10 pc from the Sun. This list is as volume-complete as possible from current knowledge and it provides a list of benchmark stars. We also explore the new products made available in the most recent third Gaia data release.

1 Introduction

Making a census of the nearest stars has been a long term goal in astronomy starting in the end of the nineteenth century, when the first stellar distances were measured from their trigonometric parallaxes. The nearby sample is a fundamental census where all objects can be studied with accuracy. It provides core constraints to understand stellar and galactic physics, as well as ideal targets for exoplanet searches. Following in the steps of Louise F. Jenkins, who published a list of 127 stars with their known companions and gathered the knowledge at that time on the neighbours whose distance is less than 10 pc from the Sun (Jenkins, 1937), we give here the current snapshot of the nearby sample within 10 pc.

In Reylé et al. (2021), we used the unprecedented high precision parallaxes of Gaia Early Data Release 3 (Gaia EDR3, Gaia Collaboration et al. 2021a) to review the census of objects within 10 pc. Our first compilation focused on objects observable by Gaia, as a quality assurance test for the 100 pc Gaia Catalogue of Nearby Stars (GCNS, Gaia Collaboration et al. 2021b). We complemented it with objects not in the Gaia EDR3 to get a full 10 pc census, including bright stars, close binaries, brown dwarfs, and exoplanets. In this paper, we present an update of the 10 pc census, and explore the new data products (astrophysical parameters, variability, binarity) offered by the third Gaia data release (Gaia DR3, Gaia Collaboration et al. 2022a). This new list provides their astrometry (positions, parallax, proper motions), photometry, radial velocities, and spectral types, when available for 371 stars, 85 brown dwarfs, and 85 exoplanets.

2 Updates

2.1 Added objects

As predicted by Reylé et al. (2021), the expected additions are cool objects hiding near the Milky Way plane, very close companions resolved by spectroscopic, adaptive optics, or interferometric observations (e.g. Vrijmoet et al. 2022), and exoplanets that numerically should outnumber the other objects within 10 pc. Two brown dwarfs and eight exoplanets orbiting M-dwarfs are added to our list.

- CWISEP J225628.97+400227.3, a Y dwarf that we previously missed from Kirkpatrick et al. (2021);
- CWISEP J181006.00−101001.1, a peculiar, metal-poor brown dwarf close to the galactic plane discovered by Schneider et al. (2020) and whose parallax was later derived by Lodieu et al. (2022);
- a companion to GJ 666 B, found from the astrometric orbital solution of Gaia DR3 (see Section 5.1). This close binarity was wrongly attributed to GJ 666 A by RagHAVan et al. (2010) and Jenkins et al. (2015);
- GJ 411 c, a long-period planet discovered by Rosenthal et al. (2021) and confirmed by Hurt et al. (2022);
- LTT 1445 A c, a second planet transiting the primary star of the triple system LTT 1445 (Winters et al. 2022);
- GJ 393 b, a terrestrial planet discovered by Amado et al. (2021);
- GJ 514 b, a super-Earth planet on an eccentric orbit Damasso et al. (2022);
• GJ 367 b, a dense, ultra-short period sub-Earth planet (Lam et al. 2021).
• HD 260655 b and HD 260655 c, two rocky planets transiting the furthest star of our list (Luque et al. 2022).
• Wolf 1069 b, an Earth-mass planet in the habitable zone (Kossakowski et al. 2023).

2.2 Rejected objects
Nine low-mass stars and brown dwarfs are removed because they have a better parallax measurement that places them outside of the 10 pc limit, or because they were wrongly considered as binary objects.

• 2MASS J16471580+5632057 has a more accurate parallax of 42.9 ± 2.1 mas by Best et al. (2020).
• 2MASS J07584037+3247245 has a better Gaia EDR3 parallax of 91.92 ± 1.73 mas than the one that we considered (Kirkpatrick et al. 2021).
• CFBDs J213926+022023 A and B is actually a single object (Kirkpatrick et al. 2021) and has a better parallax of 96.5 ± 1.1 mas by Zhang et al. (2021);
• GJ 666 Ab, a close companion wrongly attributed to GJ 666 A instead of GJ 666 B by Raghavan et al. (2010) and Jenkins et al. (2015).
• GJ 748 AB has a more accurate and robust Hubble parallax of 98.4 ± 0.3 mas taken into account the effects of binarity (Benedict et al. 2016).
• GJ 424 B (Docobo et al. 2006) was not confirmed with adaptive optics (Ward-Duong et al. 2015) and long term high precision radial velocity monitoring rules out the proposed companion candidate (Butler et al. 2017).
• UPM J0815–2344 B is a background object that is close to UPM J0815–2344 and was wrongly attributed as a physical companion by Henry et al. (2018).
• WISE J081117.81–805141.3 was wrongly listed in the 10 pc sample. Having a parallax of 98.5 ± 7.7 mas (Tinney et al. 2014), it is now part of the candidate list.

2.3 Candidates
Star and brown dwarf candidates are tabulated in the list (numbered from NB_OBJ equal 1001 to 1021). They are mostly brown dwarfs that have large parallax uncertainties and are still compatible with a parallax larger than 100 mas at the 1σ level.

Exoplanet candidates are given in the COMMENT field of the list. Three new candidates are GJ 411 d (Hurt et al. 2022), LTT 1445 A d (Lavie et al. 2022), and Proxima Cen d (Faria et al. 2022). None of our previous candidates have been confirmed yet. However, we flagged the planet around Barnard’s Star announced by Ribas et al. (2018) as controversial rather than candidate based on the stellar activity study by Lubin et al. (2021).

We also add a note on GJ 229 B: the high dynamical mass derived by Brandt et al. (2021) may denote the existence of an unseen companion.

2.4 Additional objects with a Gaia parallax larger than 100 mas
Three additional objects have a Gaia EDR3 parallax larger than 100 mas. The random forest classification procedure used for the construction of the GCNS (Gaia Collaboration et al. 2021b) found that these objects have a bad solution based on astrometric quality assurance parameters. Their probability of having a good astrometric solution is very low (0.076, 0.082, 0.013), much lower than the 0.38 threshold defined as the reliable astrometry probability. Thus they were rejected by Reylé et al. (2021) without further discussion although we noticed inconsistencies with WISE and PanSTARRS data as described below.

Using other selection criteria, the Fifth Catalogue of Nearby Stars (CNS5) recently published by Golovin et al. (2022) kept two of the three objects with Gaia EDR3 parallax larger than 100 mas. We believe that they deserve more discussion, because the three sources, listed below, are blended and have rather low total proper motions (13, 29, 69 mas a−1) compared to the usual values of the nearby sample (mean, minimum, maximum, and standard deviation, of 1319, 68, 10393, and 1246 mas a−1, respectively).

- The faint G magnitude (20.6 mag) of Gaia EDR3 4318384355378007424 together with being nearby (Gaia EDR3 parallax of 101.08 ± 3.47 mas) would imply a red source but it appears blue in PanSTARRS. It has no G magnitude whereas as a nearby red object it should be detected. A very close (1 arcsec) bright source probably makes the Gaia observation difficult. It also was also rejected during the selection process of CNS5;
- Gaia EDR3 6305165514134625024 has a Gaia EDR3 parallax of 174.02 ± 1.90 mas. A G = 20.4 mag at this close distance is supposed to be a mid-T dwarf, but its W1 = 16.9 mag is about 4.5 mag fainter than a nearby mid-T should be. Looking at the PanSTARRS and WISE images, we instead interpret it as a red background object blended with a blue object. It is considered as a new addition to the 10 pc sample in CNS5. For the moment we tabulate it as a candidate (NB_OBJ = 1021) with a low probability to be an exotic object;
- Gaia EDR3 4479498508613790464 has a Gaia EDR3 parallax of 121.98 ± 0.94 mas is probably wrong based on recent spectroscopic observations by Kirkpatrick et al (in prep), who attributed an M2 V spectral type that matches the observed colours.

3 The 10 pc sample in Gaia DR3 products
The Gaia third data release is the outcome of the processing of data collected during the first 34 months of the mission. It was been done in two steps. The Early Data Release 3 (EDR3), published on 3 December 2020, provides new astrometry and photometry of the sources with radial velocities
from the second Gaia data release. The Data Release 3 (DR3), published on 13 June 2022, provides more radial velocities and a wealth of new data products, such as non-single stars, variability properties, and astrophysical parameters. In what follows, we show what kind of information can be found in Gaia DR3 for the 10 pc sample.

3.1 Non-single stars and exoplanets

Six objects, five M dwarfs and one white dwarf, are in the table gaiadr3.nss_two_body_orbit, which contains orbital models compatible with an orbital two-body solution. A selection of parameters, such as period, periastron argument, eccentricity or inclination, is provided in the table, depending on the solution type (namely: astrometric, spectroscopic, photometric; see Gaia Collaboration et al. 2022a). For objects with an astrometric solution, new values of the parallax and proper motions, taking into account the orbital motion, are provided. We updated these values, which are more accurate than those given in the main catalogue, in our 10 pc sample. In addition, the table gaiadr3.binary_masses provides an estimate of the masses and flux ratios, or lower and upper limits of them. We give below details on the parameters for the six objects with a non-single star solution. They are shown with open symbols in the colour absolute diagram in Fig. 1 left panel.

- GJ 1230 AC has an orbital solution from spectroscopy (SB2) and thus the secondary mass can be estimated. The value is 0.299 M⊙, confirming the low-mass star type of GJ 1230 C with no spectral type. The estimated orbital period is 2.53 days;
- GJ 867 AC received independent, astrometric and spectroscopic, orbits. The derived secondary mass, 0.655 M⊙, confirms the low-mass star nature of GJ 867 C with no spectral type. The estimated orbital period is 4.08 days;
- Wolf 227 AB has an orbital solution from astrometry. The secondary mass ranges from 0.046 to 0.364 M⊙. The lower value is compatible with the statement that it may be a brown dwarf from its mass estimate from Winters et al. (2018). The period is found to be 10.59 days;
- GJ 666 B has an unseen companion detected from its astrometric orbit. The secondary mass ranges from 0.169 to 0.734 M⊙, and the period is 87.91 days;
- GJ 876 b is the only planet at less than 10 pc detectable by Gaia according to Reylé et al. (2021) that was detected in DR3. Its true mass derived from the astrometric orbit is 3.6 MJup, larger than any of the various estimates in the literature (which range between 2.0 and 2.7 MJup). In Gaia Collaboration et al. (2022a) some discussion is provided on the possible nature of the discrepancy;
- L 88-59, a white dwarf, has an astrometric orbital solution with a secondary mass ranging from 0.007 to 0.838 M⊙ and a period of 33.65 days. The lower mass value of the secondary makes it a planet candidate, which is listed in the dedicated list of Gaia exoplanets maintained at https://cosmos.esa.int/web/gaia/exoplanets.

3.2 Variable stars

Up to 19 stars in our sample are found in the variability tables (gaiadr3.vari_summary, gaiadr3.vari_classifier_result, gaiadr3.vari_short_timescale, gaiadr3.vari_rotation_modulation), which give various parameters derived from multi-epoch observations (Eyer et al. 2022). They are shown with coloured symbols in Fig. 1 right panel. Nine are solar-like variable stars, indicating a variable phenomena similar to those observed in the Sun, mainly due to the evolution of its
magnetic active regions (dark spots and bright faculae unevenly distributed over the stellar surface). They are all M dwarfs (GJ 625, AN Sex, GJ 1151, L 49-19, G 19-7, MCC 135, BD+43 2796, BD+16 2708A), except for one white dwarf (HD 100623 B). Another seven stars, all M dwarfs, are short-term candidates with timescales between a few tens of minutes to one day (Ross 248, DENIS J104814.6-395606, GJ 643, GJ 486, L 173-19, LP 655-48, BD+61 195B). G 19-7 and GJ 867 B have in addition rotational modulation and, therefore, their stellar rotation period can be determined from the analysis of their light curve (1.20 days and 1.99 days, respectively). Finally, GJ 15 A and GJ 15 B are also part of the variability table because photometric data were obtained as part of the Gaia Andromeda Photometric Survey (Evans et al., 2022).

3.3 Radial velocities and kinematics

All stars and brown dwarfs in the sample have measurements of parallax and proper motion, which allows us to compute their transverse velocity, \( V_T \). In addition, Gaia DR3 provides new radial velocities for 23 stars, and more accurate radial velocities than previously measured for another 24 stars (Katz et al., 2022), leading to 309 stars with full kinematics in the 10 pc sample. We exclude the erroneous large value of \(-414 \text{ km s}^{-1}\) for the white dwarf EGGR 290, due to the lack of white dwarf templates in the radial velocity determination Gaia pipeline. For those stars we are able to compute the local standard of rest-corrected space velocities in the Galactic reference frame \((U, V, W)\). Figure 2 shows the resulting Toomre diagram.

Most of the nearby sample lie in the thin-disc region. There are, however, a few remarkable exceptions. The star with the highest tangential velocity (square) is Barnard’s star, which has a prograde motion and lies in the thick-disc region.

Figure 2: Toomre diagram for the 309 objects with a radial velocity measurement, coloured by their transverse velocity. The circles with total velocity of 100 and 200 km s\(^{-1}\) are indicative values to delineate thin-disc, thick-disc, and halo stars. Square: Barnard’s star, diamond: HD 103095, triangle down: Kapteyn’s star, triangle up: 2MASSW J1515008+484742.

3.4 Astrophysical parameters

Several astrophysical parameters have been derived from Gaia photometry and spectroscopy and, therefore, part of our sample has a determination of the effective temperature, gravity, metallicity and, in a few cases, global abundance of \(\alpha\)-elements with respect to iron (\(\alpha/Fe\)). Furthermore, some sample stars also have mass, luminosity, radius and age determinations from Gaia DR3 (Gaia Collaboration et al., 2022b). We did not attempt to add these values in our list, since it would ask for a large work to get a consistent picture with other values found in the literature (e.g. Cifuentes et al., 2020; Rajpurohit et al., 2020; Marfil et al., 2021; Cristofari et al., 2022). As an illustration, we show in Fig. 3 the \([\alpha/Fe]\) vs \([M/H]\) plane. This plane is often used to investigate stellar populations, (see e.g. earlier works by Fuhrmann 1998, Reddy et al., 2006, Adibekyan et al., 2013), who showed that the disc of the Milky Way is composed of \(\alpha\)-rich and \(\alpha\)-poor stars. We only plot the stars with the 13 parameter quality flags \(\leq 1\) (see Table 2 in ?). We also applied the calibrations on \([M/H]\) and \([\alpha/Fe]\) as a function of their log \(g\) as defined by ?. In Fig. 3 HD 103095 (diamond) lies in the upper (\(\alpha\)-rich) left (metal-poor) part of the diagram, pointing to an old population star, compatible with its extreme kinematics (see Fig. 2).

4 Conclusion

We provide an update of the catalogue of all objects closer than 10 pc from the Sun. This list shows the high variety of objects contained in the immediate vicinity of the Sun.
It contains 541 objects divided between 371 stars, including 21 white dwarfs, 85 brown dwarfs, and 85 confirmed exoplanets in 336 systems. It contains the most recent astrometry from the last Gaia data release when available. As (Reylé et al. [2021]) already pointed out, the updates concern close binaries, brown dwarfs, and exoplanets, and we expect that in the future the number of stars and brown dwarfs will be superseded by exoplanets. In addition, we explore the new products offered by the most recent Gaia DR3, including astrophysical parameters, additional radial velocities, non-single star orbital solutions, and variability parameters. This list provides a set of benchmark stars to be studied in detail with current and forthcoming instruments. More parameters, in particular on the non-single stars (including exoplanets) are expected in the forthcoming Gaia data releases.

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