129. Stars within 25 parsec: the CNS5

In essay 33 I wrote about Gaia's census of 'nearby stars', focusing on the EDR3-based study of stars within 100 pc by Smart et al. (2021).

As I said in my introduction there, 'nearby' is a somewhat vague term, and it is variously taken to mean the spherical region of space out to 10 pc, 20 pc, 50 pc or, in that case, even 100 pc from the Sun. Compared with the scale of our Galaxy, in which the Sun sits some 8000 pc from the Galactic centre, 'nearby stars' are dominated by members of our Galaxy's disk.

Understanding the nearby stellar population is central to many areas of astronomy. Surveys provide the foundations for defining our Galaxy's stellar luminosity and velocity distributions, the local mass density, binary and multiple stars, and the many other objects which comprise our Galaxy, including brown dwarfs, white dwarfs, exoplanets, and even black holes.

Stellar ages reflect the star-formation history of the disk. Chemical abundances as a function of age provide evidence of the chemical evolution and enrichment history of the disk. Space motions and Galactic orbits constrain the dynamical evolution of the Galaxy and the mixing of its stellar populations. And so on.

It remained a difficult task, pre-Gaia, to establish anything approaching a complete census of stars even out to 10–20 pc. Ground-based parallax surveys were successful in identifying nearby bright stars but, at the faintest luminosities, $M_V \gtrsim 15$, parallax surveys even out to 10 pc remained incomplete.

Surveys of high-proper motion stars were efficient at detecting nearby candidate stars which were then added to parallax programmes (including Hipparcos), but they resulted in a significant bias towards high-velocity halo objects. As a result, the early nearby star compilations used spectroscopic and photometric distance estimates to identify additional nearby candidates.

The *'Catalogue of Stars within 25 Parsecs of the Sun'* (Woolley et al., 1970) was one of the first attempts to compile a census of known stars in the solar neighbourhood, largely based on trigonometric parallaxes.

In recent years, important contributions have been made by various groups. Northern Arizona University 'NStars Database' aimed for a complete compilation to 25 pc. At the end of 2006 it listed 2029 systems comprising 2633 objects (Gray et al., 2006), but is now defunct.

Georgia State University's 'Research Consortium on Nearby Stars', RECONS, began in 1994 with a compilation of stars within 10 pc, extended to 25 pc in 2012. It has found more than 40 new systems (Henry et al., 2018). Many other nearby candidates have been found from extensive high-proper motion surveys (e.g. Lépine, 2005).

But for the rest of this essay, I will focus on the evolving compilation which has been maintained by the Astronomisches Rechen-Institut in Heidelberg (now part of ZAH) over the last 60 years.

Wilhelm Gliese (1957) published the *'Katalog der Sterne näher als 20 Parsek für 1950.0'*, containing 915 stars and systems within 20 pc, with probable parallax errors of 9.2 mas. Gliese (1969) published the updated *'Catalogue of Nearby Stars'*, CNS2, with a slightly enlarged distance limit of 22.5 pc. It contained 1049 stars or systems within 20 pc, and the probable errors were estimated as 7.6 mas.

The *'Third Catalogue of Nearby Stars'*, CNS3, was only published in preliminary form (Gliese & Jahreiß, 1991). This extended the census to some 1700 stars estimated to be nearer than 25 pc, based on a wide variety of parallax, photometric, and spectroscopic data.

The *'Fourth Catalogue of Nearby Stars'*, CNS4, incorporated data from Hipparcos and, while never formally published, was a major development in the comprehensive inventory of the solar neighbourhood out to distances of 25 pc (Jahreiß et al., 1998).

Although the number of stars within 25 pc remained largely the same, some important details changed: the Hipparcos measurements identified 119 'new' nearby stars of which the closest was a high-proper motion star at 5.5 pc. More significantly, the results implied a considerable shift to larger typical distances, with associated implications for the local stellar mass density.

THE LATEST IN this long series is the *'Fifth Catalogue of Nearby Stars'*, the CNS5, recently announced by Golovin et al. (2023). Containing 5931 objects, it is based on astrometric and photometric data from Gaia EDR3 and Hipparcos, and supplemented with parallaxes from ground- and space-based astrometric surveys carried out in the infrared to reach the lowest luminosities. Again, it aims for completeness out to 25 pc.

I should stress that the much larger Gaia Catalogue of Nearby Stars (GCNS, Smart et al., 2021), comprising a colossal 331 312 objects within 100 pc, and which I described in essay #33, while expected to be better than 95% complete for spectral types up to M8 (M_G = 15.7 mag), is highly incomplete for later spectral types. A number of bright and red sources are also missing since the GCNS is based only on Gaia EDR3 data.

Despite its much smaller volume, it is the greater completeness of CNS5, for later spectral types well into the brown dwarf regime, that underlies its importance.

I WILL NOT go into the details of how the EDR3 astrometry was handled in order to best define the Gaia sources within 25 pc (which involved consideration of the current parallax zero point, parallax errors, and multiple star complications). But a comment on stars within 25 pc fainter than the Gaia magnitude limit of $G = 20-21$ mag, many of the known L and T dwarfs, is in order.

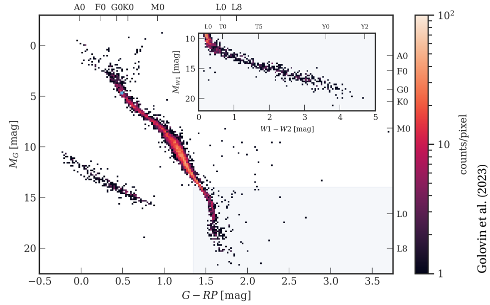
Golovin et al. supplemented the Gaia sources with ultra-cool dwarfs from Best et al. (2021). This is considered complete within 25 pc from L0 to T8, with parallaxes from the Hawaii Infrared Parallax Program (Zhang et al., 2021). Further updates and supplements were based on Spitzer parallaxes (Kirkpatrick et al., 2021).

THE CNS5 catalogue contains 5931 objects, of which 5230 are stars (4946 main-sequence, 20 red giants and 264 white dwarfs), and 701 are brown dwarfs.

The figure shows their resulting colour–magnitude diagram in the Gaia EDR3 and WISE (Wide-Field Infrared Survey Explorer) bands. The main plot includes Gaia objects with $G-R_P$ colours. It also includes objects from Hipparcos with no counterpart in Gaia EDR3, with G and R_P derived by appropriate transformations. The grey shaded area corresponds to the region in which the number of main sequence objects not present in Gaia start to increase in the WISE bands.

d (pc)	CNS1 1957	CNS2 1969	CNS3 1993	CNS4 1997	CNS5 2023
0– 5	52	54	65	61	64
5–10	179	207	268	257	329
10–20	863	918	1593	1552	2605
20–25	–	–	949	1126	2933
0–20	1094	1179	1926	1870	2998

CNS1–CNS4 from Jahreiss & Wielen (1997)
CNS5 numbers derived for this essay

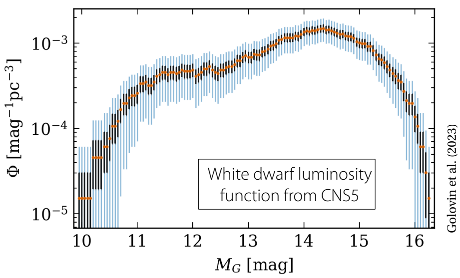


ESTIMATING THE COMPLETENESS of the CNS5 catalogue is important. For example, using space densities naively computed from the numbers within 25 pc would yield a luminosity function strongly biased due to any incompleteness at the faint end.

Working on the assumption of a uniform space density prior, in part justified by the fact that the nearest cluster, the Hyades, lies outside the 25 pc horizon, they were able to estimate the distances beyond which the observed numbers deviated from their assumed prior.

They find that CNS5 is statistically complete down to $G = 19.7$ mag, and $W1 = 11.8$ mag, corresponding to spectral type L8. The resulting stellar number density is $(7.99 \pm 0.11) \times 10^{-2}$ stars pc^{-3}, with about 72% of stars in the solar neighbourhood being M dwarfs.

They estimate that the white dwarf sample in CNS5 *is* statistically complete within 25 pc, yielding a number density of $(4.03 \pm 0.25) \times 10^{-3}$ pc^{-3}. The importance here is that the white dwarf luminosity function is sensitive to the star formation rate, such that inverting the true white dwarf luminosity function reveals the star formation history, along with any star formation bursts.



The fraction of stars relative to the fraction of brown dwarfs is also directly related to the star-formation process. They found a ratio between stars and brown dwarfs within 15 pc of 4.6 ± 0.4, rising to 7.5 ± 0.3 within 25 pc, suggesting that about one third of brown dwarfs are still missing within 25 pc... preferentially those with spectral types later than L8 and distances close to the 25 pc limit.

WITH THESE wonderful advances in our knowledge of nearby stars with just 34 months of Gaia data, compared to 10 years of data now in hand, we can look forward to future date releases with great anticipation.