33. Nearby stars

A DETAILED understanding of the nearby stellar population is central to many areas of astronomy. While 'nearby' is a vague term, it is often taken to mean the spherical region of space out to (say) 10, 20, or 50 pc from the Sun. Compared with the scale of our Galaxy, in which the Sun sits some 8000 pc from the Galactic centre, this region is dominated by stars of our Galaxy's disk.

Surveys of this nearby region provide sturdy foundations for defining our Galaxy's stellar luminosity distribution, the local mass density (in both stars and gas), their velocity distribution, the distribution and occurrence of binary and multiple stars, and the occurrence and nature of many other types of objects which comprise our Galaxy, including brown dwarfs, white dwarfs, and even exoplanets. Clearly, the best region of space to sample and to study is that closest to us, where the measurement accuracies are highest.

EVEN TODAY, it remains an enormous challenge to compile a complete census of stars in our immediate solar neighbourhood, even out to distances of, say, 10–20 pc. The pioneering ground-based parallax surveys of the early 1900s were successful in identifying nearby bright stars, but problems persist especially for the lowest luminosity stars, where a complete survey for low-mass stars and brown dwarfs even out to 10–20 pc has proven to be impossible.

Surveys searching for high-proper motion stars in the 1970–80s were successful in detecting potentially nearby stars which were then added to parallax measurement programmes, but they resulted in samples biassed towards high-velocity halo objects. For this reason, early nearby star compilations used spectroscopic *and* photometric distance estimates to try to identify more nearby candidates. The advent of accurate all-sky multicolour surveys in the past two decades has further facilitated the search for nearby, low-luminosity stars.

ONE OF THE FIRST ATTEMPTS to compile a census of stars in the solar neighbourhood, largely based on trigonometric parallaxes, was led by British Astronomer Royal Richard Woolley, and published as the *'Catalogue of Stars within Twenty-Five Parsecs of the Sun'* in 1970. Another, the Catalogue of Nearby Stars (CNS), originally led by Walter Fricke, has been updated and maintained by Heidelberg astronomers for more than 60 years.

CNS1, published in 1950, contained 915 single stars and multiple systems within 20 pc, with parallax errors of about 10 mas. CNS2, in 1969, enlarged the distance limit to 22.5 pc, and contained 1049 stars and multiple systems within 20 pc. CNS3, in 1991, extended the census to some 1700 stars nearer than 25 pc.

CNS4, in 1997, included data from the Hipparcos Catalogue, and accordingly provided the most comprehensive inventory of the solar neighbourhood up to a distance of 25 pc from the Sun at that time. But Hipparcos could only observe pre-selected stars, contained in its 'Input Catalogue'. This extended to about 11–12 mag, but with completeness only to about 9 mag.

Other ground-based surveys since then, amongst them RECONS and SUPERBLINK, have searched for faint nearby stars (such as M dwarfs) from infrared measurements or proper motion surveys.

Pre-Gaia compilations knew of some 5000 stellar systems within 25 pc, and a northern hemisphere survey has identified around 100 000 M dwarfs within 100 pc.

FOLLOWING ITS LAUNCH in 2013, Gaia is now 7 years into a potential 10-year mission, and is observing essentially every object on the sky brighter than about 21 mag. Early Data Release 3 (EDR3), published in December 2020, covered (nearly) the first 3 years of mission data, and lists nearly 2 billion stars with parallax accuracies better than about 1 mas, even for the faintest stars.

This implies that if a star is brighter than about 21 mag, and it lies within 100 pc of the Sun, it will be observed and identified as such. And with an accuracy on its distance of better (and often much better!) than 10%.

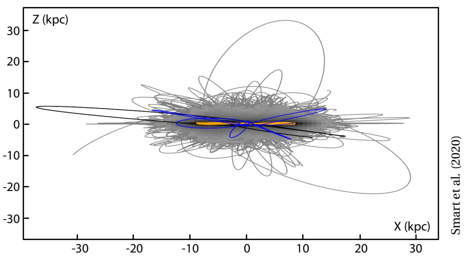
A first detailed assessment of what this means for our knowledge of stars within 100 pc was published in December 2020 (Smart et al., 2021), from which the following gives a flavour.

THIS FIRST Gaia Catalogue of Nearby Star, or GCNS, contains an unprecedented 331 312 objects within 100 pc, a factor 100 more than its ground-based forerunners. It includes stars as faint as spectral type M9, i.e. with masses down to about 1/10 that of the Sun.

Within our immediate 10 pc horizon, and including a handful of stars too bright for Gaia (amongst them Sirius, Fomalhaut, Vega, Procyon, Altair, and Mizar), we now know of 383 stars, all with accurate distances. This includes five companion stars with distances measured for the first time, but not counting a few known unresolved binary systems (notably Procyon, η Cas, and ξ UMa). A few very low-luminosity T/Y brown dwarfs are also known, but too faint to be observed by Gaia.

This enormous census is providing rich new insights into our Galaxy's structure and dynamics. We can estimate the Sun's distance from the disk's mid-plane to be about 4 pc, and characterise the disk thickness for various stellar spectral types. Space velocities, in staggering numbers, allow detailed characterisation of individual and bulk motions in our region of the Galactic disk.

Galactic orbits, integrated over 1 Gyr, show that the most common disk stars follow circular orbits in the Galactic plane, while rarer halo stars visiting our neighbourhood have higher eccentricities and inclinations.



Galactic orbits of the GCNS stars over 1 Gyr (edge-on view)

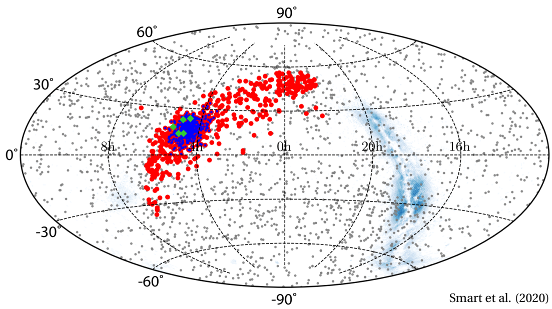
The Sun's height above the Galaxy mid-plane, its vertical velocity with respect to the plane, and the total mass of the Galaxy disk together determine the gravitationally-determined motion of the Sun up and down through its mid-plane, and the maximum height reached above and below it. Our Sun performs this oscillation with a period of about 80 million years. Knowing this allows the Sun's orbit through the Galaxy, and in particular through the Galaxy's spiral arms, to be reconstructed backwards in time over hundreds of millions of years. Some studies have linked this to 'ice house' periods in the Earth's climate over geological times (e.g., Gies & Helsel, 2005).

Of great importance in astronomy is the luminosity function (the numbers per cubic parsec) of the various star populations, such as main-sequence stars, giant stars, and white dwarfs. These estimates enter our models of star formation, and of the star formation history of our Galaxy. The Gaia Nearby Star Catalogue allows all of these to be characterised in unprecedented detail.

THE 100 PC SAMPLE contains two well-known open clusters, the Hyades (at a distance of about 47 pc, or 150 light-years) and Coma Berenices (at about 86 pc). The Hyades is an arresting sight in the dark night sky, with bright cluster members forming a loose enhancement in the distribution of bright stars over an area of about 10 degrees. The Pleiades (the Seven Sisters) is another prominent star cluster visible to the naked eye, but slightly more distant (at about 110 pc). Both the Hyades and Coma Ber clusters stand out in the GCNS as density concentrations in space, as well as in their velocities.

The Hyades members, of which some 500 are prominent in the Gaia census, show a dense concentration forming the cluster's core, and two prominent 'tidal tails', where cluster stars are slowly escaping its gravitational confines, over millions of years, as they are tugged by the pull of the Galactic centre. Studies of the Hyades with the earlier Gaia DR2 data suggest that the cluster is close to final dissolution, with only some 30 Myr of its existence remaining (Oh & Evans, 2020).

Several other stellar streams and stellar superclusters are clearly visible in the Gaia survey, including the Gaia Enceladus stellar stream (Helmi et al., 2018).



Hyades cluster members (blue) and its tidal tail (red)

STUDIES OF both intermediate-separation and wide-separation binary star systems have already been made with the first two Gaia data releases (DR1 and DR2). More than 16 000 resolved binaries are evident in the new GCNS sample, with some 10% of F, G, and K spectral types clearly seen to be wide binaries.

Wide-separation binaries have very low 'binding energies', meaning that they are, gravitationally, only loosely bound. They can therefore be used not only in models of star formation and of the dynamical evolution history of the Galaxy, but also as probes of the mass distribution and number density of potentially disruptive 'dark' objects in the Milky Way.

WHITE DWARFS stand out in the diagram of star colours plotted against their absolute magnitudes. Based on the Gaia data alone, more than 20 000 stars have a high probability of being white dwarfs, of which more than 2500 were previously unknown.