29. White dwarf surveys

WHITE DWARFS are the endpoint of stellar evolution for some 97% of all stars, specifically those below about 8 solar masses. Most are dominated by C or C/O cores, which result from the exhaustion of nuclear fusion for these stars. They have a narrow mass distribution peaking around 0.58 solar masses. White dwarfs of lower mass are expected to have He cores.

No longer held up by nuclear fusion, they have collapsed to a small and very dense state, with a mass comparable to that of the Sun, but with a size closer to that of the Earth. They have very low luminosities, attributable to the slow release of their residual thermal energy.

White dwarfs are of great importance across many fields of study: for theories of star formation and evolution, of degenerate matter at extremely high density, for distance scale determination, and for understanding planet survival beyond a star's main-sequence lifetime.

THEIR CLASSIFICATION consists of an initial D, followed by a letter describing the dominant spectral feature. Thus DA dwarfs have atmospheres dominated by H I, DB by He I, DC have a continuous spectrum, DO are dominated by He II, DQ by carbon, and DZ by metal lines.

They span a vast temperature range, with the DA class ranging from 170 000 K to 4500 K, falling slowly, over billions of years, as the white dwarf cools. Consequently, their temperature provides a direct age indicator. They overlap instability regions like those seen around the main sequence, including DA dwarfs (and the very common pulsating ZZ Ceti stars), DB dwarfs, and DO dwarfs (including pulsating GW Vir stars).

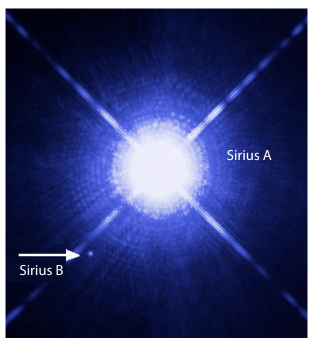
WHITE DWARFS are very common, and accordingly very numerous in the solar neighbourhood. But their very low luminosities means that any survey completeness falls rapidly with increasing distance, even within 20–50 pc. Since all reasonably bright dwarfs are also relatively nearby, their parallax distances measured from the ground were already of reasonably high relative accuracy, even in advance of the Hipparcos mission.

Catalogue of white dwarfs have been maintained by George McCook & Edward Sion since 1987, when the known count stood at 1279. The fourth edition in 1999 listed 2249, and the 2016 on-line version 14 000. The Sloan SDSS DR7 White Dwarf Catalogue lists 20 000 objects, with 13 000 DA and 1000 DB spectral types.

WHITE DWARFS PROVIDE an important insight into the behaviour of matter at extreme densities. No longer supported by nuclear fusion, they consist of a 'degenerate electron gas' at densities of $10^6 - 10^8$ gm cm^{-3}. This results in a relation between mass and radius first derived by Subrahmanyan Chandrasekhar in 1931, and later refined to included different chemical composition (He, C, Mg, Si, S, and Fe), and models with C or C/O cores and different configurations of H and/or He layers.

The mass–radius relation remains a largely theoretical construct, with observational confirmation still resting on only a handful of objects with accurately-known masses and radii. But it is a central assumption in studies of their mass distribution and luminosity function, and for a range of related applications including distances to globular clusters, ages of the Galactic disk and halo from white dwarf cooling sequences, dark matter investigations, and establishing limits on any variations of fundamental physical constants, notably $\dot{G}/G$.

The occurrence of white dwarfs in visual binaries provides one way to determine their masses and radii: masses from radial velocities and modelled orbits through Kepler's third law, while radii can be derived from their effective temperatures if their distance is known.



Hubble Space Telescope

At just 2.6 pc distance, Sirius is the prototype of the important class of Sirius-like binaries, comprising a main sequence star and a white dwarf secondary, with an orbital period of 50 years.

SINCE CHANDRASEKHAR'S work almost a century ago, it has been clear that progress in this field requires a much larger sample of white dwarfs with much better estimates of their masses and radii.

Hipparcos was able to make only a modest contribution, because their low luminosity, combined with the relatively bright limit of the satellite observations of 10–12 mag, meant that it could observe only 22 of the nearest. Of these, 11 were field white dwarfs, 4 were in visual binaries, and 7 were in common proper motion systems. The majority were of spectral type DA, but with one each of the spectral types DB, DC, DQ, and DZ.

Pre-Gaia, then, a total of some 20 000 white dwarfs were known, with around 200 within 20 pc. Pre-launch models suggested that Gaia could increase the numbers tenfold to perhaps 200 000 objects, with completeness to around 20 mag, and to distances of at least 100 pc.

ALREADY BY THE end of 2020, more than 100 scientific papers have examined different aspects of white dwarf science based on the Gaia results, using the advances of Gaia astrometry or photometry to place new constraints on previously-known white dwarfs.

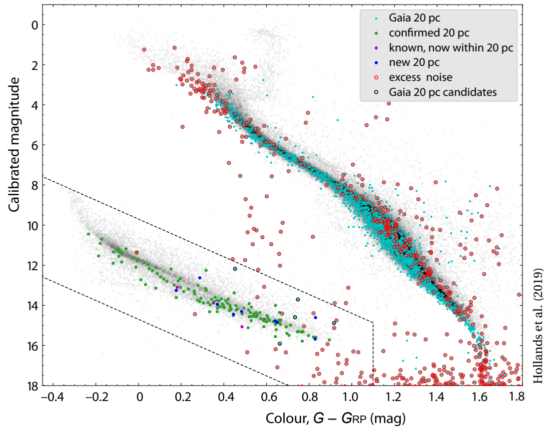
Amongst these are studies of the mass–radius relation, the discovery of new white dwarfs in binary and triple systems (including the first *triple* white dwarf system), the discovery of new white dwarfs with dusty debris disks (related to mature planetary systems), new candidates in the Hyades and Praesepe clusters as well as in the Hercules stellar stream, searches for white dwarfs in the Galactic disk, in the halo, and in other star clusters, studies of the kinematics of the Galaxy disk in the solar neighbourhood, and evidence for massive white dwarfs resulting from merger events.

BUT HERE, I will just take a look at some broad statistics from early analyses of the astrometric and photometric data of Gaia DR2. Although much better quality data is to come, we can already see that Gaia is making a major contribution to this important field.

Jiménez-Esteban et al. (2018) found 73 221 candidates from their position in the Hertzsprung–Russell diagram. Of these, 8555 are within 100 pc, yielding the largest and most complete volume-limited sample to date. Dominated by cool (< 8000 K) objects, they found 8343 C/O-core and 212 O/Ne-core candidates, and an overall space density of $4.9 \pm 0.4 \times 10^{-3}$ pc^{-3}.

Noteworthy features include a bifurcation in the Hertzsprung–Russell diagram not predicted by current theories, and a significant number of massive ($0.8M_\odot$) white dwarfs whose origin remains uncertain.

Out to larger distances and fainter magnitudes, Fusillo et al. (2019) identified 260 000 candidates to 21 mag, estimating 85% completeness for $G < 20$ mag and $T_{\rm eff}$> 7000 K, at Galactic latitudes above 20°.



The Gaia white dwarf sample within 20 pc

Out to 20 pc from the Sun, Hollands et al. (2018) used positions in the colour–magnitude diagram to identify139 systems, nine of which are new, with the closest at only 13.05 pc. They estimated the local white dwarf space-density to be $4.49 \pm 0.38 \times 10^{-3}$ pc^{-3}.

Kim et al. (2020) compiled a catalogue of 531 candidates having large transverse motions relative to the Sun (above 200 km s^{-1}), and therefore likely to be members of the local Galactic halo population.

A NUMBER OF particularly interesting objects already feature amongst this remarkable haul.

Tremblay et al. (2020) used spectroscopy of 230 new candidates out to 40 pc to confirm 191 as real. Amongst these are 89 DA, 76 DC, and 2 DQ white dwarfs. Amongst their 14 new DZ (metal-rich) white dwarfs is the first ultra-cool object with metal lines. Three show at least four different metal species. One is strong in Fe and Ni, features now taken to indicate the recent accretion of a planetesimal-type body with core-Earth composition.

About 150 extremely low-mass white dwarfs, with $M < 0.3M_\odot$, were known before Gaia. The Universe is not old enough for these to have formed as single stars, but rather imply a common-envelope binary, or following mass-overflow in a multiple system. Most will merge over a few billion years, each final merger being a strong source of gravitational waves. Recent theories have predicted a much larger space density of these objects, and Pelisoli et al. (2019) duly used the Gaia DR2 data to derive a much-enlarged sample of 5762 extremely low-mass candidates, with $M < 0.3M_\odot$.

Vincent et al. (2020) combined the 260 000 white dwarf candidates found from DR2 with ground-based photometry to measure the temperatures and masses for all white dwarfs in the northern hemisphere within 100 pc. From a sample of ZZ Ceti candidates within the instability strip, 90 were observed with high-speed photometry to reveal 38 new ZZ Ceti stars, including two very rare ultra-massive pulsators.