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The White Dwarf Binary Survey (WDB)

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Binary systems containing one or two white dwarfs are important for studying stellar evolution and interactions under a wide range of astrophysical conditions. Thanks to the Gaia mission we have identified the first statistically significant and unbiased sample of ~ 170 000 white dwarf binary candidates. It comprises both systems that never interacted that are part of common proper motion pairs and systems that evolved through mass transfer episodes resulting in close white dwarf binaries. White dwarf binaries hold the potential to observationally constrain a wide variety of key ingredients that currently limit the validity of theoretical models.

Scientific context

Over 90 per cent of stars are born with masses < 8–10 $M_{\odot}$, with the certain fate of ending up as white dwarfs (WDs). Moreover, about half of the main sequence (MS) stars in the Milky way are found in binary systems. The binary separation determines the evolution of these systems. If the binary components are separated enough to avoid mass transfer episodes (≥ 10 au), they can evolve as single stars. In these binaries, the more massive star evolves first through the typical nuclear burning phases and ends its life as a WD (García-Berro, Ritossa & Iben, 1997). The orbital separations of the resulting detached WD+MS binaries widen with time as a result of modest velocity kicks caused by asymmetric mass loss of the WD progenitors (El-Badry & Rix, 2018). In these cases, the WDs can be used as reliable cosmo-chronometers to measure stellar ages, a difficult endeavour that is otherwise subject to substantial uncertainties (Soderblom, 2010). These wide WD+MS binaries are excellent probes of the evolution of age-related changes in activity, rotation, and metallicity of the MS companions. Conversely, for smaller initial separations (< 10 au), mass-transfer interactions ensue, which lead to a common-envelope phase and to a dramatic shrinkage of the orbit (Ivanova et al., 2013). These close WD+MS binaries have orbital periods ranging from a few hours to several days and the companions sample a wide range of spectral types (A, F, G, K, M). Hence, they hold the potential to give rise to a wide range of important outcomes, for example type Ia supernovae (SN Ia), gravitational wave sources, and WD pulsars, or themselves being outcomes of fascinating phenomena, such as planetary nebulae. Indeed, binaries are overrepresented in the central star planetary nebula population (Jones & Boffin, 2017). In particular, the bipolar structures in planetary nebulae cannot be explained by single-star evolution. The WD binary survey aims to resolve a wide variety of important open problems which will ultimately help to understand the evolution of close and wide WD binaries.

Specific scientific goals

The 4MOST WD binary survey is divided into three sub-surveys, as outlined below, each aiming for different goals.

The compact white dwarf binary (CWDB) sub-survey. Within this sub-survey we aim to address important aspects of close WD evolution such as the mechanisms of angular momentum loss, the energy sources during the common-envelope phase, understanding the formation of magnetic WDs in close binaries, identifying the progenitors of AM CVn stars, and determining the dominant fate of close WD binaries. With 4MOST, the current samples of the distinct types of binaries will be significantly enlarged, without bias. The 4MOST spectra will provide the effective temperatures, surface gravities, radii, and masses that will allow the characterisation of the stellar components, while the orbital periods will be measured from the photometric data from Vera C. Rubin Observatory. These parameters will ultimately provide observational constraints to the evolutionary models.

The common proper motion pairs (CPMP) sub-survey. This sub-survey aims at using WDs as 'clocks' to provide additional observational input for improving our understanding of the chemical evolution of the Milky Way and

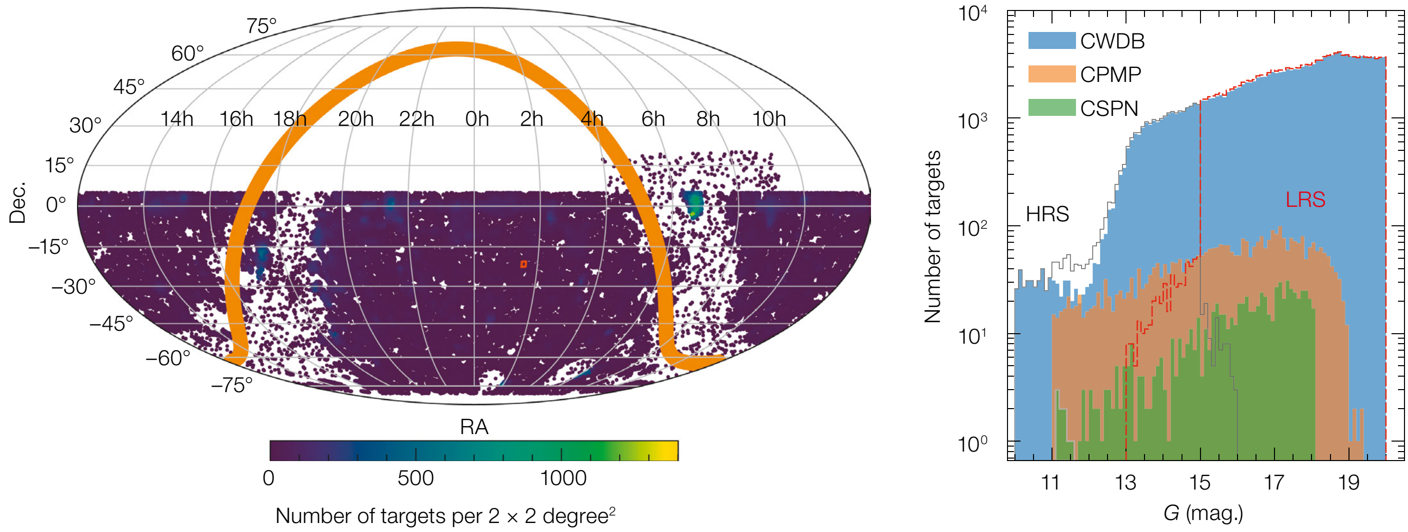

Figure 1. Left: Density map of the target catalogue in equatorial coordinates; the orange line represents the galactic plane which lacks GALEX data. We aim to follow up at least 41% and 95% of our catalogues that will be observed with the low-resolution and high-resolution spectrographs, respectively. Right: Distribution of the white dwarf binary targets for each sub-survey as a function of Gaia *G* magnitude (0.1 mag. bin). Black and red lines show the total number of targets requested to be observed with the high-resolution (HRS) and low-resolution (LRS) spectrograph, respectively.

the mechanisms that govern its dynamical heating. Moreover, by using the WD ages we will analyse the dependency between age, magnetic activity, and rotation in MS stars. Finally, these wide binaries will allow the mass-radius relation for WDs to be tested. To achieve these goals, we will use the 4MOST spectra of the MS companions of these WDs to measure their composition, effective temperatures, surface gravities and radial velocities and to detect signs of magnetic activity.

The central star of planetary nebulae (CSPN) sub-survey. This sub-survey aims to unravel the nature of the central star by searching for signs of binarity (for example, emission lines from an irradiated companion, double-lined He II lines, and central stars with F/G/K companions displaying emission of Ha and Ca H&K lines). The 4MOST spectra will also allow us to check the spectral type of each central star and to perform a spectral analysis to derive their effective temperatures, surface gravities, masses, radii, and luminosities. The same analysis can be applied to the binary component if spectral lines are visible, for example for double-lined and double-degenerate systems.

Each sub-survey contains targets that will be observed with the low-resolution and high-resolution spectrographs. The total number of targets per sub-survey for each spectral resolution is shown in Table 1.

Target selection and survey area

The compact WD binary catalogue uses the WD ultraviolet excess as a selection tool (Parsons et al., 2016). Therefore, GALEX DR6/7 is crossmatched with Gaia DR3 (Gentile-Fusillo et al. in preparation), where a simple linear cut in the GALEX/FUV-Gaia/*G* colour-magnitude diagram selects most binaries below the main sequence. QSOs are the major source of contaminants, and most of them can be identified by their lack of proper motion. Moreover, we performed a quality filter based on an astrometric excess noise cut and finally we excluded the Magellanic Clouds because of bad astrometry in crowded regions. A sample of CPMPs containing WDs is identified by cross-matching the Gentile-Fusillo et al. (2021)

	SSC: S/N for LRS	SSC: S/N for HRS	Number of targets for LRS	Number of targets for HRS	FoM for LRS	FoM for HRS
CWDB	CaT or Hα or BLUE > 13 (up to 100 for G = 15)	Hα > 150 (up to 500 for G = 10)	142 000	22 000	40%	95%
CPMP	Hα_wing > 30	BLUE_narrow > 30	2800	900	70%	90%
CSPN	Hα_wing > 50	Hα_wing > 250	670	70	71%	95%

Table 1. Relevant parameters for the three sub-surveys, compact white dwarf binary (CWDB), common proper motion pairs (CPMP), and central star planetary nebulae (CSPN), for the low-resolution spectra (LRS) and high-resolution spectra (HRS). The spectral success criteria (SSC) correspond to the median of the S/N per Ångstrom calculated assuming grey conditions. The S/N is calculated within a wavelength range as follows: *BLUE = MEDIAN(S/N 4000–4500 Å); BLUE_narrow = MEDIAN(S/N 4000–4300 Å); Hα = MEDIAN(S/N 6512–6612 Å); Hα_wing = MEDIAN(S/N 6400–6500 Å); CaT = MEDIAN(S/N 8350–8850 Å)*. The low-resolution spectra of the CWDB sub-survey utilise the combination of three wavelength ranges. The fraction of observed targets is calculated for a figure of merit (FoM) of 0.5 for each sub-survey.

catalogue with non-degenerate stars in the Gaia DR3, by adopting the selection and quality cuts defined by El Badry et al. (2021), Rebassa-Mansergas et al. (2021), and Raddi et al. (2022). The contaminants from open clusters (Cantat-Gaudin et al., 2018) are removed. Finally, the targets for the central star of planetary nebulae catalogue were selected from the catalogues of González-Santamaría et al. (2021) and Chornay & Walton (2021). In general, the combined catalogue comprises approximately 170 000 targets with brightnesses within G = 10 and G = 20 mag. (see right panel of Figure 1). Most of the targets of all the sub-surveys cover the 4MOST footprint, i.e., sky declinations –80 < dec < +5 (see left panel in Figure 1).

Spectral success criterion and figure of merit

In general, we utilise the signal to noise ratio (S/N) per Ångstrom as the spectral success criterion. The spectral energy distribution of close WD binaries results in a composite spectrum, which is either dominated by the WD or by the non-degenerate companion, depending on the temperature and radius of either of them. In the case of interacting binaries, line emission and continuous emission from an accretion disc can also be observed. The minimum requirement is an optical spectrum with sufficient S/N to recognise key features for classification of the type of binary (for example, cataclysmic variables, AM CVn stars, double WDs, post-common-envelope binaries or symbiotic binaries). The spectra with higher S/N will be fitted with templates to determine stellar parameters. In the common proper motion sub-survey, we aim to determine precise abundances, radial velocities, and stellar parameters, as well as an estimate of stellar activity by measuring the flux of chromosperic emission lines such as Hα and Ca H&K or the IR triplet. Thus, we will acquire high-resolution and low-resolution spectroscopy for the F/G/K stars and M-type companions, respectively. Finally, for the central star planetary nebula sub-survey it is important to avoid any (strong) nebular or photospheric lines when calculating the S/N such that spectral analysis can be performed. Our S/N requirements for each sub-survey are listed in Table1.

The figure of merit (FoM) measures the scientific success of each sub-survey. Table 1 shows the fraction of targets that need to be observed for each of the sub-surveys such that the success rate is 0.5, which is the minimum requirement such that the scientific goals can be achieved. However, the overall success of the WDB survey is dictated by a combined FoM, which is defined as the weighted average of all the individual FoMs.

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Located deep in the Chilean Atacama Desert, far from the light pollution associated with human activity, ESO's Paranal Observatory enjoys some of the darkest skies on Earth. Paradoxically, it is this extreme darkness that allows the sky to light up in technicolour in this image. The striking radiant light visible in the sky here is a phenomenon called airglow, which is created as atoms and molecules in the atmosphere combine and emit radiation.