The DBL Survey I: discovery of 34 double-lined double white dwarf binaries

James Munday, Ingrid Pelisoli, et al.

Speaker: Xinlei Chen

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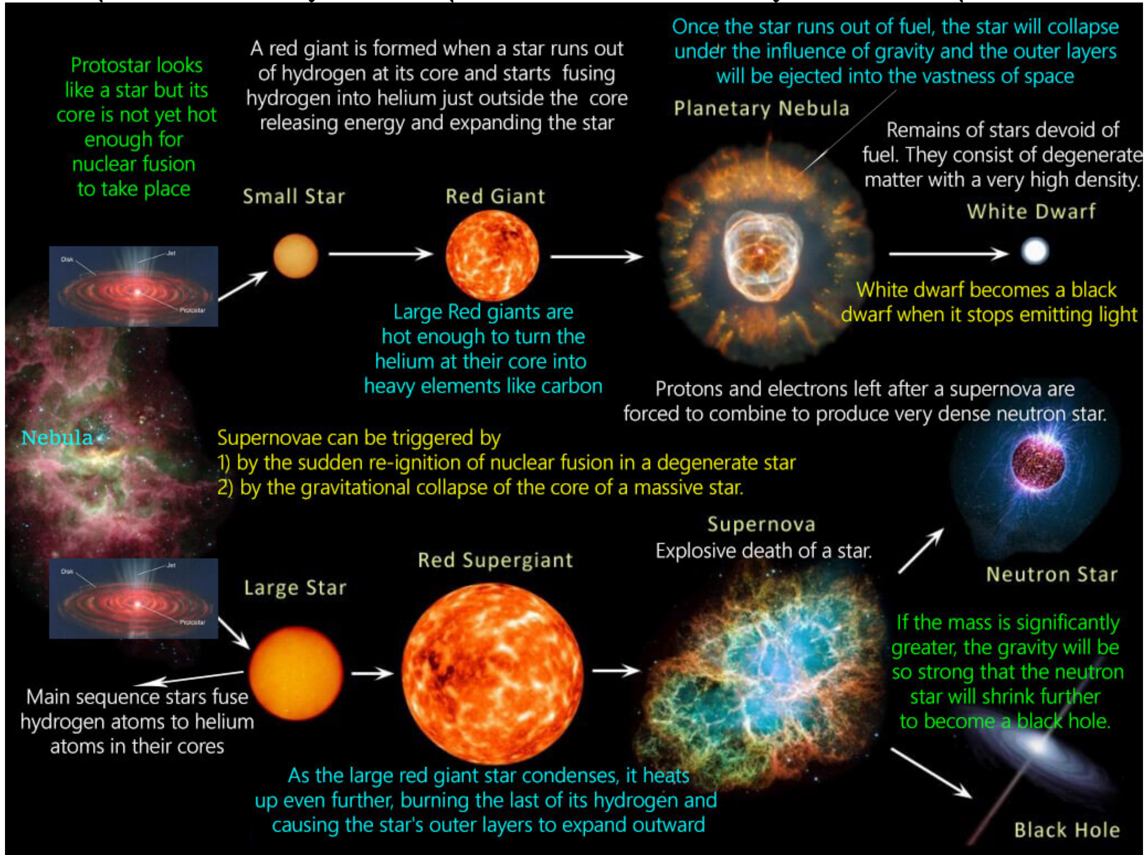
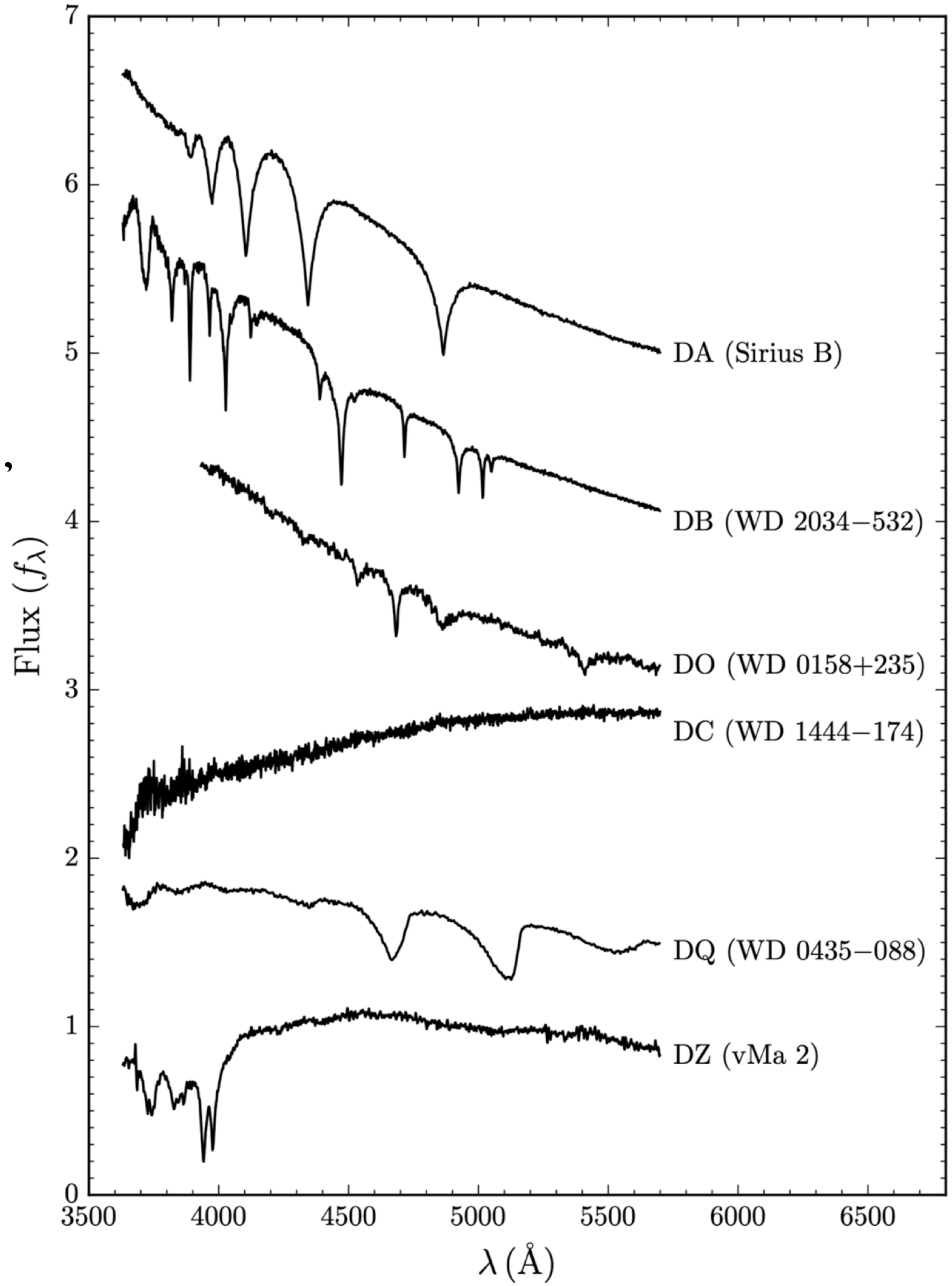
Background

White dwarf

- White dwarfs (WDs) are the final evolutionary stage of approximately 95 per cent of stars in the universe.
- Multiple types

  DA (Balmer lines), DB (HeI lines), DC (continuum only, featureless), DO (He II lines), DQ (carbon features), or DZ (metal lines).

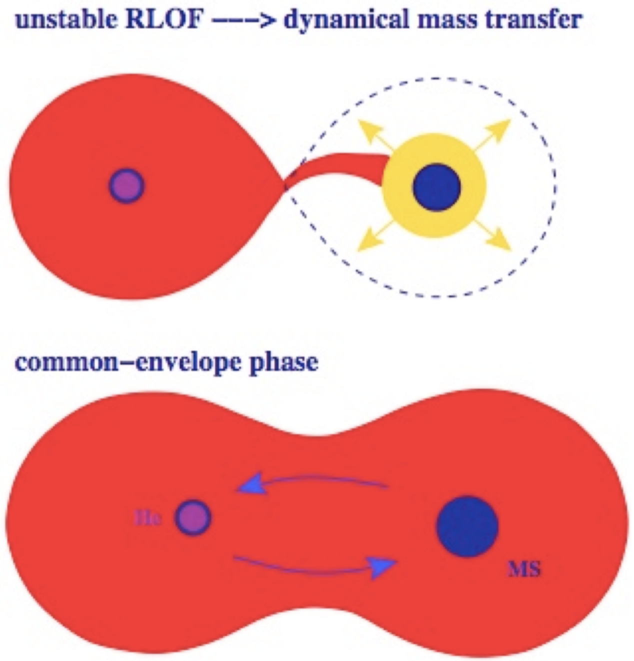


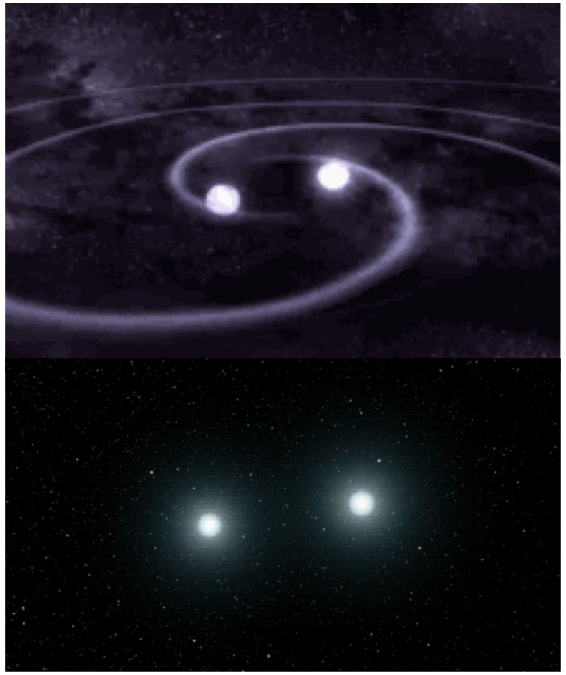


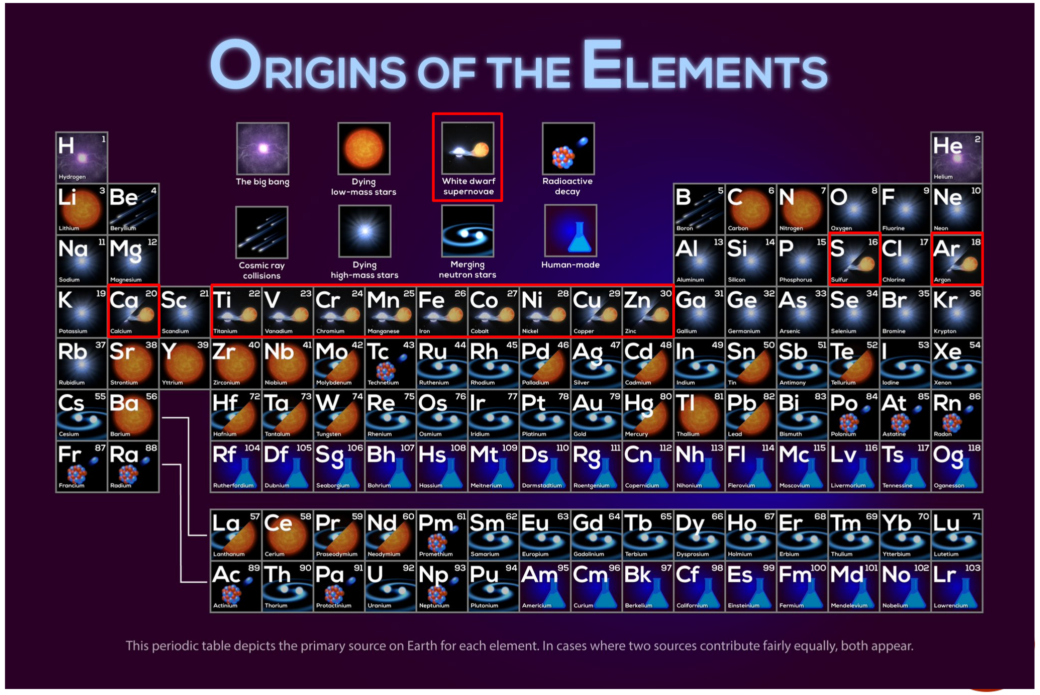
Background

Double White Dwarf (DWD) Binaries

- A population of wide double WD (DWD) binaries that formed at large orbital separations where both stars have evolved in near-isolated conditions without ever coming into contact (Heintz et al. 2022, 2024)
- The overall percentage of DWDs in the Milky Way compared to the number of WDs is predicted to be ≈5–10 per cent.
- Generally speaking, compact DWDs have a median orbital period of approximately 1 d.







Background

Double White Dwarf (DWD) Binaries

- The first definitive discovery of a compact DWD binary was L870−2, identified as a DA + DA and double-lined system with an orbital period of 1.6 d (Saffer, Liebert & Olszewski 1988).

Work	Description	Sample selection and bias
the ESO supernovae type Ia progenitor survey (SPY) (Napiwotzki et al. 2020)	643 DA WDs with measured RVs; 39 double-degenerate binaries; 20 double-lined and 19 single-lined RV variability.	Relied on WD catalogues built from surveys targeting blue objects; biased against reddened regions and against cooler WDs.
the Extremely Low Mass (ELM) survey (Brown et al. 2020; Kosakowski et al. 2023)	A final northern sample of 98 DWD binaries and southern sample of 34 ELM WD binaries	Well-defined colour selection criteria; a priority in follow-up campaigns for the shorter orbital periods.
Burdge et al. 2020; Keller et al. 2022; van Roestel et al. 2022; Ren et al. 2023	Photometric variability	short-period double-degenerate binaries; larger radii and hotter system; unavoidable deficit of high-mass binaries.
El-Badry & Rix (2018); El-Badry, Rix & Heintz (2021); Korol et al. (2022b)	Through astrometric solutions using *Gaia*; the means of a common proper motion and parallax between the two stars and a low-amplitude astrometric wobble of the centre of light.	Candidates with relatively larger separation.

Survey Sample and Biases

- The survey began in 2018.
- Gentile Fusillo et al. (2019)

Bias towards brighter and hotter systems

Bias towards at least one of the components being a WD of mass 0.6 $M_\odot$

Bias in the sample due to the large number of sources used in the spline fit

Bias introduced by the detection efficiency in the observing strategy

Starting DR2 WD catalogue: 486 641 sources

Selection for creating spline:
(PWD > 0.3) AND (GMAG < 18) AND (PLX > 6.*E_PLX)
22107 sources

Sample 20 evenly spaced bins between BP_RP = −0.65 & 1.65, fit with a spline SPL_MG = f(BP_RP).

Select for a ‘clean’ sample of candidate targets: (1)
(GMAG < 18.) AND (PLX > 10.*E_PLX)
22756 sources

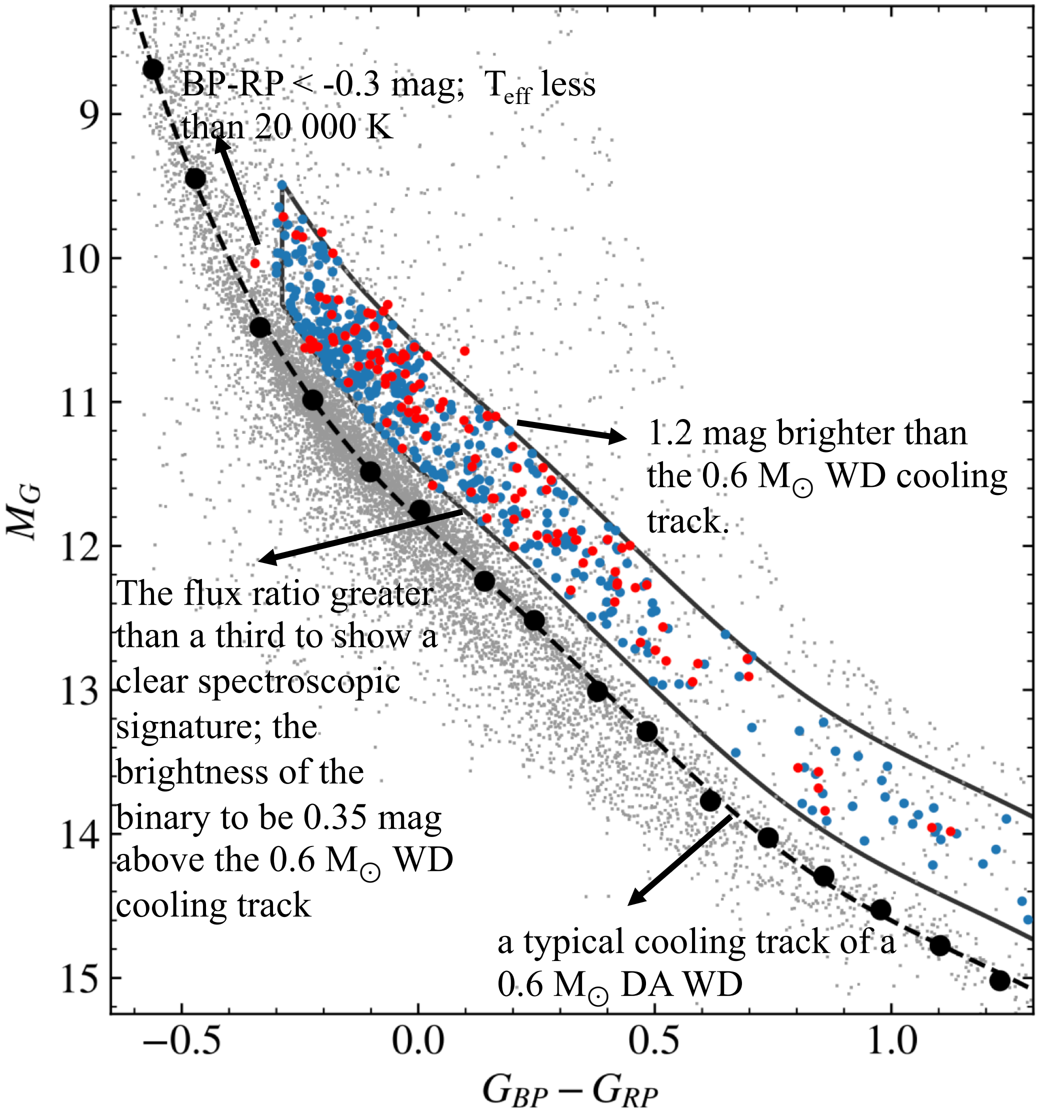
(M_G < SPL_MG−0.35) AND (M_G > SPL_MG−1.2) (2)
3494 sources

(BP_RP > −0.3) (3)
2697 sources

Select for an observable sample on the WHT telescope: (4)
(GMAG < 17.)
625 sources

(DEDEG > −20) (5)

399 sources



Observations and Data Analysis

Observations

- Obtained identification spectra of 117 candidates.
- General observing strategy was to ensure that each candidate was observed on at least two separate nights spaced two nights apart; one of these nights with a single spectrum and the other night with two consecutive exposures to be sensitive to any ultra-compact systems with rapid RV variation.

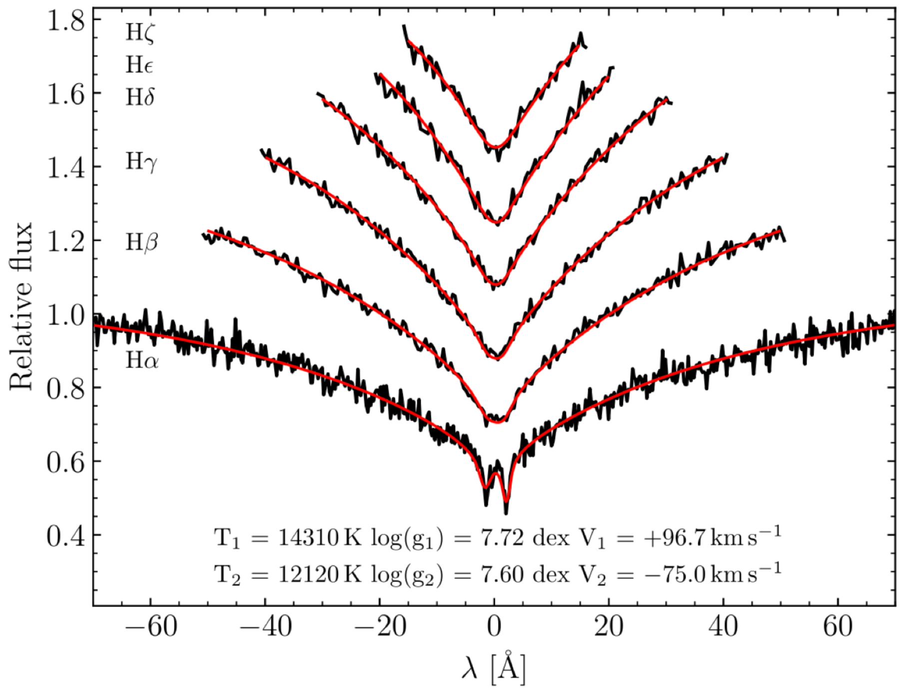
Telescope	Equipment	Configuration	Observation date	Exposure time
the 4.2 m William Herschel Telescope	the Intermediate-dispersion Spectrograph and Imaging System (ISIS)	R600B grism for the blue arm centred on 4400 Å giving a wavelength coverage of ≈3770–5030 Å and the R1200R grism for the red arm centred on 6562 Å giving a wavelength coverage of ≈6250–6870 Å. A 1.0 arcsec slit width on all nights in 2018 and 1.1 arcsec for the others, having a spectral resolution of 0.81 and 0.74 Å in the red arm and 2.2 and 2 Å in the blue arm.	2018 August 28–2018 September 5; 2019 February 13–15; 2019 February 19; 2019 April 15–17; 2019 June 10 and 11; 2019 July 6 and 7 (20 nights)	Maintained at under 30 min not to suffer greatly from orbital smearing and a S/N ratio greater than 25 in the wings and 15 in the line core of Hα

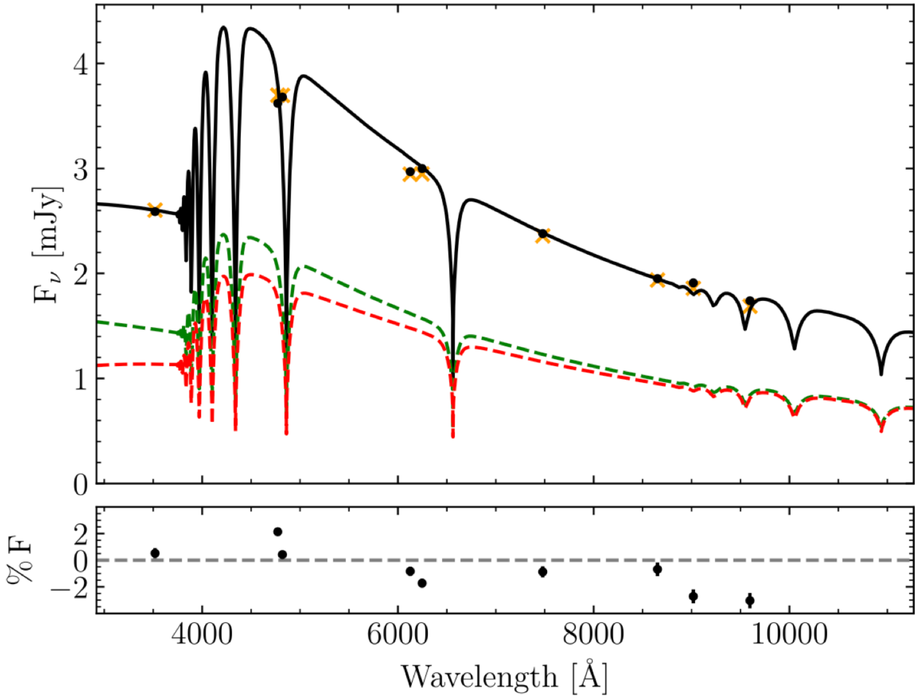
- A CuNe + CuAr arc exposure was taken for each new telescope pointing after acquiring a target for wavelength calibration, where the error in wavelength calibration for each arc frame in the blue arm was approximately 3 and 2 km s^{-1} in the red arm.
- Spectrophotometric standard stars were also taken at the start or the end of each night to flux calibrate the science exposures and correct for the instrumental response function.

Observations and Data analysis

Data analysis

- **WD – BASS**
  - The White Dwarf Binary And Single Star (WD-BASS) fitting package (Munday 2024)
  - Four primary branches: (1) one-star spectral line fitting, (2) two-star spectral line fitting, (3) simultaneous or independent photometric SED fitting, and (4) RV fitting with a fixed atmospheric solution.
- In the case of double-lined systems where multiple exposures of a target were taken, they omitted data where both stars are not visible in the spectrum in the atmospheric fitting (originating from an unfavourable orbital phase). In single-lined sources, they modeled all WHT identification spectra.
- Pan-STARRS DR1 (grizy) (Chambers & Pan-STARRS Team 2018) and SDSS DR16 (ugriz) (Ahumada et al. 2020)
- The extinction coefficient, A_V , of each source was obtained through the reddening maps of Lallement et al. (2022) at a distance determined from the inverse of the *Gaia* DR3 parallax and was converted to $E(B-V) = A_V/3.1$ before reddening the synthetic spectrum.



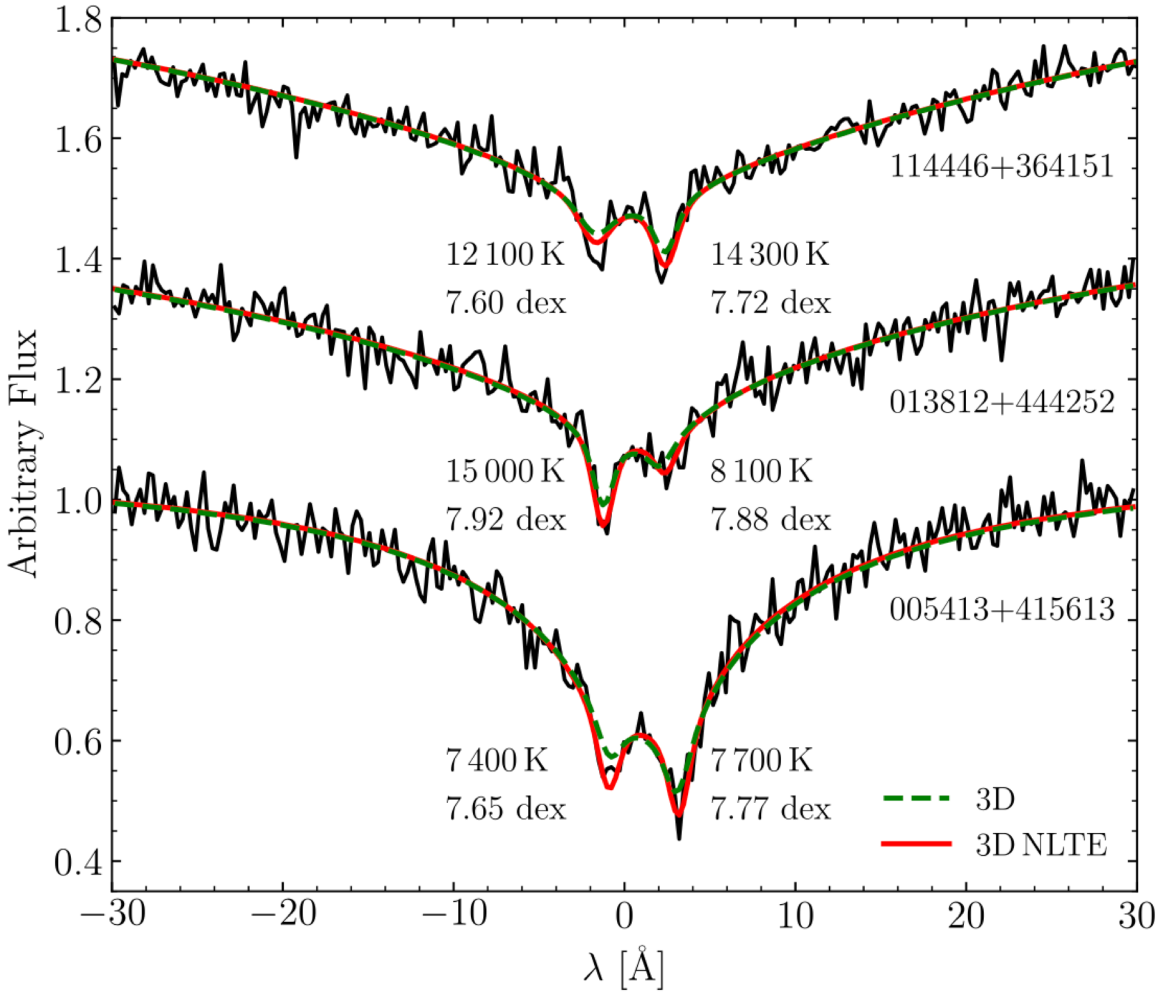


Observations and Data analysis

Data analysis

- Synthetic spectra

- For DA WDs, they created a new synthetic spectral grid that approximately includes both the 3D and NLTE effects on the line cores by dividing the NLTE and LTE grids of K21, which include identical input physics, yielding an NLTE correction factor f (λ , T_{eff}, log g), interpolated on to the wavelength grid of T15 and applied to T15 3D synthetic spectra. (3D local thermodynamic equilibrium (LTE) DA spectra of Tremblay et al. (2013b, 2015) (T15) and the 1D non-LTE (NLTE) DA spectra of Kilic et al. (2021) (K21))
- For DB WDs, they utilized synthetic spectra from Cukanovaite et al. (2021), incorporating 3D effects when possible.
- For a helium-rich atmosphere DC WD, they used the same synthetic spectra from Cukanovaite et al. (2021) but with a fixed H/He fraction of 10^{-5} (Bergeron et al. 2019; McCleery et al. 2020). For a Hydrogen-rich atmosphere DC WDs exist below approximately 5000 K and they continued using the T15 synthetic spectra to model hydrogen-rich DCs.



Observations and Data analysis

Data analysis

- Atmospheric parameters

- For double-lined DWD candidates, they identified individual spectral types by checking unique signatures of both stars in the spectra, and assigned the relevant atmosphere.

- For single-lined DWD candidates that may still have an additional flux component that reduces the accuracy of a single-star solution.
  - They performed two-star fits to all single-lined DA targets that show a missing flux component of a second WD. Type DA or DC WD ($\log g \sim 8$ dex fixed) is used to the second WD.
  - For any target where a single-star model fits well and little to no improvement in the χ^2 of the hybrid fitting when including a second star, they considered the situation entirely degenerate and reported an atmospheric solution with just the one WD.

Observations and Data analysis

Data analysis

- **Radial velocities**

➢ To determine RVs, they fitted to H α alone because of the much higher resolution in this spectral range.

➢ By unlikely assuming the stars are moving at a maximum orbital velocity and that the binary is angled edge-on (I = 90°), the maximum period can be solved for.

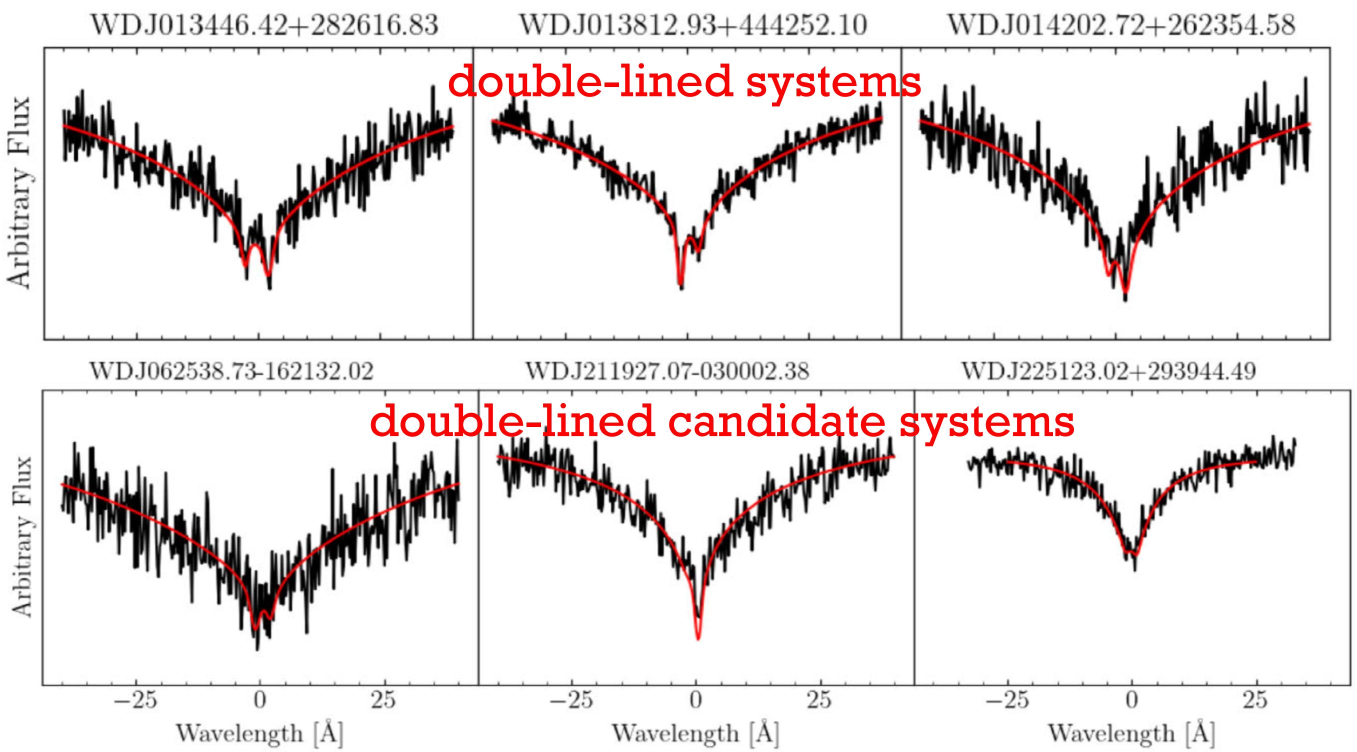
$$P_{\max} = \frac{2\pi G M_1^3}{K_{2,\min}^3 (M_1 + M_2)^2} = \frac{2\pi G M_2^3}{K_{1,\min}^3 (M_1 + M_2)^2}$$

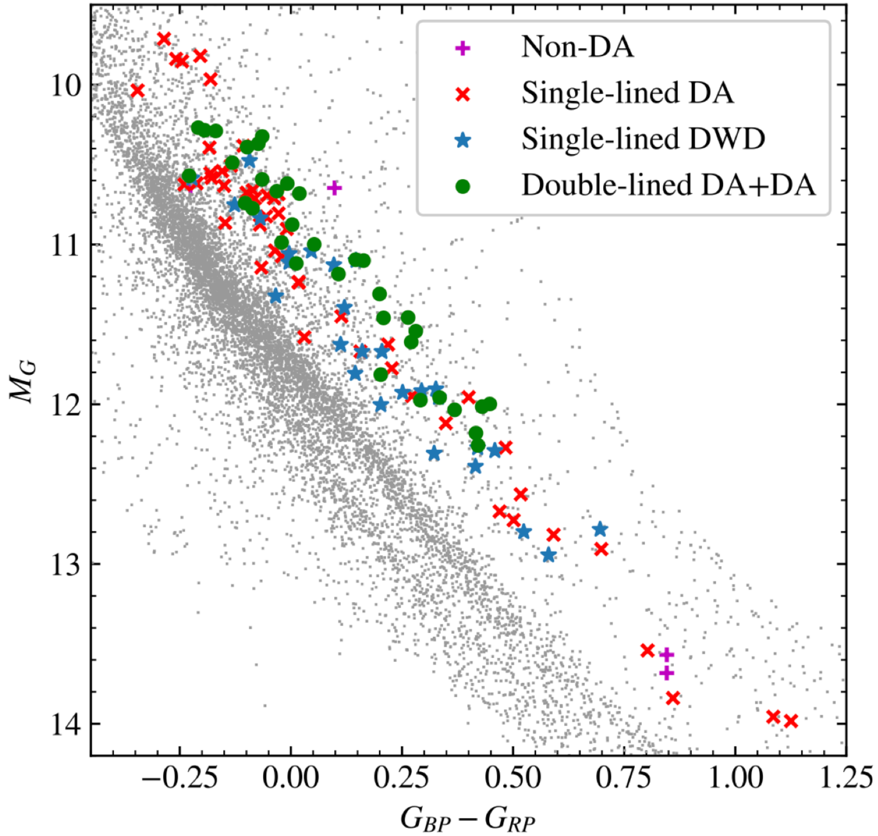
- To search for single-lined RV variability, the mean value of all extracted RVs for a source is taken and a null-hypothesis that the RV is a constant with respect to the mean is tested. They compute the χ^2 of all measurements compared to the mean and use the relevant χ^2-distribution for the number of degrees of freedom to calculate the probability that a source is not RV variable.

- For a system to be considered a candidate RV variable system, they required that it passes the 1 per cent ($\log_{10} p_{bin} < -2$) threshold and 0.01 per cent ($\log_{10} p_{bin} < -4$) to be considered as a WD binary with an unseen companion.

Results

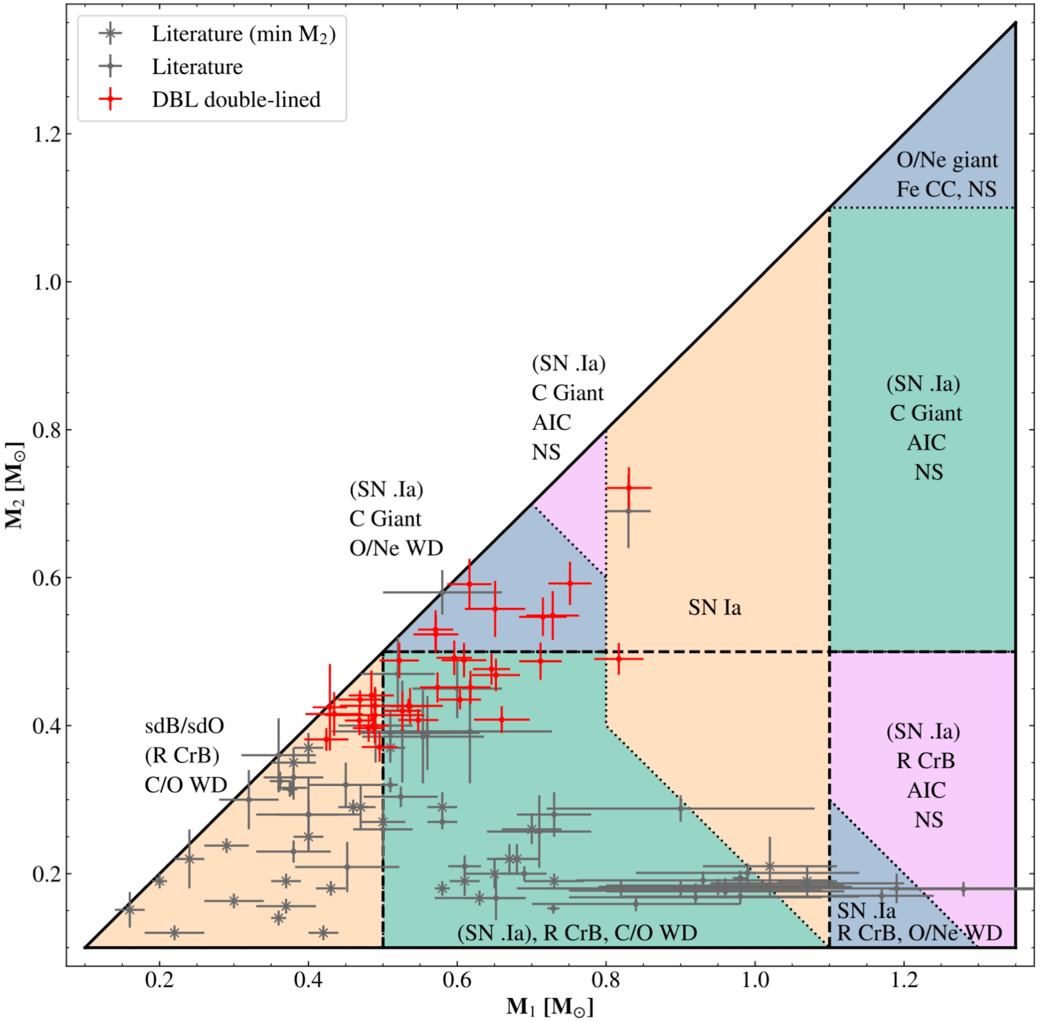
- 34 systems are double-lined DWDs (at least a 29 per cent detection efficiency in the survey); 11 are double-lined DWD candidates as they show a small hint of a double-lined signature. If all are double-lined DWDs, the detection efficiency of the survey rises to 38 per cent.
- 27 single-lined sources; a poor fit to the photometric and/or spectroscopic solution indicates that they are likely DWD binaries.
- 38 targets where a single-star model fits the photometric and spectroscopic data well.



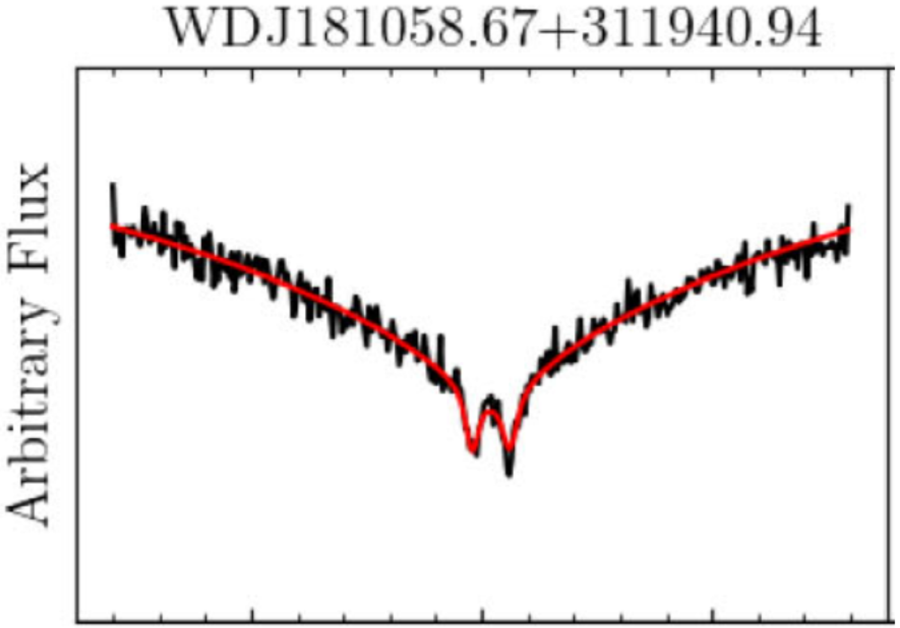


Results

- The fate of DWDs



- WDJ181058.67+311940.94
  - A total mass of 1.55 ± 0.04 $M_\odot$
  - A maximum orbital period of 2.0 d
  - 49 pc away, G=14.01 mag.
  - The second super-Chandrasekhar mass DWD discovered to date after NLTT 12 758 (Kawka et al. 2017)



WDJ name	$T_{eff,1}$ [kK]	log g_1 [dex]	M_1 [$M_\odot$]	$T_{eff,2}$ [kK]	log g_2 [dex]	M_2 [$M_\odot$]	M_T [$M_\odot$]	D [pc]	Exp #	ΔRV_{max} [km s^{-1}]	P_{max} [d]	Ref
J181058.67+311940.94	$20.2^{+0.3}_{-0.3}$	$8.16^{+0.04}_{-0.04}$	$0.72^{+0.03}_{-0.03}$	$16.5^{+0.4}_{-0.3}$	$8.35^{+0.05}_{-0.05}$	$0.83^{+0.03}_{-0.03}$	$1.55^{+0.04}_{-0.04}$	49.0	6	186 ± 5	1.9	4*

Conclusions

- A pilot study including the first results from the DBL survey based on 20 nights of observations with the WHT.
- A large sample of 117 DWD binary candidates that reside above the 0.6 $M_\odot$ WD cooling track through the exploitation of the *Gaia* DR2 HR diagram, randomly sampling candidates from a magnitude limited selection.
- Fitted and obtained atmospheric solutions for the entire sample when all visible stars in the spectra were of spectral type DA, DB, or DC with the custom-made fitting code WD-BASS that is designed for time-series spectroscopy of WDs
- At least a 29 per cent double-lined detection rate after a couple of observing epochs and that 73 of the 117 candidates show a separable spectroscopic/photometric flux contribution that must arise from a DWD configuration.
- One system (WDJ181058.67+311940.94) located just 49 pc away hosts two relatively massive WDs of mass 0.72 ± 0.03 and 0.83 ± 0.03 $M_\odot$, making it the second DWD system confirmed as super-Chandrasekhar mass.

THANKS