White Dwarfs Binaries across the H-R Diagram

Borja Anguiano

Ramon y Cajal Fellow — Centro de Estudios de Fisica del Cosmos de Aragon (CEFCA)

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Centro de Estudios de Física del Cosmos de Aragón
CEFCA

The Team

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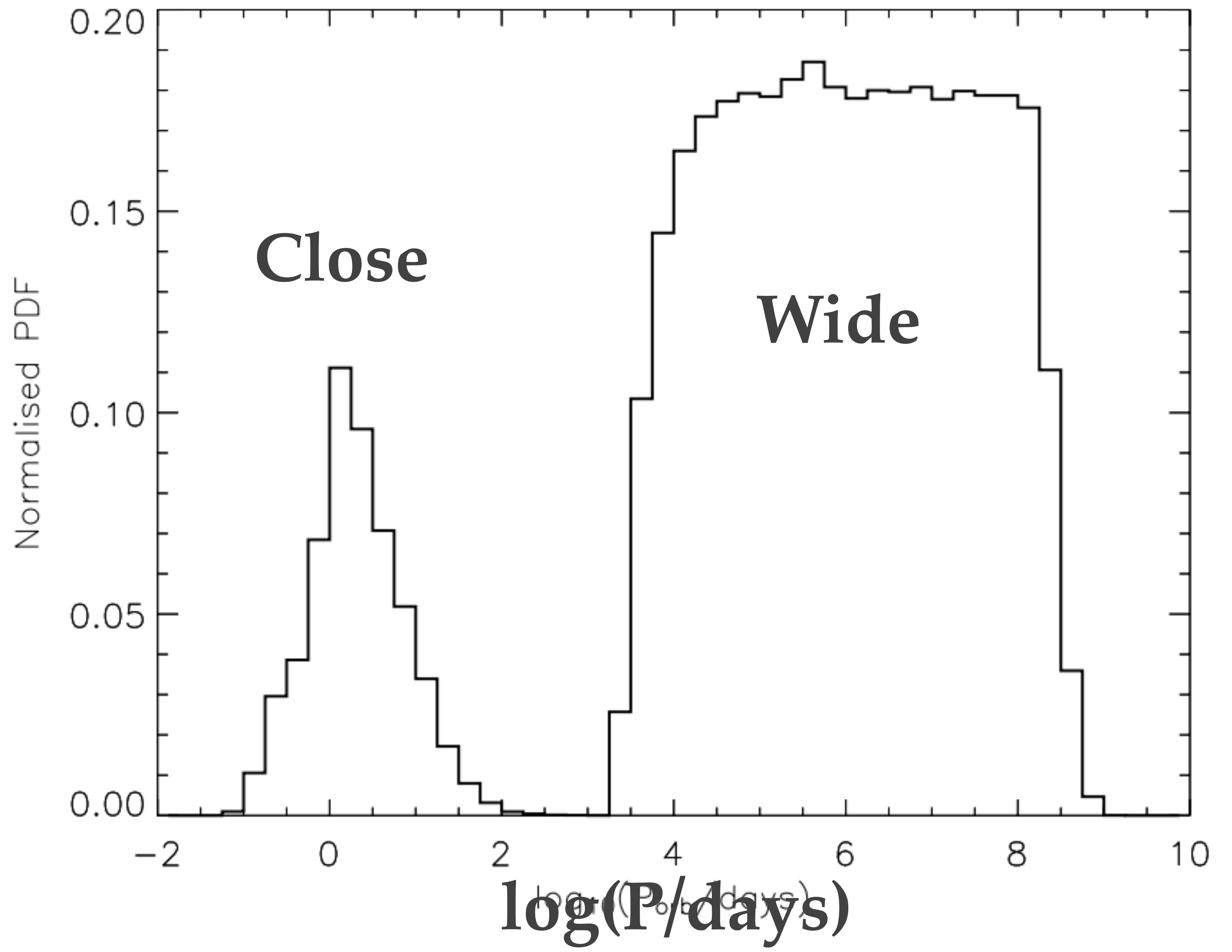
National Science Foundation (NSF) project titled "Collaborative Research: White Dwarfs in Binaries Across the H-R Diagram with the APOGEE-GALEX-Gaia Catalog"

- Borja Anguiano (PI) — University of Notre Dame - *Now in CEFCA*
- Robert Mathieu (co-PI) — University of Madison - Wisconsin
- Steve Majewski (co-PI) — University of Virginia
- Carles Badenes (co-PI) —University of Pittsburgh
- Erin Motherway, Evan Linck, Katelyn Breivik, Don Dixon, Andrew Nine, Marina Kounkel, Christine Mazzola, Adrian Price-Whelan, Nikhil Limgala, Yanbo Pan, Carlos Allende Prieto, Keivan Stassun.

Background

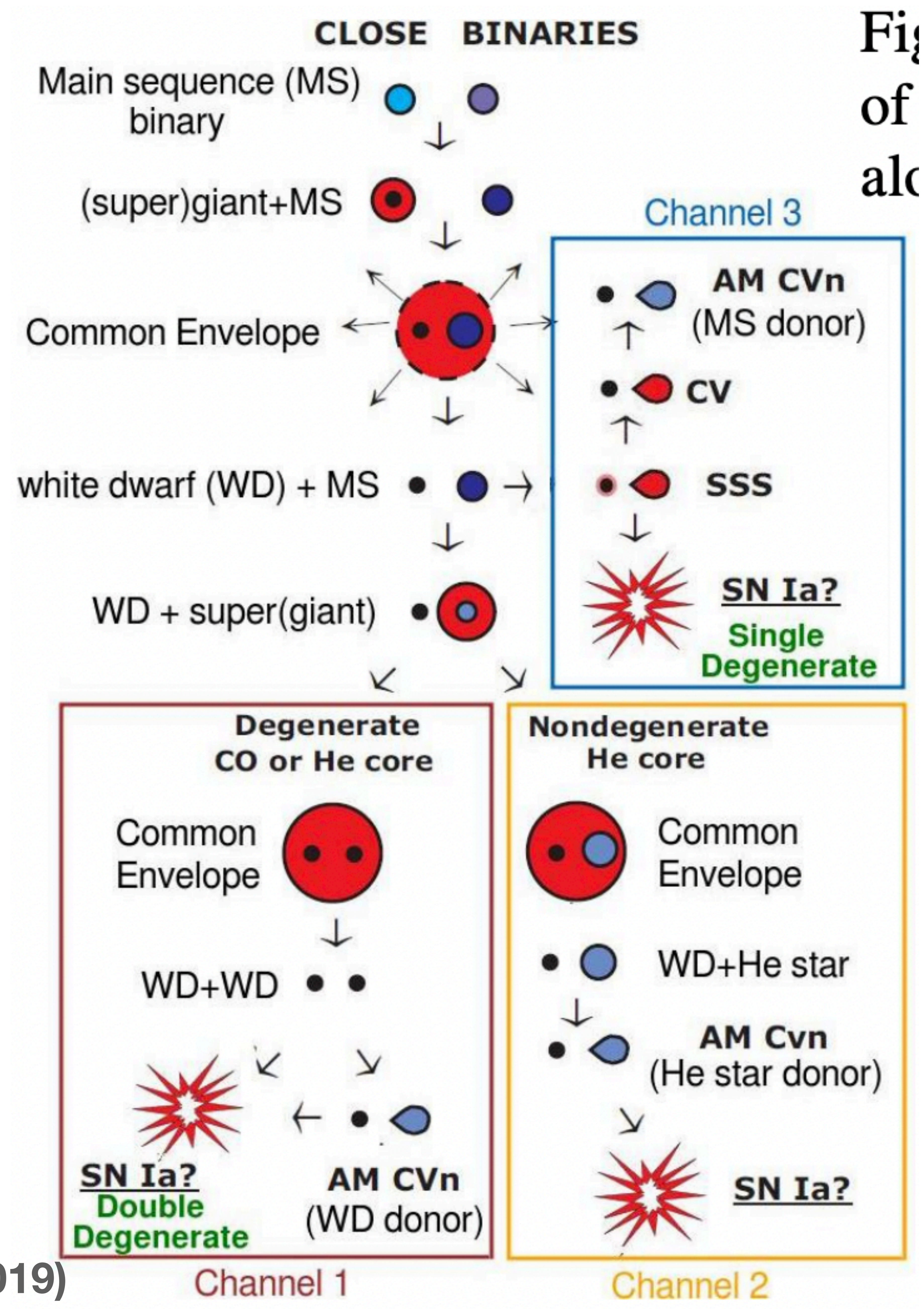
- **A majority of MS stars exist in binary systems, with orbital periods ranging from few minutes to ~10^6 years (e.g., Moe & Di Stefano 2017)**
- **Most stars in these systems are widely separated. Systems with P < 10 years —compact binaries— can undergo a stage of common envelope (CE) evolution changing the subsequent evolution of both stellar components.**

Orbital period distributions prediction of present-day WDMS binaries (Willems & Kolb 2004)



Background

- **Compact binary evolution**
- Physical understanding of Common Envelope evolution is complicated. CE phase is short (400 - 4000 yrs)
- Post-common envelope binaries (PCEBs) lead to a panoply of phenomena that play roles in numerous areas of astrophysics (e.g., CV, novae, SNe Ia, subtypes core collapse SNe). *Sources of gravitational waves and cosmological standard candles.*



PCEBs pathways leading to mass transfer systems or mergers (Toloza et al. 2019)

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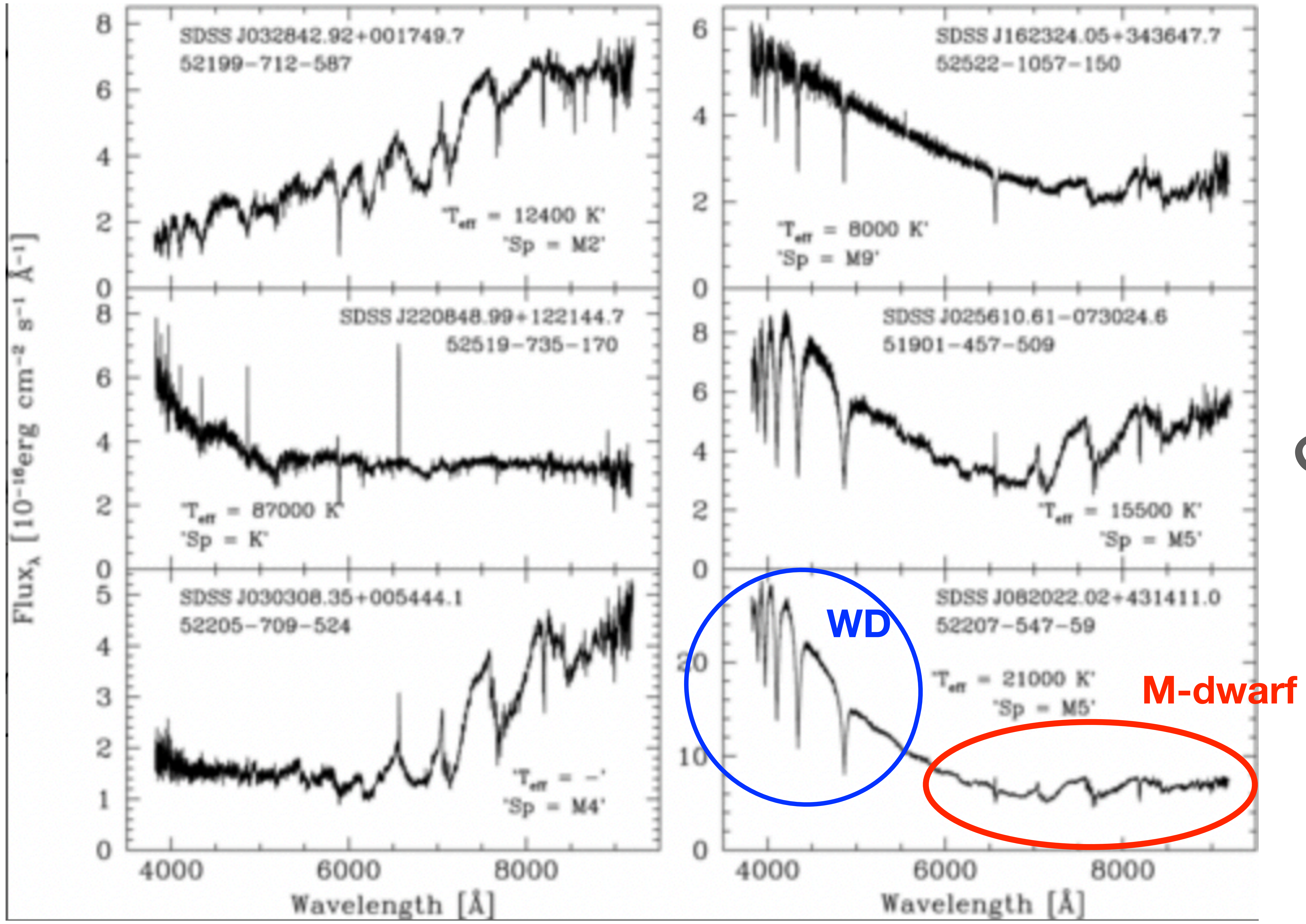
Motivation

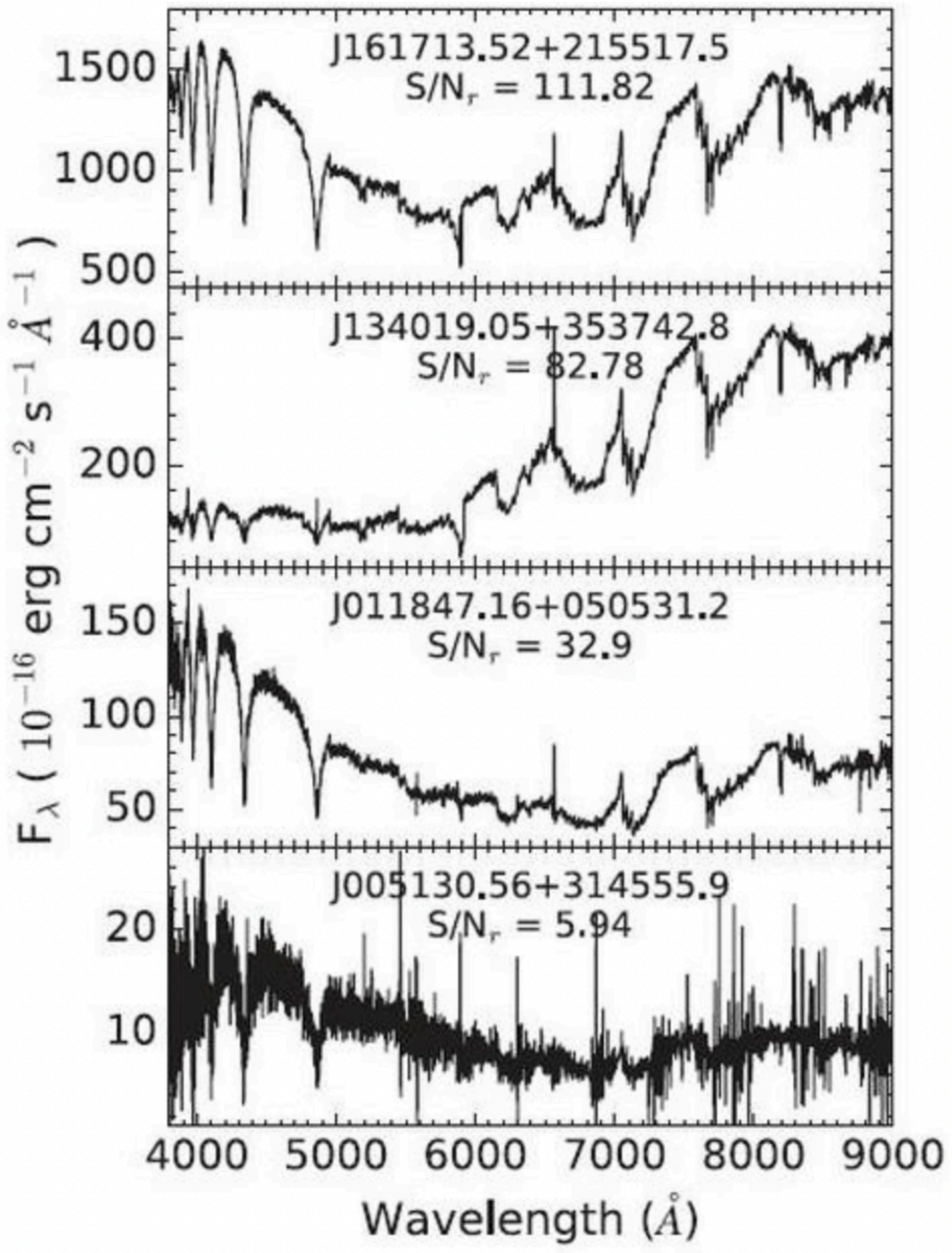
- Detected number of WD binaries (and PCEBs) has largely increased in the last years, mainly thanks to surveys like SDSS, LAMOST.

SDSS/SEGUE survey (York et al. 2000)



Optical spectra

LAMOST survey (Zhao et al. 2012)



Eisenstein et al. 2006, Silvestri et al. 2007, Heller et al. 2009, Rebassa-Mansergas et al. 2012

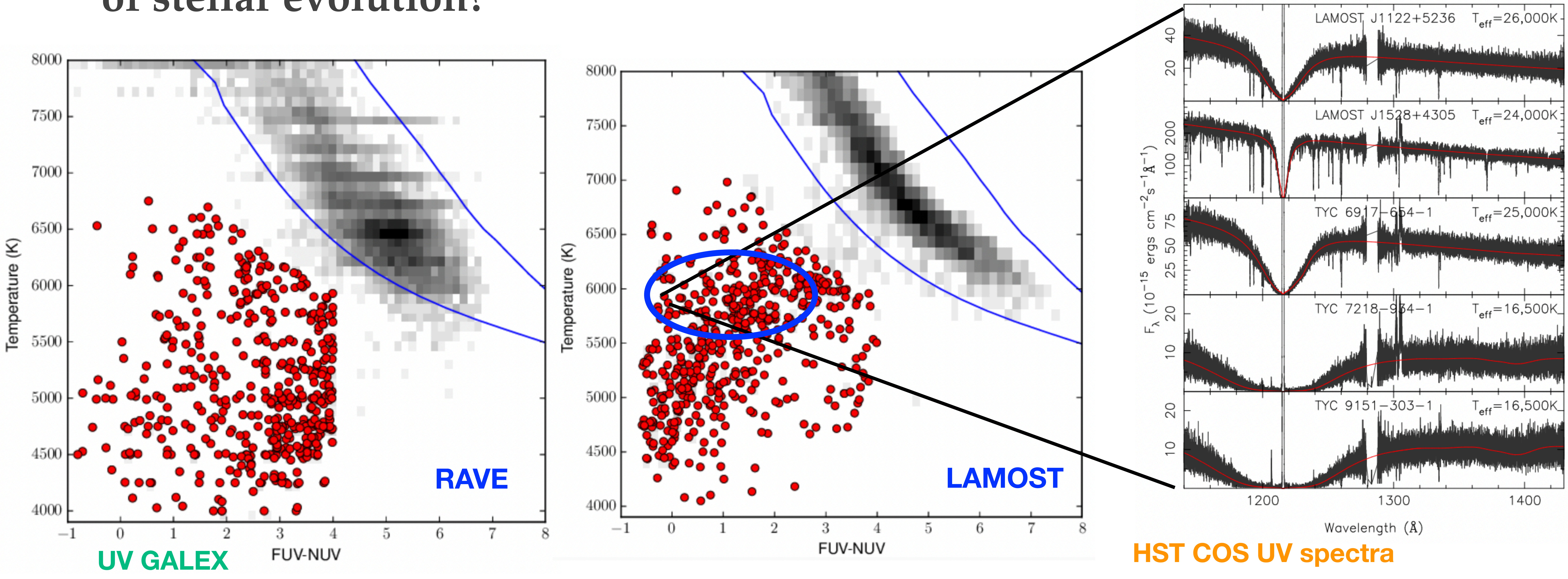
Ren et al. 2014

Motivation

- Nevertheless, the number of WD binaries with known, non-MS secondaries is small, and this limits the ability to understand the panoply of possible fates of WDMS systems after the secondary star evolves off the MS.
- Optical spectroscopic surveys typically offer only one radial velocity (RV) epoch, which does not enable characterization of the orbits.
- Dedicated programs of spectroscopic follow-up have been motivated to address this problem, but the magnitude of the task has limited to a few hundred the number of systems with well-defined orbital parameters (e.g., Schreiber et al. 2008, 2010), and only ~120 can be considered to be strong PCEB candidates (Lagos et al. 2022).

Motivation

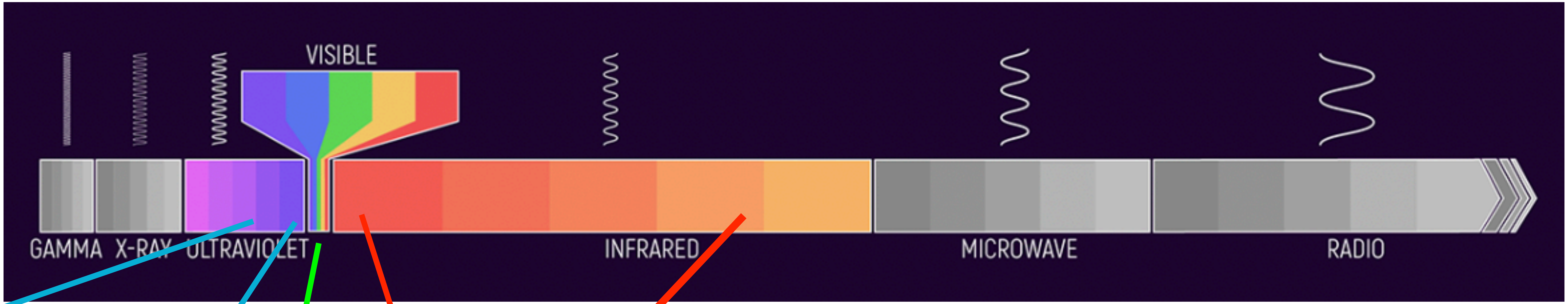
- Can we identify WD binaries across the H-R diagram, with secondary companions with a broad range of spectral types and in virtually all phases of stellar evolution?

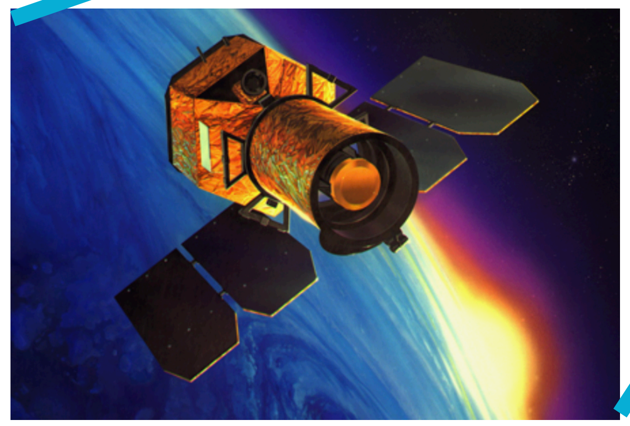


23,484 RAVE dwarf stars (log g > 3.5) with both a GALEX FUV and NUV detection

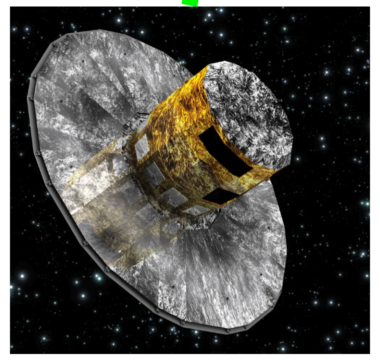
Parsons et al. 2016

APOGEE-GALEX-*Gaia* Catalog (AGGC)

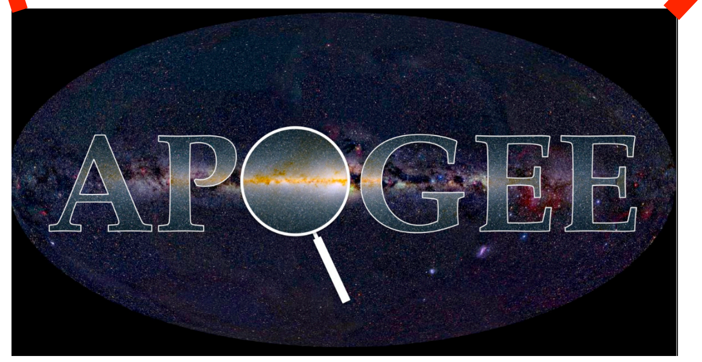




GALEX UV-photometry



Gaia
(astrometry)

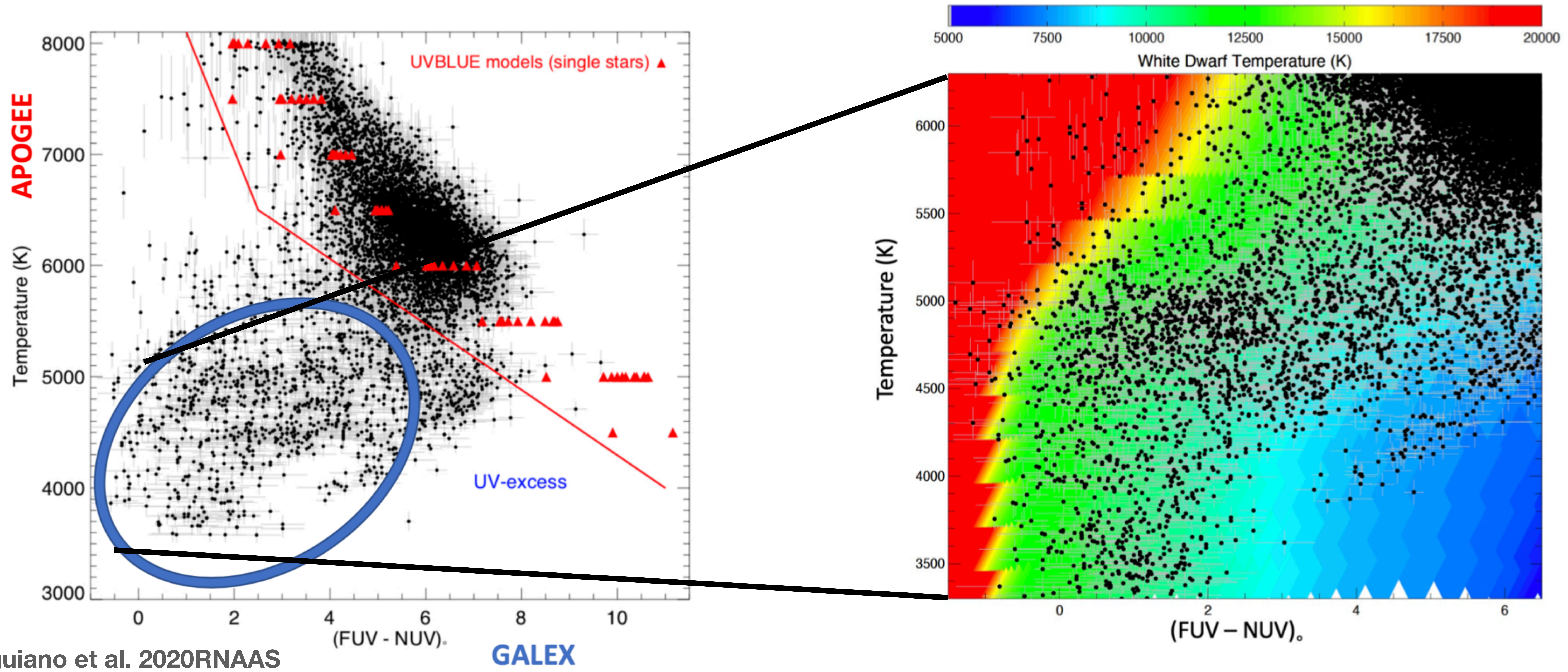


APOGEE - H-band - 2MASS + WISE

UV - optical - IR — Spectral Energy Distribution
APOGEE High-resolution spectra - H-band
Gaia parallaxes

Our goal is to perform a new, large, and systematic search for compact binary star systems containing WDs by harnessing information contained in the APOGEE (Majewski et al. 2017) spectroscopic catalog, cross-matched with data from the optical *Gaia* (Lindegren et al. 2018) and UV GALEX (Bianchi et al. 2017) space missions.

APOGEE-GALEX-*Gaia* Catalog (AGGC)



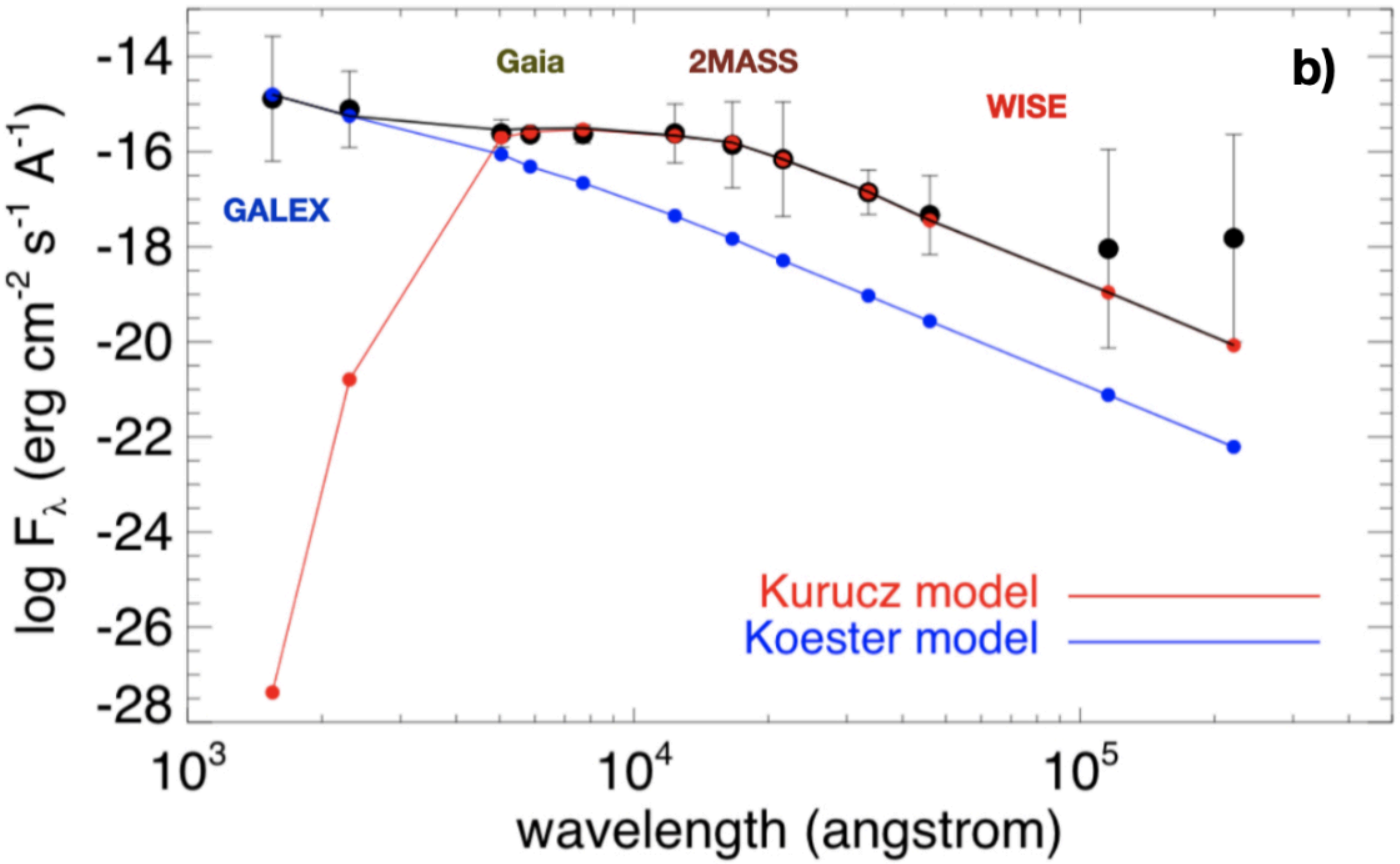
Anguiano et al. 2020RNAAS

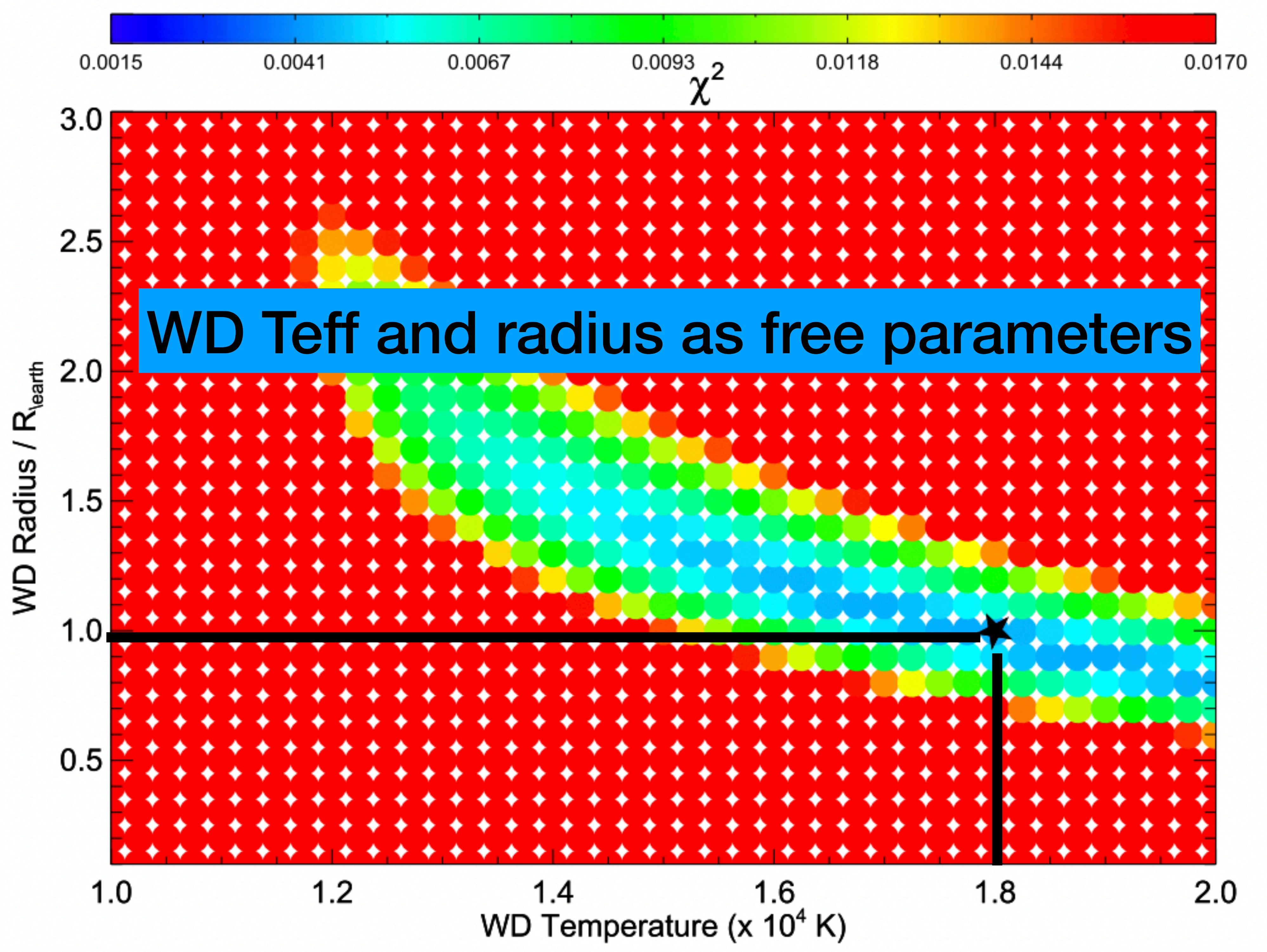
3,414 APOGEE sources that are WD binary candidates with F–M spectral type companions.

The largest number of the AGGC sources lie in modeled regions showing an inferred WD effective temperature range of 9000 K < Teff,WD < 15000 K, while a few of the WD binary candidates show potential effective temperatures hotter than 20,000 K

Physical Properties via SED fitting

$$\chi^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i},$$





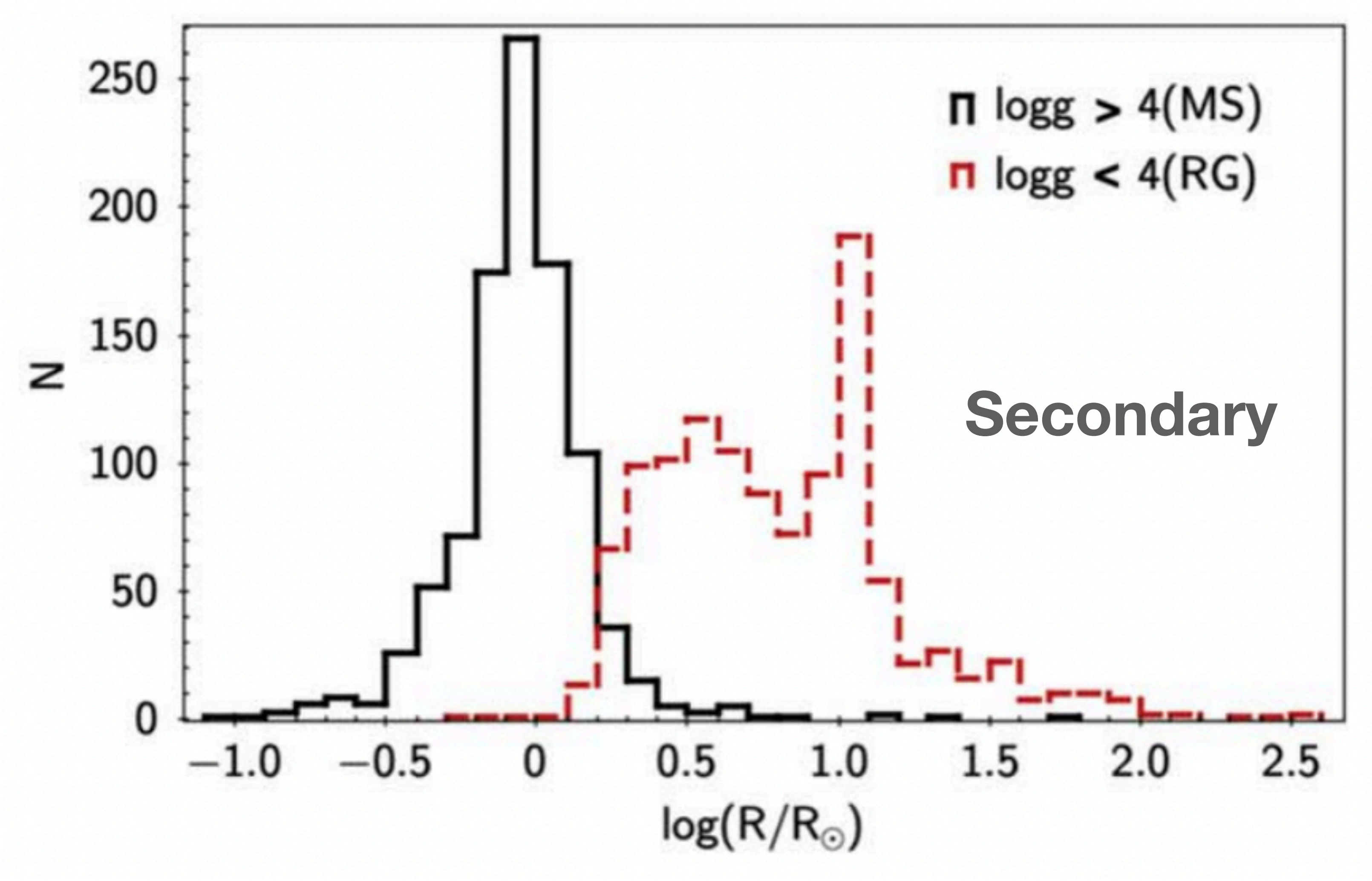
For the secondary, Teff, [M/H] and log g come from APOGEE DR17.

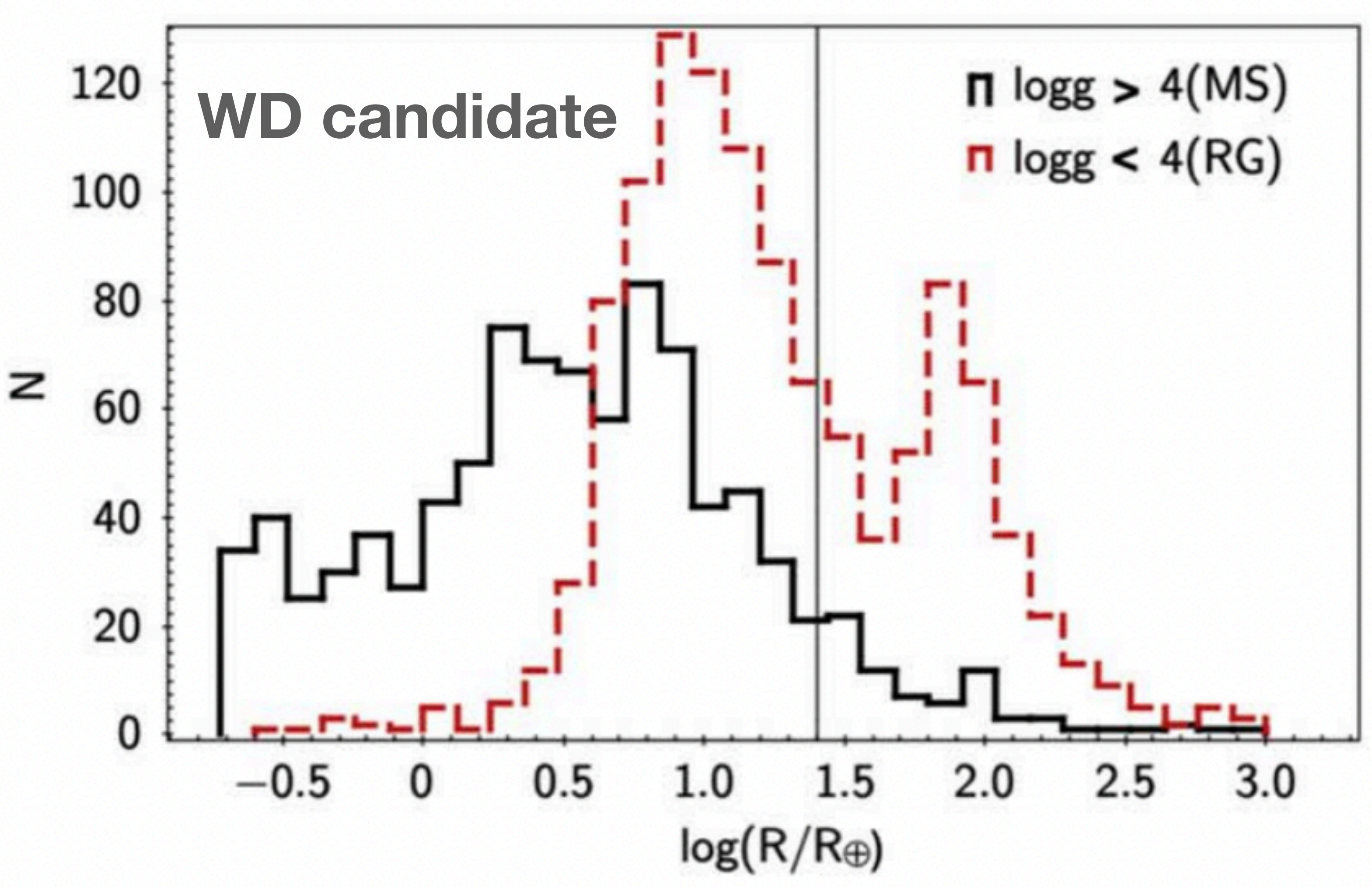
Stellar distances, r, came from Gaia eDR3 parallaxes and the Bayesian isochrone-fitting code StarHorse (Santiago et al. 2016; Queiroz et al. 2020).

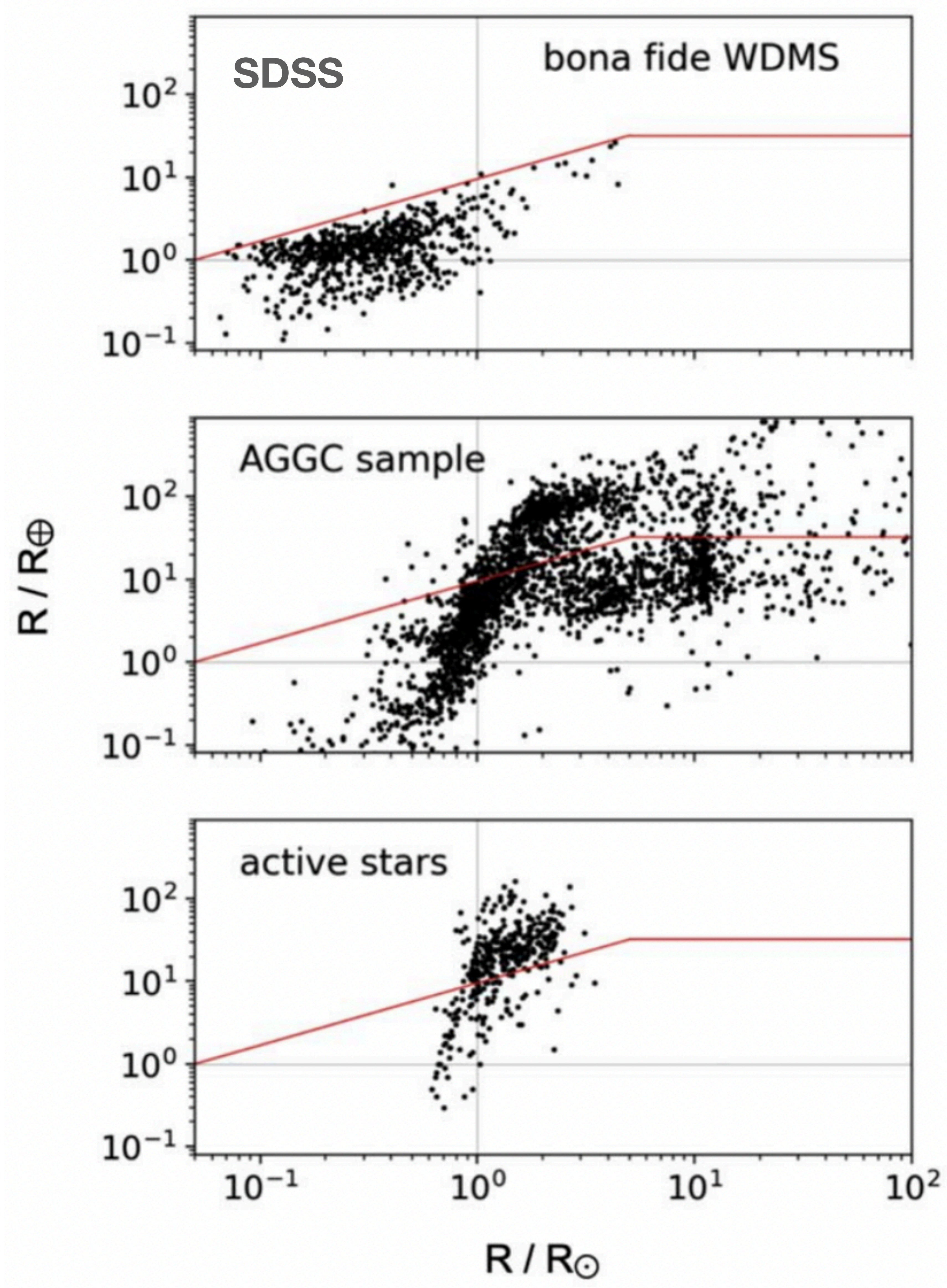
$$R = 4.43 \times 10^7 r (F_\lambda / F_{\lambda,\mathrm{surface}})^{1/2},$$

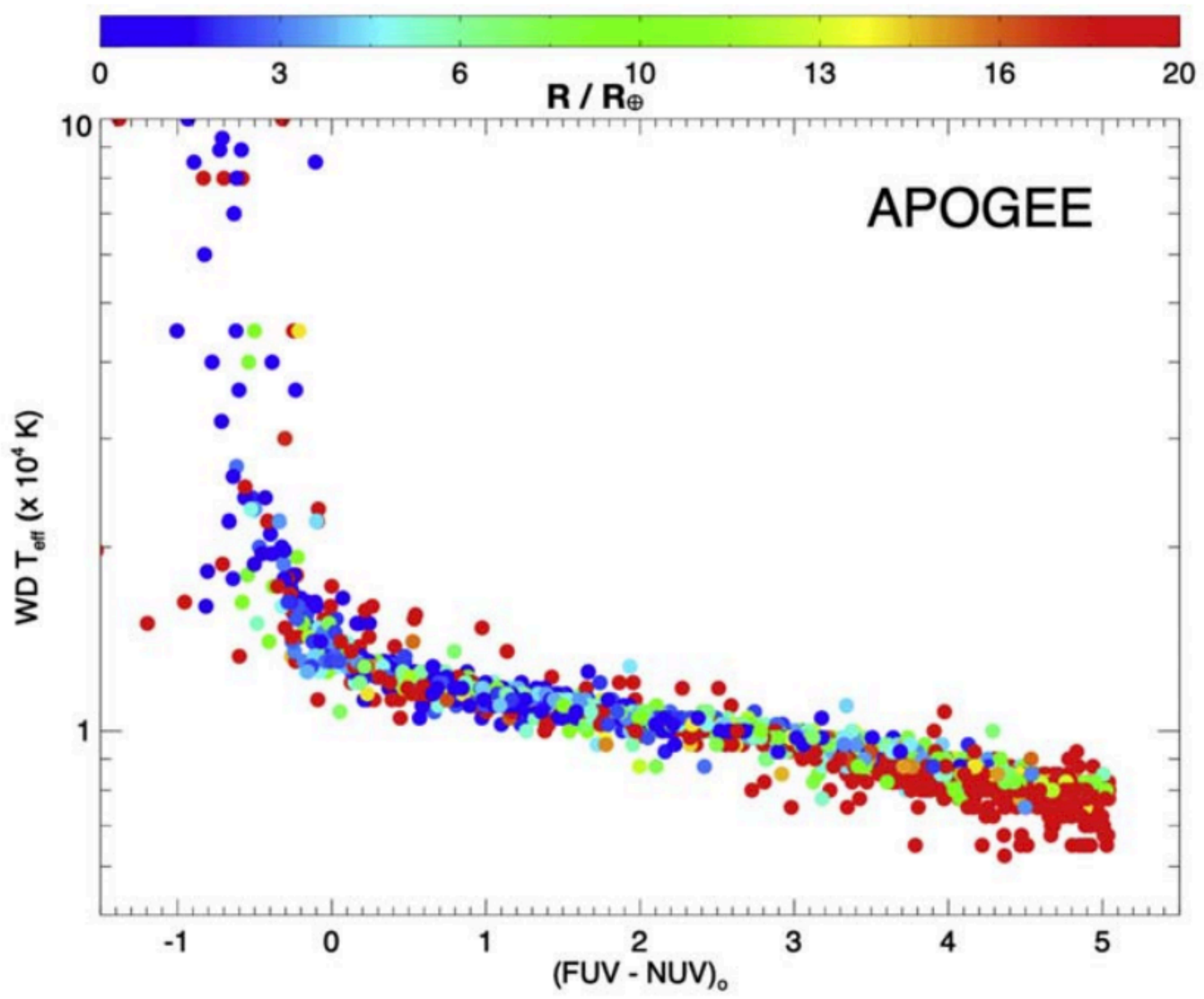
$$\epsilon R_\lambda / R = [(\epsilon F_\lambda / 2F_\lambda)^2 + (\epsilon r / r)^2]^{1/2}$$

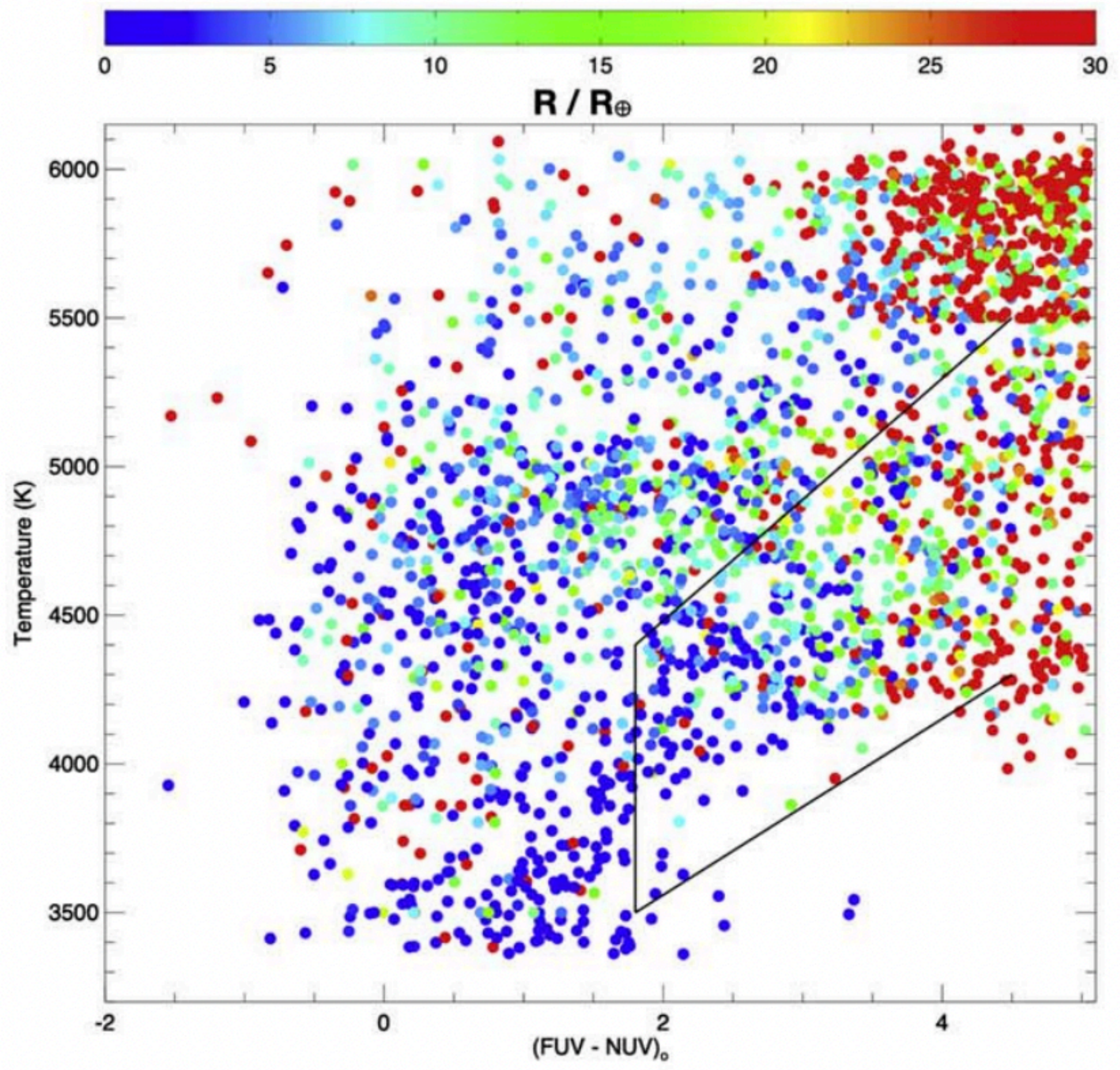
WD binaries candidates selection











White Dwarfs Binaries across the H-R diagram

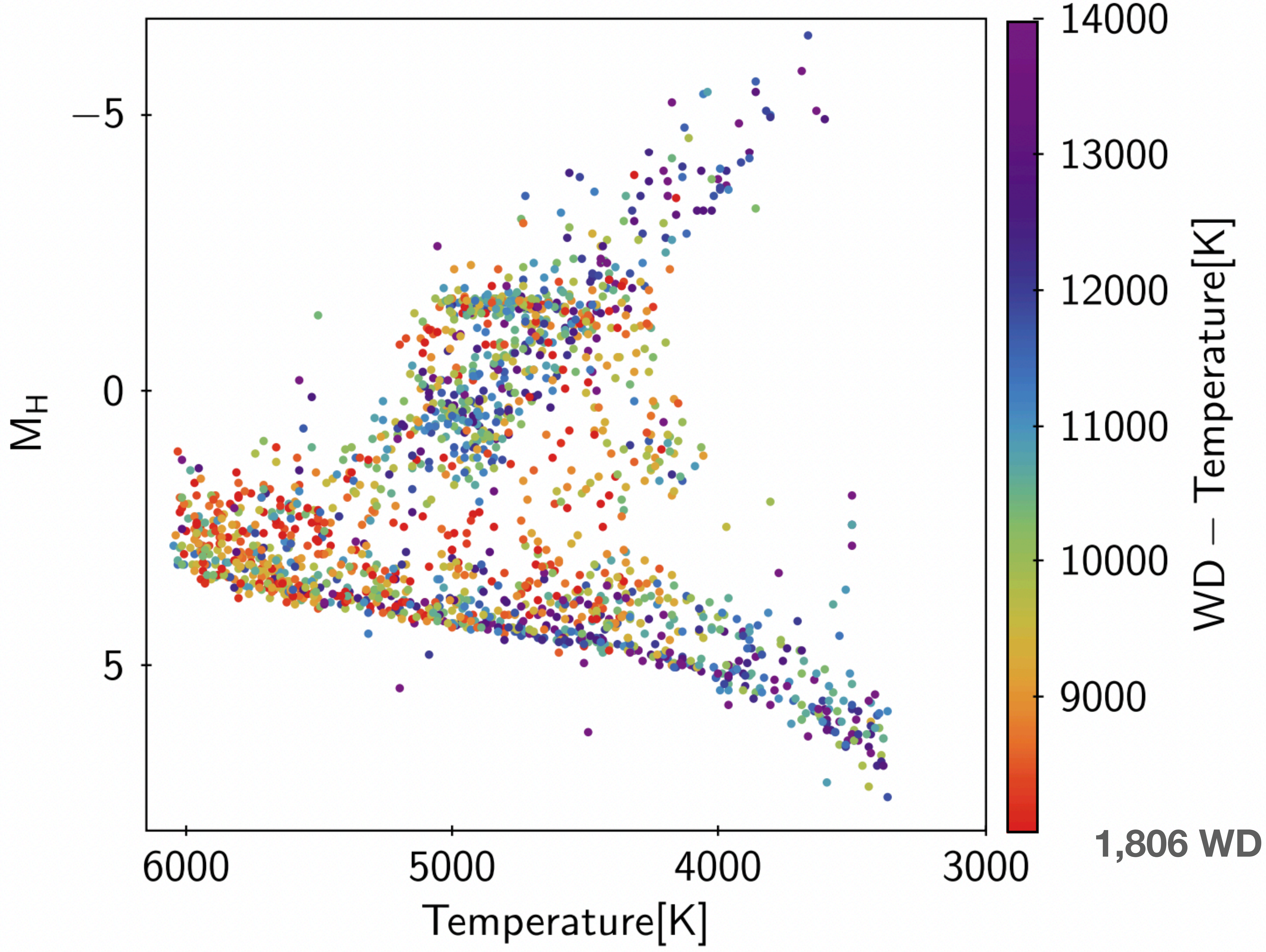


Table 1
WD Binary APOGEE DR17 Catalog

APOGEE ID	Gaia EDR3 ID	R.A. (J2000) (deg)	Decl. (J2000) (deg)	WD T_{eff} (K)	Sec T_{eff} (K)	Sec log g (cgs)	R_{WD} ($R_\oplus$)	R_{sec} ($R_\odot$)
2M00001362−1913042	2413936998069050496	0.0568	−19.2178	10683	5555	4.3	5.2	1.1
2M00031637+0203553	2739046437325768704	0.8182	2.0653	10656	4747	2.9	9.7	6.7
2M00042113+0109145	2738372917734134144	1.0881	1.1540	11810	4838	3.4	2.9	3.1
2M00081185−5220420	4972421528506663552	2.0494	−52.3450	9796	3632	4.7	0.3	0.4

H-R diagram for the AGGC, with APOGEE-derived temperatures and H-band luminosities from 2MASS photometry+Gaia parallaxes. Sources are color-coded by the inferred WD temperature from the SED fitting.

A sample of highly likely WD binaries identified across the CMD is an important step toward furthering our understanding of compact binary evolution.

1,806 WD binaries candidates

Anguiano et al. 2022 AJ

Binary Properties as a Function of RV Variability

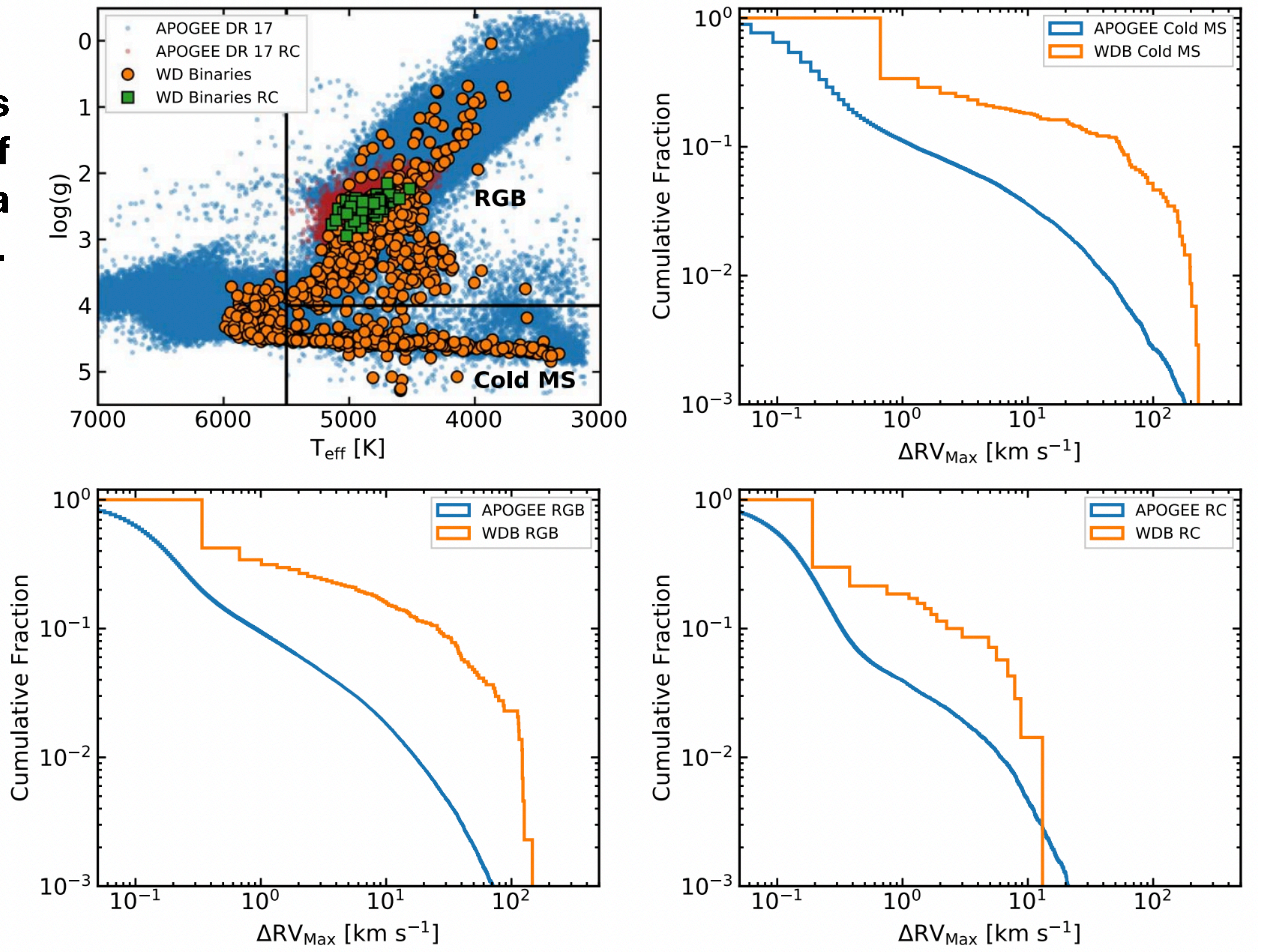
The detection of stellar multiplicity as evidenced by RV variability was one of the motivations for APOGEE being a multi-epoch survey (Majewski et al. 2017).

$$\Delta RV_{max} = \max(RV) - \min(RV)$$

Badenes & Maoz 2012

The ΔRVmax CDF for the WD binaries (orange solid lines) is clearly skewed toward larger ΔRVmax values, suggesting shorter periods for these systems.

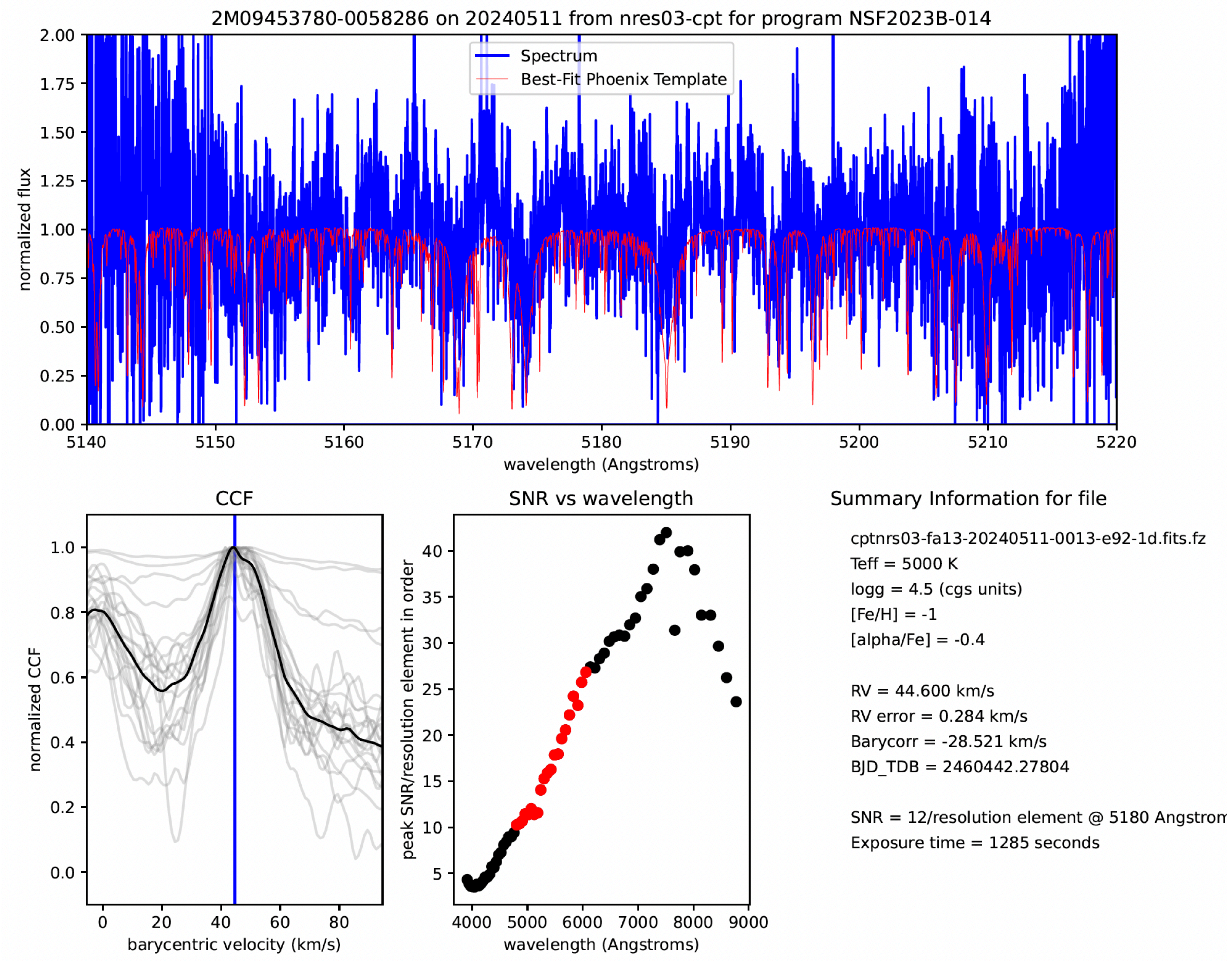
Loss of angular momentum associated with the formation of the WD, most naturally explained by a CE episode leading to the ejection of at least some of the envelope of the mass primary/WD progenitor.



Dedicated follow-up

WIYN 3.5M OBSERVATORY

LCO Las Cumbres Observatory



$P = 2.058908 \pm 0.000002$ days

$\gamma = -42.535 \pm 0.234$ km s^{-1}

$K = 33.923 \pm 0.492$ km s^{-1}

$e = 0.051 \pm 0.007$ $\Delta T = 50259.18 - 58647.92$

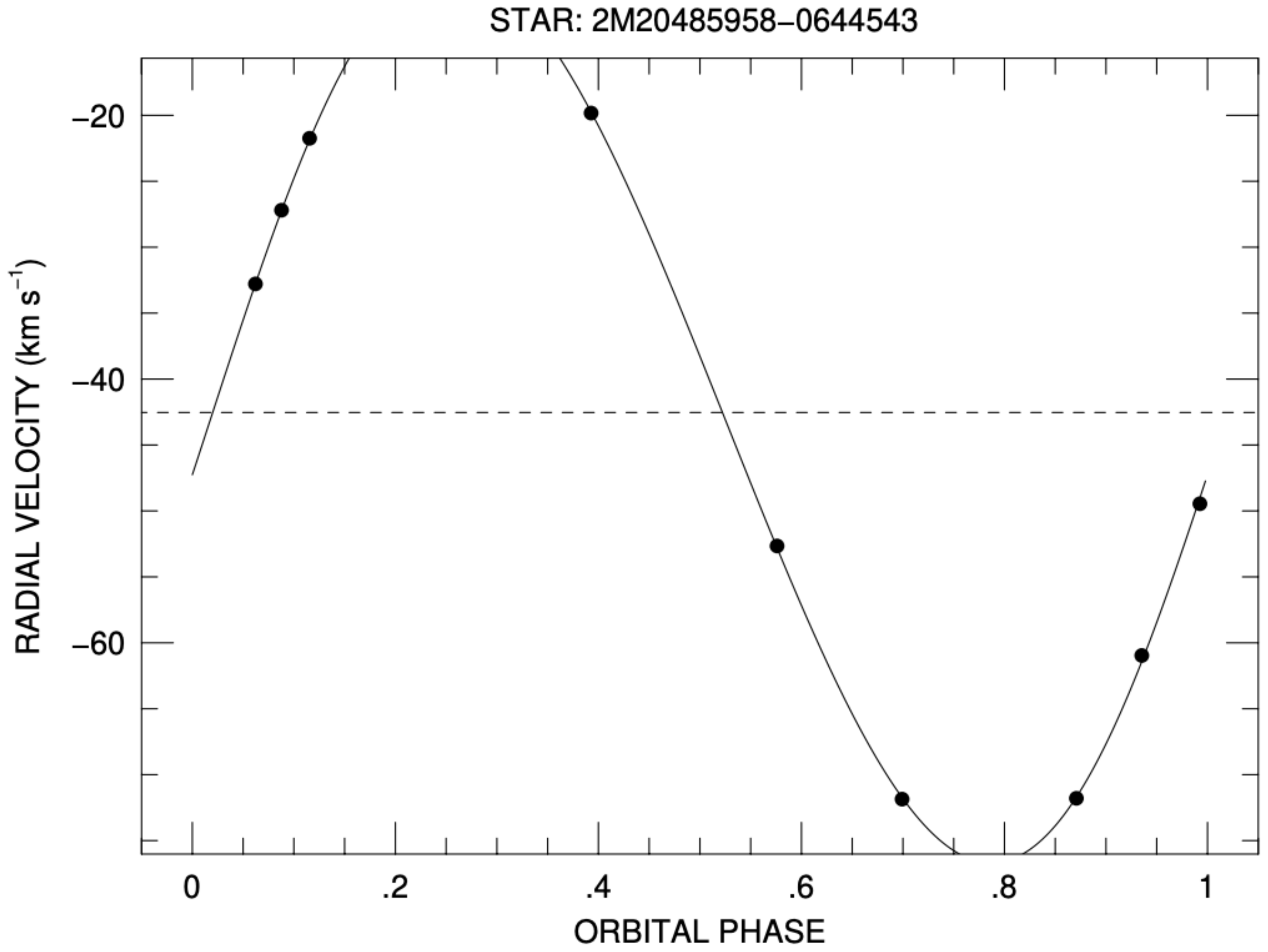
$\omega = 262.39 \pm 16.86$ deg $= 8388.74$ days

$T = 54052.306 \pm 0.095$ $= 4074.4$ cycles

$a_1 \sin i = 0.959 \pm 0.014$ Gm

$f(M) = 8.29$ E-3 ± 3.61 E-4 M_o $N = 9$

$M_2 \sin i = 0.2024\,(M_1+M_2)^{2/3}\ M_o$ $\sigma = 0.402$ km s^{-1}



The AGGC is a rich resource for investigating the evolution of WD binaries across the H-R diagram. Here we have only touched various avenues that are ripe for further development.

Among the additional available tools that we intend to exploit in our future efforts are the more than 15 elements derived in the APOGEE catalog for the WD binary sample, and looking more deeply into the orbital properties of the systems, beyond simple periods.

Gaia DR4 will be released in about a year time.

…but this meeting is about LISA!

Study the formation and evolution of compact binary stars and the structure of the Milky Way Galaxy

How large white dwarfs binaries catalogues can be useful for the LISA mission?