White Dwarfs Binaries across the H-R Diagram

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The Transient and Variable Universe 2023 - Illinois NCSA

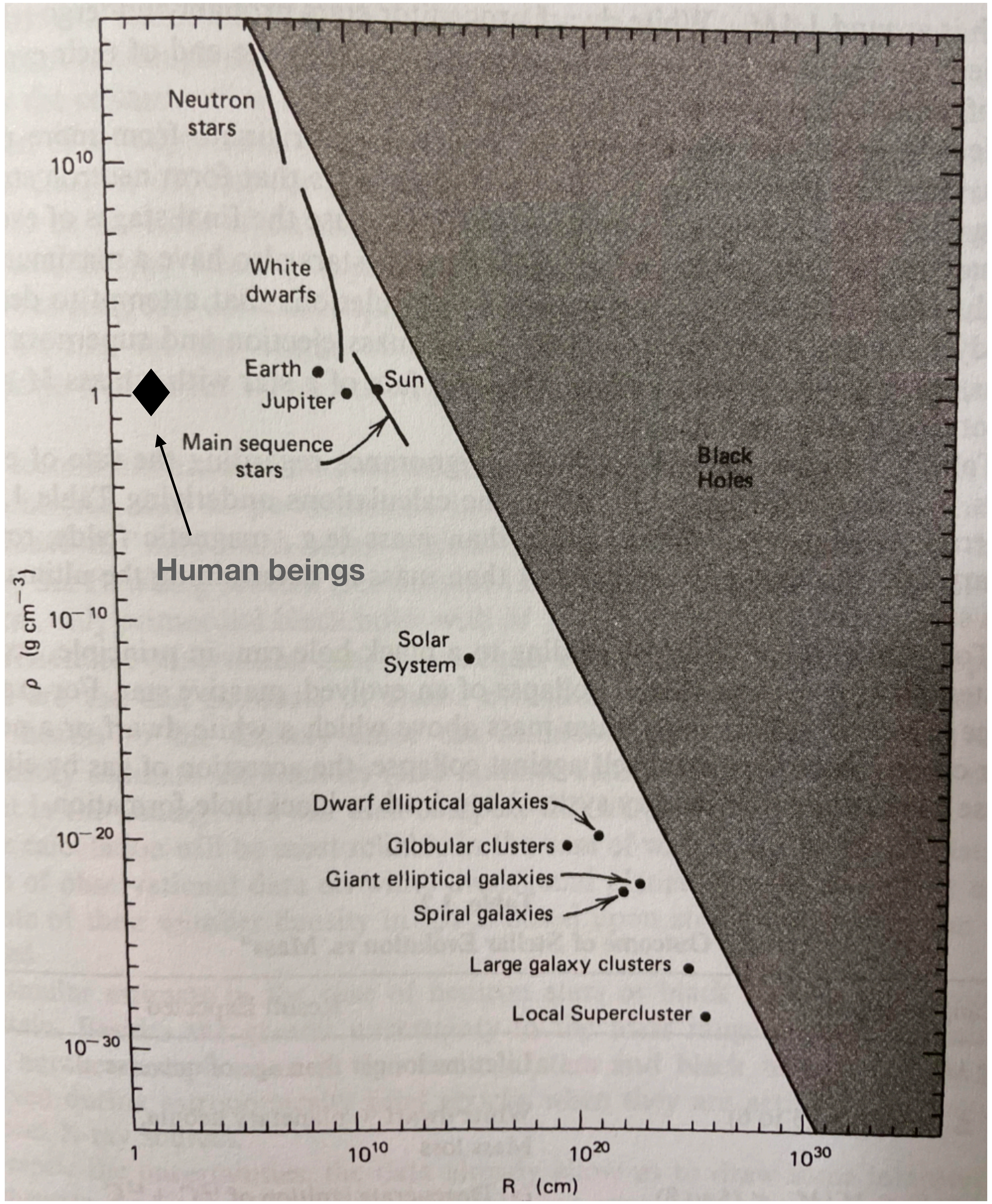
Compact Objects

- Compact objects, like white dwarfs, are born when 'normal' stars die.

They cannot support themselves against gravitational collapse by generating thermal pressure

Exceedingly small size

Mean density and radii

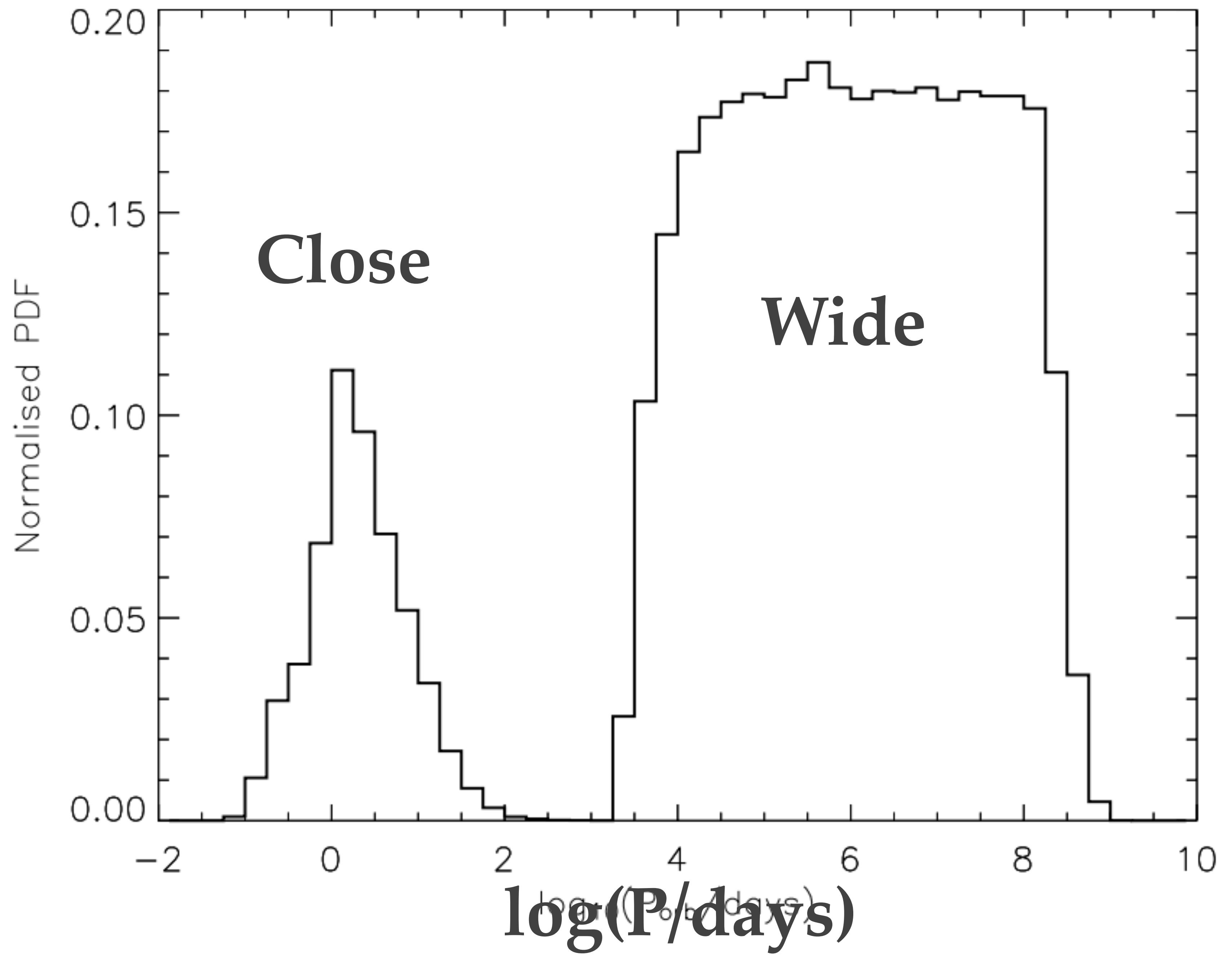


Shapiro & Teukolsky1983

Background

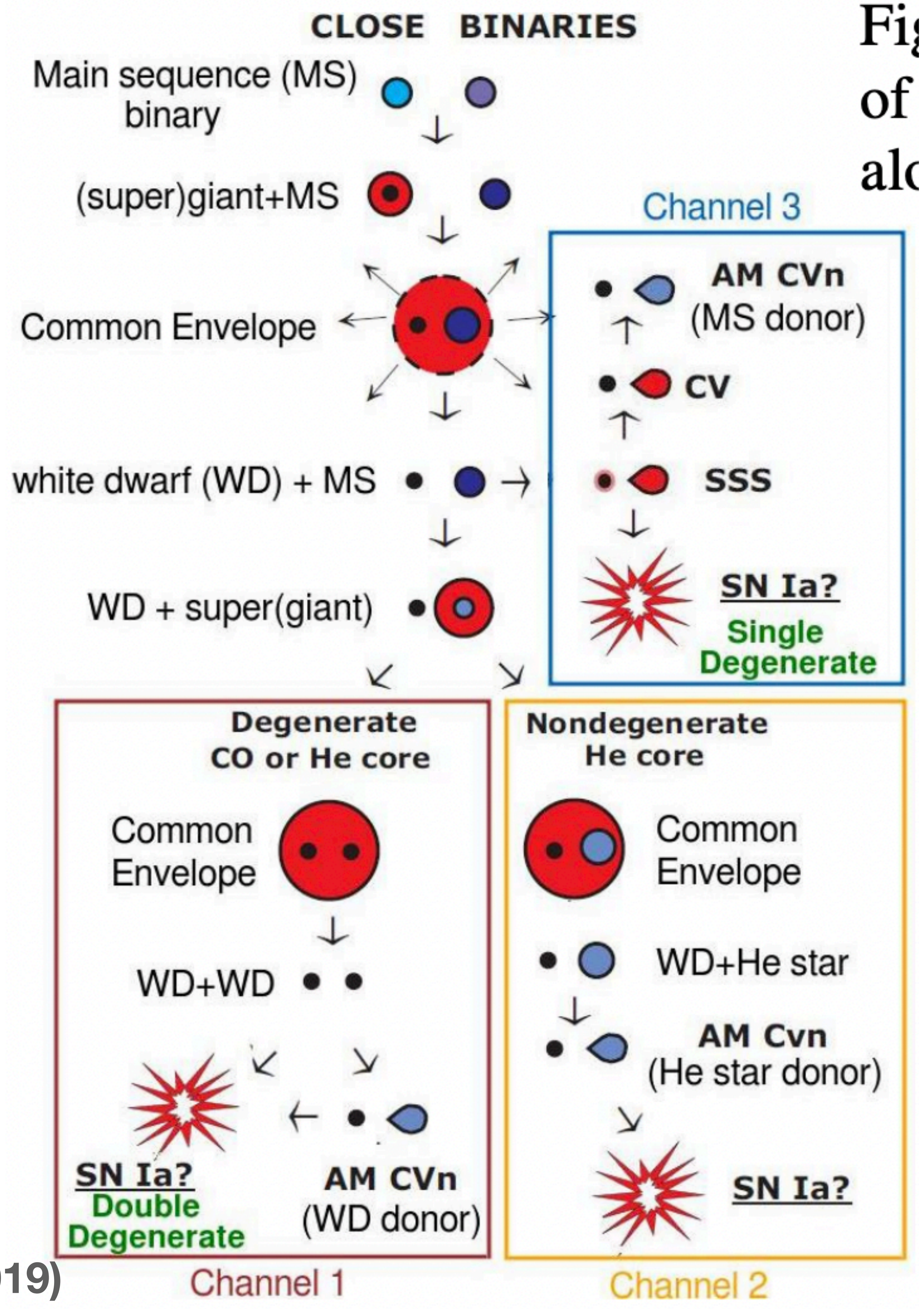
- A majority of MS stars exist in binary systems, with orbital periods ranging from few minutes to ~10^6 years (e.g., Moe & Di Stefano 2017)
- Most stars in these systems are widely separated. Systems with P < 10 years —compact binaries— can undergo a stage of common envelope (CE) evolution changing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

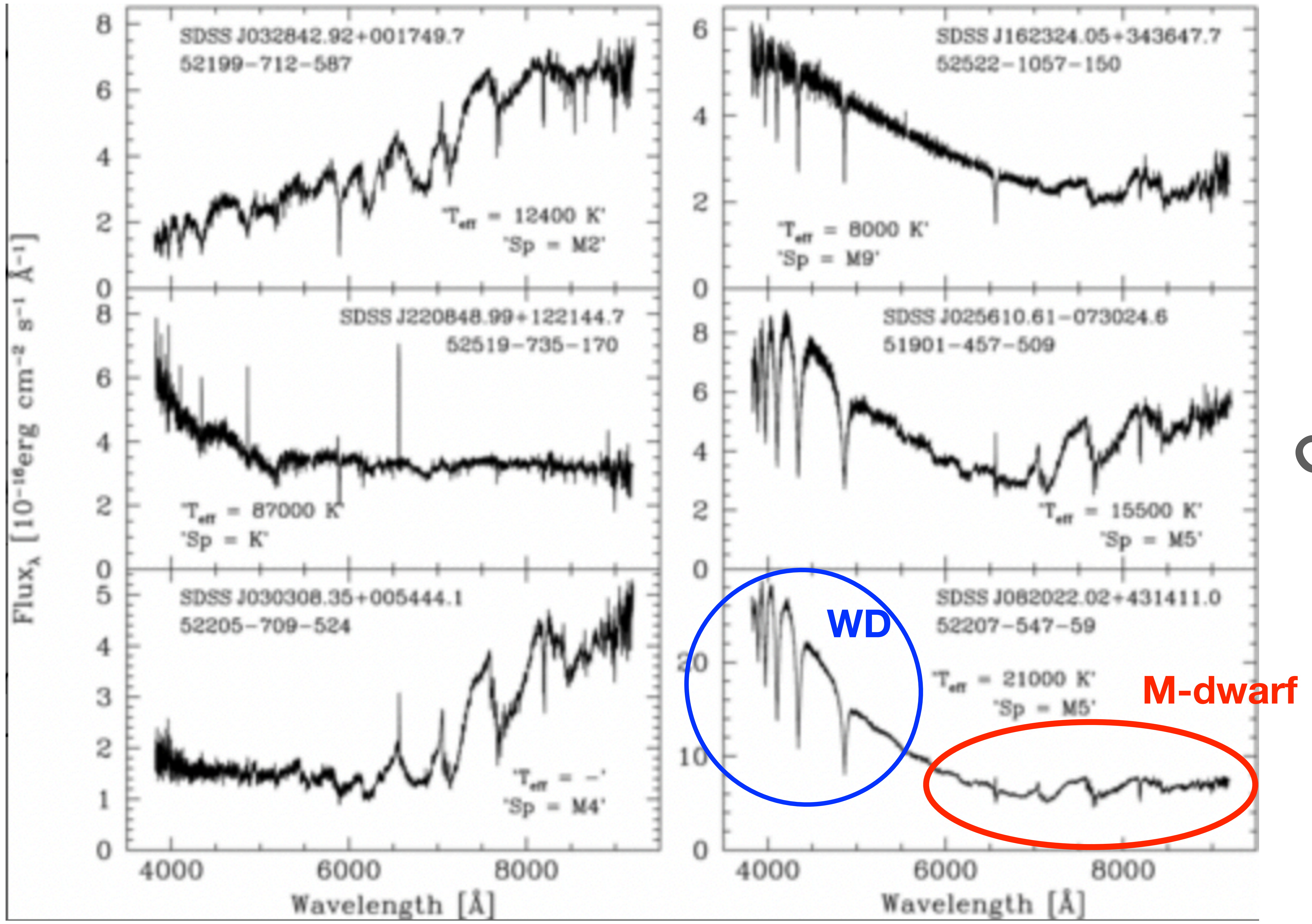


PCEBs pathways leading to mass transfer systems or mergers (Toloza et al. 2019)

Motivation

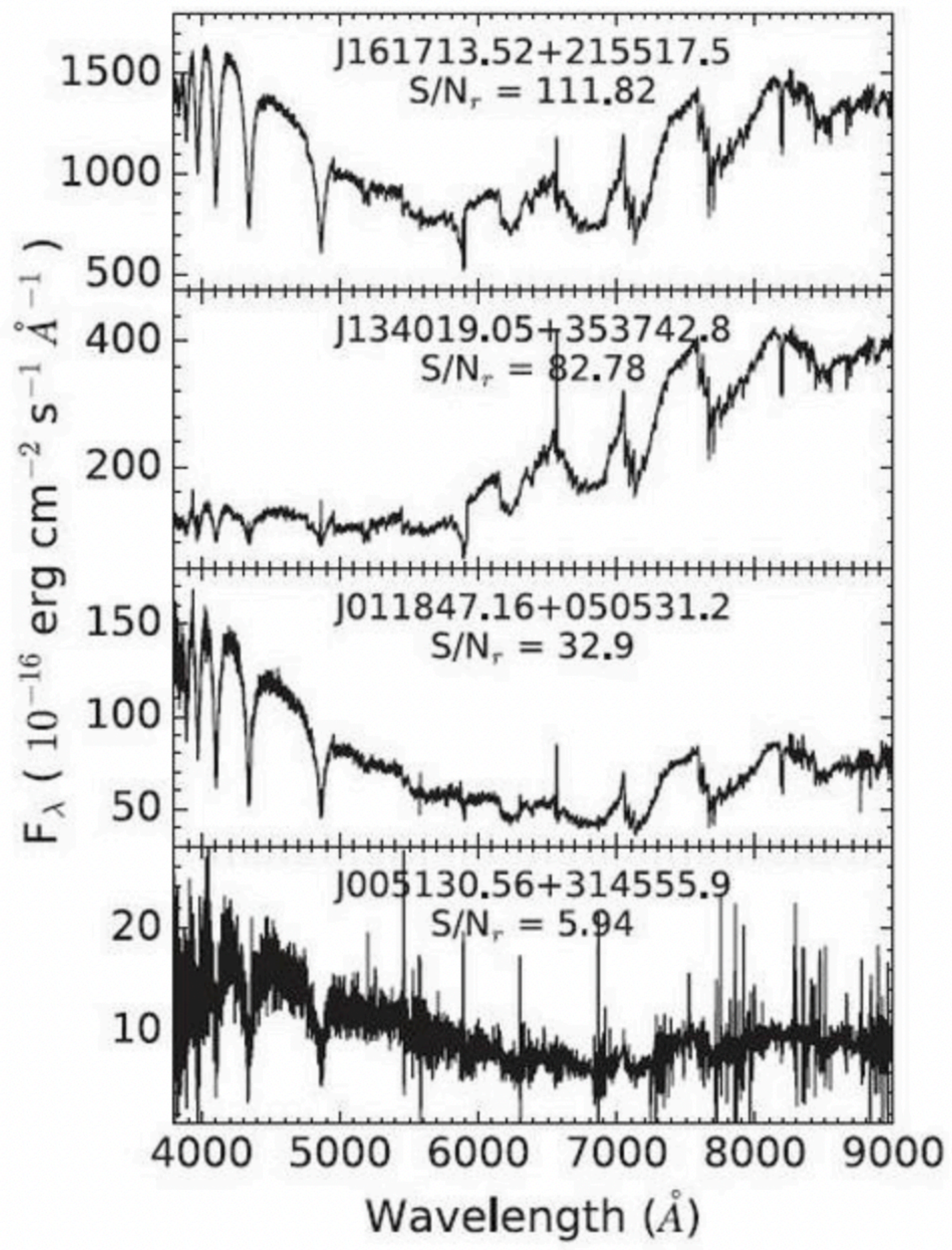
- Detected number of WD binaries (and PCEBs) has largely increased in the last years, mainly thanks to surveys like SDSS, LAMOST.

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

Ren et al. 2014

Motivation

- SDSS/LAMOST WDMS are **biased** toward systems containing **hot WDs** and secondaries of **late spectral type**.
- Some objects classified as WDMS in the SDSS sample are actually **young stellar object contaminants** (Corcoran, Lewis, Anguiano et al. 2021)

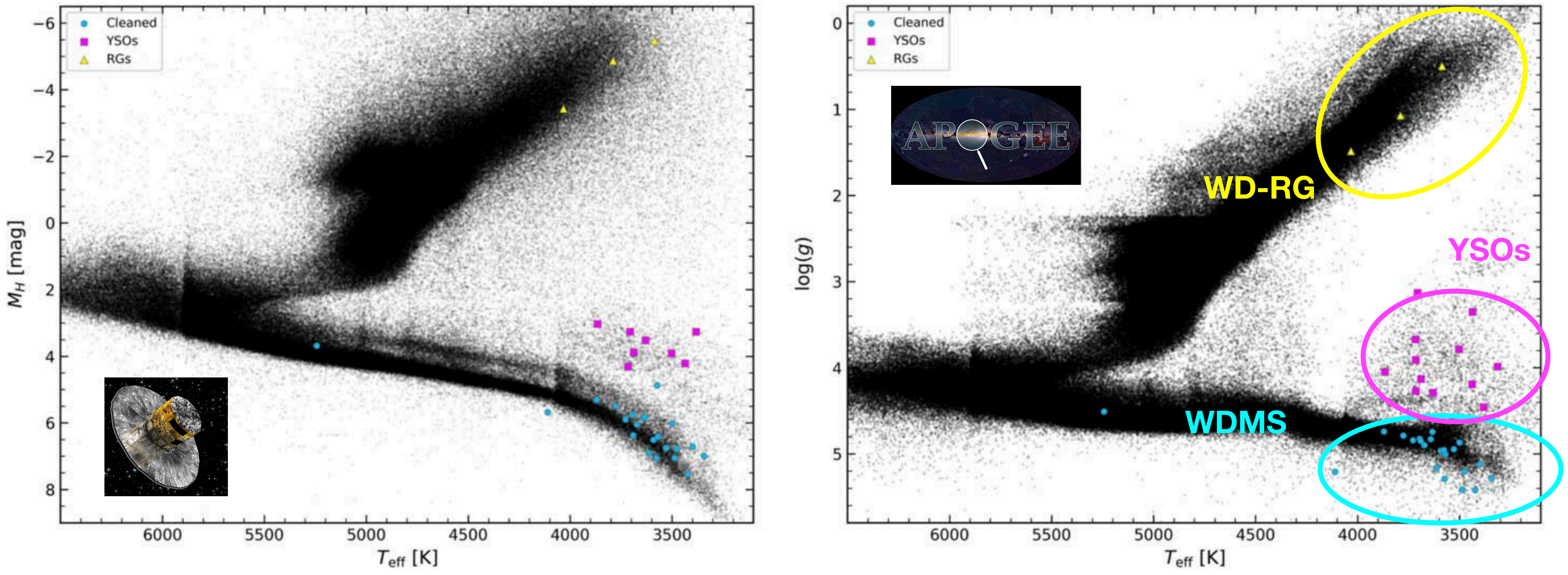


Figure 1. Confirmed or candidate WDMS systems shown against all of APOGEE. Note that not all of the 45 systems are shown due to either missing parallaxes (left) or ASPCAP parameters (right). We highlight in both plots the RG (yellow triangles) and YSO (magenta squares) contaminants, as well as the remaining cleaned sample with MS primaries (blue circles). Left: Gaia-based H-band absolute magnitude as a function of the ASPCAP $T_{\rm eff}$. Right: Kiel diagram with the ASPCAP log(g) as a function of ASPCAP $T_{\rm eff}$.

Some of these systems classified as WDMS are actually WD–red giant pairs in LAMOST

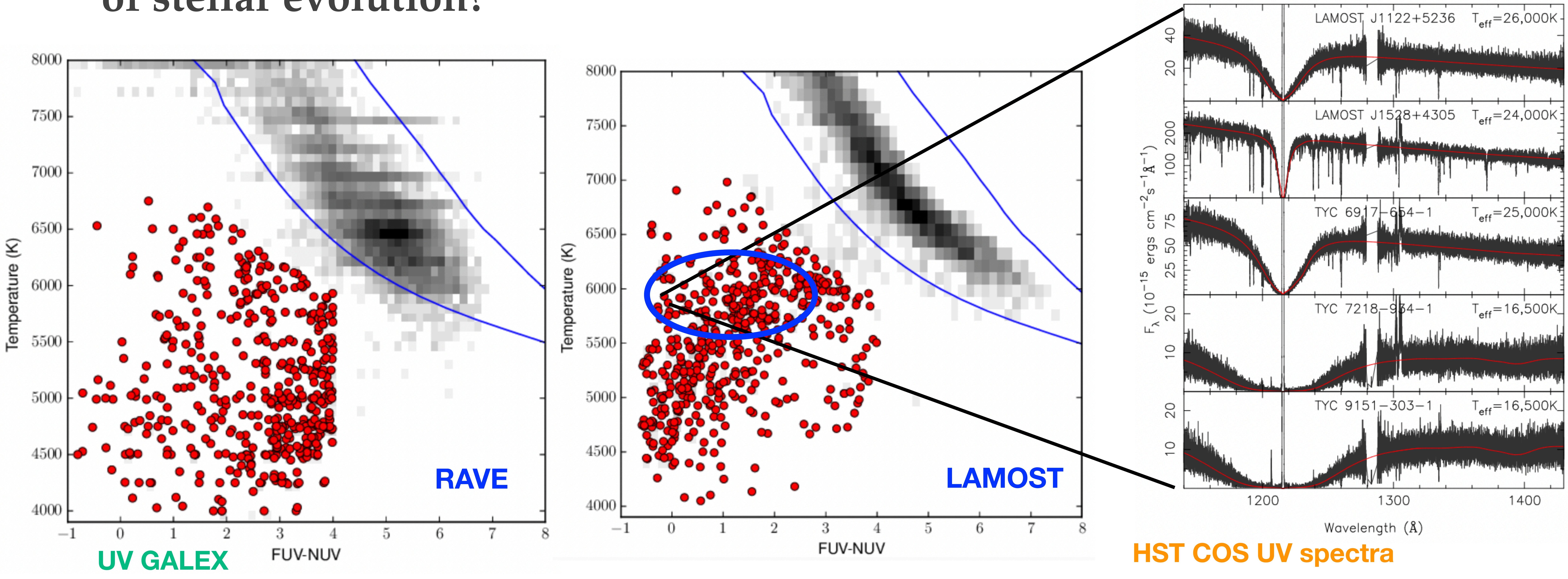
Corcoran, Lewis, Anguiano et al. 2021

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

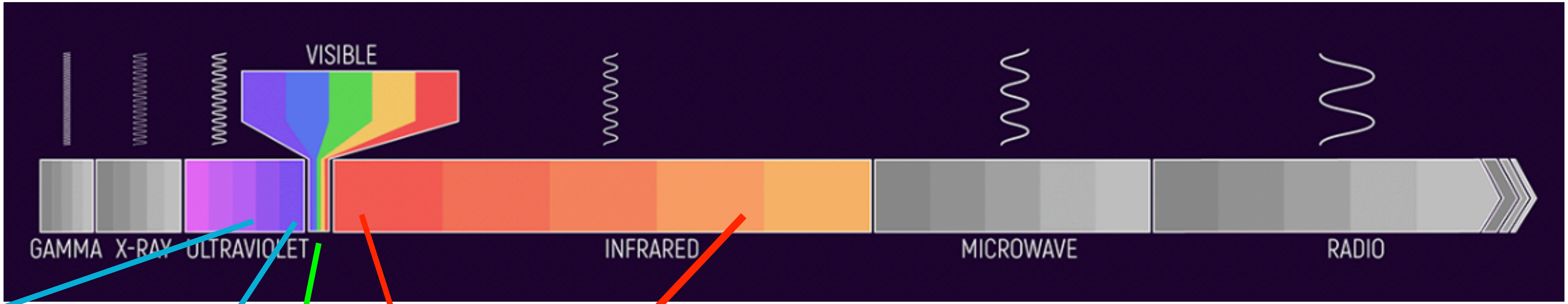
- Can we identify WD binaries across the H-R diagram, with secondary companions with a broad range of spectral types and in virtually all phases of stellar evolution?

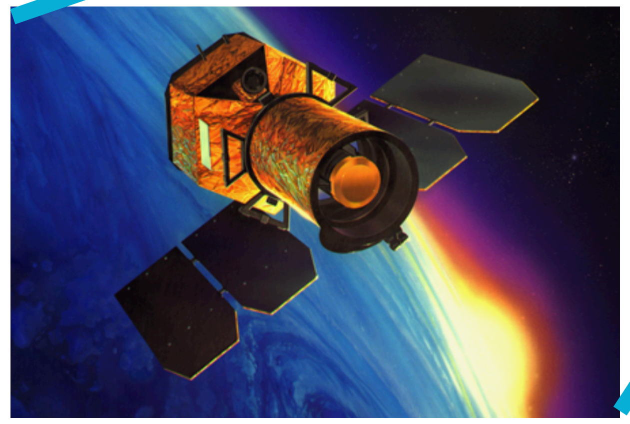


23,484 RAVE dwarf stars (log g > 3.5) with both a GALEX FUV and NUV detection

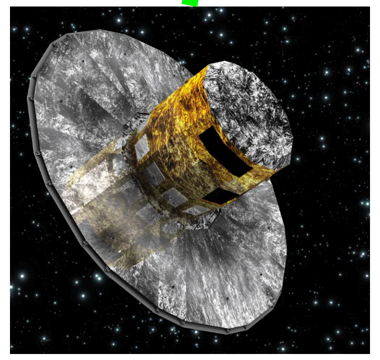
Parsons et al. 2016

APOGEE-GALEX-*Gaia* Catalog (AGGC)

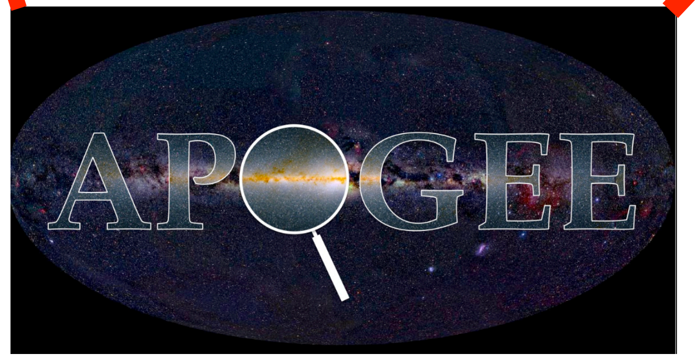




GALEX UV-photometry



Gaia
(astrometry)



APOGEE - H-band - 2MASS + WISE

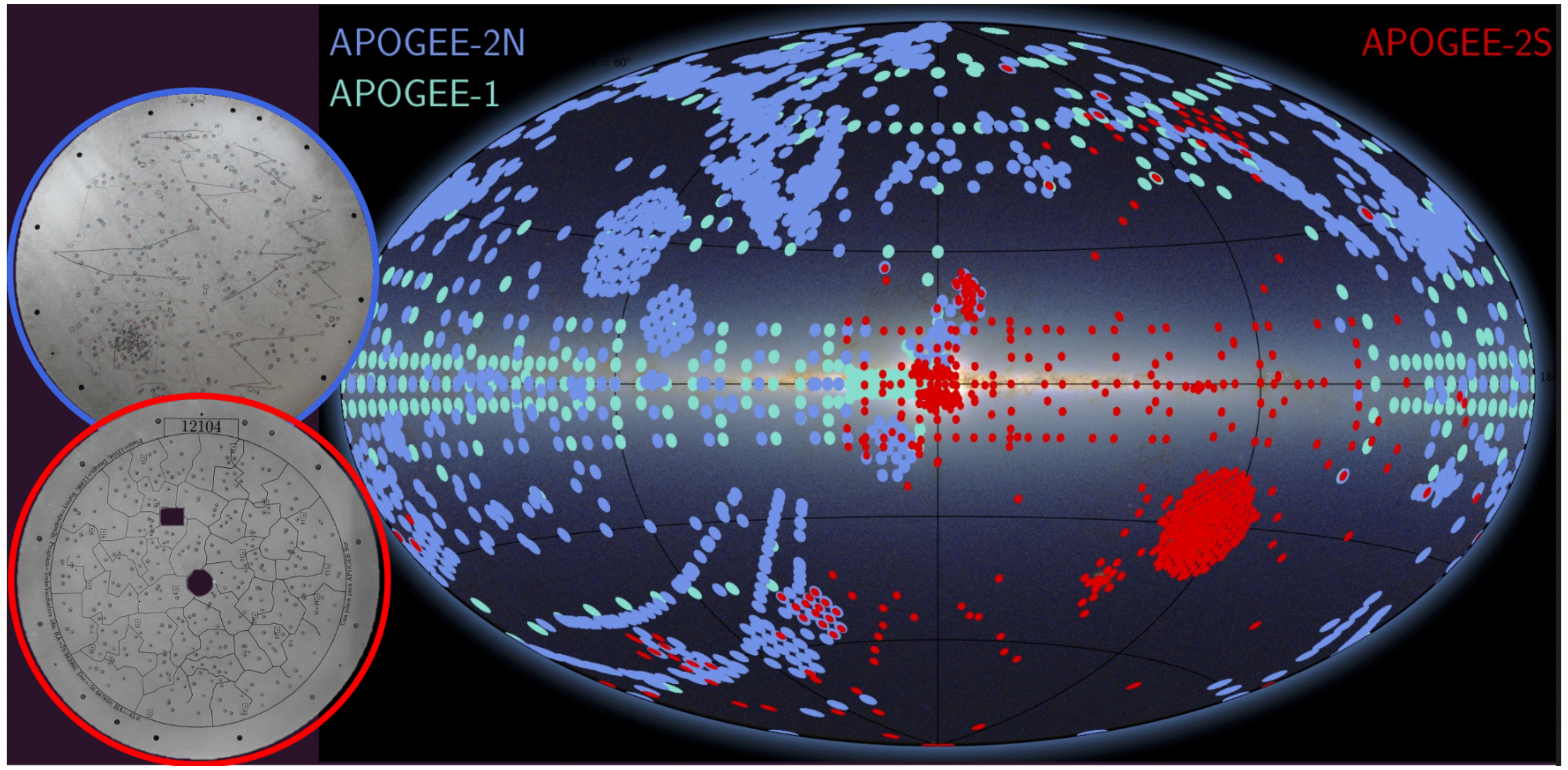
UV - optical - IR — Spectral Energy Distribution
APOGEE High-resolution spectra - H-band
Gaia parallaxes

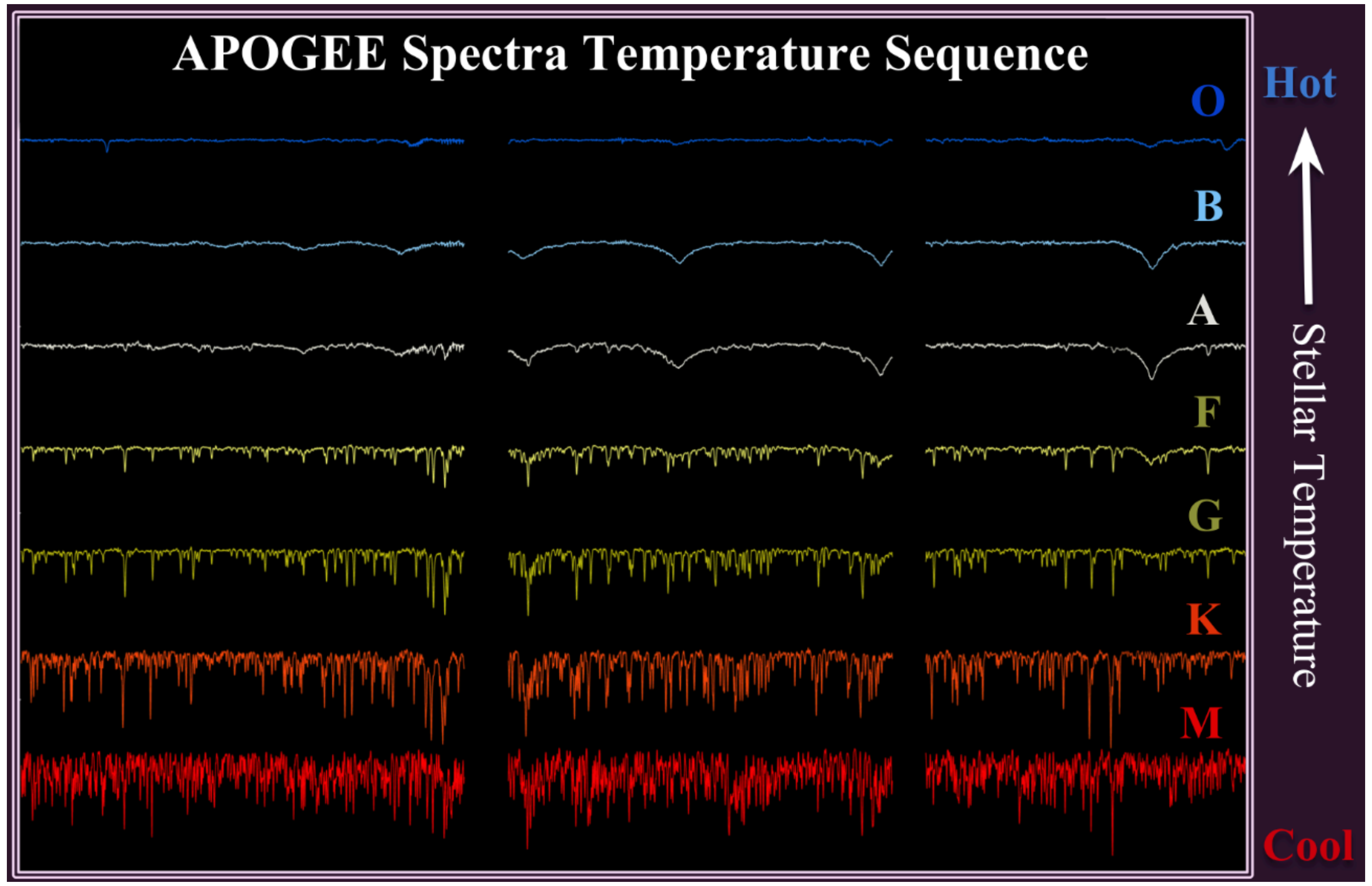
Our goal is to perform a new, large, and systematic search for compact binary star systems containing WDs by harnessing information contained in the APOGEE (Majewski et al. 2017) spectroscopic catalog, cross-matched with data from the optical *Gaia* (Lindegren et al. 2018) and UV GALEX (Bianchi et al.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

APOGEE DR17 - SDSS IV

Big Data for Addressing Big Questions:

- ✧ What are the dynamics of the Milky Way?
- ✧ What is chemical enrichment in Milky Way?
- ✧ What are the ages of stars in the Milky Way?
- ✧ Are planet-hosting stars different from planet-less stars?



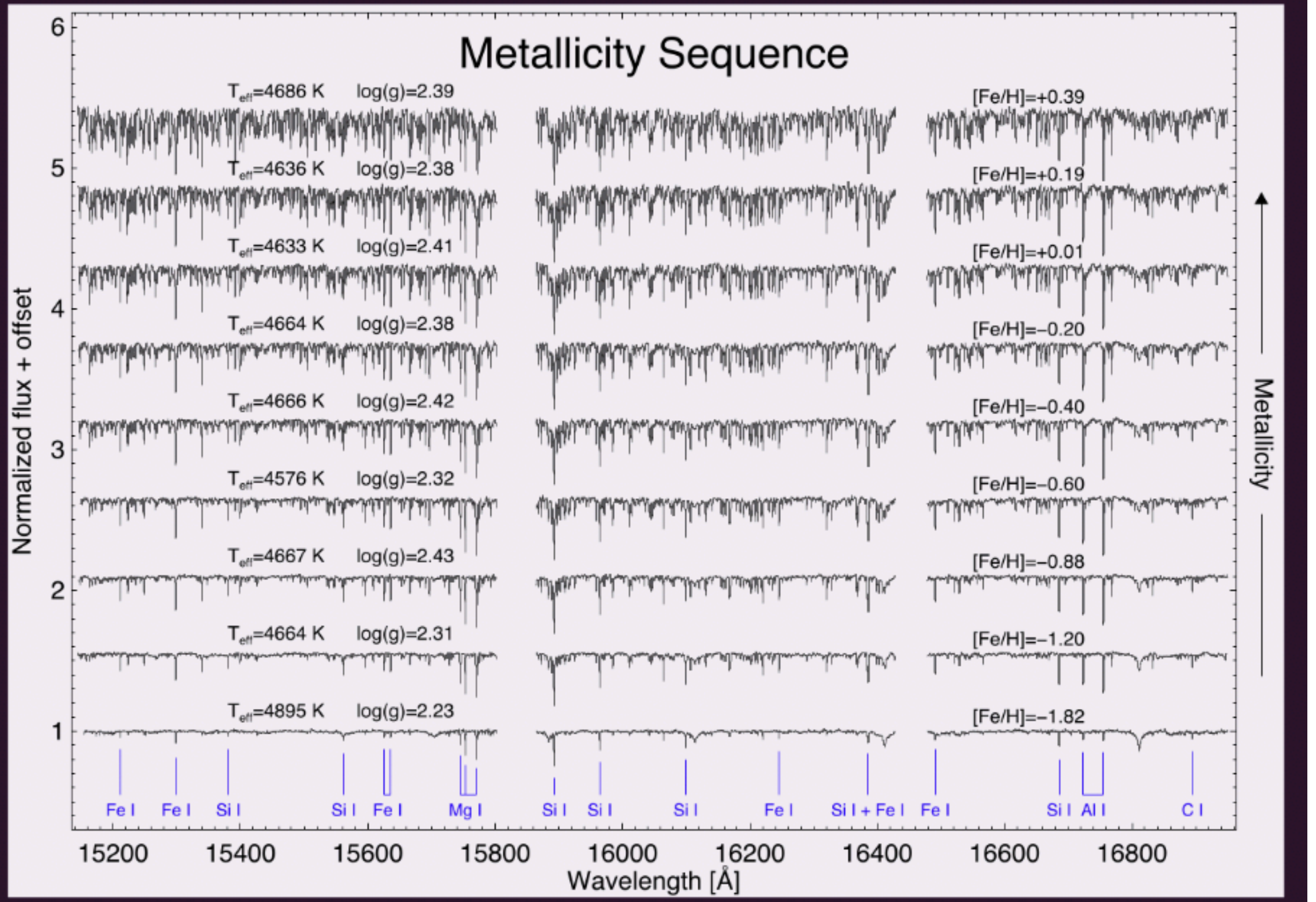


Data Release 17:

- Nearly 1 million targets
- 2.6 million spectra
- Multi-Epoch Radial Velocities
- Stellar Types
- 20 Elemental Abundances

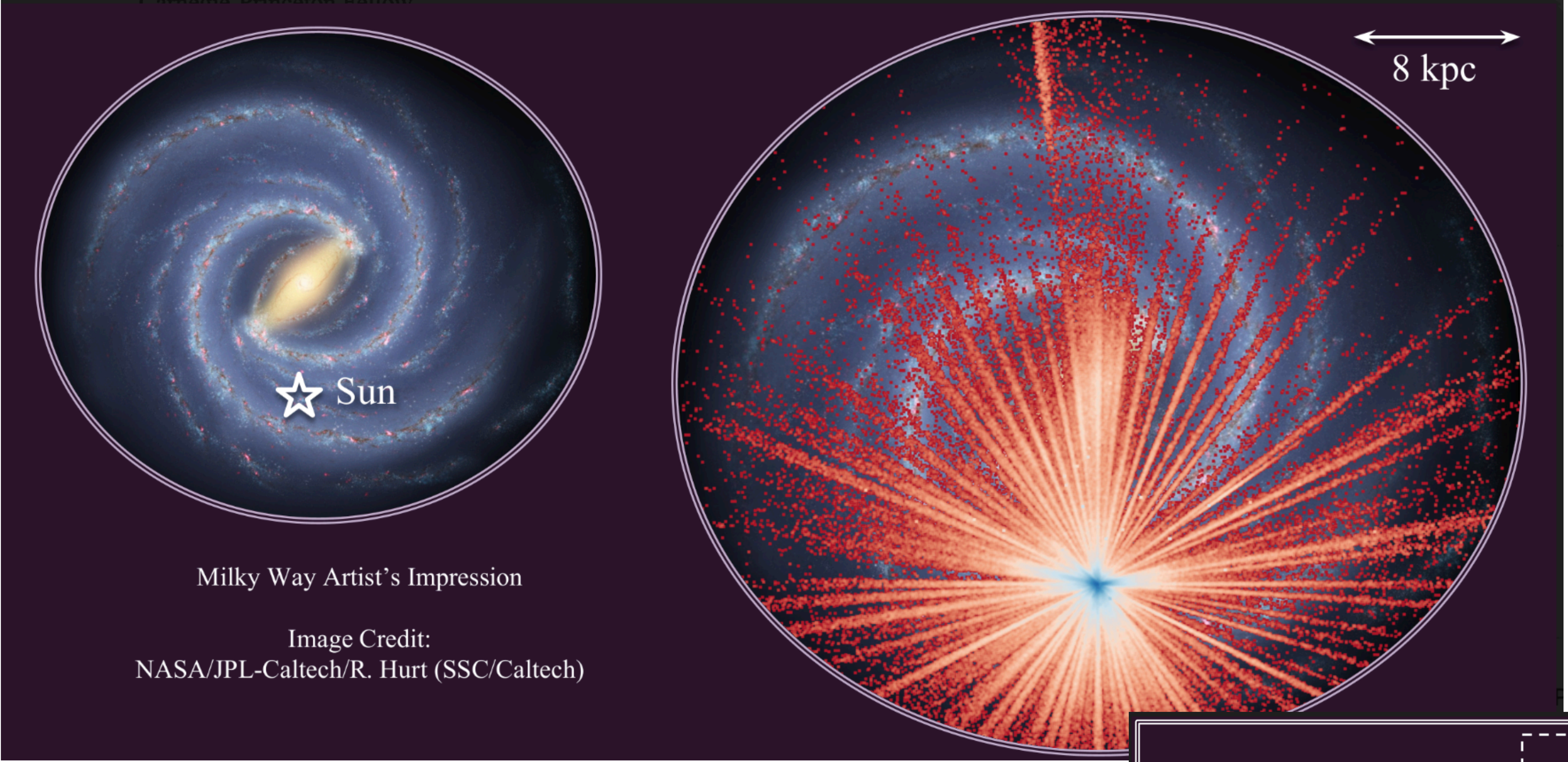
\+ *Value Added Catalogs:*

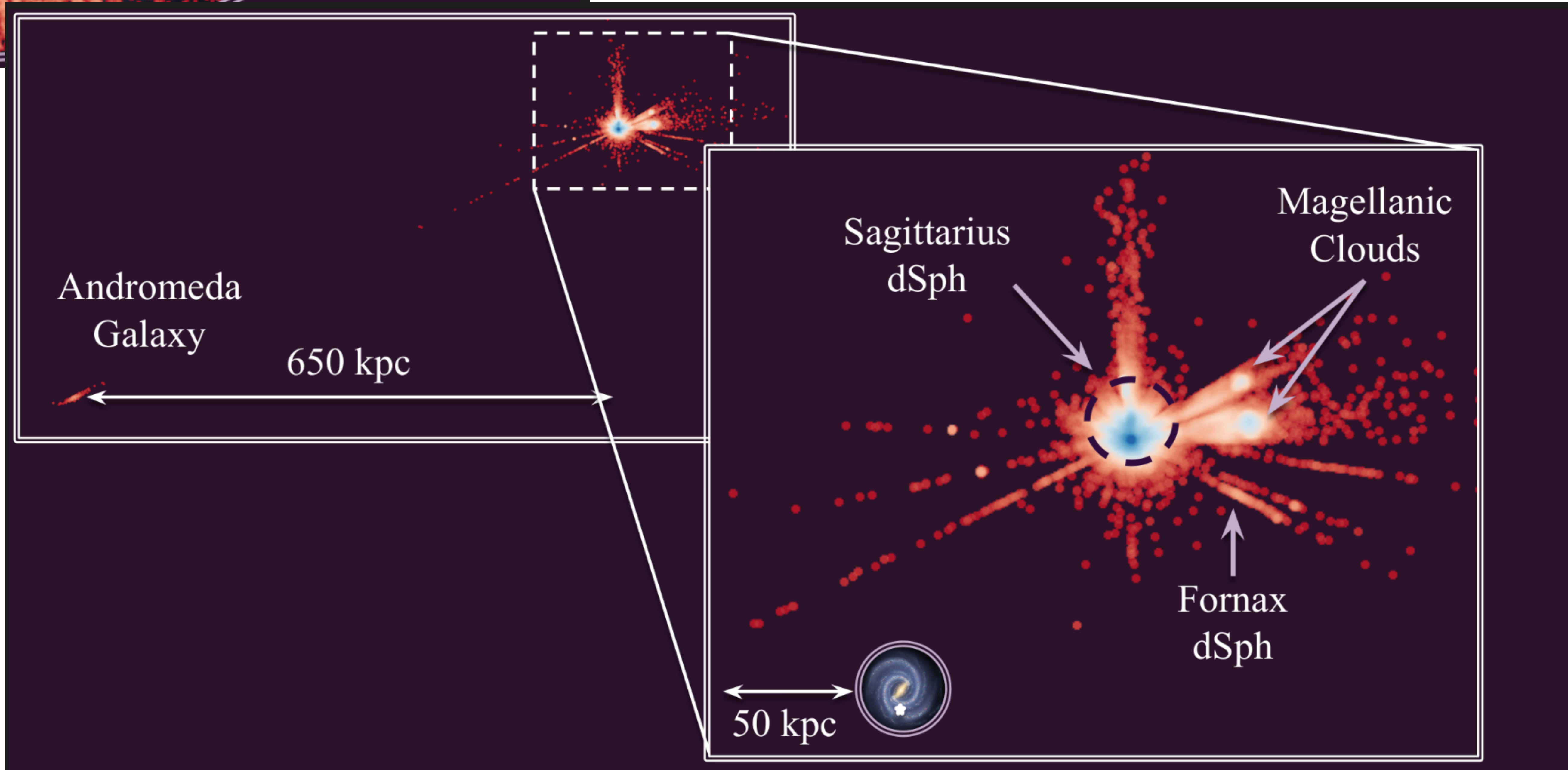
- Distances
- Binary Identifications
- Galactic Orbits
- Star Cluster Membership



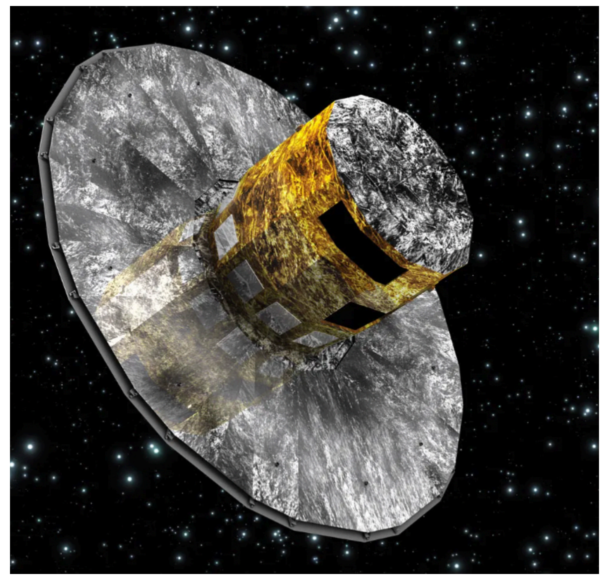
Data Release 17:
sdss.org/dr17/irspec/

PI: Steve Majewski (UVa)


8 kpc
Sun
Milky Way Artist's Impression
Image Credit:
NASA/JPL-Caltech/R. Hurt (SSC/Caltech)


Andromeda
Galaxy
650 kpc
Sagittarius
dSph
Magellanic
Clouds
Fornax
dSph
50 kpc

Gaia eDR3 (Riello et al. 2020)

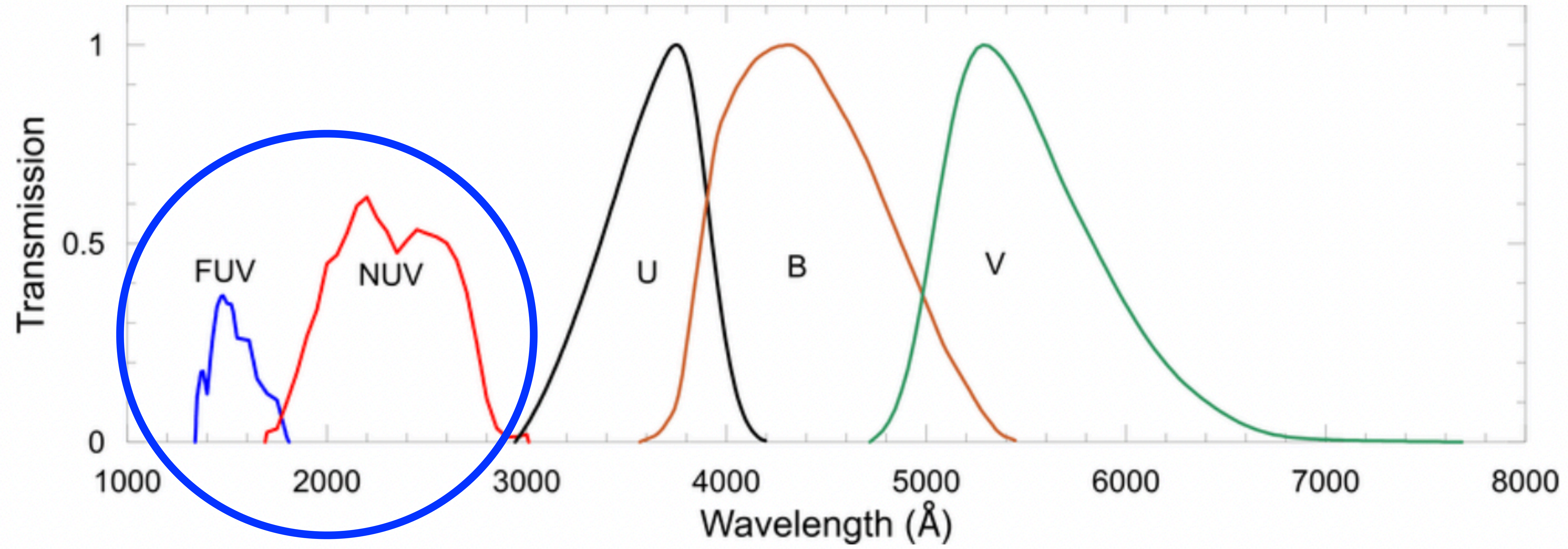


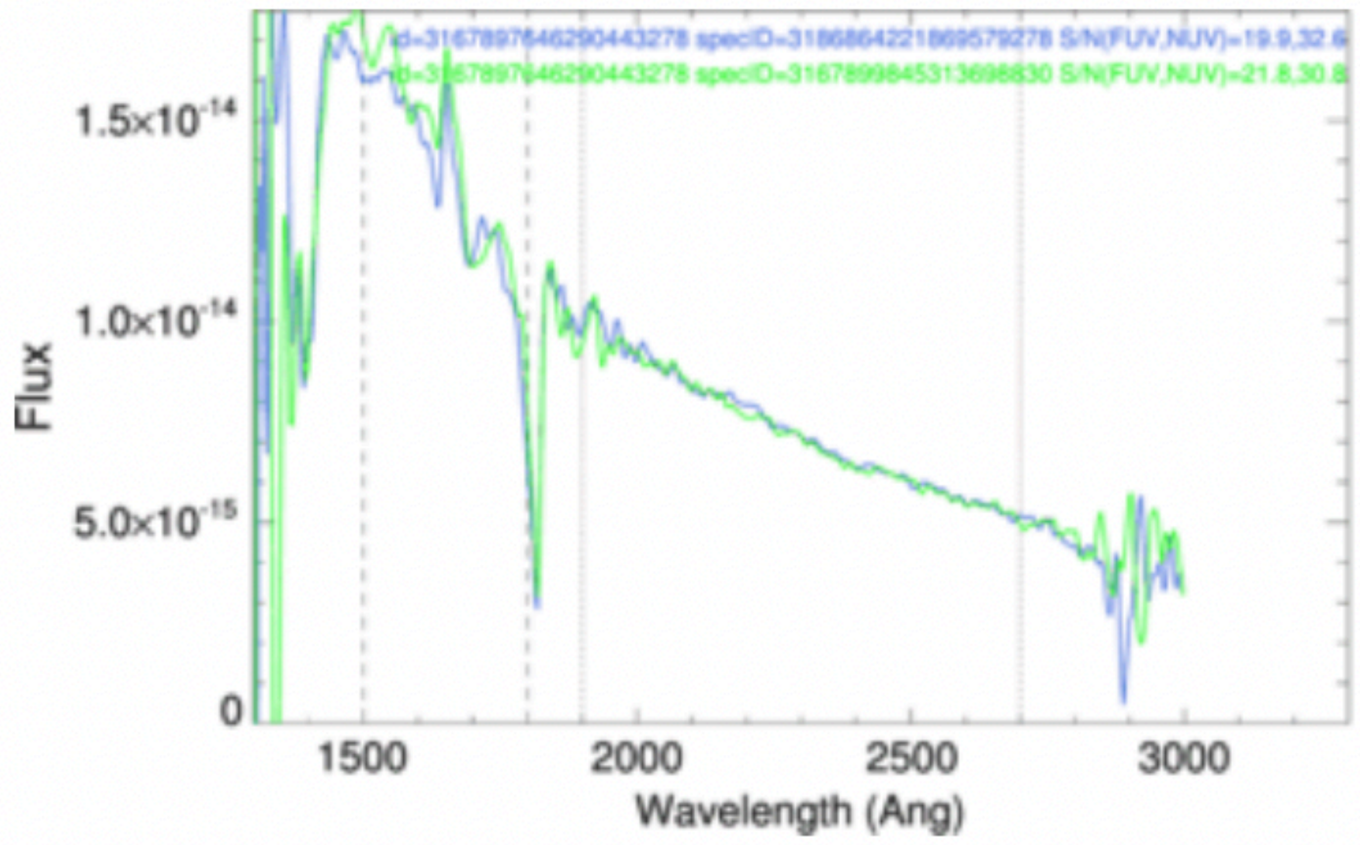
	# sources in Gaia EDR3
Total number of sources	**1,811,709,771**
Number of 5-parameter sources	585,416,709
Number of 6-parameter sources	882,328,109
Number of 2-parameter sources	343,964,953
Sources with mean G magnitude	1,806,254,432
Sources with mean G_{BP}-band photometry	1,542,033,472
Sources with mean G_{RP}-band photometry	1,554,997,939
Gaia-CRF sources	1,614,173
Sources with radial velocities	7,209,831 (Gaia DR2)
Variable sources	expected with Gaia DR3 / see Gaia DR2
Known asteroids with epoch data	expected with Gaia DR3 / see Gaia DR2
Effective temperatures (T_{eff})	expected with Gaia DR3 / see Gaia DR2
Extinction (A_G) and reddening ($E(G_{BP}$-$G_{RP})$)	expected with Gaia DR3 / see Gaia DR2
Sources with radius and luminosity	expected with Gaia DR3 / see Gaia DR2
and more...	expected with Gaia DR3

Full astrometric solution - position on the sky (α, δ), parallax, and proper motion - for around 1.468 billion sources, with a limiting magnitude of about G ≈ 21 and a bright limit of about G ≈ 3.

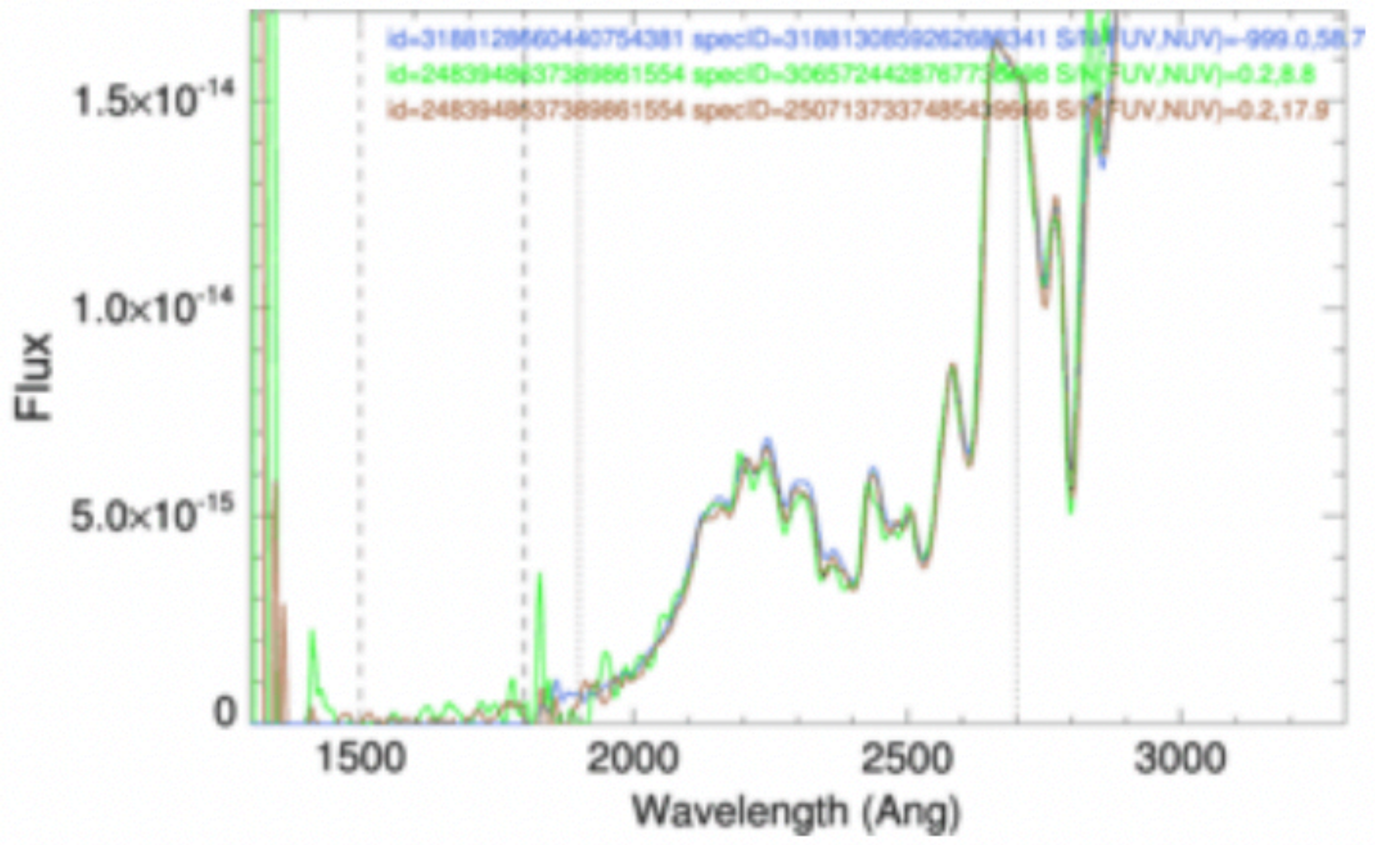
GALEX (Bianchi et al. 2017)

UV GALEX photometry helps to identify the presence of companions in the form of **hot stellar remnants**





hot star



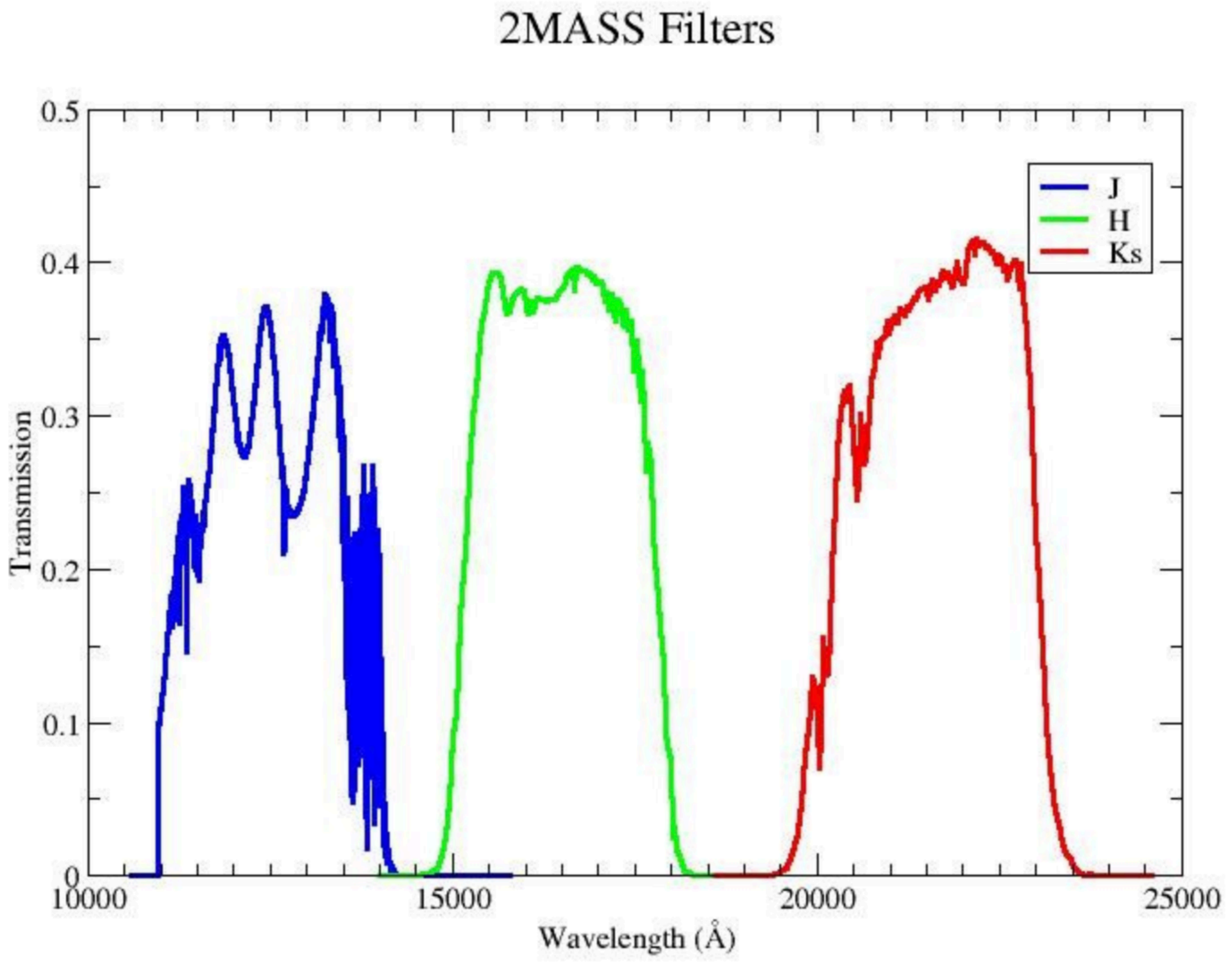
cool star

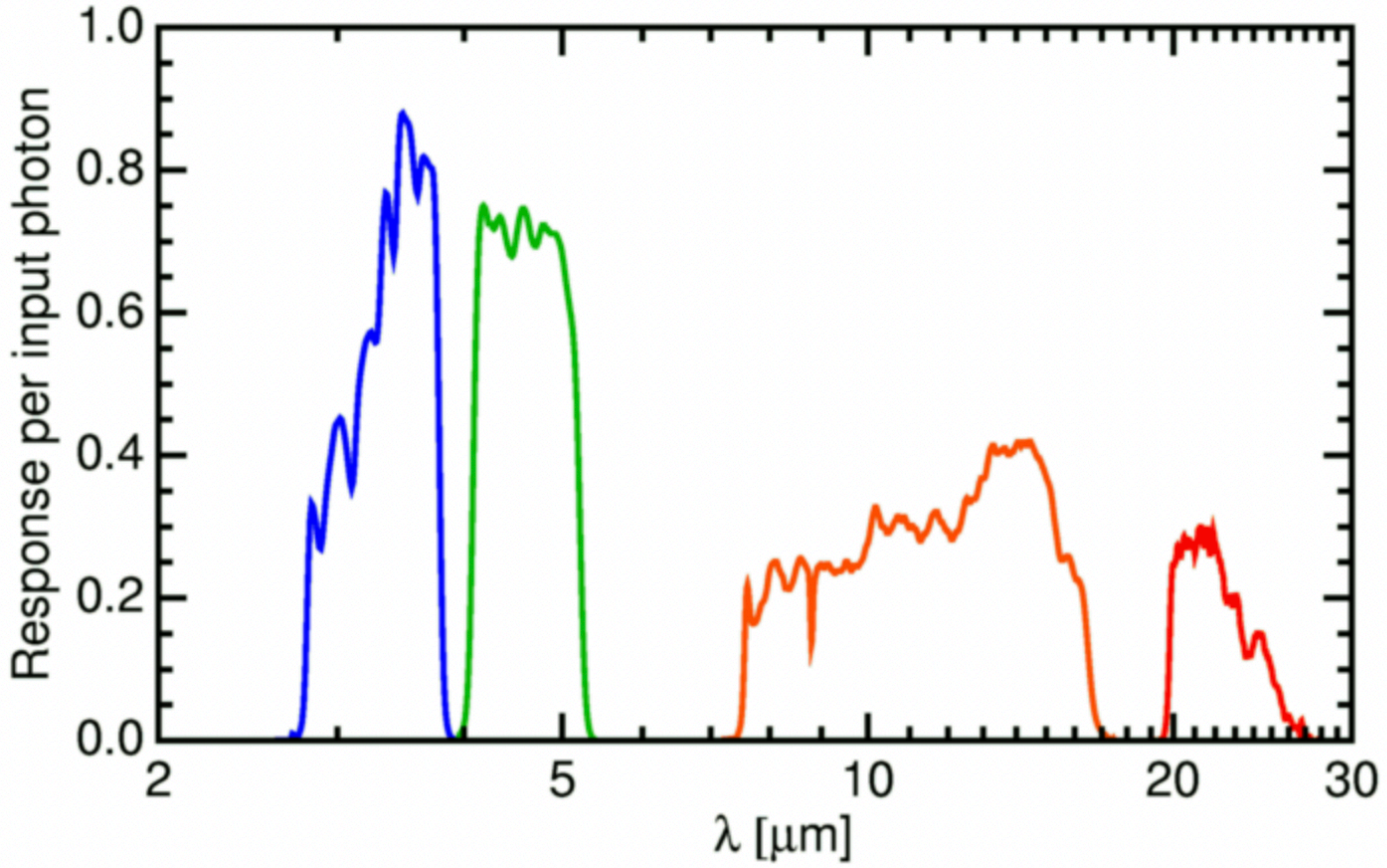
GALEX low resolution slitless **spectroscopy**

Merging of the APOGEE, GALEX, and Gaia Catalogs

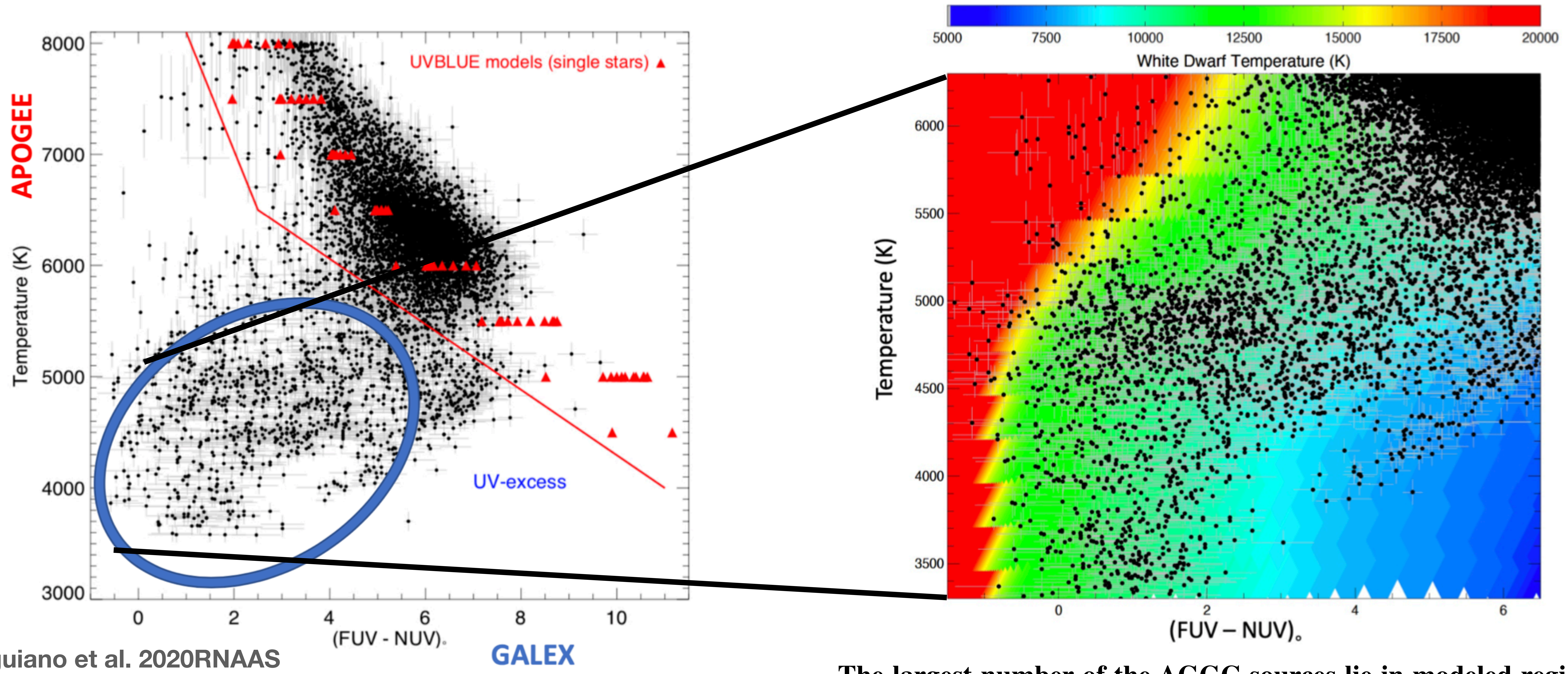
We cross-matched the APOGEE DR17 catalog against the GALEX database. This results in 244,432 stars in common using a separation smaller than 2.5 arcsec on the sky.

We then cross-match these stars against the WISE mission catalog (Wright et al. 2010), to procure mid-infrared photometry for our sources. After intersecting all of these catalogs, we create the AGGC as all cross-matched sources that have complete photometric information, defined as having valid entries for the two GALEX bands (FUV–NUV), the three Gaia bands (G, GBP, and GRP), the three 2MASS bands (J, H, Ks), and all four WISE bands (W1, W2, W3, W4). This results in a total of **242,896 objects**.





APOGEE-GALEX-*Gaia* Catalog (AGGC)



Anguiano et al. 2020RNAAS

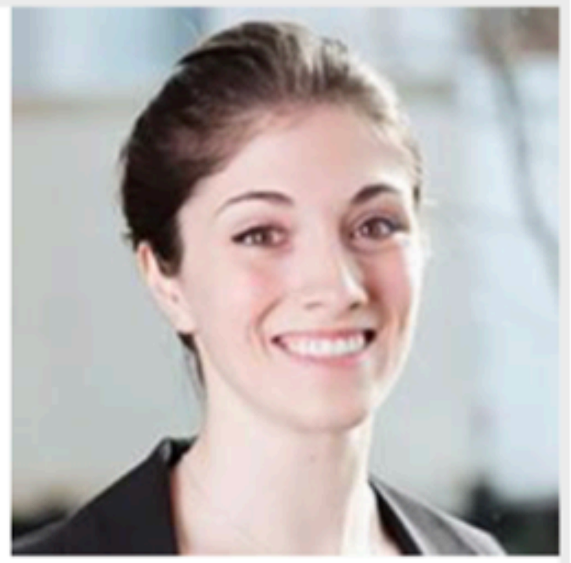
3,414 APOGEE sources that are WD binary candidates with F–M spectral type companions.

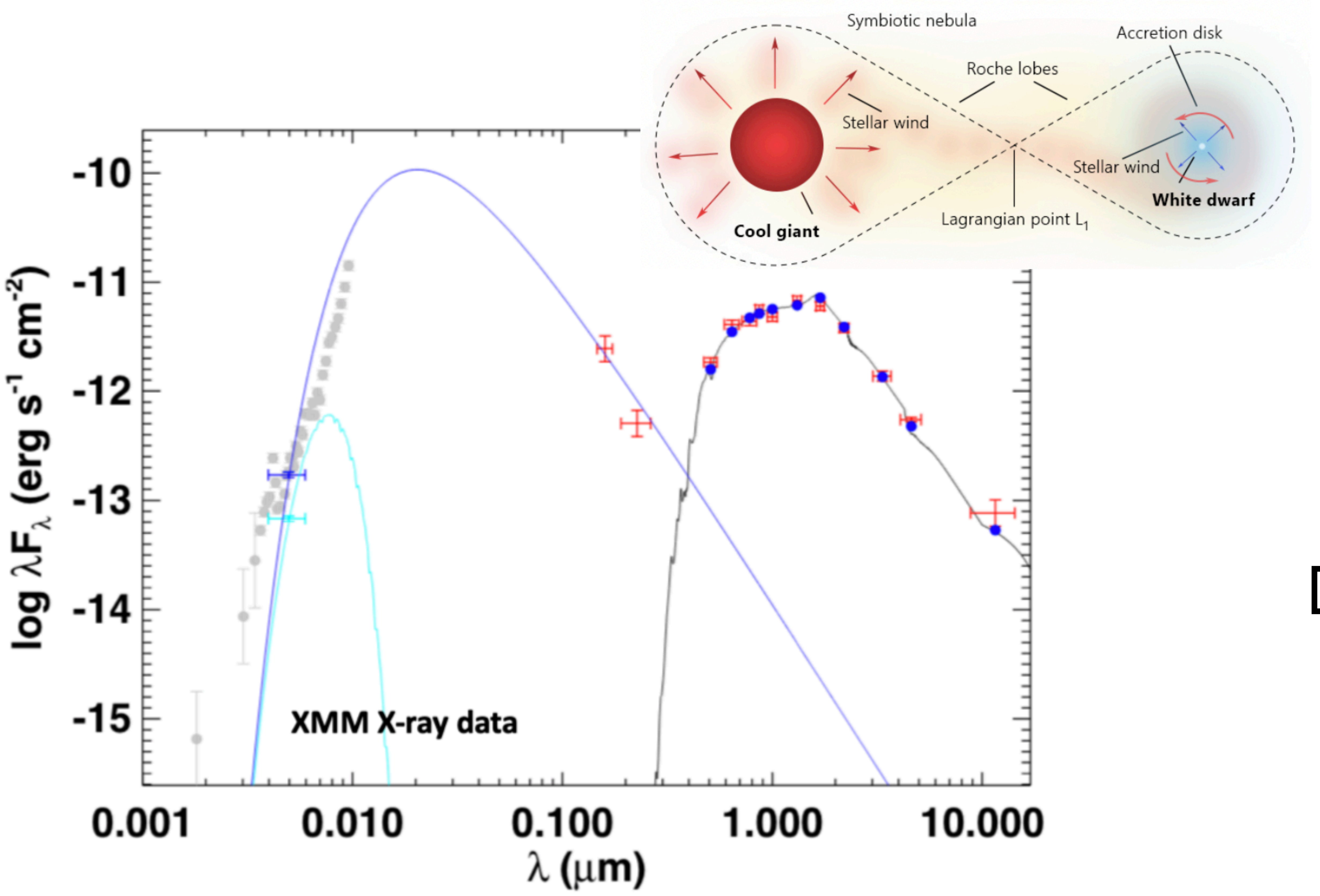
The largest number of the AGGC sources lie in modeled regions showing an inferred WD effective temperature range of 9000 K < Teff,WD < 15000 K, while a few of the WD binary candidates show potential effective temperatures hotter than 20,000 K

Symbiotic stars: Draco C1

SDSS-IV Project 0707: Geometry of the Draco C1 symbiotic binary

Lewis, Anguiano et al. 2020 ApJL





GEOMETRY OF DRACO C1

Table 1. Parameters of the Draco C1 system.

Parameter	Value	Units	Reference
Red Giant Parameters			
$T_{\rm eff}$	3734 ± 24	K	APOGEE DR14
$\log g$	0.816 ± 0.077	cgs	APOGEE DR14
[M/H]	-1.390 ± 0.013	dex	APOGEE DR14
$F_{\rm bol,RG}$	$(9.07 \pm 0.54) \times 10^{-12}$	$\rm erg\,s^{-1}\,cm^{-2}$	This work
$R_{\rm RG}$	104 ± 5	$R_\odot$	This work
$M_{\rm RG}$	2.58 ± 0.52	$M_\odot$	This work
White Dwarf Parameters			
$T_{\rm eff}$	$(1.9 \pm 0.3) \times 10^5$	K	Saeedi et al. (2018)
$R_{\rm WD}$	19 ± 6	$R_\oplus$	This work
$M_{\rm WD,min}$	$0.549^{+0.041}_{-0.045}$	$M_\odot$	This work
System Parameters			
A_V	0.04 ± 0.04	mag	This work
d	82 ± 2	kpc	Kinemuchi et al. (2008)
P	1220.0 ± 3.5	days	This work
e	0.192 ± 0.008		This work
K	5.222 ± 0.043	$\rm km\,s^{-1}$	This work
v_0	-298.991 ± 0.025	$\rm km\,s^{-1}$	This work
$a_{\rm min}$	3.26 ± 0.18	AU	This work

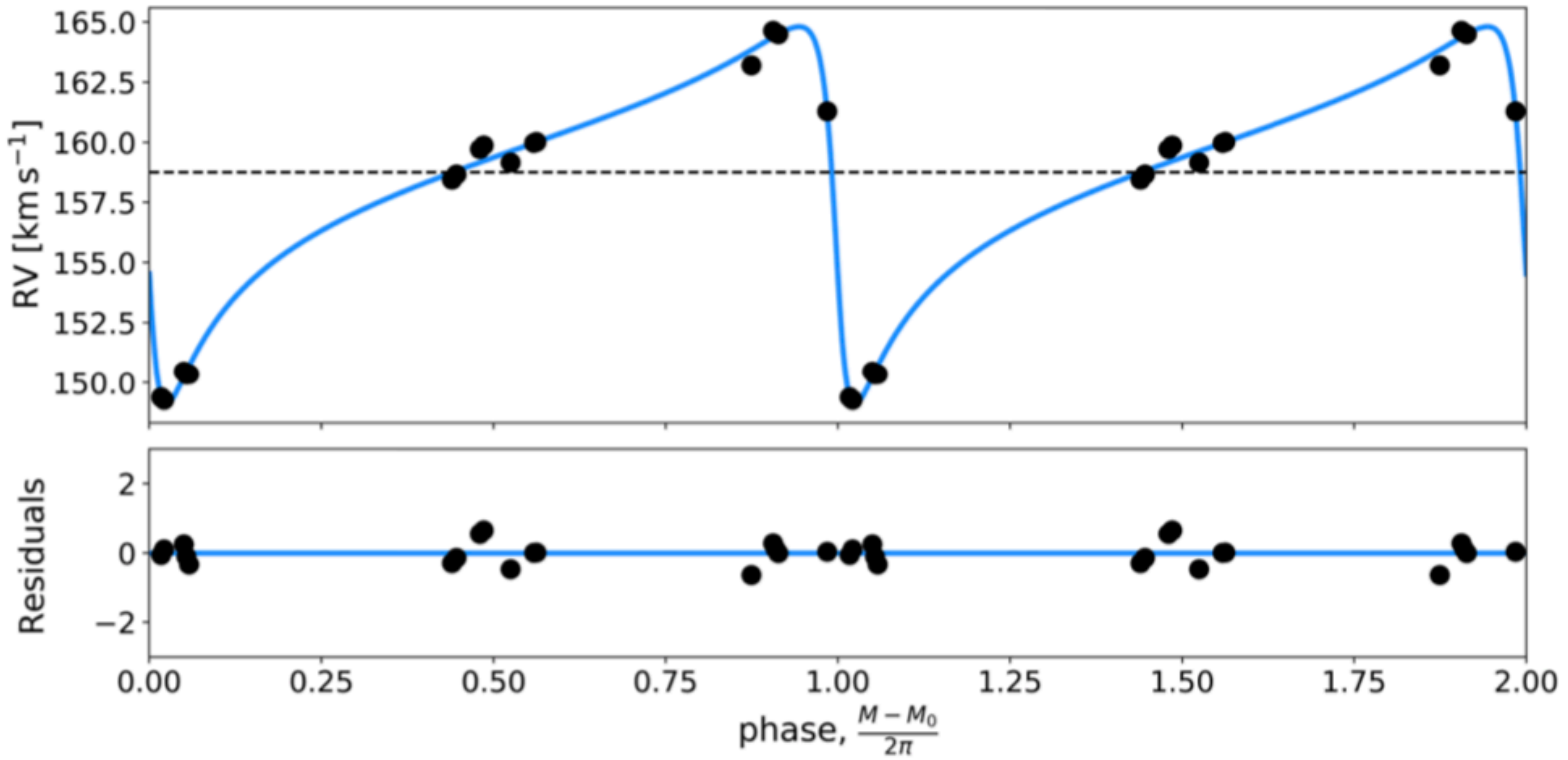
For the first time, we report precise orbital parameters for the binary system using 43 precise radial velocity measurements from APOGEE spanning an observational baseline of more than 3 years

LIN 358 & SMC N73

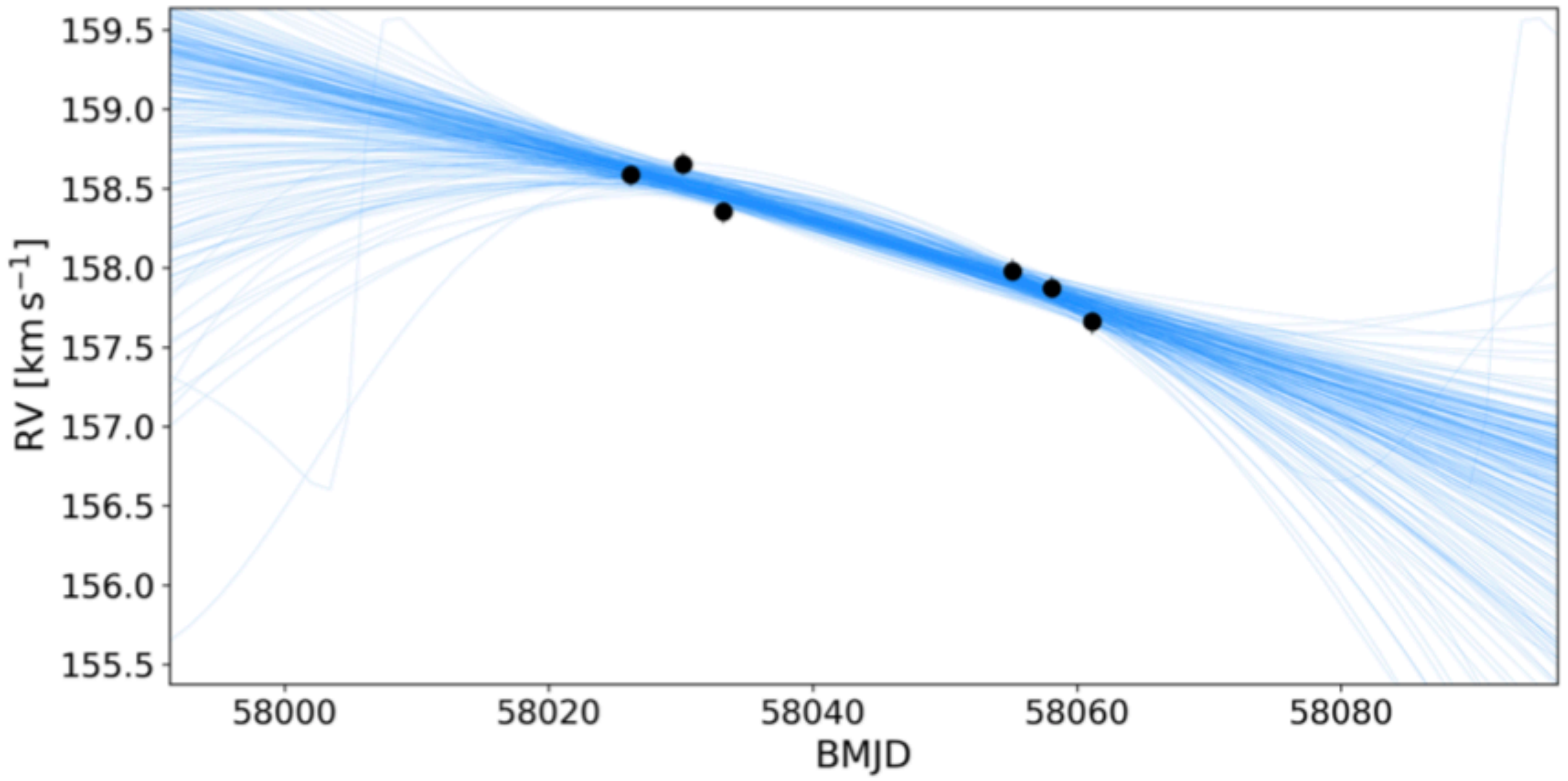
SDSS-IV Project 0710: Symbiotic stars in the APOGEE survey: The case of LIN 358 and SMC N73

Washington, Lewis, Anguiano et al. 2021 ApJ

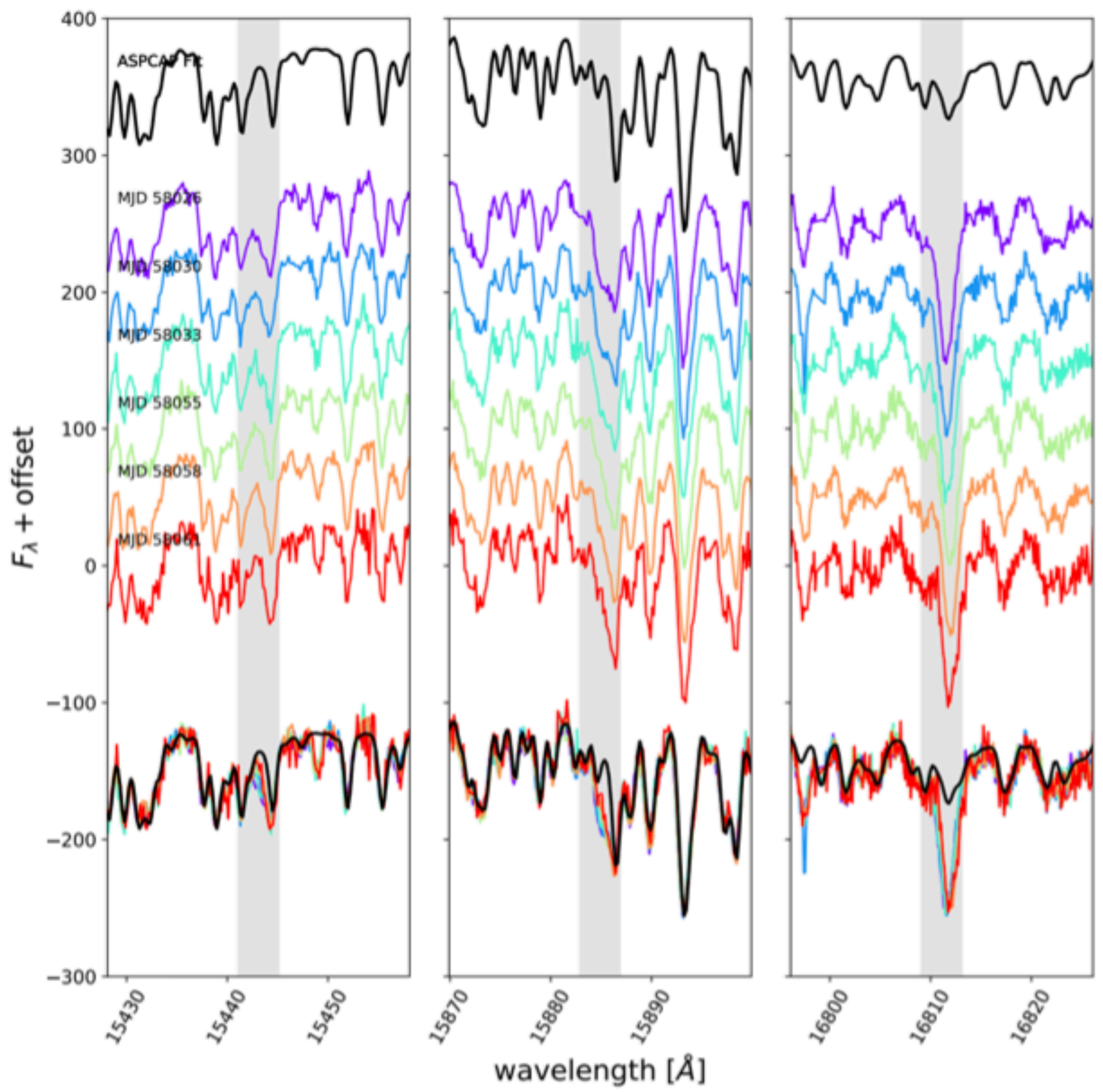
Parameter	LIN 358 Value	SMC N73 Value	Units	Reference
T_{eff}	3800	3800	K	APOGEE DR16
$\log(g)$	1.0	0.5	cgs	APOGEE DR16
[Fe/H]	0.0	-1.0	dex	APOGEE DR16
$R_\odot$	204.4 ± 7.5	193.6 ± 7.1	$R_\odot$	This work
$M_\odot$	15.2 ± 1.1	4.3 ± 0.3	$M_\odot$	This work
White Dwarf Parameters				
T_{eff}	$(15.5 \pm 0.5) \times 10^4$	$(17.9 \pm 0.1) \times 10^4$	K	This work
R_{WD}	41.5 ± 1.5	16.0 ± 0.6	$R_\oplus$	This work
$M_{WD,min}$	0.8 ± 0.2	< 1.0	$M_\odot$	This work
System Parameters				
d_{SMC}	63.4 ± 2.3		kpc	Marconi et al. (2017)
P	760 ± 117	777 ± 845	days	This work
e	0.8 ± 0.3	0.0 ± 0.2		This work
K	7.9 ± 0.5	15.7 ± 8.9	km s^{-1}	This work
v_0	158.8 ± 1.3	143.6 ± 4.9	km s^{-1}	This work

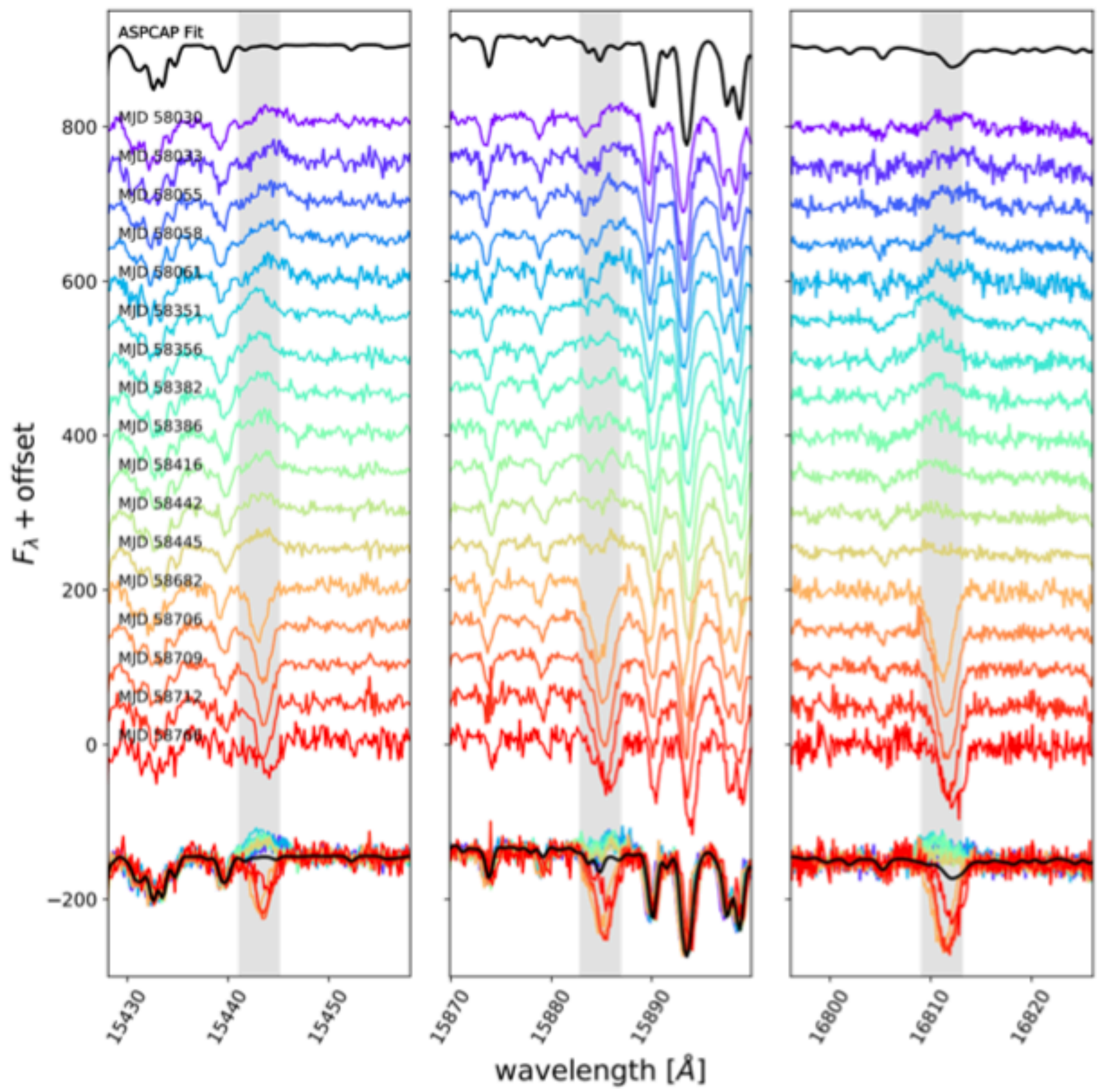


Very first time reporting orbital parameters for these two extragalactic Symbiotic binaries thanks to the multi-epoch APOGEE radial velocities



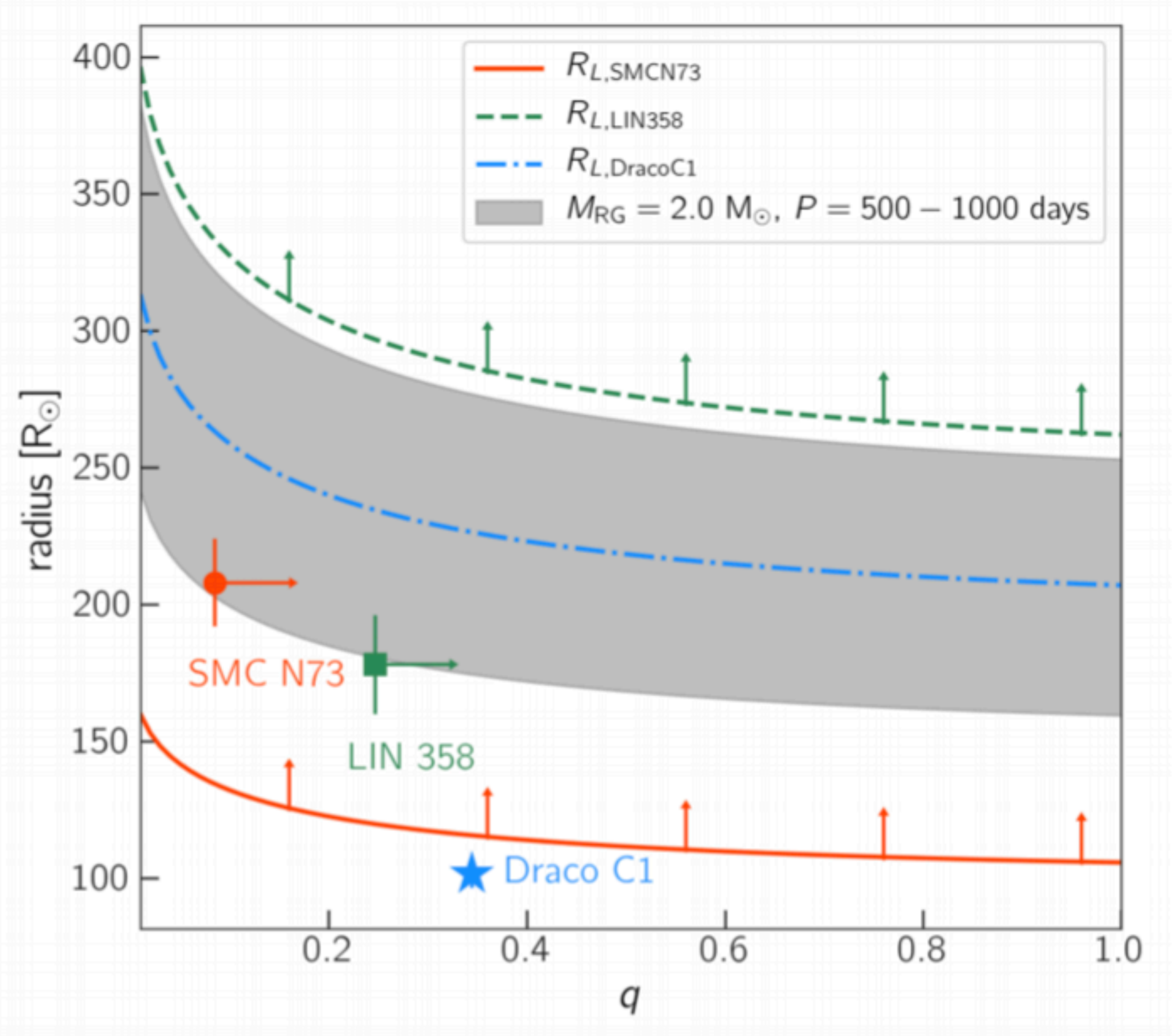
The Joker (Price-Whelan et al. 2017)





Hydrogen Brackett series lines: Long temporal baseline of APOGEE shows accretion signatures

$$R_L = \frac{0.49q^{-\frac{2}{3}}}{0.6q^{-\frac{2}{3}} + \ln\left(1+q^{-\frac{1}{3}}\right)} \times \left(\frac{GM_{\mathrm{RG}}P^2(1+q)}{4\pi^2}\right)^{\frac{1}{3}},$$



Radius of the Roche lobe, RL, of the RG components of the symbiotic systems, compared to the radius of the RG photosphere, RRG.

Using the calculated Roche lobe radius for the giant component and the mass ratio for each system, it is found that LIN 358 is likely undergoing mass transfer via wind Roche lobe overflow while the accretion mechanism for SMC N73 remains uncertain

A Giant Meal for a Dwarf: Astronomer… examine symbiotic stars in nearby galax…

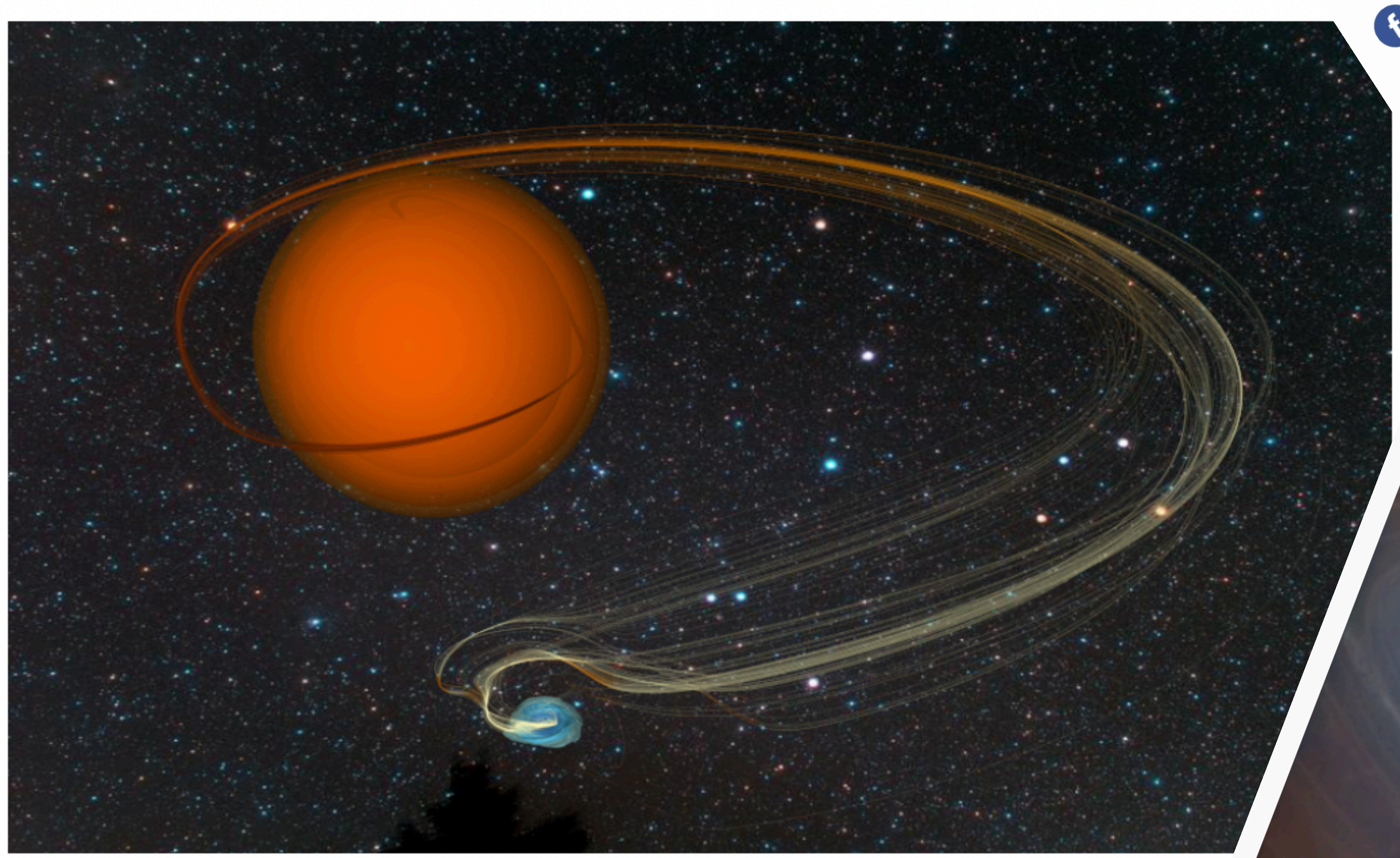
January 12, 2021

Astronomers from the Sloan Digital Sky Survey have, for the first time, revealed detai… red giant stars in other galaxies feed their white dwarf companions.

The results, announced today at the 237th meeting of the American Astronomical Society, give researchers the first view of the orbital motions of any symbiotic binary star system outside the Milky Way.

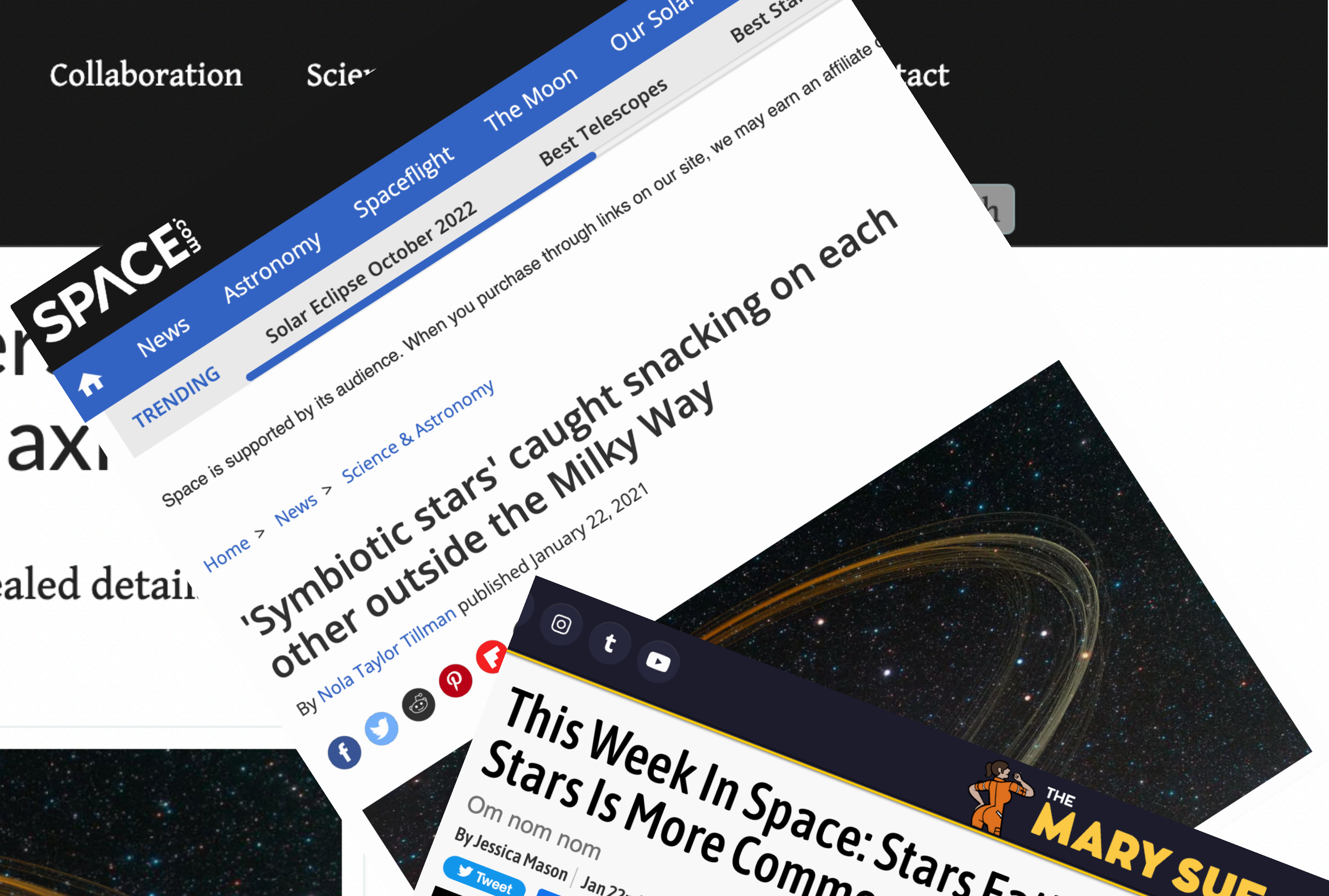
“Measuring the orbits of these symbiotic star systems is an important step towards learning whether other galaxies create binary stars like those here in the Milky Way,” says Jasmin Washington of Steward Observatory at the University of Arizona, the lead author of the study.

Binary stars are common here in the Milky Way; in fact, more than half of all stars in our Galaxy come in pairs. There is no reason to think that they should not be just as common in other galaxies too — but astronomers have not yet been able to confirm this. Other galaxies are so far…



An artistic impression based on a computer simulation of the Draco C… symbiotic binary star system showing material flowing off the red giant star onto the white dwarf.

Image credit: John Blondin, North Carolina State University



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'Symbiotic stars' caught snacking on each other outside the Milky Way

By Nola Taylor Tillman published January 22, 2021

THE MARY SUE

This Week In Space: Stars Eating Other Stars Is More Common Than You'd Think!

Om nom nom

By Jessica Mason | Jan 22nd, 2021, 6:00 pm

Tweet Share reddit

7 comments

MaNGA data…

Confirmed Symbiotic stars (and new candidates…)

"A binary star, combining a red giant (RG) and a companion hot enough to sustain HeII (or higher ionization) emission lines." (Allen 1984)

Symbiotic stars are interacting binaries consisting of a giant star transferring mass onto a hot, compact companion – typically, a white dwarf (WD).

In APOGEE we have 16 confirmed SySts, most of these binaries they have poor orbital solutions in the literature.

New Online Database of Symbiotic Variables

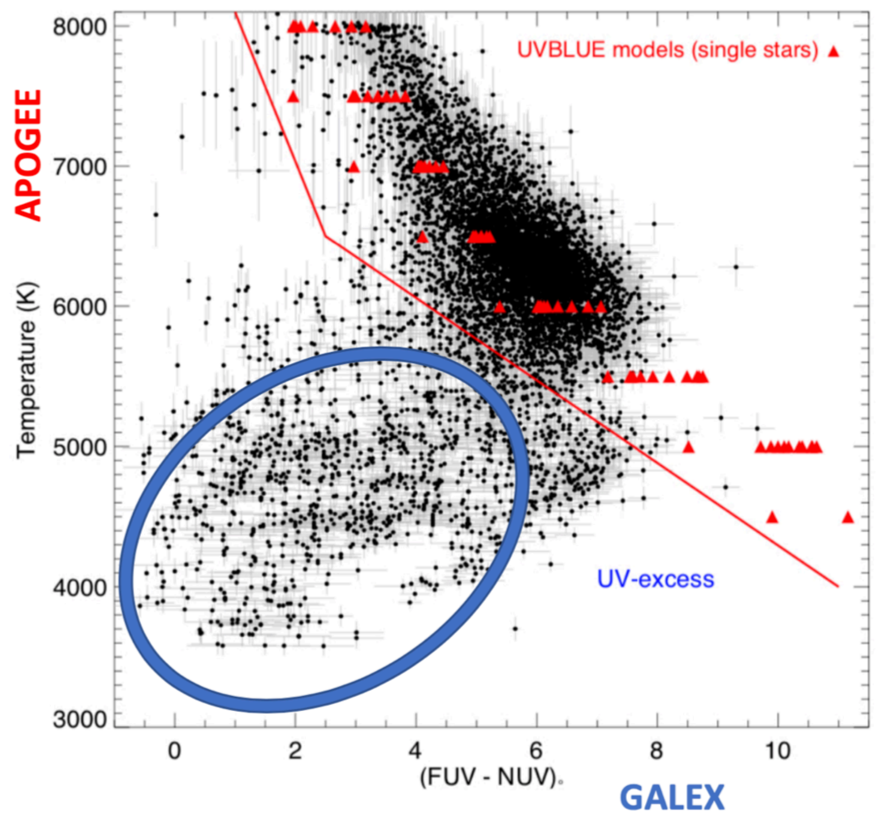
Merc et al. 2019

…and do not forget it, a high-resolution spectra in the H-band -> characterization of the cool component.

Star Name	NVISITS	VSCATTER
AG Dra	1	0.
AG Peg	1	0.
AS 255	1	0.
AX Per	1	0.
BX Mon	1	0.
EG And	1	0.
HBHA 201-02	3	2.00162
IPHAS J190924.64-010910.2	5	1.74718
IV Vir	1	0.
LAMOST J122804.90-014825.7	3	0.373221
StHA 169	1	0.
UV Aur	1	0.
V1016 Cyg	1	0.
V1261 Ori	2	9.24313
V934 Her	1	0.
Z And	1	0.

-------> **Aid the number of visits in APOGEE with a dedicated follow-up with the main goal of fitting Keplerian orbits.**

APOGEE-GALEX-*Gaia* Catalog (AGGC)



Stellar Chromospheric Activity

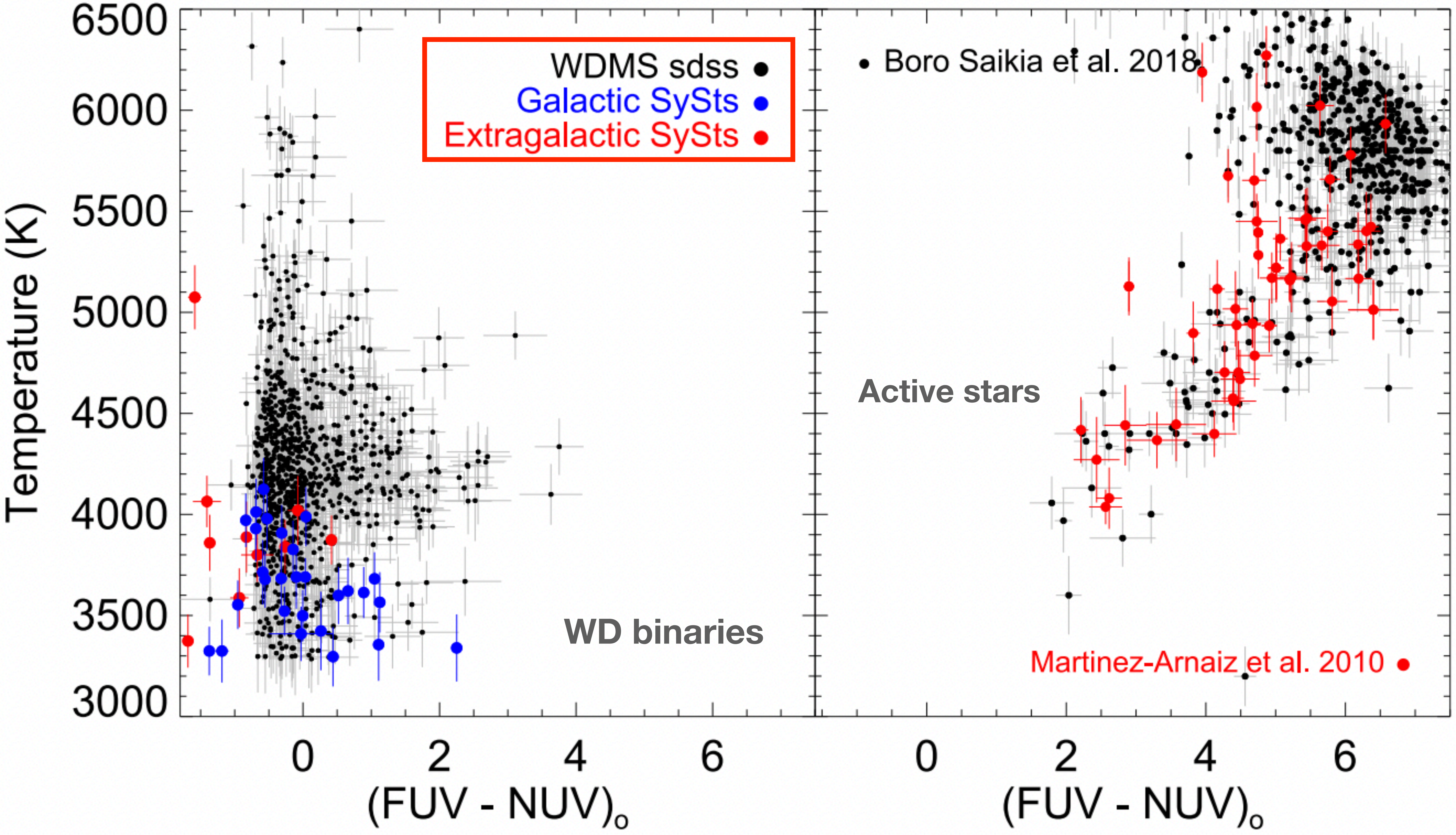


Figure 2. The UV color vs. temperature diagram for WDMS binaries found in the SDSS/SEGUE survey and the galactic and extragalactic symbiotic variables (SySts) reported in Merc et al. (2019; left panel) and chromospherically active stars explored by Boro Saikia et al. (2018) and Martínez-Arnáiz et al. (2010; right panel).

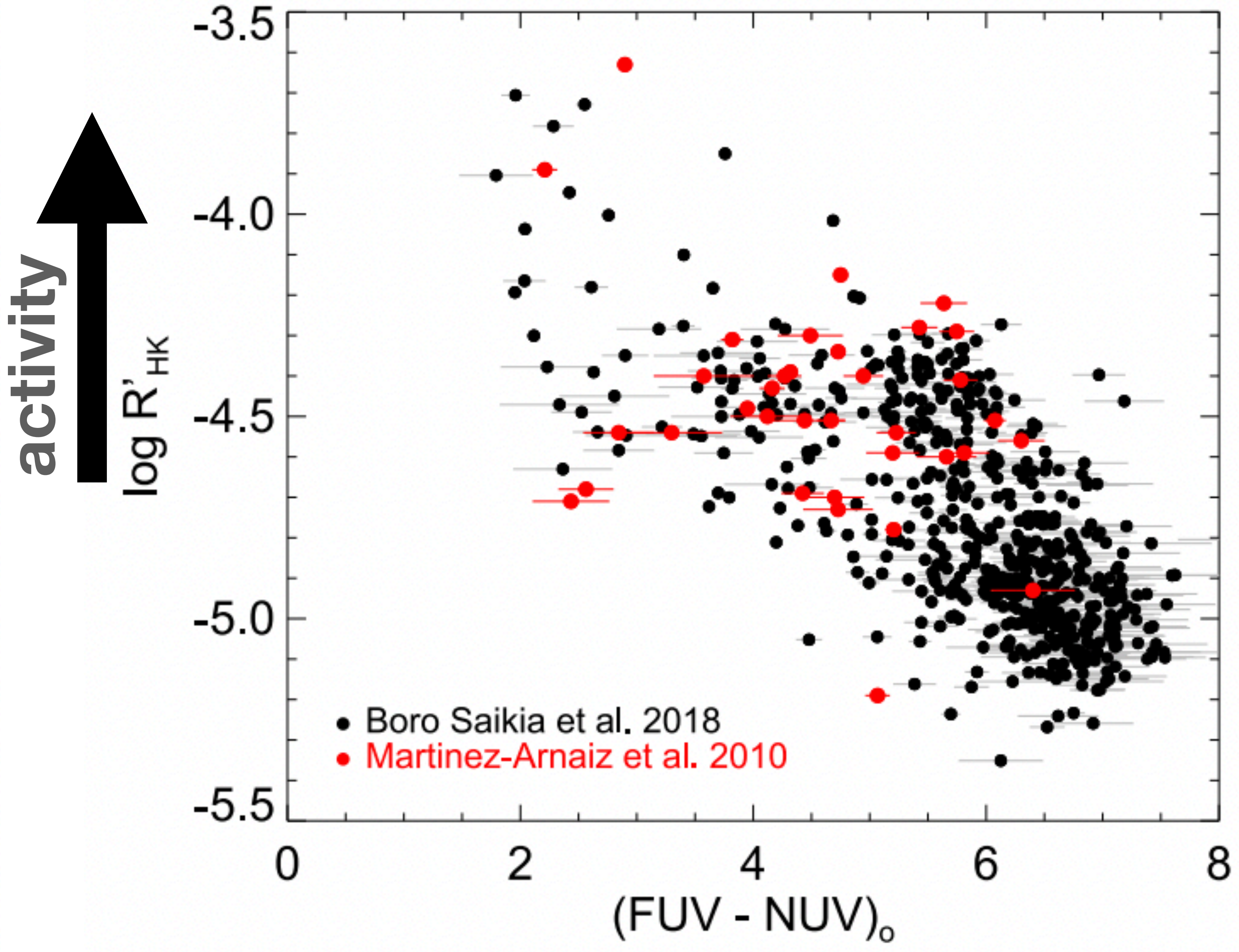
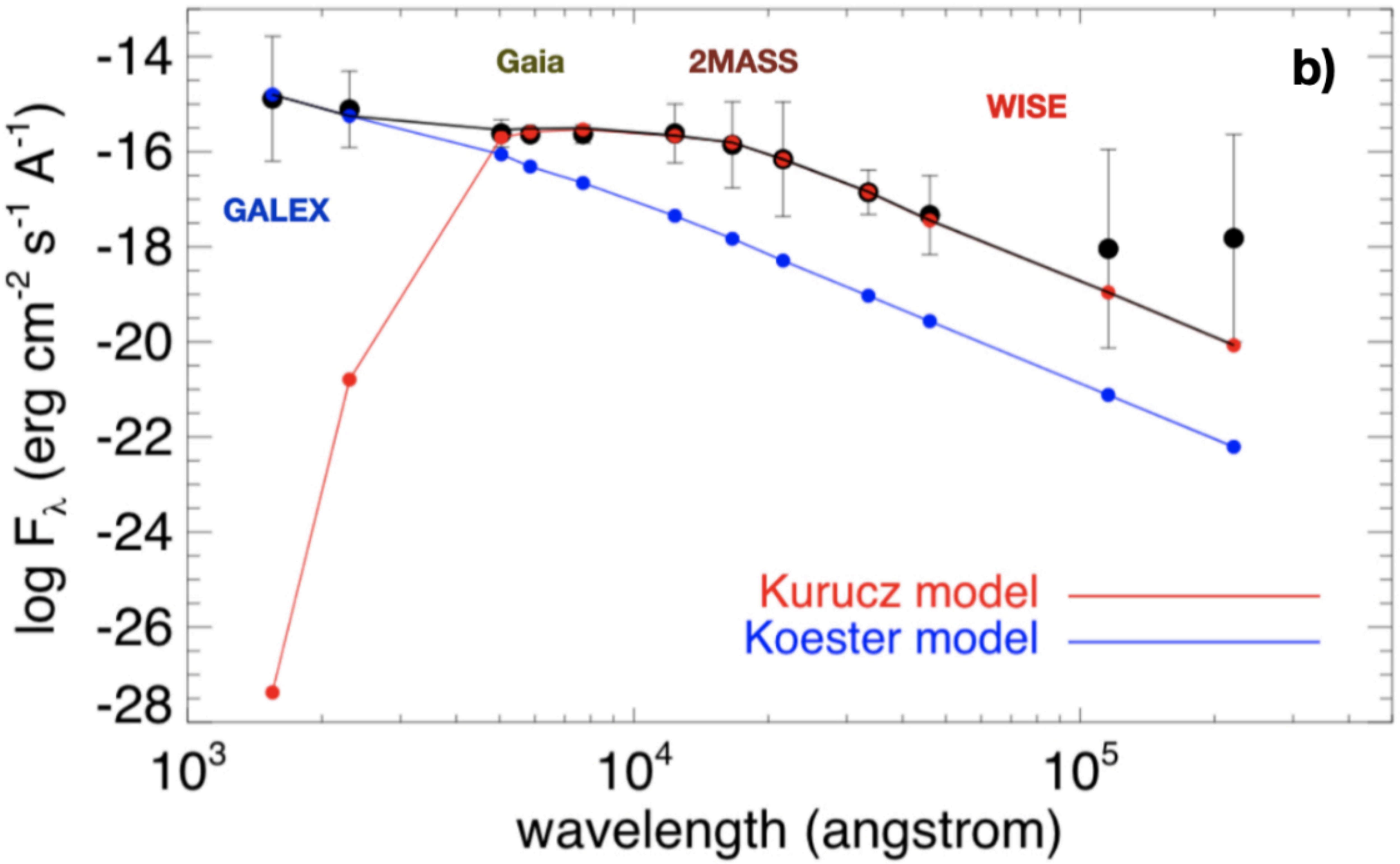


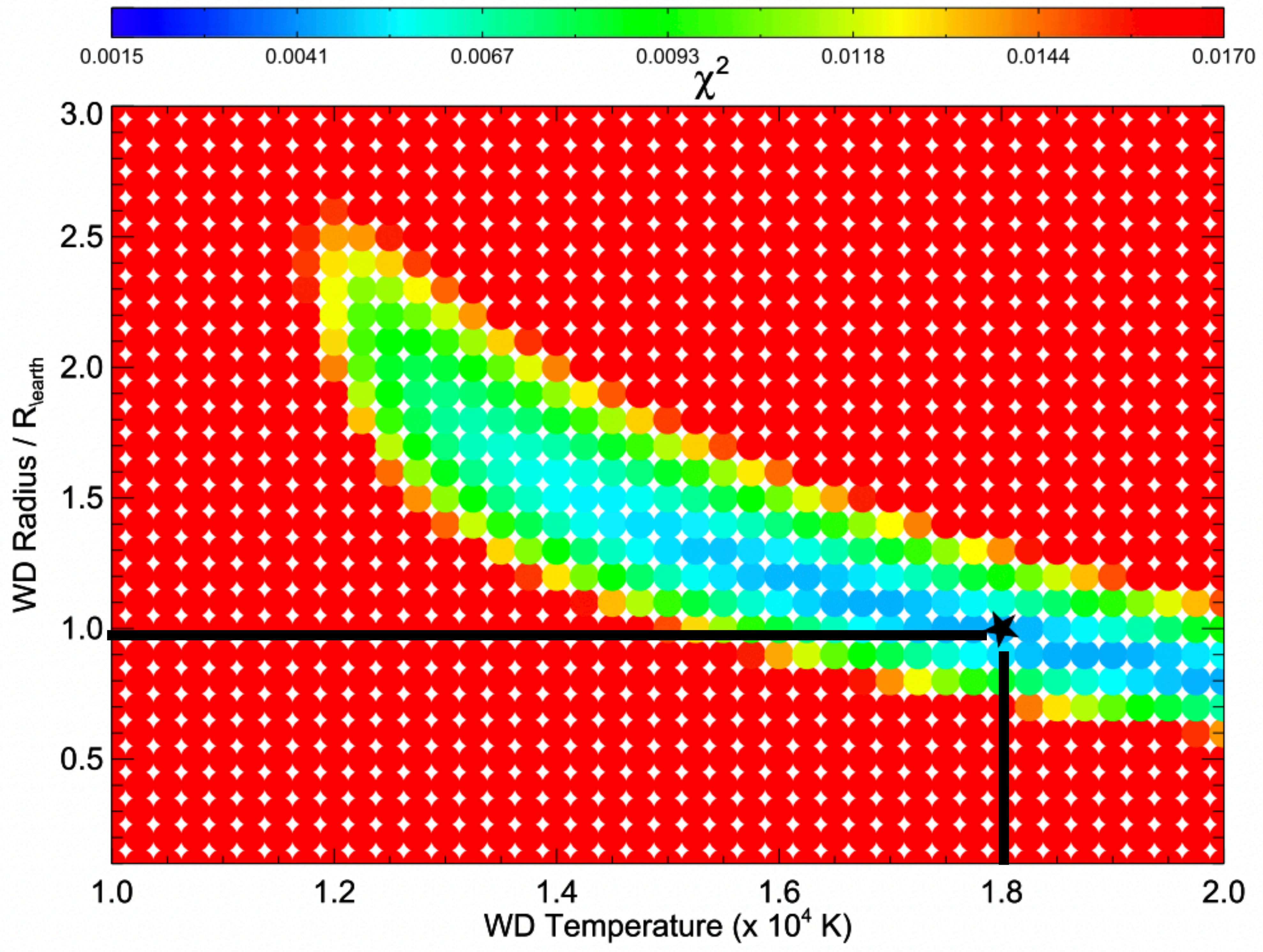
Figure 3. The UV color vs. $\log R'_{HK}$ diagram for the Boro Saikia et al. (2018; black circles) and Martínez-Arnáiz et al. (2010; red circles) catalogs. The most active stars tend to have UV colors $(FUV–NUV)_o < 4.0$.

Hot chromospheres of active stars can result in them possessing quite blue UV colors (e.g., Stelzer et al. 2013; Smith 2018).

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.

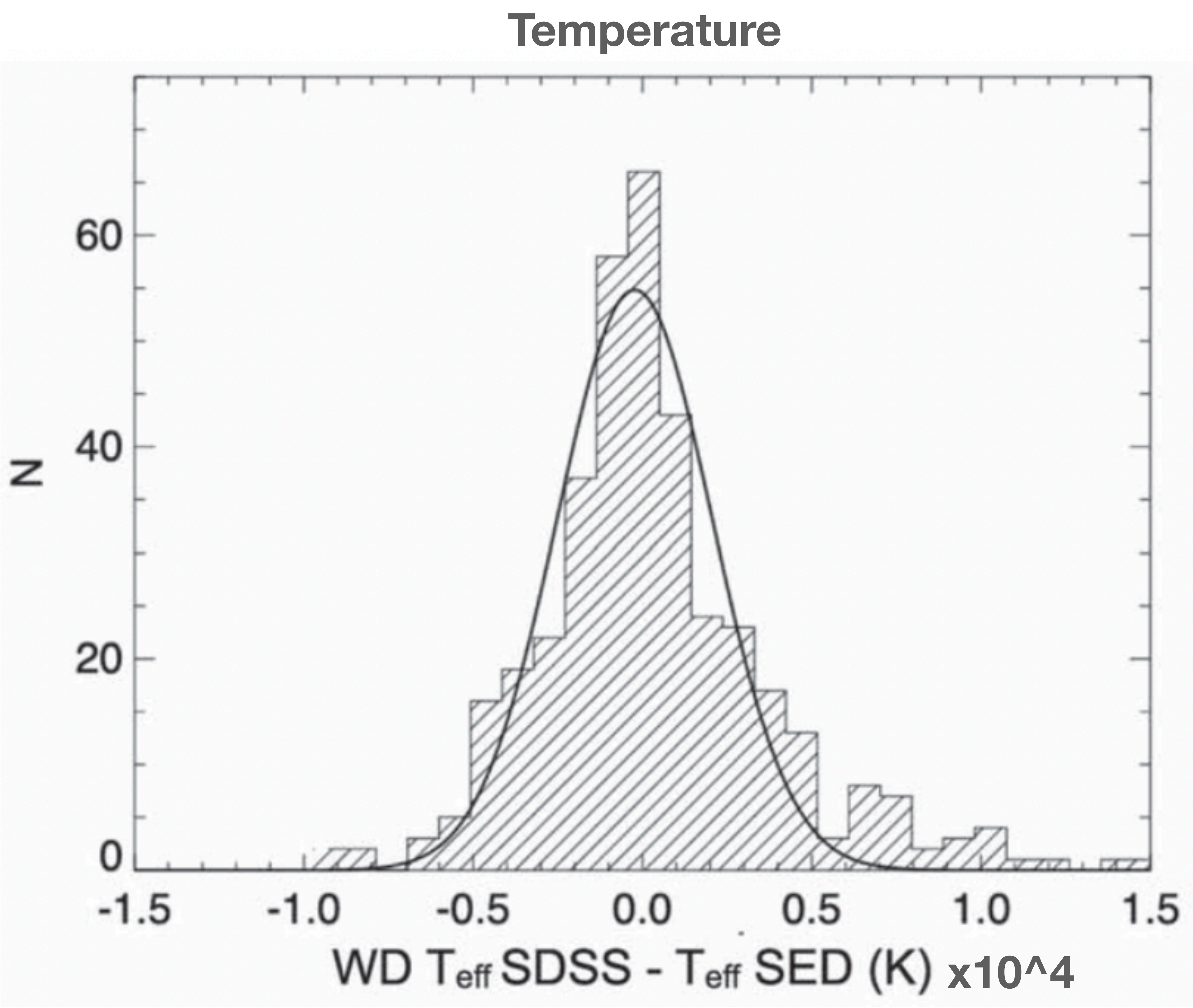
Stellar distances, r, came from Gaia eDR3 parallaxes and the Bayesian isochrone-fitting code StarHorse (Santiago et al. 2016; Queiroz et al. 2020).

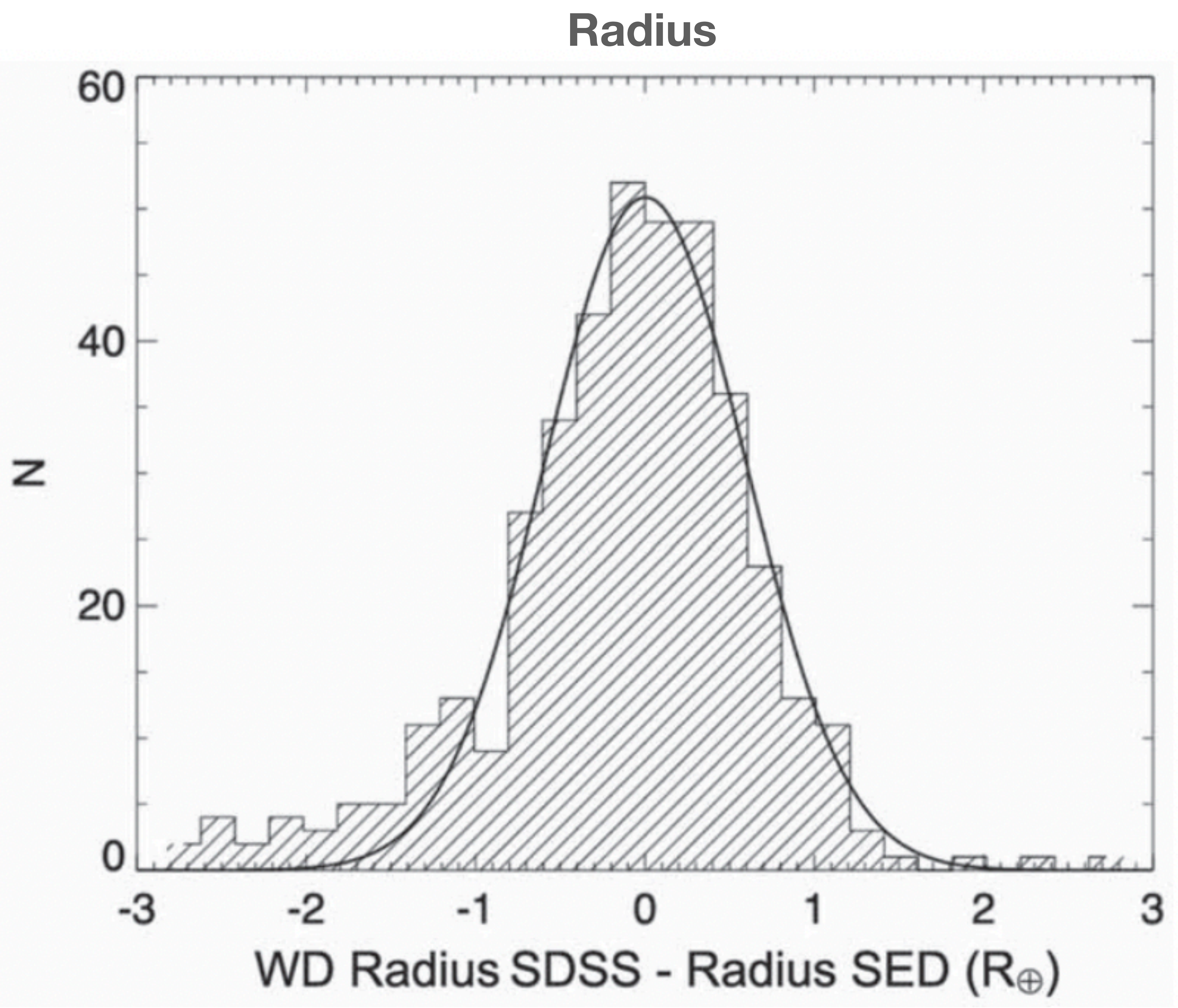
$$R = 4.43 \times 10^7 r (F_\lambda / F_{\lambda,\mathrm{surface}})^{1/2},$$

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

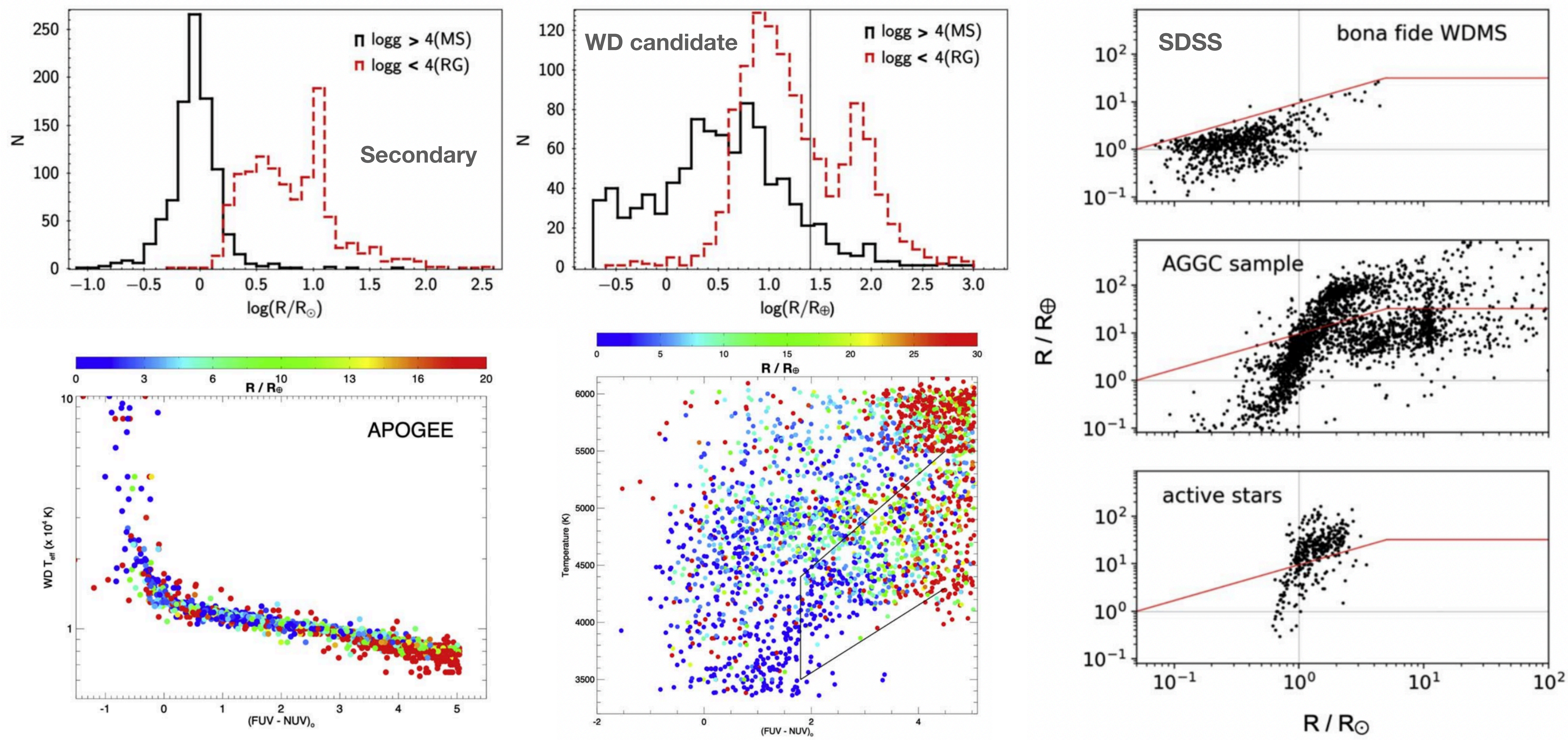
Physical Properties via SED fitting/Validation against SDSS WDMS Binaries

We tested the WD effective temperatures and radii derived using this SED-fitting procedure against these same parameters as derived independently for the SDSS WDMS pairs.





WD binaries candidates selection



White Dwarfs Binaries across the H-R diagram

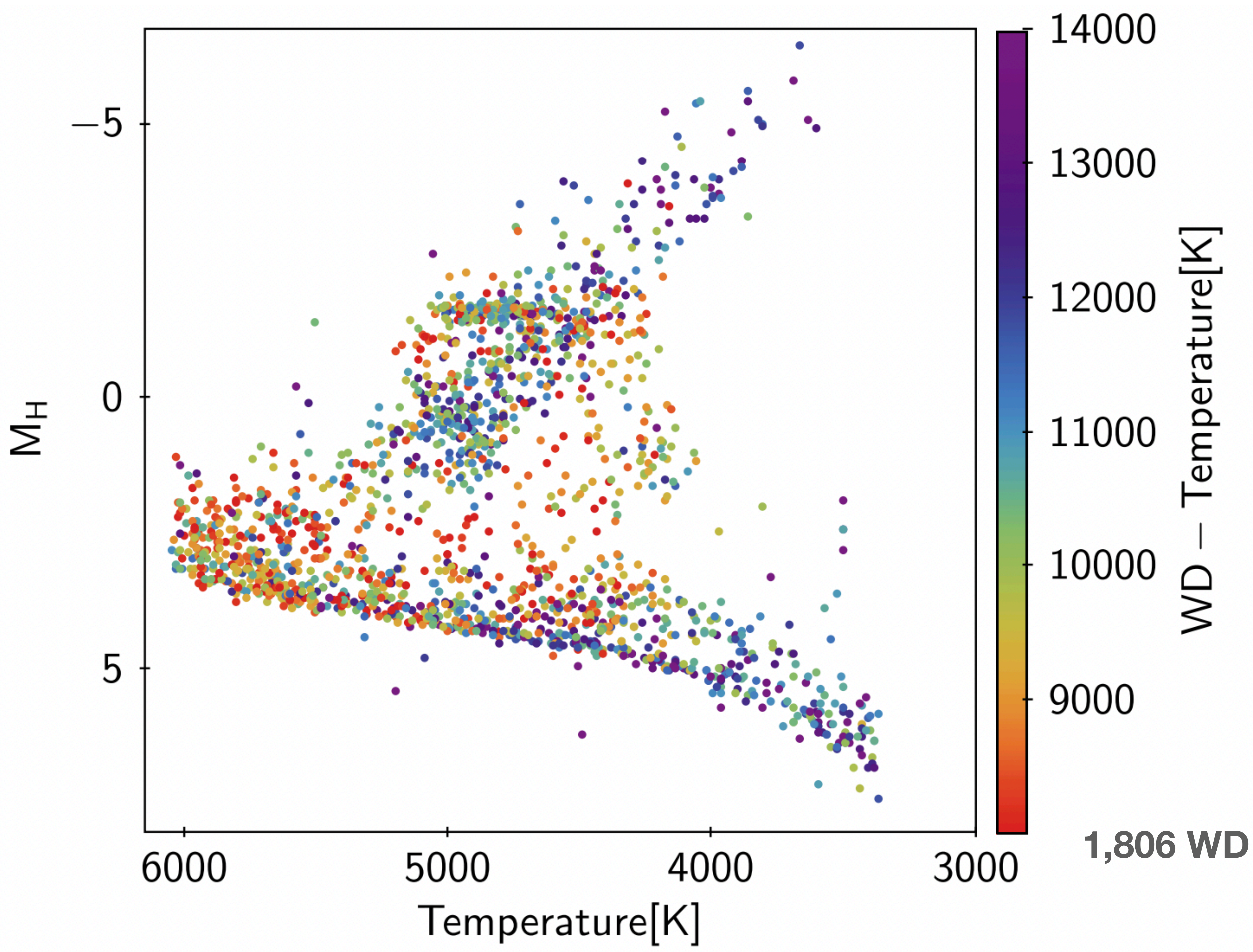


Table 1
WD Binary APOGEE DR17 Catalog

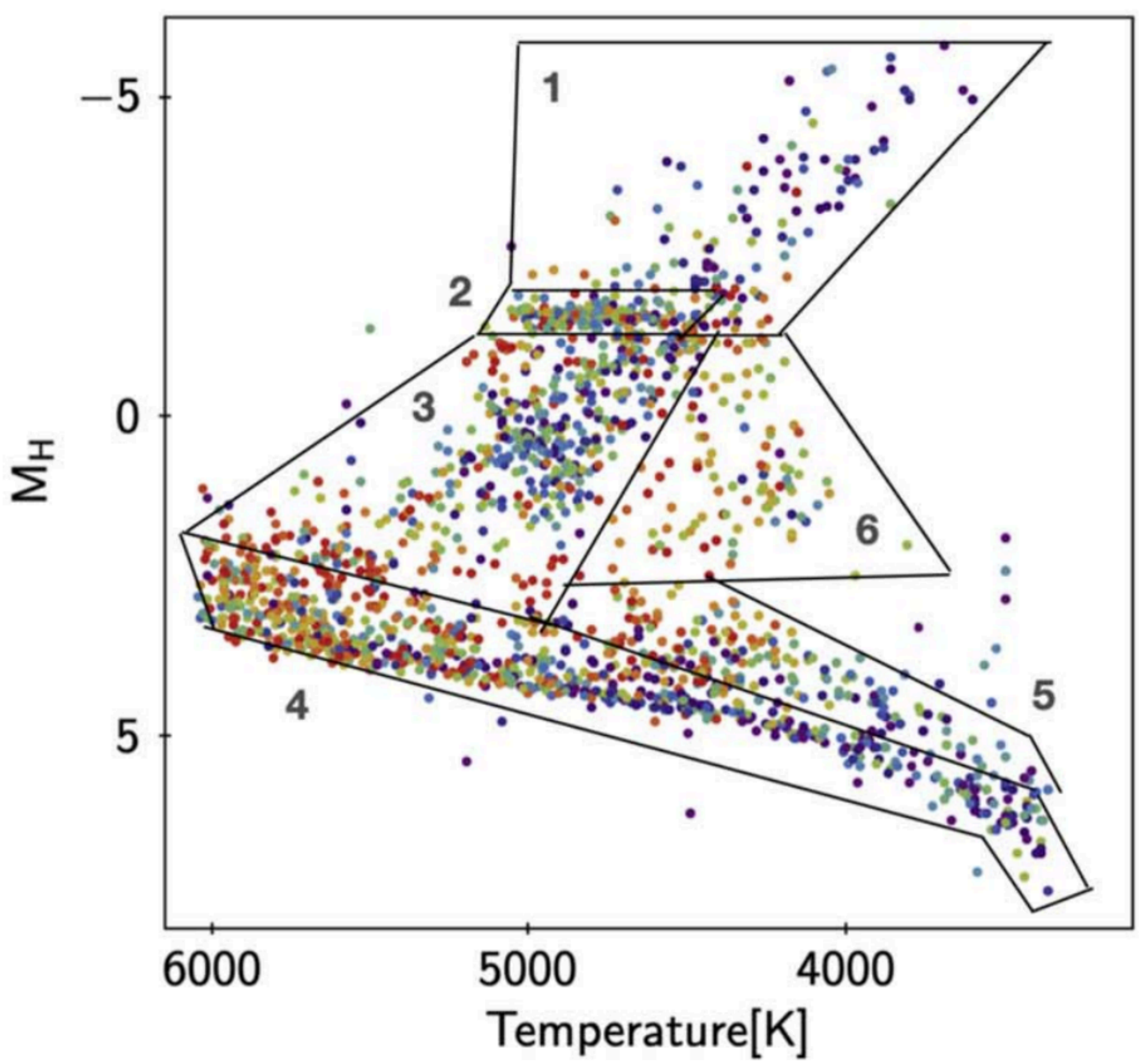
APOGEE ID	Gaia EDR3 ID	R.A. (J2000) (deg)	Decl. (J2000) (deg)	WD T_{eff} (K)	Sec T_{eff} (K)	Sec log g (cgs)	R_{WD} ($R_\oplus$)	R_{sec} ($R_\odot$)
2M00001362−1913042	2413936998069050496	0.0568	−19.2178	10683	5555	4.3	5.2	1.1
2M00031637+0203553	2739046437325768704	0.8182	2.0653	10656	4747	2.9	9.7	6.7
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

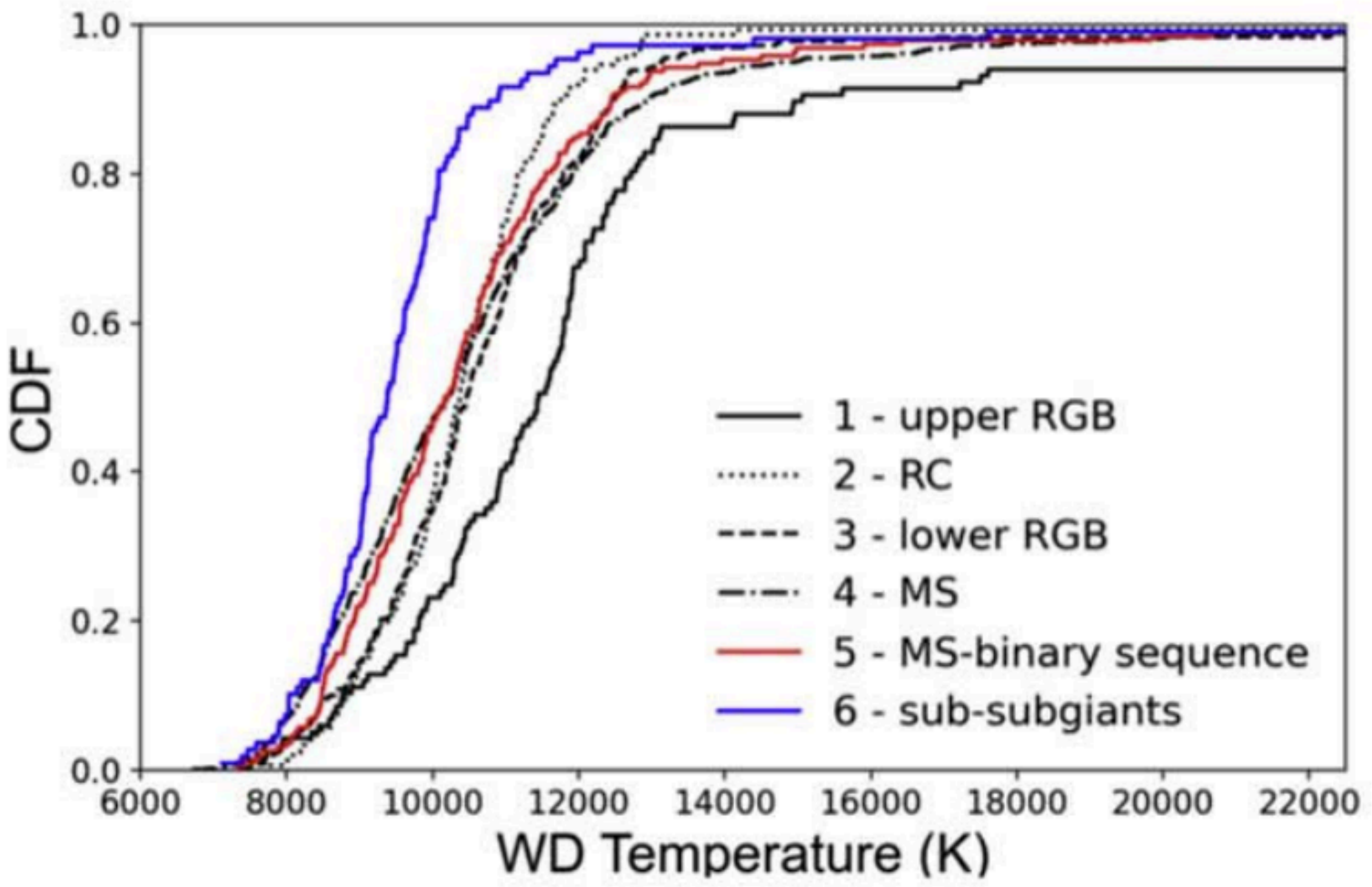
H-R diagram for the AGGC, with APOGEE-derived temperatures and H-band luminosities from 2MASS photometry+Gaia parallaxes. Sources are color-coded by the inferred WD temperature from the SED fitting.

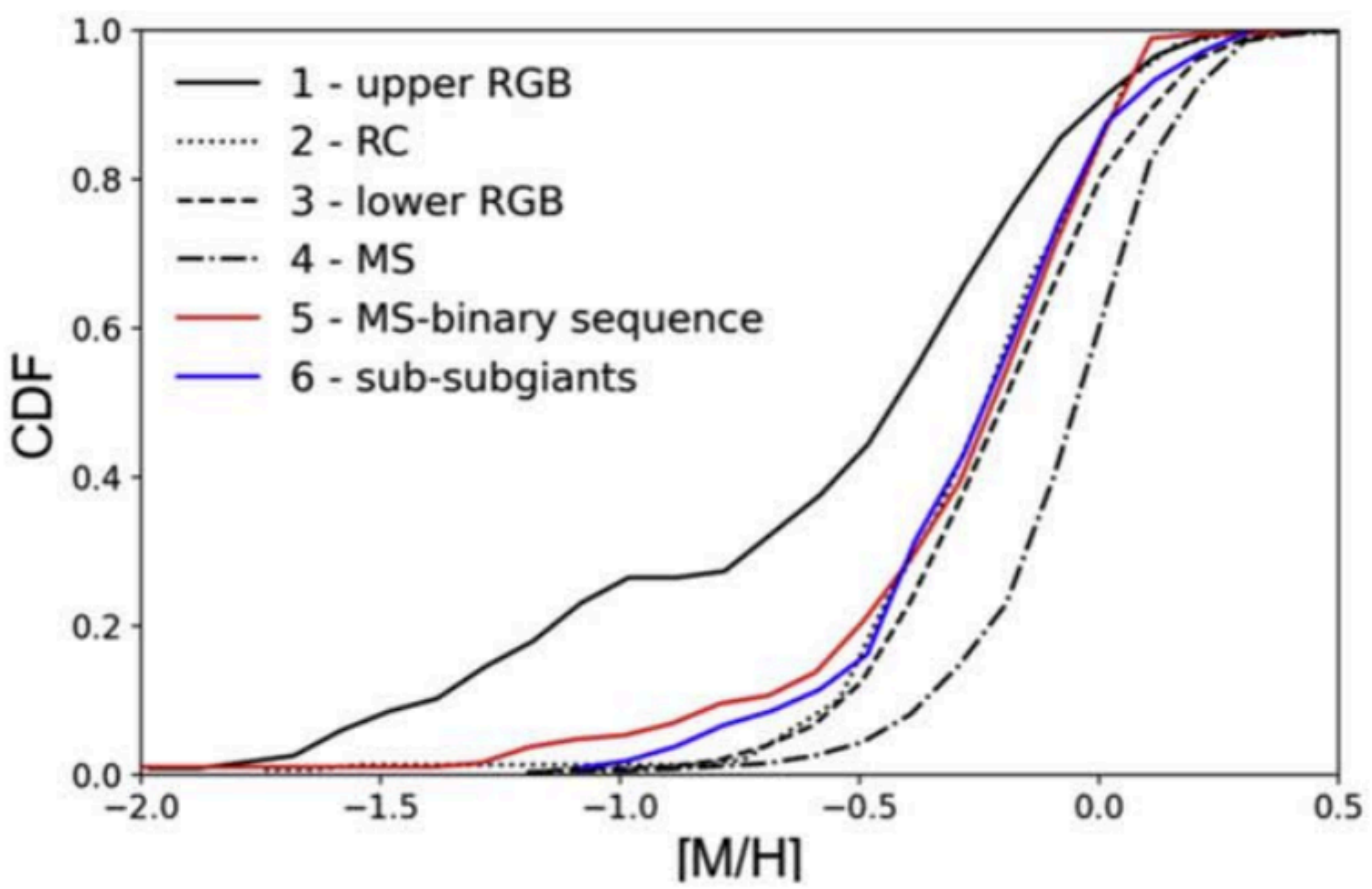
A sample of highly likely WD binaries identified across the CMD is an important step toward furthering our understanding of compact binary evolution.

1,806 WD binaries candidates

Properties of White Dwarf Binaries across the H-R Diagram







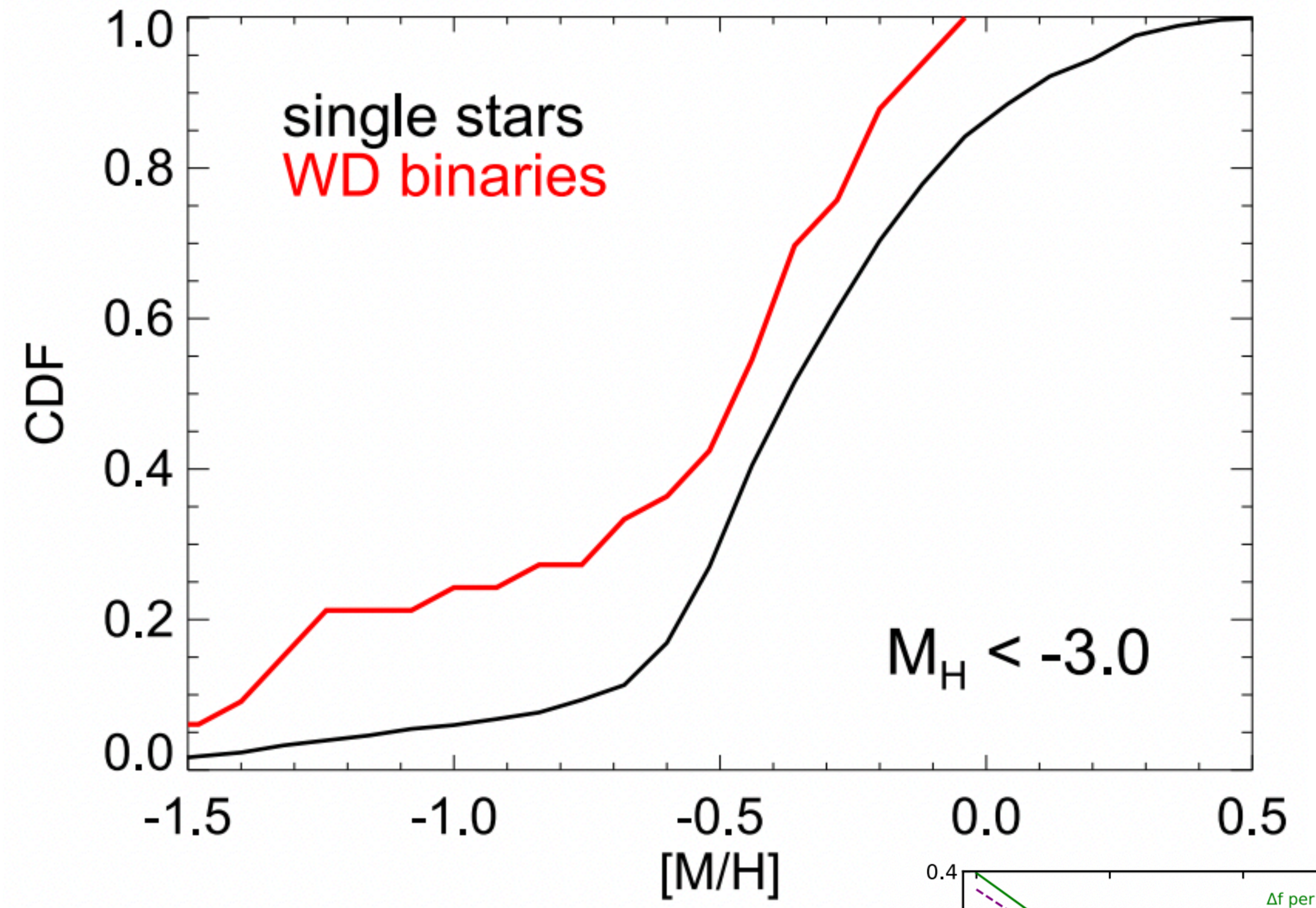
We find that the upper RGB shows the largest number of hottest WDs, followed by the MS population, compared to the other regions of the CMD. The RC temperature distribution shows a WD temperature distribution closer to the lower RGB region.

The number of metal-poor systems ([Fe/H] < –0.7) on the upper RGB is much larger than for the RC and the lower RGB.

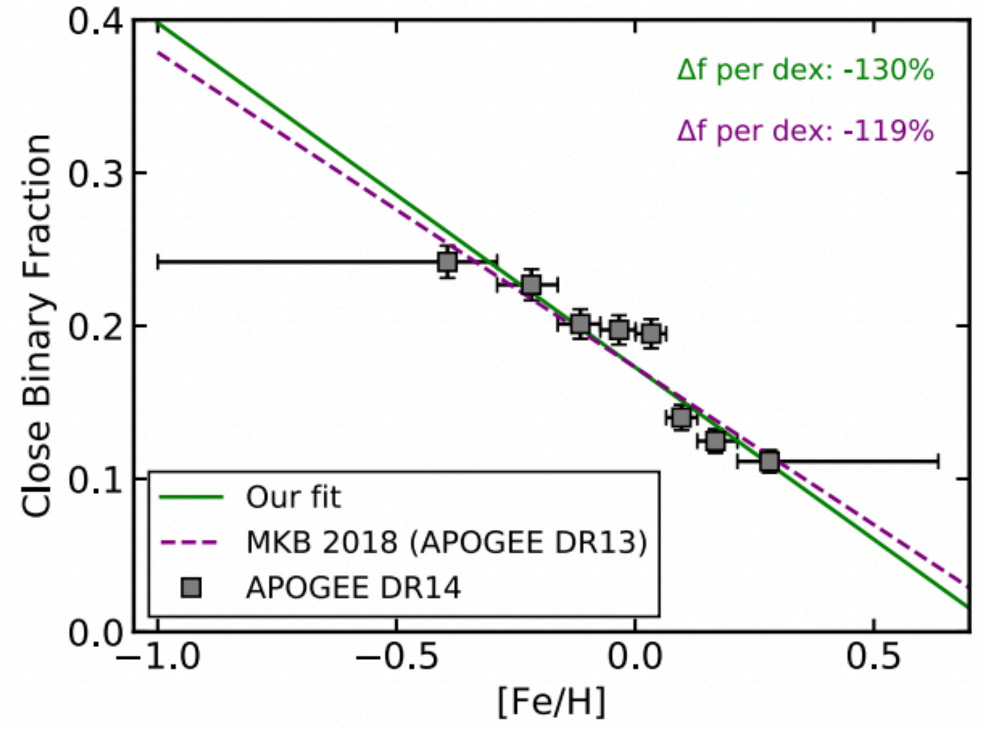
Potential abundance variations induced in the secondary star during the CE phase?

Properties of White Dwarf Binaries across the H-R Diagram

NVISIT > 5
VSCATTER $< 300\,\mathrm{m\,s^{-1}}$
BAD_PIXELS
VERY_BRIGHT_NEIGHBOR
LOW_SNR
STAR_BAD



Strong anticorrelation between close binary fraction and chemical composition (Mazzola et al. 2020)

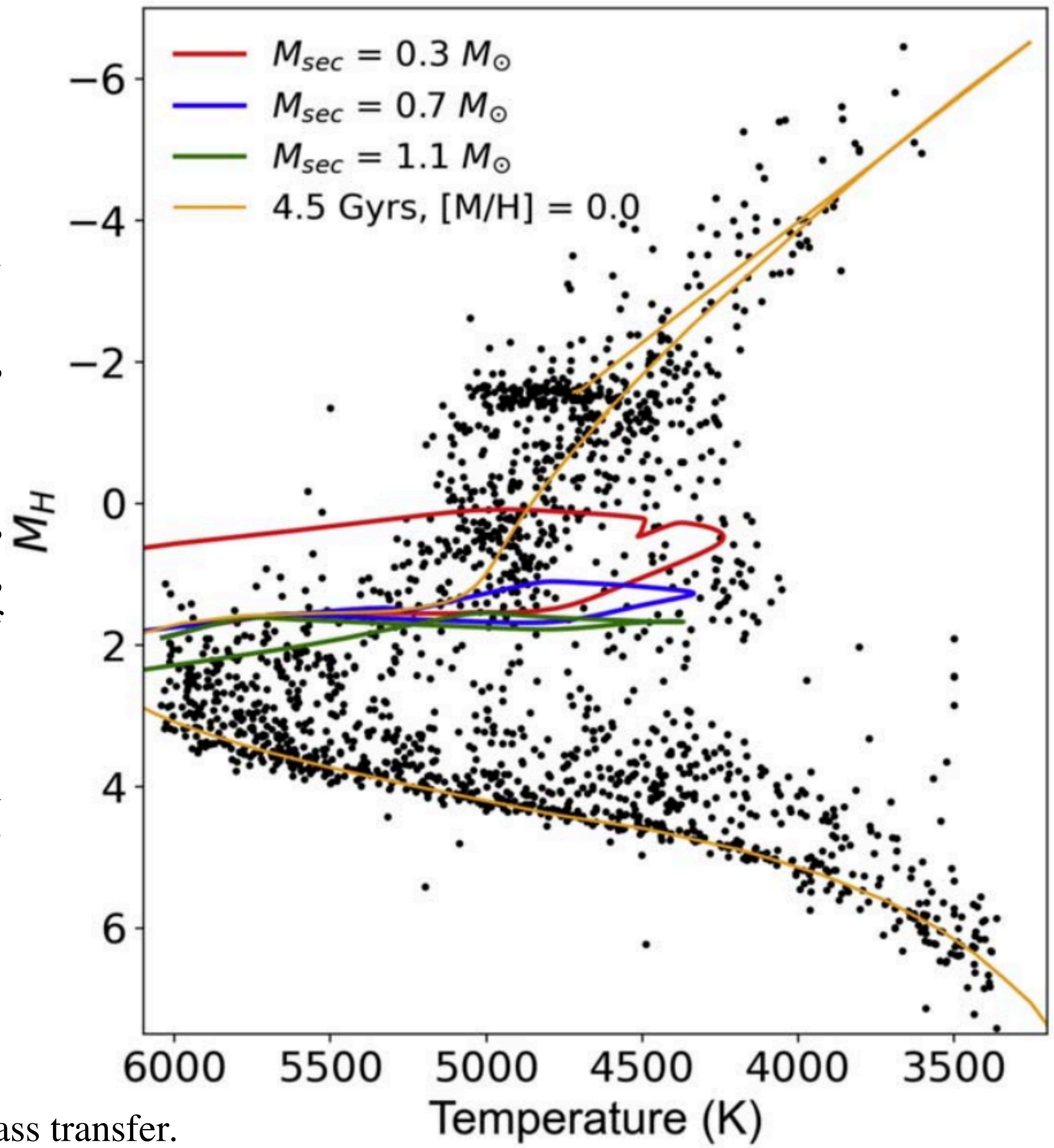


Sub-Subgiants

SSG stars have been recognized as likely representing unusual stellar evolution pathways ever since their initial detection as anomalies in the CMDs of some open clusters (see, e.g., Mathieu et al. 2003)

Mass transfer in a binary system, collision of two MS stars, mass loss of subgiant envelopes through dynamical encounters, and reduced luminosity due to the strong surface coverage of magnetic starspots (see, e.g., Leiner et al. 2017)

If these SSGs all possess a WD companion, could be an opportunity to make substantial new progress in understanding these enigmatic systems.



Evolutionary models from Leiner et al. (2017) of SSGs experiencing mass transfer.

Sub-Subgiants

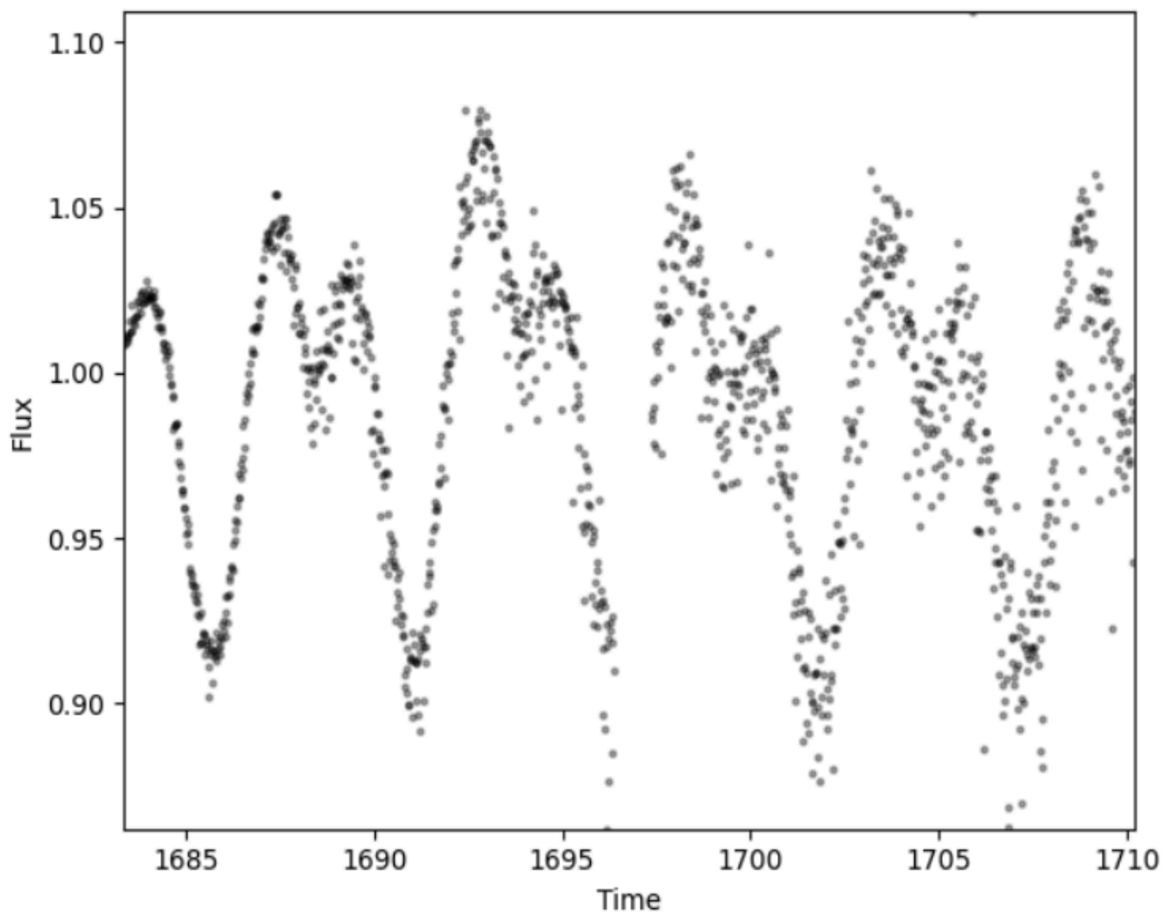
TIC 233063311 / APOGEE 2M18002441+634952

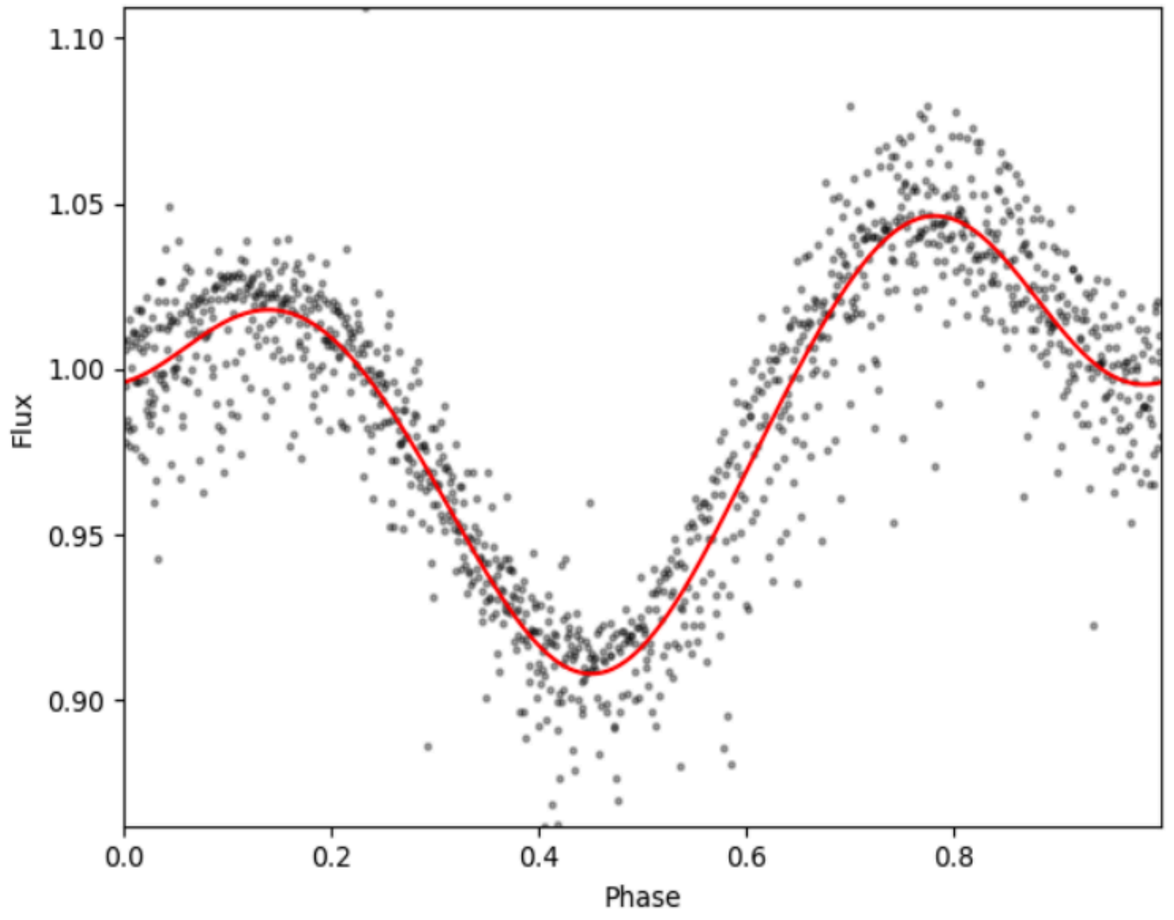
Sector: 14 Camera: 3 CCD: 1

Hmag: 9.819 Tmag: 11.595 Gmag: 12.2678

Teff: 4198.195 LOGG: 3.2602572 [M/H]: -0.21529

NVIS: 2 VSCATTER: 50.617847 Period: 5.320322





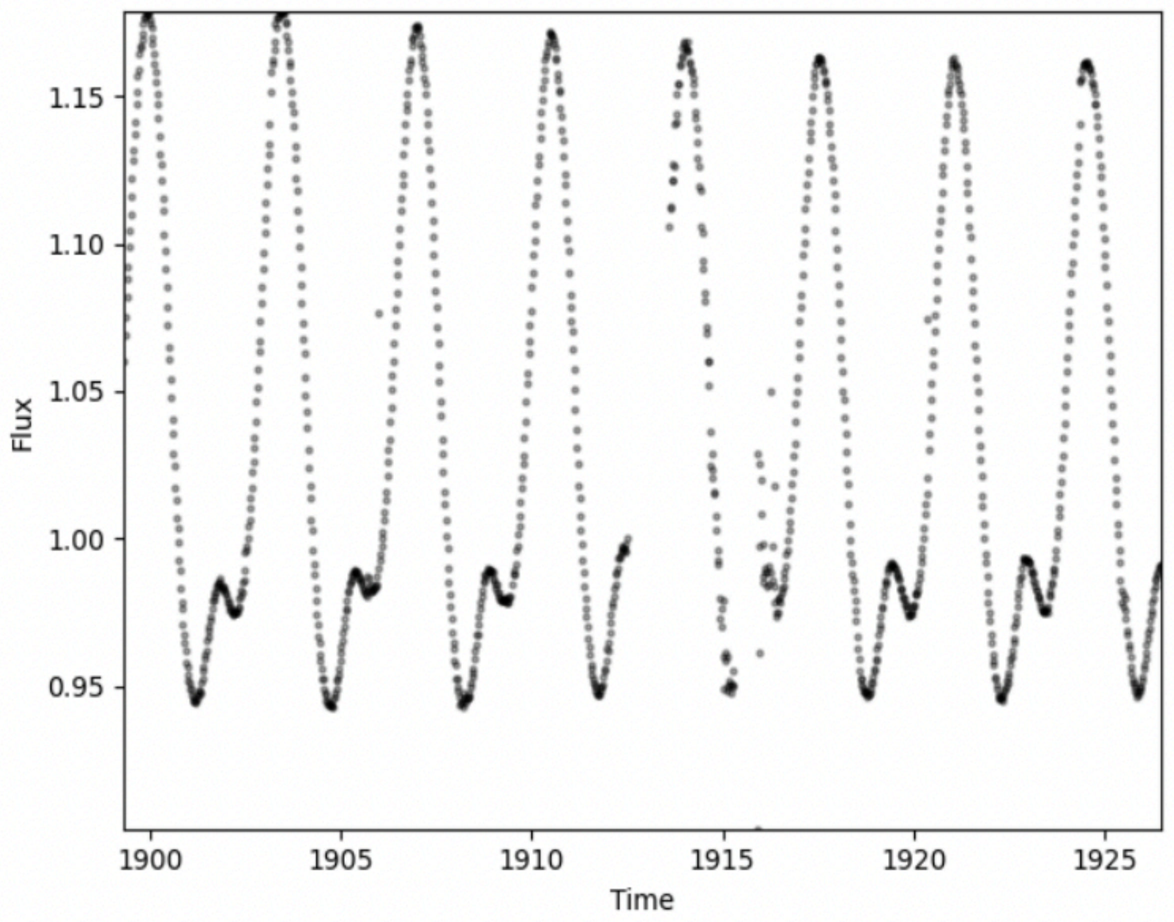
TIC 86180649 / APOGEE 2M12031564+1606376

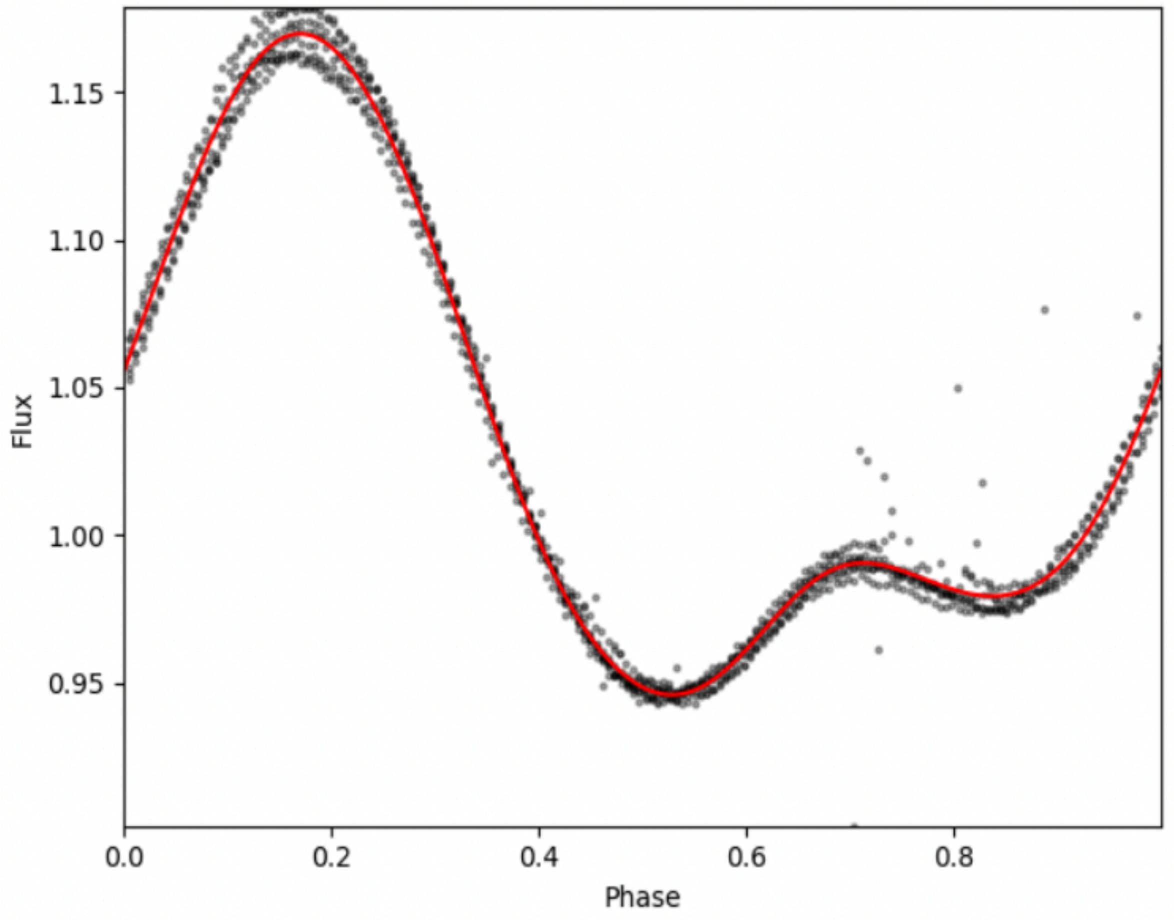
Sector: 22 Camera: 1 CCD: 4

Hmag: 9.12 Tmag: 11.158 Gmag: 11.8972

Teff: 3946.901 LOGG: 3.4711967 [M/H]: -0.39121

NVIS: 3 VSCATTER: 18.835245 Period: 3.521358





Don Dixon - Vanderbilt

Binary Properties as a Function of RV Variability

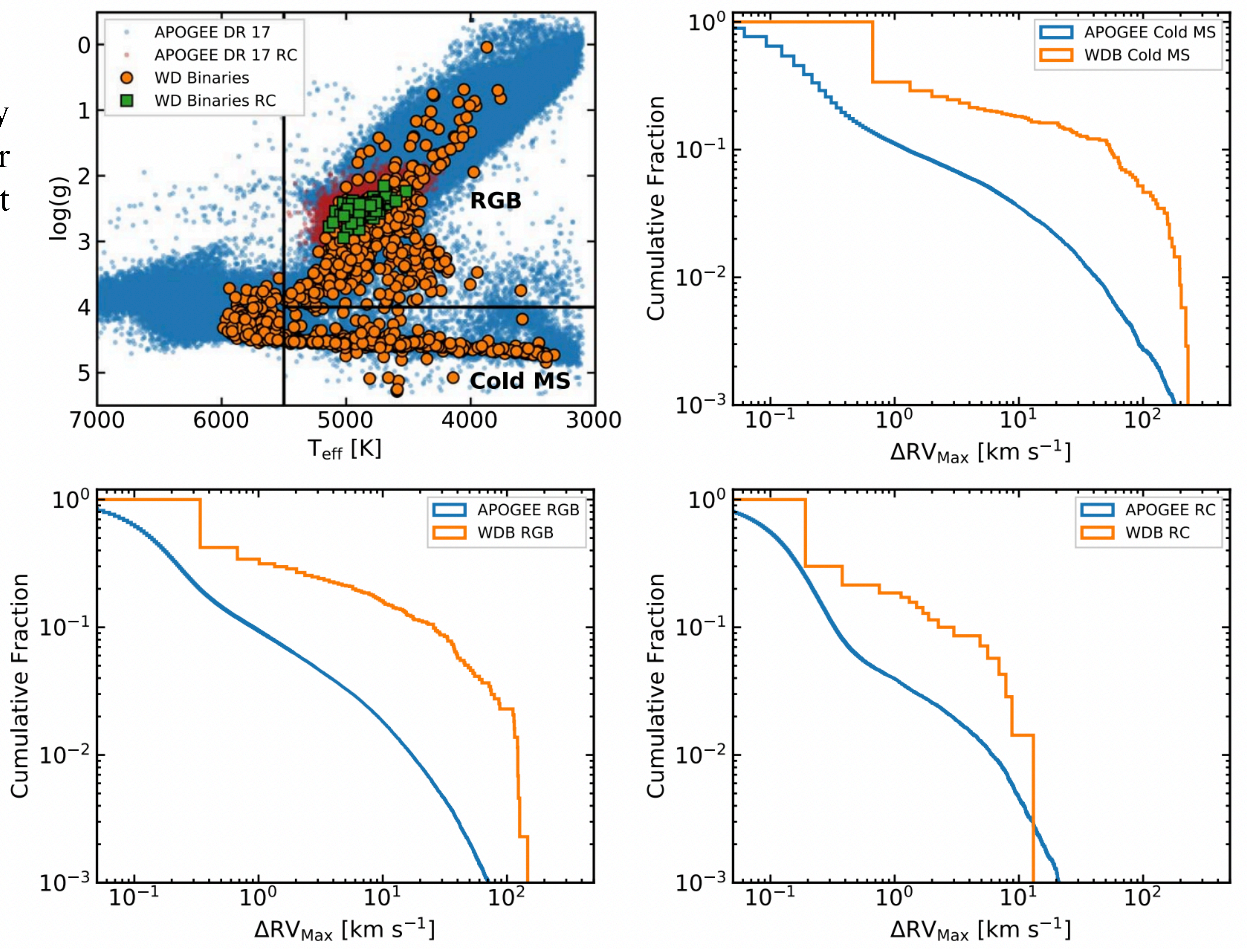
The detection of stellar multiplicity as evidenced by RV variability was one of the motivations for APOGEE being a multi-epoch survey (Majewski et al. 2017).

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

Badenes & Maoz 2012

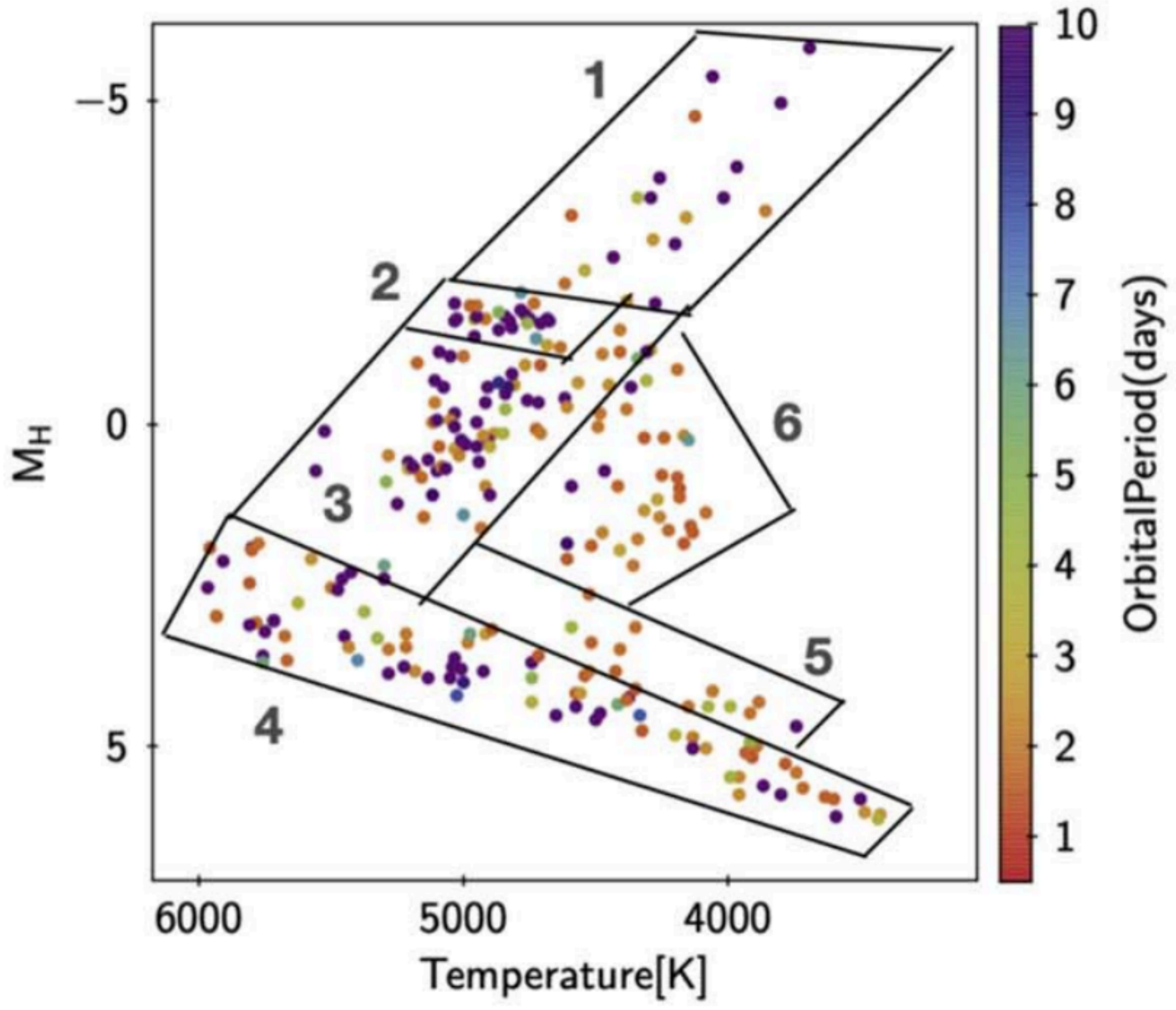
The ΔRVmax CDF for the WD binaries (orange solid lines) is clearly skewed toward larger ΔRVmax values, suggesting shorter periods for these systems.

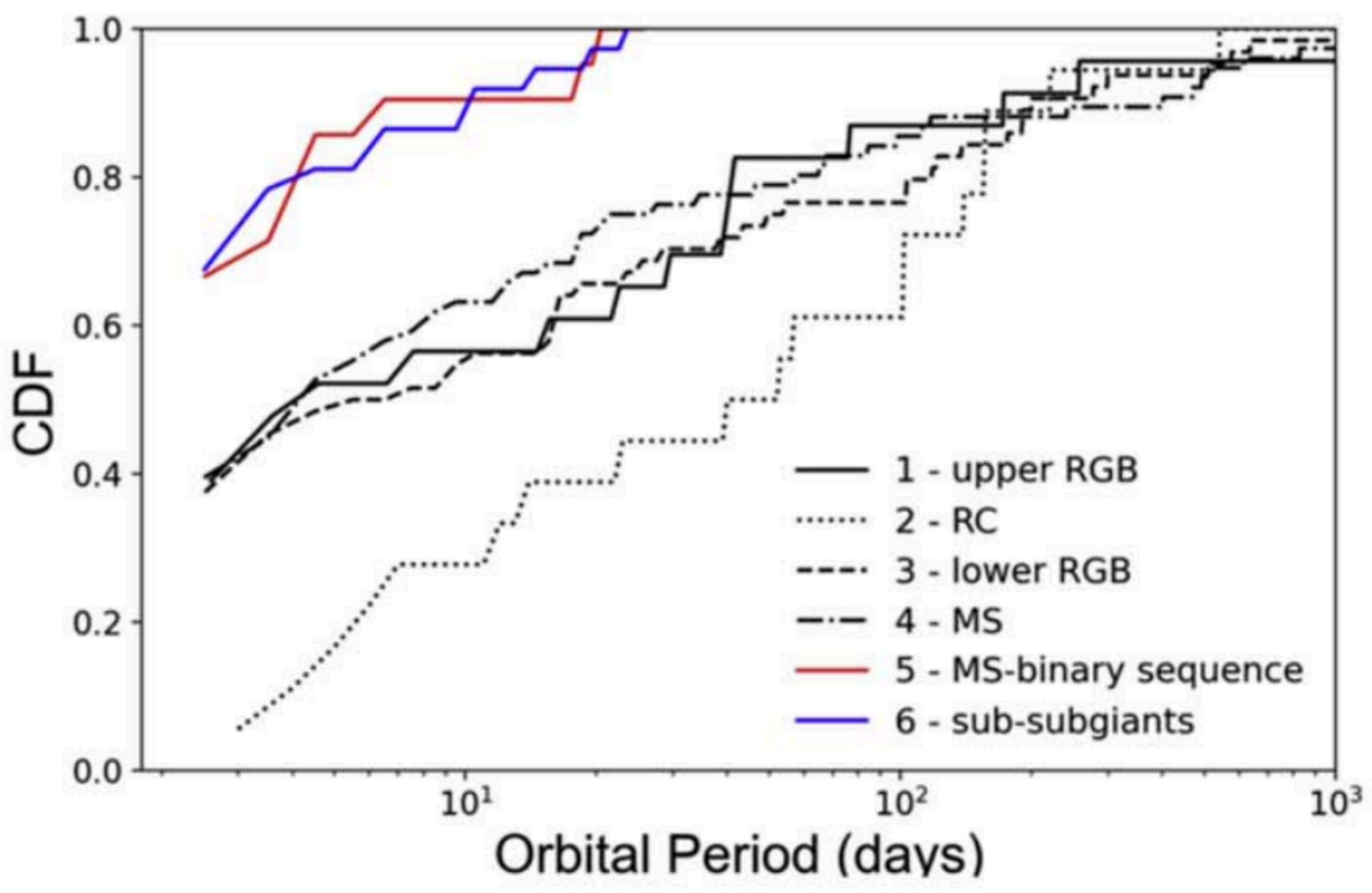
Loss of angular momentum associated with the formation of the WD, most naturally explained by a CE episode leading to the ejection of at least some of the envelope of the mass primary/WD progenitor.

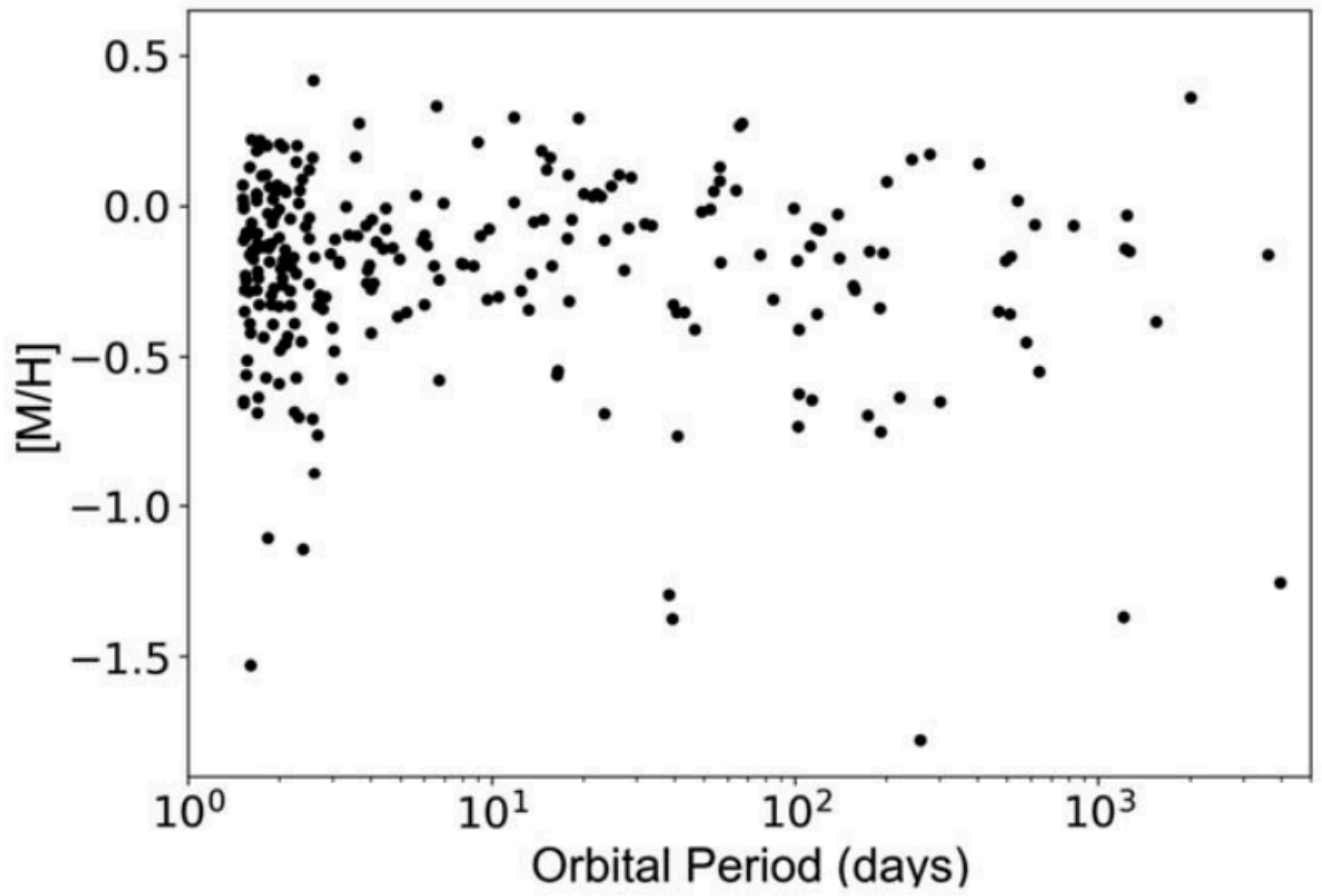


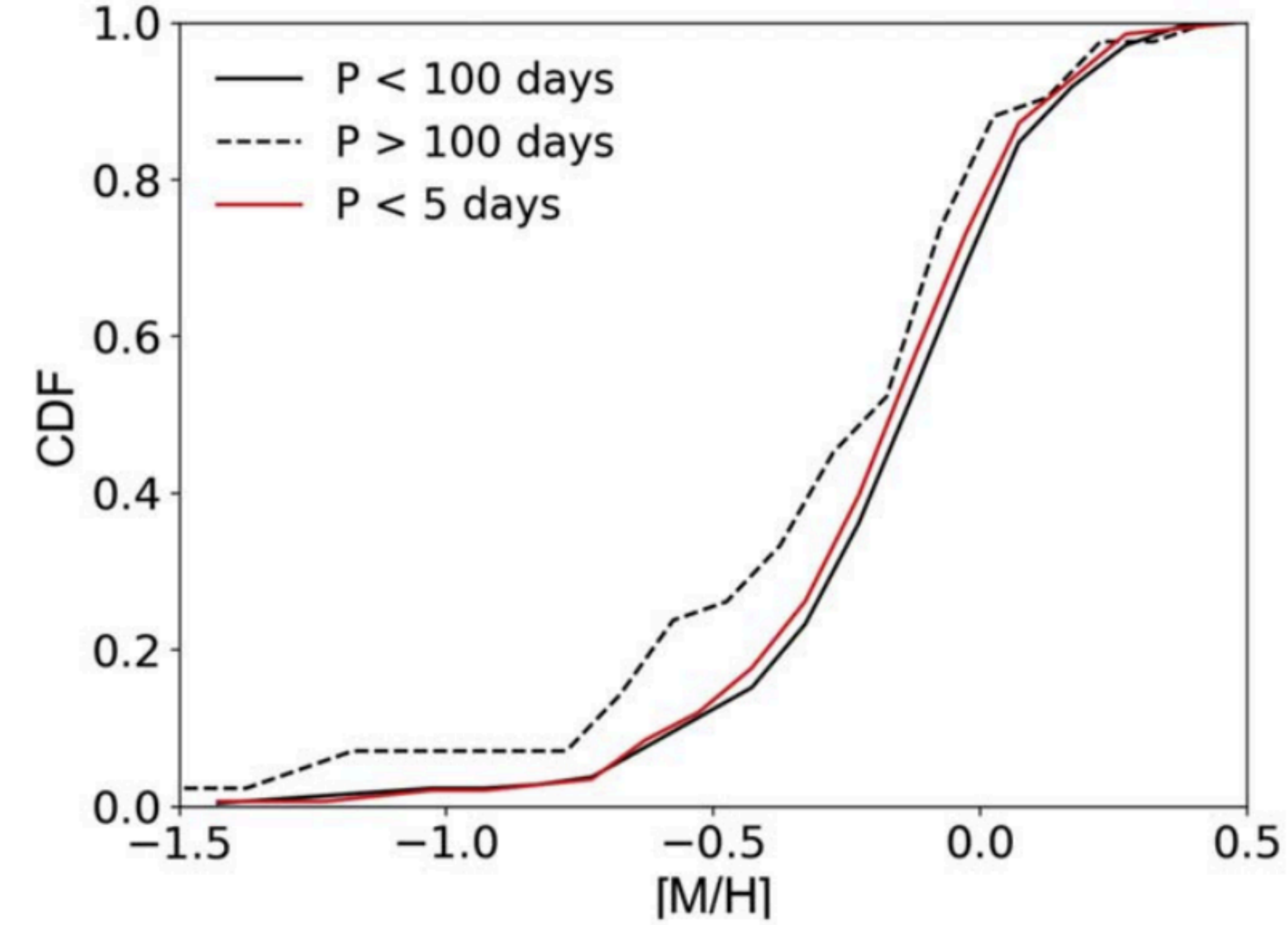
Binary Properties as a Function of Orbital Period

APOGEE DR17 value-added catalog (Price-Whelan et al. 2020) containing posterior samplings of Keplerian orbital parameters (e.g., orbital period) derived using The Joker (Price-Whelan et al. 2017)









How the CE phase and the mass loss affect binary evolution and the chemical abundances measured for compact binaries is still not well understood

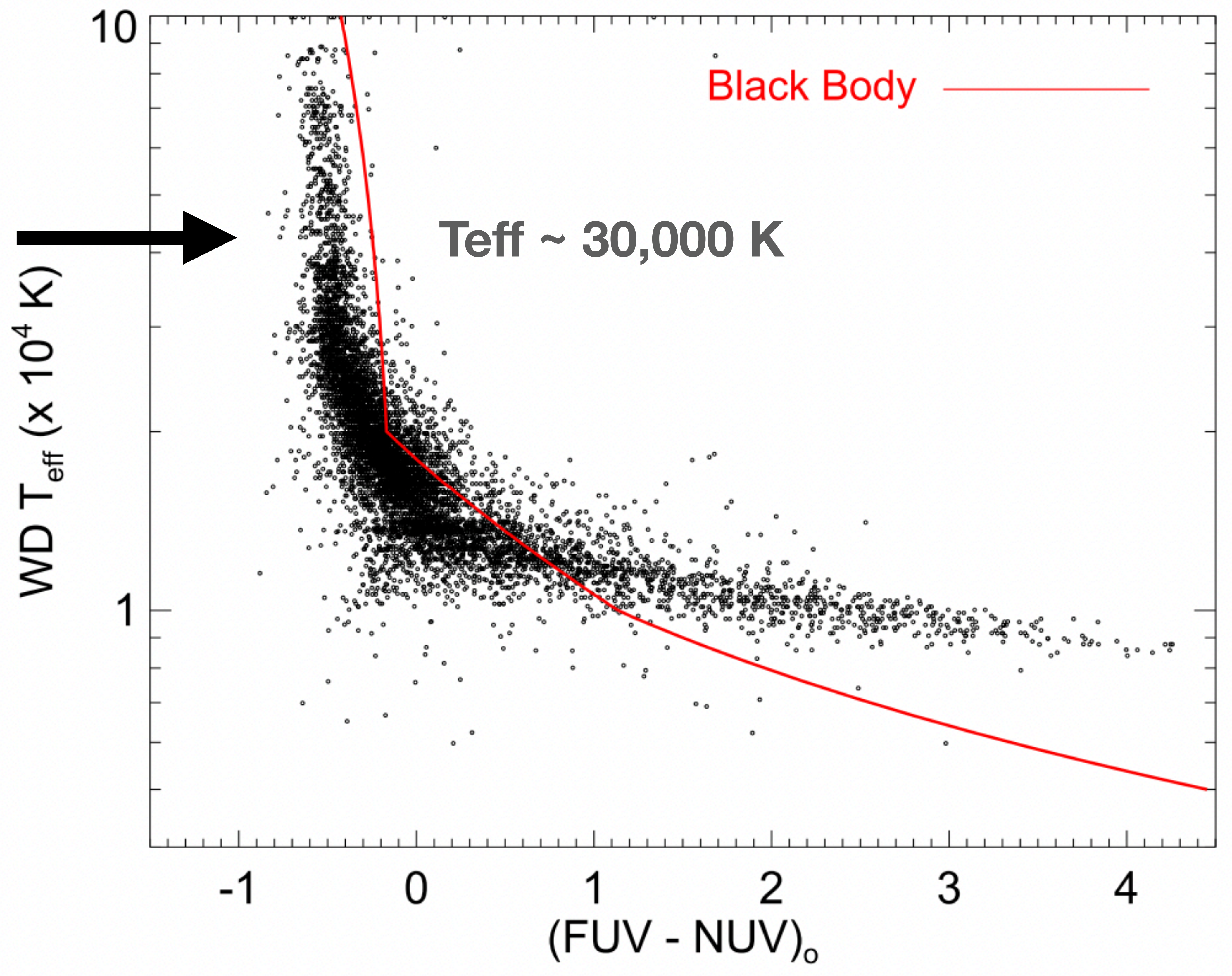
enrichment of the secondary star’s surface chemistry during the CE phase?

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.

Physical Properties via SED fitting

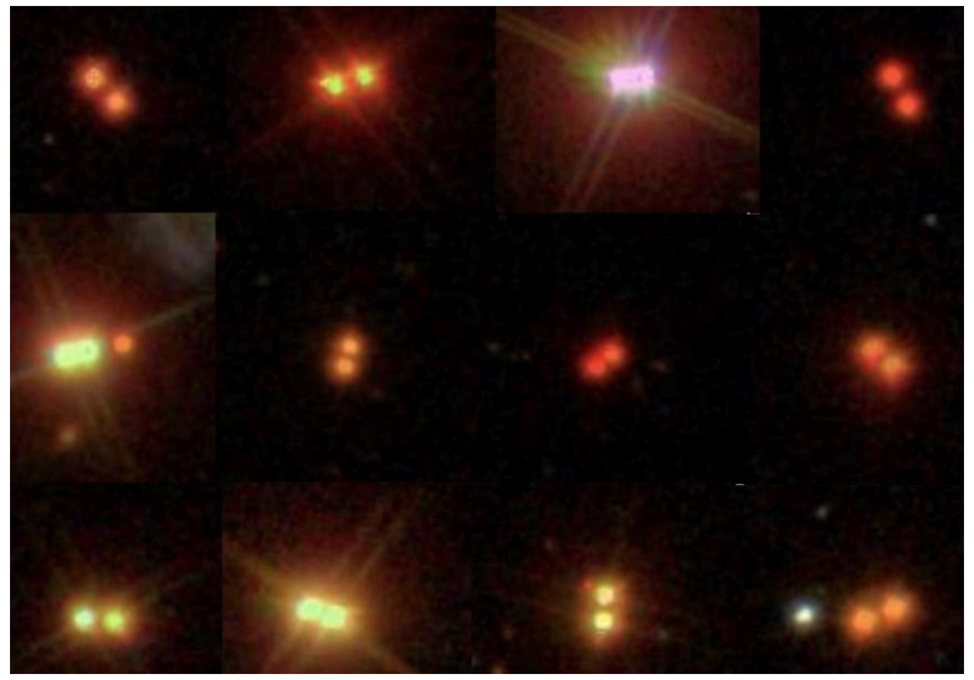
The empirical SED for the AGGC sample is an aid not only in identifying WD binaries but also in deriving system parameters like the WD effective temperature and radius.

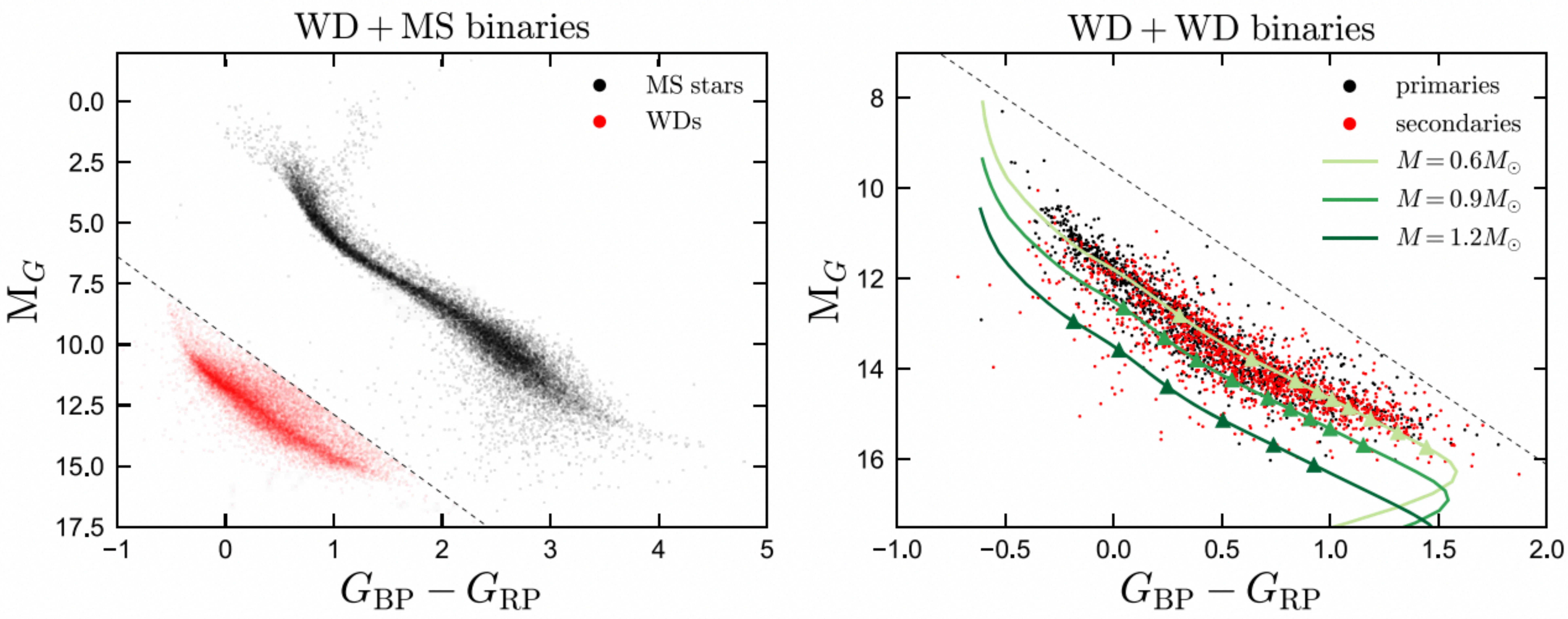


This temperature is the primary driver of the GALEX UV color.

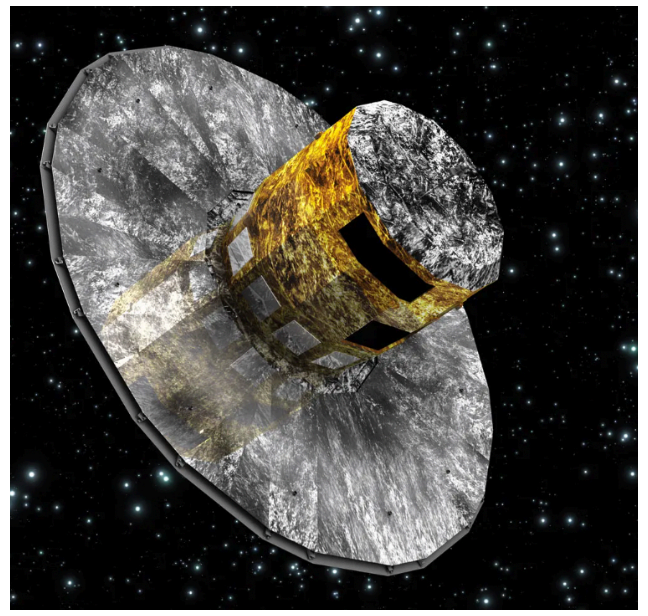
SDSS DR12 WD catalog with spectroscopic temperatures used in Anguiano et al. (2017). In this case, the WD effective temperatures were derived (Kepler et al. 2016) by fitting the Balmer lines using WD models (Koester 2010)

…what about WD wide binaries





El-Badry et al. 2021



Gaia astrometric solution

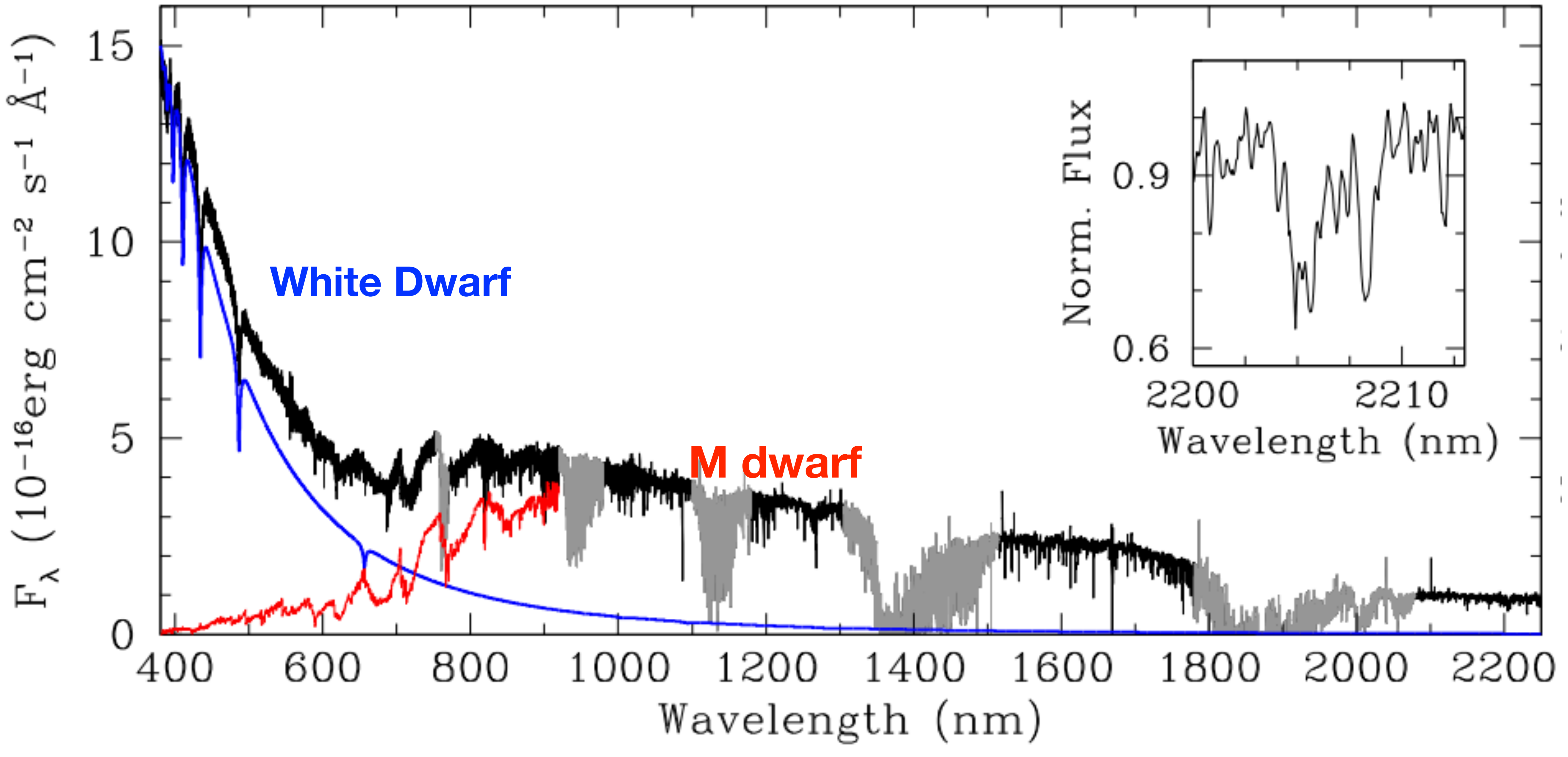
$$\theta \approx \sqrt{(\alpha_1 - \alpha_2)^2 \cos\delta_1 \cos\delta_2 + (\delta_1 - \delta_2)^2}$$

$$\Delta\mu \approx \sqrt{(\mu^*_{\alpha,1} - \mu^*_{\alpha,2})^2 + (\mu_{\delta,1} - \mu_{\delta,2})^2},$$

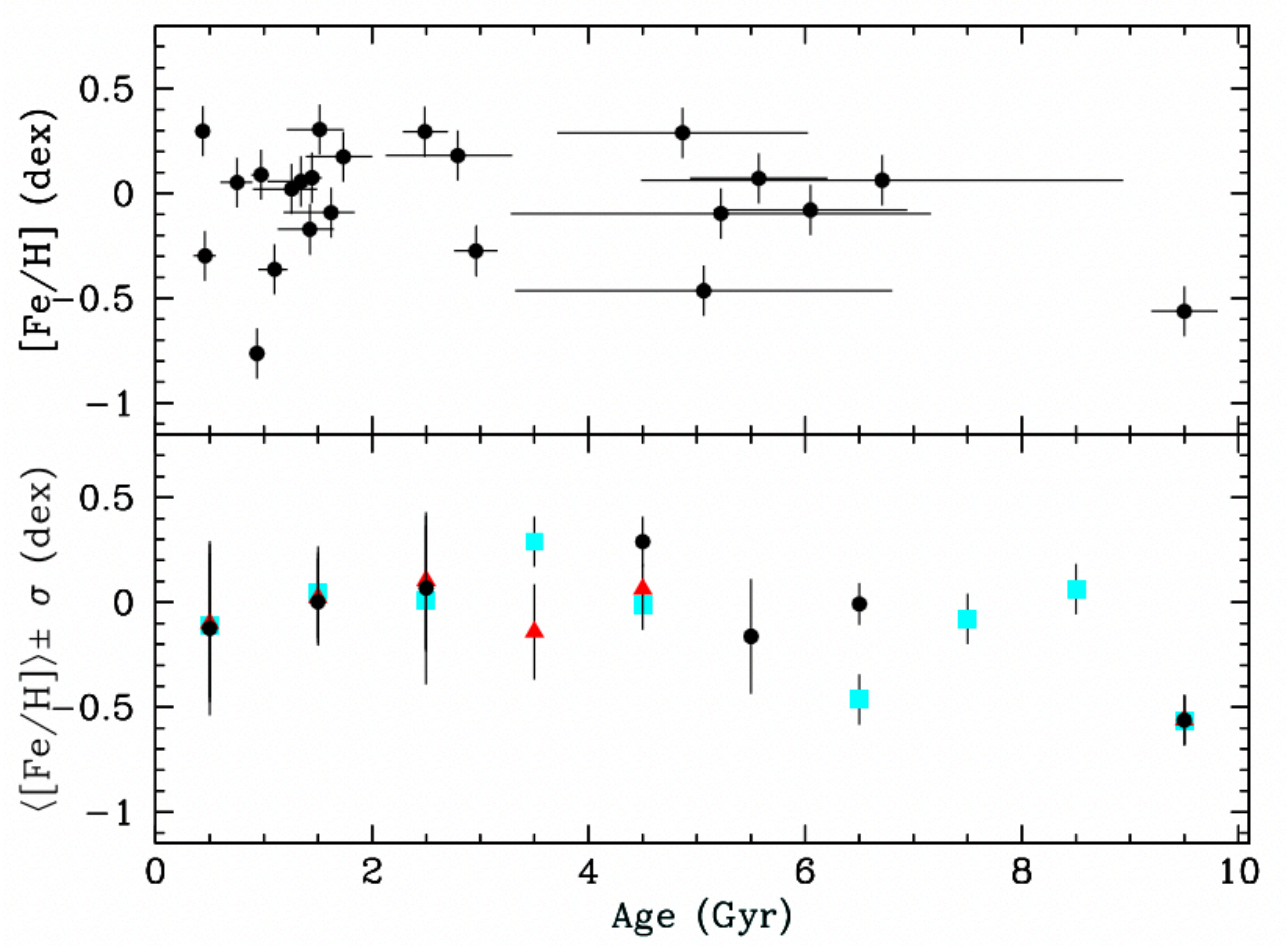
$$x_i \equiv \{\theta,\ \Delta\mu',\ \mathrm{RV}'_1,\ \mathrm{RV}'_2\}$$

Andrews, Anguiano et al. 2019

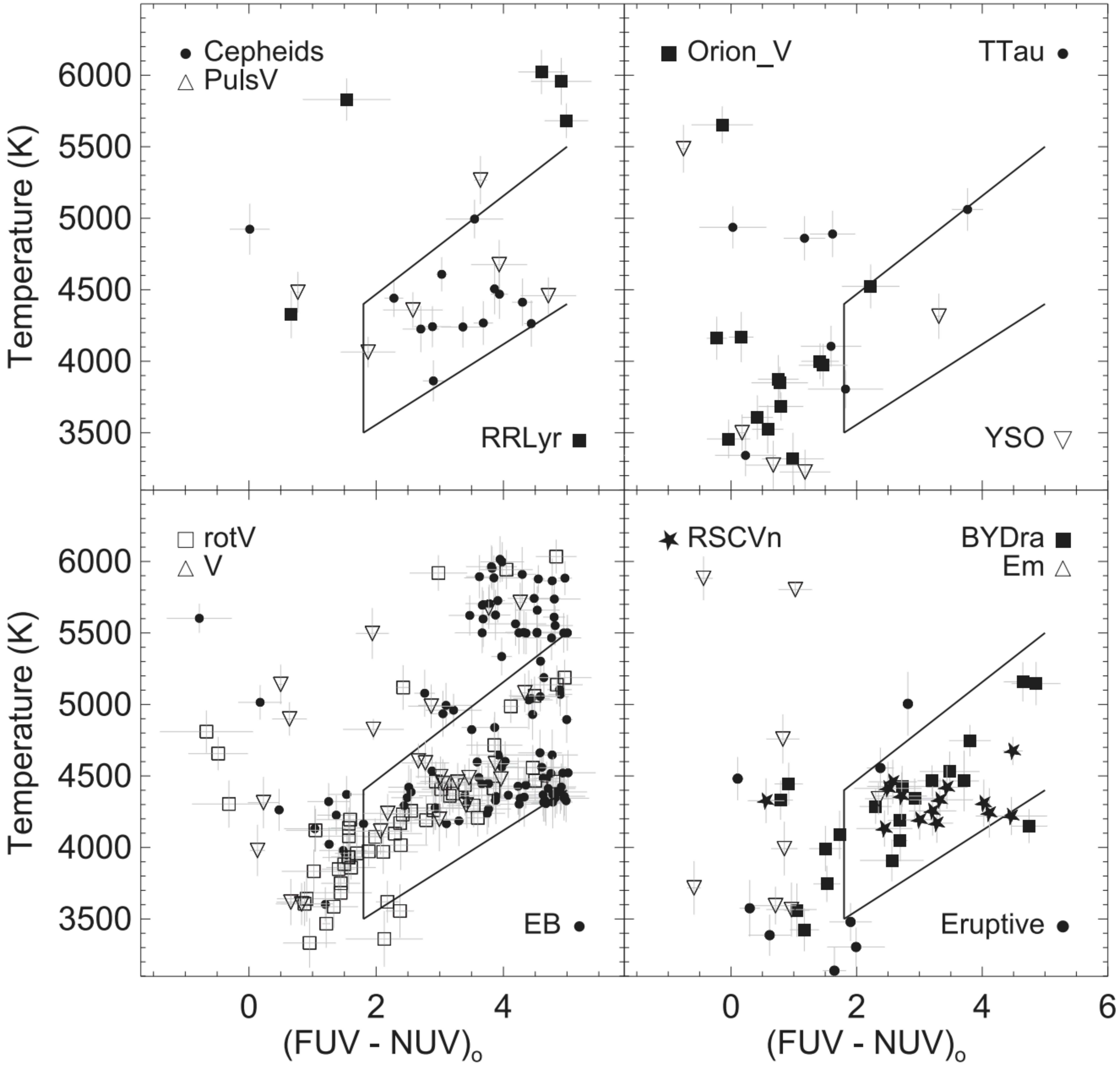
Age-metallicity relation using WDMS wide binaries



VLT X-Shooter spectrum of SDSSJ 0036+0700, an SDSS WDMS.



Metallicities can be directly determined from the M-dwarf, and ages can be determined from the observed properties of the WDs. The two components in each binary are coeval (Rebassa-Mansergas, Anguiano et al. 2016)



Vast majority of our system candidates are classified as "Star" or "High Proper-motion Star," which demonstrates our overall ignorance about these objects.

- Cepheids / RR Lyr
- Pulsating Variable Star
- T-Tau
- Young Stellar Object
- Eclipsing Binaries
- Rotational Variable Stars
- RS Canum Venaticorum*
- Variable BY Draconis

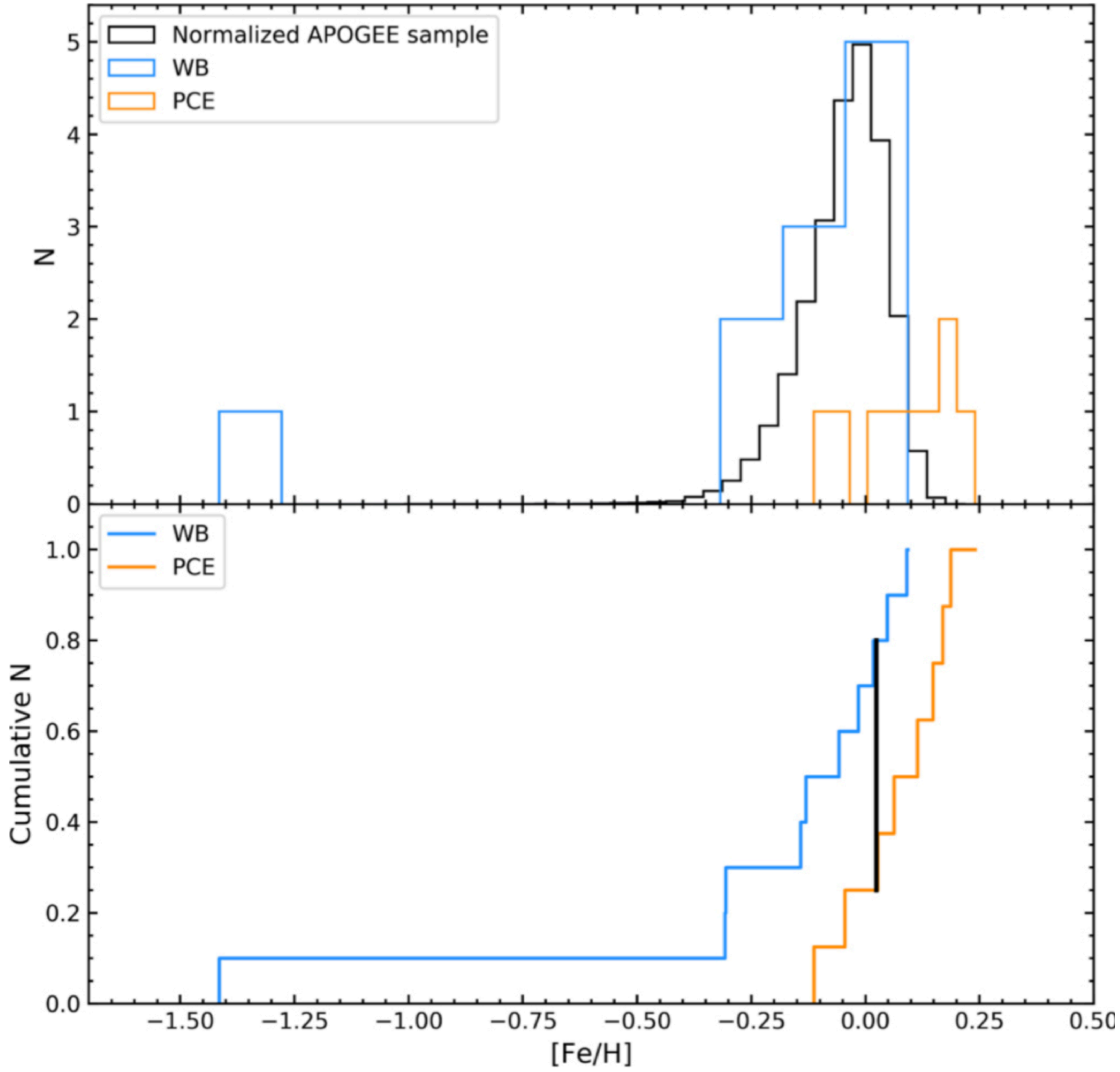
*Latin: hunting dogs

SIMBAD database (Wenger et al. 2000)

Corcoran, Lewis, Anguiano et al. 2021 AJ 161 143C

- The WB stars have a MDF significantly skewed to lower metallicities than the PCE stars.

- The difference in the [Fe/H] distribution of WB and PCE systems could speculatively point to some sort of alteration of a system's surface chemistry during the CE phase



Analysis of Previously Classified White Dwarf Main-Sequence Star Binaries Using Data from the APOGEE Survey

SDSS-IV Project 0702: White Dwarf-Main Sequence Binaries Observed in the APOGEE Survey

Corcoran, Lewis, Anguiano et al. 2021 AJ 161 143C

Currently 45 previously classified WDMS systems in the APOGEE dataset, the majority of these have multiple RV-epochs!

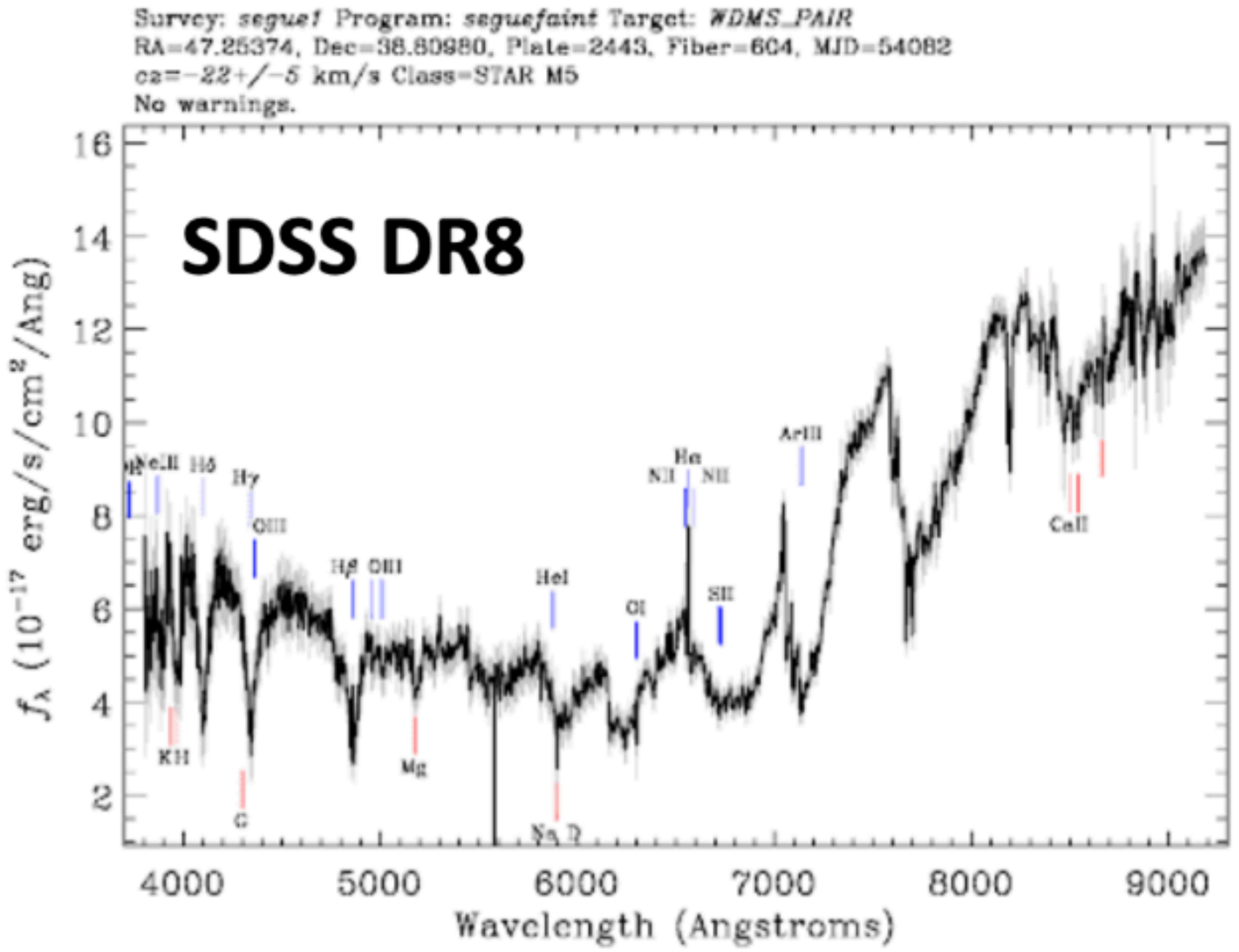


Table 1. APOGEE system parameters derived using *The Joker*. Here $m \sin i$ refers to the WD as the M dwarf (M_*) is the star being fit by the RV template.

APOGEE ID	P [days]	e	K $[\mathrm{km\,s^{-1}}]$	γ $[\mathrm{km\,s^{-1}}]$	M_* $[M_\odot]$	$m \sin i$ $[M_\odot]$
2M10243847+1624582	0.5258733 ± 0.0000056	0.0295660 ± 0.0143324	145.6 ± 2.3	-8.5 ± 1.7	0.423 ± 0.027	0.537 ± 0.013
2M10552625+4729228	2.1866303 ± 0.0023683	0.0033047 ± 0.0157235	82.4 ± 1.0	8.2 ± 0.9	0.446 ± 0.029	0.476 ± 0.009
2M11463394+0055104	0.4087104 ± 0.0000114	0.0272674 ± 0.0135032	186.8 ± 2.1	-12.5 ± 2.8	0.440 ± 0.028	0.717 ± 0.014

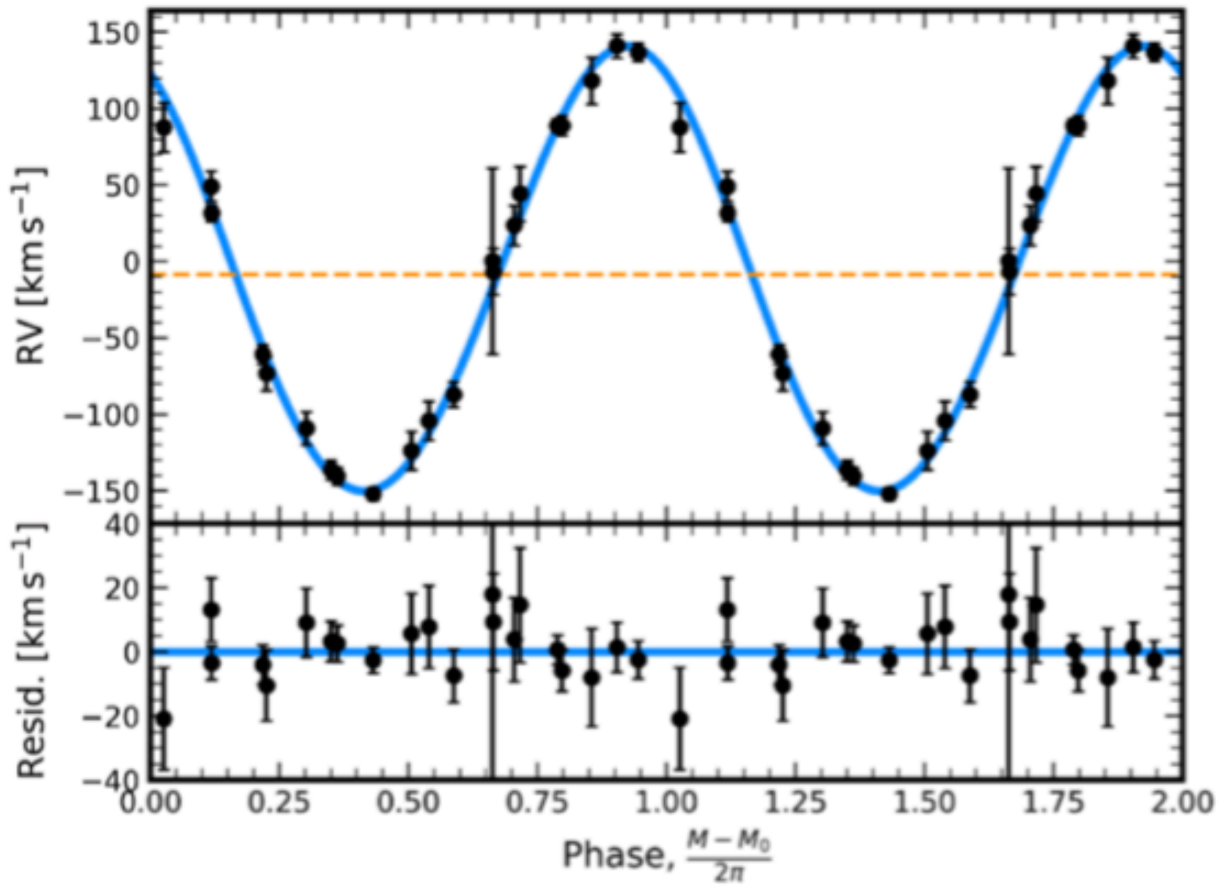


Figure 1. 2M10243847+1624582

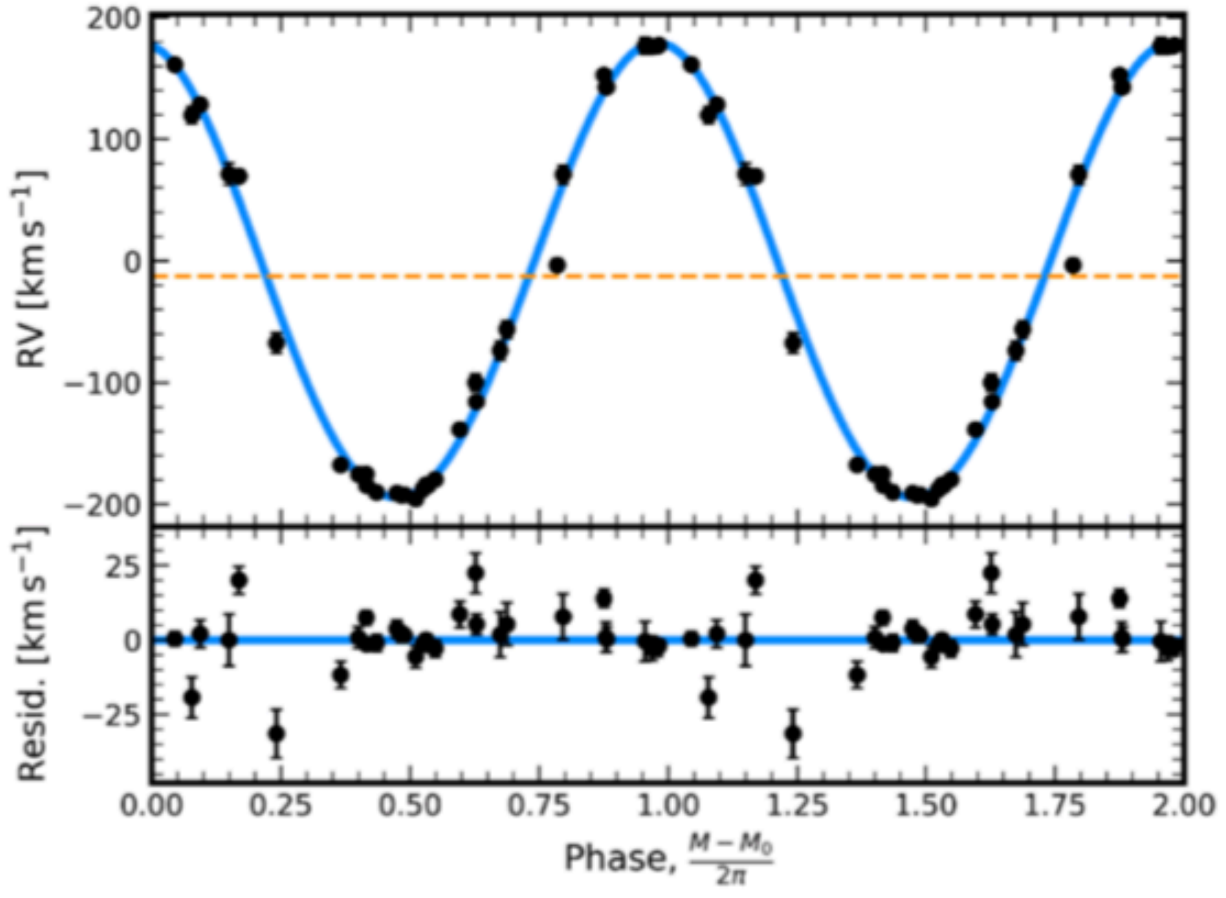


Figure 3. 2M11463394+0055104

Corcoran et al. 2021 AJ 161 143C **brings for the first time reliable orbital parameters for these systems using APOGEE multiple RV-epochs.**