राष्ट्रीय प्रौद्योगिकी संस्थान राउरकेला
National Institute of Technology Rourkela
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UC SANTA BARBARA
Kavli Institute for Theoretical Physics

Detection of extreme low mass white dwarfs in globular clusters M3 and M13

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5th year PhD (SRF)

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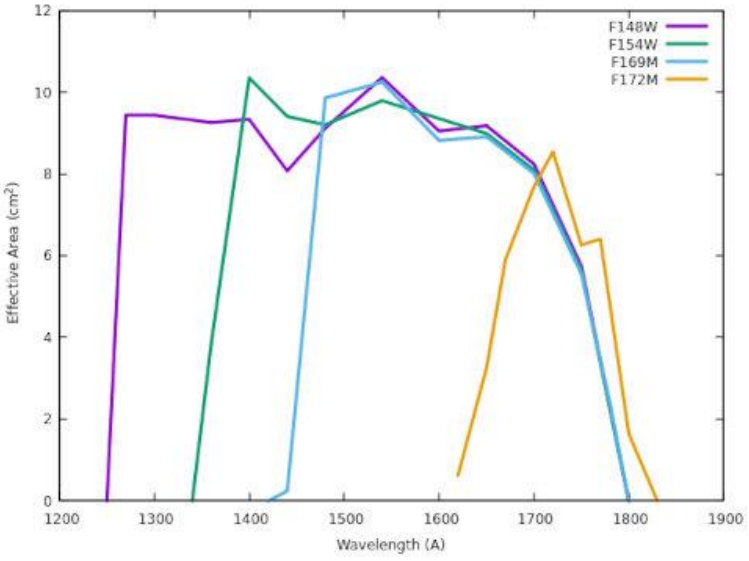
Globular clusters (GCs): M3 and M13

Name	RA (J2000) (hh:mm:ss.ss)	DEC (J2000) (dd:mm:ss.s)	D (kpc)	Age (Gyr)	[Fe/H] (dex)	Mass ($\times 10^5$ $M_\odot$)
NGC 5272 (M3)	13:42:11.62	+28:22:38.2	10.2	11.8	-1.50	4.1
NGC 6205 (M13)	16:41:41.24	+36:27:35.5	7.1	12	-1.53	5.5

- M3 and M13 are twin GCs having similar metallicity ([Fe/H] $\sim -1.5\ dex$) and age ~ 12 Gyr
- A perfect candidate to study "the second parameter" of horizontal branch (HB) morphology in globular clusters.
- M3 has red- HB and blue-HB whereas M13 has blue-HB and extreme-HB sequence.
- Relatively larger AGBs in M3 than in M13; or M13 populates more AGB-manque/post-early AGB stars than M3 (however the statistics is not clear yet!).
- The cooling process of WDs of M13 is slower than that of M3 (Chen et al. 2021).

M3 and M13: Observations

- Two filters of Ultra-violet Imaging Telescope (UVIT) onboard AstroSat –
  - F148W: $\lambda_{eff} = 1481$ Å and $\Delta\lambda = 500$ Å
  - F169W: $\lambda_{eff} = 1608$ Å and $\Delta\lambda = 290$ Å



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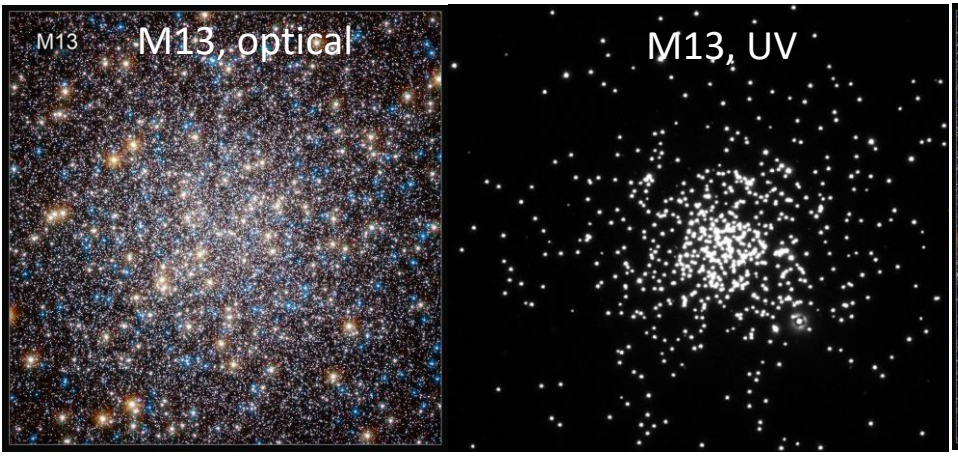
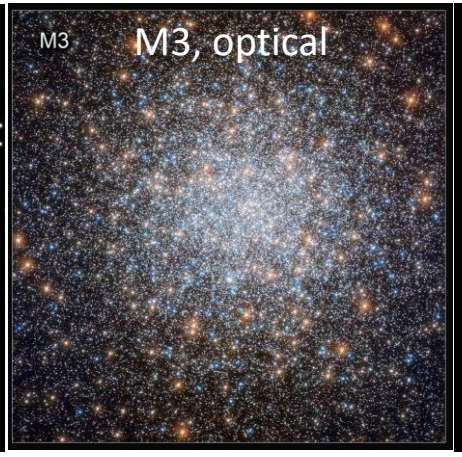
- Five filters of HST (HST Legacy Survey of Galactic Globular Clusters, Nardiello et al. 2018) for inner regions of GCs –

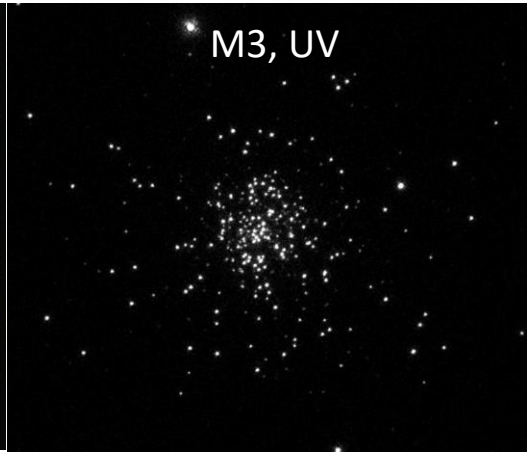
  F275W, F336W, F438W, F606W, and F814W

- U, B, V, R, I filters for outer regions of GCs (Ground based observations, Stetson et al. 2019)

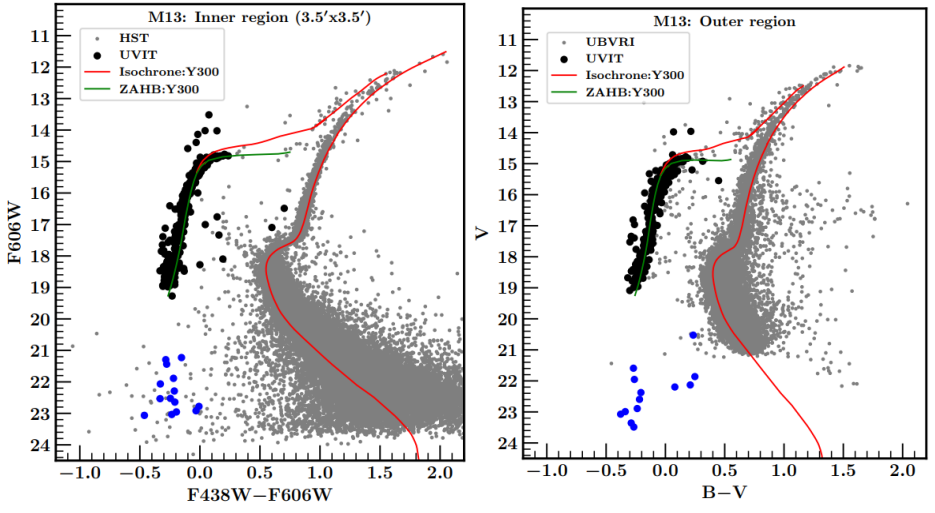
Globular clusters (GCs): M3 and M13



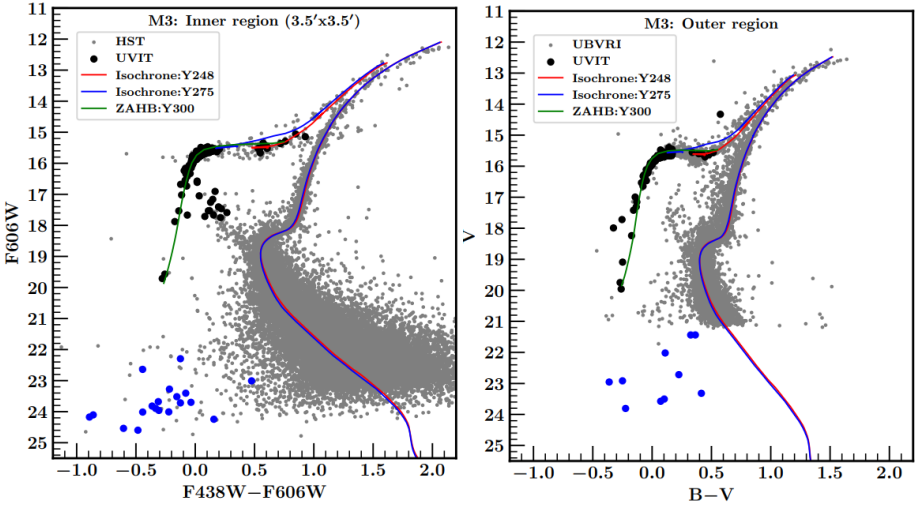




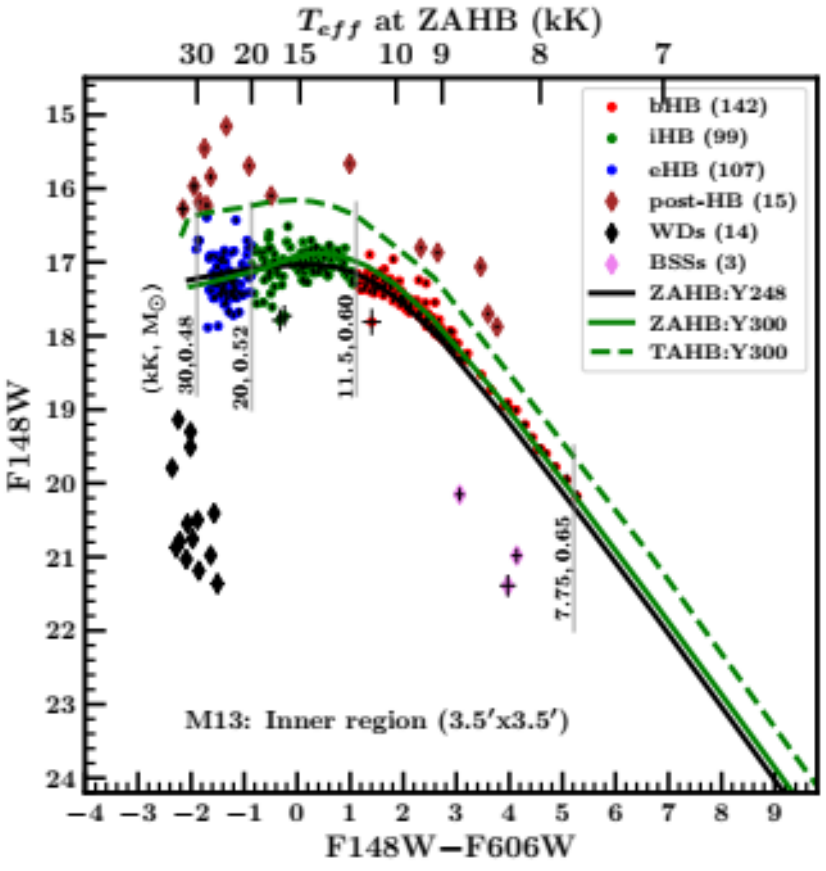
NGC 6205 (M13)

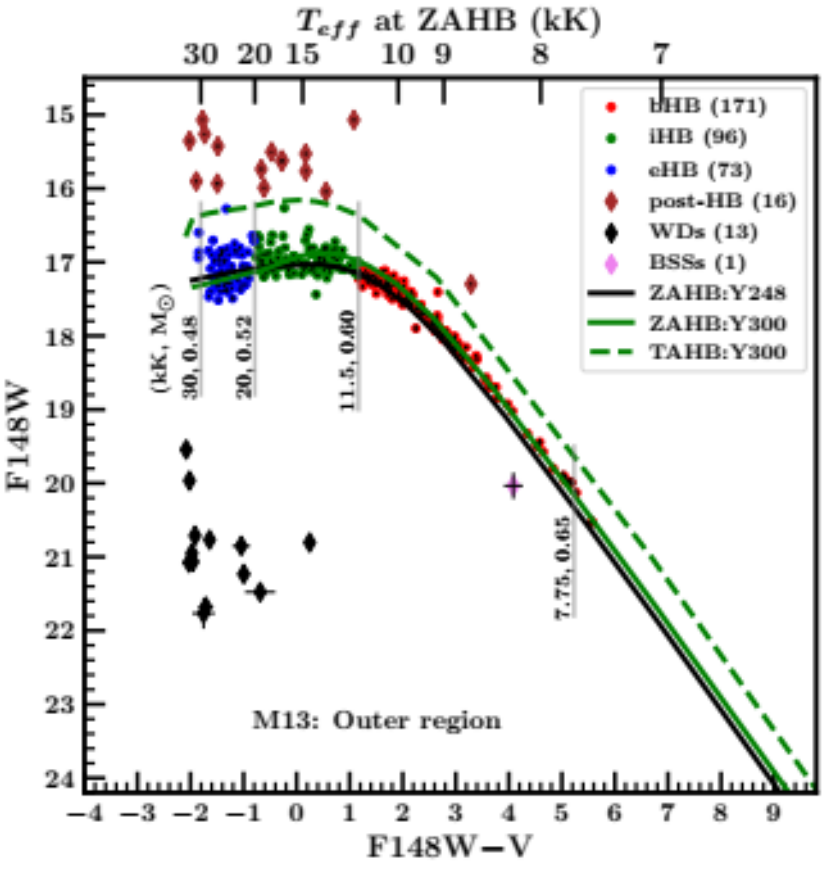


NGC 5272 (M3)



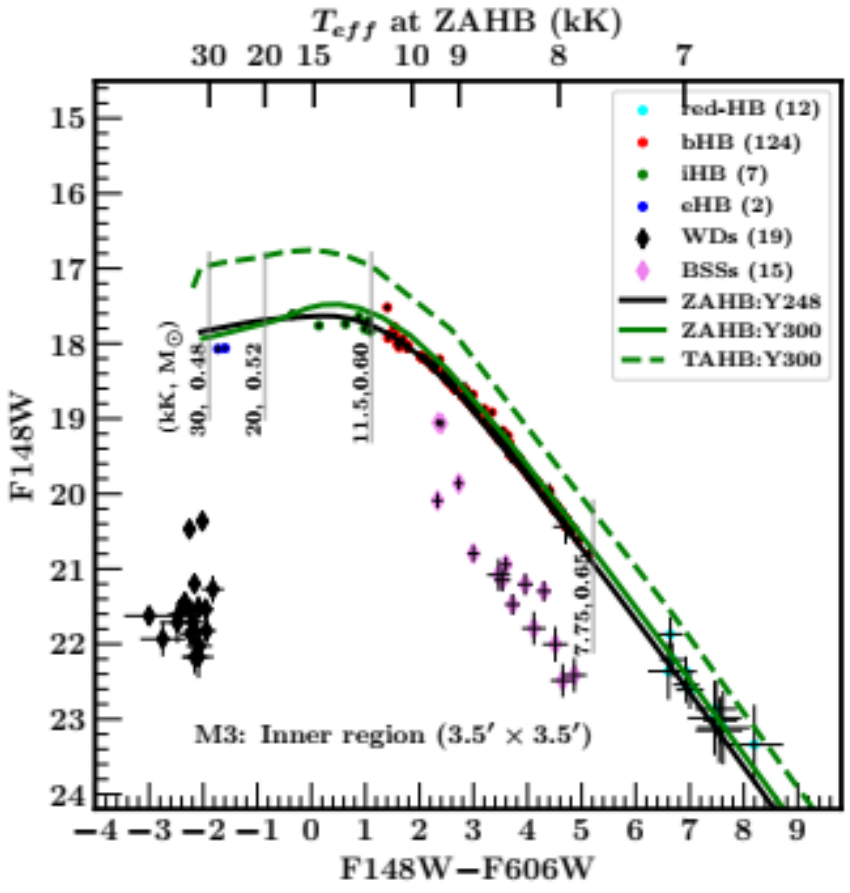
UV-optical CMDs of M13

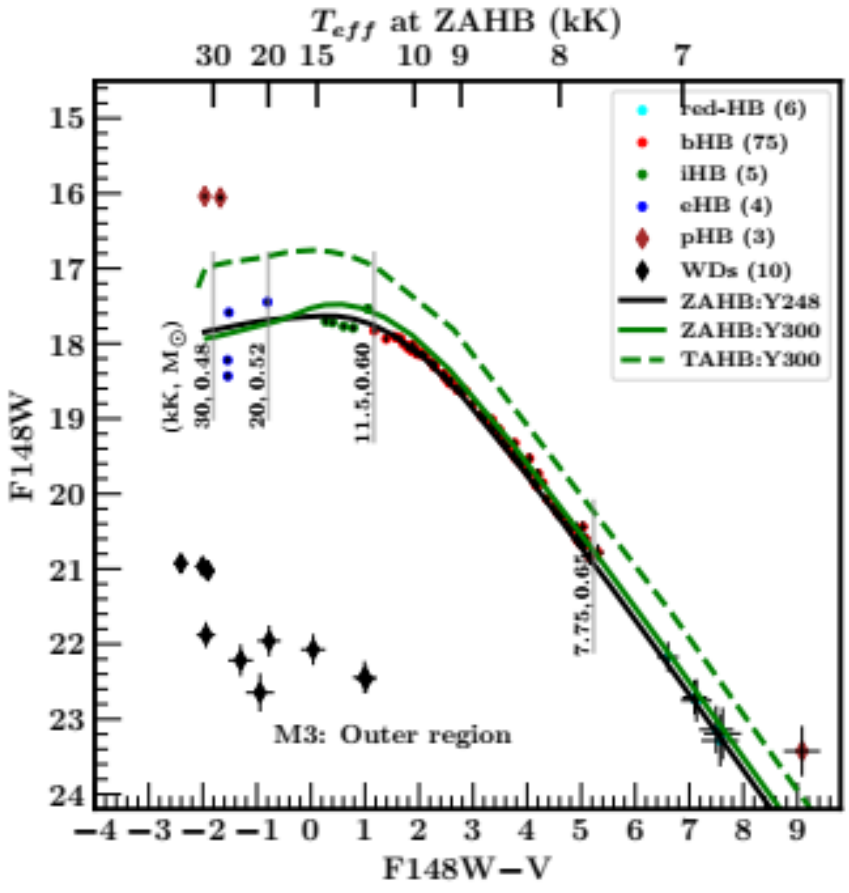




A total of 570 horizontal branch (HB) stars, 31 post-HB stars, 27 white dwarfs (WDs), and 4 blue-straggler stars in M13.

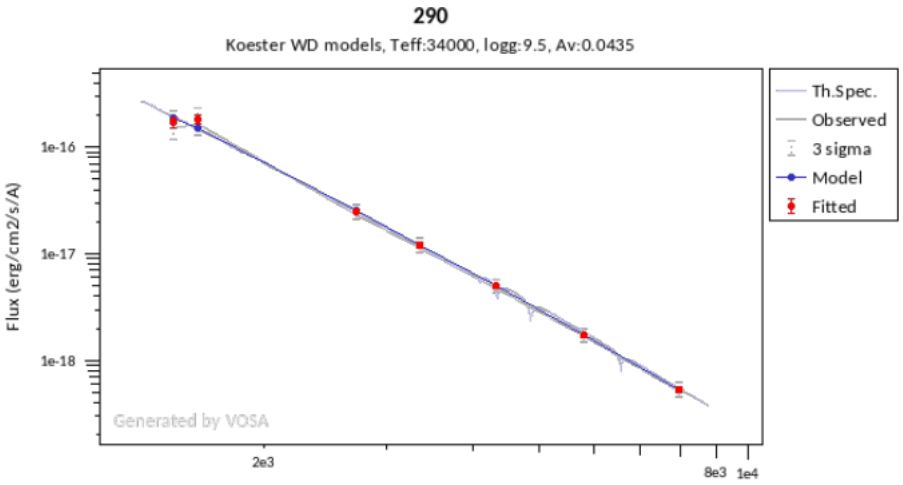
UV-optical CMDs of M3

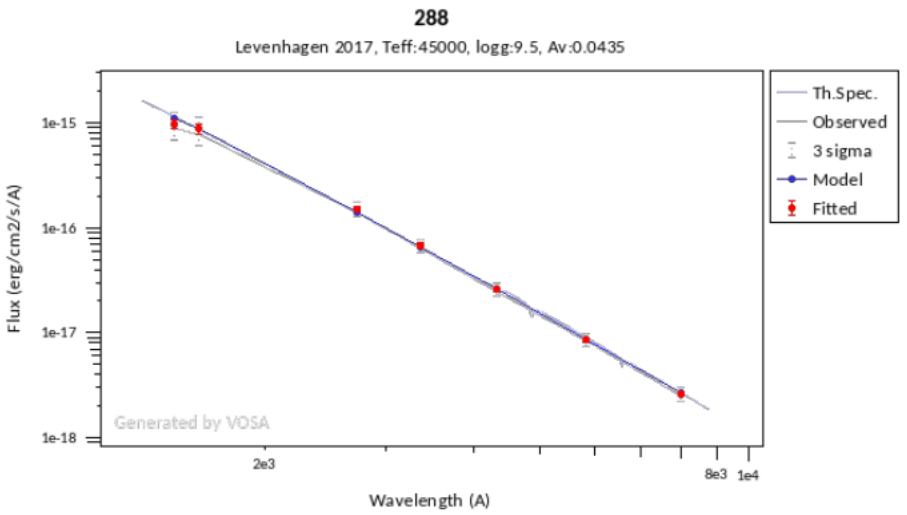




A total of 235 horizontal branch (HB) stars, 3 post-HB stars, 29 white dwarfs (WDs), and15 blue-straggler stars in M3.

SED fitting of WDs





Inputs:

Observed fluxes -

- UVIT + HST filters for inner region (3.5'x3.5' at cluster core)
- UVIT + UBVRI filters for outer region (outside of 3.5'x3.5' central region)

Theoretical fluxes –

- Koester WD model

Teff: 5,000 to 80,000 K and log(g): 6.5 to 9.5 dex

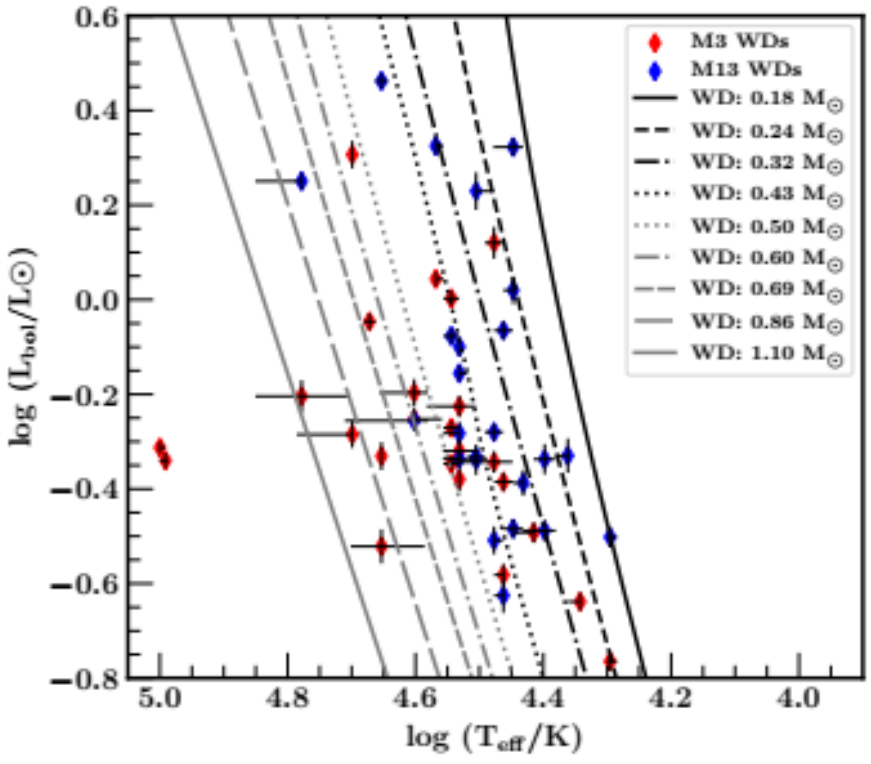
- Levenhagen WD model

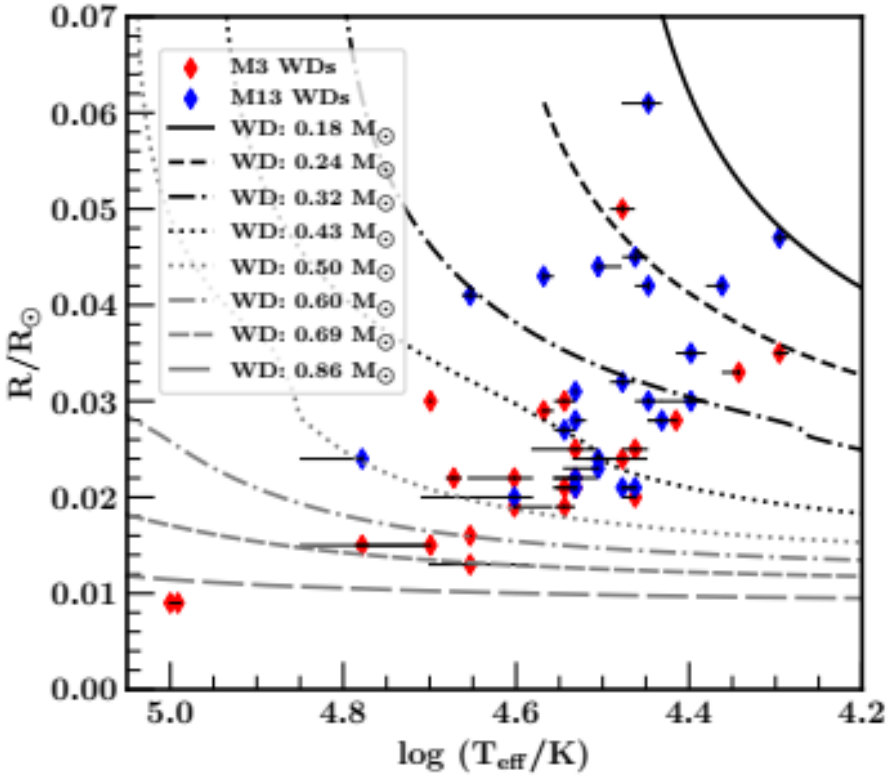
Teff: 17,000 to 100,000 K and log(g): 7.0 to 9.5 dex

ID	RA (degree)	DEC (degree)	Teff (K)	eTeffp (K)	eTeffm (K)	logg (dex)	elogg (dex)	L ($L_\odot$)	eL ($L_\odot$)	R ($R_\odot$)	eR ($R_\odot$)	chi	echi	Model	region	Radial (arcsec)	Mass ($M_\odot$)	eMassp ($R_\odot$)	eMassm ($R_\odot$)
6	250.4462	36.34667	29000.0	1000.0	0.0	7.24	0.2	0.237	0.02	0.021	2.0E-4	1.01	0.13	levenhagen17	ubvri	413.6	0.47	0.035	0.035
36	250.3822	36.39391	19750.0	250.0	500.0	8.32	0.22	0.315	0.016	0.047	5.0E-4	9.87	0.06	koester2	ubvri	263.7	0.182	0.01	0.01
45	250.33501	36.41498	34000.0	2000.0	0.0	6.82	0.28	0.522	0.029	0.022	2.0E-4	2.86	0.07	koester2	ubvri	298.9	0.21	0.03	0.03
46	250.25591	36.43906	27000.0	1000.0	0.0	8.6	0.49	0.41	0.026	0.028	3.0E-4	7.04	0.07	koester2	ubvri	486.3	0.34	0.02	0.02
74	250.5079	36.38501	32000.0	3000.0	0.0	6.85	0.32	0.459	0.034	0.023	2.0E-4	2.27	0.17	koester2	ubvri	367.1	0.47	0.035	0.035
149	250.26241	36.47466	25000.0	1000.0	1000.0	9.1	0.34	0.46	0.034	0.035	4.0E-4	8.77	0.1	koester2	ubvri	464.6	0.28	0.04	0.04
196	250.4158	36.43419	40000.0	10000.0	2000.0	9.25	0.25	0.555	0.022	0.02	2.0E-4	3.63	0.11	koester2	HST	94.1	0.6	0.26	0.1
288	250.4319	36.4391	45000.0	1000.0	1000.0	9.34	0.14	2.899	0.111	0.041	4.0E-4	1.08	0.0	levenhagen17	HST	80.2	0.47	0.035	0.035
290	250.40359	36.44783	34000.0	2000.0	0.0	9.2	0.24	0.461	0.019	0.021	2.0E-4	1.09	0.03	koester2	HST	68.3	0.47	0.035	0.035

A total of 48 out of 56 WDs were fitted properly with Koester and Levenhagen WD models.

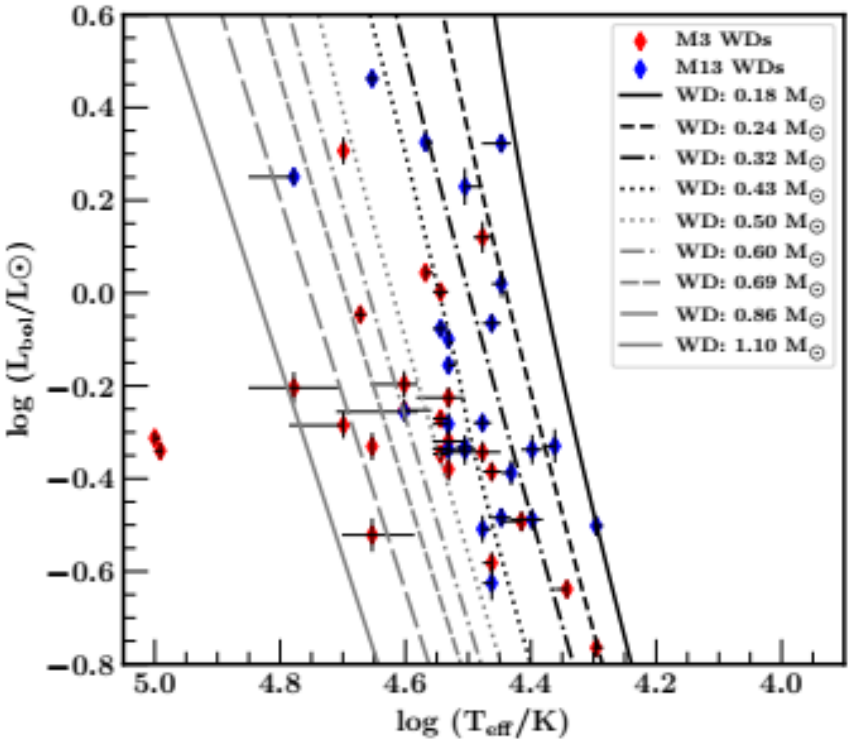
WDs of M3 and M13

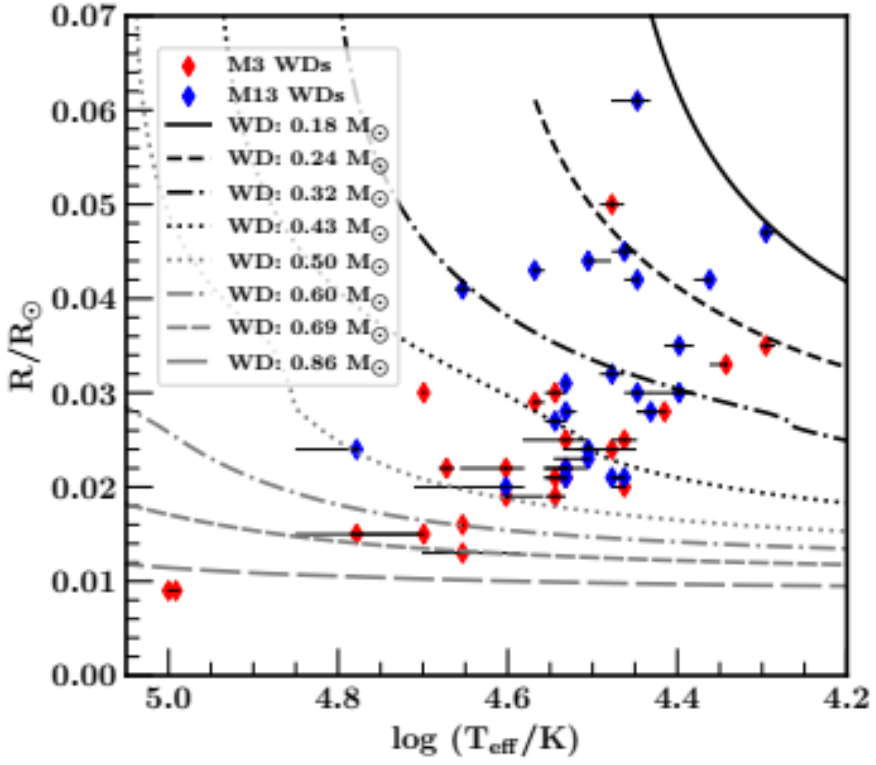




	M3	M13
Teff:	19,750 - 100,000 K	19,750 - 60,000 K
Luminosity:	0.172 - 2.026 $L_\odot$	0.237 - 2.899 $L_\odot$
Radius:	0.009 - 0.050 $R_\odot$	0.020 - 0.061 $R_\odot$

WDs of M3 and M13

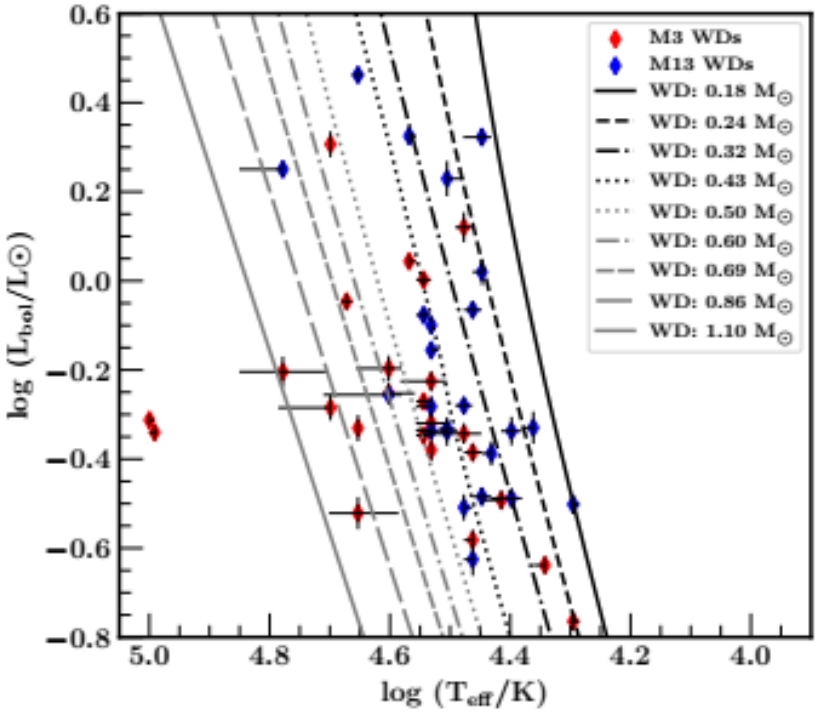


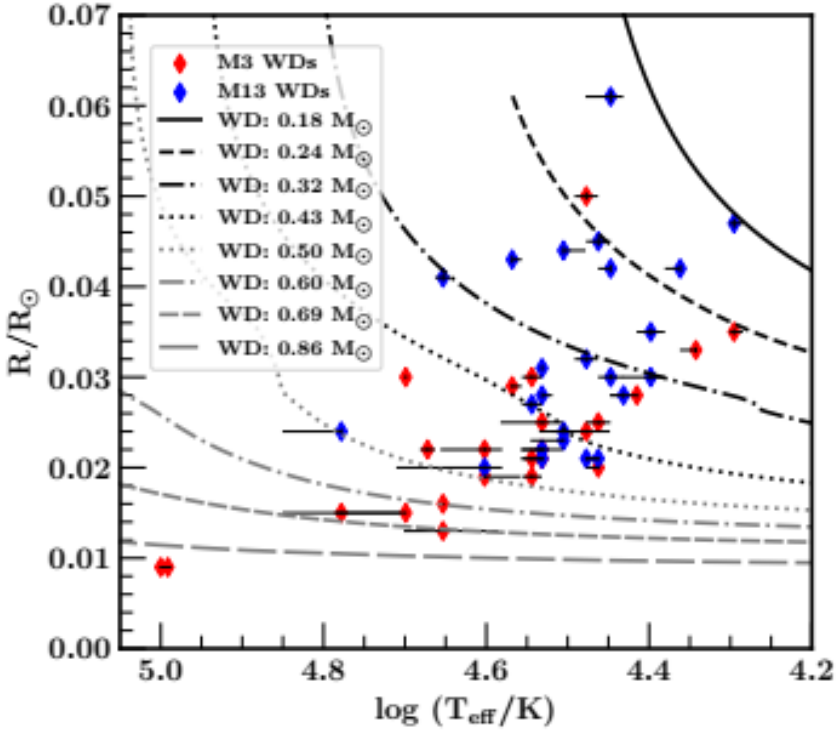


Cooling sequences in the mass-range 0.18 - 1.10 $M_{\odot}$

- Extremely low mass (ELM) He-core WDs; mass-range of 0.15 – 0.43 $M_{\odot}$ (Althaus et al. 2013)
- CO-core WD cooling sequence; mass range of 0.50 – 0.86 $M_{\odot}$ (Renedo et al. 2010)
- Massive WD cooling sequence; mass-range of 1.06 – 1.28 $M_{\odot}$ (Althaus et al. 2007)

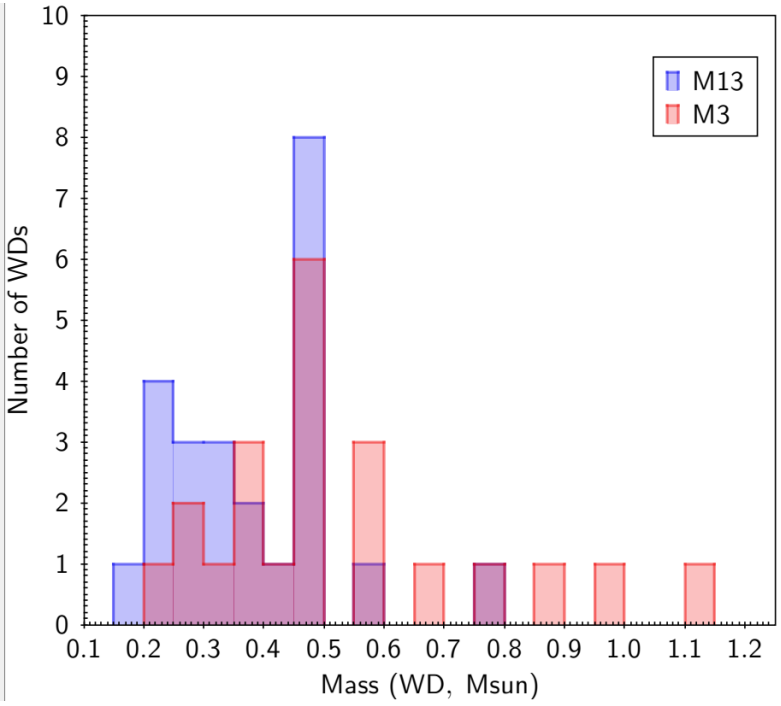
WDs of M3 and M13

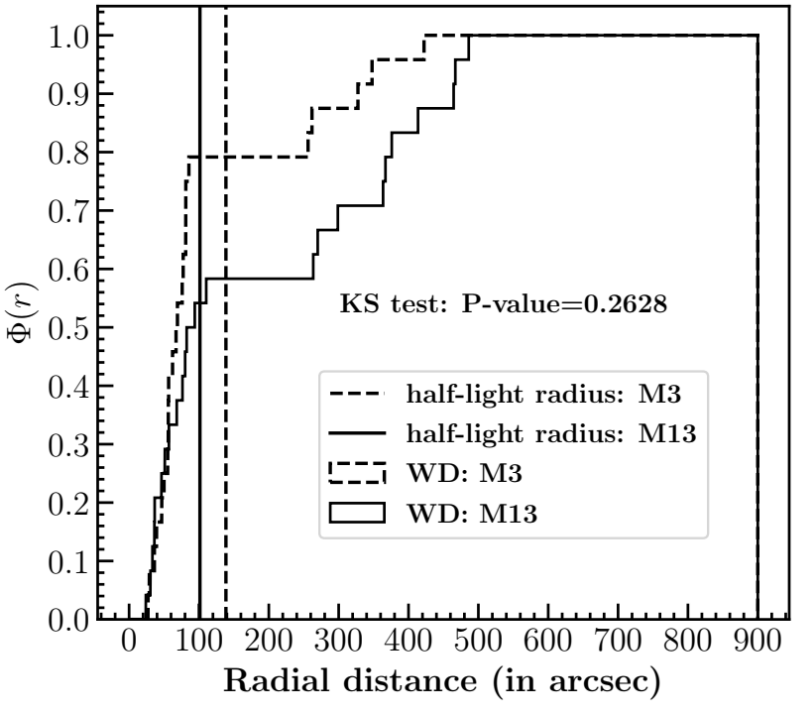




- 7 WDs of M3 and 12 WDs of M13 lying within 0.18 and 0.43 $M_{\odot}$ WD cooling sequence
- 15 WDs are lying in-between 0.43 – 0.50 $M_{\odot}$ WD cooling sequence
- 5 WDs in M3 lying even bluer than 0.86 M WD cooling sequence
- 2 WDs of M3 are at log (Teff /K) ~ 5.0 where we do not have than any WD cooling sequence to be fitted.

Distribution of detected WDs in M3 and M13





- The observed WDs of M13 are clustered in the mass-range 0.15 – 0.50 $M_{\odot}$.
- The distribution of observed WDs suggest that 80% (58%) WDs are in the central region of the cluster M3 (M13).

Conclusions

- We find 24 probable WD candidates each in M3 and M13 GCs in the UV observations .
- The SED fitting of WDs suggest Teff, Luminosity and Radius of UV bright WDs are in the range of 19,750 – 100,000 K (19,750 – 60,000 K), 0.172 - 2.026 $L_{\odot}$ (0.237 - 2.899 $L_{\odot}$), and 0.009 - 0.050 $R_{\odot}$ (0.020 - 0.061 $R_{\odot}$), respectively in M3 (M13).
- A comparison Teff, log L and radius of the observed WDs and WD cooling sequence of different masses suggest that
  - 19 WDs are in the mass-range of 0.18 – 0.43 $M_{\odot}$
  - 15 WDs are in the mass-range of 0.43 – 0.50 $M_{\odot}$
  - 6 WDs are in the mass-range of 0.50 – 0.86 $M_{\odot}$
  - 3 WDs are in the mass-range of 0.86 – 1.10 $M_{\odot}$
- 80% (58%) WDs are in the central region of the cluster M3 (M13).

– Under review in MNRAS

Thank You!

and

Questions!