

SPECTROSCOPIC ANALYSIS OF WHITE DWARFS IN MESSIER 67



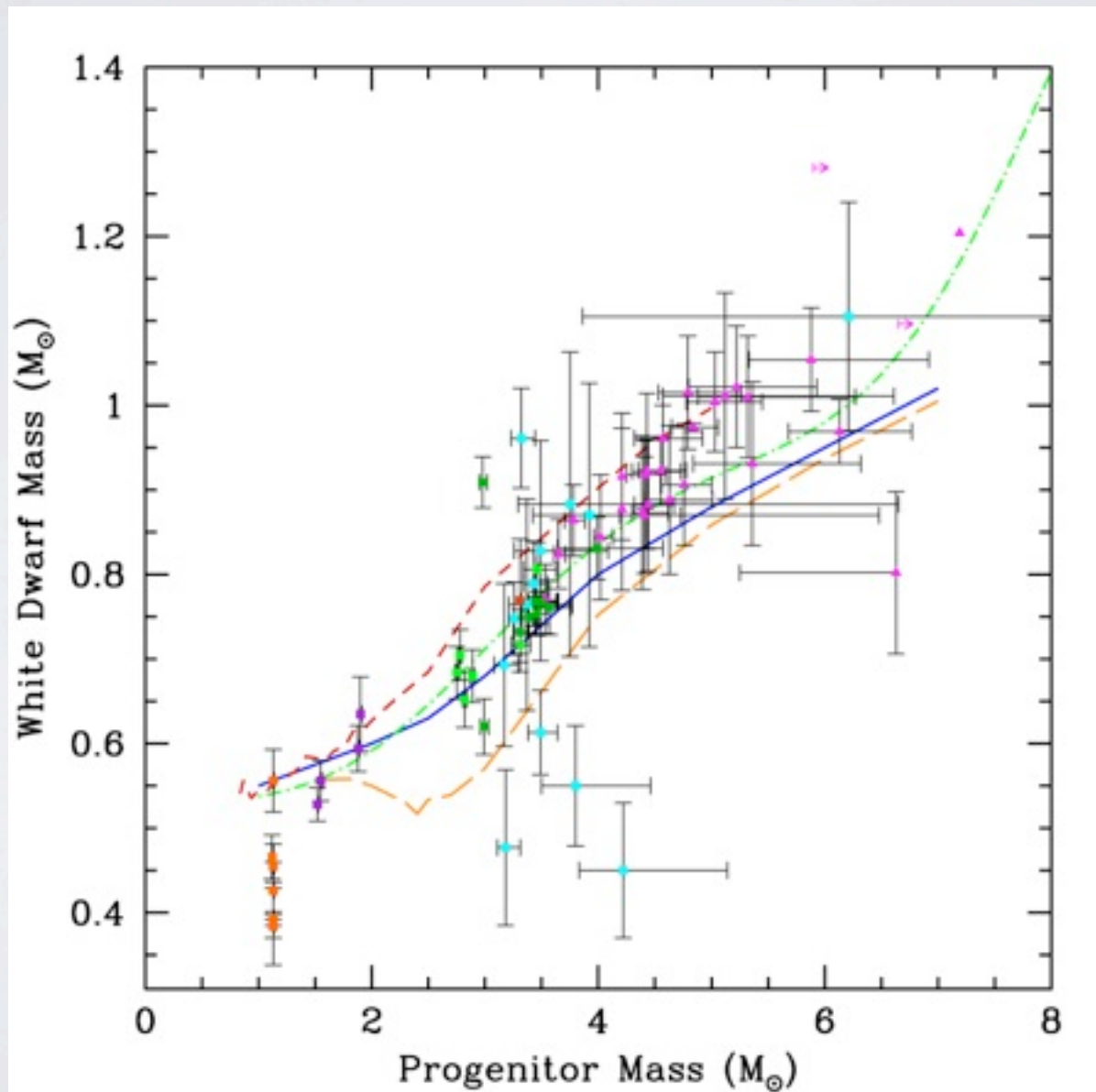
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Collaborators: M. Bolte, K. Rubin, A. Bellini, L. Bedin, G. Piotto, J.
Kalirai, J. Liebert, S. Howell

M67 is an ideal laboratory for studying the remnants of solar-type stars.

- $[Fe/H]=+0.05\pm 0.02$ (Pancino et al 2009)
- $(m-M)_0=9.60\pm 0.09$ (Percival & Salaris 2003)
- $E(B-V)=0.04\pm 0.03$ (Pancino et al 2009)
- Age= 4 ± 0.25 Gyr
- $M_{MSTO}=1.36M_{\odot}$



Our goals are to determine the initial-final mass relation for Z_{\odot}, M_{\odot} stars, to study WD atmospheric compositions in clusters, and to look for outliers.



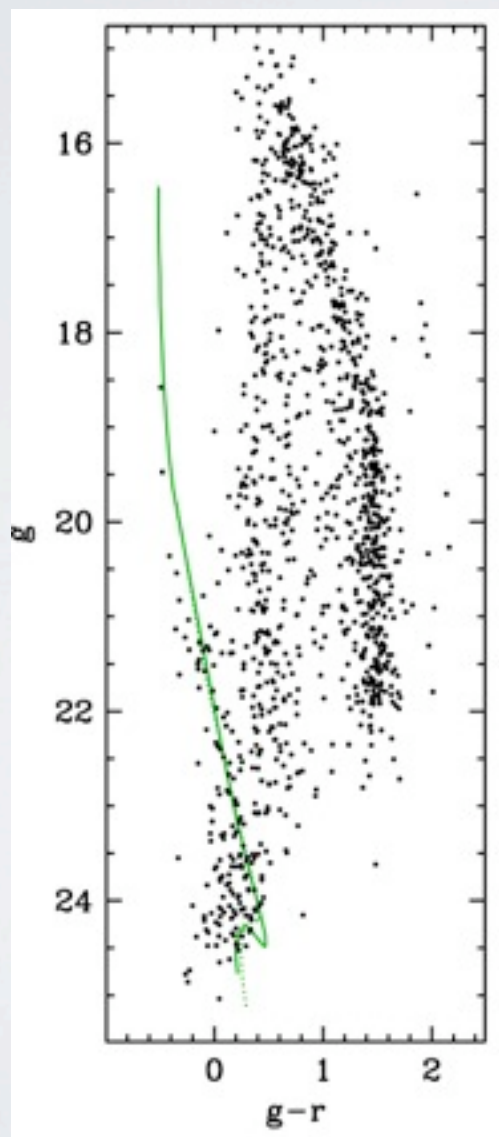
As of Williams et al. (2009)

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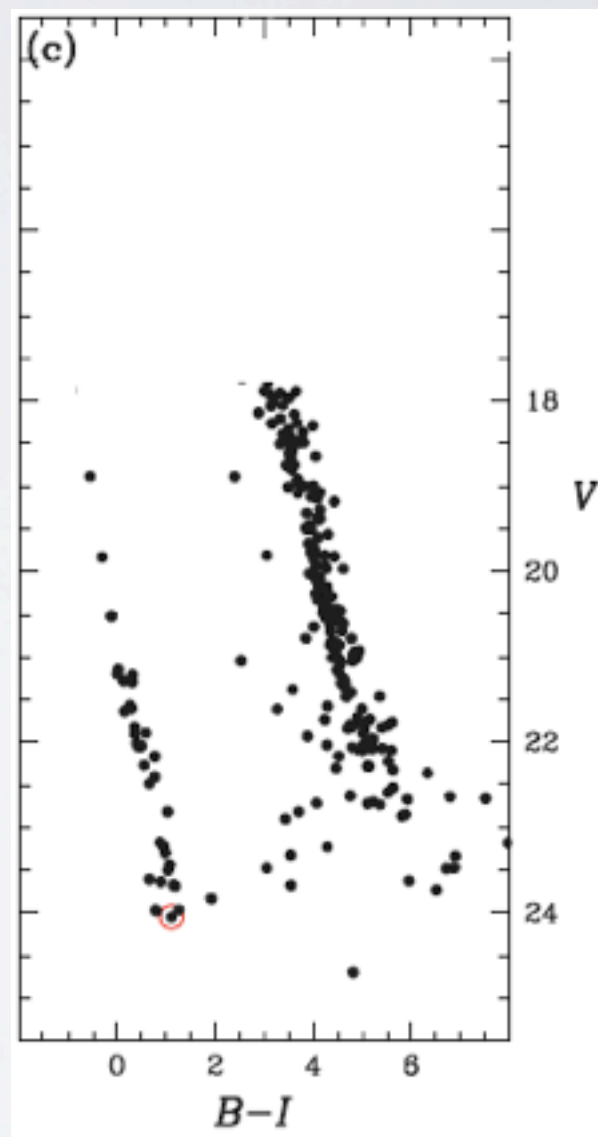
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N.B. Catalan, Oswalt, and others have used field stars for low mass end. Clusters give precision snapshot at given time and metallicity. Field stars give greater numbers and M_i coverage at cost of precision.

Photometry resulted in a large sample of likely cluster WDs; proper motions of Bellini et al. (2010) were used to select cluster members.

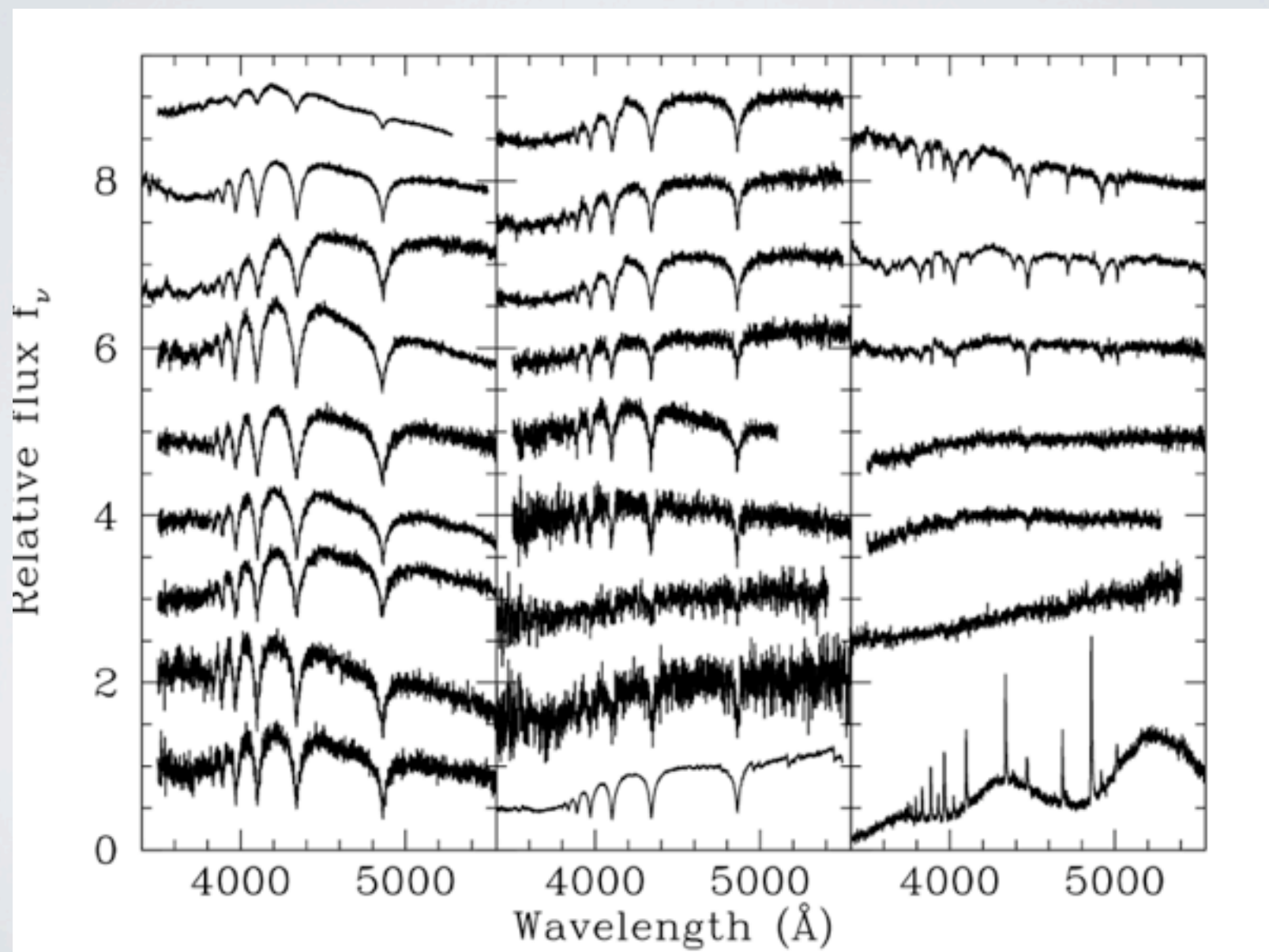


Our data



Bellini et al (2010), on similar scale

Keck spectroscopy of 23 cluster (proper-motion member) WDs and 3 WDs with no PM data: 17 DAs, 1 DA+dM, 6 DBs, 1 polar, and 1 $z=0.205$ post-starburst galaxy.



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S/N > 45 for $M_g < 12$ ($T_{\text{eff}} > 10500$ K)

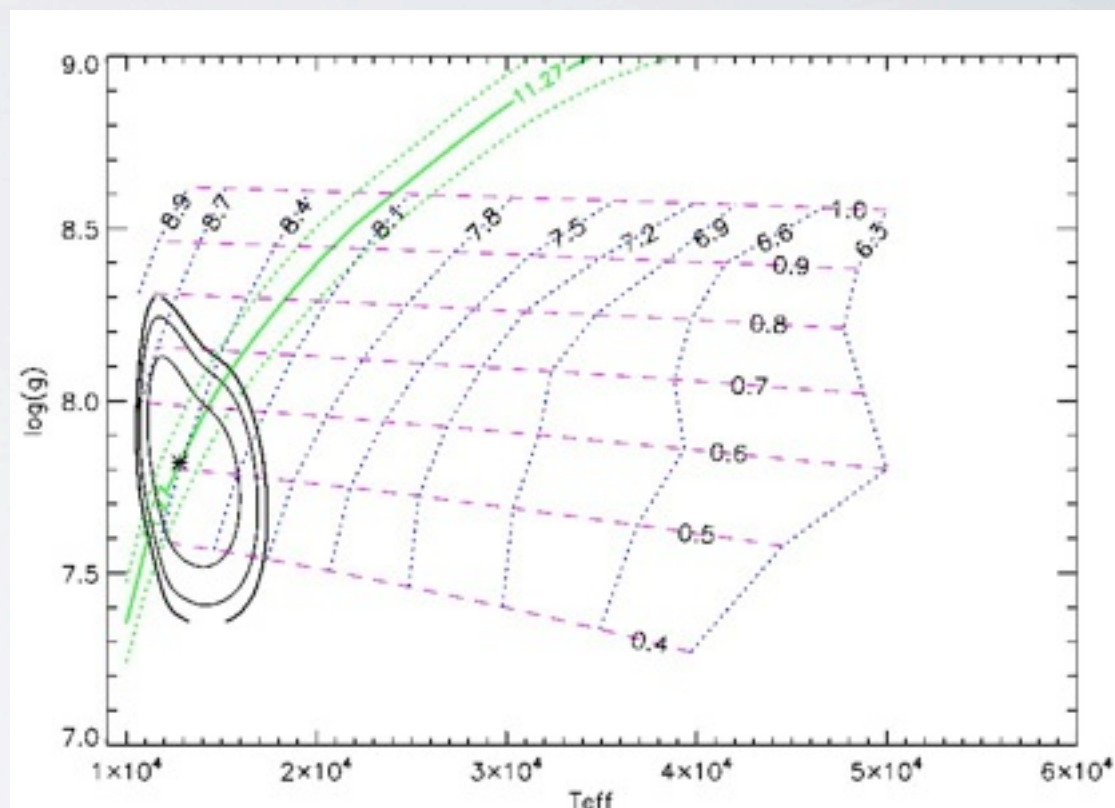
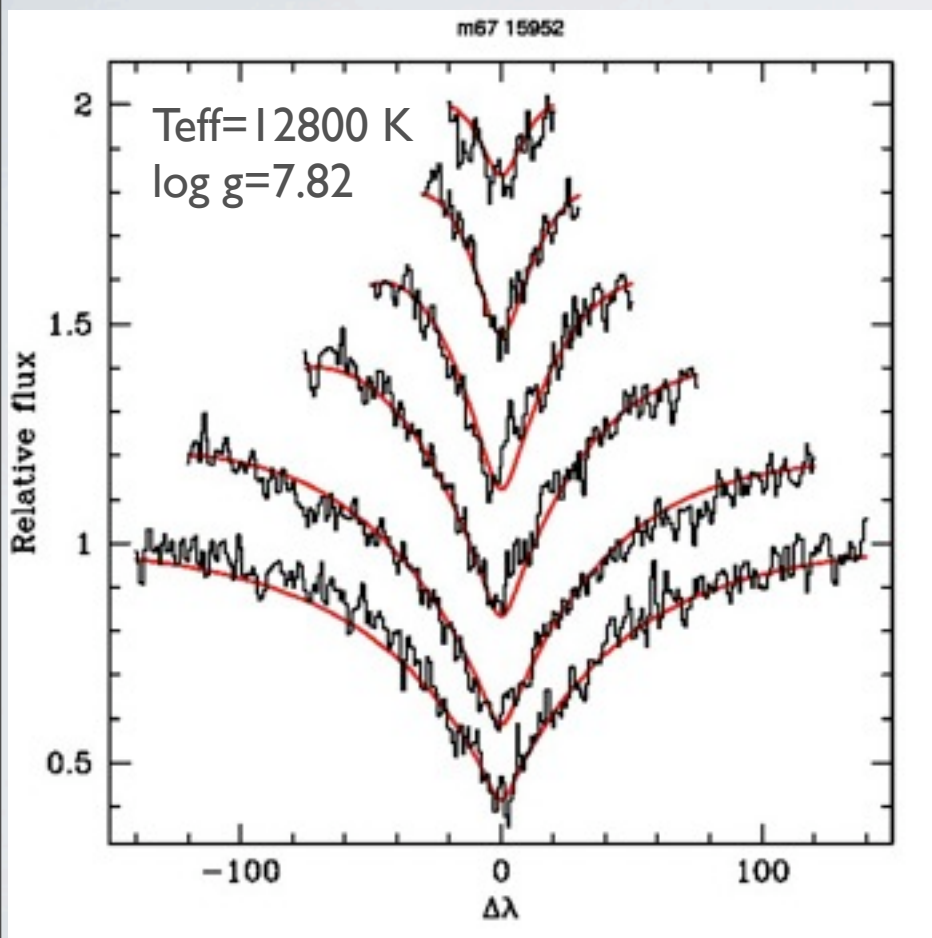
IDs for $M_g < 13.6$ ($T_{\text{eff}} > 7250$ K)

Galaxy was a likely PM member (even PMs are not infallible!)

Also had another 30 field WDs; can test membership techniques

Bright DB is LB3600, presented by Tom Fleming in 1996 workshop

Balmer-line fitting was performed for DAs with $M_g < 12$; PM memberships were cross-checked against distance modulus memberships.



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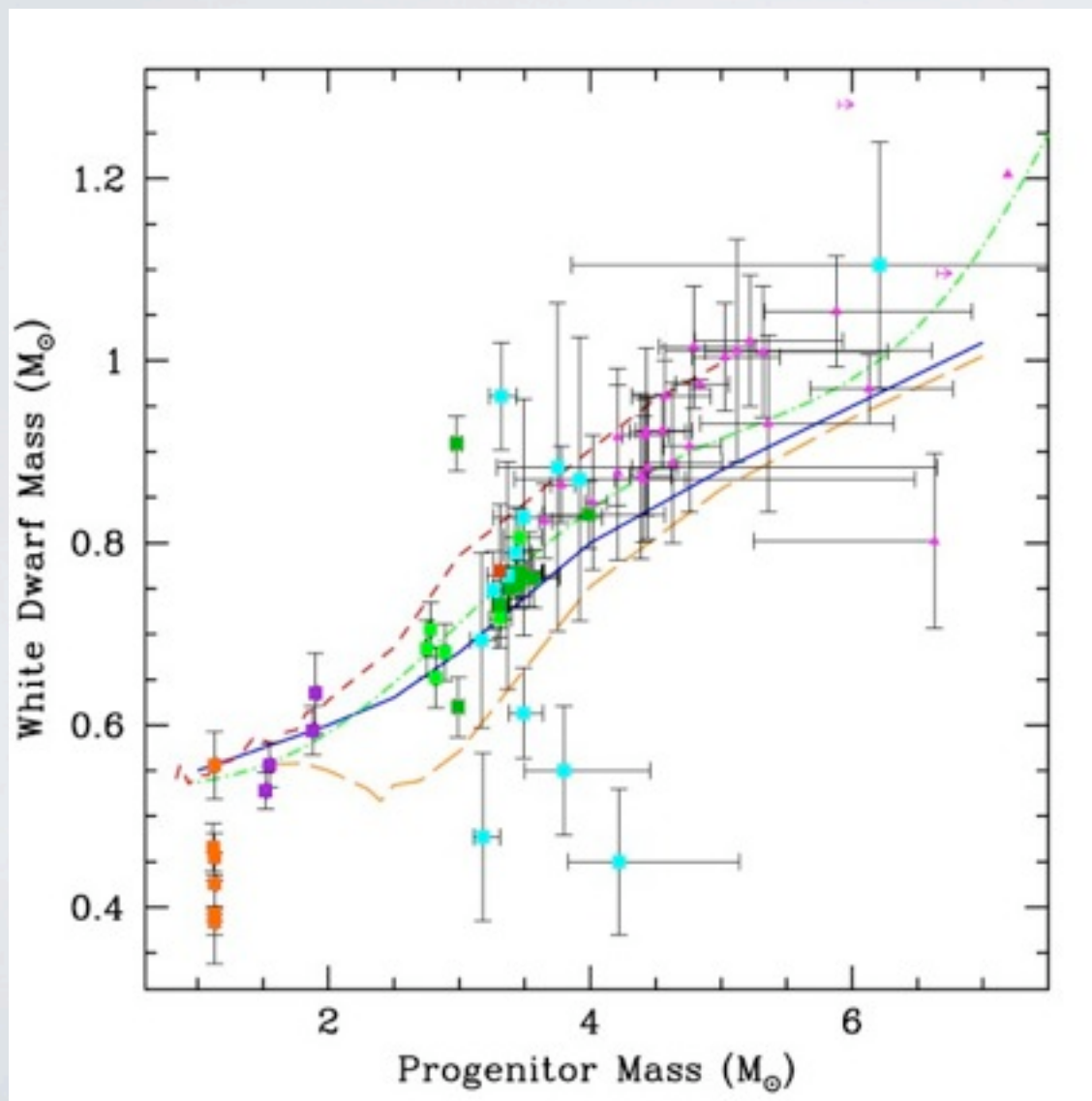
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Still using older models; no time to fix yet.

95%, 99%, and 99.9% contours

Green contours are all WD models w/ M_v consistent with cluster membership and cluster distance.

5 proper-motion member DAs with good fits and $T_{\text{eff}} > 12000$ K. Four are $\sim 0.6 M_{\odot}$; 1 is $\sim 0.5 M_{\odot}$. Two or three more to come.



Dominguez et al. 1999

Weidemann 2000

Marigo 2007

Ferrario et al. 2005

M67

NGC 6791

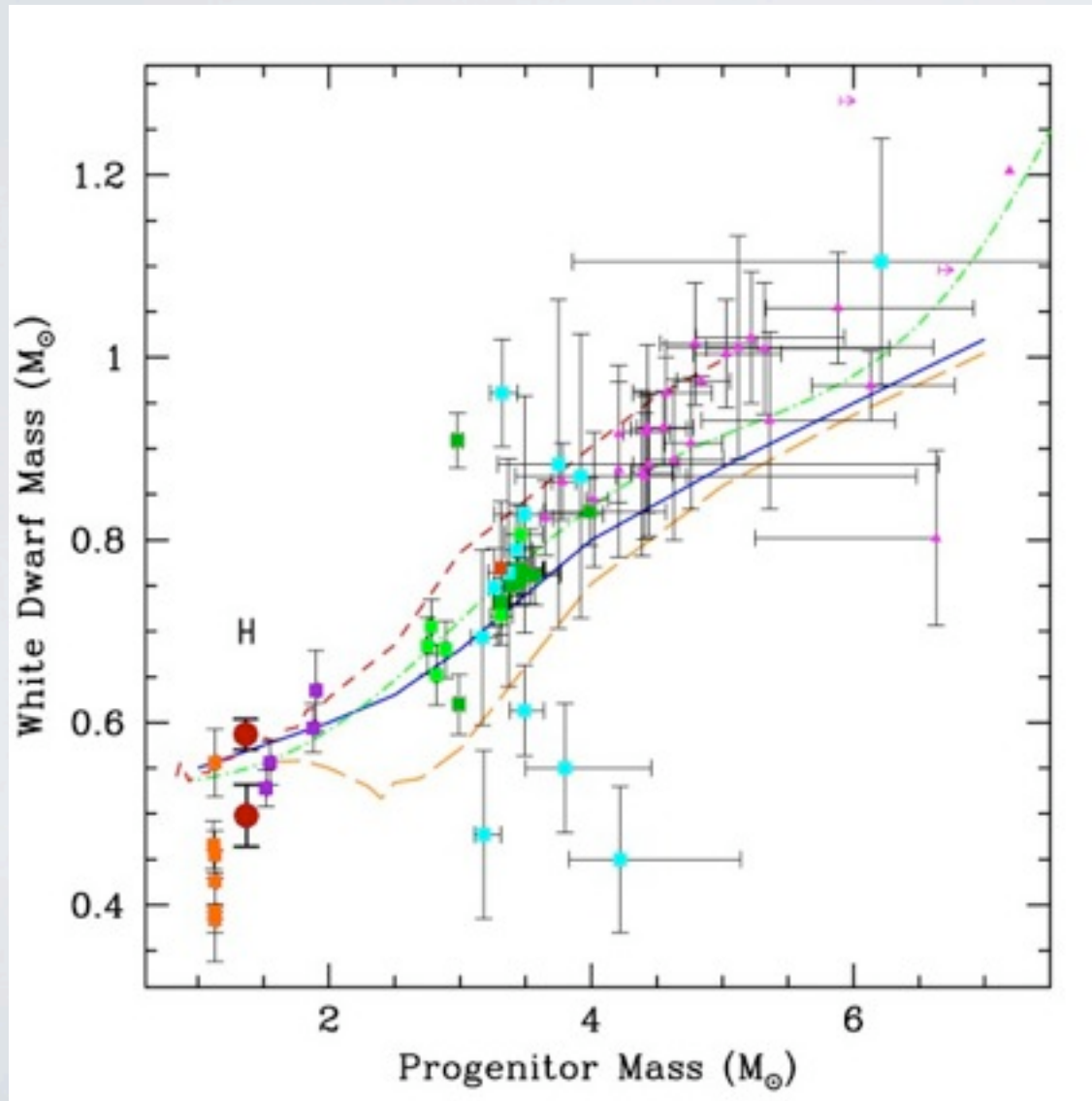
NGC 7789/6819

Hyades/Praesepe

NGC 2099

Everything else

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Everything else

One team has claimed there is a significant difference in DA:non-DA ratio in open clusters

Cluster	DAs	Non-DAs	DBs	Reference
NGC 2099	13	0	0	Kalirai et al. (2005)
NGC 6791	8	0	0	Kalirai et al. (2007)
NGC 6819	2	0	0	Kalirai et al. (2008)
NGC 7789	1	0	0	Kalirai et al. (2008)
M 4	24	0	0	Davis et al. (2010)
TOTAL	48	0	0	

Accounting for DB gap, we find nearly-normal DA:non-DA ratio in clusters with relatively complete spectroscopic data on proper-motion selected WDs.

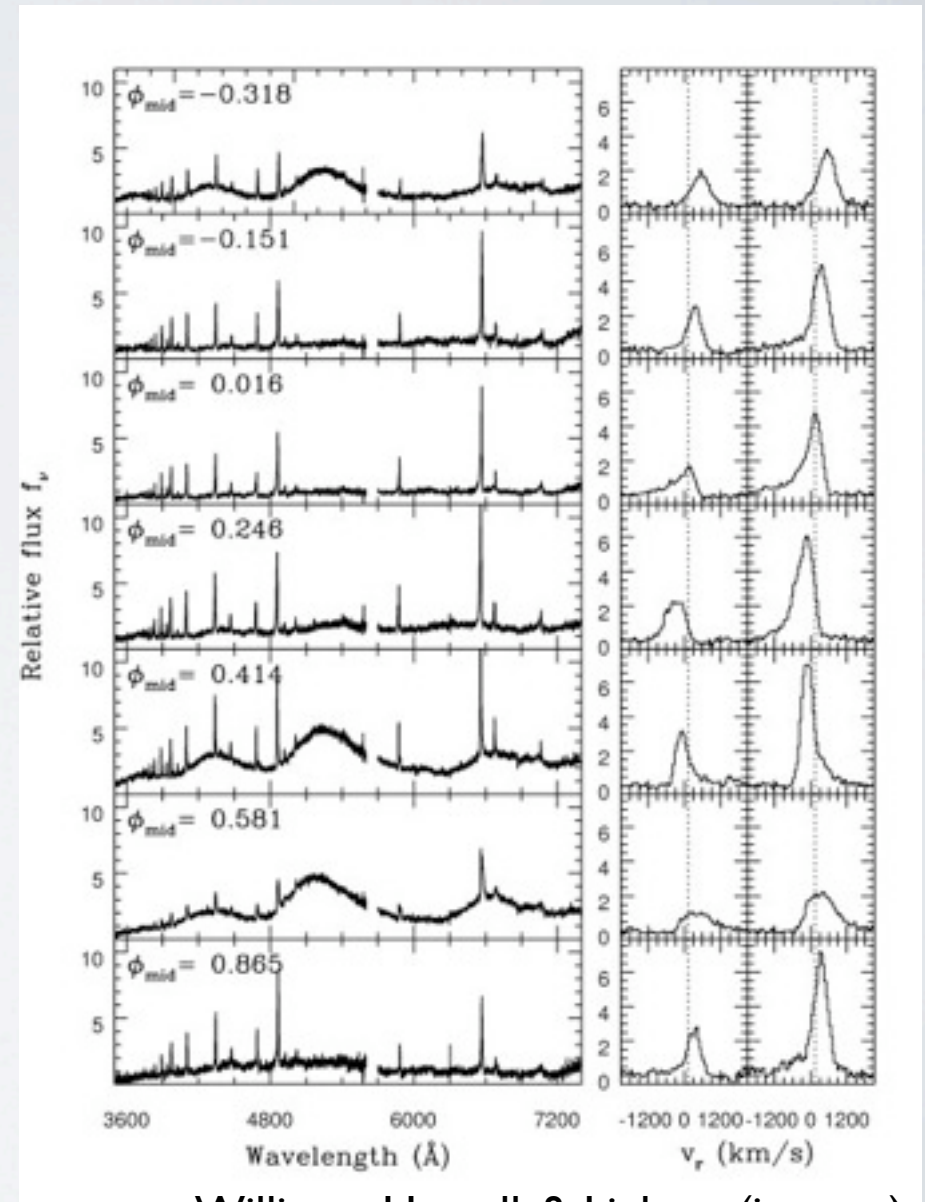
Cluster	DA	# non-DA	# DB	Notes
M 35	5	1	0	Hot DQ
NGC 2516	2	0	0	
NGC 3532	2	0	0	
NGC 2287	2	0	0	
Praesepe	10	0	0	
Hyades	5	1	0	1 DBA
M 67	15	5	4	1 DC
Totals	41	7	4	
Ratio (Total:X)	1.17:1	7:1	12:1	Field ratio 5:1; within 1σ

Is it due to magnitude-limited surveys? Some other selection effect? Or is it physical, due to cluster ages?

MUST account for DB gap!!!

The polar EU Cnc is a member of M67 but seemingly underluminous.

- Photometric amplitude and spectrum look like polar in high state.
- ALWAYS observed in high state.
- As cluster member, $M_v=12$, similar to low-state polars in globulars.
- Metallicity effect? Stuck in some intermediate state?



Williams, Howell, & Liebert (in prep)

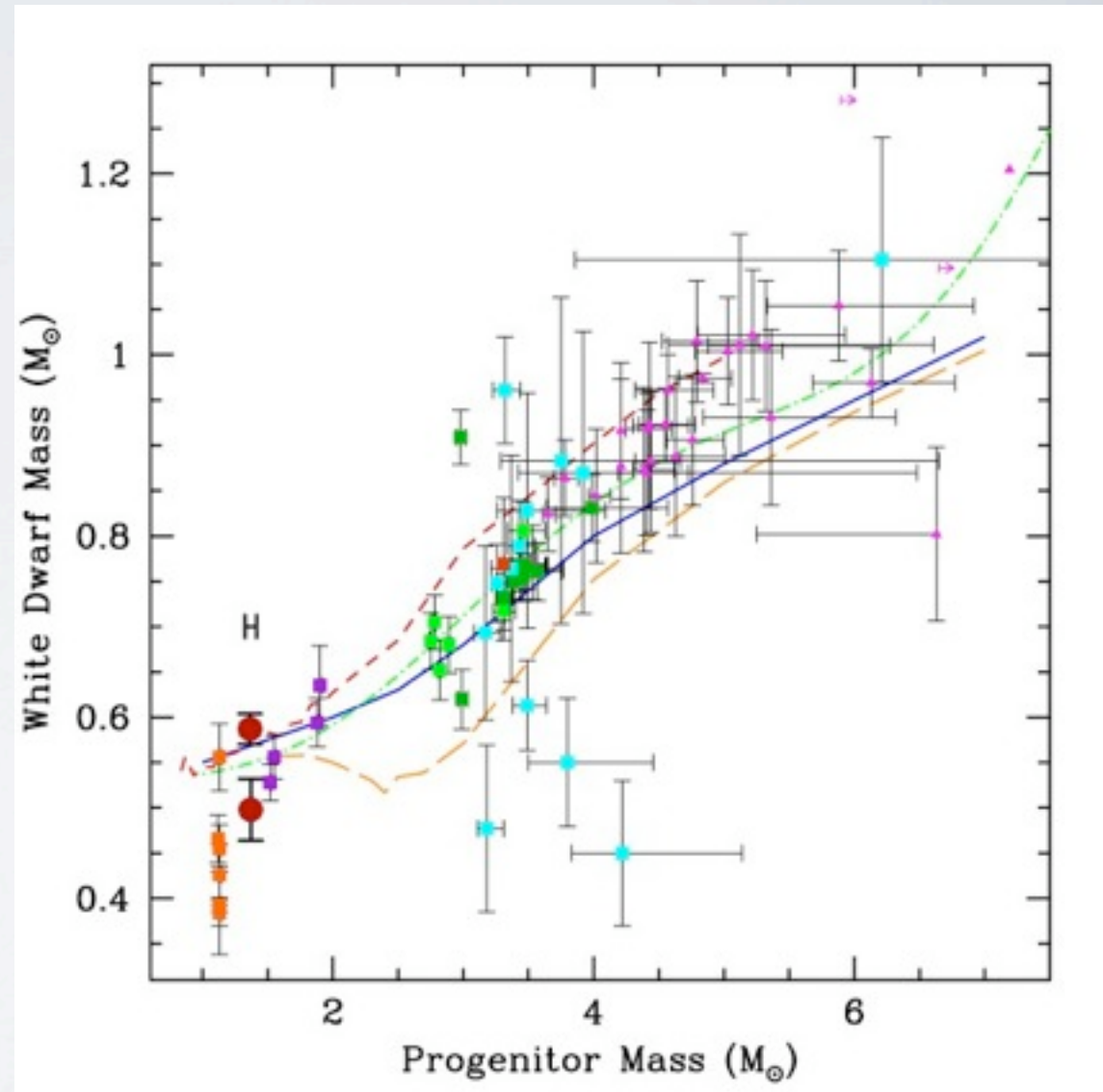
Accreting from 1 pole
P=2.091 h
H=40 MG

CONCLUSIONS

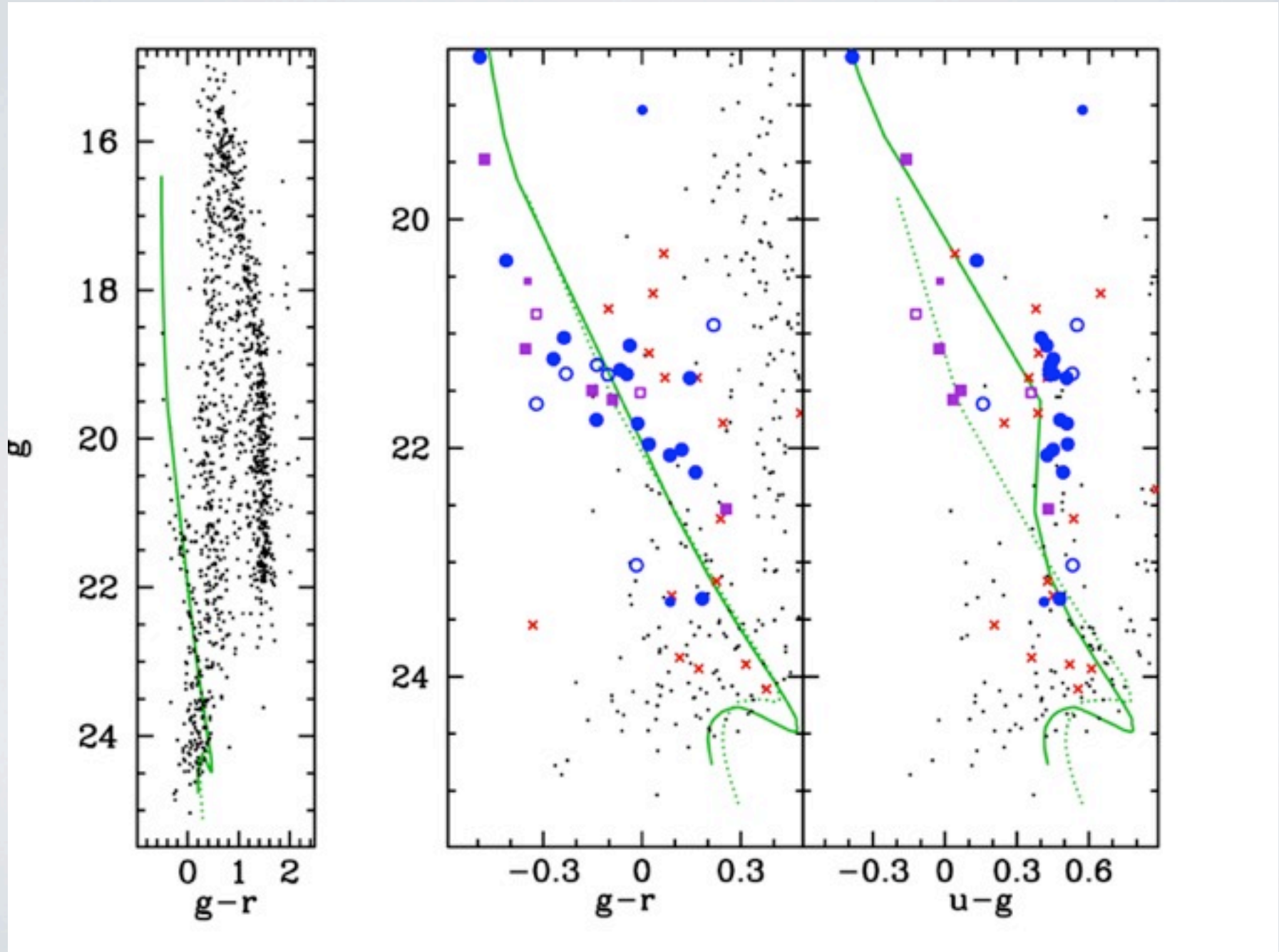
- Brighter M67 WDs have a mass of $\sim 0.6 M_{\odot}$ and fall on the expected IFMR.
- There may be at least one low-mass WD in M67.
- The DA:non-DA ratio may not be anomalous in clusters
- The polar EU Cnc is a cluster member.
- Proper motion memberships are crucial to this work

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CMD with IDs



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Blue circles are DAs, purple squares are non-DAs. Red crosses are non-WDs. Black dots are unresolved objects with no spectral observations. Filled symbols are PM members, open symbols are PM non-members.

Solid green line is 4 Gyr isochrone for Bergeron et al. DA models, Fontaine et al. evolutionary models, and my 2009 IFMR. Dotted green curve is DB isochrone from same sources. The mismatch in color between my data and the isochrones could be due to photometric color terms and should not be taken seriously yet.