Astrofísica
en la
Universitat d'Alacant
Universidad de Alicante

CLASSICAL CEPHEIDS IN OPEN CLUSTERS

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Sofia
June 2023

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Plan de Recuperación, Transformación y Resiliencia

GENERALITAT VALENCIANA

Financiado por la Unión Europea
NextGenerationEU

- Javier Alonso-Santiago (INAF-Catania)
- Berto Castro (AIP Potsdam)
- Amparo Marco (Alicante)
- Hugo Tabernero (CAB, Madrid)

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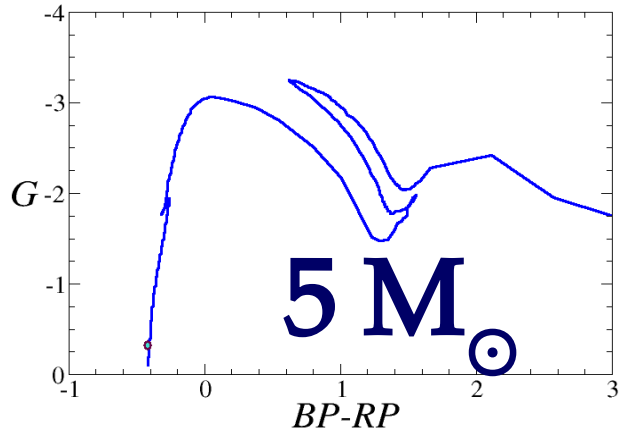
Outline

- Motivation
- NGC 6649 – fits gone awry
- NGC 7790 – which metallicity?
- The low mass end
- Red vs. yellow – does metallicity matter?
- The most massive Cepheids in clusters



The Astrophysical Journal, 938:36 (9pp), 2022 October 10 https://doi.org/10.3847/1538-4357/ac8f24

Cluster Cepheids with High Precision Gaia Parallaxes, Low Zero-point Uncertainties, and Hubble Space Telescope Photometry

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Abstract

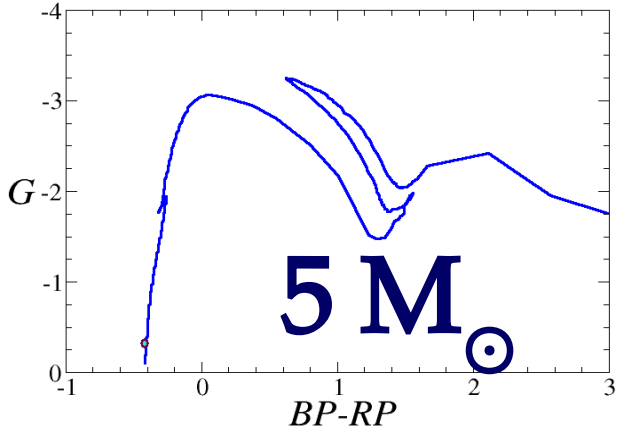
We present Hubble Space Telescope (HST) photometry of 17 Cepheids in open clusters and their cluster mean parallaxes from Gaia EDR3. These parallaxes are more precise than those from individual Cepheids ($G < 8$ mag)

cf. Cruz Reyes & Anderson 23

Motivation

- Open clusters provide an astrophysical environment for Cepheids: age, mass & metallicity.
- Comparison to other members allows gauging of their evolutionary histories.
- For this to be meaningful accurate cluster parameters are needed: do not use AI-generated lists (at least for now).

- Long-term programme running as poor-weather backup at the WHT targeting clusters with Cepheids (among others).



Javier Alonso Santiago

A&A 644, A136 (2020)
https://doi.org/10.1051/0004-6361/202038495

Astronomy & Astrophysics

Three open clusters containing Cepheids: NGC 6649, NGC 6664, and Berkeley 55

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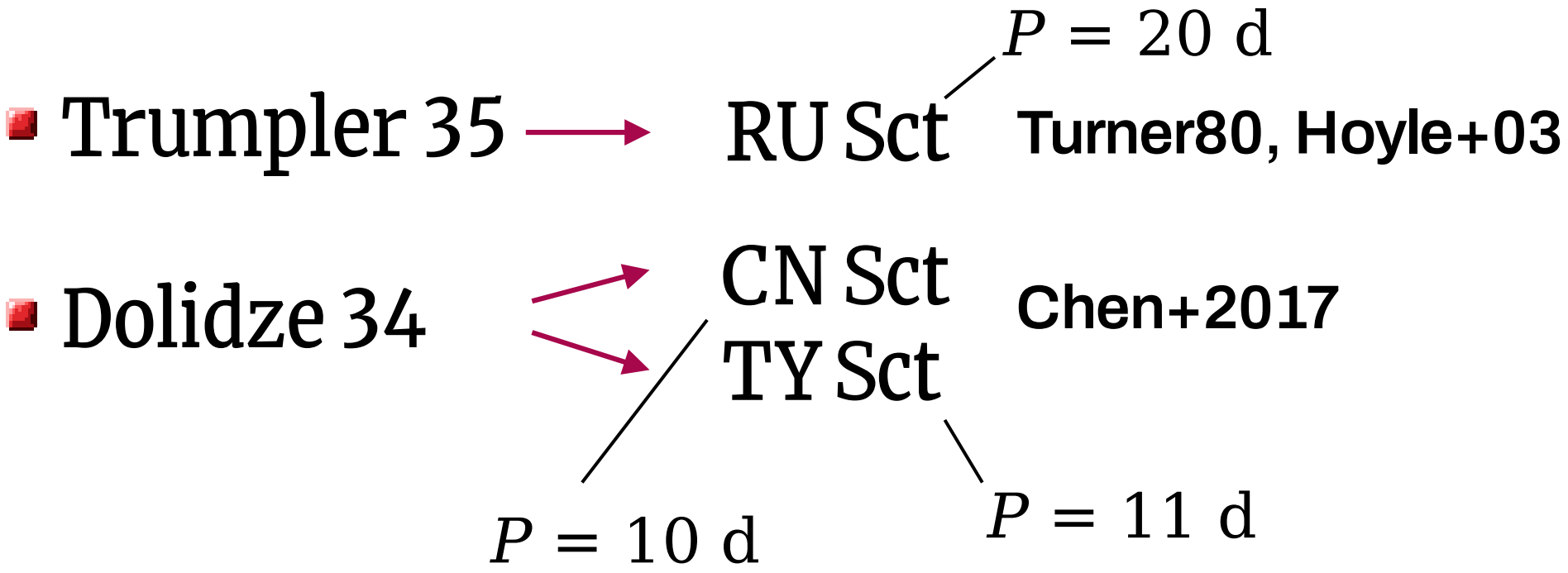
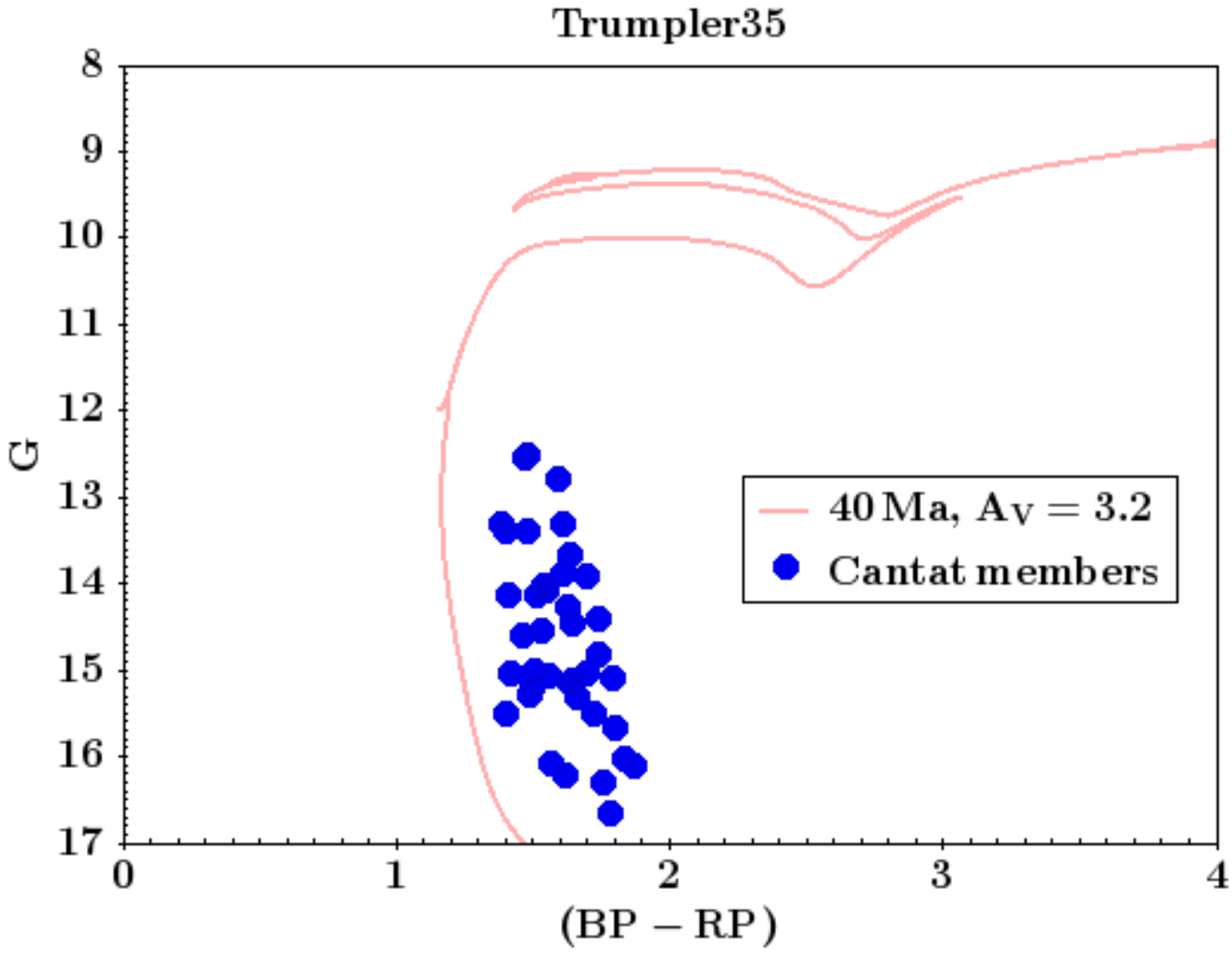
Traditional and new combos



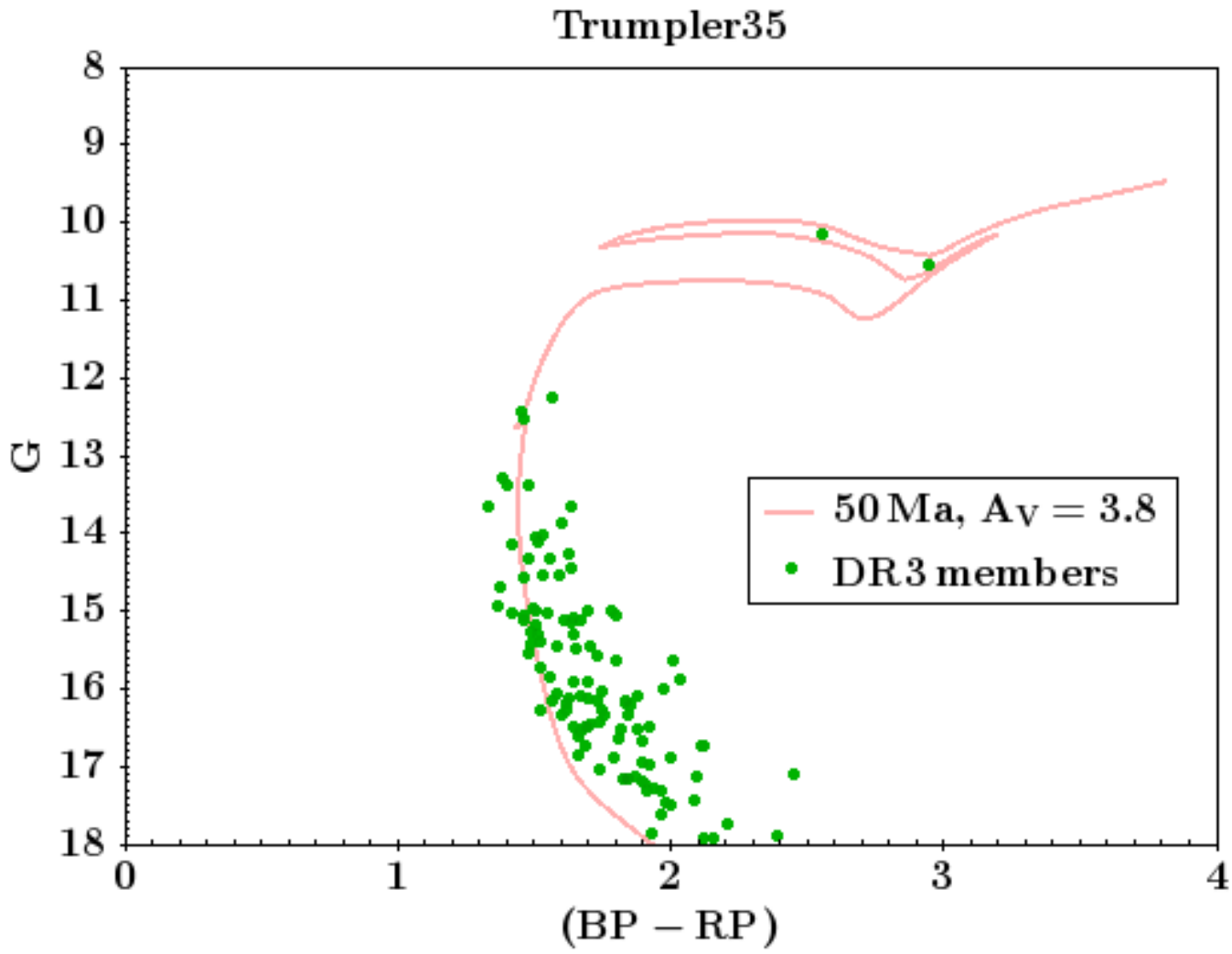
Traditional and new combos killed by Gaia

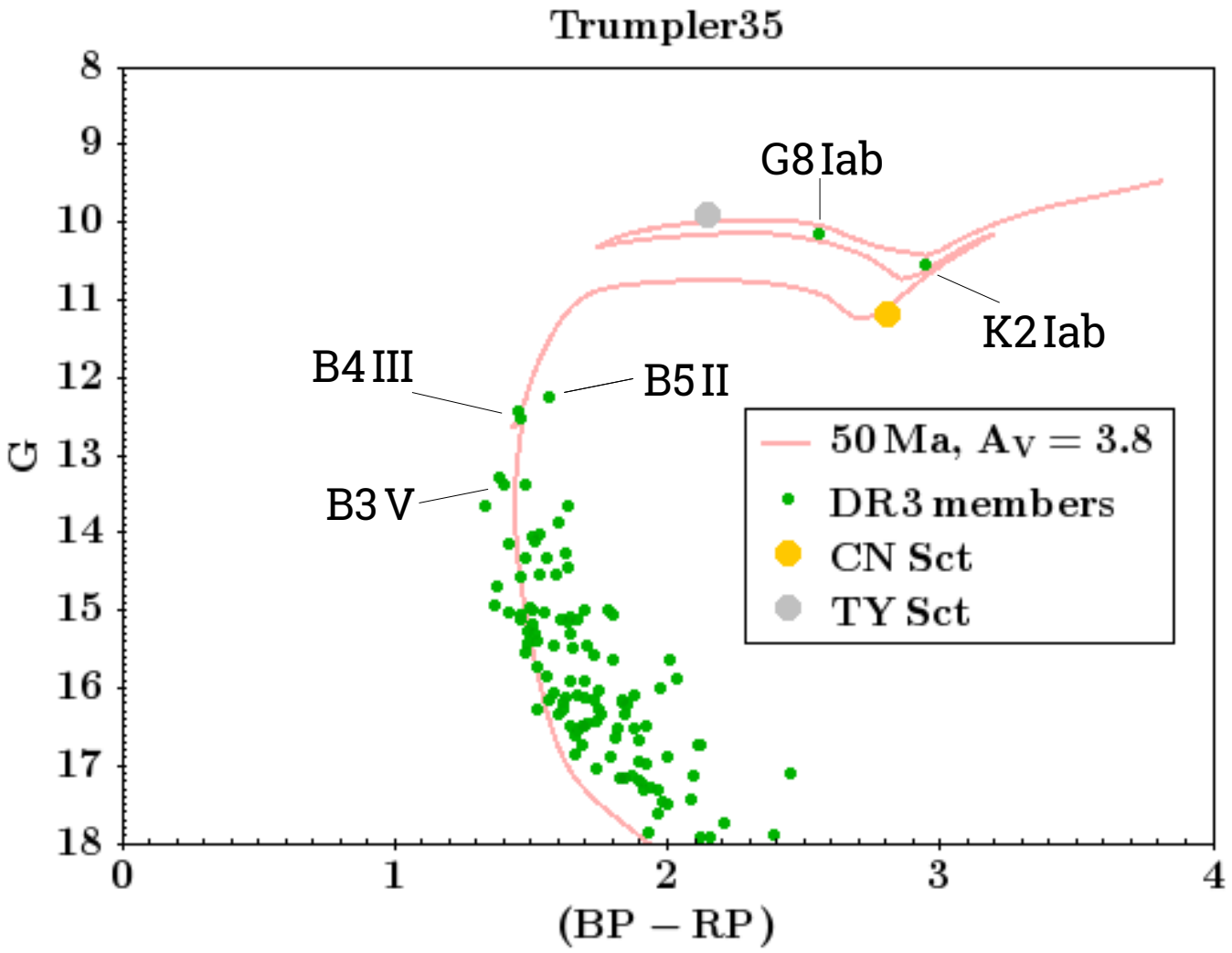
- Trumpler 35 → RU Sct — Turner80, Hoyle+03
- Dolidze 34 → CN Sct, TY Sct — Chen+2017



Members and parameters from Cantat-Gaudin+20

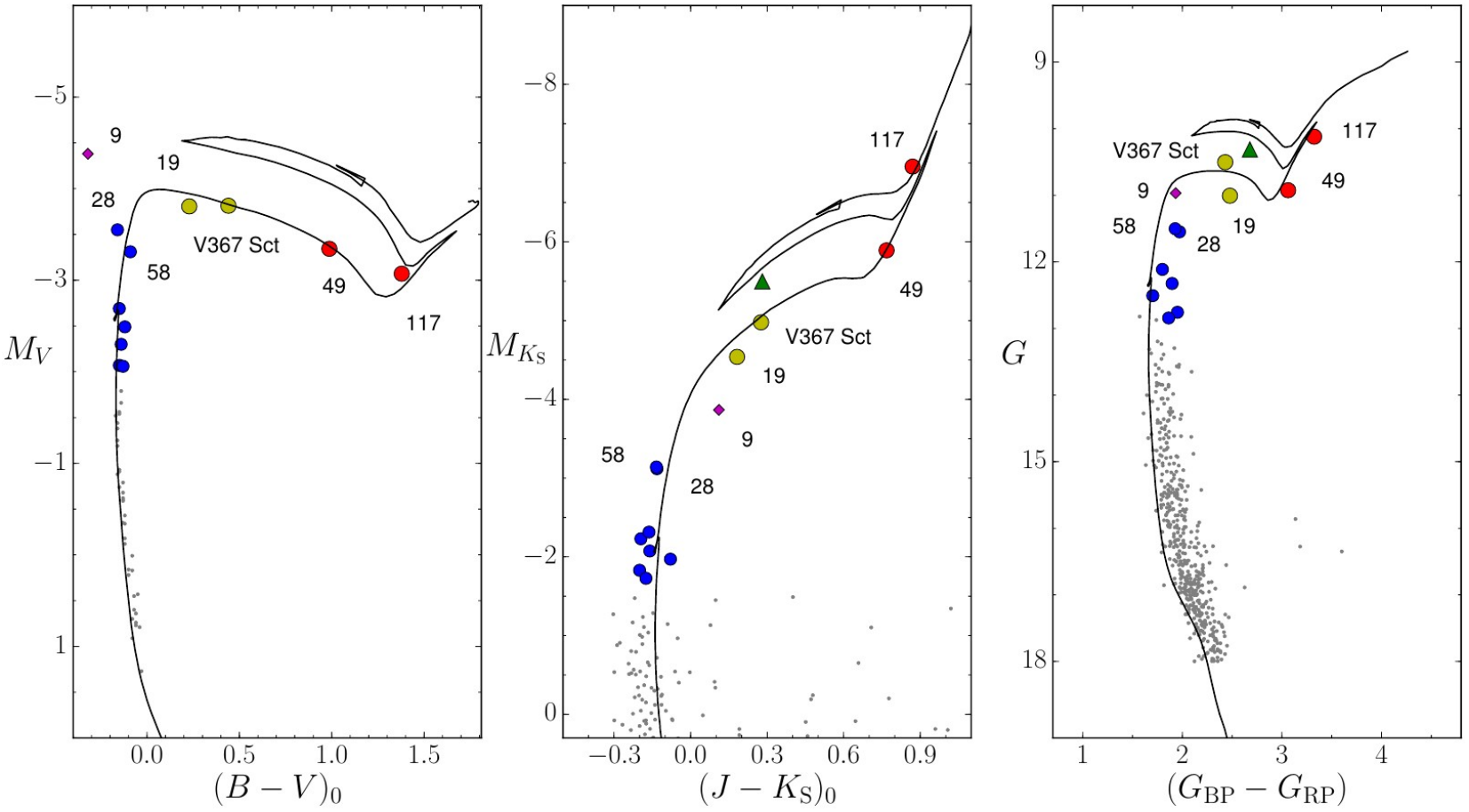
The cluster is not present in Dias+21


Trumpler35
8
9
10
11
12
13
14
15
16
17
18
G
0
1
2
3
4
(BP − RP)
50 Ma, Av = 3.8
DR3 members



Assuming $Z = Z_\odot$, these would be 7 $M_\odot$ stars

NGC 6649



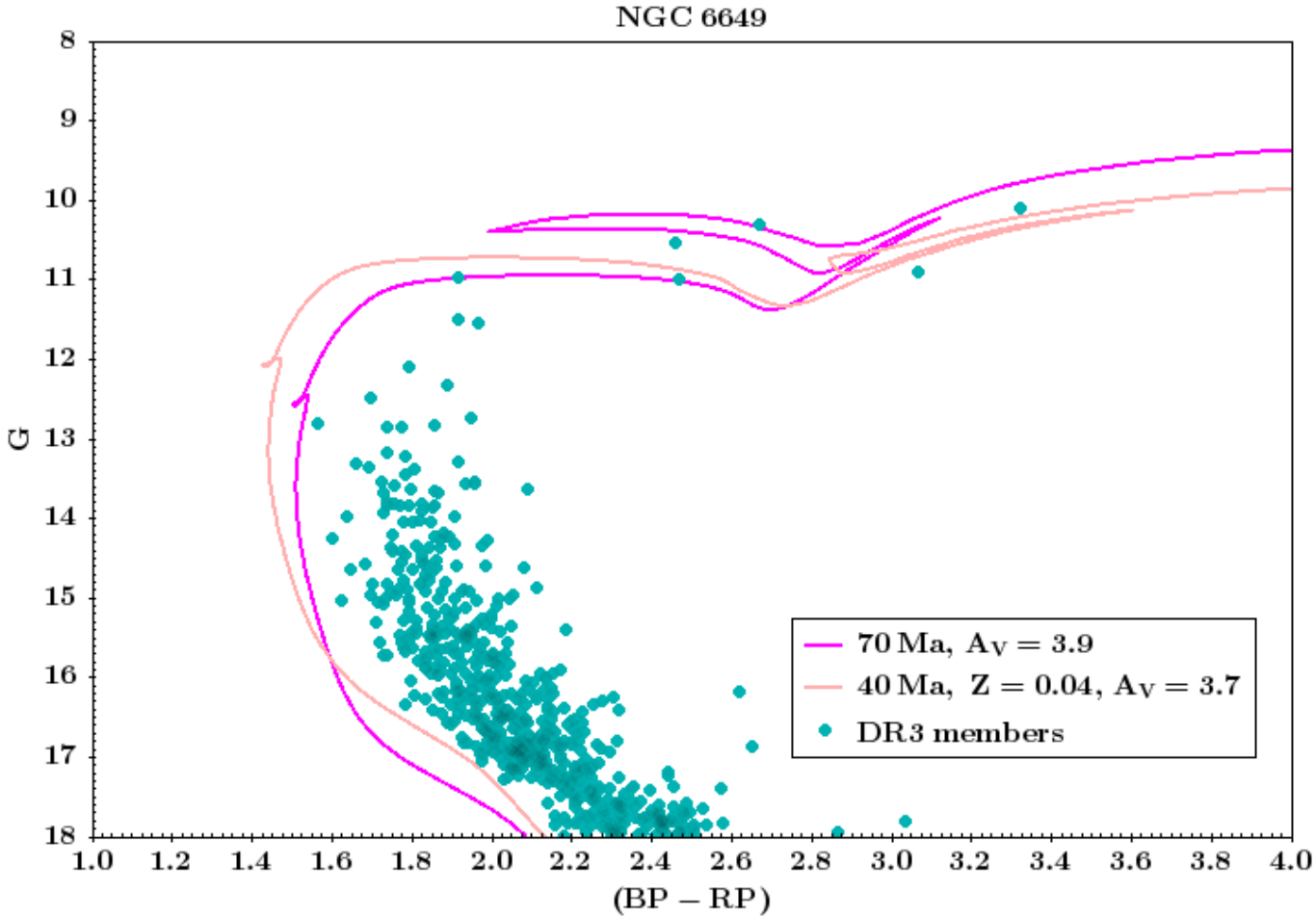
Alonso-Santiago+20

V367 Sct $P = 6.3$ d

$Z \simeq Z_\odot$, 65 Ma, $A_V = 4.3$

Double mode

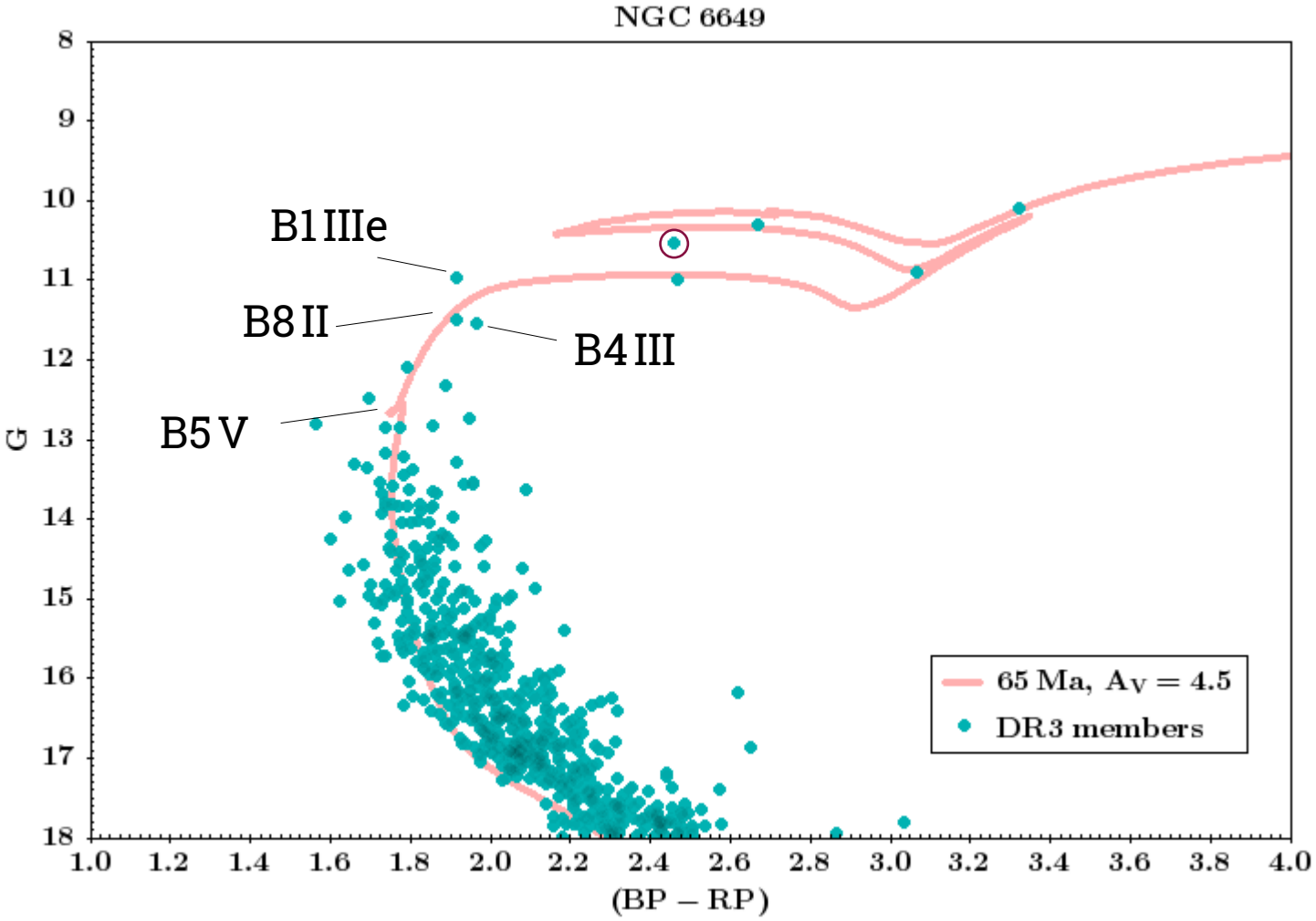
NGC 6649 and AI



Cantat-Gaudin+20 only use $\mathbb{Z}_\odot$ isochrones

Dias+21 let $\mathbb{Z}$ be a free parameter

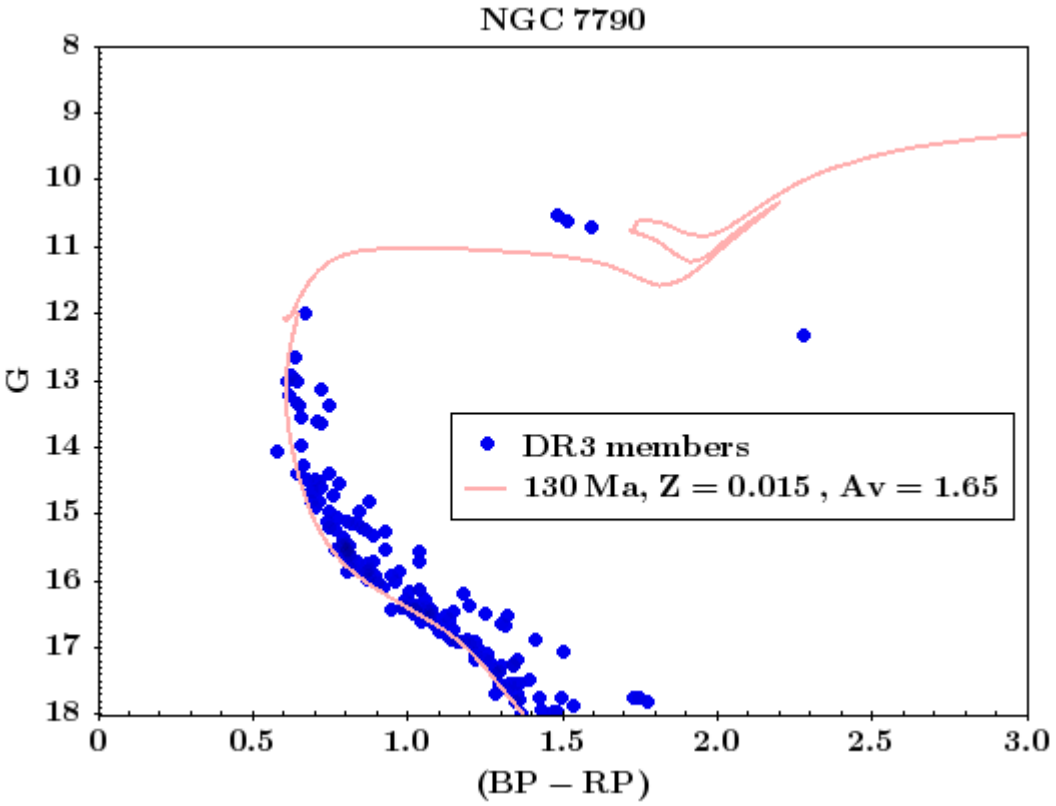
NGC 6649



For $Z = Z_\odot$, these would be 6 $M_\odot$ stars

V367 Sct $P = 6.3$ d

NGC 7790: the cluster with three Cepheids



CF Cas — 4.9 d

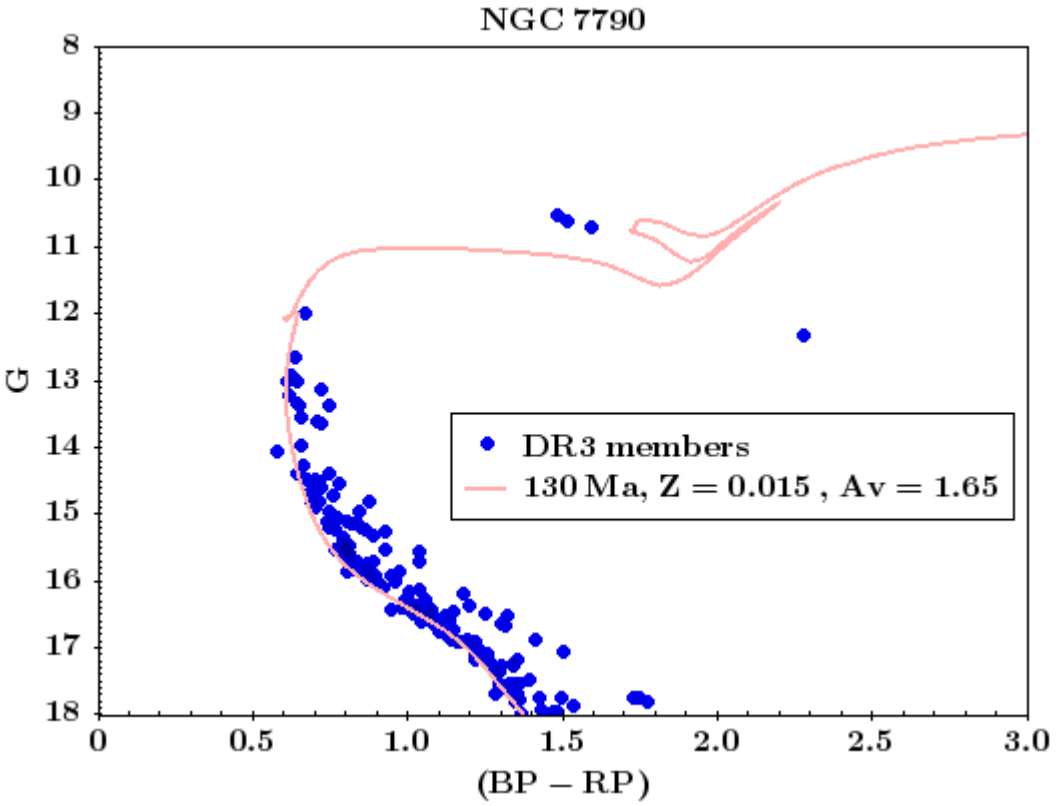
CE Cas A — 5.1 d

CE Cas B — 4.5 d

Cantat-Gaudin+20 **130** Ma, $A_V = 1.65$

Dias+21 100 Ma, $A_V = 1.8$

NGC 7790: the cluster with three Cepheids



CF Cas — 4.9 d

CE Cas A — 5.1 d

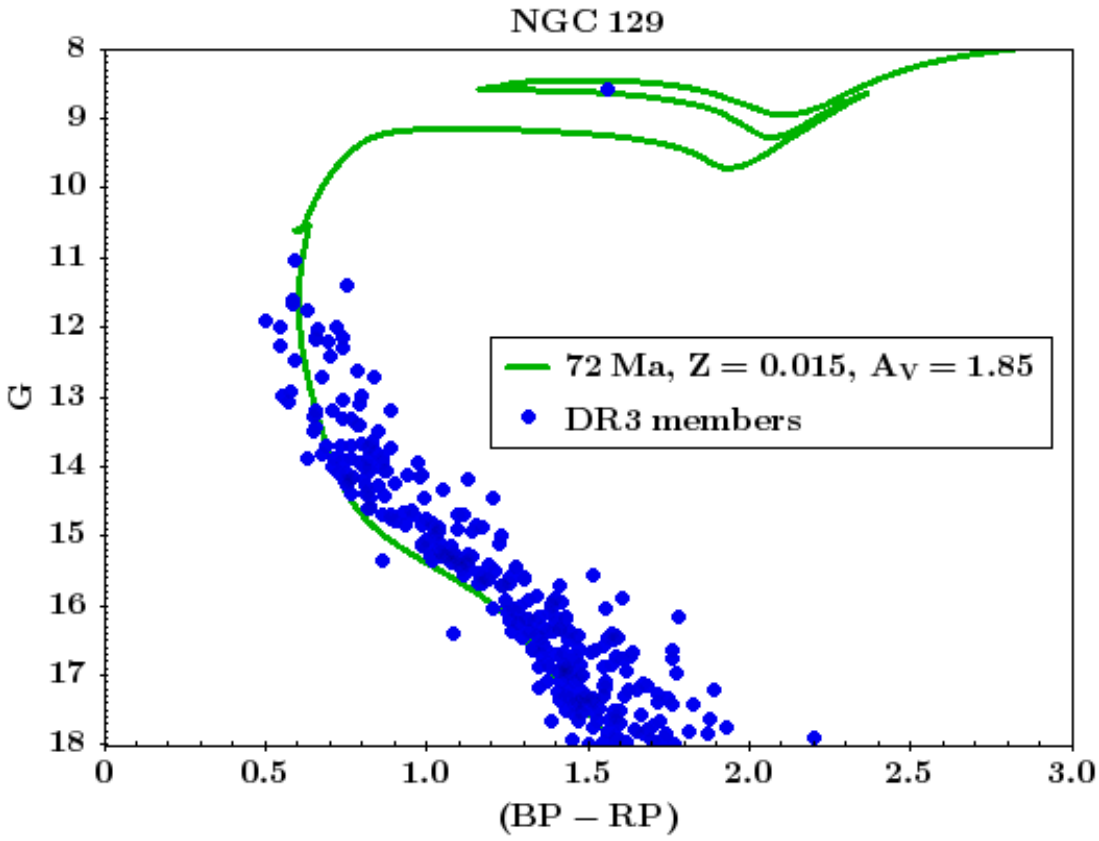
CE Cas B — 4.5 d

But CF Cas is (at least) solar! (Genovali+14, Luck18)

NGC 129

DL Cas is also solar

(Genovali+14, Luck18)



Cantat-Gaudin+20

130 Ma, $A_V = 1.5$

Dias+21

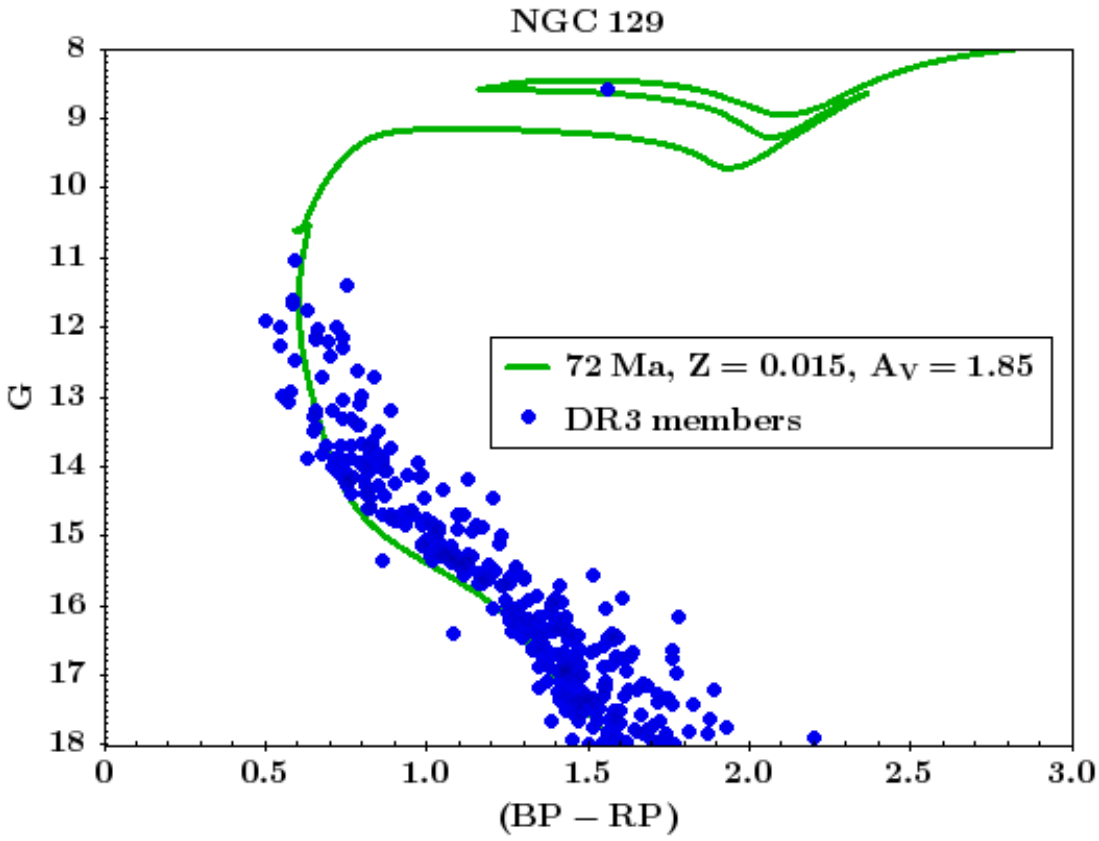
72 Ma, AV=1.7, $\approx 2\ Z_\odot$

DL Cas $P = 7.9$ d

NGC 129

Spectra not yet analysed

Possible halo member



V376 Cas $P = 4.3$ d

Anderson+13 (overtone)

Dias+21

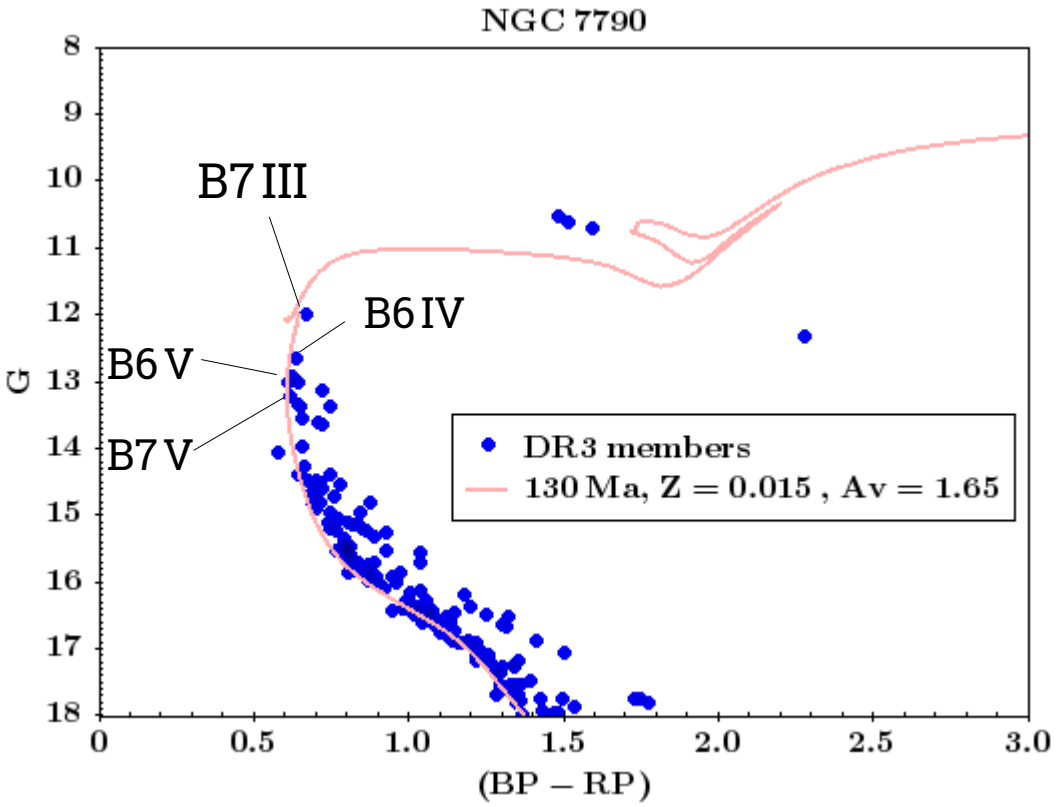
72 Ma, AV=1.7, ≈ 2 $Z_\odot$

DL Cas $P = 7.9$ d

NGC 7790: the cluster with three Cepheids

CF Cas — 4.9 d

CE Cas A — 5.1 d
CE Cas B — 4.5 d



Padova isochrones have trouble reproducing low-mass Cepheids.

For $Z = Z_{\odot}$, these would be 4.6 $M_{\odot}$ stars

The Astrophysical Journal, 621:966–977, 2005 March 10

CLASSICAL CEPHEID PULSATION MODELS. X. THE PERIOD-AGE RELATION

G. Bono,[1] M. Marconi,[2] S. Cassisi,[3] F. Caputo,[1] W. Gieren,[4] and G. Pietrzynski[4,5]

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TABLE 9

Age Estimates for Two Galactic Open Clusters that Host at Least Two Cepheids

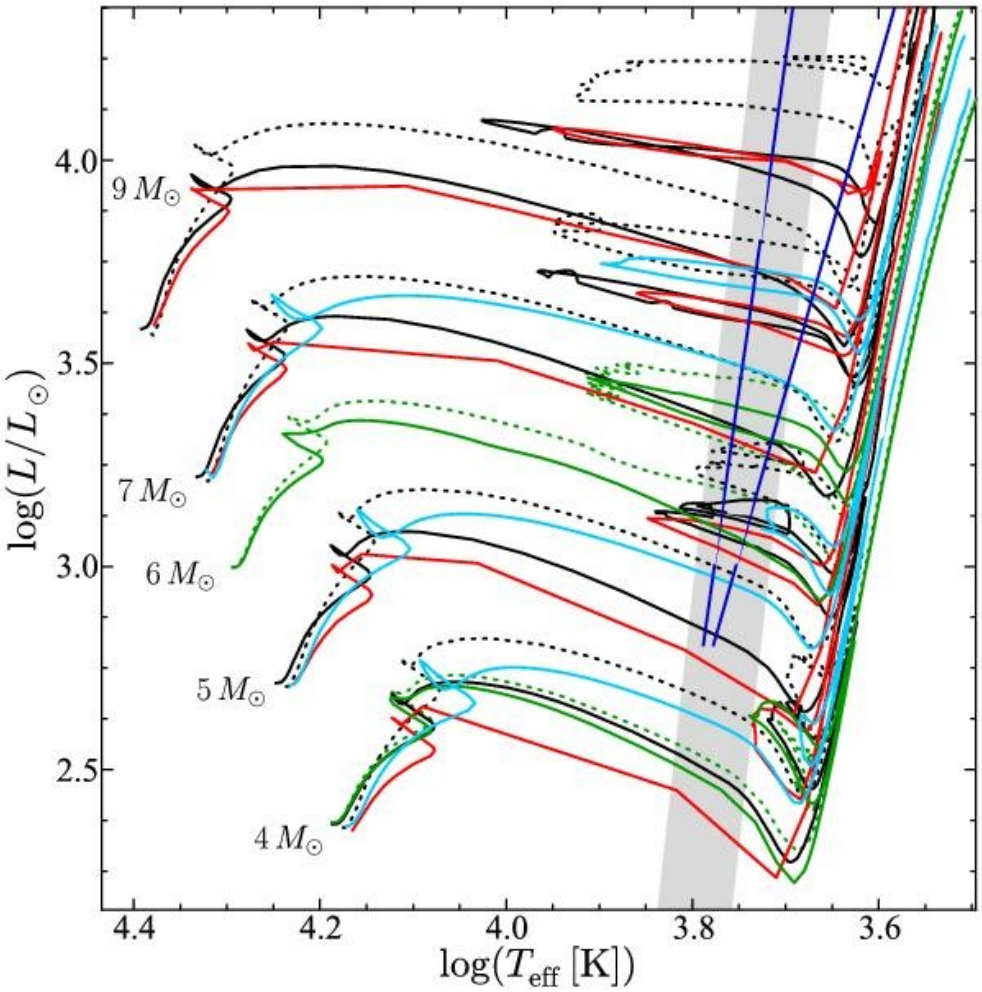
ID[a]	$\log P$[b]	$\langle B\rangle$[c]	$\langle V\rangle$[c]	$\langle I\rangle$[c]	$E(B-V)$[d]	$\log t_{\rm PA}$[e]	$\log t_{\rm PAC}^{(B-V)}$[f]	$\log t_{\rm PAC}^{(V-I)}$[g]
				NGC 7790[h]				
CEa Cas	0.711	12.070	10.920	. . .	0.562	7.834	7.788	. . .
CEb Cas	0.651	12.220	11.050	. . .	0.548	7.874	7.827	. . .
CF Cas	0.688	12.335	11.136	9.754	0.531	7.849	7.824	7.838
				NGC 6067[i]				
QZ Nor.....	0.578	9.774	8.866	7.893	0.249	7.923	7.872	7.865
V340 Nor	1.053	9.526	8.375	7.151	0.315	7.605	7.704	7.708

Geneva tracks

Table 1. Mass limits for Cepheids without and with rotation.

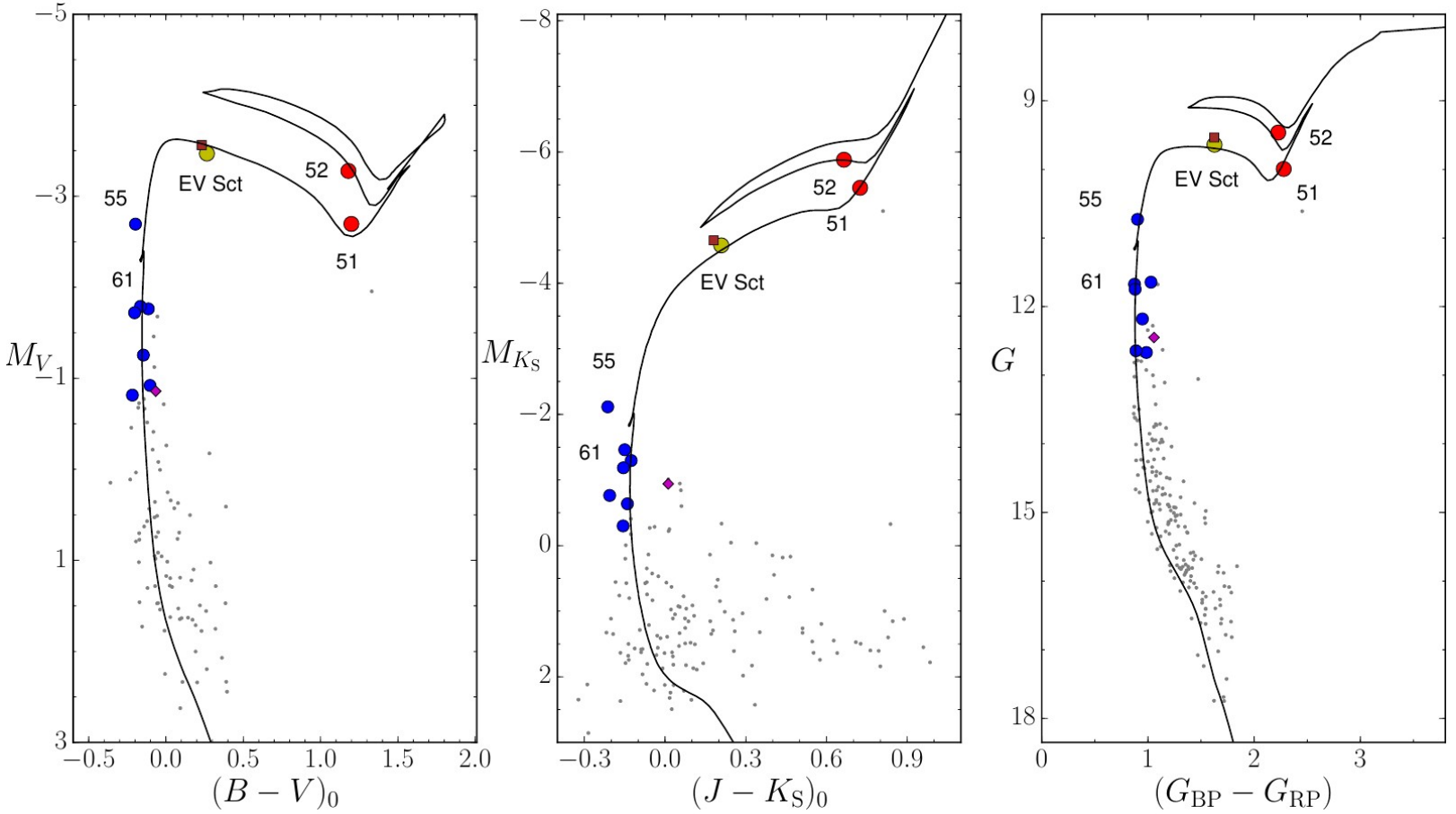
Lower mass limit		$v/v_{\rm crit}$	Upper mass limit		$v/v_{\rm crit}$
4.50 $M_\odot$	(4.25)	0.0	11.50 $M_\odot$	(11.75)	0.0
4.55 $M_\odot$	(4.50)	0.4	10.00 $M_\odot$	(10.25)	0.4

$Z = Z_\odot$



Anderson+14

NGC 6664



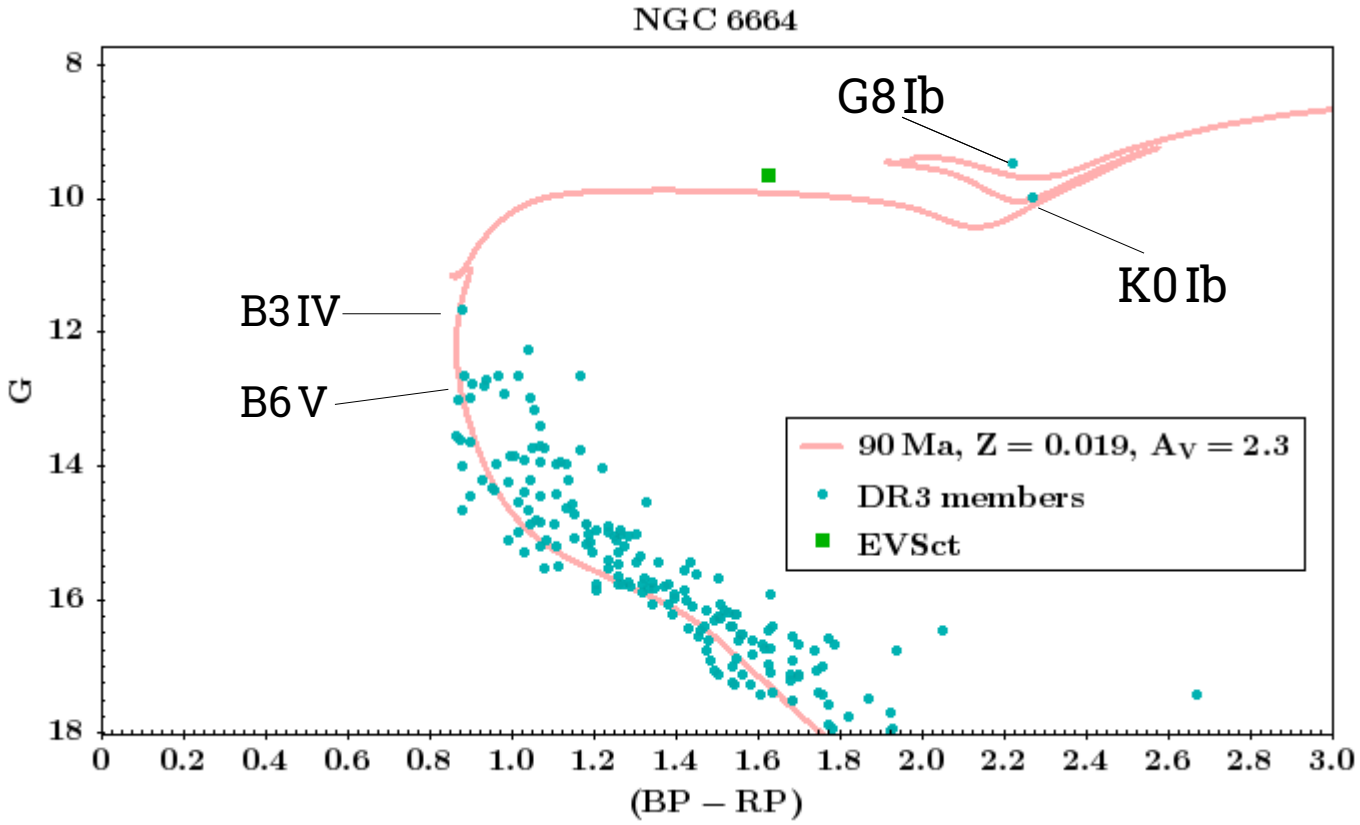
Alonso-Santiago+20

EV Sct $P = 3.1$ d

$Z \simeq Z_\odot$, 80 Ma, $A_V = 2.4$

(overtone)

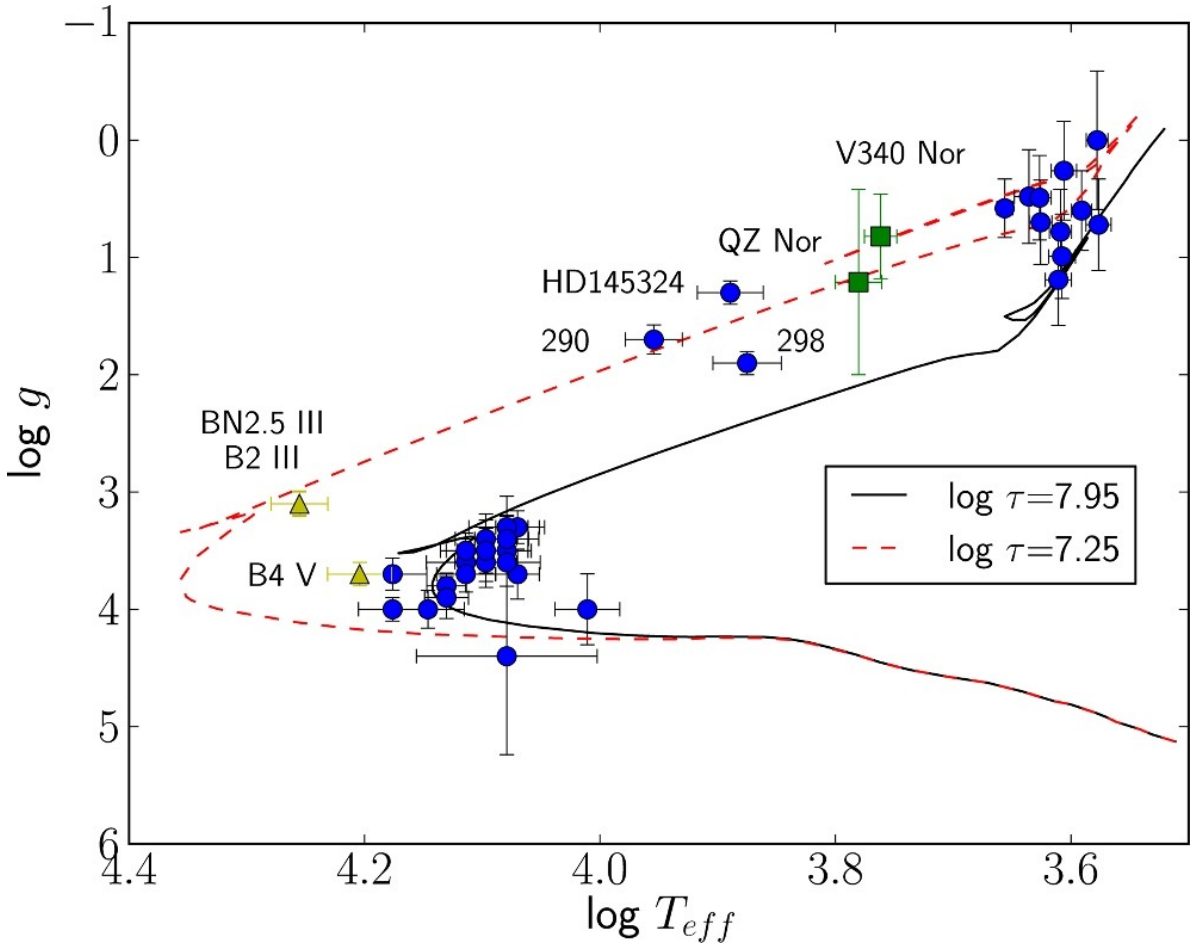
NGC 6664



Cantat-Gaudin+20 225 Ma, $A_V = 1.9$

Dias+21 12 Ma, $A_V = 2.4$

NGC 6067



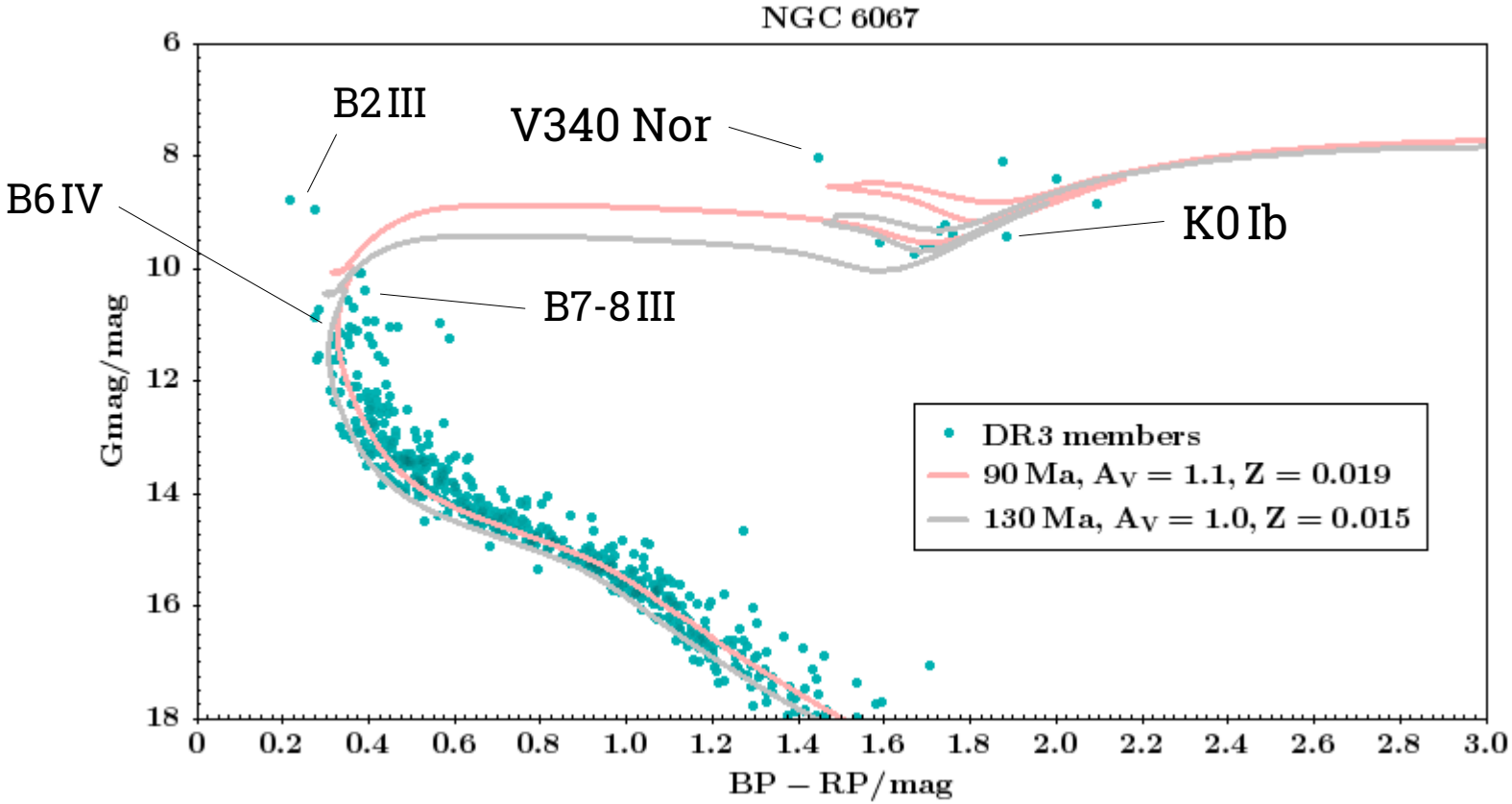
Alonso-Santiago+17

$Z \simeq 1.6\,Z_{\odot}$, 90 Ma, $A_V = 1$.

V340 Nor $P = 11$ d

QZ Nor (overtone) $P = 3.9$ d

NGC 6067



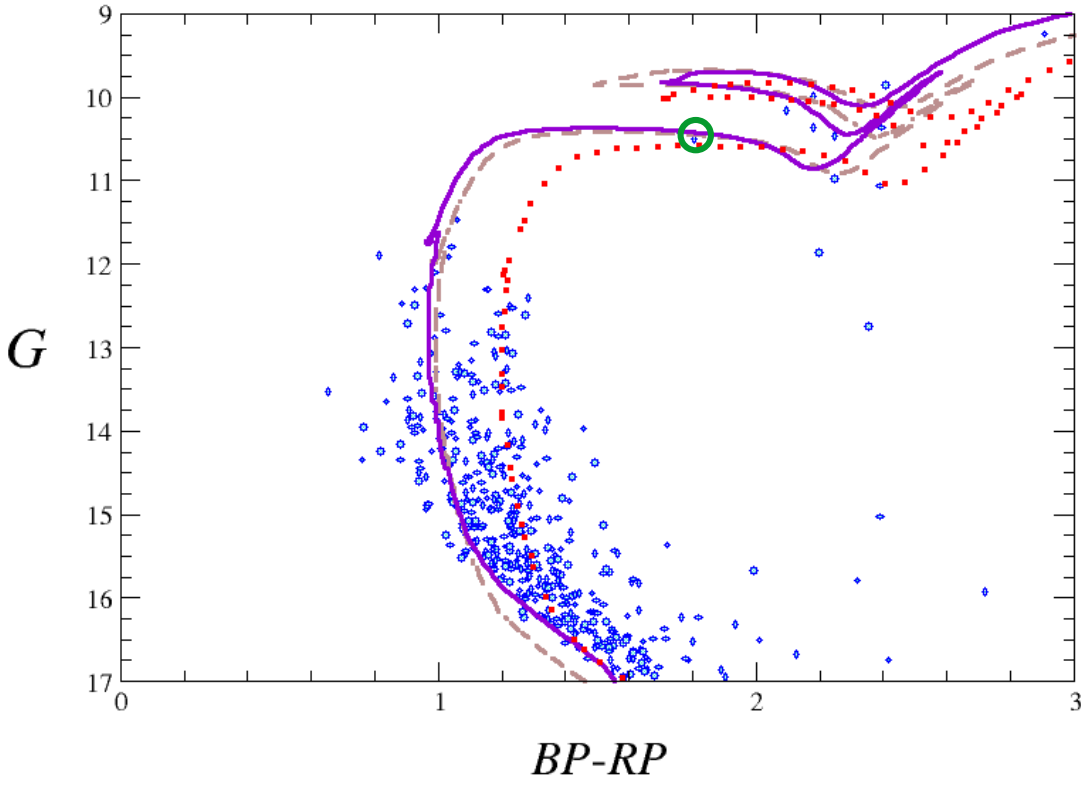
For $Z = Z_\odot$, these would be 4.6 $M_\odot$ stars

For $Z = 1.3\,Z_\odot$, these would be 5.5 $M_\odot$ stars

Val 1

70 Ma, A_V = 2.7, DM = 12.0

70 Ma, A_V = 3.2, DM = 11.8



Negueruela+21

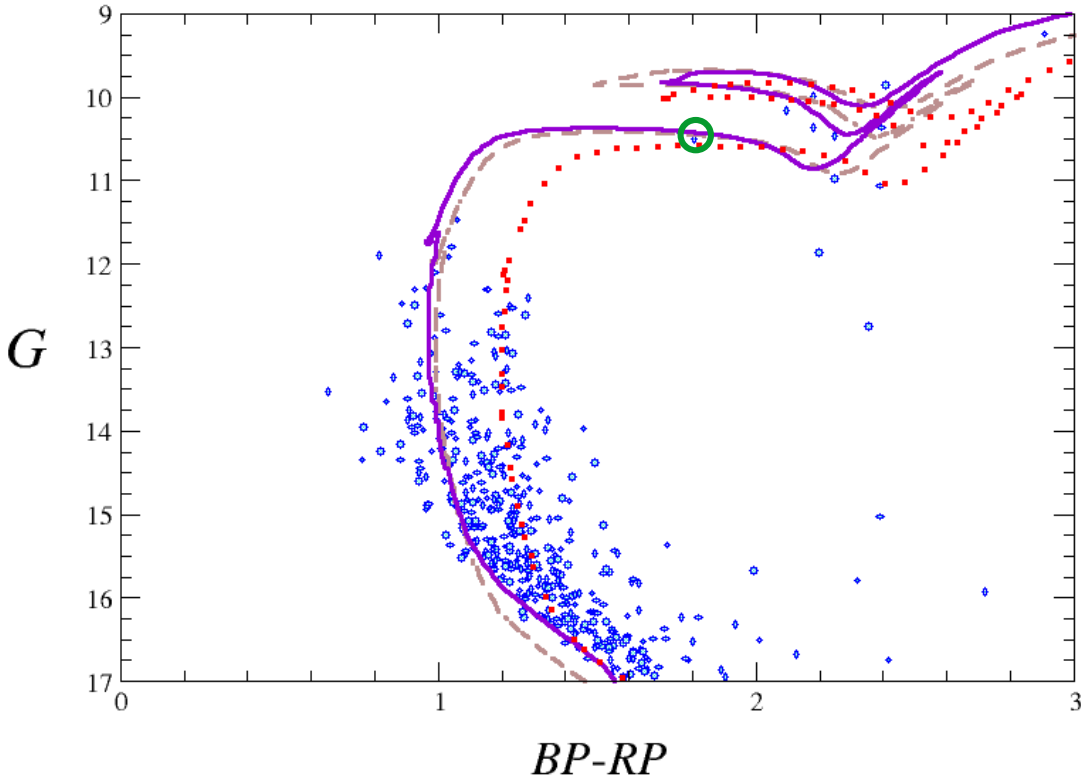
$Z \simeq Z_\odot$

CM Sct $P = 3.9$ d

Val 1

DR3 favours DM = 11.8 (Cruz Reyes & Anderson 23)

So I would go for 80 Ma, implying 5.7 $M_\odot$



Negueruela+21

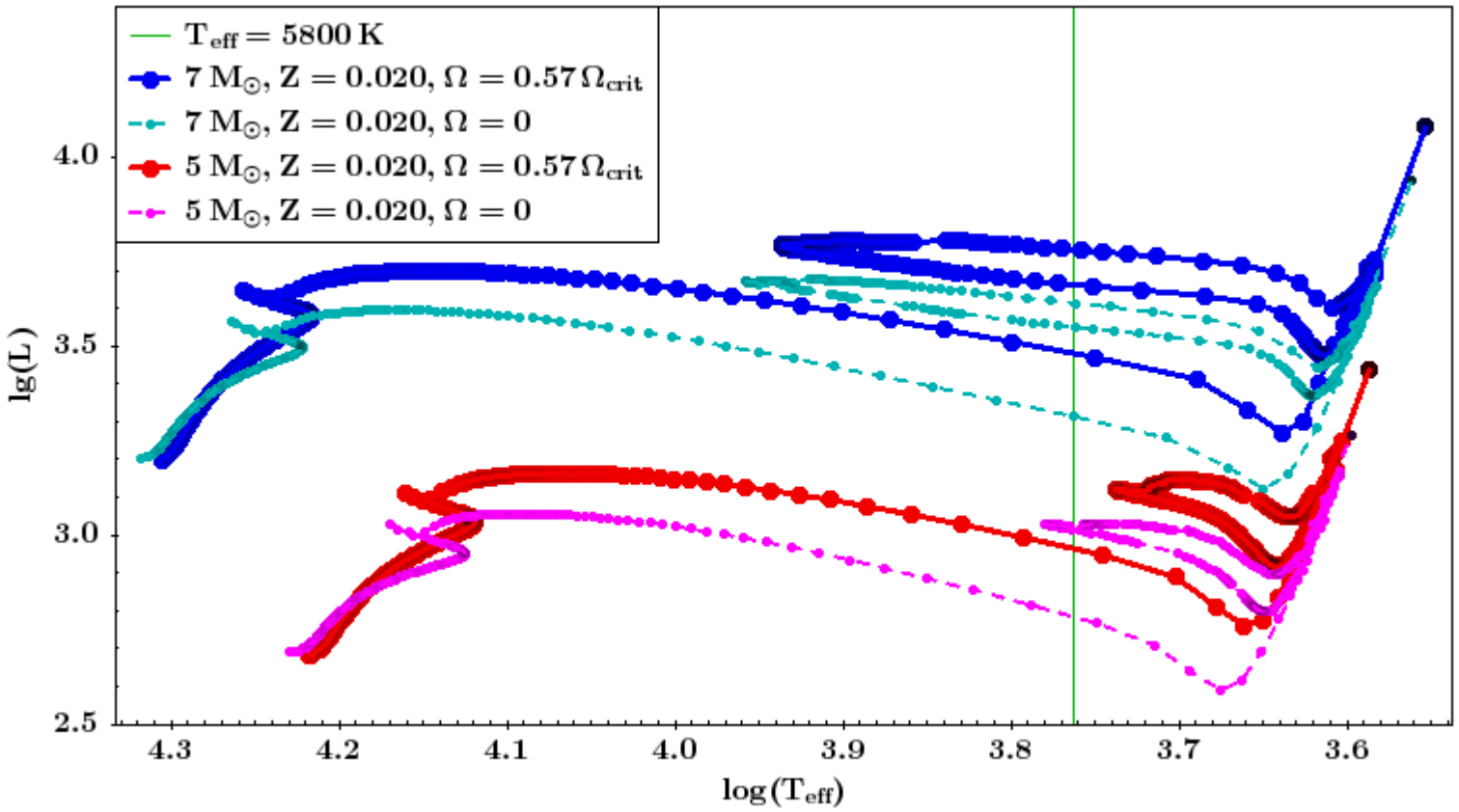
$Z \simeq Z_\odot$

CM Sct $P = 3.9$ d

Summarising so far ...

- Data are compatible with a lower mass around $4.5\ M_{\odot}$ for Milky Way Cepheids
- Padova isochrones do not extend blue loops to such low masses
- Padova isochrones do not predict blue loops for supersolar metallicities
- There are few supersolar Geneva tracks

Geneva tracks

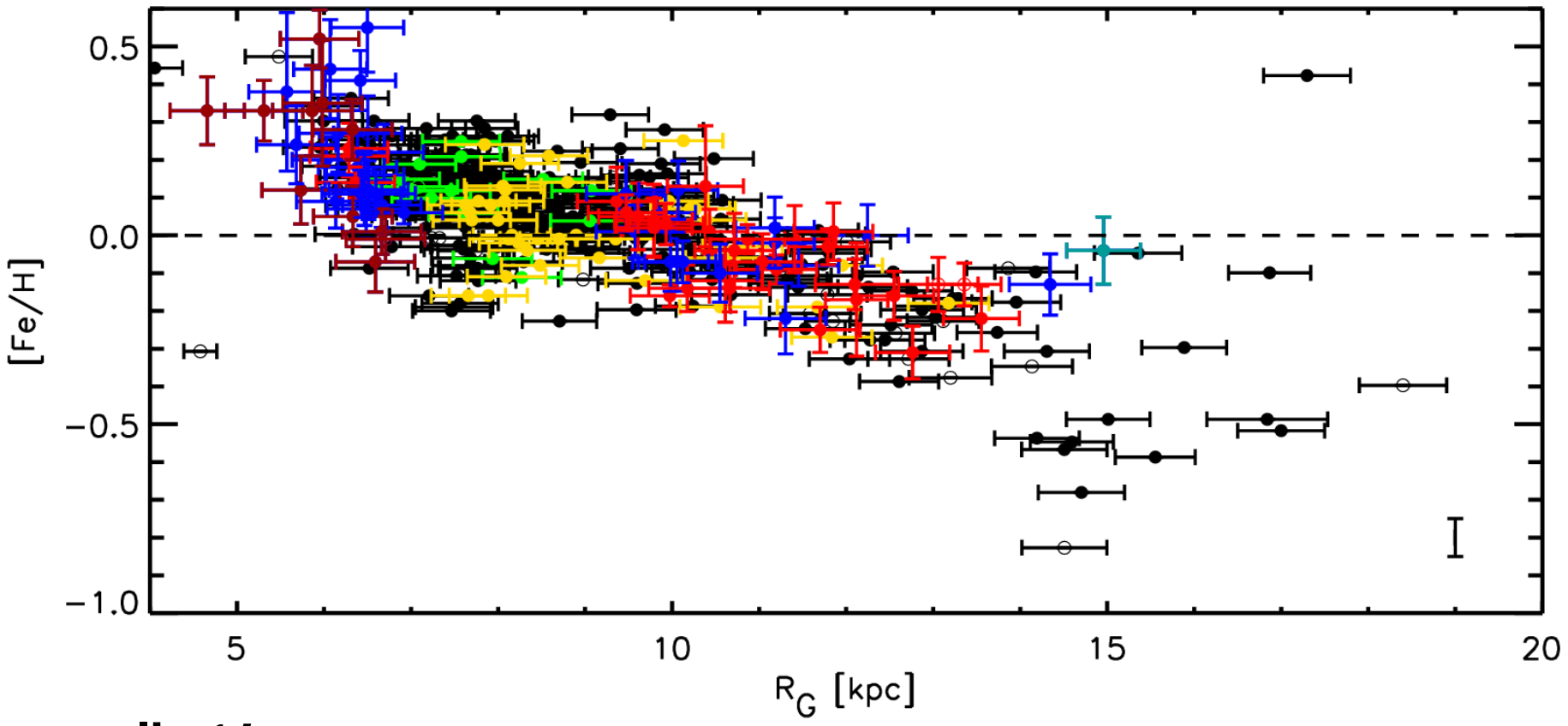


Tracks computed (not interpolated) by Yosuf+22

Summarising so far ...

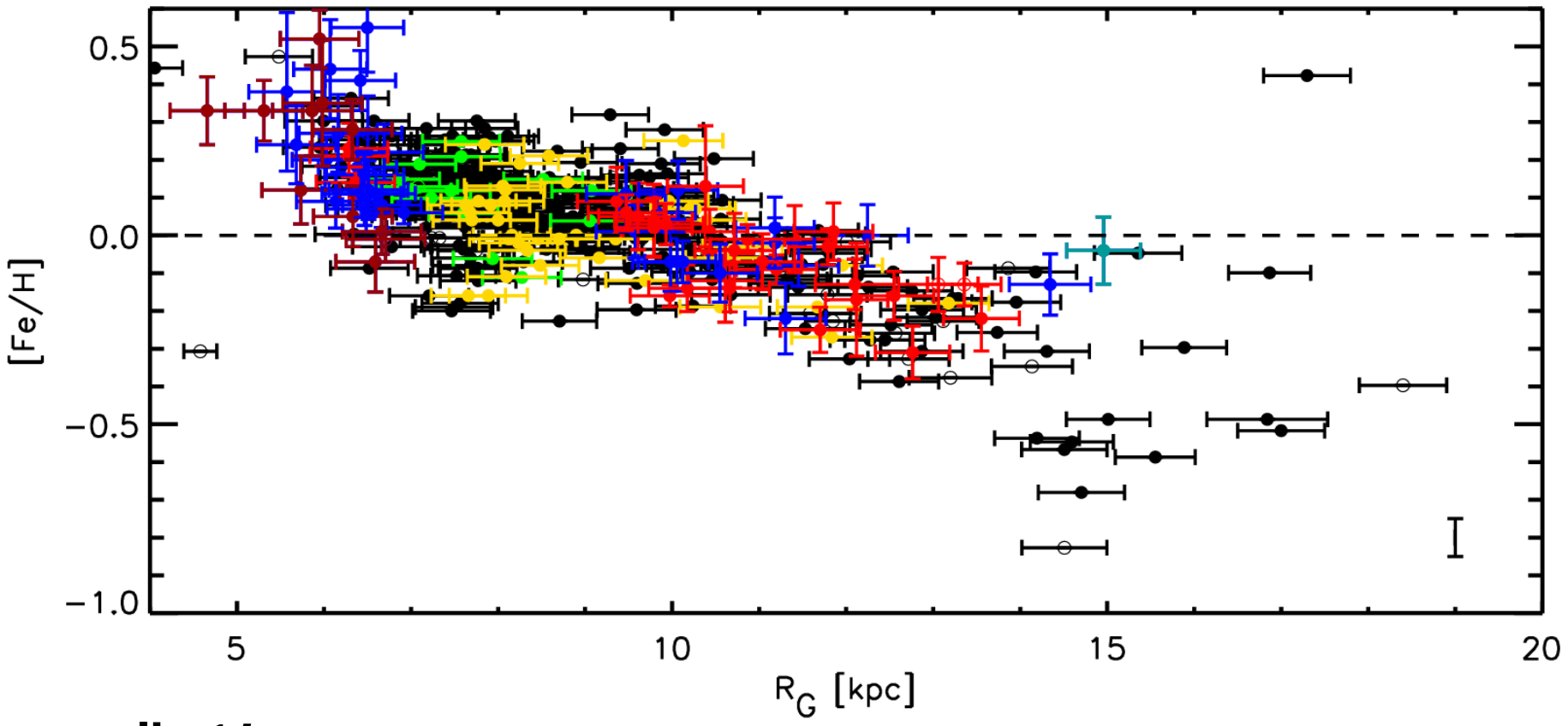
- Data are compatible with a lower mass around $4.5\ M_{\odot}$ for Milky Way Cepheids
- Padova isochrones do not extend blue loops to such low masses
- Padova isochrones do not predict blue loops for supersolar metallicities
- Geneva tracks only predict moderately massive Cepheids at slightly supersolar

Do such Cepheids exist ?



Genovali+14

Do such Cepheids exist ?



Genovali+14

Compelling cases are V1954 Sgr (P = 6.2 d, $Z = 1.8\,Z_\odot$)

RS Nor (P = 6.2 d, $Z = 1.6\,Z_\odot$)

Summarising so far ...

- Data are compatible with a lower mass around $4.5\,M_{\odot}$ for Milky Way Cepheids
- Tracks only predict moderately massive Cepheids at slightly supersolar, although there is some evidence for metal-rich Cepheids of $5-6\,M_{\odot}$
- Data from the Magellanic Clouds show evidence for enhanced blue loops at low metallicity

Big clusters

Cluster	Z	R_G (kpc)	log (Age)	Yellow (Cepheids)	Red
VdH 222	~$Z_\odot$	~3	~7.3	2 (1)	12
Val 1	~$Z_\odot$	6.3	7.8	1 (1)	10
NGC 6649	≳$Z_\odot$	6.4	7.7	3 (1)	2
NGC 6067	~1.3 $Z_\odot$	6.8	7.9	3 (2)	11
Be 51	~$Z_\odot$ (assumed)	~8.3	7.7	4 (1)	5
Be 55	~$Z_\odot$ (assumed)	8.9	7.8	1 (1)	4

Big clusters

Cluster	Z	R_G (kpc)	log (Age)	Yellow (Cepheids)	Red
VdH 222	~$Z_\odot$	~3	~7.3	2 (1)	12
Val 1	~$Z_\odot$	6.3	7.8	1 (1)	10
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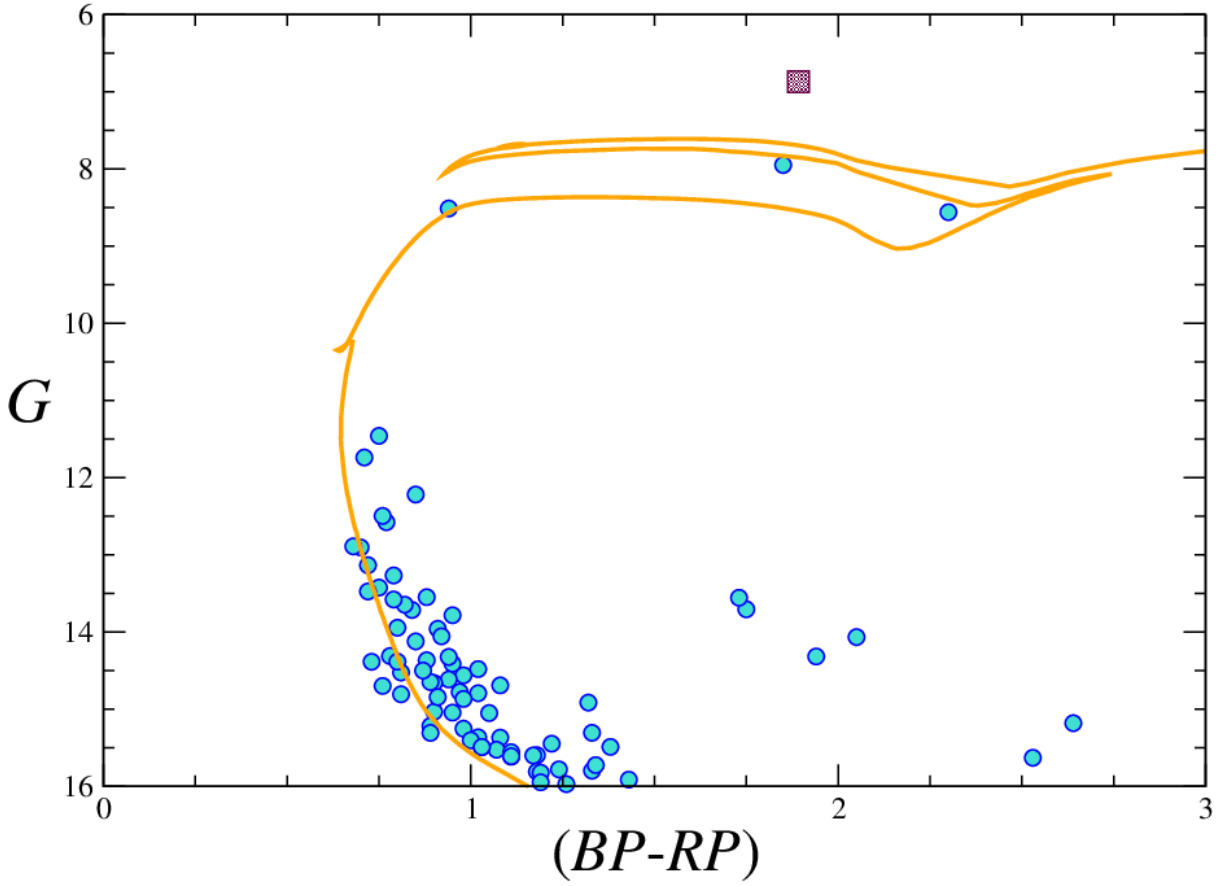
NGC 6067	~1.3 $Z_\odot$	6.8	7.9	3 (2)	11
Be 51	~$Z_\odot$ (assumed)	~8.3	7.7	4 (1)	5
Be 55	~$Z_\odot$ (assumed)	8.9	7.8	1 (1)	4
NGC 2345	~0.6 $Z_\odot$	10.3	7.7	2?	6
NGC 6124	~$Z_\odot$	7.7	8.0	0	7

Alicante 13



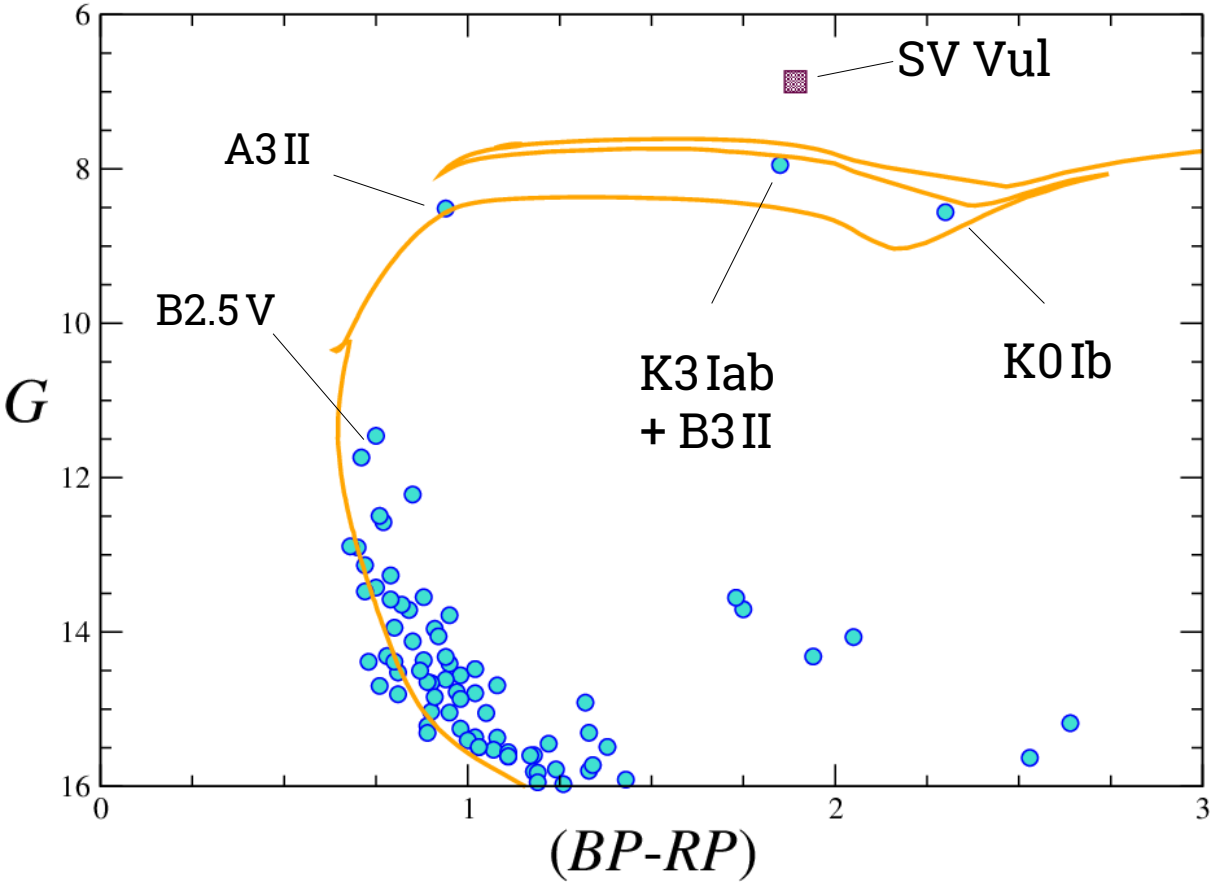
Negueruela+19

30 Ma, $A_V = 1.7$

SVVul

$P = 43$ d

Alicante 13



Negueruela+19

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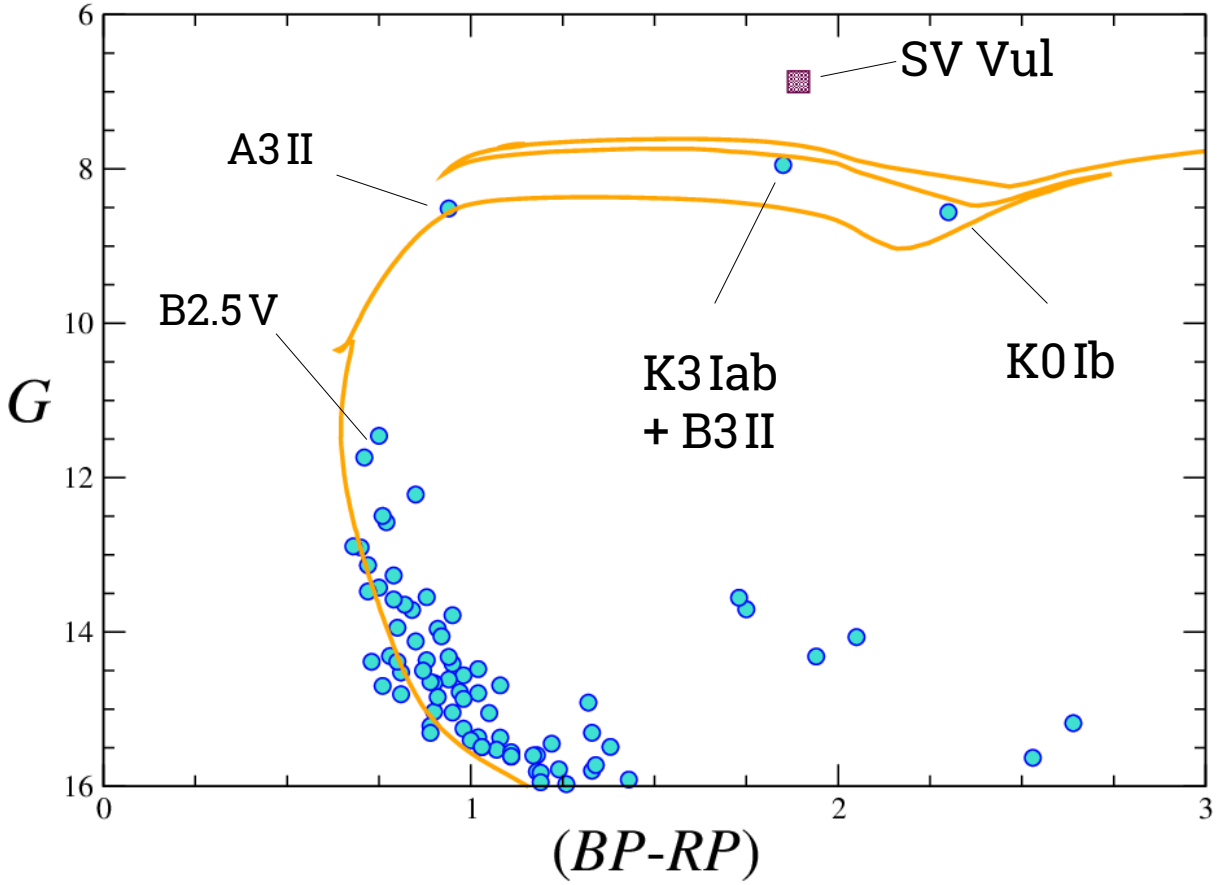
SV Vul $P = 43$ d

Alicante 13



Negueruela+19

30 Ma, $A_V = 1.7$

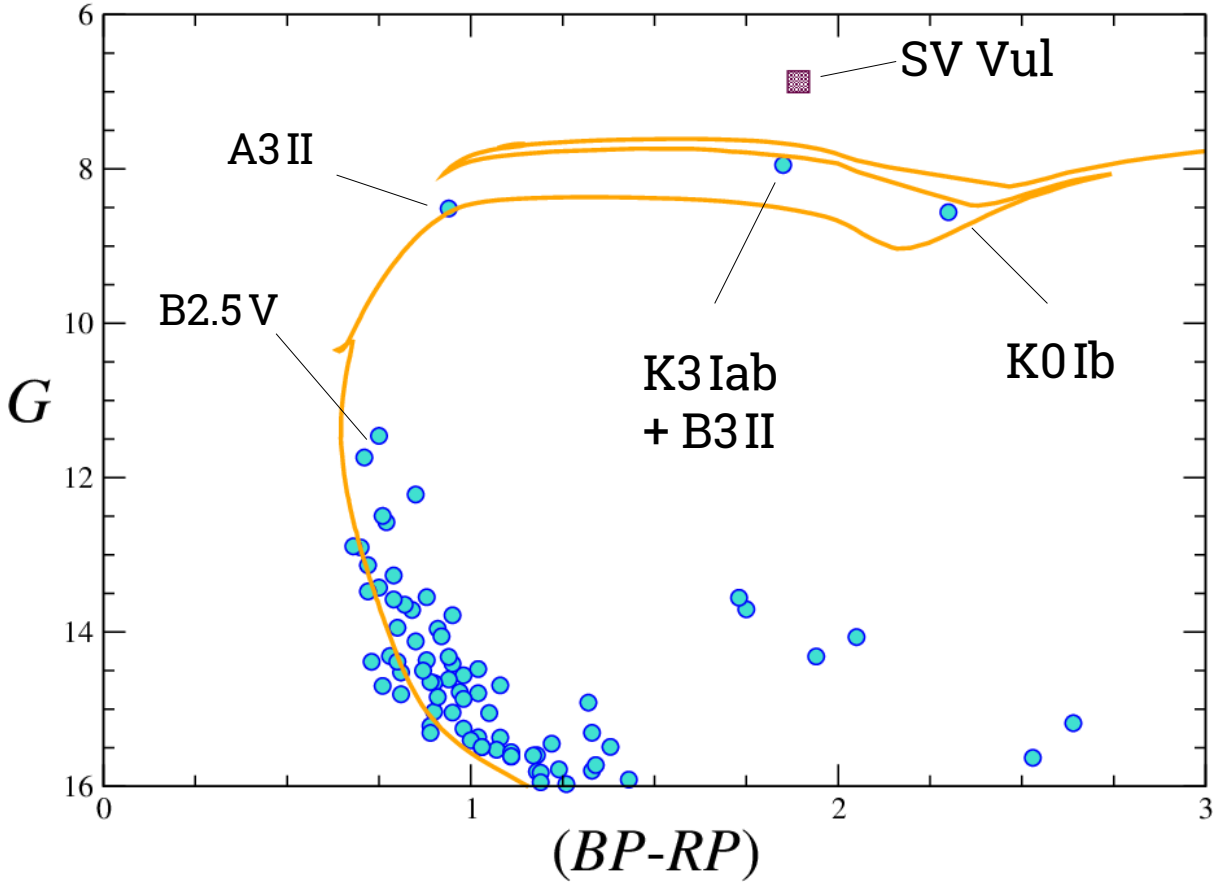
Isochrone suggests evolved stars ~9 $M_\odot$ stars

SV Vul $P = 43$ d

Position of SV Vul compatible with initially fast-rotating ~10 $M_\odot$ star

Alicante 13

No obvious novelties in DR3



Negueruela+19

30 Ma, $A_V = 1.7$

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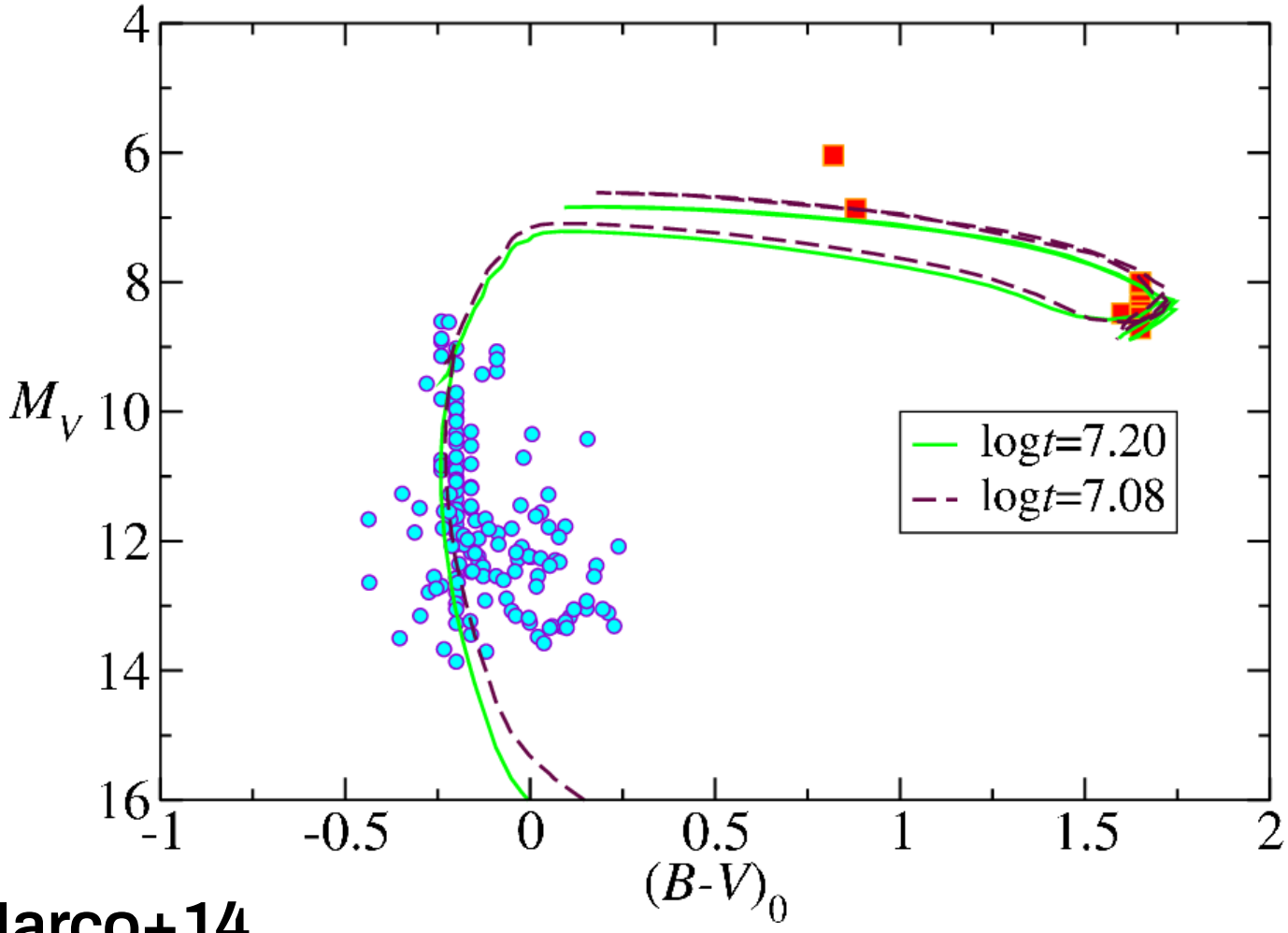
SV Vul $P = 43$ d

Position of SV Vul compatible with initially fast-rotating ~10 $M_\odot$ star

VdBH 222



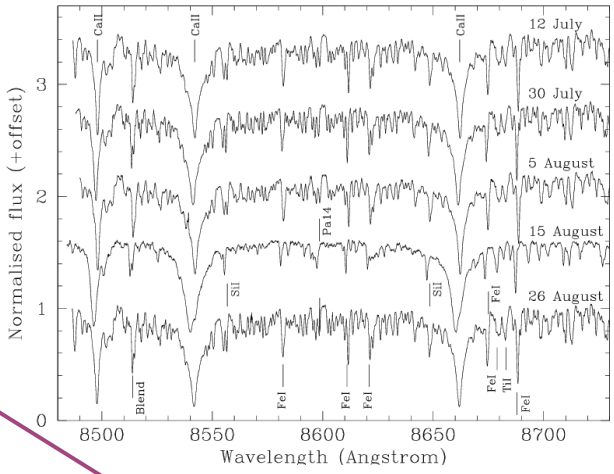
Marco+14

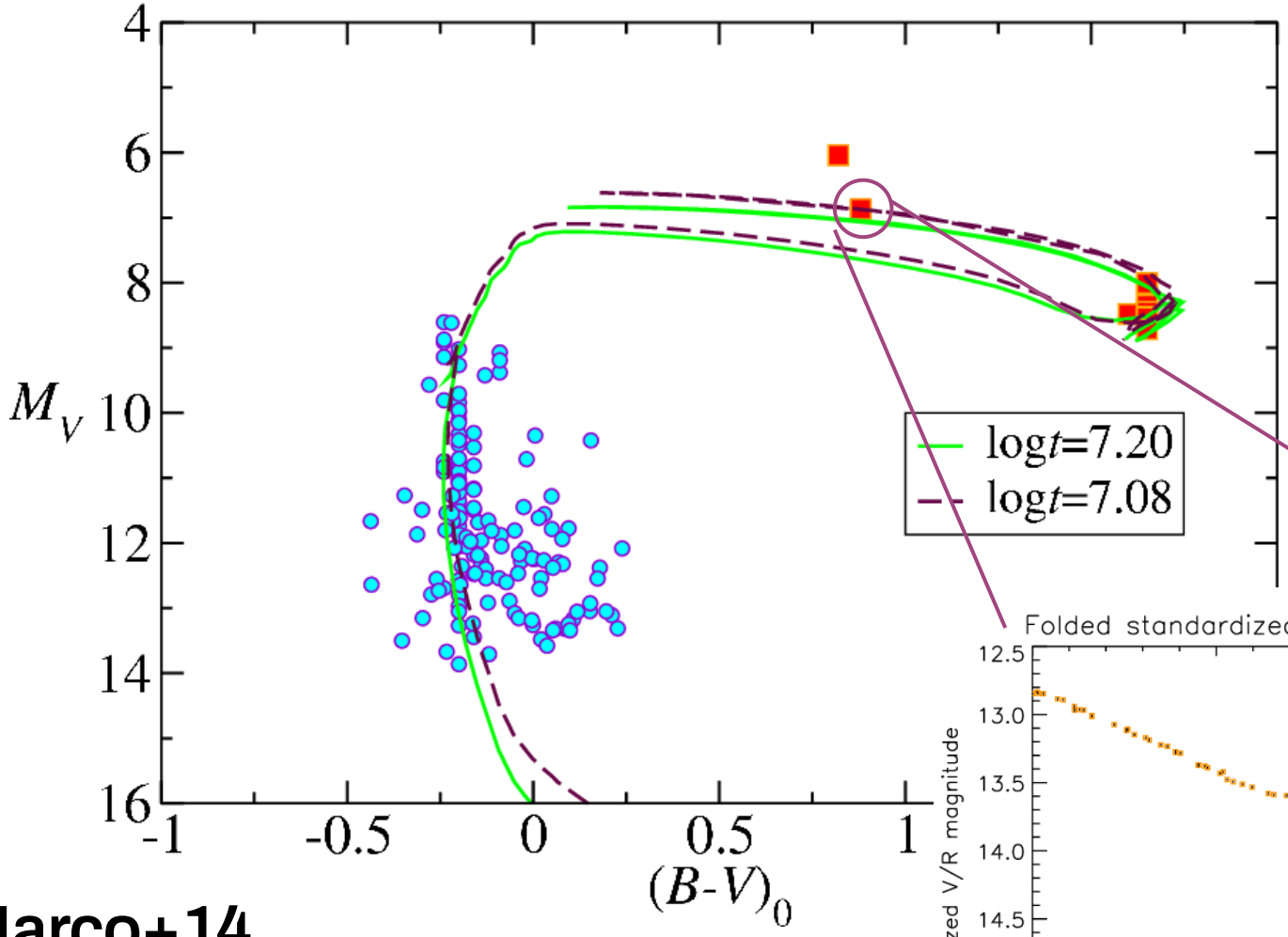
~18 Ma, $d \approx 7$ kpc, $A_V \approx 7.5$

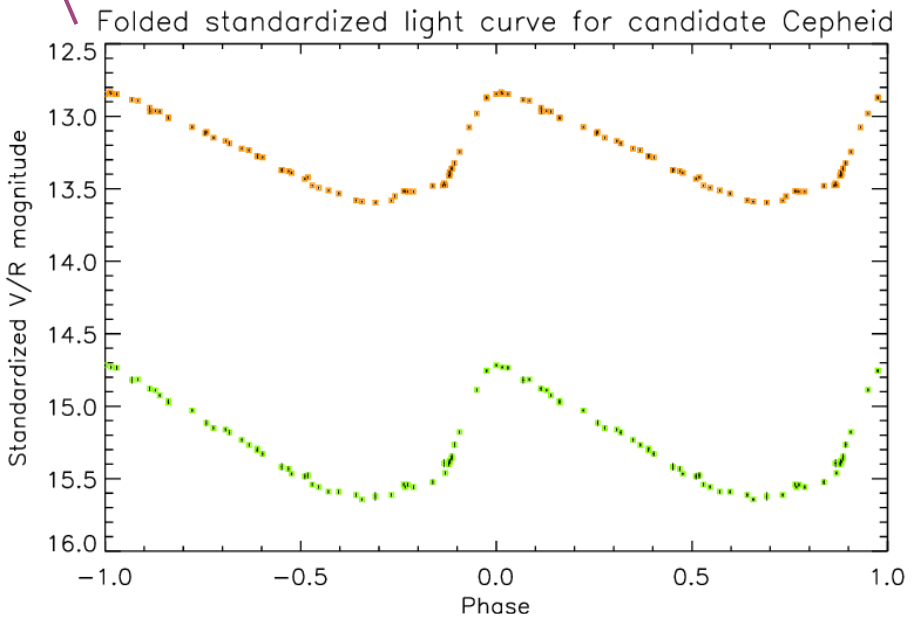
VdBH 222

$P = 23$ d

Clark+15







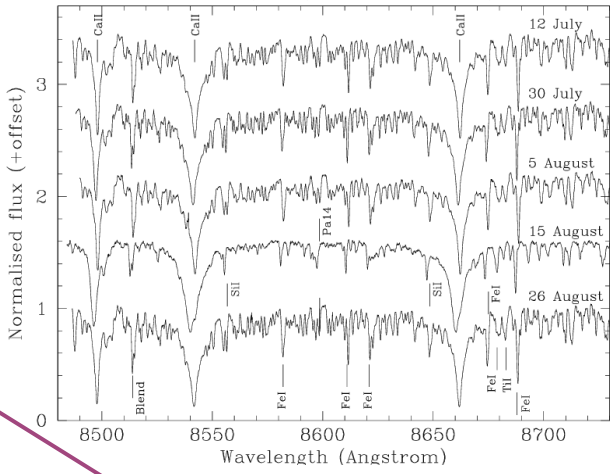
Marco+14

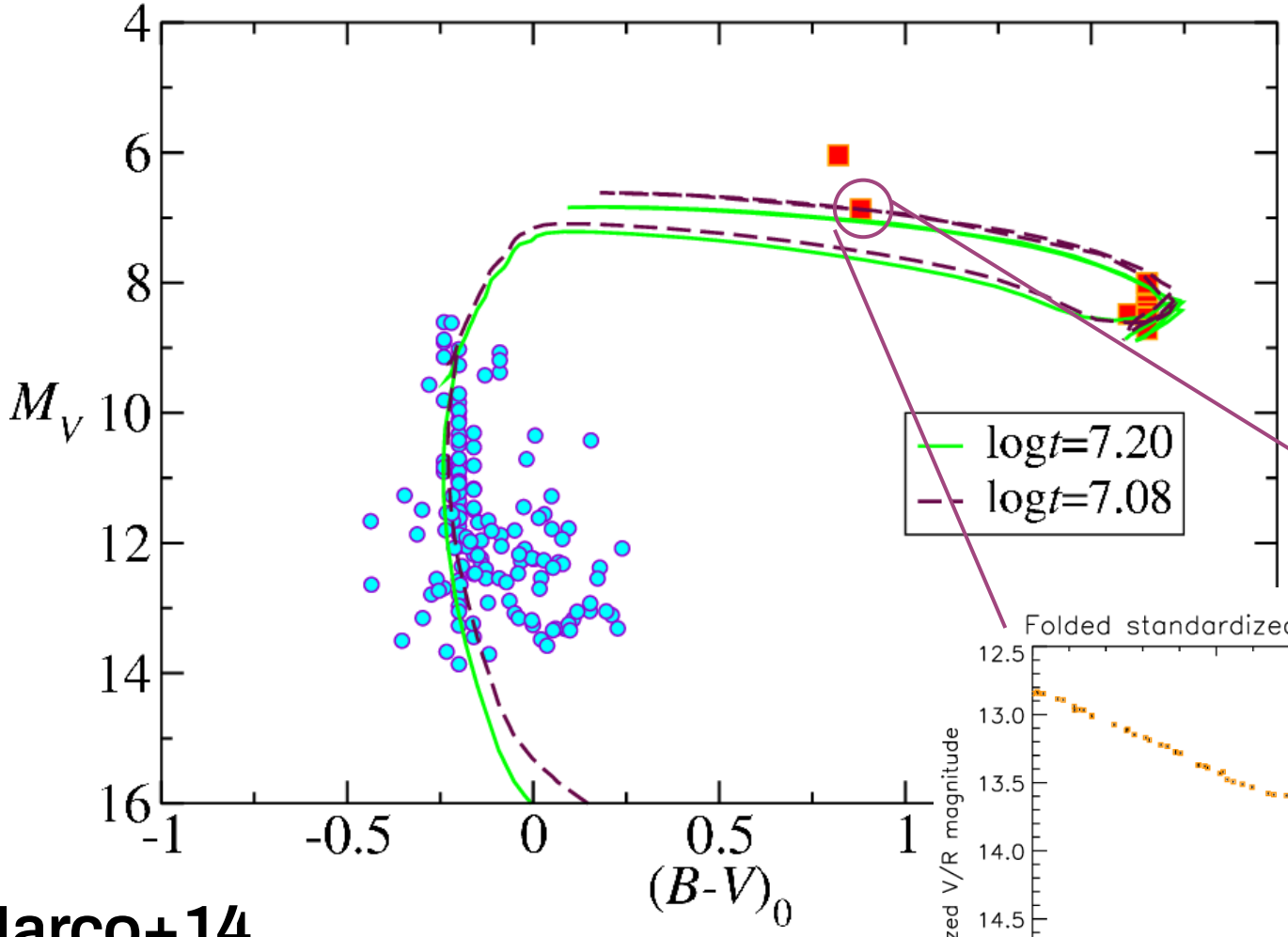
~18 Ma, $d \approx 7$ kpc, $A_V \approx 7.5$

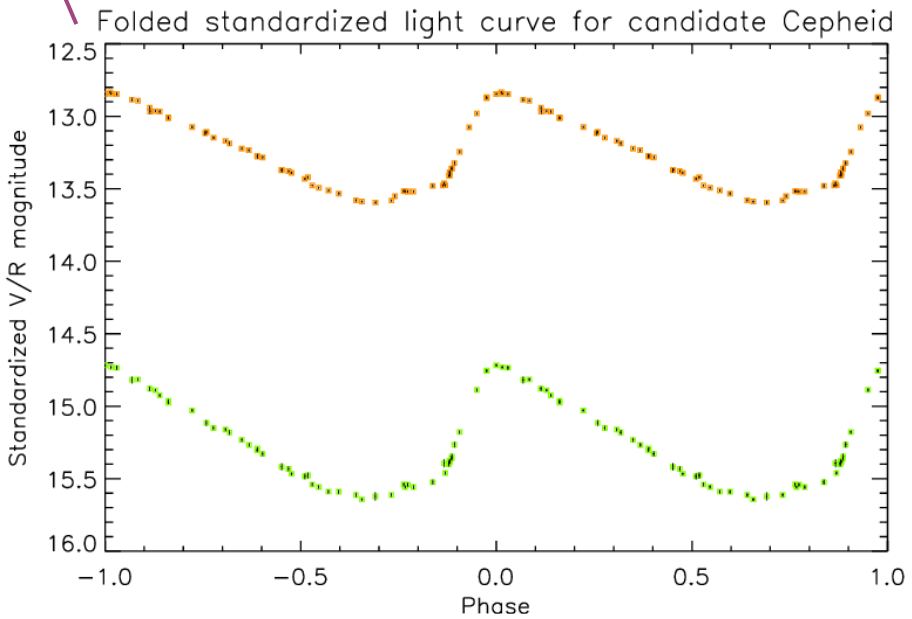
VdBH 222

$P = 23$ d

Clark+15







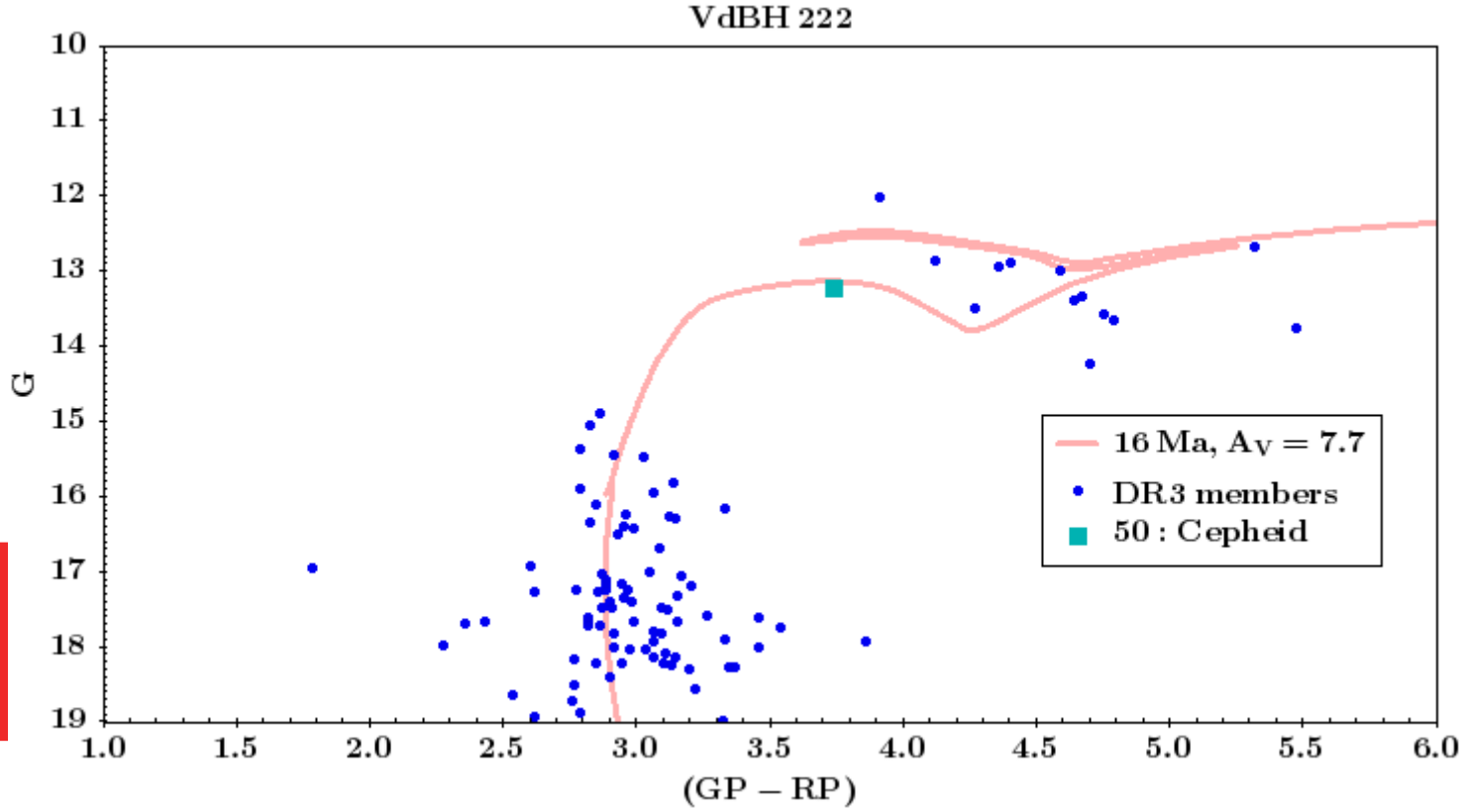
Marco+14

~18 Ma, $d \approx 7$ kpc, $A_V \approx 7.5$

VdBH 222

$P = 23$ d

Clark+15



Gaia does not help much here

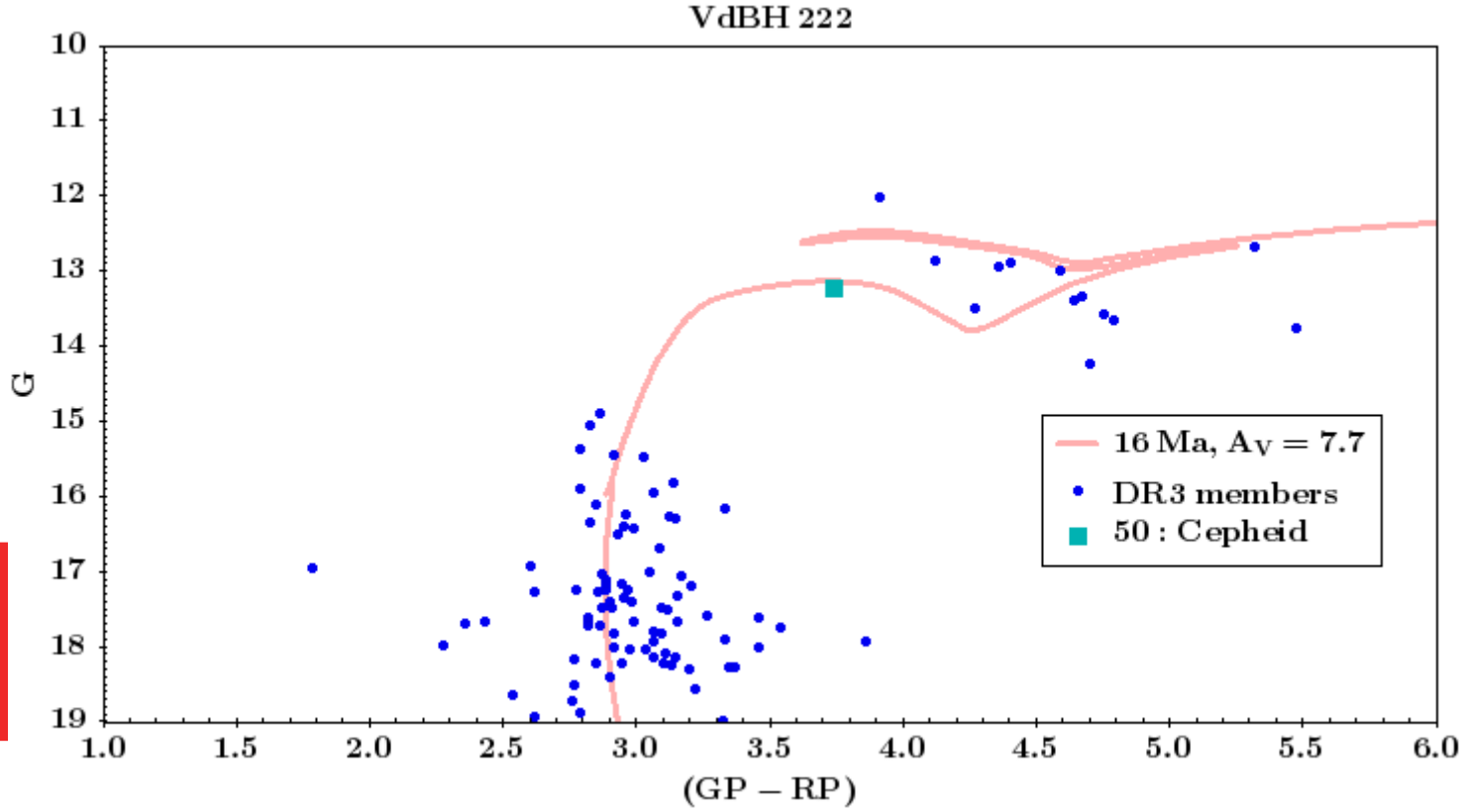
$\varpi = 0.07 \pm 0.06$ mas

$d \approx 6.5$ kpc

VdBH 222

$P = 23$ d

Clark+15



Gaia does not help much here

$\varpi = 0.07 \pm 0.06$ mas

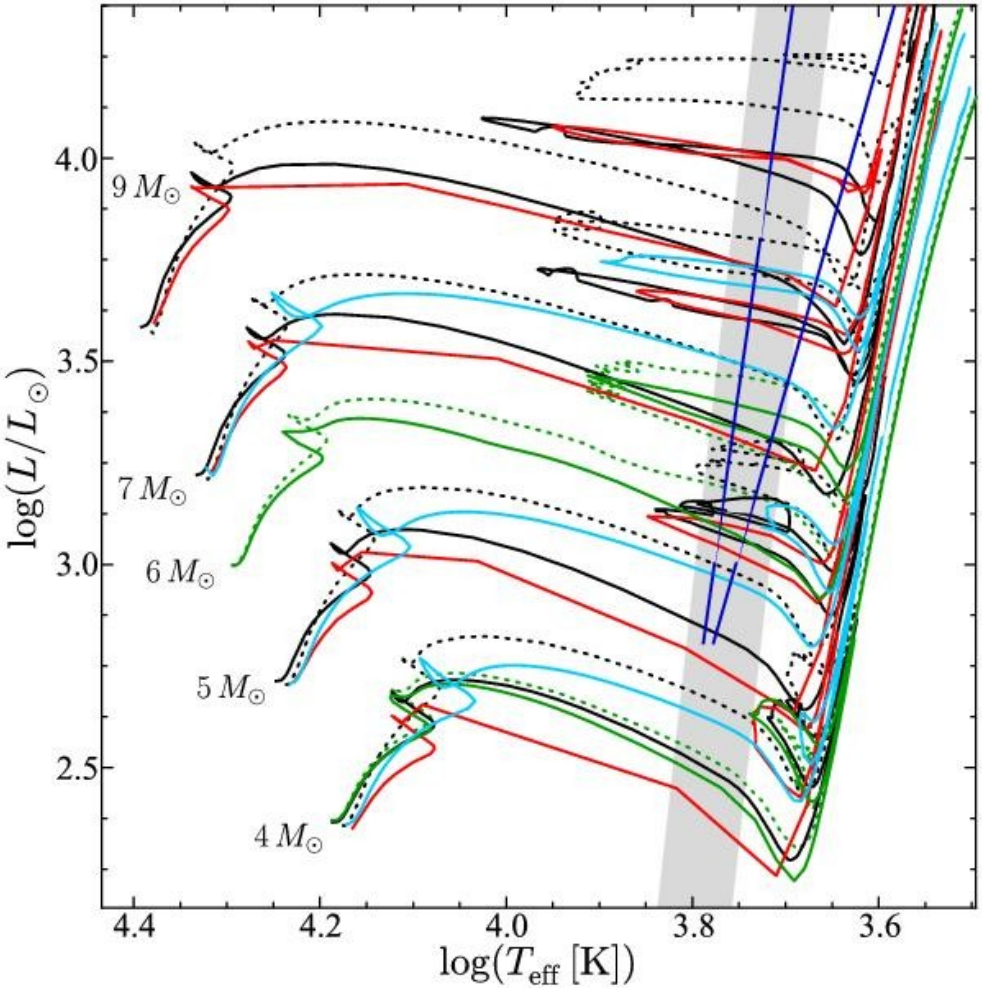
$d \approx 6.5$ kpc $\Rightarrow$ this is the brightest Cepheid cluster, with 11 – 12 $M_\odot$

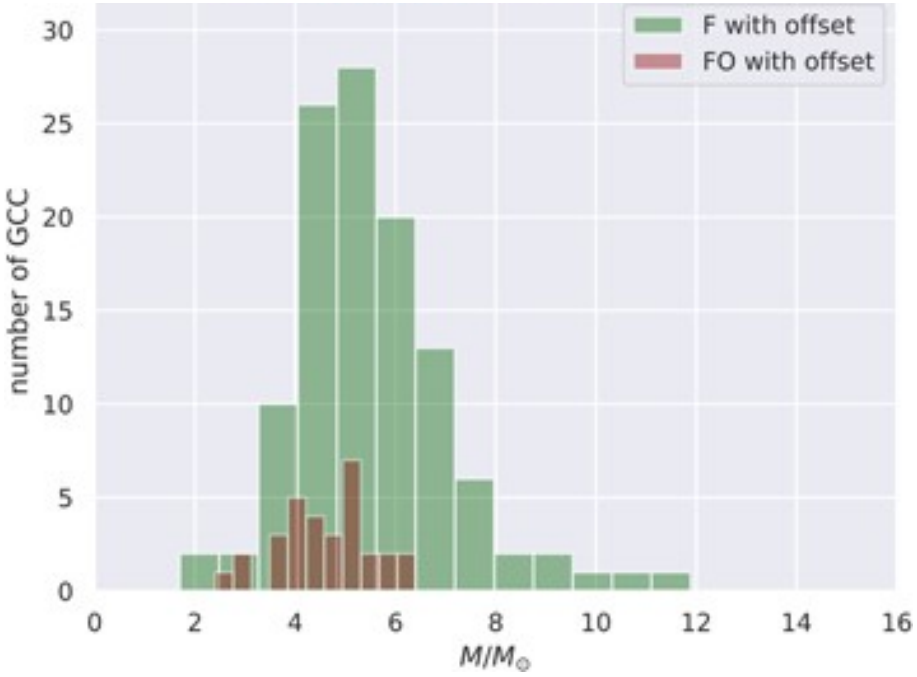
Table 1. Mass limits for Cepheids without and with rotation.

Lower mass limit		$v/v_{\rm crit}$	Upper mass limit		$v/v_{\rm crit}$
4.50 $M_\odot$	(4.25)	0.0	11.50 $M_\odot$	(11.75)	0.0
4.55 $M_\odot$	(4.50)	0.4	10.00 $M_\odot$	(10.25)	0.4

Anderson+14

$Z = Z_\odot$





Marconi+20

Summarising ...

- Data are compatible with a lower mass $\sim 4.5\ M_\odot$ and an upper mass limit $\lesssim 12\ M_\odot$ for Milky Way Cepheids. A few more clusters to analyse, but deviations are unlikely.
- Tracks only predict moderately massive Cepheids at slightly supersolar, although there is some evidence for metal-rich Cepheids of 5-6 $M_\odot$
- We cannot find any strong observational evidence for a different ratio of yellow to red supergiants at different Galactocentric distances.
- There are many non-pulsating YSGs with the same location in the CMD as the Cepheids.