Not-so-simple stellar populations in nearby, massive star clusters

YOUNG AND MIDDLE-AGED

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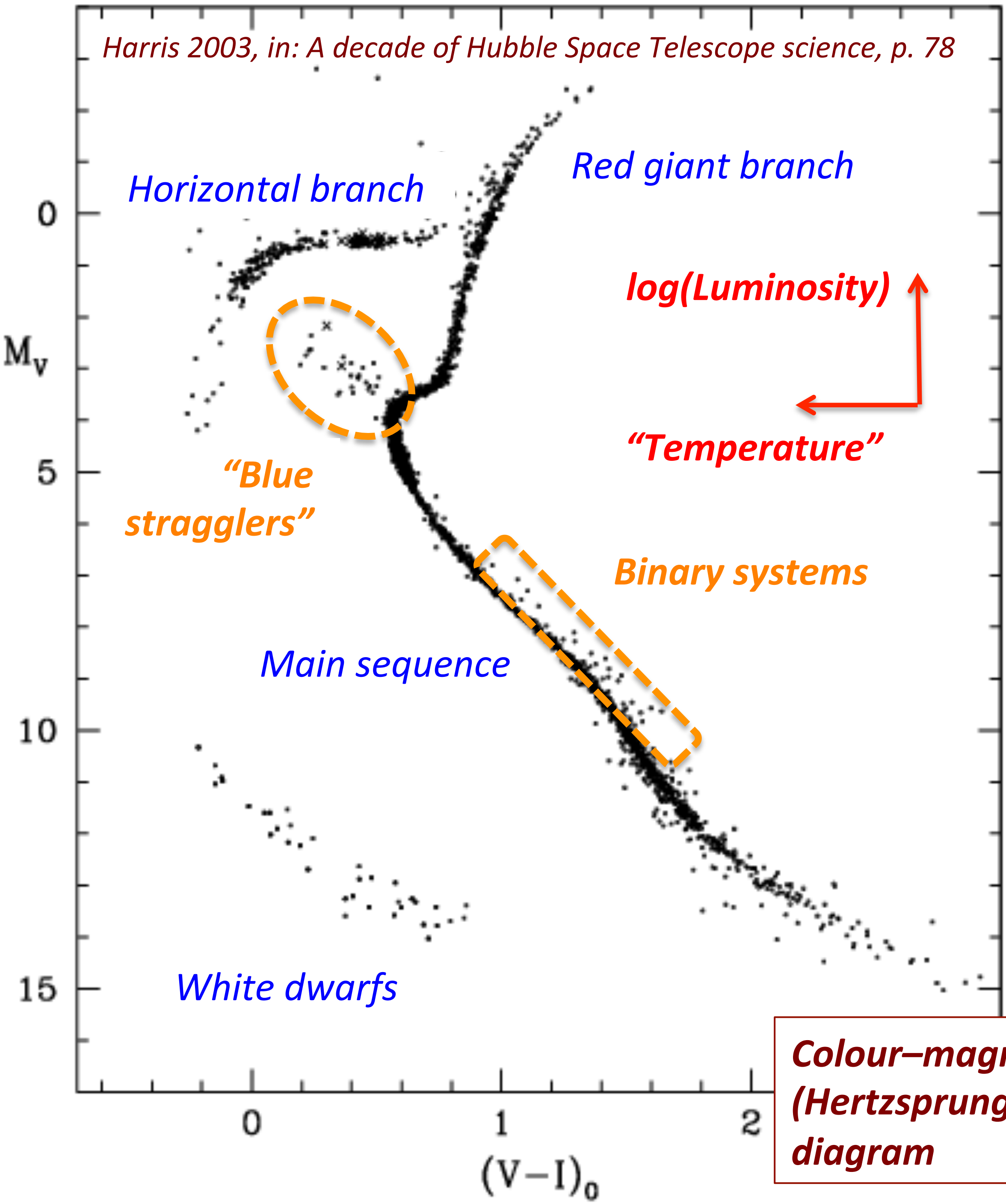

Colour–magnitude (Hertzsprung–Russell) diagram

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Simple stellar populations?

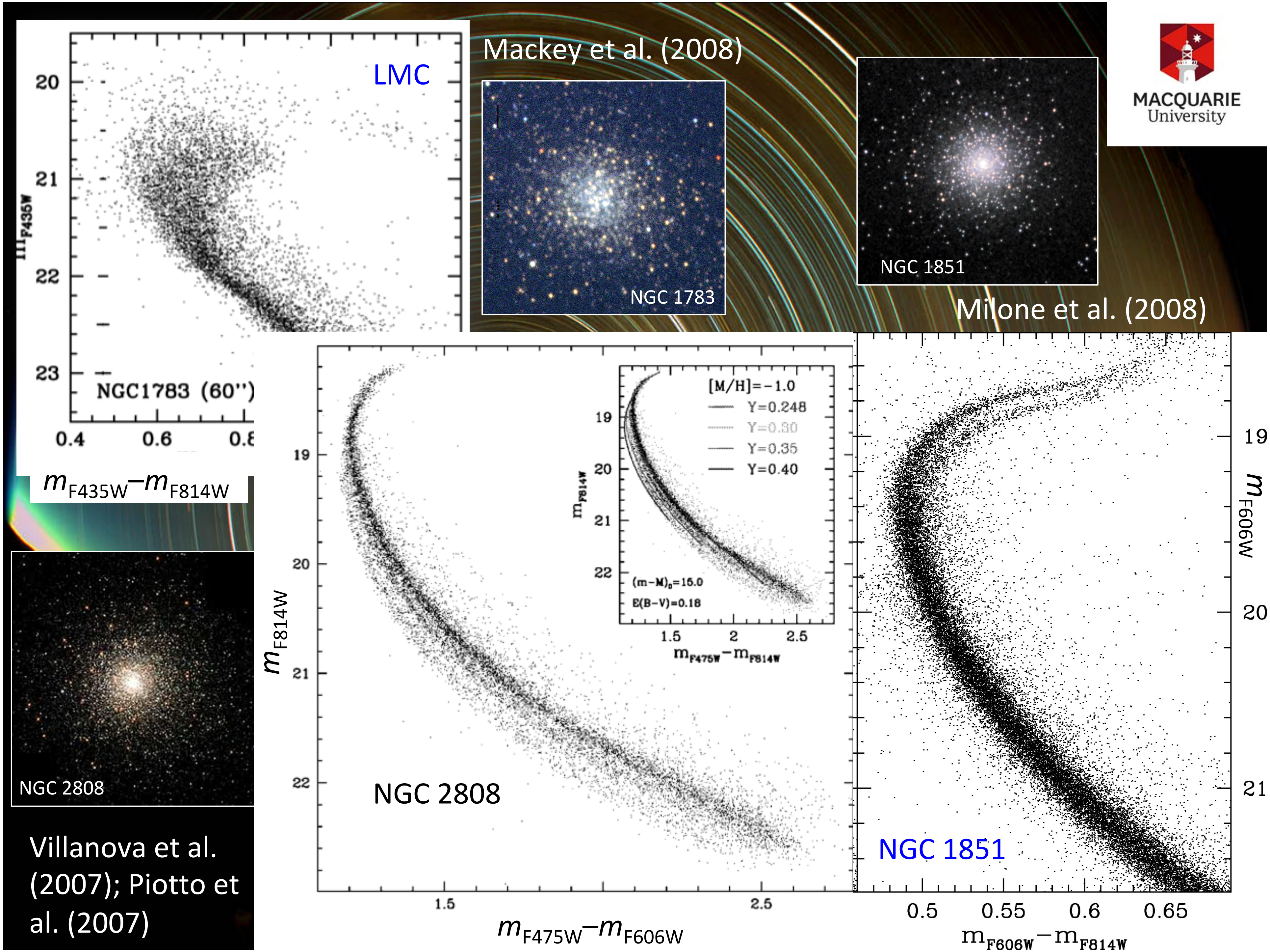
Single age: sharp, narrow MSTO
Single metallicity: narrow CMD
Mass range given by the IMF
… but for ***single stars*** only!

$M_V = -2.5 \log L_V\,[L_\odot]$ + constant at $D = 10$ pc (*absolute magnitude*)

$(V-I) = m_V - m_I = -2.5 \log L_V/L_I$

Subscript "**0**": corrected for the effects of extinction (dust)

M3, M55, M68, NGC 6397, NGC 2419



Mackey et al. (2008)
LMC
NGC1783 (60'')
m_{F435W}
$m_{F435W} - m_{F814W}$
NGC 1783
NGC 1851
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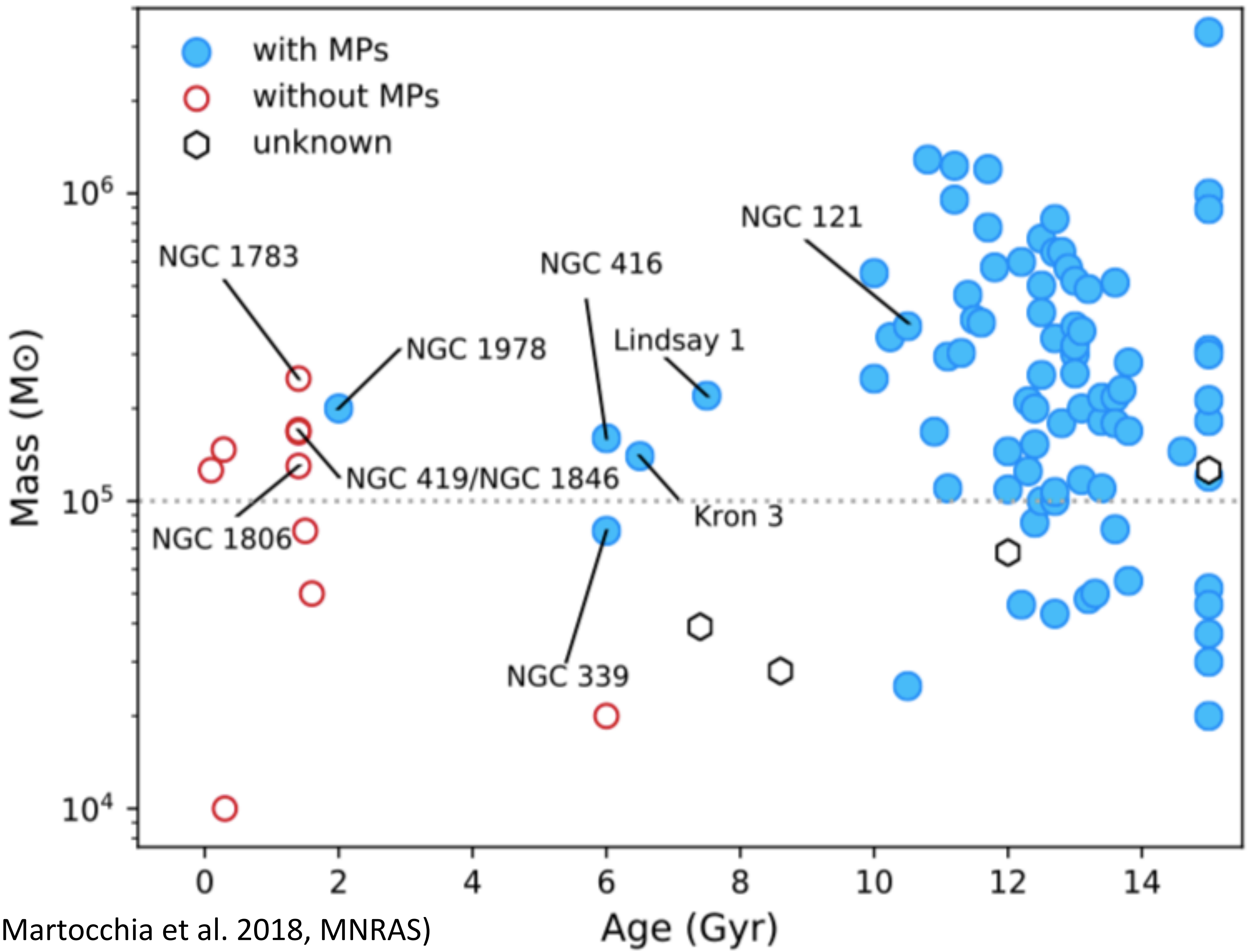
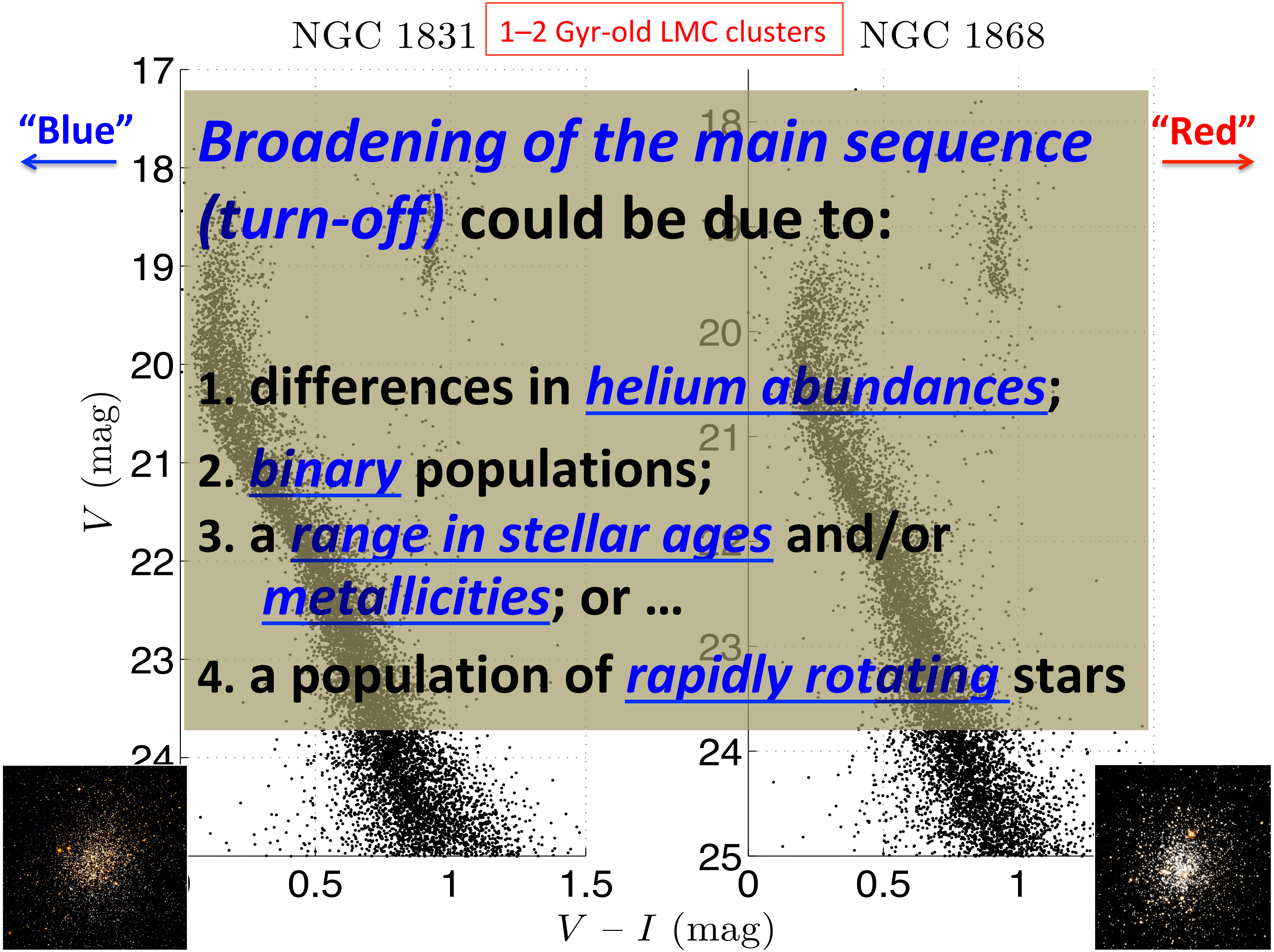
Milone et al. (2008)
NGC 2808
Villanova et al. (2007); Piotto et al. (2007)
NGC 2808
m_{F814W}
$m_{F475W} - m_{F606W}$
[M/H]=−1.0
Y=0.248
Y=0.30
Y=0.35
Y=0.40
$(m-M)_0$=15.0
E(B−V)=0.18
$m_{F475W} - m_{F814W}$
NGC 1851
m_{F606W}
$m_{F606W} - m_{F814W}$

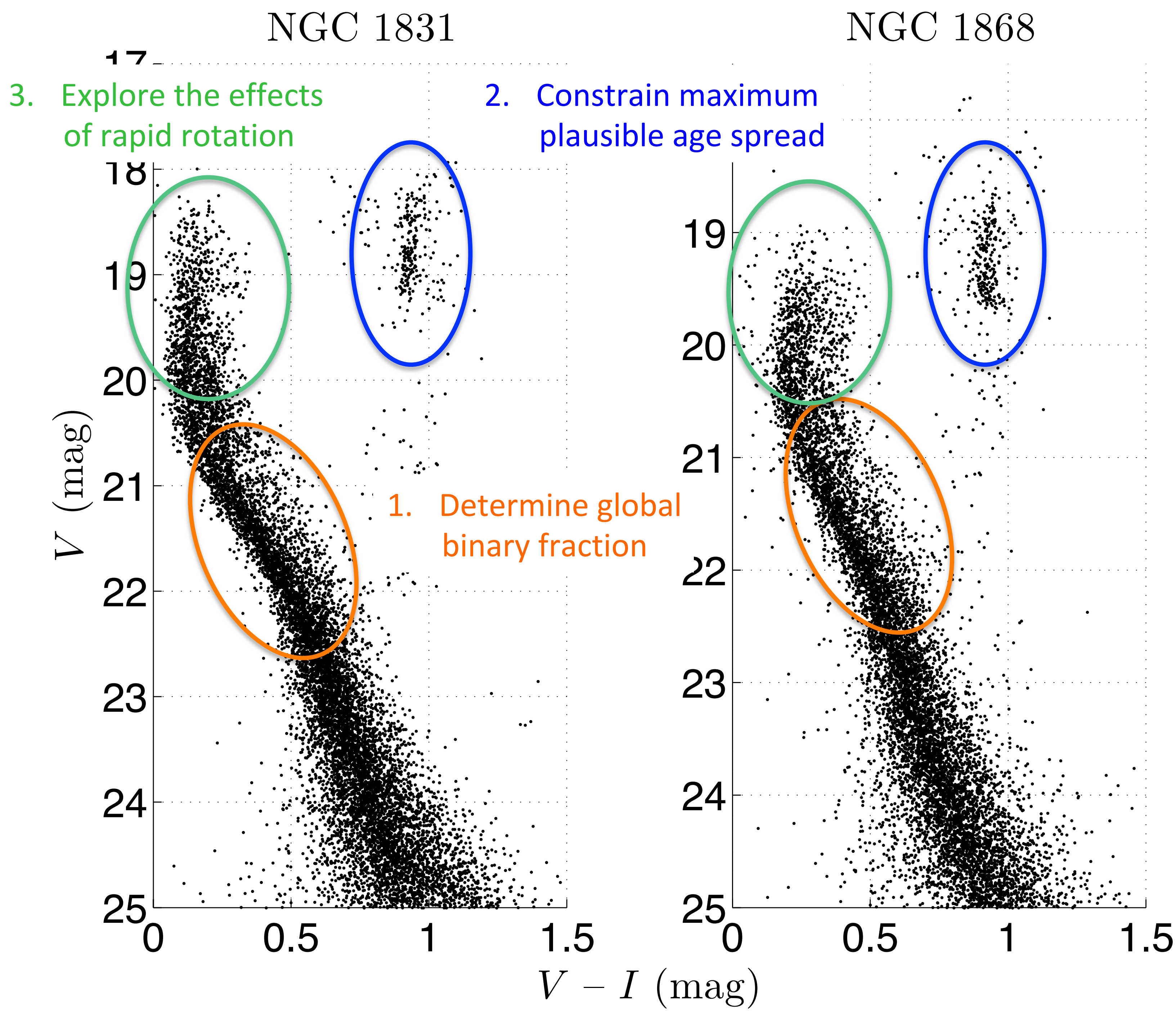


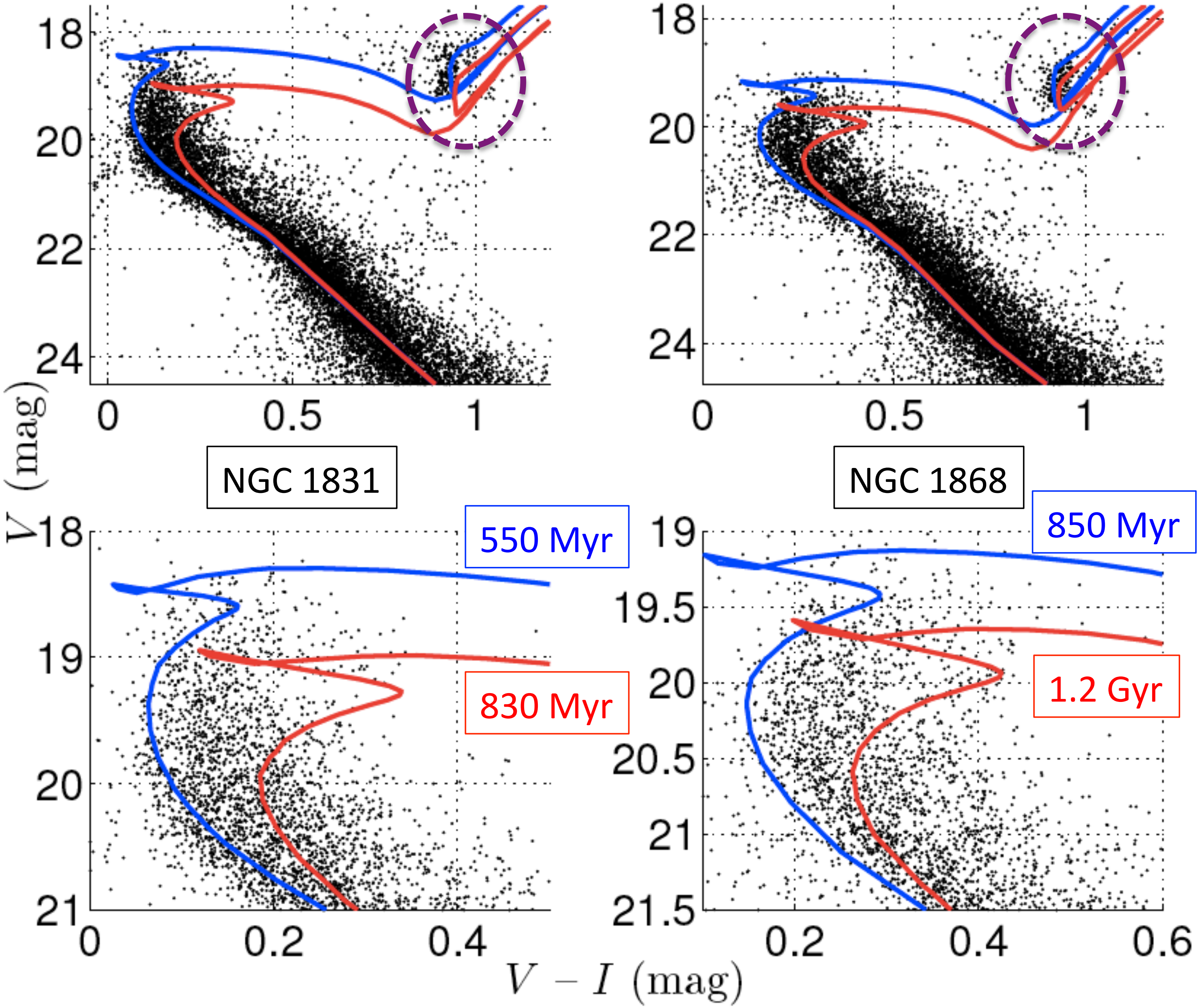
(Martocchia et al. 2018, MNRAS)



Broadening of the main sequence (turn-off) **could be due to:**

1. differences in ***helium abundances***;
2. ***binary*** populations;
3. a ***range in stellar ages*** and/or ***metallicities***; or …
4. a population of ***rapidly rotating*** stars


NGC 1831
NGC 1868
3. Explore the effects of rapid rotation
2. Constrain maximum plausible age spread
1. Determine global binary fraction
V (mag)
V − I (mag)
17
18
19
20
21
22
23
24
25
0
0.5
1
1.5



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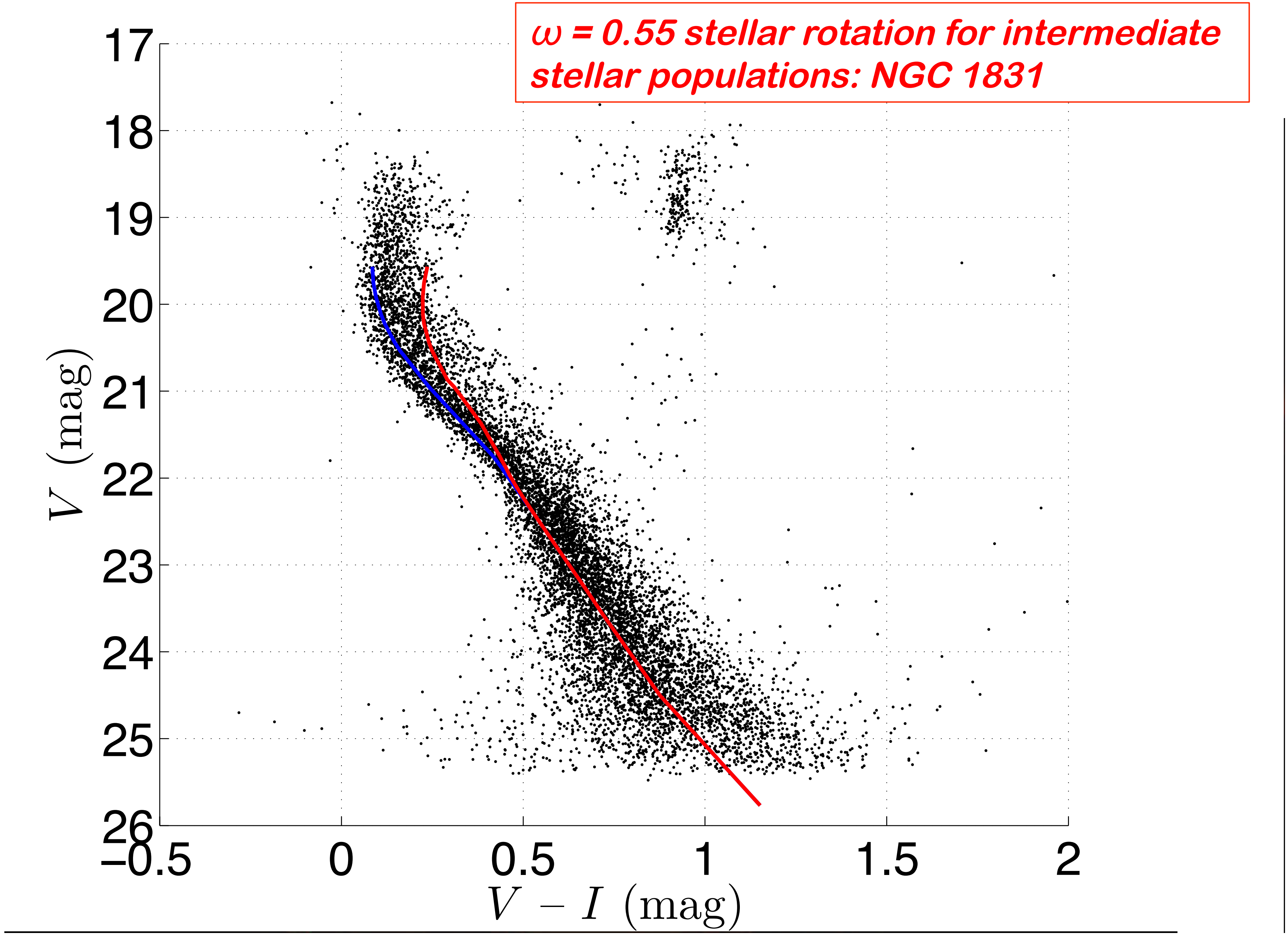
(Li, de Grijs, & Deng, 2014, ApJ, 784, 157)


ω = 0.55 stellar rotation for intermediate stellar populations: NGC 1831
17
18
19
20
21
22
23
24
25
26
V (mag)
−0.5
0
0.5
1
1.5
2
V − I (mag)

(Li, de Grijs, & Deng, 2014, ApJ, 784, 157)

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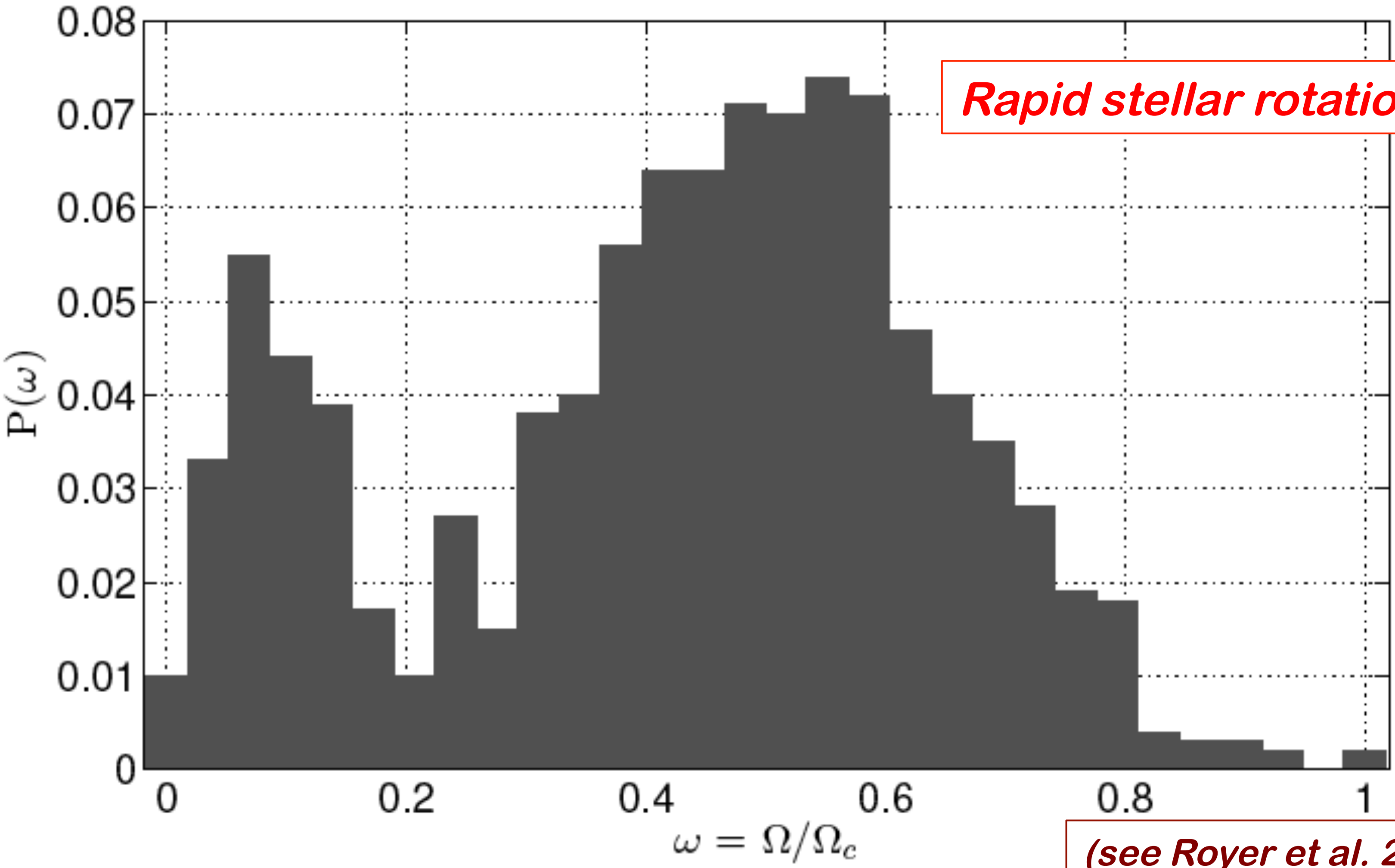

Rapid stellar rotation?

(see Royer et al. 2007; Bastian & de Mink 2009)

Fig. 15.— ω (fraction of the critical break-up rate) distribution of rotating stars, with double Gaussian peaks at 0.10 and 0.50, and standard deviations of 0.05 and 0.15, respectively.

(Li, de Grijs, & Deng, 2014, ApJ, 784, 157)

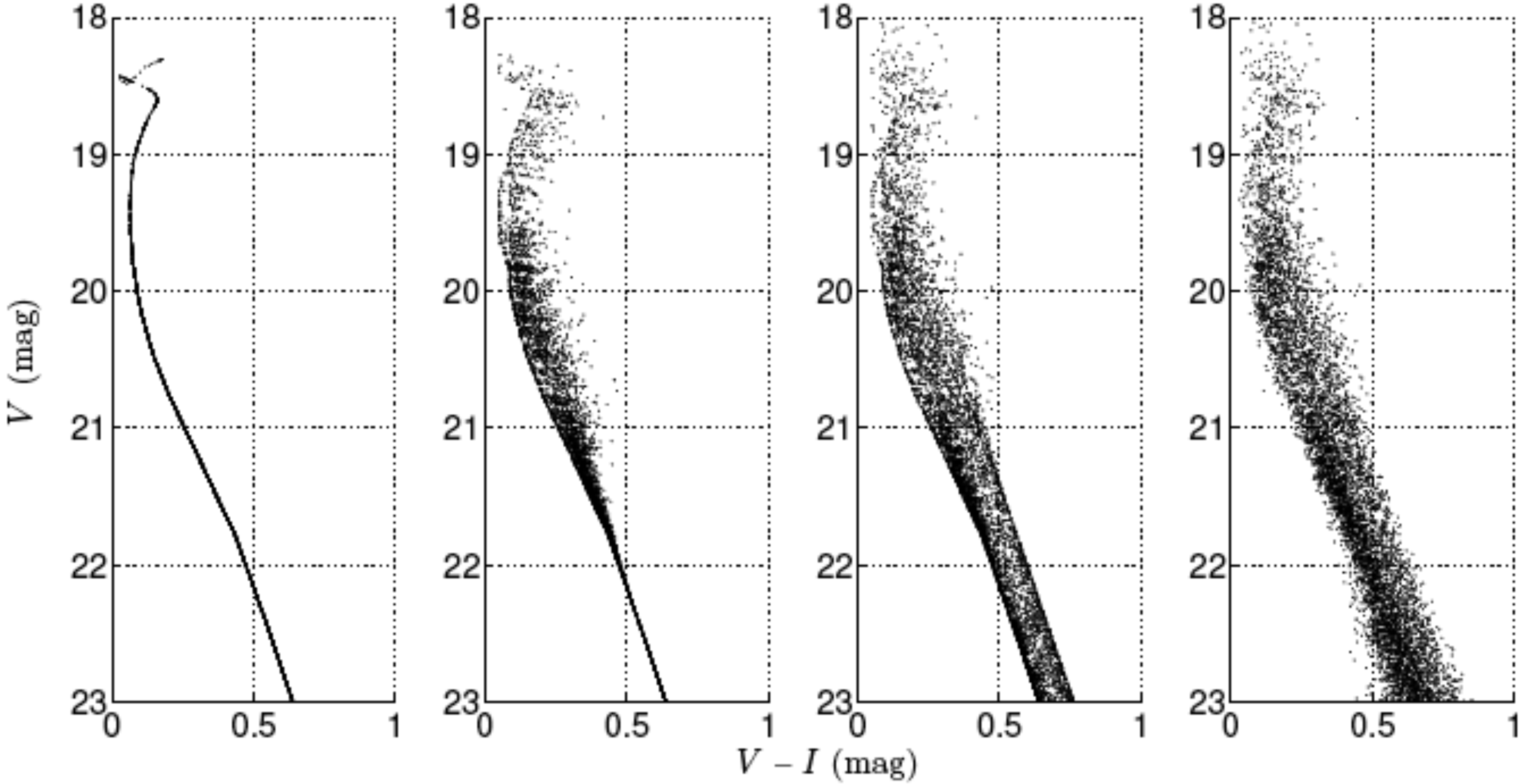

Fig. 16.— Steps to generate our simulated NGC 1831 CMD. From left to right: (1) We generate stars that exactly match the parameters given by the adopted isochrone. (2) For stars more massive than $1.2 M_\odot$, we randomly assign rotation velocities, based on the ω distribution of Fig. 15. (3) We assign 'binary status' to 70% of the artificial stars and adjust their photometry based on the adopted binary properties. (4) We adopt the appropriate photometric uncertainties according to Eq. (1).

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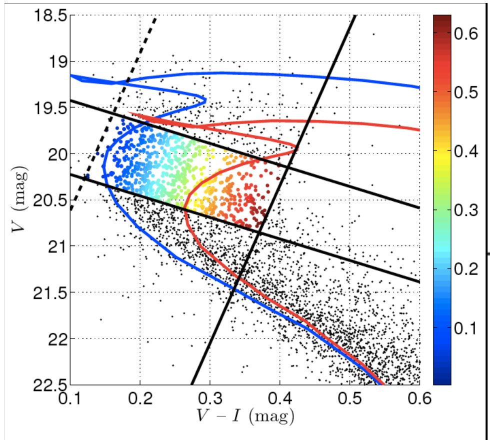
(Li, de Grijs, & Deng, 2014, ApJ, 784, 157)



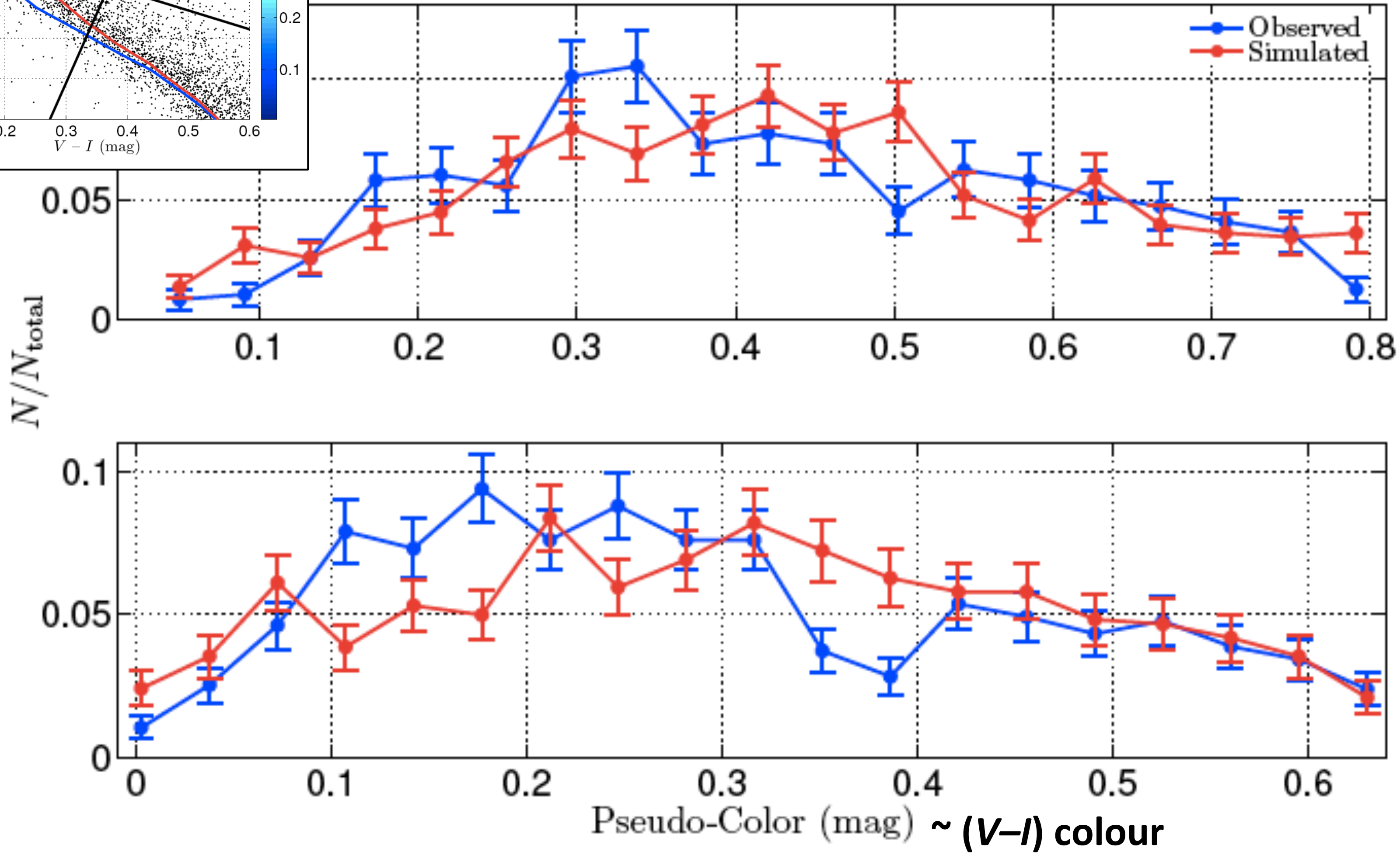
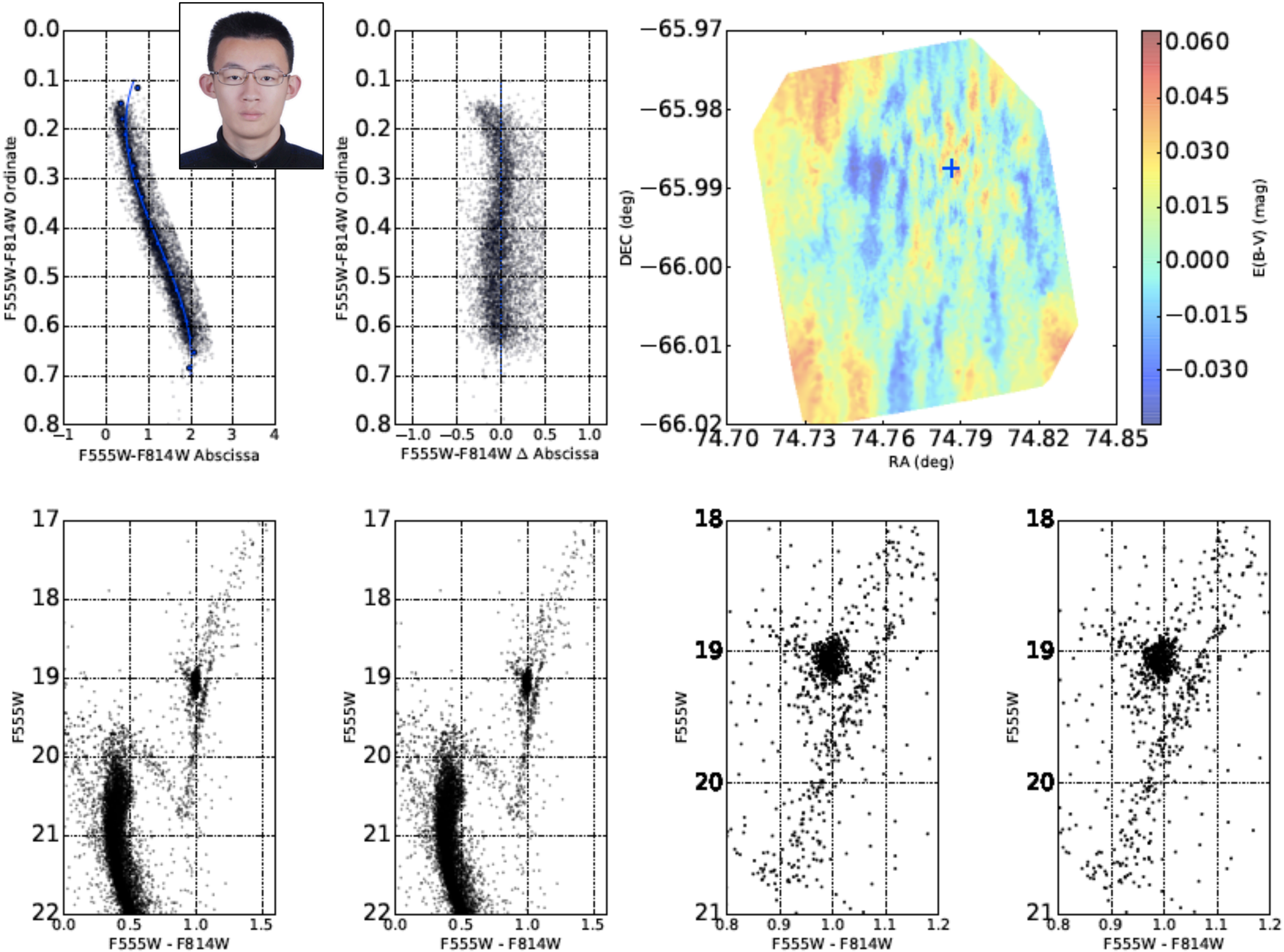
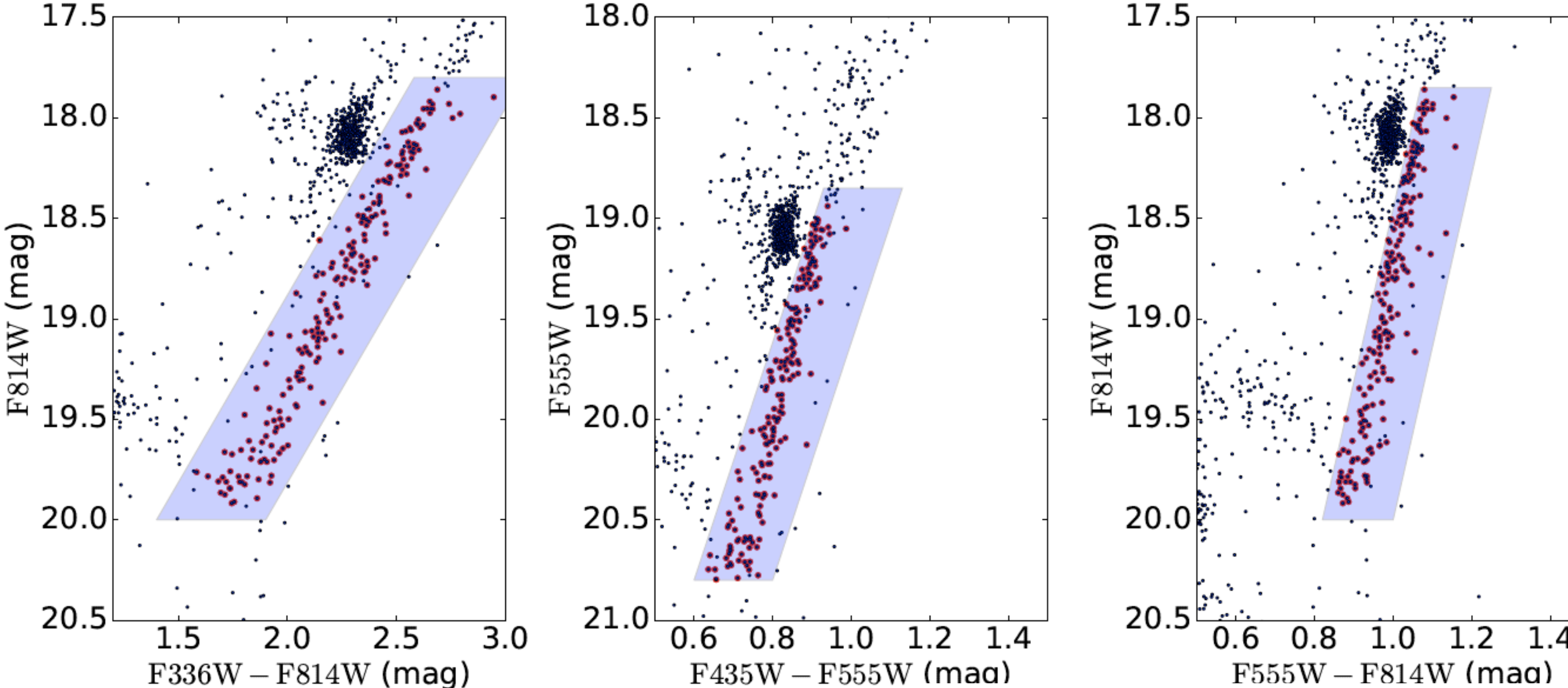
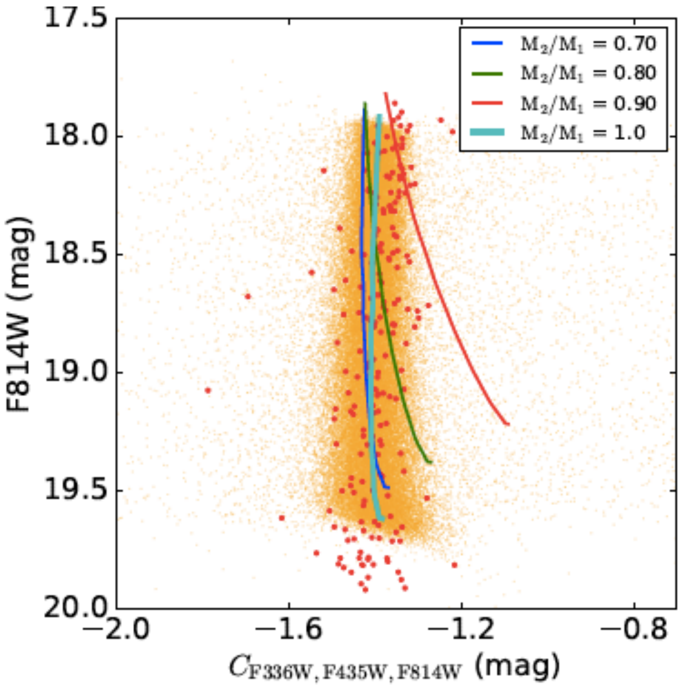


Fig. 19.— Pseudo-color distributions of (red) the simulated MS TO stars and (blue) the observed MS TO stars for (top) NGC 1831 and (bottom) NGC 1868.

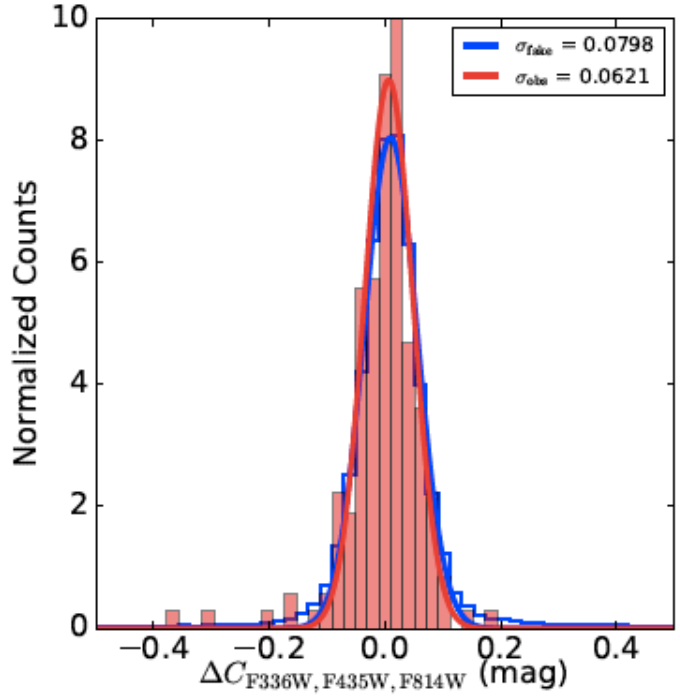


F555W-F814W Ordinate
F555W-F814W Abscissa
F555W-F814W Δ Abscissa
DEC (deg)
RA (deg)
E(B-V) (mag)
F555W
F555W - F814W





Zhang, de Grijs, Li & Wu, 2018, ApJ, 853, 186; cf. Martocchia et al. 2018)



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NGC 1651: An unexpected discovery

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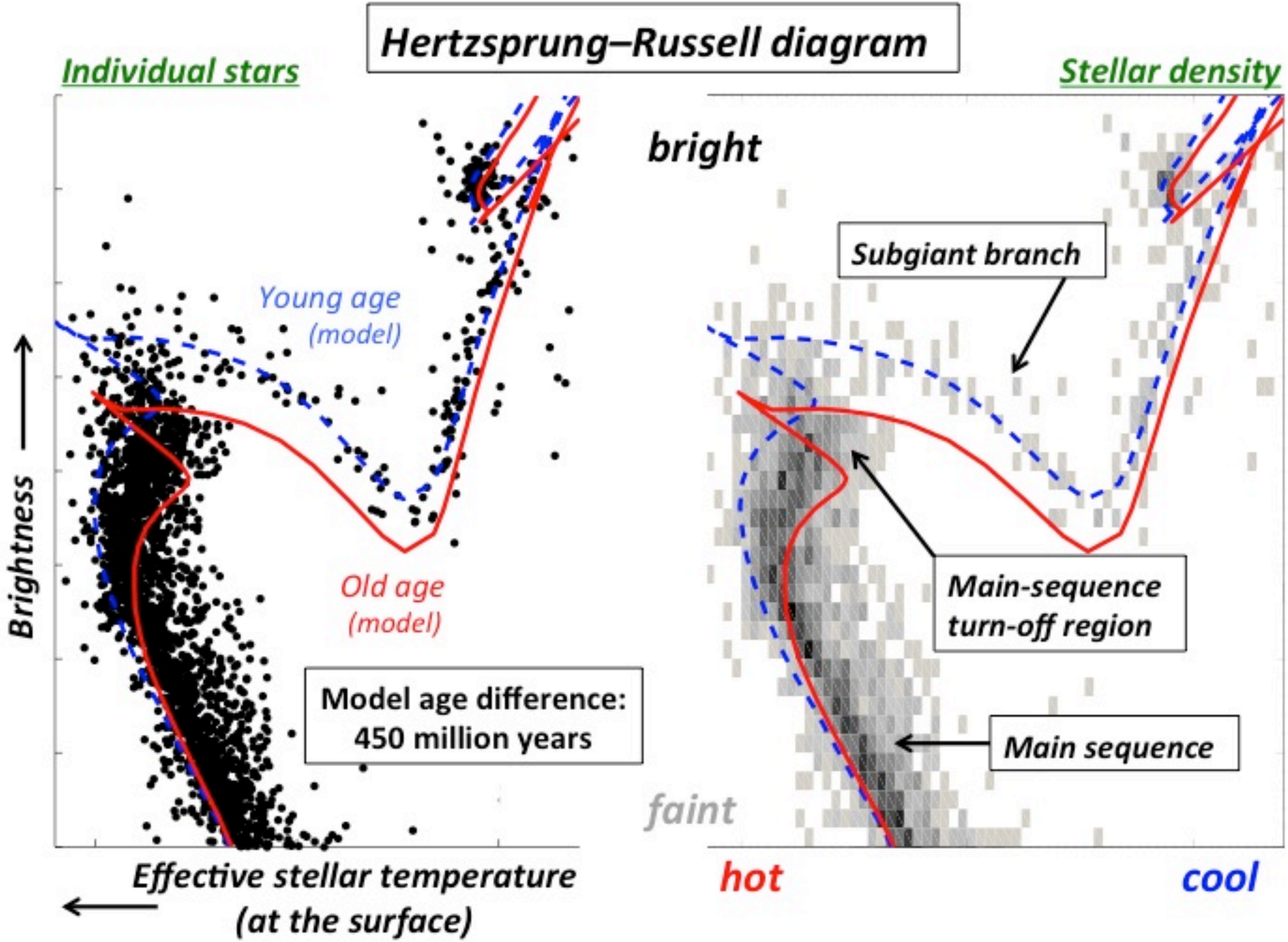
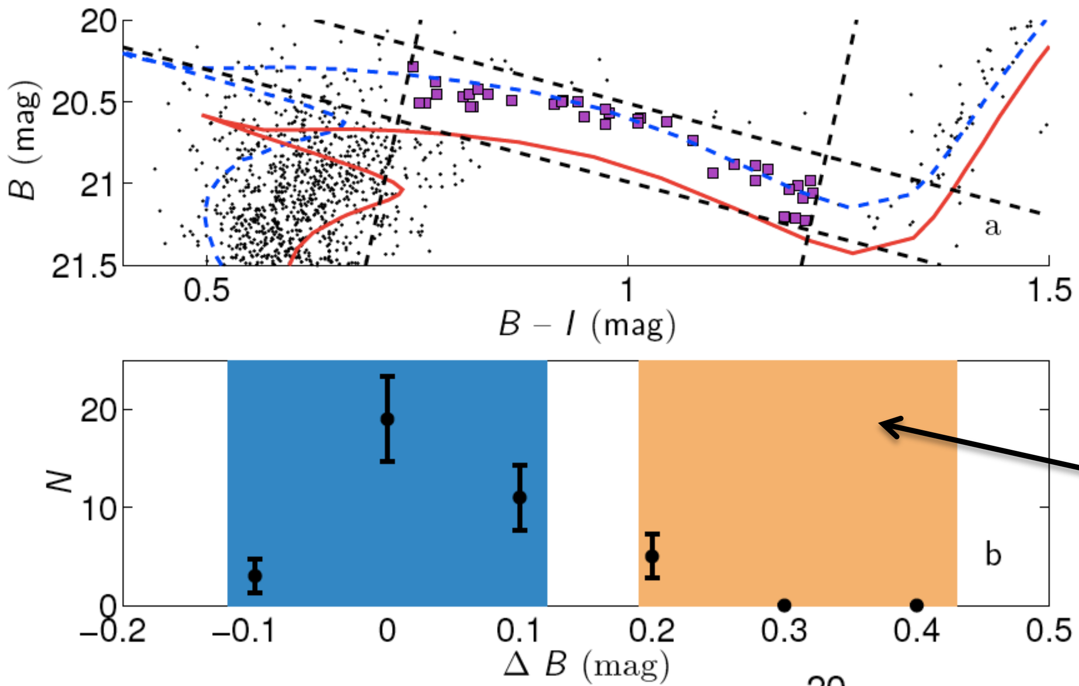
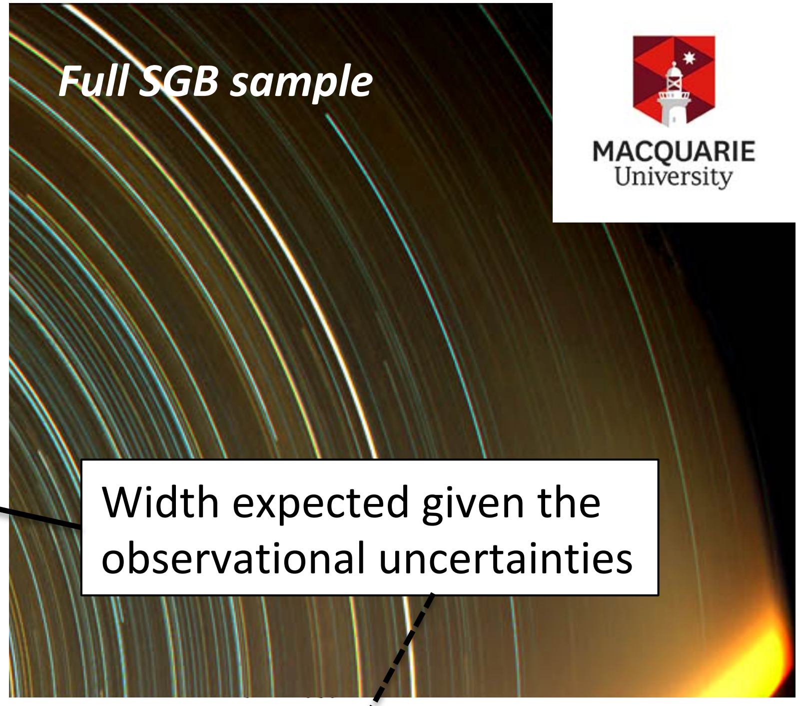


(Li, de Grijs & Deng, 2014, *Nature*, 516, 367)





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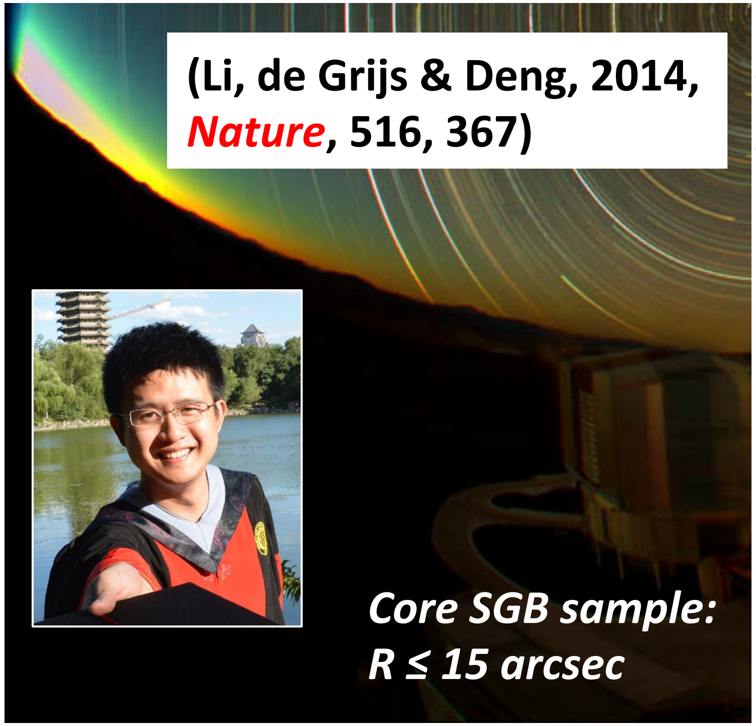
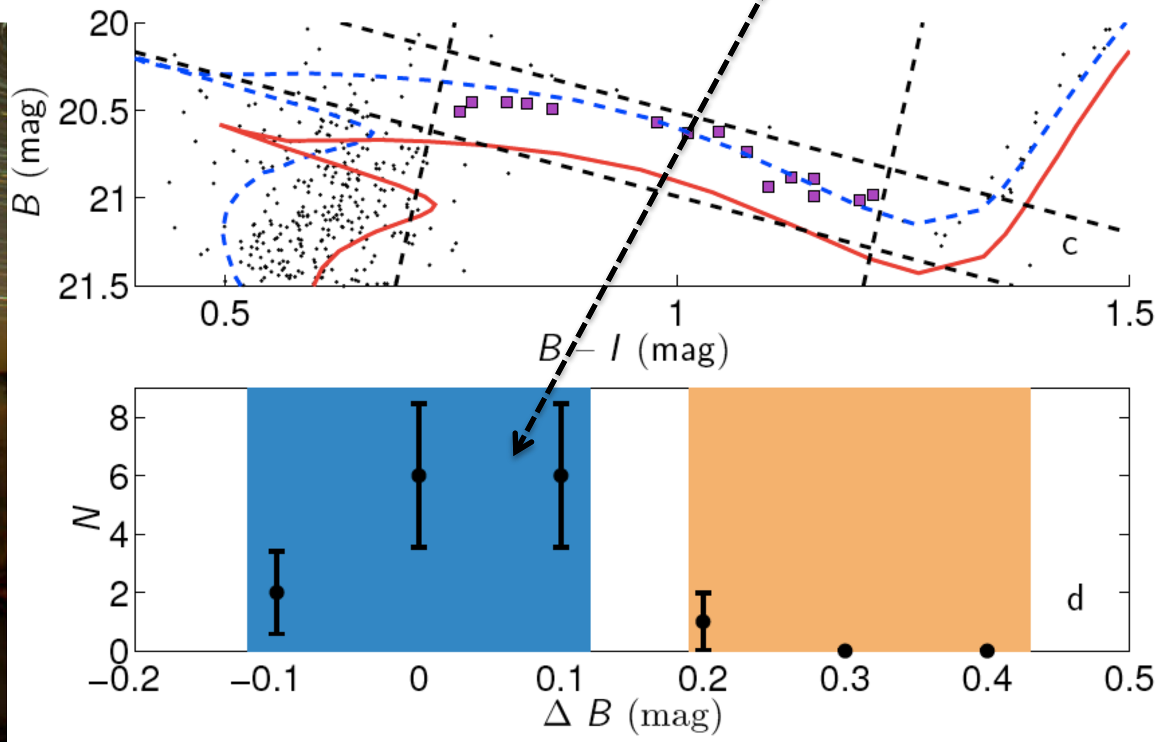
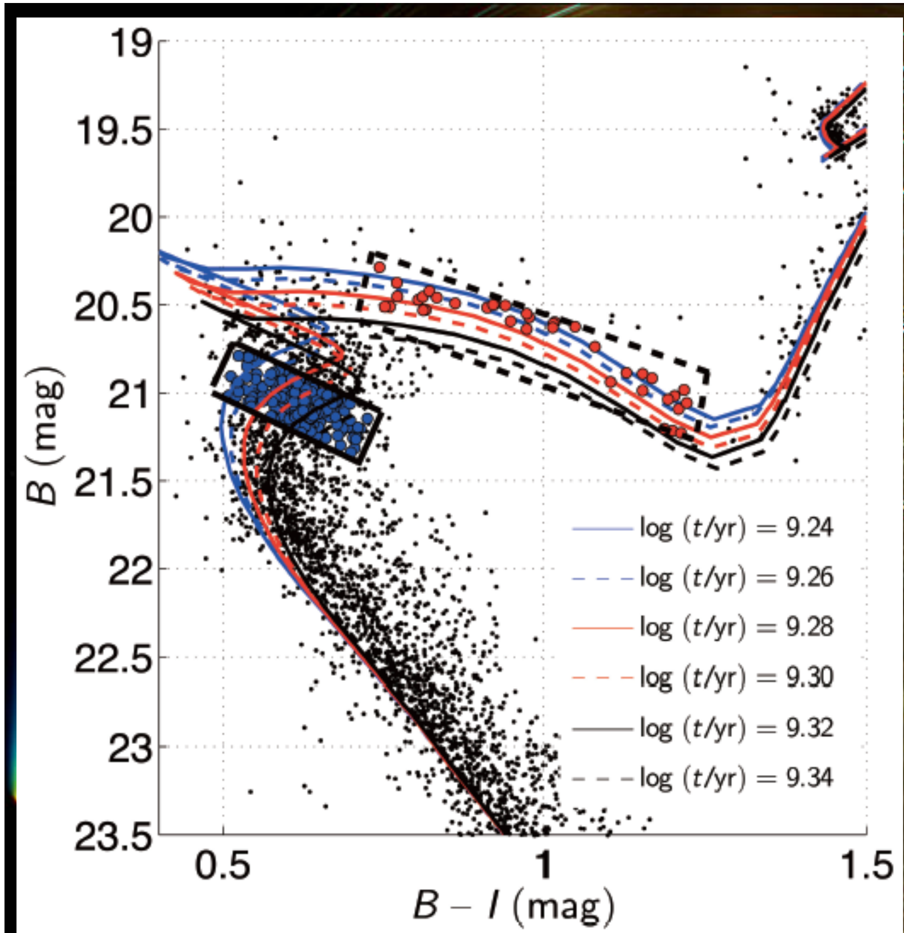
Width expected given the observational uncertainties

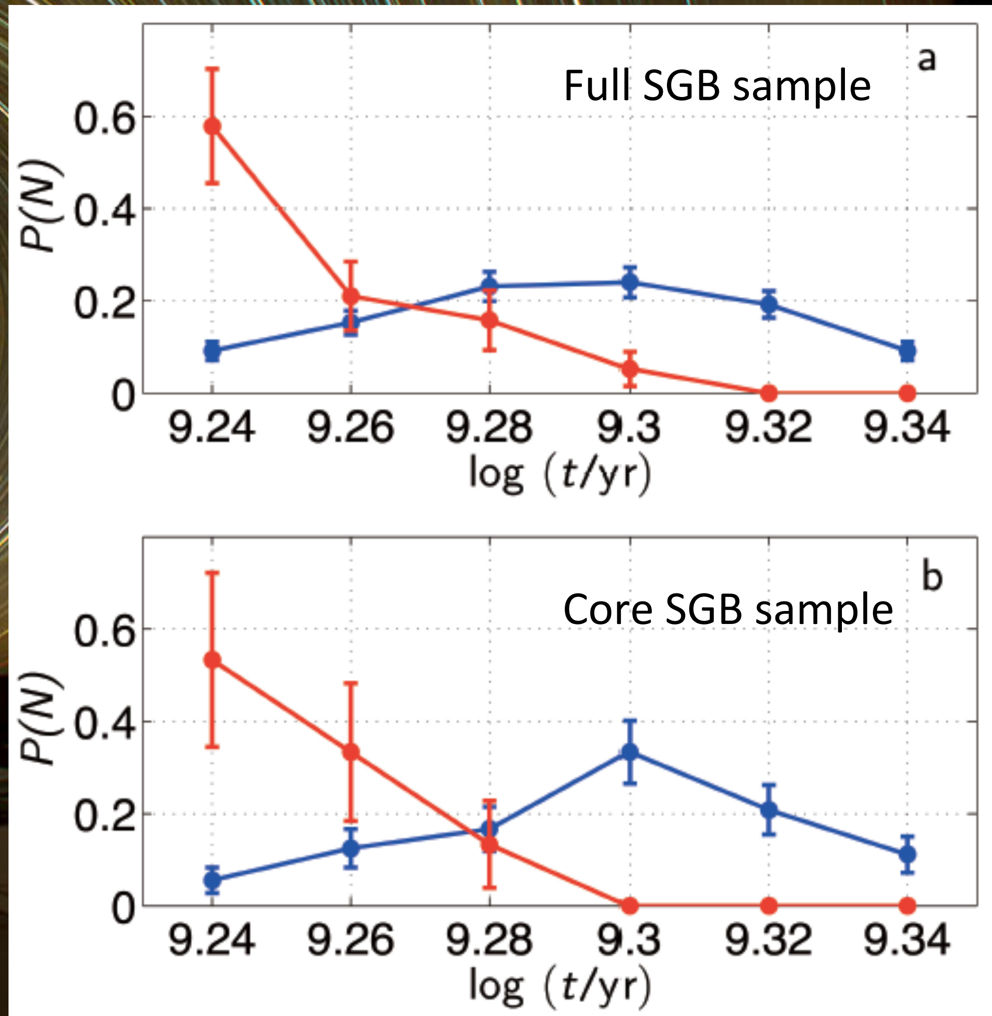


(Li, de Grijs & Deng, 2014, *Nature*, 516, 367)



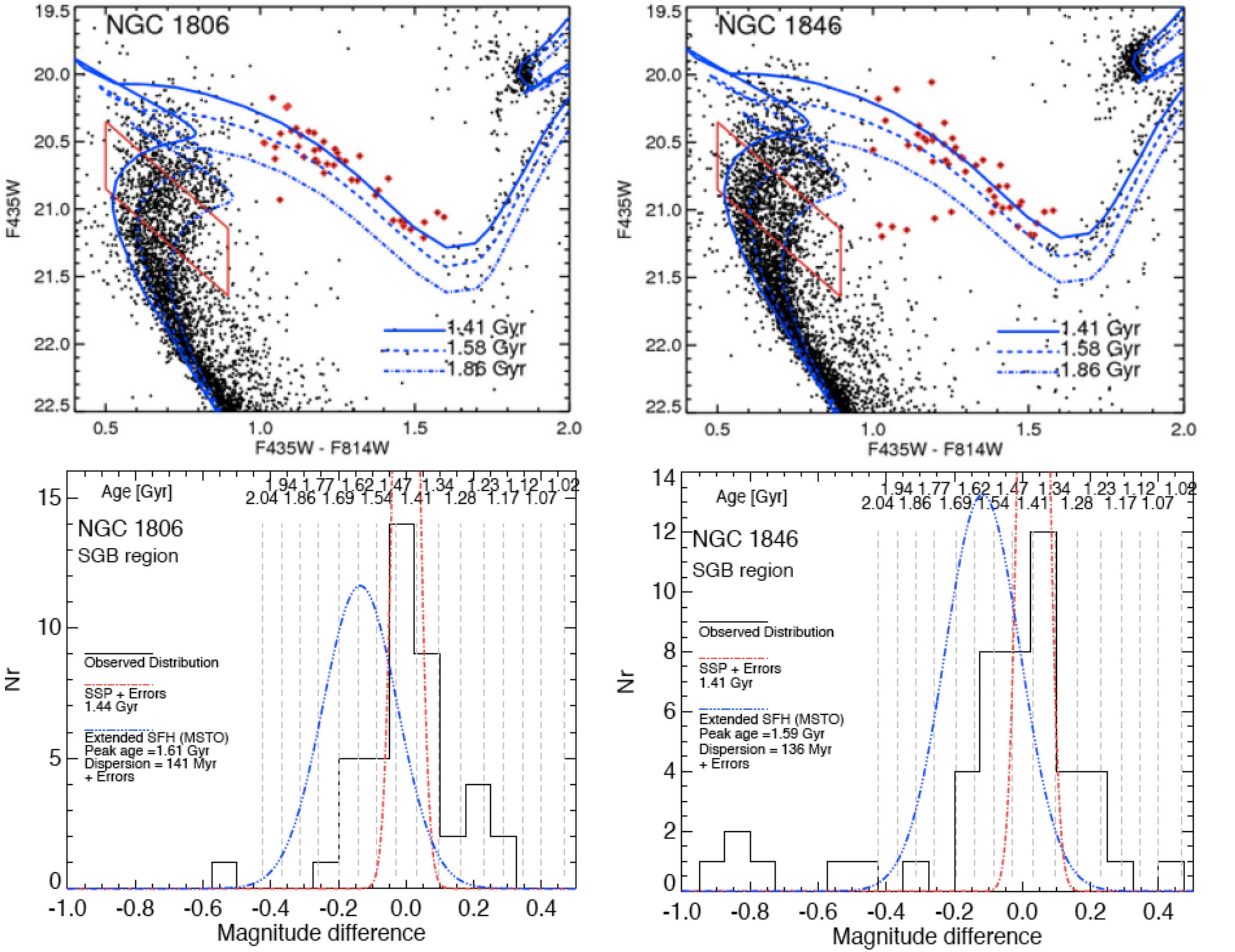


(Li, de Grijs & Deng, 2014, *Nature*, 516, 367)



Maximum plausible age range allowed by the SGB width: 80 Myr

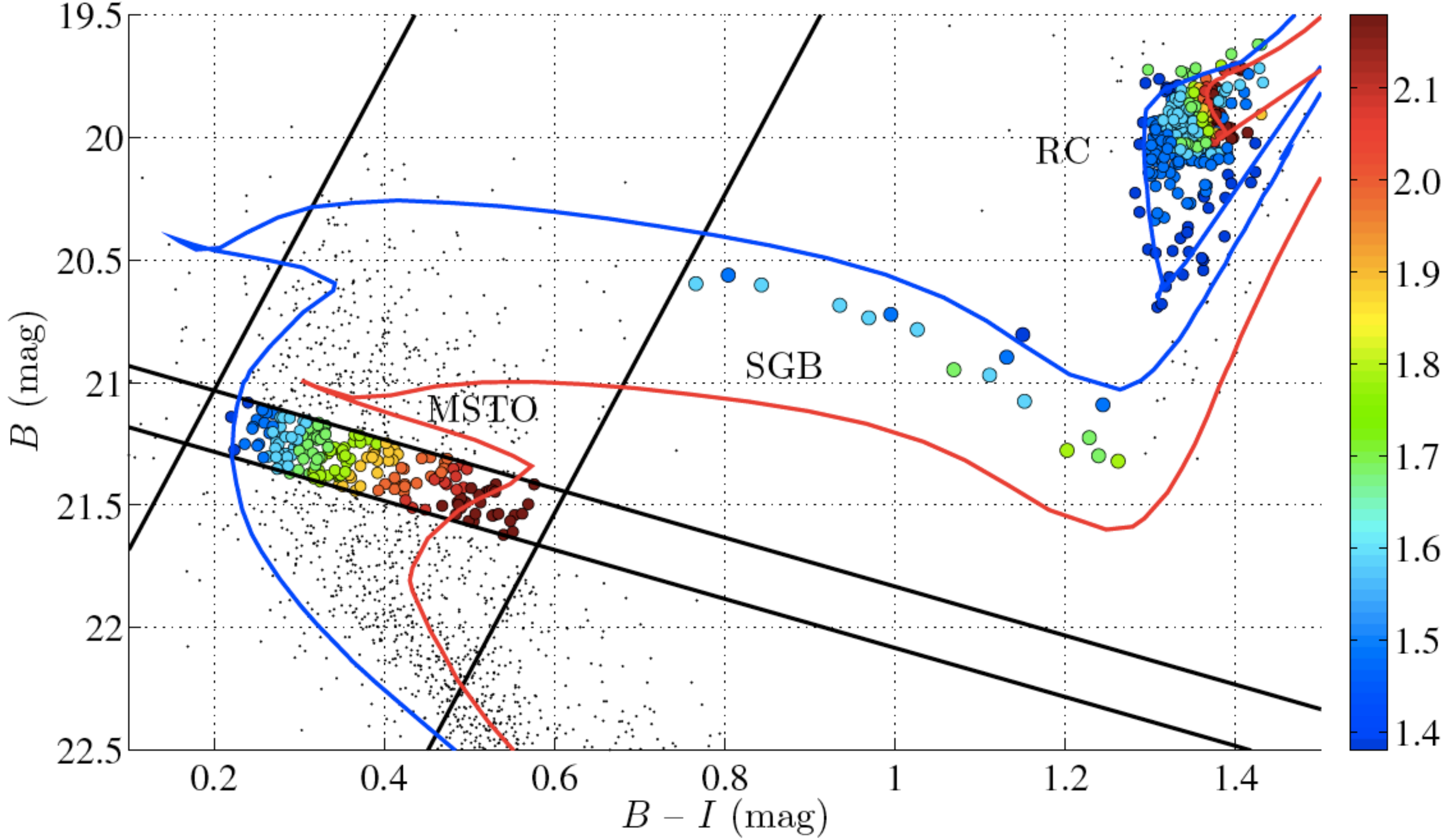
Bastian & Niederhofer 2015, MNRAS, 448, 1863



(Li, de Grijs, et al. 2016, MNRAS, 461, 3212)

NGC 411

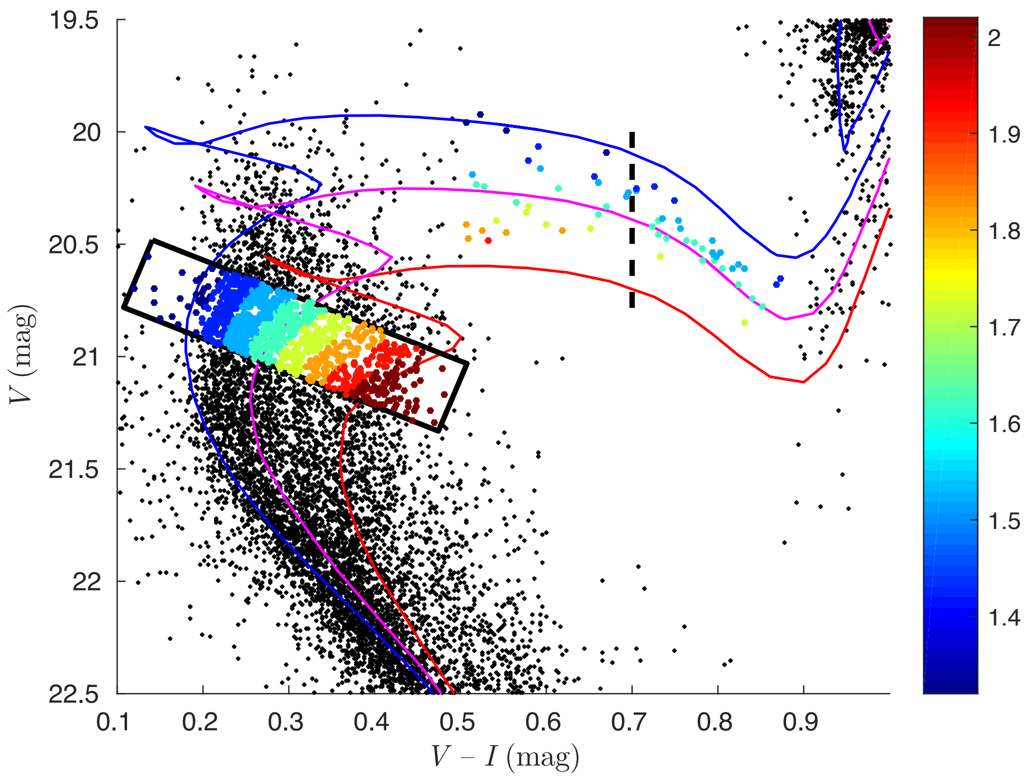
- Most extended MSTO known
- Lowest escape velocity of an MSTO cluster

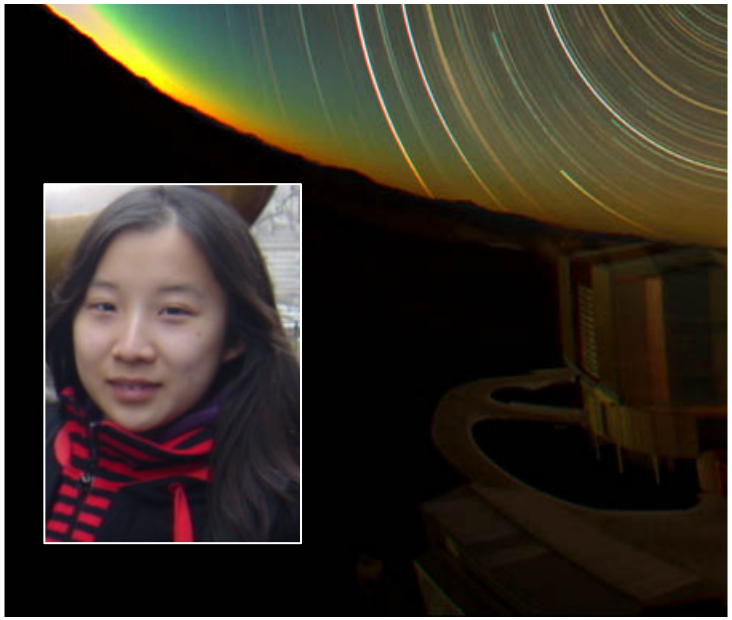


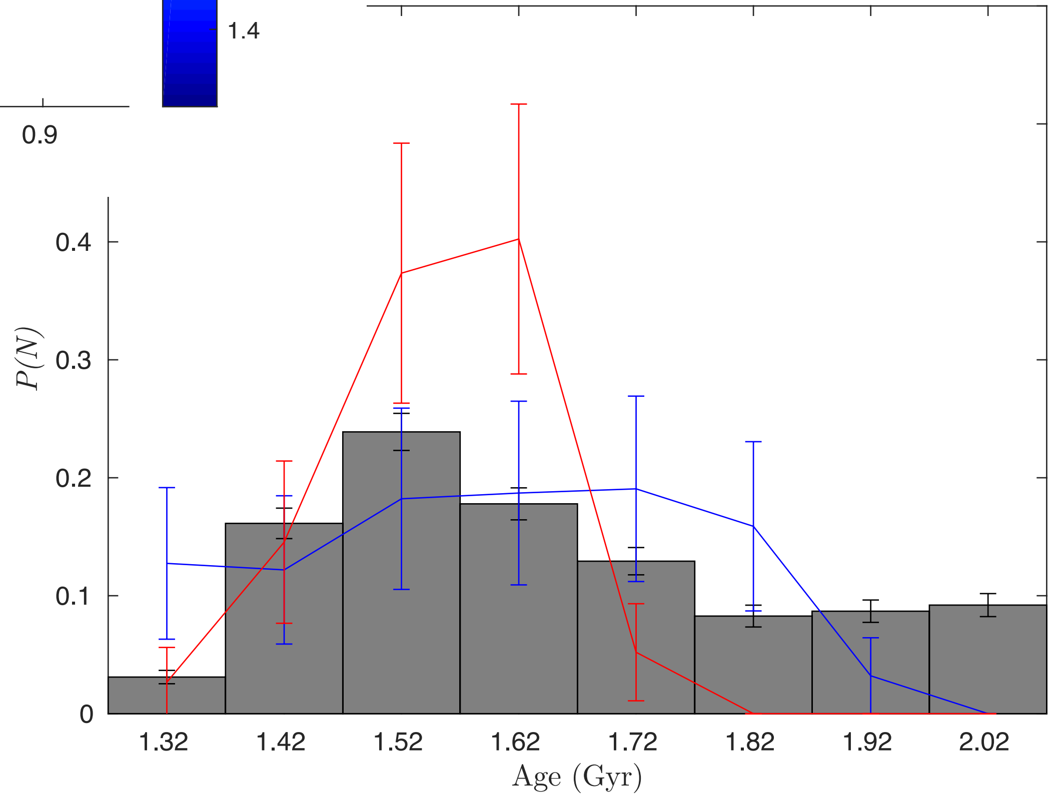
NGC 419

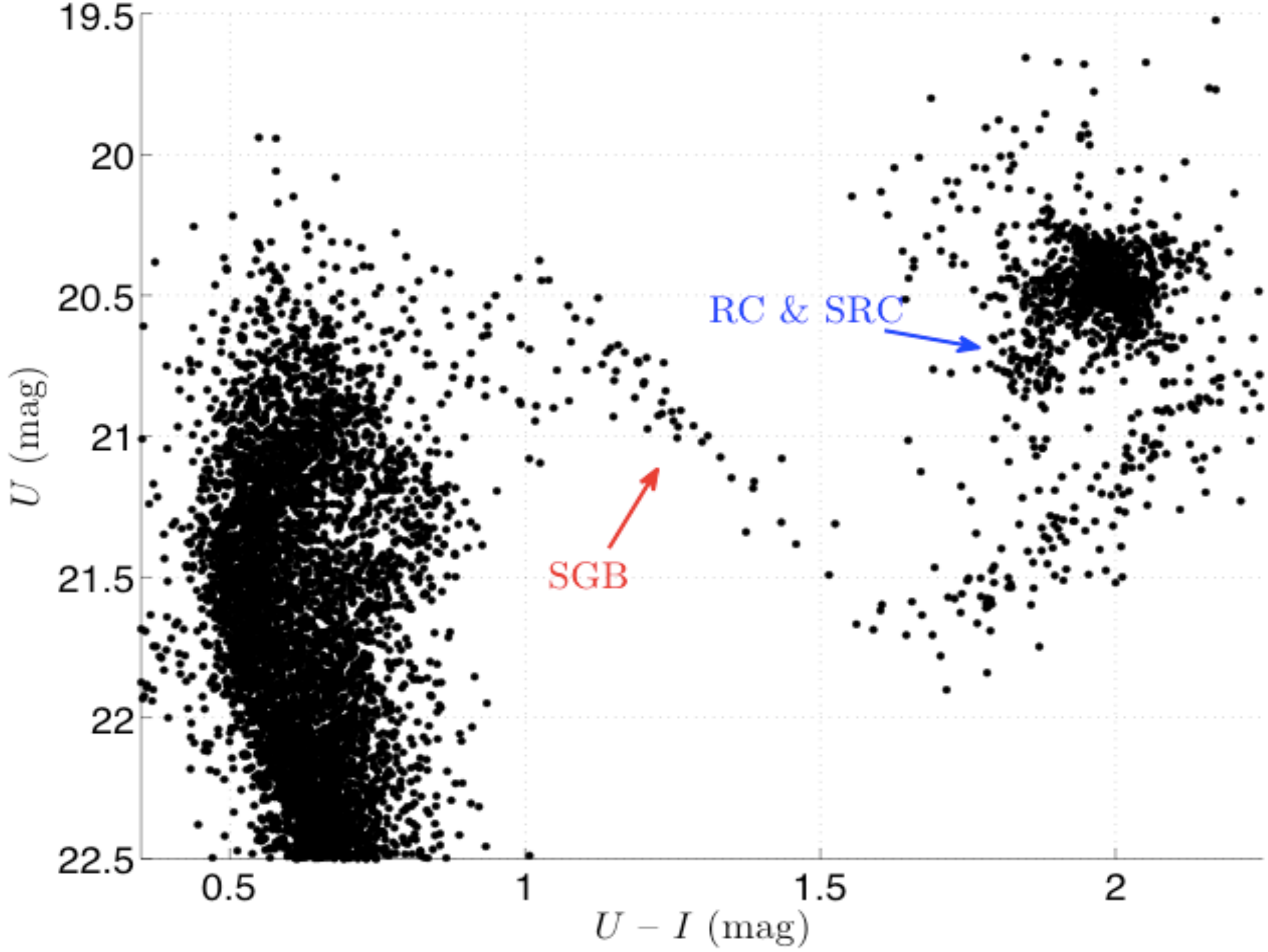
Rotational deceleration?

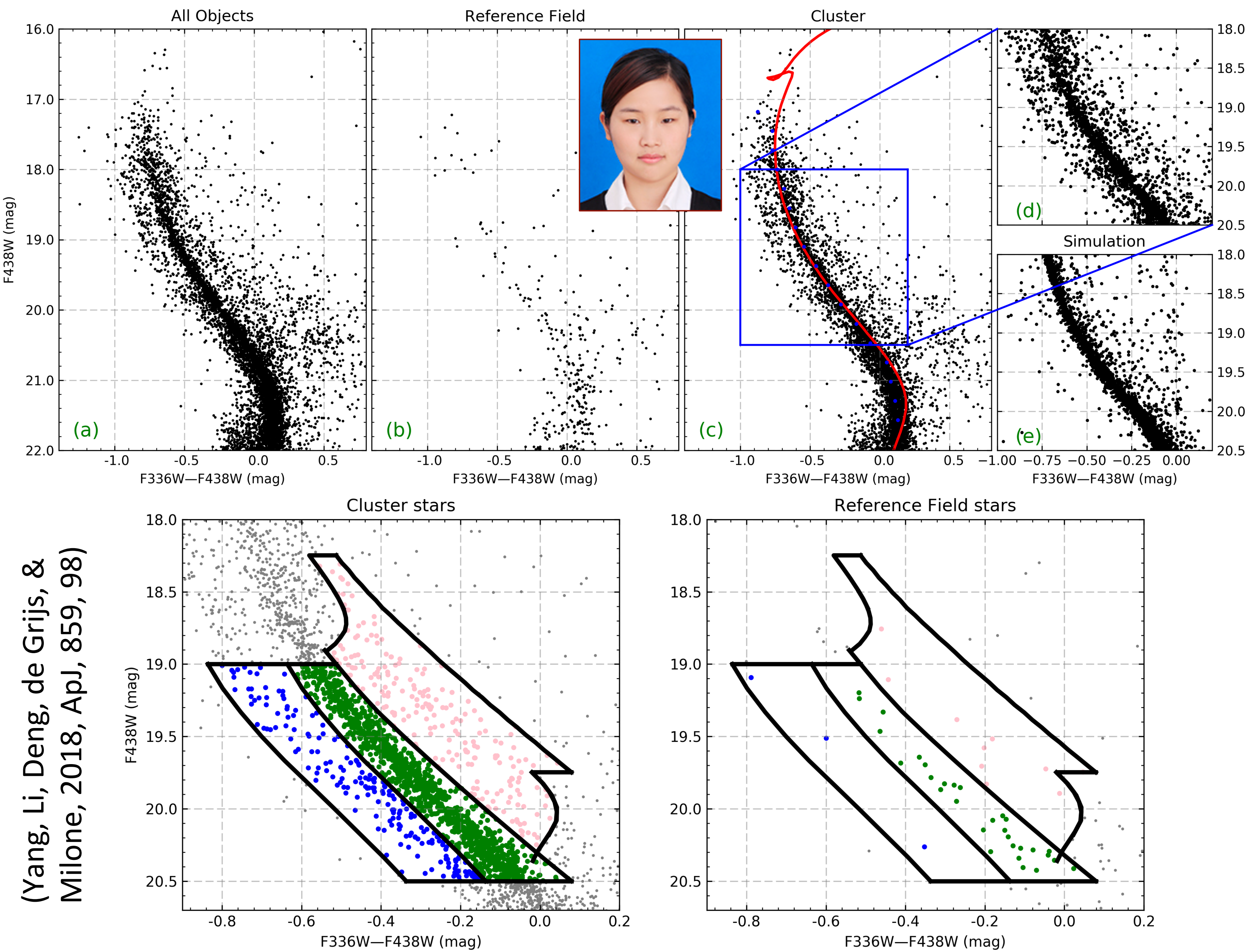
Wu, Li, de Grijs, & Deng, 2016, ApJL, 826, L14





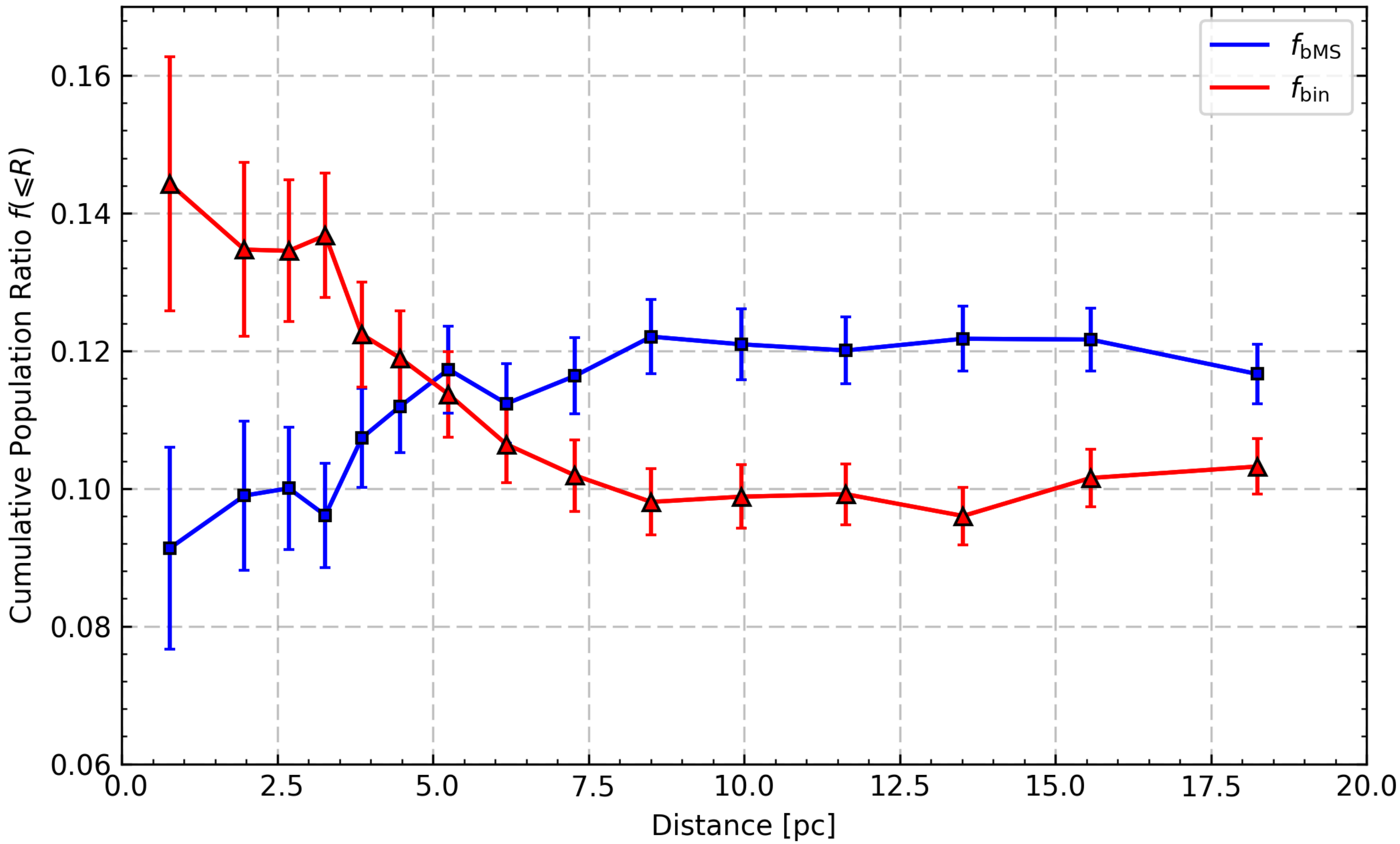



19.5
20
20.5
21
21.5
22
22.5
U (mag)
0.5
1
1.5
2
U − I (mag)
RC & SRC
SGB



(Yang, Li, Deng, de Grijs, & Milone, 2018, ApJ, 859, 98)

(Yang, Li, Deng, de Grijs, & Milone, 2018, ApJ, 859, 98)



Take-home messages

1–3 Gyr

- At intermediate ages, *extended Main-Sequence Turn-Offs* imply the presence of an *age spread* or a population of *rapidly rotating* MSTO stars.

- A *simple stellar population* including rapidly rotating stars seems the "best" match to intermediate-age clusters

- The presence of an extended MSTO *does not necessarily imply* an age spread

- Our most recent results suggest that a *major reassessment* of the *multiple stellar population paradigm* is sorely needed!

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