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Chemical Fingerprints of Mass Transfer in Open Clusters

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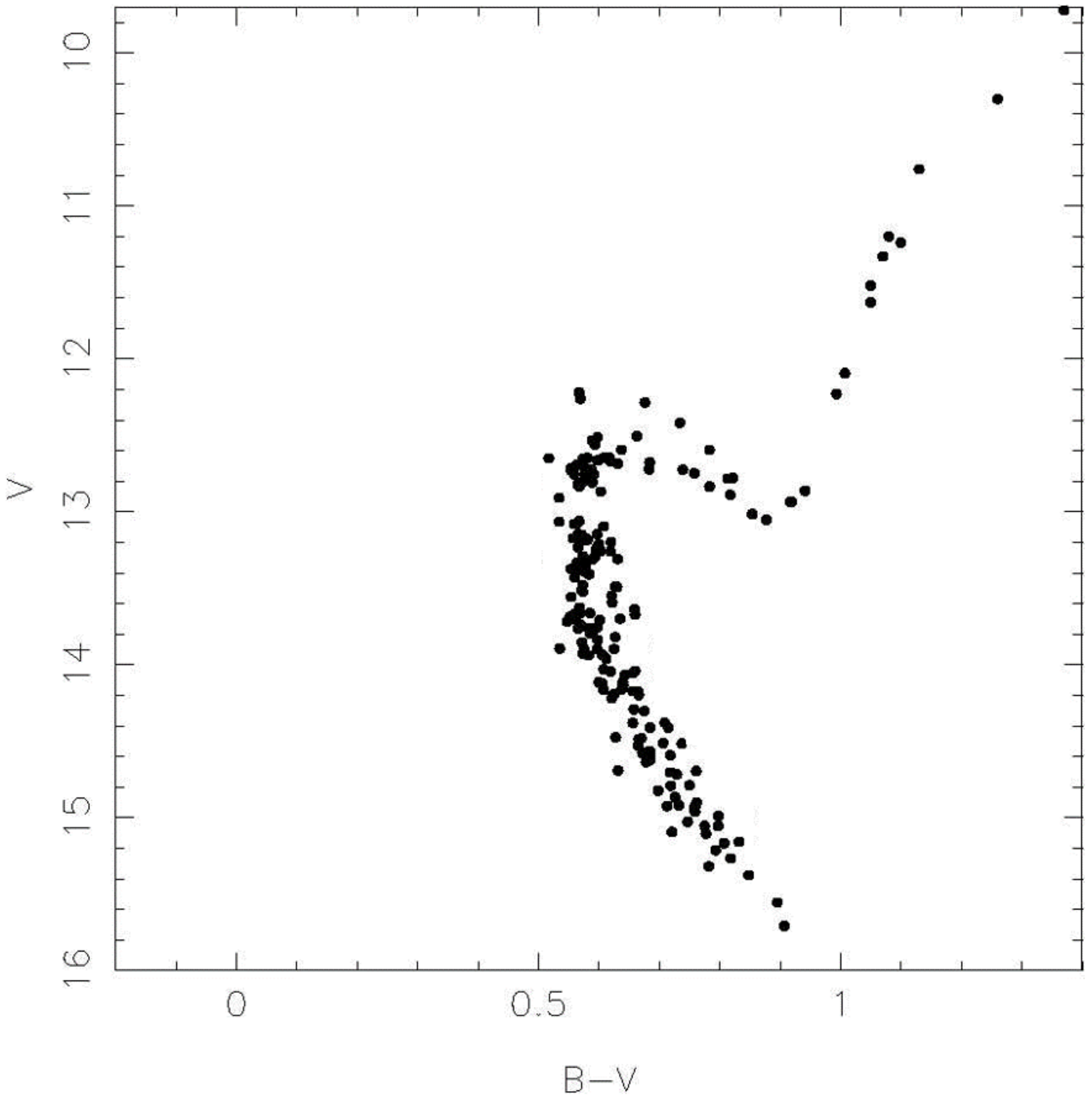
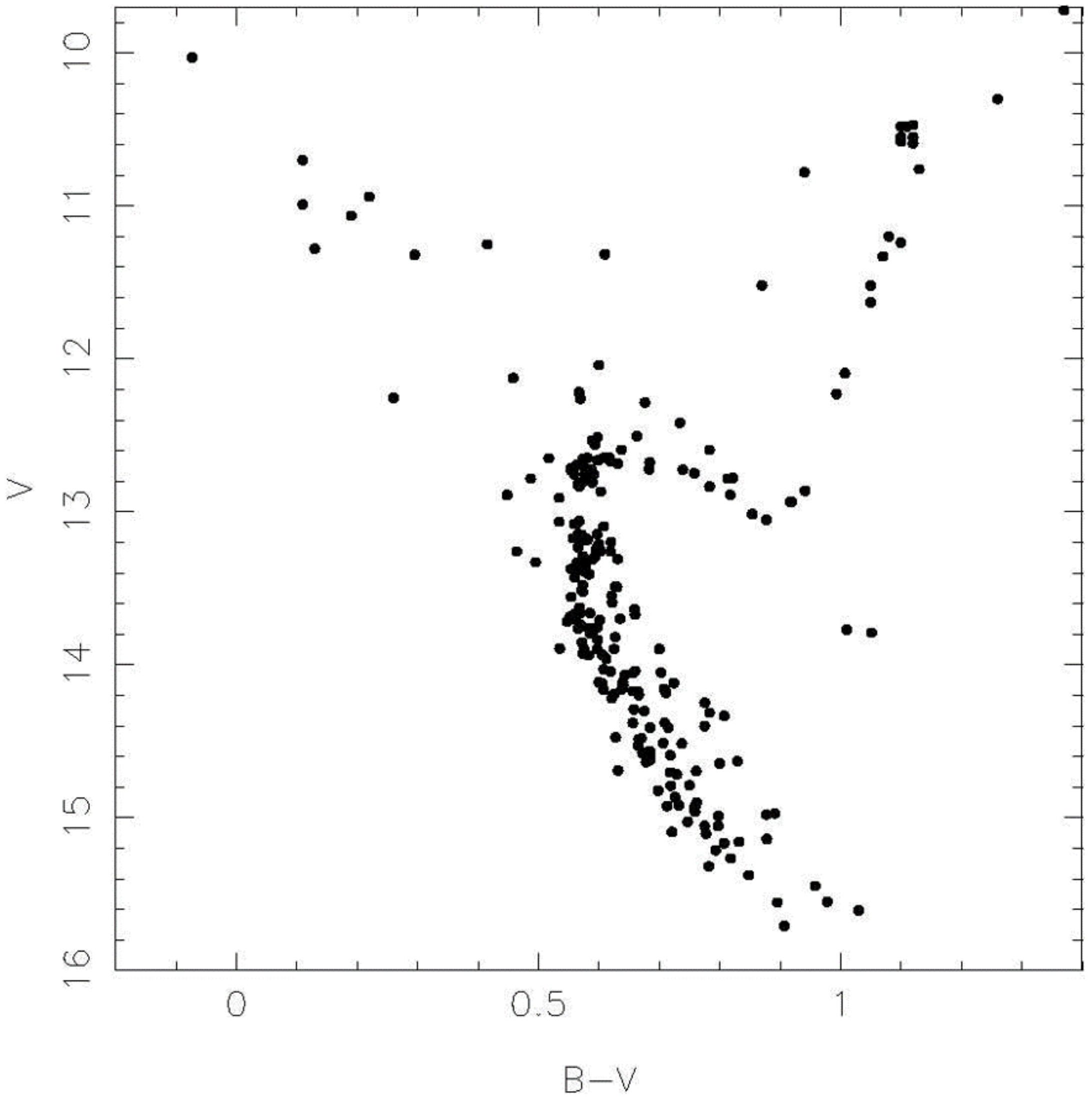


Courtesy of R. D. Mathieu



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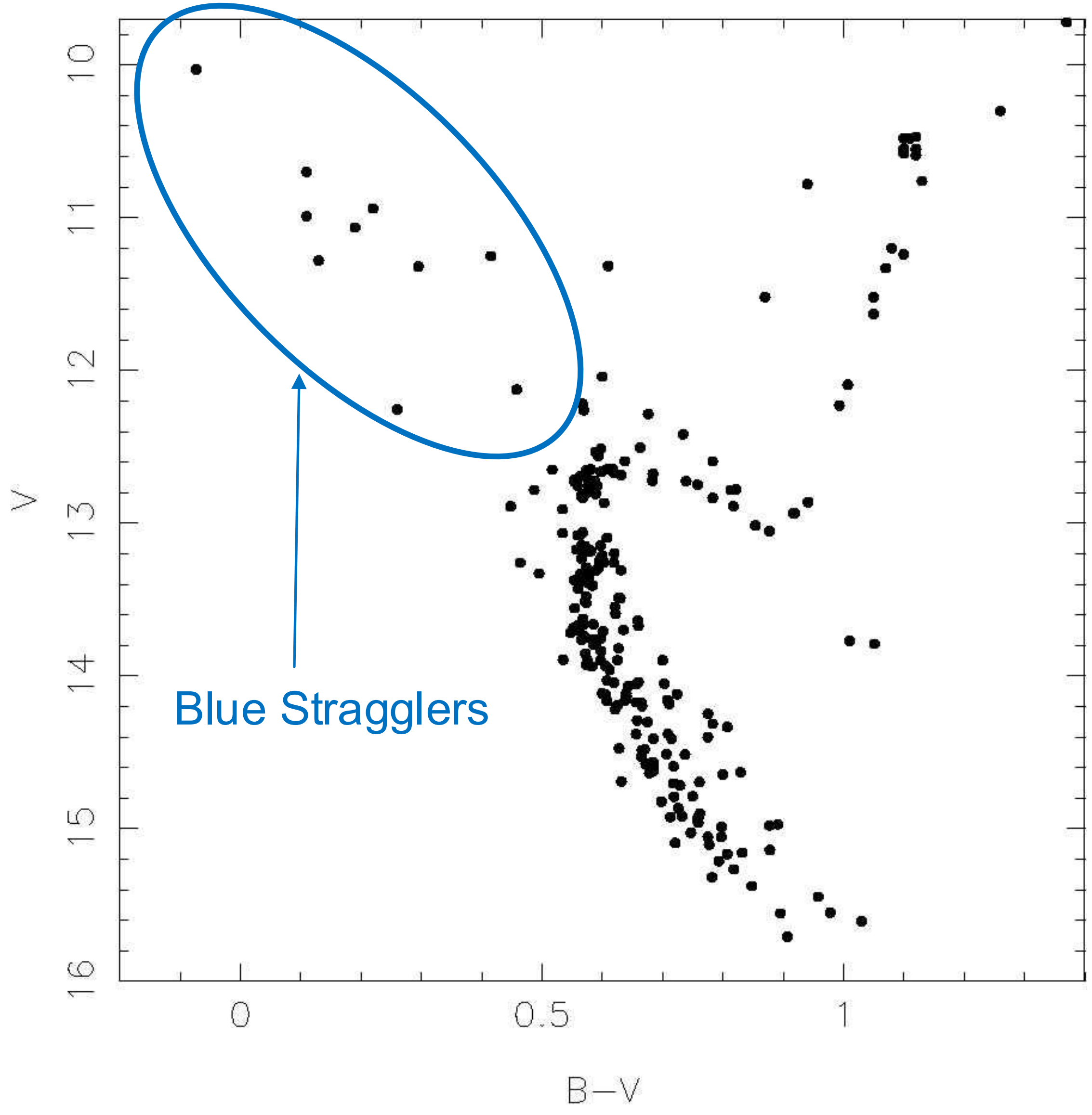

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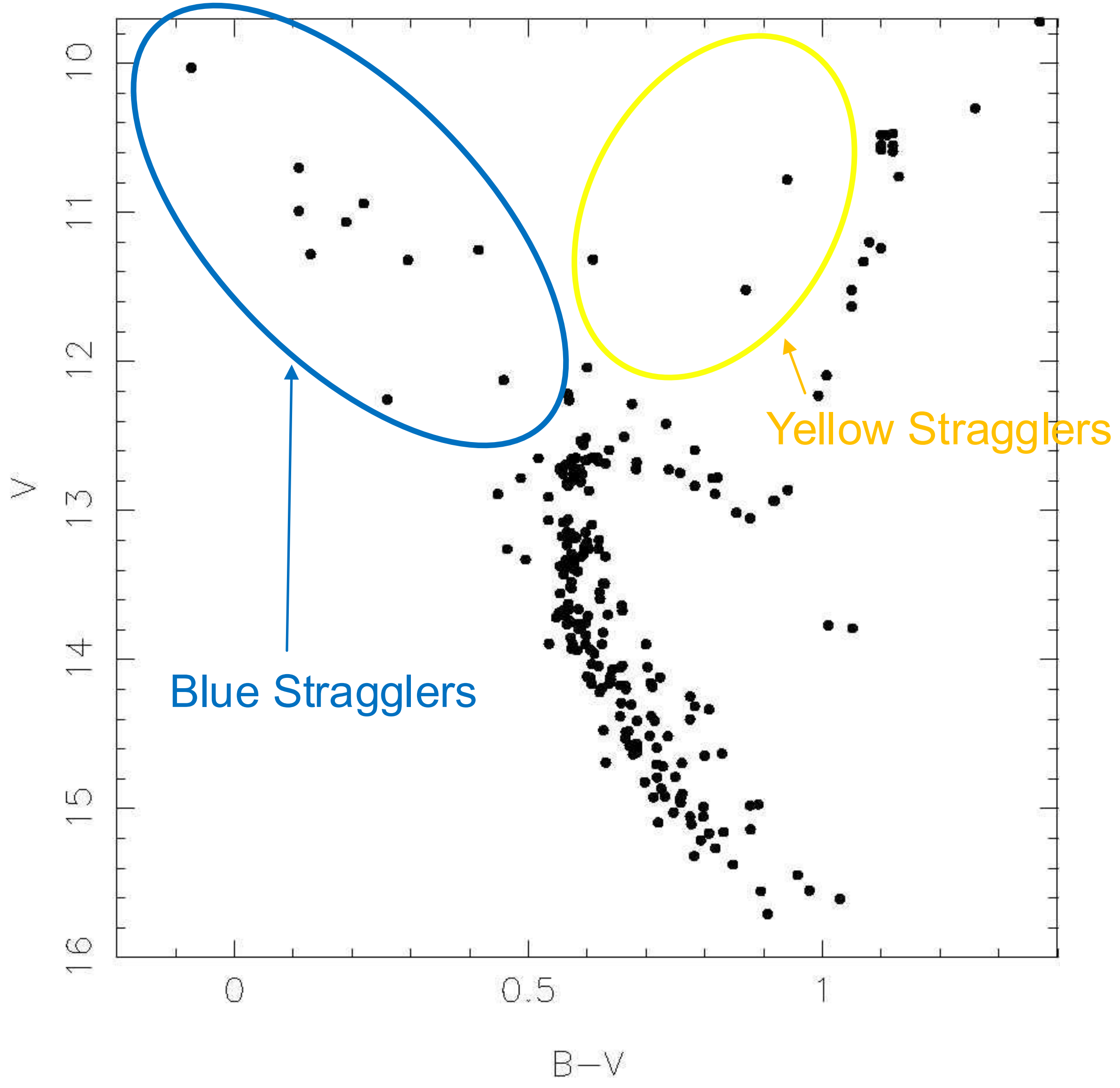

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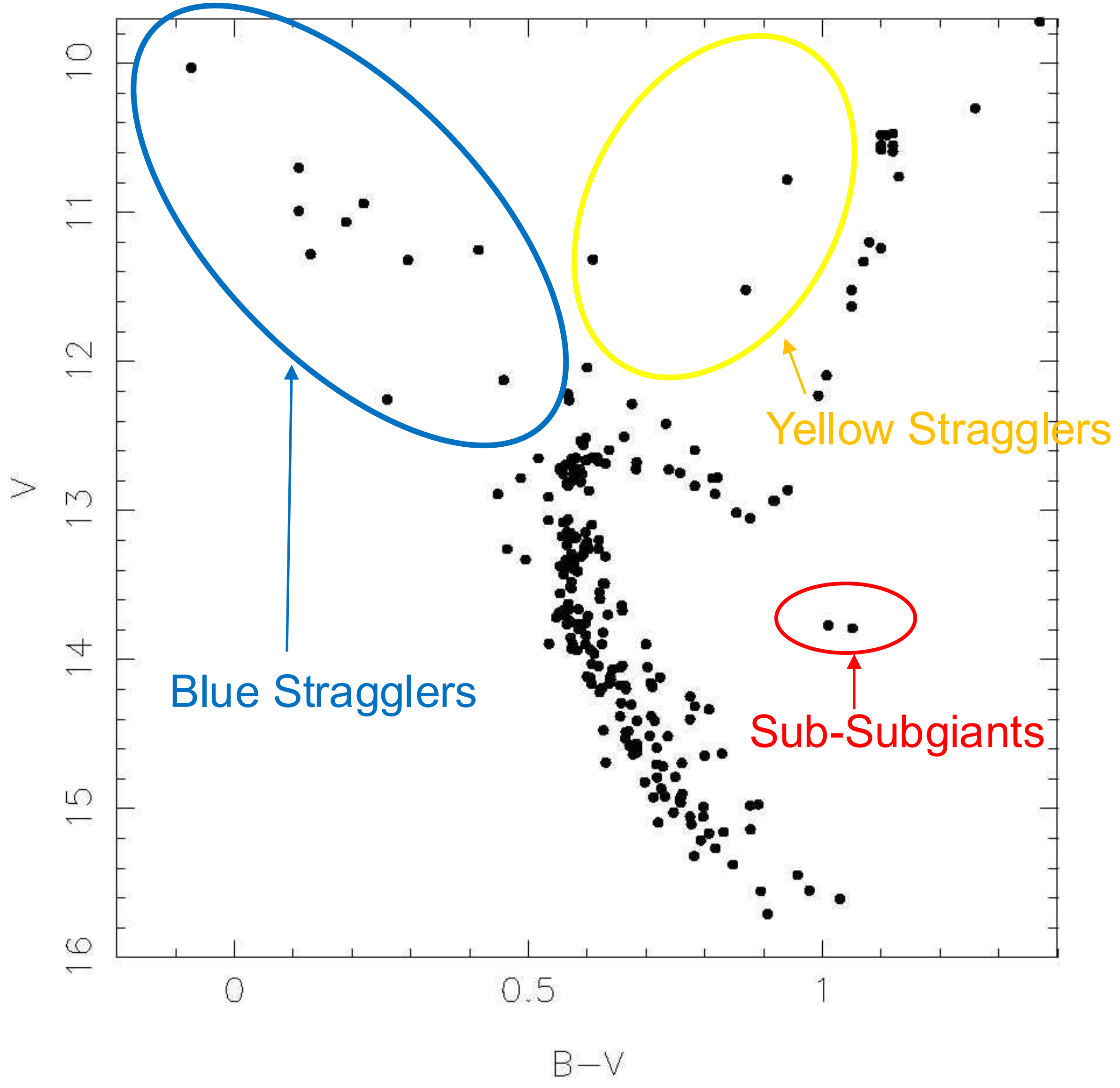

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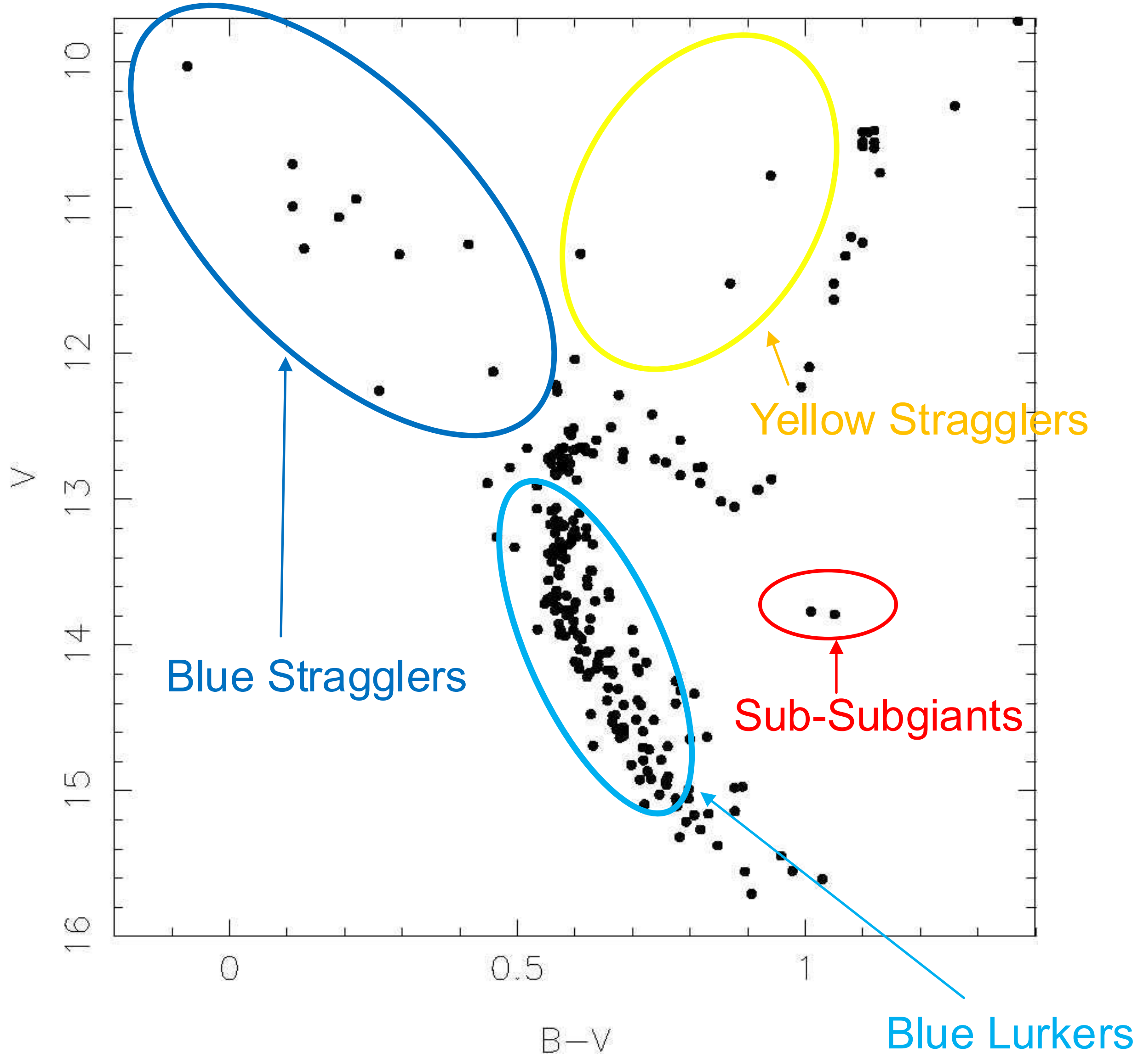

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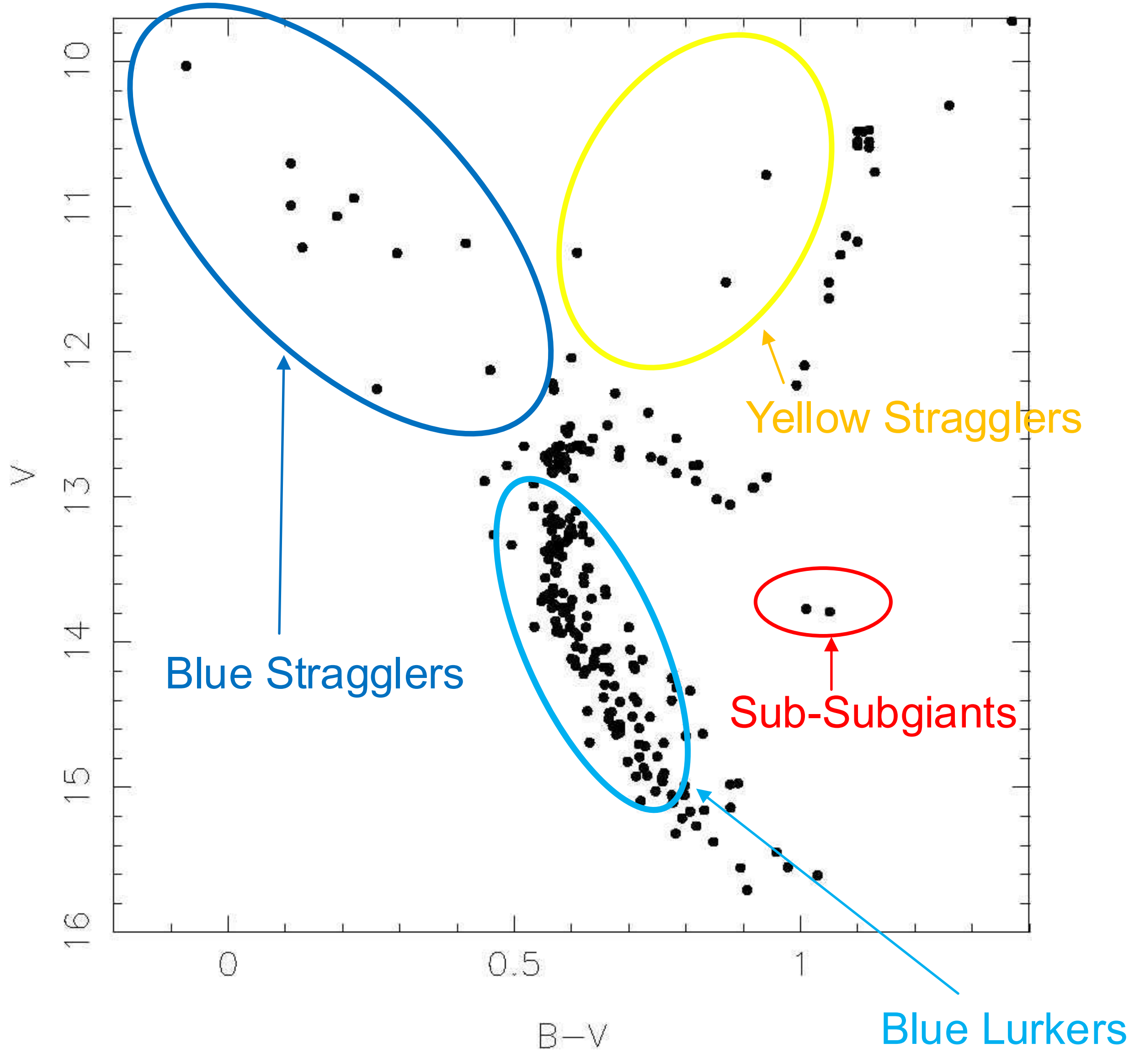

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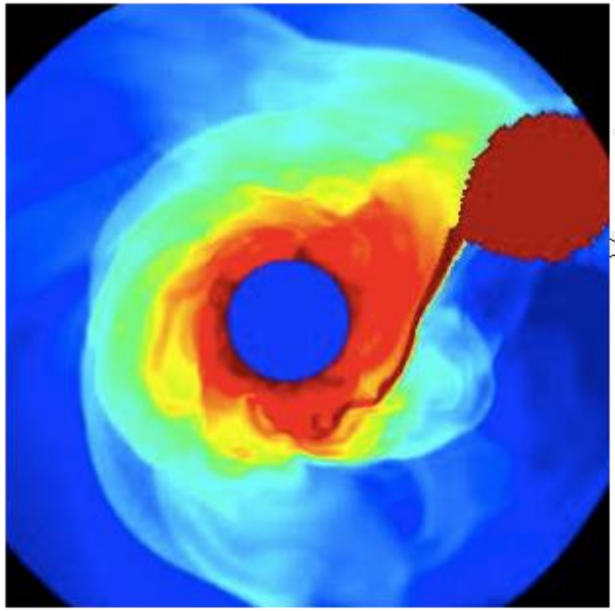
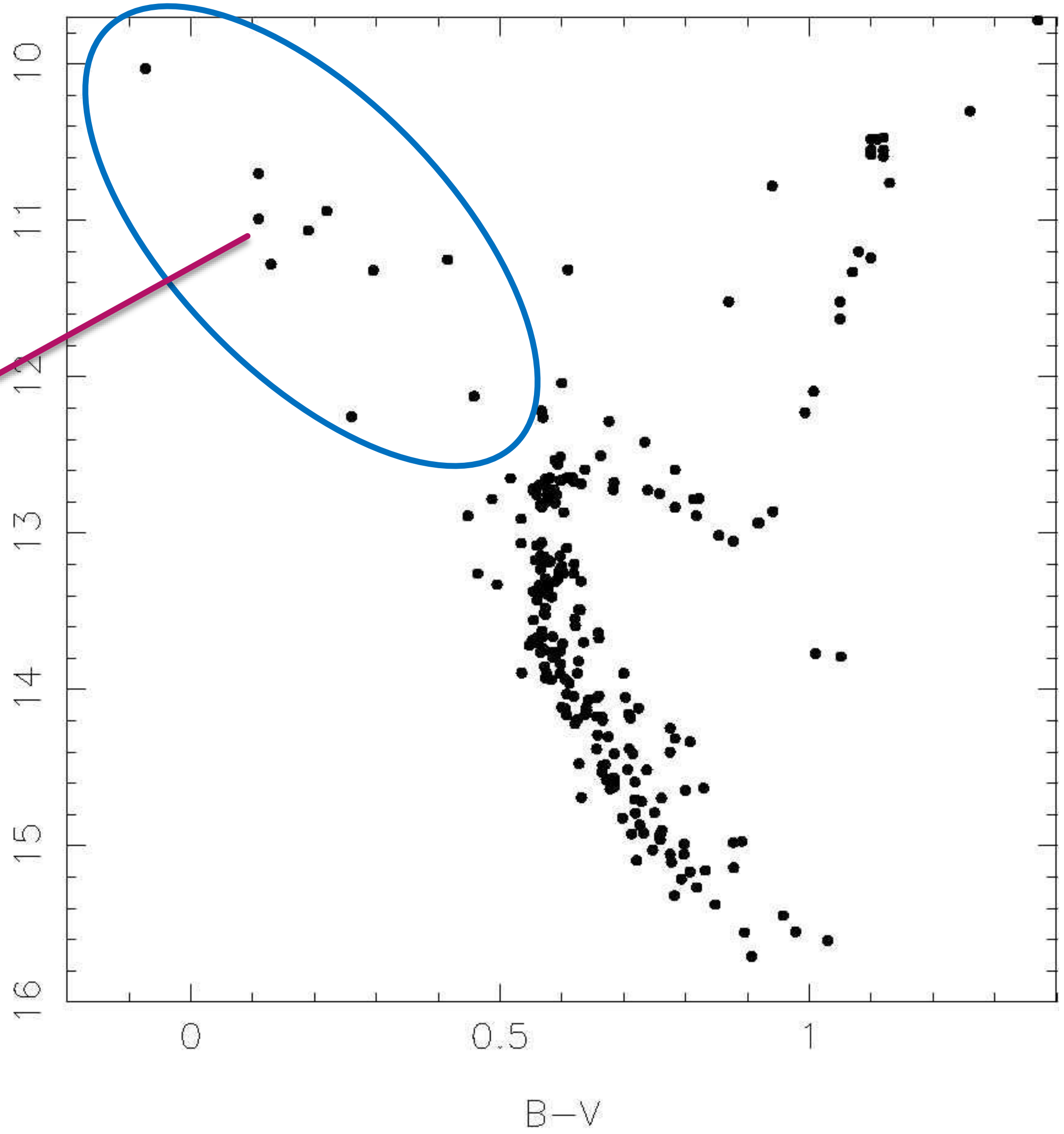
See Nine et al. (2023)



Blondin, Richards, & Malonowski



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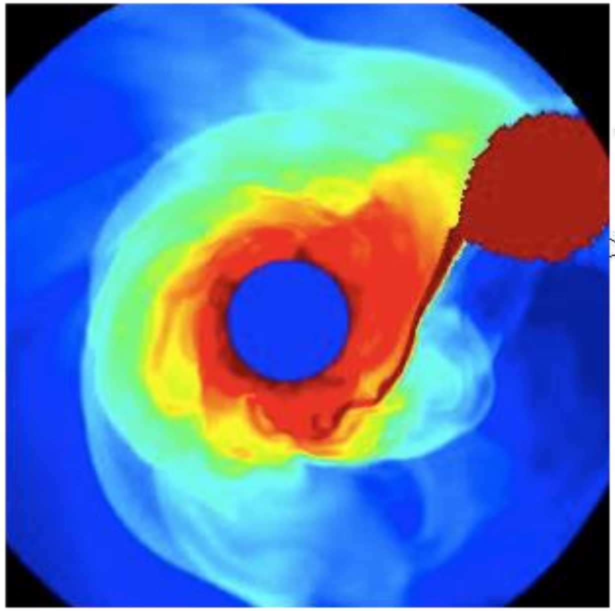

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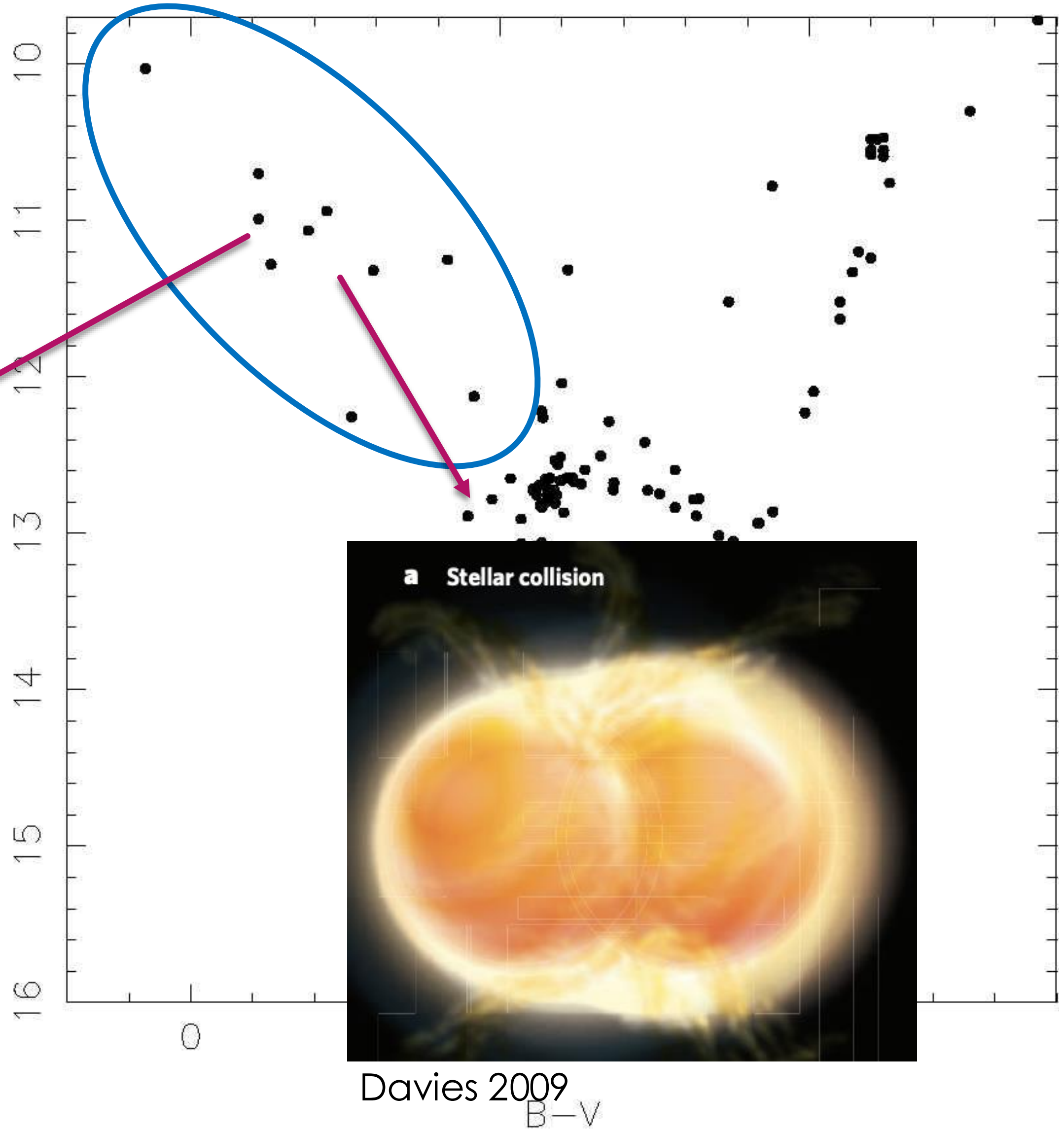
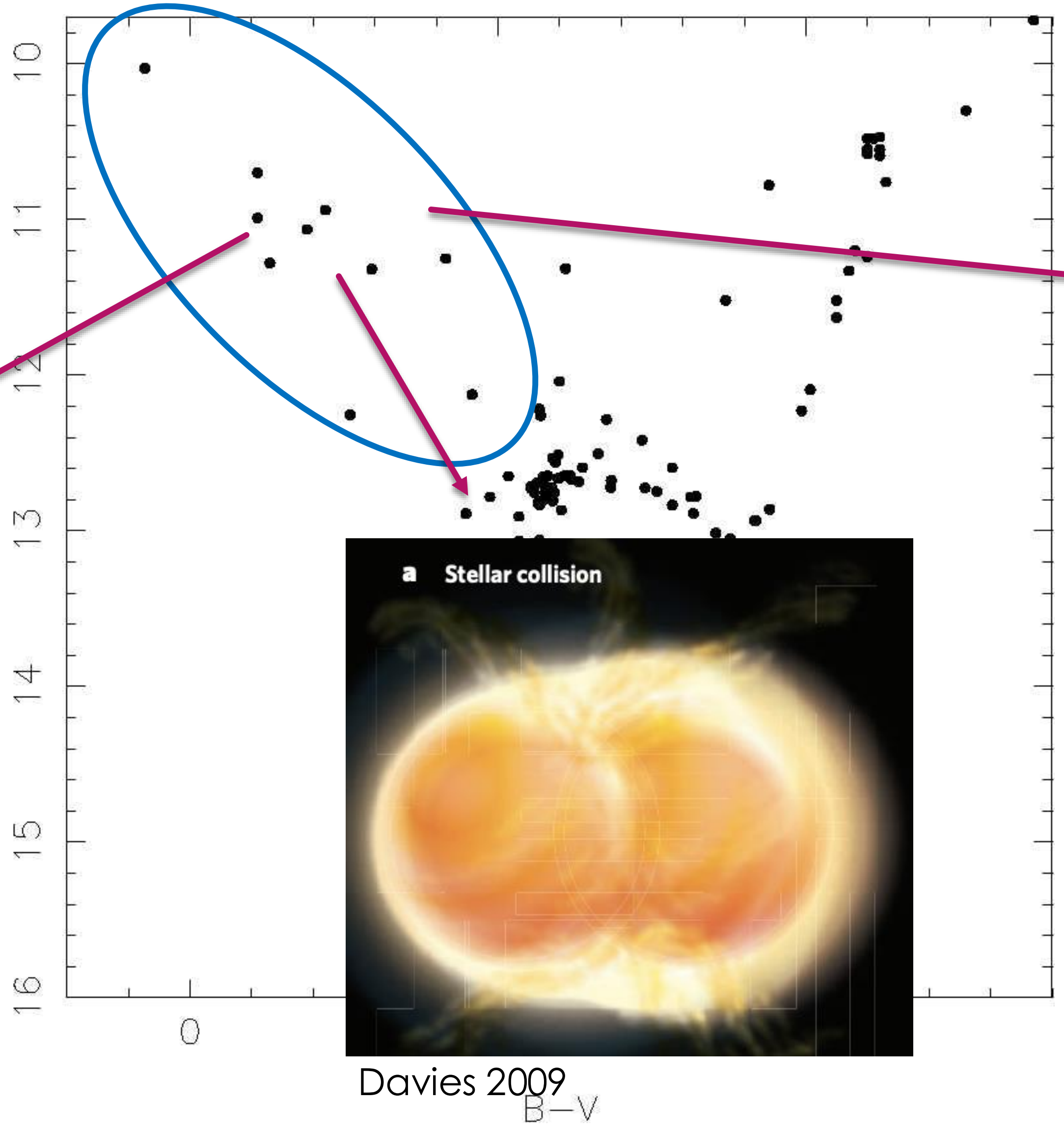


Davies 2009

Courtesy of R. D. Mathieu



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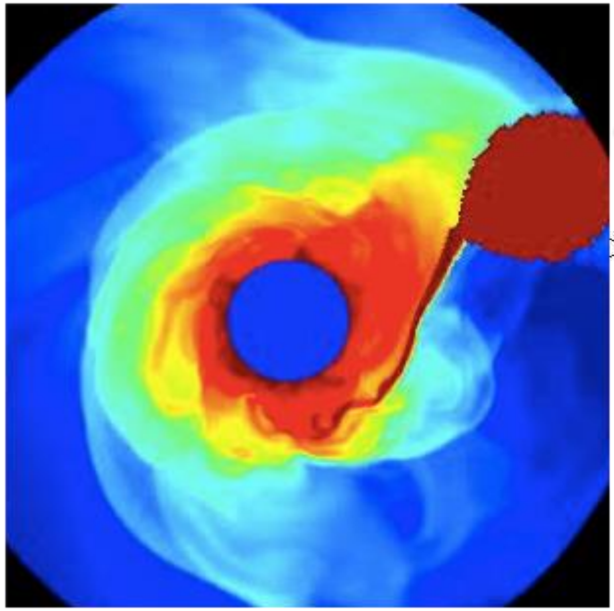

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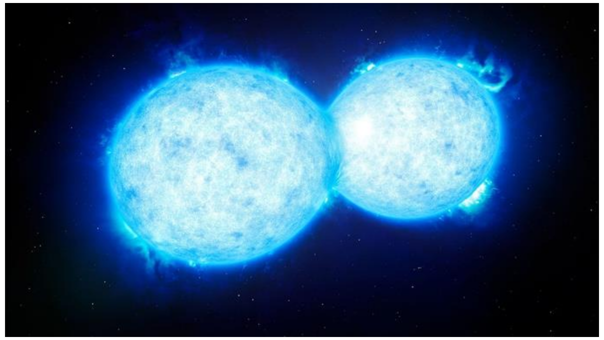


ESO/L. Calçada

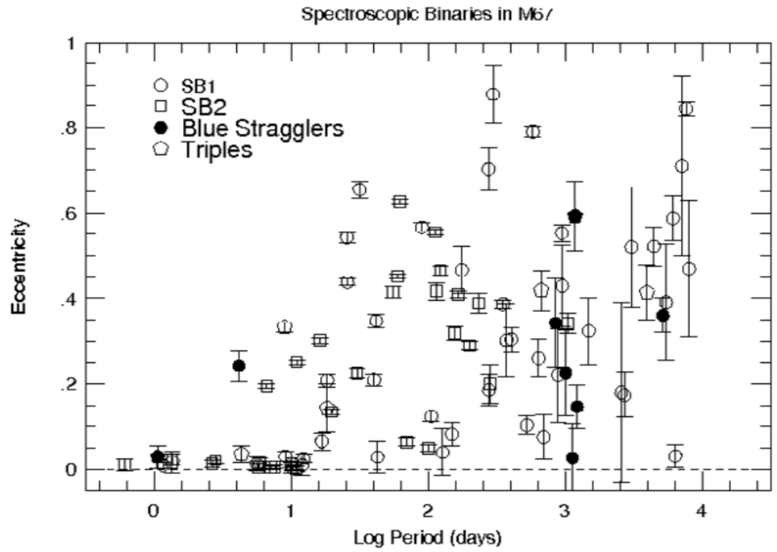
Courtesy of R. D. Mathieu

Blue Stragglers and Mass Transfer

	Case B	Case C	Wind MT	Wind RLOF
Participant Stars	RGB-MS	AGB-MS	AGB-MS	AGB-MS
Remnant	He WD	CO WD	CO WD	CO WD
Mechanism	Classical Roche lobe overflow	Classical Roche lobe overflow	Accretion in outflow	Focused stream through L_1
Final Orbital Period	~100 days	~1000 days	$\gtrsim 10^4$ days	$\gtrsim 10^4$ days

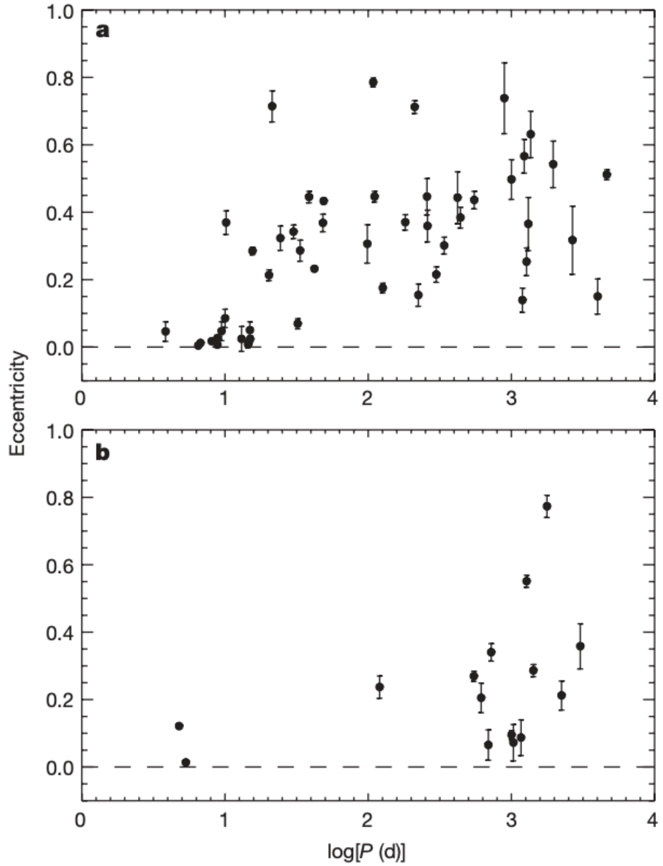
Hints of Case C: M67 and NGC 188

M67 (4 Gyr)



Latham 2007

NGC 188 (7 Gyr)



Mathieu & Geller 2009

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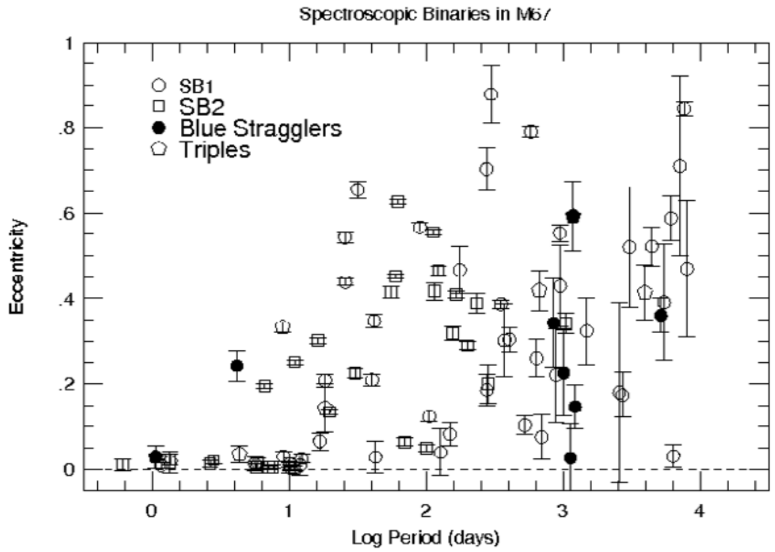
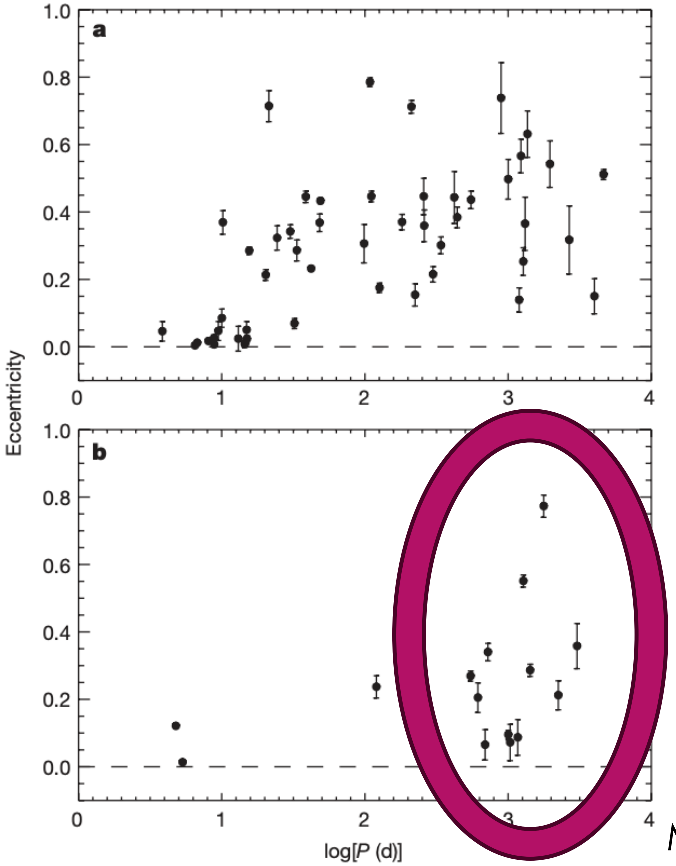
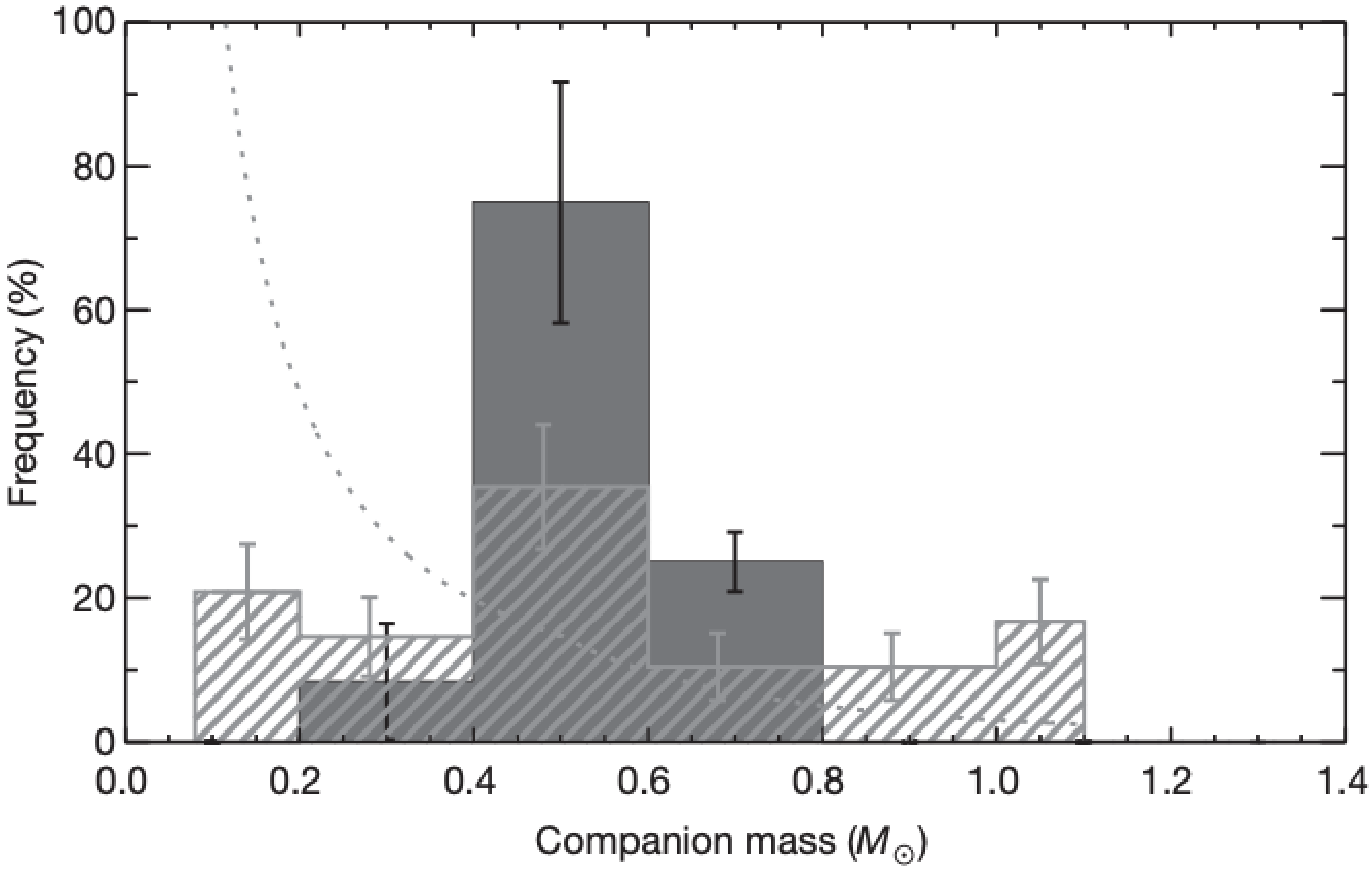


Latham 2007

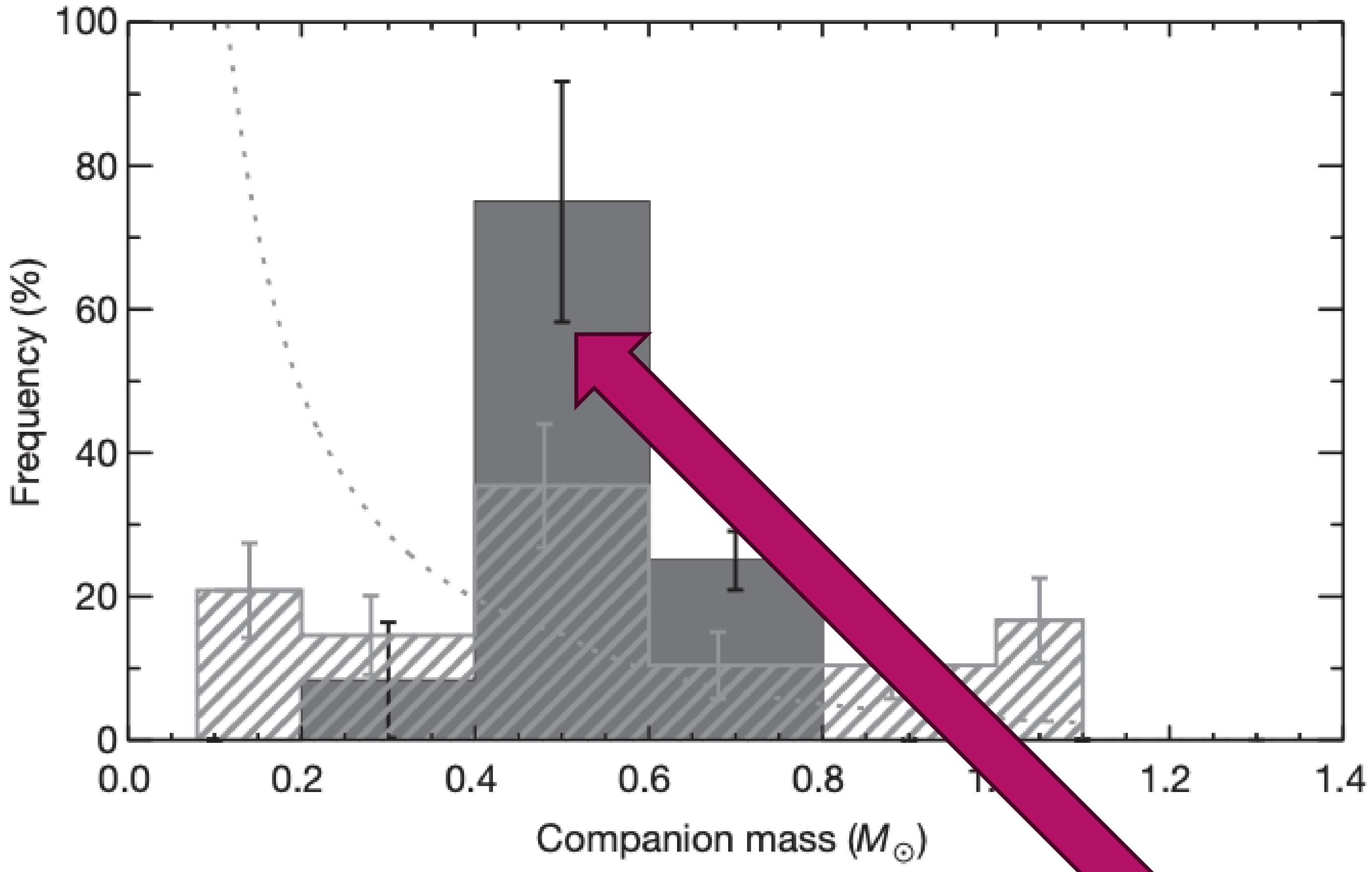
NGC 188 (7 Gyr)



Mathieu & Geller 2009



Geller & Mathieu 2011



Geller & Mathieu 2011

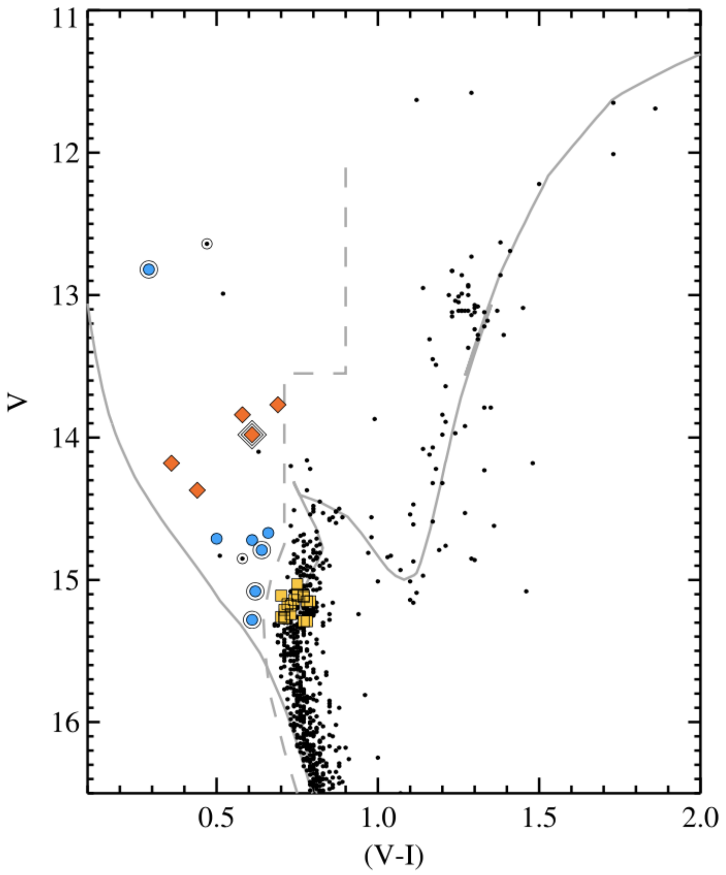
0.53 $M_\odot$!

Barium as a Tracer of AGB Mass Transfer

- Most barium in the Universe is produced in the interiors of AGB stars through the *s*-process
- Ba is then brought up to the surface of the star during third dredge-up (TDU) in the final stages of AGB evolution
- If mass transfer occurs during TDU in the AGB star, the accreting star may become enriched in Ba
- Models of AGB evolution predict that AGB stars < 1.3 $M_{\odot}$ do not undergo TDU and do not bring Ba up to their surfaces
  - Cristallo et al. (2016)
- Ba enrichment may then be used as a tracer of mass transfer from a thermally-pulsing AGB star

Previous work: NGC 6819 and NGC 188

NGC 6819:
2.5 Gyr



Milliman+ 2015

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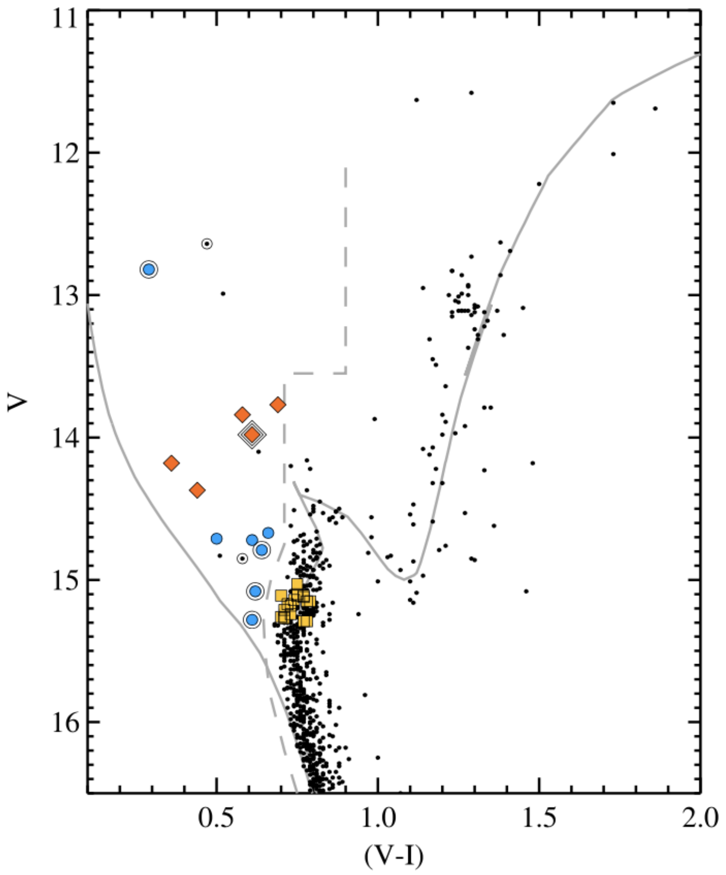

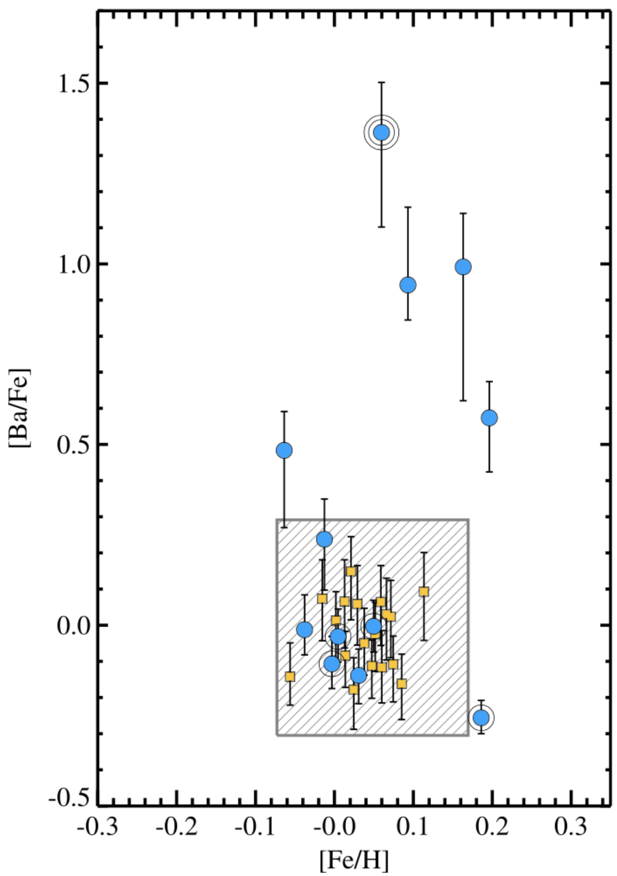

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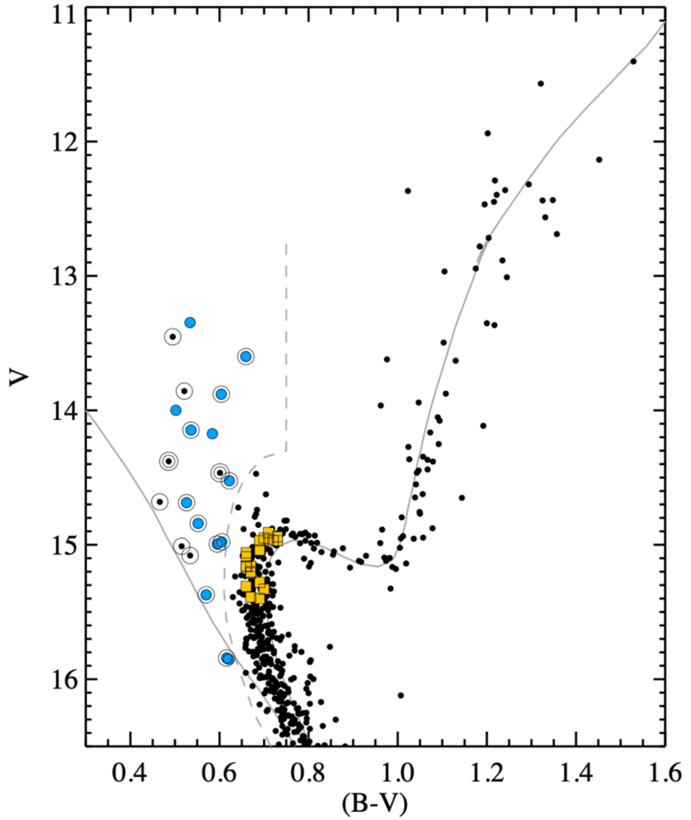

Milliman 2016

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NGC 188:
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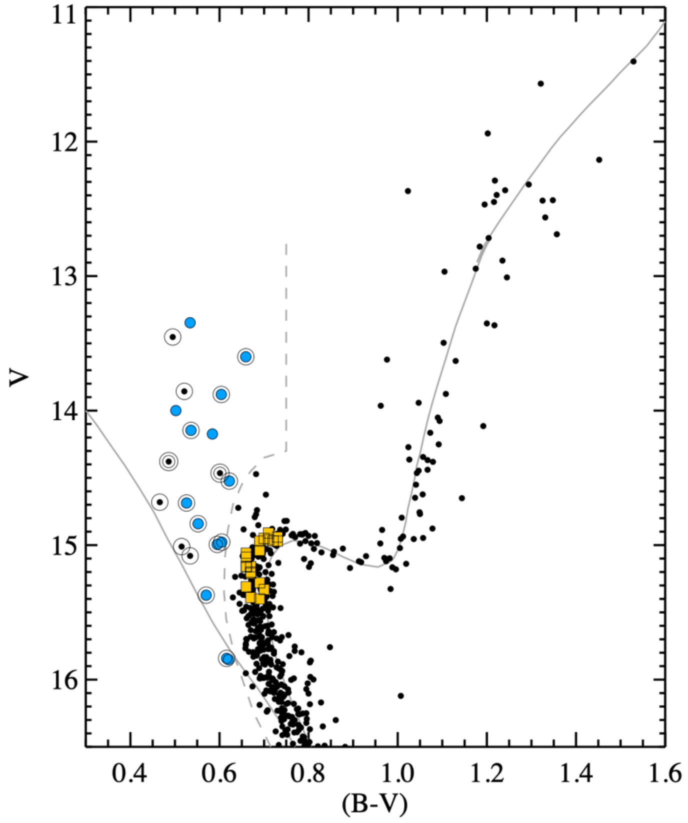
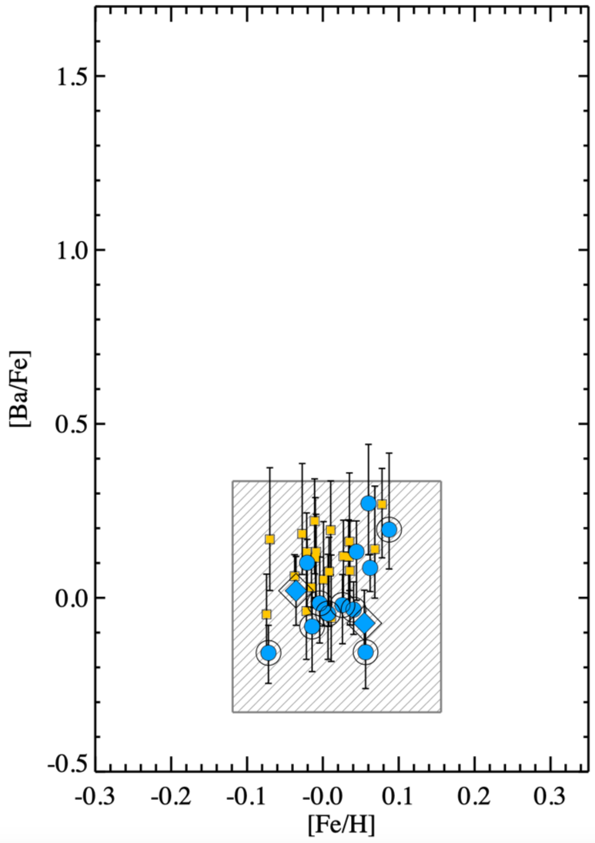


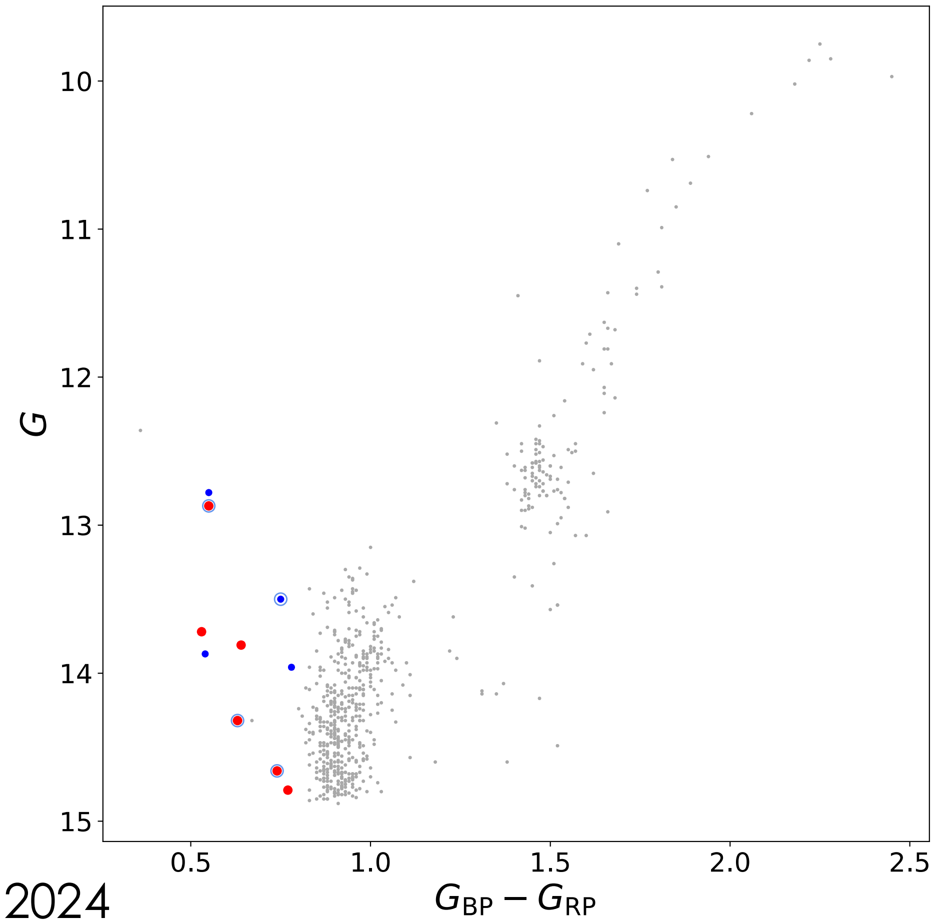


Milliman 2016

Filling In the Gaps: NGC 7789 and M67

- We observed the BSSs of NGC 7789 (1.6 Gyr) and M67 (4 Gyr) with the Hydra Multi-Object Spectrograph on the WIYN 3.5m telescope, focusing on Ba II 5853.7 Å
- We conducted simultaneous observations of single MS members as control
  - BSS IDs and MS members for NGC 7789 were drawn from Nine et al. (2020); for M67, Geller et al. (2015)
- Our spectra have resolutions of *R*~17,000 and a typical SNR of >100

NGC 7789: Abundance Results



Nine et al. 2024

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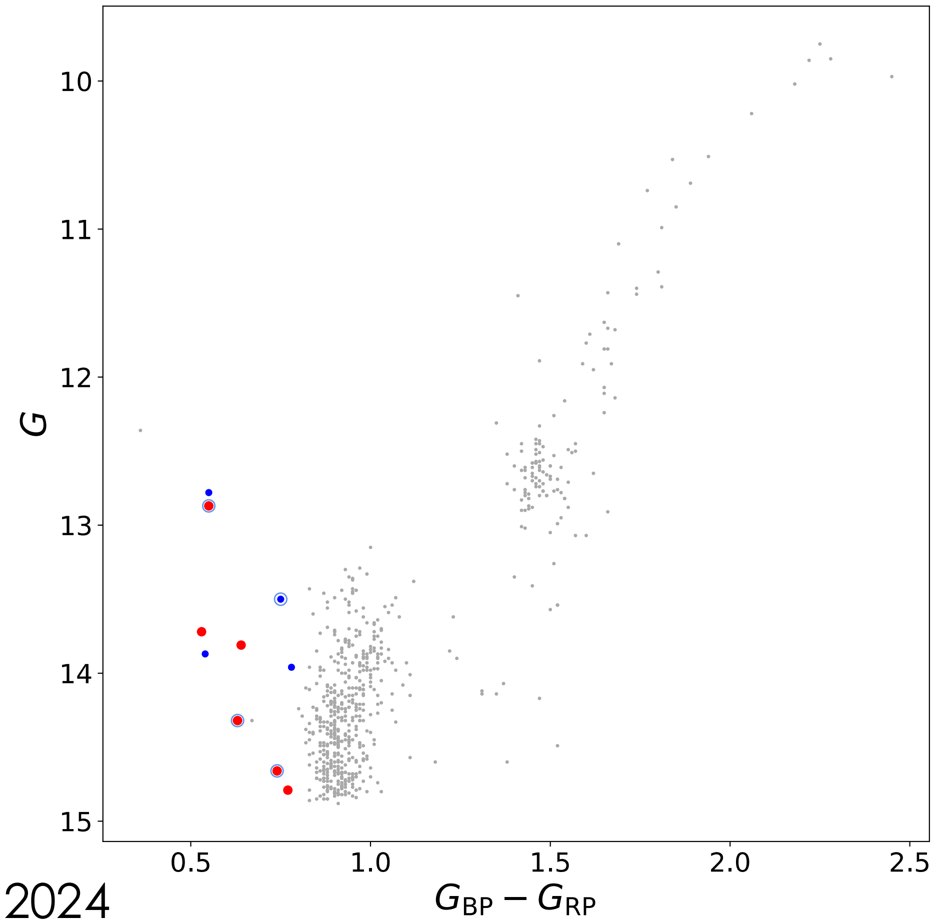
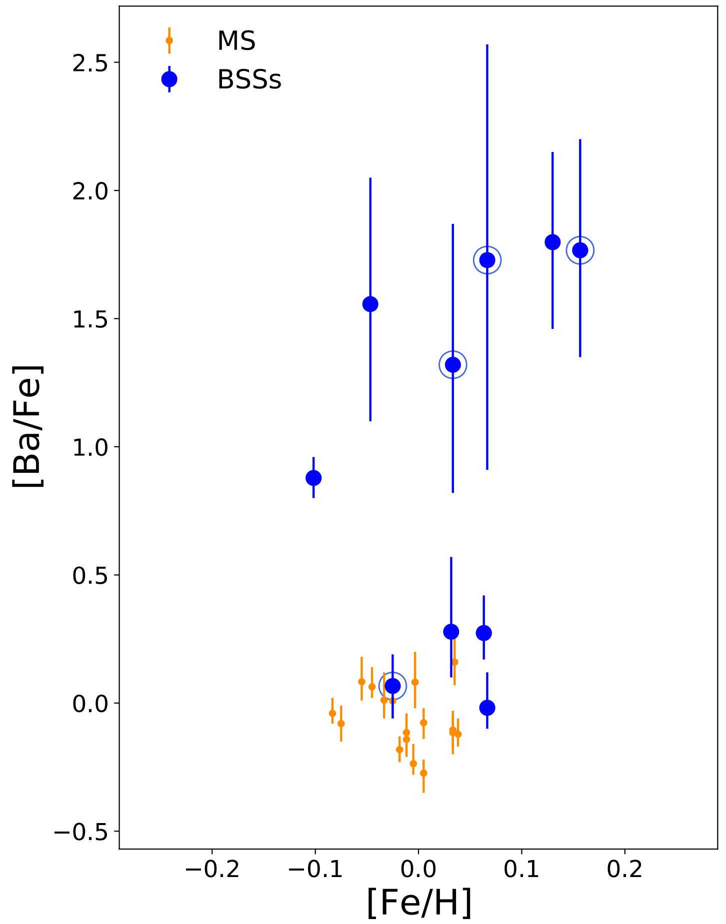
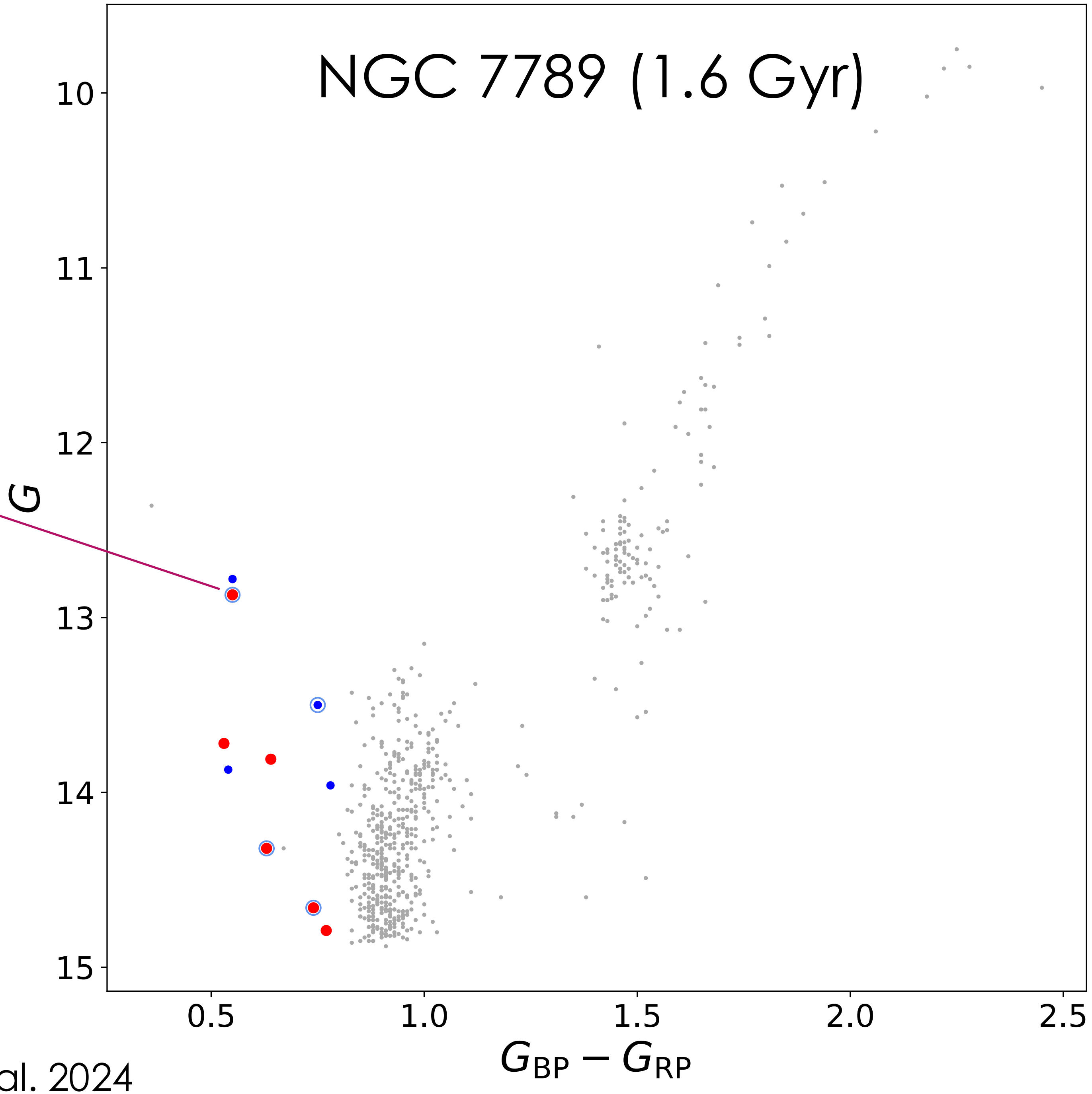




Nine et al. 2024

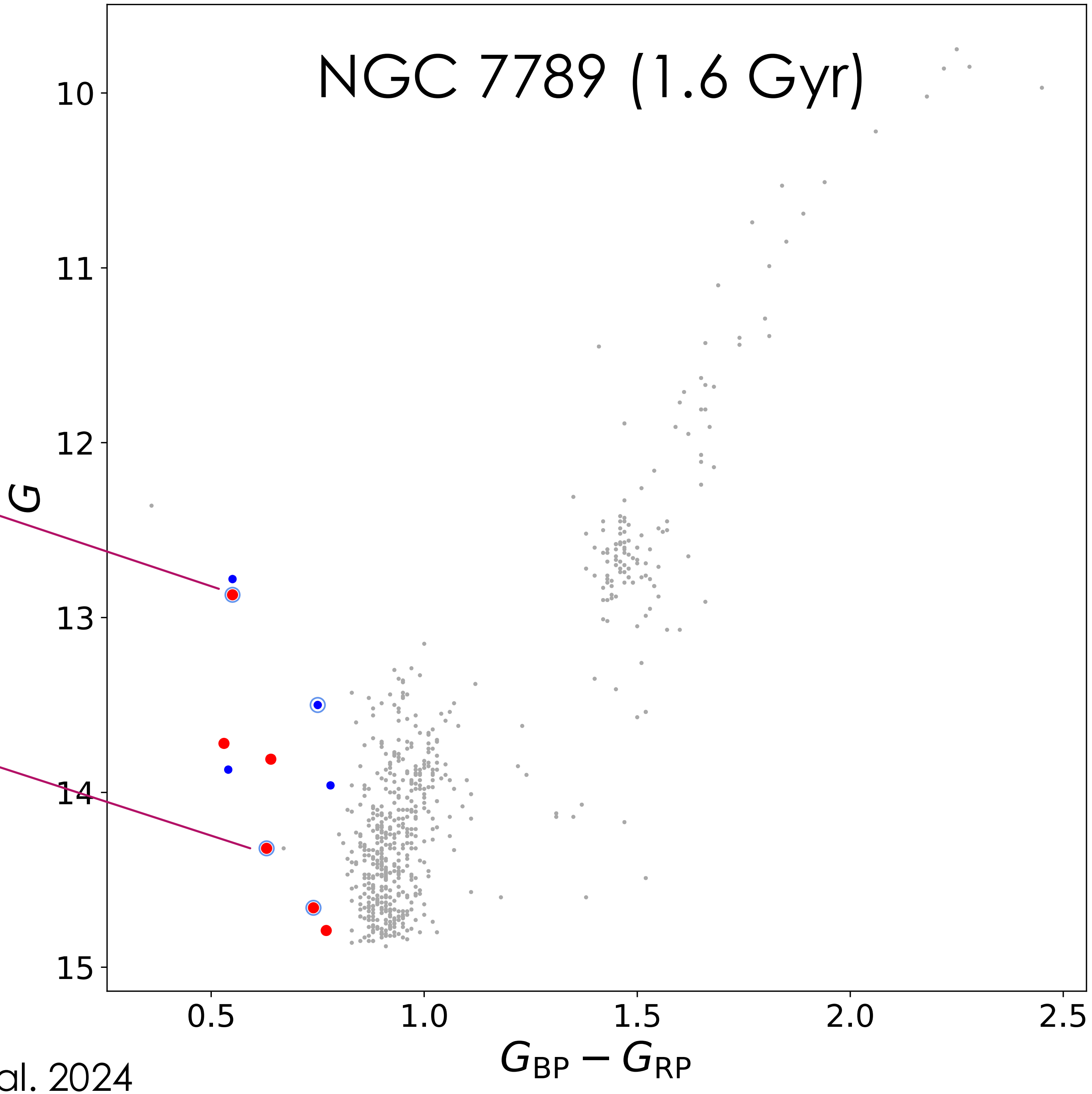
WOCS 5011:
P = 2710 d,
e = 0.32



Nine et al. 2020; Nine et al. 2024

WOCS 5011:
P = 2710 d,
e = 0.32

WOCS 20009:
P = 4190 d,
e = 0.27



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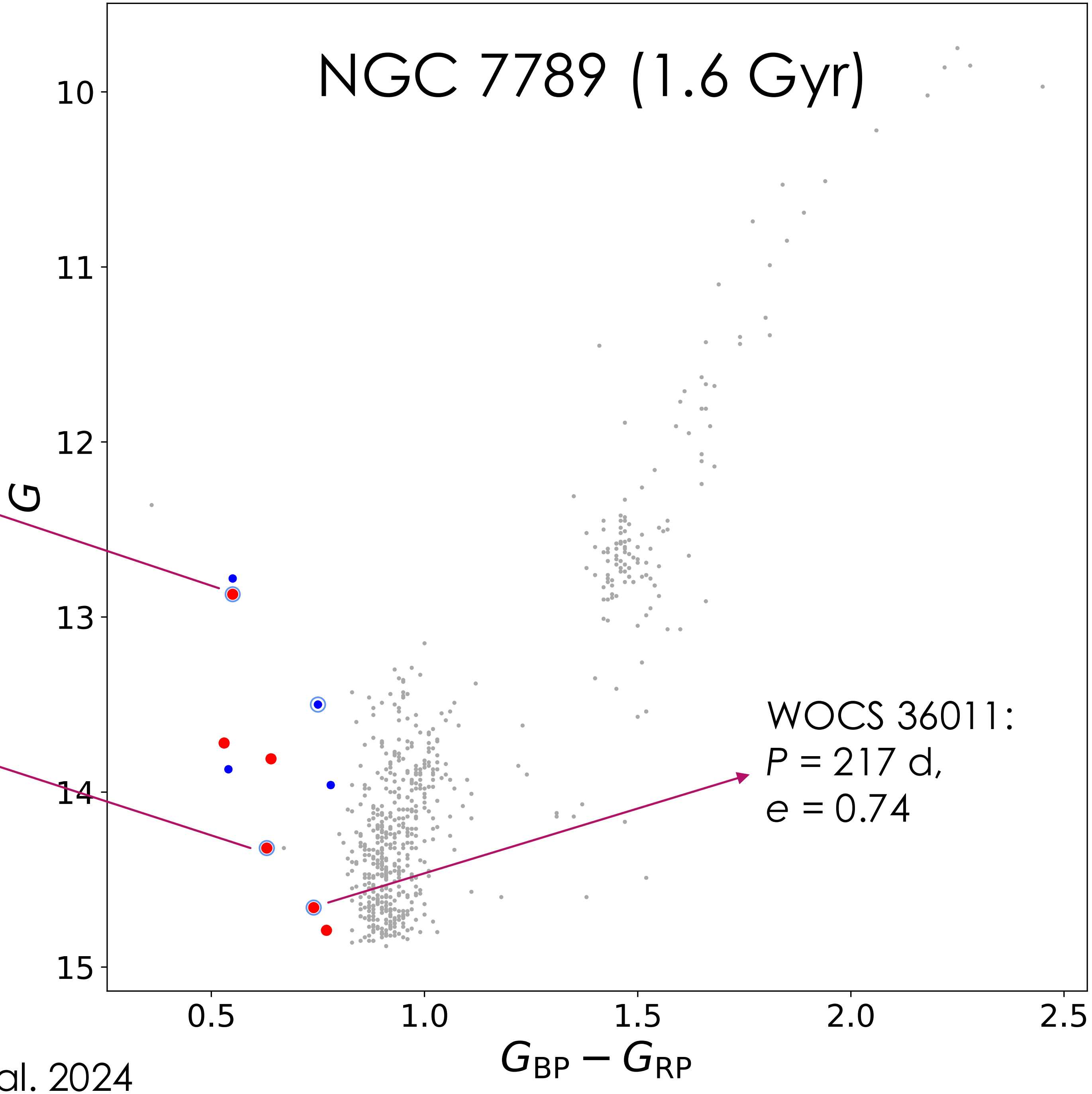

WOCS 5011:
P = 2710 d,
e = 0.32

WOCS 20009:
P = 4190 d,
e = 0.27

WOCS 36011:
P = 217 d,
e = 0.74

Nine et al. 2020; Nine et al. 2024

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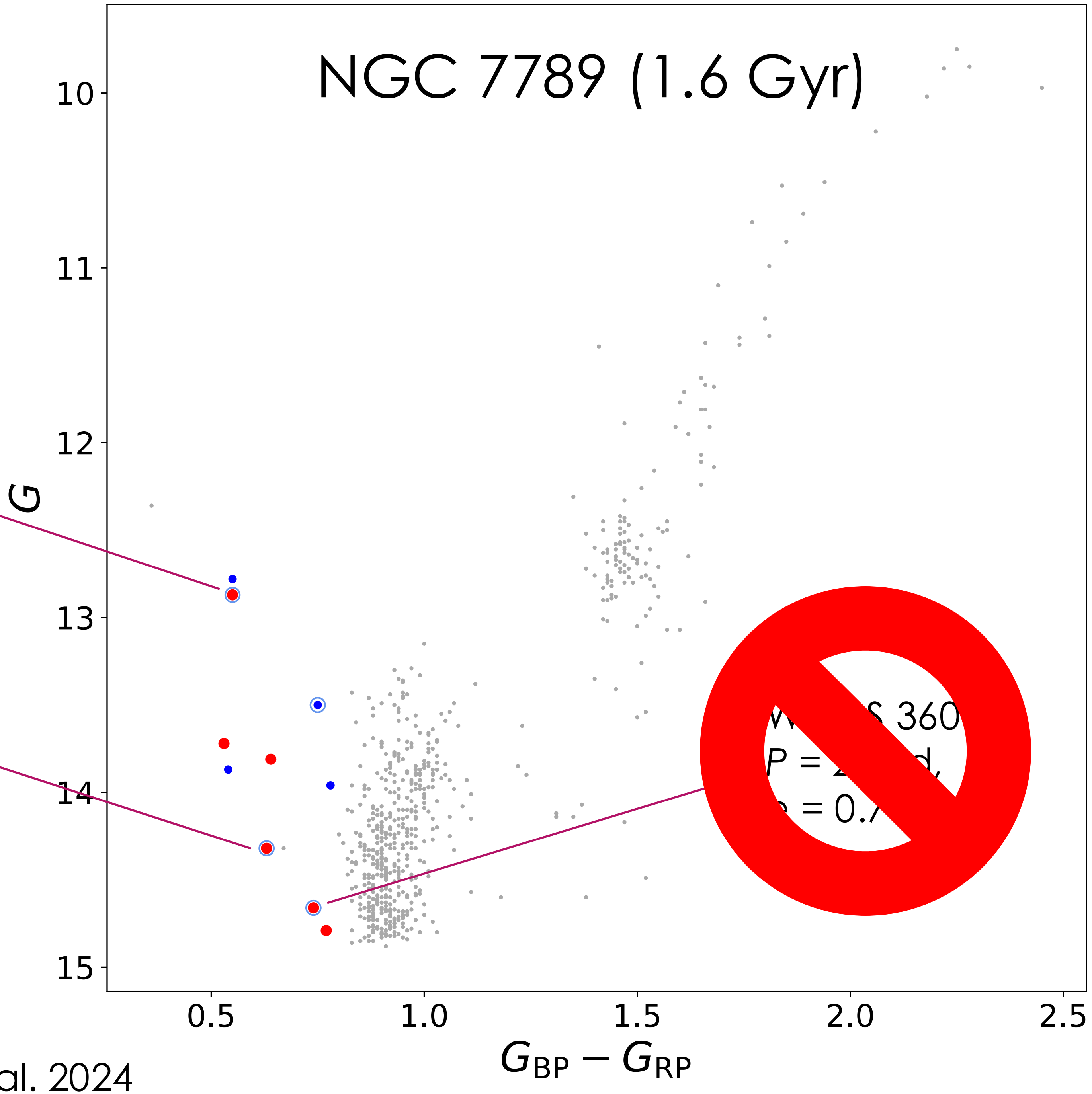
P = 2710 d,
e = 0.32

WOCS 20009:
P = 4190 d,
e = 0.27



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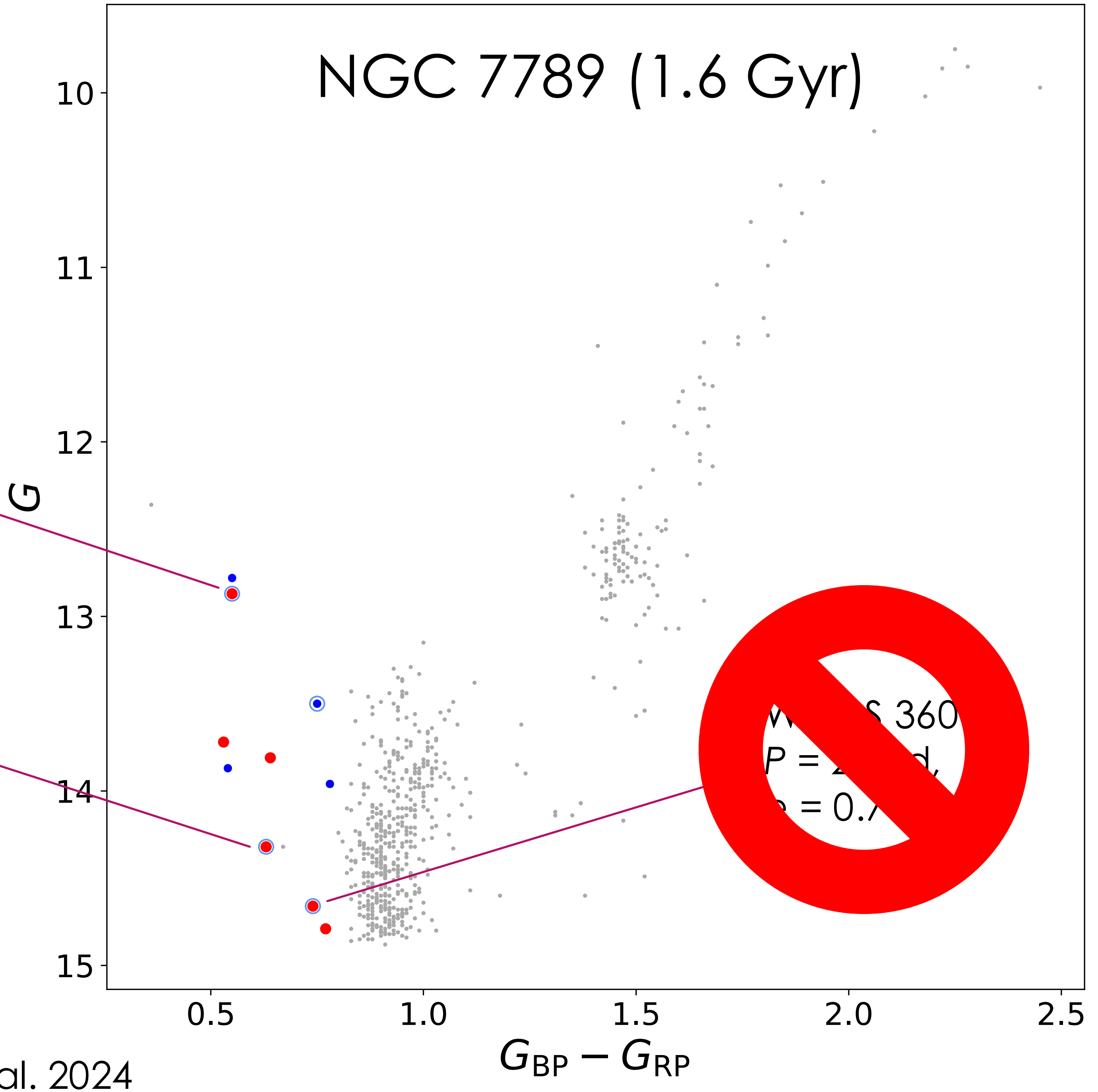
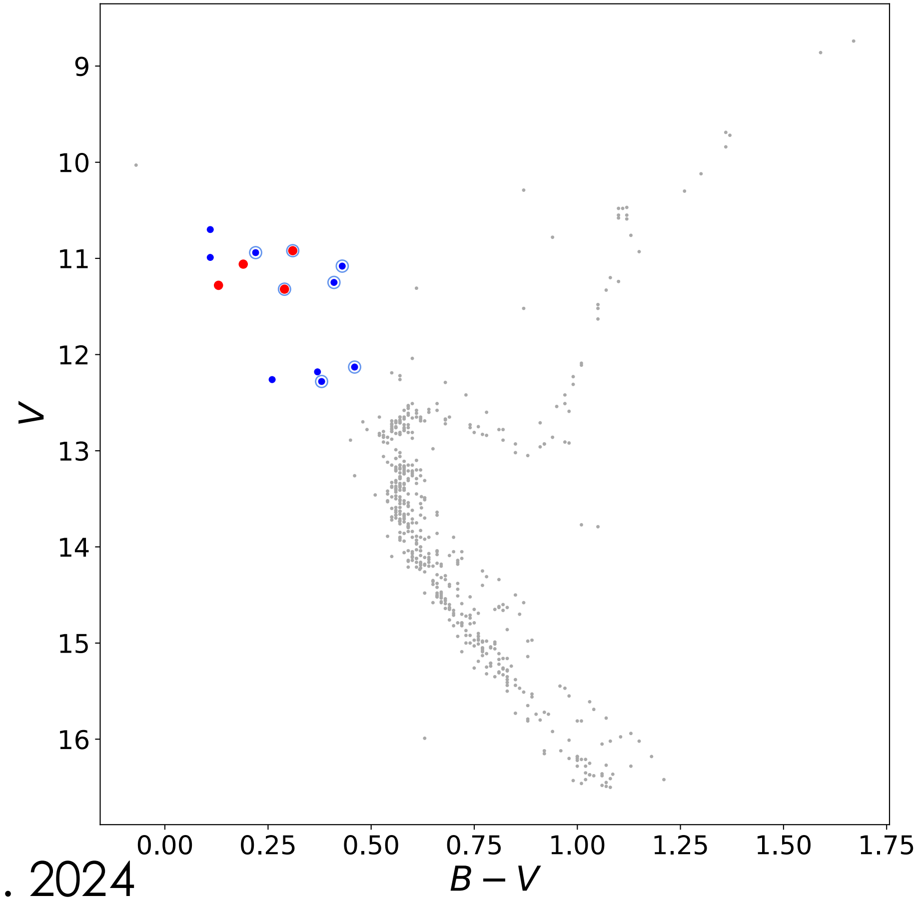


WOCS 36011:
P_{inner} < 100 d,
P_{outer} > 4000 d

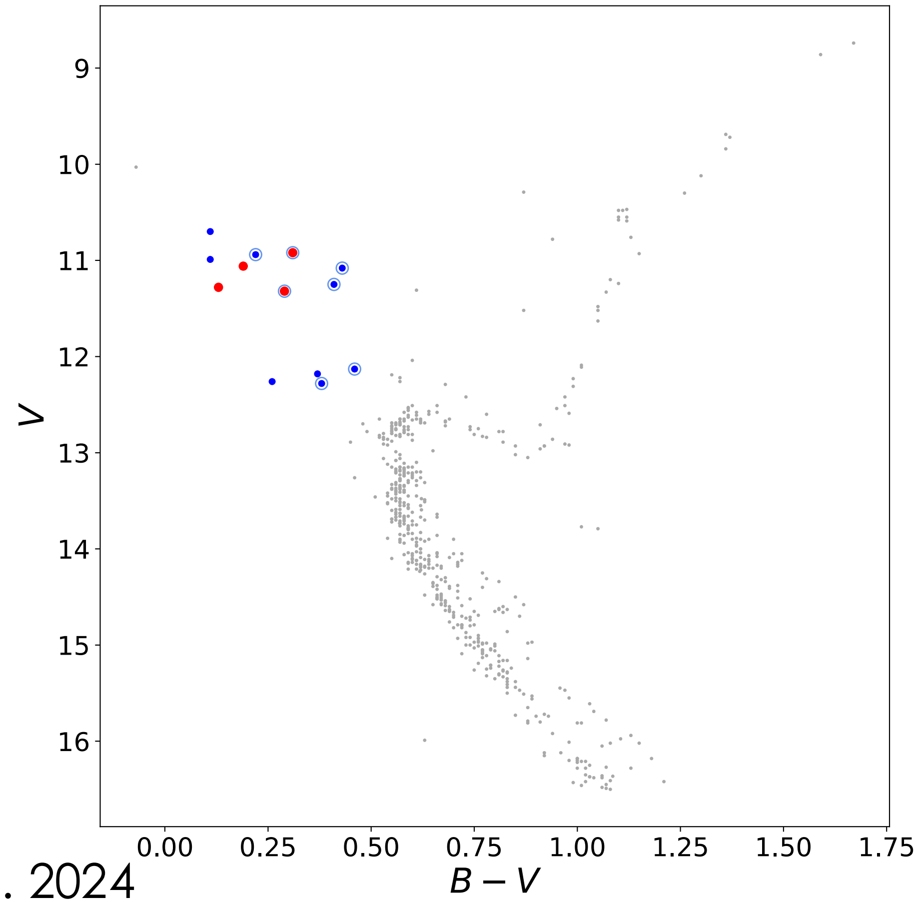
Nine et al. 2020; Nine et al. 2024

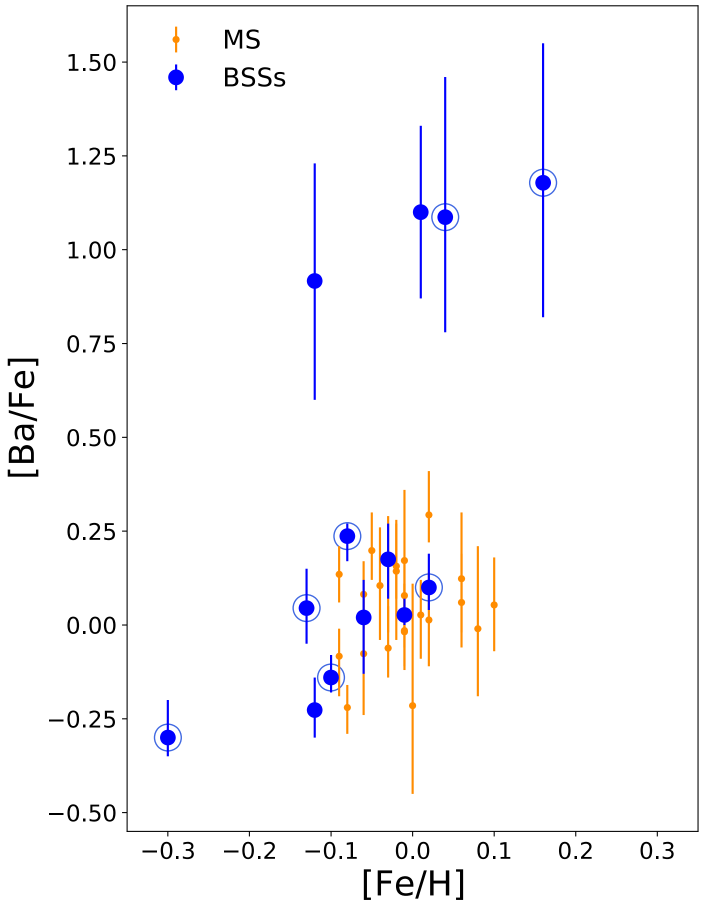
M67: Abundance Results



Nine et al. 2024

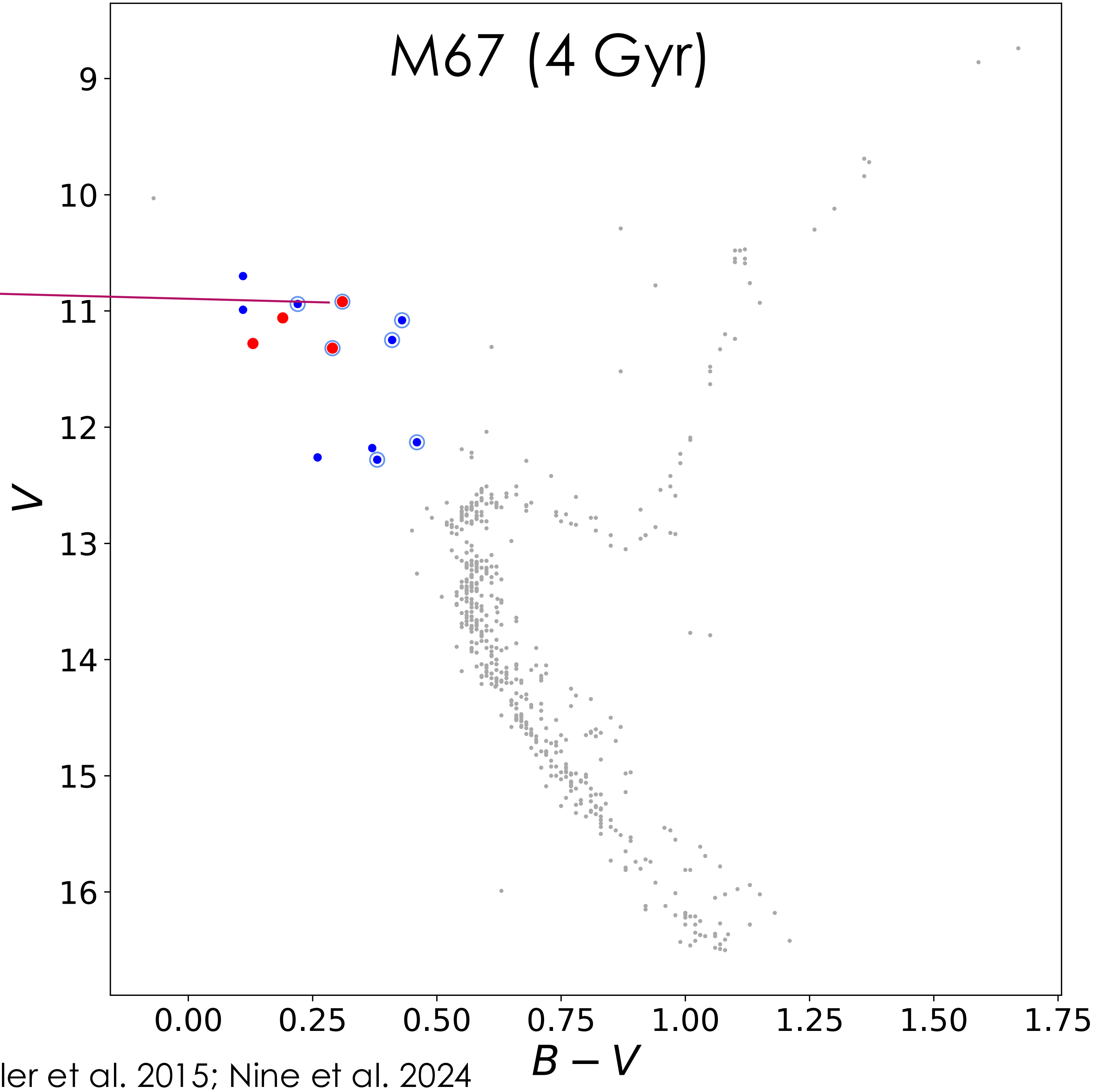
M67: Abundance Results





Nine et al. 2024

WOCS 2013
(S1267):
P = 846 d,
e = 0.475



Latham & Milone 1996; Geller et al. 2015; Nine et al. 2024

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P = 846 d,
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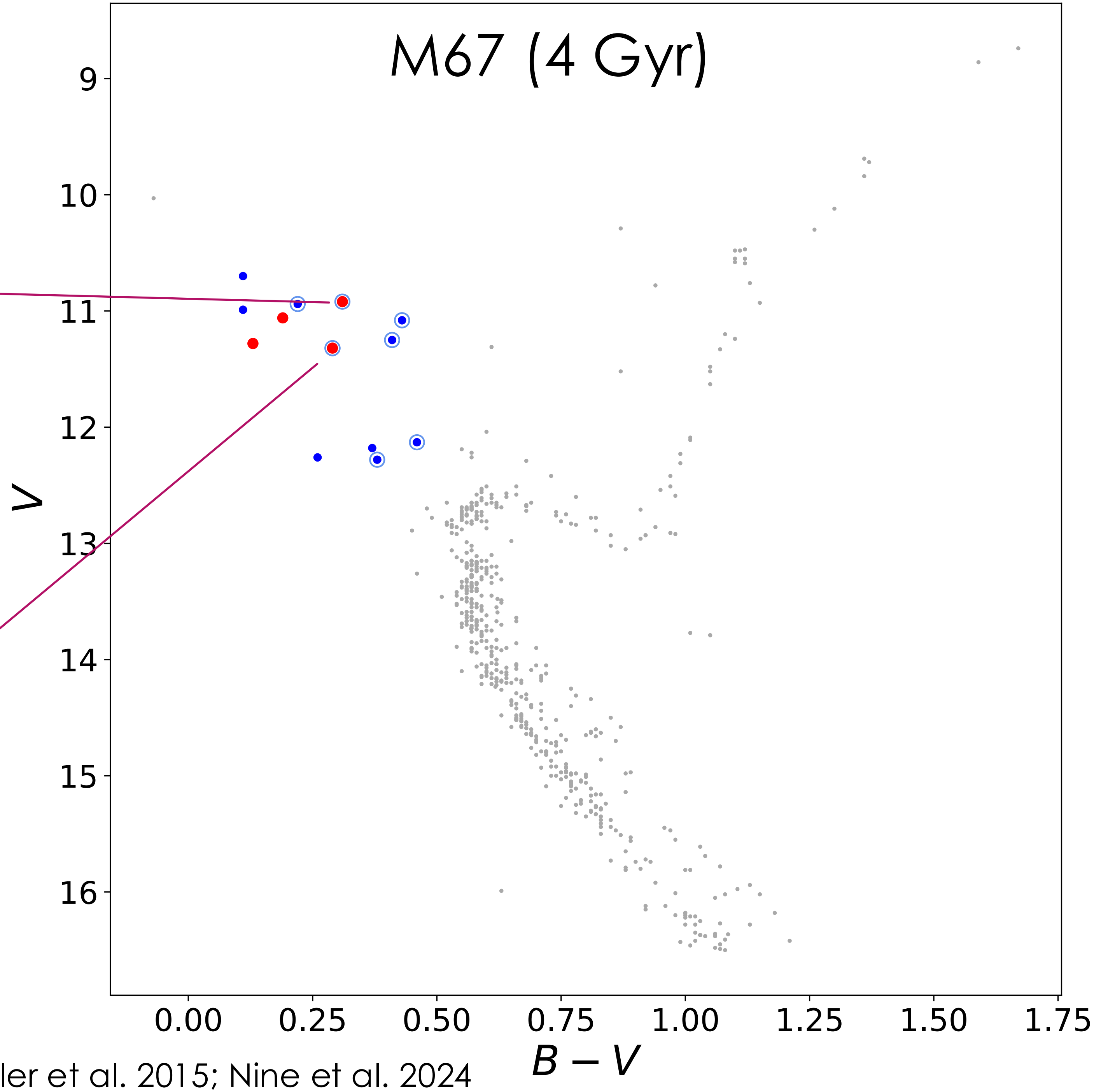
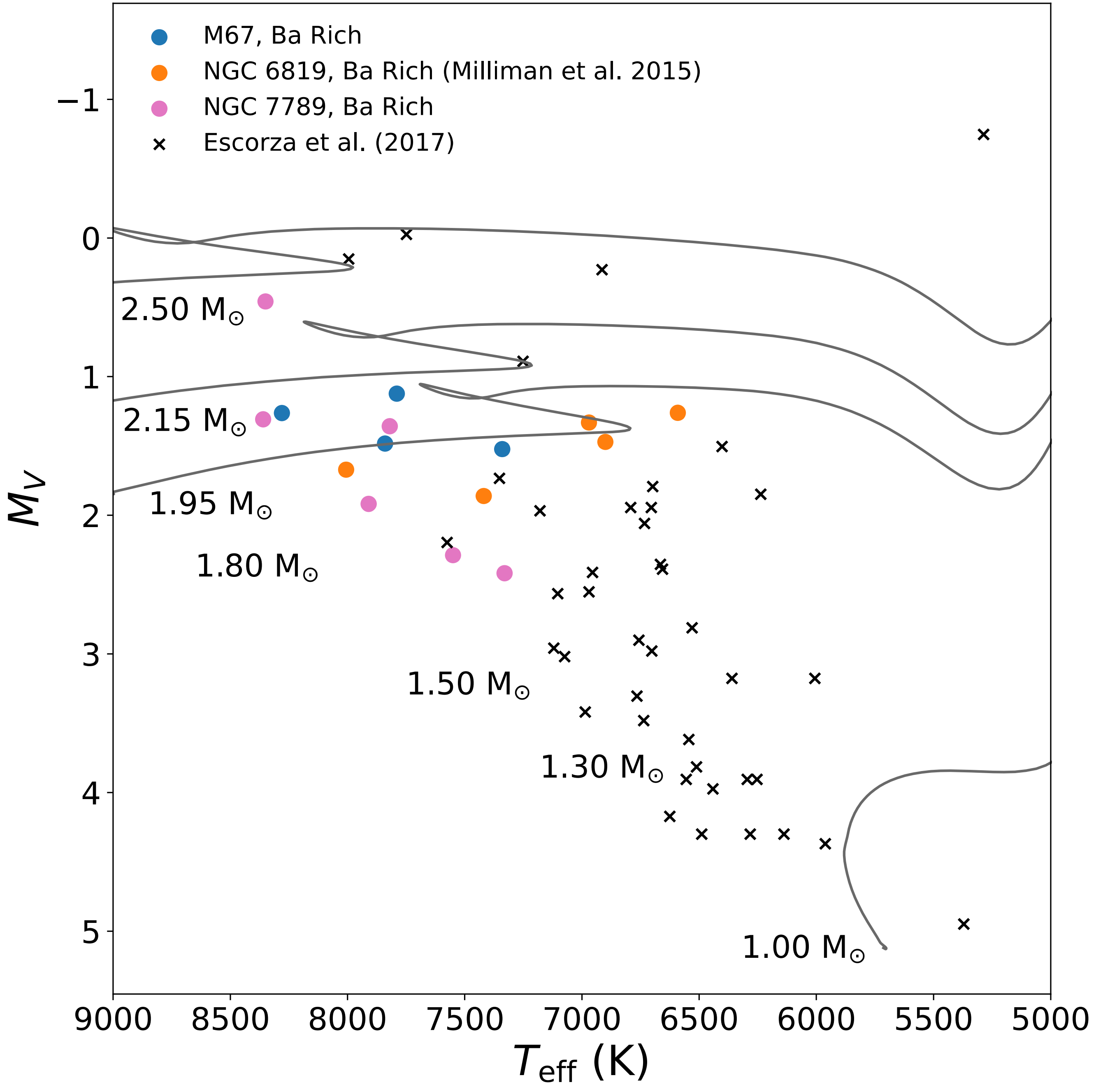
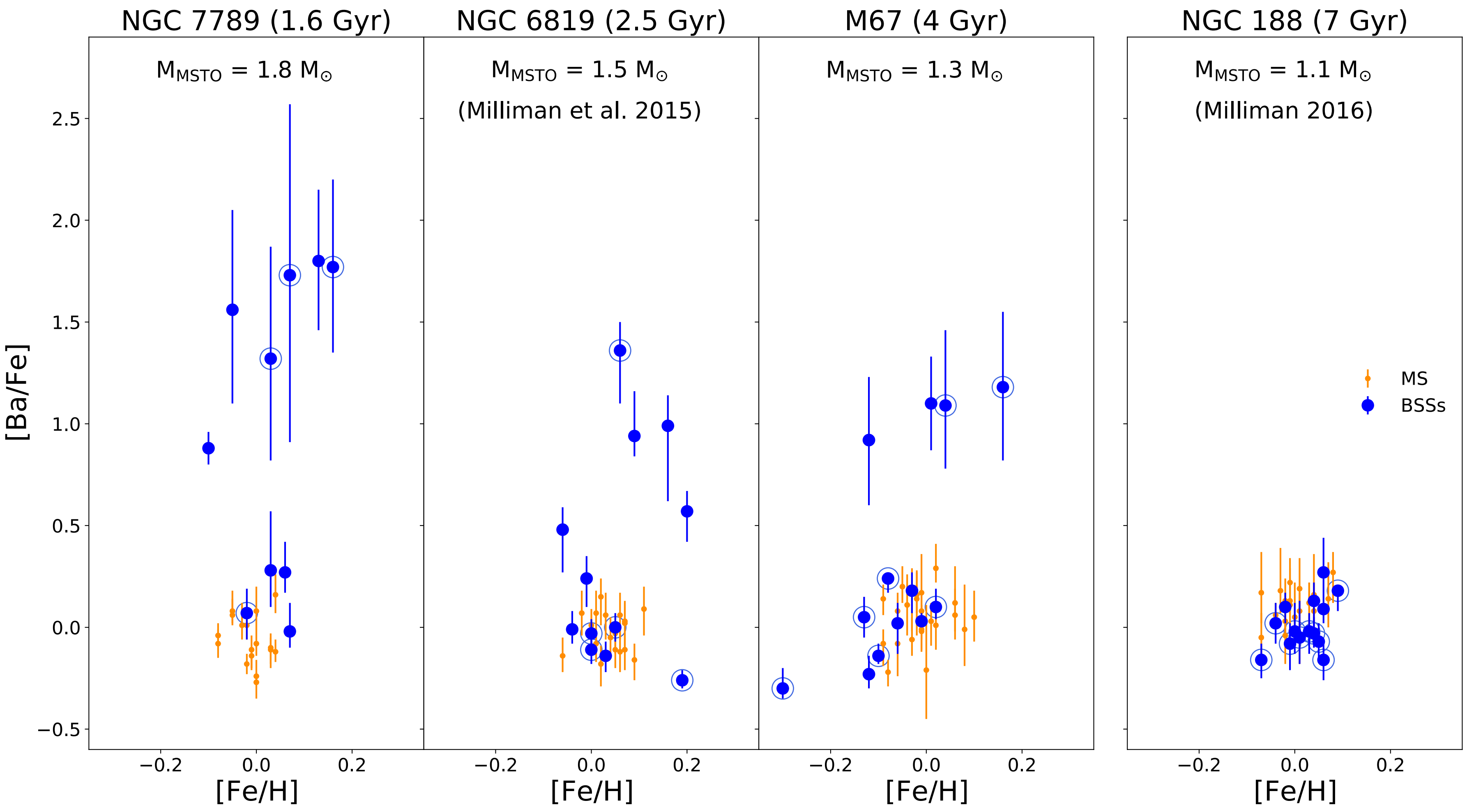


WOCS 3013
(S752):
P = 1003 d,
e = 0.317

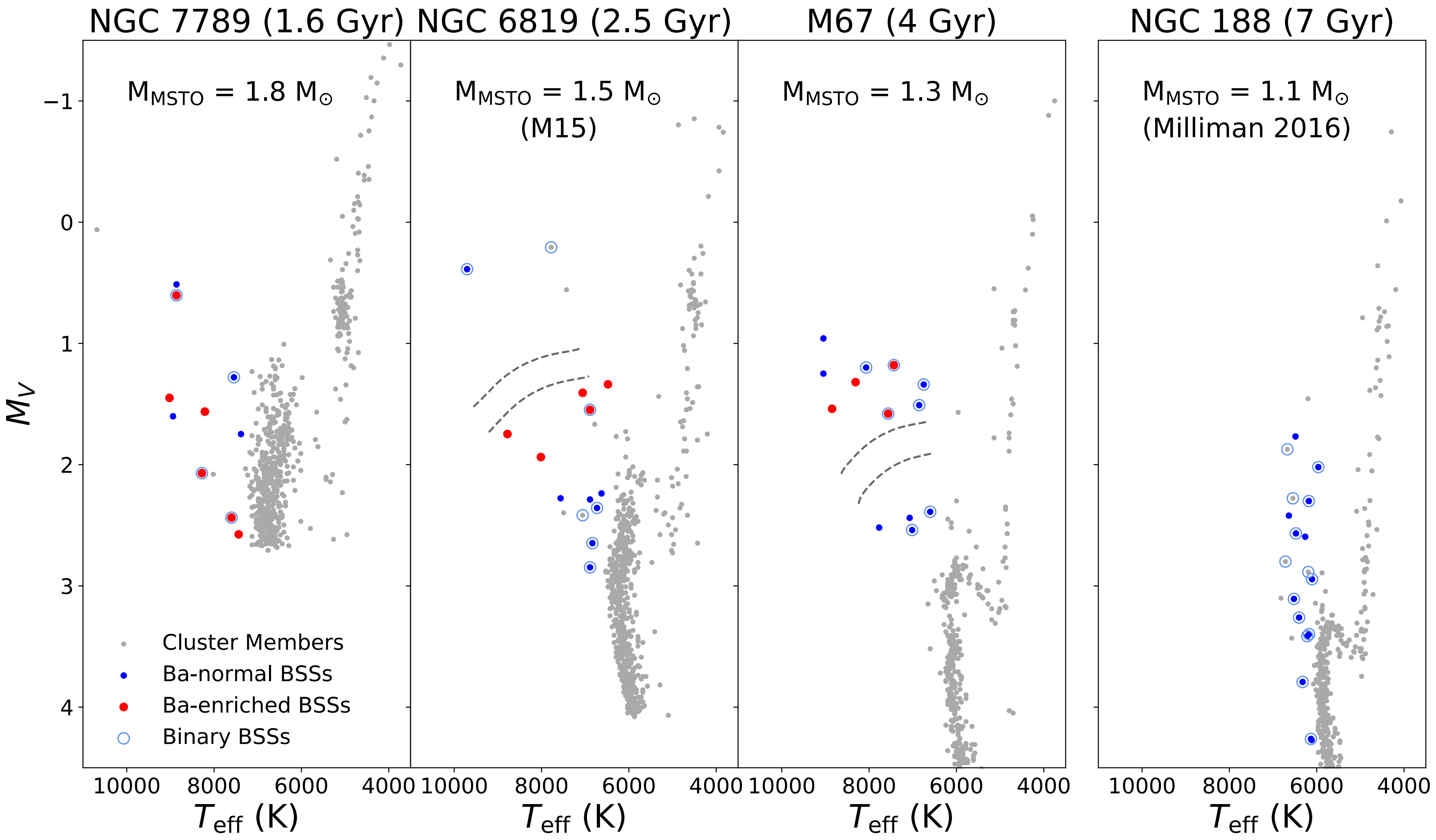
Latham & Milone 1996; Geller et al. 2015; Nine et al. 2024



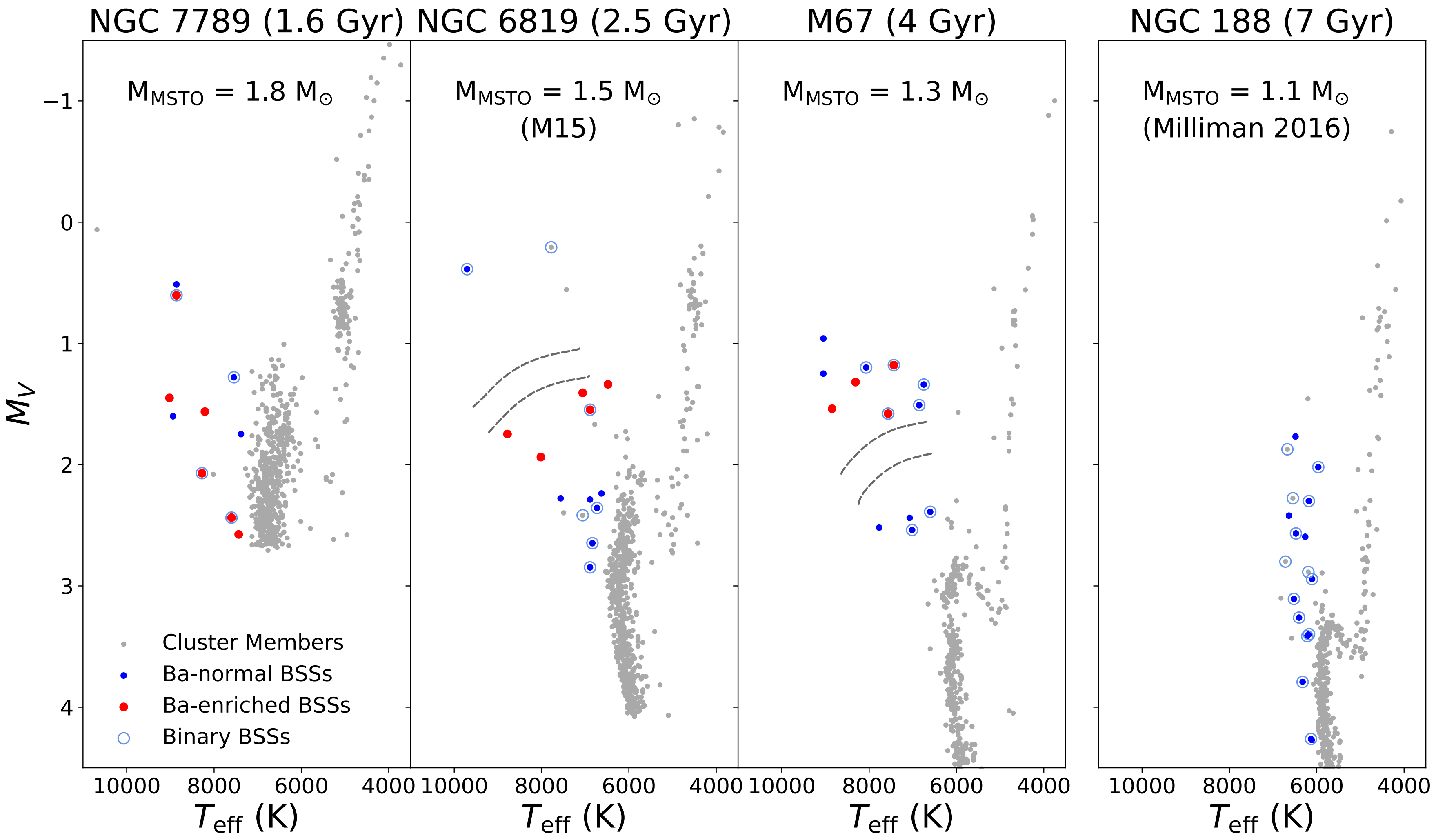
MIST: Choi et al. 2016; Escorza et al. 2017



Nine et al. 2024



NGC 7789 (1.6 Gyr)
NGC 6819 (2.5 Gyr)
M67 (4 Gyr)
NGC 188 (7 Gyr)
$M_{MSTO} = 1.8\ M_\odot$
$M_{MSTO} = 1.5\ M_\odot$
(M15)
$M_{MSTO} = 1.3\ M_\odot$
$M_{MSTO} = 1.1\ M_\odot$
(Milliman 2016)
M_V
T_{eff} (K)
Cluster Members
Ba-normal BSSs
Ba-enriched BSSs
Binary BSSs



Less Conservative Mass Transfer → More Conservative Mass Transfer

All of the Ba-enriched BSSs are in same region of the HR diagram

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There is an anticorrelation between cluster age and Ba enrichment

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The distribution of all BSSs with respect to the MSTO hints at a trend of less massive AGB stars experiencing more conservative MT

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There is an anticorrelation between cluster age and Ba enrichment

The distribution of all BSSs with respect to the MSTO hints at a trend of less massive AGB stars experiencing more conservative MT

The lack of Ba enrichment in NGC 188 is consistent with predictions that AGB stars $< 1.3\ M_{\odot}$ do not undergo TDU

The majority of Ba-enriched BSSs are apparently single!

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We detect 40±16% of Ba-enriched BSSs with P_{orb} < 10,000 days

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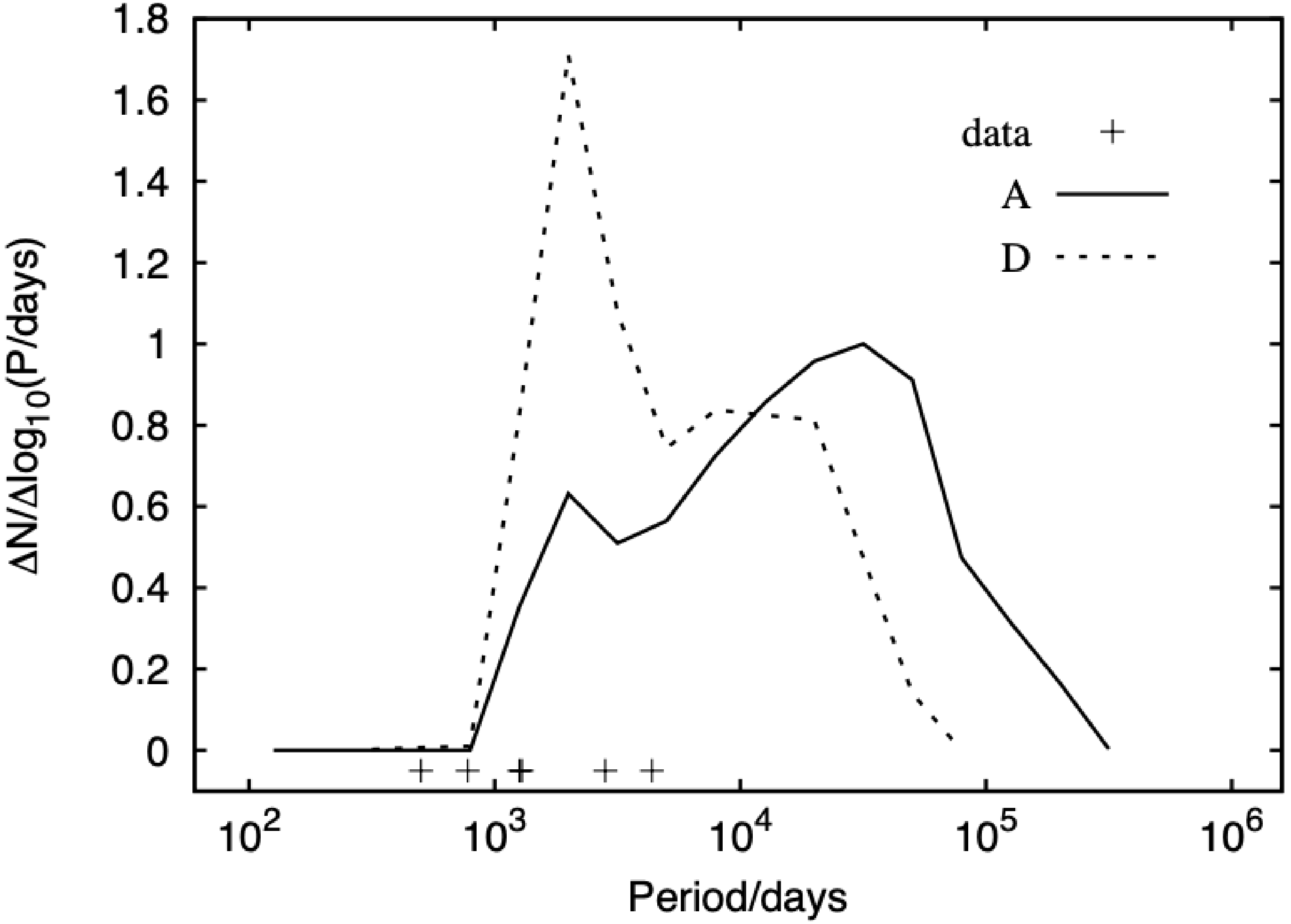
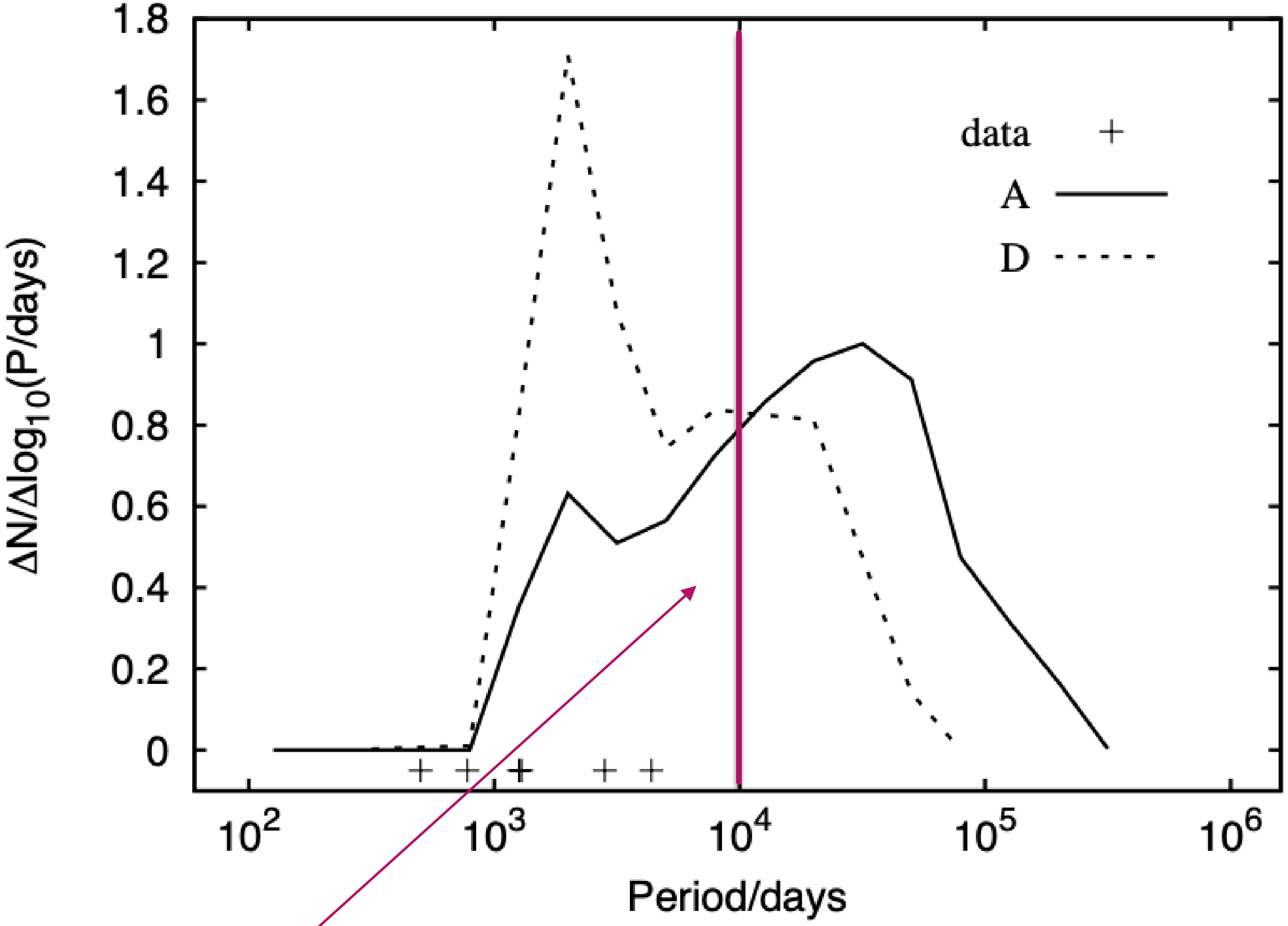
Why does this pattern occur?



Abate et al. 2013



Abate et al. 2013

Our RV detection limit

Summary

- We conducted a survey of Ba abundances in the BSSs of 4 open clusters with ages spanning ~10 Gyr
- We find an anticorrelation between cluster age and the degree to which BSSs are enhanced in Ba
- We find that 40±16% of Ba-enriched BSSs are in RV binaries with $P_{orb} < 10{,}000$ days
- The Ba enrichments trace various mechanisms of AGB mass transfer

- **AGB mass transfer may be the dominant contributor to the formation of classical BSSs in open clusters older than ~1 Gyr, even among apparently single stars.**

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