GEORG-AUGUST-UNIVERSITÄT GÖTTINGEN IN PUBLICA COMMODA SEIT 1737

INSTITUT FÜR ASTROPHYSIK & GEOPHYSIK

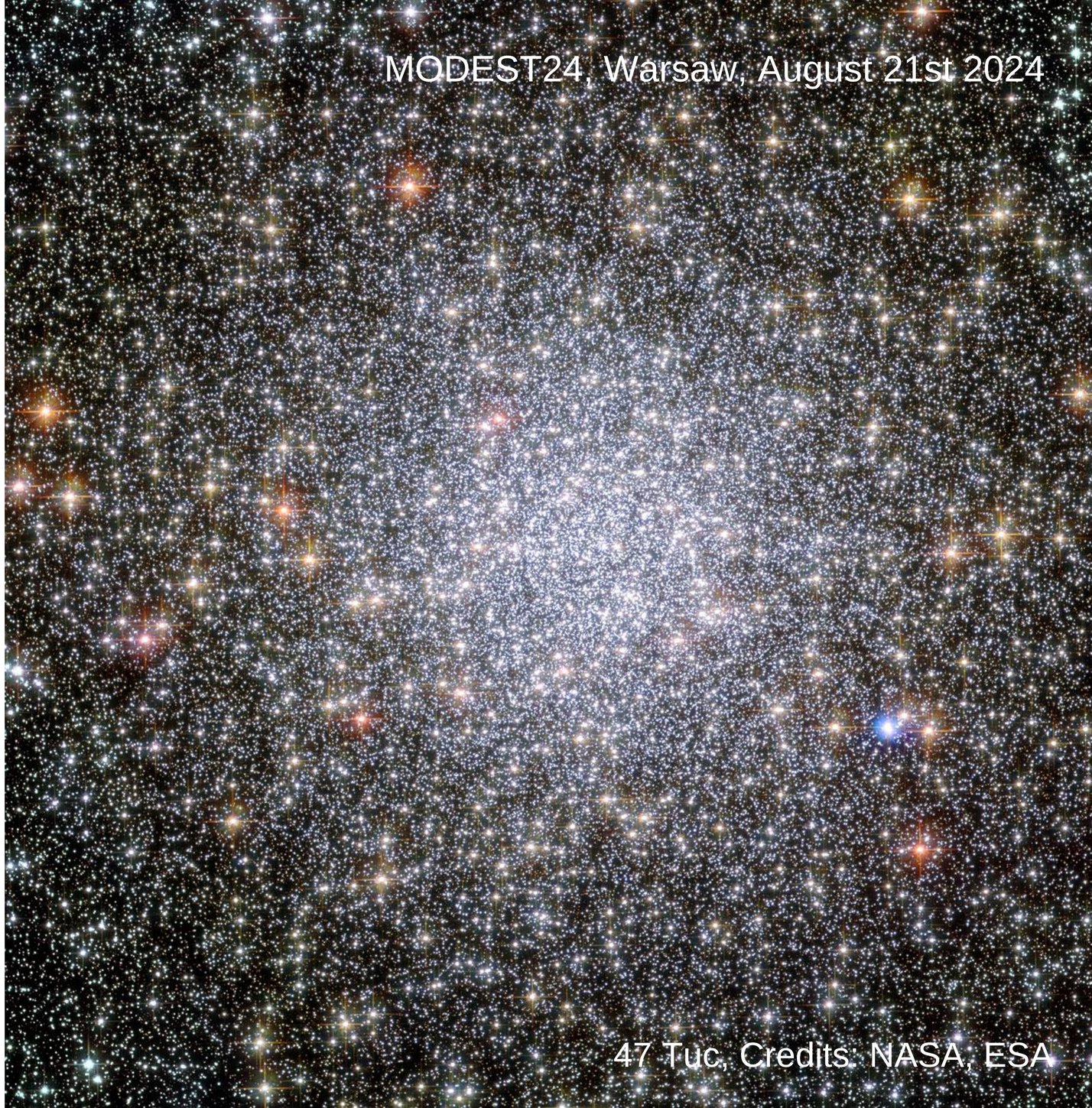
muse multi unit spectroscopic explorer

MODEST24, Warsaw, August 21st 2024

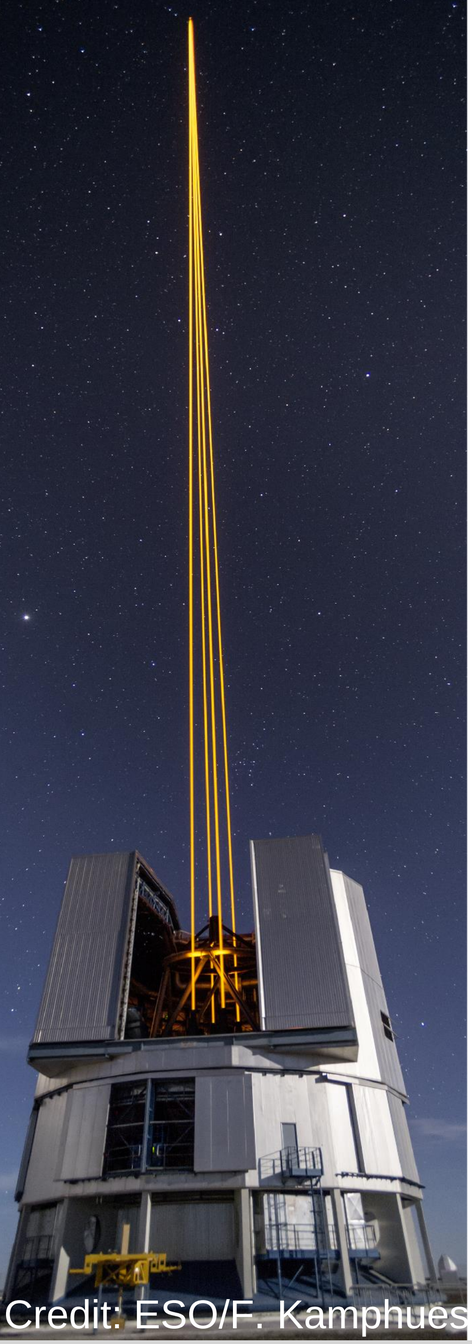
Binaries in 47 Tuc: Confronting cluster simulations with observations

A&A submitted

Johanna Müller-Horn, ***Stefan Dreizler****, Fabian Göttgens, Sebastian Kamann, Sven Martens, Sara Saracino, Claire Ye*



47 Tuc, Credits: NASA, ESA

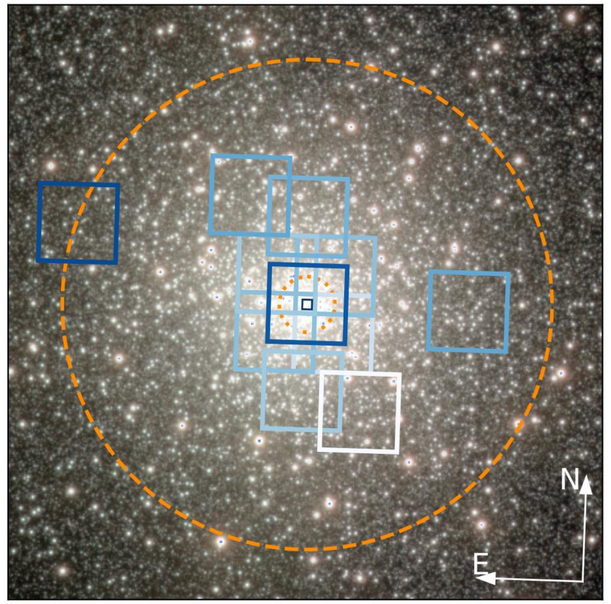

Credit: ESO/F. Kamphues

MUSE view of 47 Tuc

47 Tuc old, massive and nearby globular cluster

MUSE observing campaign of globular clusters

- 8 years of observations
- reliable spectra of >20,000 stars *(1)*
- on average 11 epochs per star



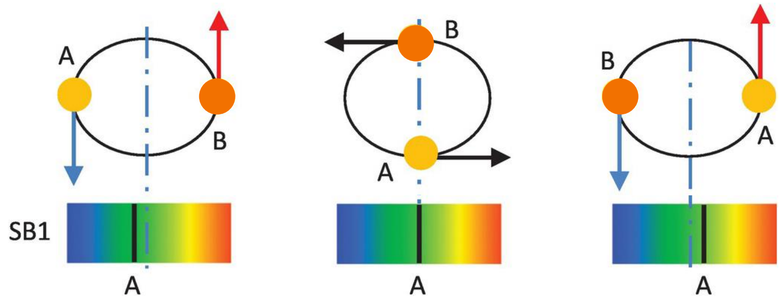
MUSE FoV of 47 Tuc,
image taken from VMC survey

(1) Kamann et al. (2013)

Search for SB1 binaries

data $t, v_{\mathrm{rad}}, \sigma_{v_{\mathrm{rad}}}$

model $v_{\mathrm{rad}} = v_{\mathrm{z}} + K(\cos(\omega + f) + e\cos(\omega))$

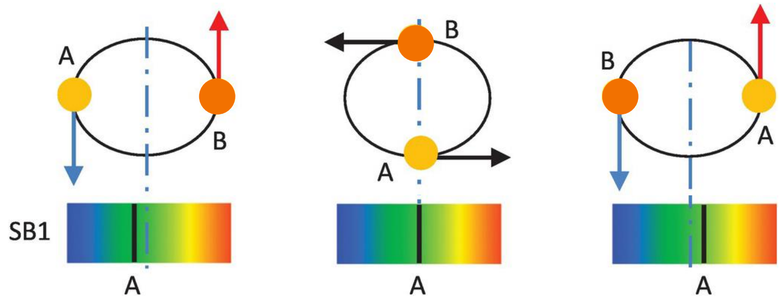


Walker (2017)

Search for SB1 binaries

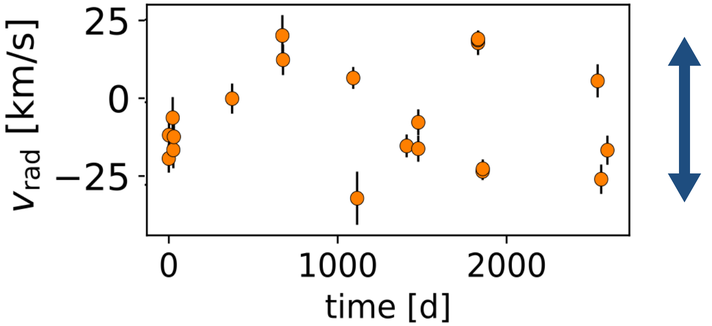
data $t, v_{\mathrm{rad}}, \sigma_{v_{\mathrm{rad}}}$

model $v_{\mathrm{rad}} = v_{\mathrm{z}} + K(\cos(\omega + f) + e\cos(\omega))$



Walker (2017)

A. identify binaries in a statistical approach *(Giesers et al. 2019)*

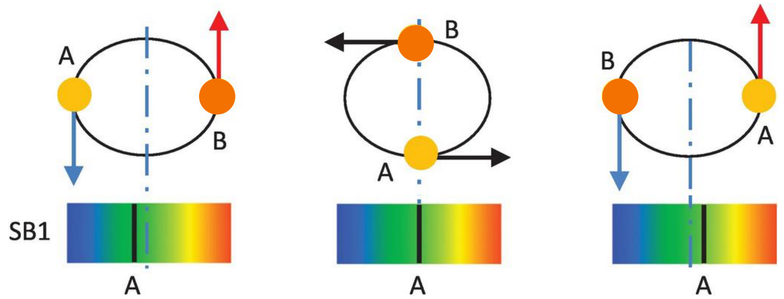


larger RV scatter ⇔
higher binary probability

Search for SB1 binaries

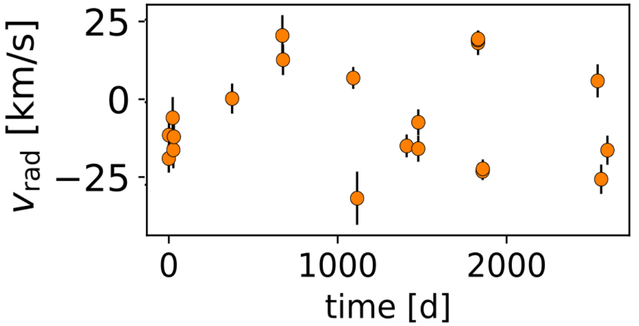
data $t, v_{\mathrm{rad}}, \sigma_{v_{\mathrm{rad}}}$

model $v_{\mathrm{rad}} = v_{\mathrm{z}} + K(\cos(\omega + f) + e\cos(\omega))$



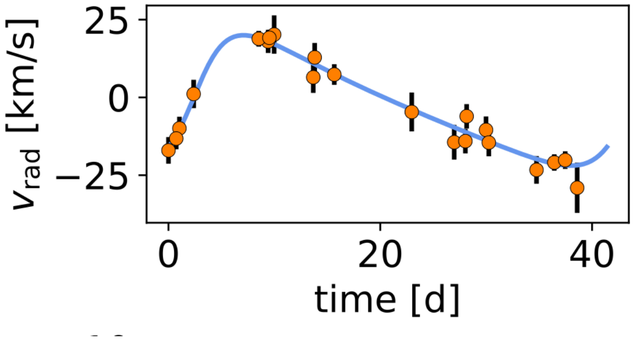
Walker (2017)

A. identify binaries in a statistical approach *(Giesers et al. 2019)*



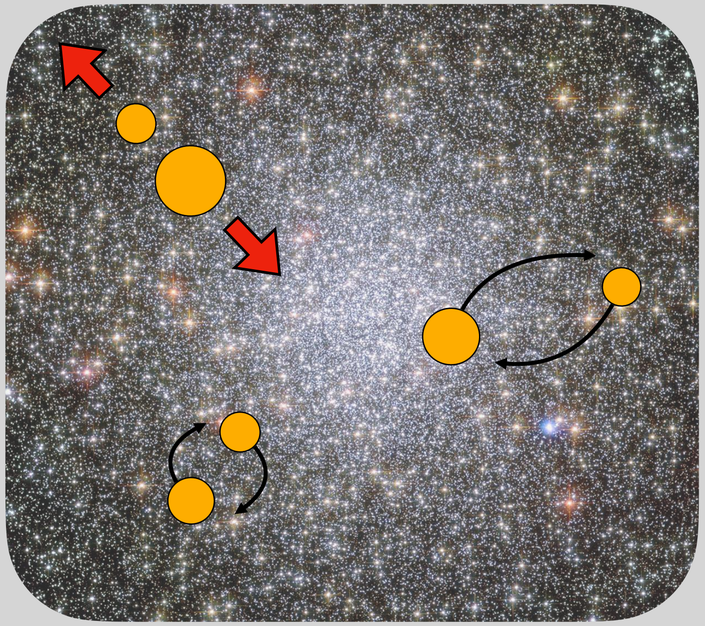
larger RV scatter ⇔ higher binary probability

B. determine orbital parameters using nested sampling *(Buchner 2021)*



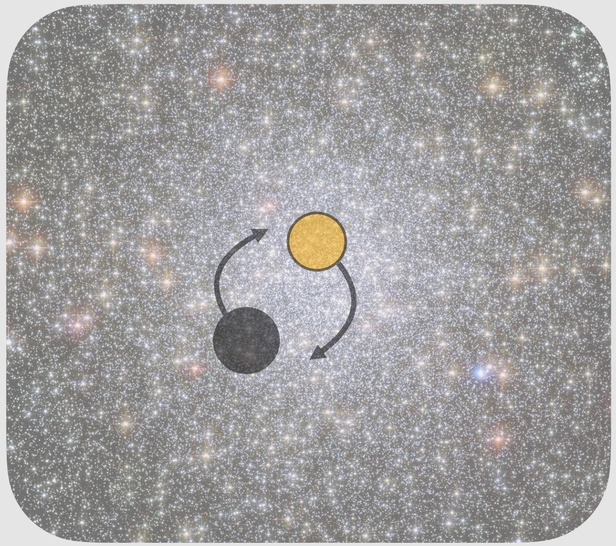
nested sampling works well for multi-modal solutions

Research aims



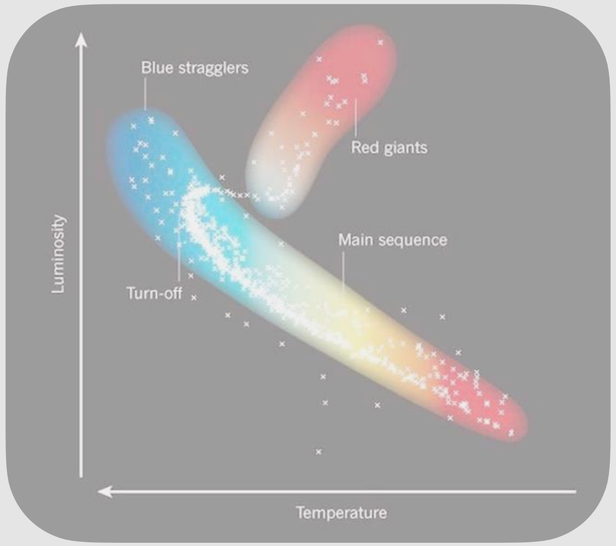
47 Tuc, Credits: NASA, ESA

study binary fraction and demographics



47 Tuc, Credits: NASA, ESA

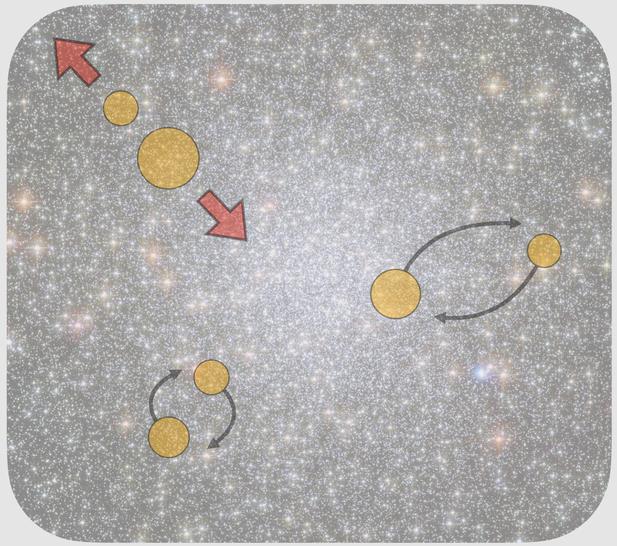
probe the dormant BH population



C. Tout (2011)

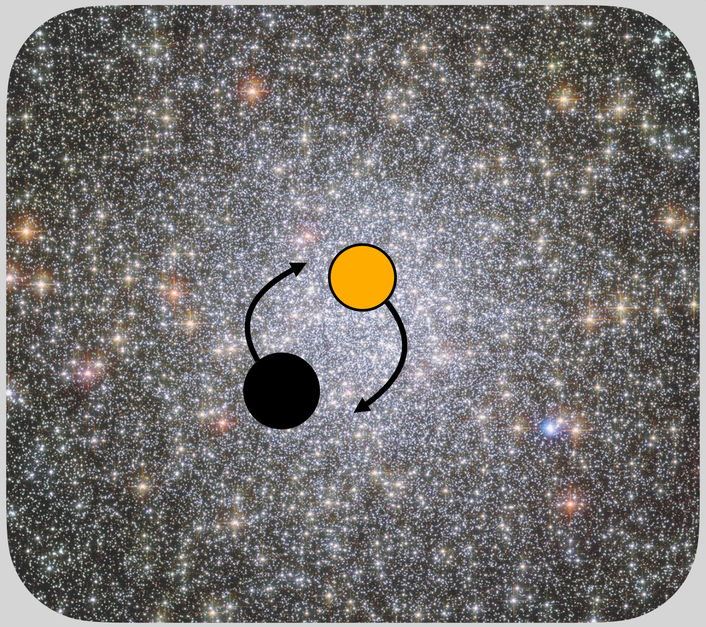
study binarity among blue straggler stars

Research aims



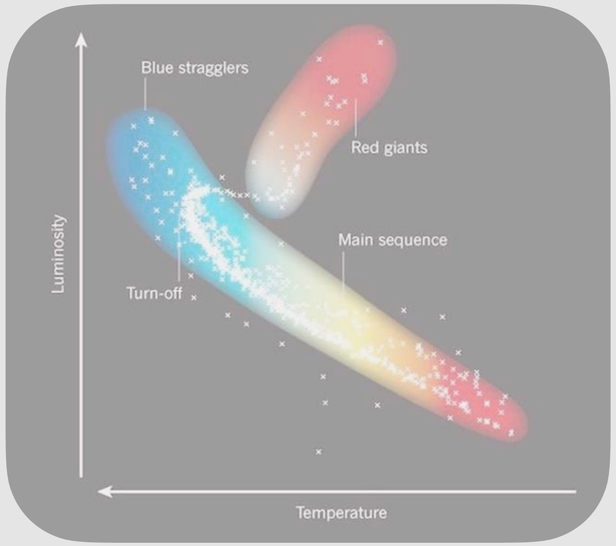
47 Tuc, Credits: NASA, ESA

study binary fraction and demographics



47 Tuc, Credits: NASA, ESA

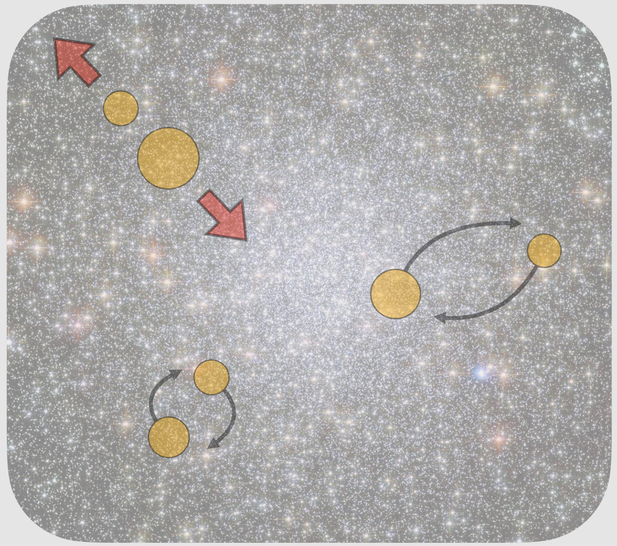
probe the dormant BH population



C. Tout (2011)

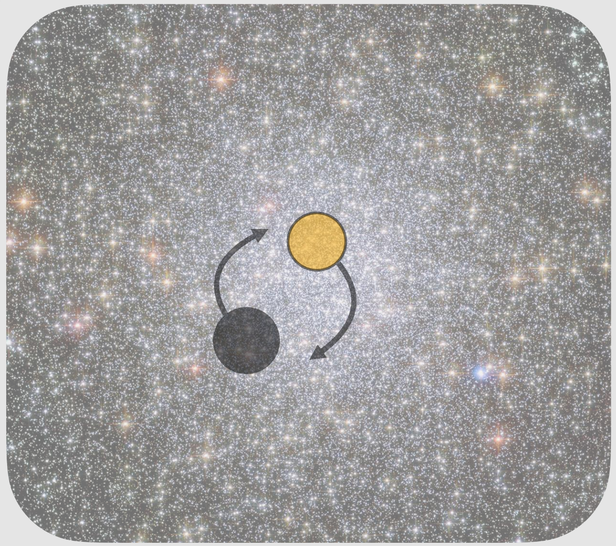
study binarity among blue straggler stars

Research aims



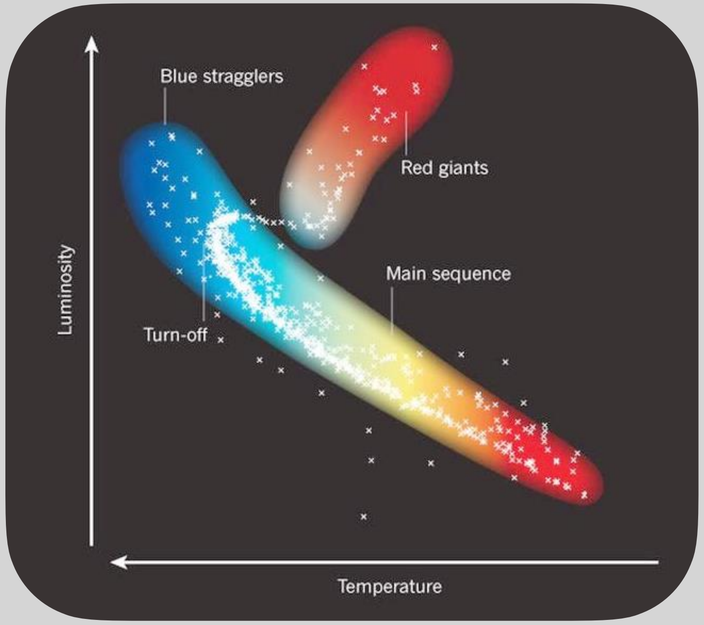
47 Tuc, Credits: NASA, ESA

study binary fraction and demographics



47 Tuc, Credits: NASA, ESA

probe the dormant BH population



C. Tout (2011)

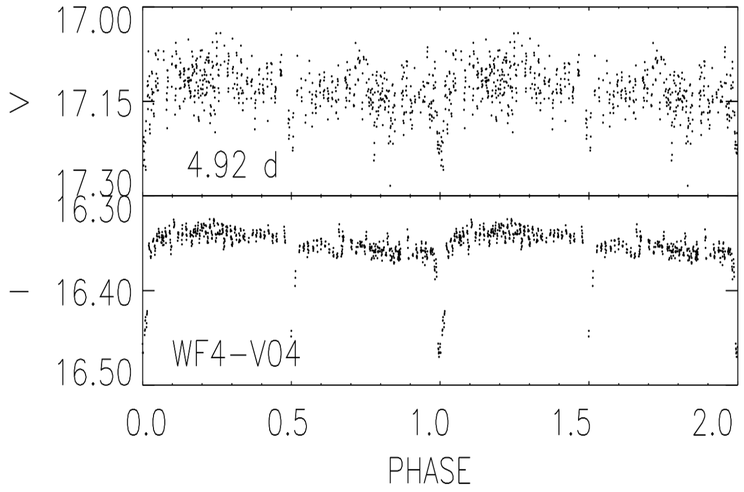
study binarity among blue straggler stars

Previous observations

eclipsing binaries

Albrow & Gilliland (2001),
Weldrake & Sackett (2004),
Kaluzny et al. (2013),
Nardiello et al. (2019)

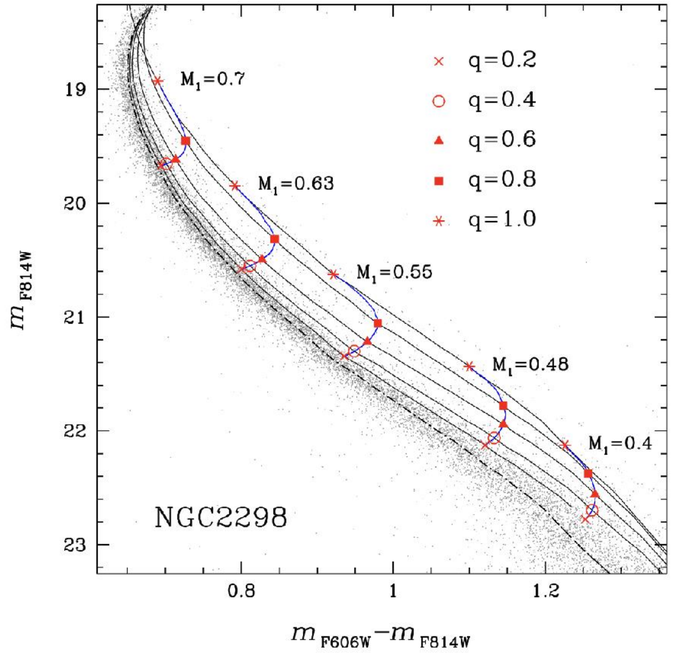
Albrow & Gilliland (2001)



binary main sequence

Milone et al. (2012),
Ji & Bregmann (2015)

Milone et al. (2012)



radio & X-ray sources

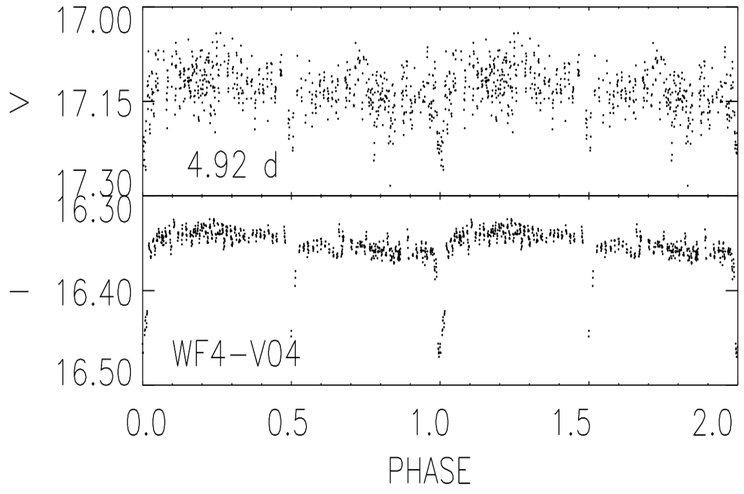
Heinke et al. (2005)
Bahramian et al. (2017),
Miller-Jones et al. (2015)
Rivera Sandoval et al. (2018)

Previous observations

eclipsing binaries

Albrow & Gilliland (2001),
Weldrake & Sackett (2004),
Kaluzny et al. (2013),
Nardiello et al. (2019)

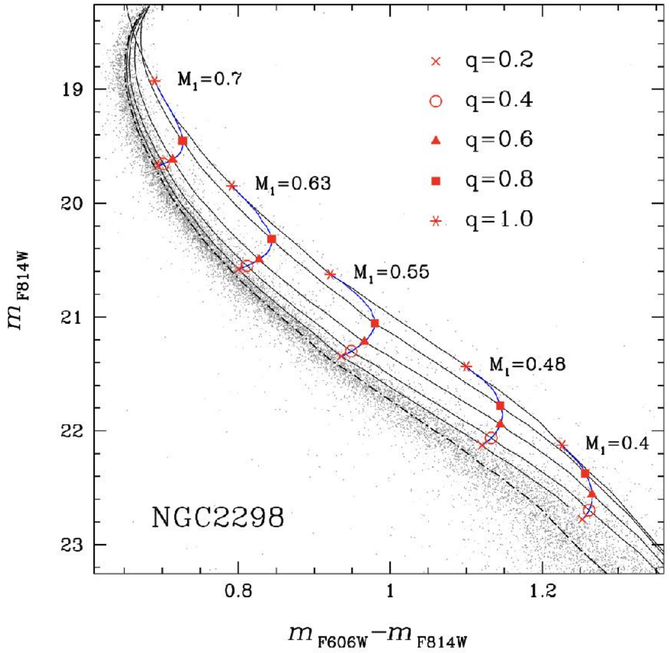
Albrow & Gilliland (2001)



binary main sequence

Milone et al. (2012),
Ji & Bregmann (2015)

Milone et al. (2012)



radio & X-ray sources

Heinke et al. (2005)
Bahramian et al. (2017),
Miller-Jones et al. (2015)
Rivera Sandoval et al. (2018)

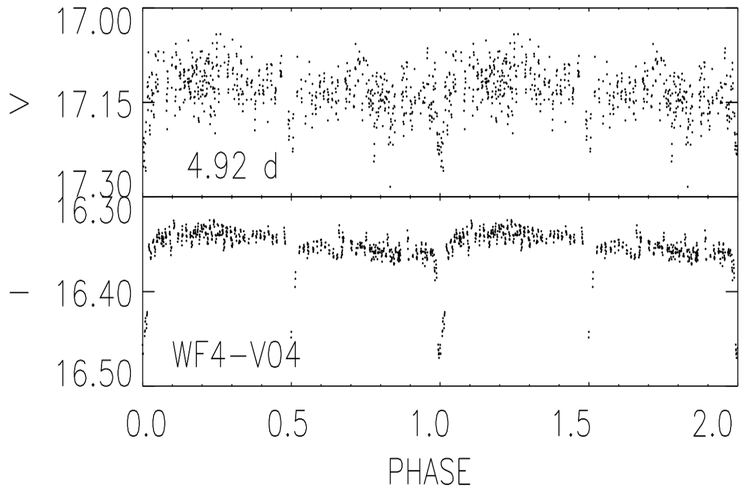
- limited information on companion masses and period distribution
- low overall binary fraction

Previous observations

eclipsing binaries

Albrow & Gilliland (2001),
Weldrake & Sackett (2004),
Kaluzny et al. (2013),
Nardiello et al. (2019)

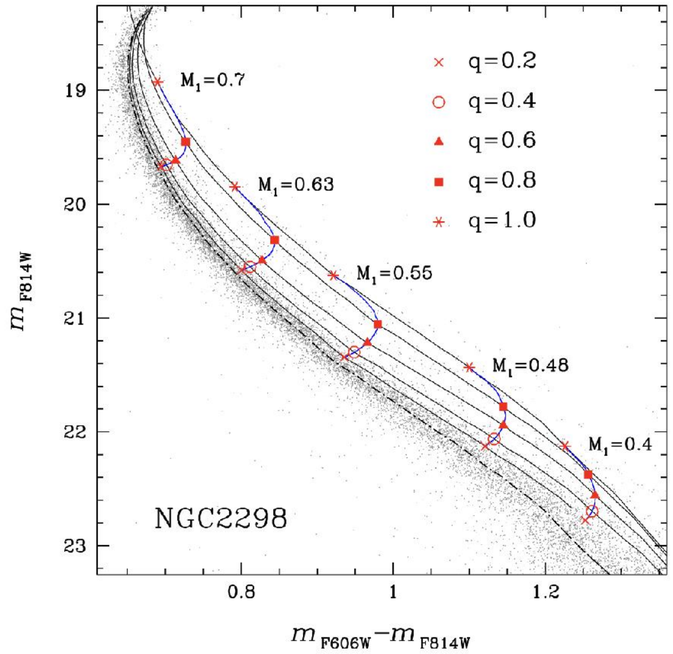
Albrow & Gilliland (2001)



binary main sequence

Milone et al. (2012),
Ji & Bregmann (2015)

Milone et al. (2012)

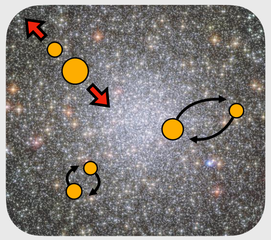


radio & X-ray sources

Heinke et al. (2005)
Bahramian et al. (2017),
Miller-Jones et al. (2015)
Rivera Sandoval et al. (2018)

need spectroscopy!

- limited information on companion masses and period distribution
- low overall binary fraction



Binary demographics

Binary fraction

Discovery binary fraction

(3.3 ± 1.1)%

↓

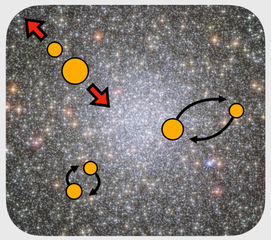
account for limited discovery probability

↓

correct for limited sensitivity and FoV

↓

Total binary fraction



Binary demographics

Binary fraction

Discovery binary fraction

↓

account for limited discovery probability

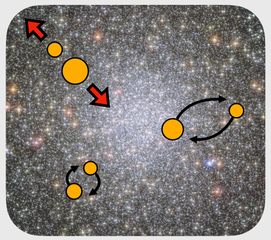
↓

correct for limited sensitivity and FoV

↓

Total binary fraction

$(2.4 \pm 0.9)\%$



Binary demographics

Binary fraction

Discovery binary fraction

↓

account for limited discovery probability

↓

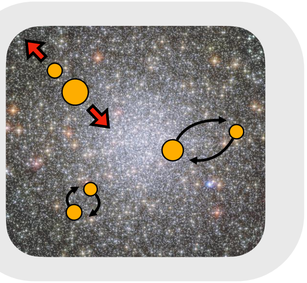
correct for limited sensitivity and FoV

↓

Total binary fraction

$(2.4 \pm 0.9)\%$

low total binary fraction, consistent with photometric estimates



Binary demographics

Binary fraction

Discovery binary fraction

↓

account for limited discovery probability ← depends on CMC binary parameters

↓

correct for limited sensitivity and FoV ← depends on CMC radial and q profiles

↓

Total binary fraction **(2.4 ± 0.9)%**

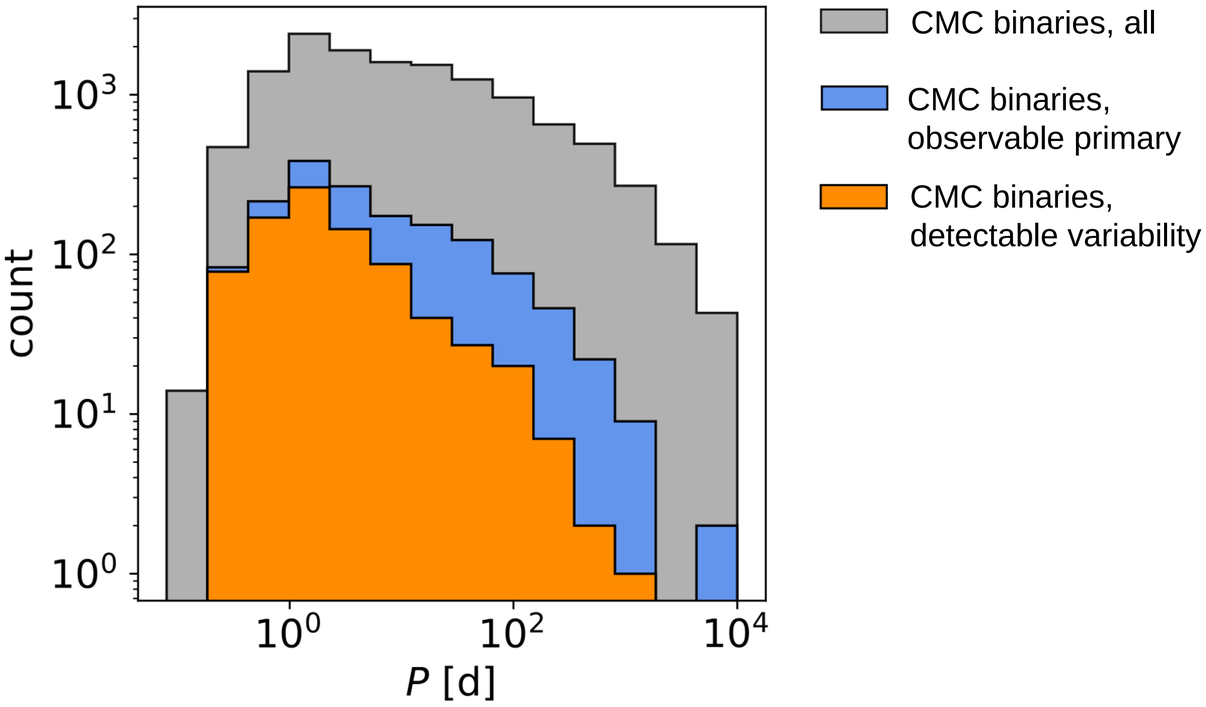
low total binary fraction, consistent with photometric estimates ✓

Cluster Monte Carlo simulations

CMC simulations of
47 Tuc (*Ye et al. 2022*)

→ make predictions for binary properties

→ account for observational biases using mock data

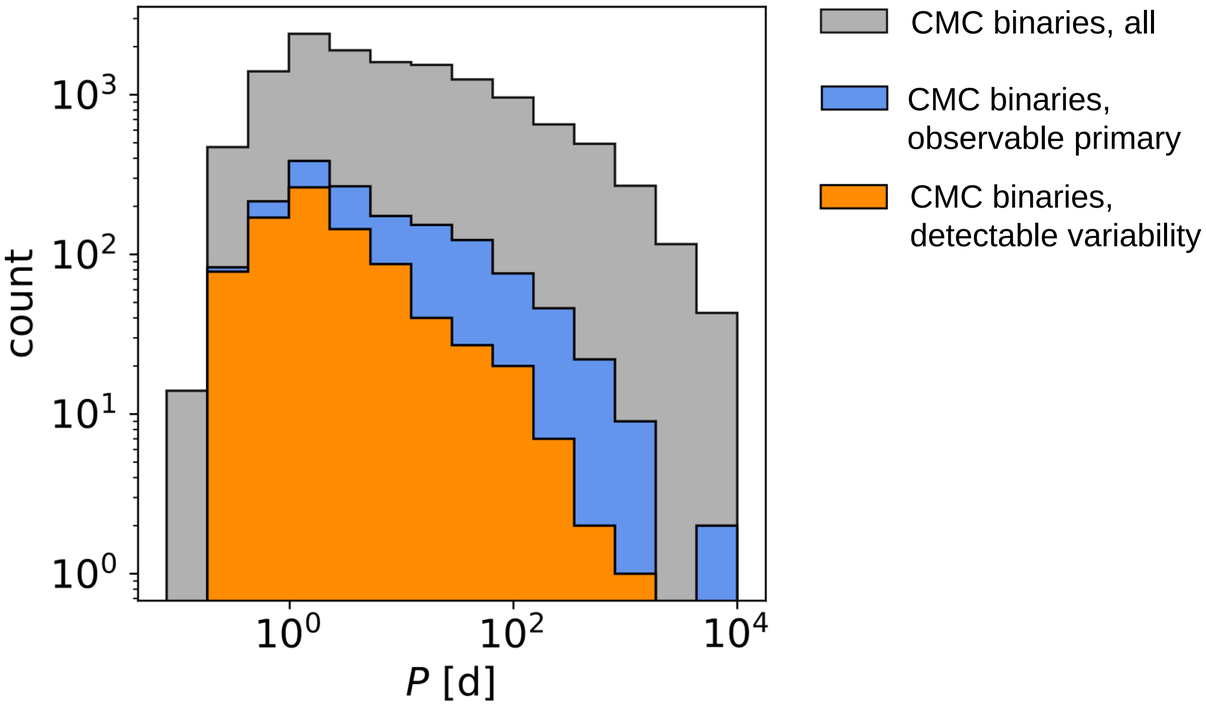


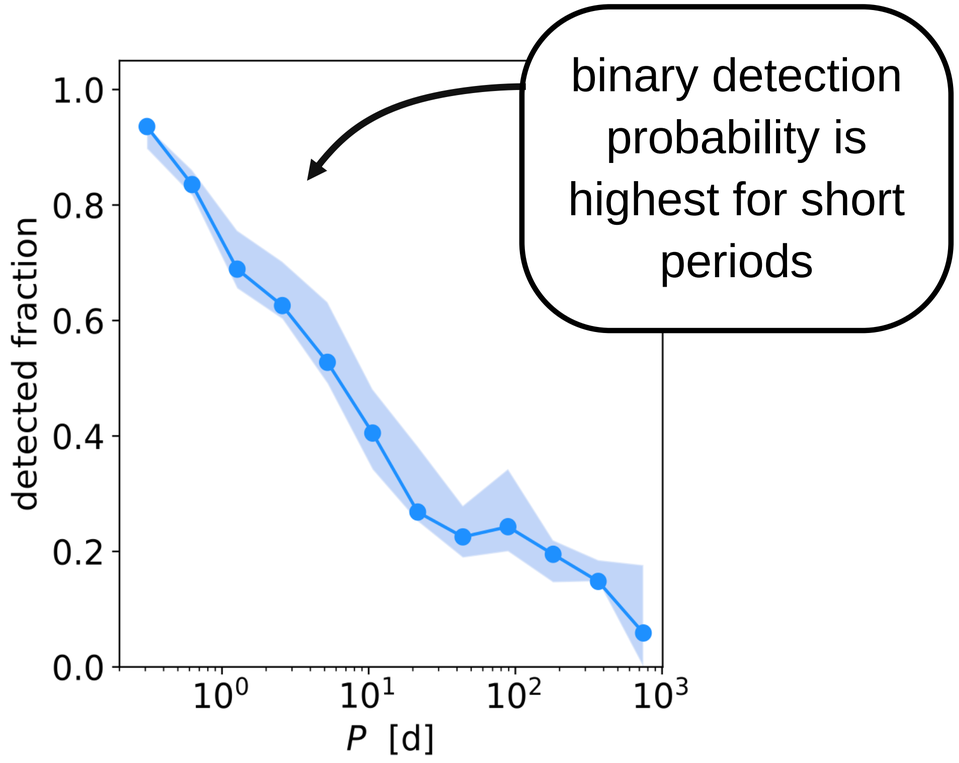
Cluster Monte Carlo simulations

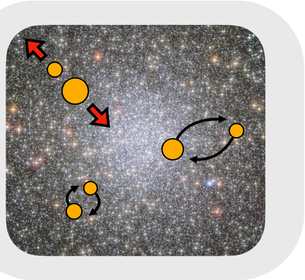
CMC simulations of
47 Tuc (*Ye et al. 2022*)

→ make predictions for binary properties

→ account for observational biases using mock data

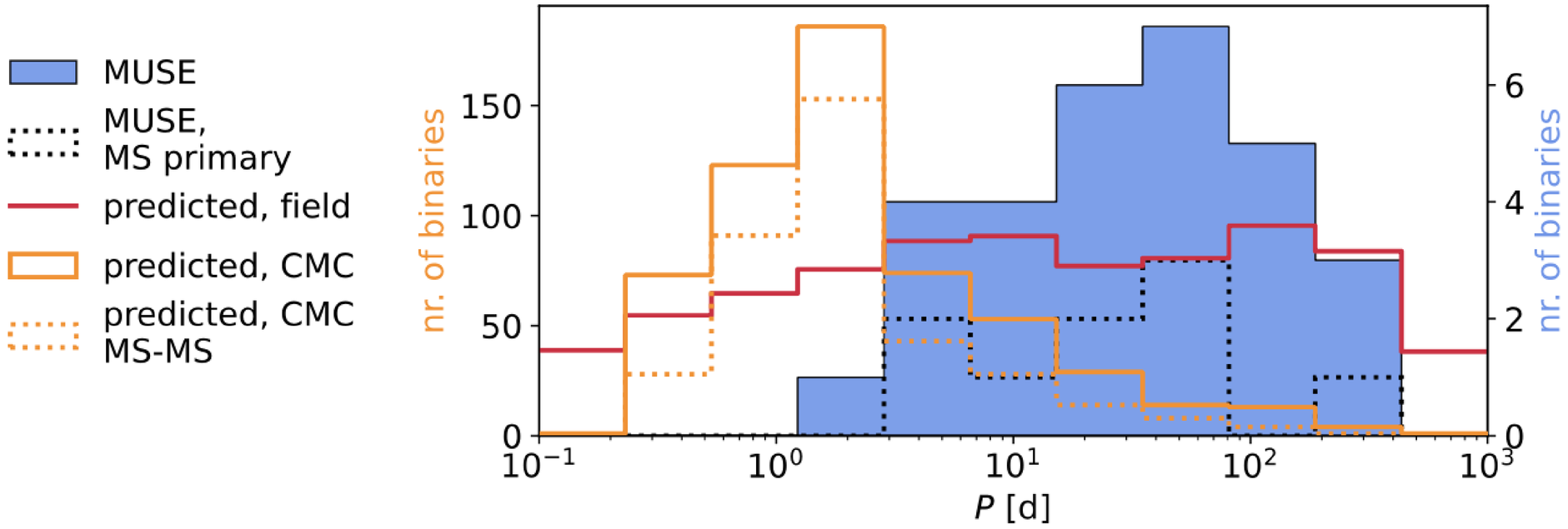


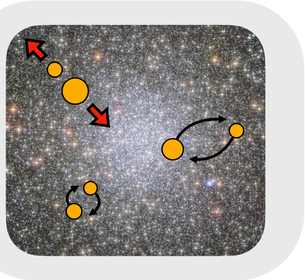




Binary demographics

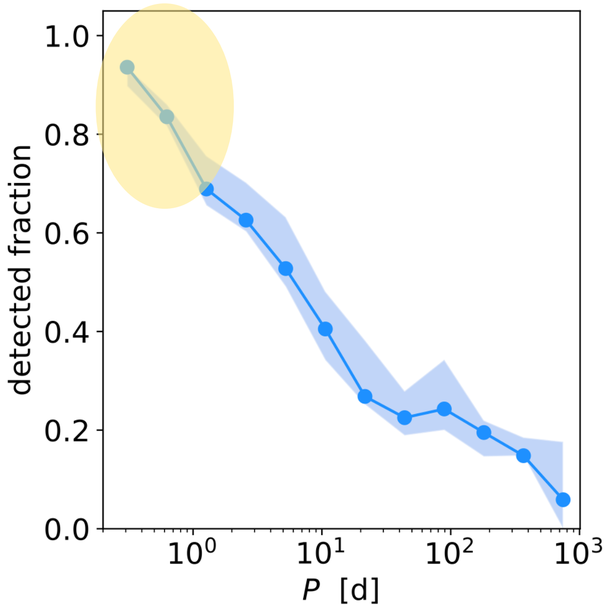
Orbital parameters

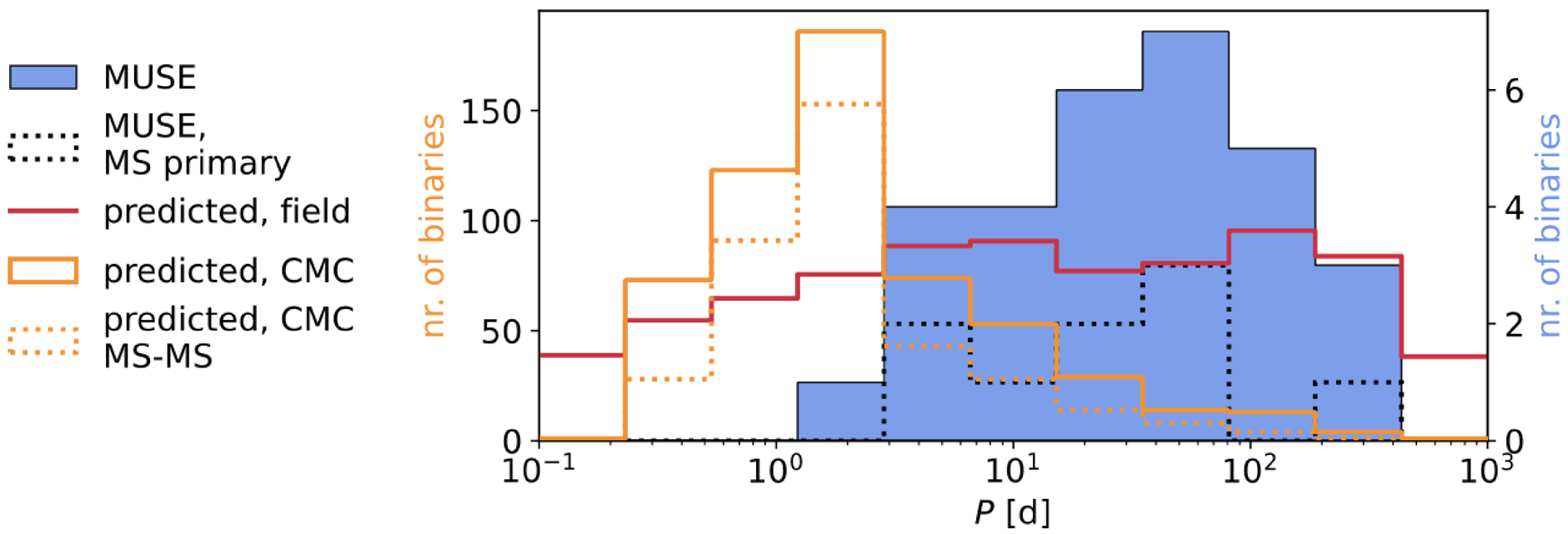


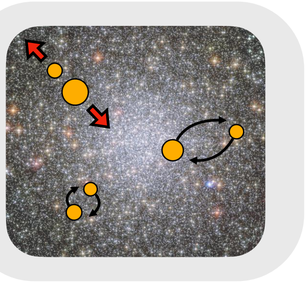


Binary demographics

Orbital parameters



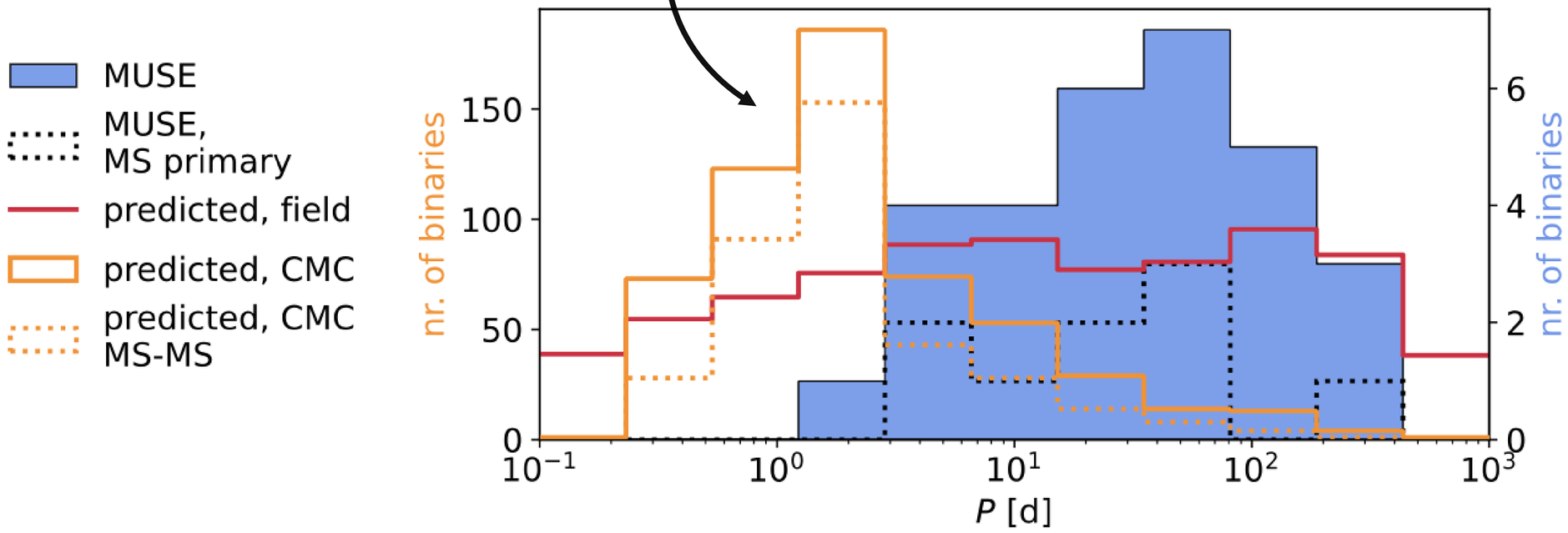


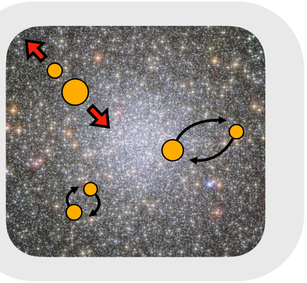


Binary demographics

Orbital parameters

We expect to find and are more sensitive to short-period binaries



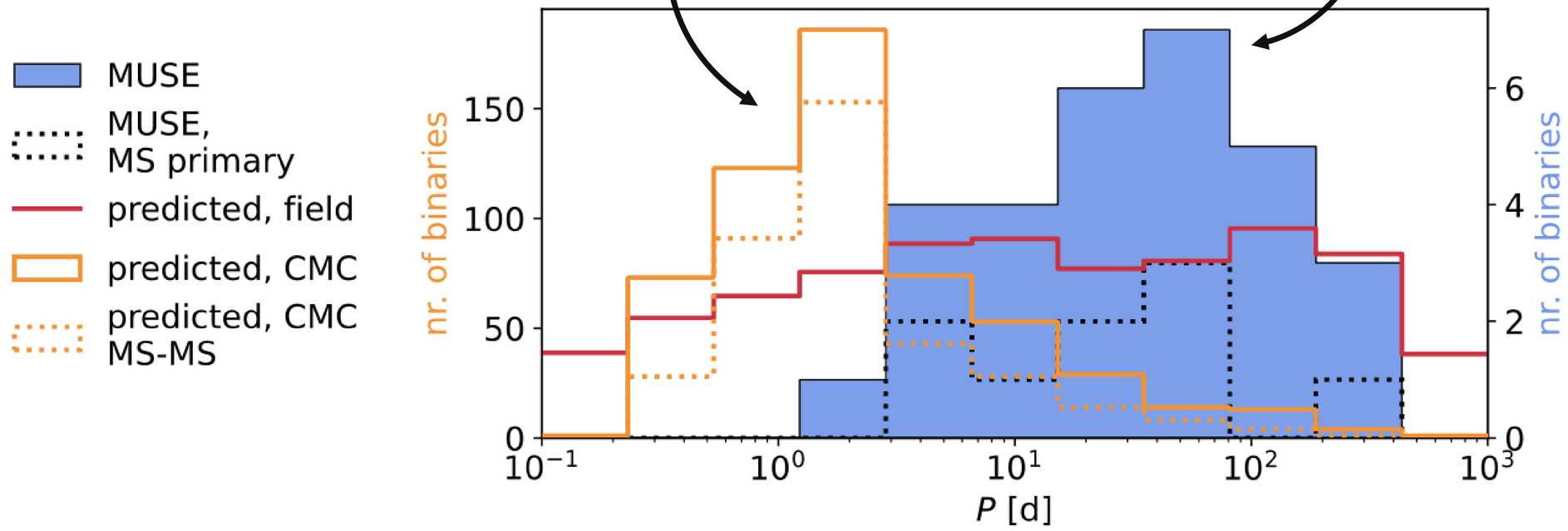


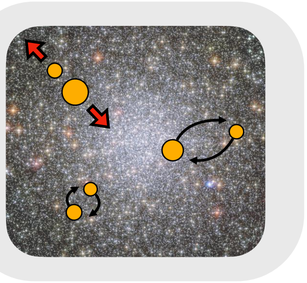
Binary demographics

Orbital parameters

We expect to find and are more sensitive to short-period binaries

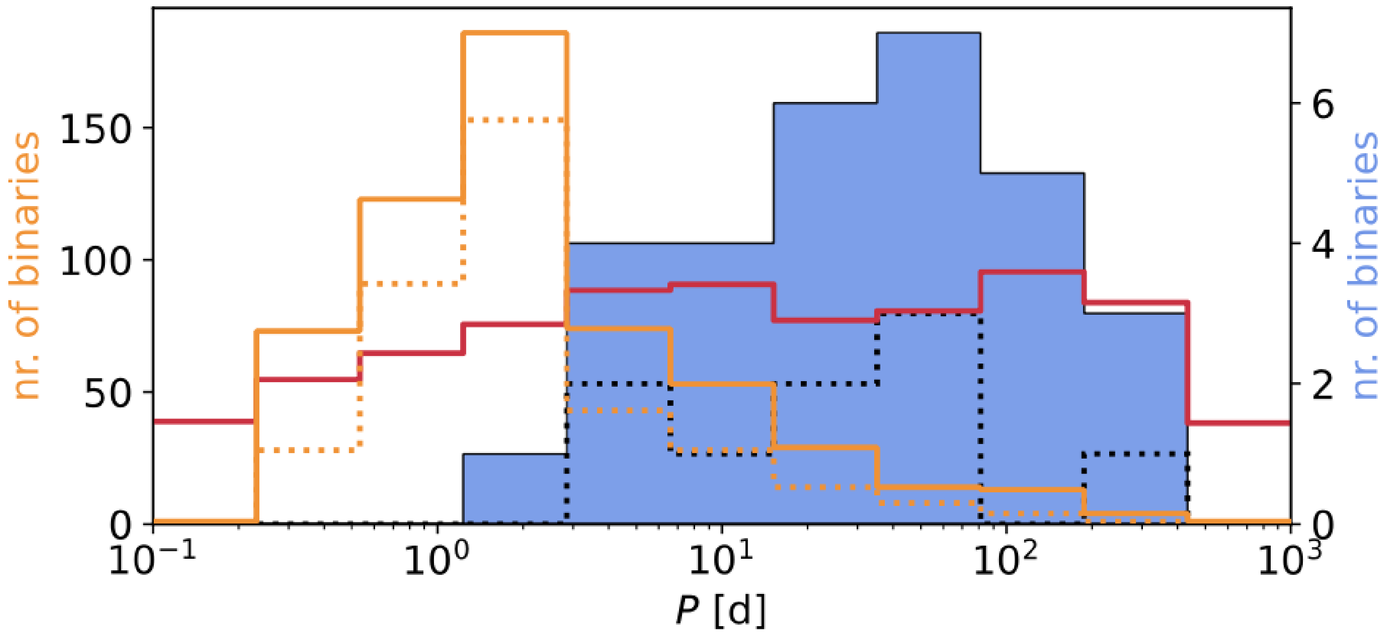
but instead we find binaries with longer periods.





Binary demographics

Orbital parameters

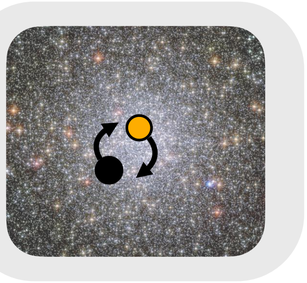


possible reasons

A. uncertainty in binary evolution models

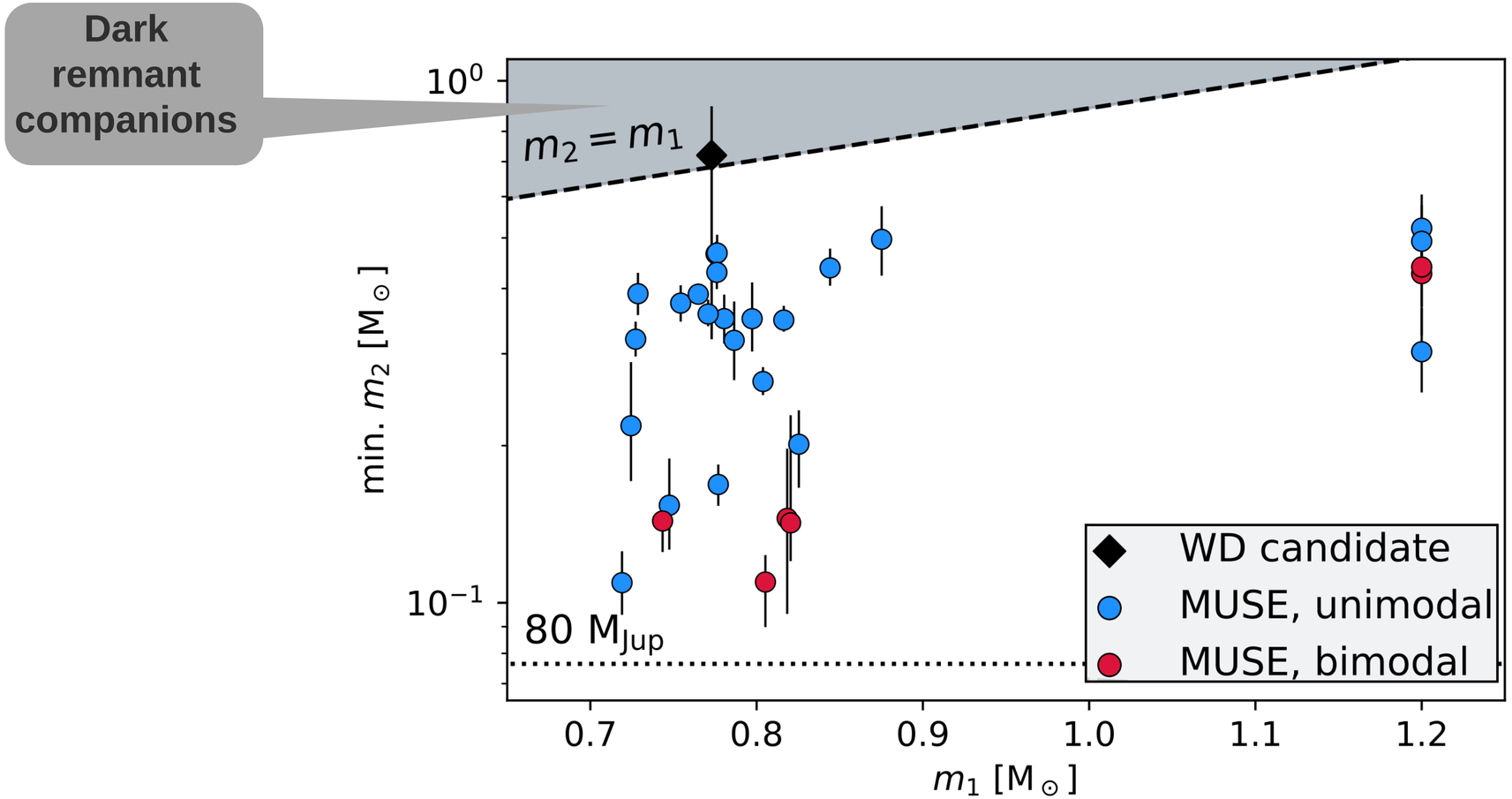
B. (excessive) dynamic hardening in CMC

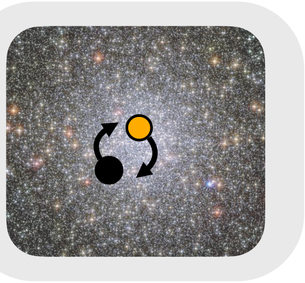
C. CMC initial conditions



Black holes in 47 Tuc

Dark remnant companions



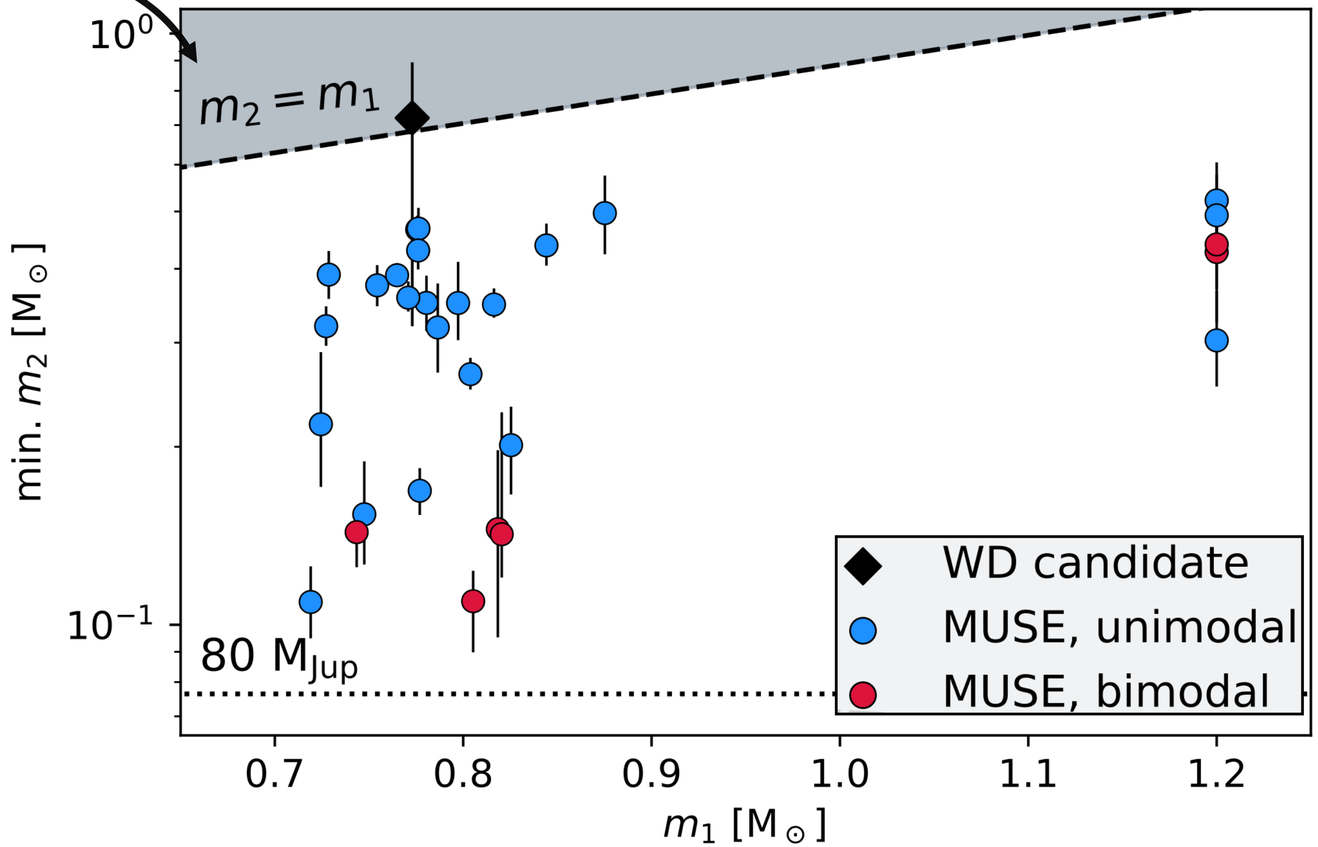


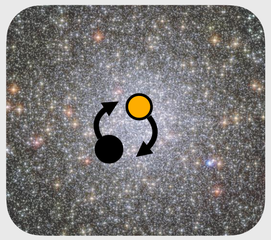
Black holes in 47 Tuc

Dark remnant companions

no evidence for BH/NS companions;
all min. $m_2 \ll 1.4\mathrm{M}_\odot$

~4 MS-BH/NS
binaries expected
from CMC simulation



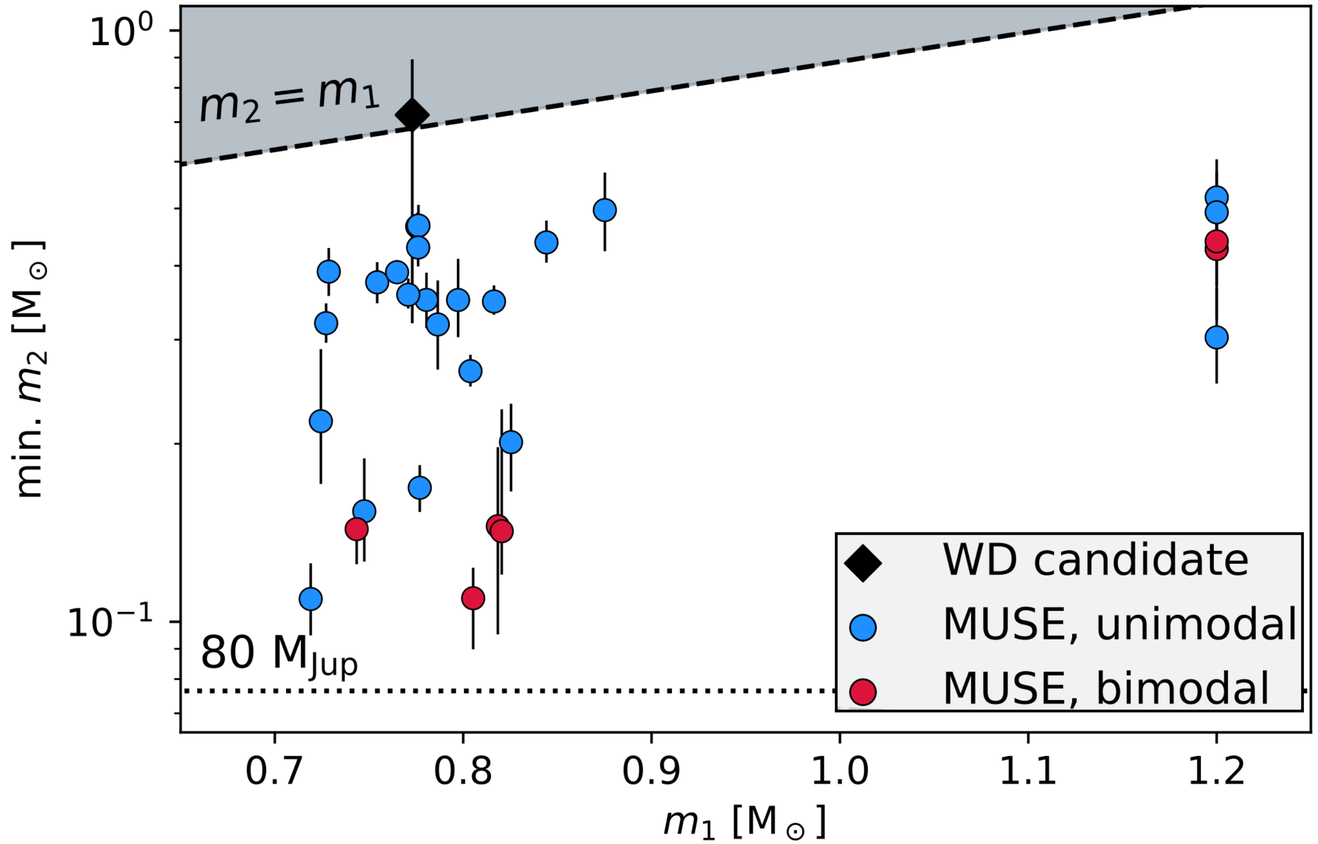


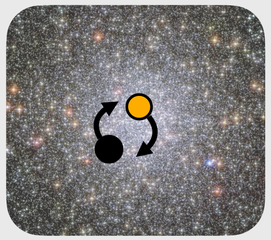
Black holes in 47 Tuc

Dark remnant companions

possible interpretation

- unfortunate time sampling
- restricted FoV
- low number of binary BHs / unobservable configurations



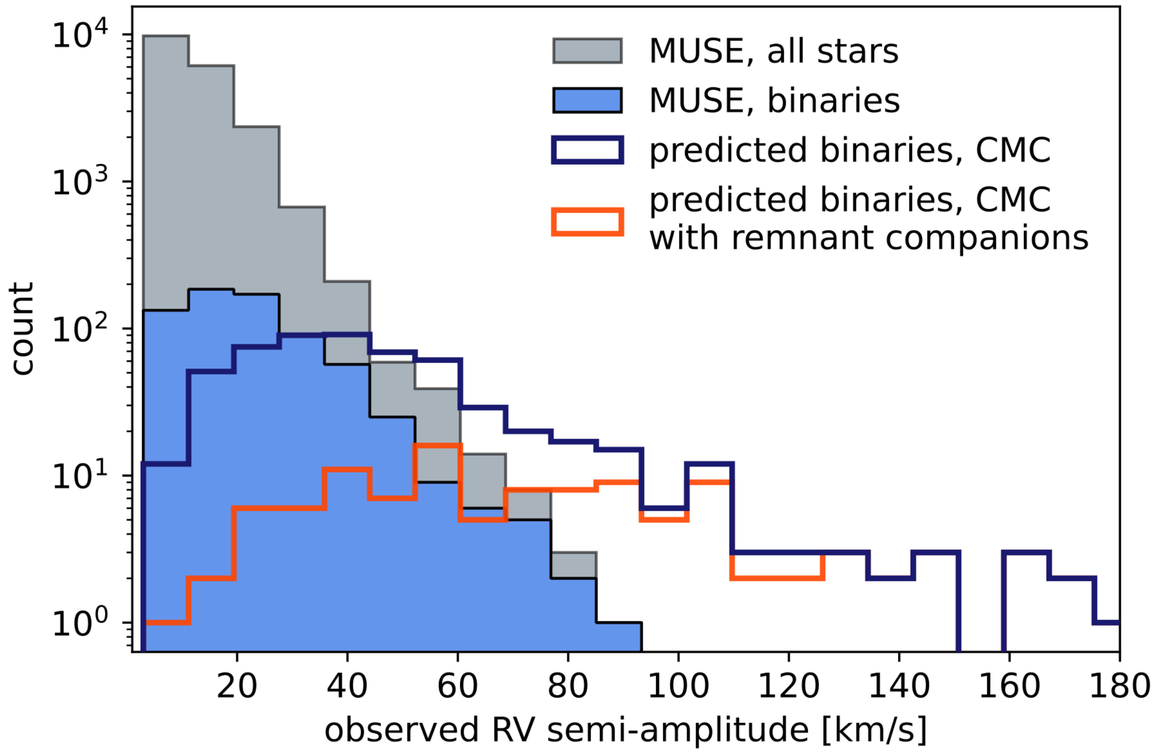


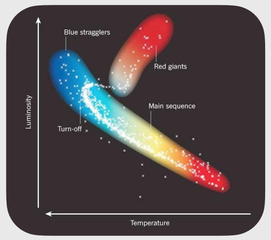
Black holes in 47 Tuc

Dark remnant companions

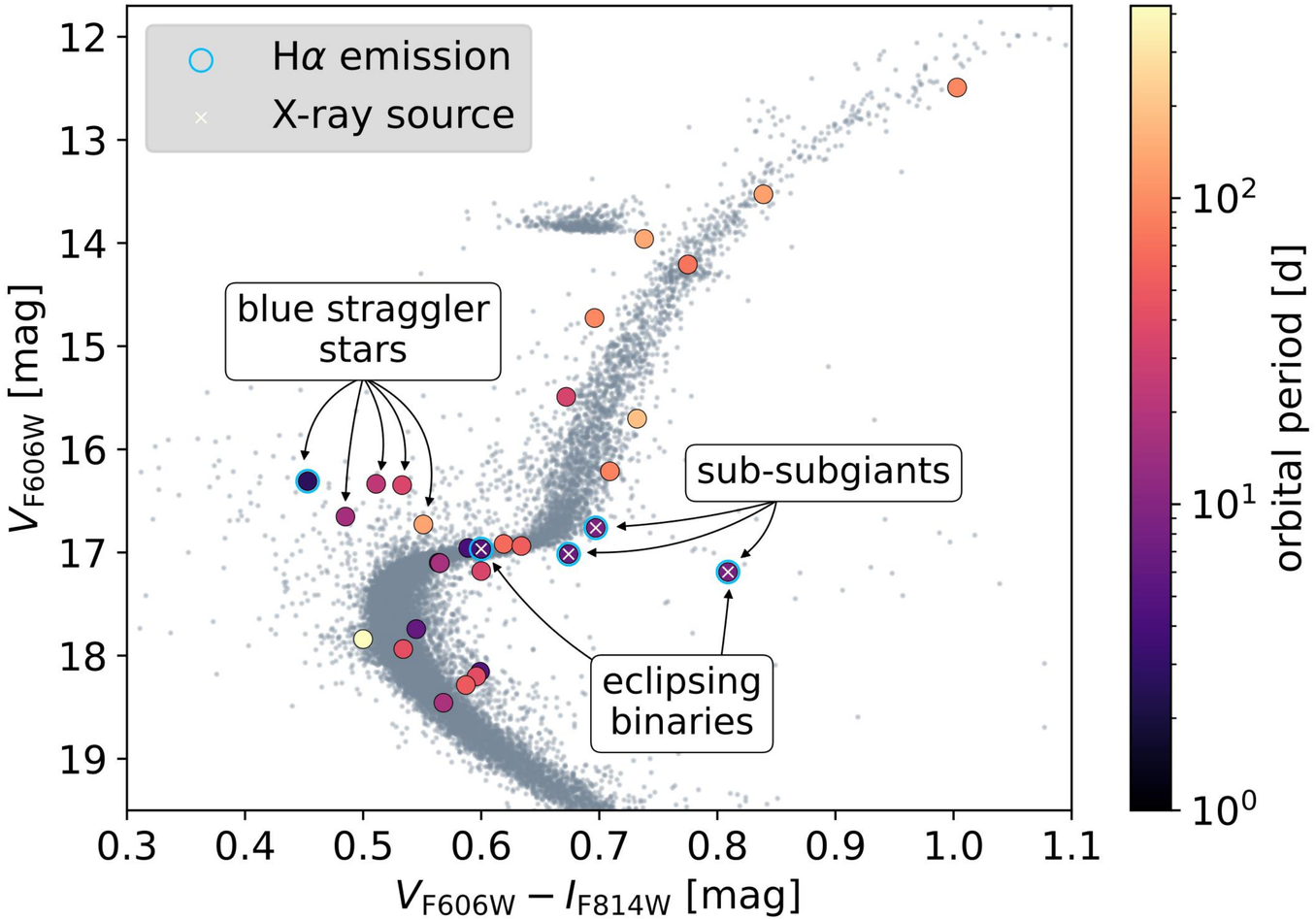
possible interpretation

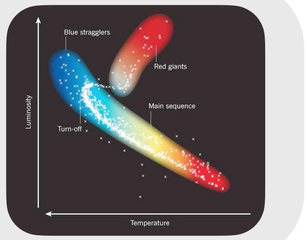
- unfortunate time sampling
- restricted FoV
- low number of binary BHs / unobservable configurations





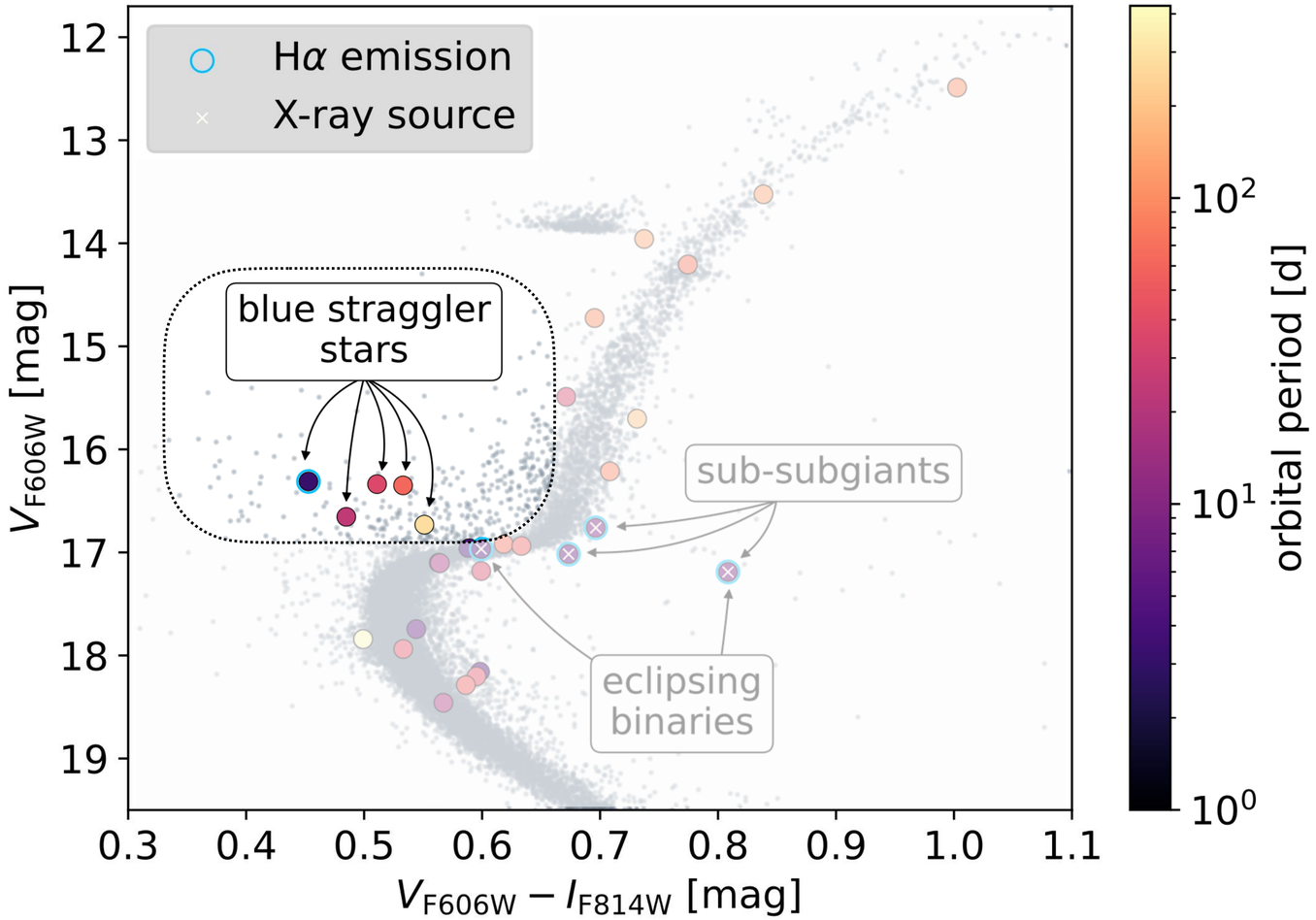
Peculiar objects

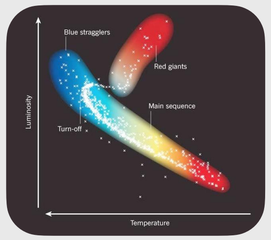




Peculiar objects

Blue straggler stars

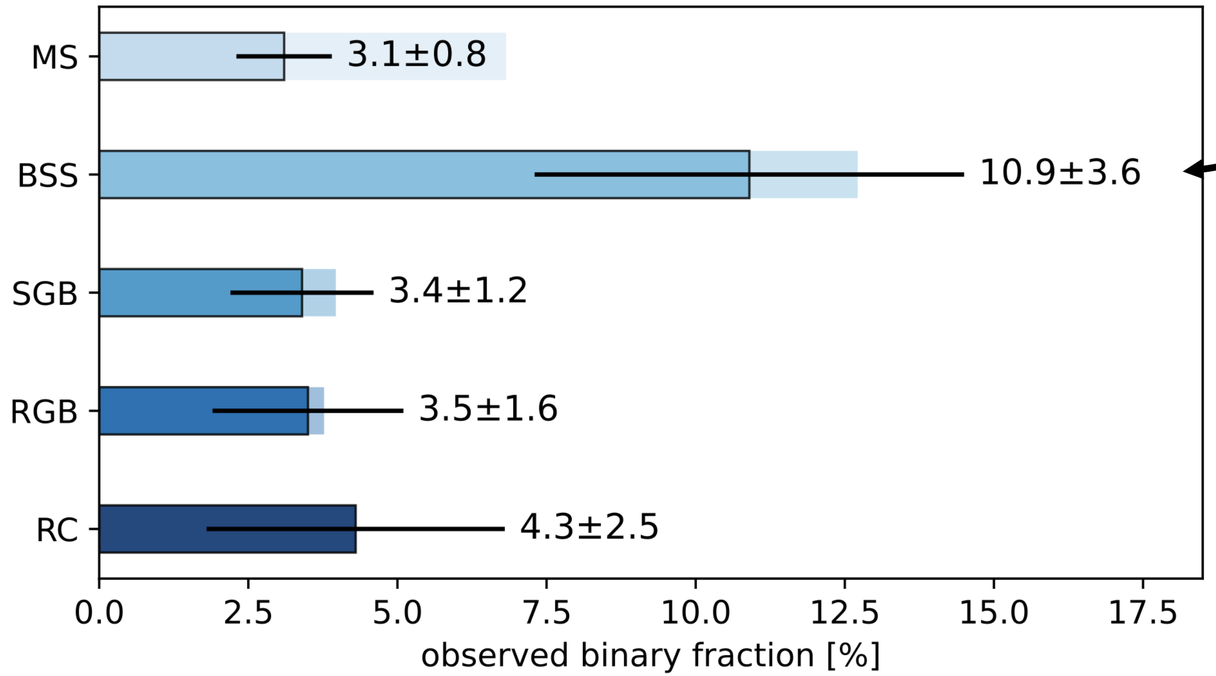




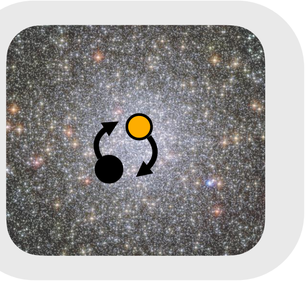
Peculiar objects

Blue straggler stars

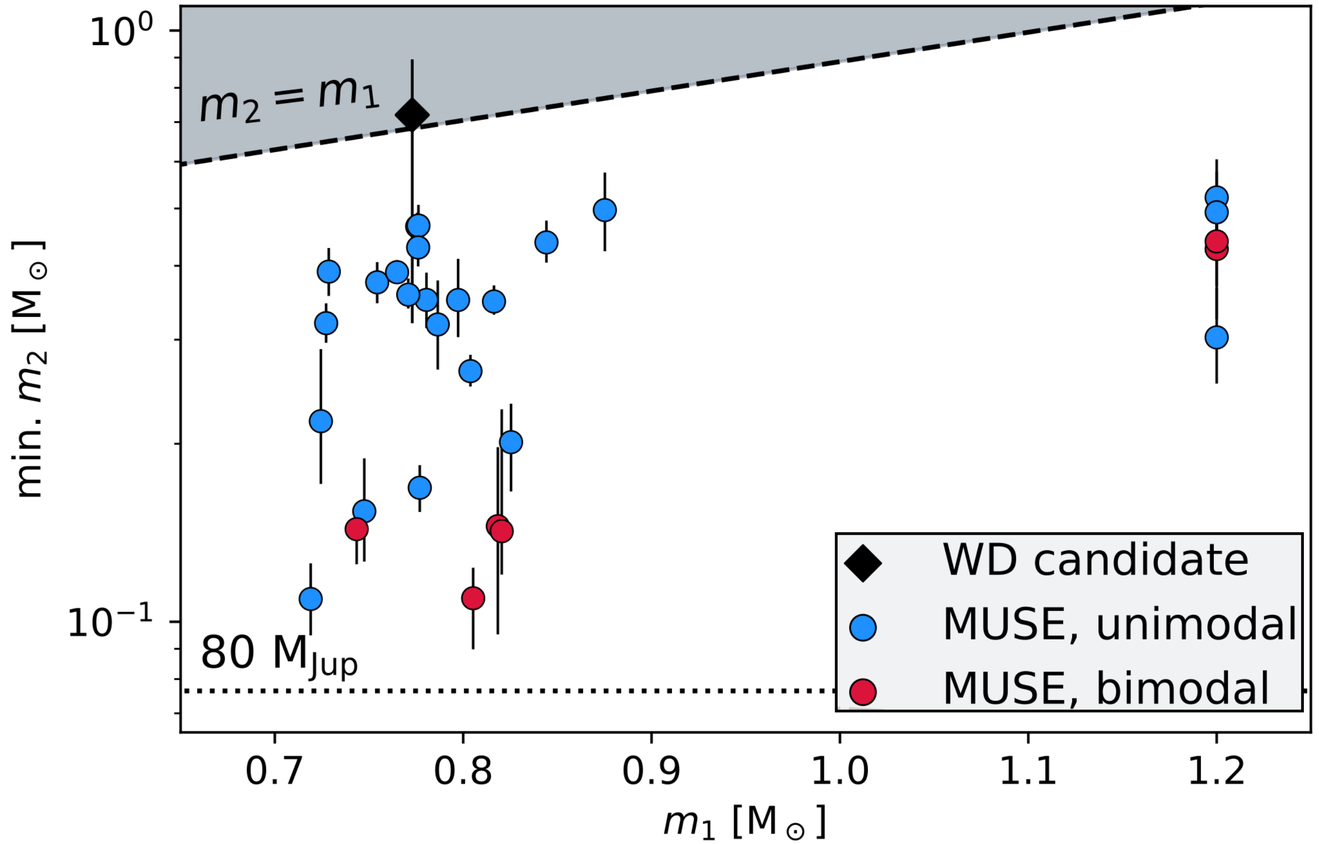
Binary fraction vs. stellar type



higher binary fraction among blue stragglers

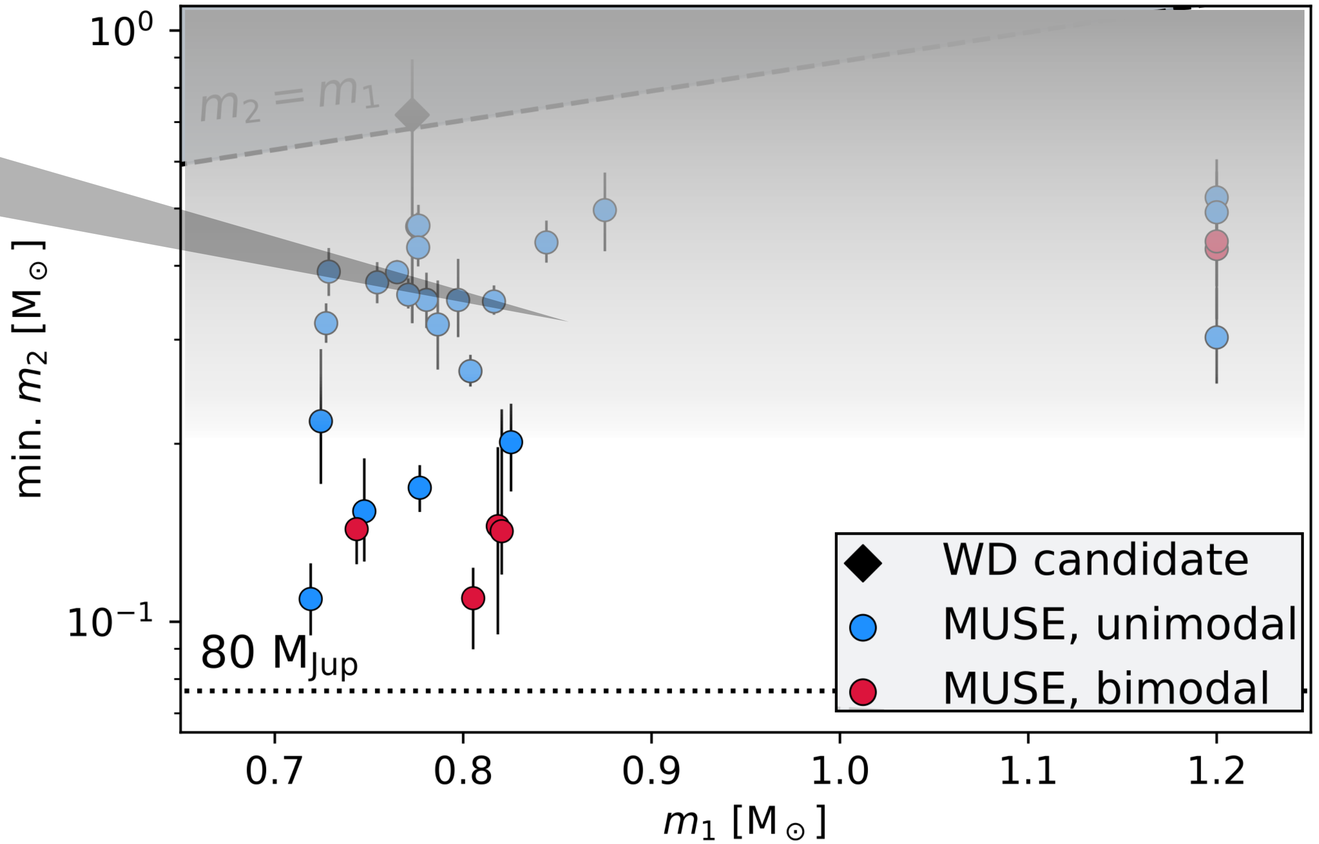


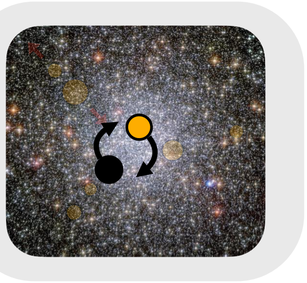
Dark remnant companions?



Dark remnant companions?

WDs

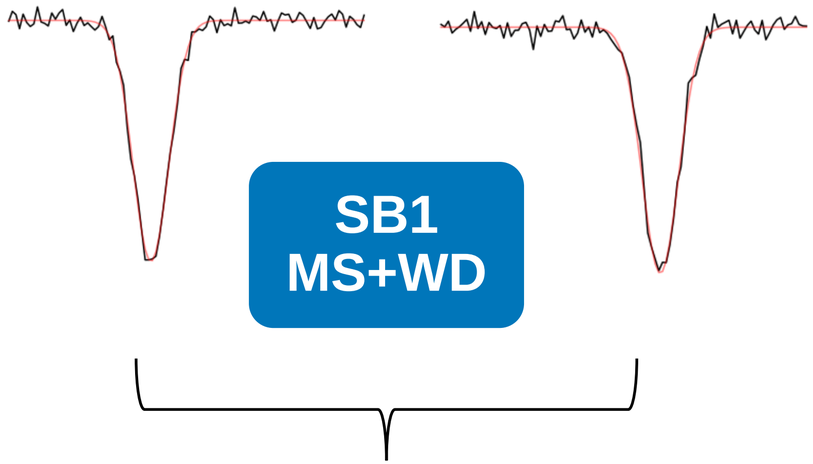




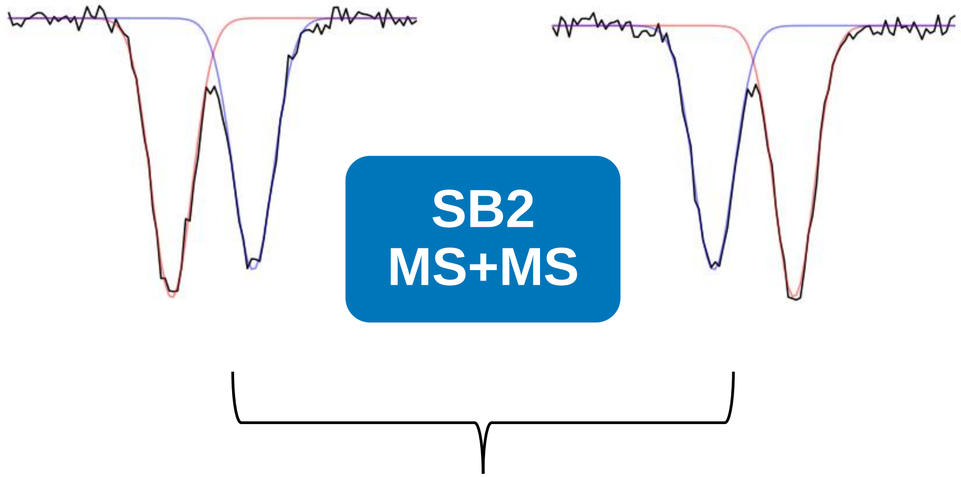
Spectroscopic binaries

High resolution spectra

Spectra

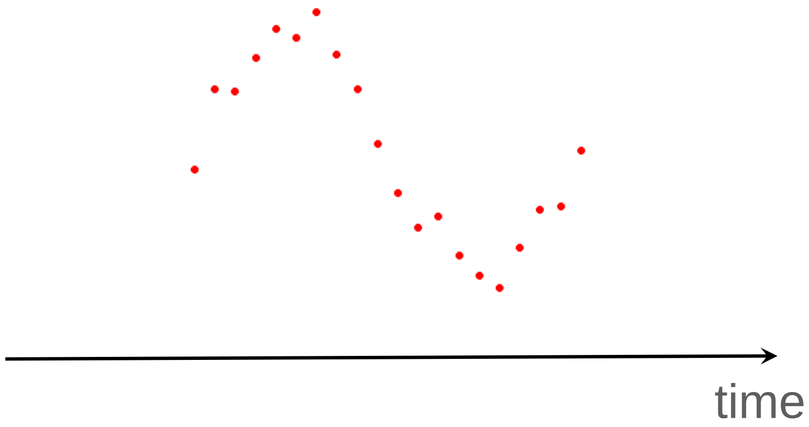


SB1
MS+WD

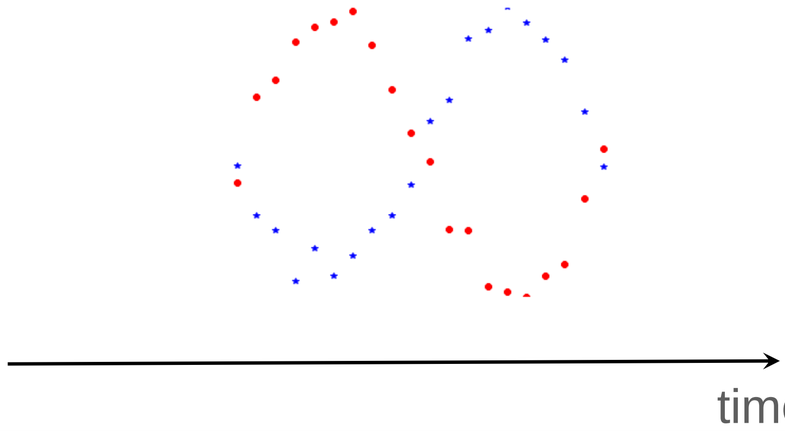


SB2
MS+MS

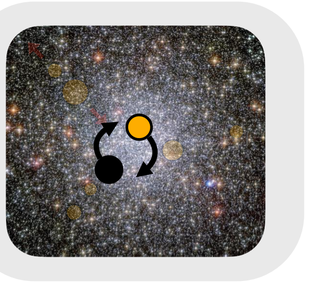
Radial Velocity



time



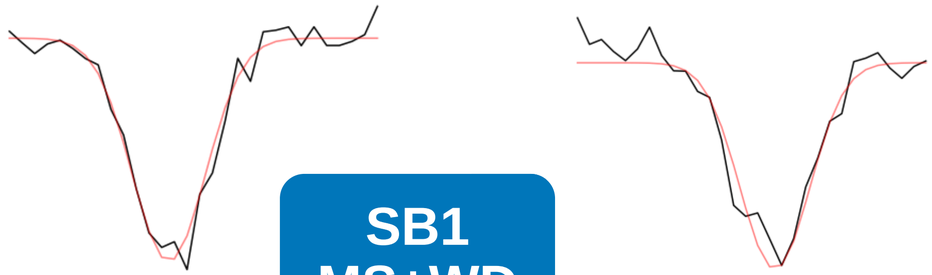
time



Spectroscopic binaries

Low resolution spectra (MUSE)

Spectra

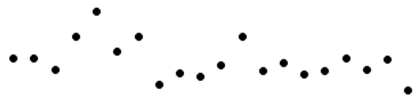


SB1
MS+WD

SB2
MS+MS

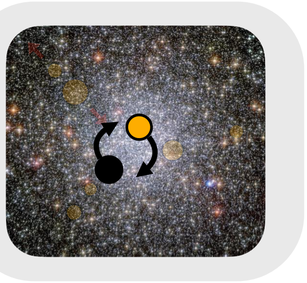
fully diluted RV

Radial Velocity



time

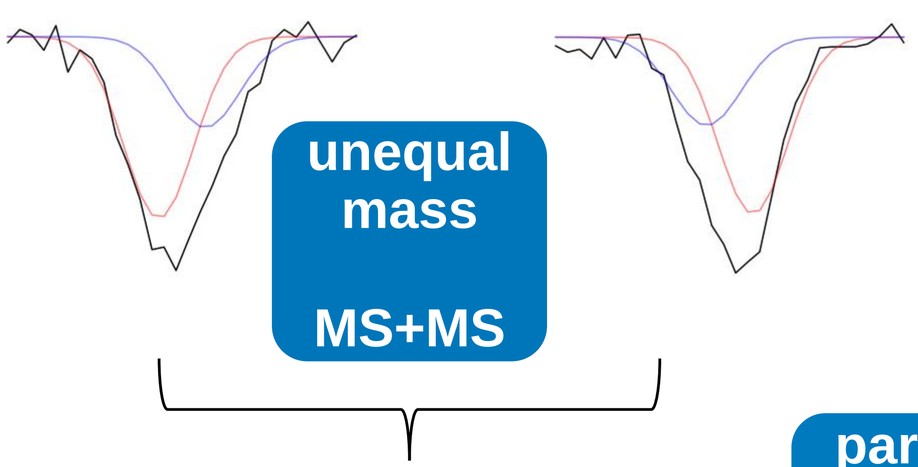
time



Spectroscopic binaries

RV dilution effect (Giesers et al. 2019)

Spectra



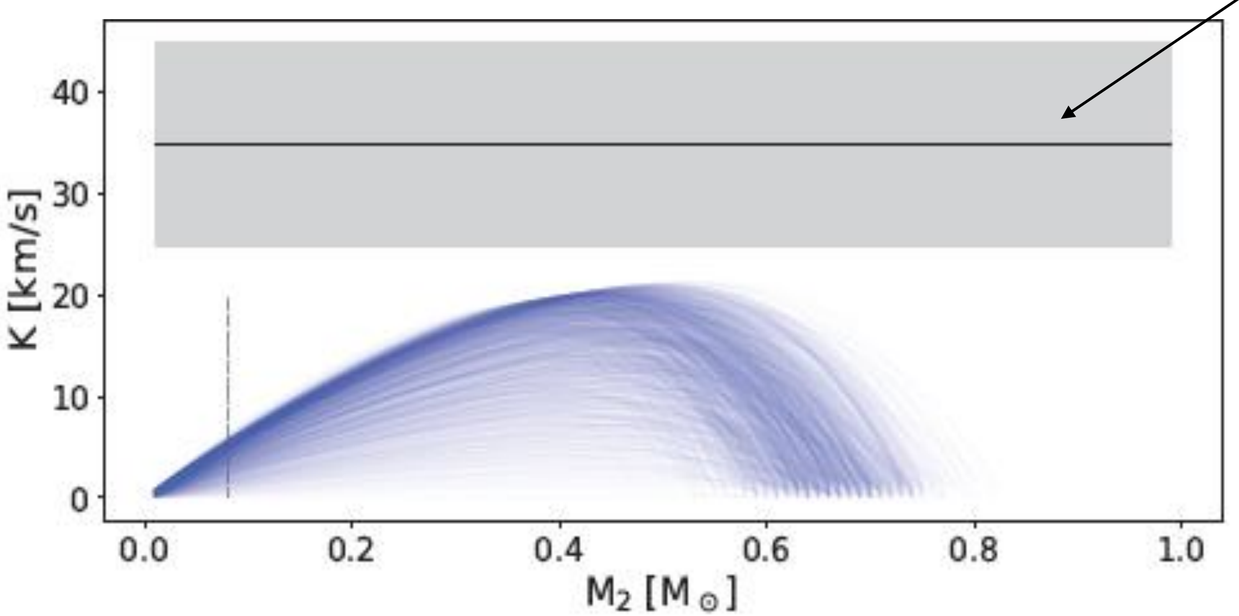
Radial Velocity

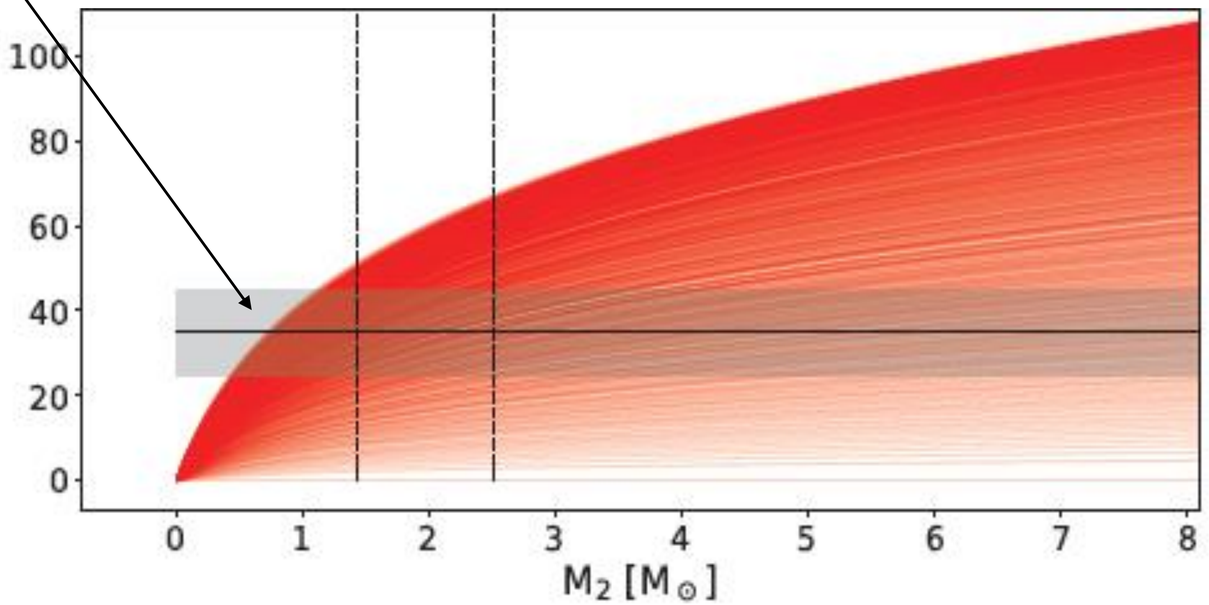
MS+WD in NGC3201

MS+MS

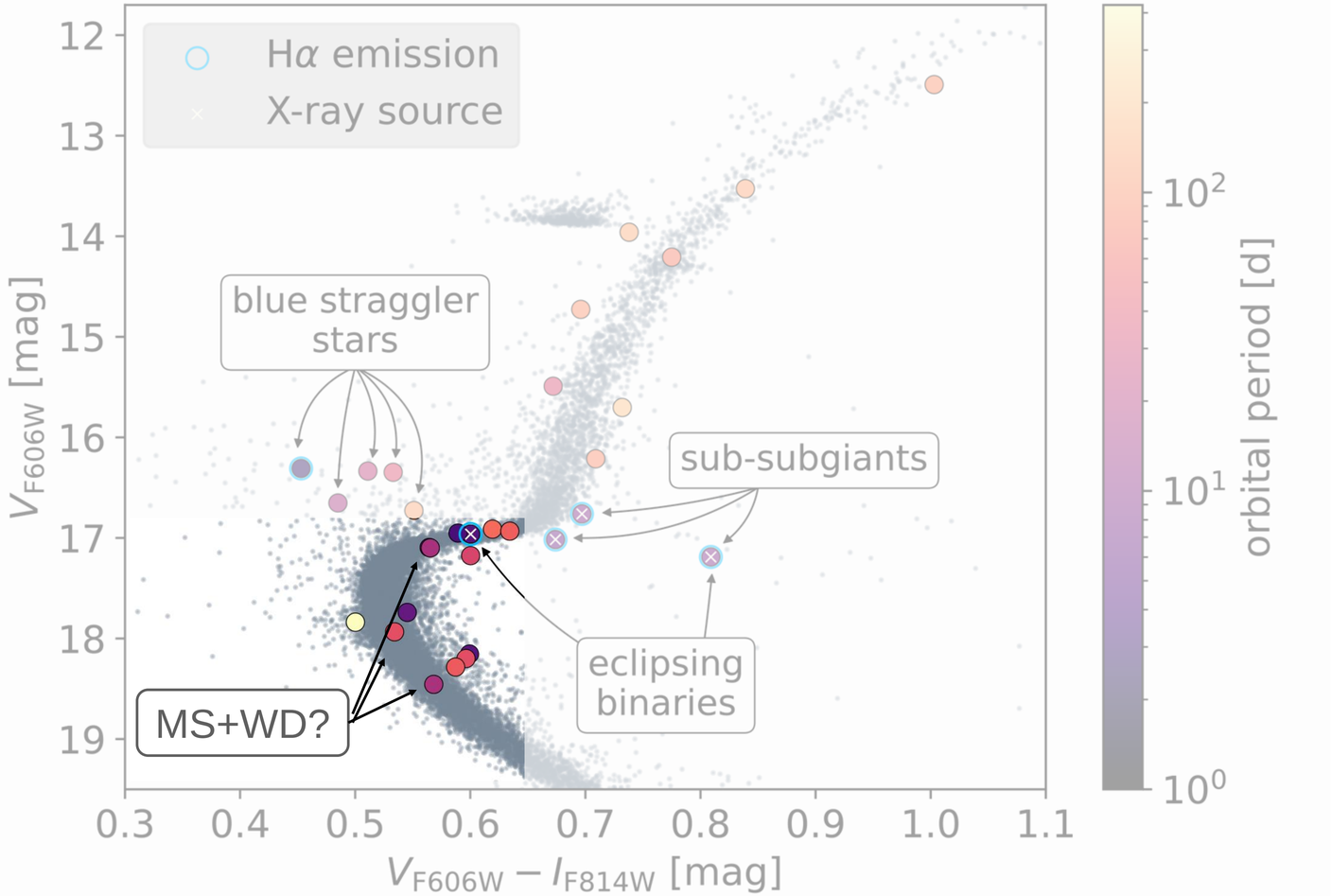
observed RV

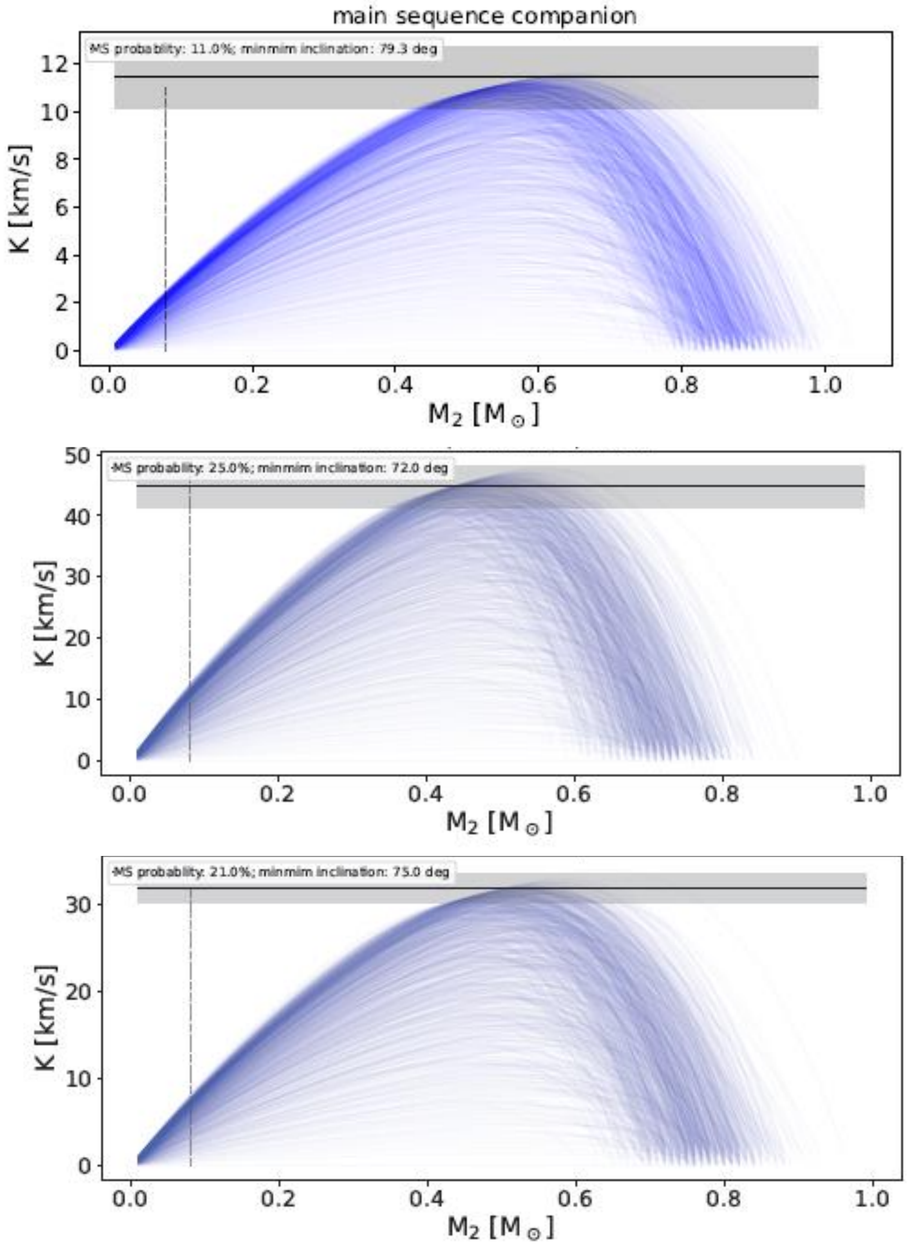
MS+dark companion



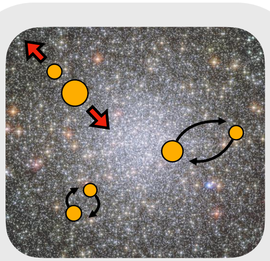


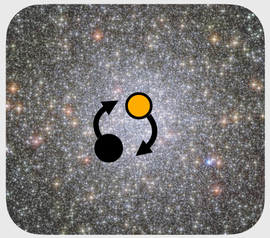
Application to NGC104

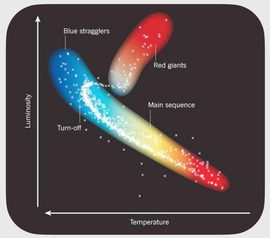




Summary



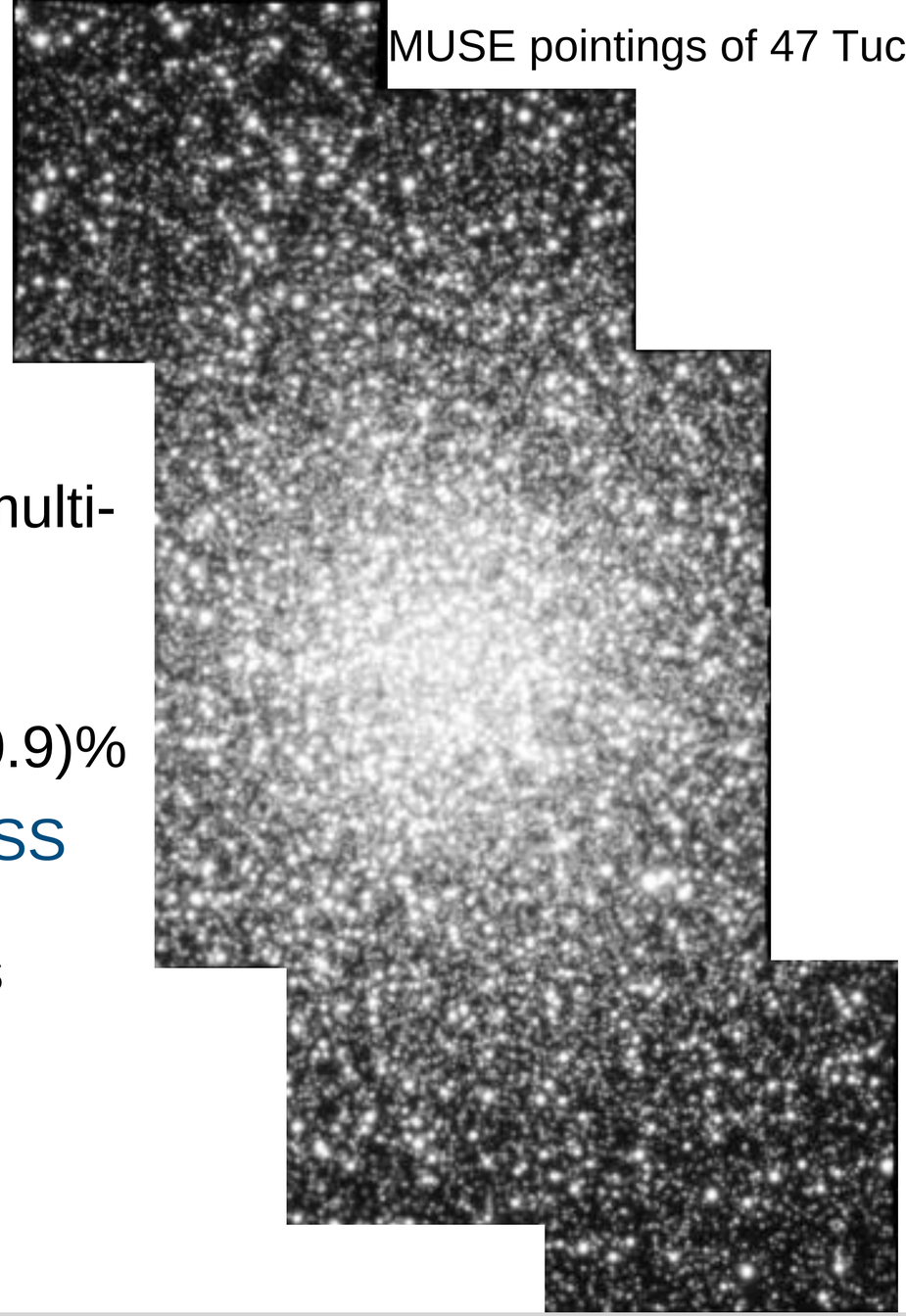


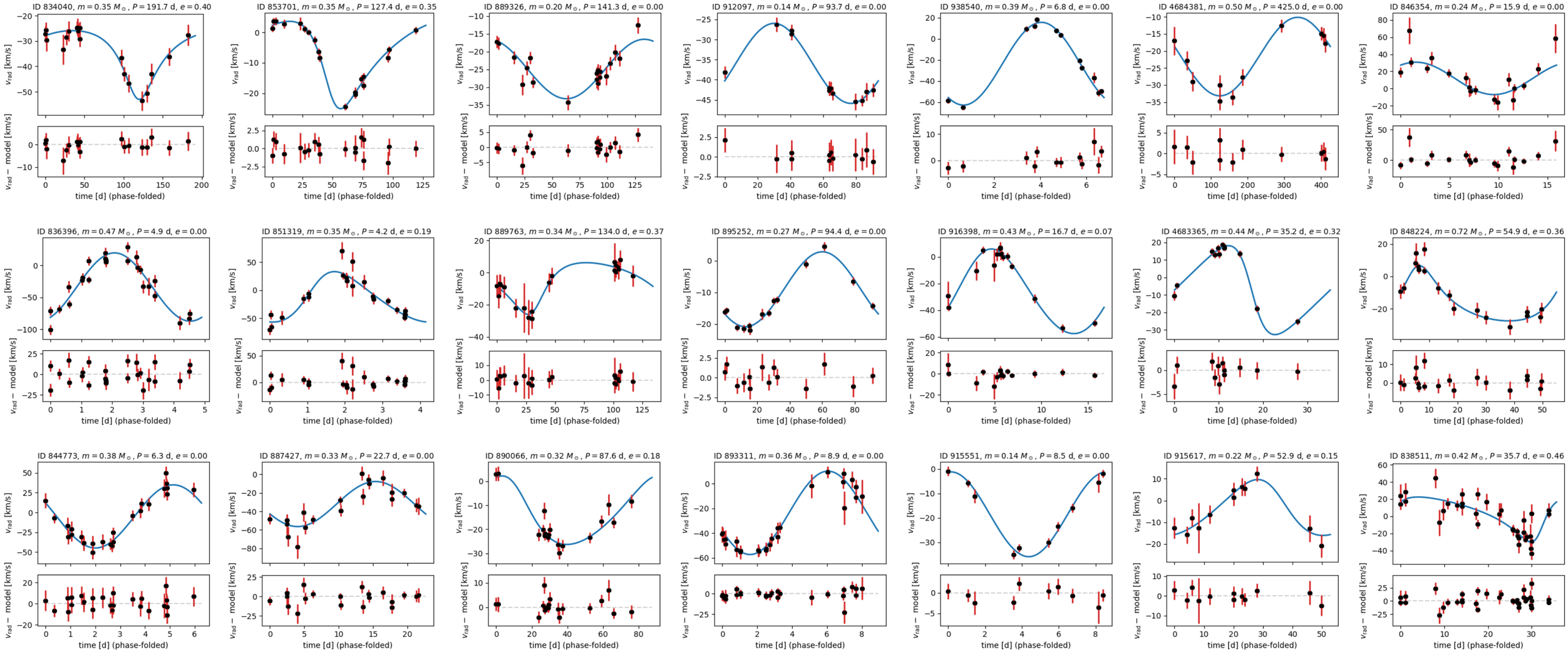


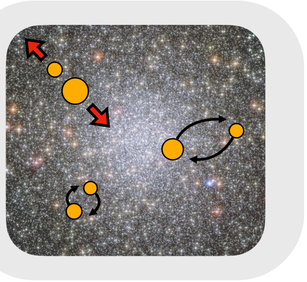
→ study binary population of 47 Tuc using multi-epoch spectroscopy from MUSE

→ determine total binary fraction of (2.4 ± 0.9)% and increased binary fraction among BSS

→ comparison with CMC simulations reveals dearth of short-period binaries and lack of binaries with massive/dark companions

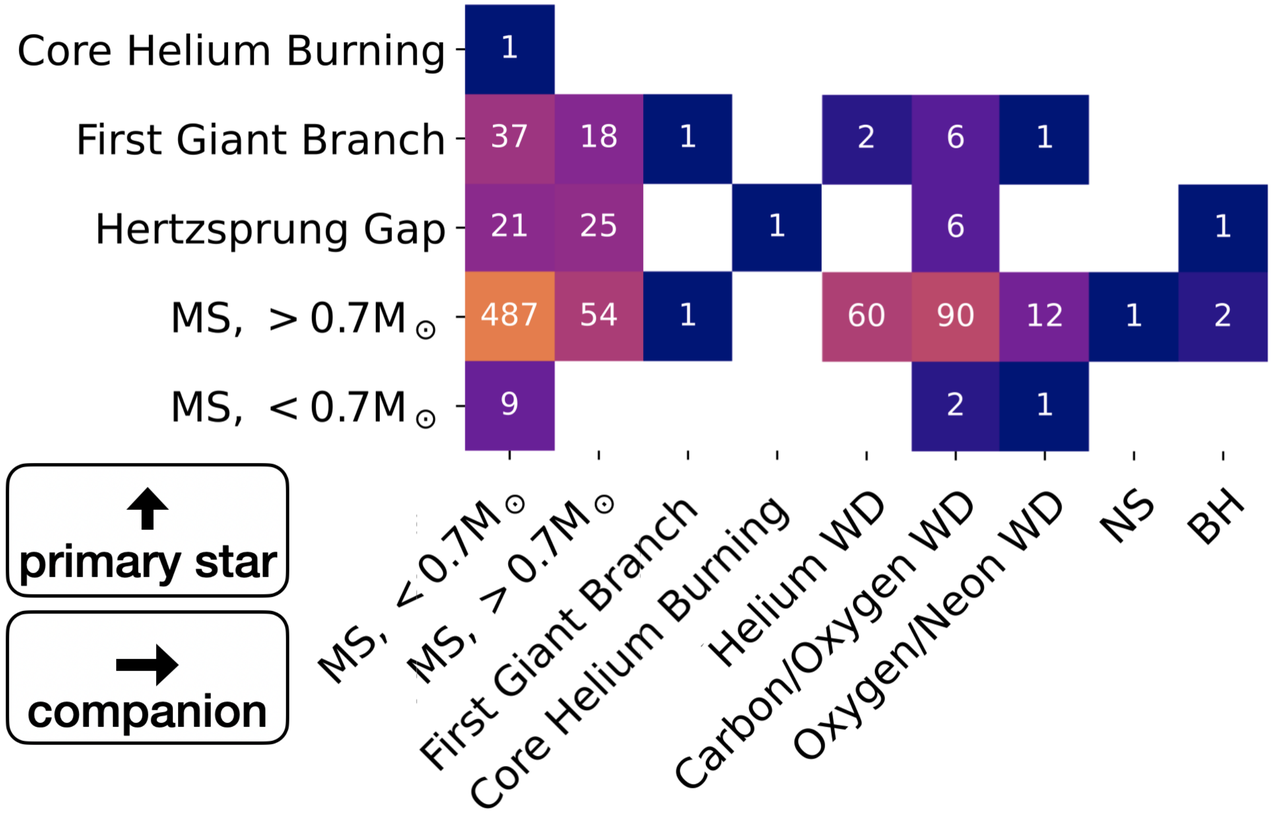

MUSE pointings of 47 Tuc


ID 834040, $m = 0.35\ M_\odot$, $P = 191.7$ d, $e = 0.40$
ID 853701, $m = 0.35\ M_\odot$, $P = 127.4$ d, $e = 0.35$
ID 889326, $m = 0.20\ M_\odot$, $P = 141.3$ d, $e = 0.00$
ID 912097, $m = 0.14\ M_\odot$, $P = 93.7$ d, $e = 0.00$
ID 938540, $m = 0.39\ M_\odot$, $P = 6.8$ d, $e = 0.00$
ID 4684381, $m = 0.50\ M_\odot$, $P = 425.0$ d, $e = 0.00$
ID 846354, $m = 0.24\ M_\odot$, $P = 15.9$ d, $e = 0.00$
ID 836396, $m = 0.47\ M_\odot$, $P = 4.9$ d, $e = 0.00$
ID 851319, $m = 0.35\ M_\odot$, $P = 4.2$ d, $e = 0.19$
ID 889763, $m = 0.34\ M_\odot$, $P = 134.0$ d, $e = 0.37$
ID 895252, $m = 0.27\ M_\odot$, $P = 94.4$ d, $e = 0.00$
ID 916398, $m = 0.43\ M_\odot$, $P = 16.7$ d, $e = 0.07$
ID 4683365, $m = 0.44\ M_\odot$, $P = 35.2$ d, $e = 0.32$
ID 848224, $m = 0.72\ M_\odot$, $P = 54.9$ d, $e = 0.36$
ID 844773, $m = 0.38\ M_\odot$, $P = 6.3$ d, $e = 0.00$
ID 887427, $m = 0.33\ M_\odot$, $P = 22.7$ d, $e = 0.00$
ID 890066, $m = 0.32\ M_\odot$, $P = 87.6$ d, $e = 0.18$
ID 893311, $m = 0.36\ M_\odot$, $P = 8.9$ d, $e = 0.00$
ID 915551, $m = 0.14\ M_\odot$, $P = 8.5$ d, $e = 0.00$
ID 915617, $m = 0.22\ M_\odot$, $P = 52.9$ d, $e = 0.15$
ID 838511, $m = 0.42\ M_\odot$, $P = 35.7$ d, $e = 0.46$
v_{rad} [km/s]
v_{rad} − model [km/s]
time [d] (phase-folded)



Binary demographics

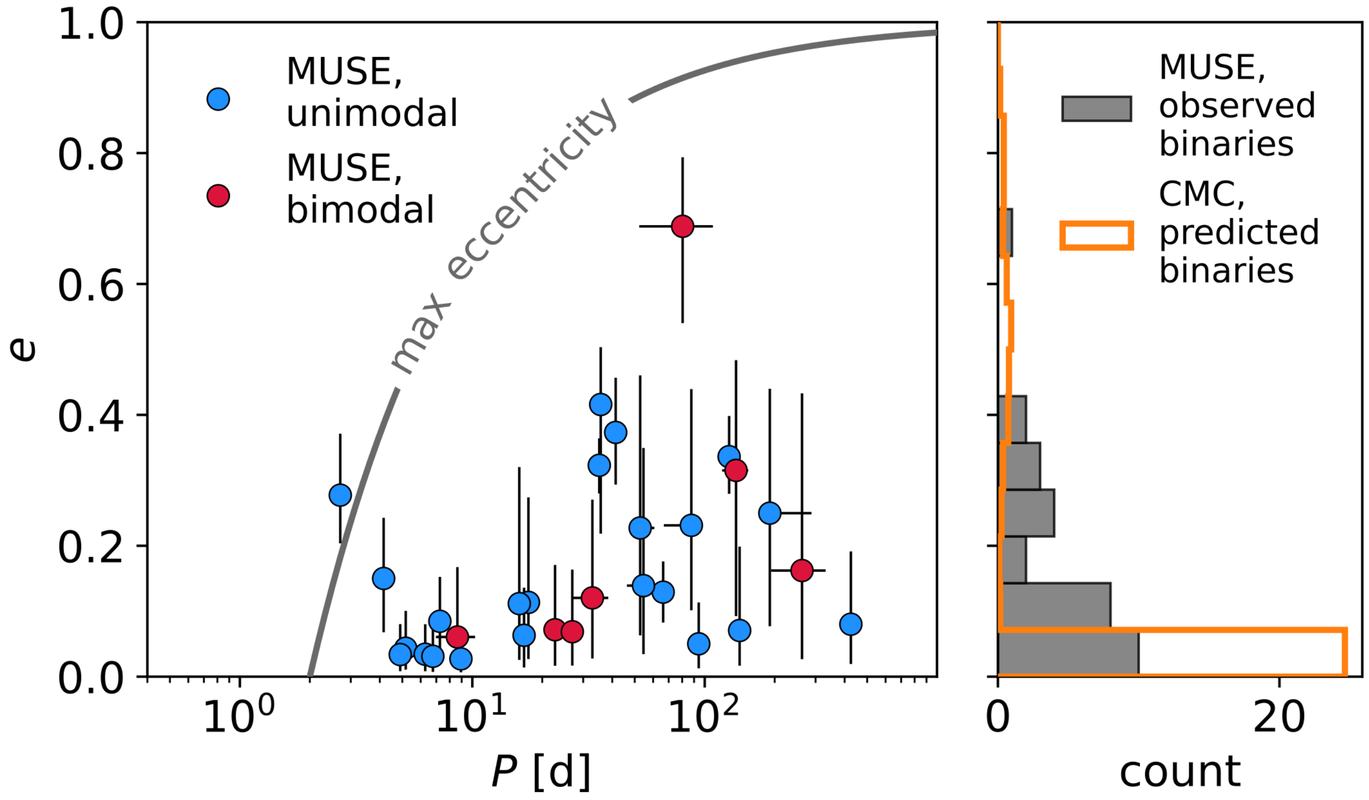
CMC simulations



Binary demographics

Orbital parameters

47 Tuc



NGC 3201

Giesers et al. (2019)