Open Clusters:

At The Interface of

Stellar Evolution

and Stellar Dynamics

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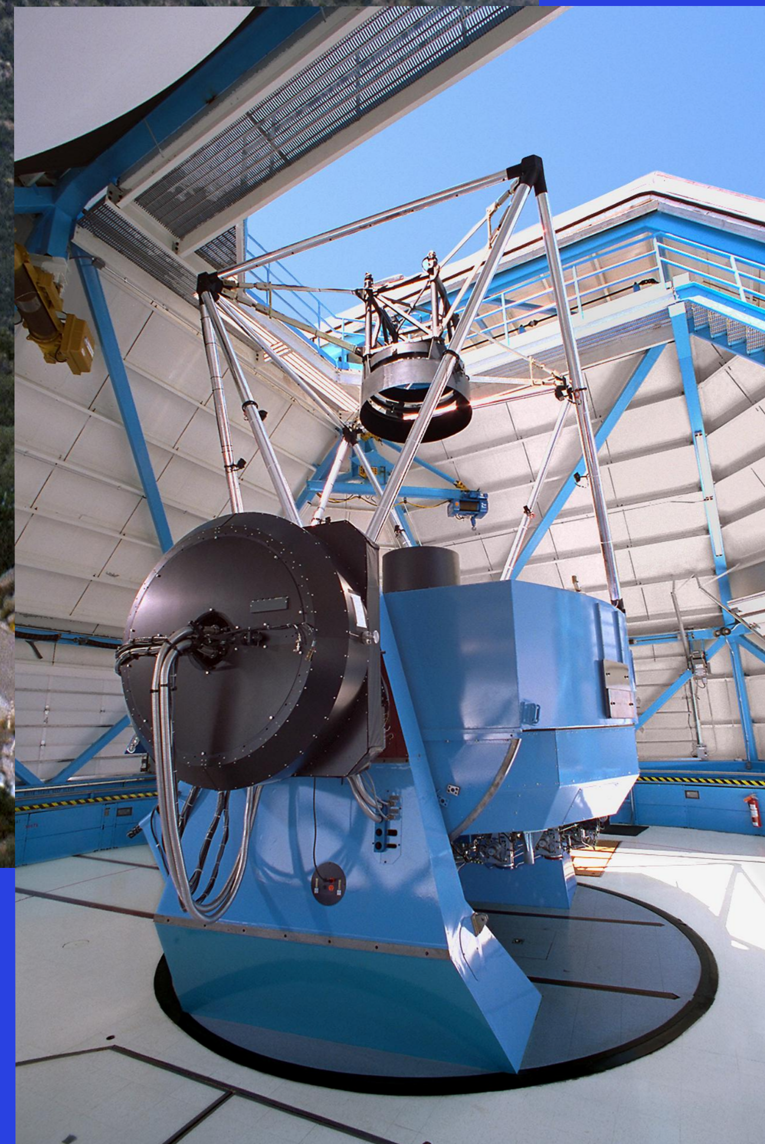
The Open Star Cluster NGC 188 (7 Gyr)

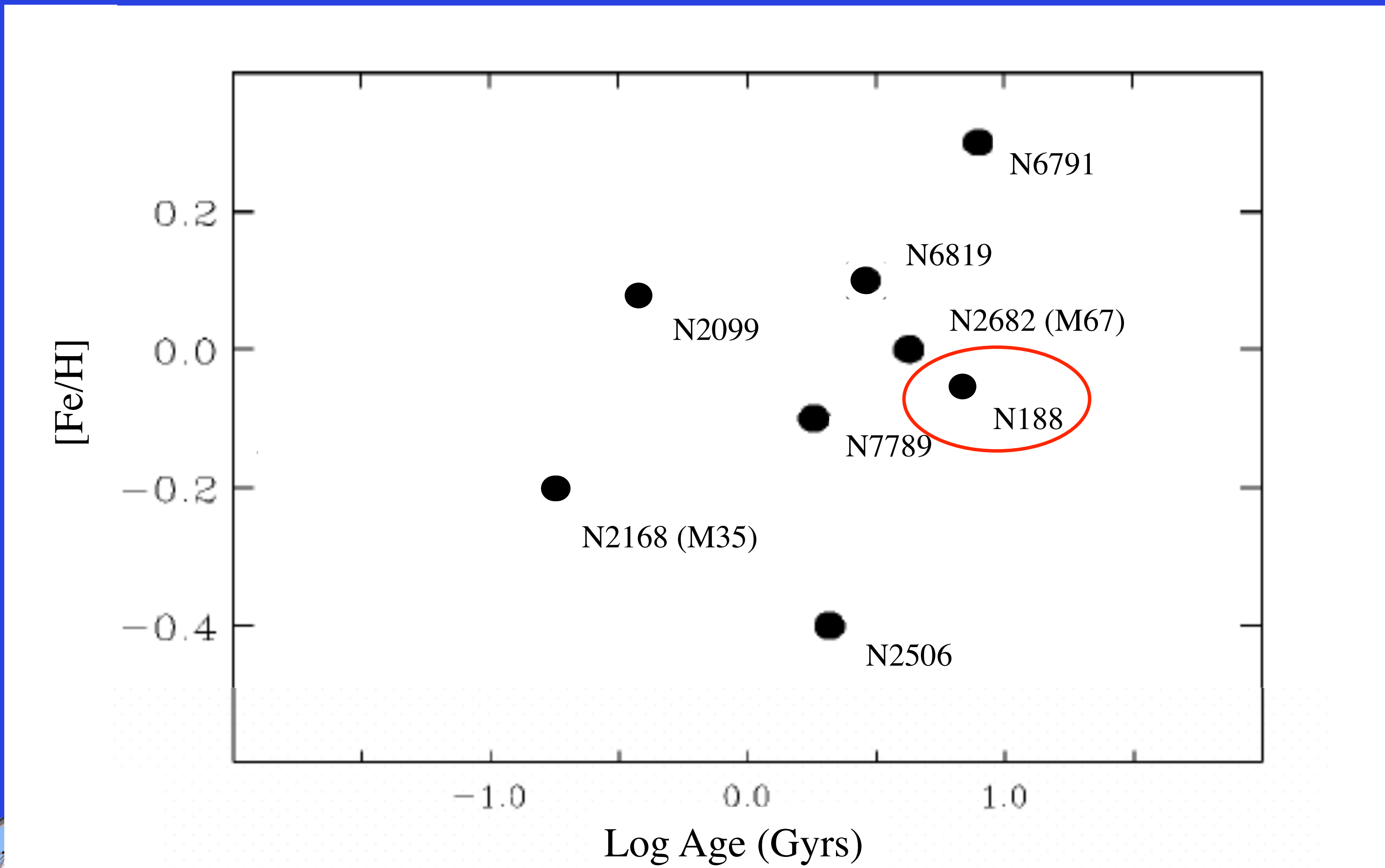
Aaron Geller

David Latham



WIYN Open Cluster Study

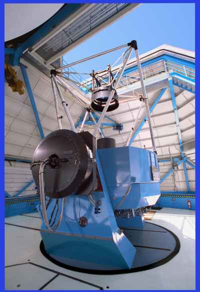
WIYN Open Cluster Study

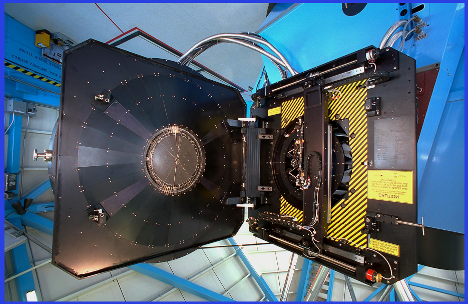


Stellar Radial Velocities

- ***NGC 188*** **(7 Gyr)**
  - **1197 stars** **($0.8\ M_o < M_* < 1.2\ M_o$) ($V < 16.5$, $B\text{-}V > 0.4$)**
  - **10,101 measurements** **($\sigma = 0.4$ km s^{-1})**
  - **132 binaries** **($P < 3000^d$)**

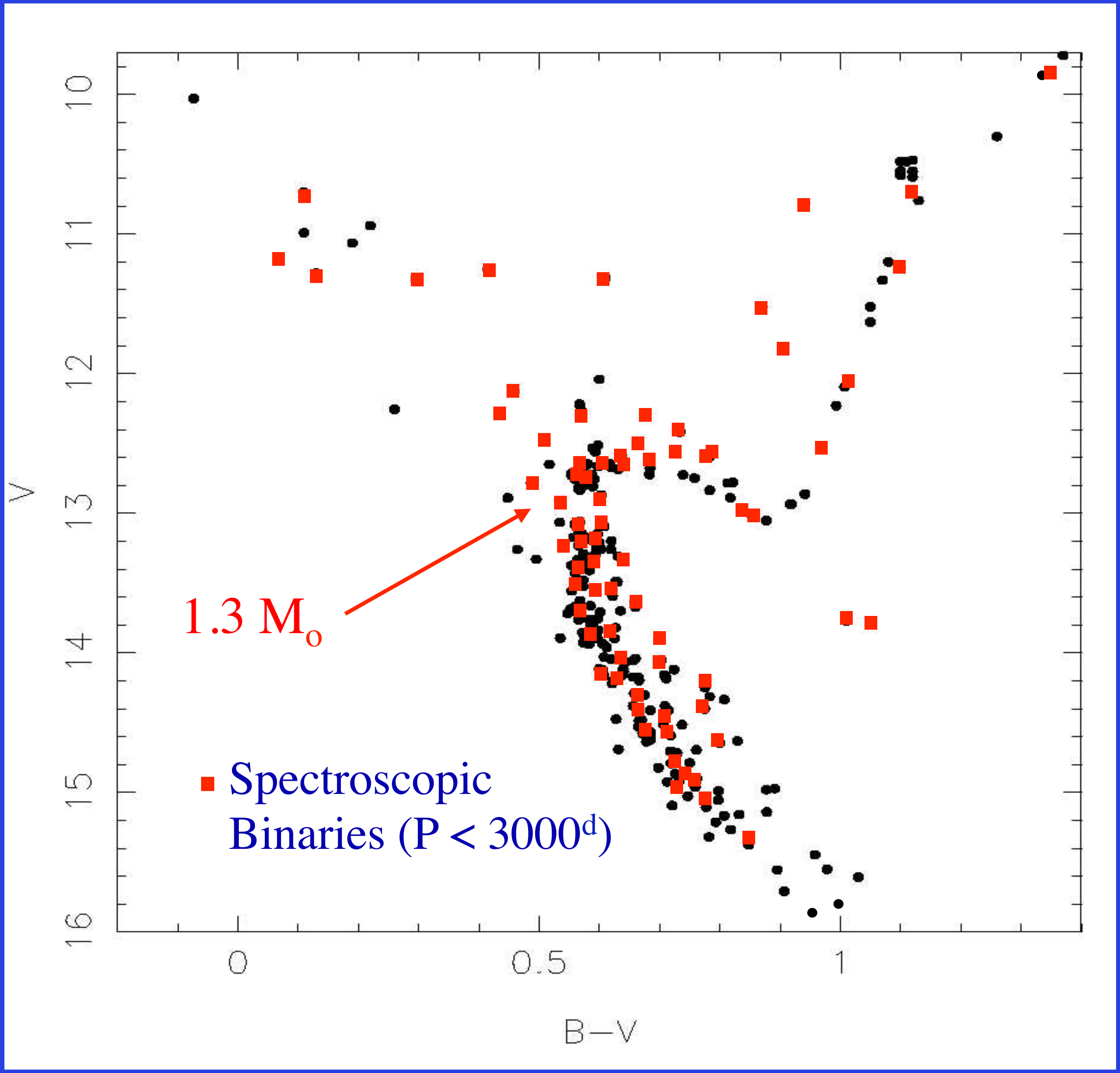
- ***NGC 2168 (M35)*** **(0.15 Gyr)**
  - **1690 stars**
  - **8323 measurements**
  - **102 binaries**
  - **For N-body initial conditions**





M67

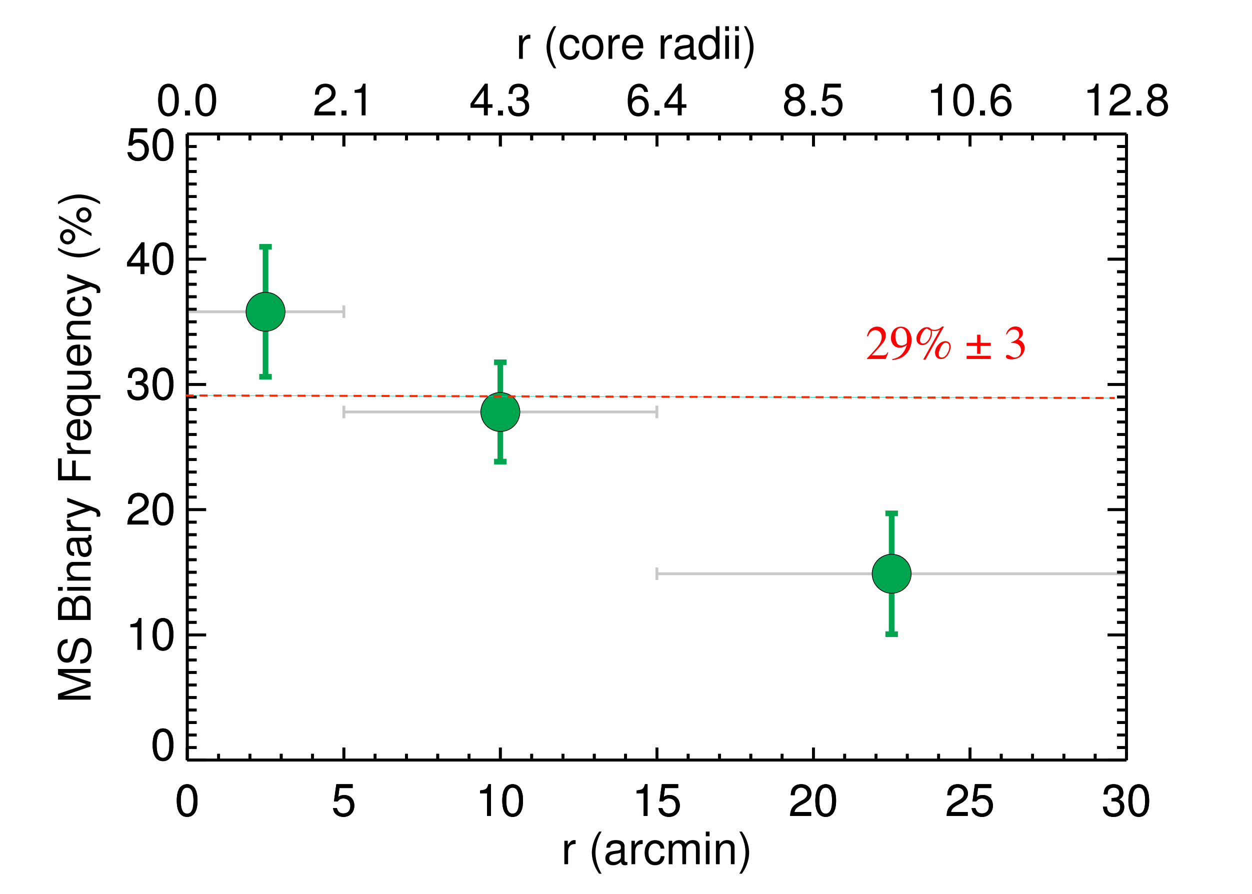
4.5 Gyr



V
10
11
12
13
14
15
16
0
0.5
1
B−V
1.3 M$_o$
Spectroscopic Binaries (P < 3000^d)

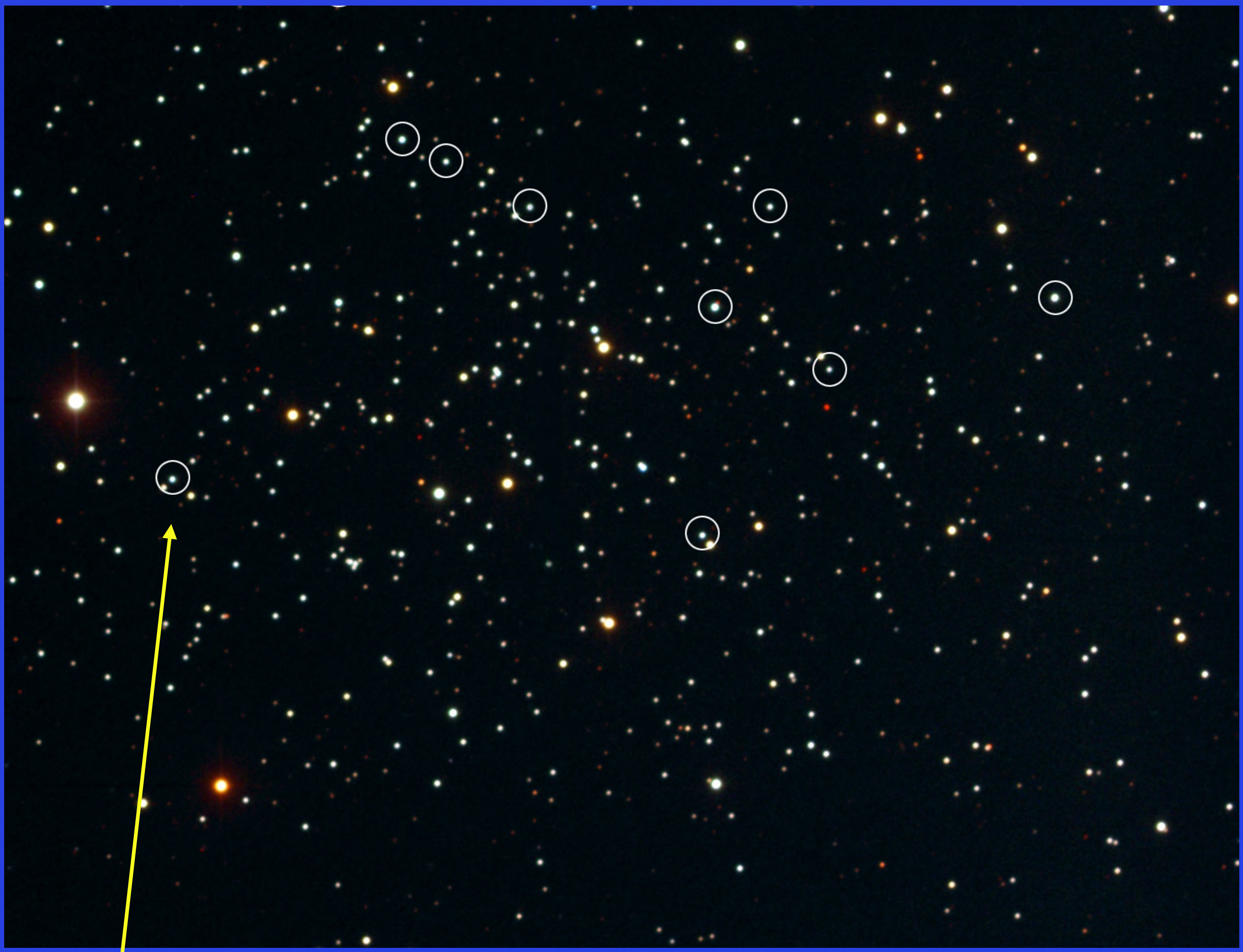
(Hard) Binary Frequency

NGC 188 (7 Gyr)



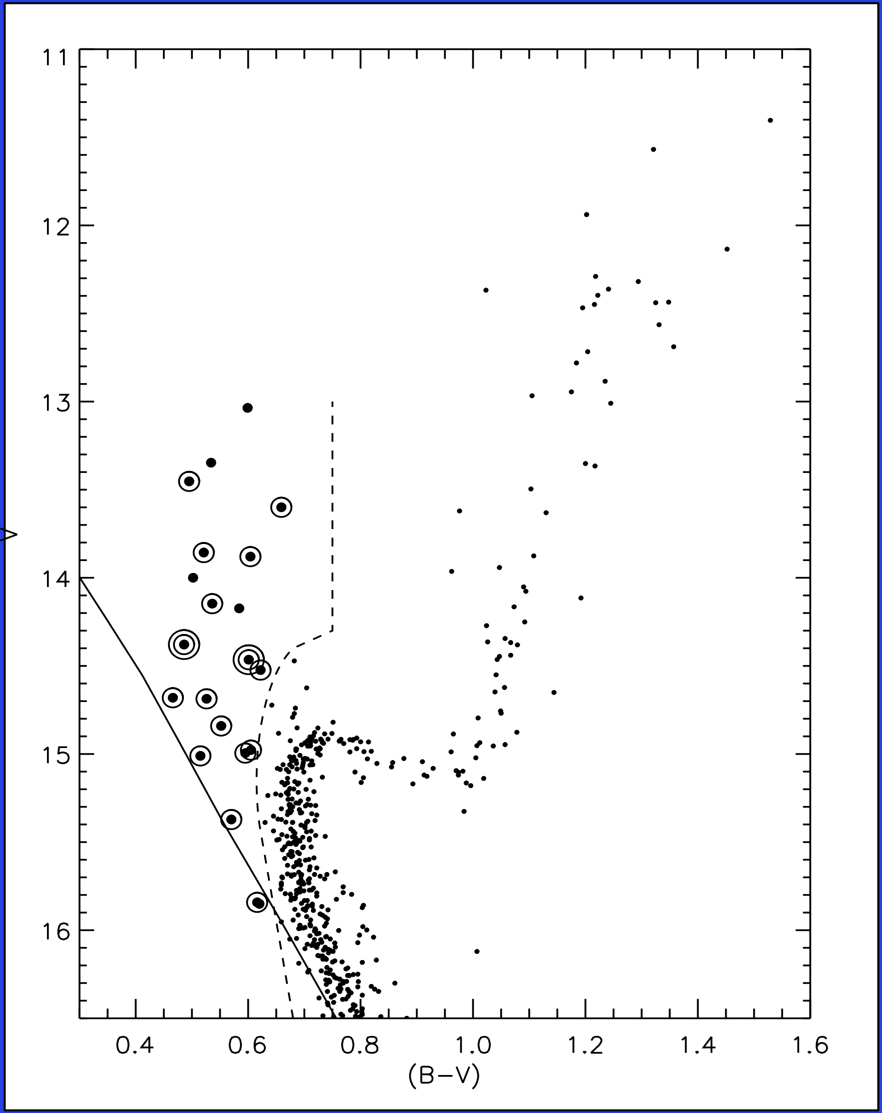
P < 10^4 days

The Open Star Cluster NGC 188 (7 Gyr)



Blue Stragglers

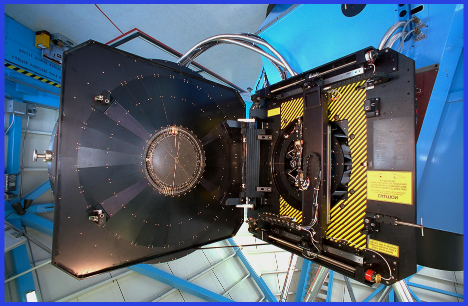
NGC 188 Blue Stragglers



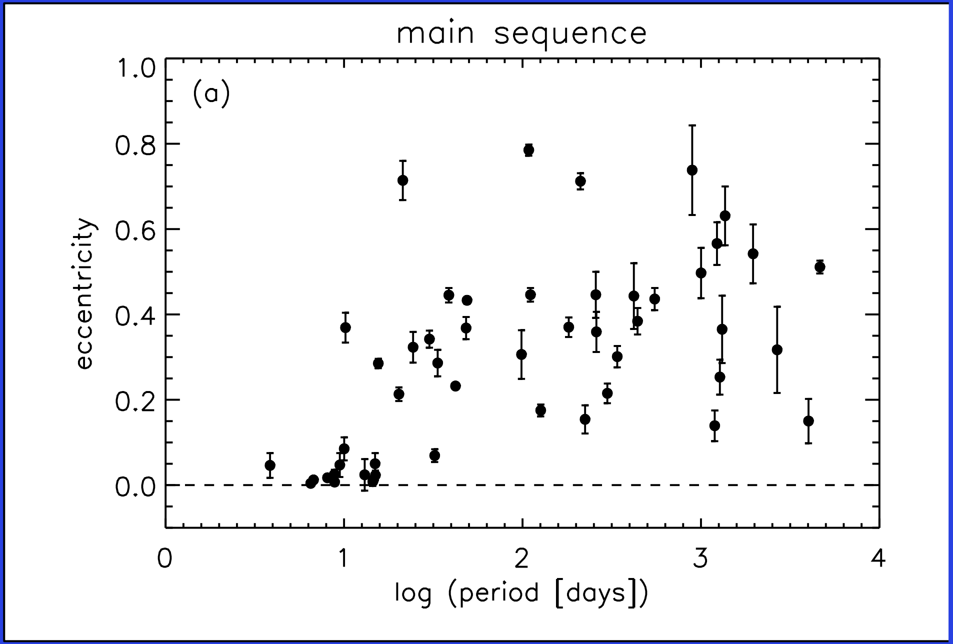
Binary Frequency
76% ± 21%

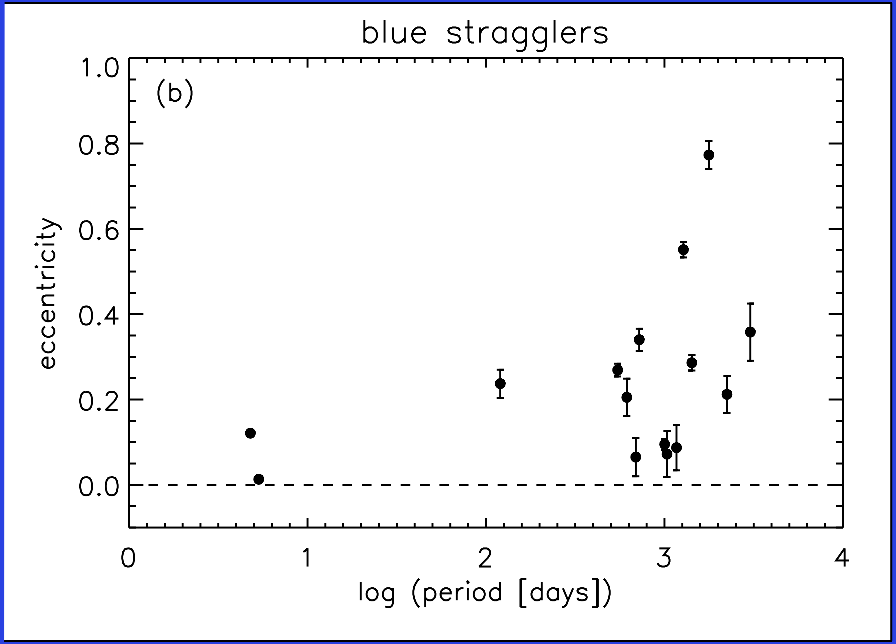
Main Sequence
29% ± 3

Mathieu & Geller 2009

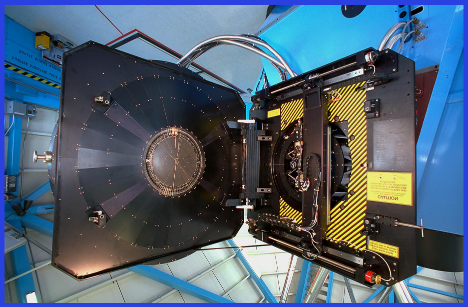


NGC 188 Blue Stragglers

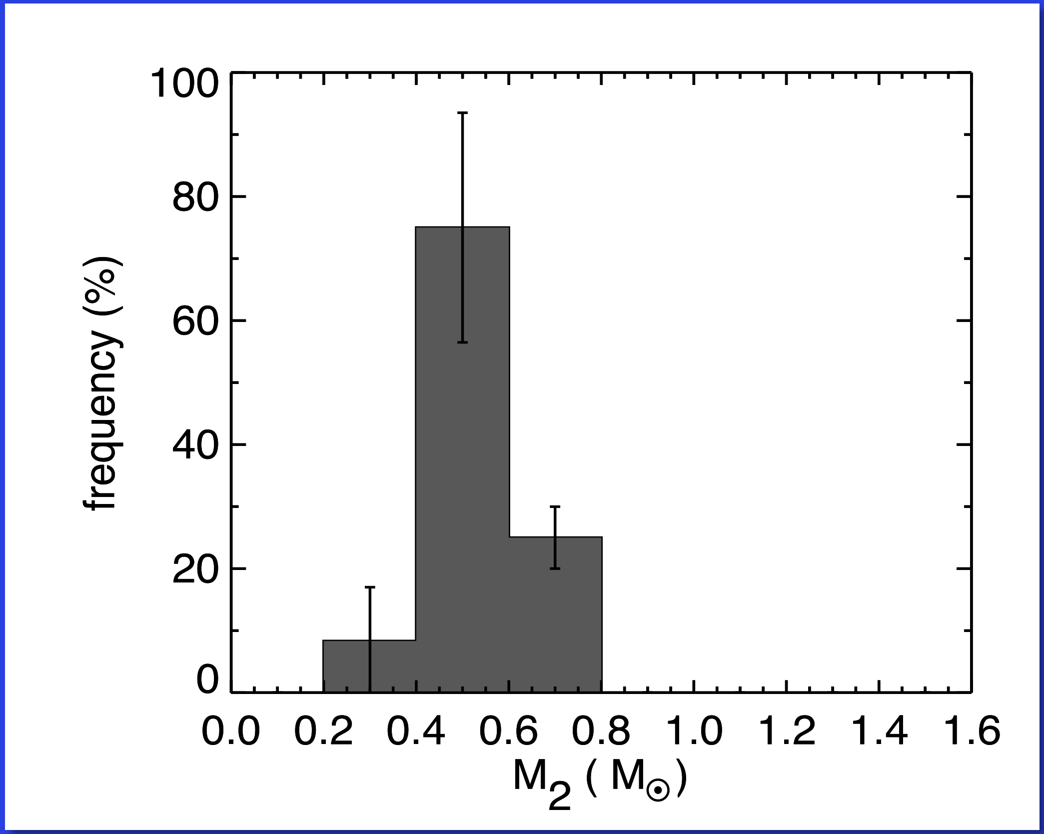




Eccentricity - Period Distribution

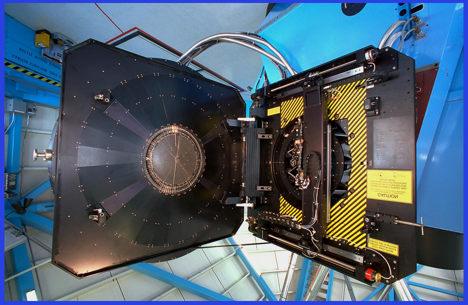


NGC 188 Blue Stragglers

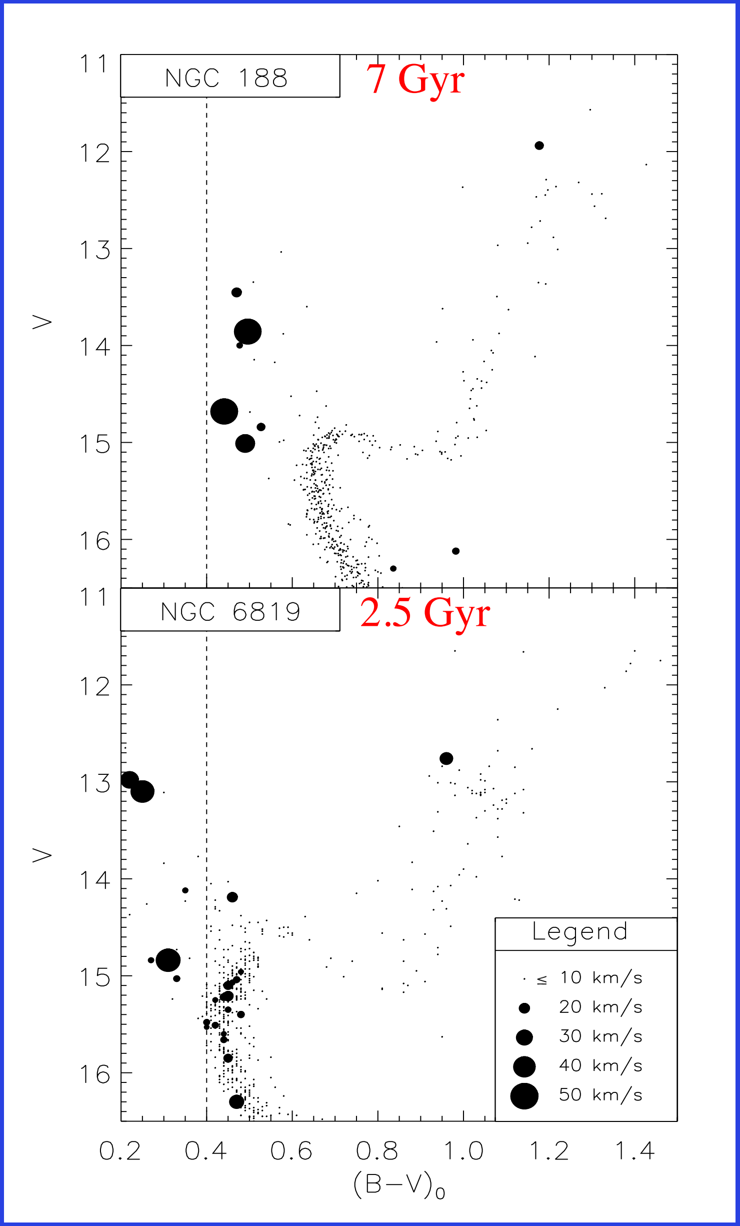


Geller & Mathieu 2011

Secondary Mass Distribution

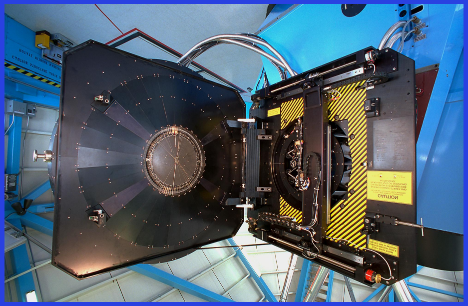


NGC 188 Blue Stragglers

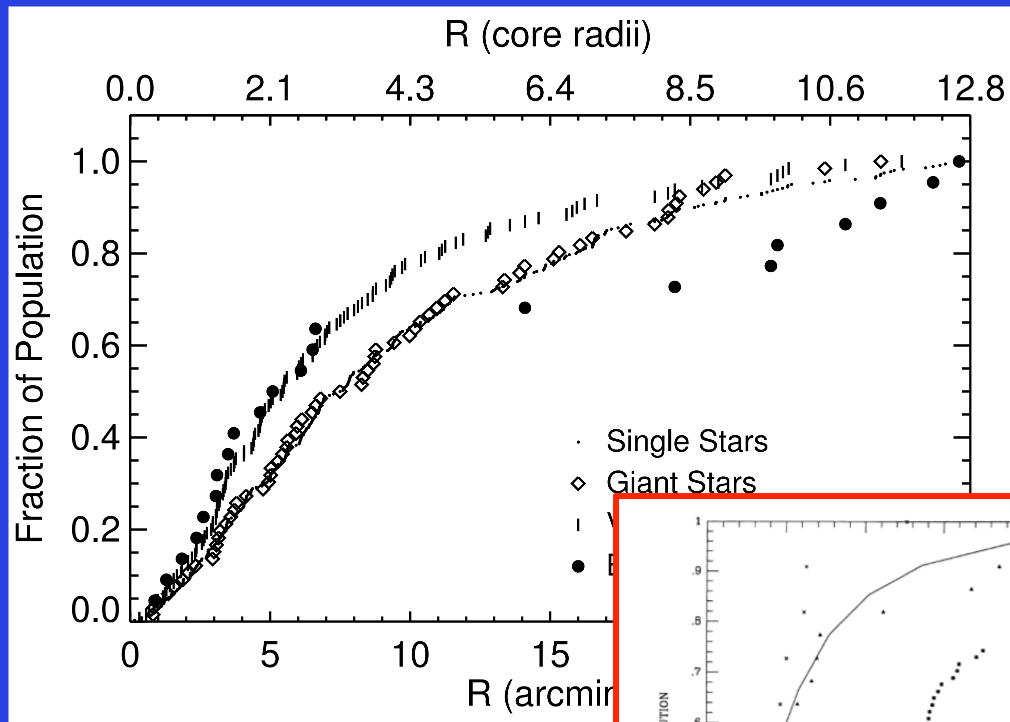


Rotation (vsin i) Distribution

Geller & Mathieu 2011



NGC 188 Blue Stragglers



Geller et al. 2008

Spatial Distrib

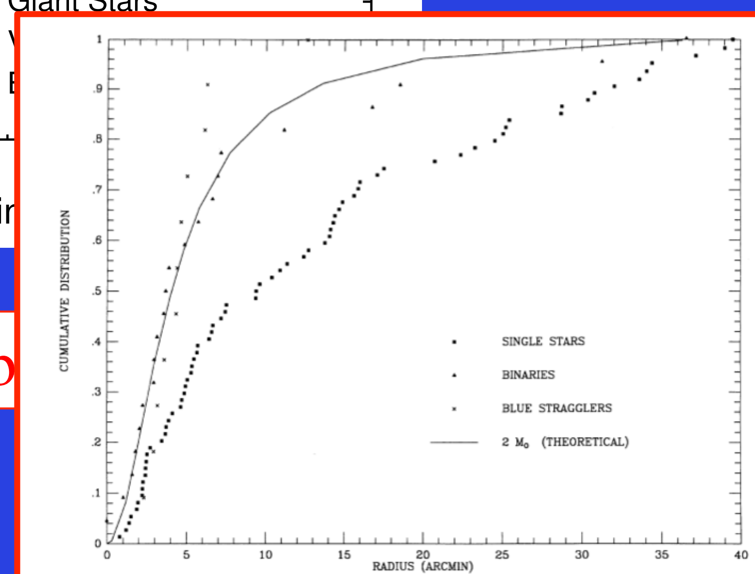


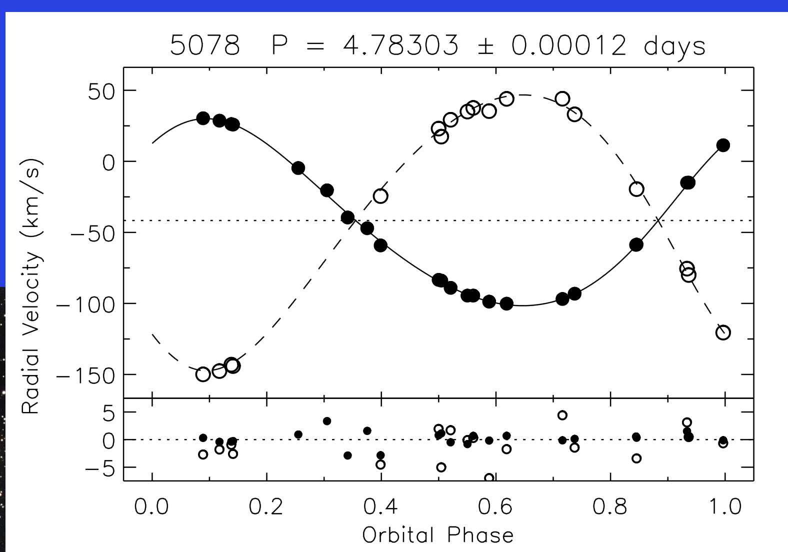
FIG. 2. Cumulative radial distribution of single stars, spectroscopic binaries, and blue stragglers in M67. The theoretical curve is derived from a multimass isotropic equipartition King model fit to the cluster stellar spatial distribution.

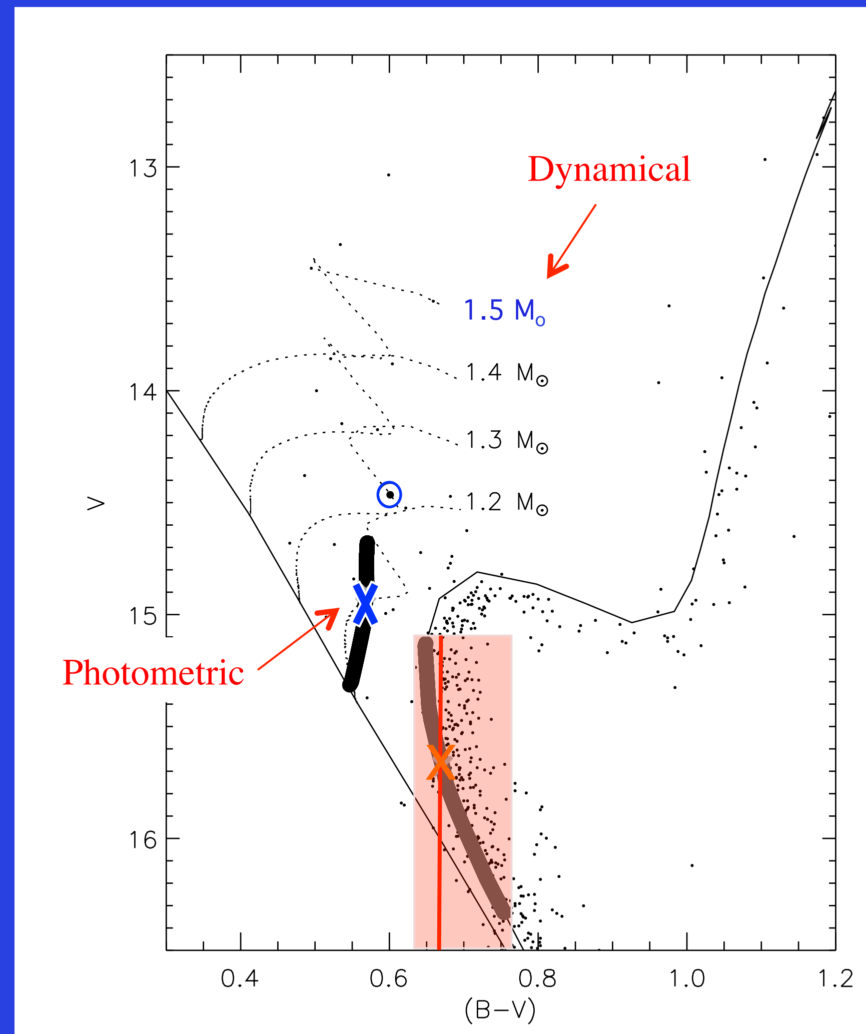
Mathieu & Latham 1986

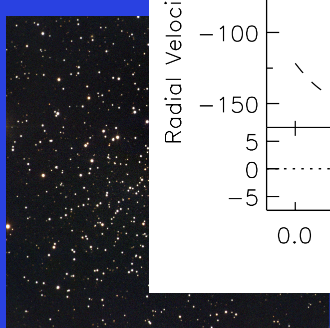
NGC 188 Blue Stragglers

Blue Straggler Mass

- Secondary $T_{eff} \Rightarrow M_2 \approx 1\ M_\odot$
- $q = 0.68 \Rightarrow M_1 \approx 1.5\ M_\odot$
- But L and $T_{eff} \Rightarrow M_1 \approx 1.2\ M_\odot$

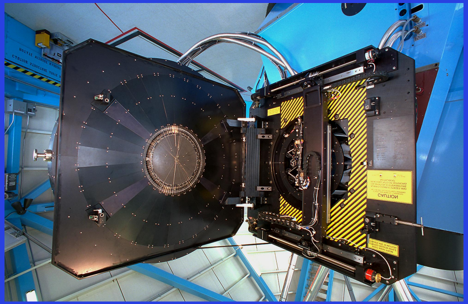




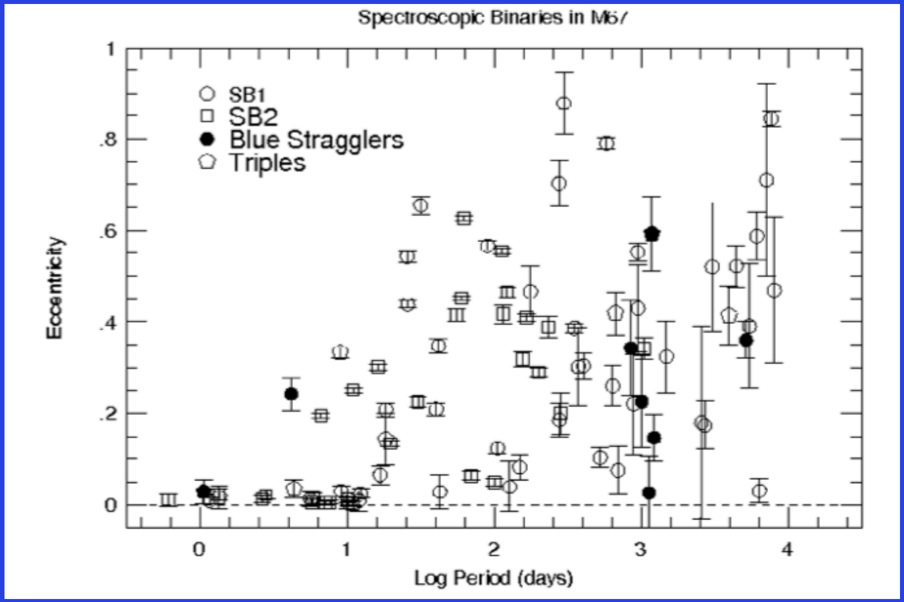


NGC 188 Blue Stragglers

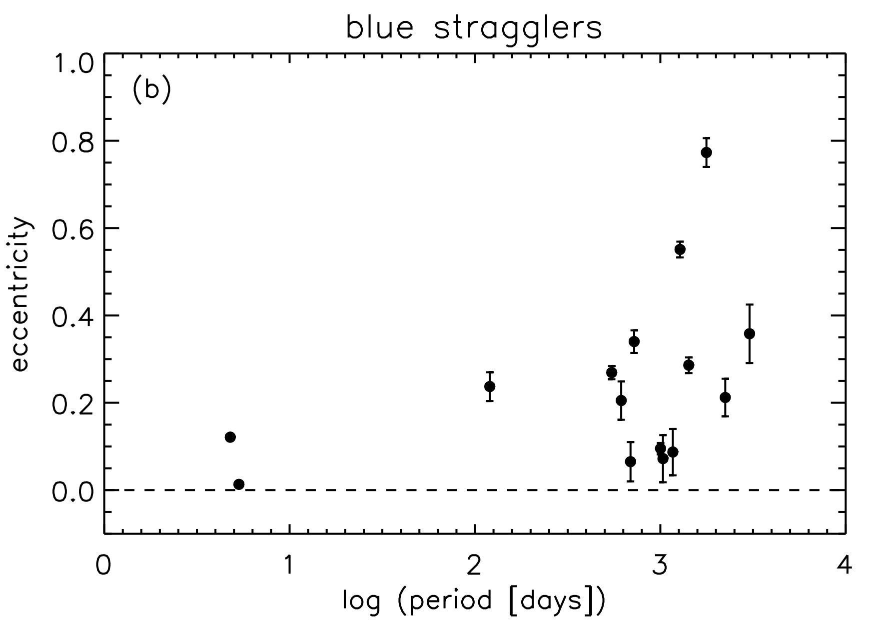
- Hard binary frequency 76%
- Typical orbital period ≈ 1000 days
- Typical secondary mass $0.5\ M_o$
- Rapidly rotating (modestly)
- Bimodal spatial distribution
- Dynamical mass < Evolution track mass



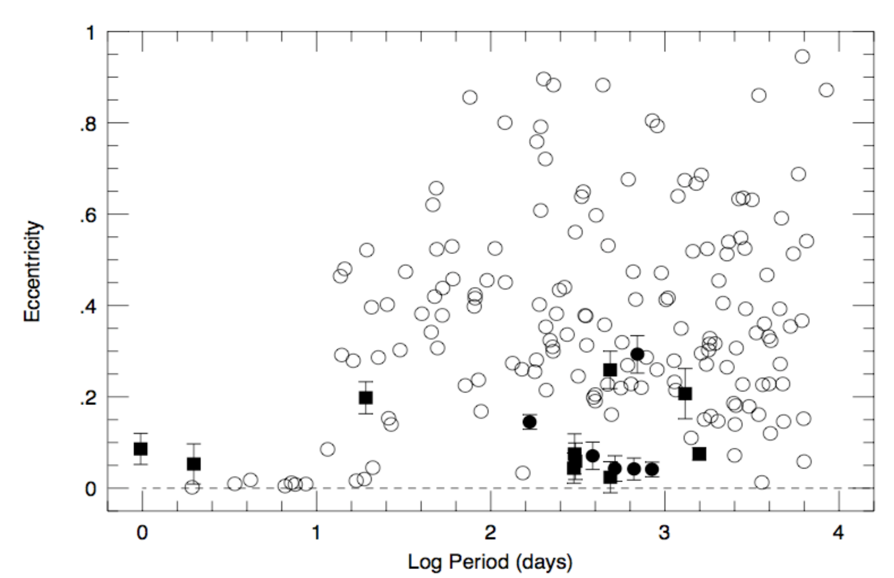
Blue Stragglers in Old Populations



M67
(Latham 2007)



NGC 188



Field
(Carney et al. 2001)

NGC 188 Blue Stragglers

How To Make Long-*P* Blue Stragglers

Hypothesis		Secondary Star
Mass transfer (Case C – AGB)	→	C/O white dwarf
Collision during binary encounter	→	Main-sequence star
Kozai-driven merger of close binary in triple	→	Main-sequence star

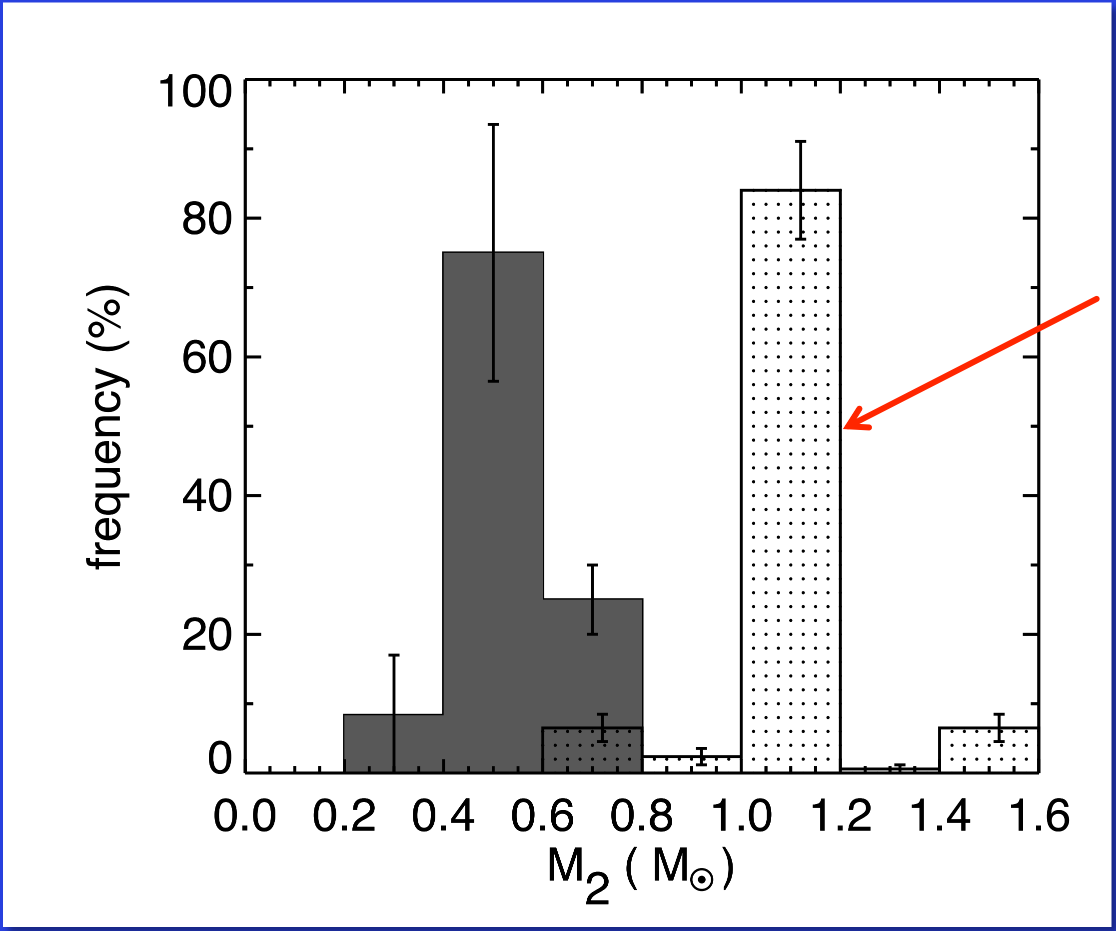
McCrea (1964), Chen & Han (2008), etc.

Leonard (1996), Leigh & Sills (2011), etc.

Ivanova (2008), Perets & Fabrycky (2009)

NGC 188 Blue Stragglers

How To Make Long-*P* Blue Stragglers



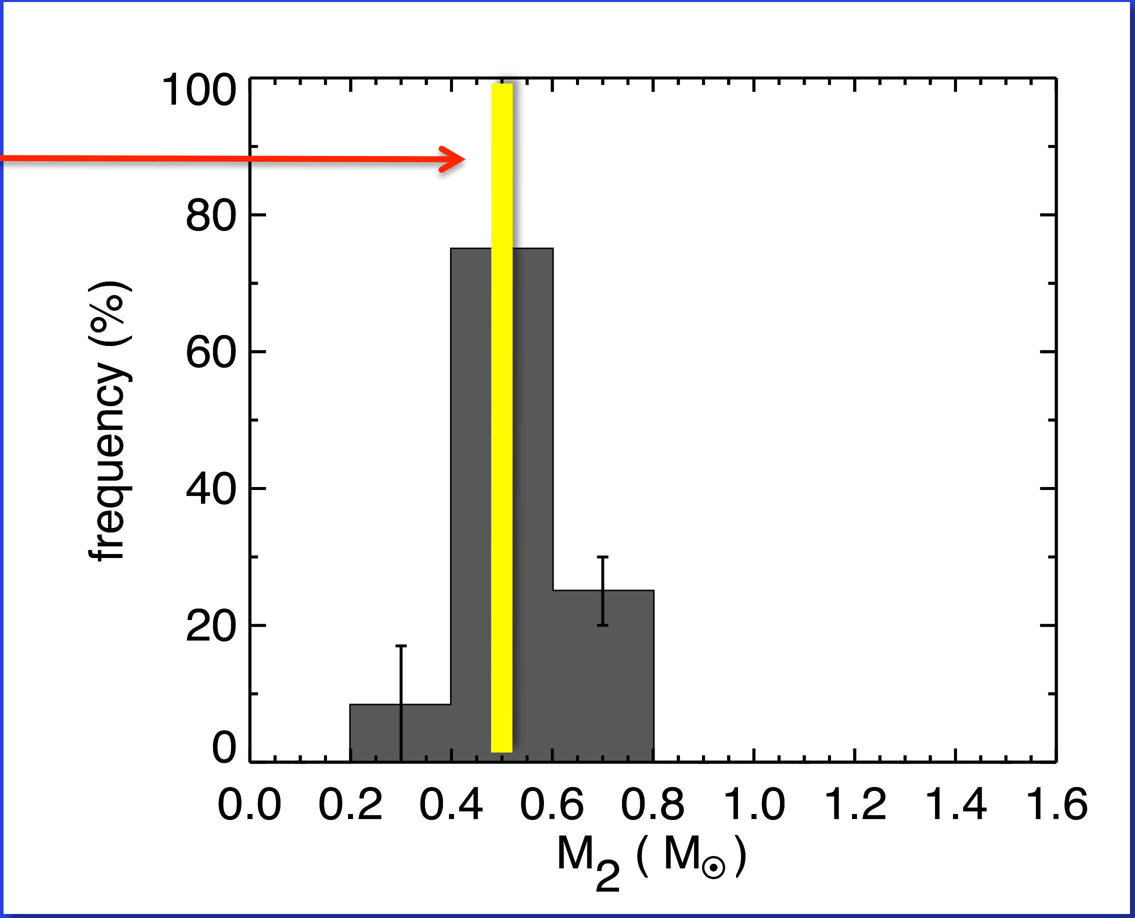
Collisions
(from *N*-body model; Geller, Hurley, Mathieu 2012)

Geller & Mathieu 2011

NGC 188 Blue Stragglers

How To Make Long-*P* Blue Stragglers

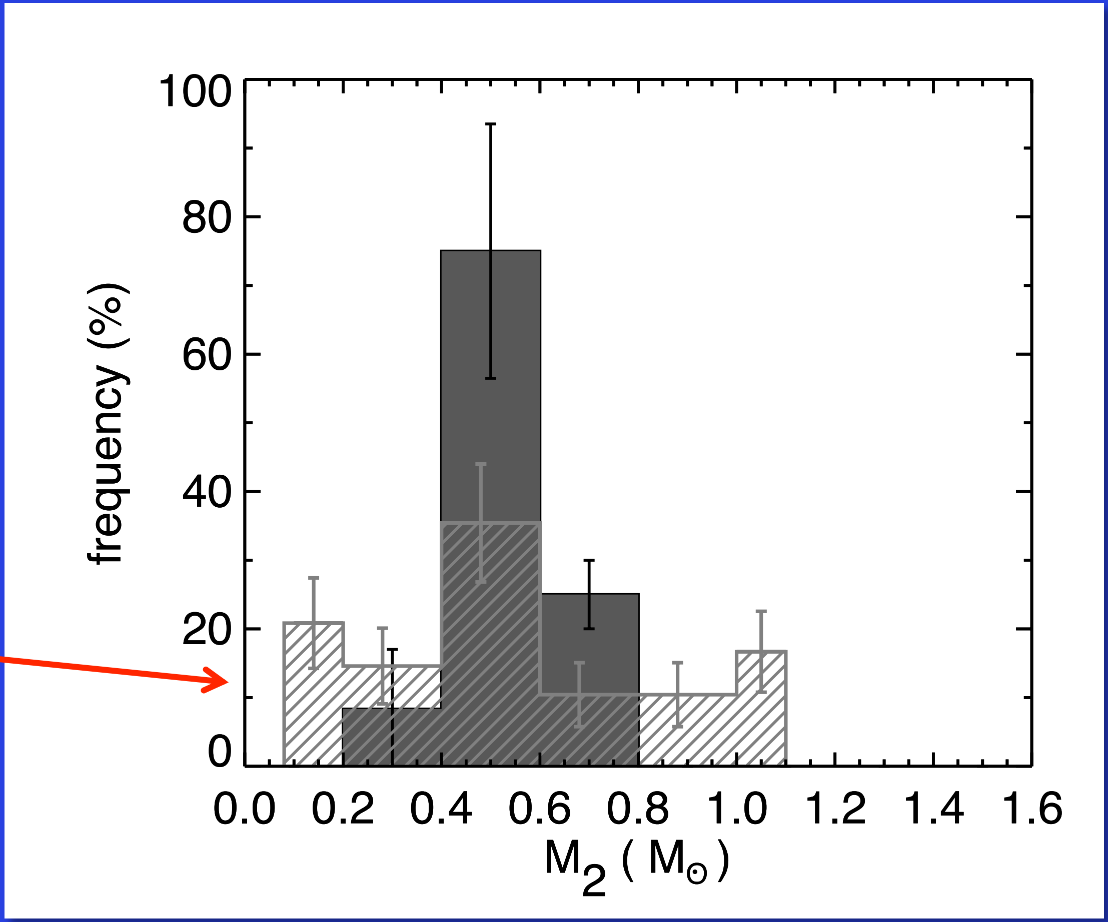
0.55 $M_{\odot}$
CO WDs
Case C
mass transfer



Geller & Mathieu 2011

NGC 188 Blue Stragglers

How To Make Long-*P* Blue Stragglers



Evolved tertiaries from field

(Tokovinin 1997, 2008)

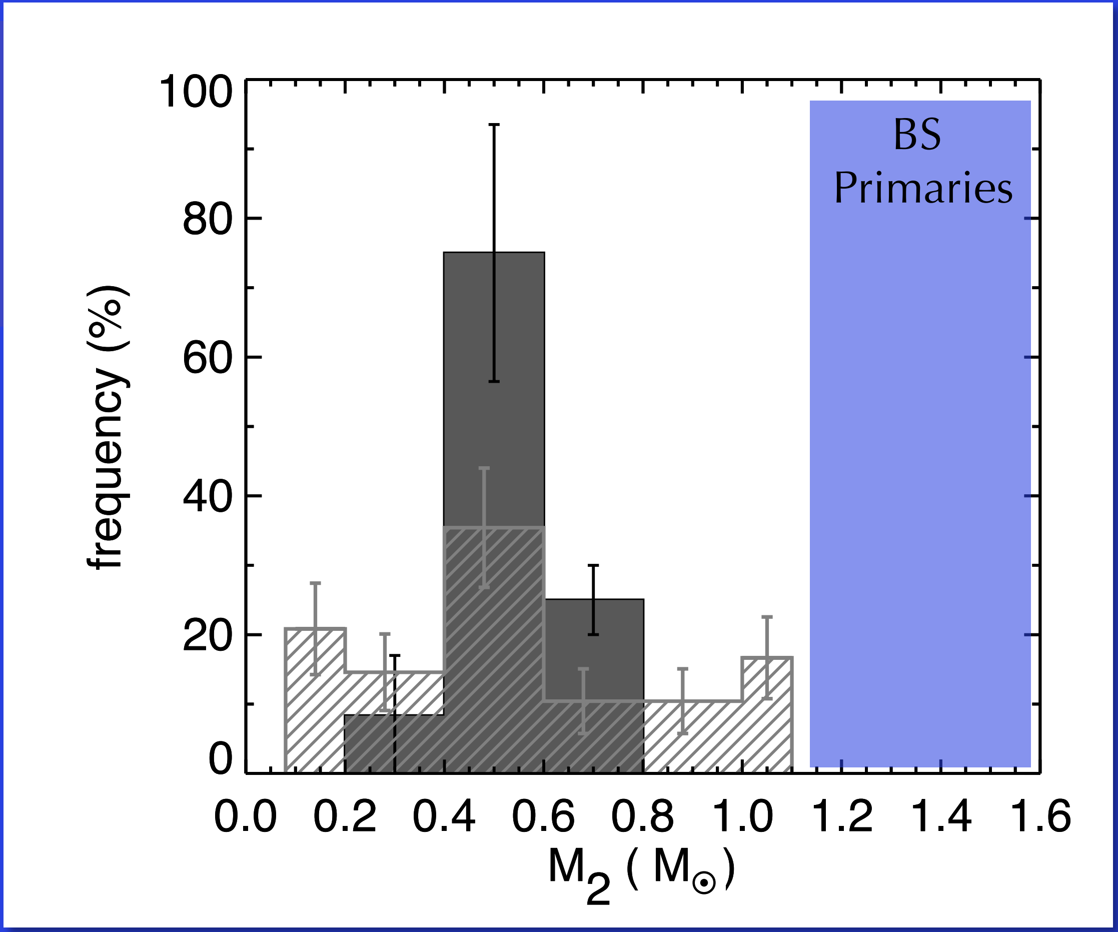
Geller & Mathieu 2011

NGC 188 Blue Stragglers

How To Make Long-*P* Blue Stragglers

One more constraint on tertiary distribution:
All SB1s

- 6.6% chance to detect zero secondaries
- 1.8% chance to also realize the observed mass-function distribution



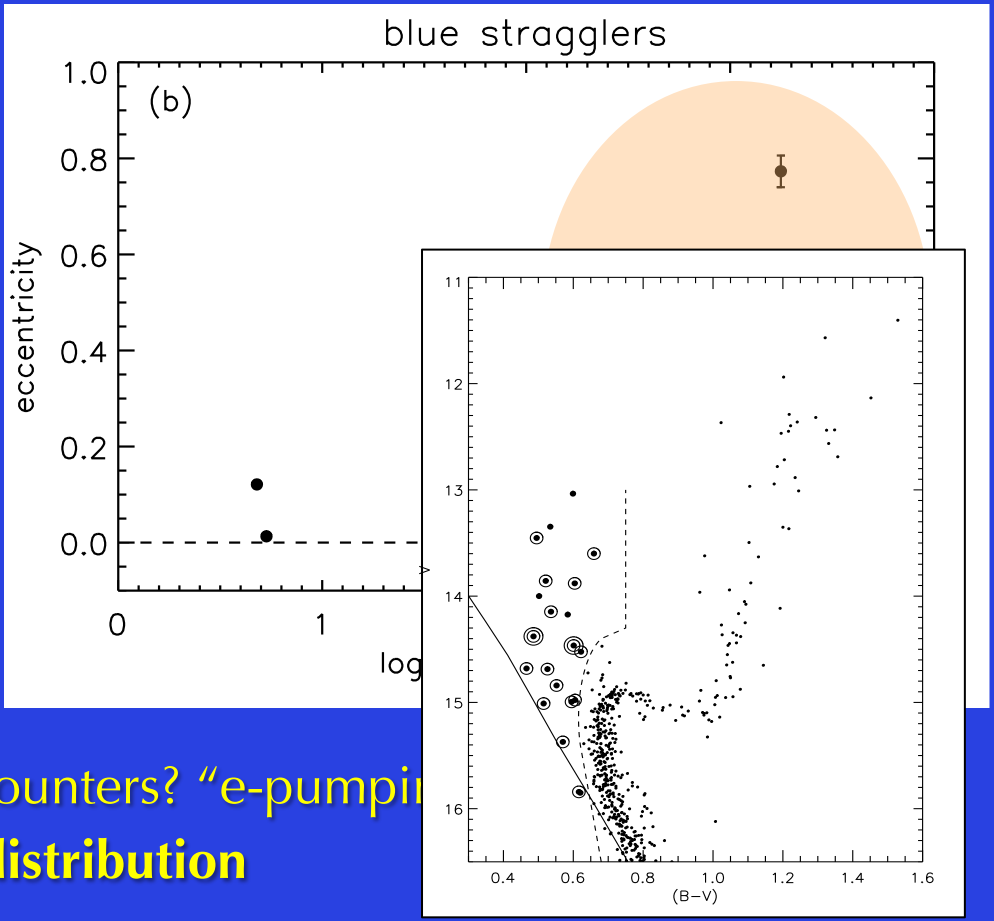
NGC 188 Blue Stragglers

How To Make Long-*P* Blue Stragglers

Primarily Case C mass transfer

Some Case B mass transfer?

Some mergers in triples?



Outstanding questions

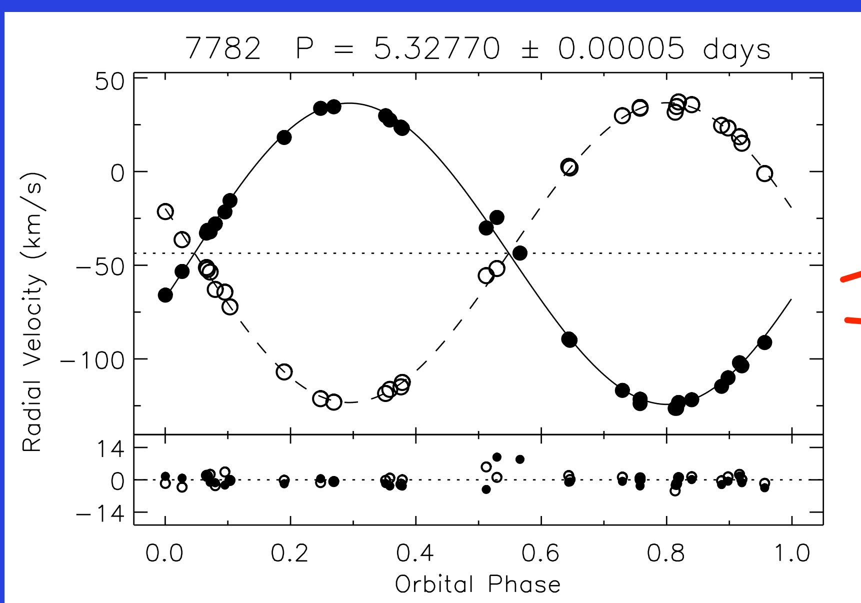
Orbital eccentricities (dynamical encounters? “e-pumpi

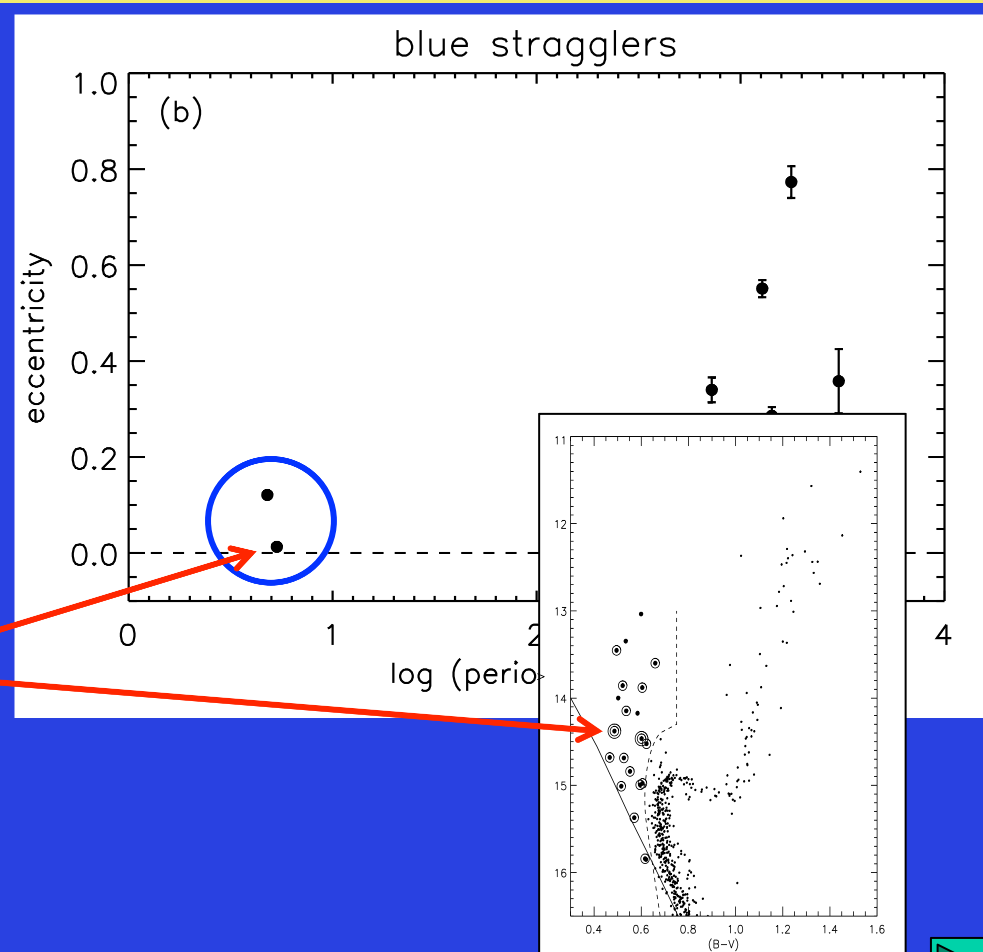
Luminosity and temperature (CMD) distribution

NGC 188 Blue Stragglers

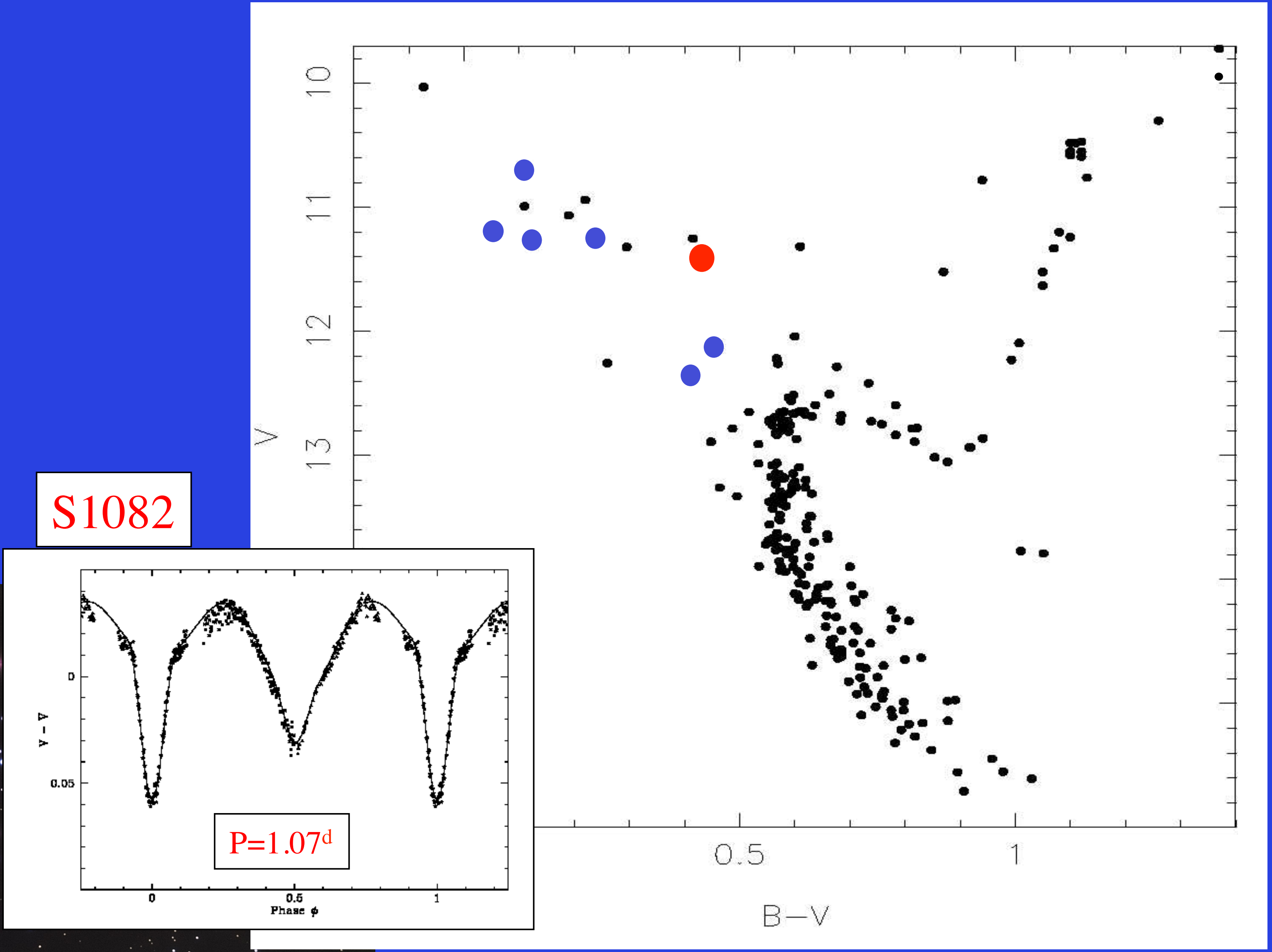
How To Make *Short-P* BSs

- SB2 => q ~ 1
- Two blue stragglers!!!

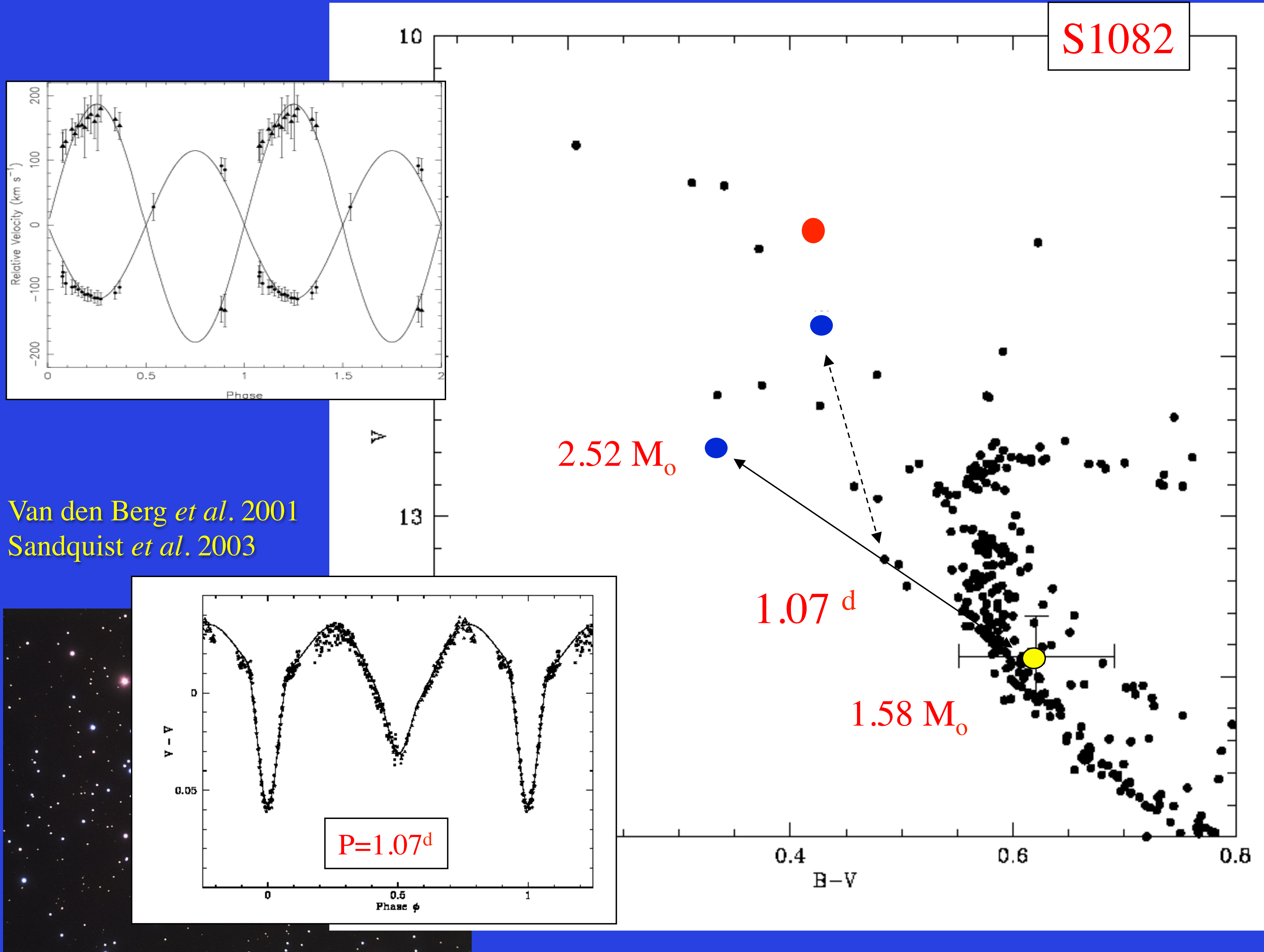




A Very Special M67 Blue Straggler



S1082



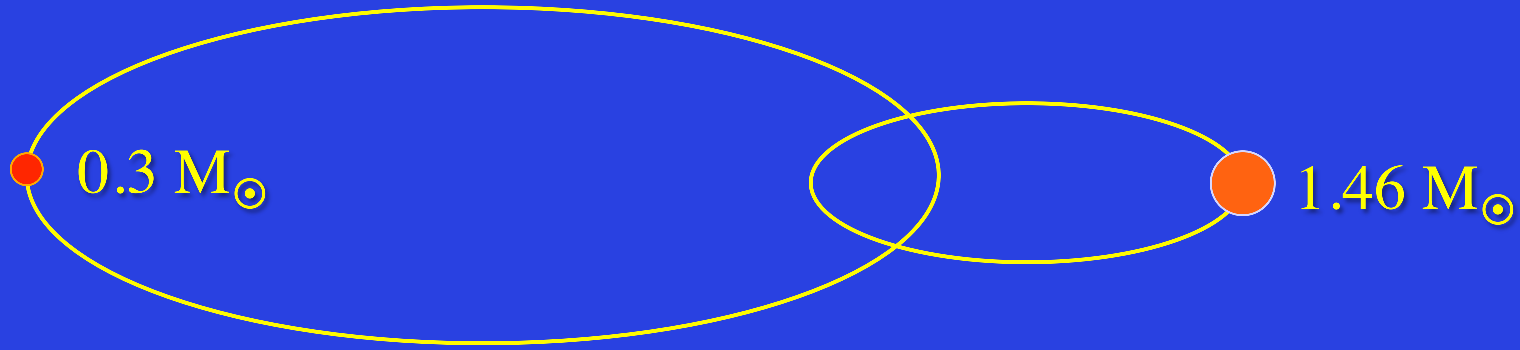
Van den Berg *et al*. 2001
Sandquist *et al*. 2003

A Caution from Stellar Dynamics
Simulation of M67

Primordial Binary

Period: 47,860 days

Eccentricity: 0.8



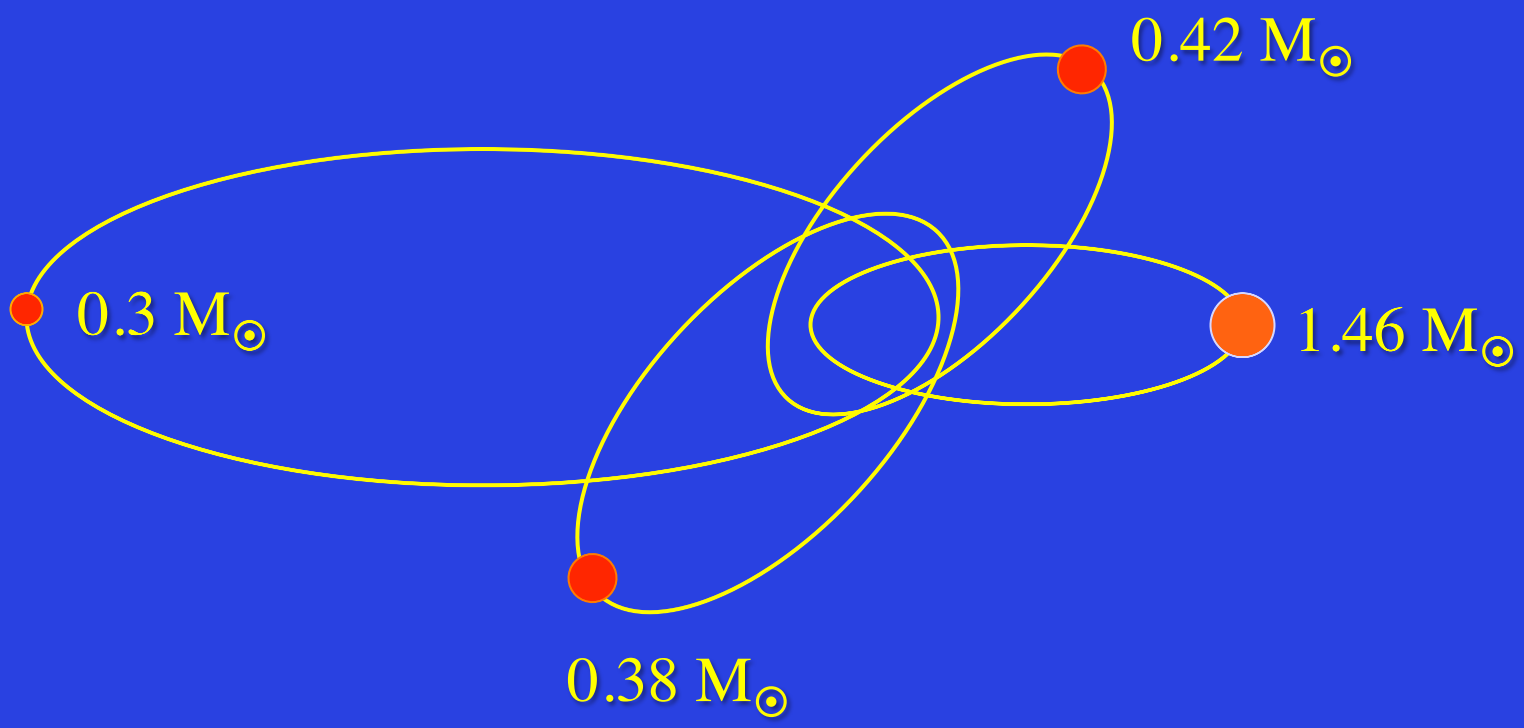
Hurley *et al*. 2005

Simulation of M67

2.089 Gyr later

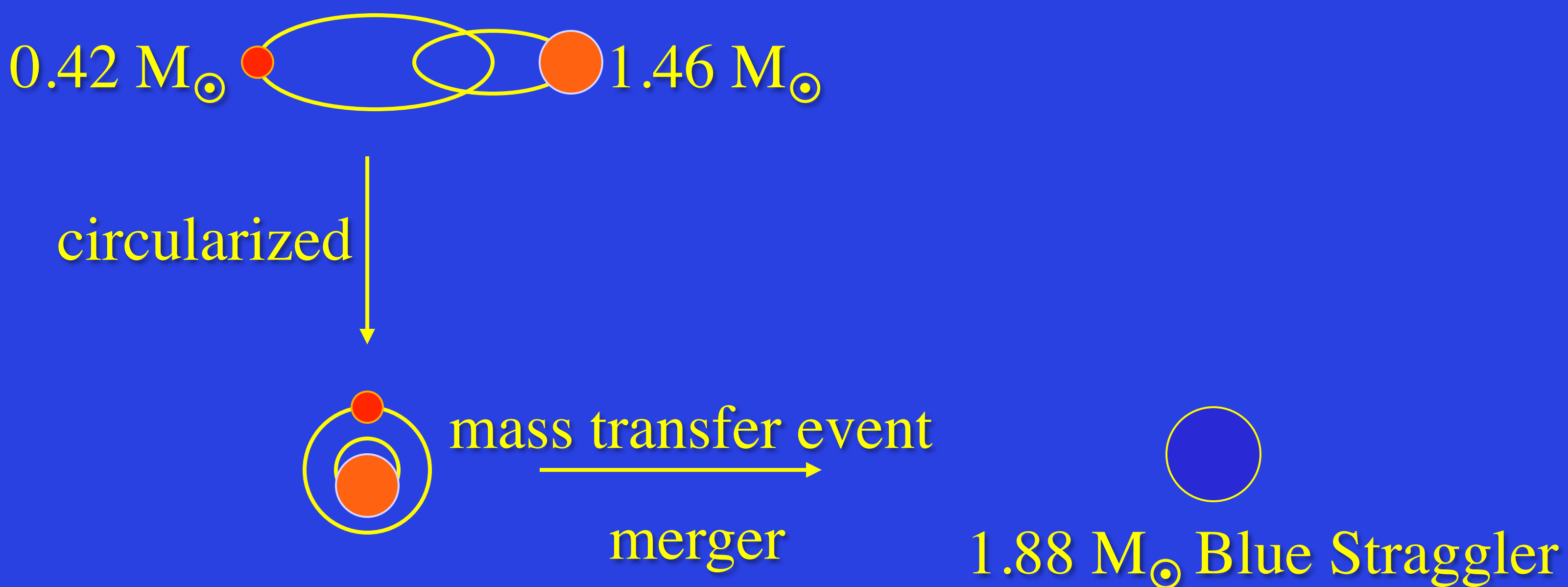
Simulation of M67

4-body interaction



Simulation of M67

Period: 1.1 days
Eccentricity   0.8



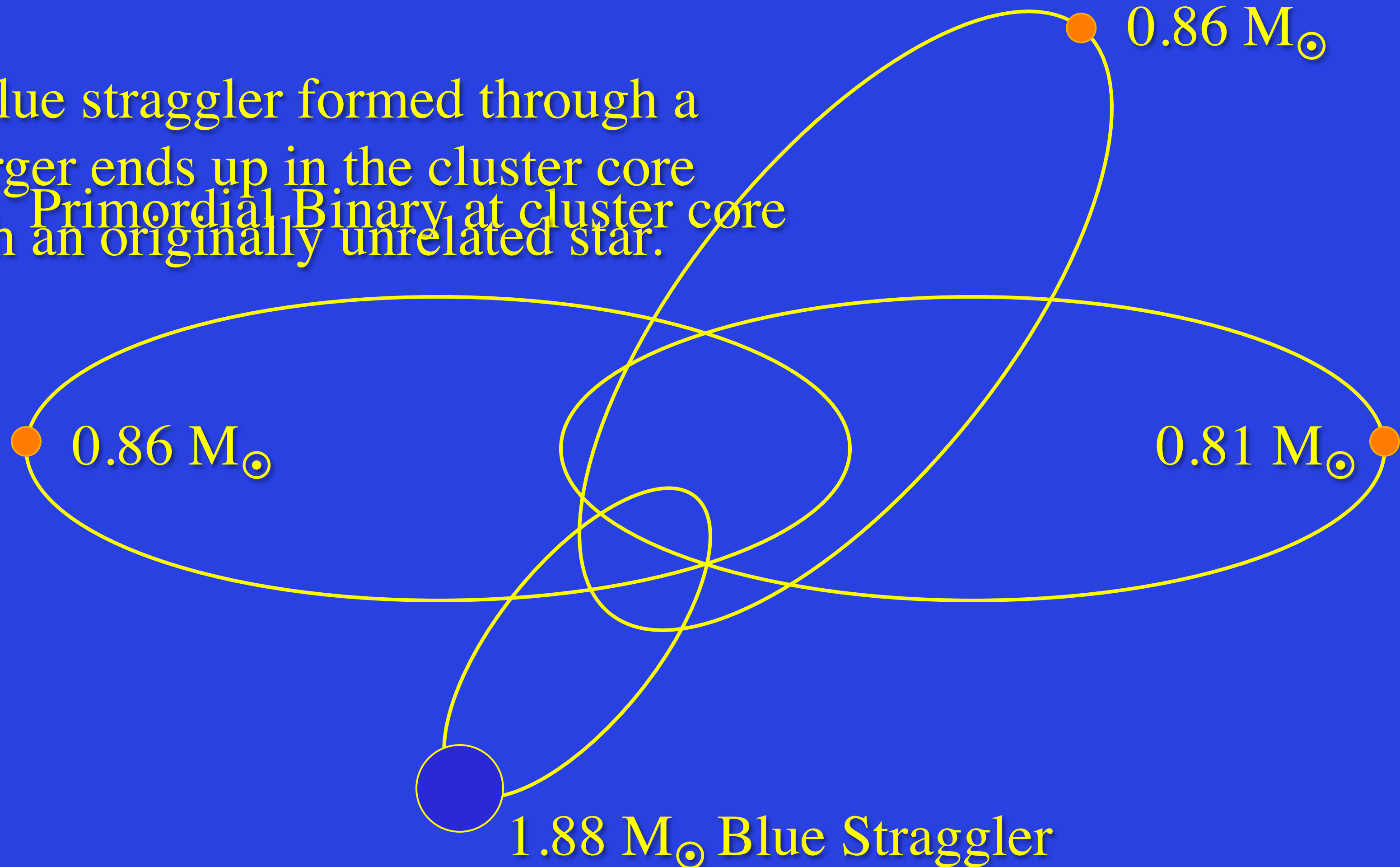
Simulation of M67

But wait…there's more

Simulation of M67

A blue straggler formed through a merger ends up in the cluster core with an originally unrelated star.

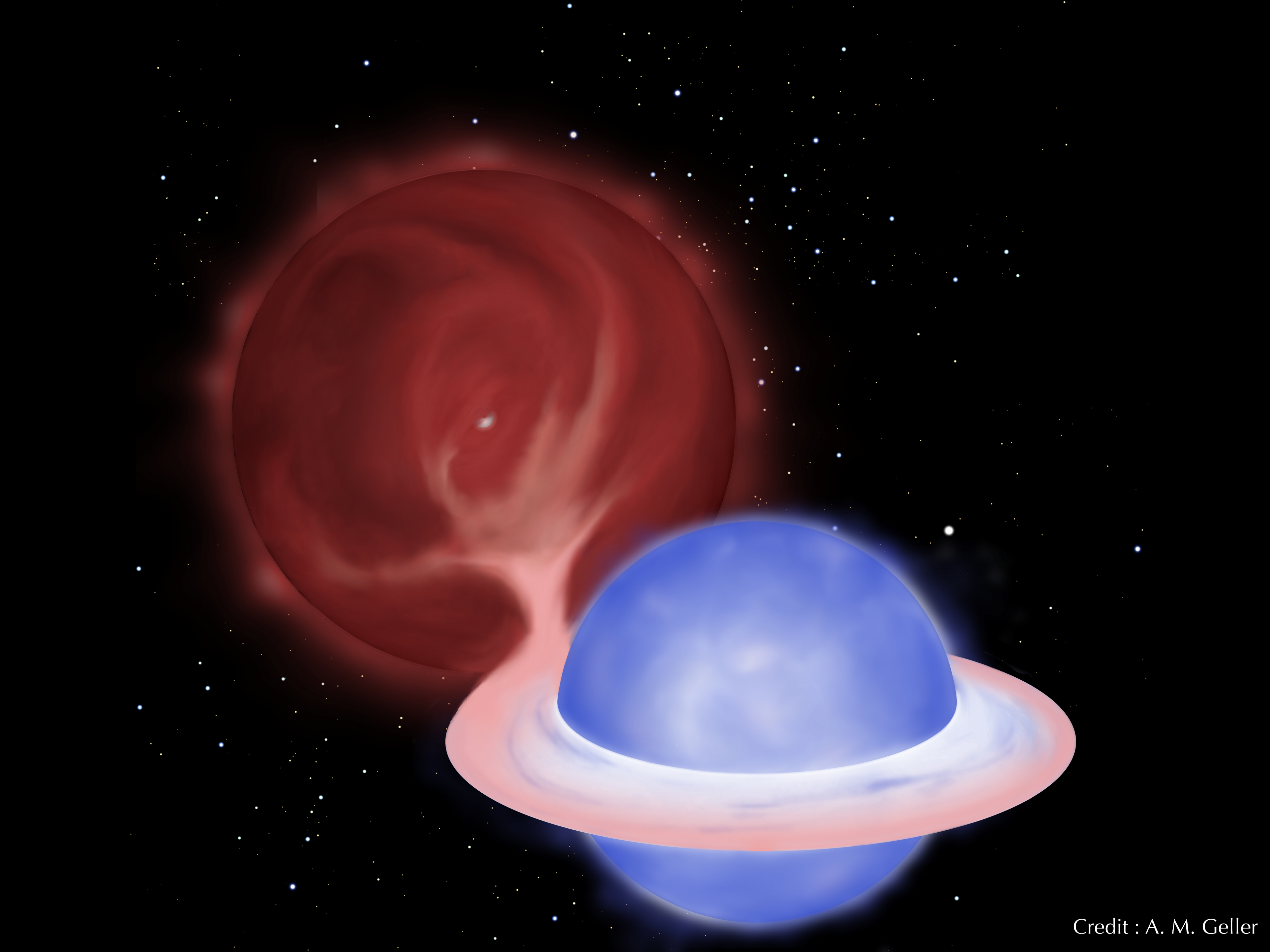
Primordial Binary at cluster core



NGC 188 Blue Stragglers

How To Make Open Cluster Blue Stragglers

Hypothesis		Frequency
Mass transfer (Case C – AGB)	→	Primary channel
Collision during binary encounter	→	What can happen, will
Merger of close binary in triple	→	What can happen, will


Credit : A. M. Geller

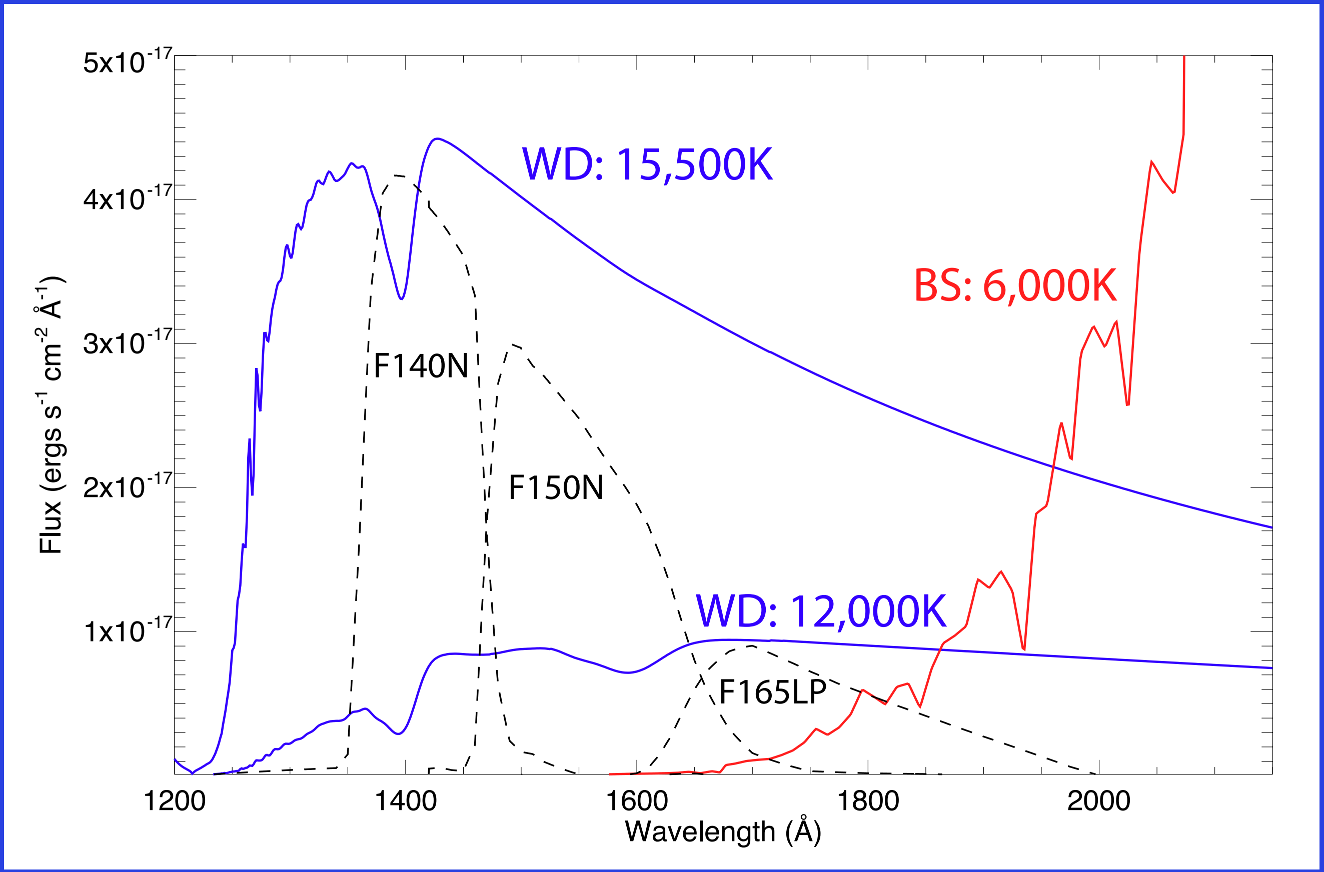
41 orbits of Hubble Space Telescope ACS to see if the white dwarfs are there!

Credit : A. M. Geller

NGC 188 Blue Stragglers

"Future" Observations

Gosnell et al. poster – UV imaging of NGC 188 BS with Hubble



NGC 188 Blue Stragglers

Findings from N-Body Simulations

Aaron Geller…on Thursday! …

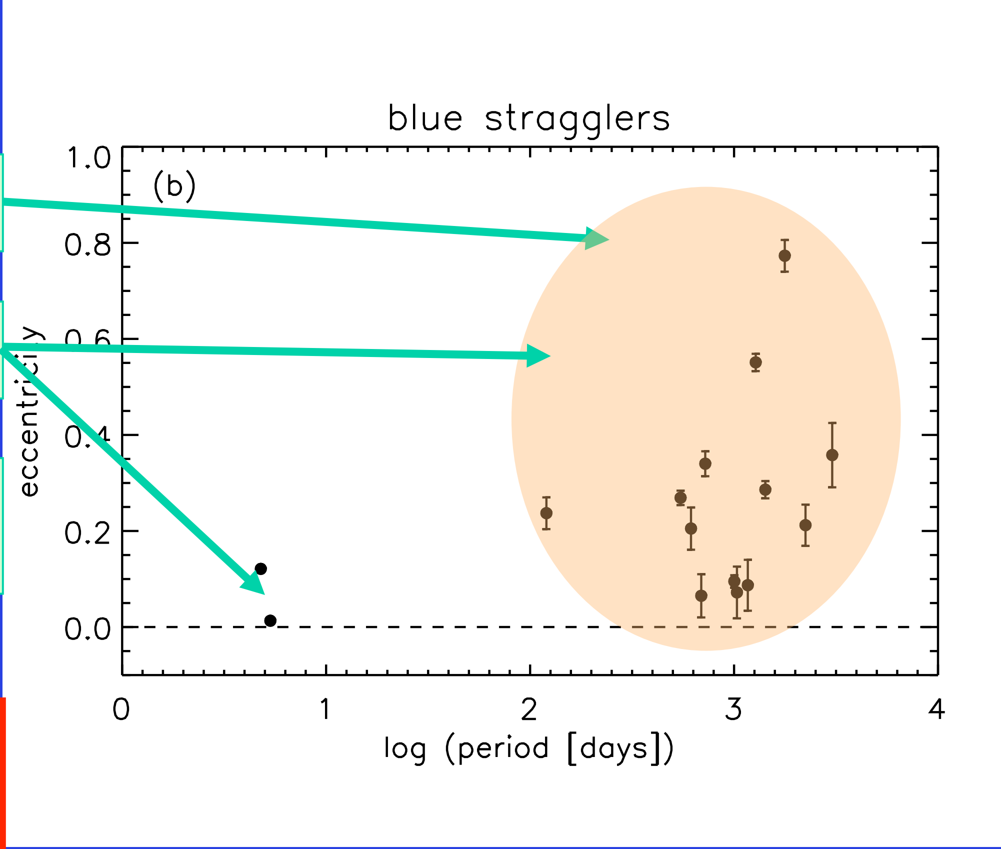
Open Cluster Blue Stragglers

Summary

Case C (& B) Mass Transfer

Dynamical Processes

And don't forget the 5 blue stragglers with constant RV (singles or long period?)



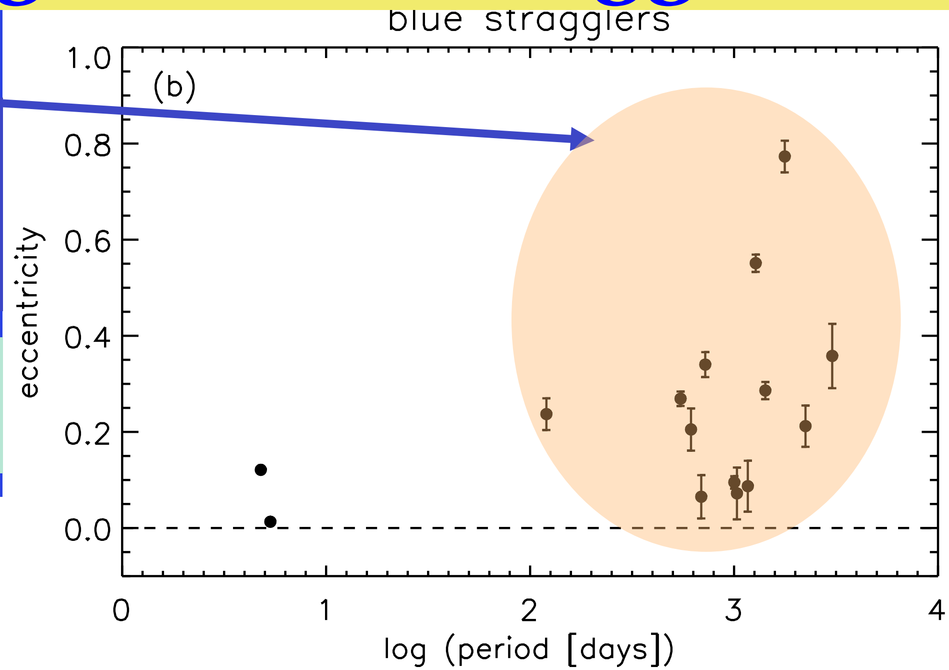
Multiple formation mechanisms, but mass transfer dominates

NGC 188 Blue Stragglers

How To Make Long-*P* Blue Stragglers

Case C (& B) Mass Transfer
(+ dynamical encounters/“e-pumping”, mergers in triples?)

And don’t forget the 5 blue stragglers with constant RV (singles?)



Multiple formation mechanisms, but mass transfer dominates