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WIYN Open Cluster Study

The Progeny of Stellar Dynamics and Stellar Evolution

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Collaborators:

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David W. Latham -- CfA
Hugh C. Harris -- USNO
Robert D. McClure -- DAO
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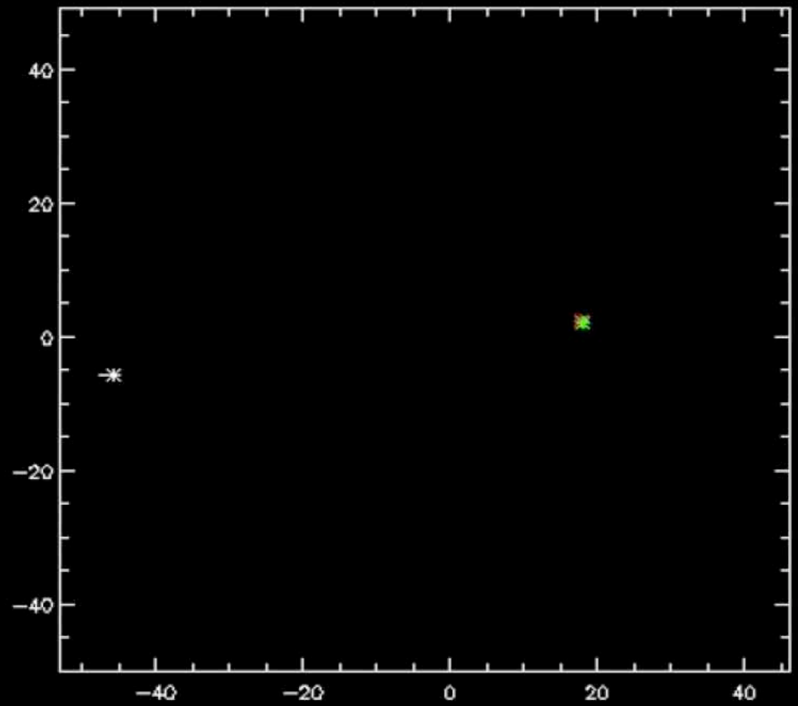
Outline



Produced using FEWBODY (Fregeau et al. 2004)

- Observations
- Recent results for NGC 188 - binaries, blue stragglers, ...
- Comparing to other observed/simulated open clusters
- Future directions

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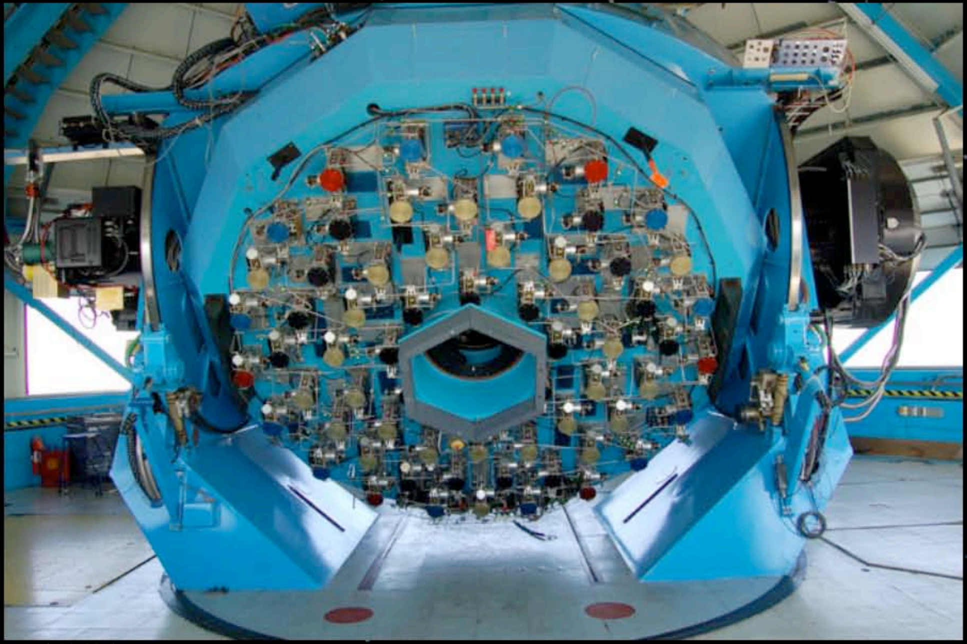
Observations

NGC 188 (7 Gyr)

- > 8000 Combined WIYN 3.5m and DAO RVs of > 1000 stars
- Observed Sample
  - $11 \leq V \leq 16.5$ (1.14 - 0.92 $M_{\odot}$) within 1° (17 pc; 13 core radii)
  - Up to 35 year time baseline (11 yr for most)
  - WIYN precision of 0.4 km s^{-1}



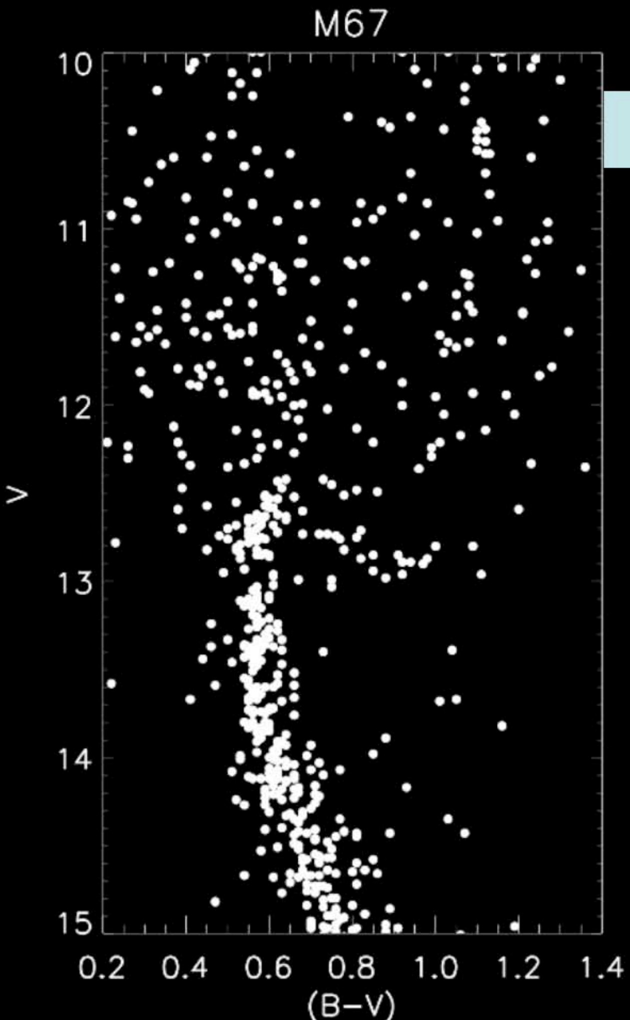
WIYN 3.5m

NGC 188 DSS

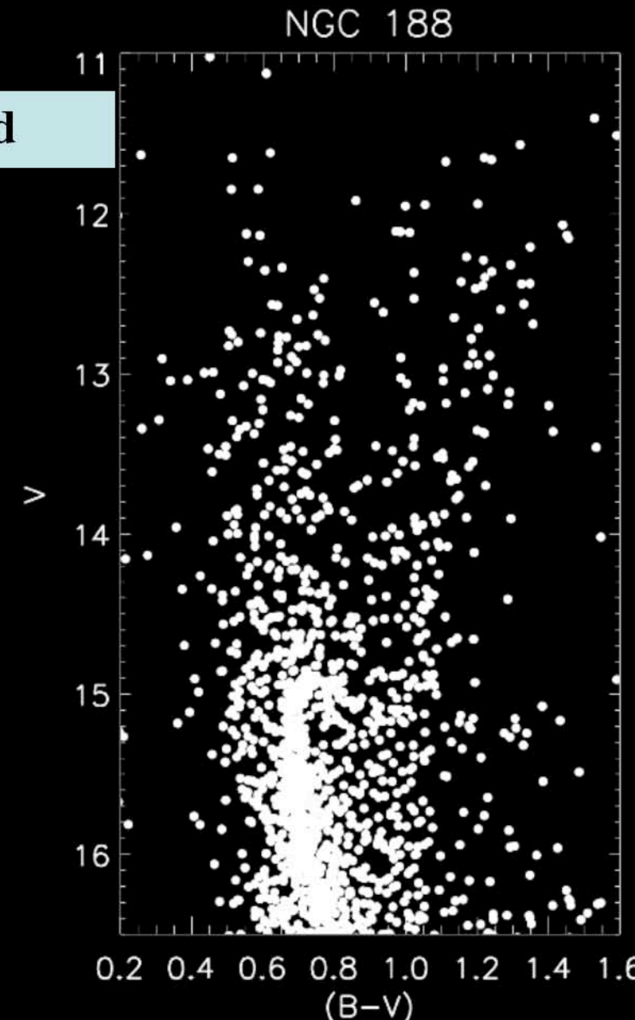
Cluster Members

- 360 Single Stars
- 132 Binaries ($P<10^4$ days)

Recent Results: *Membership & Binarity*



All stars in field



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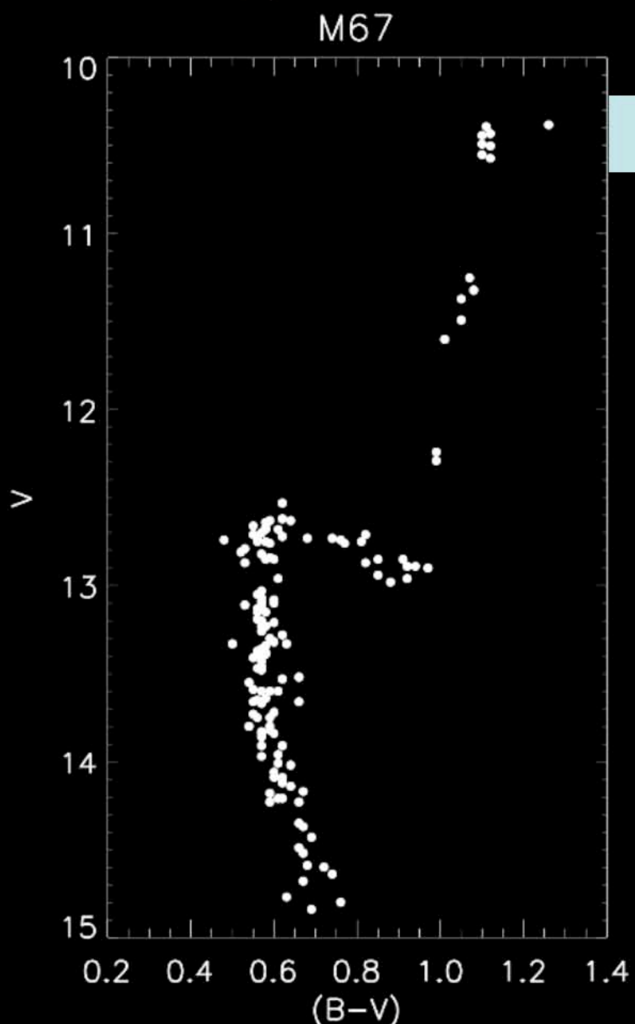
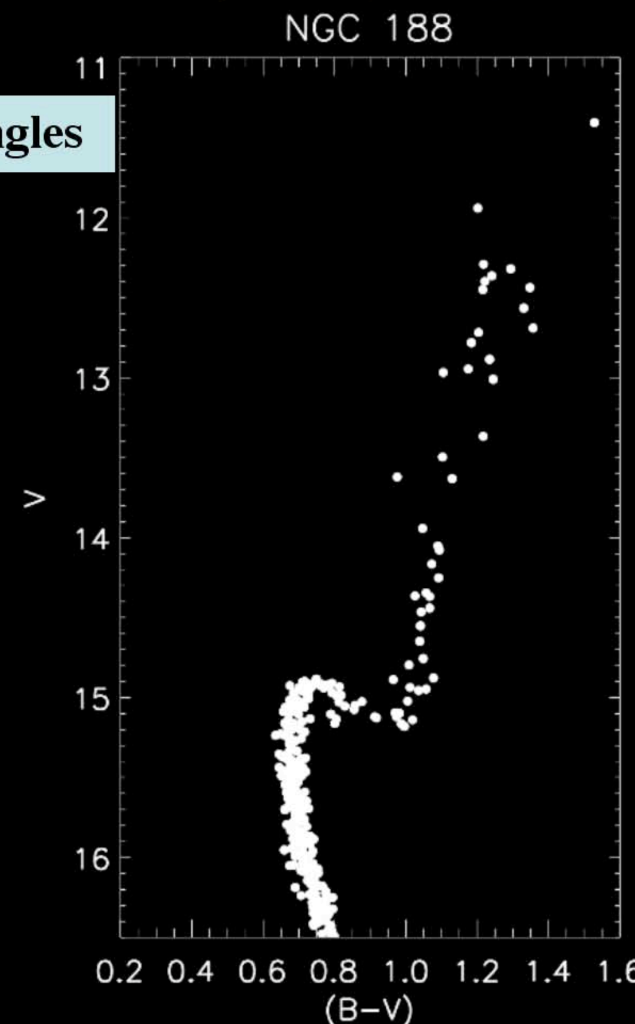
Recent Results: *Membership & Binarity*



Only "normal" singles



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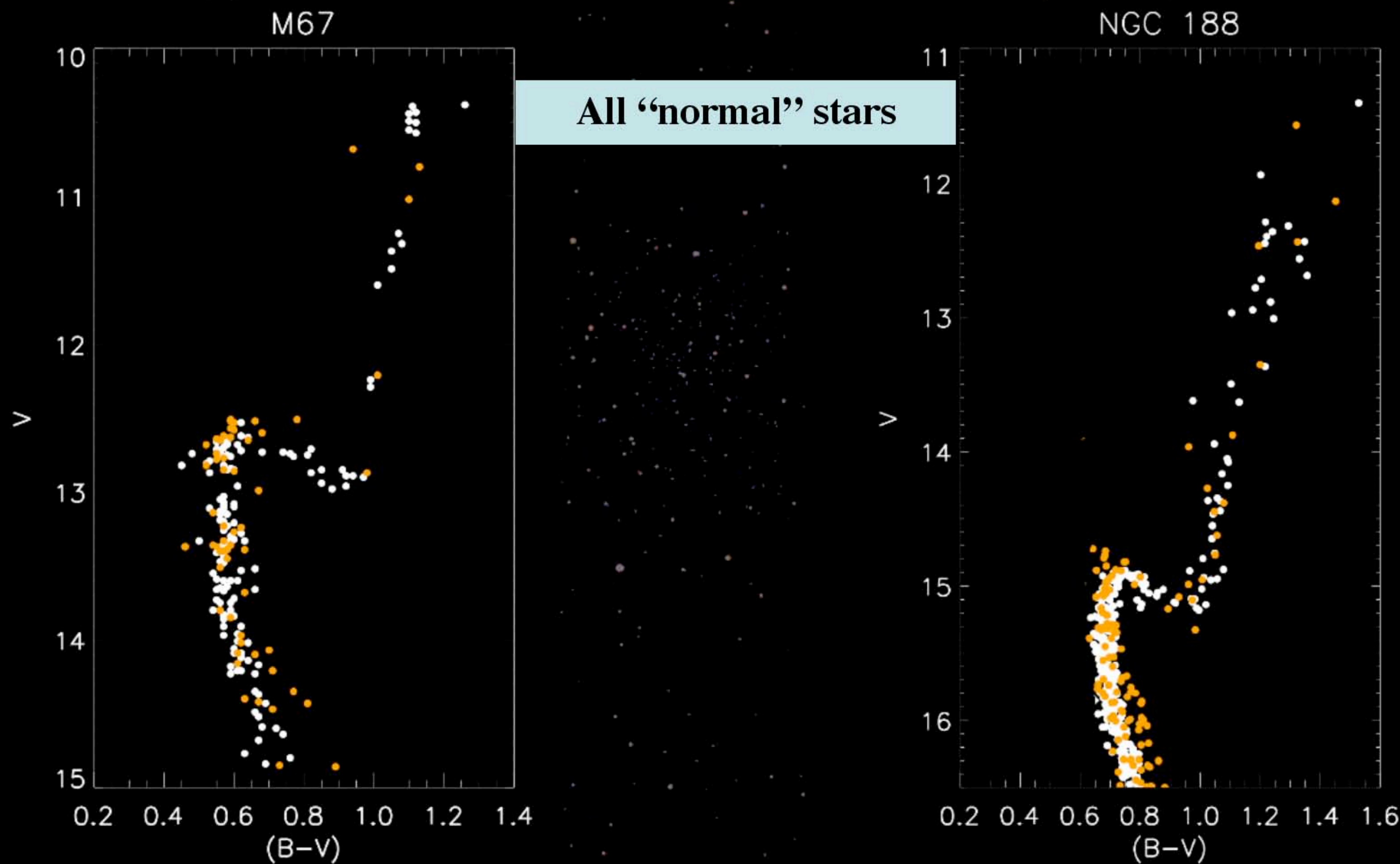
Recent Results: *Membership & Binarity*



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Recent Results: *Membership & Binarity*

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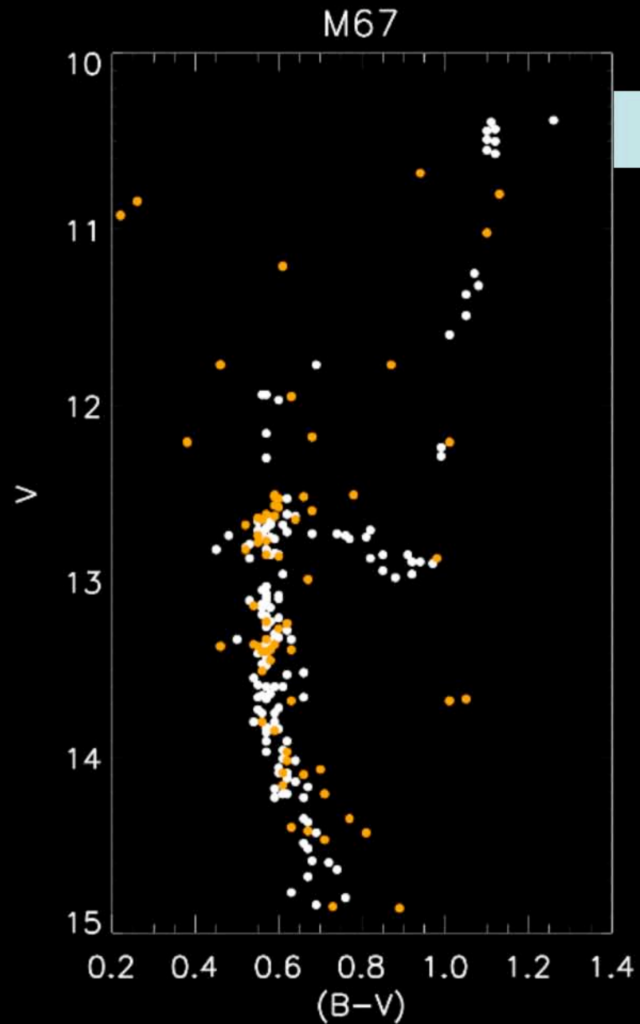
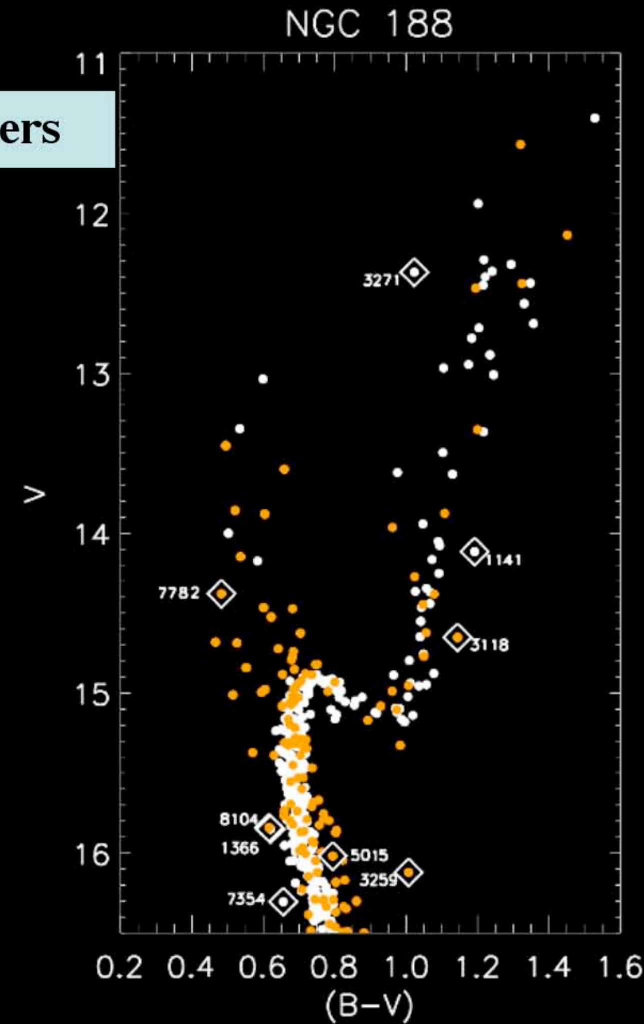


All cluster members



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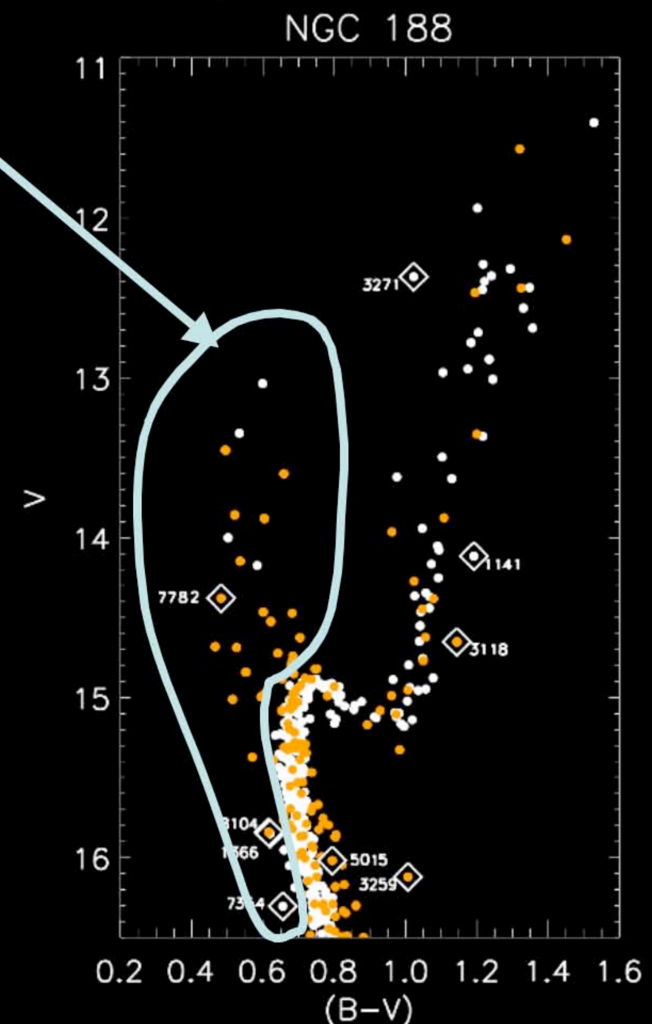
Recent Results: *Stars of Note*

Blue Straggler Population :

- 22 cluster members
- ~40% w/ detectable rotation (v sin$i$ > 10 km/s)
- 73 ± 24% binaries!



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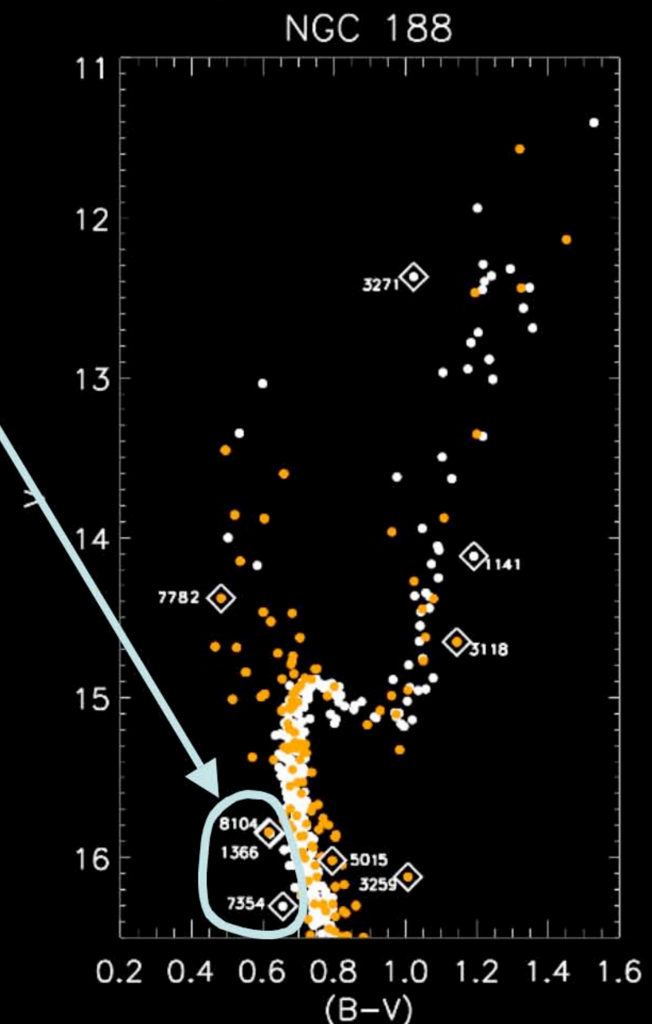
Recent Results: *Stars of Note*

BS Population - 73% in binaries!

8104, 1366 & 7354 :

- "Blue Stragglers" below the turnoff



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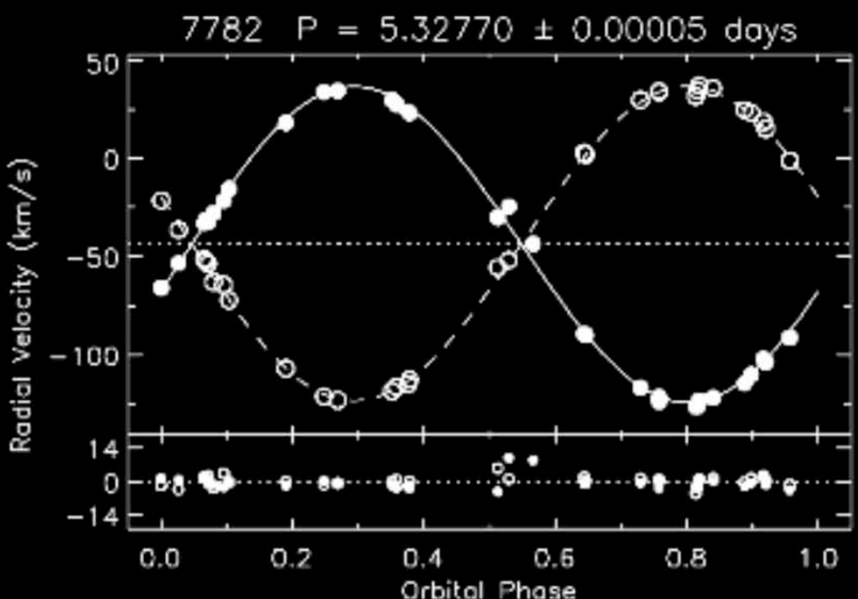
Recent Results: *Stars of Note*

BS Population - 73% in binaries!

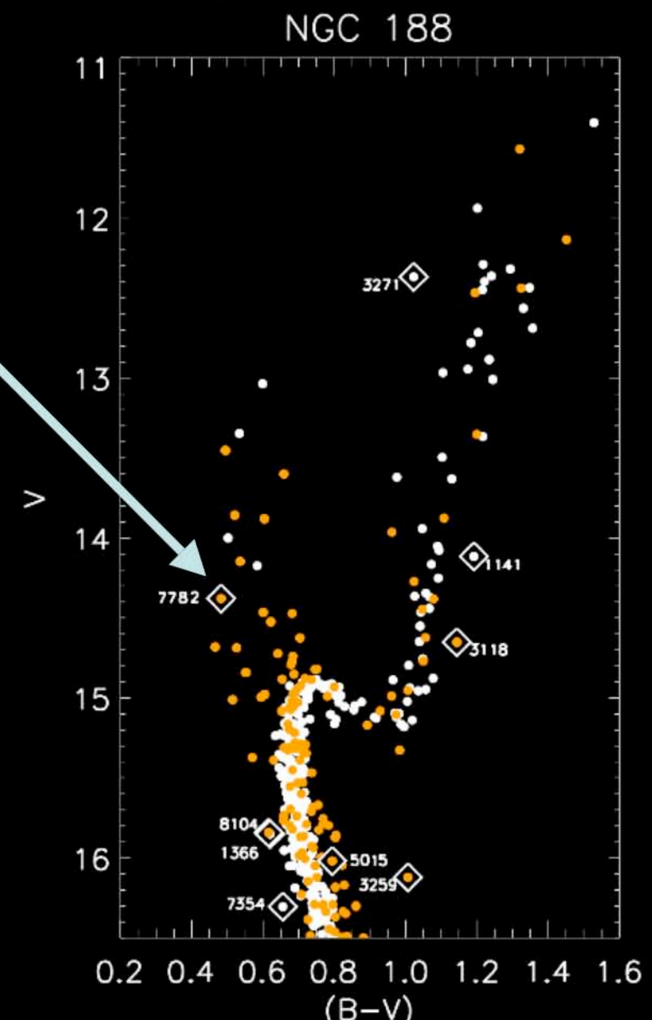
- **8104, 1366 & 7354 : below turnoff**

7782 :

- Double-lined binary blue straggler
- Mass ratio ~1 (2 blue stragglers?!)



Geller et al. 2009



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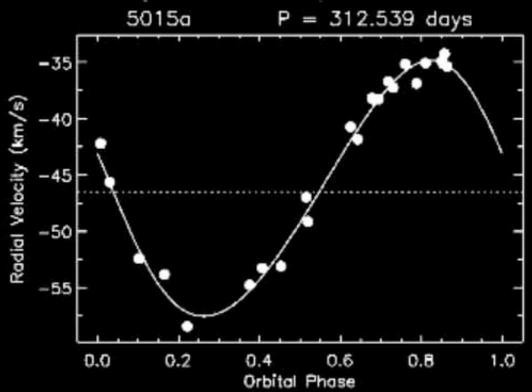
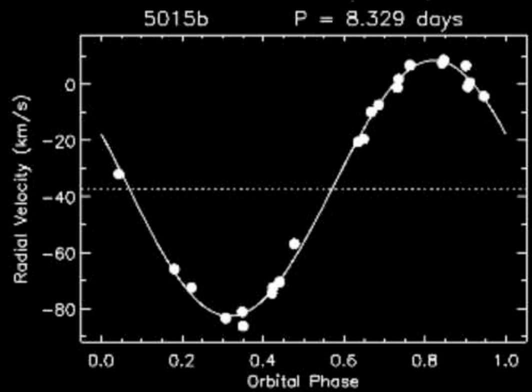
Recent Results: *Stars of Note*

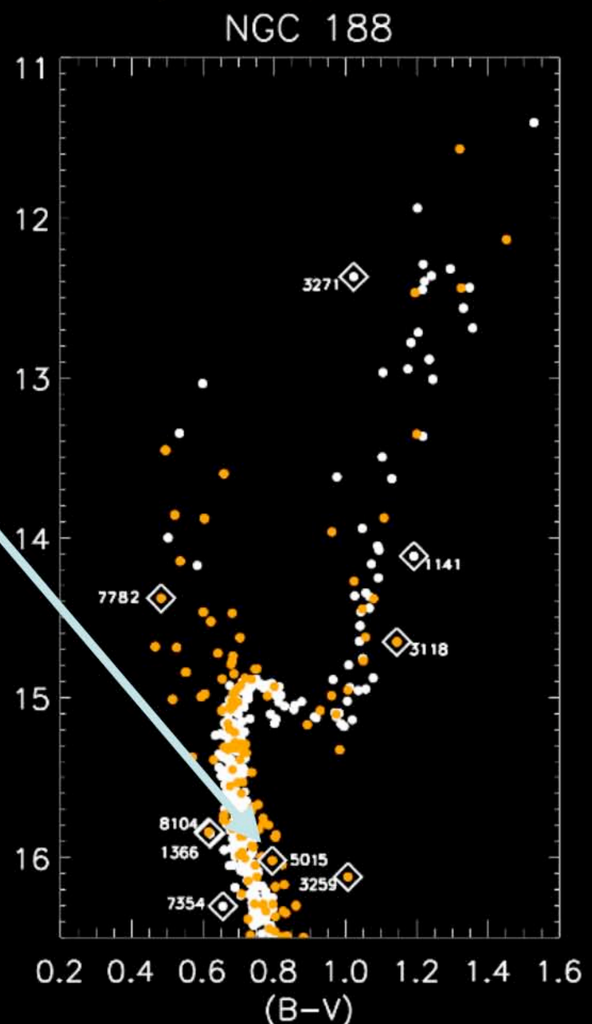
BS Population - 73% in binaries!
- **8104, 1366 & 7354 : below turnoff**
- **7782 : binary w/ 2 blue stragglers!?**

5015 :
- A likely quadruple system





Geller et al. 2009



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Recent Results: *Stars of Note*

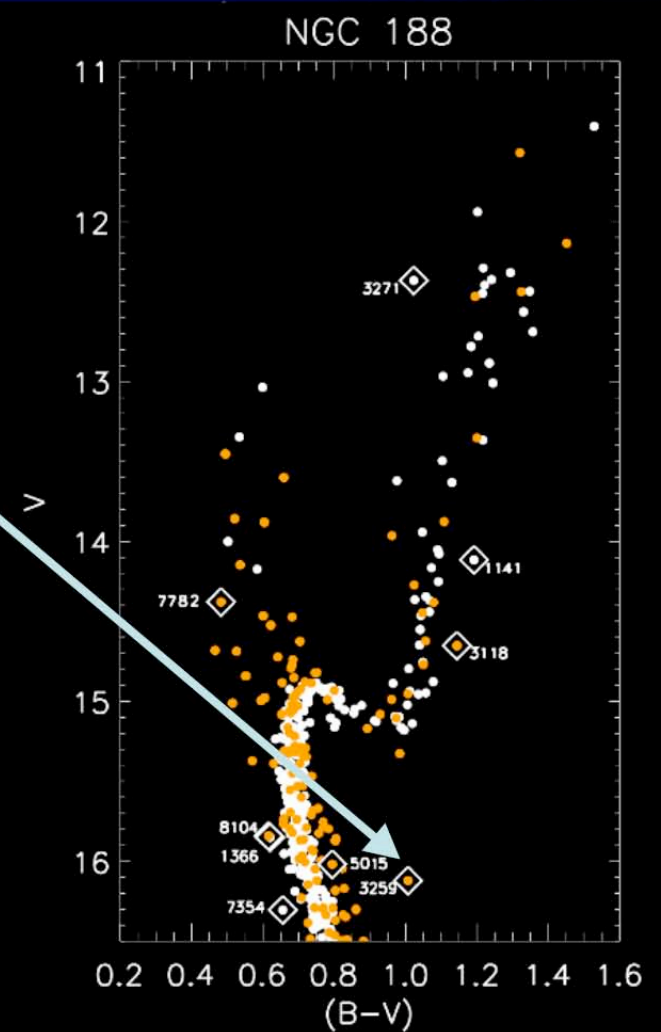
BS Population - 73% in binaries!

- **8104, 1366 & 7354 : below turnoff**
- **7782 : binary w/ 2 blue stragglers!?**

5015 : quadruple system

3259 :

- Sub-subgiant?



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Recent Results: *Stars of Note*

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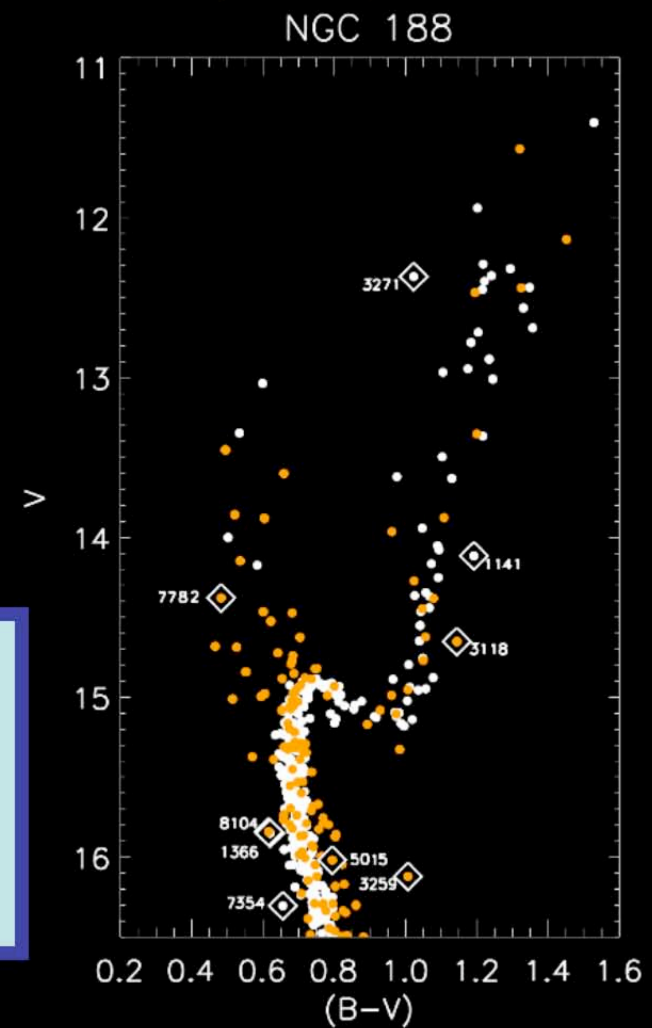
- **7782 : binary w/ 2 blue stragglers!?**

5015 : quadruple system

3259 : sub-subgiant?

Many of these stars and star systems are hard (impossible?) to explain without a combination of stellar dynamics and stellar evolution.



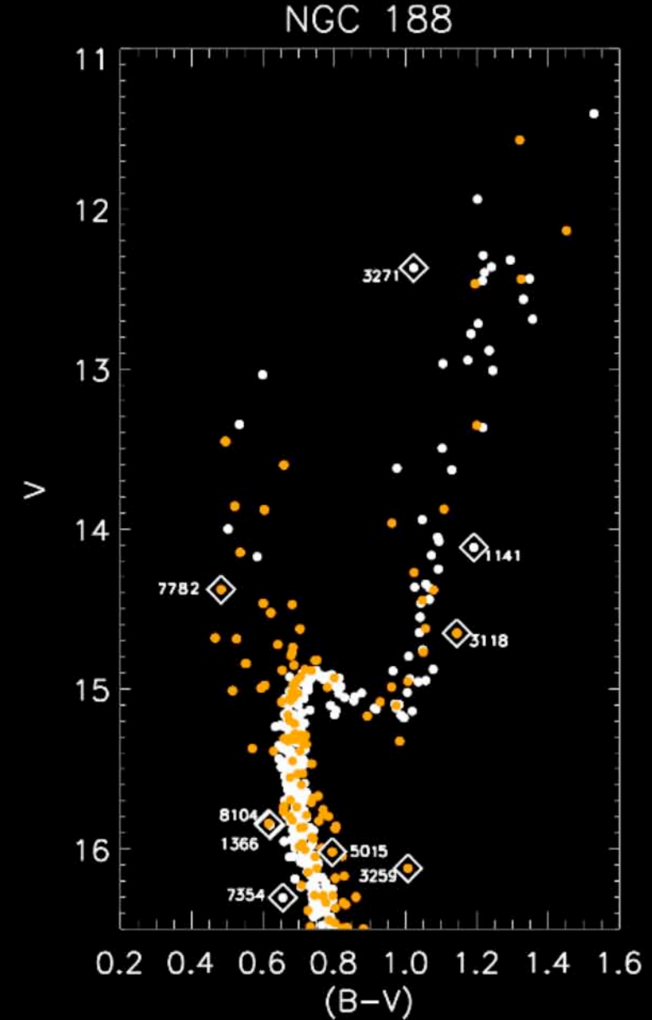
Recent Results: *Binary Population*

Binary Frequency

- We detect 93% of binaries with $P<10^3$ days and 77% of binaries with $P<10^4$ days

Observed Frequencies:

MS	79 / 376	21 ± 3 %
Giant	21 / 70	30 ± 7 %
BS	16 / 22	73 ± 24 %
Cluster	117 / 488	24 ± 3 %



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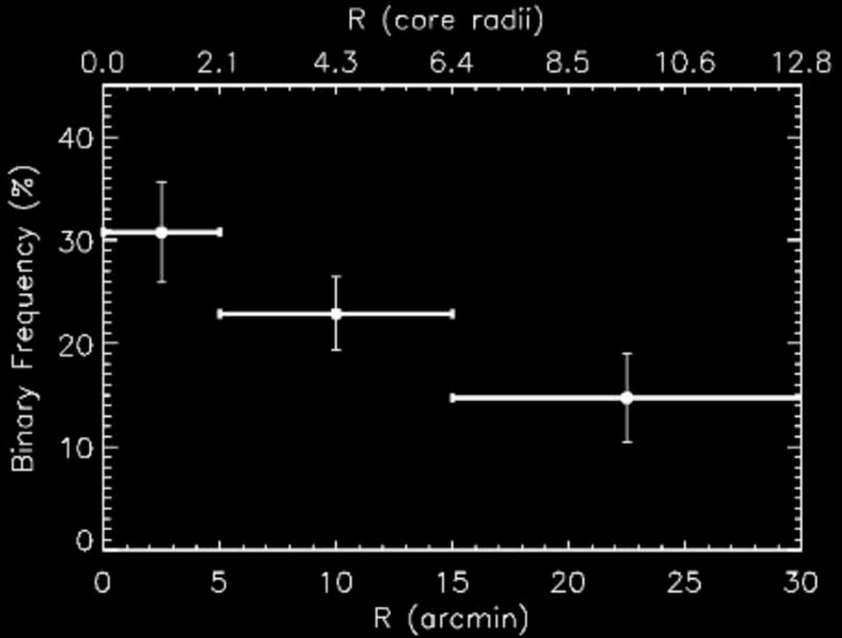


Geller & Mathieu 2009a, in prep.

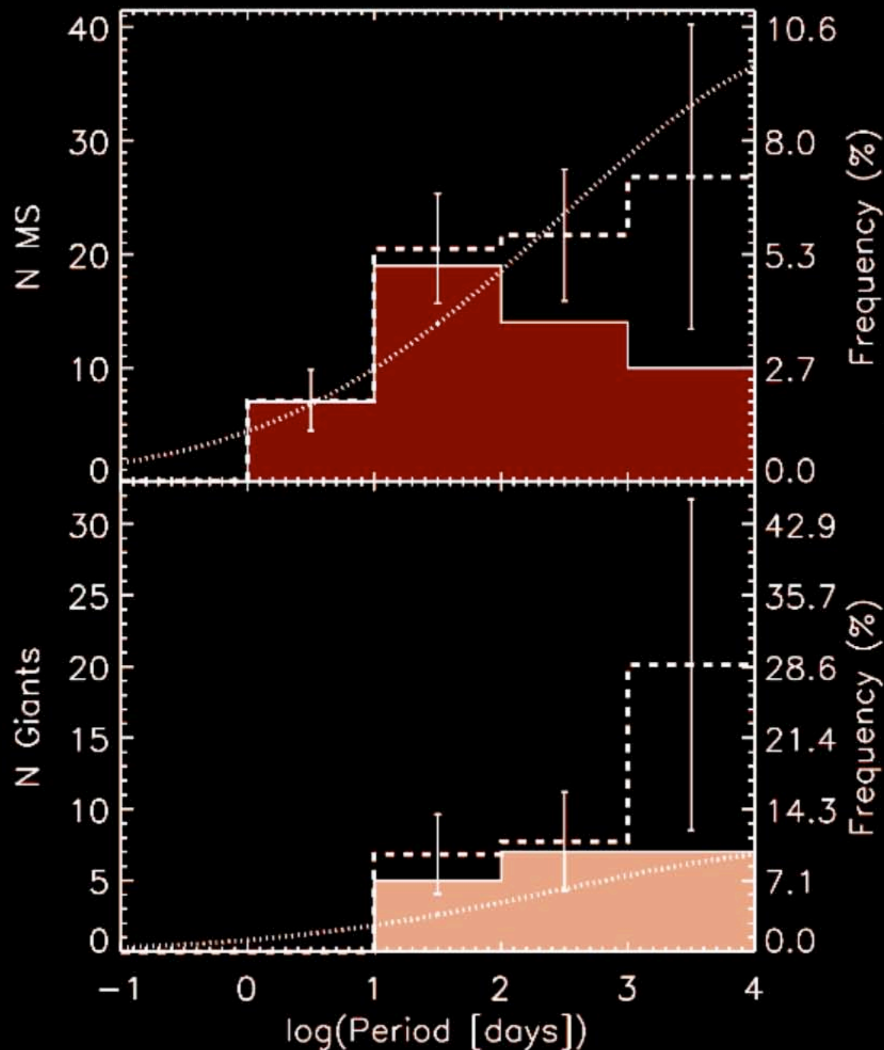
- Trend in cluster binary frequency with radius
- First and last bins are 99% distinct
- **Confirms central concentration of binaries** (found in Geller et al. 2008)

Recent Results: *Binary Population*

Period Distribution

- MS period distribution is consistent with the Galactic field from Duquennoy & Mayor (1991)

- ***Not consistent with flat in log(P)***



Geller & Mathieu 2009a, in prep.

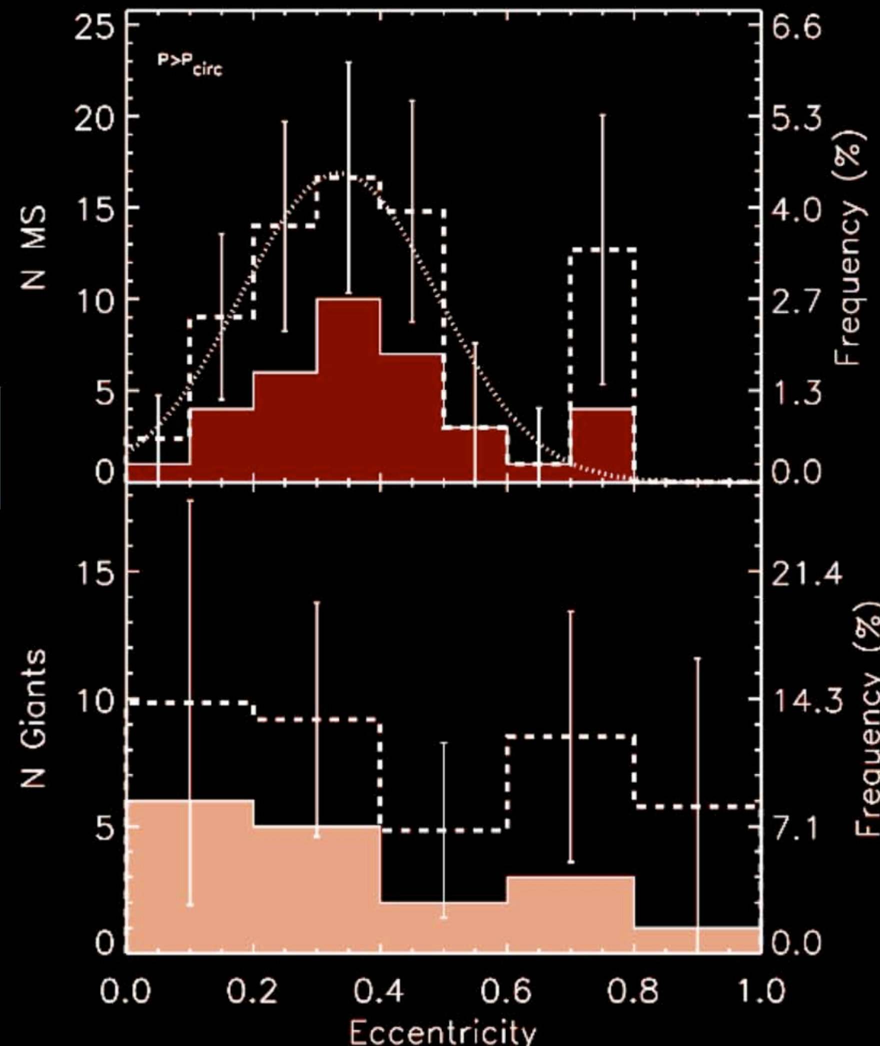
Recent Results: *Binary Population*

Eccentricity Distribution

- MS period distribution is fit well with a Gaussian centered on $e \sim 0.3$ (also similar to Galactic field)

- Some binaries with high e = encounter products?

- ***Not consistent with thermal distribution***



Geller & Mathieu 2009a, in prep.

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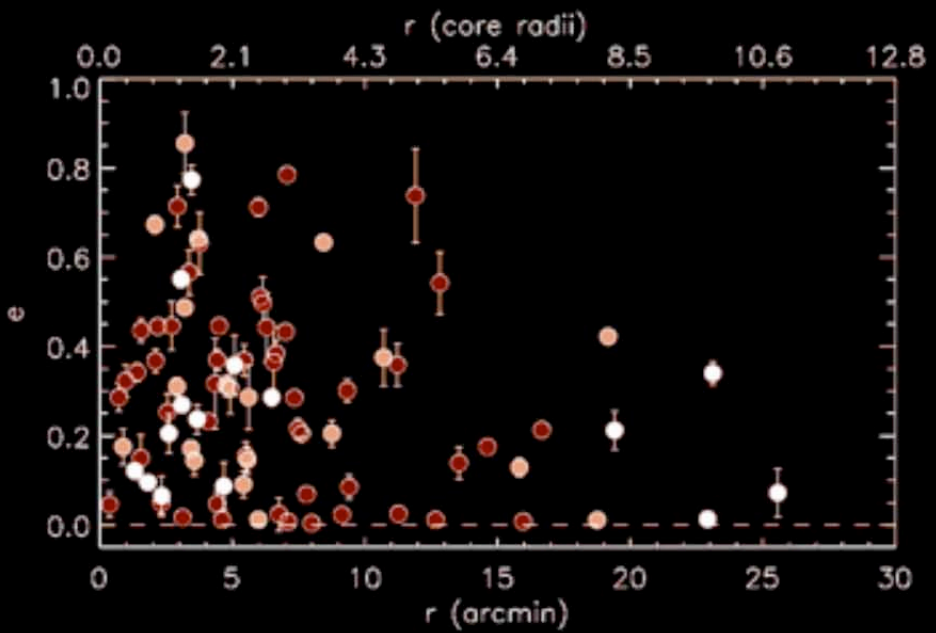
Recent Results: *Binary Population*

Eccentricity Distribution



• Possible trend :

➔ *e* appears to decrease with radius

Result of dynamical processing?

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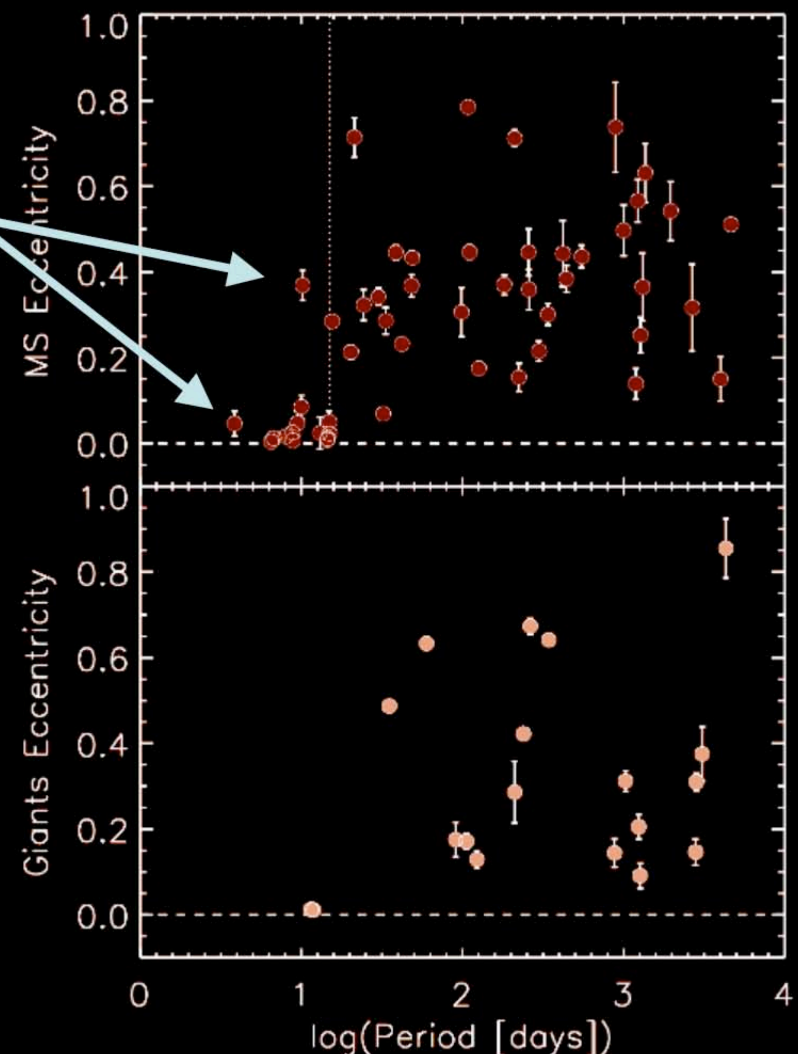
Geller & Mathieu 2009a, in prep.

Recent Results: *Binary Population*

e - log(*P*)

- $P < P_{circ}$ but $e > 0$

➔ Signature of dynamical encounter(s) or other companion(s)?



Geller & Mathieu 2009a, in prep.

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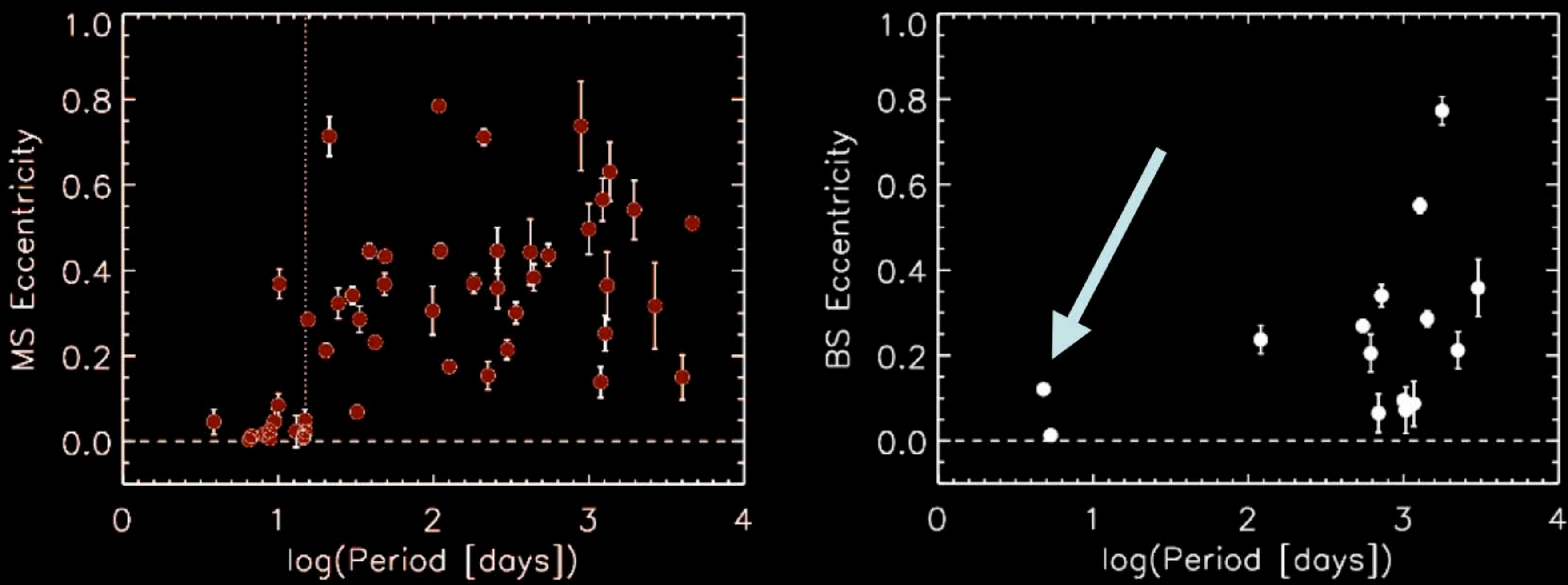
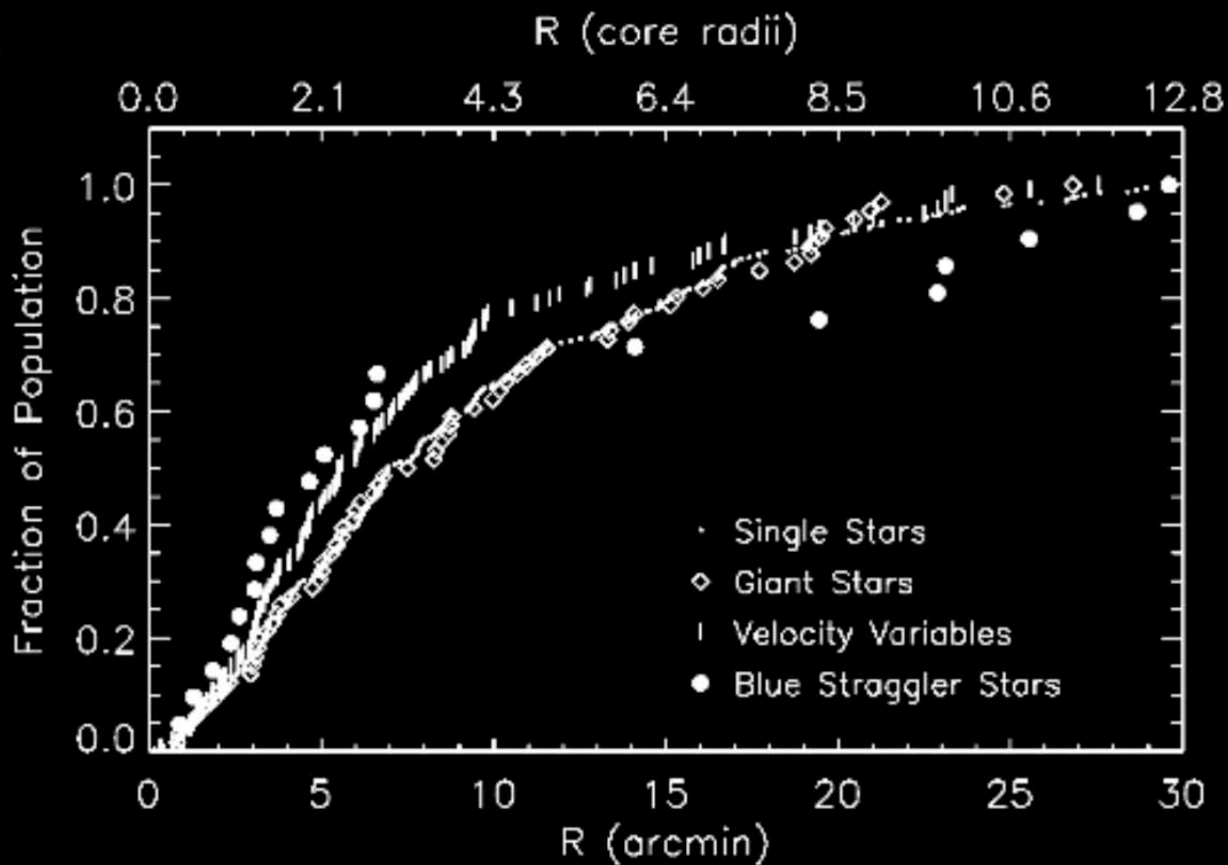
NGC 188 Blue Stragglers



- ***2D K-S test : 99% confidence that MS and BS drawn from distinct parent distributions***

Geller & Mathieu 2009a, 2009b, in prep.;
Mathieu & Geller 2009 in prep

NGC 188 Blue Stragglers



Geller et al. 2008

- NGC 188 BS have a suspiciously **bimodal** spatial distribution

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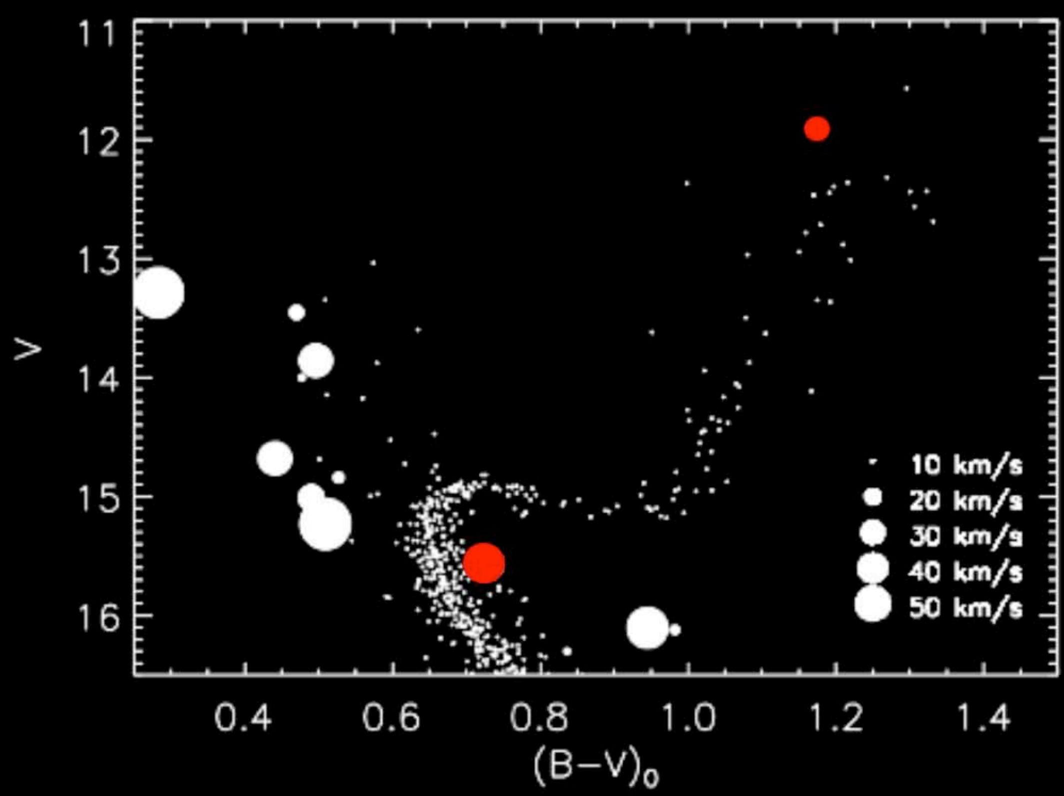
NGC 188 Blue Stragglers



Geller & Mathieu 2009b, in prep.

- ~40% of the BS show above average **rotation** (~10-70 km/s)

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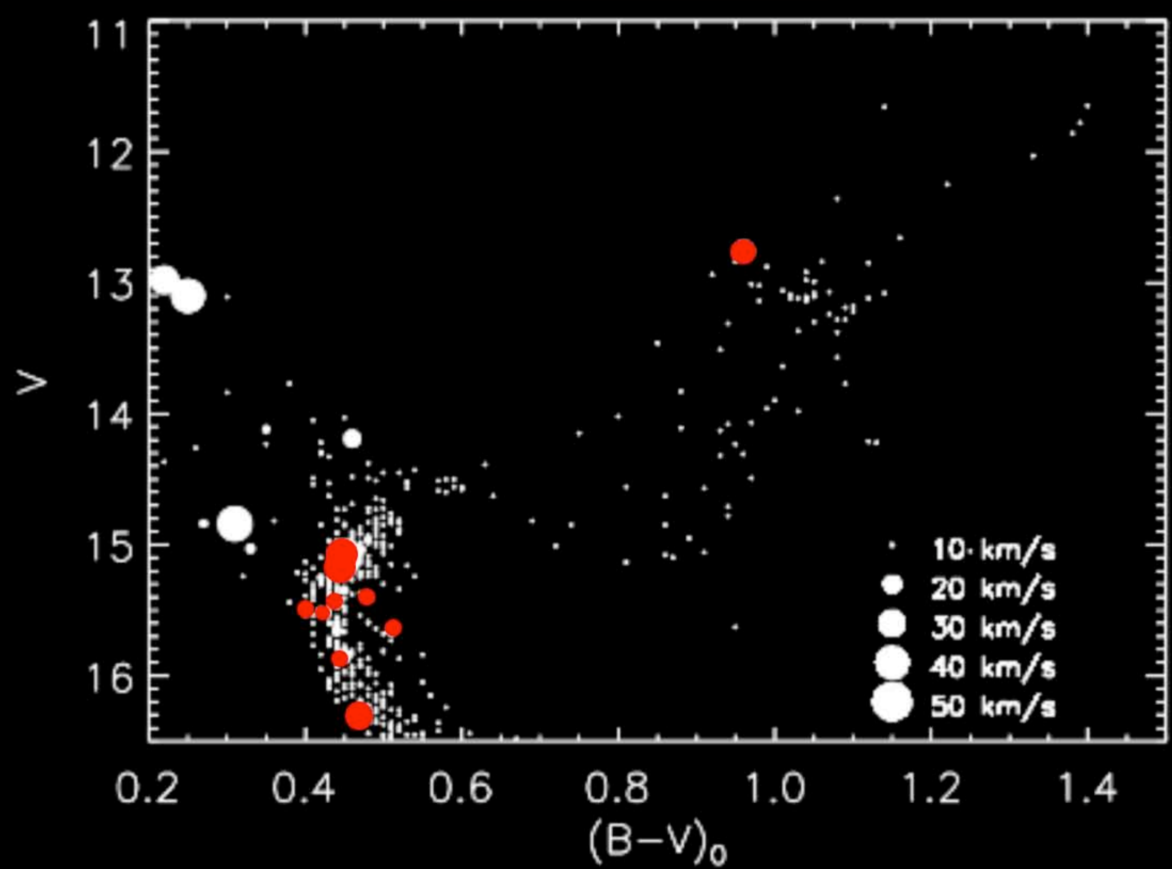
"Hidden" Blue Stragglers

NGC 6819



Geller & Mathieu 2009b, in prep.

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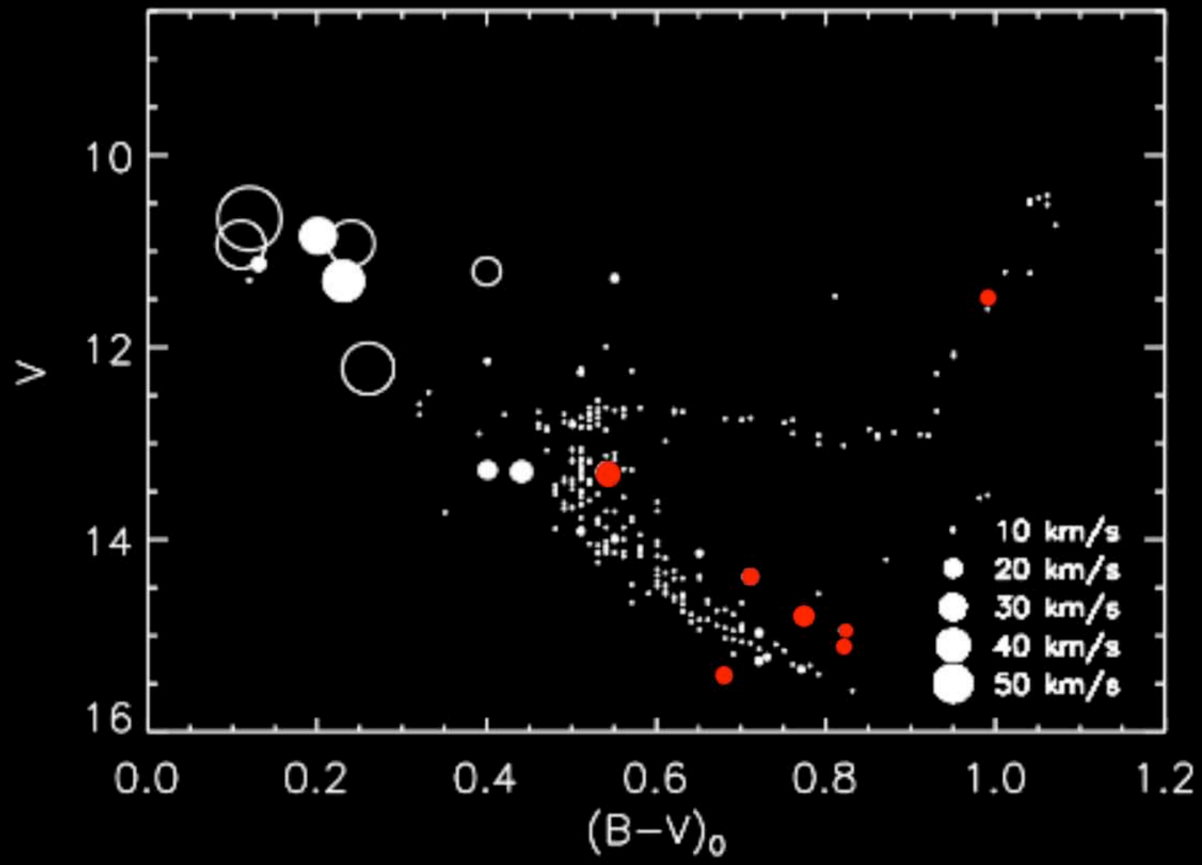
“Hidden” Blue Stragglers

M67



Geller & Mathieu 2009b, in prep.

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NGC 188 Blue Stragglers

- Have a binary frequency of **73 ± 24%** (as compared to the 21 ± 3% observed MS frequency)

- Have a suspiciously **bimodal** spatial distribution

- Show a striking concentration around **P~1000 d**, with a range of eccentricities

- ~40% show above average **rotation** (~10-70 km/s)

1. How unique are the NGC 188 BS (and binaries)?

2. What formation channels can produce this population of BS?

Comparing to Other Clusters

Binary Frequencies

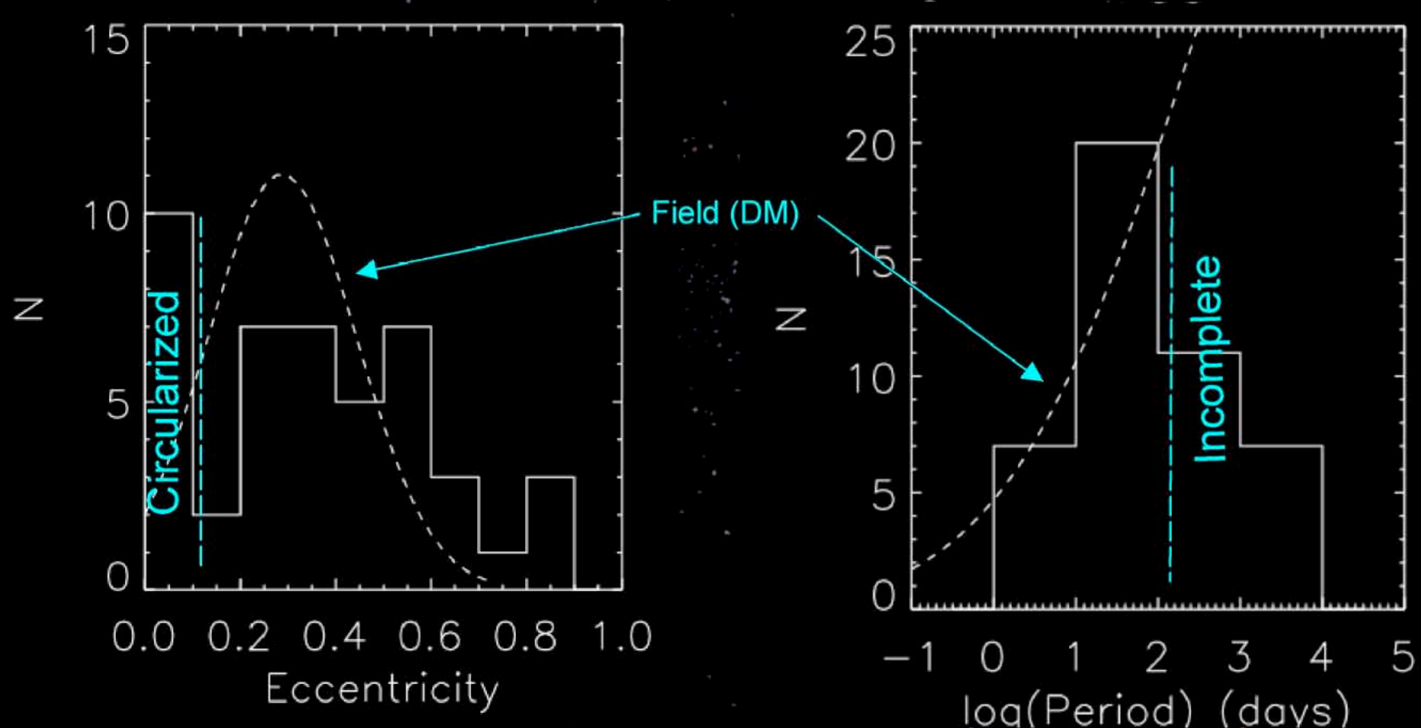
(observed inner 4 core radii, σ(RV) > 1.6, P < 10^4 days)

- M35 (NGC 2168) 0.15 Gyr
  ➔21 ± 3%
- NGC 6819 2.4 Gyr
  ➔20 ± 3%
- M67 (NGC 2682) 4 Gyr
  ➔26 ± 3%
- NGC 188 7 Gyr
  ➔27 ± 4%

These are observed binary frequencies (not corrected for incompleteness).

Comparing to Other Clusters

M35 (NGC 2168 ; ~150 Myr)



- Both distributions are consistent with the field
- Eccentricity distribution is ***NOT*** thermal & period distribution is ***NOT*** flat

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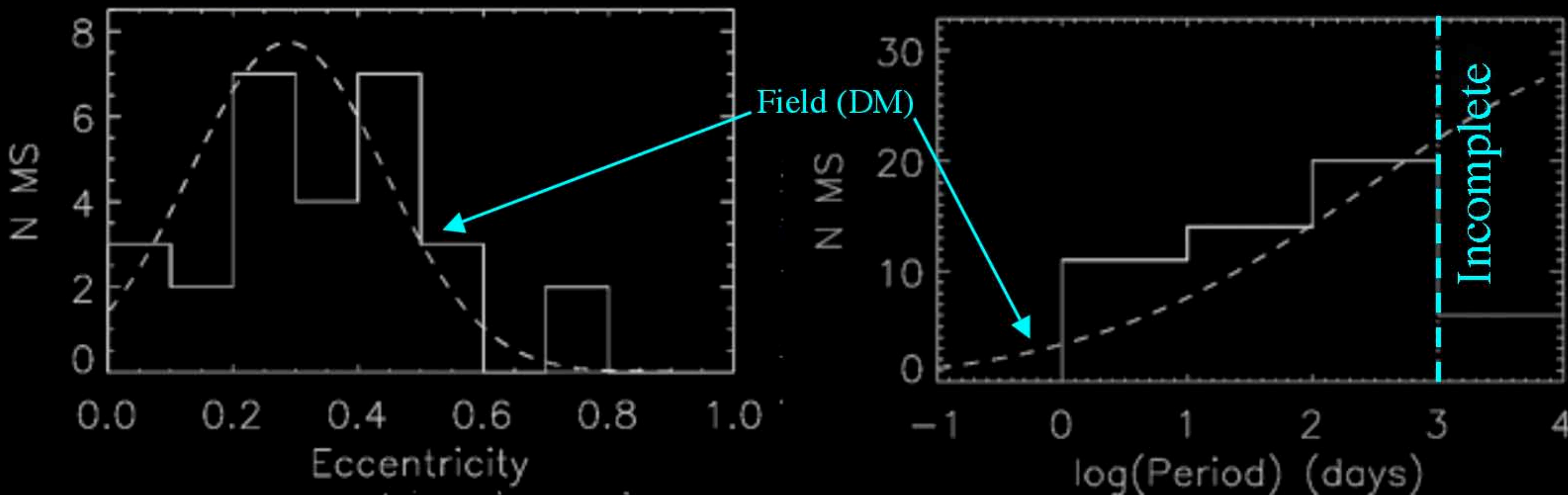
Comparing to Other Clusters

M67 (NGC 2682 ; 4 Gyr)



- Again, both distributions are consistent with the field

Note: M67 BS have a ~60% binary frequency (Latham et al. 1996) with majority at P~1000d (Latham 2006)
➔ similar to NGC 188

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Comparing to Theory (Hurley et al. 2005 Simulation)

Binary Frequency

- MS in simulation: 60 ± 5% (233 / 389)
- MS in NGC 188 : 27 ± 4% (79 / 376) / 77%

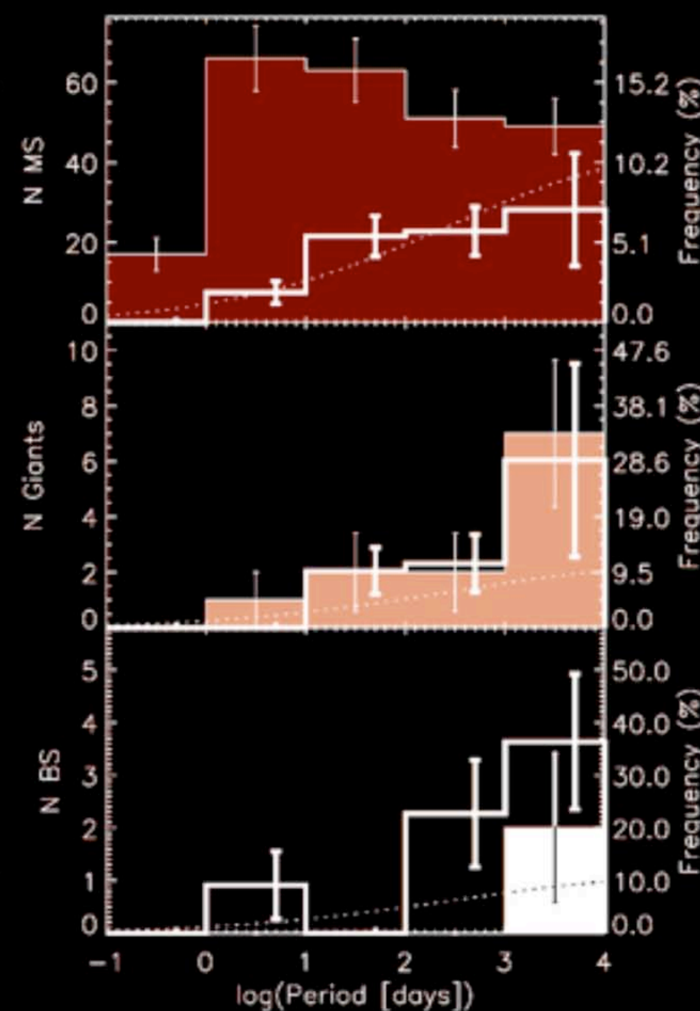
- BS in simulation: 20 ± 16% (2 / 10)
- BS in NGC 188 : 73 ± 24% (16 / 22)

Period Distribution

- Started with distribution flat in log(*P*)

- Results in too many short period MS binaries

This abundance of short-period binaries increases the BS production rate.



Geller & Mathieu 2009a, in prep.

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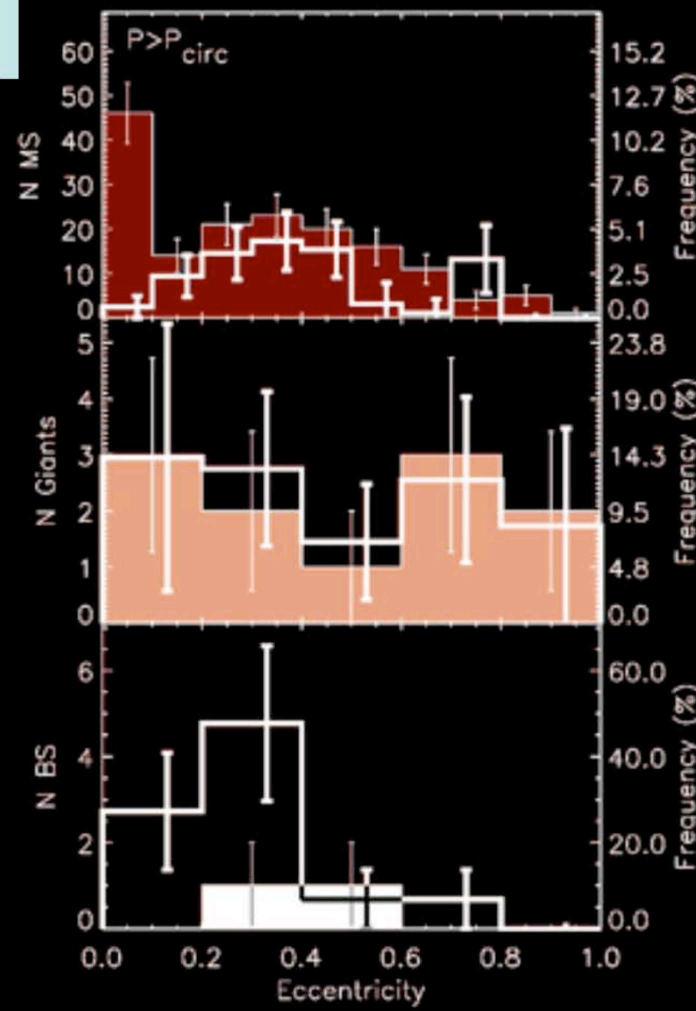
Comparing to Theory (Hurley et al. 2005 Simulation)

Eccentricity Distribution

- Started with thermal distribution
- Lost many of the high-*e* binaries
  - through interactions?
- Created too many circular binaries
  - tidal dissipation to strong/fast?

Biasing population towards high-*e* binaries and overestimating the tidal energy dissipation rate will increase the likelihood of resonant interactions that lead to mergers/collisions - BS creation.



Geller & Mathieu 2009a, in prep.

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Open Questions

- If we…
  - lower the binary frequency
  - remove some initially short-period binaries
  - remove some initially high-eccentricity binaries
  - decrease the tidal energy dissipation rate

Can we still create ***enough*** blue stragglers and will they have ***NGC 188 (and M67) characteristics***?

- How do the period, eccentricity, secondary mass, mass ratio distributions change with time?
  - "processed" by stellar dynamics and stellar evolution
  - in simulations starting with M35 initial conditions (and others)
  - comparing obs. OCs of different ages (NGC 6819, M67, NGC 188, …)

Future Directions

- Run an *N*-body simulation of NGC 188 (with Jarrod Hurley)
  - using observed initial conditions (M35)
  - matched to detailed observations of NGC 188 (binaries, BS, …)
  - studying the evolution of the binary population, BS origins, etc.
  - starting this summer (or sooner)

- Run an array of open cluster *N*-body simulation using different initial conditions to compare with open clusters of a wide range in observed characteristics

- Perform similar analyses as done for NGC 188 on the binary and BS populations of M35, NGC 6819, M67, and others

- Further observations of BS
  - do BS have magnetic fields?
  - are secondaries in BS binaries MS vs. remnant
    - ➔clue to formation mechanism (e.g., triple vs. mass transfer)

References

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