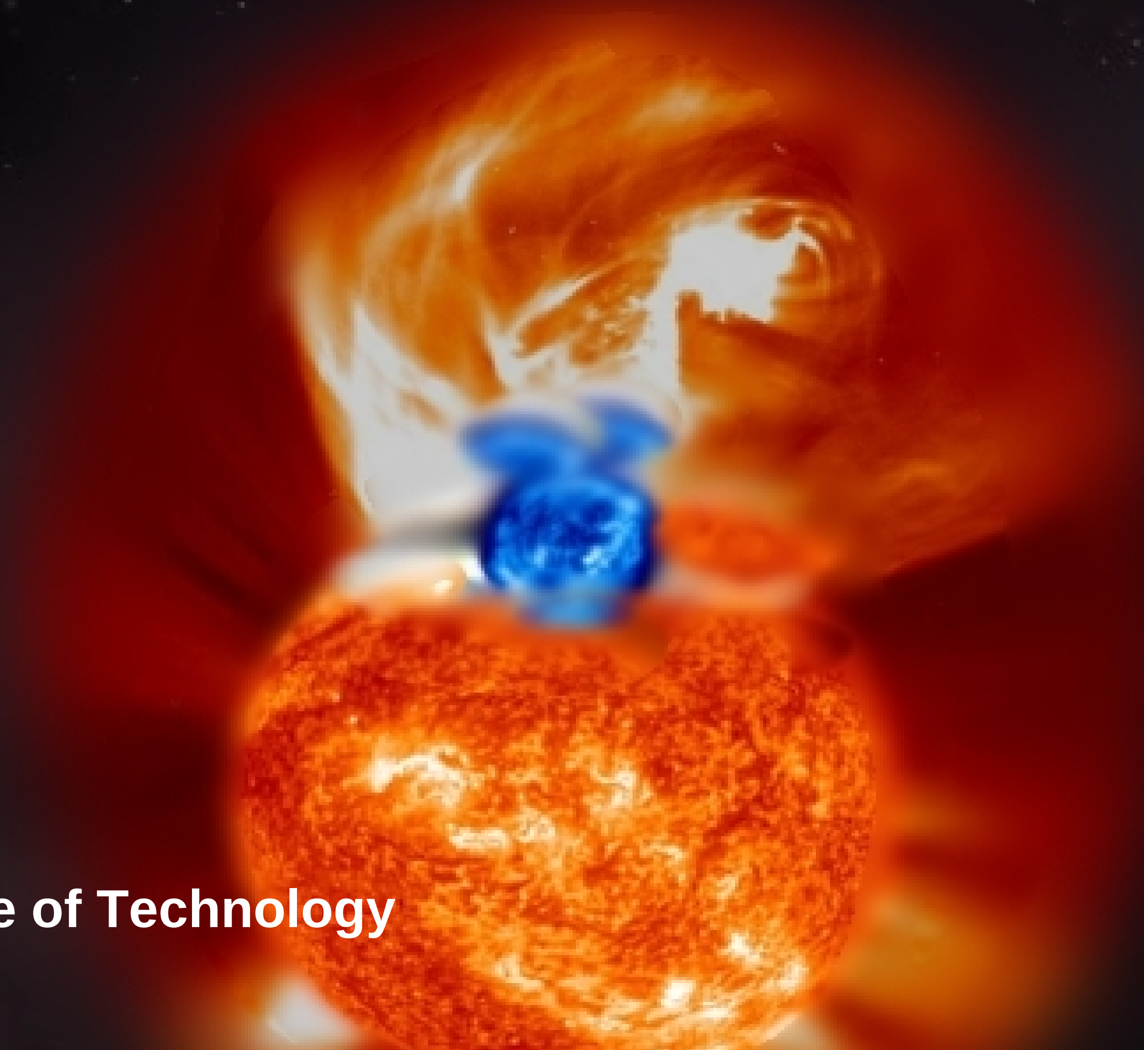
The Multiple Origin of Blue Stragglers



Hagai Perets
Technion – Israel Institute of Technology
November 8, 2012

Overview

- BSS formation channels and their predictions
  - The triple origin of blue stragglers (TRI)
  - Mass transfer (A) and mergers (MTA)
  - Mass transfer (B,C) (MTB/MTC)
  - Collisions
- Models vs. Observations: precision astrophysics in open clusters
- Halo BSs
- GC BSs

Blue stragglers exist in various environments

- Globular clusters
- Open clusters
- Galactic halo
- Young clusters
- The field

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BSs have several observational properties

- Mass/luminousity-color (compared TO mass/CMD position)
- Frequency
- Spatial distribution (in clusters)
- Binarity (and higher multiplicity)
  - Fraction
  - Orbital properties (P, e)
  - Type of companion, and its mass
  - Binary spatial distribution
- Chemical composition
- Correlation with cluster properties
- Rotation

Several formation channels were suggested: COL/MT A,B,C/TRI

- Collisions in dense environments (Hills & Day 1976)
- Mass transfer (McCrea 1964)
  - Case B mass transfer
  - Case C mass transfer
  - Case A mass transfer and mergers
- Primordial triple secular evolution leading to case A MT/mergers/collisions

(HP & Fabrycky 2009)

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(HP & Fabrycky 2009)

The progenitors of MT A/merger BSs are short period binaries

- Short period (typically <5 days) binaries would evolve through case A MT and mergers.

- Low mass (F/G/K) stars are not likely to form at such short periods

- What are the progenitors of short period low mass binaries ?

The progenitors of MT A/merger BSs are short period binaries

- Short period (typically <5 days) binaries would evolve through case A MT and mergers.
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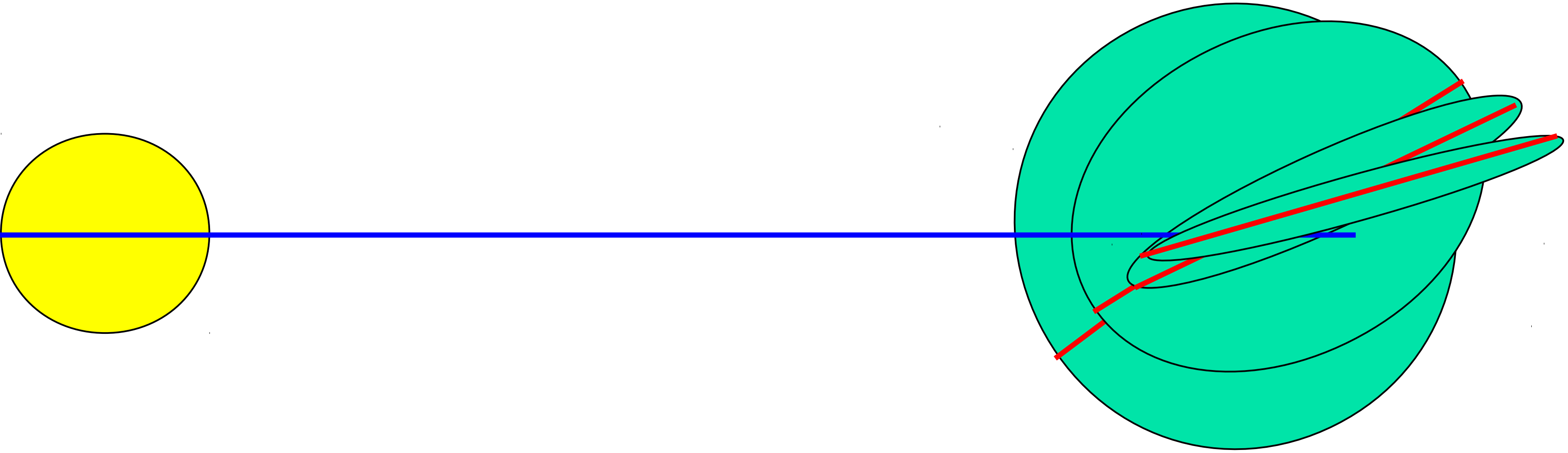
- What are the progenitors of short period low mass binaries ?

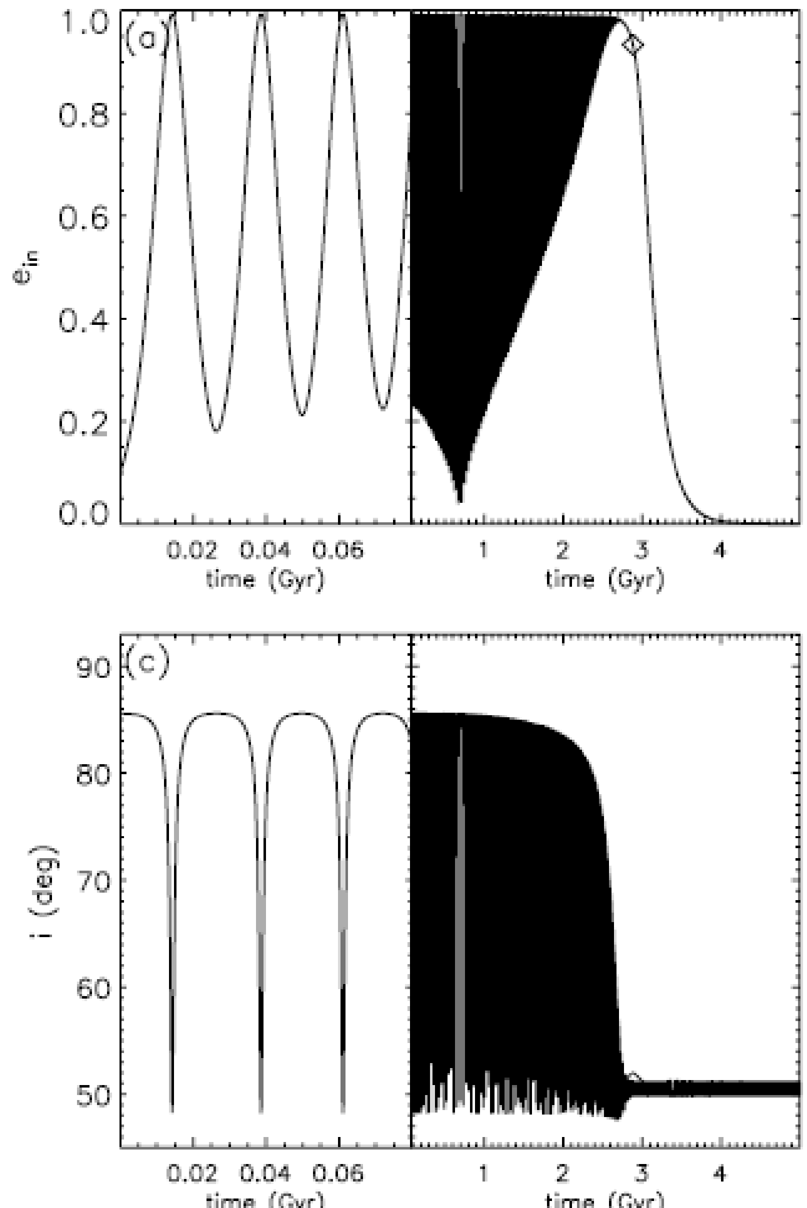
The progenitors of short period binaries are triples

Secular Kozai-Lidov evolution induces high eccentricities



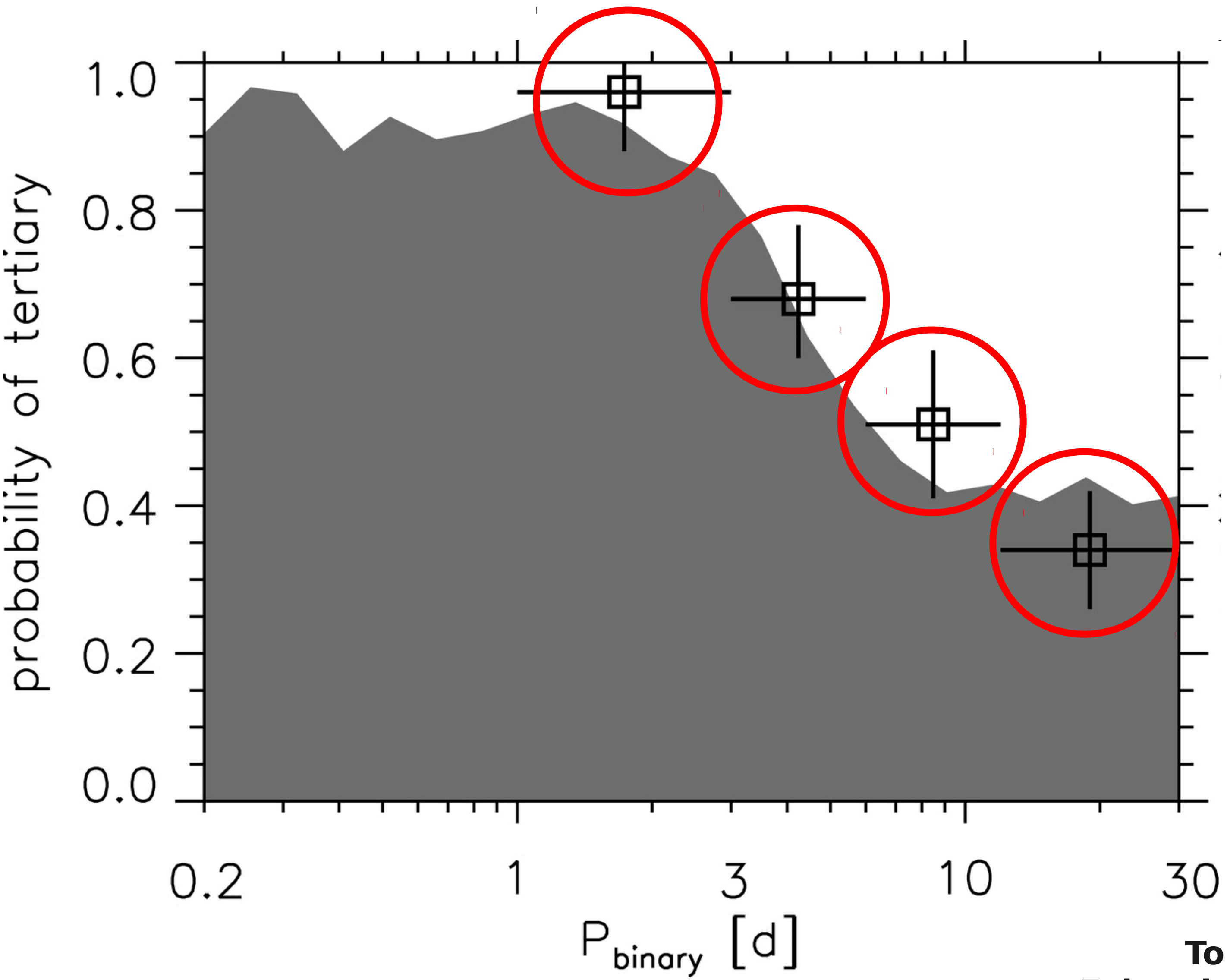
Coupling of Kozai cycles and tidal friction (KCTF) produces short period binaries

Mazeh & Shaham 1979, Eggleton 1998



Fabrycky & Tremaine 2007

Close Binaries and Tertiaries



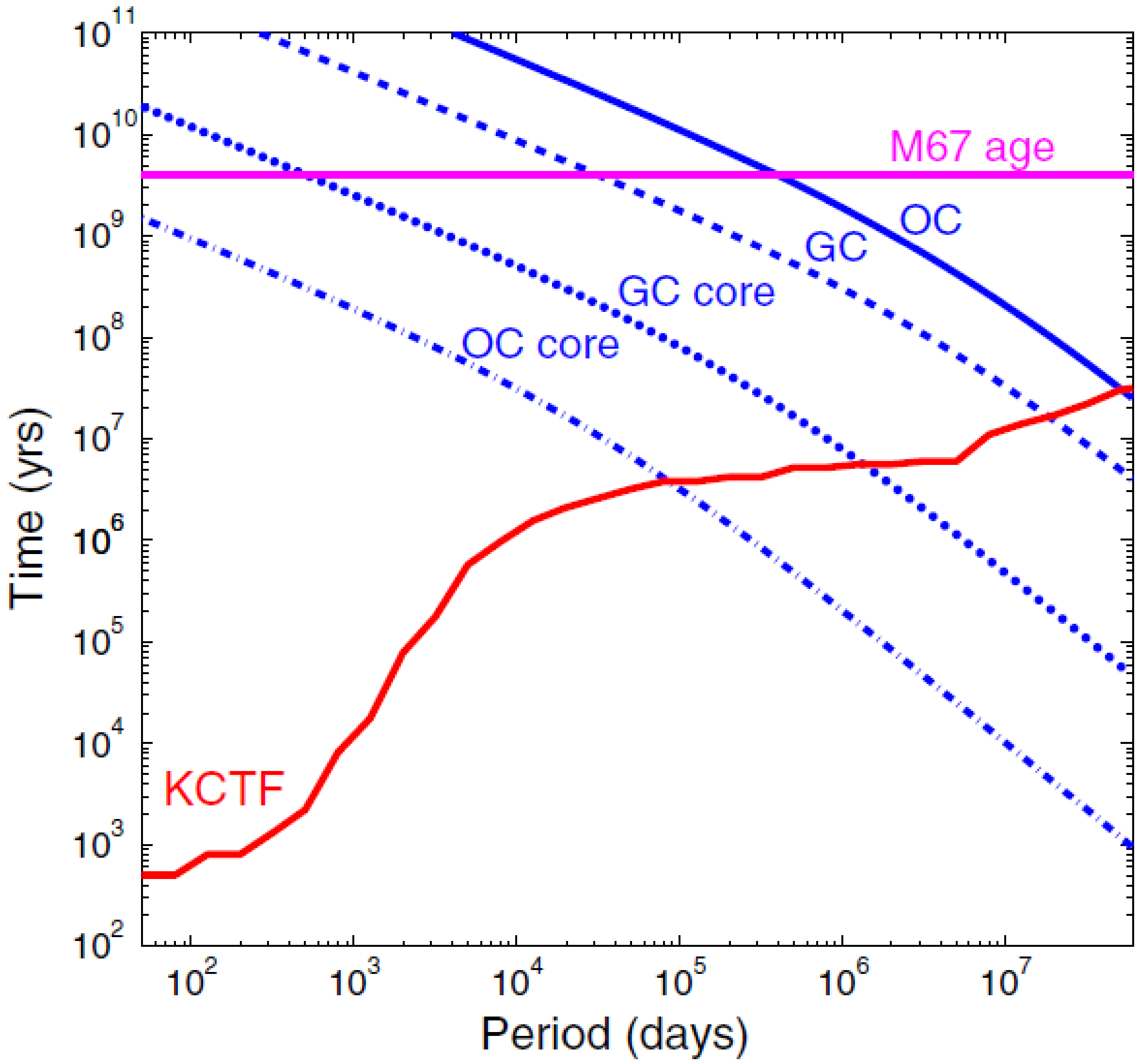
Tokovinin 2006
Fabrycky & Tremaine 2007

The triple origin of blue stragglers

- Mass transfer or merger of close binaries lead to the formation of BSs
- Close Binaries are formed in triples through KCTF evolution
- **MTA/mergers BSs are formed through KCTF evolution in triples**

(HP & Fabrycky 2009)

The triple origin of blue stragglers: Timescales



HP & Fabrycky 2009

Formation channels:
Case A mass transfer & mergers

- Diverse luminosity/mass extends to twice (or even more) TO mass/luminousity
- Some dependence on encounters (dynamical formation of short period binaries), but relevant for low density environment
- Either single or short period binaries
- Spatial distribution, similar to close (<~5 d) binaries

Formation channels:
Triple evolution

- Very similar to Case A MT/mergers with important changes:
  - BSs always have wide orbit companion
  - P,e distribution similar to that of outer binaries (P typically > ~700 d, diverse eccentricity)
  - Companions similar to regular binaries, i.e. typically MS, but WD fraction age dependent

Formation channels:
Triple evolution

- Potential dependence on environment density/collisional parameter (existence of third companion; inclination change)
- Spin orbit-inclination dependence

Formation channels: Physical Collisions

- Diverse luminosity/mass extends to twice (or even more) TO mass/luminousity
- Relevant only for dense enough clusters
- Correlations with collisional parameters
  - Should also be seen in spatial distribution – higher in the core
- Binarity: Low to regular binary fraction, high eccentricity, hard binaries
- Any type of MS/compact companions; preference to high-mass companions

Formation channels:
Case B mass transfer

- Diverse luminosity/mass extends to twice (or even more) TO mass/luminousity, but typically lower
- Relevant to low density environments
- High binary fraction: Typical periods of 10s-100s days; low eccentricity
- WD companion (He WD? 0.2-0.4 Msun)
- Distribution similar to binary population
- Anti-correlation wrt. collisional parameter (?)
- Chemical signatures of MT

Formation channels:
Case C mass transfer

- Low luminousity, mass < TO-mass + ~0.2 Msun
- Relevant to low density environments
- High binary fraction: Typical periods of hundreds to thousands of days; low eccentricity
- WD companion (CO WD ? ~0.5-0.6 Msun)
- Distribution similar to binary population
- Anti-correlation wrt. collisional parameter (?)
- Chemical signatures of MT

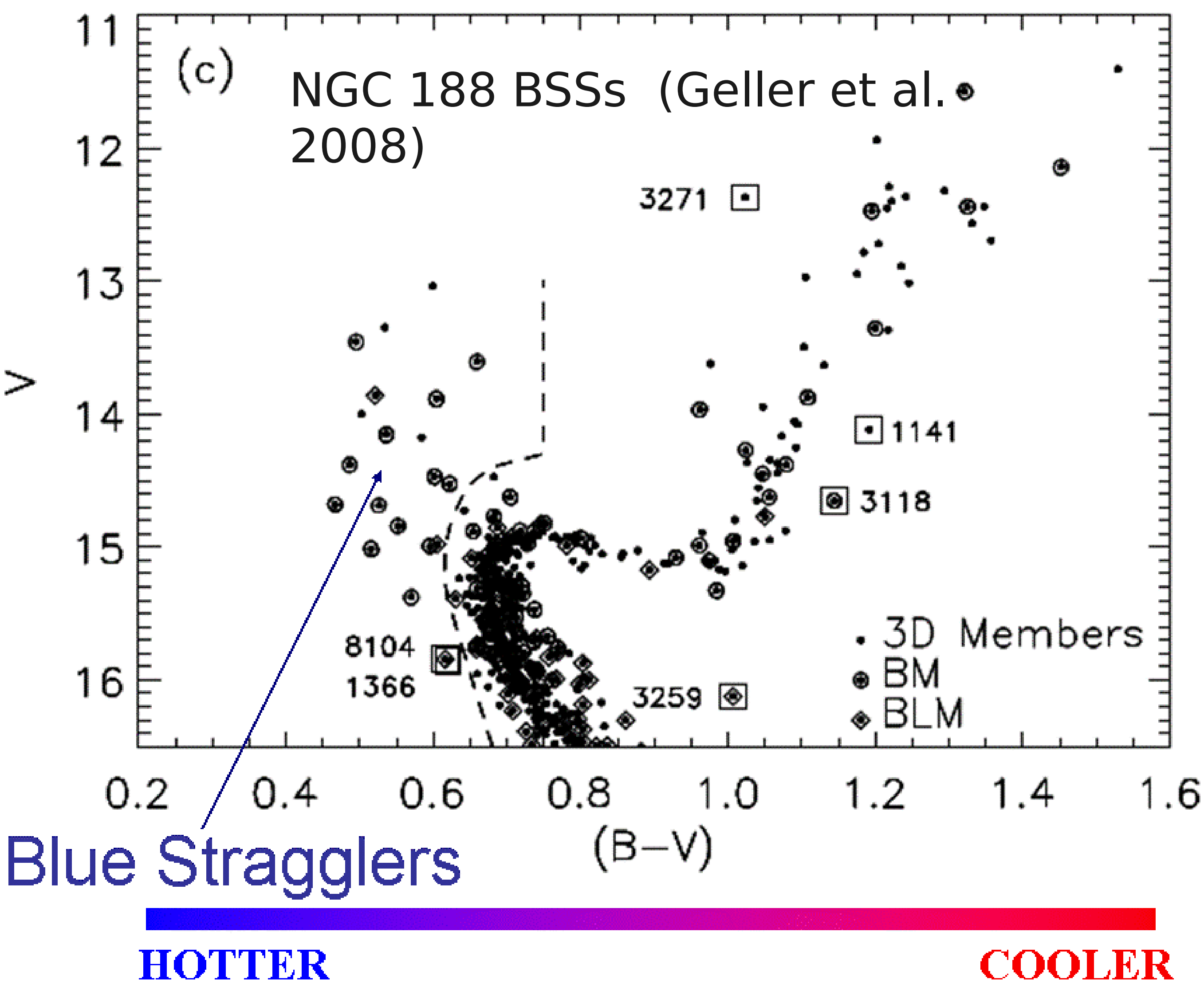
Precision astrophysics in open clusters

- Compare models with detailed observational data:
  - Mass/luminousity/type (BSS and companions)
  - Binary fraction
  - Period-eccentricity distribution
  - Radial distribution
  - Fractions

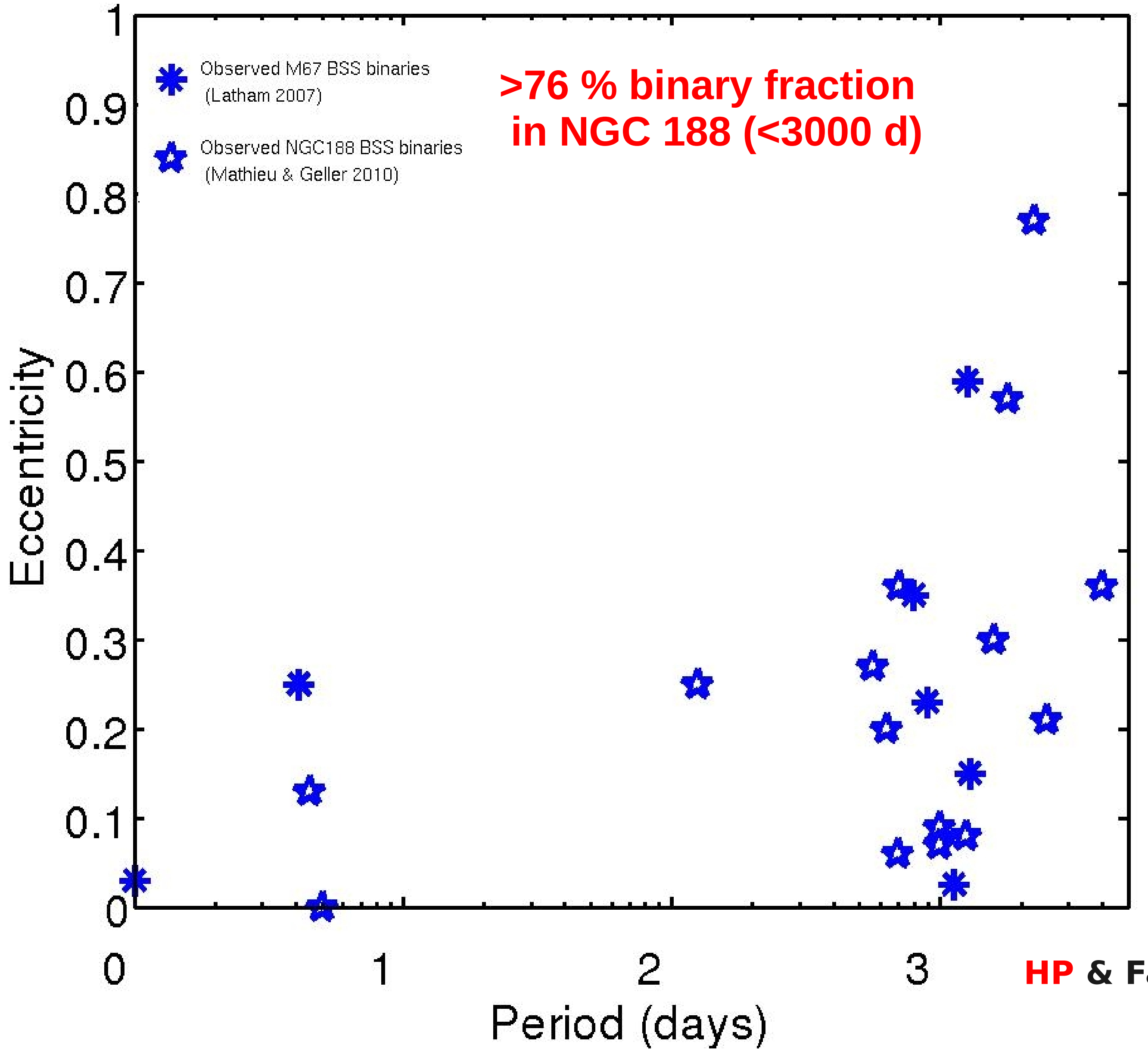
Precision astrophysics in open clusters

- Compare models with detailed observational data:
  - Mass/luminousity/type (BSS and companions)
  - Binary fraction
  - Period-eccentricity distribution
  - Radial distribution
  - Fractions (see Geller talk; note triples)

Color Magnitude Diagram

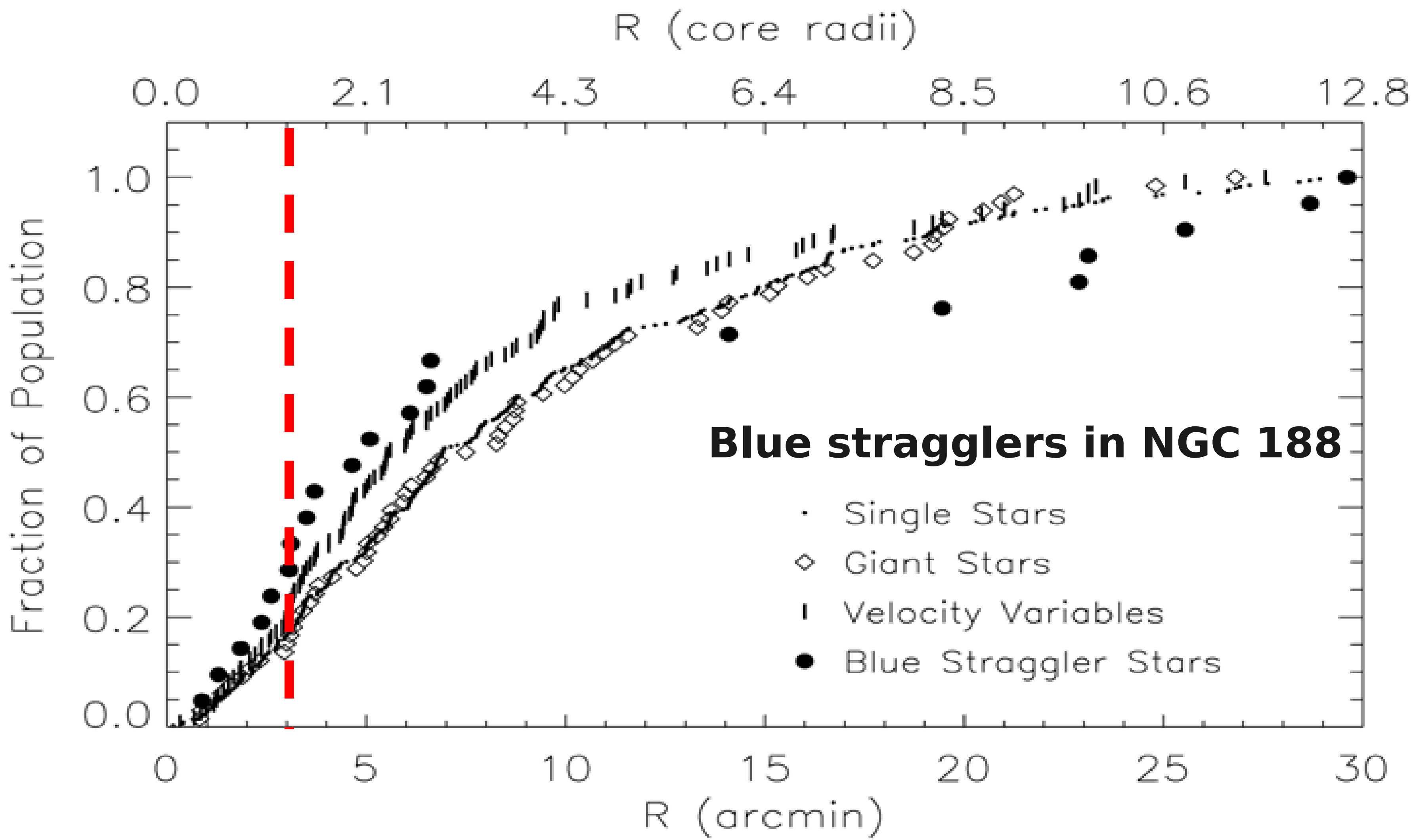


Open clusters binarity:
Fractions and Period-Eccentricity distribution



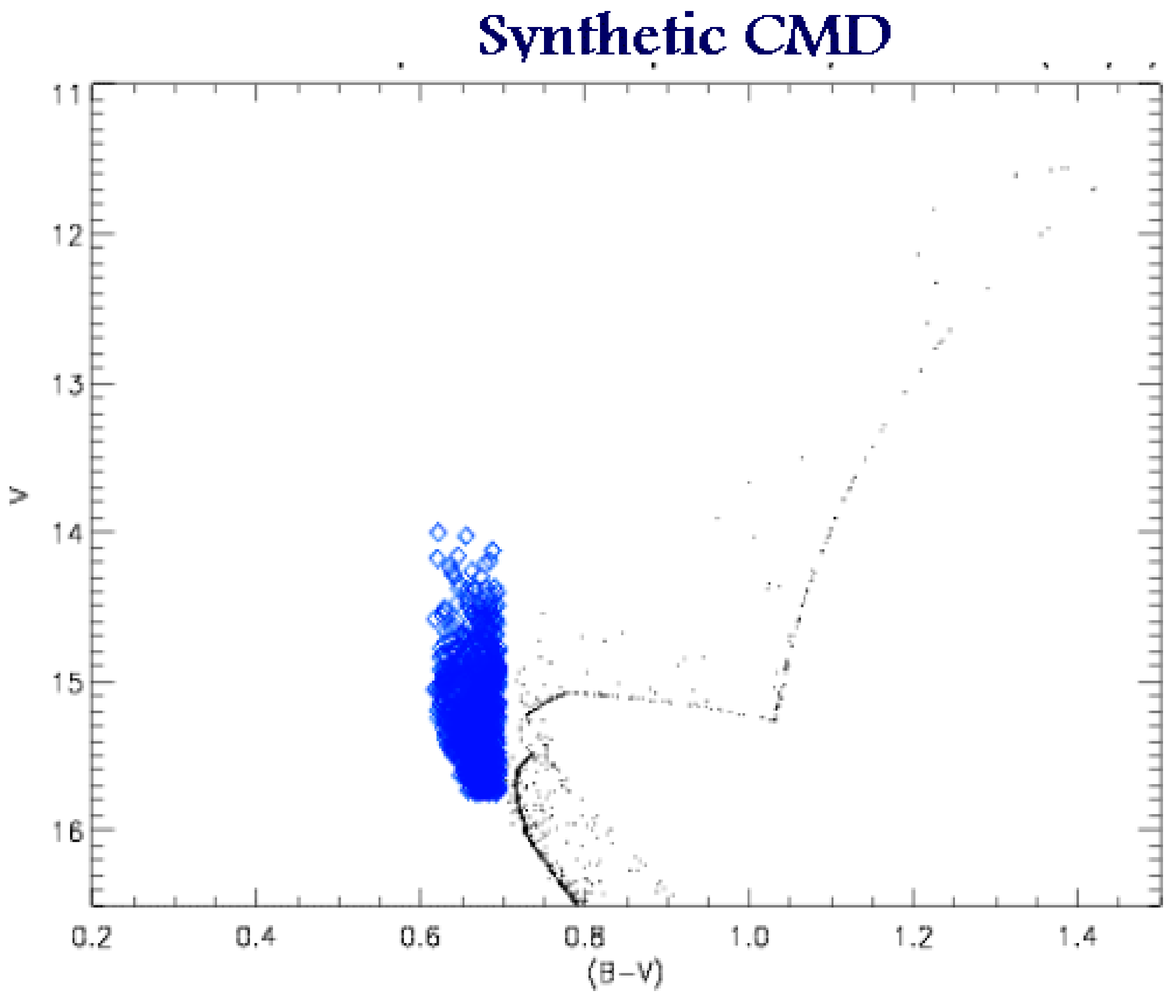
HP & Fabrycky 2009

Spatial distribution of blue stragglers



Geller et al. 2008

Color Magnitude Diagram
Case C mass transfer



Bailey & Mathieu,
Priv. com.

Color Magnitude Diagram
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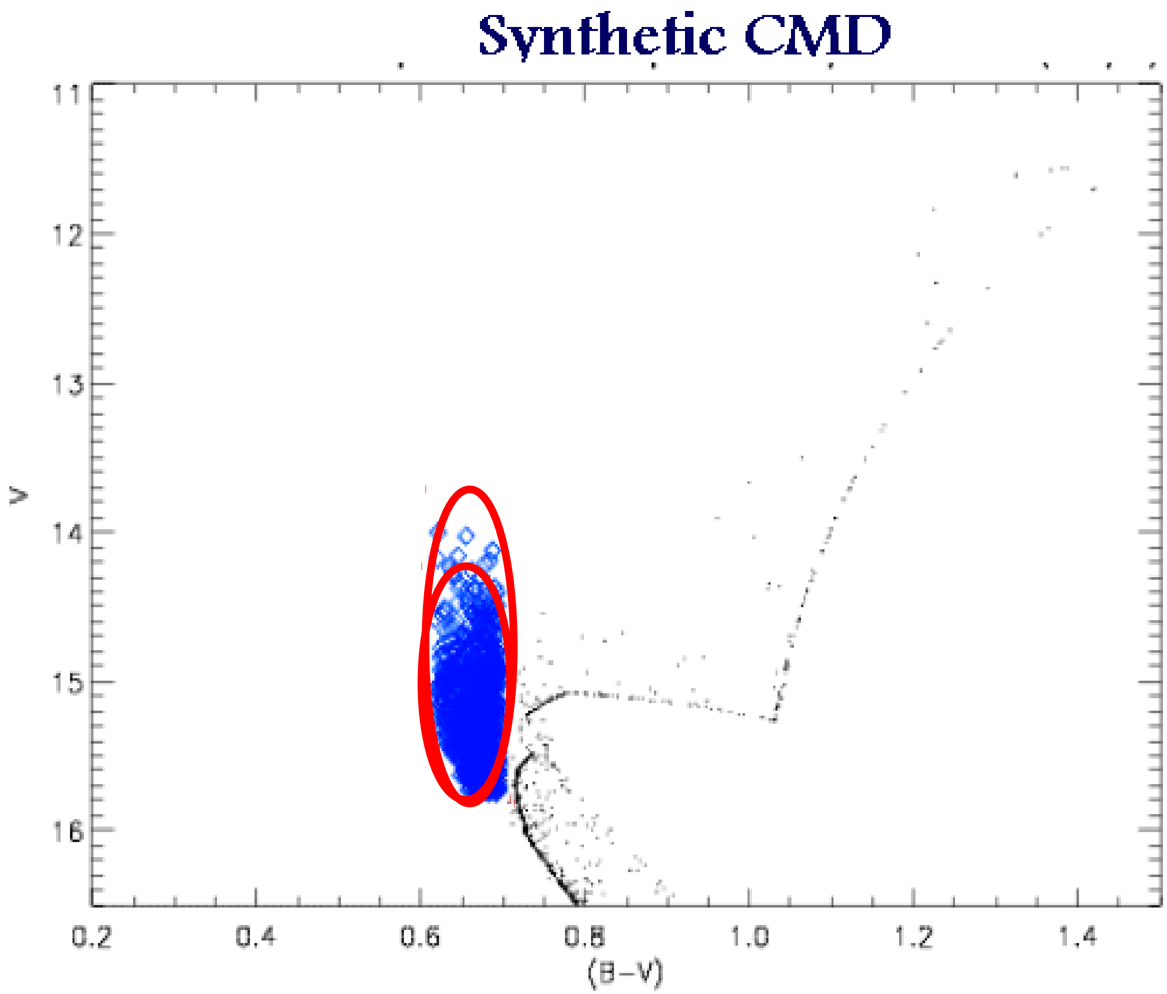

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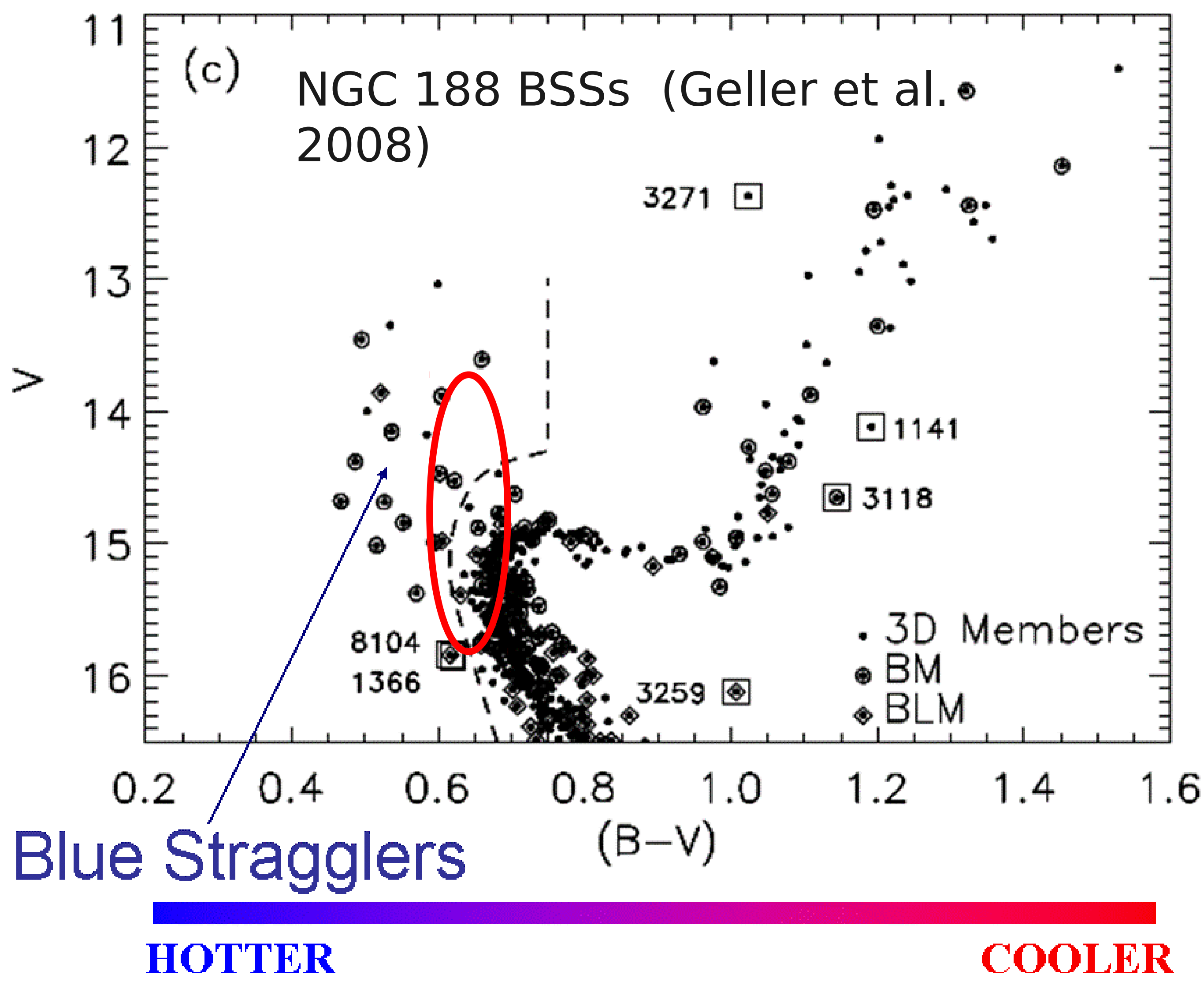
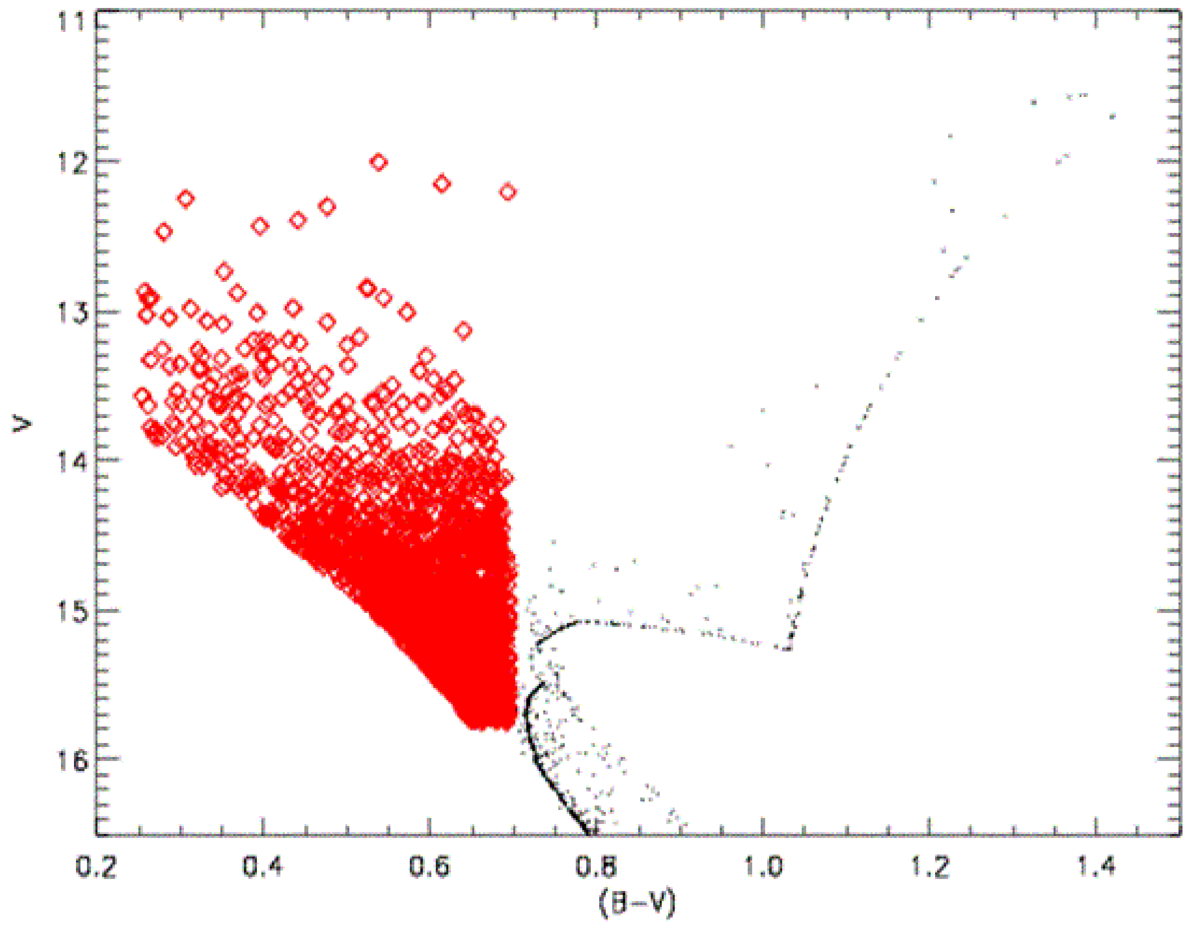


Color Magnitude Diagram: Collisions, MTA and TRI



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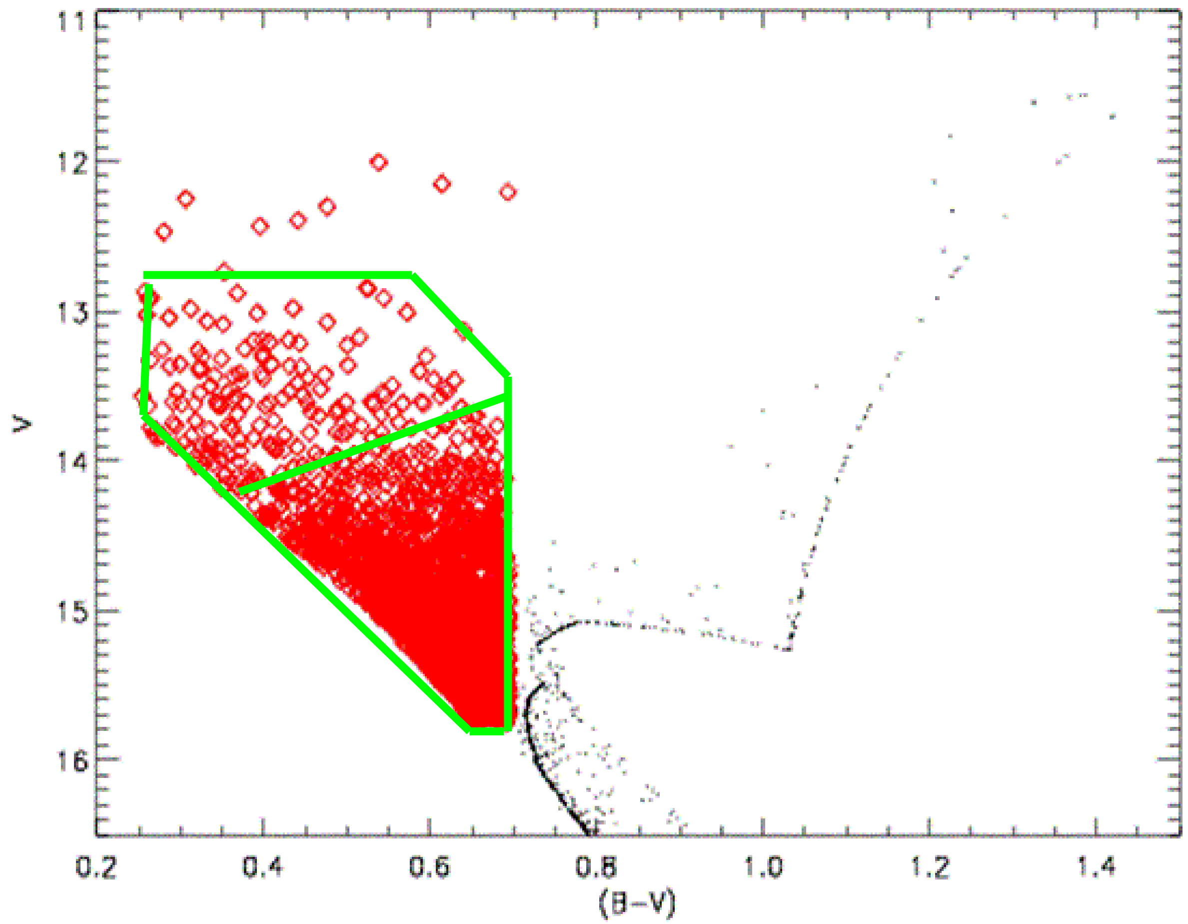

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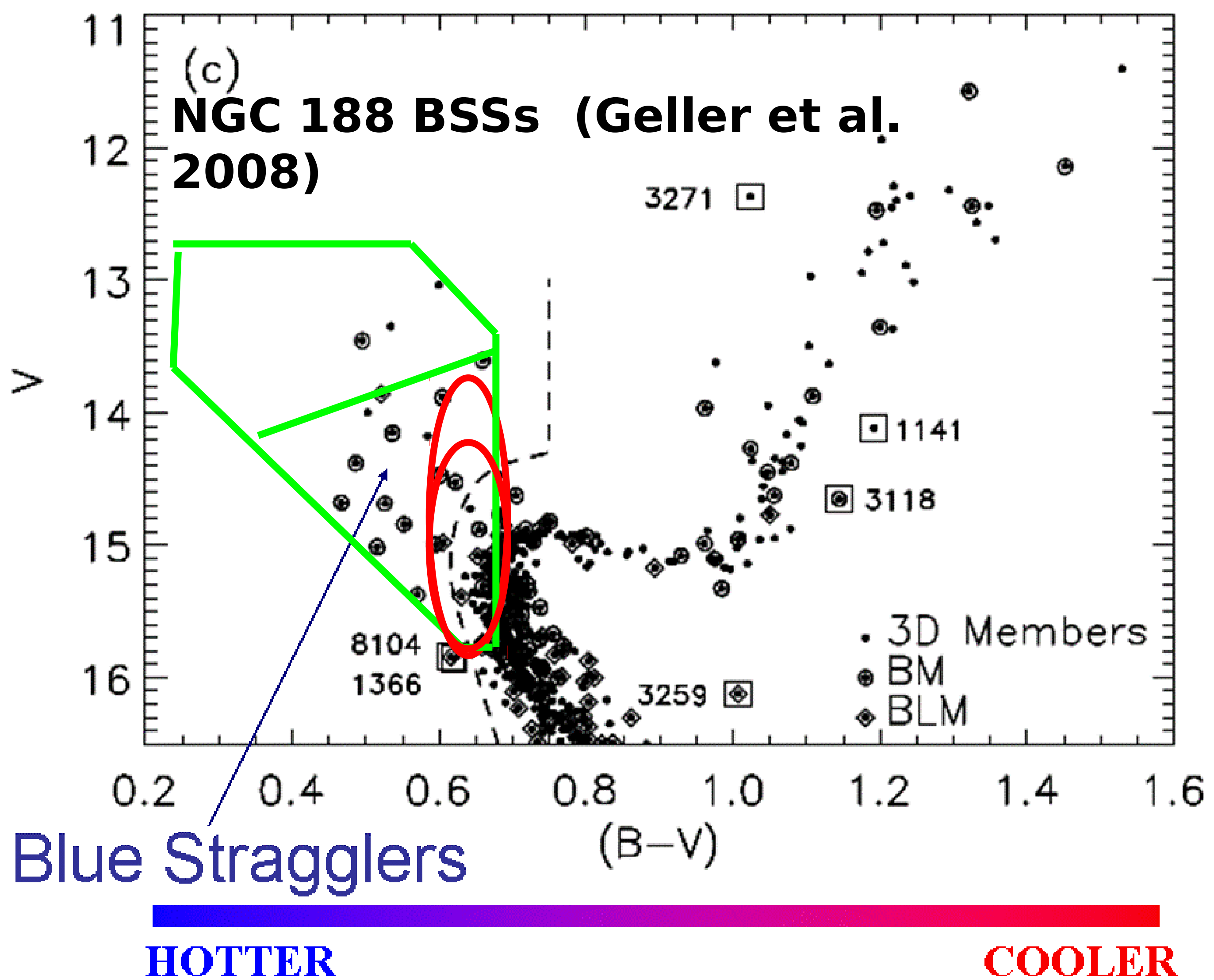
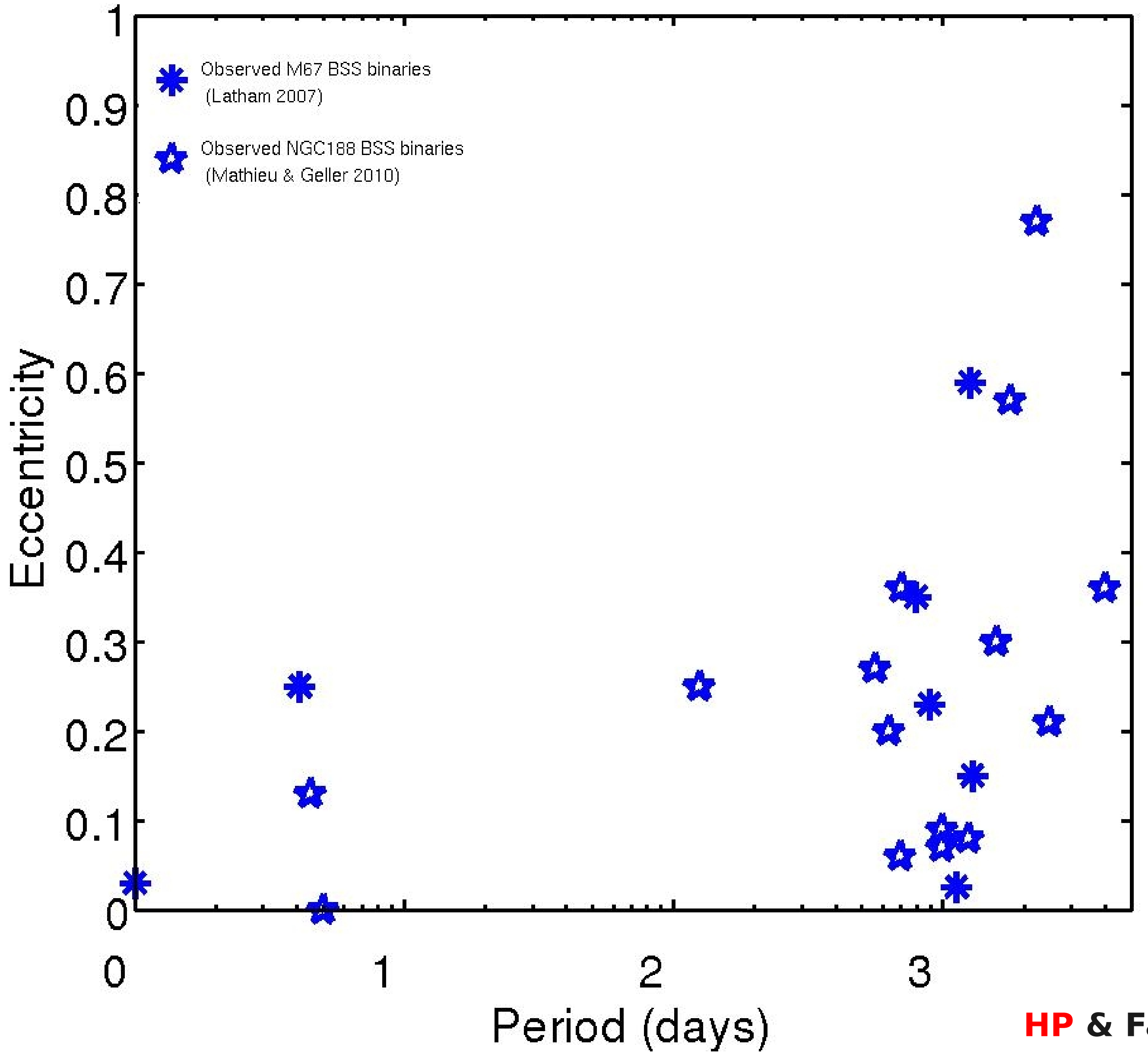


Period-Eccentricity distribution



HP & Fabrycky 2009.

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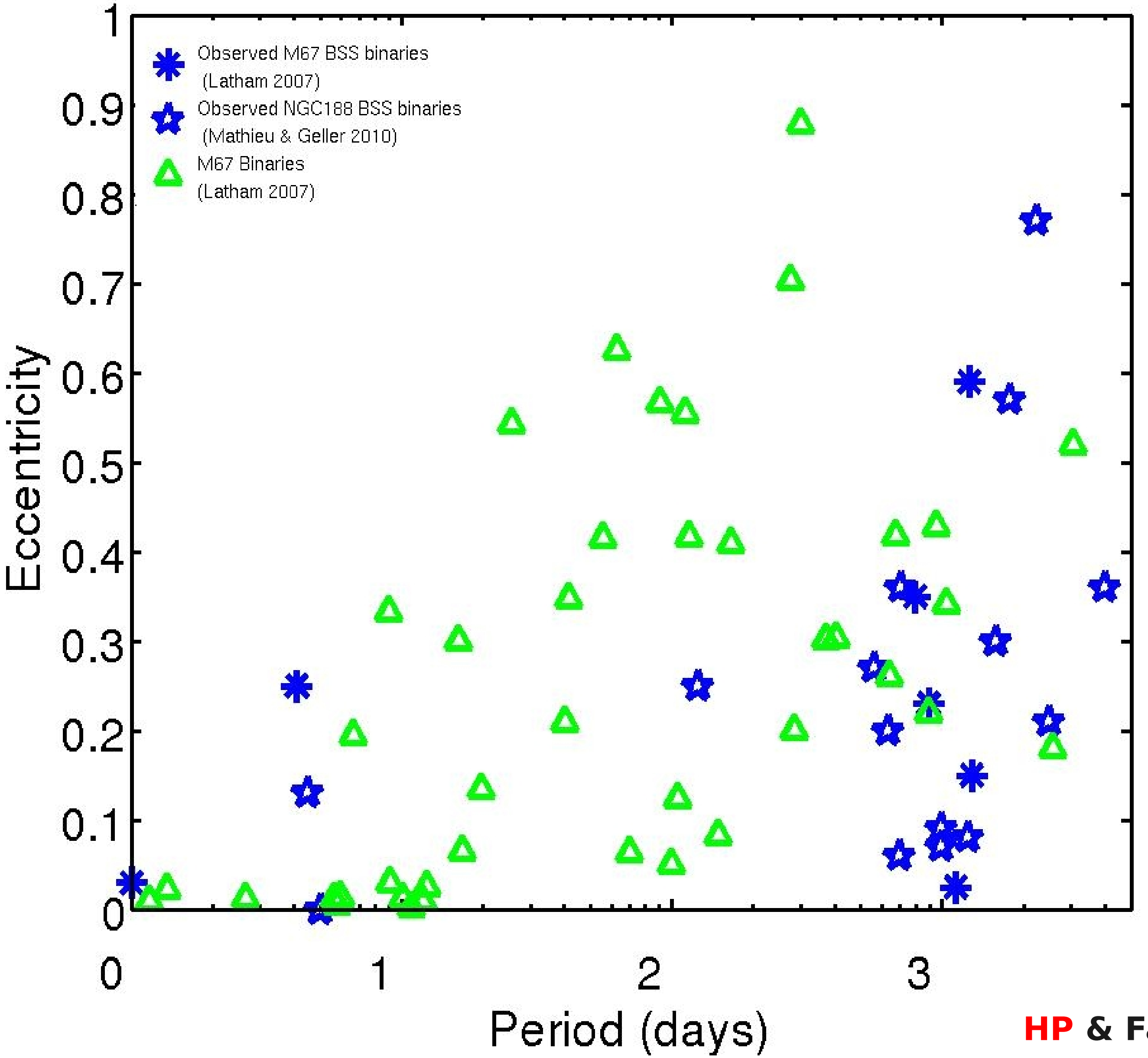
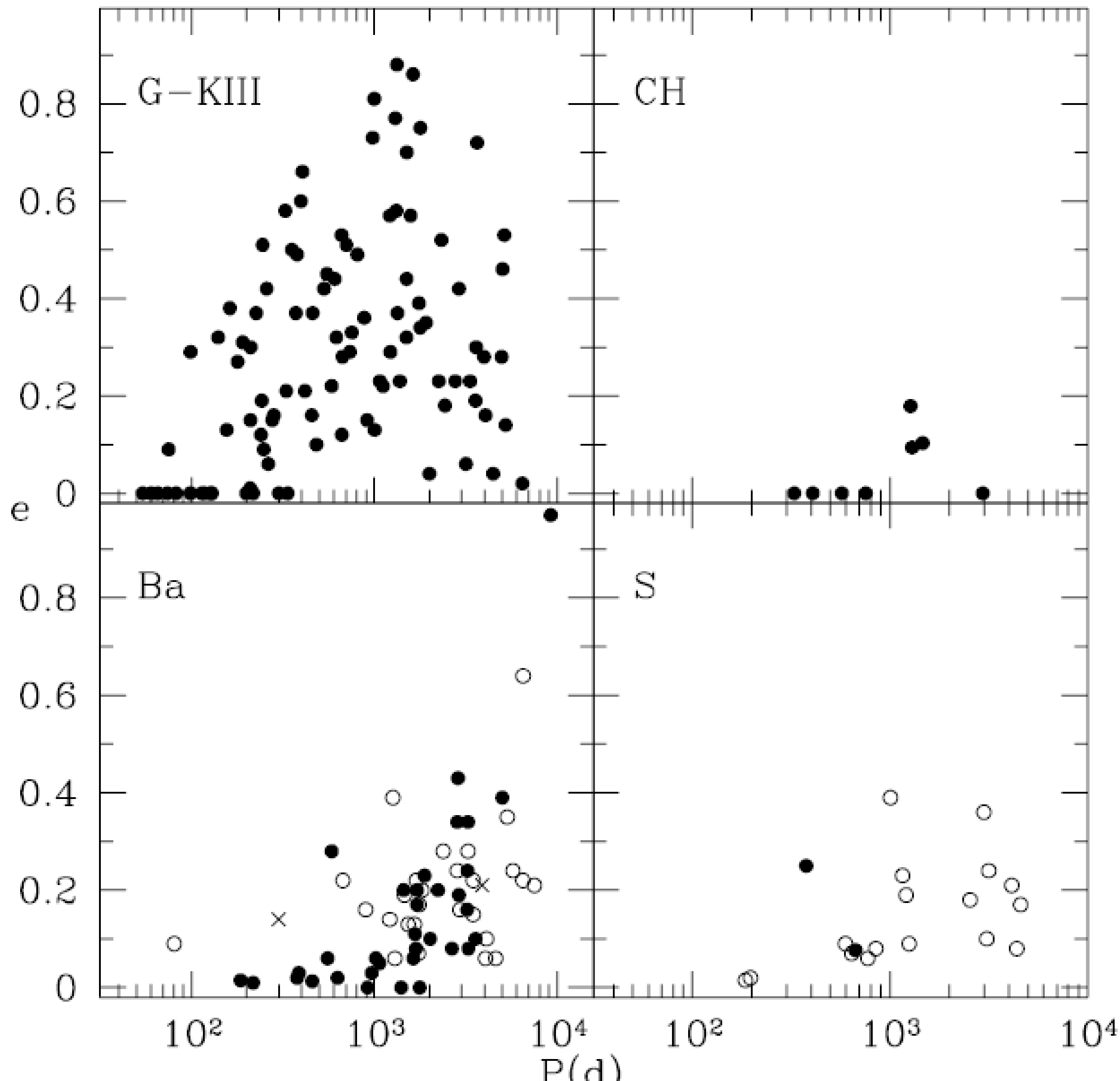


HP & Fabrycky 2009.

Period-Eccentricity distribution: Case C MT (?)



Jurrisen et al. 1998

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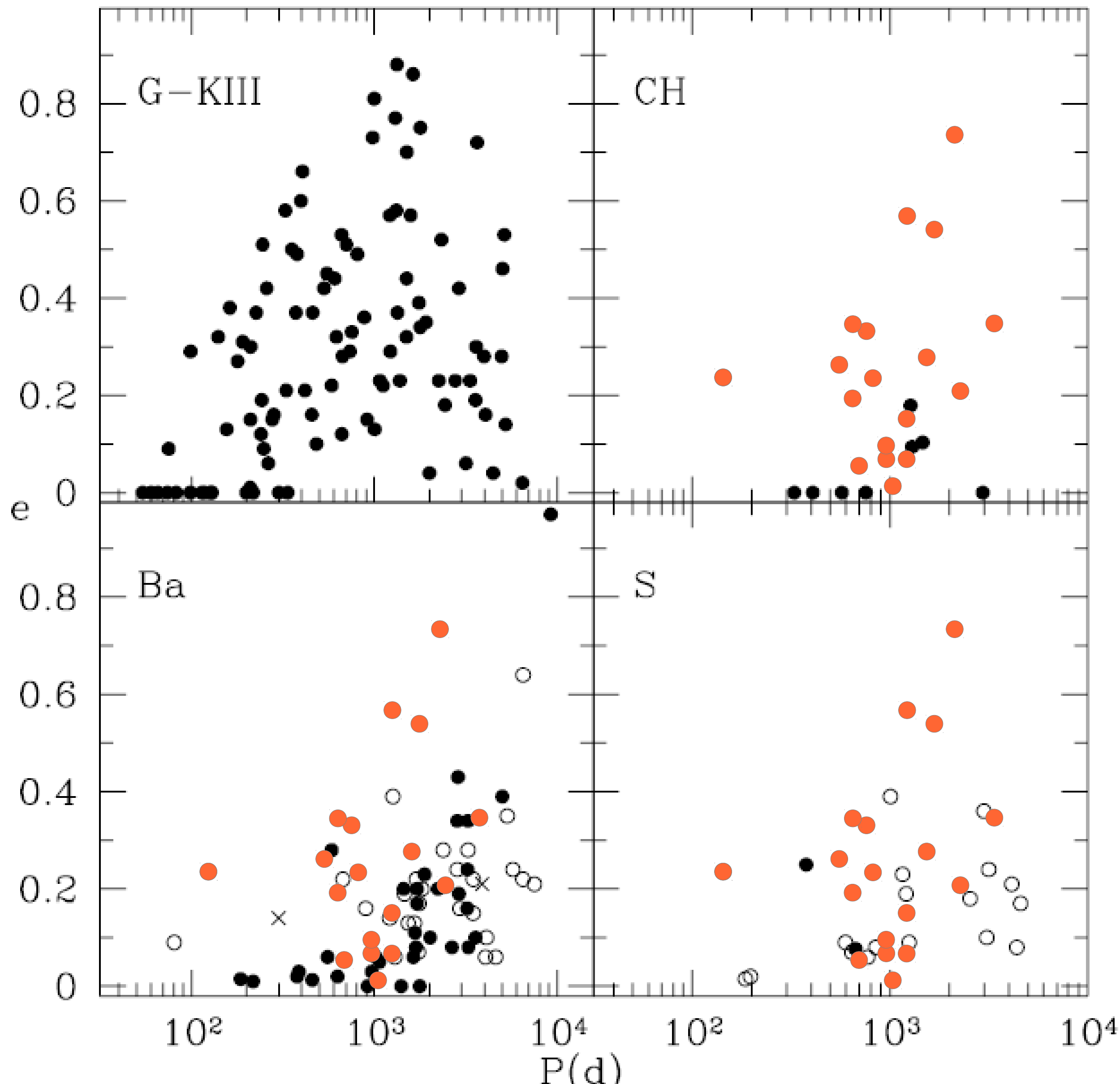

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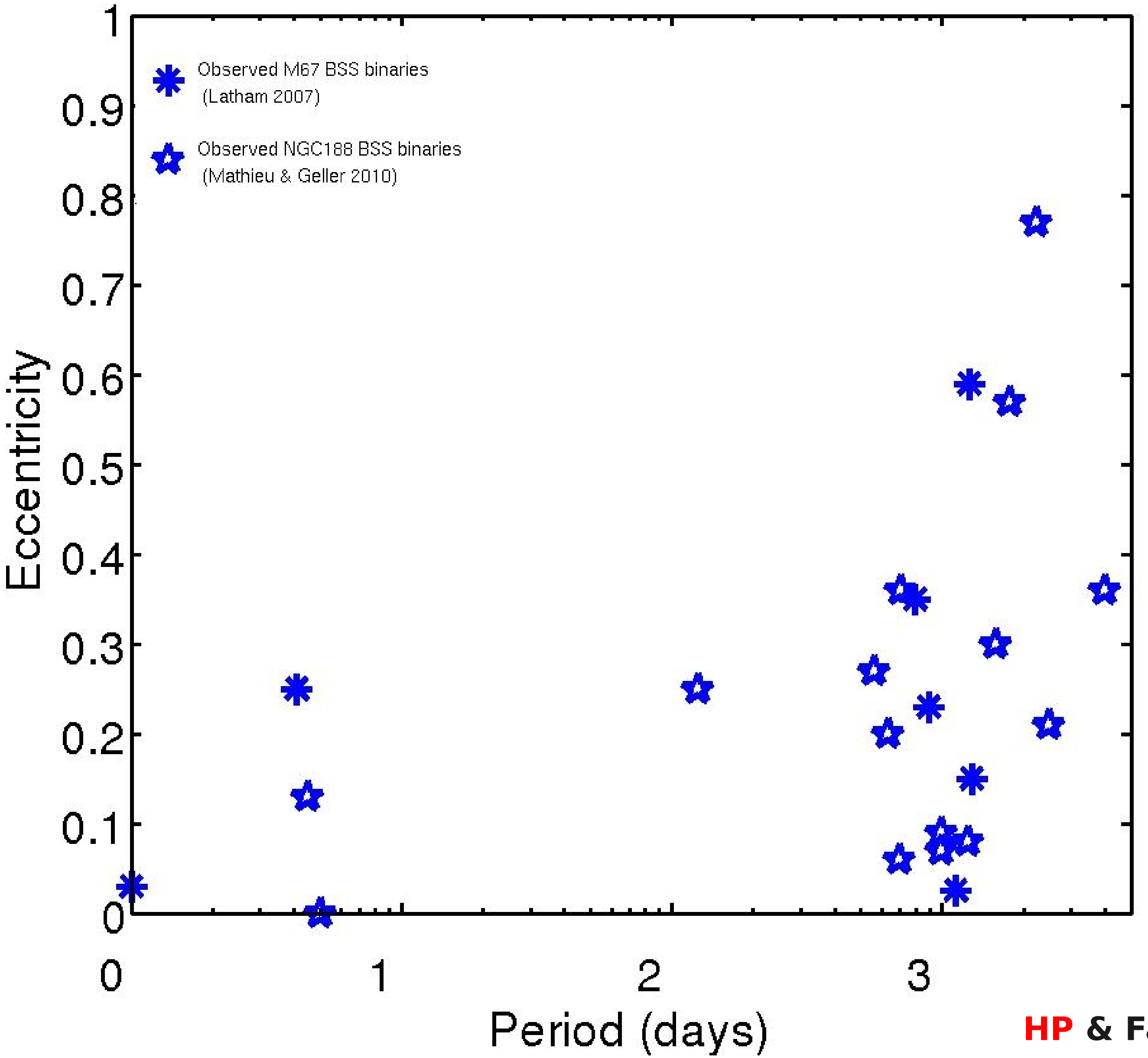
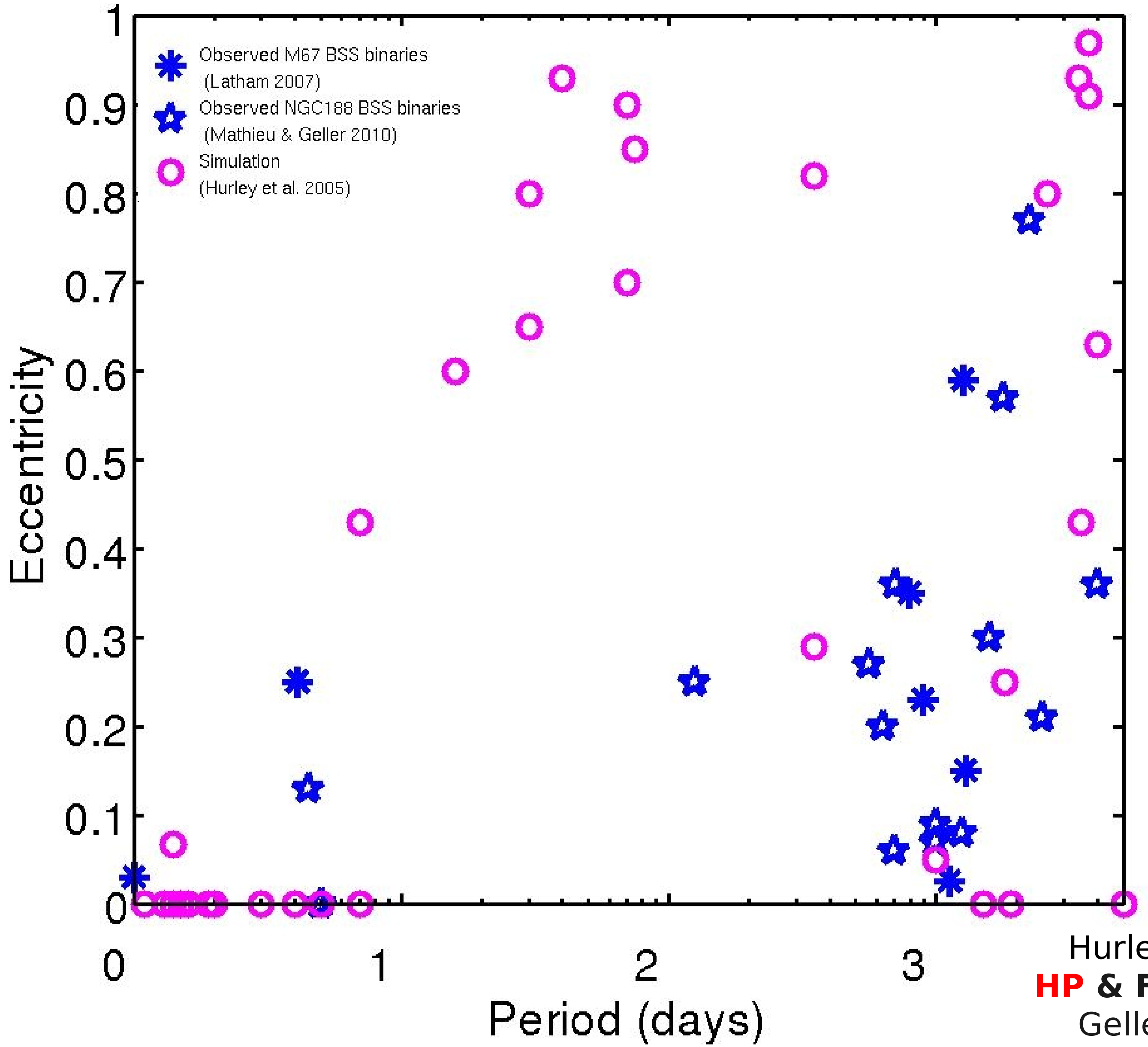
Period-Eccentricity distribution



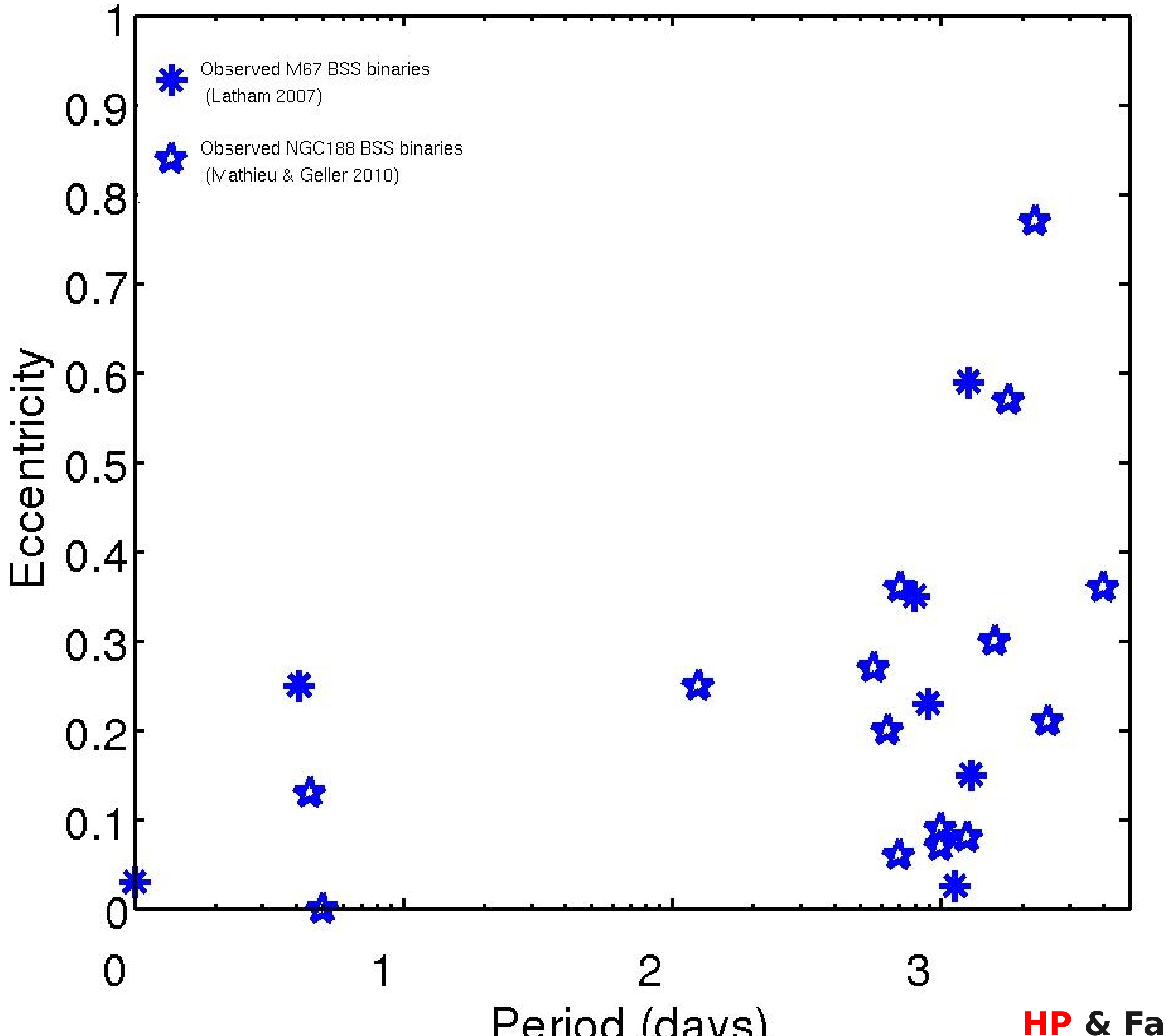
HP & Fabrycky 2009.

Period-Eccentricity distribution
Collisions and dynamical encounters



Hurley et al. 2005,
HP & Fabrycky 2009
Geller et al. 2012

The triple origin of blue stragglers: Binary blue stragglers



HP & Fabrycky 2009.

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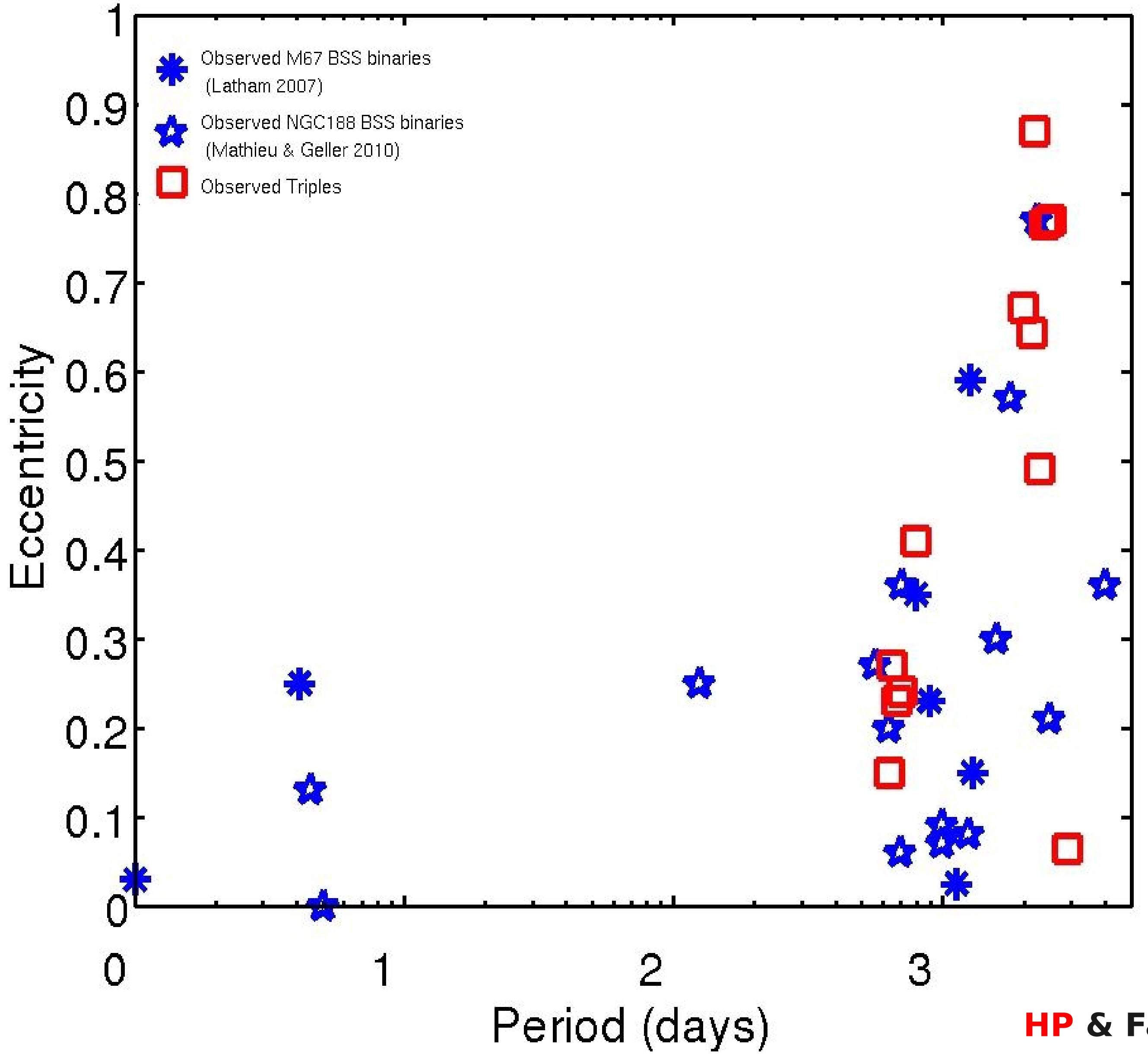
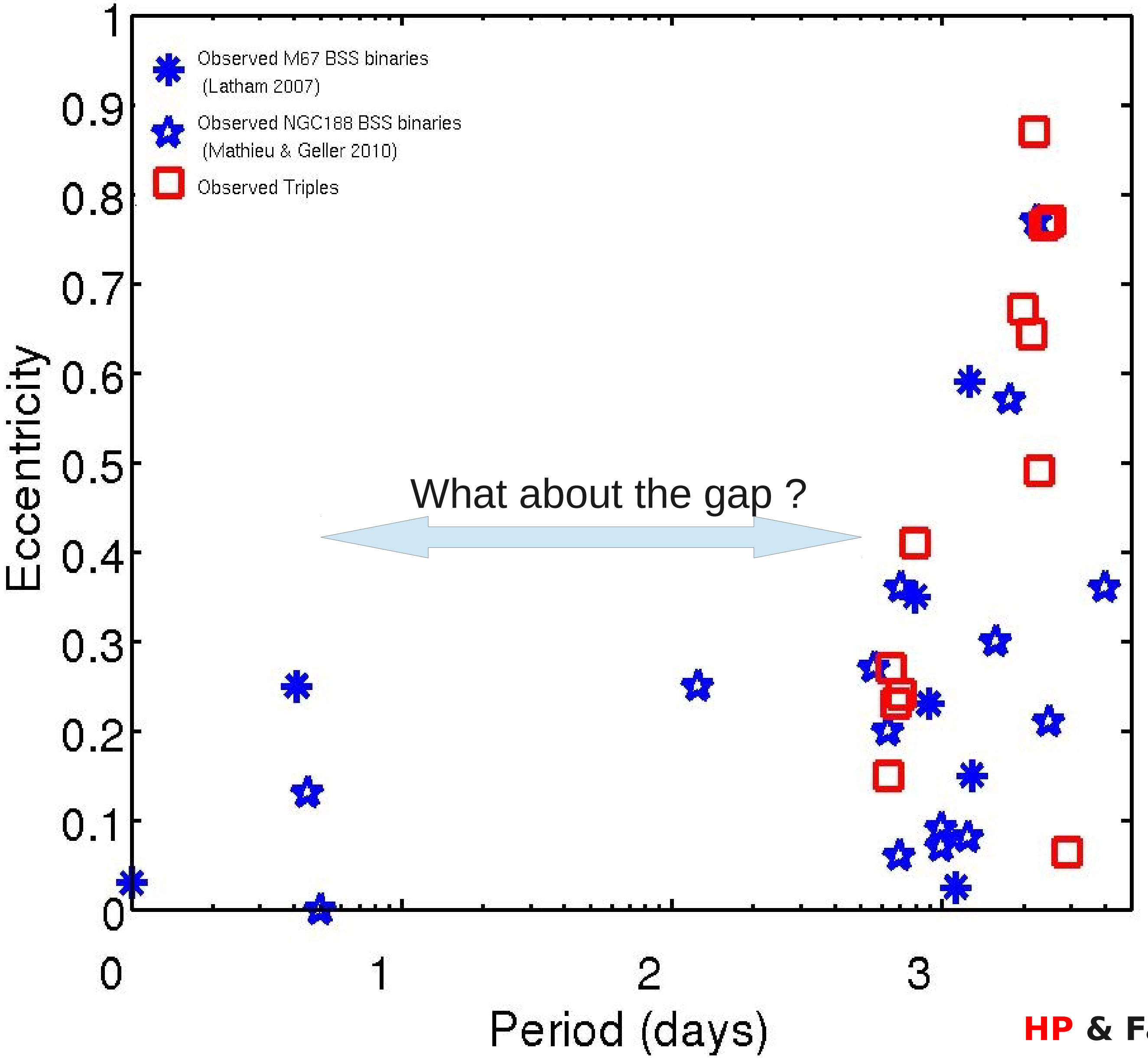


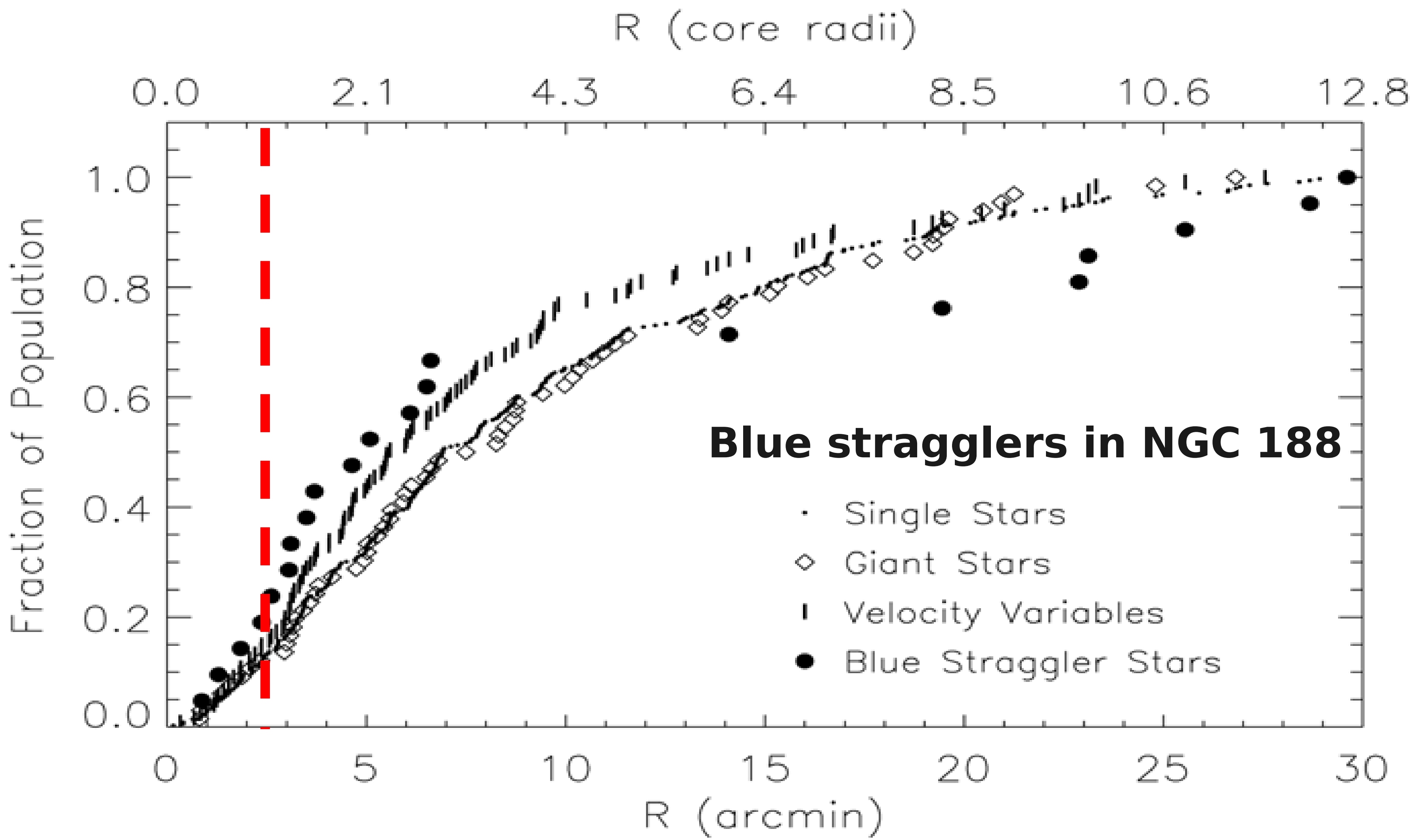
HP & Fabrycky 2009.

The triple origin of blue stragglers: Mind the gap



HP & Fabrycky 2009.

Spatial distribution of blue stragglers



Geller et al. 2008

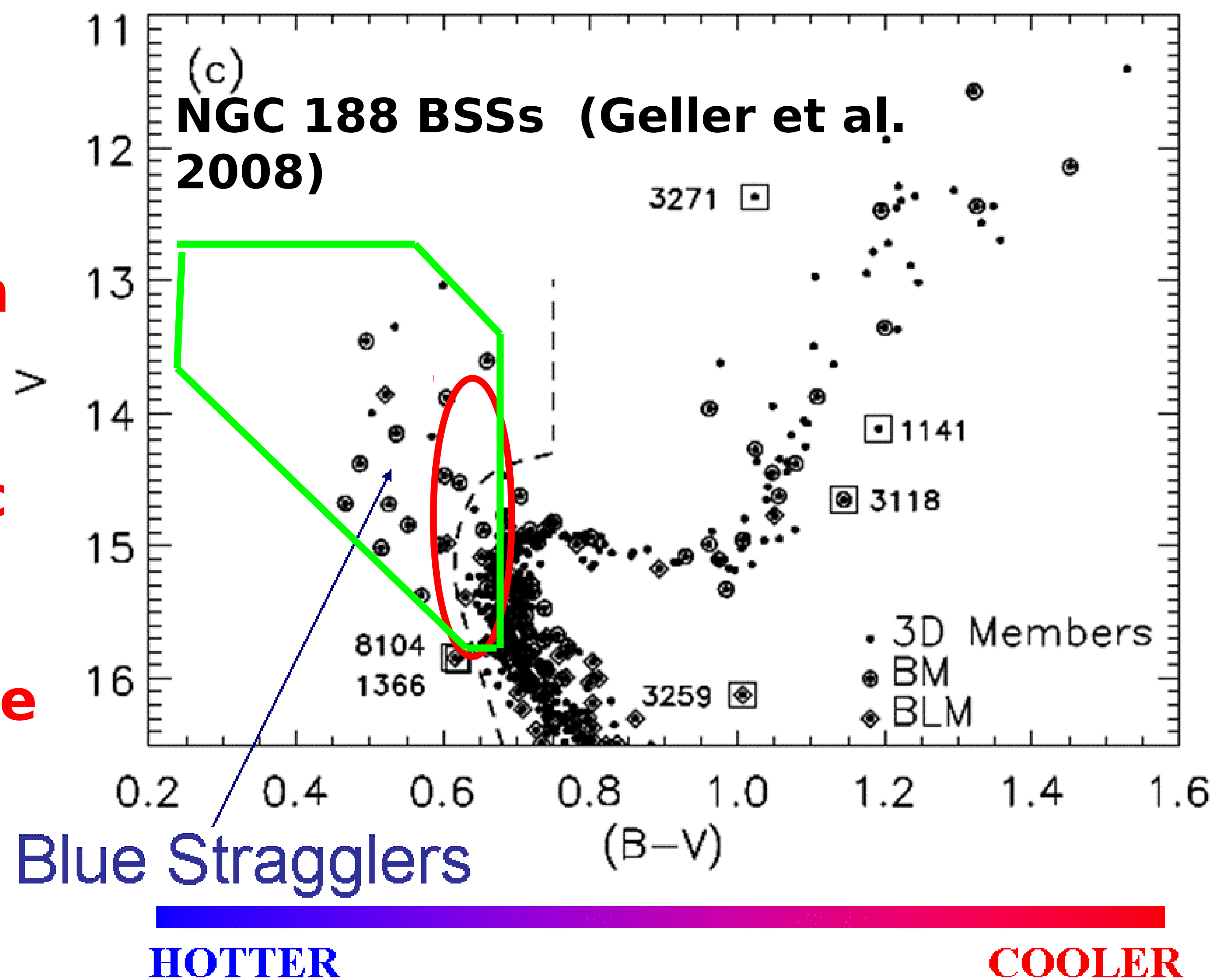
Open clusters
Observations vs. models

Luminous, massive

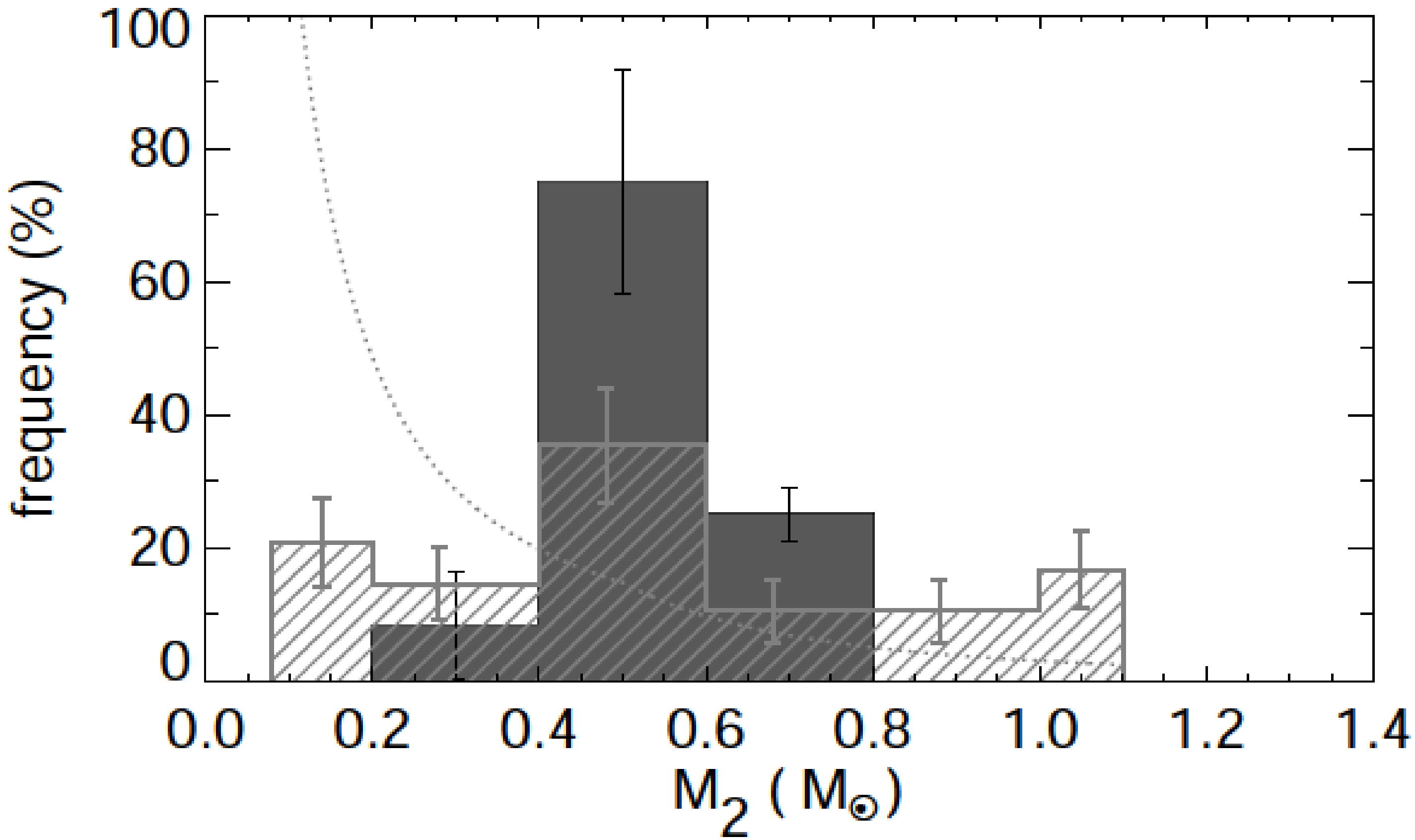
Binary fraction > 76 %

Wide eccentric orbits

Double massive BSS



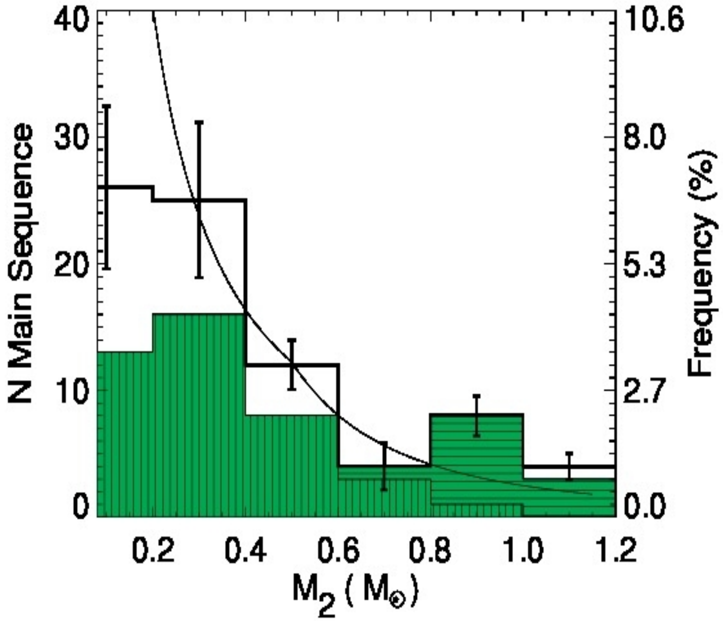
Secondary mass function



A K-S test comparing the observed mass-function distribution for the long-period blue straggler binaries in NGC 188 to that of the evolved tertiaries, find the two distributions to be consistent (36% ; Geller & Mathieu 2011)

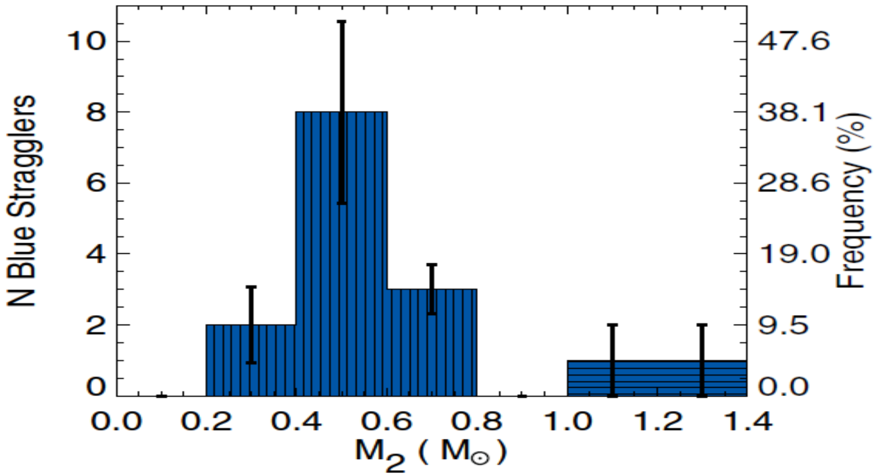
Probability for MS secondary detection

4 out of 7 (Prob=0.57) secondaries in the 0.6-0.8 bin are directly detected



For simplicity, assuming the same detection probability, 1.7 BSS companion are expected to be found, while none are detected

This is not statistically significant (low statistics)



Geller, Mathieu et al. 2011, 2012

The multiple origin of BSs in open clusters

- Small contribution from collisions+encounters
  - ~10 % got open clusters (Leonard et al. 1996)
- Larger fractions from mergers in triples and MTC
- If we were to believe the BSE CMD locations

  >60-80% Merger of which at least 2/3 triples)

  + <10-20% MTC
- Let's try predicting again Bob:

  -> Total expected WDs in NGC 188 BSs secondaries

  ~2-3 in TRI binaries + 2-3 in MTC (subluminous BSs)
- Bluer (relative to isochrone) Bss in younger clusters + Smaller WD fractions in younger clusters

Observations: Halo BSs

- Massive/luminous BSS close to 2xTO-mass;Unknown binarity — **COL TRI** 👍 **A** 👍 **B** 👍 **C**
- Subluminous BSs; — **COL TRI A B** 👍 **C** 👍

  high binary fraction, long periods, WD companions

- Known progenitors in the field: both triples and wide (100s-1000s days) binaries. Relative fractions – need to be studied
- Predictions: Massive BSs should have wide orbit eccentric binaries with possible MS companions

Observations: globular clusters

- Correlation with cluster mass, weaker with binarity (probably through mass-binarity correlation)
  - **Mass transfer ? Melvyn ?**
- Some show bi-modal radial distribution;
  - **COL TRI A B C**
  - potential resemblance to short period binaries ?
    - **COL TRI A B C**
- High fraction of BSSs in eclipsing binaries
  - **COL TRI A B C**

Observations: globular clusters

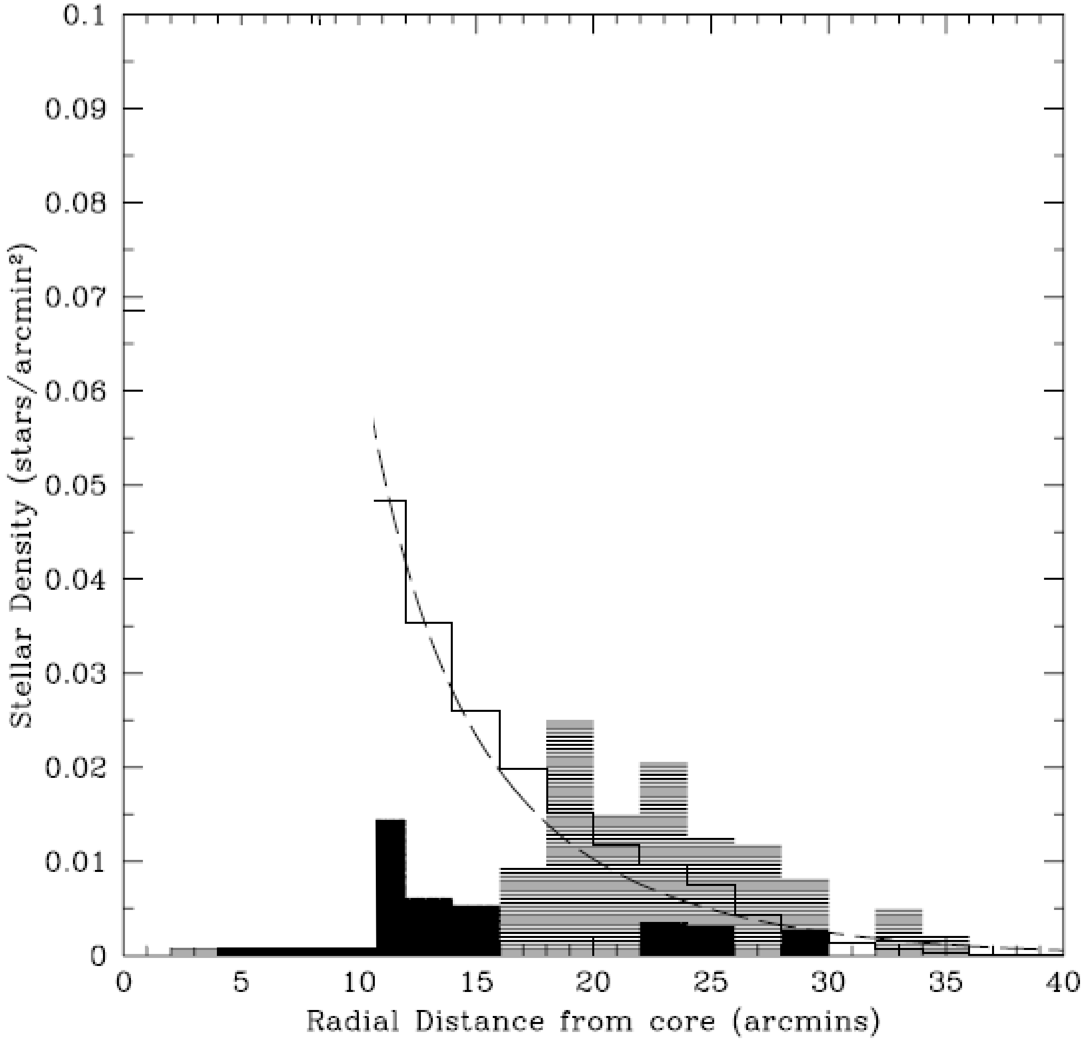
- Massive/luminous BSS
  - COL 👍 TRI 👍 A 👍 B 👍 C
- Existence of > 2TO-mass BSS
  - COL 👍 TRI A B C
- No correlation with collisional parameters
  - COL TRI 👍 A 👍 B 👍 C 👍

- Overall: BSs formation in GCs could be very similar open clusters, likely with higher collisional fraction

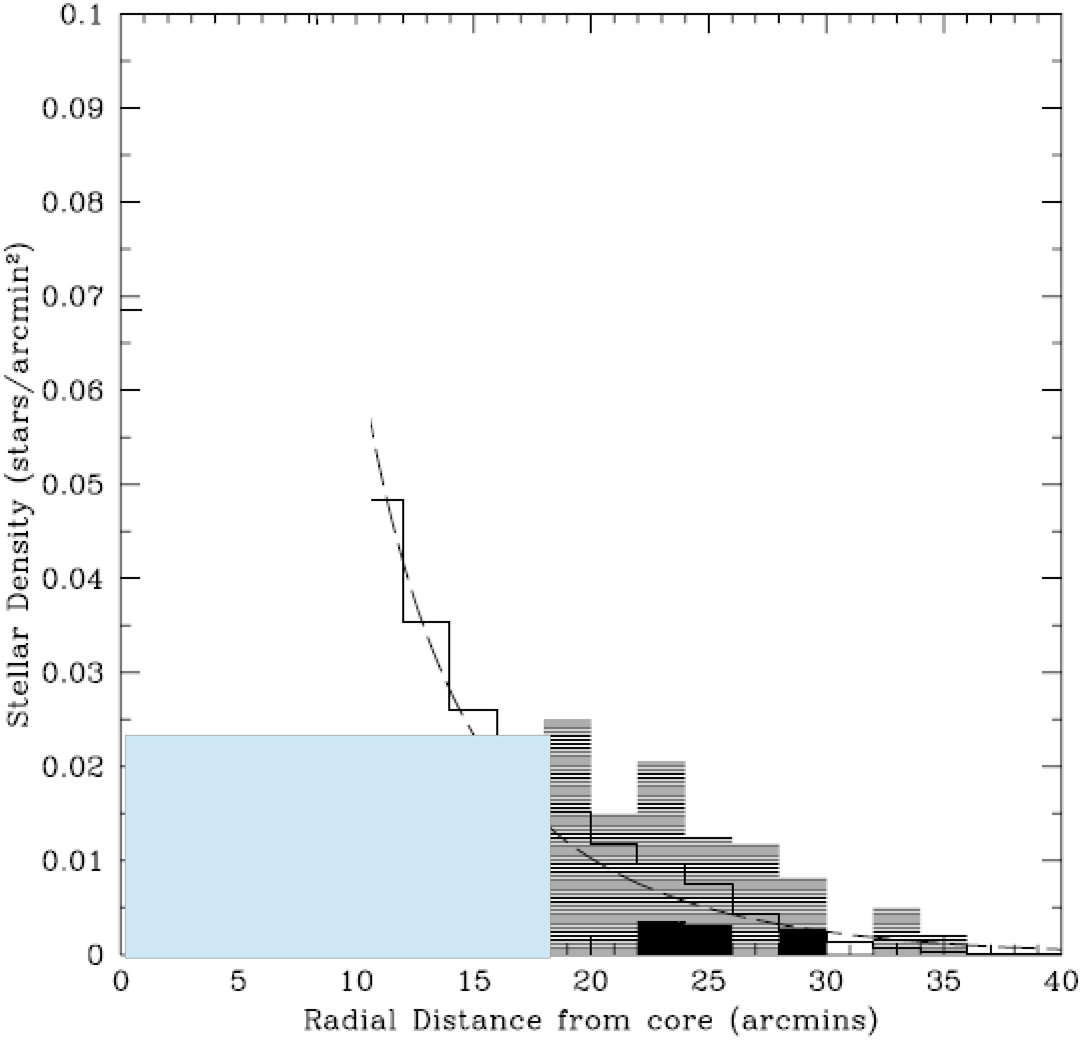
Observations vs. models

- Predictions/implications/future studies:
  - Radial distribution follows binaries, or at least short period binaries (use eclipsing binaries)
  - Appropriate choice of BSs in specific locations in CMD would provide much better correlation with collisional parameters
  - Comparison with reliable (:-) stellar evolution expectations for CMD locations can provide relative ratios for BSs formation channels
  - Omega-Cen would show far BSs bump >20'

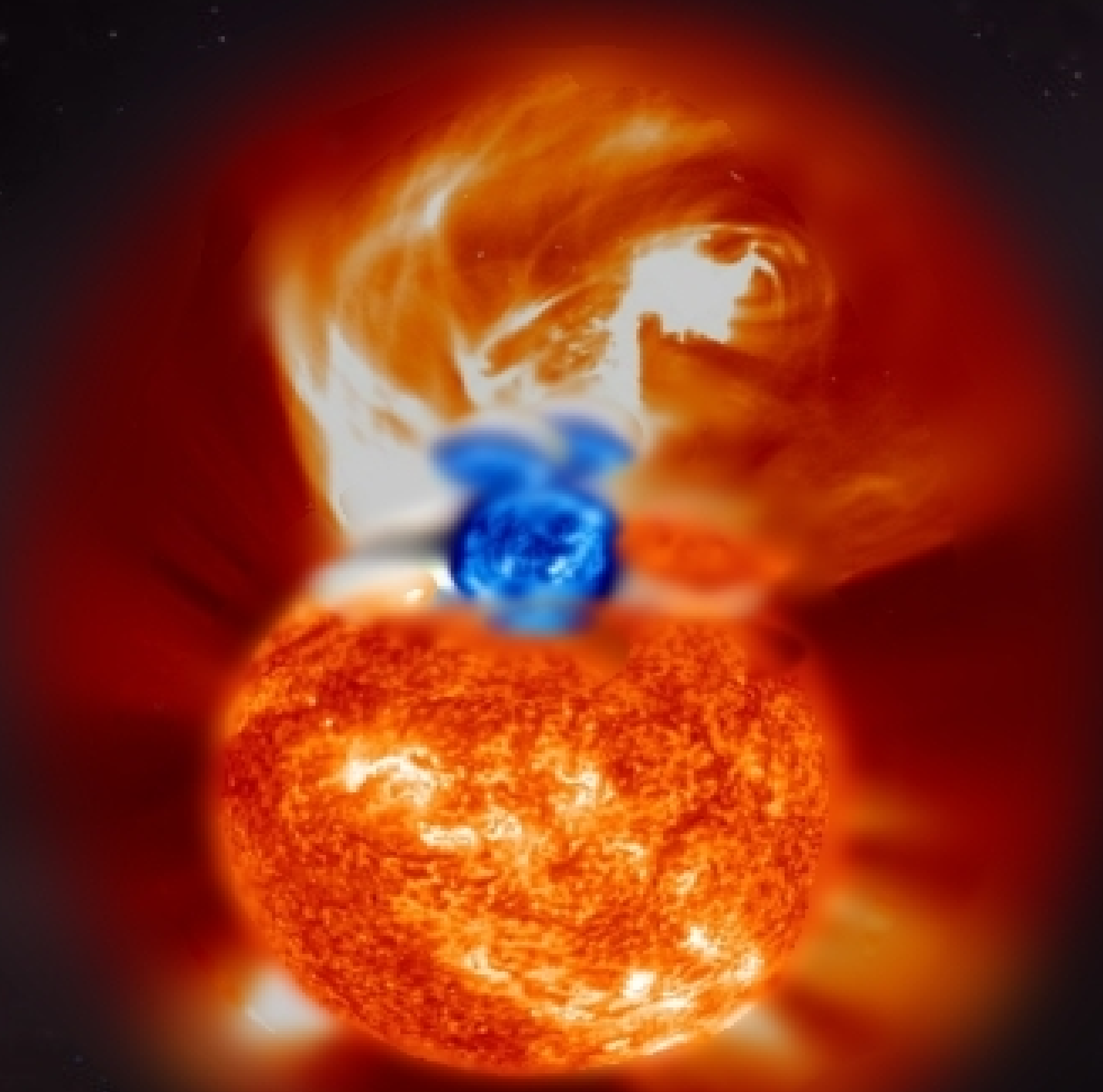
Eclipsing binaries in GCs: Bi-modal distribution



Eclipsing binaries in GCs: Bi-modal distribution expected in ωCen



Thanks !



Triples and BSs
Summary

- The mechanism of Kozai cycles and tidal friction have a major role in the evolution of triple systems
- Evolution in triples is likely to be the dominant route for the formation of BSs, solving many long standing puzzles regarding their properties
- Primordial triples could have an important role in the evolution of stellar clusters

Environments vs. Formation Channels

- Globular clusters
- Open clusters
- Galactic halo
- Massive BSS
- Field

- Collisions
- Triple evolution
- Mass transfer
- Close binary merger

Basic properties - observed

	Globular Clusters	Open Clusters	Galactic Halo
Mass/ Luminoisity			Up-to turn-off mass +0.1 Msun (Preston et al.) - By selection
Frequency	~1/2000	~1/2000	?
Chemical abundance	Most MS like Some C/O depleted	?	High metallicity
Spatial distribution	Segregated Bi-modal core-halo	Segregated Bi-modal core-halo	--
Binarity	Known eclipsing binaries	High frequency P>700 day Non-circular Some close and double BSS	High frequency 200<P<800 day Low, but non-circular eccentricity
Correlations	With GC mass Weaker Correlation with binarity		--

- Rotation ?

Octupole vs. quadrupole approximation

- Show plots from Naoz et al.

Clusters: Models vs. observations

Collisions in dense environments (Hills & Day 1976)

- Successes
  - Double binary BSS; short period eccentric binary BSS
  - Potentially explain ~10% of GCs BSS
- Problems:
  - No correlation with collision rate in clusters (Knigge et al. 2008; Leigh, Knigge, Alison, HP et al. 2012)
  - Large BSS populations outside cores and in open clusters
  - Binarity and period eccentricity mismatch (Hurley et al. 2005, HP & Fabrycky, Mathieu & Geller 2009)

Clusters: Models vs. observations

- Mass transfer or merger of close binaries (McCrea 1964)
  - Problems:
    - Mergers can't explain binarity, and especially enhanced binarity
    - Strong mass transfer can't explain binary period eccentricity distribution
    - Mass transfer can't explain CMD location

Observations: open clusters

- No correlation with collisional parameters
- Some show bi-modal radial distribution;
  - Check if follows binaries in M67 and NGC 188
- High binary fraction; 76-97 % in NGC 188
- Some BSSs are short period binaries, even double BSS, seen both in M67 and NGC 188
-