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
Blue stragglers exist in various environments:

- Globular clusters
- Open clusters
- Galactic halo
- Young clusters
- The field
BSs have several observational properties

- Mass/luminosity-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)
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)
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.

- 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 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

The diagram shows a log-log plot with axes labeled as follows:

- Y-axis: Time (yrs)
- X-axis: Period (days)

The plot includes several lines labeled:
- M67 age
- GC
- OC
- GC core
- OC core
- KCTF

The curves are plotted on a logarithmic scale, indicating the evolution of different parameters over time and period.
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 $> \sim 700$ 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/luminosity
- 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/luminosity/type (BSS and companions)
  – Binary fraction
  – Period-eccentricity distribution
  – Radial distribution
  – Fractions (see Geller talk; note triples)
Color Magnitude Diagram

(c) NGC 188 BSSs (Geller et al. 2008)

Blue Stragglers

- 3D Members
- BM
- BLM
Open clusters binarity:
Fractions and Period-Eccentricity distribution

>76% binary fraction in NGC 188 (<3000 d)

HP & Fabrycky 2009
Spatial distribution of blue stragglers

Blue stragglers in NGC 188

- Single Stars
- Giant Stars
- Velocity Variables
- Blue Straggler Stars

Geller et al. 2008
Color Magnitude Diagram
Case C mass transfer

Synthetic CMD

Bailey & Mathieu,
Priv. com.
Color Magnitude Diagram
Case C mass transfer

Synthetic CMD

Bailey & Mathieu,
Priv. com.
Color Magnitude Diagram

NGC 188 BSSs (Geller et al. 2008)

Blue Stragglers

HOTTER

COOLER
Color Magnitude Diagram: Collisions, MTA and TRI

Bailey & Mathieu, Priv. com.
Color Magnitude Diagram: Collisions, MTA and TRI

Bailey & Mathieu, Priv. com.
Color Magnitude Diagram: Collisions, MTA and TRI

NGC 188 BSSs (Geller et al. 2008)

Blue Stragglers
Period-Eccentricity distribution

- Observed M67 BSS binaries (Latham 2007)
- Observed NGC199 BSS binaries (Mathieu & Geller 2010)
Period-Eccentricity distribution

- Observed M67 BSS binaries (Latham 2007)
- Observed NGC188 BSS binaries (Mathieu & Geller 2010)
- M67 Binaries (Latham 2007)
Period-Eccentricity distribution: Case C MT (?)
Period-Eccentricity distribution: Case C MT (?)
Period-Eccentricity distribution

- Observed M67 BSS binaries (Latham 2007)
- Observed NGC189 BSS binaries (Mattei & Geller 2010)
Period-Eccentricity distribution
Collisions and dynamical encounters
The triple origin of blue stragglers: Binary blue stragglers

![Graph showing the relationship between eccentricity and period for observed M67 and NGC198 BSS binaries. The graph includes annotations for observed M67 BSS binaries (Latham 2007) and observed NGC198 BSS binaries (Mathieu & Geller 2010).]
The triple origin of blue stragglers: Binary blue stragglers

- Observed M67 BSS binaries (Latham 2007)
- Observed NGC188 BSS binaries (Mathieu & Gallet 2010)
- Observed Triples

Eccentricity vs. Period (days)
The triple origin of blue stragglers: Mind the gap

What about the gap?
Spatial distribution of blue stragglers

Blue stragglers in NGC 188

Geller et al. 2008
Open clusters
Observations vs. models

Luminous, massive
Binary fraction > 76 %
Wide eccentric orbits
Double massive BSS

Blue Stragglers
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)
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).
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

- Subluminous BSs; 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)
- Some show bi-modal radial distribution;
  - potential resemblance to short period binaries?
- High fraction of BSSs in eclipsing binaries

Mass transfer? Melvyn?

<table>
<thead>
<tr>
<th>COL</th>
<th>TRI</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>COL</td>
<td>TRI</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>COL</td>
<td>TRI</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
</tbody>
</table>
Observations: globular clusters

- Massive/luminous BSS
- Existence of > 2TO-mass BSS
- No correlation with collisional parameters

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

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