Blue Straggler Stars
Formation Channels

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Ways to make blue stragglers

Produced in collisions/mergers between two single stars (during 1+1, 2+1, or 2+2 encounters)

Produced via mass transfer within binaries

Produced via Kozai mechanism within triples
Stellar encounter timescales

Cross section is given by

\[ \sigma = \pi R_{\text{min}}^2 \left( 1 + \frac{2G(M_1 + M_2)}{R_{\text{min}}V_\infty^2} \right) \]

Timescale for a given star to undergo an encounter is

\[ \tau_{\text{enc}} \sim 10^{11} \text{yr} \left( \frac{10^5/pc^3}{n} \right) \cdot \left( \frac{M_\odot}{M} \right) \cdot \left( \frac{R_\odot}{R_{\text{min}}} \right) \cdot \left( \frac{V_\infty}{10km/s} \right) \]
What can collide with what?

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Stellar radius vs cumulative number of collisions

(Sills, Adams, and Davies 2005)
A stellar collision between two MS stars

0 < 10 < 600

(Sills, Adams, and Davies 2005)
Outcomes of collisions in globular clusters

- Mass loss: 1-10 % (more for MS-CO)
- Typical delta V ~100km/s for collisions, so collisions lead to mergers
- Capture for $R_{\text{min}} \sim 3 \, R_{\text{star}}$ (Fabian, Pringle, and Rees 1975)
Modelling post-collision evolution is very difficult

- Significant rotation
- Possible mixing of material
- Angular momentum loss?

(e.g. Sills et al. 2005; 2009; and Glebbeek et al. 2008)
Now consider encounters involving binary stars
Encounter timescales involving binaries

Timescale for a given star to undergo an encounter with a binary is

\[ \tau_{enc} \sim 10^{11} \text{ yr} \left( \frac{10^5 \text{ pc}^3}{n} \right) \cdot \left( \frac{M}{M_\odot} \right) \cdot \left( \frac{R}{R_{\min}} \right) \cdot \left( \frac{V_\infty}{10 \text{ km/s}} \right) \]

Where now R\(_{\min}\) is roughly the size of the binary, which can be much larger than the radius of a star.

Can have situation where \( \Gamma_{1+1} \sim \Gamma_{2+1} \)
Possible outcomes of encounters between a binary and a single star.
Concepts concerning binary-single encounters

• Hard-soft boundary

\[ d_{hs} \simeq 6 \text{AU} \left( \frac{V_\infty}{10 \text{km/s}} \right)^{-2} \]

• Soft binaries get broken up

• Hard binaries get harder

• Thermal distribution of eccentricities

• Clean exchanges: lowest-mass star ejected

• Stellar collisions occur during encounters
Interacting binaries are made dynamically

(Pooley et al. 2003)
Clusters containing LMXBs have dense cores

(Bregman et al. 2006)
Now consider making blue stragglers via binary evolution
Making blue stragglers through binary evolution

1. MS \rightarrow MS \rightarrow MS

2. MS \rightarrow MS \rightarrow MS

3. Evolved donor \rightarrow MS \rightarrow MS

4. Blue Straggler

(Davies, Piotto, & De Angeli 2004)
How does blue straggler formation rate scale with cluster mass?

Collision rate between main-sequence stars given by

$$\Gamma_{\text{coll}} \propto \frac{\rho^2 r_c^3}{\sigma} \propto \frac{\rho^2 r_c^3}{\sqrt{M_{\text{tot}}/r_h}} \propto \frac{M_c^2 r_c^{-3}}{\sqrt{M_{\text{tot}}/r_h}} \propto \frac{f_c^2 r_h^{1/2}}{r_c^3} M_{\text{tot}}^{3/2}$$

Number of blue stragglers made in collisions

$$N_{\text{bs,coll}} \propto M_{\text{tot}}^{3/2}$$

Number of blue stragglers made in binaries

$$N_{\text{bs,bin}} \propto f_{\text{bs,bin}} M_{\text{tot}}$$
There are roughly the same number of blue stragglers in all clusters!

(e.g. Piotto et al. 2004)
The effect of encounters on binaries

Encounters reduce the number of binaries which can make BSs today

(Davies, Piotto, & De Angeli 2004)

See also Milone et al. 2012

(Hut, McMillan, & Romani 1992)
Predicted BS numbers from both collisions and binaries

(Davies, Piotto, and De Angeli 2004)
Summary

A mix of encounter products and a binary population depleted via encounters can give a flatter population of BSs as is seen in GCs.

The best (well, only) way to determine in detail the frequency of various outcomes is to model the entire cluster (Monte Carlo or N-body).

This is already being done for open clusters Just beginning to be possible for larger N.