The evolution of stellar mergers

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This work in collaboration with Onno Pols, Evghenii Gaburov, Simon Portegies Zwart, Selma de Mink, Nathan Leigh, Alison Sills
Outline

- Introduction
- Mergers of low mass stars
- Mergers of high mass stars
- Collision runaways
- Simulating merger populations
I. Introduction
• Mergers of main sequence (or turnoff) stars
⇒ no sdB or R CrB stars (see Wednesday).
Stellar evolution code due to Peter Eggleton
• Rapid mergers ($\tau_{\text{merger}} \ll \tau_{\text{KH}}$)
⇒ hydrodynamics (SPH, in collaboration with Evghenii Gaburov), “entropy” “sorting”
Merging stars can (easily) have more angular momentum than can be accommodated by a single star. The merger remnant needs to lose angular momentum before it can settle down into equilibrium. How to lose the angular momentum efficiently is an unsolved problem. Magnetic fields may help here (e.g. Sills & al. 2001). The usual “solution” is to assume that a process that removes the angular momentum operates. For blue stragglers, this does not contradict observations.
Because low entropy material tends to sink to the centre, the core of the most evolved star (usually) becomes the core of the merger remnant.
Example: $1.3 + 0.6 \, M_\odot$

**Primary, $M = 1.3 \, M_\odot$**

**Secondary, $M = 0.6 \, M_\odot$**
Example: $1.3 + 0.6 M_\odot$

Merger remnants may not be rejuvenated significantly.
Merger remnants may not be rejuvenated significantly.
II. Mergers of low mass stars
Motivation: blue stragglers

Sills & al. (various, since 1997); Glebbeek, Pols & Hurley (2008); Glebbeek & Pols (2008)
Merger evolution

Abundance by mass

Hydrogen

Helium
Normal evolution track
Fully mixed merger track
Initial contraction
Late evolution
Merger lifetime

\[ t_{\text{ms}} \quad \text{[Gyr]} \]

\[ \tau_{\text{ms}} \quad \text{[Gyr]} \]
Blue straggler luminosity function

Glebbeek & al. in prep.
Blue straggler luminosity function

\[ Y_1 = Y_2 = 0.24 \]
\[ Y_1 = 0.24, Y_2 = 0.32 \]

NGC 2808

Glebbeek & al. in prep.
Merger products are not strongly mixed
Merger products have a reduced lifetime compared to normal stars
Major uncertainties: angular momentum, magnetic fields
III. Mergers of massive stars
Motivation: Intermediate mass black holes

Walk before you run.

- First things first: evolution of massive merger products
- Relevant for massive binary evolution
- Relevant for formation of rapidly rotating stars (γ-ray bursts?)
Collisions between massive stars

$10 + 10M_{\odot}, \, t = \frac{1}{2} t_{ms}$

Gaburov, Glebbeek & al. in prep.
Collisions between massive stars

$10 + 7M_{\odot}, t = t_{\text{ms,10}}$

Abundance by mass

Hydrogen

Helium

Gaburov, Glebbeek & al. in prep.
Collisions between massive stars

$10 + 7M_\odot$, $t = t_{\text{ms},10}$

Gaburov, Glebbeek & al. in prep.
Collisions between massive stars

$10 + 7M_{\odot}, \ t = t_{\text{ms,}10}$

Gaburov, Glebbeek & al. in prep.
Collisions between massive stars

$10 + 1M_\odot, t = \frac{1}{2} t_{\text{ms,10}}$

![Graph showing abundance by mass as a function of mass (M). The graph plots Hydrogen and Helium abundances with distinct lines for each.](image)

Gaburov, Glebbeek & al. in prep.
Collisions between massive stars

$10 + 1M_\odot, \ t = \frac{1}{2} t_{ms,10}$

Graph showing the evolution of various processes over time, including:
- Convection
- Thermohaline mixing
- Nuclear burning

The graph is labeled 'Gaburov, Glebbeek & al. in prep.'
High mass star summary

- Qualitatively similar to low mass mergers
- Merger products may be blue super giants
- Major uncertainties: angular momentum, magnetic fields
IV. Collision runaways
Evolution track

\[ \log_{10} \frac{L}{L_\odot} \]

\[ \log_{10} T_{\text{eff}}/\text{K} \]

\( \eta \text{ Car} \)

Pistol star

ZAMS

HD-limit
Mass of collision product

- Original N-body
- Detailed evolution

Mass of collision product [$M_\odot$] vs. time [$t$ [Myr]]
### Chemical yields

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</table>

Does not include supernova yields!

Soon: more detailed nucleosynthesis!
Merger runaway summary

- Outcome of merger runaway is determined by mass loss rates
- Outcome of merger runaway is *not* an intermediate mass black hole
- Work in progress: chemical abundance signature?
- Major uncertainties: angular momentum, magnetic fields, mass loss rates at low metallicity
V. Simulating merger populations
   A tool under development
Stellar Collider Input parameters

Collide two stars of your choice and view the evolution track on your screen. The Stellar Collider will interpolate the parameters you enter on a grid of evolution tracks for collision products and present the results. The stellar evolution tracks were calculated with a version of Peter Eggleton’s TWIN stellar evolution code, the collisions themselves are calculated with James Lombardi’s Make Me A Star package. Details of the collision grids are described in Glebbeek & Pols 2008. The interpolation scheme is essentially the same that described in Pols & al. 1998. There are a few restrictions and caveats that you should be aware of:

1. The parameters you enter must fall within the parameters of the calculated grid (what these are depends on the grid you interpolate on).
2. The Stellar Collider will only be able to calculate evolution tracks for collisions between main sequence stars. In other words, if one of the colliding stars has evolved off the main sequence you will get an error message. In practice you may run into problems if you’re trying to collide stars that are near the main sequence turn off; it’s very likely that one of the models needed for the interpolation is not available because the progenitors had actually evolved off the main sequence. In this case, you’ll get an error message.
3. The evolution tracks can only be calculated for times up to which the evolution tracks are available in the database. Normally this should be fine up to a Hubble time (13.7 Gyr), but your mileage may vary.

At the moment you can only view Hertzsprung-Russell diagrams for individual evolution tracks. Eventually I will update this so you can also simulate a population of stellar collision products.

If you have questions or have problems using the Stellar Collider, let me know!

If you plan to use the Stellar Collider for serious work, definitely let me know!

Collision grid: \( Z = 0.001 \)

Primary mass: 0.6 \( M_{\odot} \)
Secondary mass: 0.2 \( M_{\odot} \)
Time of collision: 9000 Myr

http://www.physics.mcmaster.ca/~glebbbee/cgi-bin/query.cgi
Result for collision between $0.6 \, M_{\text{sun}}$ and $0.5 \, M_{\text{sun}}$ at 9000 Myr, $Z = 0.001$

- Mass of collision product: $1.03 \, M_{\text{sun}}$
- Mass lost in the collision: $0.07 \, M_{\text{sun}}$ (6.6 %)
- Main sequence lifetime: 3.81 Gyr
- Thermal relaxation time: 3.15 Myr
- Time of last point on track: 13.85 Gyr

http://www.physics.mcmaster.ca/~glebbbee/cgi-bin/query.cgi
The end

Thank you!