Binaries Part 2:
Common Envelope Evolution
SNe in Binaries
Compact Remnant Binaries
Population Synthesis

@astro_jje
Introduction

- JJ Eldridge, prefer them/they genderless pronouns.
- Do stellar population synthesis with binaries.
- Going to introduce what binaries do to everything we've heard about. Interacting binaries change (nearly) every prediction of stellar evolution theory.
Selected binary astro-ers

- Bohdan Paczyński
- Theorists: Selma de Mink, Natalia Ivanova, Shazrene Mohamed, Sung-Chul Yoon, Philipp Podsiadlowski, Norbert Langer, Christopher Tout, Ross Church, Richard Stancliffe
- Detailed pop synth: JJ Eldridge, Dany Vanbeveren
- Rapid pop synth: Ashley Ruiter, Vicky Kalogera, Zhahwen Han, Robert Izzard, Kris Belczynski, Jarrod Hurley
- Observers: Orsula de Marco, Mercedes Richards, Hugues Sana
Some initial thoughts on binaries:

Sana et al. (2012) – 70% of massive stars have their evolution affected by binary evolution.
Problem: wide range of orbits to consider (or why everyone ignores binaries) – need to make lots of stellar models. Requires grid/cloud computing!

It's not just an effect to switch on/off, need to consider a wide range of possible initial separations & mass ratios, many different evolutionary paths are possible. People often ask “does X happen”, answer is “yes but so does Y, Z, Ж and Ė”.

- Core Hydrogen Burning
- Core Helium Burning
- End of evolution
Lots of single stars are from binaries

(a) Apparently single
\( K < 10 \text{ km s}^{-1} \)

(b) Detectable as binary
\( K > 10 \text{ km s}^{-1} \)

de Mink et al. (2013, 2014)
Common Envelope Evolution

the most uncertain phase of binary evolution.
Ivanova et al. (2012)
Cataclysmic Variable Star

- Accretion Disc
- Hot Spot
- Accretion Stream
- White Dwarf
- Secondary Star
Energy balance

\[ E_{\text{bind}} = \Delta E_{\text{orb}} = E_{\text{orb},i} - E_{\text{orb},f} = -\frac{Gm_1m_2}{2a_i} + \frac{Gm_{1,c}m_2}{2a_f} \]

\[ \frac{m_1m_{1,\text{env}}}{\lambda R_1} = \alpha_{\text{CE}} \left( -\frac{Gm_1m_2}{2a_i} + \frac{Gm_{1,c}m_2}{2a_f} \right) \]

Or maybe angular momentum

\[ \frac{\Delta J_{\text{lost}}}{J_i} = \frac{J_i - J_f}{J_i} = \gamma \frac{m_{1,e}}{m_1 + m_2} \]

Problem: \( \alpha \) & \( \gamma \) are free parameters, the same for all events?

Ivanova et al. (2012)
Fig. 3 Common envelope event with a $1.2M_\odot$ early giant and $0.6M_\odot$ MS star, resulting in a merger of two stars. Simulation performed for this review by J. Lombardi and R. Scruiggs, simulated with $2.2 \times 10^5$ SPH particles. For more technical details on the code, see Gaburov et al. (2010) and Lombardi et al. (2011). Visualization (images and on-line video) are generated using SPLASH (Price, 2007).
Tylenda et al.: V1309 Sco

I (magnitude) vs. JD 2450000+

Tylenda+ (2010)
Fig. 6 Post-CE planetary nebulae with known compact binaries as central objects. Top left – Necklace Nebula (image credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA), for details see Corradi et al. (2011)); top right – NGC 6337 (credit to Corradi, for more details see Corradi et al. (2000)); bottom left – ETHOS 1 (credit to B. Miszalski, for more details see Miszalski et al. (2011); Boffin & Miszalski (2011)); bottom right – NGC 6778 (credit: Guerrero & Miranda (2012))
SNe in Binaries
### Evidence for binaries?

#### Relative supernova rates

<table>
<thead>
<tr>
<th>Supernova Type</th>
<th>Type II (% ± %)</th>
<th>Type Ib/c (% ± %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>71±9%</td>
<td>29±6%</td>
</tr>
<tr>
<td>Single stars</td>
<td>85%</td>
<td>15%</td>
</tr>
<tr>
<td>Mix</td>
<td>71%</td>
<td>29%</td>
</tr>
<tr>
<td>Binaries</td>
<td>63%</td>
<td>37%</td>
</tr>
</tbody>
</table>

Supernova 1987A
Binary progenitor
Supernova 1993J
Binary progenitor
SN 1993J (Maund et al., 2004)

SN 1987A (Posiadlowski 1993)
No detections for most type Ib/c SNe

Eldridge et al. (2013)
Type Ib SN iPTF13bvn
Single stars

Binaries

Eldridge et al. (2013)

See also Yoon (2015)
Predicted location of WR stars?

Eldridge et al. (2013)
Post-SN Binaries
What happens to a binary after the first supernova?
Hobbs et al. (2005)
Supernova kicks
Result is all about energy

- Simple proof that if more than half the mass of the total mass is ejected system becomes unbound.
- But note: kicks can make it easier to unbind a binary but can also make a binary remain bounded. So typically need to iterate over a large number of kicks and directions.
- We can get constrains on space velocity of runaway/walkaway stars and compact remnant binaries.
Belczynski et al. (2012)
Population Synthesis:
what we need to consider
and
some example results
What we want to model:
Let's put it all together...
Also need...

- Initial Mass Function
- Initial mass ratio and period distributions
- Log(time) bins
- Atmosphere spectra so you know what stars “look” like.
Look at predicted locations on the HR diagram
Number of ionizing photons?

Wofford et al. (2016)
Number of ionizing photons during reionization?

\[ N(\lambda<912\text{A} \text{photon})/\times10^{53} \text{s}^{-1} \text{M}_\odot^{-1} \text{yr} \]

Metallicity vs. \( Z/Z_0 \):
- 0.05: 0.50
- 0.10: 0.70
- 0.15: 1.00
- 0.20: 1.50
- 0.30: 2.00

Stanway, Eldridge & Becker (2016)
Summary

- Binaries give opportunities for mass loss and mass gain and these allow pathways that are not possible by single-star evolution (yes even with rotation!).
- It is possible to draw wrong conclusions in observational samples unless binaries are considered.
- Most rapidly rotating stars in the Universe come from binaries.
- It is difficult but we are developing tools (e.g. BPASS).
LMC, 8Myr
But predict RSG and WR population as well?

![Graph showing WR/RSG ratio vs. metallicity (Z). The graph includes lines for BPASSv1 - Binaries, BPASSv2 - Binaries, Single stars, and Observations from Phil Massey. The x-axis represents metallicity (Z) ranging from 0.001 to 0.010. The y-axis represents the WR/RSG ratio ranging from 0.001 to 10.000. The graph includes observations and predictions for different stellar populations.](#)
Emission Line Diagnostics in high-z galaxies

Emission Line Diagnostics in high-z galaxies

What we need to consider: 5/5

\[ \tau_{GW} = \frac{5}{256} \frac{c^5}{G^3} \frac{a^4}{m_1 m_2 (m_1 + m_2)}. \]

(Peters, 1964)
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