Implications of binary evolution for electron-capture SNe

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Outline

- Observations of SN progenitors, how to rule in/our super-AGB stars.
- What about Ib/c supernovae?
- Checking: linking SNe to stellar populations.
- Ib/c electron-capture events and Ib/c SN populations.
- Constraints from supernova kicks.
“Where do all these numbers come from?”

Binary Population And Spectral Synthesis

Can be used to study a broad range of astrophysical systems: stars, supernovae, clusters and galaxies.

BPASS.AUCKLAND.AC.NZ

Version 1.1 based on 15,000 models available, Z=0.00001 to 0.040 and paper on the way.

“If you have a problem with binaries, if no one else can help, and if you can find them, maybe you can hire the BPASS-Team.”
The Binary Population and Spectral Synthesis code (BPASS, Eldridge & Stanway, 2009) is the result of combining my stellar evolution models with libraries of synthetic atmosphere spectra to create a unique tool to model many details of stellar populations. While similar codes (such as starburst99) exist BPASS has five important features, each of which set it apart from other codes and in combination make it the cutting edge. First, and most important, is the inclusion of binary evolution in modelling the stellar populations. The general effect of binaries is to cause a population of stars to look bluer at an older age than predicted by single-star models. Secondly, detailed stellar evolution models are used rather than an approximate rapid population synthesis method. Thirdly, I use only theoretical model spectra in my syntheses with as few empirical inputs as possible to create completely synthetic models to compare with observations. Fourthly, I use Cloudy (Ferland et al., 1998) to determine the nebular emission. This means I model not only the stars in detail but also the surrounding gas. Finally, the code is easily adaptable to determine the input physical parameters required to match observations.

On this site we make available standard outputs from our code for single and binary star populations. Select the data you require from the menu on the left. If you require data that is not here please email us.

The current version of the code is **Version 2.0**.

Version 2.0 is discussed in:
- Eldridge, Stanway, Xiao, Taylor, Ng, McClelland, Bray and Izzard, in prep.

**Version 1.1**: This now includes models that experience quasi-homogeneous evolution at the lowest metallicities of Z = 0.001 and 0.004. The version and results are outlined in:

**Version 1.0**: This was the first version of the code. The models and synthesis code are outlined in the following papers:

**BPASS results**: outling the predictions from BPASS and the importance of interacting binaries on stellar populations are outlined in:
- Wafford, Charlot, Bruzual, Eldridge, Calzetti et al., MNRAS accepted. A Comprehensieive Comparative test of seven widely-used spectral synthesis models against multi-band photometry of young massive clusters.

This site also hosts other results from the Auckland Stars Group that are not included in BPASS. These can be found under the **Other Results** page. To date these numbers can be found at:

**Current members of the BPASS team:**
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**Have questions not answered here? CONTACT US**: j.edridge(at)astronomy.org.uk and e.stanway(at)warwick.ac.uk
How does BPASS work?

- Evolve primary star detailed model until end.
- If SN work out if bound:
  - Bound: include in grid of secondary models and calculate.
  - Unbound: treat as single runaway star and calculate model.
- Combine models to create synthetic population and predict observables from population.

- Note: stellar models are detailed models so slower than rapid population synthesis codes but with smaller reaction network and doesn't include e.g. detailed rotation physics so faster than most codes but maybe follow common-envelope evolution more accurately.
- Quick (i.e. a week to make 200,000 models). Future aim is to create large grids quickly to explore parameters as done by rapid pop synth codes.
There are many past contributors to the physics in BPASS: Aida Wofford, Monica Relano, Norbert Langer, Morgan Fraser, Chris Tout, Justyn Maund, Stephen Smartt, Robert Izzard
PhD Students

Liam McClelland
Helium & Wolf-Rayet stars

Lin Xiao
Spectral synthesis and supernovae

John Bray
Supernova kicks and binary population synthesis
For stars between 8ish and 20ish times the mass of the Sun
(Image not to scale).

Smartt et al. (2009), Smartt (2009), Eldridge et al. (2013), Smartt (2015)
For stars between 8 and 20 times the mass of the Sun (Image not to scale).

Smartt et al. (2009), Smartt (2009), Eldridge et al. (2013), Smartt (2015)
Supernova 2008bk

Mattila et al. (2008)
Interesting at low-mass end...
How to rule in/out S-AGBs

Eldridge+ (2007)
An Alternative Stellar Lifecycle

For stars more massive than 20 times the mass of the Sun (Image not to scale).

Smartt et al. (2009), Smartt (2009), Eldridge et al. (2013), Smartt (2015)
No detections for type Ib/c SNe

Eldridge et al. (2013)
Single stars

Eldridge et al. (2013)
Consider two stars in a binary...
More massive star becomes a RSG
H-envelope lost! Also secondary *may* accrete some mass

Bottom line – more hot & luminous stars
Single stars             Binaries

Eldridge et al. (2013)
### Evidence for binaries? Relative supernova rates

<table>
<thead>
<tr>
<th>Supernova</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>
But predict RSG and WR population as well?
Type Ib/c SN iPTF13bvn

Single stars

Binaries

Eldridge et al. (2013)
Ejecta masses of IIb/Ib/Ic SNe

Lyman+ (2016)
So let's look for electron capture SN progenitors from binary evolution.
Figure 1 from Rapidly Evolving and Luminous Transients from Pan-STARRS1
So what about supernova kicks?
What happens to a binary after the first supernova?
What to do about kicks?

- Usually just use distribution from Hobbs+ (2005)
- Let's try to do some simple physics and assume:
  \[-M_{\text{ejecta}} \Delta V = M_{\text{remnant}} V_{\text{kick}}\]
- So let us assume that there is a constant $\Delta V$ for all supernovae so that:
  \[-V_{\text{kick}} = (M_{\text{ejecta}}/M_{\text{remnant}}) \Delta V + \beta\]
- Thus the kick velocity distribution depends mainly on ejecta mass distribution of SN progenitors.
Single star population

Cumulative probability

Single NS velocity (kms⁻¹)

Best fit KS 3D synth to 3D Hobbs
Hobbs best fit 3D distribution
What are the numbers then?

• So let us assume that there is a constant $\Delta V$ for all supernovae so that:

$$-V_{\text{kick}} = \left(\frac{M_{\text{ejecta}}}{M_{\text{remnant}}}\right) \Delta V + \beta$$

• For single stars: $\Delta V = 30 \text{ km s}^{-1}$ & $\beta = 50 \text{ km s}^{-1}$

• For binary stars: $\Delta V = 130 \text{ km s}^{-1}$ & $\beta = 70 \text{ km s}^{-1}$

• So the main result is that kick velocity may indicate ejecta mass, and therefore maybe collapse mechanism.
Any other observations we can match?
(Using stochastic star-formation models not just integrating IMF and time.)
Summary

You can't ignore binaries. And need to match stars and their supernovae.

Electron-capture SNe at solar metallicity are mostly Ib/c? At lower Z type II?

Supernova kicks might be useful to follow, if our simple models hold.

Get binary model results, you don't even have to talk to me, take my models: bpass.auckland.ac.nz

And FINALLY you are all invited to...
IAU Symposium:

The Lives and Death-Throes of Massive Stars

Auckland, 28th November, 2016

JJ Eldridge, Margaret Hanson & Artemio Herrero
Joe Anderson, Matteo Cantiello, Ben Davies,
Sylvia Ekstrom, John Hillier, Coralie Neiner,
Fernanda Nieva, Lida Oskinova, Alicia Soderberg,
Nicole St-Louis, Jorick Vink, Sung-Chul Yoon

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Image: ©Firefly photography
Cyril Geory:
Mass-loss rate during the RSG phase. Observations from Mauron and Josselin (2011) (blue stars) and van Loon et al. (2005): M-type stars (red stars), MS- and S-type stars (green), and carbon RSGs (purple). The black curves show the mass-loss rate according to de Jager et al. (1988), for log($T_{\text{eff}}$) = 3.5 (solid), 3.6 (dashed) and 3.7 (dotted-dashed). The red zone correspond to the mass-loss rate used in the Geneva stellar evolution code for standard mass-loss rate (lower line), or increased one (top line).