Implications of binary evolution for electron-capture SNe

JJ Eldridge
Elizabeth Stanway
John Bray, Lin Xiao, Liam McClelland,
Joe Walmswell, Morgan Fraser,
Justyn Maund, Stephen Smartt

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND

Outline

- BPASS: Binary Population & Spectral Synthesis with detailed stellar evolution models.
- 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

Version 2 based on **250,000 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 BP**A**SS**-Team**."

BPASS

Binary Population and Spectral Synthesis

Have questions not answered here? CONTACT US: j.eldridge [at] auckland.ac.nz and e.stanway [at] warwick.ac.uk

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.
- Stanway, Eldridge & Becker, 2015, MNRAS, 456, 485. Stellar population effects on the inferred photon density at reionization.

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:

- Eldridge & Stanway, 2012, MNRAS, 419, 479. The effect of stellar evolution uncertainties on the rest-frame ultraviolet stellar lines of C IV and He II in high-redshift Lyman-break galaxies.
- Eldridge, Langer & Tout, 2011, MNRAS, 414, 3501. Runaway stars as progenitors of supernovae and gamma-ray bursts.

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

- Eldridge & Stanway, 2009, MNRAS, 400, 1019. Spectral population synthesis including massive binaries.
- Eldridge, Izzard & Tout, 2008, MNRAS, 384, 1109. The effect of massive binaries on stellar populations and supernova progenitors.

BPASS results: outlining the predictions from BPASS and the importance of interacting binaries on stellar populations are outlined in:

- Wofford, Charlot, Bruzual, Eldridge, Calzetti et al., MNRAS accepted. A Comphrehensive Comparitive test of seven widely-used spectral synthesis models against multi-band photometry of young massive clusers.
- Xiao & Eldridge, 2015, MNRAS, 452, 2597. Core-collapse supernova rate synthesis within 11 Mpc
- Eldridge, 2012, MNRAS, 422, 794. Stochasticity, a variable stellar upper-mass limit, binaries and star-formation rate indicators.
- Eldridge & Relaño, 2011, MNRAS, 411, 235. The red supergiants and Wolf-Rayet stars of NGC 604.
- Eldridge, 2009, MNRAS, 400, 20. A new-age determination for γ2 Velorum from binary stellar evolution models.

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:

- McClelland & Eldridge (2015), submitted.

Current members of the BPASS team:

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.

BPASS-team

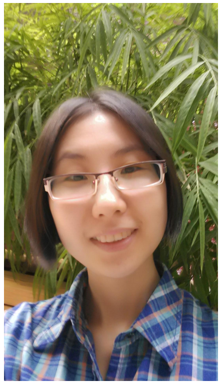
JJ Eldridge
Stellar models, population and spectral synthesis

Elizabeth Stanway
High-z, dust, IR, radio and unresolved population SED fitting

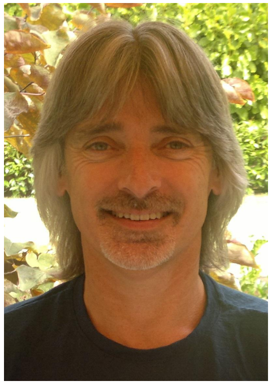
There are many past contributors to the physics in BPASS:
Aida Wofford, Monica Relano, Norbert Langer, Morgan Fraser, Chris Tout, Justyn Maund, Stephen Smartt, Robert Izzard

PhD Students

Liam McClelland
Helium & Wolf-Rayet stars

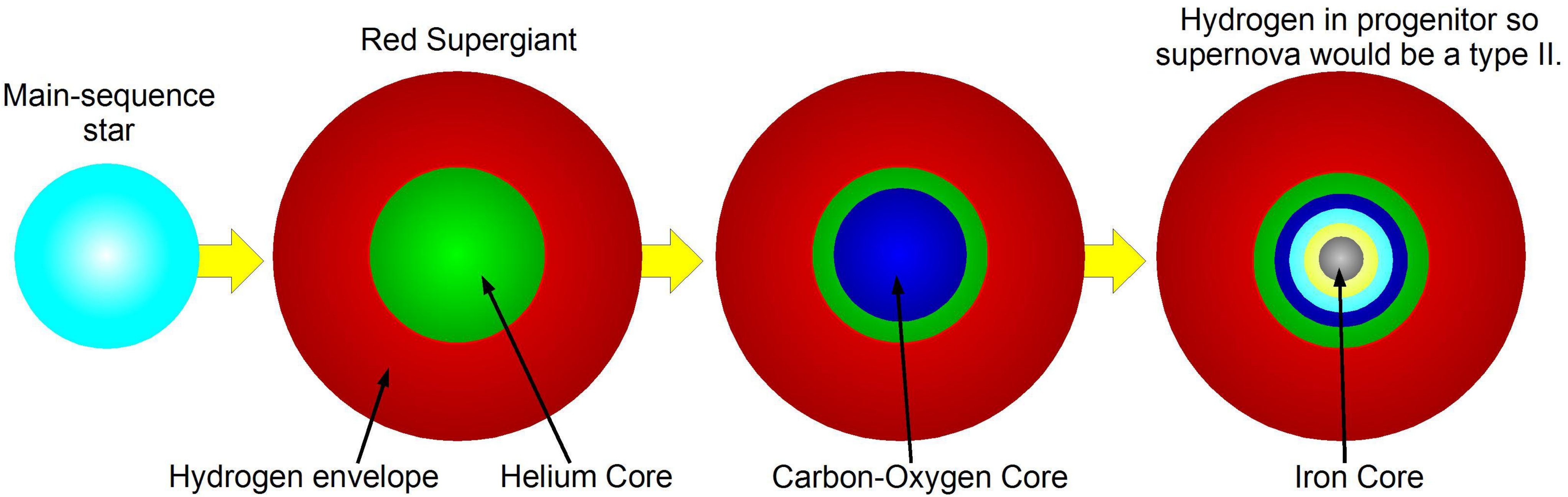


Lin Xiao
Spectral synthesis and supernovae



John Bray
Supernova kicks and binary population synthesis

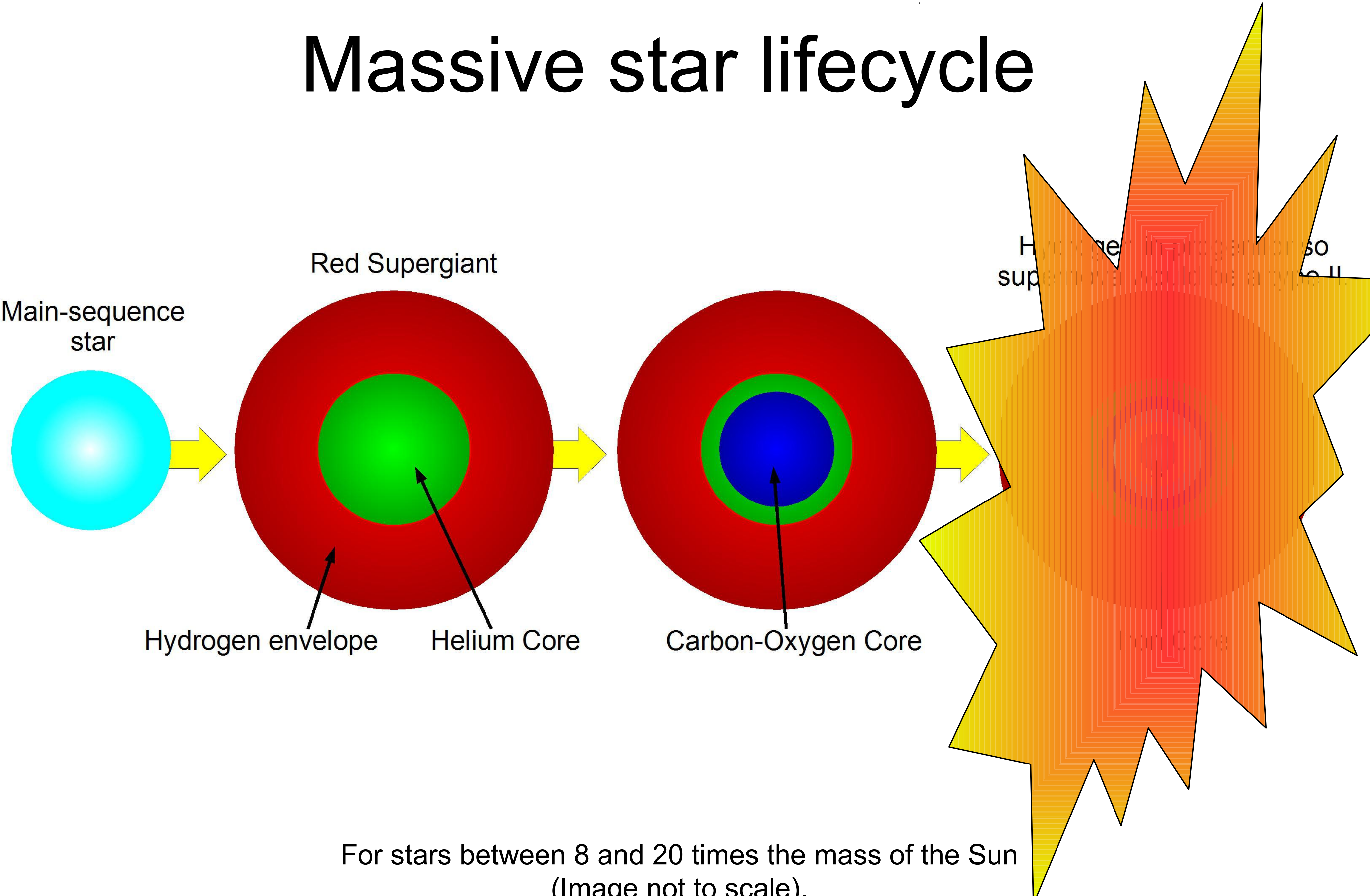
Massive star lifecycle



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)

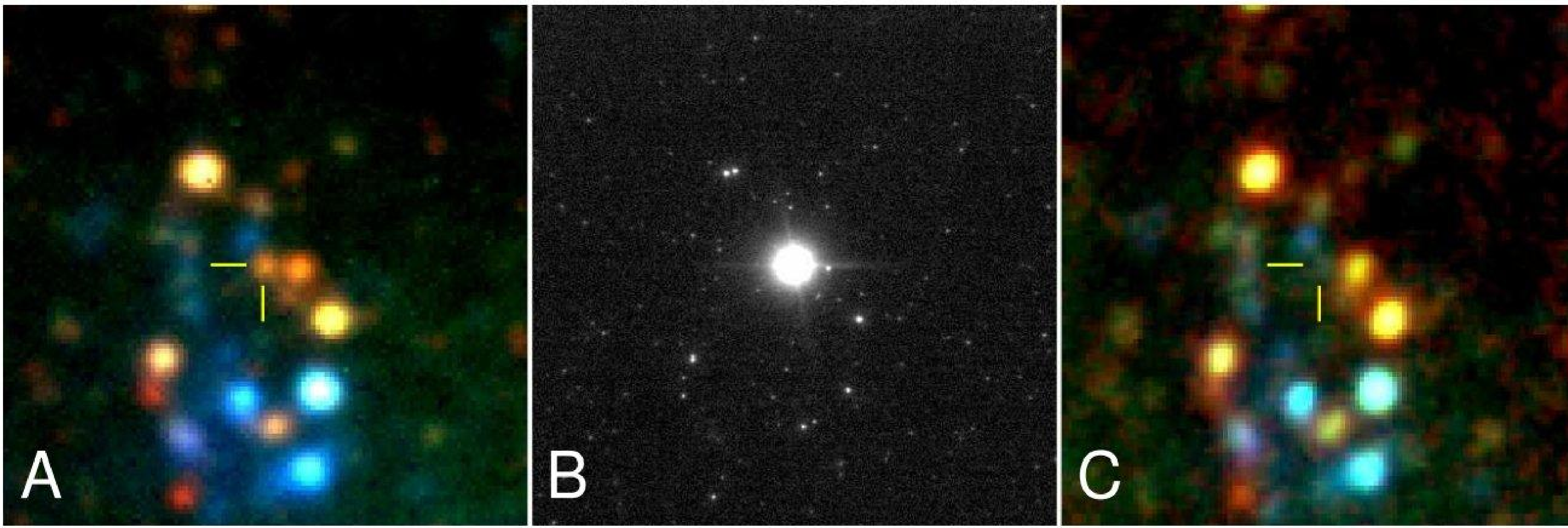
Massive star lifecycle



For stars between 8 and 20 times the mass of the Sun
(Image not to scale).

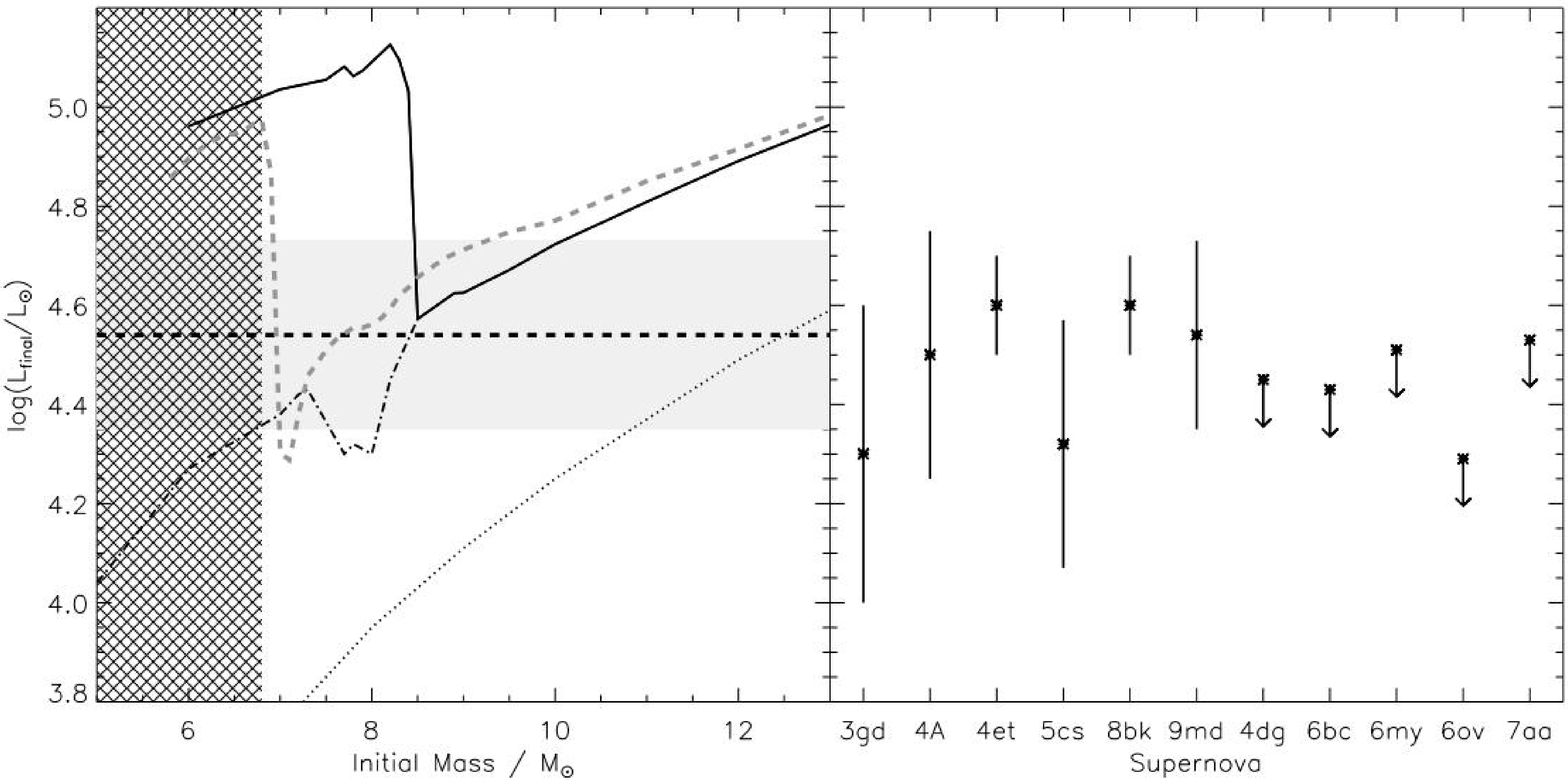
Smartt et al. (2009), Smartt (2009), Eldridge et al. (2013), Smartt (2015)

Supernova 2008bk



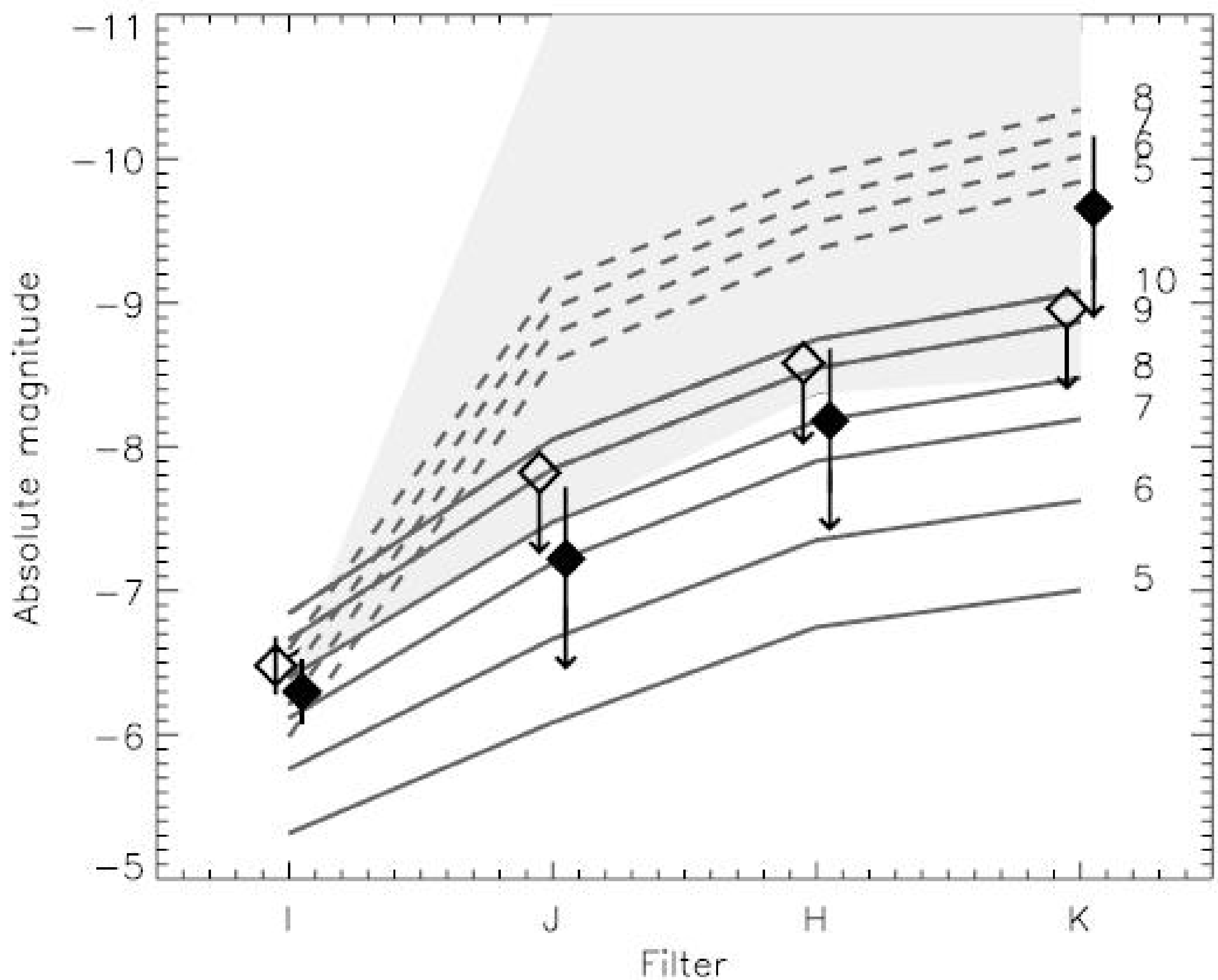
Mattila et al. (2008)

Interesting at low-mass end...



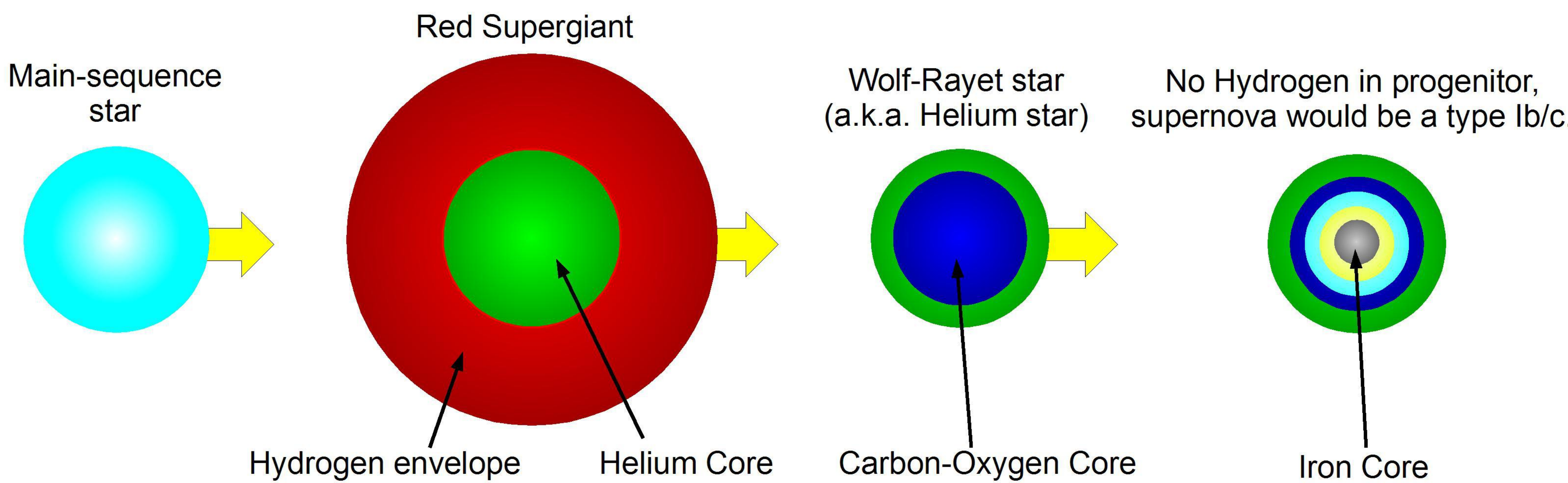
Fraser, Ergon et al. (2011)
& Eldridge & Tout (2004)

How to rule in/out S-AGBs



Eldridge+ (2007)

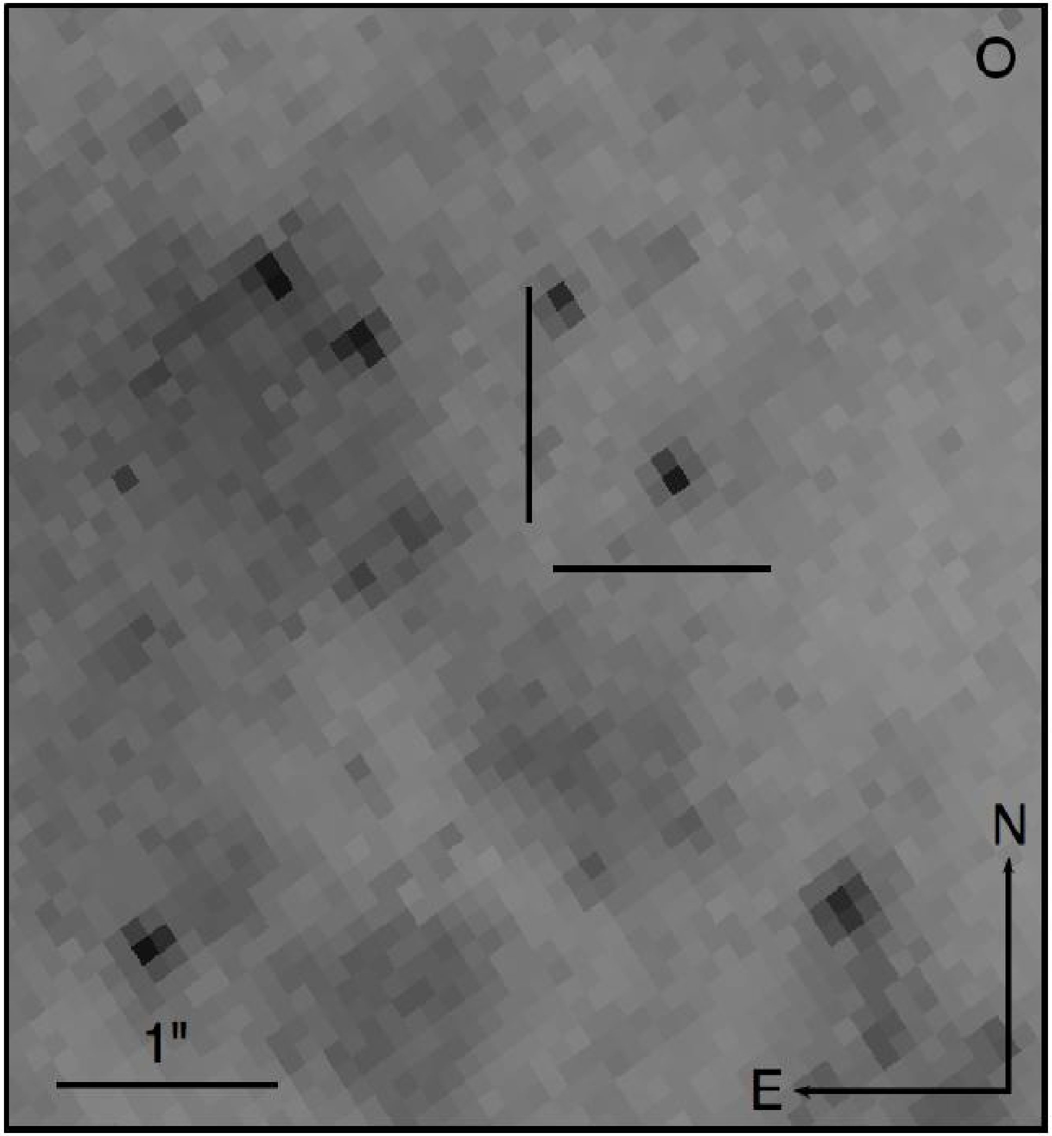
An Alternative Stellar Lifecycle



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

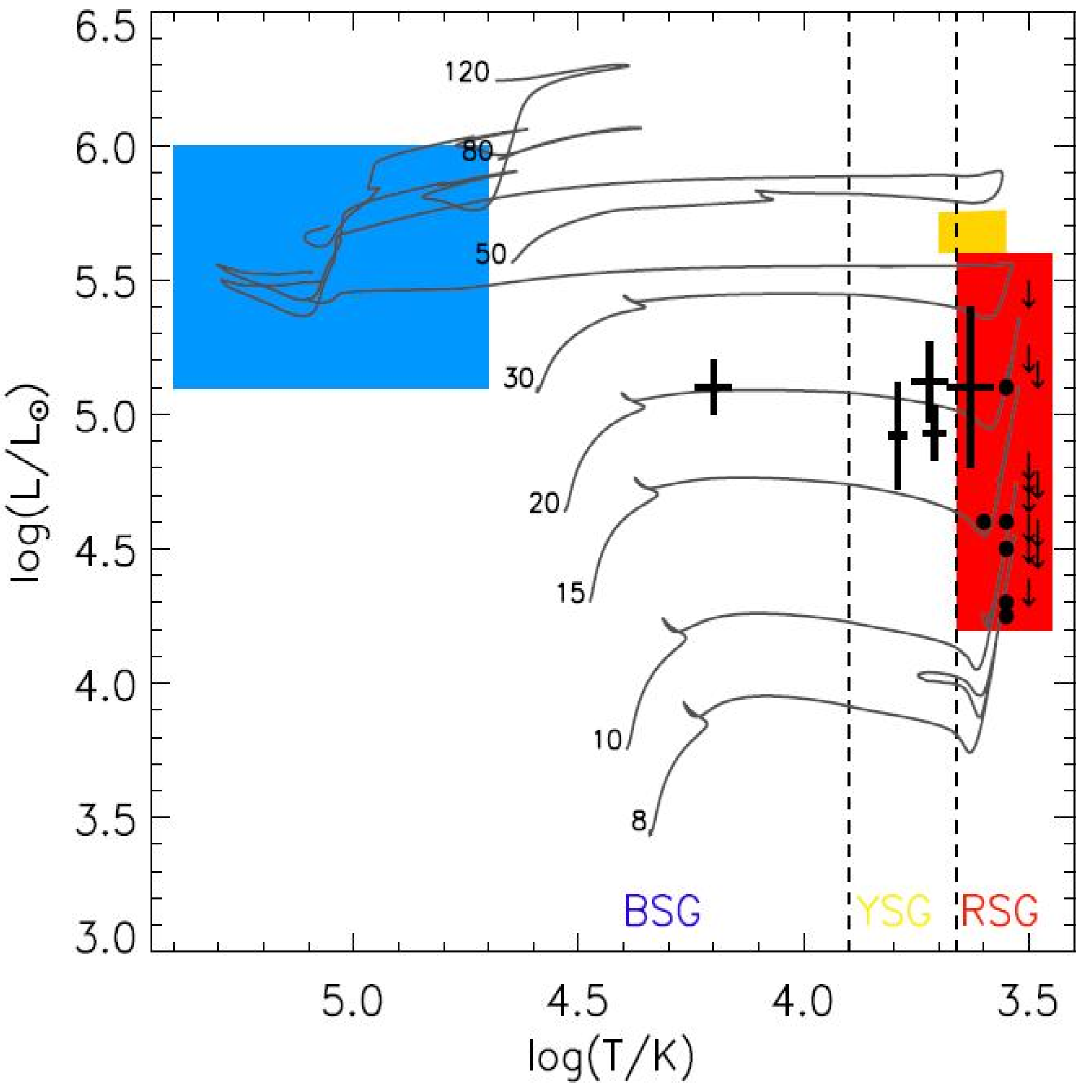
Smartt et al. (2009), Smartt (2009), Eldridge et al. (2013), Smartt (2015)

No detections for type Ib/c SNe



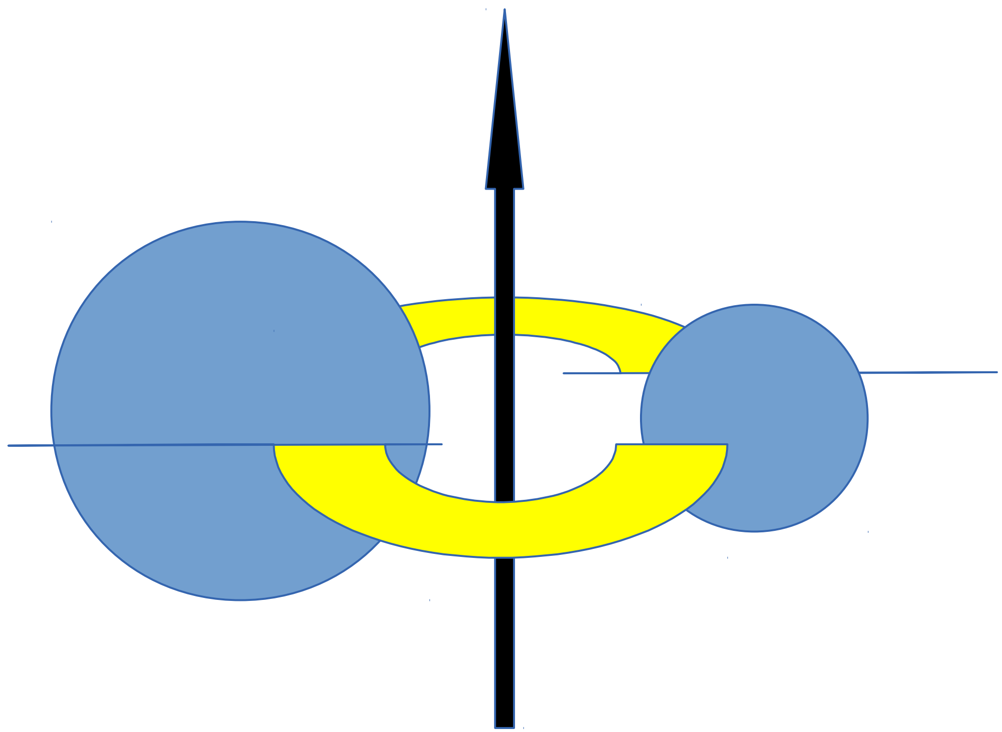
Eldridge et al . (2013)

Single stars

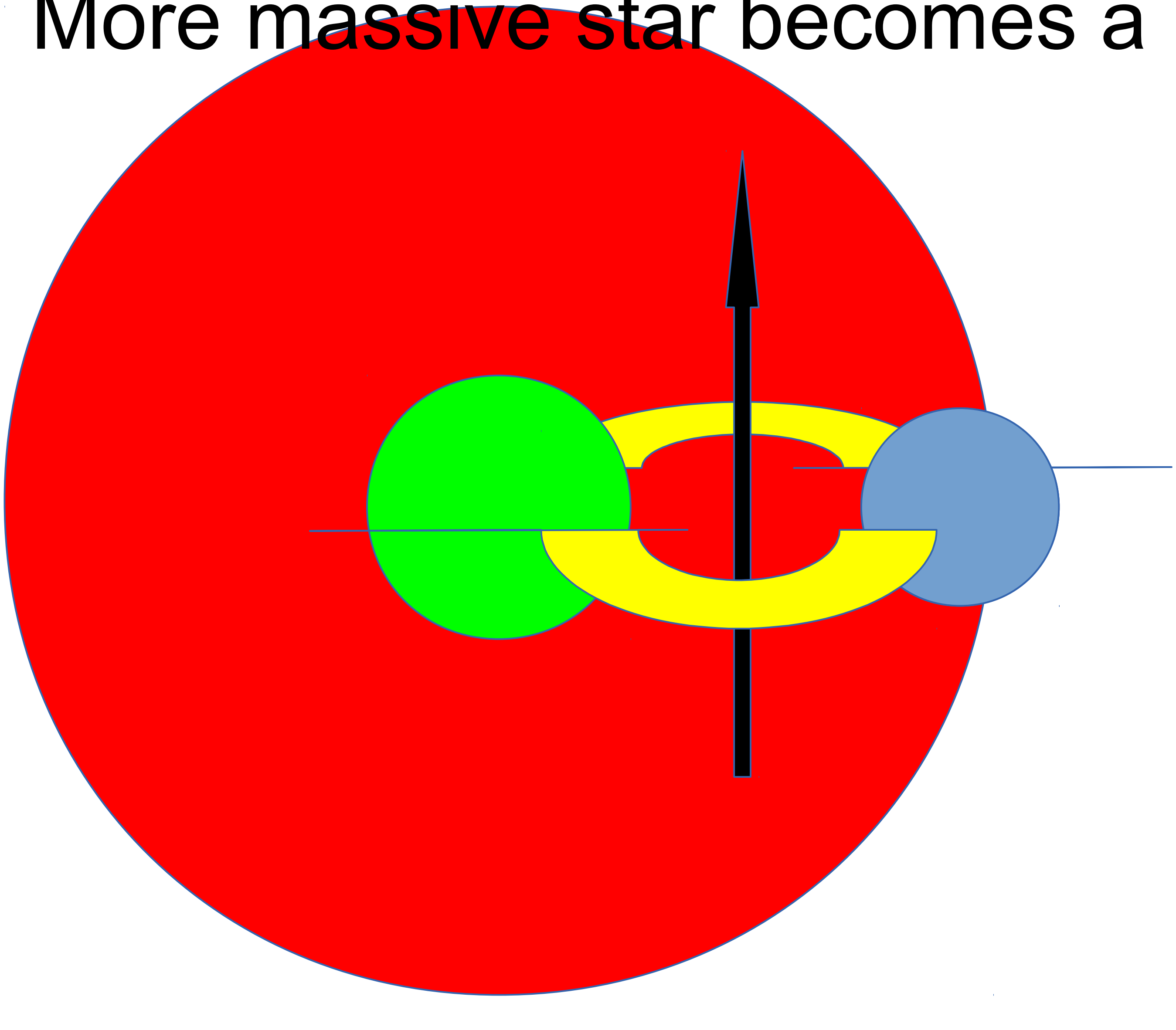


Eldridge et al . (2013)

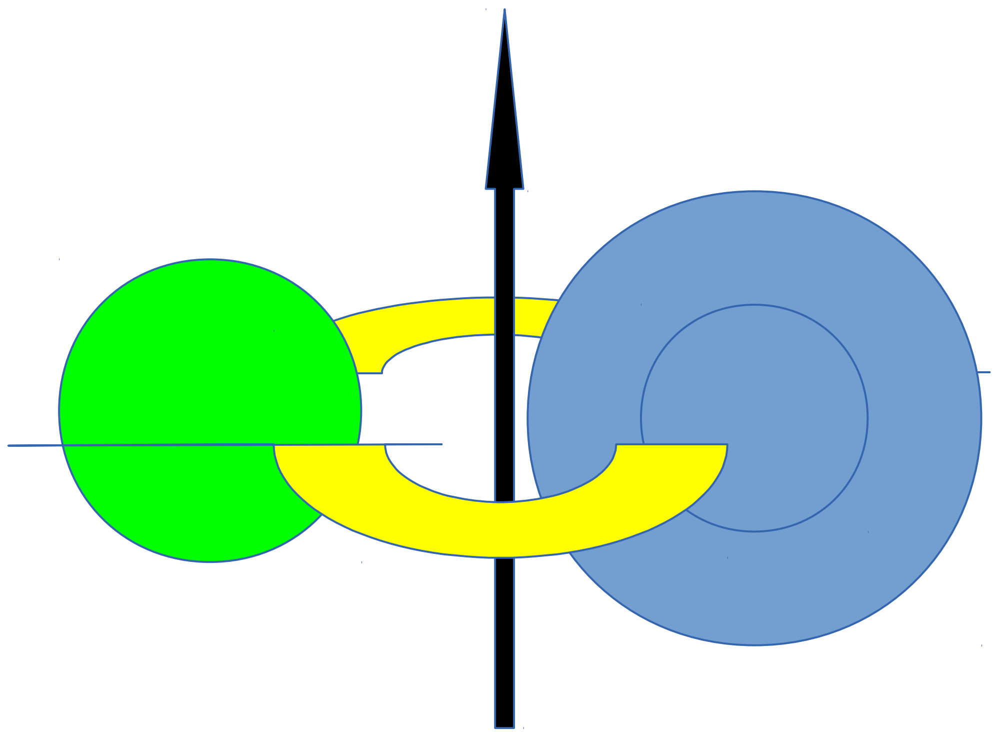
Consider two stars in a binary...



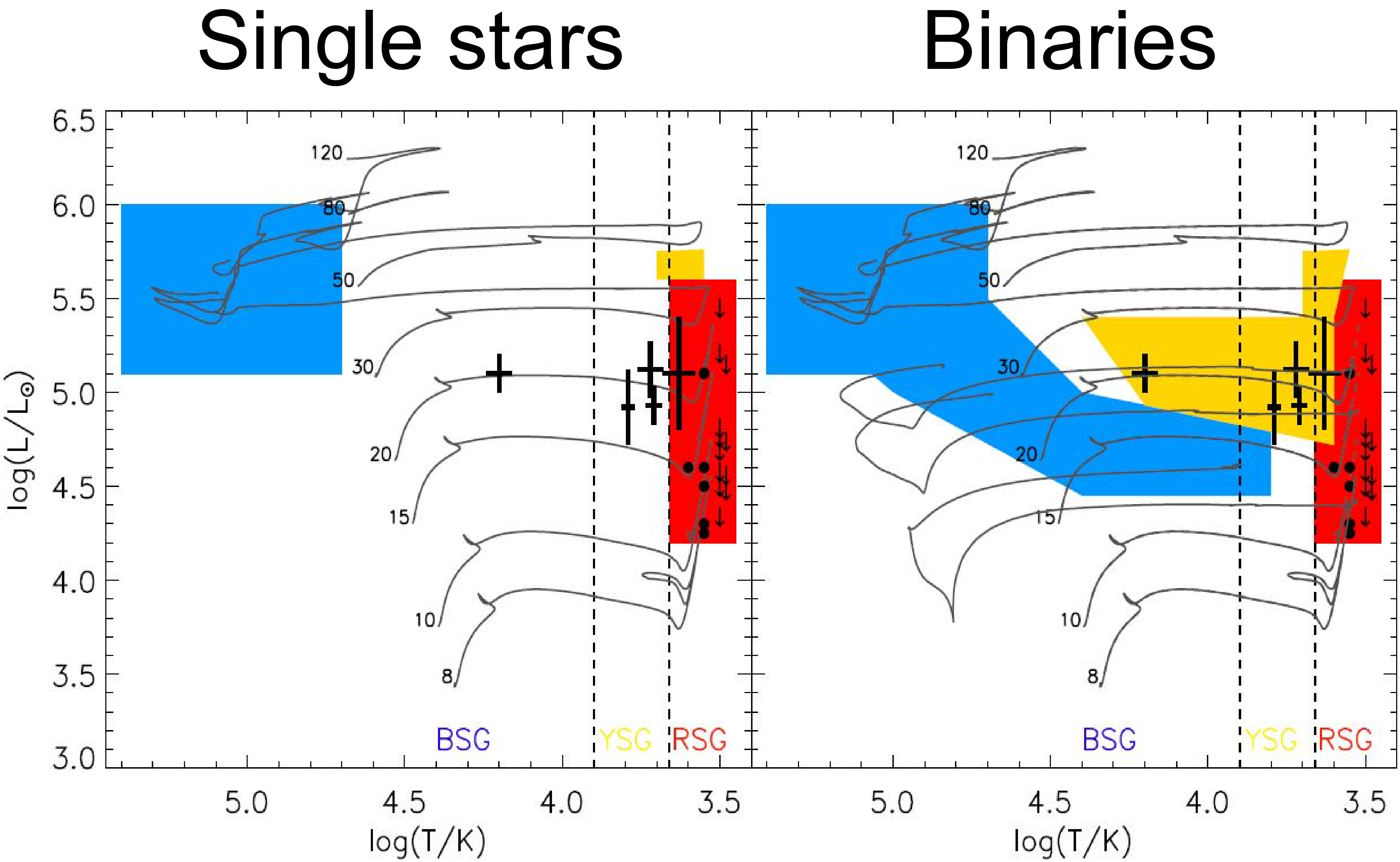
More massive star becomes a RSG



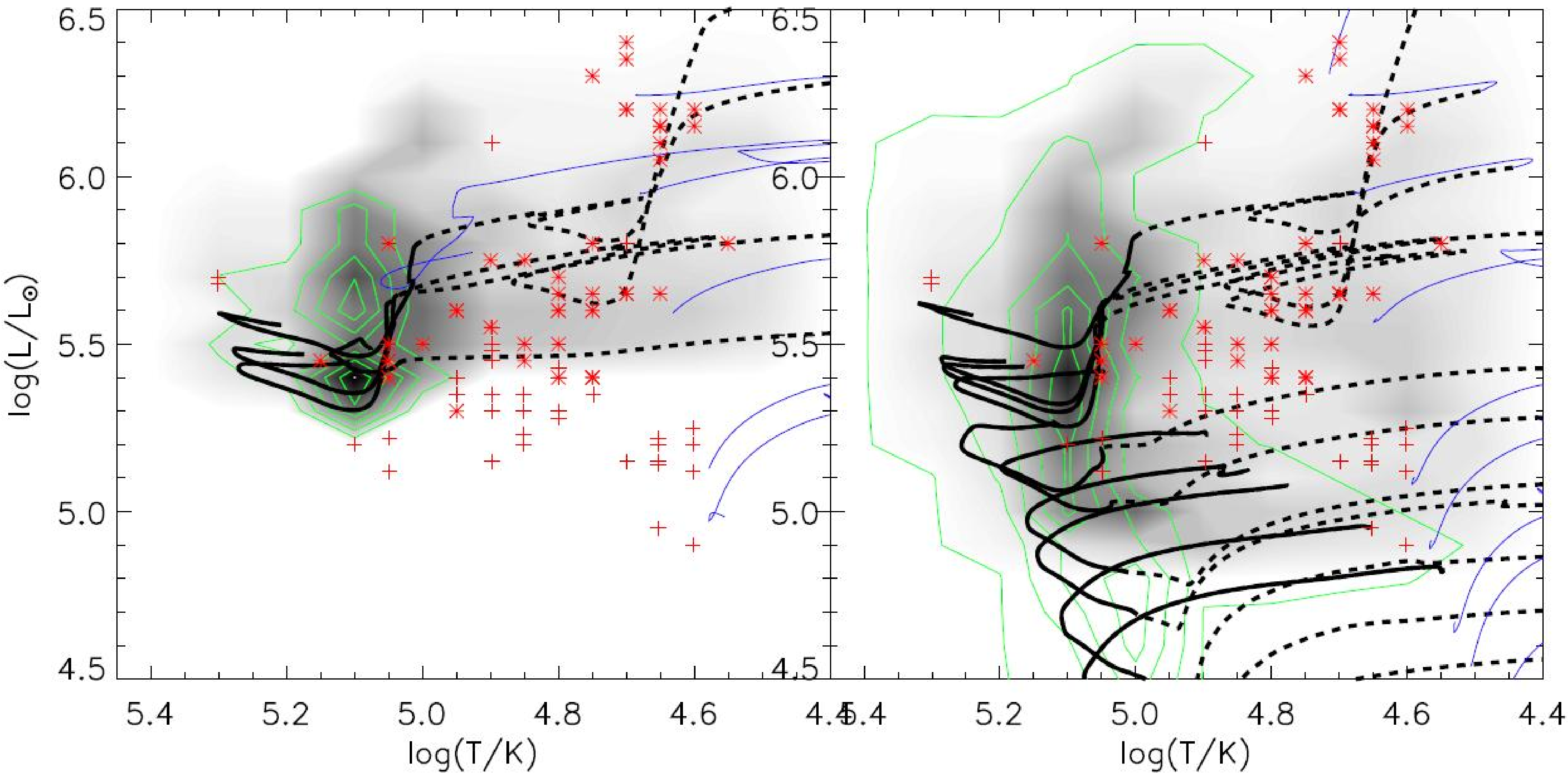
H-envelope lost! Also secondary ***may*** accrete some mass



Bottom line – more hot & luminous stars

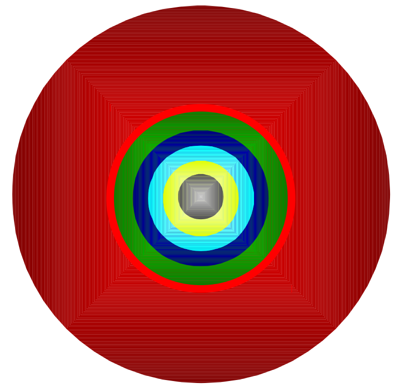
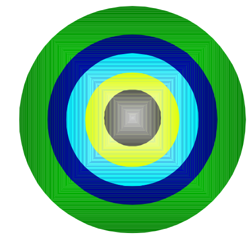


Eldridge et al . (2013)



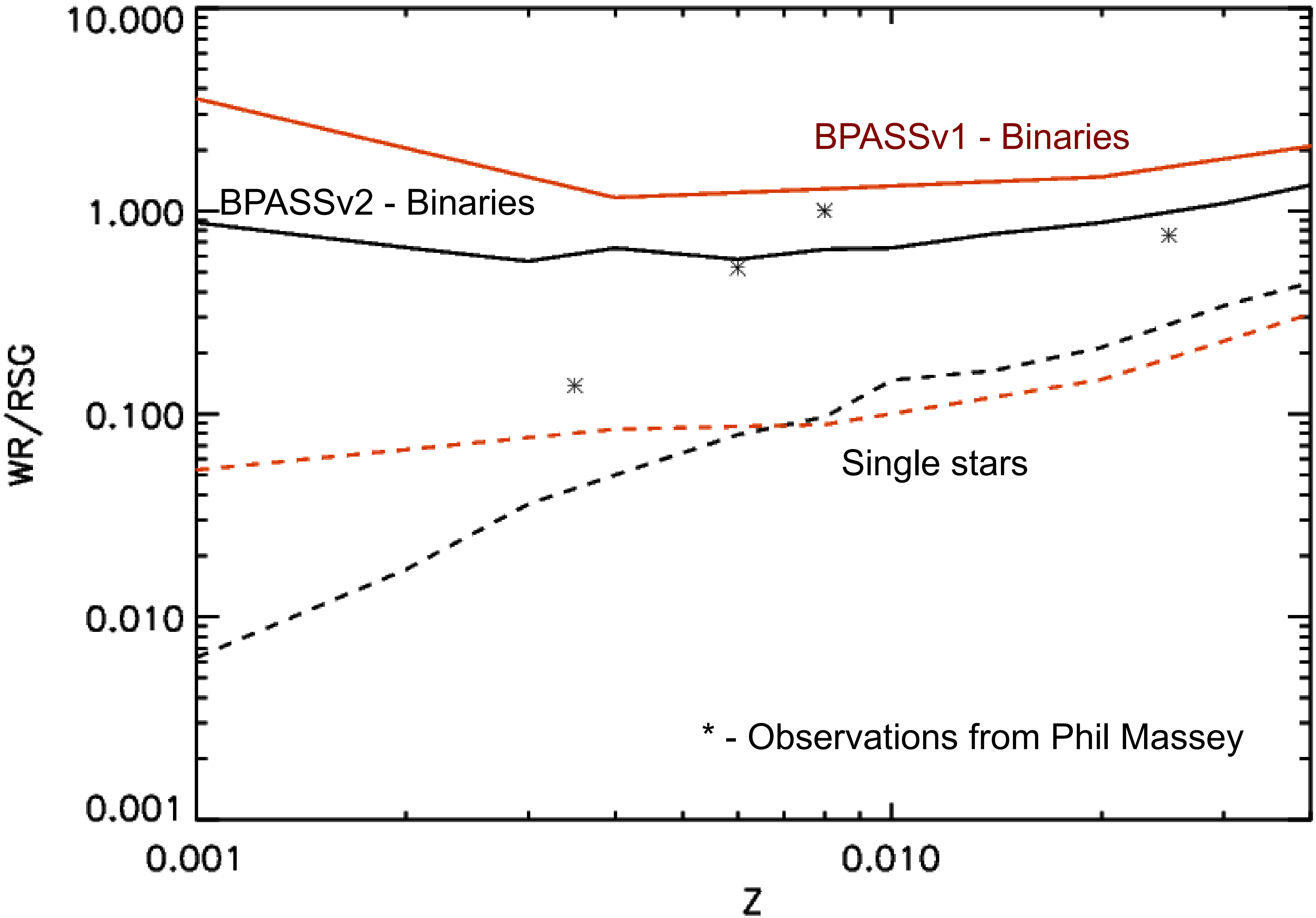
Eldridge et al . (2013)

Evidence for binaries?
Relative supernova rates

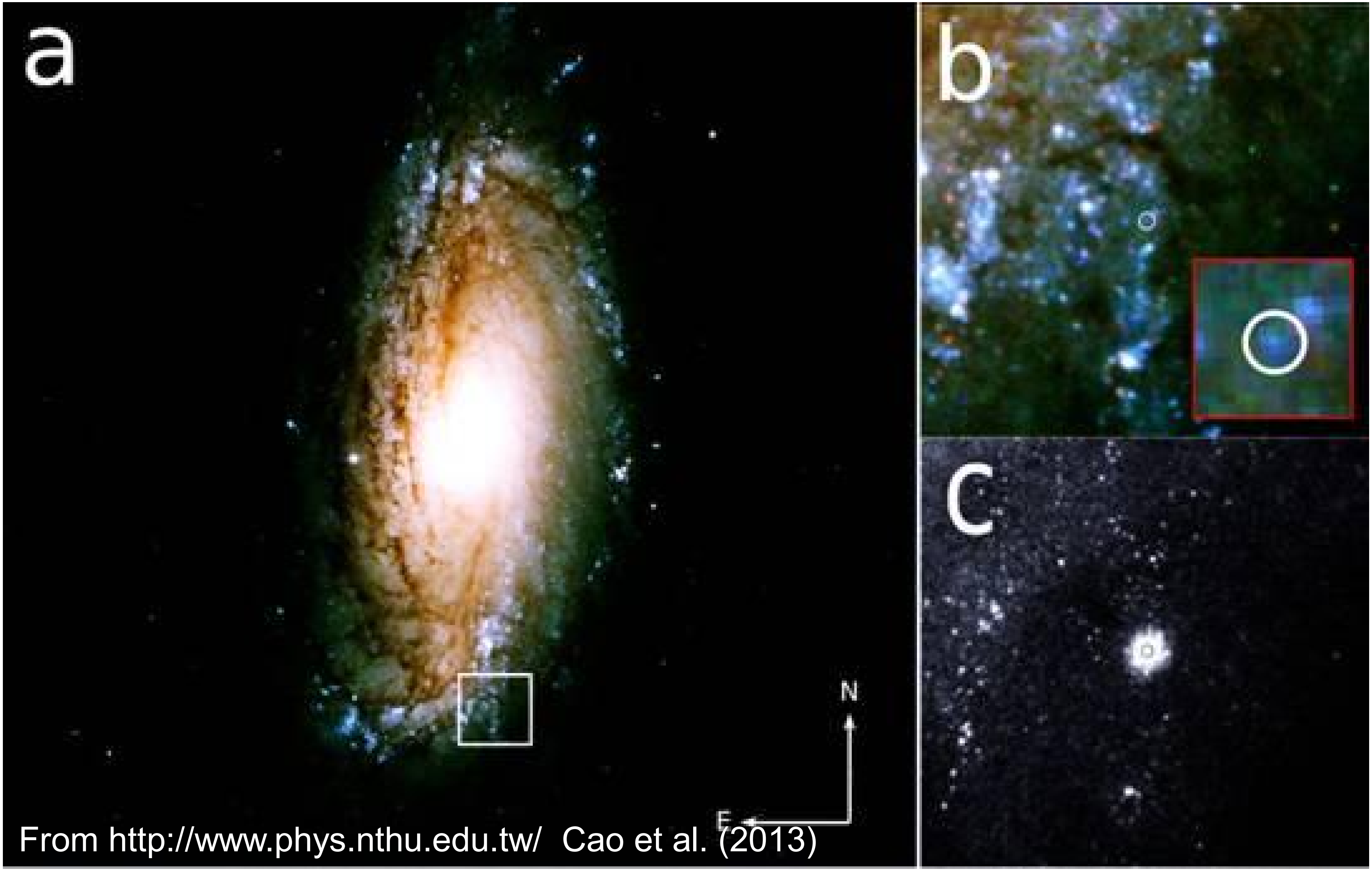



Supernova	**Type II**	**Type Ib/c**
Observations	71±9%	29±6%
Single stars	85%	15%
Mix	71%	29%
Binaries	63%	37%

But predict RSG and WR population as well?

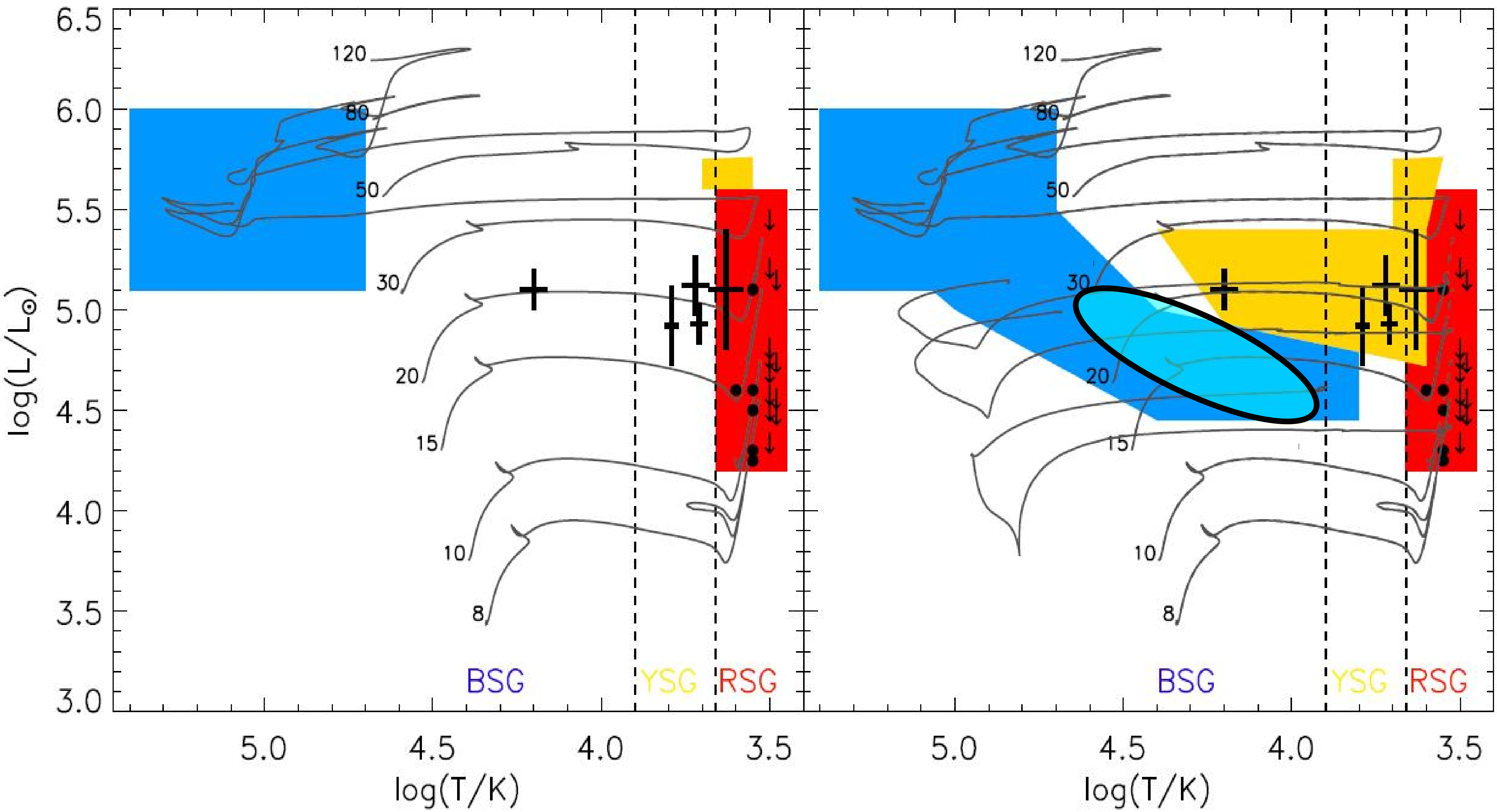


Type Ib/c SN iPTF13bvn



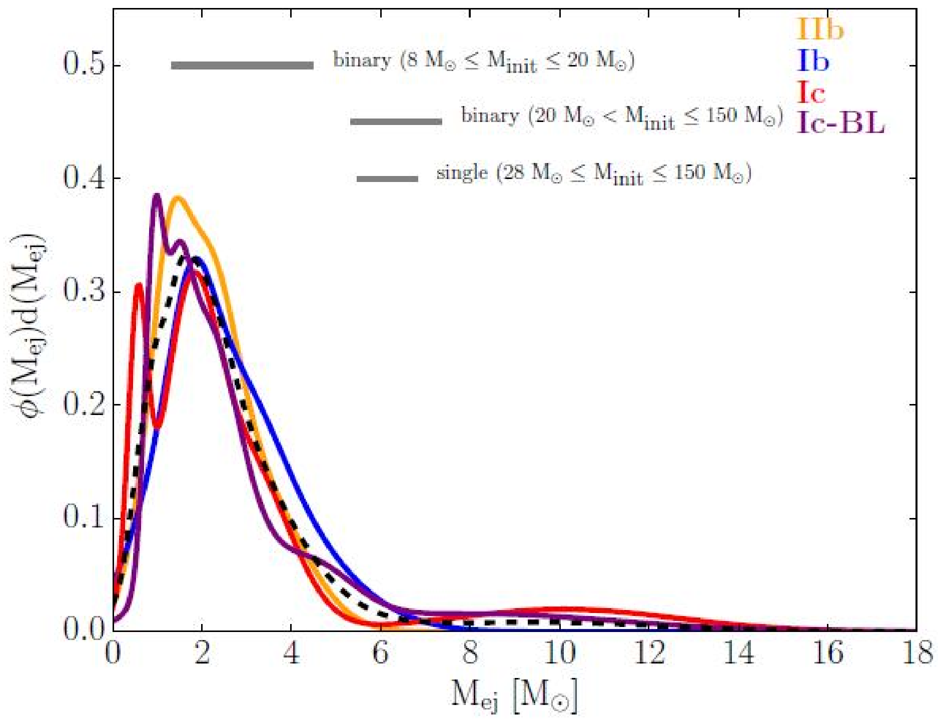
From http://www.phys.nthu.edu.tw/ Cao et al. (2013)

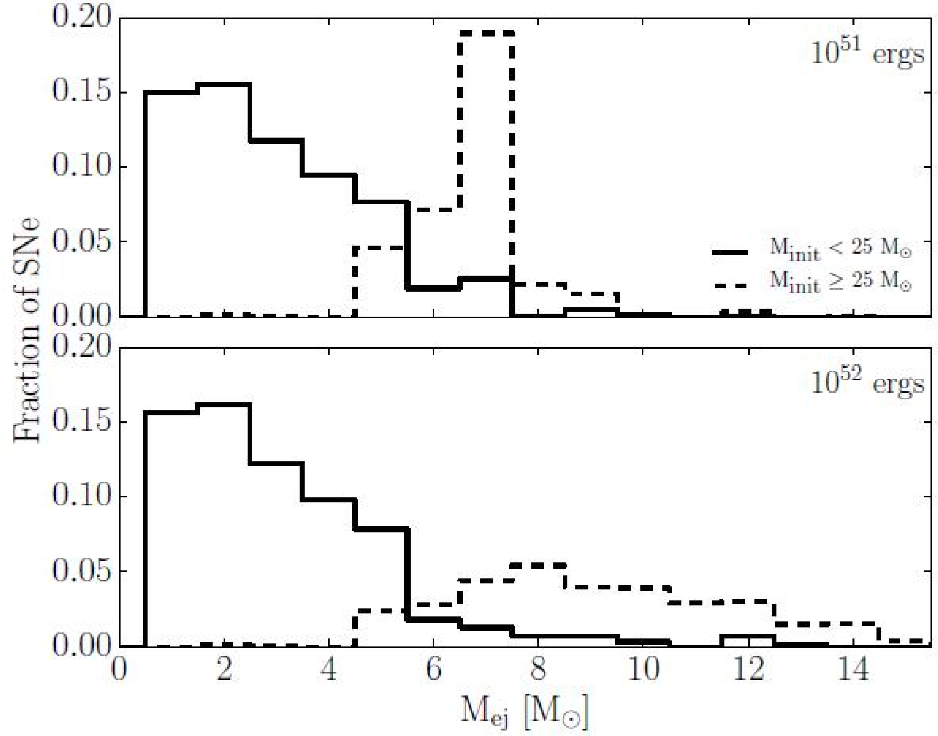
Single stars   Binaries



Eldridge et al . (2013)

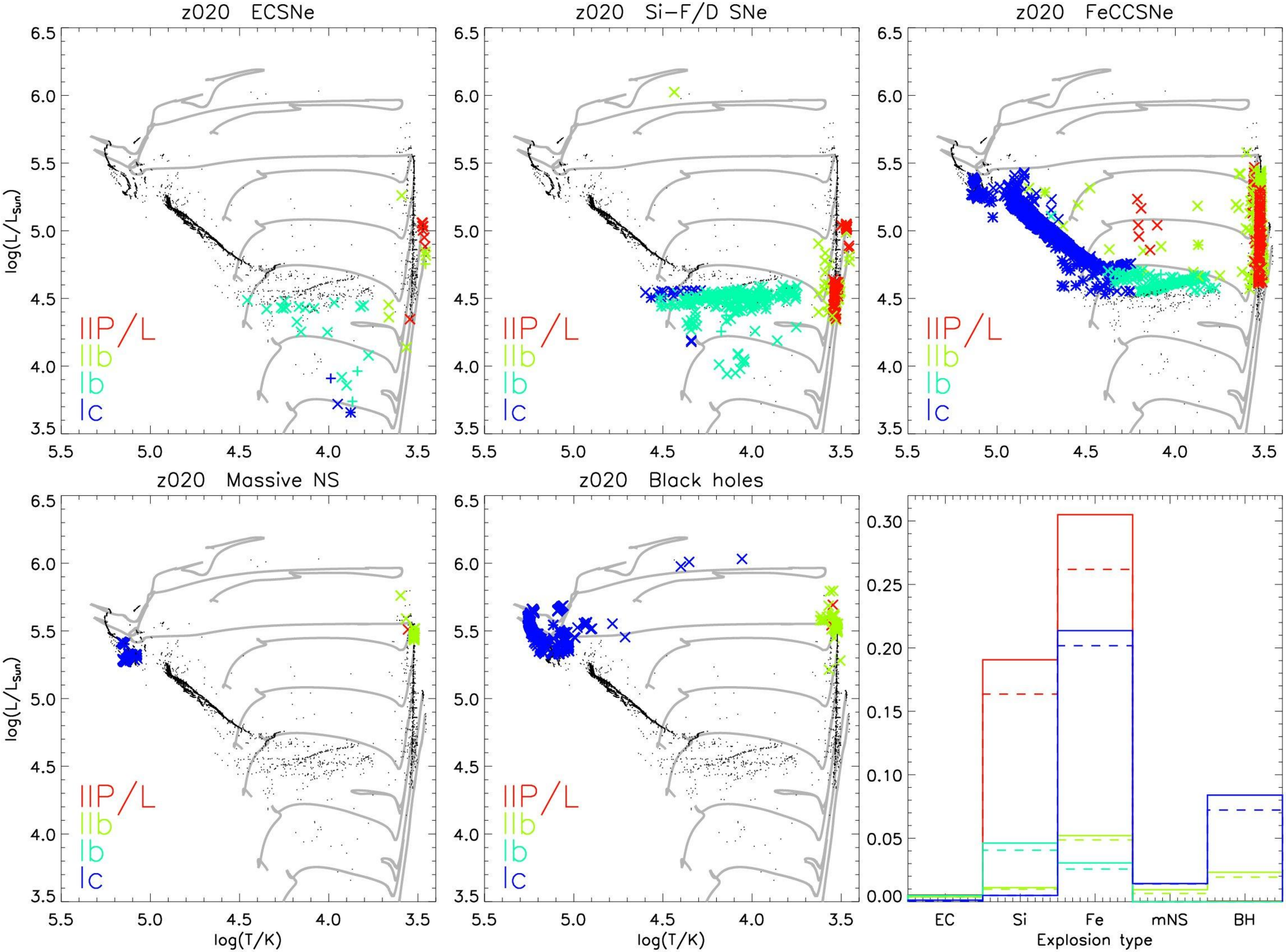
Ejecta masses of IIb/Ib/Ic SNe

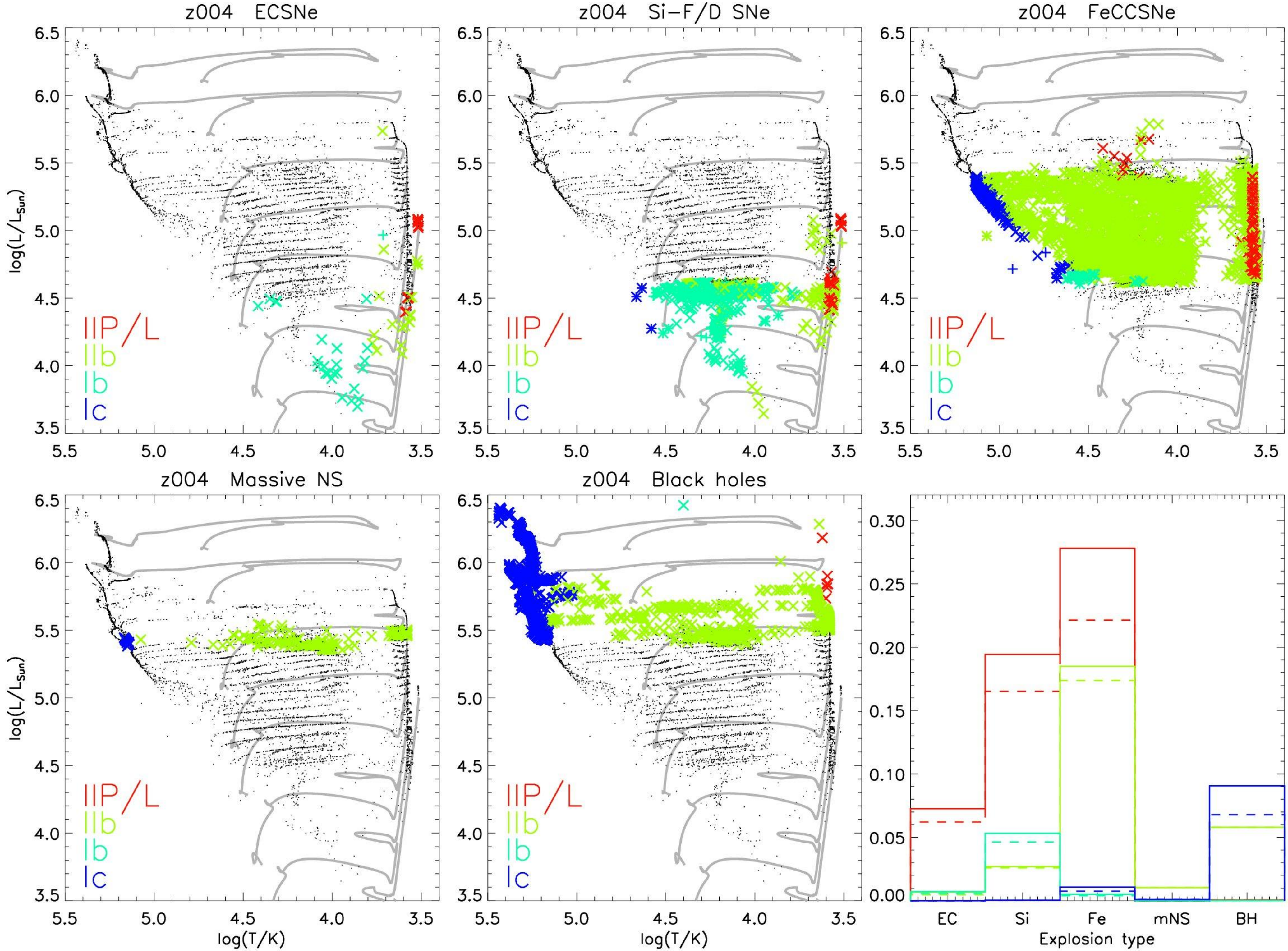




Lyman+ (2016)

So lets look for electron capture SN progenitors from binary evolution.

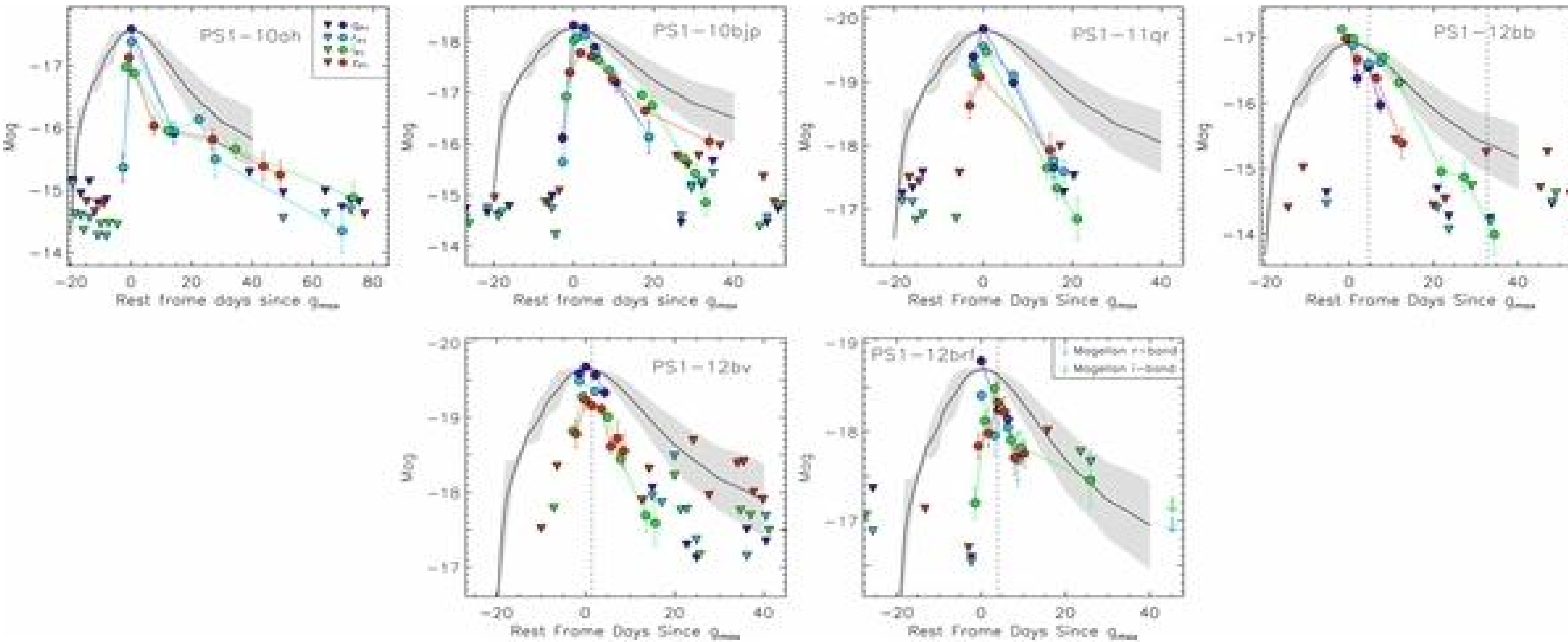

z020 ECSNe
z020 Si-F/D SNe
z020 FeCCSNe
z020 Massive NS
z020 Black holes
log(L/L_Sun)
log(T/K)
IIP/L
IIb
Ib
Ic
EC
Si
Fe
mNS
BH
Explosion type



z004 ECSNe
z004 Si−F/D SNe
z004 FeCCSNe
z004 Massive NS
z004 Black holes
IIP/L
IIb
Ib
Ic
log(L/L$_{Sun}$)
log(T/K)
Explosion type
EC
Si
Fe
mNS
BH

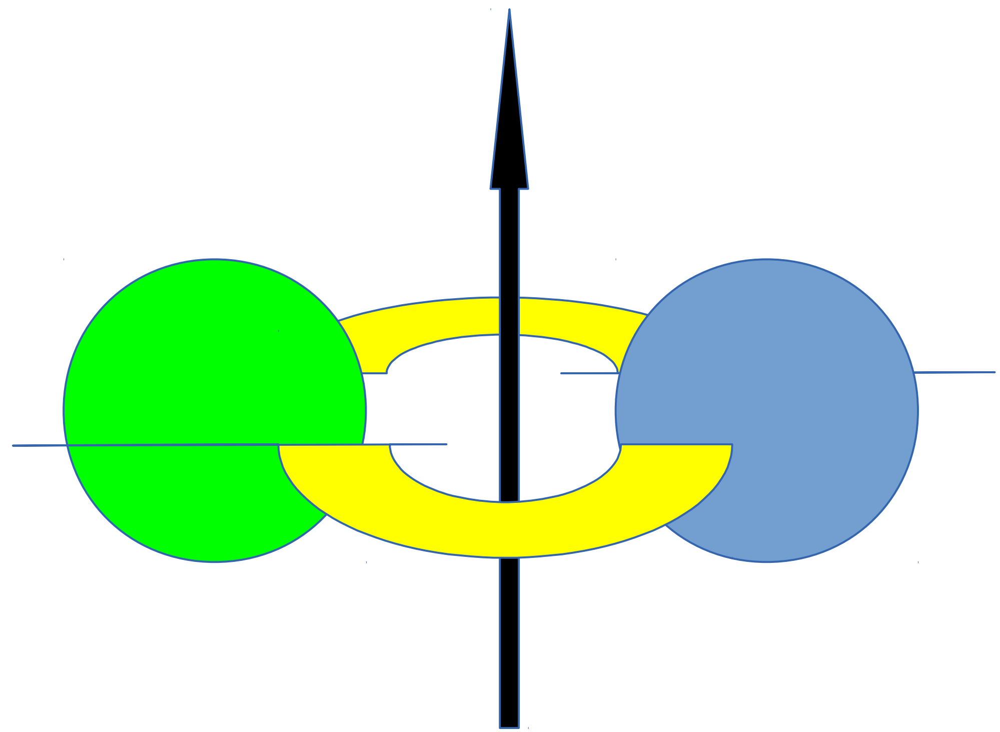
Figure 1 from Rapidly Evolving and Luminous Transients from Pan-STARRS1

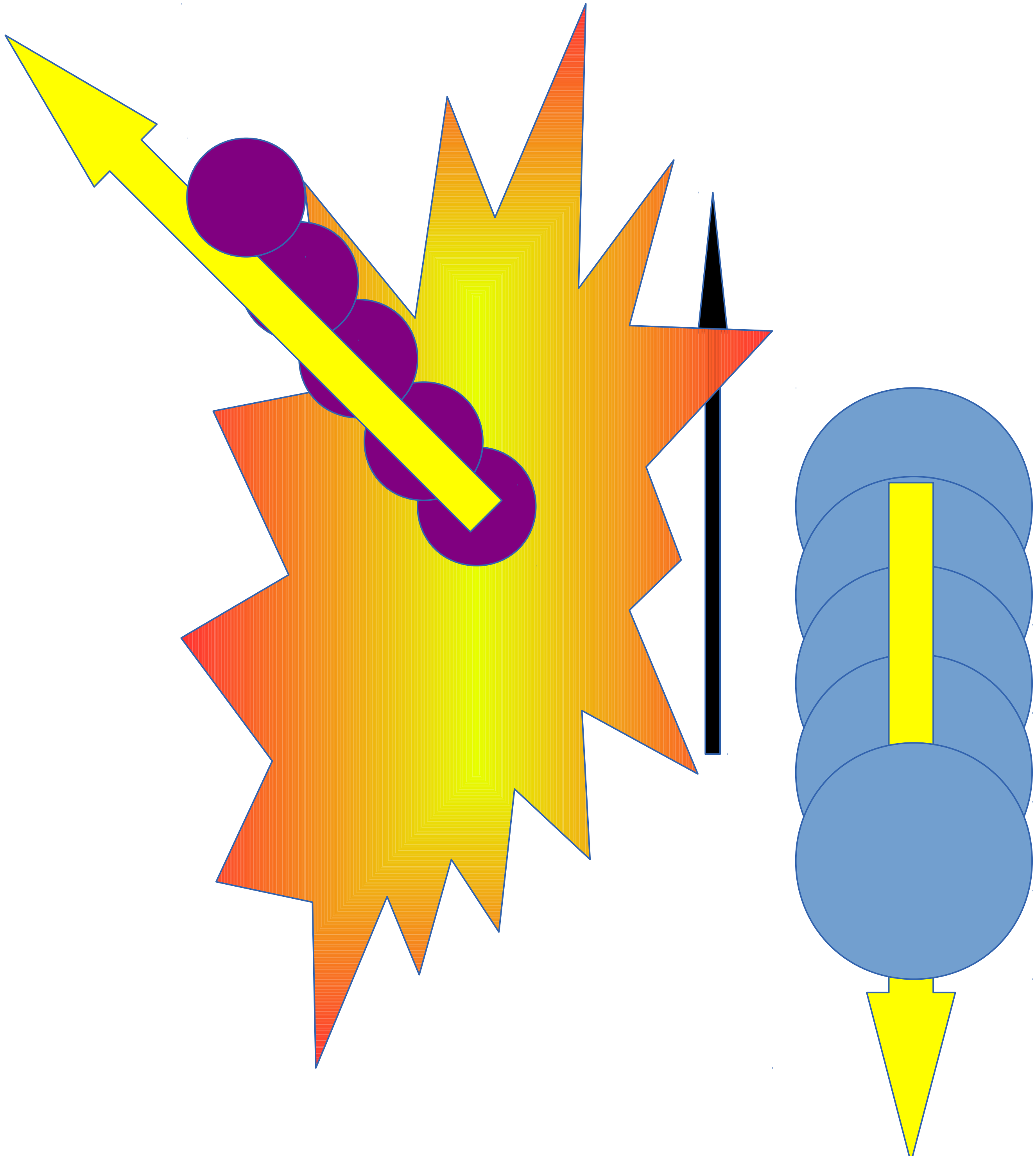
M. R. Drout et al. 2014 ApJ 794 23 doi:10.1088/0004-637X/794/1/23

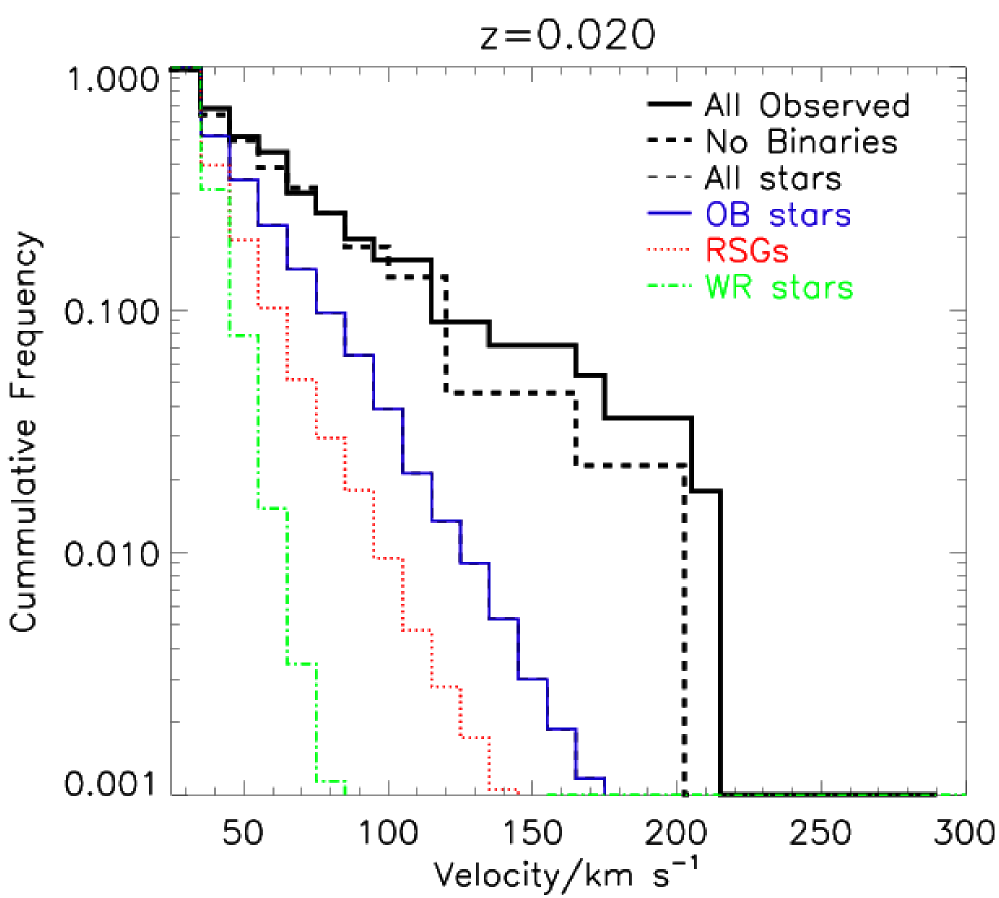


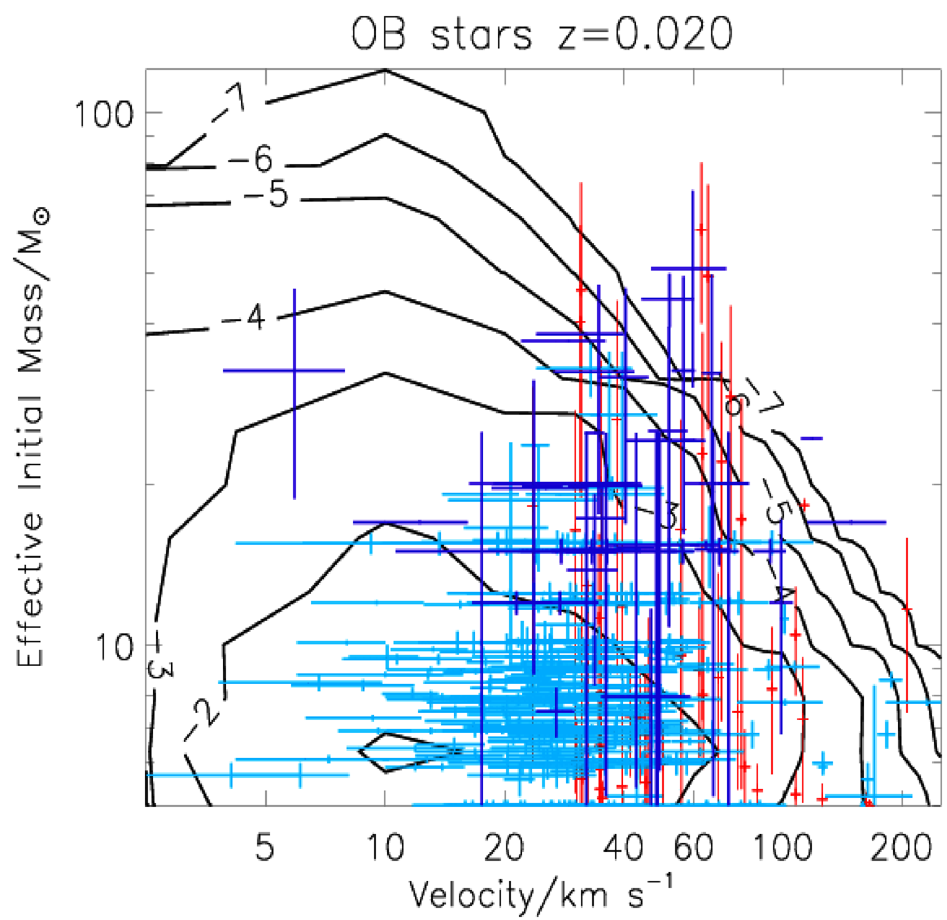
So what about supernova kicks?

What happens to a binary after the first supernova?





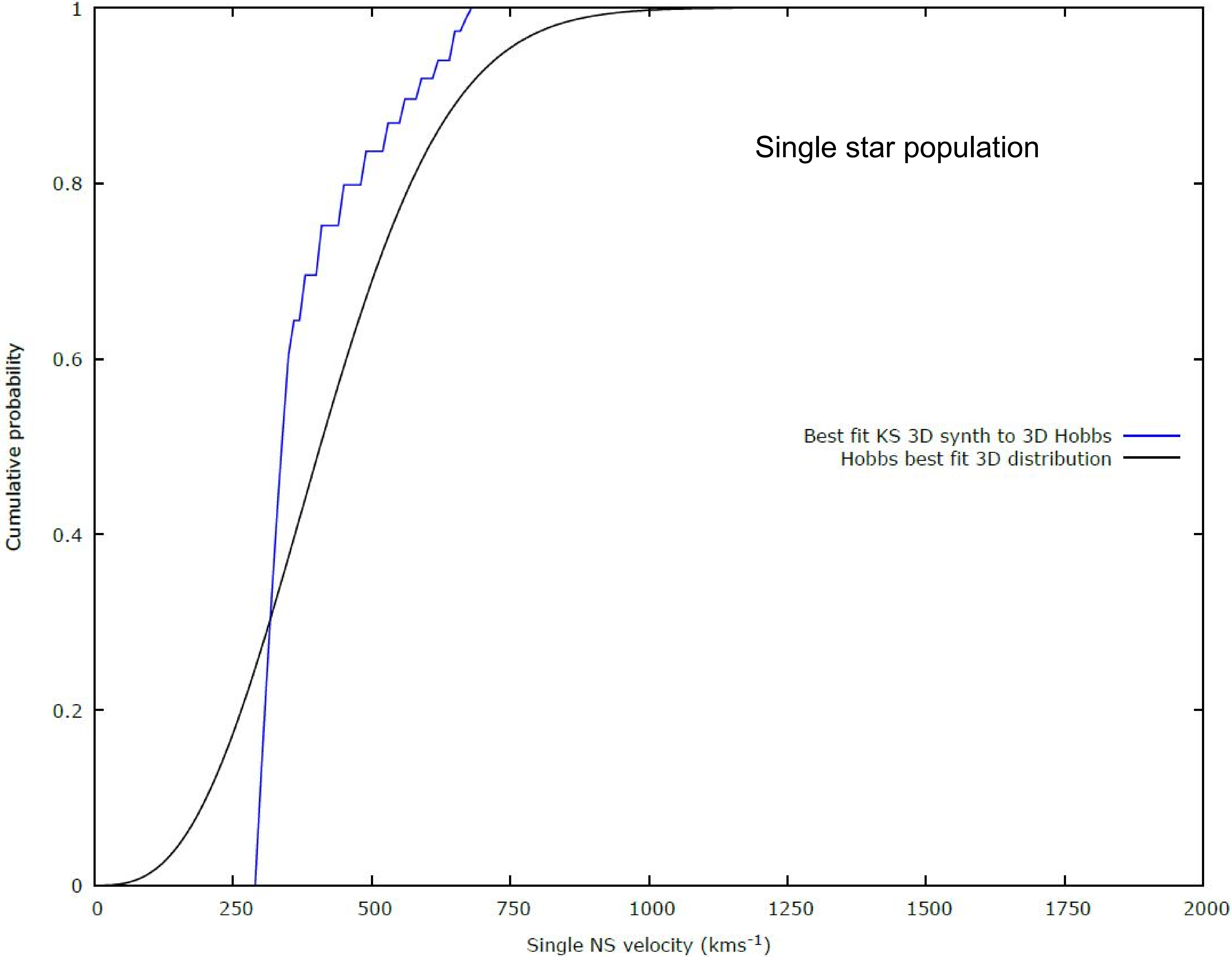


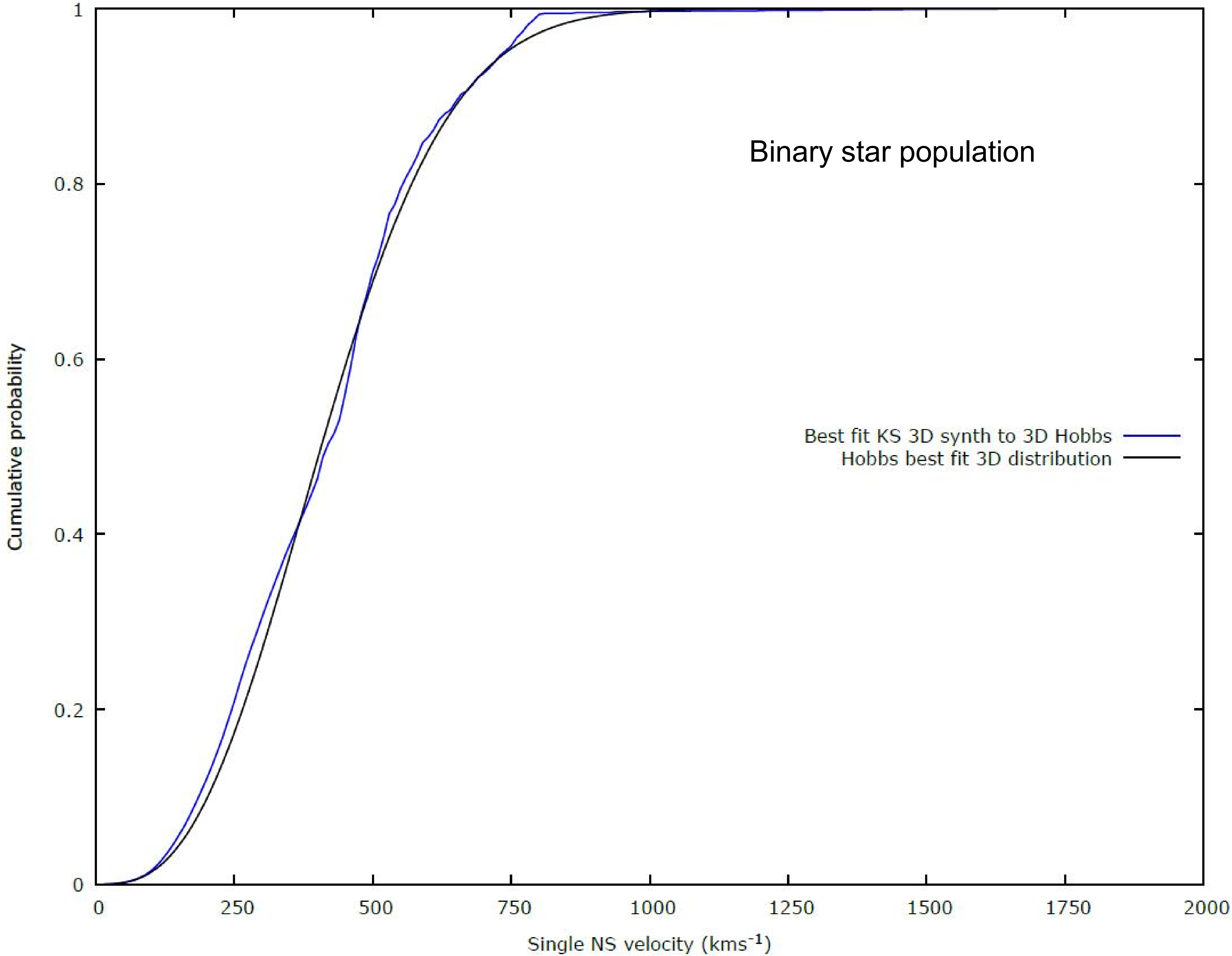


Eldridge, Langer & Tout (2011)
Hoogerwerf et al. (2001)
Tetzlaff et al. (2011)

What to do about kicks?

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


Single star population
Best fit KS 3D synth to 3D Hobbs
Hobbs best fit 3D distribution
Cumulative probability
0
0.2
0.4
0.6
0.8
1
0
250
500
750
1000
1250
1500
1750
2000
Single NS velocity (kms^{-1})



Binary star population
Best fit KS 3D synth to 3D Hobbs
Hobbs best fit 3D distribution
Cumulative probability
Single NS velocity (kms-1)
0
0.2
0.4
0.6
0.8
1
0
250
500
750
1000
1250
1500
1750
2000

What are the numbers then?

- So let us assume that there is a constant ΔV for all supernovae so that:

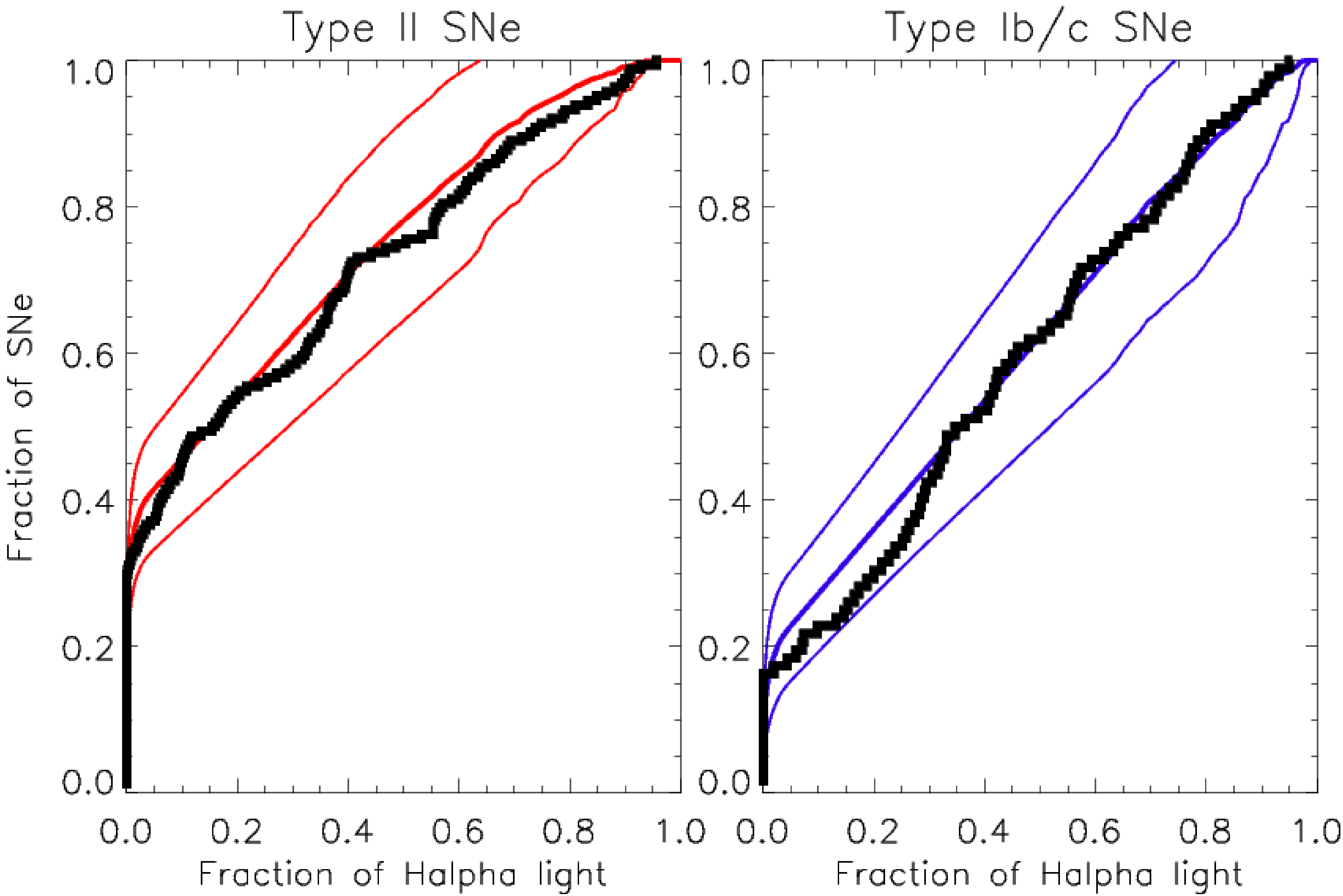
$$-V_{kick} = (M_{ejecta}/M_{remnant})\ \Delta V + \beta$$

- 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?


July 7, 2005
SN2005cs


June 7, 2011
SN2011dh



(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

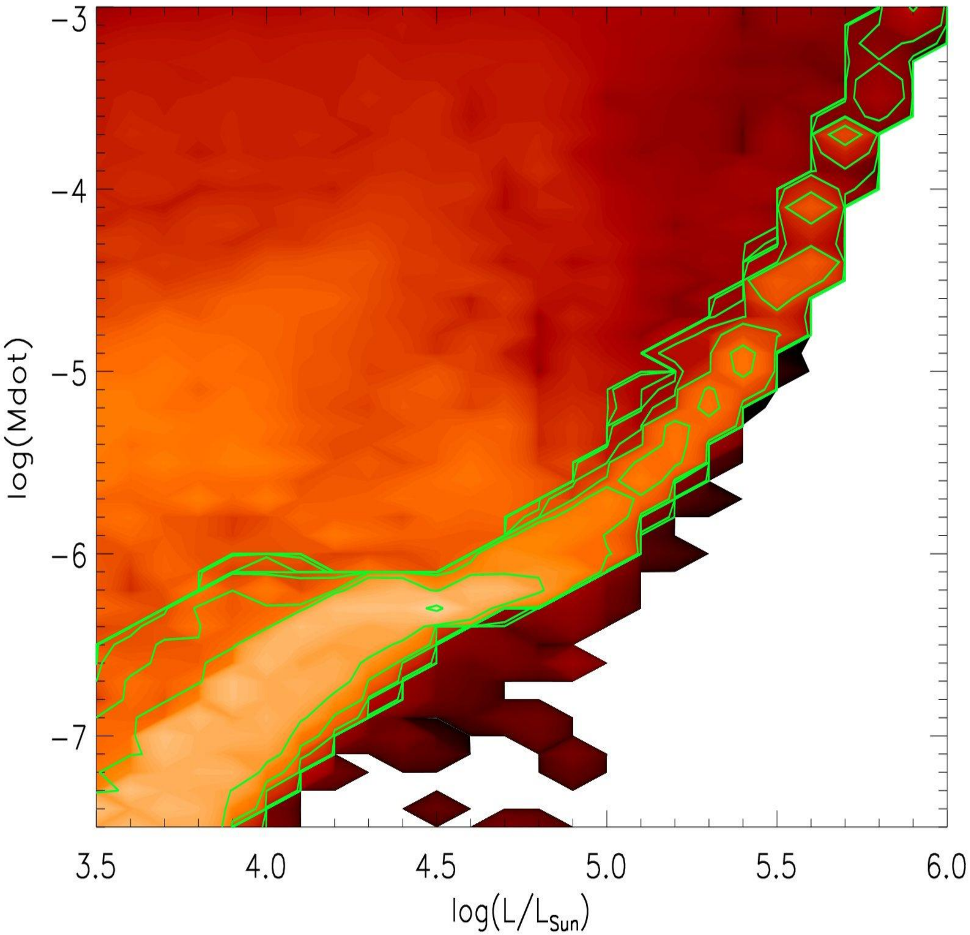
Auckland, 28th November, 2016

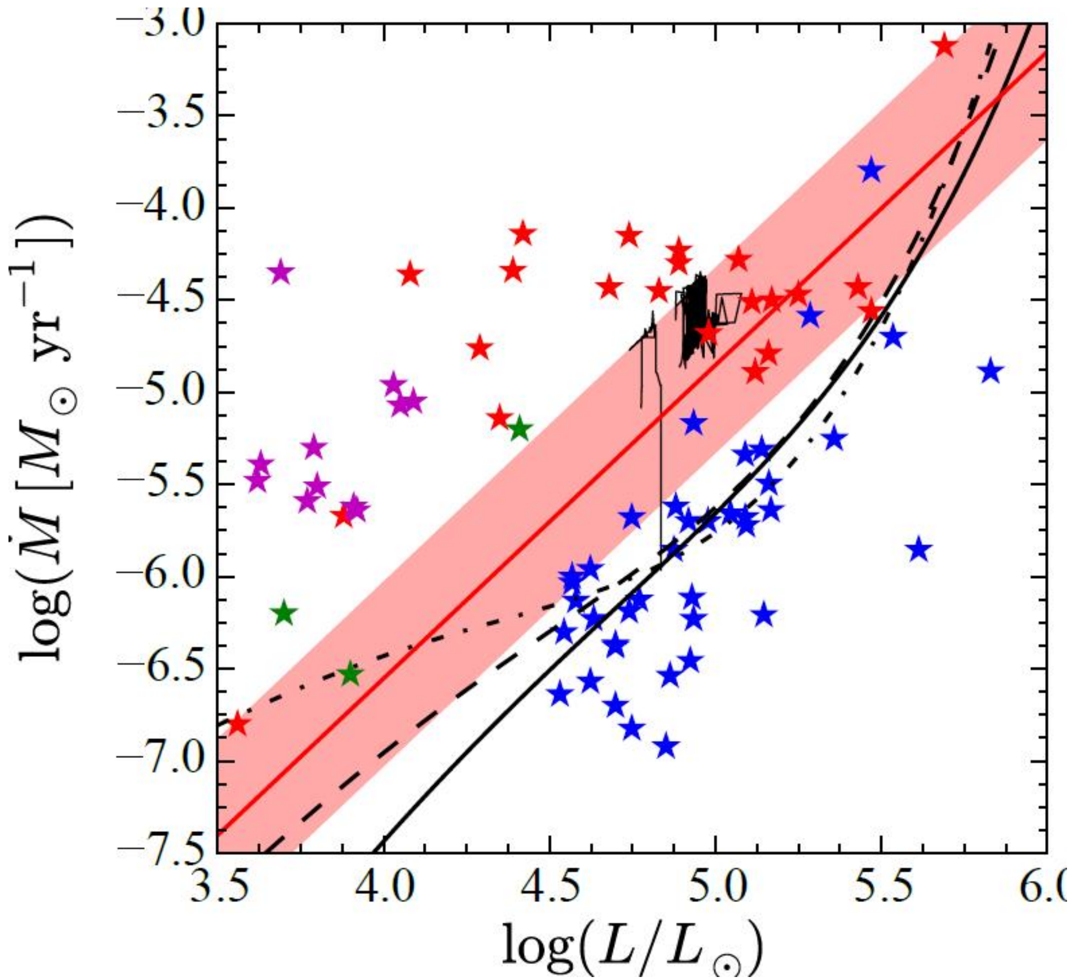
JJ Eldridge, Margaret Hanson & Artemio Herrero
Joe Anderson, Matteo Cantiello, Ben Davies,
Sylvia Ekstrom, John Hillier, Coralie Neiner,
Fernanda Nieva, Lida Oskinova, Alicia Soderberg,
Nicole St-Louis, Jorick Vink , Sung-Chul Yoon

\

Email: j.eldridge@auckland.ac.nz

Image: ©Firefly photography





Cyril Georgy:
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(Teff) = 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