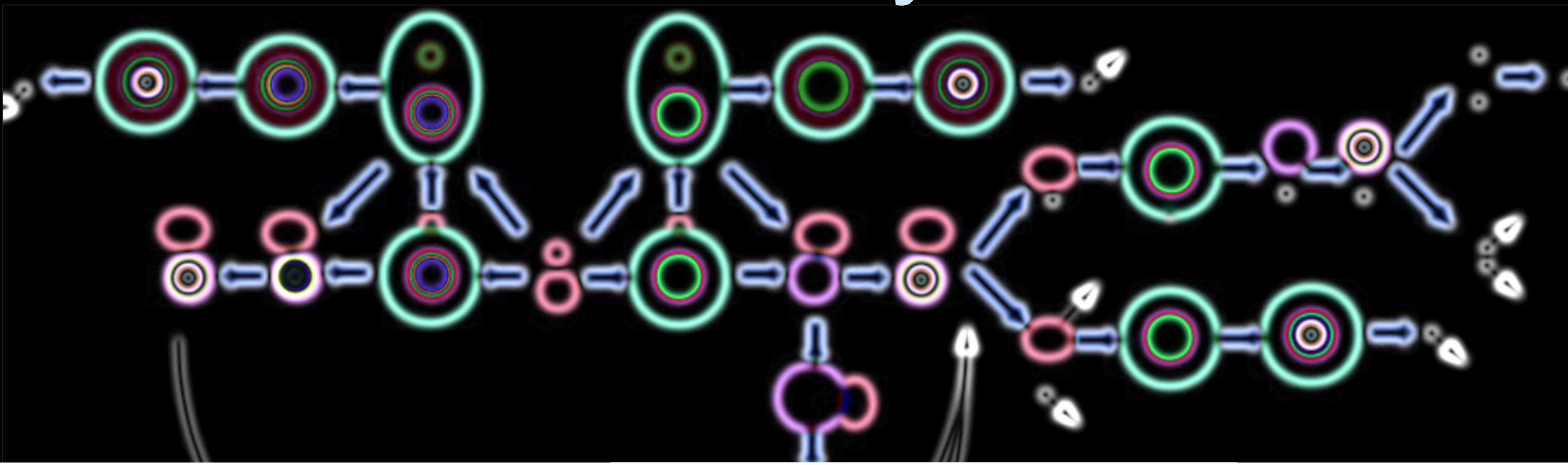
A double look at EM and GW transients with BPASS & CURVEPOPS

JJ Eldridge
with Elizabeth Stanway & BPASS team



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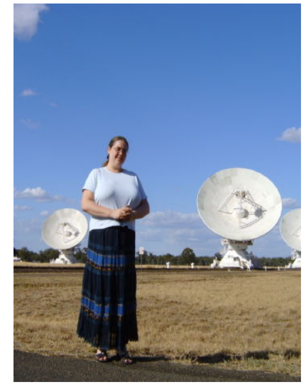
binary population and spectral synthesis

JJ Eldridge
University of Auckland



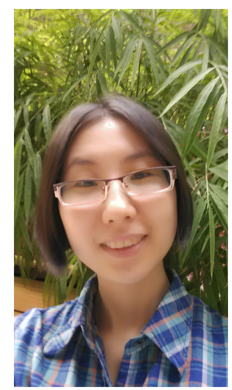
Elizabeth Stanway
University of Warwick

Incoming: Héloïse Stevance

Students: Ashley Chrimes, Petra Tang, Wouter van Zeist, Sohan Ghodla, Girish Narayanan, Itwinder Singh

Past Students: Liam McClelland, Georgie Taylor, Mason Ng, Lillian Guo, Nicole Rodrigues, Lucas Ostrowski

Also thank you to the many past contributors to the physics and development of BPASS.



Lin Xiao
Nebula emission spectral synthesis & supernovae
(University of Science & Technology of China)

John Bray
Supernova kicks & binary population synthesis
(Open University)

binary population and spectral synthesis

Developed to study a broad range of astrophysical systems in the Universe:
stars, supernovae, clusters, galaxies, compact remnant mergers

Ethos:

1) "Yes there are uncertainties but let's take our best guess, no tuning, and see if we can be less wrong than single star populations".

2) "Be the theoretical equivalent of multi-messenger observations, make one model of stars in the Universe and observe in every way possible".

BPASS.AUCKLAND.AC.NZ

Version 1.1 based on 15,000 detailed stellar models.
Eldridge et al. (2008, 2011), Eldridge & Stanway (2009, 2012)

Version 2.2 based on **250,000 models DETAILED binary models**, Z=0.00001 to 0.040, binaries from 0.1 to 300$M_\odot$

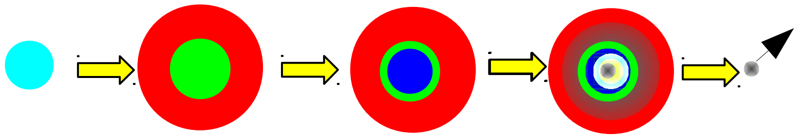
binary population and spectral synthesis

The main papers:

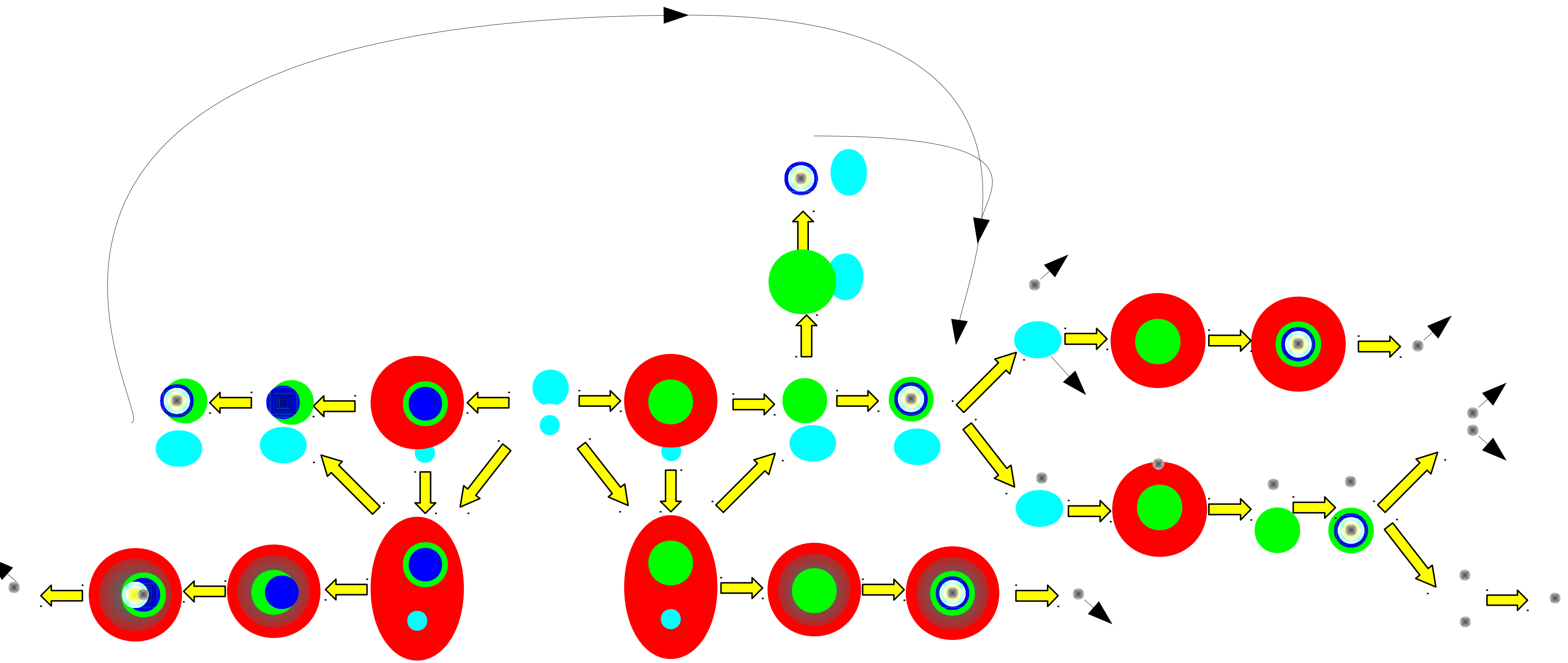
- Stanway, Eldridge & Becker (16) – Reionization **v2.0**
- Eldridge & Stanway (16) – GW events
- Bray & Eldridge (16,18) – Supernova kicks
- **Eldridge, Stanway et al. (17)** – Instrument paper ***v2.1 Kiwi***
- Xiao, Stanway & Eldridge (18,19) – HII regions
- **Stanway & Eldridge (18)** – Old populations ***v2.2 Tuatara***
- Eldridge, Stanway & Tang (19) – GW & EM transients
- Eldridge, Tang, Bray & Stanway (18) – Chirp mass distribution of GW events
- Eldridge, Xiao et al. (18) – CURVEPOPS 1
- Stanway & Eldridge (19) – IMF and ionizing photons
- Eldridge & Xiao (19) – NGC 6946 distance & progenitors
- Eldridge, Guo, Rodriguez et al. (under revision) – CURVEPOPS 2
- Coming soon: X-ray binaries, GW+SFH, RSG age estimates, more... I need more time....

Note: each new version is an “improvement” on the previous one and we are beginning to implement rigorous testing procedures.

The evolution of single stars….

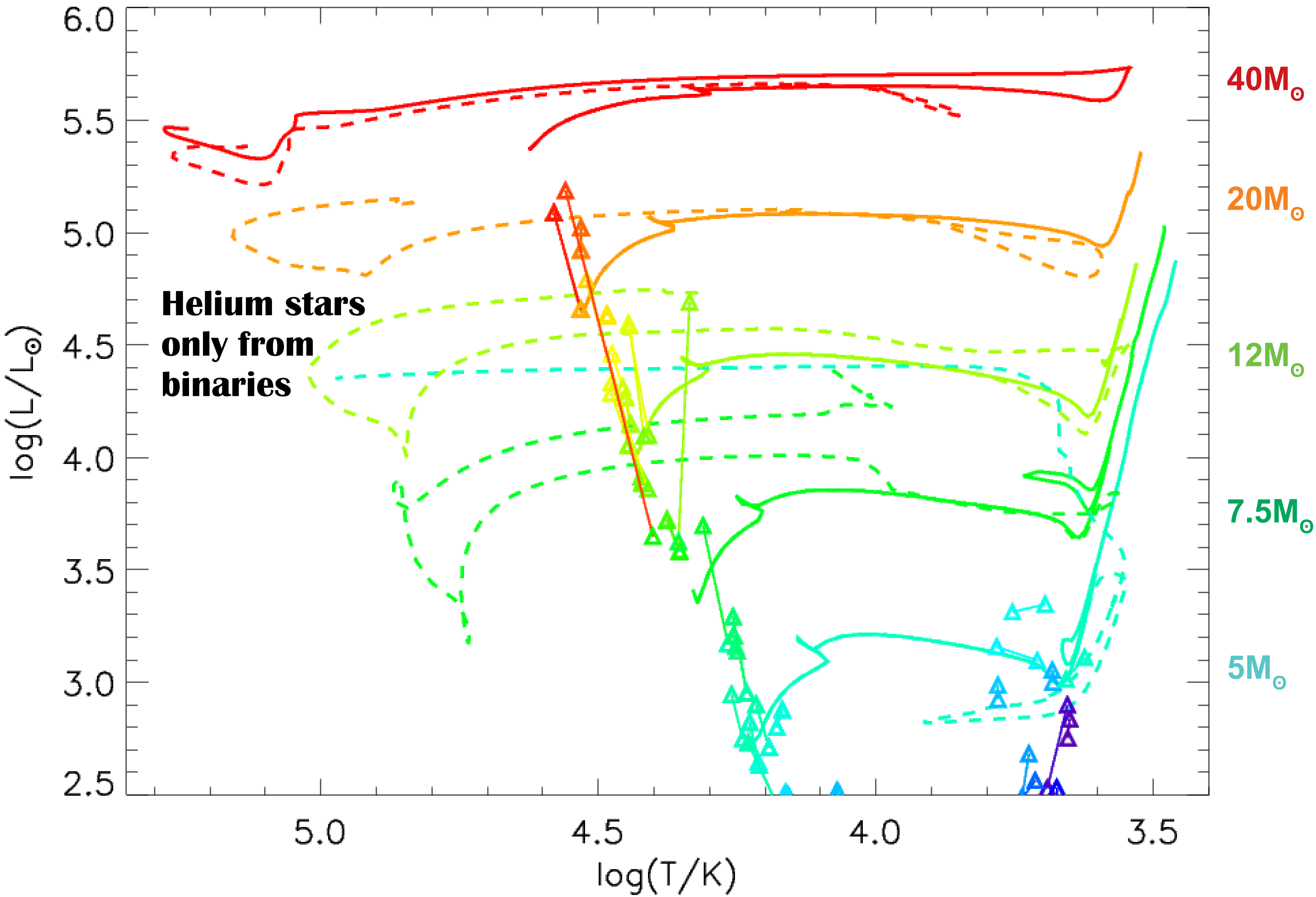


A few of the **binary** evolutionary pathways that must be included

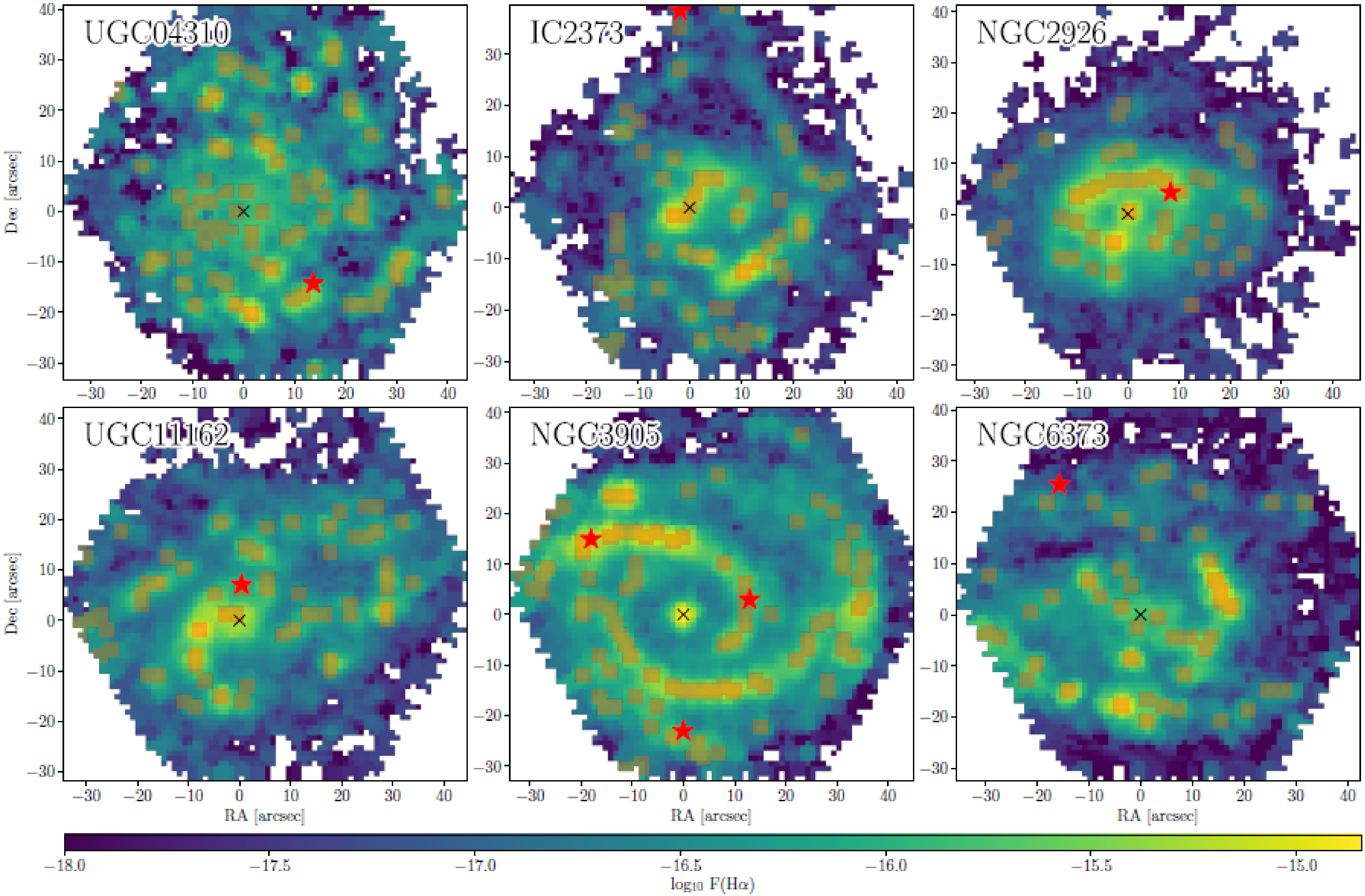


Key point: a **new stellar type – helium stars** – occurs, at masses intermediate to Wolf-Rayet and sdB/sdO stars (see also Götberg et al., 2017; 2018).

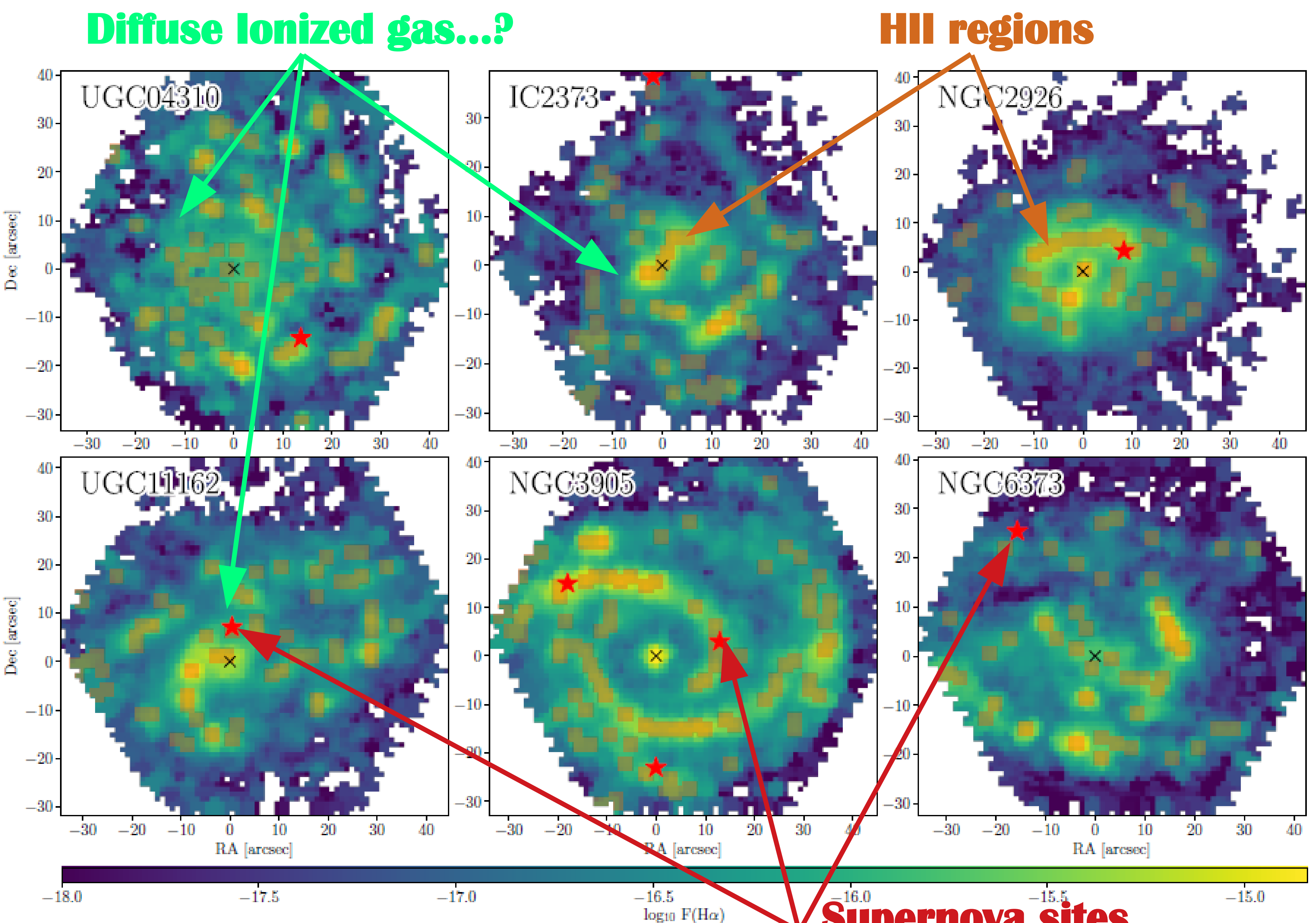
And on the HR diagram…



Binaries cause more hydrogen-free supernovae and at the same time more hot stars can we see this in galaxies?

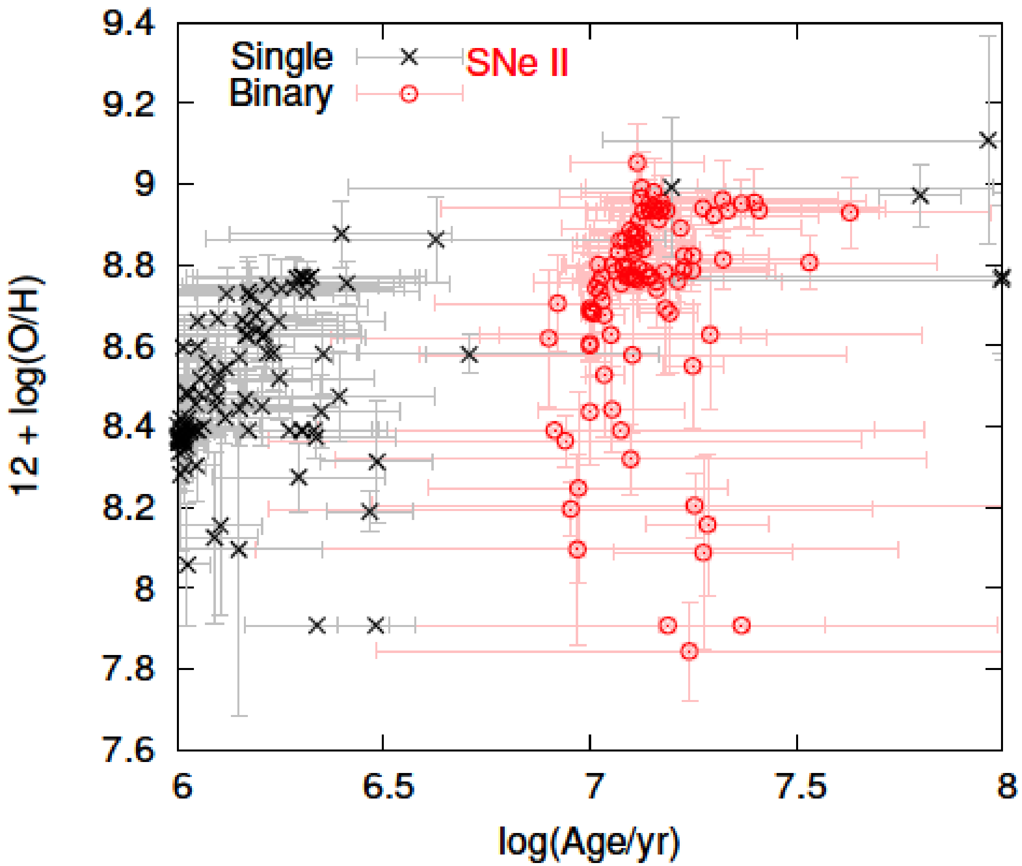


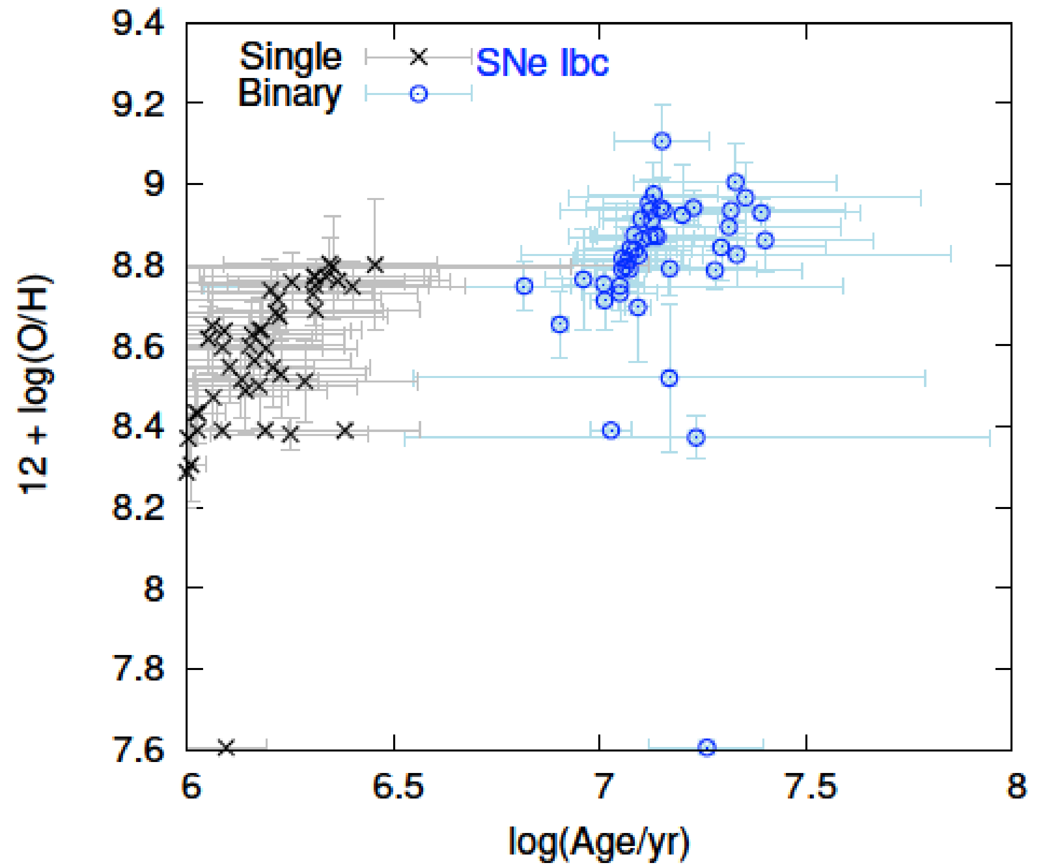
Galbany et al. (2018) - “PISCO: The PMAS/PPak Integral-field Supernova Hosts Compilation”.



Galbany et al. (2018) - “PISCO: The PMAS/PPak Integral-field Supernova Hosts Compilation”.

What happens when we attempt to age observed stellar populations at supernova sites with single star or interacting binary populations?

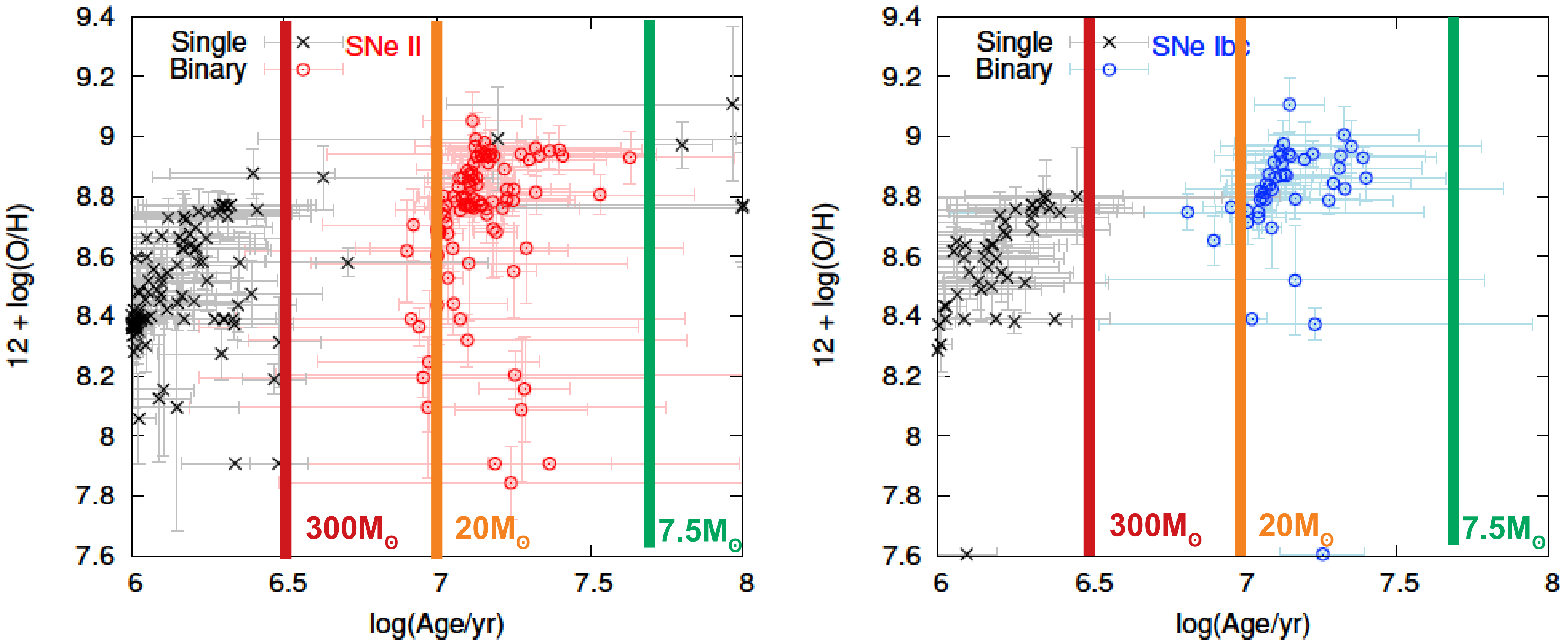




Warning: [O/H] ≠ [Fe/H] – stars care about the latter not the former.

BPASSv2.1

Xiao et al . (2018, 2019) and see works by Götberg et al. and Zapartus et al..



BPASSv2.1 **Xiao et al . (2018, 2019)** and see works by Götberg et al. and Zapartus et al..

We haven't looked at long-GRBs, SLSNe or Ic-BL SNe yet but from the location of sites on the BPT diagrams they come from younger stellar pops so more massive stars.

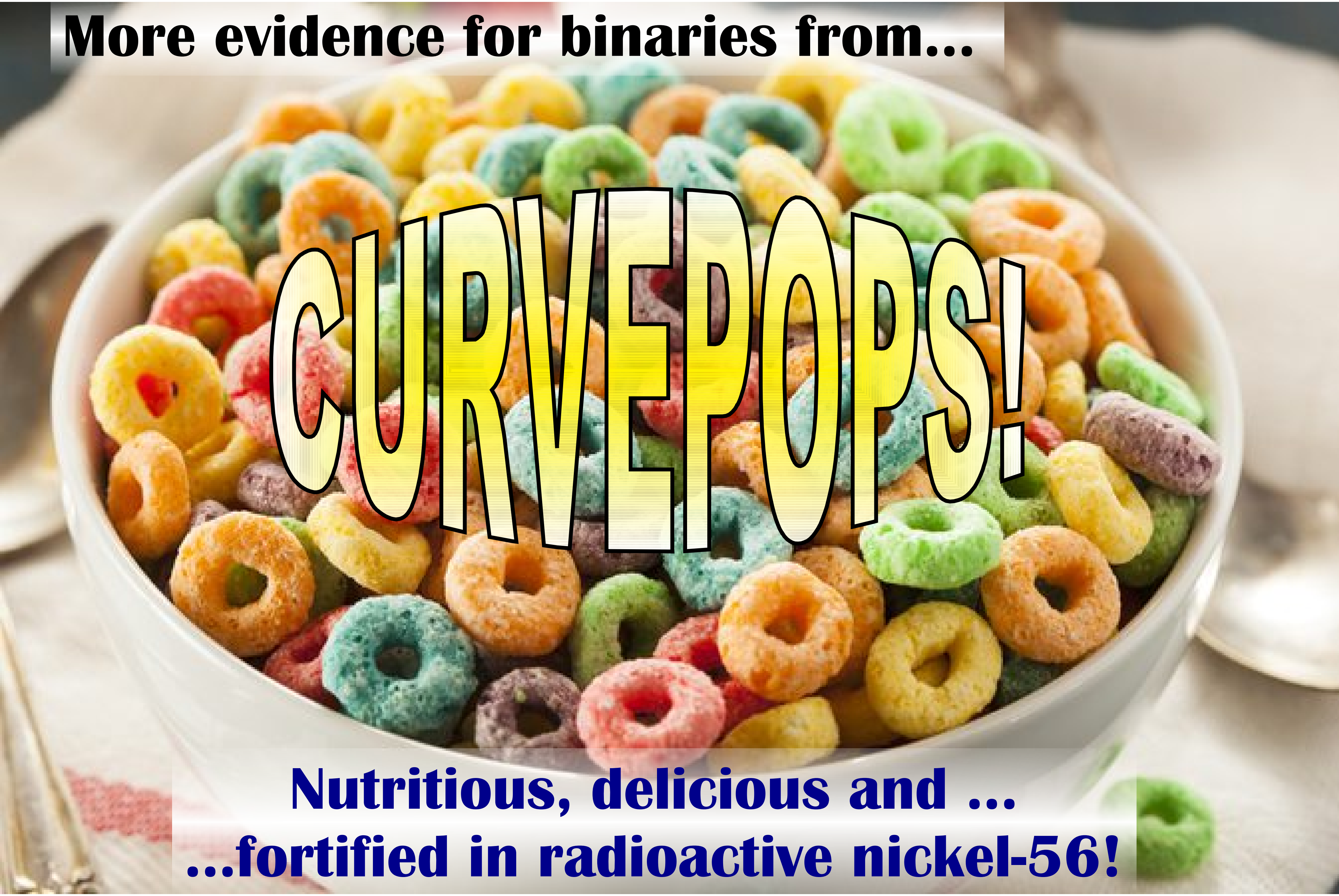


Image from bhofack2/iStock/GettyImages

We can take our detailed model outputs, put them into SNEC and explode them! (Morozova et al., 2015)

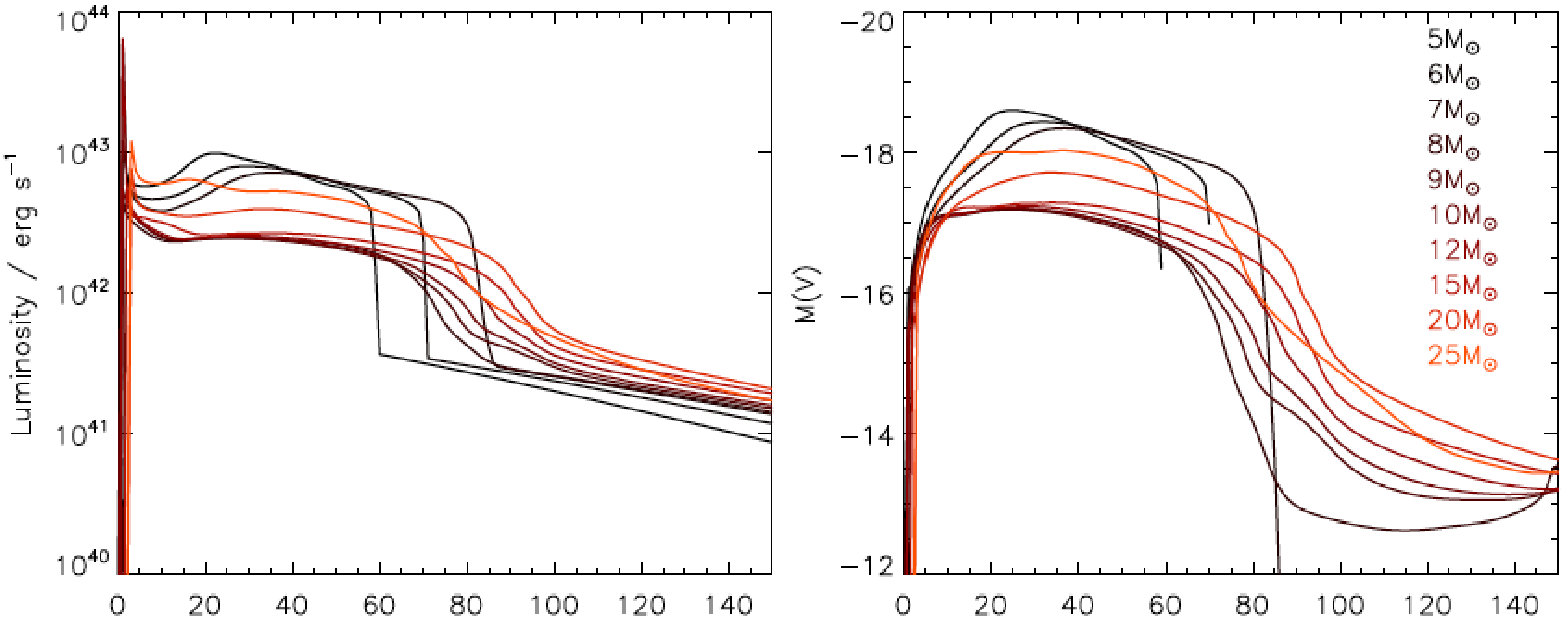
Then type those and see if we can reproduce the expected observations in nature…

Supernova LightCURVE POPulation Synthesis

Eldridge et al. (2018, 2019…).

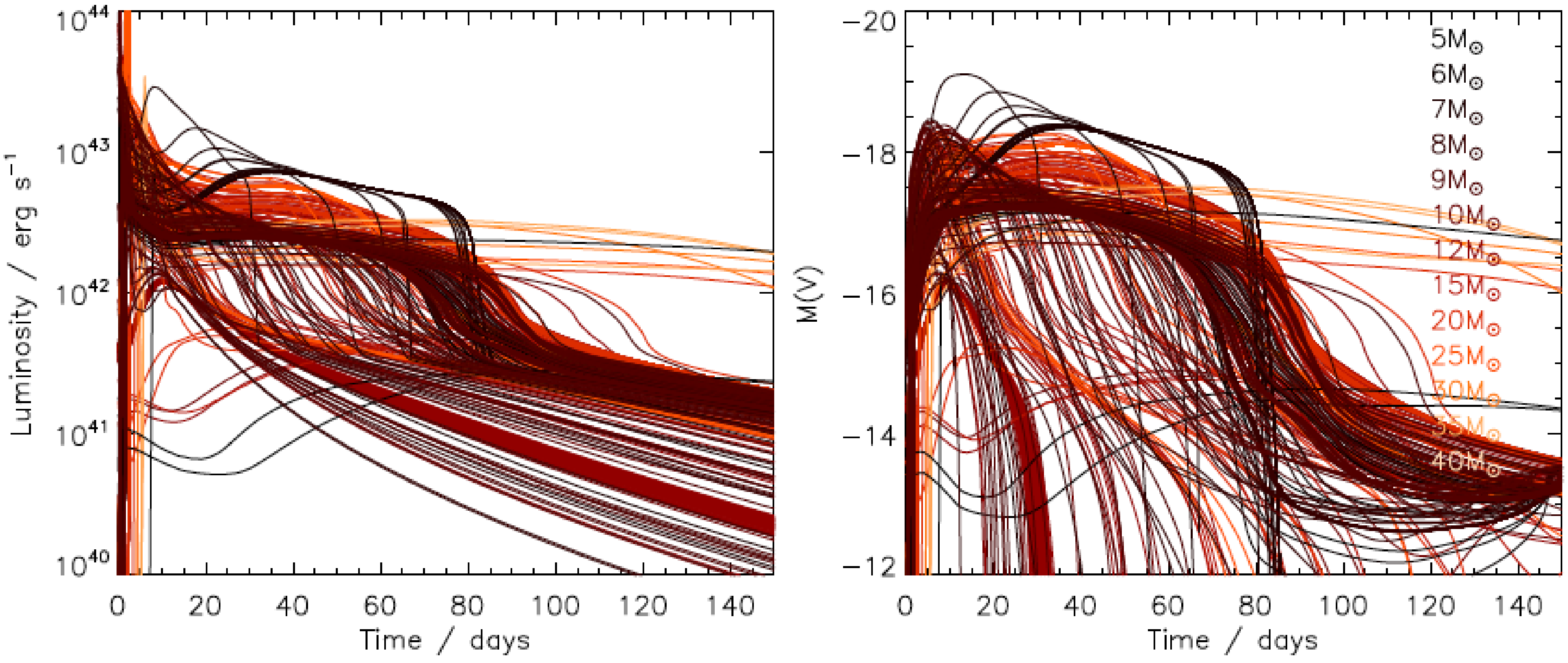
Note: here only vary structure, constant explosion energy and nickel mass. Also models only up to end of carbon burning.

Type II SN lightcurves from single stars....

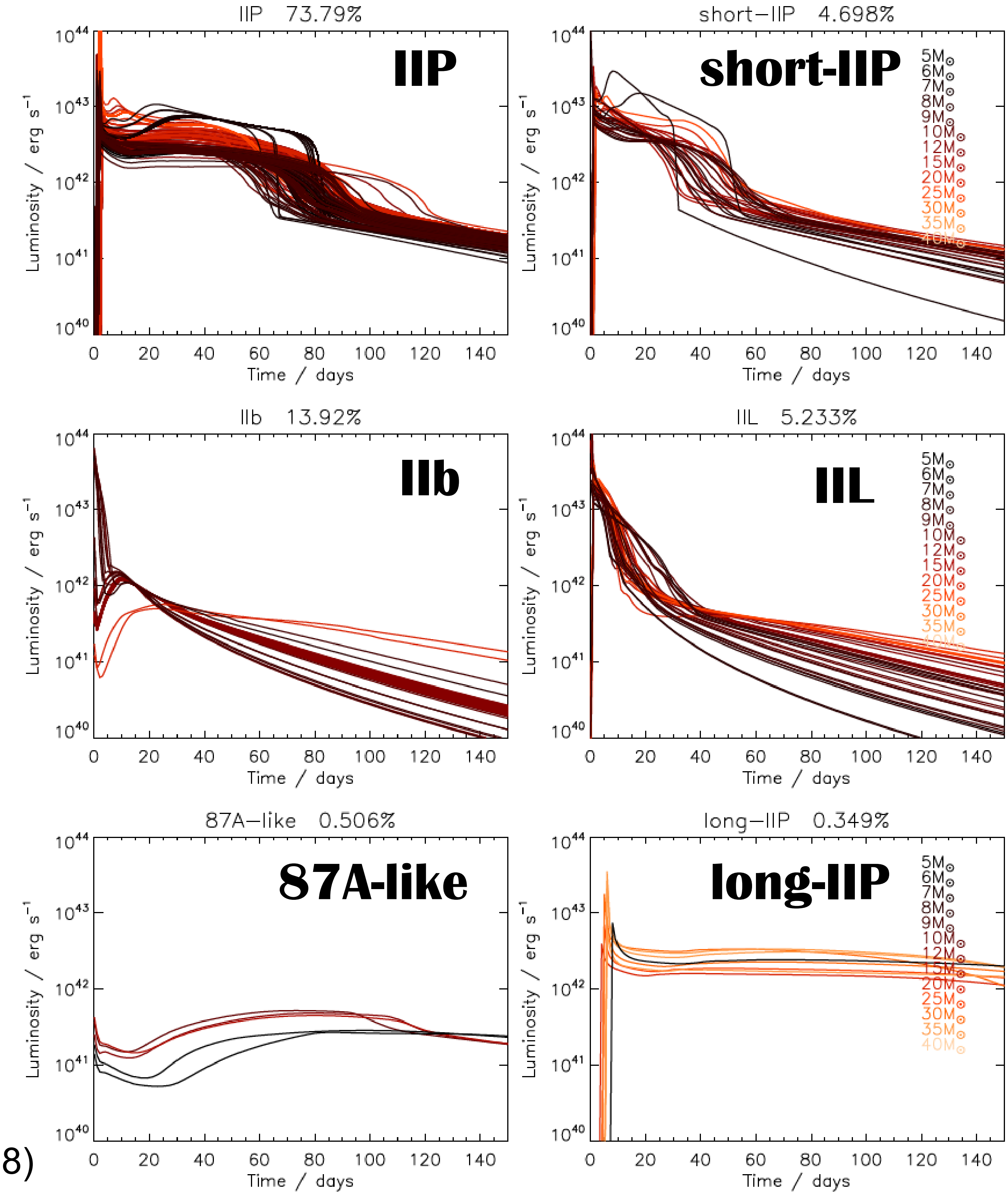


CURVEPOPS 1
Eldridge et al. (2018)

Type II SN lightcruves from interacting binaries

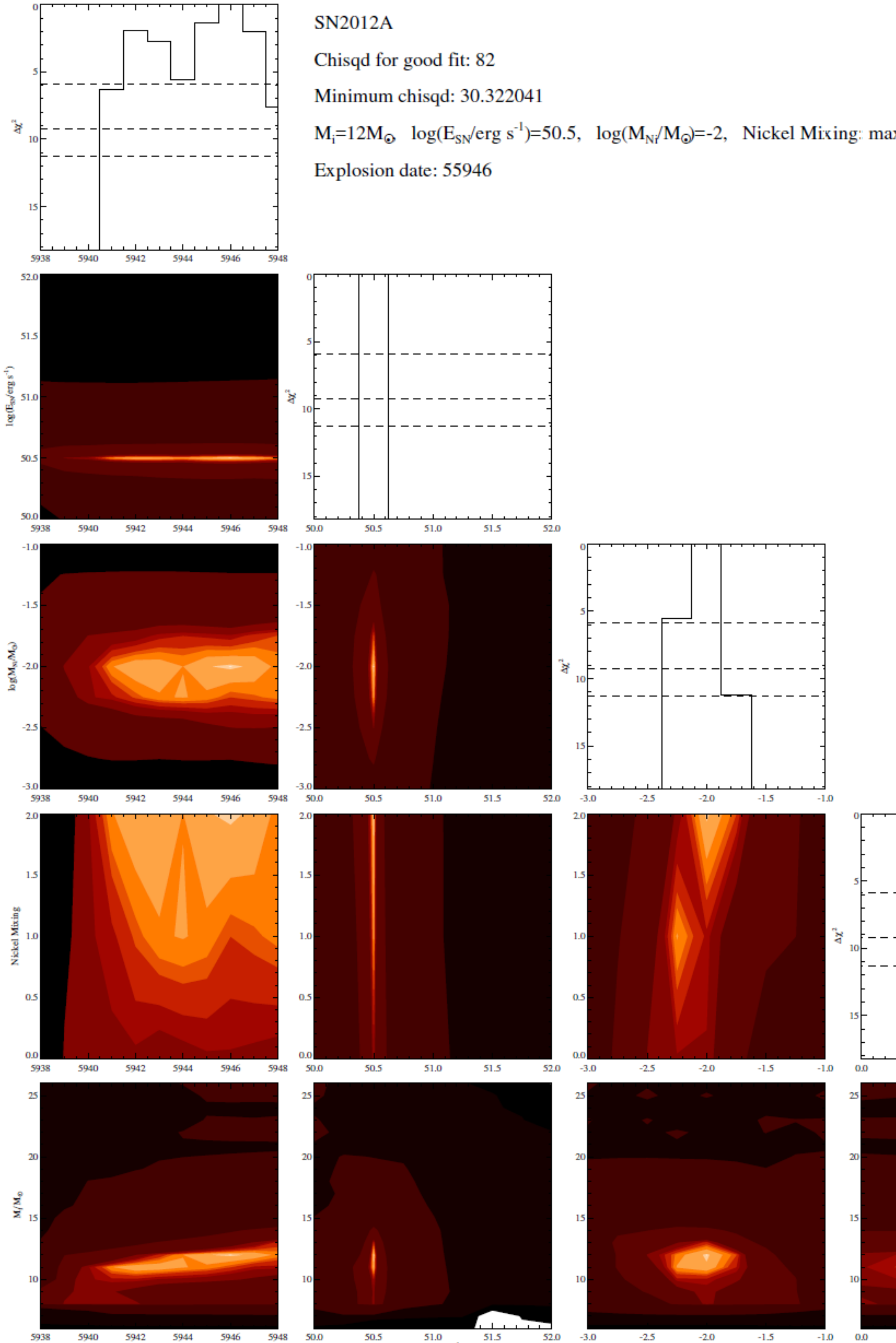
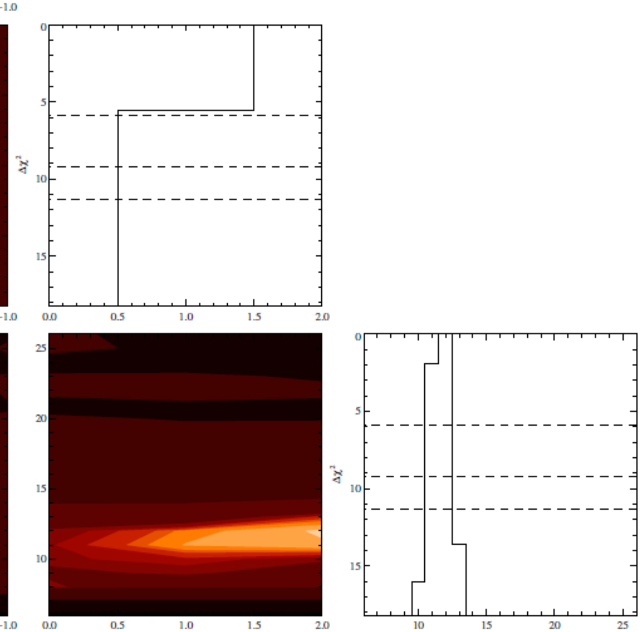


CURVEPOPS 1
Eldridge et al. (2018)



CURVEPOPS 1
Eldridge et al. (2018)

Currently comparing to SN with progenitor detections.

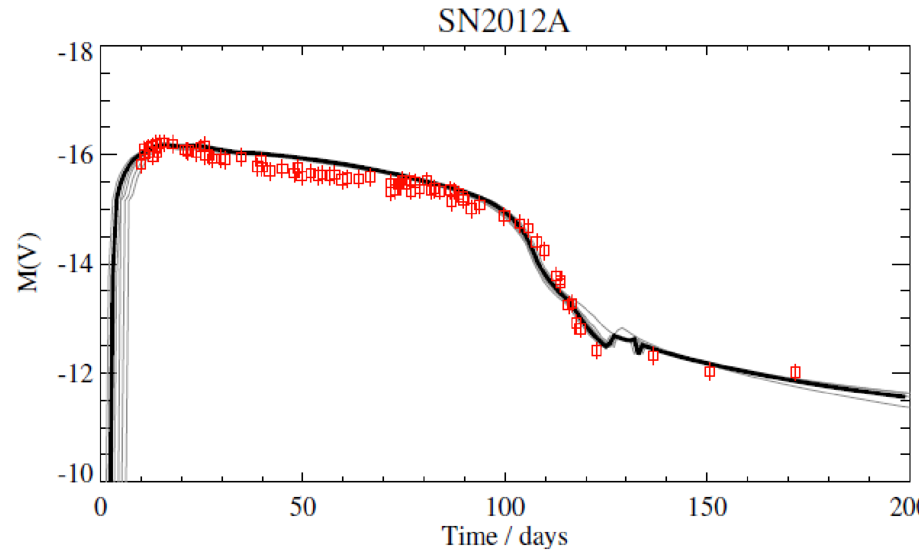


Table 2 Reference and Free Fitted Parameters

		Initial Mass / $M_\odot$					^{56}Ni Mass / 10^{-3} $M_\odot$			
SN Name	Fit Quality	Smartt	Maund	Morozova et al.	Davies & Beasor	This Work	Literature	This Work	log(Explosion Energy / ergs)	^{56}Ni Mixing parameter, X
SN2003gd	A	7^{+4}_{-1}	5–14	–	$6.4^{+0.6}_{-0.4}$	14^{+1}_{-6}	16^{+10}_{-6} [3]	$10.0^{+3.3}_{-2.5}$	$50.75^{+0.13}_{-0.38}$	$0.9^{+0.1}_{-0.3}$
SN2004A	A	13^{+6}_{-3}	7–10	–	$12.7^{+1.6}_{-1.5}$	16^{+4}_{-5}	46^{+31}_{-17} [4]	$31.6^{+68.4}_{-7.9}$	$50.5^{+0.38}_{-0.13}$	0.5±0.5
SN2004et	B	12 ± 3	17±2	$16.5^{+5.5}_{-1.5}$	$10.7^{+0.9}_{-0.8}$	$20^{+0.5}_{-2}$	60 ± 20 [5]	$31.6^{+10.5}_{-7.9}$	50.75±0.13	0.5±0.3
SN2005cs	C	8^{+4}_{-1}	7.9±0.5	$9.5^{+2.5}_{-0.5}$	$7.1^{+0.5}_{-0.5}$	8.0±0.5	3^{+1}_{-1} [5]	$3.2^{+1.1}_{-0.8}$	50.25±0.13	$0.1^{+0.3}_{-0.1}$
SN2006my	C	10^{+3}_{-2}	–	–	$13.9^{+2.9}_{-3.0}$	15^{+11}_{-7}	30 ± 15 [5]	$17.7^{+82.2}_{-4.4}$	$50.75^{1.13}_{-0.63}$	$0.1^{+0.9}_{-0.1}$
SN2008bk	B	12 ± 3	11±0.8	–	$8.3^{+0.6}_{-0.6}$	$10.0^{+0.5}_{-2}$	7 ± 1 [6]	$10.0^{+3.3}_{-5.8}$	50.00±0.13	$0.9^{+0.1}_{-0.3}$
SN2009md	B	9^{+4}_{-2}	13±1	–	$8.0^{+1.9}_{-1.5}$	8.0±0.5	5 ± 1 [7]	$3.2^{+4.3}_{-1.8}$	50.00±0.13	$0.9^{+0.1}_{-0.7}$
SN2012A	A	10^{+4}_{-2}	–	$9.5^{+4.5}_{-0.5}$	$8.6^{+0.9}_{-0.8}$	$12^{+0.5}_{-1}$	11 ± 4 [8]	$3.2^{+1.1}_{-1.8}$	50.50±0.13	$0.9^{+0.1}_{-0.7}$
SN2012aw	B	13 ± 2	13.5±1	20^{+3}_{-1}	$13.0^{+1.9}_{-2.0}$	$14^{+1}_{-0.5}$	56 ± 13 [9]	$56.2^{+18.8}_{-14.1}$	50.75±0.13	0.5±0.3
SN2012ec	A	16 ± 5	16-27	$10.5^{+7.5}_{-1.5}$	$16.8^{+1.4}_{-1.3}$	18±2	30 ± 10 [10]	$17.8^{+5.9}_{-10.3}$	50.50±0.13	0.5±0.5
SN2013ej	B	10^{+4}_{-2}	14±1.5	$13^{+5.5}_{-3}$	$9.8^{+0.8}_{-0.7}$	14^{+1}_{-2}	20 ± 2 [11]	100±90	51.00±0.13	$0.9^{+0.1}_{-0.7}$

Note:

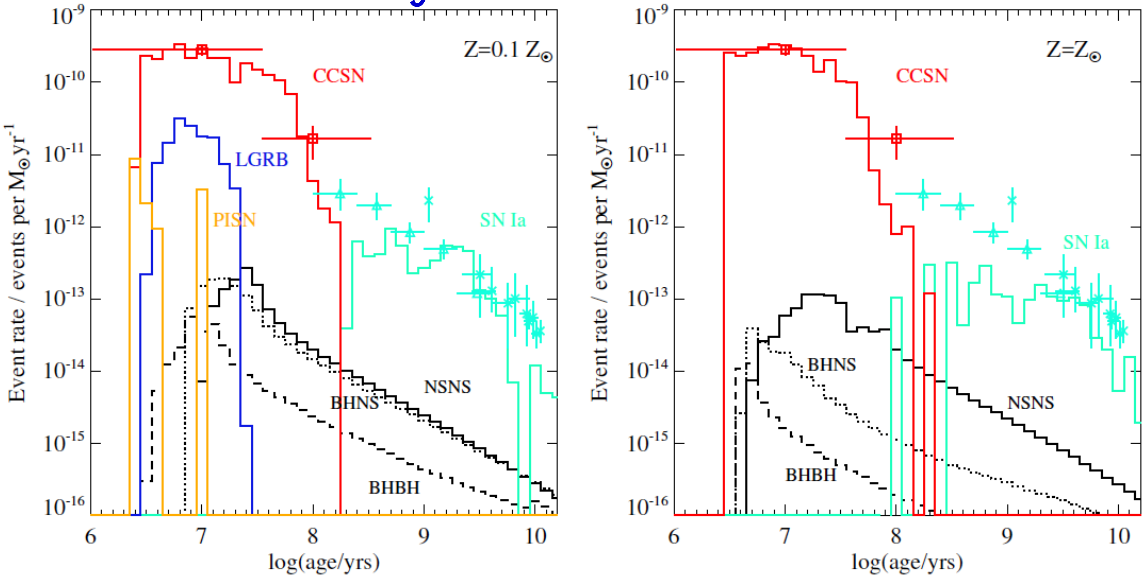
1) we learnt yesterday there are degeneracies here but I believe in stellar evolution – and using same stellar models that have been tested against many other observations.

2) SN2004et is in NGC6946 and the distance is bigger than previously thought.

CURVEPOPS 2
Eldridge et al. (to be resubmitted)

Now lets look at the very big picture, transients through cosmic history…

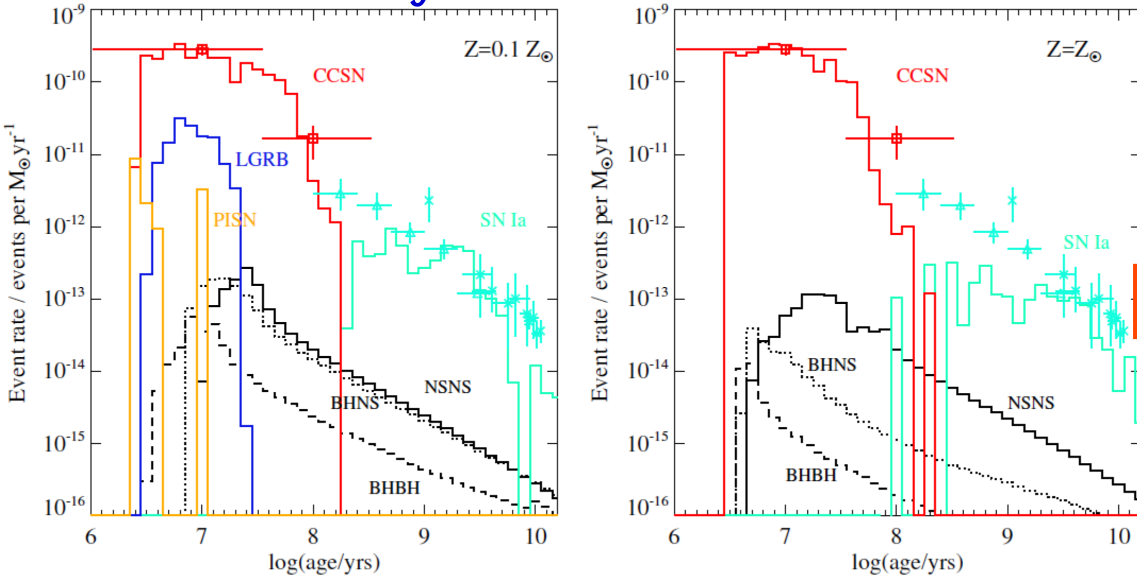
Delay-time distribution



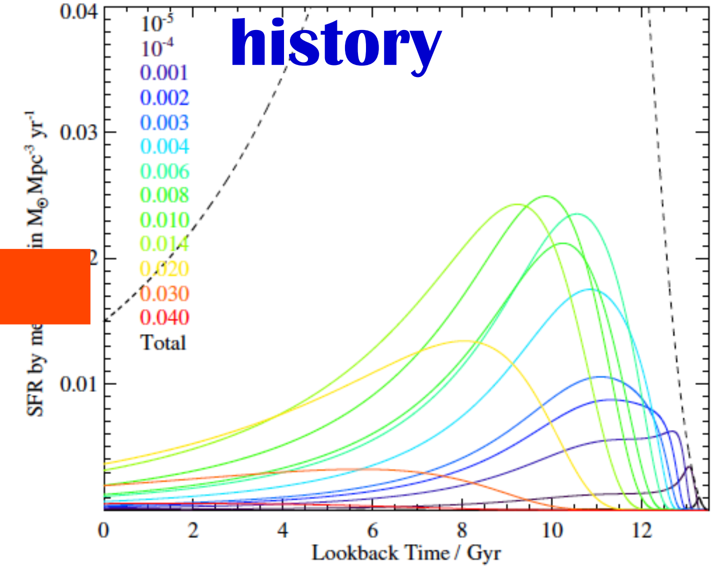
BPASSv2.2

Eldridge, Stanway & Tang (2019).

Delay-time distribution



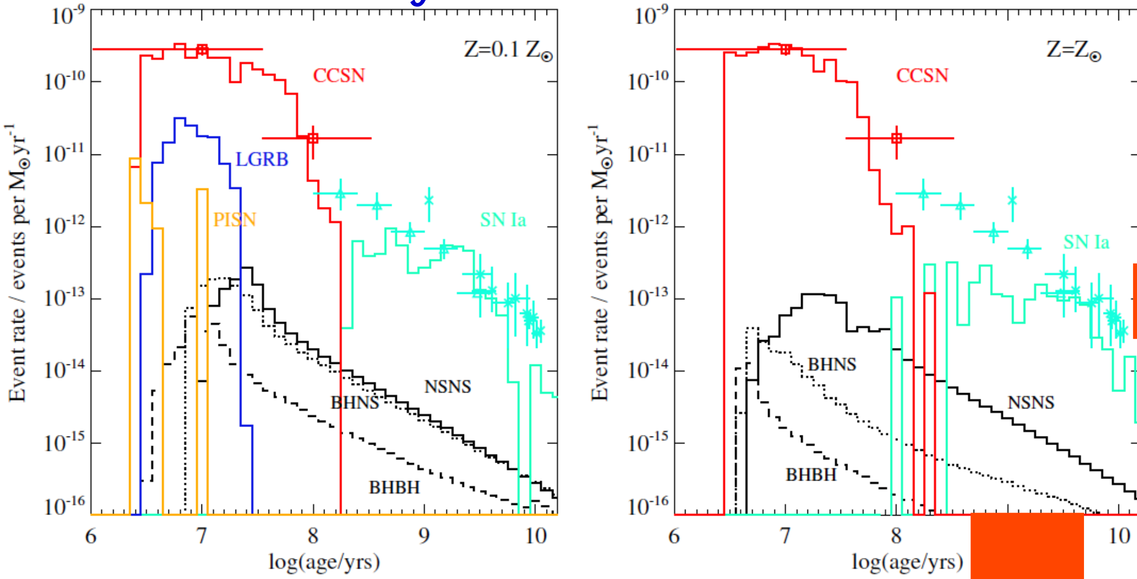
Cosmic star formation history



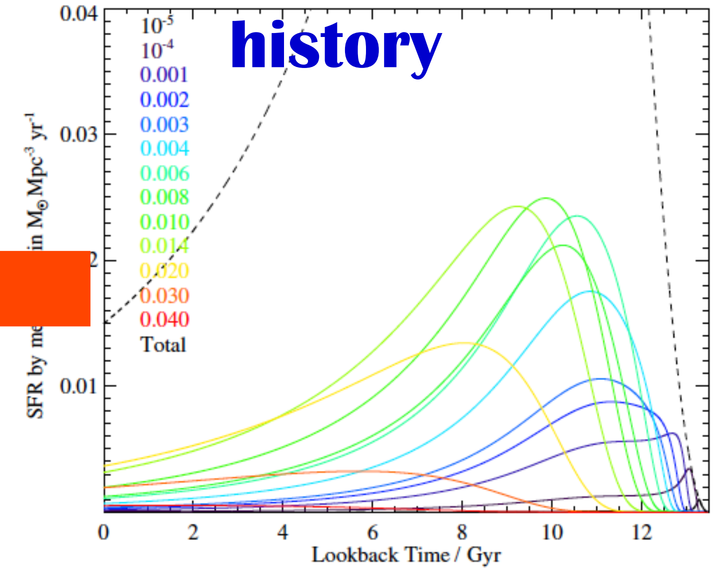
BPASSv2.2

Eldridge, Stanway & Tang (2019).

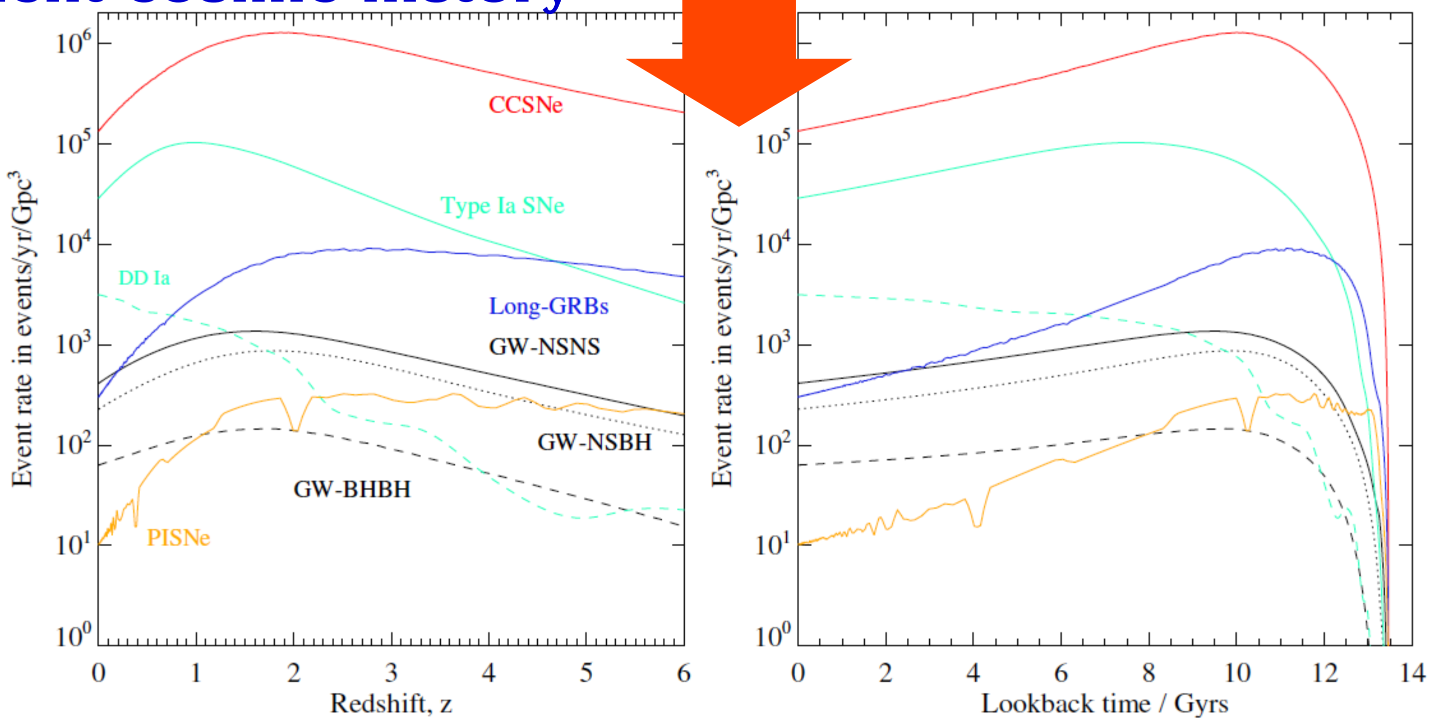
Delay-time distribution



Cosmic star formation history



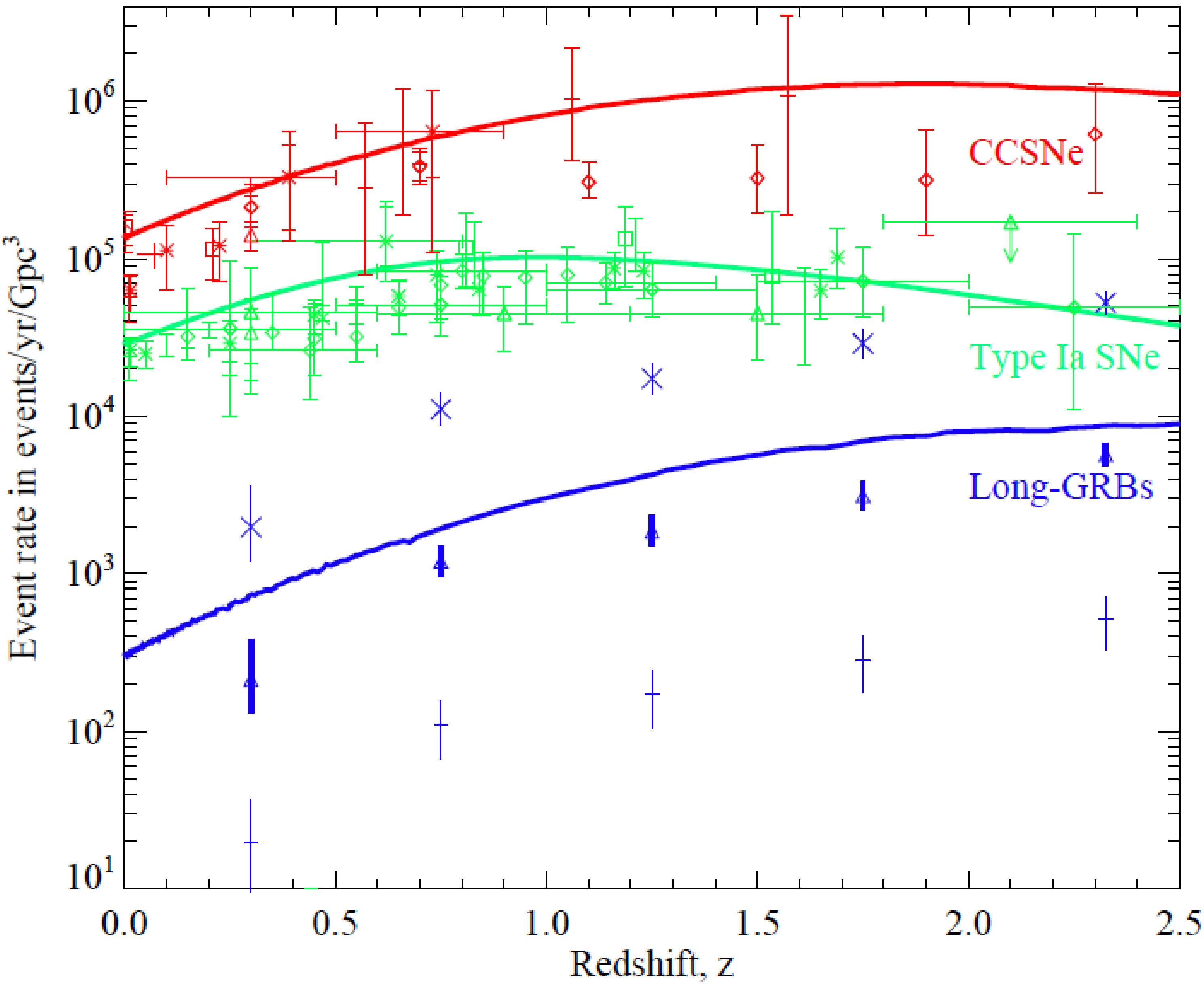
Transient cosmic history



BPASSv2.2

Eldridge, Stanway & Tang (2019).

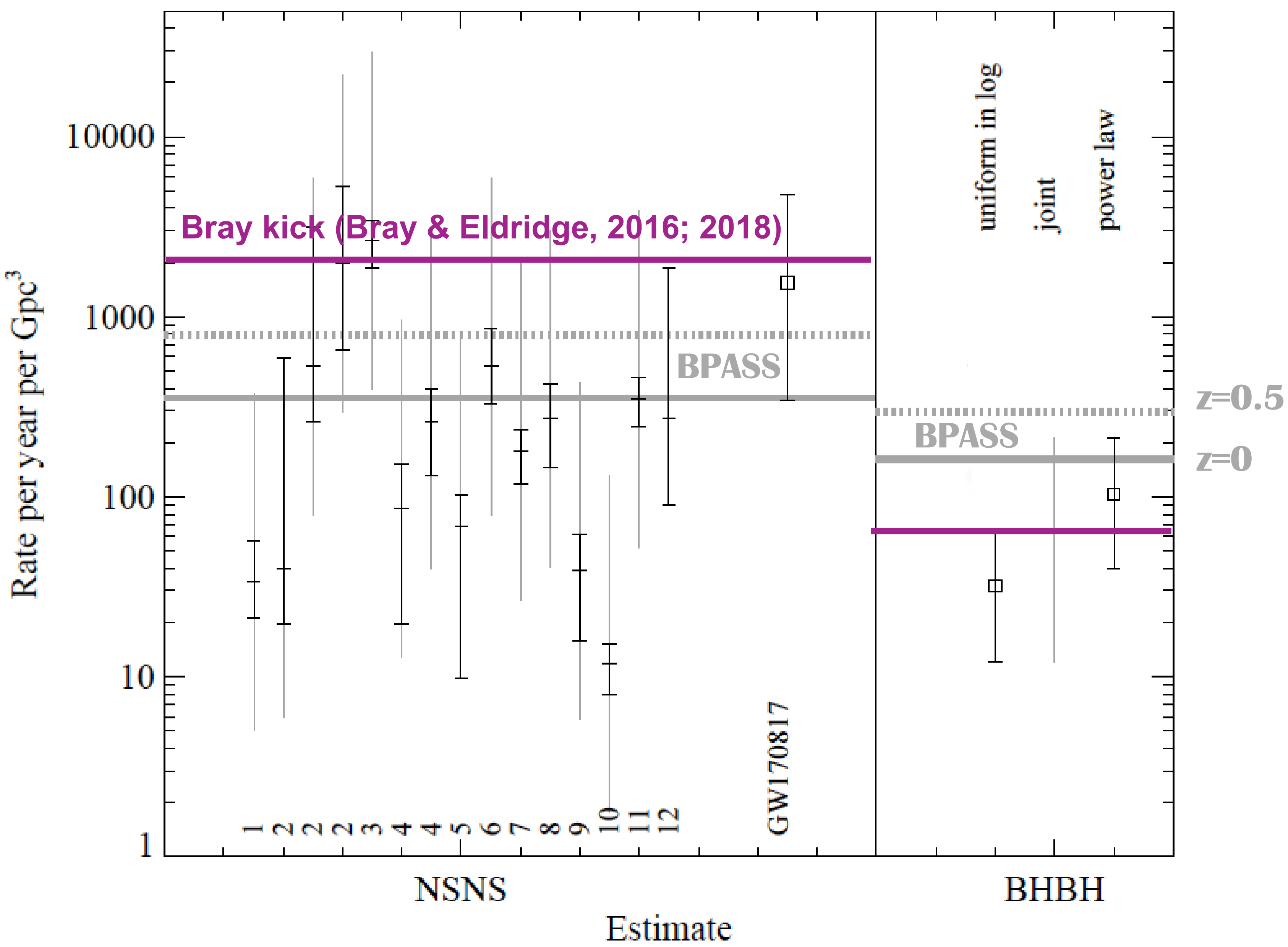
EM event rates
(supernovae)



BPASSv2.2

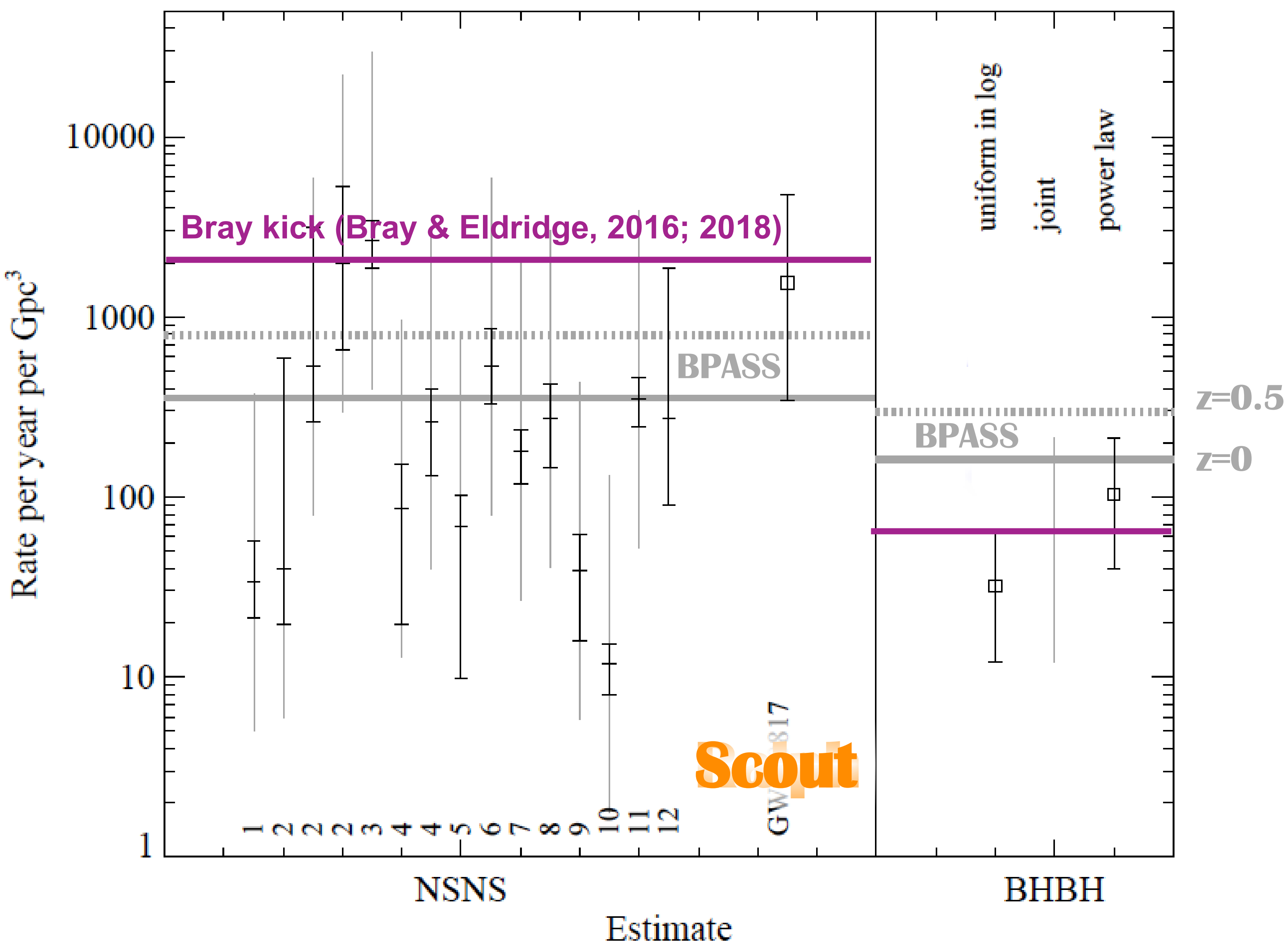
Eldridge, Stanway & Tang (2019).

GW event rates



BPASSv2.2 **(Ask me about the chirp mass distribution in the question time)** Eldridge, Stanway & Tang (2019).

GW event rates



BPASSv2.2 **(Ask me about the chirp mass distribution in the question time)** Eldridge, Stanway & Tang (2019).

University of Auckland Marsden Grant PhD Scholarship in Gravitational Wave Event Population Synthesis

A Scholarship to support an international or domestic PhD student who is undertaking research in gravitational wave transients.

About the scholarship

Application status: No application required
Applicable study: PhD in Astrophysics
Opening date: By nomination
Closing date: By nomination
Tenure: Up to 36 months
For: Assistance with study
Number on offer: 1
Offer rate: One-off
Value: $27,900pa plus compulsory fees and international health insurance (if required)

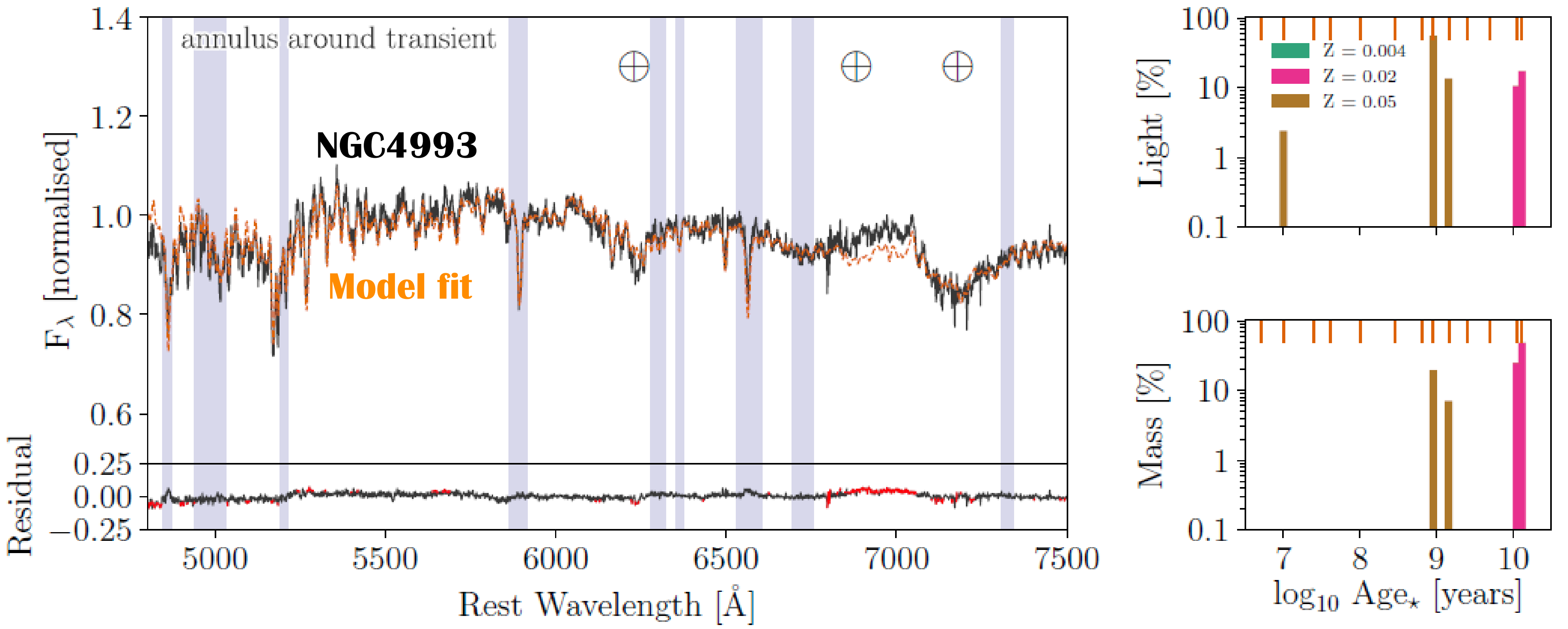
The Scholarship was established in 2019 and is funded by a Marsden Grant awarded to an academic staff member from Department of Physics in the Faculty of Science at the University of Auckland.

What is our next step for

GW transients?

Host galaxies…


GWScout 7...
Aug 22, 2017
Aug 26, 2017
Aug 28, 2017
What about the galaxy...?
CREDIT: NASA and ESA: A. Levan (U. Warwick),
N. Tanvir (U. Leicester), and A. Fruchter and O. Fox (STScI)



A reminder – yes we've looked at the host galaxies but with single star populations only…

GW event rate for single stars = 0 (almost).

Levan et al. (2017)

What is the difference between extant models and BPASS models with old ages?

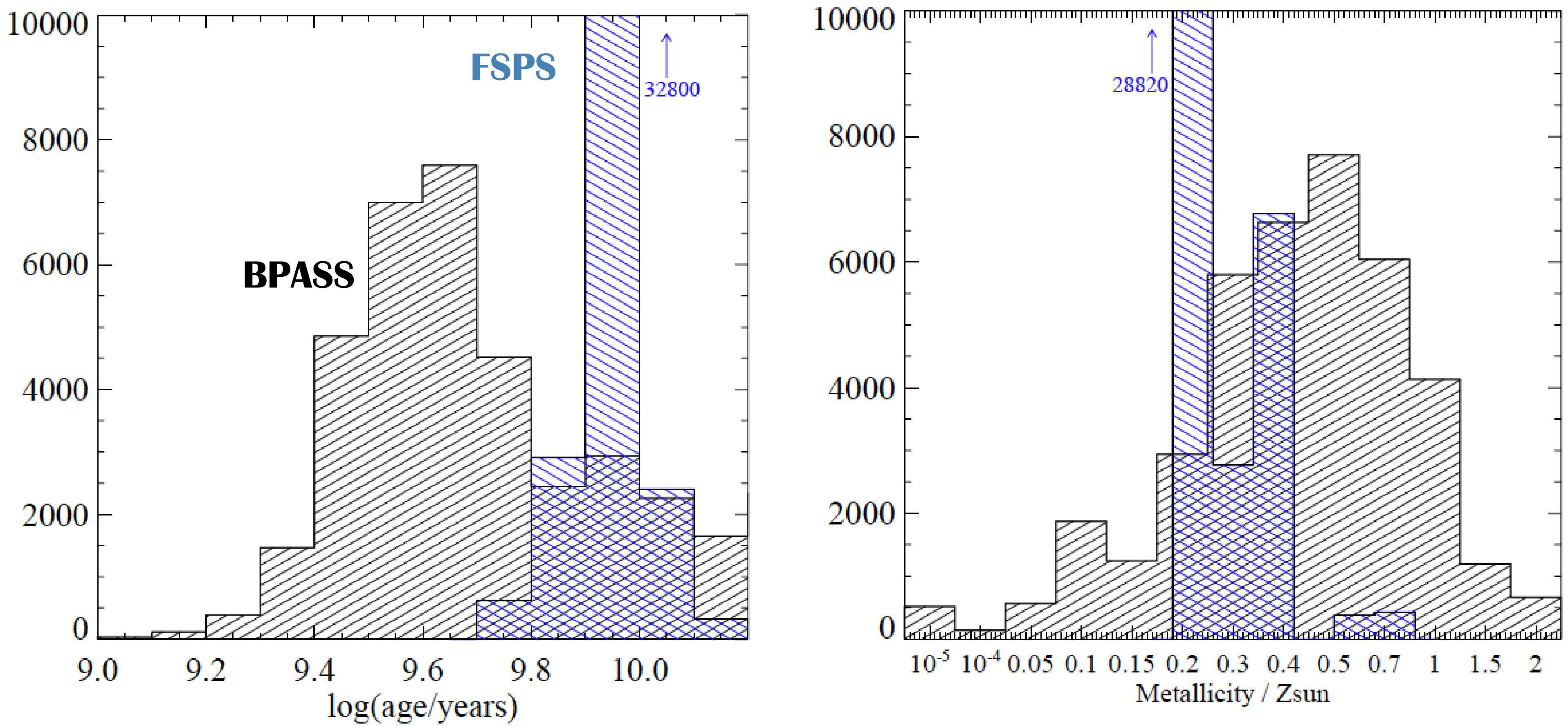


Figure 13. Age and metallicity of SDSS quiescent galaxies. The BPASS v2.2 parameters are based on best fitting MgFe50 vs Hβ index (shown in black). These are compared to FSPS stellar population fitting results for the same objects (blue). FSPS histograms extend to number counts well beyond the plotted area, due to the narrow range of fitted age and metallicity values in these models.

BPASSv2.2

Stanway & Eldridge (2018)

Final thoughts

The key point I would like you all to take away is that **interacting binary stars change our understanding** of stellar populations when **previous studies** mostly assume all **stars are single**.

An example that we should worry about is that **all studies** of **NGC4993**, the host galaxy of **G** **Scout** **7** involved using **single-star spectral synthesis models**. But the progenitor was a **binary star**....

In O3 things are getting interesting... (btw BPASS predicts 1 NSNS per 10ish BHBH...)

Possibly arranging **BPASS school/workshop** in:
December in NZ and Mid/late-2020 in UK.

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