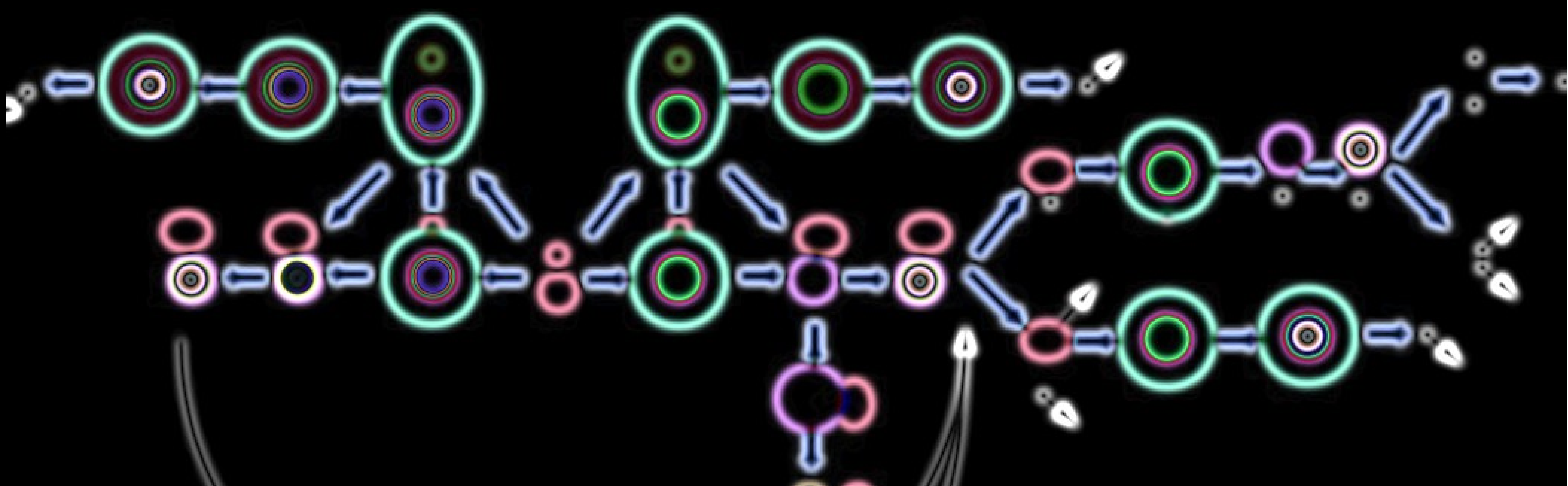
THE UNIVERSITY OF AUCKLAND
Te Whare Wānanga o Tāmaki Makaurau
NEW ZEALAND

ASTRONOMY & ASTROPHYSICS

Population and spectral synthesis: it doesn't work without binaries!

JJ Eldridge
with Elizabeth Stanway & BPASS team



Outline

- Who am I?
- Who is the BPASS team?
- What is BPASS?
- How do you "do" spectral synthesis.
- Implications of interacting binaries for:
  - Individual stars
  - Star clusters
  - Galaxies
  - Ionizing radiation and BPT diagrams
  - Supernovae

Who am I?

- I prefer to be called **JJ**.
- I prefer **them/they** pronouns.
- "I study exploding binary stars and try to explode the myth of a gender binary".
- Also work on equity and inclusivity in academia.
- Read/watch too much sci-fi.
- Twitter: @astro_jje

binary population & spectral synthesis

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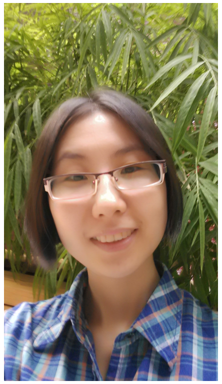
JJ Eldridge
Stellar models, population and spectral synthesis

Elizabeth Stanway
High-z, dust, IR, radio and unresolved population SED fitting
(University of Warwick)

Liam McClelland
Helium & Wolf-Rayet stars



Lin Xiao
Nebula emission spectral synthesis & supernovae

John Bray
Supernova kicks & binary population synthesis

Undergrad Students: Georgie Taylor & Mason Ng

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

Developed to study a broad range of astrophysical systems:
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) "Give the community an easy tool to use in modelling the Universe with binary populations rather than all the single star codes out there".

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 based on **250,000 models detailed stellar models**, Z=0.00001 to 0.040, binaries from 0.1 to 300$M_{\odot}$

Instrument paper on the way: Eldridge, Stanway, Xiao, McClelland, Bray, Taylor, Ng & Greis (all 60 pages of it!)

Papers by team already available using v2.0:
Stanway et al, Eldridge & Stanway, Bray & Eldridge, Eldridge & Maund

binary population & spectral synthesis

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But don't take our word for it:

- Wofford et al., 2016 – Young massive LEGUS clusters
- Shenar et al., 2016 – Wolf-Rayet stars in the SMC
- Heikkila et al., 2016 – X-ray binaries as SN progenitors.
- Moriya & Eldridge, 2016 – ECSNe fast transients
- **Steidel et al., 2016** – High-z galaxies rest frame UV and optical emission lines
- **Wilkins et al. 2016** – Binaries key for reionization
- **Ma et al., 2016** - Binaries key for reionization
- Graur et al., 2017 – SN rates versus metallicity

Summary: if you have colleagues using starburst99, GALEV, GALAXEV(BC03) or any other single star spectral synthesis codes, tell them to use BPASS. (They don’t have to talk to me just go to bpass.auckland.ac.nz).

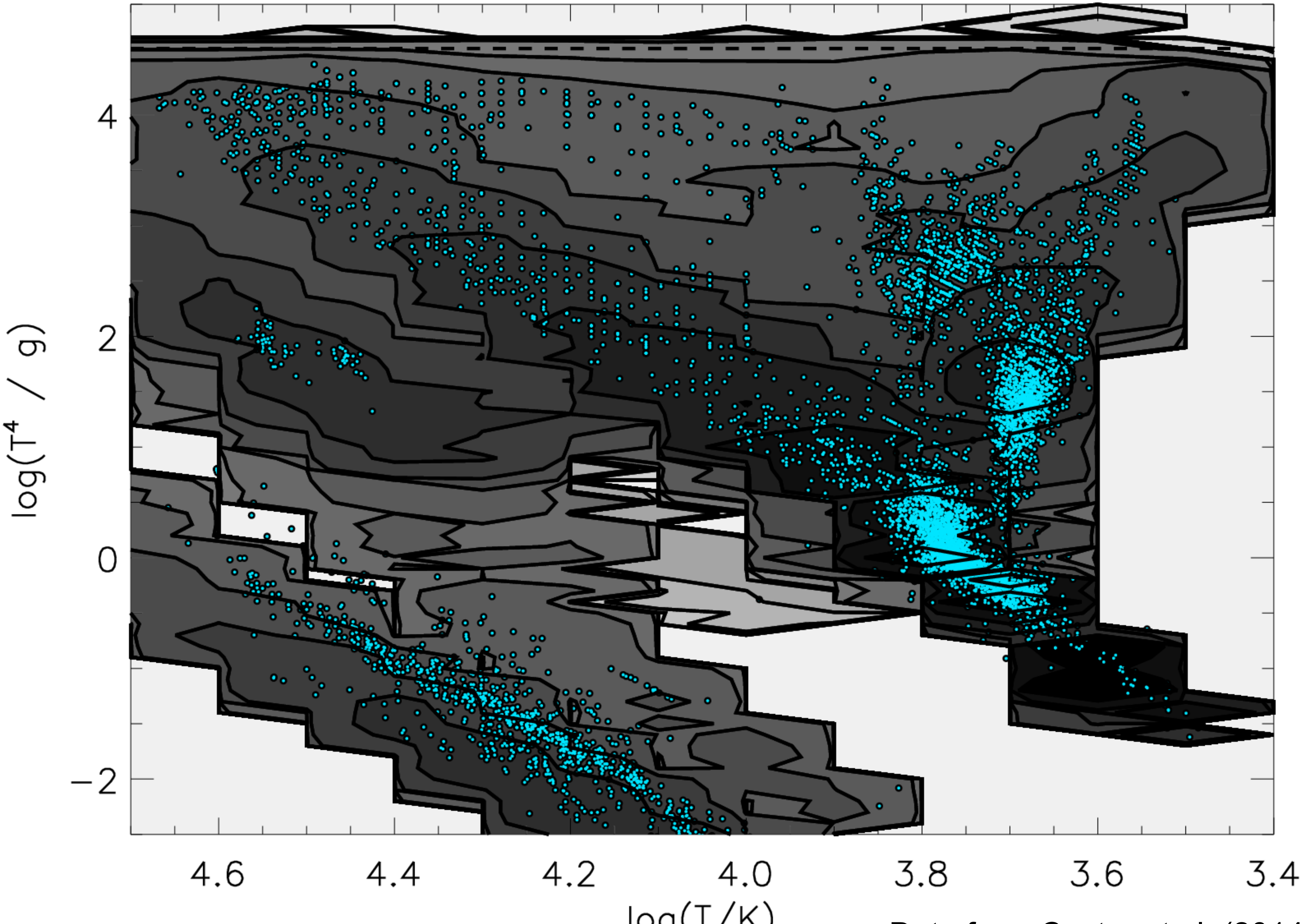
So how do you "do" spectral synthesis?

1) Calculate stellar models, i.e. population synthesis (Izzard, Klencki, Neijssel, Ruiter talks).
2) Find surface gravity, temperature and composition of stellar models.
3) Select relevant atmosphere model
4) Combine into population (using hilfskonstrukts).

Where do atmosphere models come from?
In BPASS: WM-Basic, PoWR & BaSeL v3.1.

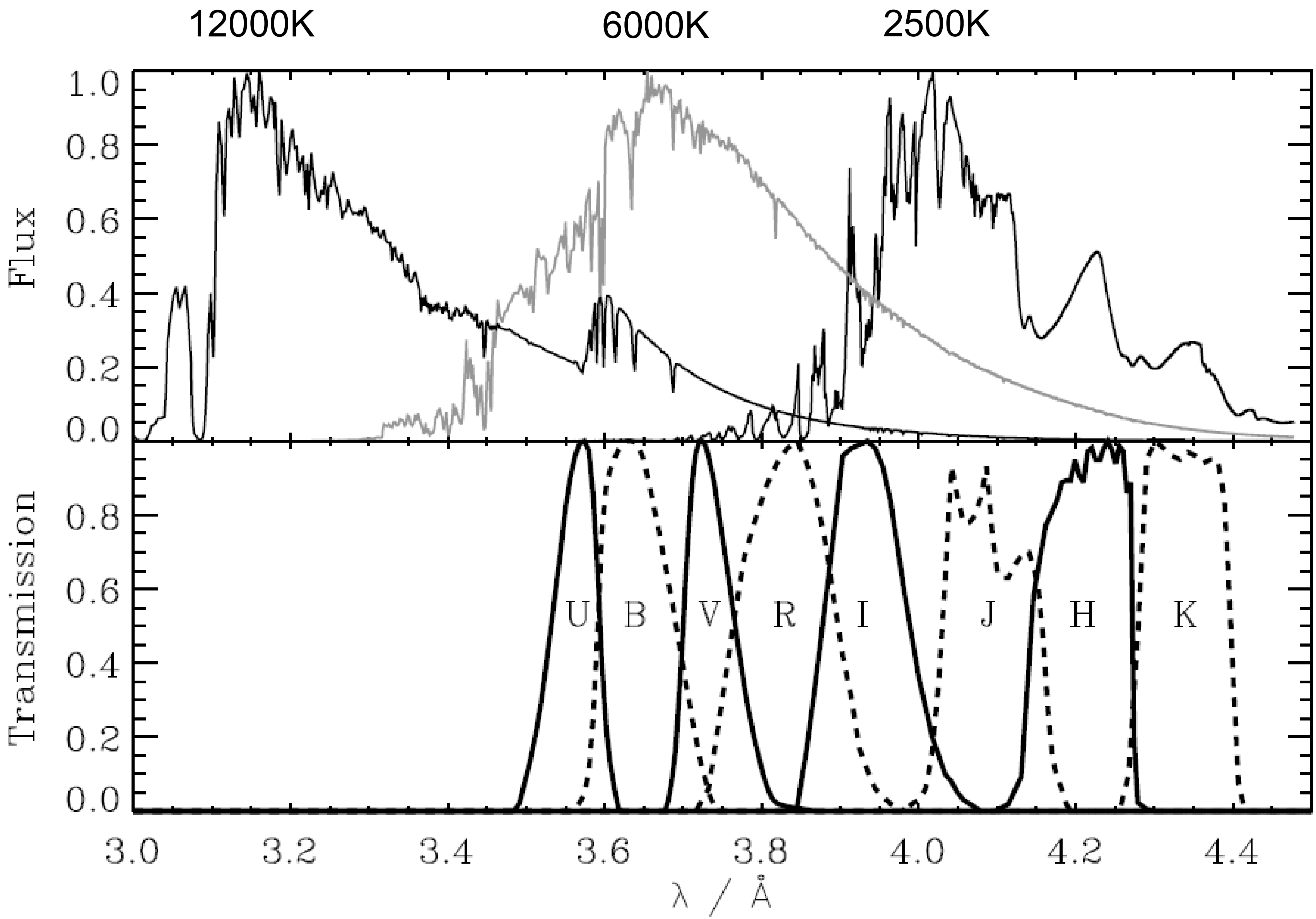
Or can calculate directly, see work of:
Jose Groh on combining Geneva models directly with CMFGEN models, also see Rix et al. (2004).

Starting point: spectroscopic HR diagram (binaries)



Data from Castro et al. (2014).

Link to spectral models, and use broad-band filters



Eldridge & Tout (in prep)

The resultant spectra for an instantaneous burst.

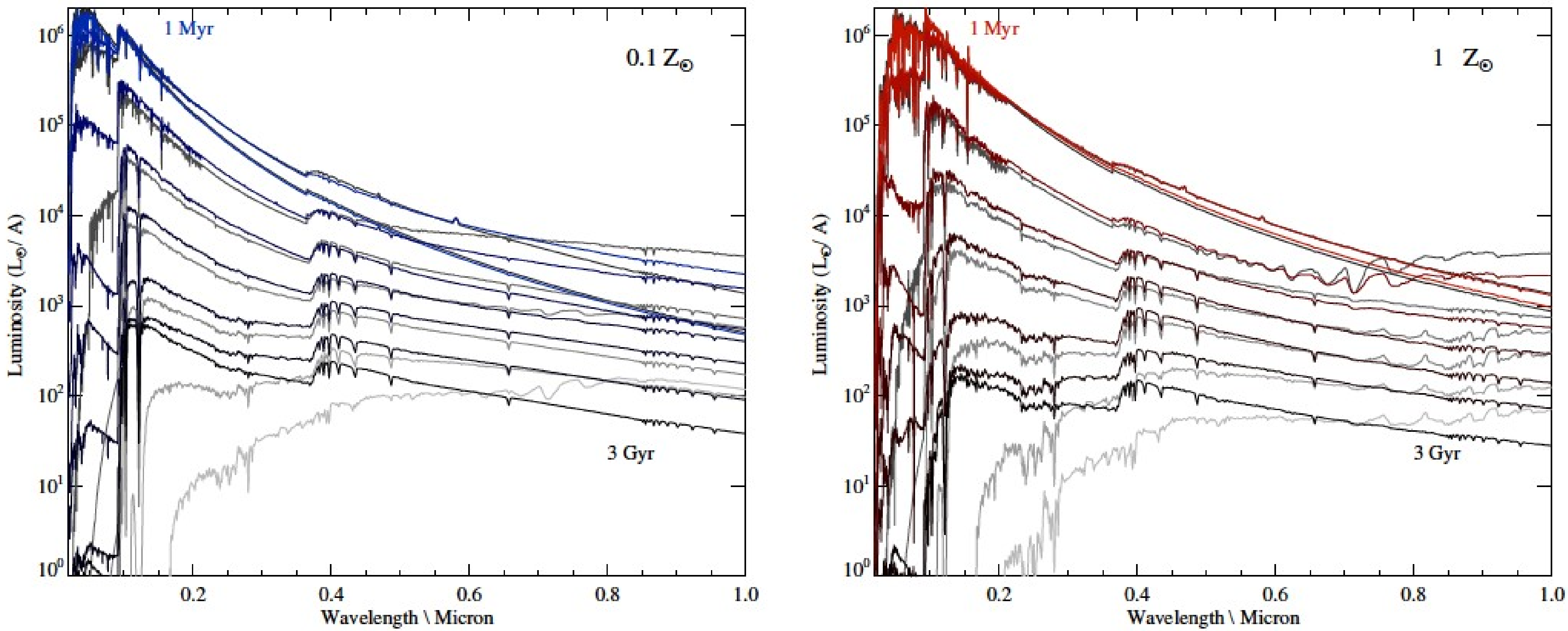


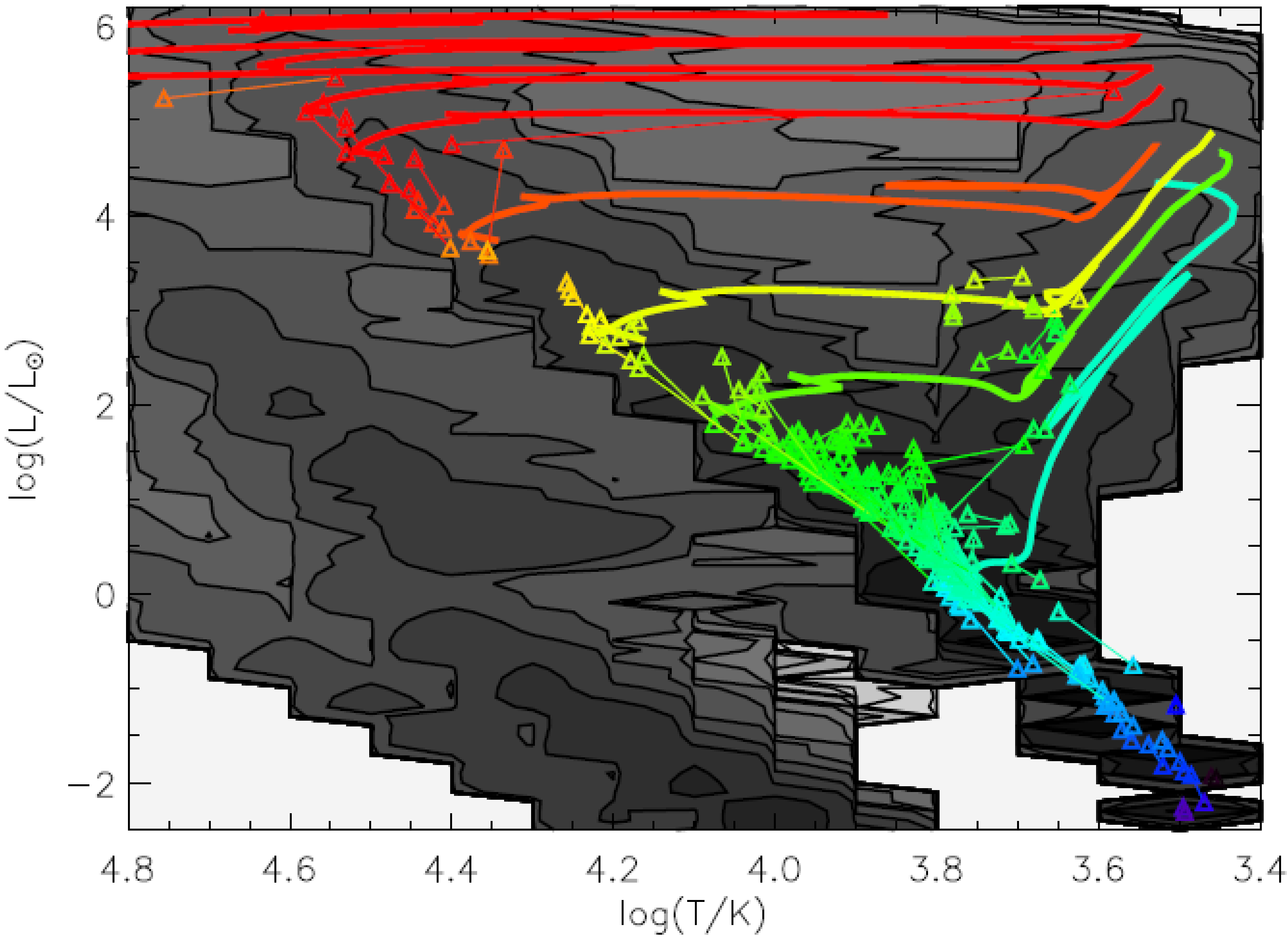
Figure 3. The synthetic spectra produced for a co-eval population (i.e. instantaneous starburst) at times of 1, 3, 10, 30, 100, 300, 1000 and 3000 Myr after star formation. Spectra are shown for binary populations (bold, coloured lines) and single stars (pale, greyscale line), and at metallicities of Z=0.002 and Z=0.020.

BPASSv2.1

Eldridge et al . (in prep)

But how do we test this? First let us look at individual resolved stars.

HR diagram for eclipsing binaries

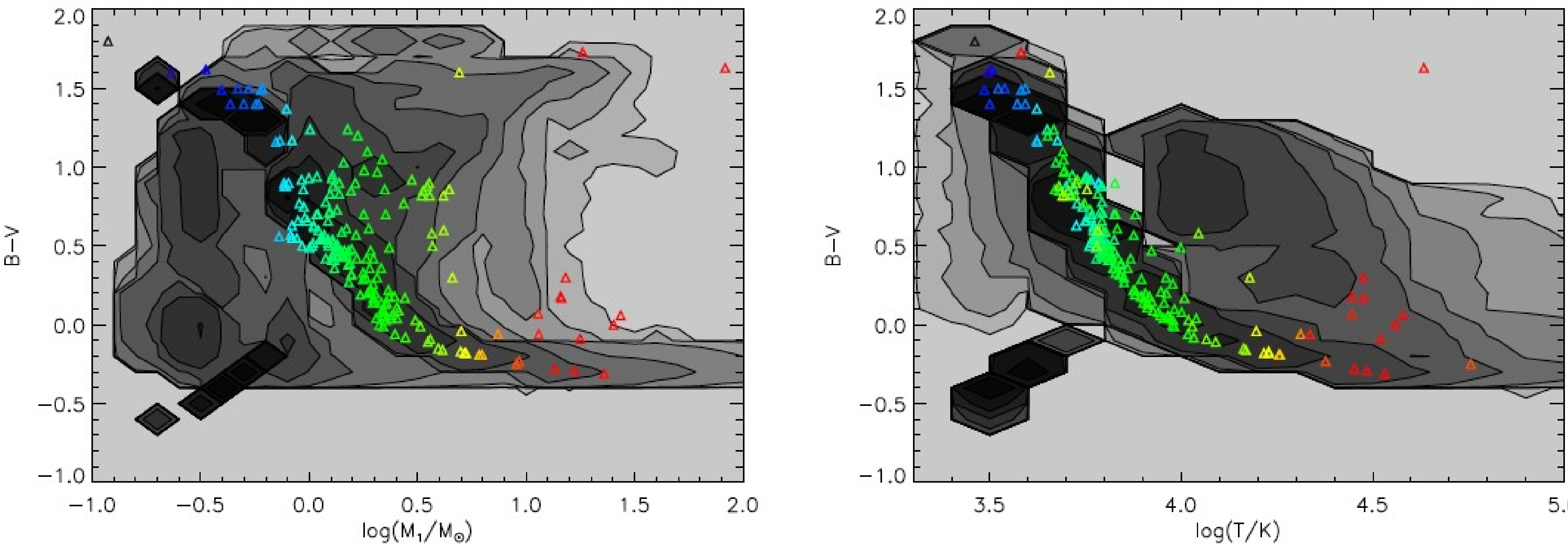


Data: DEBCat + VV Cephei + ɣ-Velorum + WR20a

BPASSv2.1

Eldridge et al . (in prep)

Eclipsing binary broad-band colours...

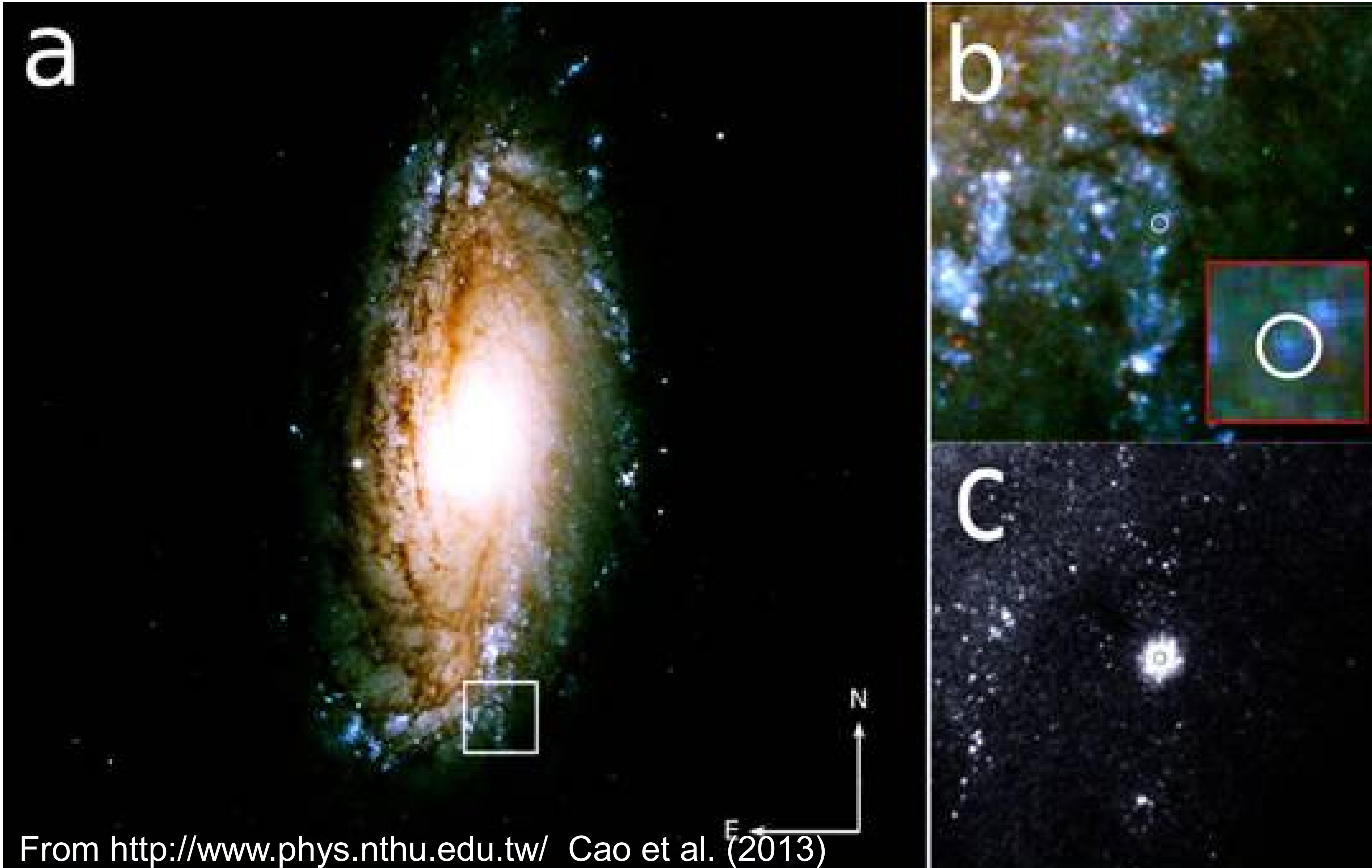


Data: DEBCat + VV Cephei + γ-Velorum + WR20a

BPASSv2.1

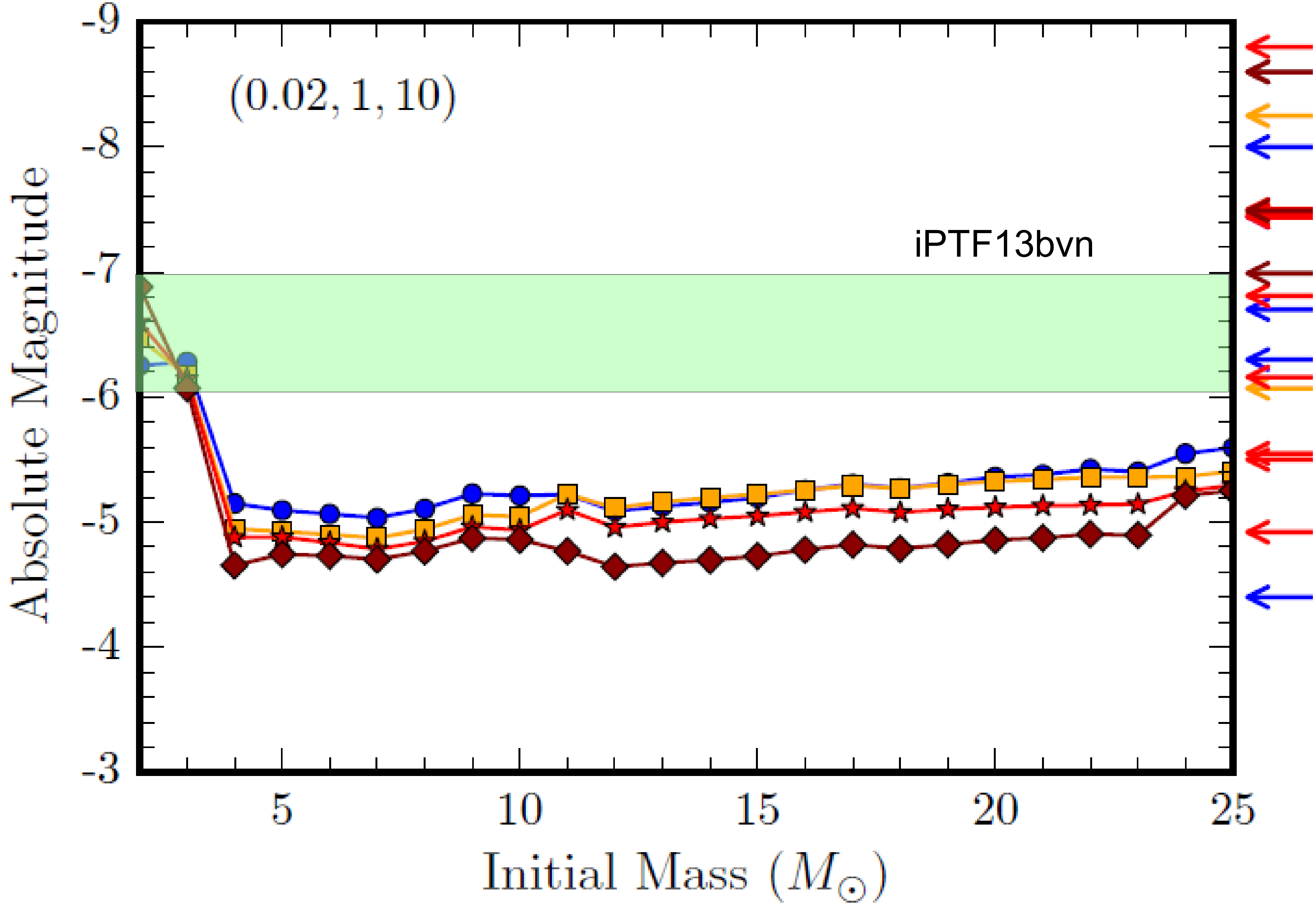
Eldridge et al . (in prep)

Type Ib SN iPTF13bvn



Bernsten et al. (2013); Eldridge et al . (2013, 2015, 2016)

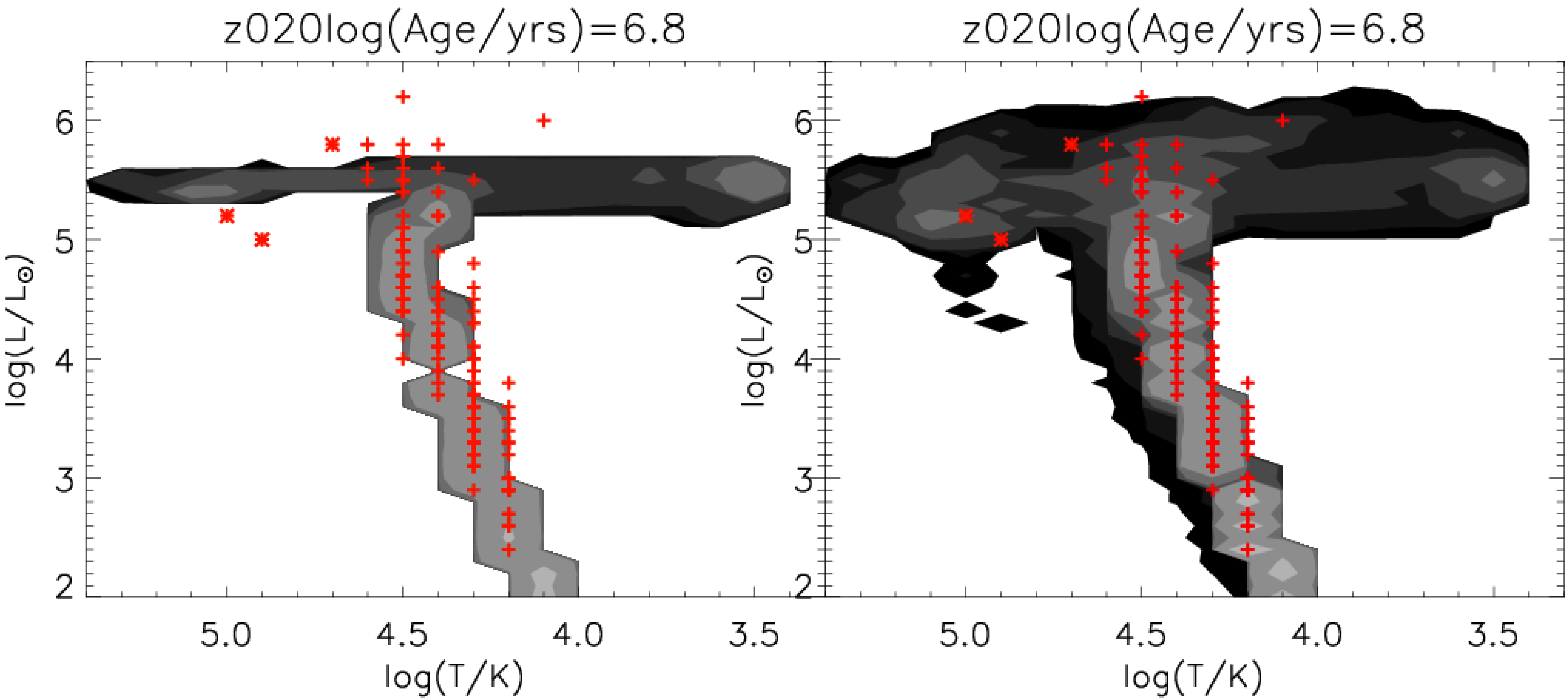
Progenitors of type Ib/c supernova progenitors



McClelland & Eldridge (2016) also see Yoon et al. (2012) and Yoon (2017)

So lets think about entire stellar populations....

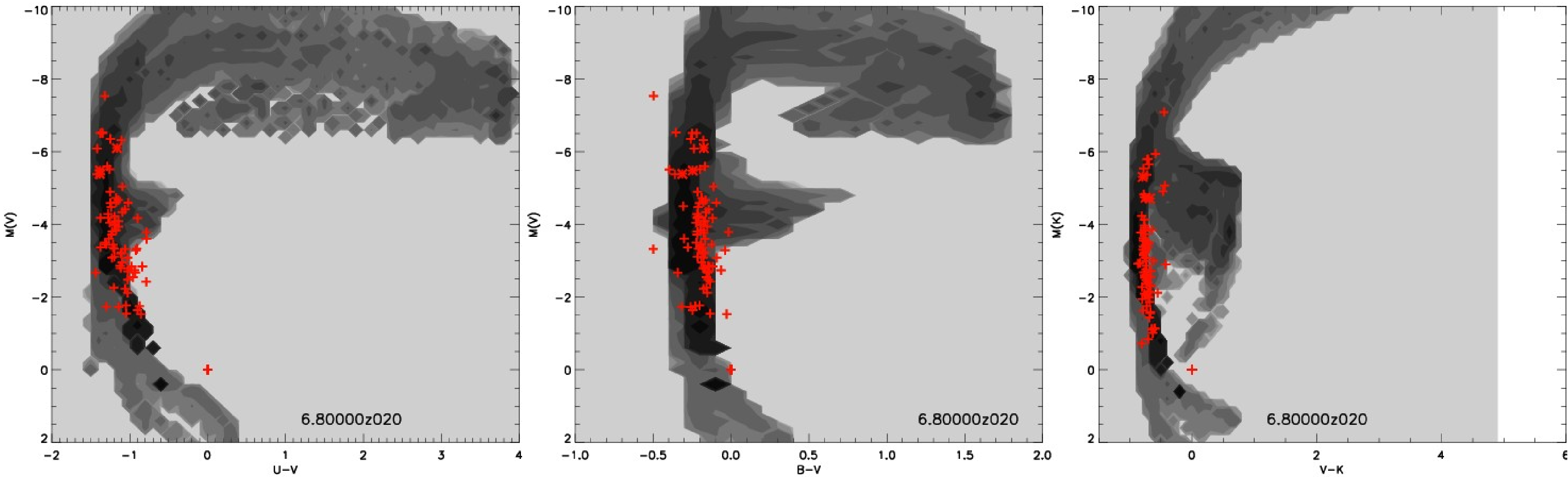
Cygnus OB2 – log(age/yr)=6.8



BPASSv2.1

Eldridge et al . (in prep)

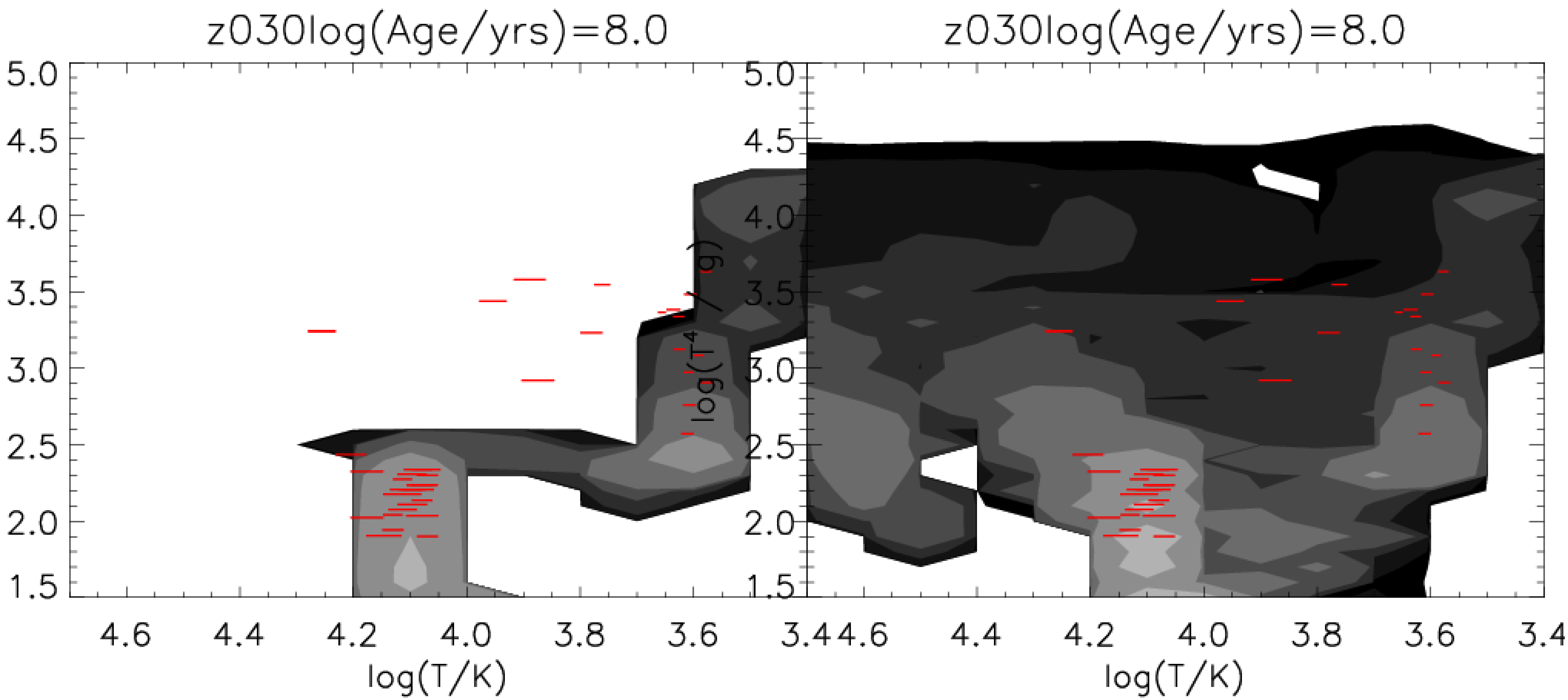
Cygnus OB2 – log(age/yr)=6.8



BPASSv2.1

Eldridge et al . (in prep)

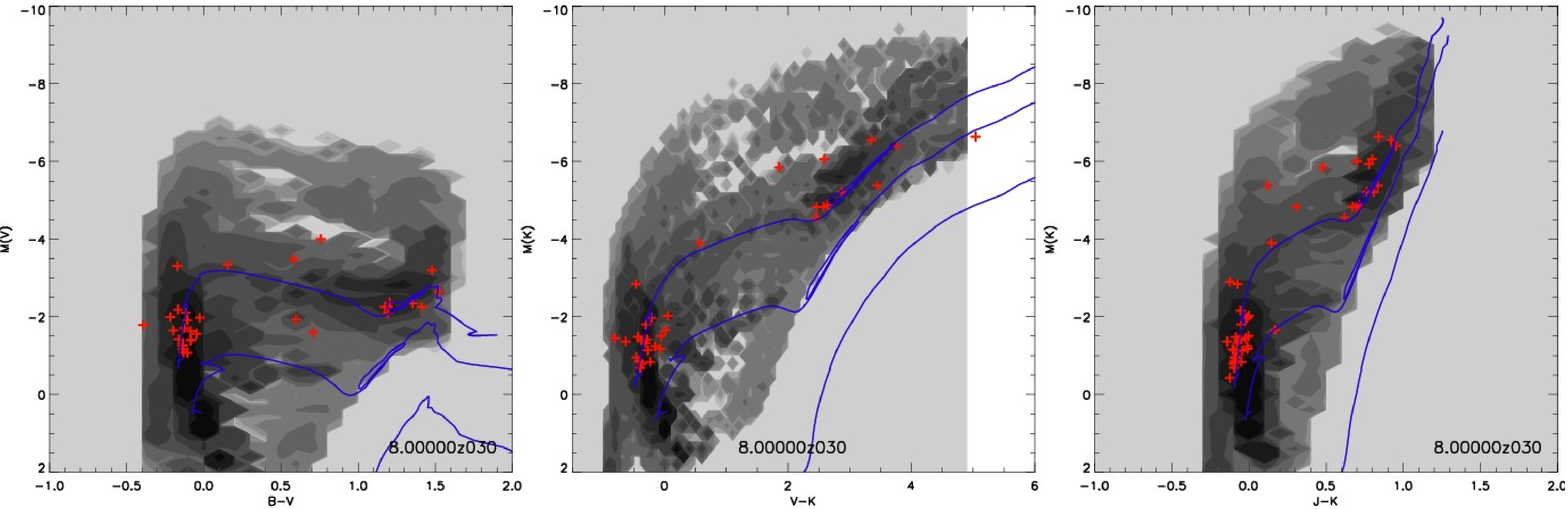
NGC6067 – log(age/yr)=8.0



BPASSv2.1

Eldridge et al . (in prep)

NGC6067 – log(age/yr)=8.0



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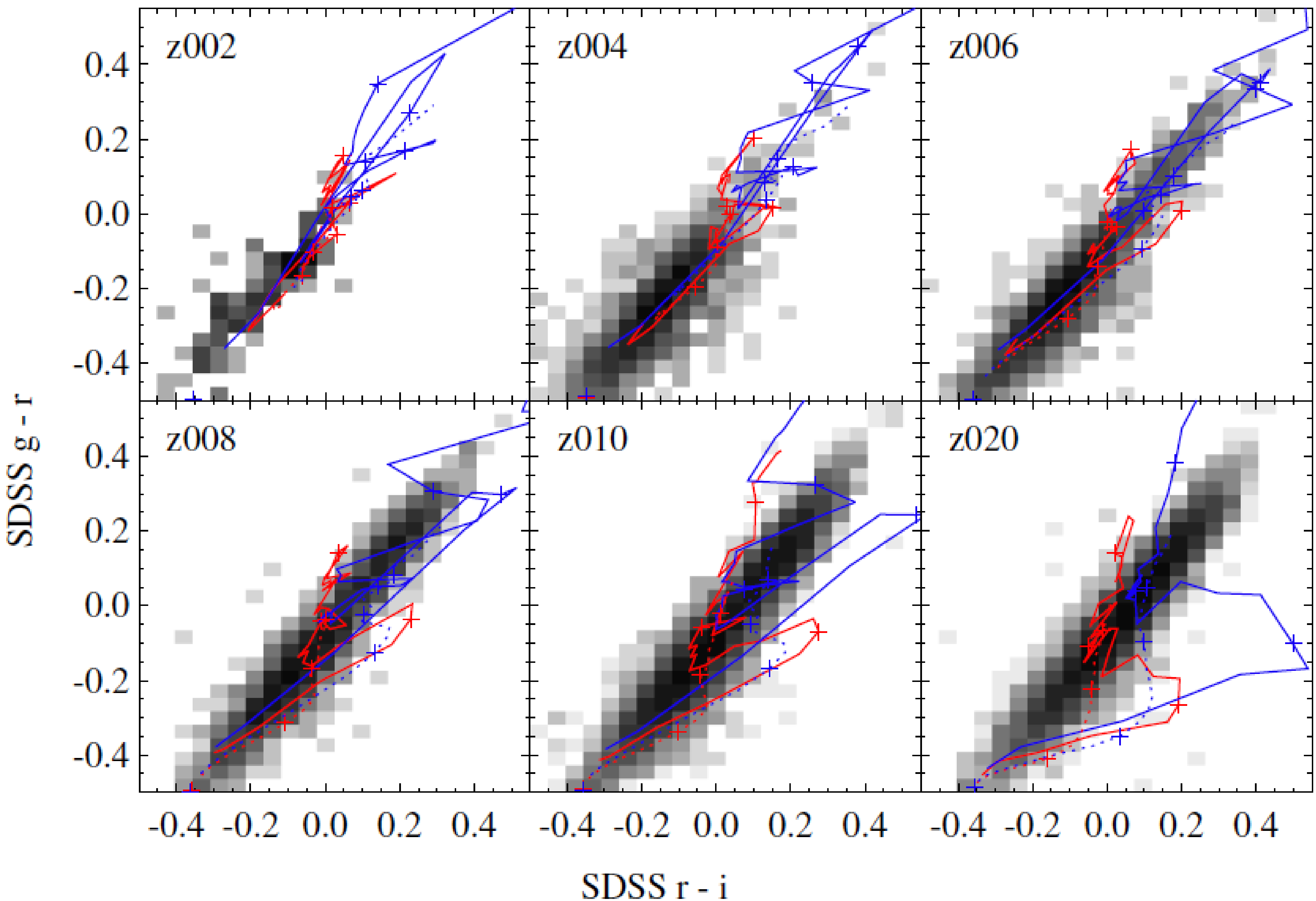
Eldridge et al . (in prep)

What about unresolved stellar populations?

Colours of SDSS star-forming galaxies



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Eldridge et al . (in prep)

Spectra of star-forming regions

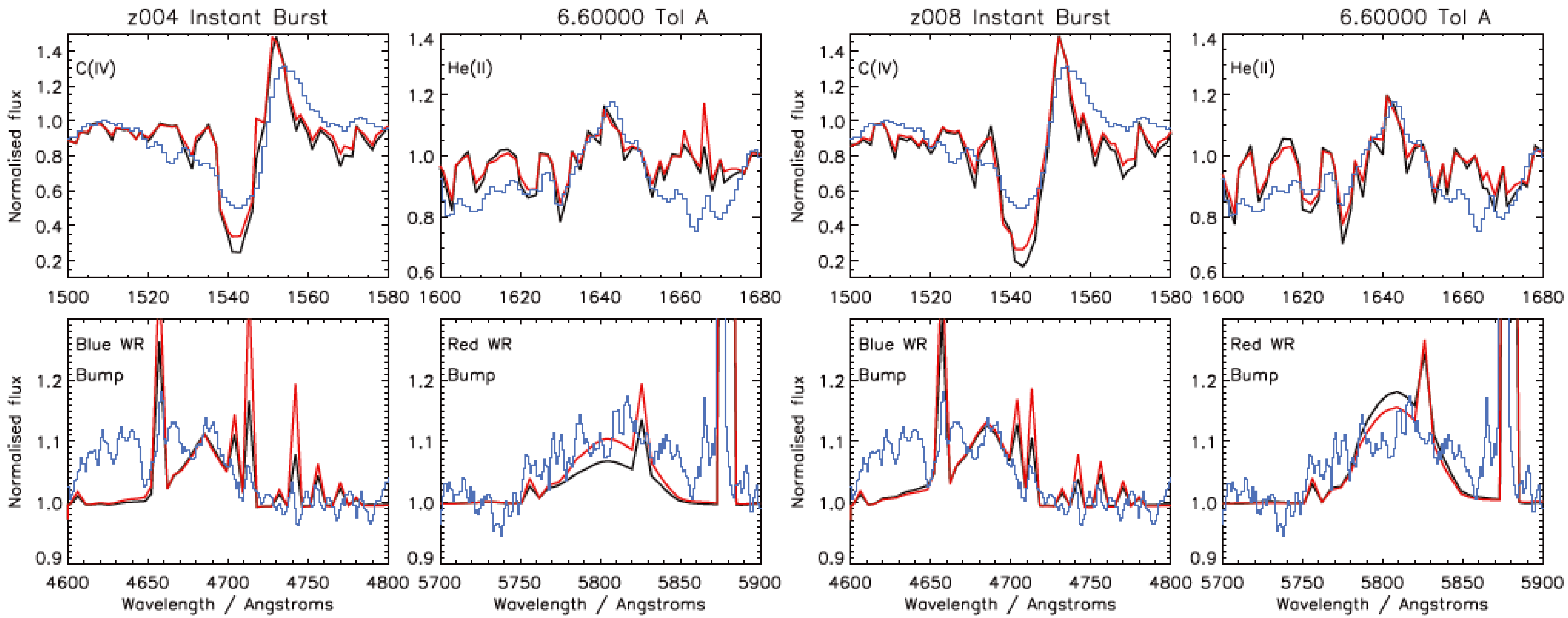
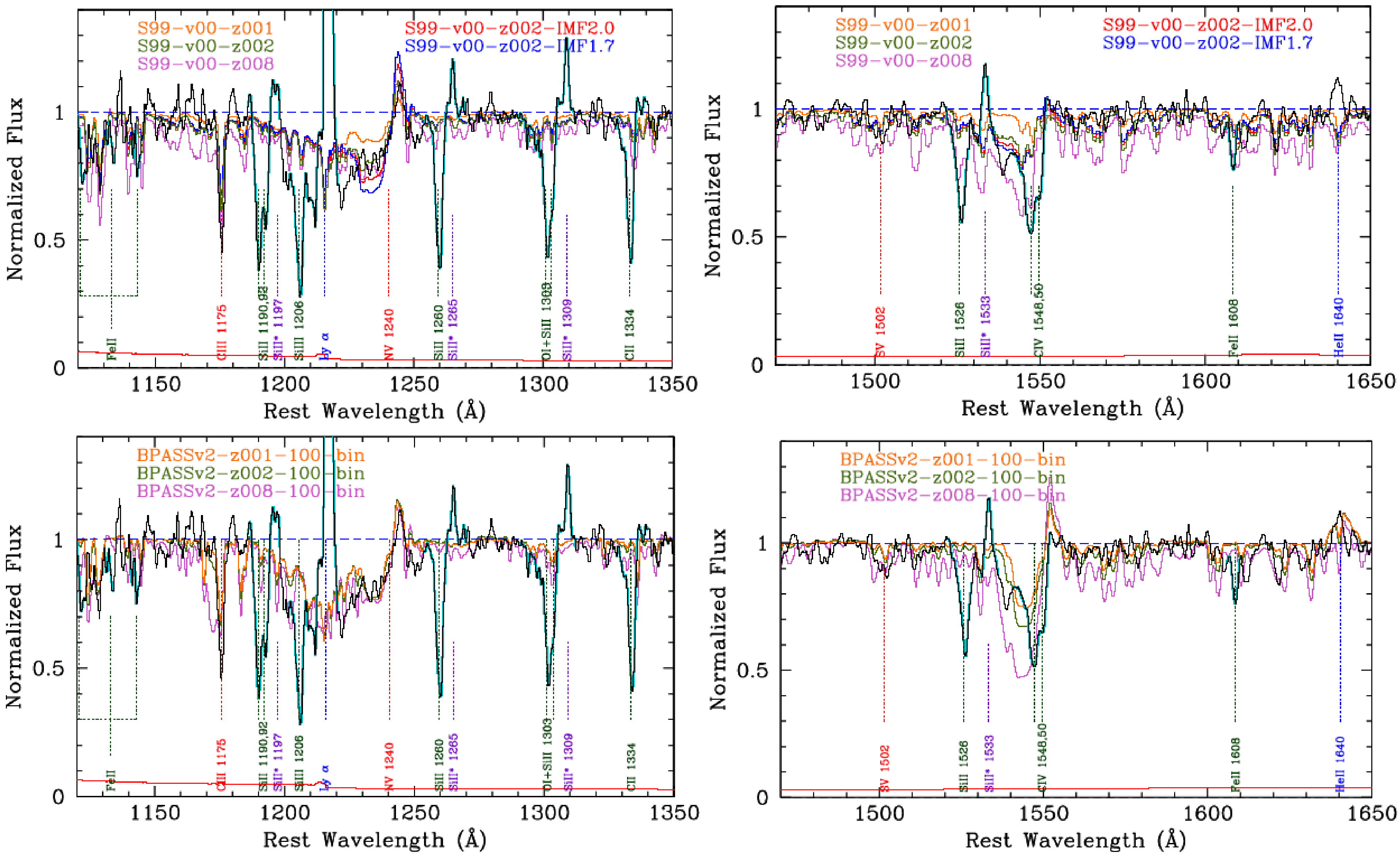


Figure 7. Our best-fitting spectra for Tol A both for an age of $10^{6.6}$ yr. The left-hand panel is for a SMC-like metallicity, $Z = 0.004$. The right-hand panel is for an LMC-like metallicity, $Z = 0.008$. The observations are shown in blue. The single-star models are shown with solid black lines while the binary models are the solid red lines.

Eldridge & Stanway (2009)

BPASSv1.0

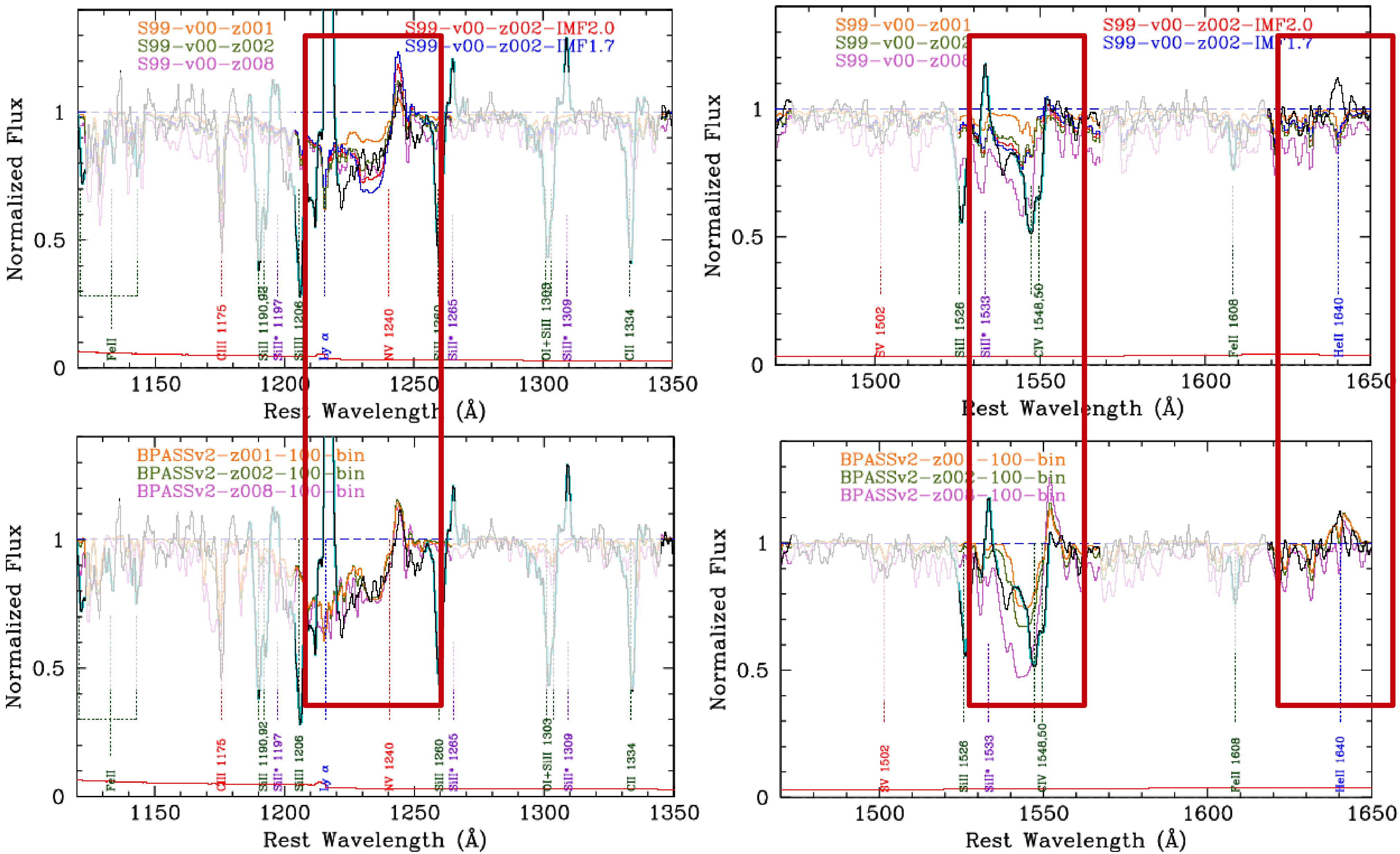
Stellar emission lines in high-z galaxies



Steidel et al. (2016)
See also Eldridge & Stanway (2012)

BPASSv2.0

Stellar emission lines in high-z galaxies

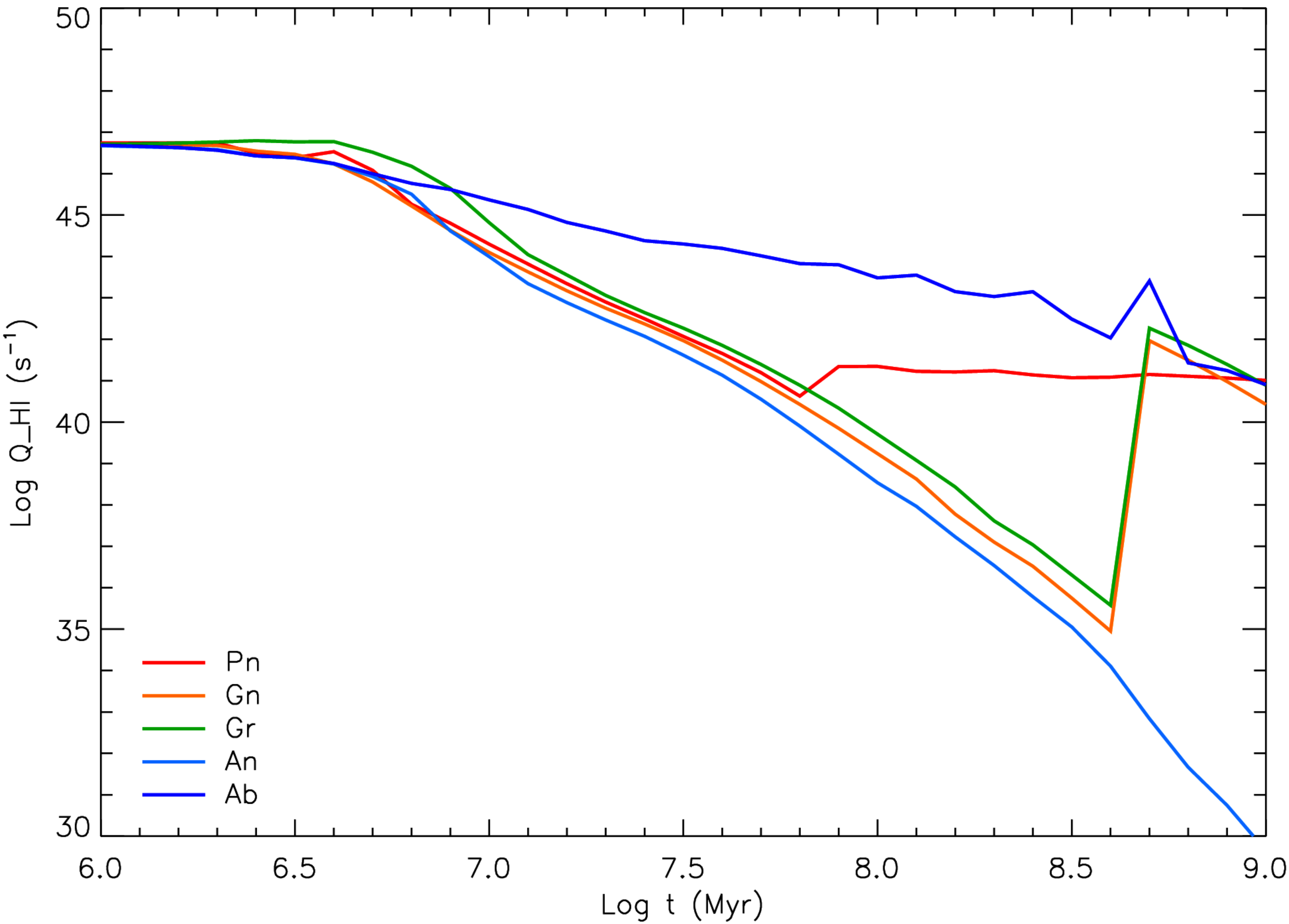


Steidel et al. (2016)
See also Eldridge & Stanway (2012)

BPASSv2.0

So what is the one thing that binaries do that single stars can't?

Hot stars at times older than 10Myrs.
(Also see Ylva Goetberg's work)



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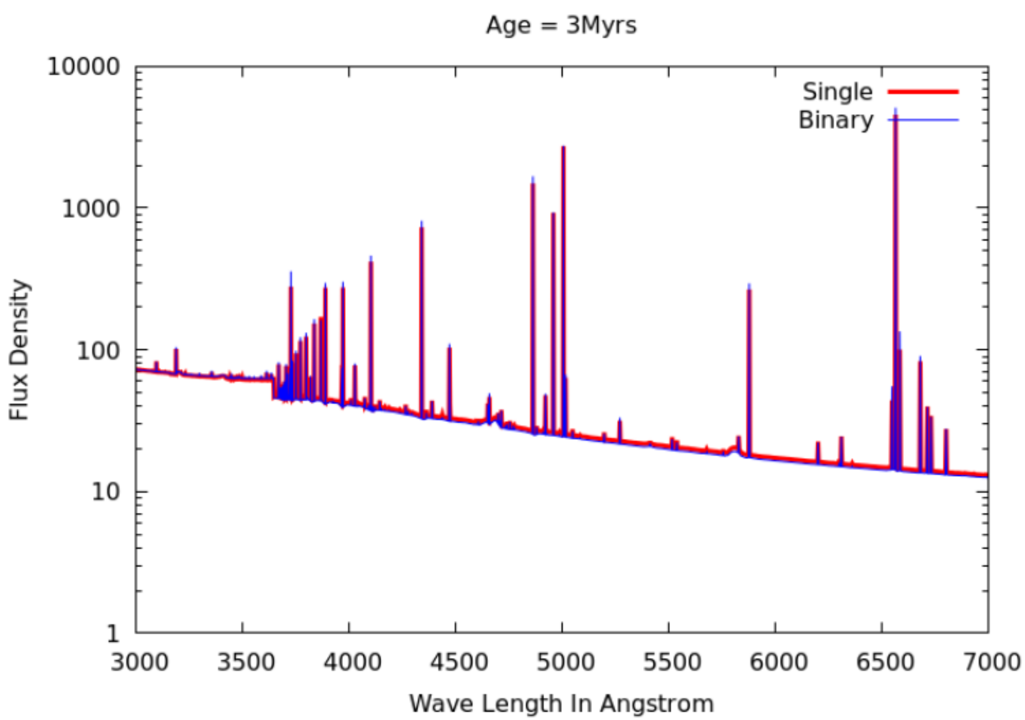
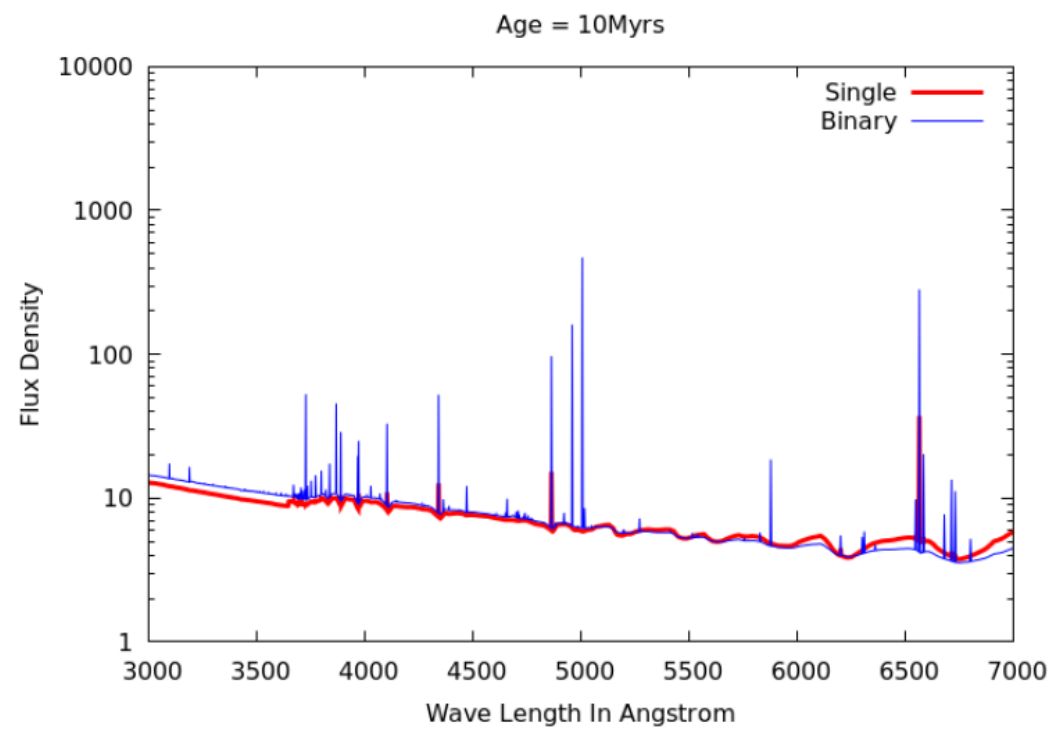
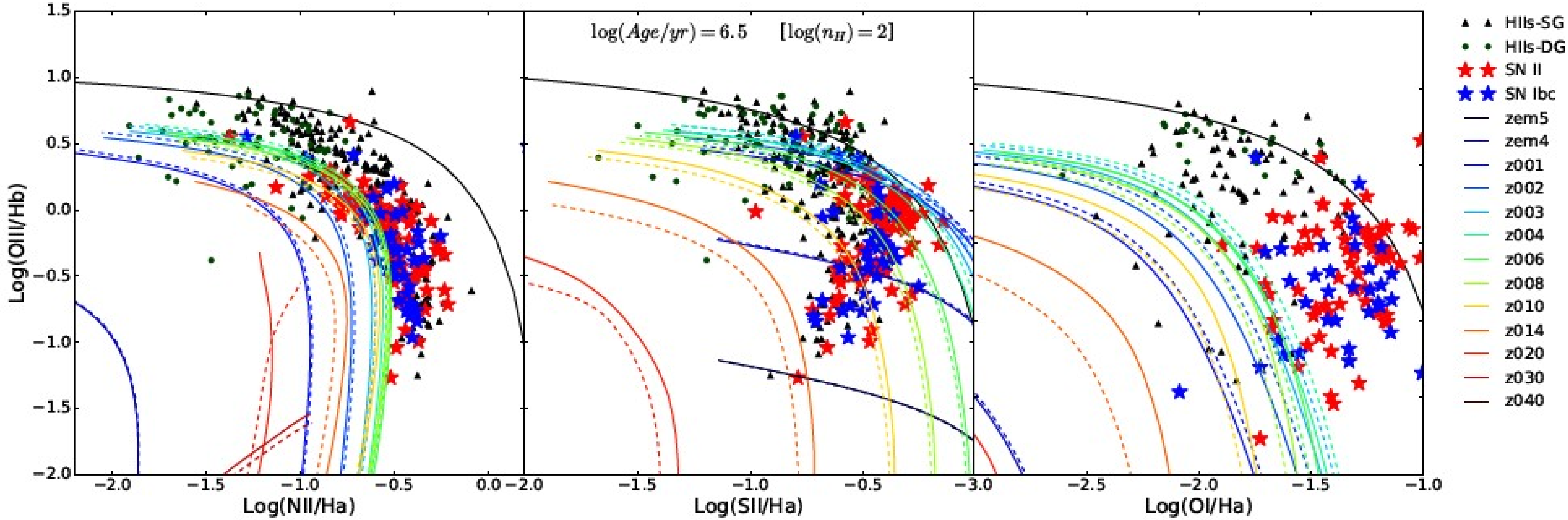
Wofford et al. (2016)

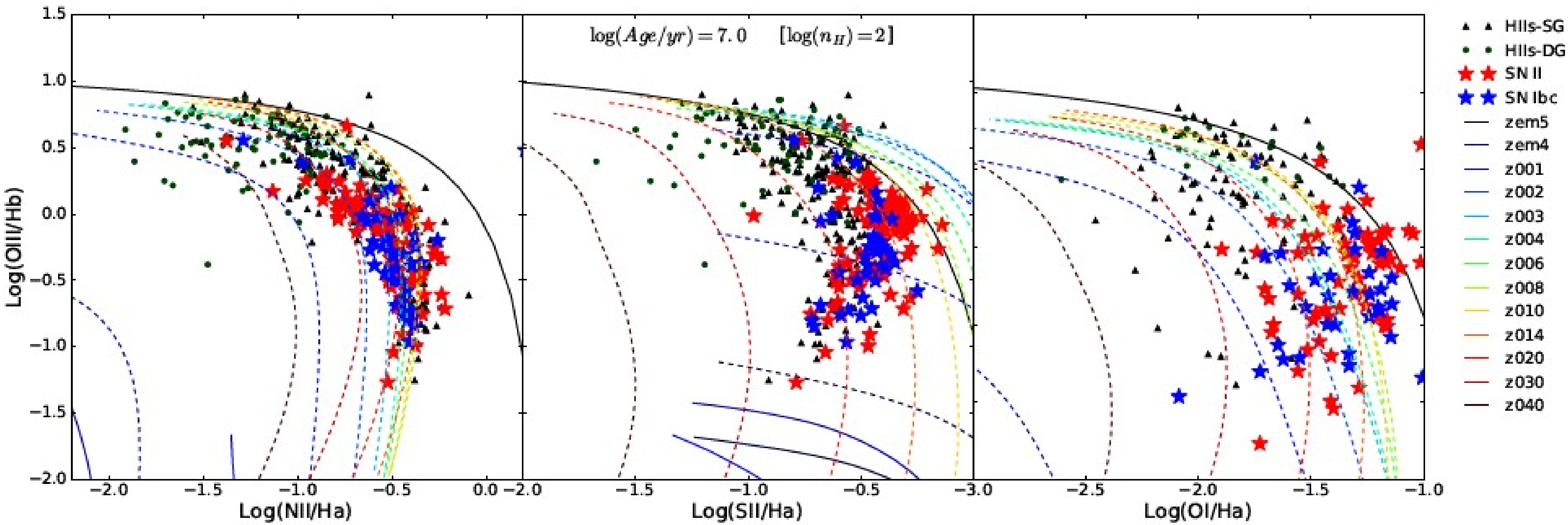




BPASSv2.1

Lin Xiao, J.J. Eldridge, Elizabeth Stanway, Lluis Galbany (in prep).





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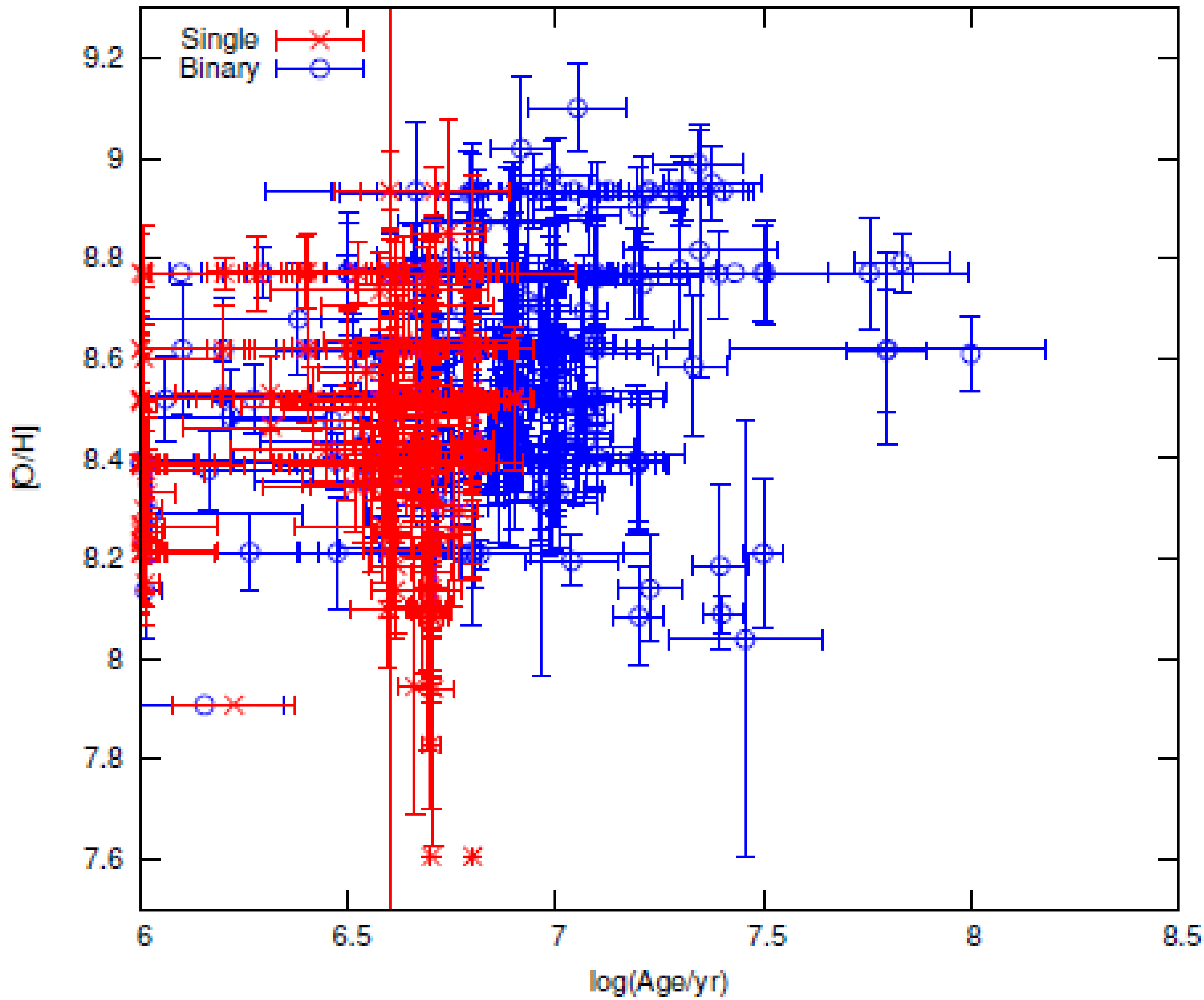

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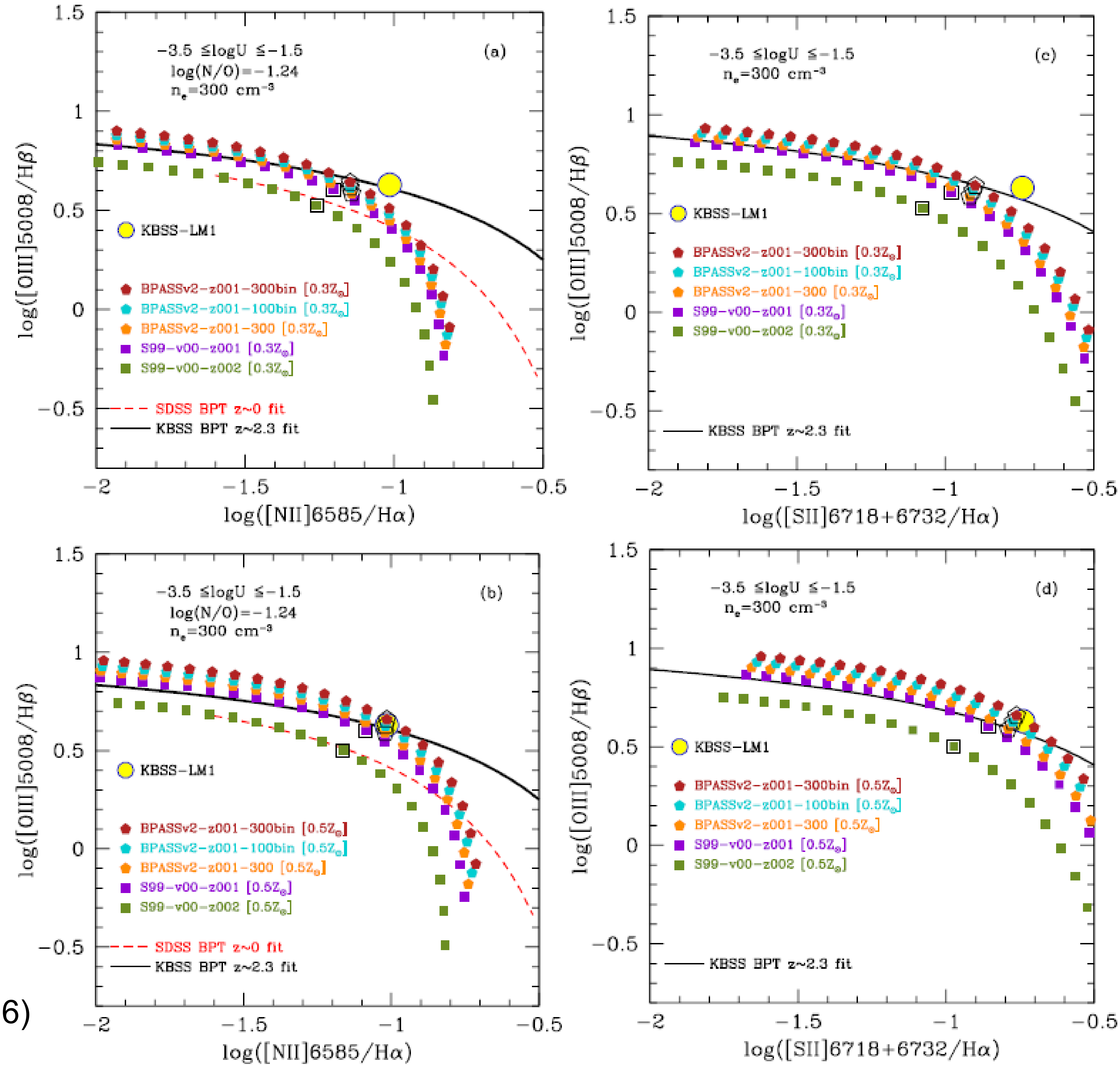
Lin Xiao, J.J. Eldridge, Elizabeth Stanway, Lluis Galbany (in prep).



Steidel et al. (2016)

Summary

Spectral synthesis includes: stars, star clusters (resolved & unresolved), broad-band colours, spectral features, nebula emission lines and even supernova lightcurves.

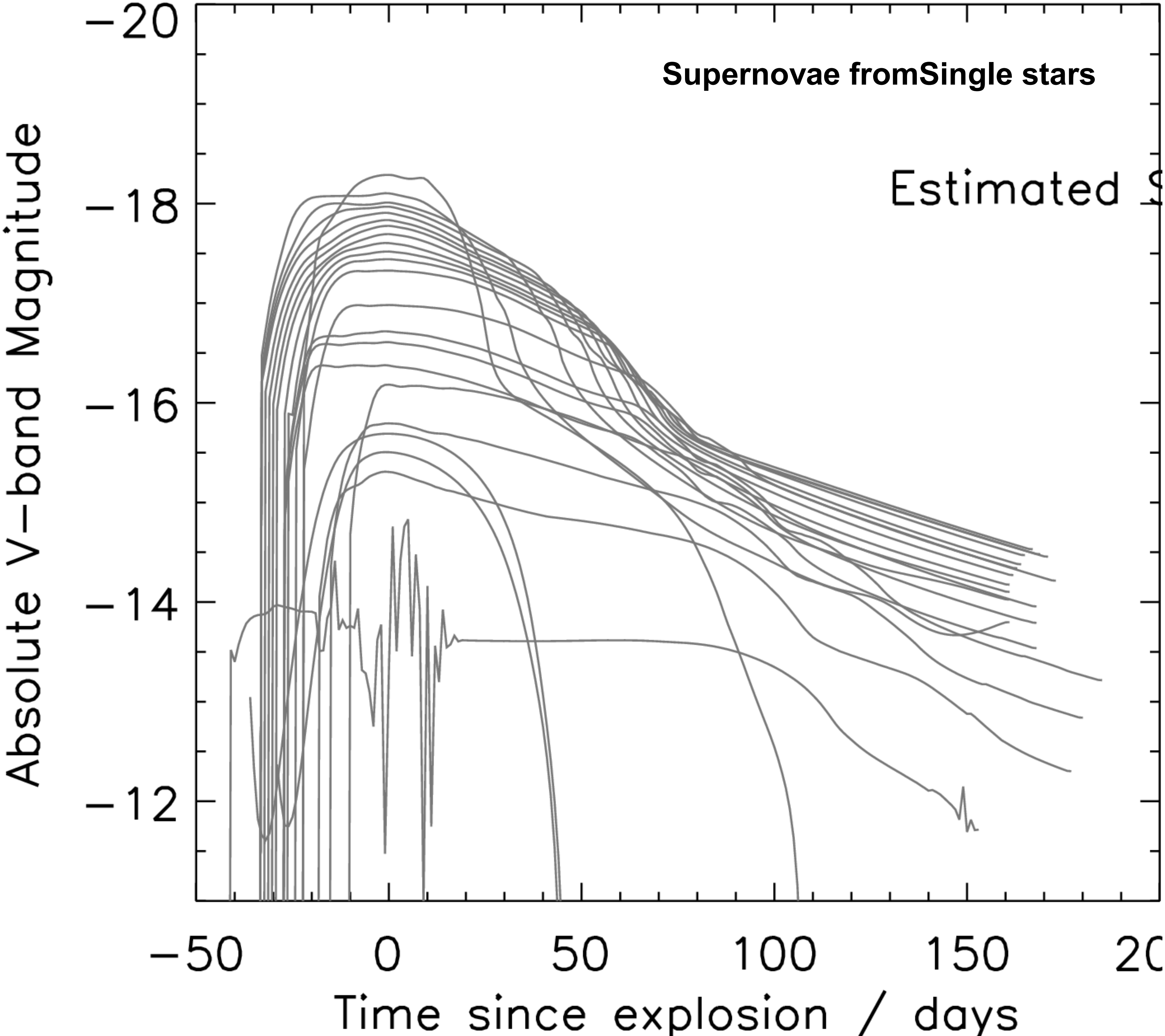
“Observing” models gives effective ways to constrain and test stellar and population models.

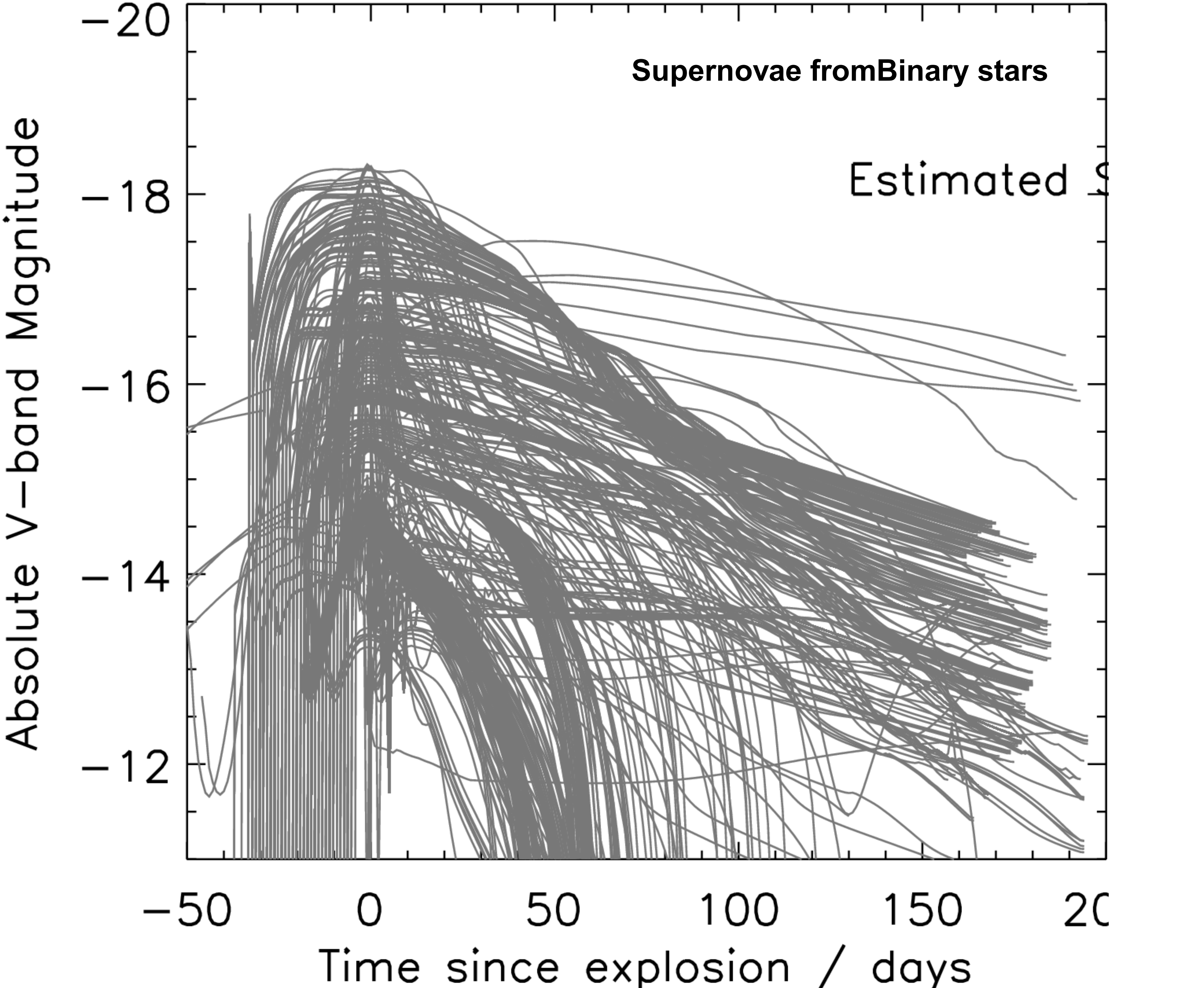
It is also key to not focus on one observable and instead work for the broader view.

Other things I’m also thinking about:

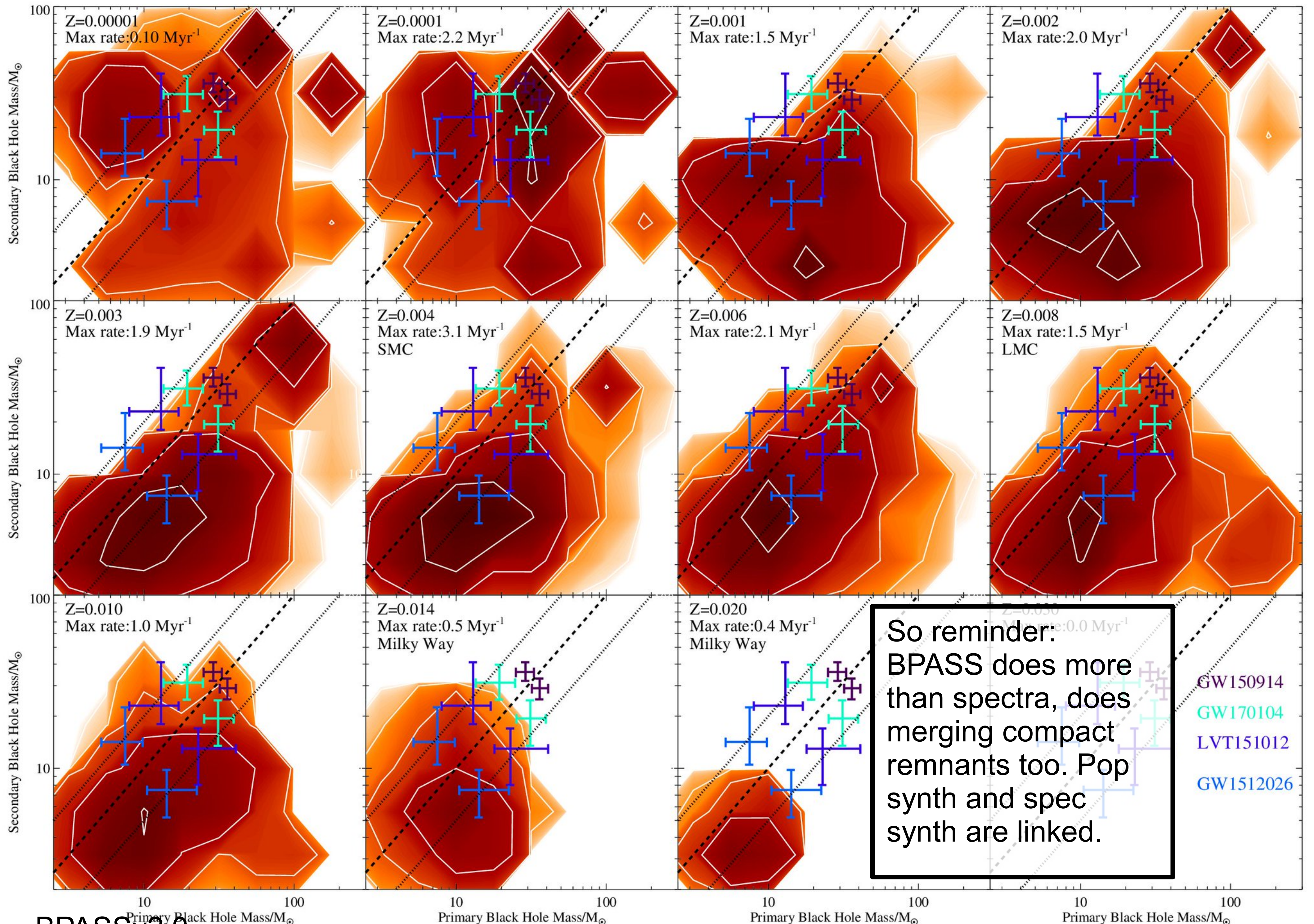
Common Envelope Evolution, GW sources, neutron-star & black-hole kicks stocasticity, X-ray binaries, very massive stars, superluminous supernovae, GRBs, PISN, red supergiant mass-loss rates, remnant mass distribution….

Last thing, with detailed models we can put them into “The Supernova Explosion Code” by Viktoriya Morozova et al., and create the synthetic supernova lightcurves.


Supernovae fromSingle stars
Estimated S
Absolute V−band Magnitude
−20
−18
−16
−14
−12
−50
0
50
100
150
20
Time since explosion / days



Supernovae fromBinary stars
Estimated S
Absolute V−band Magnitude
−20
−18
−16
−14
−12
−50
0
50
100
150
20
Time since explosion / days



BPASSv2.0

Eldridge & Stanway (2016)

The resultant spectra for constant star-formation

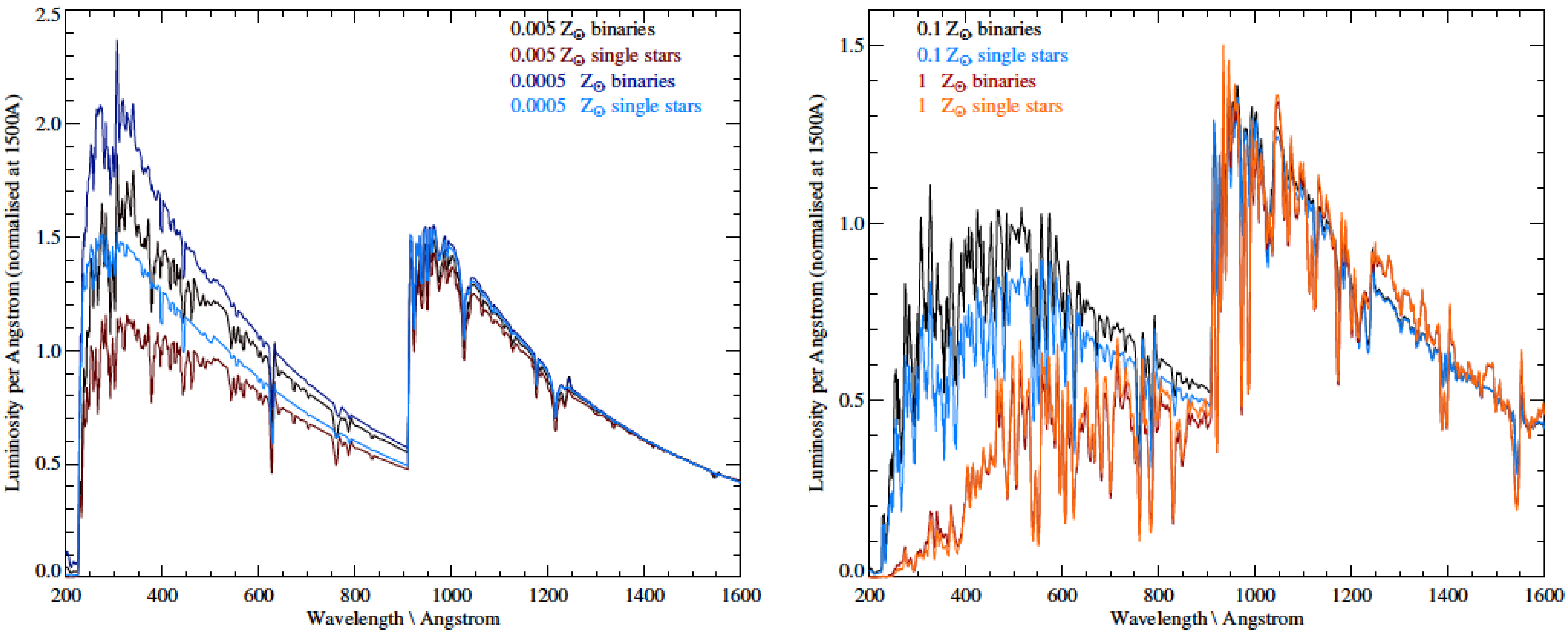
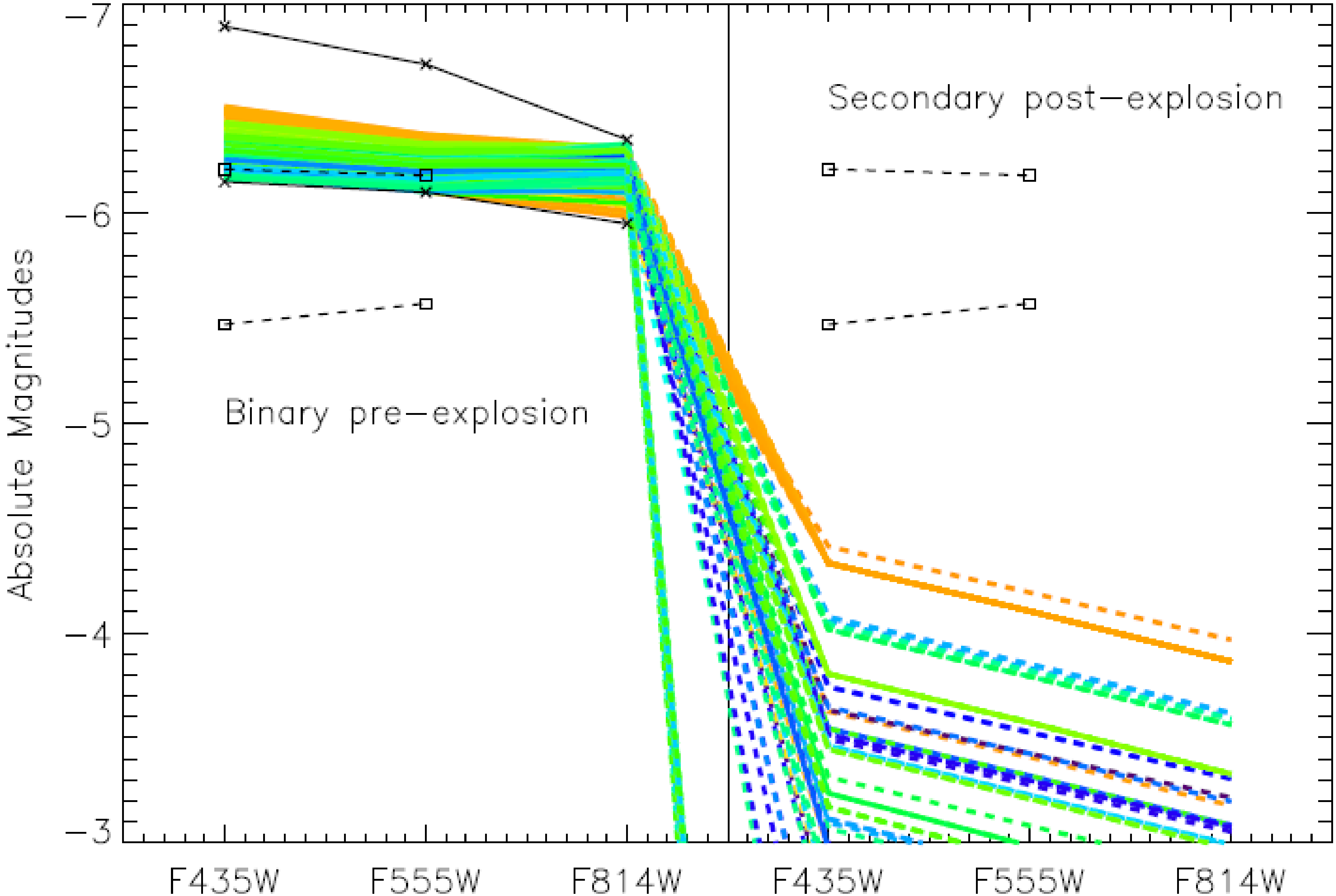


Figure 4. The extreme ultraviolet spectral region in synthetic spectra produced for a co-eval population (i.e. instantaneous starburst) at a time 30 Myr after star formation, as a function of metallicity and single star vs binary evolution. The effect of binary evolution is to increase the hardness of the spectrum, and hence the ionizing photon output, particularly at very low metallicities. Synthetic spectra have been scaled to a common luminosity at 1500Å.

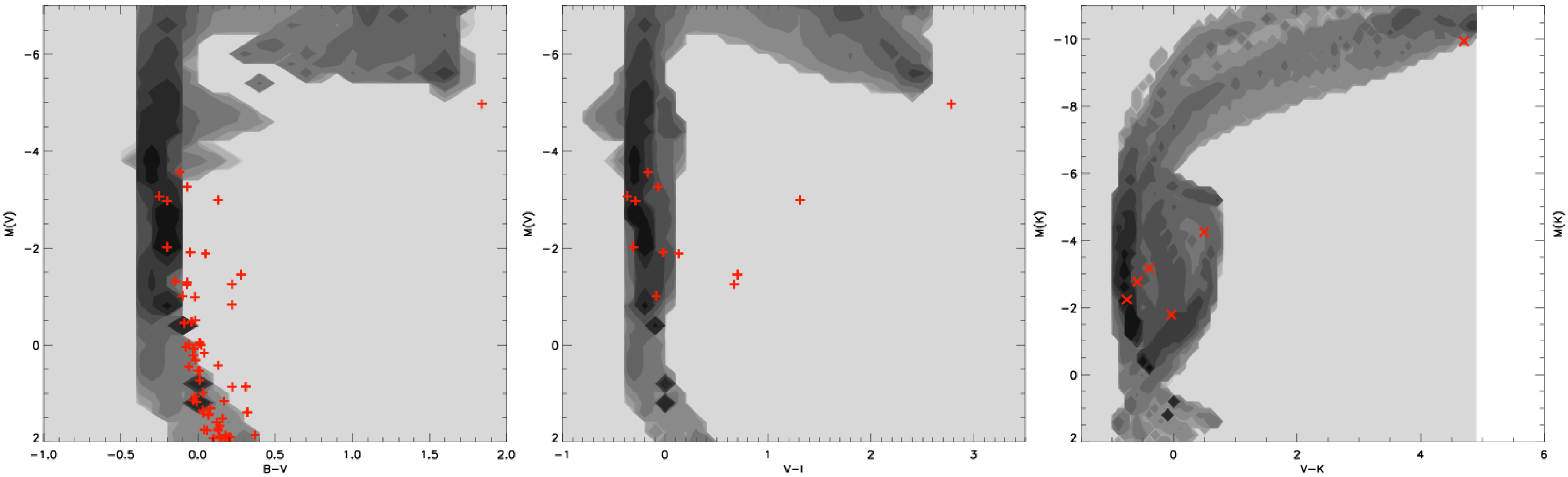
BPASSv2.1

Eldridge et al . (in prep)

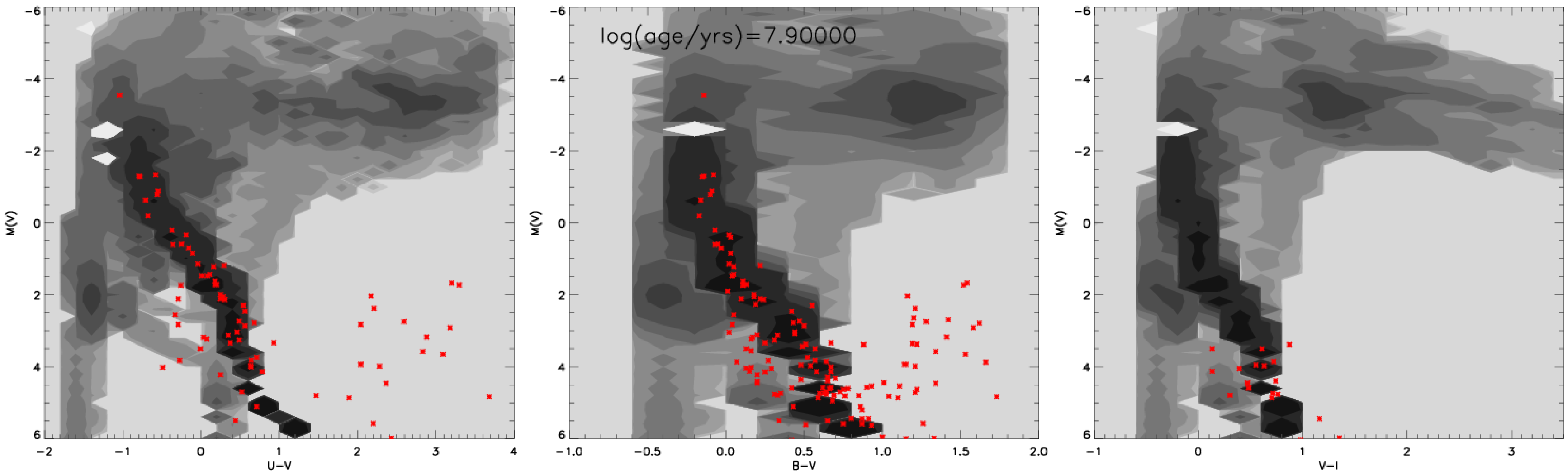


Eldridge & Maund (2016)

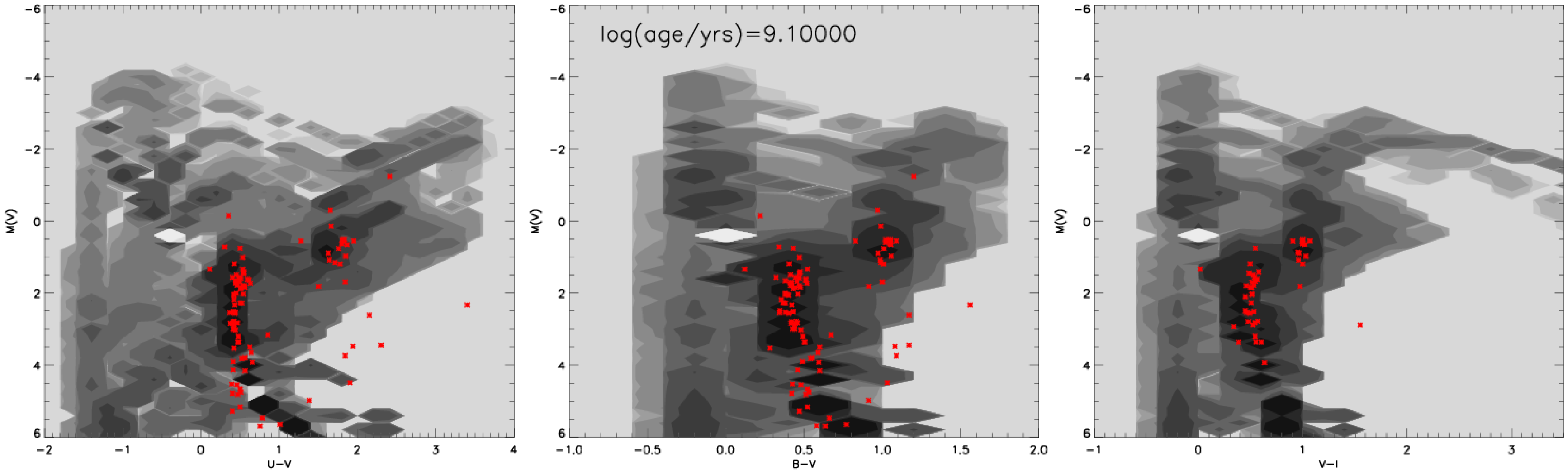
Upper Sco – log(age/yr)=7.0



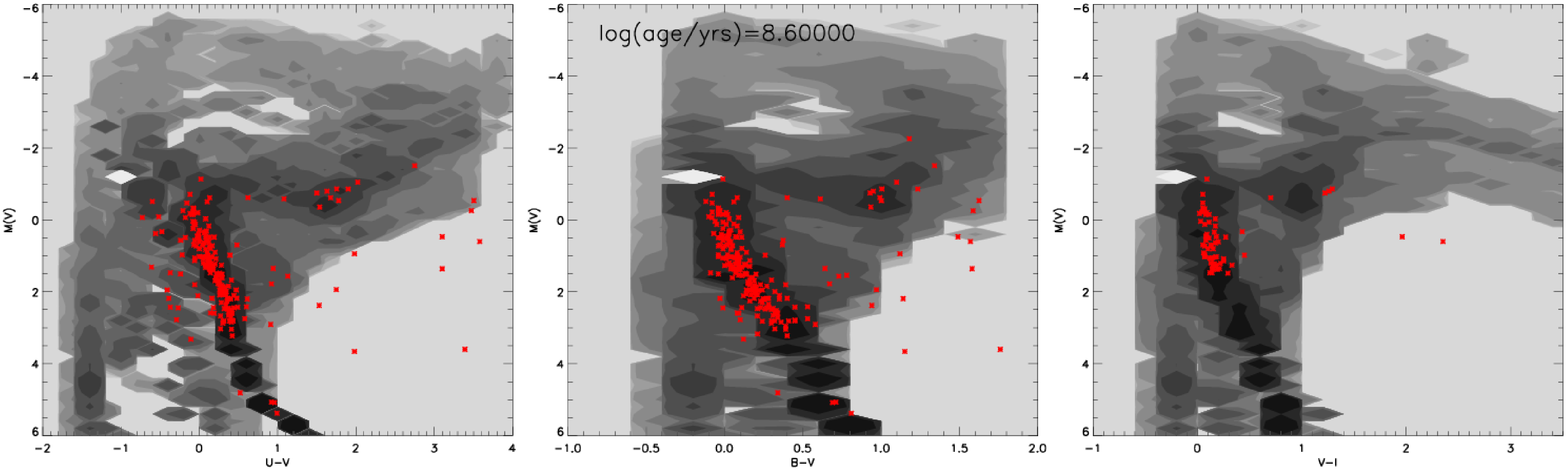
IC2602 – log(age/yr)=7.9 (7.5)

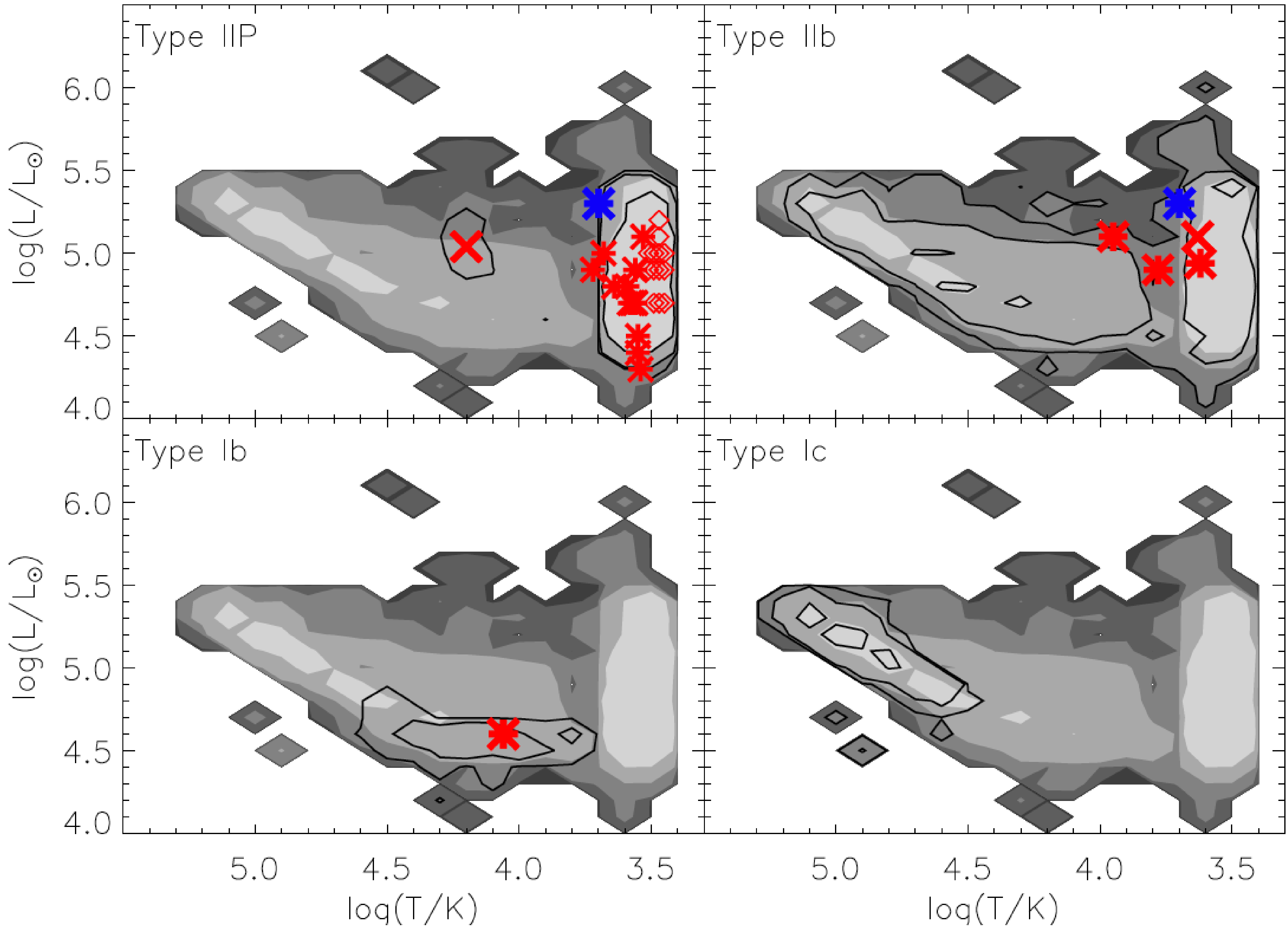


NGC752 – log(age/yr)=9.1



NGC3532 – log(age/yr)=8.6 (8.5)





Eldridge et al . (in prep)