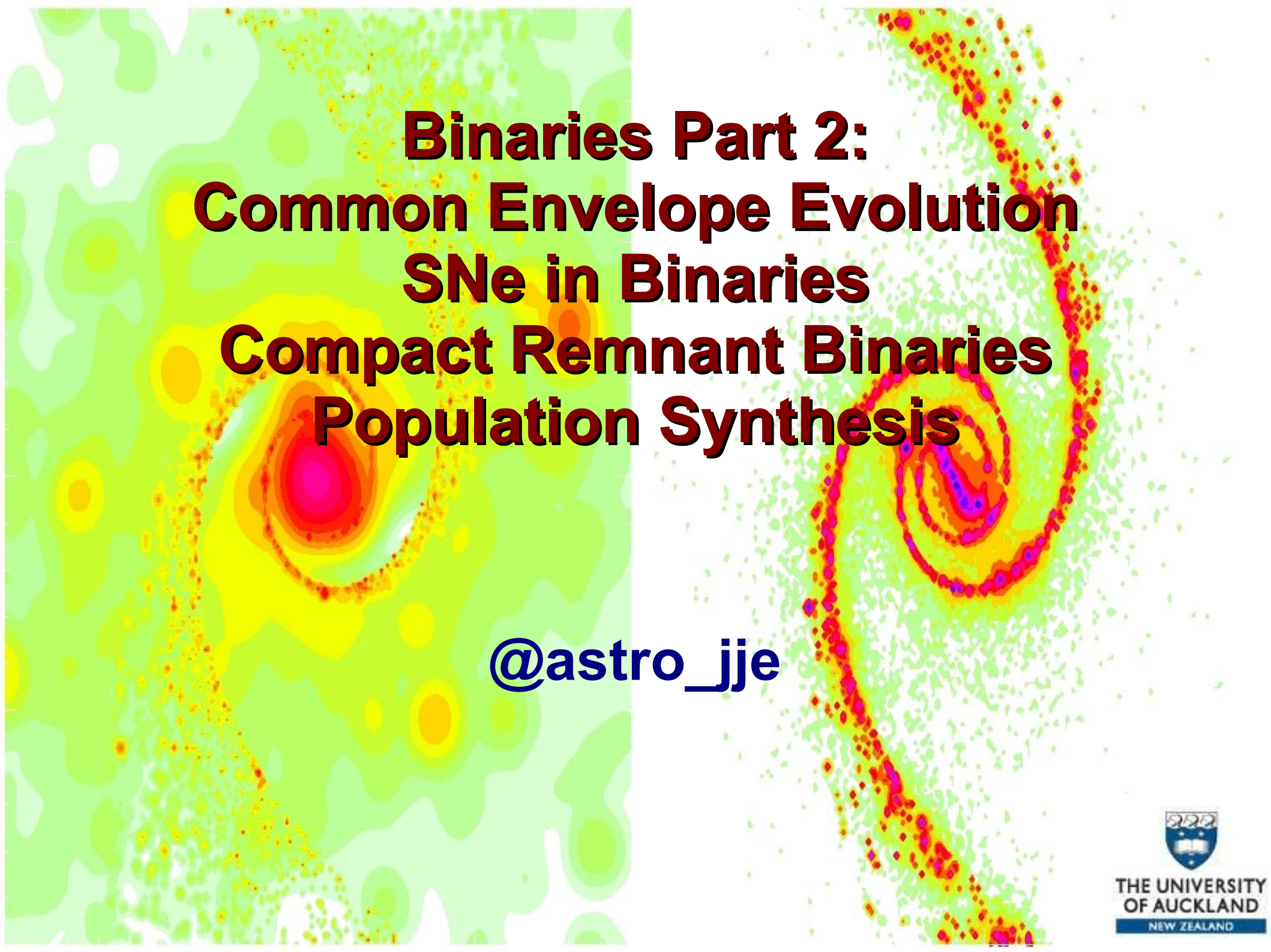


Binaries Part 2:
Common Envelope Evolution
SNe in Binaries
Compact Remnant Binaries
Population Synthesis

@astro_jje

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND

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.

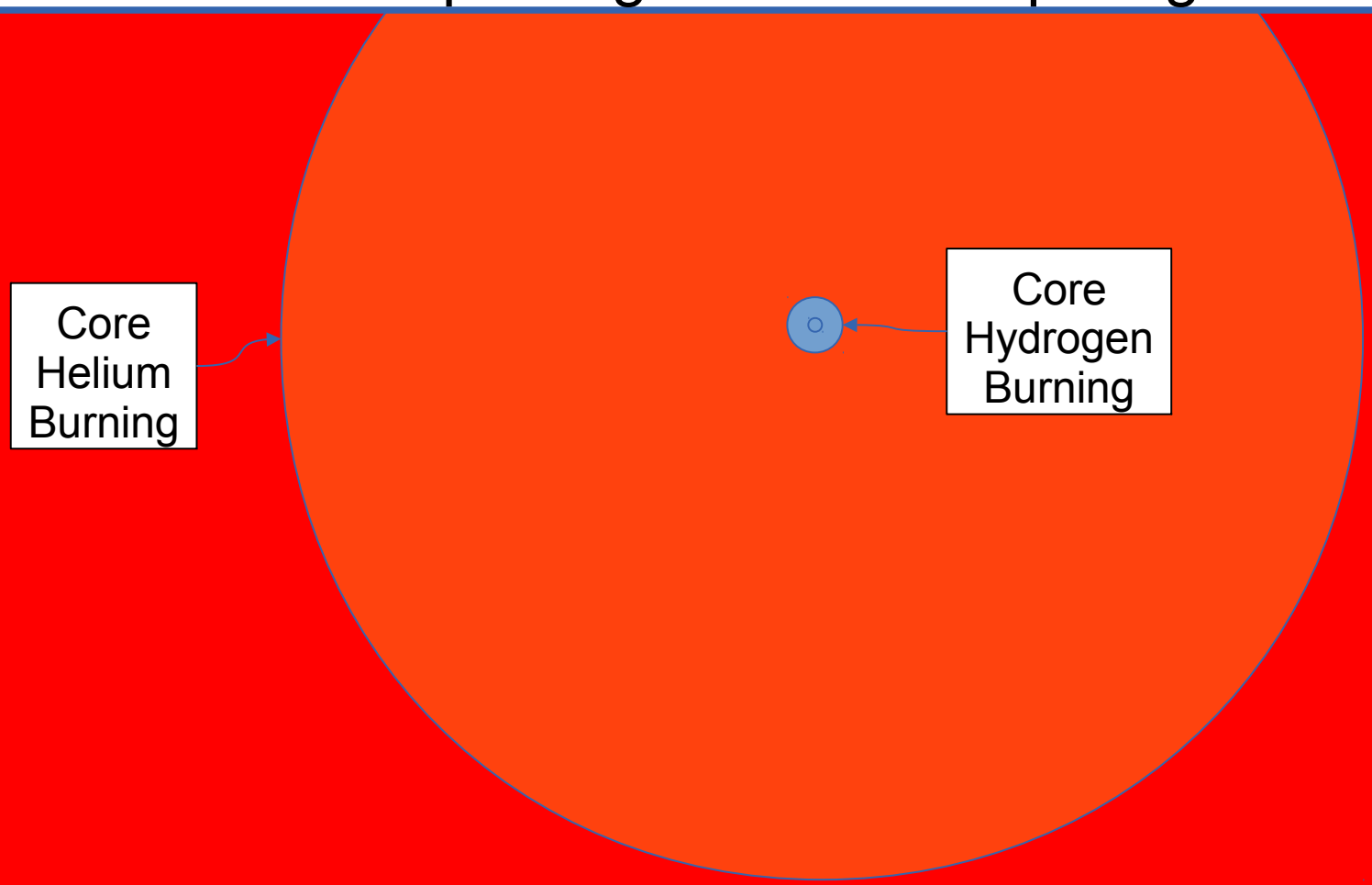
Selected binary astro-ers

- 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

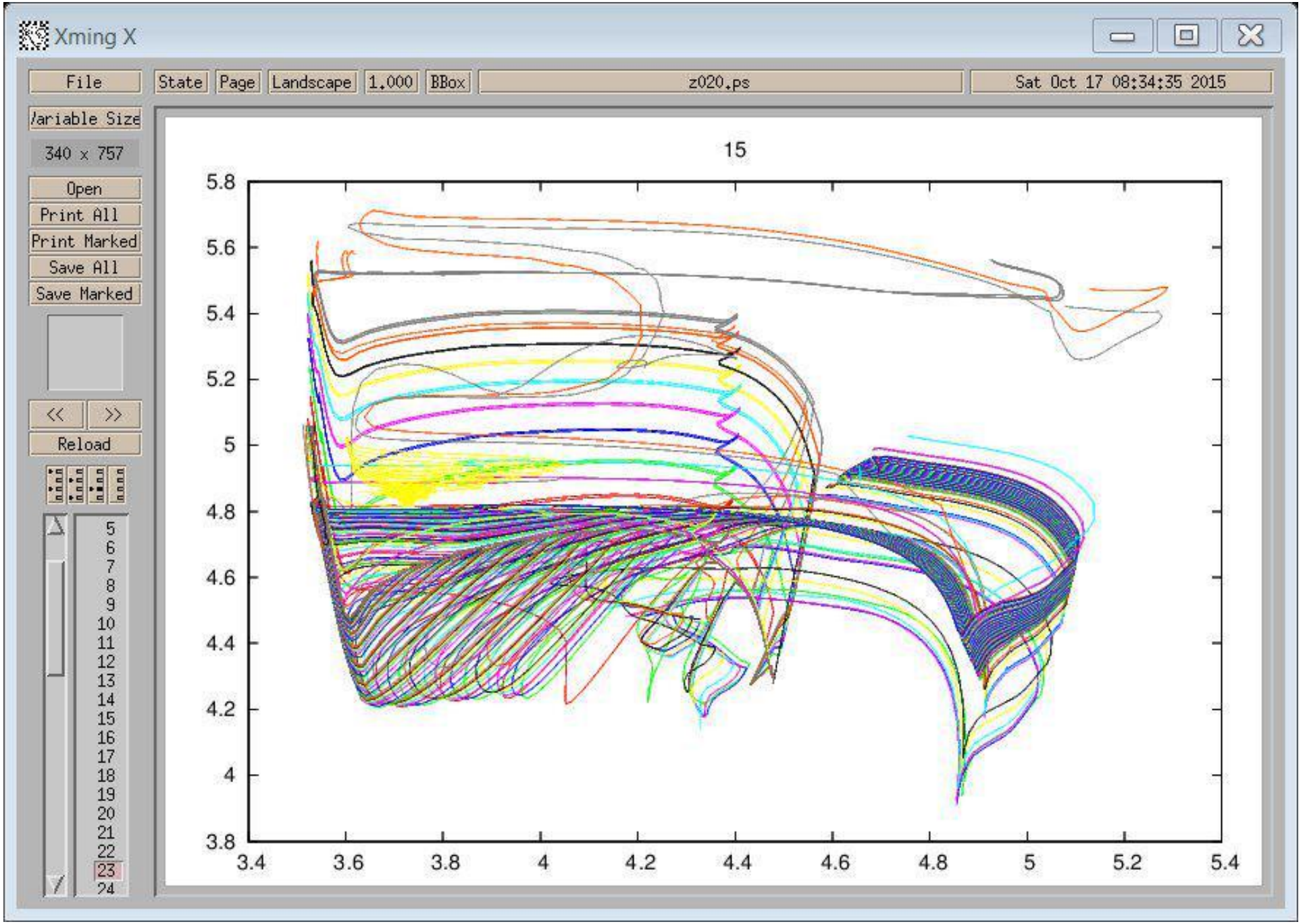
Some initial thoughts on binaries:

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 Æ”.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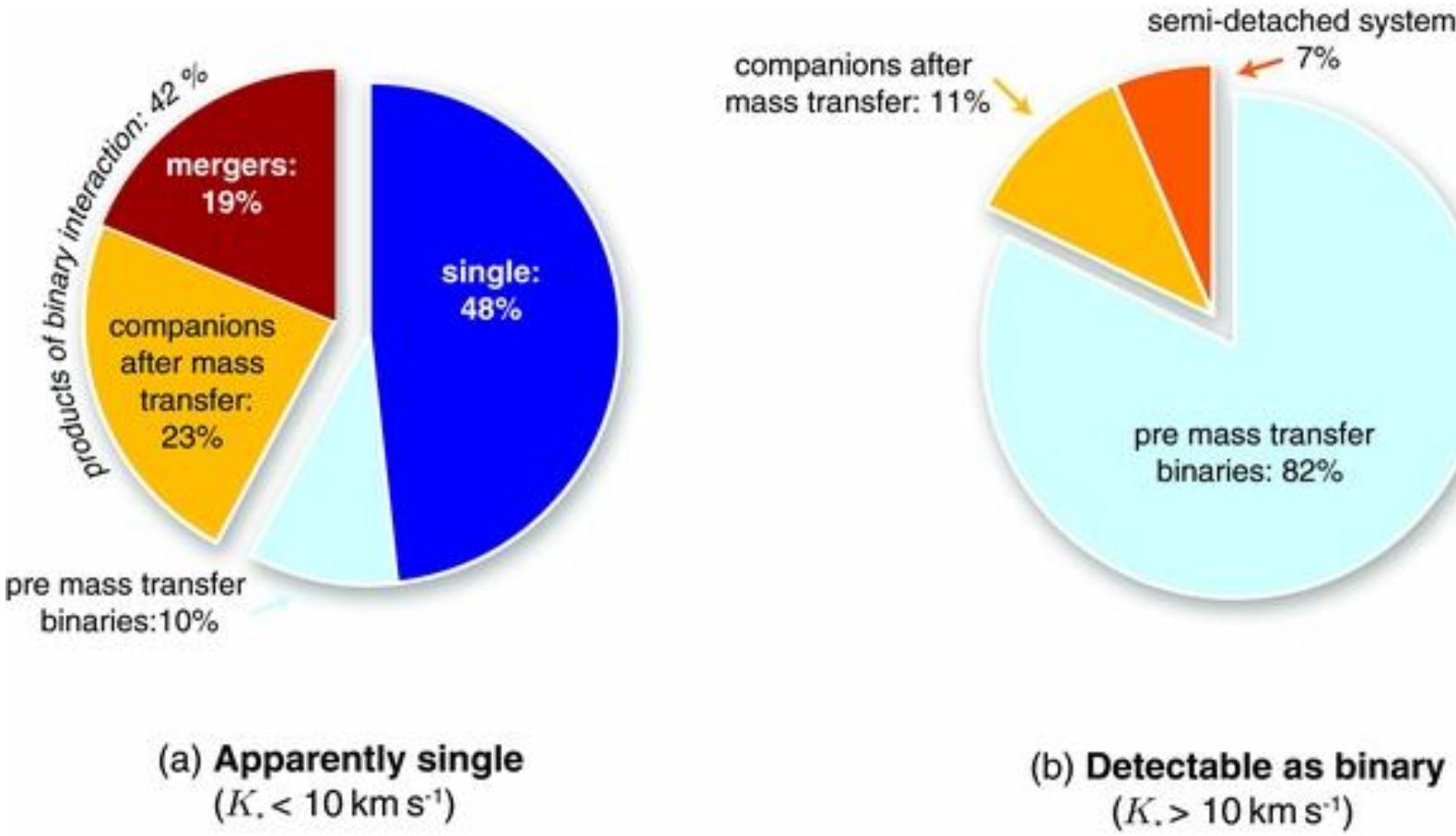
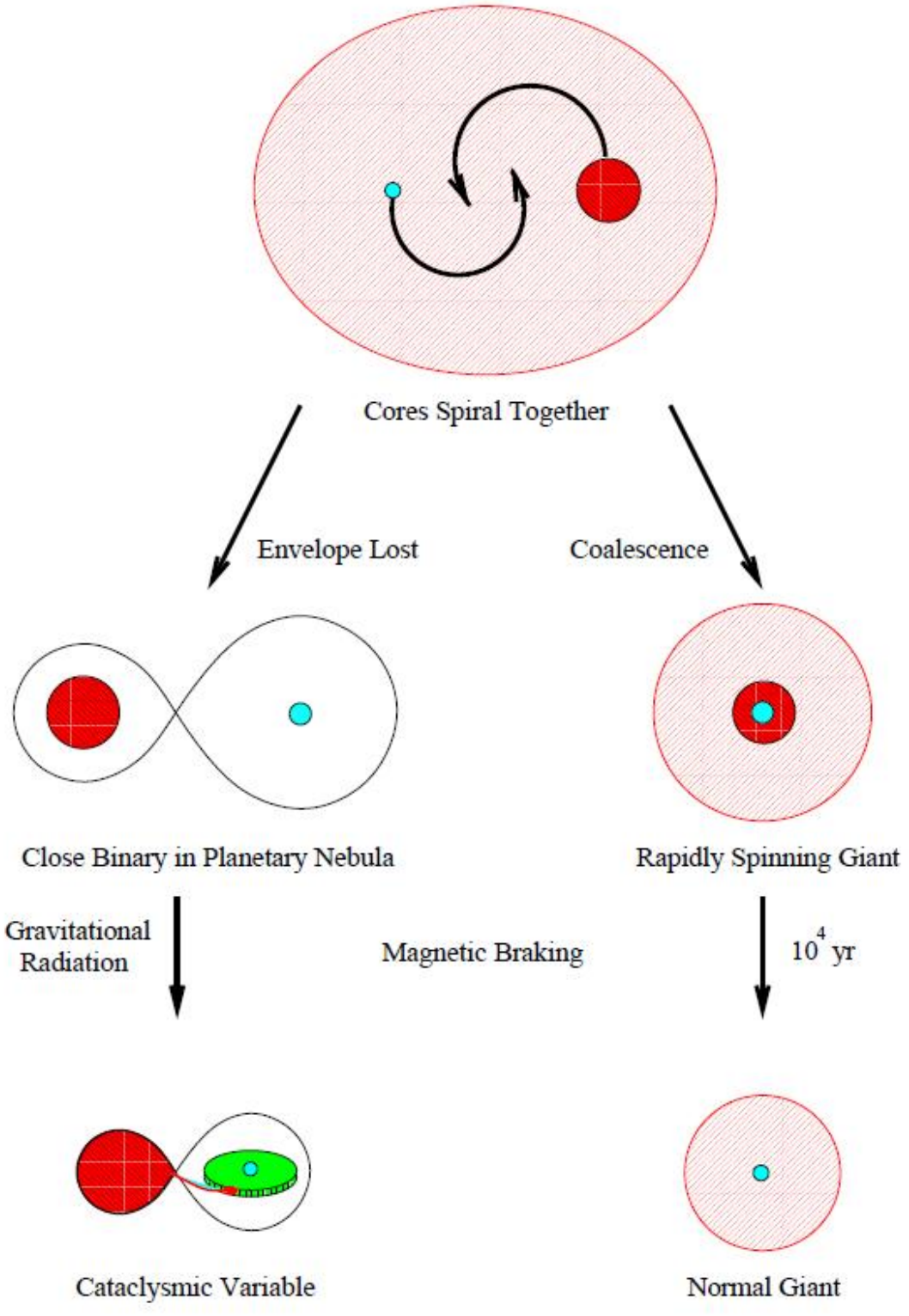
Lots of single stars are from binaries



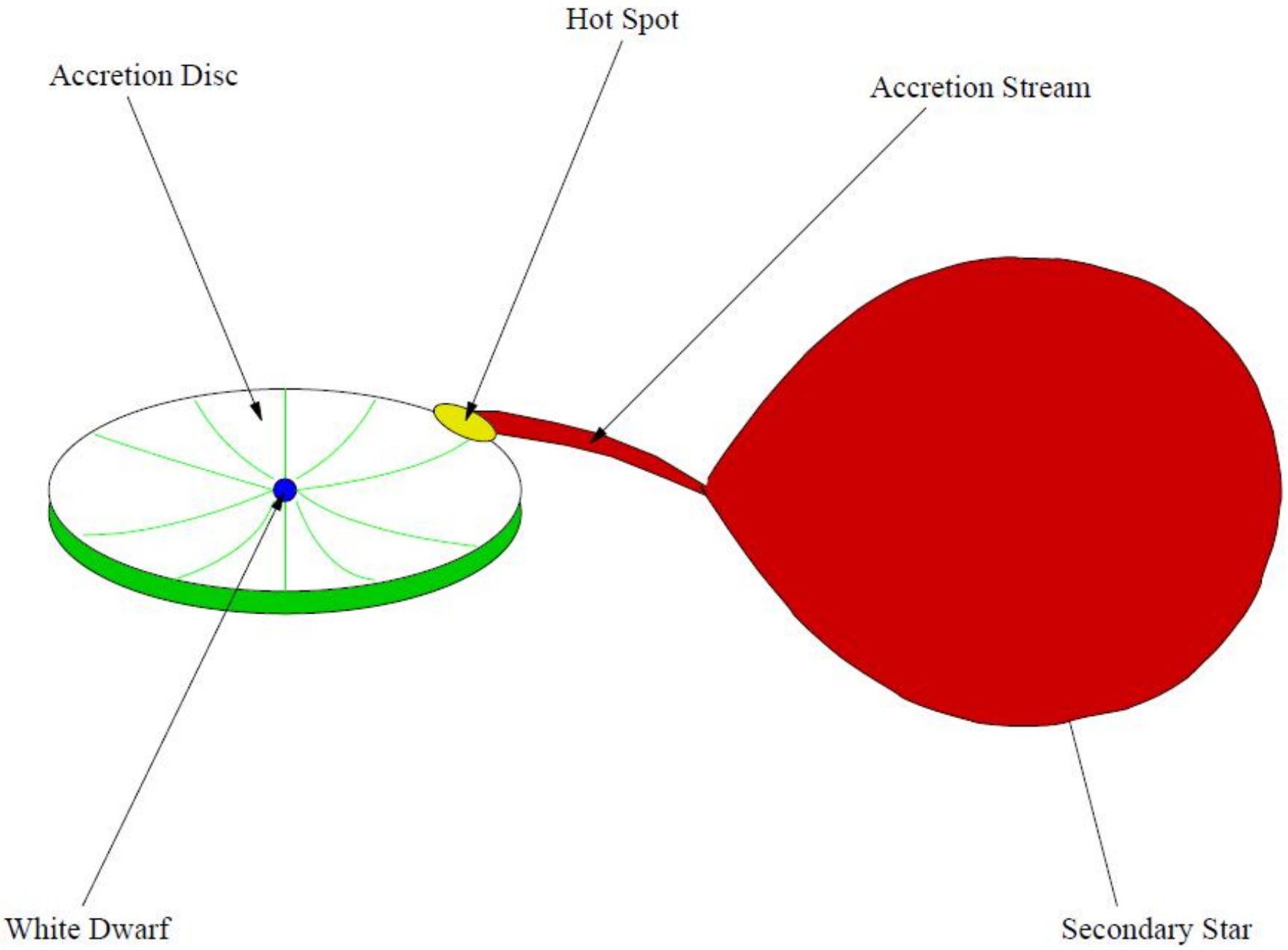
de Mink et al. (2013, 2014)

Common Envelope Evolution

the most uncertain phase of binary evolution.



Ivanova et al. (2012)



Cataclysmic Variable Star

Energy balance

$$E_{\rm bind} = \Delta E_{\rm orb} = E_{\rm orb,i} - E_{\rm orb,f} = -\frac{Gm_1m_2}{2a_{\rm i}} + \frac{Gm_{1,\rm c}m_2}{2a_{\rm f}}$$

$$\frac{m_1 m_{1,\rm env}}{\lambda R_1} = \alpha_{\rm CE}\left(-\frac{Gm_1m_2}{2a_{\rm i}} + \frac{Gm_{1,\rm c}m_2}{2a_{\rm f}}\right)$$

Or maybe angular momentum

$$\frac{\Delta J_{\rm lost}}{J_{\rm i}} = \frac{J_{\rm i} - J_{\rm f}}{J_{\rm i}} = \gamma\frac{m_{1,\rm e}}{m_1 + m_2}$$

Problem: α & γ are free parameters, the same for all events?

Ivanova et al. (2012)

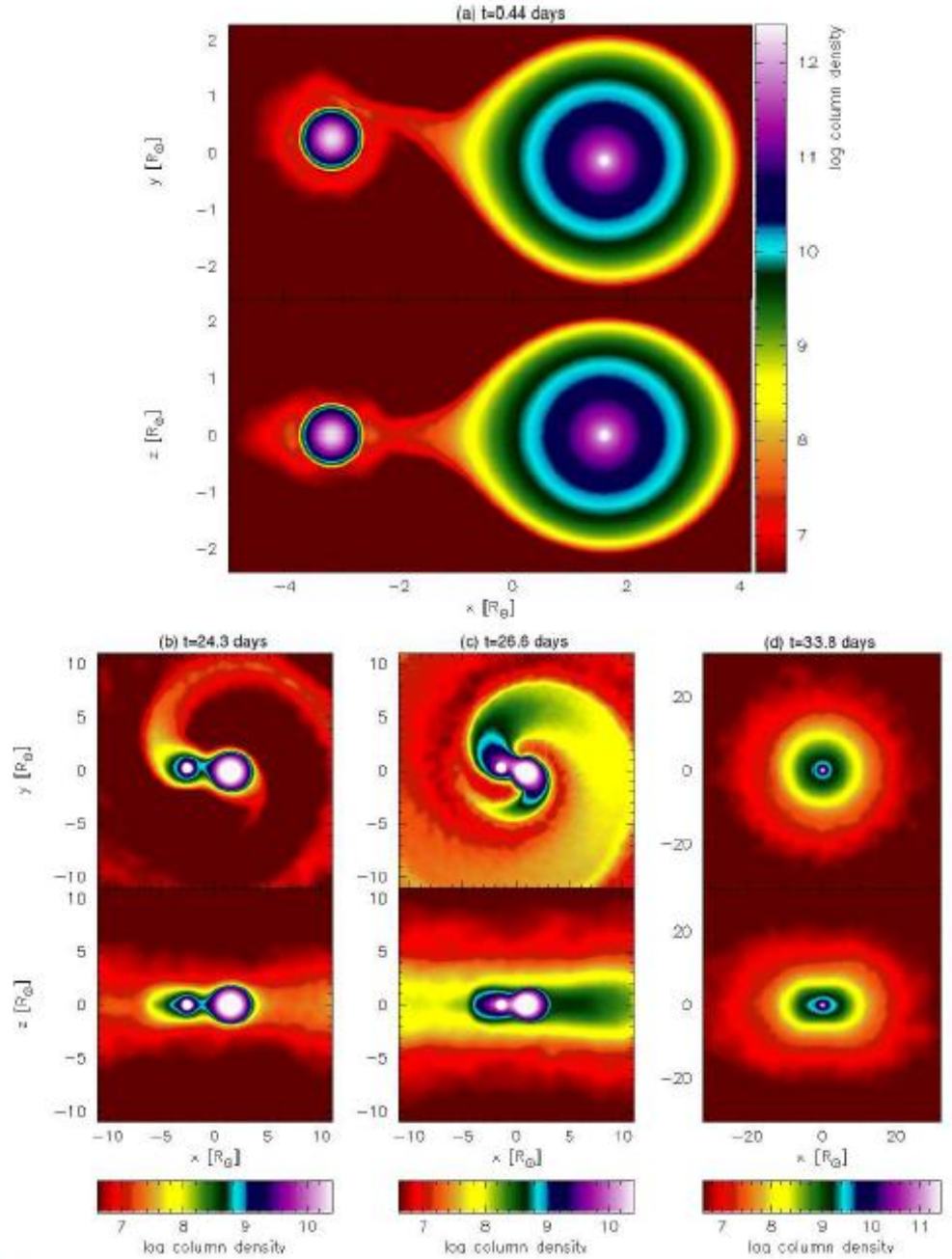
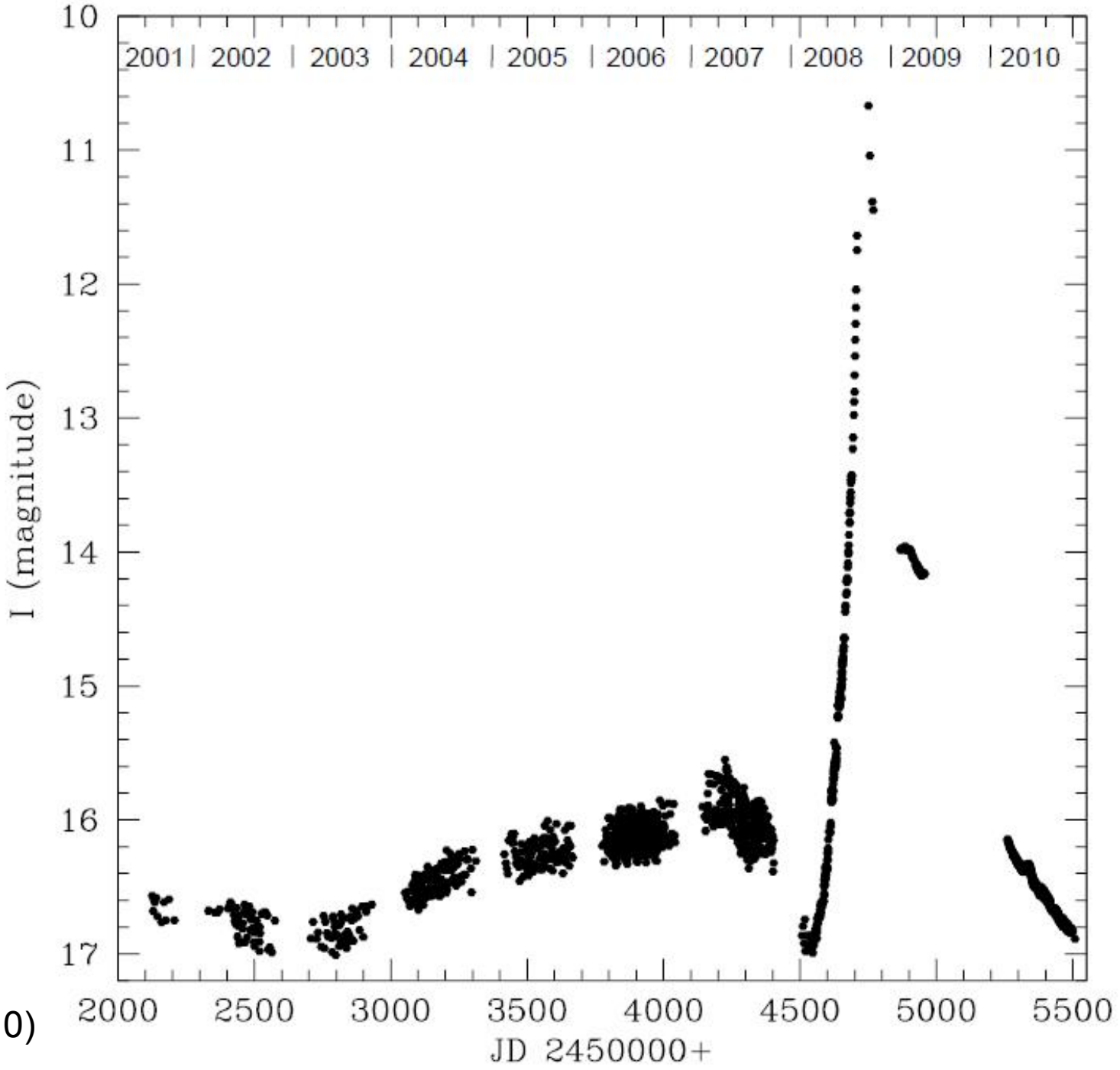


Fig. 3 Common envelope event with a $1.2M_{\odot}$ early giant and $0.6M_{\odot}$ MS star, resulting in a merger of two stars. Simulation performed for this review by J. Lombardi and R. Scruggs, simulated with 2.2×10^5 SPH particles. For more technical details on the code, see Gaburov et al. (2010) and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

Ivanova et al. (2012)



Tylenda+ (2010)

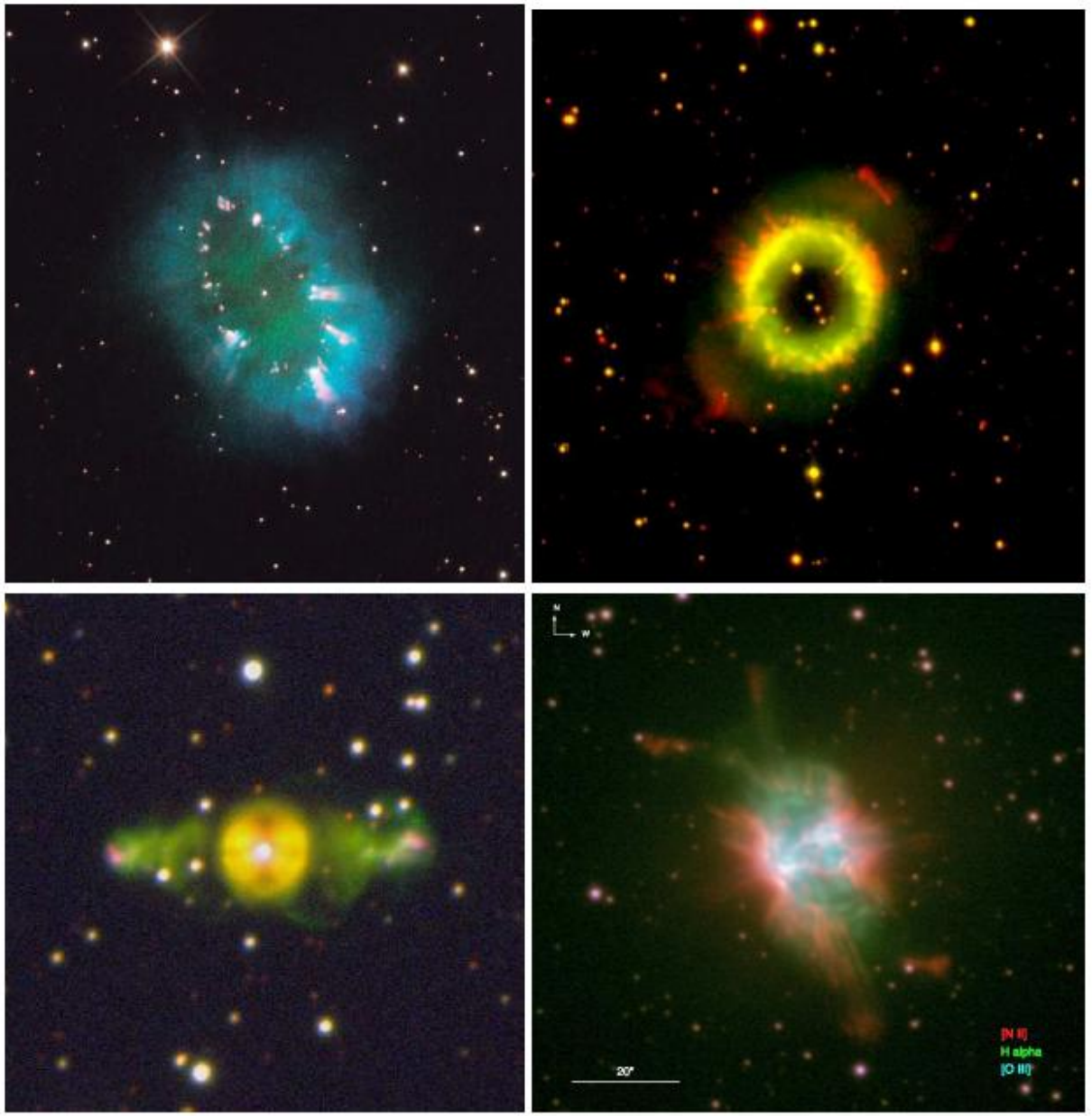
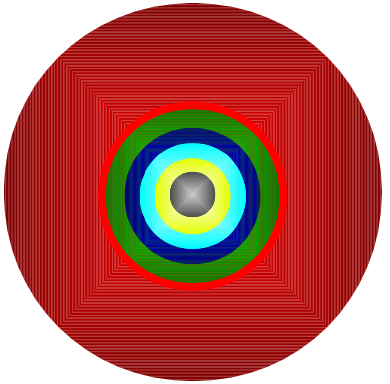


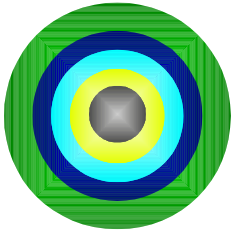
Fig. 6 Post-CE planetary nebulae with known compact binaries as central objects. Top left – Necklace Nebula (image credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA), for details see Corradi et al. (2011)); top right – NGC 6337 (credit to Corradi, for more details see Corradi et al. (2000)); 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))

Ivanova et al. (2012)

SNe in Binaries

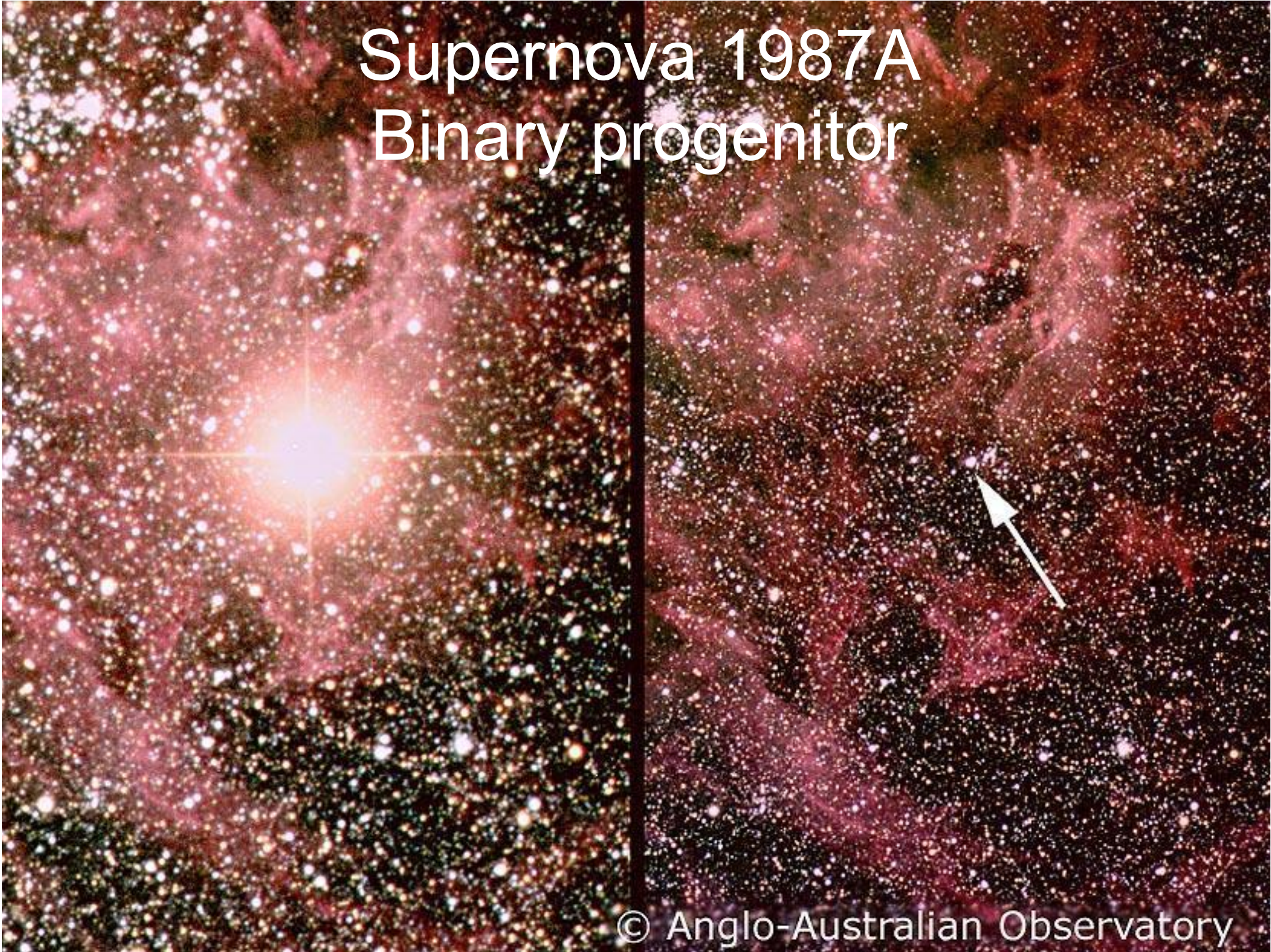
Evidence for binaries?
Relative supernova rates

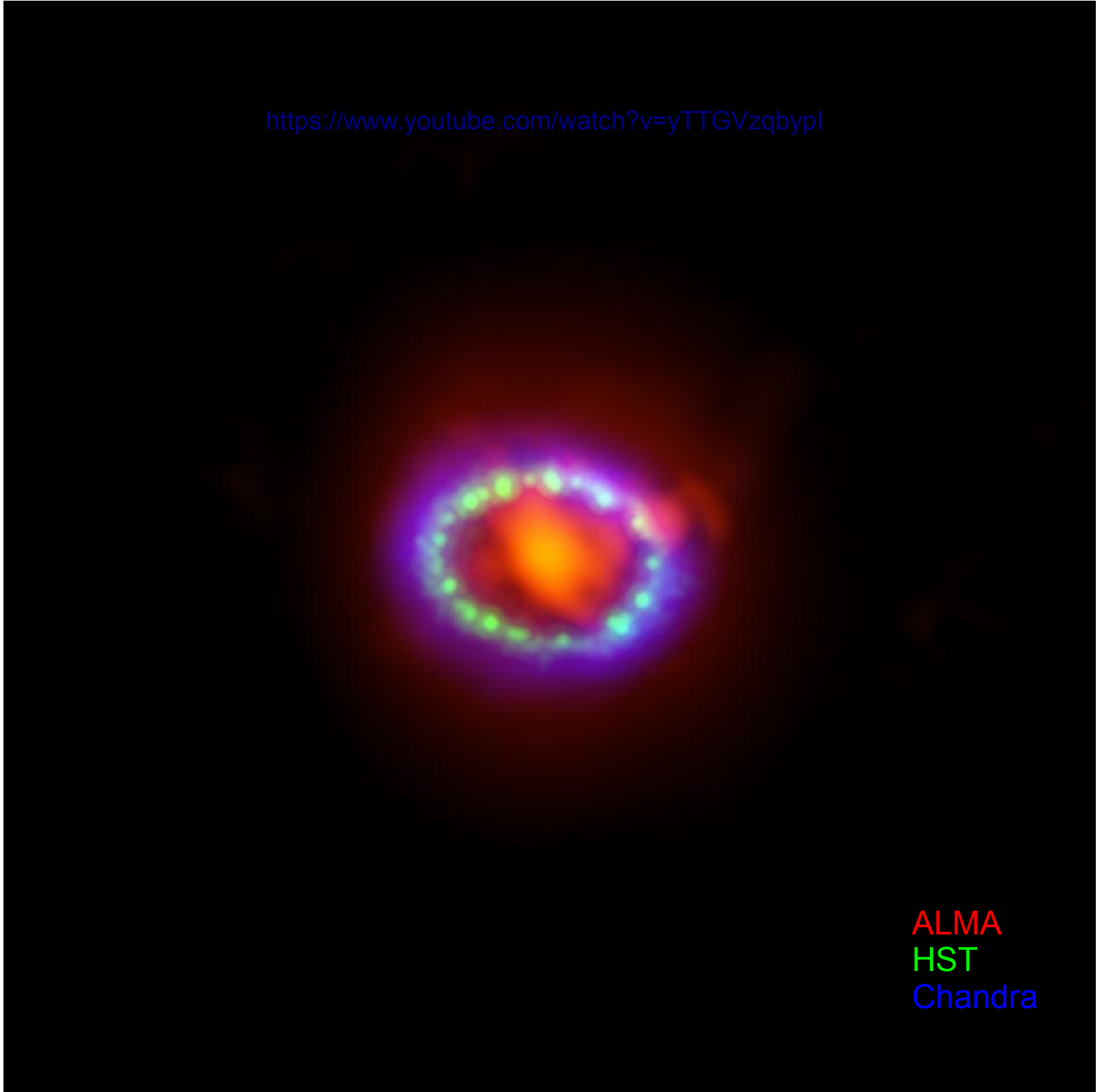




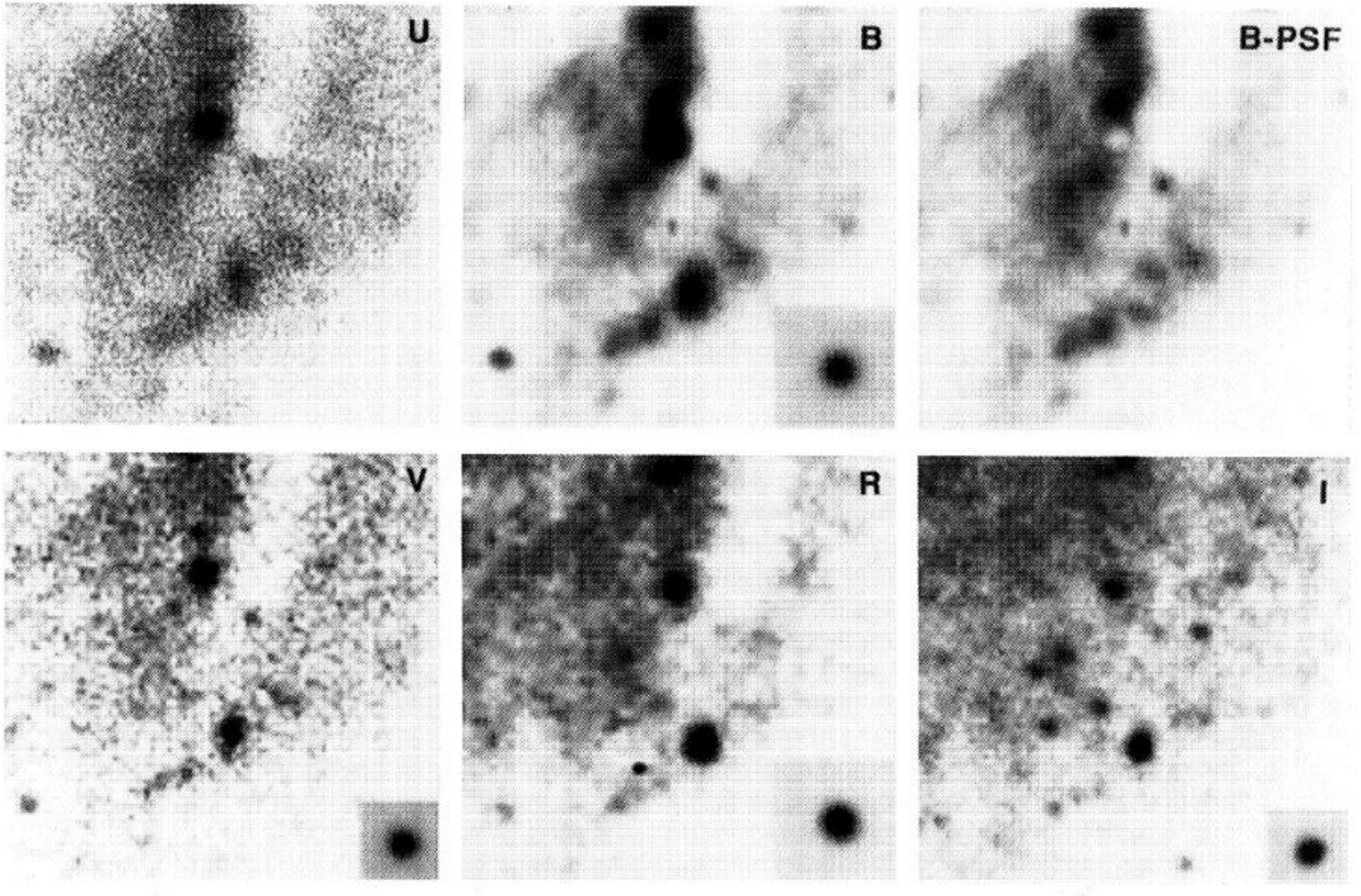
Supernova	Type II	Type Ib/c
Observations	71±9%	29±6%
Single stars	85%	15%
Mix	71%	29%
Binaries	63%	37%

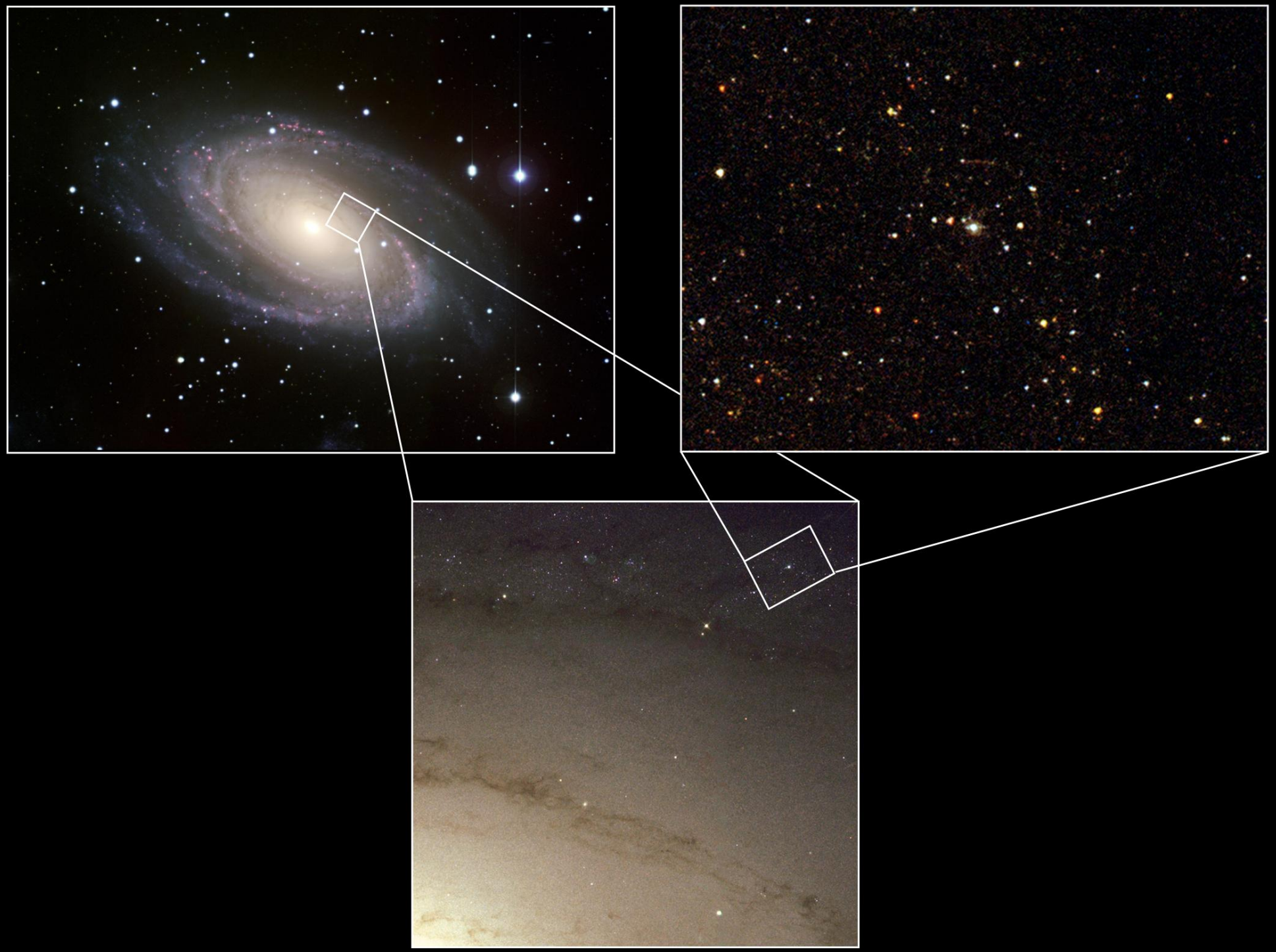
Eldridge+ (2008, 2013), Smith+ (2011), Podsiadlowski+ (1992)

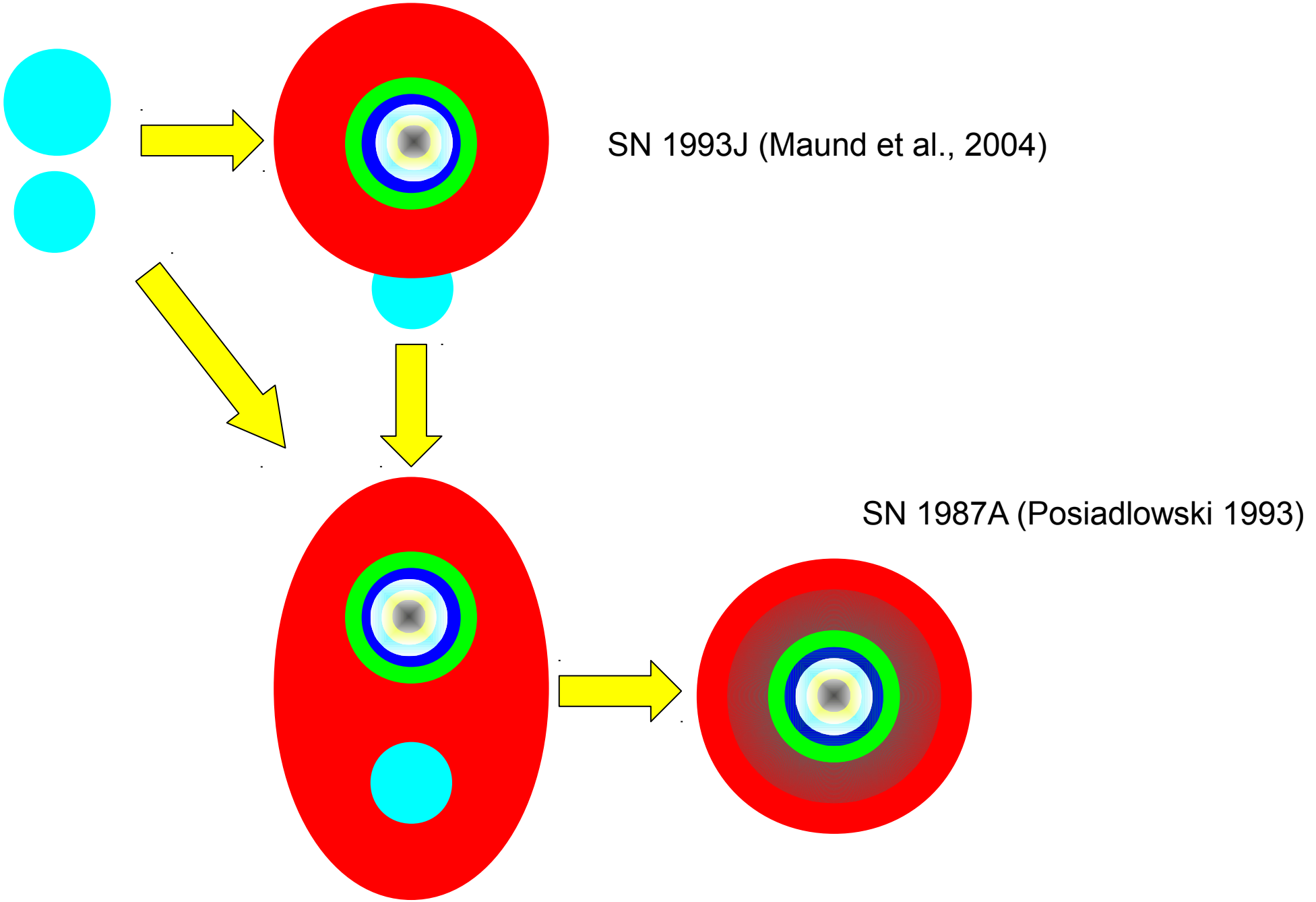

Supernova 1987A
Binary progenitor
© Anglo-Australian Observatory


https://www.youtube.com/watch?v=yTTGVzqbypI
ALMA
HST
Chandra

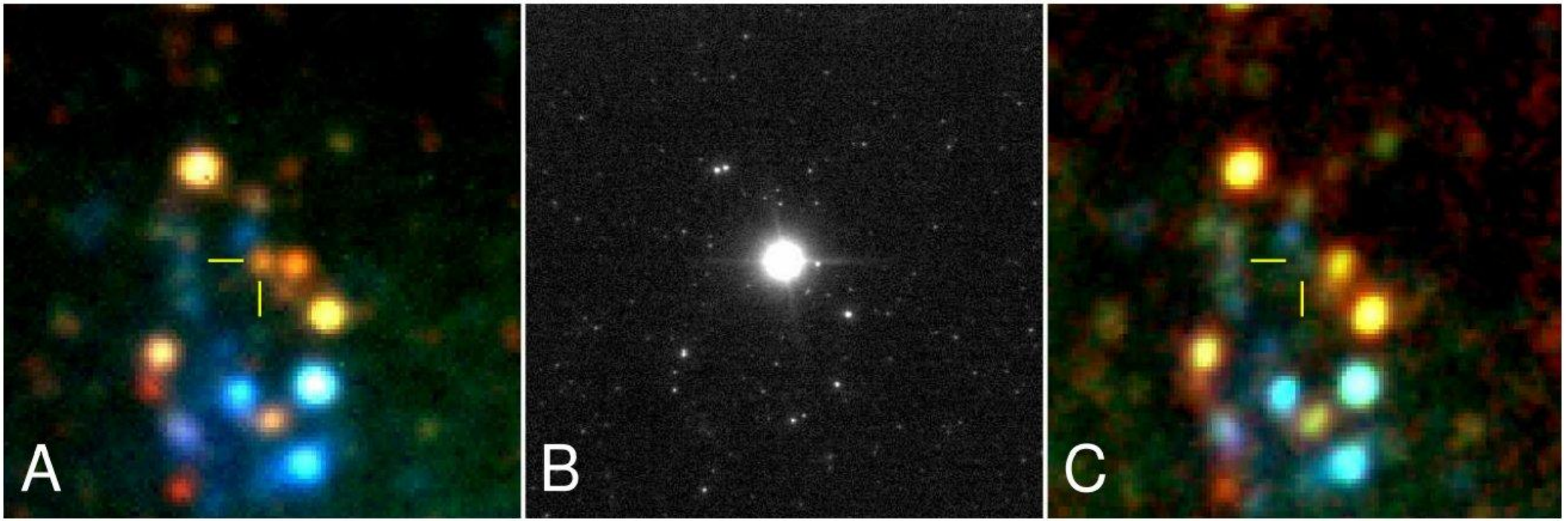
Supernova 1993J
Binary progenitor





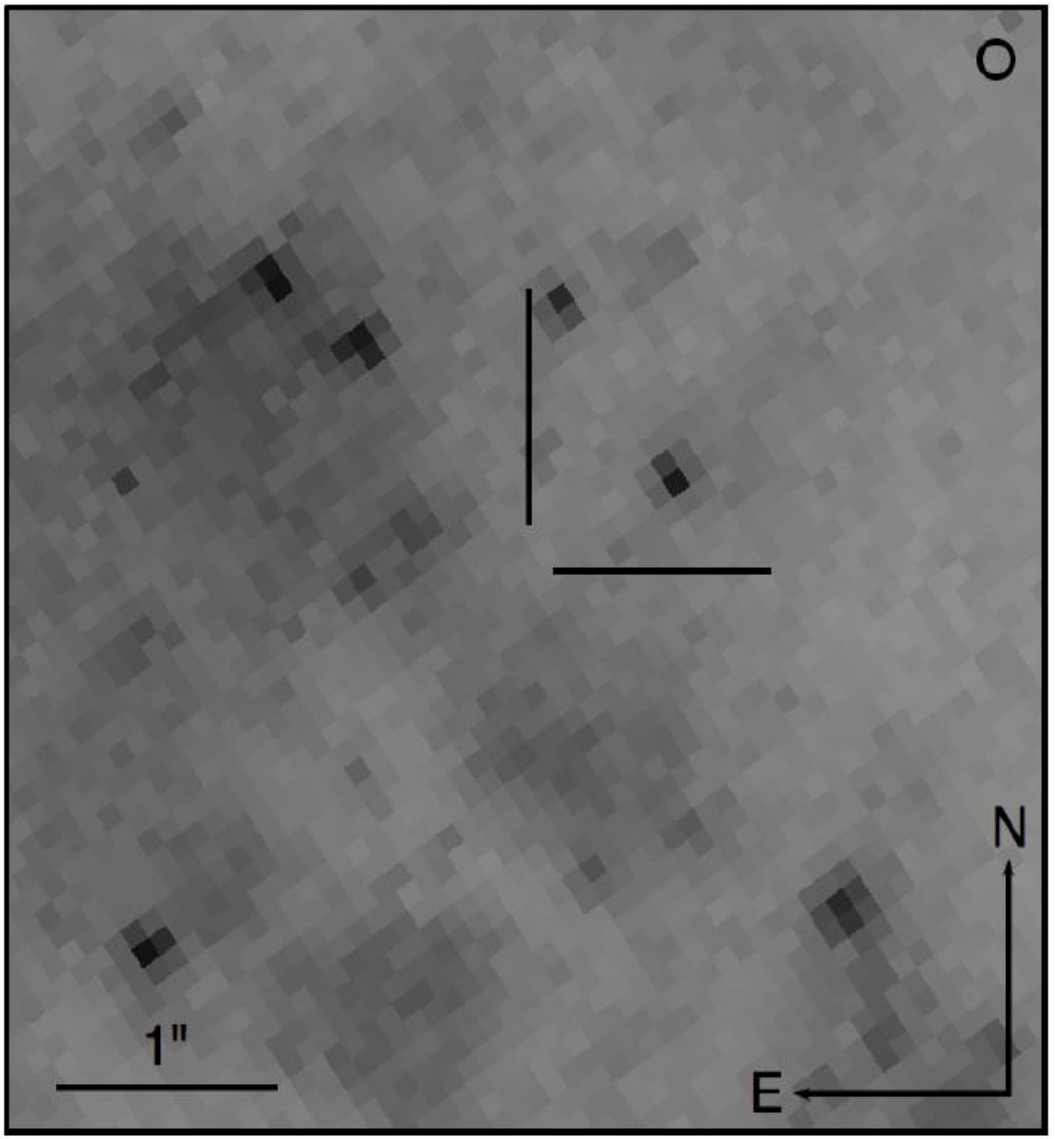

SN 1993J (Maund et al., 2004)
SN 1987A (Posiadlowski 1993)

Type IIP Supernova 2008bk



Mattila et al. (2008)

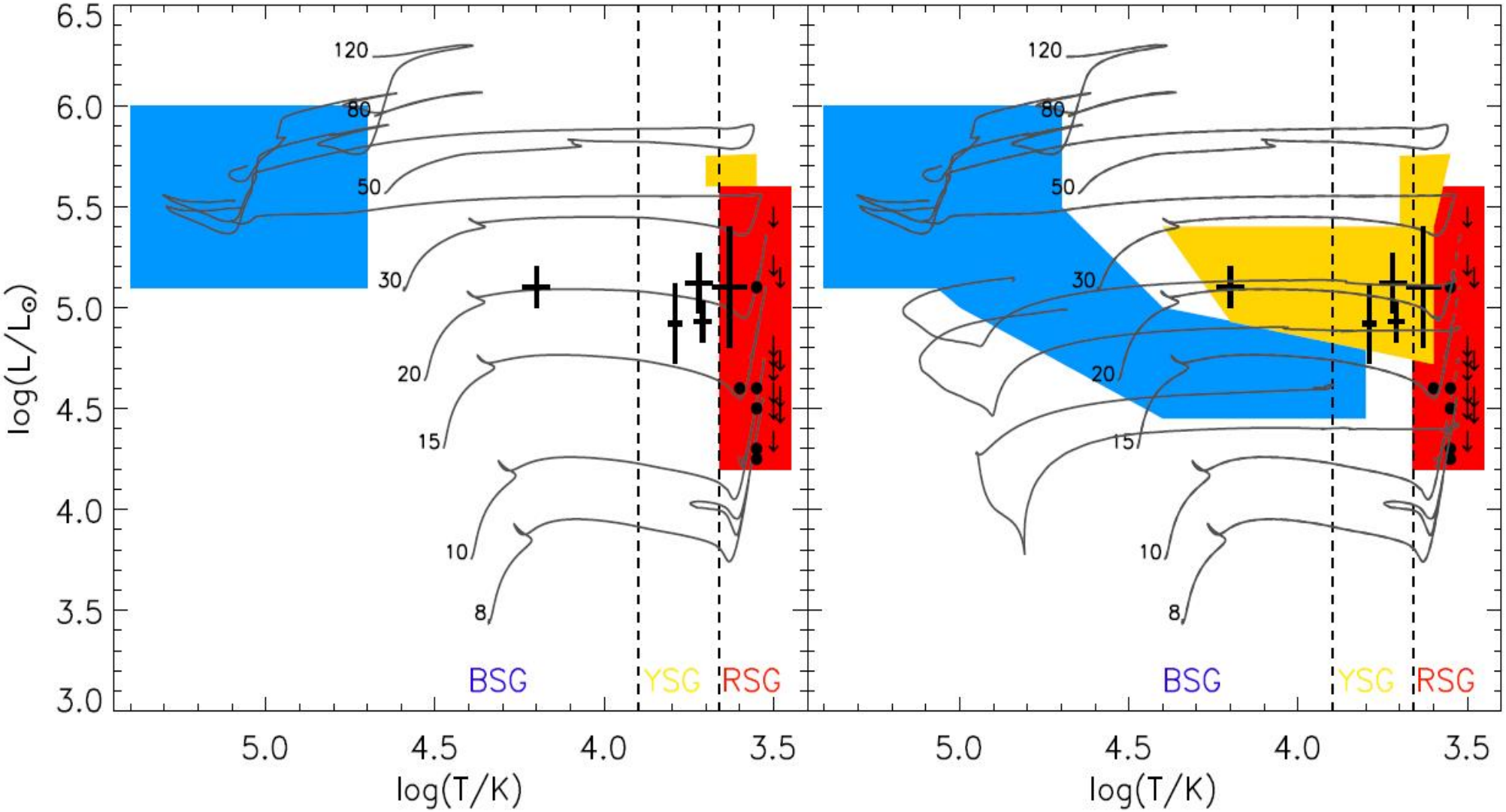
No detections for most type Ib/c SNe



Eldridge et al . (2013)

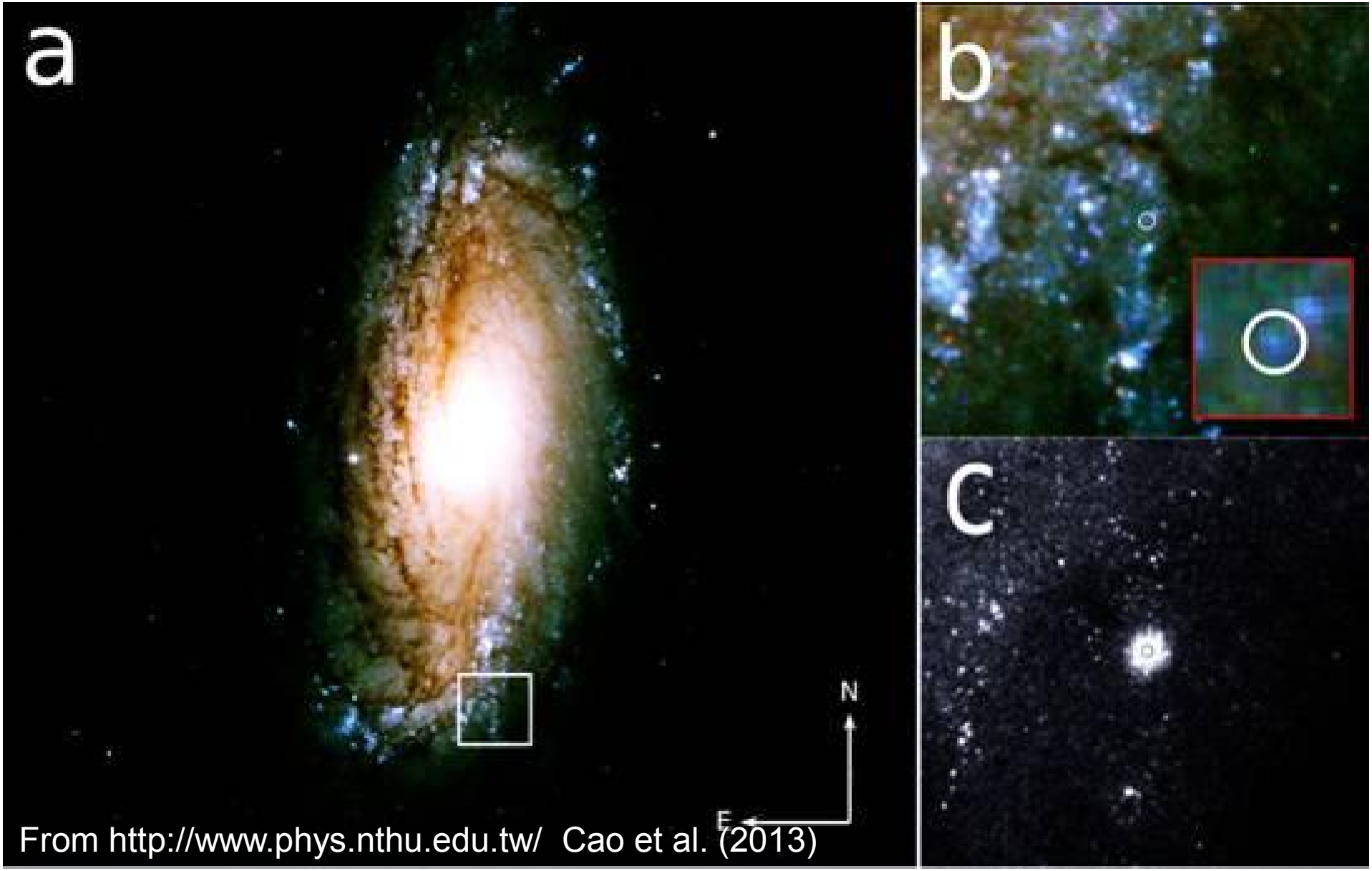
Single stars

Binaries



Eldridge et al . (2013)

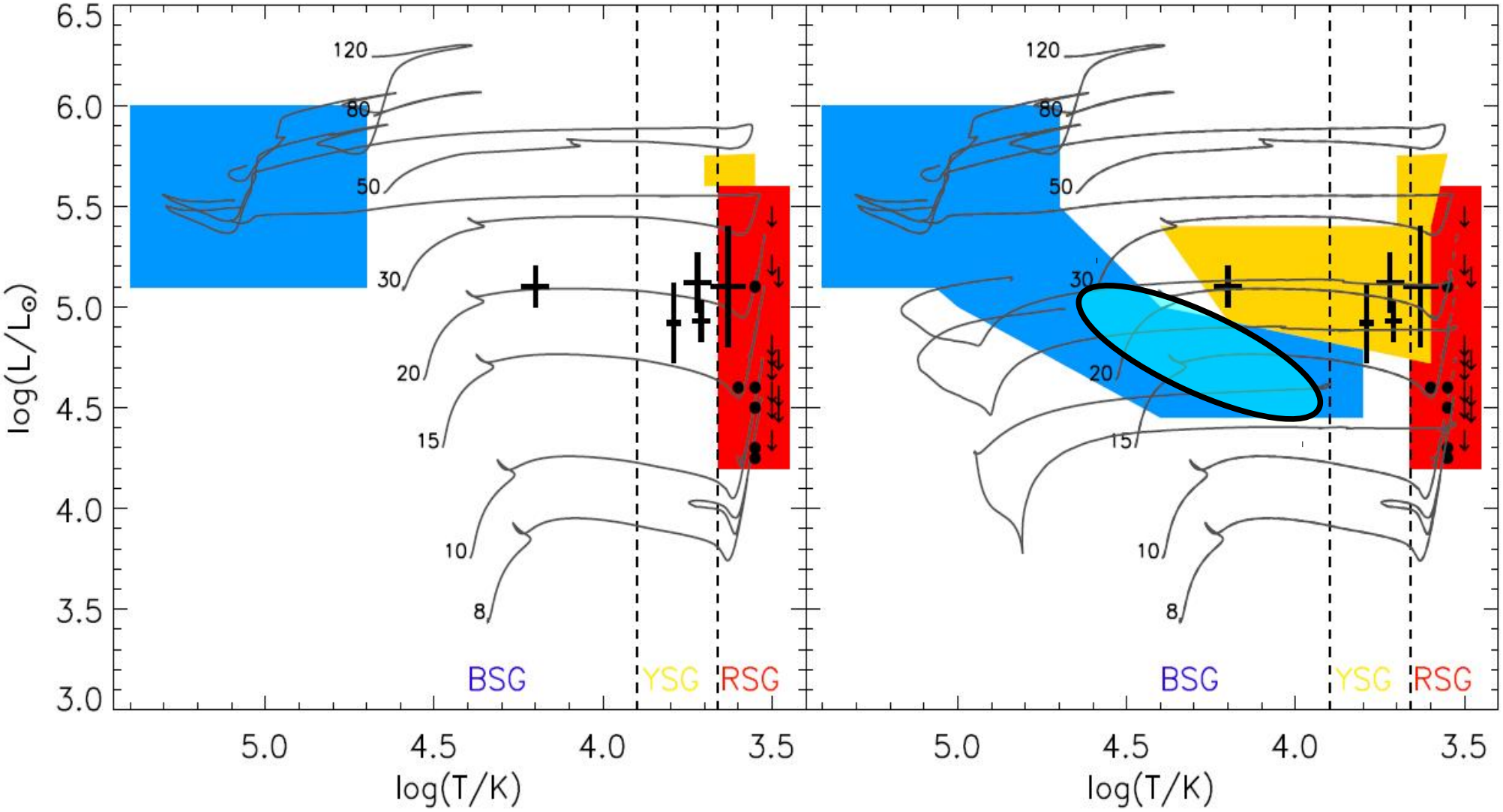
Type Ib SN iPTF13bvn



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

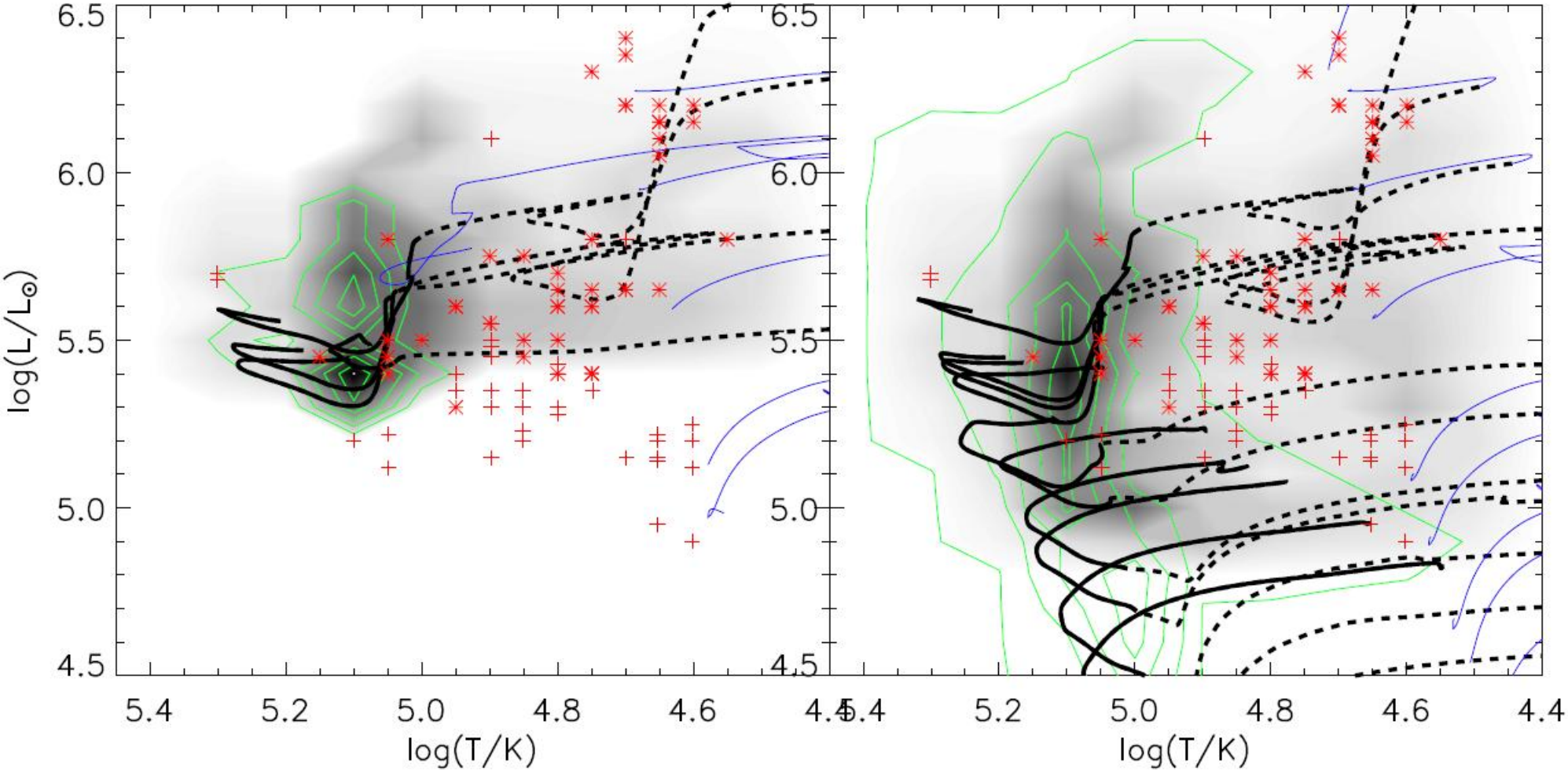
Single stars

Binaries



Eldridge et al. (2013)
See also Yoon (2015)

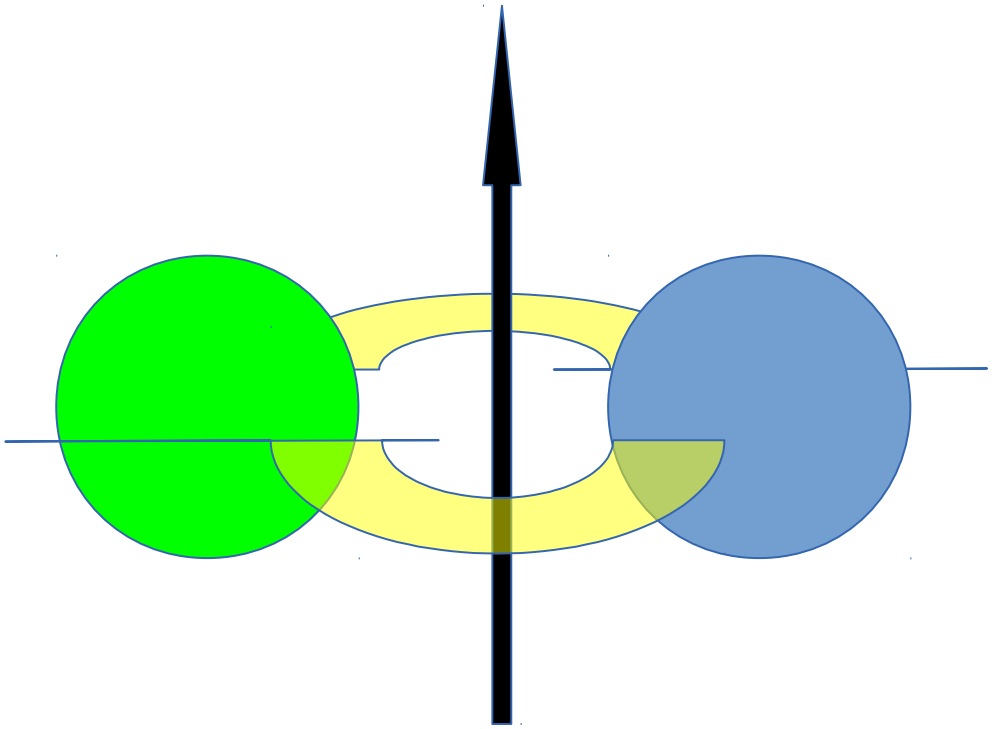
Predicted location of WR stars?

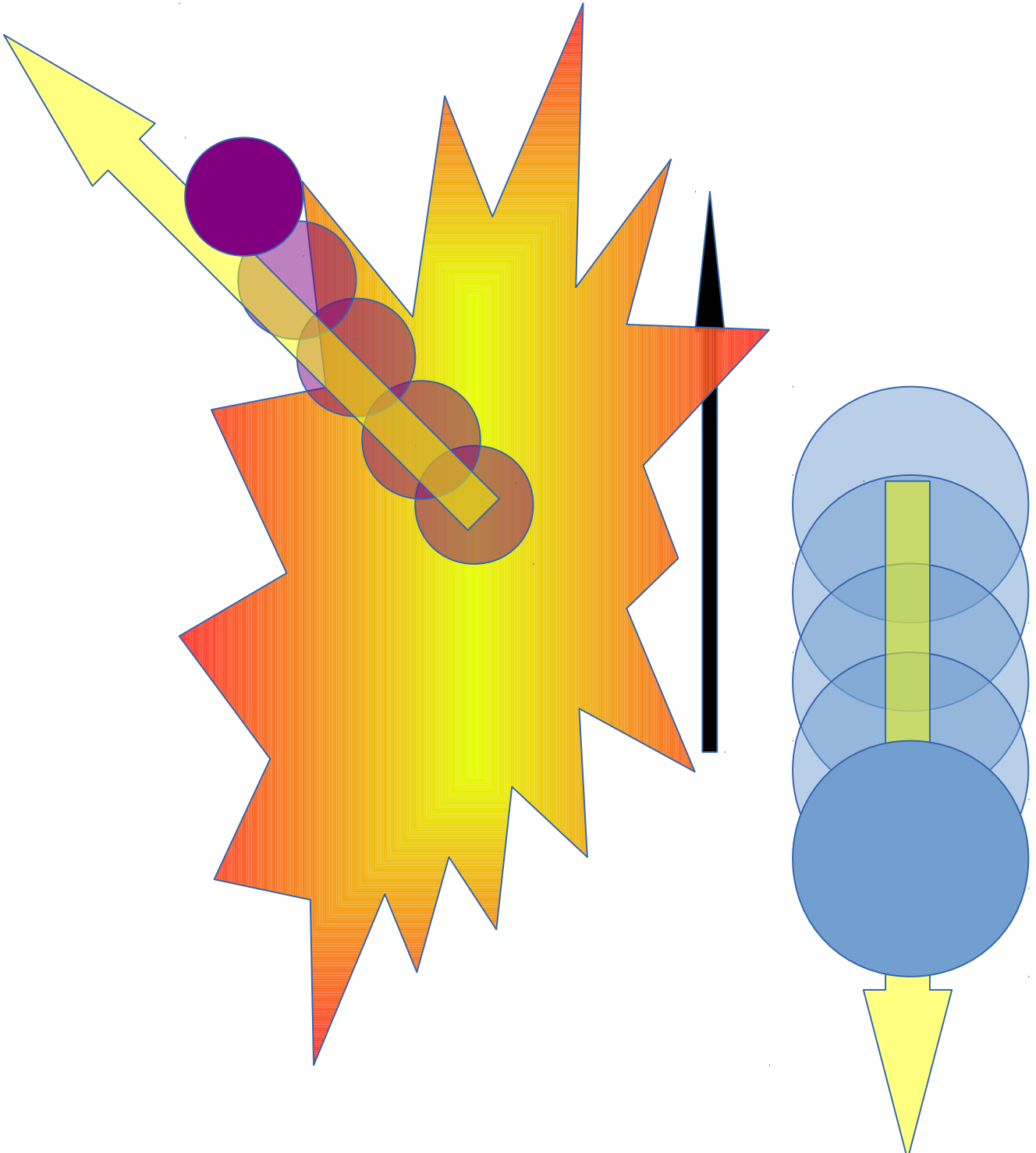


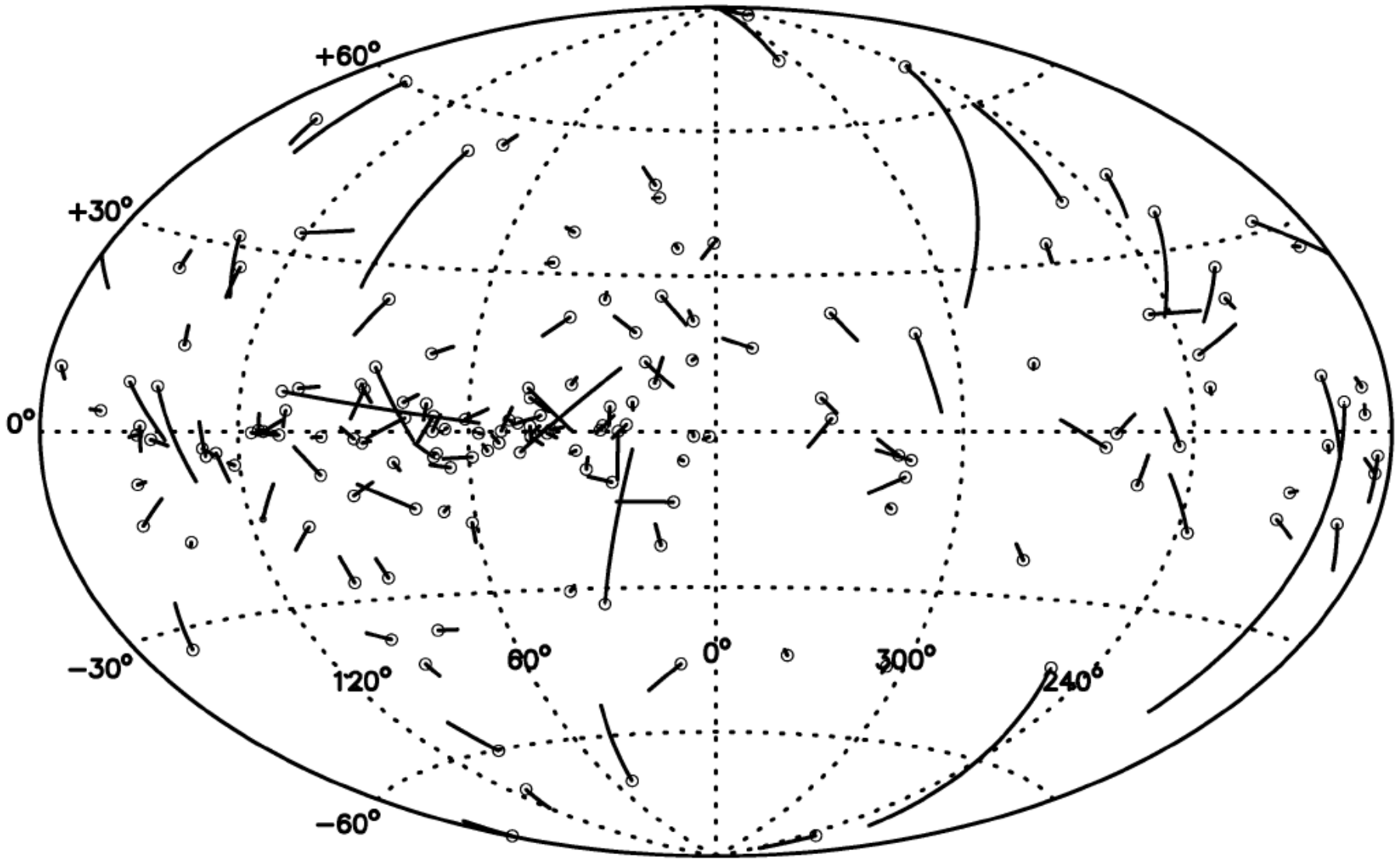
Eldridge et al . (2013)

Post-SN Binaries

What happens to a binary after the first supernova?

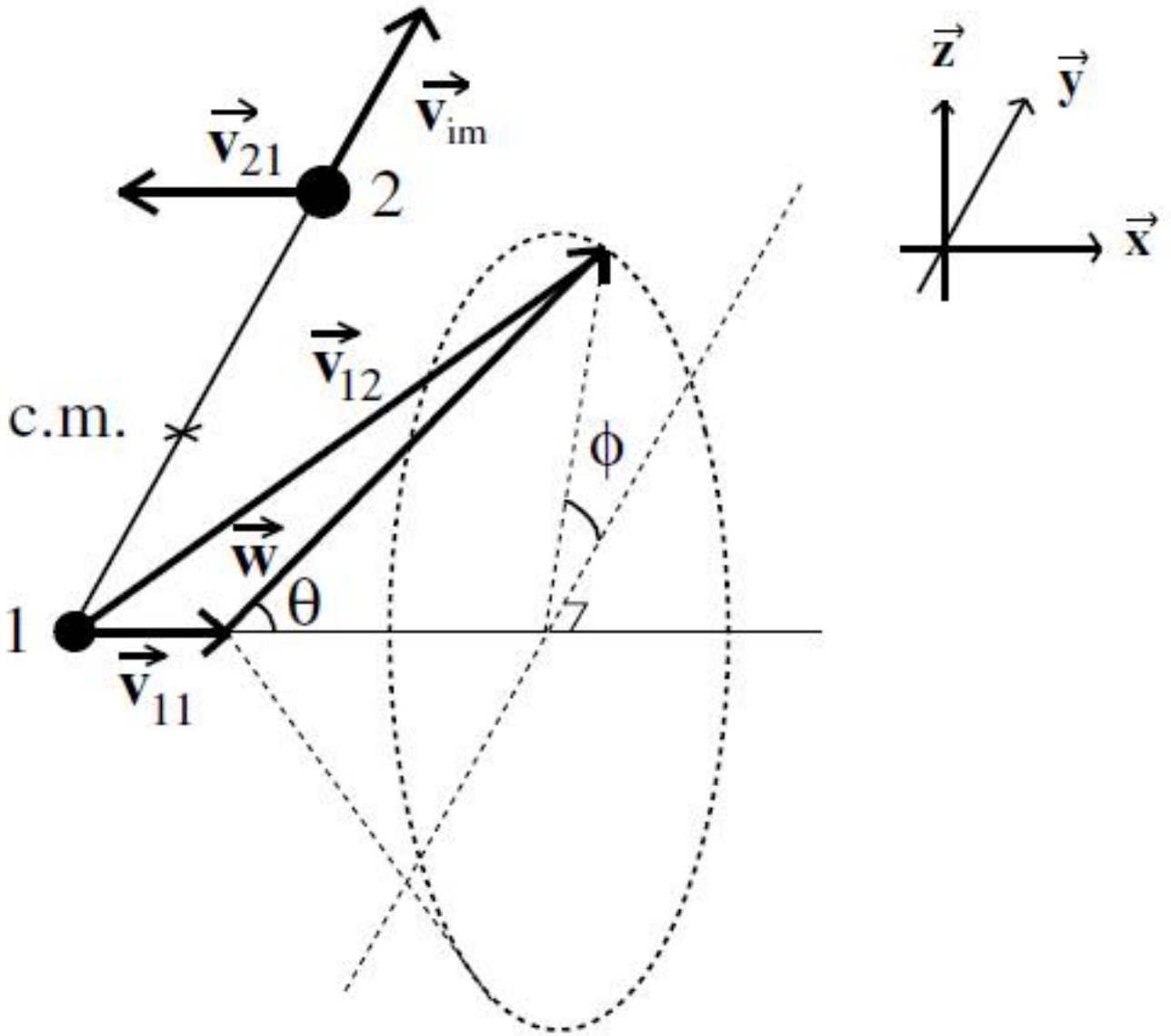






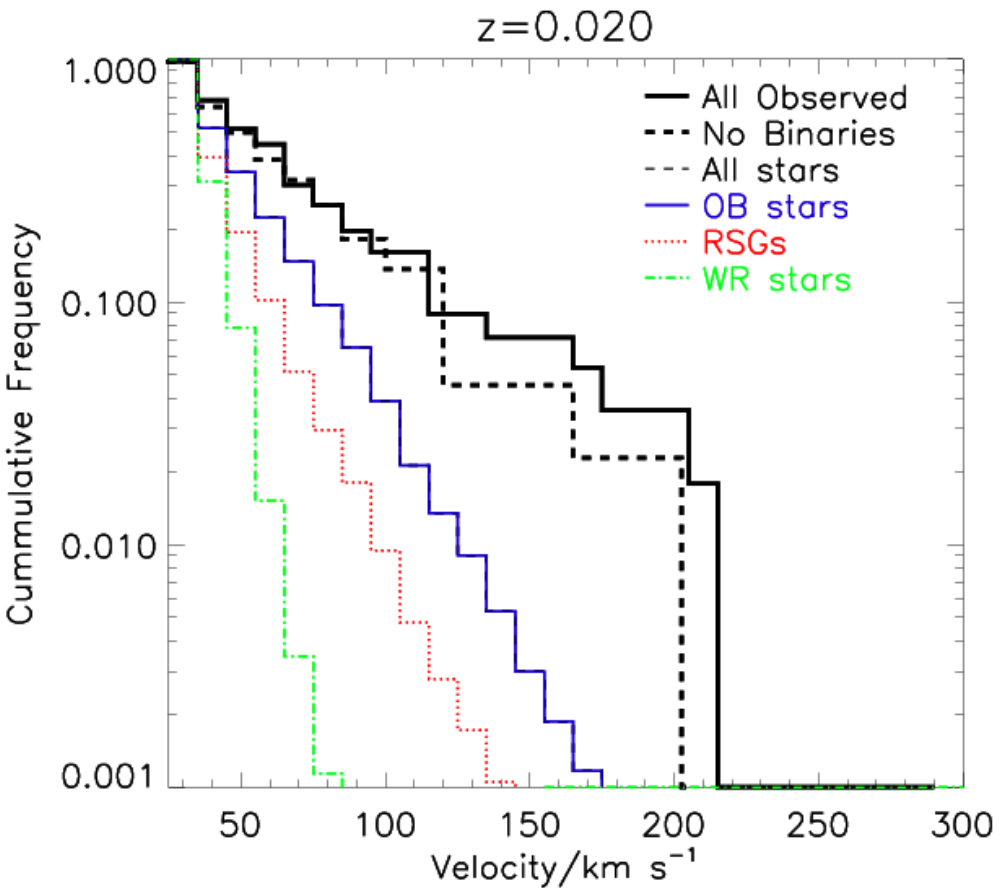
Hobbs et al. (2005)

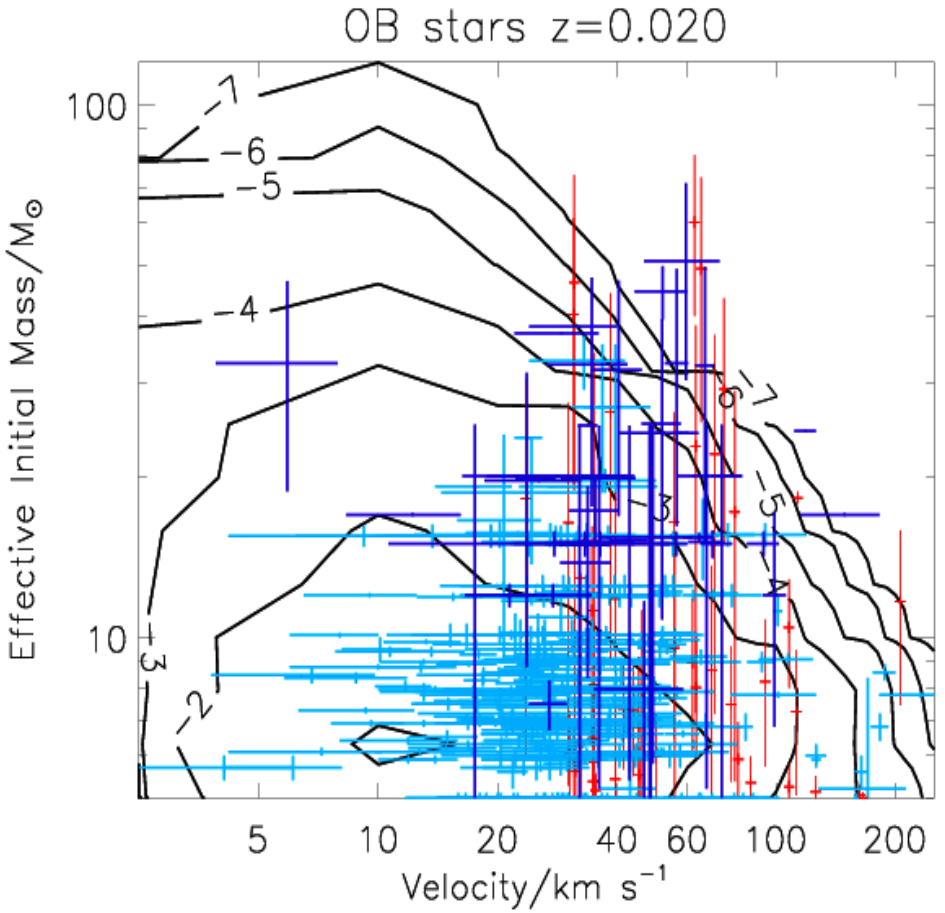
Supernova kicks



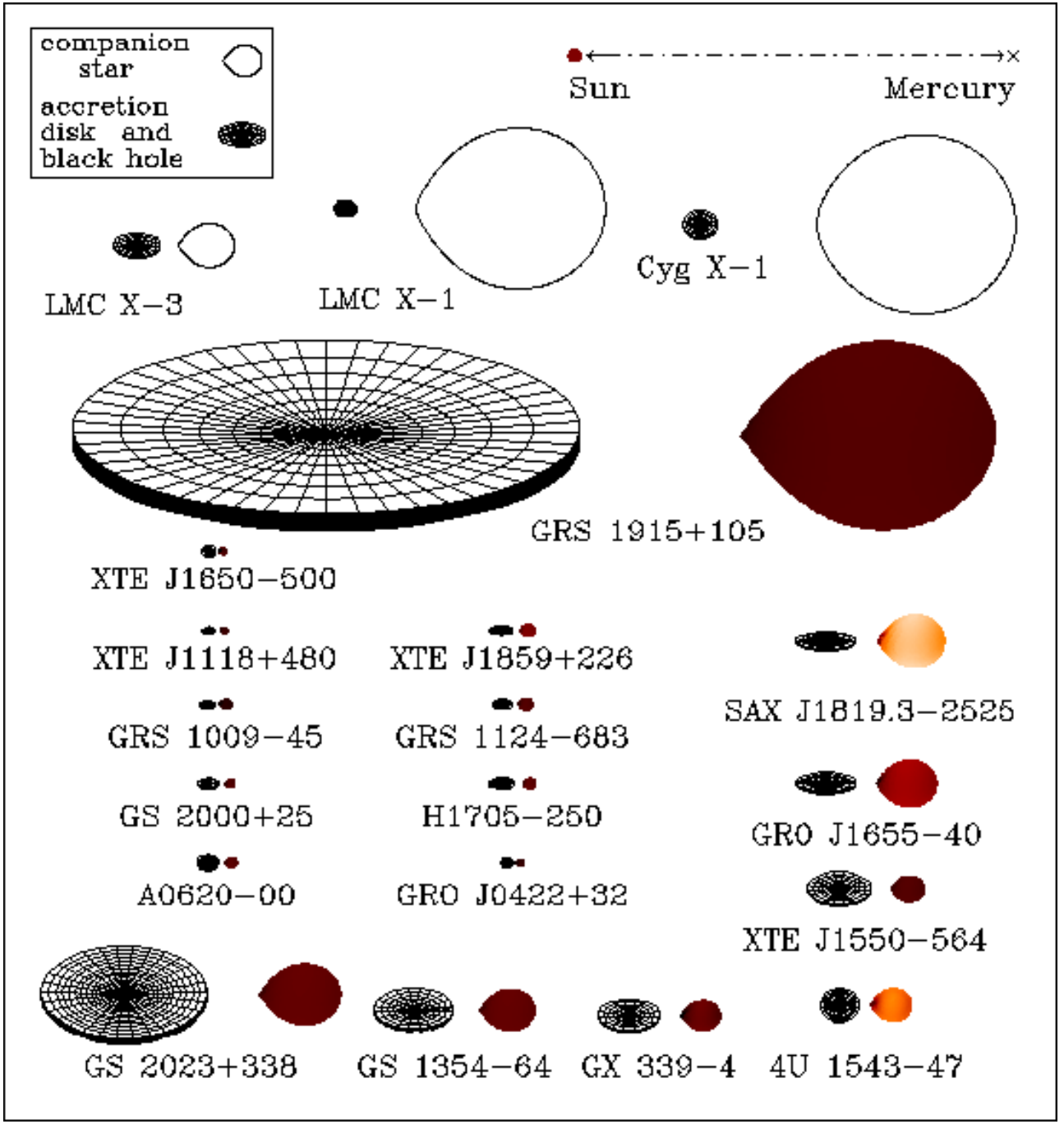
Result is all about energy

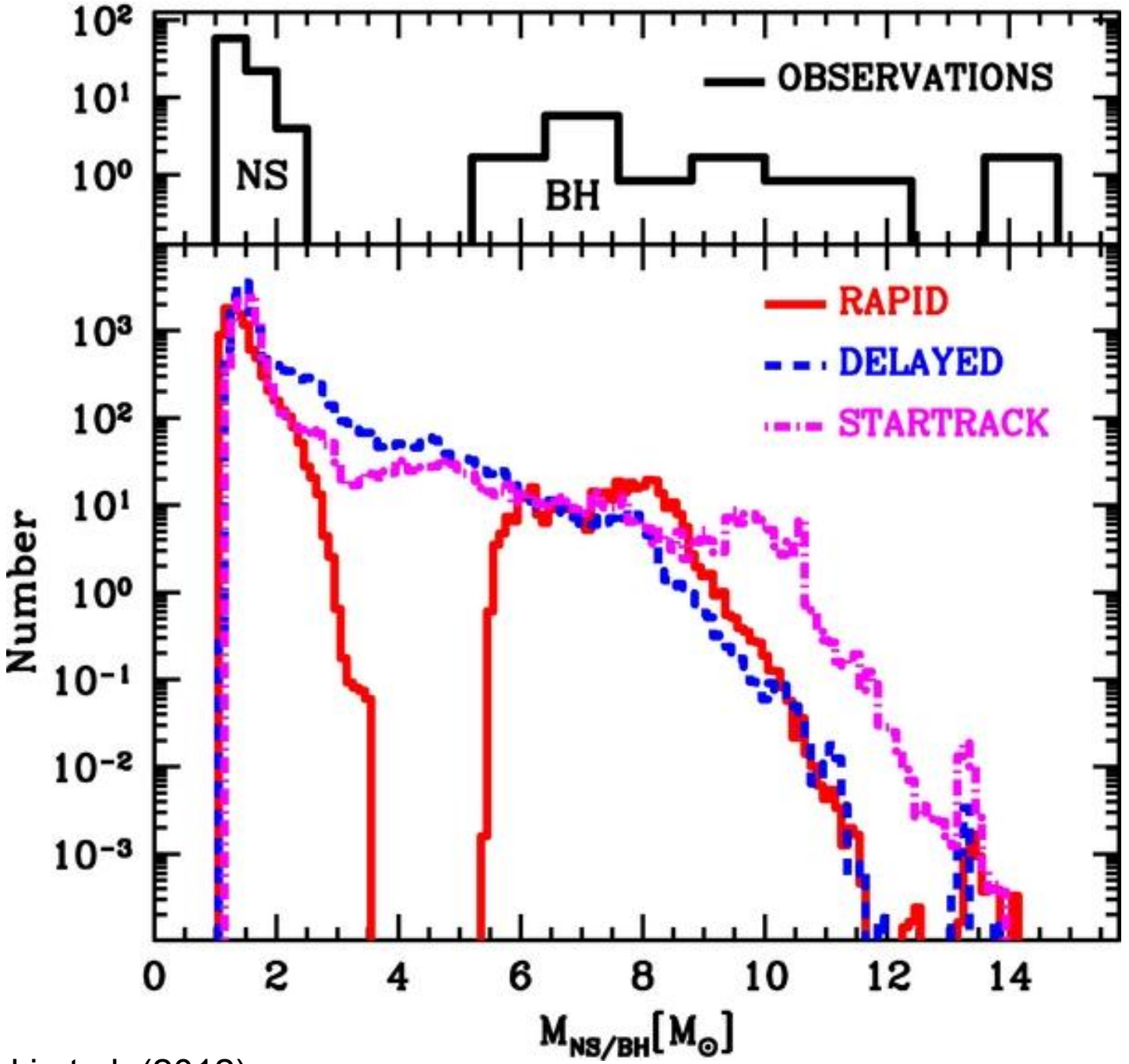
- Simple proof that if more than half the mass of the total mass is ejected system becomes unbound.
- But note: kicks can make it easier to unbind a binary but can also make a binary remain bounded. So typically need to iterate over a large number of kicks and directions.
- We can get constrains on space velocity of runaway/walkaway stars and compact remnant binaries.





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

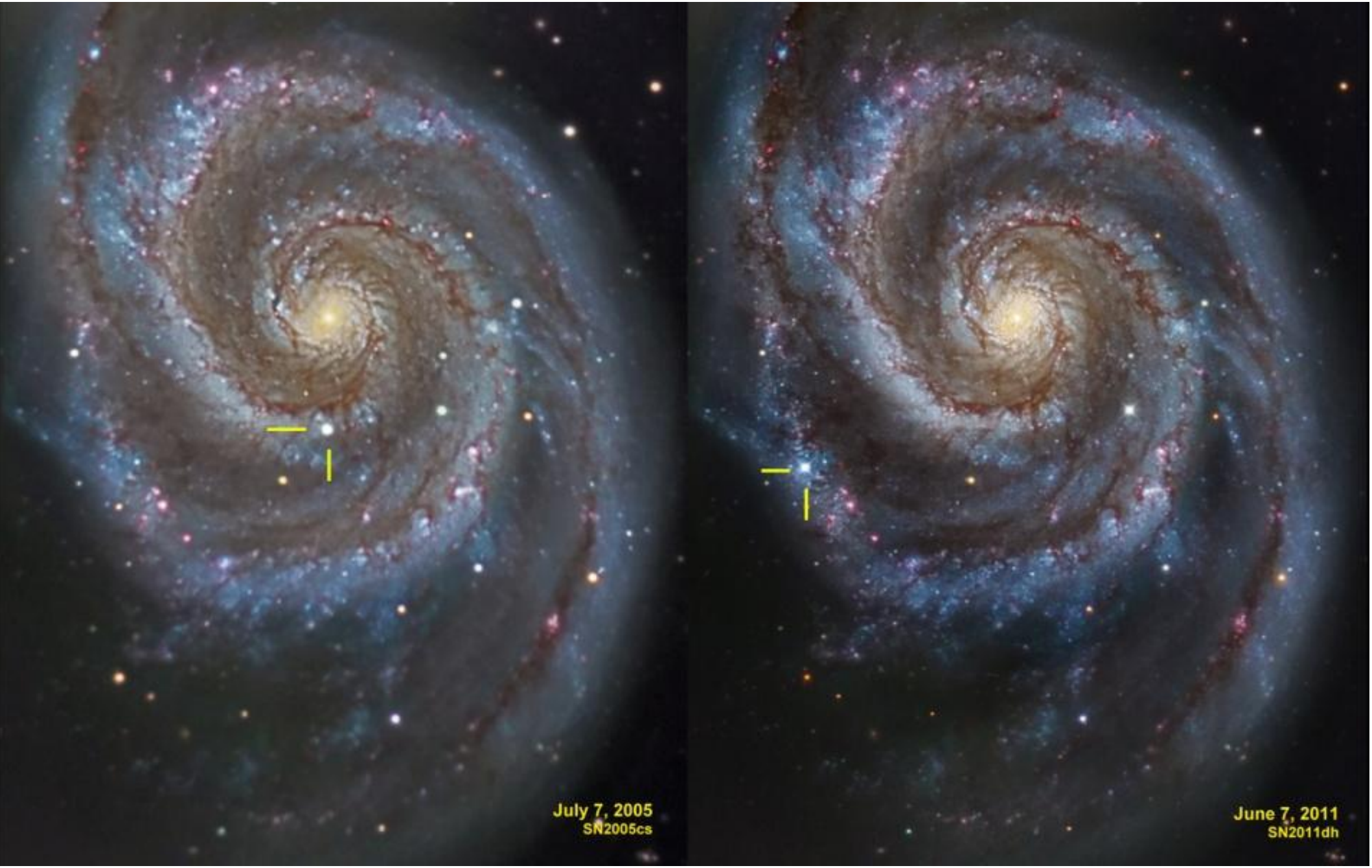

companion star
accretion disk and black hole
Sun
Mercury
LMC X−3
LMC X−1
Cyg X−1
GRS 1915+105
XTE J1650−500
XTE J1118+480
XTE J1859+226
SAX J1819.3−2525
GRS 1009−45
GRS 1124−683
GS 2000+25
H1705−250
GRO J1655−40
A0620−00
GRO J0422+32
XTE J1550−564
GS 2023+338
GS 1354−64
GX 339−4
4U 1543−47



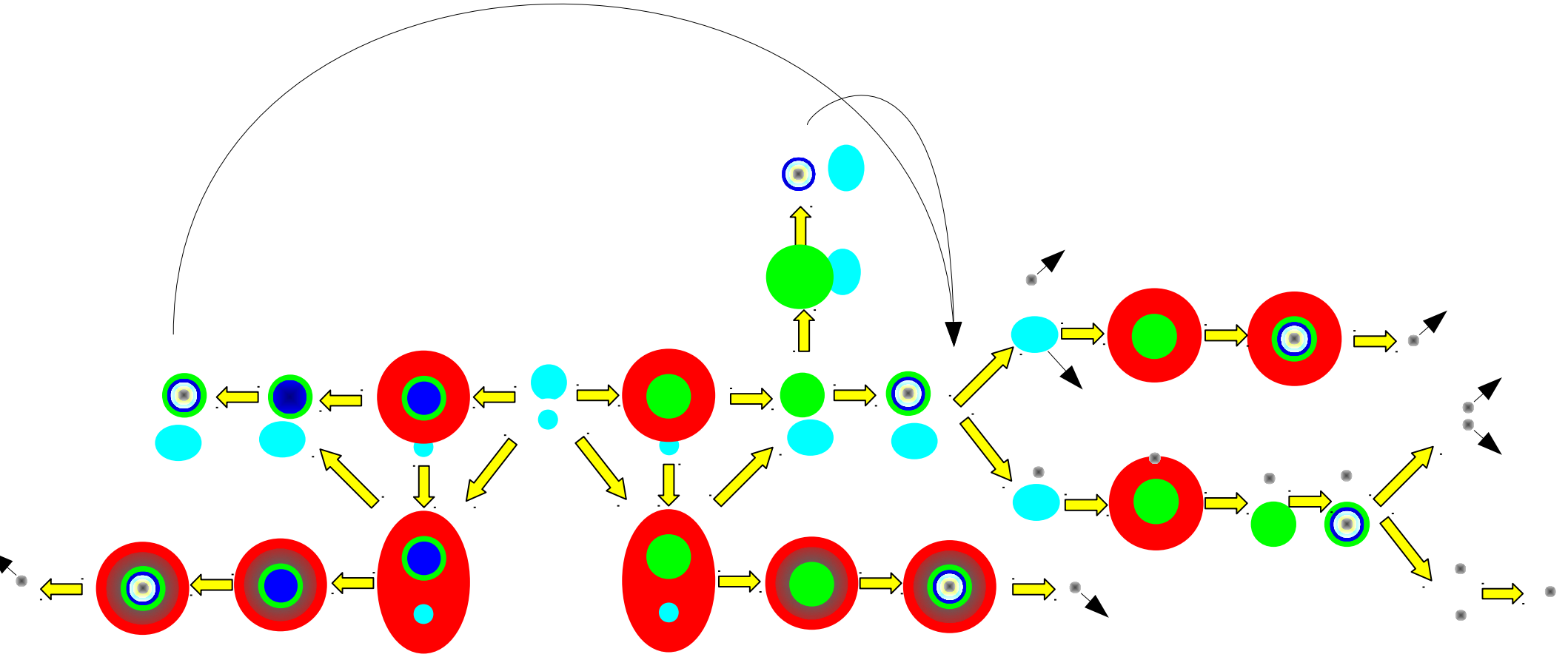
Belczynski et al. (2012)

Population Synthesis: what we need to consider and some example results

What we want to model:



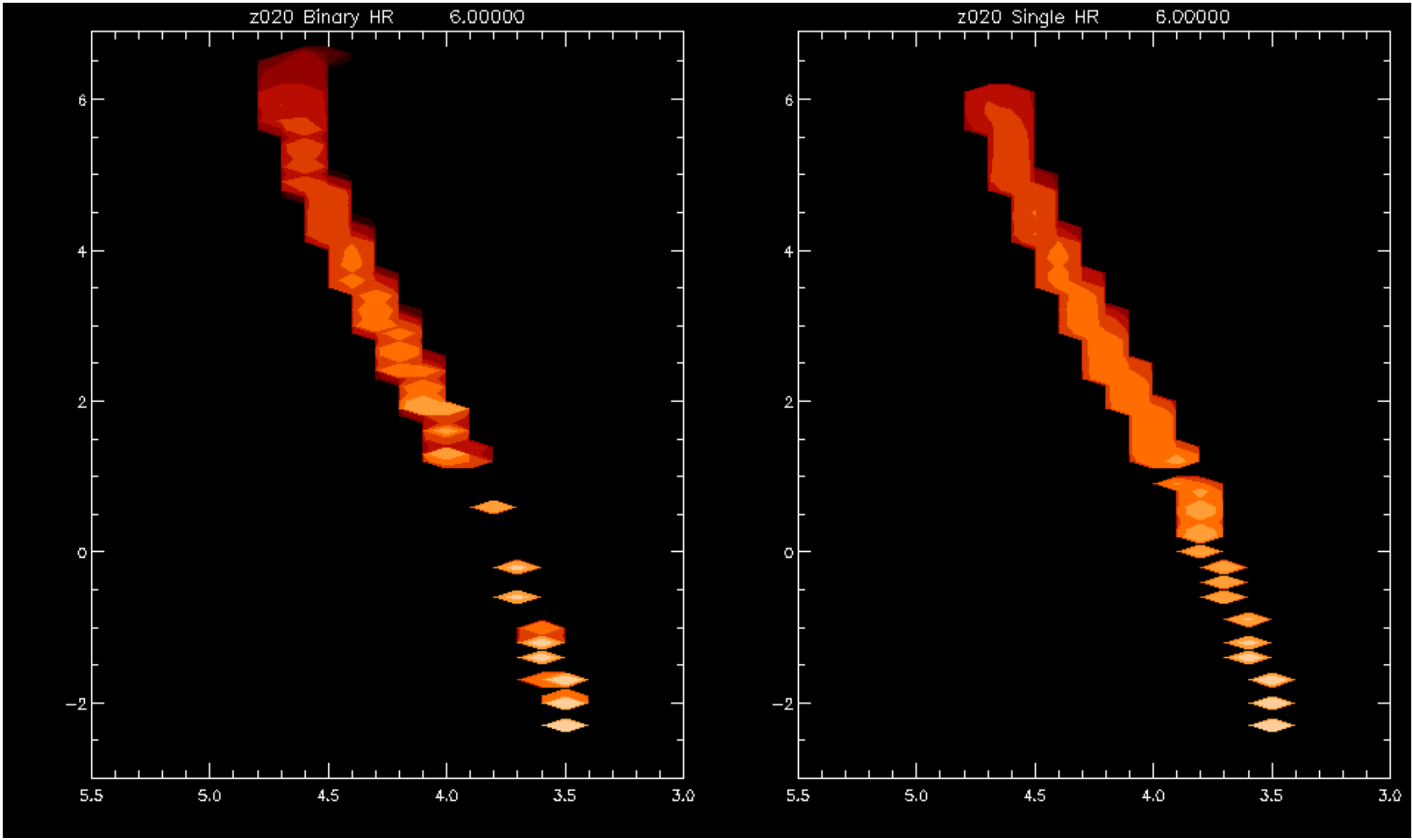
Lets put is all together...



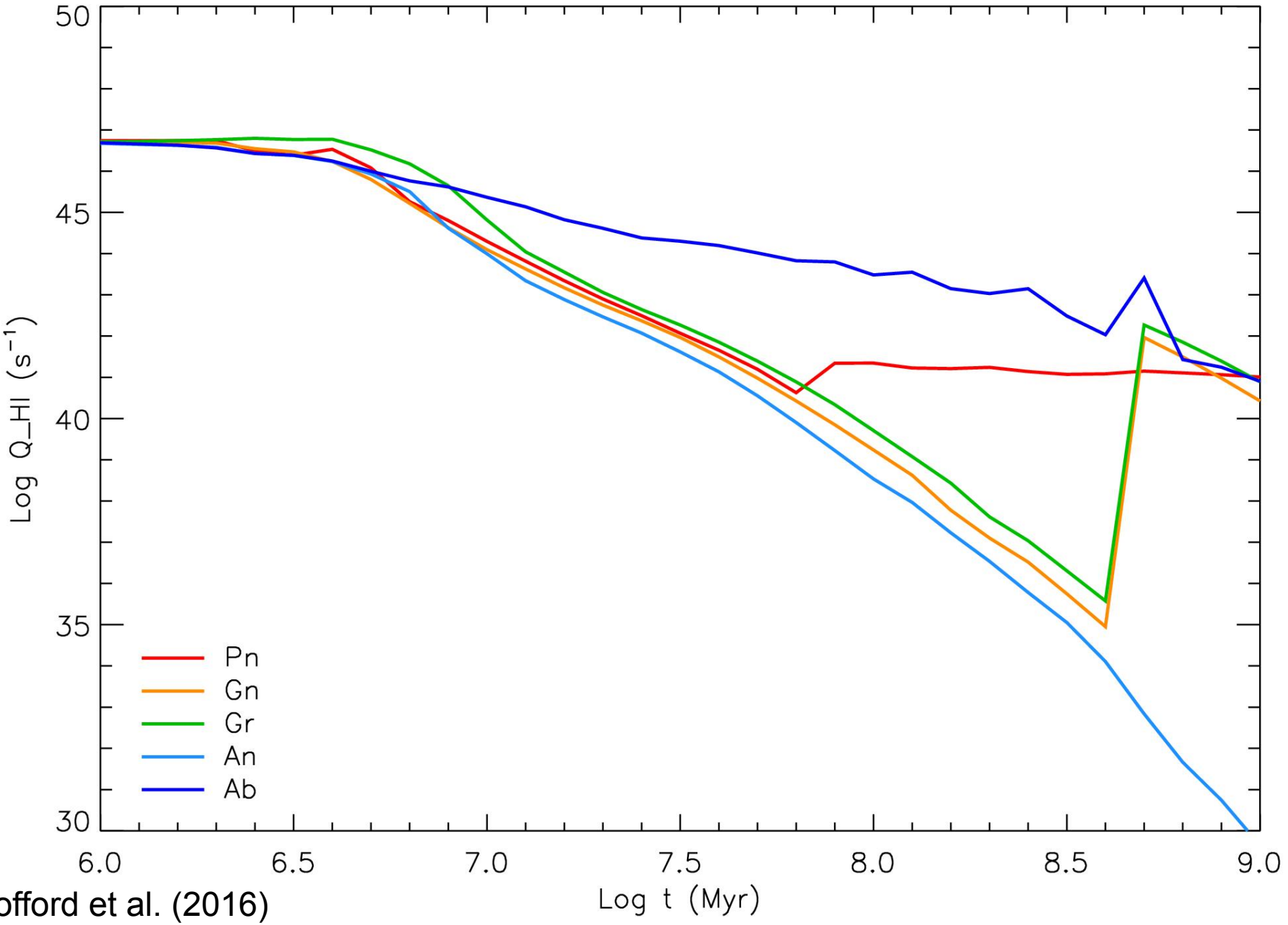
Also need...

- 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 theHR diagram

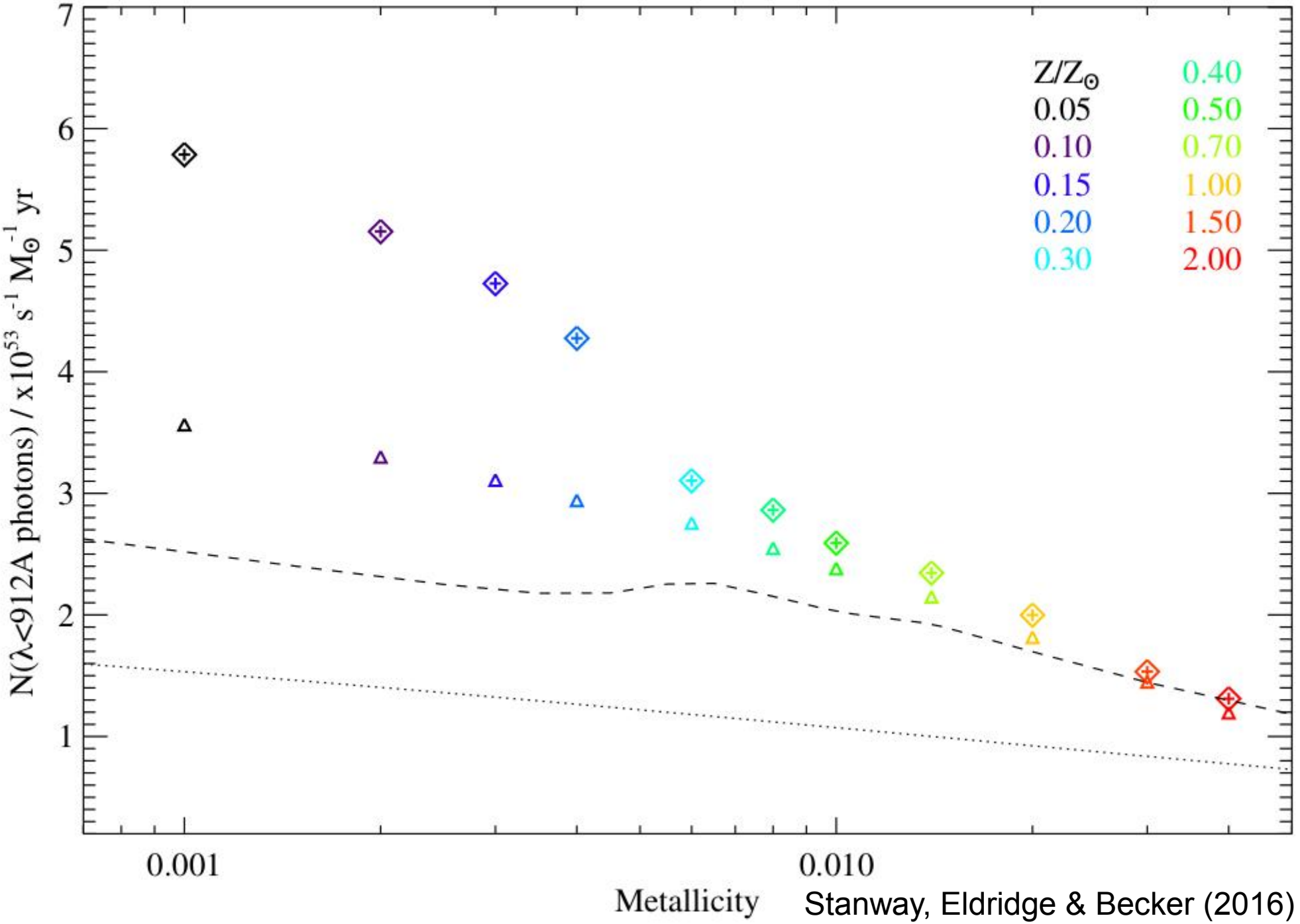


Number of ionizing photons?



Wofford et al. (2016)

Number of ionizing photons during reionization?

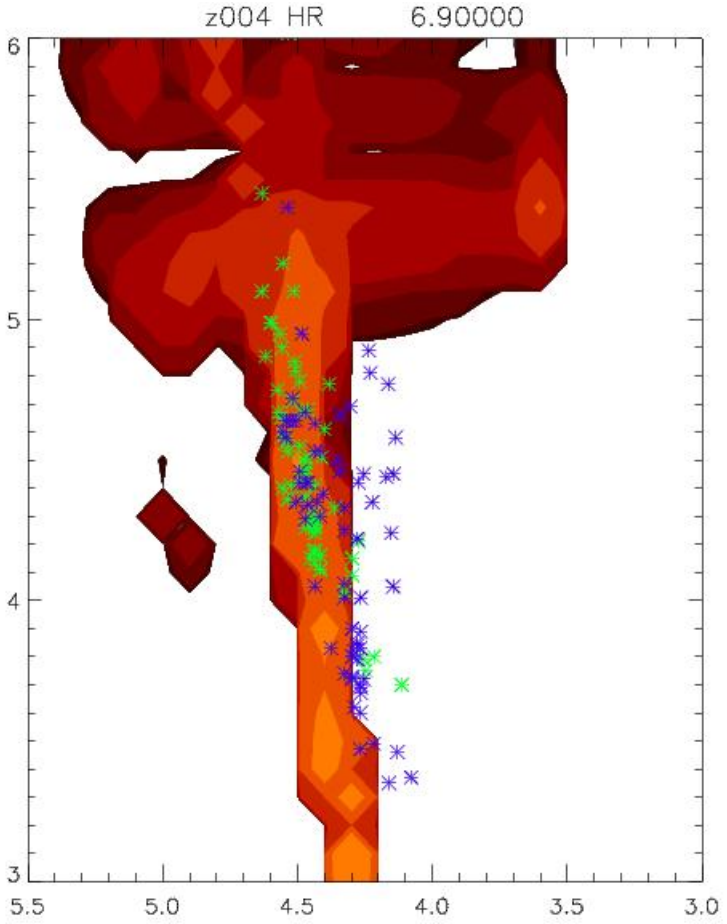


Stanway, Eldridge & Becker (2016)

Summary

- Binaries give opporunities 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).

SMC, 8Myr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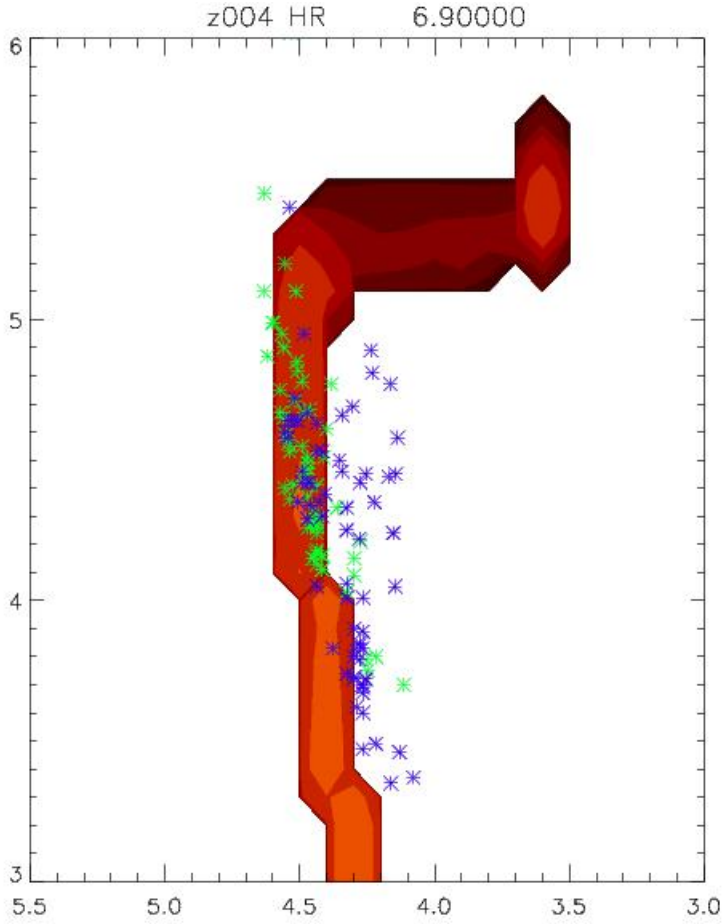
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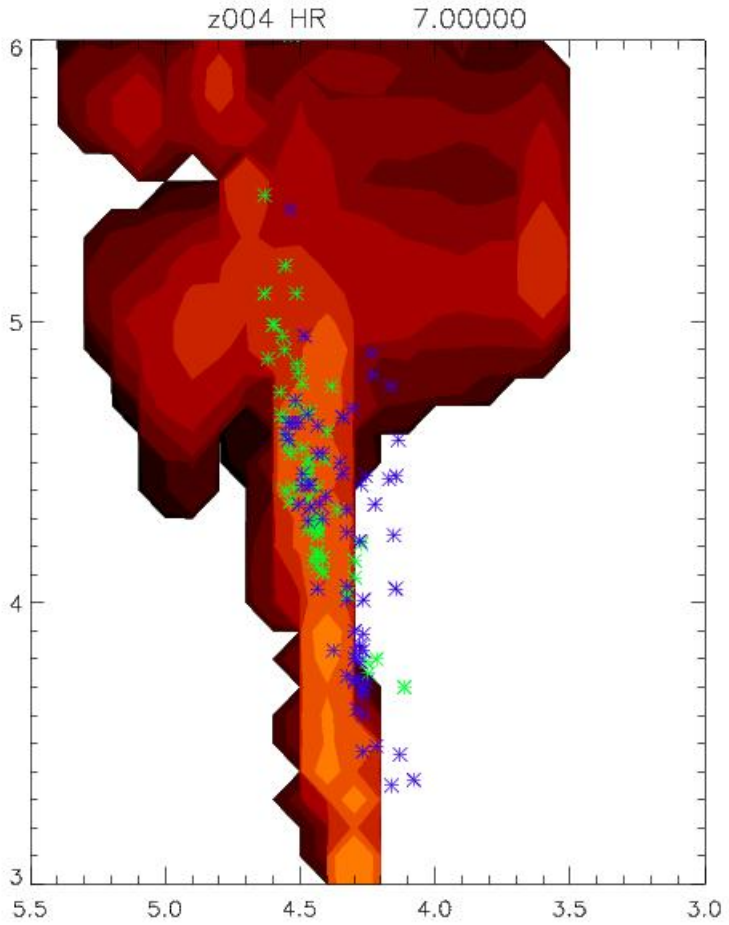
SMC, 10Myr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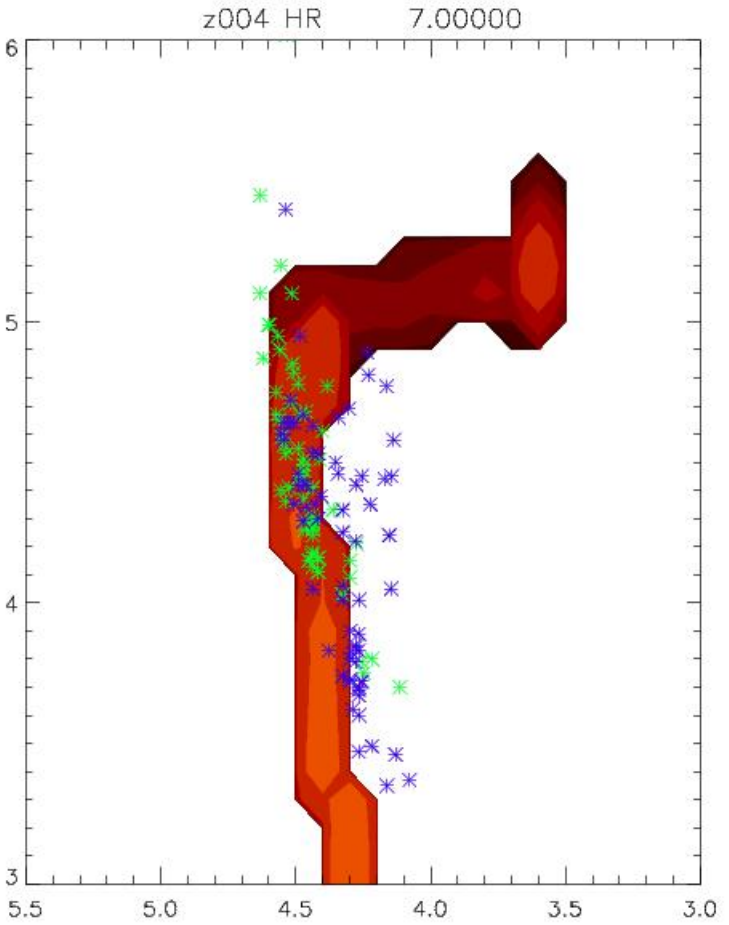
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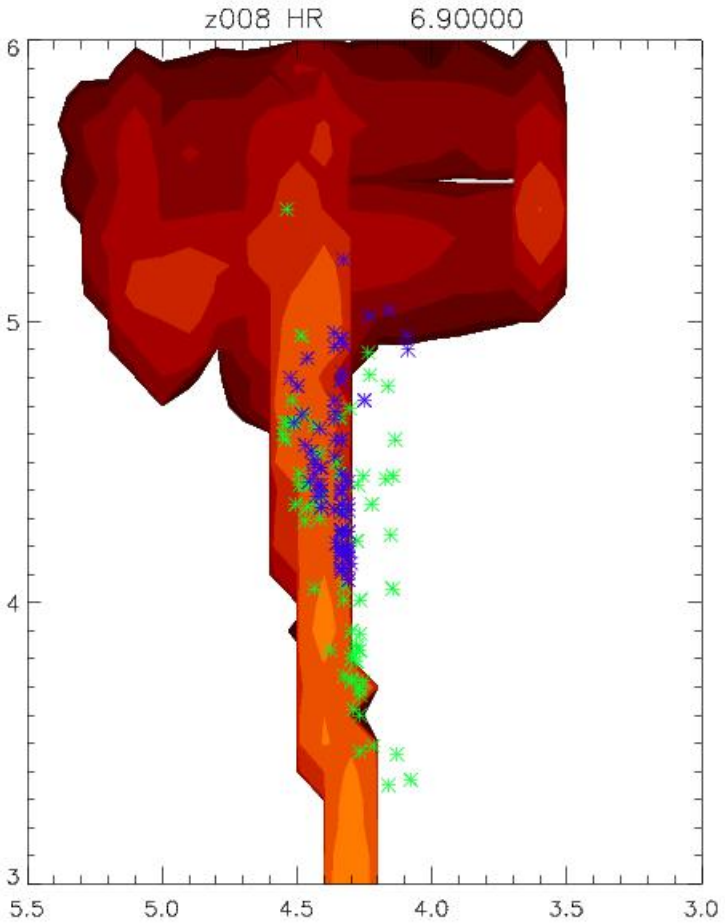
LMC, 8Myr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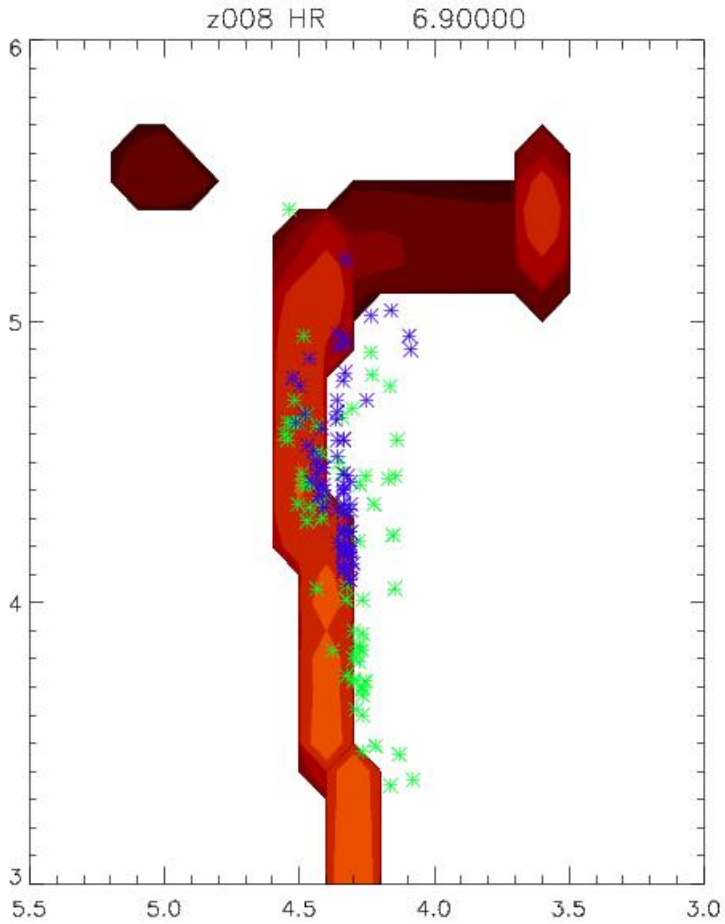
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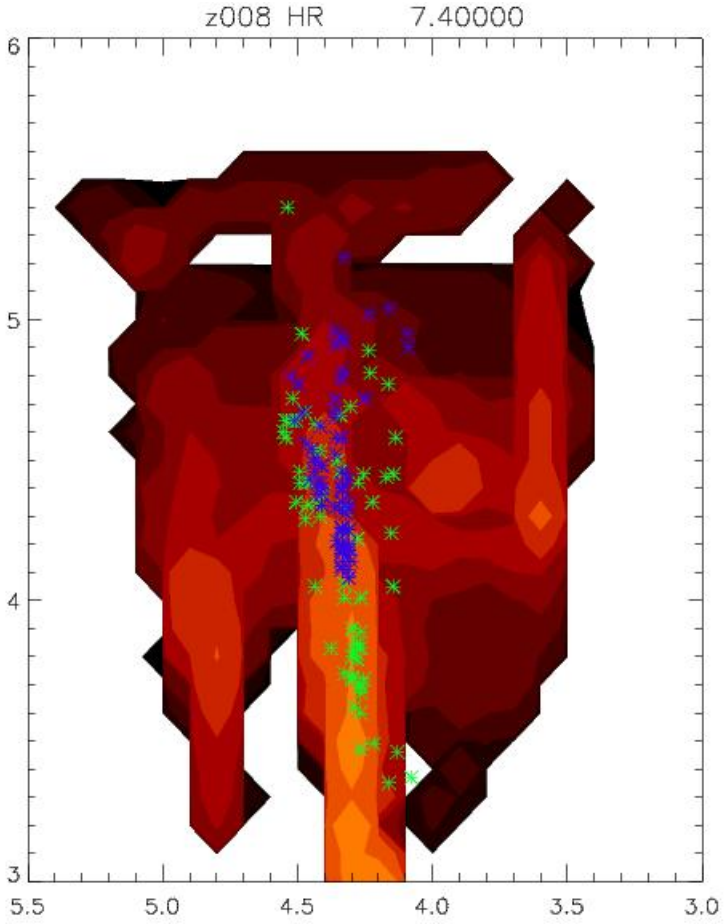
LMC, 25Myr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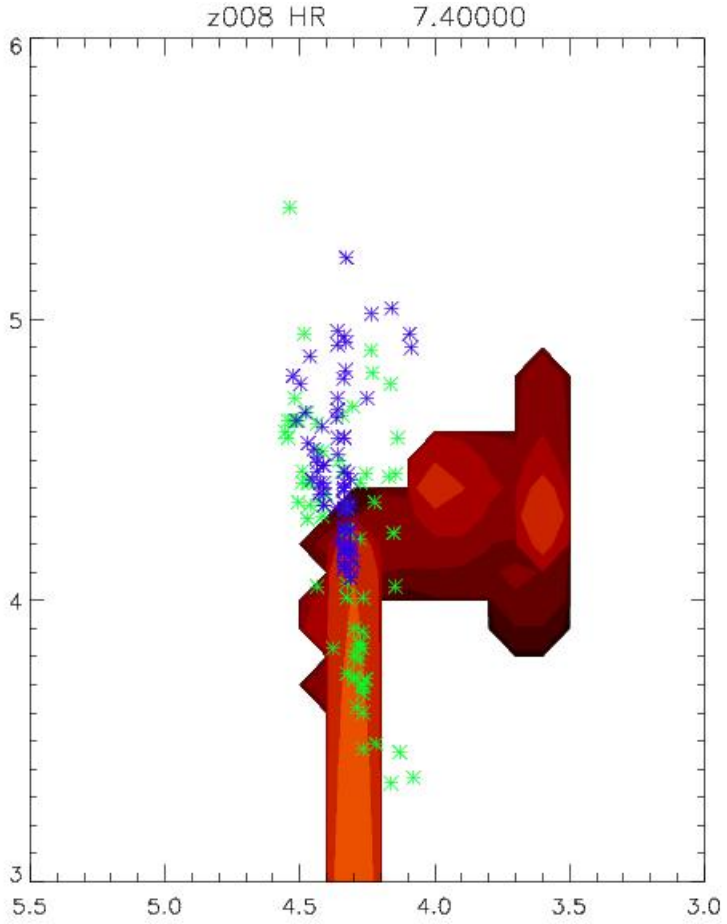
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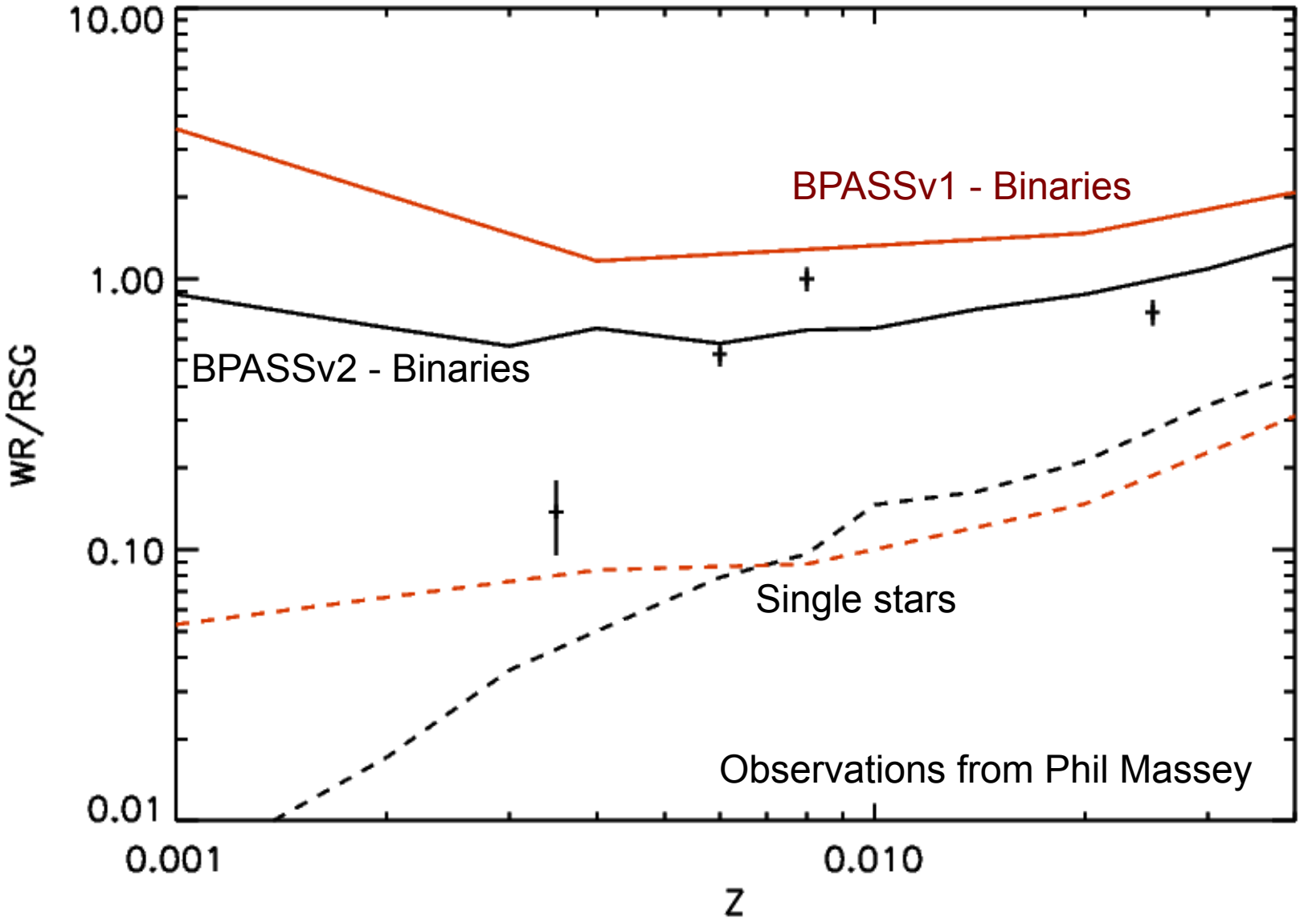
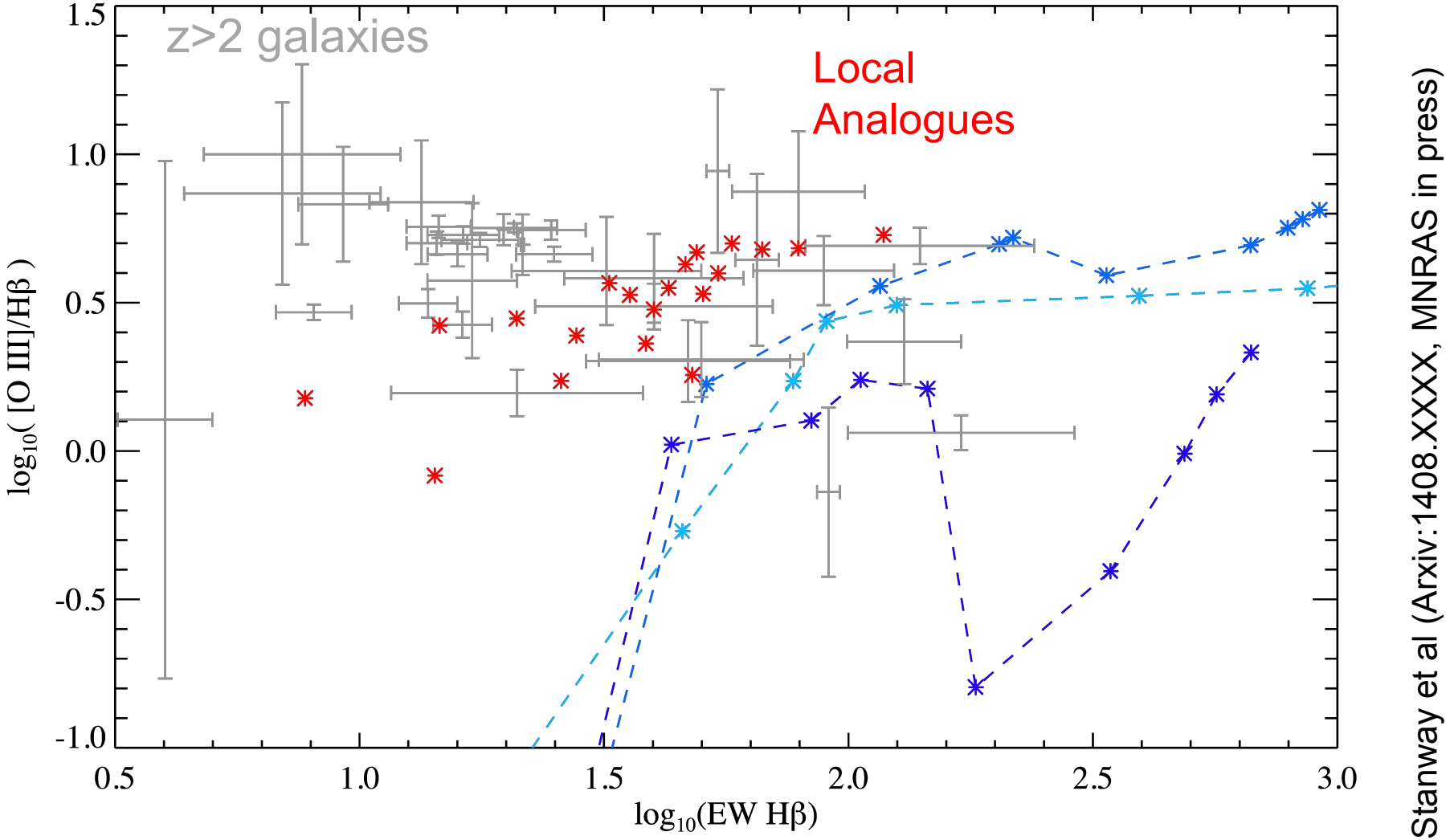
3.0

But predict RSG and WR population as well?



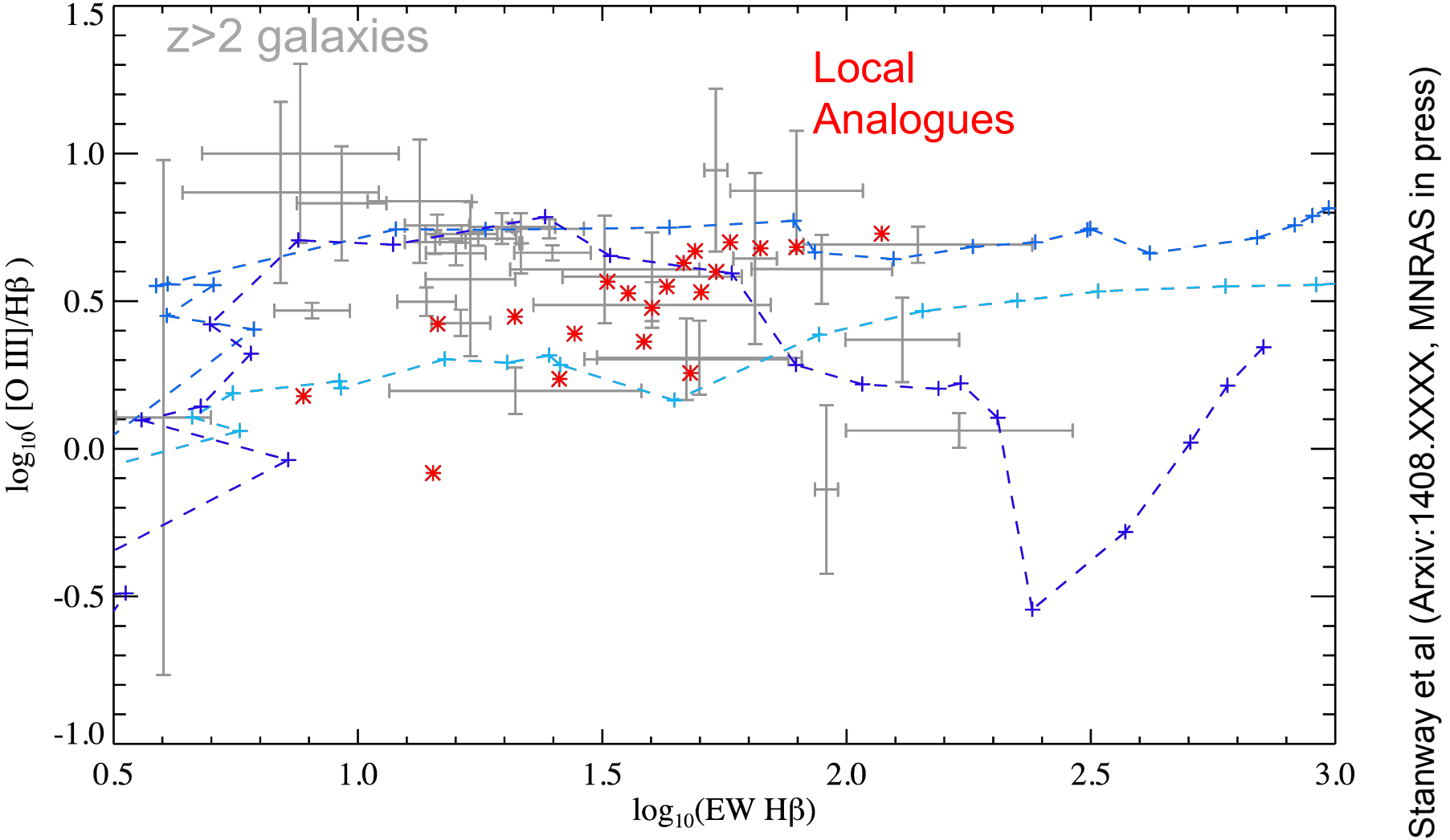
Eldridge et al . (in prep)

Emission Line Diagnostics in high-z galaxies



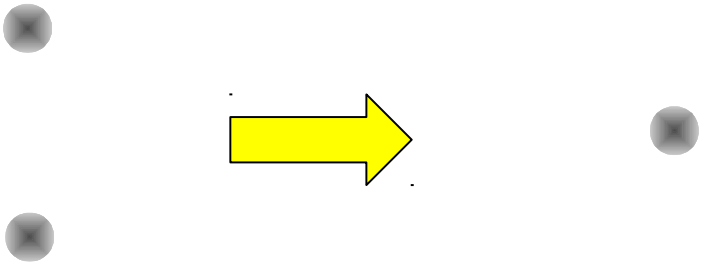
Stanway et al (Arxiv:1408.XXXX, MNRAS in press)

Emission Line Diagnostics in high-z galaxies



Stanway et al (Arxiv:1408.XXXX, MNRAS in press)

What we need to consider: 5/5



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

(Peters, 1964)

Summary

- Binaries give opporunities 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).