The Impact of Binaries on Stellar Evolution
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Explaining Galactic antimatter with faint thermonuclear supernovae

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Article

Diffuse Galactic antimatter from faint thermonuclear supernovae in old stellar populations

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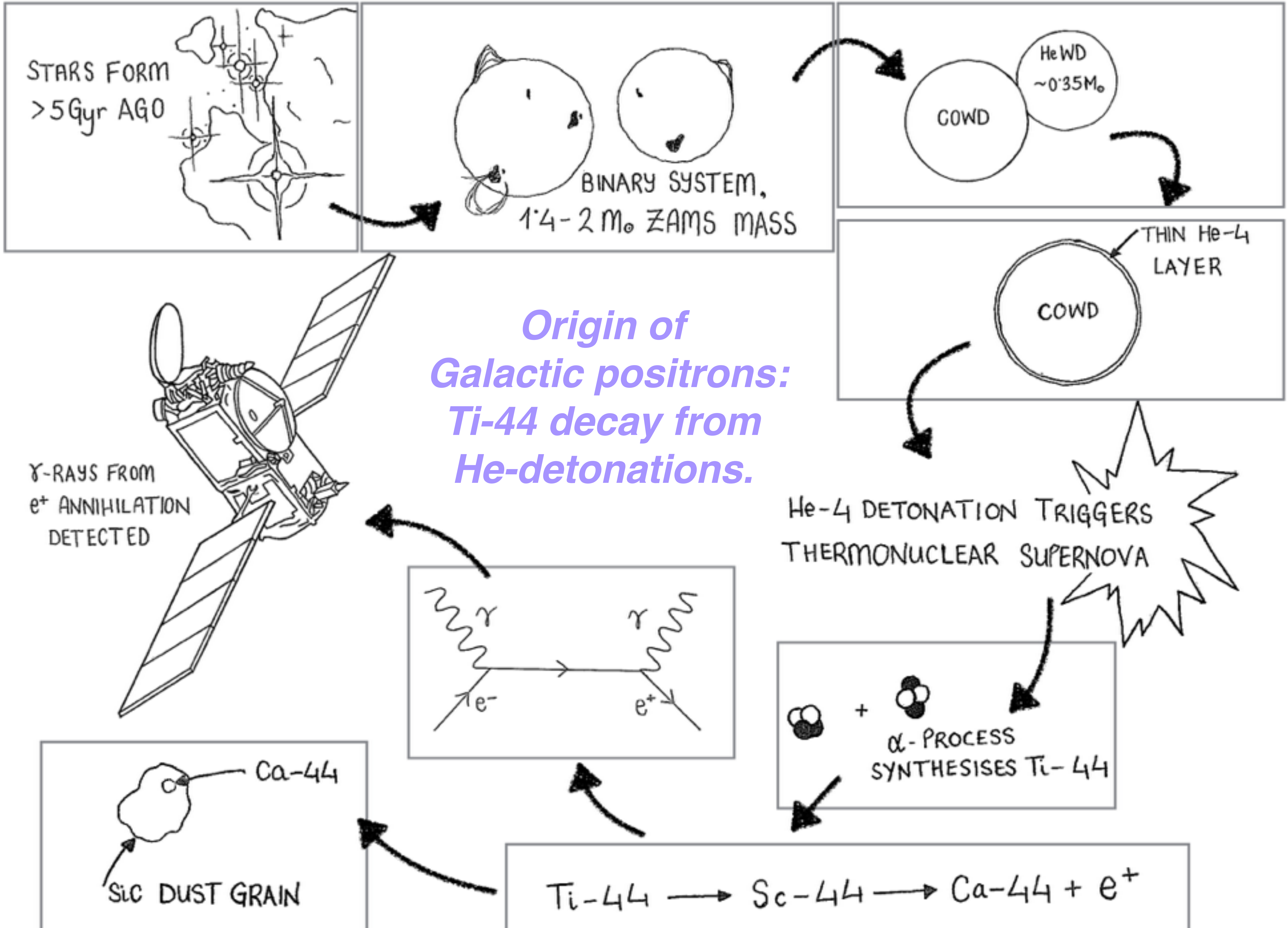
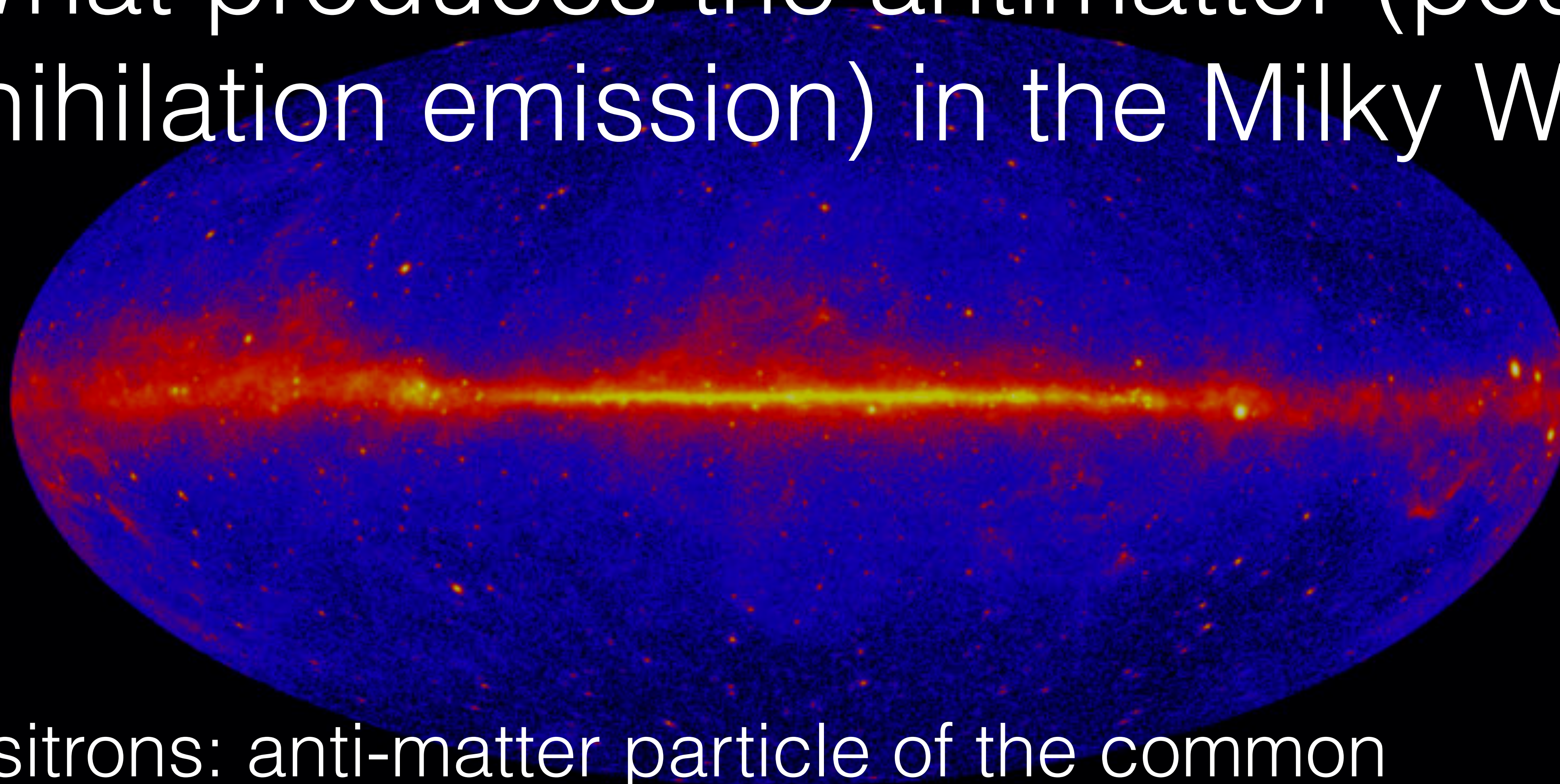


Figure by Fiona H. Panther

Q: What produces the antimatter (positron annihilation emission) in the Milky Way?



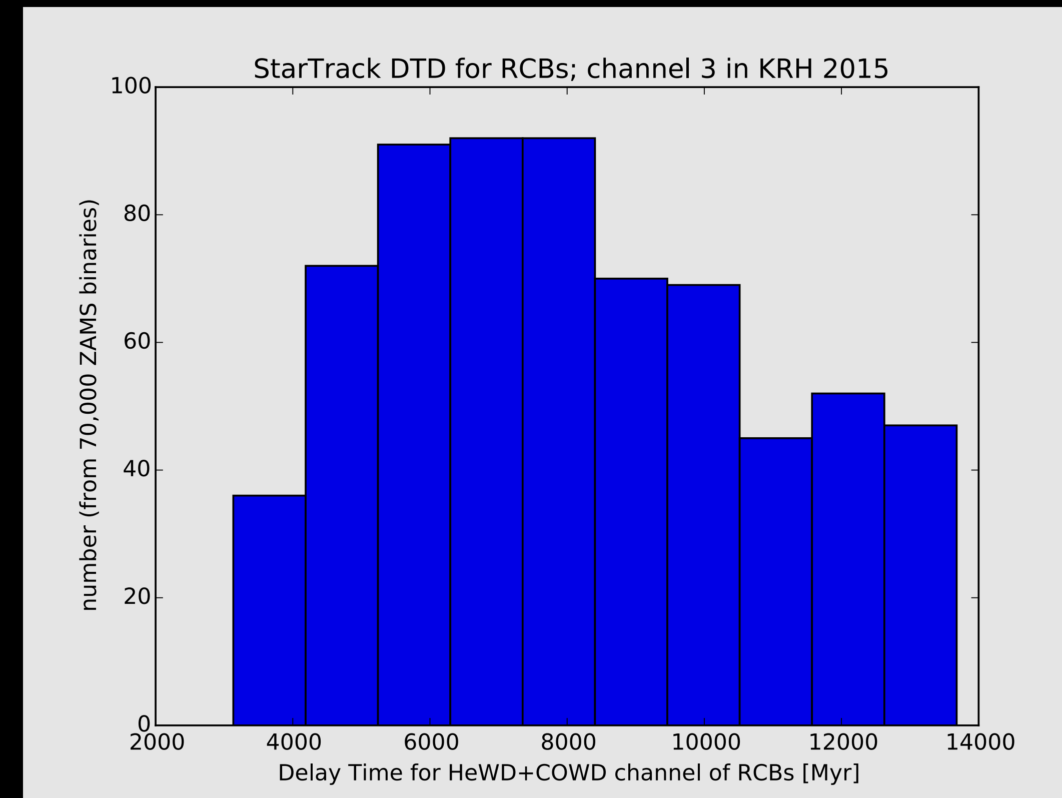
NASA/DOE/Fermi/LAT

- Positrons: anti-matter particle of the common electron.

- Gamma ray satellites reveal the Galaxy is a strong source of 511 keV emission. The emission is evidence for annihilation of positrons (~5 x10^43 per s)!

- What could be the source? 40+ year old problem.

Possible sources?



- Dark matter particle annihilation?
- Milky Way supermassive black hole?
- Flaring microquasars?
- Core collapse SNe? Thermonuclear SNe?
- None of these sources can fully explain simultaneously the emission spatial morphology **and** the injection energy (which is rather low).
- *Recent finding for MW positron luminosity*:

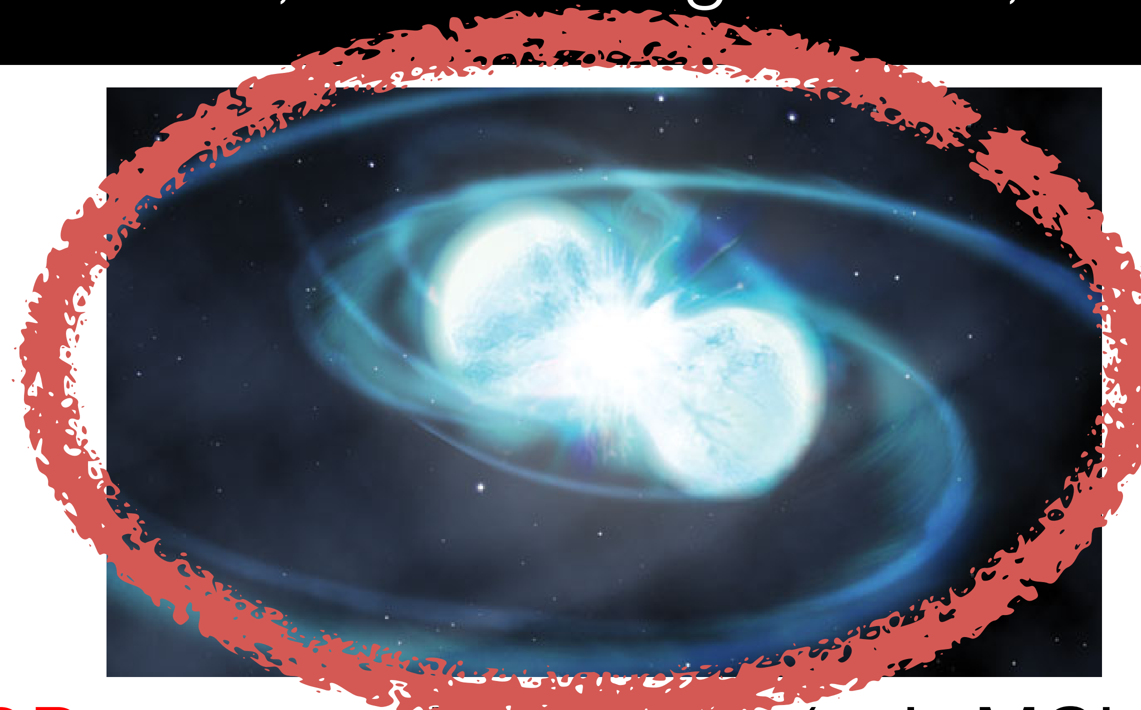
L_bulge / L_disc ~ 0.4 = approx stellar mass ratio bulge/disc. This suggests that **source is related to (old) stars** (see Siegert et al. 2016).

For a stellar source: can figure out what the characteristic age (or ‘delay time’) has to be for an adopted Galactic SFH (van Dokkum+ 2013, Snaith+ 2014). Use *StarTrack* binary pop synth code (Belczynski et al. 2008).

Type Ia supernovae

main proposed progenitors: single degenerate; double degenerate, etc.

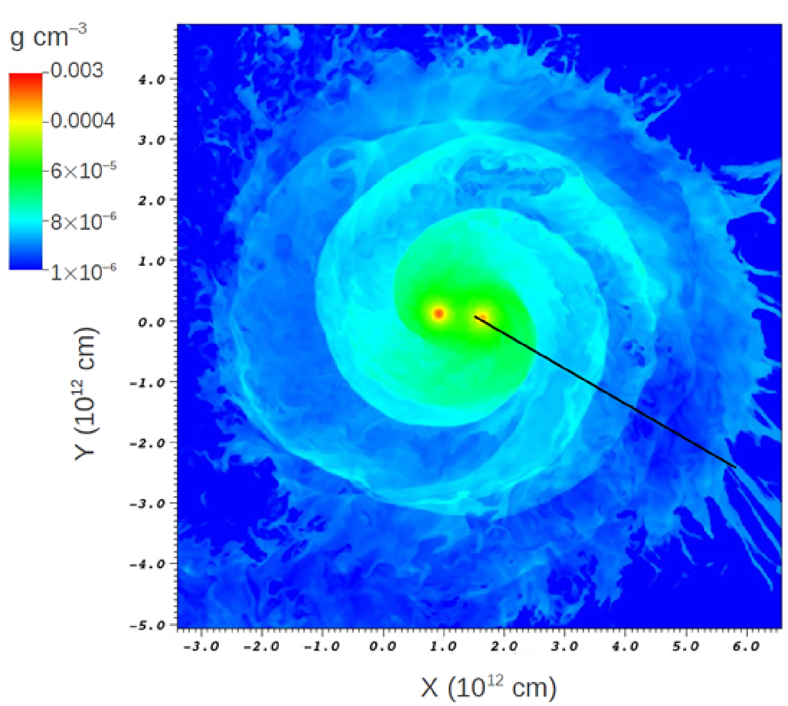
D. A. Hardy



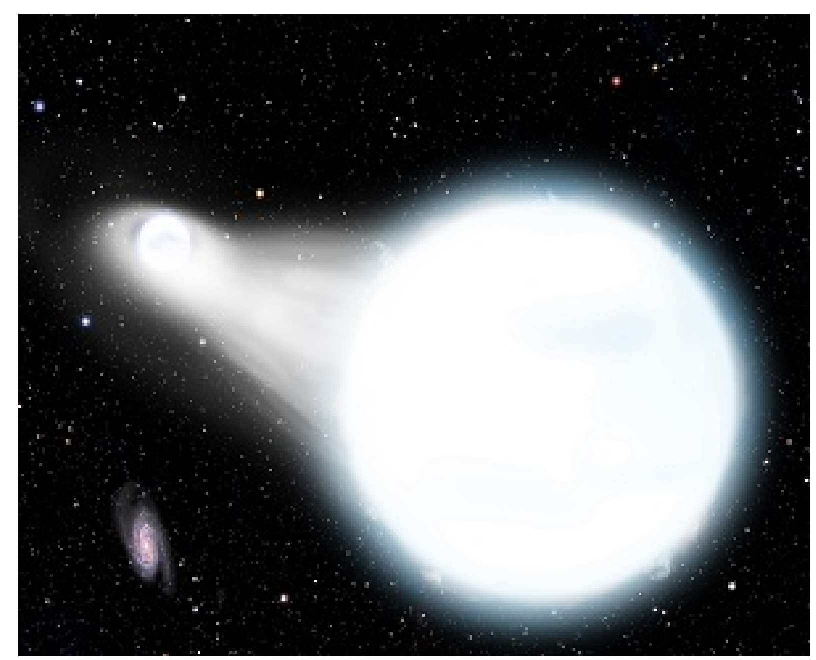
Nature

SD, e.g. delayed detonation: MCh mass WD explodes.

DD, prompt detonation (sub-MCh), or possible accretion toward MCh?



ASIAA



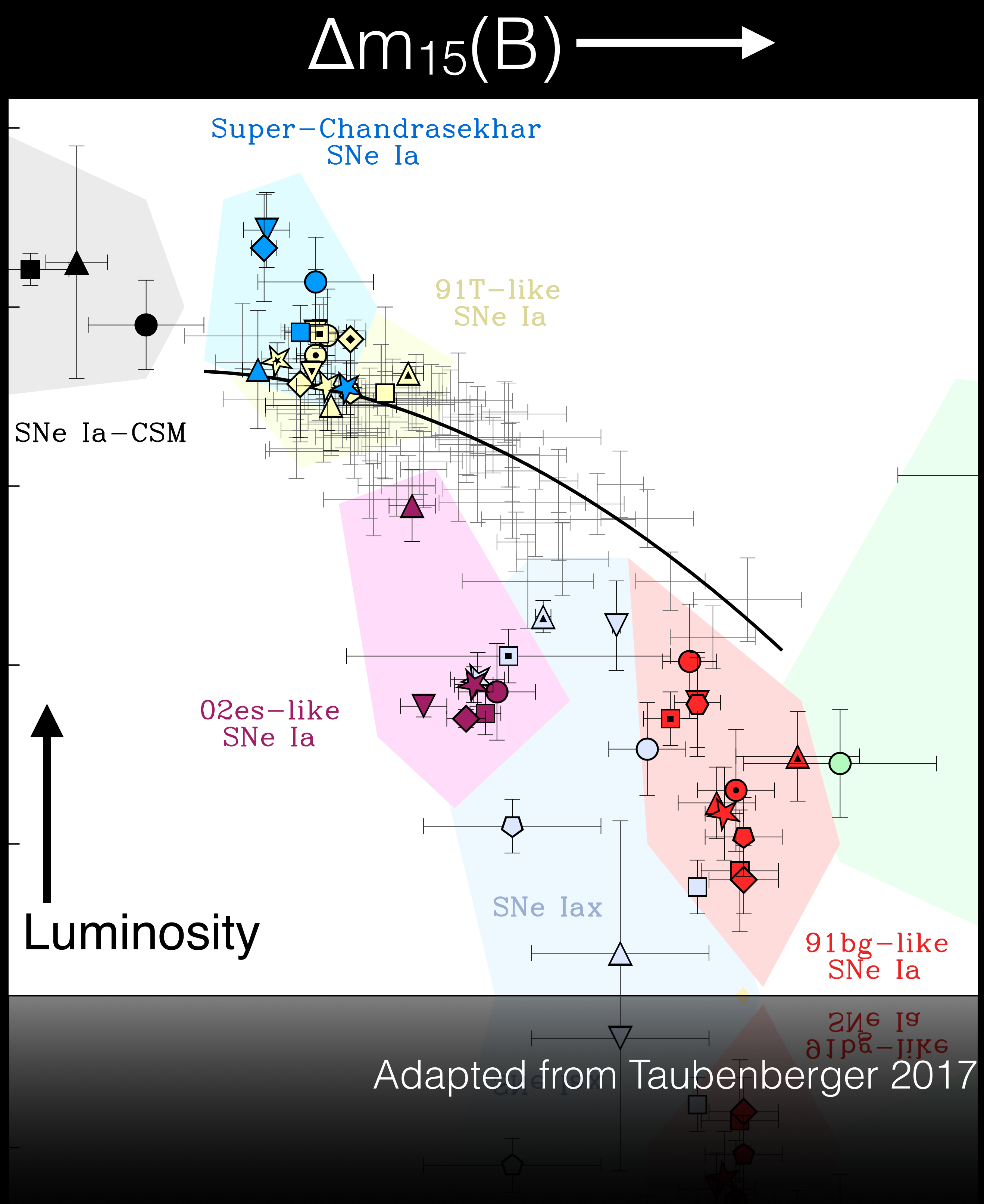
D. A. Aguilar

core degenerate, merger in a common envelope, explodes later.

'classic' double detonation: usually WD+He-rich star; $\dot{M}$ slow or fast.

91bg-like SN progenitors

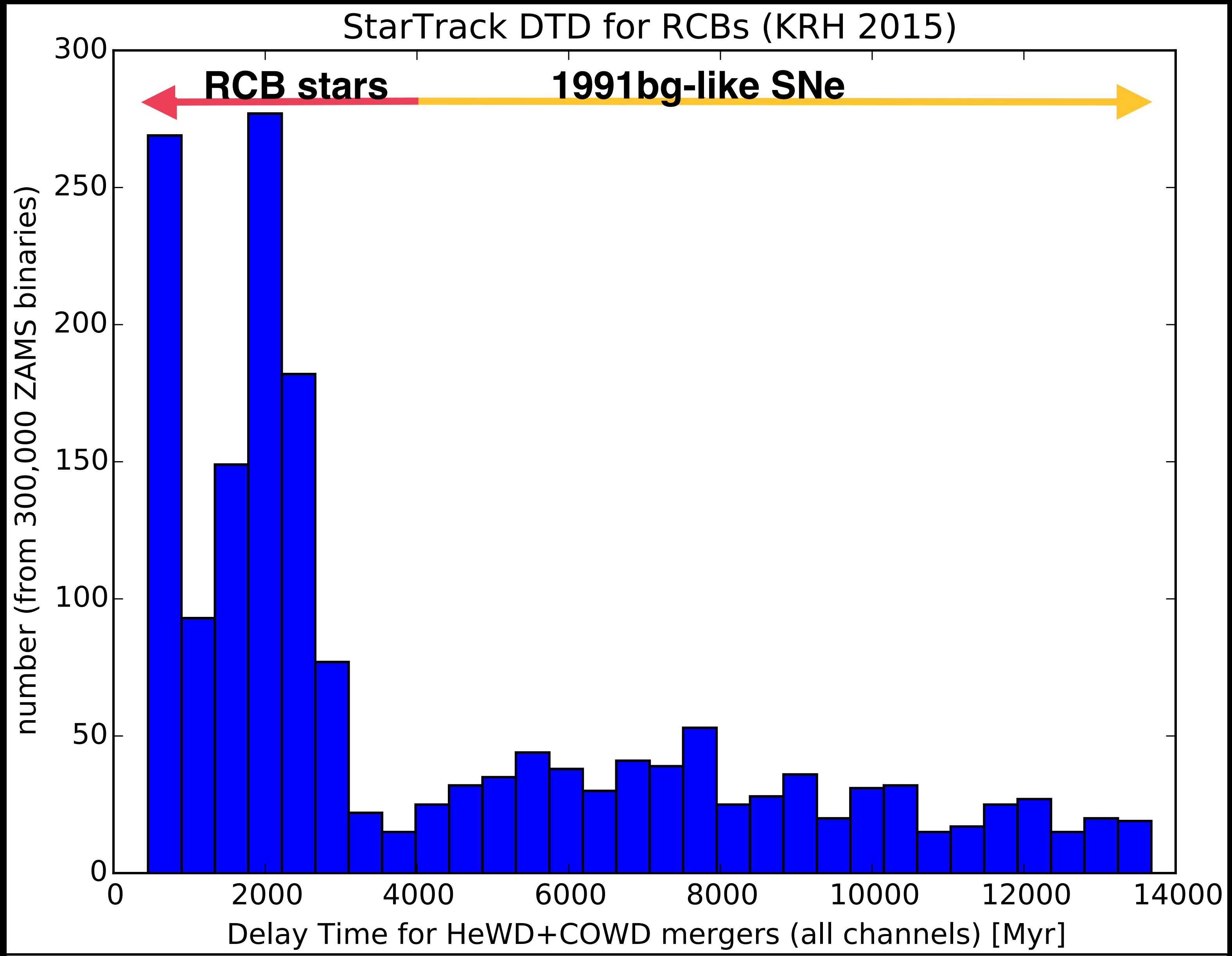
- *Just to clarify*: WE DON'T KNOW ANY OF THE SN Ia PROGENITORS!
- **91bg** are <u>fainter</u> than 'normal' SNe Ia; typically found among old stellar populations.
- Postulated by Pakmor et al. 2013 to arise from mergers of He + CO white dwarfs.
- Some He+CO WD mergers produce **R Coronae Borealis** variable stars (see Han 1998; Karakas, Ruiter & Hampel 2015), while others could produce **faint Type Ia supernovae** (Crocker et al. 2017).



Adapted from Taubenberger 2017

Why do we think HeWD+COWD mergers are likely the **1991bgs**?

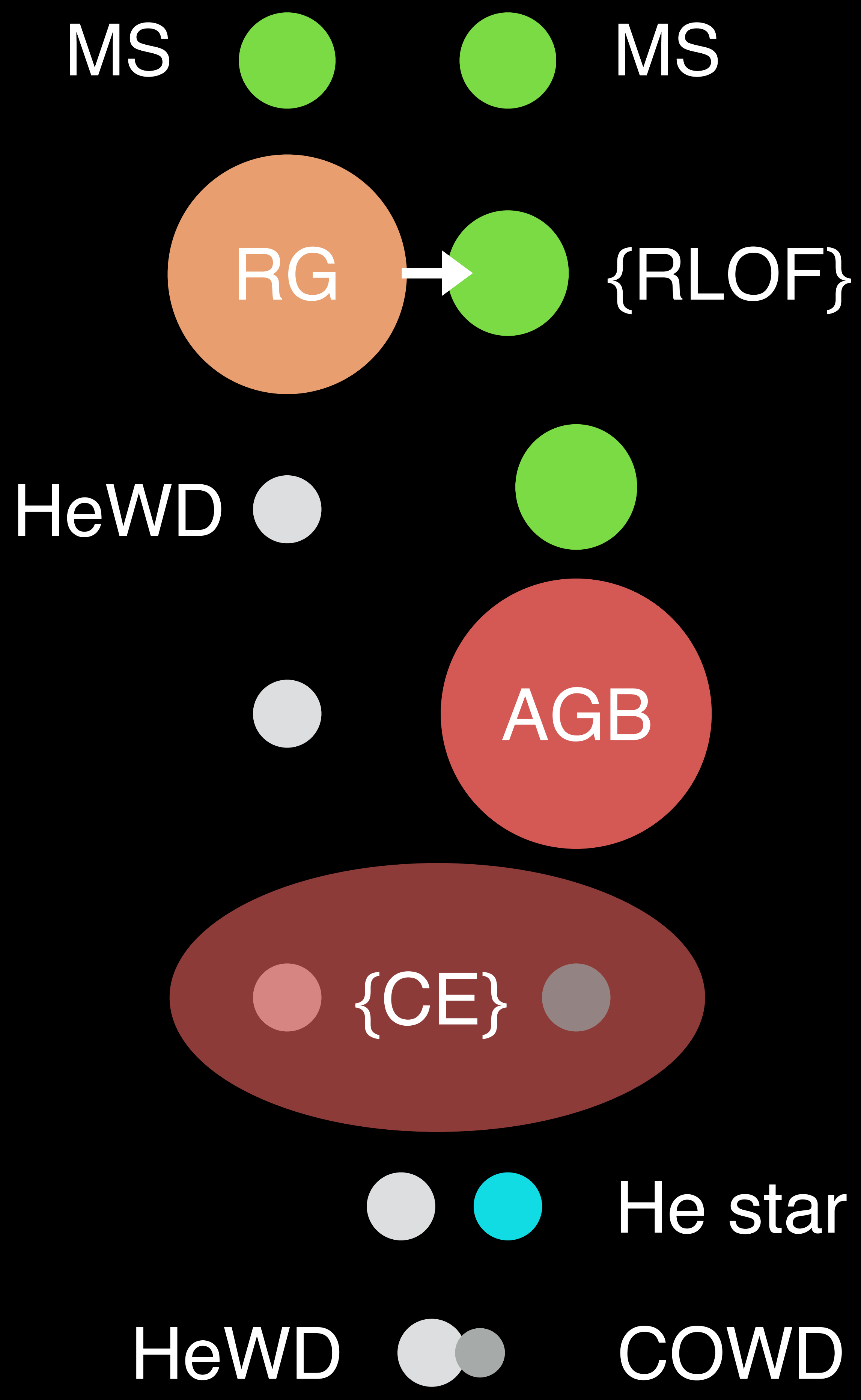
- Old stellar population (galactic bulge-like).
- Nuclear burning of **helium** can plausibly give the amount of **titanium-44** that can explain antimatter (positron signal) in the Milky Way. (cf. Woosley et al. 1986).
- A sub-set of CO+He-rich WD mergers have the right **delay times** ~4+ Gyr.



Based on Karakas, Ruiter & Hampel (2015)
'channel 3' for R Coronae Borealis (RCB) formation.

- Binary evolution population synthesis (binaries evolved in the field, e.g. no N-body / triples)
- *StarTrack* code evolutionary channel leading to He-CO double WD merger:

1. ZAMS masses ~1.5 - 2 Msun
2. low-mass (~0.3 - 0.35 Msun) **He WD** forms first via RLOF envelope stripping
3. **CO WD** (~0.55 - 0.6 Msun) forms later via CE event on the early AGB
4. WDs merge ~4000 Myr - Hubble time after star formation



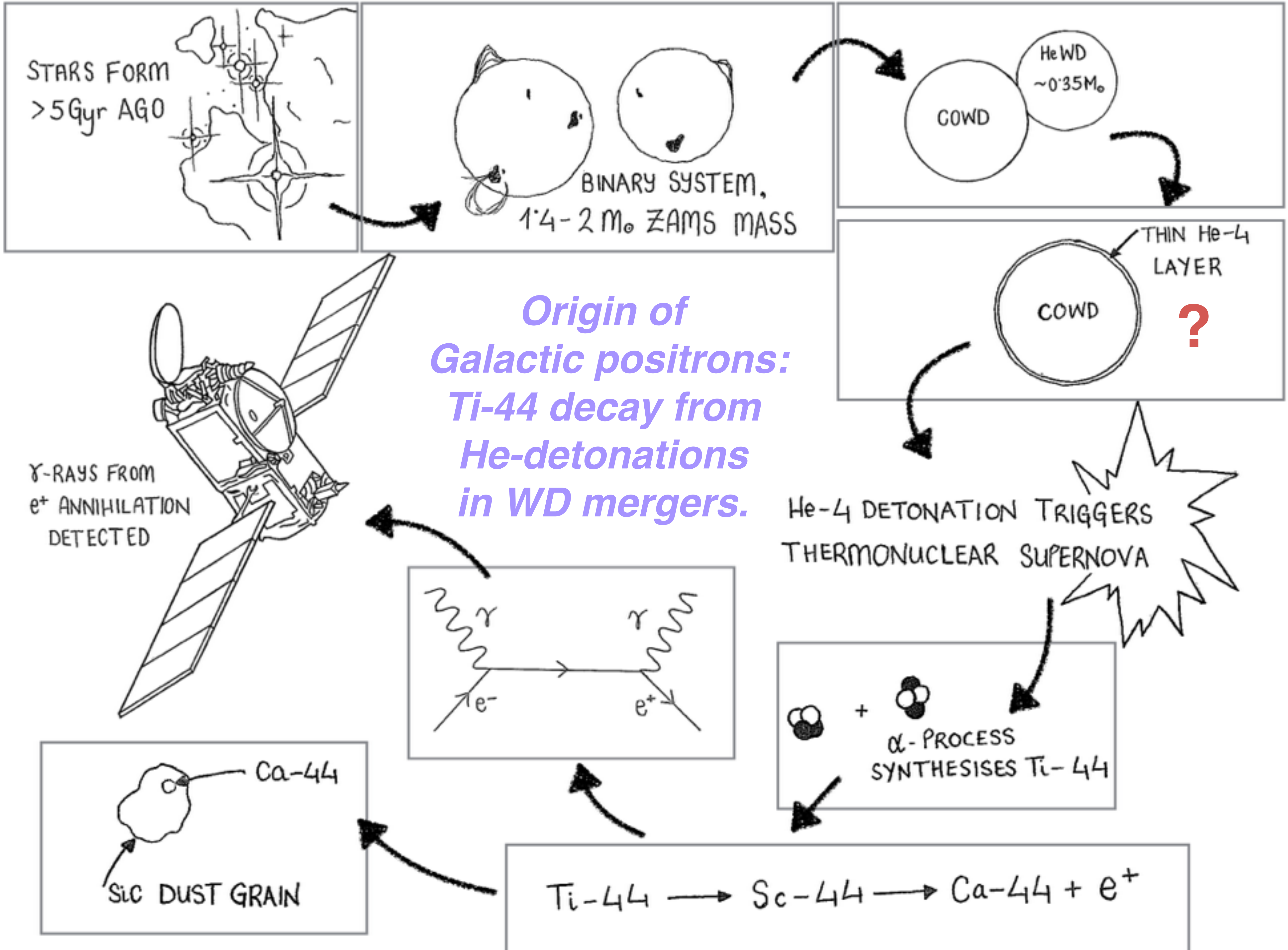
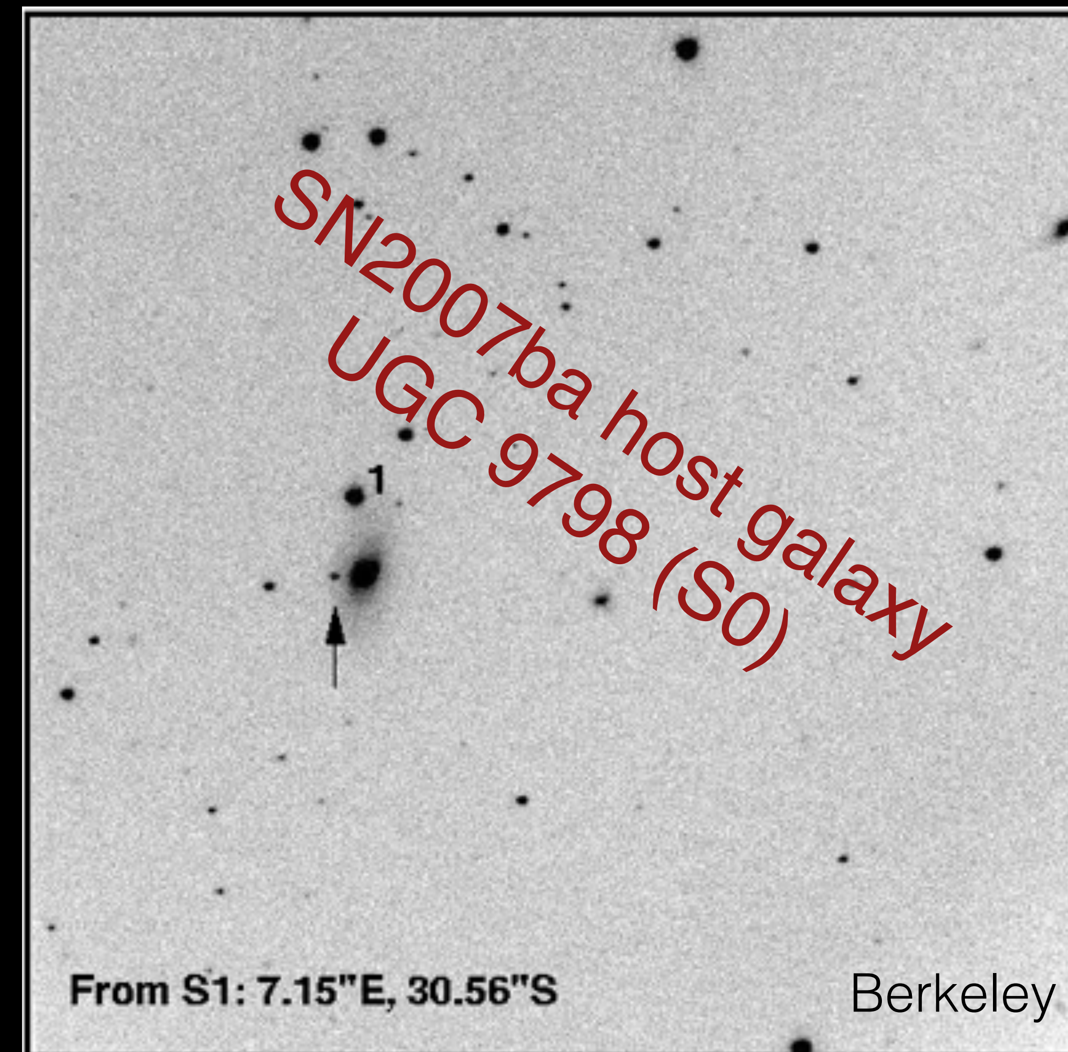


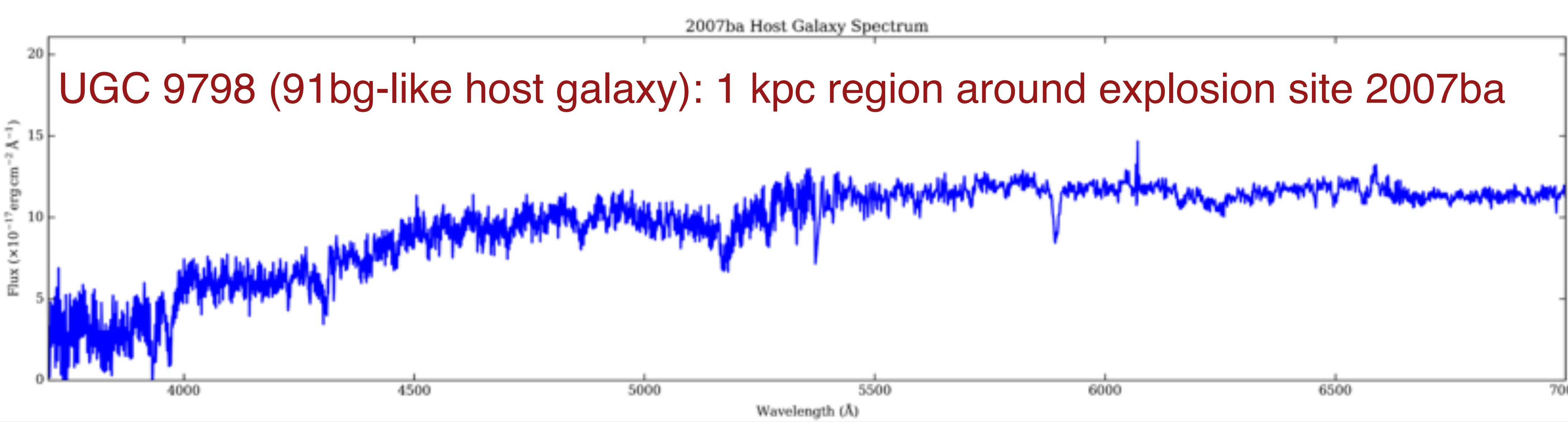
Figure by Fiona H. Panther

To do!

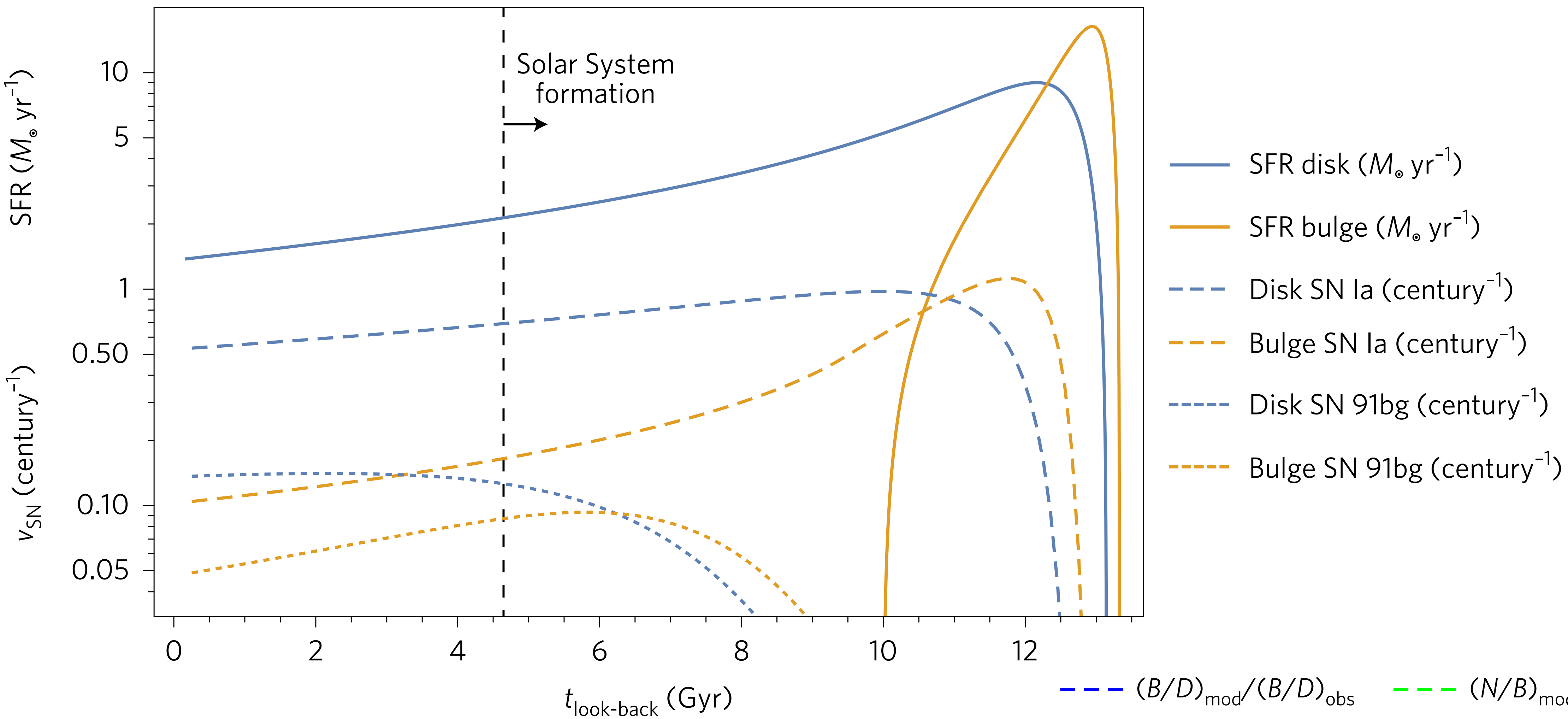
- PhD student Fiona Panther observed host populations of **historic 91bg SNe to derive SN ages** (delay times). Consistent with our predictions (Panther et al. in prep).

- Merger simulations to determine e.g. How does the helium detonate? How much Ti-44 is synthesised? (require 0.013-0.03 Msun per event).

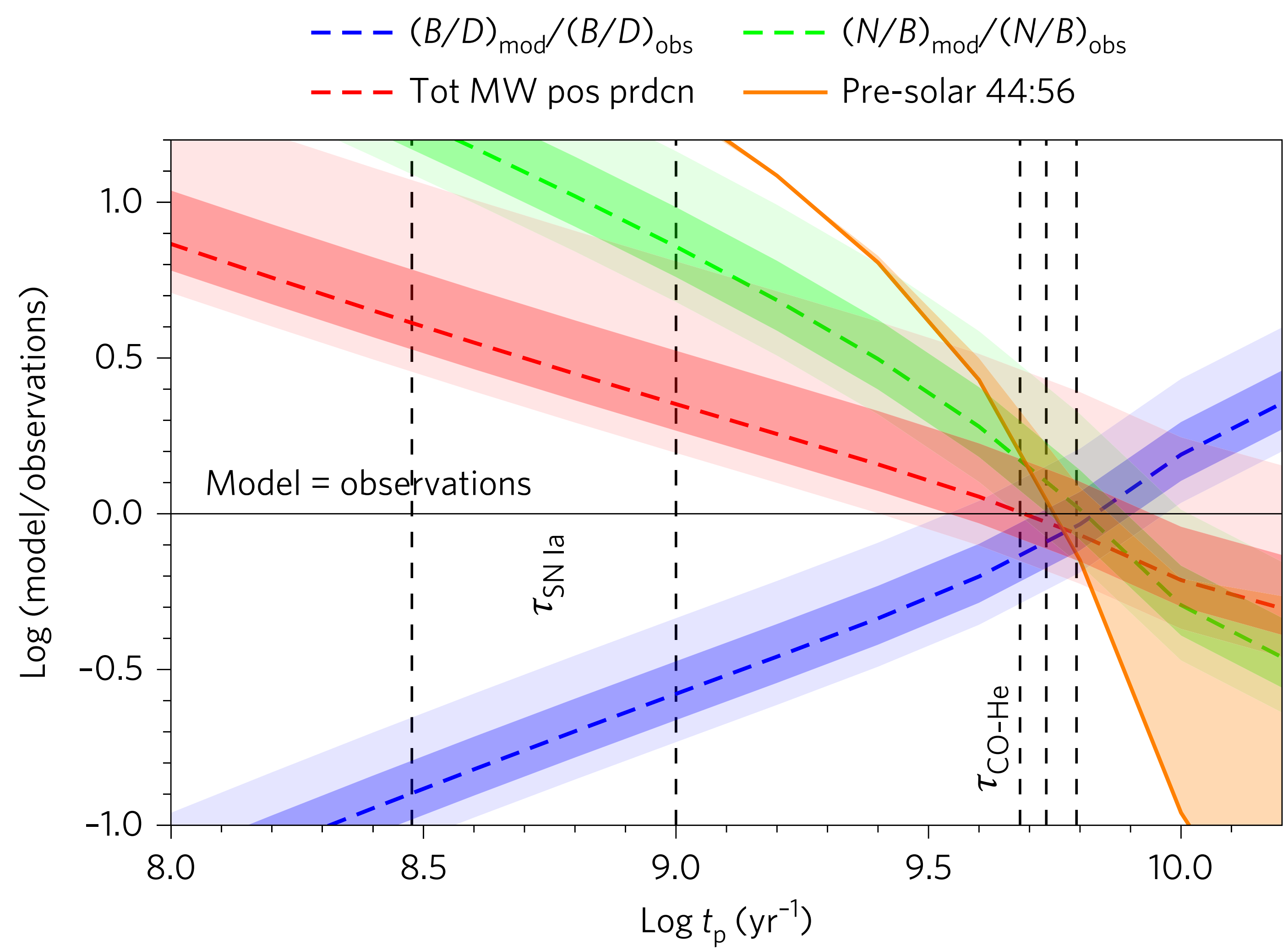




WiFeS
F. Panther



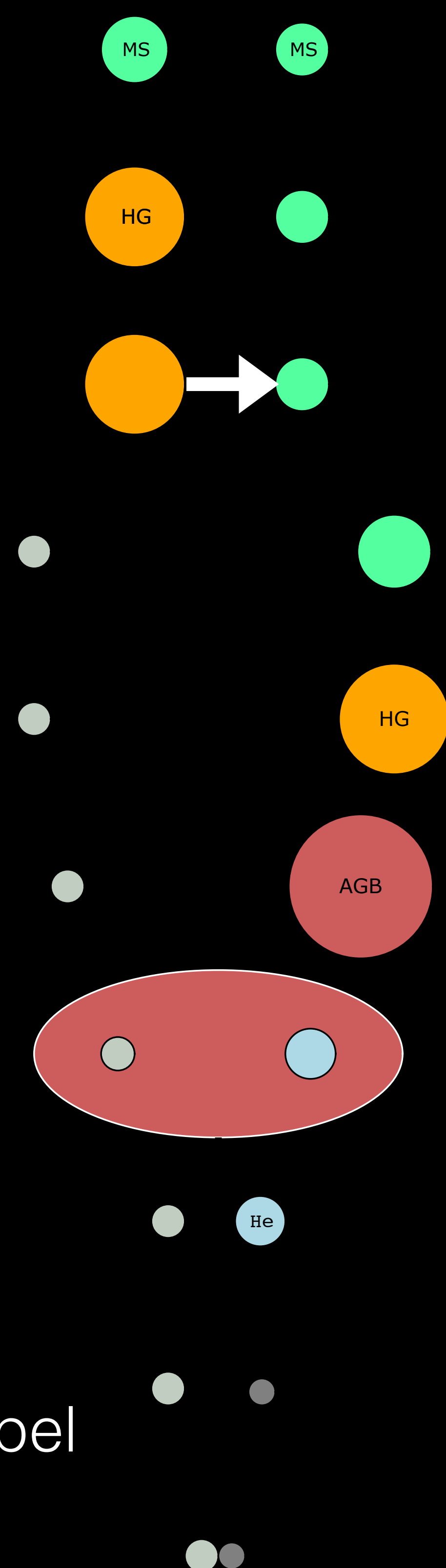
SFR ($M_⊙$ yr^{-1})
v_{SN} (century^{-1})
Solar System formation
SFR disk ($M_⊙$ yr^{-1})
SFR bulge ($M_⊙$ yr^{-1})
Disk SN Ia (century^{-1})
Bulge SN Ia (century^{-1})
Disk SN 91bg (century^{-1})
Bulge SN 91bg (century^{-1})
$t_{look\text{-}back}$ (Gyr)



$(B/D)_{mod}/(B/D)_{obs}$
$(N/B)_{mod}/(N/B)_{obs}$
Tot MW pos prdcn
Pre-solar 44:56
Log (model/observations)
Model = observations
$\tau_{SN\ Ia}$
$\tau_{CO\text{-}He}$
Log t_p (yr^{-1})

Two WD merger formation channels with *StarTrack*: CO+He and CO+CO

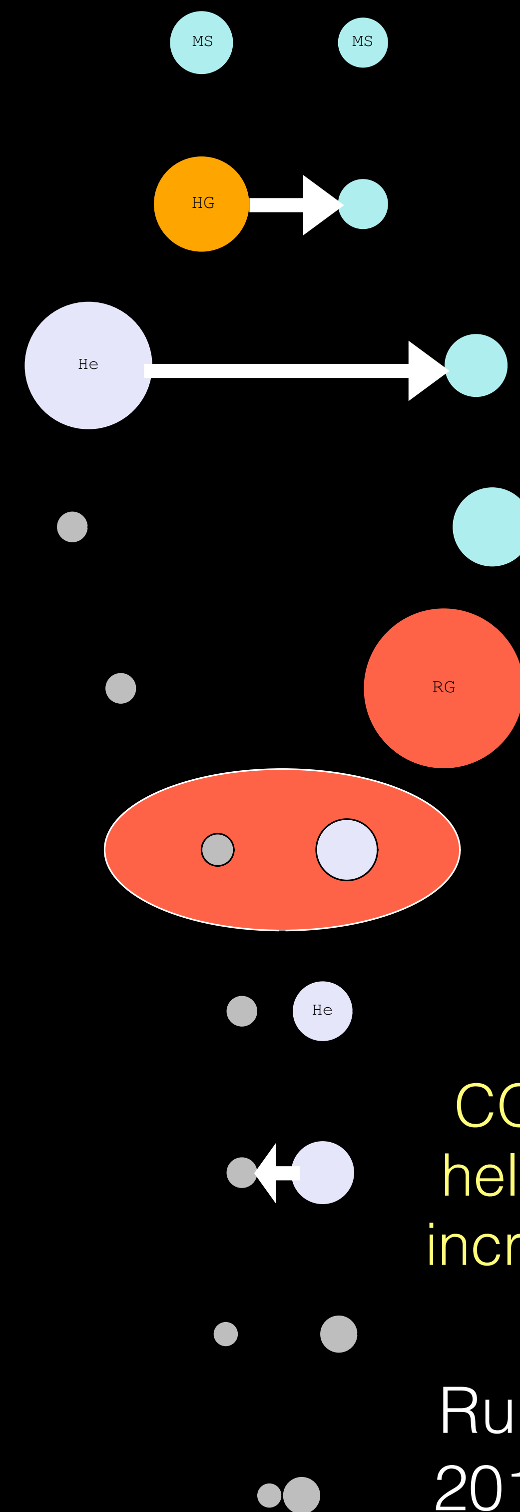
R Coronae Borealis: merger between HeWD + COWD



common envelope

Karakas, Ruiter & Hampel 2015, ApJ 809, 184

Type Ia Supernova: merger between COWD + COWD

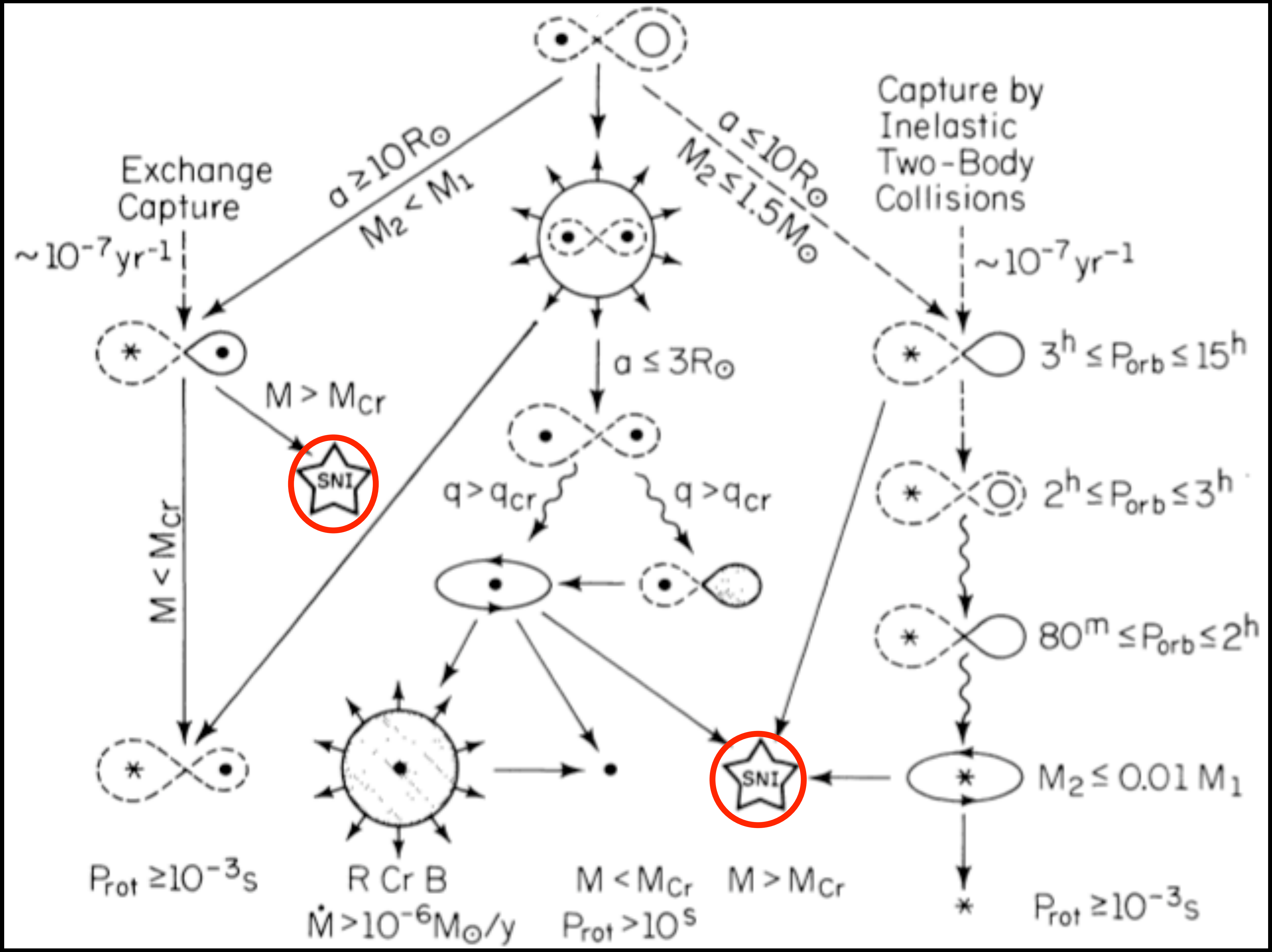


common envelope

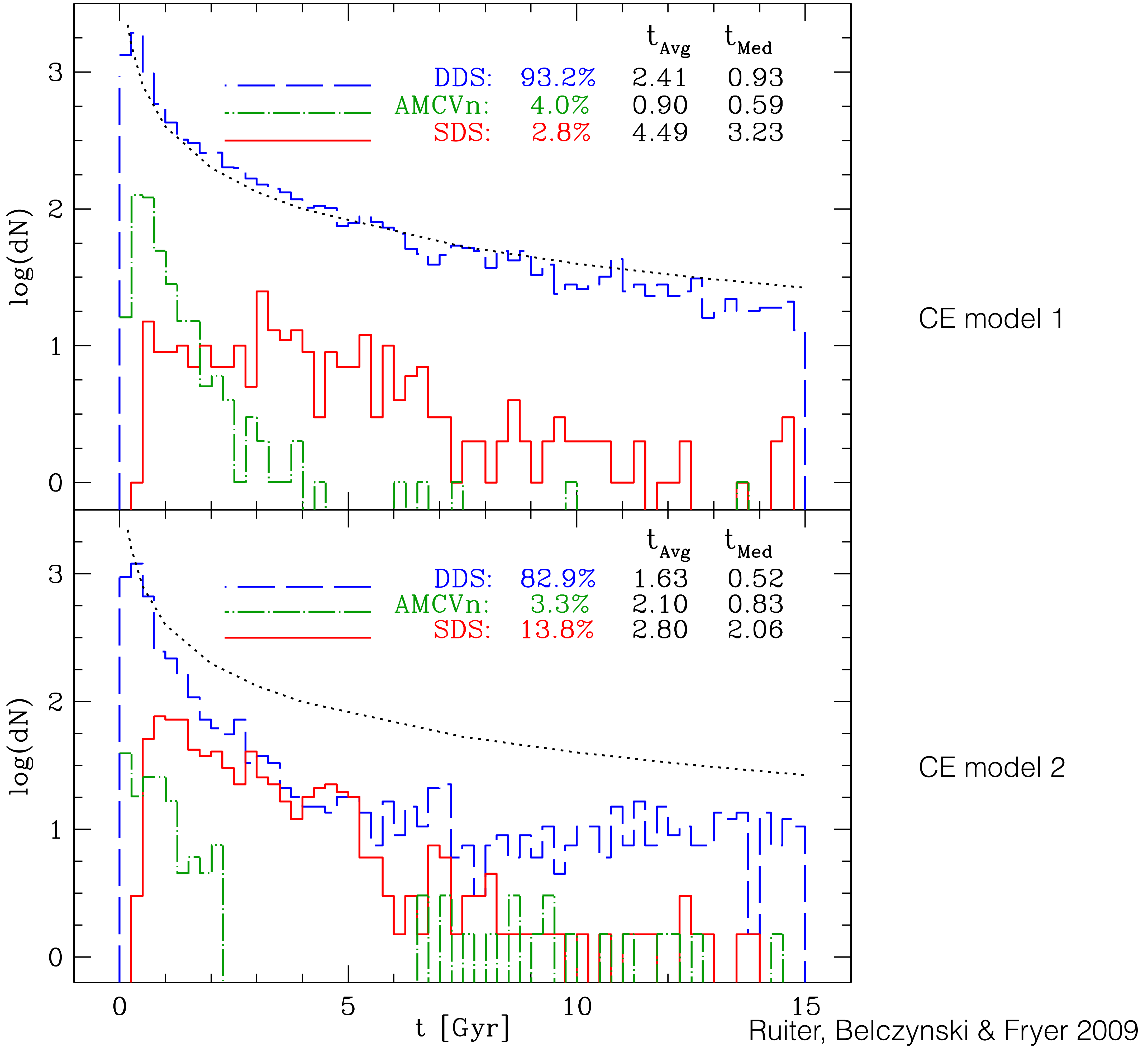
CO primary accretes from helium-burning secondary: increase in mass ~0.2 Msun

Ruiter, Sim, Pakmor et al. 2013, MNRAS 429, 1425

Binary evolution channels: What follows after ZAMS depends on initial masses, mass ratio, separation, [eccentricity]



Iben & Tutukov 1984



t_Avg t_Med
DDS: 93.2% 2.41 0.93
AMCVn: 4.0% 0.90 0.59
SDS: 2.8% 4.49 3.23
CE model 1
t_Avg t_Med
DDS: 82.9% 1.63 0.52
AMCVn: 3.3% 2.10 0.83
SDS: 13.8% 2.80 2.06
CE model 2
log(dN)
t [Gyr]
0
5
10
15
0
1
2
3
Ruiter, Belczynski & Fryer 2009