Close white dwarfs with unevolved companions: constraints on the common envelope phase

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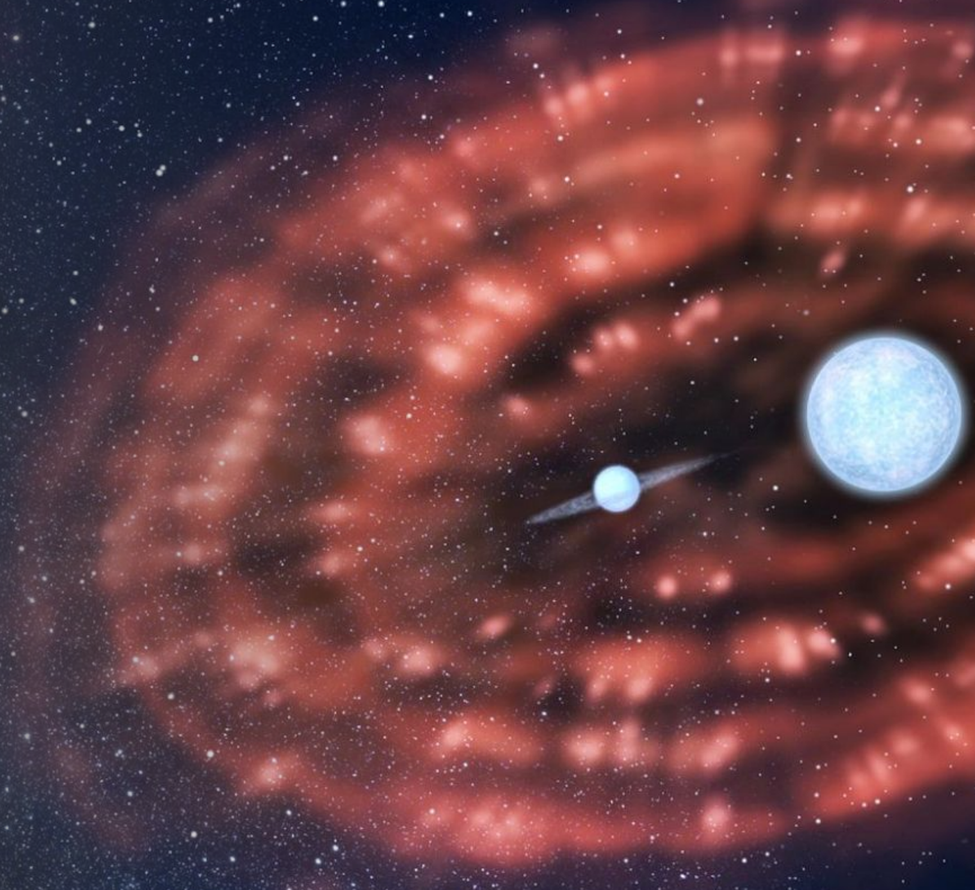
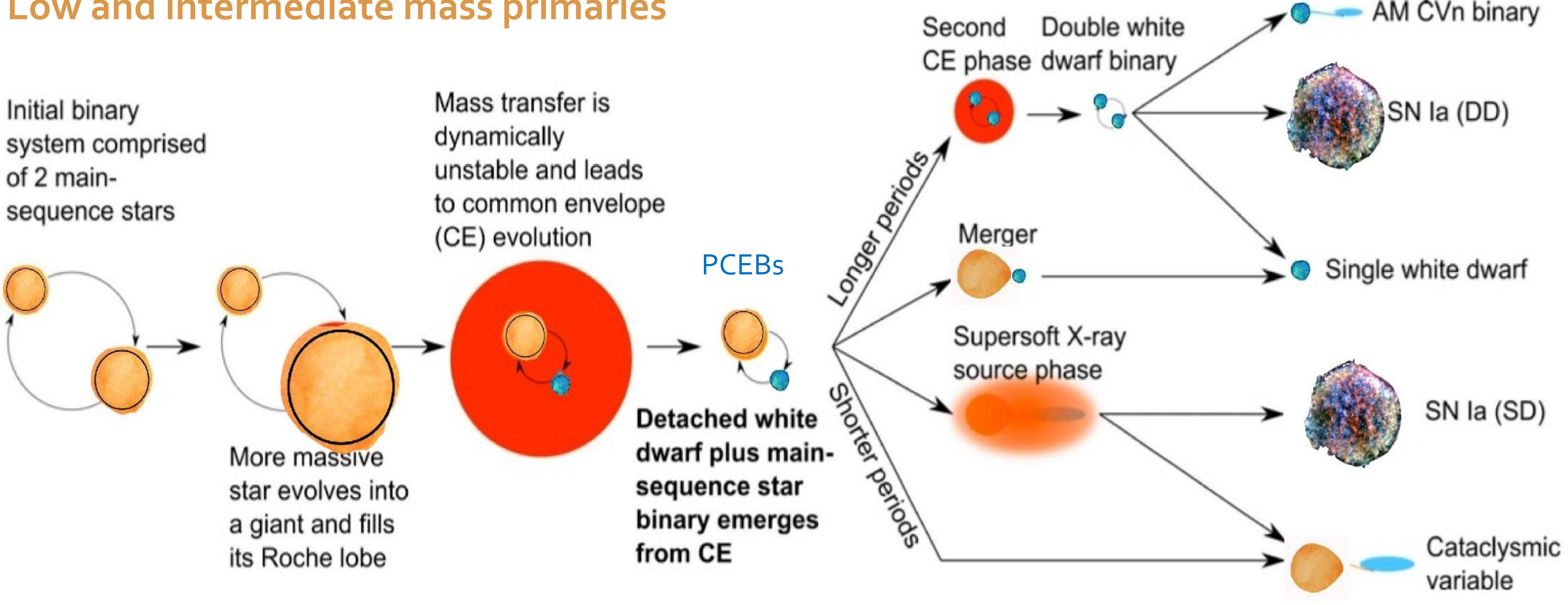


Artist's impression
CE ejection in J 1920
Credit: Jingchuan Yu

CE evolution

Paczynski 1976

Low and intermediate mass primaries

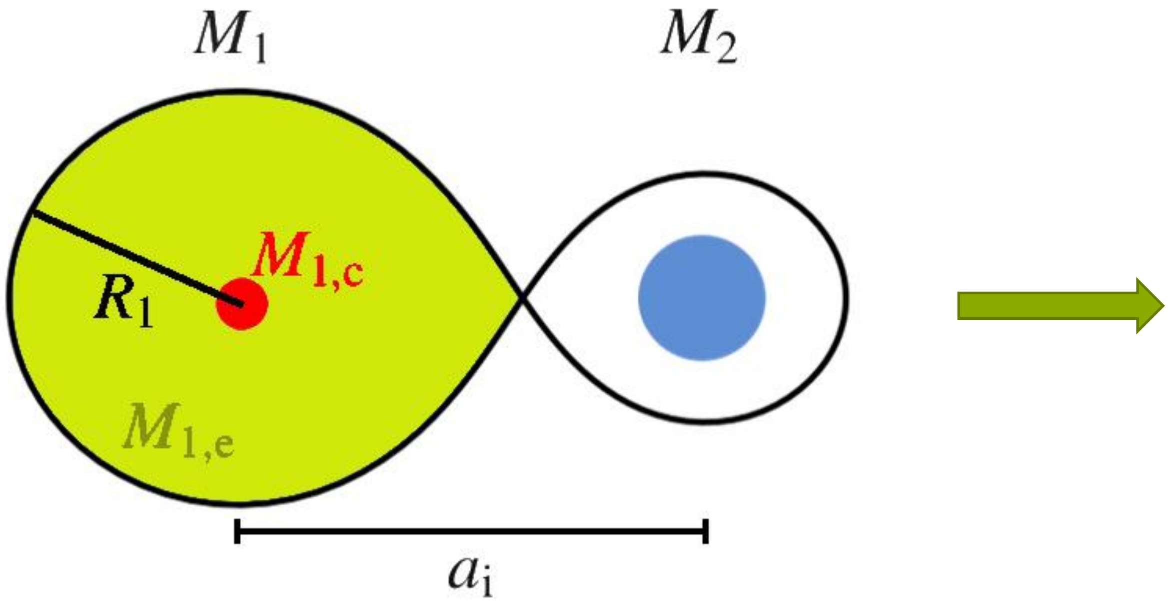


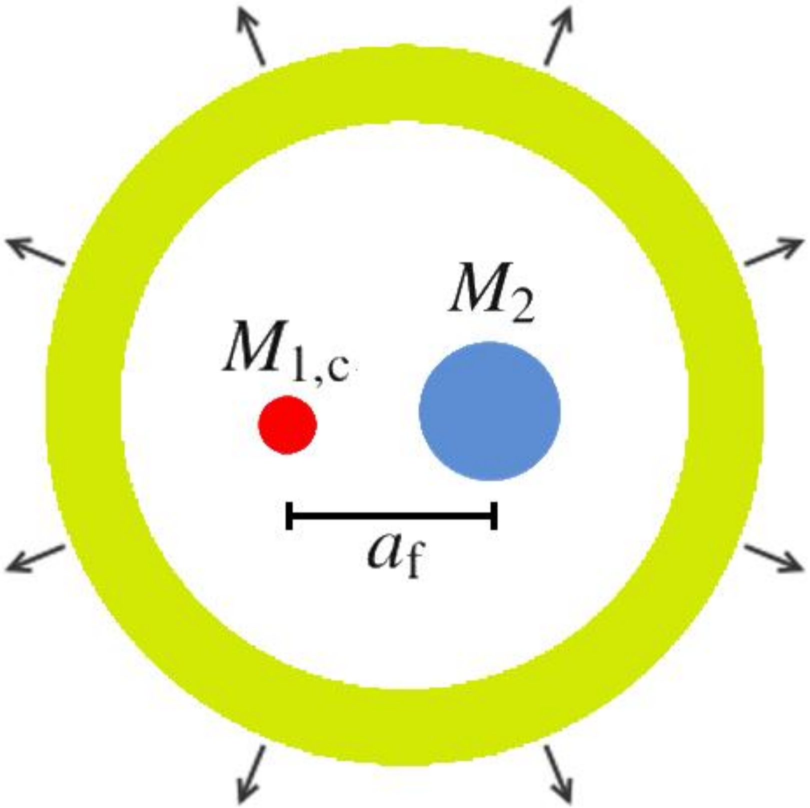
Adapted by M. S. Hernandez from Kulkarni et al. (2021)

Energy formalism

Webbink 1984, Livio and Soker 1988

$$E_{\rm bind} = \alpha_{\rm CE} \Delta E_{\rm orb}$$





$$E_{\rm orb,i} = \frac{1}{2}\frac{GM_{1,c}M_2}{a_i} \; ; E_{\rm bind} = -\frac{GM_1M_{1,e}}{\lambda R_1}$$

$$E_{\rm orb,f} = \frac{1}{2}\frac{GM_{1,c}M_2}{a_f}$$

Energy formalism

Webbink 1984, Livio and Soker 1988

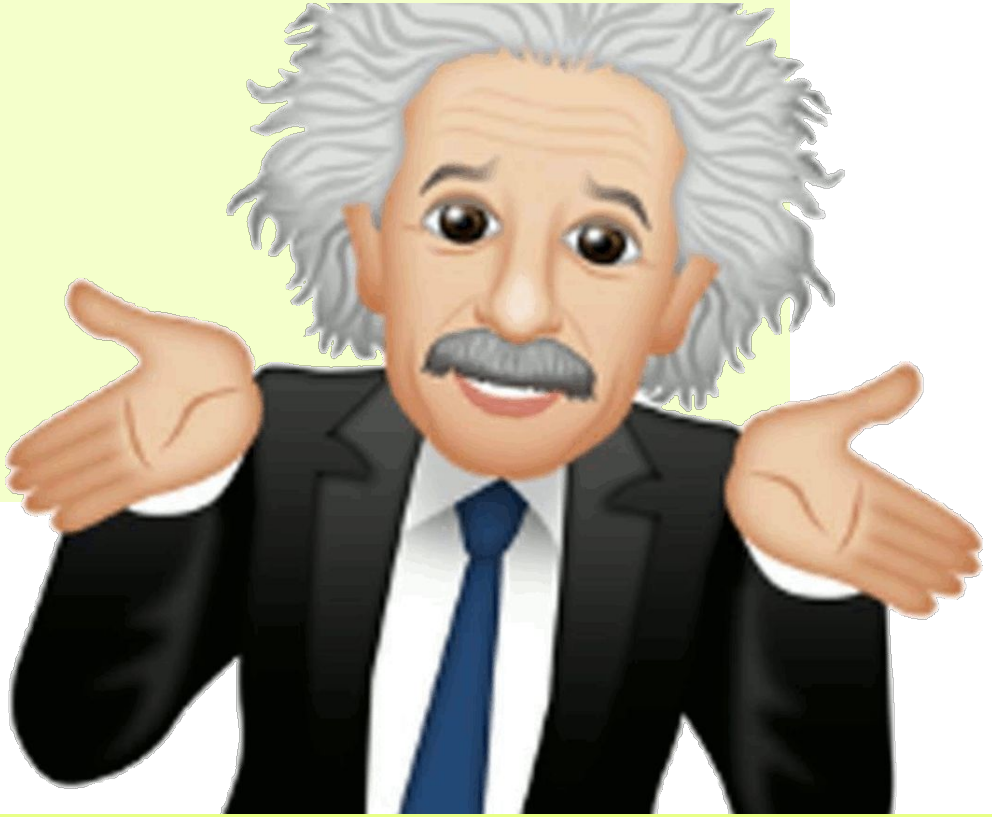
$$E_{\rm bind} = \alpha_{\rm CE} \Delta E_{\rm orb}$$

Is α_{CE} a universal constant?

What is λ?

Careful with $E_{orb,i}$

(some authors use M_1 here)



$$E_{\rm orb,i} = \frac{1}{2}\frac{G M_{\rm 1,c} M_2}{a_{\rm i}} \; ; E_{\rm bind} = -\frac{G M_1 M_{\rm 1,e}}{\lambda R_1}$$

The λ parameter

Accounts for the “real” binding energy of the envelope

$$E_{\rm bind} = -\frac{GM_1M_{1,\rm e}}{\lambda R_1}$$

Different studies assumed:

- Fixed λ value (typically 0.5 or 1.0)
- λ calculated from pure gravitational energy of the envelope

$$-\frac{GM_1M_{1,\rm e}}{\lambda R_1} = -\int_{M_{1,\rm c}}^{M_1} \frac{Gm}{r(m)}\,{\rm d}m$$

- λ calculated from gravitational + a fraction of “internal” energy:

$$-\frac{GM_1M_{1,\rm e}}{\lambda R_1} = \int_{M_{1,\rm c}}^{M_1} \left(-\frac{Gm}{r(m)} + \alpha_{\rm int}U_{\rm int}(m)\right){\rm d}m$$

The λ parameter

Internal energy can include:

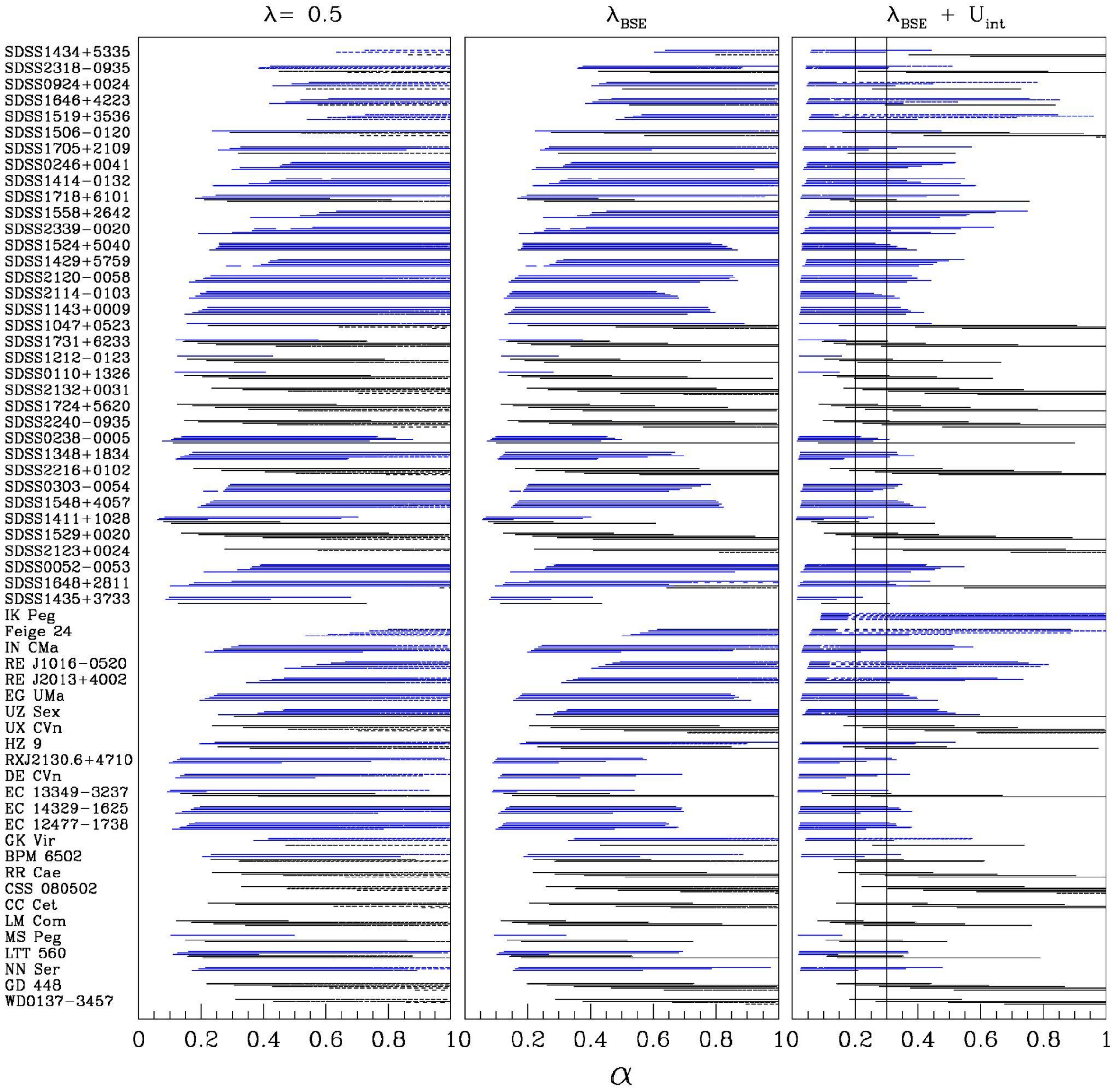
- Thermal energy
- Recombination
- Radiative losses
- Enthalpy
- Convective transport
- ...

(e.g. Dewi & Tauris 2000; Ivanova et al 2013; Wilson & Nordhaus 2022)

all with different efficiencies!

$$E_{\rm bind} = -\frac{G M_1 M_{1,\rm e}}{\lambda R_1} = \int_{M_{1,\rm c}}^{M_1} \left(-\frac{Gm}{r(m)} dm + \alpha_{\rm th} U_{\rm th} + \alpha_{\rm rec} U_{\rm rec} + \ldots \right) dm$$

Zorotovic et al. (2010)



- Left: λ = 0.5

$$E_{\rm bind} = \frac{G M_1 M_{1,\rm e}}{0.5 R_1}$$

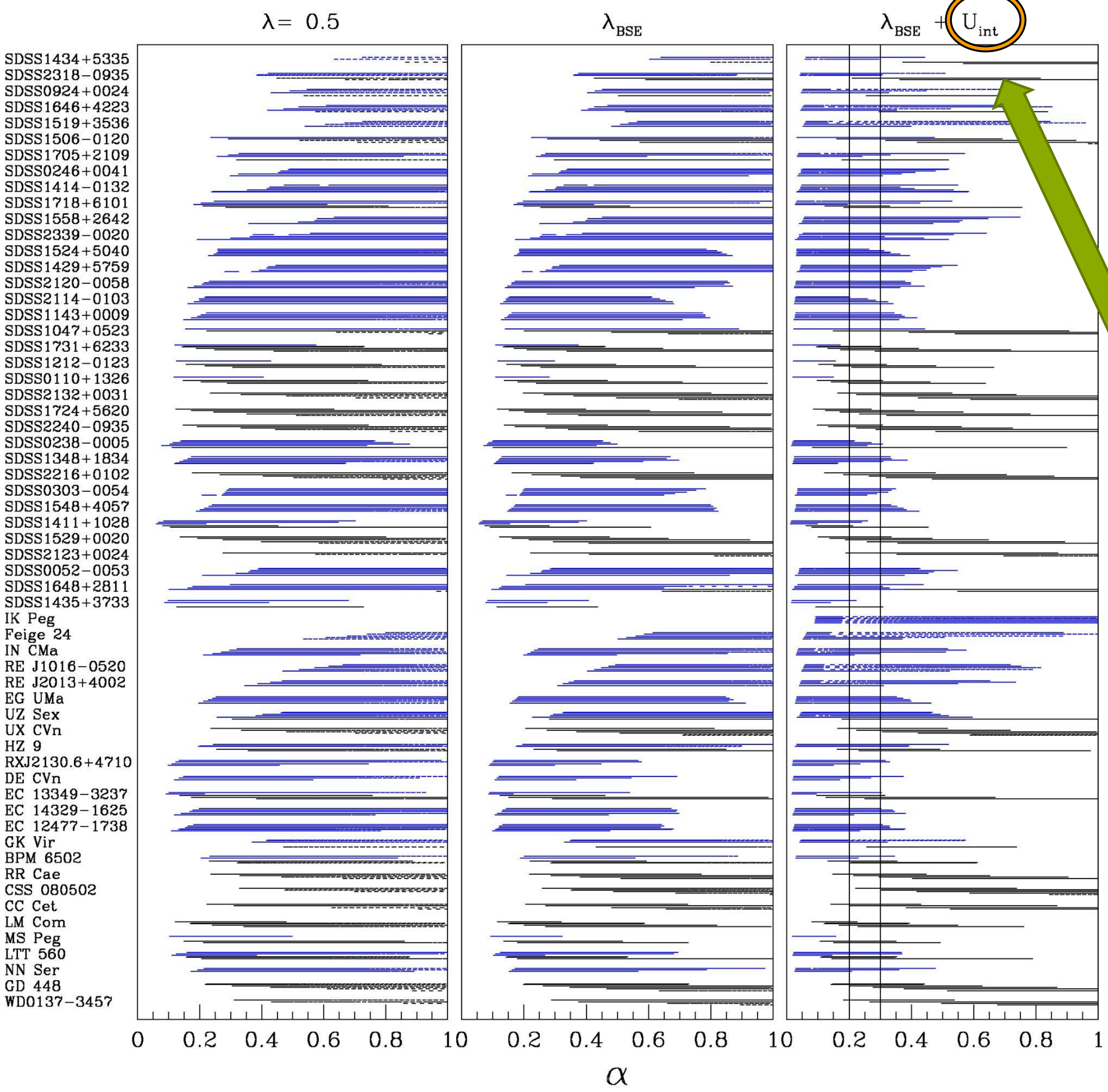
- Middle: λ from BSE code (Hurley et al 2002) without U_{rec}

- Right: λ from BSE code with a fraction

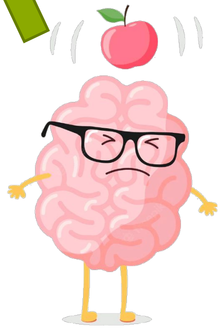
  $\alpha_{rec} = \alpha_{CE}$ of U_{rec}

$\alpha_{CE} \sim 0.25$

Zorotovic et al. (2010)



"I suppose I'll be the one to mention the elephant in the room."



This was not U_{int}

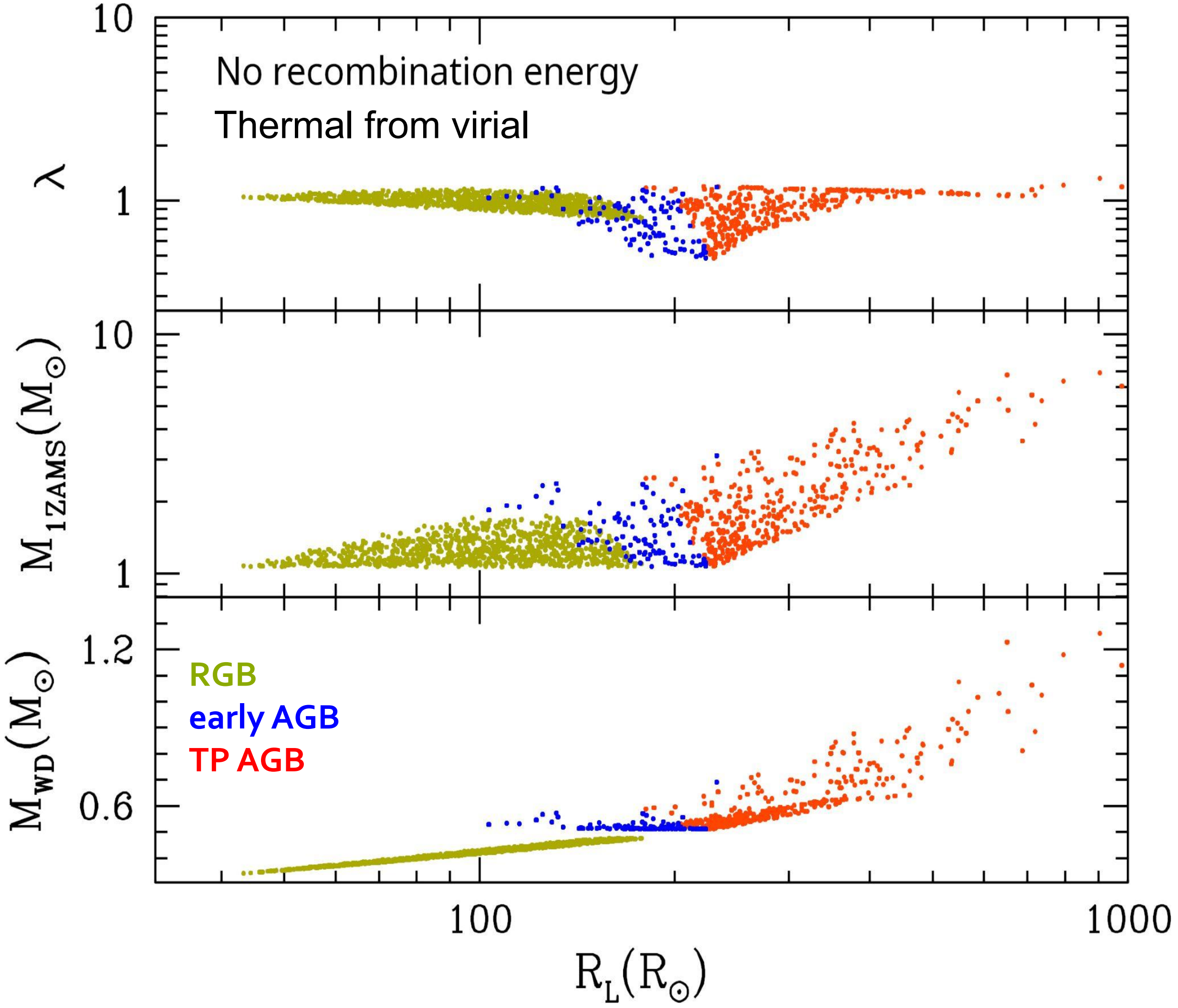
It was U_{rec}

U_{th} included (virial)*

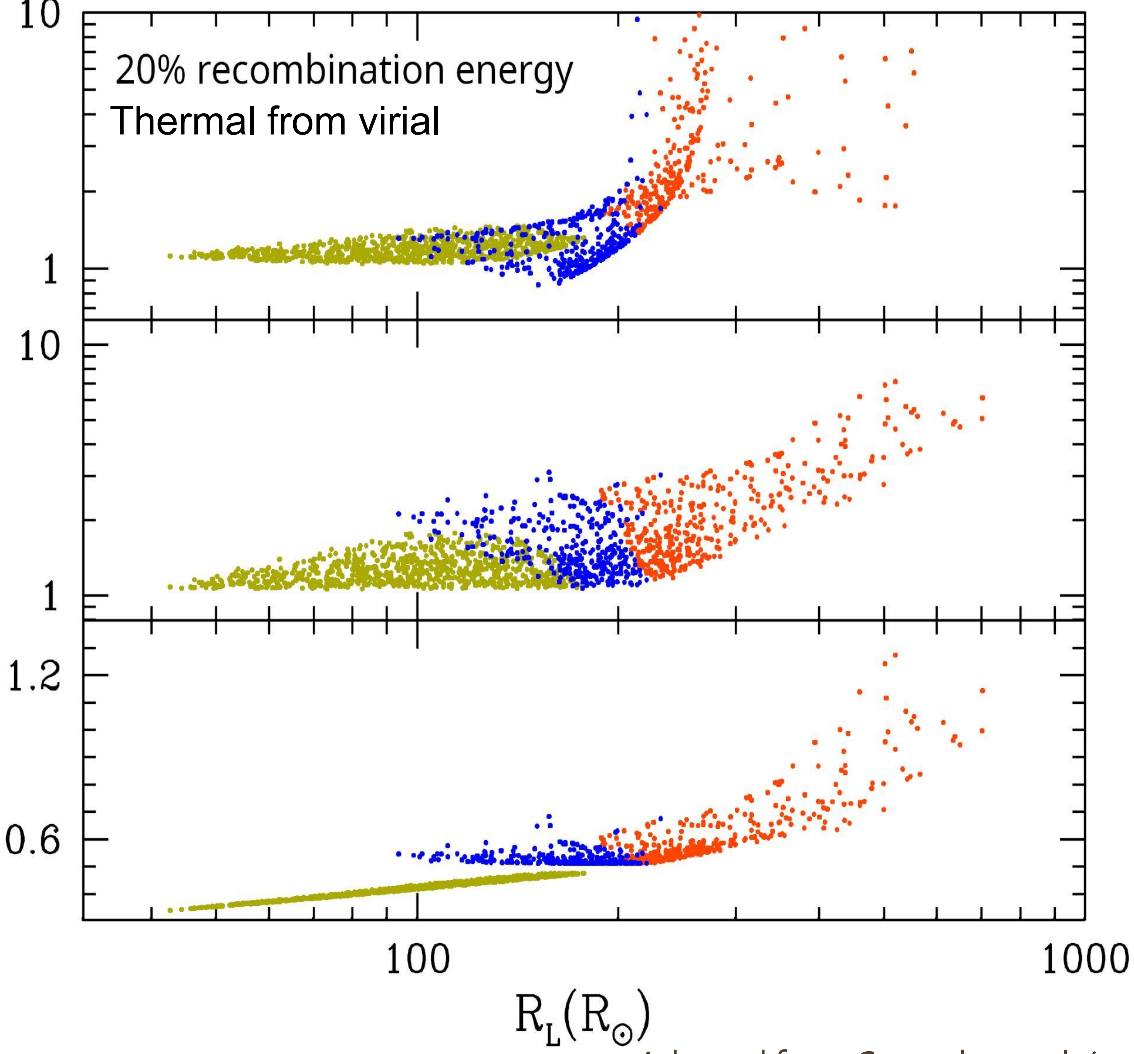
*not clarified in the BSE code, nor in Robert Izzards's PhD thesis (2004) or Claeys et. al (2014) where the fitting formulae was published. But λ is multiplied by 2 at the end, consistent with virial theorem (e.g. De Marco et al. 2011)

λ from BSE

λ~1.0



λ typically > 1, and >> for TP AGB



Adapted from Camacho et al. (2014)

Close WD+dM binaries

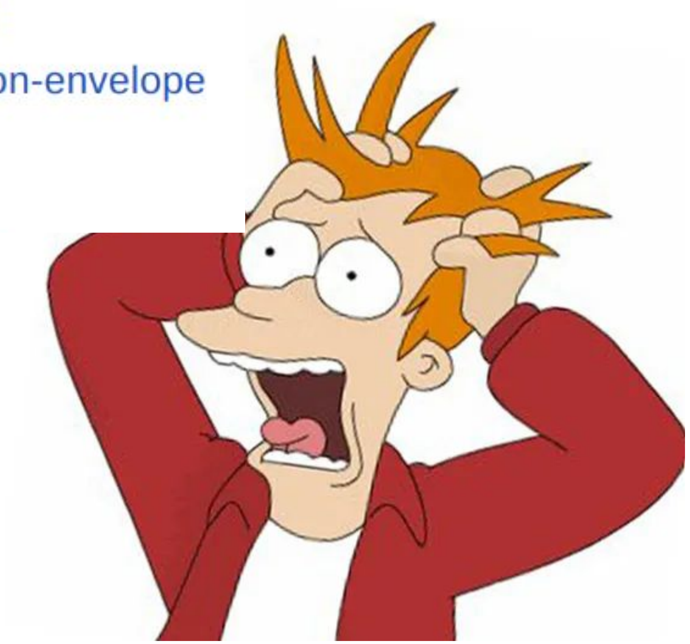
- From reconstruction of observed systems:
  α_{CE} ~0.25 from Zorotovic et. al (2010) was valid for $\alpha_{CE} = \alpha_{rec}$

  25% of recombination energy seems unrealistic!

2010A&A...520A..86Z 2010/09 cited: 209

Post-common-envelope binaries from SDSS. IX: Constraining the common-envelope efficiency

Zorotovic, M.; Schreiber, M. R.; Gänsicke, B. T. *and 1 more*



Close WD+dM binaries

- From reconstruction of observed systems:
  α_{CE} ~0.25 from Zorotovic et. al (2010) was valid for $\alpha_{CE} = \alpha_{rec}$

  25% of recombination energy seems unrealistic!

However….

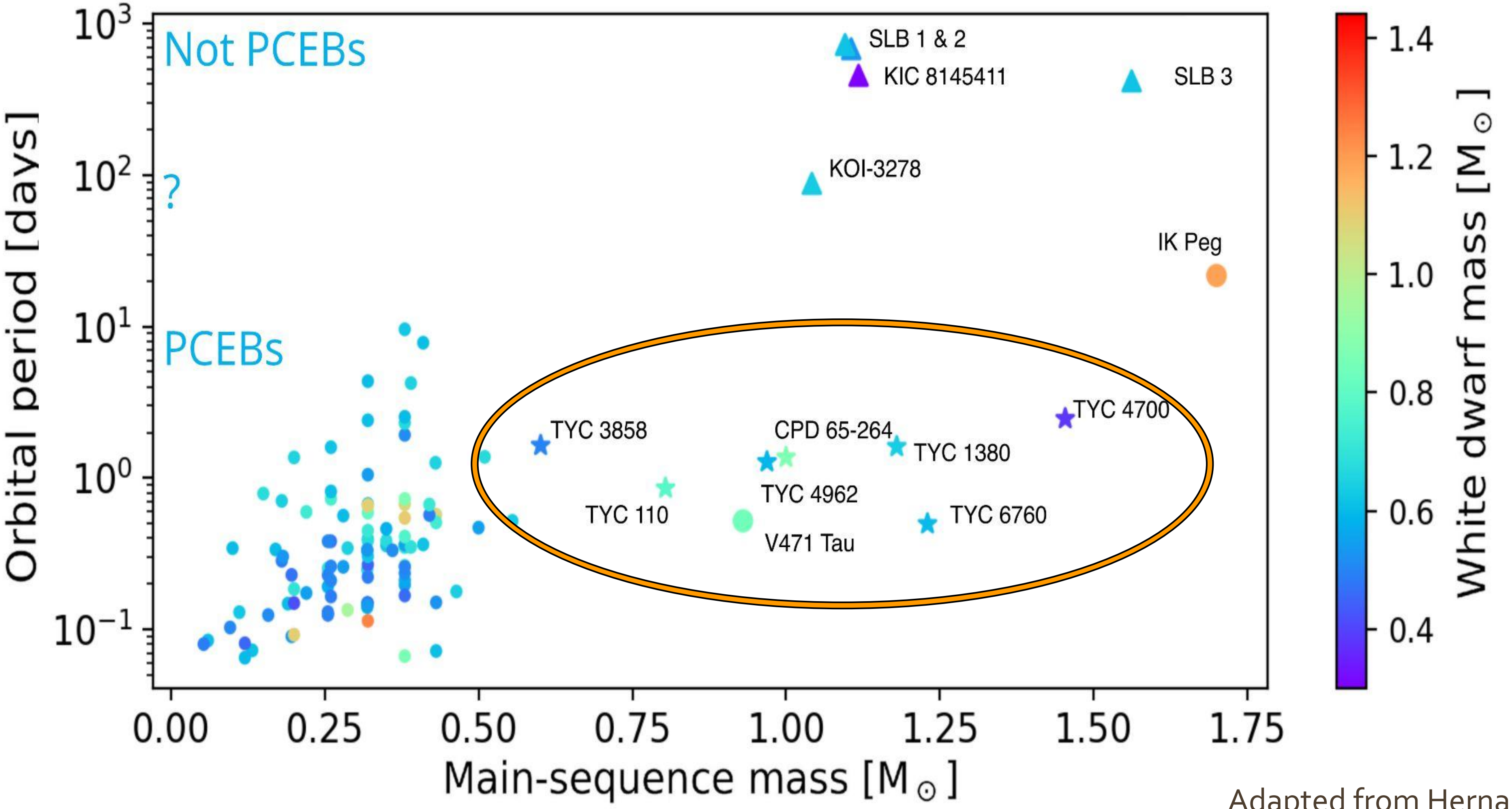
- From simulations vs observations (WD+dM SDSS sample):

  Camacho et al. (2014) favored models with $\boldsymbol{\alpha_{CE} \sim 0.3}$ and no U_{rec} (or at least a very small fraction)

  Toonen & Nelemans (2013) also favored low α_{CE} ($\alpha_{CE}\lambda \sim 0.25$, consistent if $\lambda \sim 1$, i.e. no recombination)

Close WD+AFGK binaries

The white dwarf binary pathways survey



Adapted from Hernandez et al. (2021)

TYC 6760, “The first pre-supersoft X-ray binary” (Parsons et al 2015)

α_{CE} = 0.08–0.89 for AGB progenitor (most likely) and > 0.9 for RGB

Object	α_{CE}	WD mass ($M_\odot$)	$M_{1,i}$ ($M_\odot$)	$P_{orb,i}$ (d)	Age (Gyr)
TYC 4700	0.2–0.3	0.40–0.44	1.30–1.53	203–386	2.78–4.81
	0.18–1.0	0.38–0.44	1.29–1.90	109–395	
TYC 1380	0.2–0.3	0.64–0.85	2.54–3.94	706–2222	0.22–0.77
	0.10–1.0	0.64–0.85	2.36–4.06	126–2222	
TYC 4962	0.2–0.3	0.59–0.77	2.28–3.36	617–1917	0.35–1.04
	0.07–1.0	0.59–0.77	1.75–3.46	103–1917	

Hernandez et al. (2021)

Object	α_{CE}	WD mass ($M_\odot$)	$M_{1,i}$ ($M_\odot$)	$P_{orb,i}$ (d)	CE age (Gyr)
TYC 110 (*HST*)	0.2–0.3	0.75–0.82	3.24–3.71	929–1947	0.26–0.38
	0.19–1.0	0.75–0.82	3.15–3.75	147–2015	0.26–0.42
TYC 3858	0.2–0.3	0.34–0.62	0.98–2.11	103–1477	1.29–13.29
	0.03–1.0	0.27–0.68	0.98–2.98	22–1591	0.49–13.29

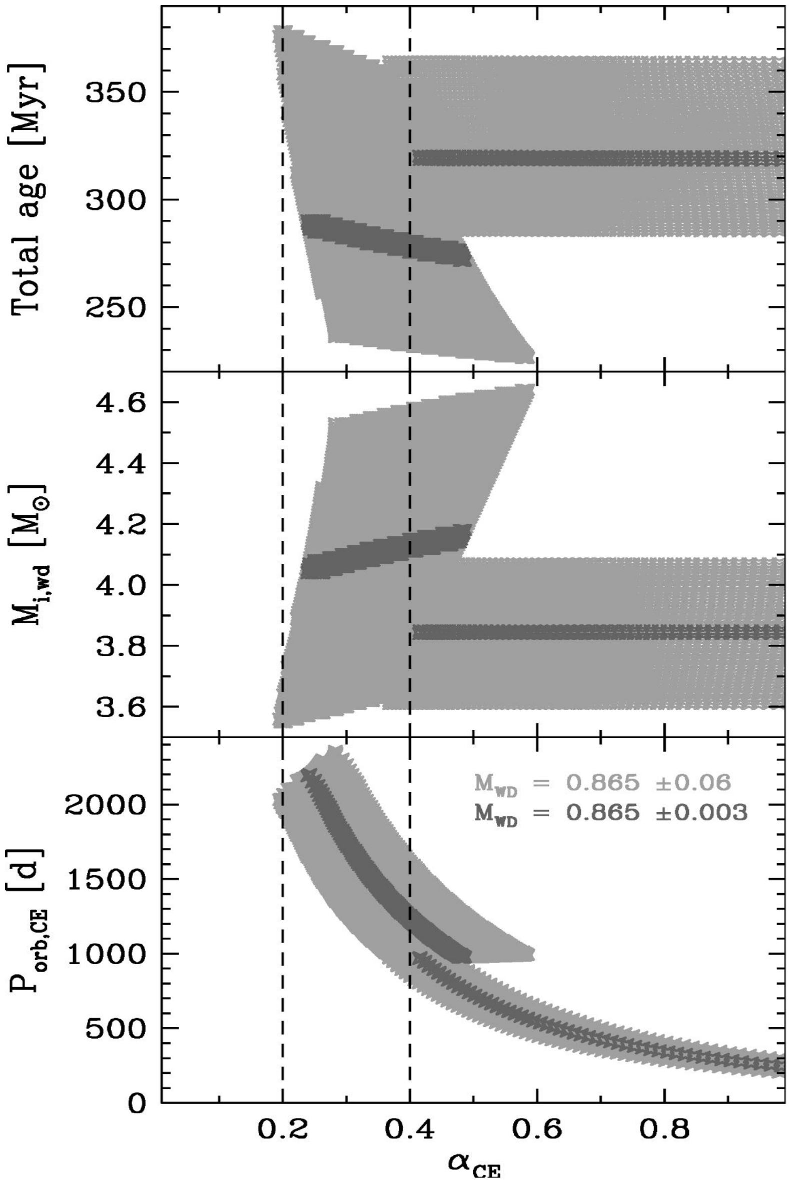
Hernandez et al. (2022a)

All systems wit P_{orb} < 3 days

No recombination energy needed (thermal included)

$\alpha_{CE} \gtrsim 0.2$ works for all

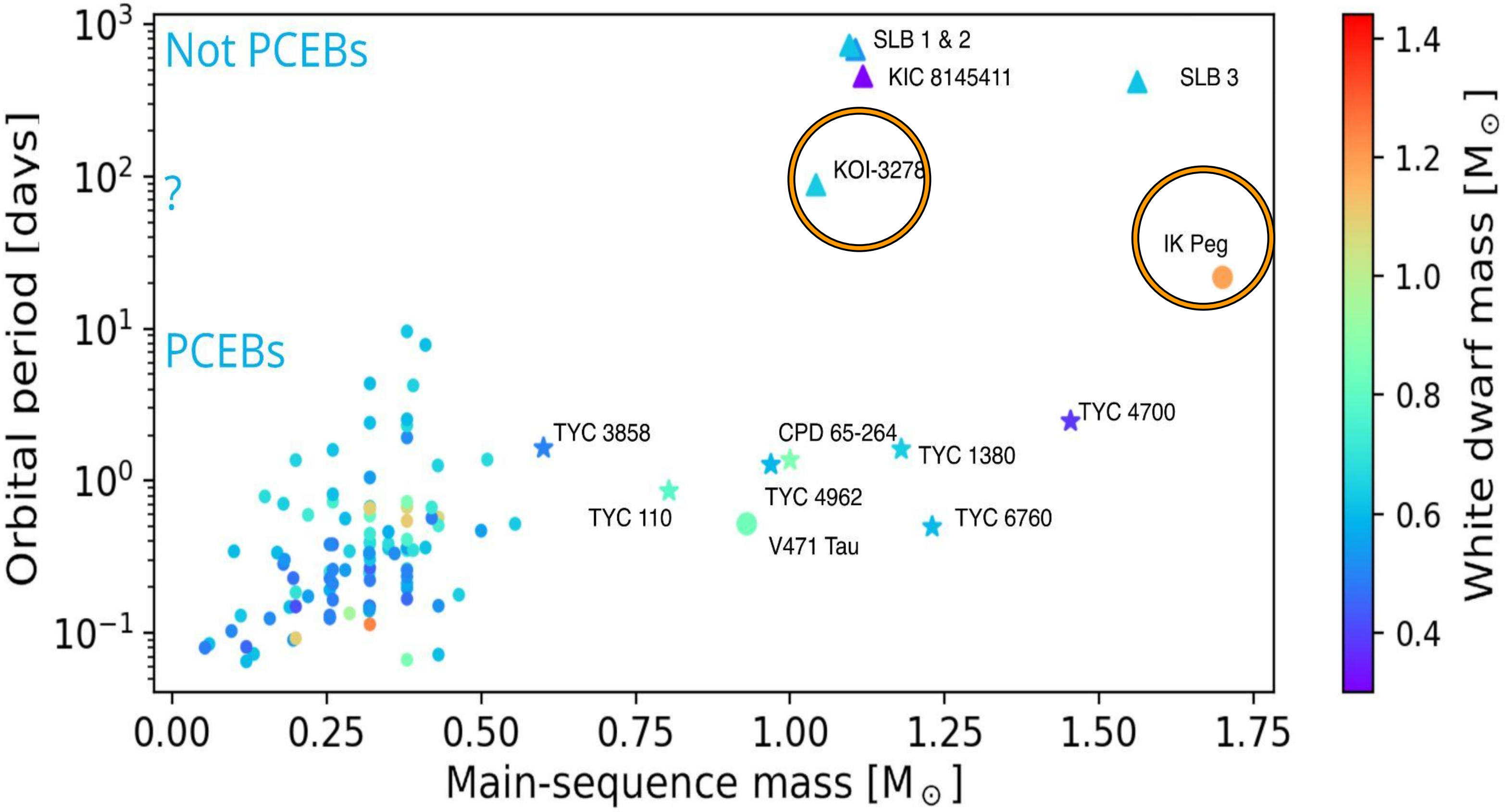
CPD-65 264



Hernandez et al. (2022b)

IK Peg and KOI 3287

Outliers?

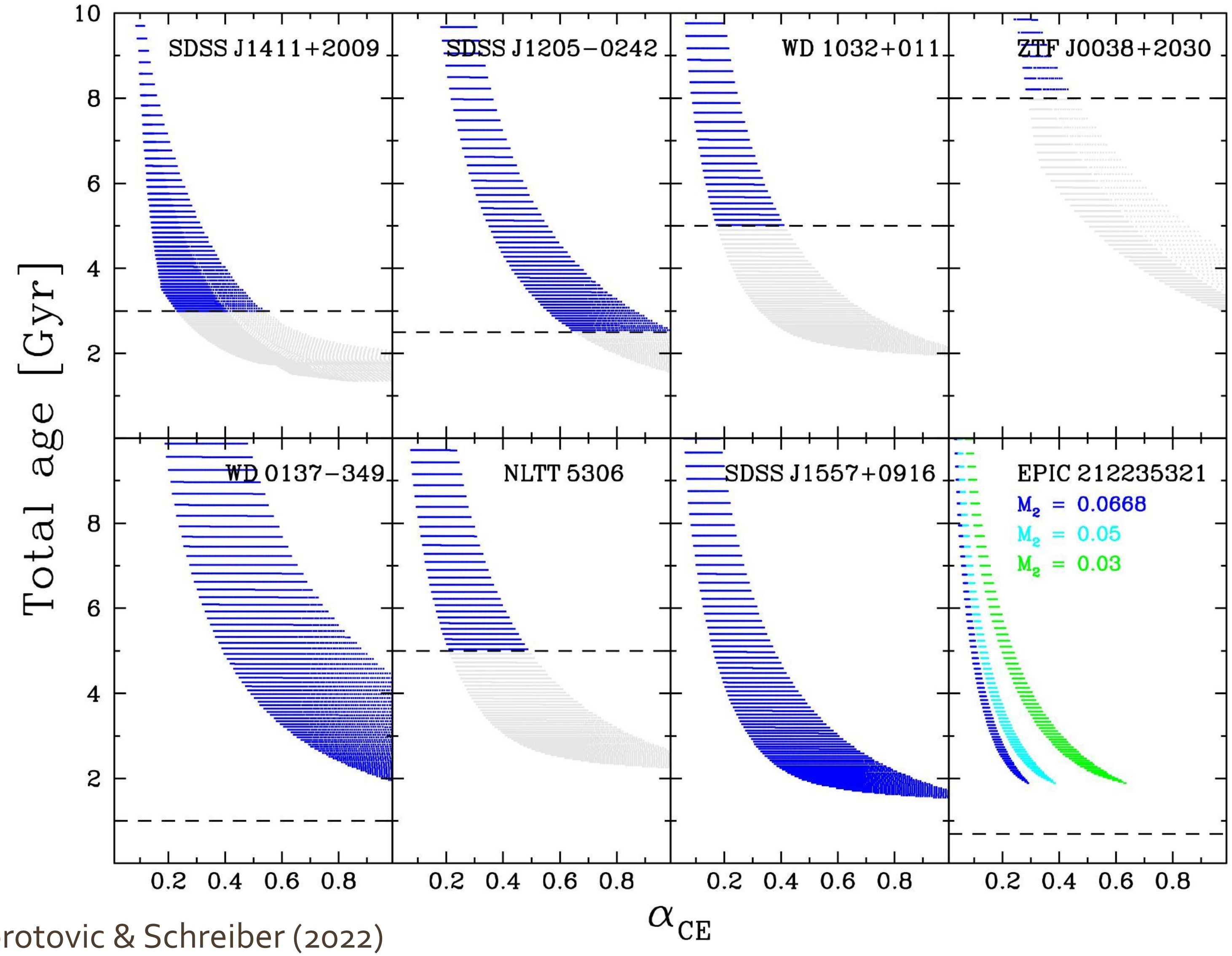


Adapted from Hernandez et al. (2021)

Only 1-2% of recombination energy needed to get $\alpha_{CE} < 1$

Or any other source of extra energy?

Close WD+BD binaries



Zorotovic & Schreiber (2022)

7 systems with P_{orb} < 0.1 days

1 system with P_{orb} ~ 0.43 days

No recombination energy needed (thermal included)

α_{CE} = 0.24 – 0.41 works for all when considering age restrictions (dashed lines)

Metallicity effects

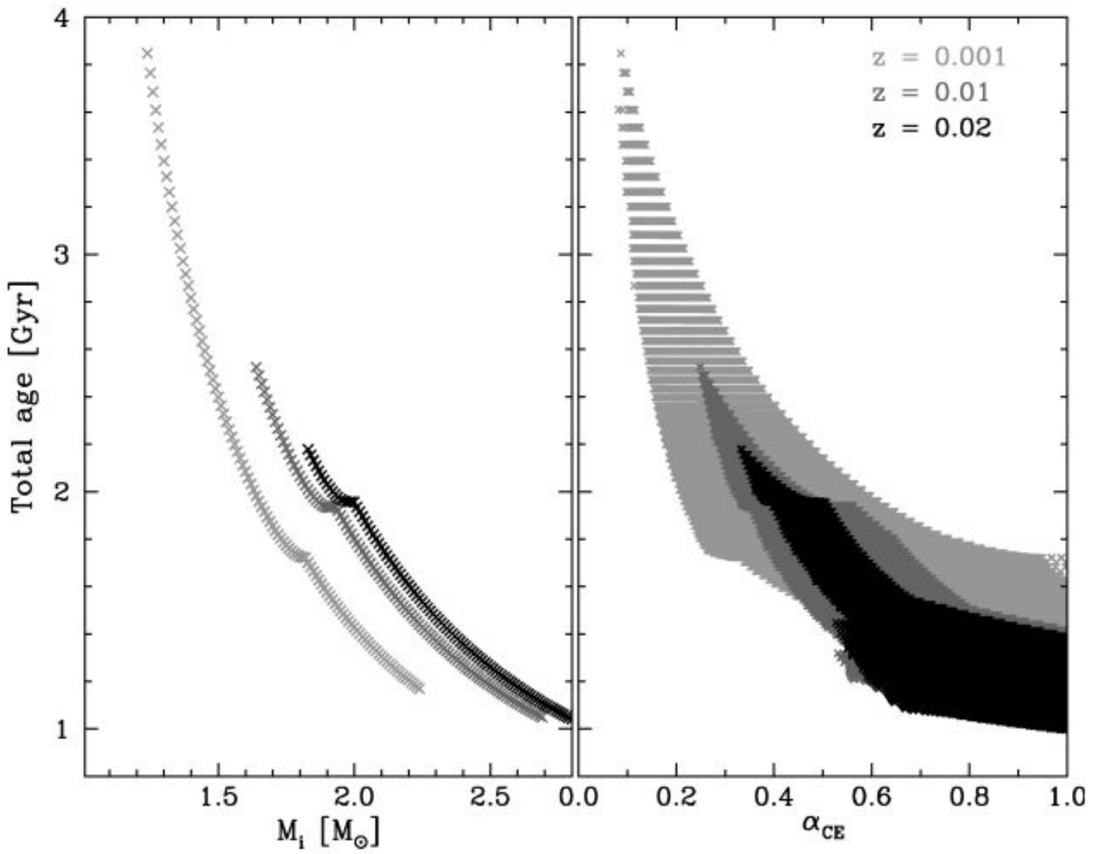


Figure 6. Total age of the system as a function of initial mass of the progenitor of the white dwarf (*left*) and common-envelope efficiency α_{CE} (*right*) derived from our reconstruction for three different assumptions of the initial metallicity (z). A white dwarf mass of $0.6 - 0.7 M_\odot$ and a brown dwarf mass of $0.085 M_\odot$ were assumed in this figure.

Casewell et al. (in prep)

Work in progress for GD 1400

Another WD+BD with P_{orb} ~ 0.4 days

Lower z allows for smaller initial masses

→ smaller α_{CE} (less mass in the envelope)

→ longer evolutionary timescale (older systems).

Summary

- We need to be consistent in the treatment of λ in order to constrain α_{CE}
- **Recombination energy is not needed for the vast majority of systems** (only 1-2% needed to explain outliers, could be something else)
- WD+dM PCEBs: $\alpha_{CE} \sim 0.3$
- WD+AFGK PCEBs: $\alpha_{CE} \gtrsim 0.2$
- WD+BD PCEBs: $\alpha_{CE} = 0.24 – 0.41$
- WD+WDs: $\alpha_{CE} \sim 1/3$? (see Peter Scherbak's talk this afternoon)
- Metallicity matters!