Does metallicity influence the evolution and rate of Type Ia supernovae? (WD mergers)

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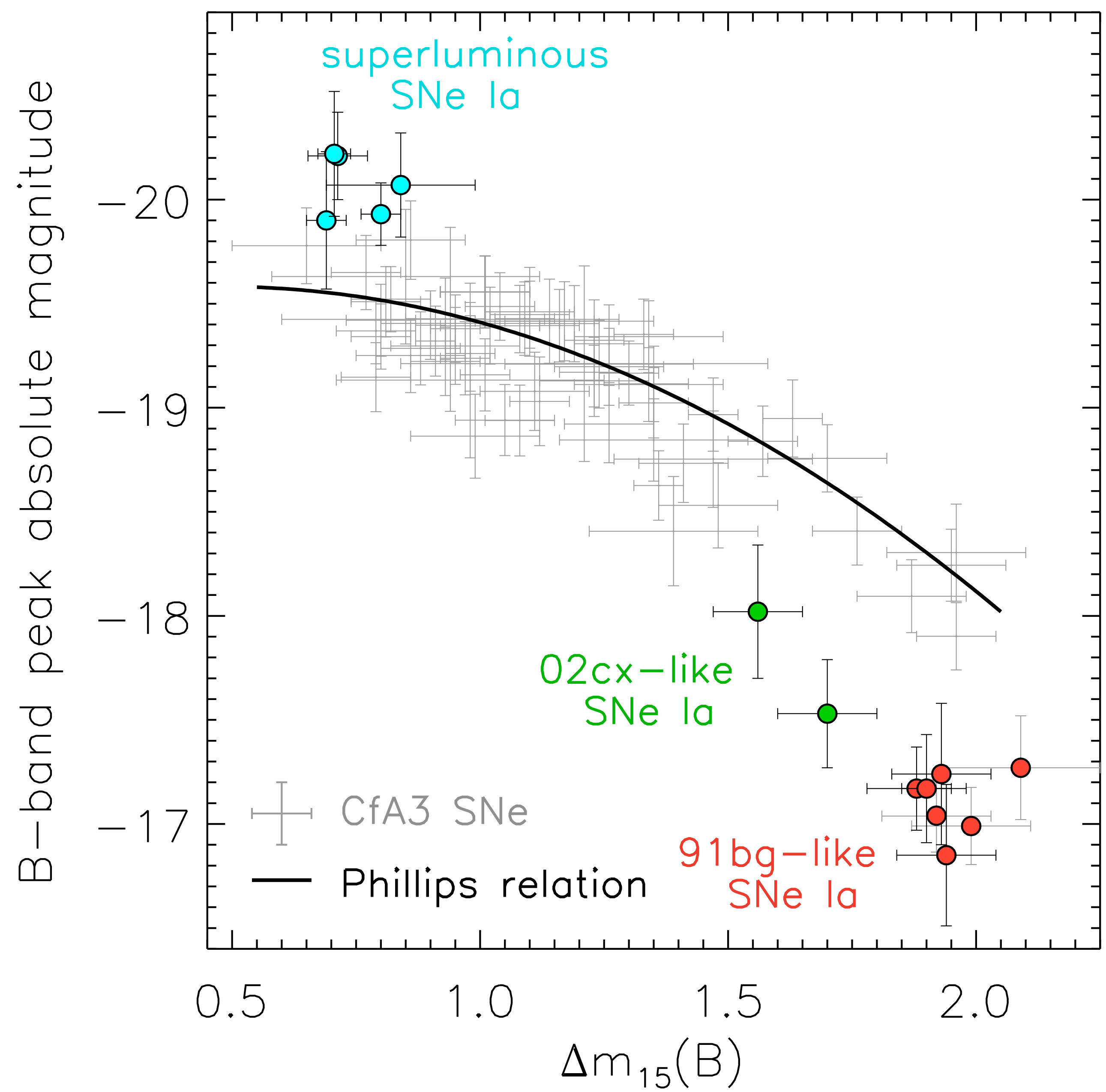
What is the cause of diversity among SN Ia population?

- Diversity in SN Ia properties ⇒ progenitors likely form via more than one evolutionary channel.
- Support that ∼50% of SNe Ia need to be $< 1.4\ M_\odot$ (sub-Chandra); *Scalzo et al. 2014, MNRAS 445, 2535*.
- Mix of sub-MCh and MCh WD progenitors best explains solar abundance of manganese; *Seitenzahl et al. 2013, A&A 559, L5*.



Hillebrandt et al. 2013

- 'Old paradigm' of Chandrasekhar mass explosion still supported, but there's likely more to this story.

Why look at metallicity (Z)?

effect on progenitor evolution, explosion mech, etc.?

- Relation between **SN Ia progenitor age** (metallicity?) **and galaxy mass** (e.g. Childress, Johansson). Important to understand trends for SN cosmology!

- **Metallicity effect for some progenitors**: can't make SDS SNe Ia @ [Fe/H] < -1 (Kobayashi et al.) since WD cannot achieve MCh (*WD needs to produce a wind*). See also Howell et al. 2009; Kistler et al. 2013.

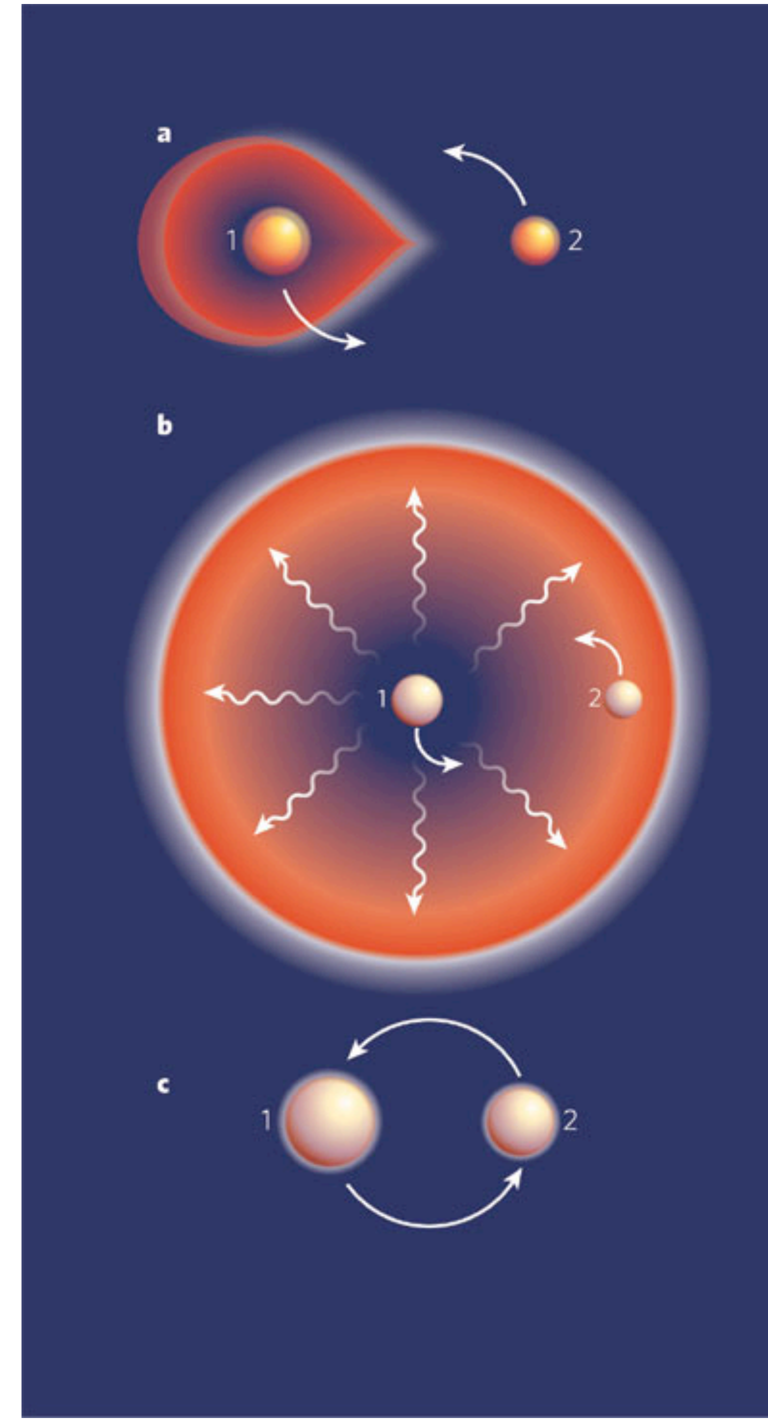
- Other than **stellar winds**: **Z-dependent Common Envelope (CE)**? Lower-Z stars generally less bloated -> higher binding energy -> **less efficient CE** (Xu & Li; M. Dominik, private communication).

Biggest uncertainty in population synthesis: mass transfer/accretion and common envelope.

- Angular Momentum Loss (AML) through Roche-lobe overflow (RLOF), Common Envelope (CE), magnetic braking, gravitational radiation $\rightarrow \dot{J}_{\rm orb}$
- On what timescale does mass transfer proceed? $\rightarrow \dot{M}_{\rm nuc}$ or $\dot{M}_{\rm th}$,?
  Non-degenerate vs. degenerate?
  CE: $\dot{M}_{\rm dyn}$, **two formalisms** we use in BPS: Webbink (α); Nelemans (γ):

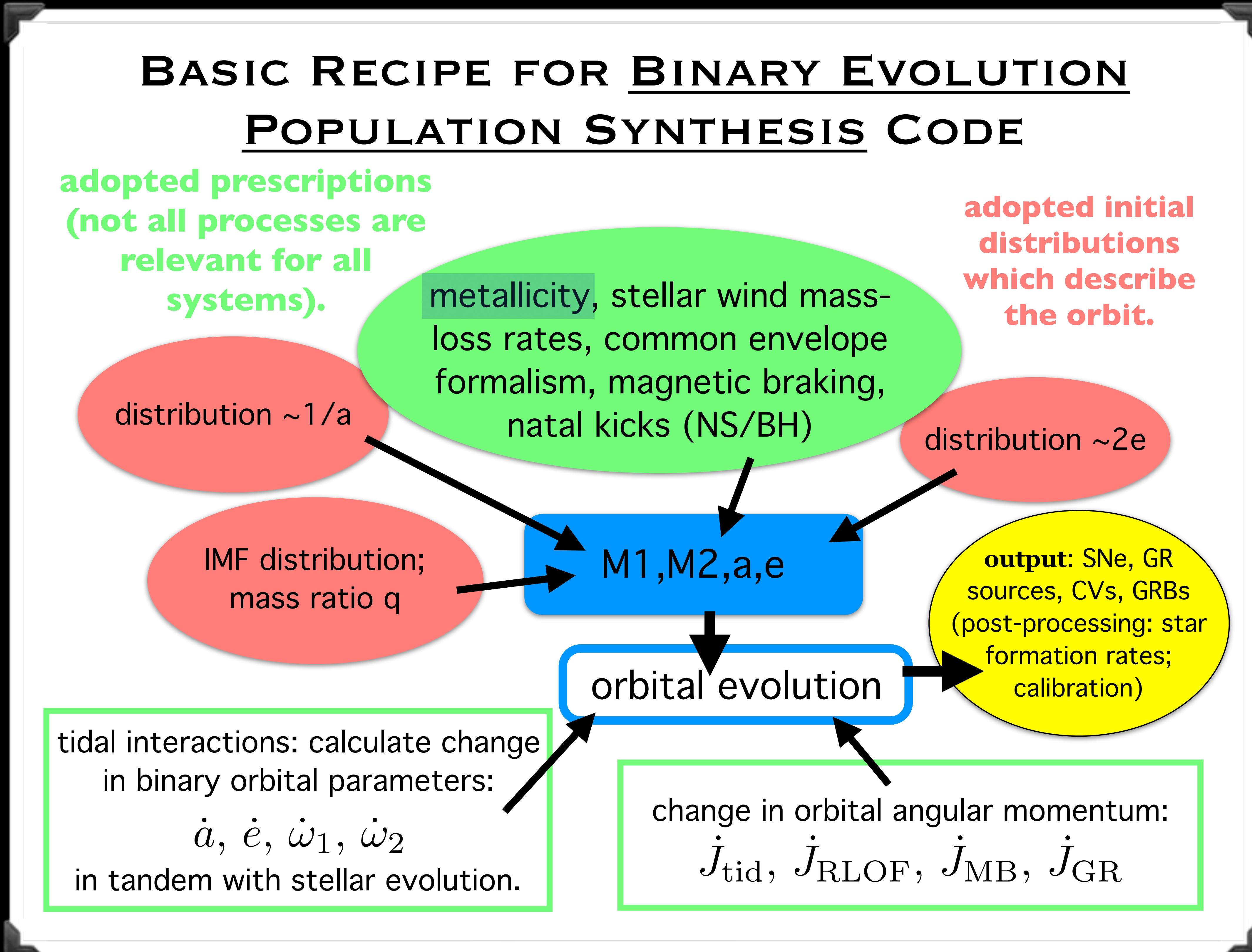
$$\alpha\left(\frac{-G\,M_{\rm rem}\,M_2}{2a_{\rm f}} + \frac{G\,M_{\rm giant}\,M_2}{2a_{\rm i}}\right) = -\frac{G\,M_{\rm giant}\,M_{\rm env}}{\lambda\,R_{\rm giant}}$$

$$\gamma\,\frac{J_{\rm i}}{M_{\rm giant}+M_2} = \frac{J_{\rm i}-J_{\rm f}}{M_{\rm env}}$$



Binding energy parameter "λ" may have *metallicity dependence* (Xu & Li, 2010).

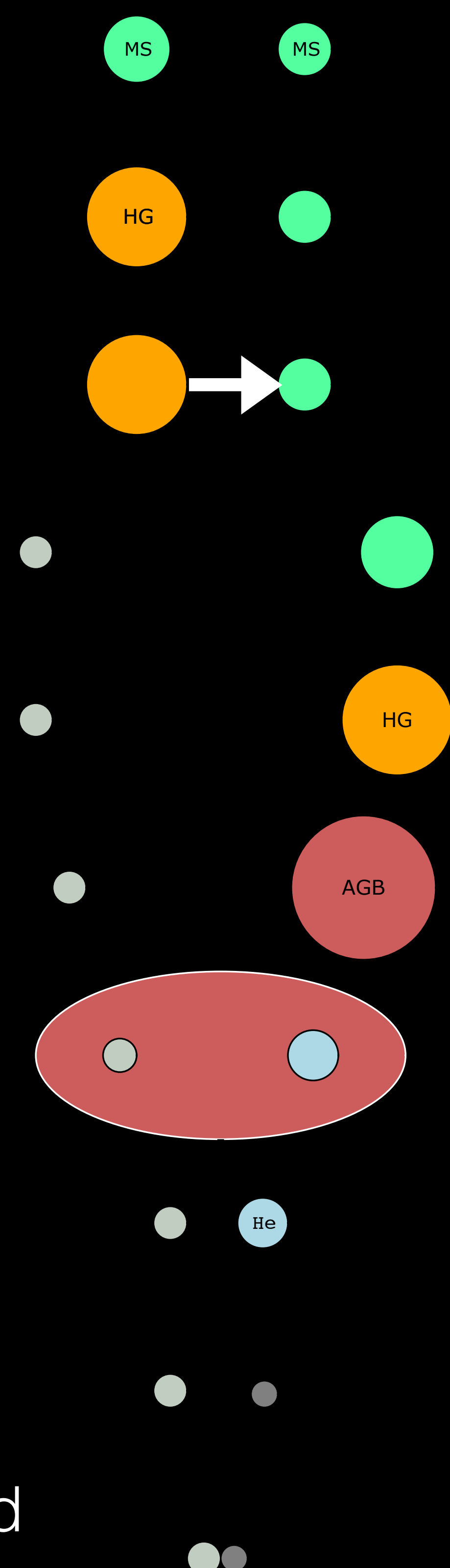
StarTrack BPS code (e.g. Belczynski et al. 2008).
Orbital equations evolved in tandem with stellar evolution.



Orbital separation 'a', eccentricity 'e', Initial Mass Function (IMF) of stars: chosen via Monte Carlo from probability distribution functions that are based on observational data.

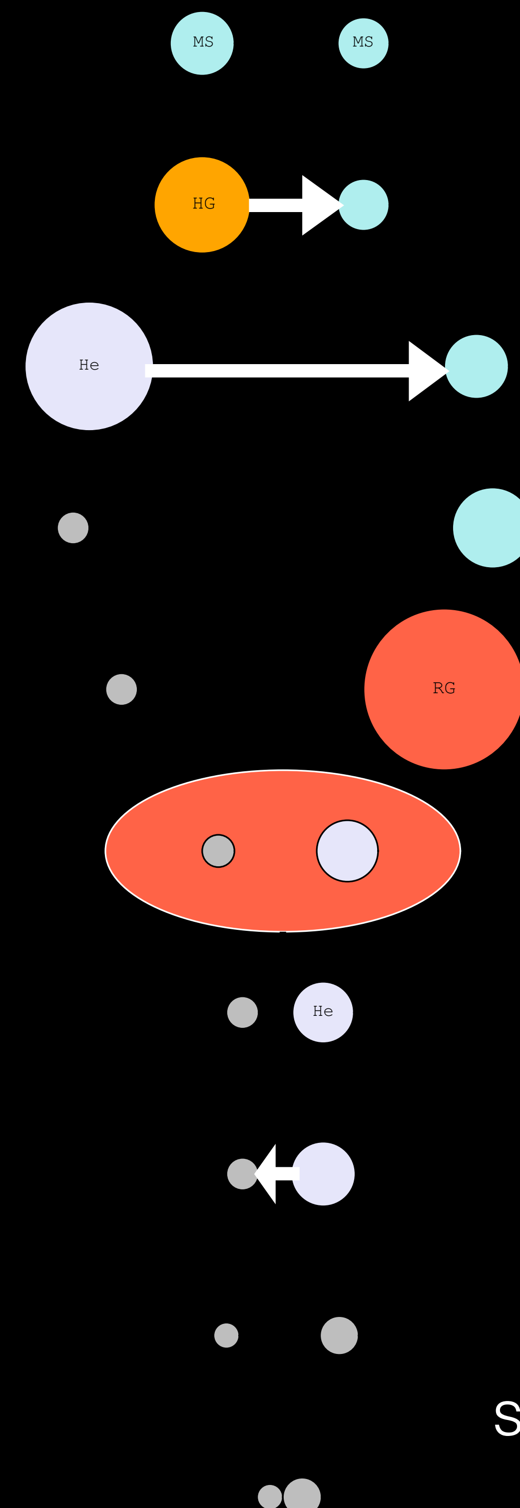
- We investigate the **effect of Z on WD-WD mergers**, and use an improved CE parametrization ("γ; αλ"). Below: 2 WD merger formation channels.

R Coronae Borealis:
merger between
HeWD + COWD



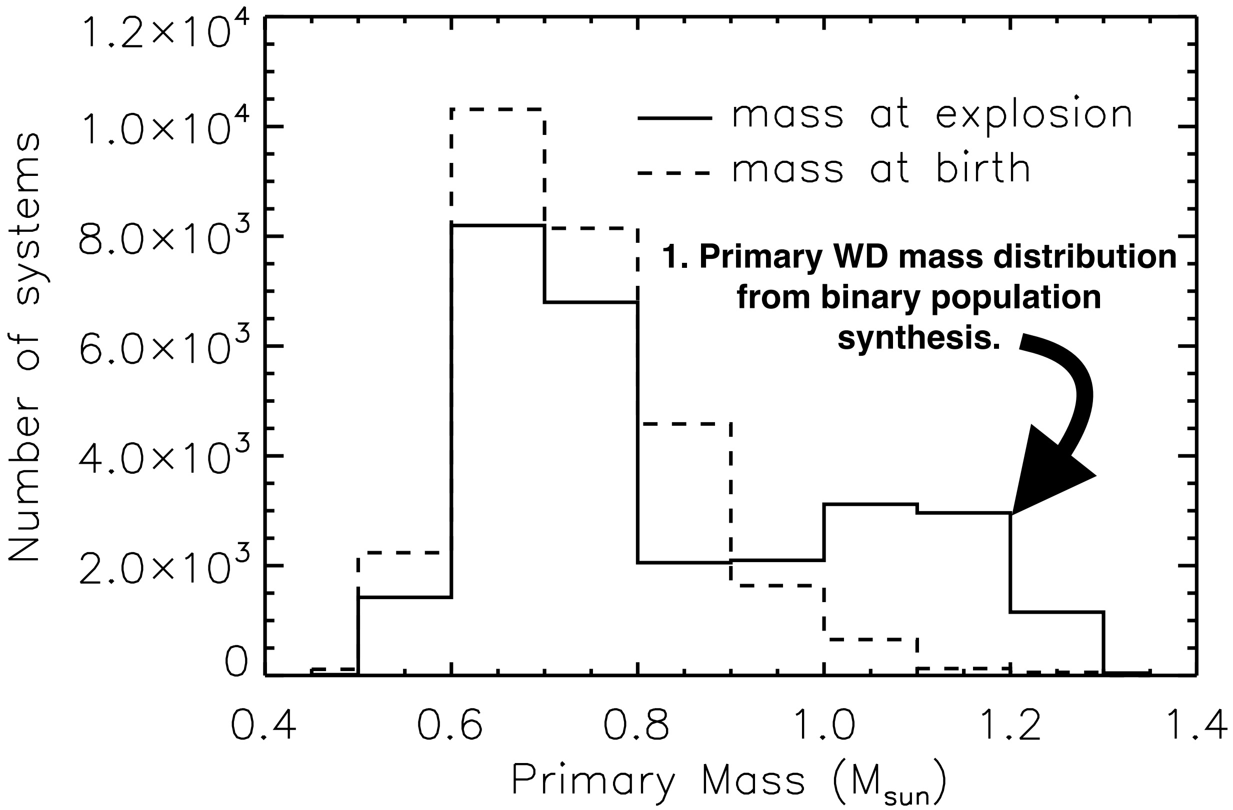
see Karakas, Ruiter & Hampel 2015, Accepted

Type Ia Supernova:
merger between
COWD + COWD

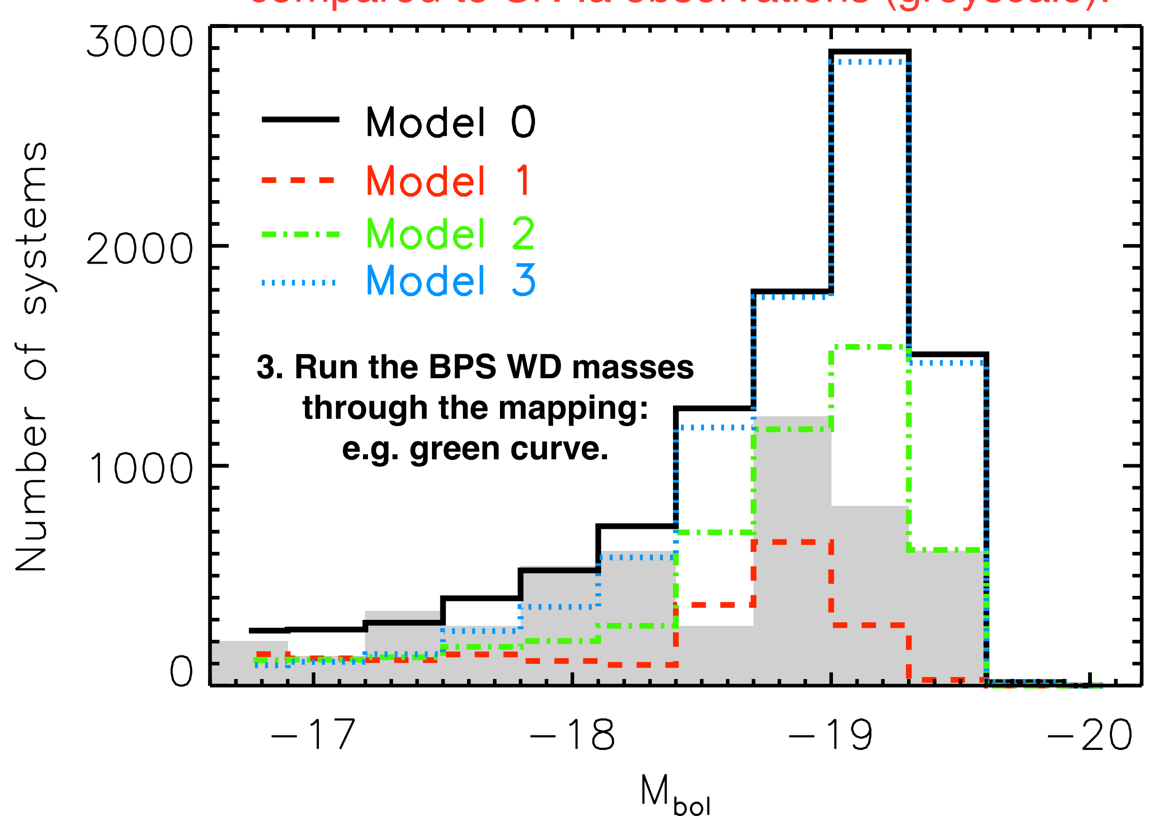


see Ruiter et al. 2013, MNRAS 429, 1425

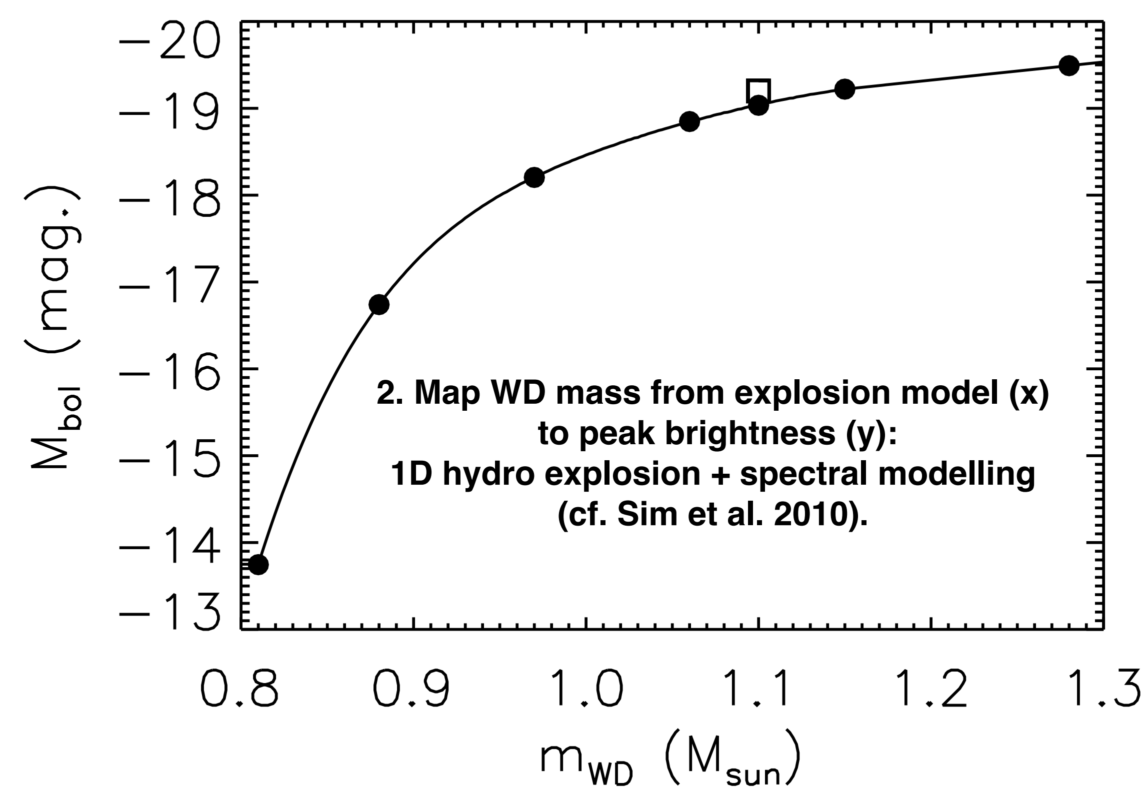
CO+CO mergers at ~Solar (Z=0.02) metallicity, αλ CE (2013).



Peak brightness of merging WDs (coloured lines) compared to SN Ia observations (greyscale).



Result:
Theoretical peak brightness distribution of merging white dwarfs matches the peak brightness distribution of SNe Ia.
Ruiter et al. 2013



Implications:
1. Substantial fraction of SNe Ia result from sub-Chandrasekhar mass WDs (~1 M☉).
2. New formation channel revealed (WD mass is 'beefed up' before merger).

Main findings: CO-CO merger progenitors for two metallicities:

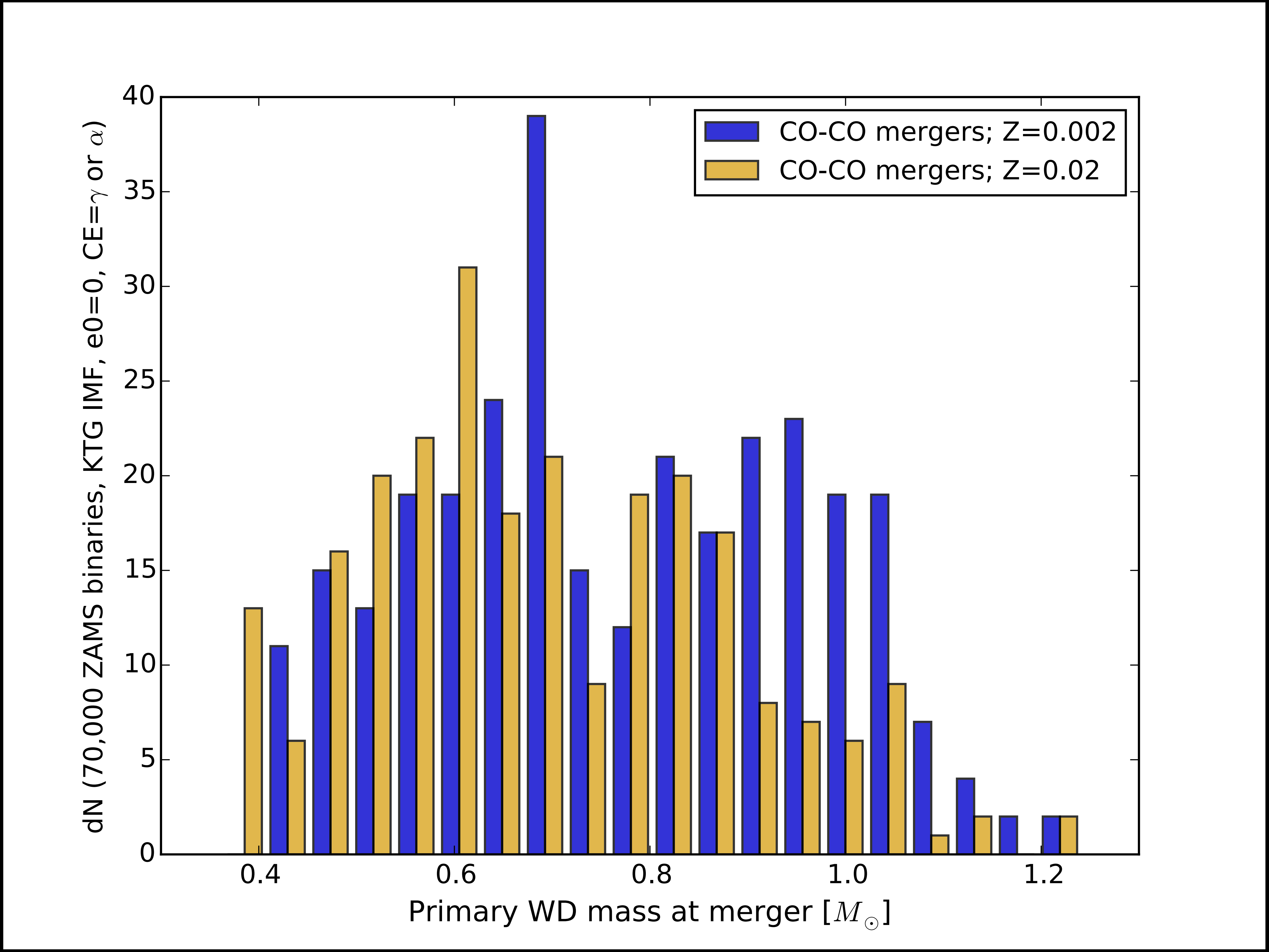
(near) Solar: Z = 0.02 ☀ (Pop I)

- stellar winds more efficient, leads to SMALLER CORE MASSES -> smaller WD masses.
- directly affects WD primary mass, e.g. **dimmer Type Ia supernovae in CO+CO mergers.**
- Observations: Pan et al 2014: fainter, faster events occur in older, massive, metal-rich galaxy hosts.

10%-Solar: Z=0.002 (Pop II)

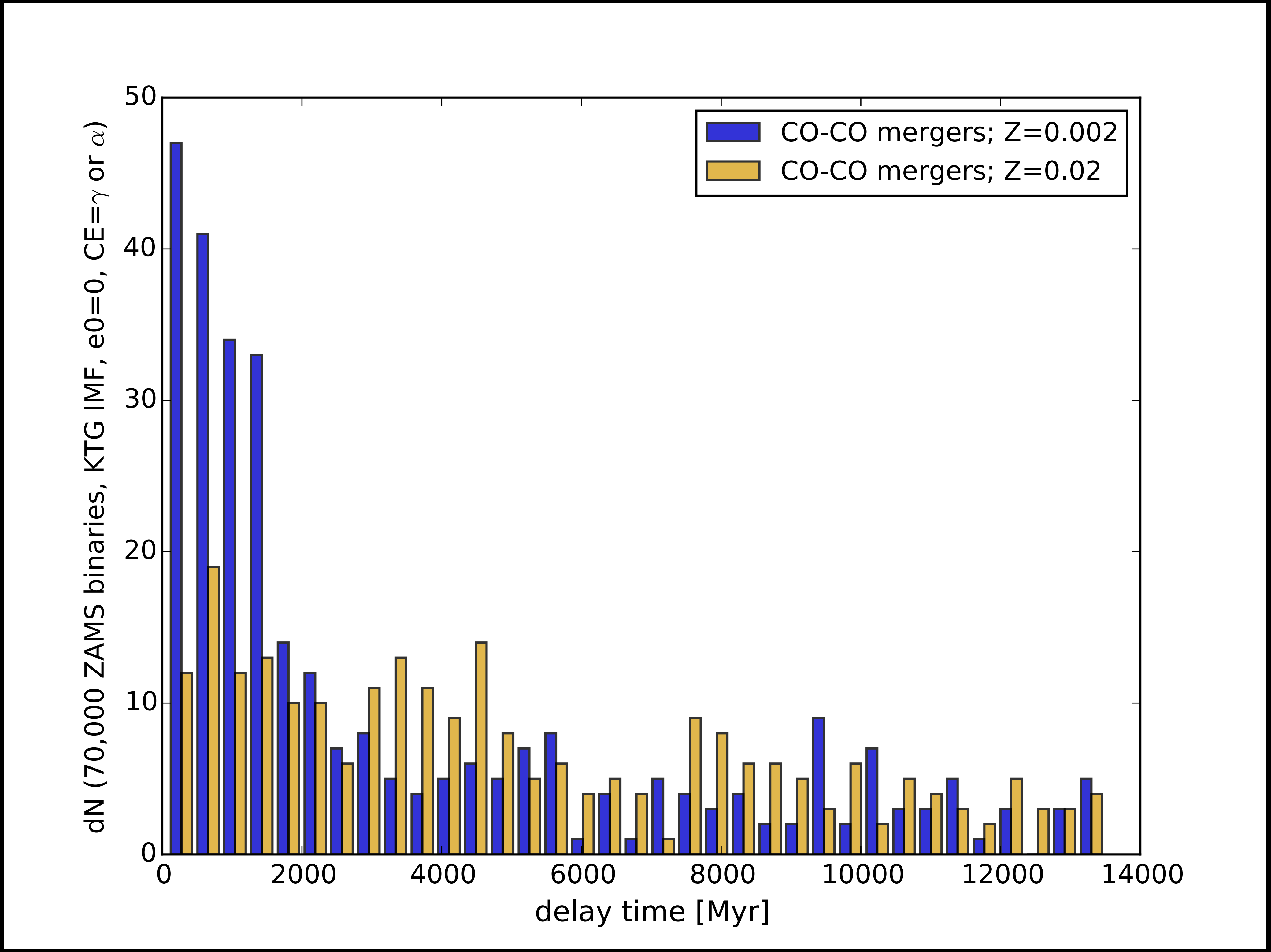
- stellar winds less efficient leads to LARGER CORE MASSES -> larger WD masses.
- comparatively more massive WDs (**brighter explosions for merger scenario**).
- Observations are in agreement with these findings: intrinsically brighter SNe Ia occur in metal-poor (Pop II) environments.

Primary WD mass distribution (NOT total mass)!
for two metallicities. Low-Z model has higher mass peak.
Looks better than (new) Solar-Z model!



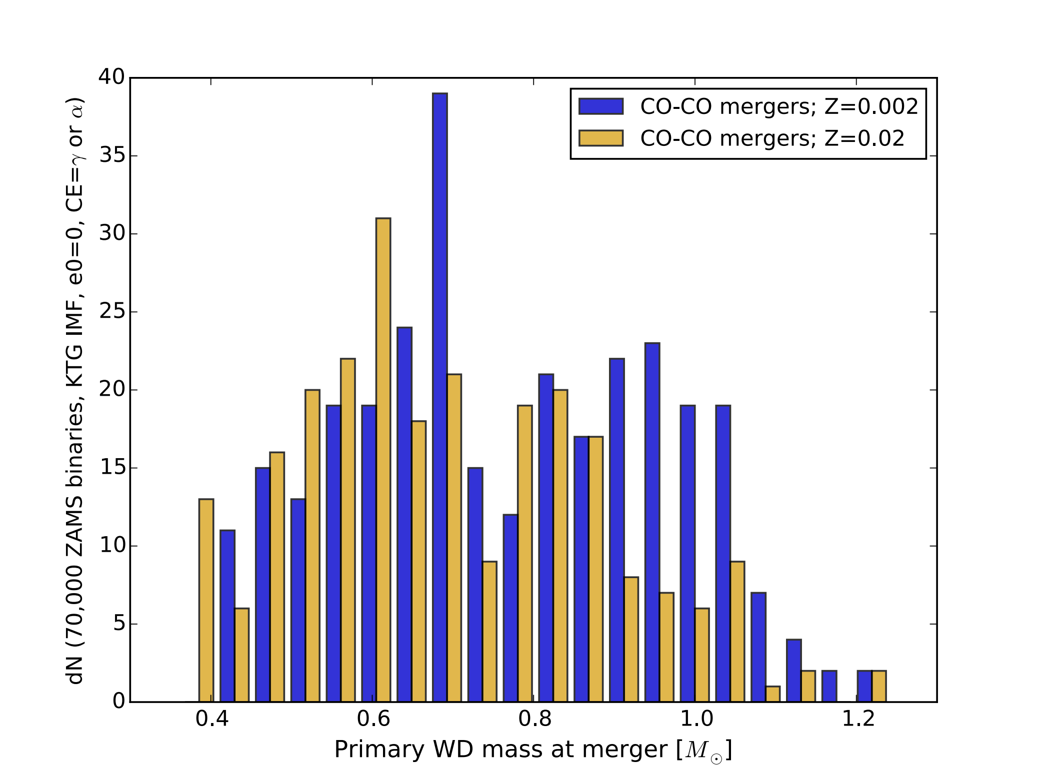
Delay time Distribution for two metallicities: CO+CO WD mergers.

Again: lower-Z model looks better. Prompt ones not as readily produced in new solar model (CE effects).



Pop I (Z>50% sol, or Z>0.01)
vs.
Pop II (Z<= 50% sol, or Z<=0.01)

- Model: "**Pop I**" is Z>50%-solar. The 50%-solar population (Z=0.01) would look **similar** to the 10%-solar population (Z=0.002) of "**Pop II**".



- ***Other progenitors*** involving Chandrasekhar mass WDs:

- A factor of 2 x more *ONe WDs* that accrete to MCh in low-Z model (**AIC**, **ONe or CONe hybrid SNe Ia**, cf. Marquardt et al. 2015, Kromer et al. 2015).

- **Canonical MCh SDS** (*CO WD*): wider variety of donors, shorter delay times in low-Z model compared to standard model.

D.A.Hardy

Summary

- **We adopted a revised CE prescription that includes an evolutionary stage-dependent, binding energy parameter (λ) that is lower for low-Z systems** (see Xu & Li 2010). (**Translation**: lower-Z systems encounter smaller post-CE orbital separations).

- **For this tested CE prescription** (γ,αλ)**, lower metallicity -> higher rates** (post-CE sep. -> delay time distribution).

- **Main result: Lower Z** CO+CO merger progenitors systematically have **higher primary mass @ merger** (due to weaker stellar winds).

- **These results agree** with recent observational studies that suggest more **metal-rich**, older, massive galaxies host **intrinsically fainter** SNe Ia (e.g. Pan et al. 2014).

- *Even without a Z-dependent CE effect, lower Z systems will produce more massive WDs.* **This leads to intrinsically brighter SN Ia events in the violent merger scenario for lower-Z host environments.**

Metallicity certainly affects the **evolution**, probably the properties (**luminosity**), & possibly the **rates**, of SNe Ia

- Comment: Common Envelope: we are a long way from modelling this, but progress is happening - upcoming exciting results (S. Ohlmann in prep.; also works of O. De Marco et al. and others).
- Question(s): What's the best way to determine metallicity of a SN Ia? Gas-phase or stellar Z? How much variability in Z is present in a given host? Active vs. passive galaxies (e.g. Bravo & Badenes, 2011)?