Population Synthesis Uncertainties and Binary Merger Rates

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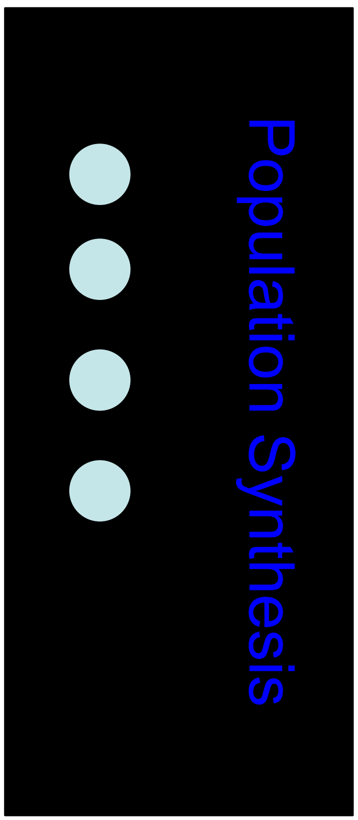
- Compact Remnant Masses
- Common Envelope Evolution
- Efficiency of Orbital Energy Transfer
- Stellar Compactness

The Black Box of Population Synthesis



Population Synthesis has many uncertainties, parameterized in a number of knobs in the population synthesis machinery:

- Initial stellar mass distribution
- Initial orbital separations
- Initial orbital eccentricity
- Stellar radii
- Common Envelope Evolution
- Supernova kicks on neutron stars
- Compact Remnant Masses

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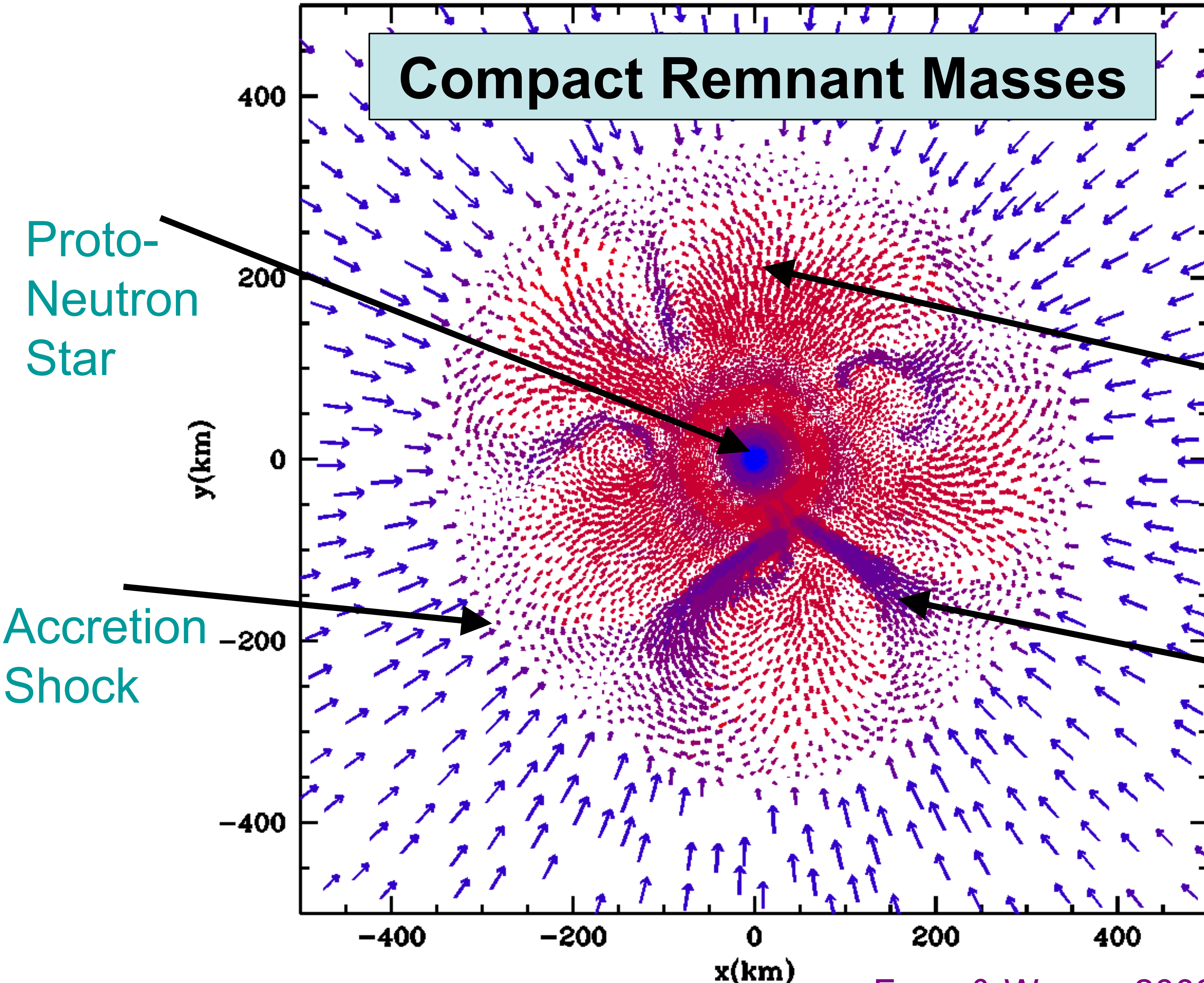
Compact Remnant Masses

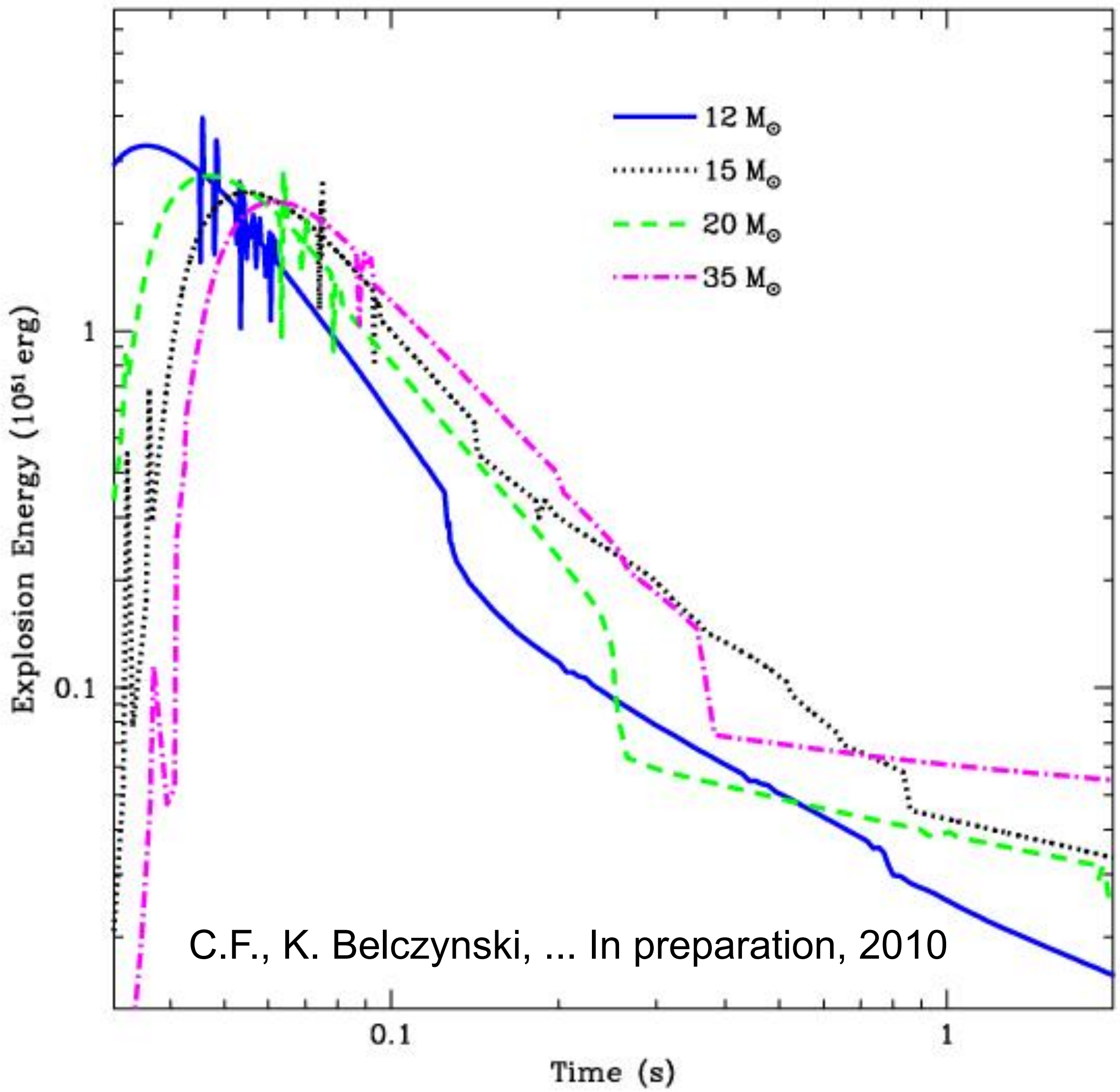


Anatomy Of the Convection Region

Fryer & Warren 2002

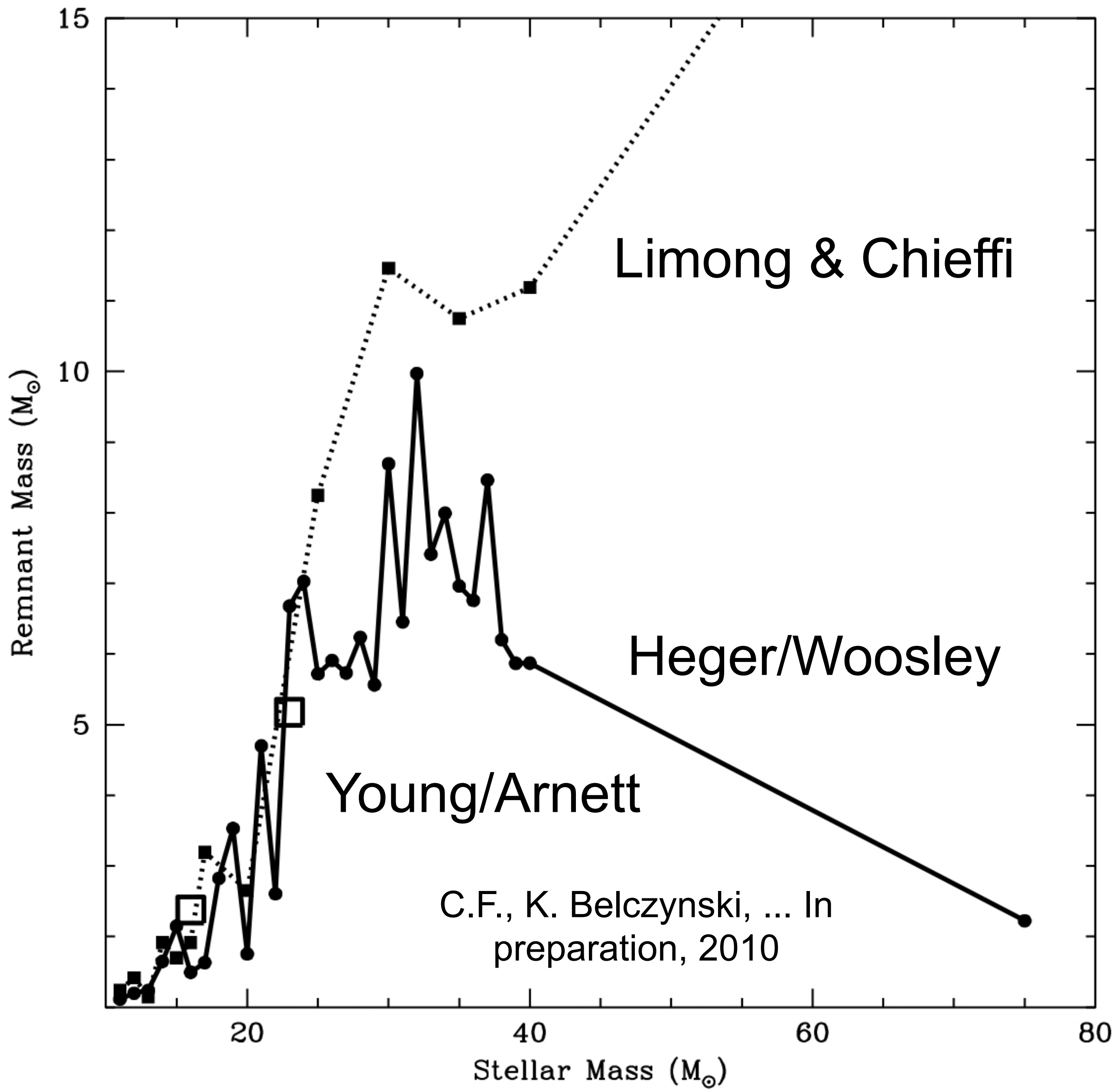
Estimating Supernova Explosions Energies in the Neutrino (Convection Enhanced) Model

The pressure at the accretion shock decreases with time. Hence, the energy required to drive an explosion decreases with time. On the flip side, this means that the maximum total energy in the convective region must decrease with time.

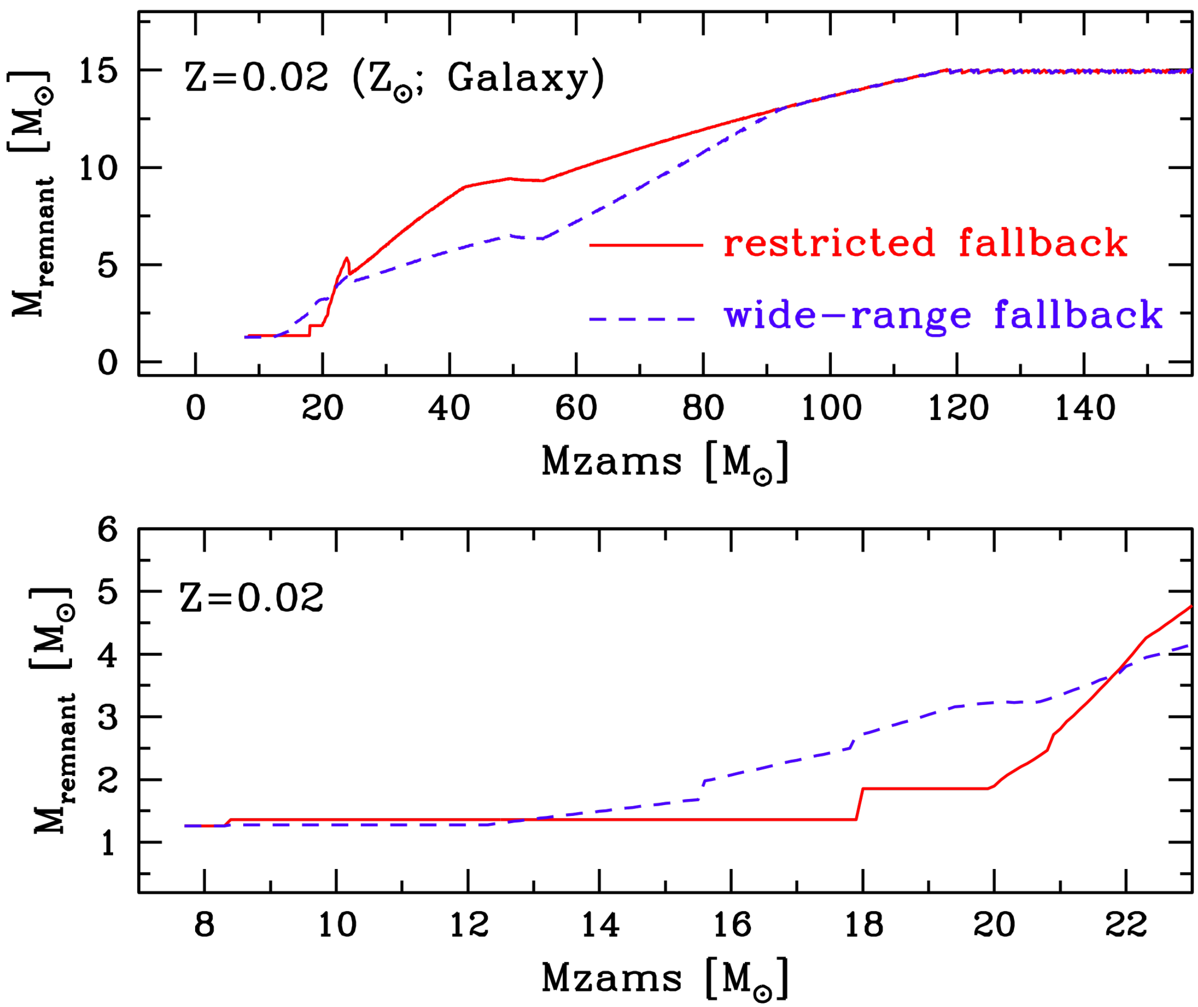


Calculating Remnant Masses

Under the convective engine paradigm, we can construct a distribution of remnant masses given a stellar progenitor.



Delayed supernova models (e.g. SASI-induced) likely produce more intermediate-mass remnants. We may be able to rule this out with observations of BH X-ray binaries and supernovae.



C.F., K. Belczynski, ... In preparation, 2010

Common Envelope Evolution

$$\frac{a_{\rm final}}{a_{\rm initial}} = \frac{M_{\rm primary\,core}}{M_{\rm primary}} \frac{1}{1 + 2M_{\rm envelope}/(M_{\rm secondary}\alpha_{\rm CE}\lambda r_{\rm L})}$$

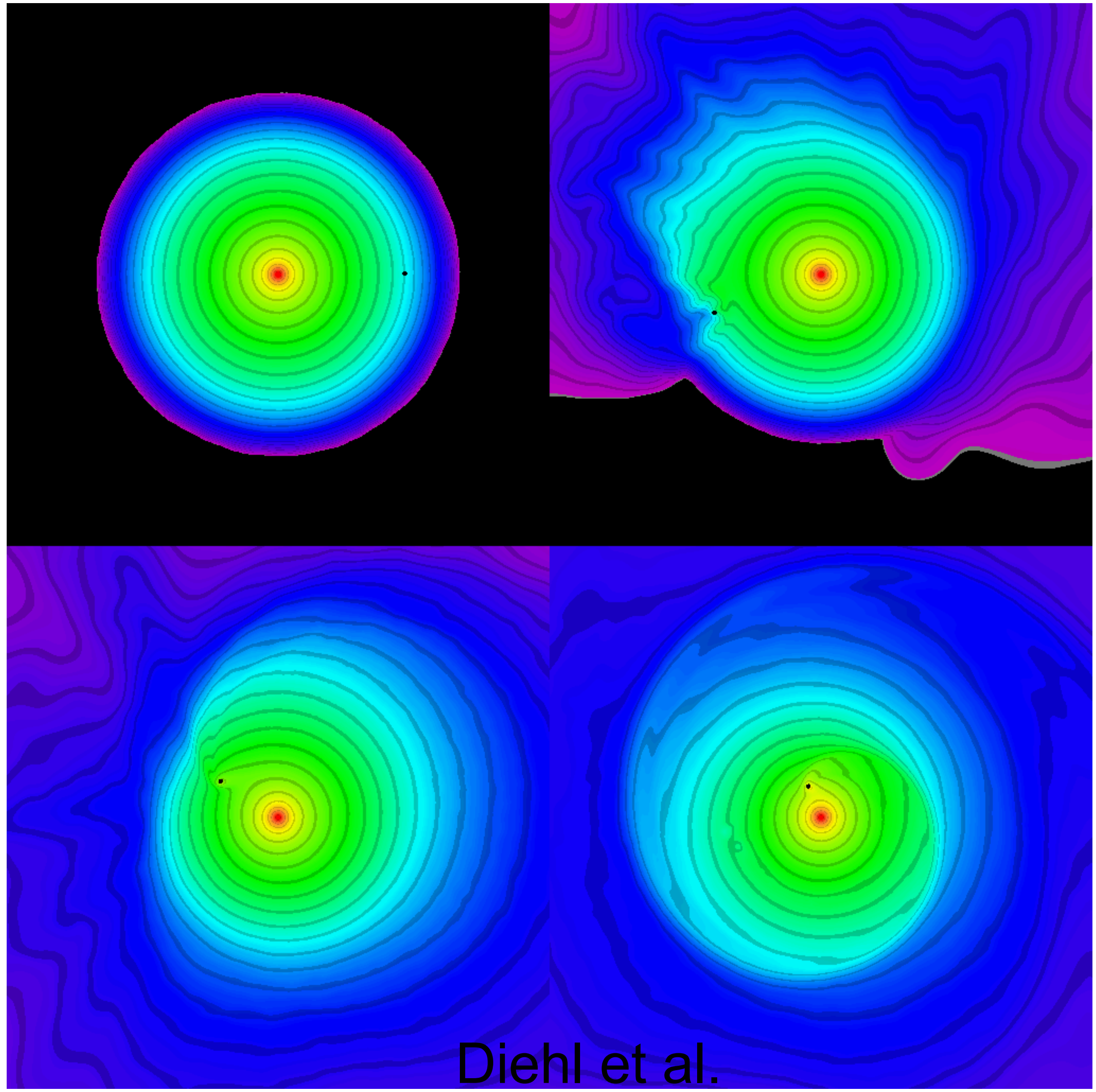
Determining the fate requires knowing two pieces of physics: the compactness of the star (λ), and the efficiency at which orbital energy ejects the envelope (α_{CE}).

$$\lambda = \frac{GM_{\rm primary}M_{\rm envelope}}{a_{\rm initial}r_{\rm L}} \frac{1}{E_{\rm binding}}$$

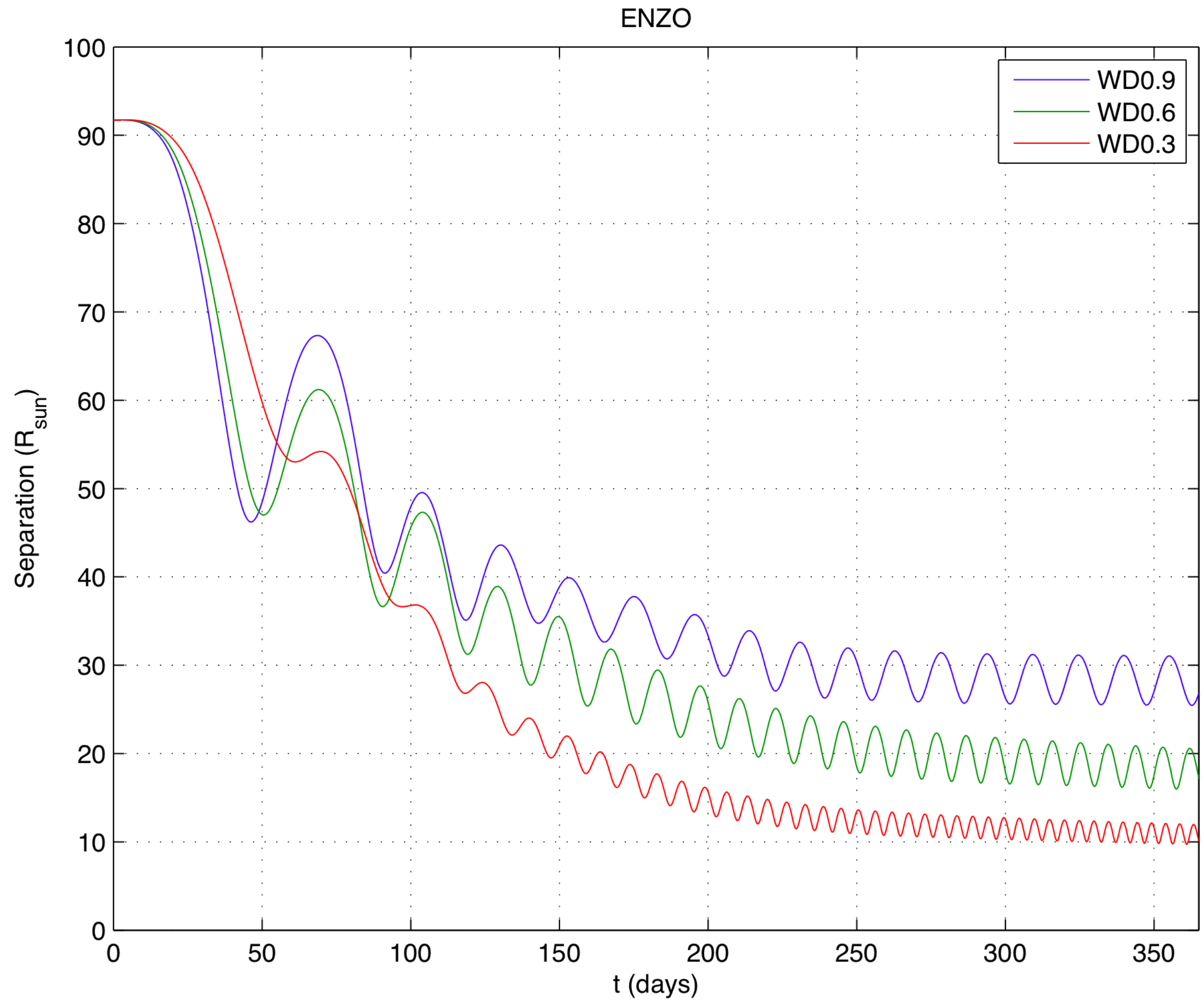
$$E_{\rm binding} = \int_{M_{\rm primary\,core}}^{M_{\rm primary}} -\frac{GM(r)}{r}dm + \beta_{\rm ejection}\int_{M_{\rm primary\,core}}^{M_{\rm primary}} U dm$$

α_{CE}: fraction of orbital energy that unbinds envelope

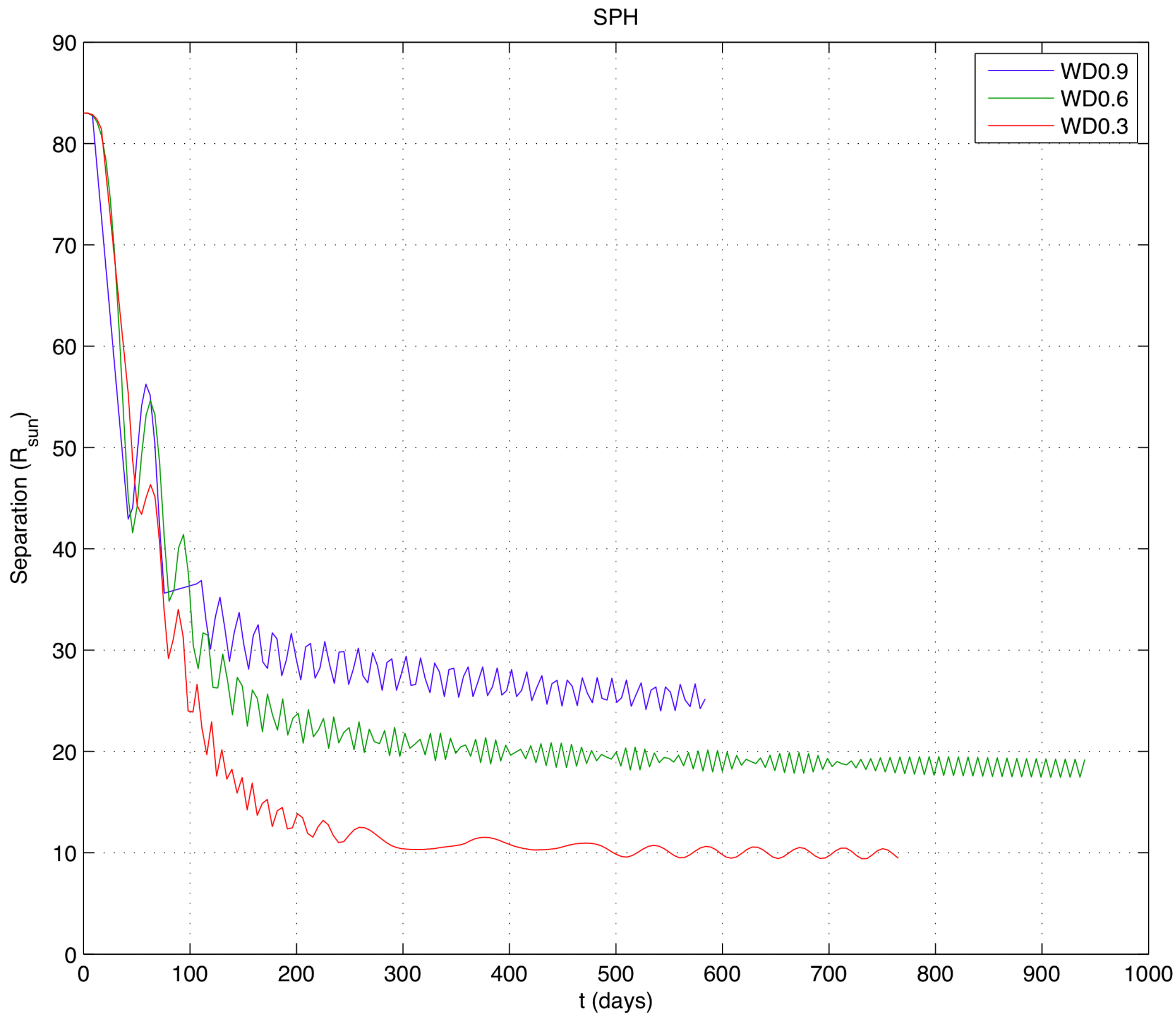
- Taam and collaborators have modeled common envelope evolution for over 3 decades: “Double core evolution. I” appeared in 1978
- Calculations are difficult exercises: angular momentum conservation critical, resolution for deep inspirals difficult to achieve.



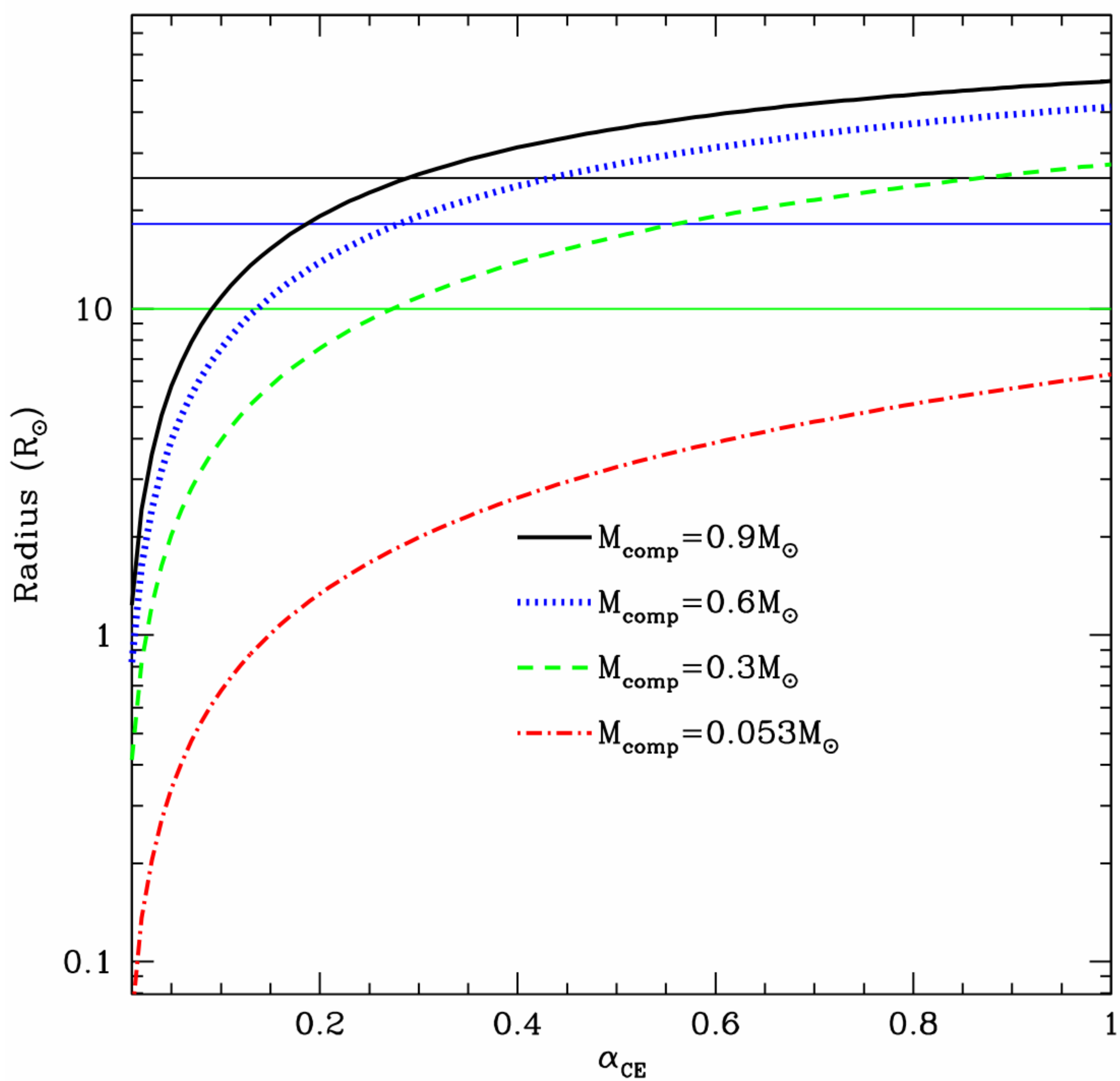
ENZO: Passy et al. in preparation



SNSPH: Passy et al. in preparation



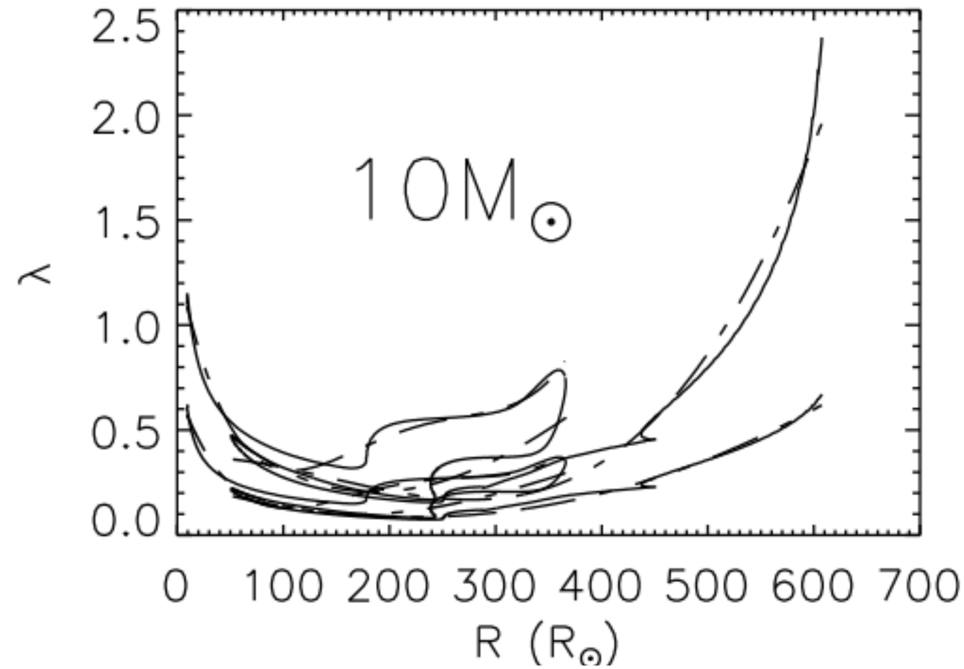
With CE simulations, we can directly calculate the value for α_{CE}. For all masses in this model, the value for α_{CE} is constant. α_{CE}=0.25 matches some observation analyses. But we have only modeled 1 primary star structure.

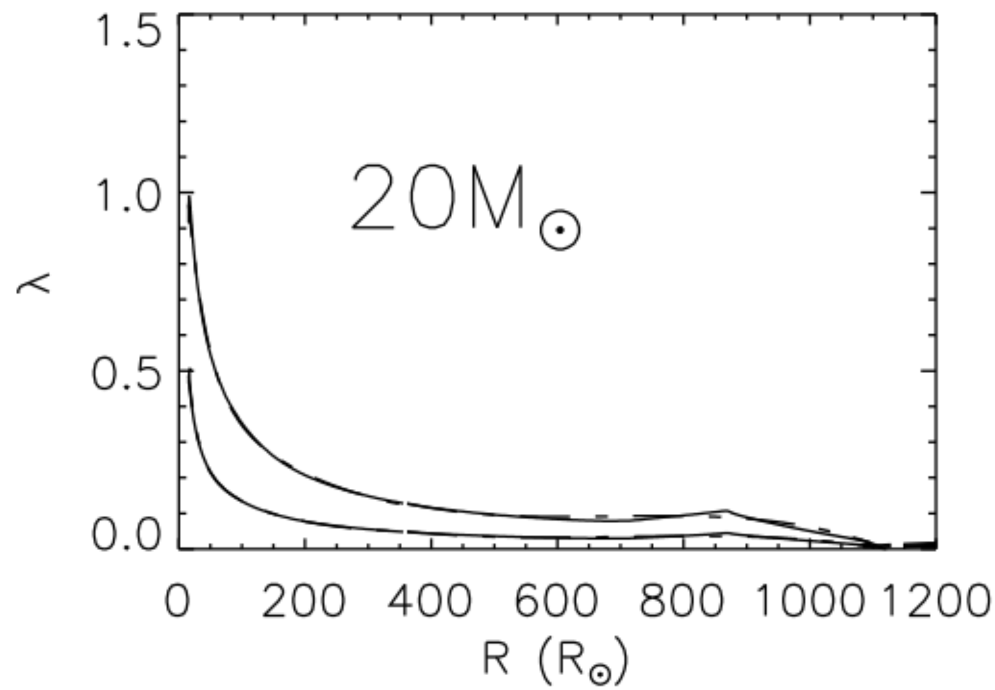


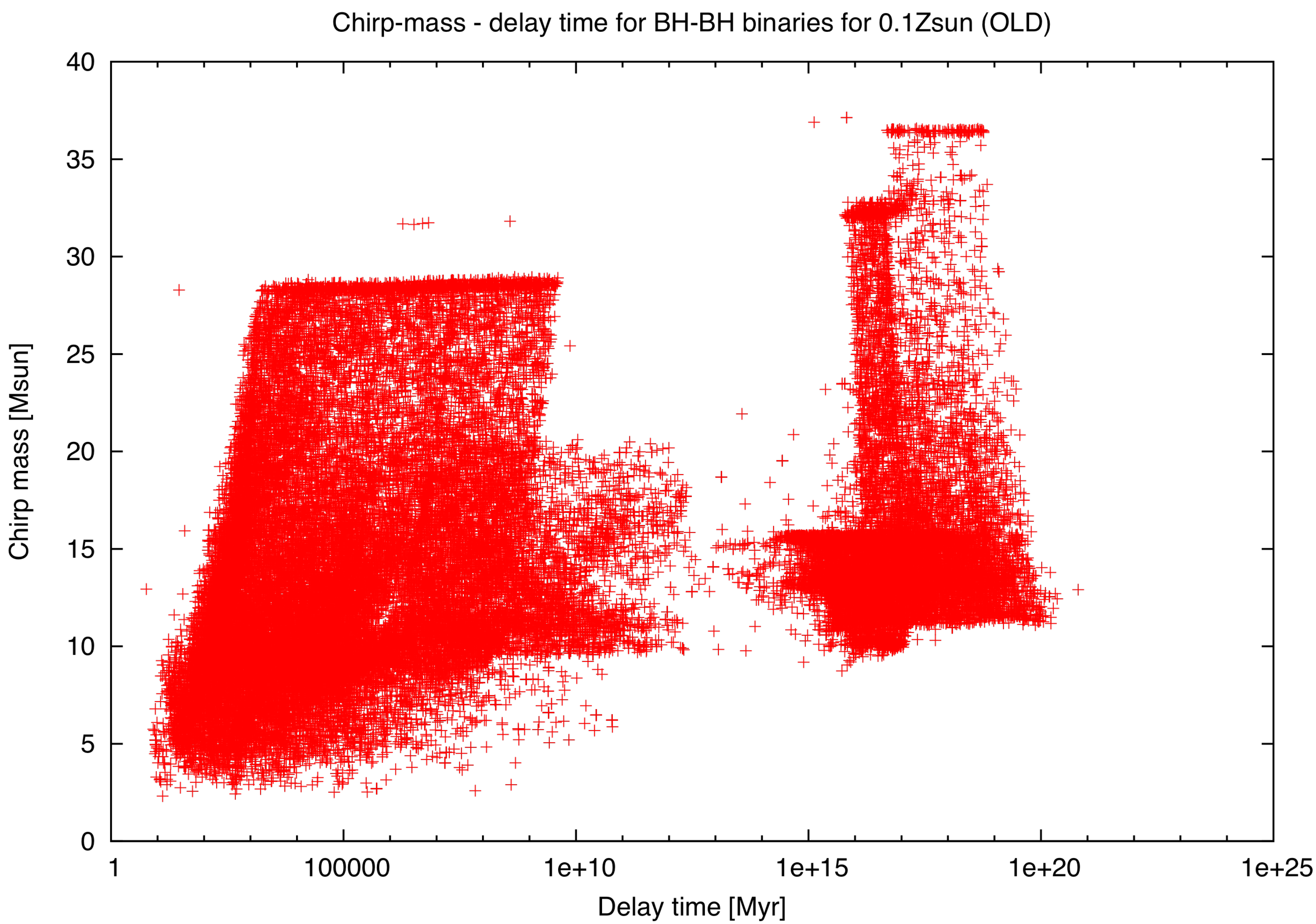
Common Envelope λ

$$\lambda = \frac{GM_{\rm primary}M_{\rm envelope}}{a_{\rm initial}r_{\rm L}}\frac{1}{E_{\rm binding}}$$

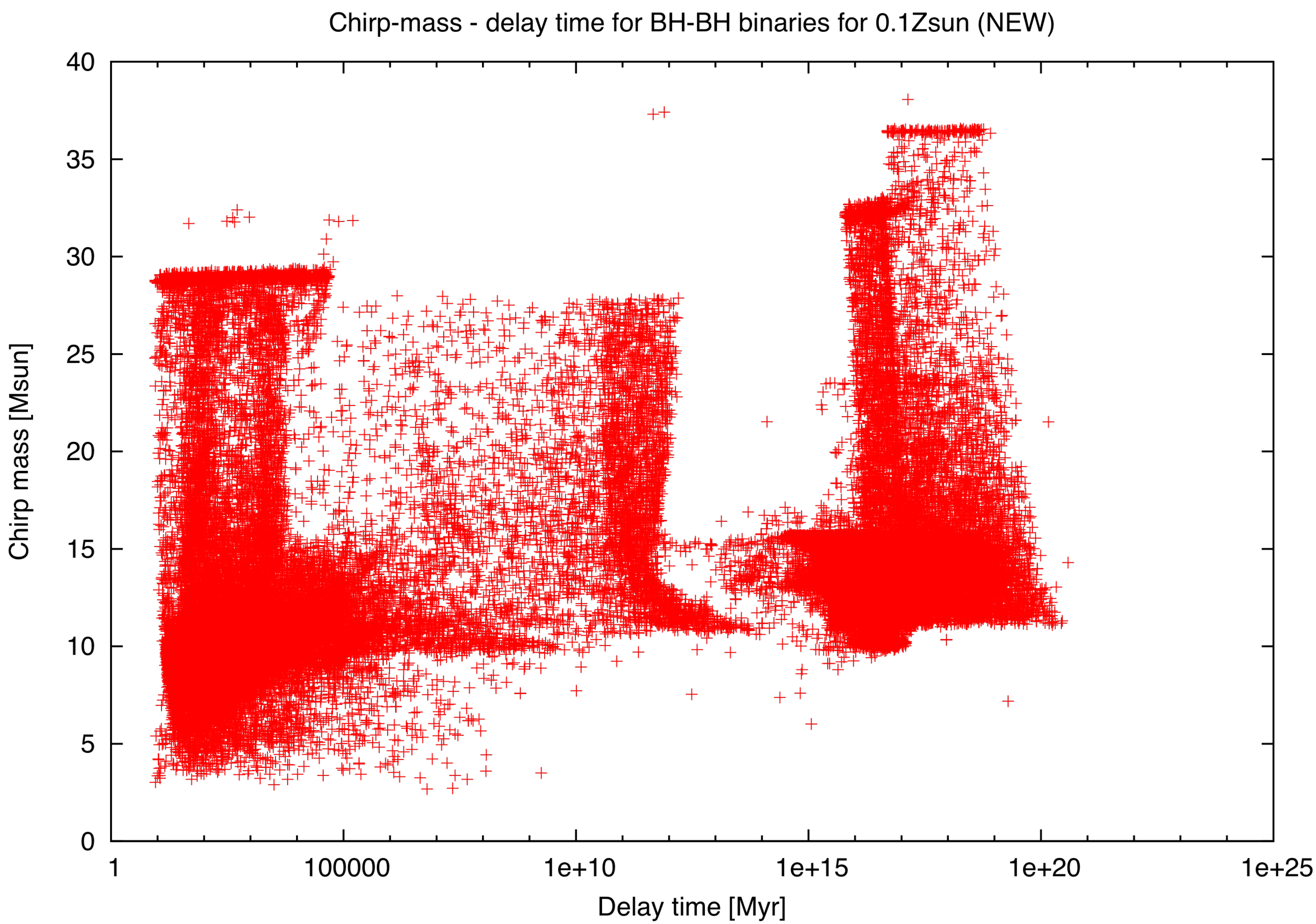
- λ depends on both stellar mass and stage in evolution.
- More massive stars are more compact (Xu & Li 2010)







Chirp-mass - delay time for BH-BH binaries for 0.1Zsun (OLD)
Chirp mass [Msun]
Delay time [Myr]
0
5
10
15
20
25
30
35
40
1
100000
1e+10
1e+15
1e+20
1e+25



Chirp-mass - delay time for BH-BH binaries for 0.1Zsun (NEW)
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Summary

- A number of uncertainties still plague population synthesis calculations.
- Many of these uncertainties are not fully parameterized in existing models.
- Computational resources are improving, allowing us to make decided progress in understanding these uncertainties better.

Institute for Nuclear Theory Meeting: Jul 11 – Aug 5, 2011, Seattle, WA

Astrophysical Transients: Multi-messenger Probes of Nuclear Physics (INT-11-2b)

Organizers: Ed Brown, Chris Fryer, Bennett Link, Sanjay Reddy