Uncertainties in Common Envelope Evolution

(with lessons from white dwarf binaries)

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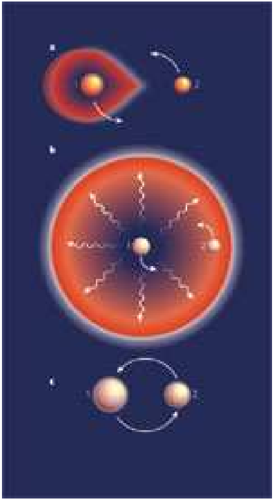
August 9, 2016

What happens before, during, and after a Common Envelope phase?

Following Ivanova+ 2013

- Loss of co-rotation
- Dynamical plunge-in
- Self-regulating phase
- Termination of self-regulating phase
- Post-CE evolution



Problems with Parametrizations

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

- m_1 := initial mass of the donor
- $m_{1,\mathrm{c}}$:= “core mass” of the donor
- $m_{1,\mathrm{env}}$:= “envelope mass” of the donor
- R_1 := radius of the donor
- m_2 := companion mass
- a_{i} := initial separation
- a_{f} := final separation
- α_{CE} := “efficiency” with which orbital energy is used to drive envelope expansion
- λ := parametrizes the structure of the star

Problems with parametrization

- Traditionally $\alpha\lambda$ grouped together into one constant, even done recently e.g. Fragos$+$ 2013, who found values $\lesssim$ 0.1 needed to account for observed X-ray binary populations, results quite sensitive to this parameter.
- Unfortunately, we know that the product $\alpha\lambda \neq$constant. λ varies by 1 – 2 orders of magnitude for stars of different masses and evolutionary states. Fortunately, many fits exist (e.g. Xu & Li 2010, Loveridge, Kalogera, & van der Sluys 2011, etc.) under different conditions (with/without internal energy, different Z).
- Zorotovic$+$ find $\alpha \lesssim 0.3$ for white dwarf binaries in SDSS.

Question: should α be constant? (e.g., Davis$+$ 2011)

Where does the “envelope” stop and the “core” begin?

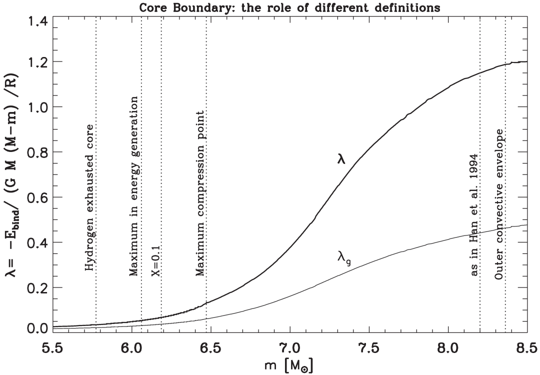


Fig. 5 λ as a function of mass shown on example of 20 $M_\odot$ star when it has $R = 750R_\odot$ ($Z = 0.02$, overshooting 0.2 of the pressure scale and no wind loss). For comparison shown λ_g when only gravitational binading energy is taken into account (thin solid line) and when internal energy is taken into account as well (thick solid line). Dotted lines correspond to several possible core definitions, as discussed in §4.1.

Problems with Parametrizations

Alternate parameterizations: Is there a better Greek letter?

$$\frac{\Delta J_{\rm lost}}{J_i} = \gamma \frac{m_{d,env}}{m_d + m_a}$$

Inspired by early work of Paczynski & Ziolkowski (1967).

Motivation arose from study of double white dwarf binaries.

Problems with Parametrizations

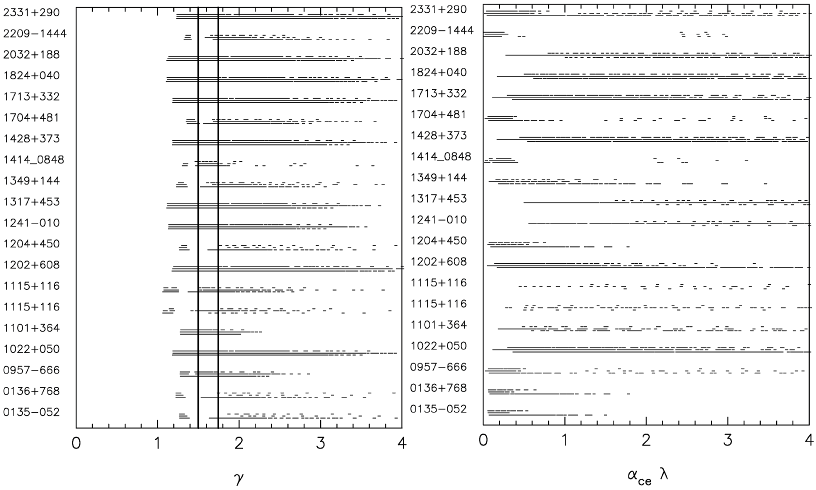
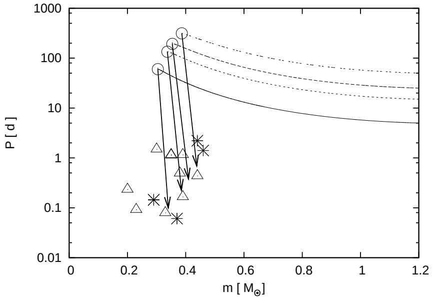


Figure 5. Left: reconstructed γ values for the last phase of mass transfer in the formation of double white dwarfs (see Table 1). Right: reconstructed $\alpha\lambda$ values for the same.

Problems with Parametrizations

- Try evolving with detailed stellar evolution code – 1st MT stable for e.g. 1.2+1.1$M_\odot$ systems! (Woods+ 2012)
- 2nd phase unstable (due to much higher q). Leads to WD M's, P's, q's in line with that observed for DWDs!
- No need for γ formalism in its original context. See also Woods+ 2011, Ivanova+ 2013



Orbital evolution as a function of (initial) primary mass through stable, non-conservative Roche lobe overflow. Companion stars will undergo a common envelope upon reaching the RGB; final masses are indicated with arrows.

To CE or not to CE?

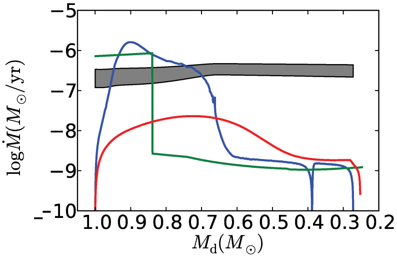
- How did we get the binary evolution so wrong initially?
  $\rightarrow$ Assumption that donors with deep convective envelopes prone to runaway mass loss.
- Based on Hjellming & Webbink, 1987, invoking polytropes:

$$\zeta_{\mathrm{ad}} = \left(\frac{d \log m}{d \log R} \right)_{\mathrm{ad}} = \frac{2}{3} \frac{m_c/M_1}{1 - m_c/M_1} - \frac{1}{3}$$

- Known to underestimate mass transfer stability since at least early 2000's (Han, Nelson, Rappaport, and others).

To CE or not to CE

- Some studies have opted for a cutoff in MT rate instead
- Problematic! Different pop synth codes use different prescriptions for stable mass transfer, generally don't agree with detailed stellar evolution calculations (Chen, Woods+ 2014).



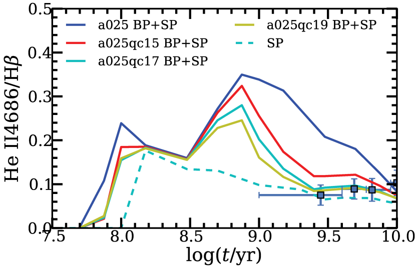
- Example: 1.0$M_\odot$ giant with $0.8M_\odot$ WD, P_orb=3 days
- Blue: MESA, green: IBIS, red: BSE

To CE or not to CE?

- Stable mass transfer found above polytropic limit over wide range of donor masses, mass ratios. Confirmed in several codes (Woods & Ivanova 2011, Passy+2012)
- Response of star depends sensitively on treatment of outermost, superadiatic surface layer. Need to understand boundary conditions, recombination, treatment of MLT.
- No easy prescription on core mass fraction or q alone
- Best bet seems to be overflow of outer Lagrangian (Pavlovskii & Ivanova 2015). Gives critical mass ratios $\sim$ twice that of simple polytropic approximation.

To CE or not to CE

- Can constrain the problem with other observables, look for impact on other well-understood problems.
- Example: If you're not careful, it's easy to predict accreting WDs dominate the ionizing background in many early-type galaxies! (see Woods & Gilfanov 2013, 2014, Johansson, Woods+ 2014, 2016, Chen, Woods+ 2015



- Example: He II/Hβ ratio as a function of mean stellar age with single stars only (SP, Bruzual & Charlot 2003) and w/ different accreting WD populations.

Questions you can use to bug your friends in population synthesis!

- How did you choose α? How is the binding energy computed? (with contribution from internal energy? recombinations?) How do you define the remnant mass in any common envelope event?
- How is thermal timescale mass loss treated? Have you compared with detailed models?
- Do you simultaneously model other, related stellar populations? Are they consistent with known statistics? What about constraints on ionizing/X-ray emission? (Ma+ 2016, Eldridge et al).