Simulations of the Common Envelope Interaction using Grid-Based and SPH Codes

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Collaborators - Acknowledgment

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1. Direct observations are unlikely → simulations should help
2. So far, only a few "recent" hydrodynamics simulations exist
    - Sandquist et al. 1998
    - De Marco et al. 2003
    - Ricker & Taam 2008
3. No comparison between different numerical methods
4. No comparison with observations

- **Enzo**, a 3D AMR grid-based code (Eulerian)
- **SNSPH**, a 3D Smoothed-Particle Hydrodynamics code using tree gravity (Lagrangian)

	ENZO	SNSPH
Type	Eulerian	Lagrangian
Numerical viscosity	Yes	No
Conservative	$\approx$	Inherent
Bound. Cs	Large finite grids	Vacuum/None
Resolution	Adaptive	Mass
Shocks	+	-
Res. at given N	+	-

Both codes solve the **fully compressible hydrodynamics** equations with **self-gravity** included.

In the case of a CE interaction between a giant star (primary) and a MS companion (secondary) :

- The radius of the secondary (≈ 0.5 $R_\odot$) $\ll R_1$
  $\Rightarrow$ Secondary as a point mass particle
- The primary's core is also very small (≈ 0.01 $R_\odot$) and dense
  $\Rightarrow$ Primary core also as a point mass particle

- 1D model of a RGB obtained with EVOL (Herwig 2000): $M_1 = 0.88$ M$_\odot$, $M_c = 0.392$ M$_\odot$, $R = 83$ R$_\odot$
- Companion masses from 0.9 down to 0.1 M$_\odot$

	N_{part} or N_{tot}	M_2 (M$_\odot$)	A_0 (R$_\odot$)	P_0 (days)	v_0/v_{circ}
SPH1	500 000	0.9	83	66	1
SPH2	500 000	0.6	83	72	1
SPH3	500 000	0.3	83	81	1
SPH4	500 000	0.15	83	86	1
SPH5	500 000	0.1	83	88	1
Enzo1	128^3	0.9	91	75	1
Enzo2	128^3	0.6	91	83	1
Enzo3	128^3	0.3	91	93	1
Enzo4	128^3	0.15	91	99	1
Enzo5	128^3	0.1	91	102	1
Enzo6	256^3	0.9	85	68	1
Enzo7	256^3	0.6	85	75	1
Enzo8	256^3	0.3	85	84	1
Enzo9	256^3	0.15	85	89	1
Enzo10	256^3	0.1	85	92	1
Enzo11	128^3	0.6	91	83	1.05
Enzo12	128^3	0.6	95.55	83	1

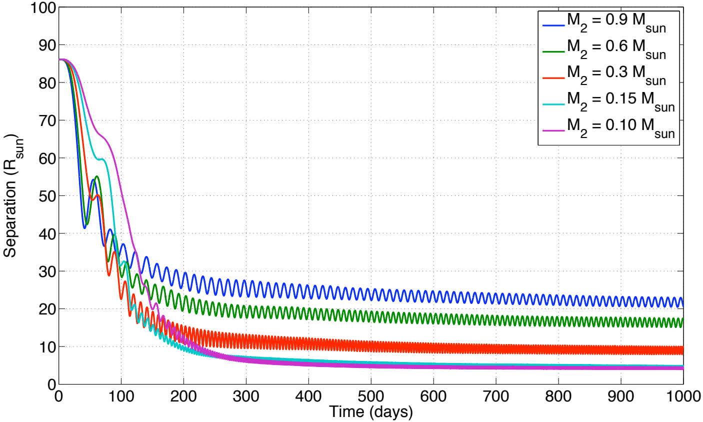
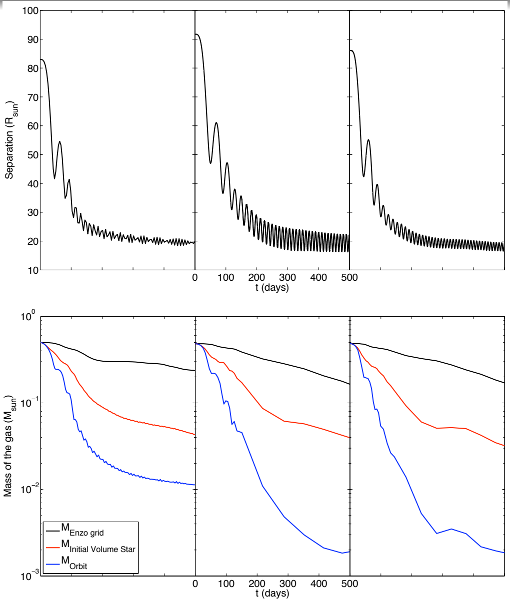
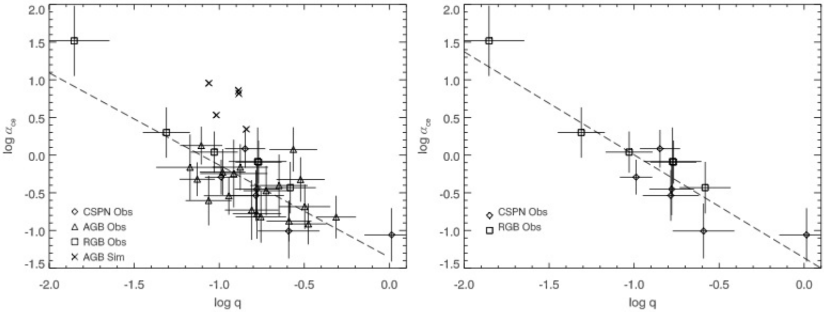


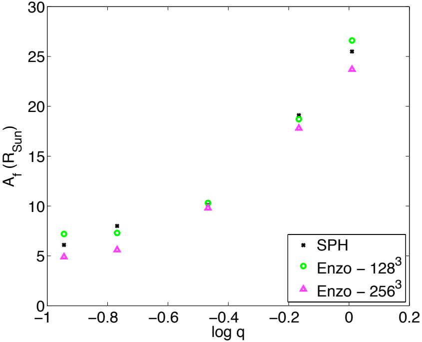
Figure: Orbital separation for the 256^3 **Enzo** simulations.

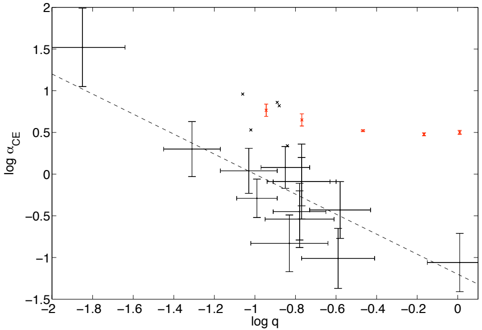

Separation (R$_{sun}$)
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
t (days)
Mass of the gas (M$_{sun}$)
10^0
10^{-1}
10^{-2}
10^{-3}
M$_{Enzo\ grid}$
M$_{Initial\ Volume\ Star}$
M$_{Orbit}$
0
100
200
300
400
500
t (days)

In De Marco et al. 2011:

- Modification of the α-formalism
- Calculation of the λ parameter using SE tracks
- Deduction the initial configuration of 31 PCE systems
- Derivation a possible anti-correlation of α with q





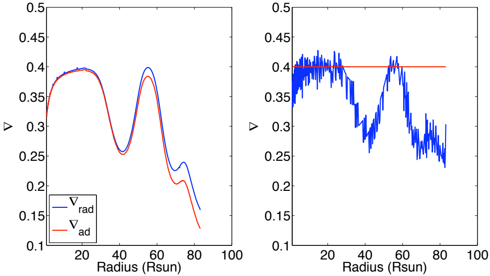


- For $M_2 \geq 0.3$ M$_\odot$, the results converge
- For $M_2 < 0.3$ M$_\odot$, the resolution is not sufficient
- α are higher than the ones given by De Marco et al. 2011
- Final separations larger than almost any know post-CE systems

- The adiabatic mass-radius exponent is defined as

$$\xi_{ad} \equiv \left(\frac{\partial \ln M_1}{\partial \ln R_1} \right)_{ad}$$

- For a convective star, $-1/3 \leq \xi_{ad} \leq 0$
  $\Rightarrow$ adiabatic mass loss (Hjellming & Taam 1987, Ge et al. 2010)
- Convection occurs if $\nabla_{ad} < \nabla_{rad}$



- **80 % of the gas is still bound at the end !**
- a_{rad} is 2 orders of mag. smaller than a_{grav}
- Fall back ? Circumbinary disk ?
- Planet formation ? (Geier 2009, Beuermann et al 2010)
- Envelope eventually unbound ? (later phase, recombination...)

- 17 simulations carried out with **Enzo** and **SNSPH**
- Results are very similar for $M_2 \geq 0.6$ M$_\odot$
- For lower masses, Enzo resolution needs to be increased
- Envelope is not unbound and A_f are larger than observations

- Run more simulations with different primaries
- Use Enzo with nested grids/AMR
- Reproduce convection with an ideal gas EOS