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

Jean-Claude Passy (UVic, AMNH)

March 8, 2011
Collaborators - Acknowledgment

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- Greg L. Bryan (Columbia)
- Jefferey S. Oishi (Kavli Institute)
- NSF grant 0607111
1 Motivation

2 Code description
   - The hydrodynamics codes
   - Model

3 The simulations - Results
   - Runs
     - Different \( M_2 \) - Same numerical setup
     - Different numerical setup - \( M_2 = 0.6 \, M_\odot \)

4 Discussion
   - Comparison with observations
   - The role of convection
   - Unbinding the envelope

5 Summary
Direct observations are unlikely → simulations should help

So far, only a few “recent” hydrodynamics simulations exist

- Sandquist et al. 1998
- De Marco et al. 2003
- Ricker & Taam 2008

No comparison between different numerical methods

No comparison with observations
- **Enzo**, a 3D AMR grid-based code (Eulerian)
- **SNSPH**, a 3D Smoothed-Particle Hydrodynamics code using tree gravity (Lagrangian)

<table>
<thead>
<tr>
<th></th>
<th>ENZO</th>
<th>SNSPH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>Eulerian</td>
<td>Lagrangian</td>
</tr>
<tr>
<td><strong>Numerical viscosity</strong></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Conservative</strong></td>
<td>≈</td>
<td>Inherent</td>
</tr>
<tr>
<td><strong>Bound. Cs</strong></td>
<td>Large finite grids</td>
<td>Vacuum/None</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>Adaptive</td>
<td>Mass</td>
</tr>
<tr>
<td><strong>Shocks</strong></td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td><strong>Res. at given N</strong></td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

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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 \((\approx 0.5 \, R_{\odot}) \ll R_1\) \(\Rightarrow\) Secondary as a point mass particle
- The primary’s core is also very small \((\approx 0.01 \, R_{\odot})\) 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 \( M_\odot \)

<table>
<thead>
<tr>
<th></th>
<th>( N_{\text{part or } N_{\text{tot}}} )</th>
<th>( M_2 (M_\odot) )</th>
<th>( A_0 (R_\odot) )</th>
<th>( P_0 ) (days)</th>
<th>( v_0/v_{\text{circ}} )</th>
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**Figure:** Orbital separation for the $256^3$ Enzo simulations.
Motivation

Code description

The simulations - Results

Discussion

Summary

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Runs

Different $M_2$ - Same numerical setup

Different numerical setup - $M_2 = 0.6 M_\odot$
In De Marco et al. 2011:

- Modification of the $\alpha$-formalism
- Calculation of the $\lambda$ parameter using SE tracks
- Deduction the initial configuration of 31 PCE systems
- Derivation a possible anti-correlation of $\alpha$ 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
$\alpha$ 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!

- \( a_{\text{rad}} \) is 2 orders of mag. smaller than \( a_{\text{grav}} \)
- Fall back? Circumbinary disk?
- Planet formation? (Geier 2009, Beuermann et al. 2010)
- Envelope eventually unbound? (later phase, recombination...)

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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