Modelling the evolution of double white-dwarf systems

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Outline

• Introduction and context
• Observed double white dwarfs
• Common envelope and spiral-in
• Stable first mass transfer
• Conclusions and future work
Astrophysical context

• Possibly progenitors of Supernova type Ia
• Sources of low-frequency gravitational waves
Astrophysical context

- Possibly progenitors of Supernova type Ia
- Sources of low-frequency gravitational waves

- Binary evolution theory
- White dwarf cooling theory
- Population synthesis
# Observed double white dwarfs

<table>
<thead>
<tr>
<th>System</th>
<th>$P_{\text{orb}}$ (d)</th>
<th>$a_{\text{orb}}$ ($R_\odot$)</th>
<th>$M_1$ ($M_\odot$)</th>
<th>$M_2$ ($M_\odot$)</th>
<th>$q_2 = M_2/M_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>WD 0135–052</td>
<td>1.556</td>
<td>5.63</td>
<td>0.52</td>
<td>0.47</td>
<td>0.90 ± 0.04</td>
</tr>
<tr>
<td>WD 0136+768</td>
<td>1.407</td>
<td>4.98</td>
<td>0.37</td>
<td>0.47</td>
<td>1.26 ± 0.03</td>
</tr>
<tr>
<td>WD 0957–666</td>
<td>0.061</td>
<td>0.58</td>
<td>0.32</td>
<td>0.37</td>
<td>1.13 ± 0.02</td>
</tr>
<tr>
<td>WD 1101+364</td>
<td>0.145</td>
<td>0.99</td>
<td>0.33</td>
<td>0.29</td>
<td>0.87 ± 0.03</td>
</tr>
<tr>
<td>PG 1115+116</td>
<td>30.09</td>
<td>40.0</td>
<td>0.43</td>
<td>0.52</td>
<td>1.19 ± 0.30</td>
</tr>
<tr>
<td>WD 1204+450</td>
<td>1.603</td>
<td>5.72</td>
<td>0.52</td>
<td>0.46</td>
<td>0.87 ± 0.03</td>
</tr>
<tr>
<td>WD 1349+144</td>
<td>2.209</td>
<td>6.65</td>
<td>0.44</td>
<td>0.44</td>
<td>1.26 ± 0.05</td>
</tr>
<tr>
<td>HE 1414–0848</td>
<td>0.518</td>
<td>2.93</td>
<td>0.55</td>
<td>0.71</td>
<td>1.28 ± 0.03</td>
</tr>
<tr>
<td>WD 1704+481a</td>
<td>0.145</td>
<td>1.13</td>
<td>0.56</td>
<td>0.39</td>
<td>0.70 ± 0.03</td>
</tr>
<tr>
<td>HE 2209–1444</td>
<td>0.277</td>
<td>1.89</td>
<td>0.58</td>
<td>0.58</td>
<td>1.00 ± 0.12</td>
</tr>
</tbody>
</table>

See refs in: Maxted et al., 2002 and Nelemans & Tout, 2005.
Common envelope

• Average orbital separation: $7 \, R_\odot$

• Progenitors: $R_\star \gtrsim 50 \, R_\odot$
Common envelope

- Average orbital separation: $7 \, R_\odot$
- Progenitors: $R_* \gtrsim 50 \, R_\odot$

- Second mass transfer phase was a spiral-in
- Mechanism: Common envelope
Common envelope
Common envelope

Classical CE: (Webbink, 1984)

- Friction causes spiral-in of the cores
- Orbital energy is used to expell envelope:

\[
U_{\text{bind}} = \alpha_{\text{CE}} \left( \frac{GM_{\text{wd1}} M_{\text{wd2}}}{2a_f} - \frac{GM_{\text{wd1}} M_{\text{g2}}}{2a_i} \right)
\]
Common envelope

- CE much faster than nuclear evolution
- Core mass does not change during CE
- First WD mass does not change during CE
Common envelope

- CE much faster than nuclear evolution
- Core mass does not change during CE
- First WD mass does not change during CE
- Radius of the giant gives orbital period
- Envelope binding energy gives $\alpha_{\text{CE}}$
Giant branch models

100 models
0.8-10 $M_\odot$

RGB
AGB
Giant branch models

\( R_\star \) provides \( P_{\text{orb}} \) at onset of CE

RGB

AGB
Giant branch models

Envelope $U_{\text{bind}}$ provides $\alpha_{CE}$

RGB

AGB
Assumed no errors in observed masses

$\sim 25\%$ of models give a solution
CE results

Accept solutions with $0.1 < \alpha_{CE} < 10$
CE results

No errors in observed masses
CE results

Introduce errors in observed masses:
\[ \pm 0.05 M_\odot \]
CE results

Maximum $P_{\text{orb}}$ after stable mass transfer with $q_i = 0.62$
(Nelemans et al., 2000)

Only 5 systems have CE solutions with $P_{\text{orb}} < P_{\text{max}}$
CE results

CE solutions that may be formed by stable mass transfer

Conservative mass transfer: $M_{\text{tot}}$ and $J_{\text{orb}}$ fixed

1 free parameter: $q_i$
Conservative mass transfer

230 binary models calculated:

\[ \text{log} \frac{P}{\text{d}} \text{ vs. } M_g (M_\odot) \]

- 39% dynamical
- 18% contact
- 43% DWD

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Conservative mass transfer

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Conservative mass transfer

\[ M_{wd1} \text{ too low} \]

\[ \Rightarrow P_{orb} \text{ too high} \]

\[ \Rightarrow M_{wd2} \text{ too high} \]
Conservative mass transfer

1414 fits 0957 and 1101 almost fit

Out of ten systems, 1 can be explained, 2 are close
HOWEVER...
Conclusions and future work:

- More accurate models change CE only slightly
- Conservative mass transfer cannot produce white-dwarf primaries of sufficiently high mass
- We can explain 0.5 out of 10 systems
Conclusions and future work:

- More accurate models change CE only slightly
- Conservative mass transfer cannot produce white-dwarf primaries of sufficiently high mass
- We can explain 0.5 out of 10 systems
- Non-conservative, stable first mass transfer phase
- $\alpha$-CE and $\gamma$-CE as first mass transfer