Cosmic Butterflies:
The product of tempestuous stellar marriages

DR DAVID JONES
PLANETARY NEBULA

Ejected envelope

Ionising nucleus (pre-WD)
HOW DO YOU MAKE AN HOURGLASS?

• Rapid rotation?
• Magnetic fields?
• ¡Binaries!
An aside on morphologies
(a) [O III] $\lambda 5007$ Å
(b) $90^\circ$
(c) $10^\circ$
(d) $15^\circ$
COMMON ENVELOPE

BINARY EVOLUTION
COMMON ENVELOPE

BINARY EVOLUTION
COMMON ENVELOPE

BINARY EVOLUTION
COMMON ENVELOPE

BINARY EVOLUTION
THE LORD OF THE RINGS
WHERE ARE THEY ALL THEN?
HOW DO YOU DETECT A BINARY?
HOW DO YOU DETECT A BINAR Y?
Hen 2-428: A perfect candidate
Mercator Observations

2.1 hours!
Mercator Observations
Mercator Observations

4.2 hours
Ellipsoidal modulation \((i=90^\circ)\)
Ellipsoidal modulation (i=90°)
Radial Velocity analysis
Modelling in PHOEBE

PHysics Of Eclipsing BinariEs
Modelling in PHOEBE
Hen 2-428

• Equal mass twins: $M=0.88\,M_{\odot}$, $R=0.67\,R_{\odot}$, $T\sim31\,kK$

• Overcontact

• Binary inclination $\sim$ Nebula inclination

• Separation $= 1.59 \, R_{\odot}$
Hen 2-428

Total mass > Chandrasekhar mass (1.44 Msol)

Time to merger ~ 700Myr

=> Supernova Type Ia progenitor!
History?

Tovmassian et al. (2010)
Double-degenerates should be rare!

but they aren’t …
Theorists have big problems...

Han et al. (1995)
Hydro models predict period $\sim$ 100-1000 years

Raga et al. (2009)
Much shorter period!

**Period** = 1.1953 days

**Boffin et al. (2012)**
Jets were formed before orbital shrinkage!

<table>
<thead>
<tr>
<th>PN</th>
<th>Neb. age (yrs)</th>
<th>Jet age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fg 1</td>
<td>2000</td>
<td>2500-7000</td>
</tr>
<tr>
<td>Necklace</td>
<td>1100</td>
<td>2400</td>
</tr>
<tr>
<td>Ethos 1</td>
<td>900</td>
<td>1800</td>
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<tr>
<td>Abell 63</td>
<td>3500</td>
<td>5200</td>
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</table>

Jones (2014)
History?

Tovmassian et al. (2010)
Younger jets = mass transfer
Younger jets = mass transfer

Carbon dwarf secondary

Miszalski, Boffin & Corradi (2013)
Inflated secondaries
More evidence of mass transfer!

Every well constrained main-sequence secondary is inflated!

Abell 46
Hen 2-155

Jones et al. (2015a)
Nebular abundances

Abundances calculated from ORLs and CELs are discrepant, on average by a factor of 2-5.

Some show much higher ads, most of those are in binaries.

Corradi et al. (2015)
Jones et al. (2015b)

<table>
<thead>
<tr>
<th>PN</th>
<th>adf</th>
<th>Period (days)</th>
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<tbody>
<tr>
<td>A30</td>
<td>&gt;&gt;100</td>
<td>?</td>
</tr>
<tr>
<td>A46</td>
<td>120</td>
<td>0.47</td>
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<tr>
<td>A58</td>
<td>89</td>
<td>?</td>
</tr>
<tr>
<td>Hf 2-2</td>
<td>70</td>
<td>0.40</td>
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<tr>
<td>Ou 5</td>
<td>56</td>
<td>0.36</td>
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<tr>
<td>NGC 6778</td>
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<td>0.15</td>
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<tr>
<td>Hen 2-161</td>
<td>11</td>
<td>~1</td>
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<tr>
<td>A63</td>
<td>8</td>
<td>0.46</td>
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<tr>
<td>Hen 2-155</td>
<td>6</td>
<td>0.15</td>
</tr>
</tbody>
</table>
"Real" planetary nebulae?

- Abundance are actually more nova-like
- High $adfs$ imply a second metal-rich component to the nebula
  - Seems to be centrally concentrated
- Low nebular masses

Corradi et al. (2015)
Jones et al. (2015b)
Bear & Soker (2015)
Summary

• Binaries are responsible for shaping (some/most/all) PNe

• Strong evidence for pre-CE mass transfer

• Good laboratories for studying binary evolution

• Critical for understanding lots of other phenomena