Compact binary evolution

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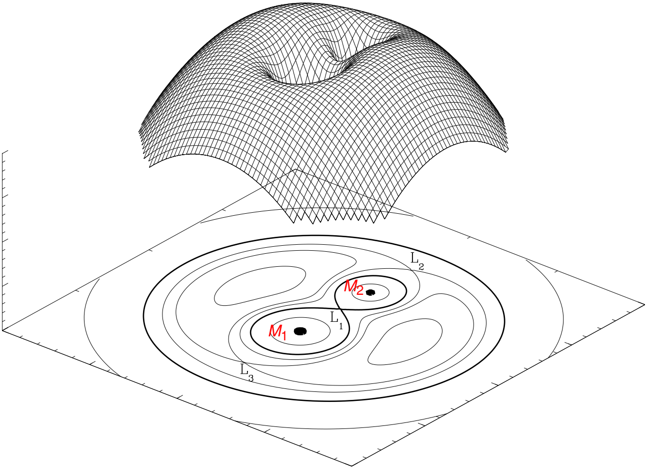
Outline

Roche lobes



$$\frac{R_{\mathrm{Rl,i}}}{a} \approx \frac{2}{3^{4/3}} \left(\frac{M_{(3-i)}}{M_{\mathrm{T}}}\right)^{1/3}$$

accurate within 1% (?) for $q_i < 0.8$ (Paczyński, 1971).

$$\frac{R_{\mathrm{Rl,i}}}{a} \approx \frac{0.49\, q_i^{2/3}}{0.6\, q_i^{2/3} + \ln\left(1 + q_i^{1/3}\right)}$$

accurate within 1% for $0 < q_i < \infty$

(Eggleton, 1983).

Conservative mass transfer

Angular momentum for binary component *i* in a circular orbit:

$$J_i = |\vec{J}_i| = M_i \left|\vec{v}_i \times \vec{a}_i\right| = M_i v_i a_i = M_i a_i^2 \omega$$

$$J = J_1 + J_2 = \mu a^2 \omega = G^{2/3} \frac{M_1 M_2}{M_{\rm T}^{1/3}} \left(\frac{P}{2\pi}\right)^{1/3}$$

$$\frac{\dot{J}}{J} = \frac{\dot{M}_1}{M_1} + \frac{\dot{M}_2}{M_2} - \frac{1}{3}\frac{\dot{M}_{\rm T}}{M_{\rm T}} + \frac{1}{3}\frac{\dot{P}}{P}$$

Conservative: $\dot{J} = 0, \dot{M}_{\rm T} = 0$:

$$\frac{\dot{P}}{P} = 3\,\dot{M}_1 \frac{M_2 - M_1}{M_1 M_2}$$

Conservative mass transfer

Mass and angular-momentum loss

Non-conservative mass transfer (lose fraction β of transferred mass):

$$\left(\frac{\dot{J}}{J}\right)_{\mathrm{MT}} = -\alpha(1-\beta)\frac{M_i}{M_{(3-i)}}\frac{\dot{M}_i}{M_{\mathrm{T}}},$$

Gravitational waves (Peters, 1964):

$$\left(\frac{\dot{J}}{J}\right)_{\mathrm{GW}} = -\frac{32}{5}\frac{G^{5/3}}{c^5}\left(\frac{2\pi}{P}\right)^{8/3}\frac{M_1 M_2}{M_{\mathrm{T}}^{1/3}}$$

Magnetic braking, *e.g.* Verbunt & Zwaan, 1981:

$$\left(\frac{dJ}{dt}\right)_{\mathrm{MB}} = -3.8\times10^{-30} M R^4 \omega^3 \;\mathrm{dyn\;cm}$$

Magnetic braking, *e.g.* Sills et al., 2000:

$$\begin{aligned}\left(\frac{dJ}{dt}\right)_{\mathrm{MB}} &= -K\left(\frac{R}{R_\odot}\right)^{1/2}\left(\frac{M}{M_\odot}\right)^{-1/2}\omega^3, \quad \omega \le \omega_{\mathrm{crit}}\\ &= -K\left(\frac{R}{R_\odot}\right)^{1/2}\left(\frac{M}{M_\odot}\right)^{-1/2}\omega\omega_{\mathrm{crit}}^2, \quad \omega > \omega_{\mathrm{crit}}\end{aligned}$$

Low-mass X-ray binaries

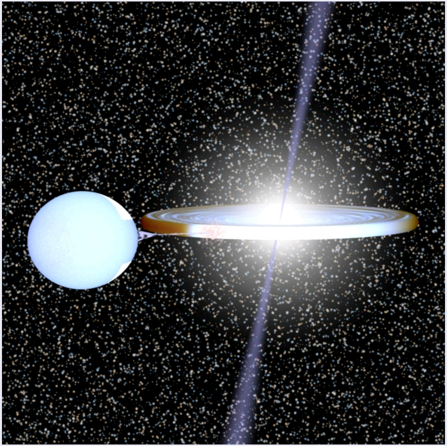
Mechanism

- Low-mass star transfers mass to neutron star or black hole
- Gravitational acceleration causes X-rays:

$$L_{\mathrm{x}} \approx \frac{GM_{\mathrm{ns}}}{R_{\mathrm{ns}}} \dot{M}_{\mathrm{tr}}$$

- Optical radiation comes from reprocessed X-rays in accretion disk

BinSim

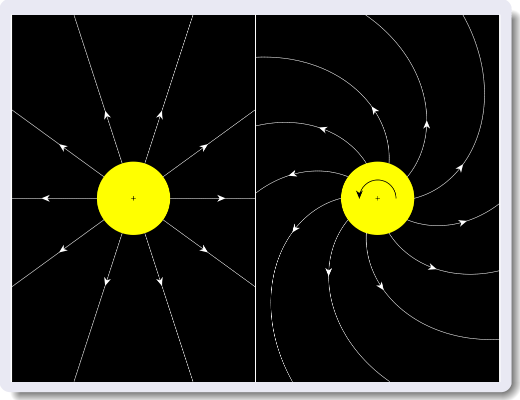


BinSim, R. Hynes, LSU

Scenario 1: Magnetic braking

Magnetic wind

- Rotating stars can have magnetic fields
- Evolved stars can have strong winds
- Stellar wind follows magnetic-field lines
- Star loses angular momentum efficiently
- Tidal coupling causes orbit to shrink in case of a binary



Observed double white dwarfs

System	***P*orb** (d)	***a*orb** ($R_\odot$)	$\boldsymbol{M_1}$ ($M_\odot$)	$\boldsymbol{M_2}$ ($M_\odot$)	$\boldsymbol{q_2}$ (M_2/M_1)	$\Delta\tau$ (Myr)
WD 0135–052	1.556	5.63	0.52 ± 0.05	0.47 ± 0.05	0.90 ± 0.04	350
WD 0136+768	1.407	4.99	0.37	0.47	1.26 ± 0.03	450
WD 0957–666	0.061	0.58	0.32	0.37	1.13 ± 0.02	325
WD 1101+364	0.145	0.99	0.33	0.29	0.87 ± 0.03	215
PG 1115+116	30.09	46.9	0.7	0.7	0.84 ± 0.21	160
WD 1204+450	1.603	5.74	0.52	0.46	0.87 ± 0.03	80
WD 1349+144	2.209	6.59	0.44	0.44	1.26 ± 0.05	—
HE 1414–0848	0.518	2.93	0.55 ± 0.03	0.71 ± 0.03	1.28 ± 0.03	200
WD 1704+481a	0.145	1.14	0.56 ± 0.07	0.39 ± 0.05	0.70 ± 0.03	-20[a]
HE 2209–1444	0.277	1.88	0.58 ± 0.08	0.58 ± 0.03	1.00 ± 0.12	500

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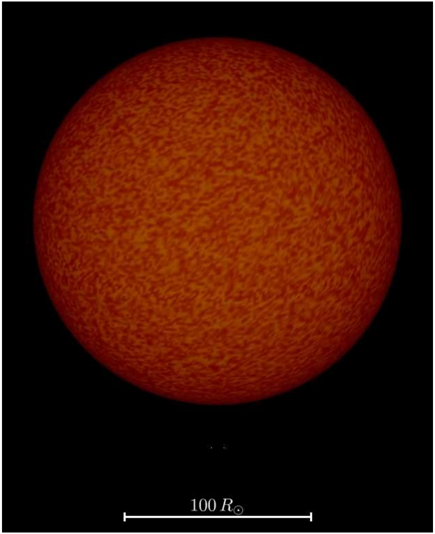
[a] Unclear which white dwarf is older

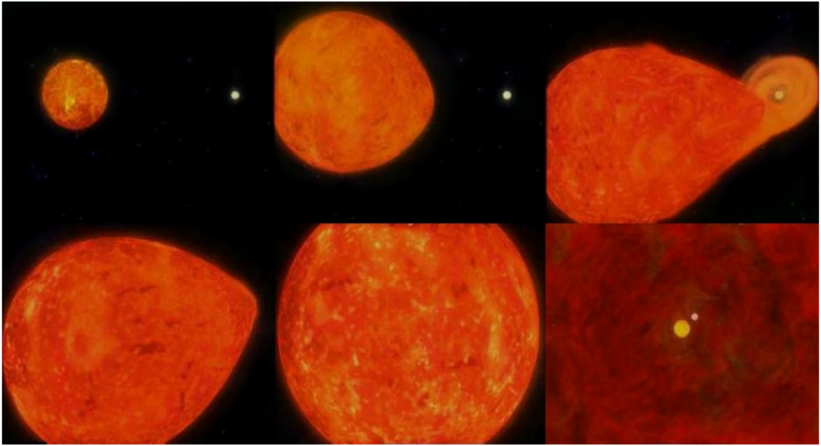
See references in: Maxted et al., 2002 and Nelemans & Tout, 2005.

Common envelope



- Average orbital separation:
  - $7\ R_\odot$
- Typical progenitor:
  - $M_c \gtrsim 0.3\,M_\odot$
  - $R_* \sim 100\,R_\odot$

Common envelope



Envelope ejection

- Classical α-common envelope (spiral-in):
  - orbital energy is used to expel envelope (Webbink, 1984):

$$U_{\mathrm{bind}} = \alpha_{\mathrm{CE}} \left[\frac{G\, M_{1\mathrm{f}}\, M_2}{2\, a_{\mathrm{f}}} - \frac{G\, M_{1\mathrm{i}}\, M_2}{2\, a_{\mathrm{i}}} \right]$$

  - α_{CE} is the common-envelope efficiency parameter

- γ-envelope ejection (EE, spiral-in not necessary):
  - envelope ejection with angular-momentum balance (Nelemans et al., 2000):

$$\frac{J_{\mathrm{i}} - J_{\mathrm{f}}}{J_{\mathrm{i}}} = \gamma_{\mathrm{CE}} \frac{M_{1\mathrm{i}} - M_{1\mathrm{f}}}{M_{1\mathrm{i}} + M_2}$$

  - $\gamma_{\mathrm{CE}} \approx 1.5$ is the efficiency parameter

Envelope ejection

Assumption:

- Envelope ejection occurs much faster than nuclear evolution, hence:
  - core mass does not grow during envelope ejection
  - no accretion by companion during envelope ejection