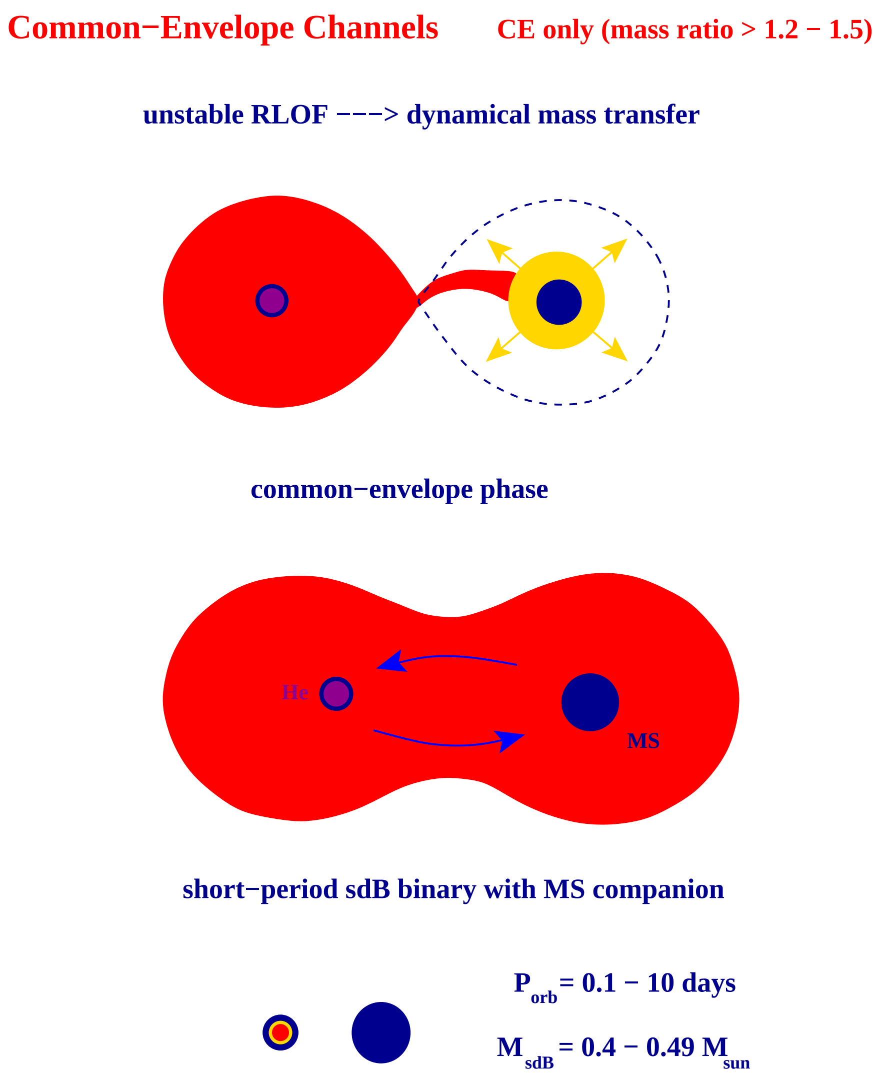
Common-envelope evolution and ejection

- dynamical mass transfer leads to a CE and spiral-in phase
- if envelope is ejected $\rightarrow$ short-period binary (Paczyński 1976)
- CE ejection criterion?
  - ▷ qualitatively: $\alpha_{\rm CE}\,|\Delta E_{\rm orb}| > E_{\rm env}$
  - ▷ the role of recombination energy (Han et al. 2002/03)?
  - ▷ $\alpha_{\rm CE}\,|\Delta E_{\rm orb}| > |E_{\rm grav} + \alpha_{\rm therm} E_{\rm therm}|$
  - ▷ sdB binaries: $\alpha_{\rm CE} = 0.75$, $\alpha_{\rm therm} = 0.75$
  - ▷ CE ejection efficient, recombination energy important



The criterion for dynamical mass transfer

- dynamical mass transfer is caused by a mass-transfer runaway (giant expands, Roche lobe shrinks)
  - ▷ for $n = 1.5$ polytrope: $q > q_{crit} = M_{donor}/M_{accretor} = 2/3$
  - ▷ real stars: $q_{crit} \gtrsim 1.1 - 1.3$ (finite core mass, inefficient convection)
- problem:
  - ▷ many S-type symbiotics (with $q > 2 - 3$) appear to fill their Roche lobes (Mikołajewska)
  - ▷ sdB binaries: best fit: $q_{crit} \simeq 1.2$
- the role of 'near-RLOF'?

The role of non-conservative mass transfer

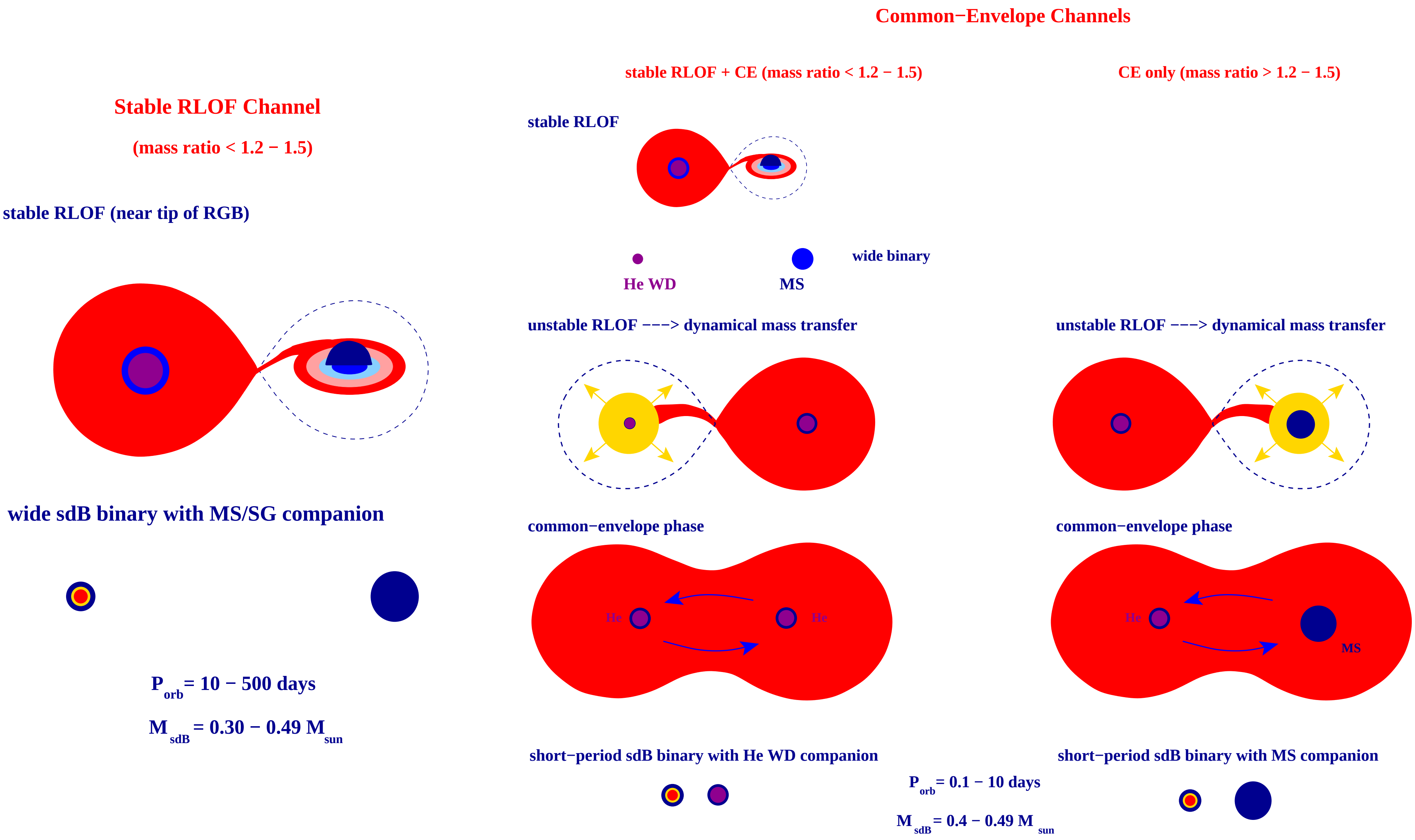
- mass transfer is often very non-conservative
- angular-momentum loss affects orbital evolution
  - ▷ different prescriptions give very different outcomes (e.g. can stabilize/destabilize mass transfer)
  - ▷ no good theoretical model, weak observational constraints
- sdB binaries: mass transfer in stable systems has to be very non-conservative to produce short-period sdB binaries with WD companions

Testing Binary Evolution: sdB Stars

(Han et al. 2002, 2003)

- sdB stars are helium-core-burning stars (with $M \simeq 0.5\,M_{\odot}$) that have lost most of their envelopes by binary interactions
- prototypical evolution for forming compact binaries
  - ▷ stable Roche-lobe overflow
  - ▷ common-envelope (CE) evolution
  - ▷ binary mergers
- all channels appear to be important ($\gtrsim 50\,\%$ are short-period, post-CE binaries; Maxted, Heber, Napiwotzki)
- mass transfer must have started near the tip of the red-giant branch (helium burning!)

→ ideal systems to test/constrain binary evolution

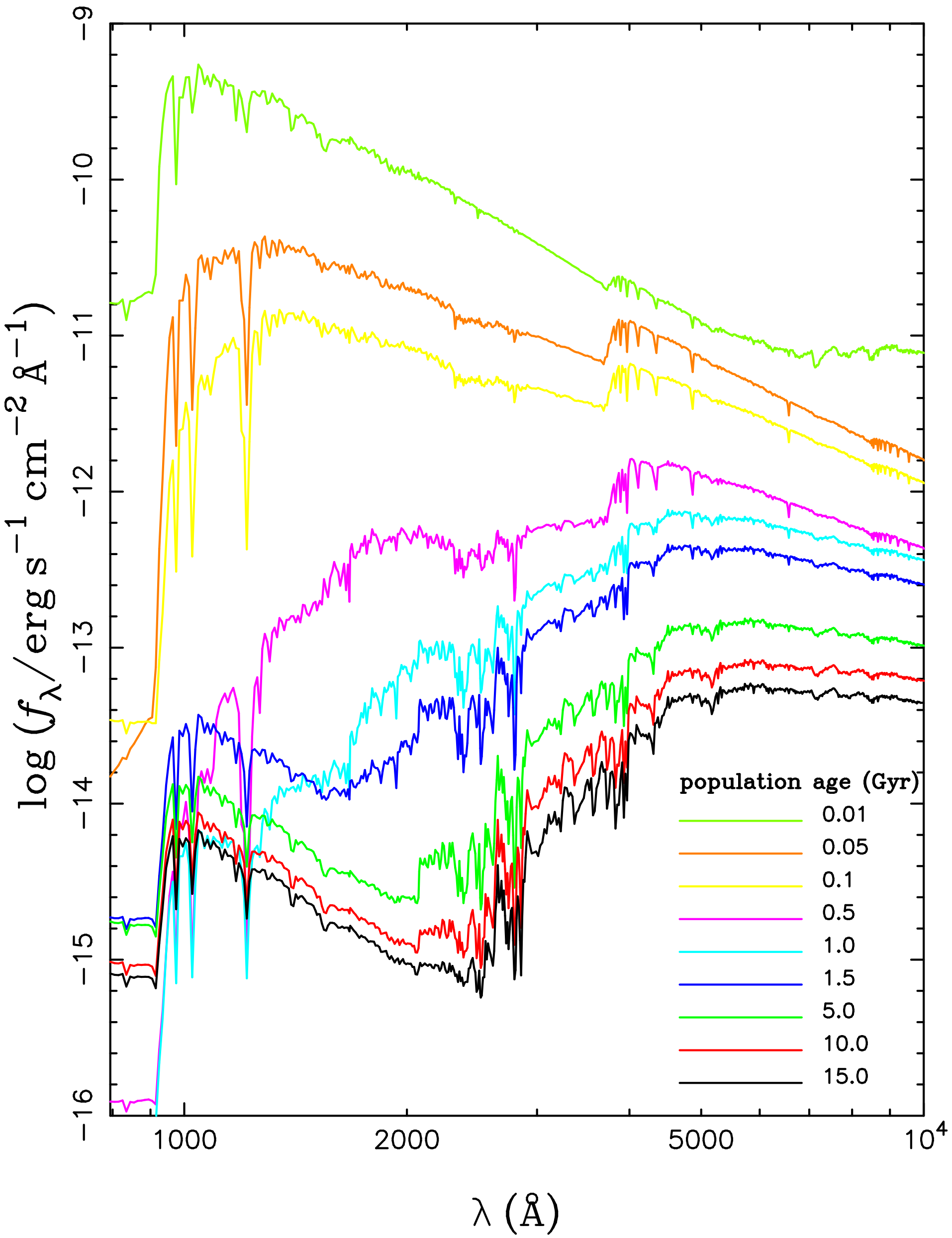

Common−Envelope Channels
stable RLOF + CE (mass ratio < 1.2 − 1.5)
CE only (mass ratio > 1.2 − 1.5)
Stable RLOF Channel
(mass ratio < 1.2 − 1.5)
stable RLOF (near tip of RGB)
stable RLOF
He WD
MS
wide binary
unstable RLOF −−−> dynamical mass transfer
unstable RLOF −−−> dynamical mass transfer
wide sdB binary with MS/SG companion
common−envelope phase
common−envelope phase
He
He
He
MS
P_{orb} = 10 − 500 days
M_{sdB} = 0.30 − 0.49 M_{sun}
short−period sdB binary with He WD companion
short−period sdB binary with MS companion
P_{orb} = 0.1 − 10 days
M_{sdB} = 0.4 − 0.49 M_{sun}

Galaxy Modelling

(single population)

(Han et al. 2007, MNRAS, 380, 1098)

- standard model is the 'best' model to explain hot subdwarfs in the Milky Way
- single stars included by default ('wide binaries')
- add spectral library
  - ▷ hydrogen-rich stars: BaSeL library (Lejeune 1997, 1998)
  - ▷ hot subdwarfs: calculated spectra with ATLAS9 stellar atmosphere code (Kurucz)

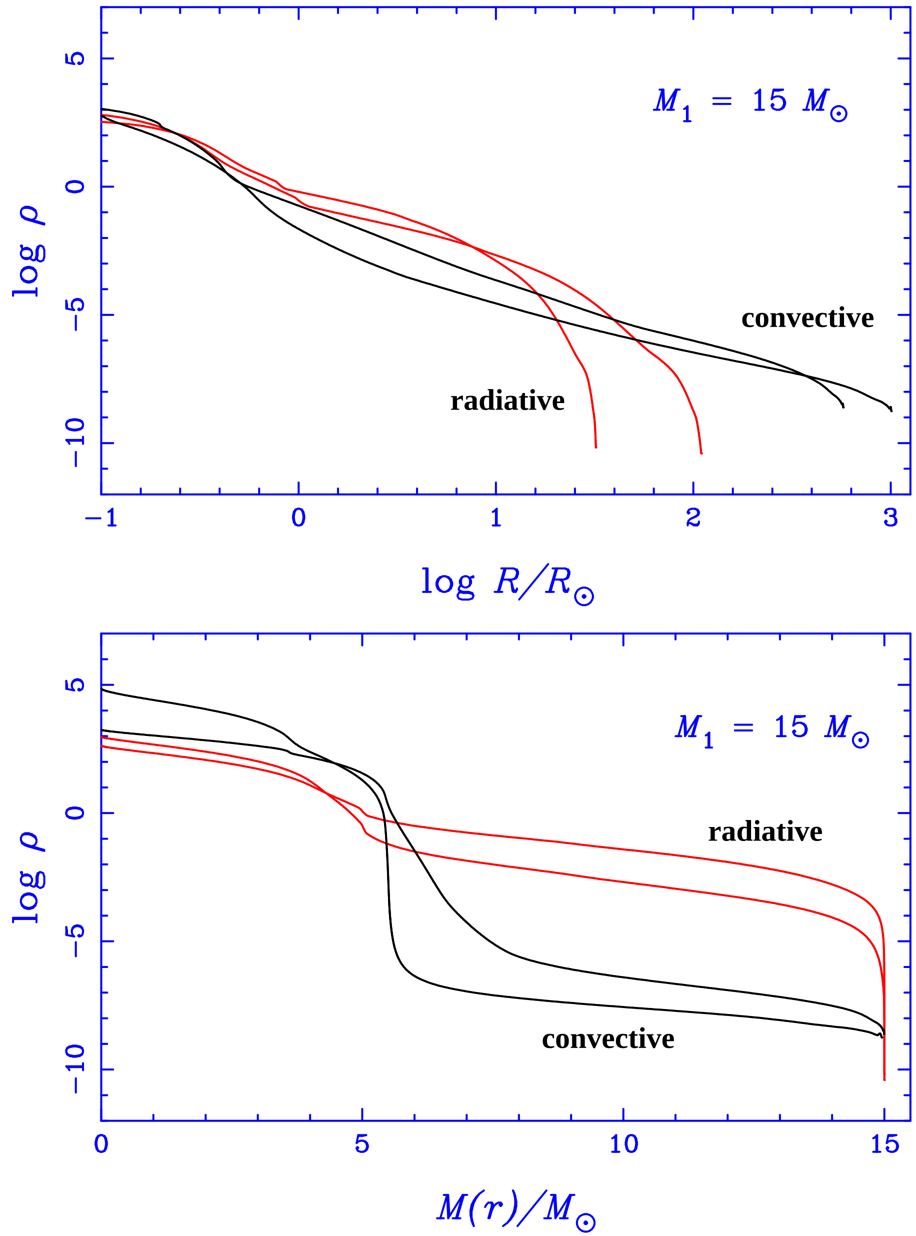


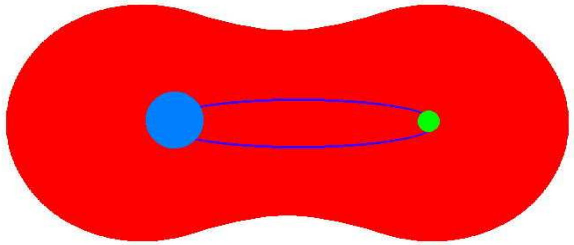
Binary Mergers

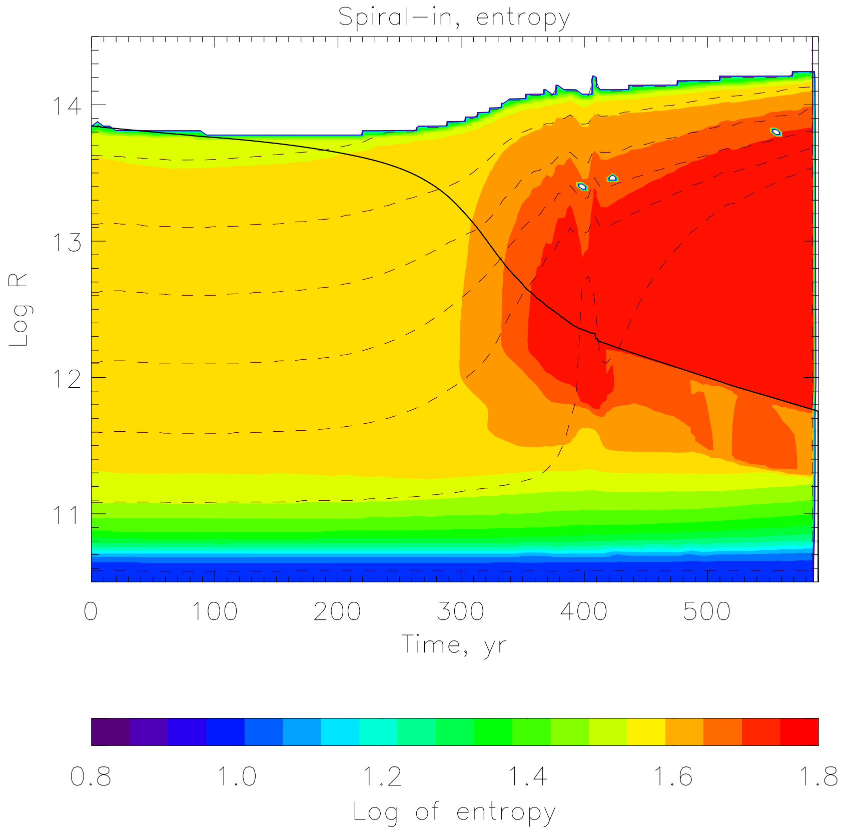
- one of the most important, but not well studied binary interactions
- BPS: $\sim 10\,\%$ of all stars are expected to merge with a companion star $\rightarrow$ 1 binary merger in the Galaxy every 10 yr!
- efficient conversion of orbital-angular momentum to spin orbital-angular momentum
- if mergers occur early in the evolution $\rightarrow$ subsequent spin-down just as for single stars
- late mergers to affect the nearby CSM and pre-SN structure (e.g. case C mass transfer)

Merger Types

- merging timescales depend on the **structure of the envelope** which determines the **friction timescale**
- **radiative envelopes: low-density outer** region with very little mass and **steep density gradient**
  - $\rightarrow$ long-lasting initial **"contact" phase,** ($10^2 - 10^4$ yr?; for $q \sim 1$ temporary CE phase? avoid spiral-in?)
  - $\rightarrow$ followed by **runaway spiral-in** (i.e. no self-regulation possible)
- **convective envelopes: higher density** and **shallow density gradient**
  - $\rightarrow$ **self-regulated spiral-in** possible, where envelope expands and reduces friction, until **frictional luminosity** can be **radiated away** at the surface (Meyer, Meyer-Hofmeister 1979)

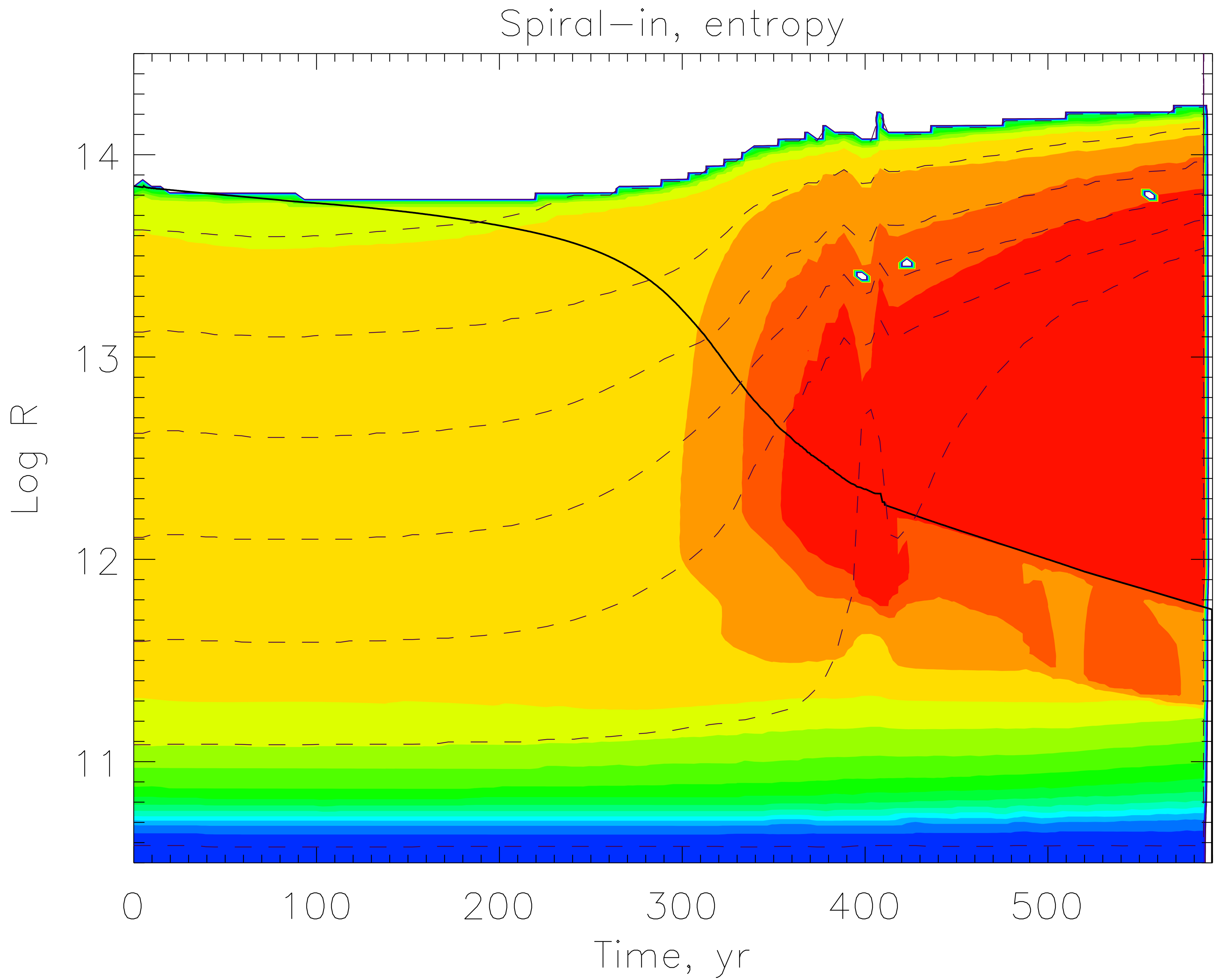


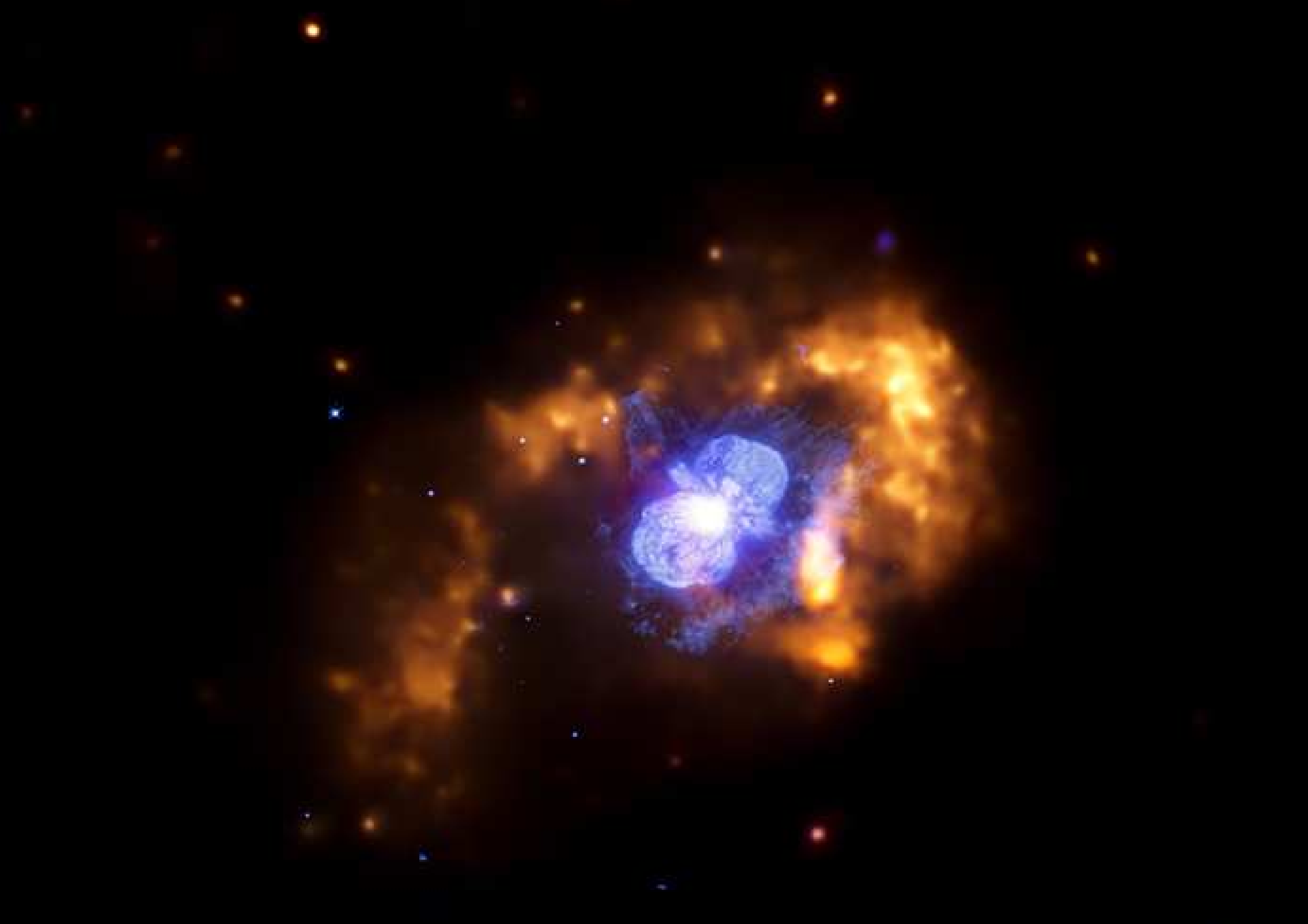




Types

- dynamical mergers (early case B/C)
- slow mergers (100's yrs, late case B/C)
- collisional mergers (in clusters)


Spiral–in, entropy
Log R
14
13
12
11
0
100
200
300
400
500
Time, yr



Eta Carinae

- Major outburst from 1840 to 1860, L up to $10^{7.4}\,L_\odot$
- nebula ejected during outburst, KE 10^{50} ergs (? 10 % of SN energy!) (Smith 2003)
- ejected mass: $\sim 10\,M_\odot$?!
- spectroscopic binary: $P_{orb} = 5.5\,yr$, $e \gtrsim 0.6 \rightarrow$ wide binary, not directly related to outburst
- latitude dependent wind ($\rightarrow$ rotation)
- if indeed $\sim 10\,M_\odot$ have been lost with an energy of $\sim 10^{50}$ ergs, this requires dramatic dynamical event (cannot be envelope instability)

$\rightarrow$ binary merger?

- can provide
  - ▷ the energy for the mass ejection
  - ▷ the spin-up of the merger product
  - ▷ excess thermal energy that needs to be radiated away which drives post-eruption stellar wind with $\dot{M}_{wind} \sim 10^{-3}\,M_\odot\,yr^{-1}$

The B[e] supergiant R4 (SMC)

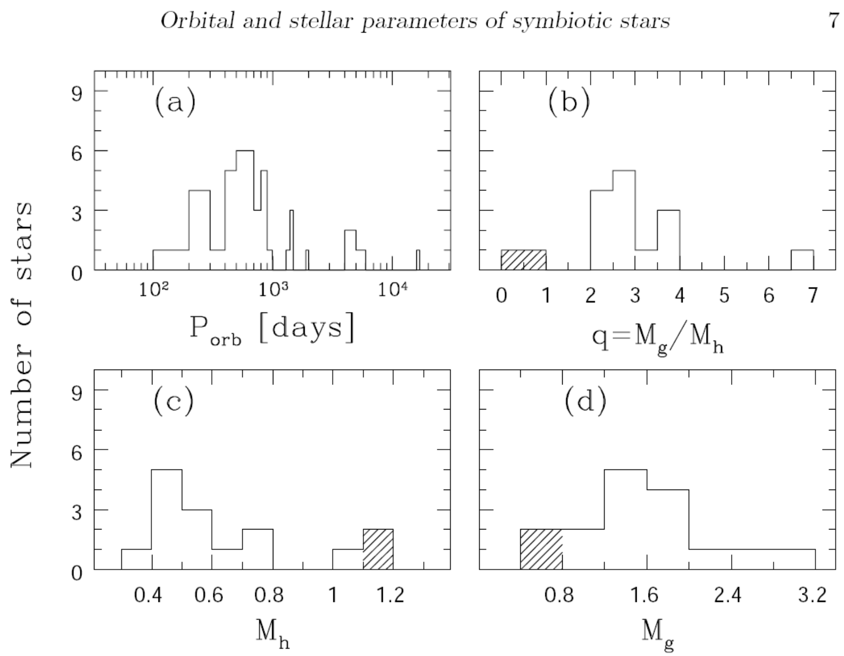
- 21.3 yr binary with evolved A supergiant companion (Zickgraf et al. 1996)
- B[e] component: $\sim 12\,M_\odot$, $\log L/L_\odot \simeq 5$, $T_{eff} \sim 27000\,K$
- NTT spectra: "cloverleaf" (double bi-polar) nebula with $v \sim 100\,km/s$, size 2.4 pc, dynamical age of 10^4 yr, N enriched (Pasquali et al. 2000)
- puzzle: more evolved A supergiant much less luminous (factor 10) than the B[e] supergiant

→ merger model (Langer & Heger): triple system where a $\sim 12\,M_\odot$ star merged with a close MS companion of $\sim 11\,M_\odot$

- equatorial outflow associated with outflow from L_2 in contact phase, bipolar outflow with mass loss from merger (+ subsequent wind interaction)

S-Type Symbiotics

- symbiotic binaries: (most commonly) white dwarf accreting from a red giant/Mira variable

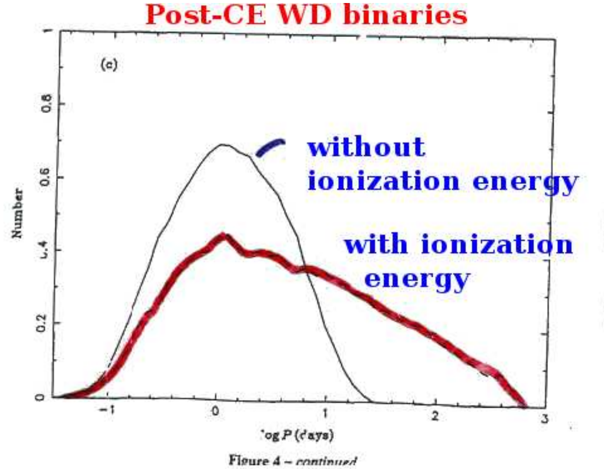


(Mikolajewska 2003)

Key Issues

- the origin of the orbital period distribution
- their possible link to Type Ia Supernovae
- the stability of mass transfer

Symbiotic Binaries



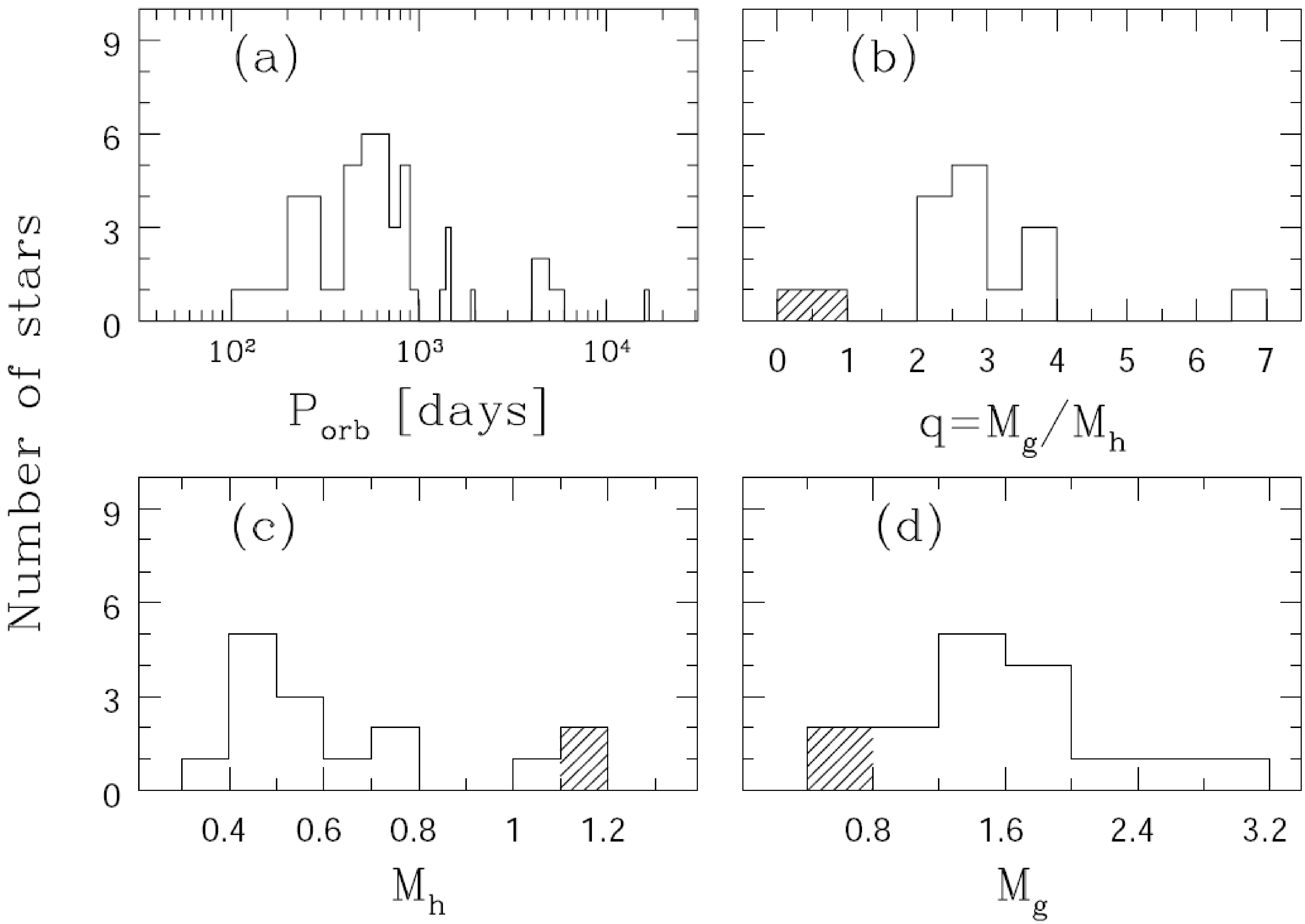
Han et al. (1995)

Problem: binary population synthesis simulations do not produce systems with the observed periods

- ▷ stable RLOF → wide systems with $P_{orb} \gtrsim 10^3\,d$
- ▷ CE evolution → close systems with $P_{orb} \lesssim 10^2\,d$

→ gap in period distribution for systems with $P_{orb} \sim 200 - 1000\,d$ (e.g. Han, Frankowski)

→ suggests problem with binary evolution model

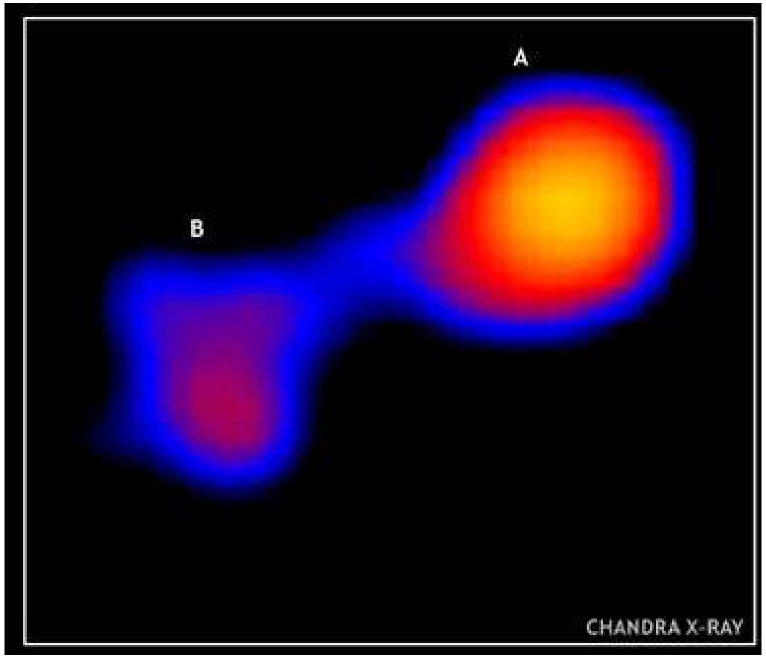

Number of stars
(a)
(b)
(c)
(d)
0
3
6
9
10^2
10^3
10^4
P_{orb} [days]
0 1 2 3 4 5 6 7
$q=M_g/M_h$
0.4 0.6 0.8 1 1.2
M_h
0.8 1.6 2.4 3.2
M_g

Quasi-dynamical mass transfer?

- need a different mode of mass transfer (Webbink, Podsiadlowski)
- very non-conservative mass transfer but without significant spiral-in
- also needed to explain the properties of double degenerate binaries (Nelemans), υ Sgr, etc.
- transient CE phase or circumbinary disk (Frankowski, Dermine)?

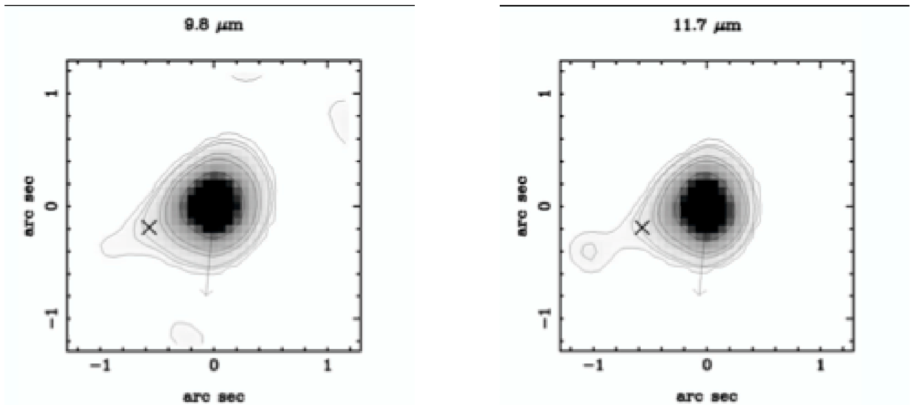
The Symbiotic Binary Mira AB

- wide binary ($P_{orb} \gtrsim 1000\,yr$), consisting of Mira A ($P_{puls} \simeq 330\,d$) and an accreting white dwarf
- $\dot{M} \sim 10^{-7}\,M_\odot\,yr^{-1}$



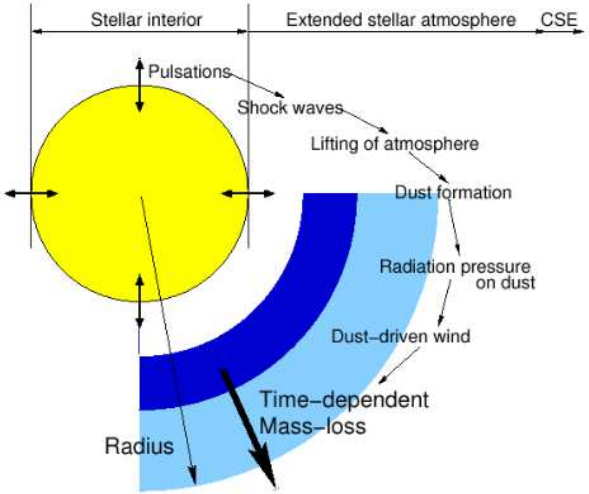
Recent Observations:

- soft X-rays (Chandra, Karovska et al. 2005) from both components (shocks in the wind of Mira A and from accretion disk)
- the envelope of Mira is resolved in X-rays and the mid-IR (Marengo et al. 2001)
  - ▷ the slow wind from Mira A fills its Roche lobe ($R_{RL} \sim 40\,AU$)
  - ▷ but: radius of Mira A: $1-2\,AU$
- a new mode of mass transfer(?): wind Roche-lobe overflow
- important implications for D-type symbiotics



Mass Loss from Mira Variables in Binaries (Mohamed, P.)

The atmosphere of an AGB star



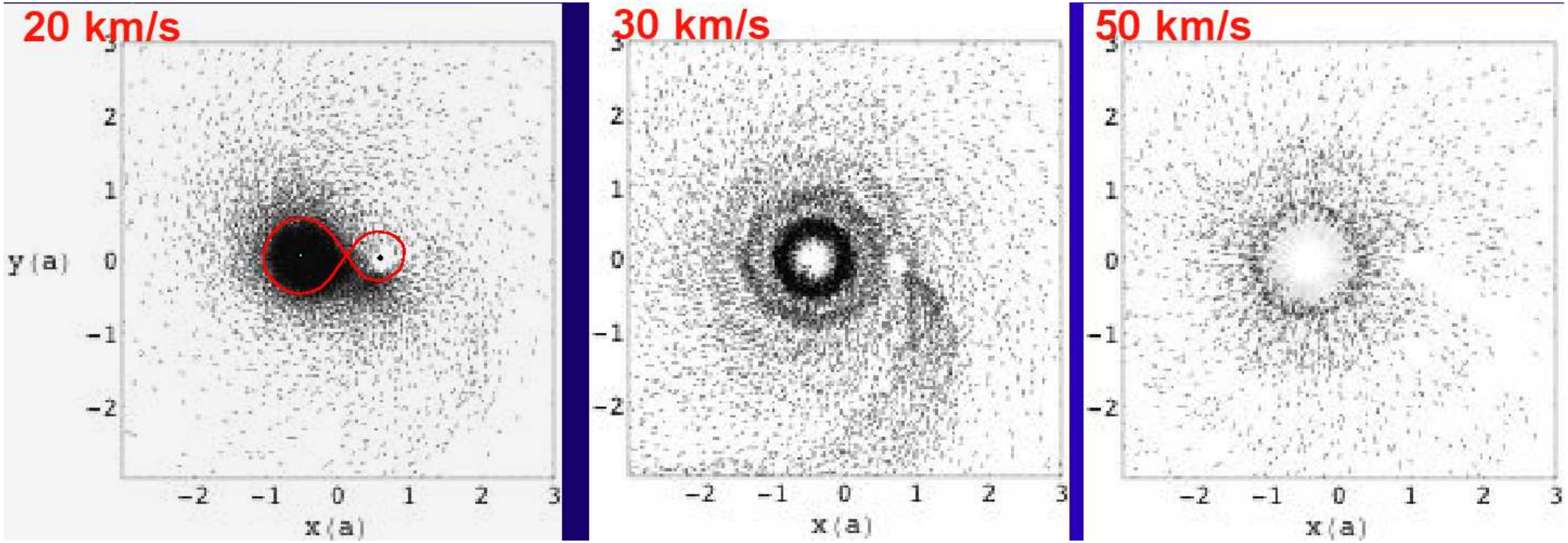
- large-amplitude Mira pulsations lift matter of the atmosphere (but not to escape speed)
- pumping mechanism → till gas reaches low temperatures for dust formation
- radiation pressure on dust accelerates matter to escape speed

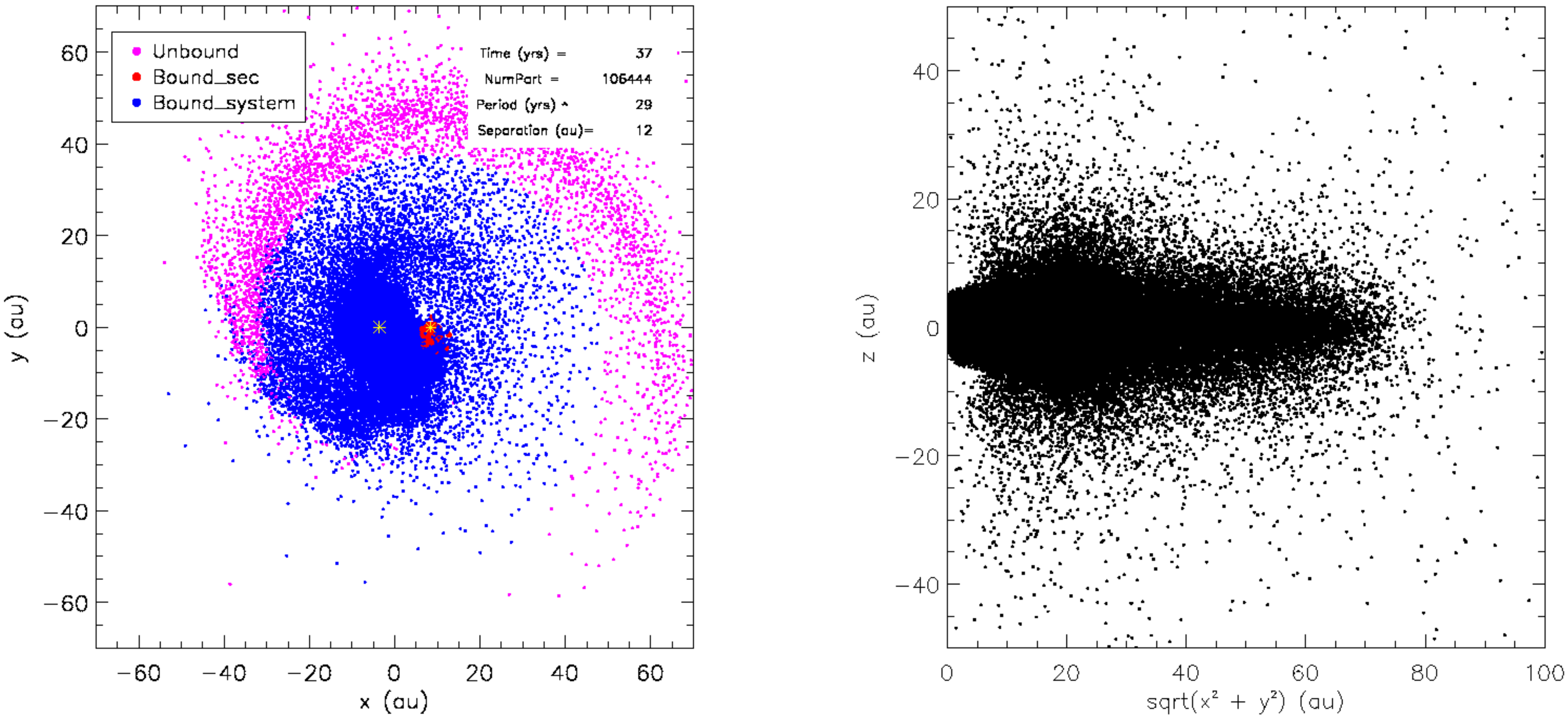
Mira variables in binaries

- if dust-formation radius (R_{dust}) is a significant fraction of the Roche-lobe radius (R_{RL})→ binary effects affect the mass-loss geometry
- transition from
  - ▷ spherical wind for $R_{dust} \ll R_{RL}$
  - ▷ disk-like outflow
  - ▷ wind Roche-lobe overflow for $R_{dust} \sim R_{RL}$
  - ▷ unstable mass transfer? for $R_{dust} > R_{RL}$
- formation of circumbinary disk possible plus bipolar component from accreting source

NB: Application to WR binaries?

- where R_{RL} less than the outer wind acceleration radius (Gräfener & Hamann 2005)


20 km/s
30 km/s
50 km/s
y (a)
x (a)
x (a)
x (a)



Unbound
Bound_sec
Bound_system
Time (yrs) = 37
NumPart = 106444
Period (yrs) = 29
Separation (au)= 12
y (au)
x (au)
z (au)
sqrt(x² + y²) (au)

Wind Roche-Lobe Overflow

- a new mass-transfer mode for wide binaries
- high mass-transfer fraction (compared to Bondi-Hoyle wind accretion) → more efficient accretion of s-process elements for the formation of barium stars (without circularization)
- accretion rate in the regime where WDs can accrete? → increase the range for SN Ia progenitors (but may not be efficient enough)
- asymmetric system mass loss → formation of circumstellar disks and bipolar outflows from accreting component (e.g. OH231.8+4.2)

  → shaping of (proto-)planetary nebulae

  ▷ binaries with longer orbital periods important

Case D Mass Transfer

- extension of case C mass transfer, but potentially more important (possibly larger orbital period range)
- also: massive, cool supergiants with dynamically unstable envelopes (e.g. Yoon & Langer)
- large mass loss just before the supernova?
- possible implications for Type II-L, IIb supernovae (increases rate estimates), SN 2002ic
- delays onset of dynamical mass transfer

  → produces wider S-type symbiotic binaries (i.e. solve orbital period problem)

  → solve the problem of black-hole binaries with low-mass companions