Common Envelope: the current issues

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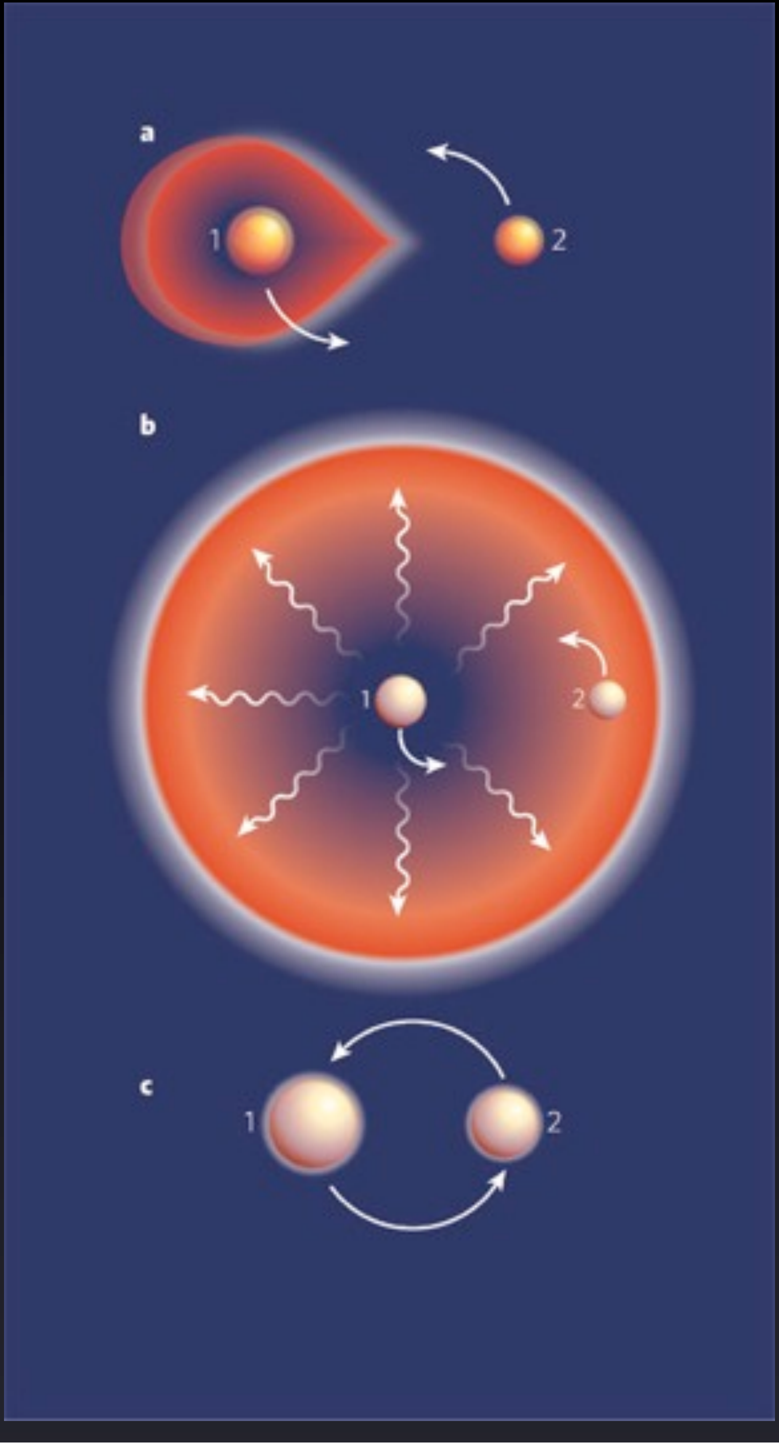
KITP, Dec 1

Common envelope: standard αλ- formalism



common envelope (CE) - phase, during which the low-mass star spirals inward through the extended envelope of the more massive primary star

The phase is terminated upon ejection of the common envelope or merger

$$\alpha_{\rm CE}\Delta E_{\rm orb} < E_{\rm bind\ env} = \frac{GMM_{\rm core}}{R_{\rm RL}\lambda_{\rm ce}}$$

$$\Delta E_{\rm orb} = \frac{GMM_{\rm d}}{2a_{\rm f}} - \frac{GM_{\rm core}M_{\rm d}}{2a_{\rm i}}$$

$$\text{standard:}\ \ \alpha_{\rm CE}\lambda_{\rm ce} = 1$$

(Webink 1984, Livio & Soker 1988)

Simple parameterization fails

α Romani 1998 :

observed formation rate: 1 per mln yr per Milky Way (10^{-6} per gal per yr)

Kalogera (1999):

unrealistically high values of α_{ce} are required for agreement with the observationally inferred BH-LMXB birthrate.

Theoretical formation rate is at least 100 times less!

λ

Podsiadlowski et al. 2003:

BHs with low mass secondaries can only form with apparently unrealistic assumption.

Realistic λ_{ce} is only ~0.1! (Dewi & Tauris 2001, Podsiadlowski et al. 2003)

a companion has to be at least few Msun (Justham et al. 2006)

Outline

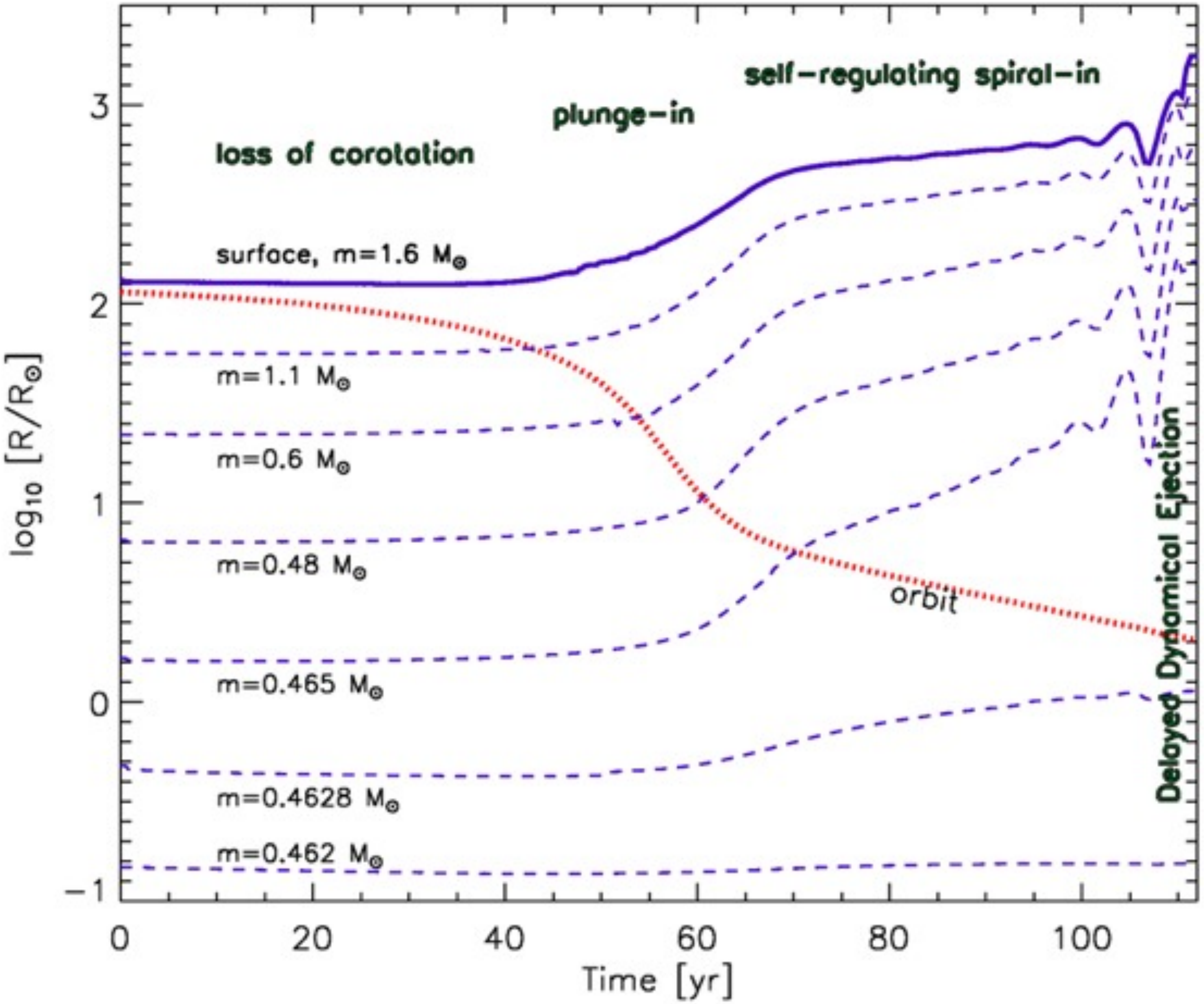
What is really α?

- Do we know what we need to start the ejection?
- Do we know how much we need at the end?
- Do we know how much we loose via other ways?
- Do we know what are the energy sources?
- What is the role of Super-Eddington accretion?

What is really λ?

- Do we know what fraction of the envelope is ejected?
- Is it connected with when the spiral-in/ejection stops?
- Is there a bifurcation point that separates the exposed core from the ejected envelope?

Common envelope: main phases



About λ-parameter

λ is the parameter that links together the "properly" found "binding energy" and its parametrized form

$$E_{\lambda,\mathrm{bind}} = \int_{\mathrm{core}}^{\mathrm{surface}} \left(\frac{Gm}{r(m)} - \varepsilon(m) \right) dm = \frac{G m_{\mathrm{d}} m_{\mathrm{d,e}}}{\lambda r_{\mathrm{d}}}$$

- How to calculate it right if you have a star and know what is the core?
- What is the range of values?
- Where is the core?

How to calculate λ if you know what is the core?

$$E_{\lambda,\mathrm{bind}} = \int_{\mathrm{core}}^{\mathrm{surface}} \left(\frac{Gm}{r(m)} - \varepsilon(m) \right) dm = \frac{G m_{\mathrm{d}} m_{\mathrm{d,e}}}{\lambda r_{\mathrm{d}}}$$

- Straightforward. No simplifications needed.
- Simplification is usually made by the use of a virial theorem

Virial theorem is valid only for a whole star $2K+\Omega=0$

Virial theorem connects the total potential energy Ω and the total kinetic energy K

$$K = \frac{3}{2} \int \frac{P}{\rho} dm \neq U$$

K=U ONLY in the case of γ-law EOS with γ=5/3!!!

$W=U+\Omega$, $E_{\mathrm{bind}}=-W=-U-\Omega \not\equiv -\Omega/2$

for a constant γ:

$$E_{\mathrm{bind}} = -\frac{3\gamma-4}{3(\gamma-1)}\Omega$$

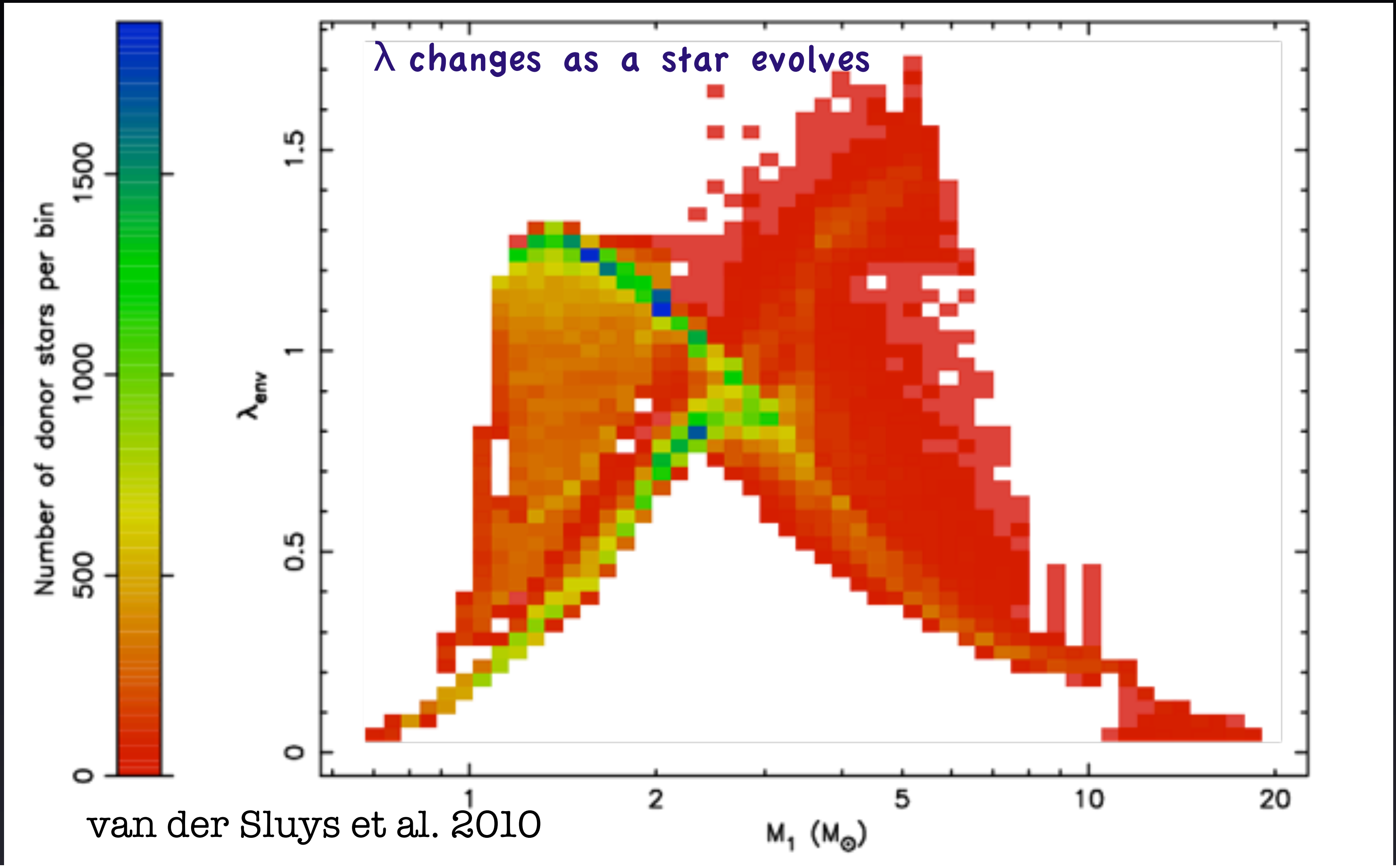
$$E_{\mathrm{bind}} = -\frac{1}{2}\Omega \quad \text{for} \quad \gamma = \frac{5}{3}$$

$$E_{\mathrm{bind}} = 0 \quad \text{for} \quad \gamma = \frac{4}{3}$$

What are λ values in stars?

Historical guess $\lambda=1$:

- It is approximately valid only for low-mass stars
- it is a function of mass & radius (Dewi & Tauris, 2000), $0.1<\lambda<45$
- Massive stars could have $\lambda<0.1$ (Podsiadlowski 2003)



van der Sluys et al. 2010

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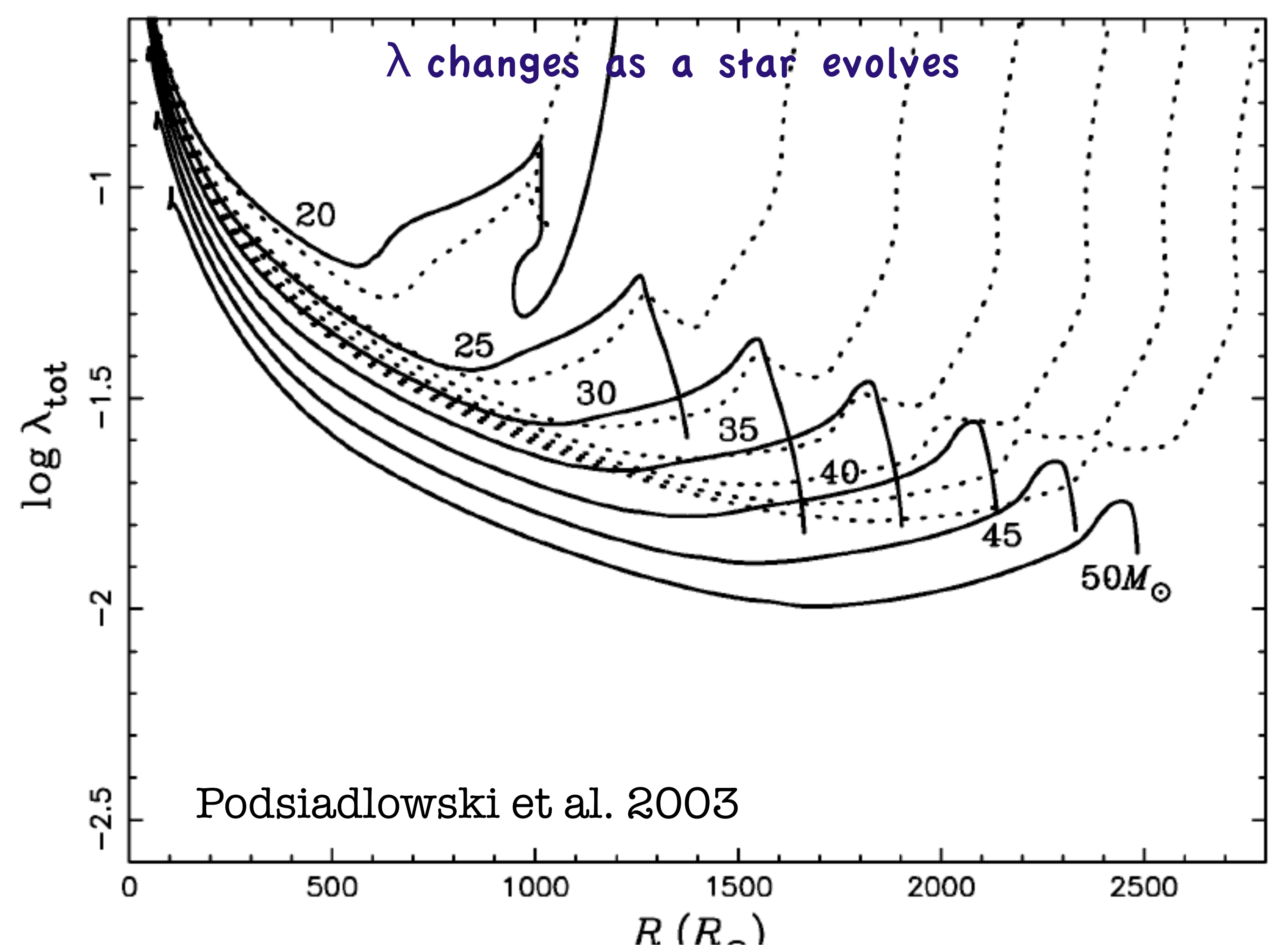


λ changes as a star evolves

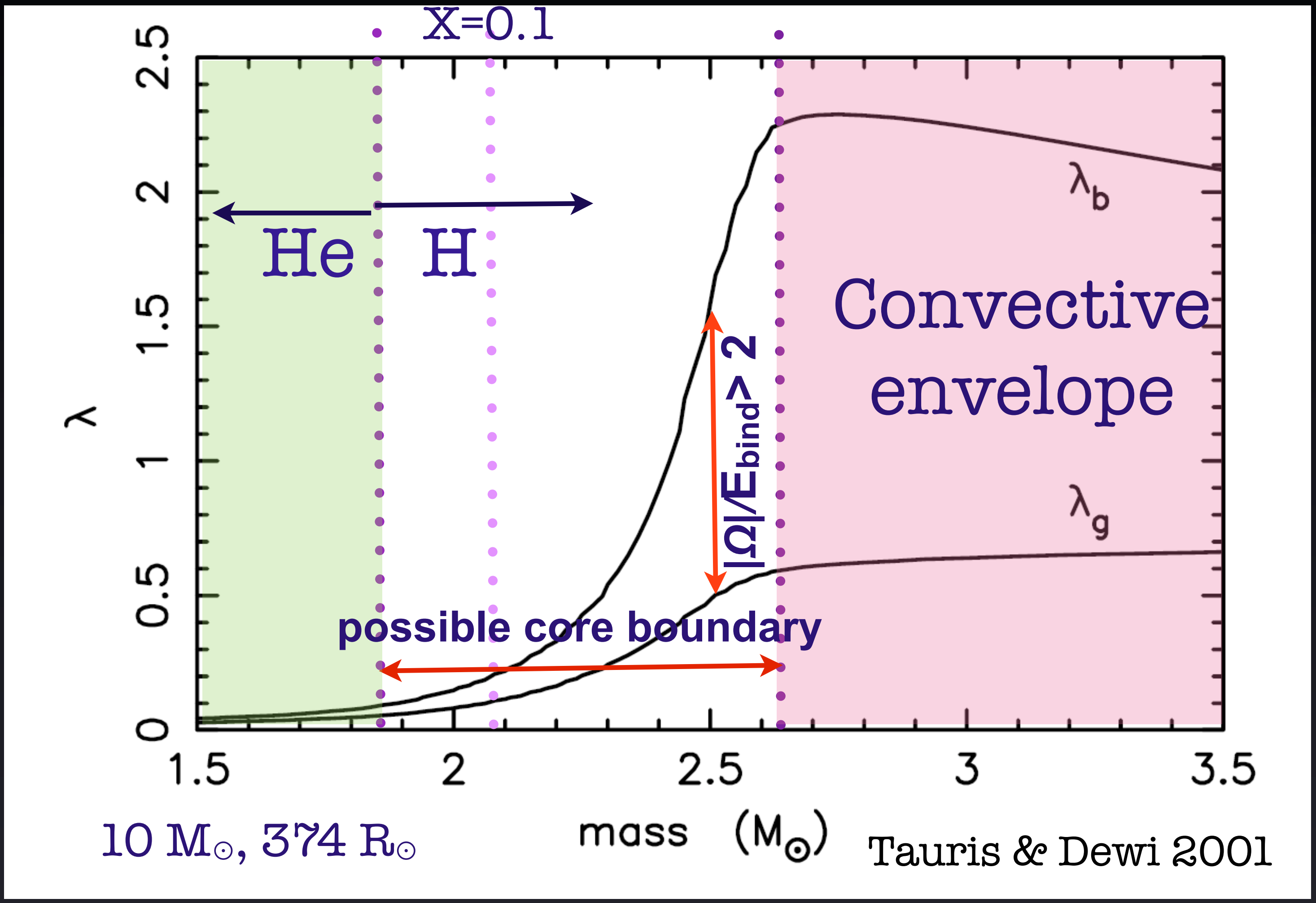
Podsiadlowski et al. 2003

What is the core and why is it important?

for most stars, λ would vary within the core by 10-100 times producing

the same uncertainty in final binary separations

Difference is increasing with mass.



Core definition: the bifurcation point?

low-mass red giants:

- minimum envelope mass to re-expand (Deinzer & von Sengbusch 1970)
- SPH collisions could not remove all the material (Lombadri et al 2006)

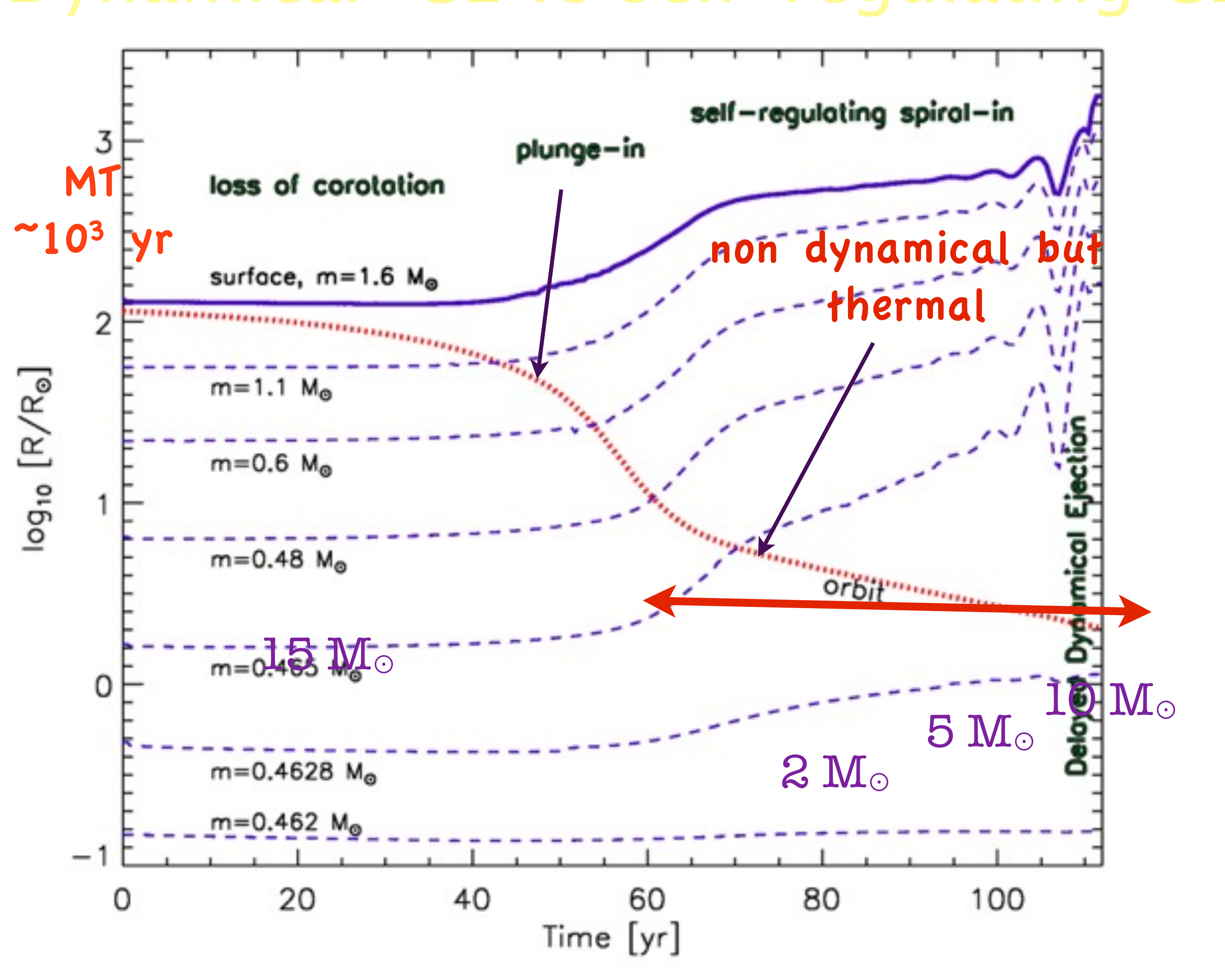
Idea:

- existence of a unique divergence point m_d such that
  - if the final core mass < m_d, the remnant shrinks
  - if the final core mass > m_d, the remnant reexpands

This is a post-CE core

(Ivanova 2011)

"Dynamical" CE vs self-regulating CE



MT

~10^3 yr

non dynamical but thermal

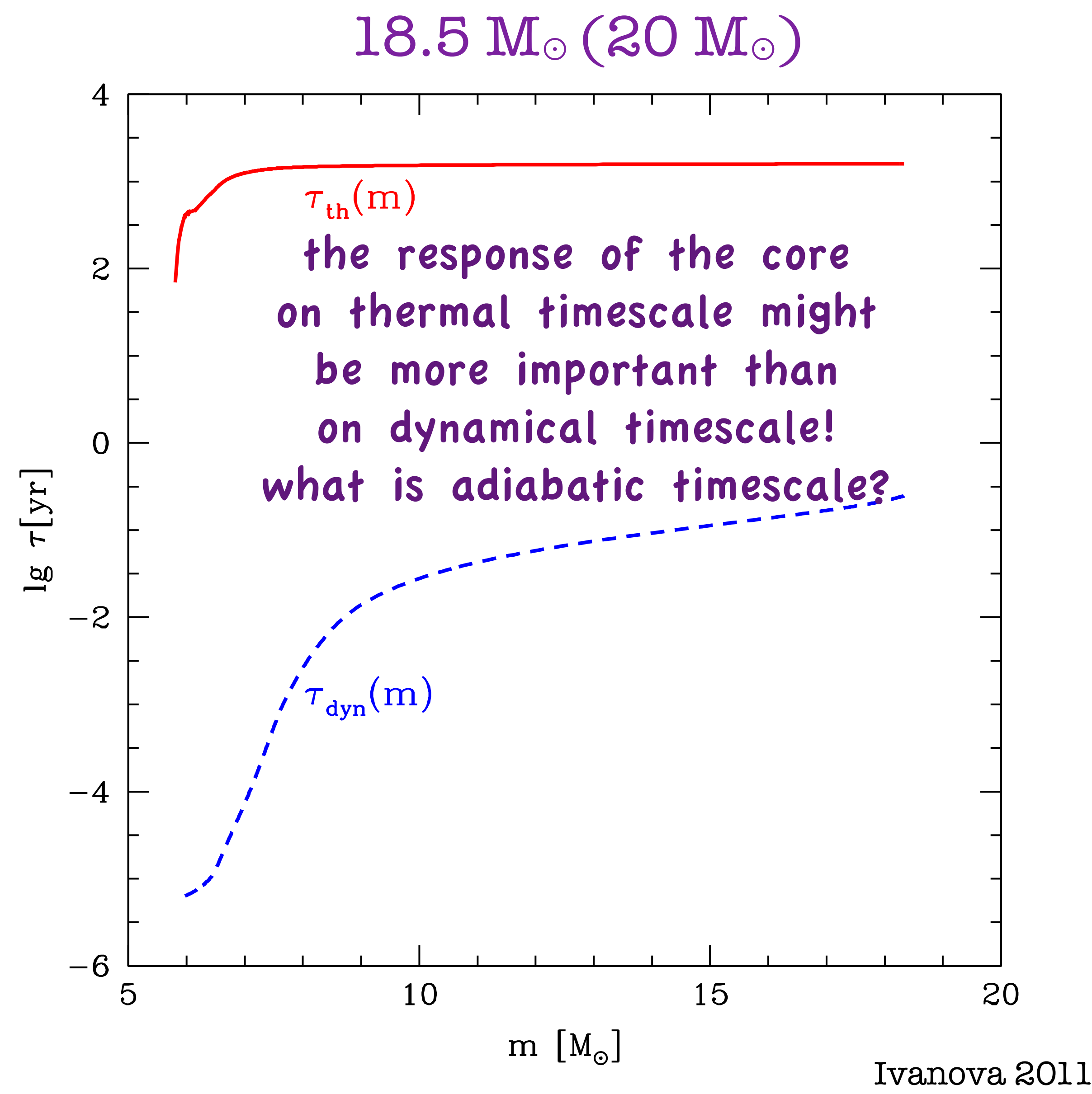
15 $M_\odot$

10 $M_\odot$

5 $M_\odot$

2 $M_\odot$

Timescales inside a giant



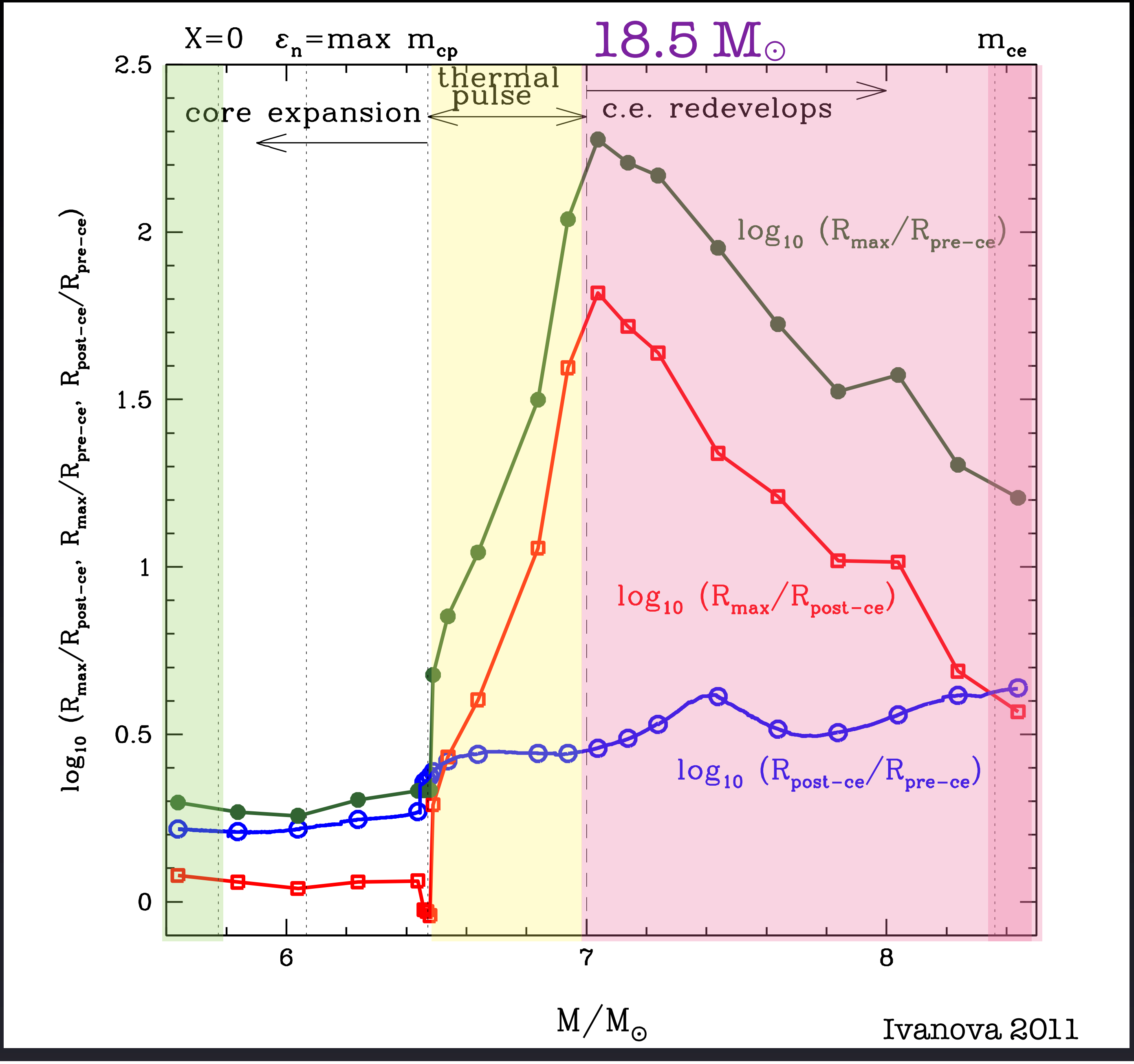
18.5 $M_\odot$ (20 $M_\odot$)

the response of the core
on thermal timescale might
be more important than
on dynamical timescale!
what is adiabatic timescale?

Ivanova 2011

Core definition: the bifurcation point?

maximum compression point P/ρ



About α–parameter

α is the parameter that links together the available orbital energy and the binding energy

$$\alpha \Delta E_{\rm orb} < E_{\rm bind}$$

$0 < \alpha < 1$

what energy is really required?

what energy is really available?

Envelope stability with respect to ejection: not so much about E_{bind}

It has roots in an the hypothesis that an W>0 envelope will be dispersed

- A star with W>0 can be kinetically stable (Bisnovaty-Kogan & Zeldovich 1967)
- Instability against adiabatic perturbations $\Gamma_1<4/3$
- W>0 is when $\Gamma_3<4/3$

$\Gamma_3 \neq \Gamma_1$!!! $\Gamma_3 = 1 + \Gamma_1 \nabla_{ad}$

Envelope's stability: outflows

Energy conservation equation for each lagrangian shell in the star

$$(\delta q(m) + \Psi + \epsilon + \tfrac{p}{\rho})_{\rm start} = (\tfrac{1}{2}u^2 + \Psi + \epsilon + \tfrac{P}{\rho})_{\rm exp} = \Sigma = const$$

q is some arbitrary heat, u is velocity at infinity

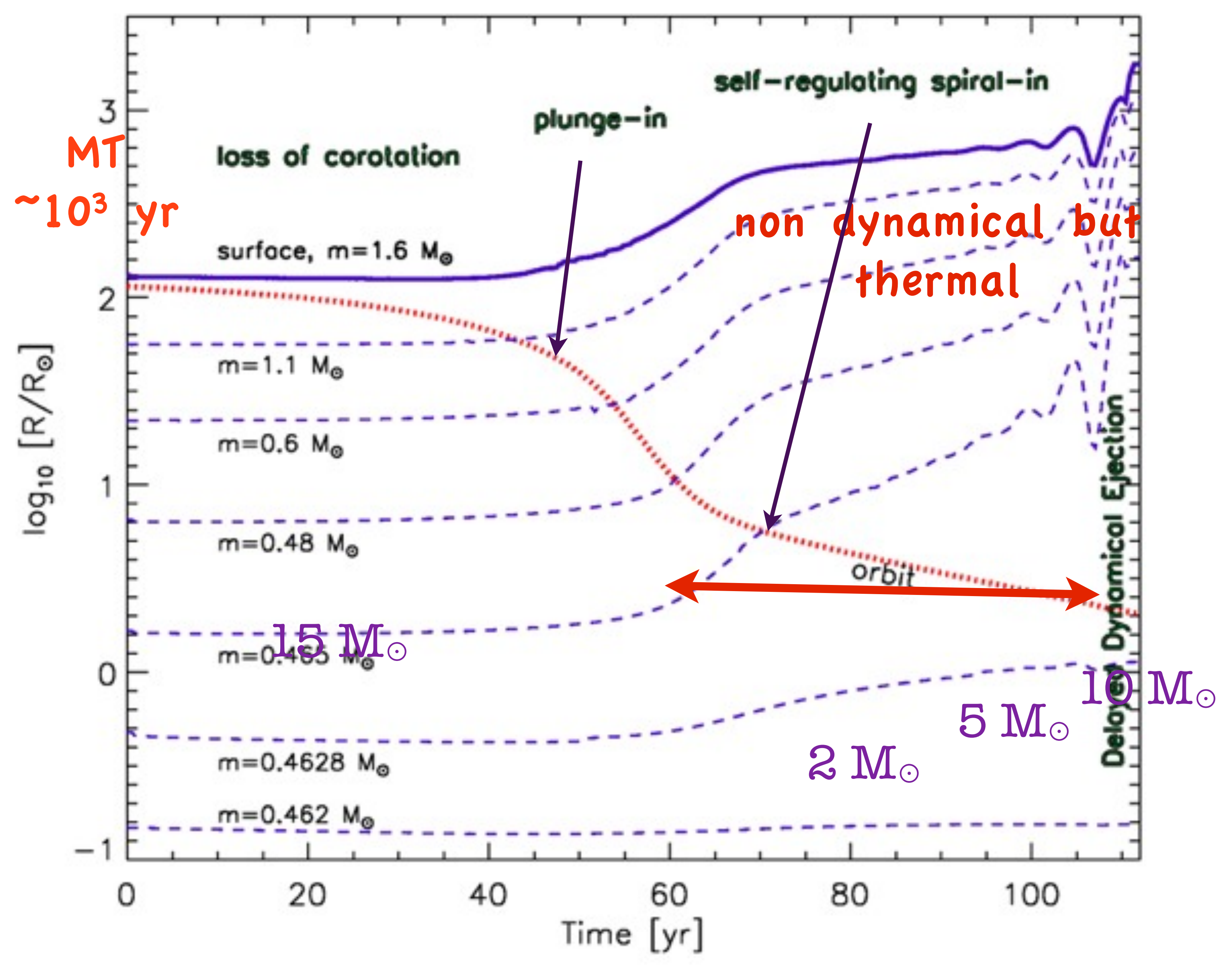
if $\Sigma_{\rm env}>0$, envelope starts outflowing

$$Q + \int_{\rm core}^{\rm surface} \left(\Psi(m) + \epsilon(m) + \boxed{\frac{P(m)}{\rho(m)}} \right) dm = 0$$

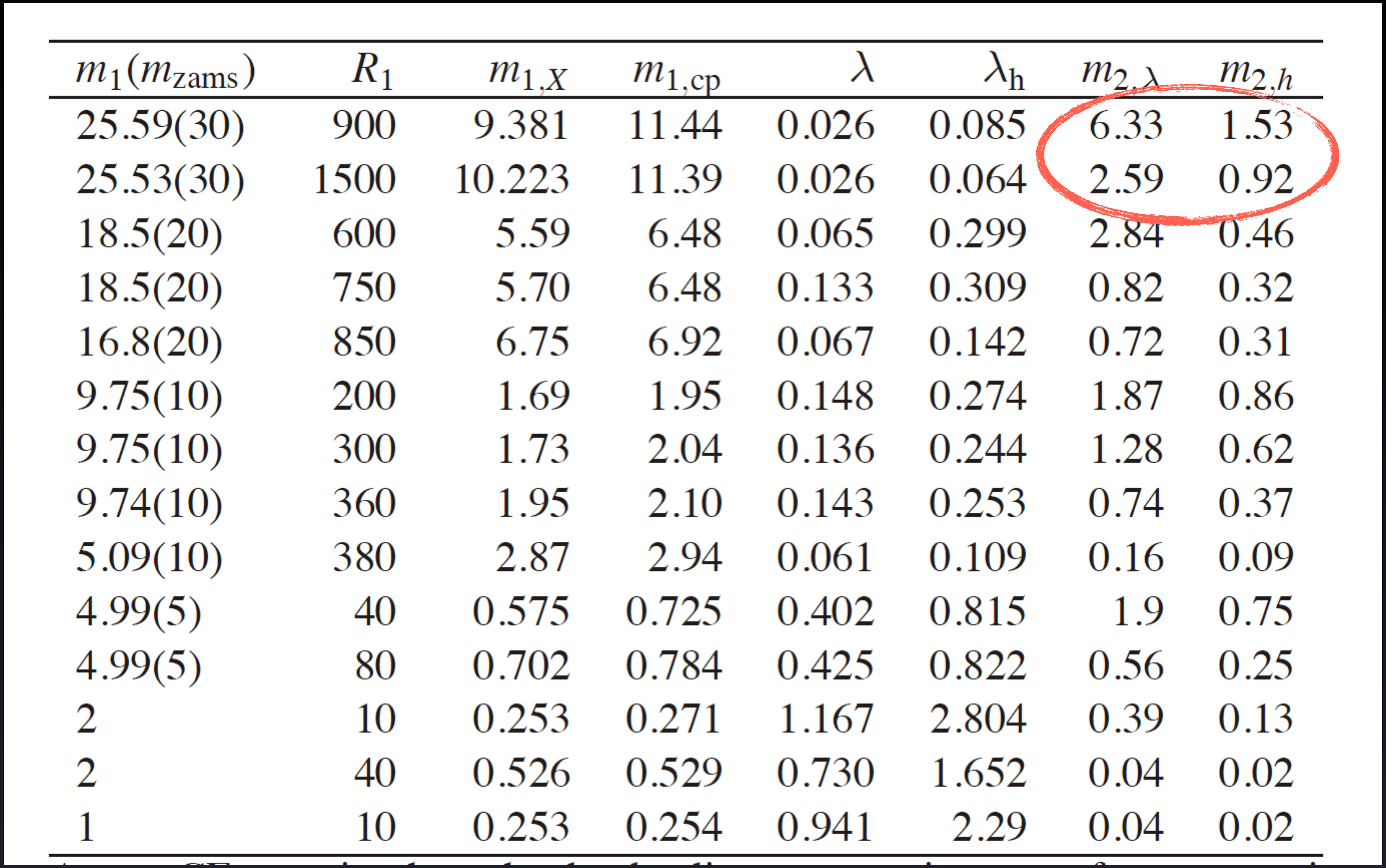
For γ-law EOS with γ=5/3, P/ρ = 2/3 ϵ

P/ρ + ϵ = h - enthalpy

“Dynamical” CE vs self-regulating CE



Enthalpy vs internal energy



$m_1(m_{\rm zams})$	R_1	$m_{1,X}$	$m_{1,\rm cp}$	λ	$\lambda_{\rm h}$	$m_{2,\lambda}$	$m_{2,h}$
25.59(30)	900	9.381	11.44	0.026	0.085	6.33	1.53
25.53(30)	1500	10.223	11.39	0.026	0.064	2.59	0.92
18.5(20)	600	5.59	6.48	0.065	0.299	2.84	0.46
18.5(20)	750	5.70	6.48	0.133	0.309	0.82	0.32
16.8(20)	850	6.75	6.92	0.067	0.142	0.72	0.31
9.75(10)	200	1.69	1.95	0.148	0.274	1.87	0.86
9.75(10)	300	1.73	2.04	0.136	0.244	1.28	0.62
9.74(10)	360	1.95	2.10	0.143	0.253	0.74	0.37
5.09(10)	380	2.87	2.94	0.061	0.109	0.16	0.09
4.99(5)	40	0.575	0.725	0.402	0.815	1.9	0.75
4.99(5)	80	0.702	0.784	0.425	0.822	0.56	0.25
2	10	0.253	0.271	1.167	2.804	0.39	0.13
2	40	0.526	0.529	0.730	1.652	0.04	0.02
1	10	0.253	0.254	0.941	2.29	0.04	0.02

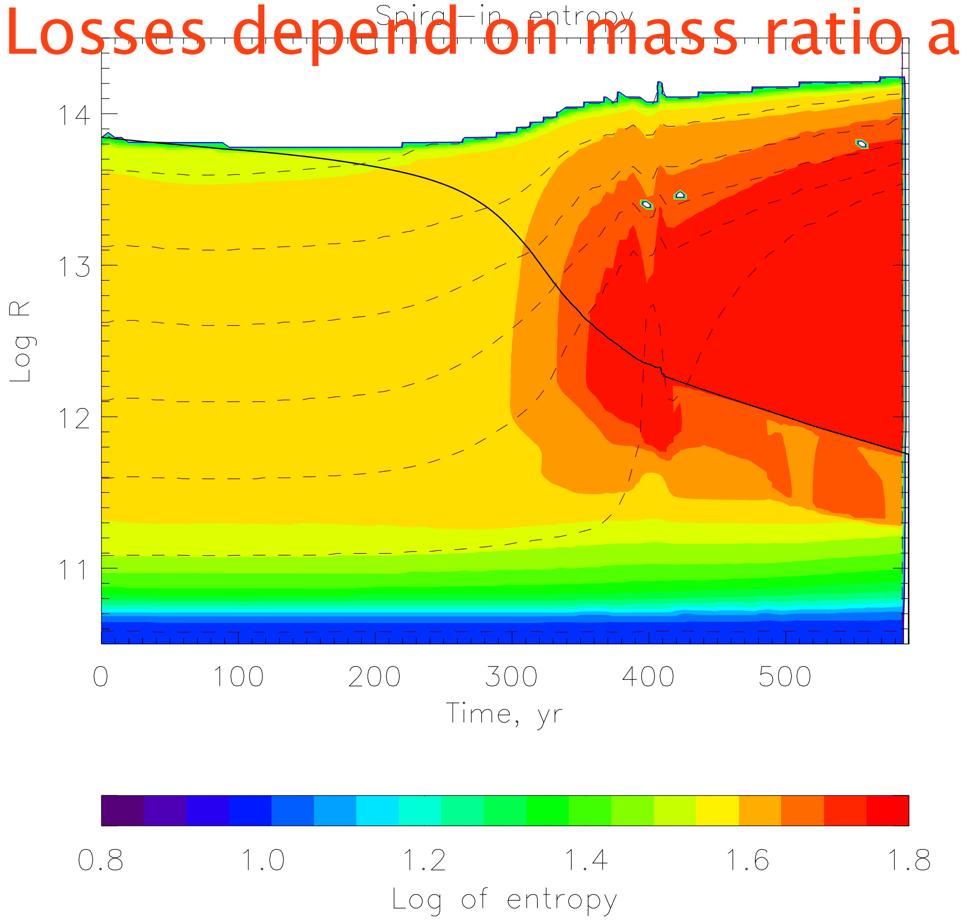
Ivanova & Chaichenets 2011

Energy loss: self-regulating spiral-in

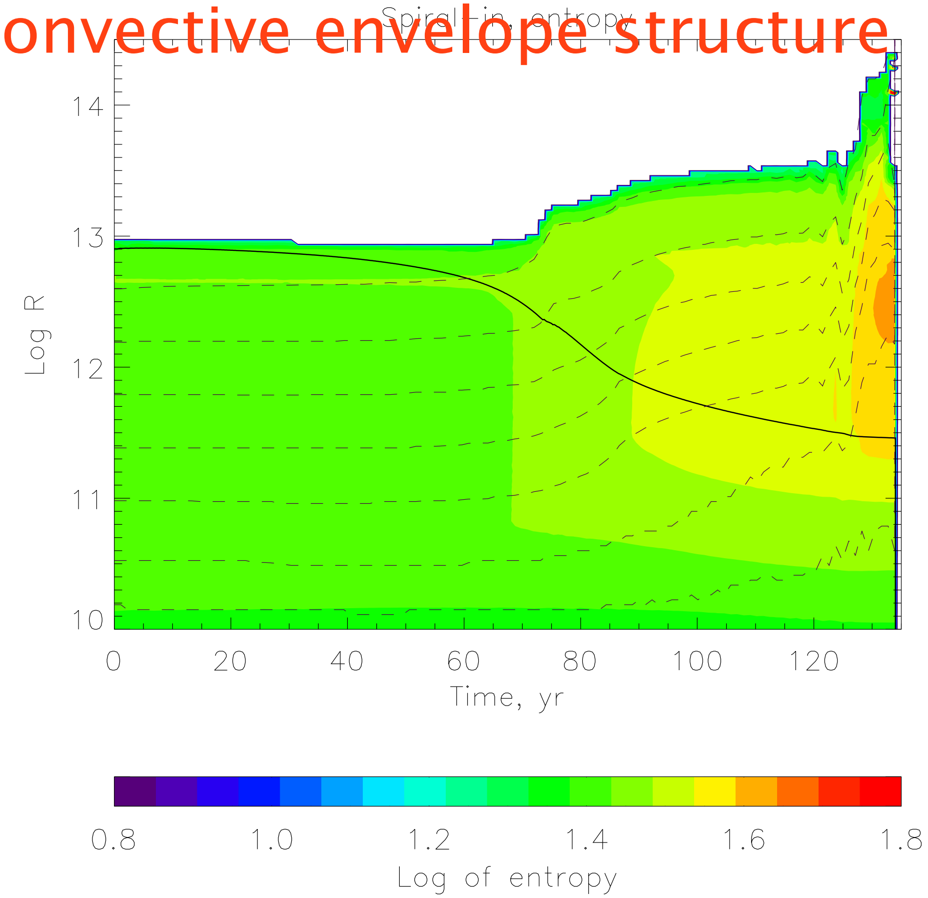
Most of energy is released at the end, when the spiral-in slows down

Radiative losses up to 10^{49} ergs! - almost the same or bigger than available E_{orb}!

Losses depend on mass ratio and convective envelope structure



20+5 $M_\odot$



1.6+0.3 $M_\odot$

Ivanova 2002

Energy loss: non-zero velocity at ∞

$$\left(\delta q(m) + \Psi + \epsilon + \frac{p}{\rho}\right)_{\mathrm{start}} = \left(\boxed{\frac{1}{2}u^2} + \Psi + \epsilon + \frac{P}{\rho}\right)_{\mathrm{exp}} = \Sigma = const$$

At the moment: u is assumed to be zero.

It means ideal fine-tuning!!!

From SPH simulations: K can be from 15% to 70% of E_{orb}

Energy sources: re-ionization

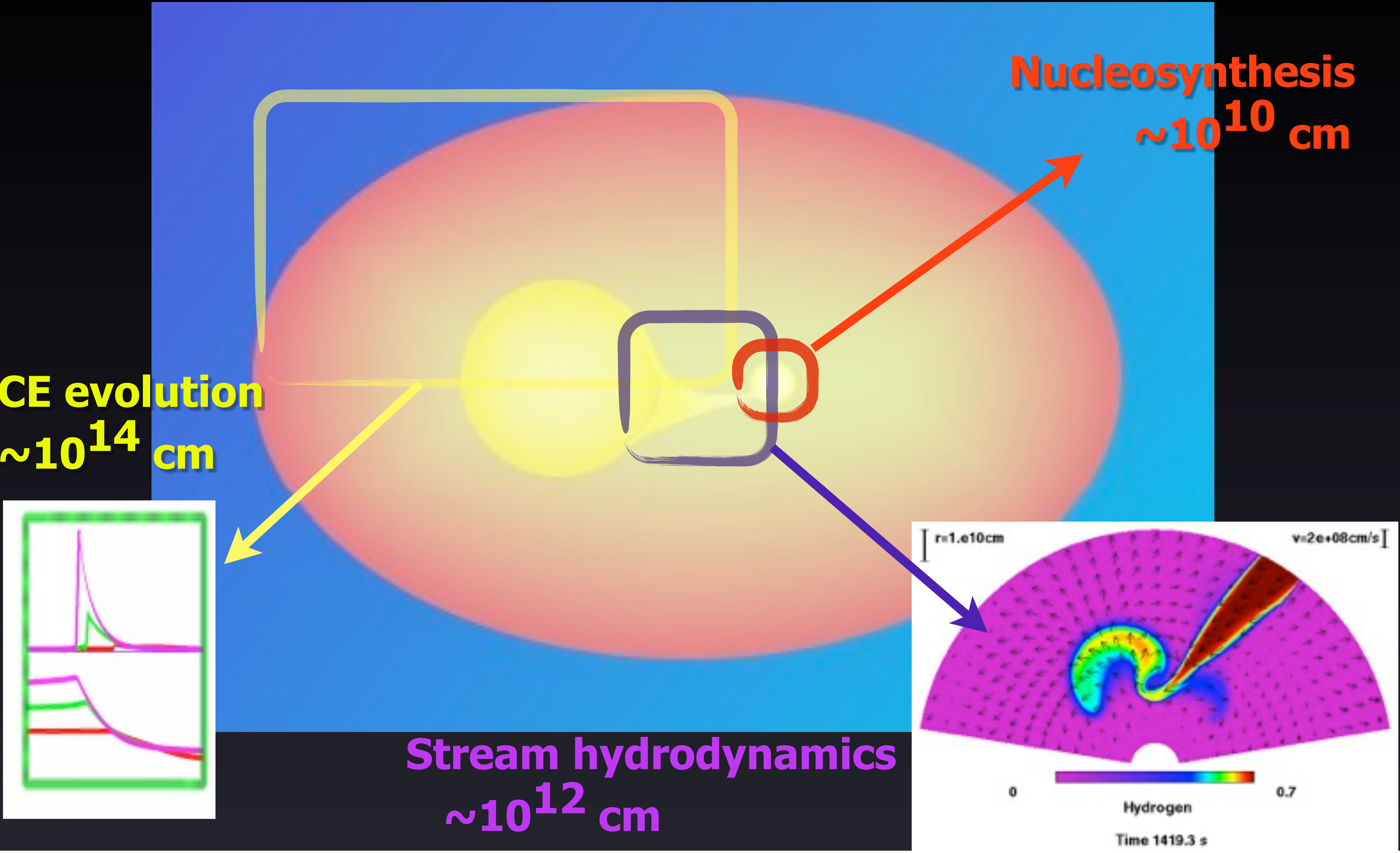
Han et. al. 1995

If included in W, CE could start with positive total energy
Helps to explain very wide post-CE binaries like T CrB (a~100 Rsun)

Soker & Harpaz (2003):
opacity argument: can not be used

Energy sources: nucleosynthesis

Ivanova (2002), Ivanova & Podsiadlowski (2003): CE that should result in mergers

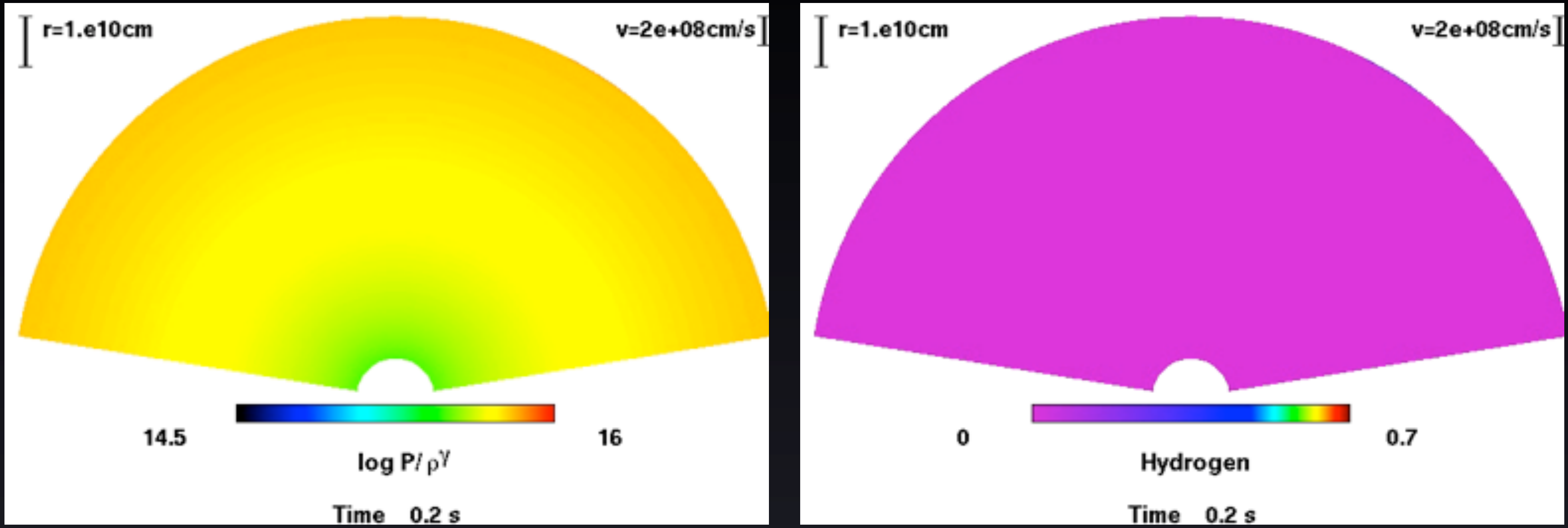


Nucleosynthesis $\sim 10^{10}$ cm

CE evolution $\sim 10^{14}$ cm

Stream hydrodynamics $\sim 10^{12}$ cm

a steady hydrogen stream onto the core!



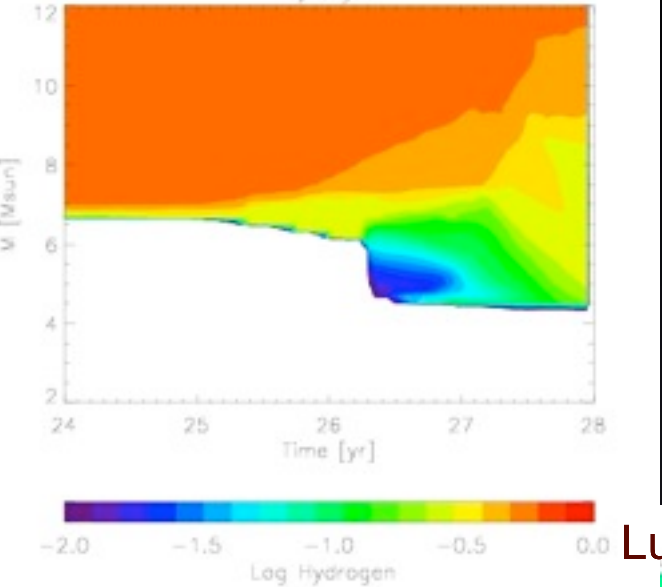
Ivanova 2002

a steady hydrogen stream onto the core!

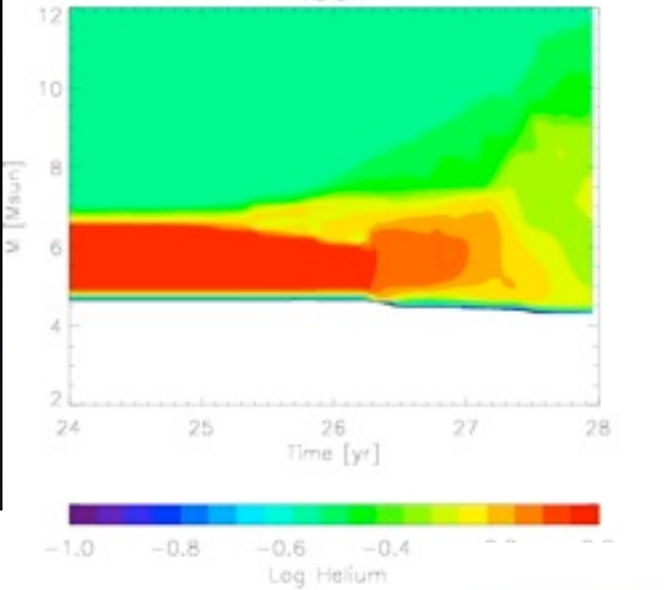
It has been found that one of the possible outcomes leads to the explosion of the He shell:

Nuclear driven CE ejection! few x 10^{51} erg is released ~ E_{bind} of He shell

Hydrogen

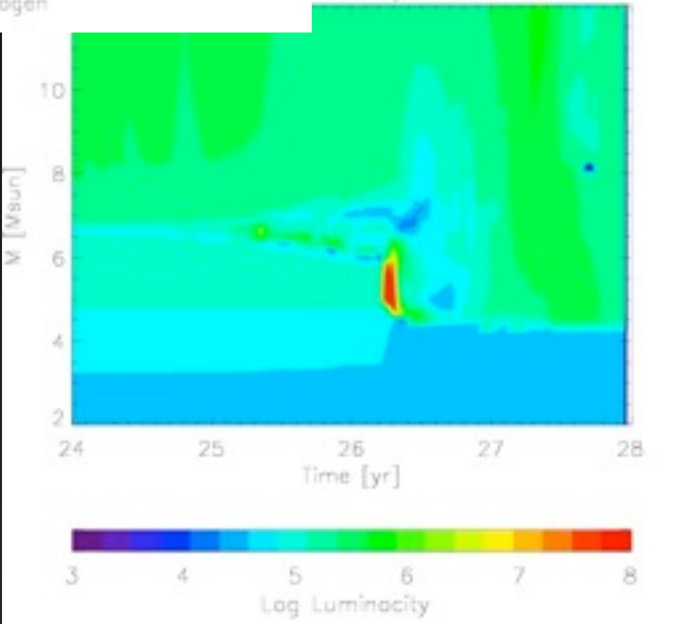


Helium

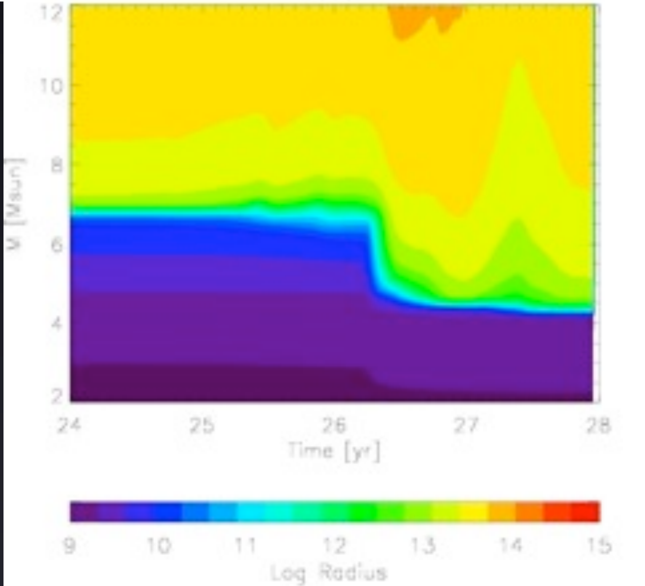


Ivanova 2002

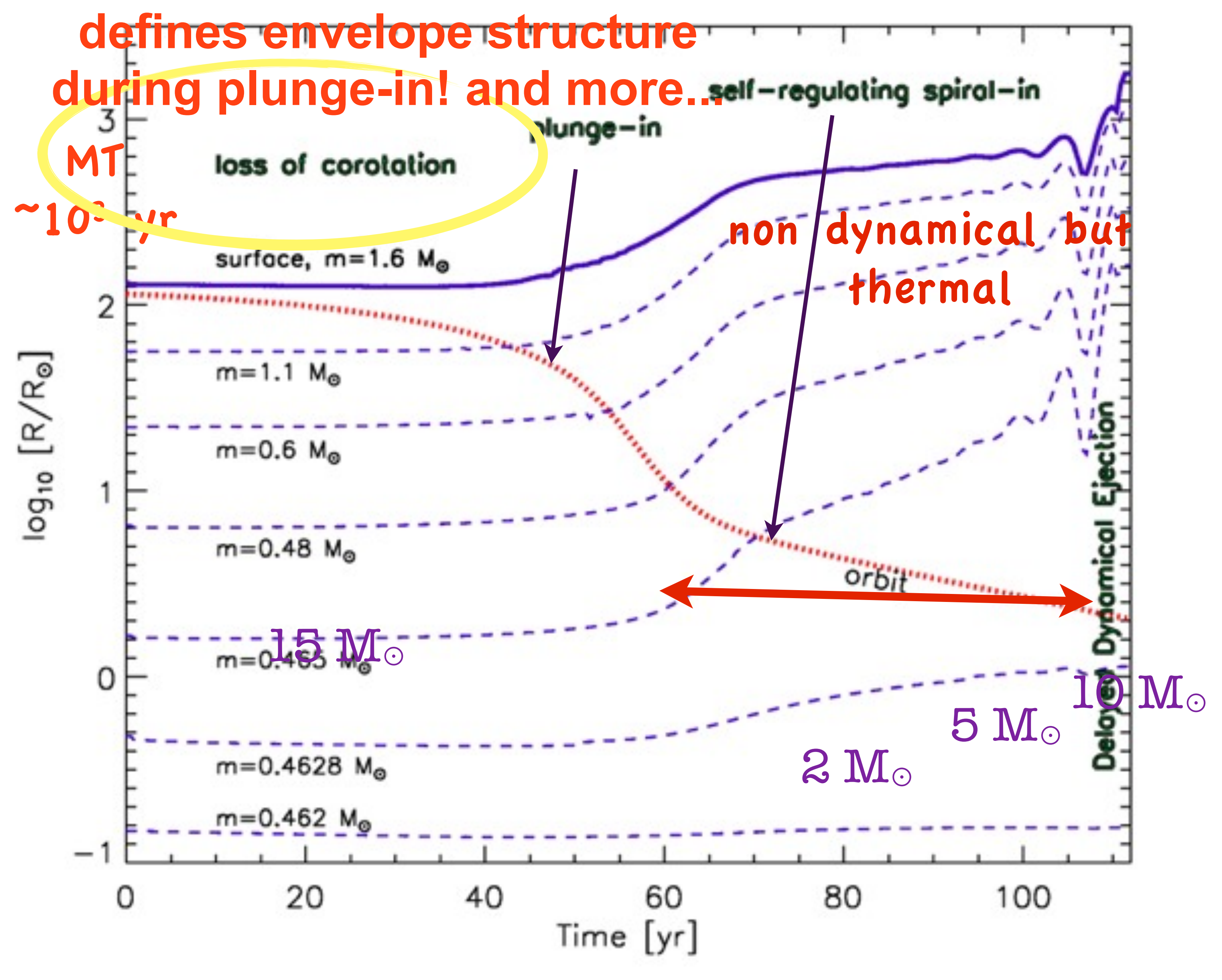
Luminosity



Radius



“Dynamical” CE vs self-regulating CE



defines envelope structure during plunge-in! and more...

MT

~10^3 yr

non dynamical but thermal

15 M$_\odot$

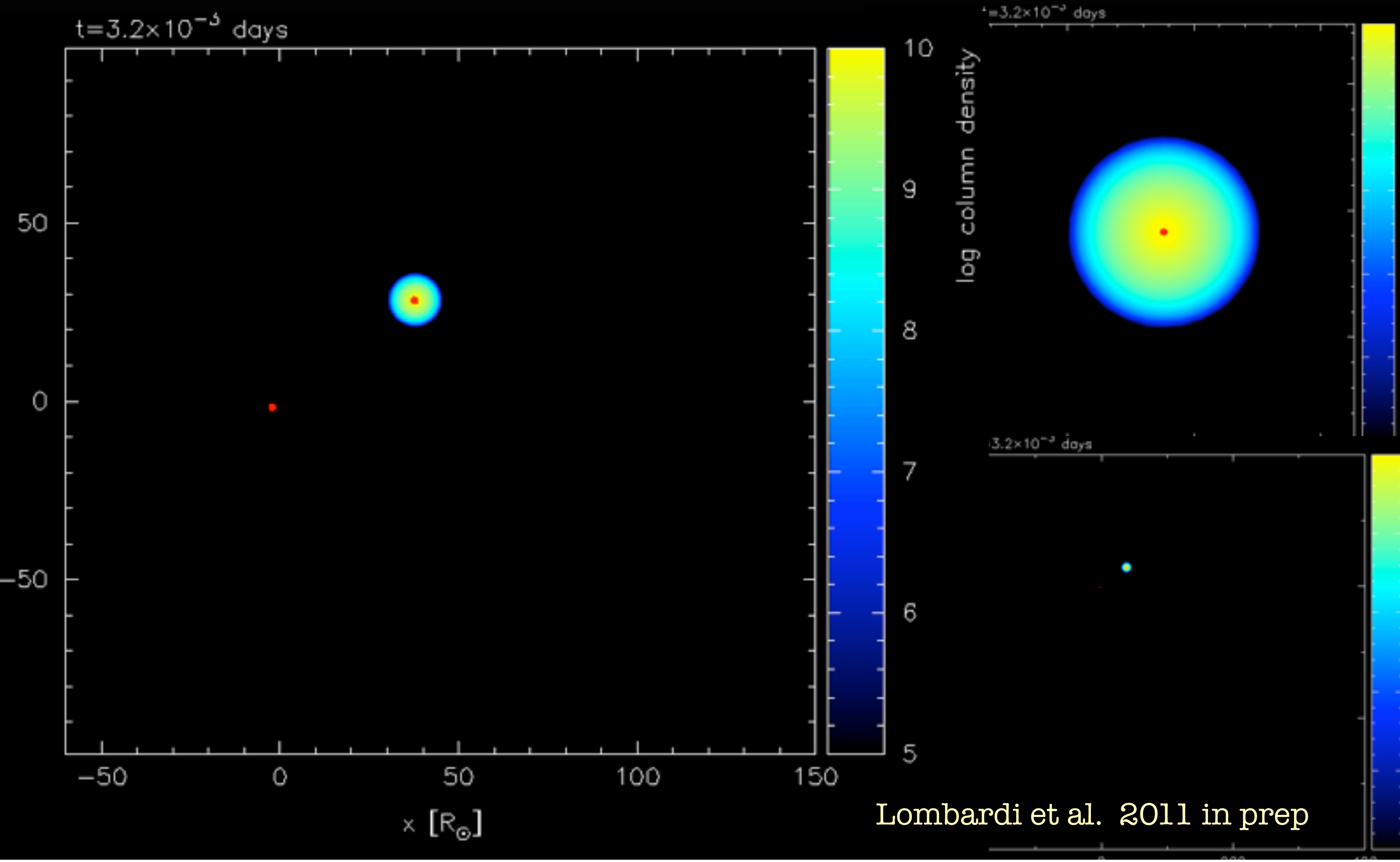
2 M$_\odot$

5 M$_\odot$

10 M$_\odot$

BH-RG: collisions

$5\,M_\odot$ BH + $0.9M_\odot$ RG

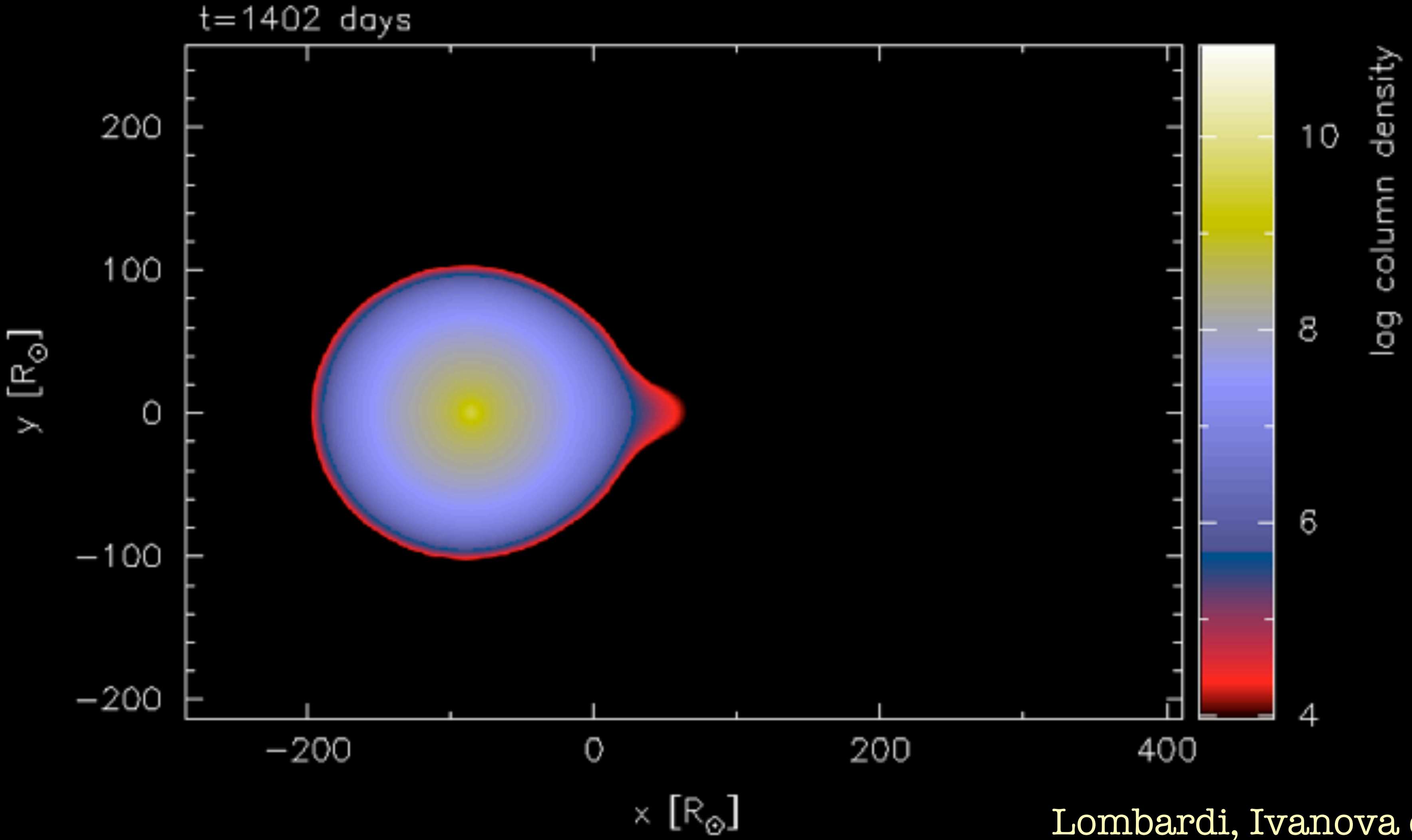


Lombardi et al. 2011 in prep

BH-RG: start of the MT

5 $M_\odot$ BH + 8$M_\odot$ RG

in 6 yr: 0.084$M_\odot$ ejected ,
0.025 $M_\odot$ went to circumbinary disk,
Effective ML about 0.02 $M_\odot$/yr



Lombardi, Ivanova et al. in prep

Start of the MT: how dynamical is it?

It is really hard to start.
One needs a deviation of some sort at the start:

- Roche lobe overflow
- tidal perturbation

All this might change how realistic are the simulations and alter the final result via entering into plunge-in stage at a wrong time

E.g. stellar codes now can sow that for many cases it will be NO unstable MT, despite what dynamical codes show
Reason: superadiabatic layer

So

If you know well how to do well tidal perturbations (onset of MT)
If you understand well thermally driven pulsations (DDE)

PLEASE COME TO ME TO TALK!!!