Common Envelope Evolution

Paul Ricker
University of Illinois

Collaborators

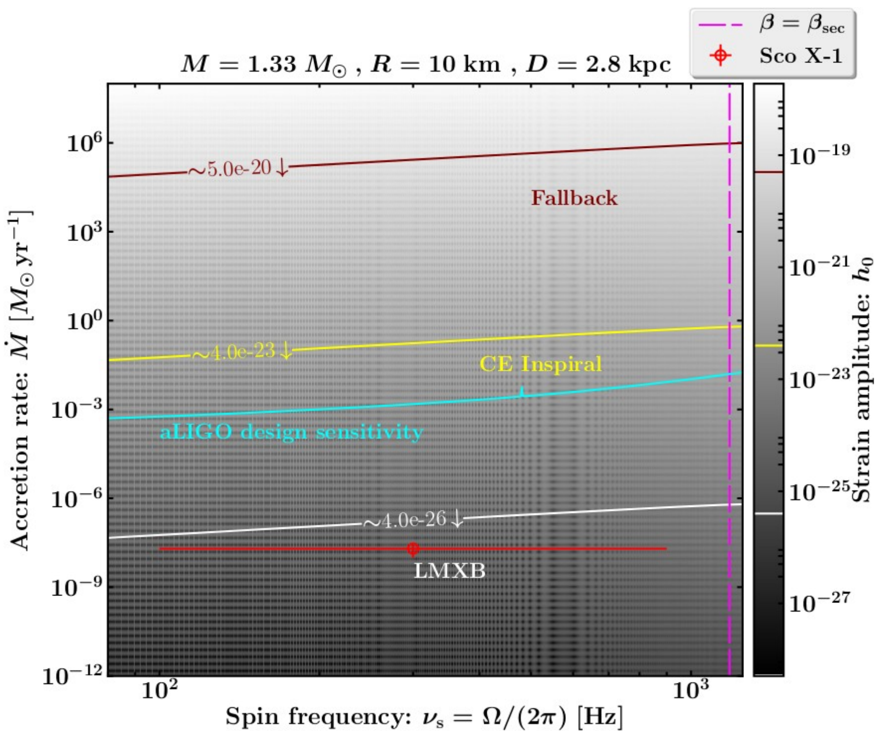
Ronald Taam, Ronald Webbink, Frank Timmes,
Miguel Holgado, Eliu Huerta

Phenomena, Physics, & Puzzles of Massive Stars
and Their Explosive Outcomes
Kavli Institute for Theoretical Physics
March 20, 2017

Your talk will start in...

Please visit Miguel Holgado's poster

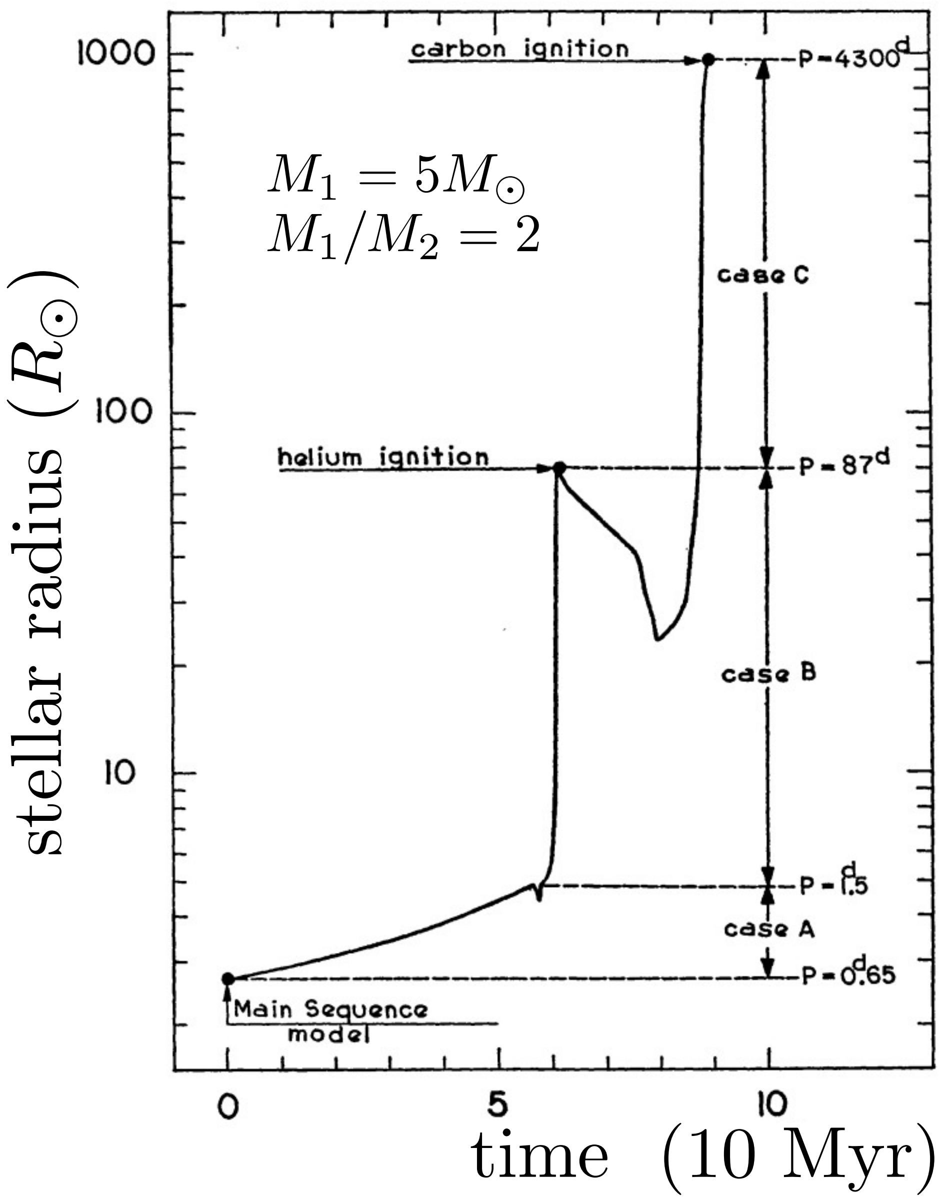
Continuous Gravitational Waves from Accreting Neutron Stars Undergoing Common Envelope Inspiral



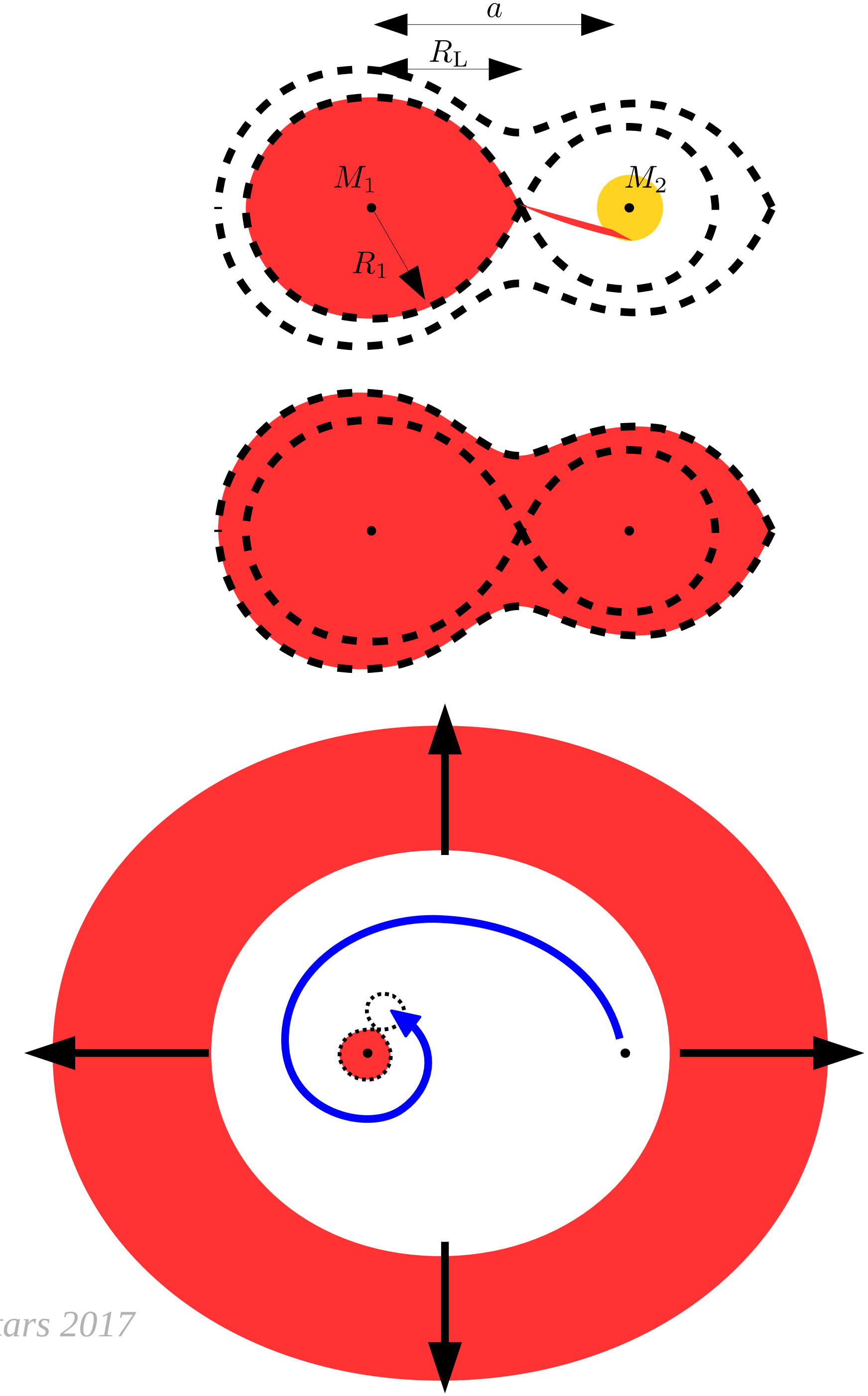
Holgado, PMR, Huerta (in prep)

Miguel Holgado

Common envelope mass transfer



Paczynski (1971)



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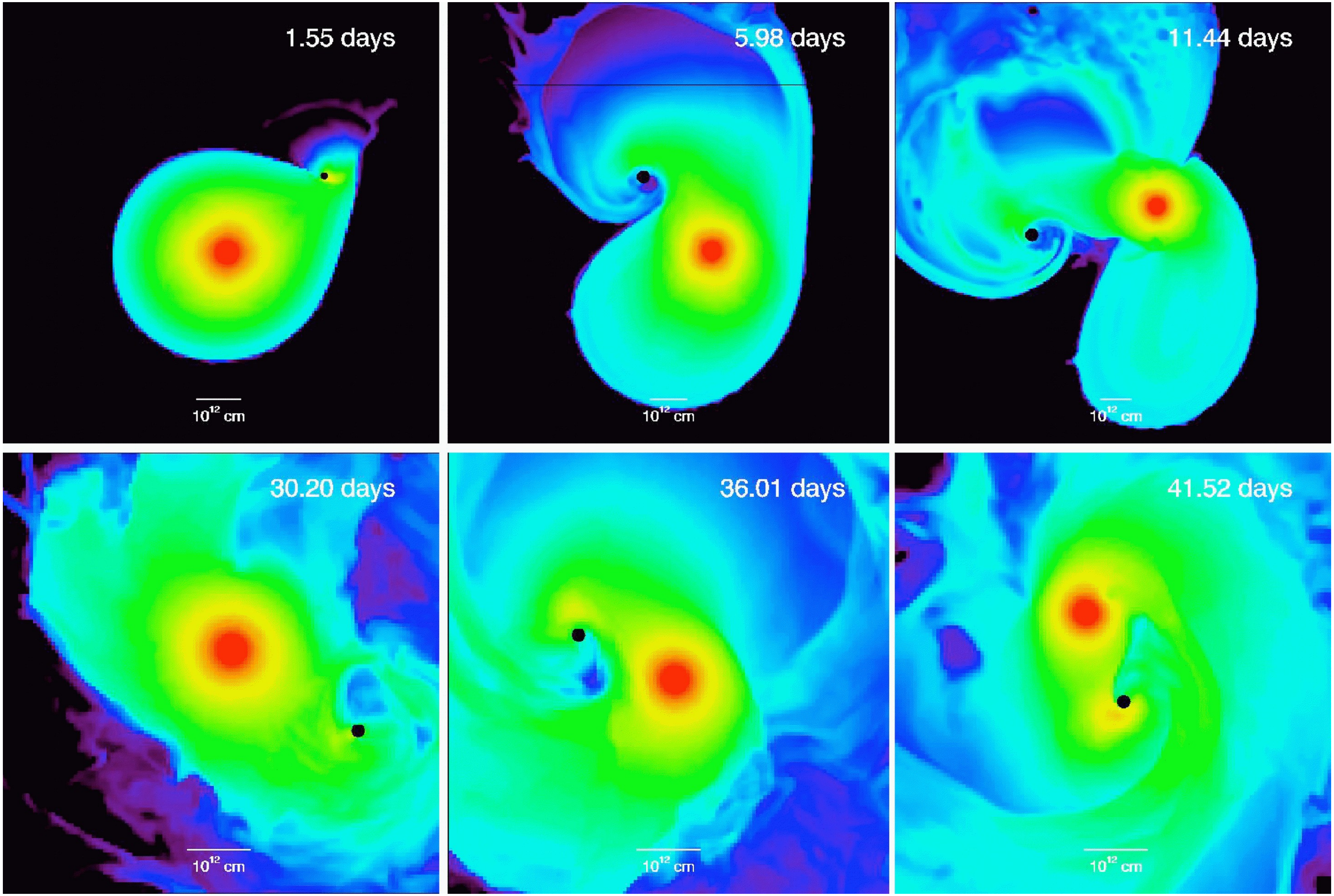


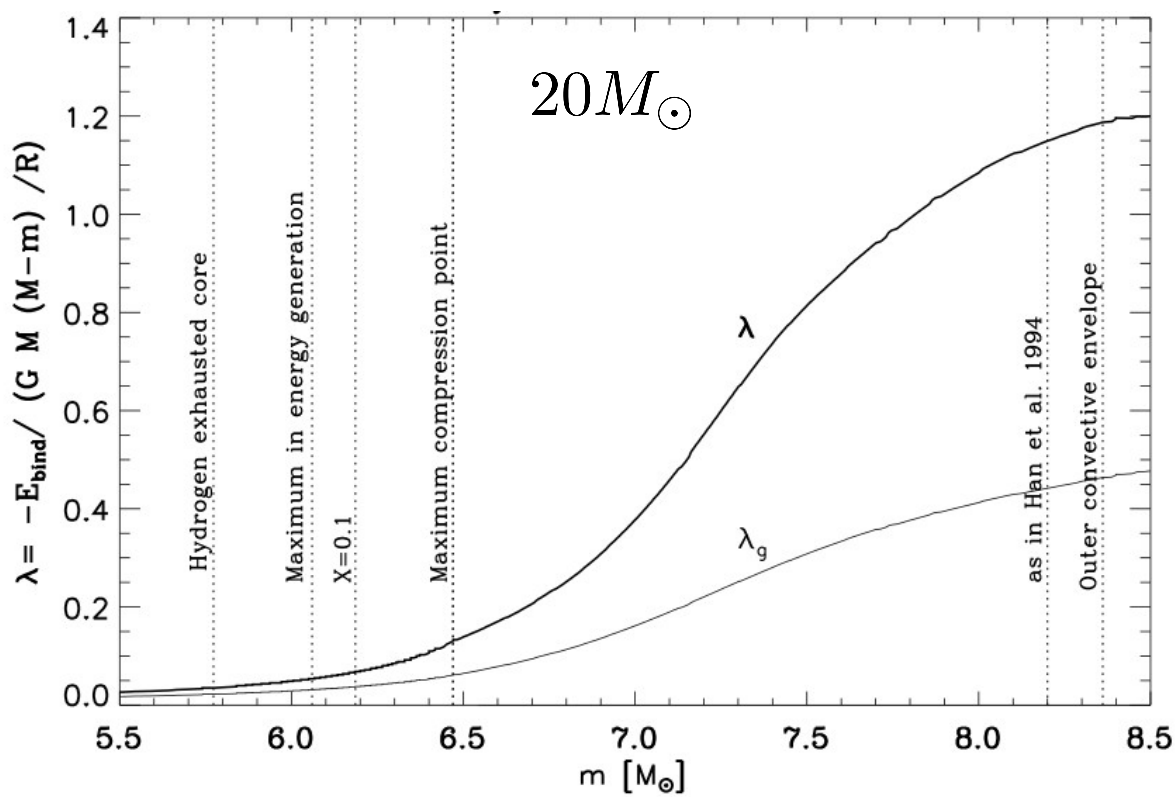
Taam & Ricker (2010)

Energy formalism *(van den Heuvel, Webbink, de Kool, ...)*

- Orbital energy used to eject envelope (efficiency α)
- Parametrized envelope binding energy (λ parameter)

$$-\frac{GM_1 M_{1,\mathrm{env}}}{\lambda R_1} = \alpha \left(-\frac{GM_1 M_2}{2a_{\mathrm{init}}} + \frac{GM_{1,\mathrm{core}} M_2}{2a_{\mathrm{final}}} \right)$$

- Problems
  - α and λ are not constants!
  - Core/envelope split
  - Systems requiring $\alpha \gg 1$



Ivanova et al. (2013)

Achieving envelope ejection

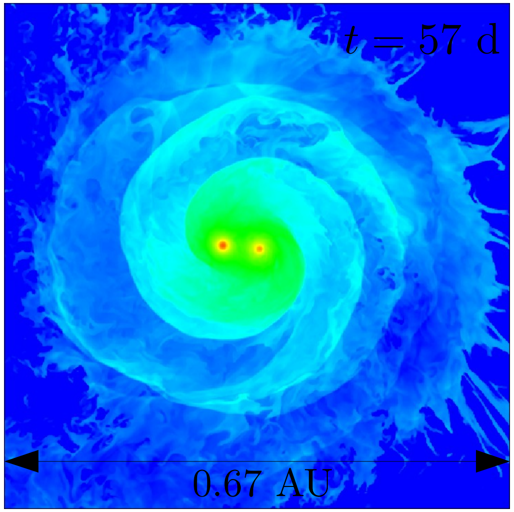
Basic 3D simulation results

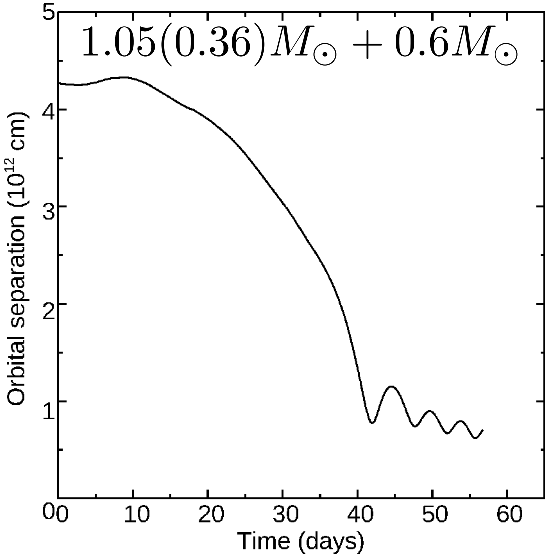
- Spiral shocks drive ejection
- Dynamical plunge followed by slow inspiral

Outstanding problems

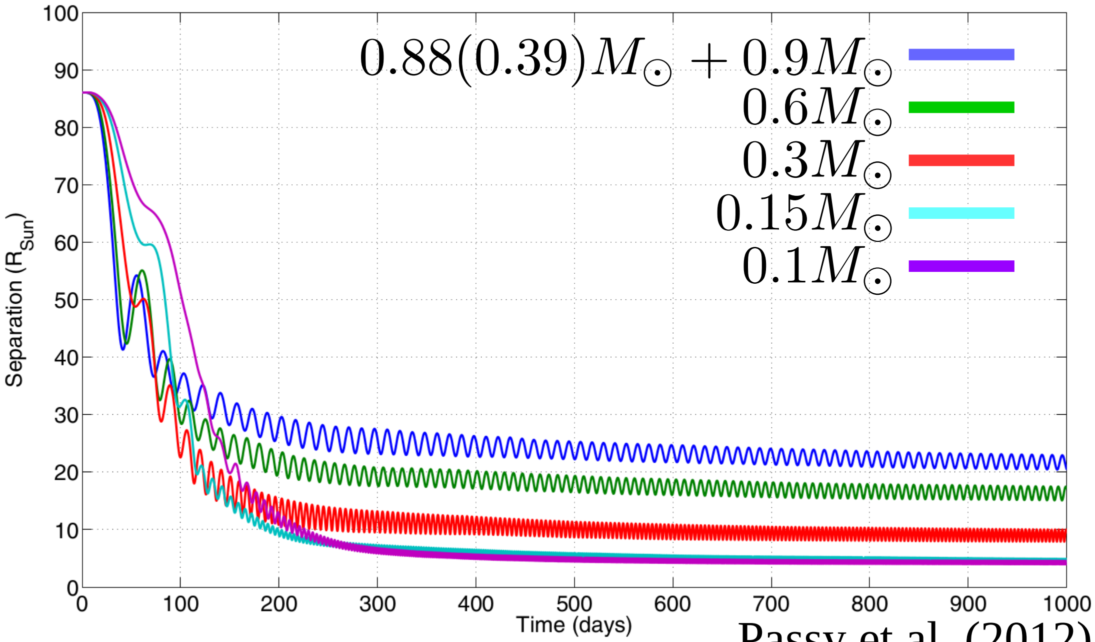
- Insufficient inspiral
- Failure to achieve full envelope ejection
- Initial conditions issues
- Physics/parameter coverage

Terman et al. (1994, 1995, 1996); Rasio & Livio (1996); Sandquist et al. (1998, 2000); Ricker & Taam (2008, 2012); Passy et al. (2012); Nandez et al. (2015, 2016); Ohlmann et al. (2016); Iaconi et al. (2017)





Ricker & Taam (2012)



Passy et al. (2012)

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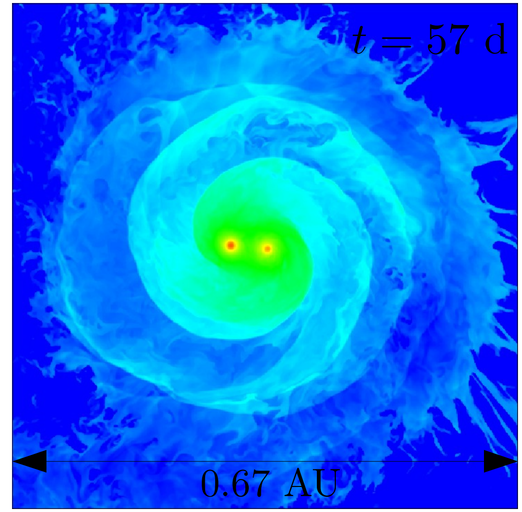

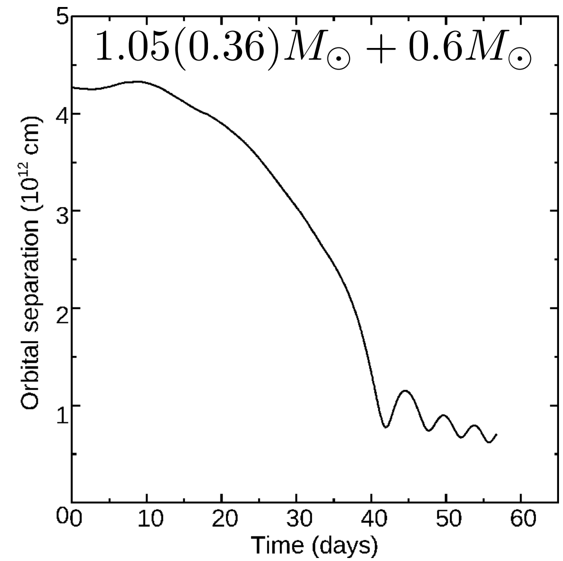

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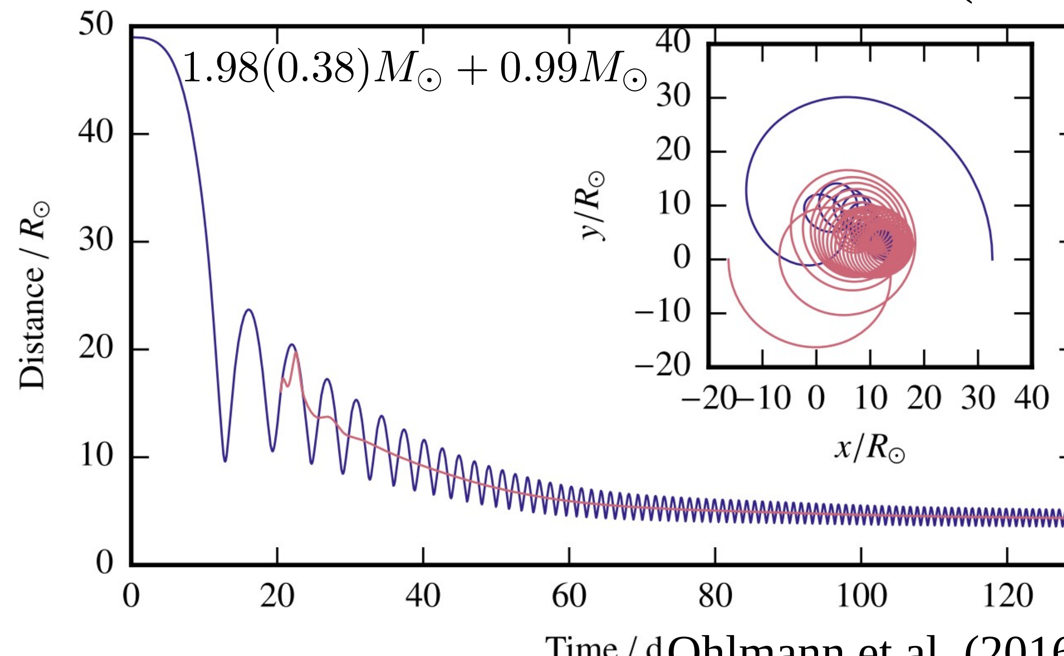
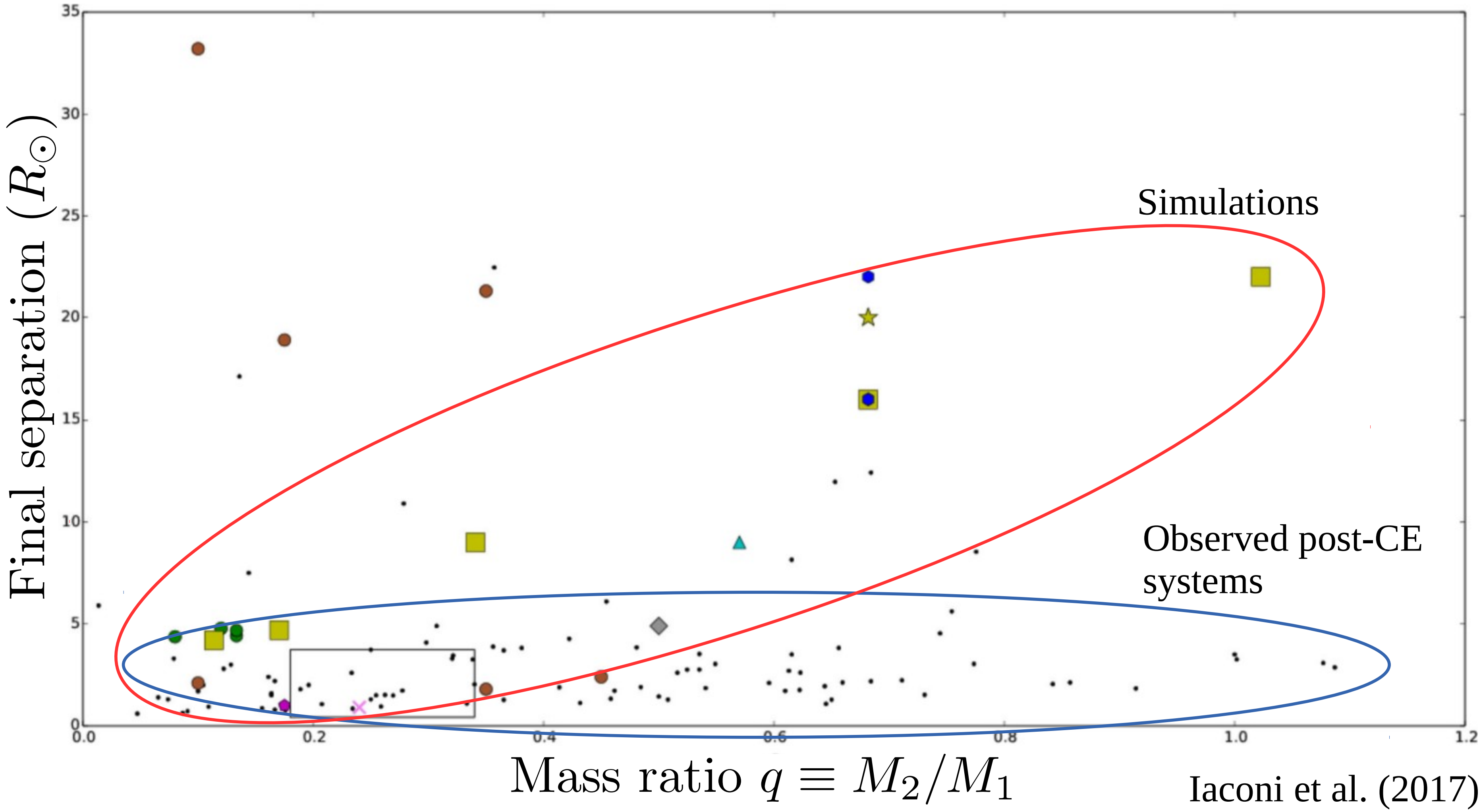


Ohlmann et al. (2016)

Final separation



Iaconi et al. (2017)

Additional energy sources/sinks

- (+) H/He recombination
- (+) Core expansion
- (+) Nuclear
- (+) Accretion
- (–) Terminal kinetic energy
- (–) Radiation

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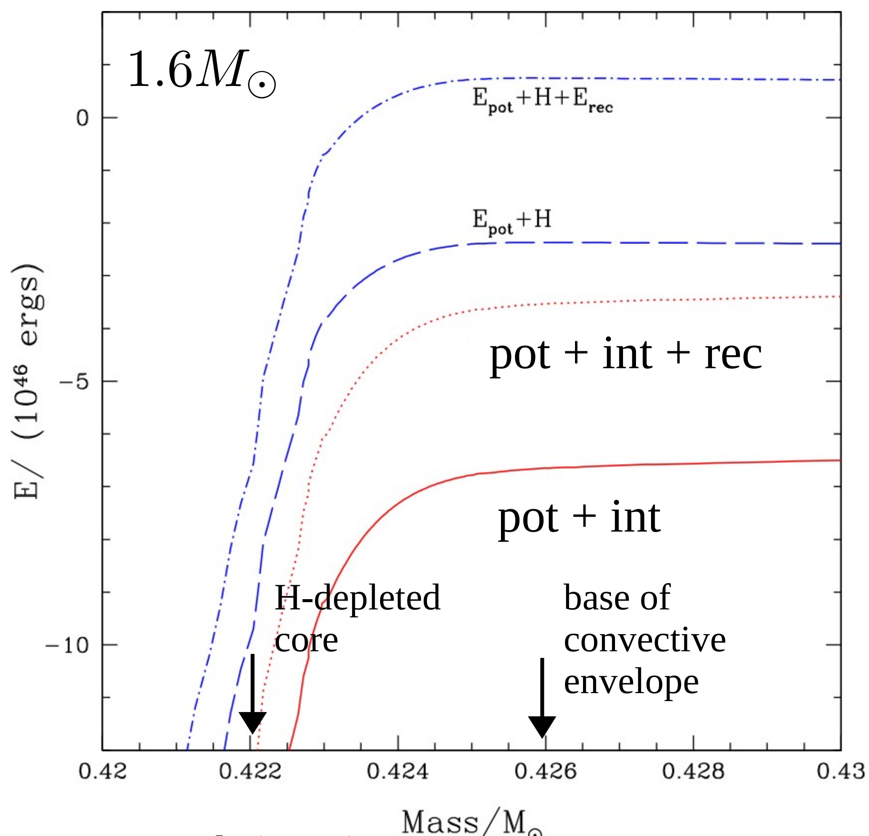
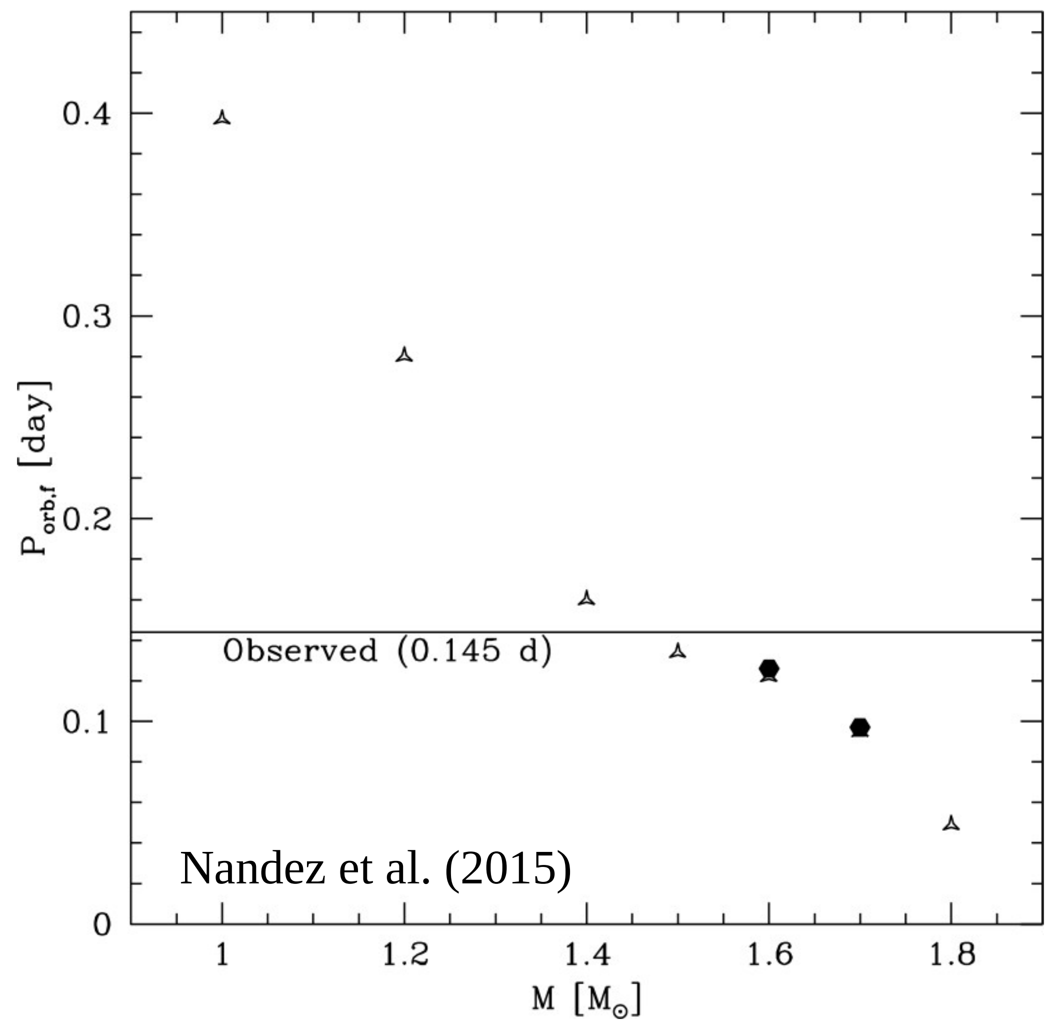
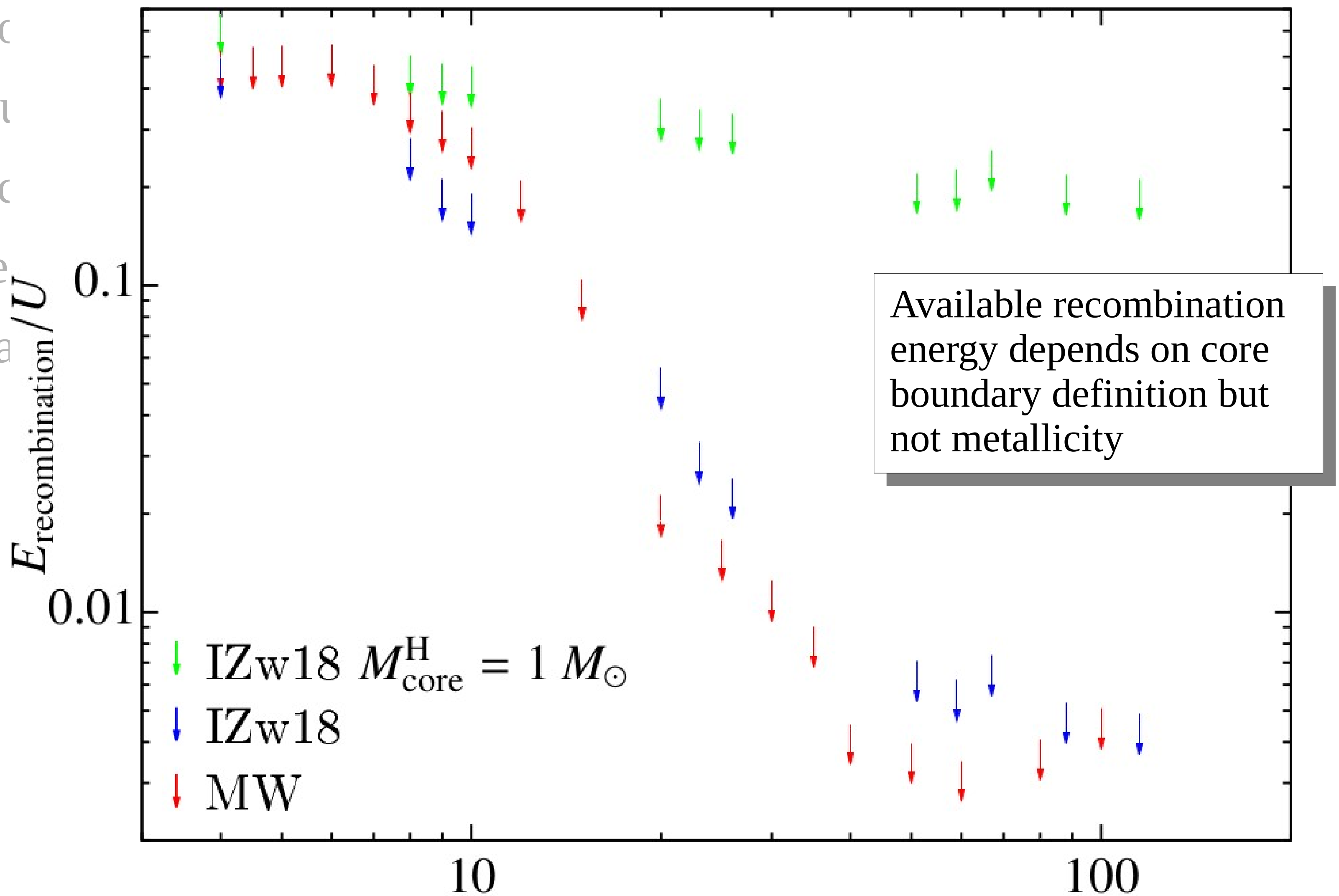


Ivanova et al. (2015)



Additional energy sources/sinks

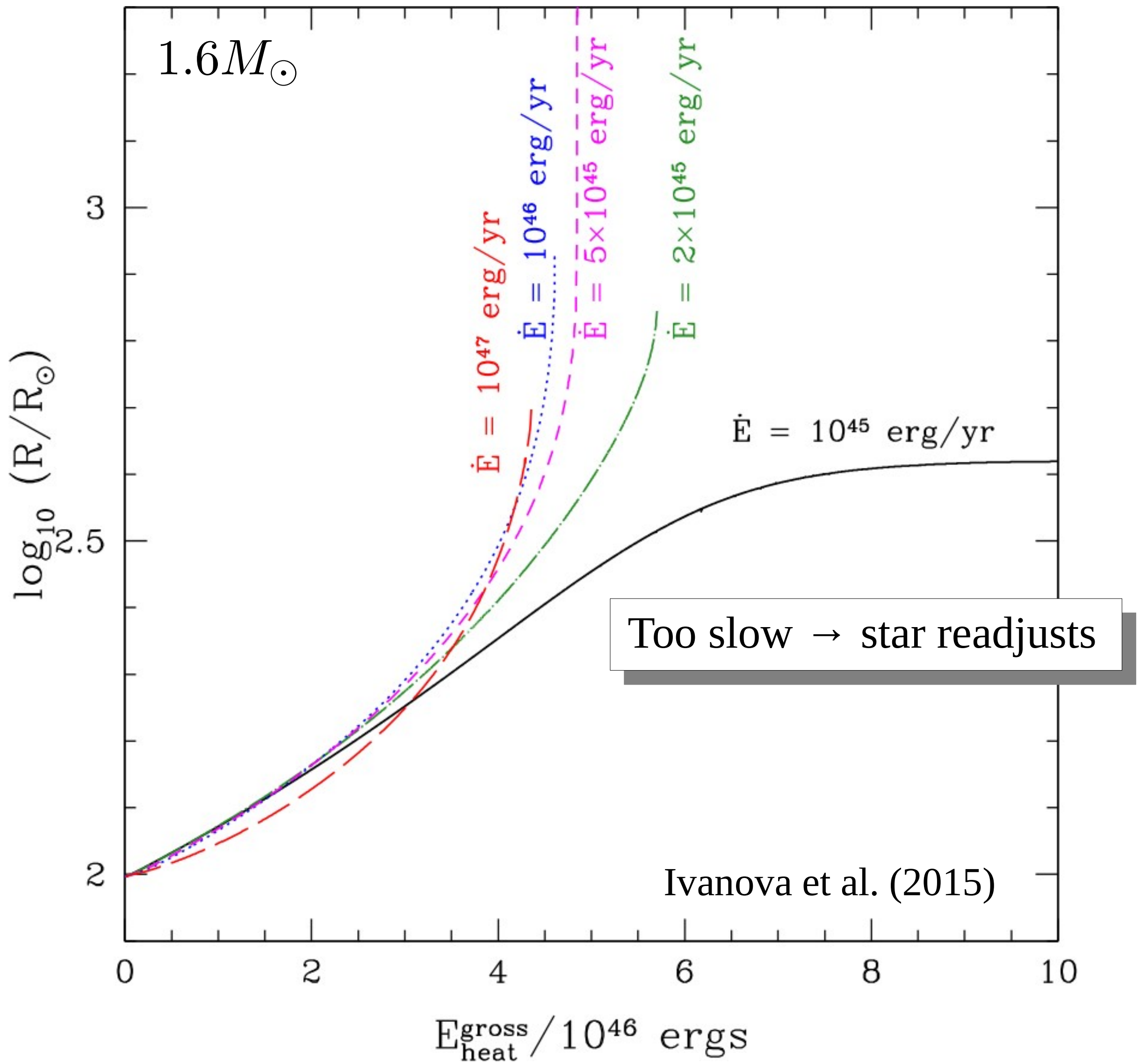
- (+) H/He recombination
- (+) Co
- (+) Nu
- (+) Ac
- (–) Te
- (–) Ra



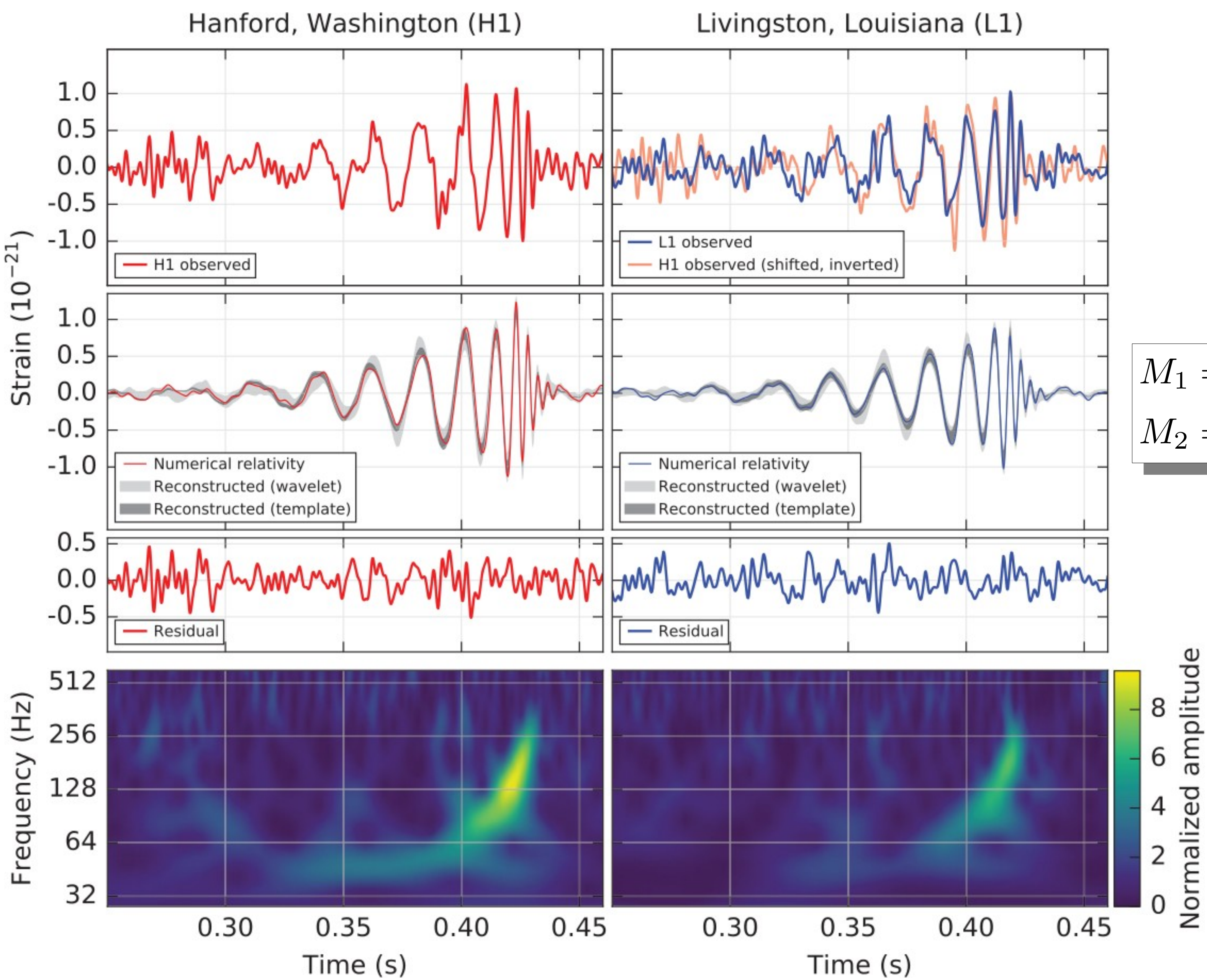
Kruckow et al. (2016)

Envelope ejection timescale

Link between ejection timescale and energy sources that can be tapped



GW150914

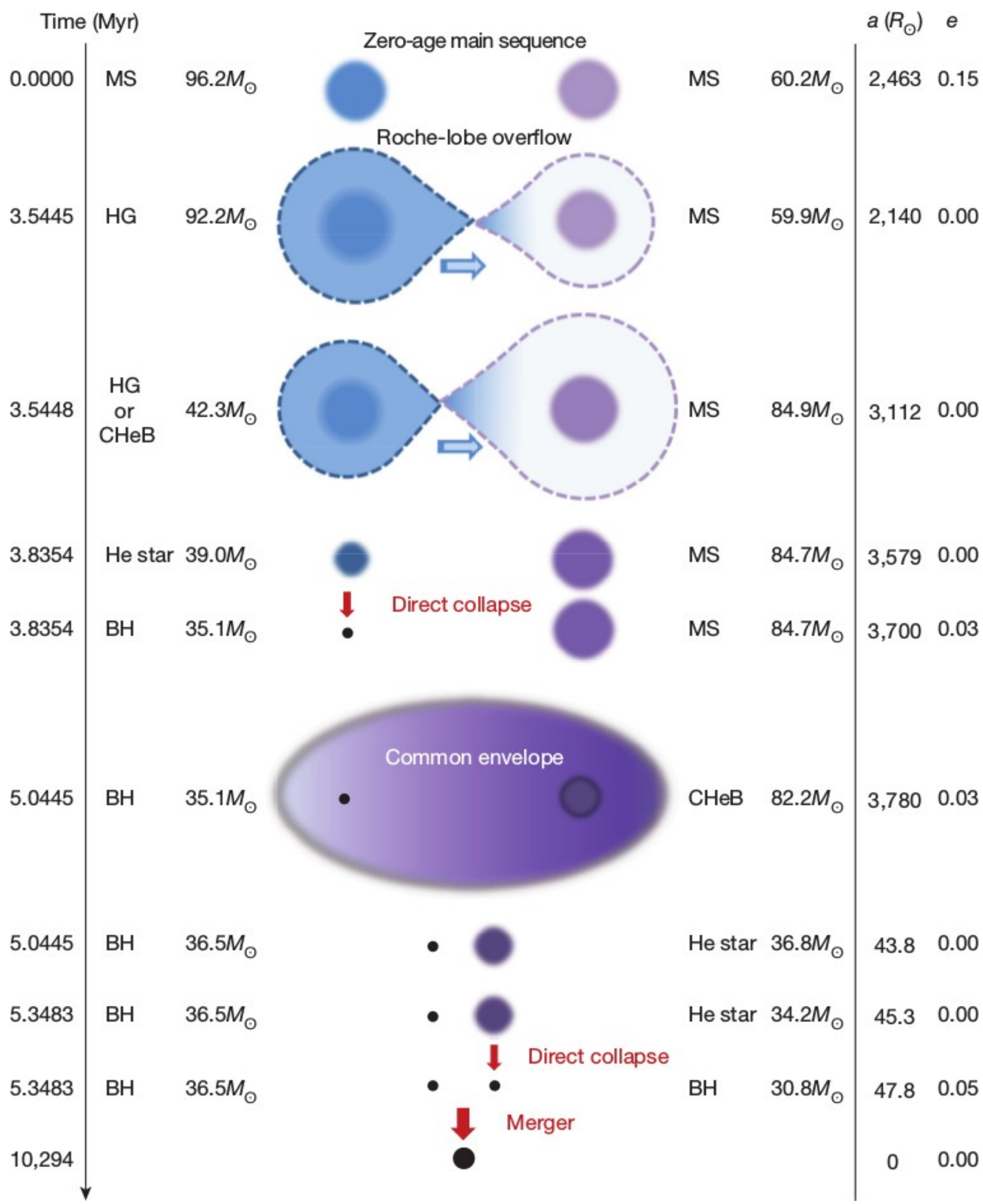


$$M_1 = 36^{+5}_{-4} M_\odot$$

$$M_2 = 29^{+4}_{-4} M_\odot$$

Abbott et al. (2016)

CE channel for BHBH mergers

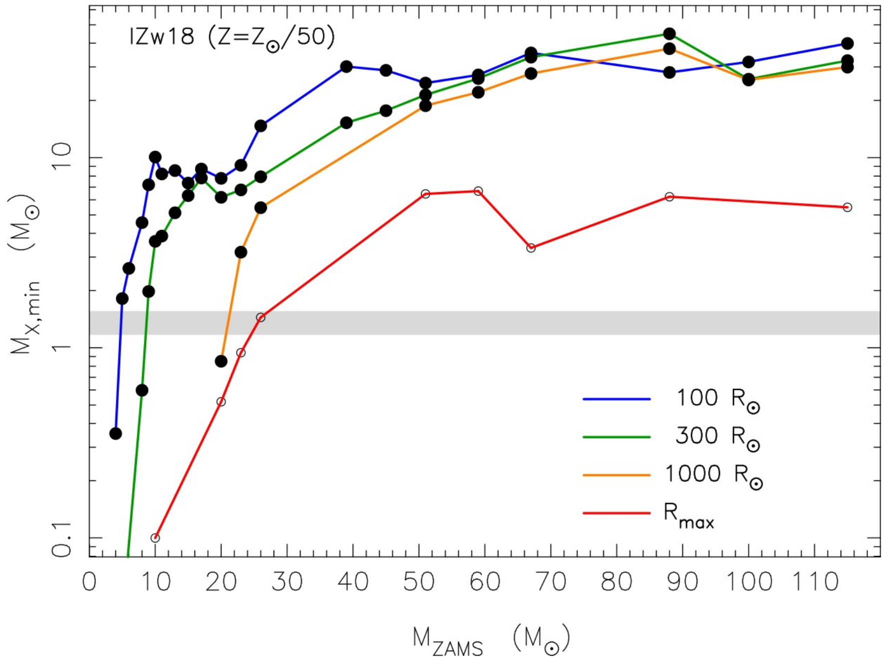


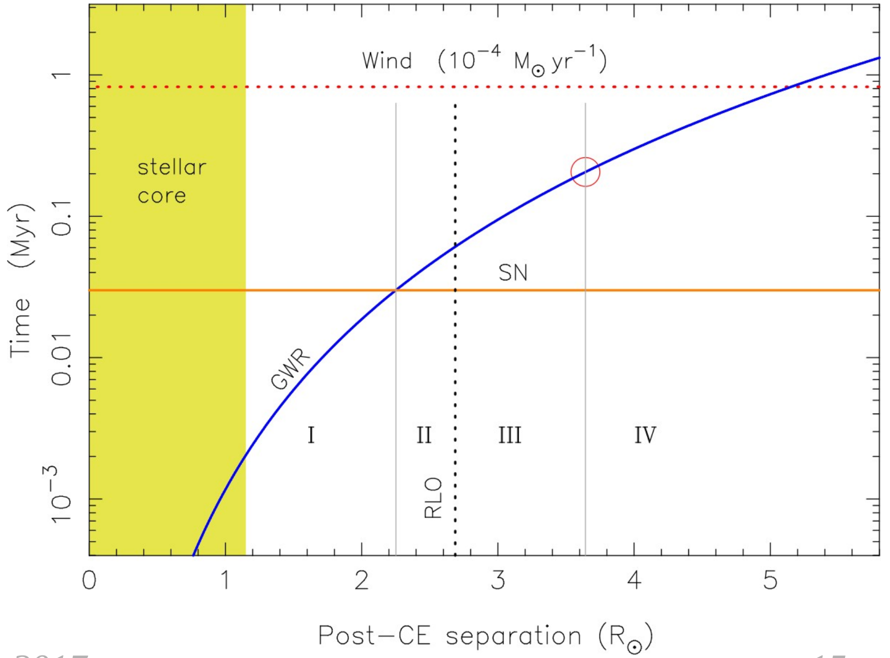
- Second mass transfer phase is CE with core helium burning donor
- Require $Z < 0.1Z_\odot$ to avoid excessive mass loss
- Assumptions to be tested in 3D
  - Stability of each phase?
  - Efficiency of each phase?
  - Final core mass and separation?

Belczynski et al. (2016)

Massive star CE

- Donor binding energy vs. radius sets minimum companion mass needed to eject envelope
  - Easiest near maximum expansion
  - $35 M_\odot$ companion easily enough for $80+ M_\odot$ donor
- Must also avoid merger due to GW emission before 2nd supernova
  - Depends on core/envelope split

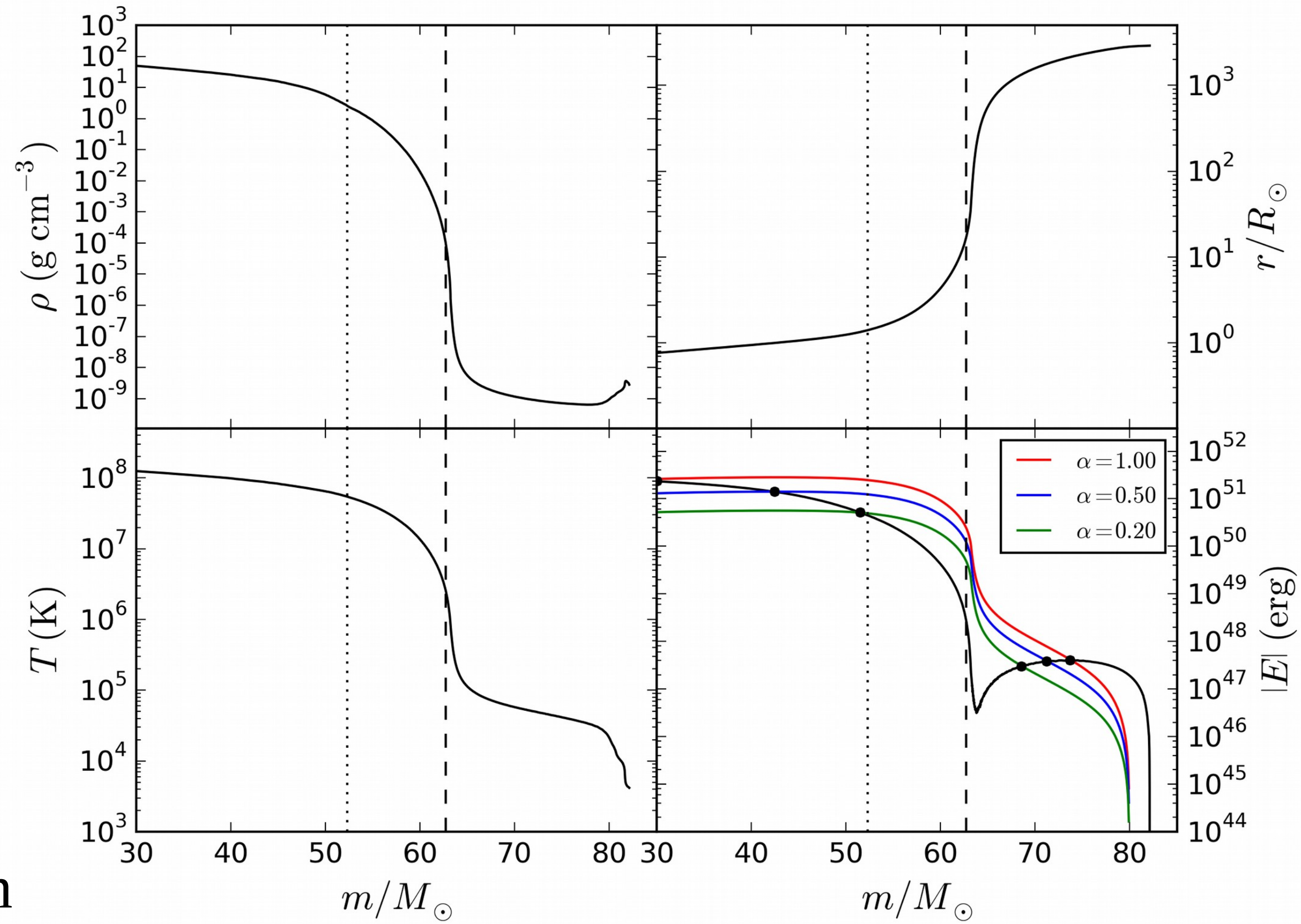




Kruckow et al. (2016)

Massive star CE simulation (PR, Taam, Timmes)

- Evolve 1D $88M_\odot$, $Z{=}Z_\odot/50$ model from ZAMS to tip of RGB with MESA (Paxton et al. 2015)
- Relax in 3D binary potential with $35M_\odot$ companion using SPH code StarCrash (Faber & Rasio 2002)
- Map SPH particles into FLASH AMR simulation with partial-ionization Timmes EOS



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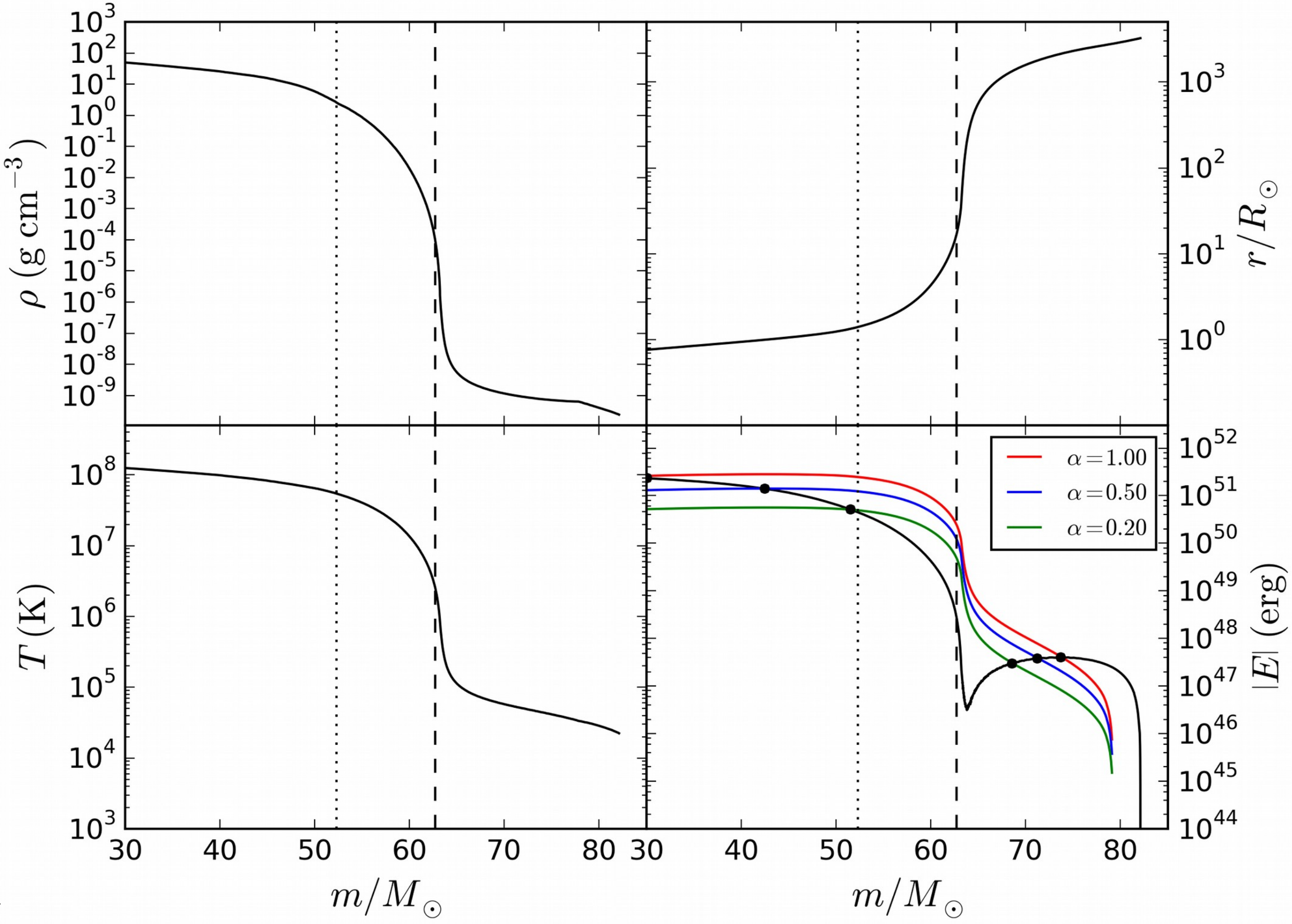

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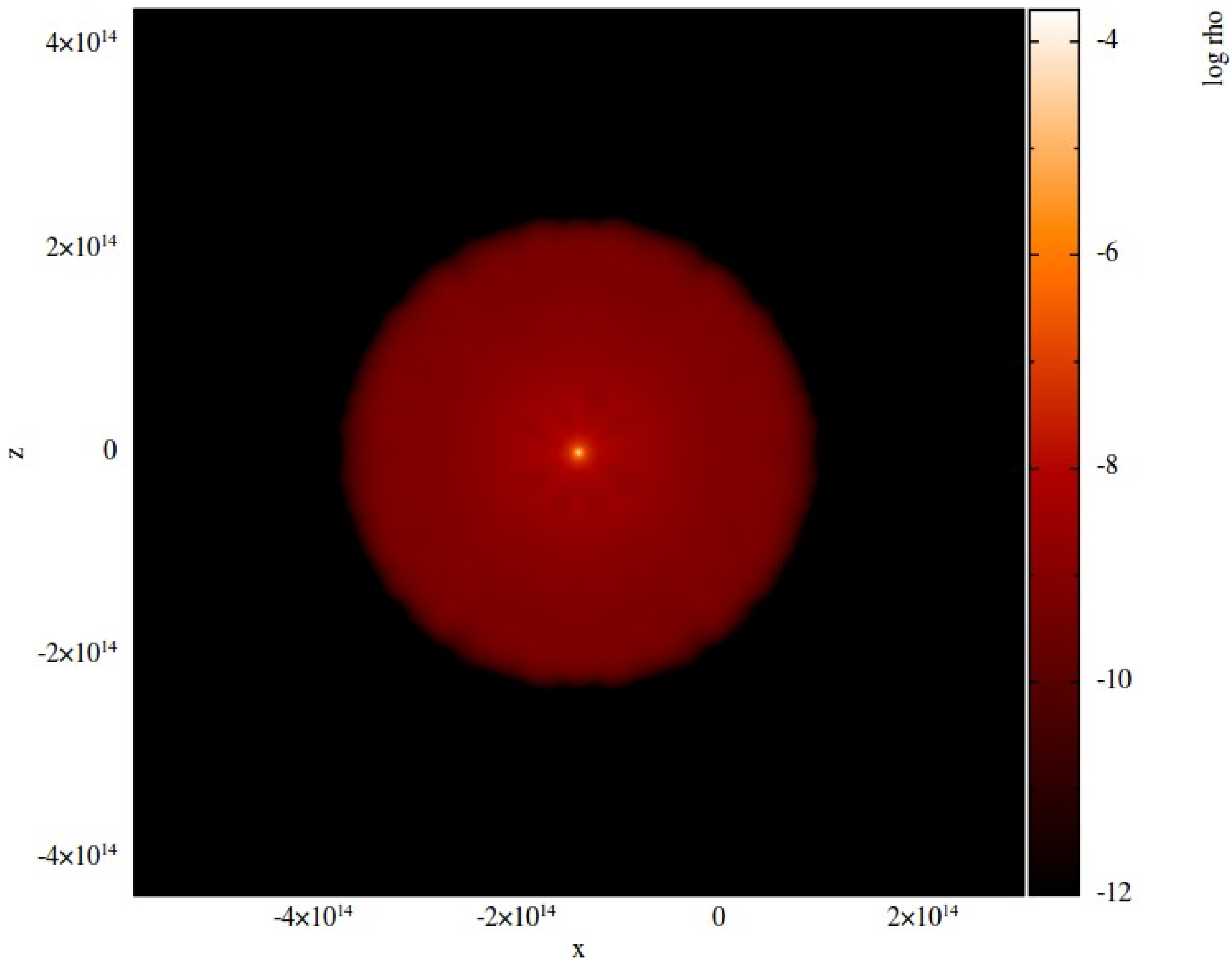
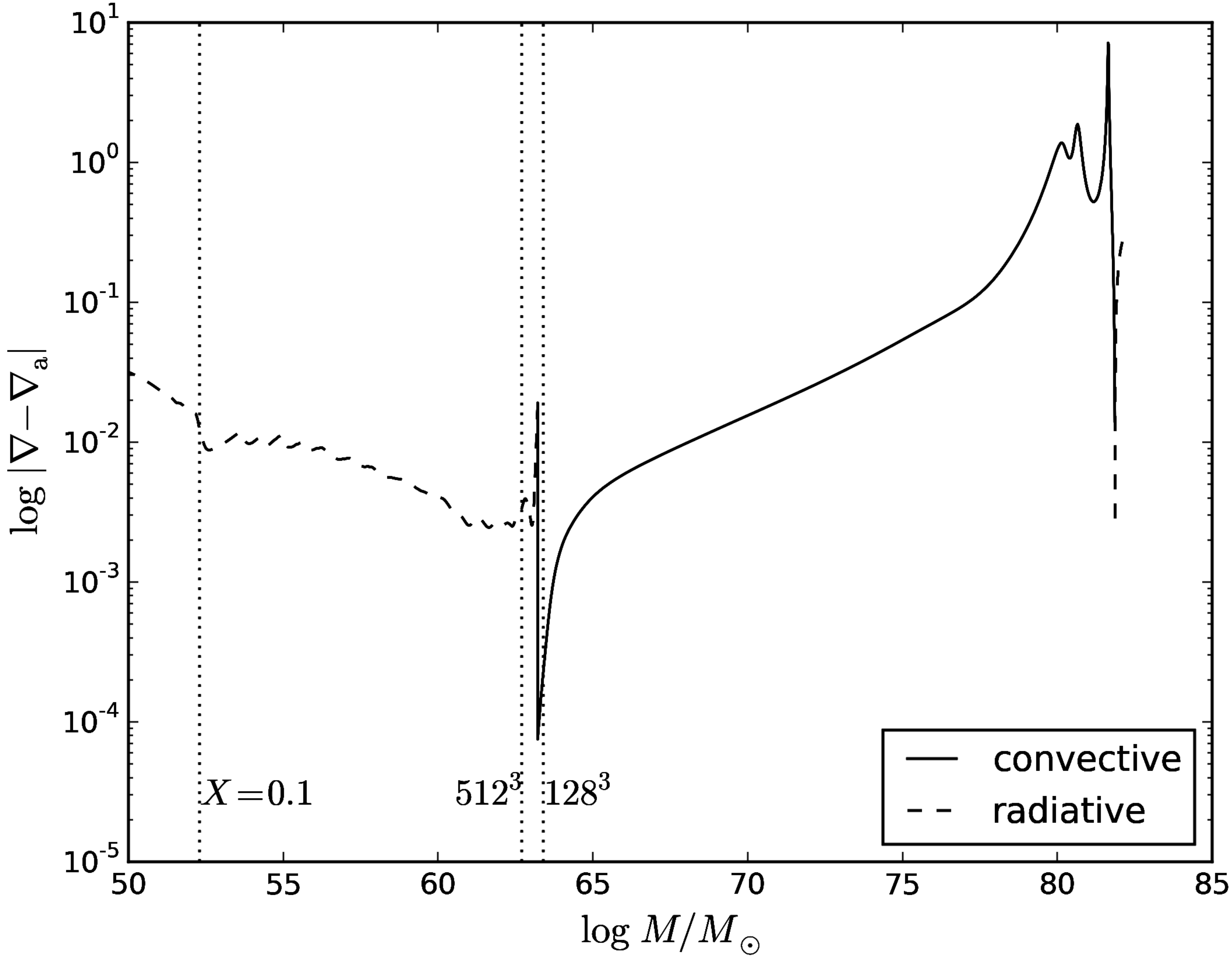


- Flattened-density model
- Low-resolution case: 512^3 potential mesh, 10^5 SPH particles
- Star mass $82.1 M_\odot$
- Core mass $62.7 M_\odot$
- Run for $3.5 t_{dyn}$ (127,000+ steps)
- Stampede: 1024 cores, 24 hours

Massive star CE simulation *(PR, Taam, Timmes)*



Massive star CE simulation (PR, Taam, Timmes)

Run → Quantity ↴	X=0.1 core	Low-res core
$M_{\rm core}/M_\odot$	53.4	62.7
$R_{\rm core}/R_\odot$	1.41	16.8
Effective grid (17,200$R_\odot$ box)	12,200	1,024
$t_{\rm dyn,core}$ (sec)	230	8700
Timesteps (10 orbits w/35$M_\odot$ BH at 6366$R_\odot$)	2.0×10^6	54,000

Summary

- Common envelope stage important for close binary formation and compact object mergers
- 3D simulations require additional energy sources to eject envelope
- Major outstanding questions
  - Envelope ejection criterion and efficiency
  - Core-envelope boundary
  - Energy sources and timescales
- Massive star uncertainties
  - Mass loss and envelope structure