COMMON ENVELOPE SIMULATIONS IN PHANTOM

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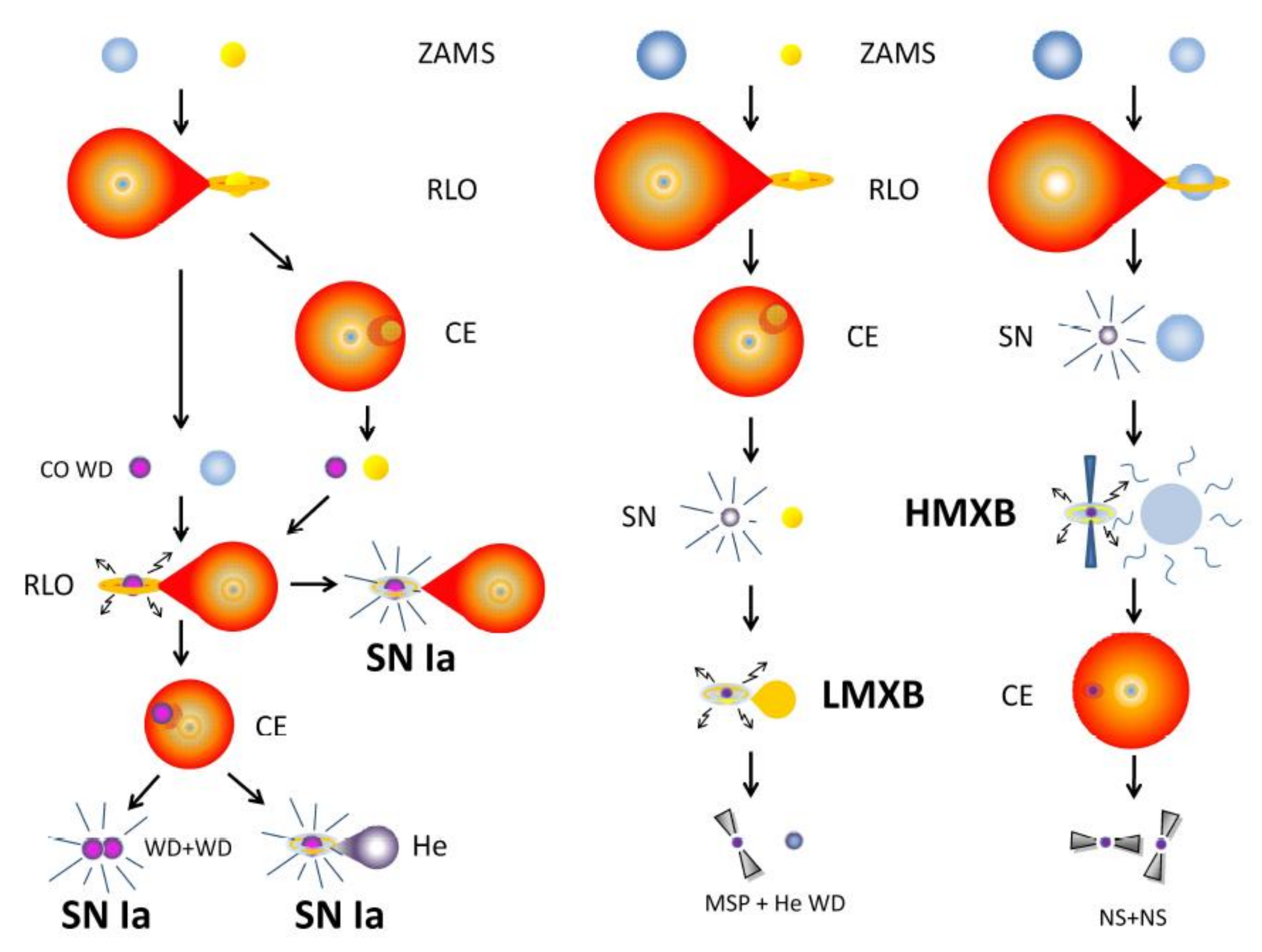
WHAT IS THE COMMON ENVELOPE BINARY INTERACTION?

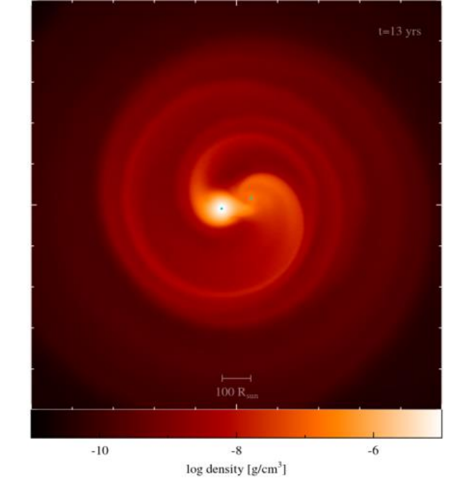
- Interaction reduces the orbital separation of binary systems.
- Necessary for formation of any system with an orbital separation shorter than past stellar radius.
- Cataclysmic variables, Type Ia SNe, X-ray binaries, gravitational wave sources, non-spherical PNe.

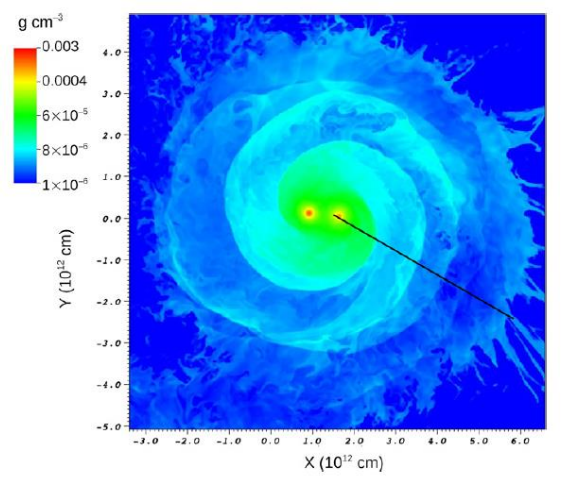


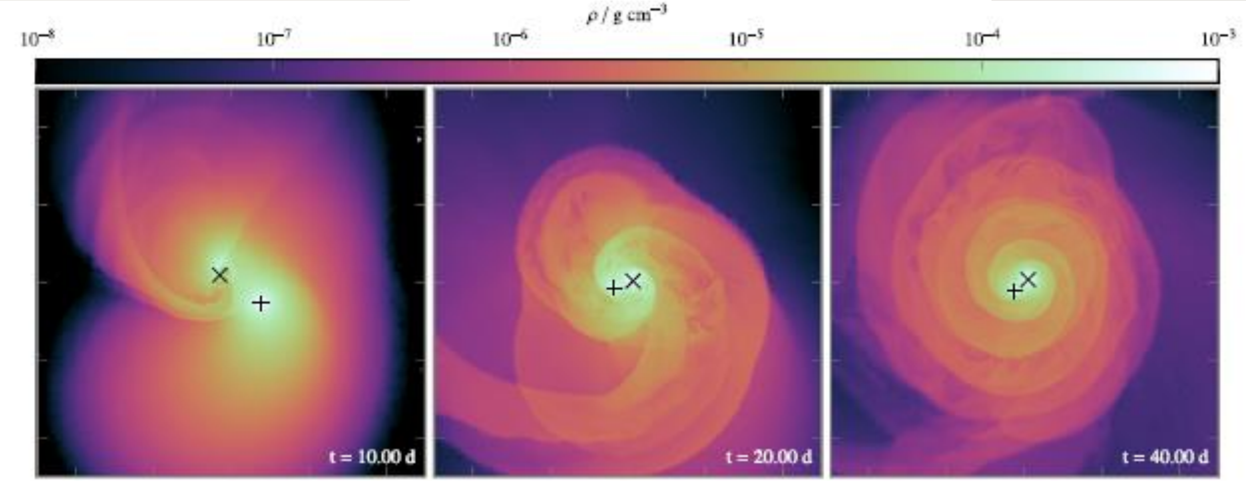
Various channels which go through common envelope interactions to form particular systems. Image credit: Ivanova et al. (2013)

CURRENT COMMON ENVELOPE SIMULATIONS

- In recent years, with the increase of computational power and the optimisation of codes, simulations have become ever better. An inexhaustive list of the more recent simulations are:
- SPH: SNSPH (Passy et al., 2012), Starsmasher (Nandez et al., 2014, 2015, 2016; Ivanova et al., 2015, 2016), and Phantom (Iaconi et al., 2017).
- Grid: FLASH (Ricker and Taam, 2010, 2012), Enzo (Staff et al., 2016a, b; Iaconi et al., 2017)
- Moving Mesh: AREPO (Ohlmann, 2016a, b).

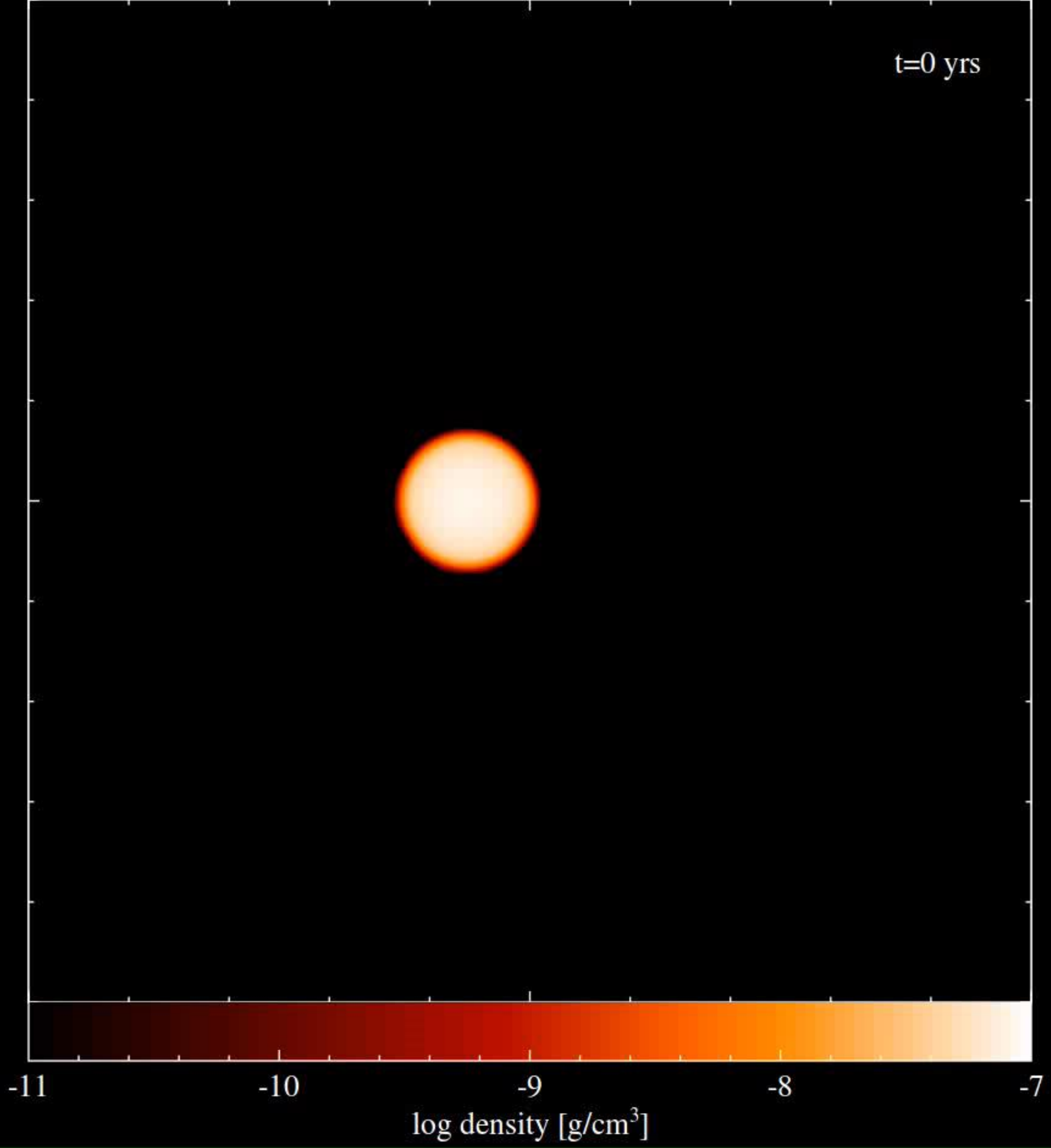






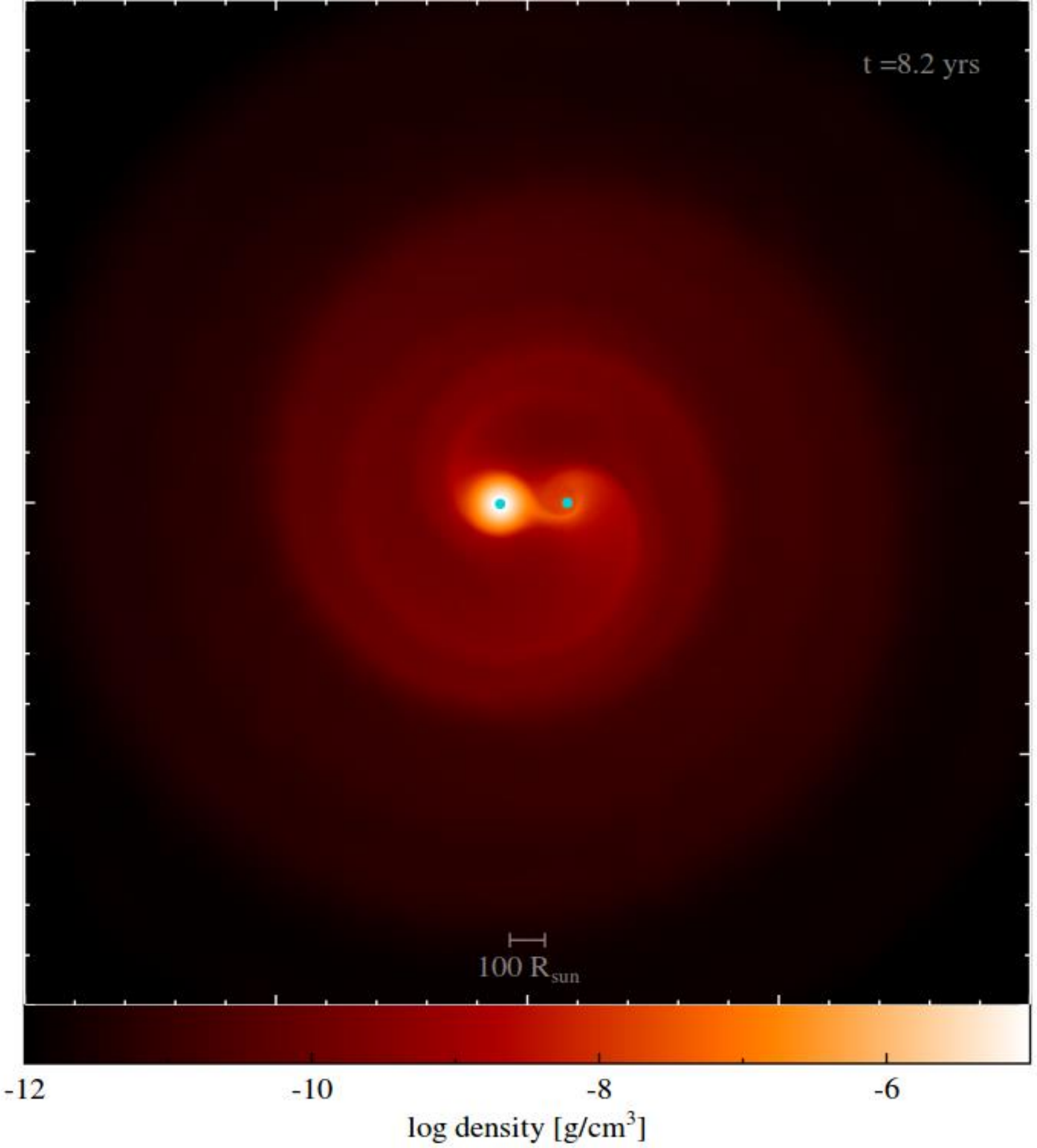
PHANTOM COMMON ENVELOPE SIMULATIONS

- Create a profile in 1D stellar evolution code, MESA (Paxton et al., 2010). Typically low mass RGB stars (~0.88 $M_\odot$).
- Star is mapped into Phantom, and allowed to relax into equilibrium with damped velocities for several dynamical times.
- Point mass companion (typically 0.6 $M_\odot$) is placed into the system to model a main sequence star, and then the system is left to evolve.
- Typical resolutions: 1×10^5 to 2.3×10^6 SPH particles, global timesteps.



1 million particles
0.88 $M_\odot$ primary mass
0.6 $M_\odot$ companion mass
218 $R_\odot$ initial separation

“Dancing with the Stars”
https://www.youtube.com/watch?v=8F-fS5IaTKY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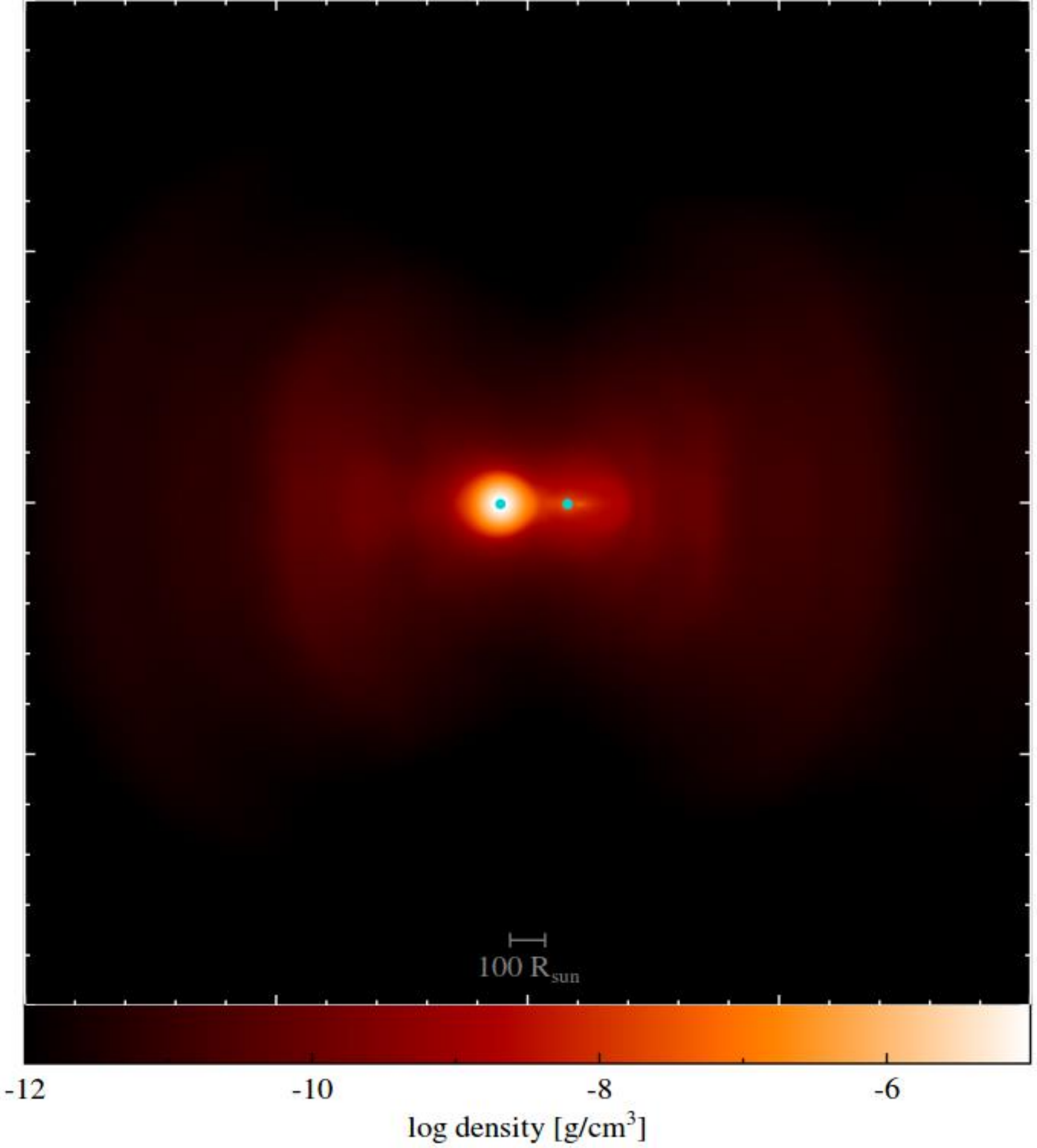
-10
-8
-6
log density [g/cm^3]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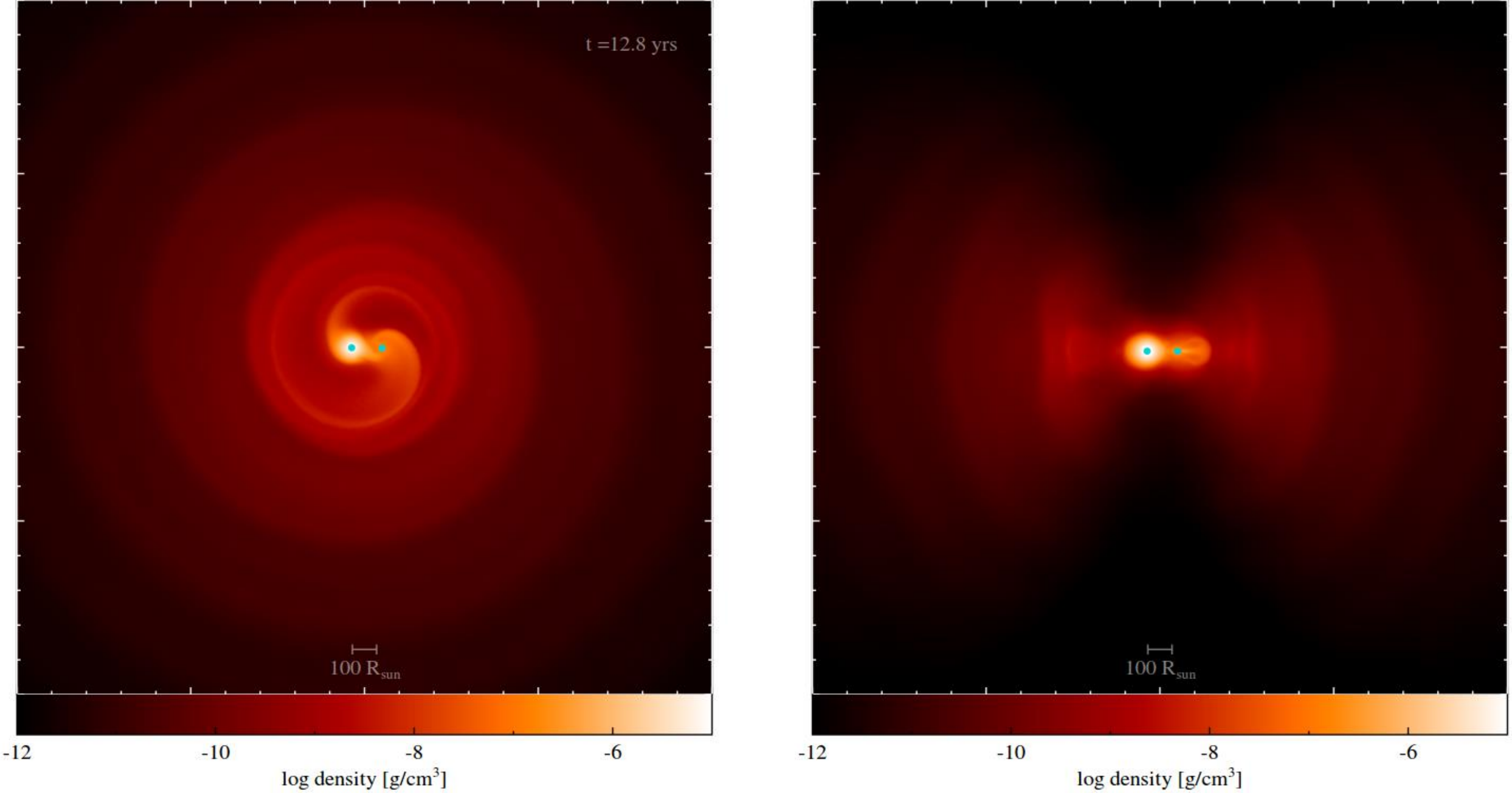
log density [g/cm^3]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log density [g/cm^3]
100 R_{sun}
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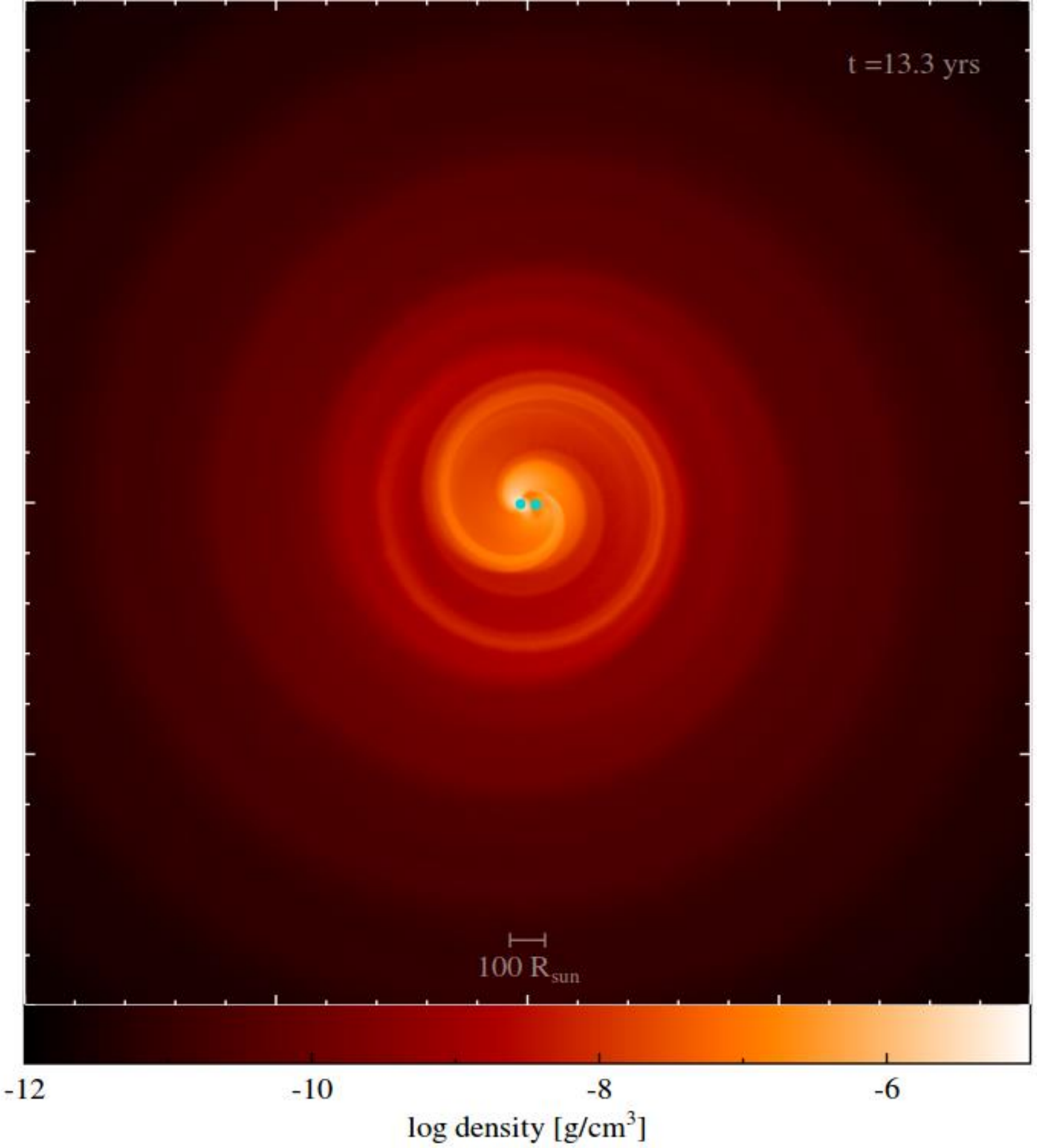
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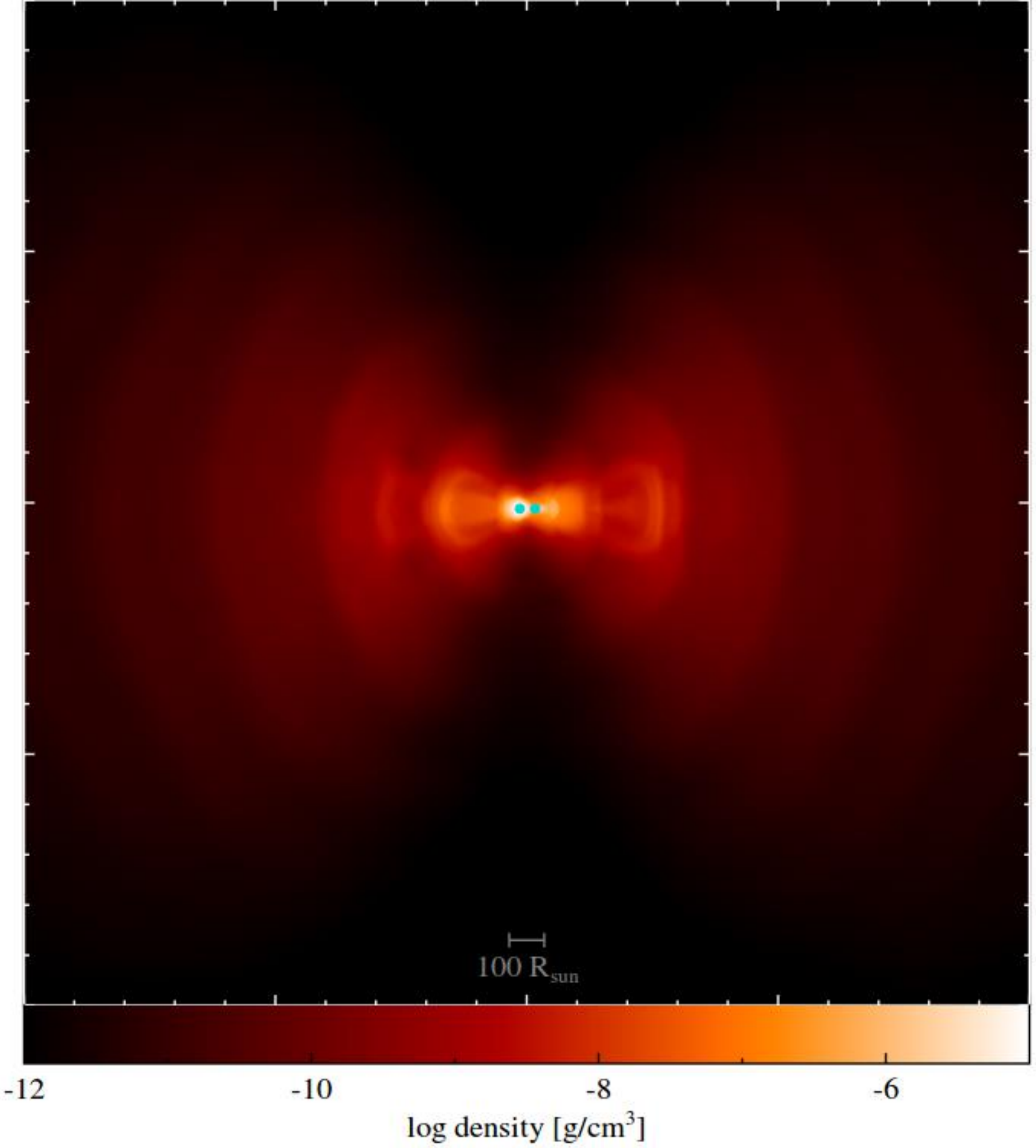
-6
log density [g/cm^3]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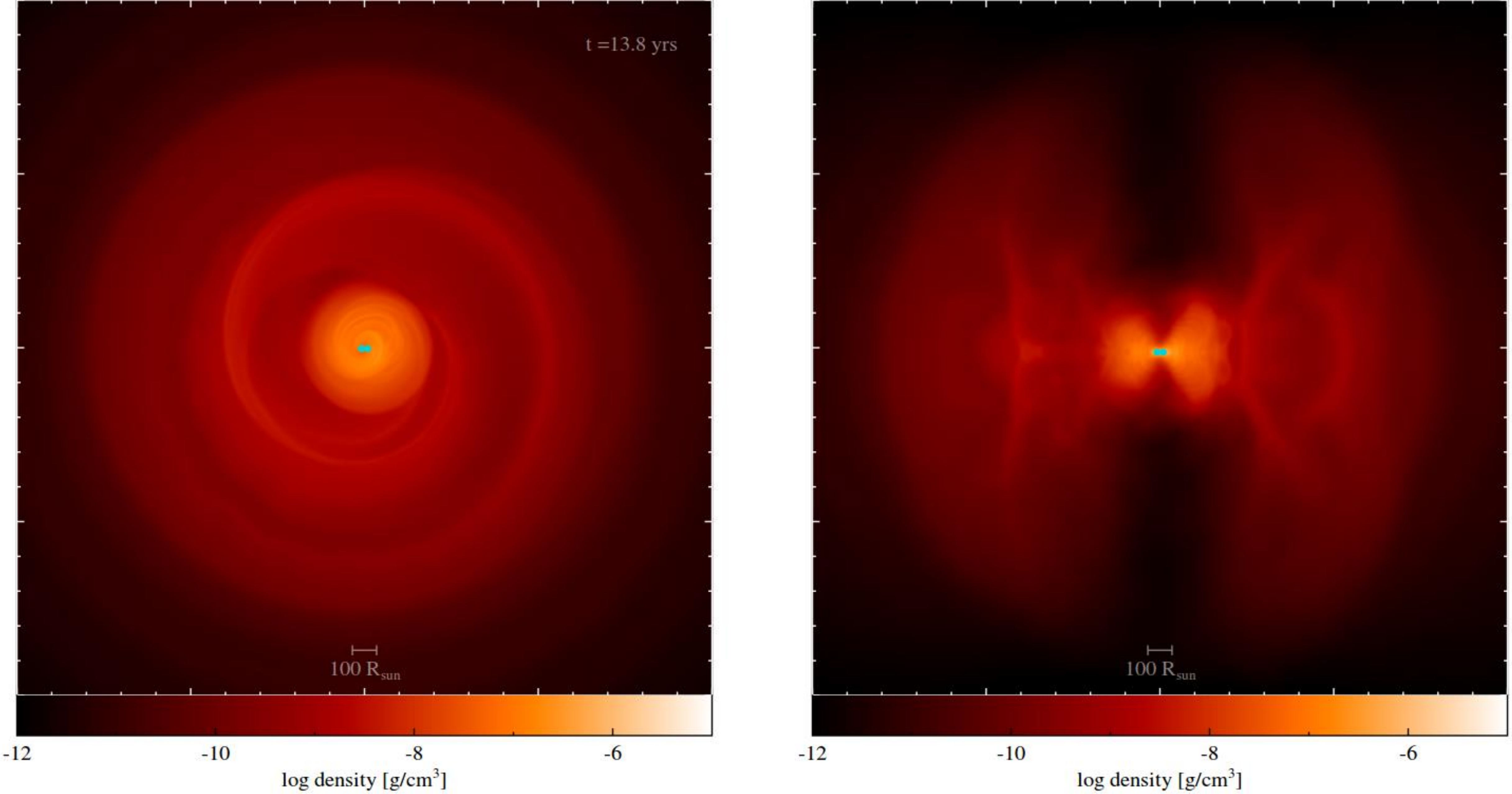
log density [g/cm^3]


t =13.8 yrs
100 R_{sun}
-12
-10
-8
-6
log density [g/cm^3]
100 R_{sun}
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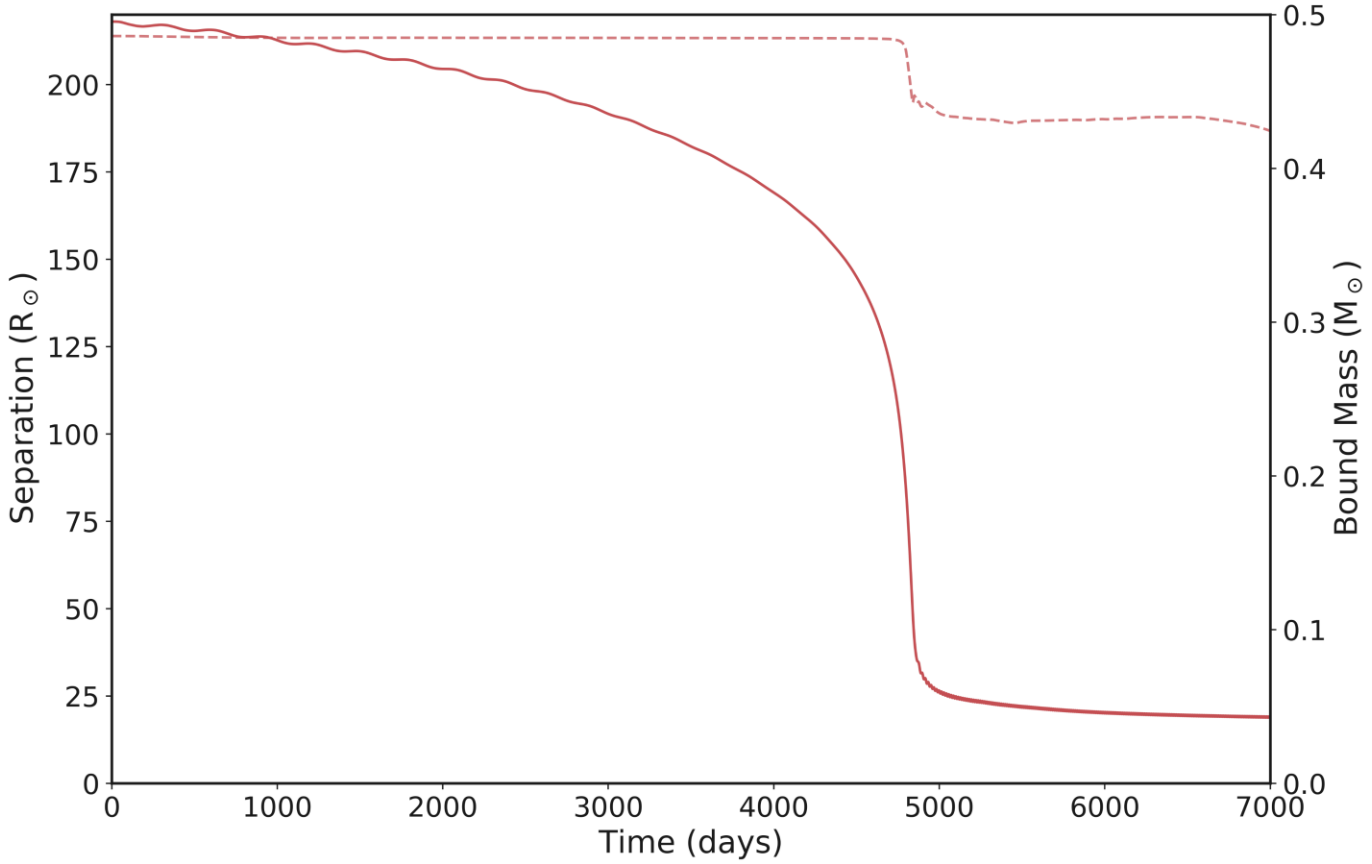
COMMON ENVELOPE SIMULATION

- Separation drops by ~90% over the course of the simulation (more than 60% of which is during the fast inspiral – ~1 year timescale).
- The entire envelope is not unbound, but instead is increasingly dragged into corotation.
- These simulations almost perfectly conserve energy and angular momentum.



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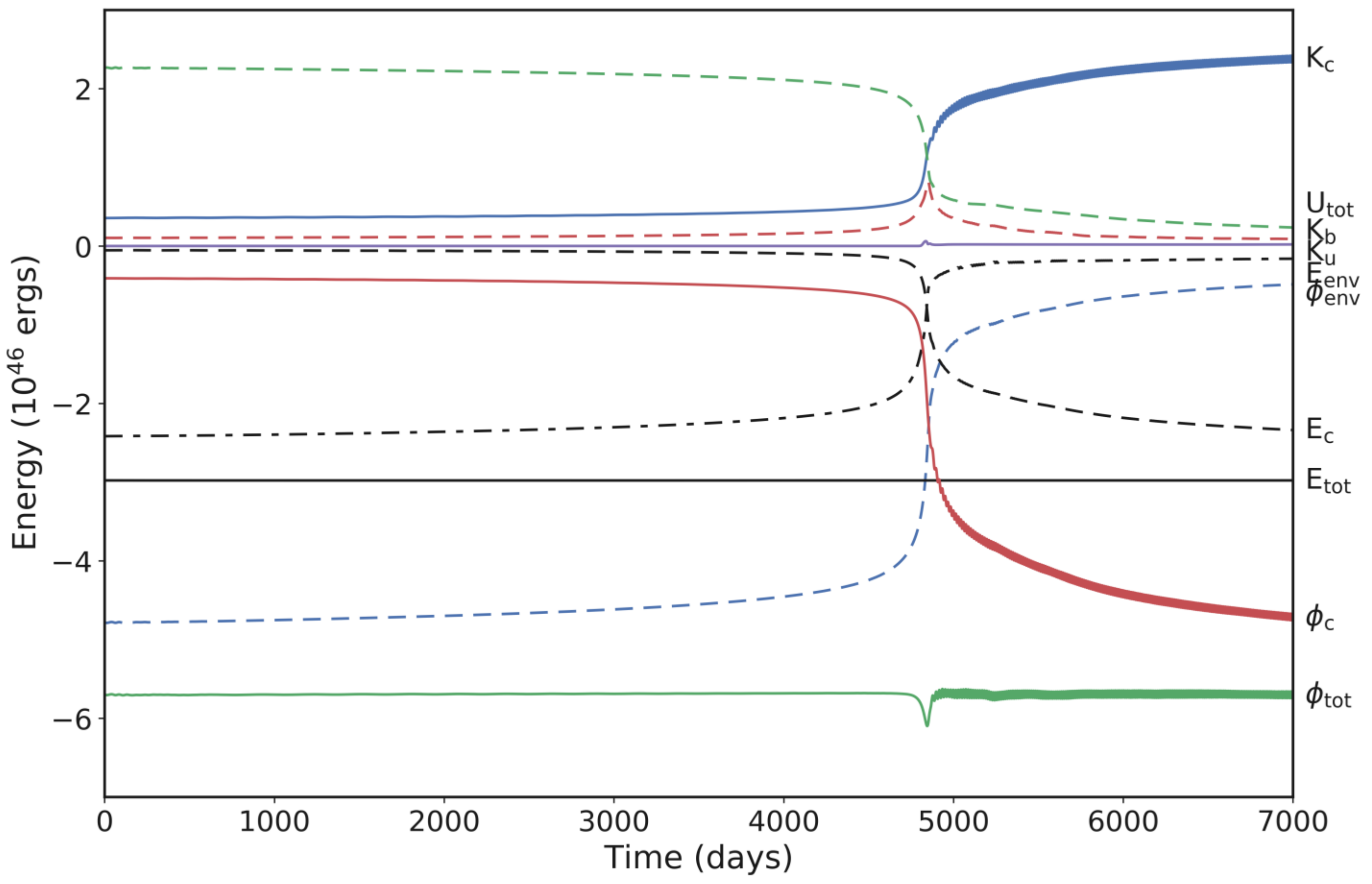

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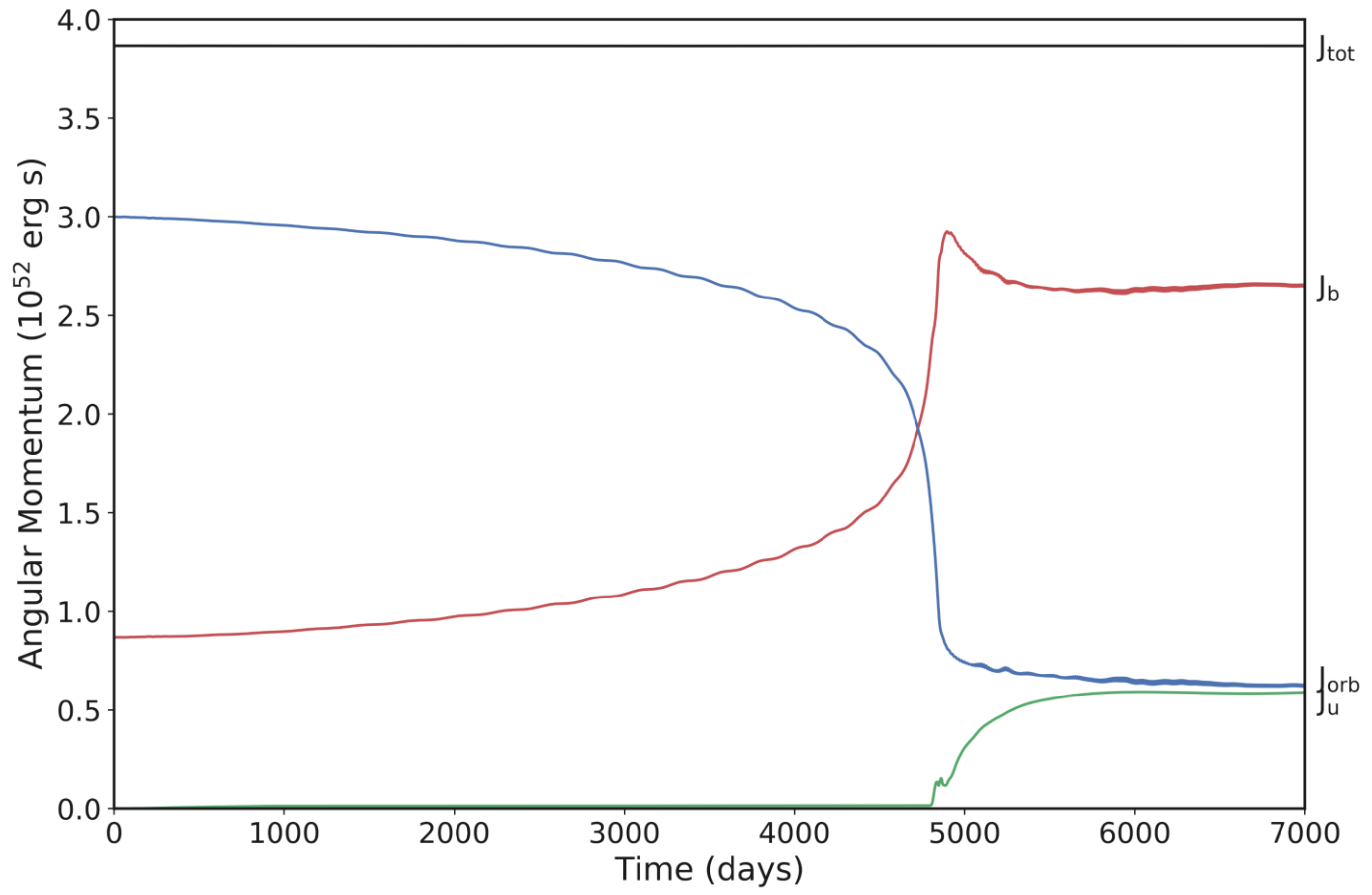
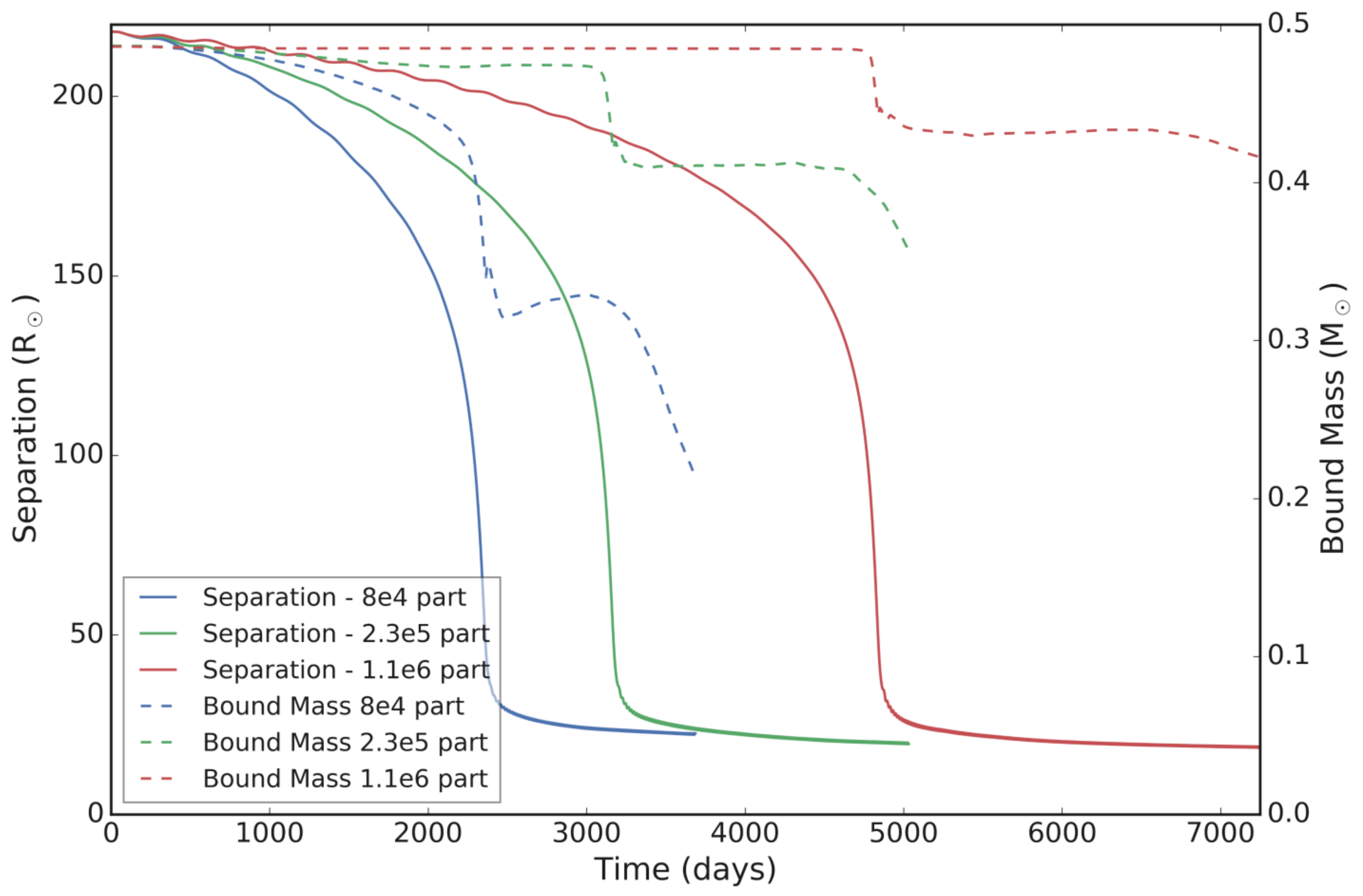


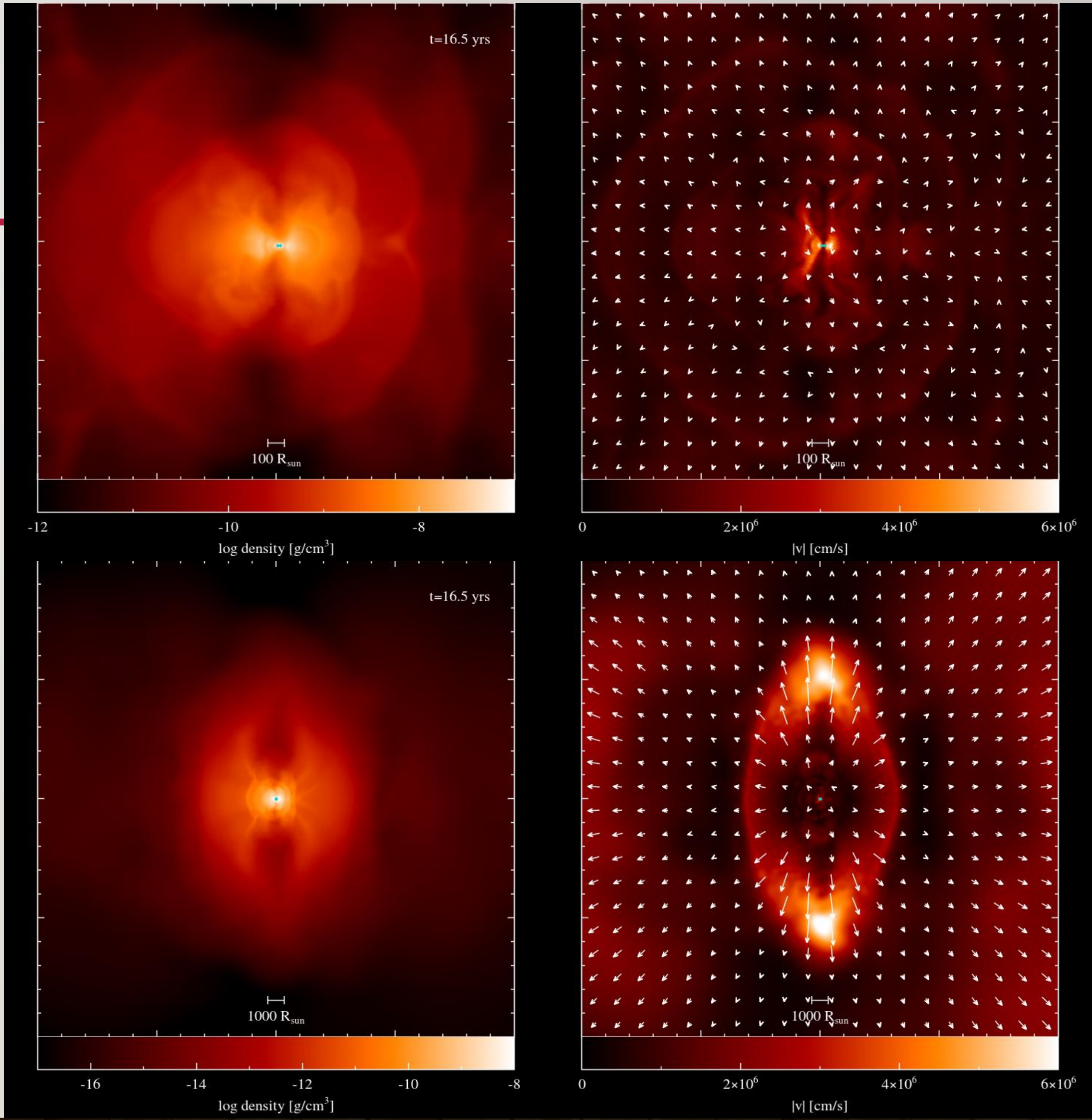
RESOLUTION TESTS

- Final orbital separation is largely unaffected.
- Amount of unbound material appears to reduce with increasing resolution.
- Higher resolution simulations appear to take longer to fall in.
- Simulations are thus converged in some areas, but not all.



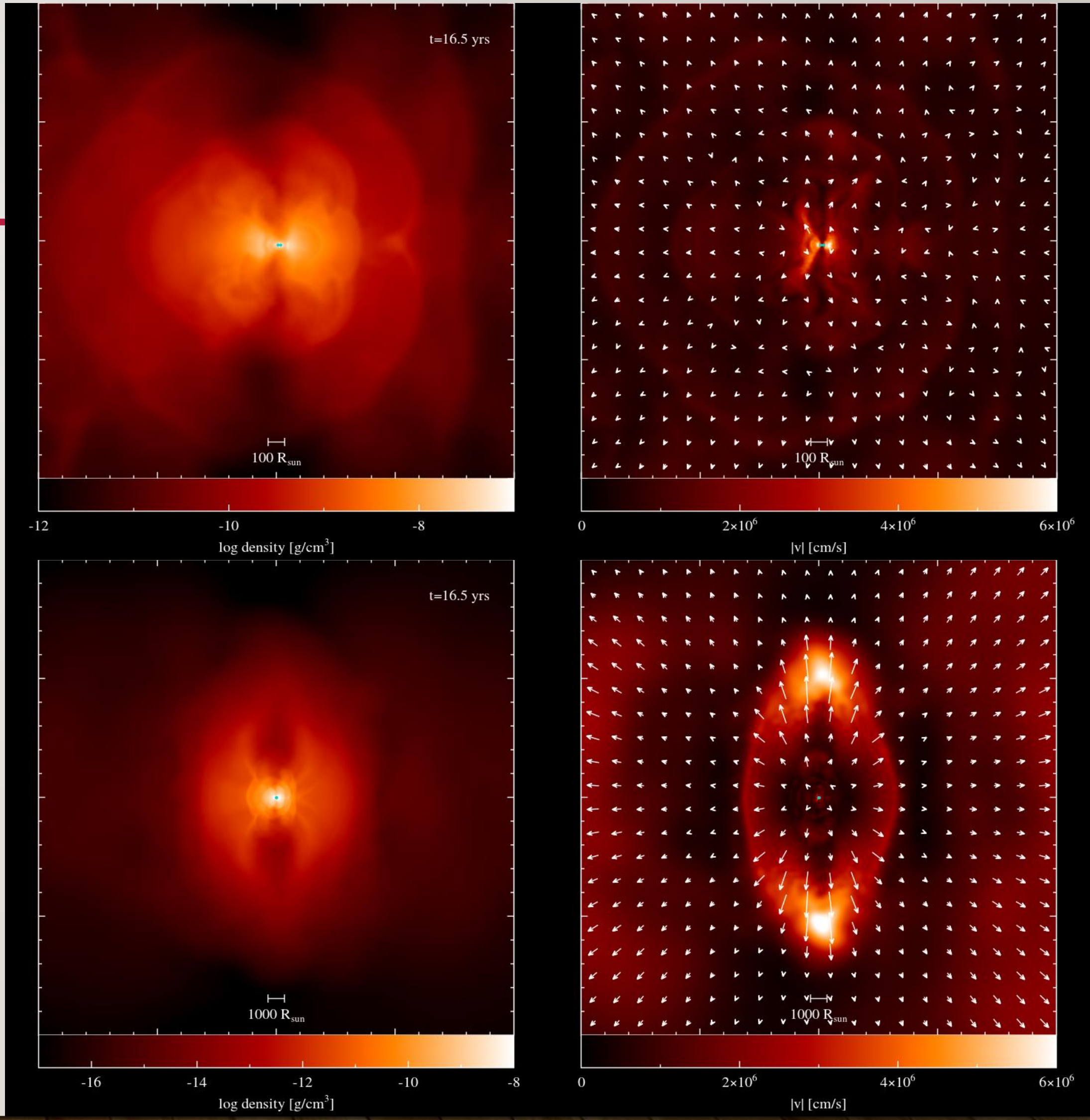
PN FROM COMMON ENVELOPES

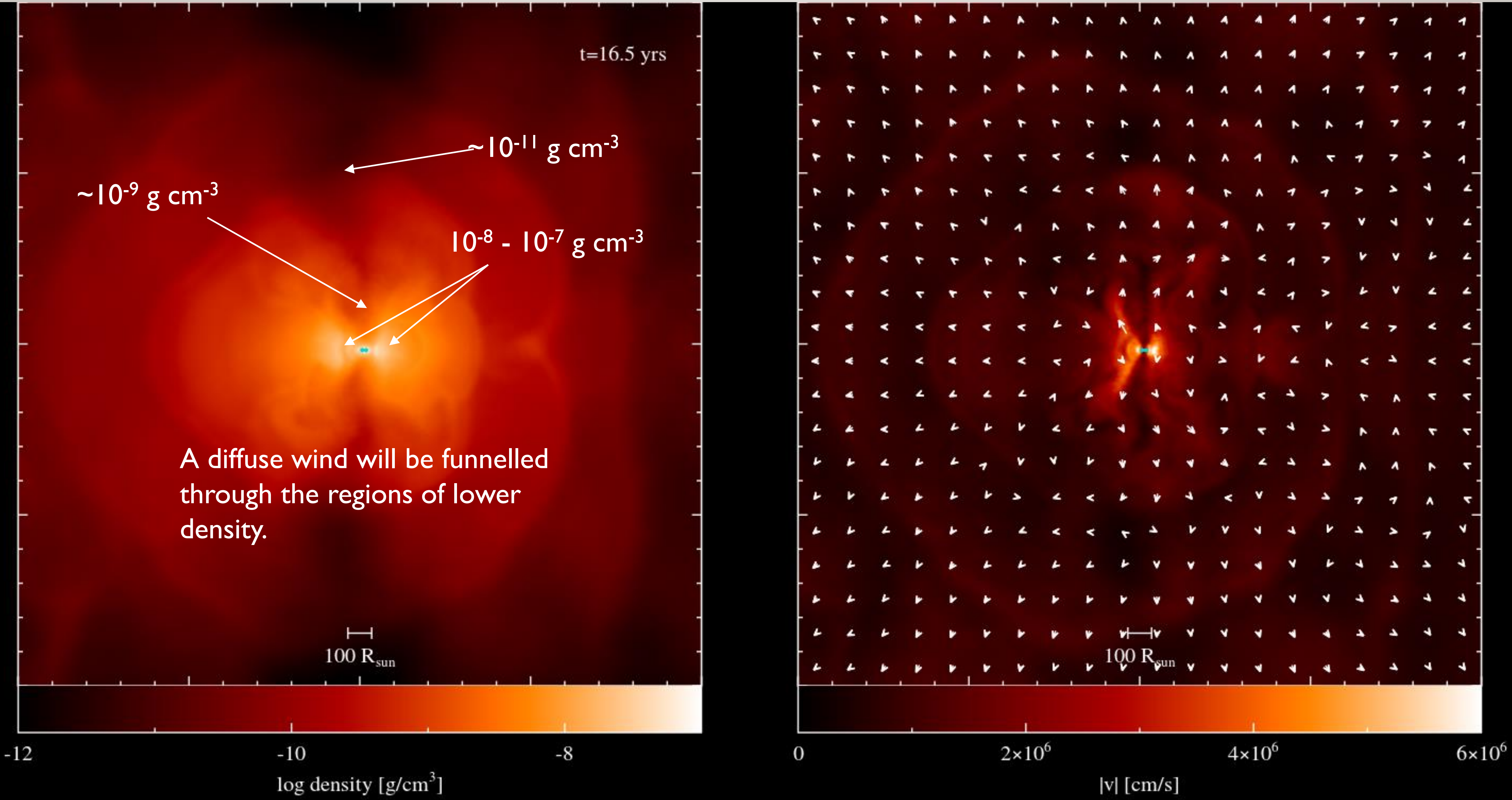
- After envelope ejection, central star (now a post-AGB star), releases a fast, tenuous wind in all directions.
- This wind more easily blasts through less dense regions: in this case, the poles.
- We would expect then to see bubbles form in the polar directions.
- Hot central star ionizes the resultant gas distribution, producing a bipolar planetary nebula.



PN FROM COMMON ENVELOPES

- Slice is approximately 3 years after the end of the fast in-spiral.
- Very distinct funnels of a much lower density (10-100 times less dense than surrounding material).
- Material is typically moving out at around 30 km s^{-1}, hence density will fall approximately 9 orders of magnitude in ~100-1000 years.



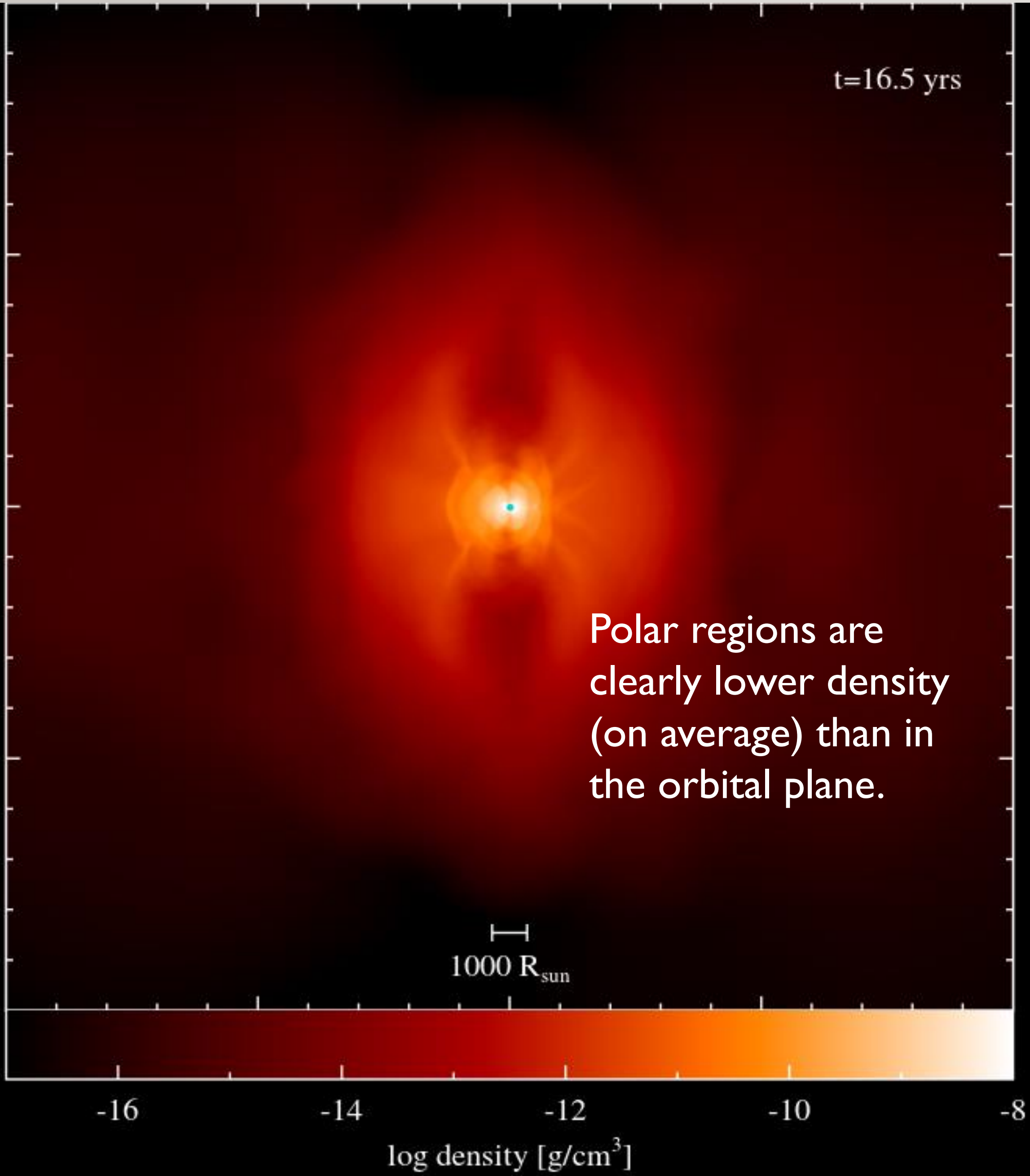


$\sim10^{-11}$ g cm^{-3}

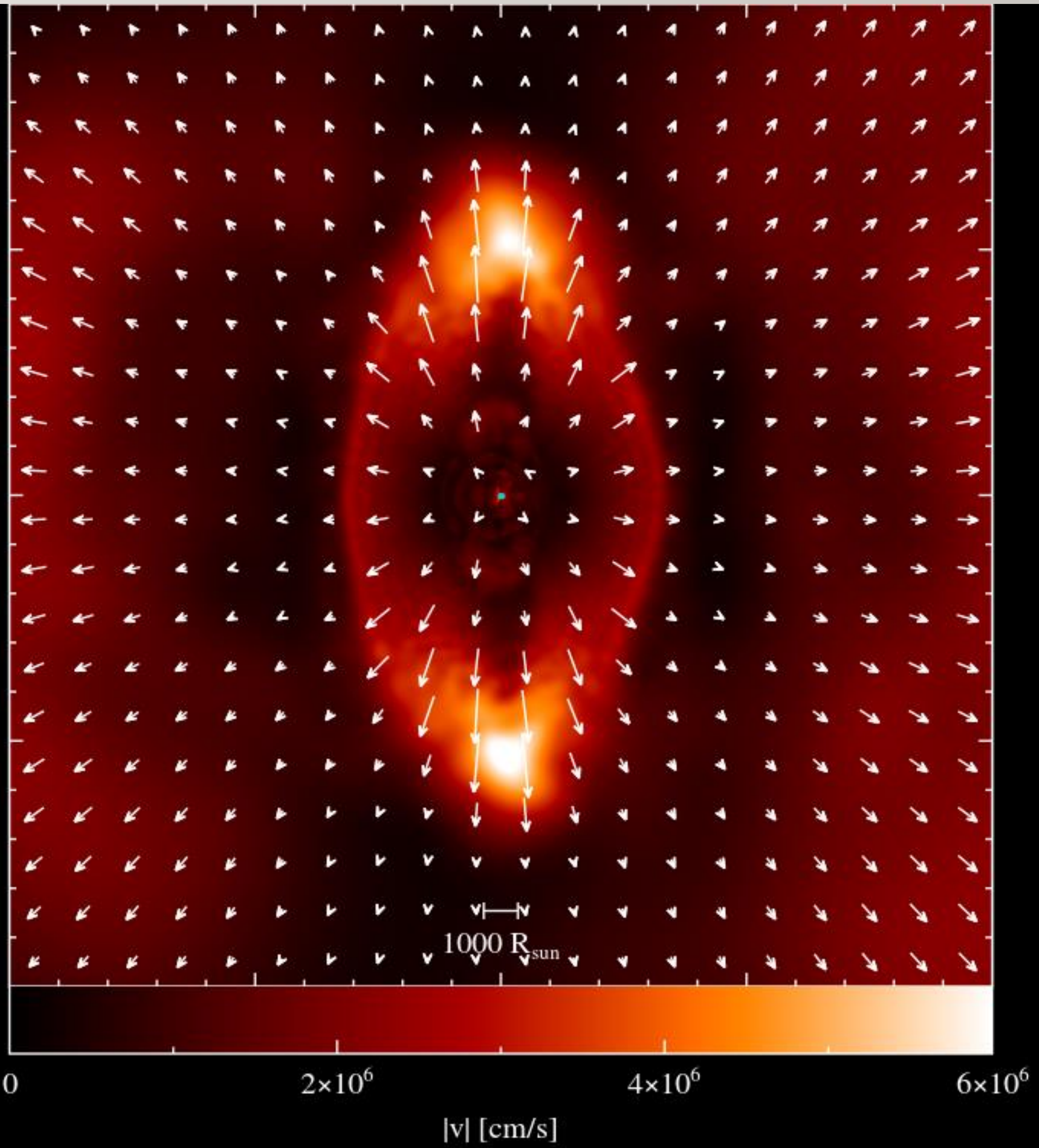
$\sim10^{-9}$ g cm^{-3}

10^{-8} - 10^{-7} g cm^{-3}

A diffuse wind will be funnelled through the regions of lower density.

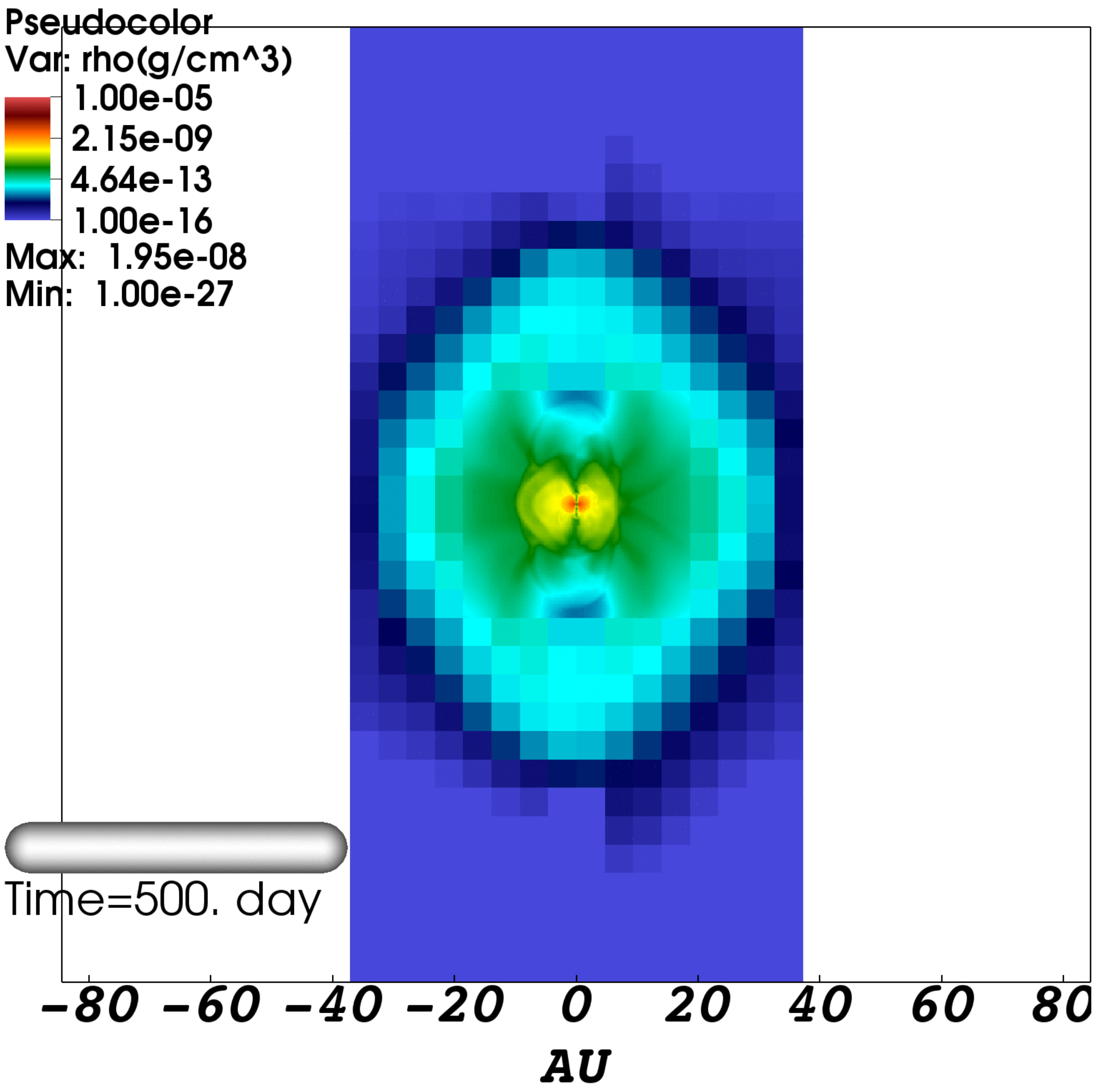


Polar regions are clearly lower density (on average) than in the orbital plane.



ASTROBEAR SIMULATIONS

- Density distribution from Phantom is mapped onto three nested grids (128^3 cells, 128,000 $R_\odot$ per side for the largest, 128^3 cells, 8000 $R_\odot$ per side for medium, and 192^3 cells, 1500 $R_\odot$ per side for the smallest), using Splash.
- Grids were then loaded into AstroBEAR (by Zhuo Chen), and the code was allowed to refine on two levels between each of the static grids. Total of 7 levels of refinement with AMR and nested grids.
- Central portion of the simulation is replaced with a sphere of radius 46.875 $R_\odot$, hence the binary no longer had to be simulated.
- Fast wind (300 km s^{-1}, 6.35 x 10^{-4} $M_\odot$ yr^{-1}) is released from surface of the sphere, and hydrodynamically collimated to produce lobes.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Time=500. day
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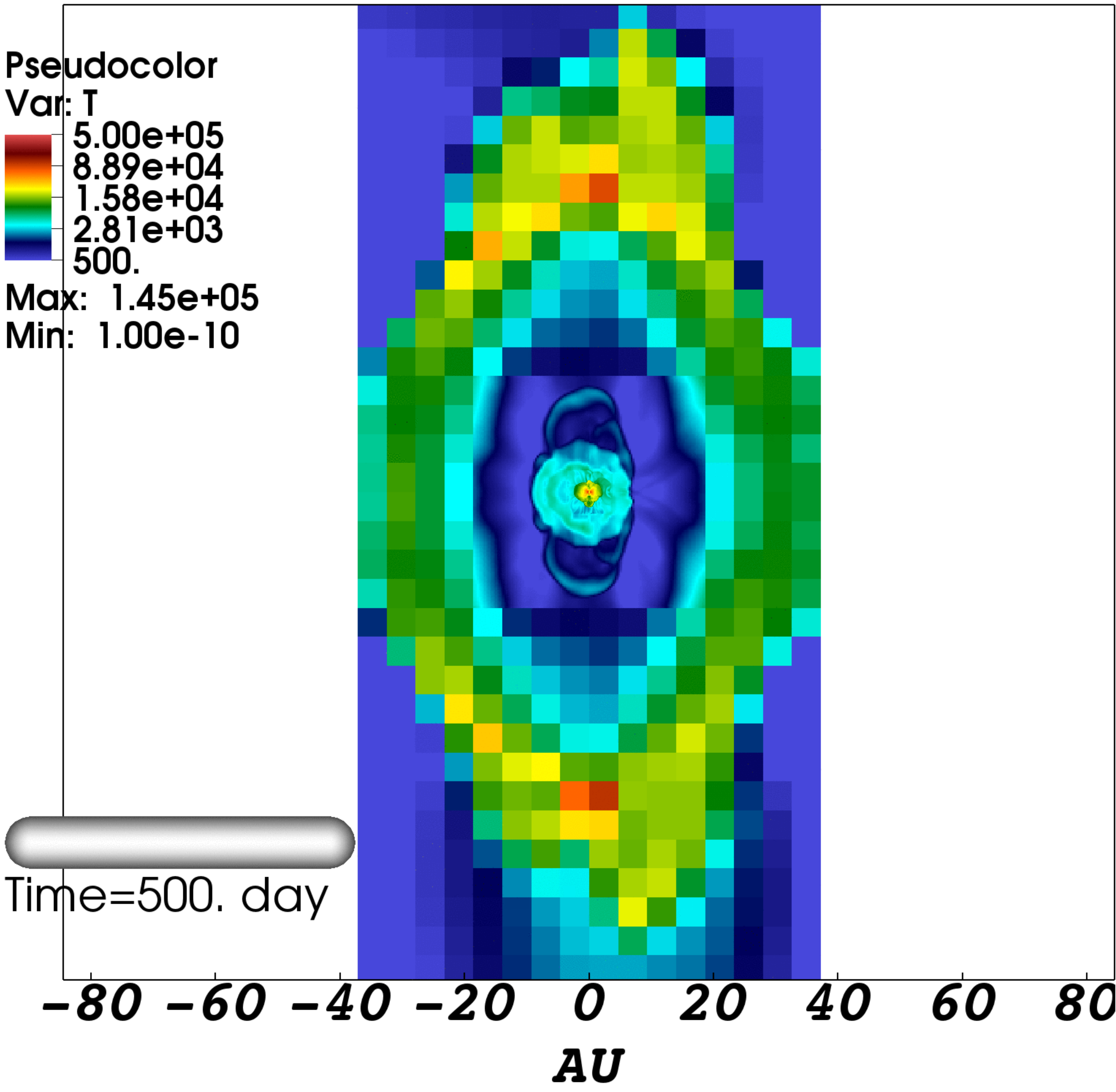
AU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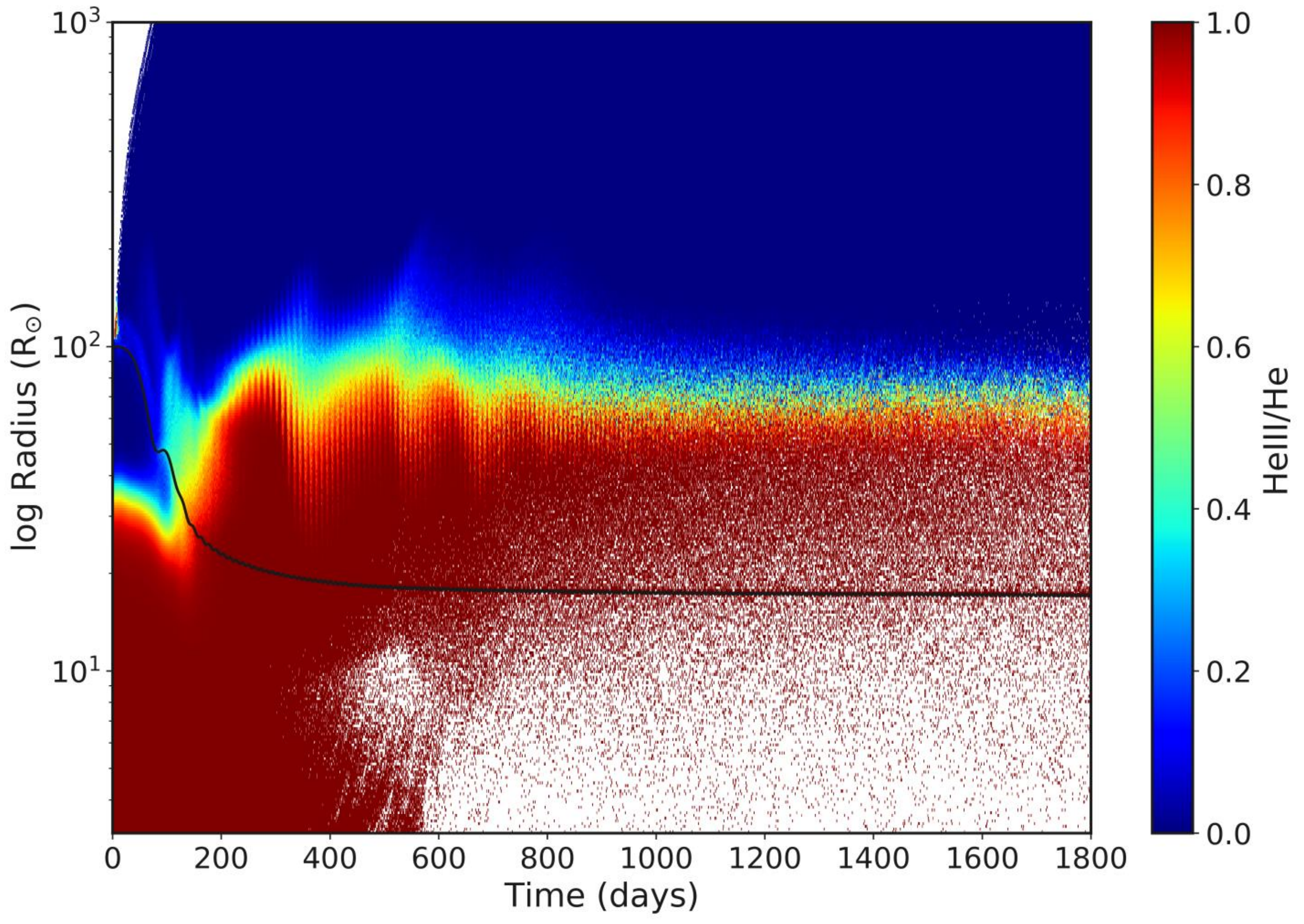
Time=500. day
-80 -60 -40 -20 0 20 40 60 80
AU

RECOMBINATION ENERGY

- The addition of recombination energy into the equation of state can help unbind the envelope.
- MESA (Paxton et al., 2010) equation of state is tabulated, much more realistic than ideal equation of state, taking recombination into account along with other physical processes.
- The use of this equation of state has been primarily driven by Nandez et al. (2015).
- Map ionisation fractions to determine where recombination is occurring.



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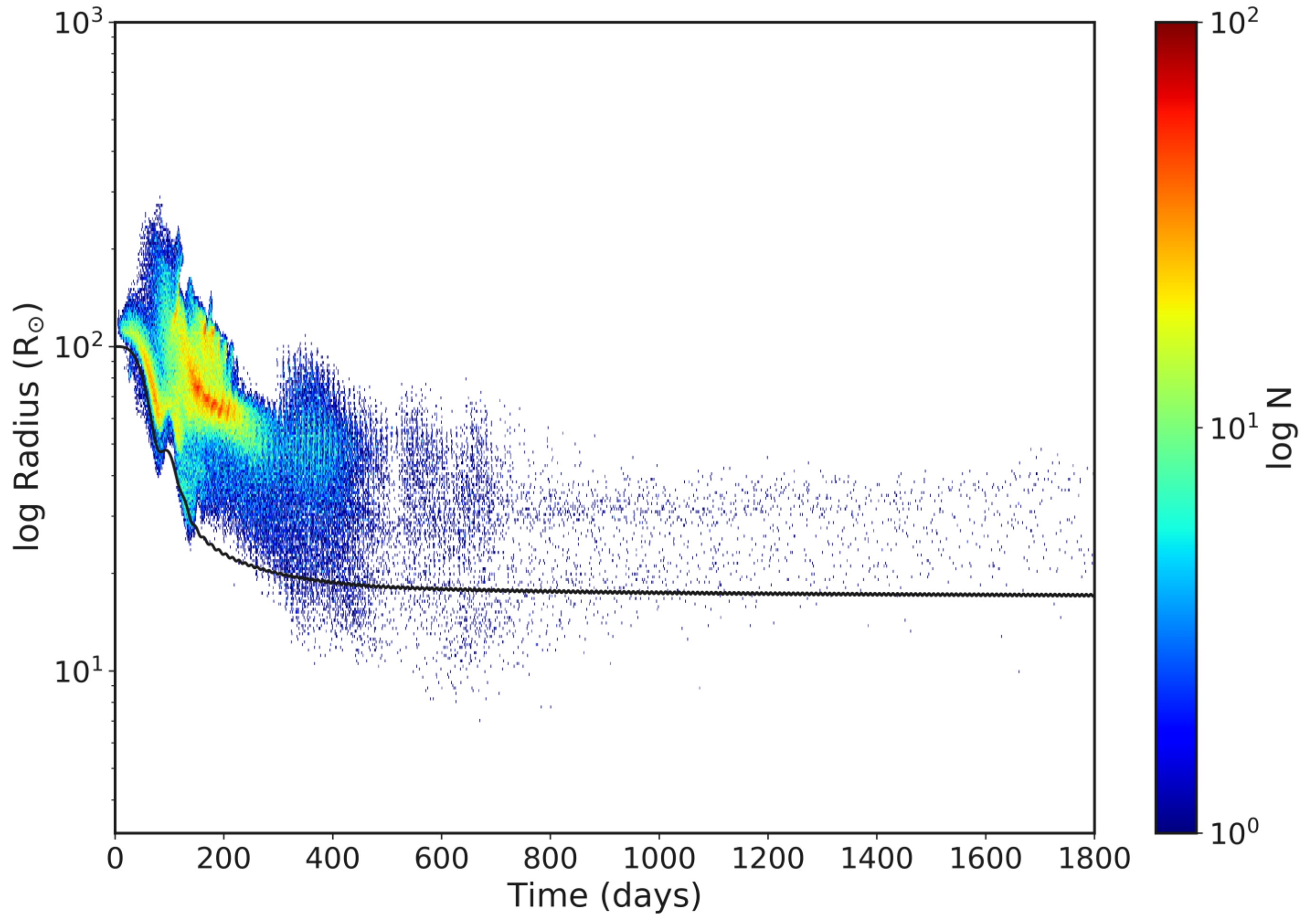

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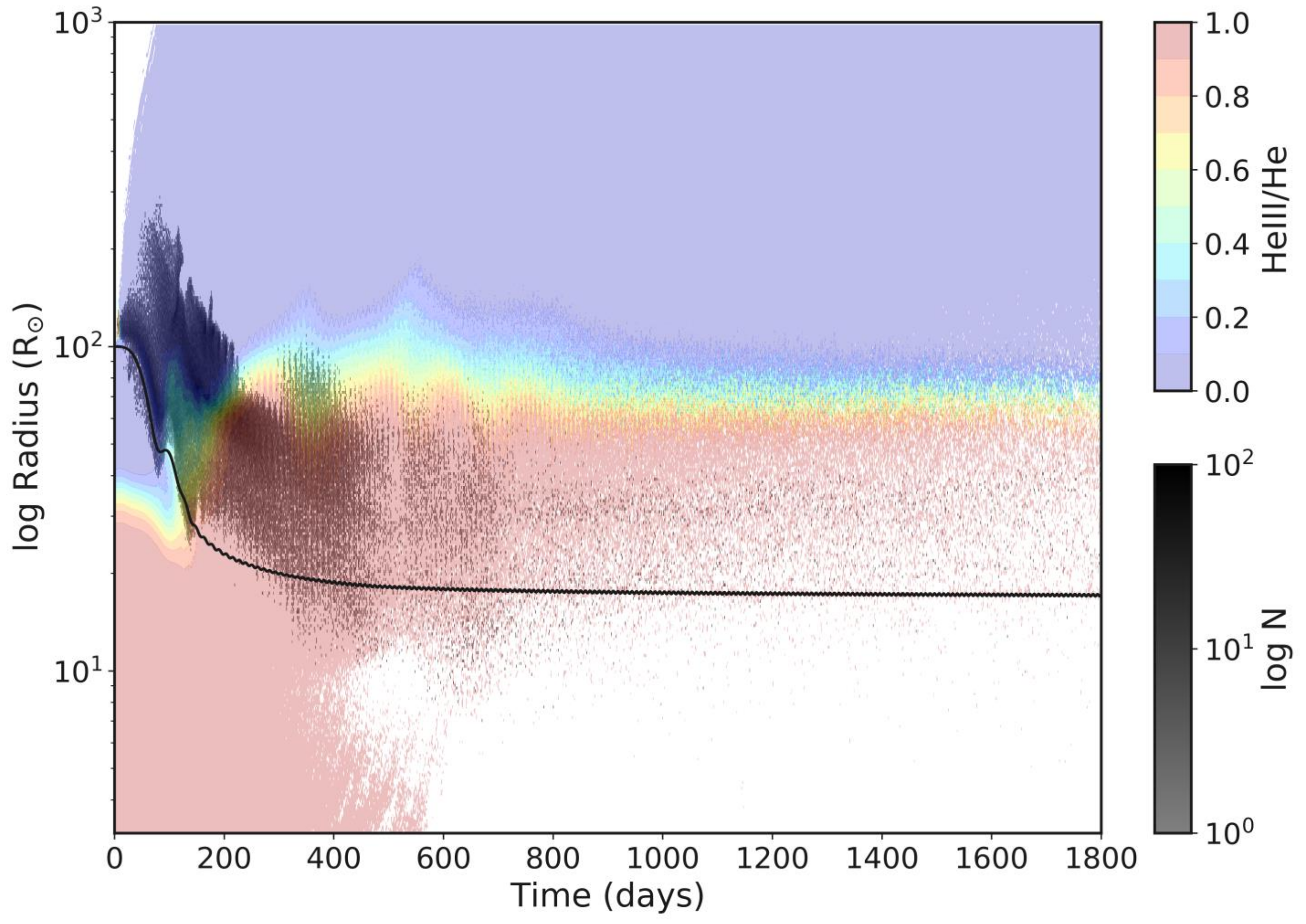
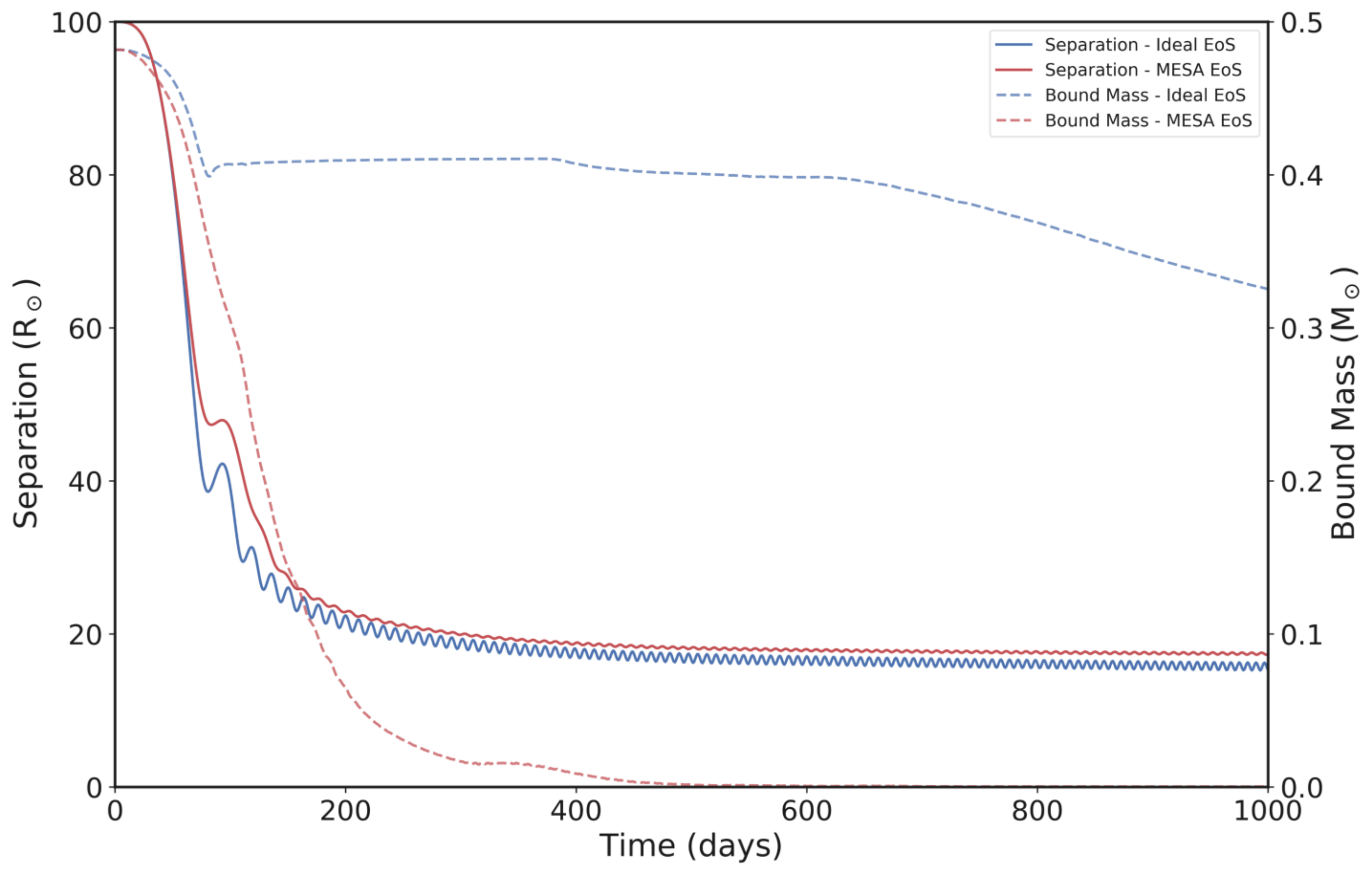


EQUATION OF STATE COMPARISON

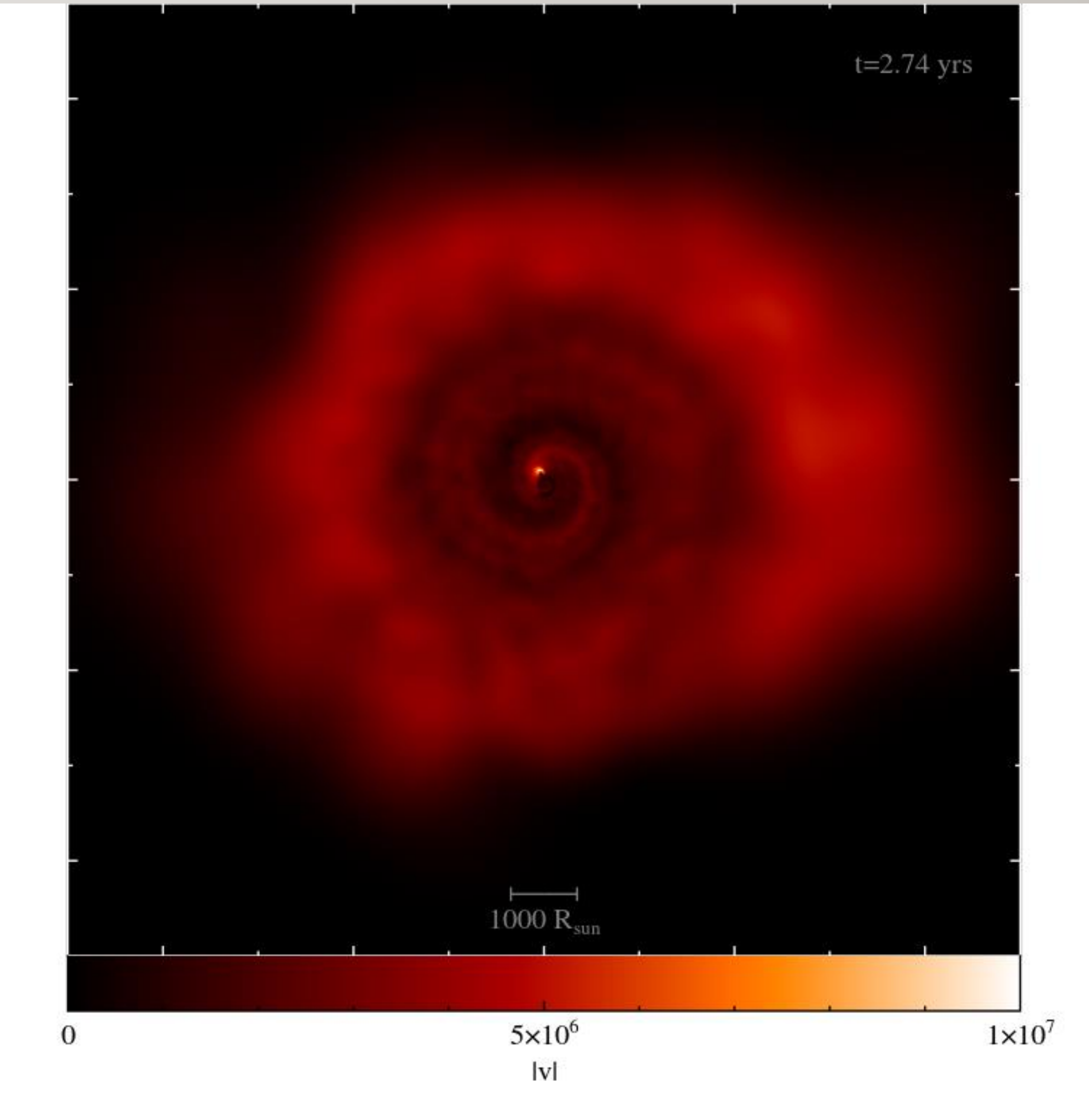
- By using the MESA equation of state, we unbind the entire envelope in a very short period of time.
- In reality, recombination photons may be lost from the system, hence this should be treated as a maximal case.
- As the final separation is ~10% larger when using MESA EoS, the energy for unbinding is (not surprisingly) not coming from the orbit.



Simulations with 100 $R_\odot$ initial separation are used here, as this is preliminary work, and 218 $R_\odot$ initial separation simulations have not yet been run.

EQUATION OF STATE COMPARISON: EJECTA VELOCITIES

- After only1000 days, MESA EoS simulation is already considerably more spread out.
- Ejecta velocities are larger approximately by a factor of two (~4 x 10^6 cm s^{-1} for ideal EoS, and ~8 x10^6 cm s^{-1} for MESA EoS).
- The increase in ejecta velocities will more quickly lead to a diffuse gas distribution.



Velocities in cm/s.

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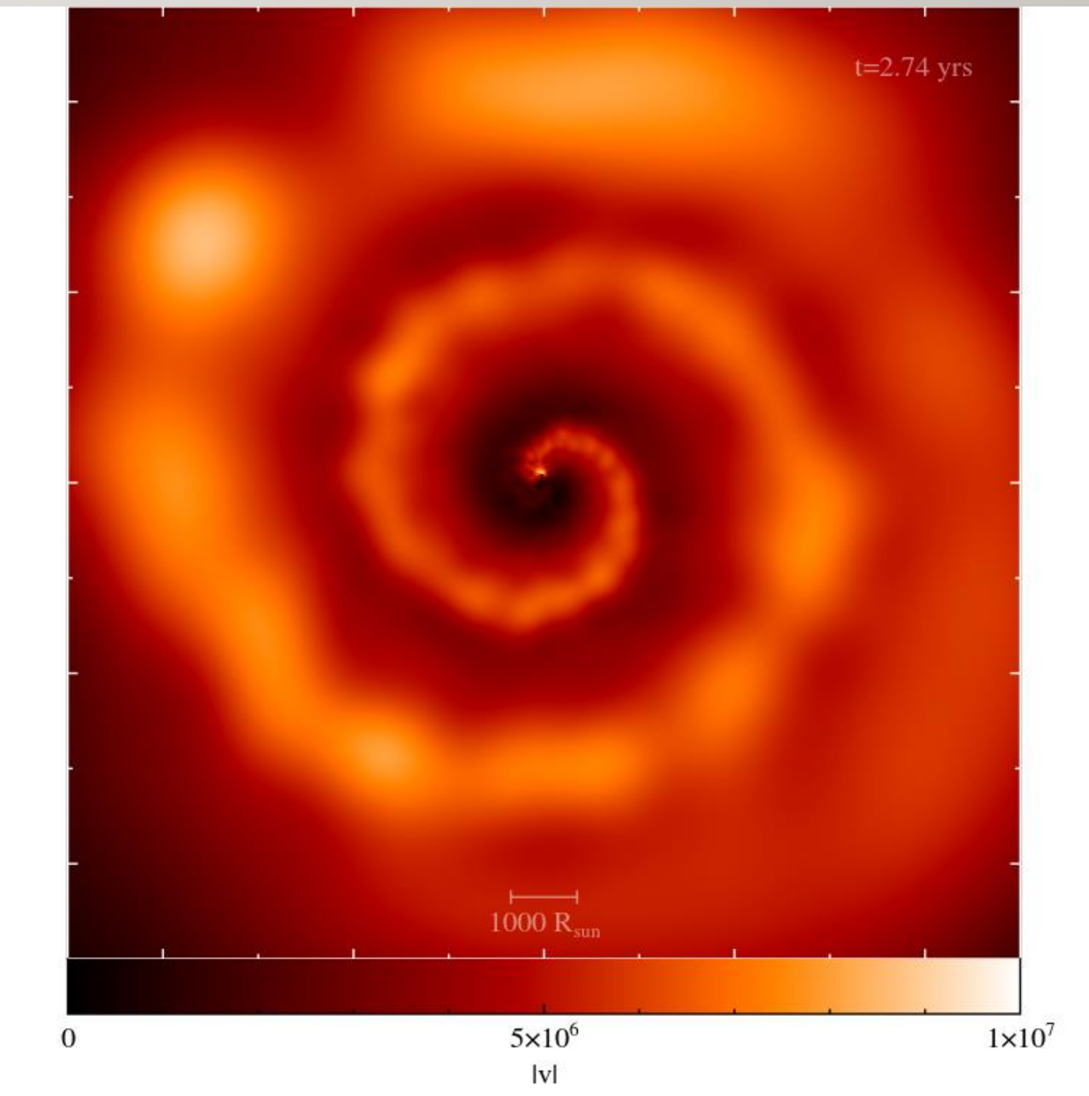

Velocities in cm/s.

SUMMARY

- The common envelope interaction is fundamental to understanding a wide variety of astrophysical phenomena.
- Hydrodynamical simulations are striving to produce density distributions which may be useful for forming planetary nebula morphologies.
- Planetary nebula simulations are possible by blowing a diffuse wind (to mimic a post-AGB star) into the resultant gas distributions.
- Implementing MESA EoS gives more physically realistic simulations, and gives a more extended (and thus less dense) gas distribution.