Dust implementation in CE simulations

MIGUEL GONZALEZ-BOLIVAR, ORSOLA DE MARCO,
LIONEL SIESS, LUIS CARLOS BERMUDEZ-BUSTAMANTE,
DANIEL PRICE, MIKE LAU, RYOSUKE HIRAI, MANSI
KASLIWAL

Phantom and MCFOST Users Workshop 2023

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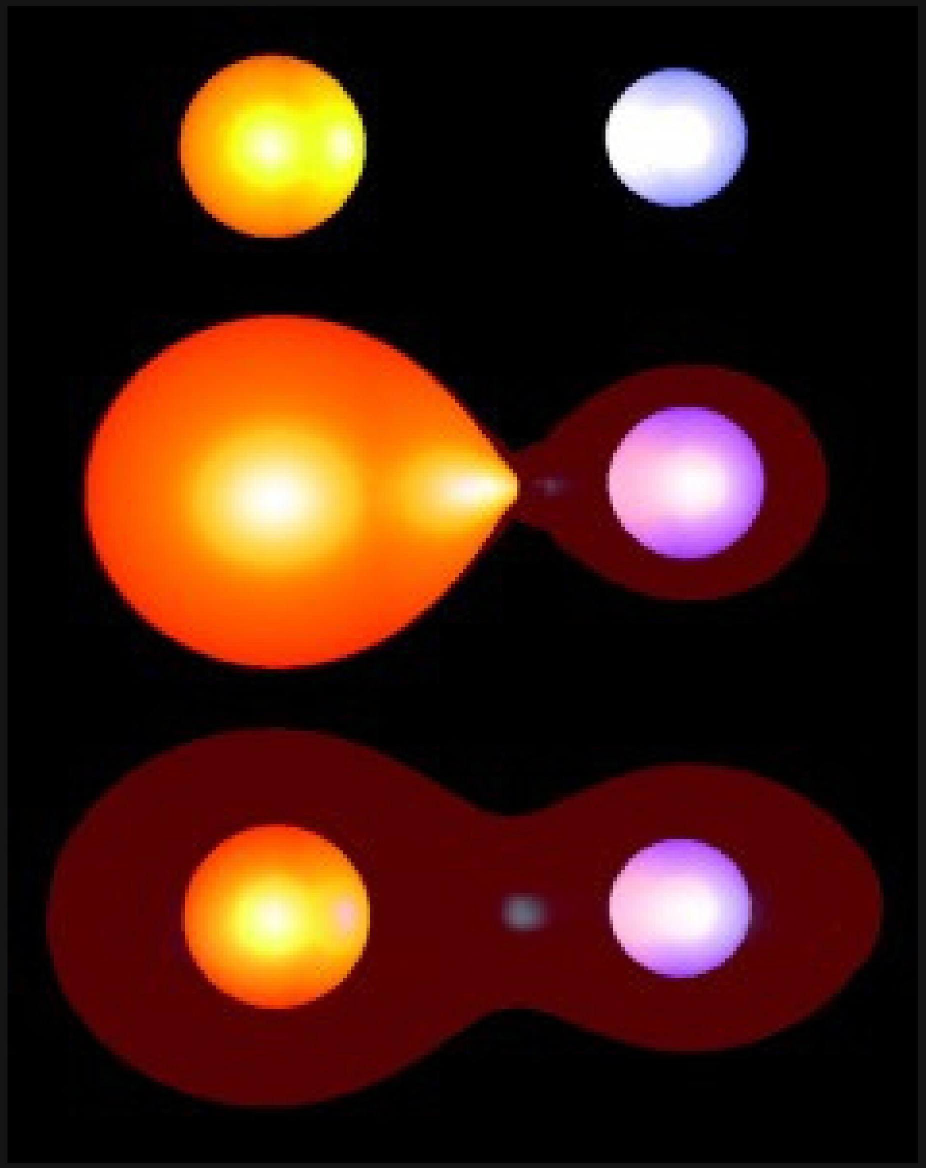
PHANTOM

What is common envelope evolution (CCE)?

CCE TAKES PLACE WHEN A STAR IN A BINARY EXPANDS AND, GIVEN THE RIGHT CONDITIONS, ENGULFS THE COMPANION.



Credits: Adrian Potter

What is common envelope evolution (CCE)?

PRIMARY (LEFT) EXPANDING

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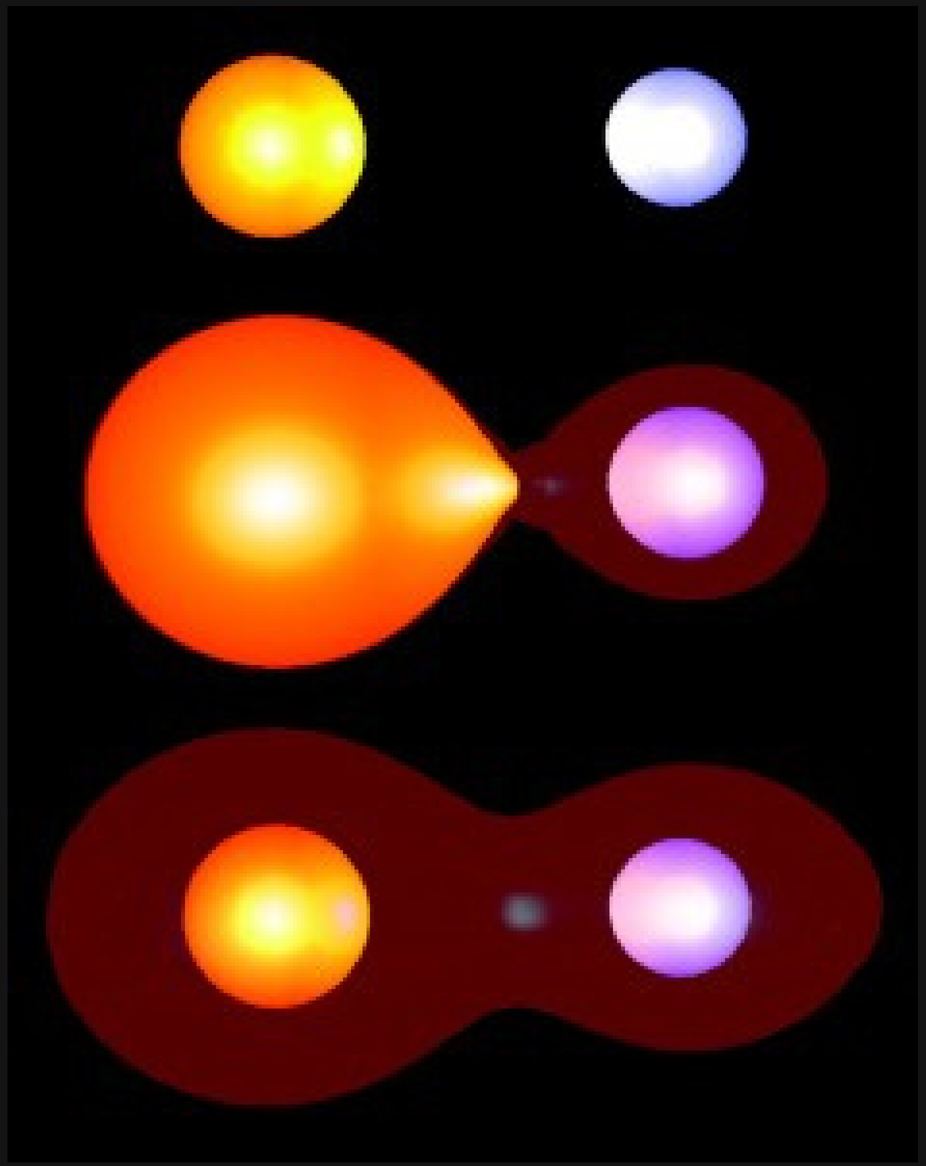

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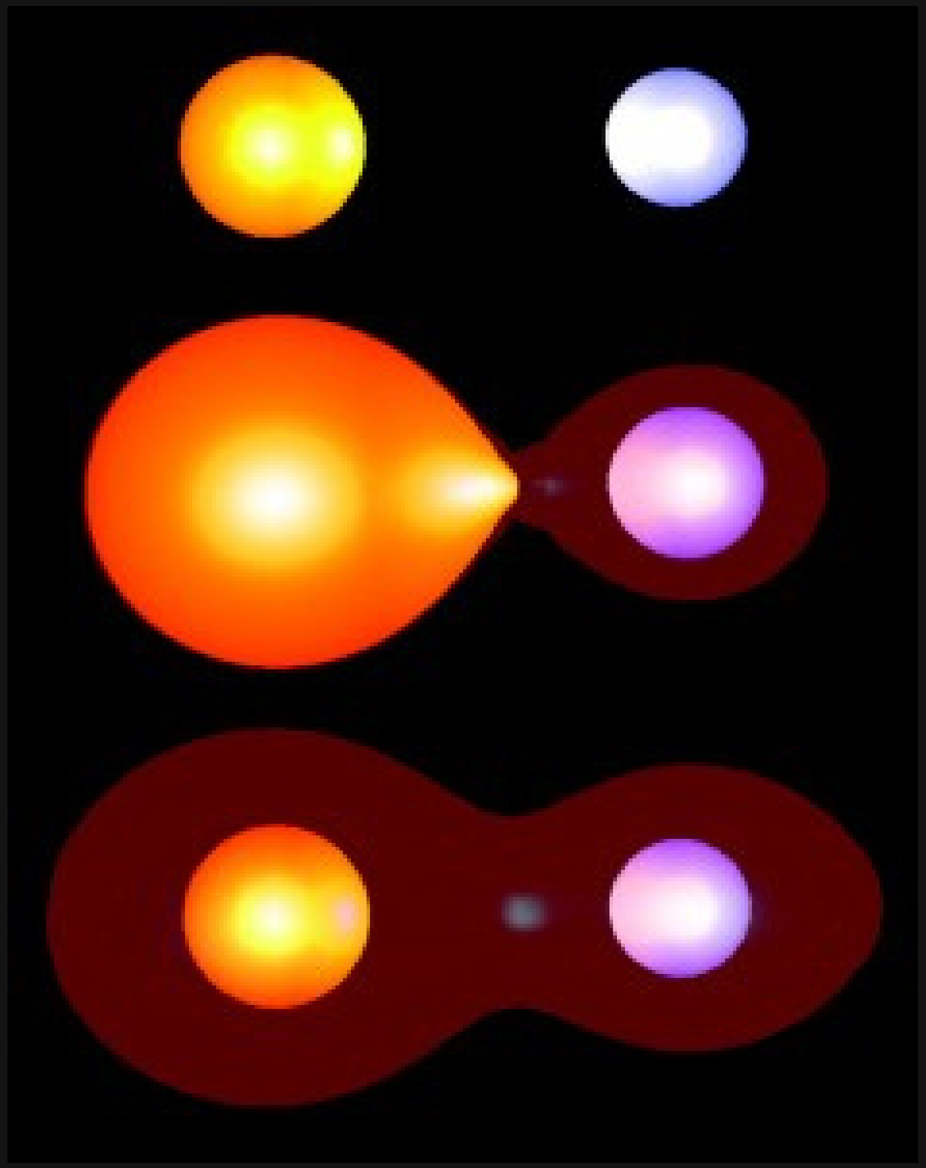
PRIMARY (LEFT) EXPANDING

ROCHE LOBE OVERFLOW



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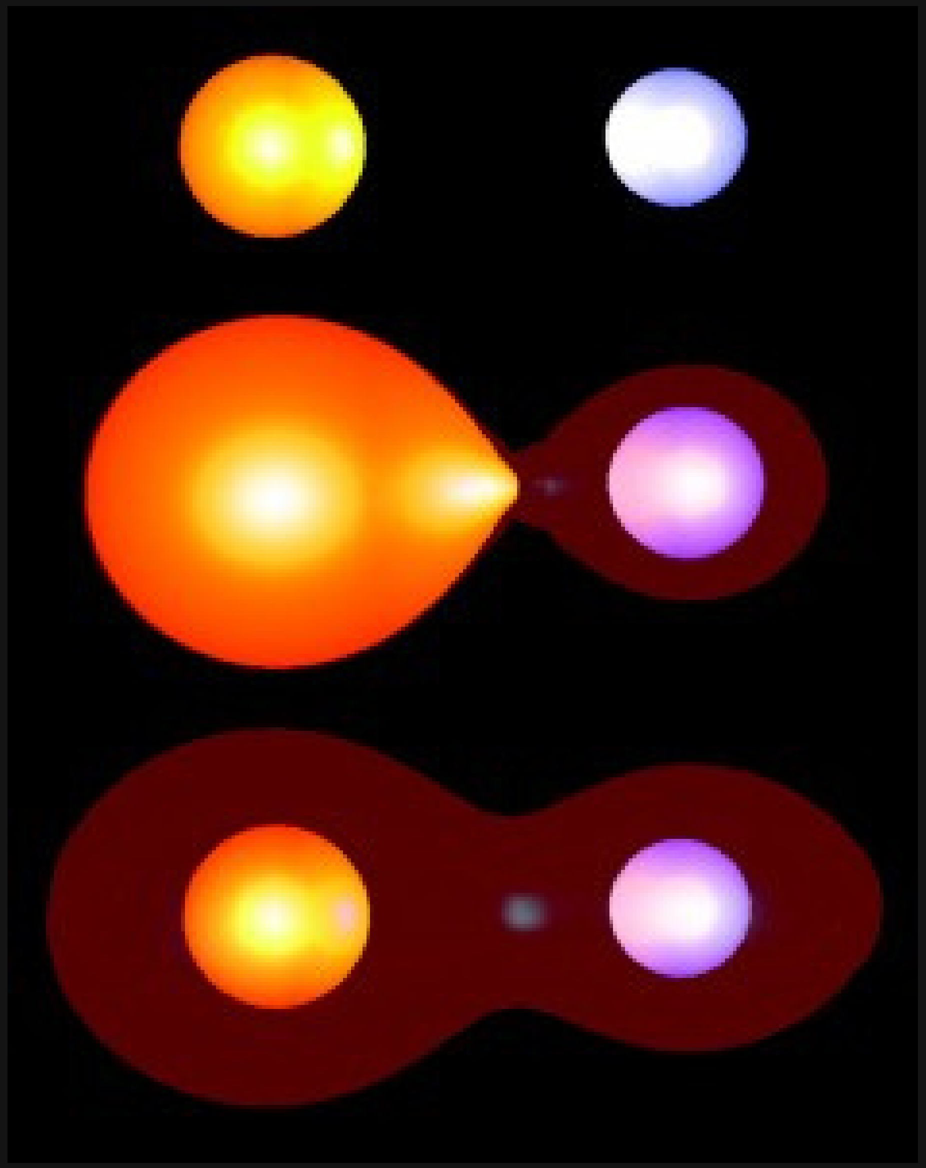
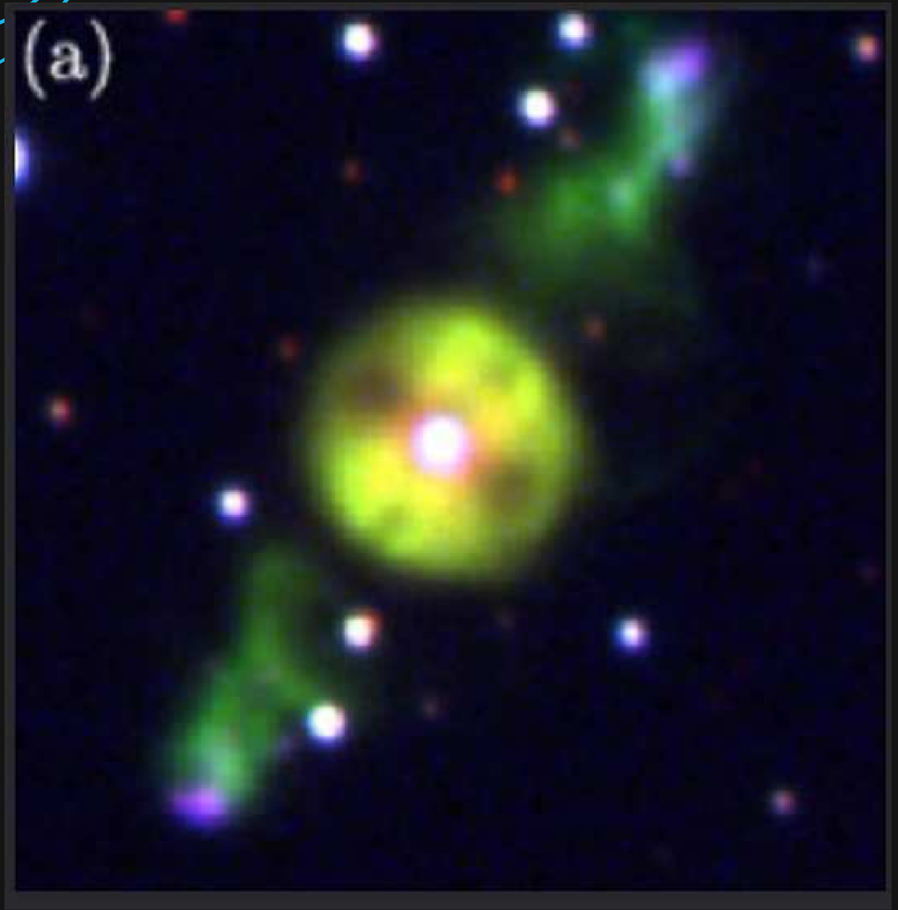


PRIMARY (LEFT) EXPANDING

ROCHE LOBE OVERFLOW

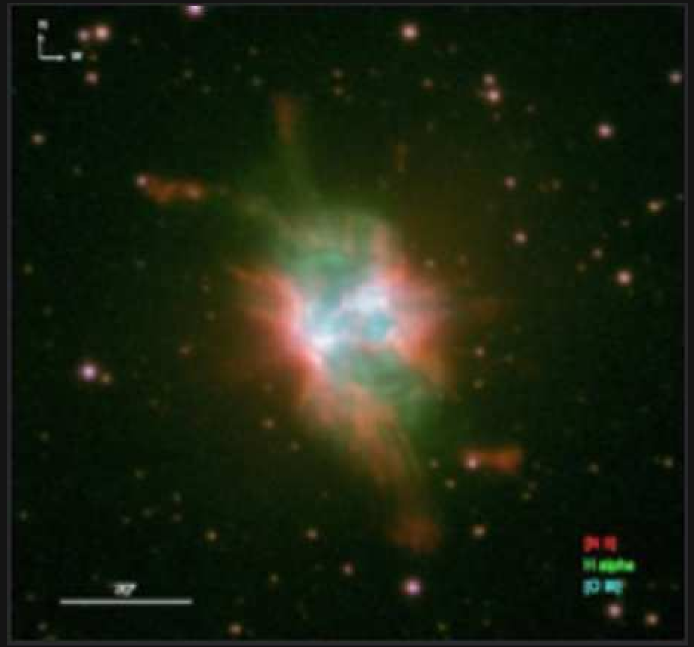
COMMON ENVELOPE

Credits: Adrian Potter

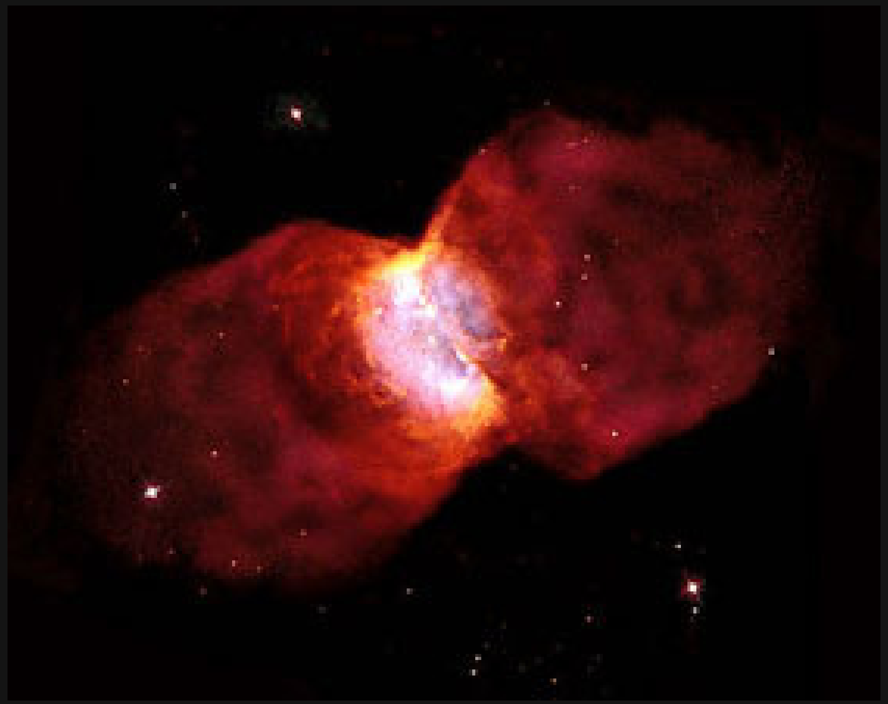


Ethos 1

Fleming 1



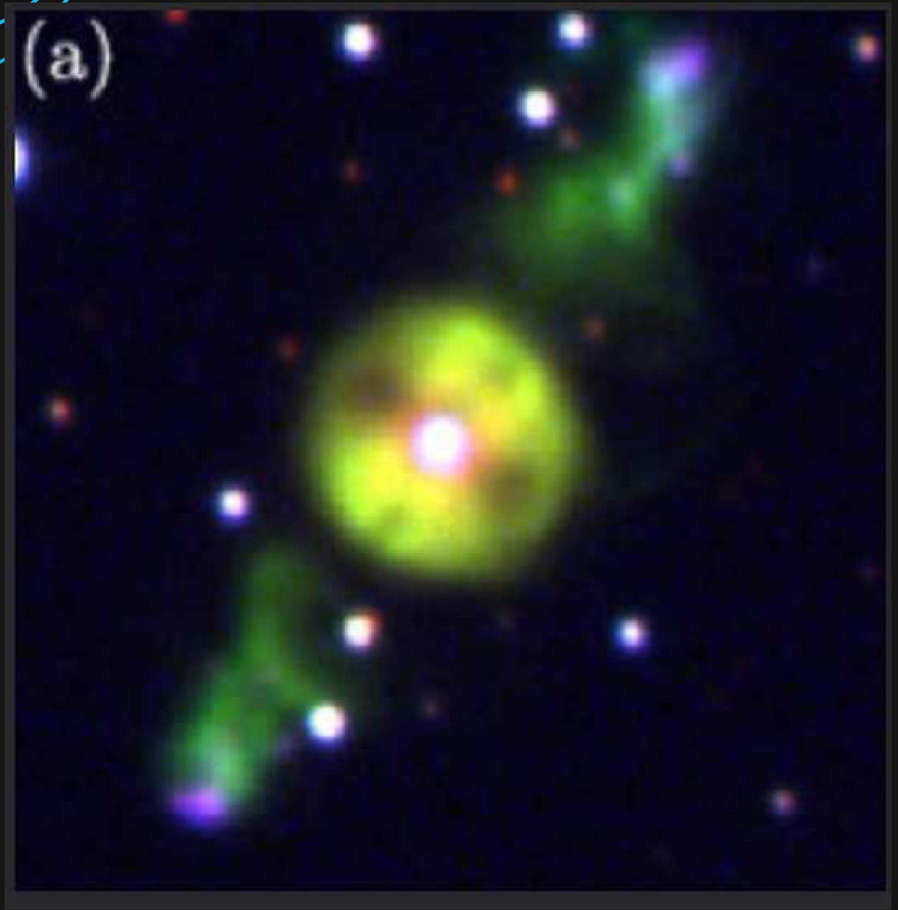
NGC 6778



NGC 2346

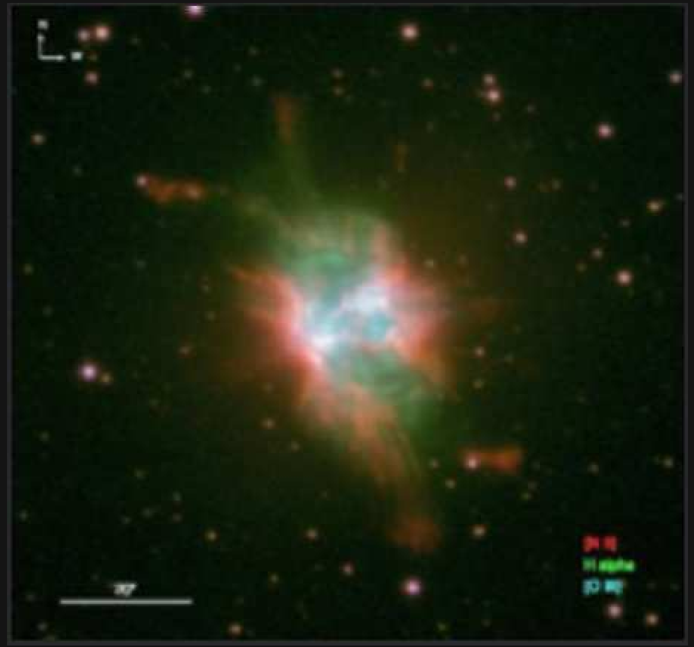
Necklace nebula

POST CE SYSTEM → ASYMMETRIC PLANETARY NEBULAE (APN)

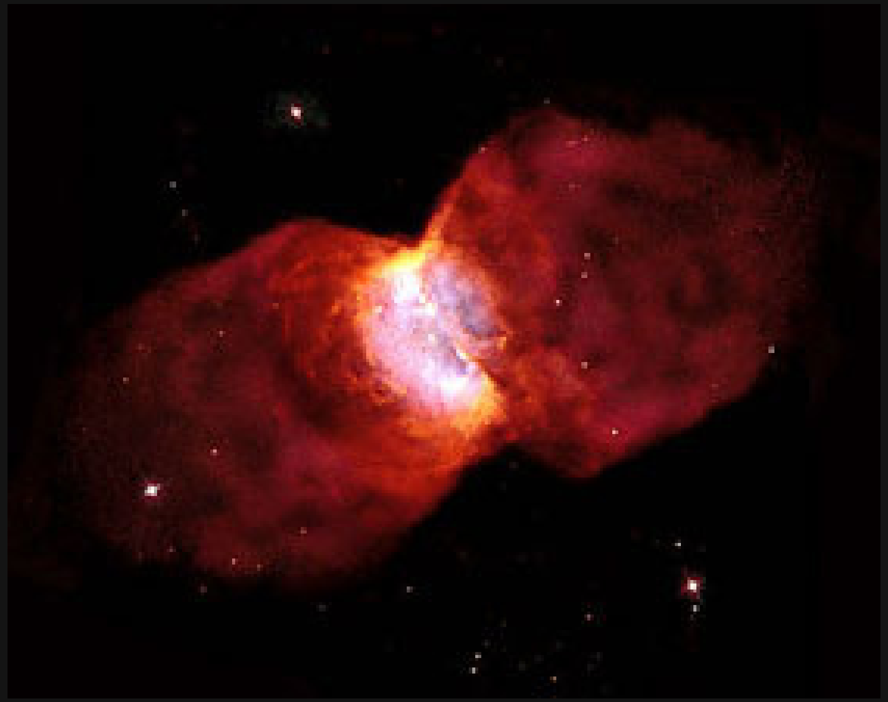


Ethos 1

Fleming 1



NGC 6778



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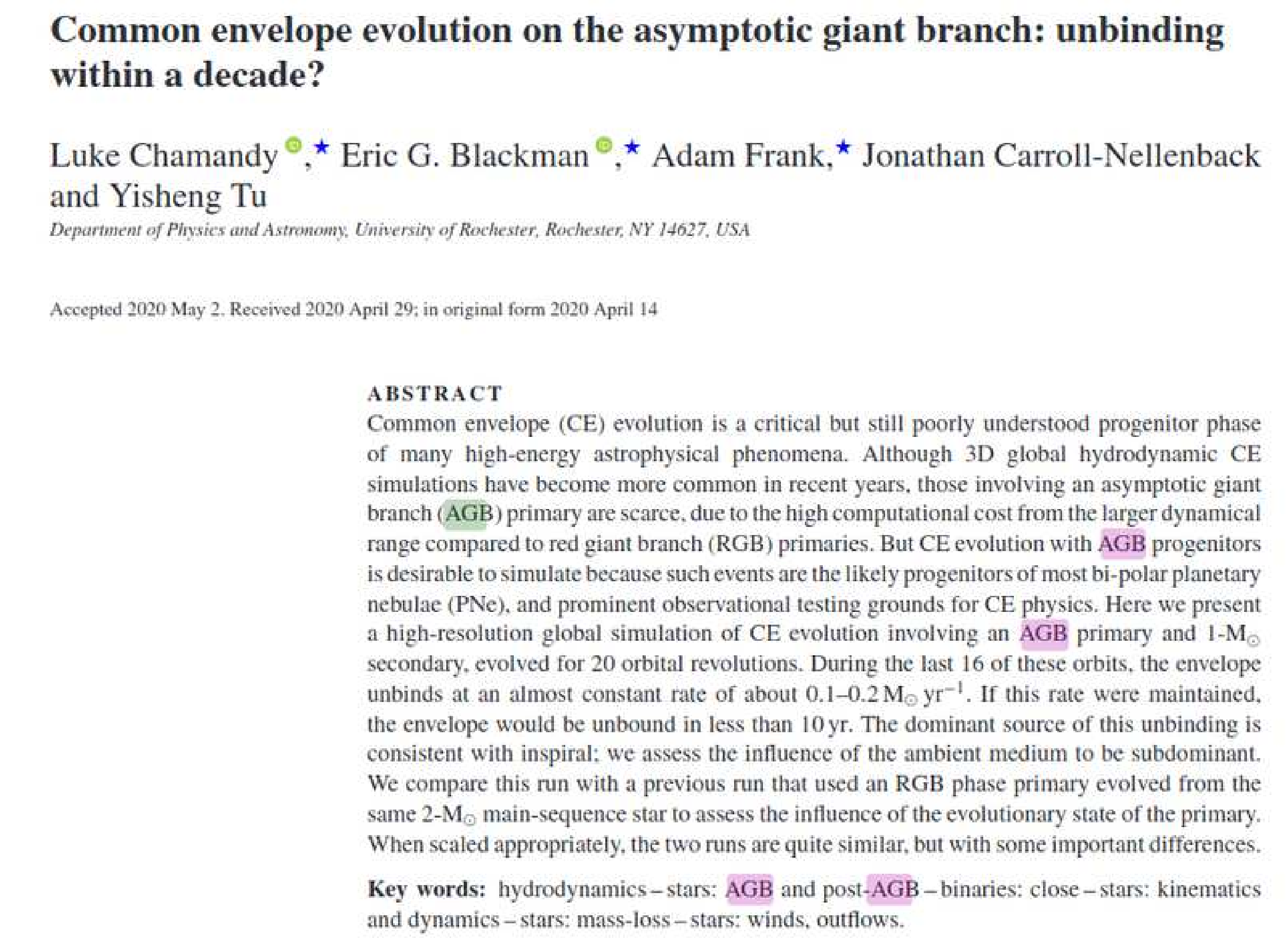


Common envelope evolution on the asymptotic giant branch: unbinding within a decade?

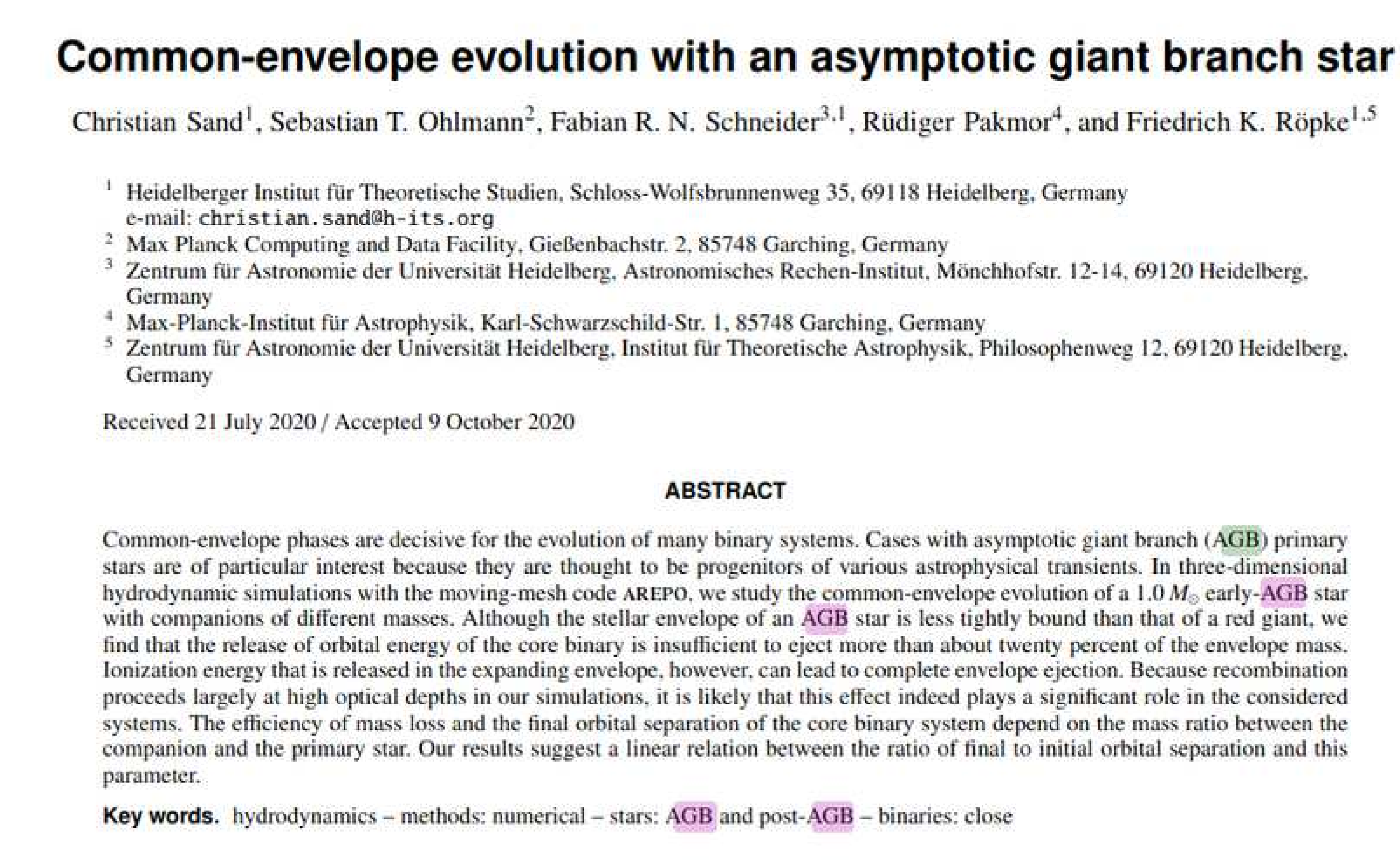
Luke Chamandy,★ Eric G. Blackman,★ Adam Frank,★ Jonathan Carroll-Nellenback and Yisheng Tu
Department of Physics and Astronomy, University of Rochester, Rochester, NY 14627, USA

Accepted 2020 May 2. Received 2020 April 29; in original form 2020 April 14

ABSTRACT

Common envelope (CE) evolution is a critical but still poorly understood progenitor phase of many high-energy astrophysical phenomena. Although 3D global hydrodynamic CE simulations have become more common in recent years, those involving an asymptotic giant branch (AGB) primary are scarce, due to the high computational cost from the larger dynamical range compared to red giant branch (RGB) primaries. But CE evolution with AGB progenitors is desirable to simulate because such events are the likely progenitors of most bi-polar planetary nebulae (PNe), and prominent observational testing grounds for CE physics. Here we present a high-resolution global simulation of CE evolution involving an AGB primary and 1-$M_\odot$ secondary, evolved for 20 orbital revolutions. During the last 16 of these orbits, the envelope unbinds at an almost constant rate of about 0.1–0.2 $M_\odot\,\mathrm{yr}^{-1}$. If this rate were maintained, the envelope would be unbound in less than 10 yr. The dominant source of this unbinding is consistent with inspiral; we assess the influence of the ambient medium to be subdominant. We compare this run with a previous run that used an RGB phase primary evolved from the same 2-$M_\odot$ main-sequence star to assess the influence of the evolutionary state of the primary. When scaled appropriately, the two runs are quite similar, but with some important differences.

Key words: hydrodynamics – stars: AGB and post-AGB – binaries: close – stars: kinematics and dynamics – stars: mass-loss – stars: winds, outflows.



Common-envelope evolution with an asymptotic giant branch star

Christian Sand[1], Sebastian T. Ohlmann[2], Fabian R. N. Schneider[3,1], Rüdiger Pakmor[4], and Friedrich K. Röpke[1,5]

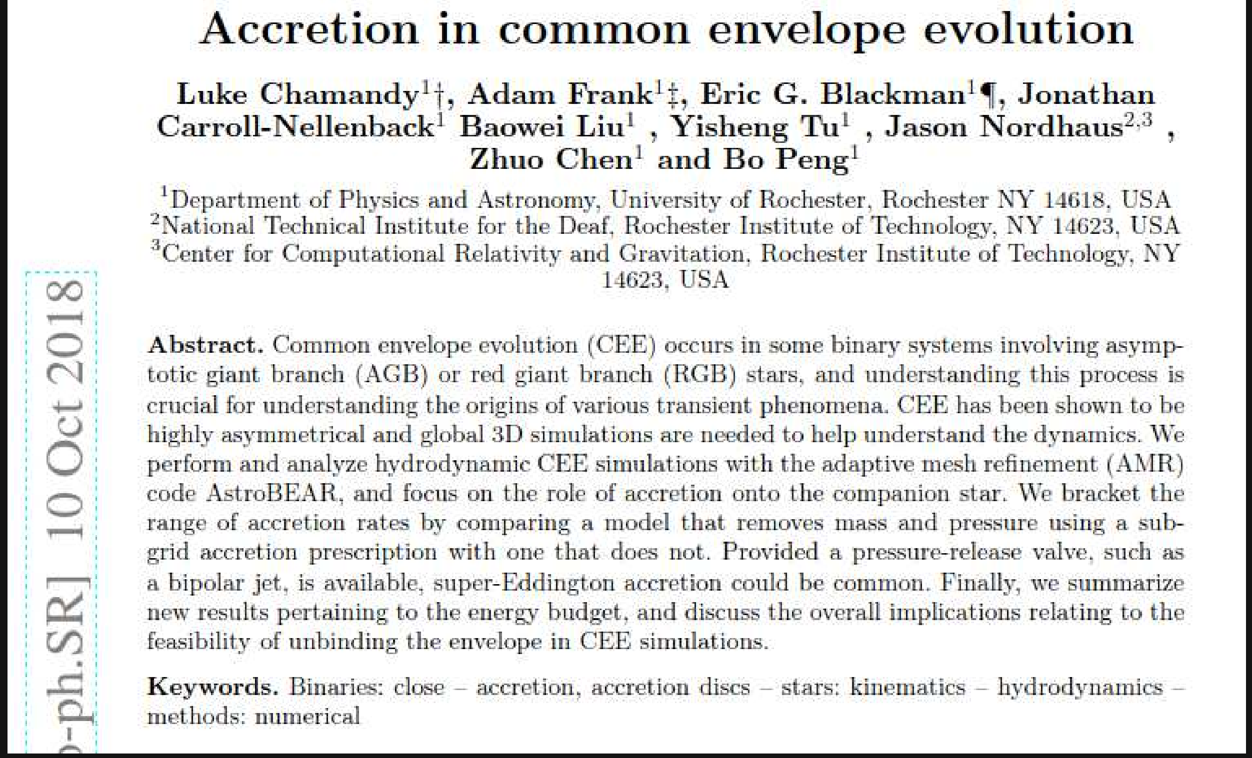
[1] Heidelberger Institut für Theoretische Studien, Schloss-Wolfsbrunnenweg 35, 69118 Heidelberg, Germany
e-mail: `christian.sand@h-its.org`
[2] Max Planck Computing and Data Facility, Gießenbachstr. 2, 85748 Garching, Germany
[3] Zentrum für Astronomie der Universität Heidelberg, Astronomisches Rechen-Institut, Mönchhofstr. 12-14, 69120 Heidelberg, Germany
[4] Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85748 Garching, Germany
[5] Zentrum für Astronomie der Universität Heidelberg, Institut für Theoretische Astrophysik, Philosophenweg 12, 69120 Heidelberg, Germany

Received 21 July 2020 / Accepted 9 October 2020

ABSTRACT

Common-envelope phases are decisive for the evolution of many binary systems. Cases with asymptotic giant branch (AGB) primary stars are of particular interest because they are thought to be progenitors of various astrophysical transients. In three-dimensional hydrodynamic simulations with the moving-mesh code AREPO, we study the common-envelope evolution of a 1.0 $M_\odot$ early-AGB star with companions of different masses. Although the stellar envelope of an AGB star is less tightly bound than that of a red giant, we find that the release of orbital energy of the core binary is insufficient to eject more than about twenty percent of the envelope mass. Ionization energy that is released in the expanding envelope, however, can lead to complete envelope ejection. Because recombination proceeds largely at high optical depths in our simulations, it is likely that this effect indeed plays a significant role in the considered systems. The efficiency of mass loss and the final orbital separation of the core binary system depend on the mass ratio between the companion and the primary star. Our results suggest a linear relation between the ratio of final to initial orbital separation and this parameter.

Key words. hydrodynamics – methods: numerical – stars: AGB and post-AGB – binaries: close



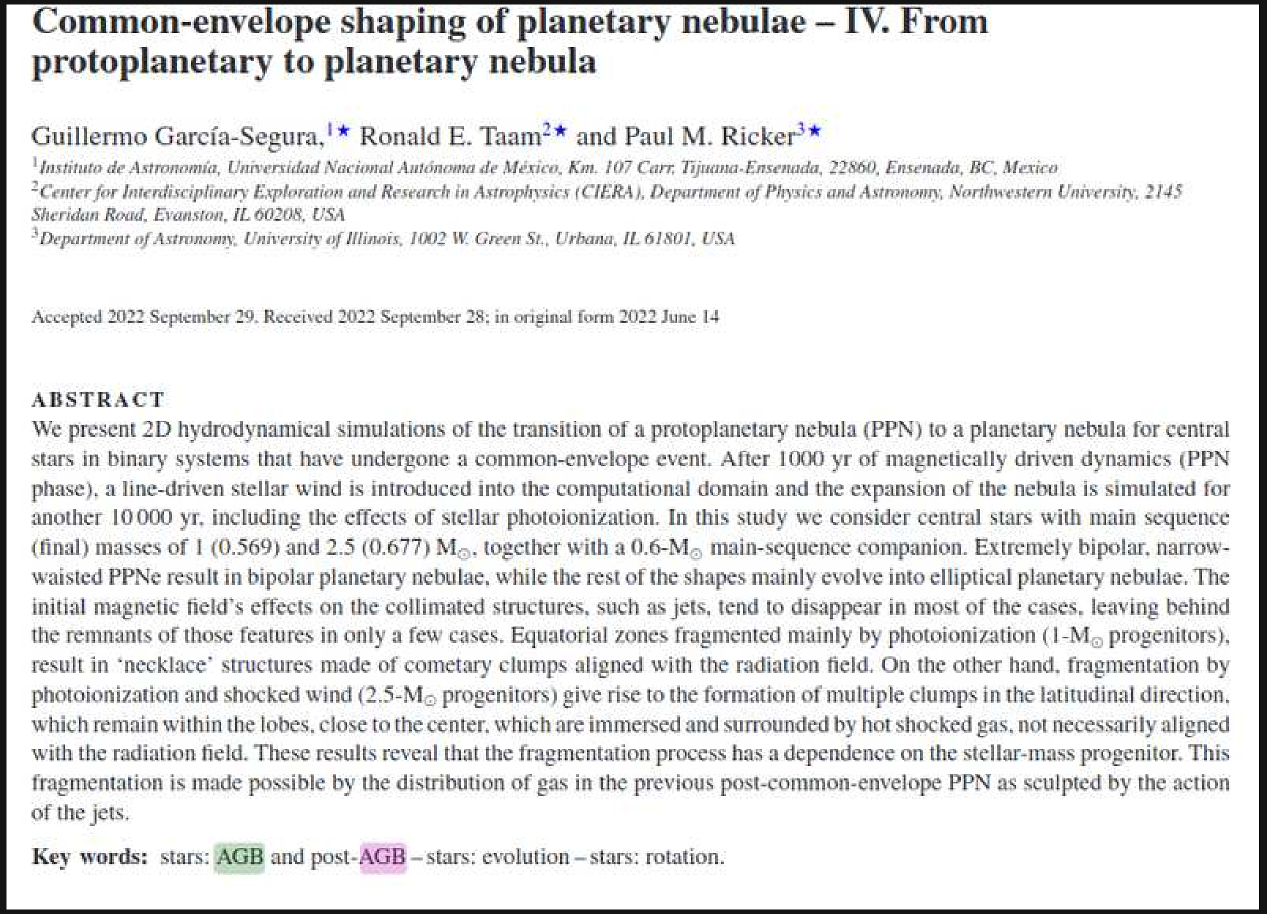
Accretion in common envelope evolution

Luke Chamandy[1]†, Adam Frank[1]‡, Eric G. Blackman[1]¶, Jonathan Carroll-Nellenback[1] Baowei Liu[1] , Yisheng Tu[1] , Jason Nordhaus[2,3] , Zhuo Chen[1] and Bo Peng[1]

[1]Department of Physics and Astronomy, University of Rochester, Rochester NY 14618, USA
[2]National Technical Institute for the Deaf, Rochester Institute of Technology, NY 14623, USA
[3]Center for Computational Relativity and Gravitation, Rochester Institute of Technology, NY 14623, USA

Abstract. Common envelope evolution (CEE) occurs in some binary systems involving asymptotic giant branch (AGB) or red giant branch (RGB) stars, and understanding this process is crucial for understanding the origins of various transient phenomena. CEE has been shown to be highly asymmetrical and global 3D simulations are needed to help understand the dynamics. We perform and analyze hydrodynamic CEE simulations with the adaptive mesh refinement (AMR) code AstroBEAR, and focus on the role of accretion onto the companion star. We bracket the range of accretion rates by comparing a model that removes mass and pressure using a subgrid accretion prescription with one that does not. Provided a pressure-release valve, such as a bipolar jet, is available, super-Eddington accretion could be common. Finally, we summarize new results pertaining to the energy budget, and discuss the overall implications relating to the feasibility of unbinding the envelope in CEE simulations.

Keywords. Binaries: close – accretion, accretion discs – stars: kinematics – hydrodynamics – methods: numerical



Common-envelope shaping of planetary nebulae – IV. From protoplanetary to planetary nebula

Guillermo García-Segura,[1]★ Ronald E. Taam[2]★ and Paul M. Ricker[3]★
[1]*Instituto de Astronomía, Universidad Nacional Autónoma de México, Km. 107 Carr. Tijuana-Ensenada, 22860, Ensenada, BC, Mexico*
[2]*Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA), Department of Physics and Astronomy, Northwestern University, 2145 Sheridan Road, Evanston, IL 60208, USA*
[3]*Department of Astronomy, University of Illinois, 1002 W. Green St., Urbana, IL 61801, USA*

Accepted 2022 September 29. Received 2022 September 28; in original form 2022 June 14

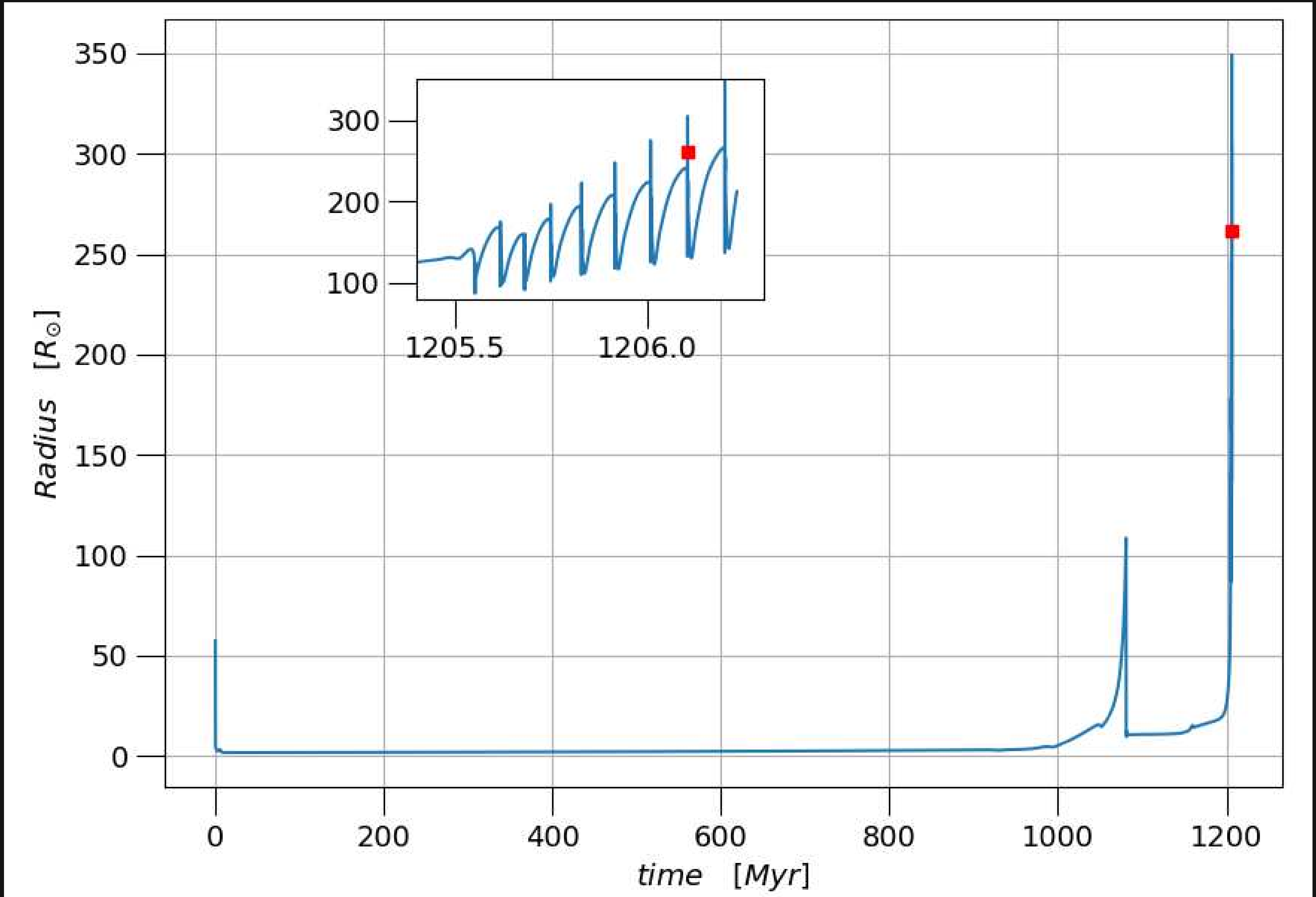
ABSTRACT

We present 2D hydrodynamical simulations of the transition of a protoplanetary nebula (PPN) to a planetary nebula for central stars in binary systems that have undergone a common-envelope event. After 1000 yr of magnetically driven dynamics (PPN phase), a line-driven stellar wind is introduced into the computational domain and the expansion of the nebula is simulated for another 10 000 yr, including the effects of stellar photoionization. In this study we consider central stars with main sequence (final) masses of 1 (0.569) and 2.5 (0.677) $M_\odot$, together with a 0.6-$M_\odot$ main-sequence companion. Extremely bipolar, narrow-waisted PPNe result in bipolar planetary nebulae, while the rest of the shapes mainly evolve into elliptical planetary nebulae. The initial magnetic field's effects on the collimated structures, such as jets, tend to disappear in most of the cases, leaving behind the remnants of those features in only a few cases. Equatorial zones fragmented mainly by photoionization (1-$M_\odot$ progenitors), result in 'necklace' structures made of cometary clumps aligned with the radiation field. On the other hand, fragmentation by photoionization and shocked wind (2.5-$M_\odot$ progenitors) give rise to the formation of multiple clumps in the latitudinal direction, which remain within the lobes, close to the center, which are immersed and surrounded by hot shocked gas, not necessarily aligned with the radiation field. These results reveal that the fragmentation process has a dependence on the stellar-mass progenitor. This fragmentation is made possible by the distribution of gas in the previous post-common-envelope PPN as sculpted by the action of the jets.

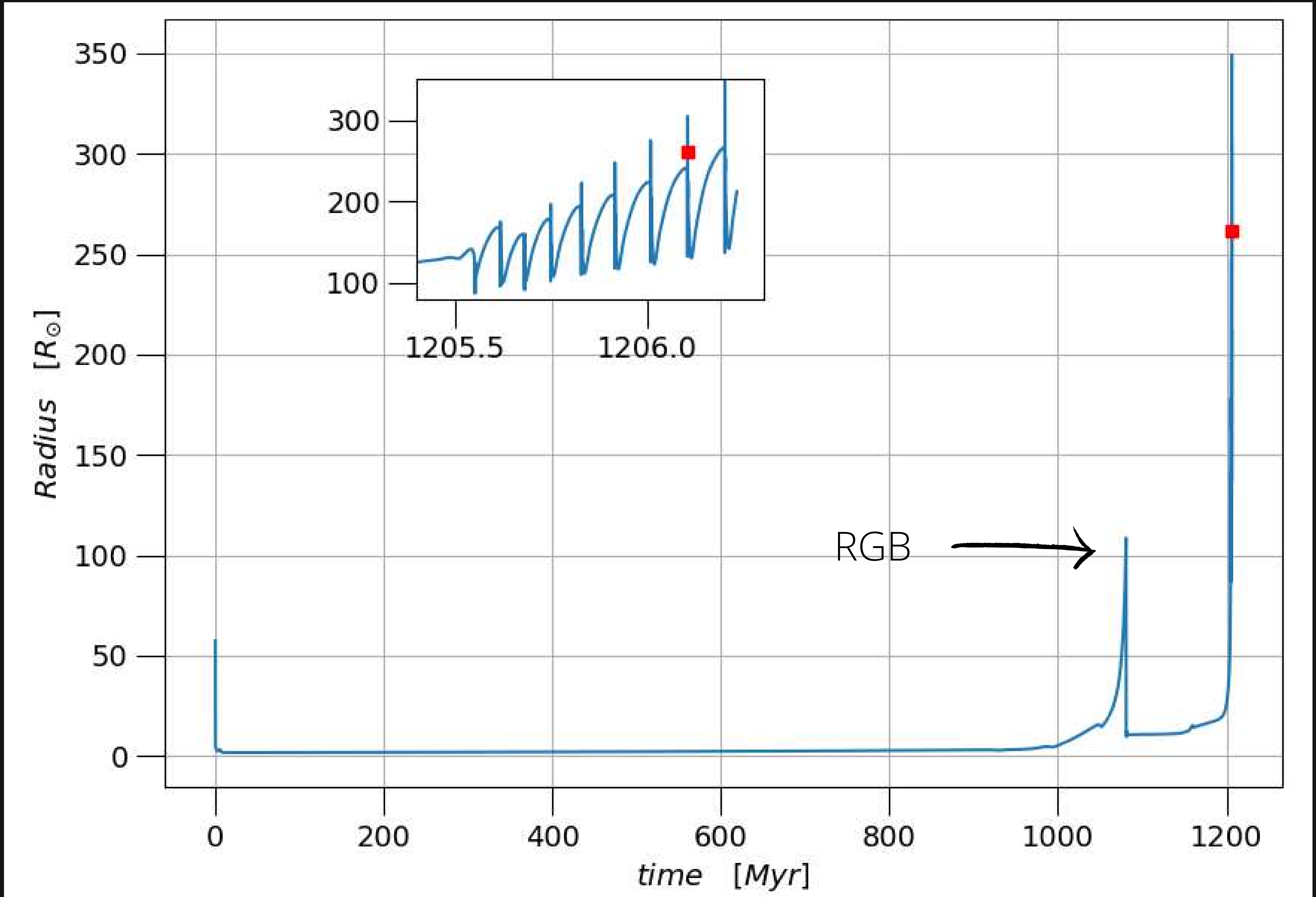
Key words: stars: AGB and post-AGB – stars: evolution – stars: rotation.

More and more CE simulations with AGB donor stars

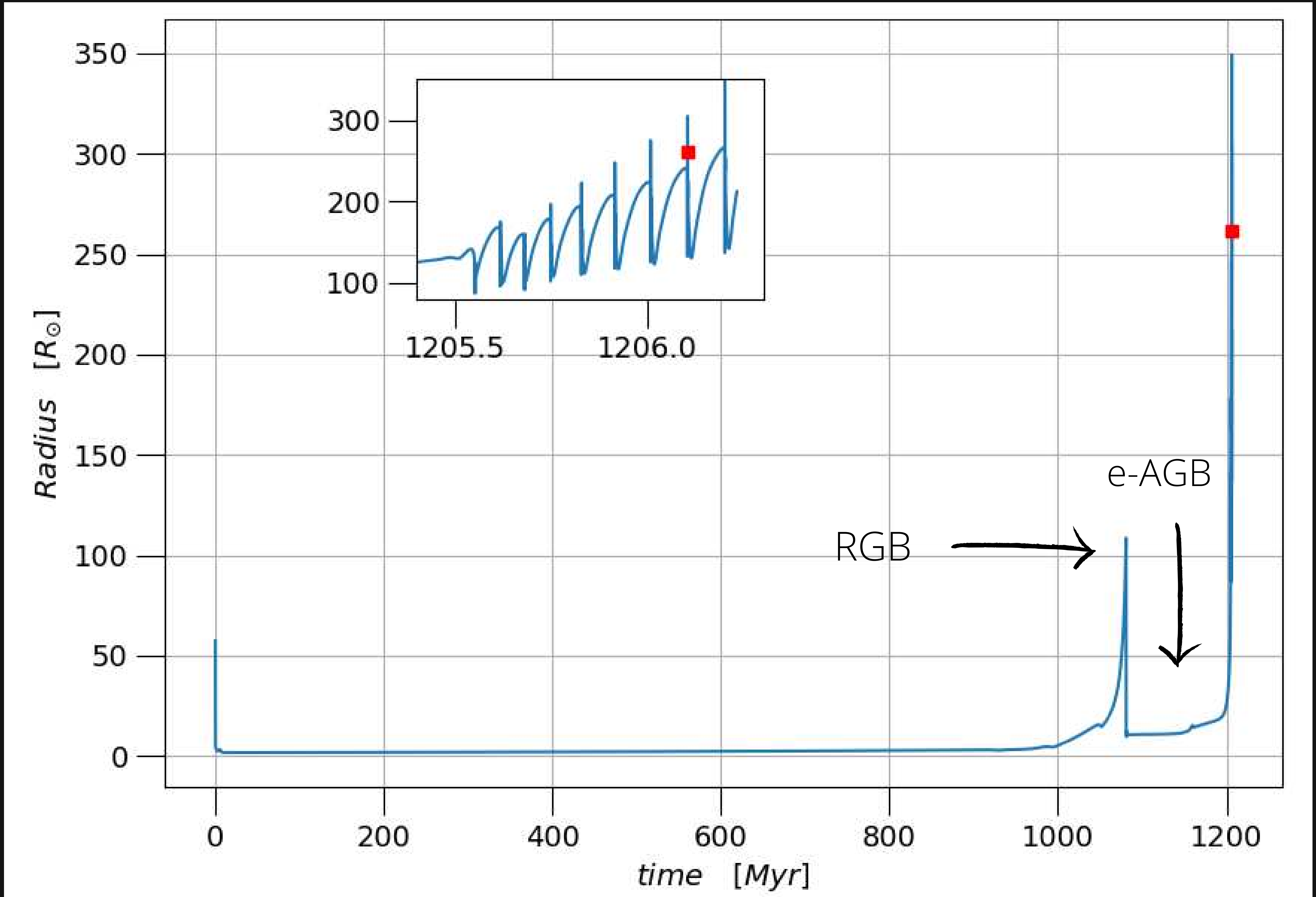
RGB vs AGB as donor star in CE



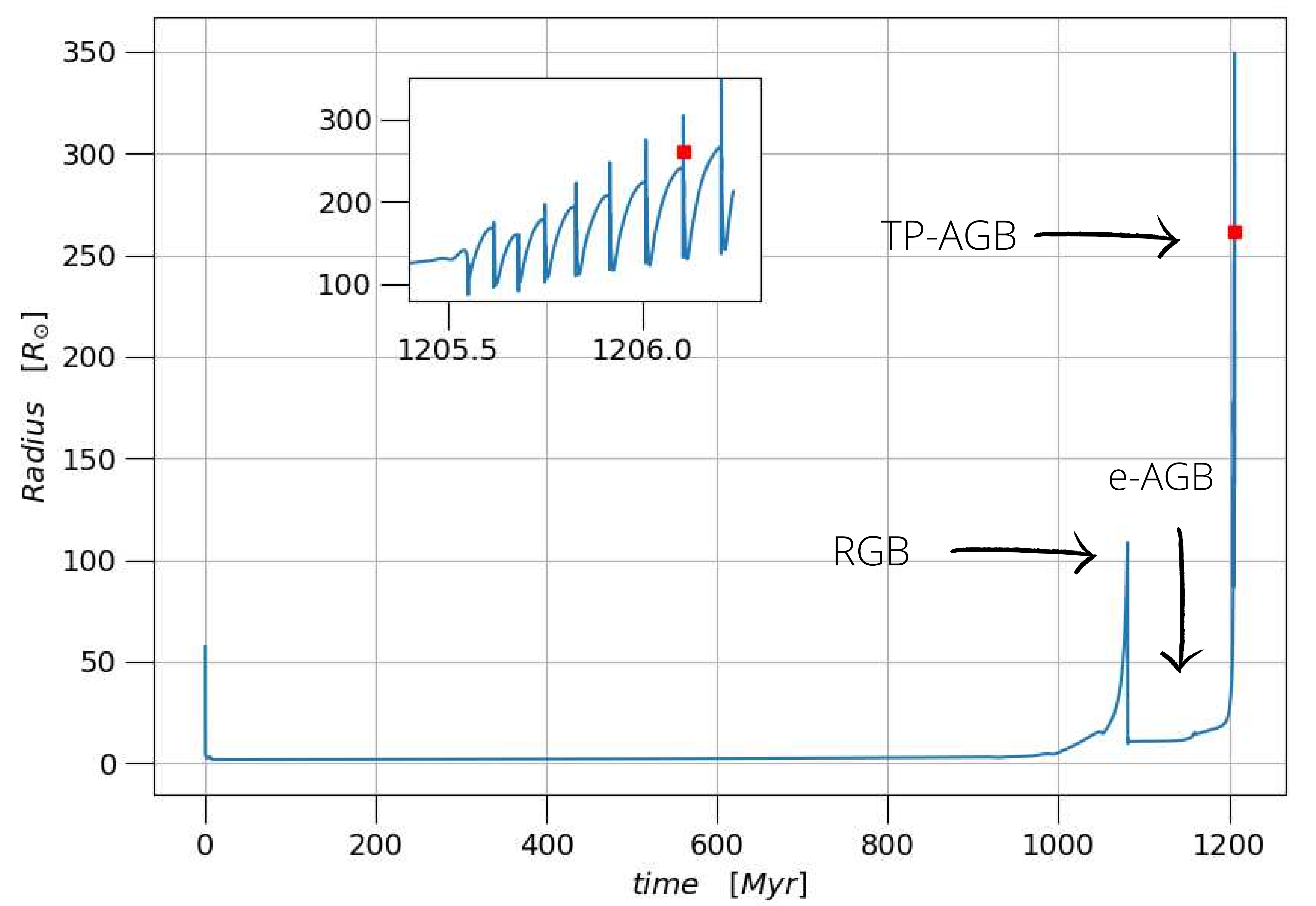
RGB vs AGB as donor star in CE



RGB vs AGB as donor star in CE



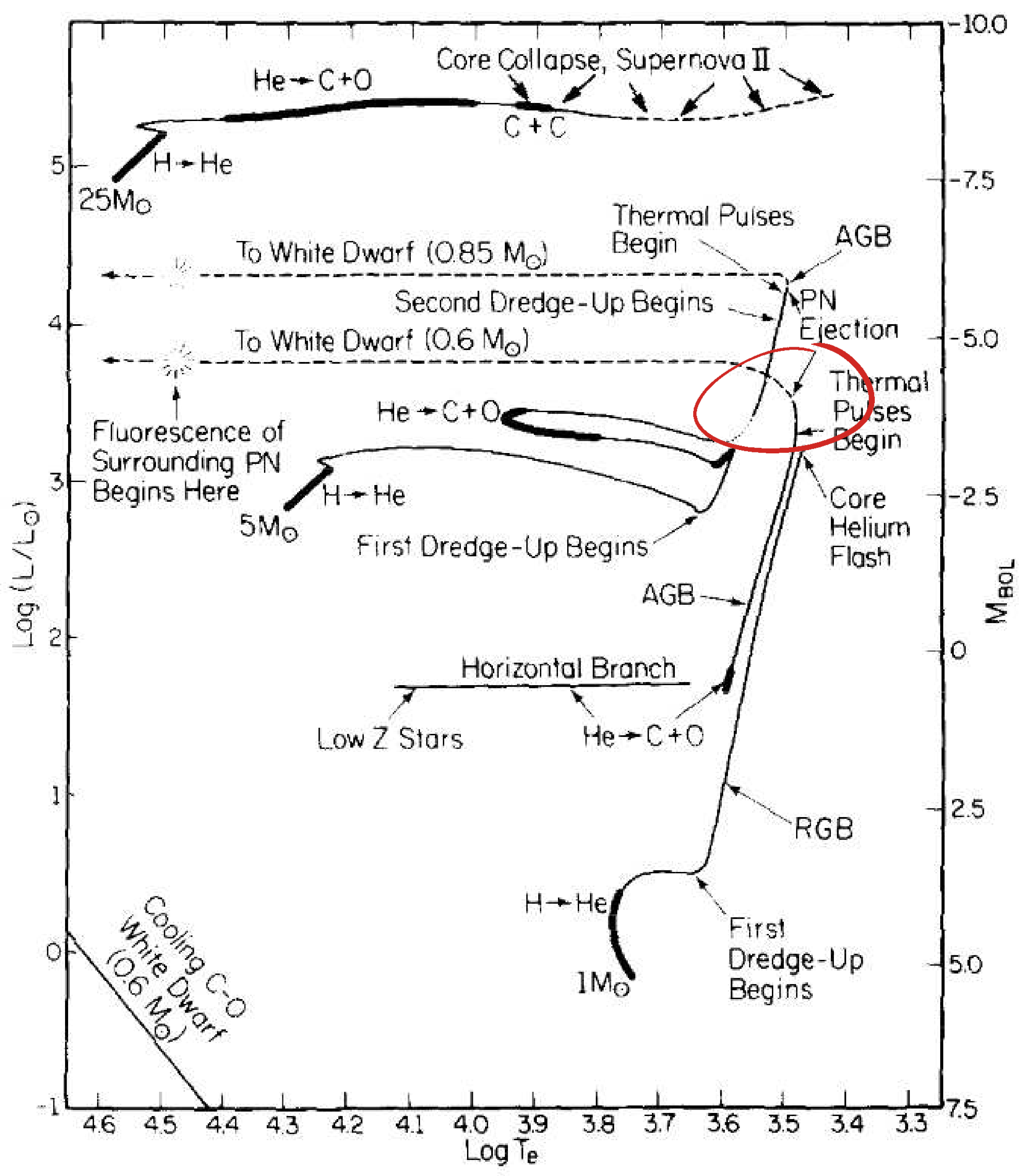
RGB vs AGB as donor star in CE



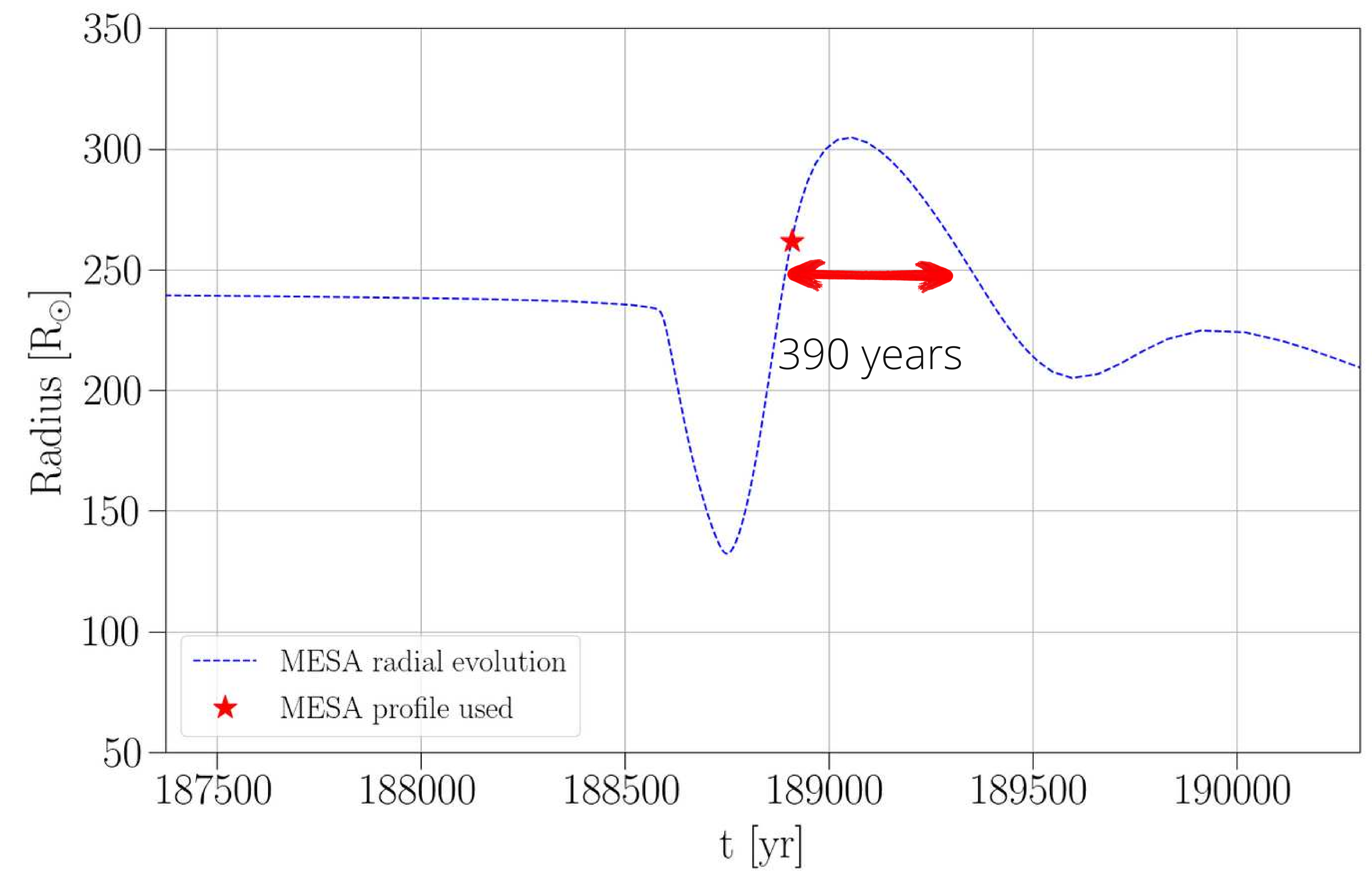
Quick recap: thermally pulsating AGB star

Helium burning shells expand the star periodically

Low mass star (~2-4Msun) have the largest size during this phase

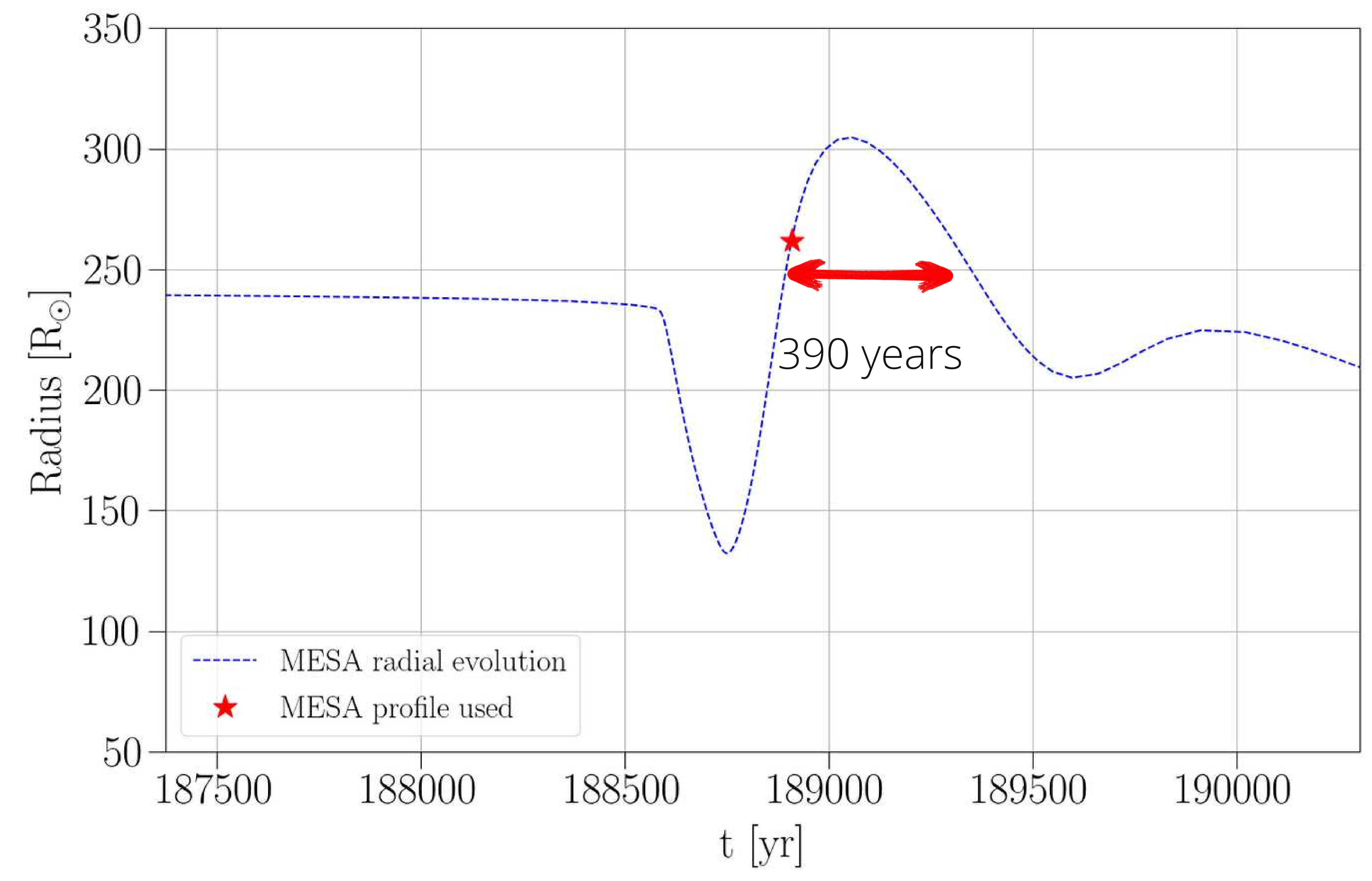


Thermally pulsating AGB star



Does CCE occurs during one of these pulses?

Thermally pulsating AGB star



Does CCE occurs during one of these pulses?

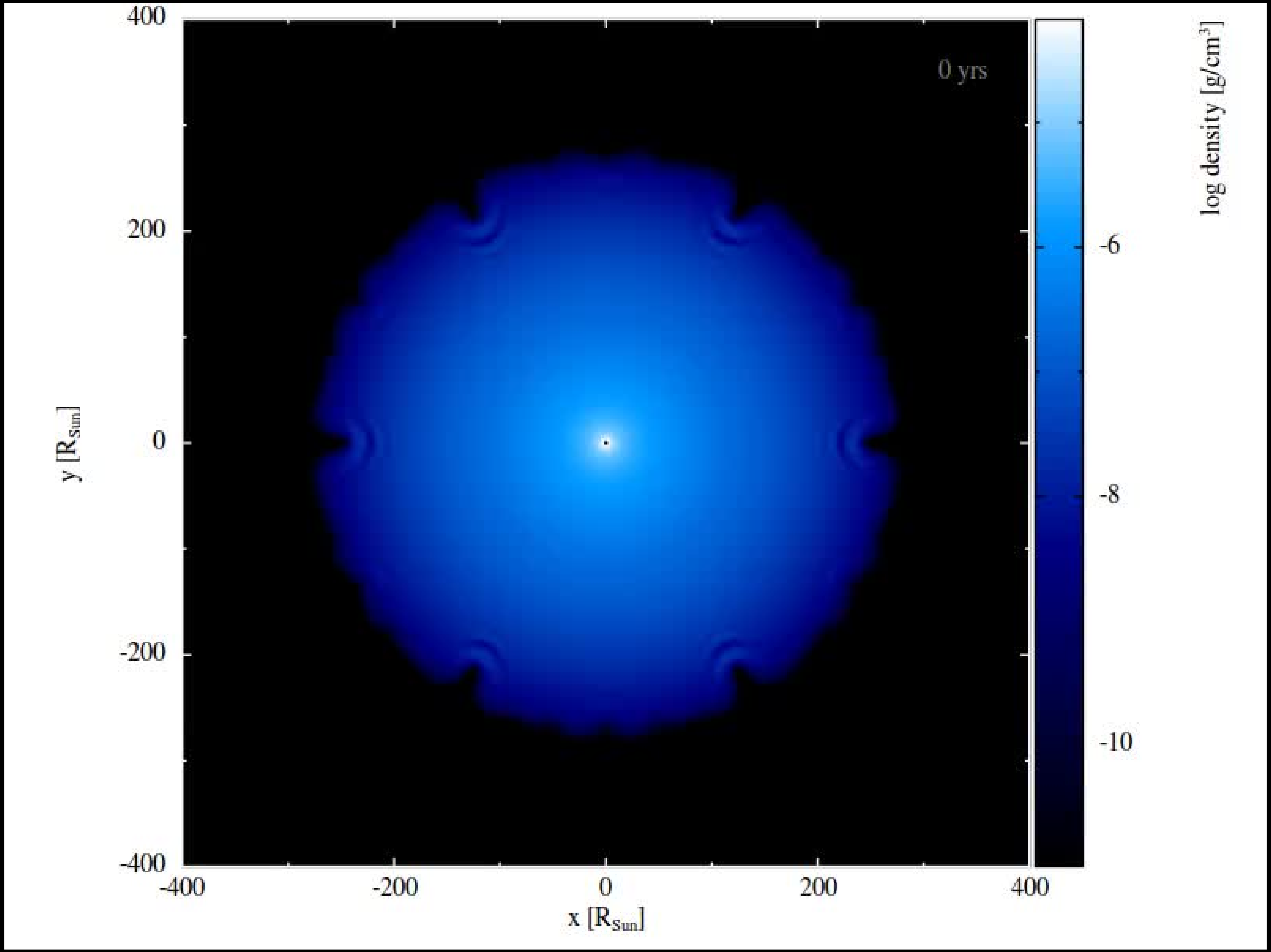
Spoiler alert: it does in simulations

MESA

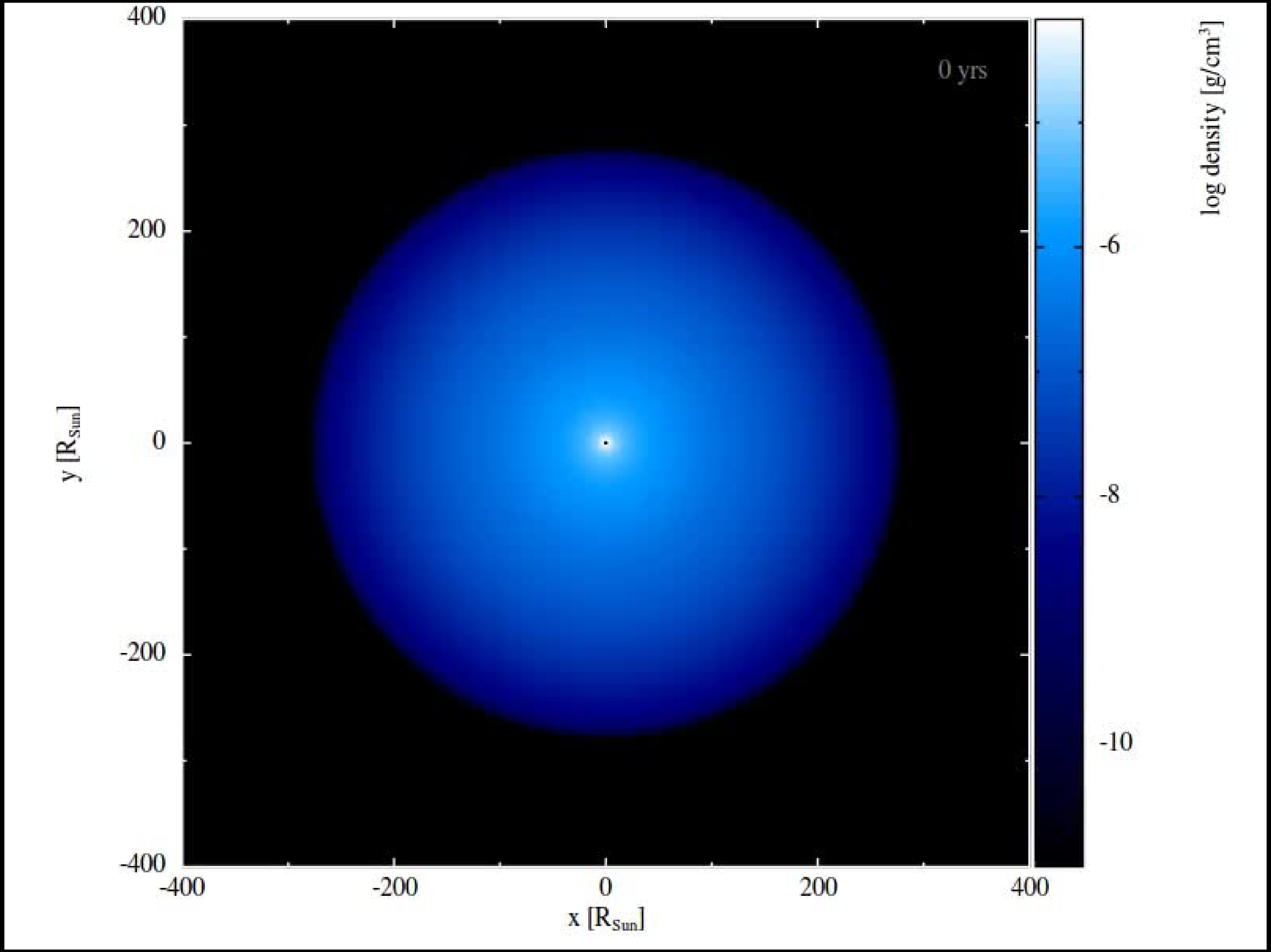
PHANTOM

We evolve a star using the MESA code and then carried out a set of simulations using the 3D hydro code Phantom with the 2Msun star + 0.6 Msun companion

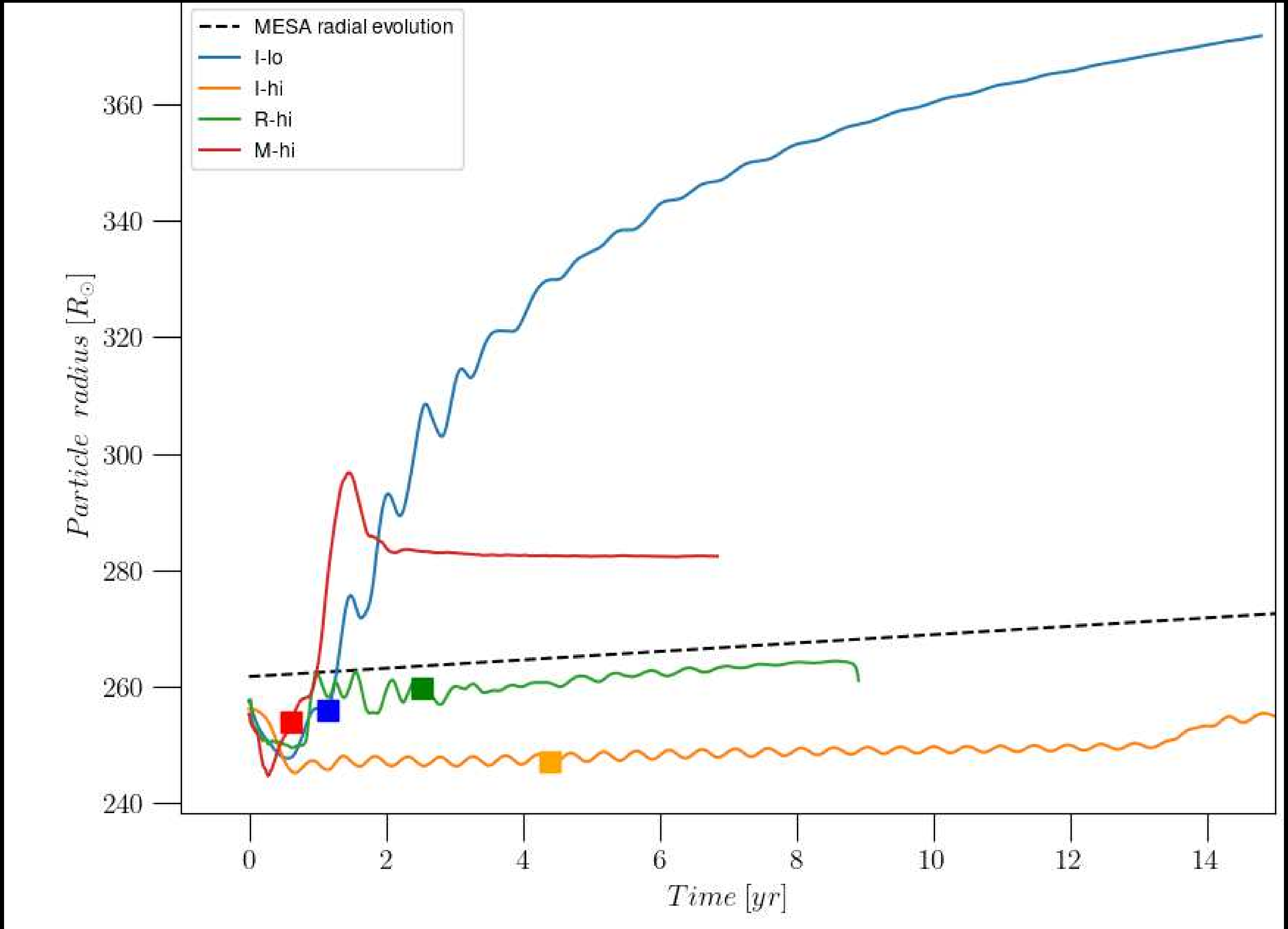
l-hi star (old relax technique)

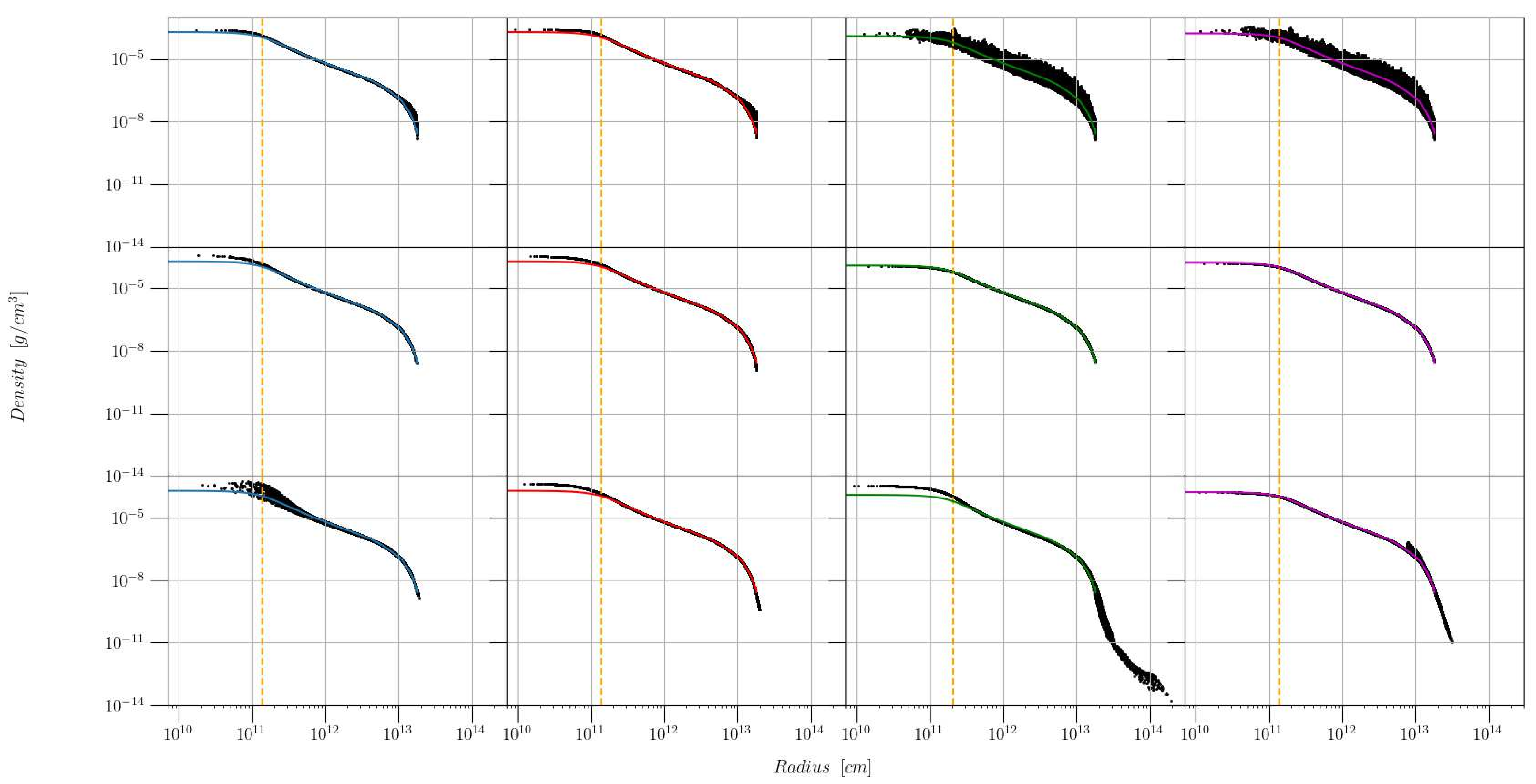


M-hi star (relax-o-matic)



Some models expand at a slower or faster rate than the original MESA generated profile



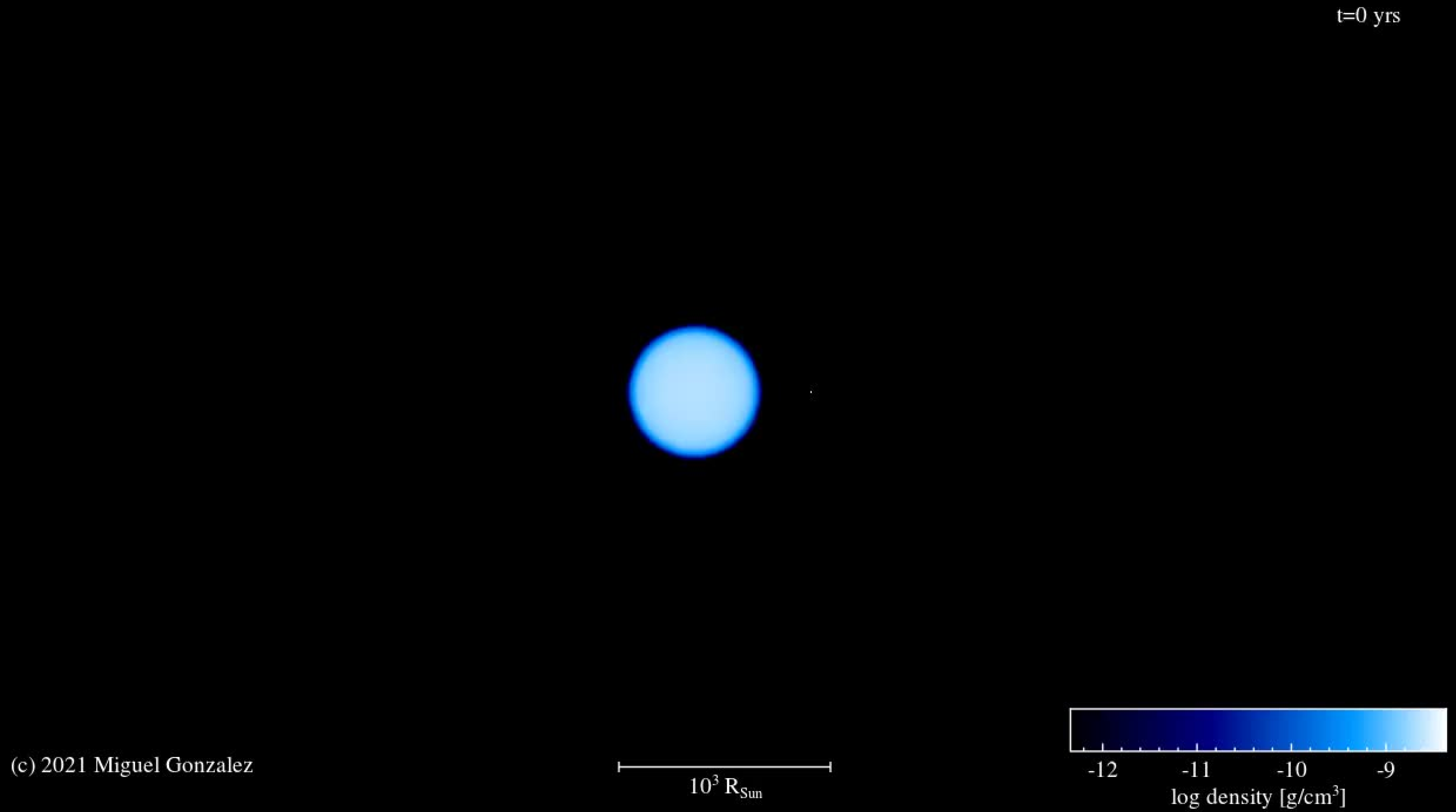


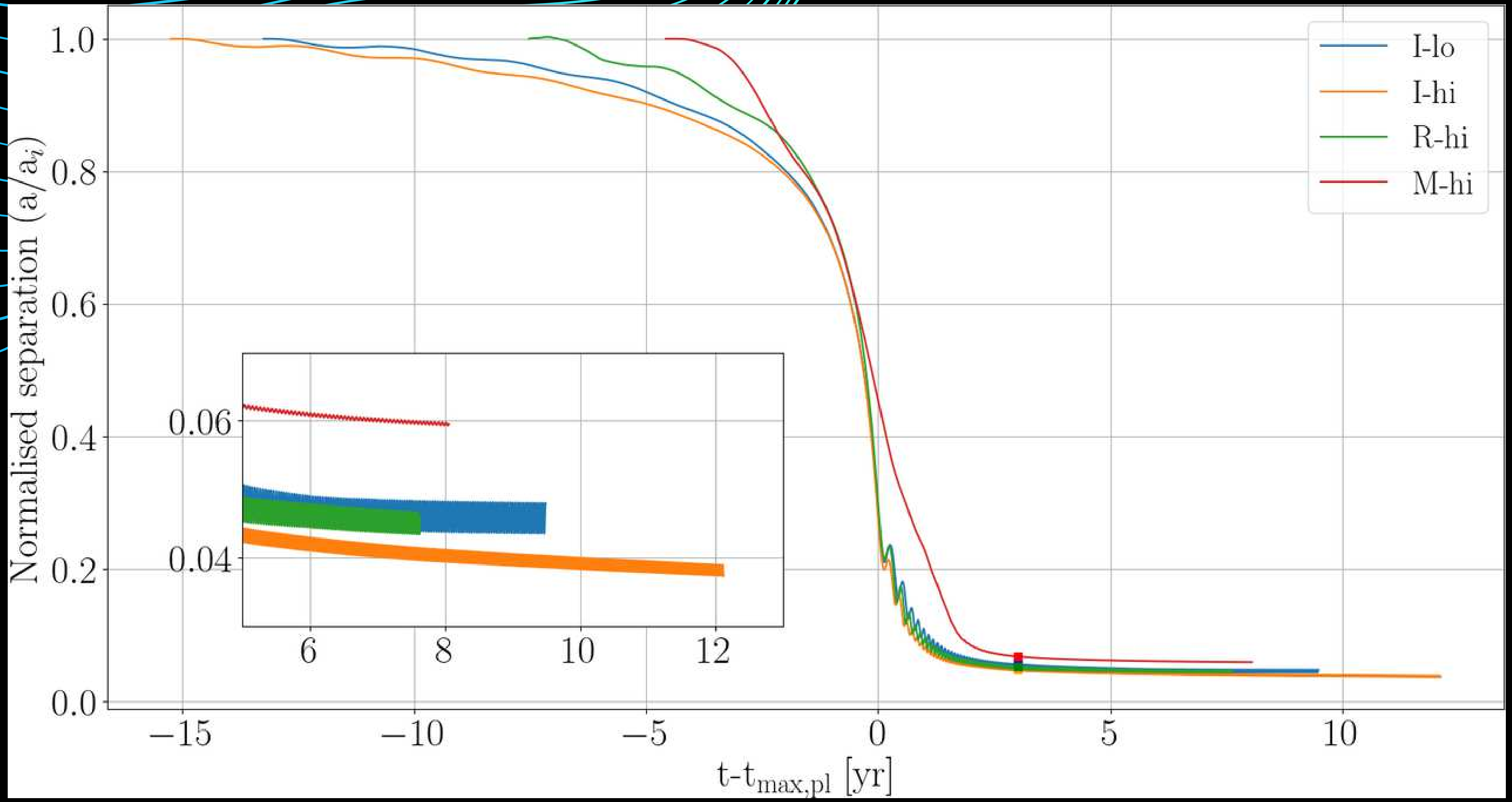
After mapping

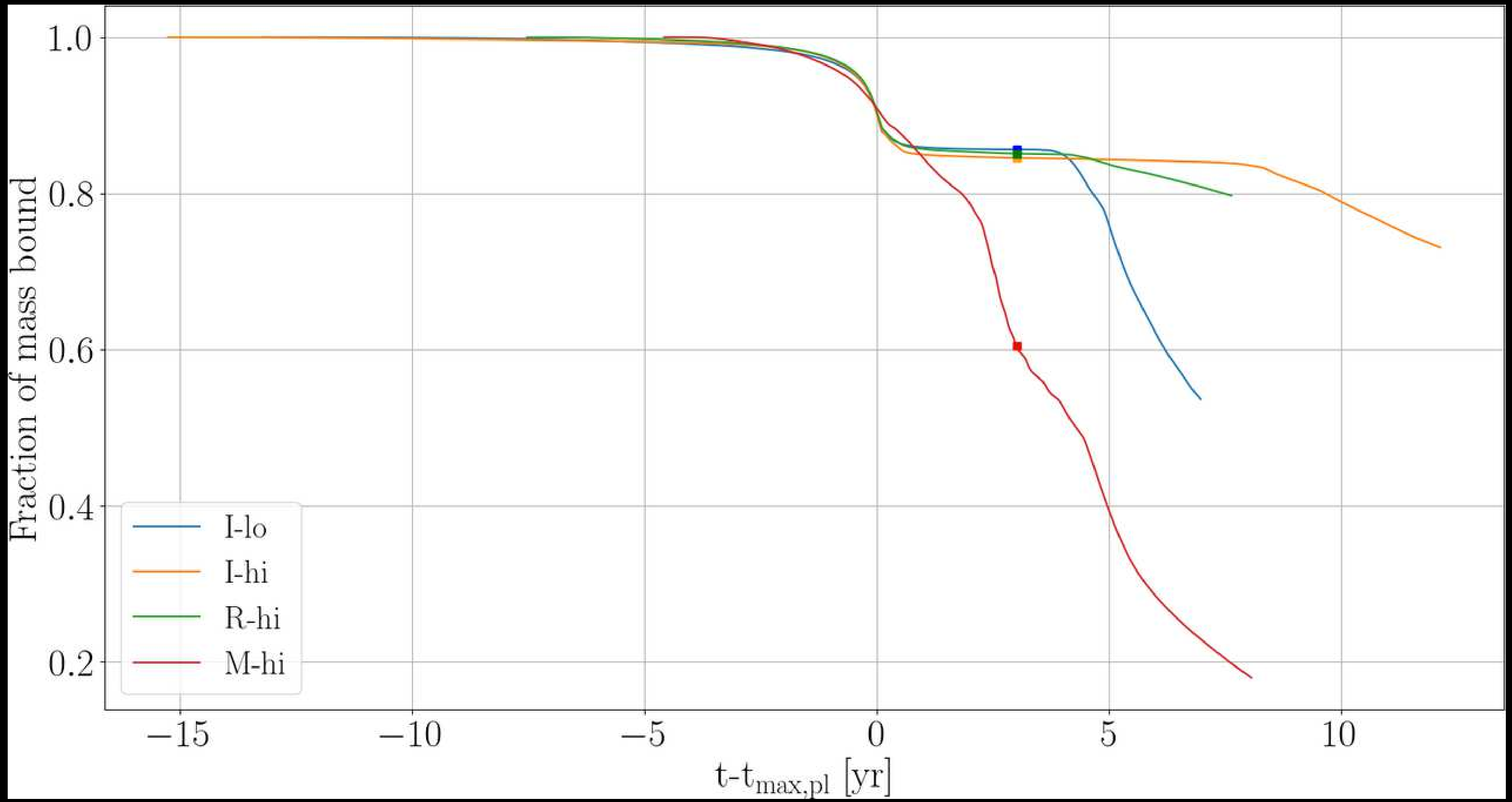
After relaxation

Implemented in
binary

Yeah, yeah right, just put the movie already! (I-hi)

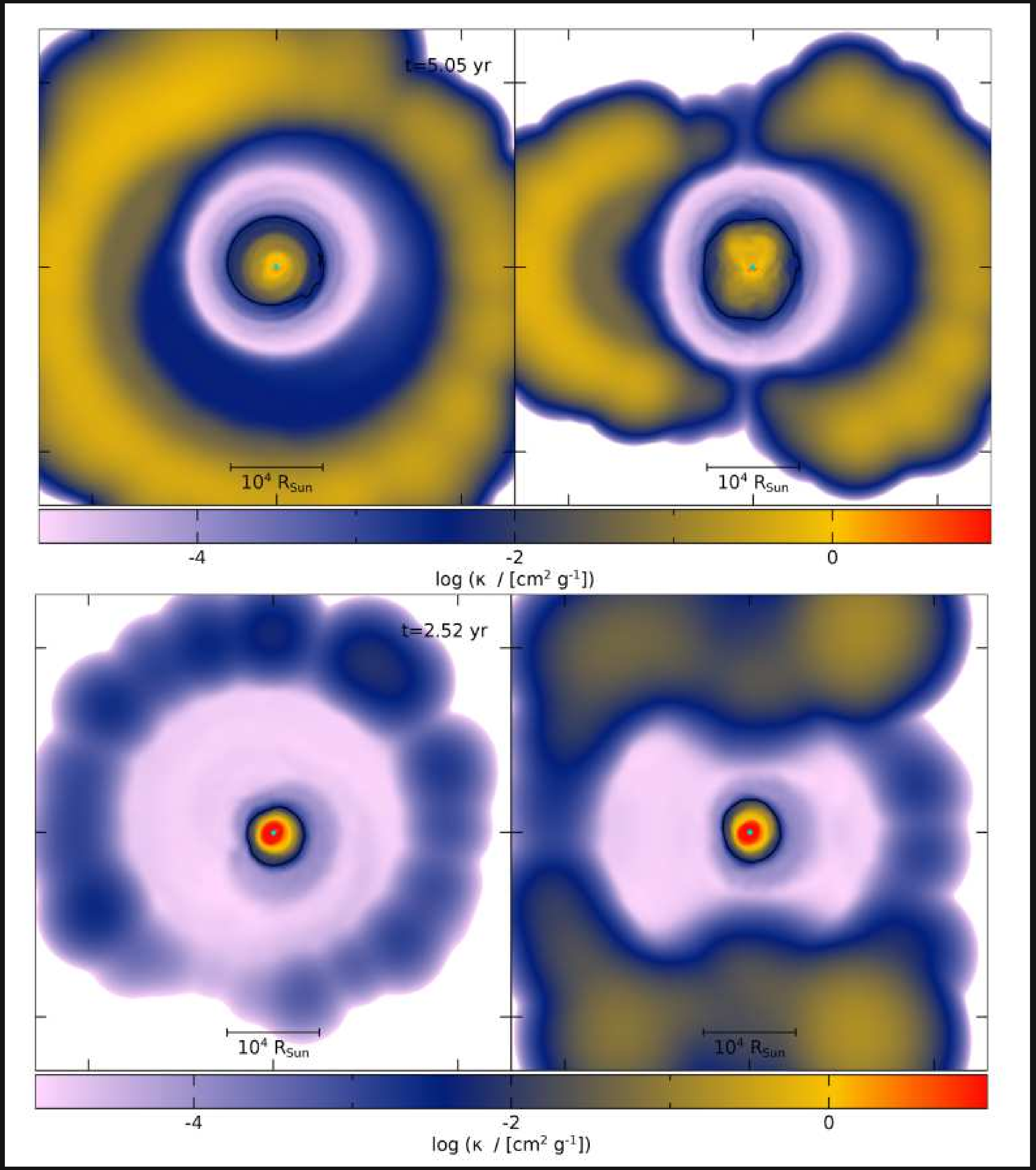




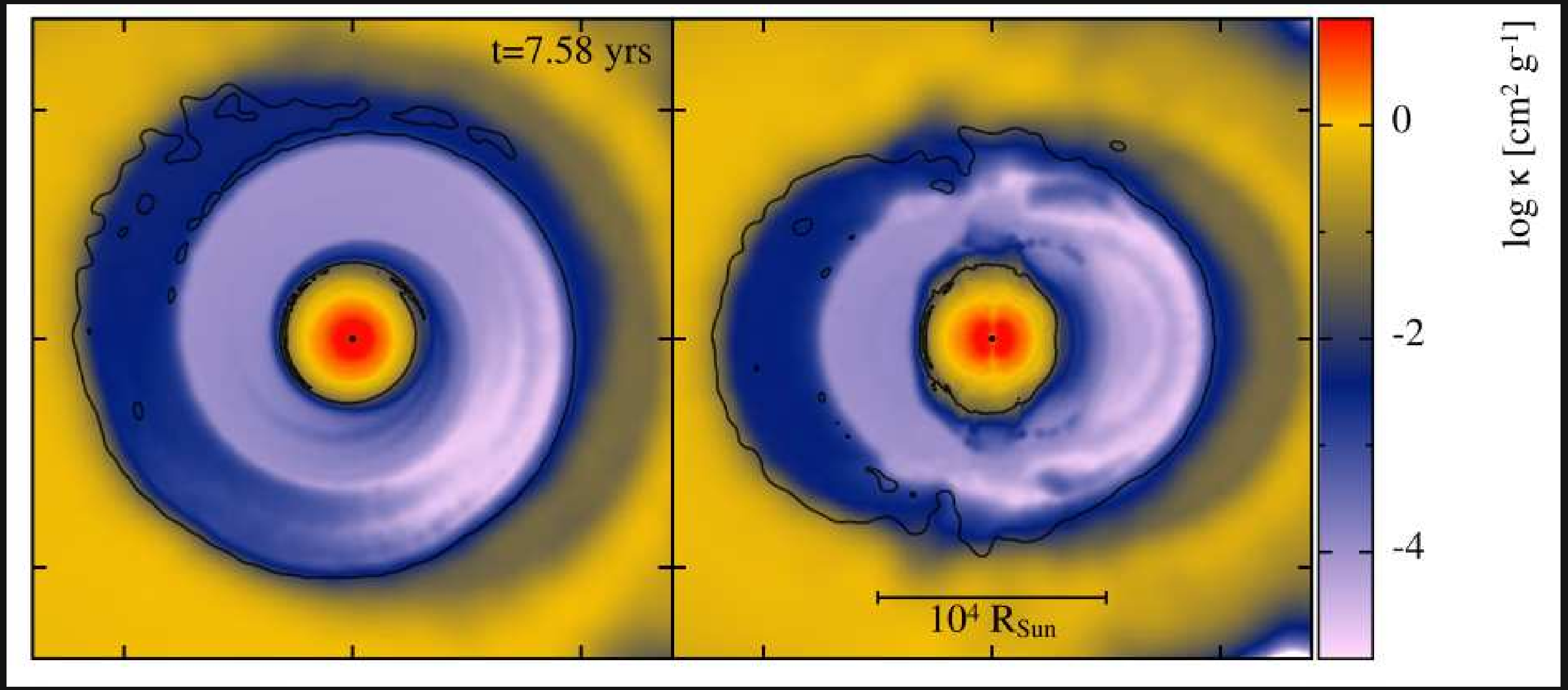


- Higher resolutions decreases final separation, contrary to CE with RGB's (Reichardt+ 2019)
- Any additional energy source (recombination, radiation pressure) increases final separation
- Recombination energy unbinds almost (all?) envelope

RGB post-CE system (Reichardt+ 2020)



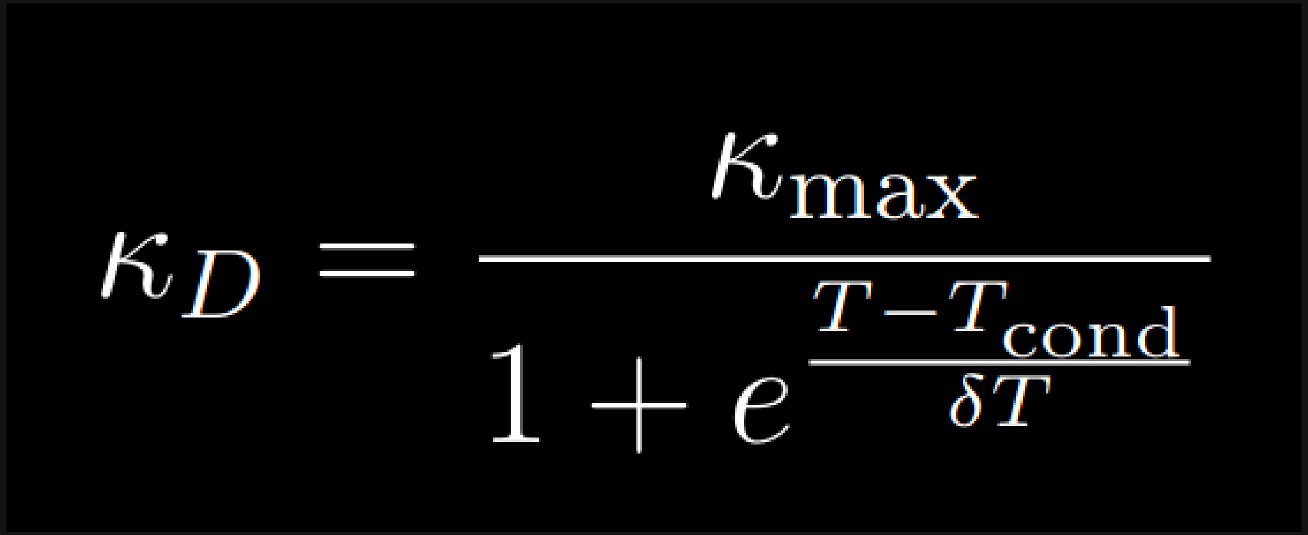
CE with AGB



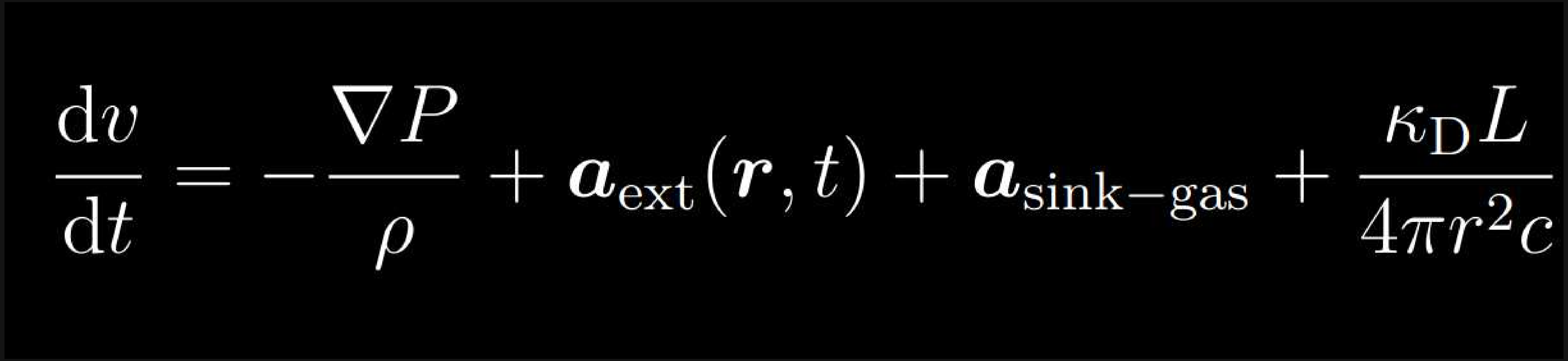
MESA opacity tables don't extrapolate to well in the outer (yellow) layers

Next step....dust

We implemented the Bowen prescription
(Bowen, 1988)
for dust-driven winds (DDW) in these CE's



$$\kappa_D = \frac{\kappa_{\max}}{1 + e^{\frac{T - T_{\mathrm{cond}}}{\delta T}}}$$



$$\frac{\mathrm{d}v}{\mathrm{d}t} = -\frac{\nabla P}{\rho} + \boldsymbol{a}_{\mathrm{ext}}(\boldsymbol{r}, t) + \boldsymbol{a}_{\mathrm{sink-gas}} + \frac{\kappa_{\mathrm{D}} L}{4\pi r^2 c}$$

Next step....dust

We implemented the Bowen prescription
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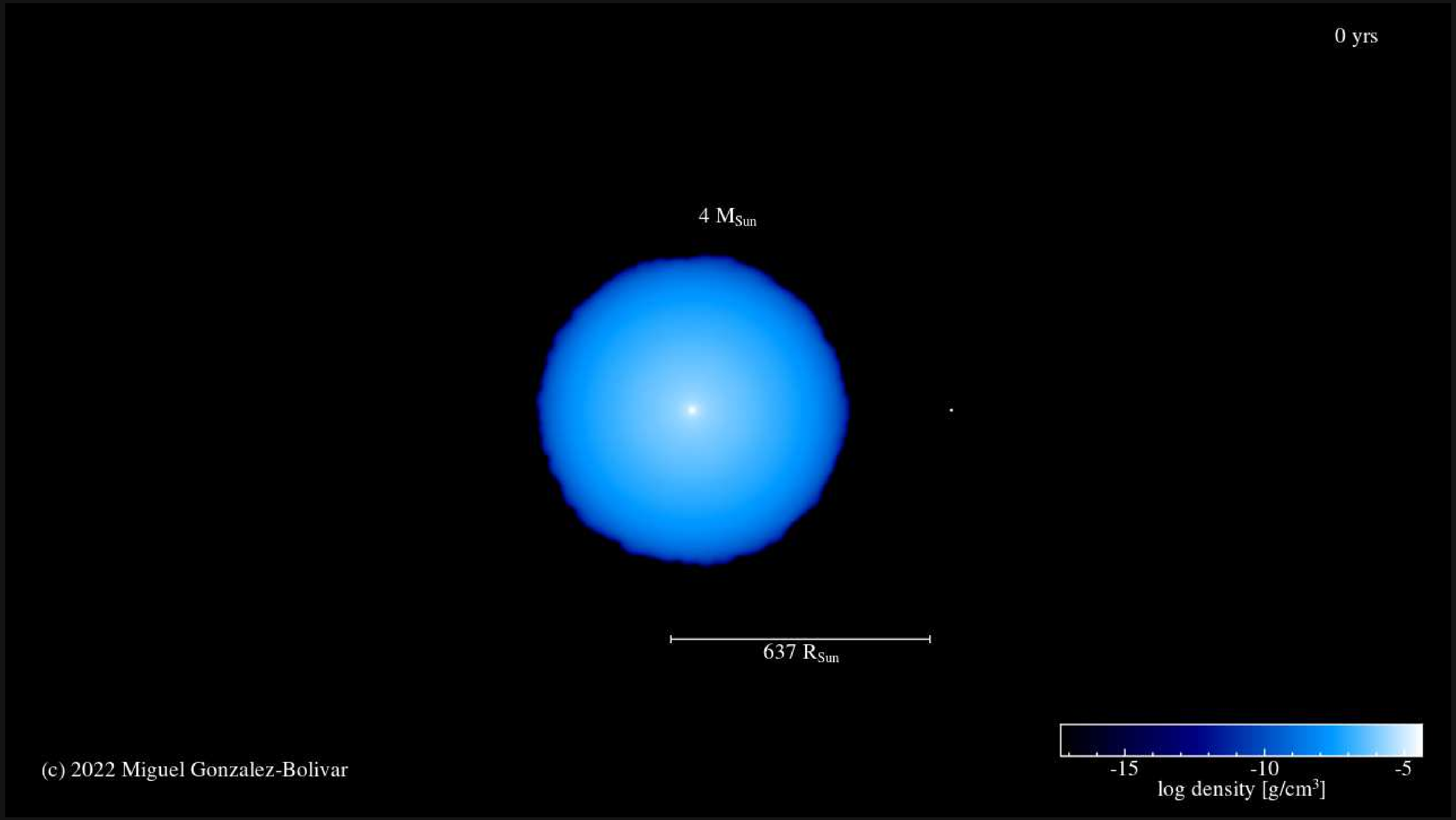
$$\kappa_D = \frac{\kappa_{\max}}{1 + e^{\frac{T - T_{\rm cond}}{\delta T}}}$$

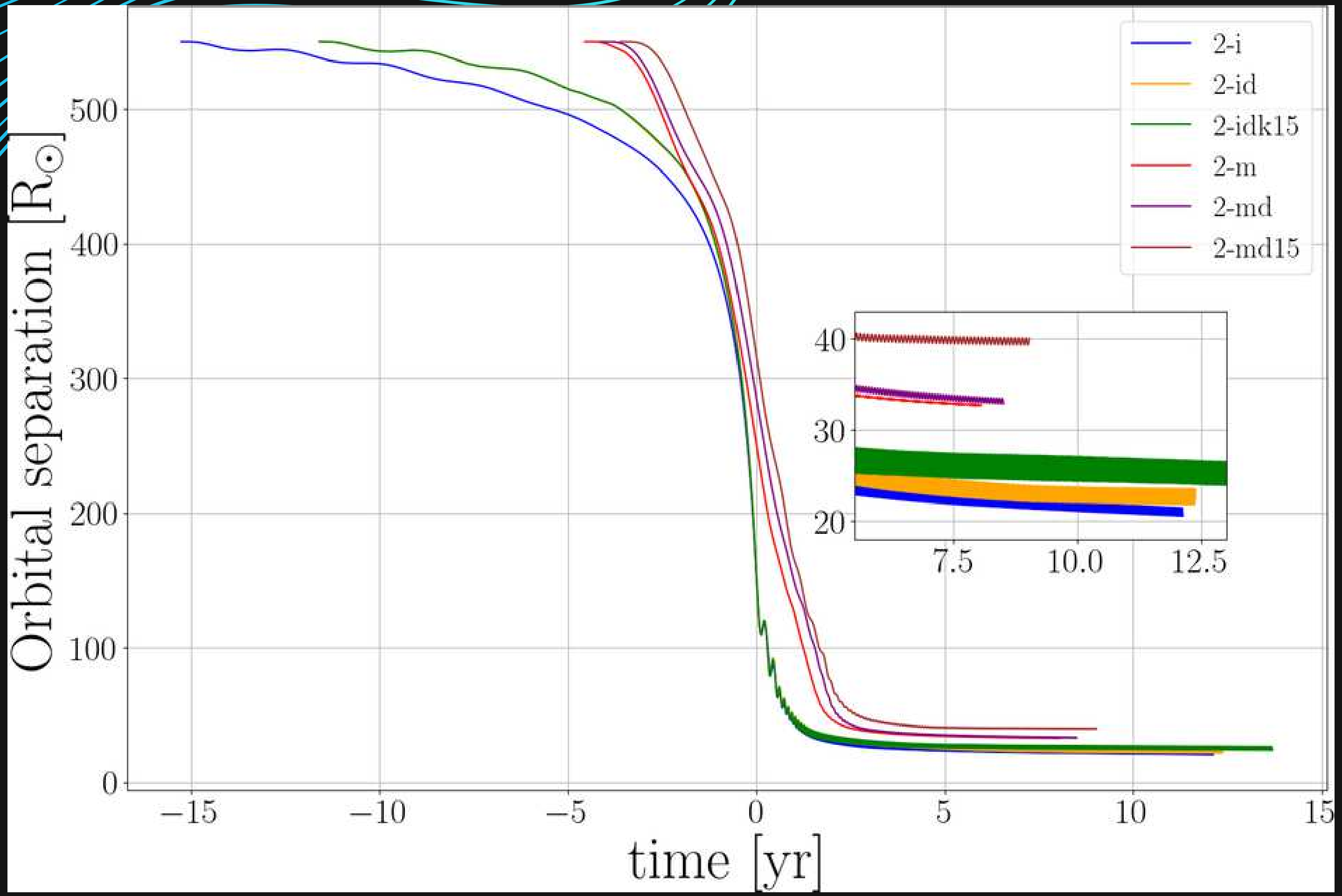
$$\frac{\mathrm{d}v}{\mathrm{d}t} = -\frac{\nabla P}{\rho} + \boldsymbol{a}_{\rm ext}(\boldsymbol{r}, t) + \boldsymbol{a}_{\rm sink-gas} \boxed{+ \frac{\kappa_{\rm D} L}{4\pi r^2 c}}$$

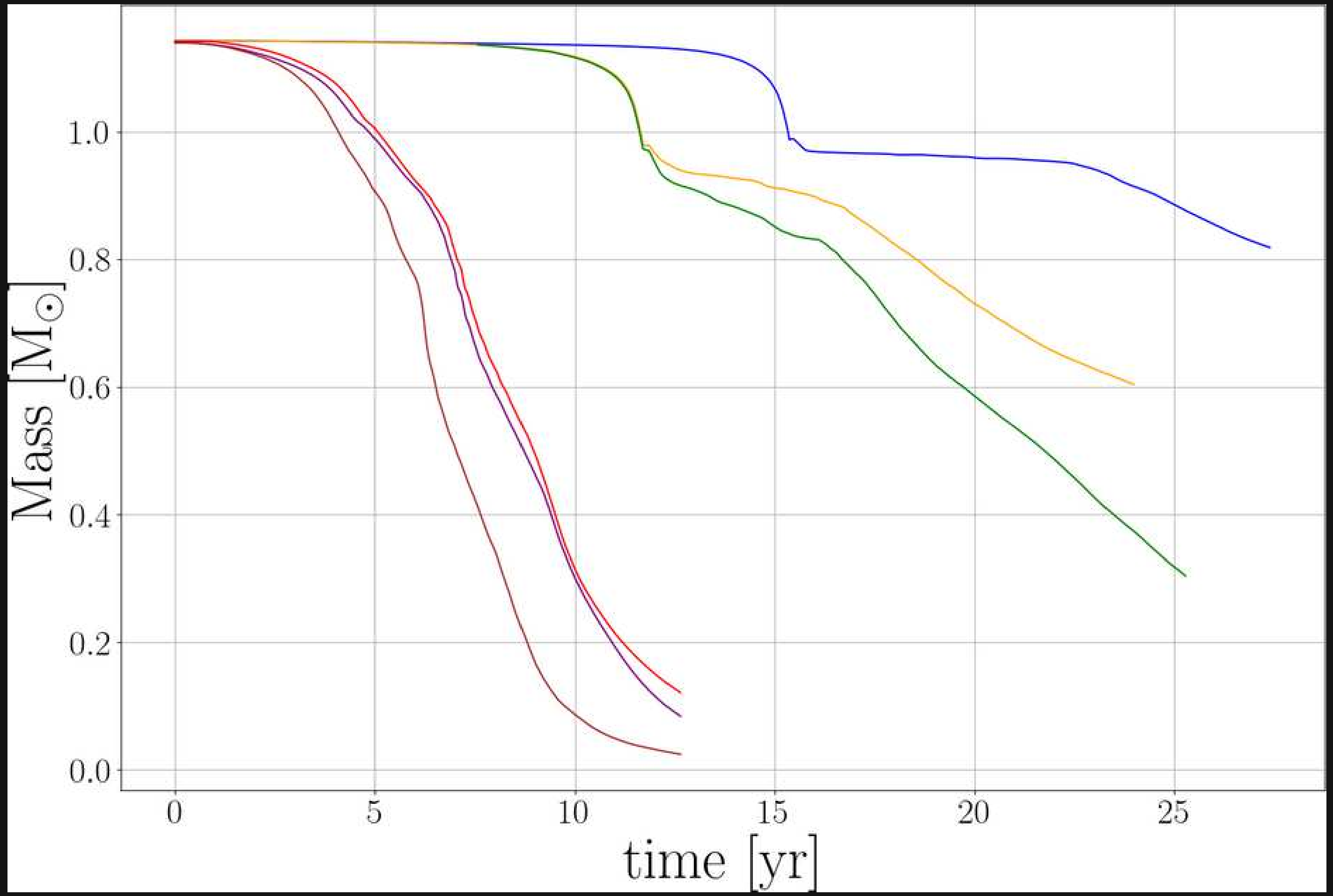
Dust-driven wind term

- We implemented DDW in the 2Msun models with ideal and MESA EoS.
- We also model a 4Msun primary until TP-AGB to check the effect on higher stars.

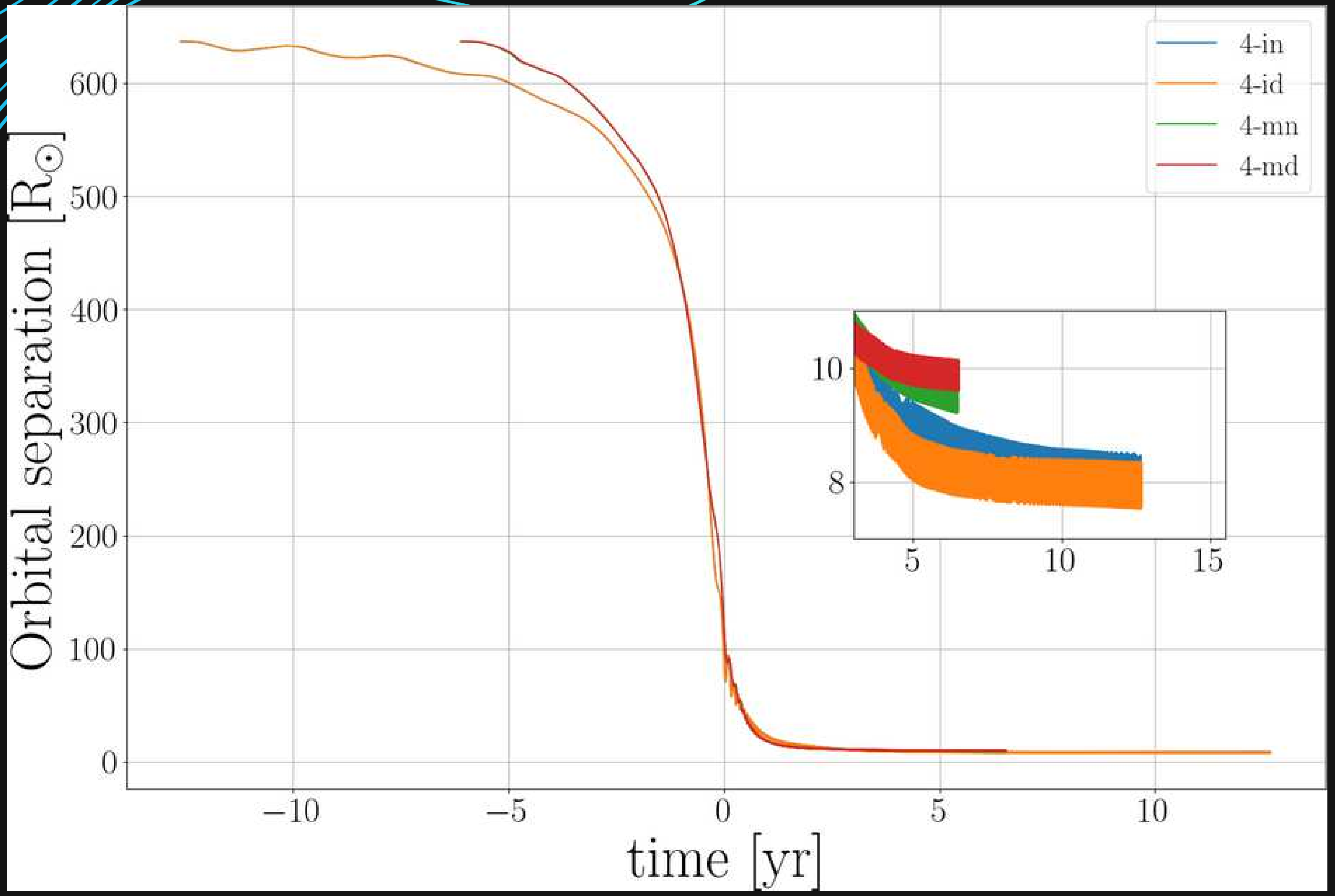


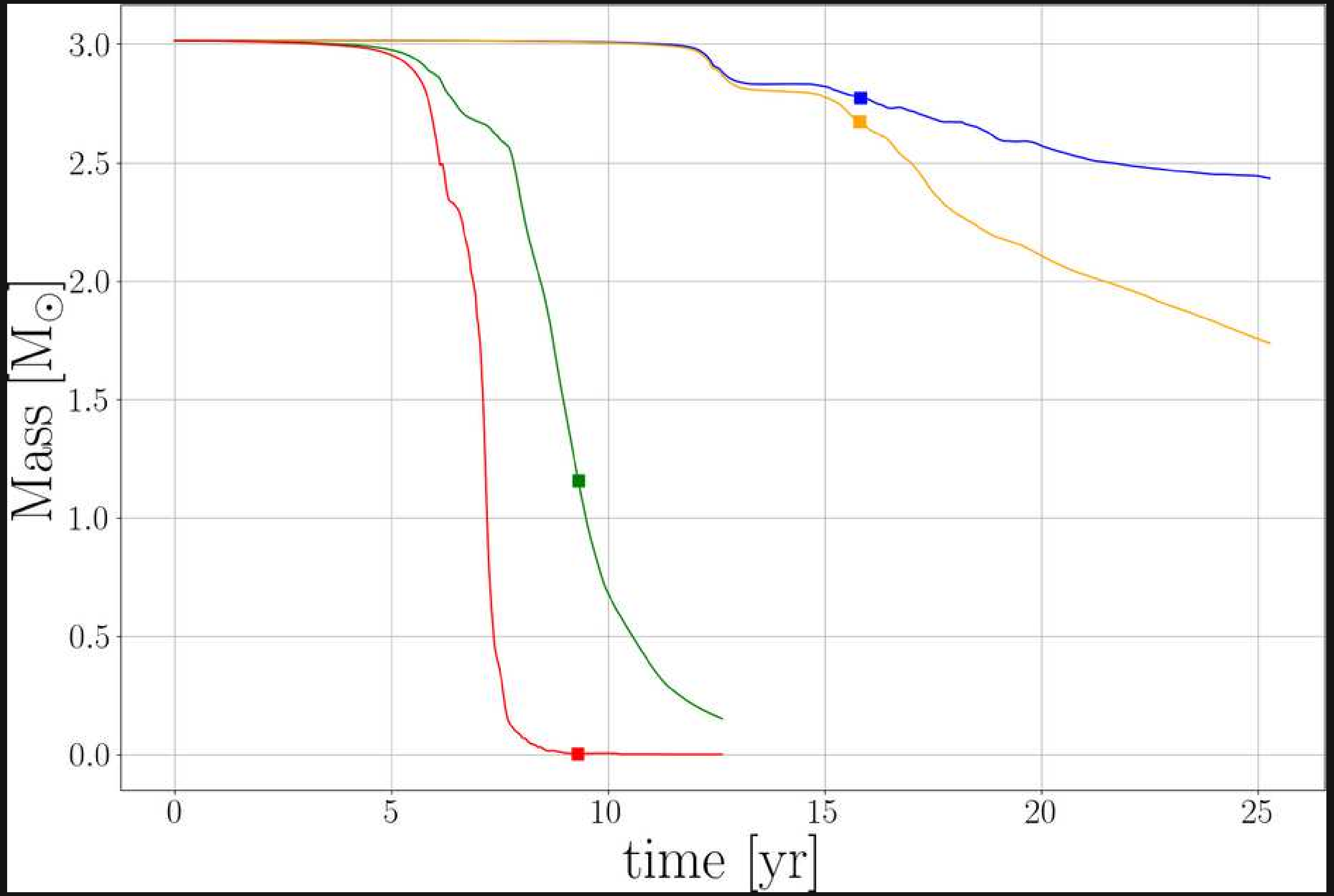
(c) 2022 Miguel Gonzalez-Bolivar





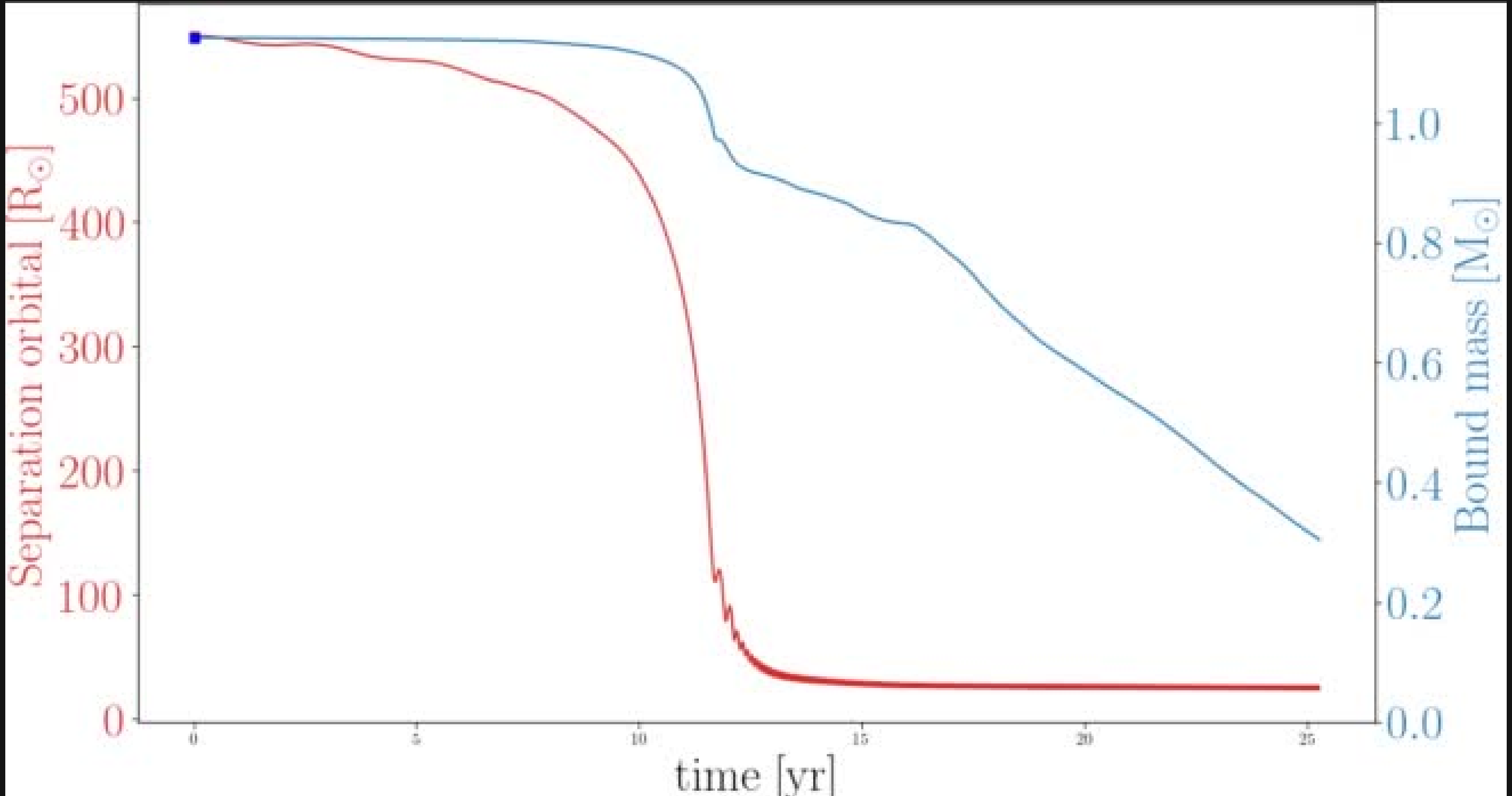
- DDW unbinds more material, but leads to larger final separation.
- Dynamical plunge-in is virtually unaffected by opacity function (expected)
- Shorter ROLF timescales with DDW
- Larger values of maximum opacity increases the effect

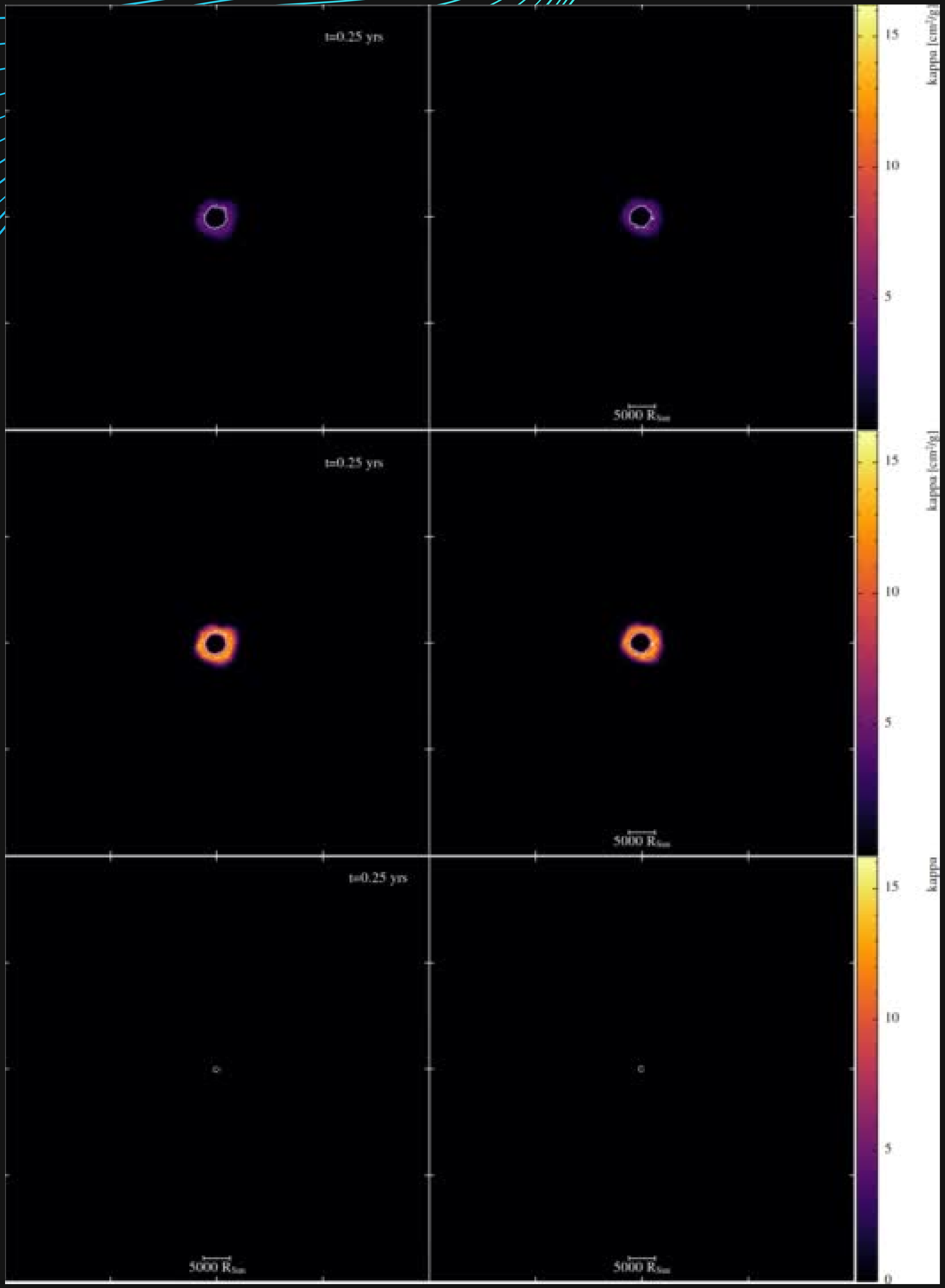




- Virtually no difference in orbital evolution
- Almost all interaction is dynamically driven (low mass ratio)
- DDW still unbinds significantly fraction of envelope


0 yrs
Roche lobe overflow phase
500 Solar radius
(c) 2022 Miguel Gonzalez-Bolivar
-13
-12
-11
-10
log density [g/cm^3]


Separation orbital [R$_\odot$]
0
100
200
300
400
500
Bound mass [M$_\odot$]
0.0
0.2
0.4
0.6
0.8
1.0
time [yr]
0
5
10
15
20
25



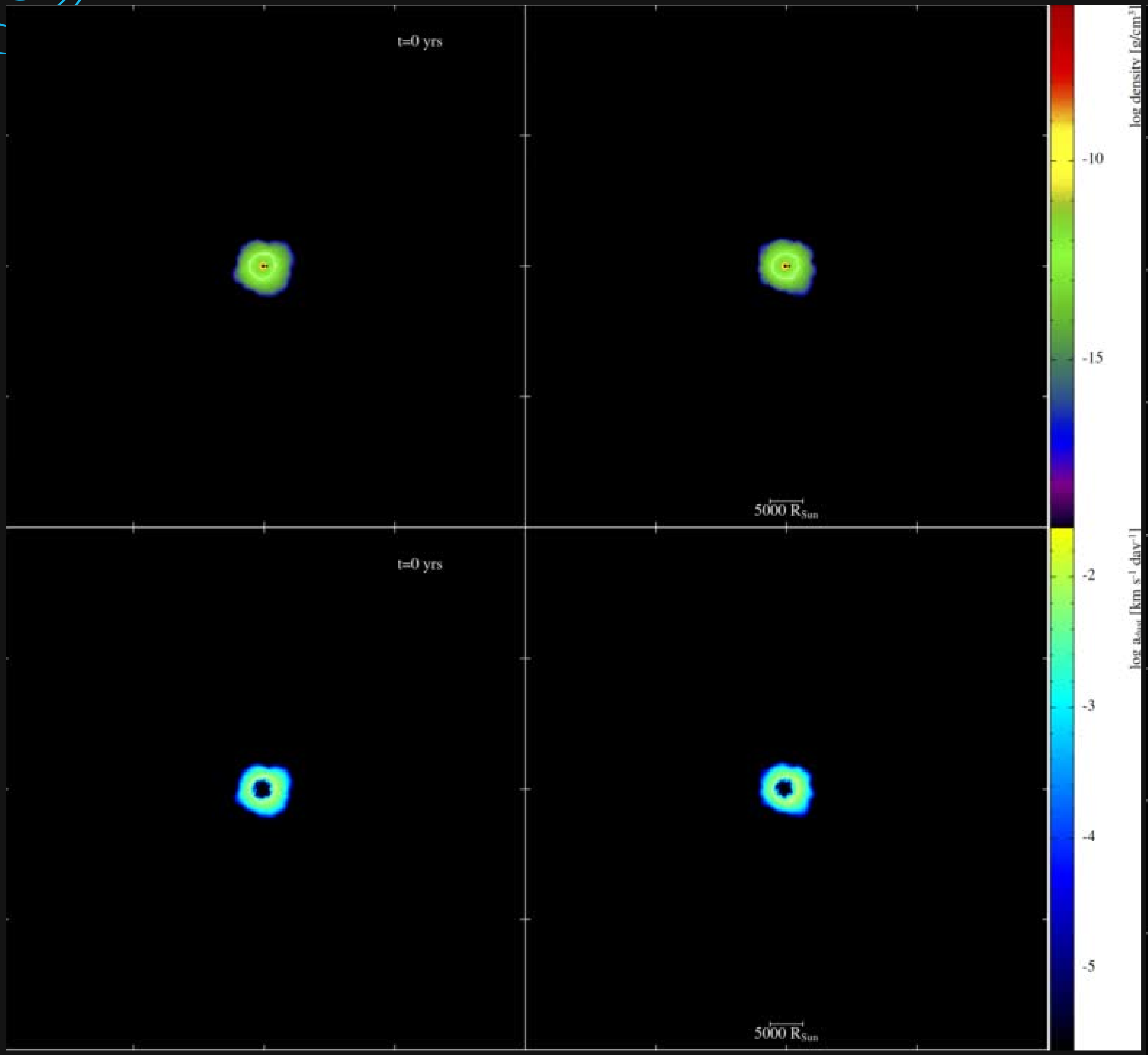
Bowen (kmax = 5 cm^2/g)

Bowen (kmax = 15 cm^2/g)

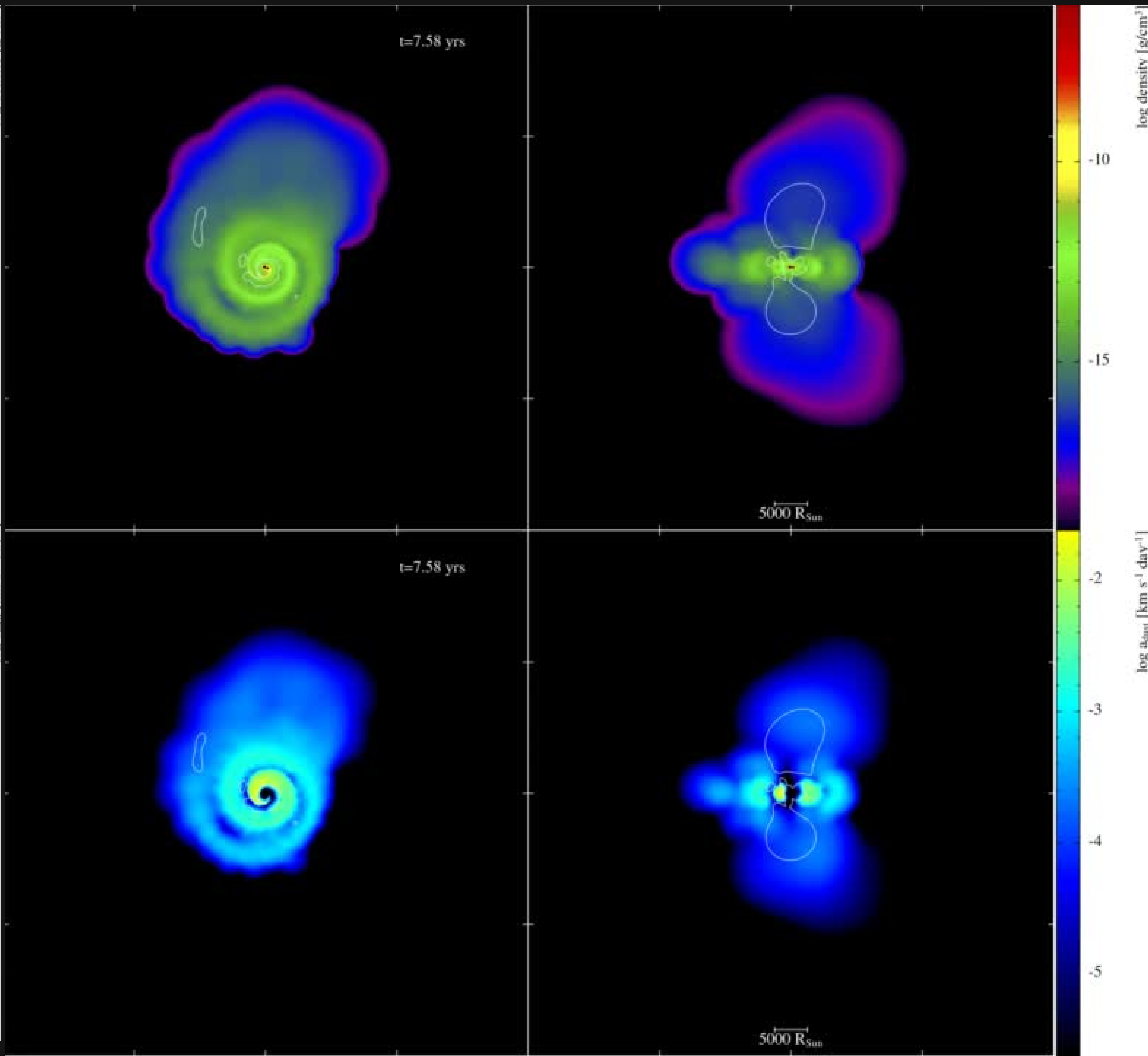
(Gonzalez-Bolivar+ 2023, in prep)

Nucleation (Bermudez-Bustamante+ 2023, in prep)

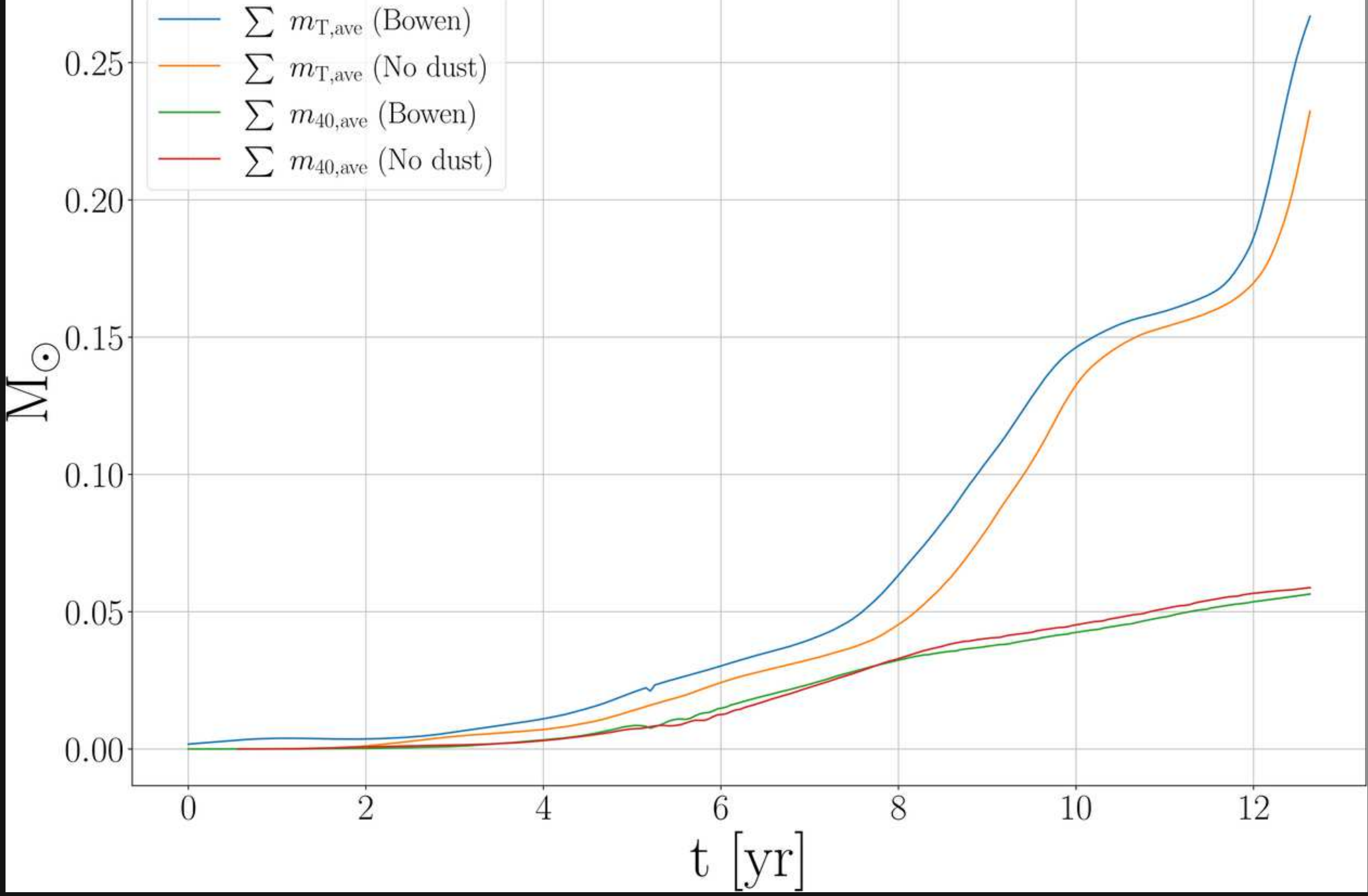
2 Msun ideal

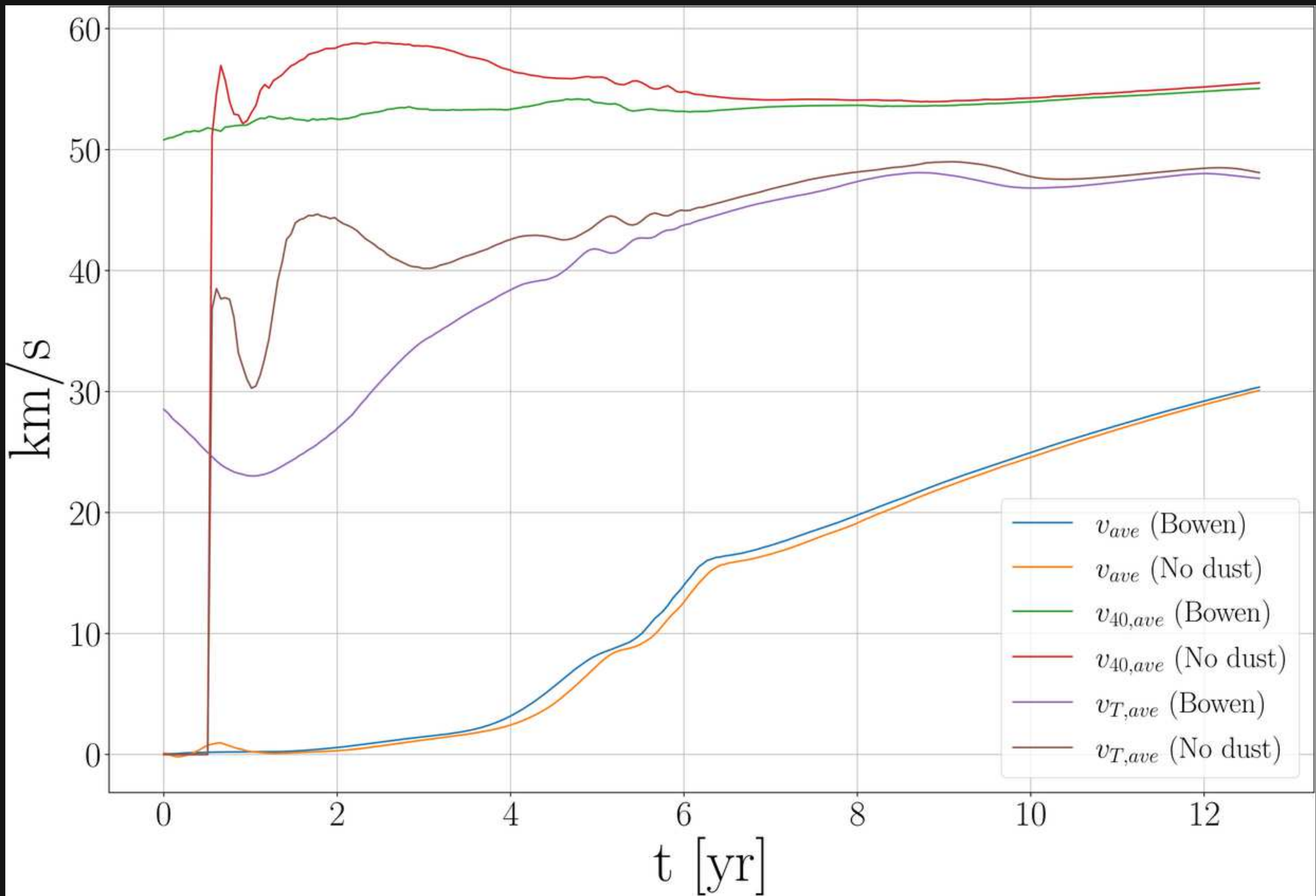


2 Msun MESA (recomb)



- For simulations with recombination energy, DDW effects are less noticeable.
- Winds are particularly strong during ROLF phase.





Conclusions

- DDW unbounds more gas in all simulations, at the cost of larger final separation values.
- Winds are particularly strong during ROLF phase and during the post-CE system
  - It will invariably influence any potential APN.
  - It increases the effect of the resolution dependent unbound
- 4 Msun is not affected strongly by the dust (dynamically dominated).
- Nucleation (Bermudez-Bustamante+23) will be a neccesary complement of this analysis

Thanks!