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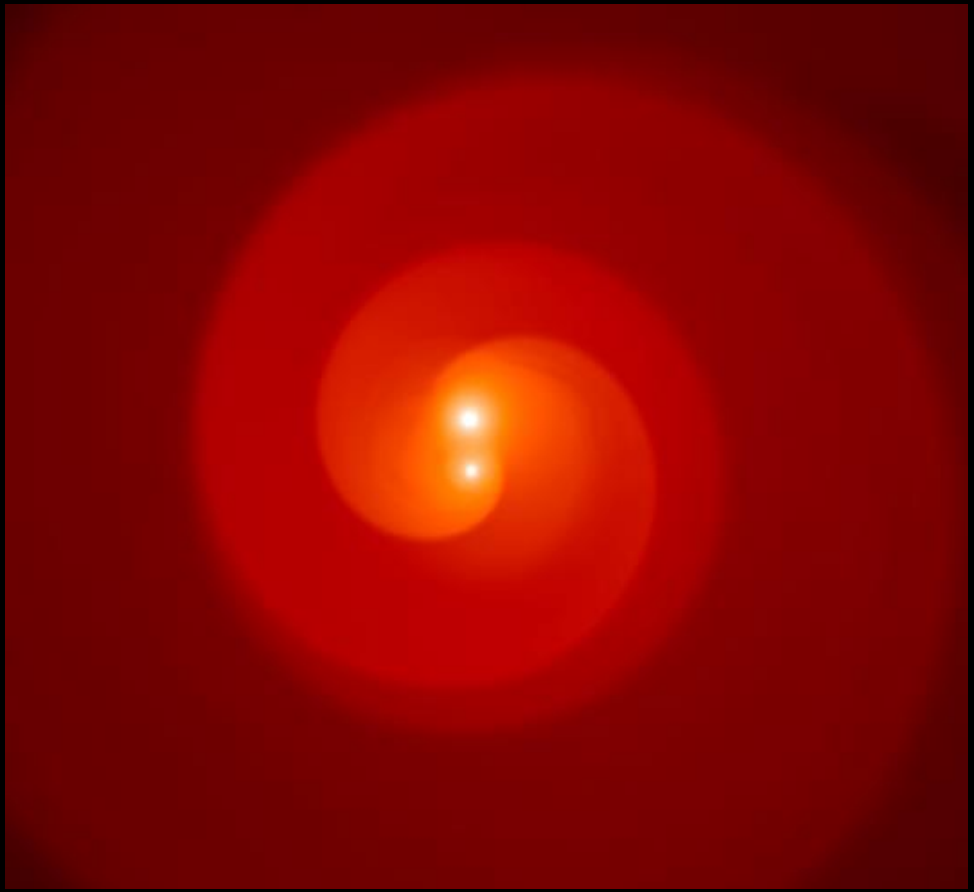

Photospheric Evolution in Common Envelope

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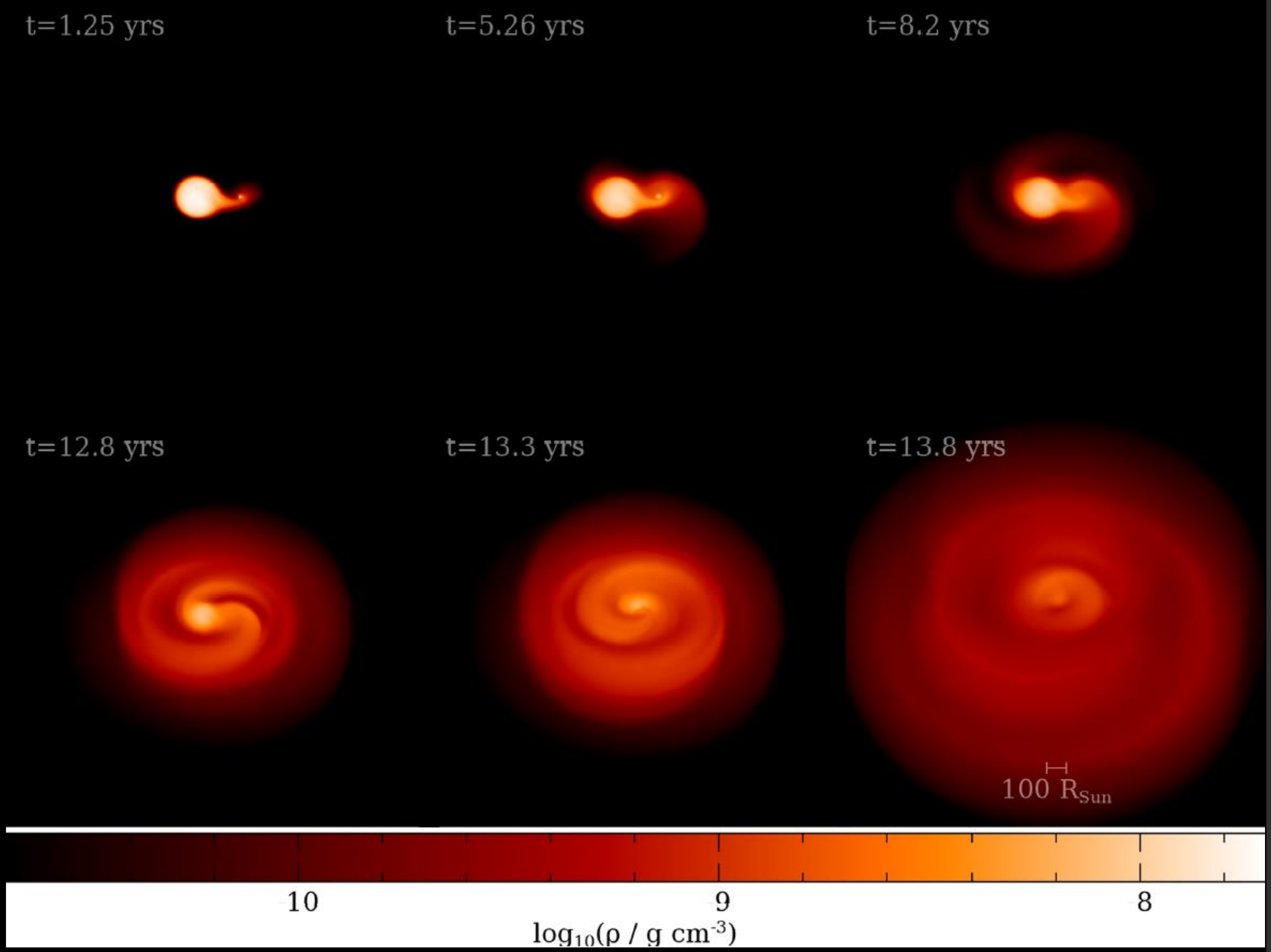
Introduction

- Common Envelope:
  - What is it?
  - Why is it hard?
  - Why do we care?

- Smoothed Particle Hydrodynamics (SPH) simulations
  - Software used:
    - Phantom
    - Sarracen

?

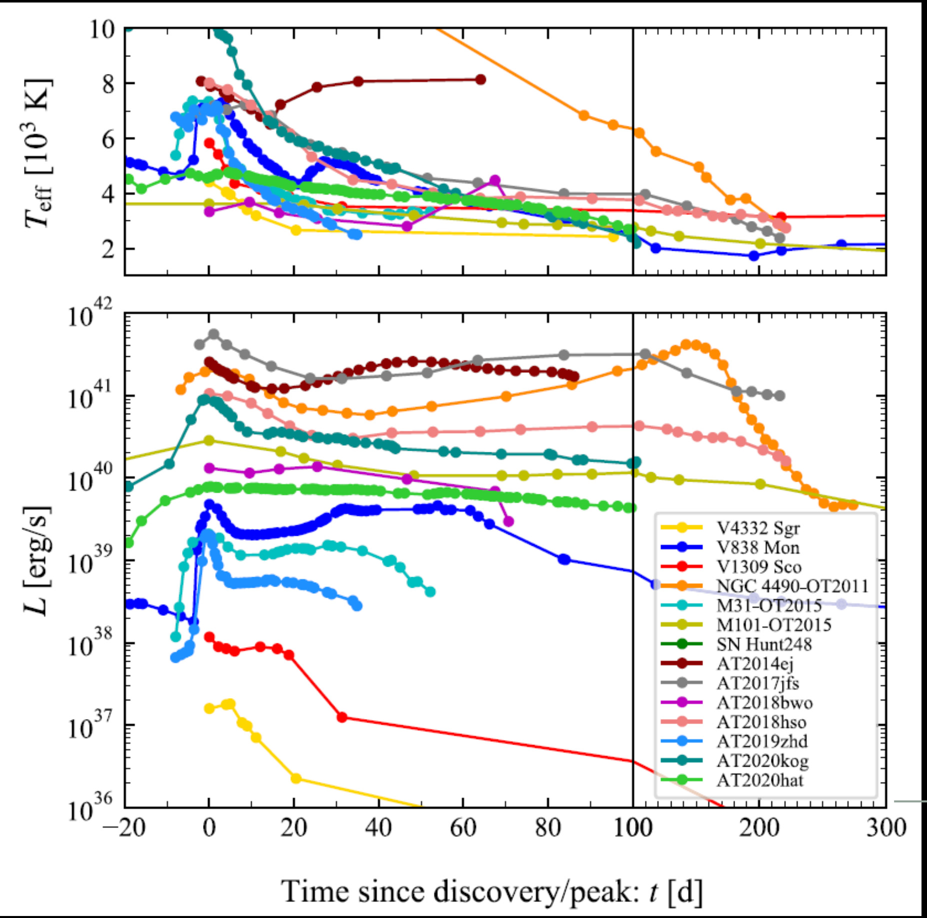
Source:
https://phantomsph.github.io/
https://github.com/ttricco/sarracen
My code also available on
https://github.com/chunliangmu/clmuphantomlib



Reichardt et al., 2019

Introduction

Optical lightcurves of luminous red novae

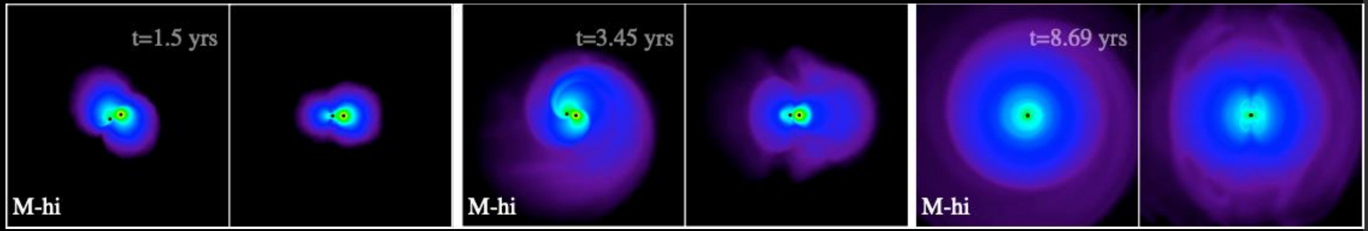


Matsumoto and Metzger, 2022

Dust form here

(~3 years)

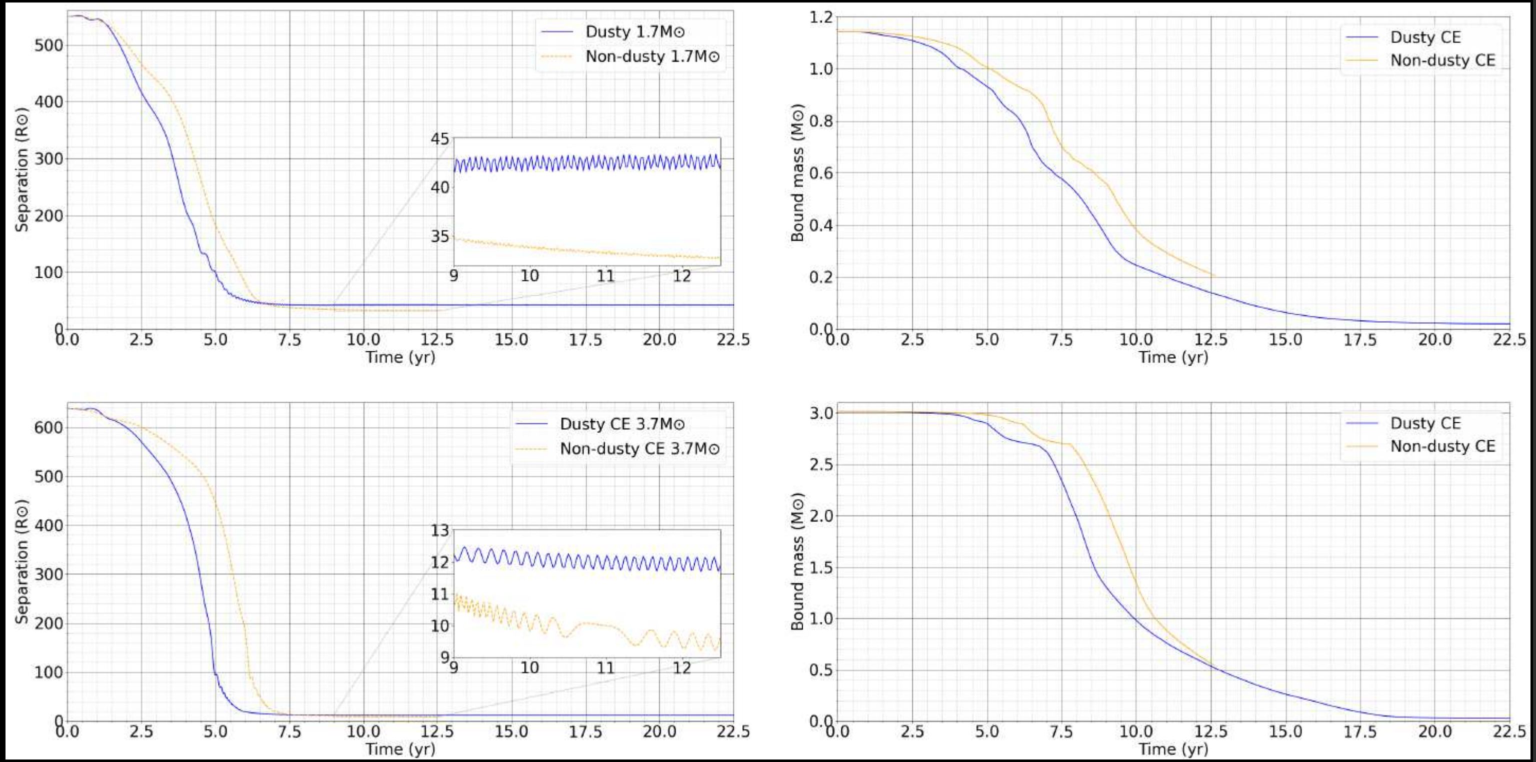
Simulations setup



González-Bolívar st al., 2022

2 simulations

- $1.7M_\odot$ & $3.7M_\odot$ primary AGB star, with $0.6M_\odot$ point-mass companion
- $1.7M_\odot$ case: $R_1 = 260R_\odot$, $a_0 = 550R_\odot, P_0 = 2.7yr$
- $3.7M_\odot$ case: $R_1 = 330R_\odot$, $a_0 = 637R_\odot, P_0 = 2.5yr$
- Nucleation dust (Gail et al., 1984) formation included, assuming **carbon rich**



Bermúdez-Bustamante et al., 2024

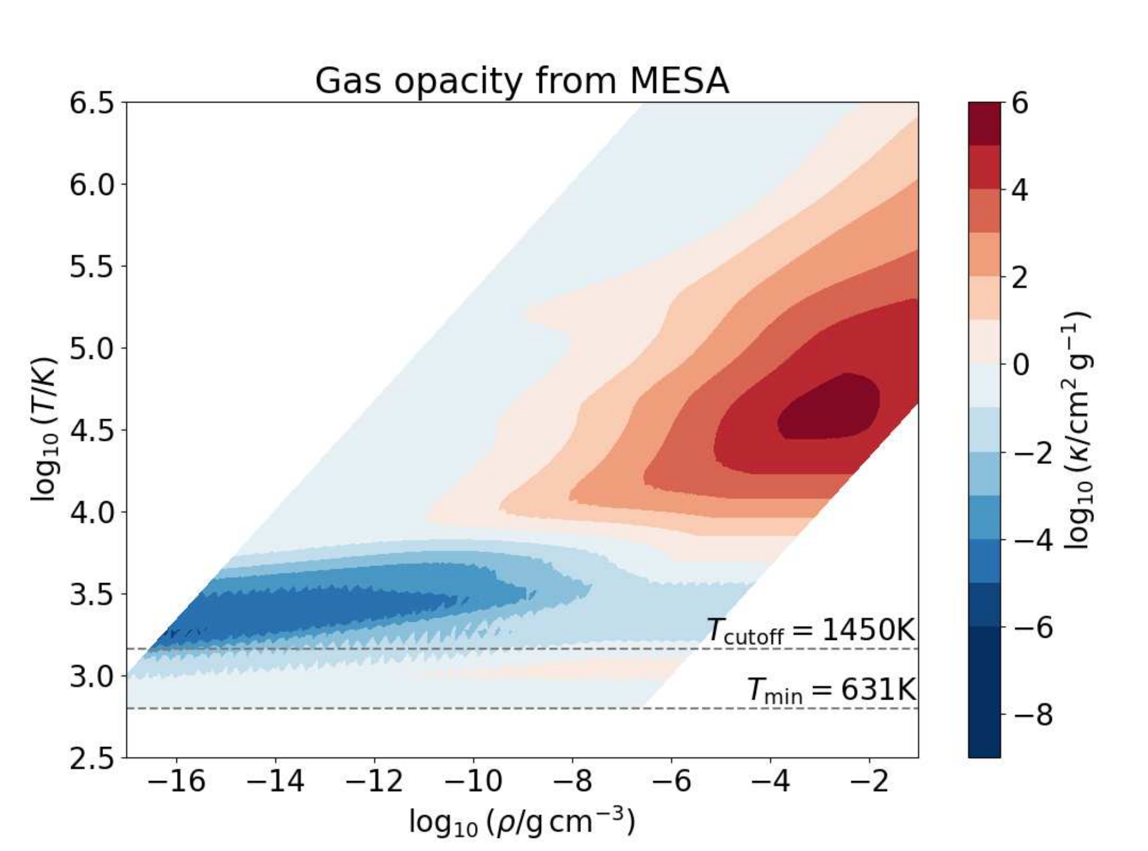
Obtaining the opacity κ

Opacity κ sources:

- Gas opacity (using tabulated MESA (1D stellar structure code))
  - NB: at low T, κ_{MESA} assumes oxygen dust
- Dust opacity (calculated in PHANTOM)

$$\kappa = \kappa_{\mathrm{dust}} + \kappa_{\mathrm{gas}}$$

$$\kappa_{\mathrm{gas}} = \begin{cases} 2 \times 10^{-4} \mathrm{cm}^2 \mathrm{g}^{-1} & \text{if } T < T_{\mathrm{cutoff}} \\ \kappa_{\mathrm{MESA}} & \text{if } T \geq T_{\mathrm{cutoff}} \end{cases}$$



How optical depth is integrated (the splash way)

Kernel Interpolation

$$\langle \kappa\rho\rangle(\boldsymbol{r}) = \sum_j \frac{\kappa_j \rho_j m_j}{h_j^3 \rho_j} w\left(q_j(\boldsymbol{r})\right)$$

Optical depth

$$\tau = \int \kappa\rho dz'$$

$$= \int_z^\infty \sum_j \frac{\kappa_j m_j}{h_j^3} w\left(q_j(z')\right) dz'$$

$$= \sum_j \frac{\kappa_j m_j}{h_j^3} \int_z^\infty w\left(q_j(z')\right) dz'$$

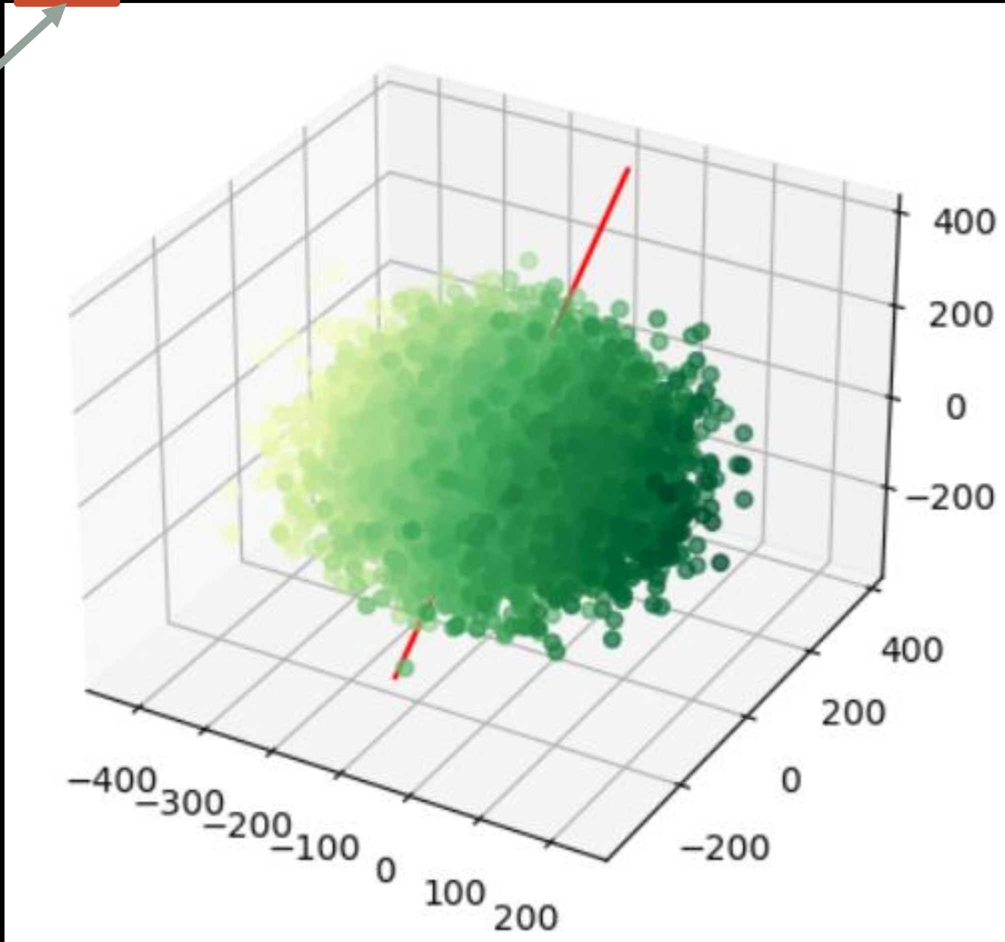
$$\approx \sum_j \frac{\kappa_j m_j}{h_j^2} w_{\mathrm{col}}\left(q_{xy,j}\right)$$

Dimensionless distance

$$q_j(\boldsymbol{r}) \equiv \frac{\boldsymbol{r} - \boldsymbol{r}_j}{h_j}$$

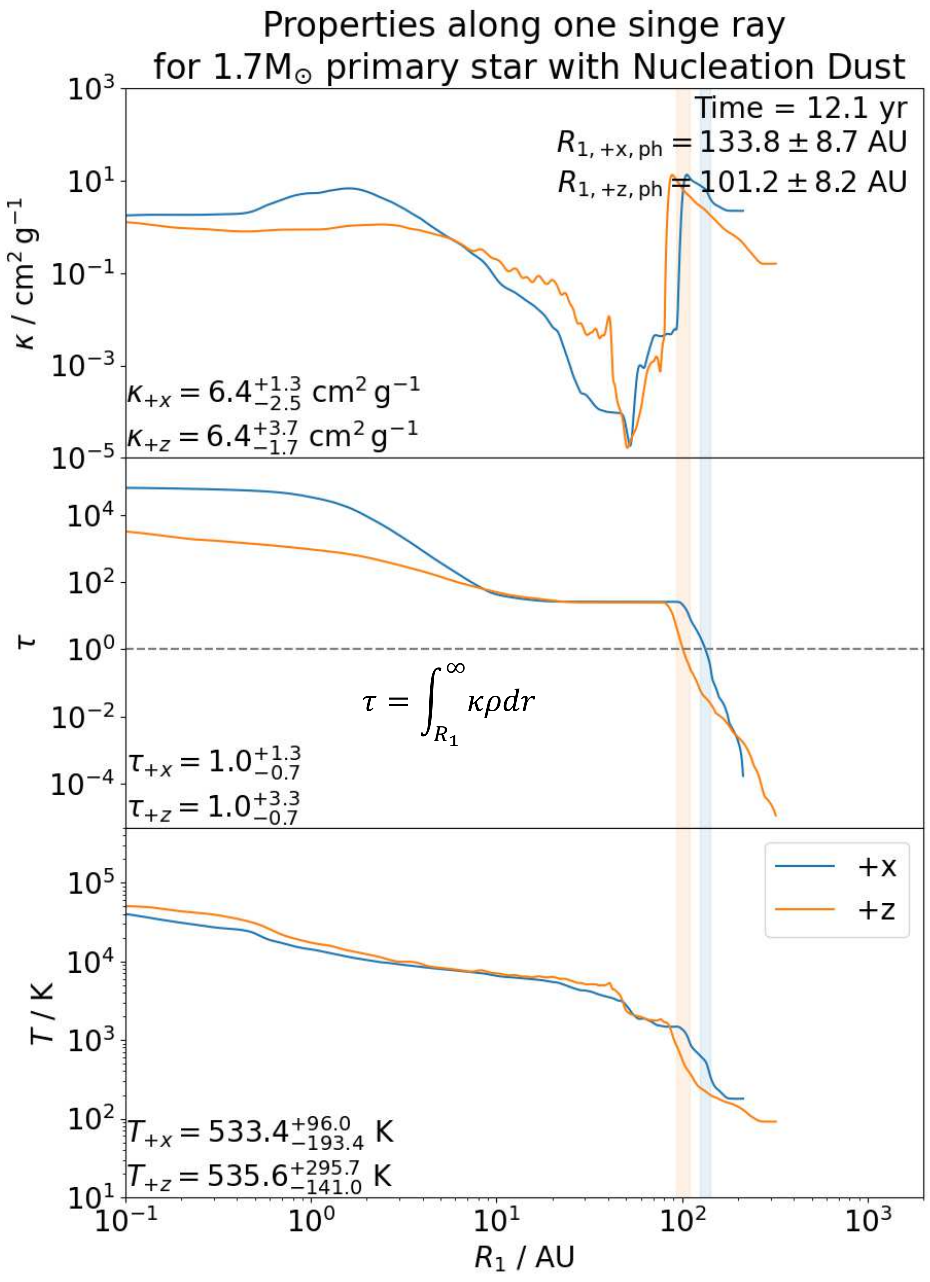
Dimensionless column kernel

$$w_{\mathrm{col}}\left(q_{xy,j}\right) \equiv \frac{1}{h_j} \int_{-\infty}^{+\infty} w\left(q_j(z')\right) dz'$$



Defining the photosphere

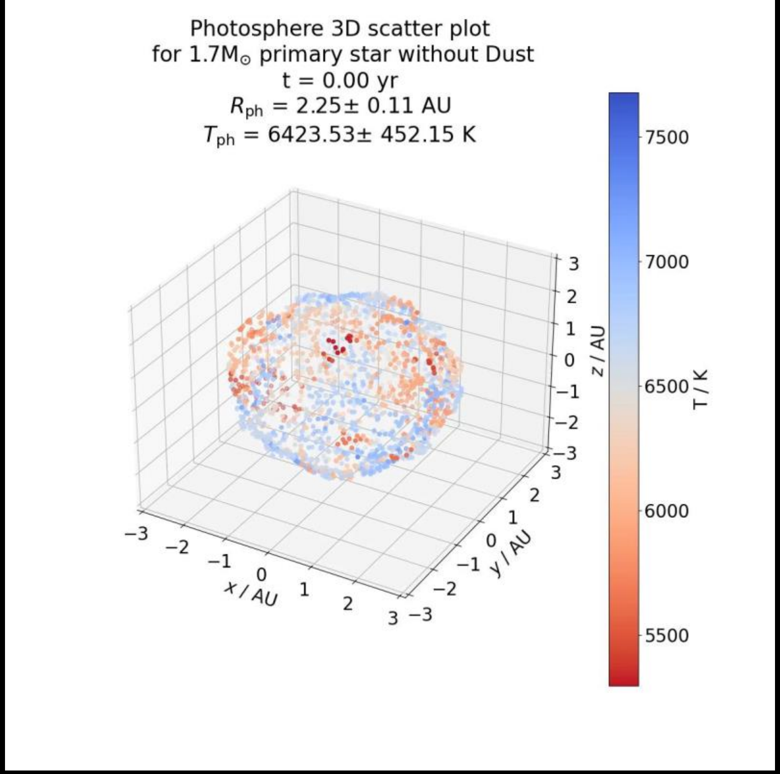
- The photosphere is the surface of last scattering – i.e. the surface you see
- The photosphere is wavelength dependent, but here we assume it is grey
- At t=12 year, the object is huge (~100AU)



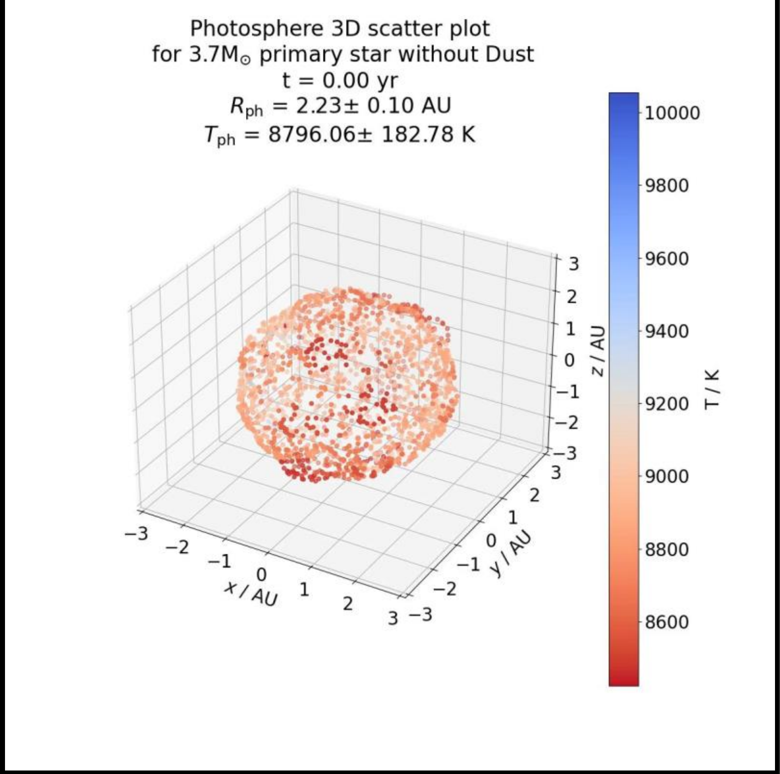
Photosphere Evolution: Shape

- Photospheres become spheres after $t \approx 8yr$
- R_{ph} contracts for $1.7M_\odot$ case
- $3.7M_\odot$ case expands faster

$1.7\text{M}_\odot$ ($q = 0.35$), no dust



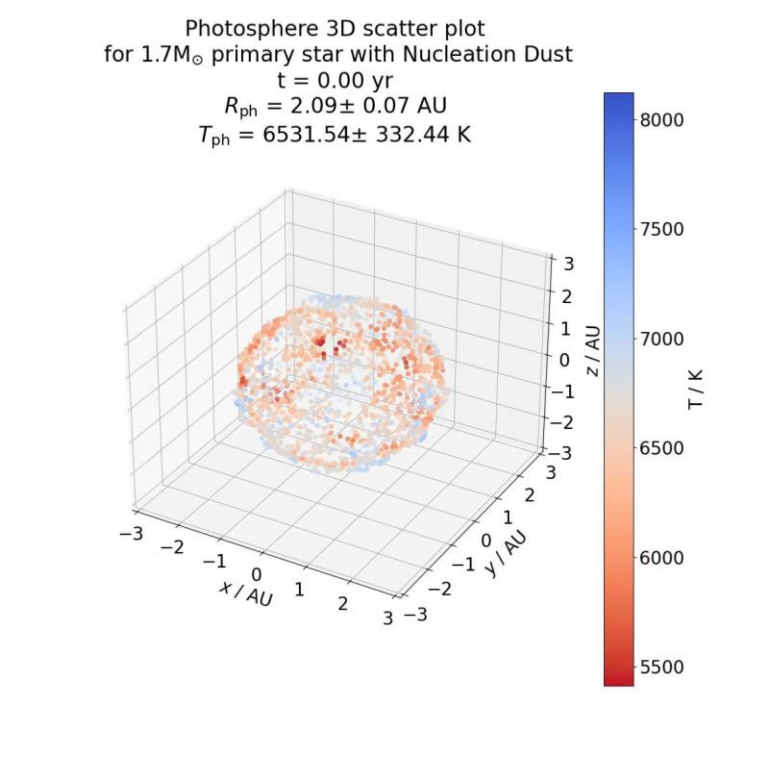
$3.7\text{M}_\odot$ ($q = 0.16$), no dust



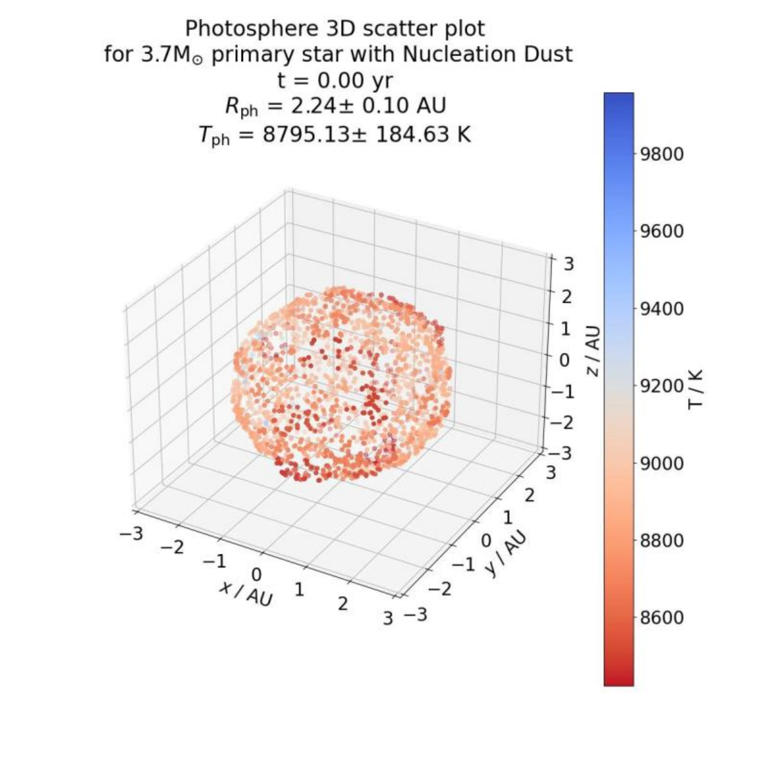
Photosphere Evolution: Shape

- Formation of a dust shell
- Happens later for $3.7M_{\odot}$ case
- $T_{\rm ph}$ hot spot near pole

$1.7\mathrm{M}_{\odot}$ $(q = 0.35)$, with dust



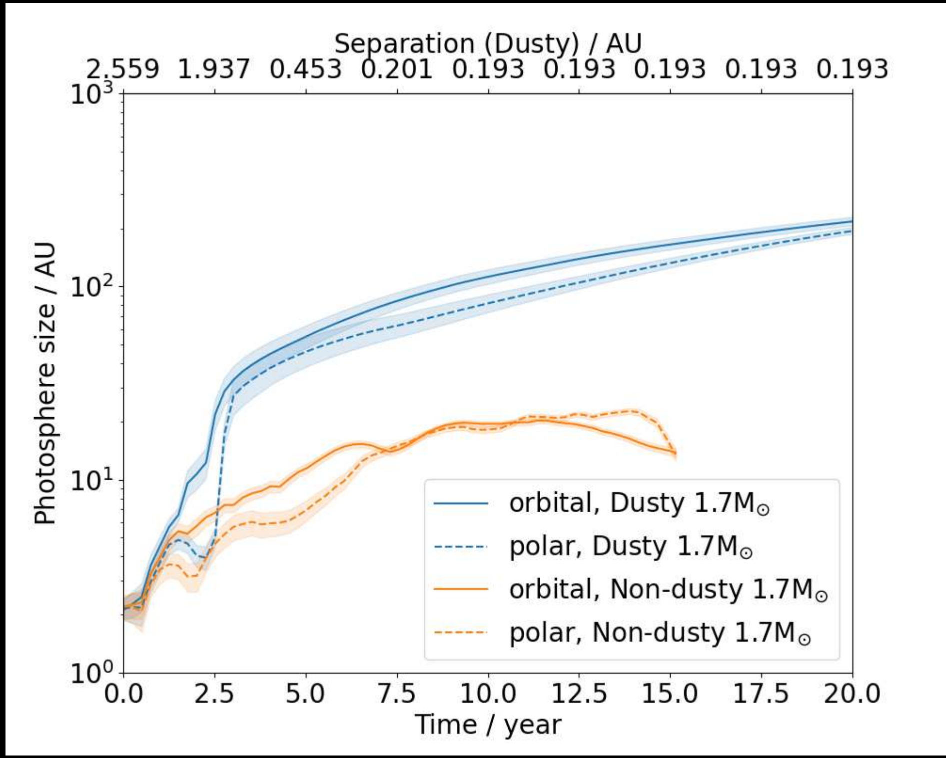
$3.7\mathrm{M}_{\odot}$ $(q = 0.16)$, with dust



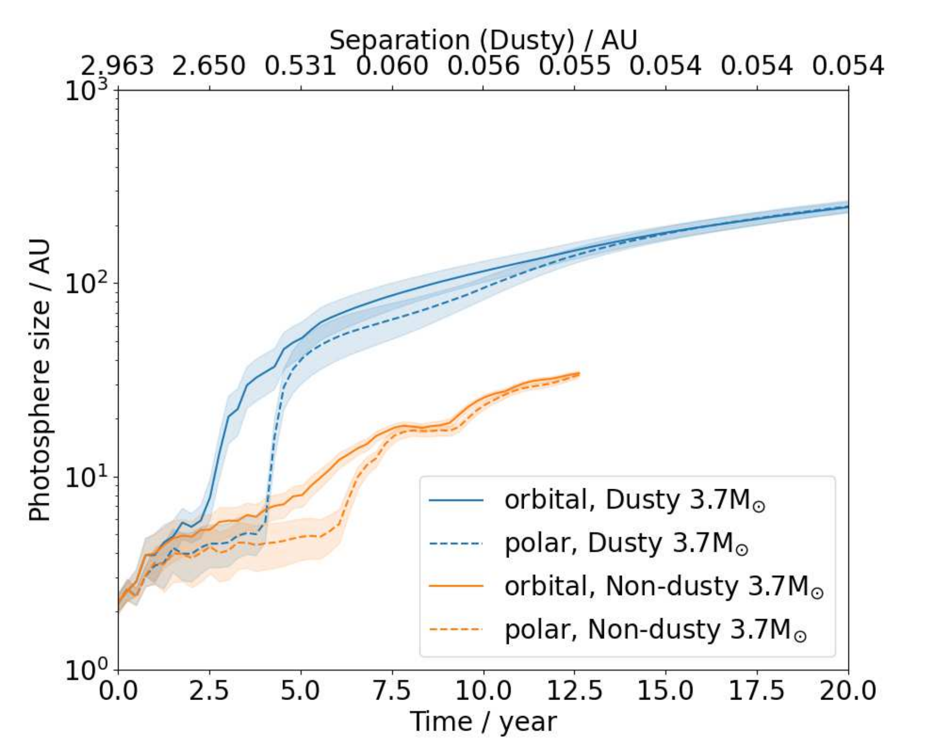
Photosphere Evolution: Size

- Dust creation increases R_{ph} with sudden jumps
- With dust R_{ph} increases steadily with t
- Without dust R_{ph} stabilizes after ~10 years
- Photosphere shape asymmetries slowly dies out later in simulations

$1.7M_\odot$



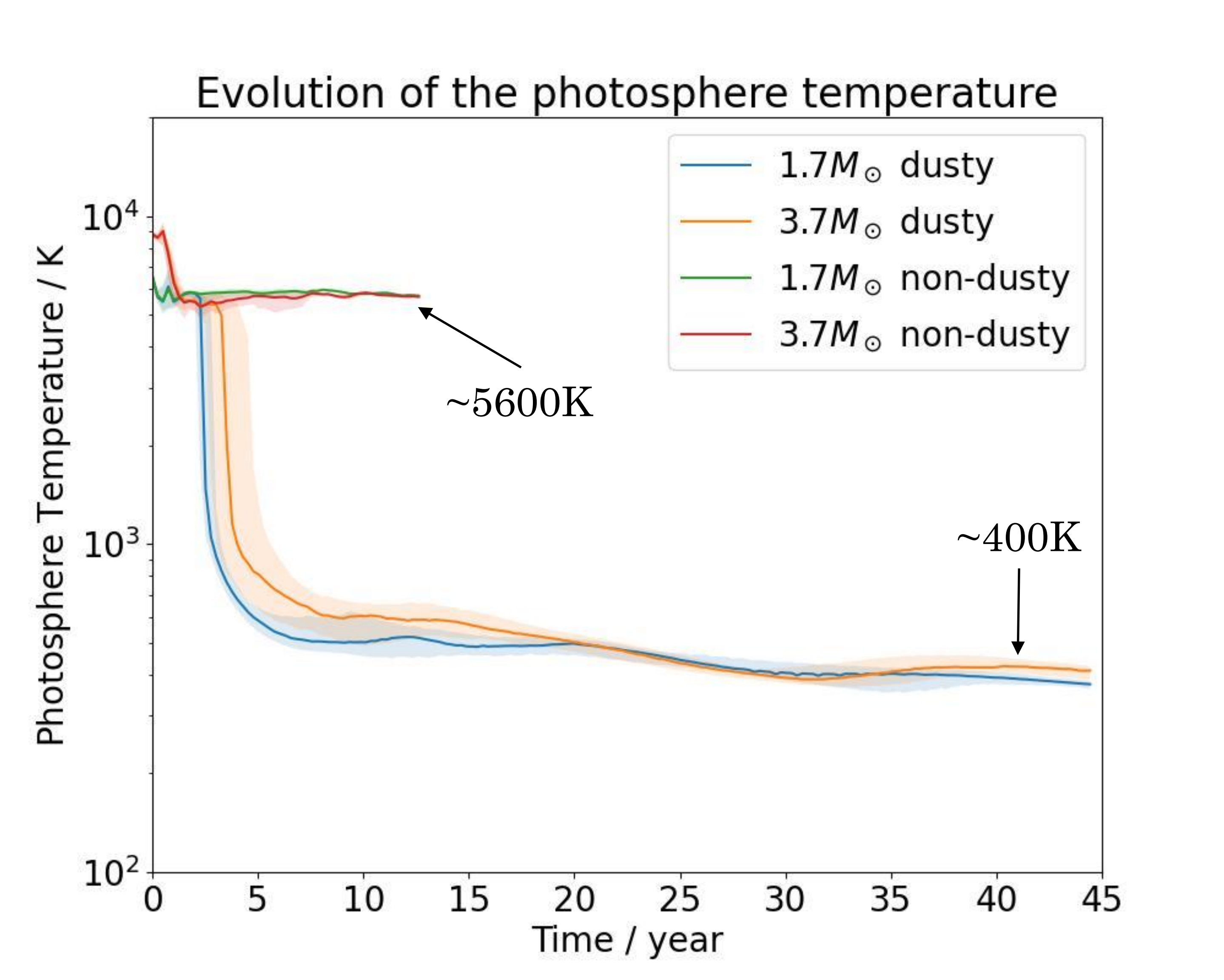
$3.7M_\odot$



Photosphere Evolution: Temperature

[Preliminary Results]

- A sudden drop in T after dust formed
- Later T stablizes and slowly declines



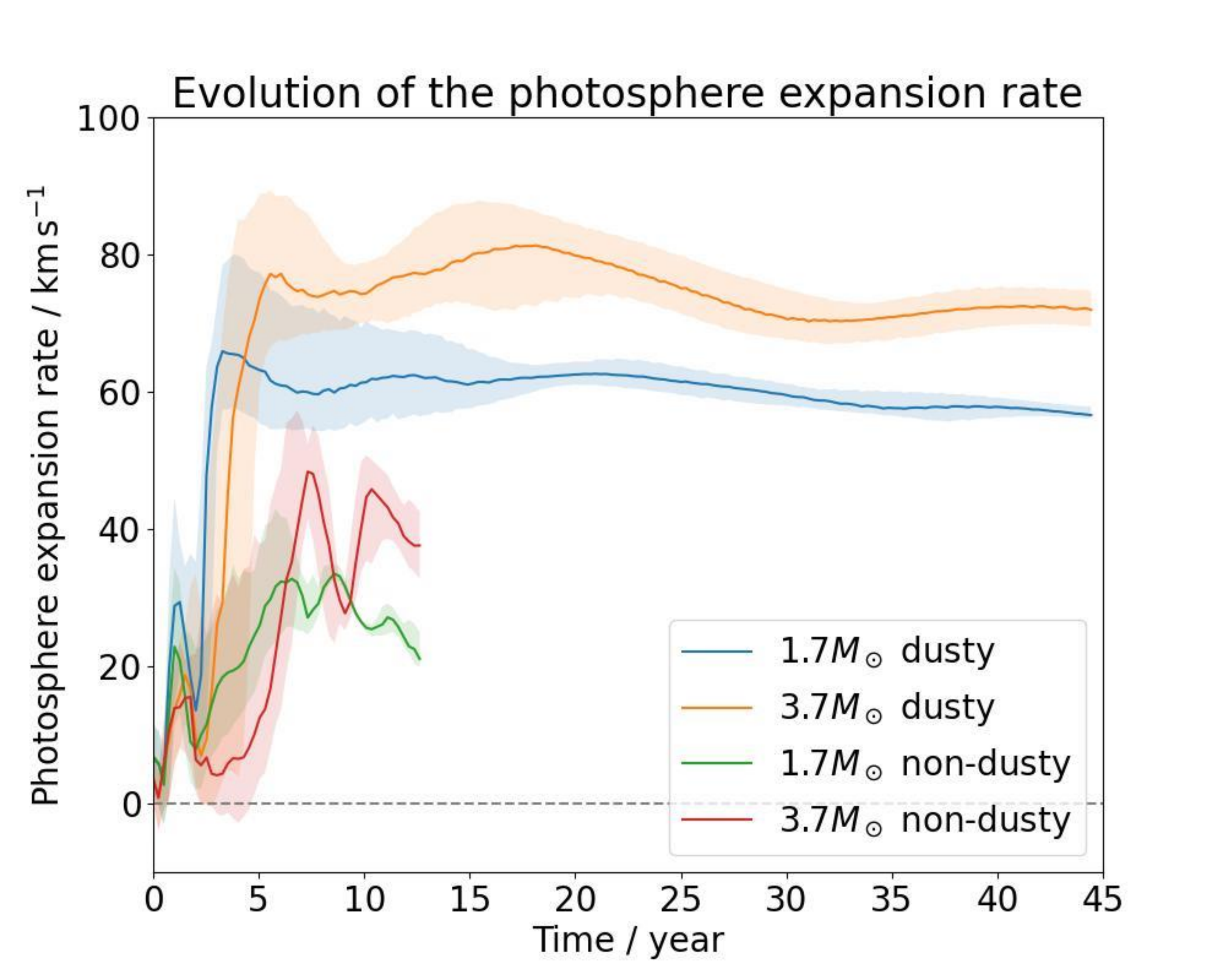
Photosphere Evolution: Fluid expansion rate

i.e. The velocity of the fluid at the photosphere (not the velocity of the photosphere)

[Preliminary Results]

- A dip at round 2nd year
- Stabilizes at later years

Changes potentially due to shift of the photosphere instead of acceleration / deceleration of the fluid



Conclusions

Summary

- Without dust formation:
  - The photosphere tends to contract after a decade
- With dust formation:
  - A dust shell is formed after 2-3 years, which is…
    - Highly opaque
    - Quickly expanding
  - Resulting in a photosphere that (after a decade) is…
    - Larger (~100AU)
    - Cooler (~500K)
    - Expands faster (60~80km/s)
    - Tend to be hotter near the poles

Limitations & future works

- Assumptions
  - Grey opacity
  - Absorption opacity only for T_{ph} calculations
  - Local Thermodynamic equilibrium
- Other limitations
  - Spatial resolution
- Future work includes adding wavelength-dependent radiative transport using MCMC

Thank you!