Evolution of photoevaporative disk dead zone Giant planet factory

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FIKUT NEXTGEN Nov. 4-6, 2026

1D evolution of protoplanetary disk

Hydrodynamical equation for gas

- $$\frac{\partial \Sigma}{\partial t} = \frac{3}{r}\frac{\partial}{\partial r}\left(\sqrt{r}\frac{\partial}{\partial r}\left(\nu(r)\,\Sigma\sqrt{r}\right)\right)$$ Lynden-Bell & Pringle (1974)

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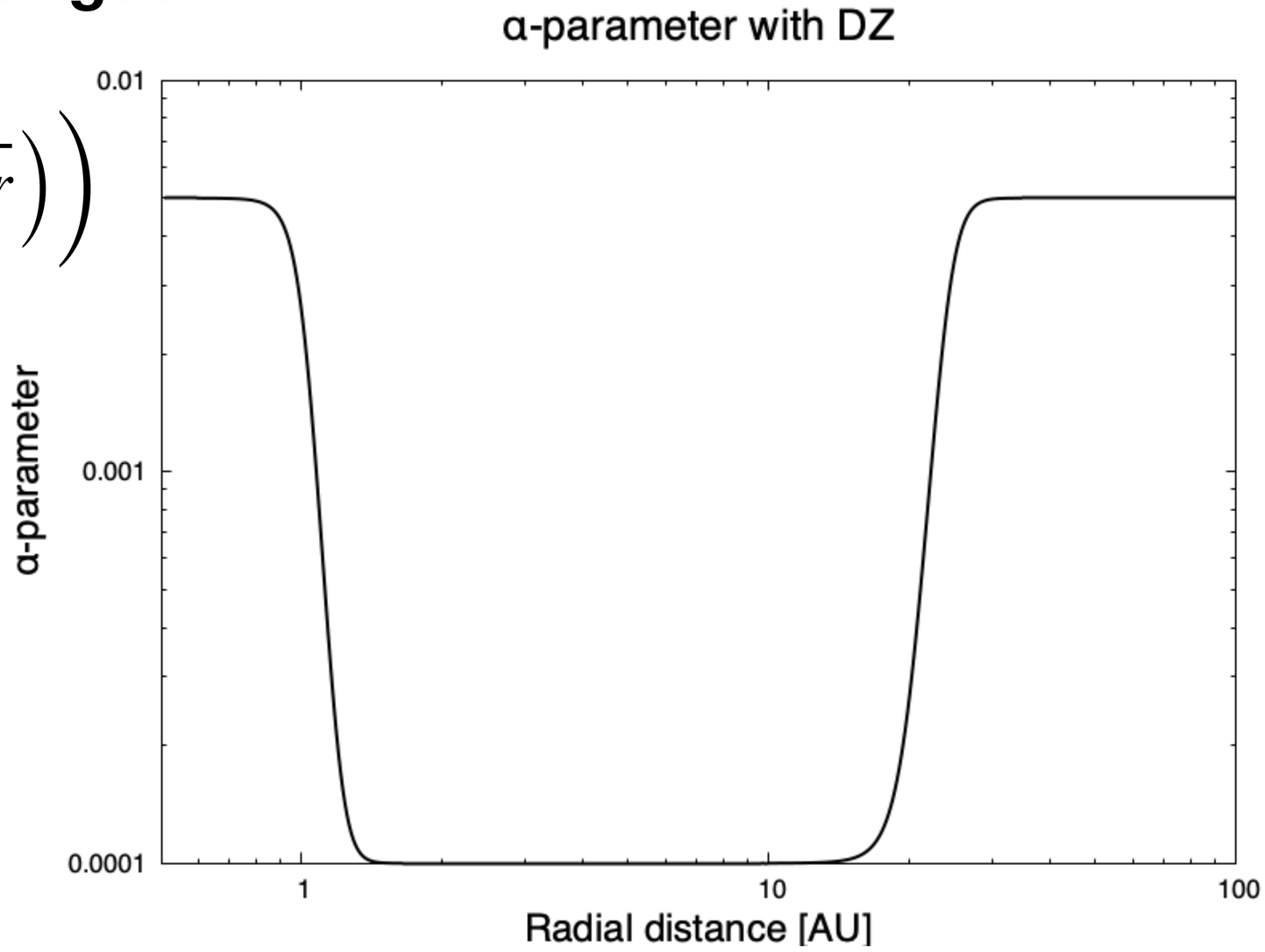
- $\nu = \alpha c_s H$ - kinematic viscosity

1D evolution of protoplanetary disk

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- Accretionally dead zone:



1D evolution of protoplanetary disk

Hydrodynamical equation for gas

- $$\frac{\partial \Sigma}{\partial t} = \frac{3}{r}\frac{\partial}{\partial r}\left(\sqrt{r}\frac{\partial}{\partial r}\left(\nu(r)\,\Sigma\sqrt{r}\right)\right) - \dot{\Sigma}_{\mathrm{w}}(r,t)$$

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Photoevaporation sink term
(Owen et al. 2012)

1D evolution of protoplanetary disk

Hydrodynamical equation for dust

- $$\frac{\partial \Sigma_{\mathrm{d}}}{\partial t} + \frac{1}{r}\frac{\partial}{\partial r}\left\{ r \cdot \left[\Sigma_{\mathrm{d}} \cdot u_{\mathrm{r}} - D_{\mathrm{d}} \cdot \frac{\partial}{\partial r}\left(\frac{\Sigma_{\mathrm{d}}}{\Sigma_{\mathrm{g}}} \right) \cdot \Sigma_{\mathrm{g}} \right] \right\} = S_{\mathrm{d}}$$ Birnstiel et al. (2010)

Stokes-number: contant

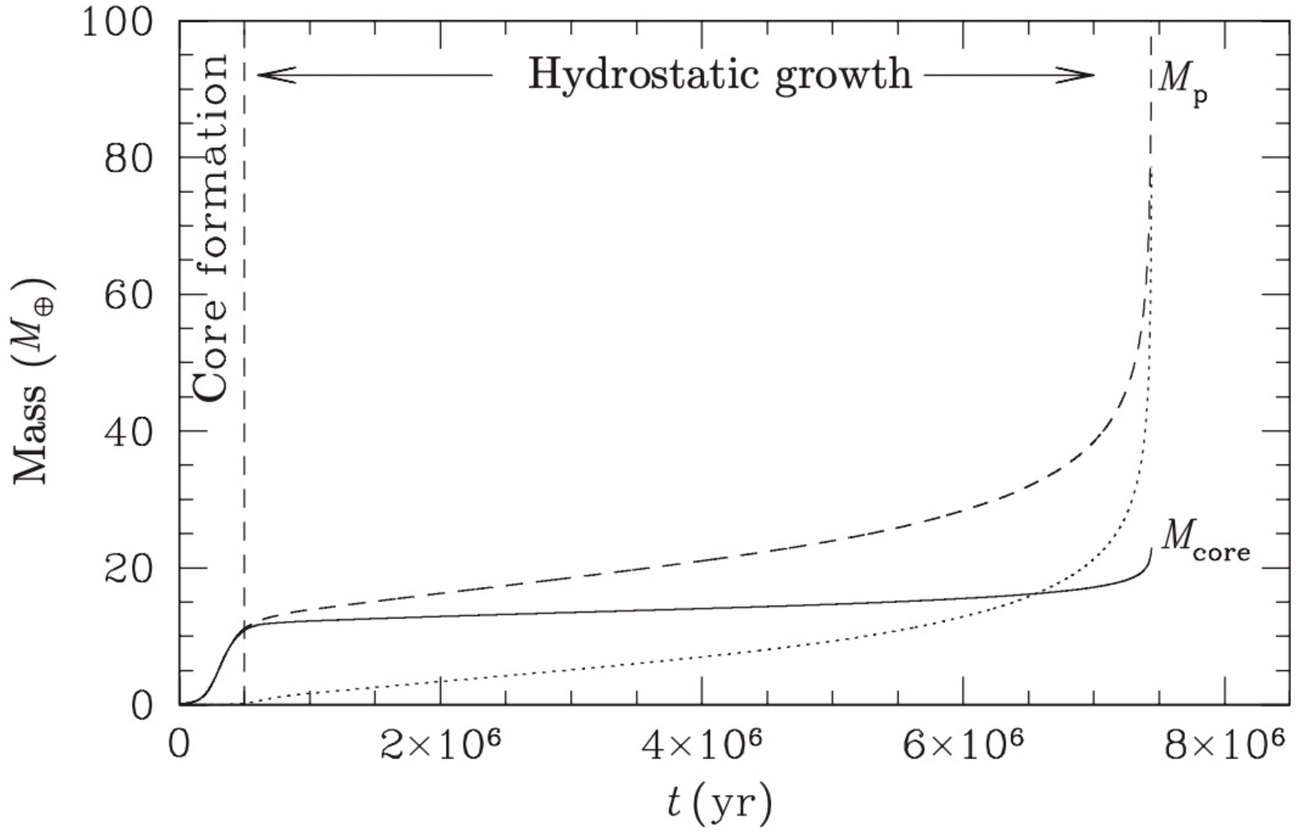
-> dictates how dust moves in relation to the gas

Formation of giant planets

Core accretion model of *Pollack et al. 1996*

- Core formation
- Slow accretion of gas
- $M_{\rm env} > M_{\rm core}$

  -> runaway growth
- At high $\Sigma_{\rm gas}$, $\Sigma_{\rm dust}$ timescales significantly shorter

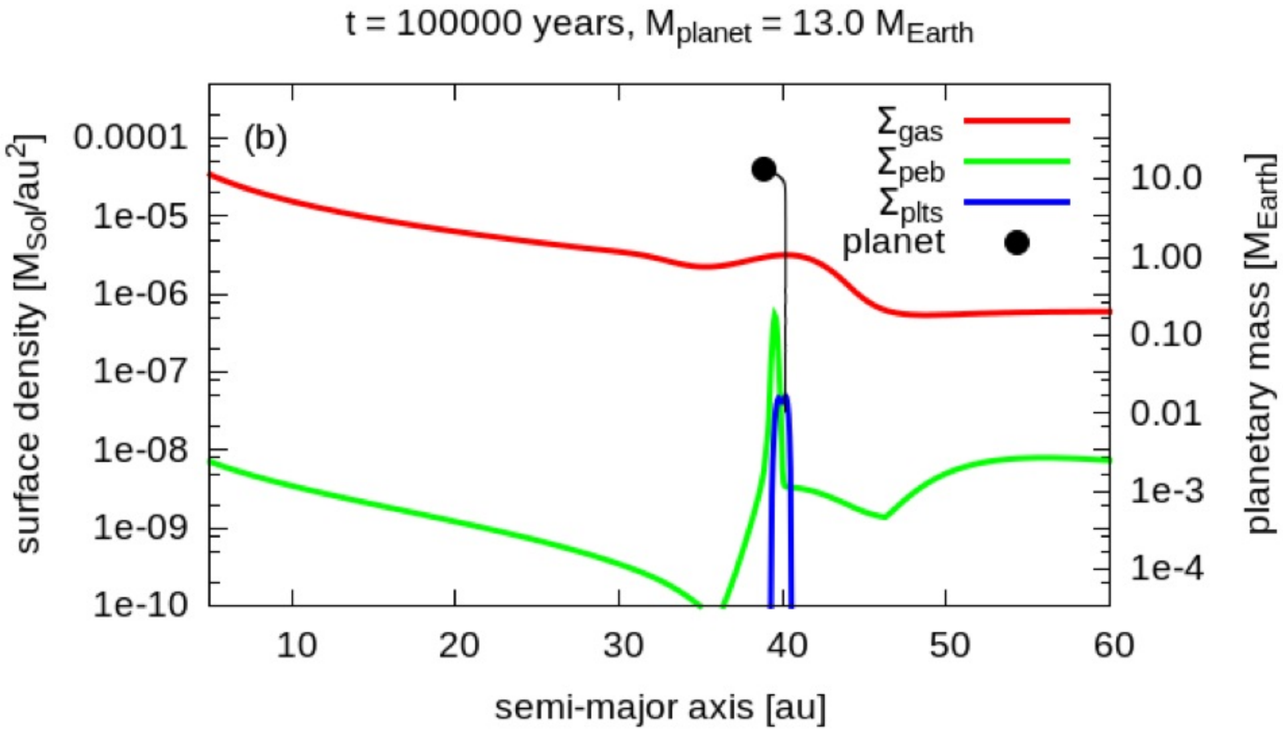


Formation of giant planets

Where can they form rapidly?

Sándor et al. 2024:
Planetesimal and planet formation in transient dust traps

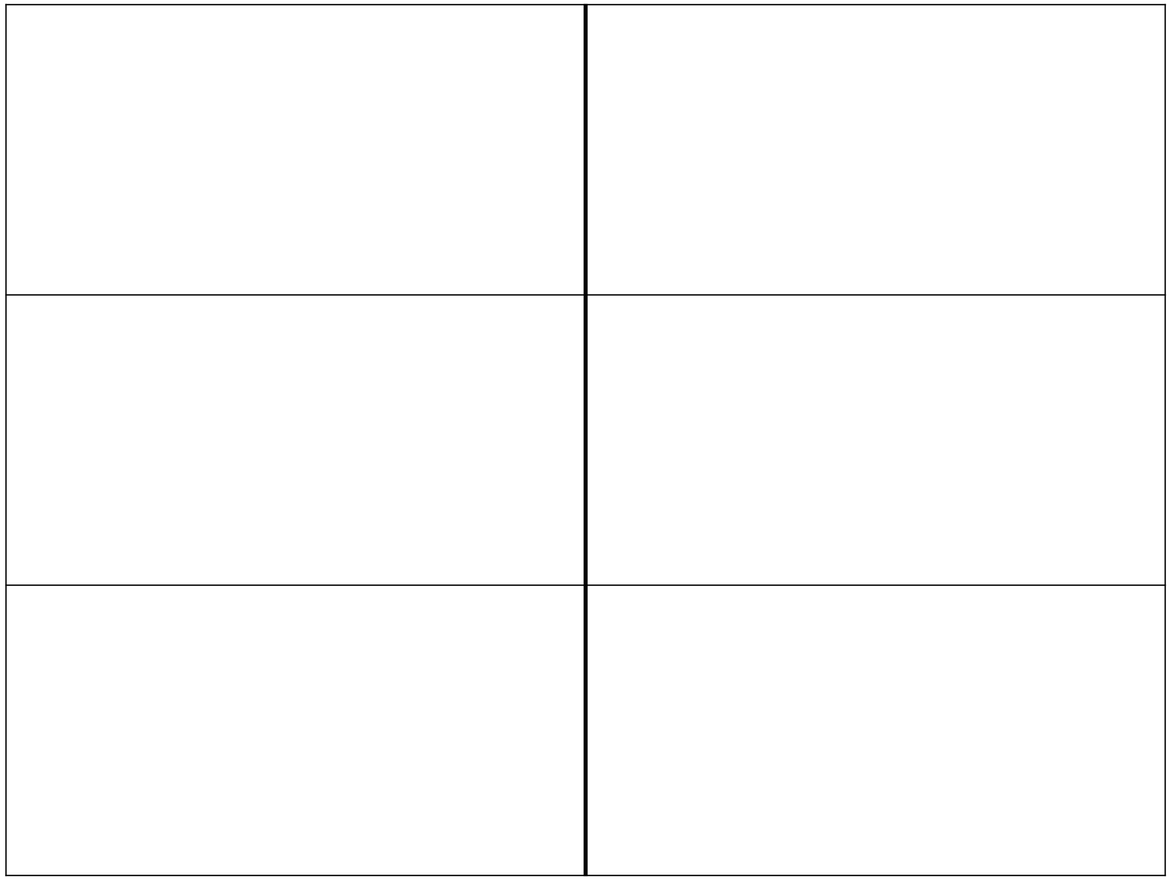
- Artificial dust trap - density jump
- Fast planet formation ~10^5 yr



Motivation

6 models

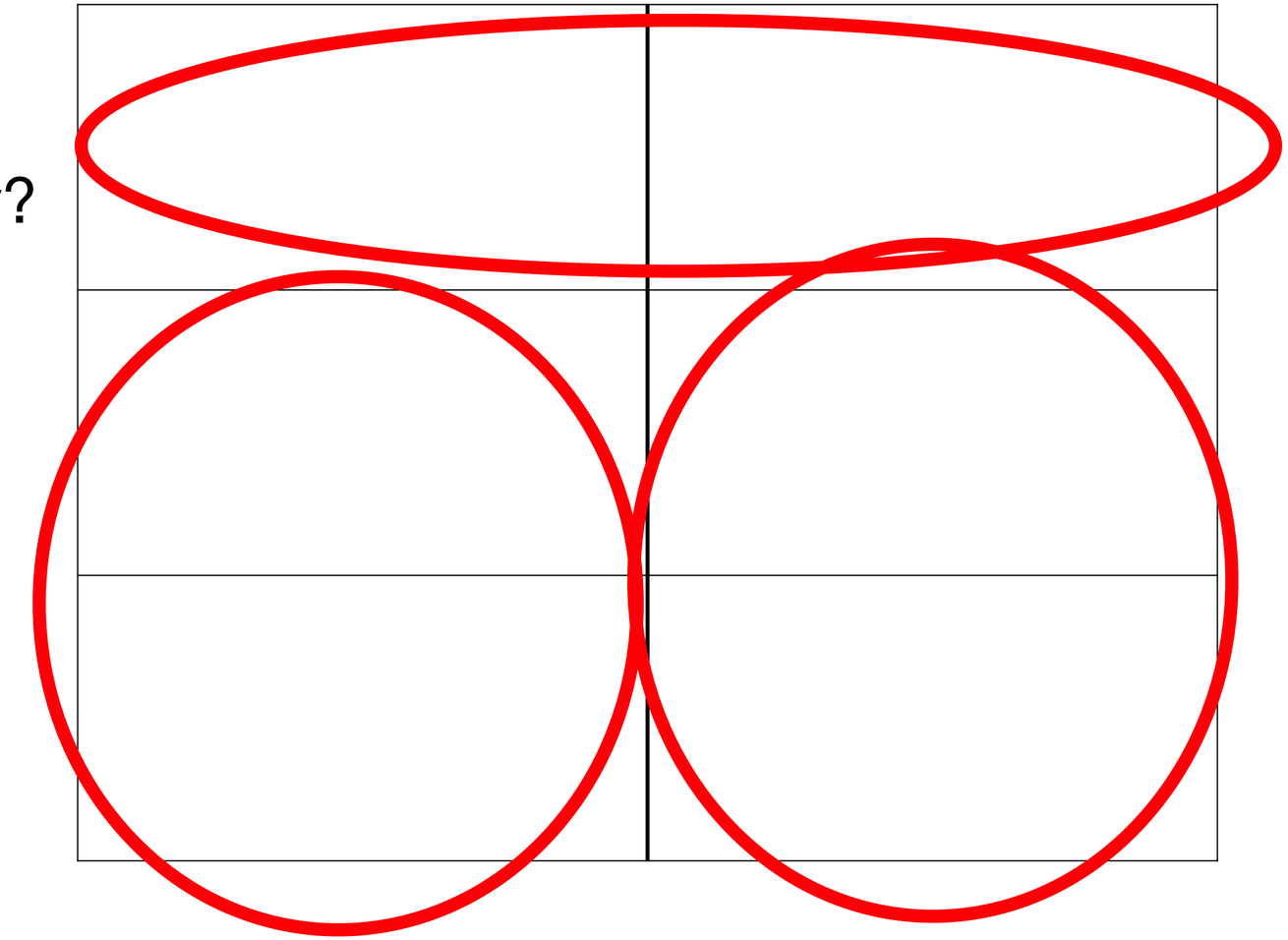
- Can dust traps form spontaneously?
- How they evolve in time?



Motivation

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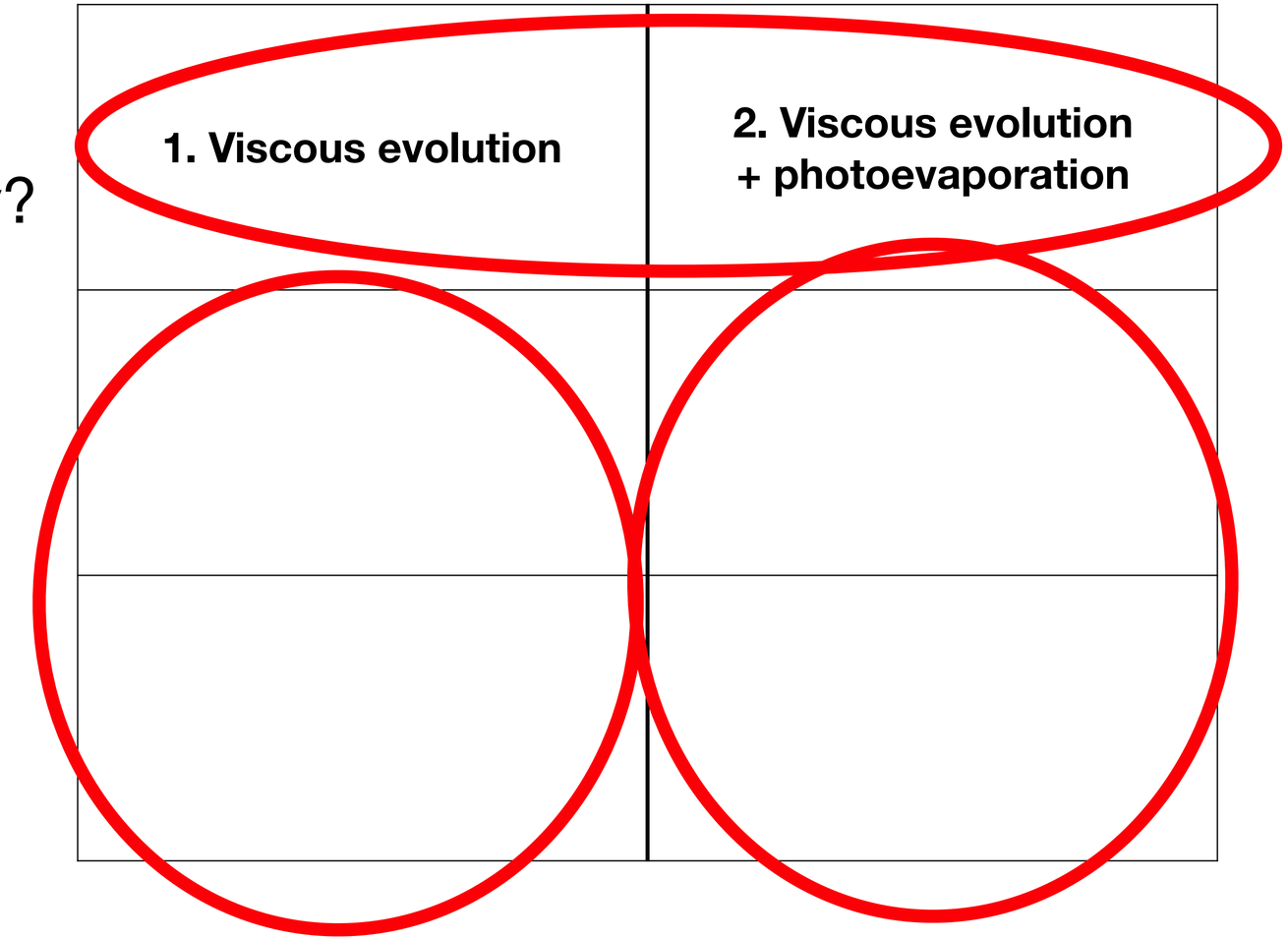
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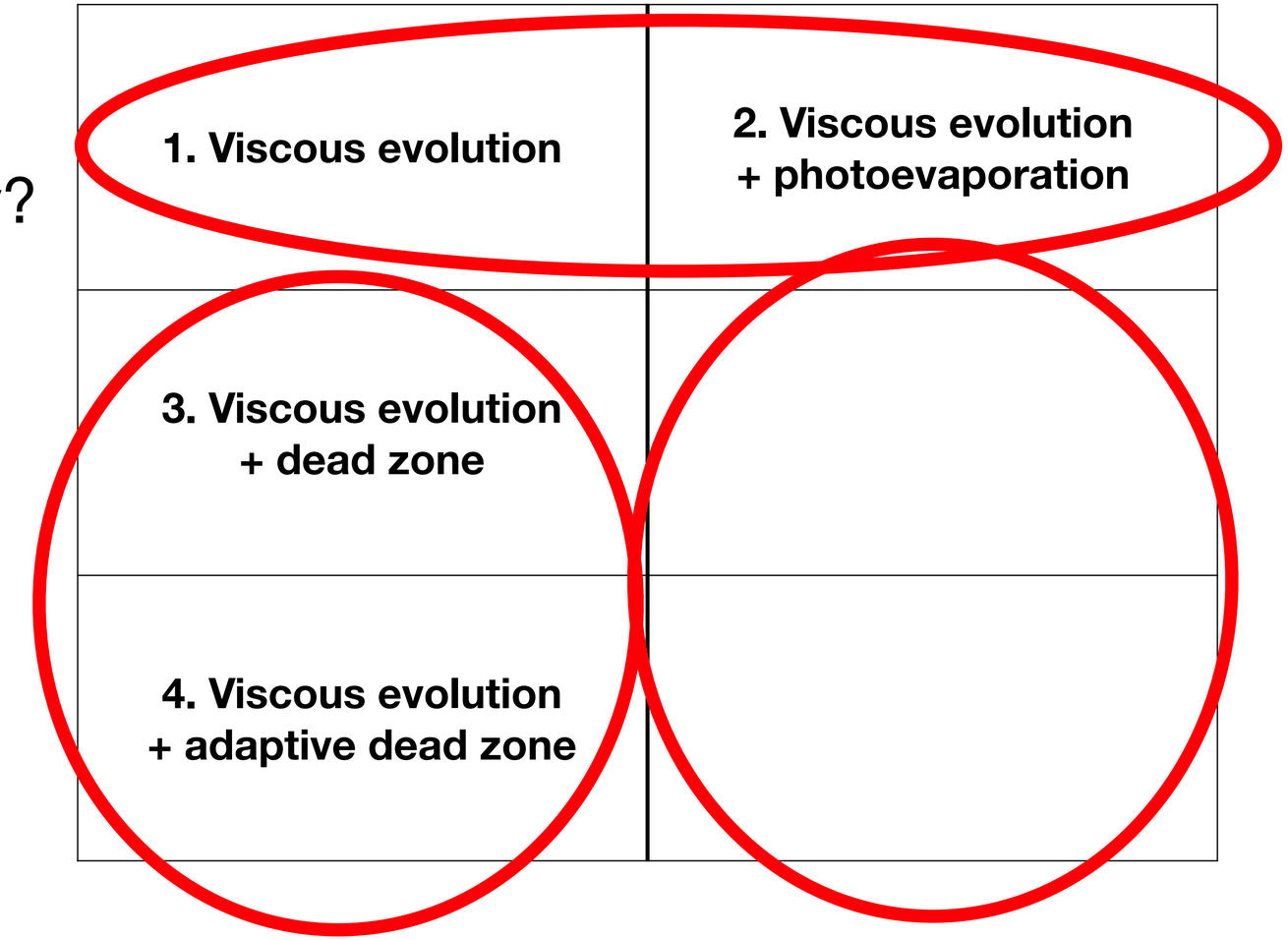
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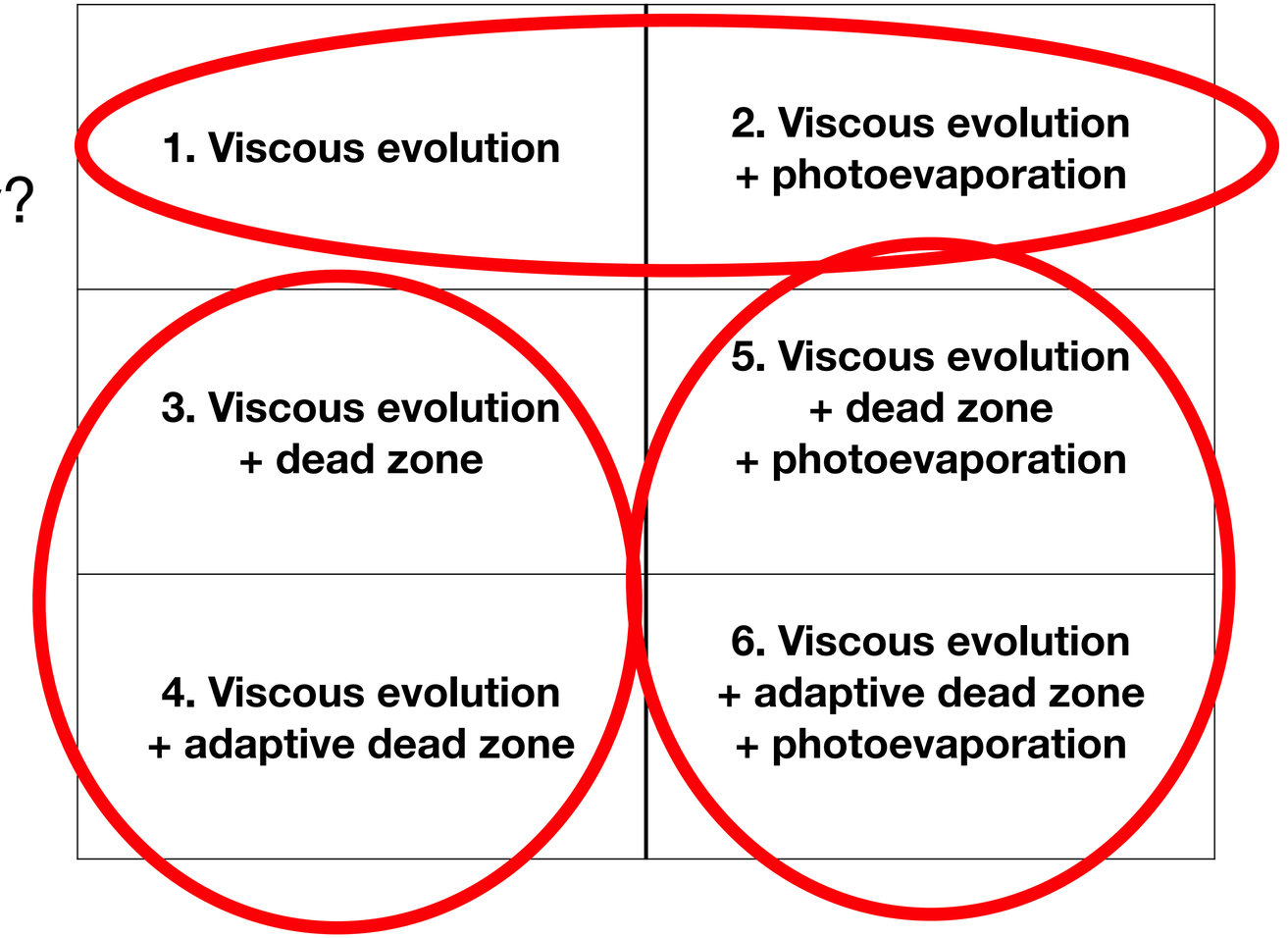
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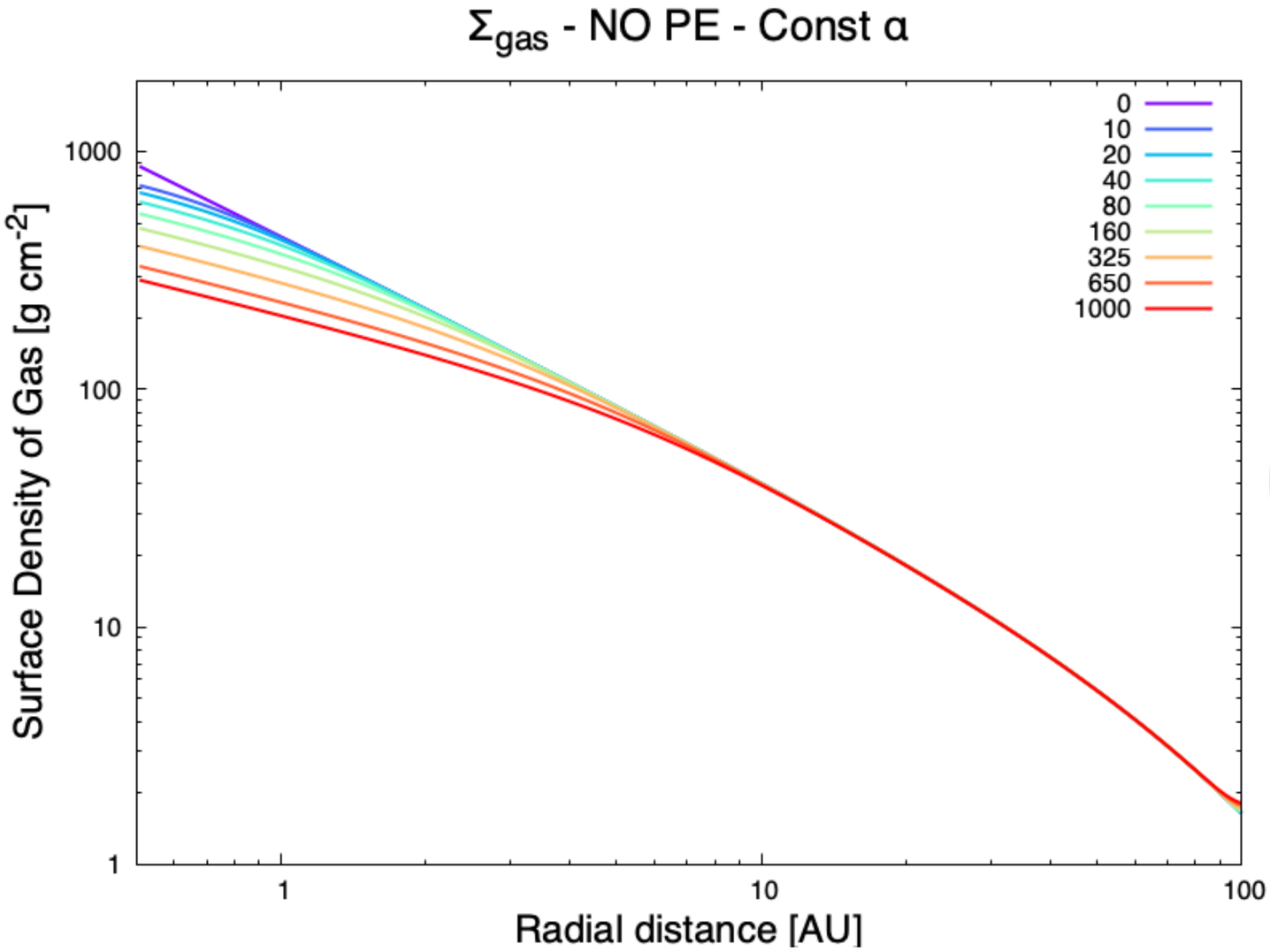
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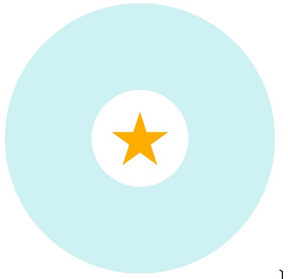
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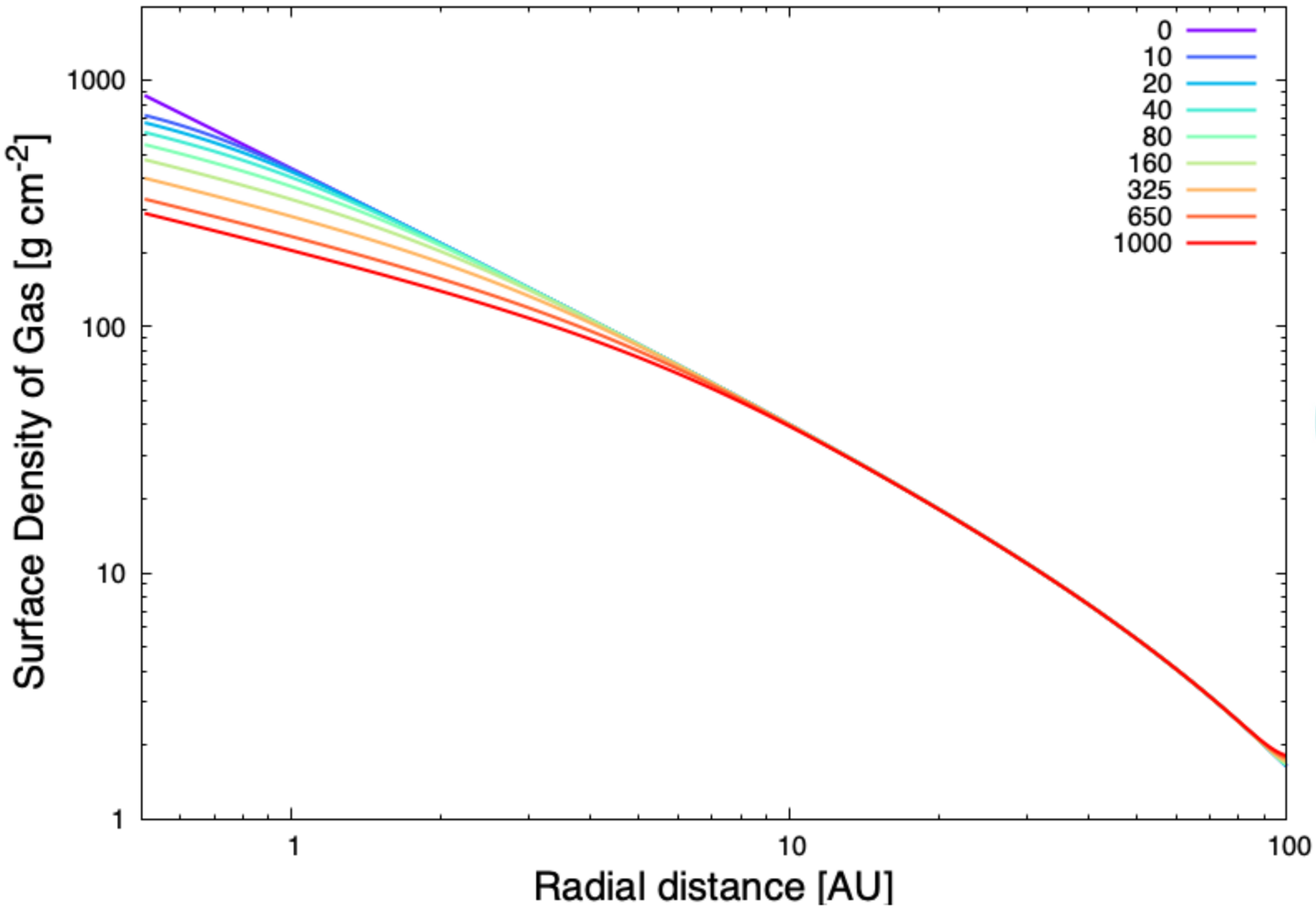


1D gas evolution: viscous

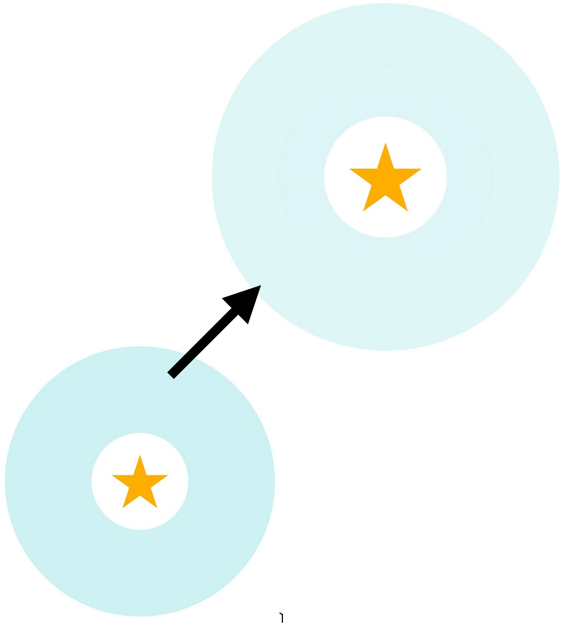




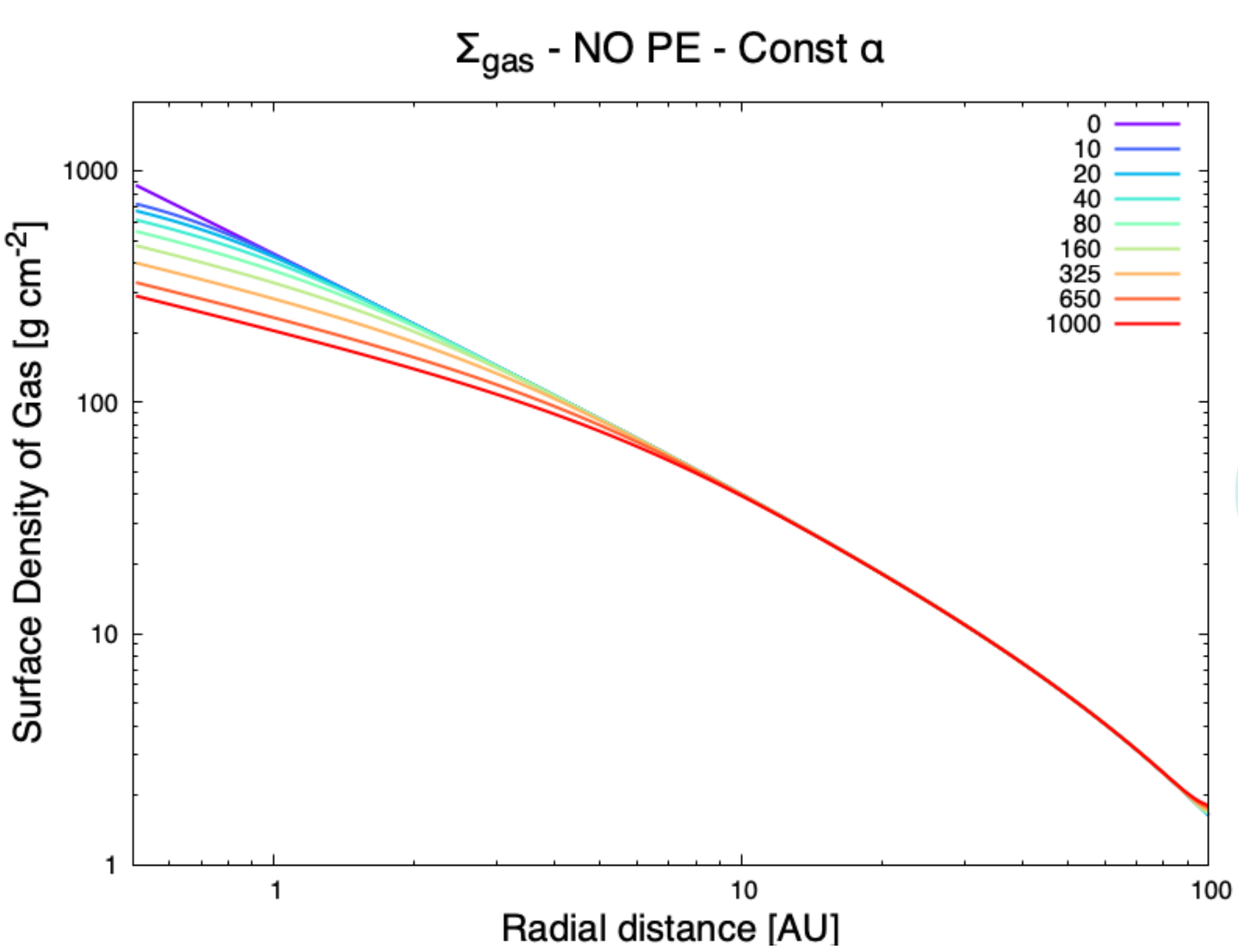
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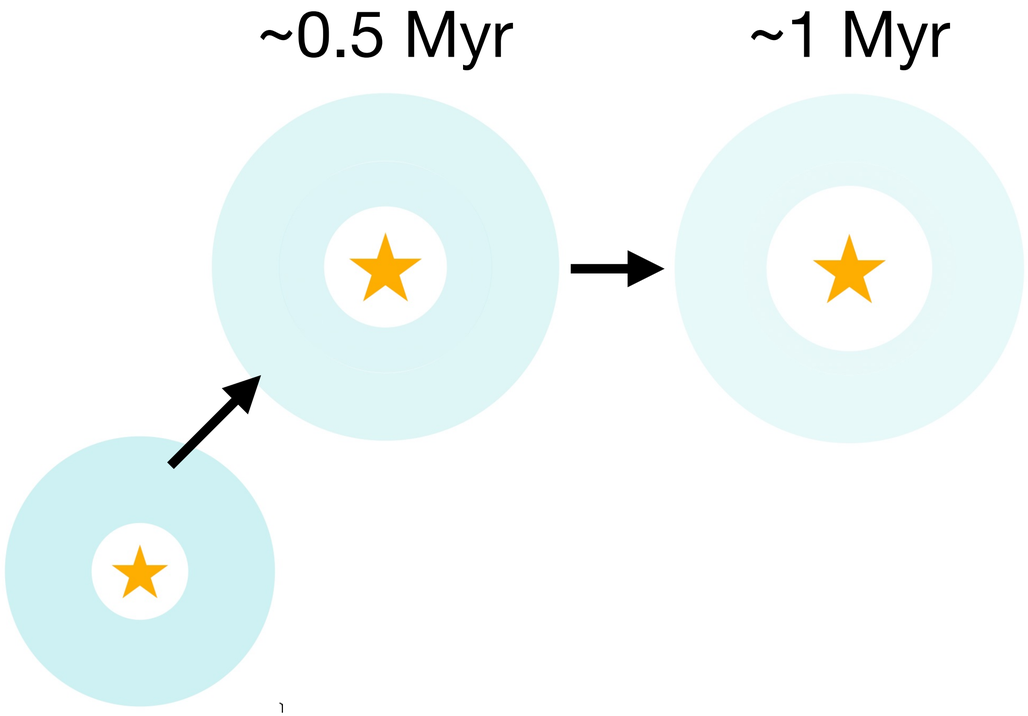


~0.5 Myr

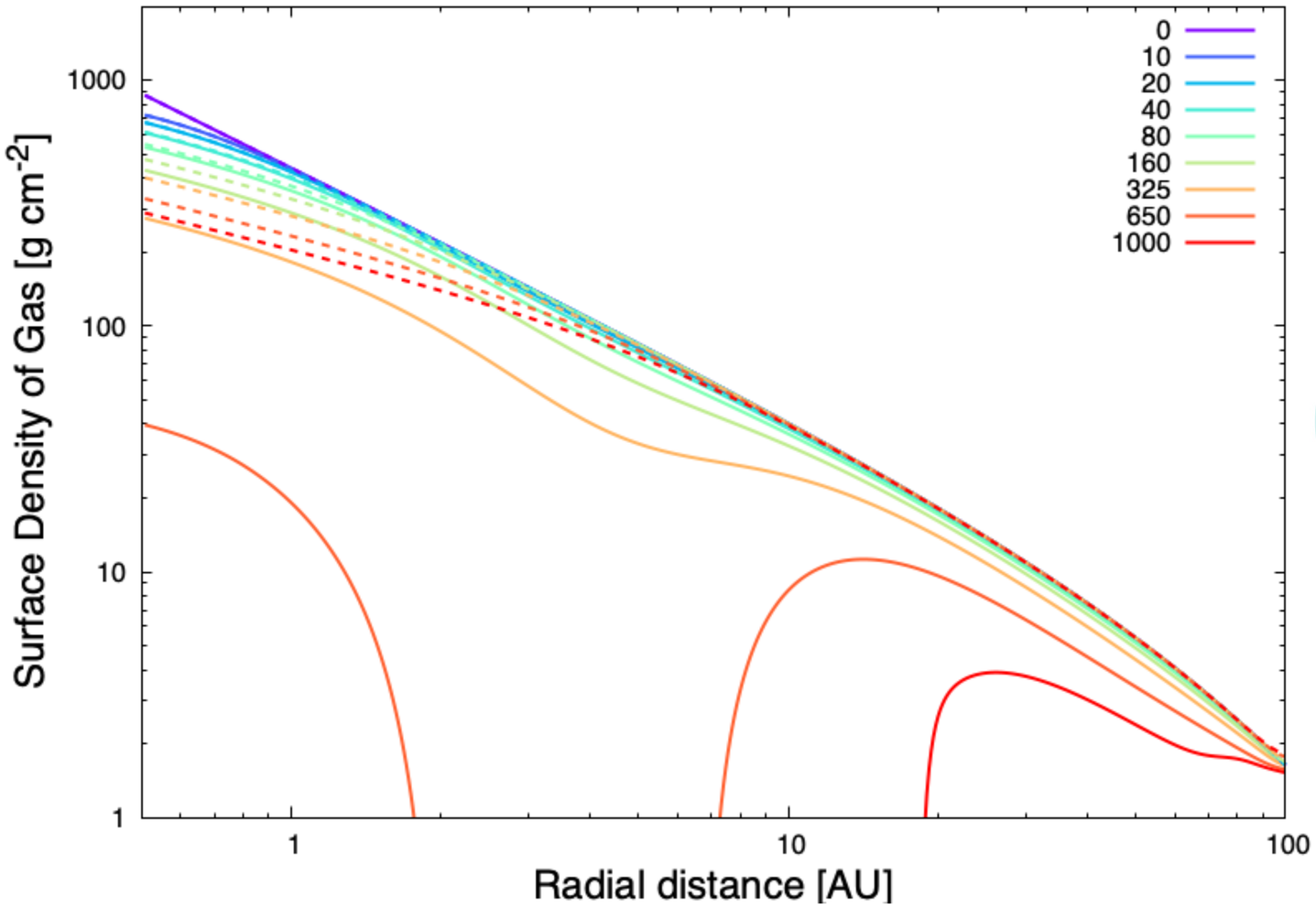


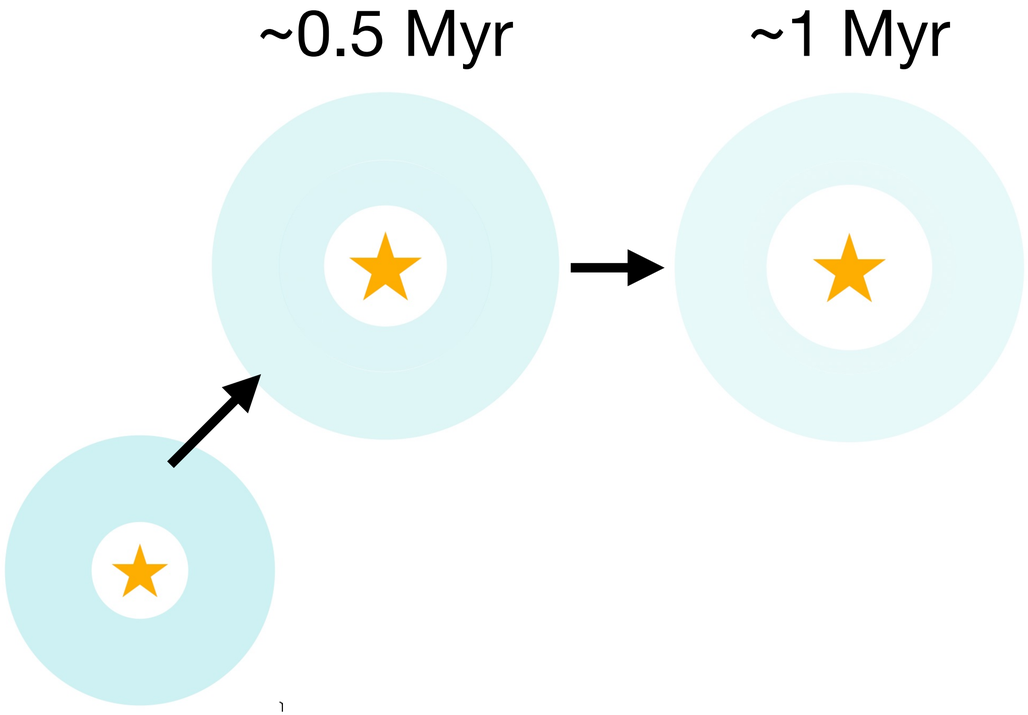
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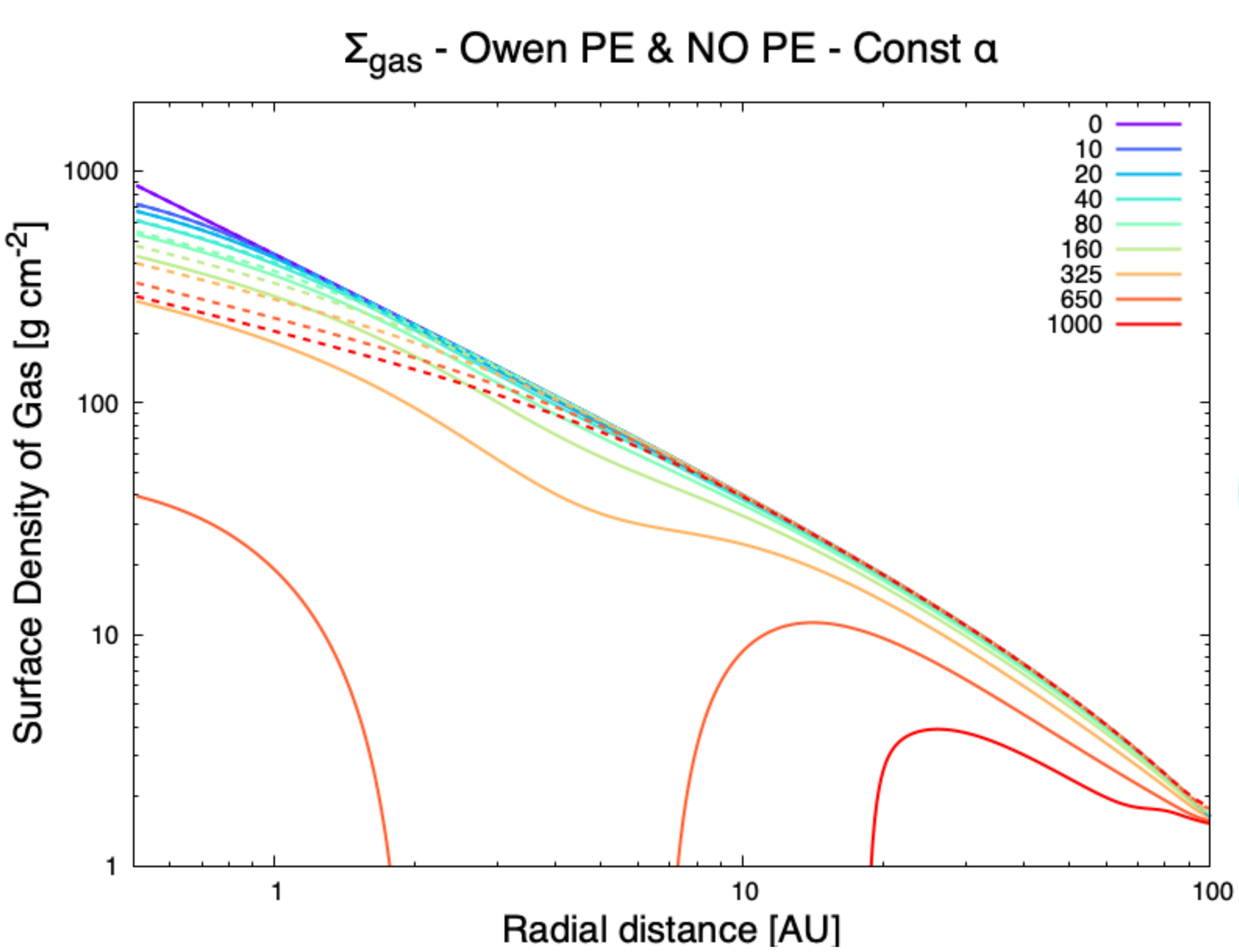


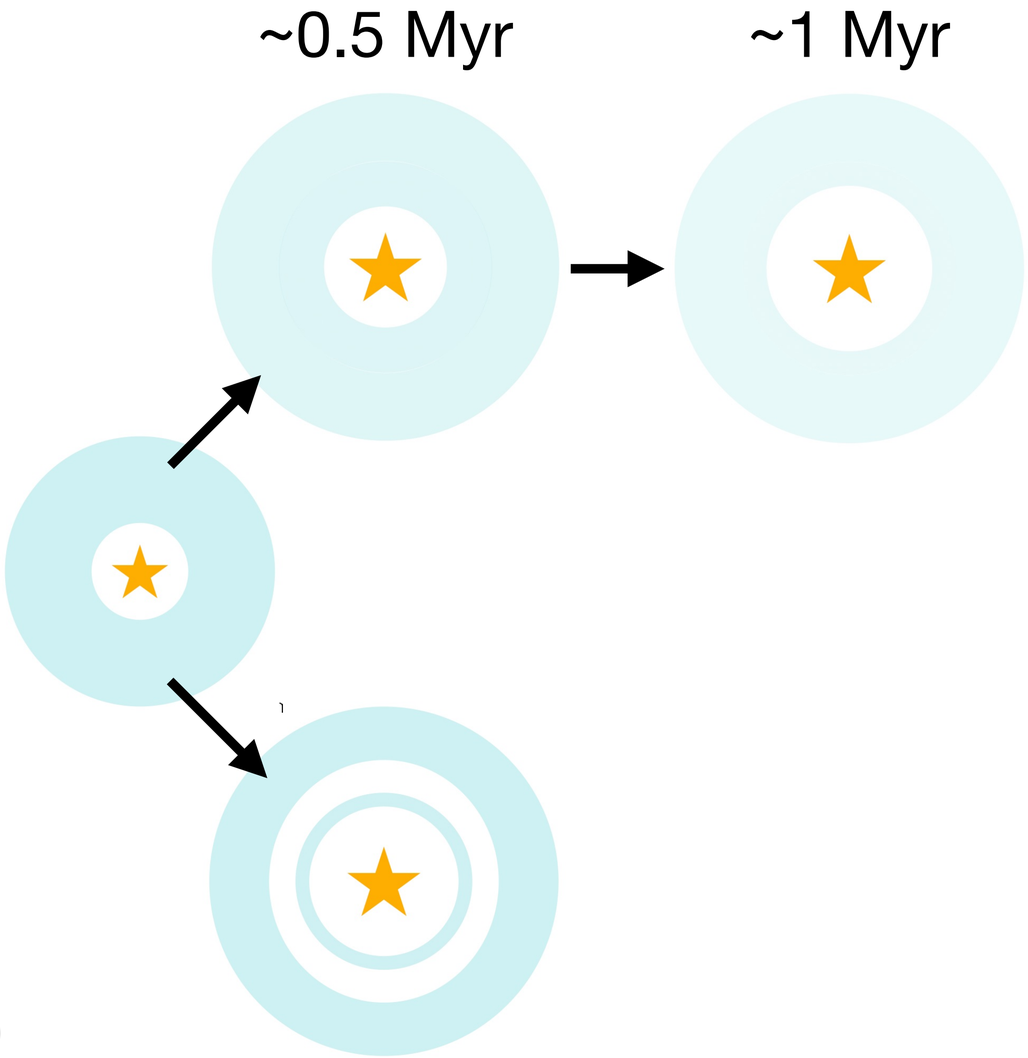
1D gas evolution: viscous + PE



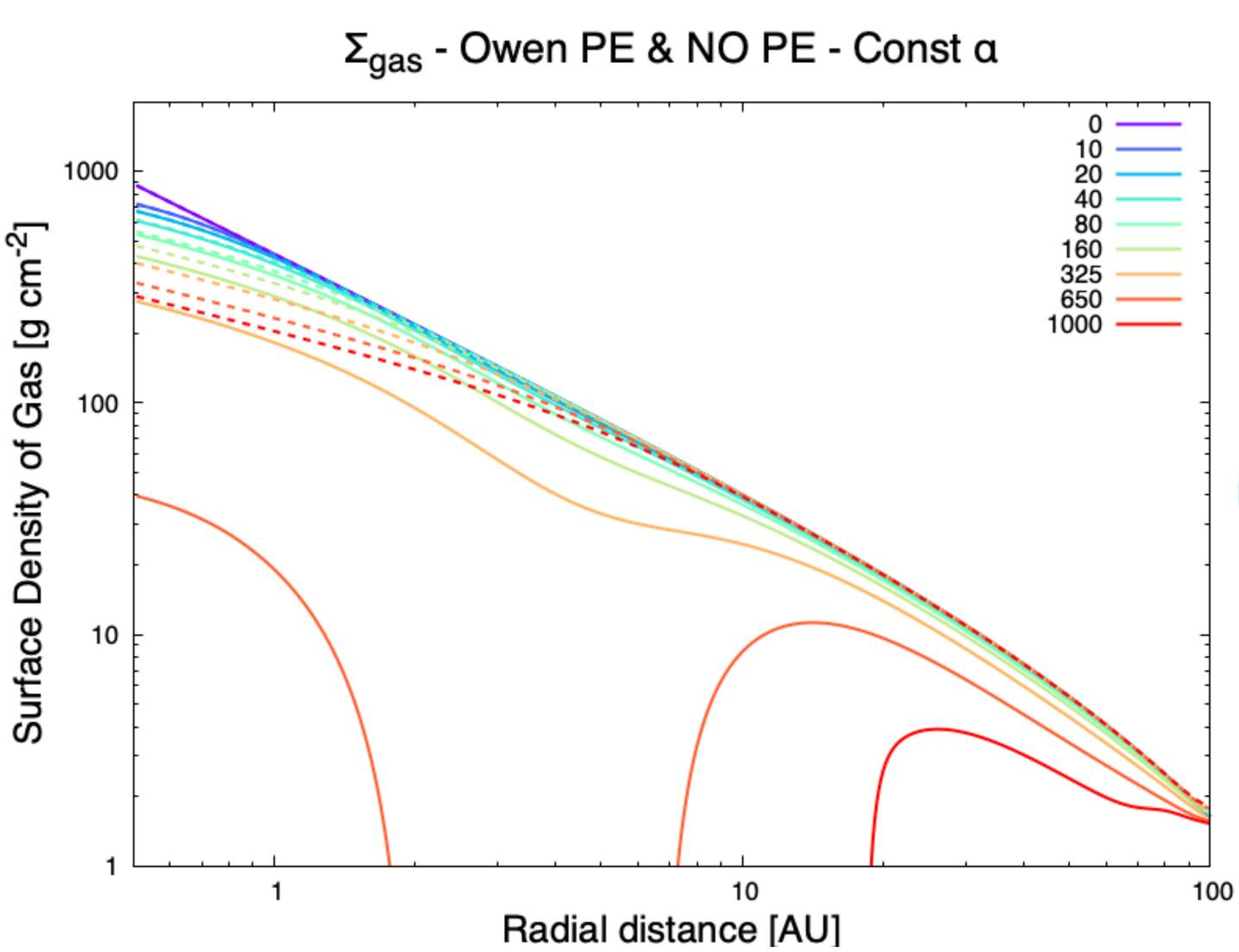


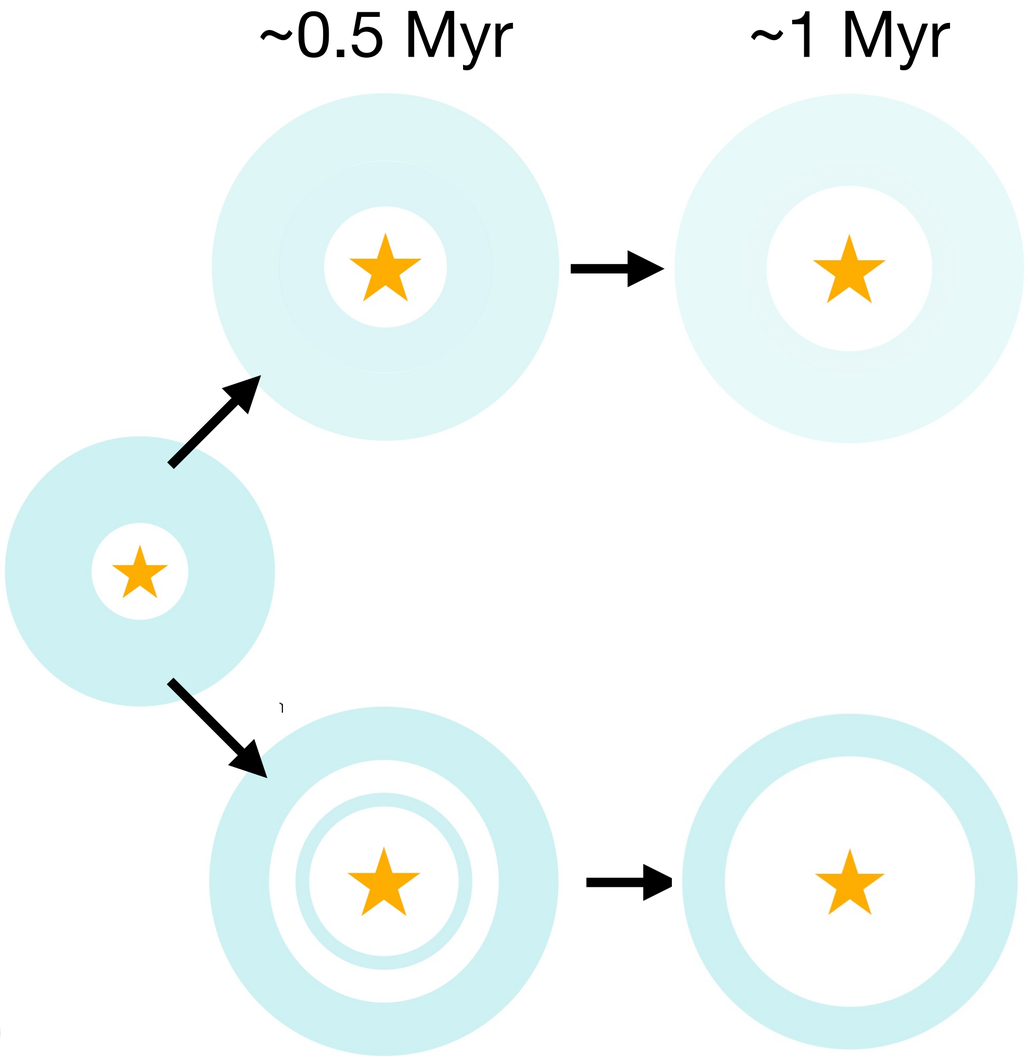
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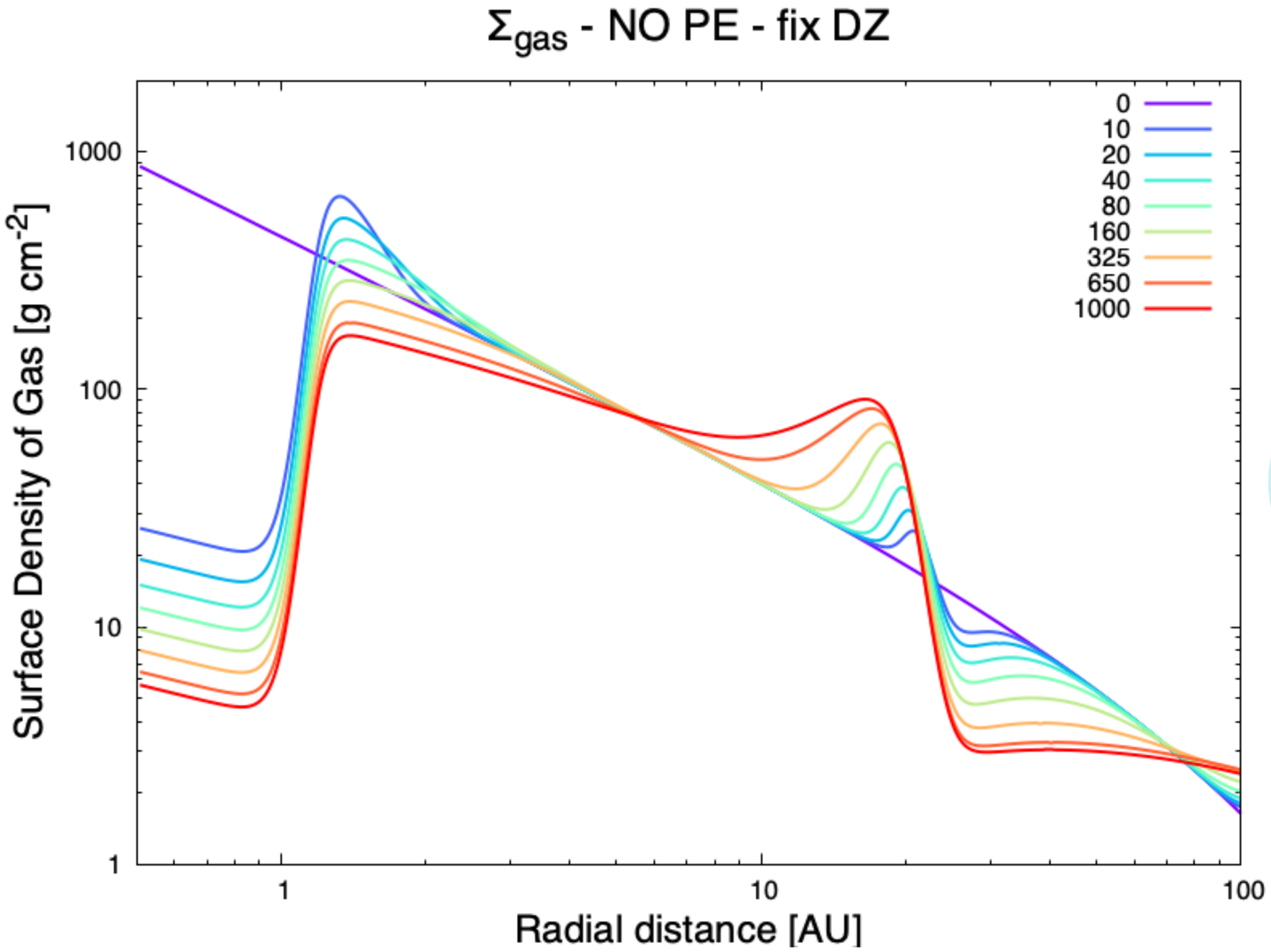


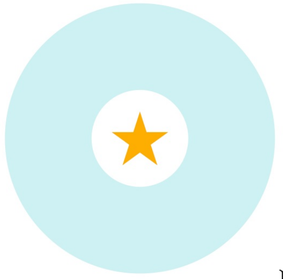
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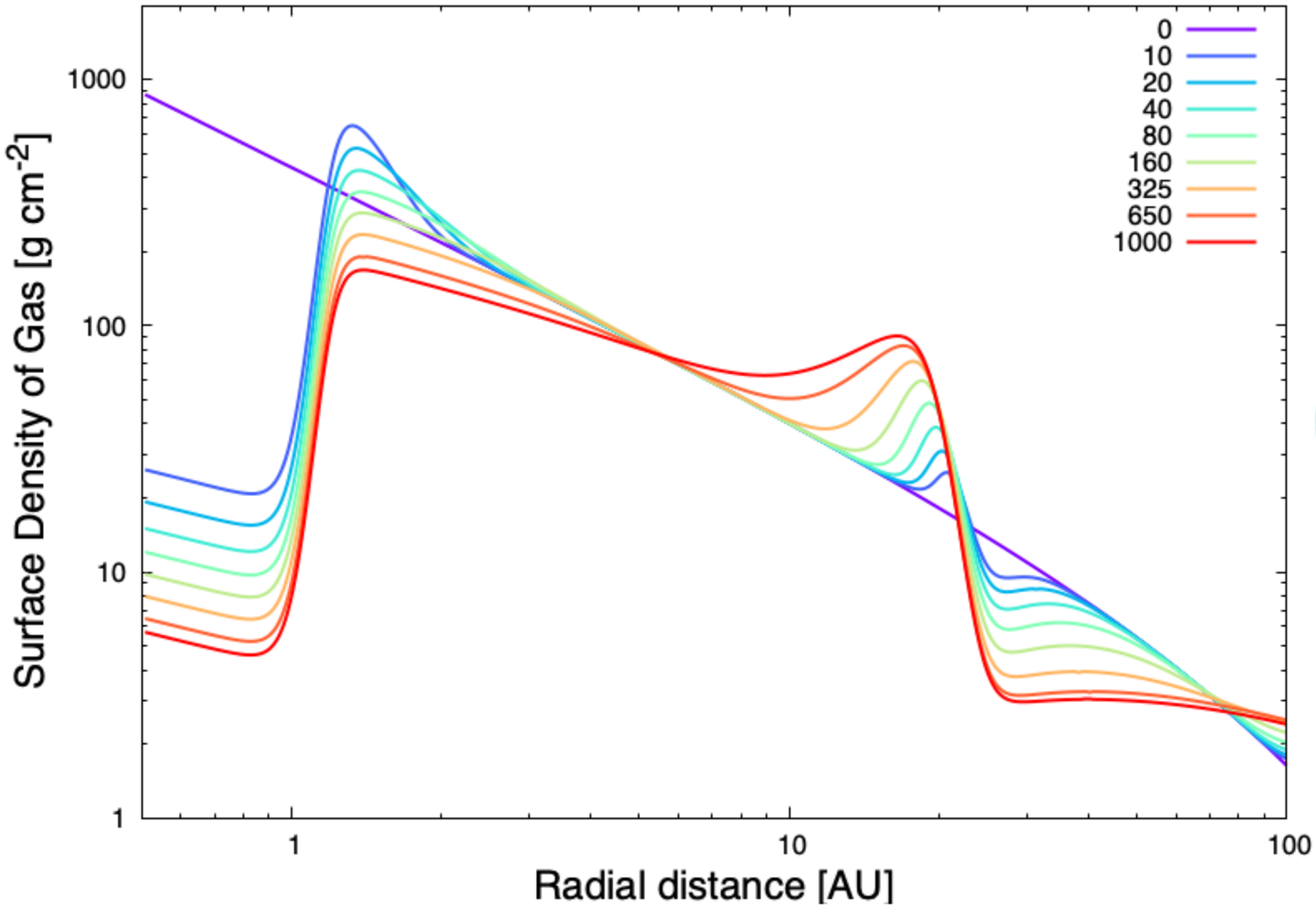


1D gas evolution: viscous + DZ

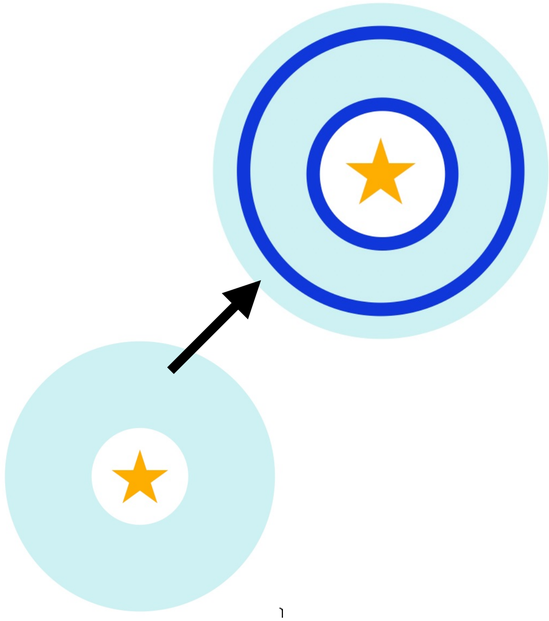




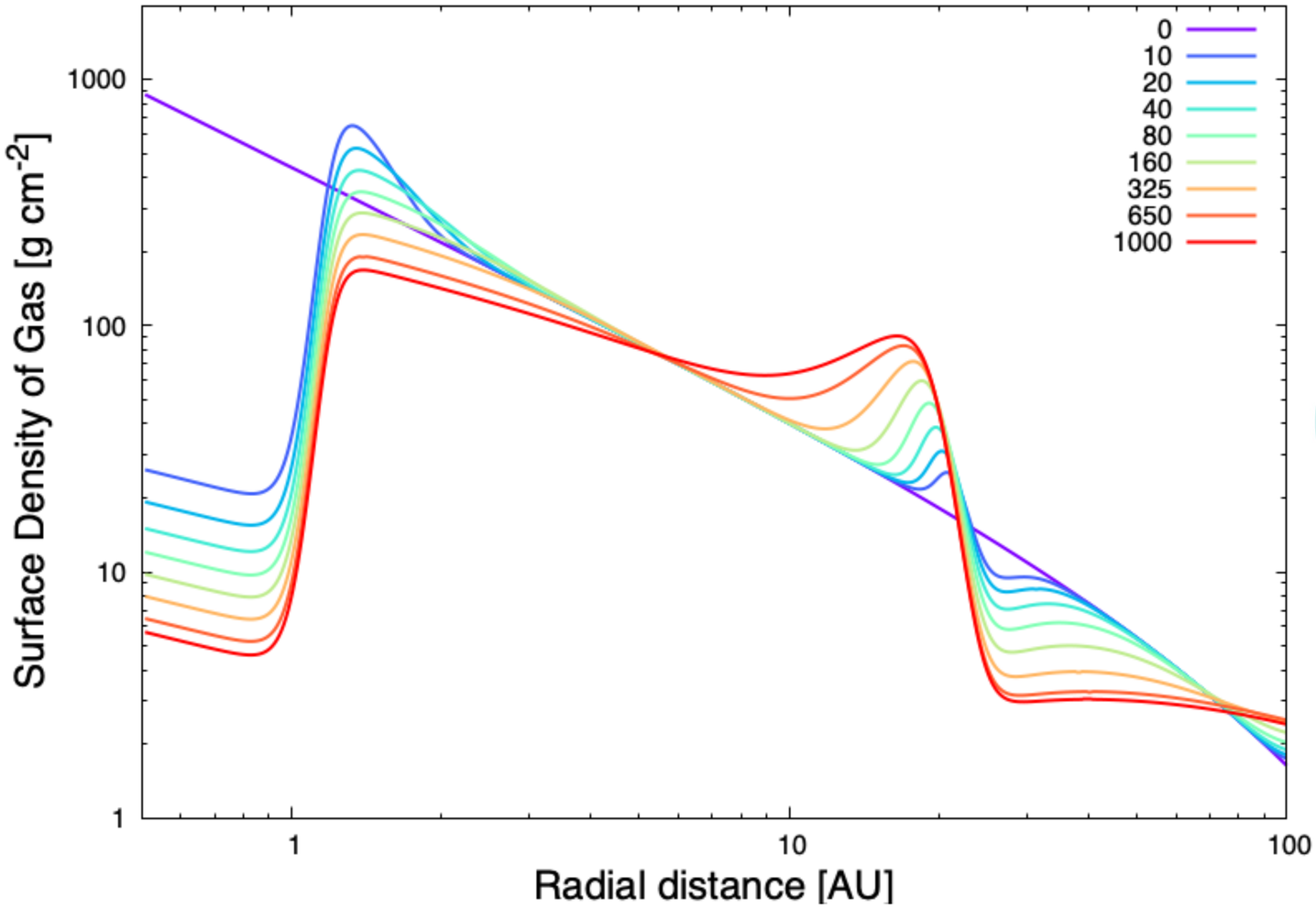
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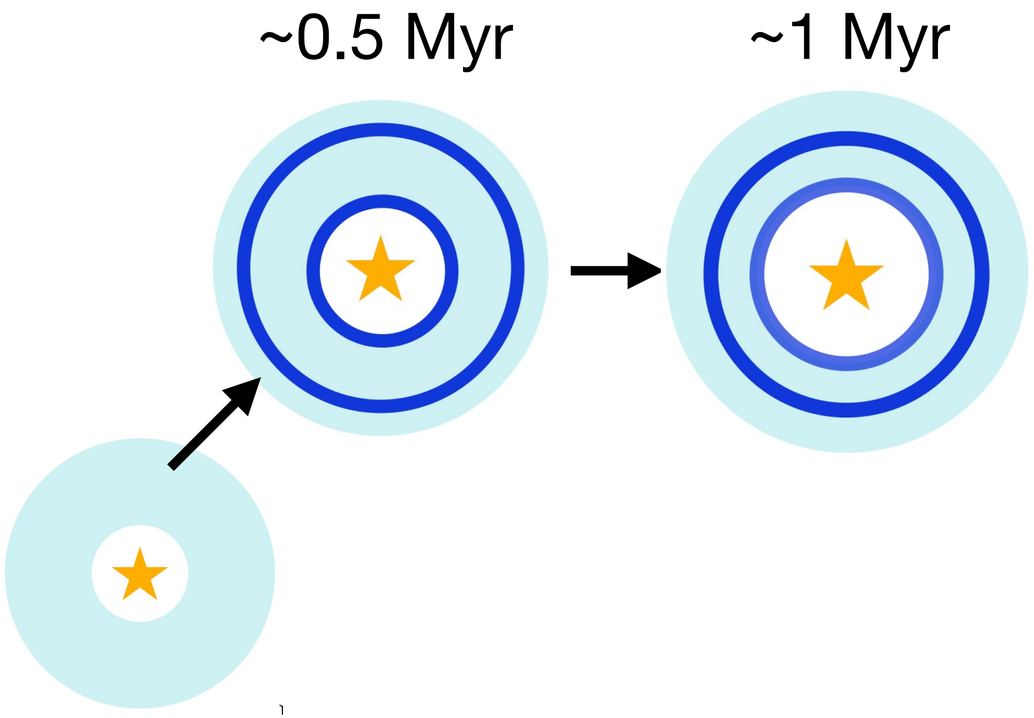


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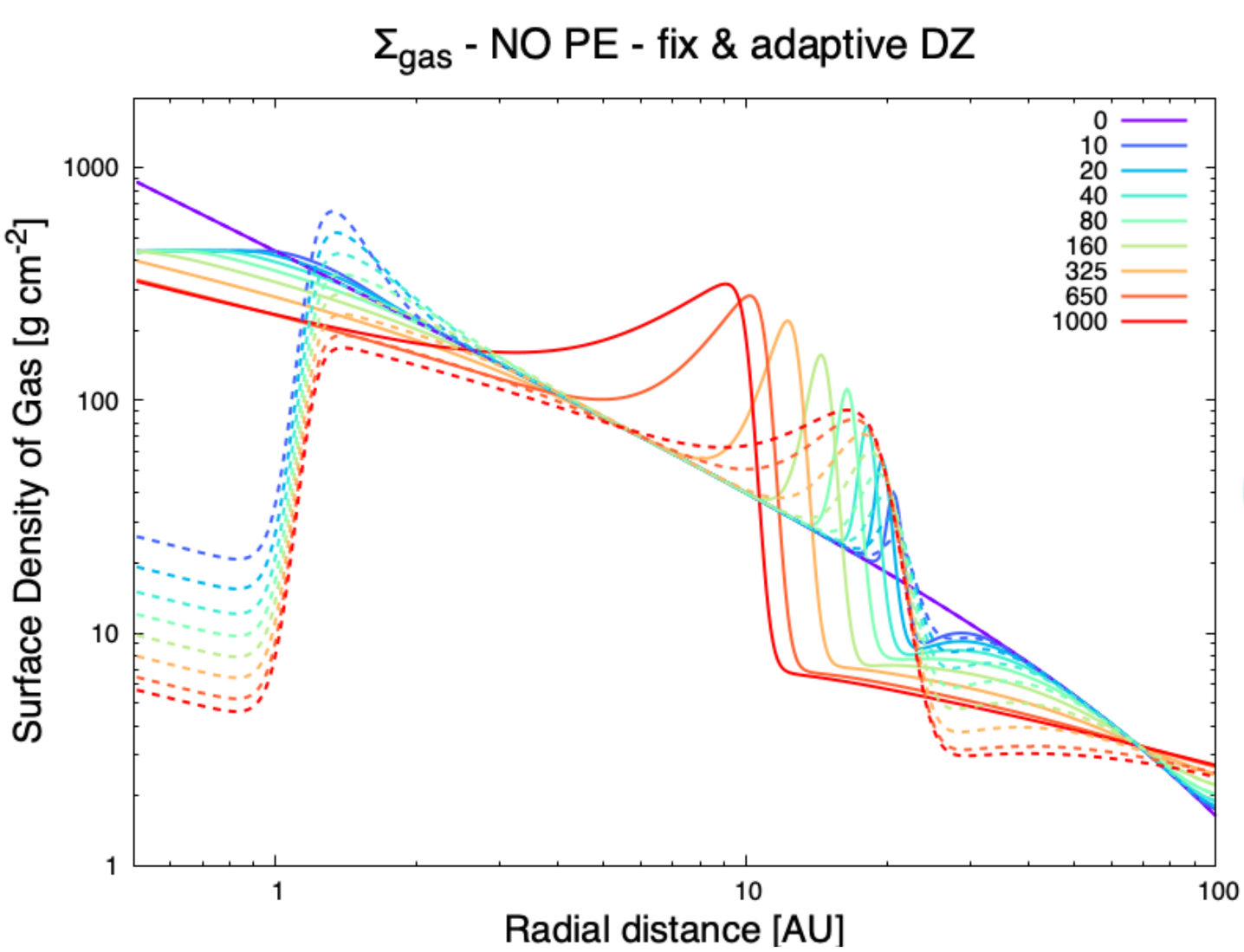


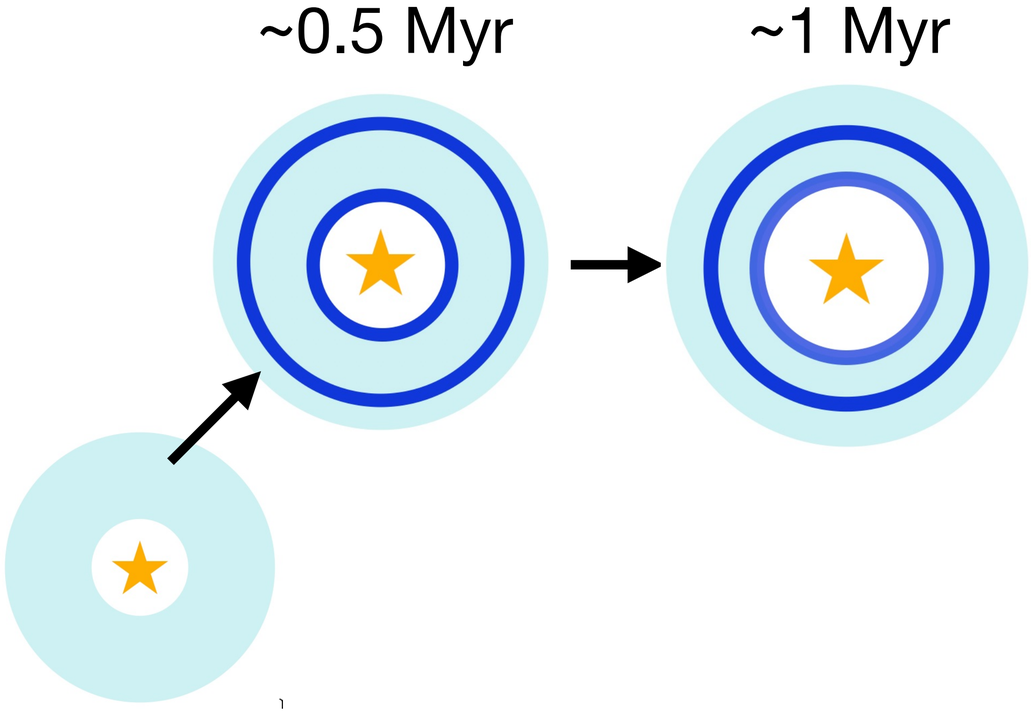
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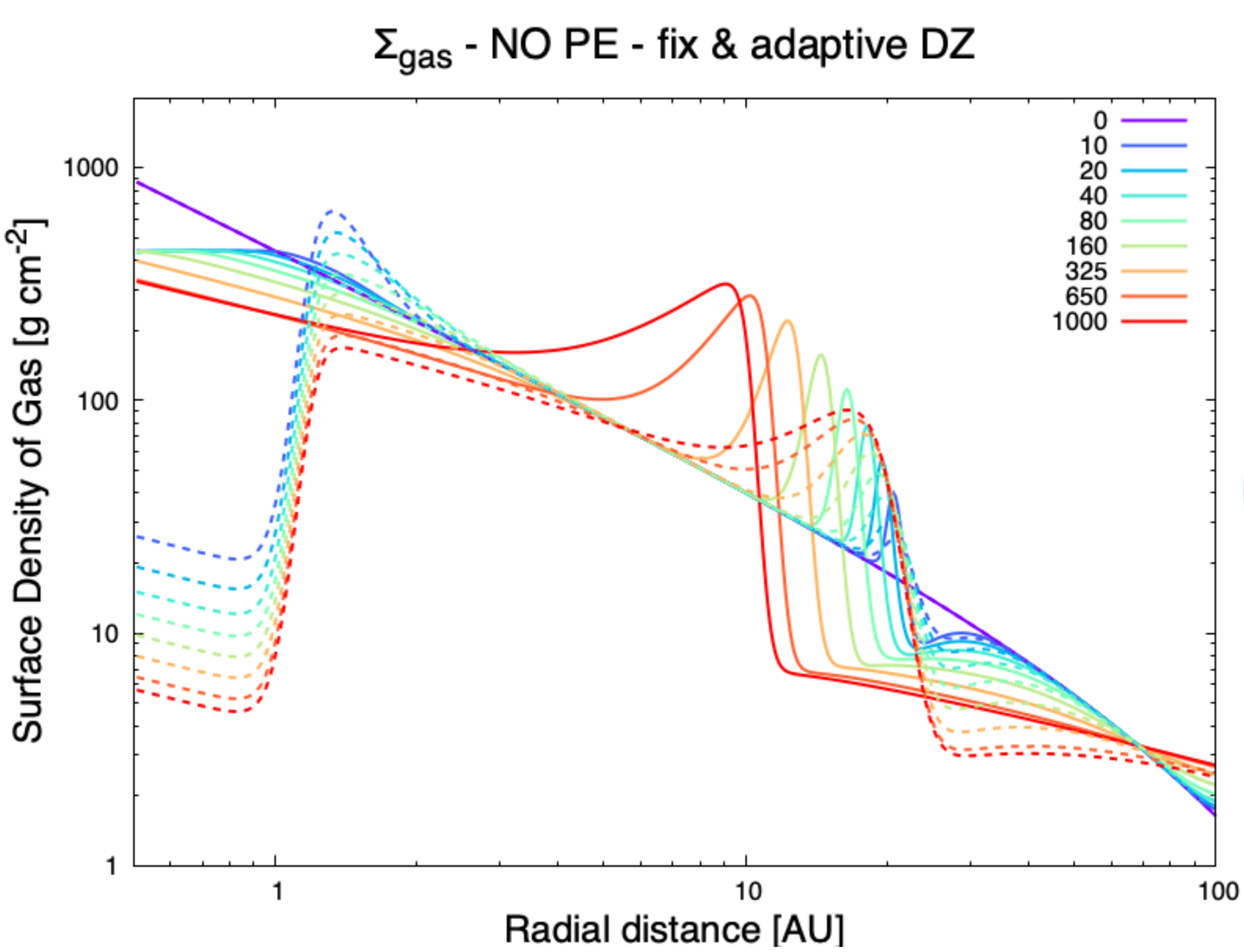


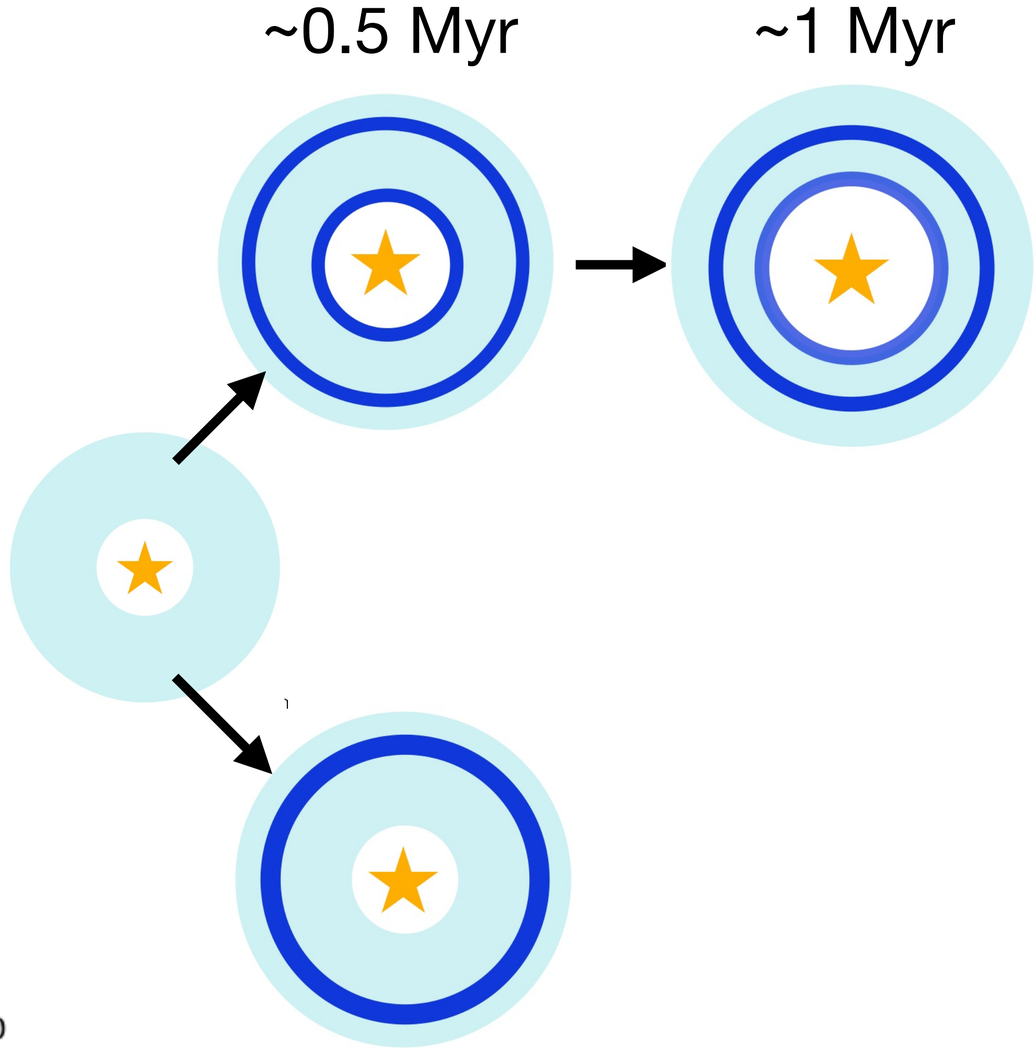
1D gas evolution: viscous + ADZ



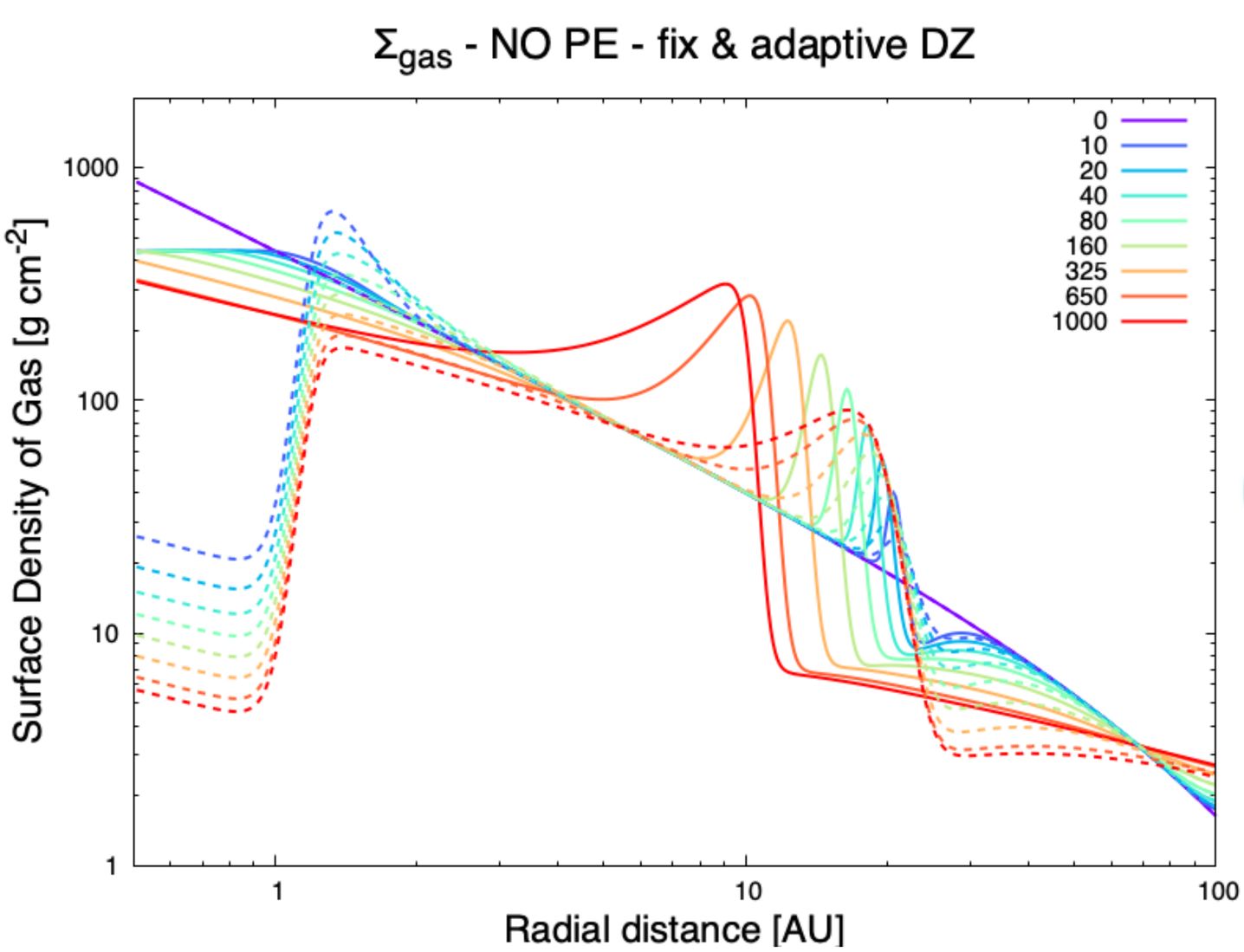


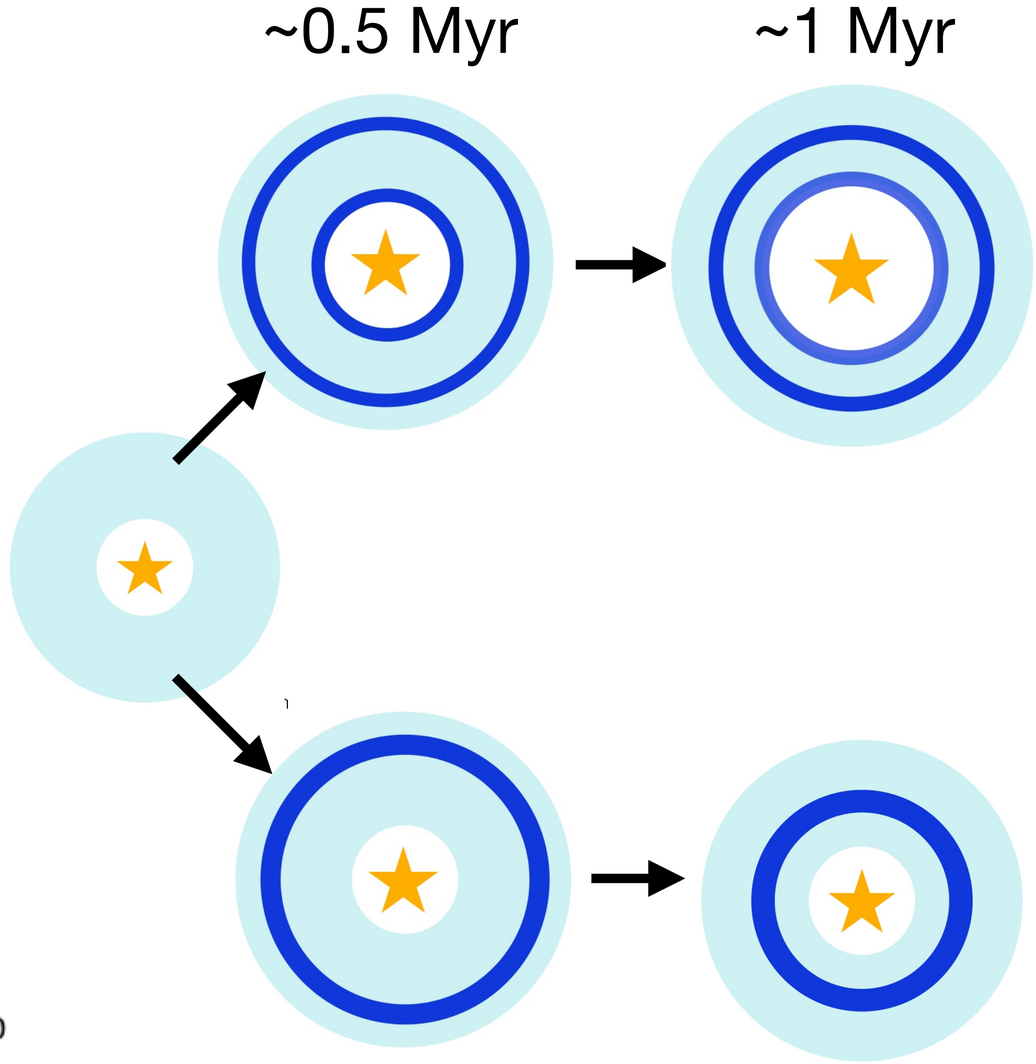
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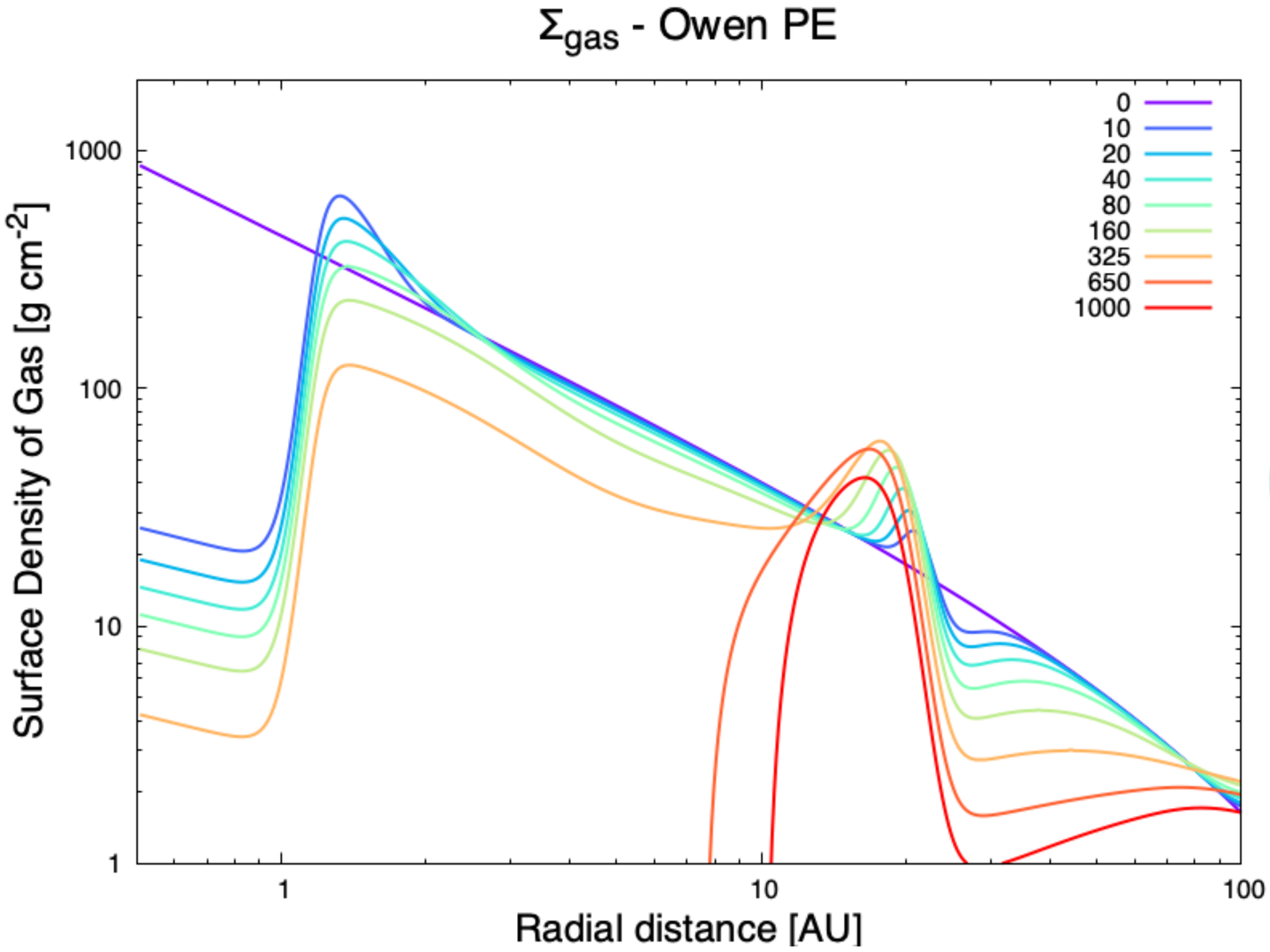


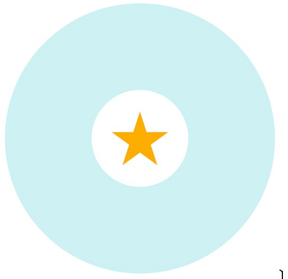
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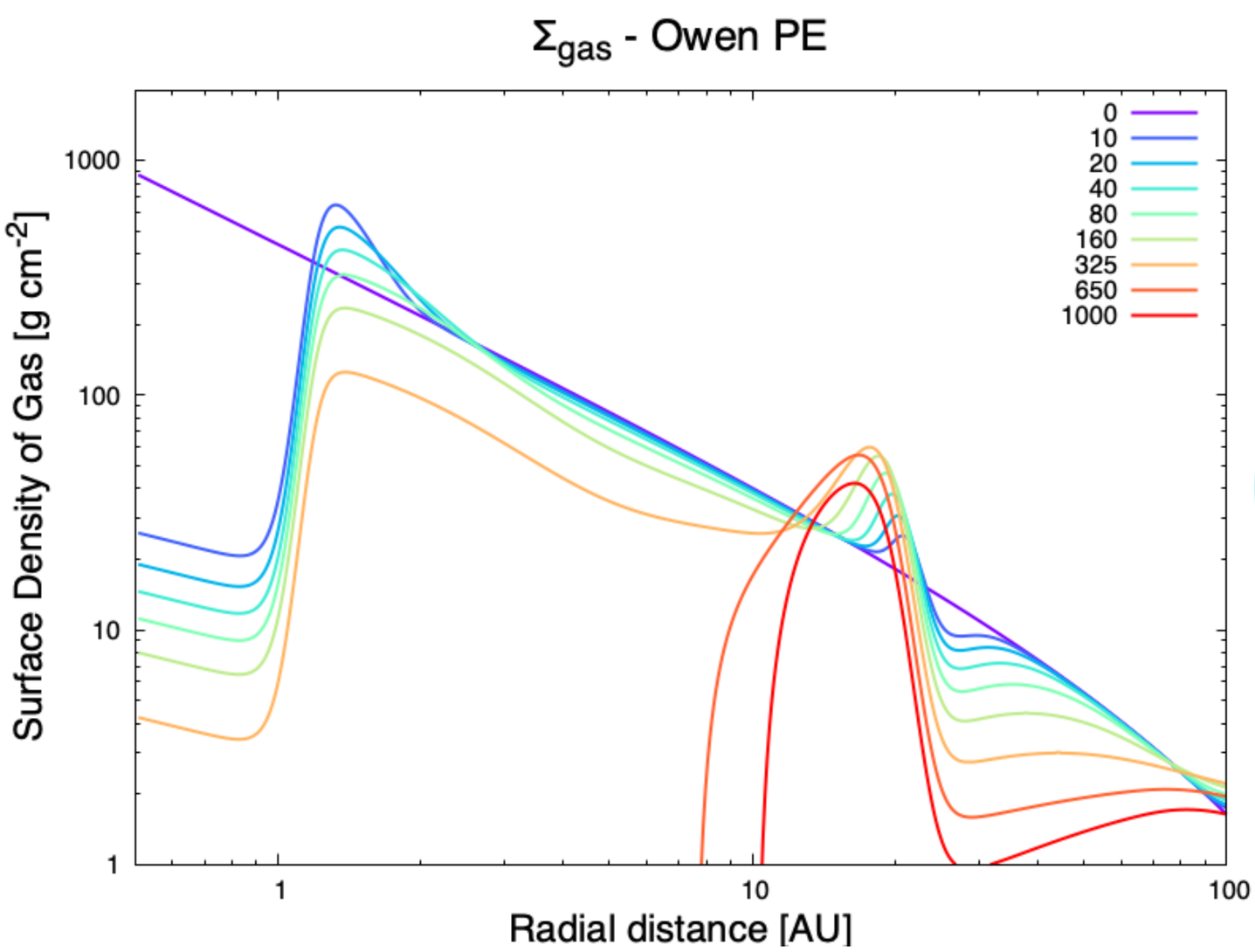


1D gas evolution: viscous + DZ + PE

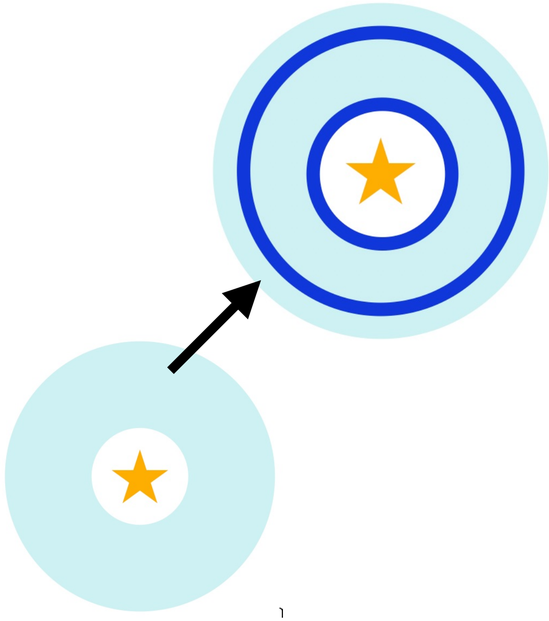




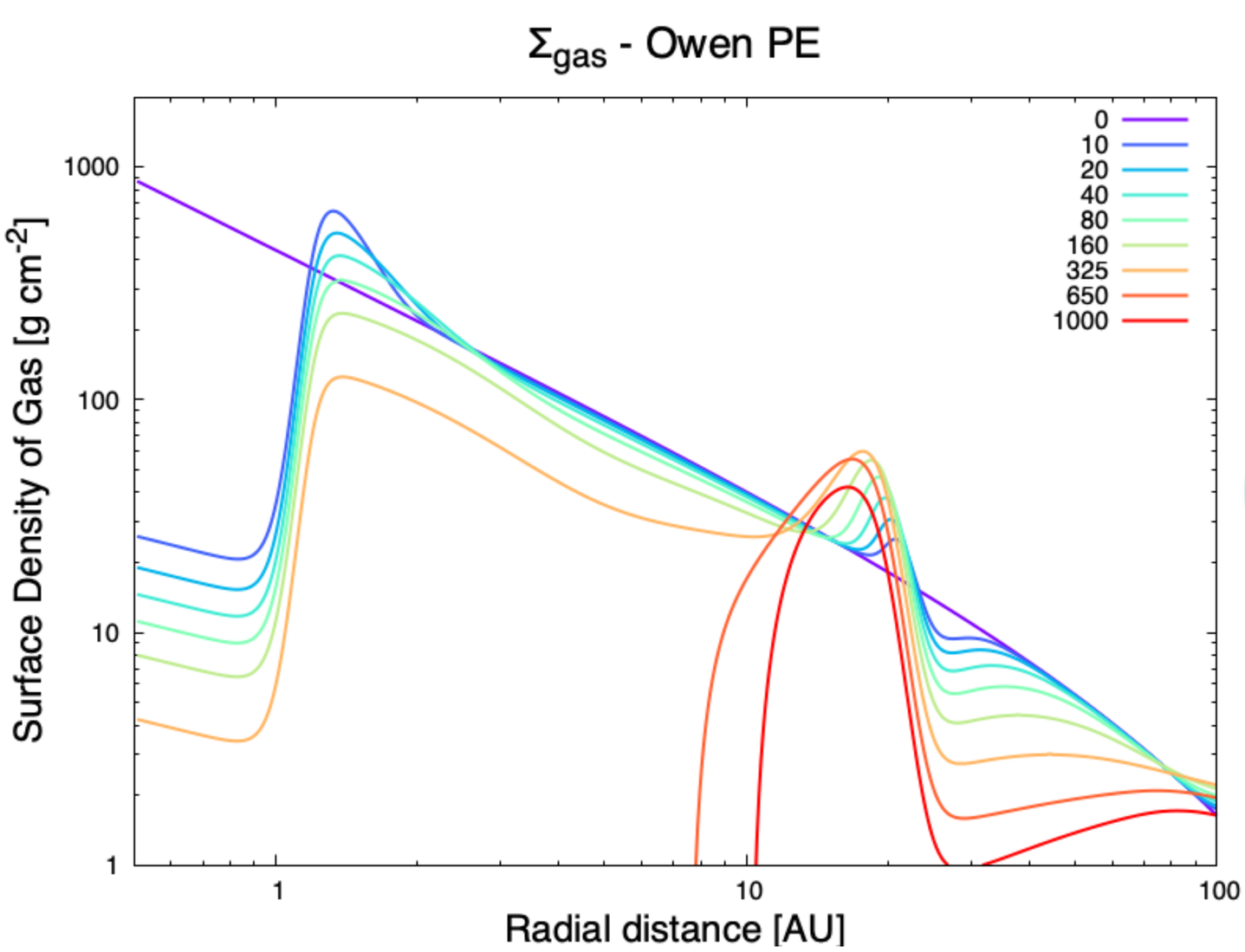
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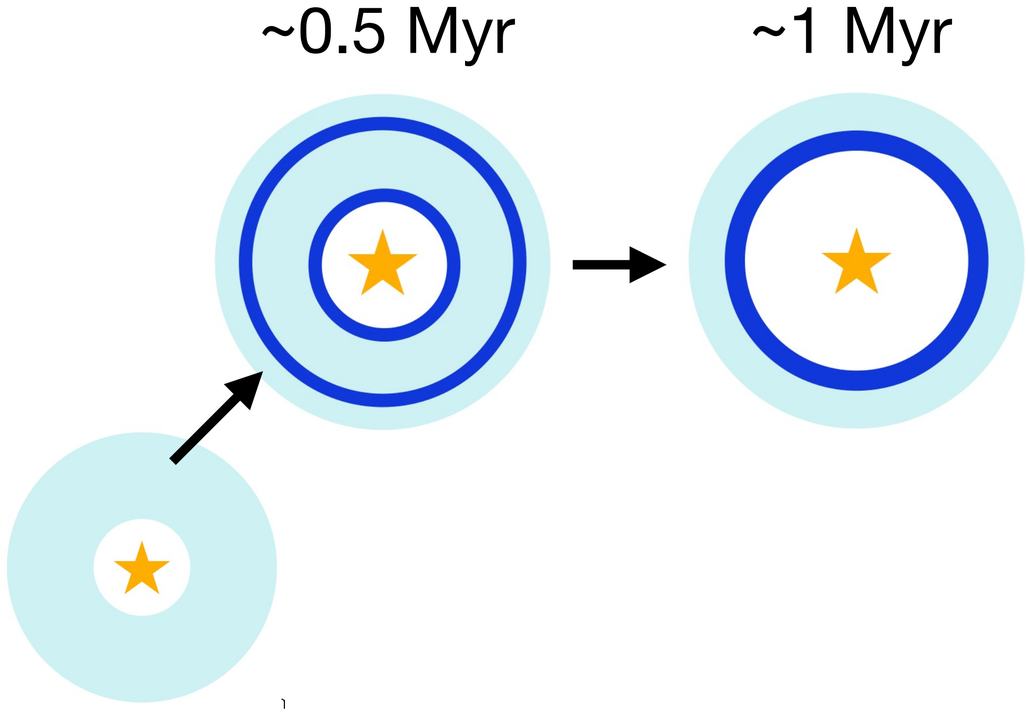


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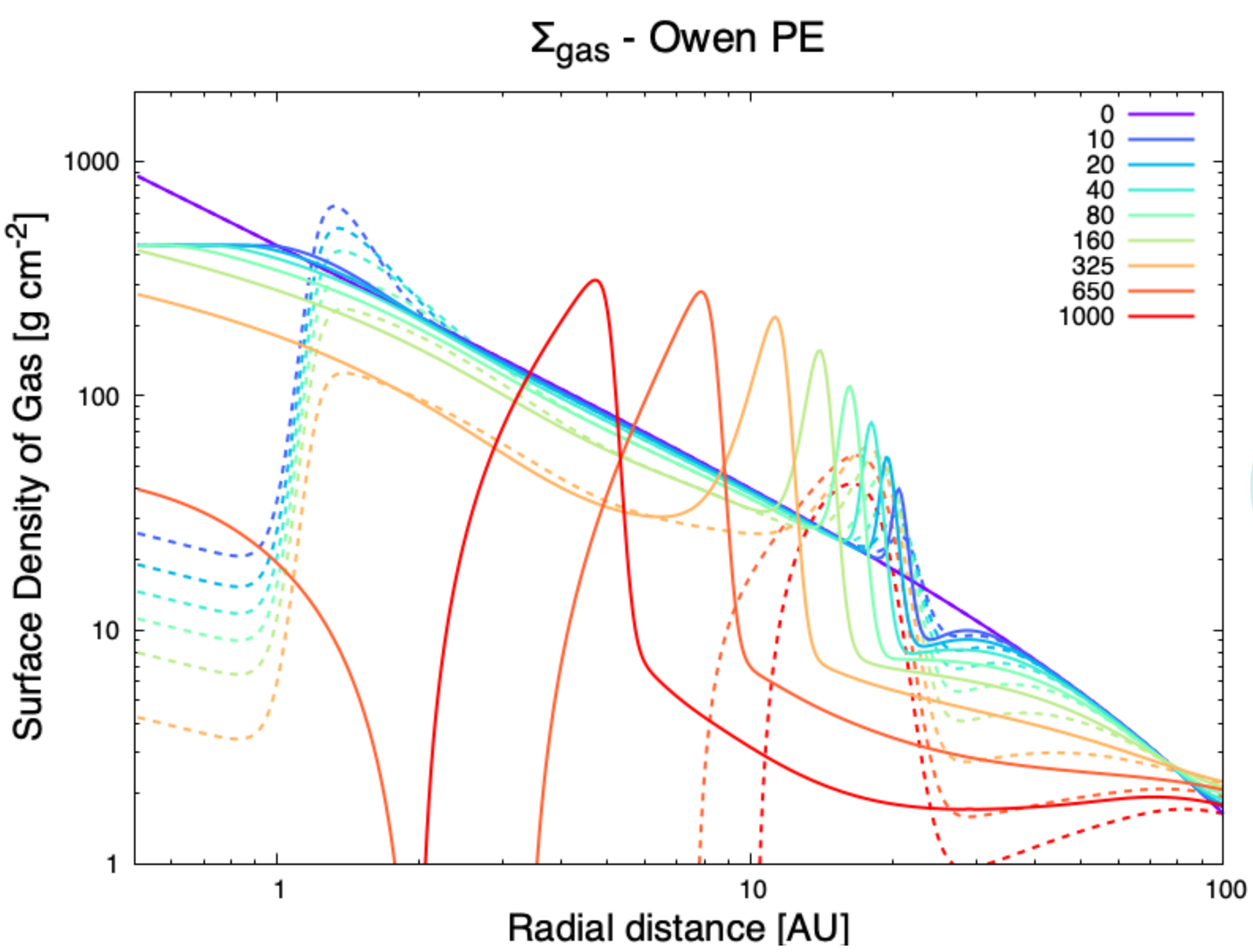


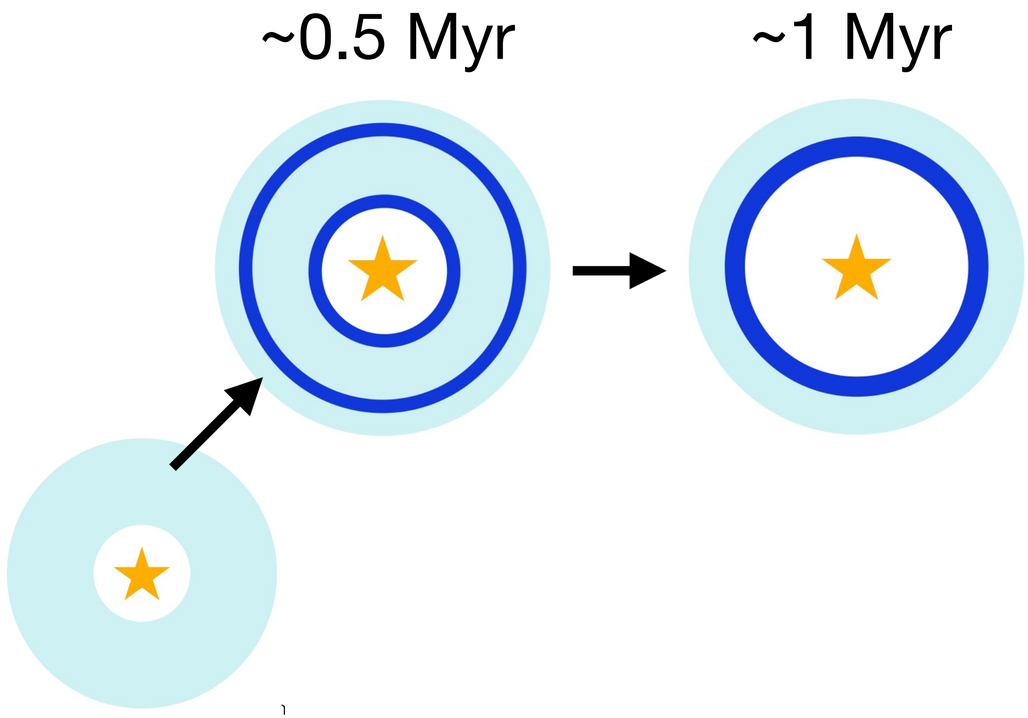
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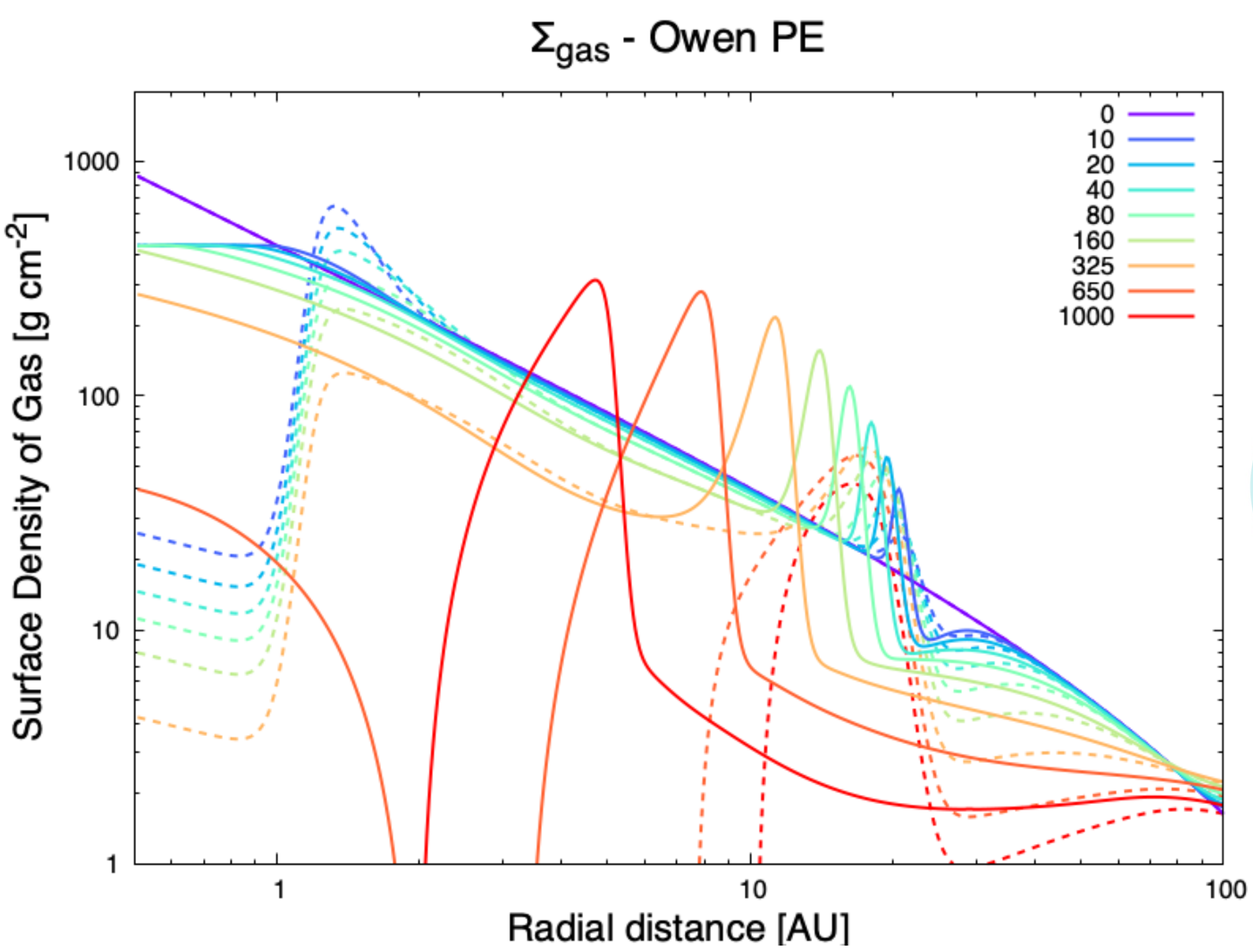


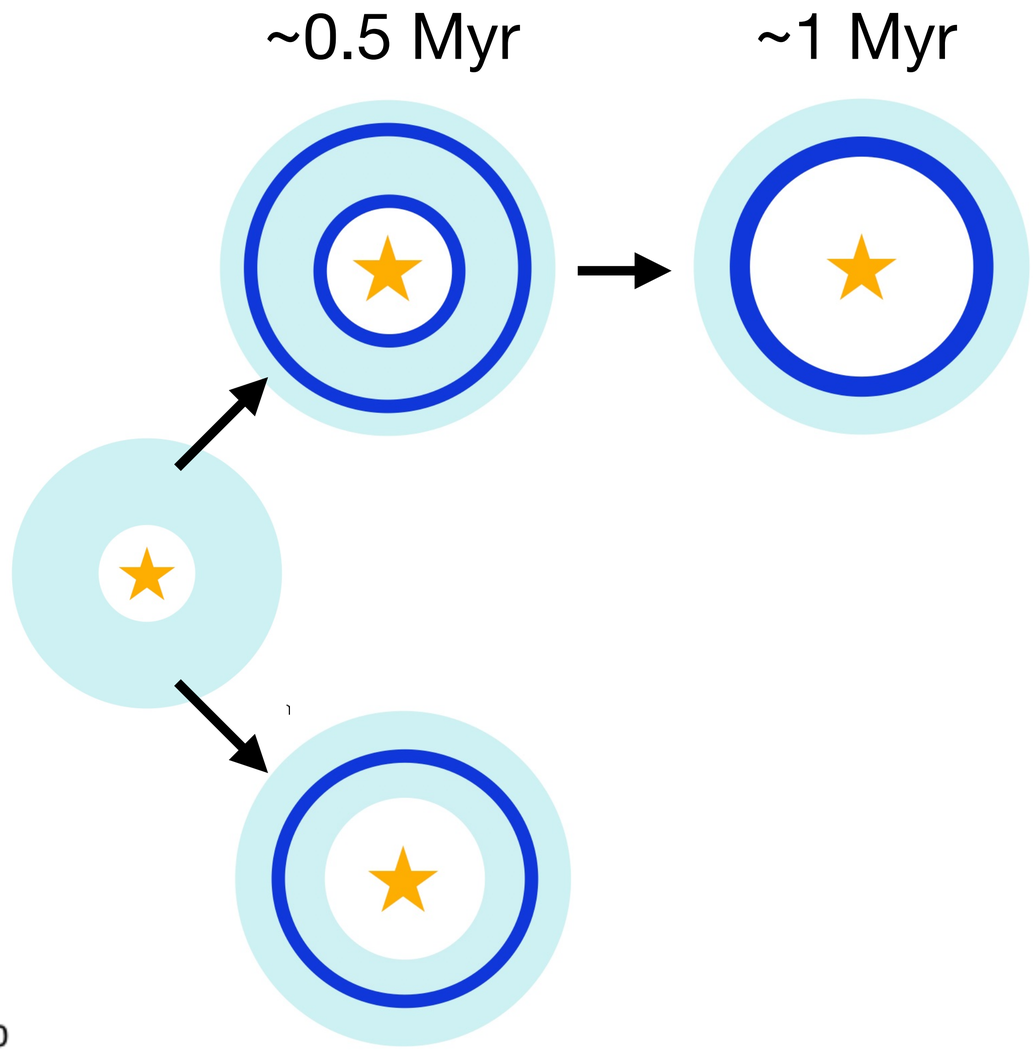
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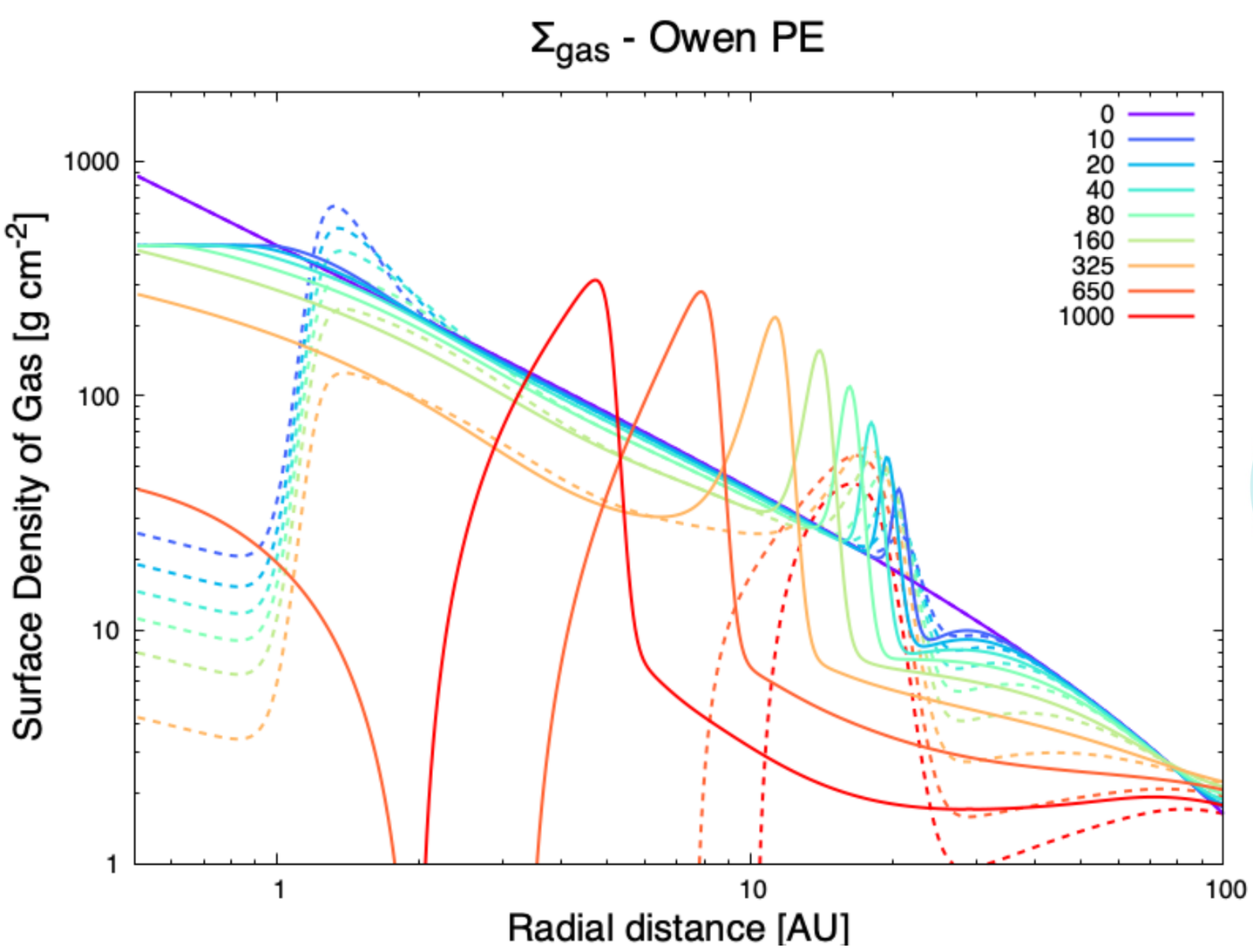


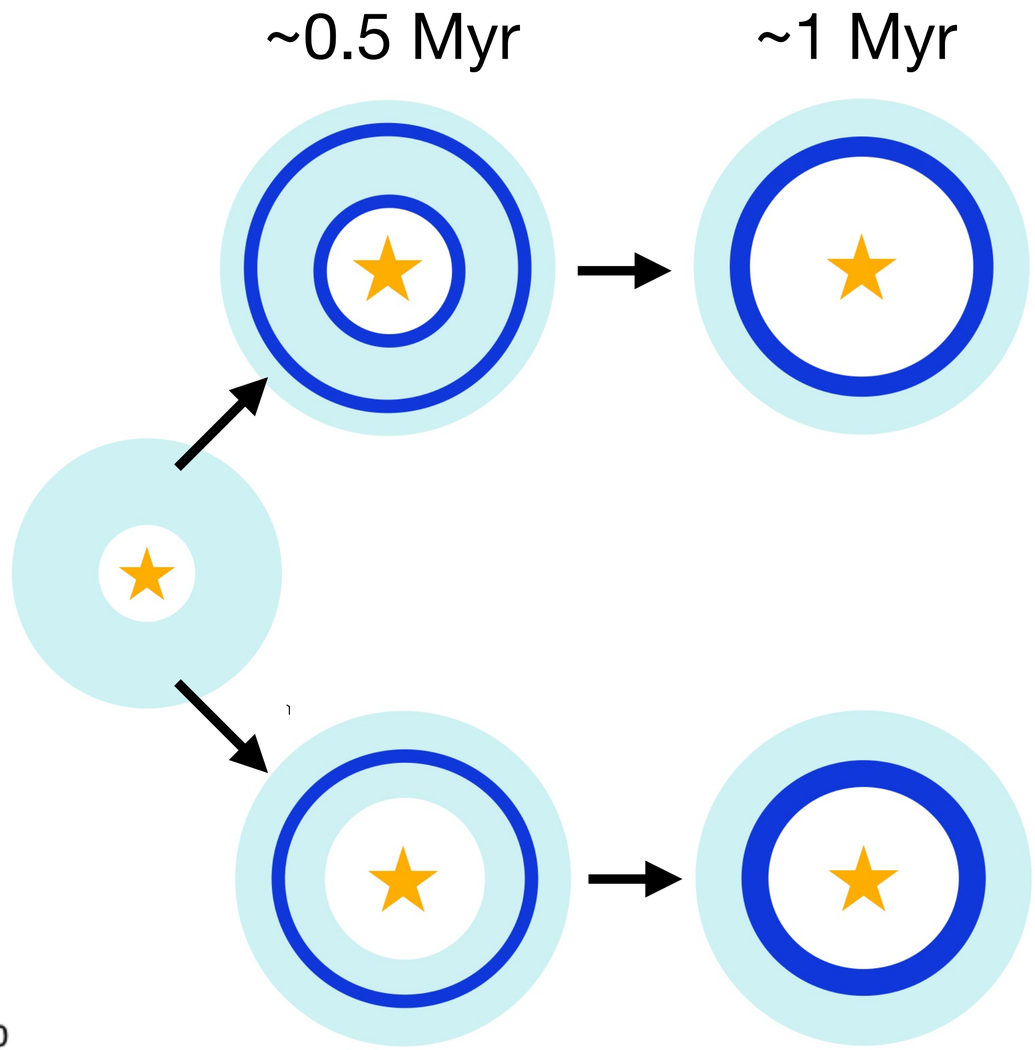
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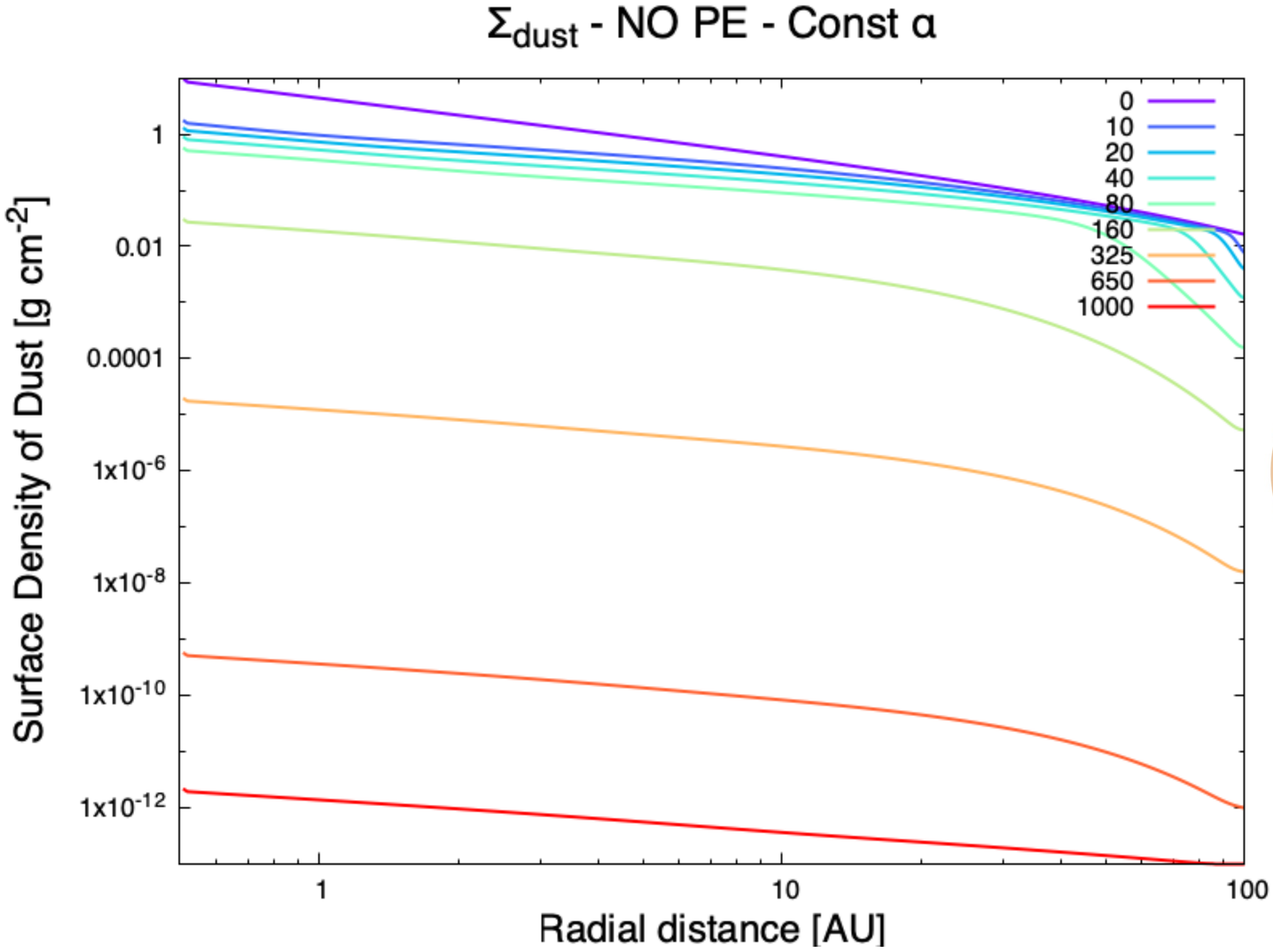


1D gas evolution: viscous + ADZ + PE



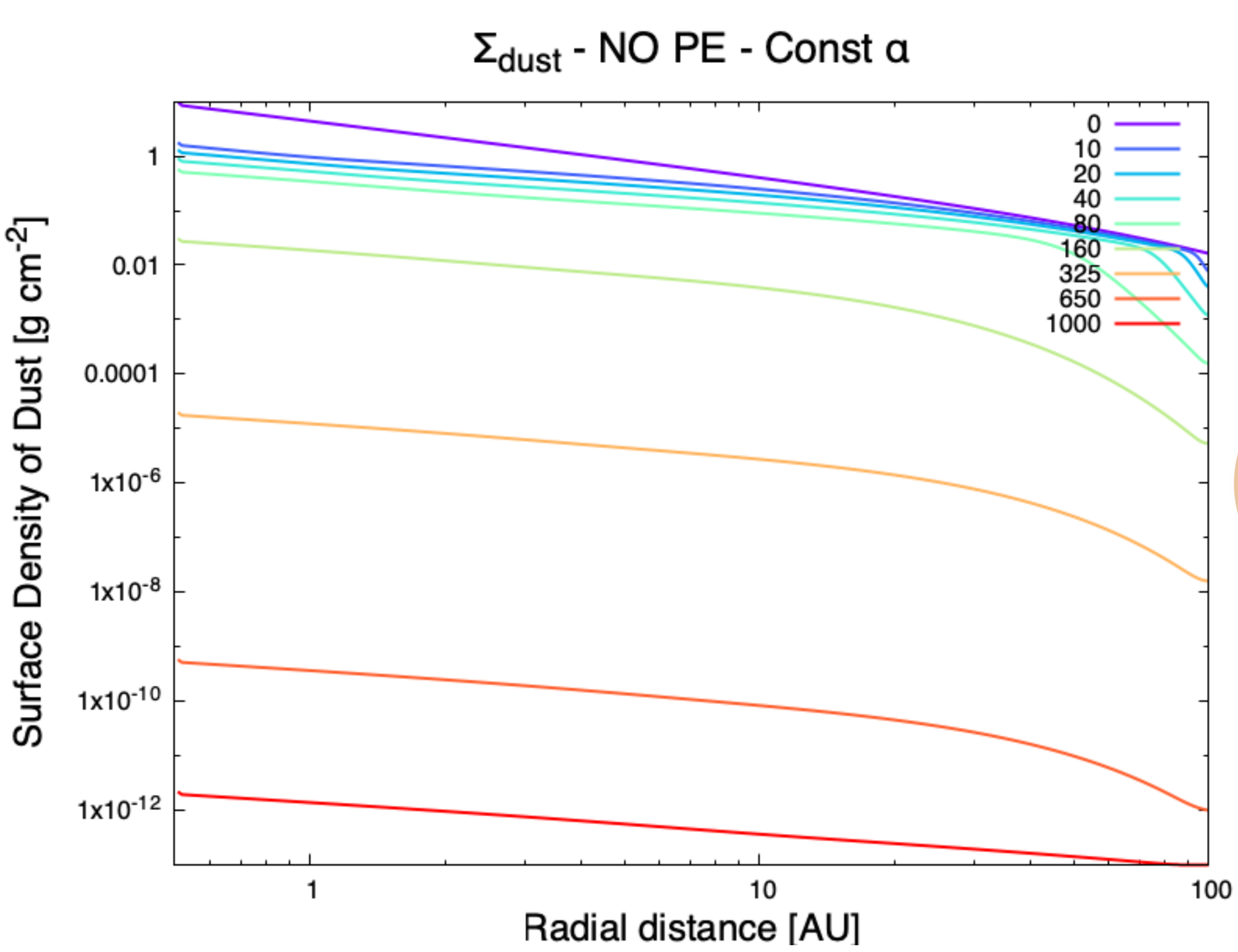


1D dust evolution: viscous

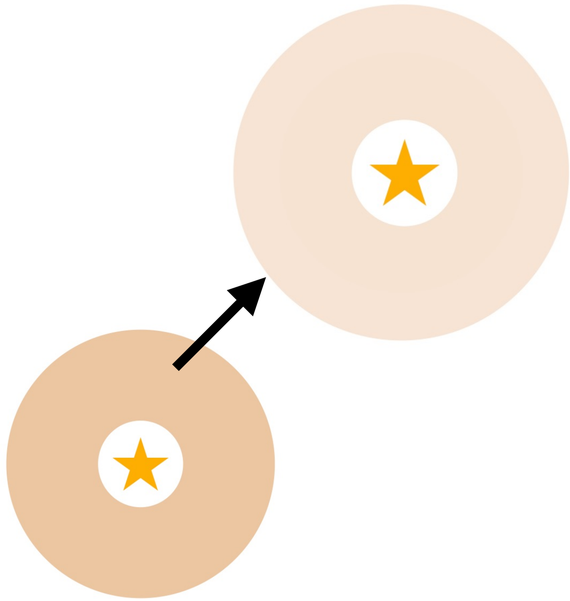




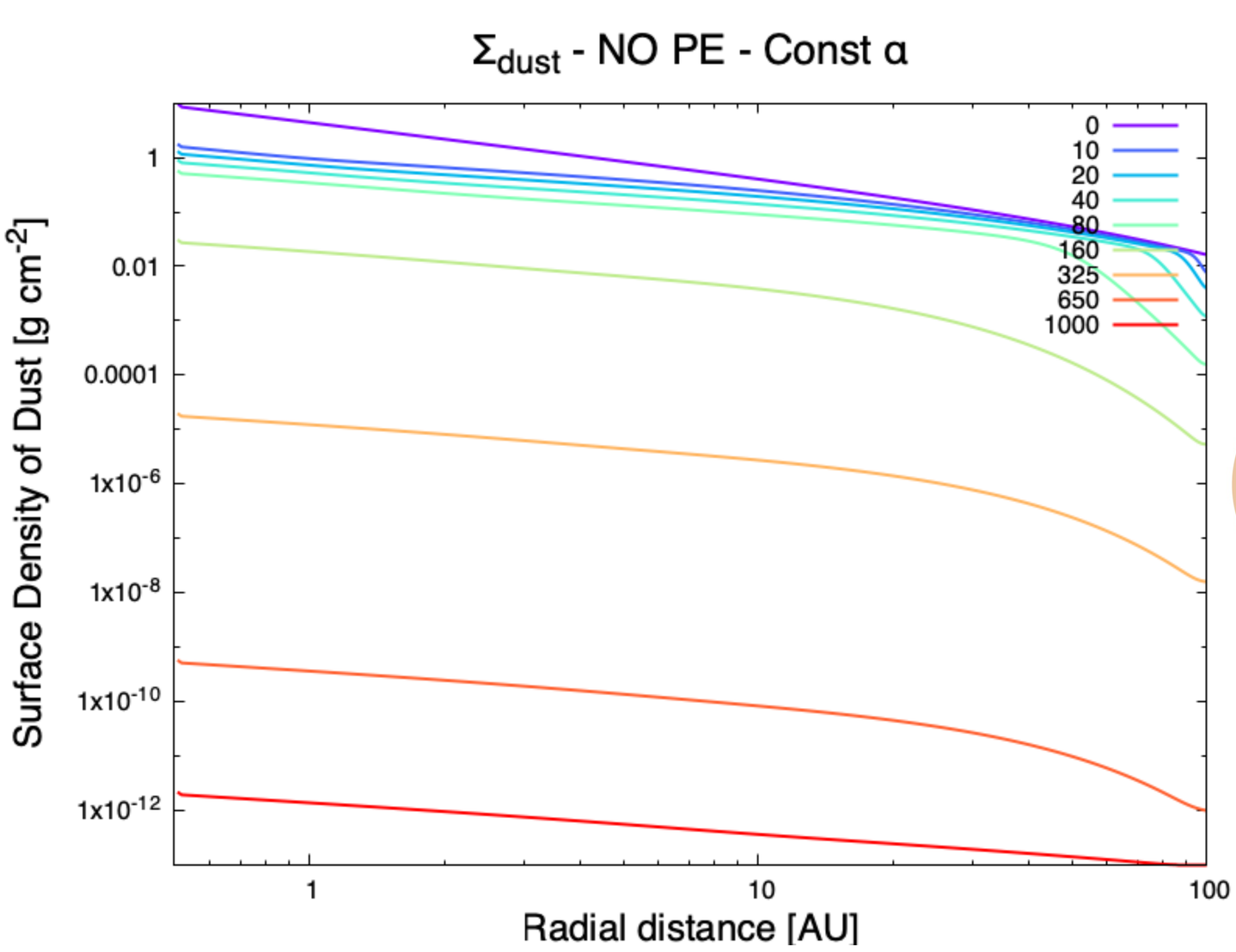
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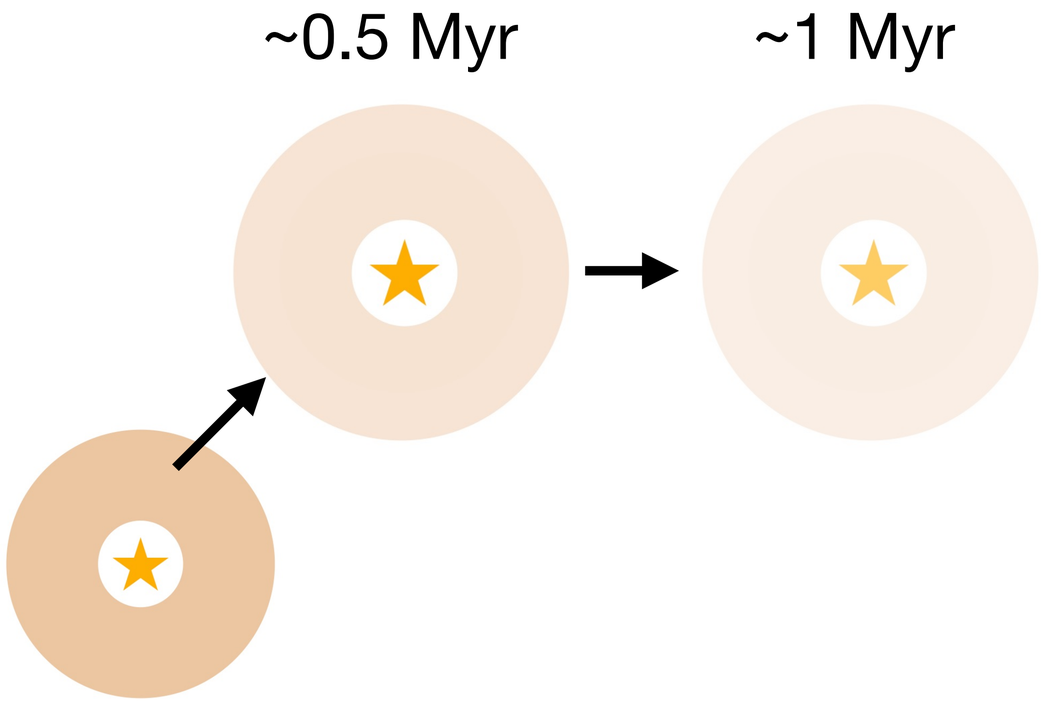


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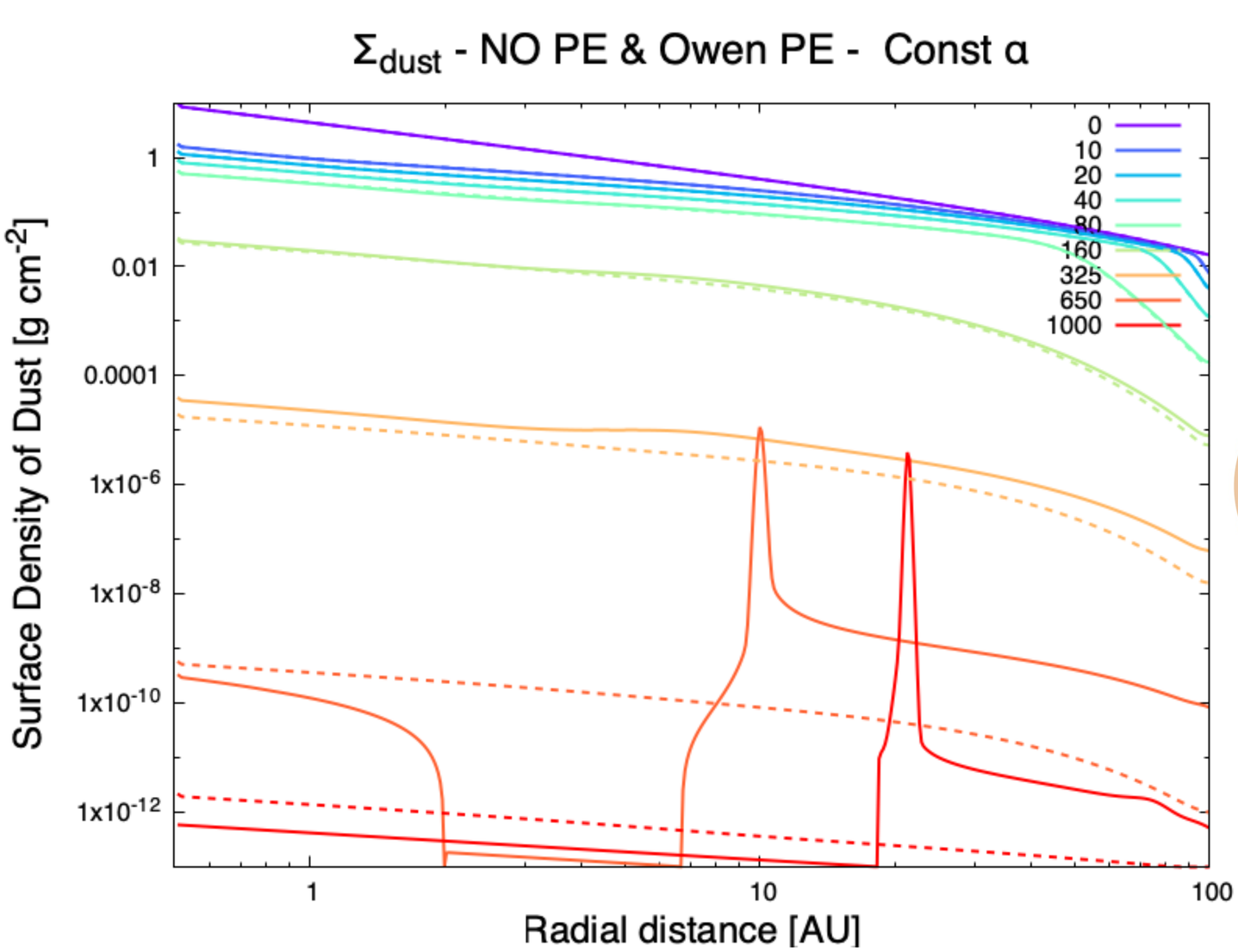


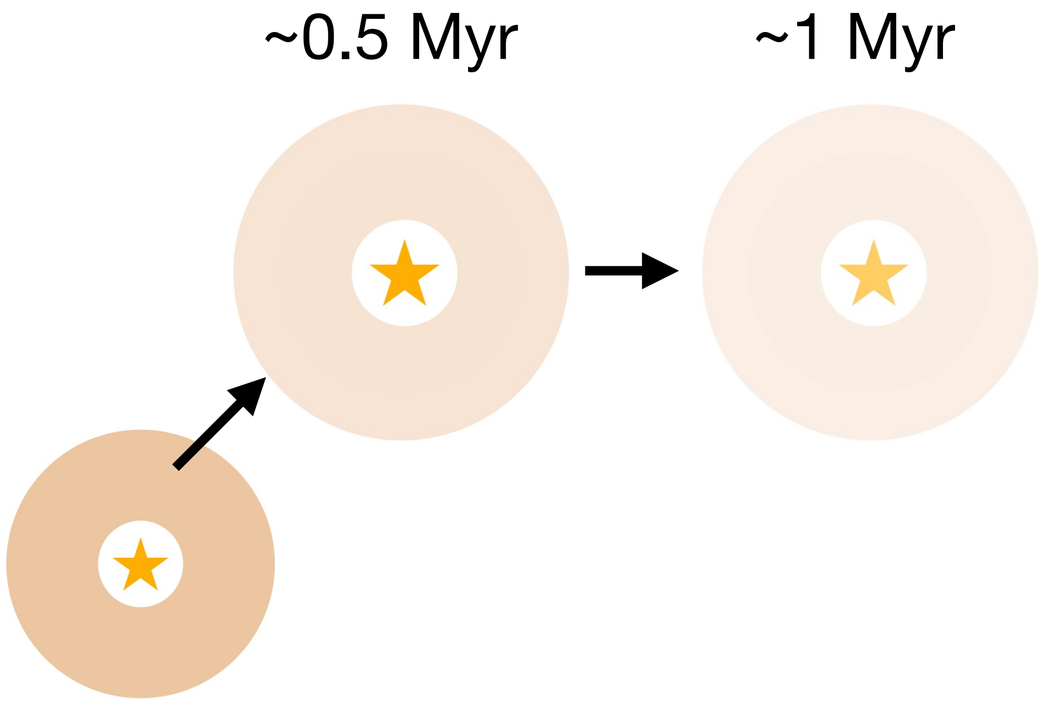
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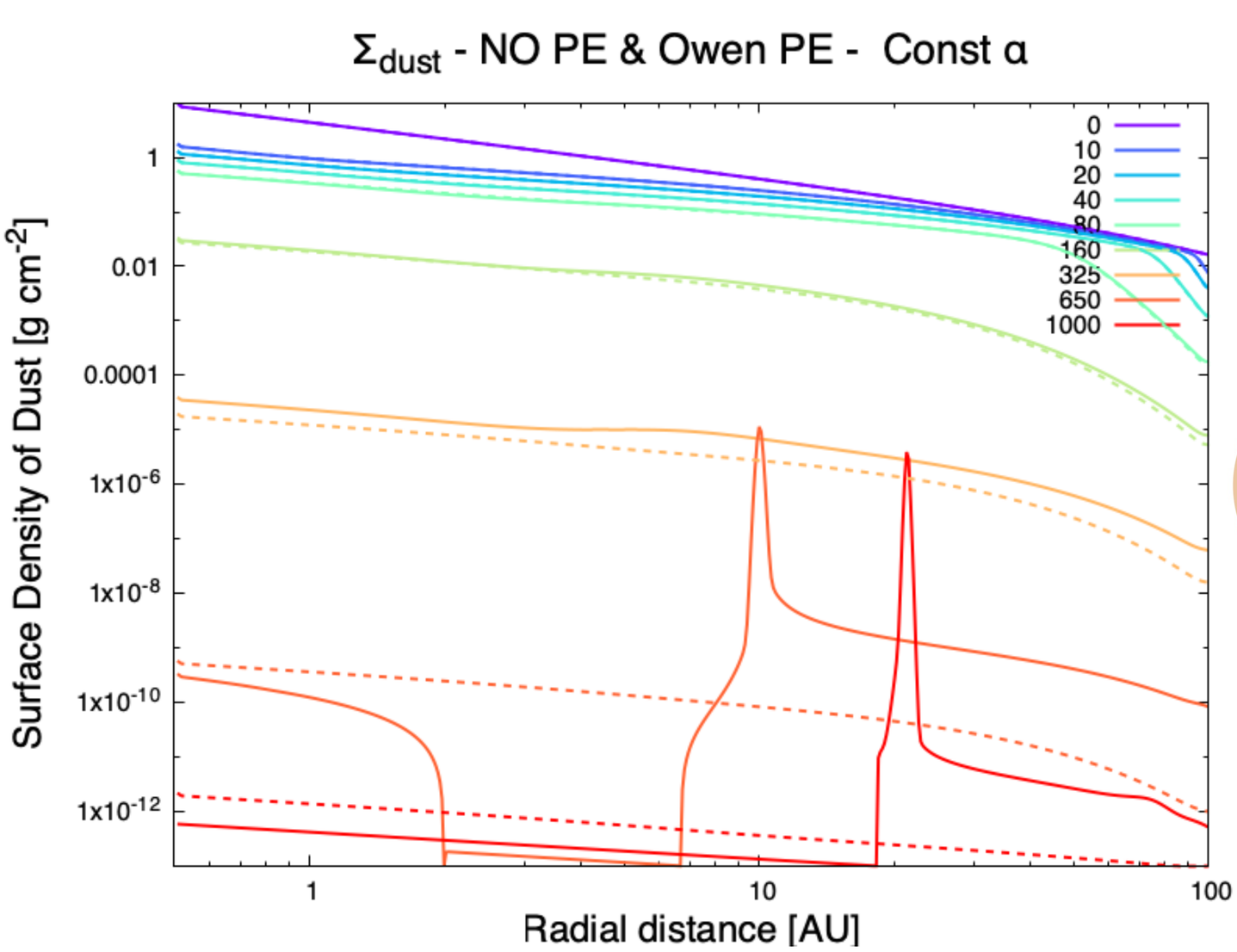


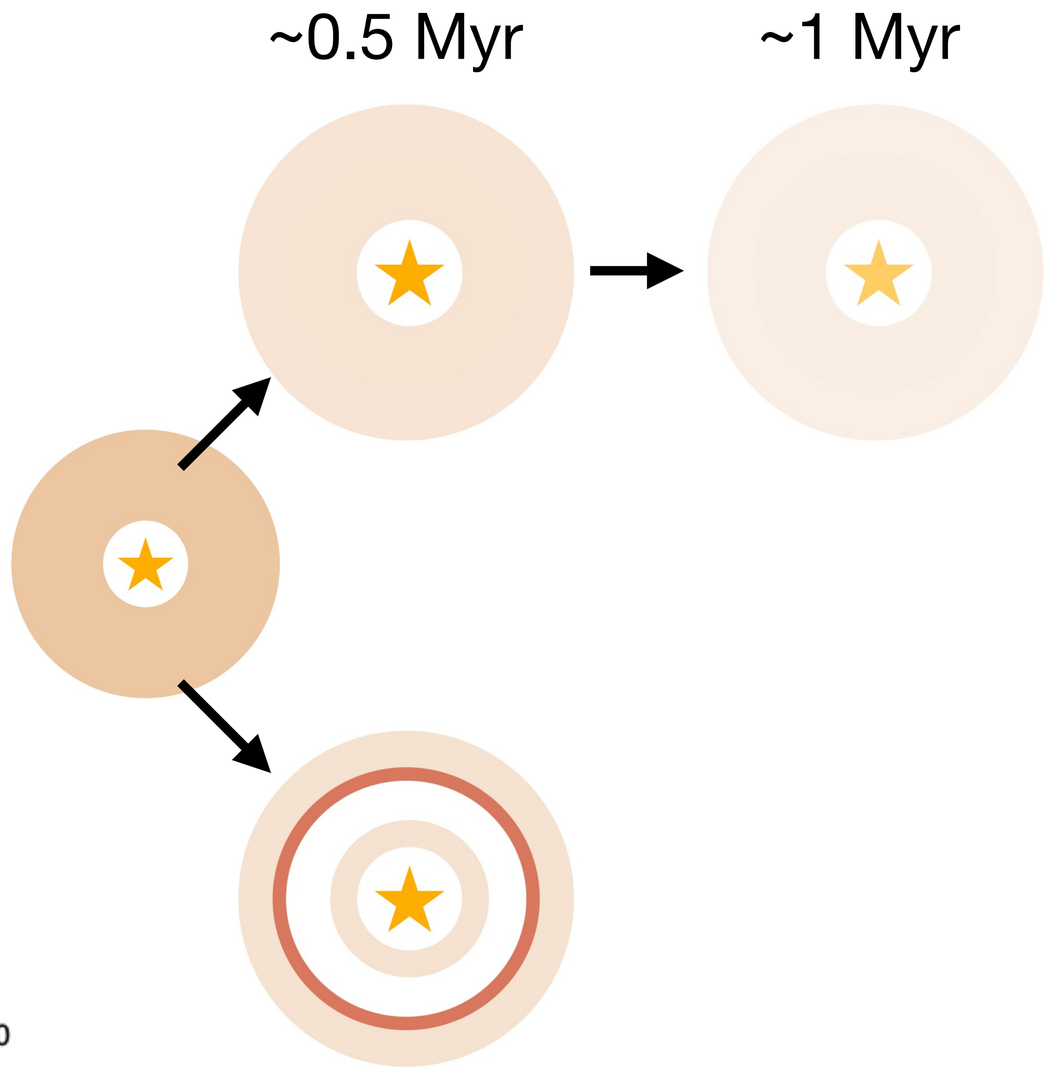
1D dust evolution: viscous + PE



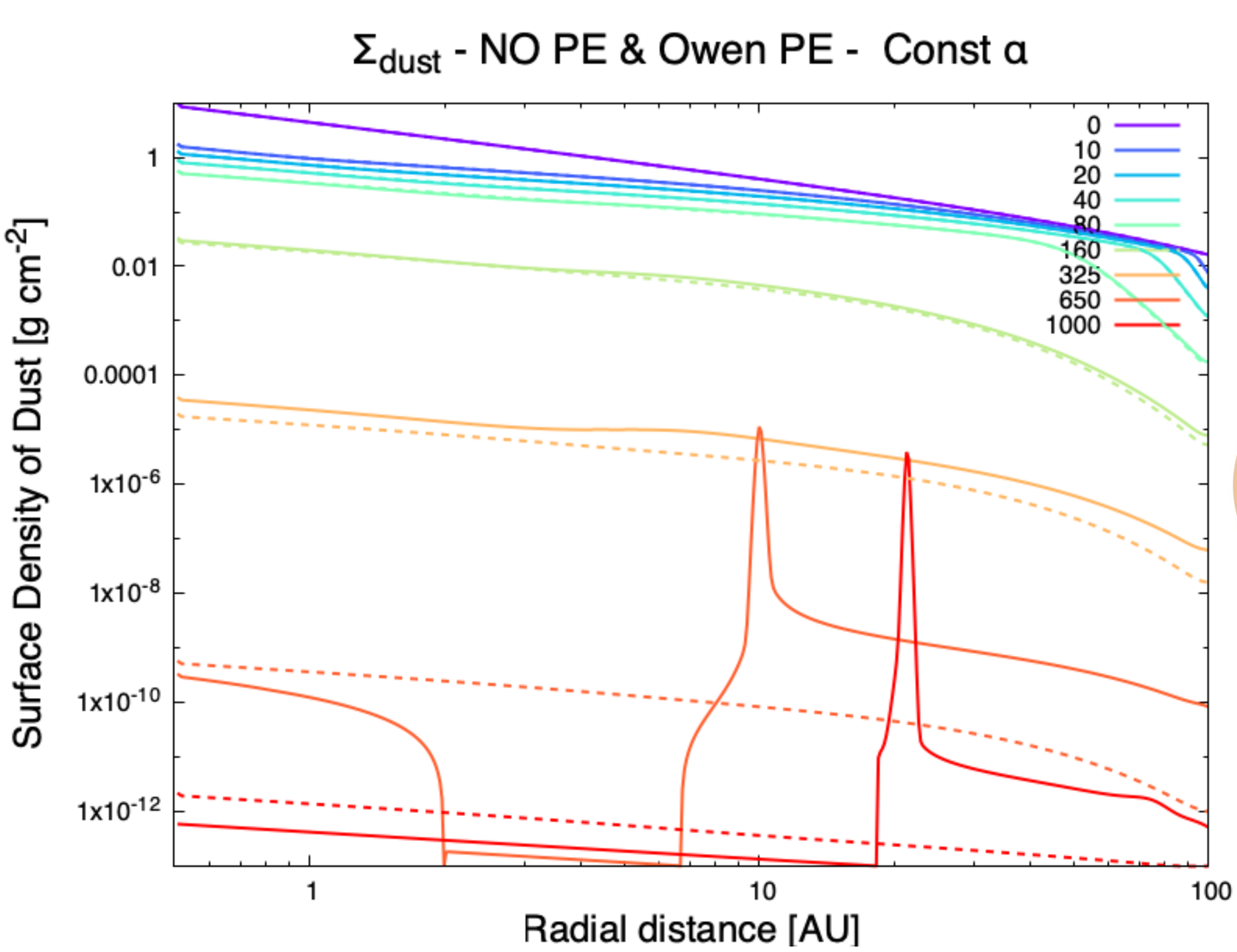


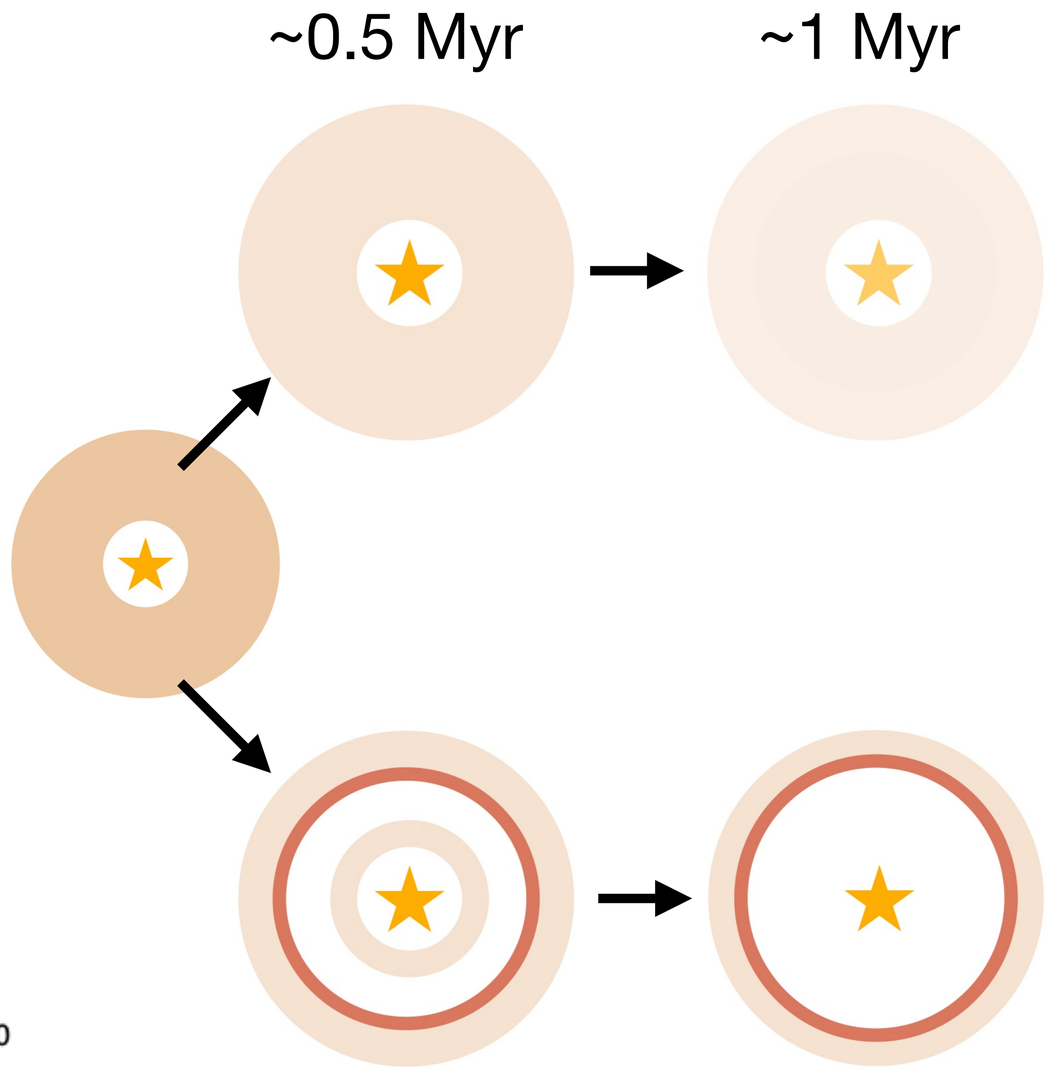
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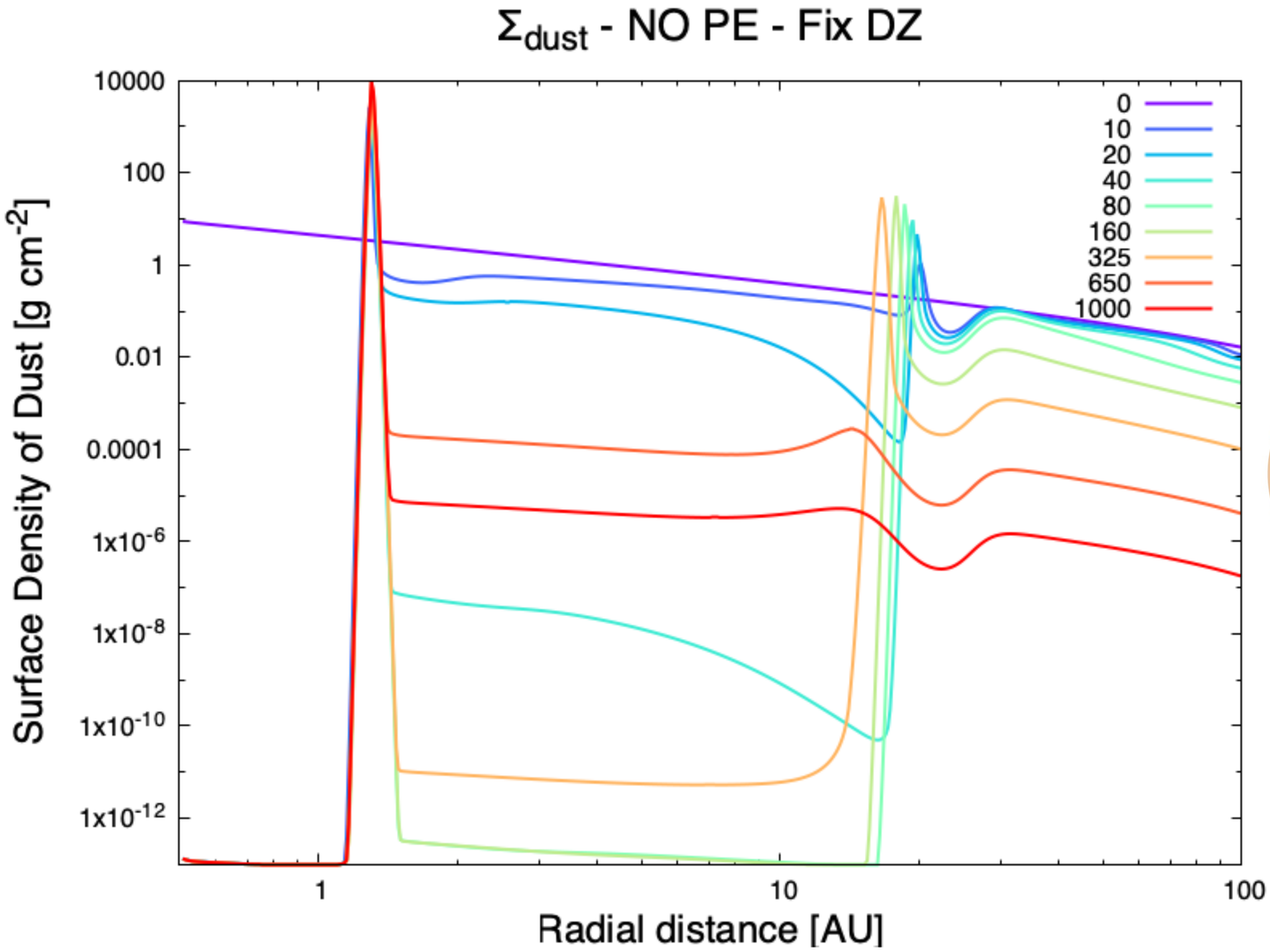


1D dust evolution: viscous + PE



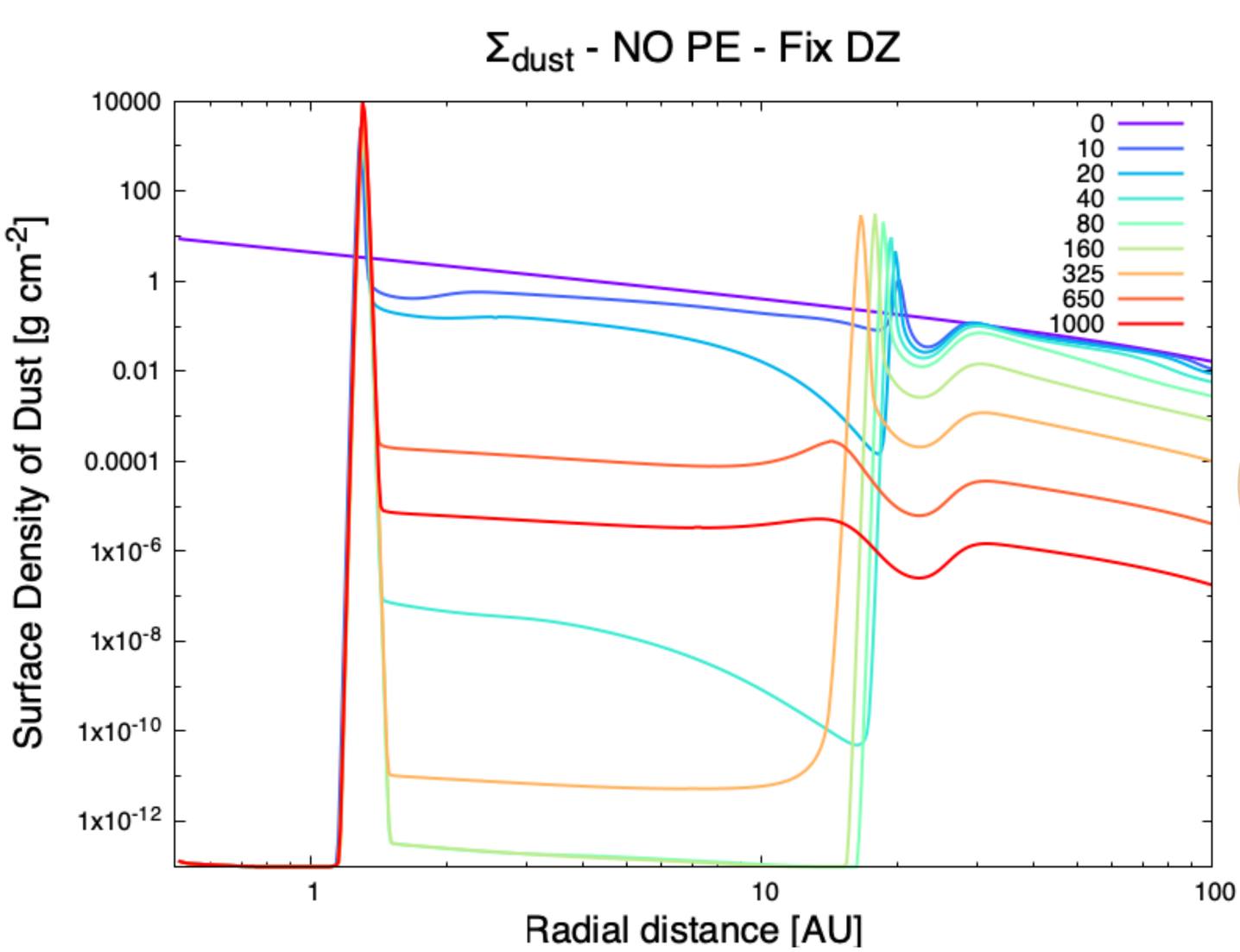


1D dust evolution: viscous + DZ

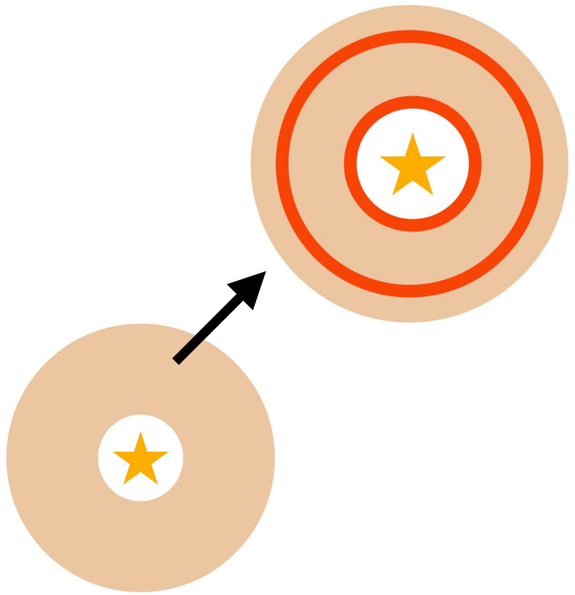




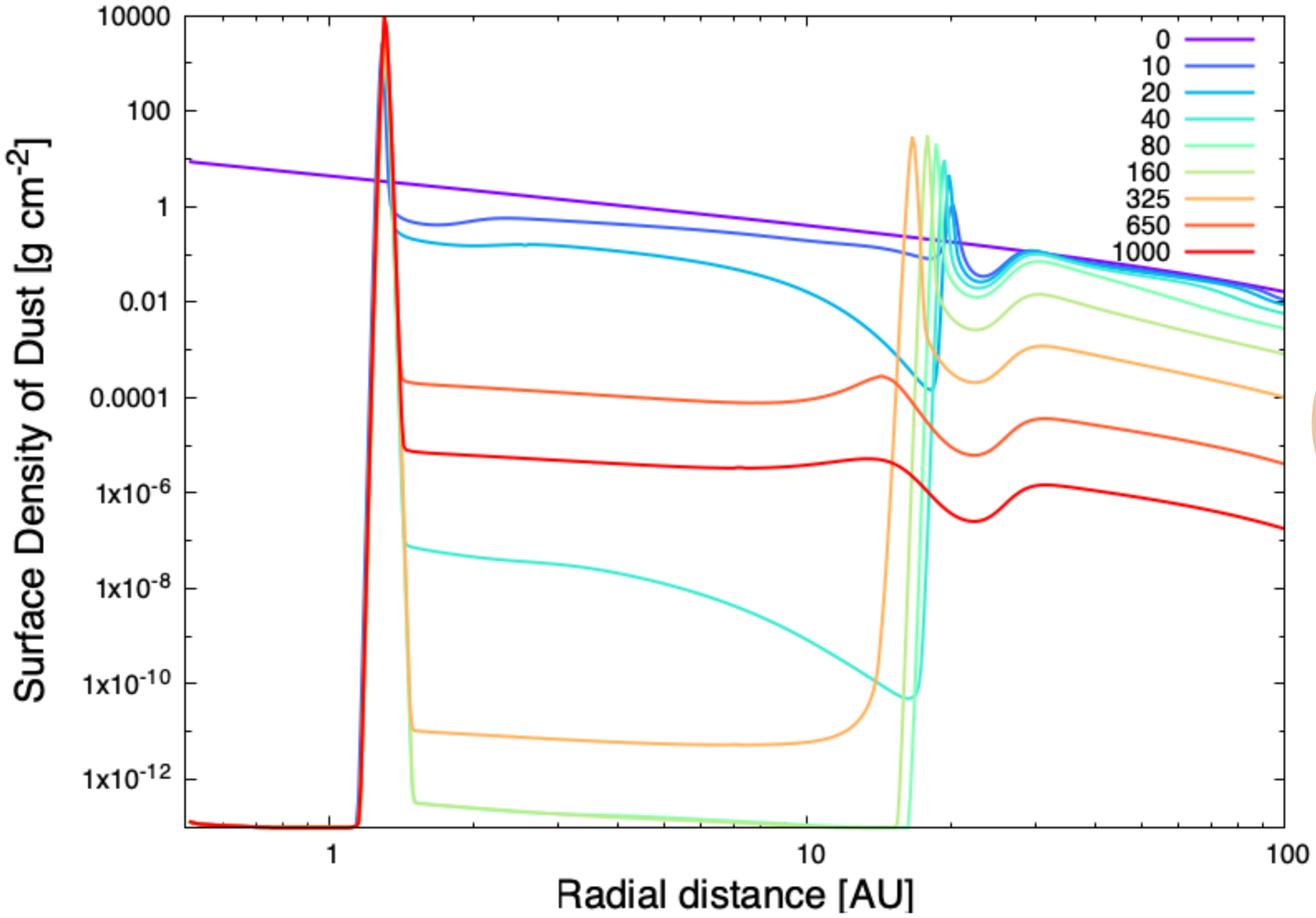
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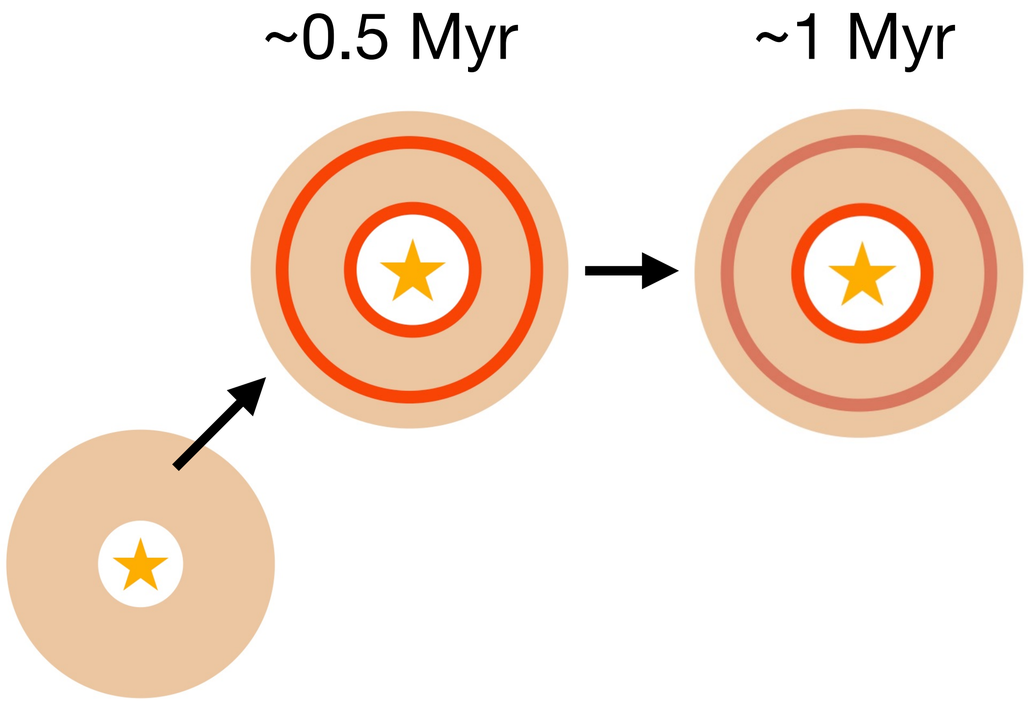


~0.5 Myr

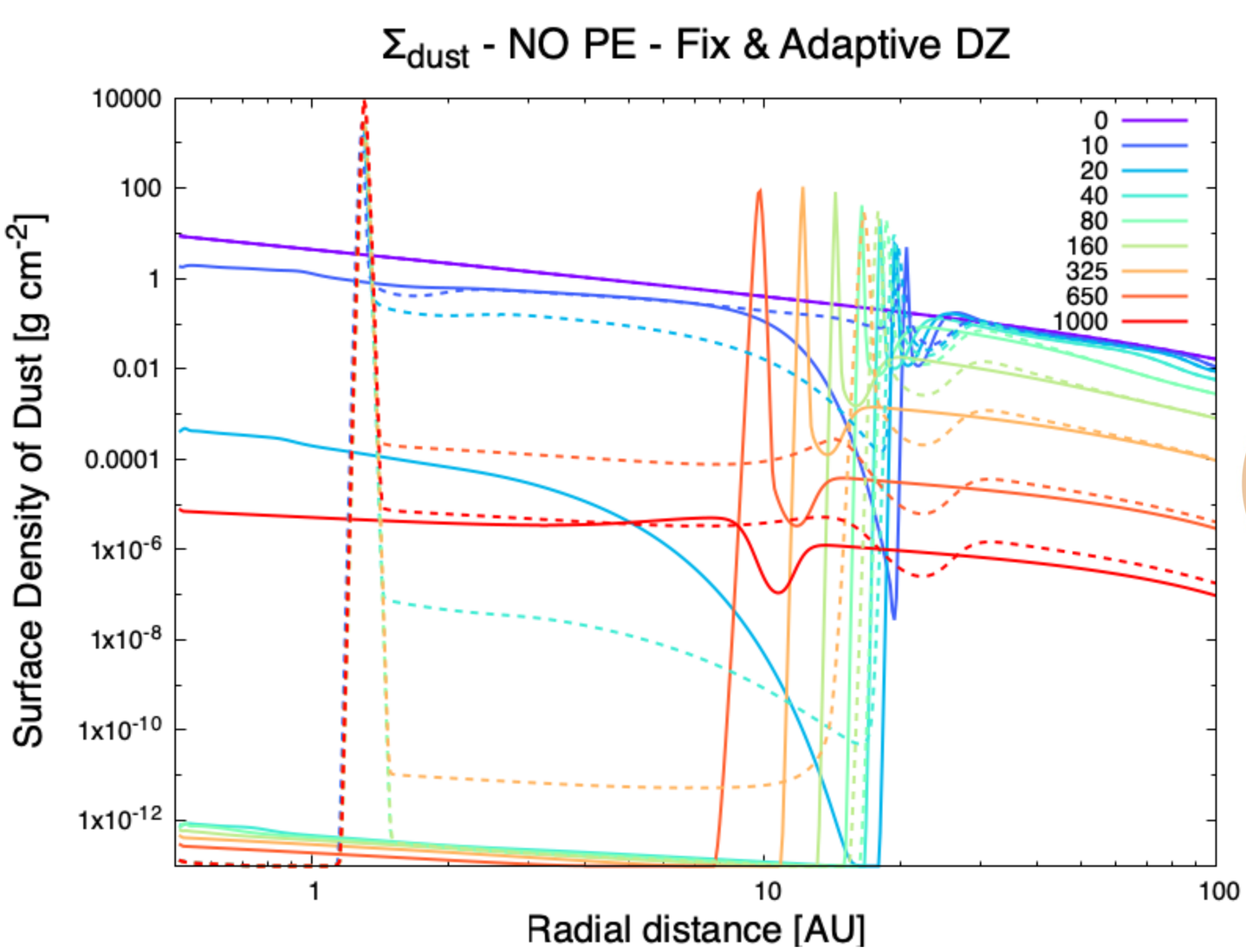


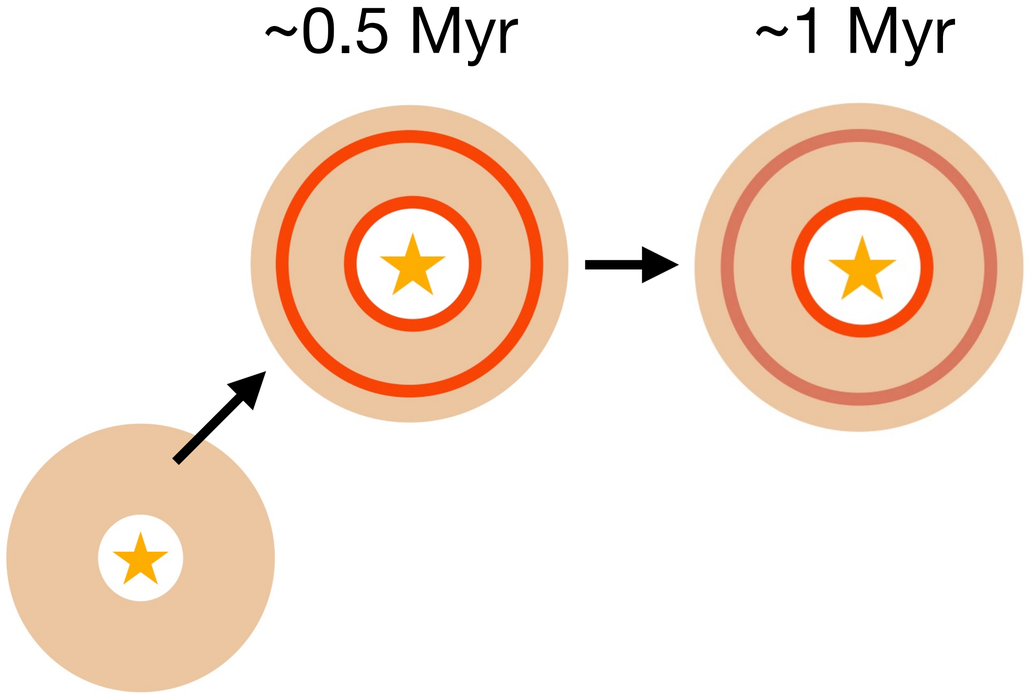
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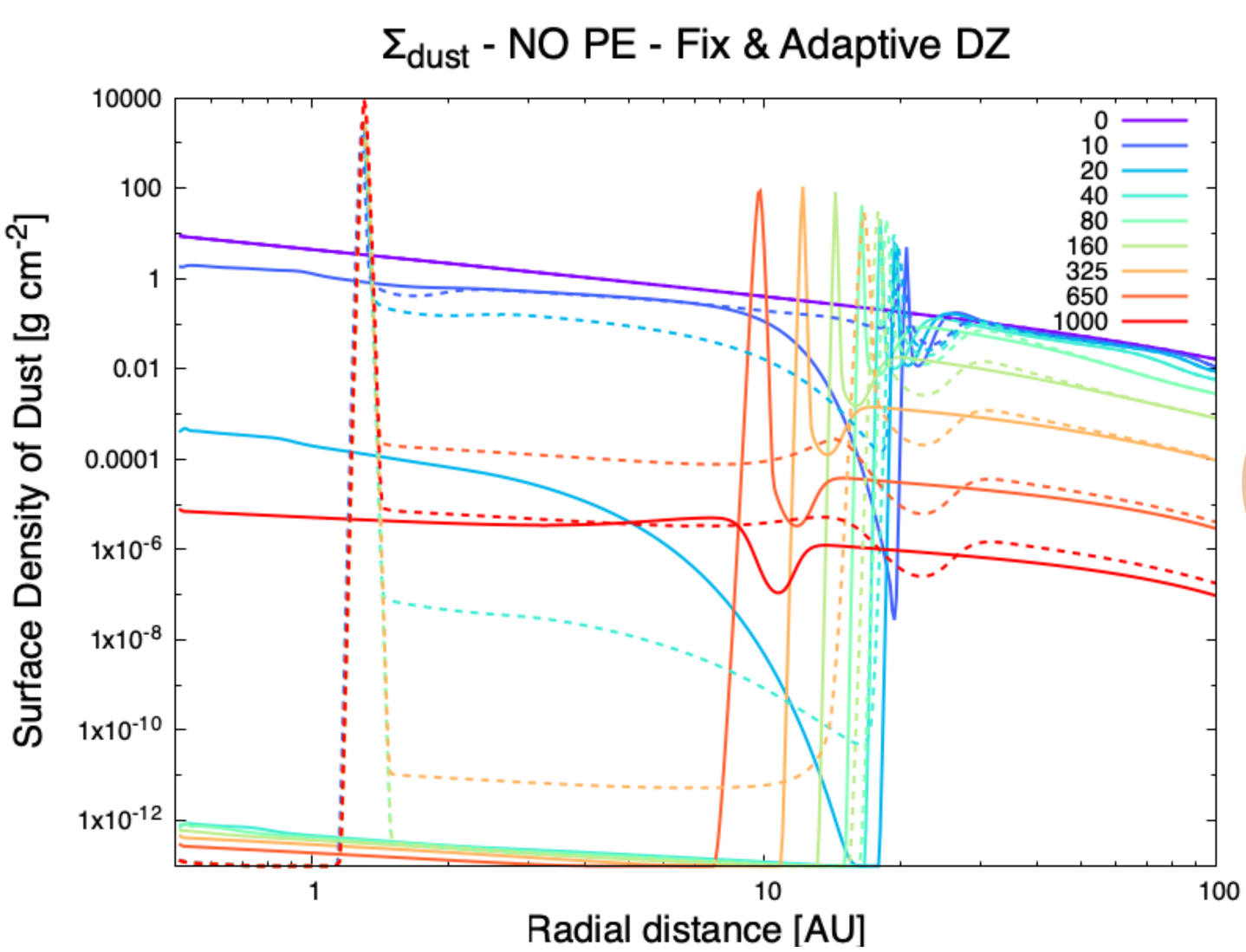


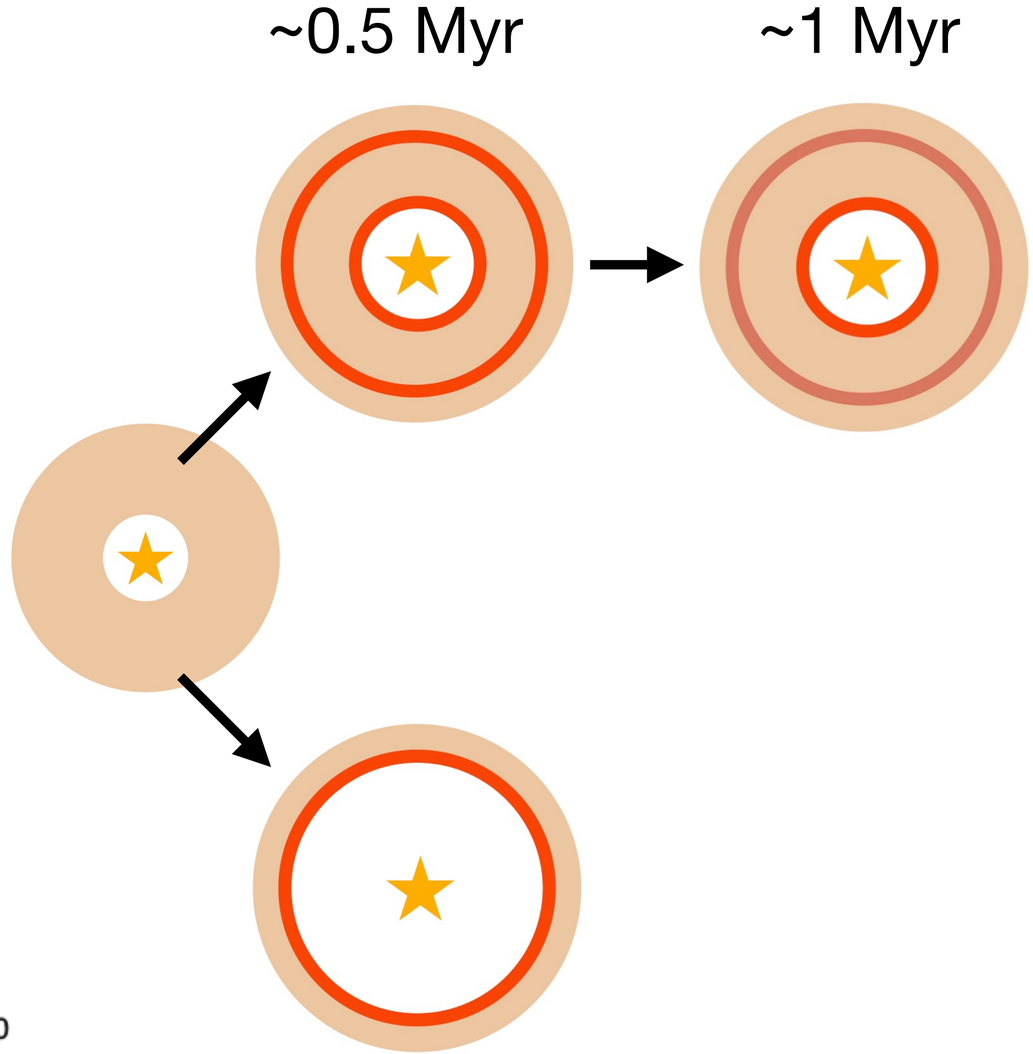
1D dust evolution: viscous + ADZ



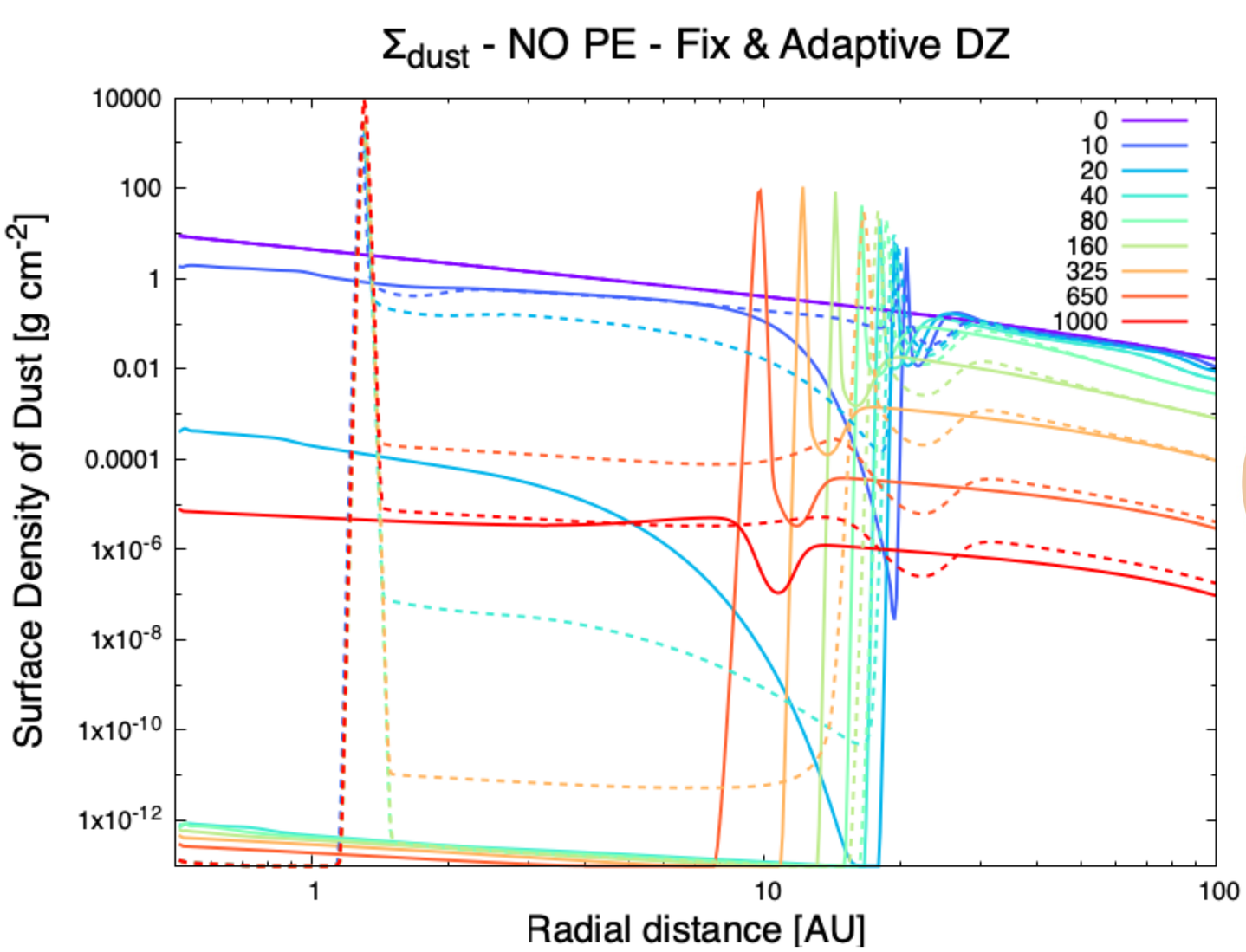


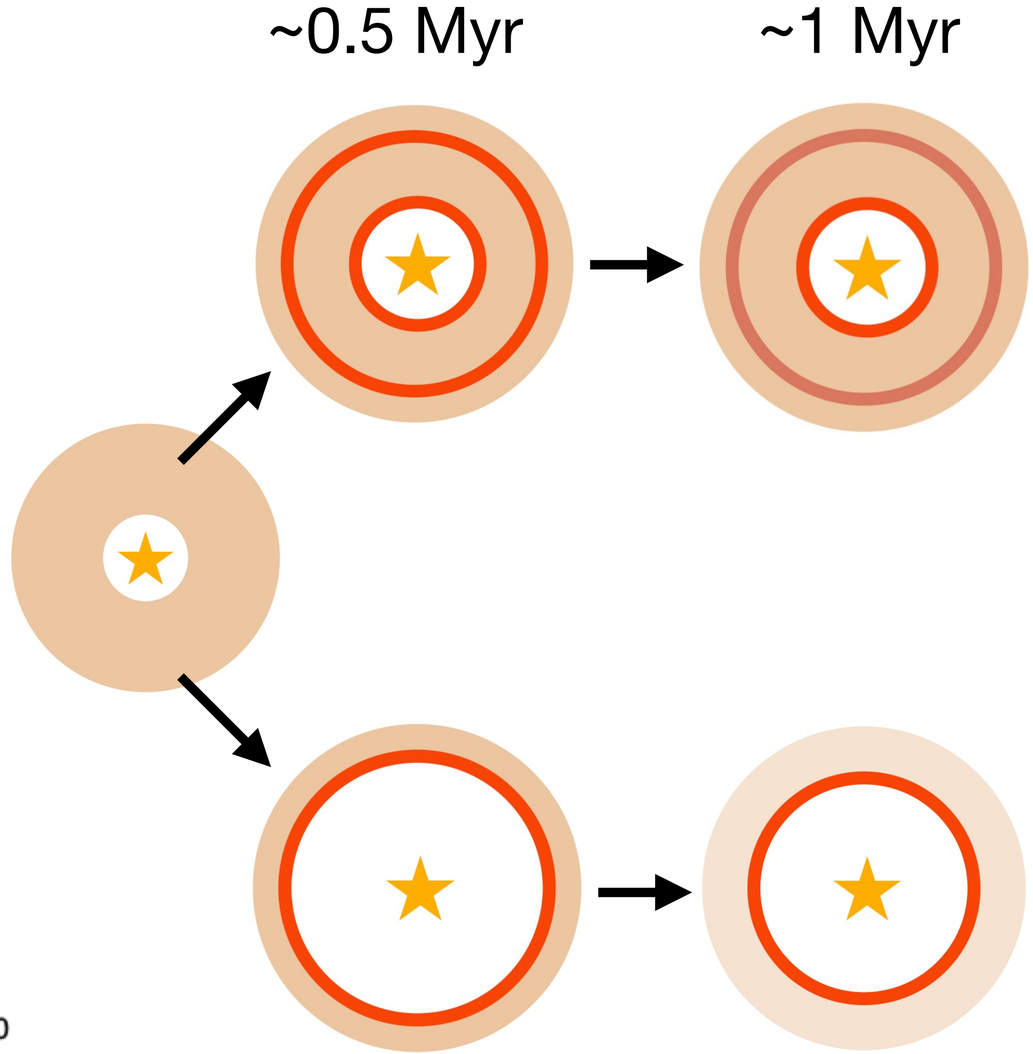
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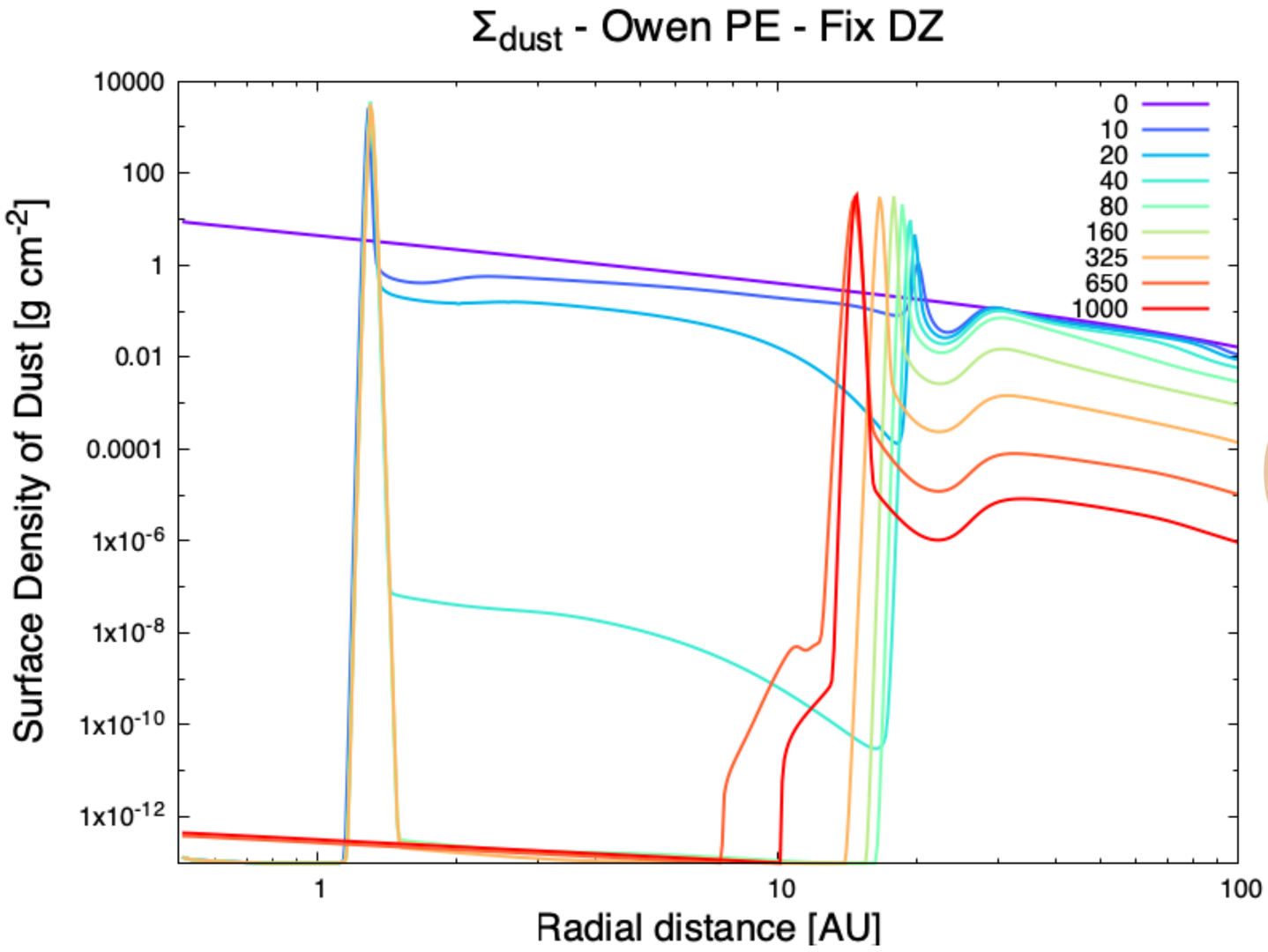


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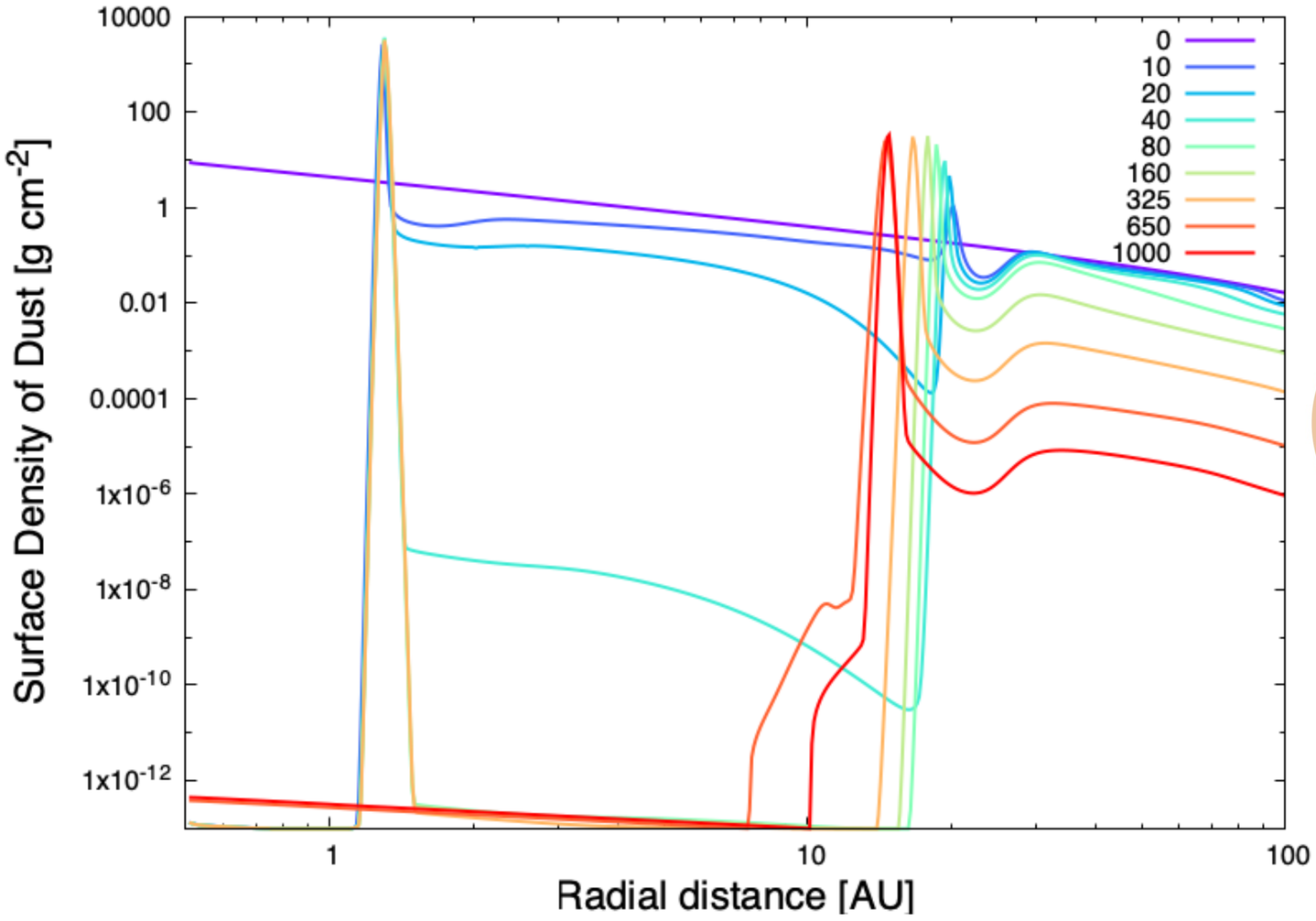


1D dust evolution: viscous + DZ + PE

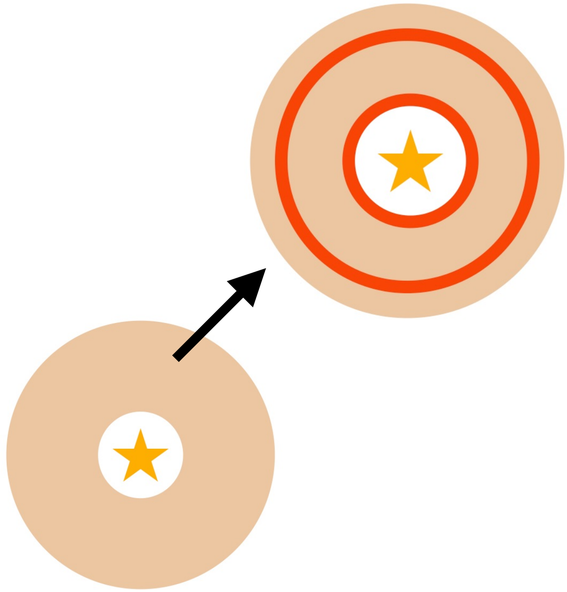




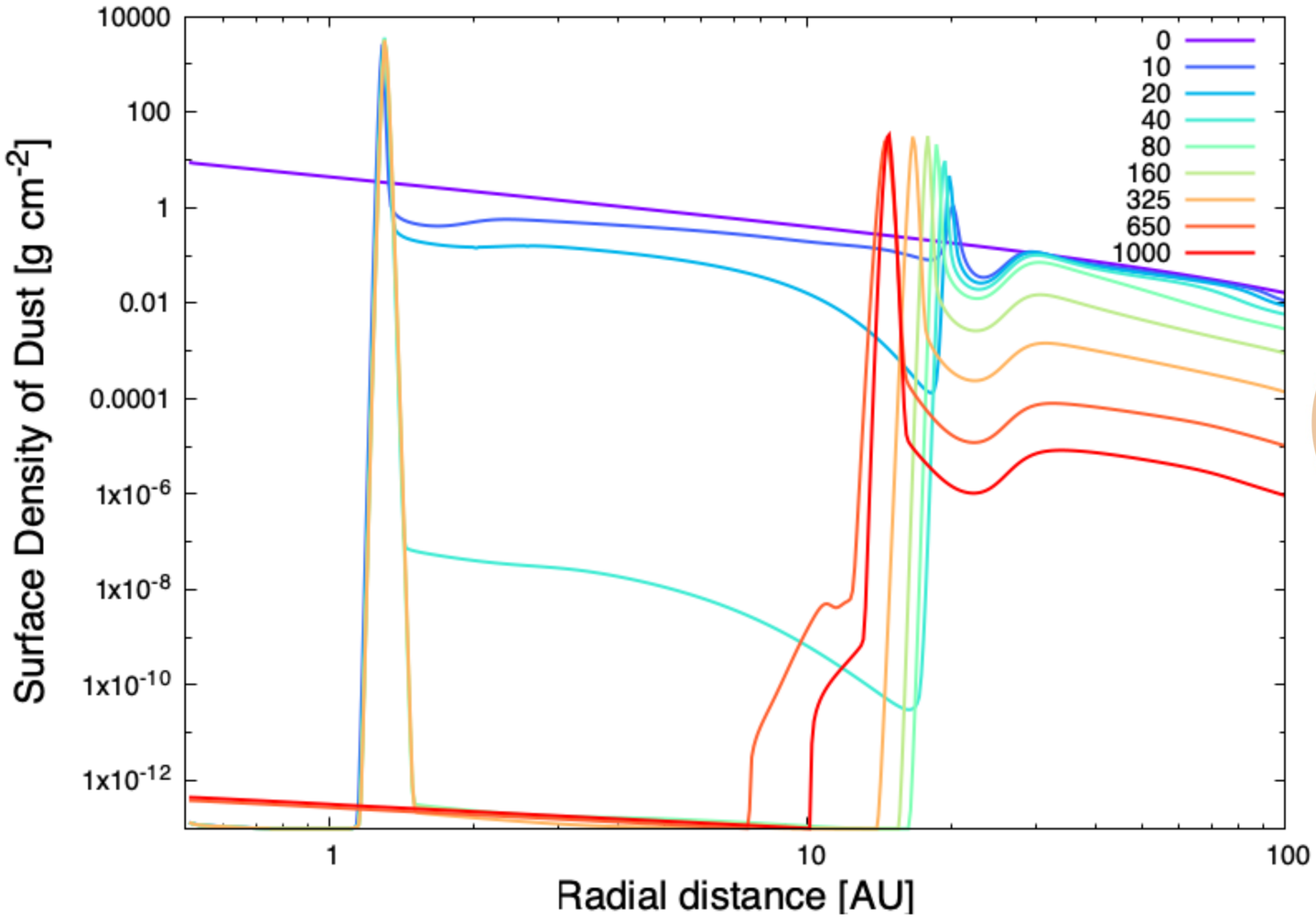
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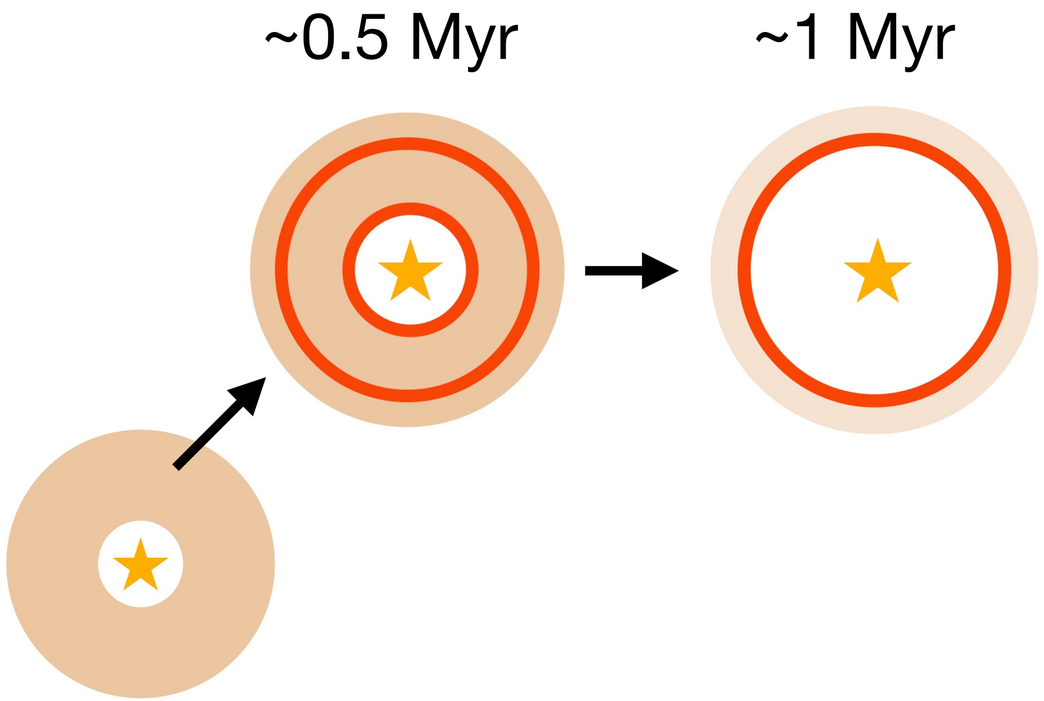


~0.5 Myr

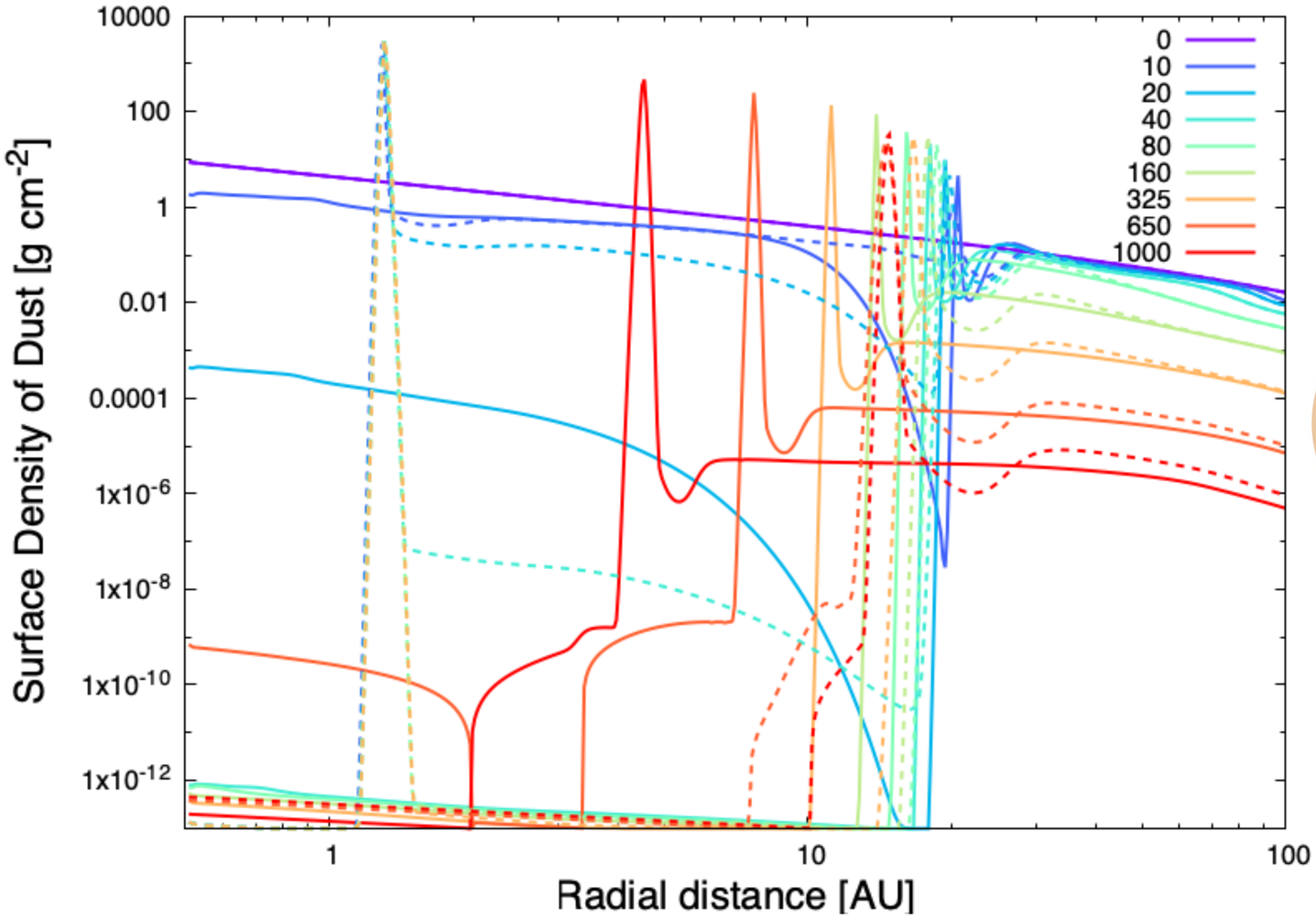


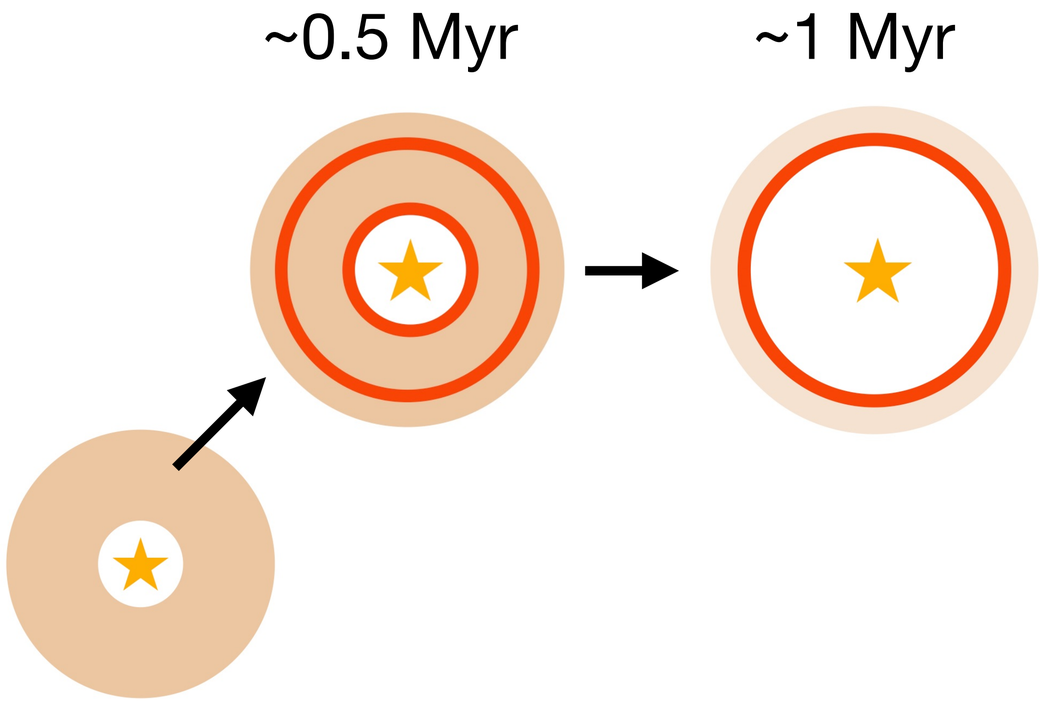
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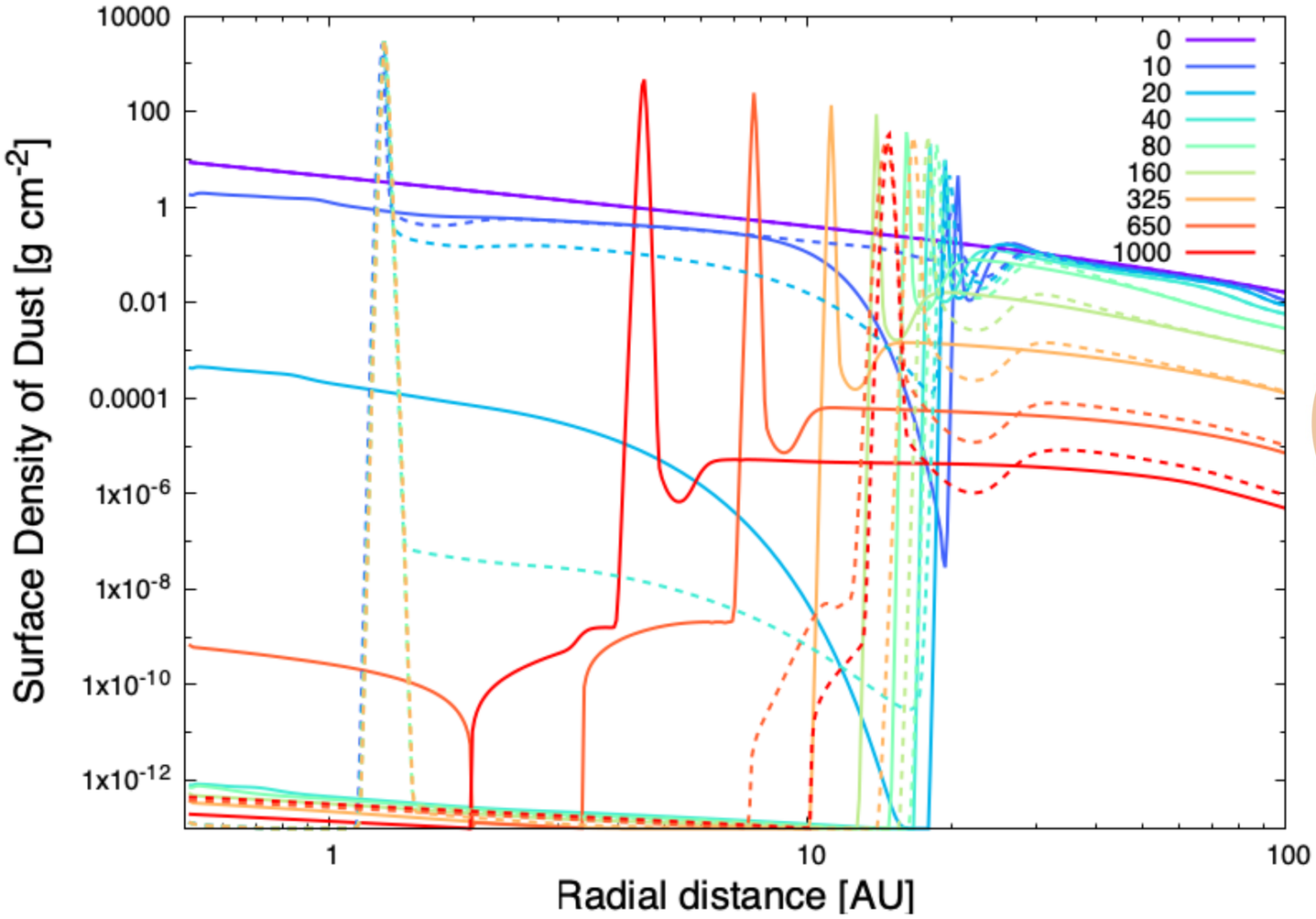


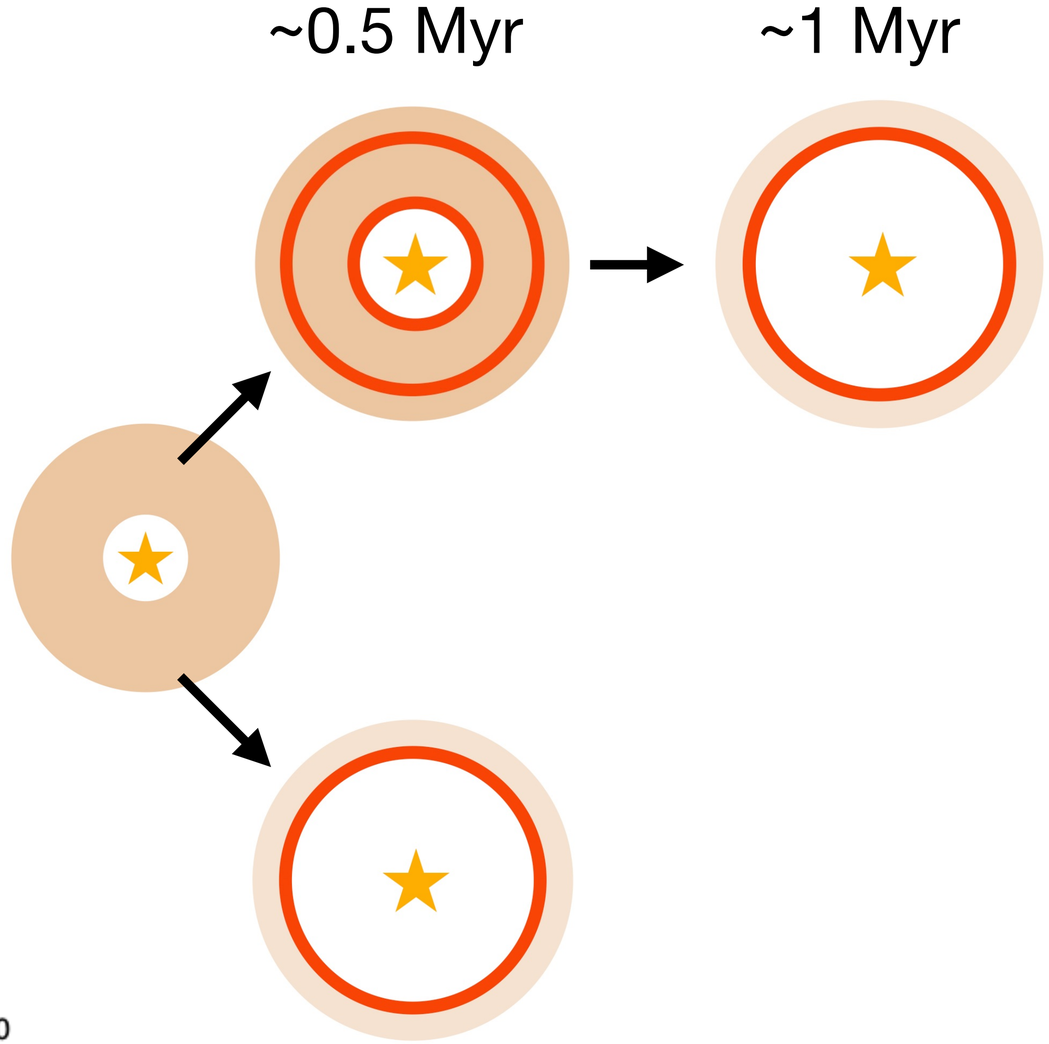
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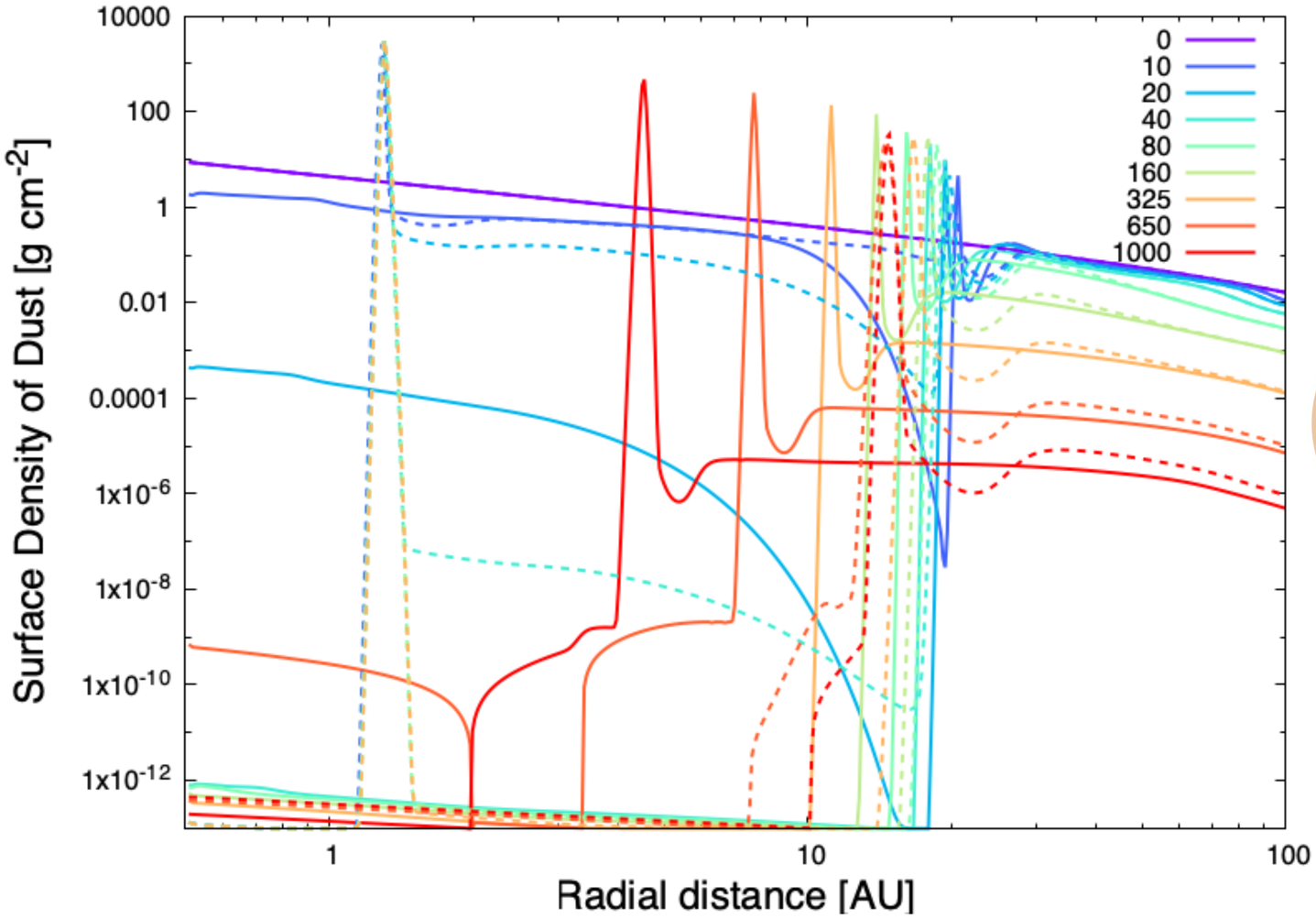


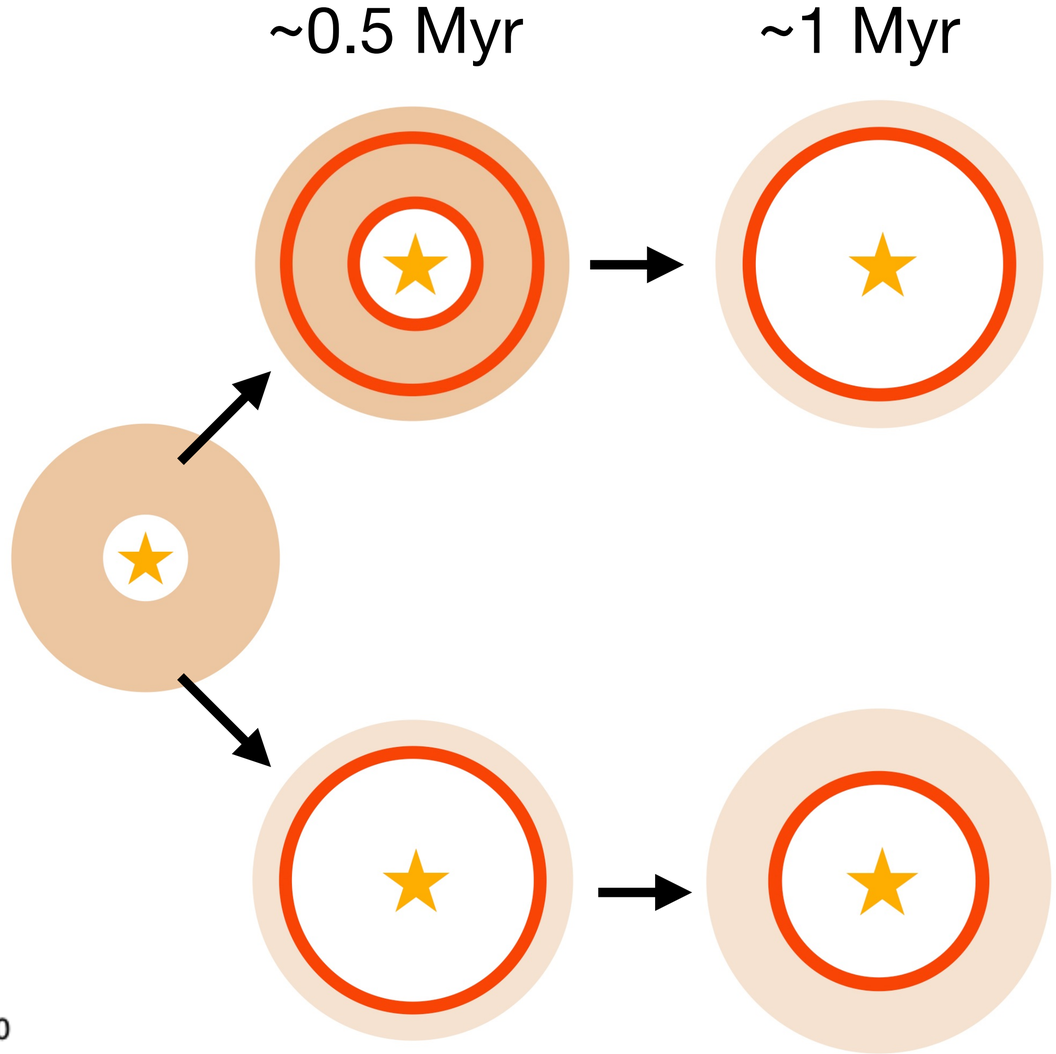
1D dust evolution: viscous + ADZ + PE





1D dust evolution: viscous + ADZ + PE





Conclusion - gas

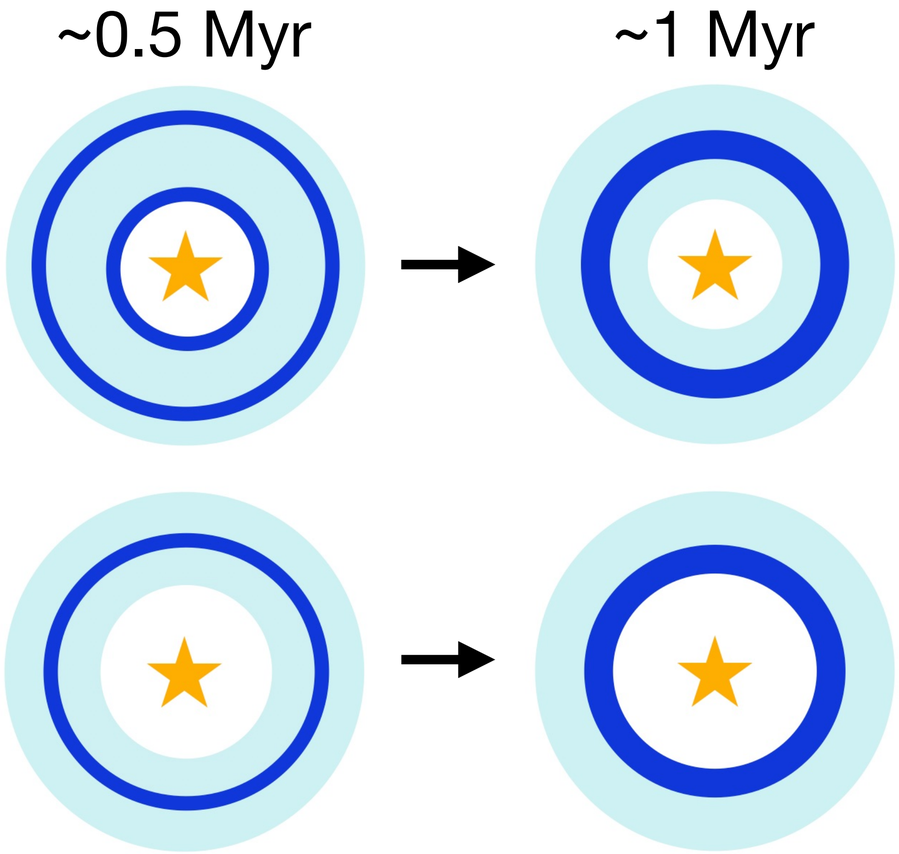
- Fix DZ +PE model:

Forms 2 jumps -> 1 jump

- Adaptive DZ + PE model

Forms 1 jump -> 1 jump

Location and width of the jump differs significantly



Conclusion - dust

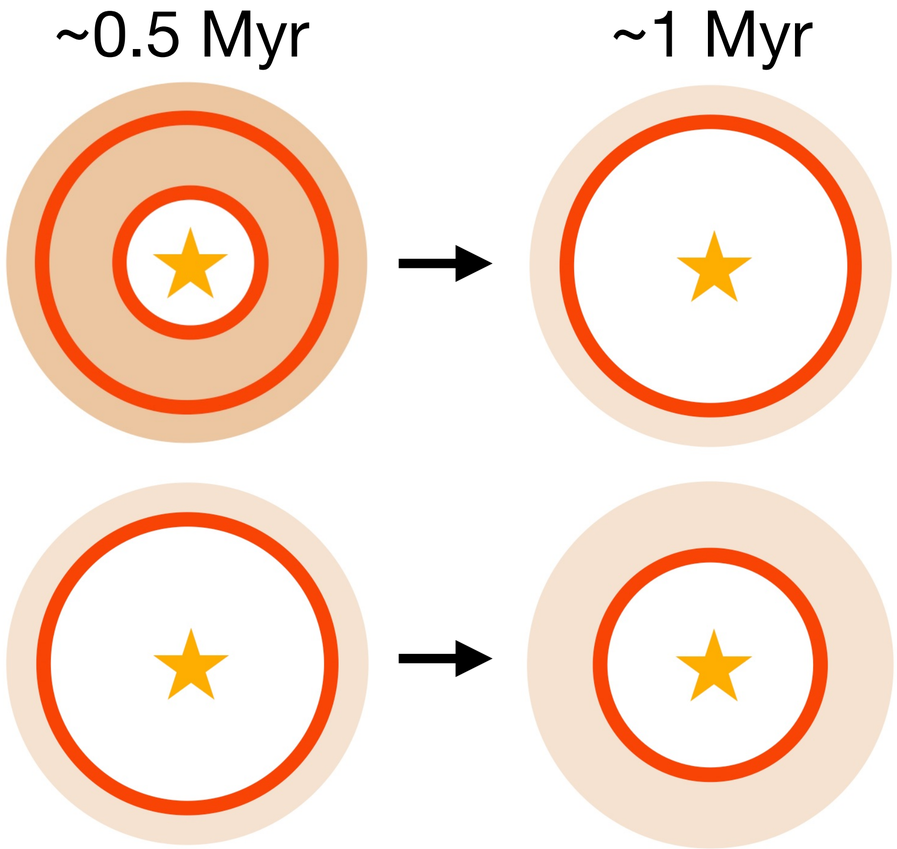
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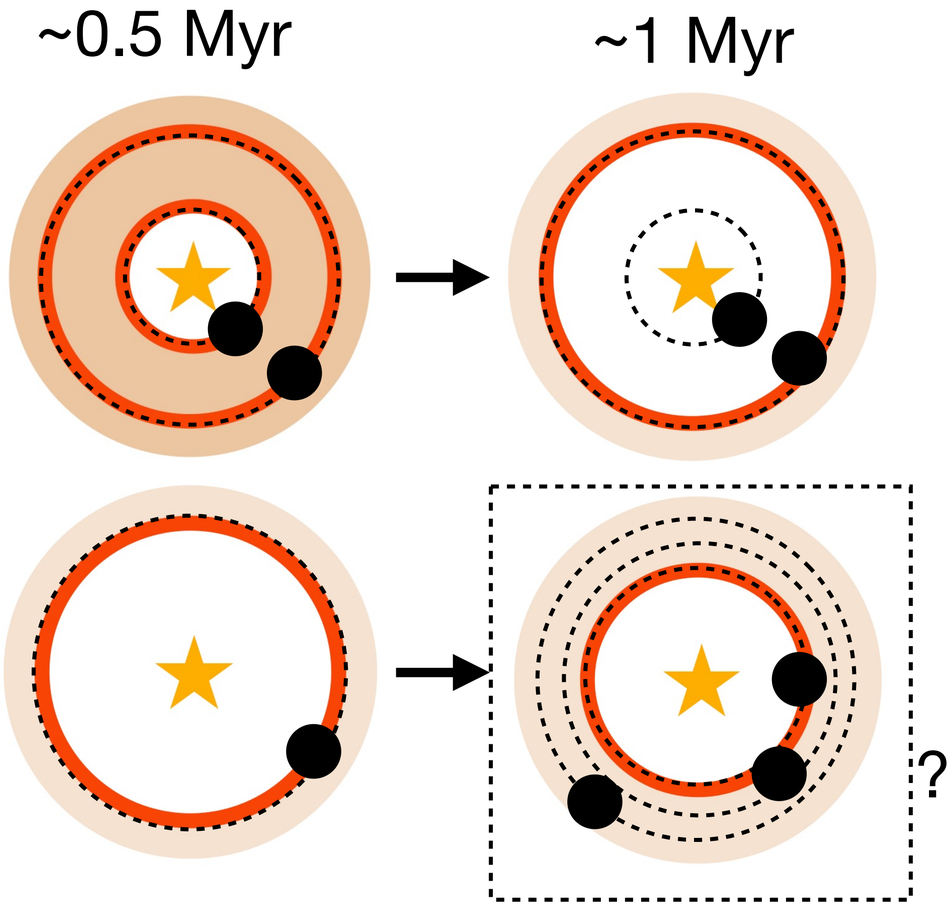
Forms 1 jump -> 1 jump

Location and width of the jump differs significantly



Conclusion - formation of giant planets

- Moving pressure maxima may induce planet formation in wide area of the protoplanetary disk
- -> possible planet factory throughout the protoplanetary disk



Future plans

- 1D: Adding magnetic disk wind model to gas evolution
- Adding planet formation and migration to the model
- See: **István Gergely Hegedüs** presentation on Friday
- Comparison with 2D models

Thank you for your attention!

Evolution of photoevaporative disk dead zone
- Giant planet factory

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