How do viscous + MHD wind discs evolve in the presence of the dead zone?

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Credit: ESO/L. Calçada

@simintong

Credit: NASA/JPL-Caltech

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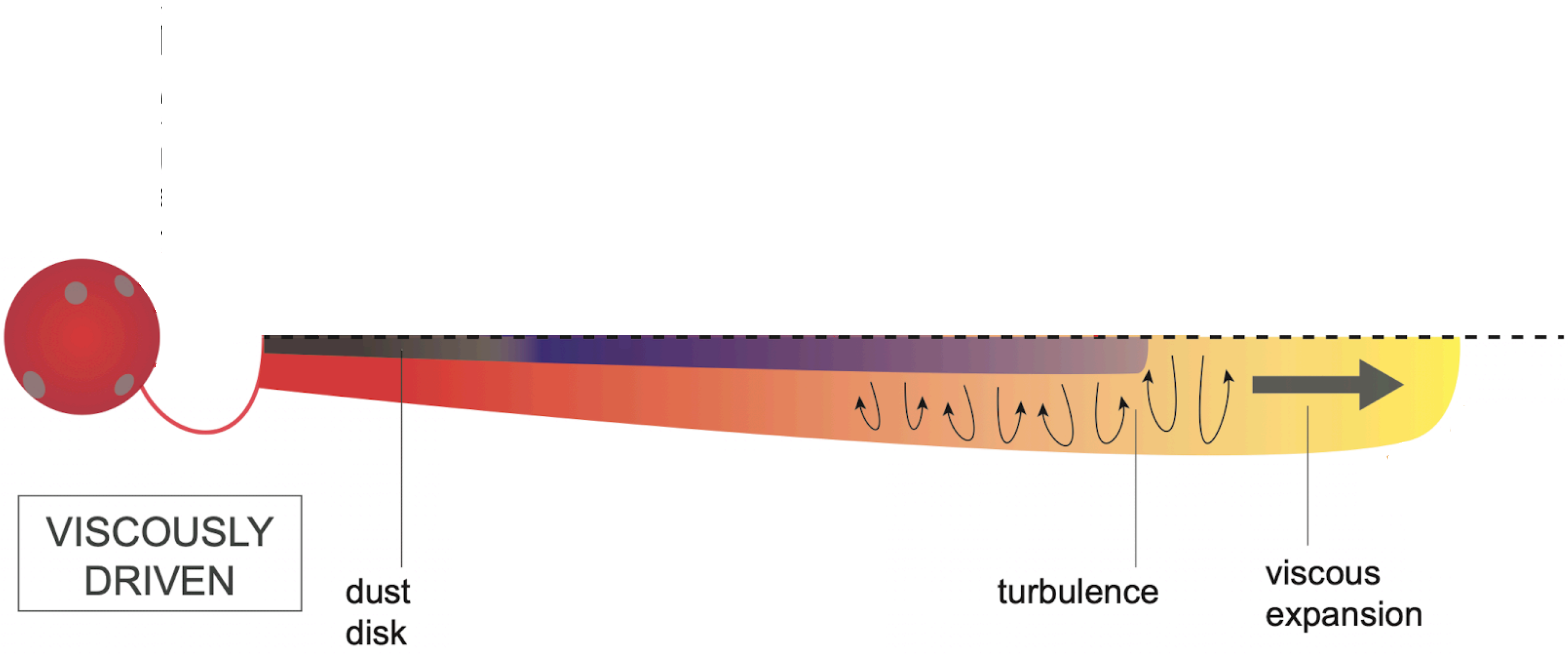
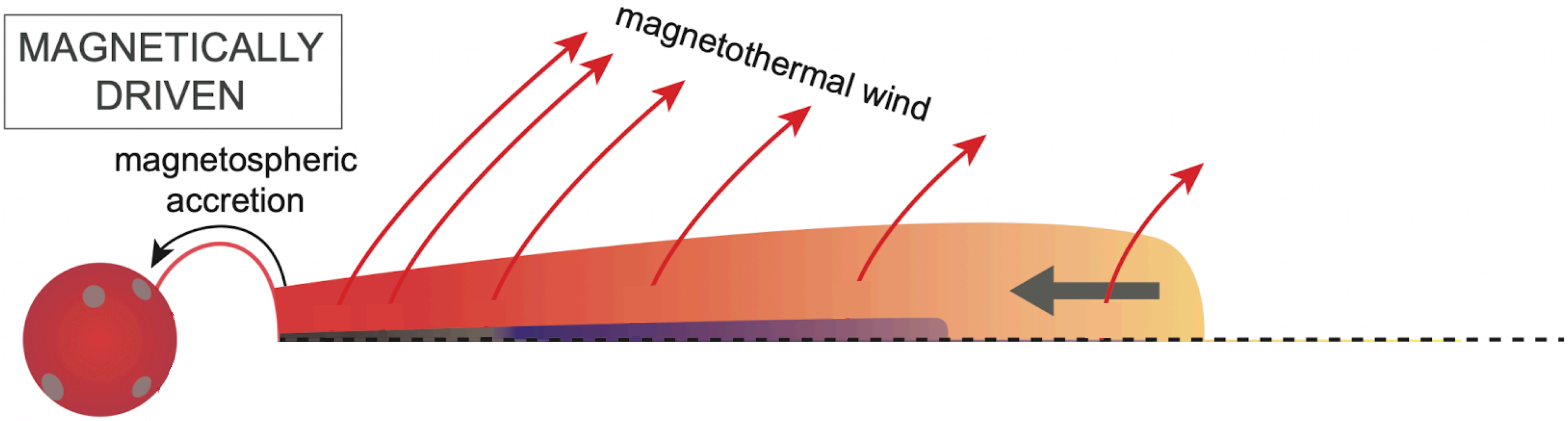


Modified from Manara+2022



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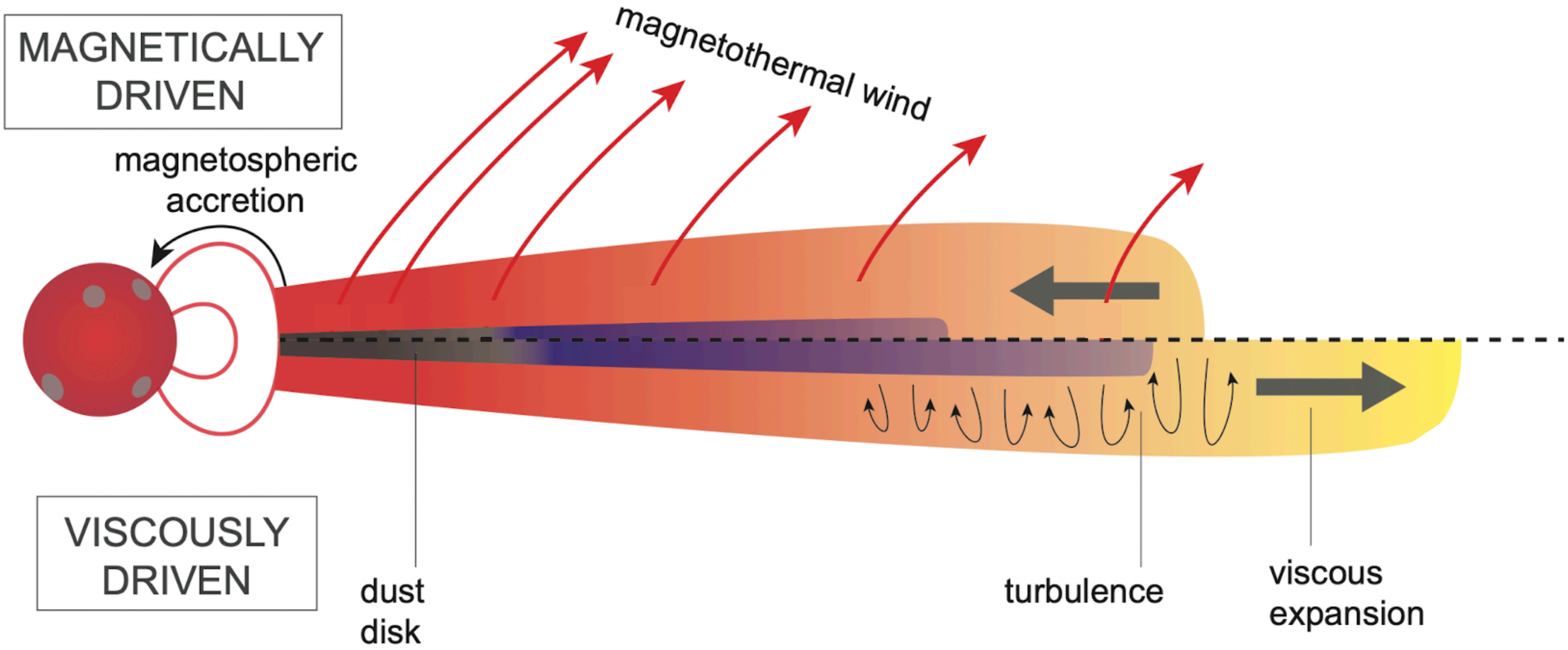

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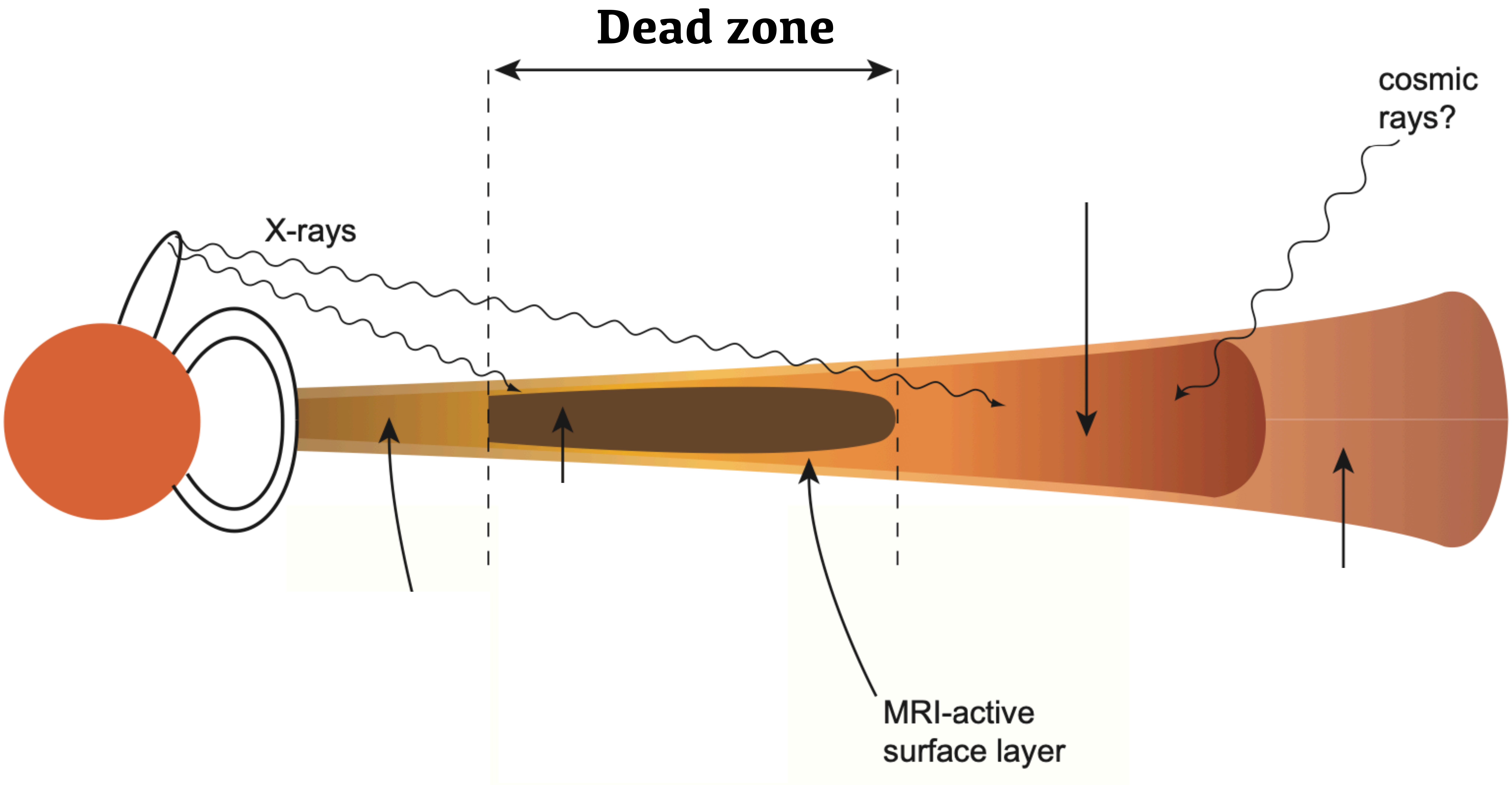
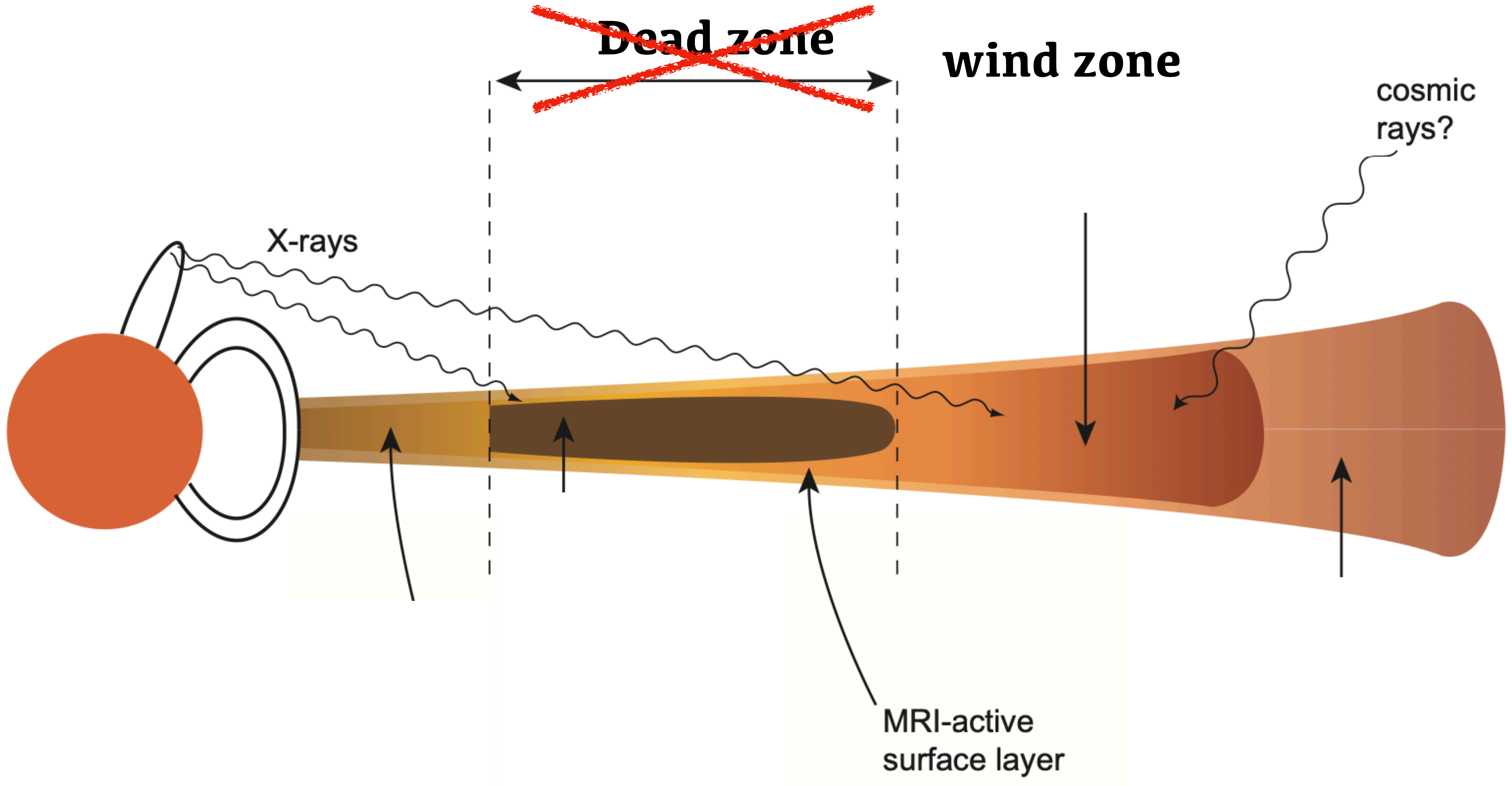


Abbreviations: MRI = magneto-rotational instability

Credit: P. Armitage



Abbreviations: MRI = magneto-rotational instability

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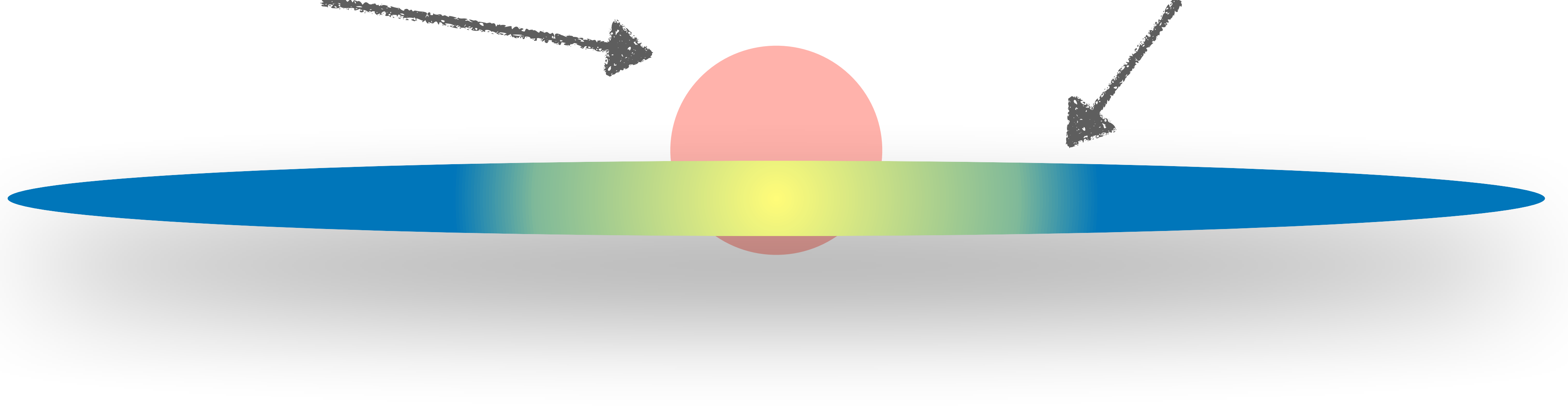
Disc Modelling: parameterised viscosity & MHD winds

Viscosity ($\alpha_{\rm SS}$) + MHD wind ($\alpha_{\rm DW}$) + internal photoevaporation

$$\frac{\partial \Sigma_g}{\partial t} = \frac{3}{R}\frac{\partial}{\partial R}\left[R^{1/2}\frac{\partial}{\partial R}(\nu \Sigma_g R^{1/2})\right] + \frac{3}{2R}\frac{\partial}{\partial R}\left(\frac{\alpha_{\rm DW}\Sigma_g c_s^2}{\Omega}\right) - \frac{3\alpha_{\rm DW}\Sigma_g c_s^2}{4(\lambda-1)R^2\Omega} - \dot{\Sigma}_w(R,t)$$

$$\nu = \alpha_{\rm SS} c_s h$$

$M_* = 1\ M_\odot$ $\quad$ $M_d = 0.01\ M_\odot$

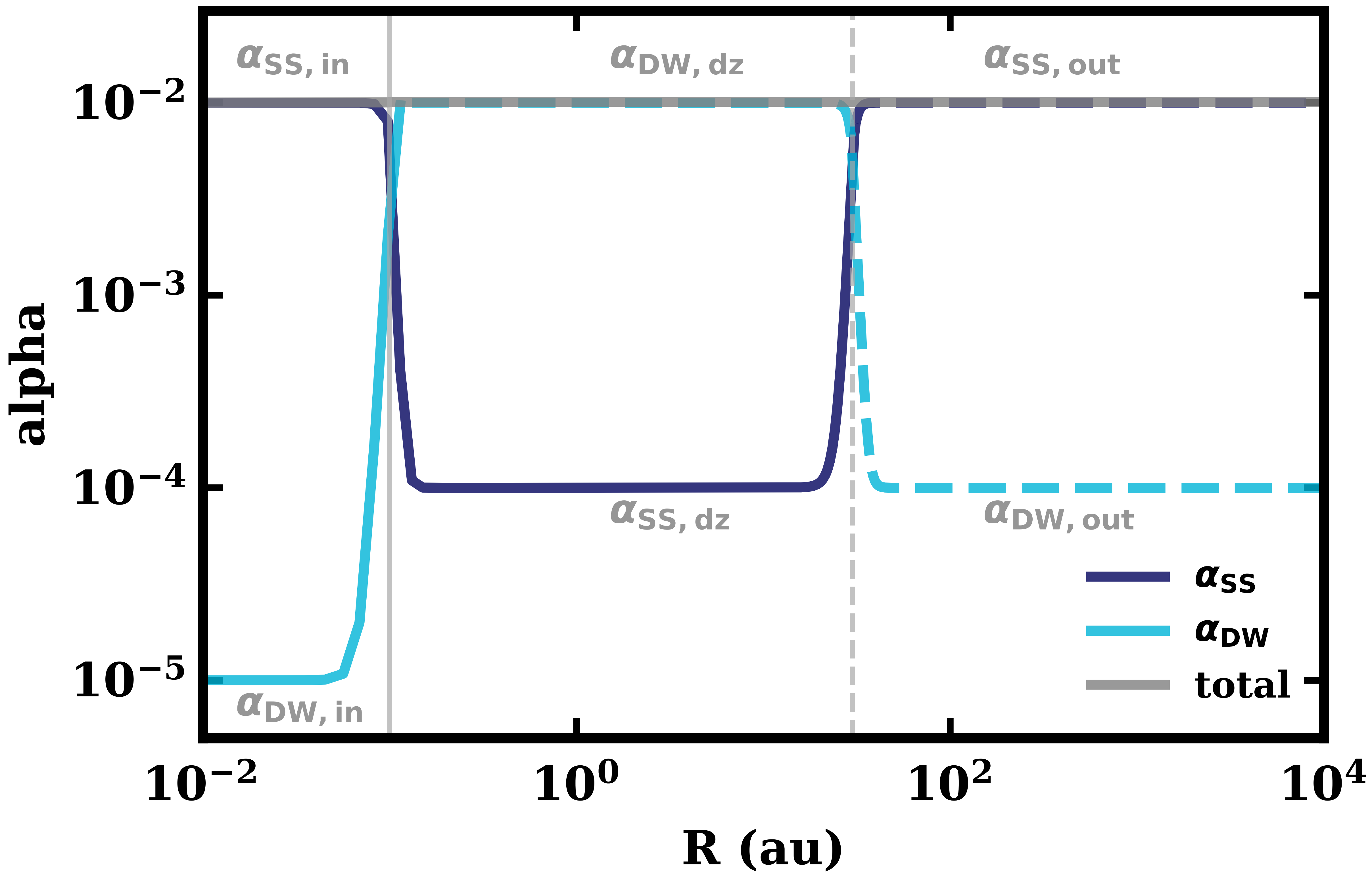


Grid: 0.008 — 20K au

Alexander 2012, Tabone+2022

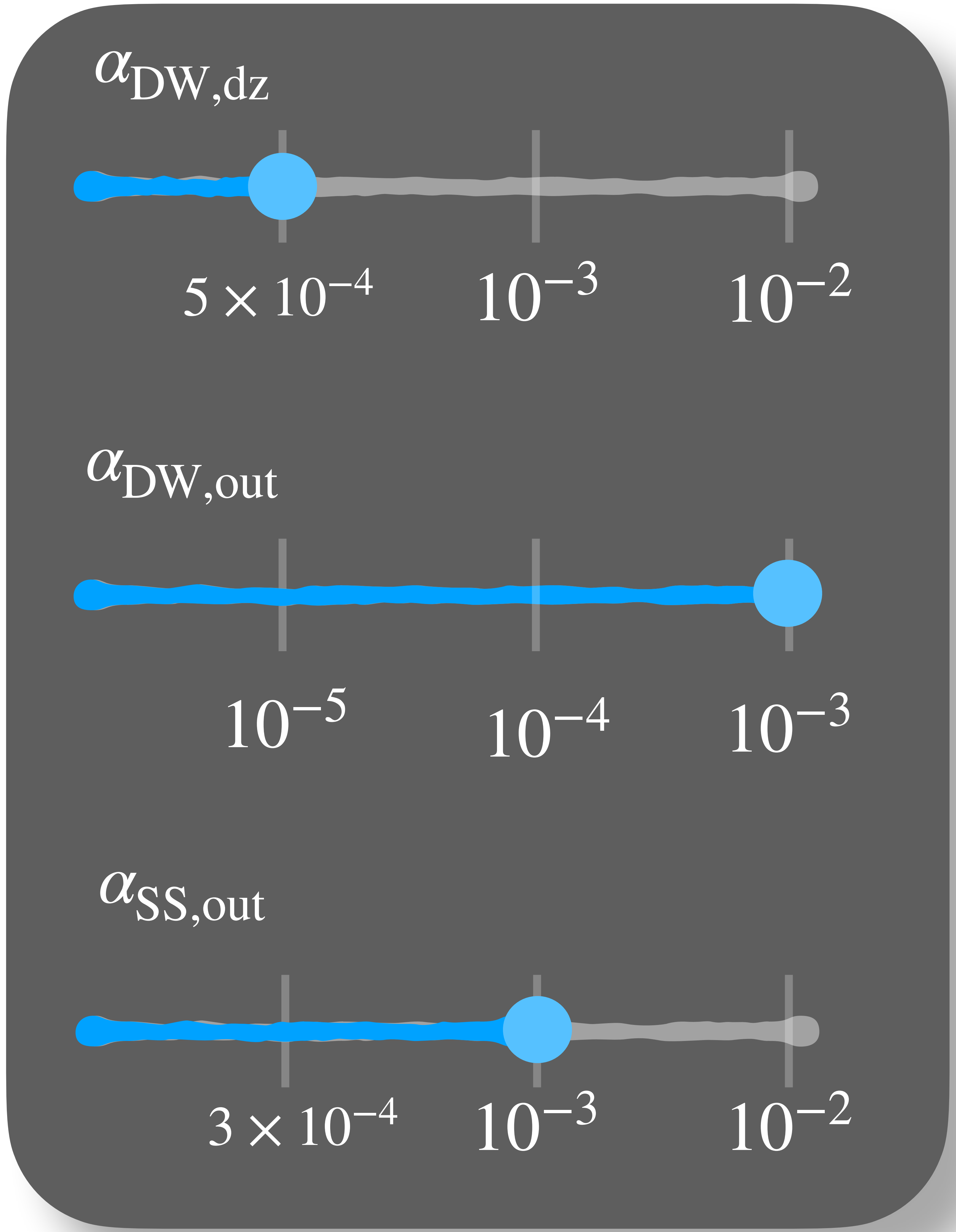
Dead Zone Modelling

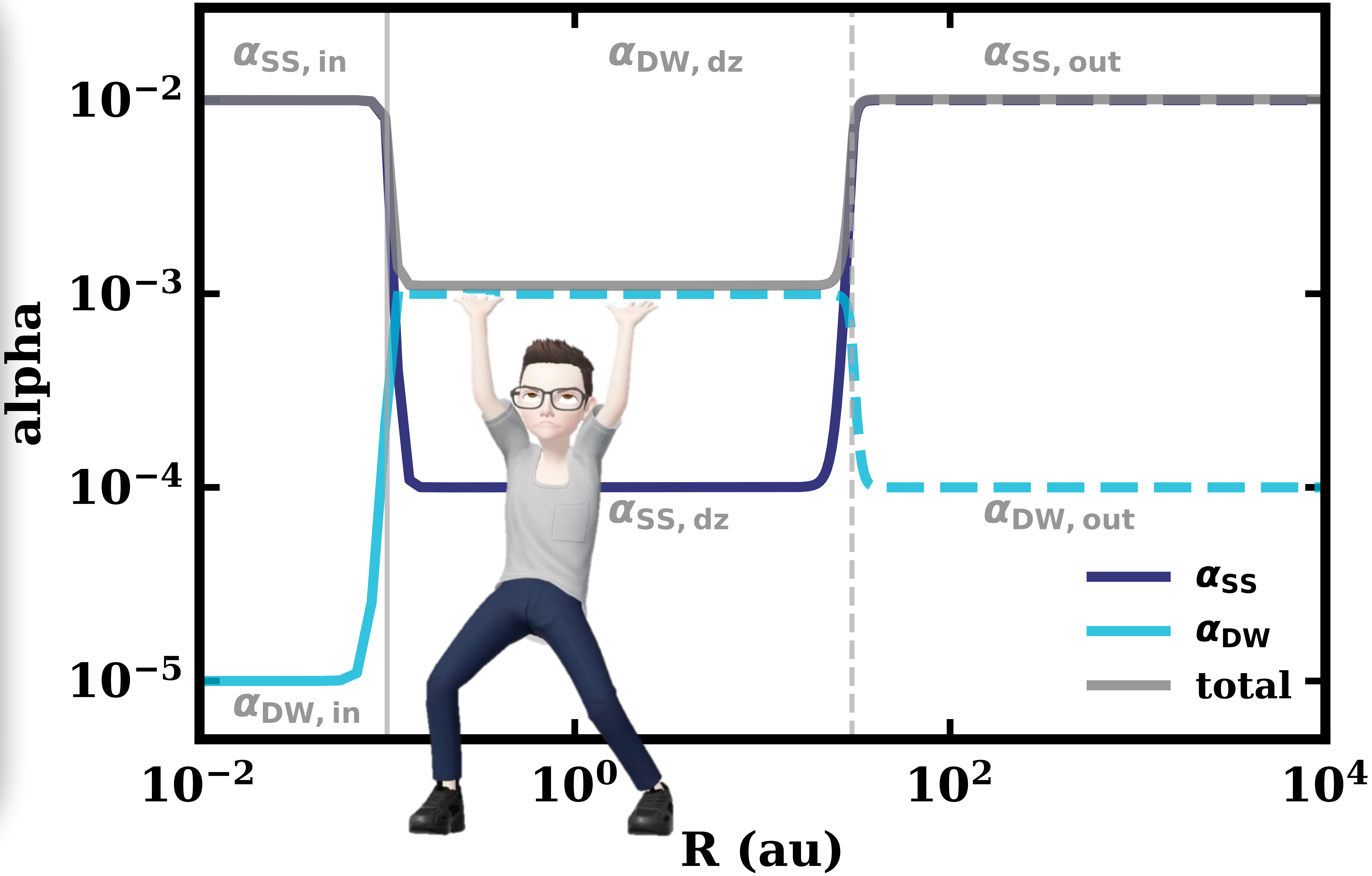
- Dead (wind) zone inner & outer edge?
  - ~ 0.1 au - tens of au
- α_{SS} in and beyond the dead zone?
  - Inner disc: 10^{-2}
  - Dead zone: 10^{-4}
  - Outer disc: ???
- α_{DW} in and beyond the wind zone?
  - Inner disc: 10^{-4}
  - Wind region and outer disc?
  - Evolution of magnetic field: $\alpha_{DW}(t) \propto \Sigma_g(t)^{-0.5}$



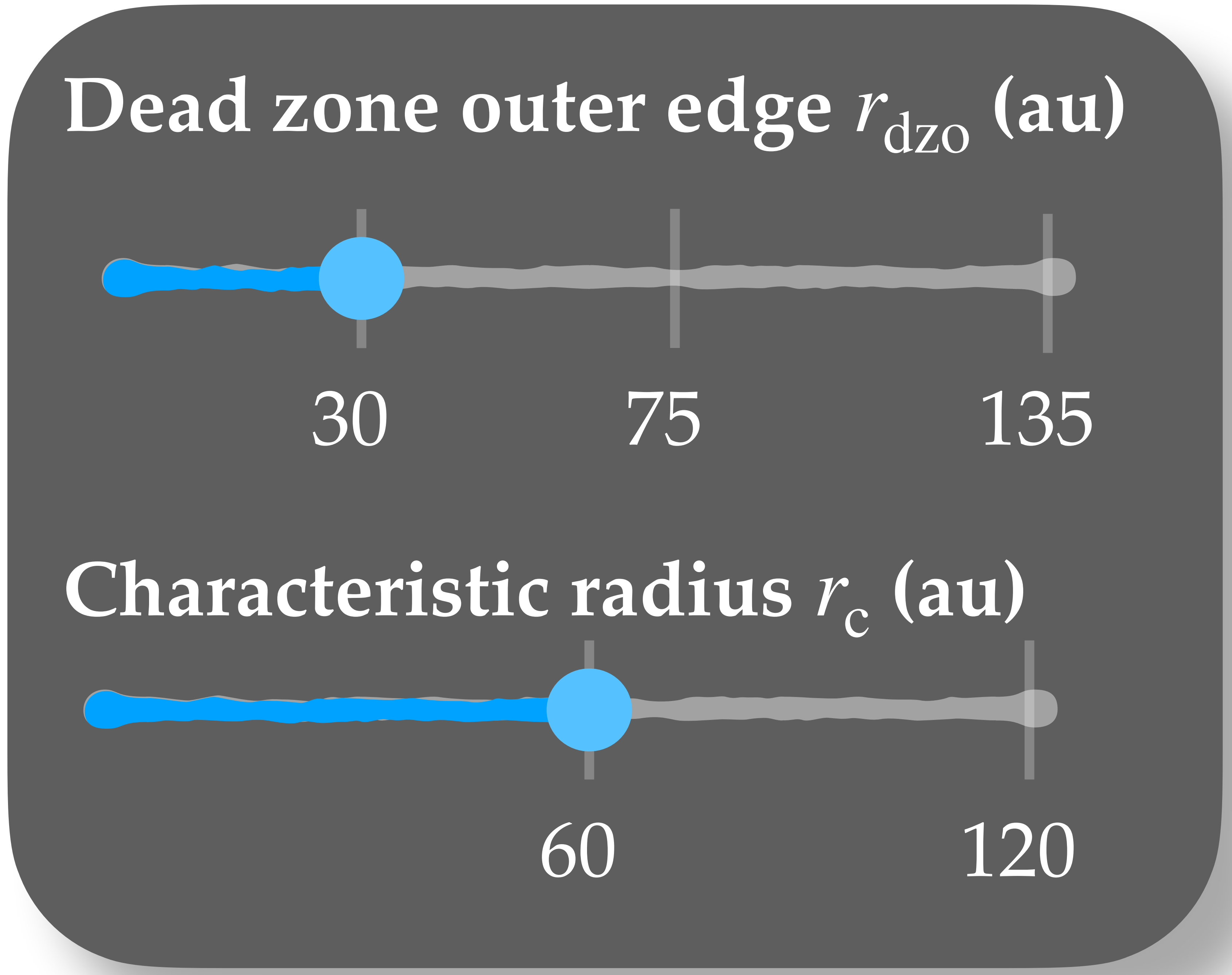
Birnstiel+2012, Mohanty+2018, Flock+2019, Gárate+2019, 2021

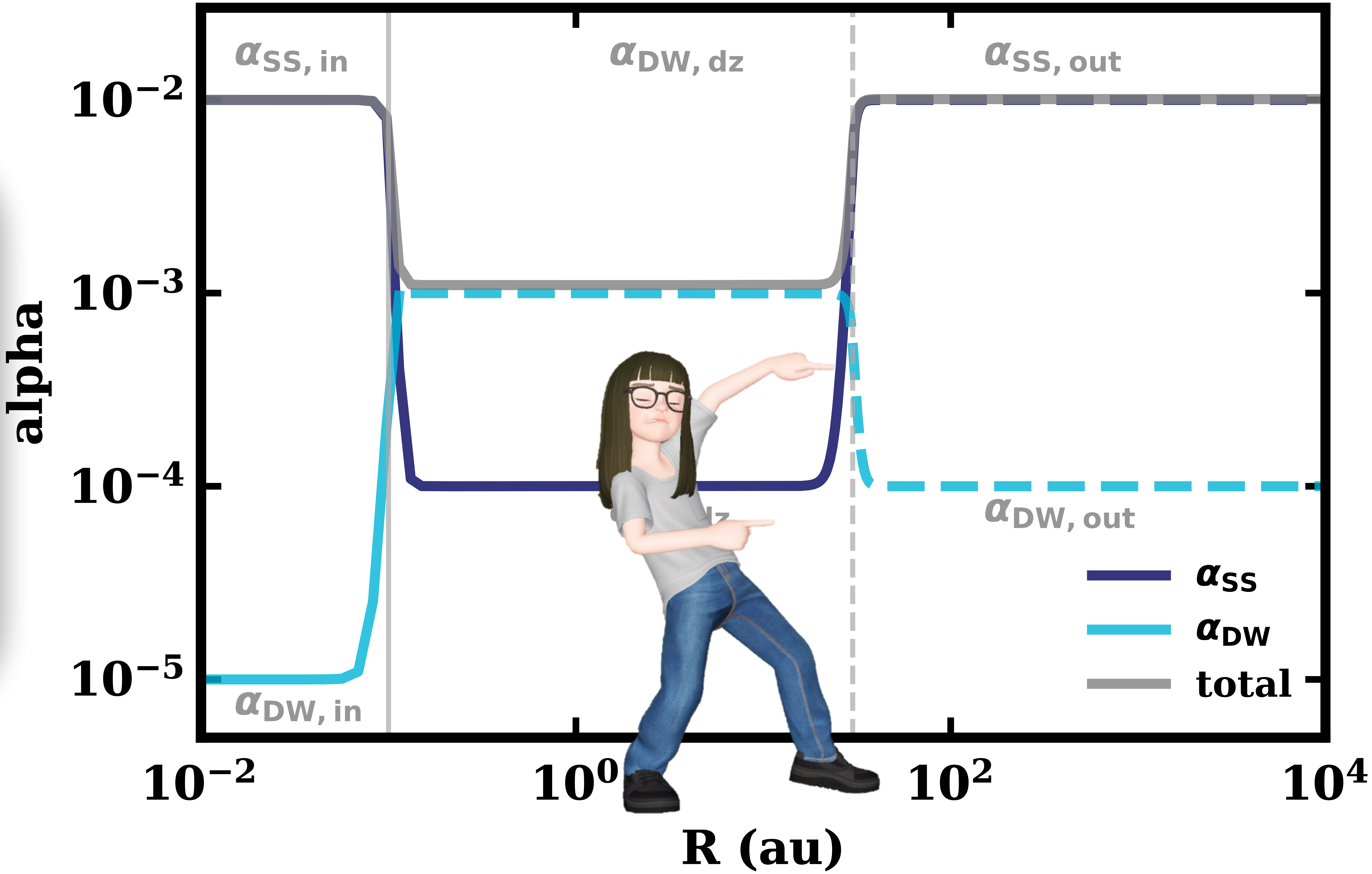
Dead Zone Modelling: Parameter space exploration



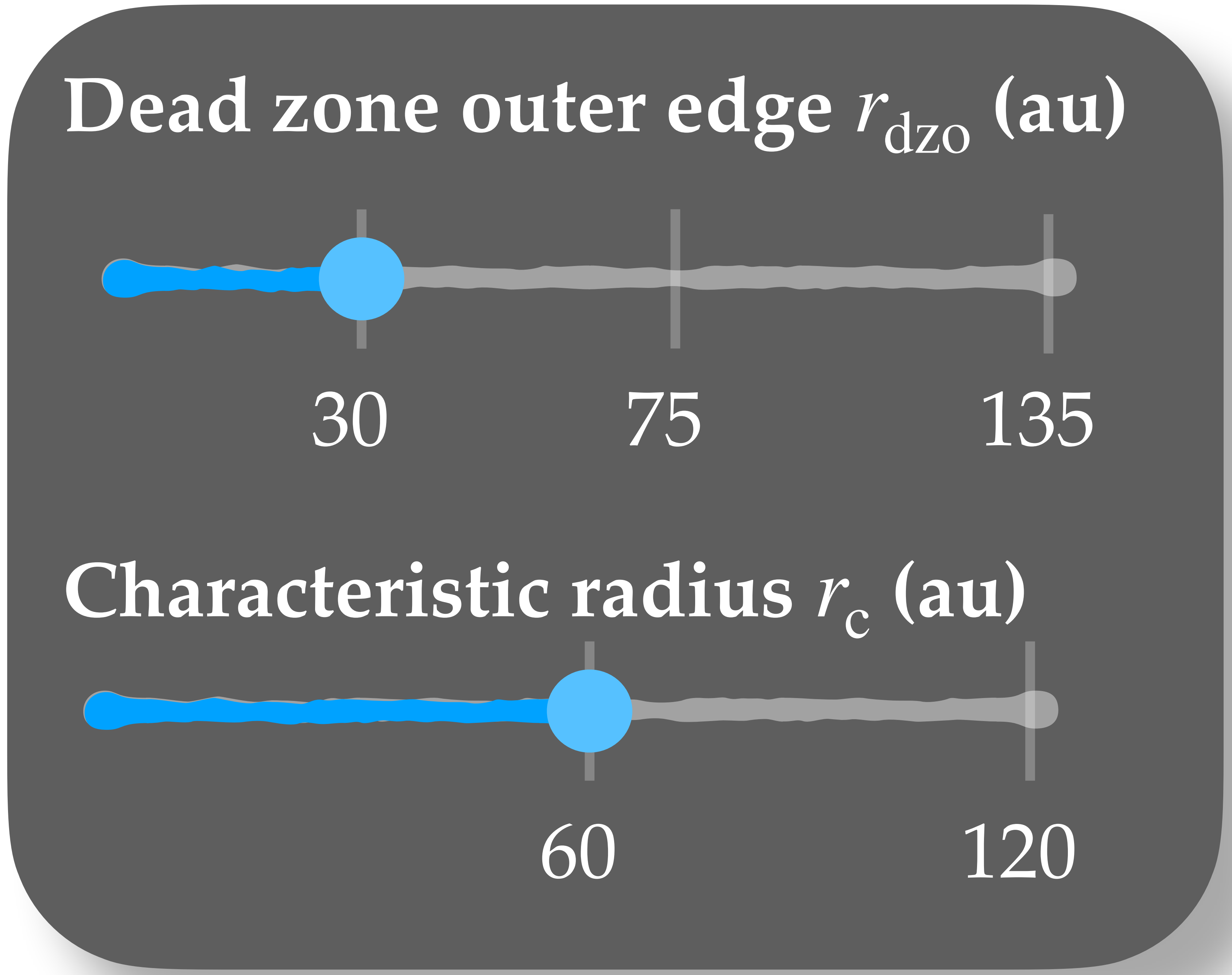


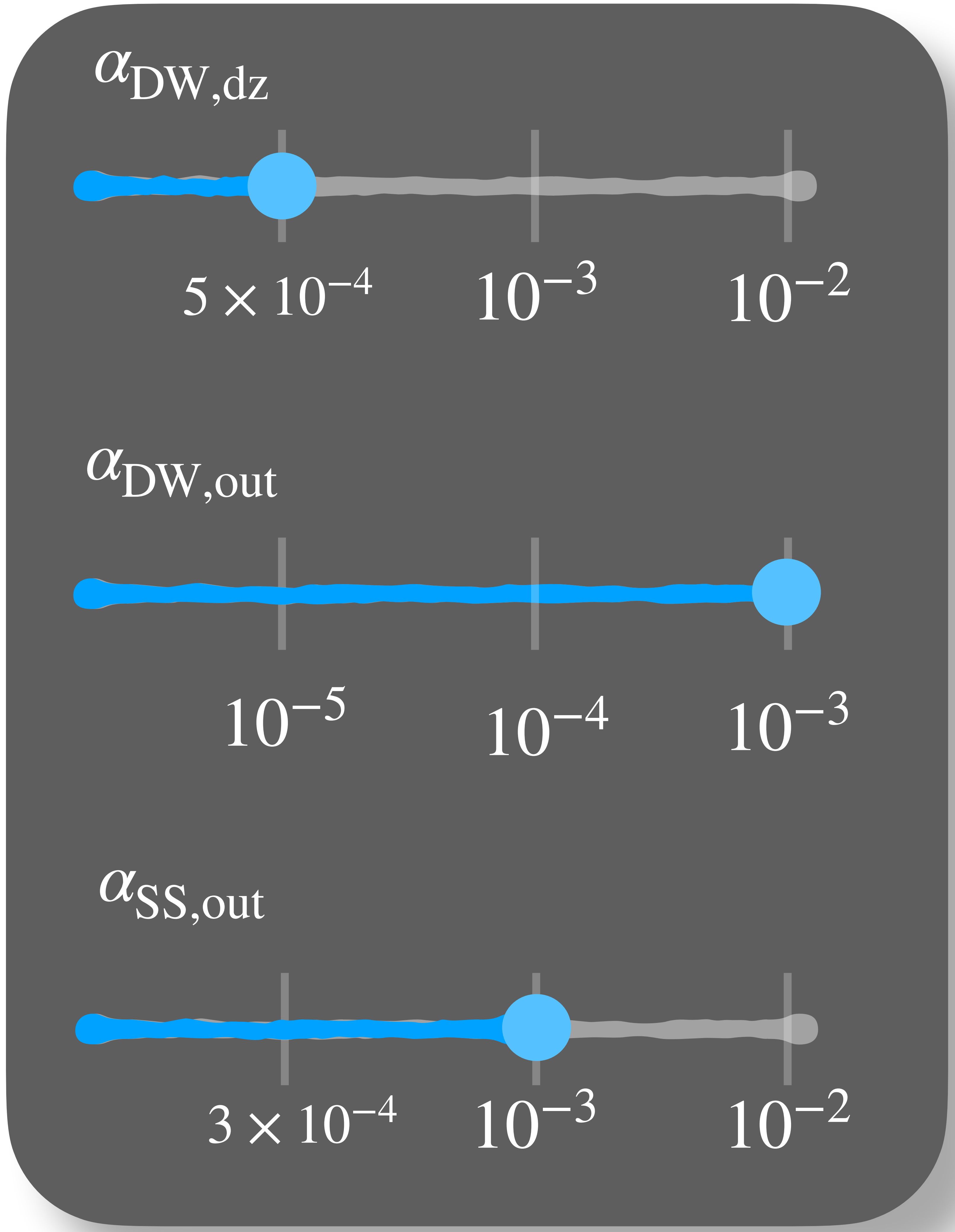
Dead Zone Modelling: Parameter space exploration





Dead Zone Modelling: Parameter space exploration

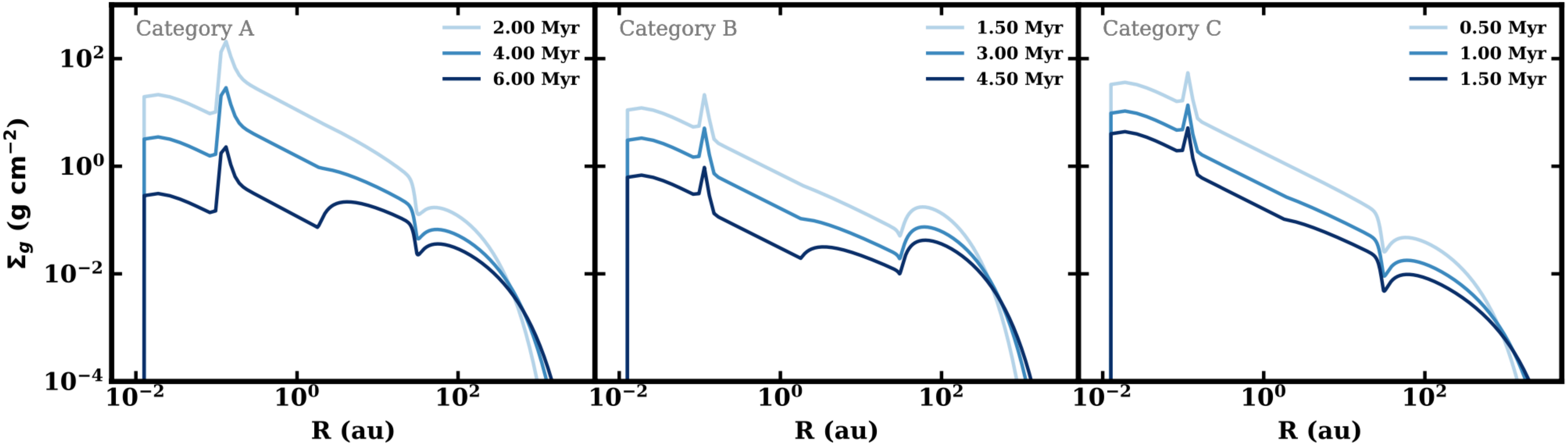




1. 3 X 3 X 3 simulations: fixed r_{dzo} and r_c
2. 13 X 6 simulations: fixed α_{DW} & α_{SS}

Preliminary result 1: Surface density classification

(Fixed disc size $r_c = 60$ au & dead zone size $r_{\rm dzo} = 30$ au)



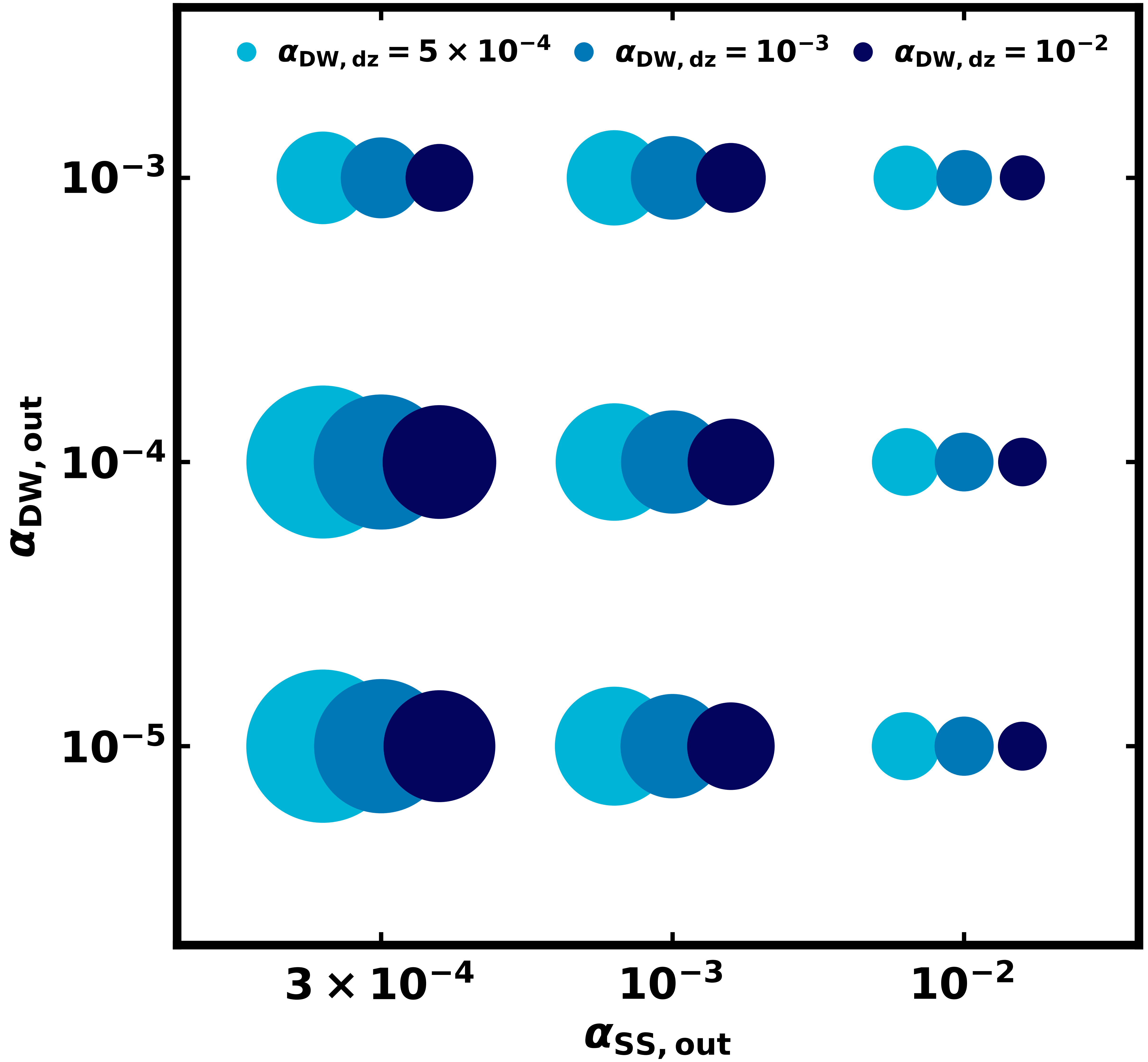
Weak MHD winds (small $\alpha_{\rm DW,dz}$)

Strong MHD winds (large $\alpha_{\rm DW,dz}$) + Inefficient outer expansion

Strong MHD winds + Efficient outer expansion

Preliminary result 2: Disc lifetime

(Fixed disc size $r_c = 60$ au & dead zone size $r_{\rm dzo} = 30$ au)

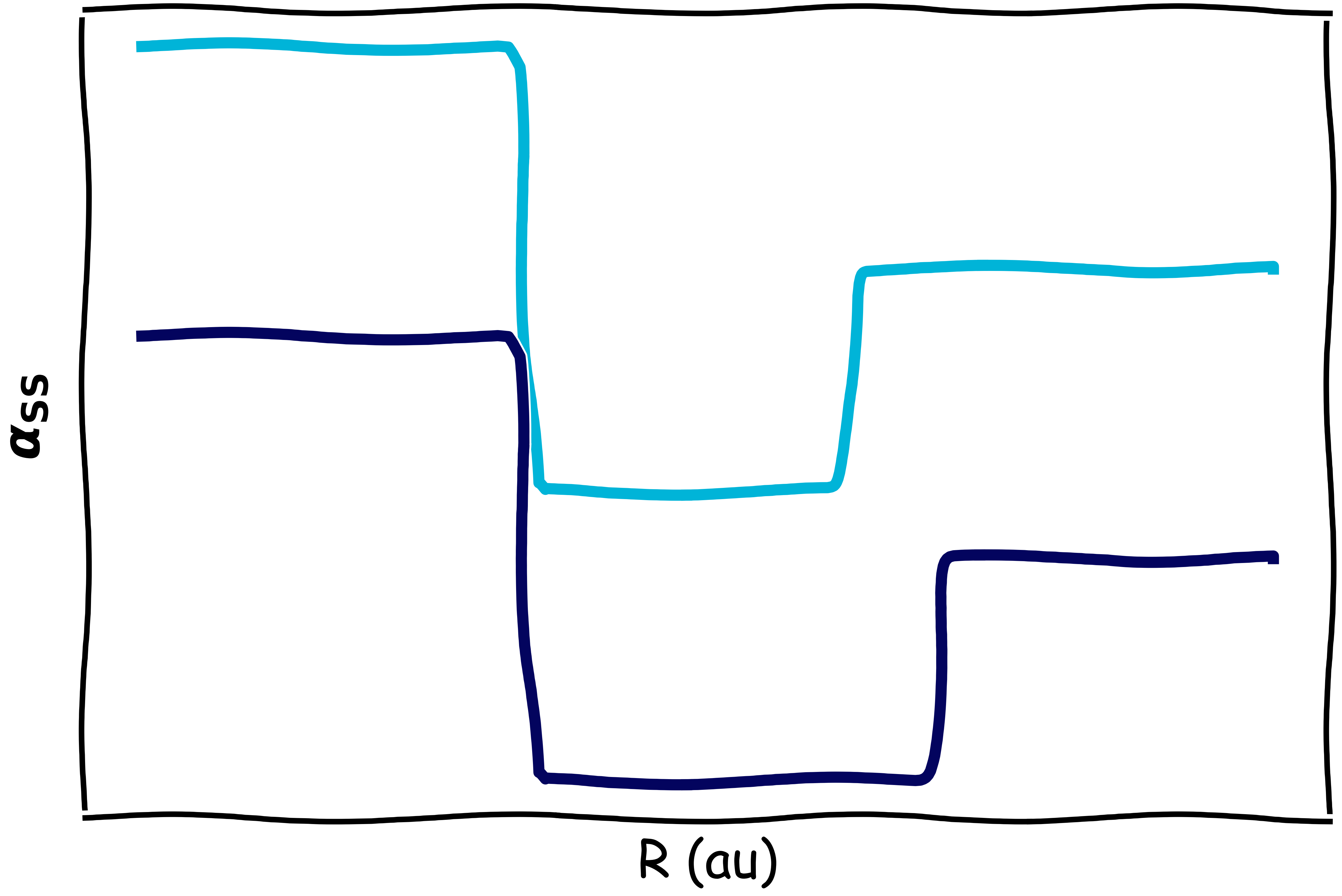


- **Short lifetime when $\alpha_{\rm DW,dz}$ and $\alpha_{\rm SS,out}$ is large (10^{-2}).**

Preliminary result 2: Disc lifetime

(Varying disc size r_c & dead zone size $r_{\rm dzo}$)

- $r_{\rm dzo} = 30 \rightarrow 75/135$ au:
  - Radially averaged $\overline{\alpha(r)}$ changes
  - Lifetime: increase or decrease
  - Exceptions



(Offset for illustration)

Preliminary result 2: Disc lifetime

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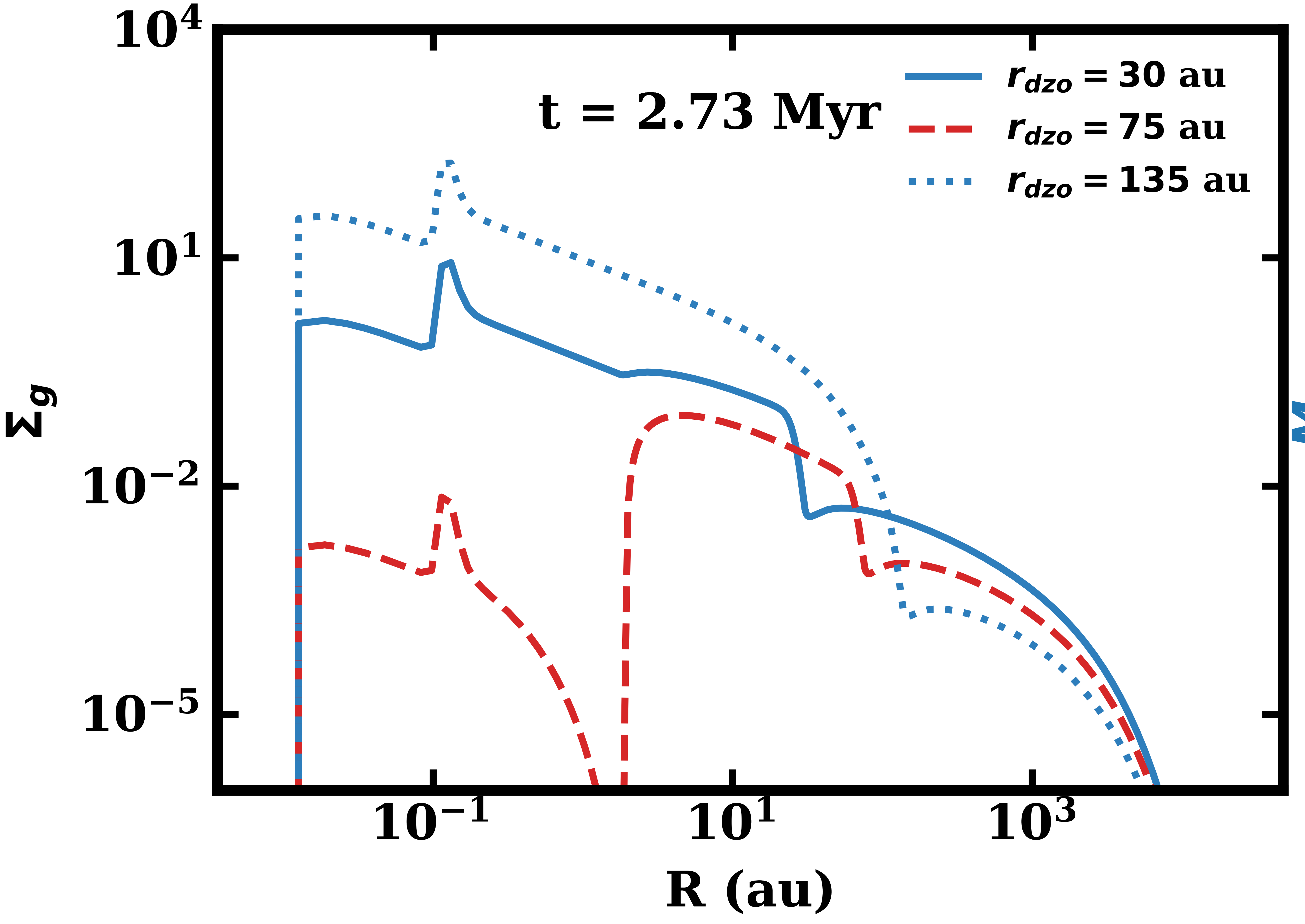
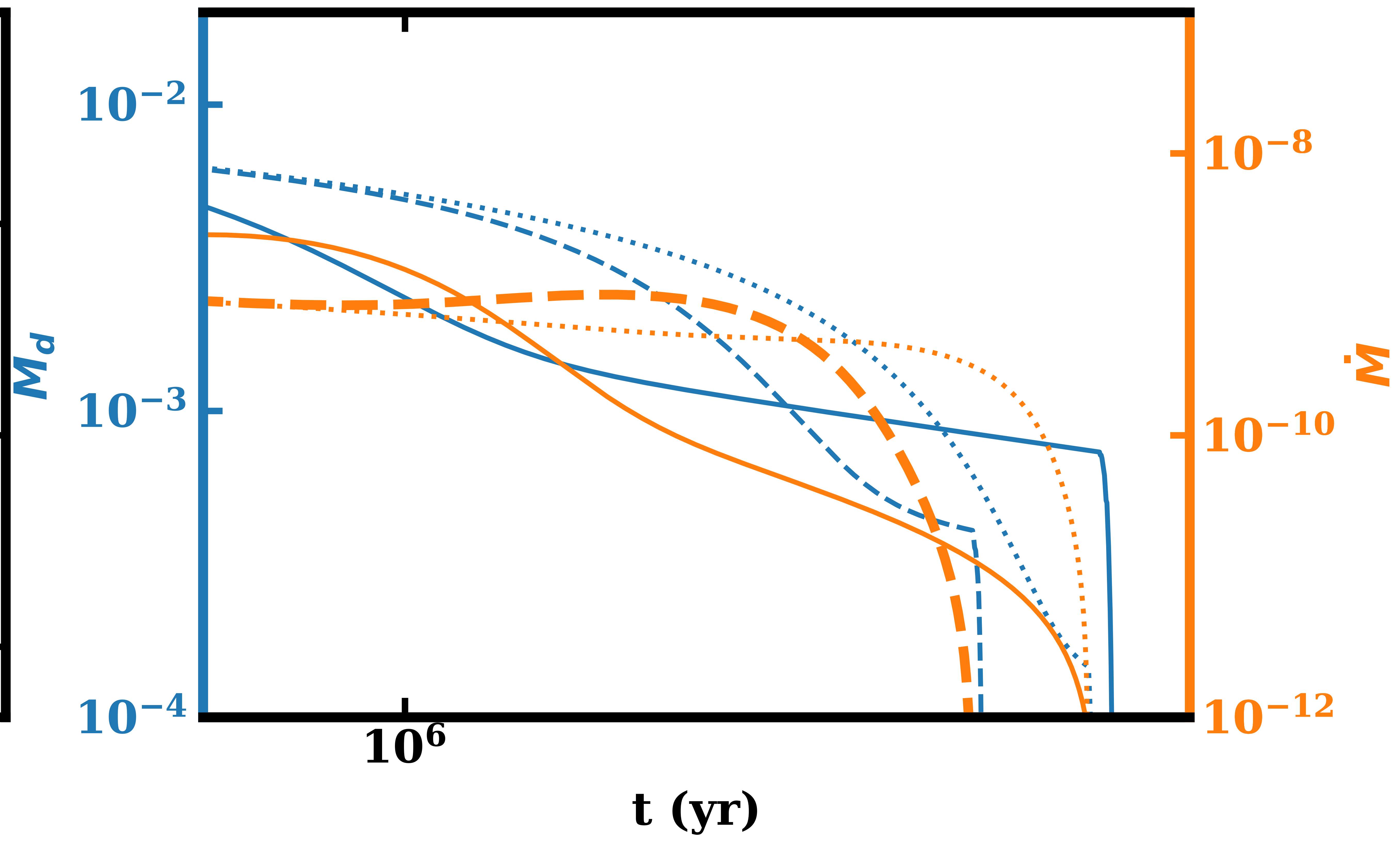
- $r_{\rm dzo} = 30 \rightarrow 75/135$ au:
  - Radially averaged $\overline{\alpha(r)}$ changes $\rightarrow$ lifetime: increase or decrease
  - Exceptions:

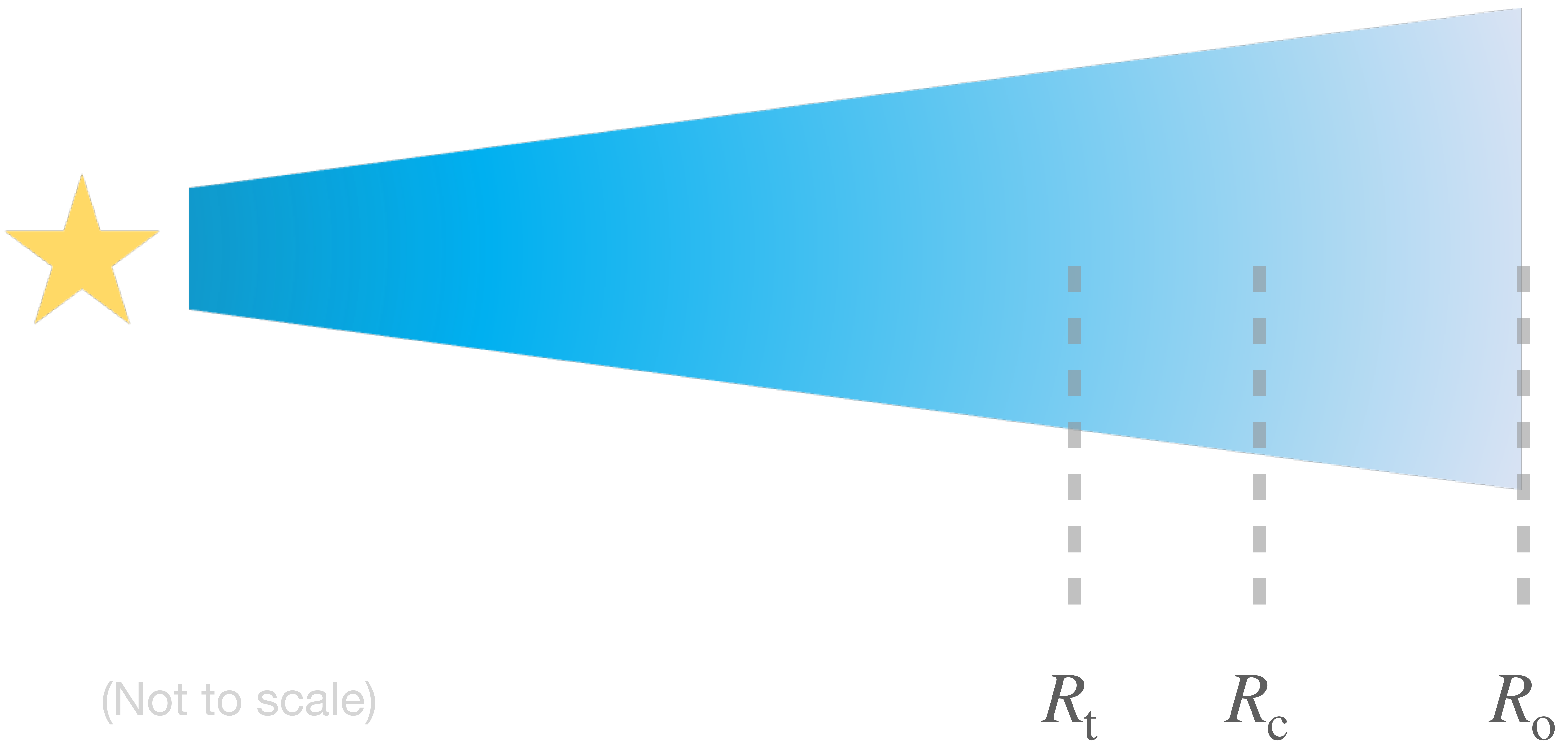




($\alpha_{\rm DW,dz} = 10^{-3}$, $\alpha_{\rm DW,out} = 10^{-4}$, $\alpha_{\rm SS,out} = 10^{-2}$)

Preliminary result 3: Outer disc spreading

(Fixed disc size $r_c = 60$ au & dead zone size $r_{\rm dzo} = 30$ au)



(Not to scale)

Preliminary result 3: Outer disc spreading

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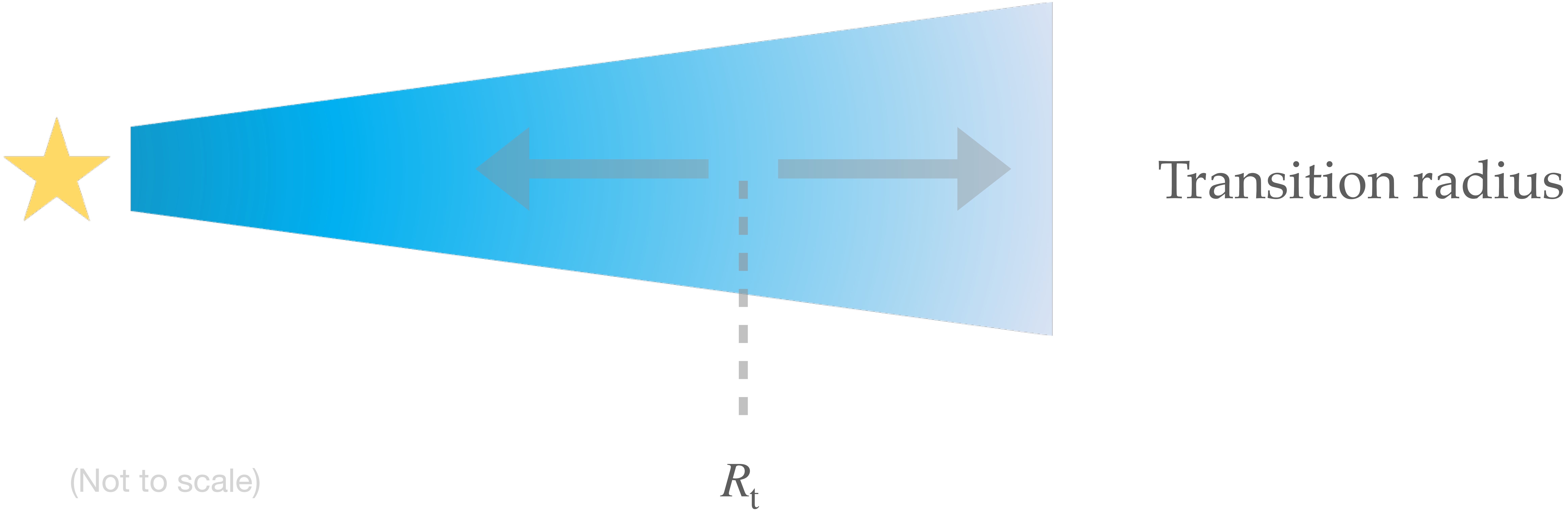

(Not to scale)

Preliminary result 3: Outer disc spreading

(Fixed disc size $r_c = 60$ au & dead zone size $r_{\rm dzo} = 30$ au)

Characteristic radius

Preliminary result 3: Outer disc spreading

(Fixed disc size $r_c = 60$ au & dead zone size $r_{\rm dzo} = 30$ au)

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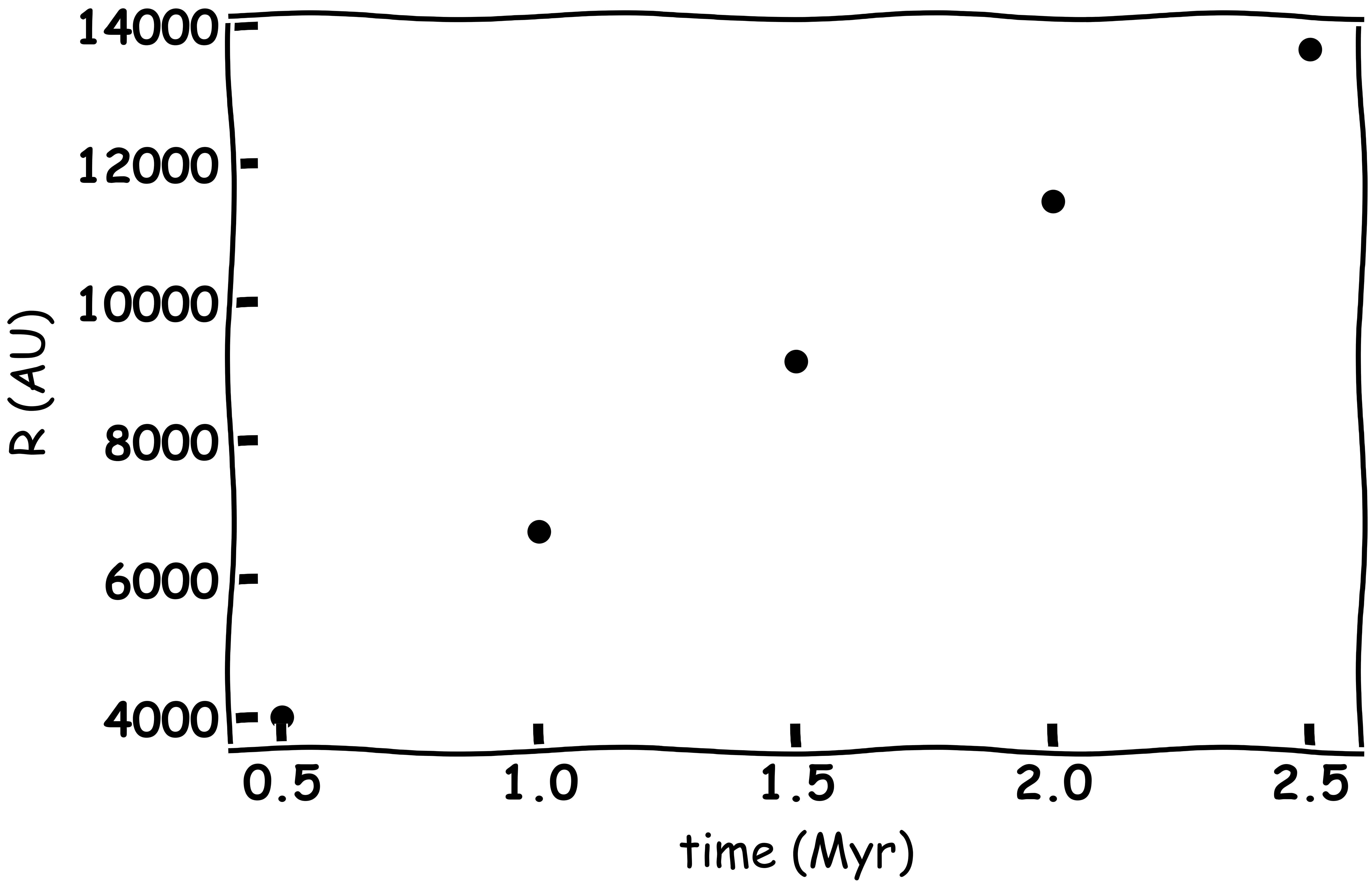

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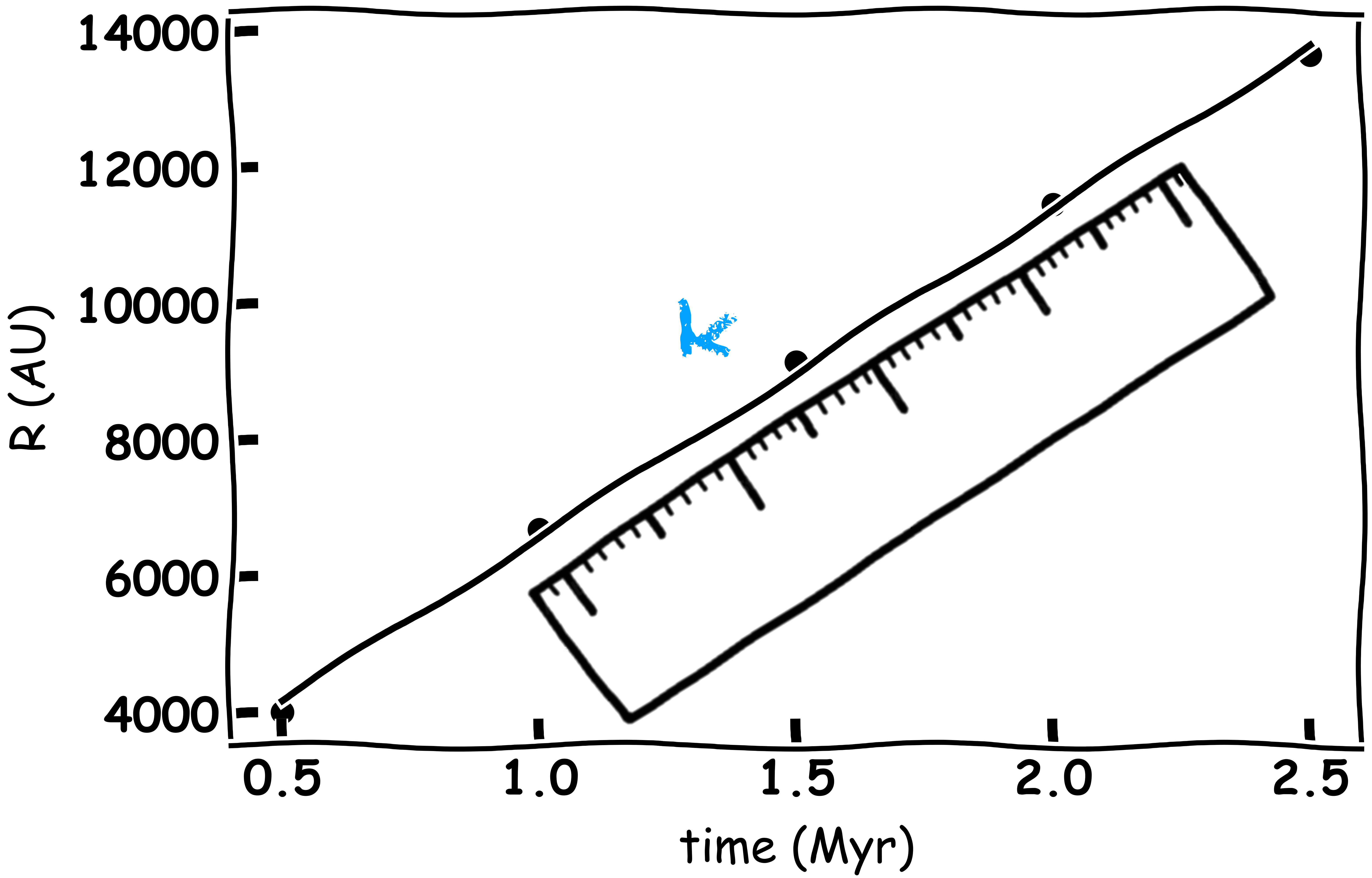


Preliminary result 3: Outer disc spreading

(Fixed disc size $r_c = 60$ au & dead zone size $r_{\rm dzo} = 30$ au)

Disc gas size expansion rates almost only depend on $\alpha_{\rm SS,out}$.

Increasing radii in most cases.

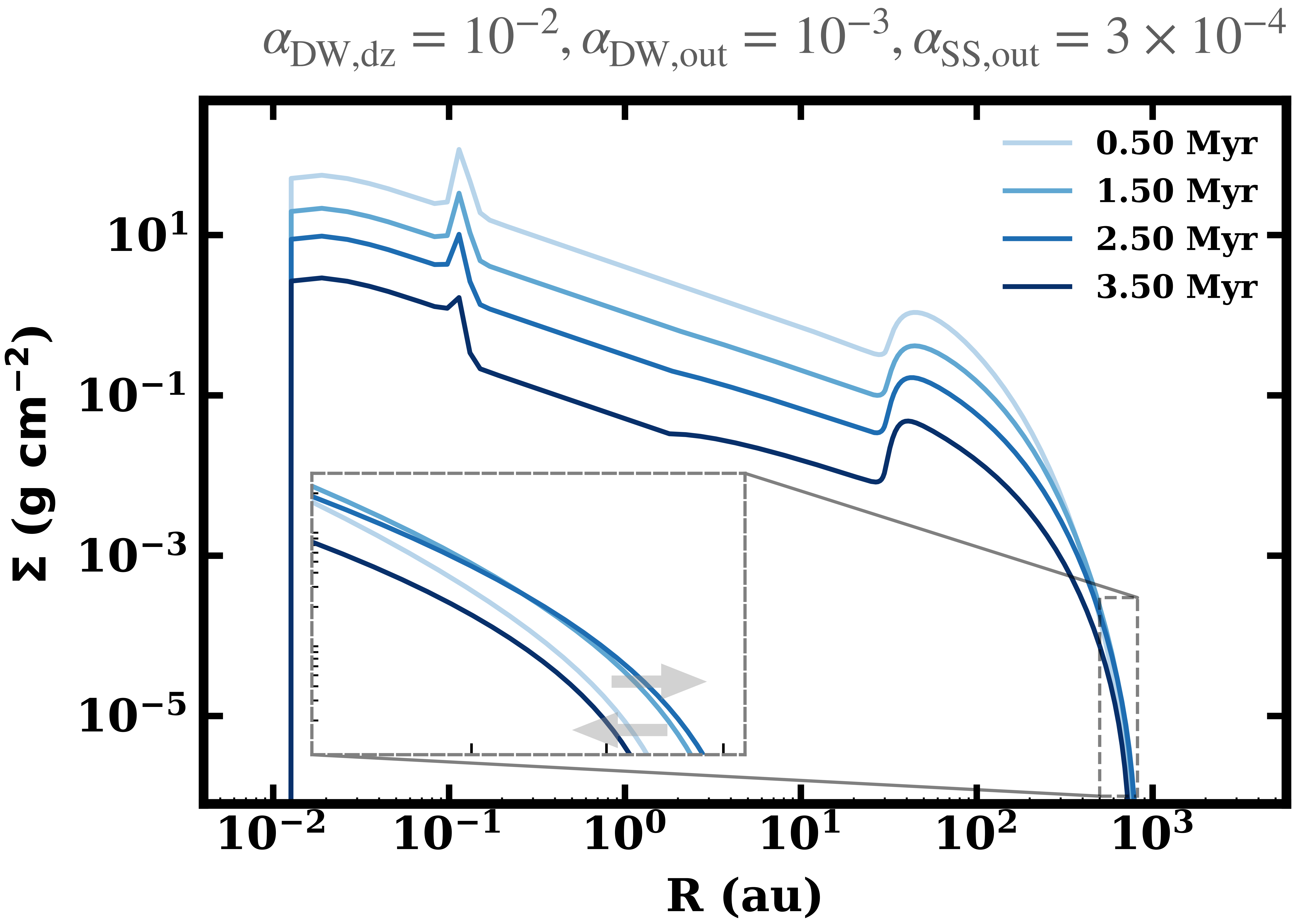
Preliminary result 3: Outer disc spreading

(Fixed disc size $r_c = 60$ au & dead zone size $r_{\rm dzo} = 30$ au)

$$\alpha_{\rm DW,out} > \alpha_{\rm SS,out}$$

Preliminary result 3: Outer disc spreading

(Fixed disc size $r_c = 60$ au & dead zone size $r_{\rm dzo} = 30$ au)

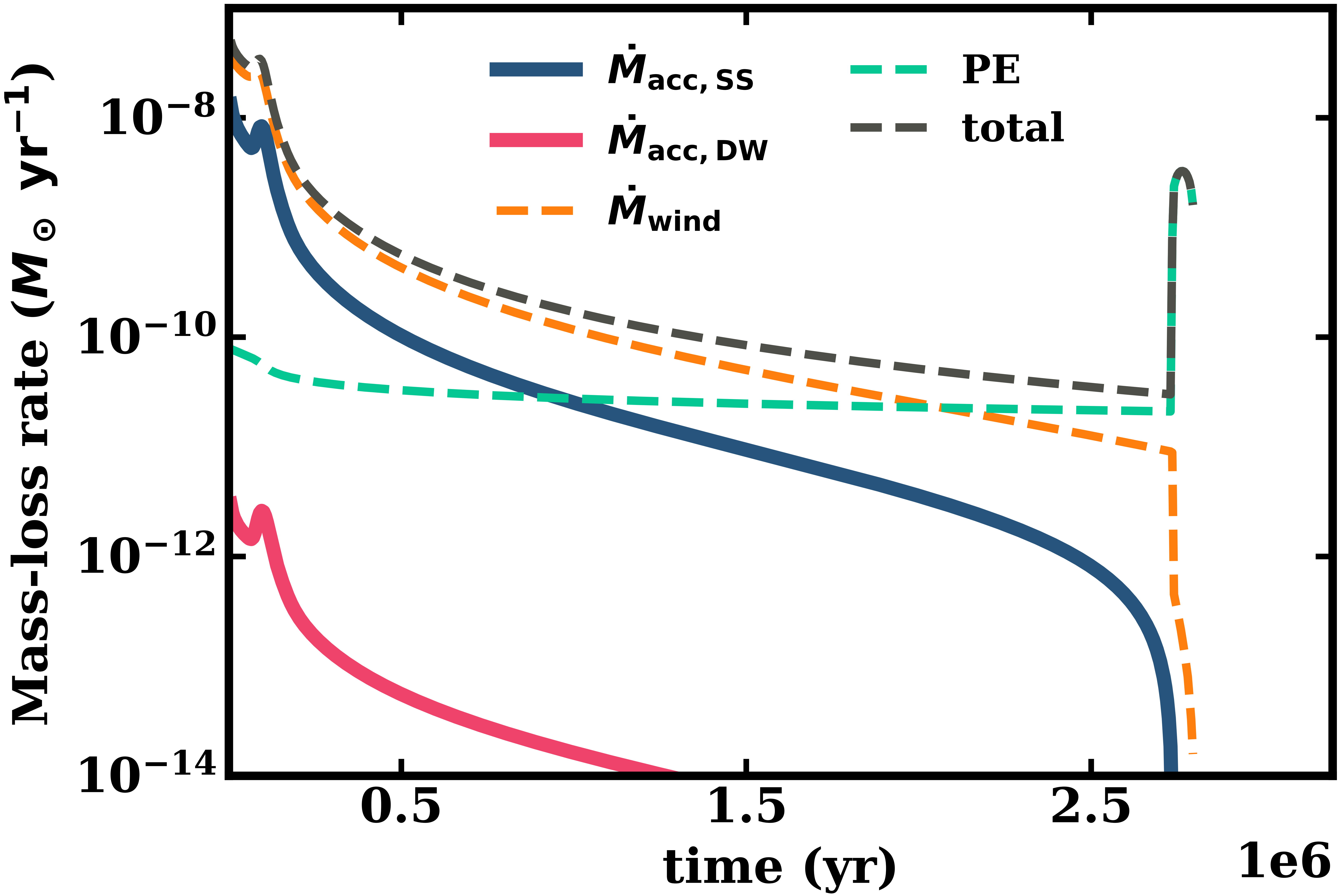


Disc gas size starts decreasing only when $\alpha_{\rm DW}$ is remarkably larger than $\alpha_{\rm SS}$.

Potential Implication 1: Gas disc size measurements

Low-sensitivity observations: $\Sigma > 10^{-2}$ g cm^{-2}
High-sensitivity observations: $\Sigma > 10^{-4}$ g cm^{-2}

Potential Implication 2: Stellar accretion rate



Abbreviations: PE = photoevaporation

Take-home messages

- We ran 1D simulations to study the evolution of disc regulated by viscosity, MHD winds, internal photoevaporation and the dead zone.
- $\alpha_{\mathrm{DW,out}}$ is important to the inner disc evolution and $\alpha_{\mathrm{SS,out}}$ is important to the outer disc evolution.
- The disc outer radius r_o only decreases when $\alpha_{\mathrm{DW,out}}$ is significantly larger than $\alpha_{\mathrm{SS,out}}$.
- **We may not be able to distinguish the "viscosity/wind" scenarios by purely measuring the gas disc sizes with time and by statistically measuring stellar accretion rates if we consider the dead zone.**
- Caveats:
    - Not easy to accurately depict the evolution of the magnetic field; MHD winds may not always drive accretion.
    - α in the dead/wind zone should be a variable of the surface density and the dead zone size shrinks over time.
    - Pure gas simulations. Dust is needed!