1st LISA Astrophysics Working Group Workshop | 12-14 Dic 2018

ACCRETION DISCS AROUND SUPERMASSIVE BLACK HOLE BINARIES:

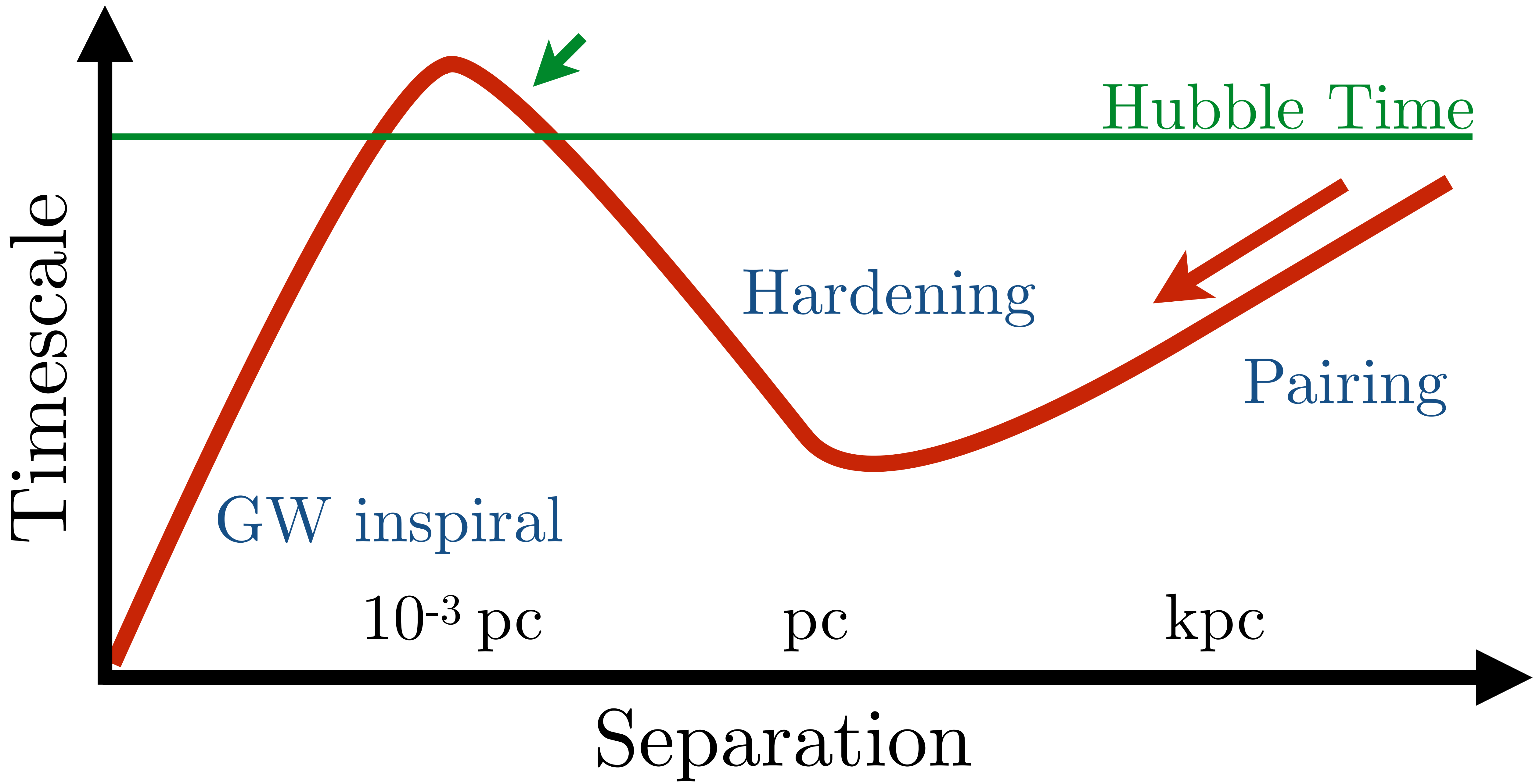
NON-STEADY LONG-TERM EVOLUTION AND SECOND DECOUPLING

Camilo Fontecilla

Collaborators:

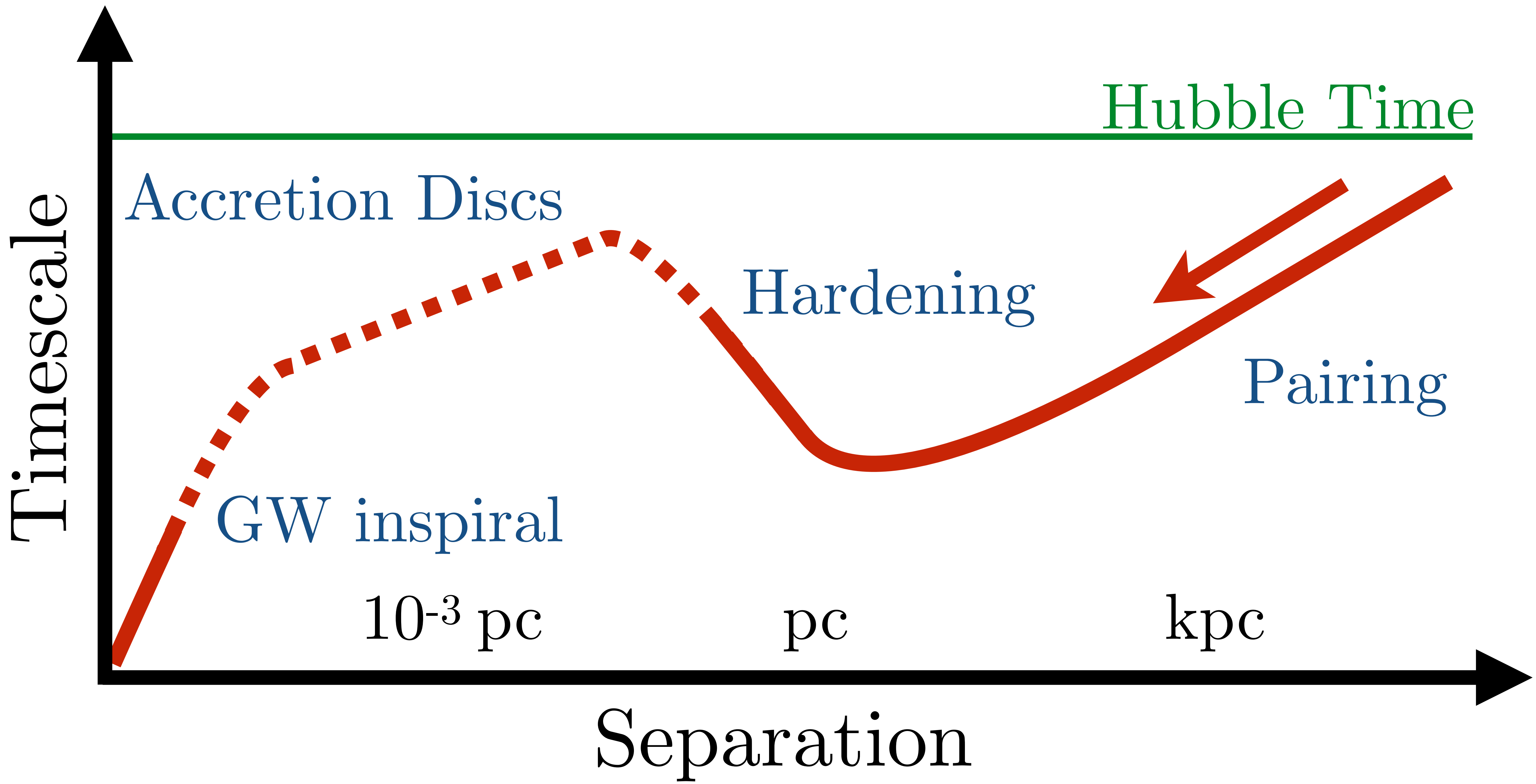
| Jorge Cuadra | Zóltan Haiman | Xian Chen |

Context



Hubble Time
Hardening
Pairing
GW inspiral
Timescale
10-3 pc
pc
kpc
Separation

Context


Hubble Time
Accretion Discs
Hardening
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pc
kpc
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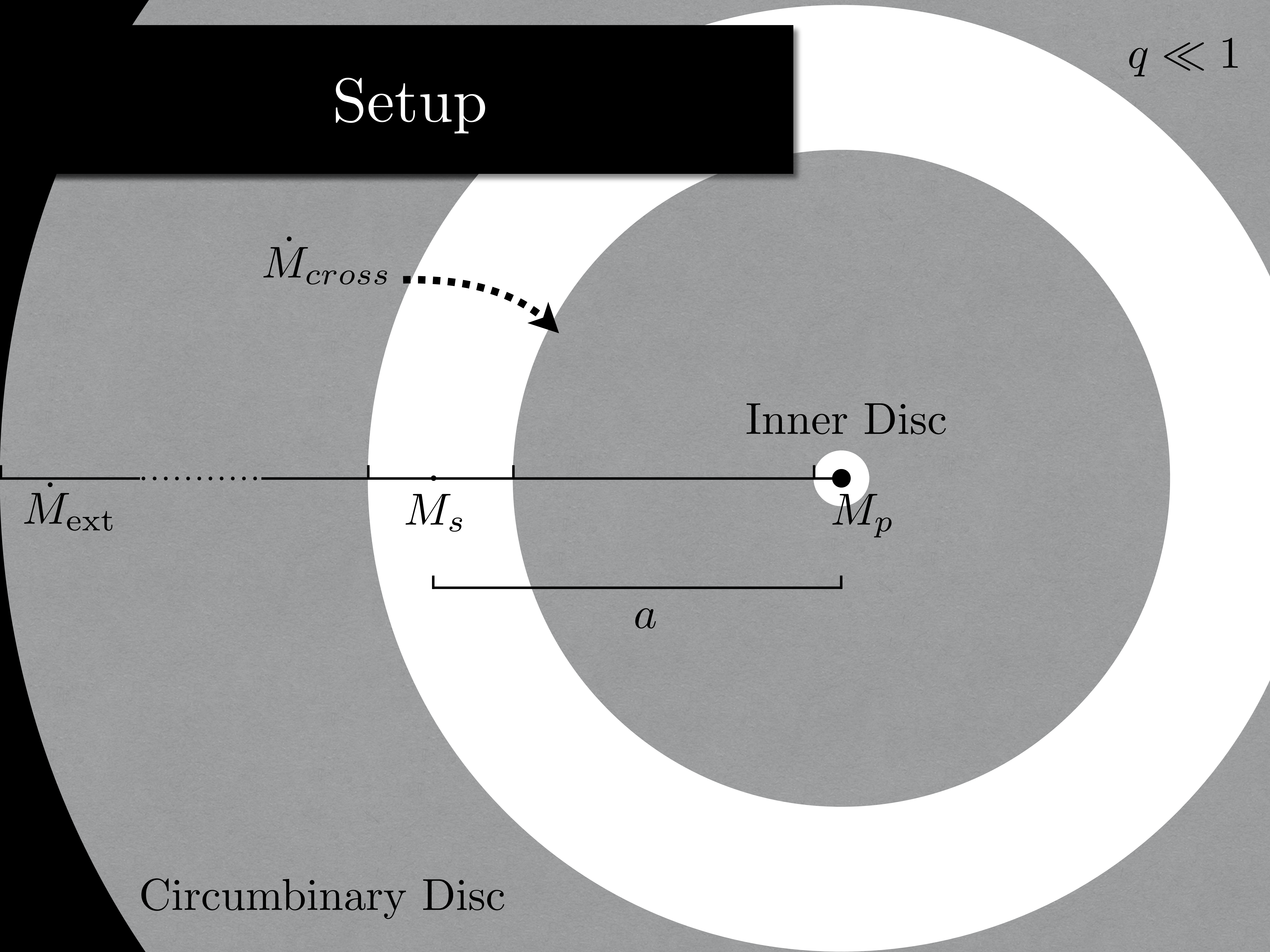
Setup

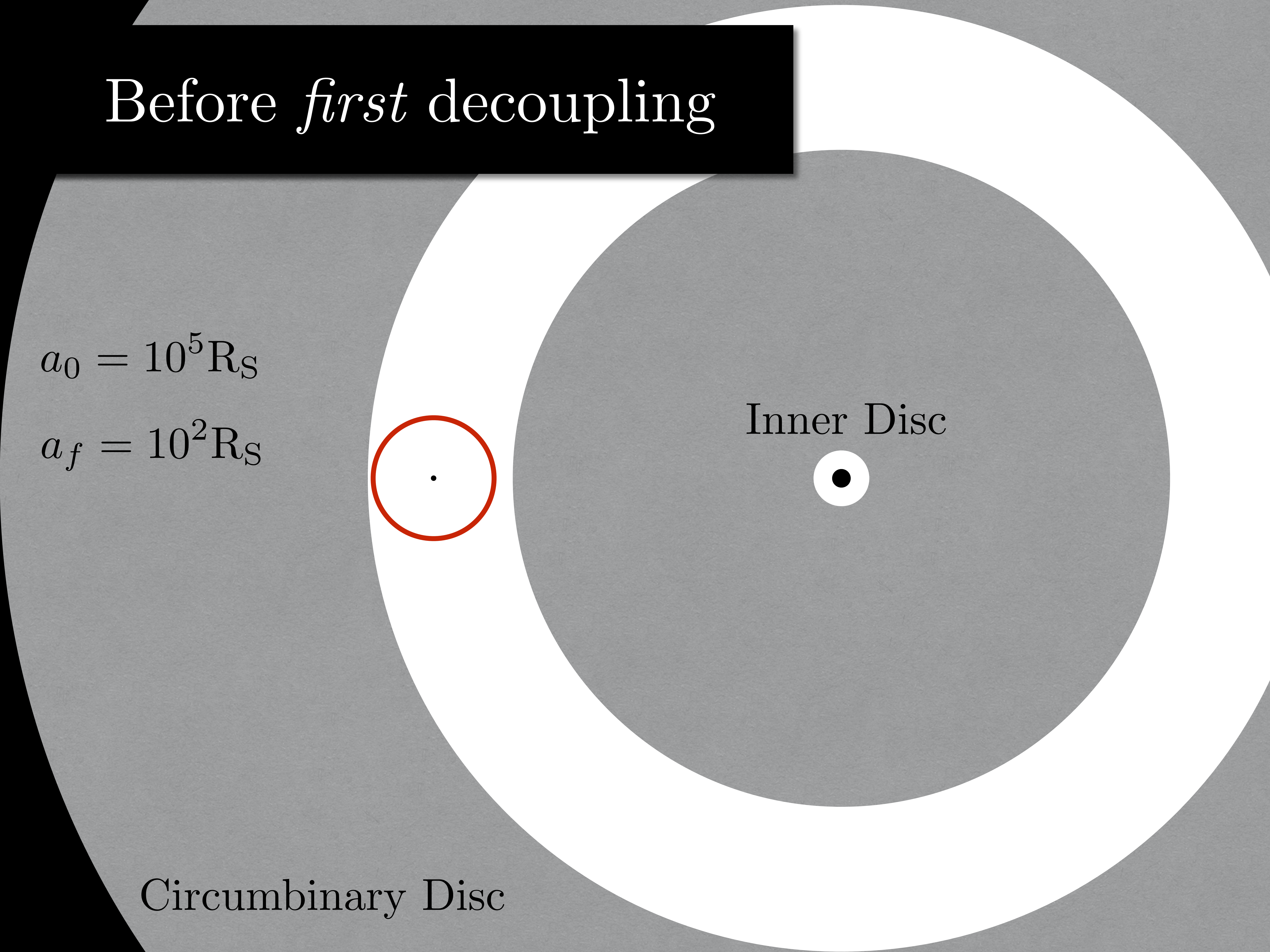


$q \ll 1$
$\dot{M}_{cross}$
Inner Disc
$\dot{M}_{\rm ext}$
M_s
M_p
a
Circumbinary Disc

Before *first* decoupling

$a_0 = 10^5 \mathrm{R_S}$

$a_f = 10^2 \mathrm{R_S}$



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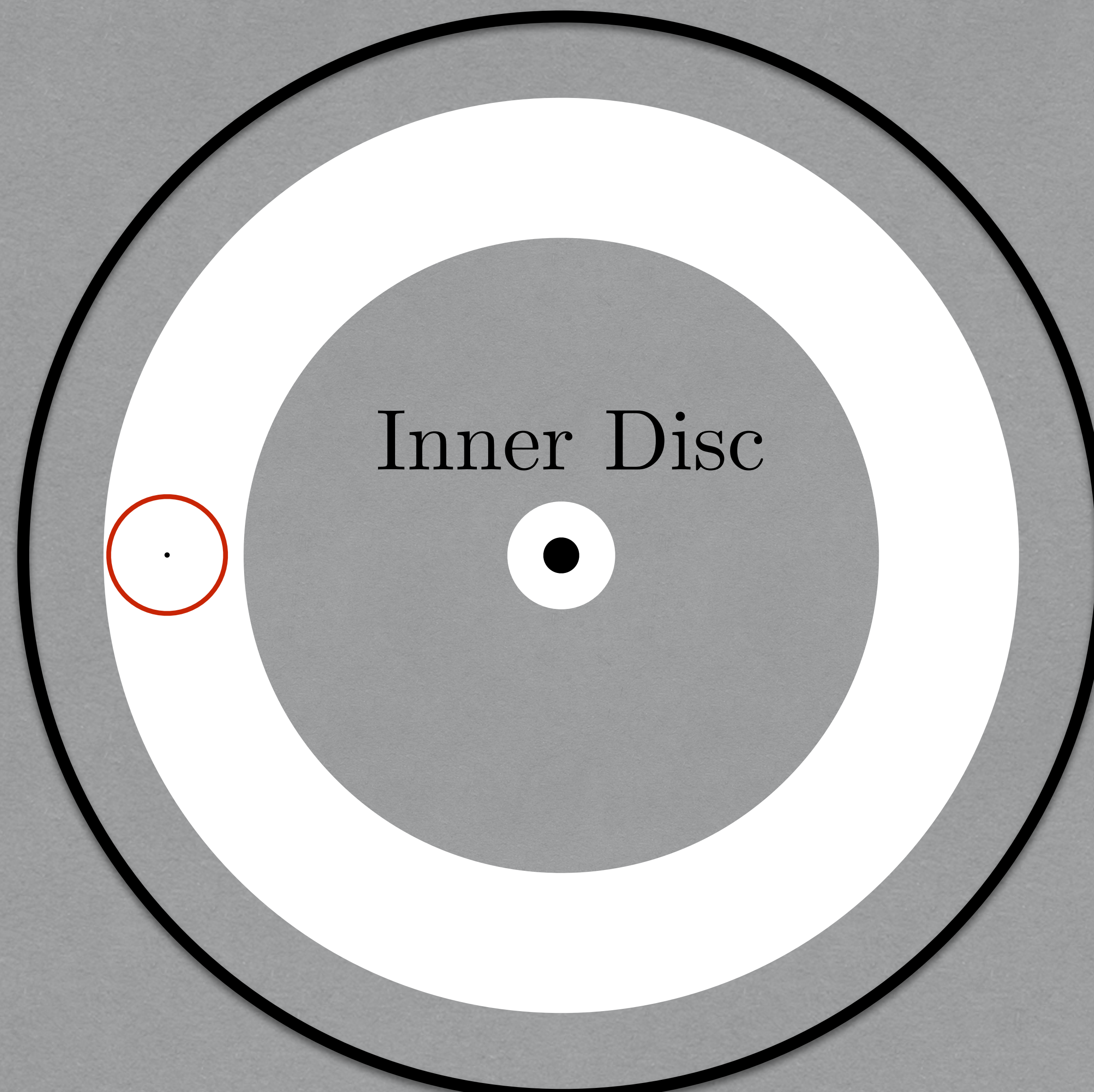
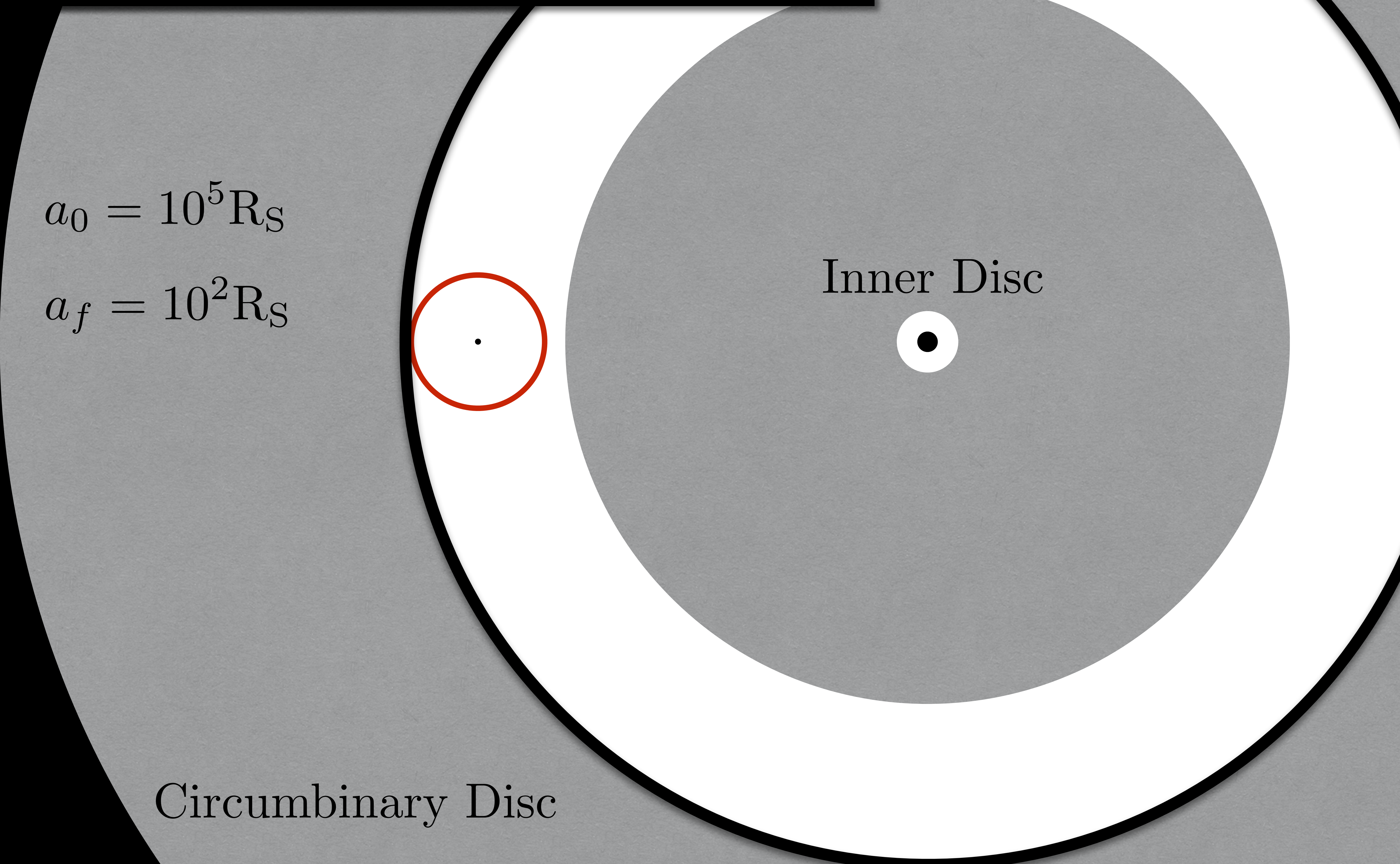
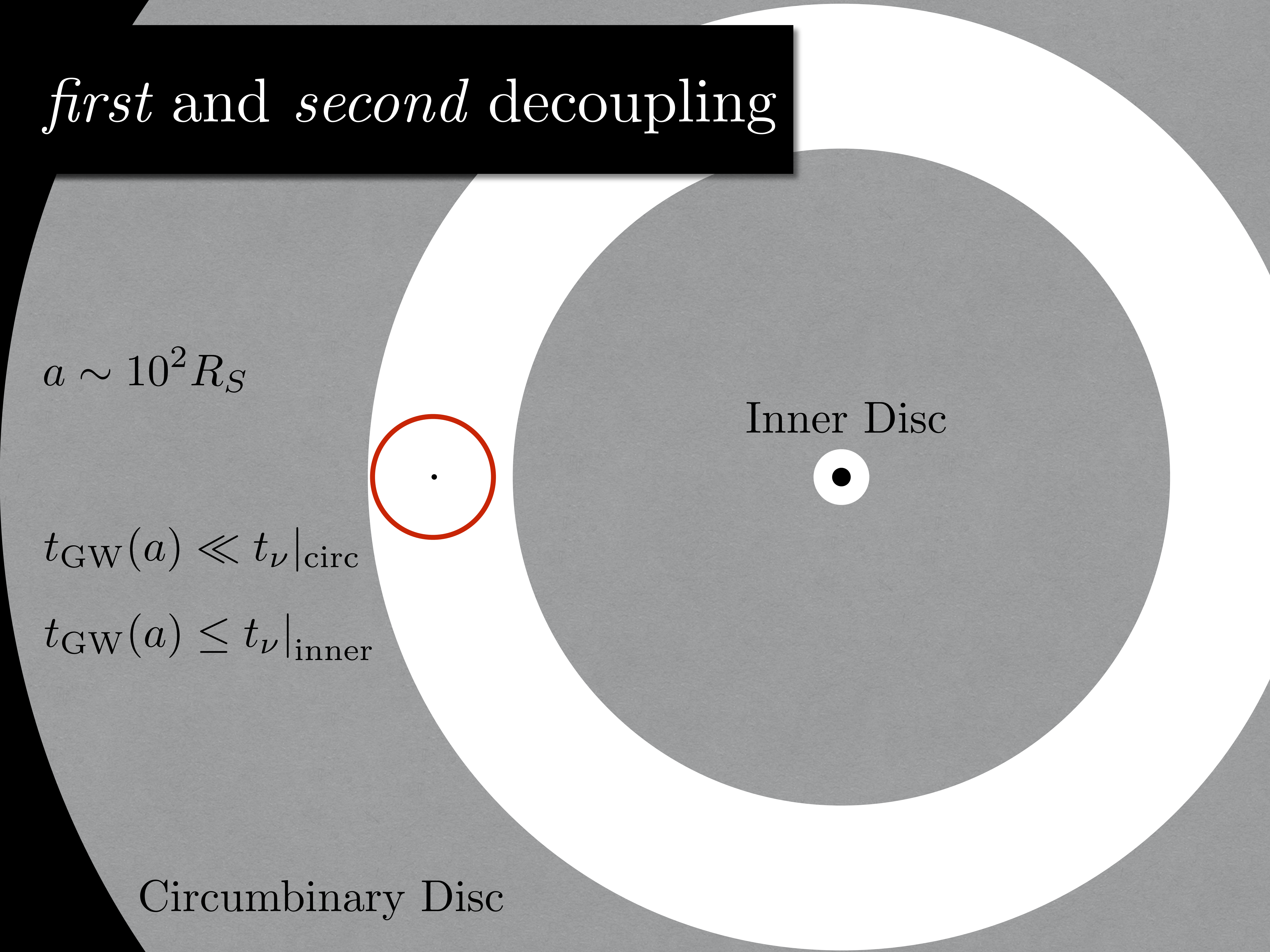


Circumbinary Disc

Before *first* decoupling



first and *second* decoupling



$a \sim 10^2 R_S$

$t_{\rm GW}(a) \ll t_\nu|_{\rm circ}$

$t_{\rm GW}(a) \leq t_\nu|_{\rm inner}$

first and *second* decoupling

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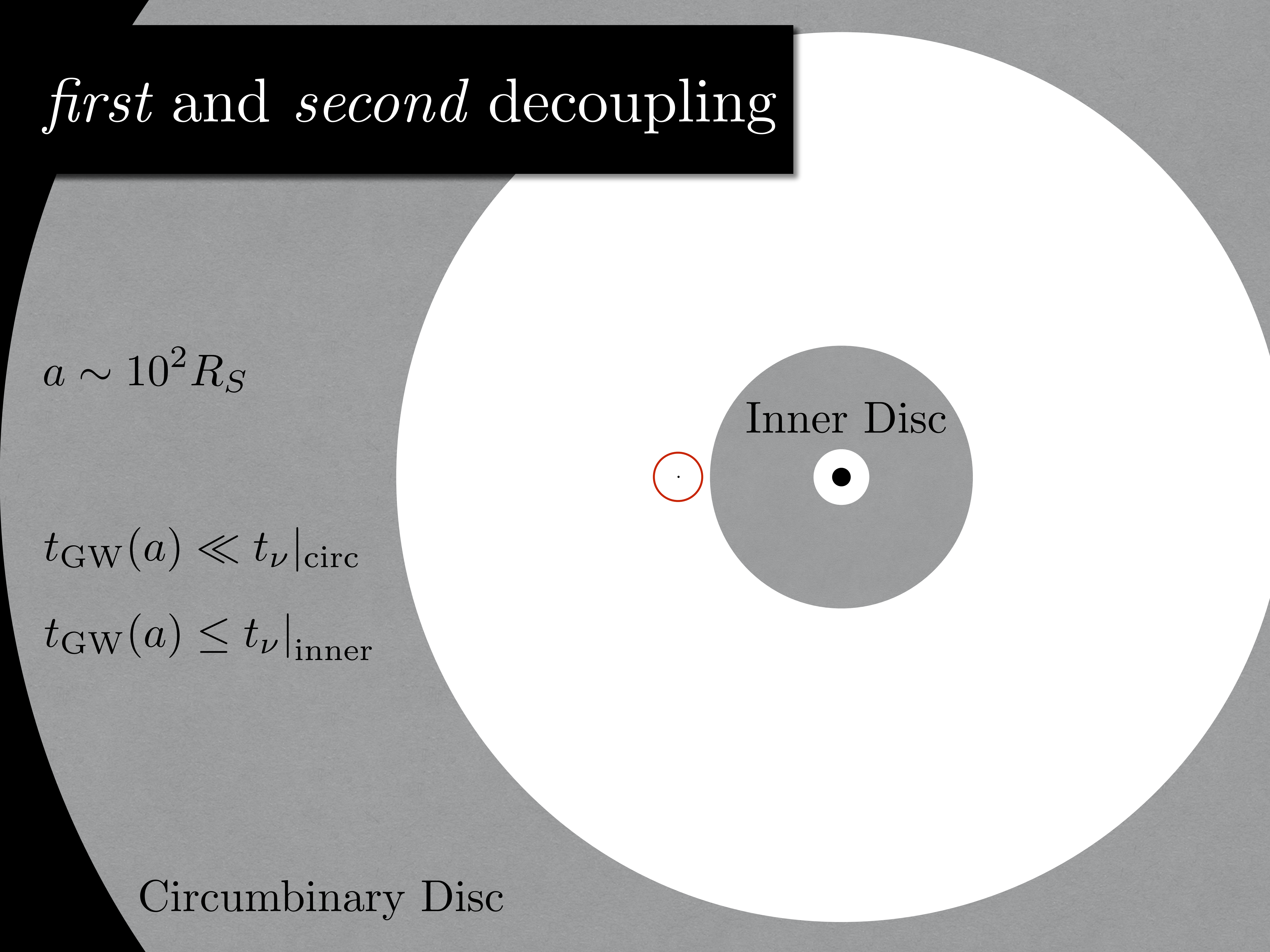


Equations

- PDE for surface density evolution :

$$\frac{\partial \Sigma}{\partial t} = \frac{1}{r}\frac{\partial}{\partial r}\left\{\underbrace{3r^{1/2}\frac{\partial}{\partial r}\left[\nu \Sigma r^{1/2}\right]}_{\text{Viscosity}} - 2\underbrace{\frac{\Lambda_T \Sigma}{\Omega}}_{\text{Tidal torque}}\right\}$$

- Binary distance evolution :

$$\frac{da}{dt} = \underbrace{-\frac{4\pi}{a M_s \Omega_s}\int \Lambda_T \Sigma r dr}_{\text{Disc interaction}} - \underbrace{\frac{8}{5}q(1+q)c\left(\frac{\mathrm{R_S}}{a}\right)^3}_{\text{GW emission}}$$

- Inflow through cavity : $\dot{M} = \gamma \Omega_s r^2 \Sigma$

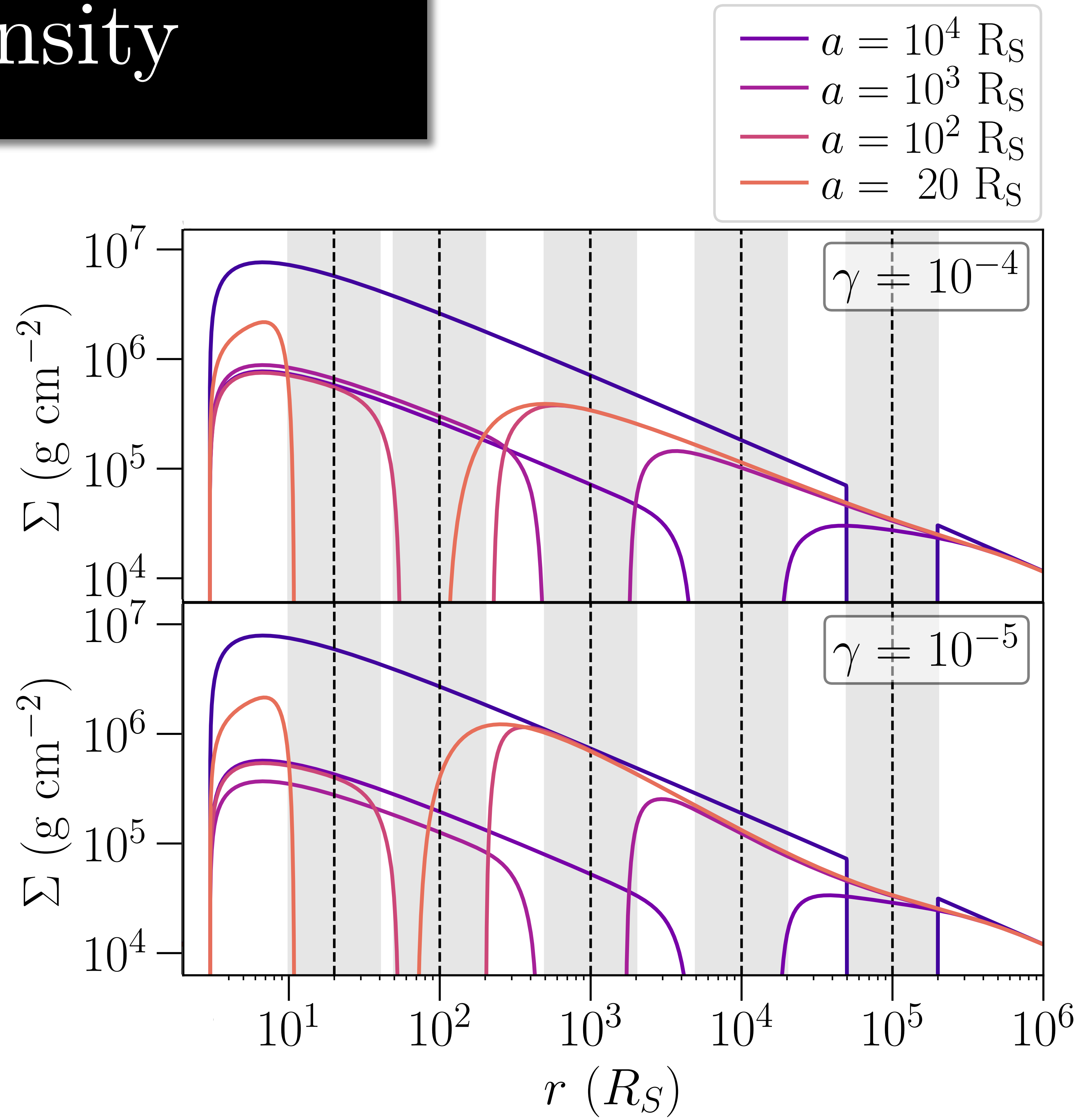
↑

Σ : surface density
r : radius
ν : viscosity
Λ_T : tidal torque
Ω : angular velocity
a : binary separation
M_s : secondary's mass
q : mass ratio
c : speed of light
$\mathrm{R_S}$: Schwarzschild radius
γ : efficiency

Results

Surface Density

- Simulation for $q = 0.1$
- Circumbinary disc shape changes with γ
- At the end, when $a = 20 R_\mathrm{S}$, the inner discs are similar



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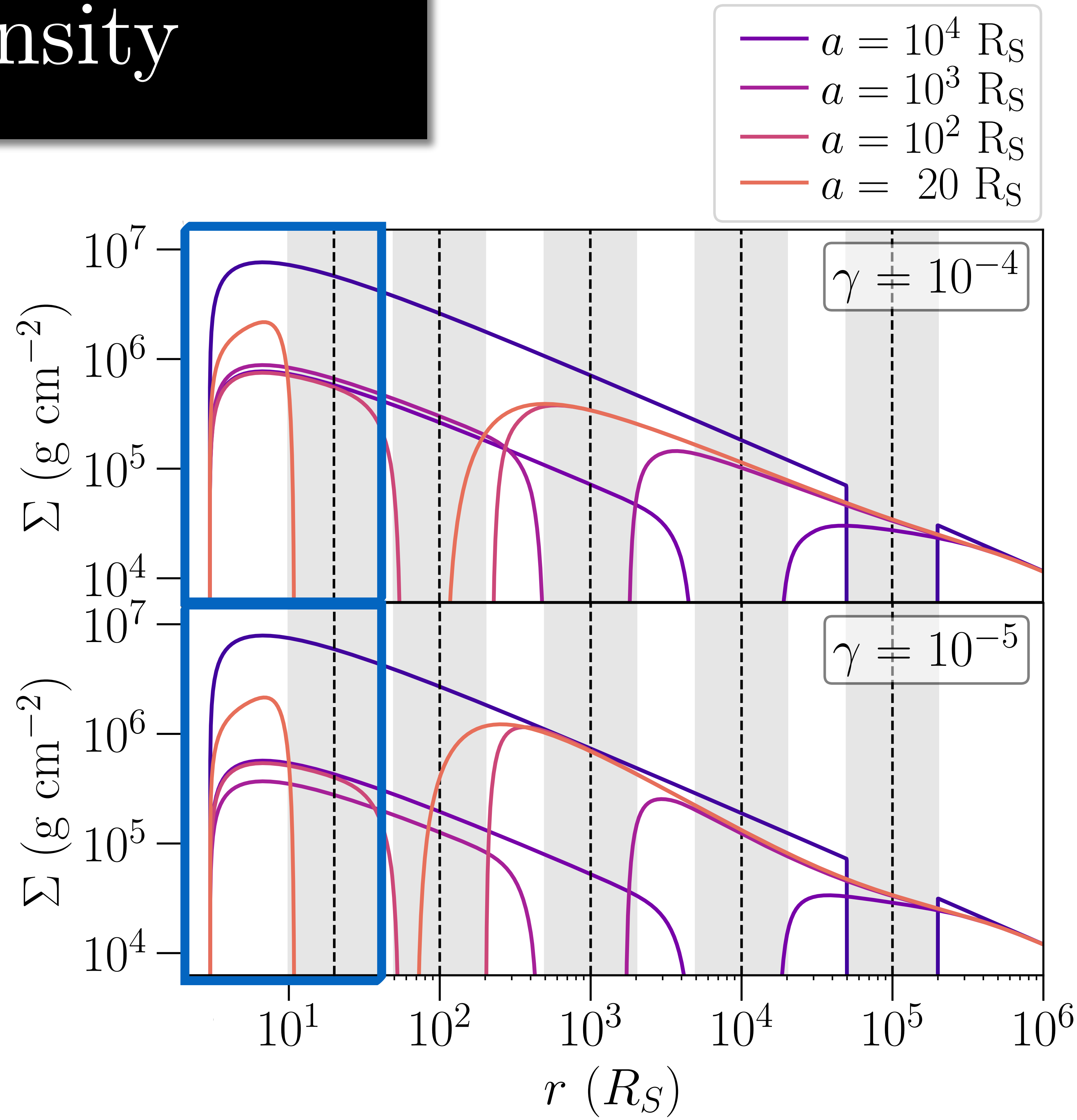
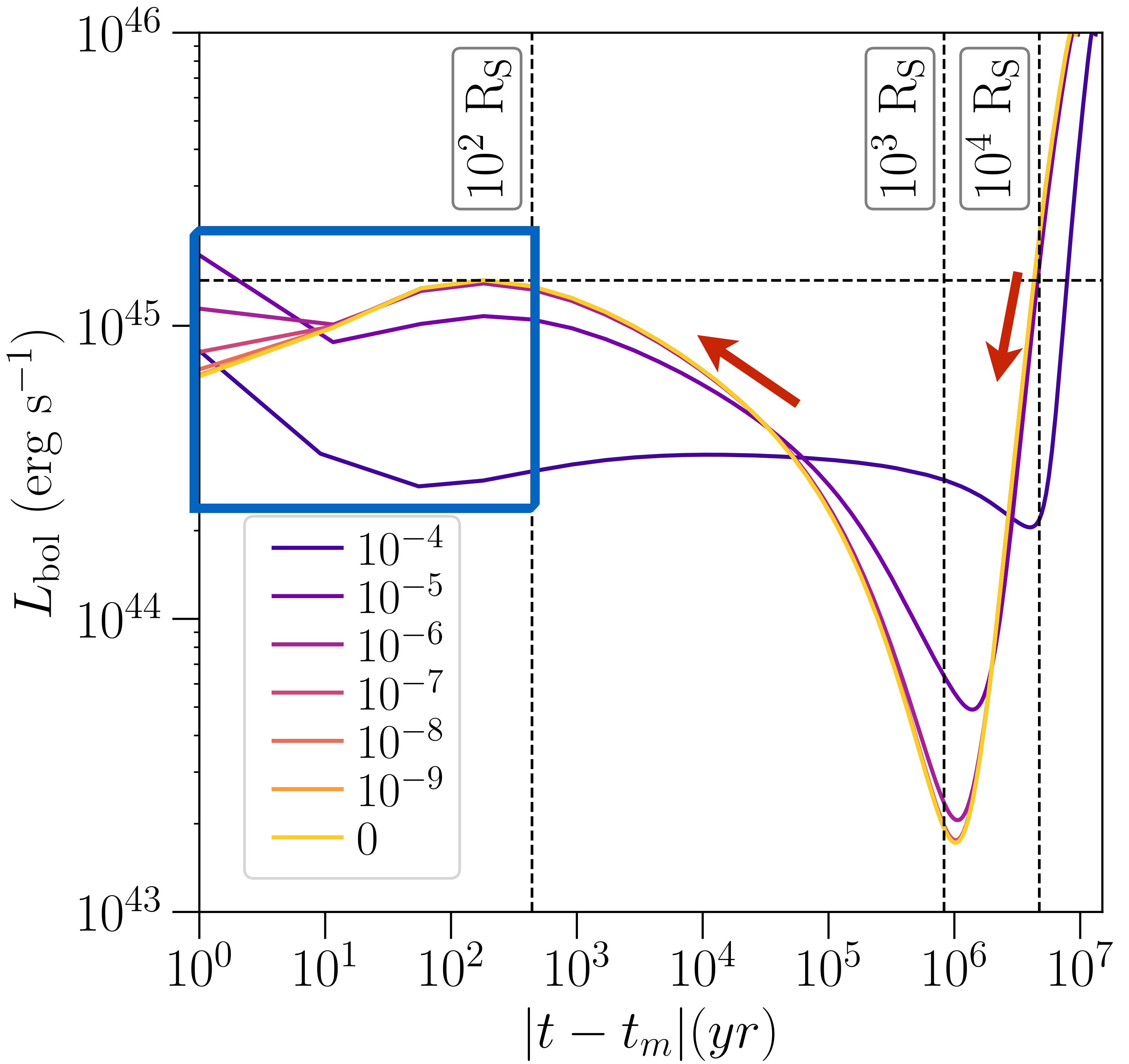


Fontecilla et al. 2018

Bolometric Luminosity

- Times moves from right to left
- Results converge when we reduce γ
- At the end: peak in EM emission

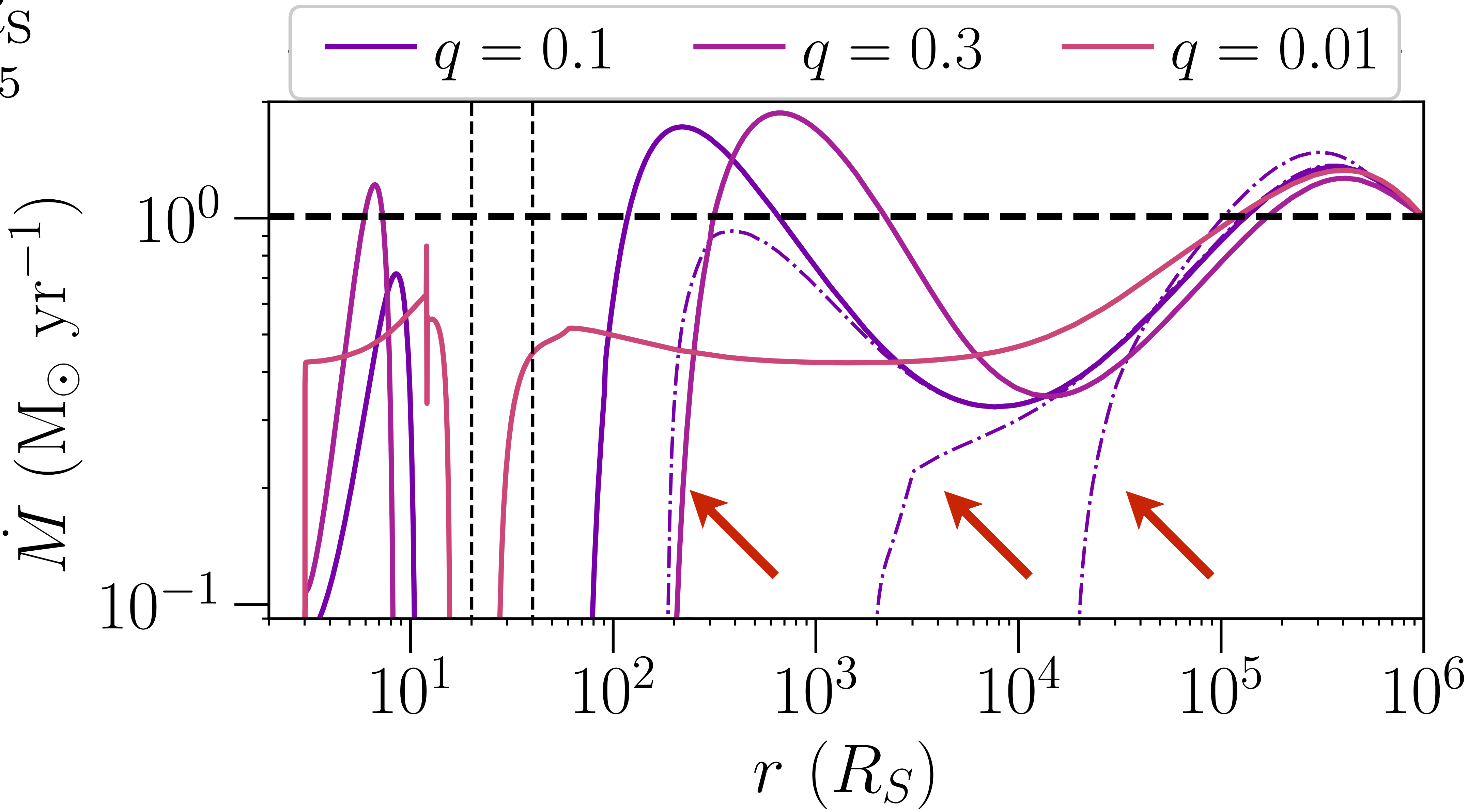


Accretion rate

- In every case, the system never reaches steady-state

$a = 20 R_\mathrm{S}$

$\gamma = 10^{-5}$

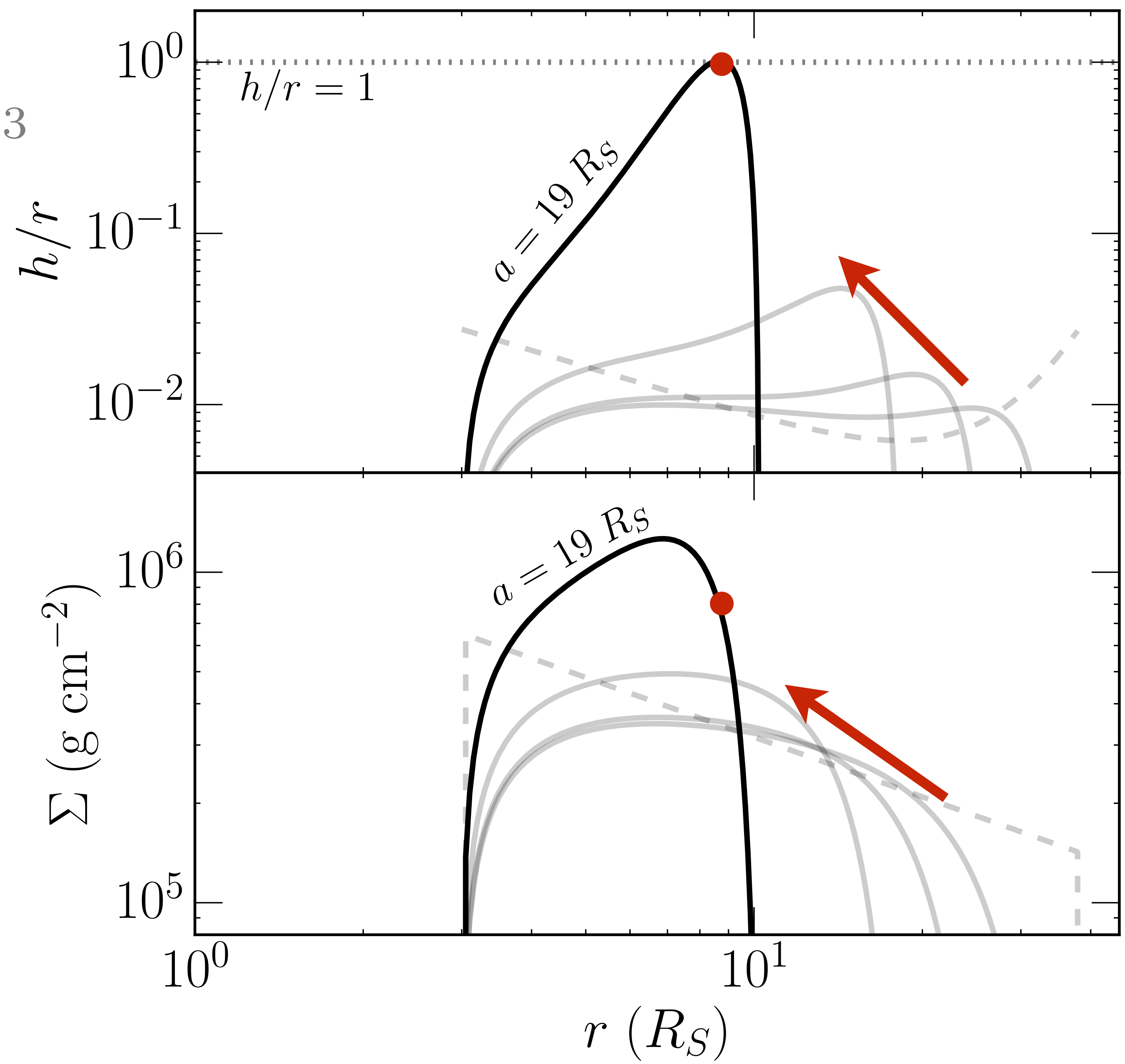


Second decoupling

- $a_{\rm cri} \simeq 20\ R_S\ \alpha^{-4/23}\dot{m}_\Lambda^{8/23} M_7^{1/23}\delta^{-3/23}[q(1+q)]^{5/23}$

- Surface density and scale height increase over time

- The disc becomes thick before coalescence



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L_{bol} and SED

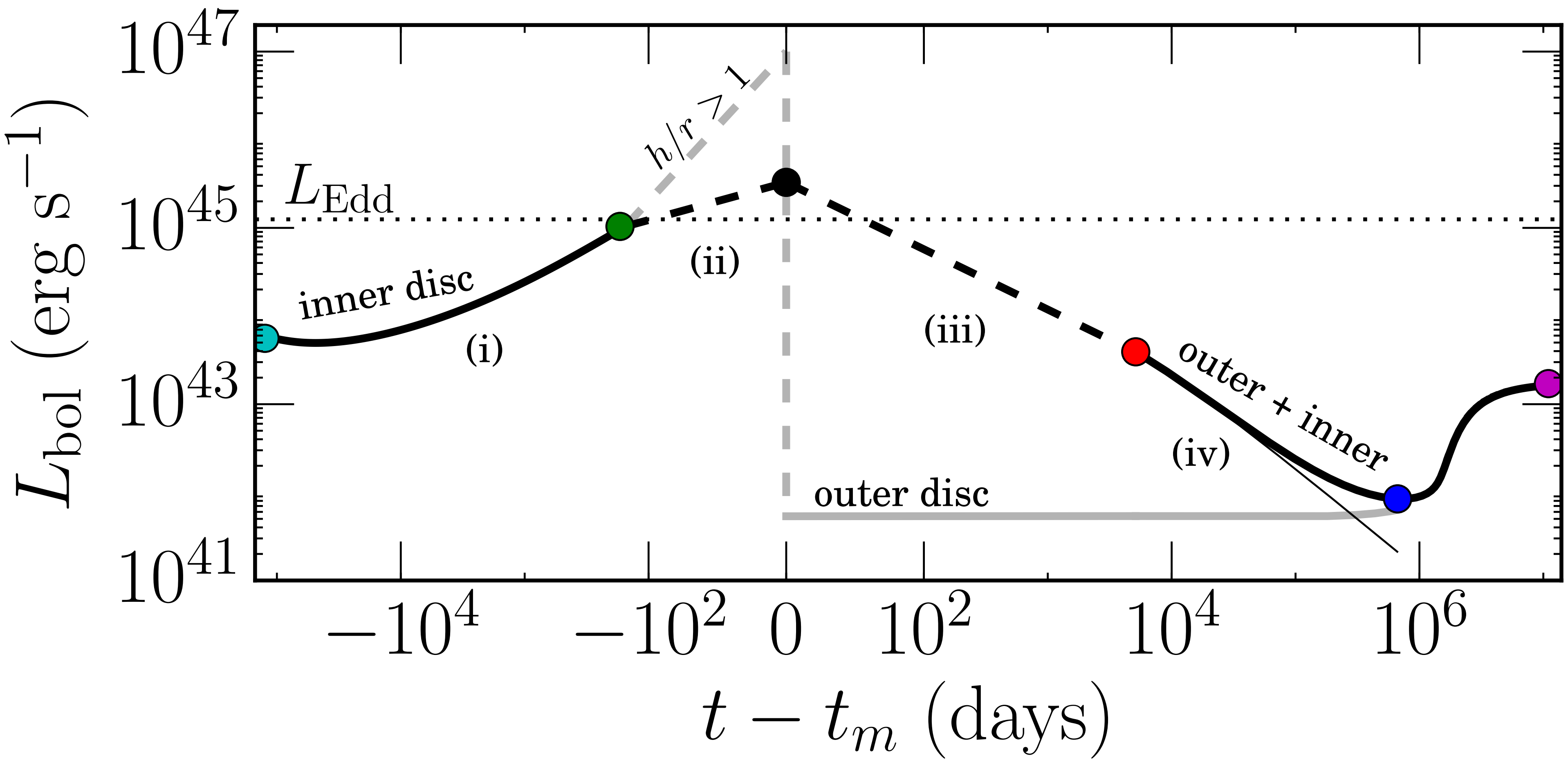
- Four phases:

(i) Squeezing

(ii) Decoupling

(iii) Cooling

(iv) Recovering



- SED at crucial times

Fontecilla et al. 2017

L_{bol} and SED

- Four phases:
  - (i) Squeezing
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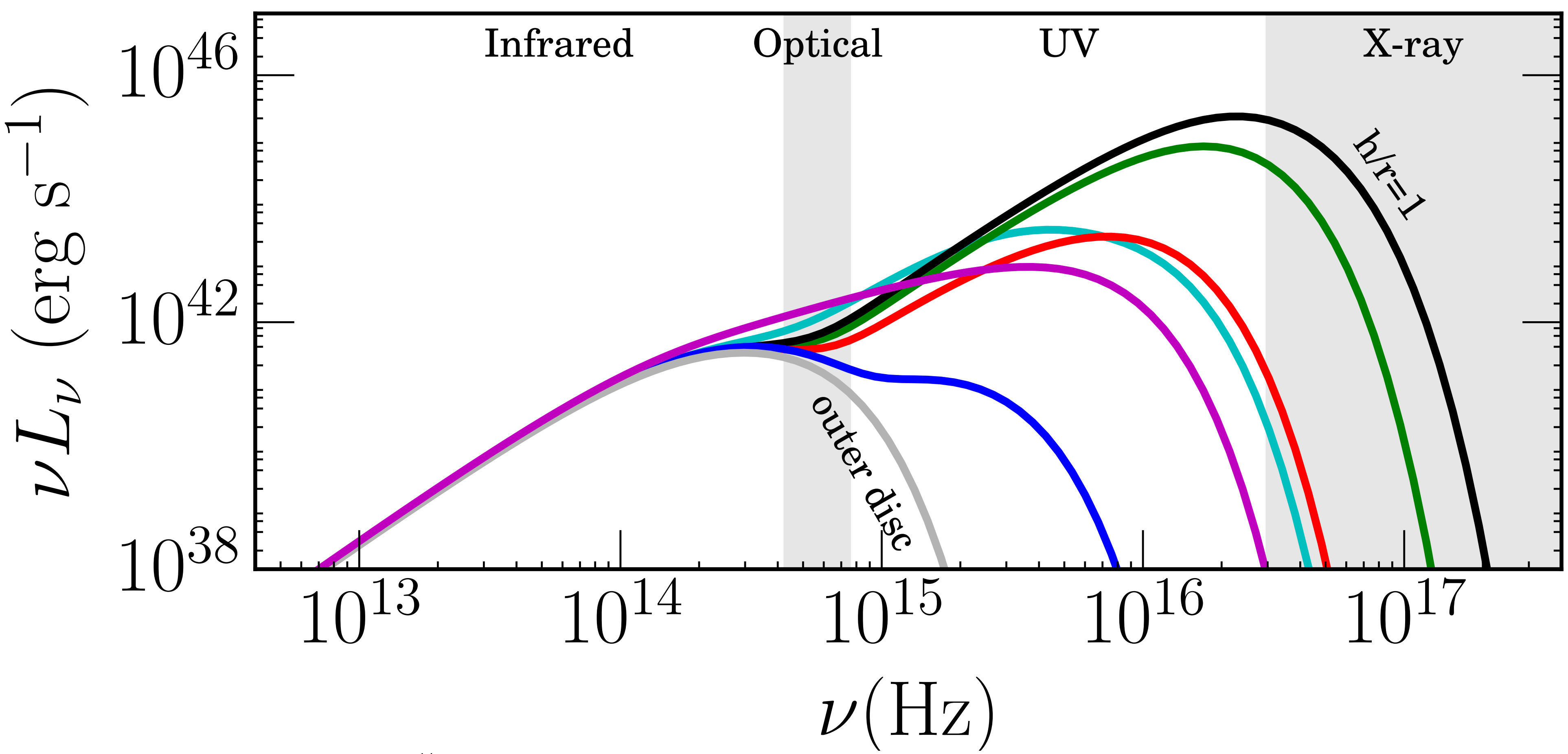

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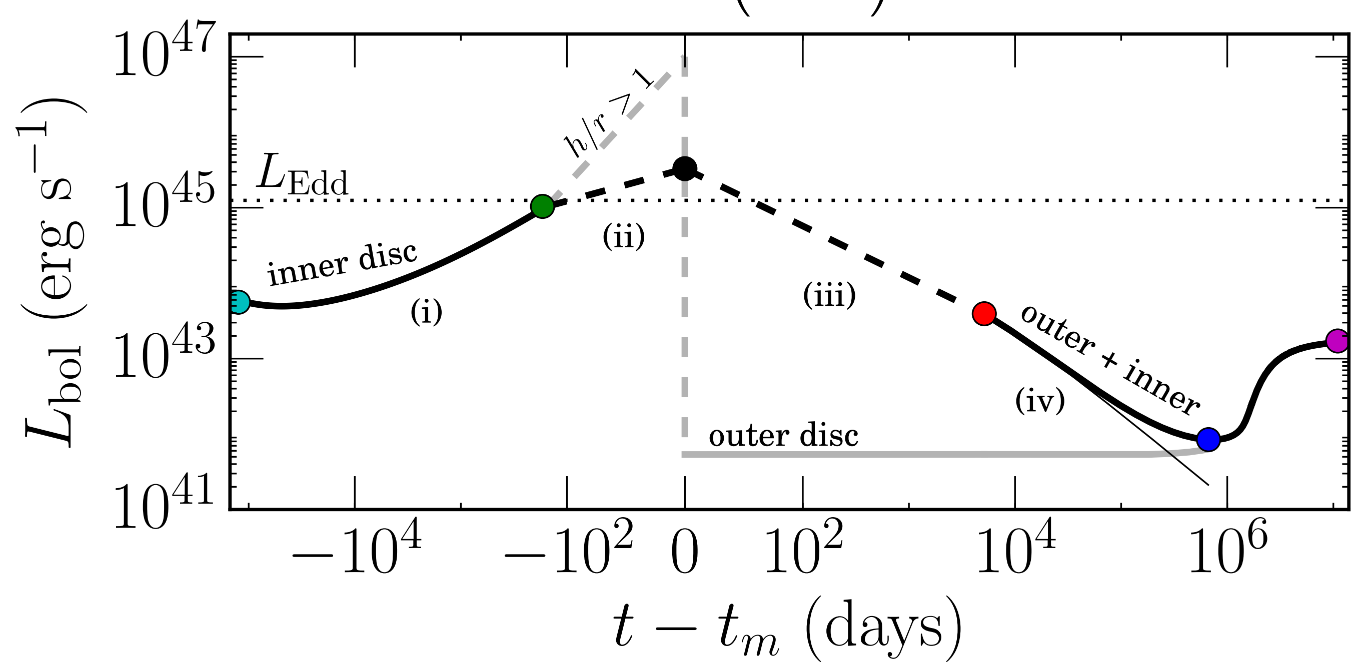

Summary

- We modeled, using 1D simulations, the evolution of a SMBHB surrounded by an accretion disc. Our main findings are:
  - No clear steady-state: the initial condition al large separations shapes the system evolution until coalescence.
  - Longer residence time and smaller surface density compared with previous analytical estimations that assume steady-state.
  - The thickness of the inner disc is enhanced by the tidal torque during the squeezing phase, producing the *second* decoupling.
  - Depending on the amount of material that crosses the gap, the EM emission peaks at the *first* or *second* decoupling.
  - Since not all the material in the inner disc is accreted, it does not produce a high precursor before the SMBHB coalescence. Instead, it will produce a continuous EM emission after the merger.

Thank you!