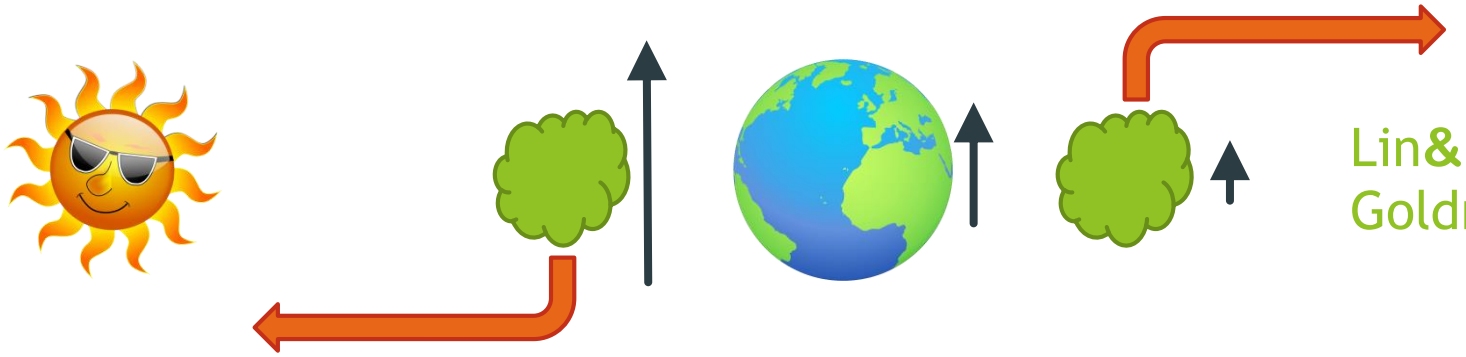
Gaps in Low-viscosity Disks

Sivan Ginzburg & Re'em Sari

The Hebrew University

Gap Opening



Lin&Papaloizou79,
Goldreich&Tremaine80

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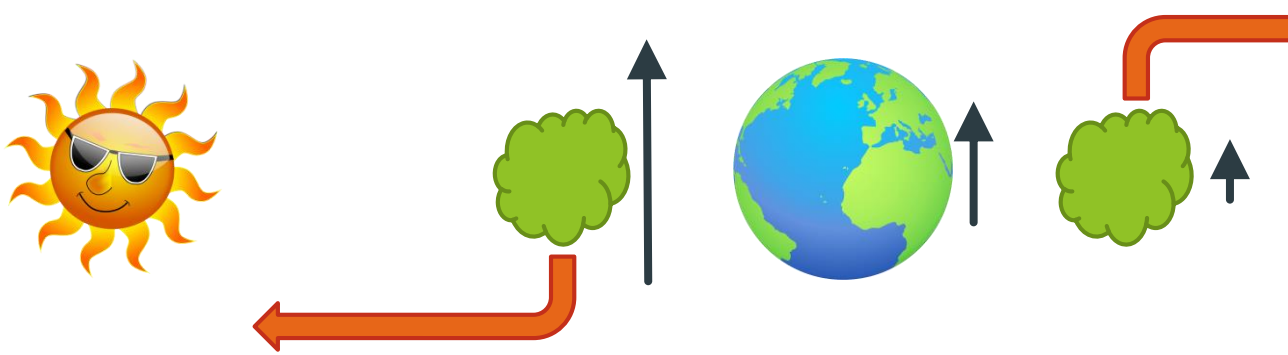

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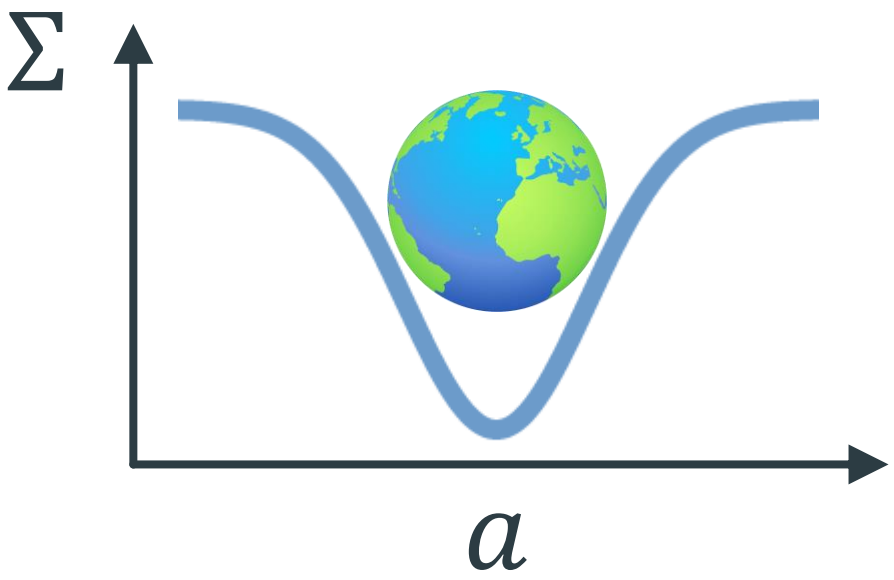

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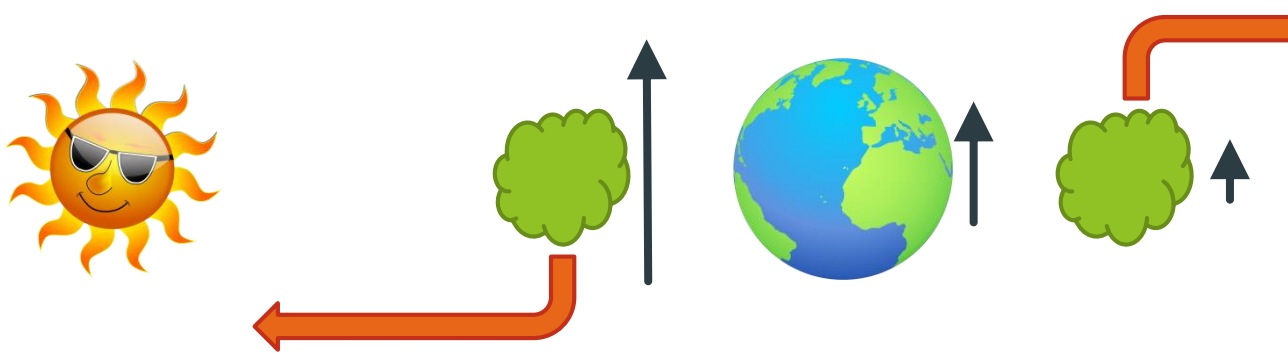

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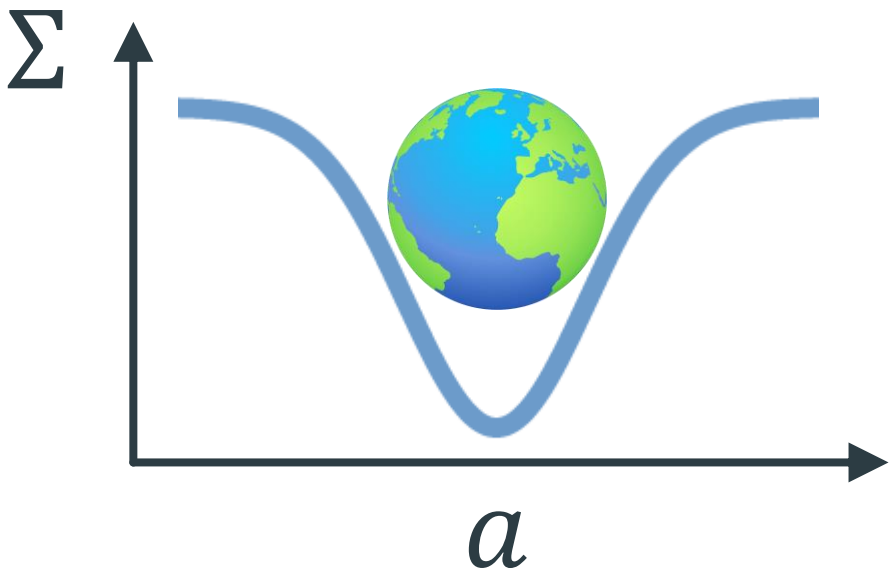
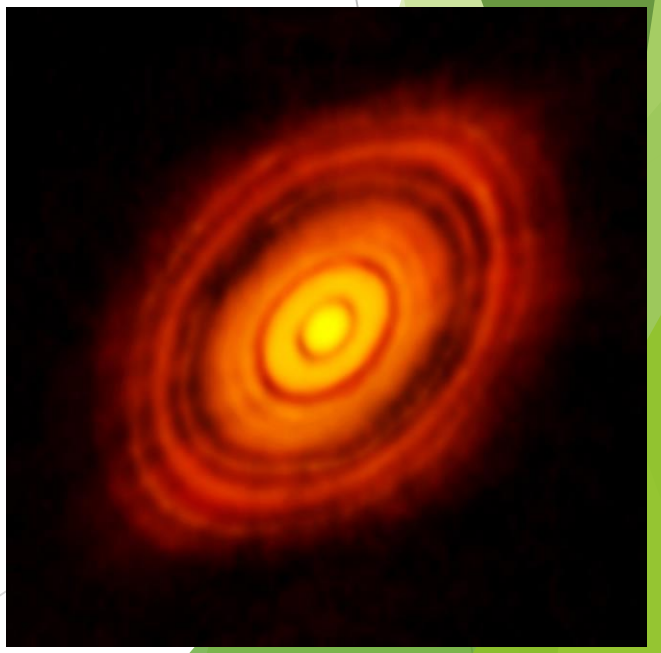


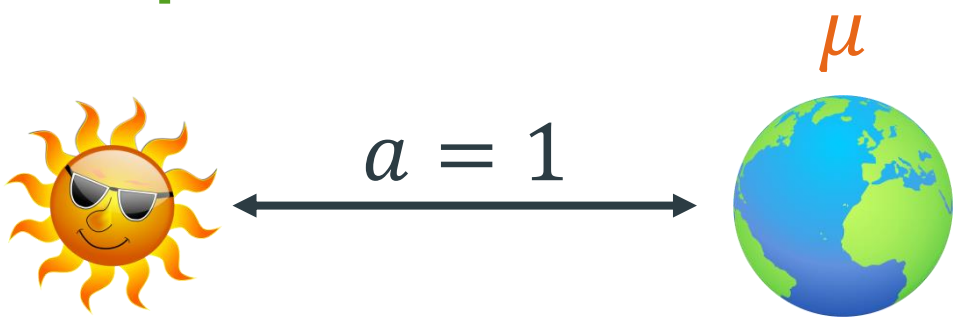
Interesting:

- Migration
- Accretion
- Observed

ALMA (2014)

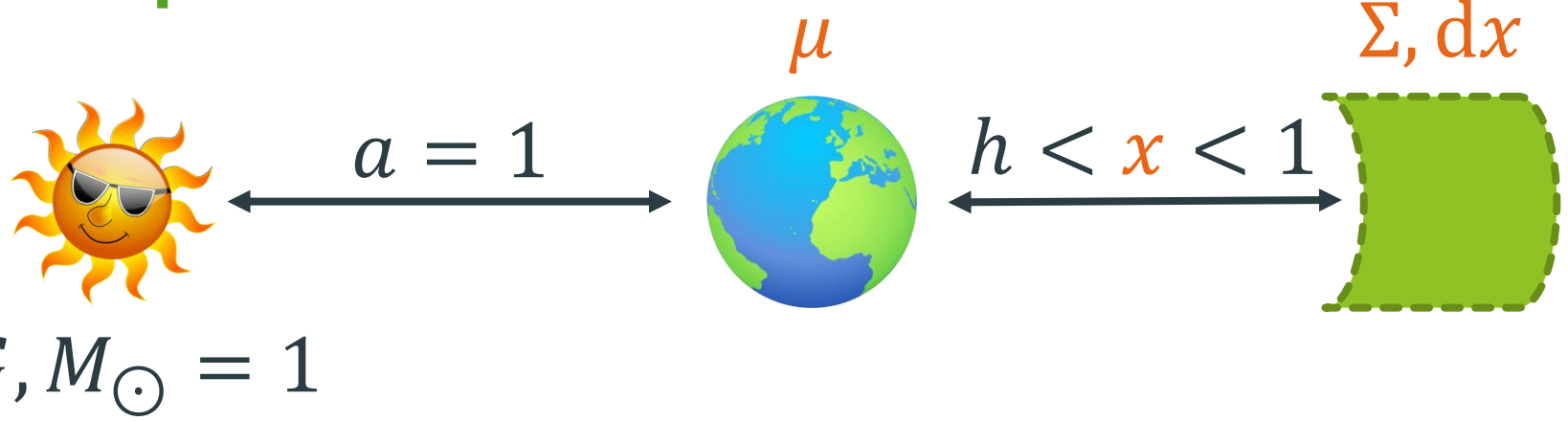


Gap Profile



$G, M_{\odot} = 1$

Gap Profile



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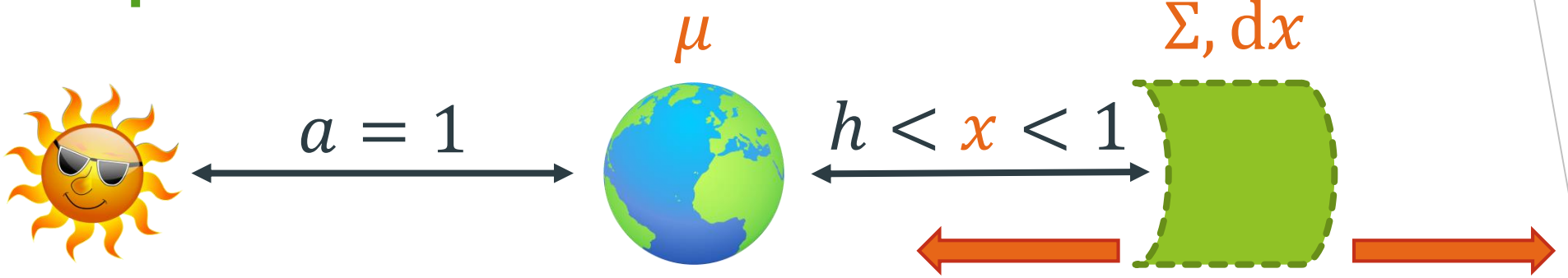
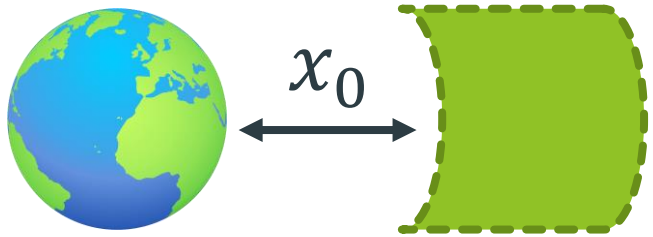
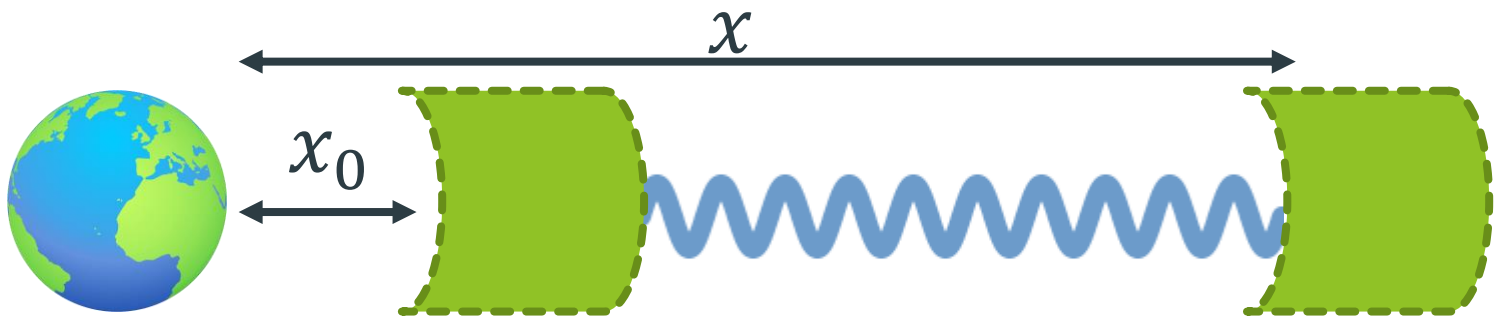

μ
$\Sigma, \mathrm{d}x$
$a = 1$
$h < x < 1$
$G, M_\odot = 1$
Viscosity
$\nu \mathrm{d}\Sigma$
$\nu \equiv \alpha h^2$
Gravity
$\frac{\Sigma \mu^2}{x^4} \mathrm{d}x$

Wave Propagation



$e > 0$

Wave Propagation



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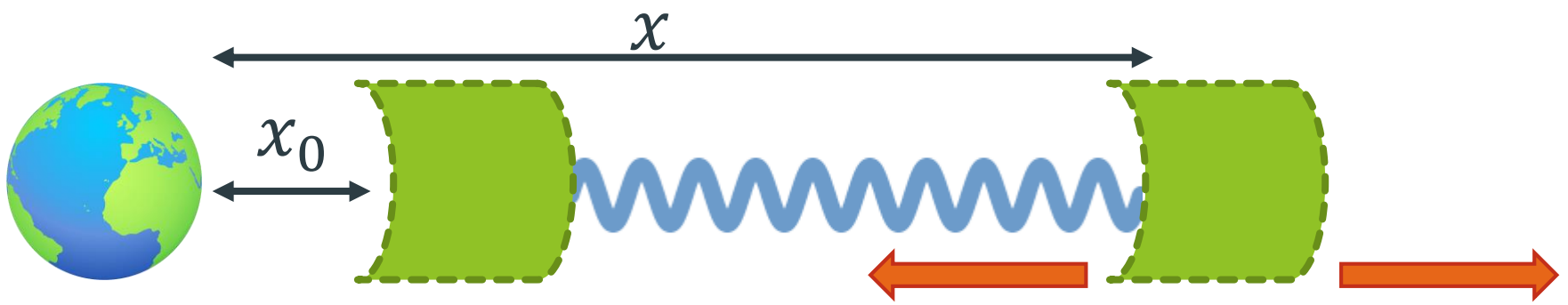

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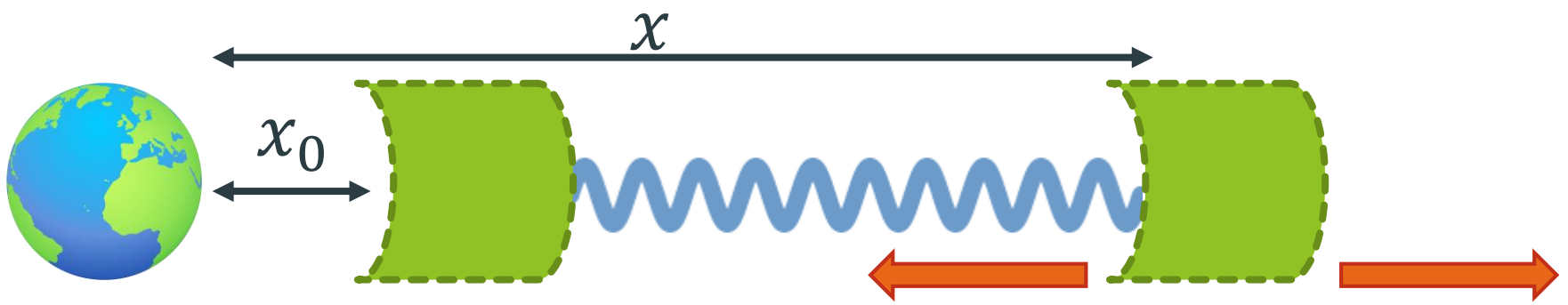
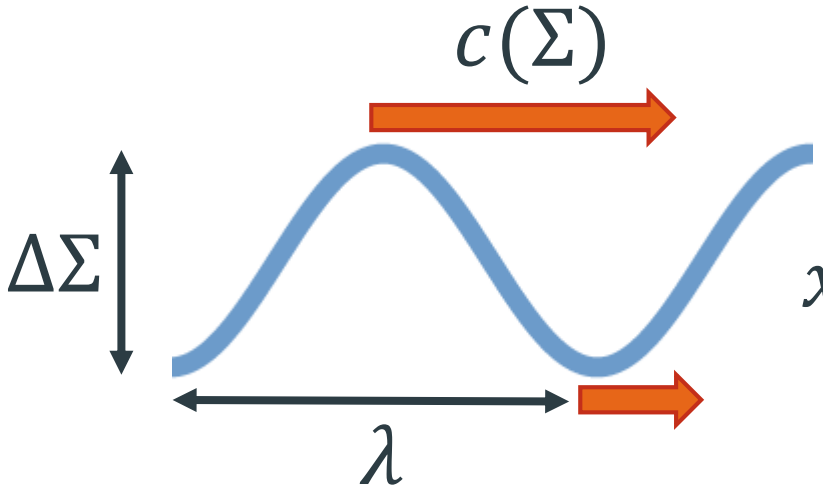


Where do the waves dissipate?

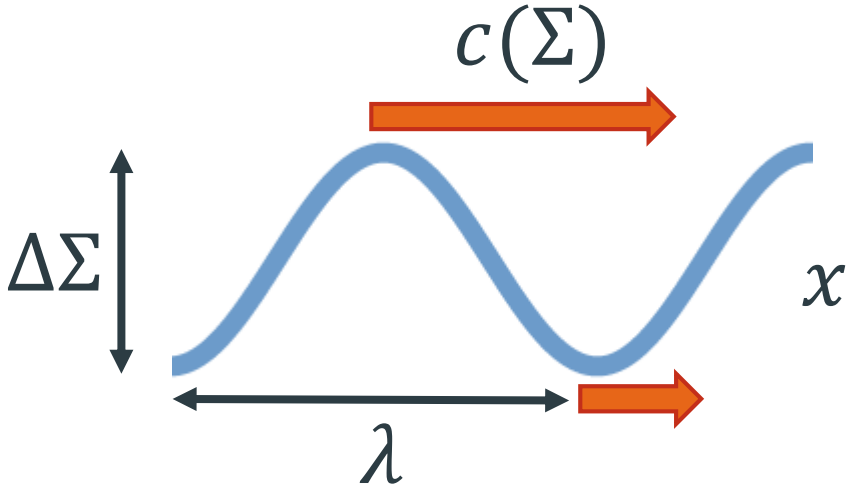
$x(x_0) = ?$

Wave Dissipation



$$x = \lambda(x)\frac{\Sigma(x)}{\Delta\Sigma(x)}$$

Wave Dissipation



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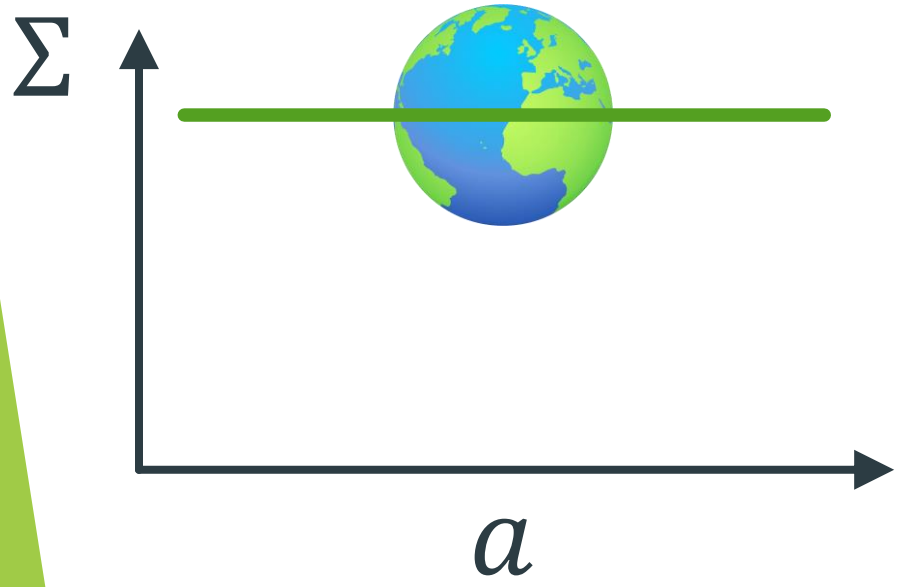
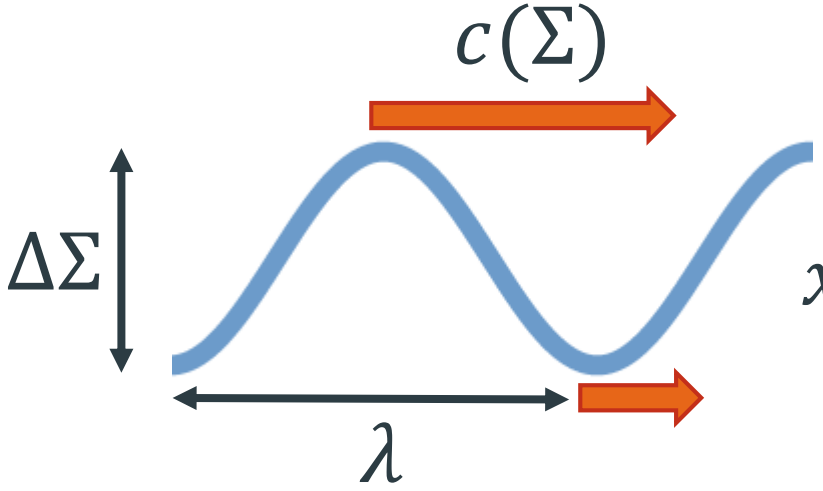


Goodman & Rafikov (01)

$$x(x_0 = h) = h\left(\frac{h^3}{\mu}\right)^{2/5}$$

Wave Dissipation



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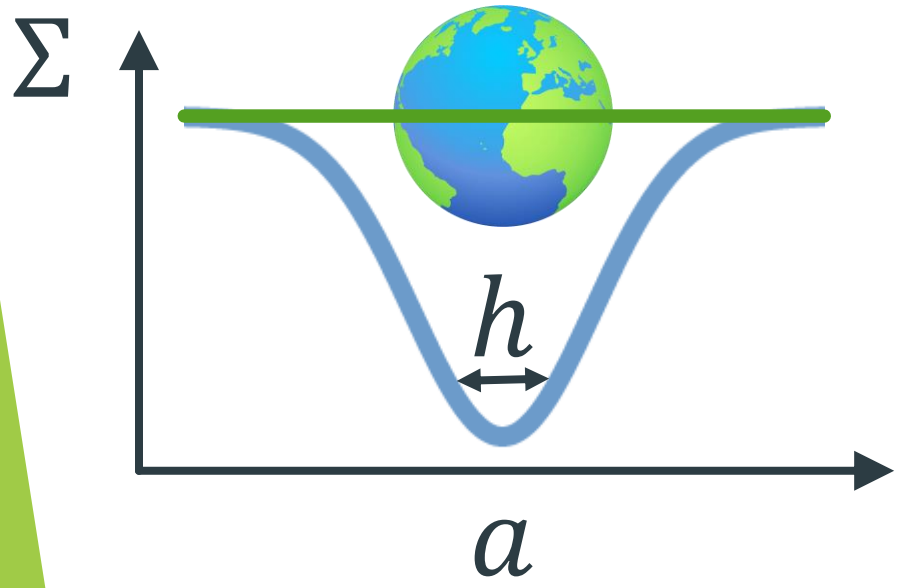

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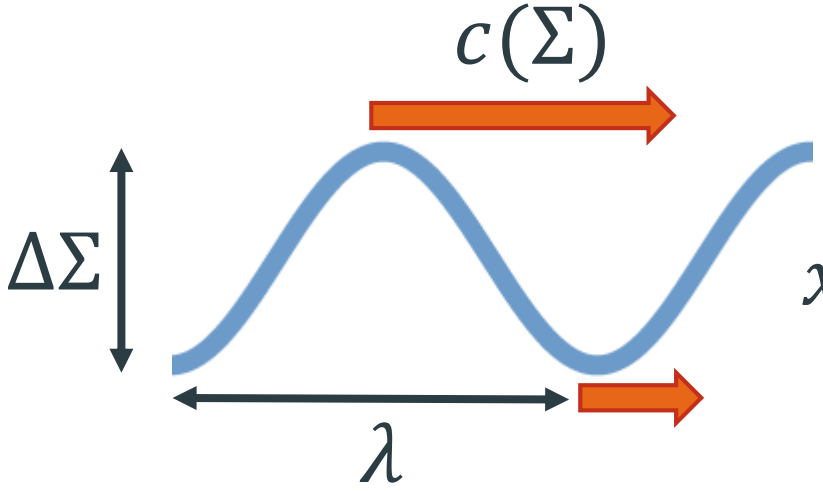

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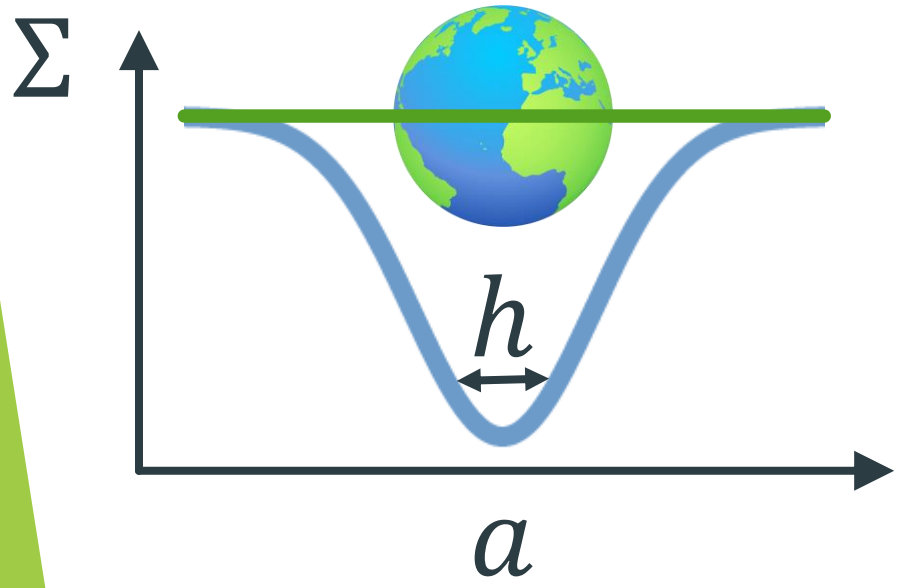
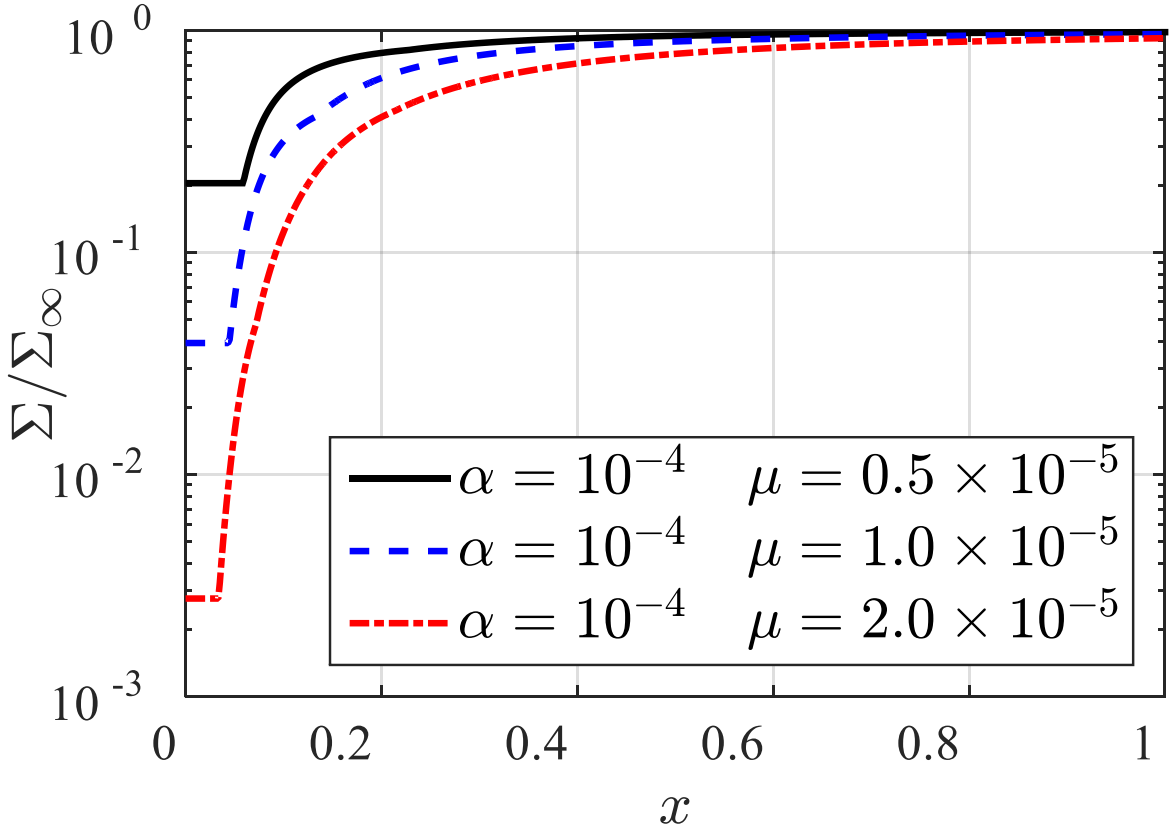
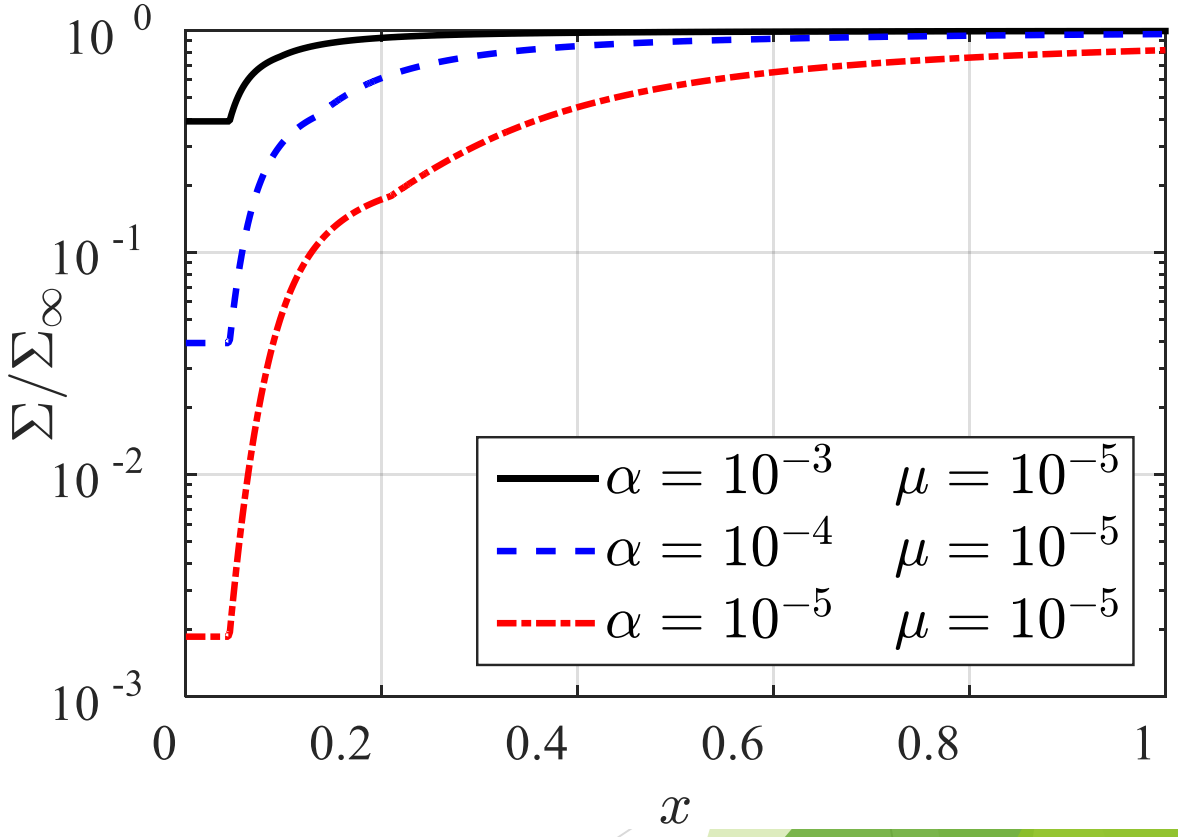


Ginzburg & Sari (18)

$$x = \left(\frac{\Sigma(x)}{\Sigma(x_0)}\frac{x_0^8 h^3}{\mu^2}\right)^{1/5}$$

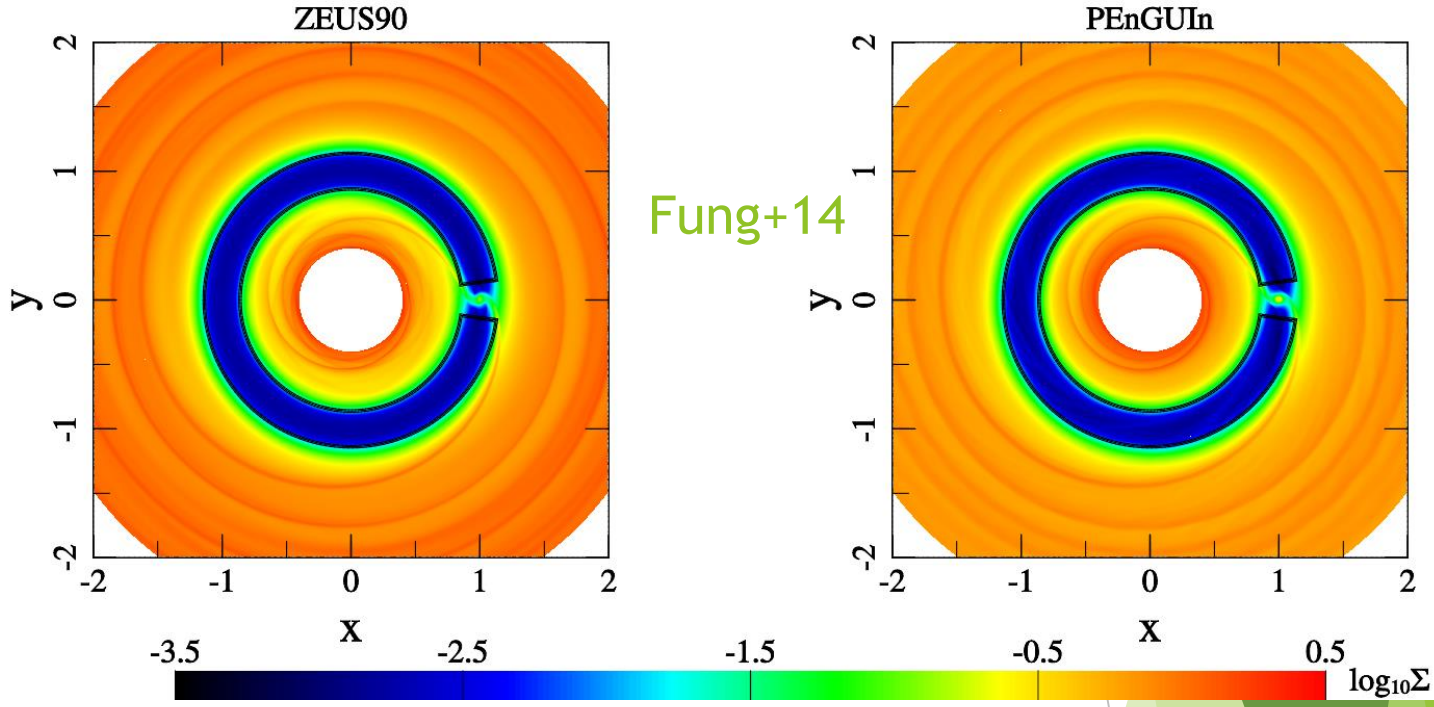
Results ($h = 0.03$)





Low-viscosity $\alpha \lll 1$

- Numerical viscosity
- Long runtime



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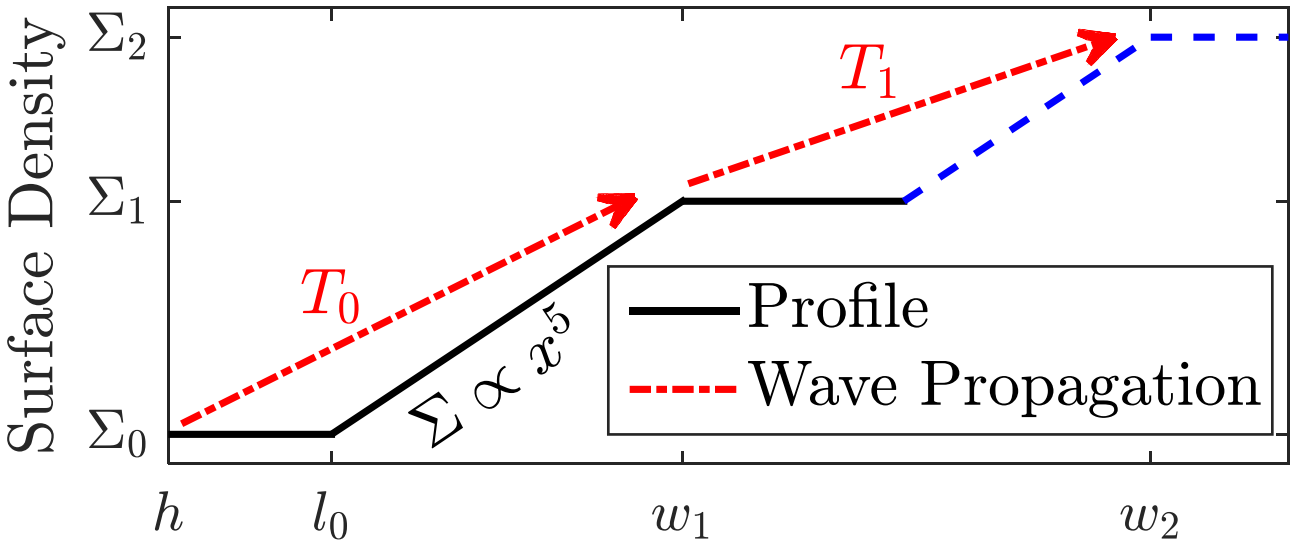
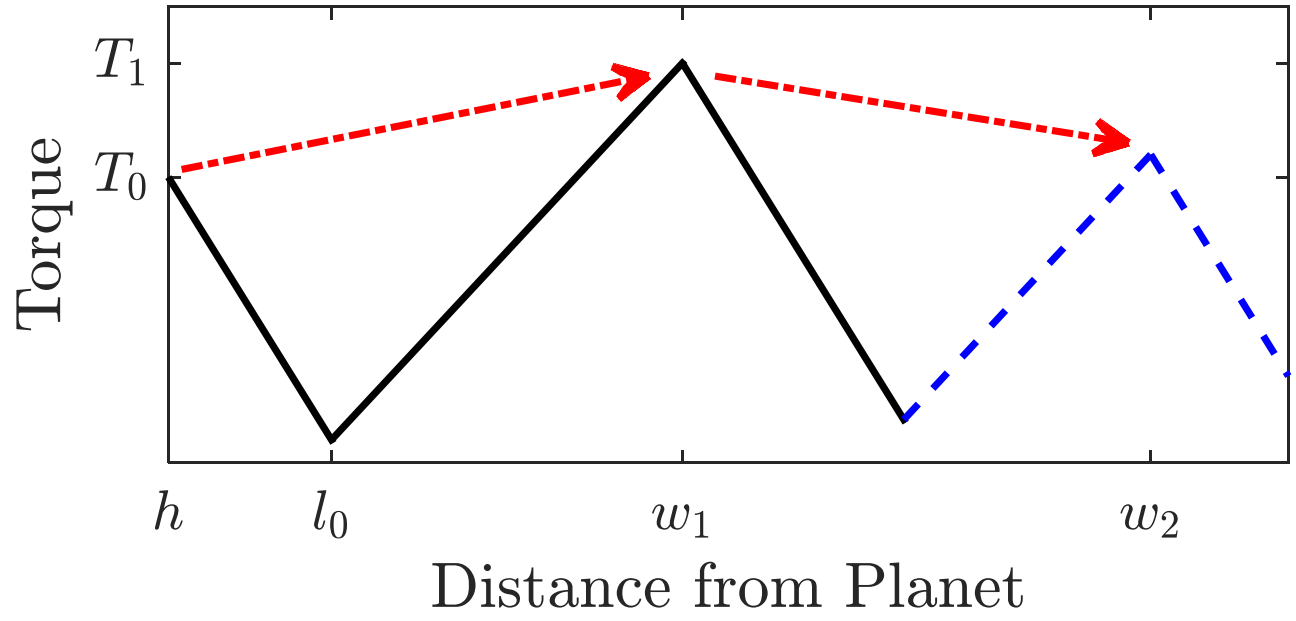
Dominant Torque

$$T(x) = \frac{\Sigma(x)\mu^2}{x^3}$$

T_0 Fung+14, Duffell&MacFadyen13

$T_1 > T_0$ low α





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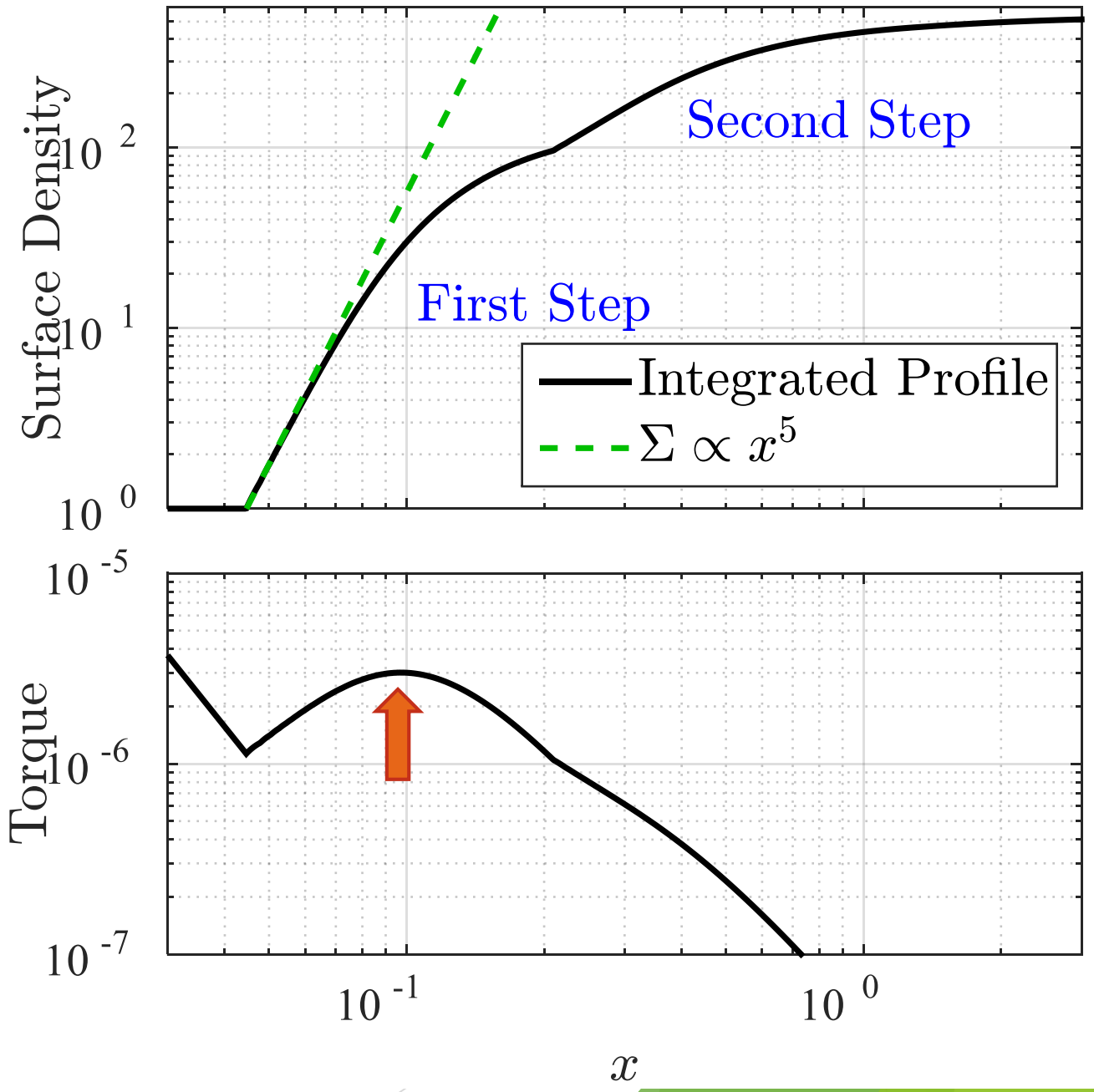
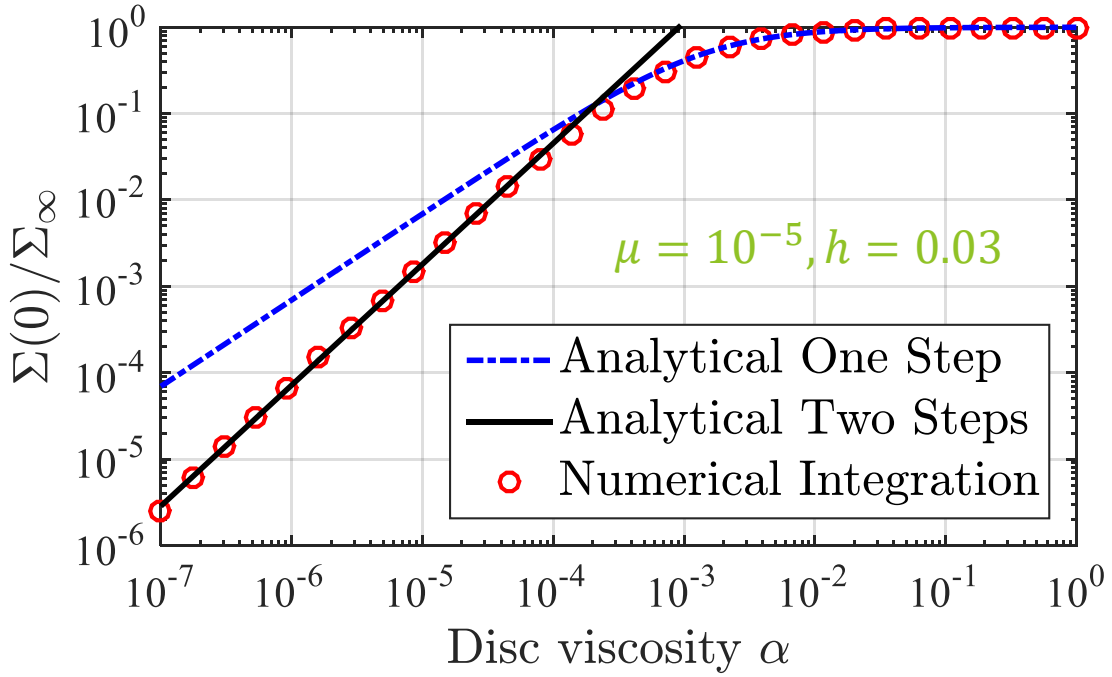
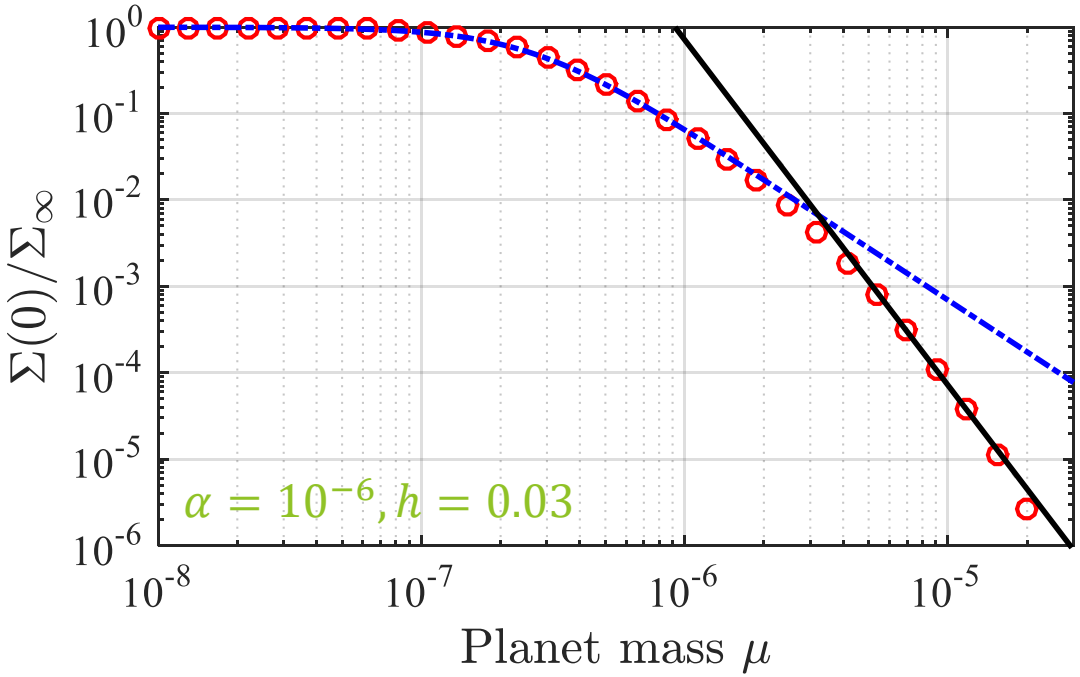
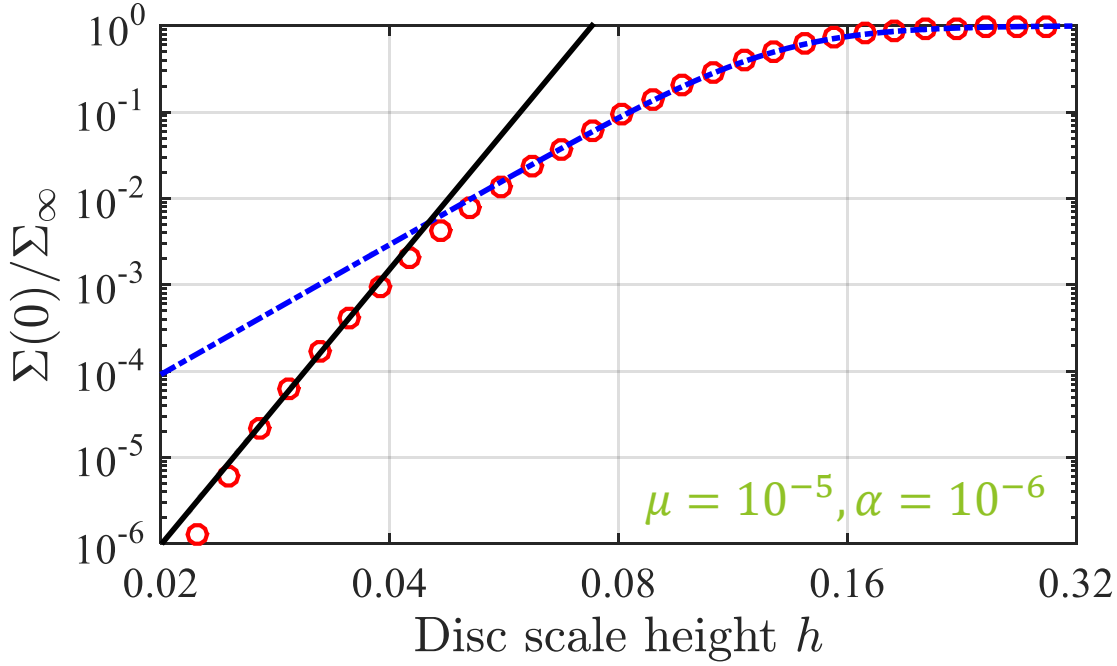
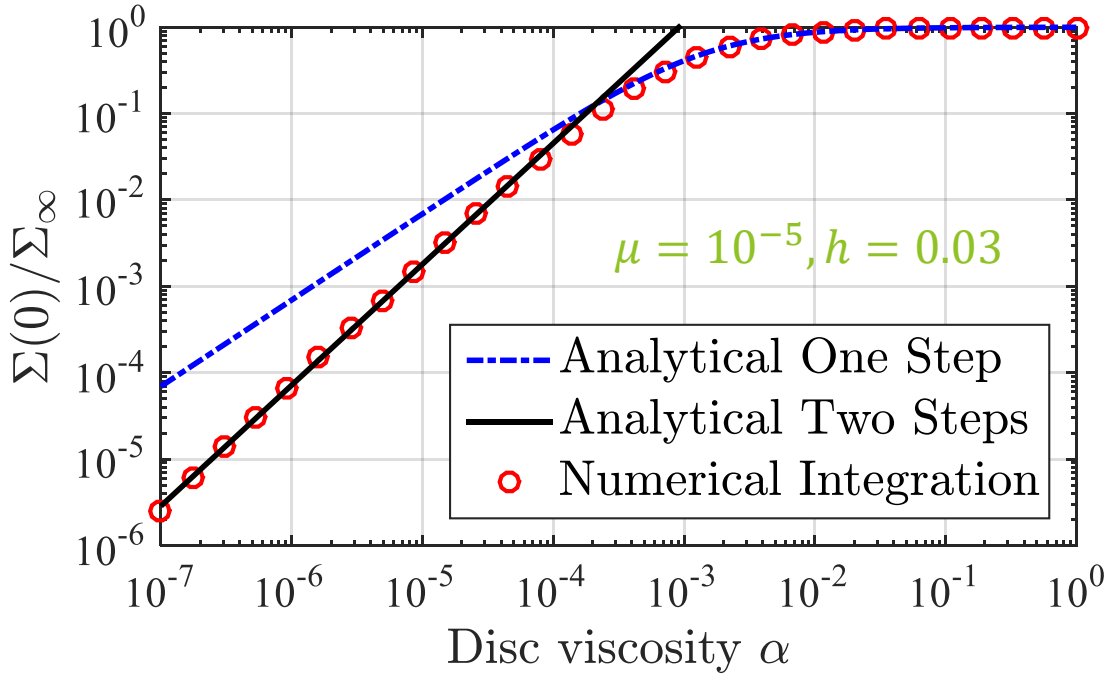
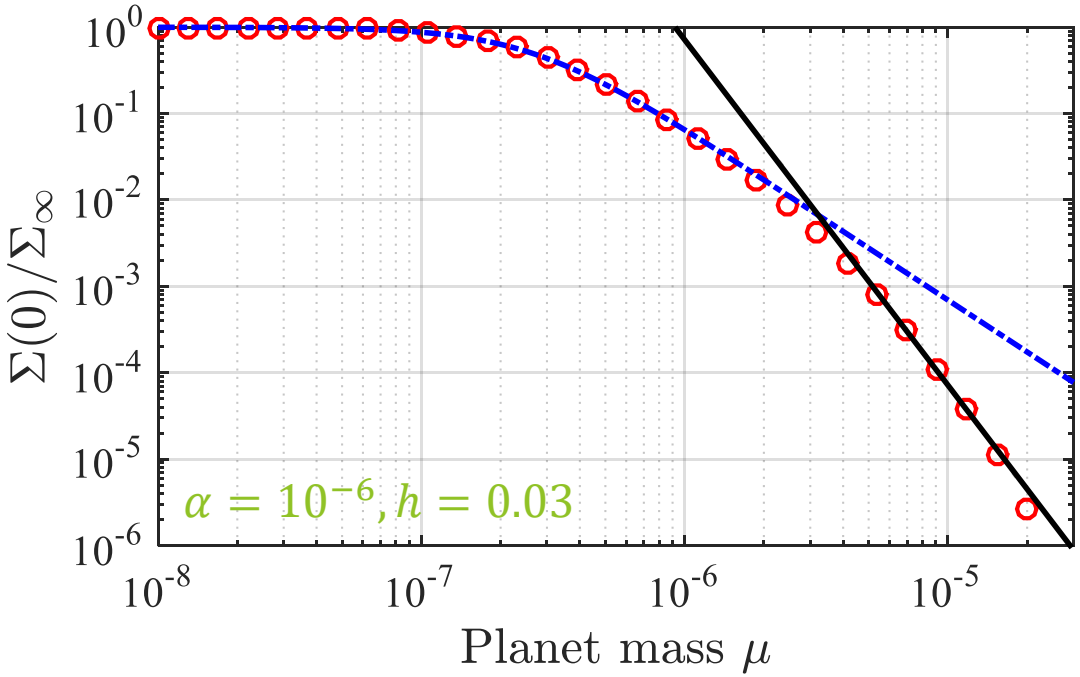


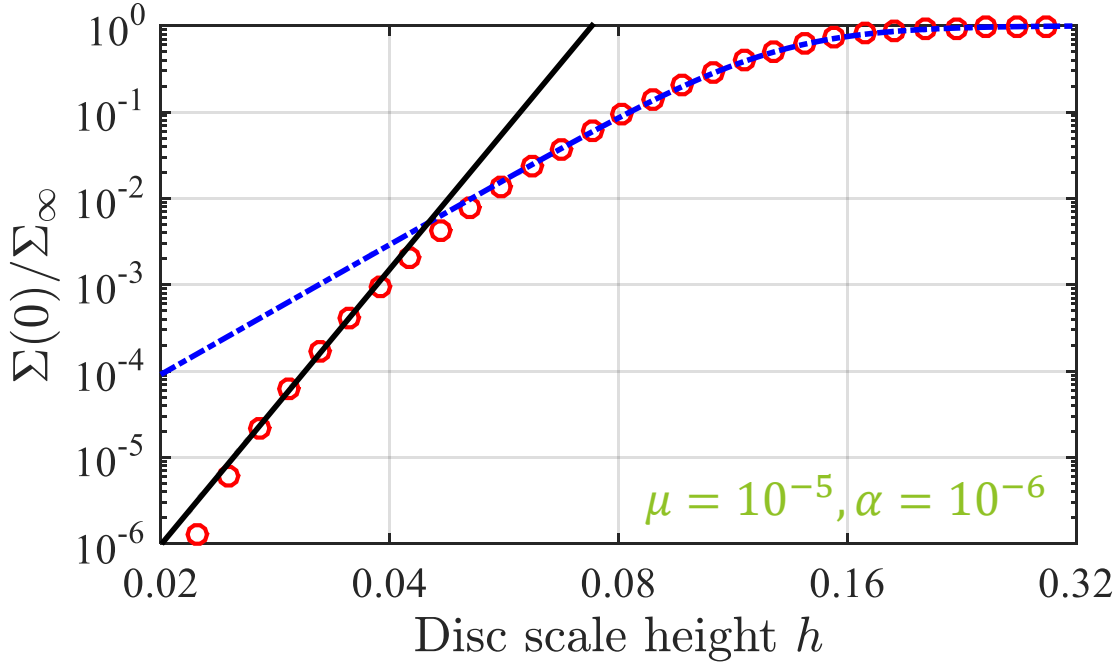

$\mu = 10^{-5}, h = 0.03$
Analytical One Step
Analytical Two Steps
Numerical Integration
$\Sigma(0)/\Sigma_\infty$
Disc viscosity α


$\alpha = 10^{-6}, h = 0.03$
$\Sigma(0)/\Sigma_\infty$
Planet mass μ

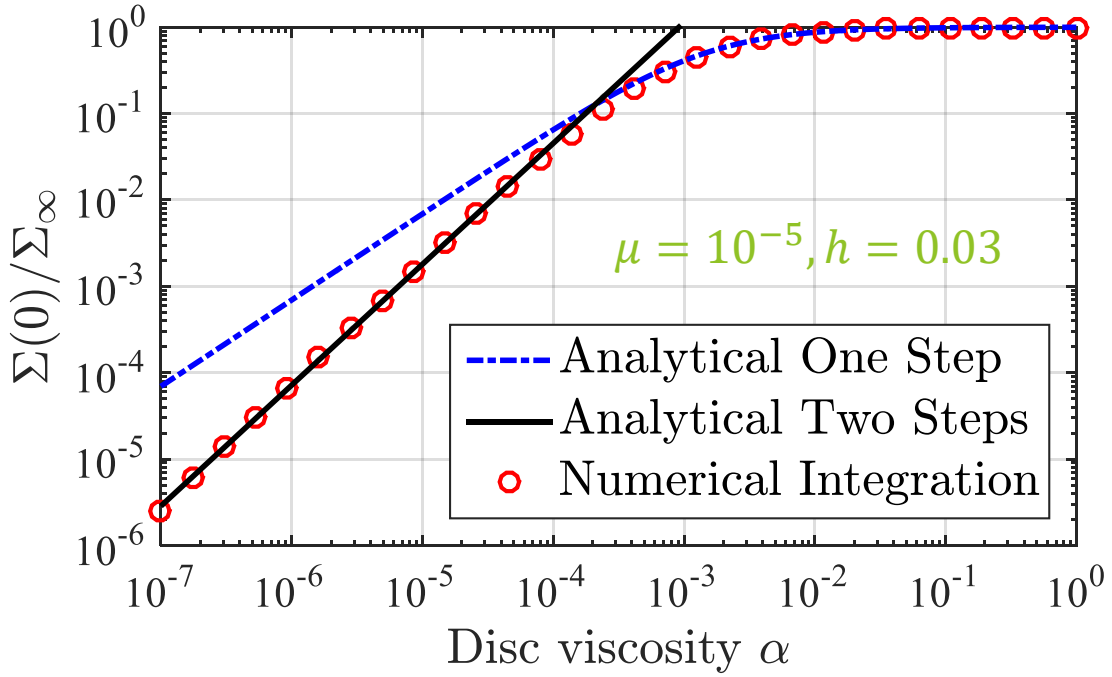

$\mu = 10^{-5}, \alpha = 10^{-6}$
$\Sigma(0)/\Sigma_\infty$
Disc scale height h

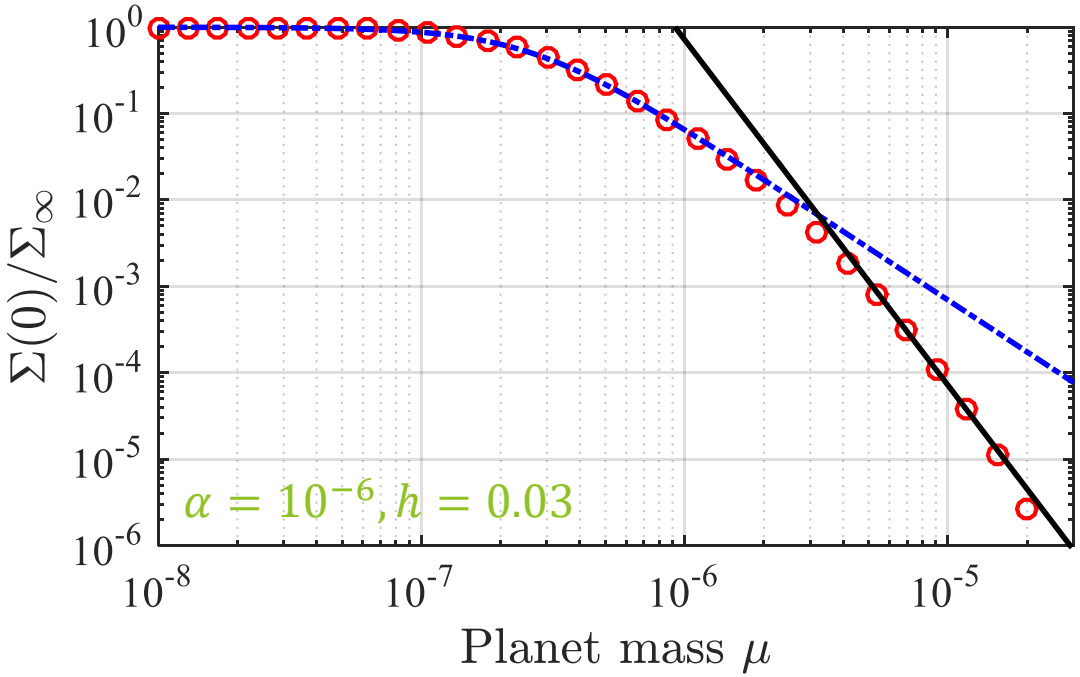


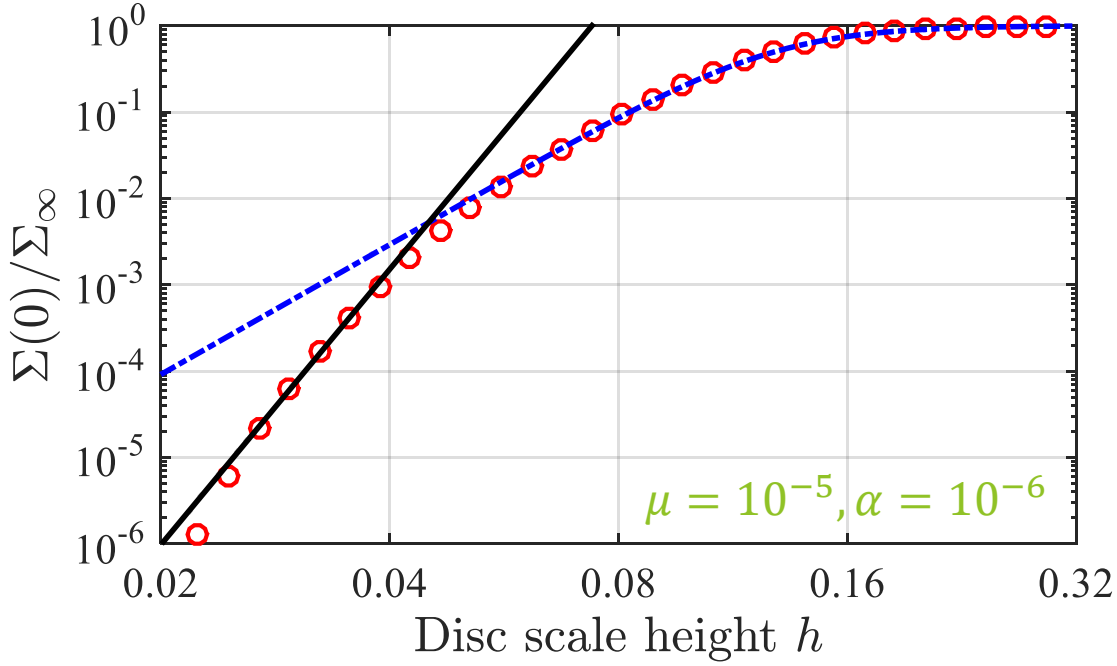




$$\frac{\Sigma(0)}{\Sigma_\infty} = \begin{cases} 1 & \text{no steps} \\ \dfrac{\alpha h^5}{\mu^2} & \text{one step} \\ \dfrac{\alpha^{7/5} h^{53/5}}{\mu^4} & \text{two steps} \end{cases}$$







Also analytically:

- Wider gaps
- Longer time

Summary

- Scheme to calculate gap profiles α, μ, h
- Low-viscosity ($\alpha \lll 1$) disks:
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  - Deeper, wider **&** slower

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- Scheme to calculate gap profiles α, μ, h
- Low-viscosity ($\alpha \lll 1$) disks:
  - Numerically challenging
  - Two-step profile: $\Sigma \propto \alpha^{7/5} \mu^{-4} h^{53/5}$
  - Deeper, wider **&** slower
- Implications: Gas accretion, Moon formation, Rings

Thank You!