The Relationship Between Ring Properties and Planet Masses

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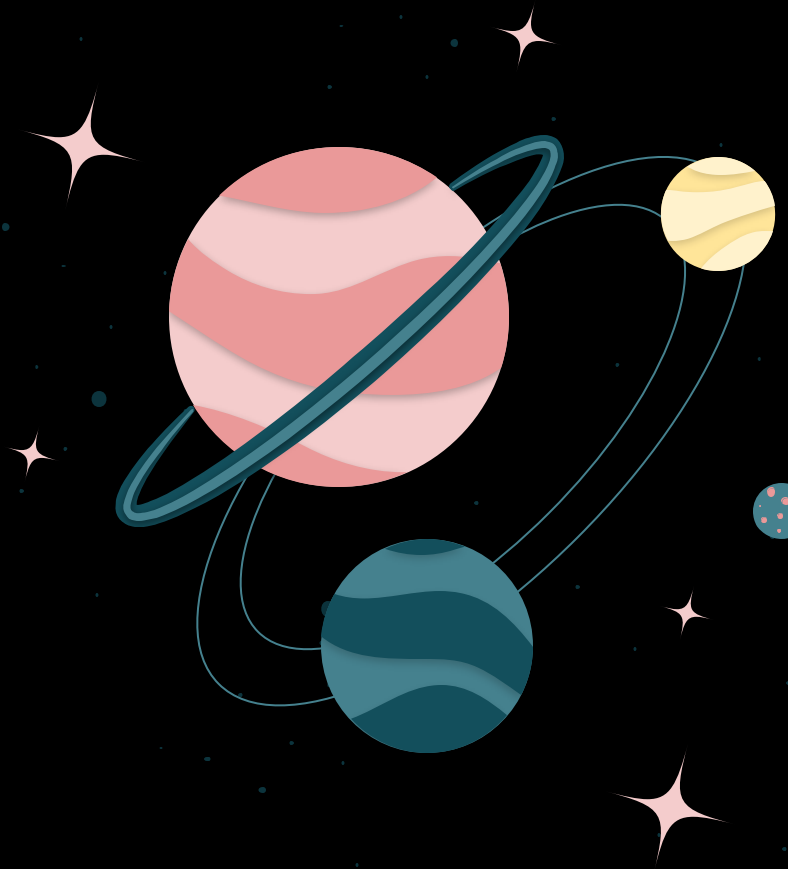
Credit: ESO/L. Calçada

01

Background & Theory

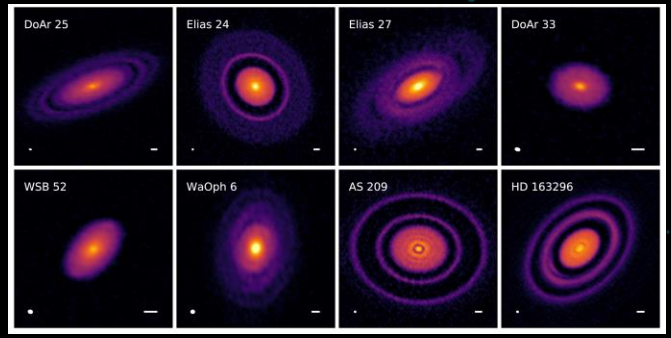


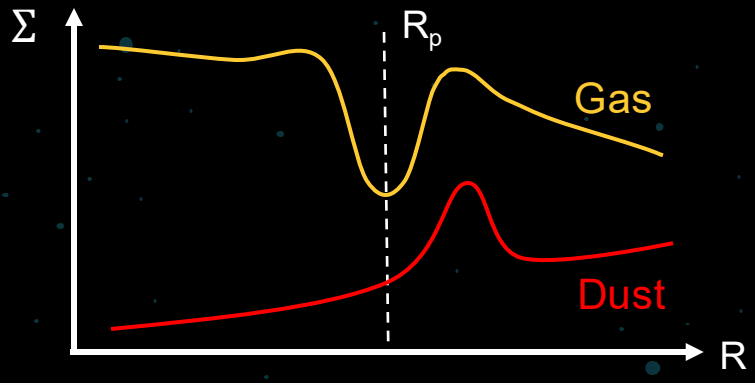
Disc Morphology

Varied morphology seen in discs – could indicate embedded planets!

Exoplanet detection techniques allow us to infer many properties of planets - mass, radius, semi-major axis…

Can ring properties tell us something about the presumed planets creating them?





Inferences from Substructure

We can infer some planet properties from observations:

$$\Delta_{dust\ gap} = 5.5 R_H$$ (Lodato et al. 2019)

$$\frac{\Delta_{gas\ gap}}{R_p} \sim \alpha^{-\frac{1}{4}} \left(\frac{h_p}{r_p}\right)^{-\frac{3}{4}} \sqrt{\frac{M_p}{M_*}}$$ (Kanagawa et al. 2016)

See also: Zhang et al. 2018

These use gaps, rather than rings to infer planet masses

Pebble Isolation Mass

Minimum planet mass able to induce a ring of pebble-sized dust (St ~ 0.1) exterior to its orbit:

$$M_{iso} = \left(\frac{h/r}{0.05}\right)^3 \left[1 - \frac{\partial \ln P / \partial \ln r + 2.5}{6}\right] \left[0.34 \left(\frac{\log 10^{-3}}{\log \alpha}\right)^4 + 0.66\right] \left(25 + \frac{\alpha}{2St(0.00476)}\right) M_\oplus$$

(Bitsch et al. 2018)

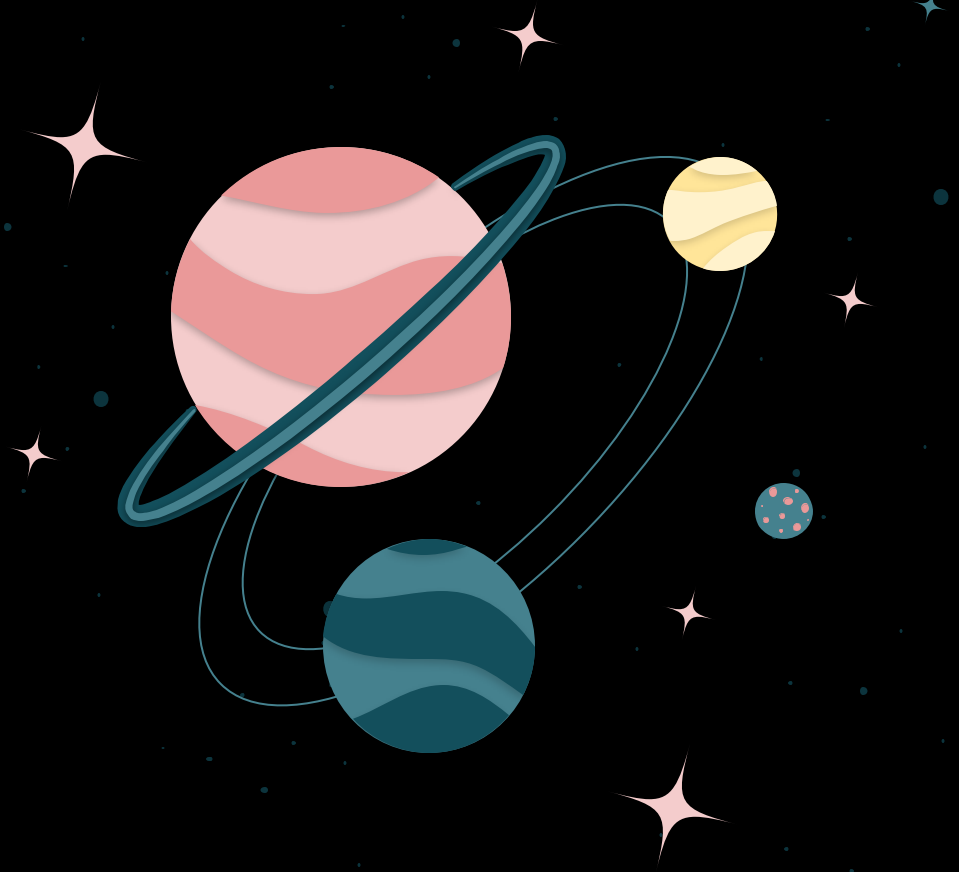
$$M_{iso} = 20 \left(\frac{h/r}{0.05}\right)^3 M_\oplus$$

(Lambrechts et al. 2014)

Given that planets form rings at specific masses, is there any relationship between planet mass and ring properties?

02

Simulation Setup & Methods



Methods & Goals

1) Run a series of 2D ($r + \phi$) FARGO3D gas + dust models at a range of planet masses above and below M_{iso}.
2) Identify any ring properties that scale with planet mass.
3) Does this tell us anything about the underlying behaviour of dust in a disc?
4) Can this allow us to infer planet masses from observations of of discs with substructure?

Parameter Space

$M_p(M_{iso})$	0.5	0.75	1.0	1.5	2.0
$h/r = 0.05$	✓	✓	✓	✓	✓
$h/r = 0.06$	✓	✓	✗	✗	✗
$h/r = 0.07$	✓	✓	✓	✓	✓

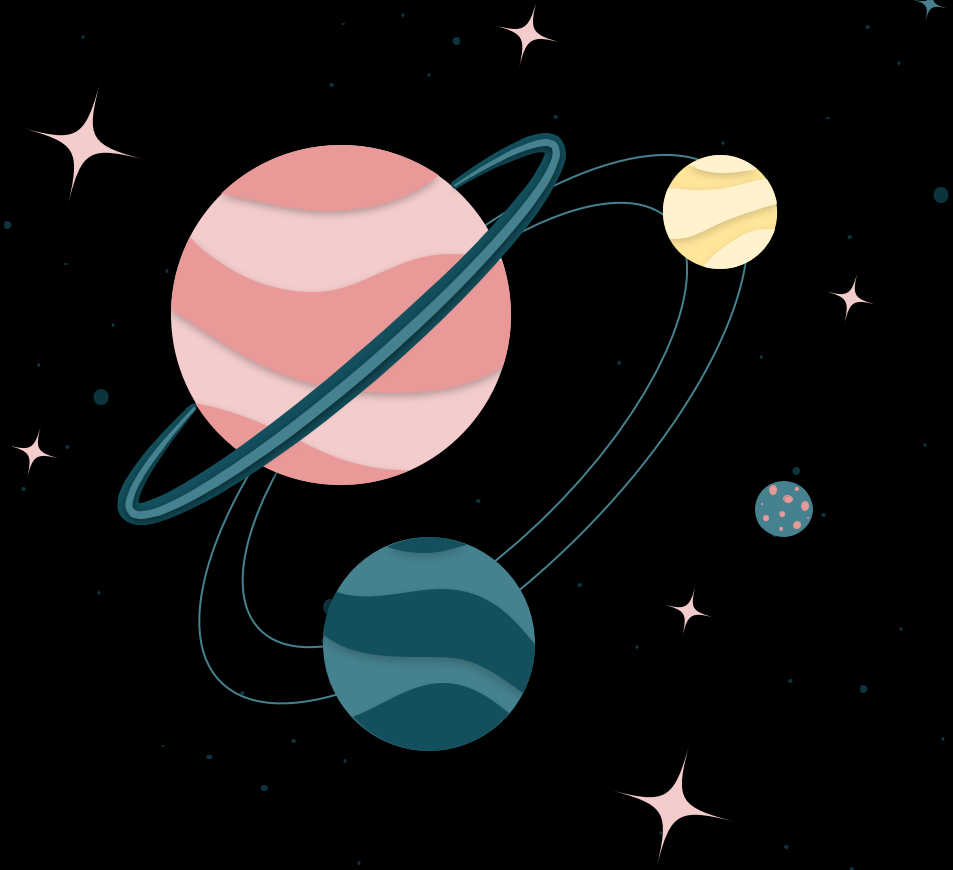
$\alpha = 10^{-4}$ (for now)

5 Stokes numbers: 0.002, 0.0063, 0.02, 0.063, 0.2

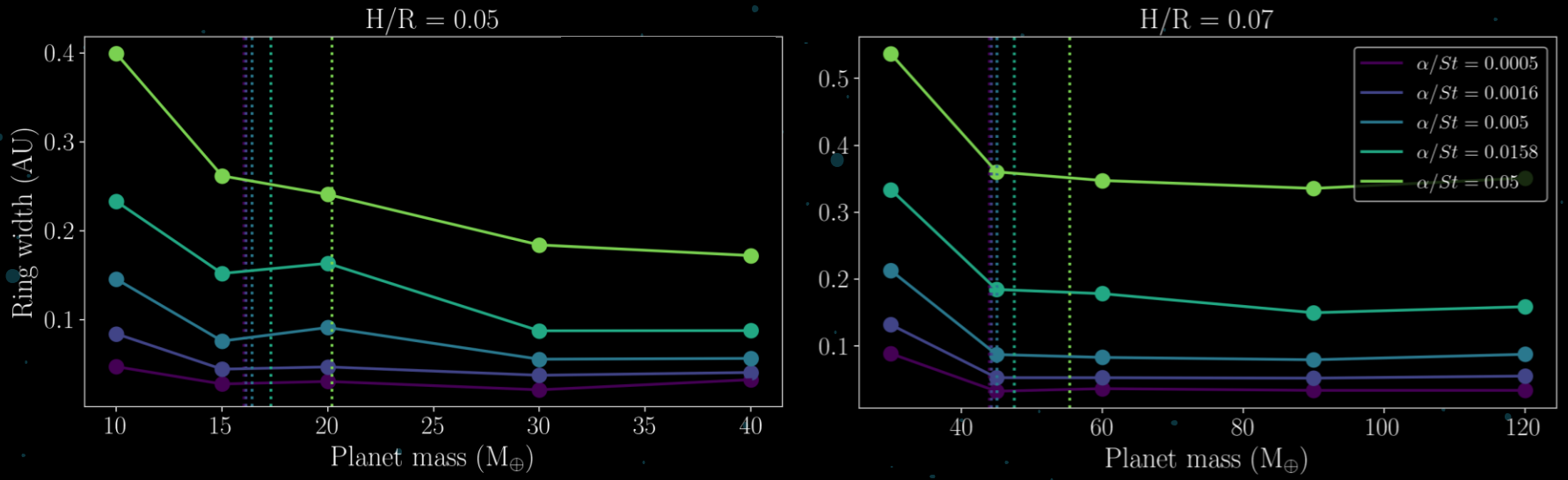
Only run to ~400-600 orbits so far…

03

Results & Analysis

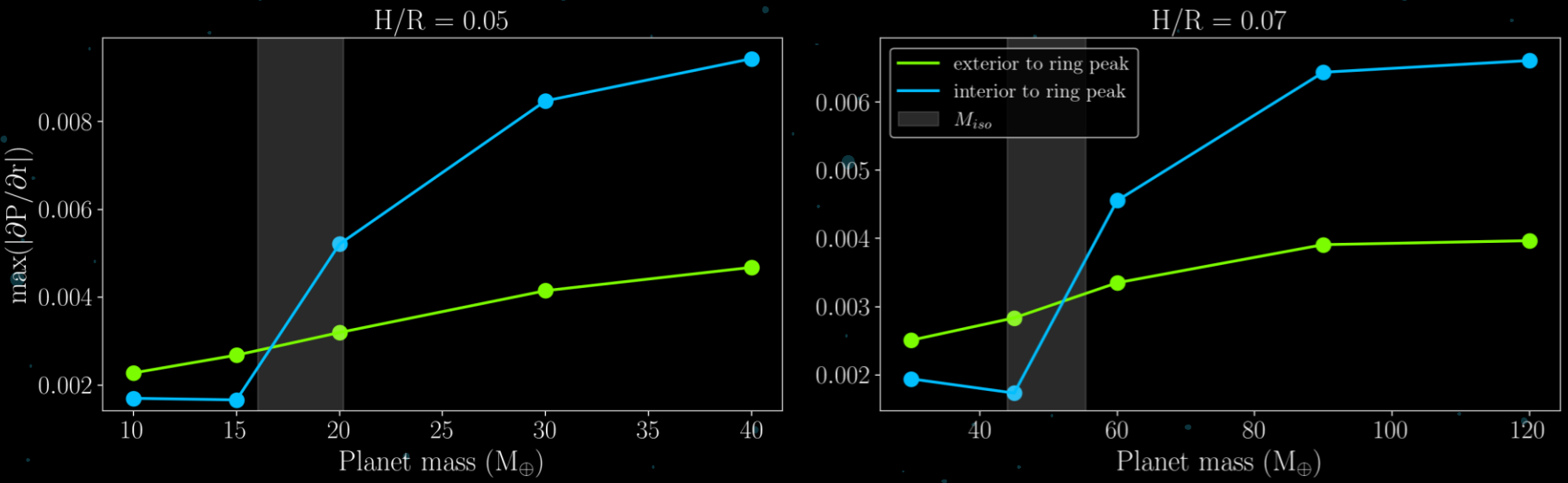


Ring Width vs. Planet Mass



Ring width plateaus for planets with masses greater than M_{iso}

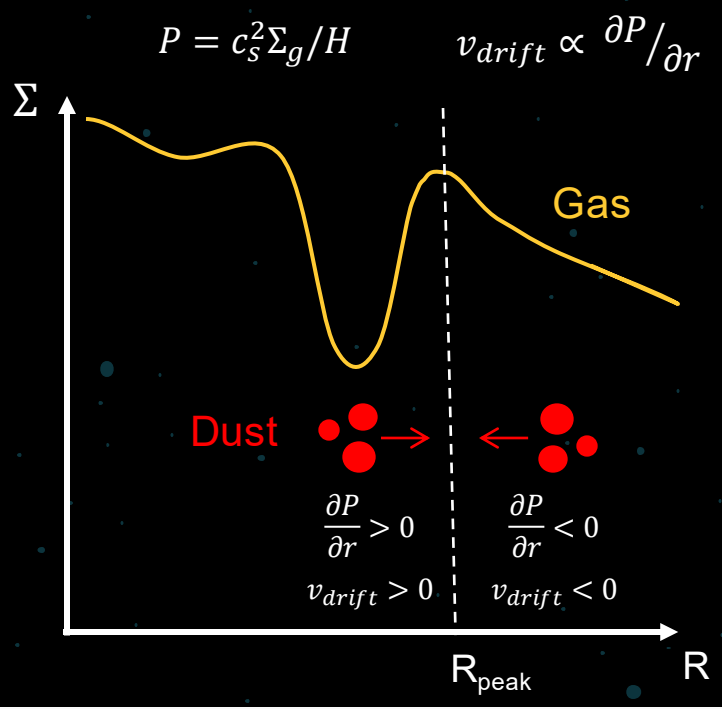
Pressure Gradients



Pebble-isolation mass corresponds to mass at which interior pressure gradient surpasses exterior pressure gradient

Underlying Theory

1) For $M_p < M_{iso}$, inward drift outpaces outward drift, material leaks out of ring and ring spreads.
2) For $M_p \approx M_{iso}$, inward drift matches outward drift, dust is trapped in a narrow ring.
3) For $M_p > M_{iso}$, inward drift is outpaced by outward drift, dust is pushed out of ring but re-enters a region with a positive pressure gradient, so remains trapped on timescales > τ_{drift}



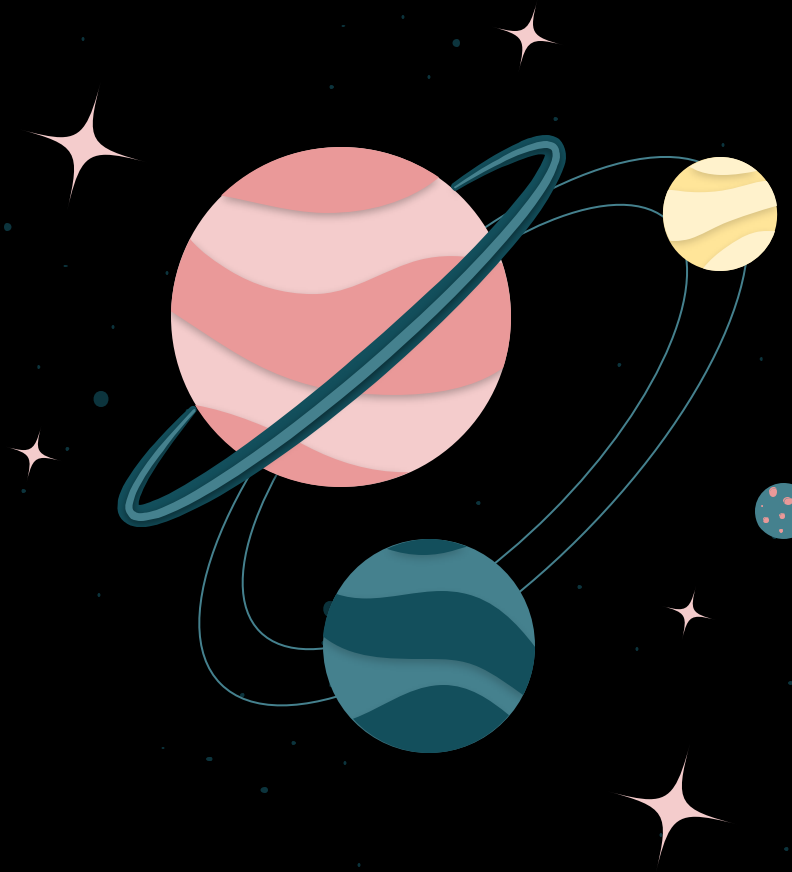
Conclusions & Future Work

- ✓ Pebble isolation mass is related to
  (a) the width of dust rings and
  (b) the ratio of the pressure gradients interior vs exterior to the ring peak – is this observable?

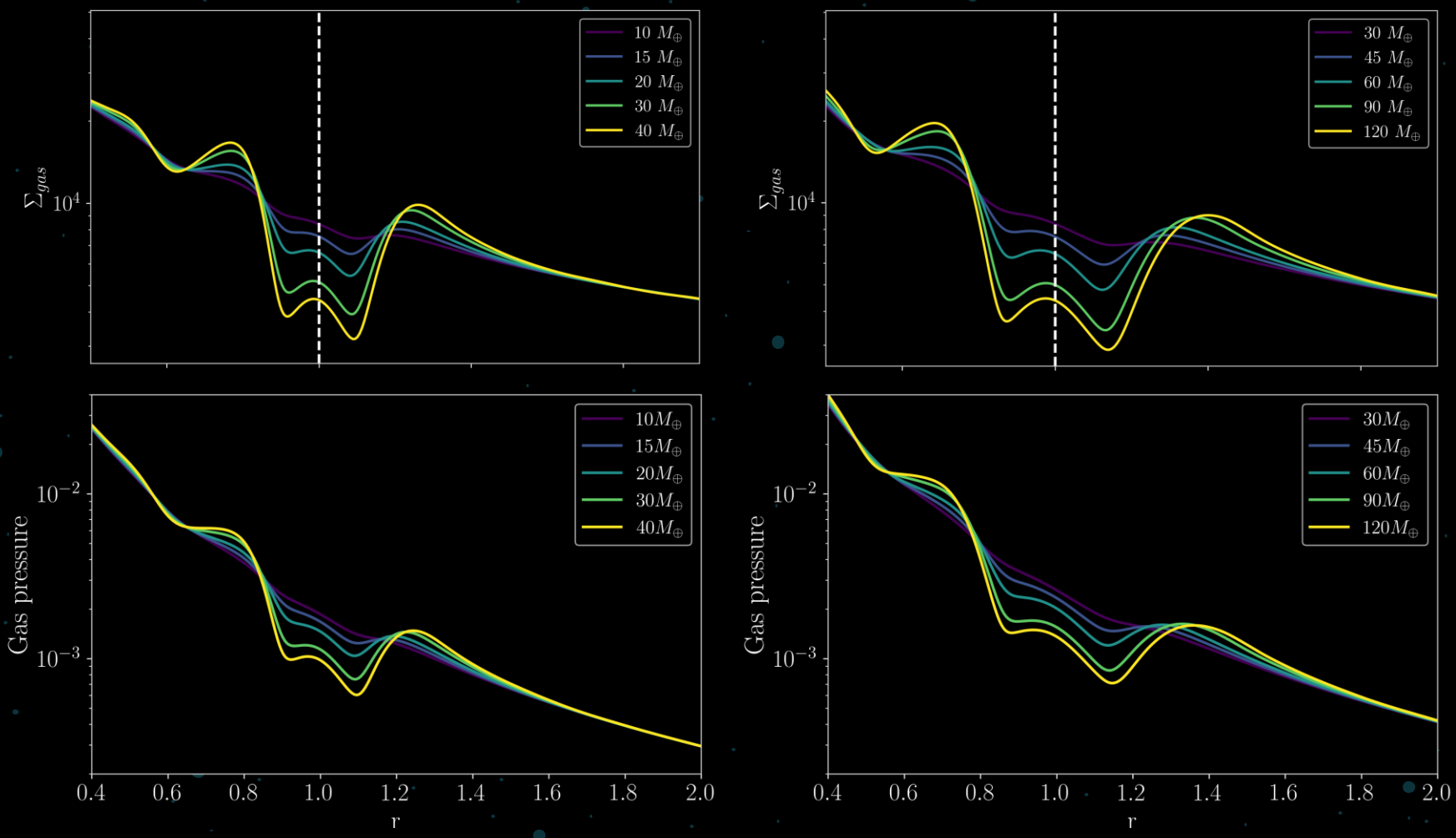
Future Work

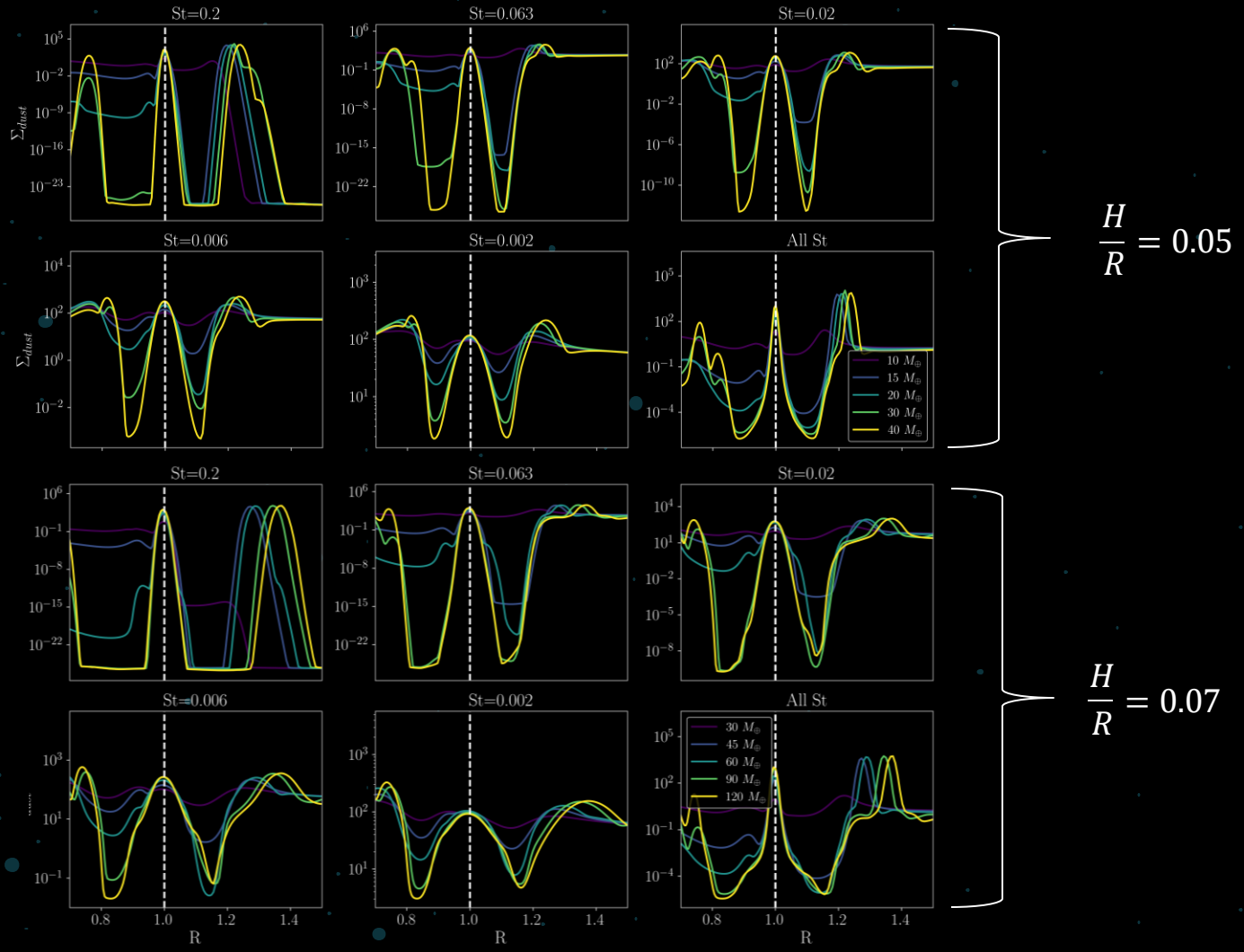
- ❑ Run all models to completion (1000+ orbits)
- ❑ Run models at different α values to check for α/St degeneracy
- ❑ Run models for additional planet masses

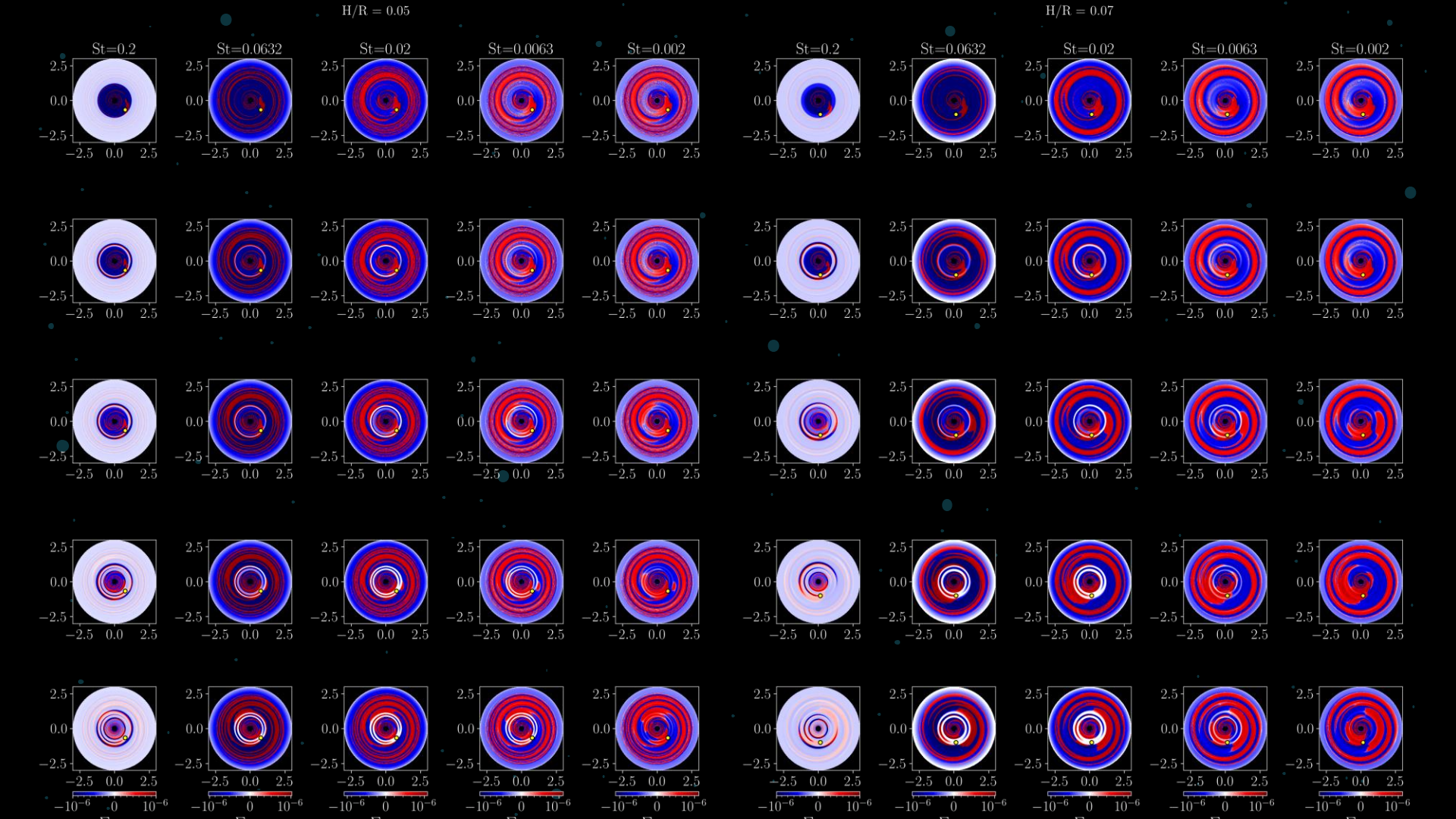
04



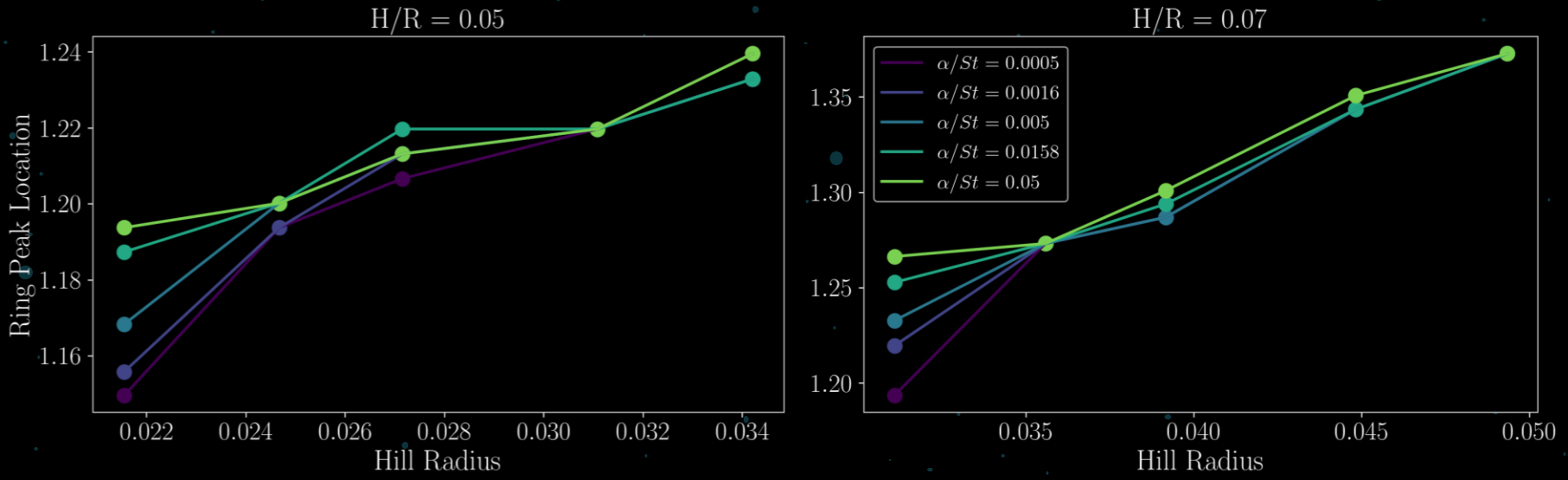
Backup Slides


Σ_{gas}
10^4
10 $M_\oplus$
15 $M_\oplus$
20 $M_\oplus$
30 $M_\oplus$
40 $M_\oplus$
30 $M_\oplus$
45 $M_\oplus$
60 $M_\oplus$
90 $M_\oplus$
120 $M_\oplus$
Gas pressure
10^{-2}
10^{-3}
$10M_\oplus$
$15M_\oplus$
$20M_\oplus$
$30M_\oplus$
$40M_\oplus$
$30M_\oplus$
$45M_\oplus$
$60M_\oplus$
$90M_\oplus$
$120M_\oplus$
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
r


St=0.2
St=0.063
St=0.02
St=0.006
St=0.002
All St
Σ_{dust}
10 $M_\oplus$
15 $M_\oplus$
20 $M_\oplus$
30 $M_\oplus$
40 $M_\oplus$
30 $M_\oplus$
45 $M_\oplus$
60 $M_\oplus$
90 $M_\oplus$
120 $M_\oplus$
R
$\frac{H}{R} = 0.05$
$\frac{H}{R} = 0.07$


H/R = 0.05
H/R = 0.07
St=0.2
St=0.0632
St=0.02
St=0.0063
St=0.002
St=0.2
St=0.0632
St=0.02
St=0.0063
St=0.002
2.5
0.0
−2.5
−10^−6
0
10^−6

Ring Peak Location



Linear correlation between ring location and Hill radius