The Impact of Planetary Migration on Collisional Growth of Dust

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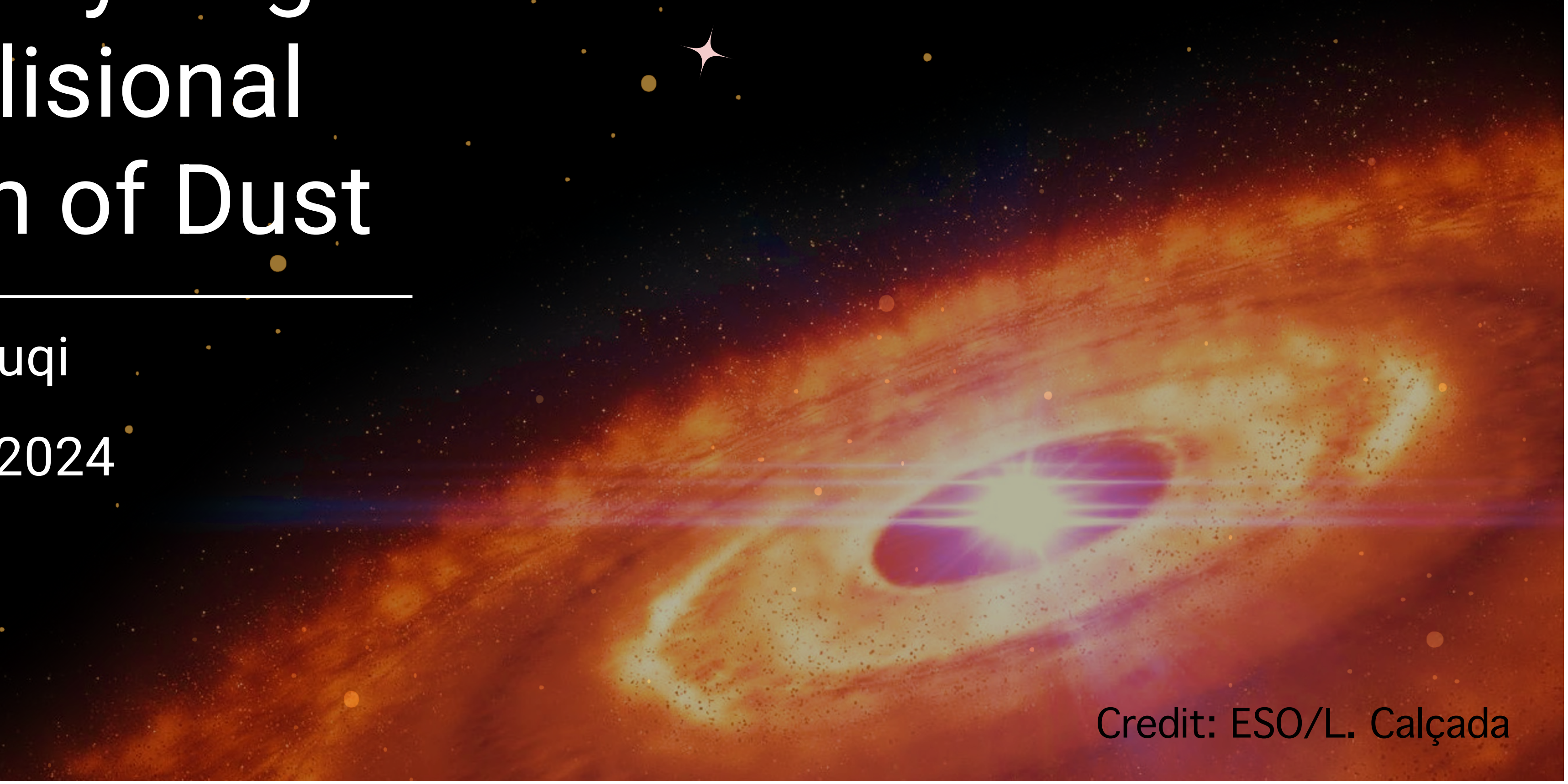
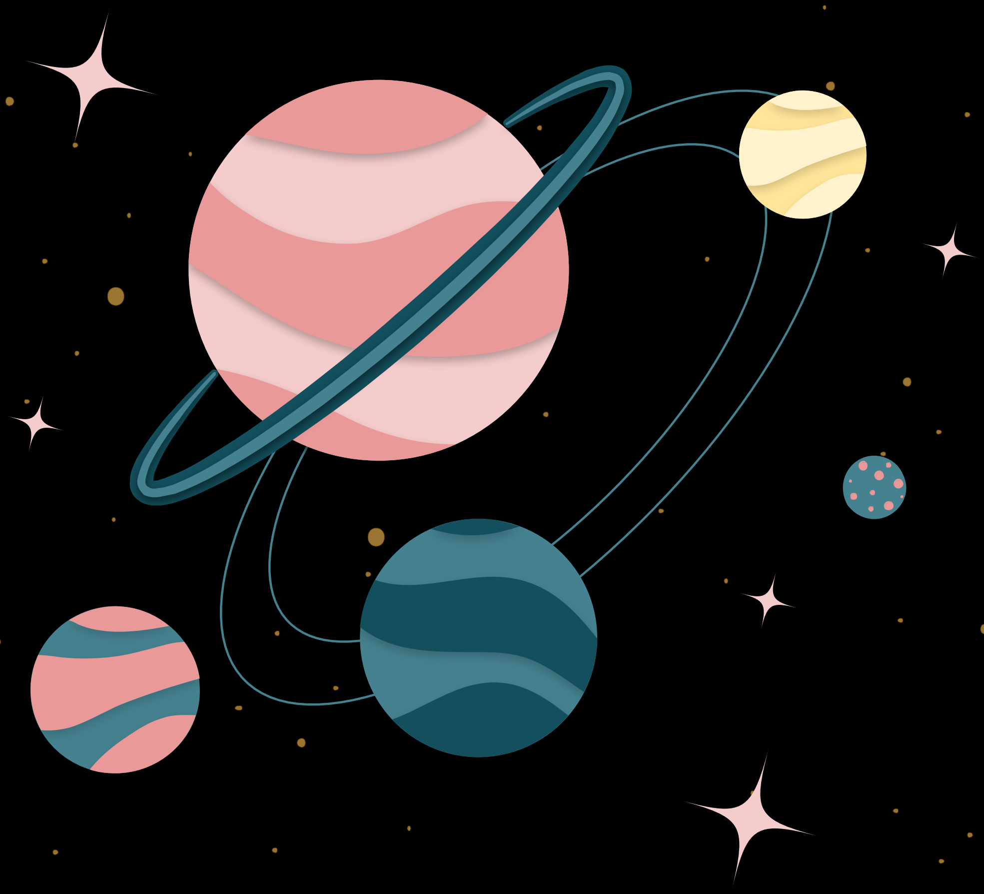


Credit: ESO/L. Calçada

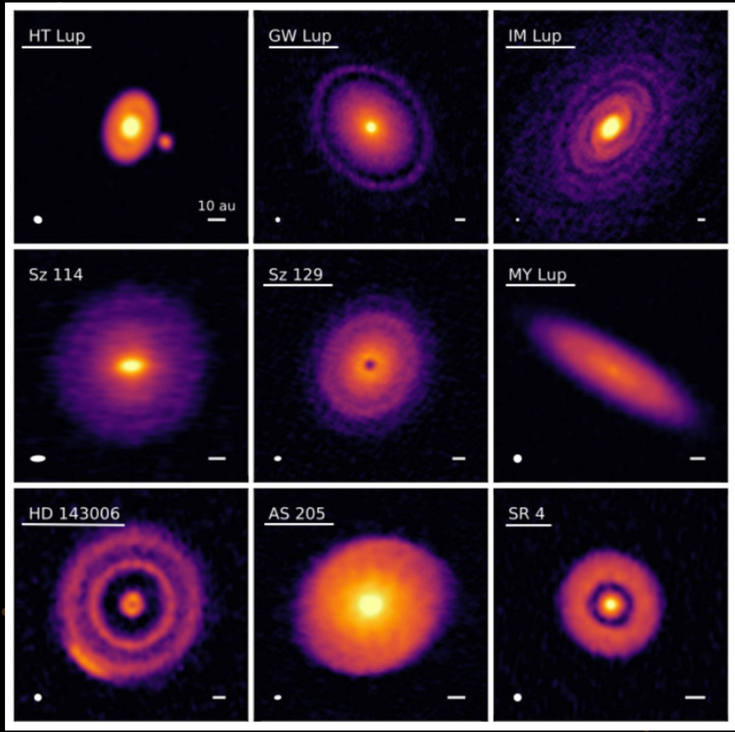
01

Background & Motivation



Observations of Discs

- Observed rings & gaps may indicate the presence of an embedded planet.
- Planet perturbs disc, carving out a gap and trapping dust interior/exterior to planet's orbit.
- ~800 multi-planet systems found – further study into how existing planets affect the formation of additional planets is required.



Source: ALMA Partnership, 2015

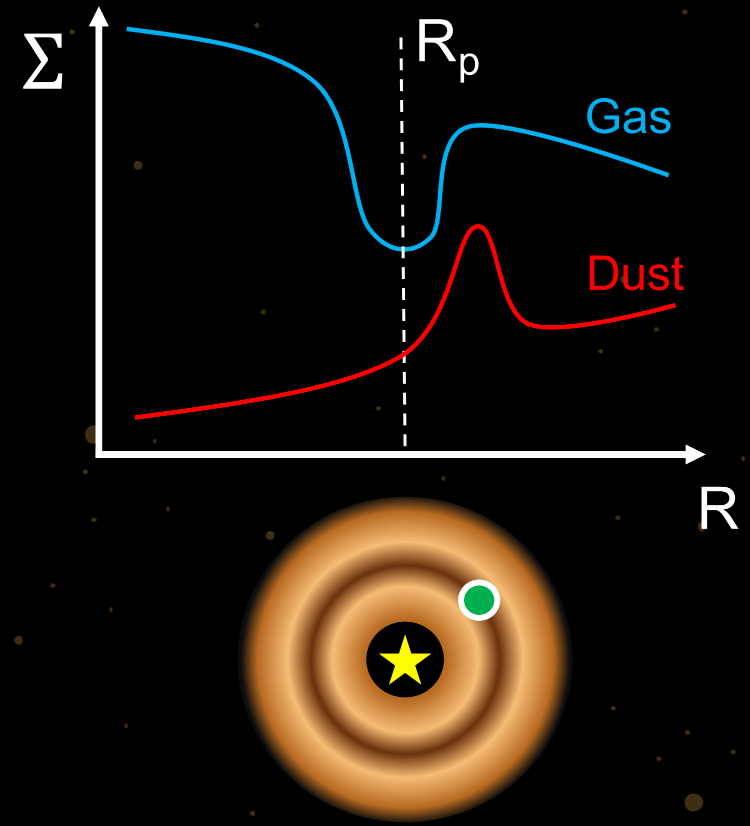
Gap & Ring Formation

Mechanisms for formation of dust rings:

1) Planets heavier than the isolation mass ($M_p > M_{iso}$) can repel large dust from their orbit, causing a dust pile-up.

2) Massive enough planets ($Mp > M_{gap}$) repel gas from the region of their orbit, opening a gap.

   Gas pressure bumps form interior/ exterior to planet, trapping dust.



Collisional Dust Growth in Rings

Collisional growth is typically inhibited by the radial drift and fragmentation of grains.

Rings comprise regions where the collision rate is higher and collisional velocities are lower, meaning

a) collisions will be more frequent, leading to more coagulation,

b) the likelihood of fragmentation is lower (lower velocities)

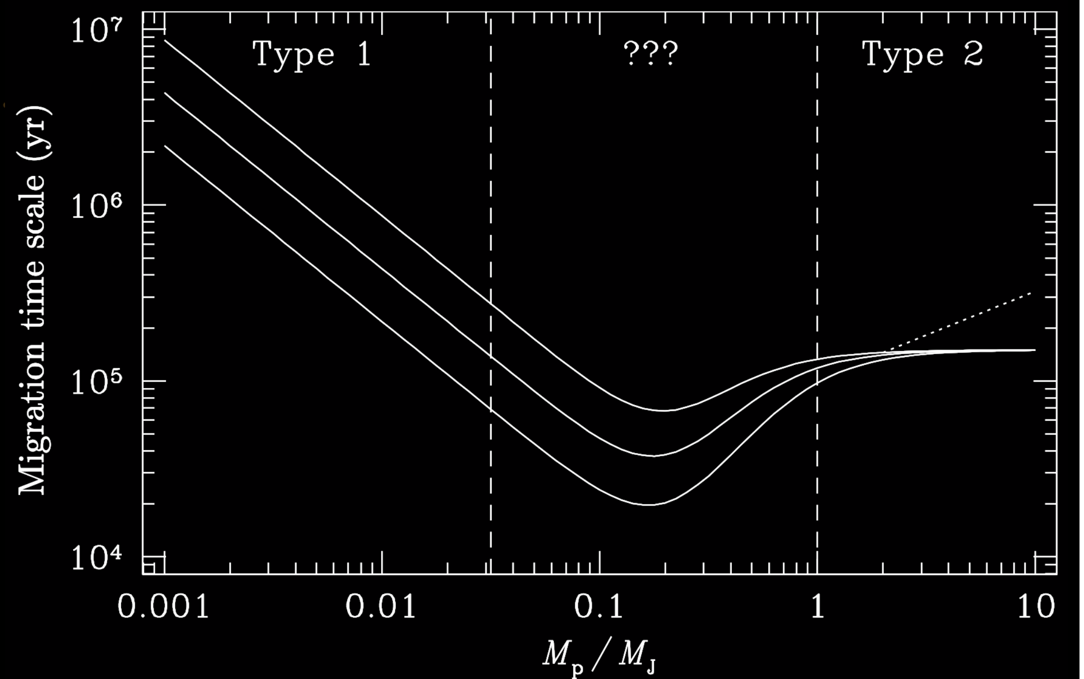
c) larger grains that form are trapped by pressure maxima, preventing them from radially drifting inwards

Planetary Migration

A planet embedded in a protoplanetary disc can perturb the disc so that the disc exerts torques on the planet, causing it to spiral inwards.

Type I: planet not capable of opening gap in disc, migration rate scales with planet mass.

Type II: planet opens gap, migration rate is much slower.



Astrophysics of Planet Formation (Armitage, 2010)

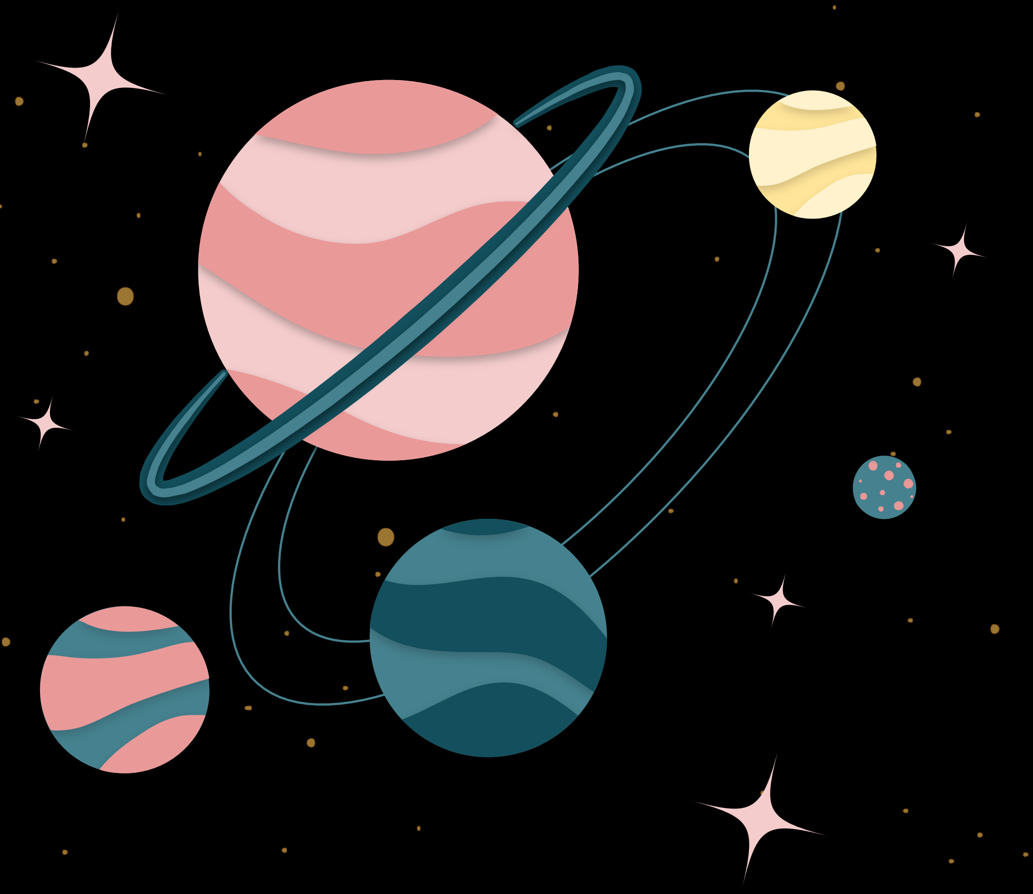
KEY QUESTIONS

How does planetary migration influence disc substructures?

How does this affect dust growth and planetesimal formation?

02

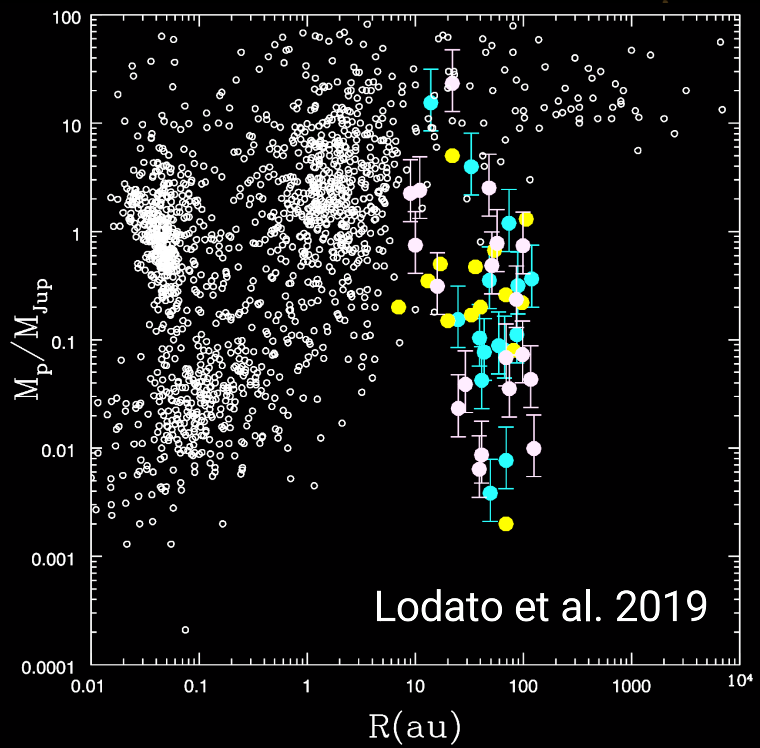
Methods



Parameter Selection

- Effect of planet masses and locations - ideally use planets with masses $M_p < M_{Jup}$, located within a few 10s of AU of the disc inner edge.
- Planet-to-disc mass ratio must be high enough for planet to perturb disc (Rosotti et al. 2016).
- Disc-to-star mass ratio < 0.1 (prevent GI).

R_p = 40AU
$M_* = 1\,M_\odot$
$M_{disc} = 0.01 M_\odot$



Mass Regimes

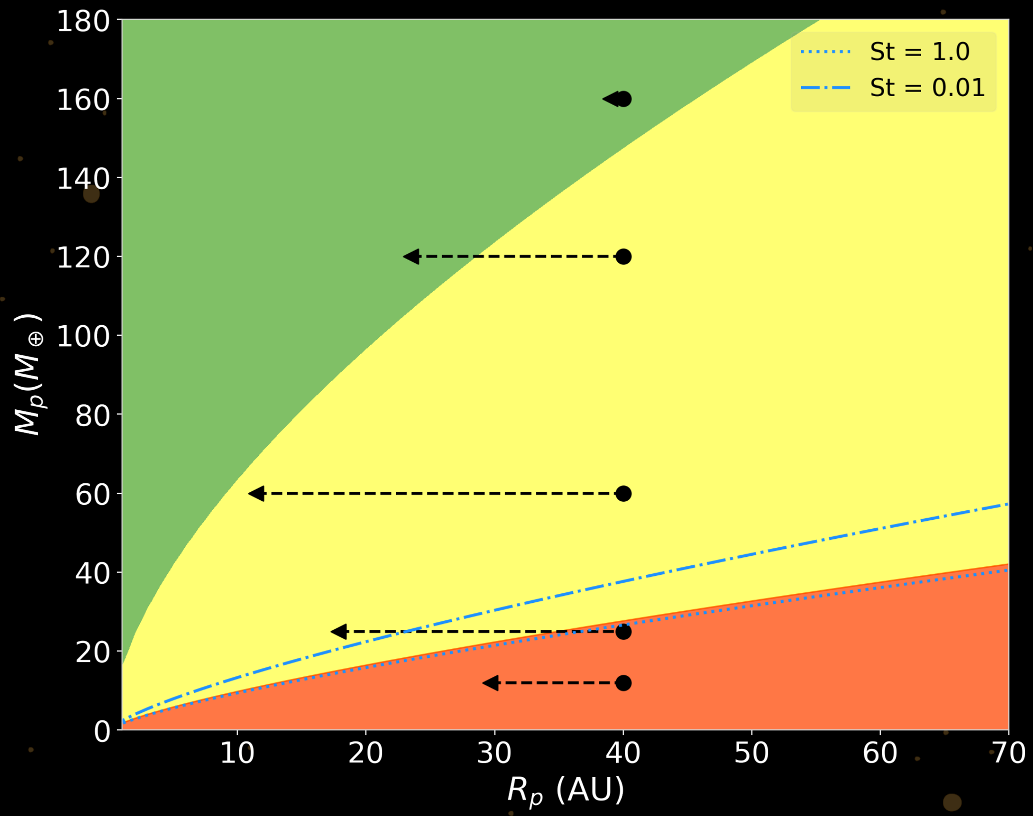
$M_P < M_{iso}$ $M_P < M_{gap}$	$M_{iso} < M_P < M_{gap}$	$M_P > M_{iso}$ $M_P > M_{gap}$
Planet not massive enough to perturb gas or dust	Planet massive enough to form dust ring but not gas gap	Planet massive enough to form gas gap and dust ring

$M_{iso} \simeq 25M_{\oplus}$, $M_{gap} \simeq 140M_{\oplus}$ for planet at 40AU in $0.01M_{\odot}$ disc

Mass Regimes with Migration

$M_P < M_{iso}$ $M_P < M_{gap}$	$M_{iso} < M_P < M_{gap}$	$M_P > M_{iso}$ $M_P > M_{gap}$
Planet not massive enough to perturb gas or dust	Planet massive enough to form dust ring but not gas gap	Planet massive enough to form gas gap and dust ring

Regime boundaries depend on planet mass and location, so migrating planets can cross regime boundaries.



Hydrodynamical Models

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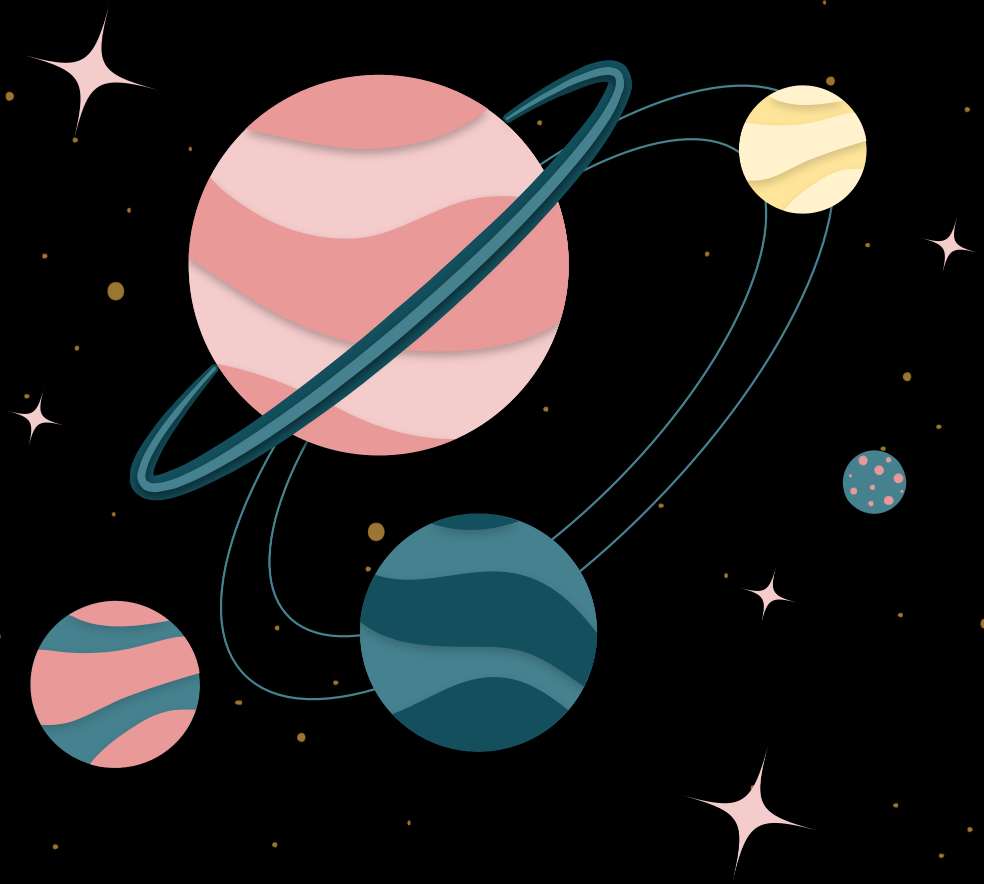
Goal: Study and compare dust growth in rings formed by an embedded planet when the planet is (a) stationary or (b) migrating.

Models run using FARGO3D + coagulation toolkit to run 2D HD models of dust advection and growth.

10 models: [3 (1 per mass regime) + 2 (crossing regime boundaries)] × 2 (migrating and stationary)

03

Results & Analysis



Regime 1: No substructure

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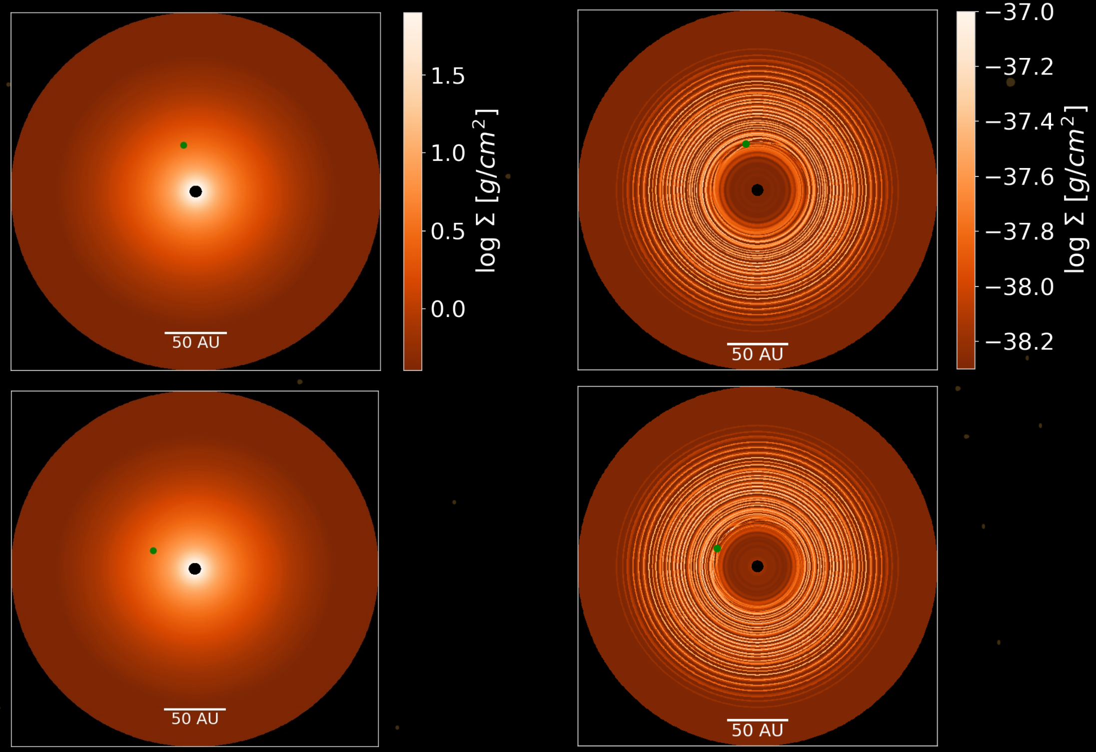
$t = 0.5$Myr
$M_p = 12M_\oplus$

Gas | Dust (10-100cm)

Stationary

Migrating



Concentric rings due to low resolution

No perturbations to disc, no difference in migrating vs. stationary model

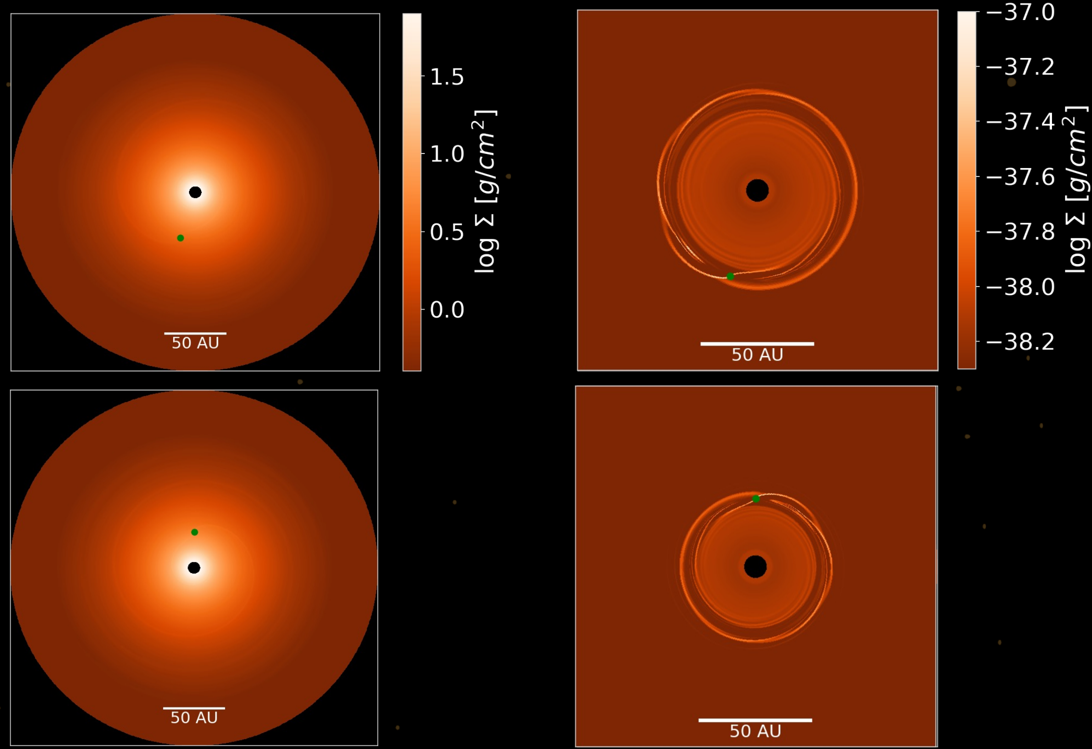
Regime 1 → 2: Weak ring

t = 0.5Myr
$M_p = 25M_\oplus$

Gas | Dust (10-100cm)

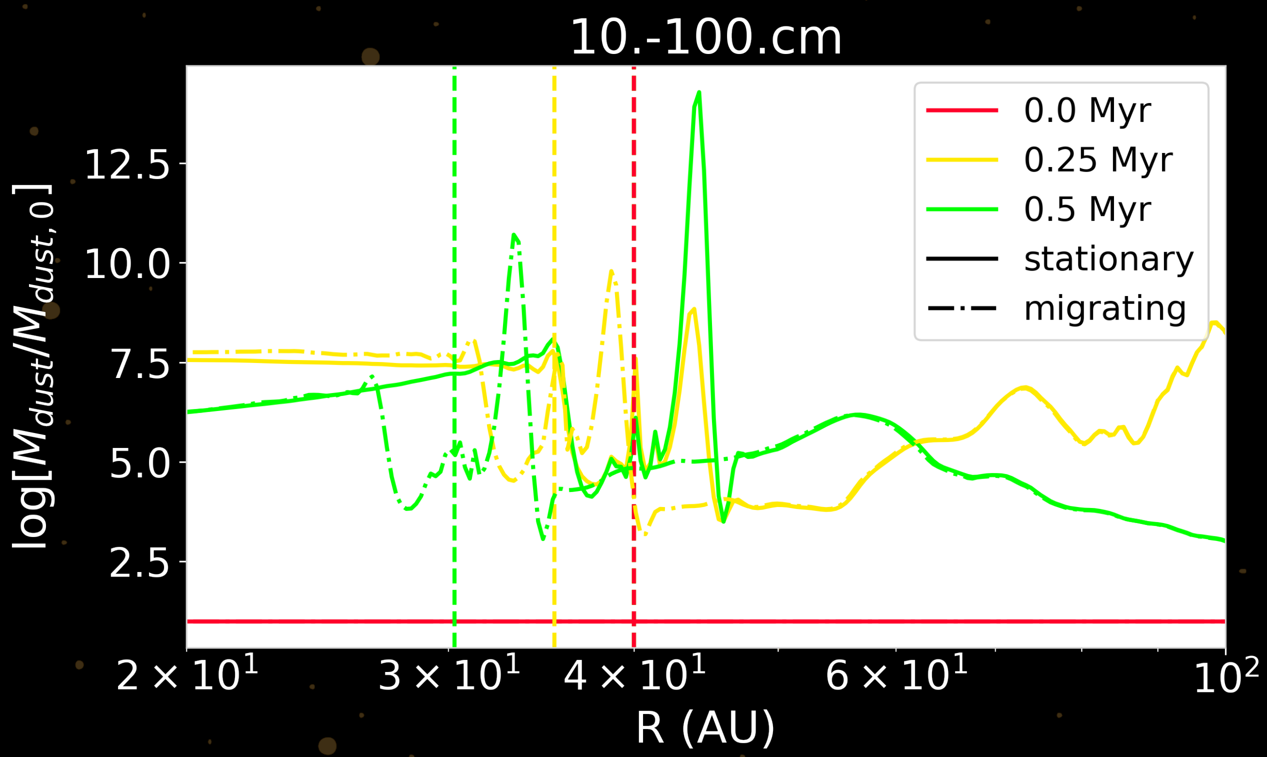
Stationary

Migrating



Weak ring but minimal difference – stationary planet produces a slightly stronger ring!

Regime 1 → 2: Weak ring



HYPOTHESIS

Dust pile-up due to pebble isolation competes with migration.

As large grains travel inwards, their St goes down and they can more readily escape the dust trap.

Regime 2: Ring (no gap)

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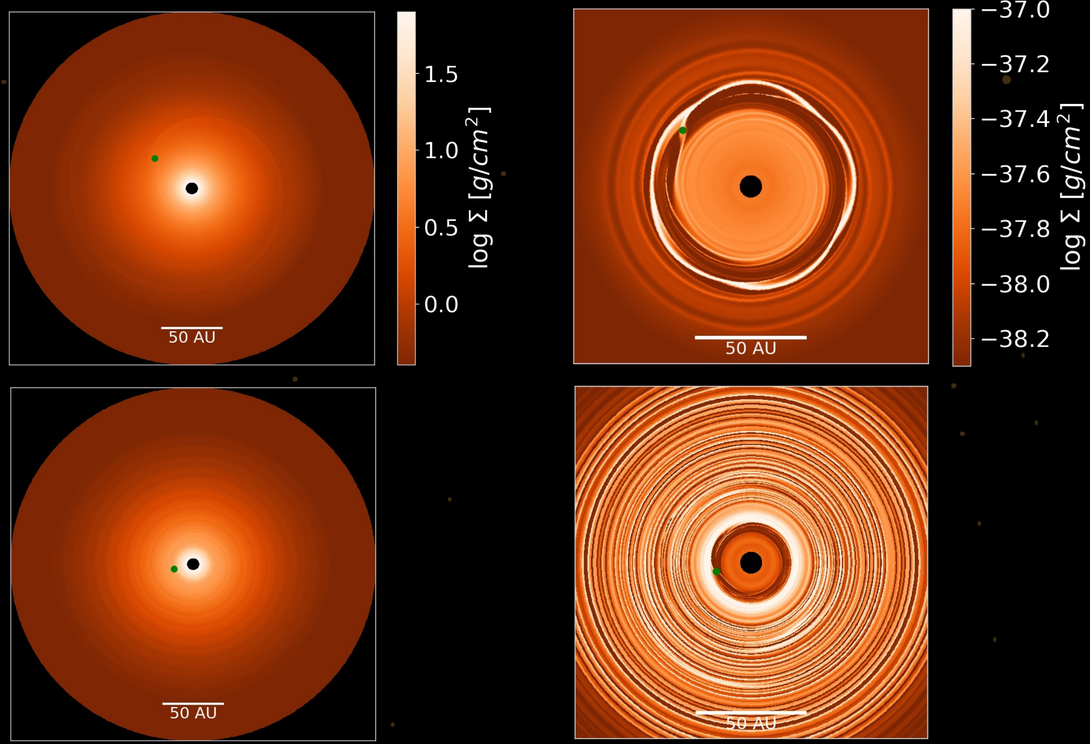
t = 0.45Myr
$M_p = 60M_{\oplus}$

Gas | Dust (10-100cm)

Stationary

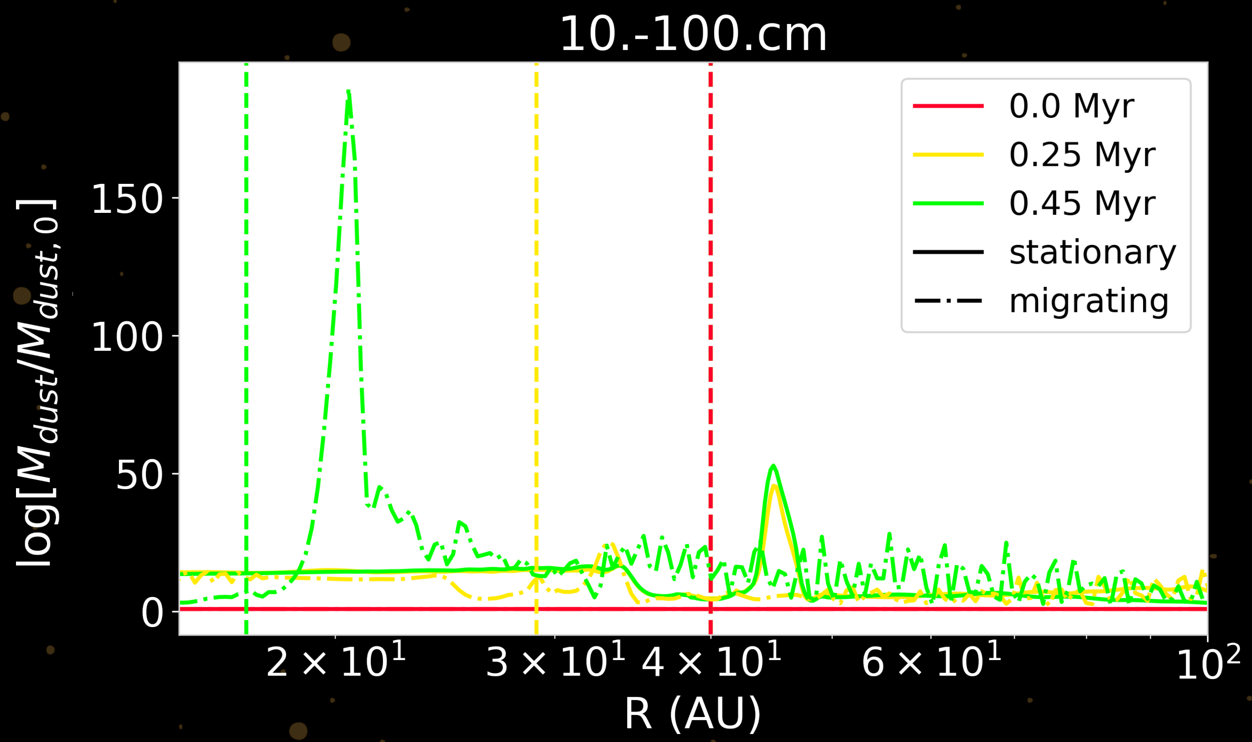
Migrating



No perturbations to gas, bright ring in large dust

Ring in migrating model is more diffuse at its outer edge – why?

Regime 2: Ring (no gap)



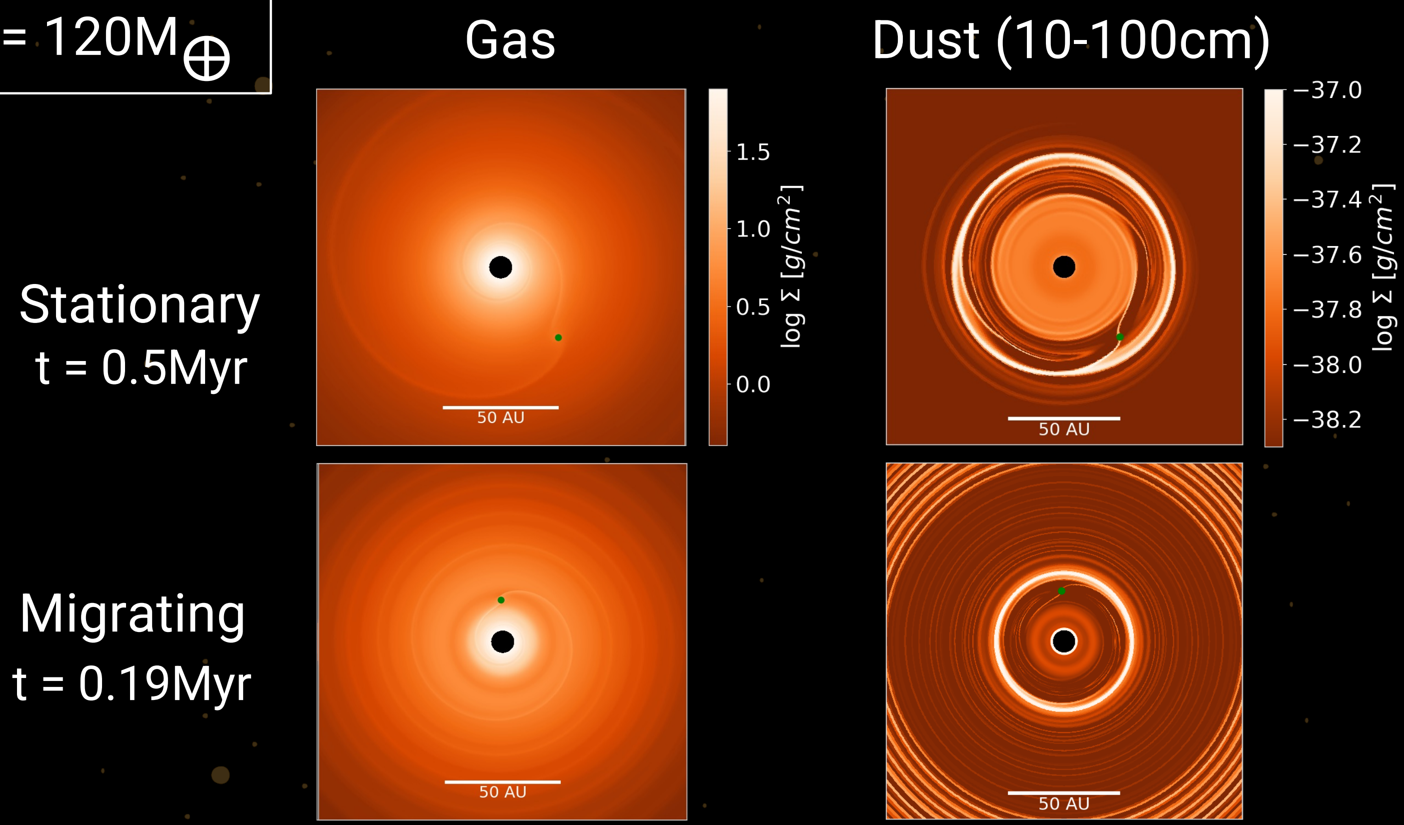
Migrating planet moves further into regime 2, traps more dust (~3 times dust mass).

Higher mass planets migrate quicker, migration outpaces the inwards drift of large particles.

Some, larger grains are unable to keep up with ring.

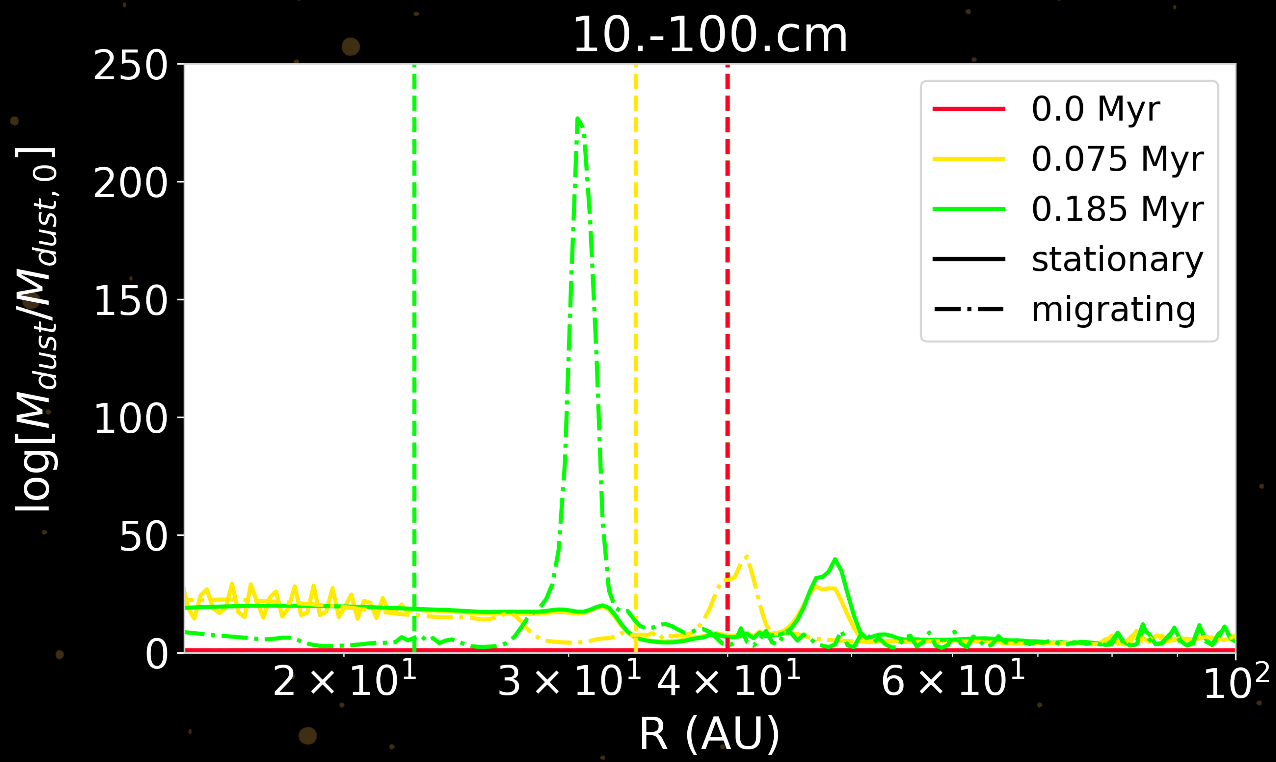
Regime 2 → 3: Weak gap

$M_p = 120 M_\oplus$



Strong ring formed in both cases, slight gap forming in migrating model.

Regime 2 → 3: Weak gap



Migrating planet traps ~4-5 times dust in ring by 0.19Myr.

Same effect as $60M_\oplus$ planet but stronger, and likely to become more pronounced over time (peak in stationary model does not grow significantly by 0.5Myr).

Regime 3: Gap formation

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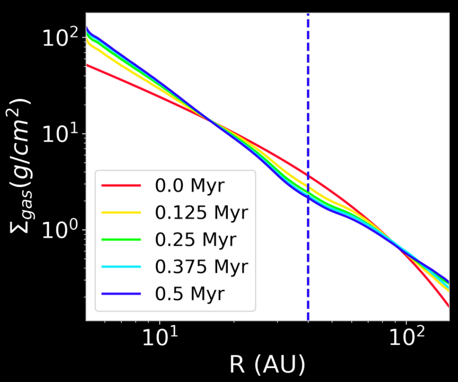
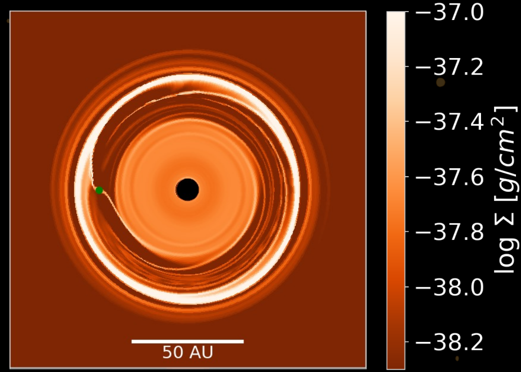
t=0.5Myr
$M_p = 160 M_\oplus$

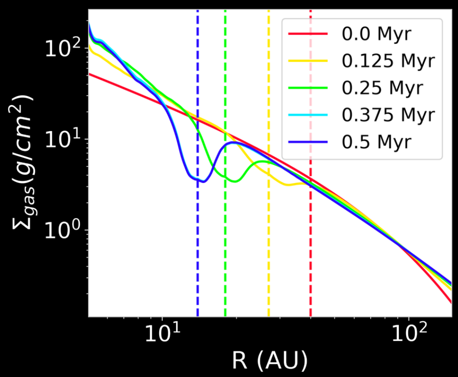
Gas | Dust (10-100cm)

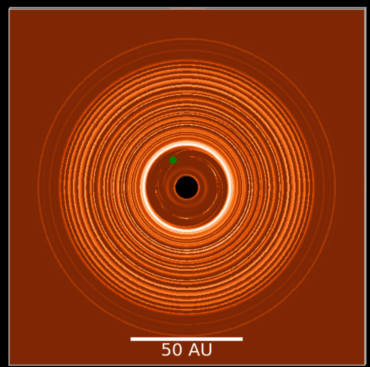
Stationary





Migrating

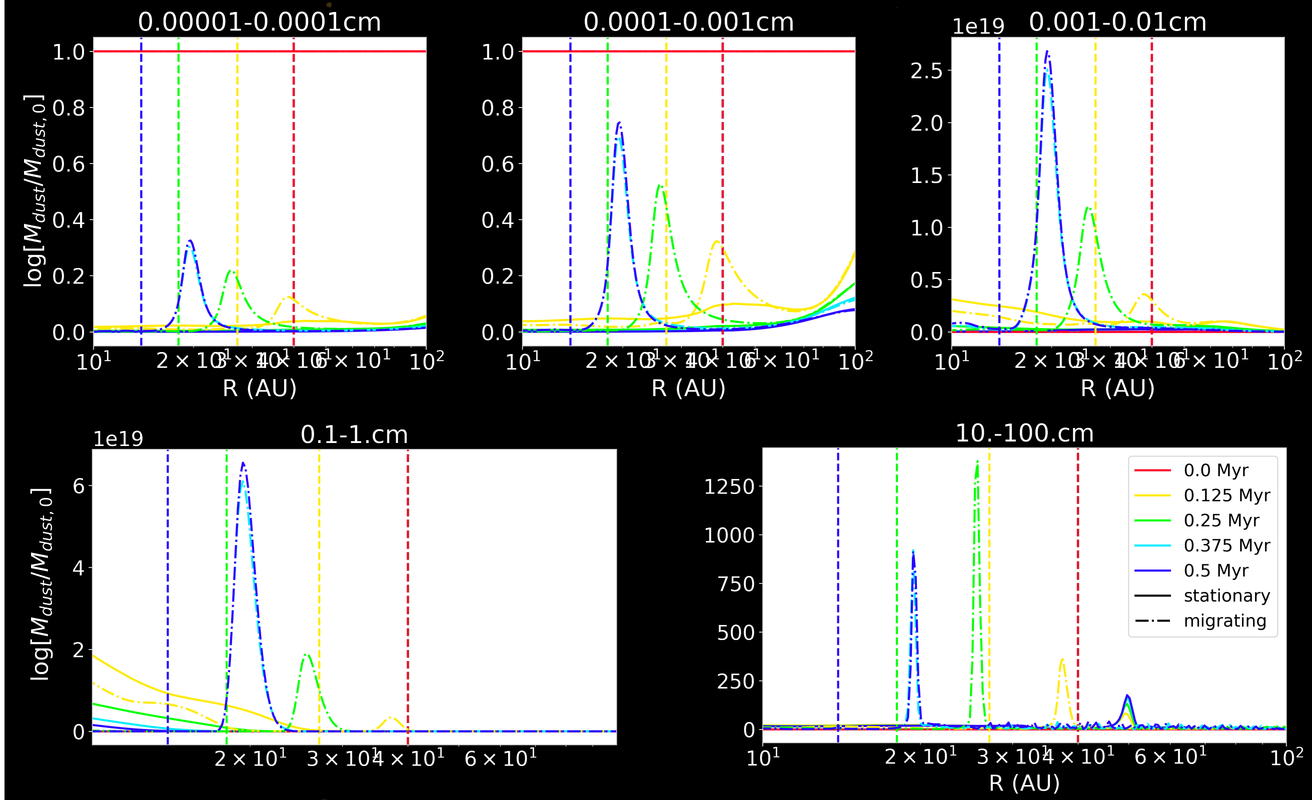




Strong ring in both cases, as expected.

Lack of visible gap in gas due to low resolution of model.

Regime 3: Gap formation



Migrating planet ring peak grows then drops, only in 10-100cm bin.

Material fragmenting more?

Summary & Conclusions

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Migrating planets affect a disc in different ways, depending on:

- ⭐ The planet mass and location – how strongly does it perturb the disc?
- ⭐ The St of grains in a dust trap, which changes as the ring migrates
- ⭐ The migration rate vs drift rate of grains in the dust trap

<u>Future & Ongoing Work</u>

- ❑ Does a migrating planet affect ring widths? (ongoing work with Ralph)
- ❑ How much mass is contained in rings/what kinds of planets can we form?
- ❑ Are there any observational signatures of the mechanisms at play?

Thank you for your time ☺