How Planetary Migration Influences Planetesimal Growth

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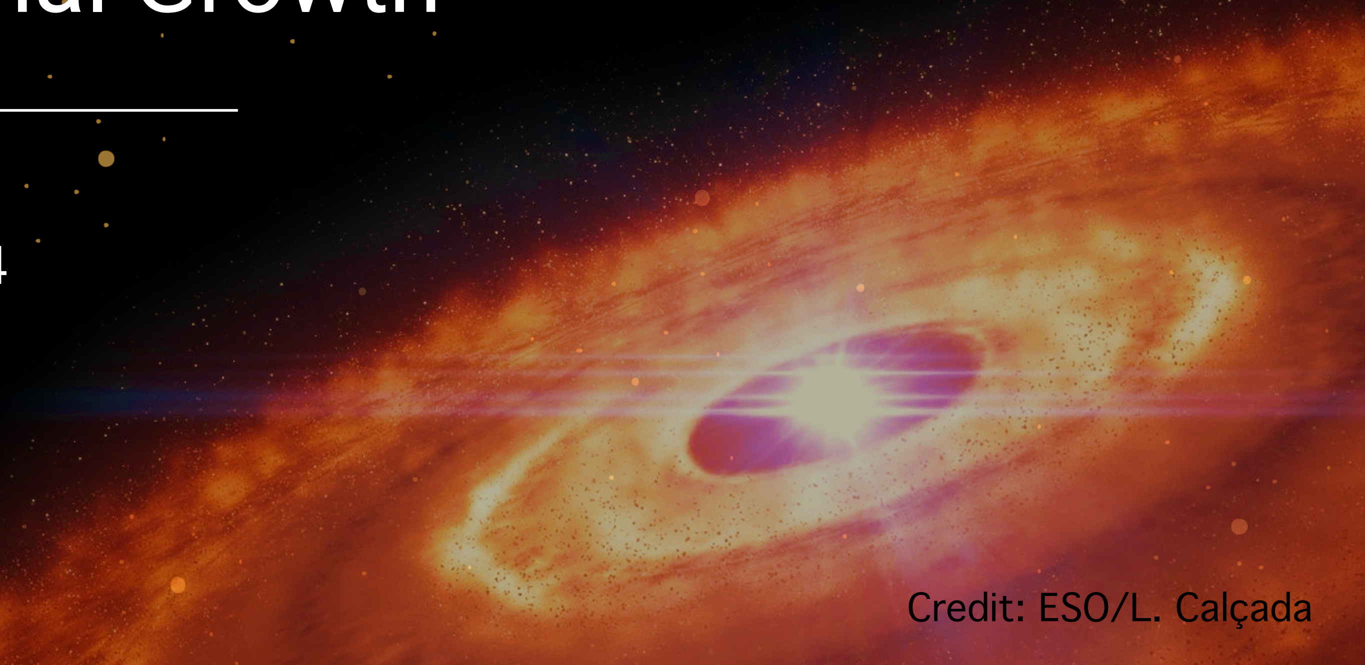
Royal Astronomical Society



Credit: ESO/L. Calçada

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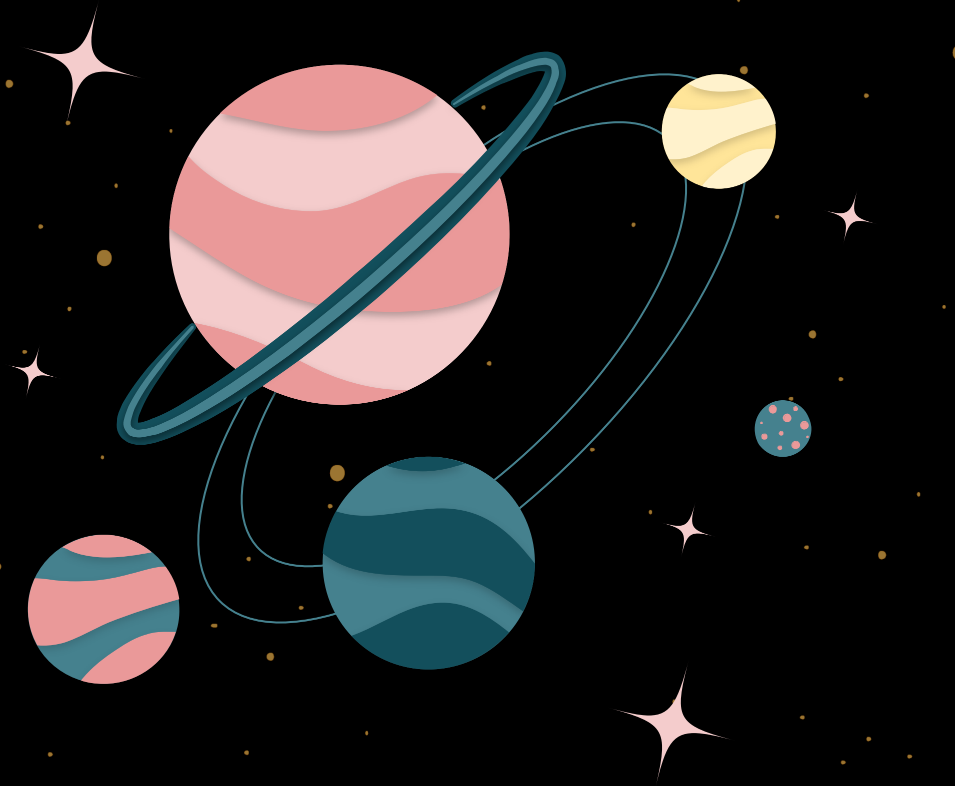
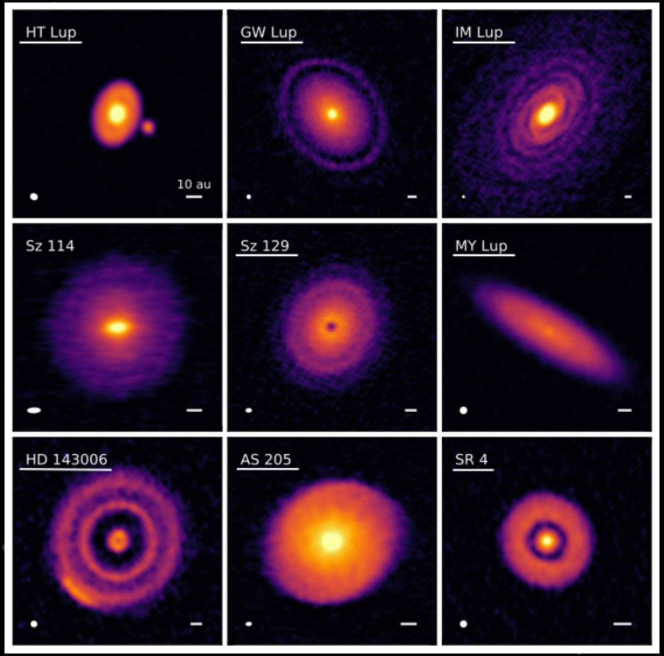
Background & Motivation



Observations of Discs

- Observed rings & gaps may indicate the presence of an embedded planet.
- Rings comprise regions of enhanced dust density i.e. potential sites for planetesimal formation.
- ~800 multi-planet systems found – further study into how existing planets affect the formation of additional planets is required.



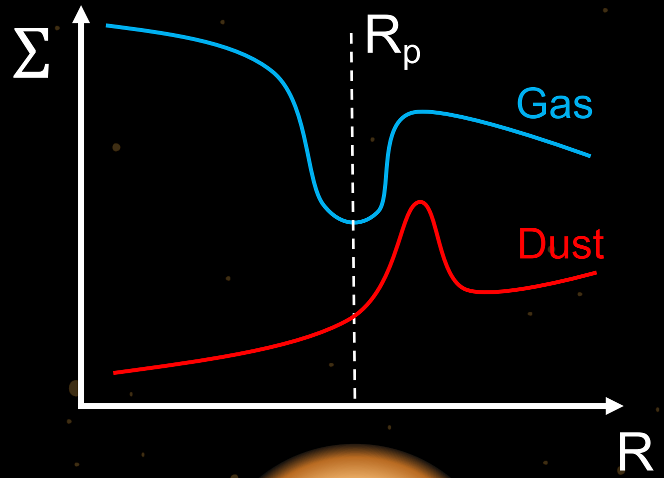
Source: ALMA Partnership, 2015

Gap & Ring Formation

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.



KEY QUESTIONS

How does planetary migration influence disc substructures?

How does this affect dust growth and planetetesimal formation?

HYPOTHESIS

Migration encourages substructure formation and growth

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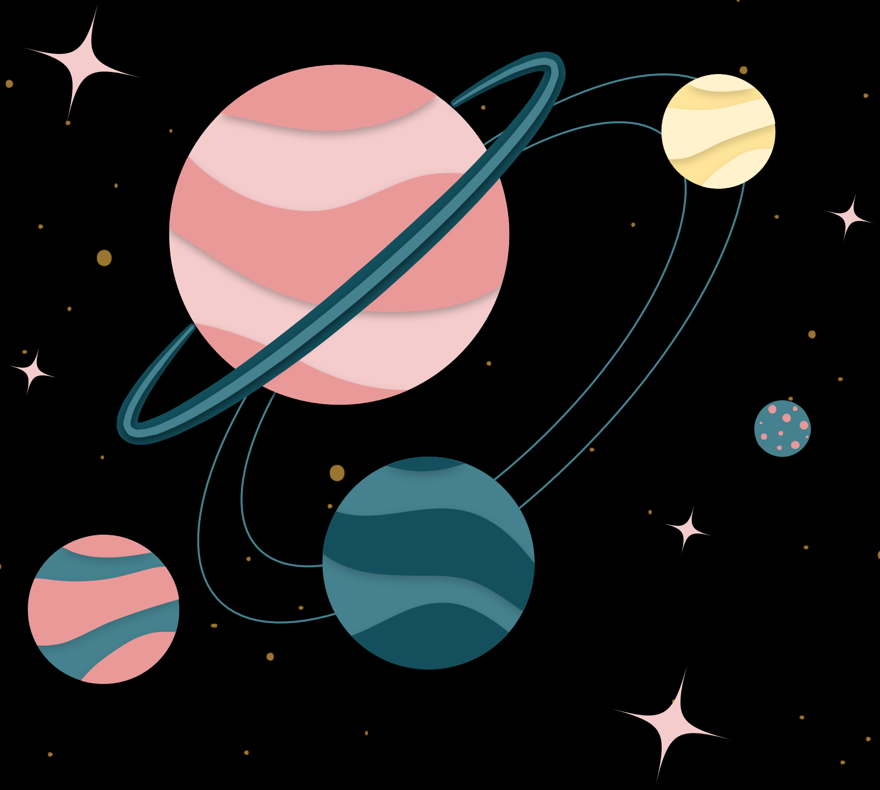
Methods



Mass Regimes

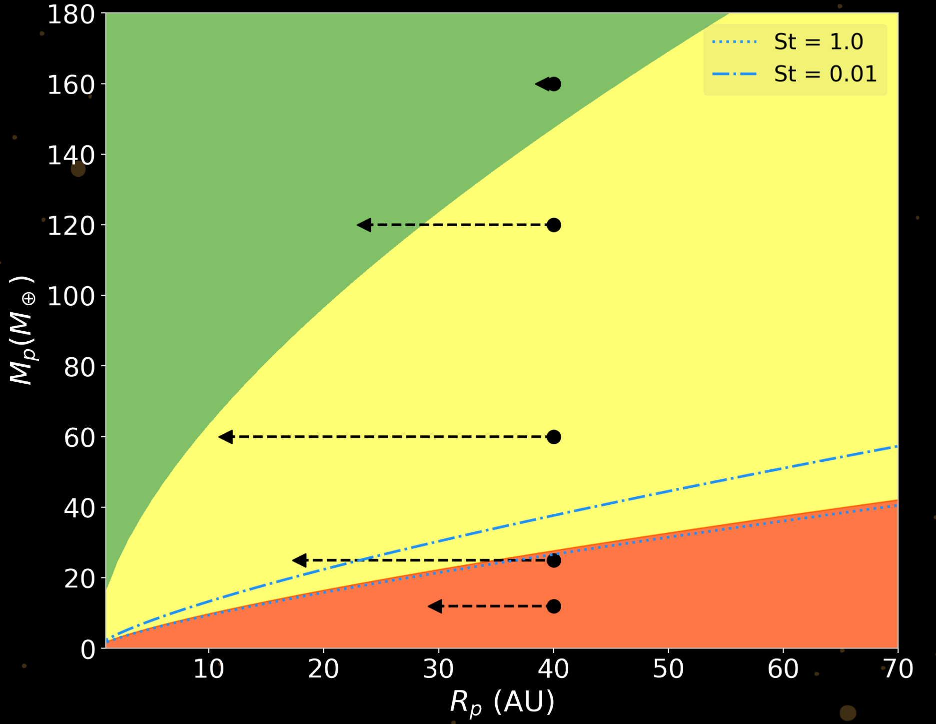
$M_P < M_{iso}$ $M_P < M_{gap}$	$M_{iso} < M_P < M_{gap}$	$M_P > M_{iso}$ $M_P > M_{gap}$
Planet not massive enough to perturb gas or dust	Planet massive enough to form dust ring but not gas gap	Planet massive enough to form gas gap and dust ring

$M_{iso} \simeq 25M_{\oplus}$, $M_{gap} \simeq 140M_{\oplus}$ for planet at 40AU in $0.01M_{\odot}$ disc (around a $1M_{\odot}$ star)

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 $(r + \phi)$ hydro models of dust advection and growth.

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

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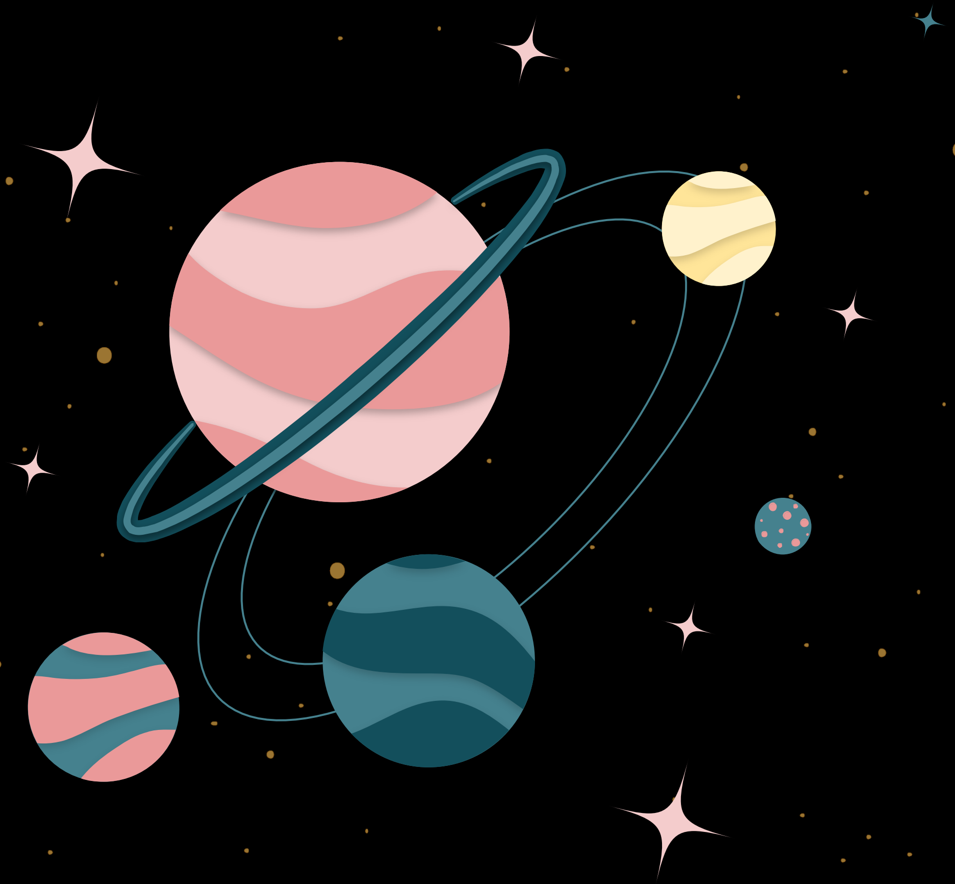
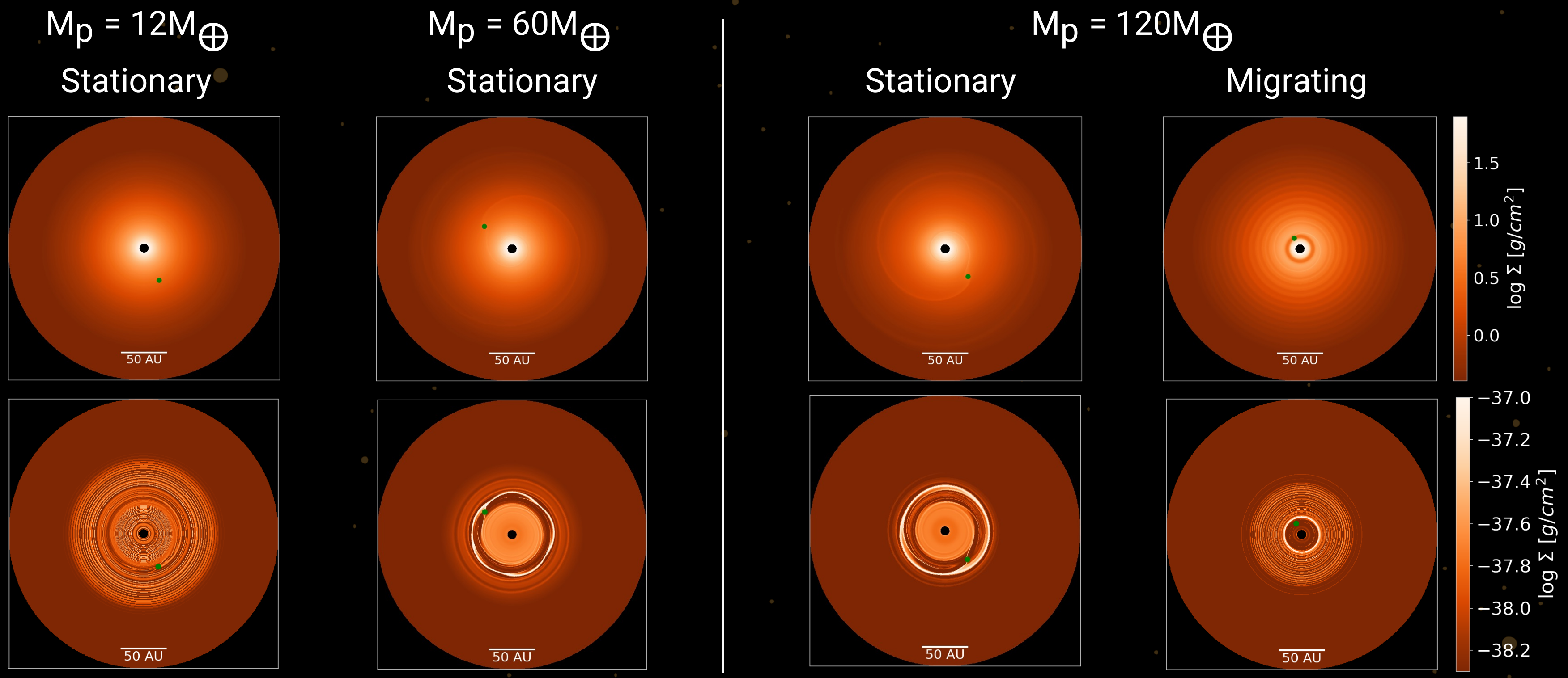
Results & Analysis



Migrating planets form rings more easily...



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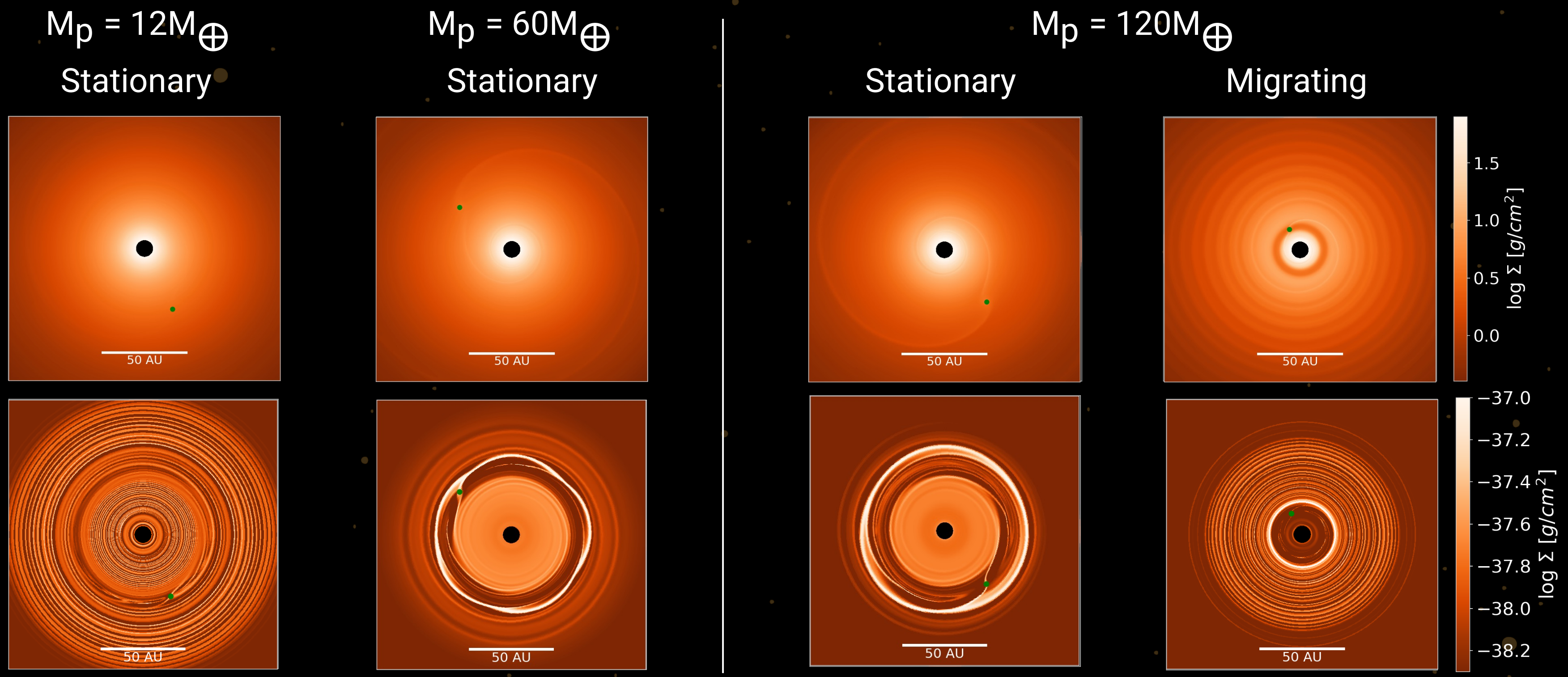

Migrating planets form rings more easily...

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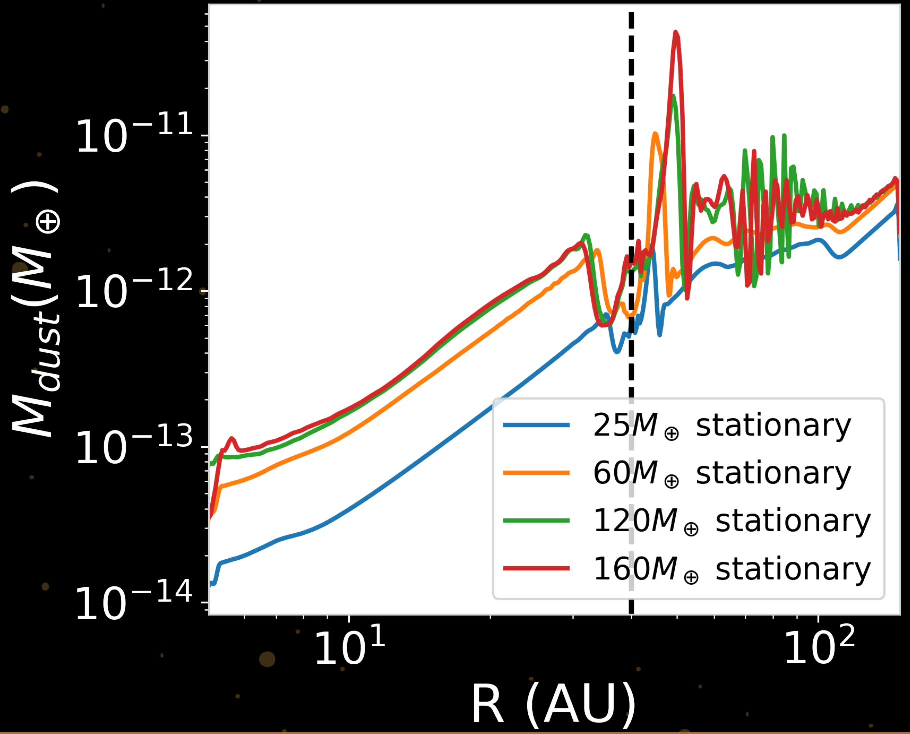

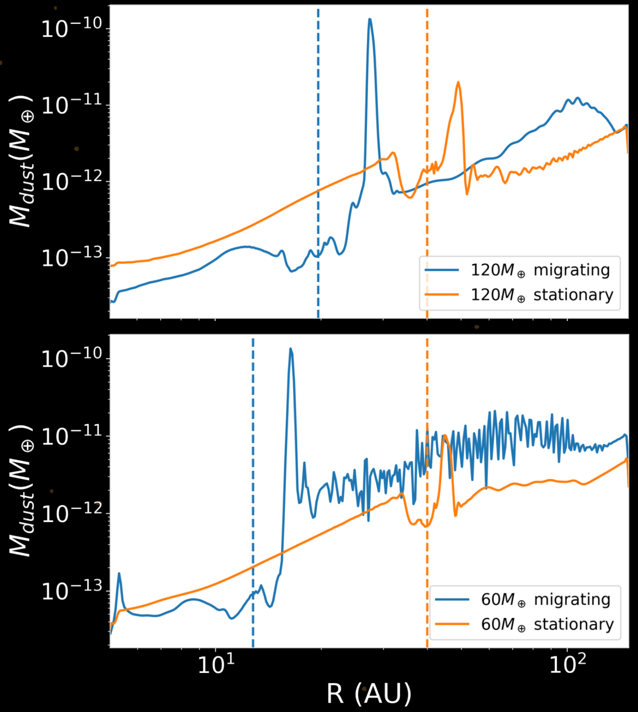

...except when at odds with other mechanisms

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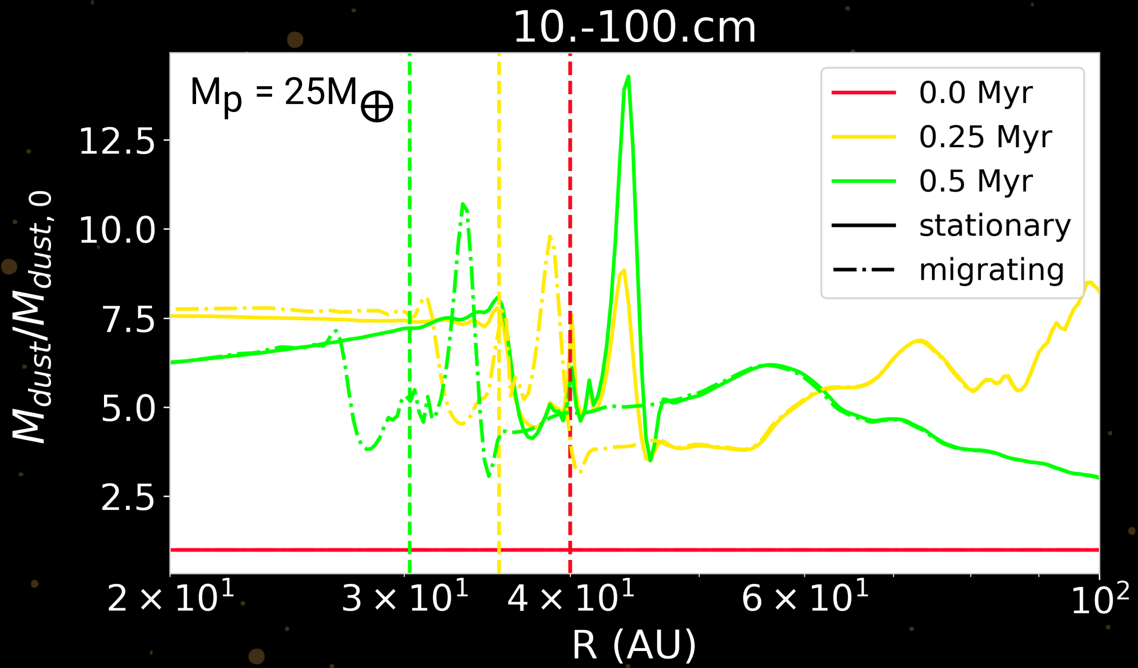
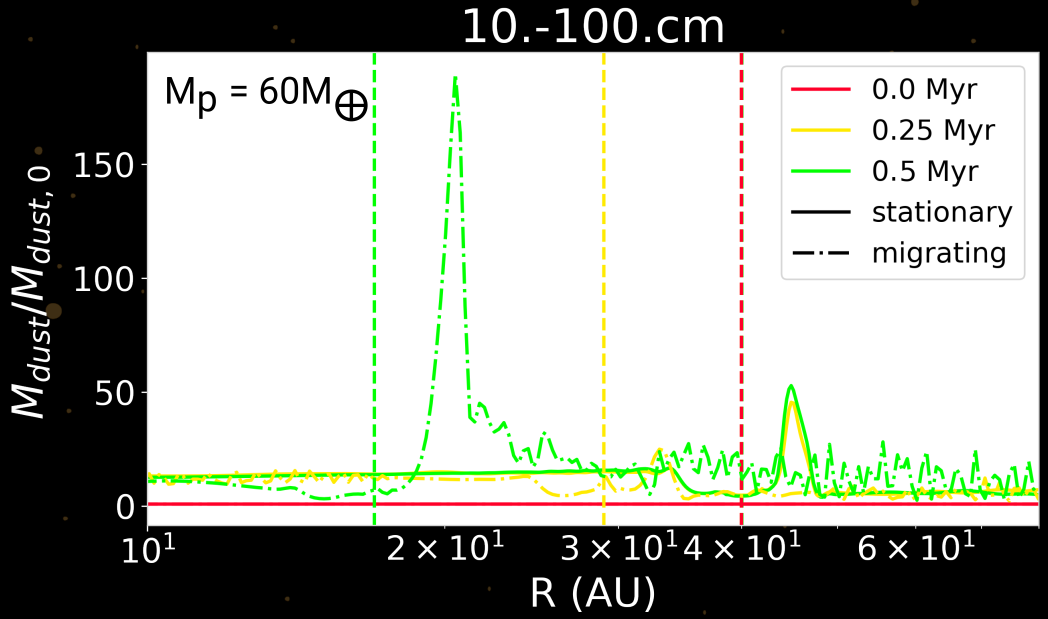
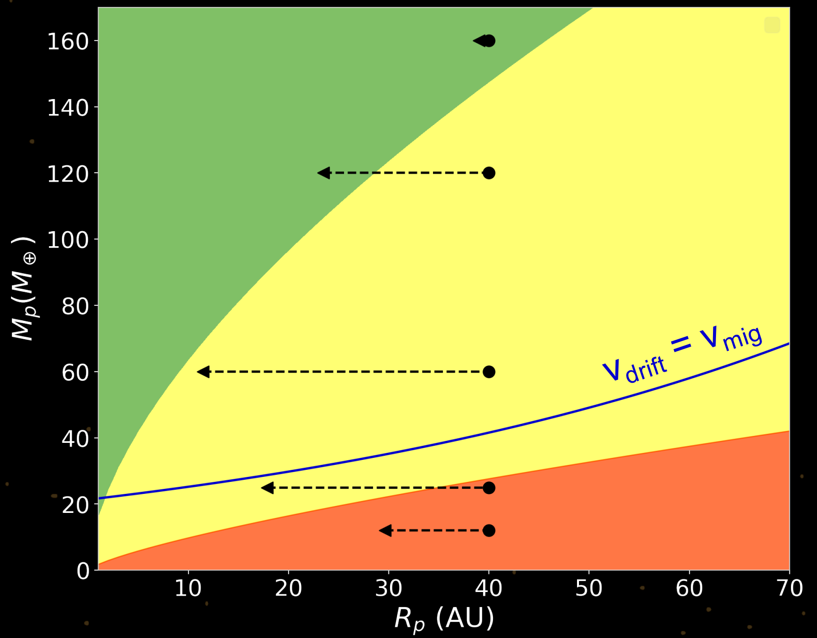


Dust pile-up due to pebble isolation competes with migration.

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

...except when at odds with other mechanisms





For higher M_p, migration outpaces the inwards drift of large particles

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

Take-home message

Migrating planets are more favourable for dust growth and ring formation but migrating rings are not!

BACKUP SLIDES

Additional Results

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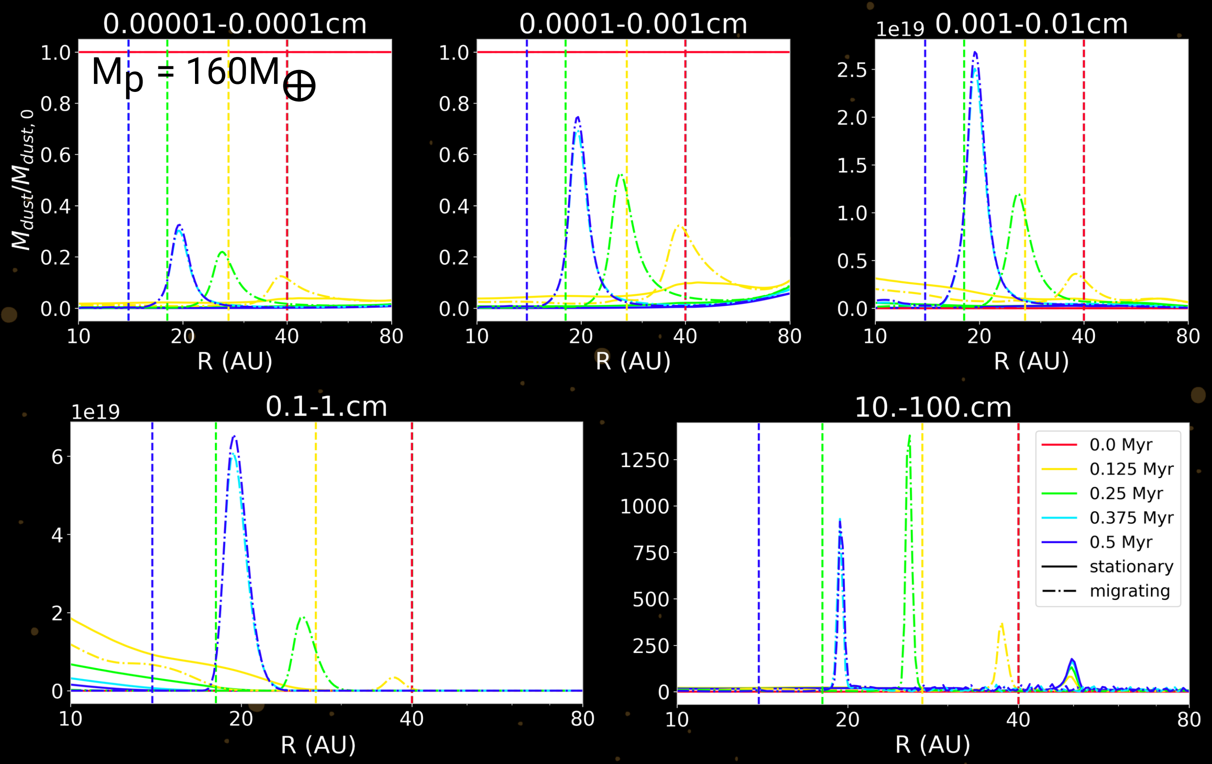

Fragmentation rate increases for a type II migrating planet (gap-opening regime)

Loss of mass in the largest size bins

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).

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

$H/R = 0.05$ $\alpha = 10^{-3}$