Pebble drift and planetesimal formation in protoplanetary disks with embedded planets

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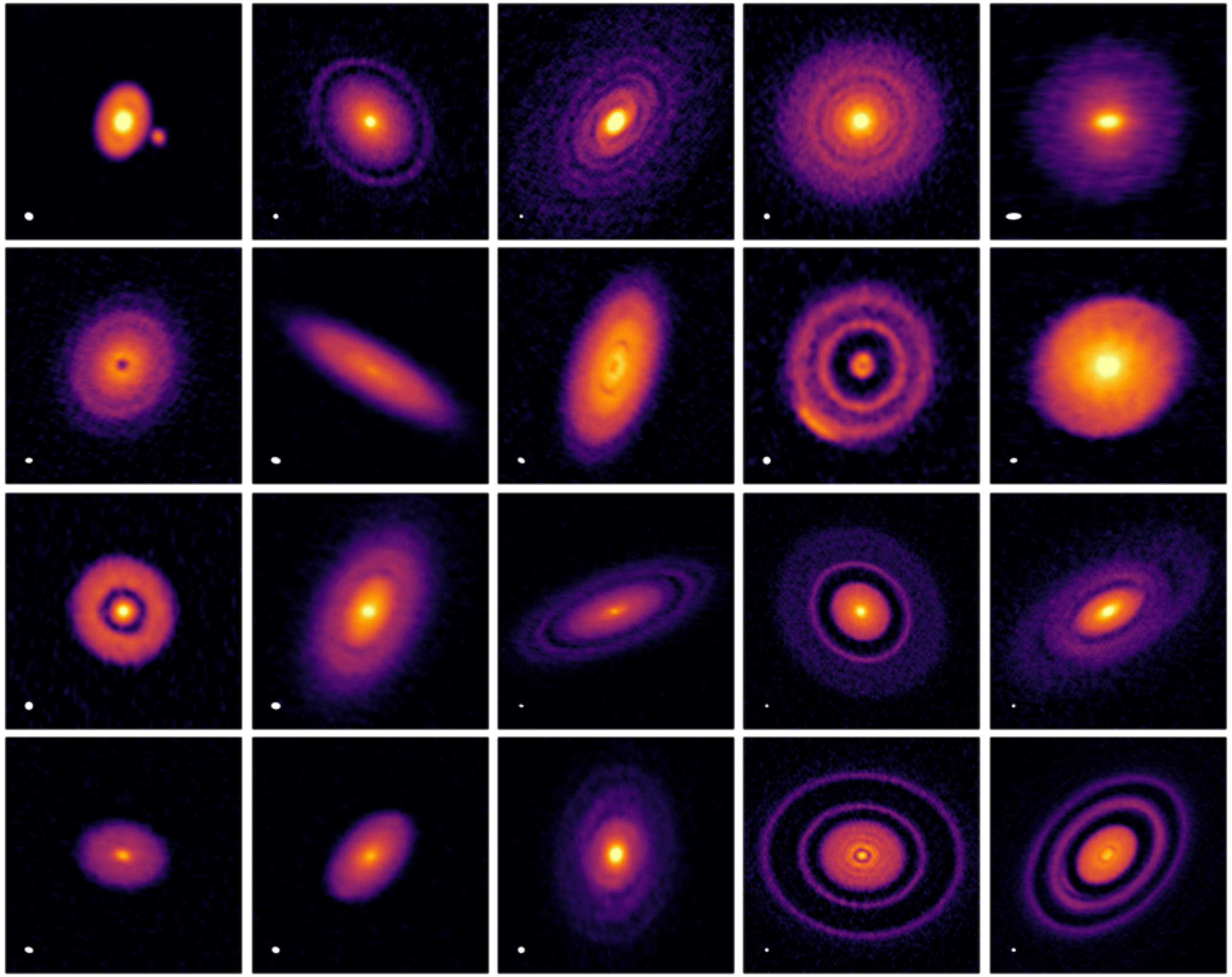
Credit: ESO/L. Calçada

DSHARP



Andrews et al. (2018)

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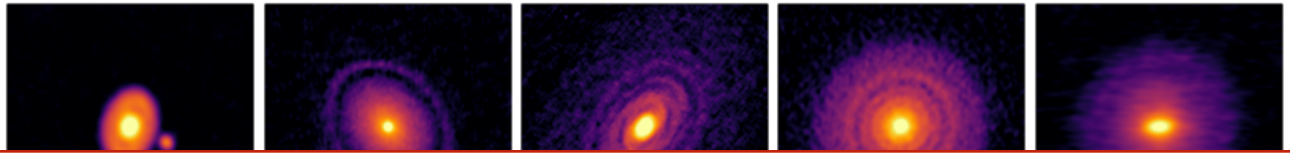
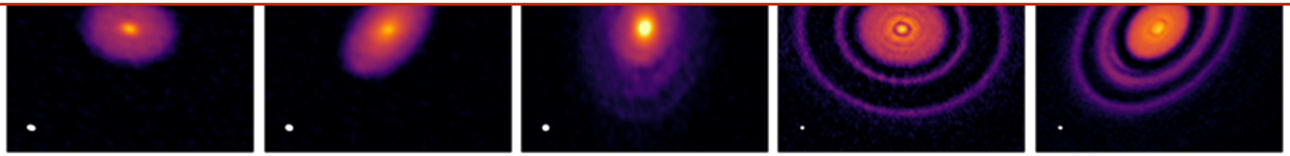


Dullemond et al. 2018:
- Dust rings consistent with dust trapping in radial pressure bumps
- Origin of pressure bumps could be forming planets

Zhang et al. 2018:
- Simulations of planet-disk interactions produce dust continuum emission maps that resembles observations

➢ Dust trapping at the edges of planetary gaps
➢ Likely site for planetesimal formation via the streaming instability



Andrews et al. (2018)

Main questions to answer

1) Do planetesimals form at the edges of planetary gaps?

2) How efficient is this mechanism?

3) What does the distribution of pebbles look like?

4) How does this compare with observations?

Main questions to answer

1) Do planetesimals form at the edges of planetary gaps?

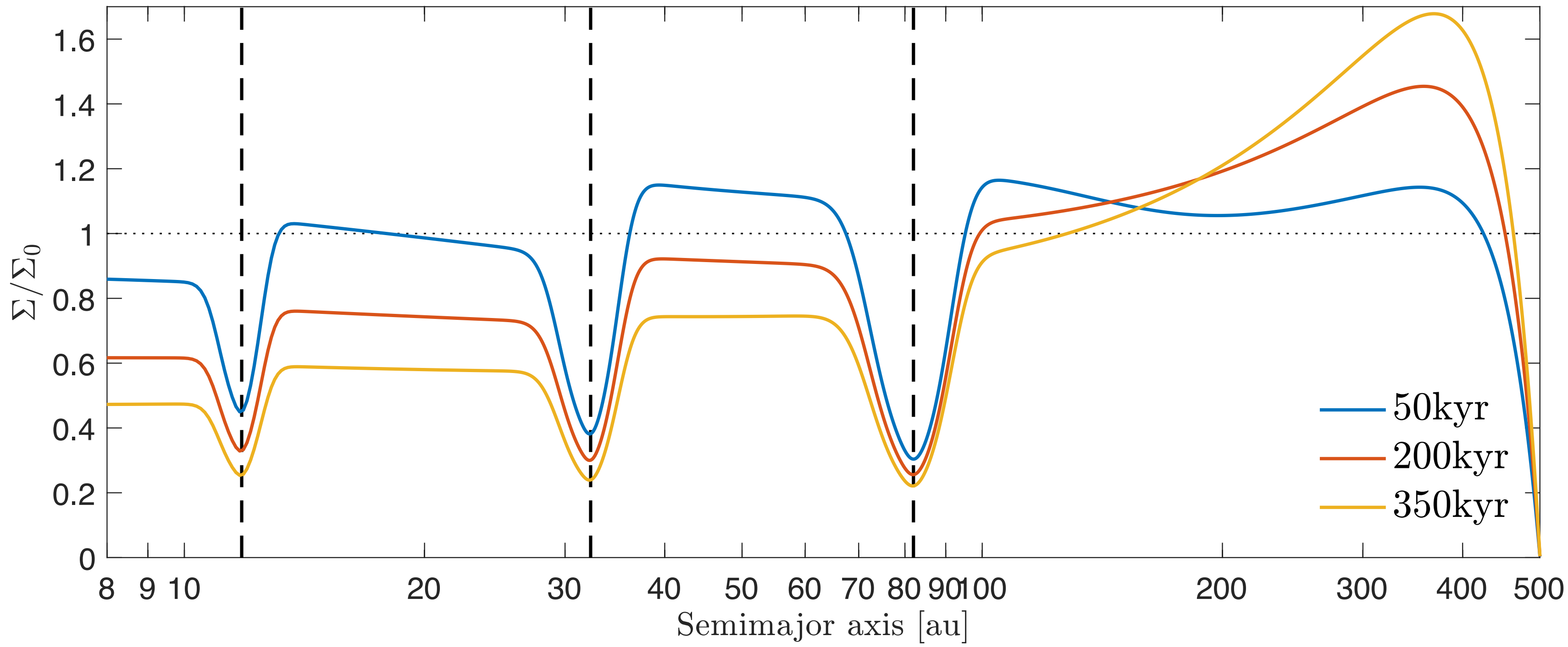
Talk by Joanna Drazkowska:
Indirect evidence of ongoing planetesimal formation in the dust ring of HD 163296

Talk by Jake Simon:
3D local shearing box simulations → planetesimals form at pressure bumps

SIMULATION AND MODEL SETUP

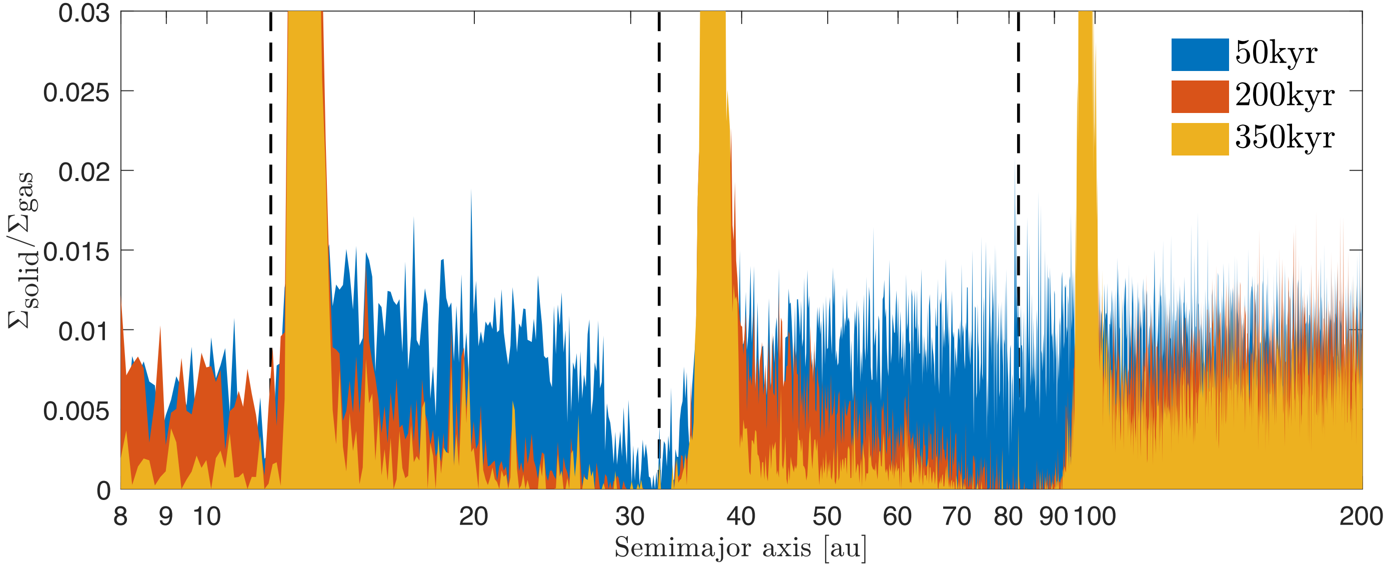
- 1D viscous evolution model (Lin & Papaloizou 1986)
- Planetary torque (D'Angelo & Lubow 2010)
- Particle drag (Nakagawa et al.1986; Guillot et al. 2014)
- Particle stirring via turbulent diffusion (Ros et al. submitted)
- Particle coagulation, max size set by bouncing barrier (Güttler et al. 2010)
- Planetesimal formation via the streaming instability (Yang et al. 2017)
- Pressure scaling (Bai & Stone 2010)
- Integration time 1 Myr

Normalized gas surface density profile – 3 planetary gaps

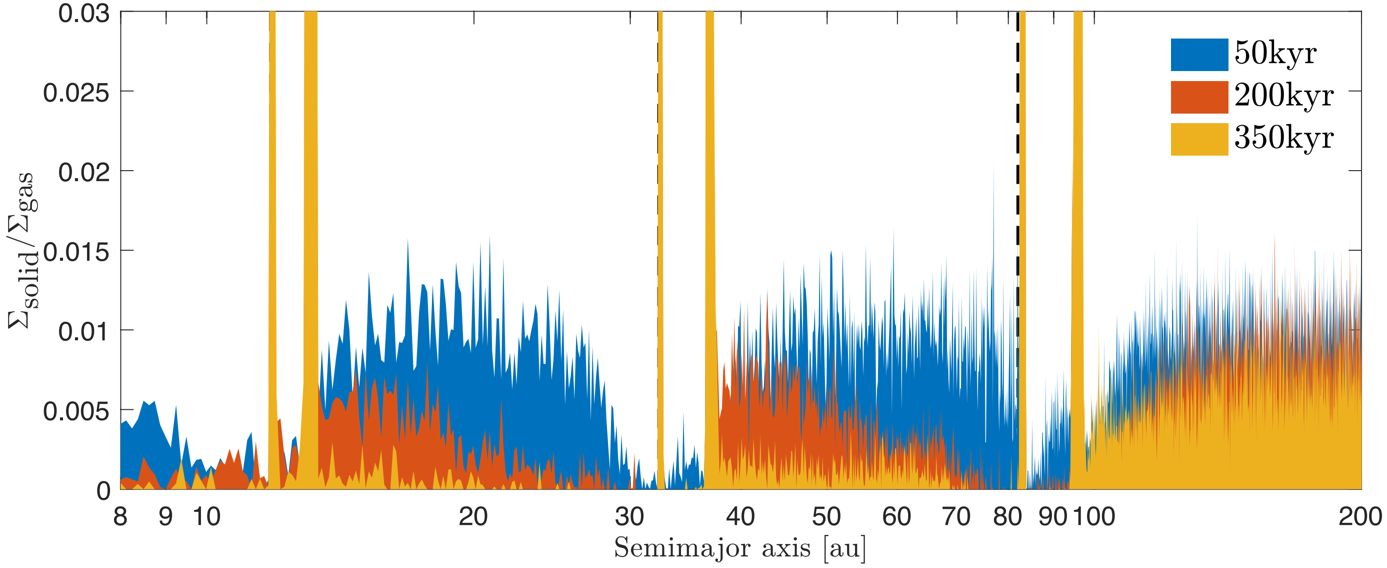


Eriksson et al. in prep.

Evolution of the solid component of the disk (dust + planetesimals)

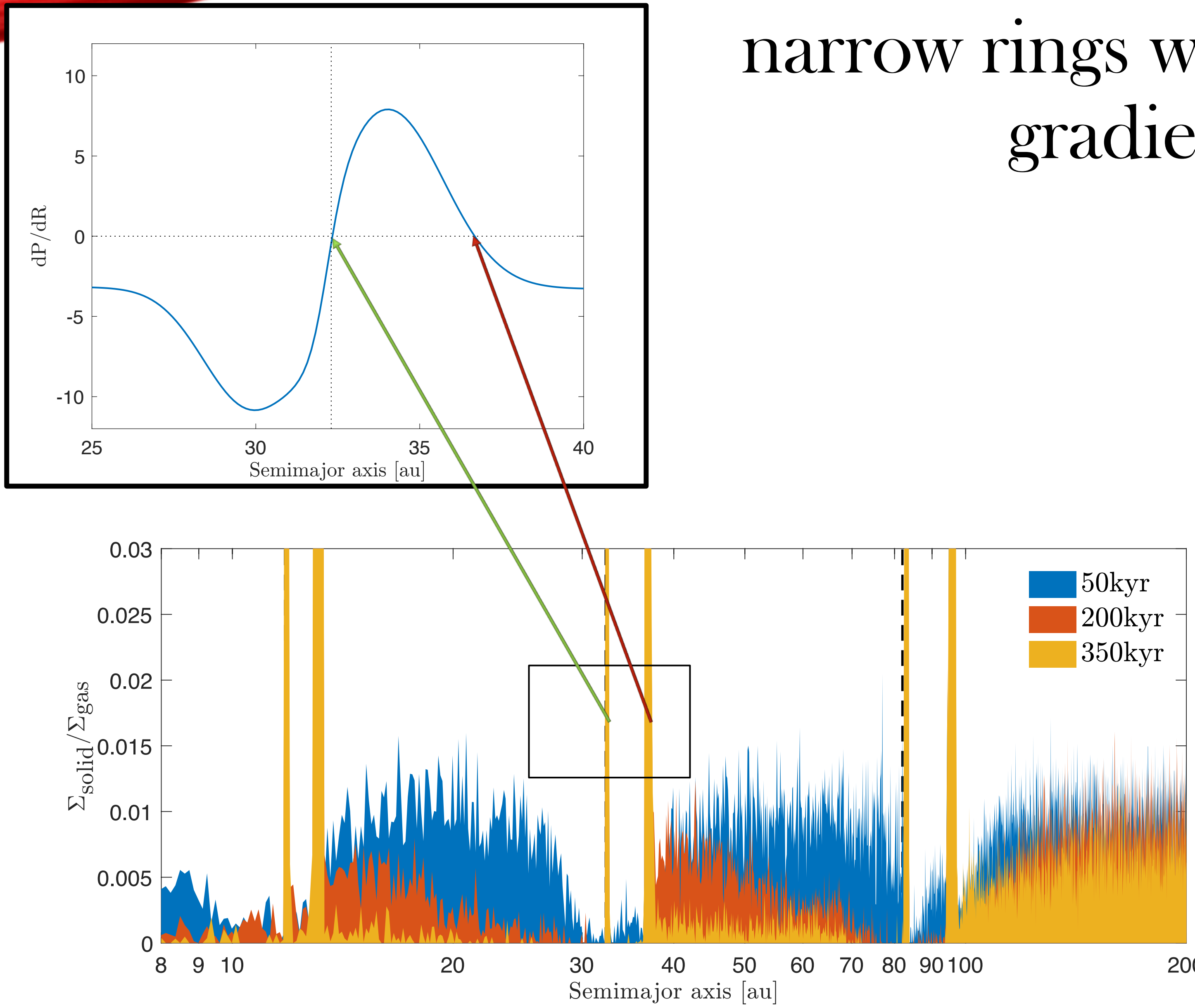


No
pressure scaling



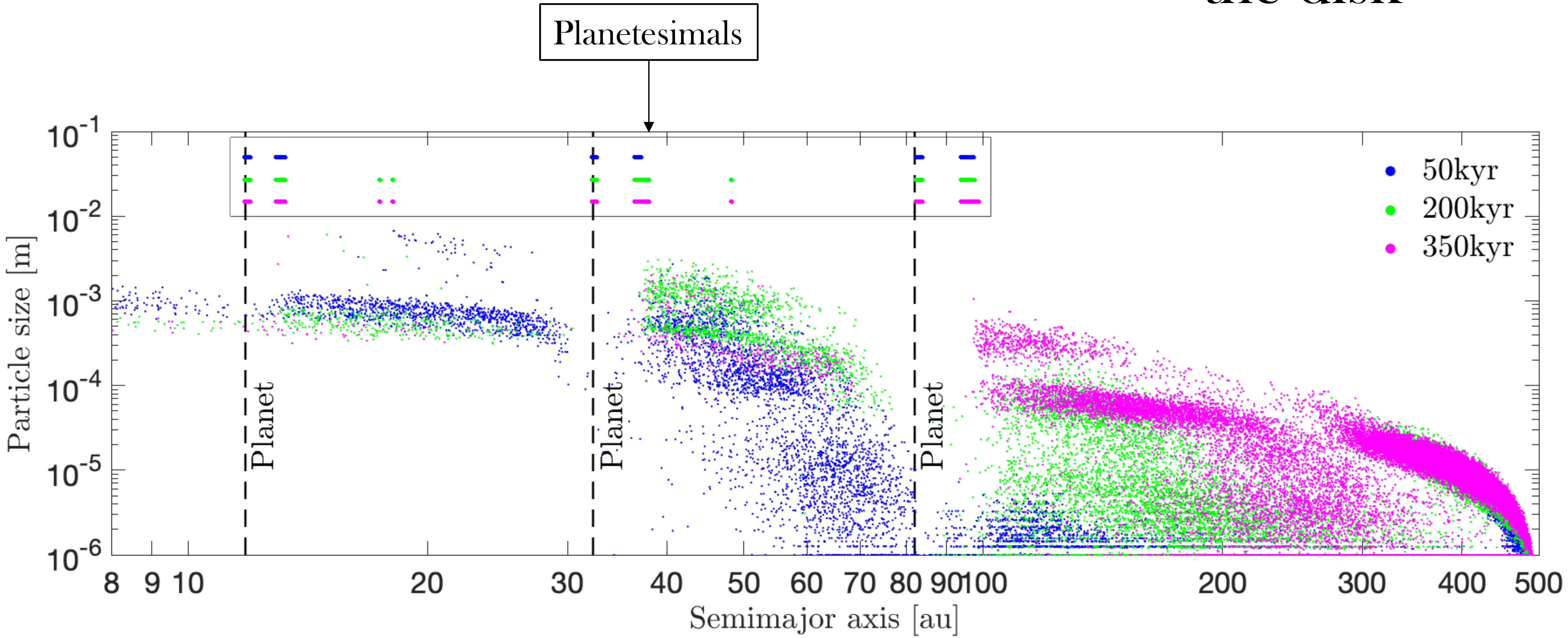
With
pressure scaling

Planetesimal formation in narrow rings where the pressure gradient is close to zero



With
pressure scaling

Size distribution of particles in the disk



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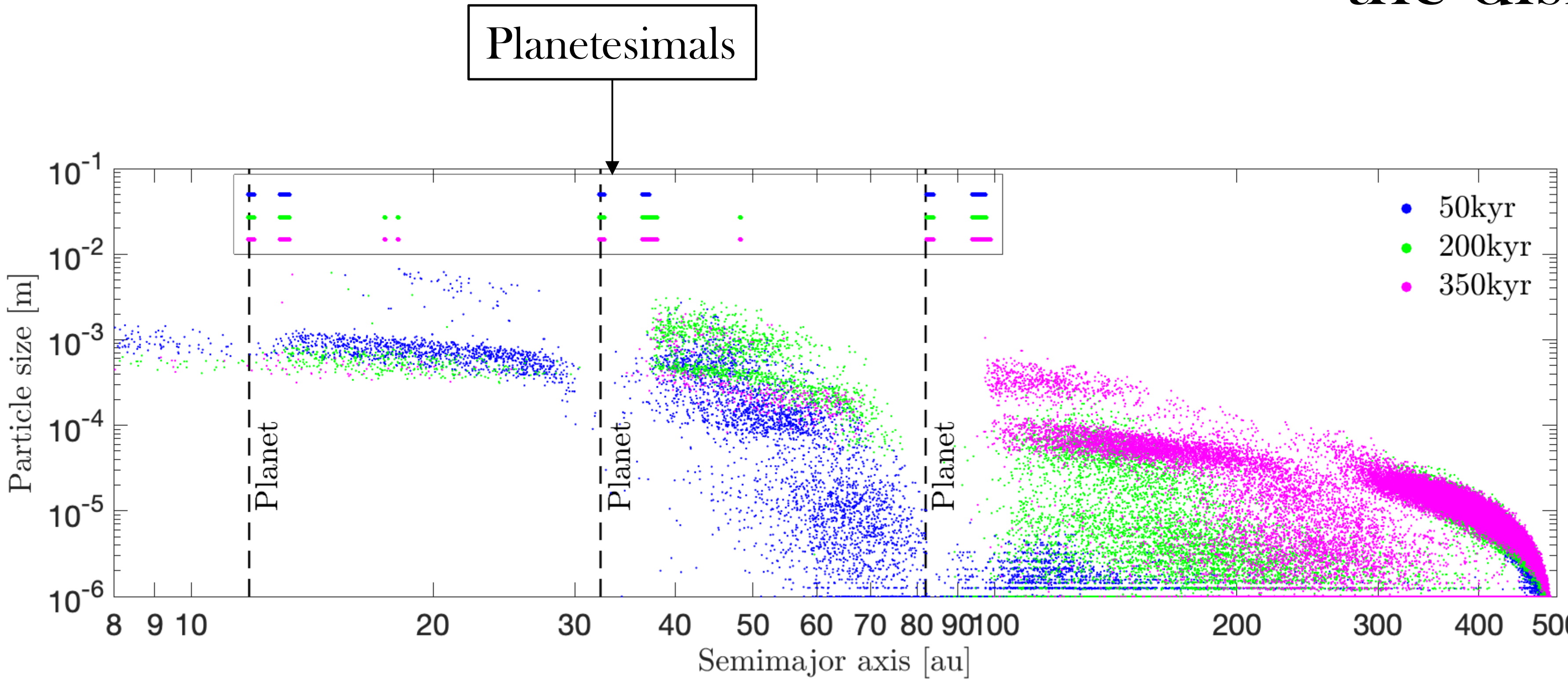
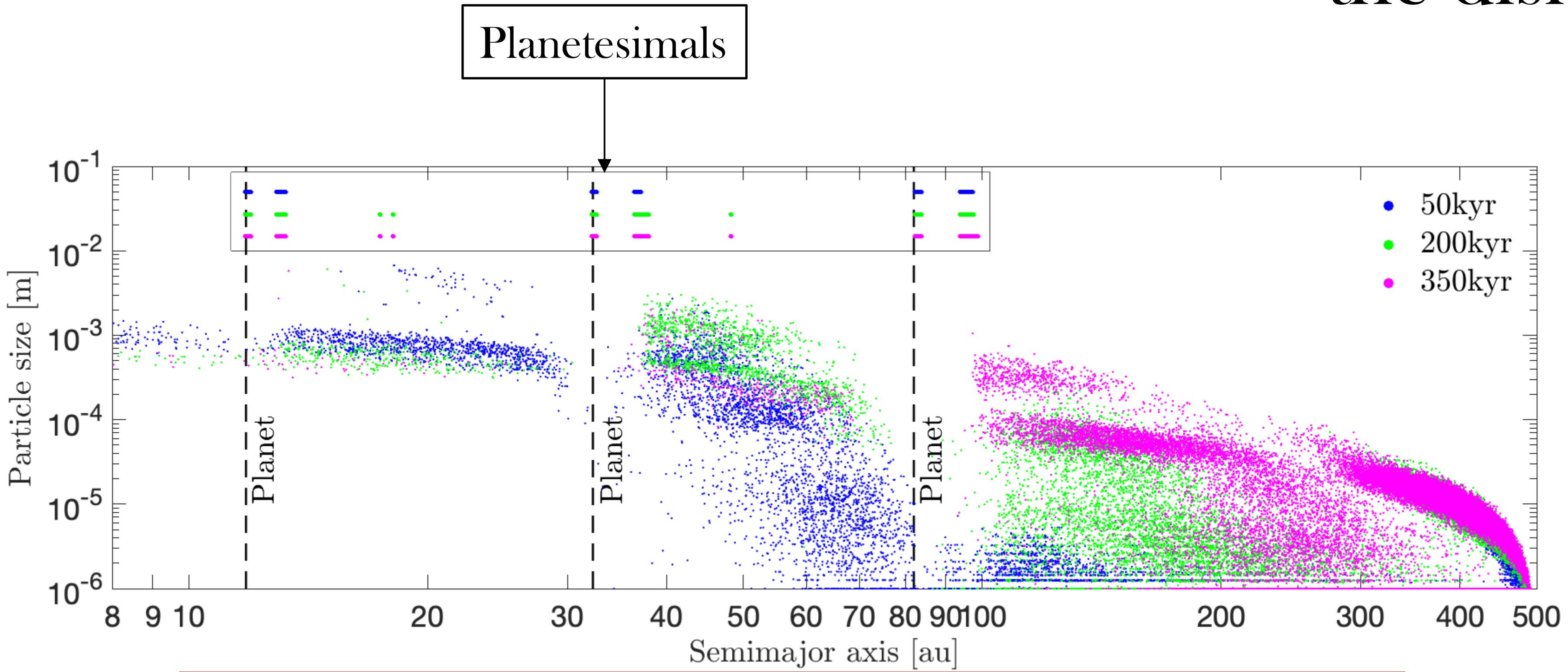


1) Do planetesimals form at the edges of planetary gaps?

- Yes

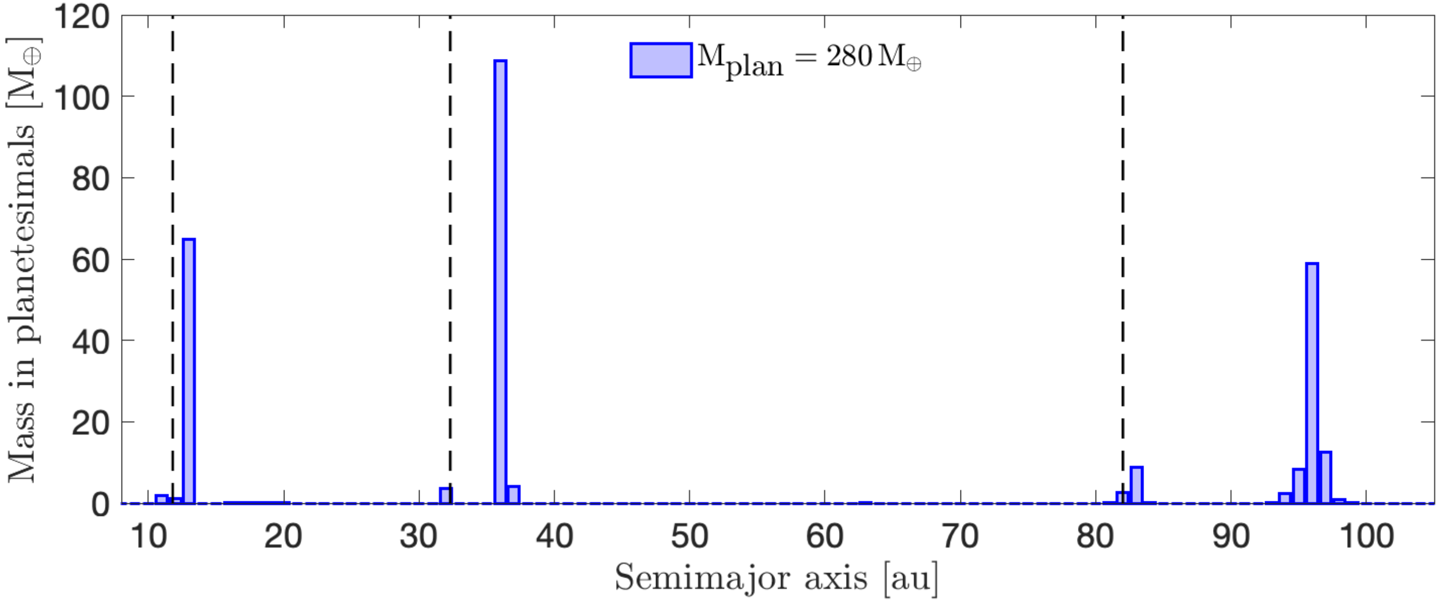
Size distribution of particles in the disk



2) How efficient is planetesimal formation at the edges of planetary gaps?

- Very efficient! Most pebbles at the gap edge are converted into planetesimals

Form 50-100 Earth masses of planetesimals in each ring



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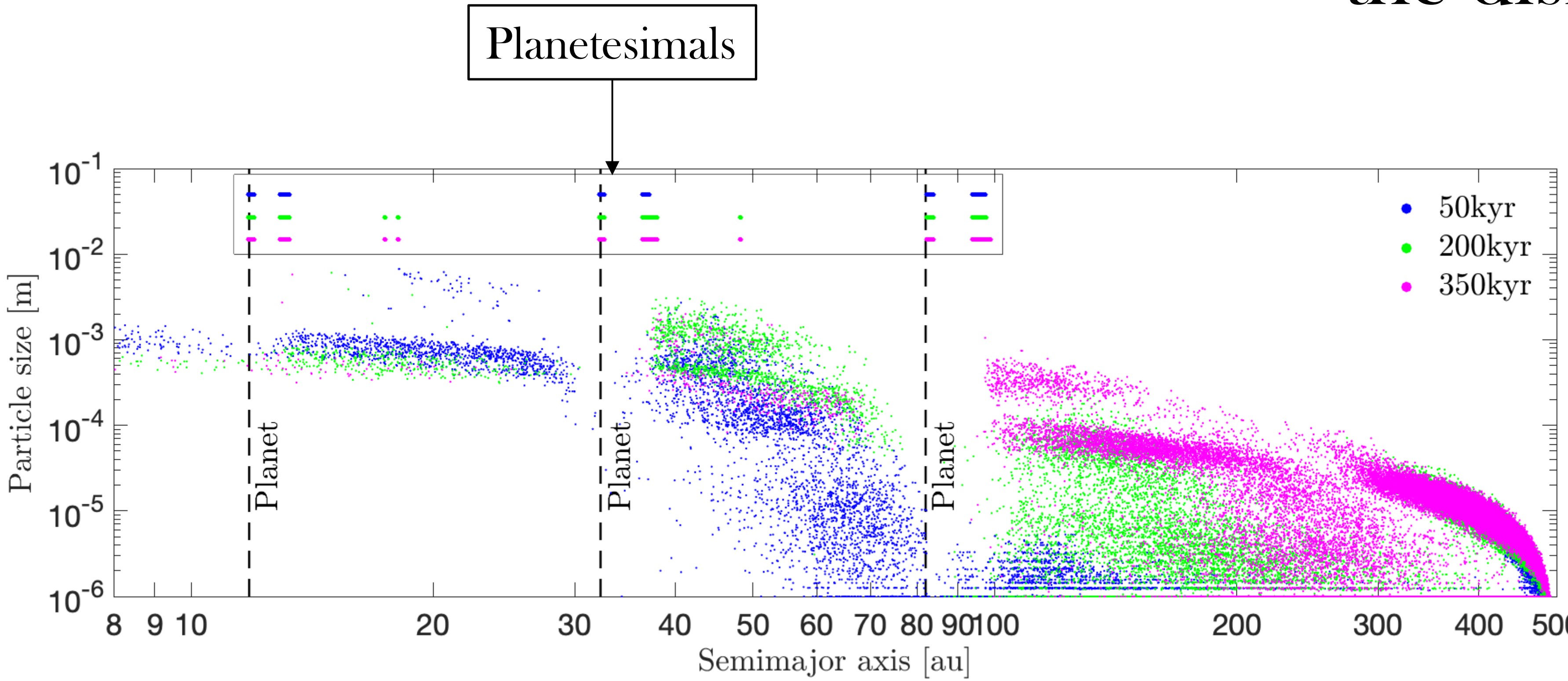
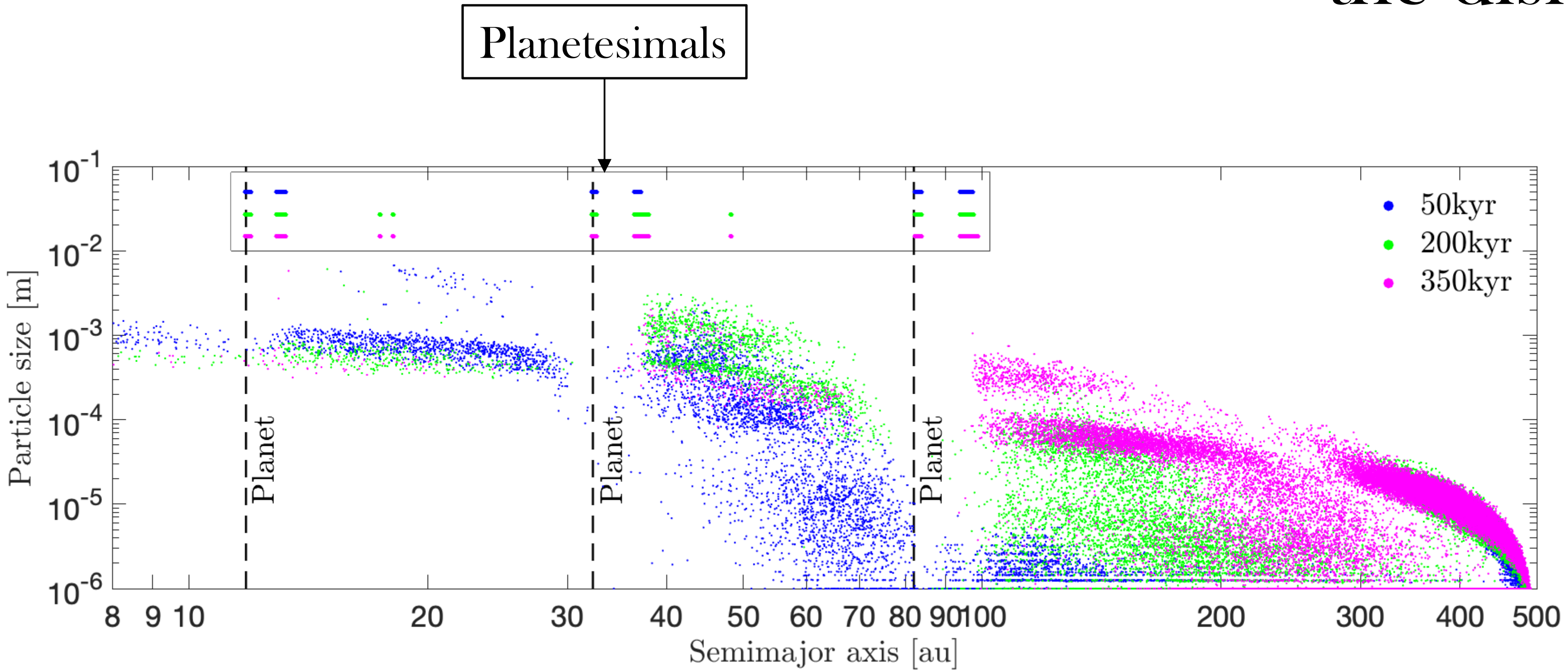


3) What does the distribution of pebbles look like?

- mm pebbles drift out of regions between planets fast
- Most pebbles are converted into planetesimals

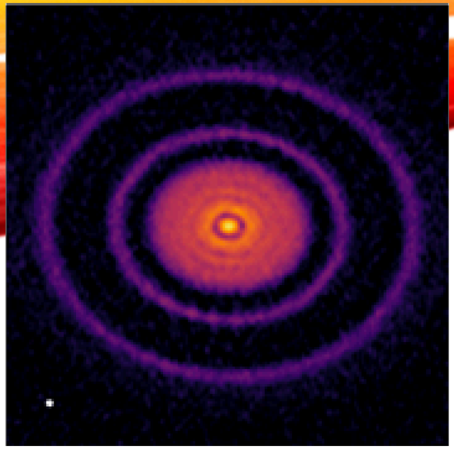
→ Almost no pebbles left interior to the outermost planet

Size distribution of particles in the disk



4) How does this compare to observations?

- Dullemond et al. (2018): Tens of Earth masses of dust in each ring
- Most observations have emission from all over the disk



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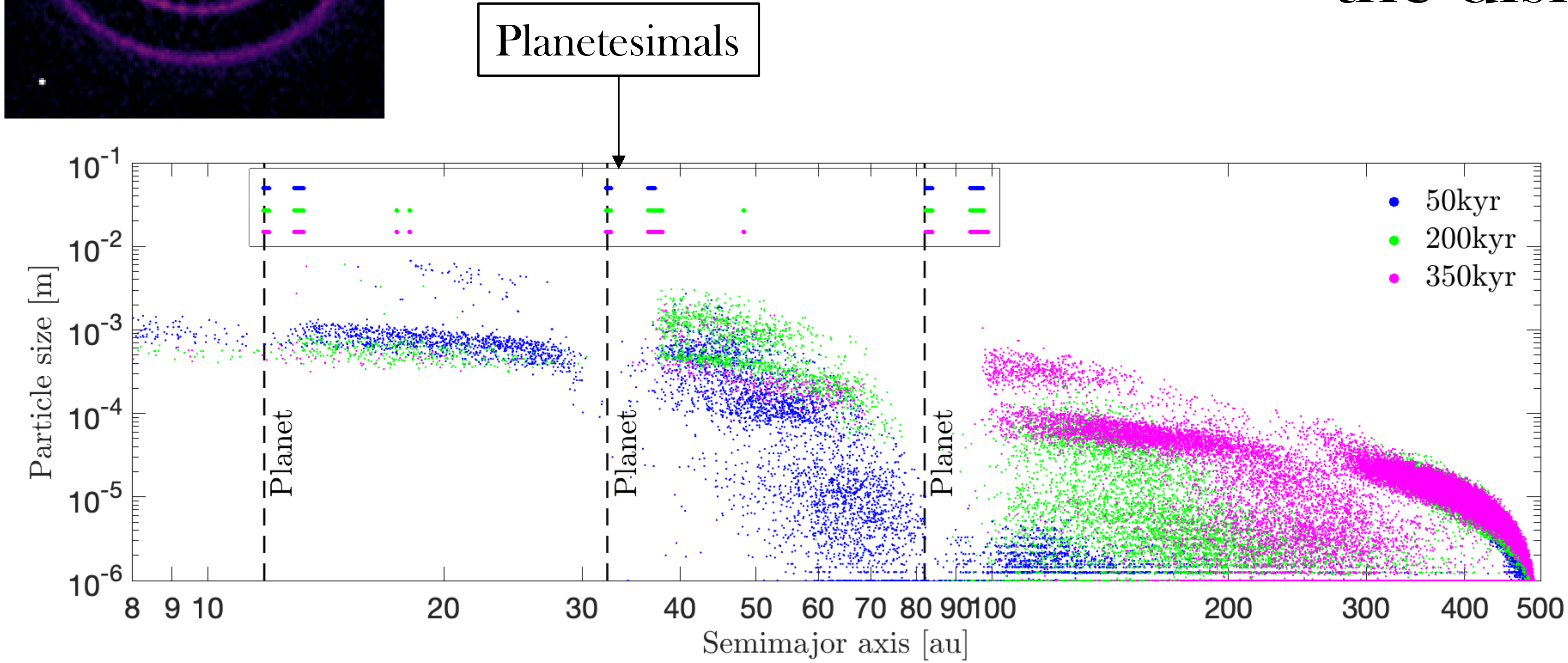

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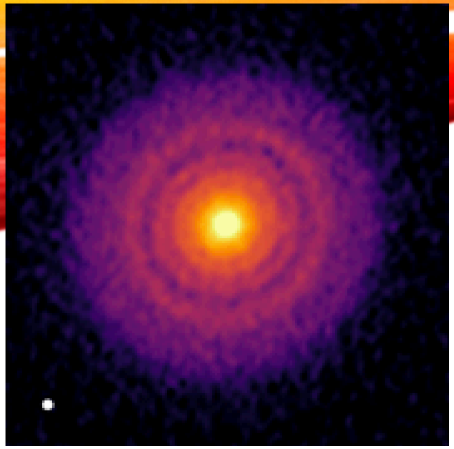

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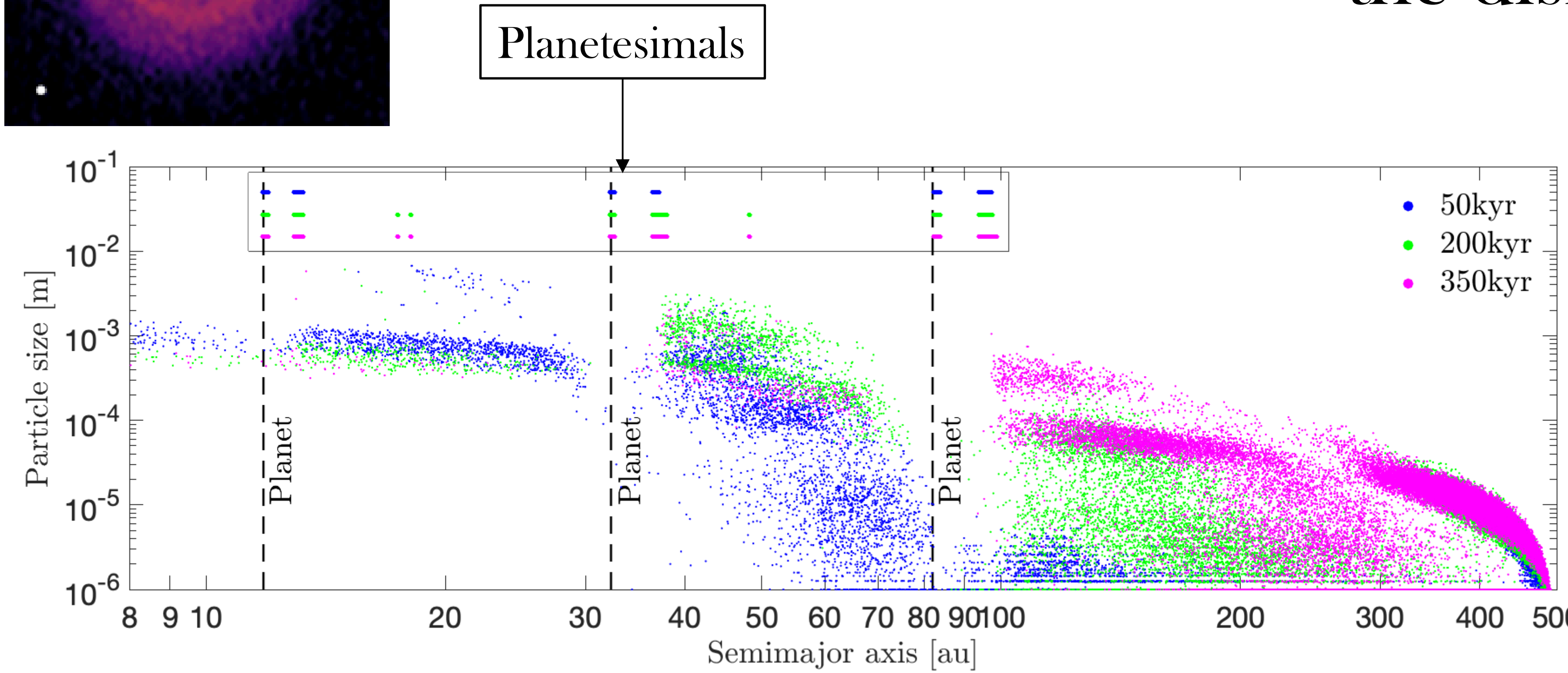

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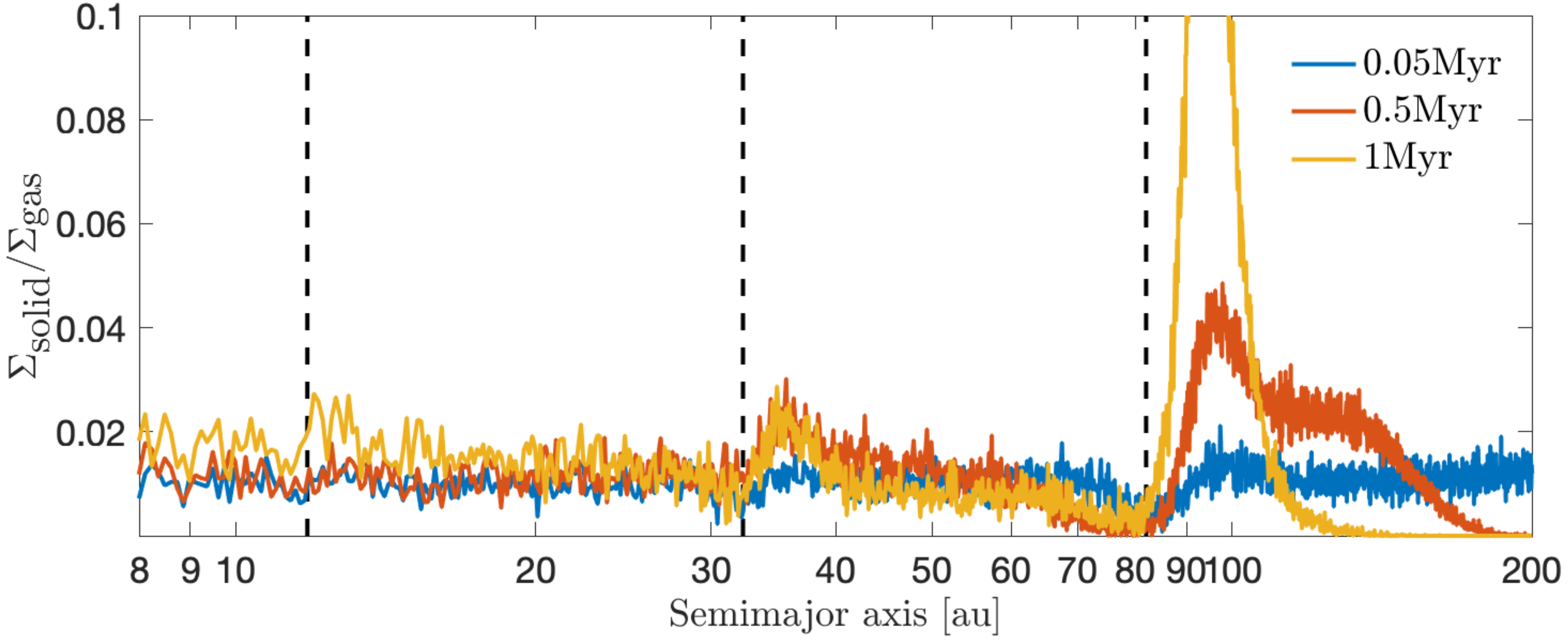
100μm-sized particles leads to slower drift and better match observations



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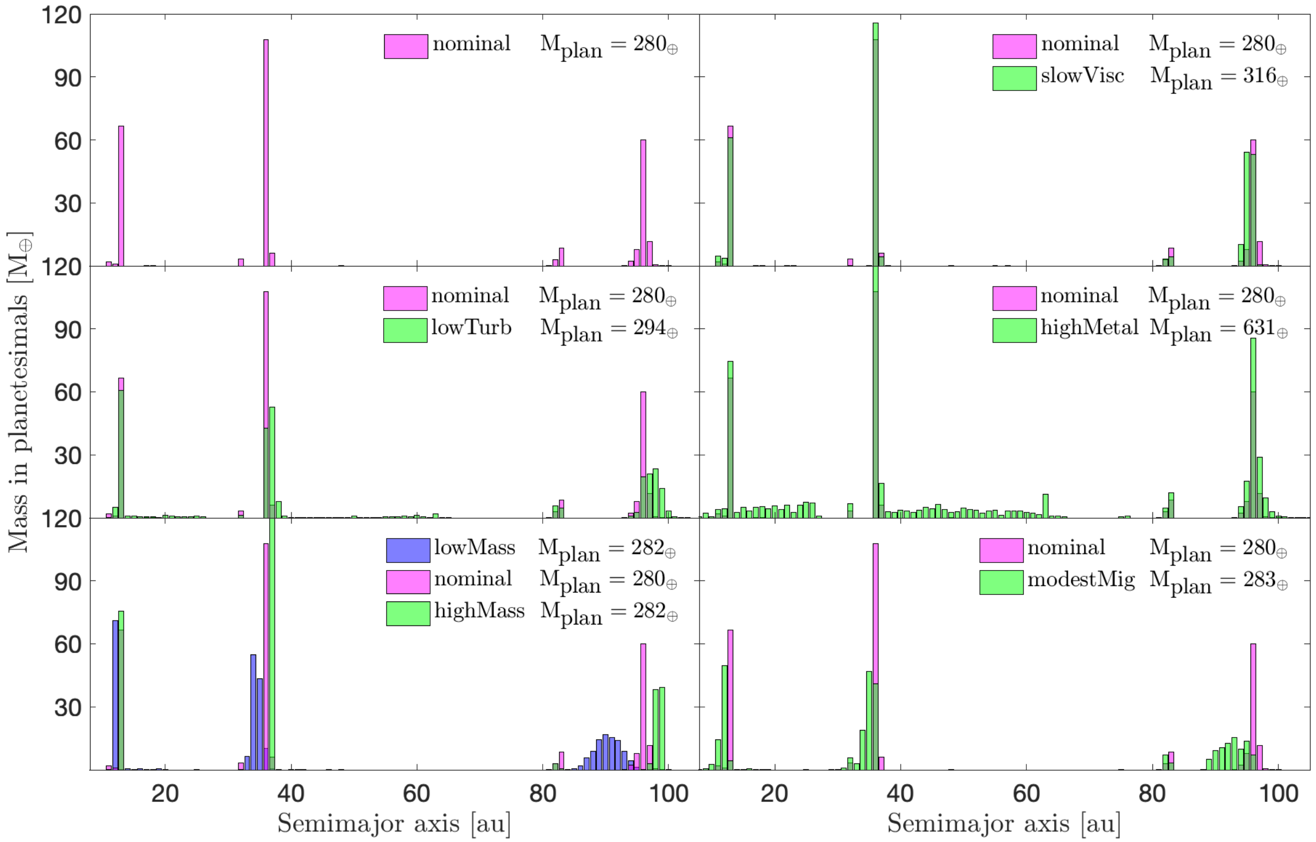
Parameter study: planetesimal formation insensitive to most parameter changes



Eriksson et al. in prep.

SUMMARY

1) Do planetesimals form at the edges of planetary gaps?
Yes

2) How efficient is this mechanism?
It produces over 100 Earth masses of planetesimals in our simulations

3) What does the distribution of pebbles look like?
- Pebbles of millimeter sizes drift out of regions between planets in ~300kyr
- Most pebbles are turned into planetesimals

→ Almost no pebbles left interior to the outermost planet

4) How does this compare with observations?
Observations suggest tens of Earth masses of dust in rings:
- Can reconcile with observations if there is some mechanism for destroying the planetesimals and replenishing the dust population in the rings (planetesimal collisions, bow shocks), or planetesimal formation efficiency is much lower

Most disks have emission from all over the disk:
- Can reconcile with observations if pebbles are 100micron and drift slowly, or dust is transported across planetary gaps (fragmentation and recoagulation)

→ **Futute:** follow dynamical evolution of formed planetesimals