

NEW PARADIGMS IN PLANET FORMATION

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Many thanks to the group:

Asmita Bhandare, Nicolas Kaufmann, Anna Penzlin, Giovanni Tedeschi,
Sebastian Stammer, Alexandros Ziampras,
Sreejita Das, Kim Melanie Weiskopf, and our collaborators

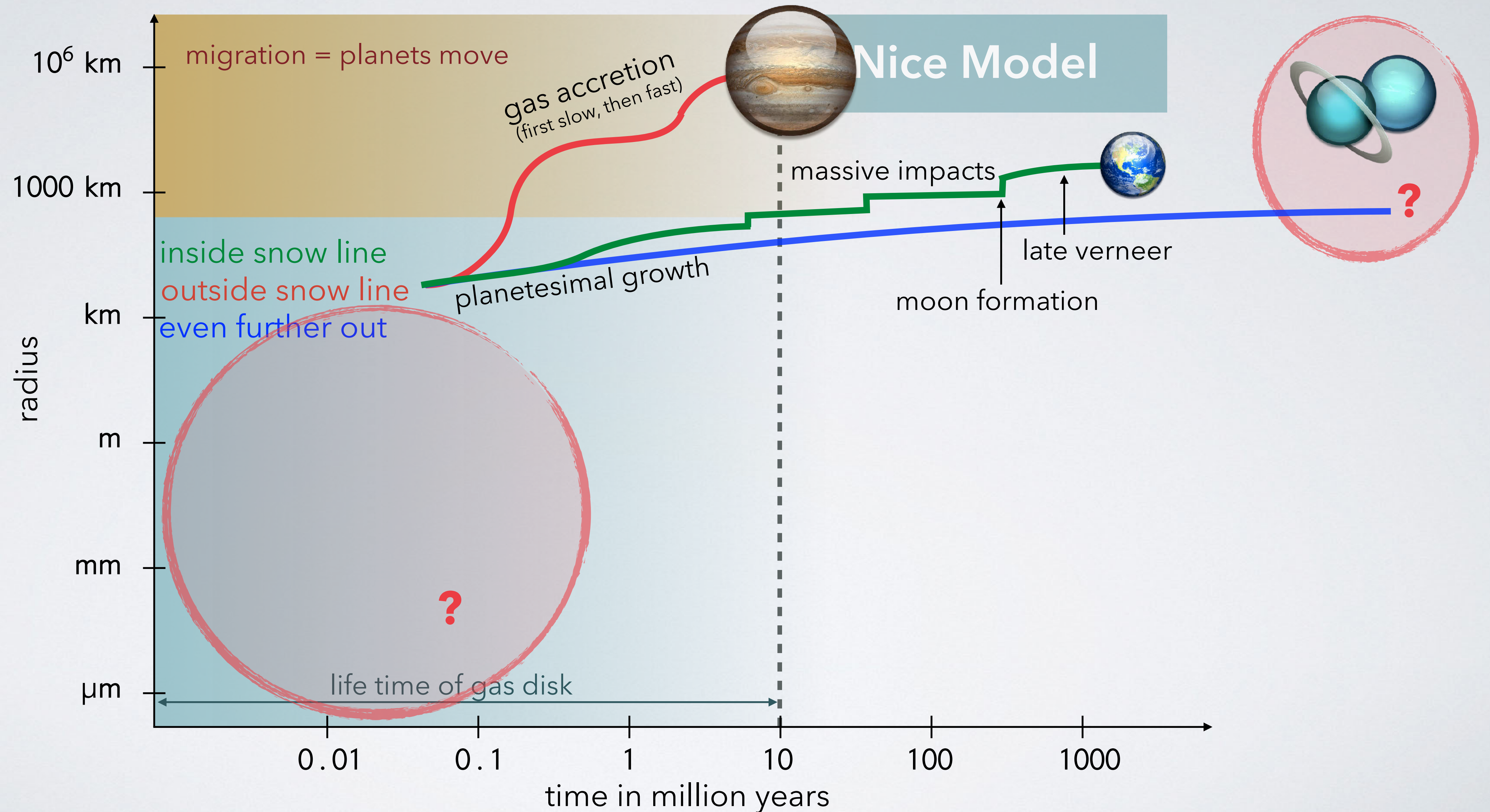


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European Research Council
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TIME SCALES OF PLANET FORMATION



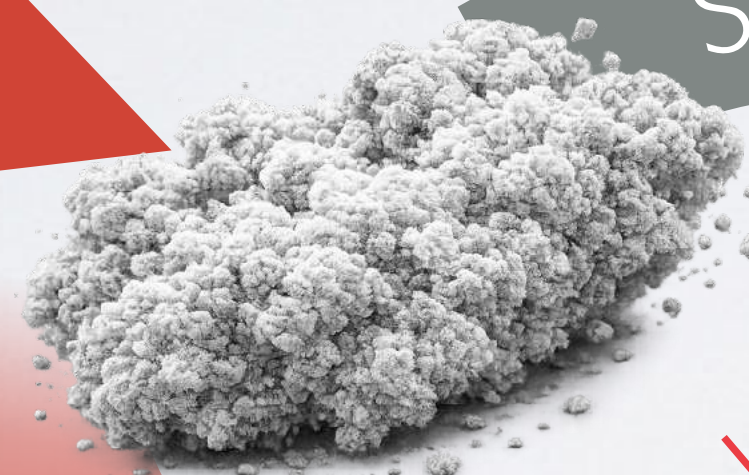
THE SCALES OF THE PROBLEM

Grain
 $\lesssim 1 \mu\text{m}$



Collisional Growth

Pebble
 $\sim 10^3 \mu\text{m}$



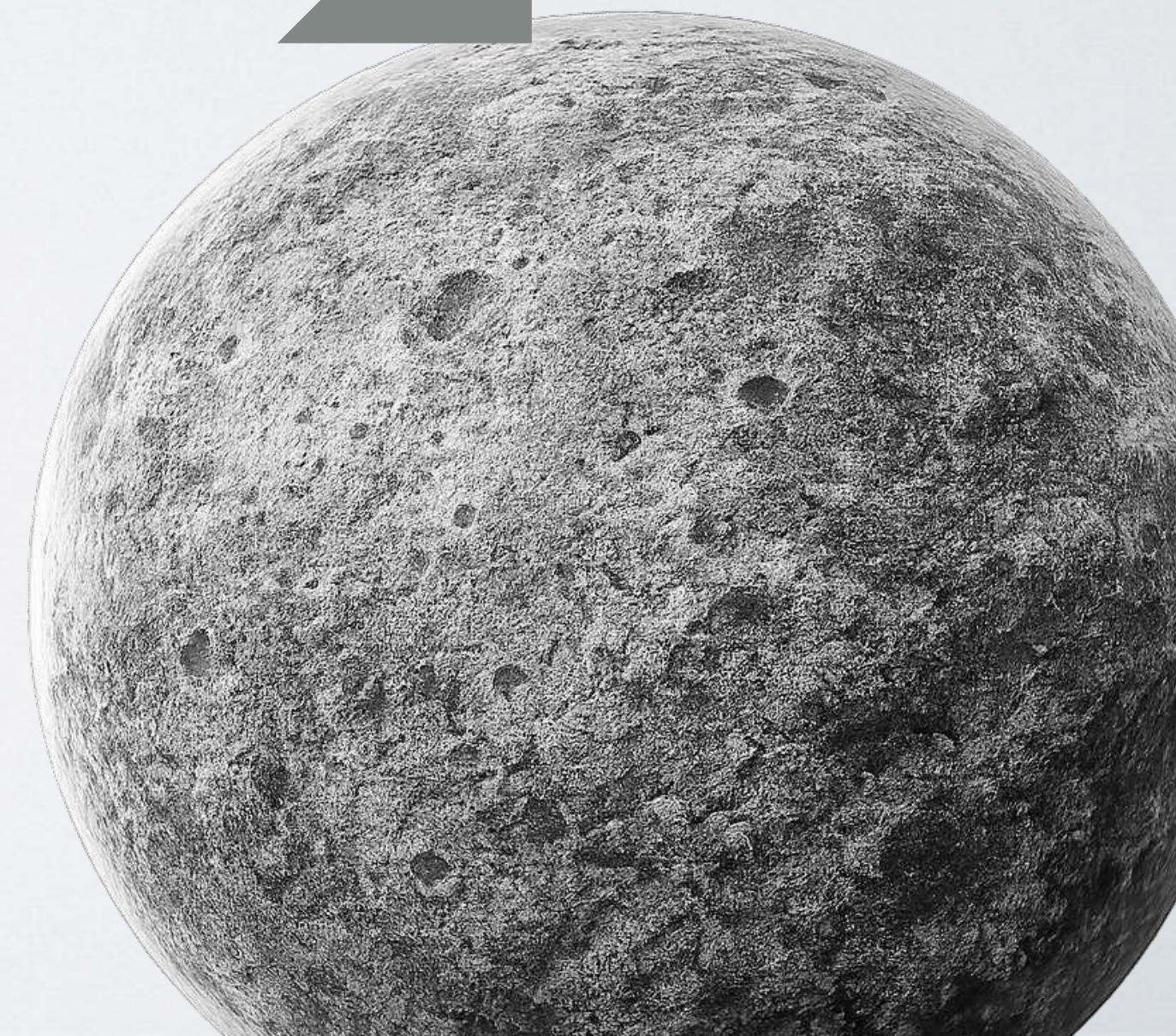
Streaming Inst.

Planetesimal
 $\sim 10^{10} \mu\text{m}$



Planetesimal Accretion

Planet
 $\gtrsim 10^{12} \mu\text{m}$



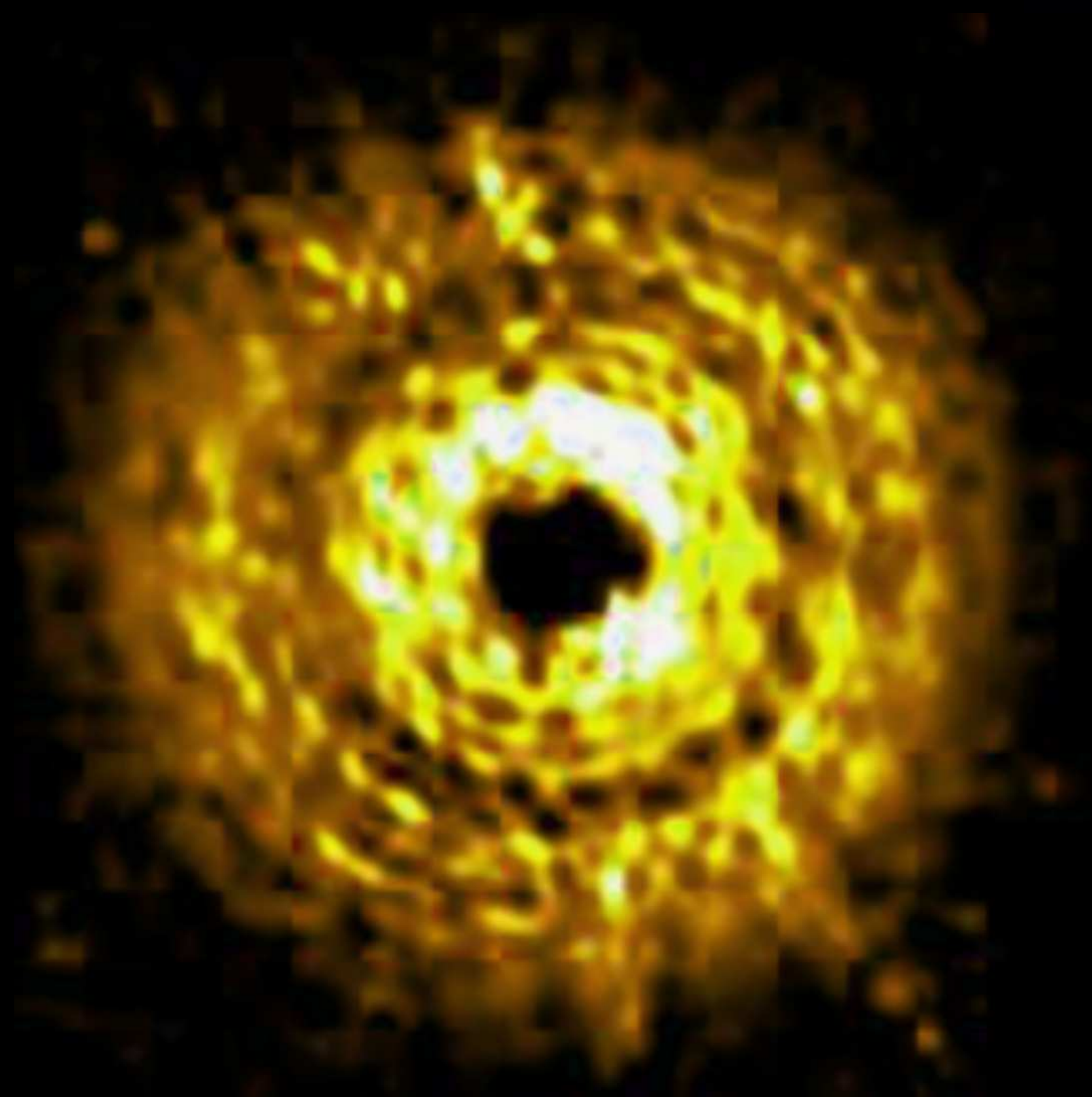
growth barriers
($\lesssim \text{mm}$)



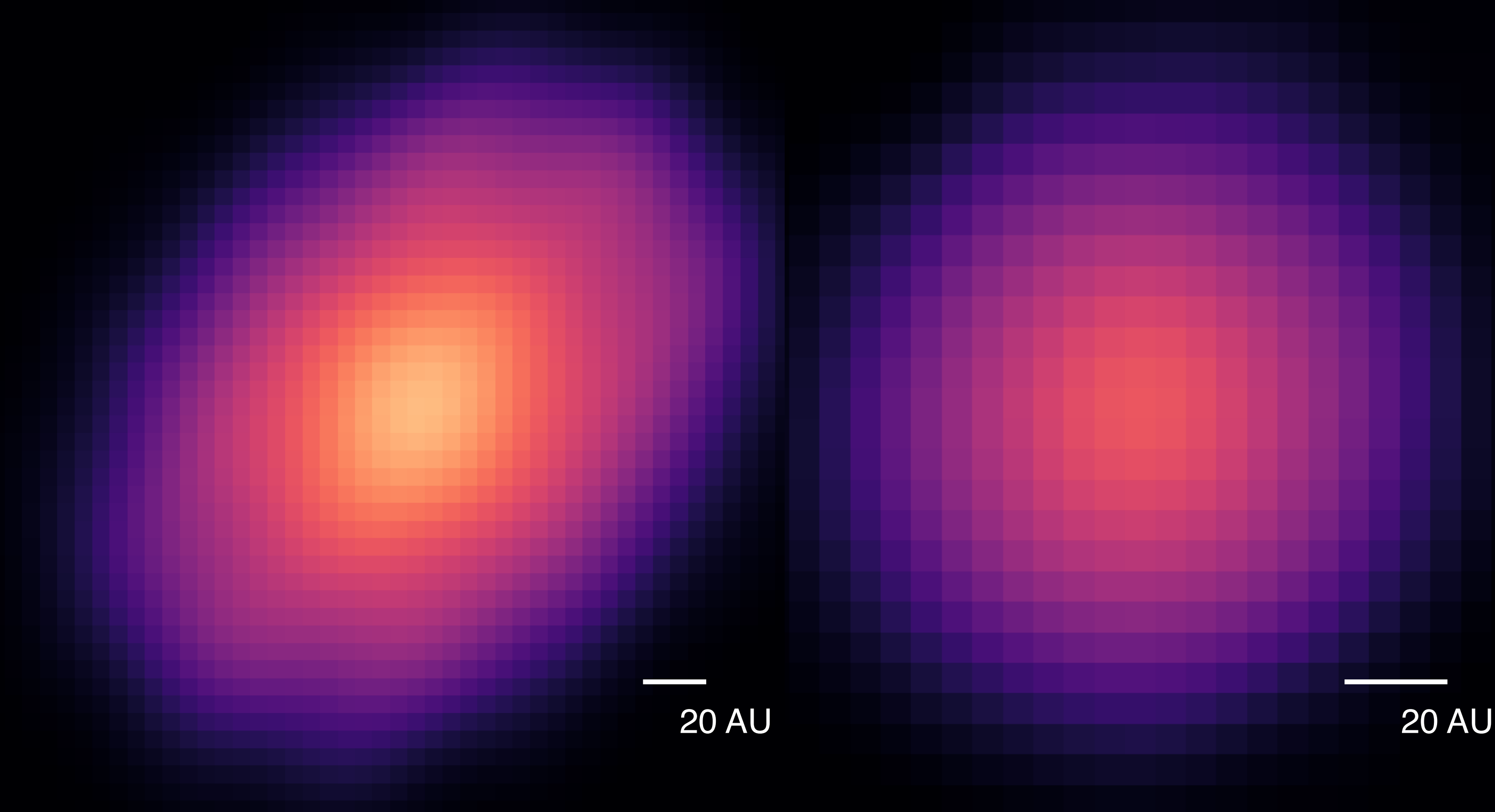
Pebble Accretion

THE ALMA/SPHERE VIEW OF DISKS

Near Infrared ($1.7\mu\text{m}$)
Hubble Space Telescope



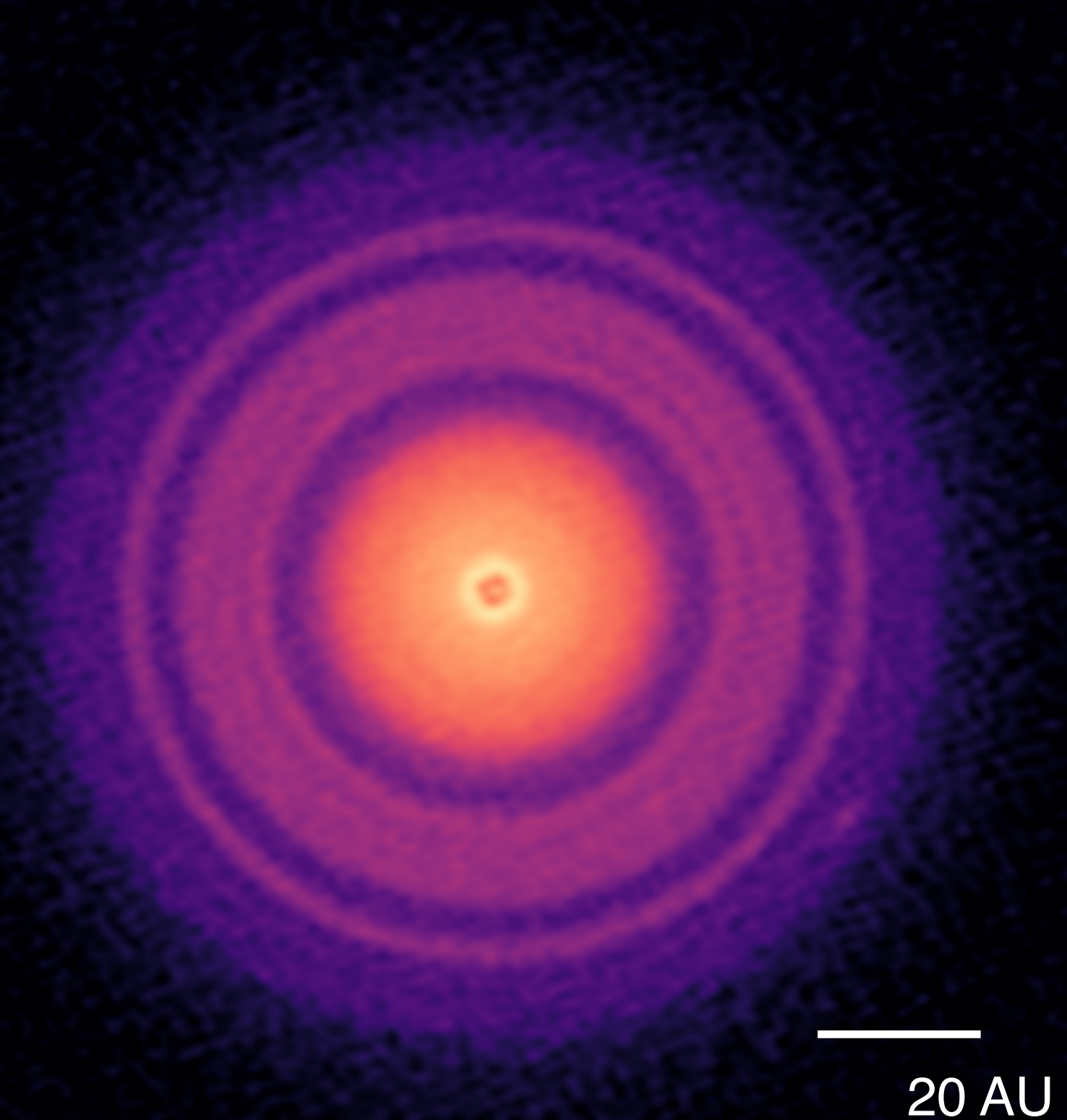
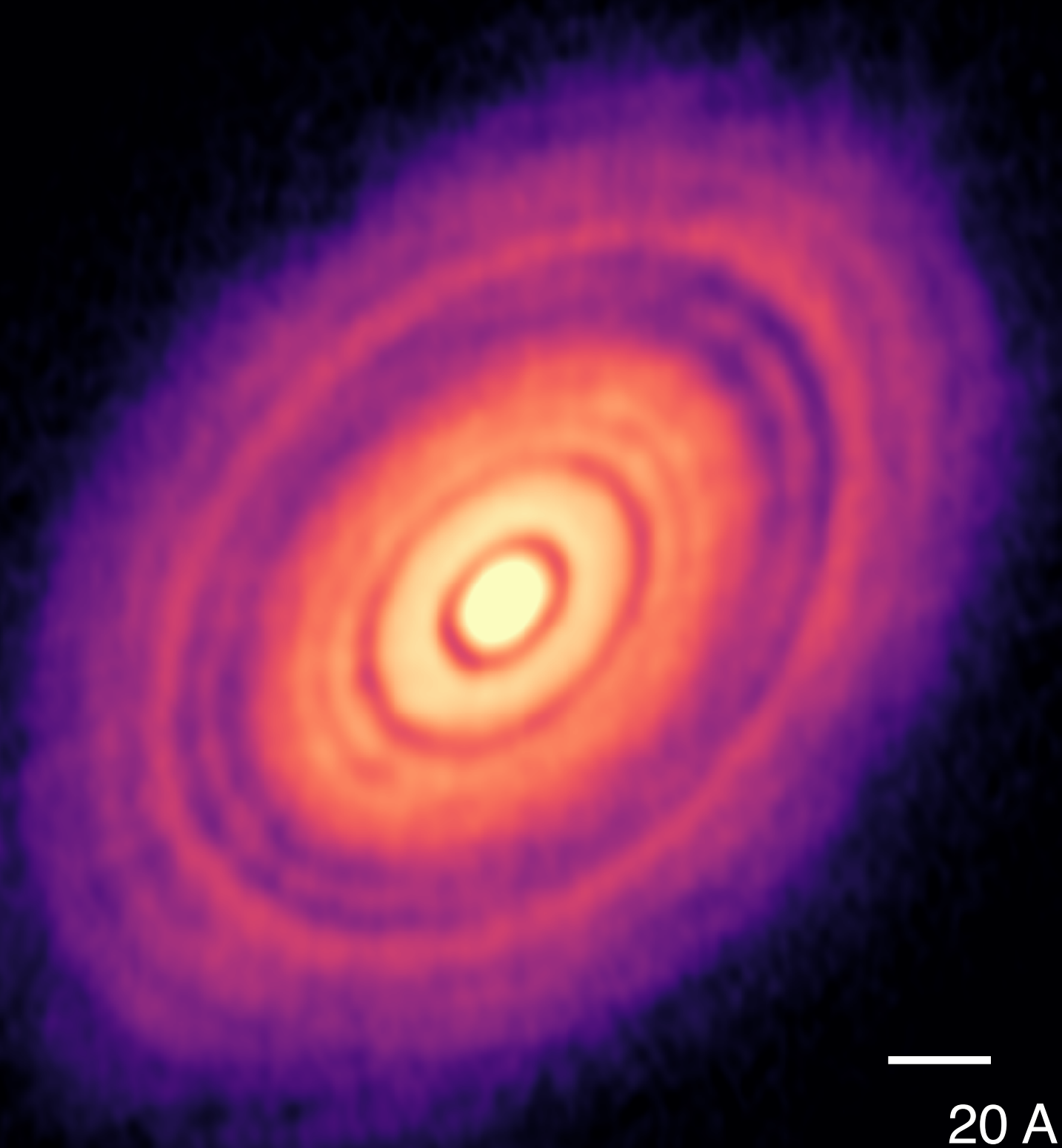
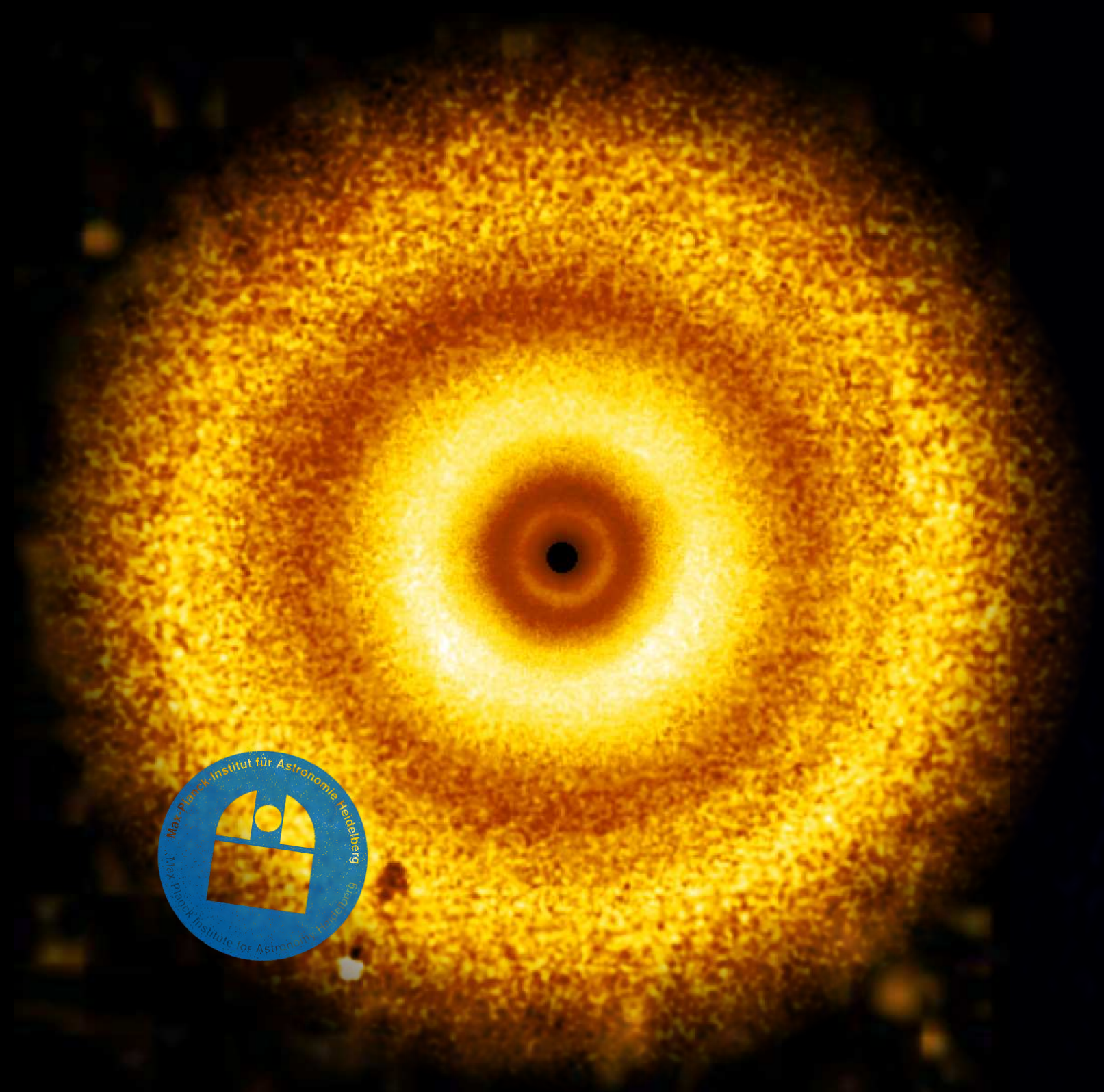
Radio (1.3 mm)
CARMA, SMA



THE ALMA/SPHERE VIEW OF DISKS

Near Infrared ($1.7\mu\text{m}$)
SPHERE@VLT

Radio (1.3 mm)
ALMA



KEPPLER 1B

~~„planet“?~~

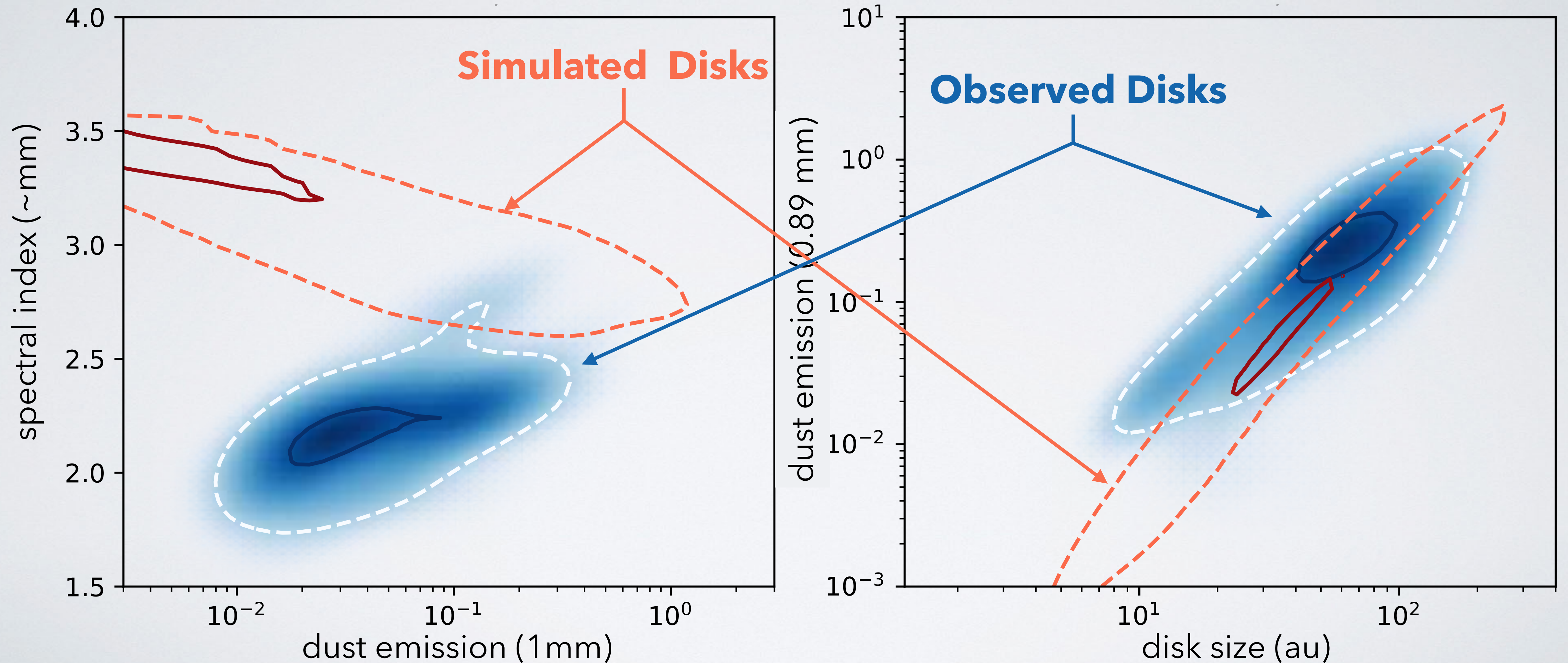


planet!



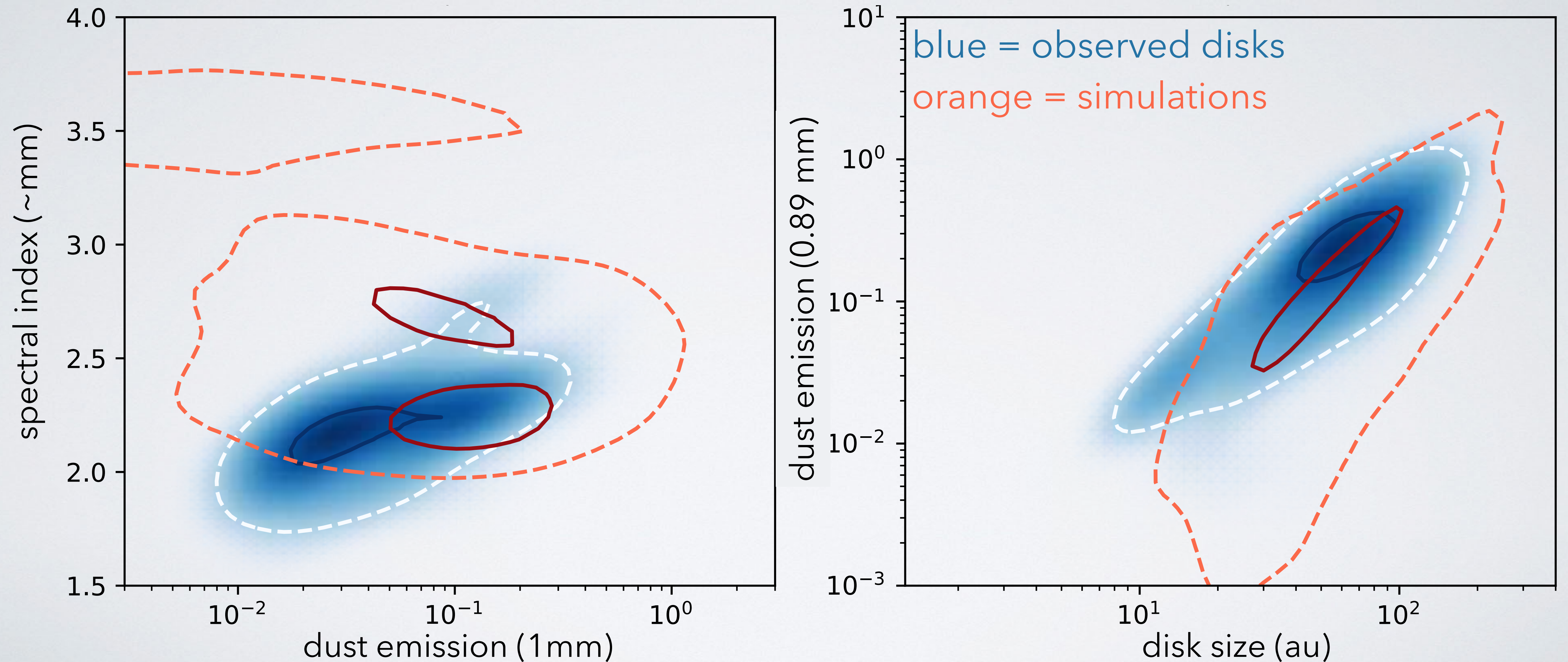
DISK POPULATIONS

Smooth disks



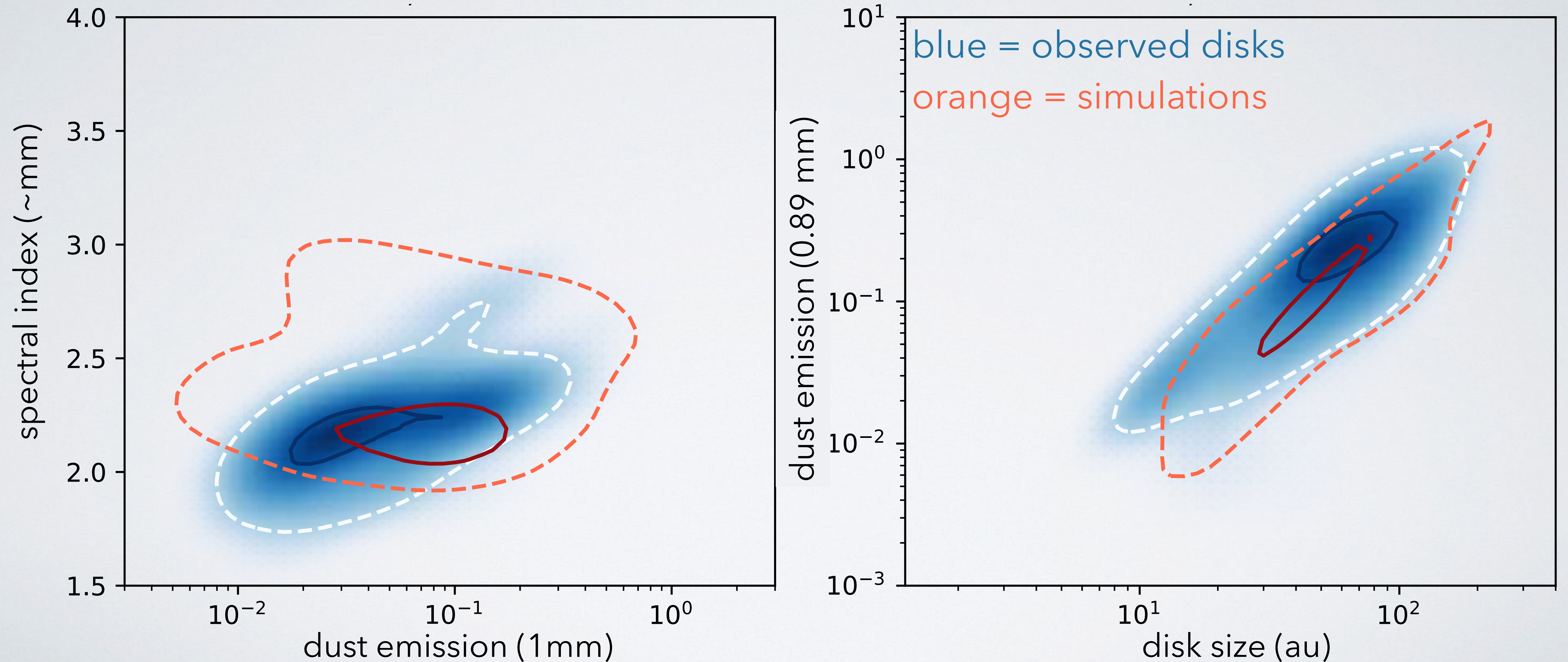
DISK POPULATIONS

Structured Disks



DISK POPULATIONS

Structured Disks, best case



SO FAR ...

Traditional Models already fail at Neptune/Uranus

Planets form faster & farther away than expected

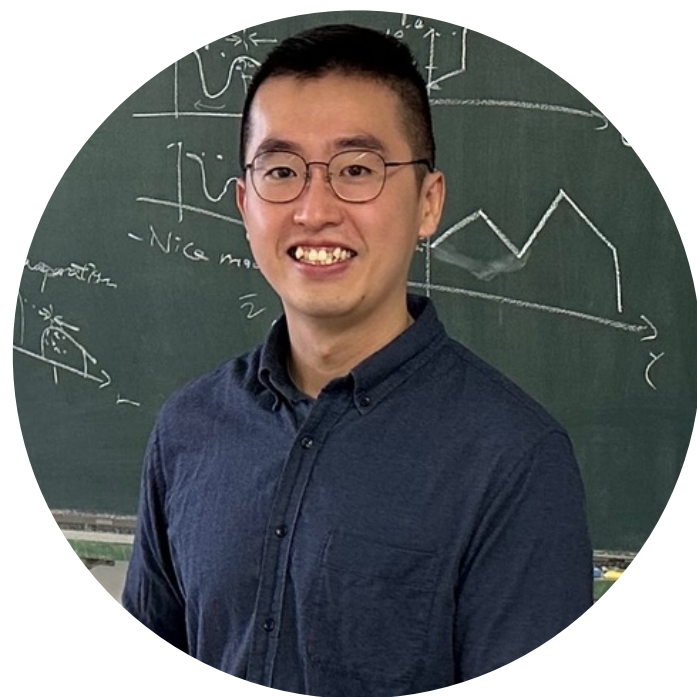
All disks are structured, starting very early

RAPID FORMATION OF PLANETARY CORES

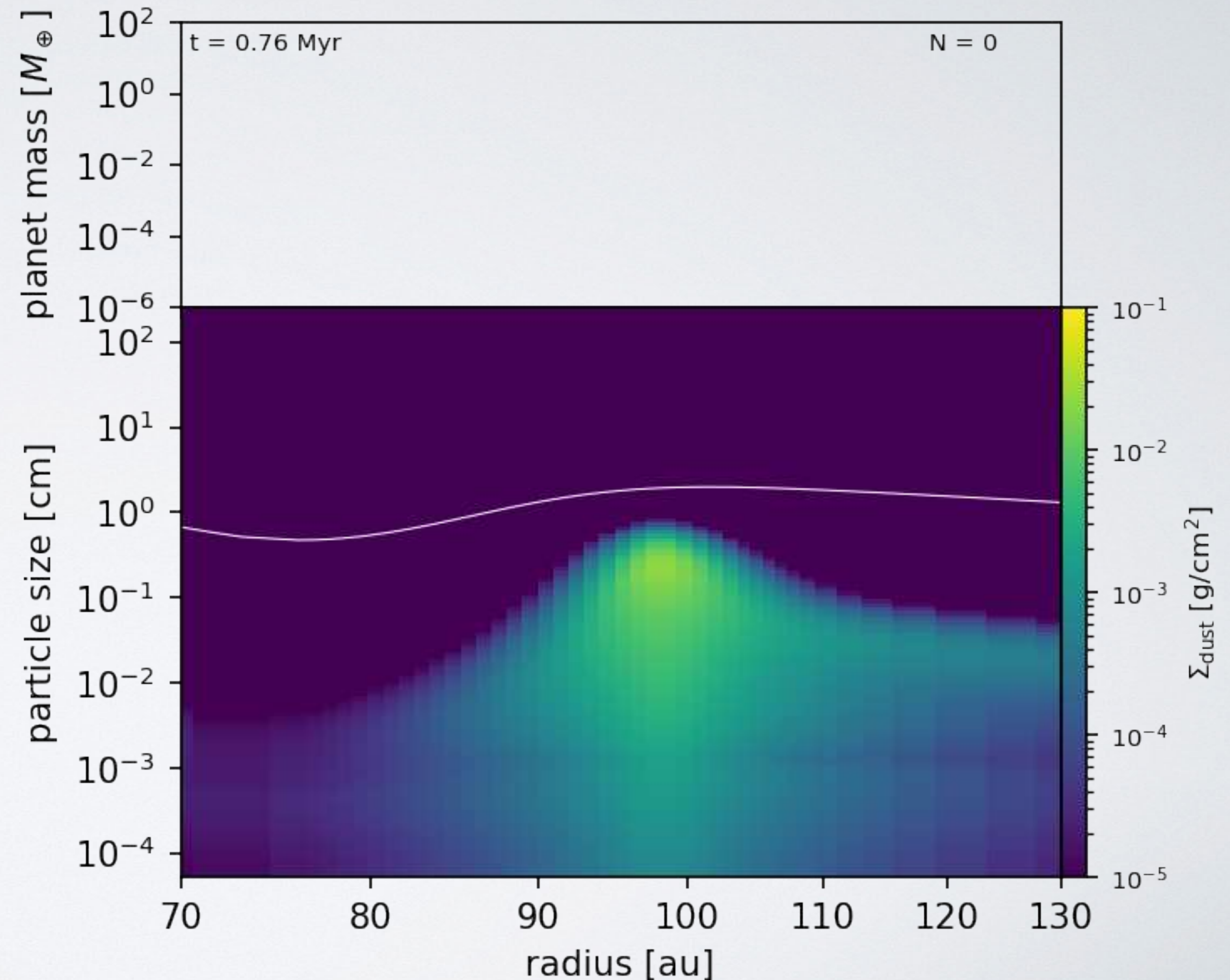
Astronomy
&
Astrophysics

Awards 2026

A&A Award for
Outstanding PhD Article



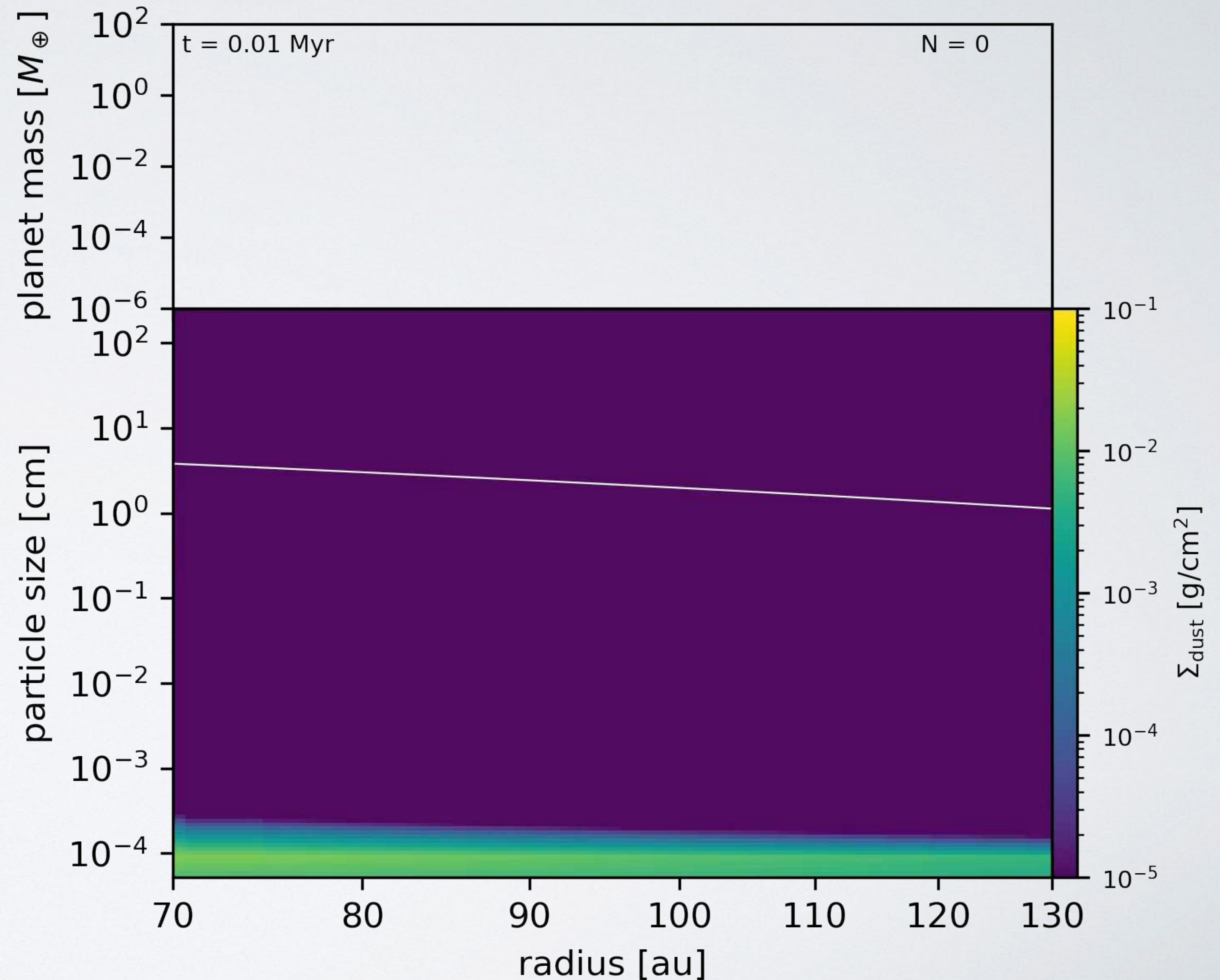
Dr. Tommy Chi Ho Lau



RAPID FORMATION OF PLANETARY CORES

No Pressure bump:

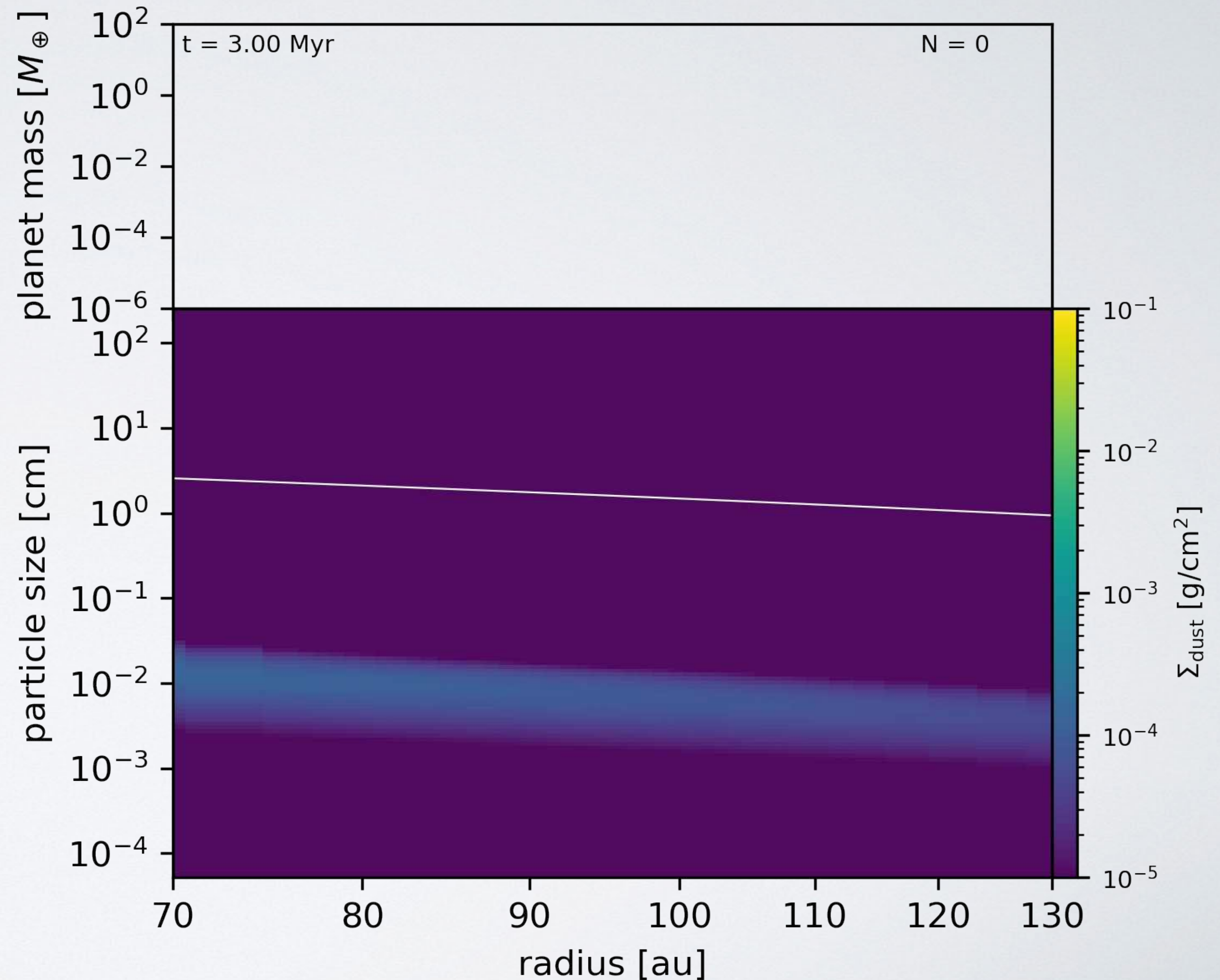
- Grains grow to ~mm
- Radial drift depletes them
- ☒ No rings
- ☒ No planetesimals
- ☒ No planets



RAPID FORMATION OF PLANETARY CORES

No Pressure bump:

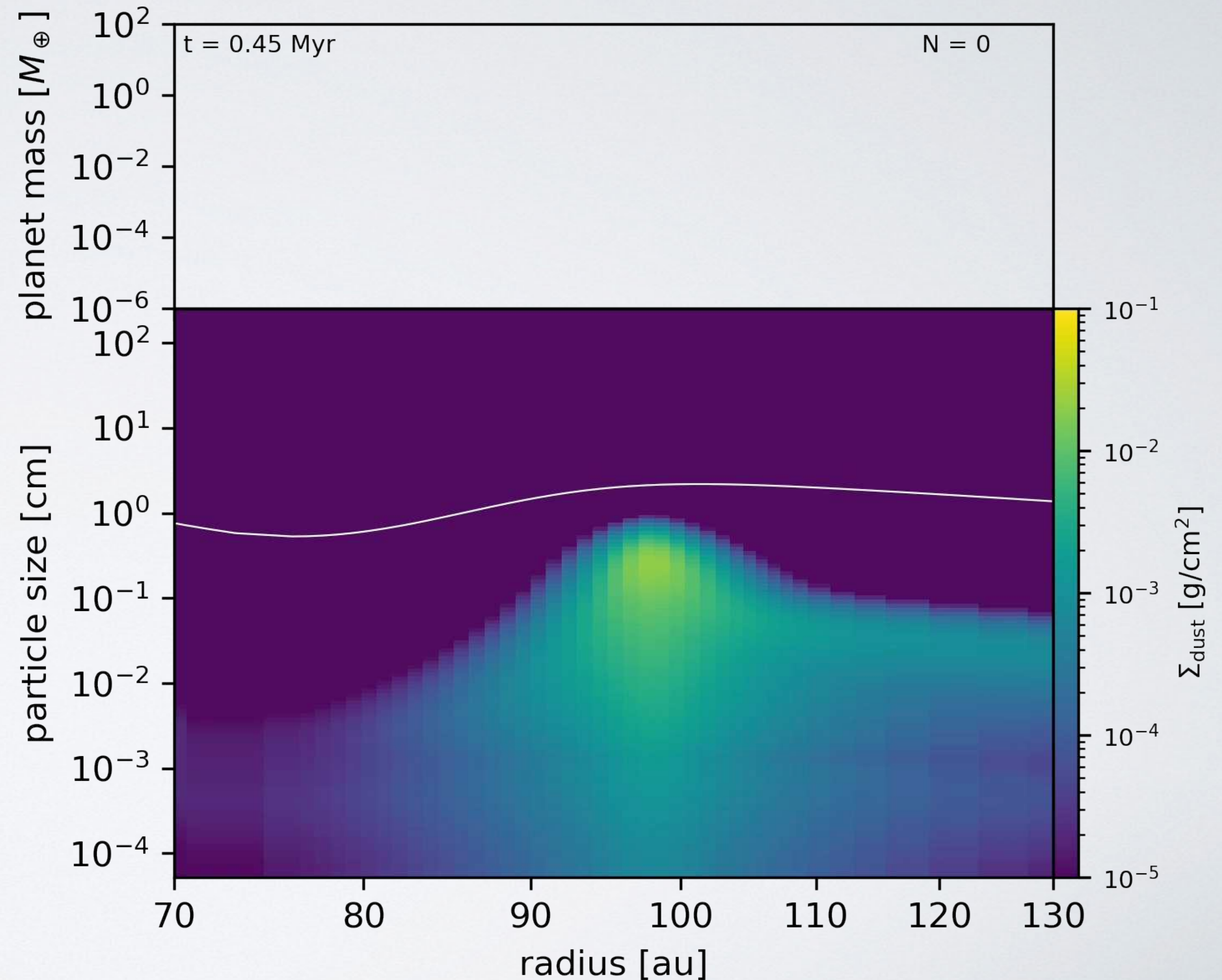
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RAPID FORMATION OF PLANETARY CORES

100 au Pressure bump:

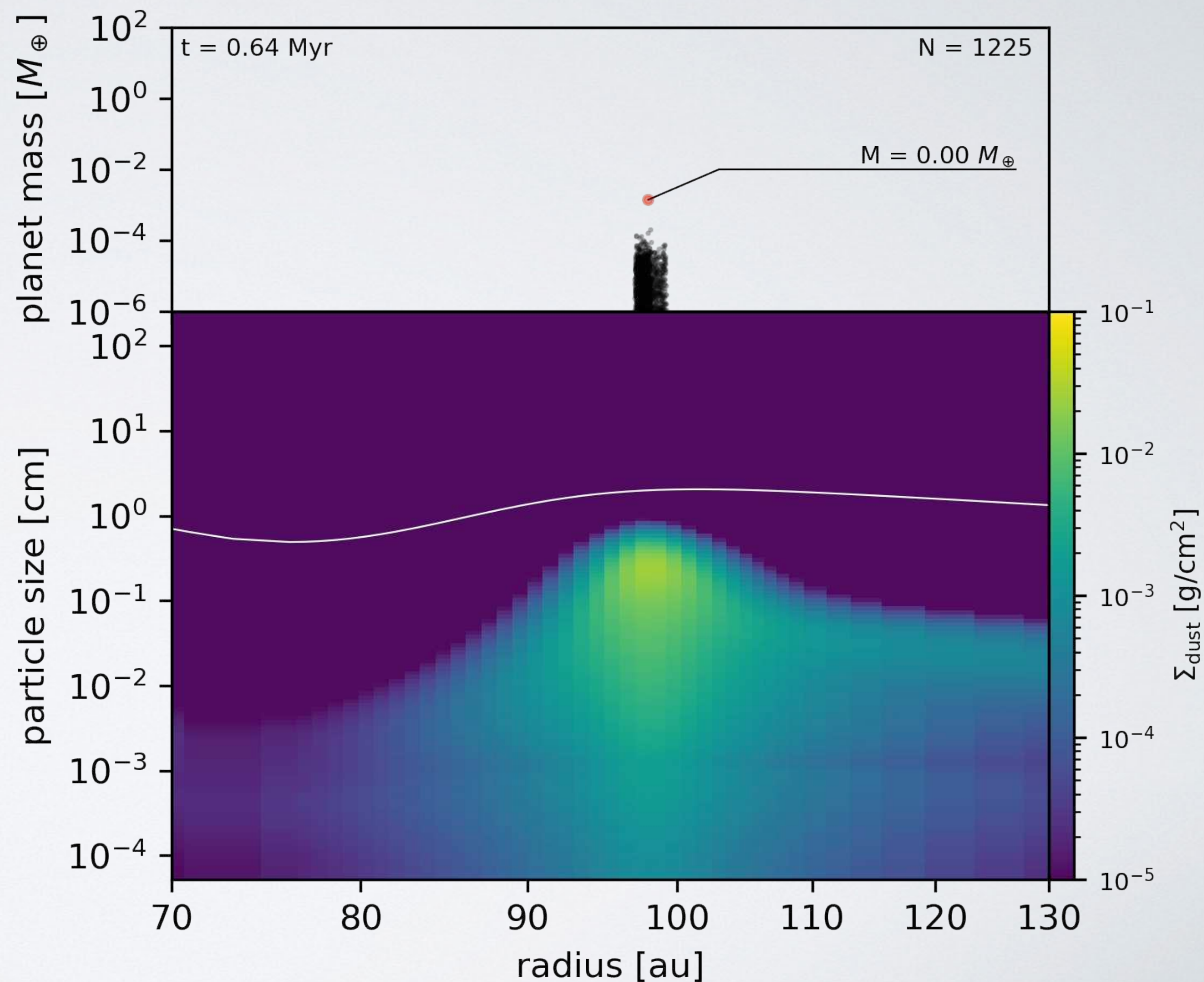
- ✓ observable ring: few 0.1 Myr
- ✓ enables growth to cm
 - traps dust



RAPID FORMATION OF PLANETARY CORES

100 au Pressure bump:

- ✓ observable ring: few 0.1 Myr
- ✓ enables growth to cm
- ✓ traps dust → triggers SI
- ✓ → lower $\dot{M}_{\text{PA, onset}}$
- ✓ → no eff. problem
- ✓ → high $\dot{M}_{\text{PA}}$



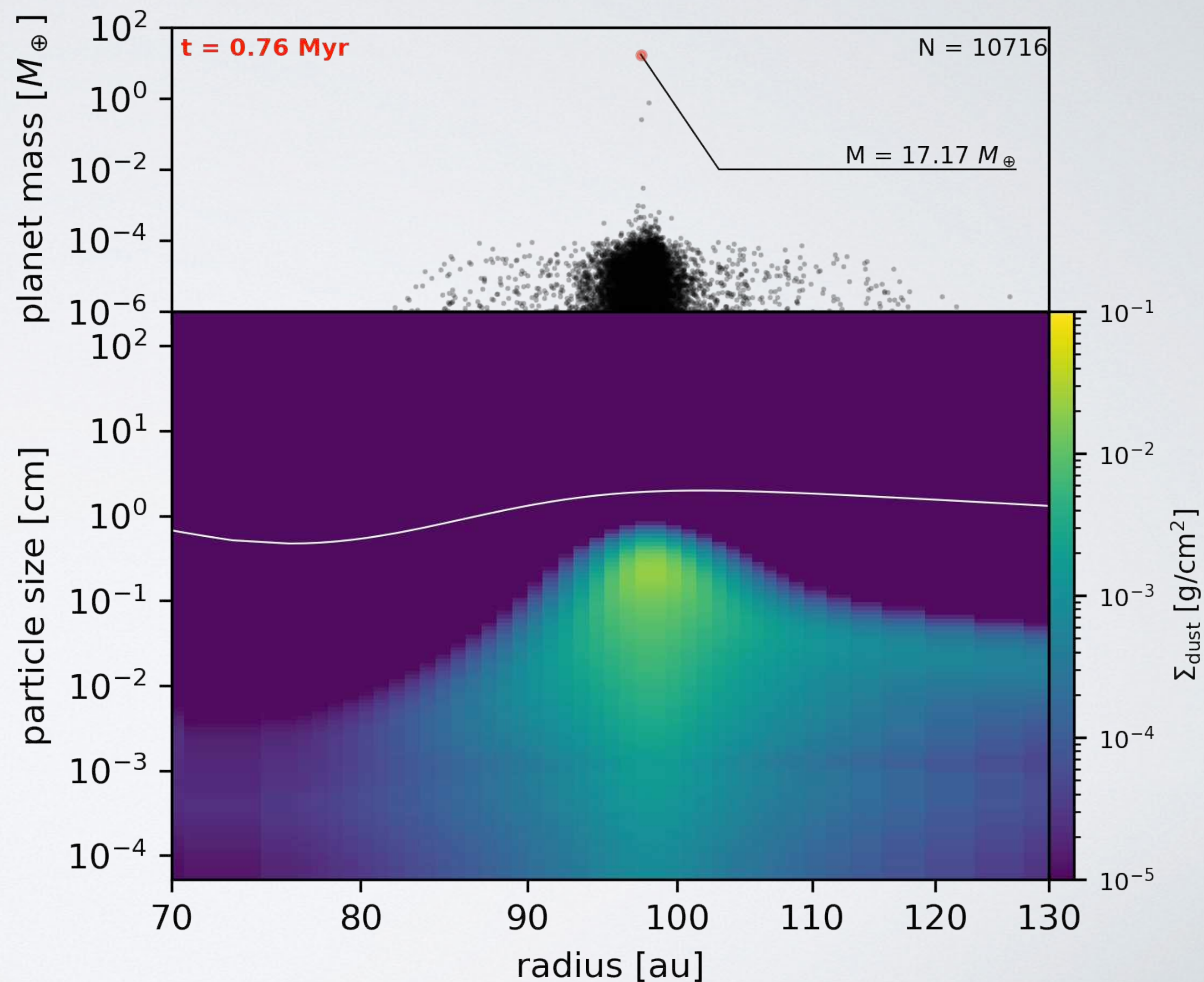
RAPID FORMATION OF PLANETARY CORES

100 au Pressure bump:

- ✓ observable ring: few 0.1 Myr
- ✓ enables growth to cm
- ✓ traps dust → triggers SI
- ✓ → lower $\dot{M}_{\text{PA, onset}}$
- ✓ → no eff. problem
- ✓ → high $\dot{M}_{\text{PA}}$
- ✓ stops type I migration



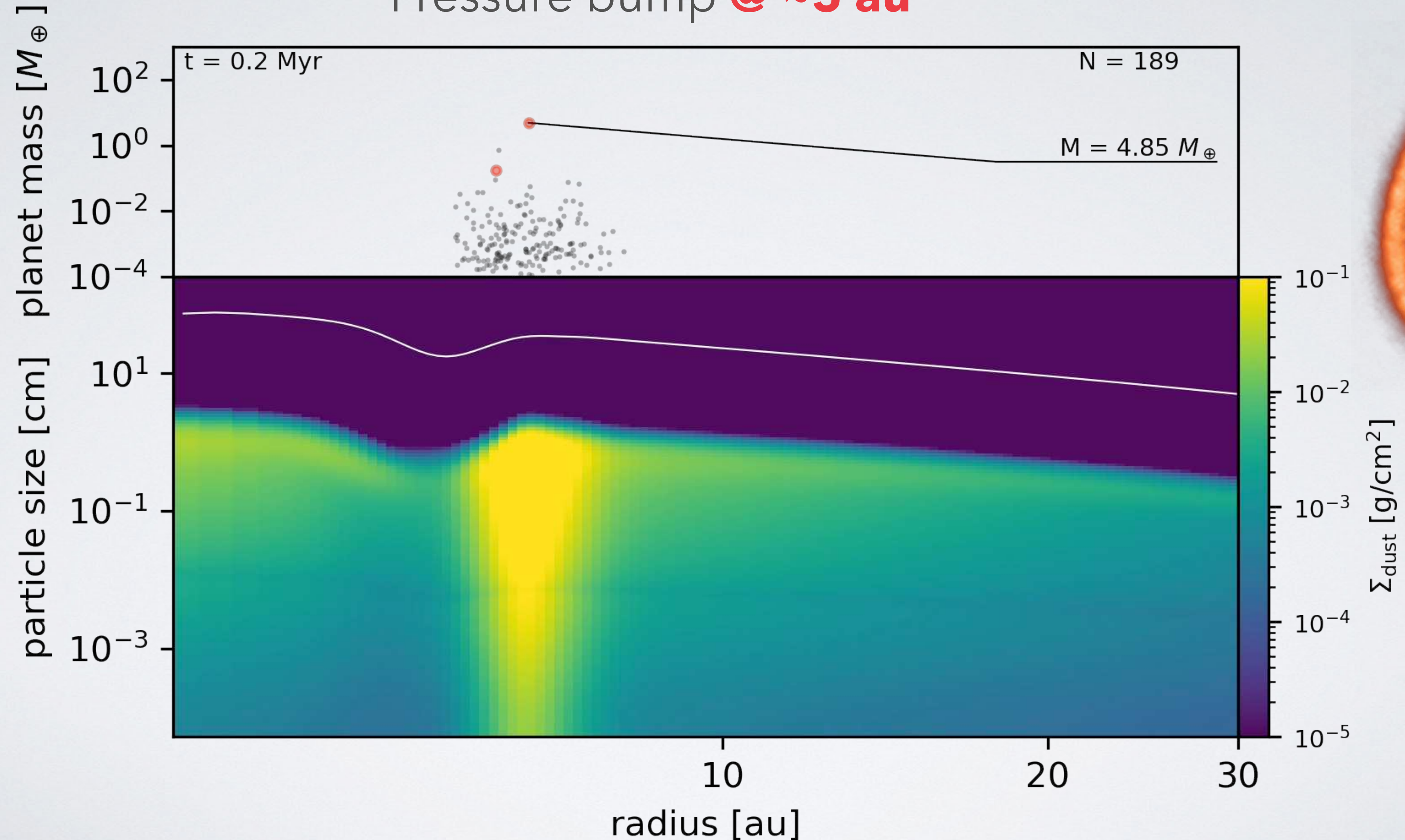
>10 $M_{\oplus}$ core at 0.75 Myr



SEQUENTIAL PLANET FORMATION

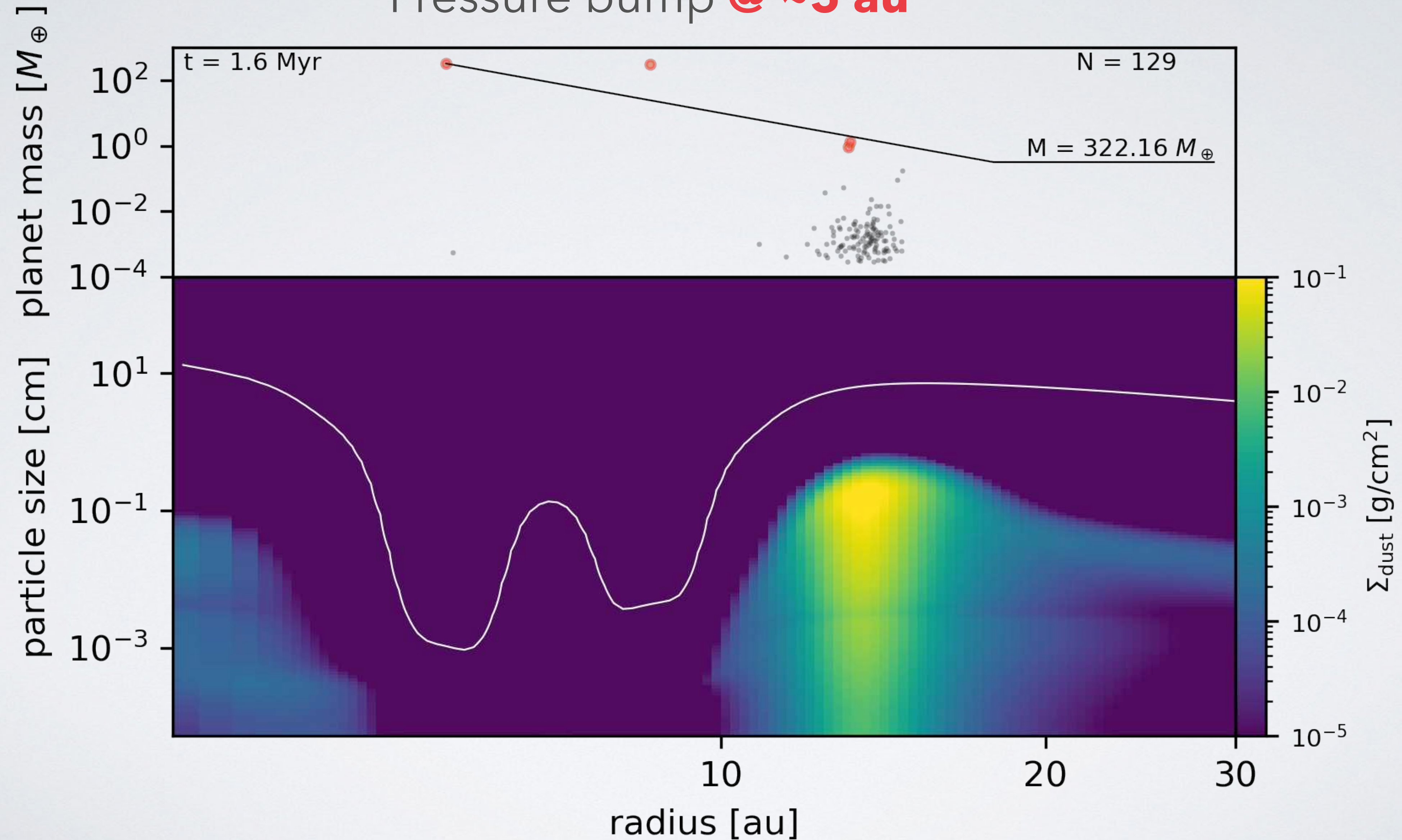
Pressure bump @ ~5 au

Notice:



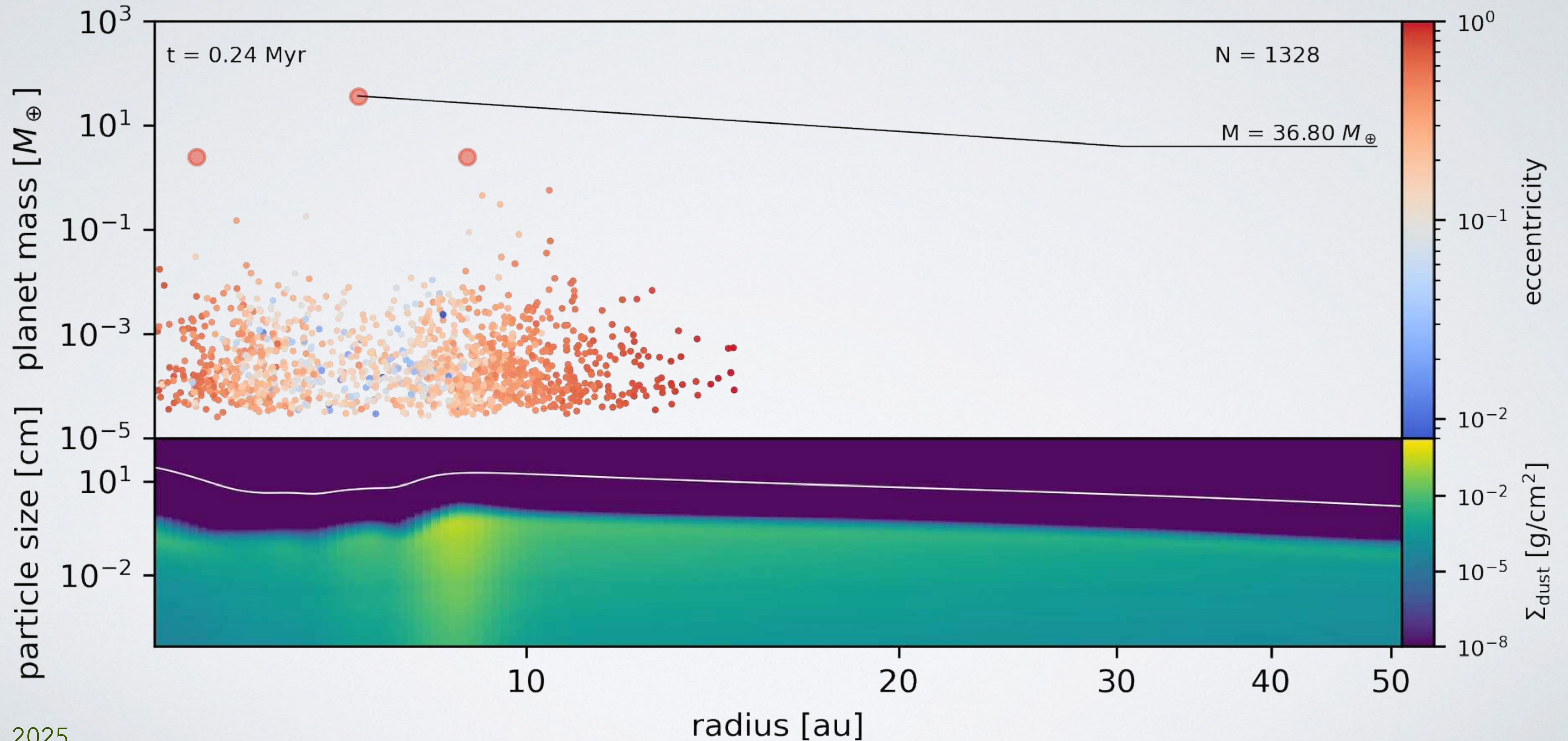
SEQUENTIAL PLANET FORMATION

Pressure bump @ ~5 au



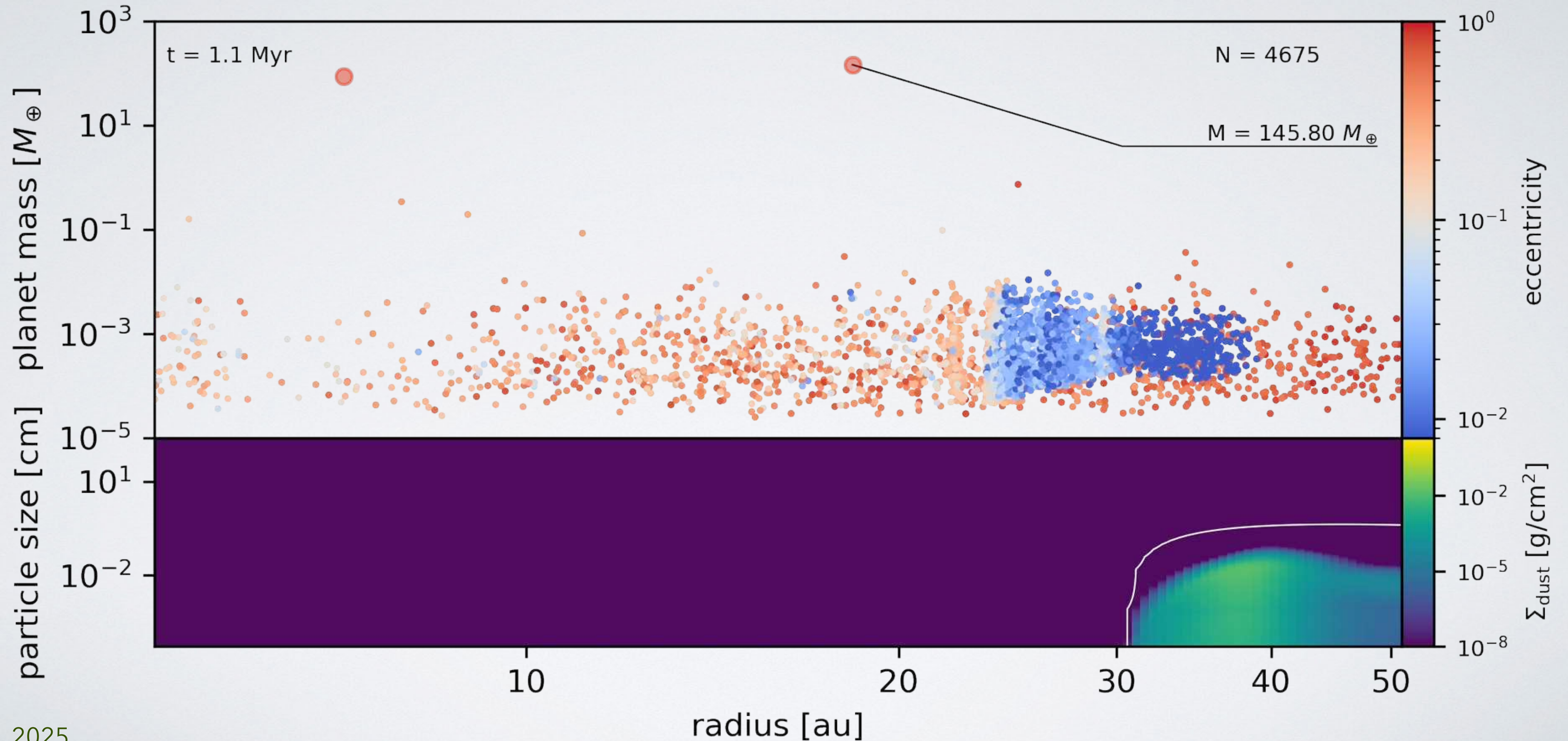
KUIPER BELT LIKE FAMILIES

adding internal photoevaporation



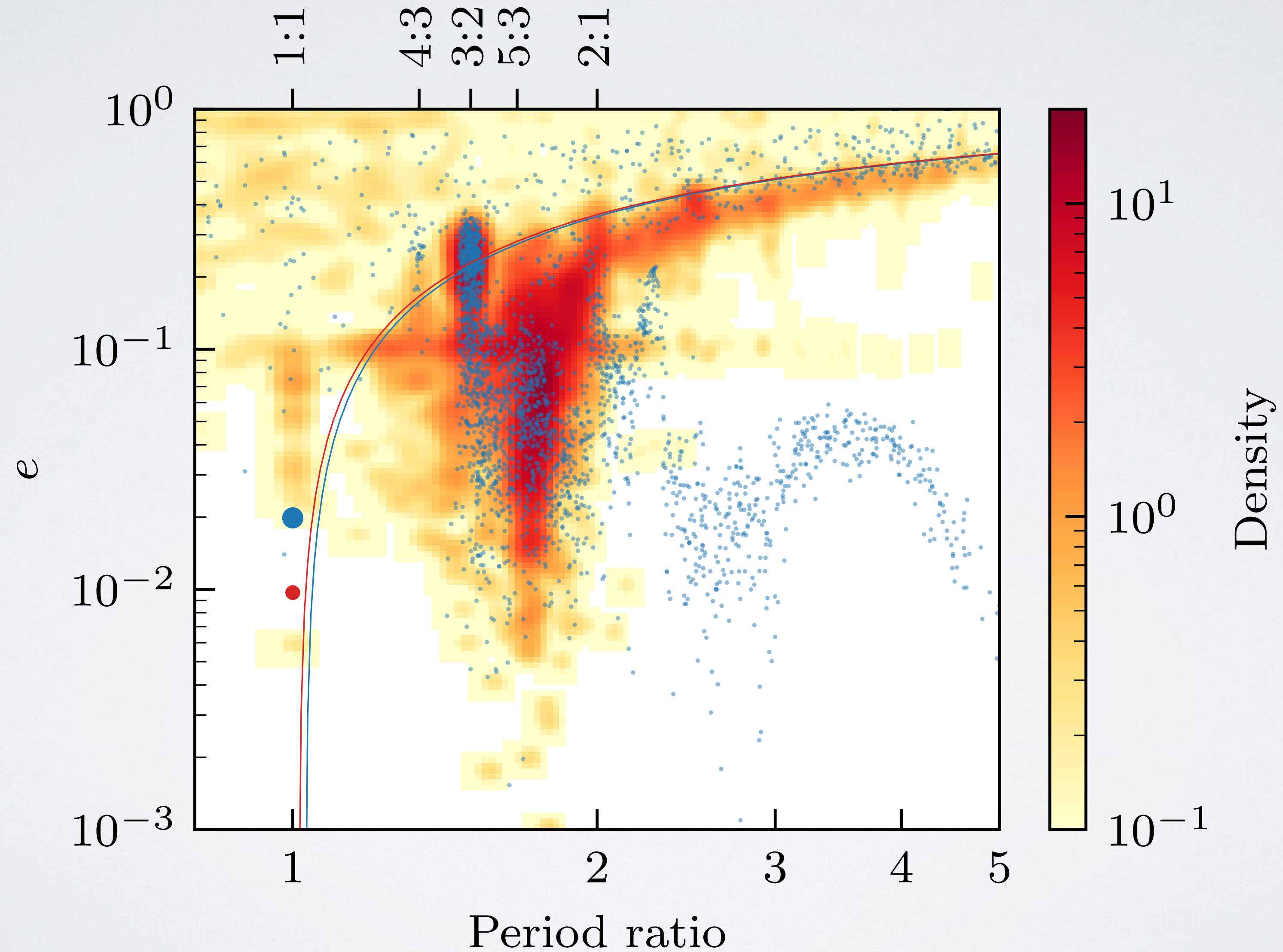
KUIPER BELT LIKE FAMILIES

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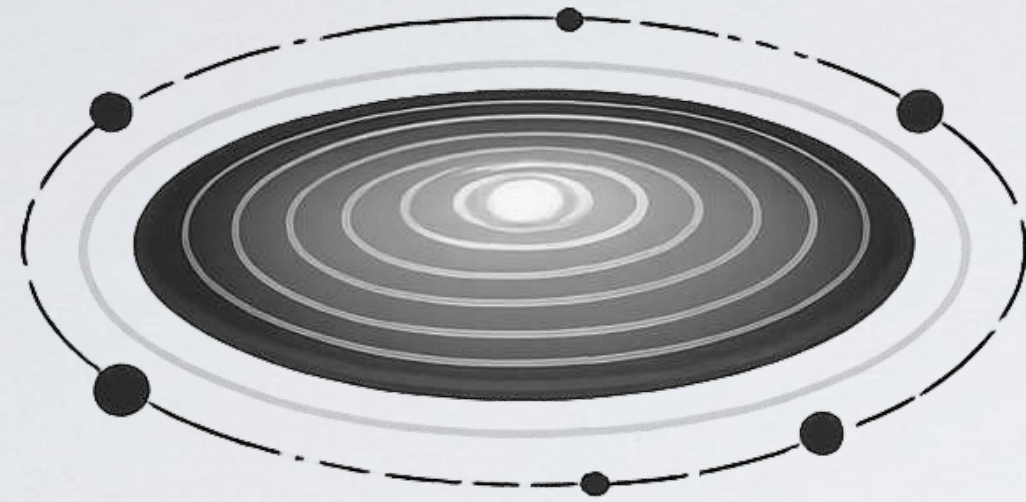


KUIPER BELT LIKE FAMILIES

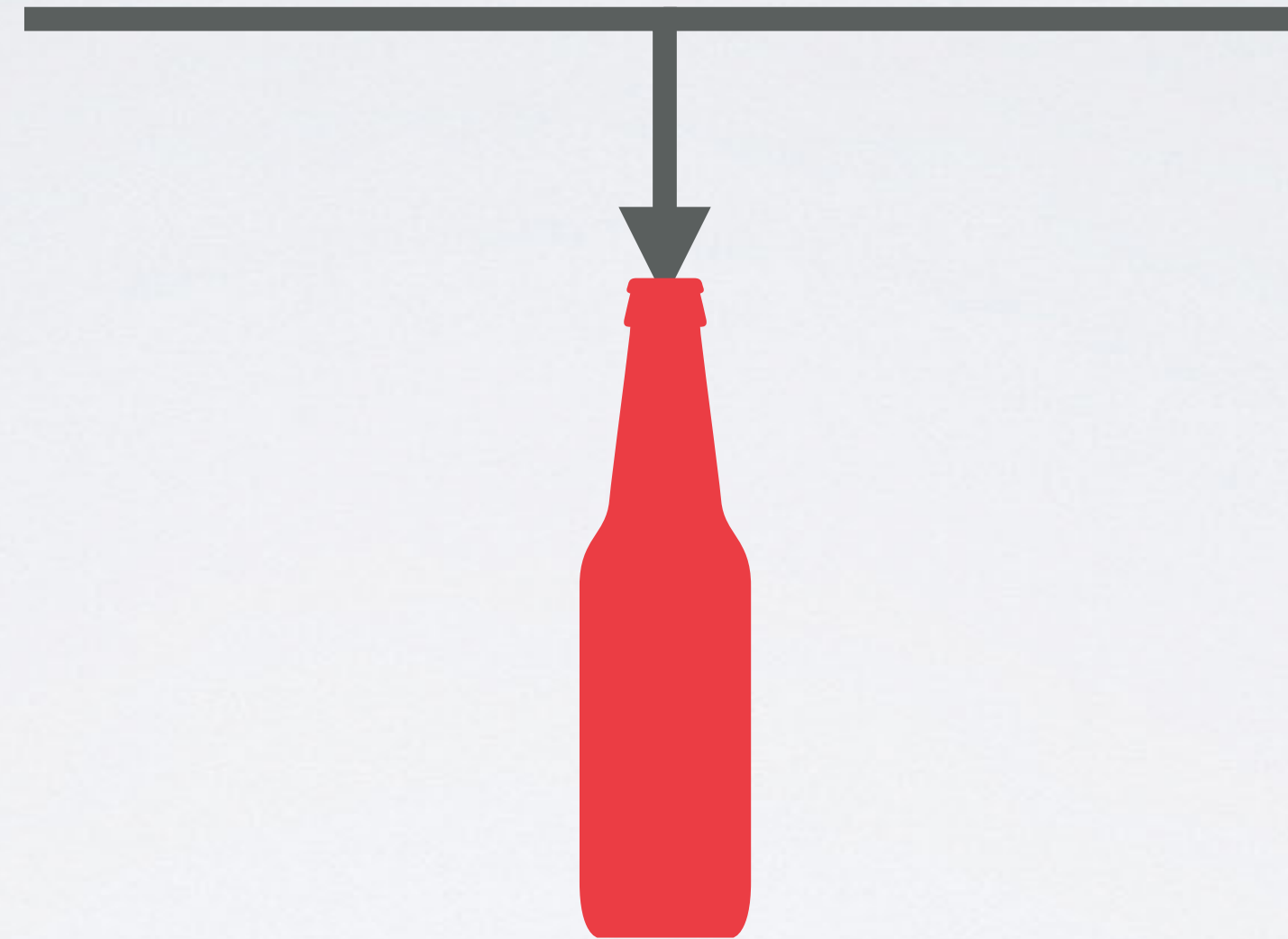
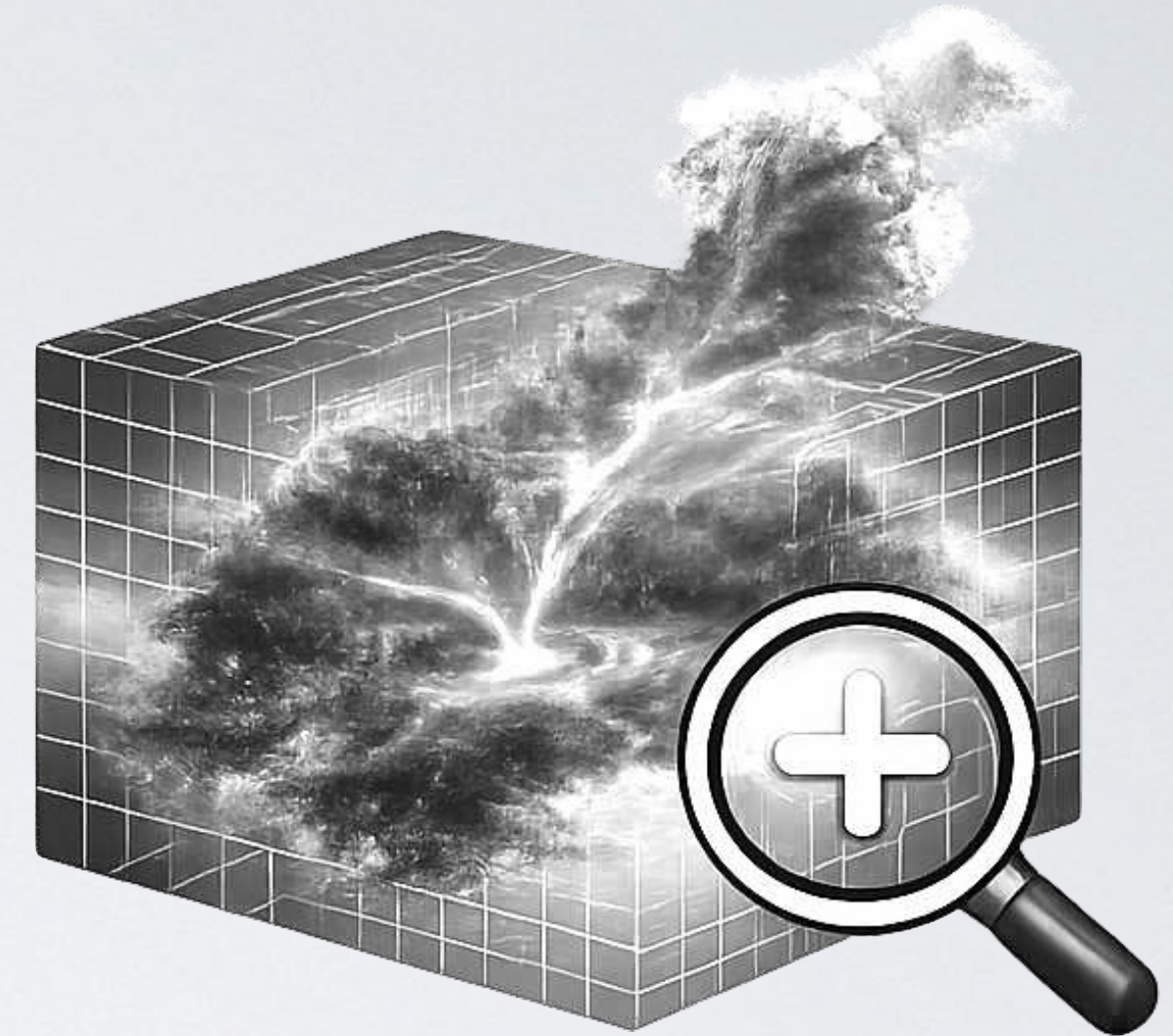
adding internal photoevaporation



POPULATION SYNTHESIS



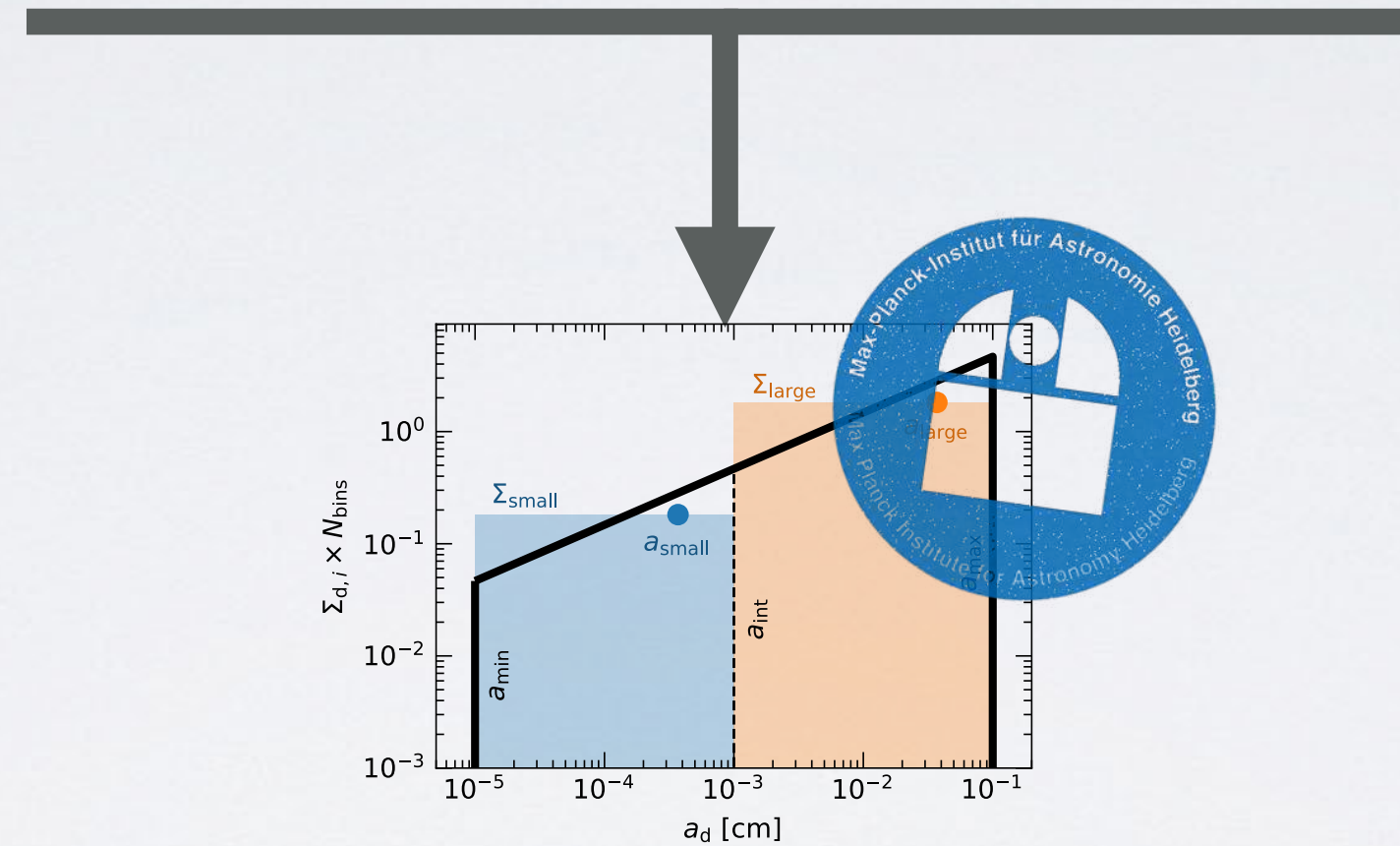
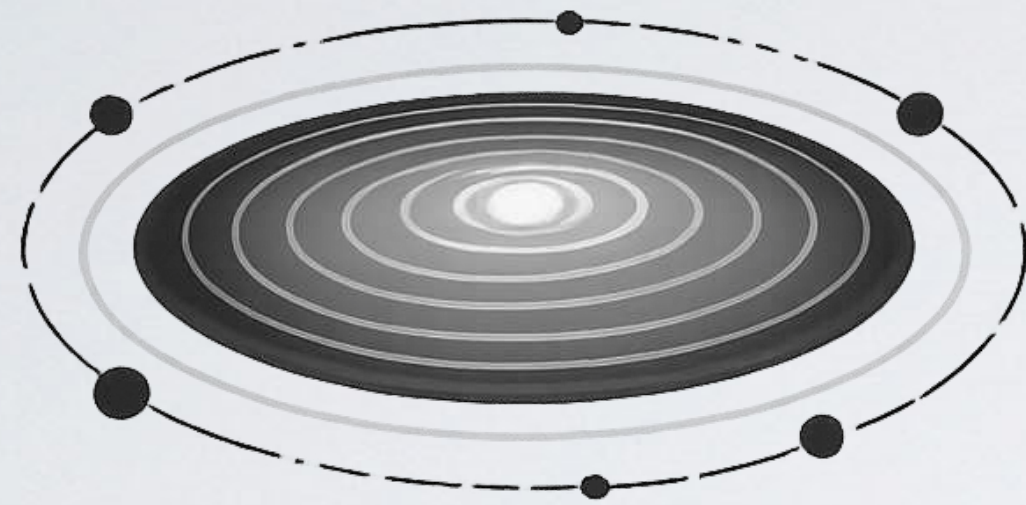
MULTI-DIM. MODELS



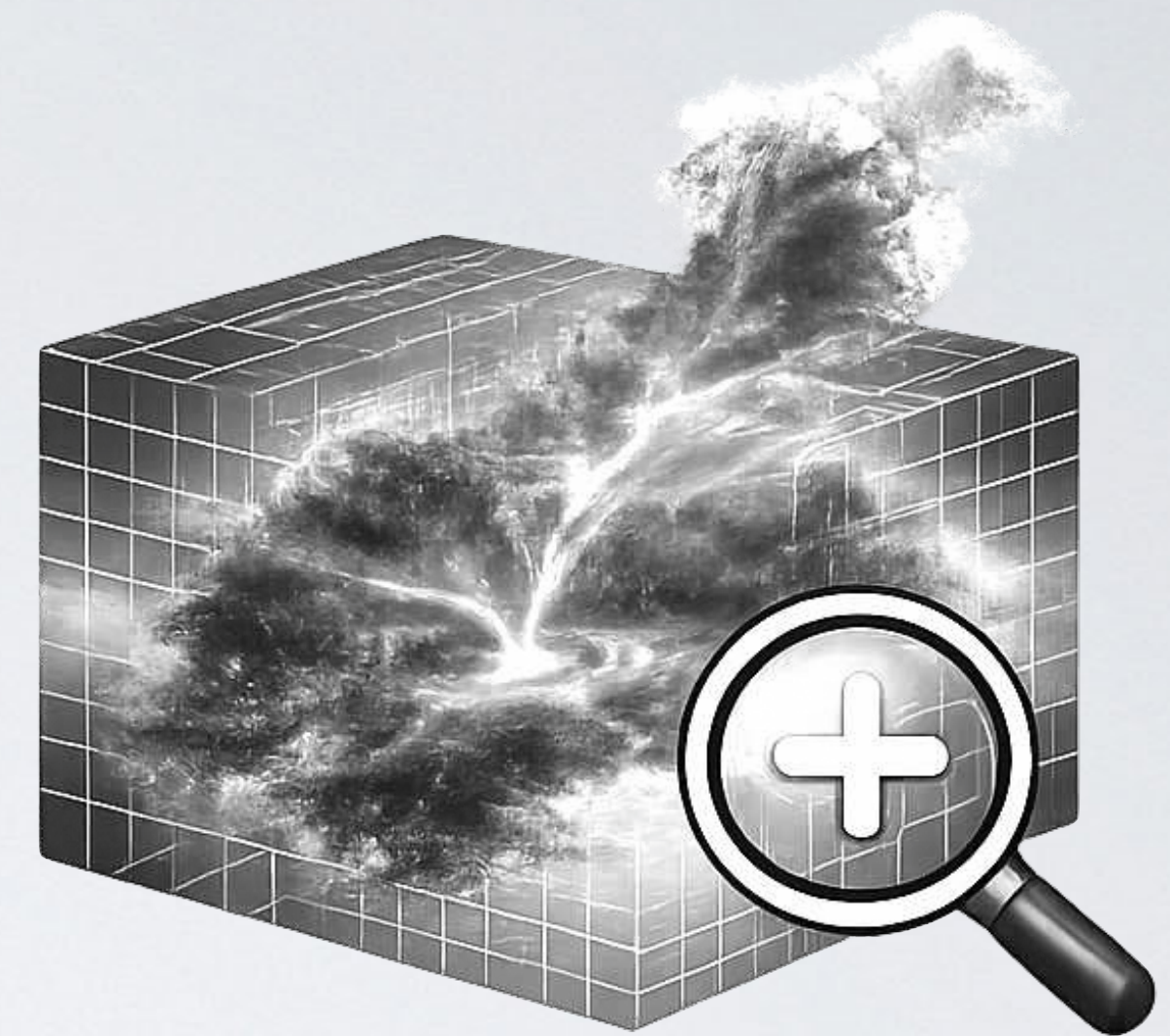
Bottleneck:
Dust Evolution

POPULATION SYNTHESIS

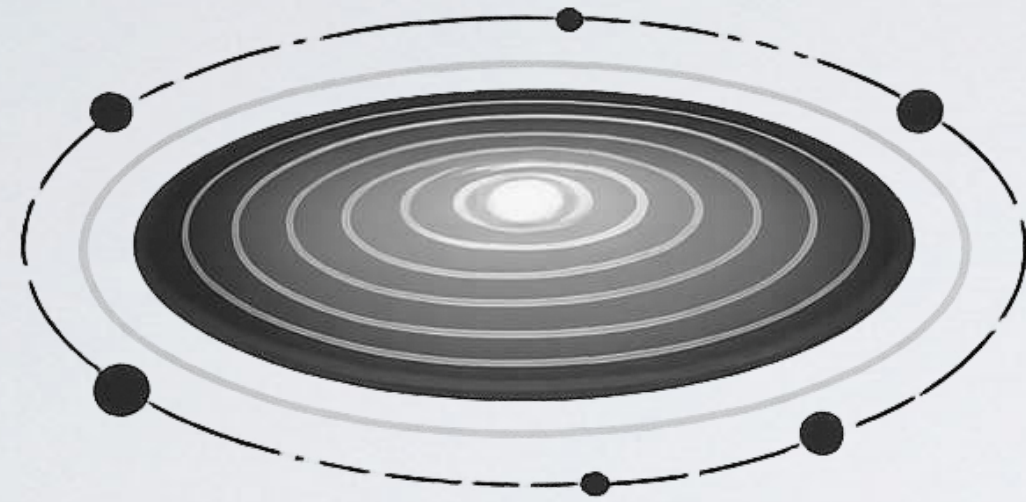
MULTI-DIM. MODELS



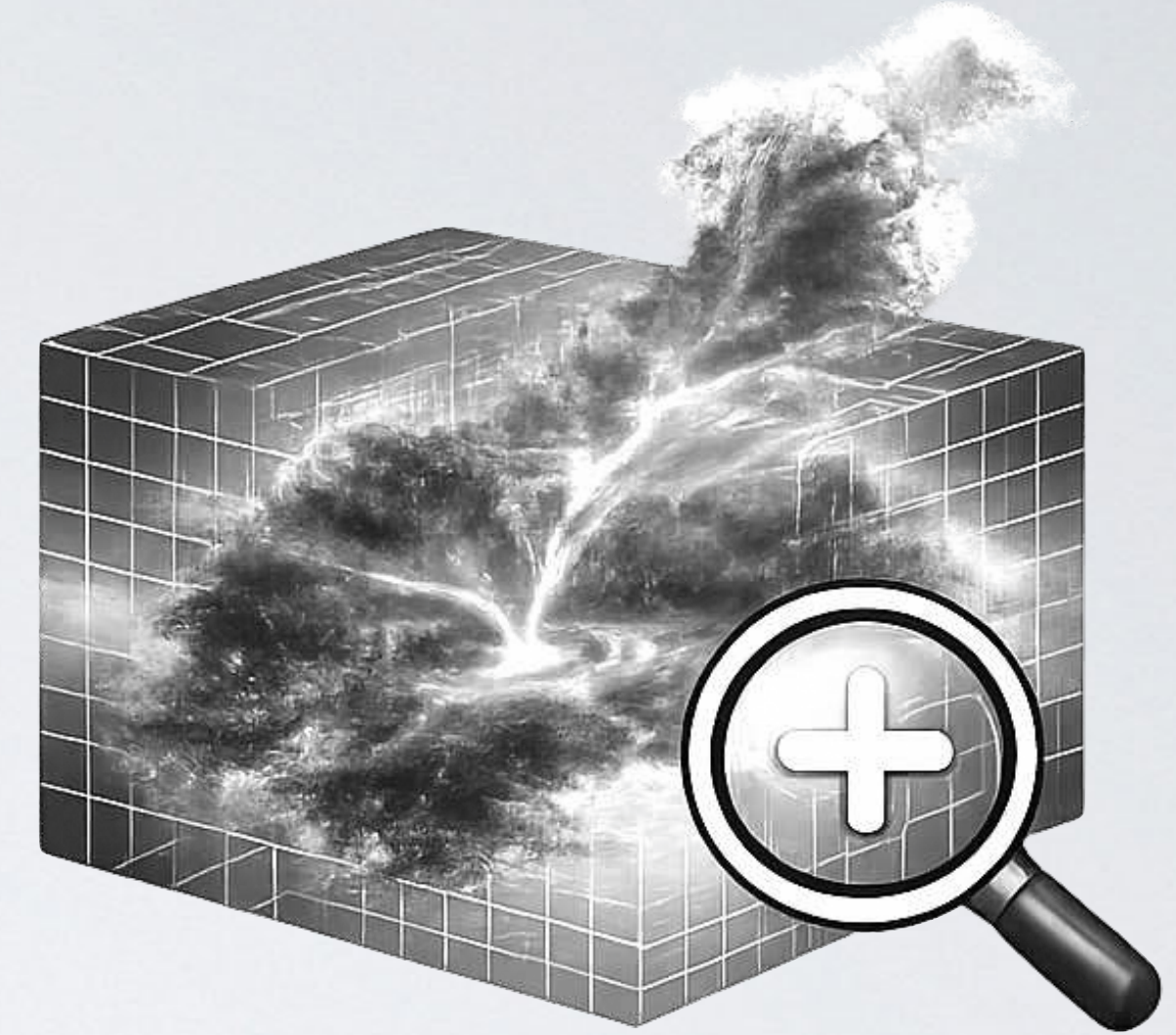
Pfeil, TB, Klahr '24



POPULATION SYNTHESIS



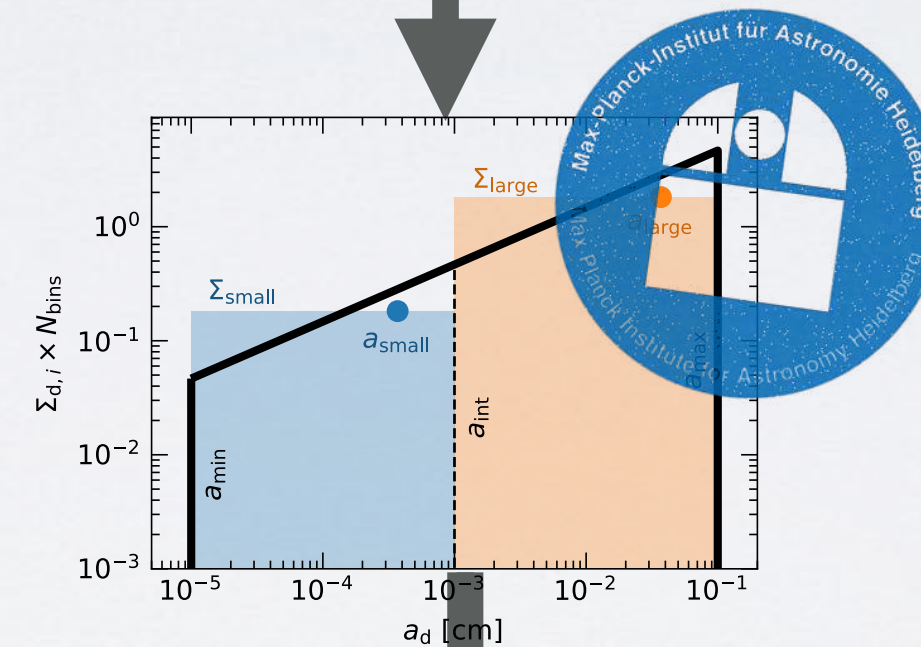
MULTI-DIM. MODELS



Python: TriPoDPy
github.com/tripod

- DUSTPY-compatible
- **composition** tracking
- sublimation/condensation
- tracers (dust or gas)
- N-Body with GENGA

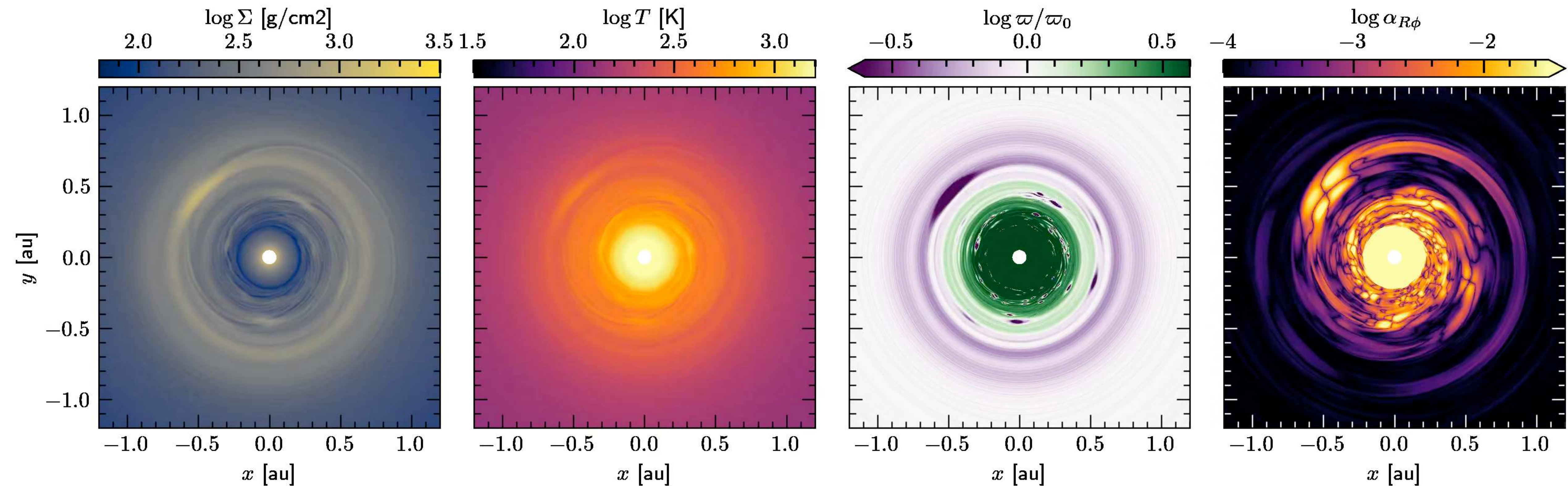
Planet & Disk
Population
Synthesis



Algorithm in:

- PLUTO
- IDEFIX
- ATHENA

TRIPoD: OUTBURSTS



Sebastian Stammerl



Anna Penzlin



Alex Ziampras



Nicolas Kaufmann
Ziampras et al. 2026b, Ziampras & Birnstiel 2026

SUMMARY

Substructure Is Needed

... early on & everywhere
... can solve many problems at once

TriPoD can help with the bottleneck of dust evolution

Enabling Disk & Population Synthesis Studies
Enabling dust-evolution effects in MultiDim Simulations

No Planets without MPIA!



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MÜNCHEN



THANKS FOR YOUR ATTENTION!



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