

y = -0.44 AU
t = 109.46 kyr

huehn@uni-heidelberg.de



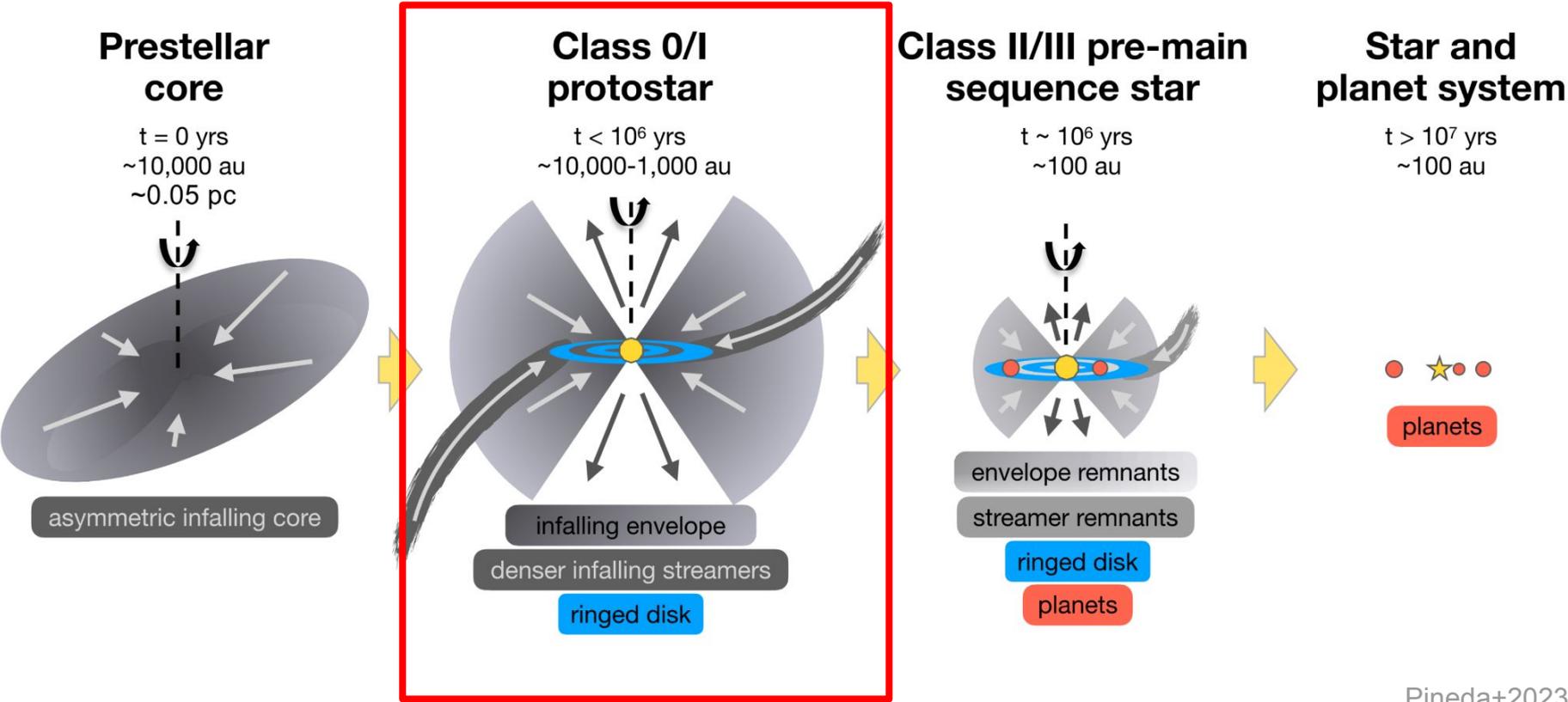
Infall Onto Disks Across Evolutionary Stages

Early Planetesimal Formation, Streamers & Substructure

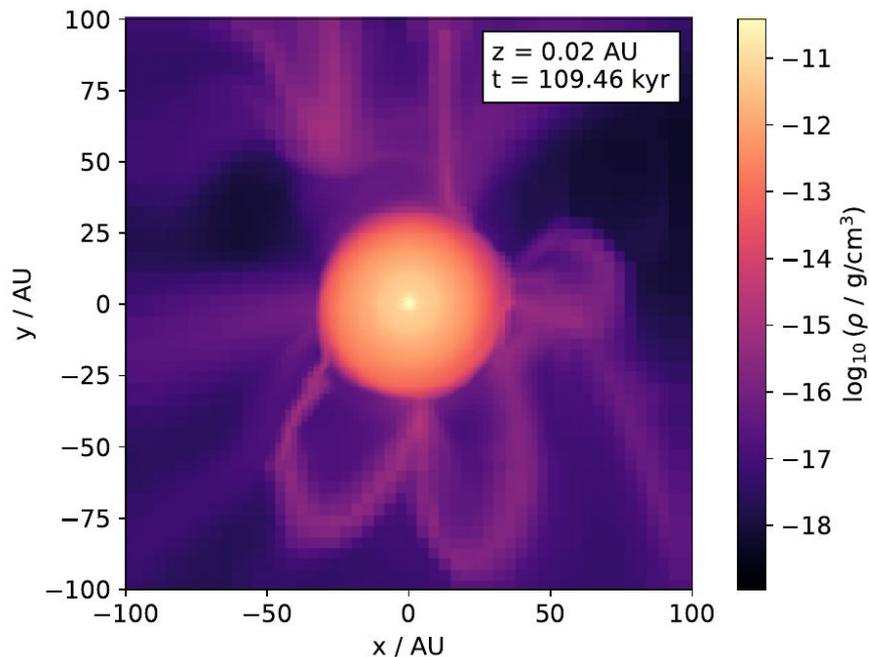
León-Alexander Hühn, ITA, Heidelberg University

SPiCE 2 Conference, March 19th 2026

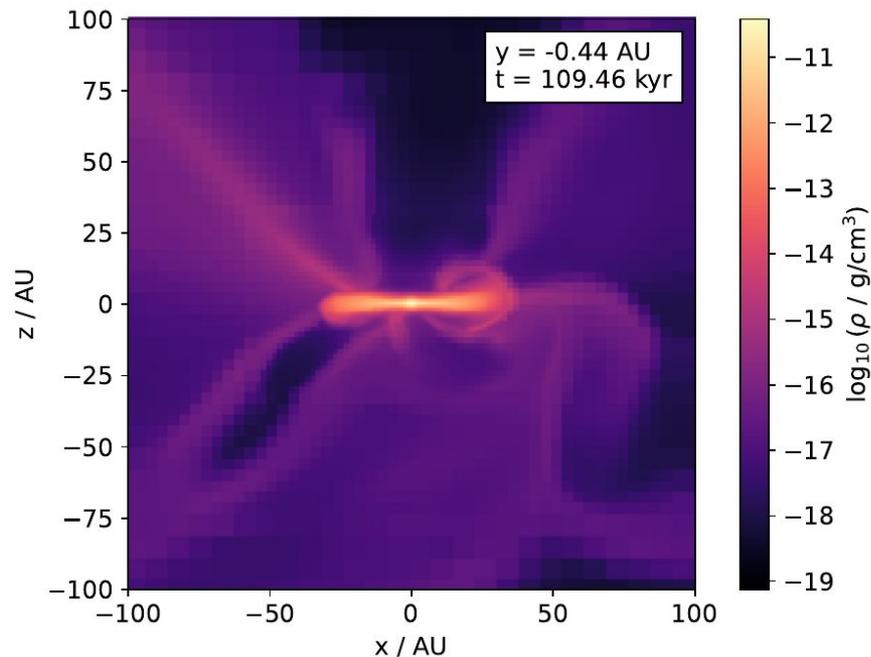
Evolutionary stages of protoplanetary disks



Environment of young disks

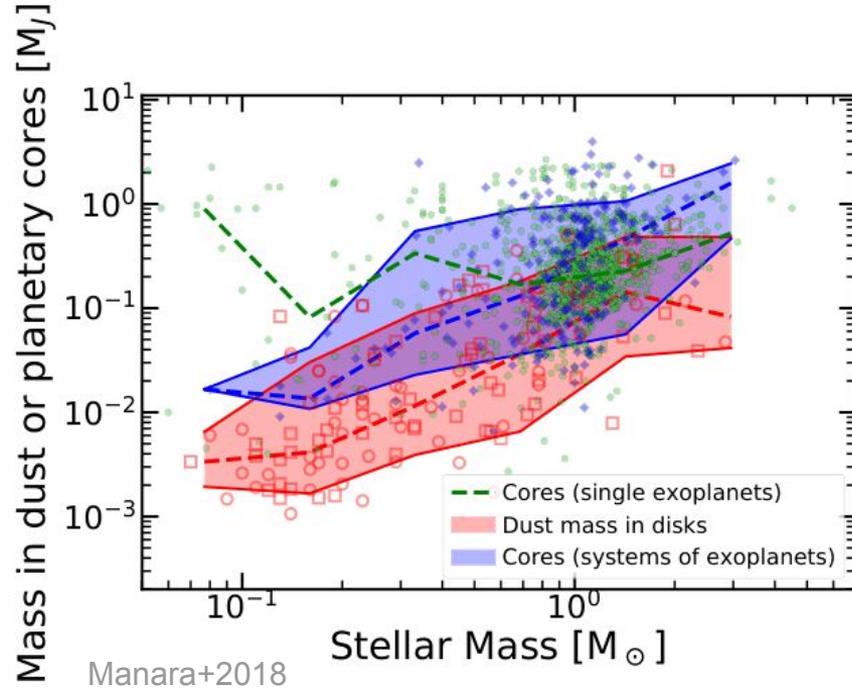


Hennebelle+2020; Hühn+2025a

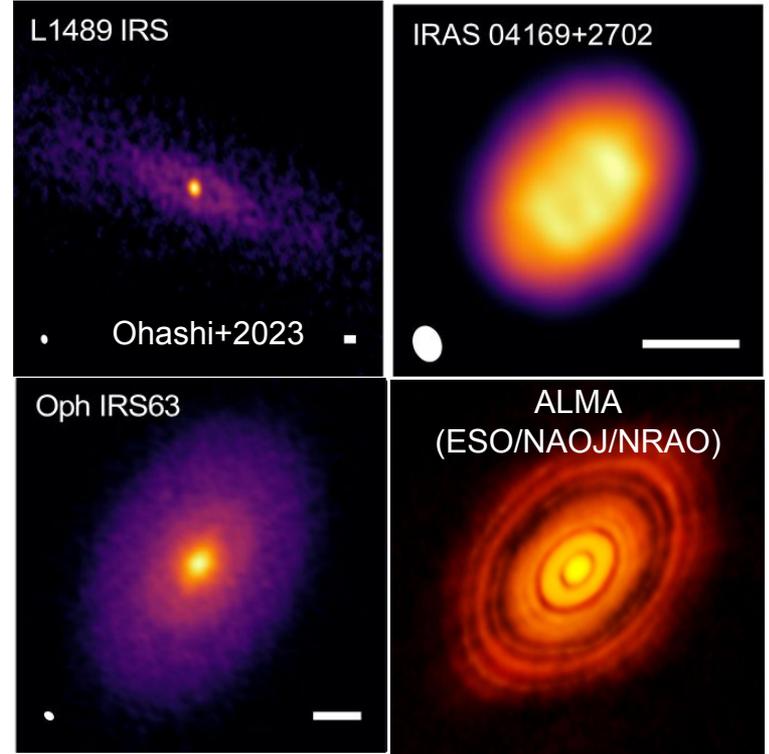


Young (Class 0/I) disks continuously accrete from their environment!

Why are young disks important to consider?

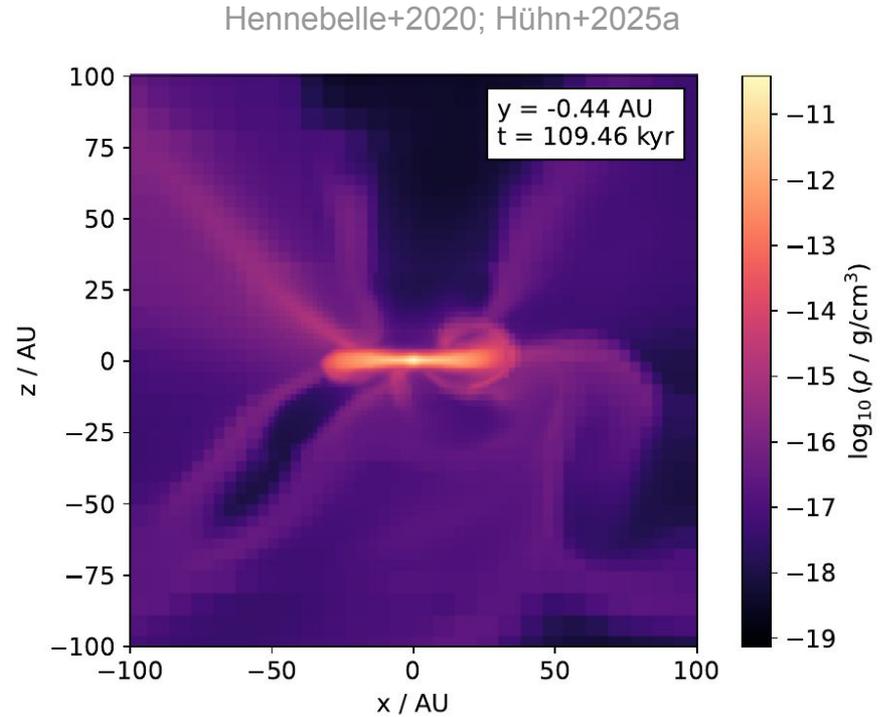
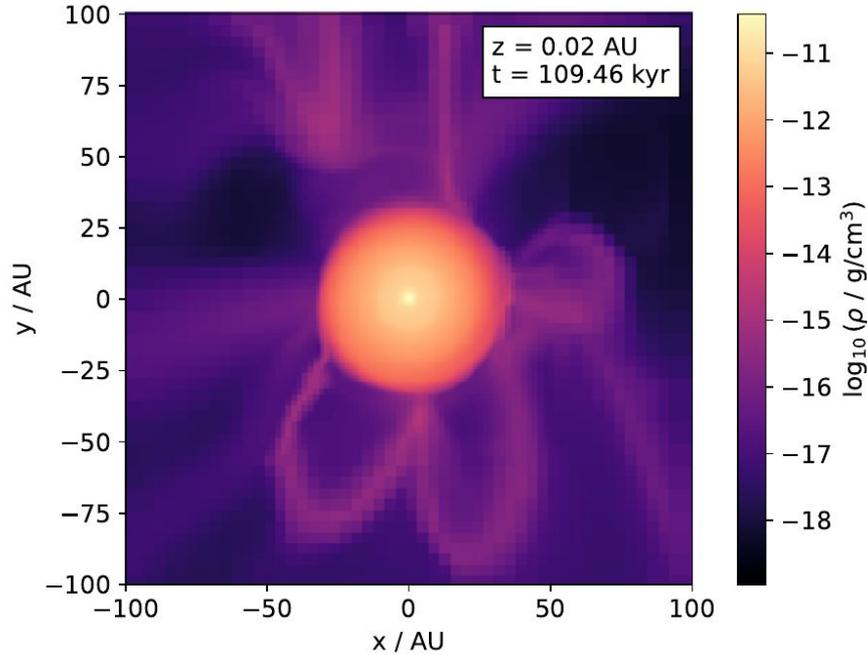


Mass budget problem



Early substructure/rings

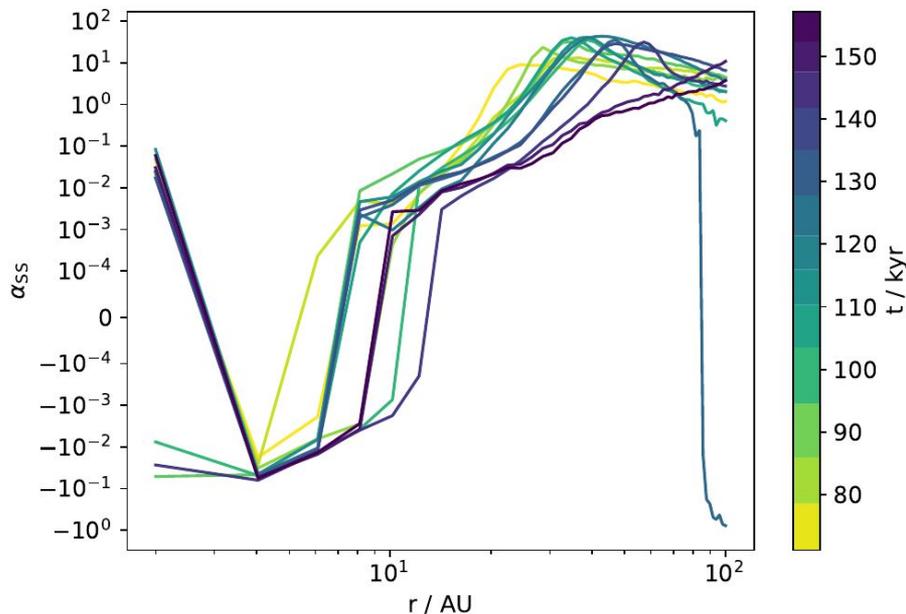
Environment of young disks



⇒ Create approximate 1D model for planetesimal formation modeling

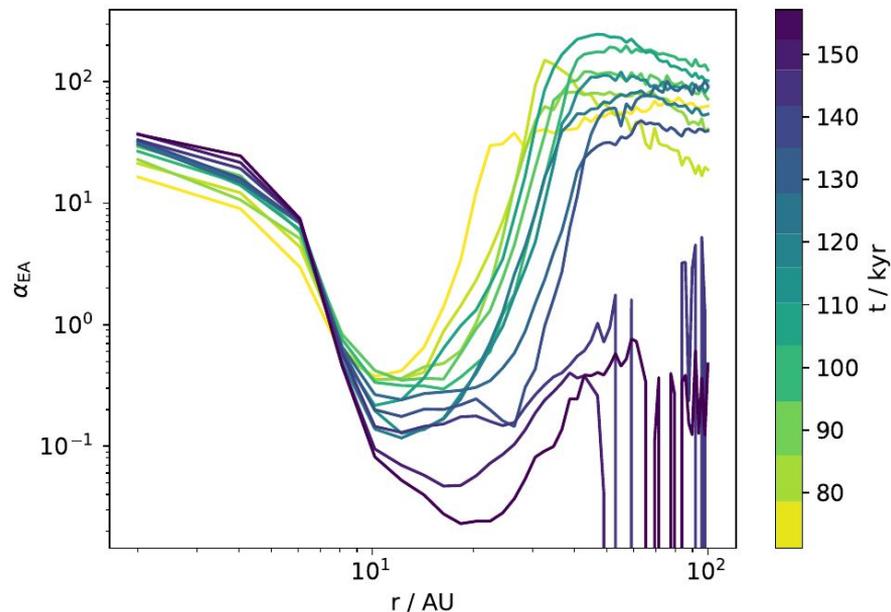
3D core collapse \Rightarrow 1D Model

“Viscous” alpha



Negative α_{SS} : Not suitable for 1D

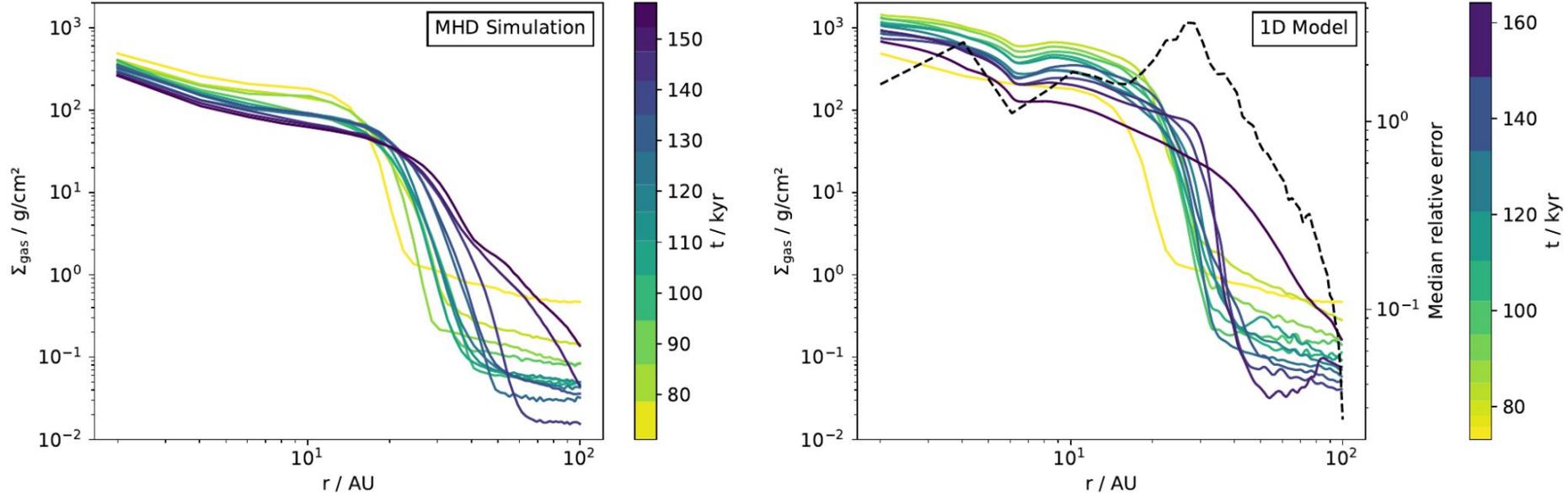
Alpha for external torque



α_{EA} : Dominates early disk evolution

1D Model

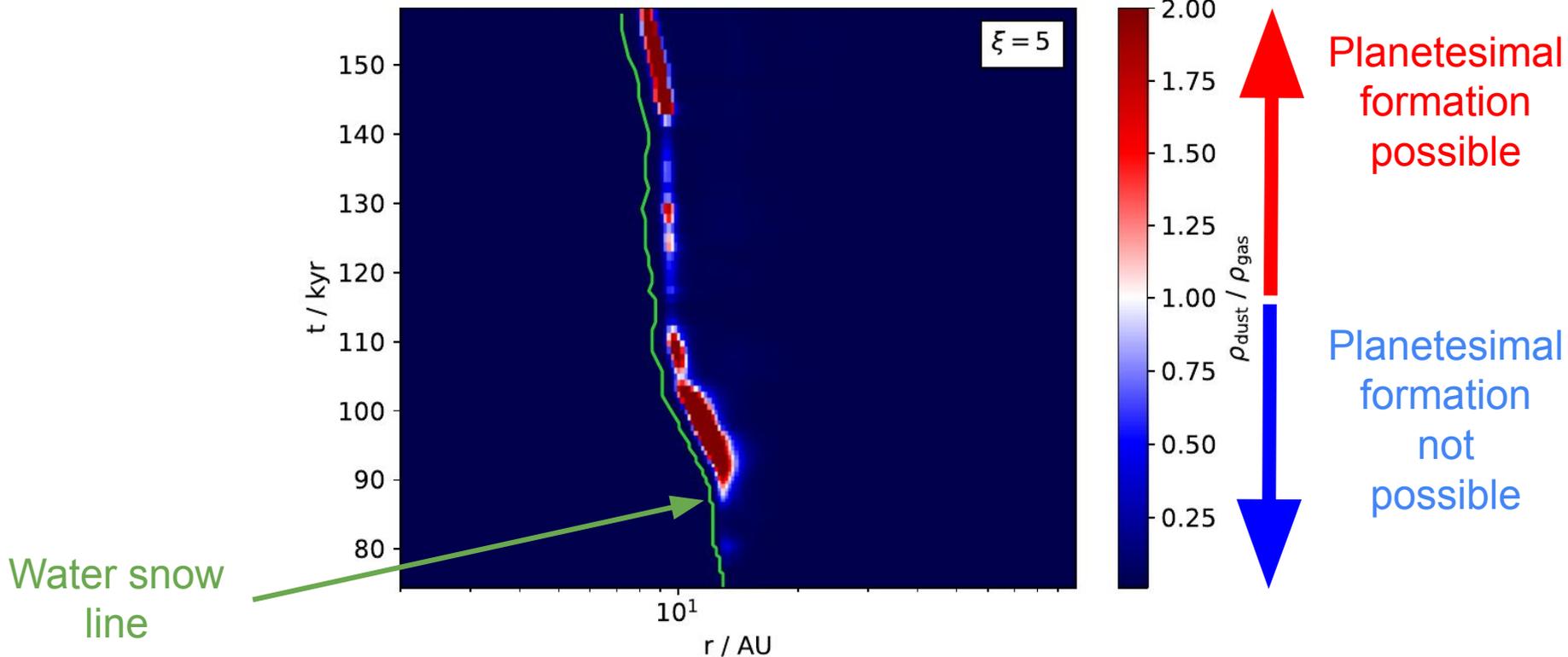
Hühn+2025a (inc. Lebreuilly, Hennebelle)



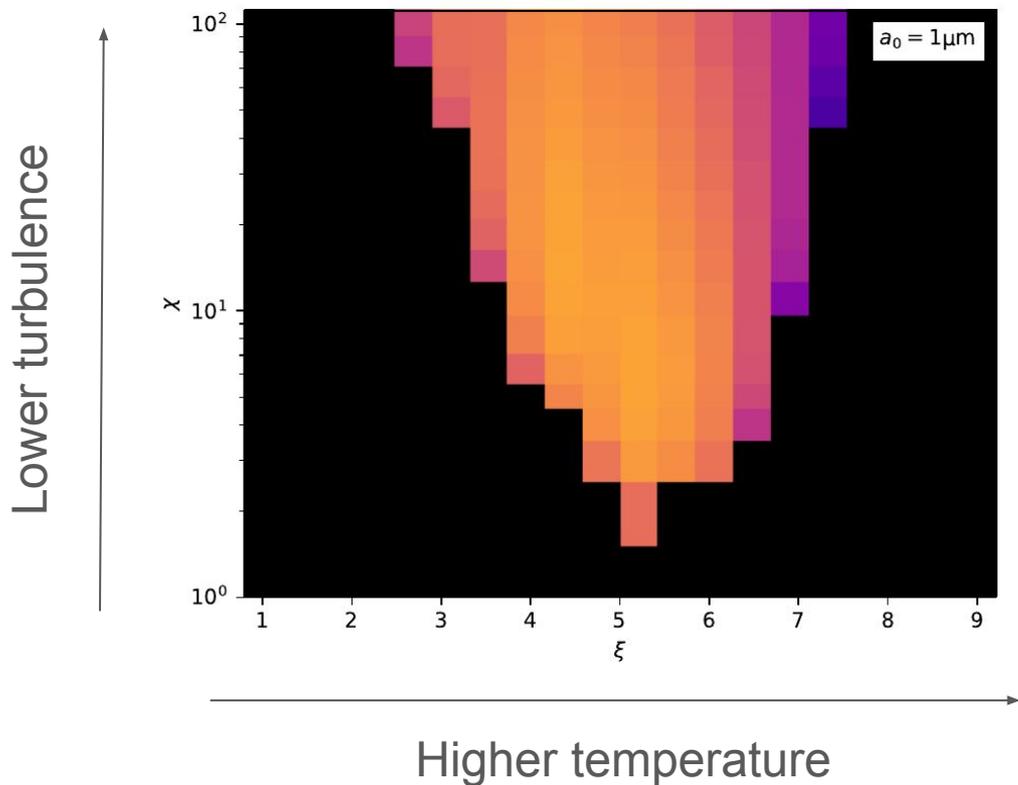
1D model approximates early disk evolution to order of magnitude

Early planetesimal formation?

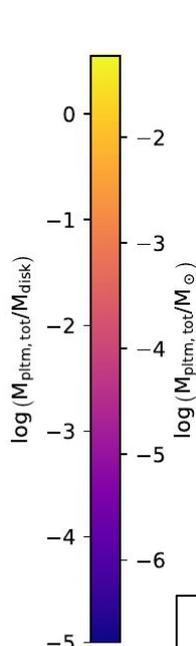
Retention of solids via
cold-finger effect



Early planetesimal formation!



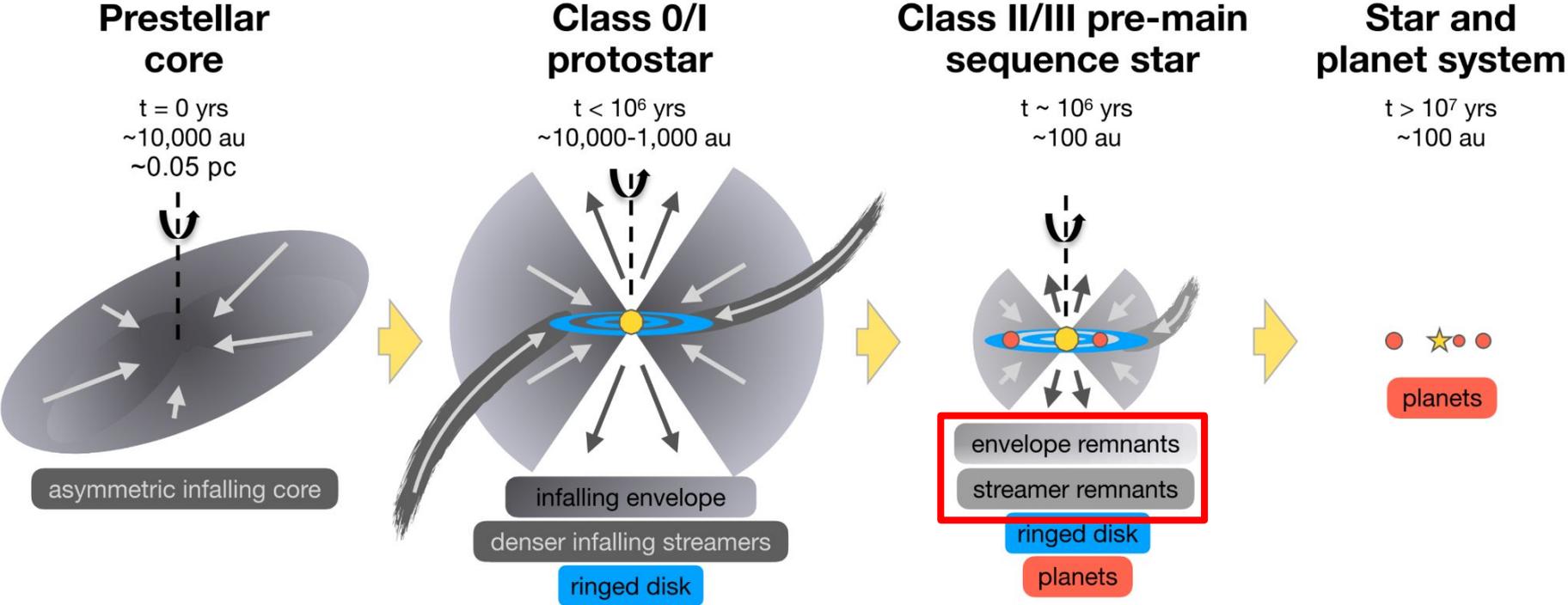
$$\log Z_{\text{crit}}(\tau_s, \alpha_D) = A'(\log \alpha_D)^2 + B' \log \tau_s \log \alpha_D + C' \log \tau_s + D' \log \alpha_D, \quad (19)$$



Lim+2024 criterion:
Size + Turbulence
⇒ Dust Density

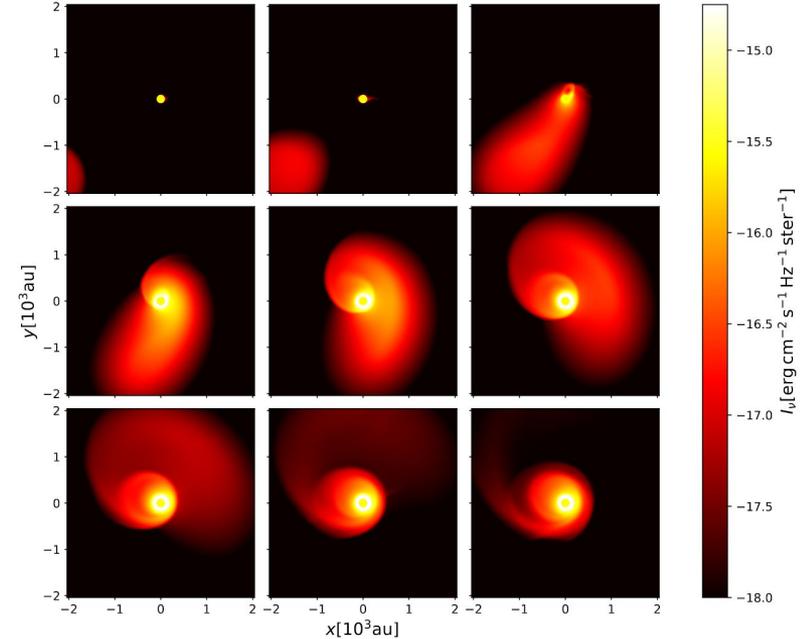
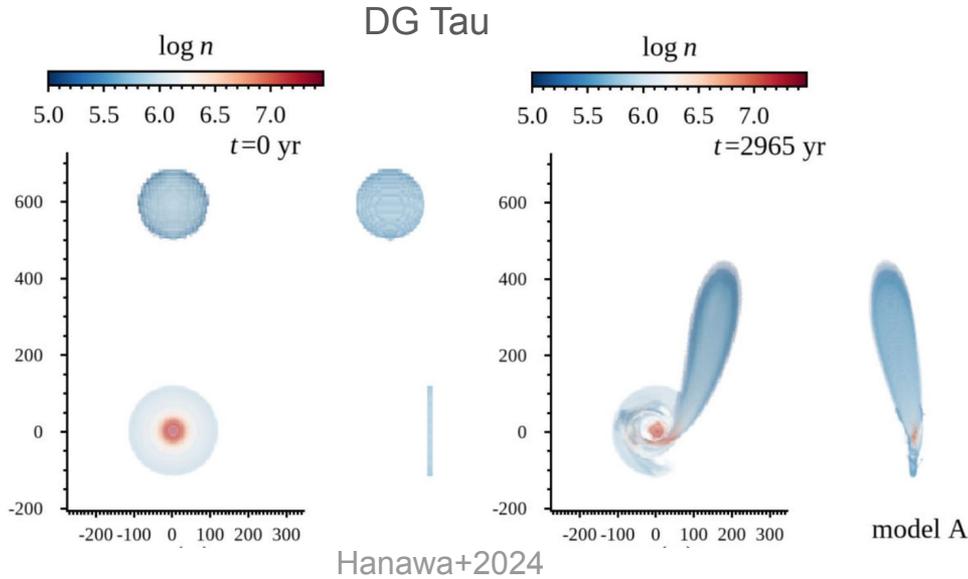
Planetesimals form **early**
(given the right conditions)

Evolutionary stages of protoplanetary disks



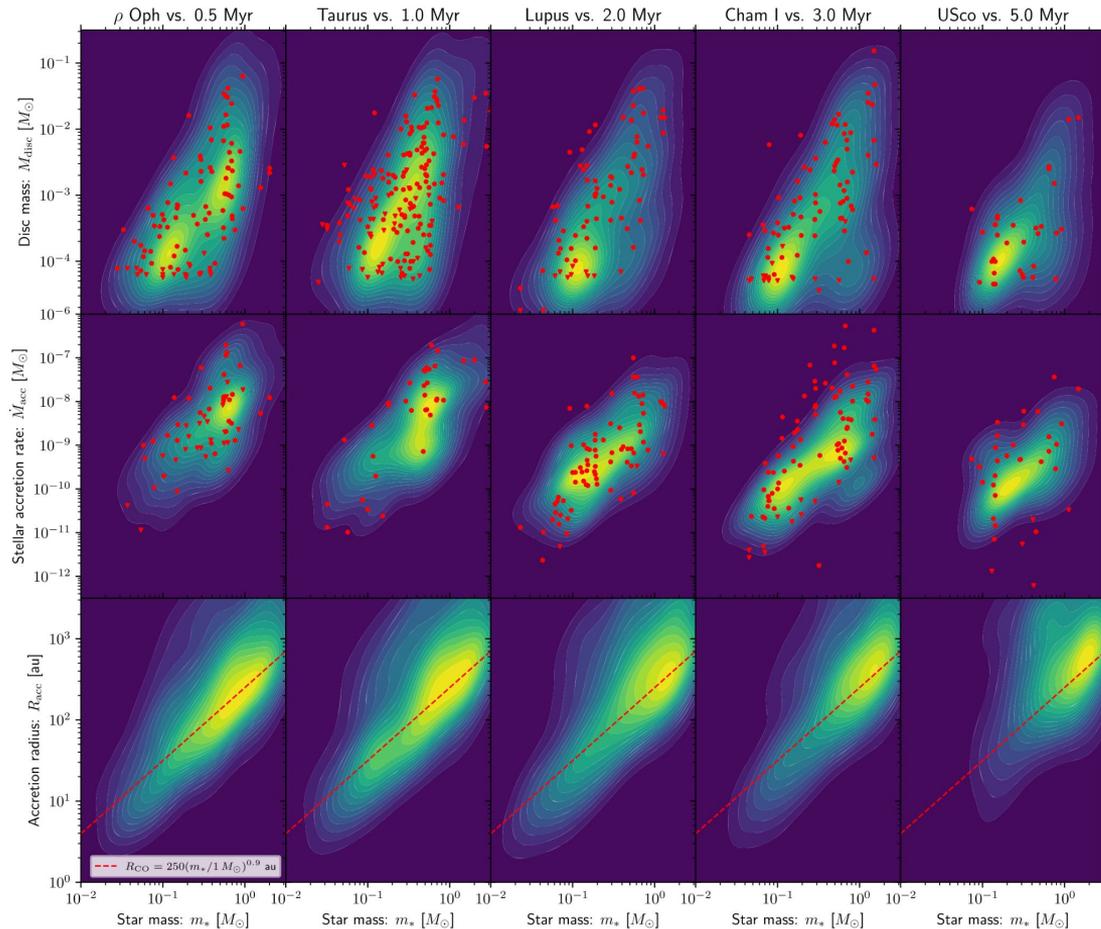
Are the large-scale structure inflow?

Dullemond+2019



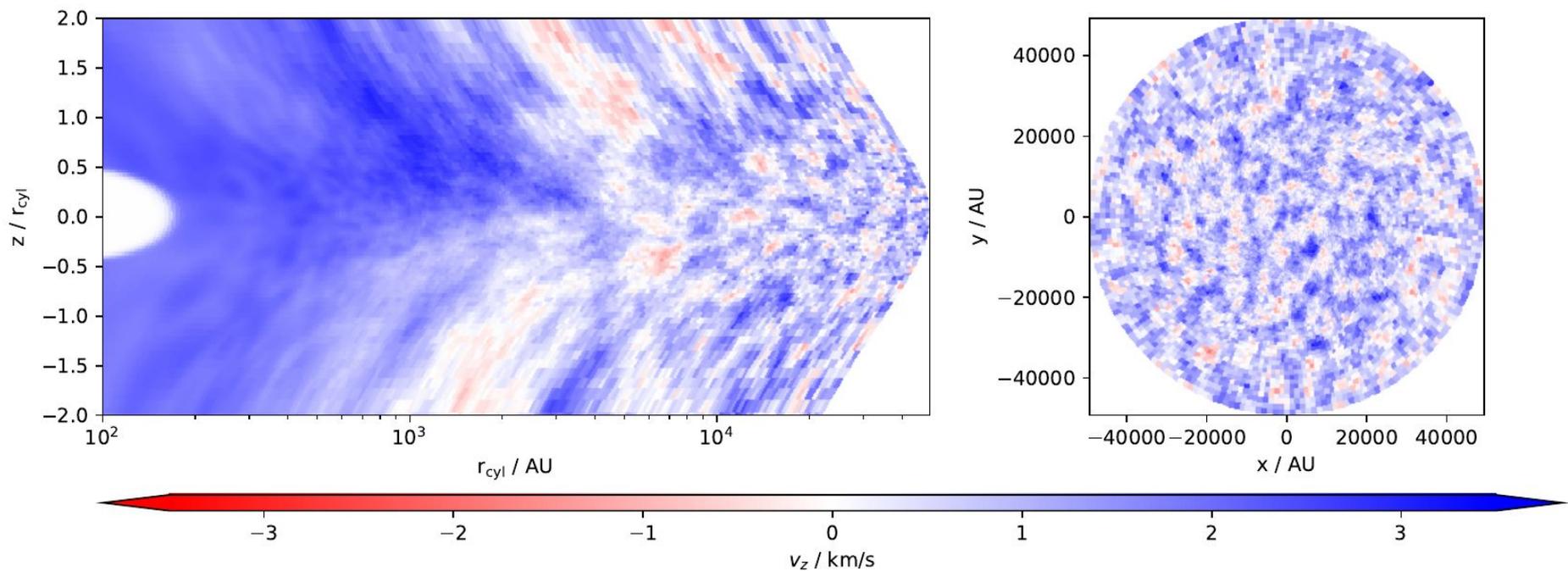
Material inflow modeled as the capture of a spherical gas cloudlet

More realistic accretion mechanism?



Models of **Bondi-Hoyle-Lyttleton accretion** can explain correlations of disk parameters with stellar mass

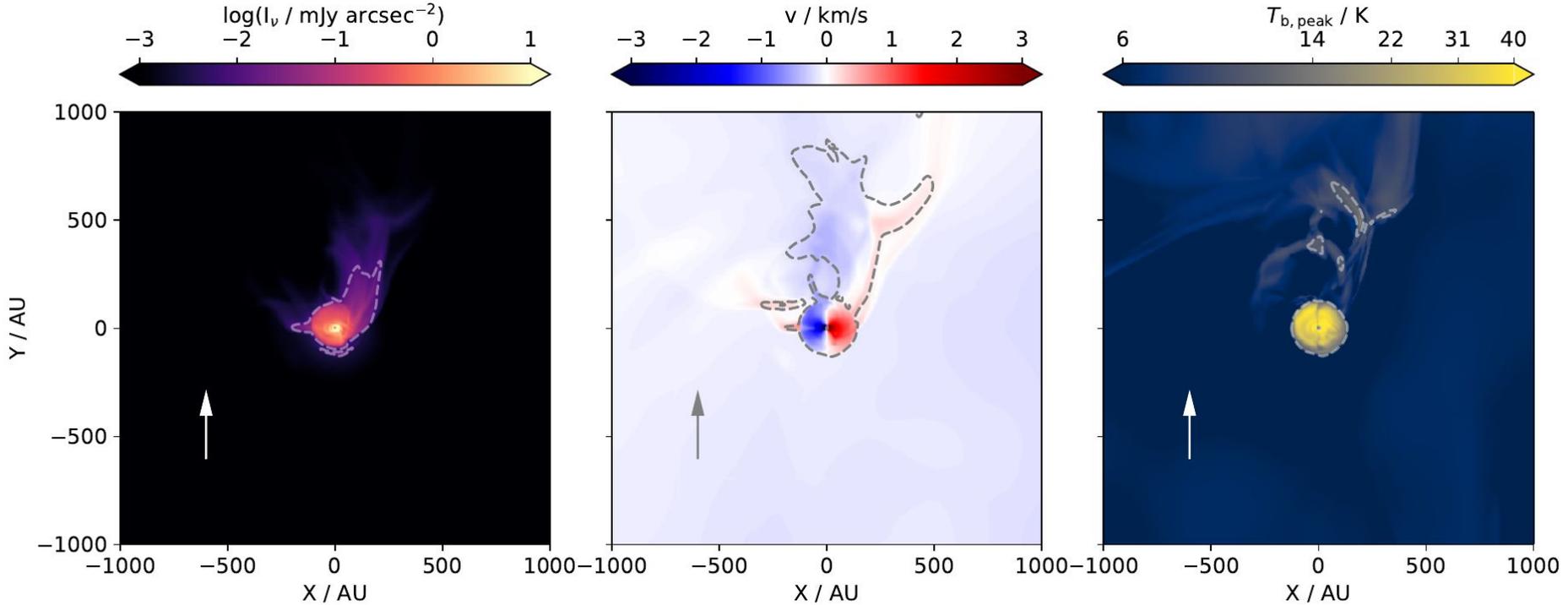
Bondi-Hoyle accretion: Initial condition



Compressible turbulence (Gaussian random field) with given power spectrum

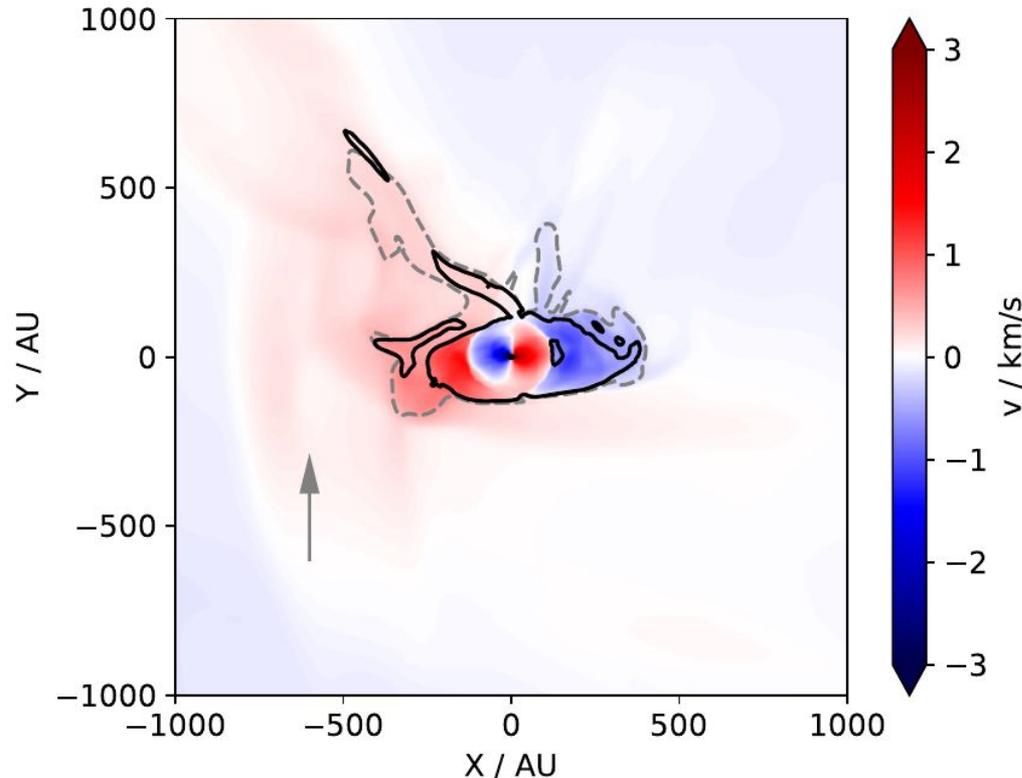
Bondi-Hoyle accretion: Streamer formation

$$\frac{d}{dt} M = 1e-8 M_{\odot} / \text{yr}$$
$$\rho_{\text{ISM}} = 3e-21 \text{ g/cm}^2$$



Infall in a turbulent medium naturally creates streamers

Bondi-Hoyle accretion: Strong turbulence, large scales



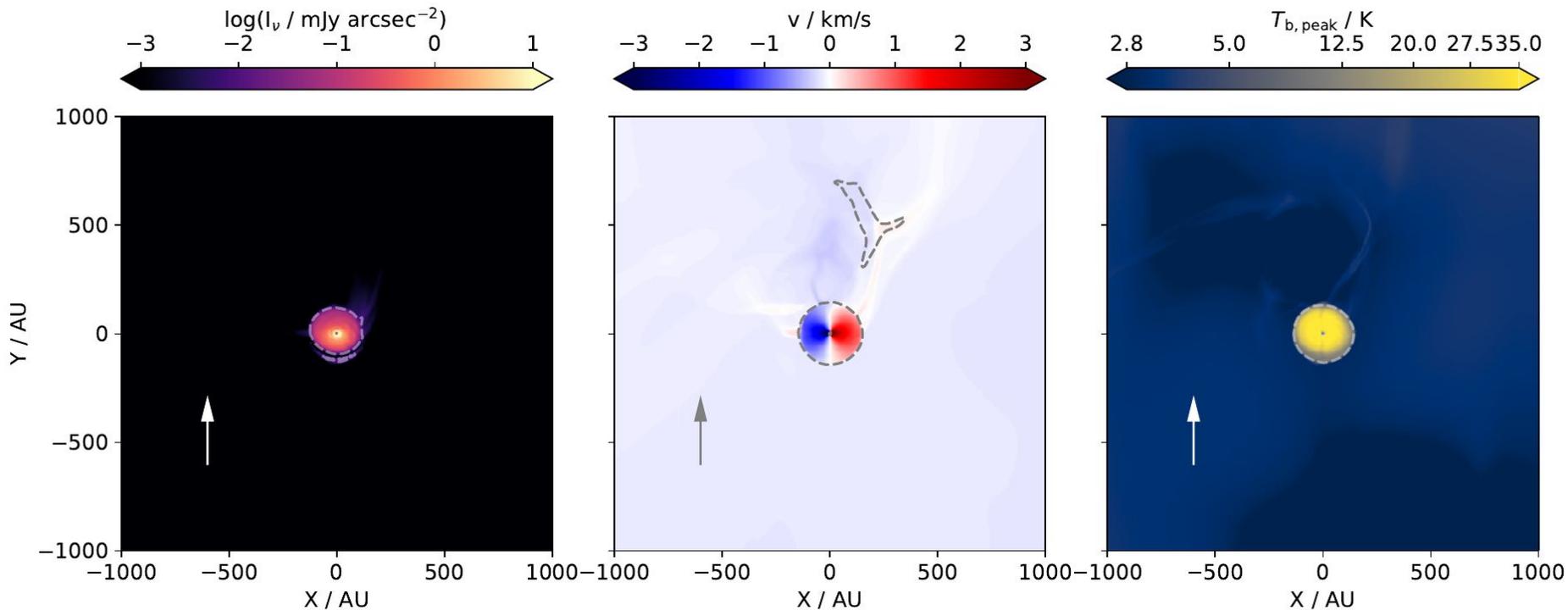
Morphology and multiplicity of the streamers depend on **environmental conditions**:

- Systemic velocity
- Turbulent scale
- Turbulent velocity
- Infall rate

Bondi-Hoyle accretion: Low infall rate

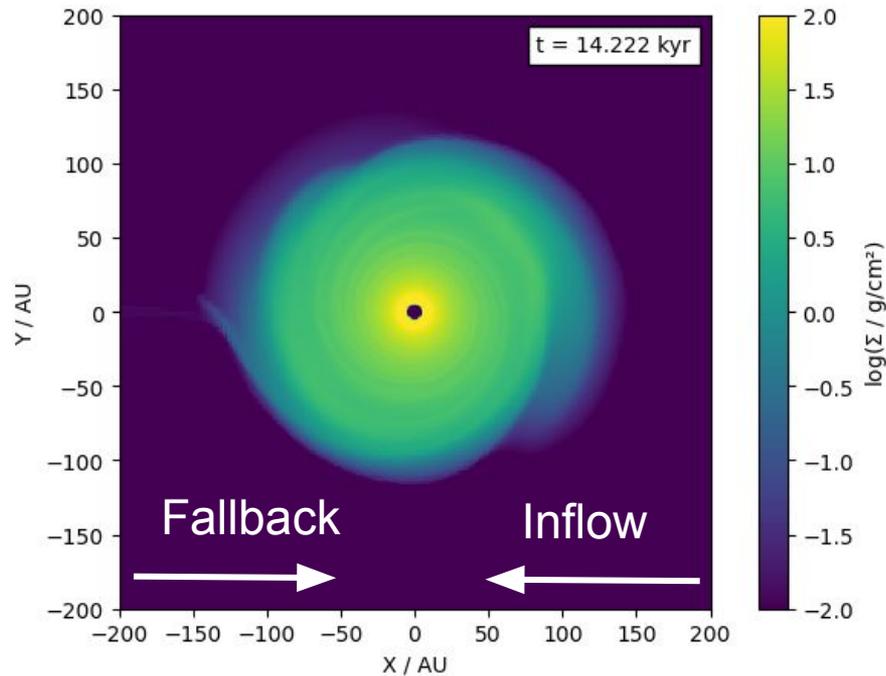
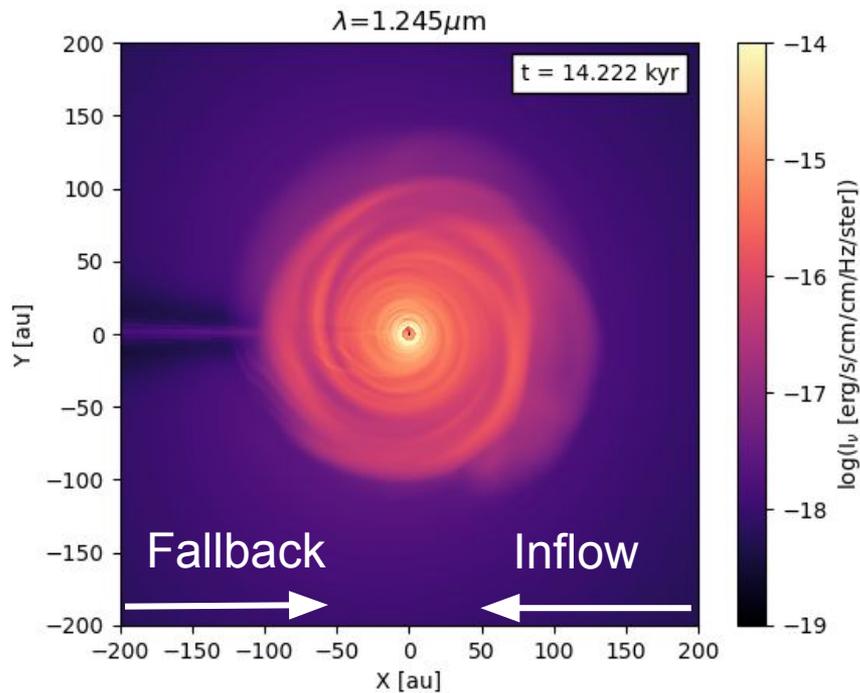
$$d/dt M = 1e-9 M_{\odot} / \text{yr}$$

$$\rho_{\text{ISM}} = 3e-22 \text{ g/cm}^2$$



No visible streamer, but the disk might still be affected

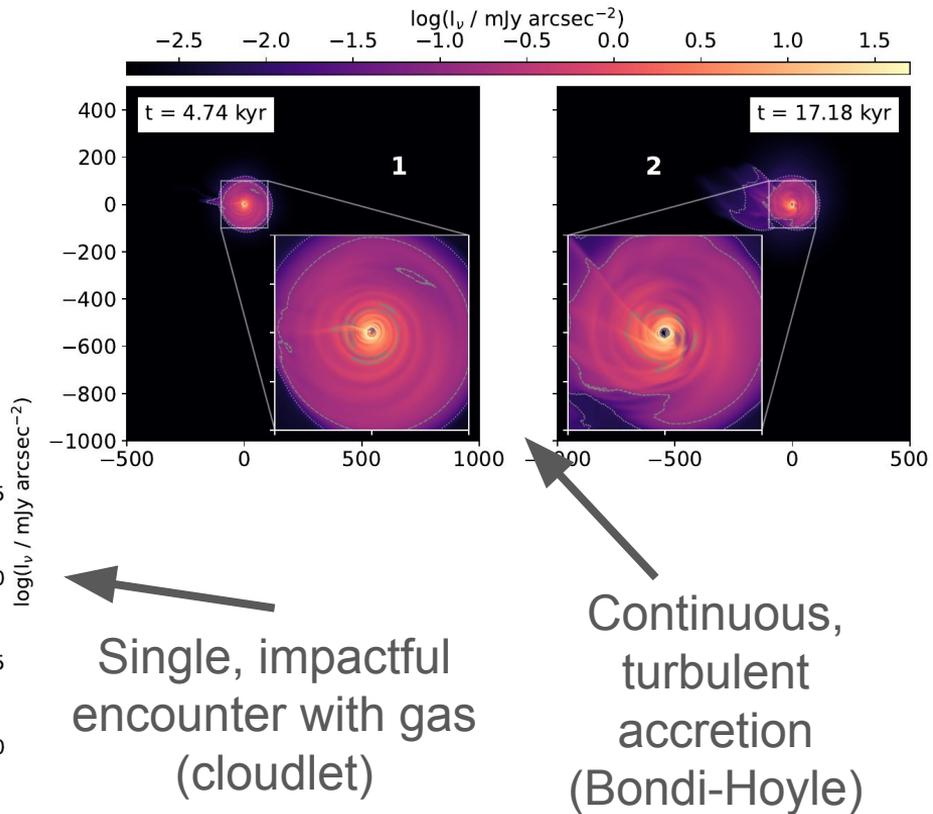
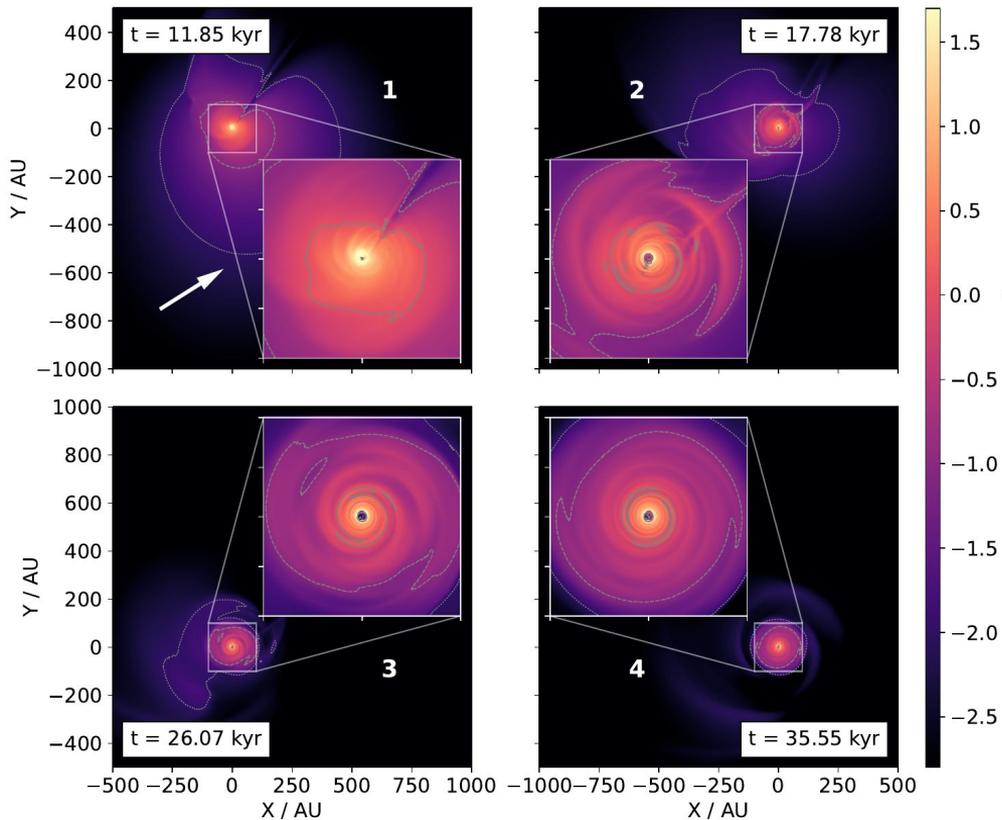
Spiral formation: Expected structure



Two-sided interaction \Rightarrow Two-armed spiral

Spiral formation

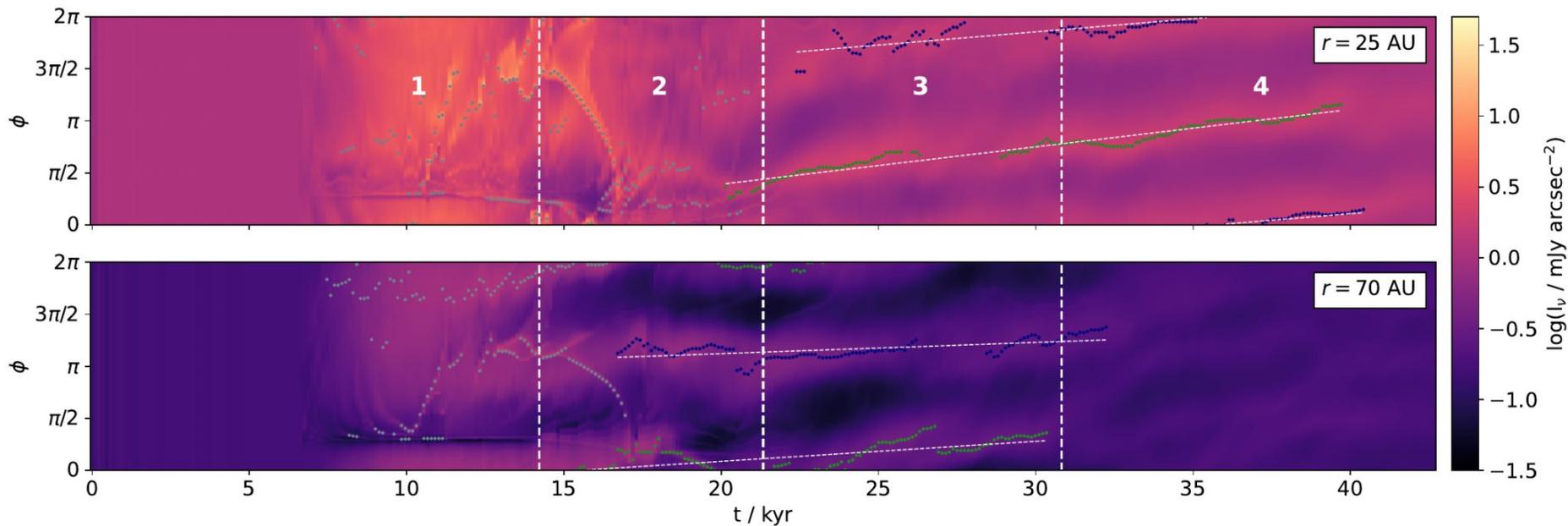
Hühn+2026



Form spirals only through infall

Pattern speed of the m=2 spirals

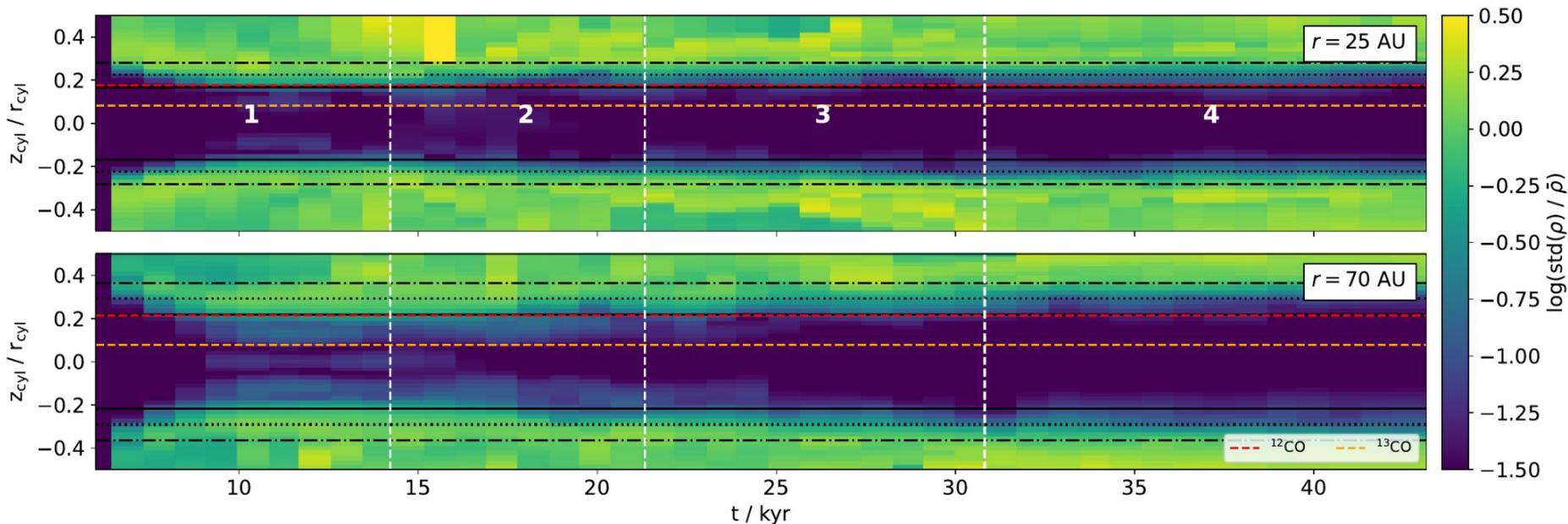
Hühn+2026



Outer spirals (almost) **stationary!** ($\sim 0.05 - 0.1 \text{ kyr}^{-1}$)

What layers of the disk are affected?

$$M_d = 0.05 M_\odot$$

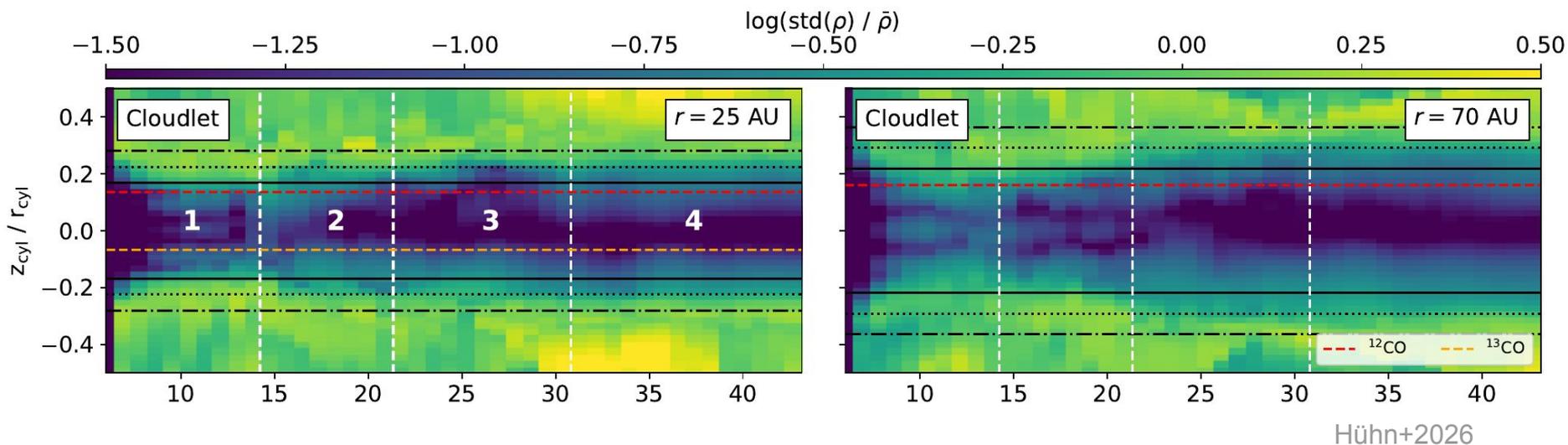


Hühn+2026

Even at the main impact, layers with $z < 3H$ are largely unaffected
⇒ Spirals are only **on the surface** for **young disks**

What layers of the disk are affected?

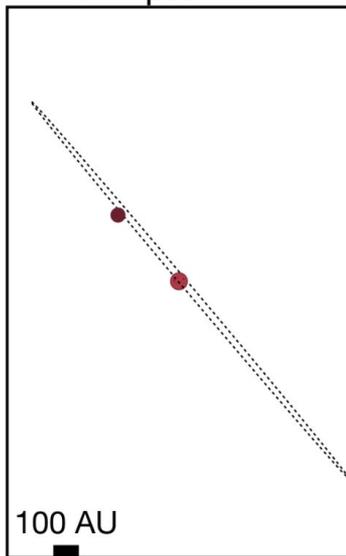
$$M_d = 0.005 M_\odot$$



- For lighter disks, **midplane layers** can be affected, especially in the outer disk
- ⇒ Late infall is more important for **older disks**
- ⇒ Different mechanisms for **planet formation here? Rejuvenation?**

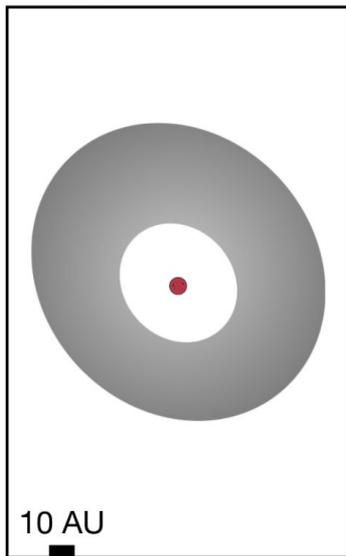
Late infall in IRAS 04125+2902?

a The binary companion

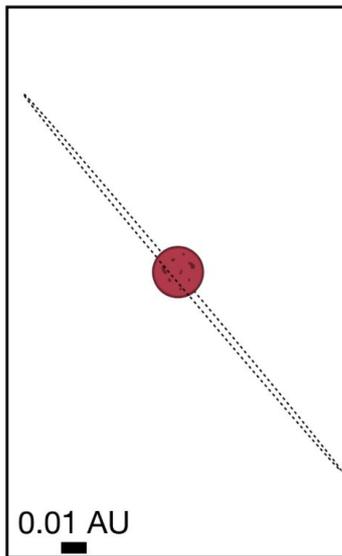


Barber+2024

b The transition disk

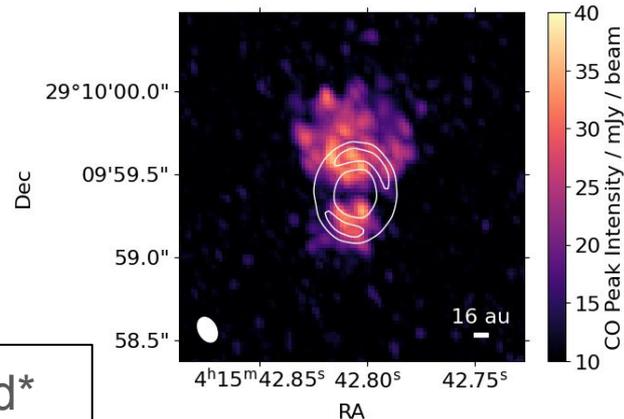
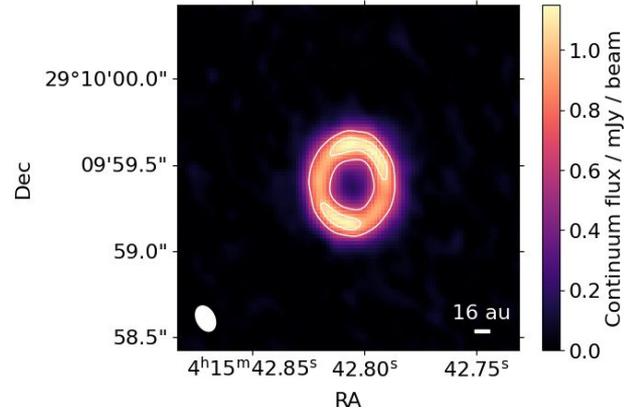


c The planet's orbit



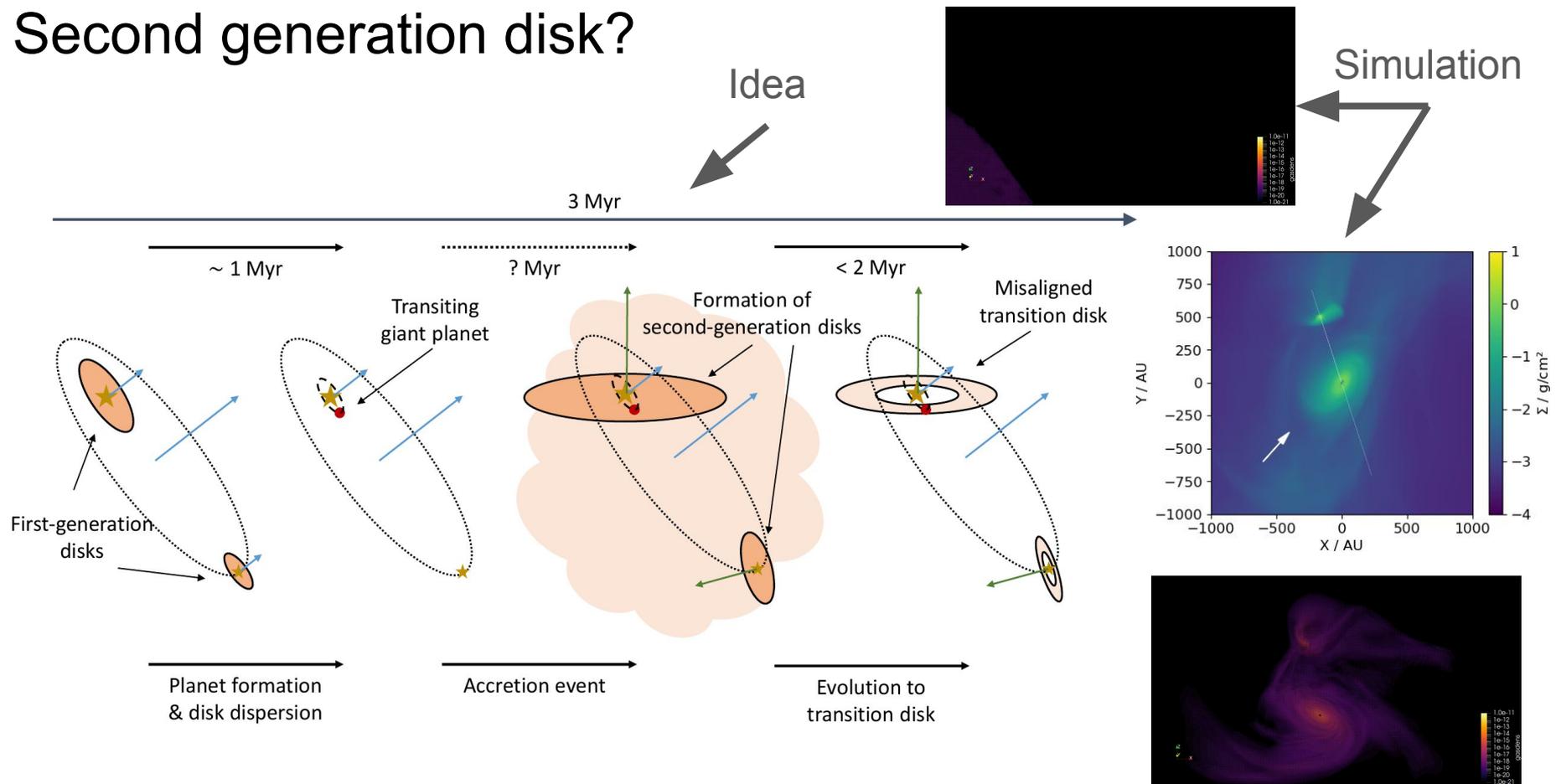
Binary and planet are aligned*
But: Protoplanetary disk is not!

Circum-primary disk



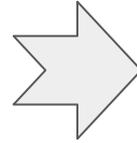
Boschaart+2025
Shoshi+2025

Second generation disk?



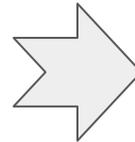
Environment / Large-scale influence on disks

- (Early) infall influences planet formation
initial conditions
- (Late) infall causes **streamers**,
delivering new material



Enhance mass budget of
first generation

- (Late) infall causes **spirals** of many
different shapes
- (Late) infall can create new **2nd
generation** disks



Rejuvenating planet
formation?

All **connected**: GMC conditions \Rightarrow Star formation \Rightarrow Early + late infall \Rightarrow Planets