Gas and dust instabilities in protoplanetary disks

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NCTS
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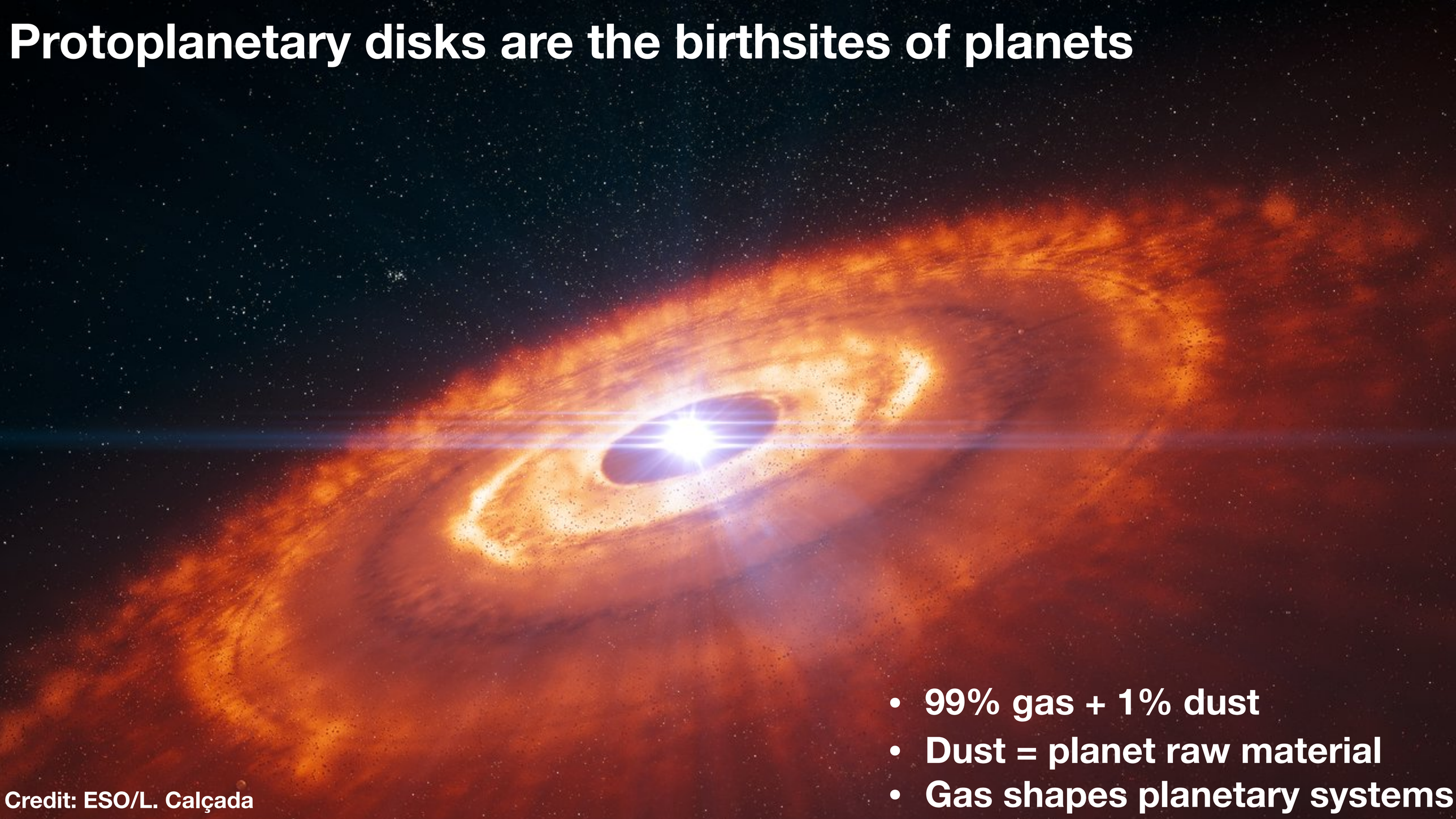
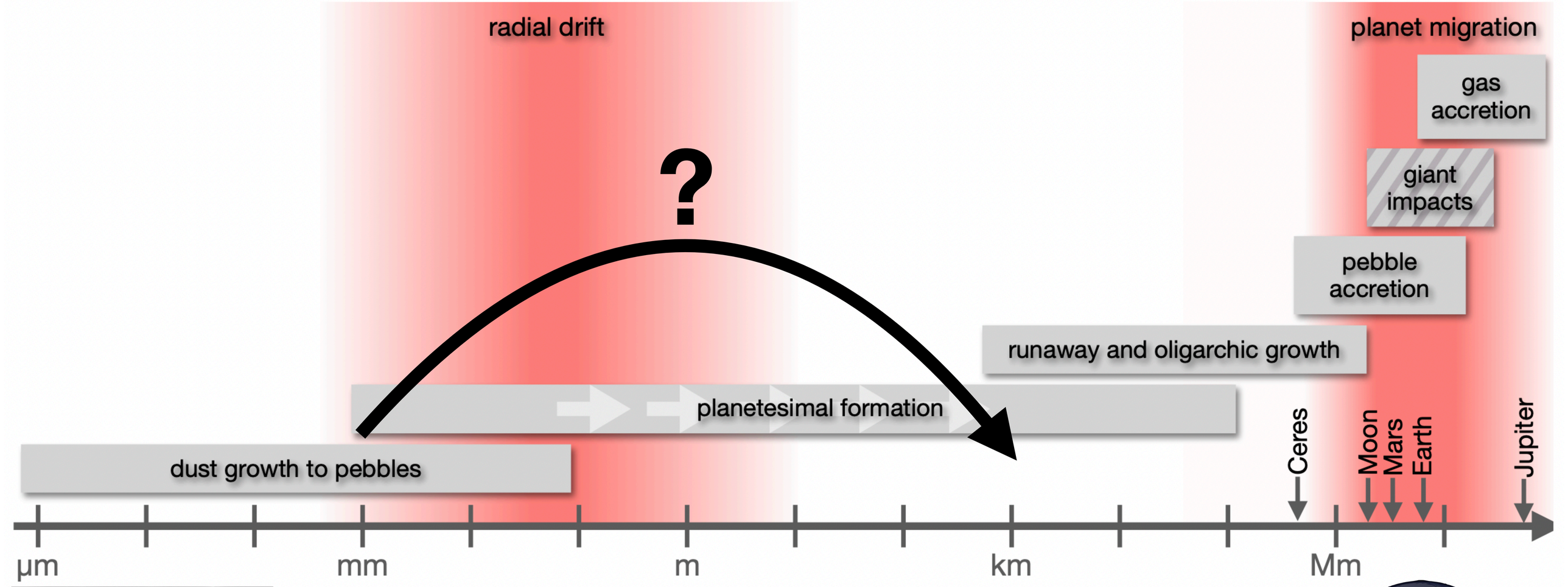
Protoplanetary disks are the birthsites of planets

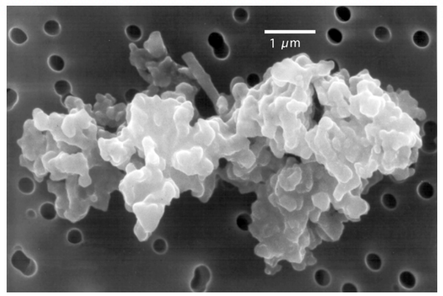


- 99% gas + 1% dust
- Dust = planet raw material
- Gas shapes planetary systems

Credit: ESO/L. Calçada

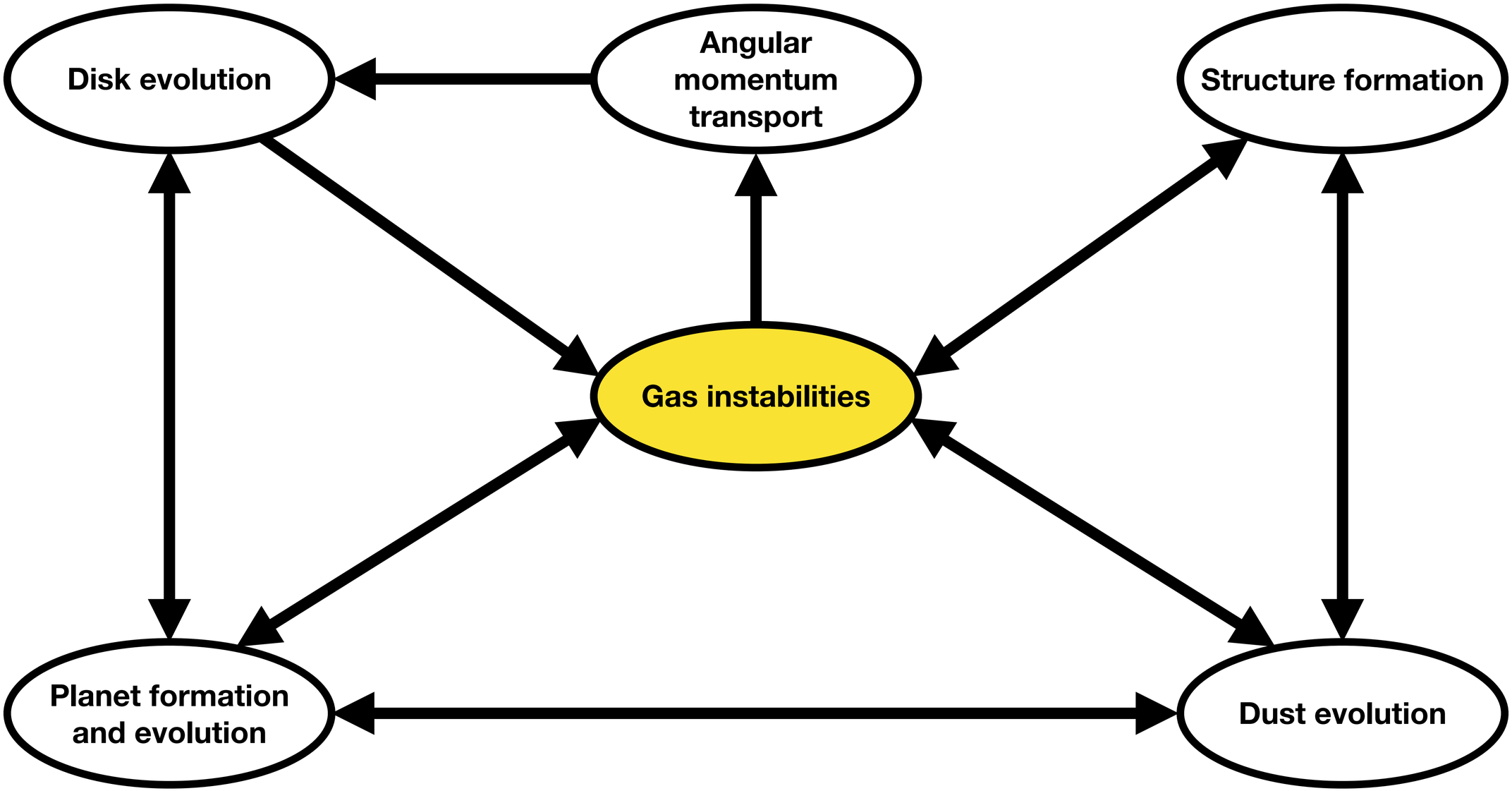
Planets start from dust grains



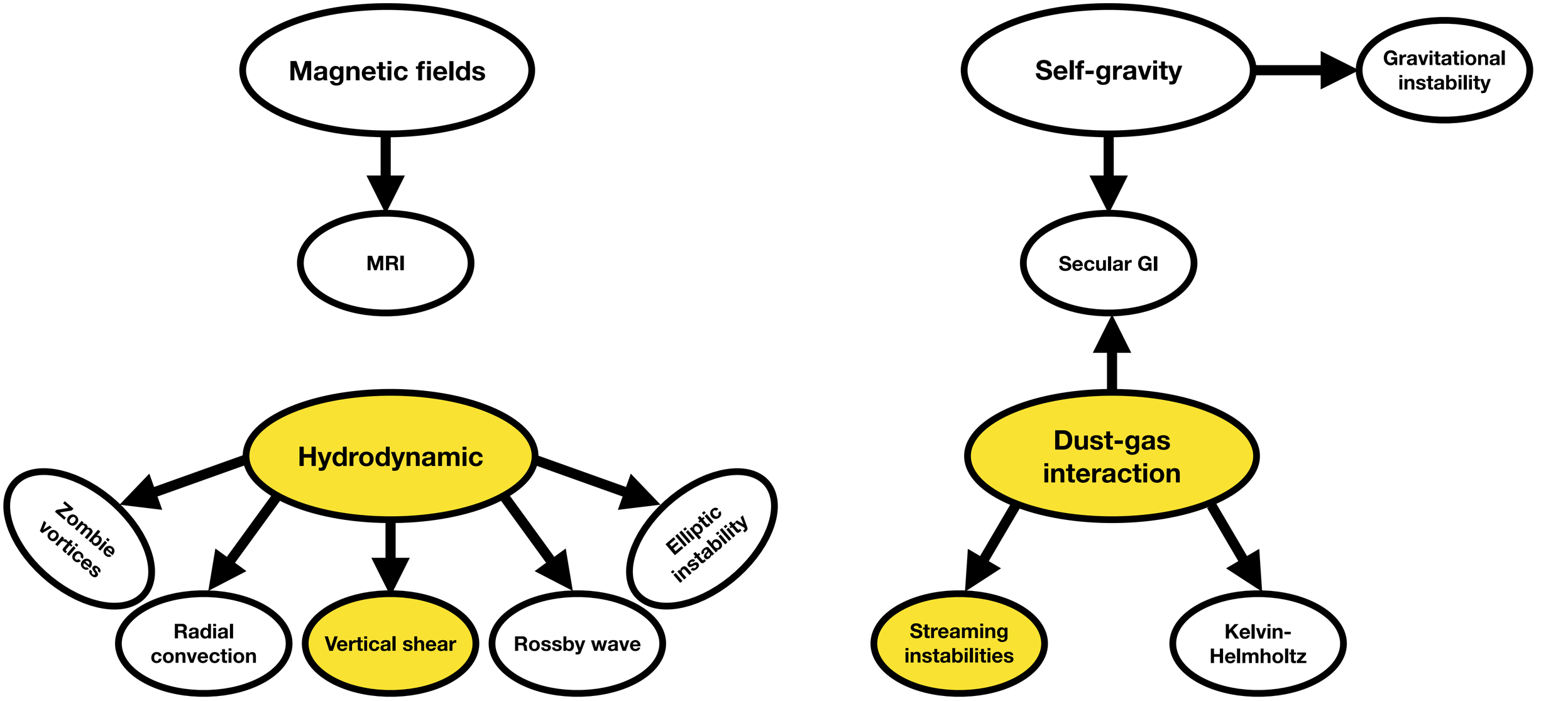


(Drazkowska et al., 2022, PPVII)

Disk mass dominated by gas

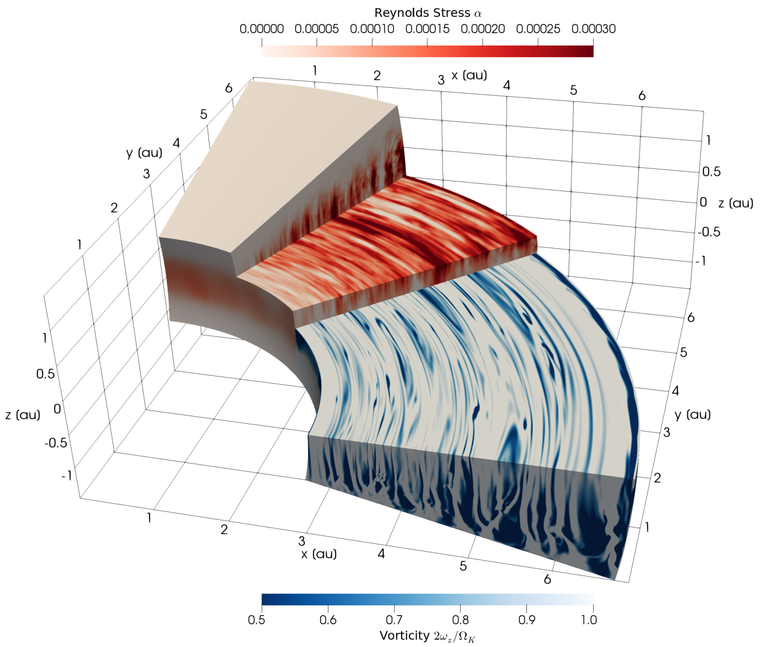


Instabilities in protoplanetary disks



Recent developments in disk hydrodynamics

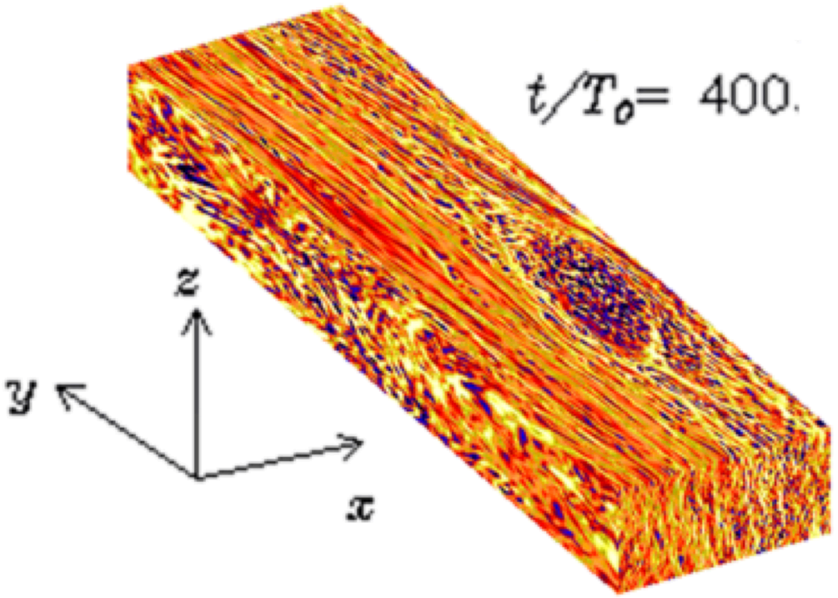
Vertical shear instability



Pfeil & Klahr (2020)

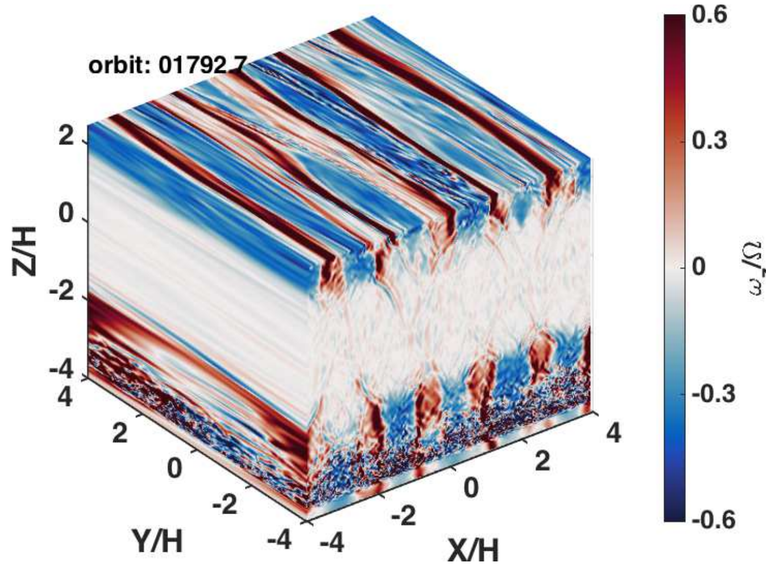
Lin & Youdin (2015)
Cui & Lin (2021)

Radial convection



Lyra (2014)

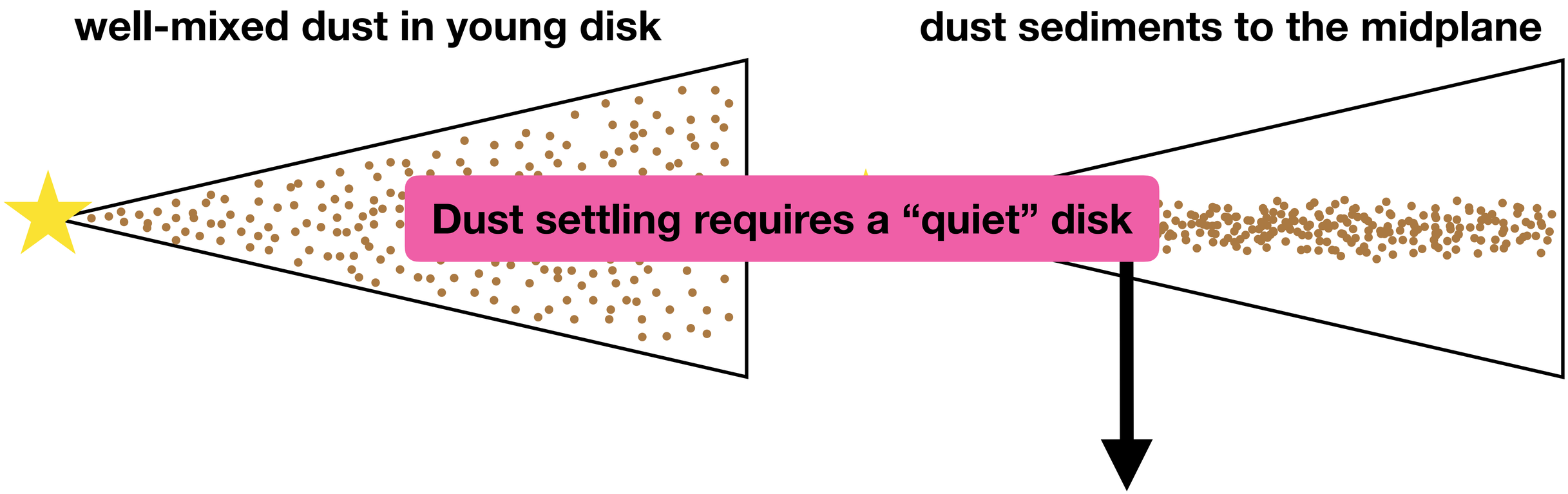
Zombie vortices



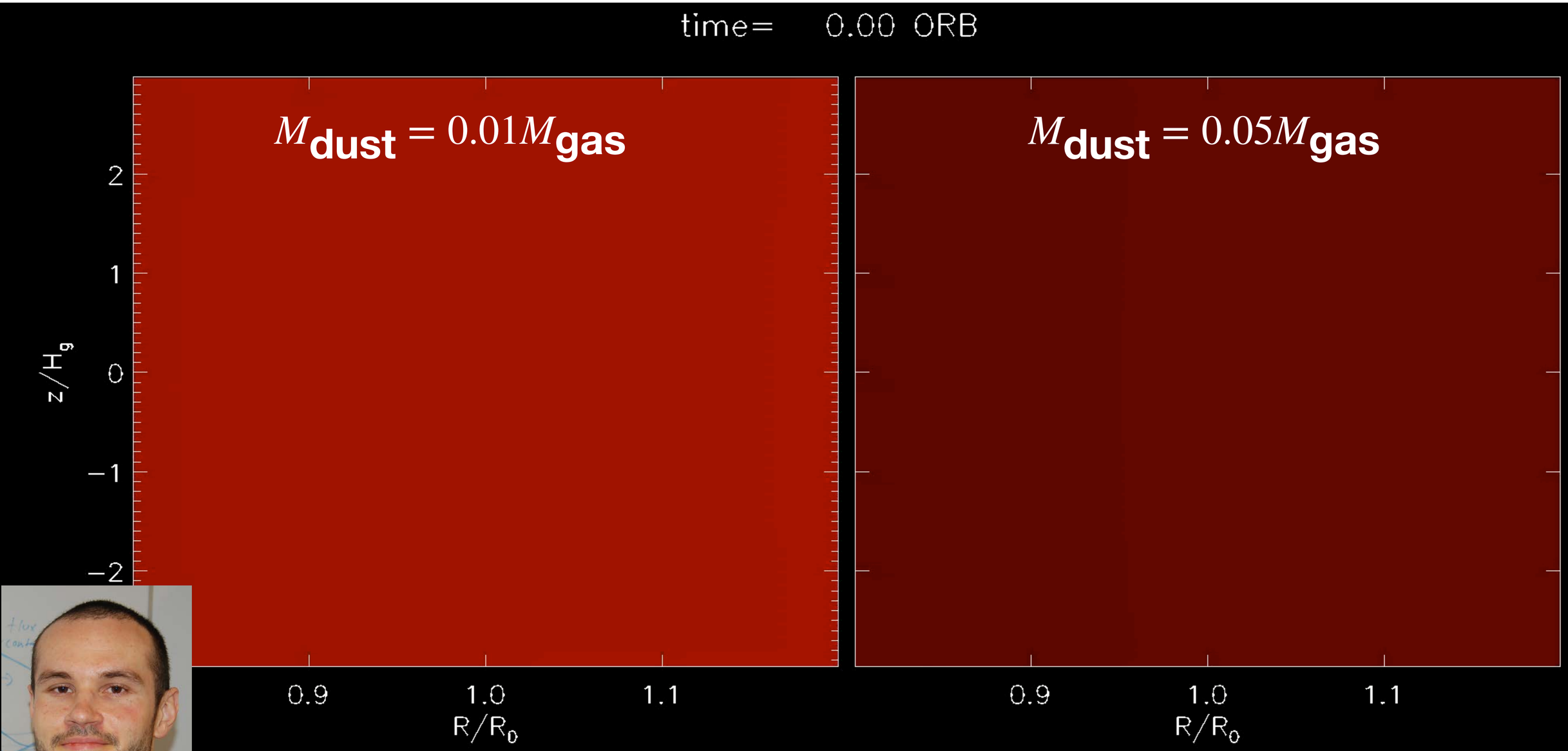
Barranco et al. (2018)

See Lesur,…, Lin, et al. (2022) PPVII review

Dust settling is the first step to planetesimal formation

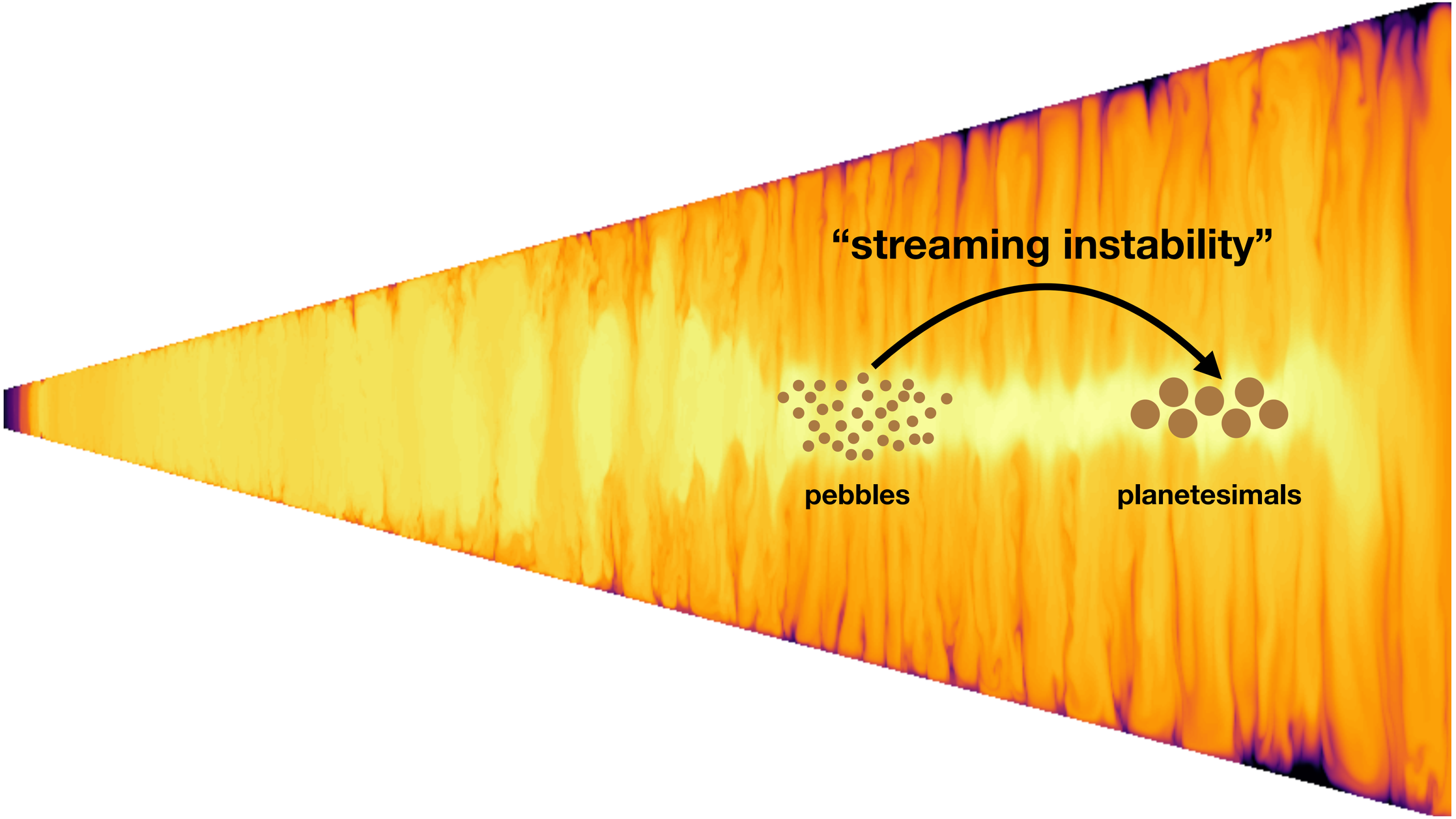


Dust settling vs. vertical shear instability

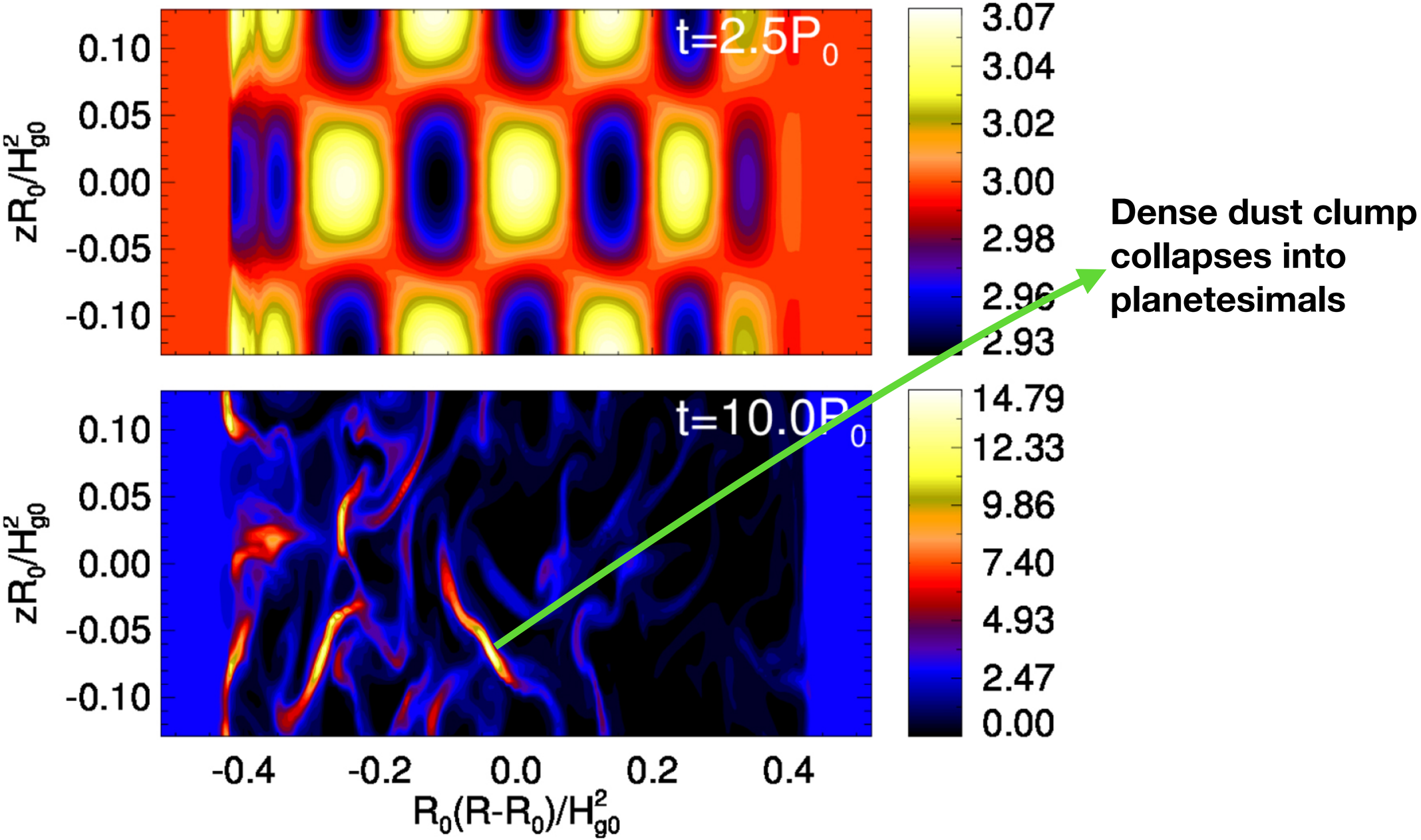


Lehmann & Lin (2022)

Planetesimal formation in the disk midplane

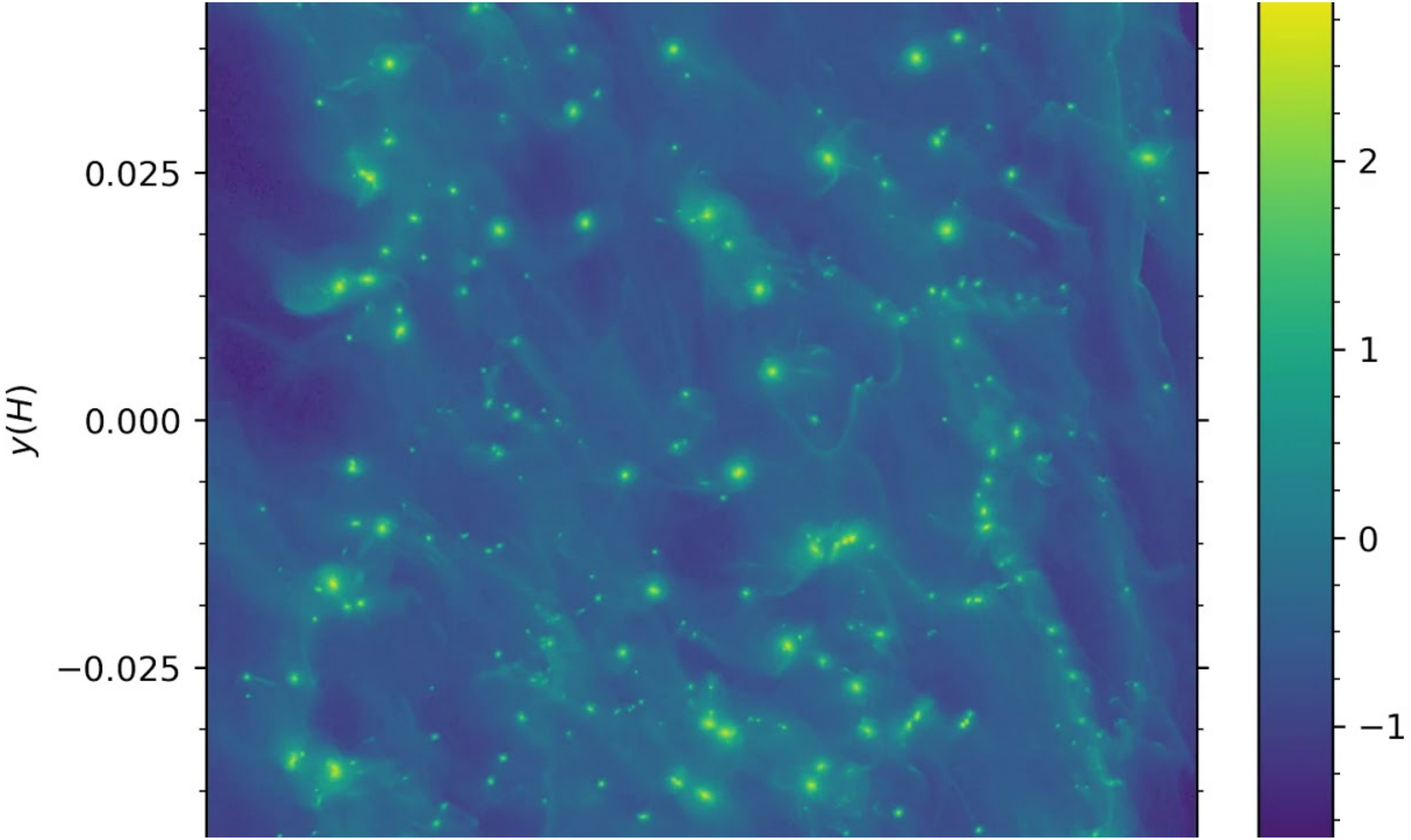


Streaming instability of dusty gas



Chen & Lin (2018)

State-of-the-art simulations (Nesvorný et al., 2020)



The SI is both simple and complex

Complex interpretation

- Resonance between dust-gas drift and inertial waves (Squire & Hopkins 2018)

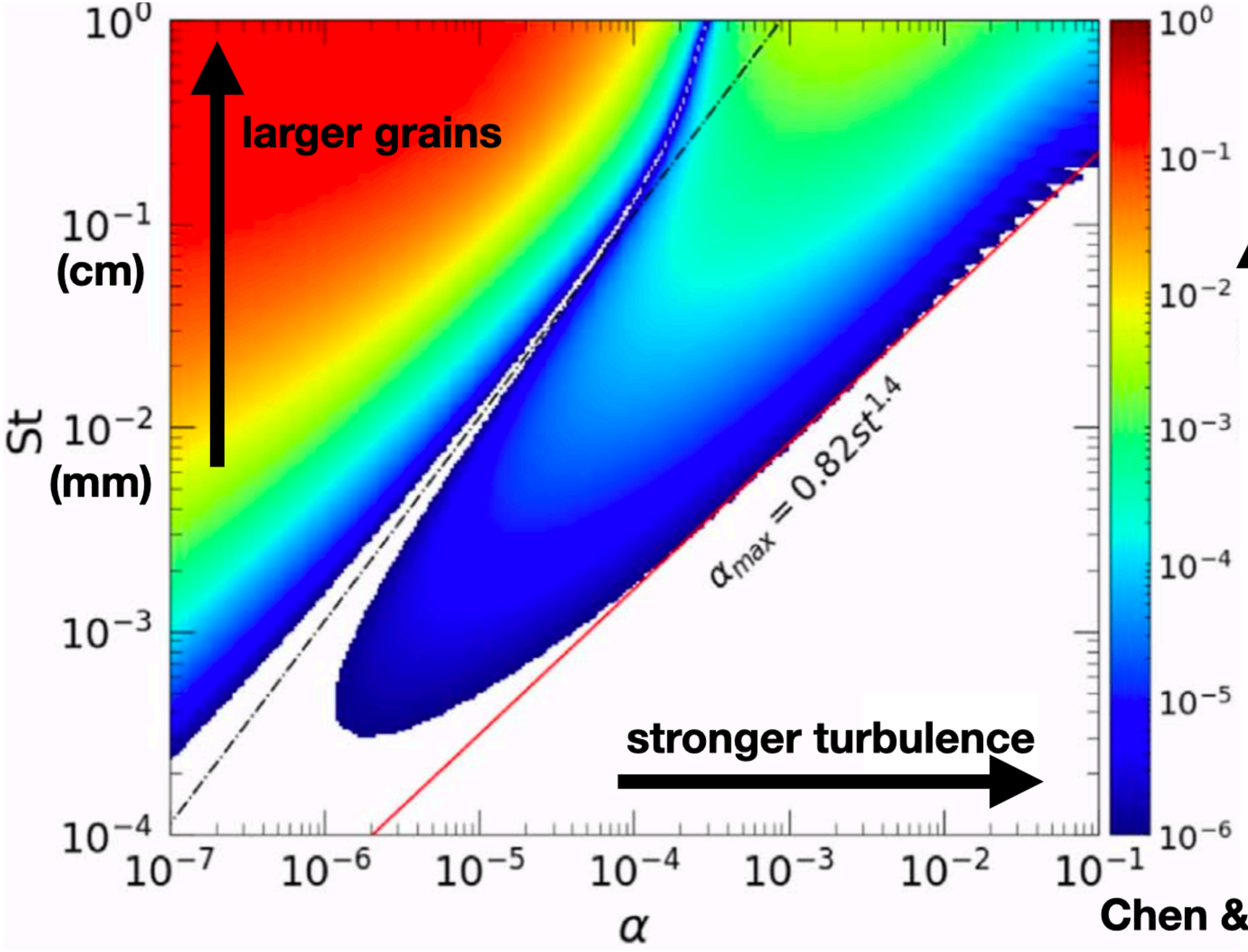
Simple ingredients:

- Mutually interacting dust and gas in rotation
- But PPDs are much more

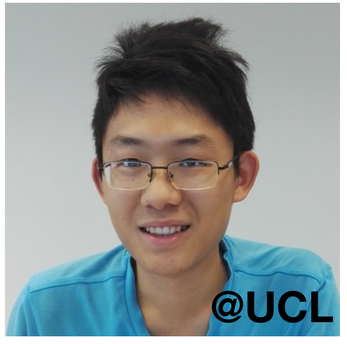
Extensions to the SI and dust dynamics

- turbulence → Chen & Lin (2020)
- vertical structure → Lin (2021)
- magnetic fields → Lin & Hsu (2022), Hsu & Lin (2022), Wu, Lin et al. (in prep.)
- thermodynamics → Lehmann & Lin (2023)

SI is easily killed by turbulent viscosity



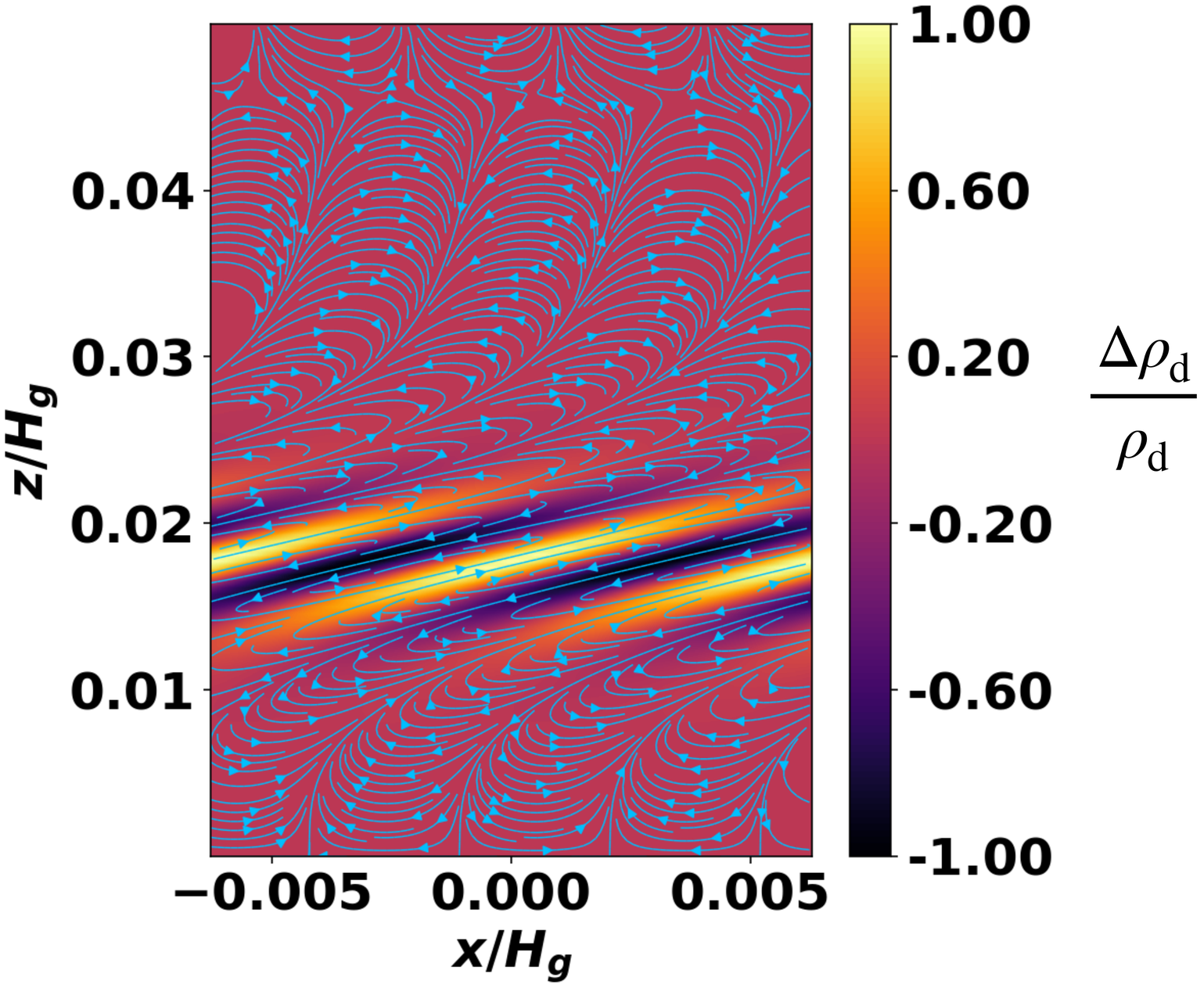
faster growth



Chen & Lin (2020)

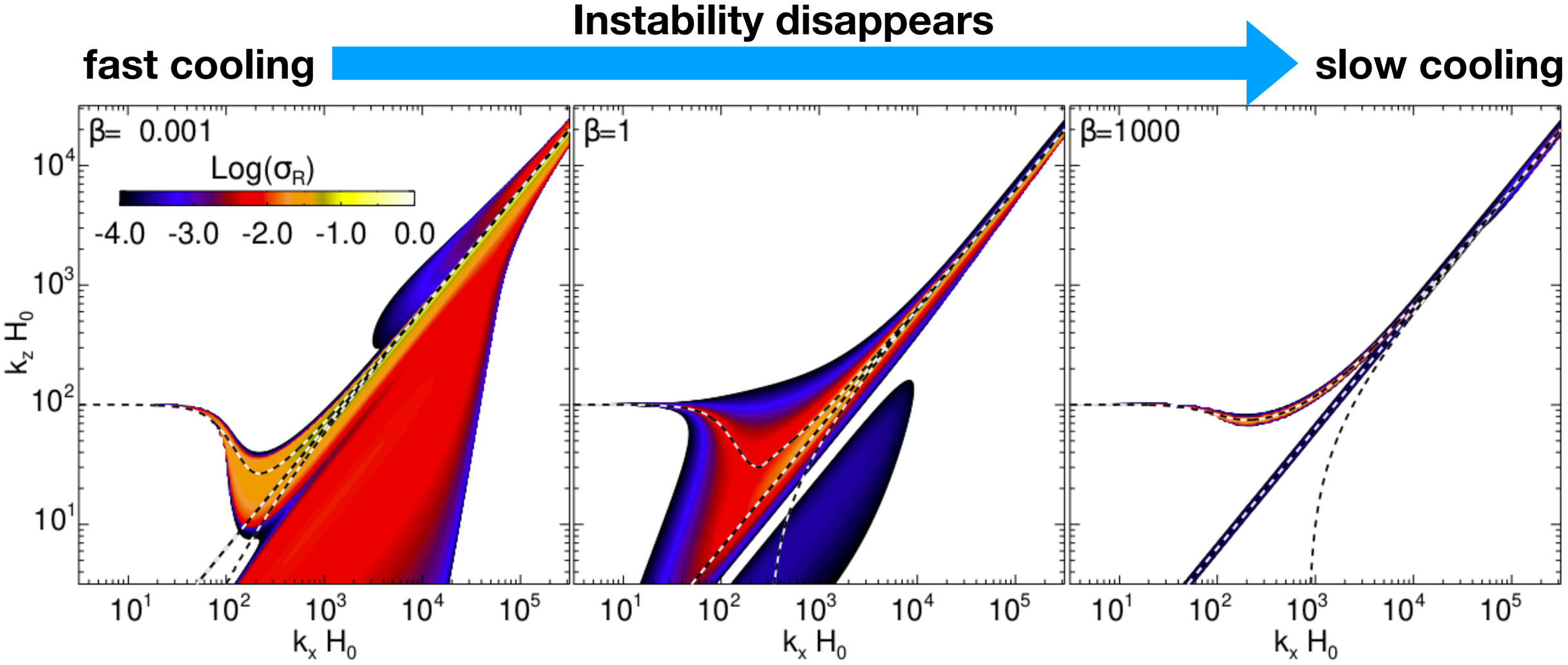
Improved model geometry: “Vertically shearing” SI

$S_{\mathbf{grow}} \sim \Omega$



Lin (2021)

SI in non-isothermal disks



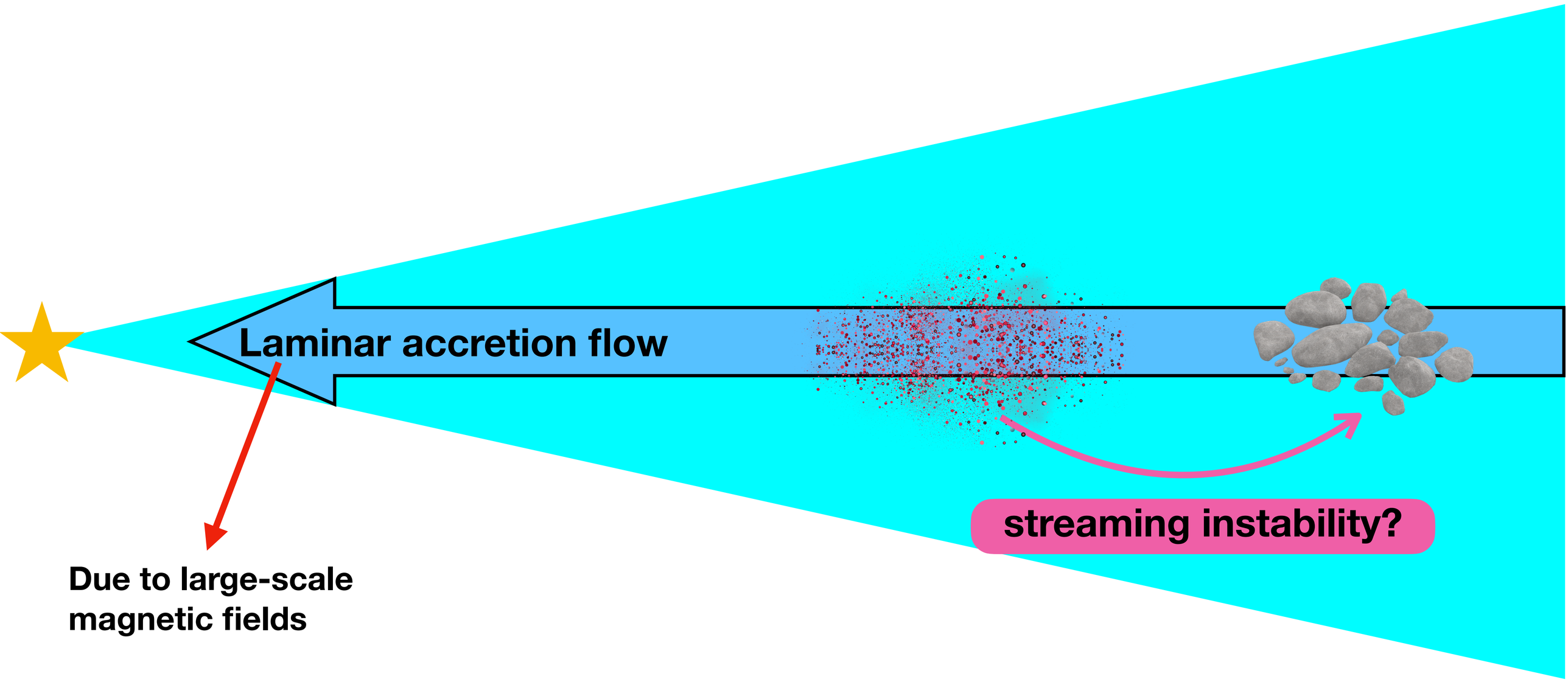
Lehmann & Lin (2023)

Do these variations of the SI help the cause?

- turbulence
- vertical structure
- thermodynamics

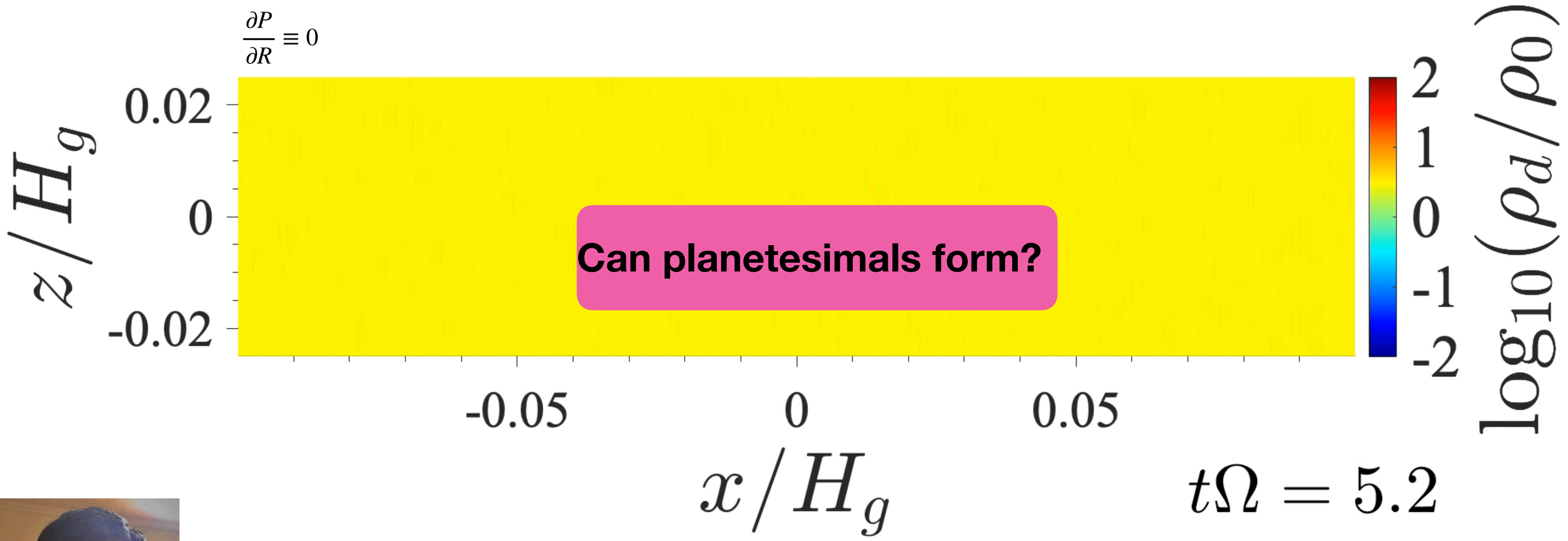
SI weakened

SI in modern disk models



(e.g. Riols et al. 2020, Cui & Bai 2021)

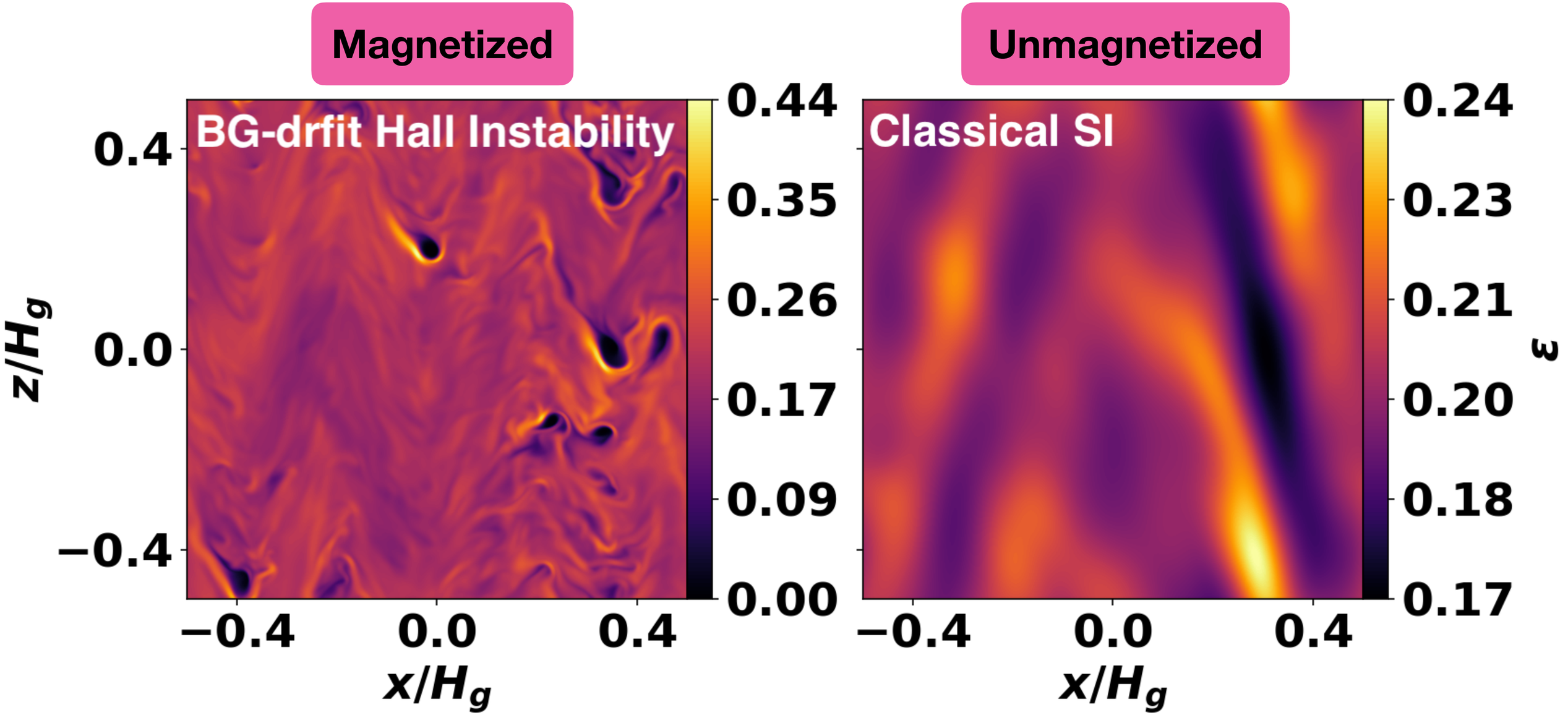
Nonlinear evolution of the SI in accreting disks



Can planetesimals form?

Lin & Hsu (2022), Hsu & Lin (2022)

SI in magnetized disks

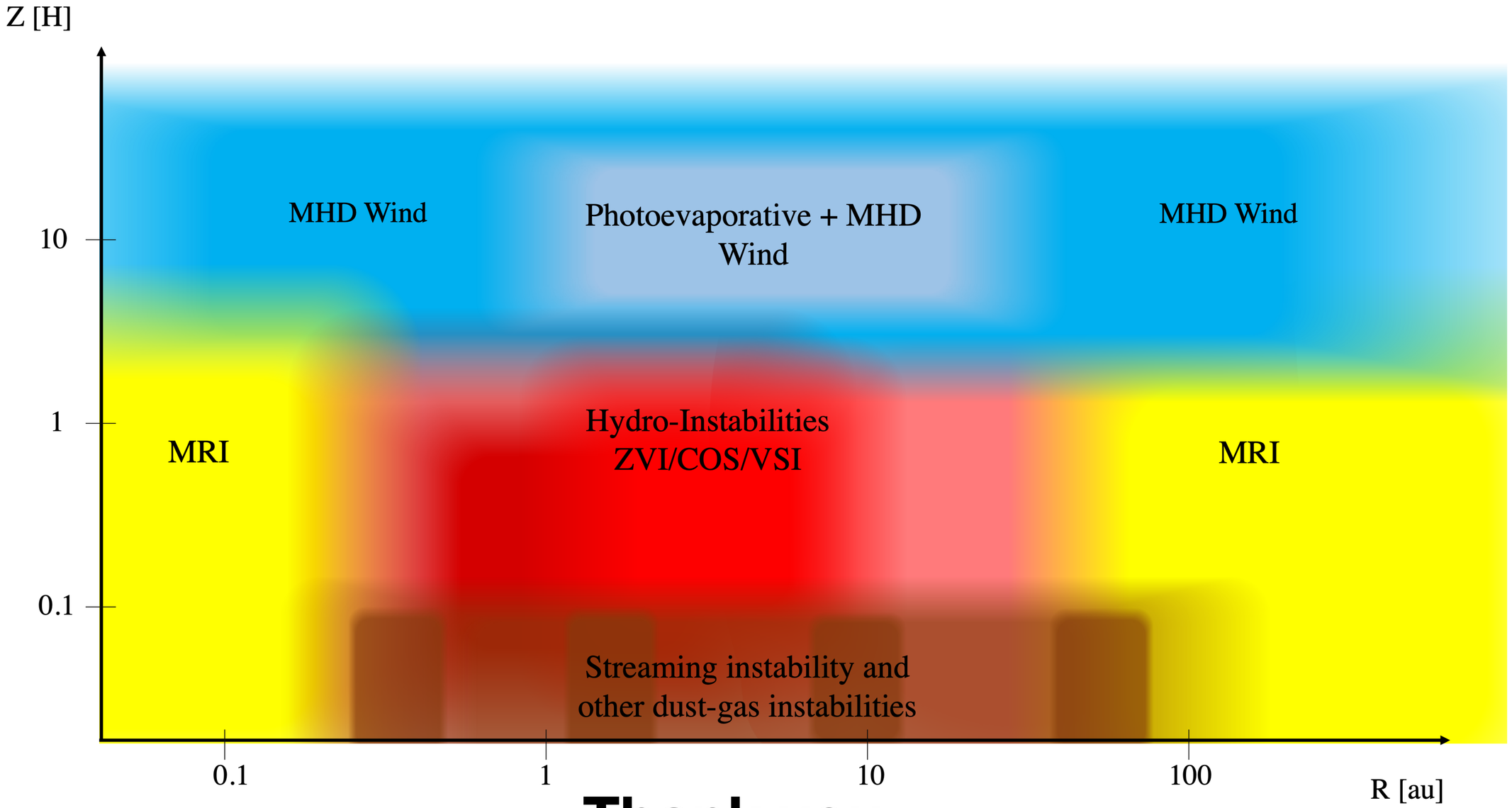


Wu, Lin, et al. (in prep.)

Our group's interests

- **Gas instabilities**: vertical shear instability, radial convection
- **Dust-gas dynamics**: dust rings, streaming instabilities
- **Disk-planet interaction**: planet migration, planet-induced disk structures
- **Methods**: linear stability analyses, computational fluid dynamics
- **Missing**: turbulence characterization, coagulation, planetestimal formation, pebble accretion, connection to solar system, geophysics

Summary



Thank you

@linminkai

Lesur,…, Lin, et al. (2022) PPVII review