Dust dynamics in radially convective regions of protoplanetary disks

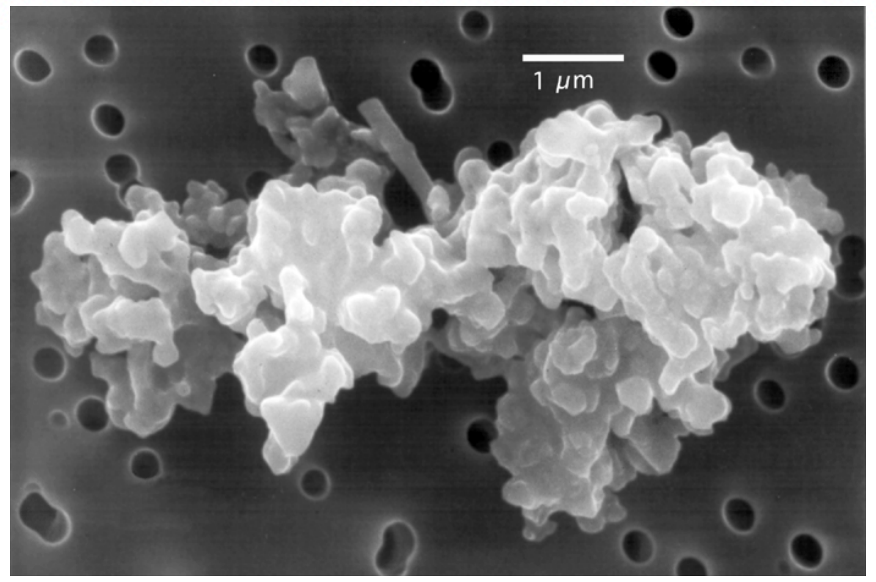
(...later)

Min-Kai Lin

November 2023

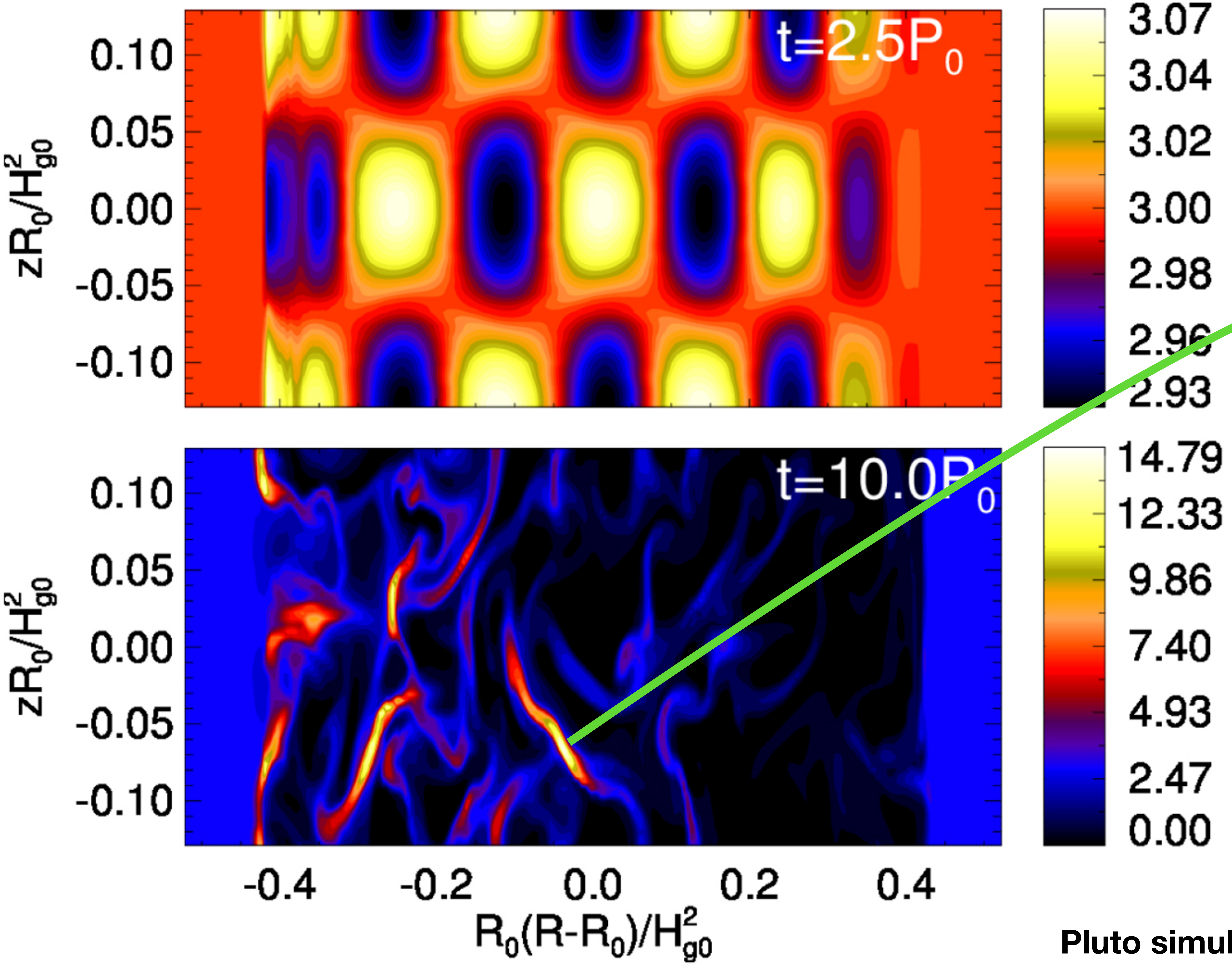
National Center for Theoretical Sciences, Physics Divisions
國家科學及技術委員會 National Science and Technology Council
財團法人國家實驗研究院
國家高速網路與計算中心 National Center for High-performance Computing

Streaming instability for planetesimal formation



(Drazkowska et al., 2022, PPVII)

Streaming instability of dusty gas

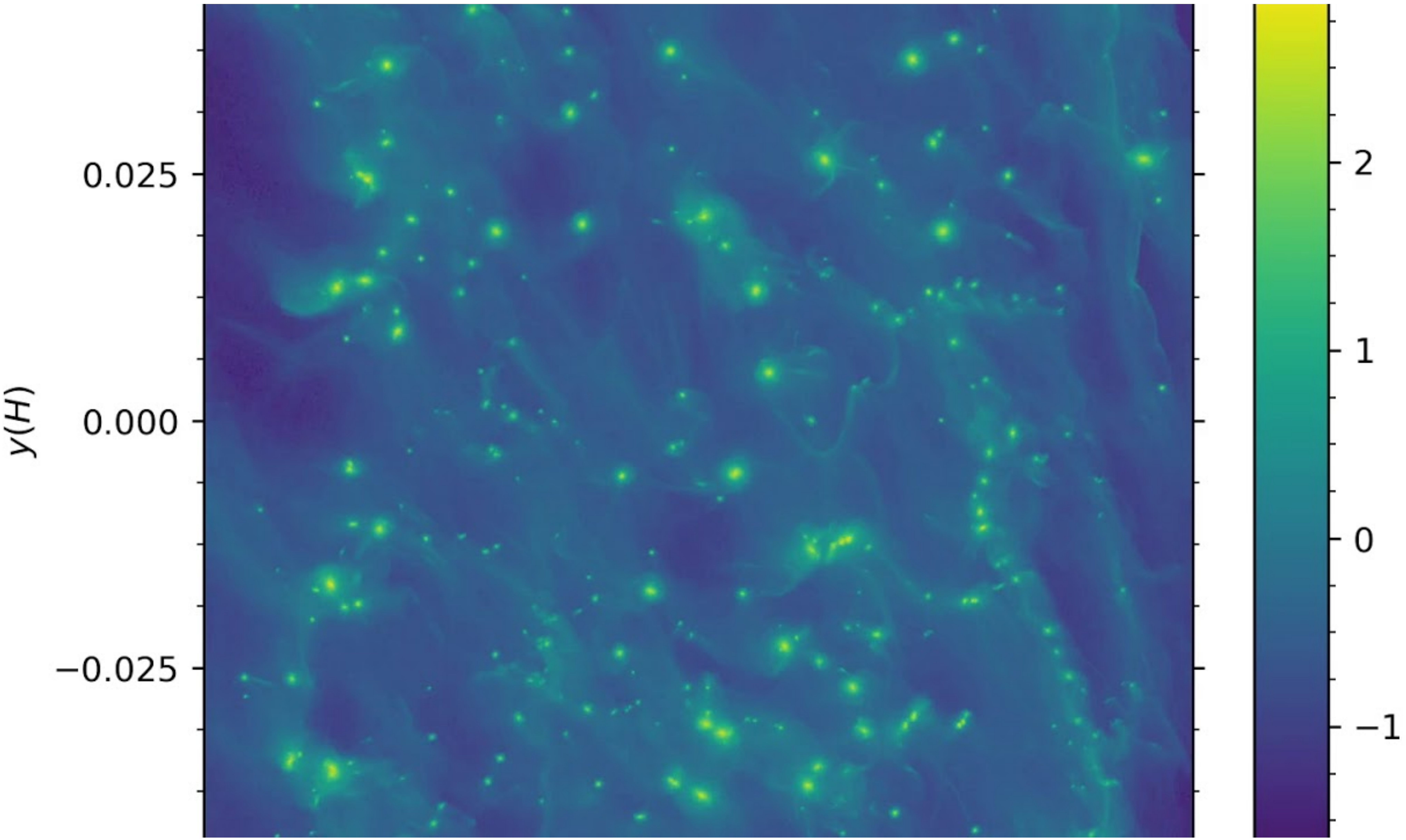


Dense dust clump collapses into planetesimals

Chen & Lin (2018)

Pluto simulation without a dust module

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



The SI is both simple and complex

Abstract interpretation

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

Simple ingredients

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

Our extensions to the SI and dust dynamics

- (alpha) turbulence: weakens the SI (Chen & Lin, 2020)
- vertical structure: “vertically shearing” SI (Lin 2021)
- magnetic fields: accretion flows, live MHD (Yinhao’s talk)
- thermodynamics

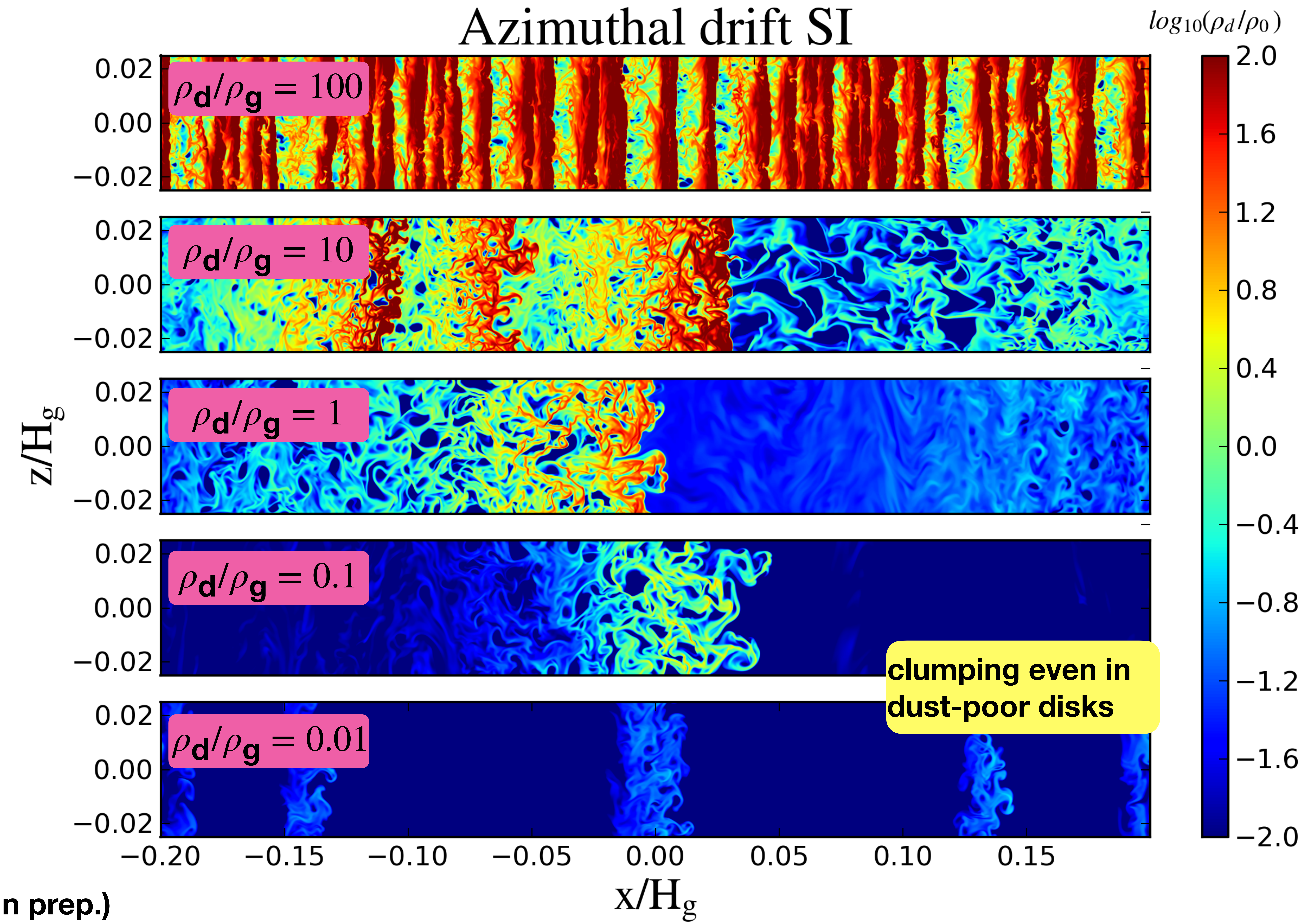
SI in modern protoplanetary disks

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

Nonlinear evolution of the SI in accreting disks

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

Parameter study



Wang & Lin (in prep.)

Decent concentrations in dust-poor disks

Wang & Lin (in prep.)

Non-isothermal gas-dust interaction

- Small dust: heating/cooling, ionization
- Large dust: dynamical interaction with gas:
    - Non-isothermal gas instabilities + dust
    - Streaming instabilities + gas heating/cooling

Bounssinesq shearing box

- **Gas: incompressible but with cooling and/or thermal diffusion (Latter & Papaloizou, 2017)**

Radial buoyancy
N_R^2

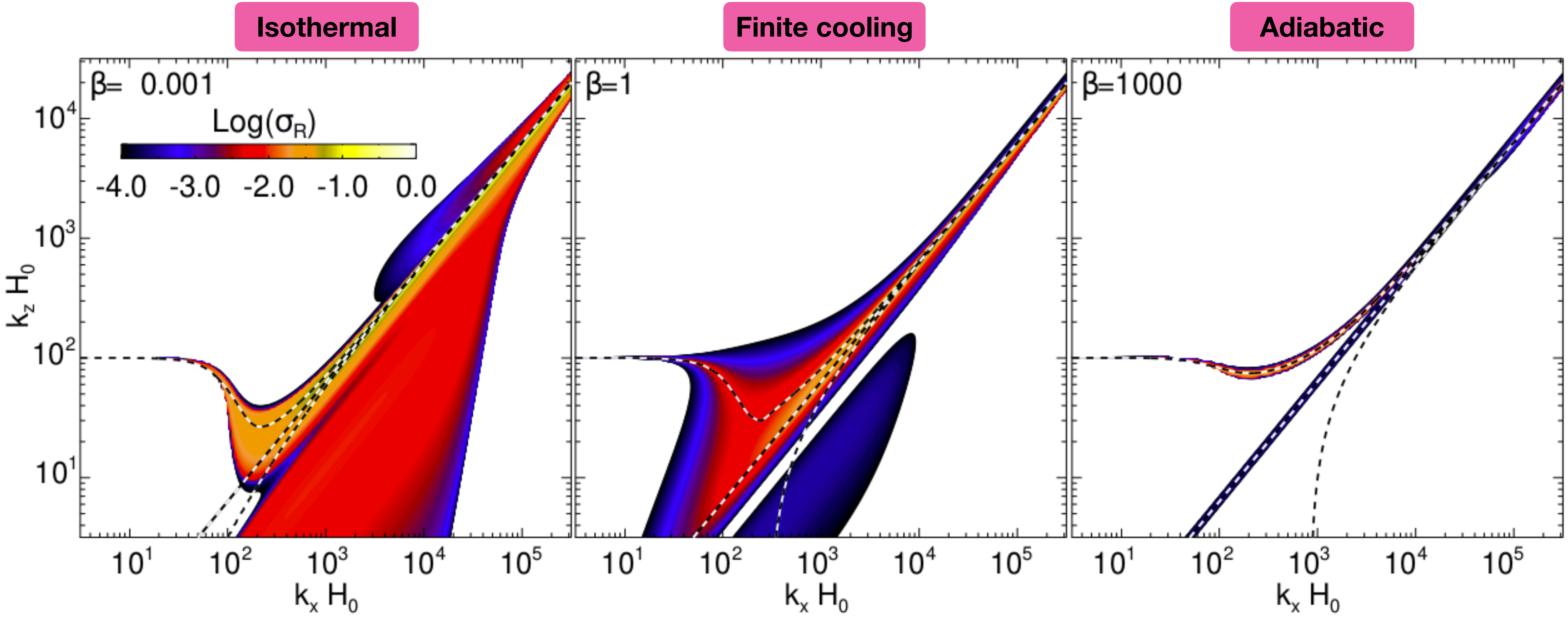
Vertical buoyancy
N_z^2

- **Dust: appended as a pressureless fluid, coupled through drag (Lehmann & Lin, 2023)**

SI + radial buoyancy $N_R^2 > 0$

Lehmann & Lin (2023)

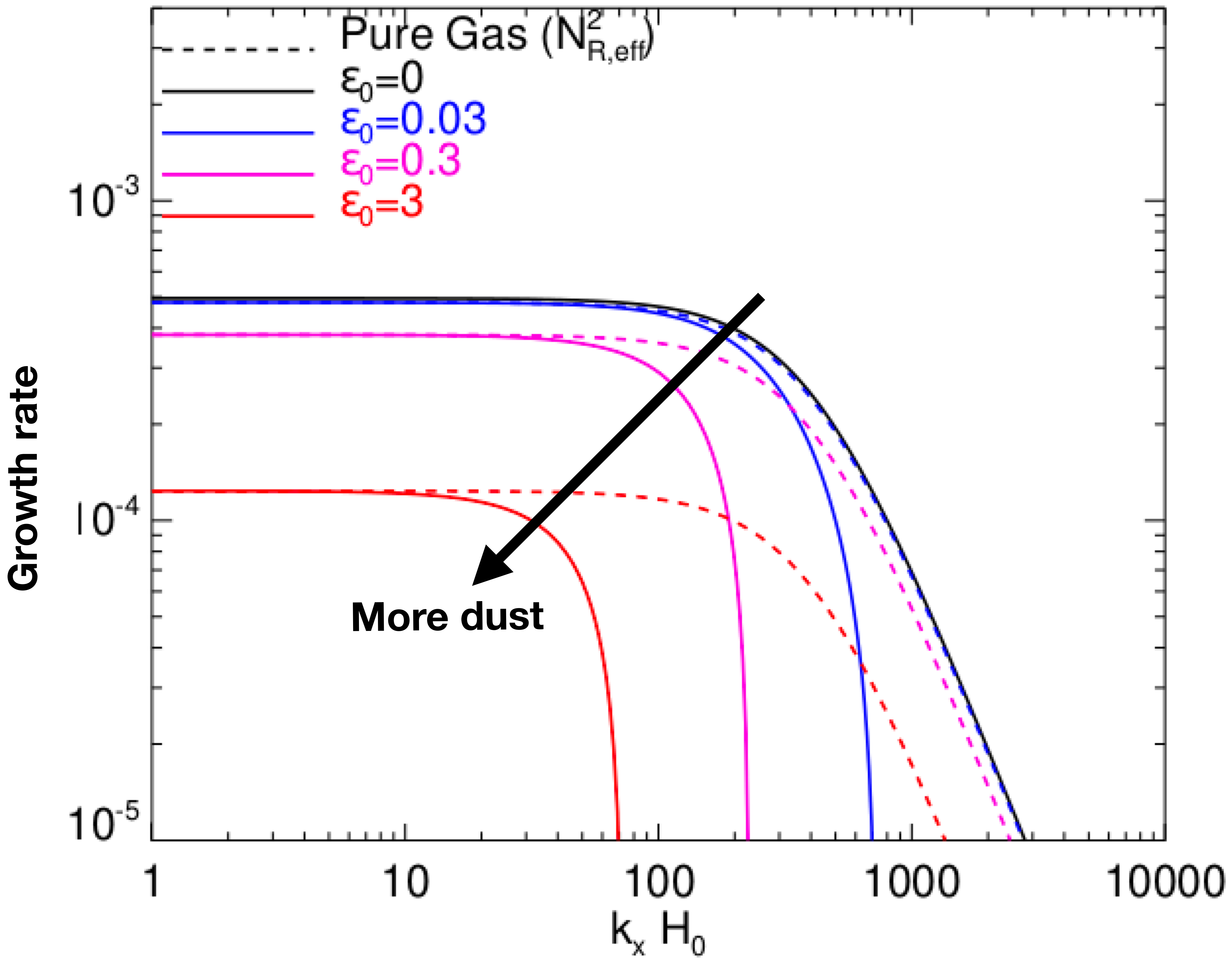
“Dust settling” instability + vertical buoyancy $N_z^2 > 0$



Lehmann & Lin (2023)

Convective overstability: $N_R^2 < 0$

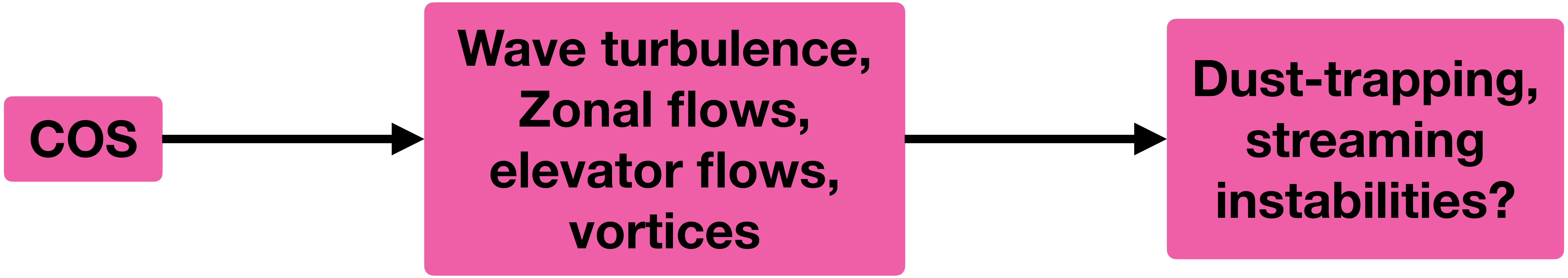
entropy decreasing outward + cooling = growing inertial waves



Dust-loading reduces $\left|N_R^2\right|$; finite drag suppresses small scales

Lehmann & Lin (2023)

Nonlinear evolution



(Teed & Latter, 2021)

(Raettig et al. 2021)

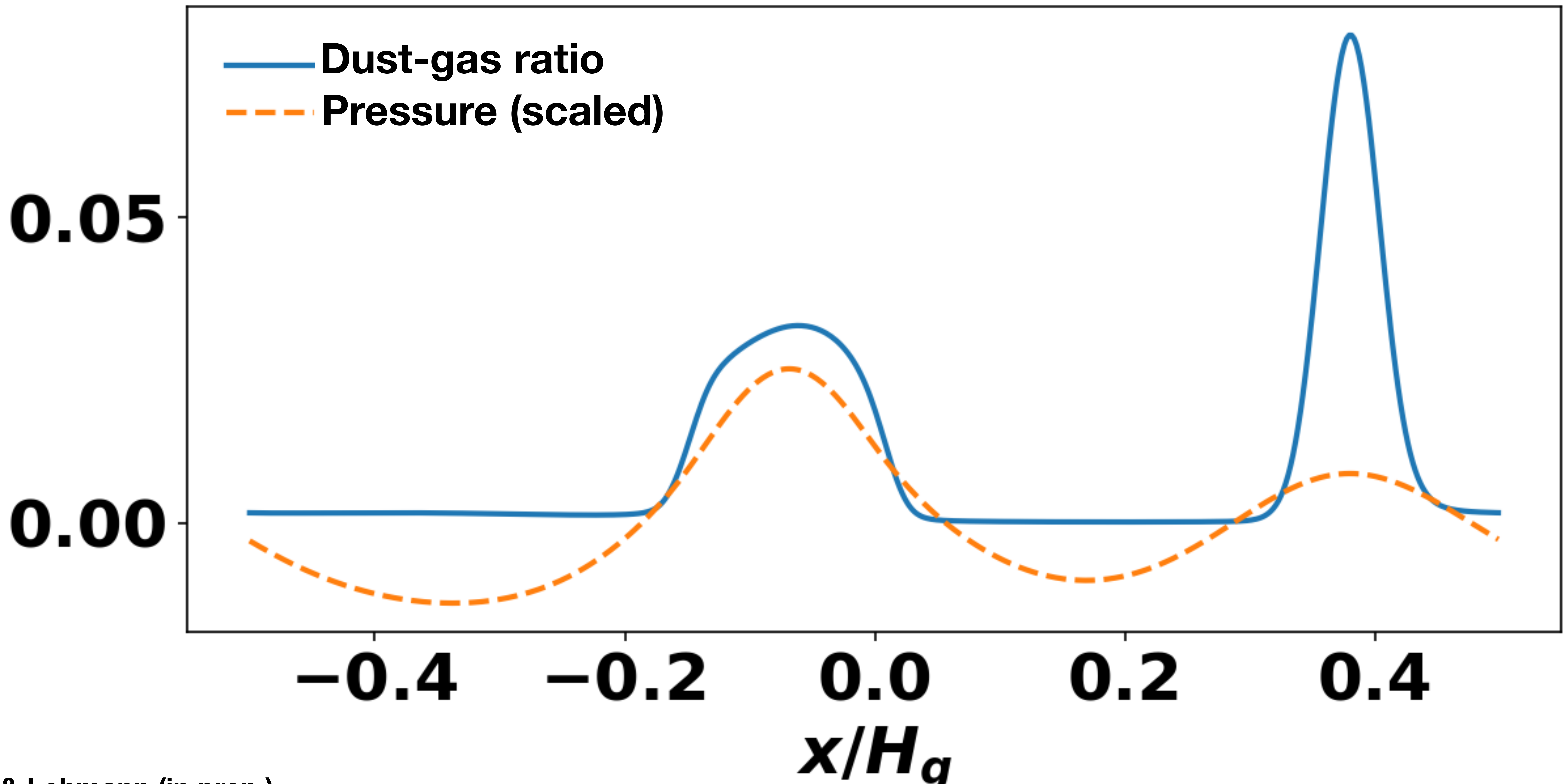
- Dedalus spectral code (Burns et al., 2019) to evolve the axisymmetric dusty Boussinesq equations + dissipation

Lin & Lehmann (in prep.)

Example run

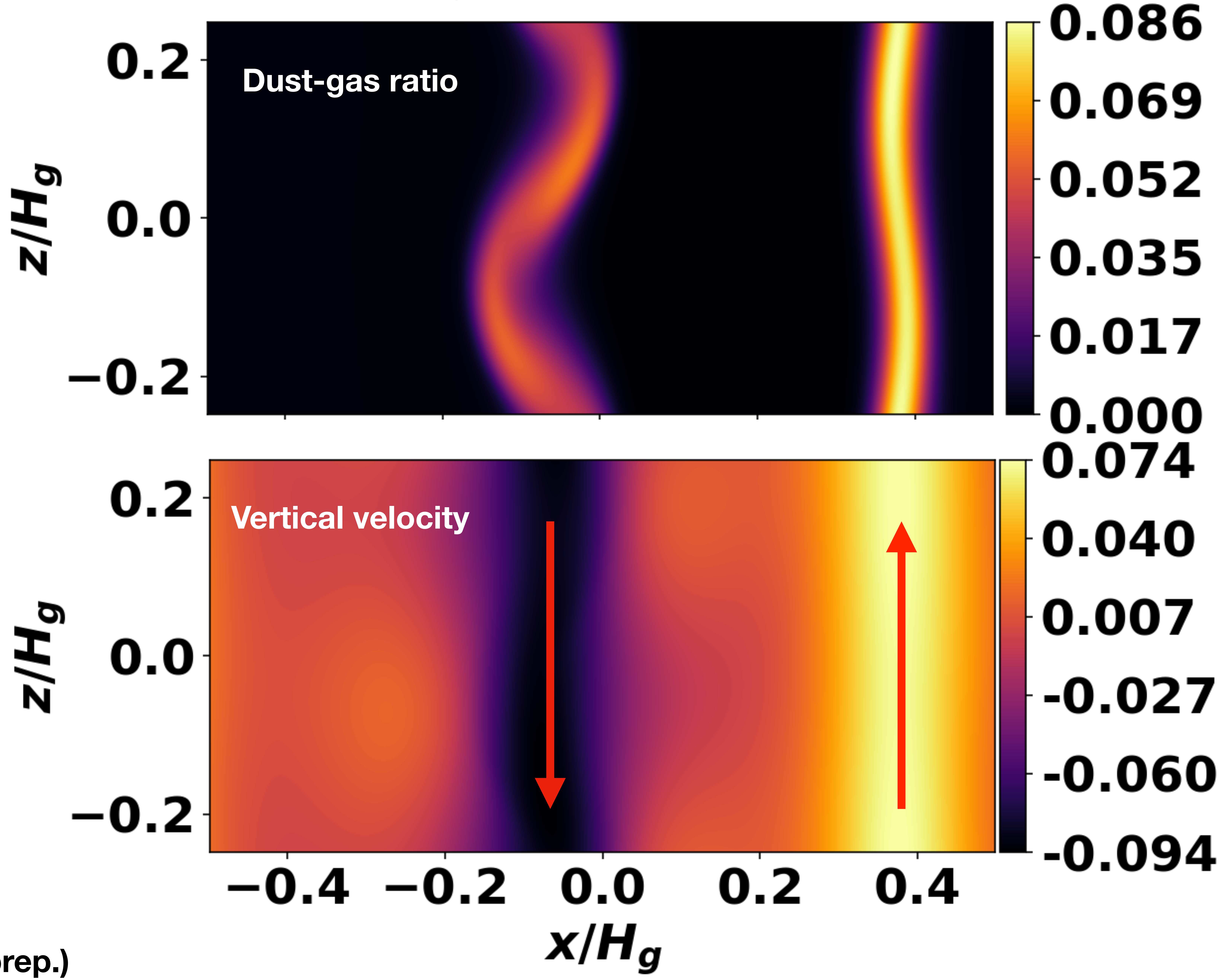
Lin & Lehmann (in prep.)

Dust rings



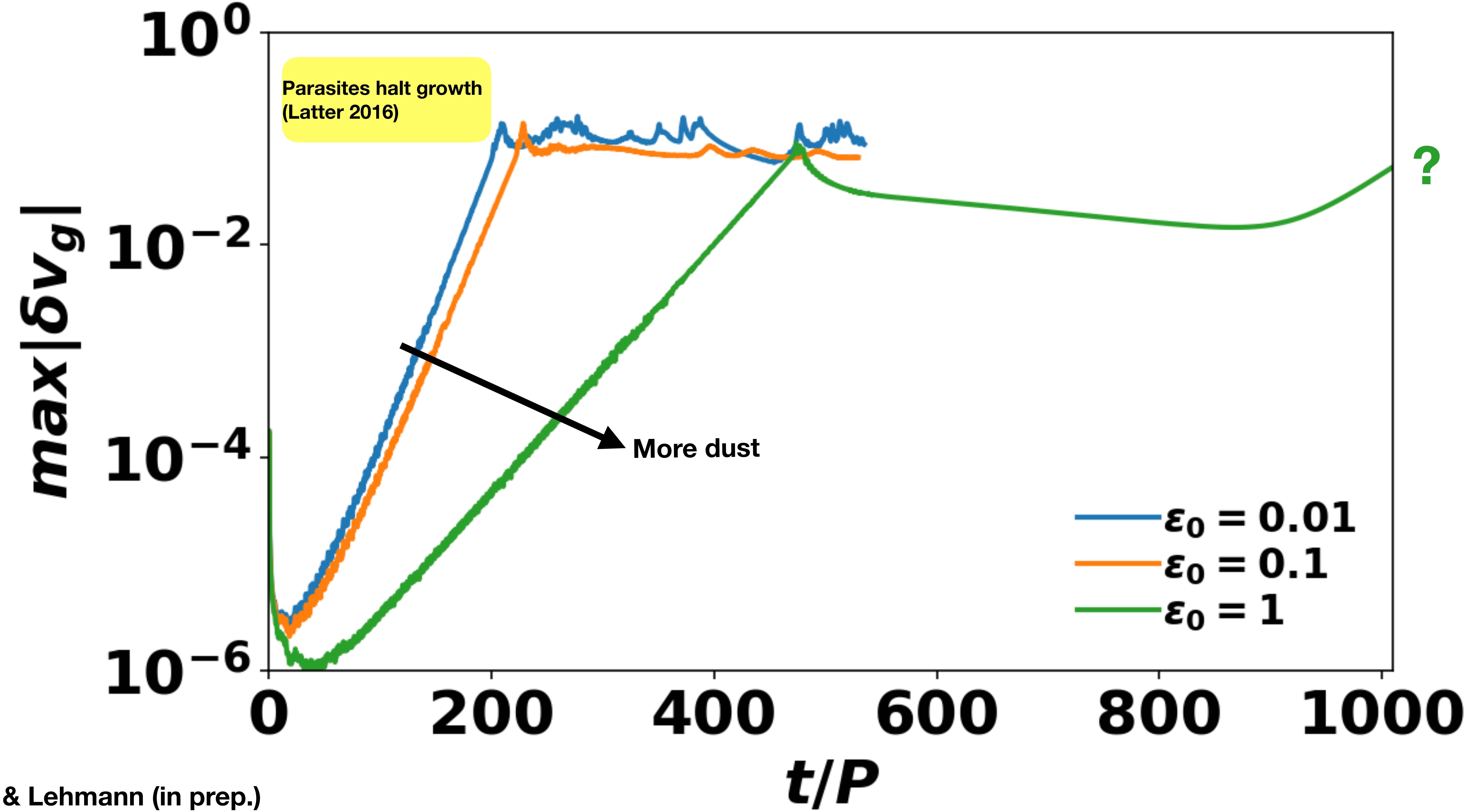
Lin & Lehmann (in prep.)

Elevator flows & buckling



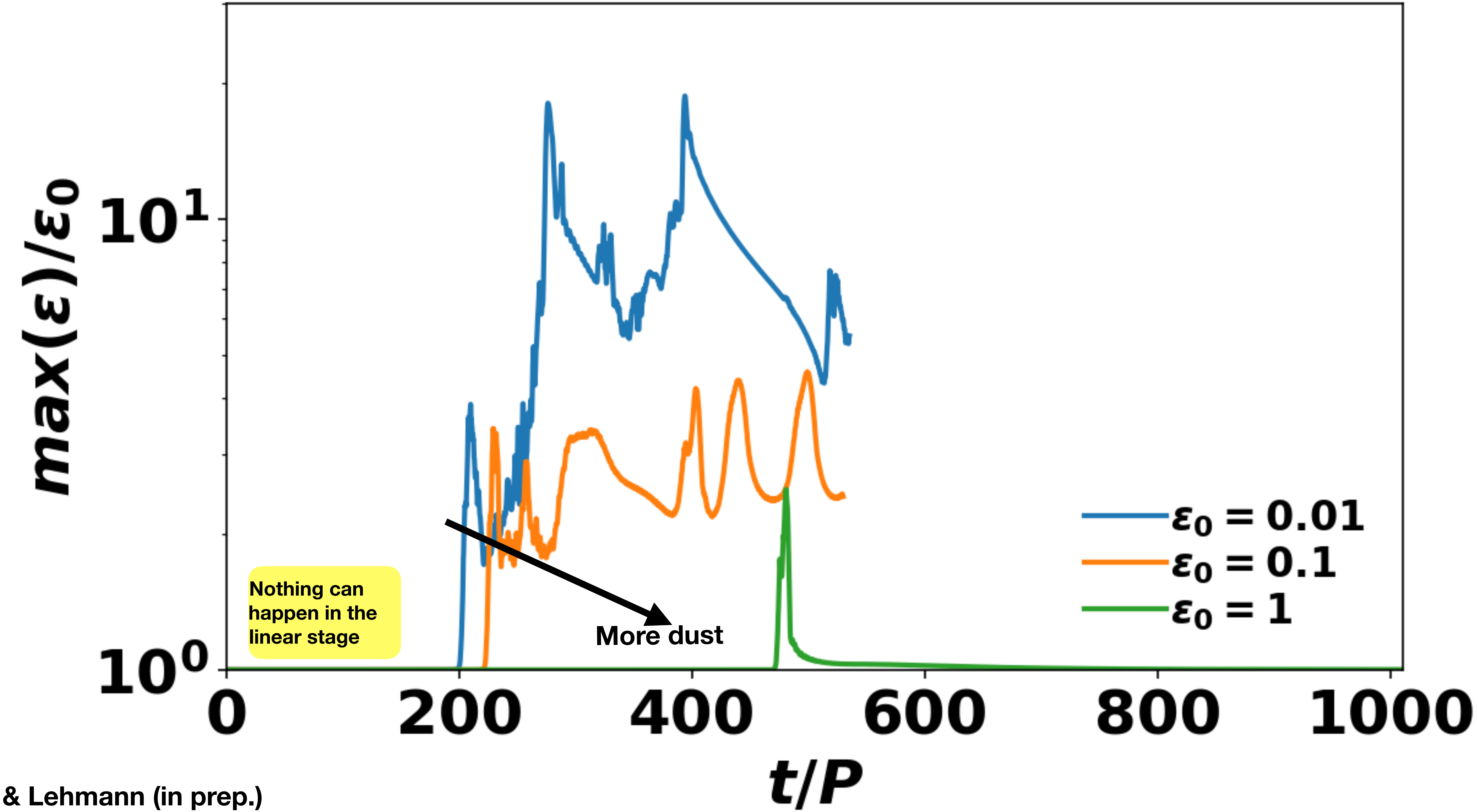
Lin & Lehmann (in prep.)

COS & dust feedback I



Lin & Lehmann (in prep.)

COS & dust feedback II



Lin & Lehmann (in prep.)

Summary

- **Extended SI: turbulence, accretion flows, MHD, non-isothermal gas**

- **Gas accretion + weak pressure gradient: moderate clumping even at low dust-to-gas ratios**

- **COS: non-steady dust rings, too much dust weakens the instability**

- **ASIAA postdoc deadline: Nov. 15**

Thank you

@linminkai