Streaming instabilities in modern protoplanetary disks

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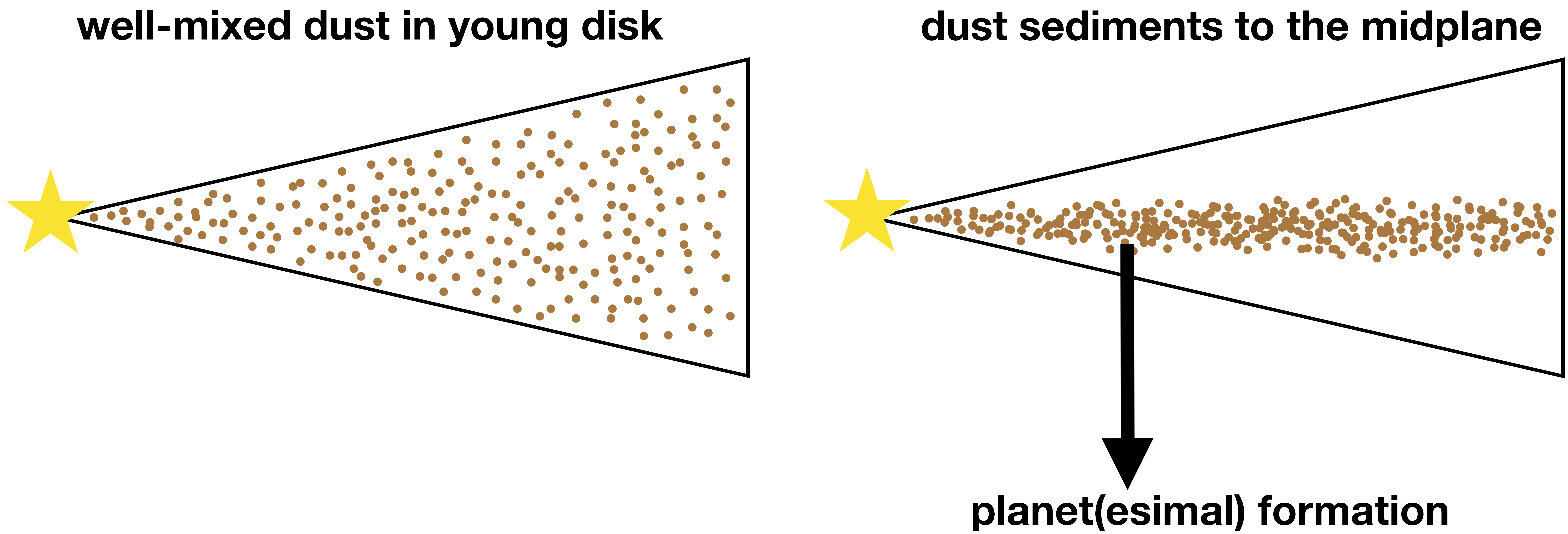
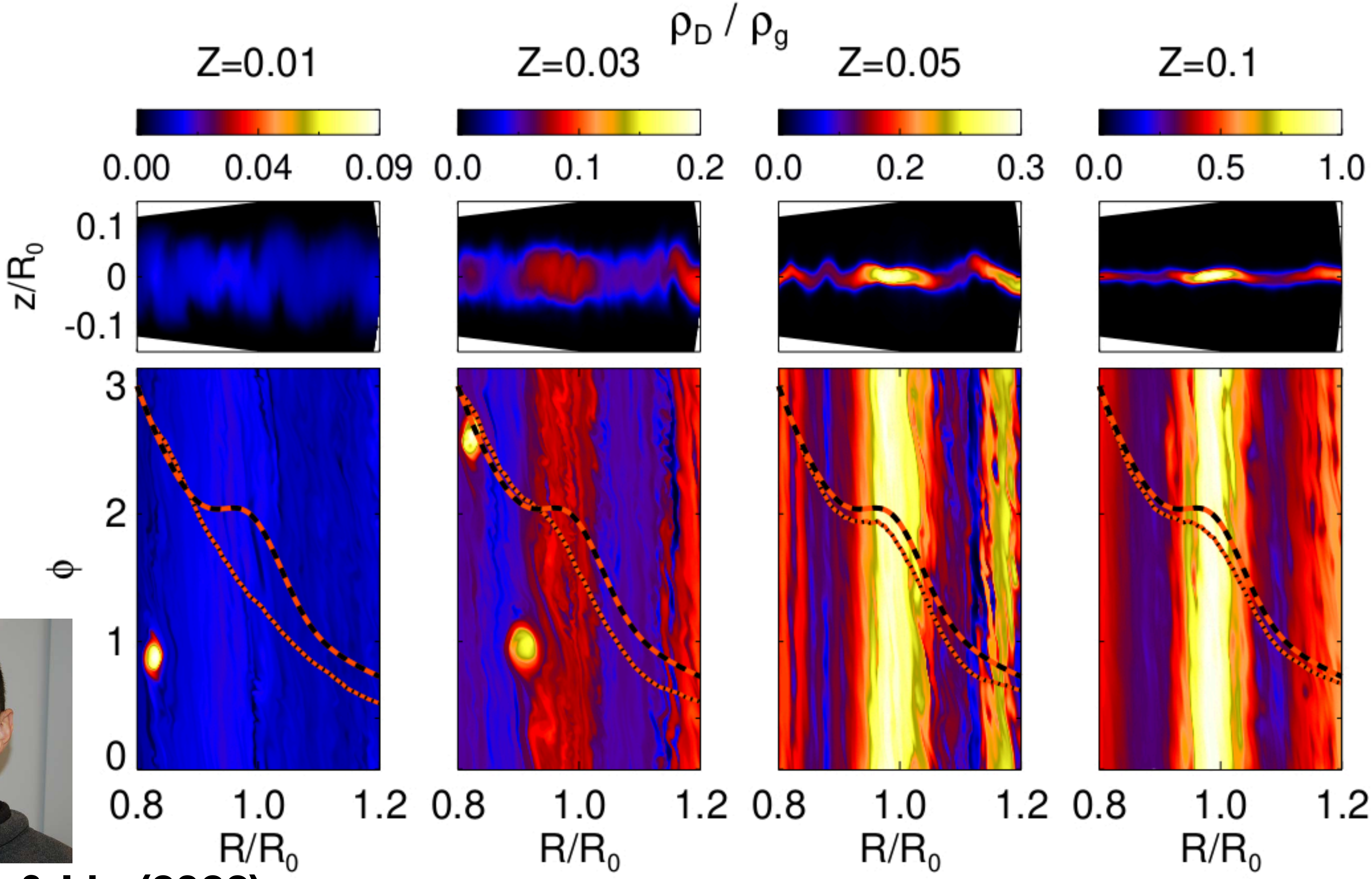
First things first: Dust settling



Dust settling vs VSI turbulence

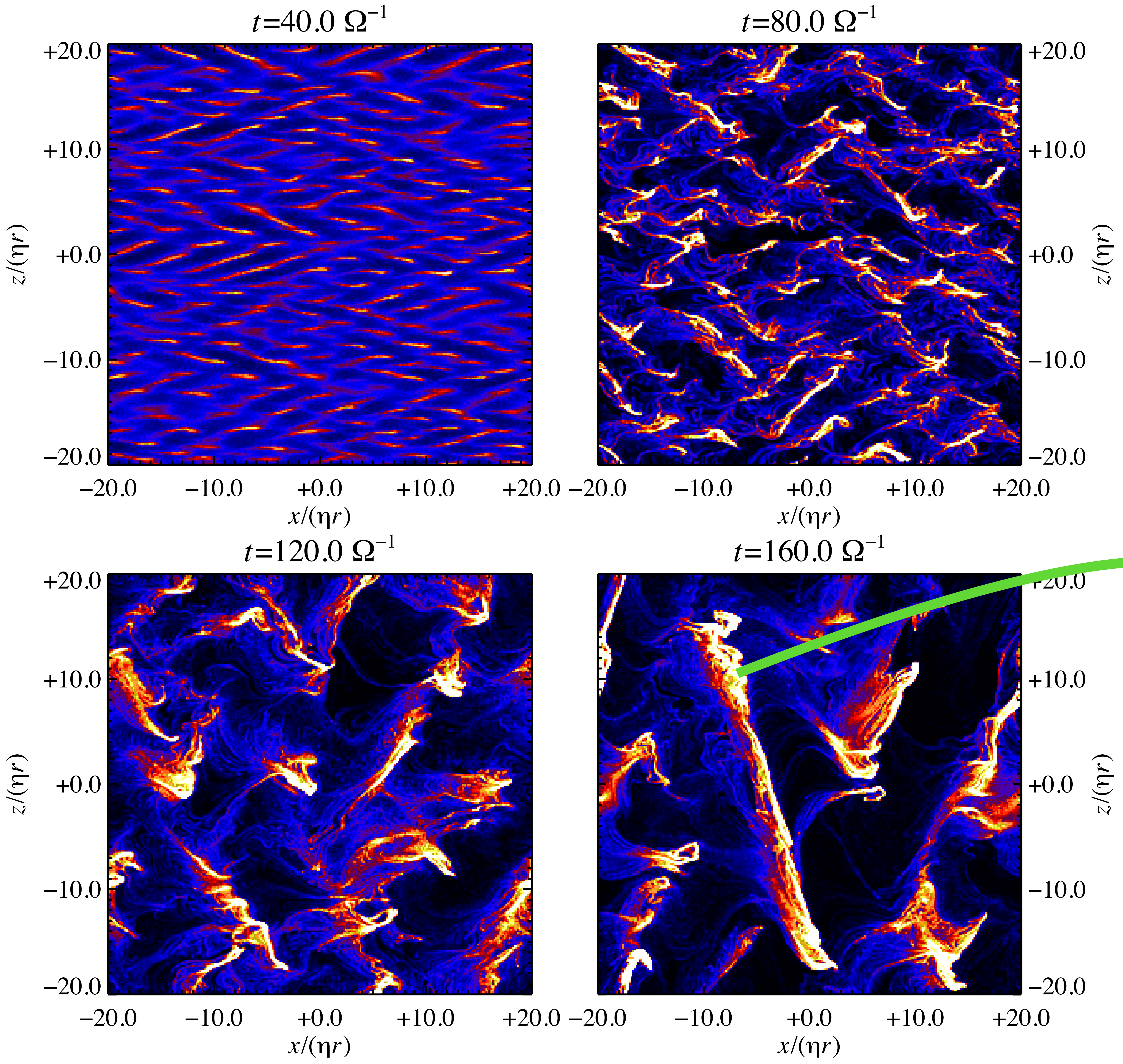
Lin (2019); Lehmann & Lin (2022)

More dust makes the disk more axisymmetric



Lehmann & Lin (2022)

Next: Streaming instability



Dense dust clump collapses into planetesimals

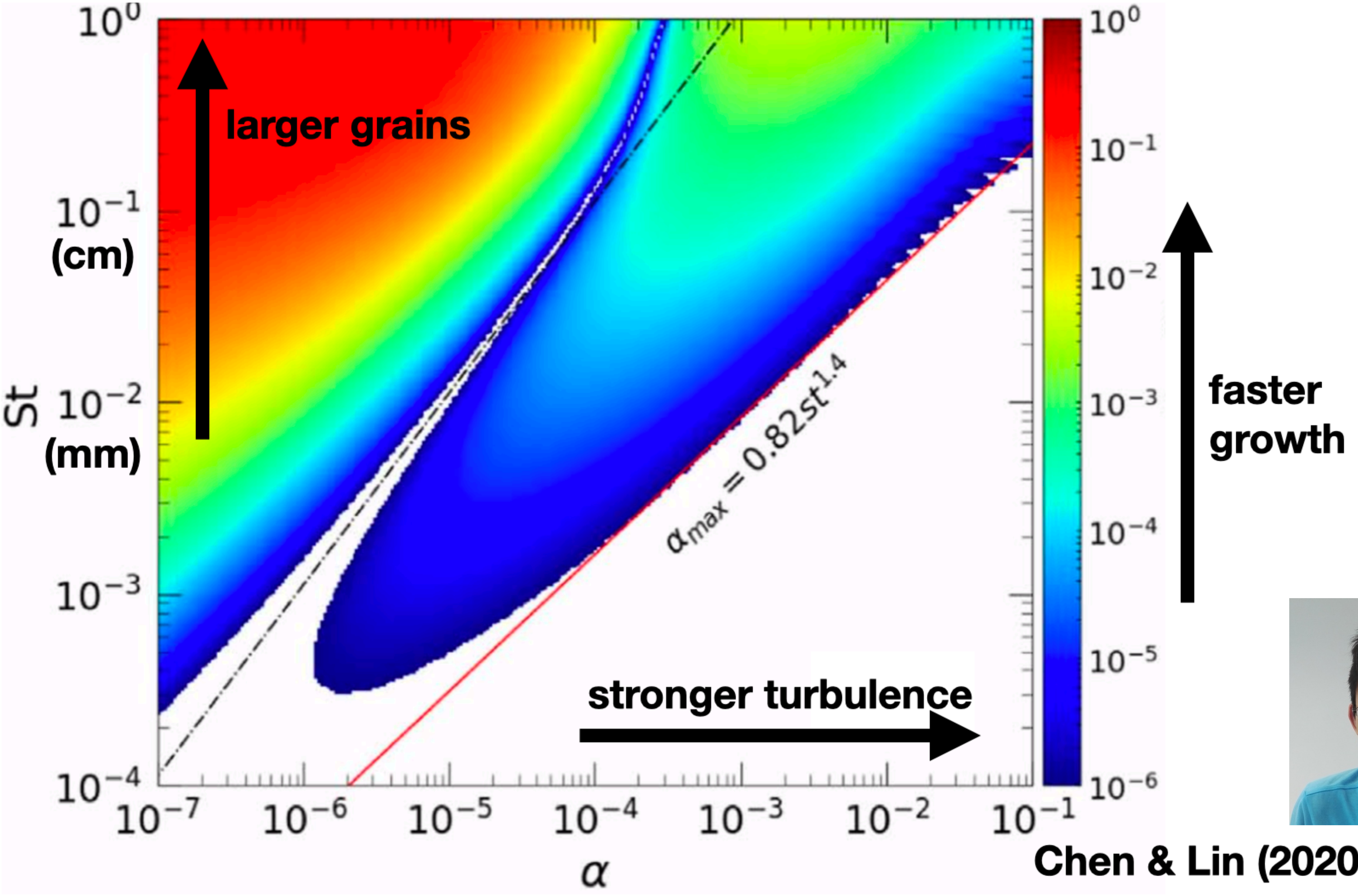
End of story?

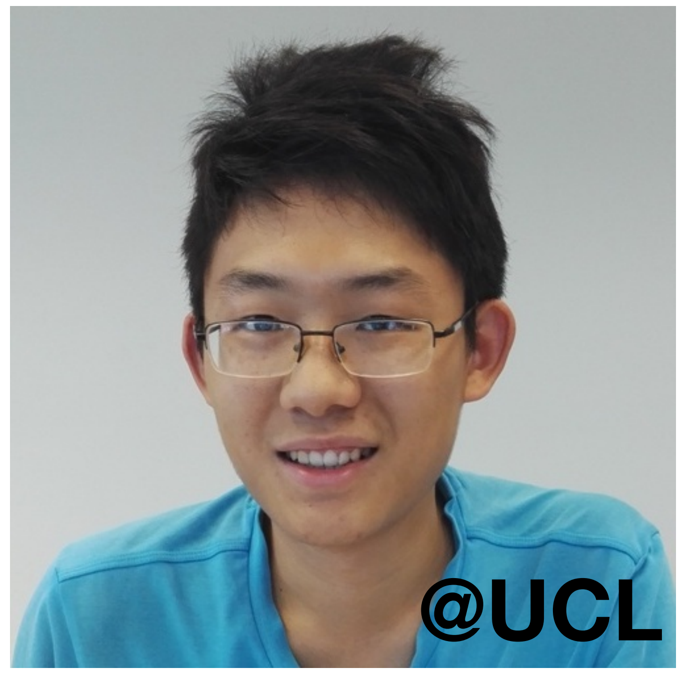
Johansen & Youdin (2007)

Ideal streaming instability

- disk is non-turbulent → Chen & Lin (2020)
- disk has no vertical structure → Lin (2021)
- disk is unmagnetized → Lin & Hsu (2022)

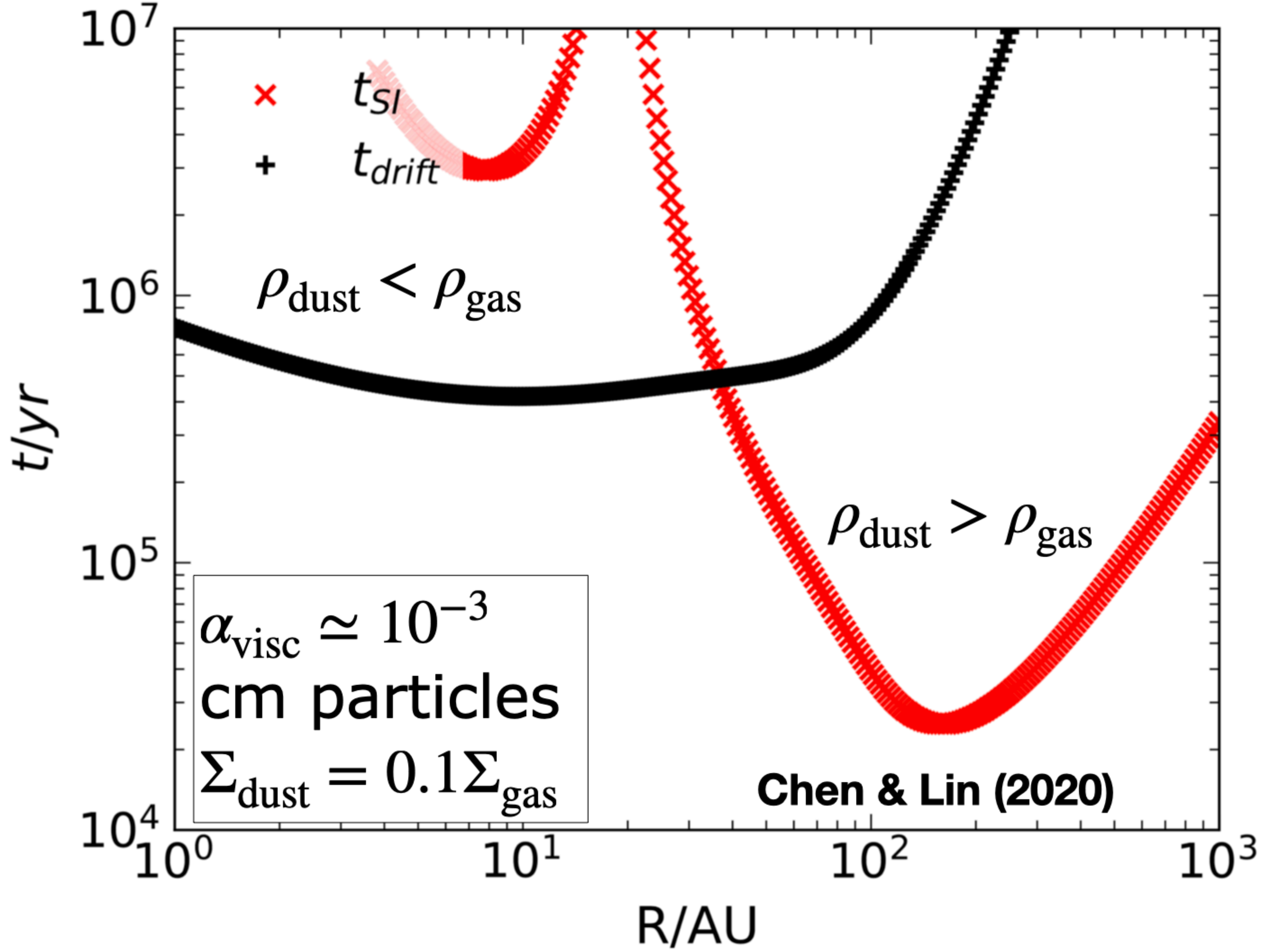
Streaming instability is easily killed by turbulent viscosity



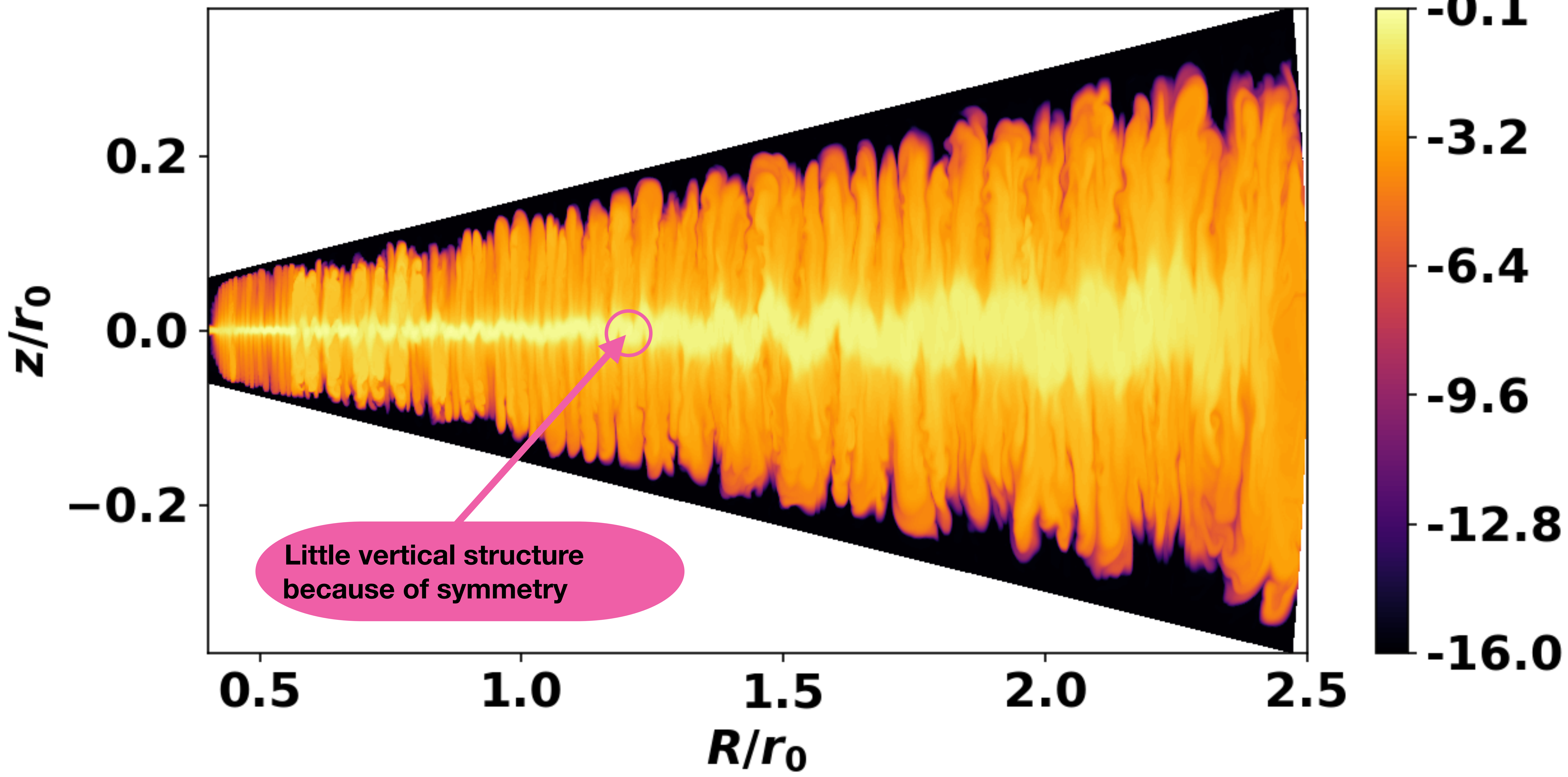


Chen & Lin (2020)

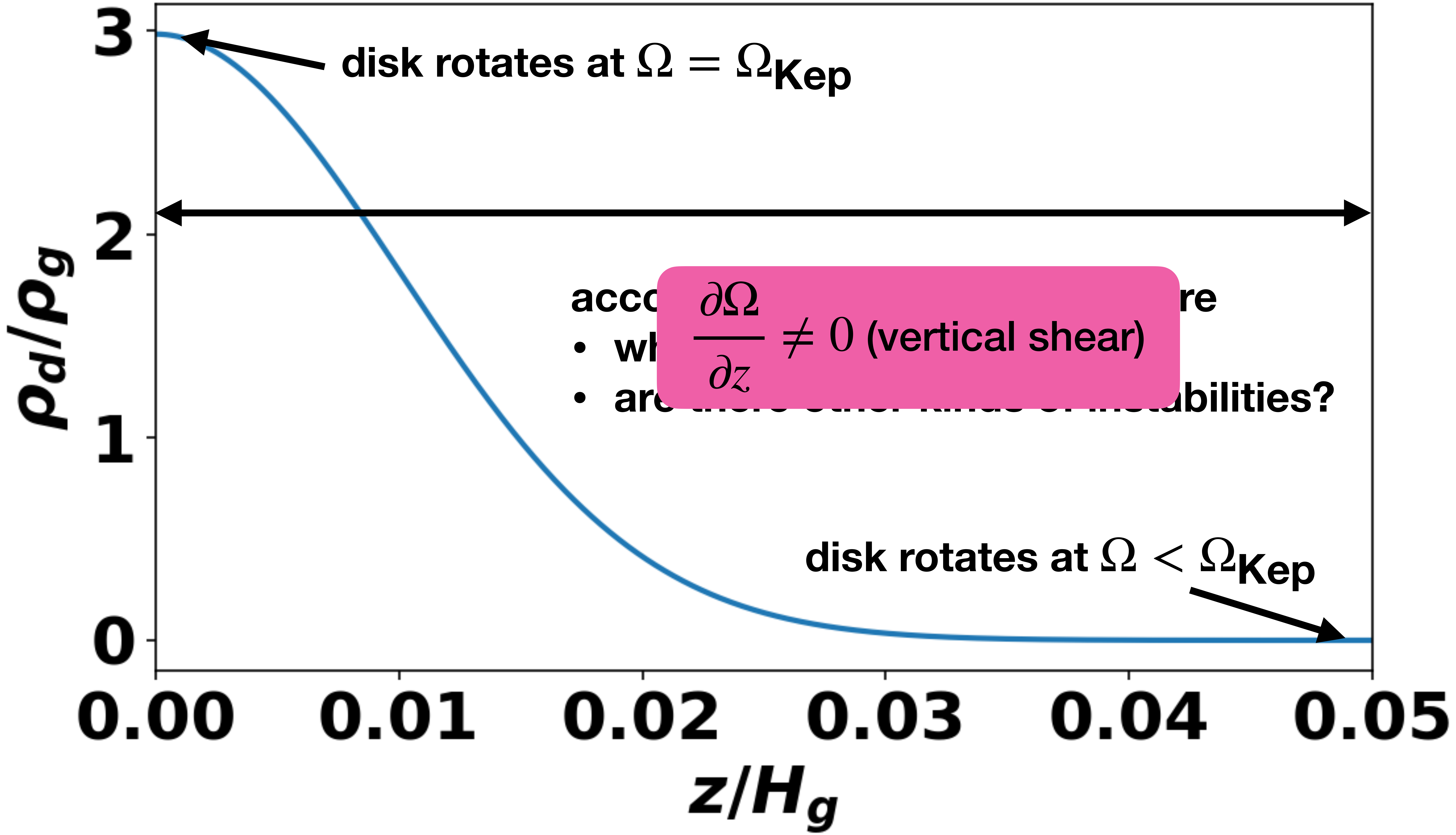
SI is easier in the outer disk



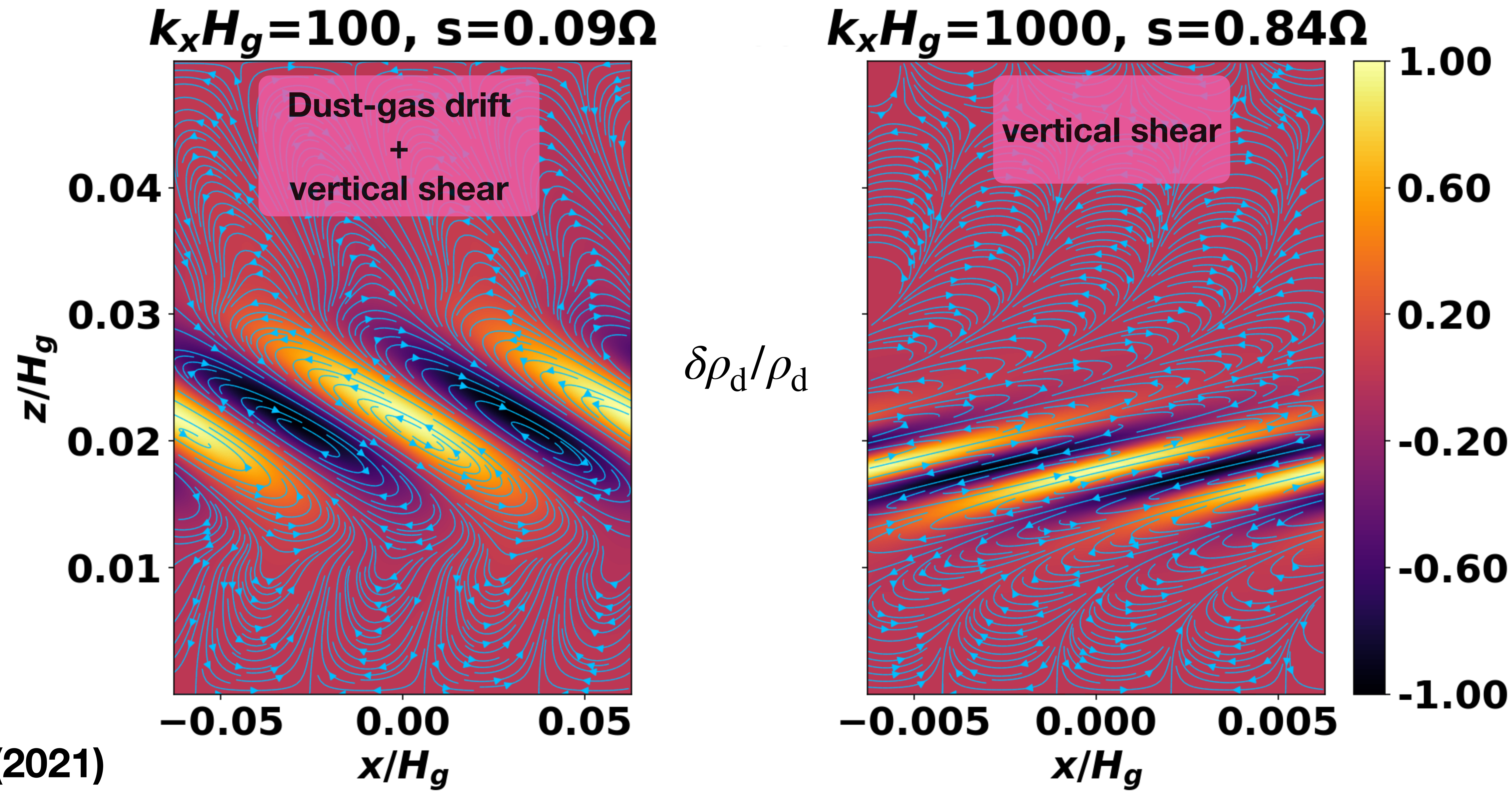
Unstratified models for midplane dynamics



Real dust layers have vertical structure



A new instability in stratified dust layers



Lin (2021)

Connection with known instabilities

Vertically shearing streaming instability
(Ishitsu et al 2009; Lin, 2021)

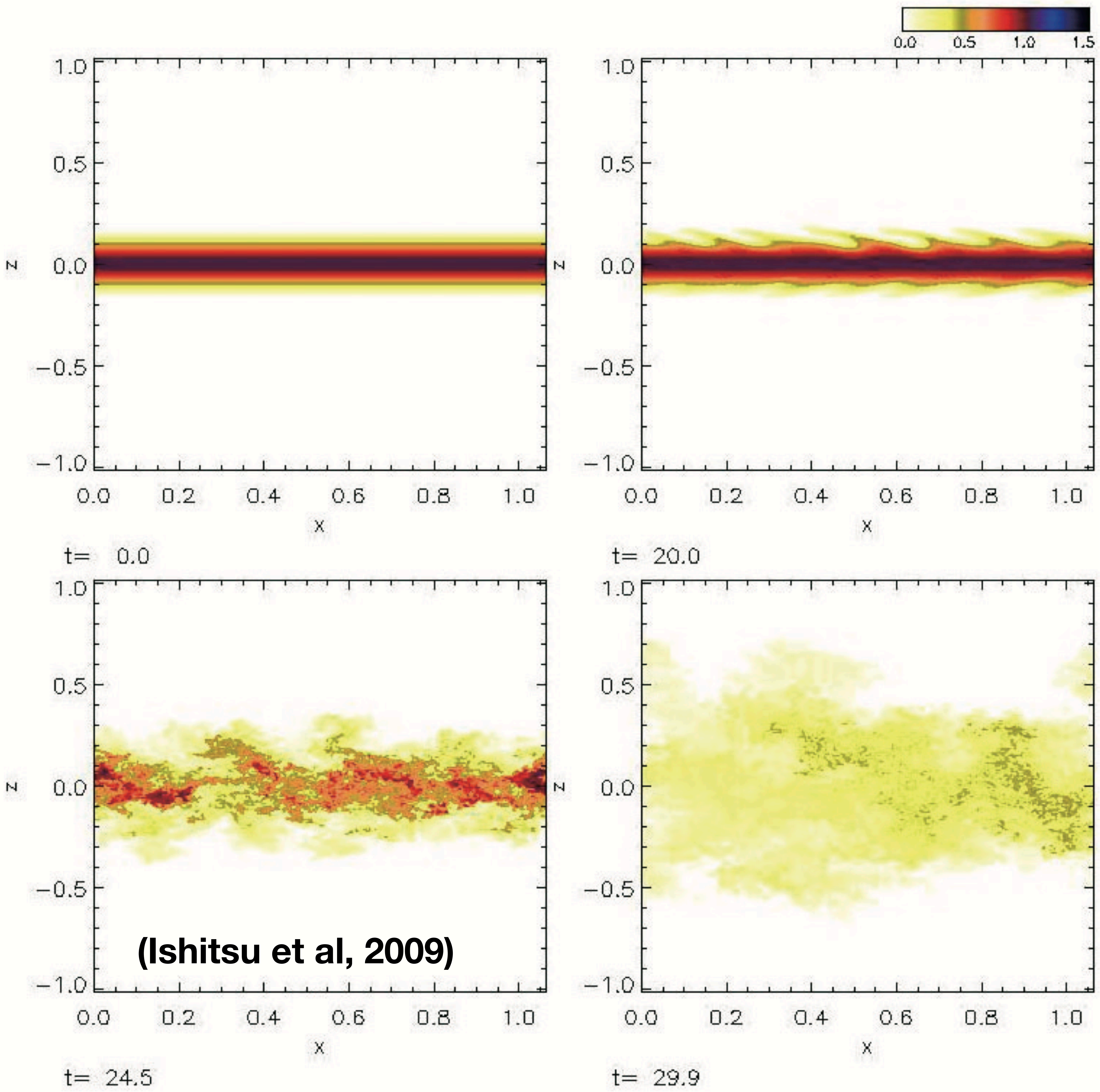
Classic streaming instability
(Youdin & Goodman, 2005)

- relative dust-gas radial drift
- partial coupling
- axisymmetric

Kelvin-Helmholtz instability
(Johansen et al, 2006; Chiang 2008)

- vertical shear
- perfect coupling (sufficient)
- non-axisymmetric

Vertically shearing SIs grow fast but…



dust layer dispersed

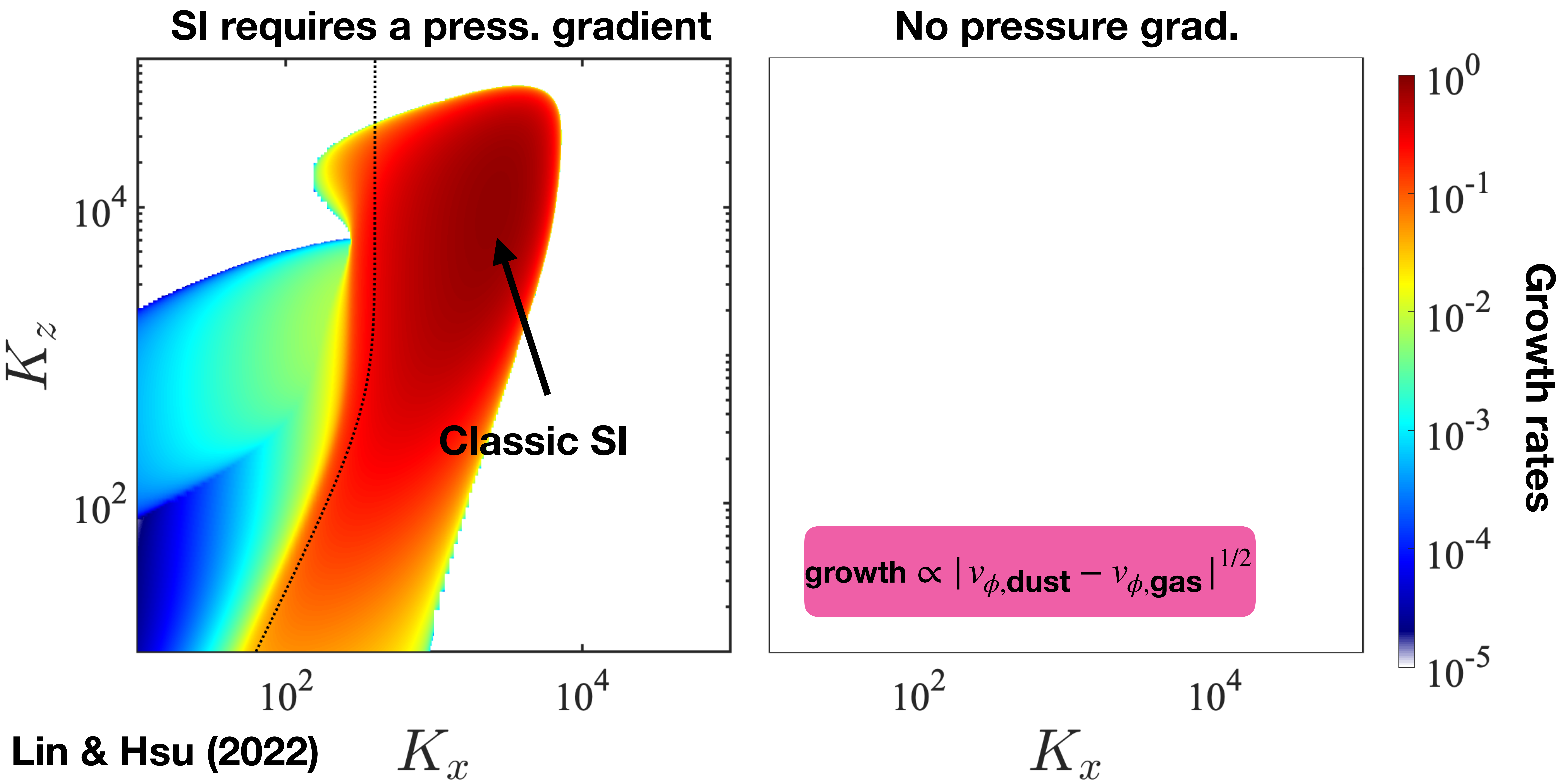
☹️

Can modern disk models help?

Due to large-scale magnetic fields/winds

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

Streaming instability without pressure gradients



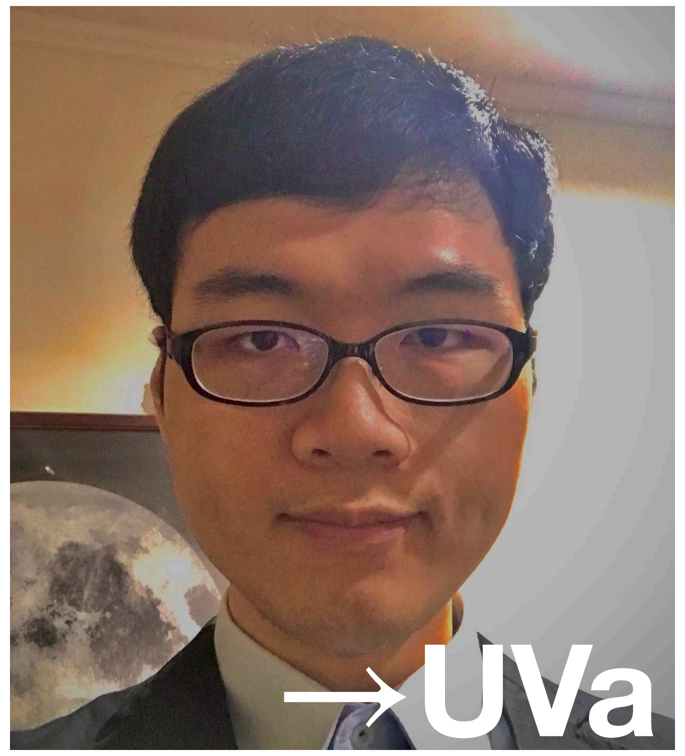
Lin & Hsu (2022)

Verification by FARGO3D

Hsu & Lin (in prep.)

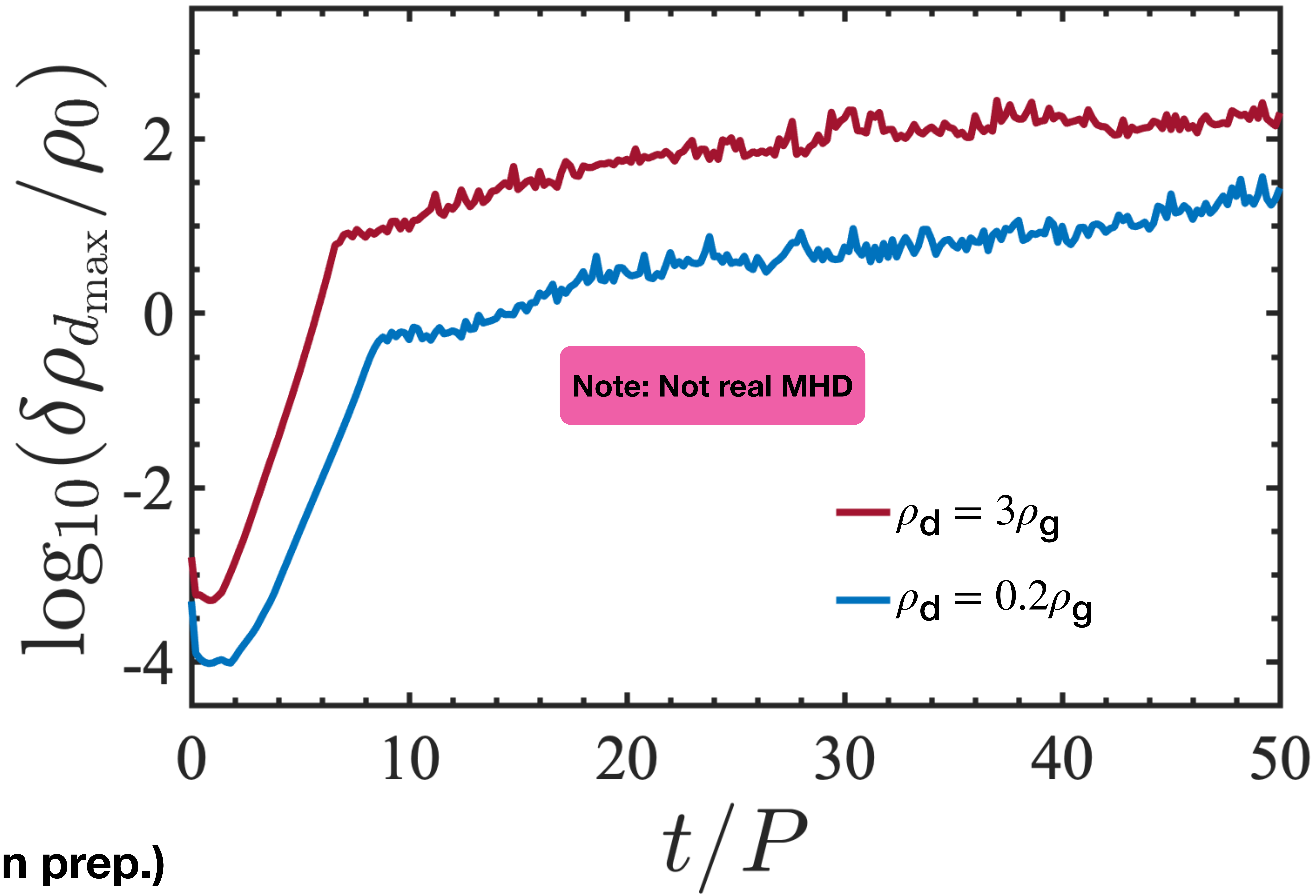
Azimuthal drift streaming instability

Hsu & Lin (in prep.)



- May apply to regions of small pressure gradients
- 1D in nature (applicable to razor-thin disks)
- Analogy with secular gravitational instability?

Dust concentrates even when $\rho_d < \rho_g$ initially

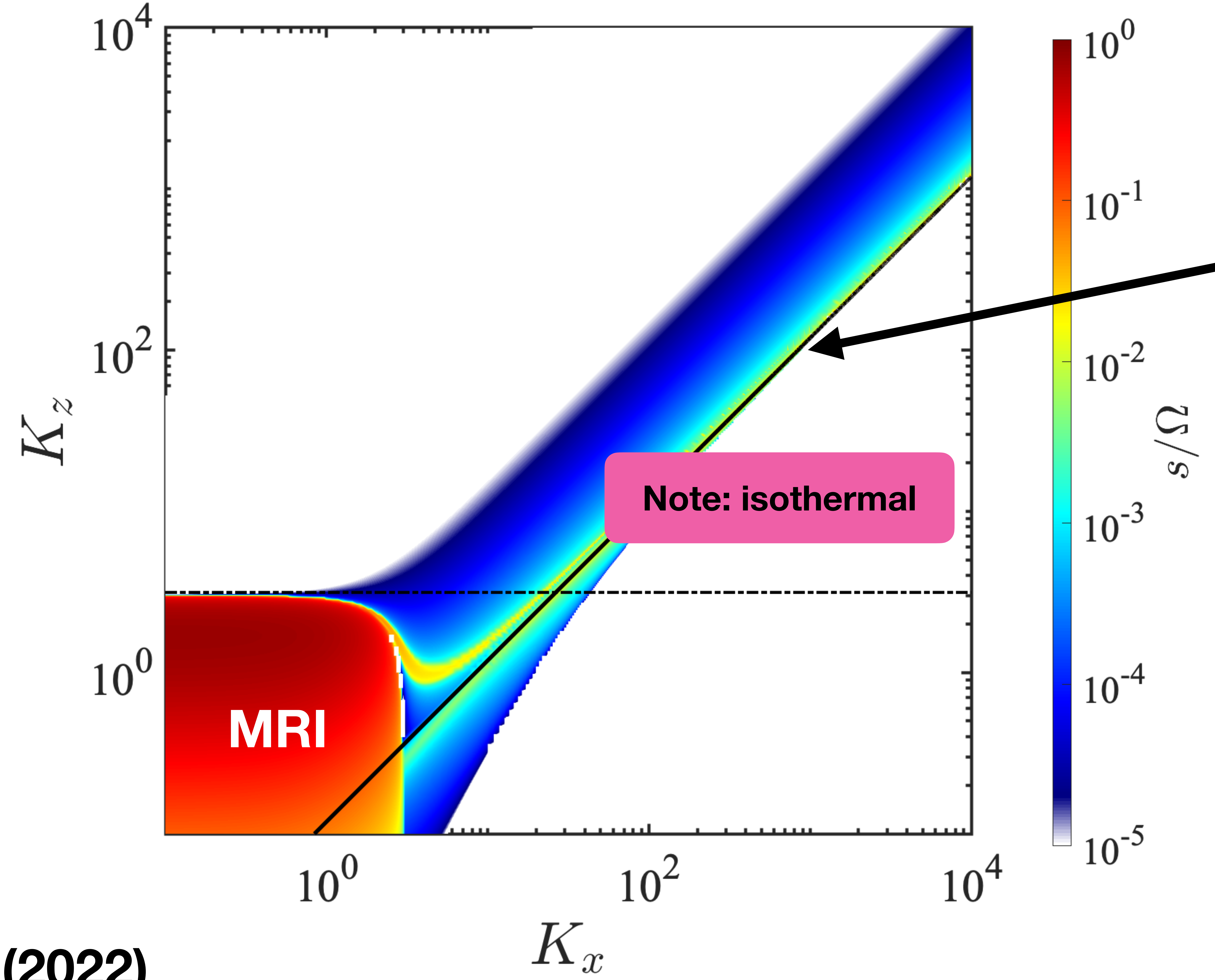


Hsu & Lin (in prep.)

Disappearance of the classic SI with magnetic fields

Lin & Hsu (2022)

Streaming instability of Alfvén waves



- Resonance between Alfvén waves and dust-gas drift
- Needs ideal MHD

Lin & Hsu (2022)

Dynamics of dust in non-isothermal gas

Dust settling instability
(Squire & Hopkins, 2018; Krapp et al. 2020)

Lehmann & Lin (in prep.)

Summary

- Dust settling opposed by turbulence
- SI is easily stabilized by viscosity
- Vertically shearing SI in stratified disks
- Azimuthal drift SI in accreting disks
- Dust & non-isothermal gas dynamics

Opportunities at ASIAA and NCTS

- Summer student programs
- Visitor programs
- Postdoc fellowships

Thank you

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