Hopes and challenges in modern planet formation

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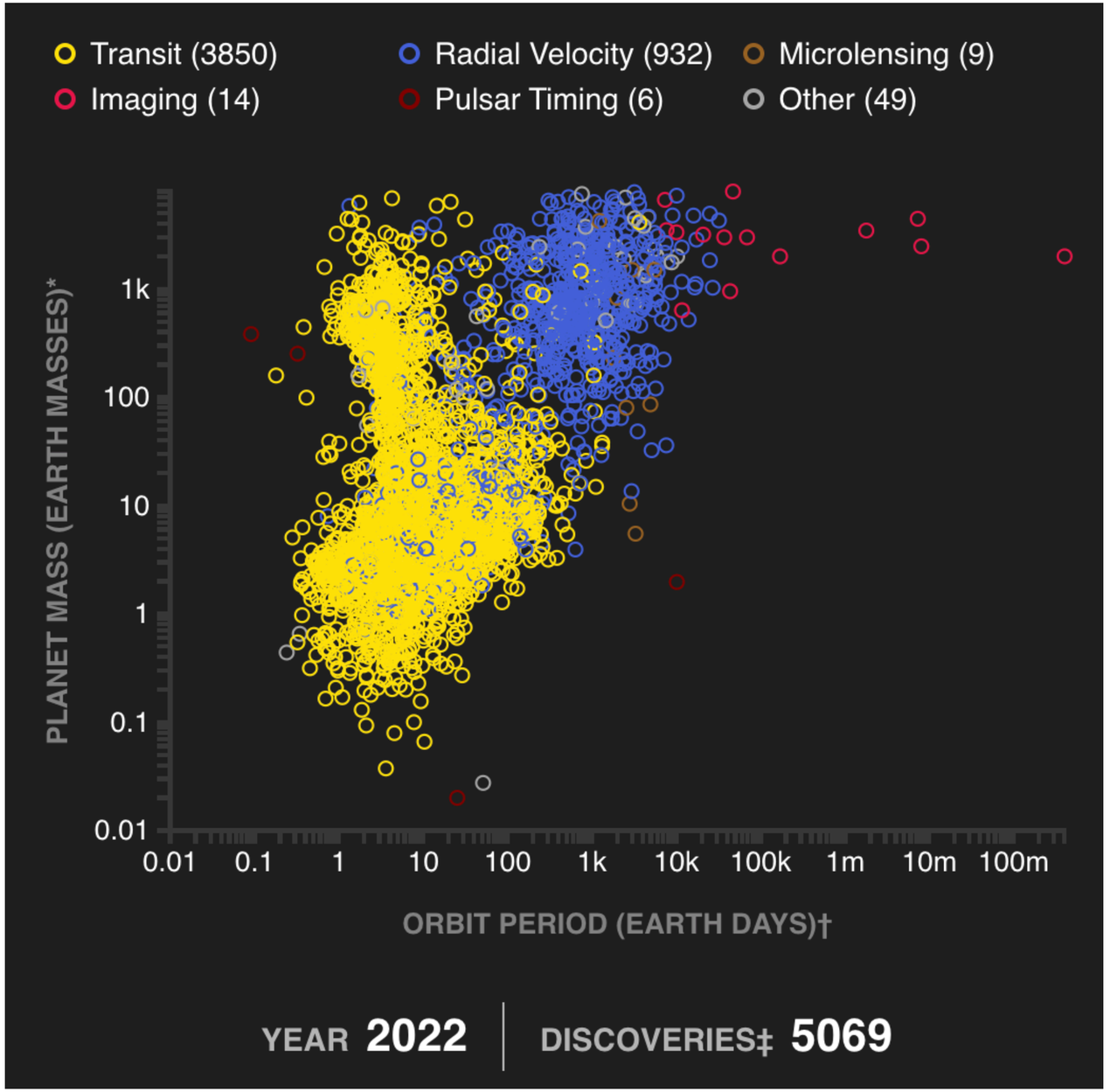
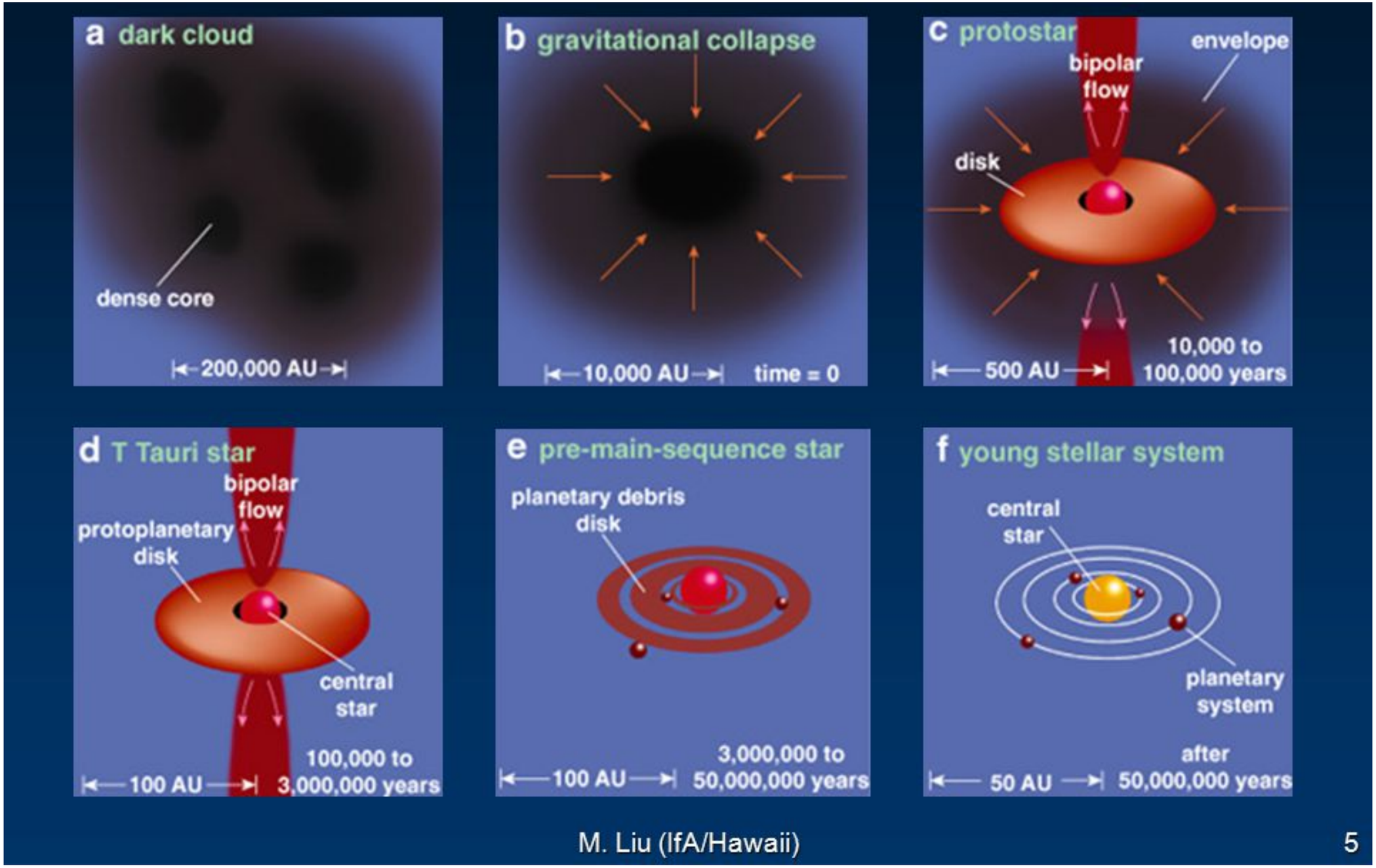
October 2022

A golden era of planet formation



(Image credit: https://exoplanets.nasa.gov/)

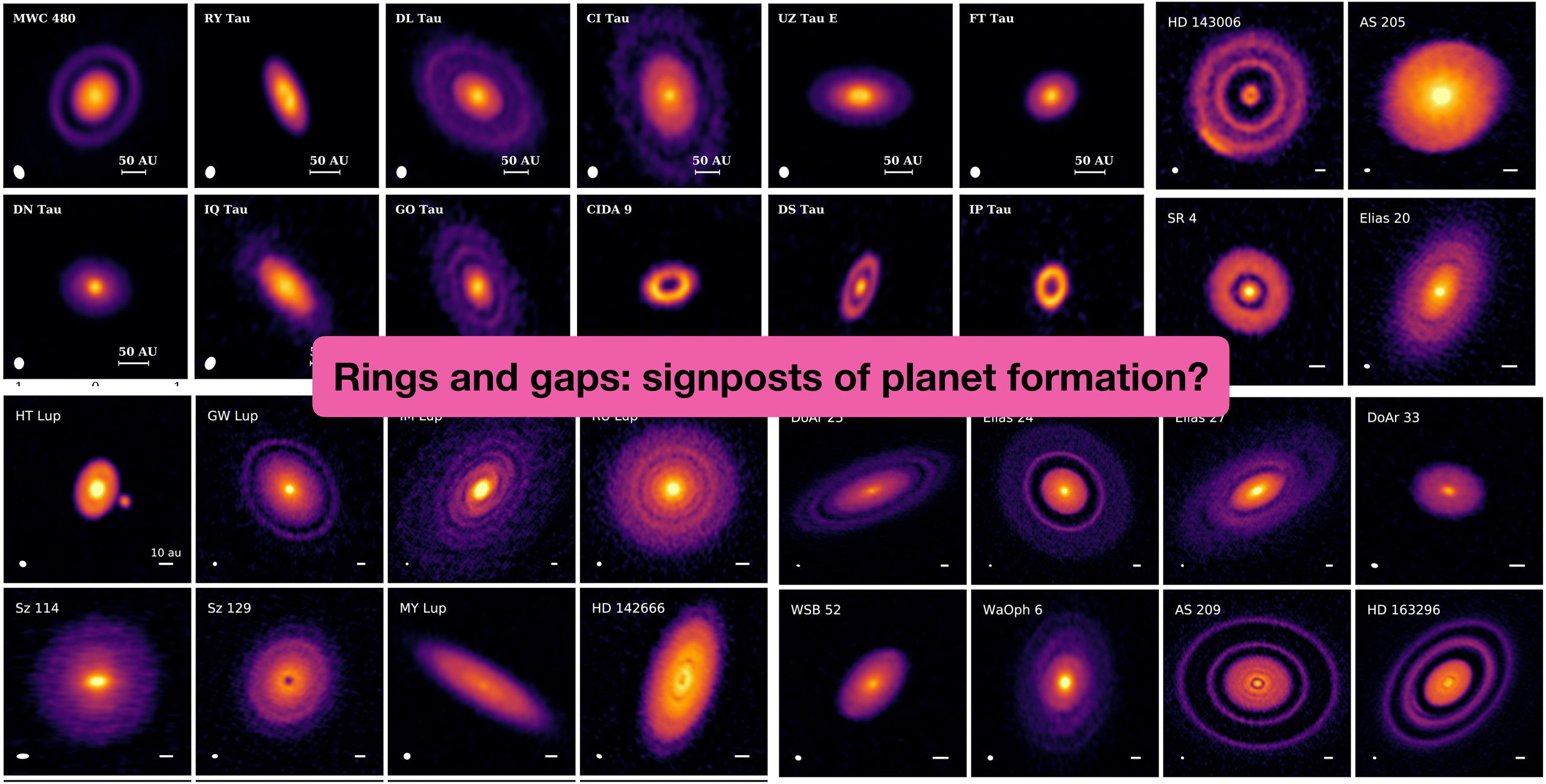
Planets form in protoplanetary disks



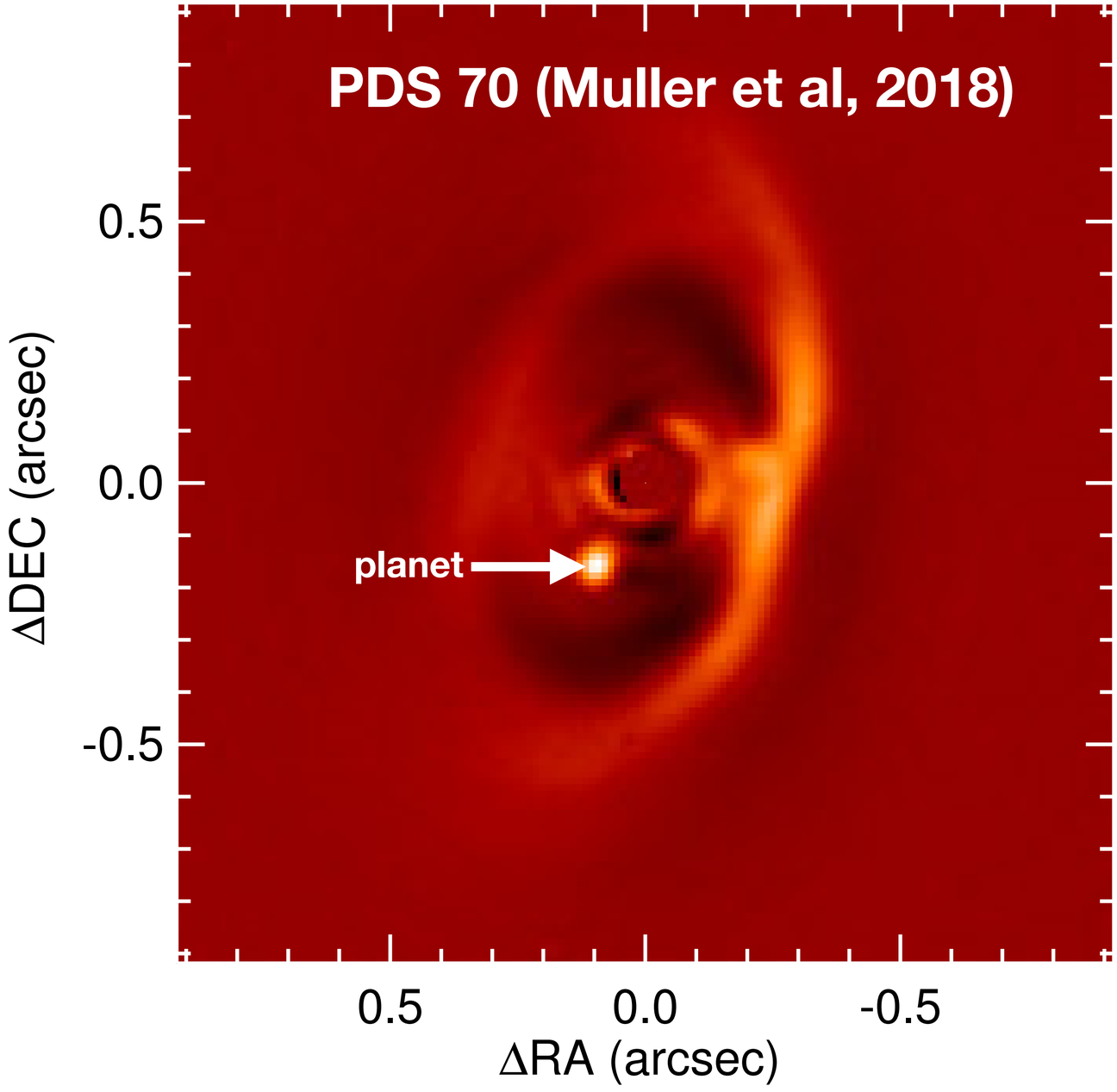
M. Liu (IfA/Hawaii)

Real protoplanetary disks

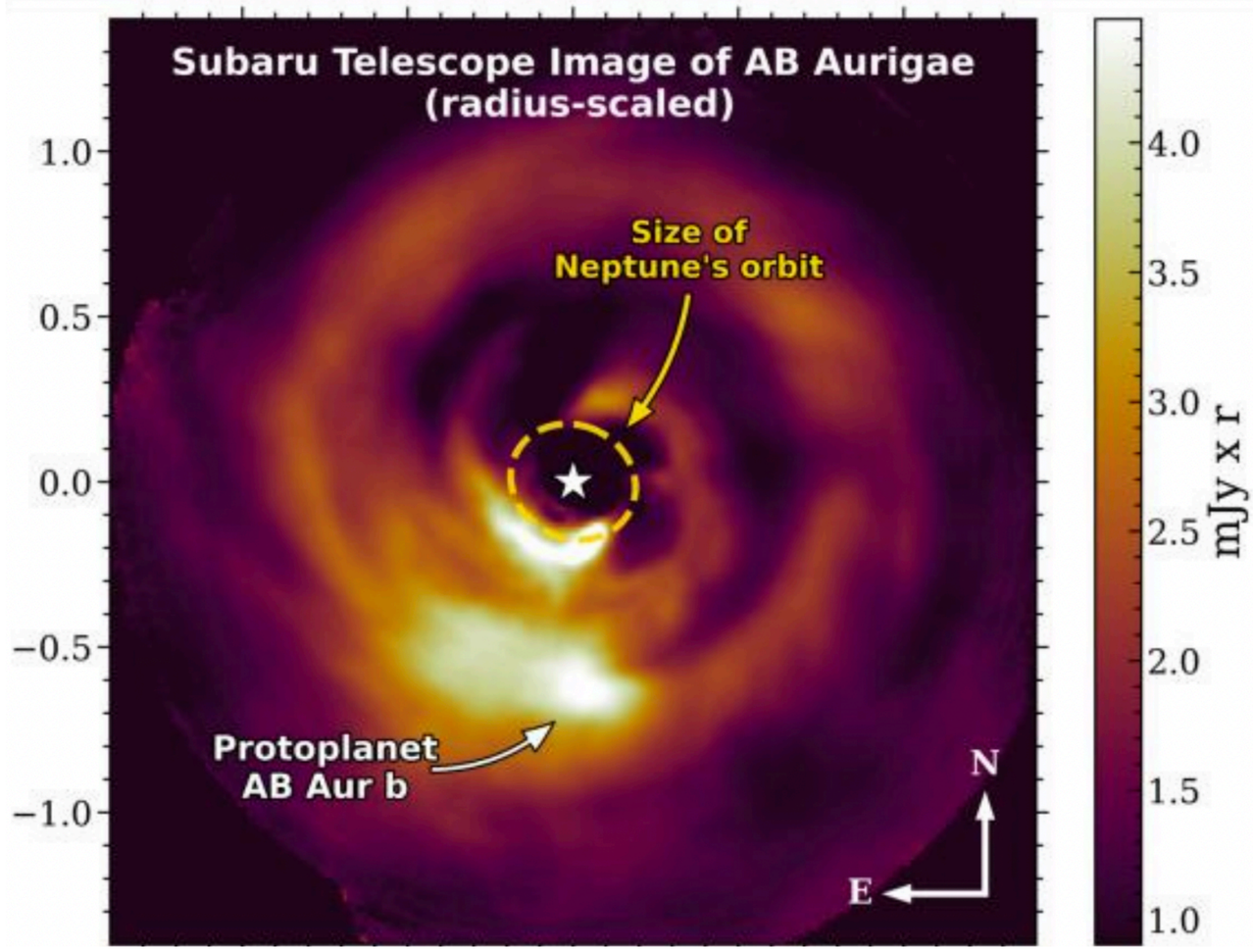
(Andrews et al, 2018; Long et al 2018)



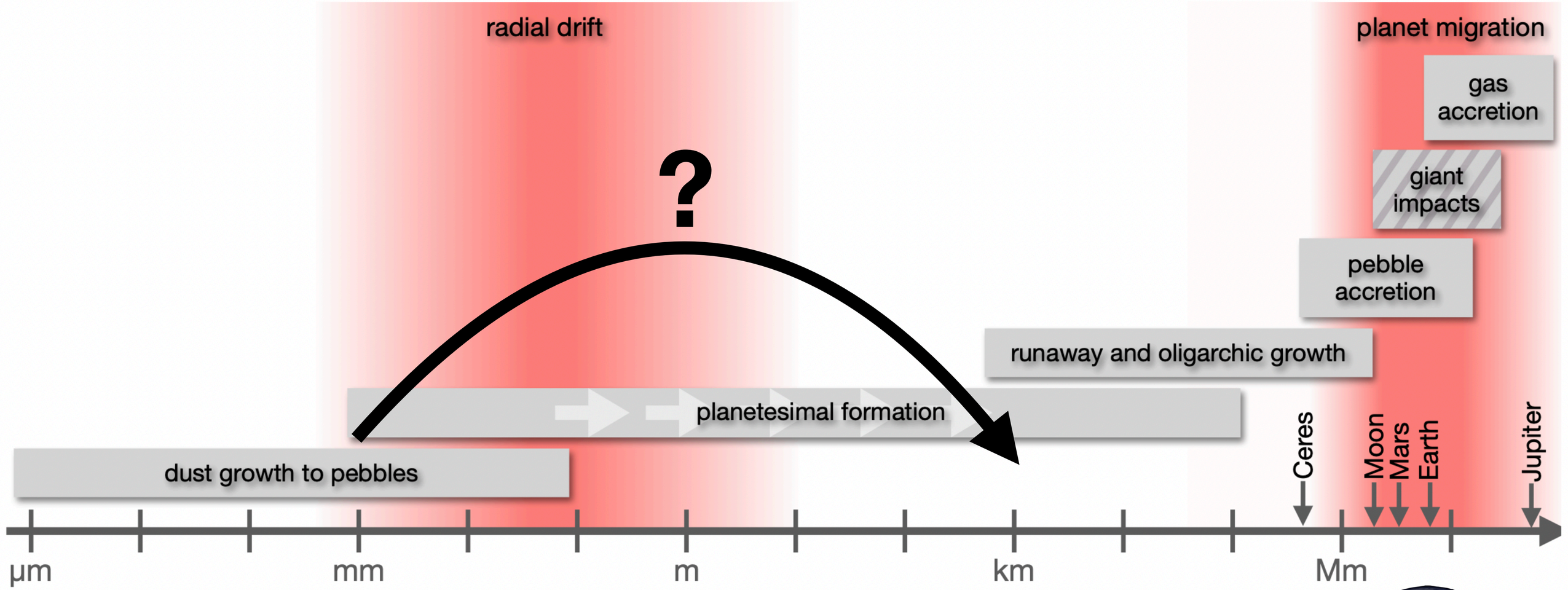
Observations of planets in a disk

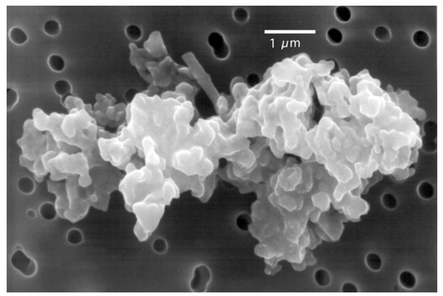


AB Aur (Currie et al, 2022)



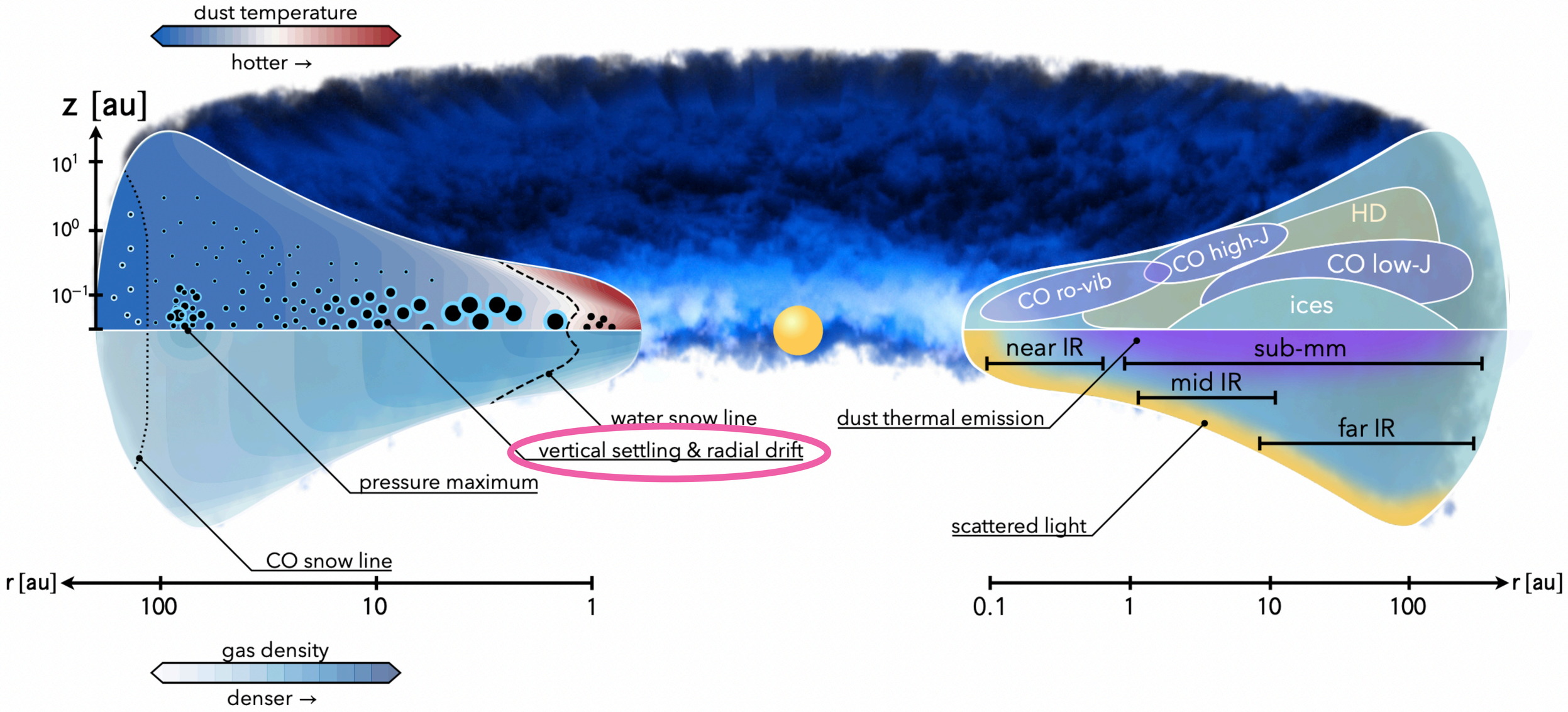
One planet, multiple scales





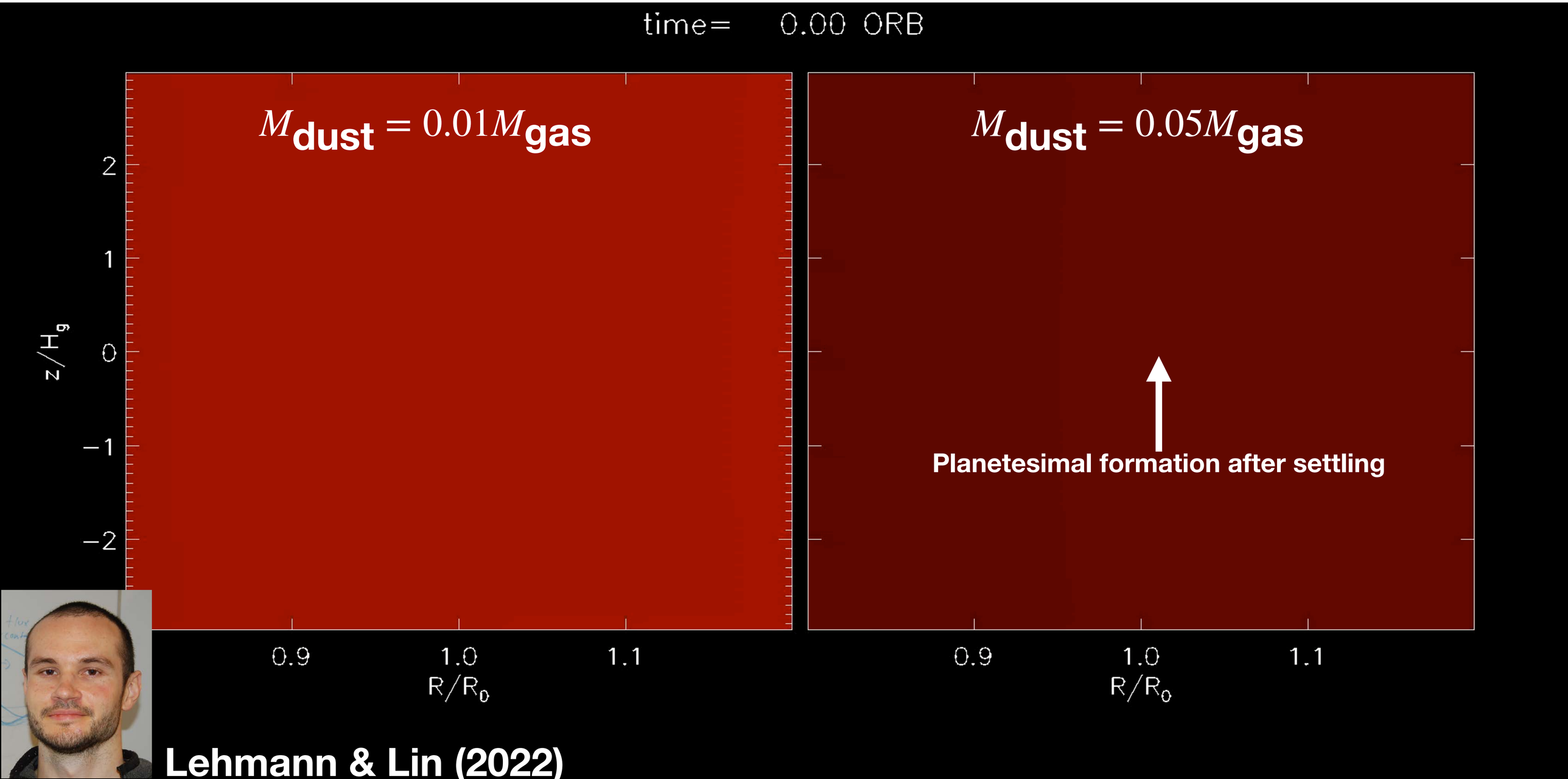
(Drazkowska et al., 2022, PPVII)

Dust in protoplanetary disks



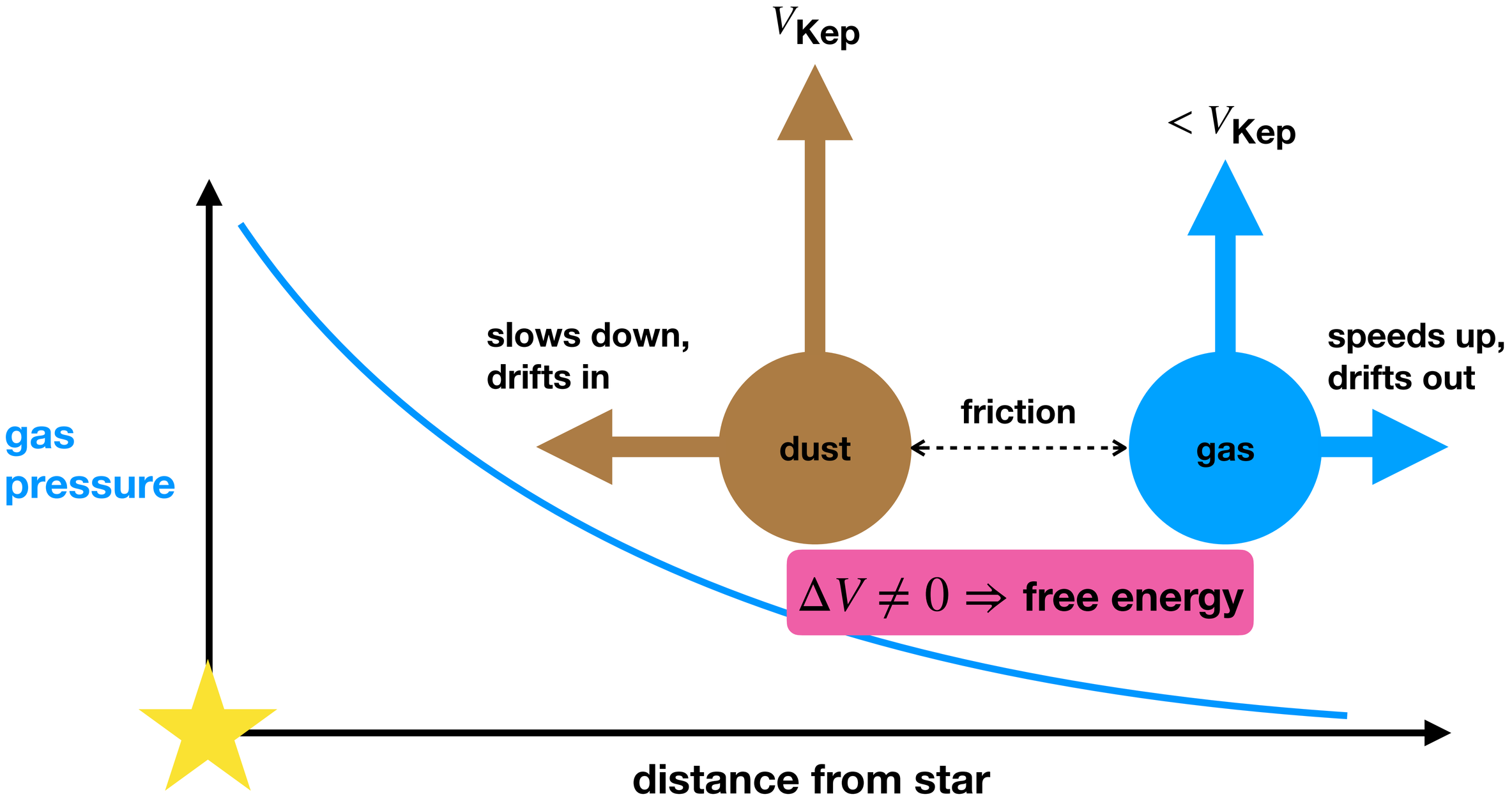
(Miotello et al., 2022, PPVII)

Vertical dust settling

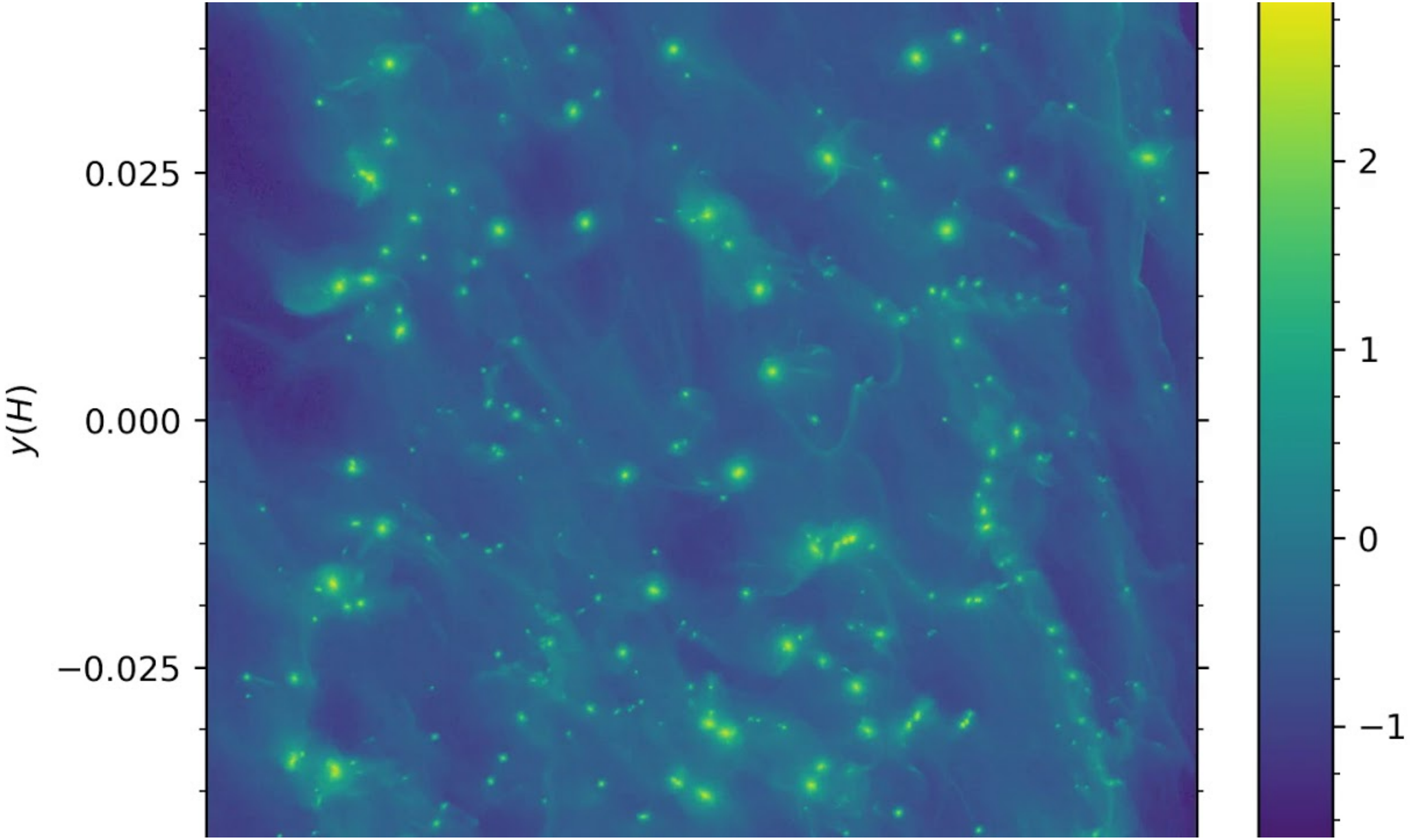


Lehmann & Lin (2022)

Radial dust drift



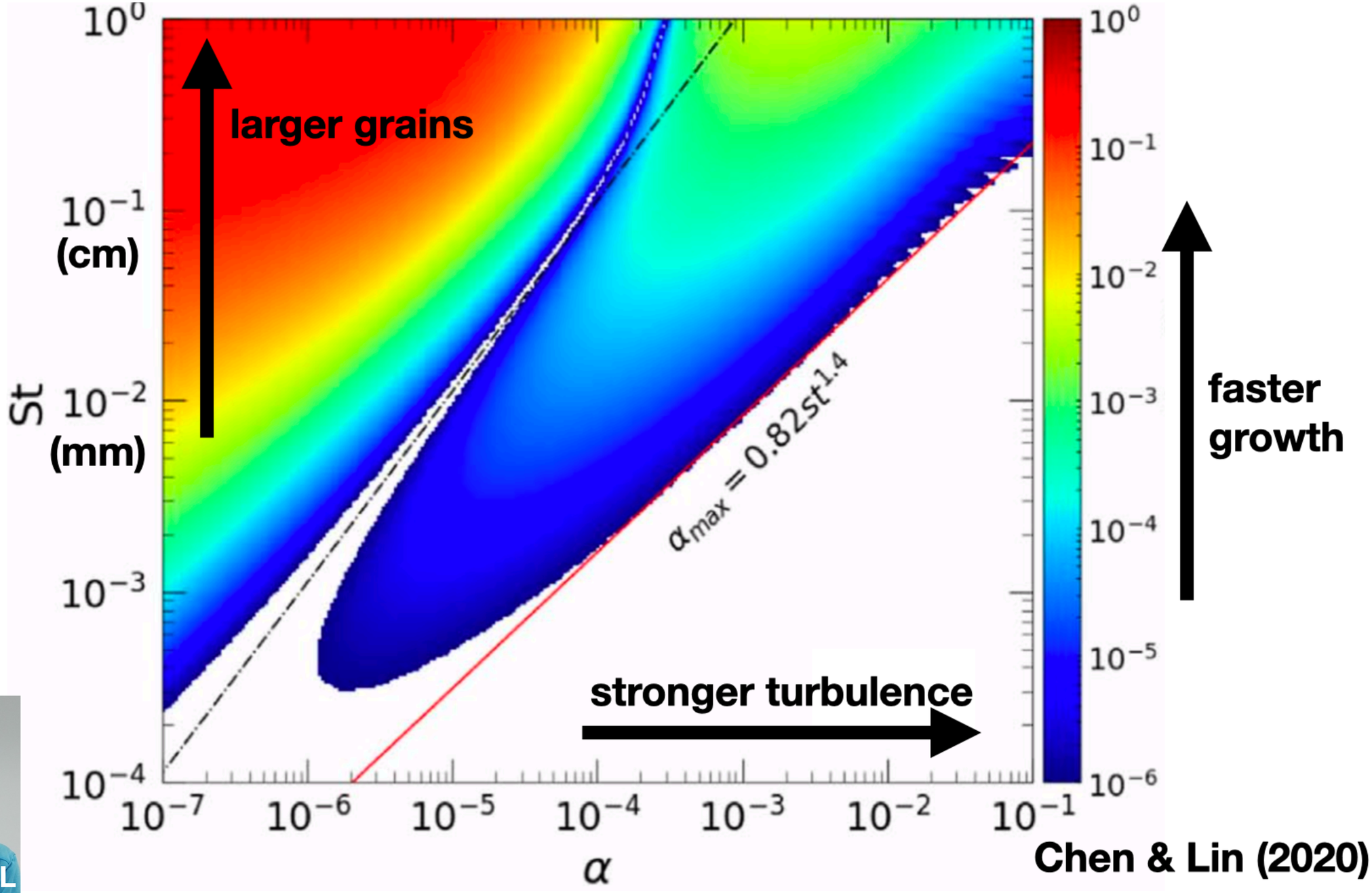
Streaming instability (Nesvorný et al., 2020)



The ideal SI

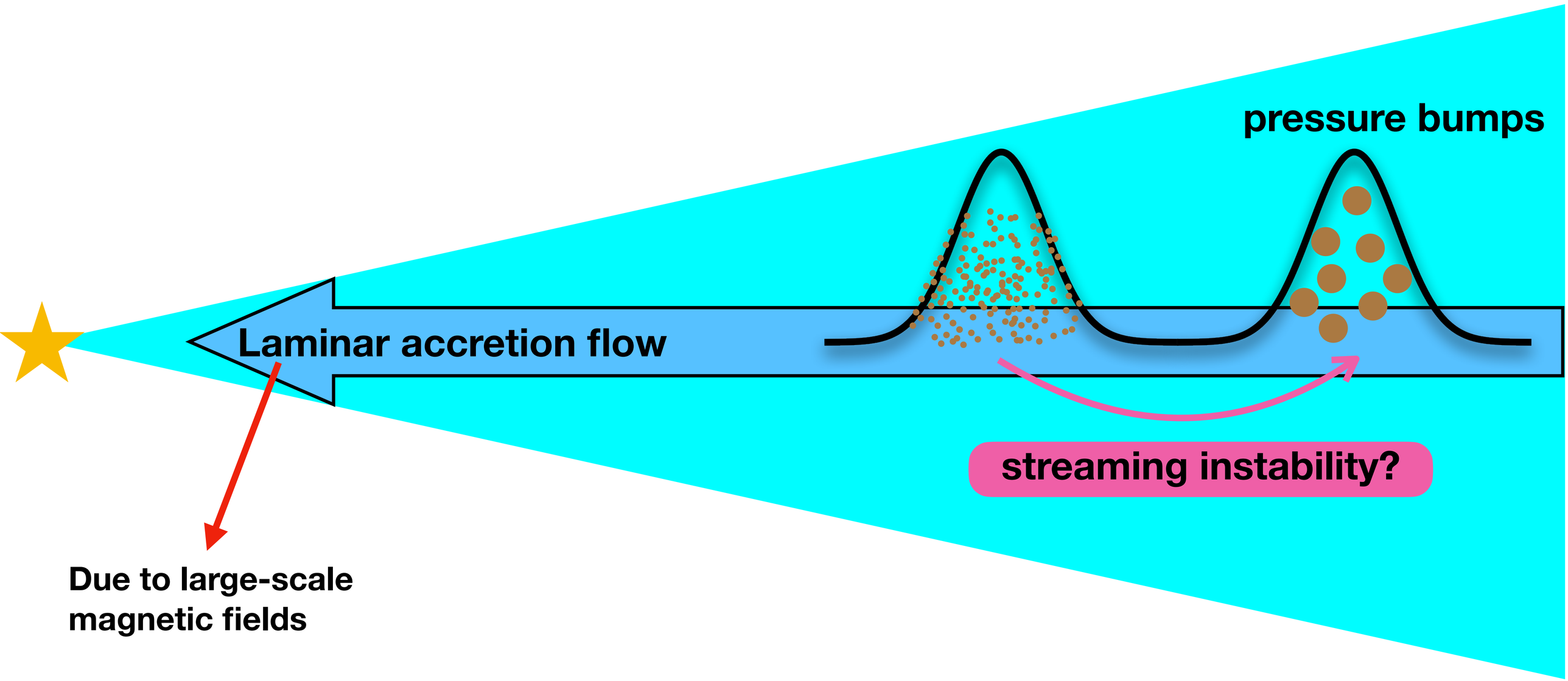
- disk is non-turbulent → Chen & Lin (2020)
- disk is unmagnetized → Lin & Hsu (2022)
Hsu & Lin (2022)

Streaming instability is easily killed by turbulence



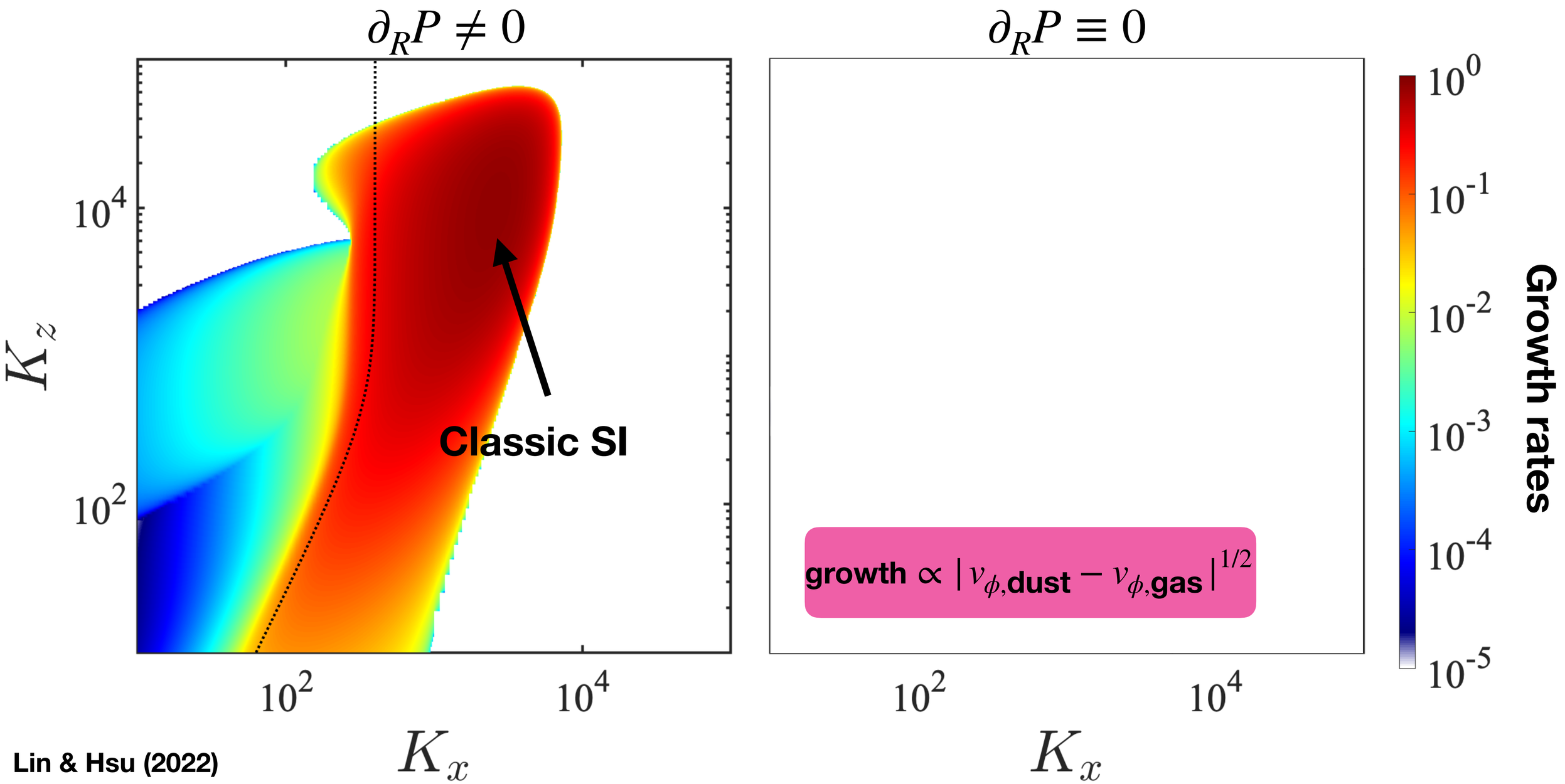
Chen & Lin (2020)

Can modern disk models help?



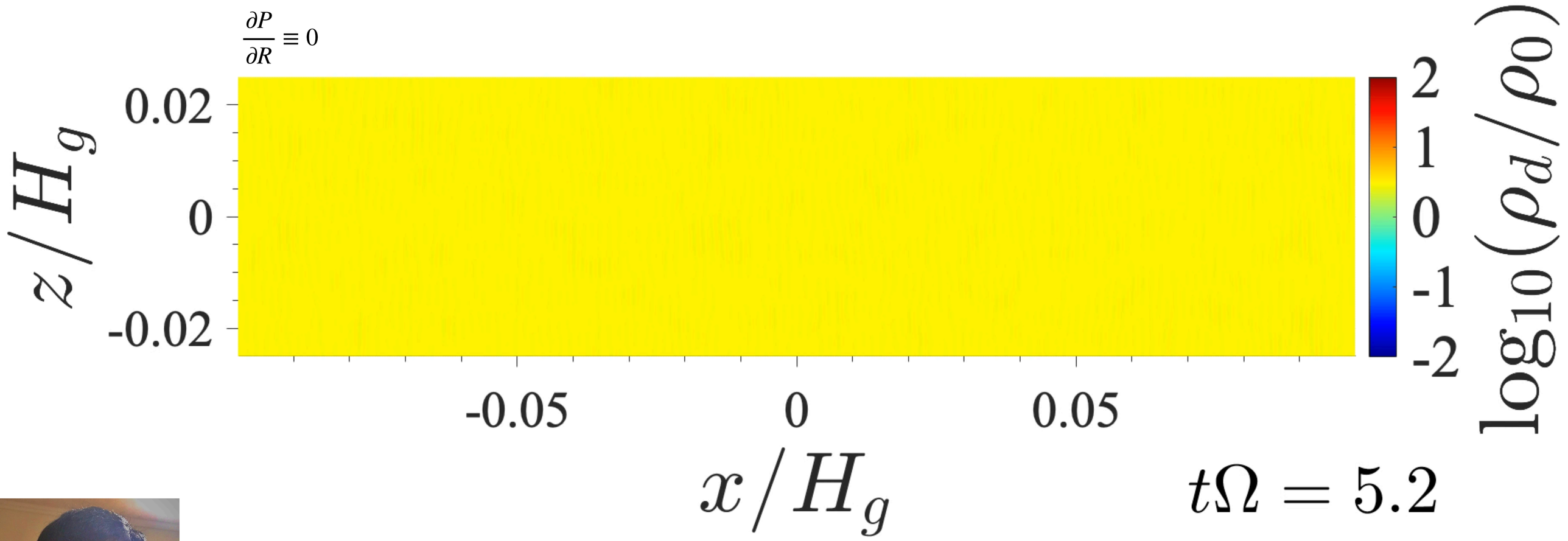
(e.g. Riols et al. 2020, Cui & Bai 2021)

SI in accreting pressure bumps



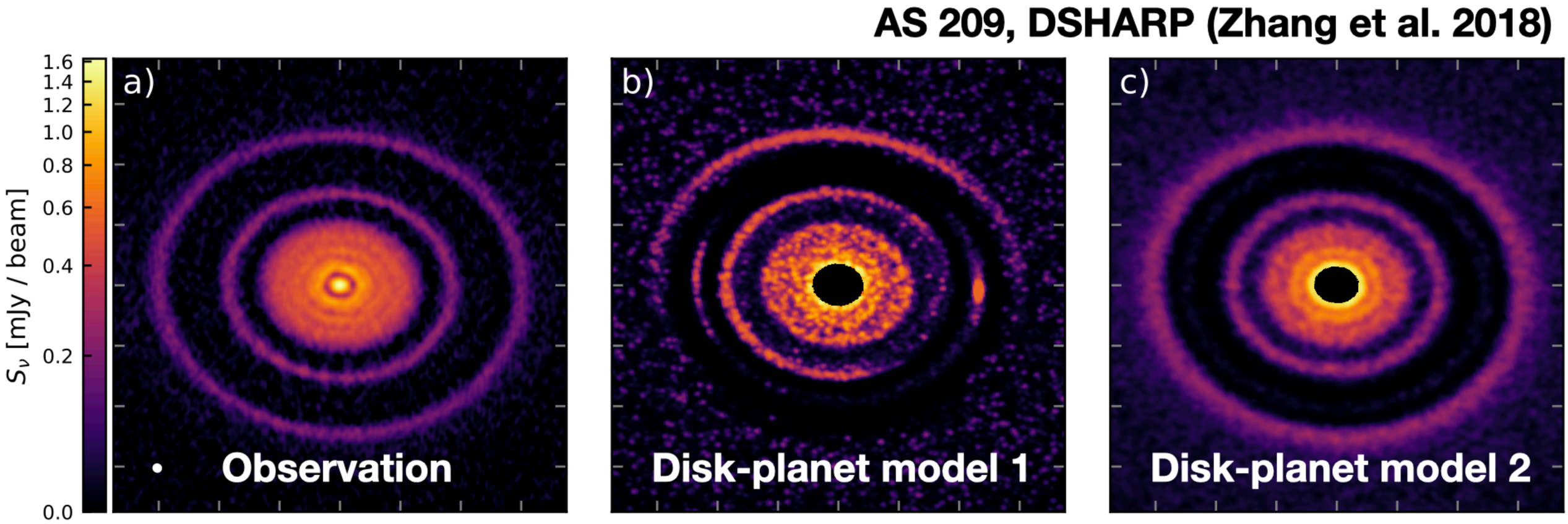
Lin & Hsu (2022)

Azimuthal drift streaming instability



Hsu & Lin (2022)

Planets form somehow, so what's next?



But each observation requires many simulations

Modeling planet gaps with artificial/convolutional NN

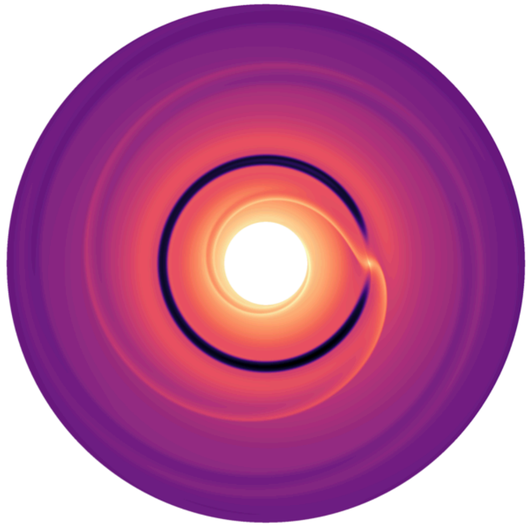


Image Data

Convolutional Neural Netwrok **ReSNet**

Numerical Data

- Aspect Ratio
- Viscosity
- Dust-to-gas ratio
- Stokes Number
- Density Profile

Muilti-layer Perceptron (MLP)

Concatenation

FC Layer Linear Activation

Planet Mass

Auddy & Lin (2020)
Auddy et al. (2021)
Auddy et al. (2022)

Estimating planet masses around HL Tau

- **Hydrodynamic simulations**

(Dong et al. 2015, Dipierro et al. 2015, Jin et al. 2016)

$$M_p = 0.2 - 0.35 M_J, 0.17 - 0.27 M_J, 0.2 - 0.55 M_J$$

- **Disk-Planet Neural Network**

(Auddy & Lin, 2020)

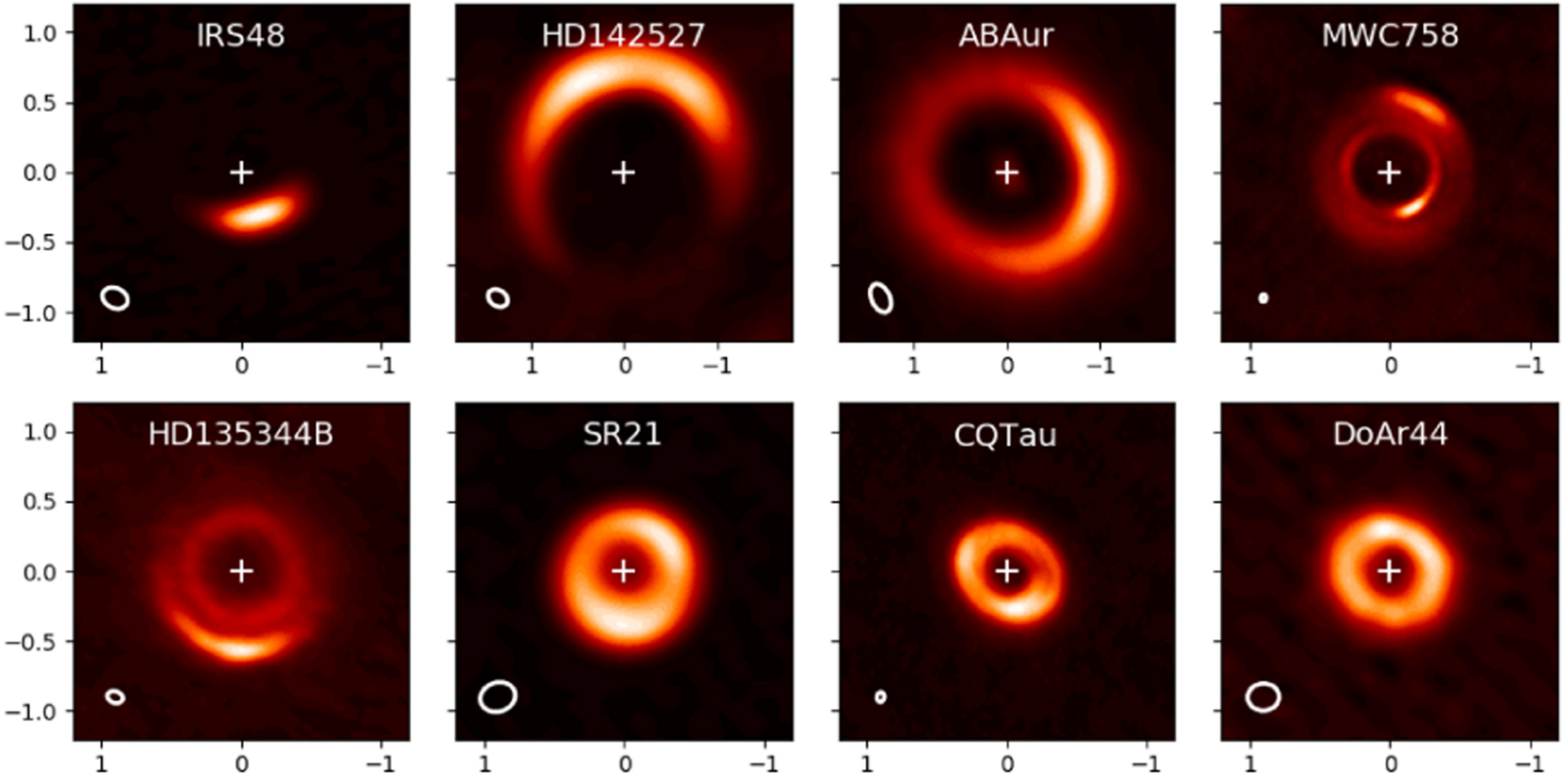
$$M_p = 0.24 M_J, 0.21 M_J, 0.2 M_J$$

Simulation caveats

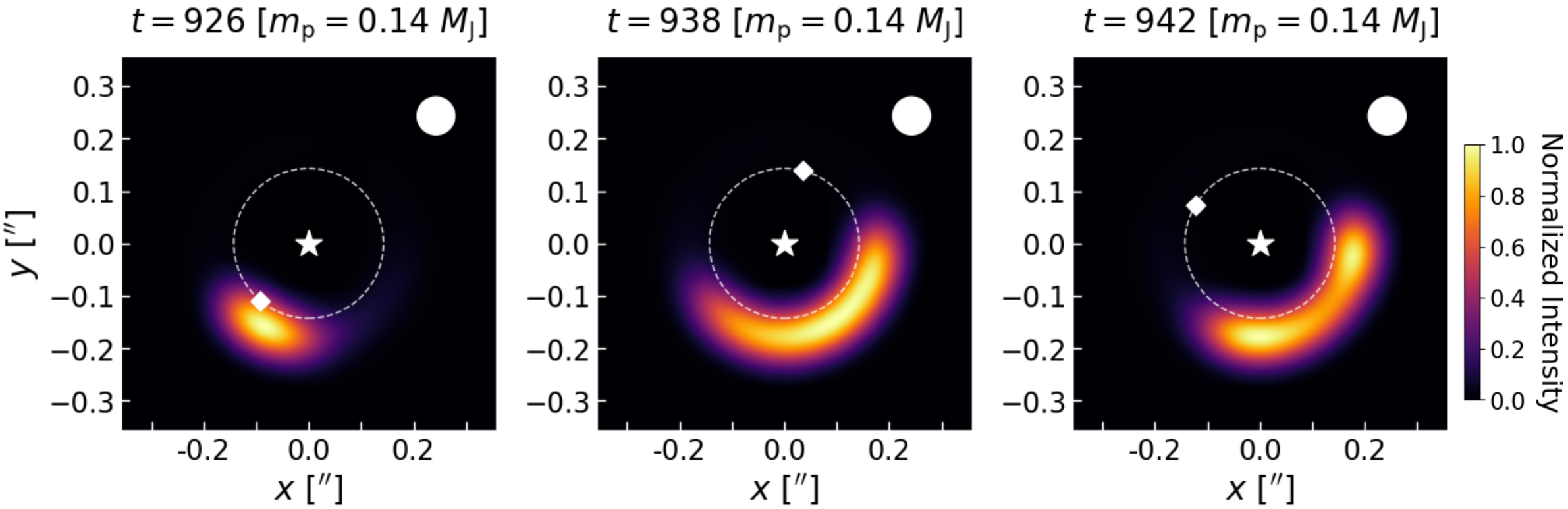
- **Focus on axisymmetric structures**
- **Planet on fixed orbits**
- **2D disk**

Some observed disks are asymmetric

(van de Marel, et al. 2021)



Can planets also explain them?

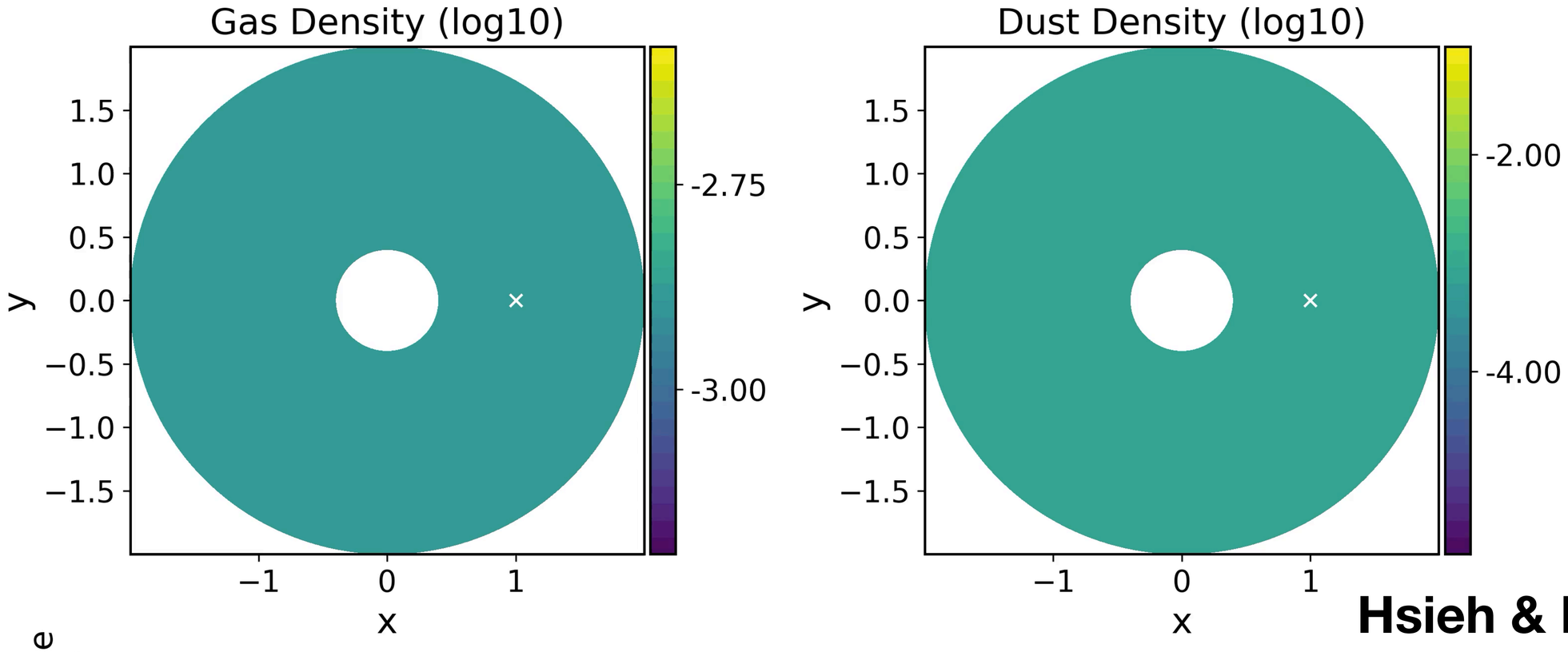


Vortex formation due to the “Rossby wave” instability

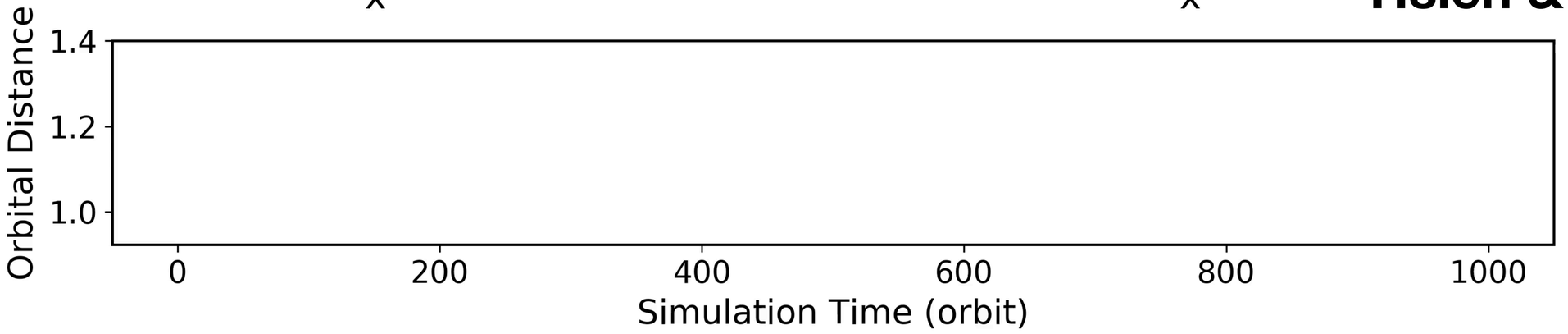
(Hammer, Lin, et al. 2021)

Migrating planets in dusty disks

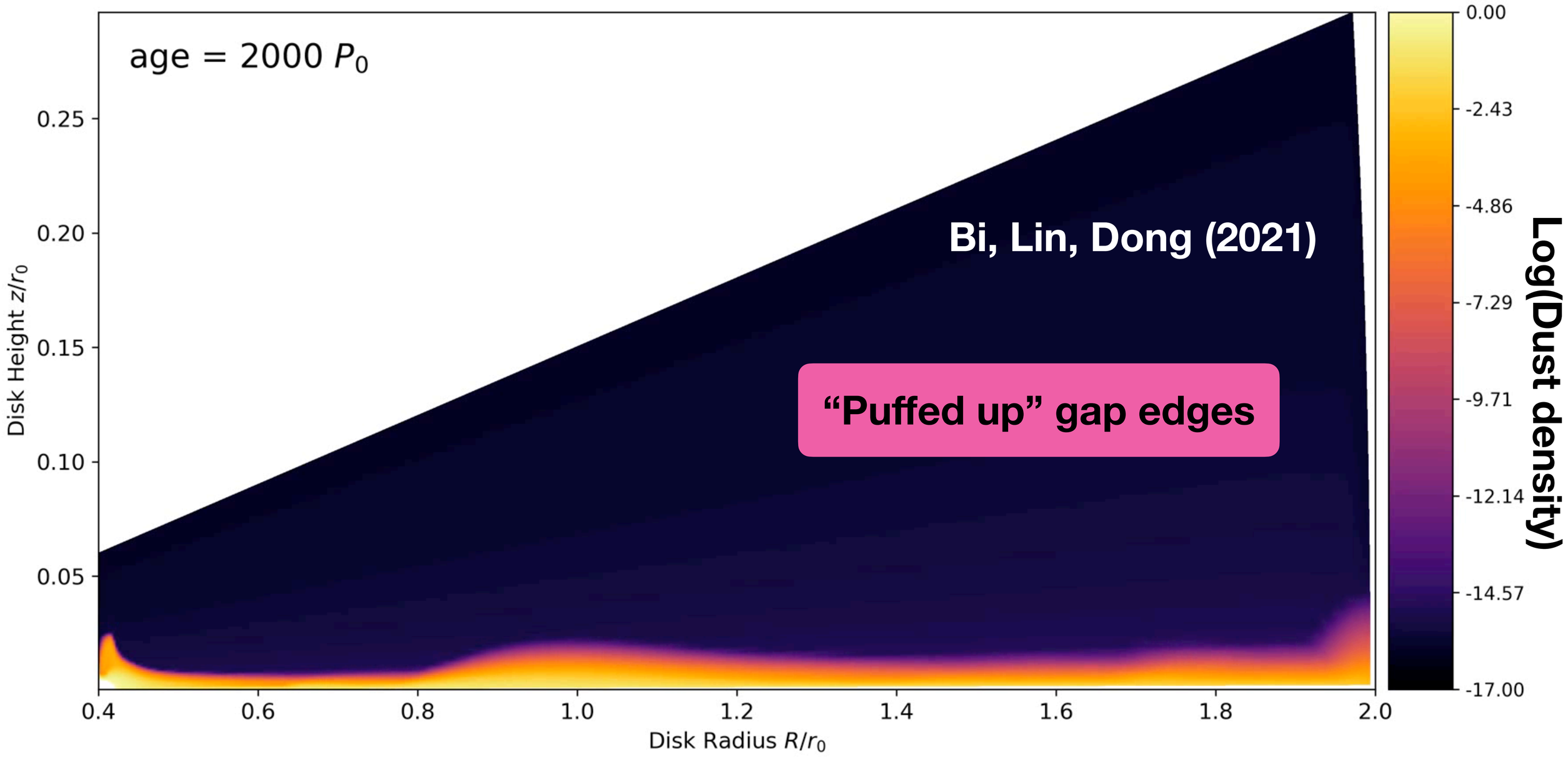
$Z = 0.5, St = 3 \times 10^{-2}$, 0 orbits



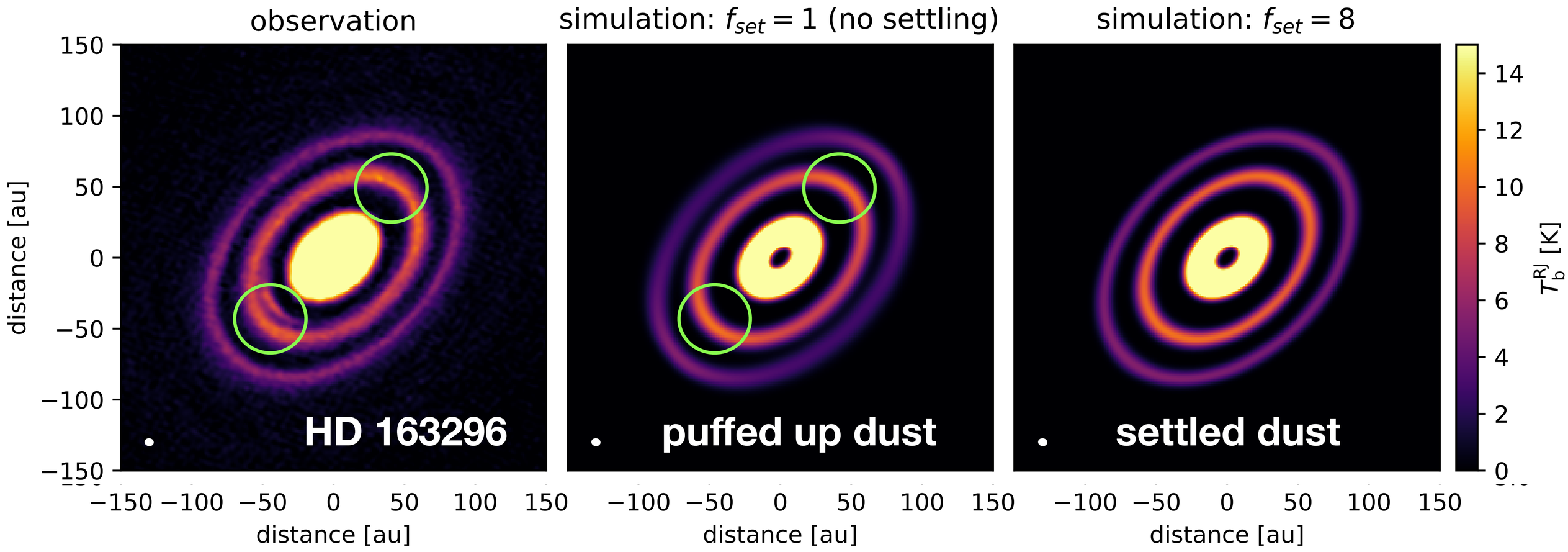
Hsieh & Lin (2020)



Three-dimensional models



Puffed up rings in observations: Sign of planets?



Doi & Kataoka (2021)

Summary

- We are in a golden age for planetary sciences
- The streaming instability is the leading theory for planetesimal formation
- Modern disk models may challenge the SI or provide new pathways to planetesimal formation
- Planet-disk interaction can potentially reveal or rule out hidden planets in observations of protoplanetary disks

Thank you

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