

Dependence on Disk Parameters: Scale Height (Sound Speed)

Density Wave Pitch Angle

$$H/R = 4.0 \%$$



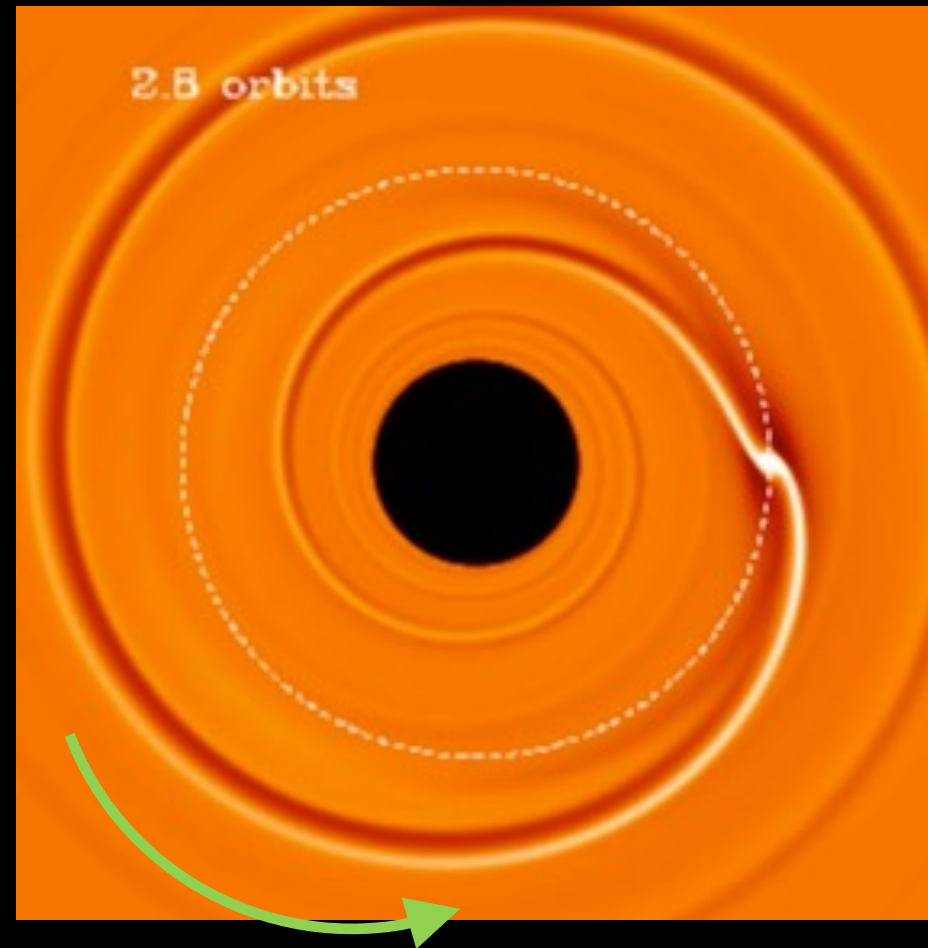
F. Masset

Planet Migration (Type I)

Planet-wave interaction

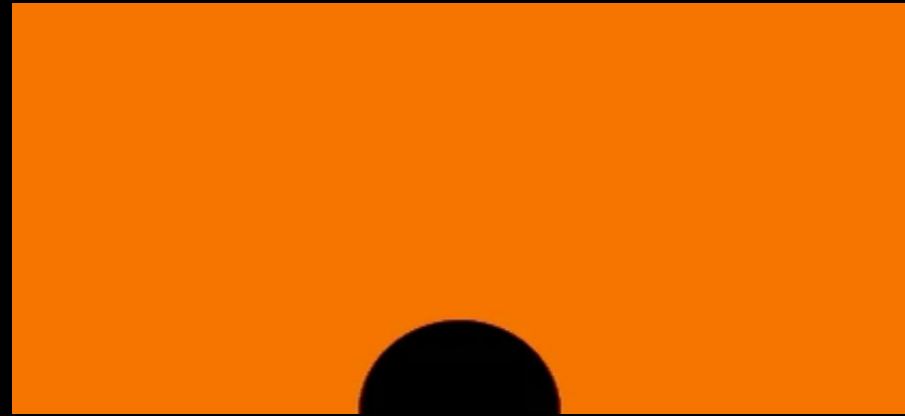
Impulse approximation

Migration rate

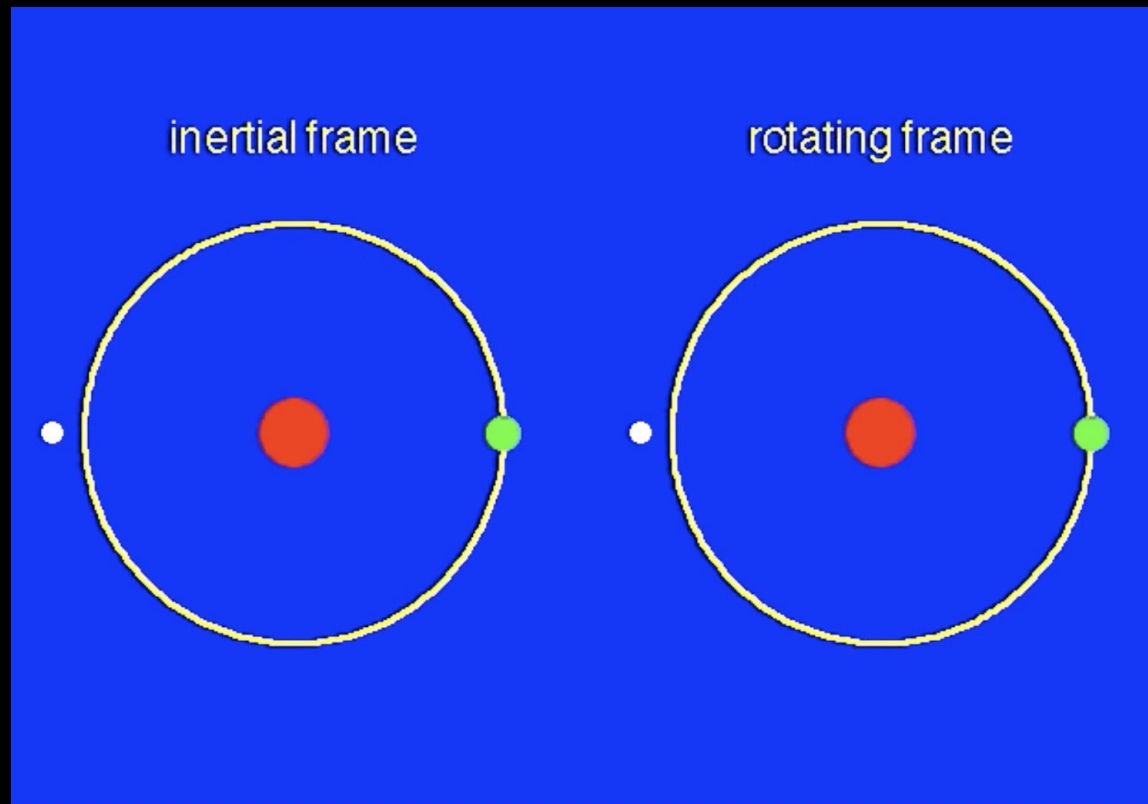


Gap Opening

Type II Migration

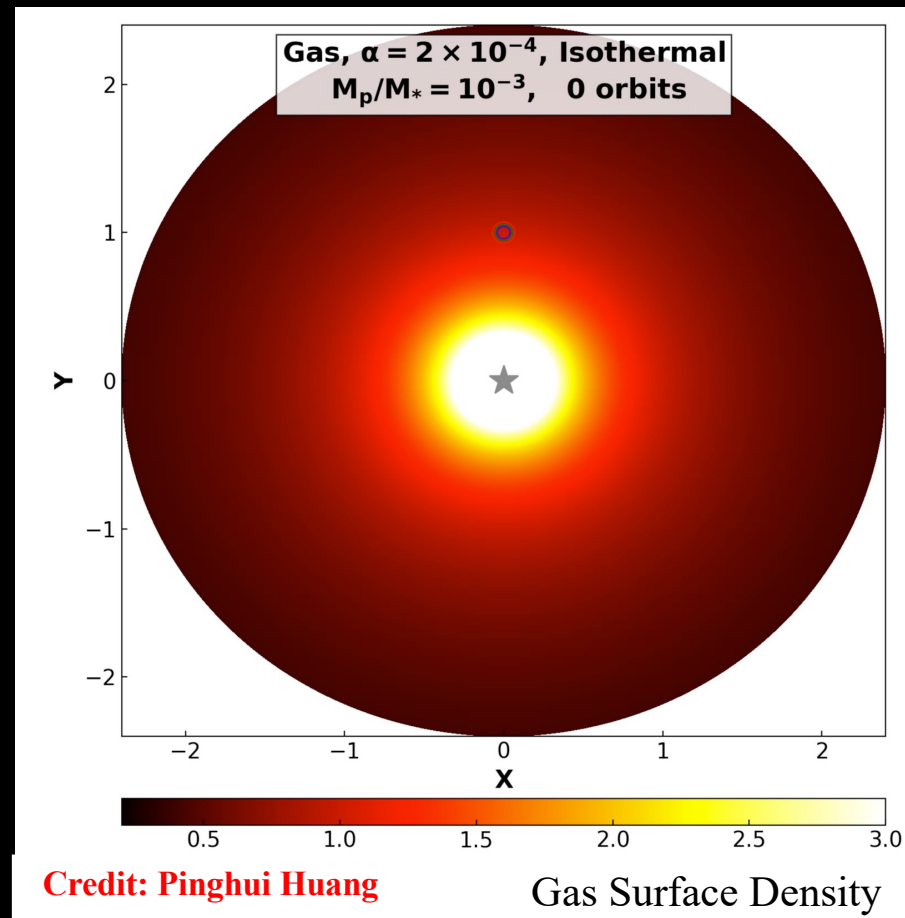


Horseshoe orbit



- Density perturbation
 - Density waves
 - Gaps
 - Additional features
- Velocity perturbation
- Temperature perturbation

Possible additional features, e.g., vortex formation

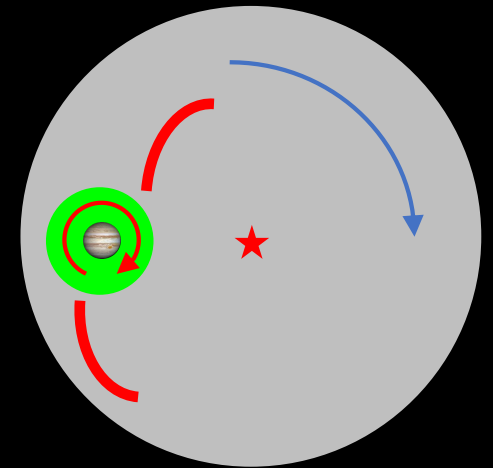
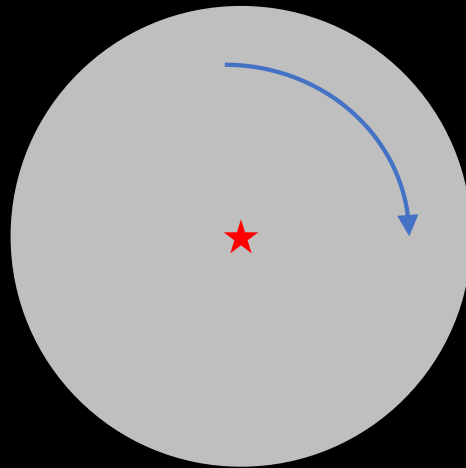


Velocity Perturbations

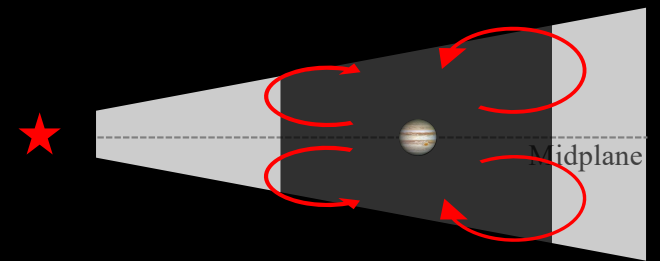
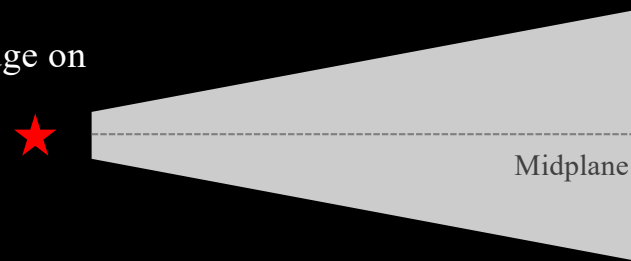
No Planet

With a Planet

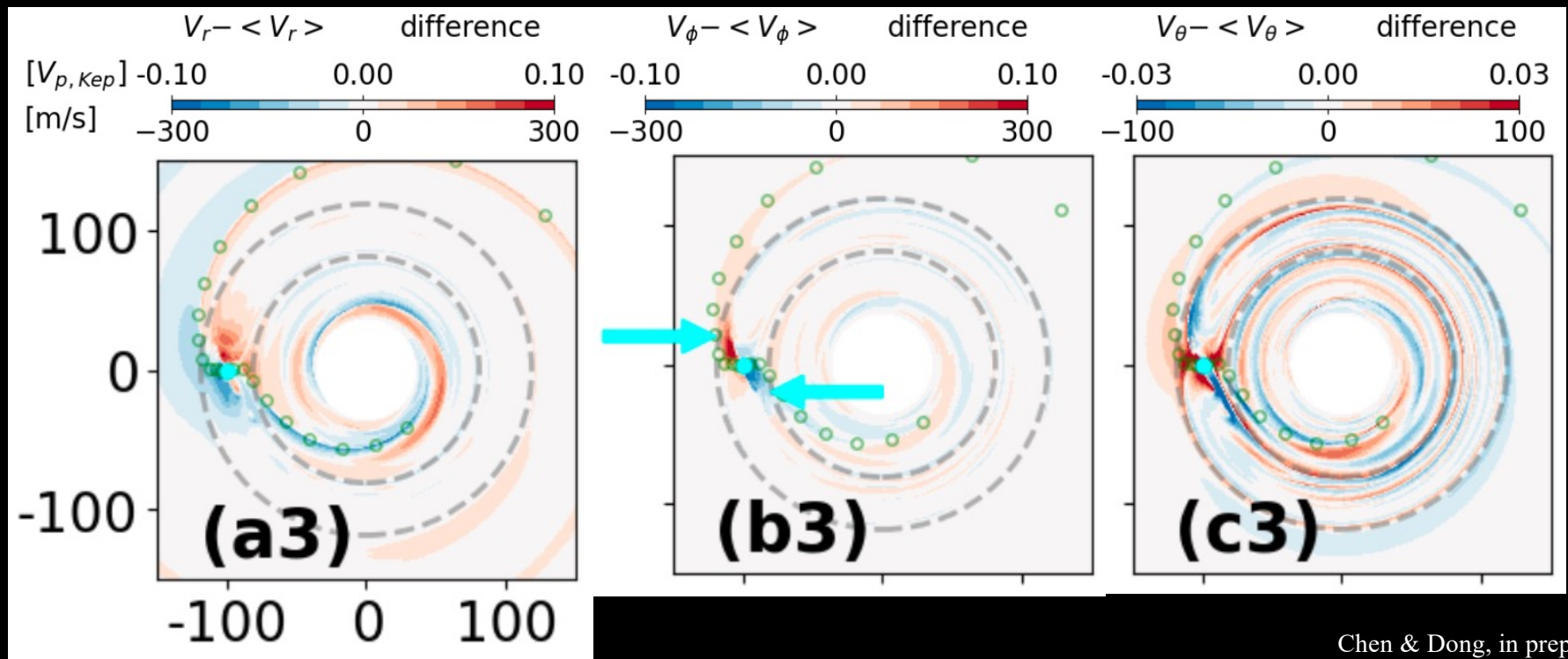
Face-on



Edge on



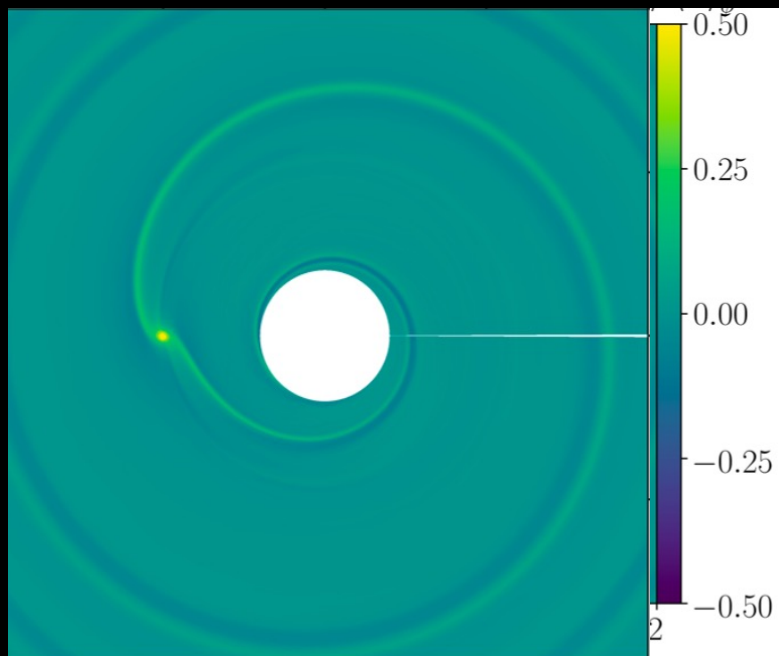
Velocity Perturbations



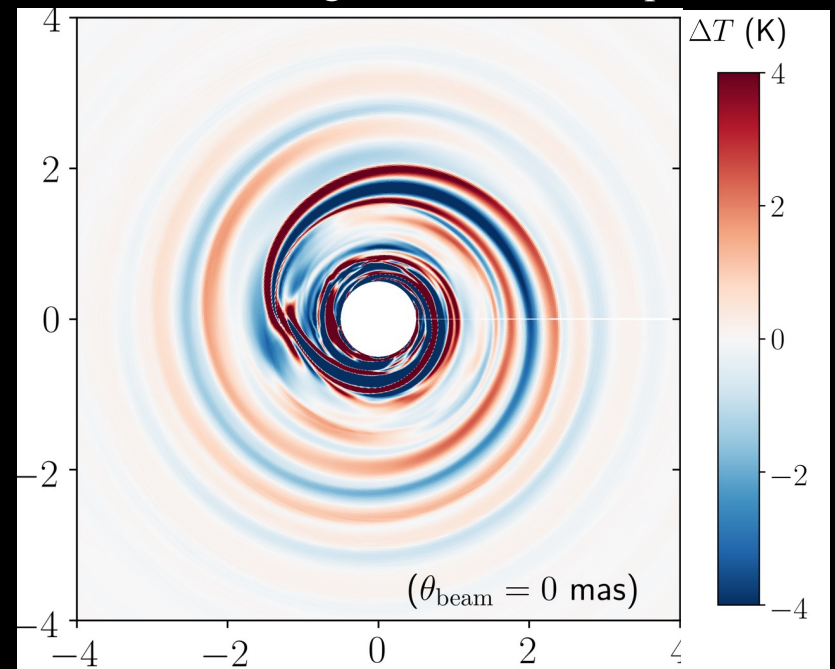
Chen & Dong, in prep.

Temperature Perturbation

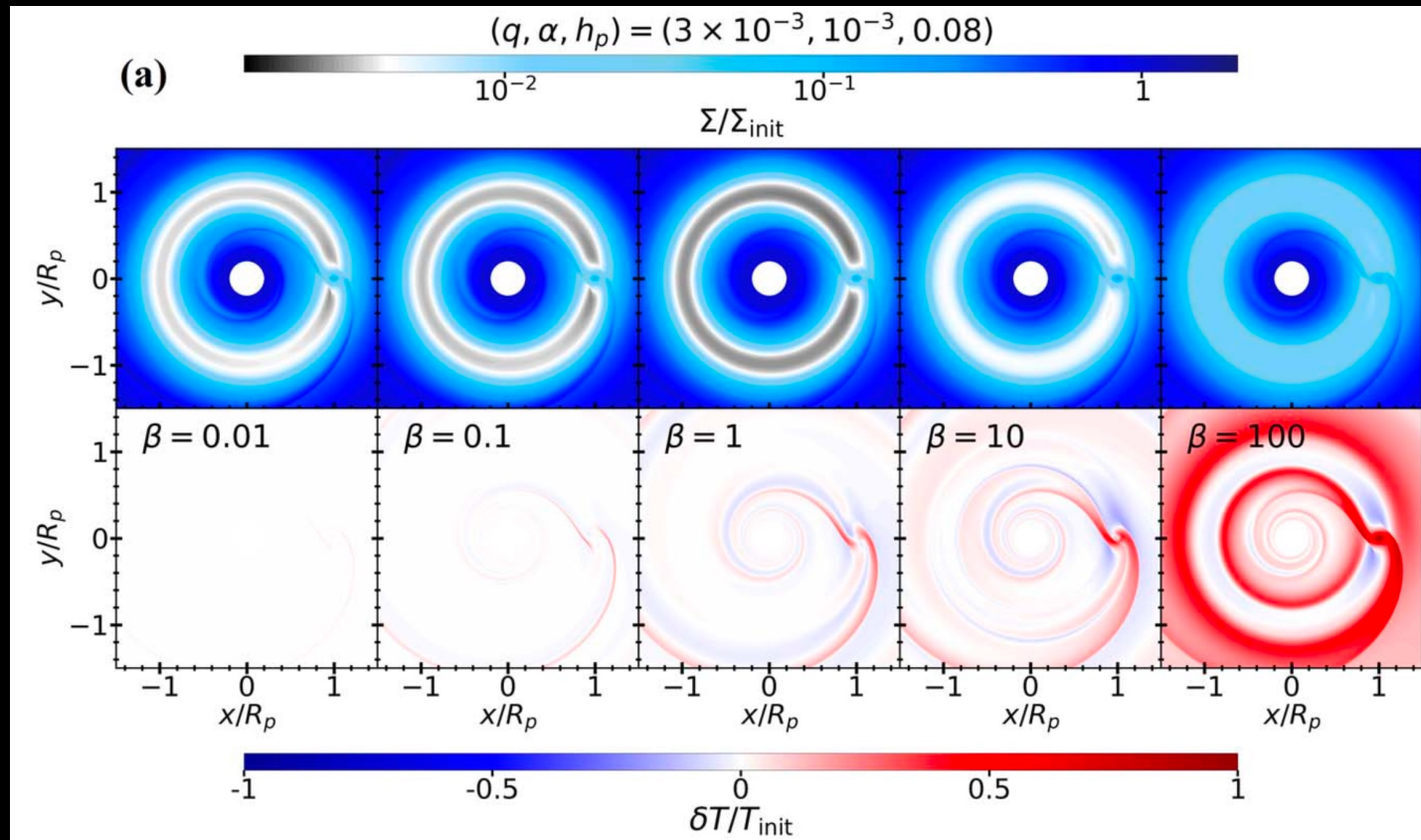
Gas Surface Density Perturbation



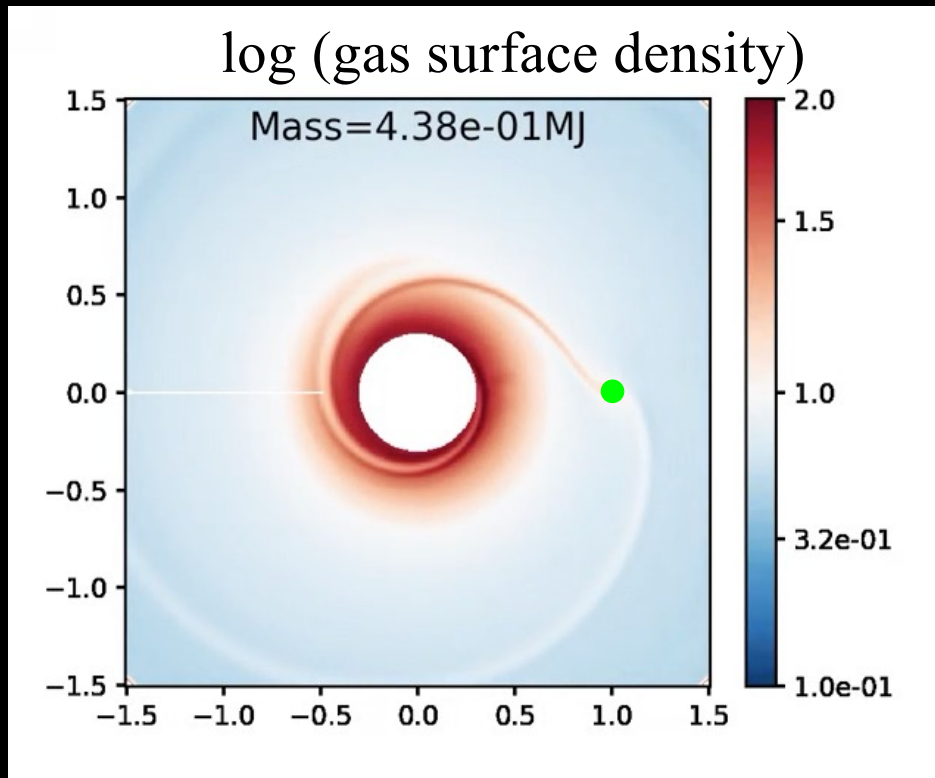
Gas Temperature Perturbation at 3 scale heights above the midplane



Dependence on Equation of State (Cooling Rate)



Dependence on Planet Mass



Mao et al. 2023

As the planet mass increases

- **Gap depth** ↑

Fung et al. 2014; Dong & Fung 2017a

- **Gap width** ↑

Zhang et al. 2018; Kanagawa et al. 2016

- **Spiral contrast** ↑

Goodman & Rafikov 2001; Dong & Fung 2017b

- **Spiral separation** ↑

Fung & Dong 2015

PPDONet

Deep Operator Networks for Fast Prediction of Steady-State Solutions in Disk-Planet Systems

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[Instructions & Help](#)

[Source code](#)

Input Parameters

Alpha viscosity (α): 8.32×10^{-4}



Scale height (h_0): 0.083



Planet mass (M_p): $0.871 M_J$



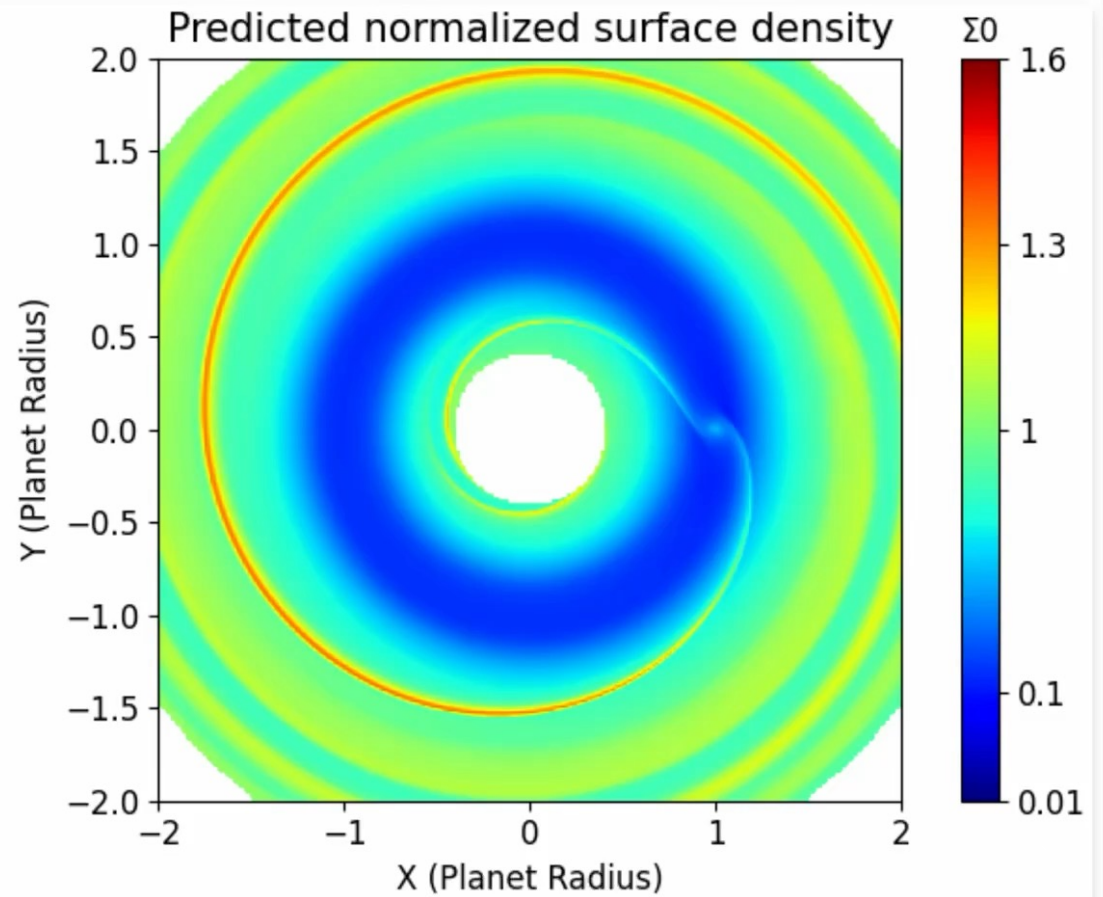
Select quantity to view

surface density

[Download FITS](#)

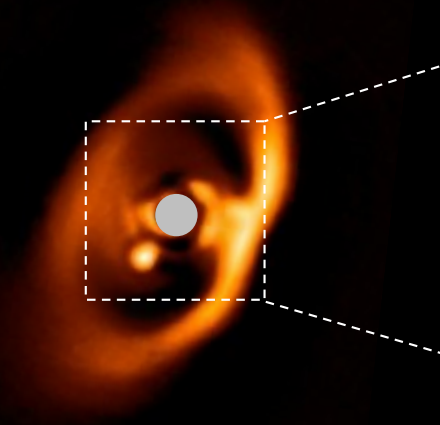


Mao et al. 2023



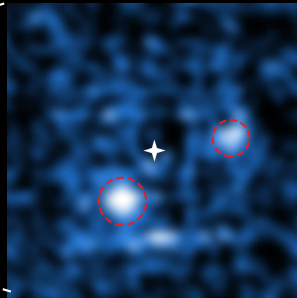
Density Structure: Gaps (PDS 70)

VLT/SPHERE
K-band (2.2 μm)



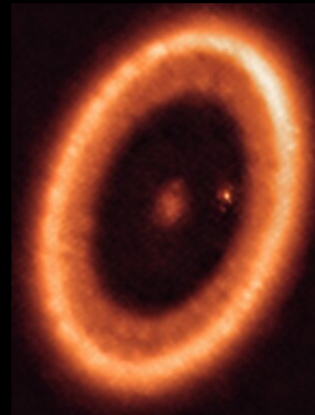
Keppler et al. 2018
Müller et al. 2018

VLT/MUSE
 $H\alpha$ (0.656 μm)



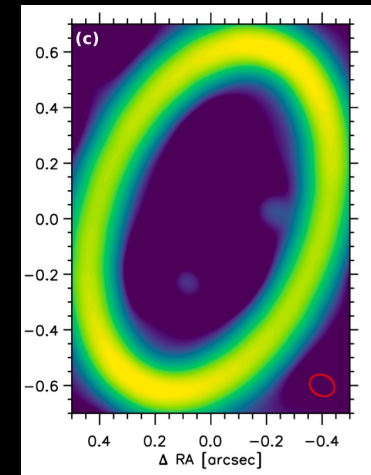
Wagner et al. 2018
Haffert et al. 2019
Hashimoto et al. 2020

ALMA
Band 7 (0.9 mm)



Benisty et al. 2021
Isella et al. 2019

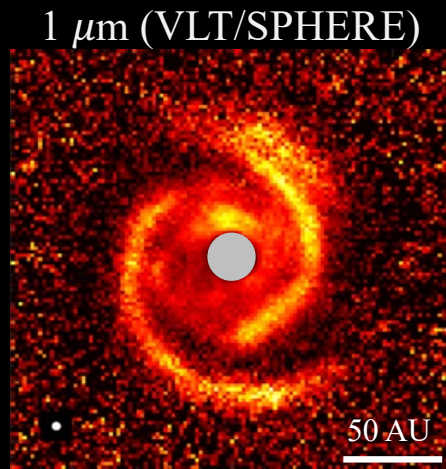
Synthetic ALMA Continuum
Observations with Planets



Bae et al. 2019

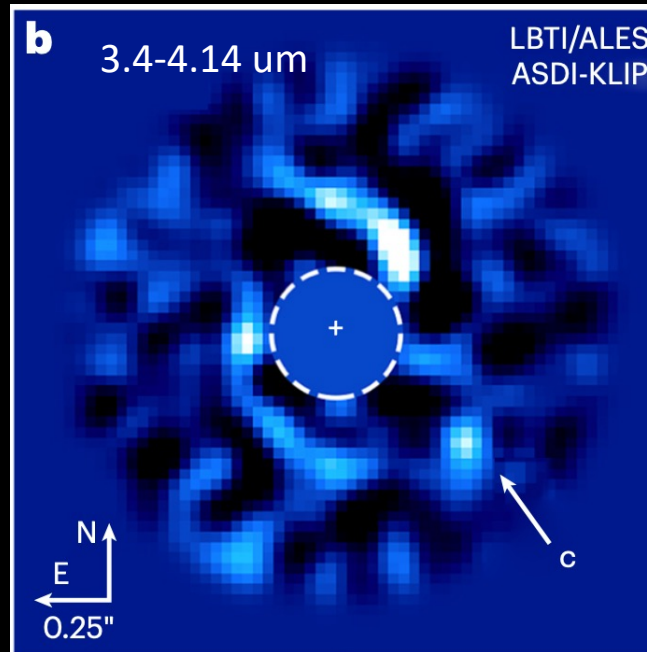
Density Structure: Spiral Arms (MWC 758)

Observations



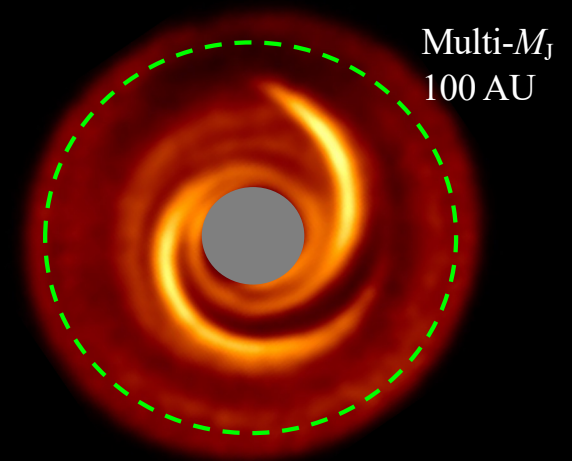
Benisty + 2015; Grady + 13

Planet Detection



Wagner et al. 2023

Models

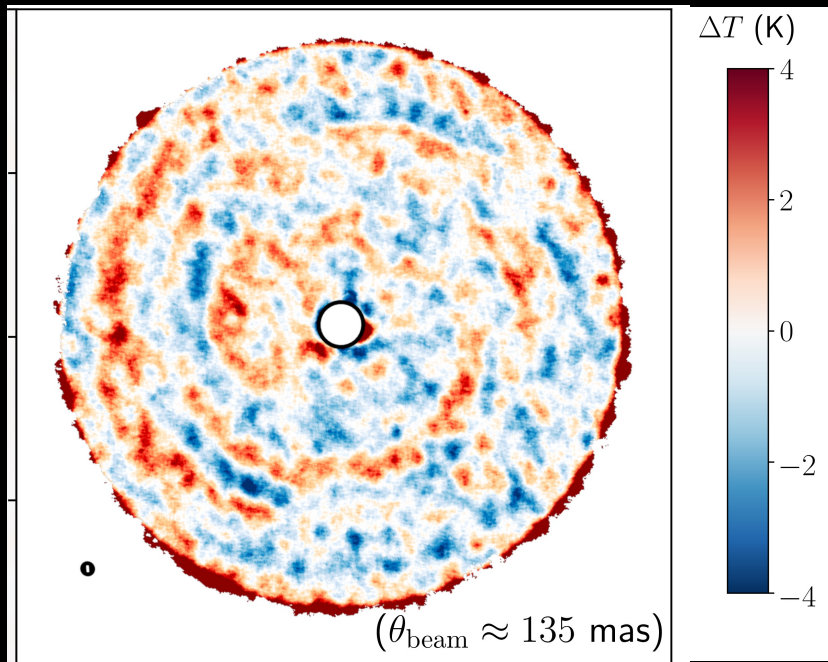


Dong, Zhu, Rafikov & Stone 2015

Temperature Structure (TW Hya)

Observation

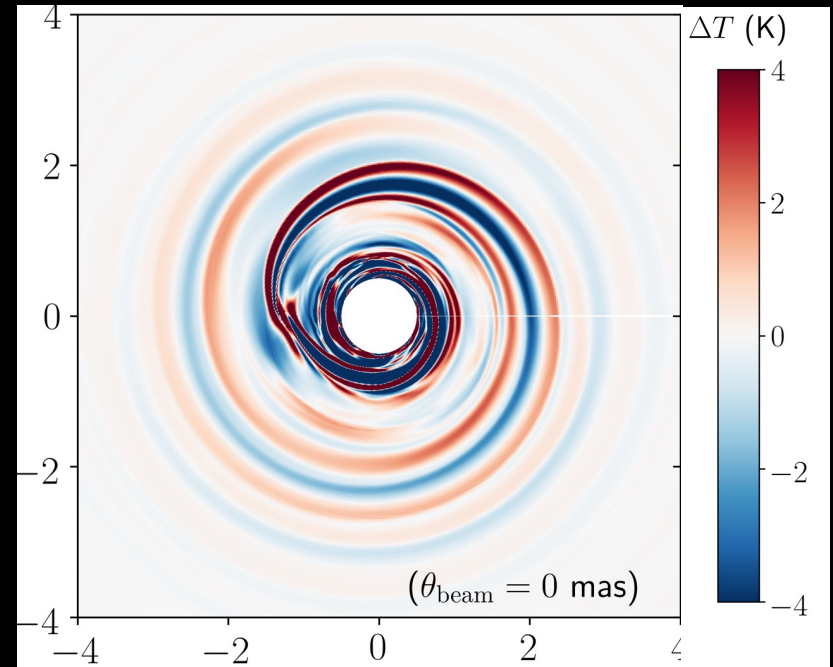
Temperature Perturbation, CO observation, ALMA



Teague + 19 85

Model

Gas Temperature Perturbation
at 3 scale heights above the midplane

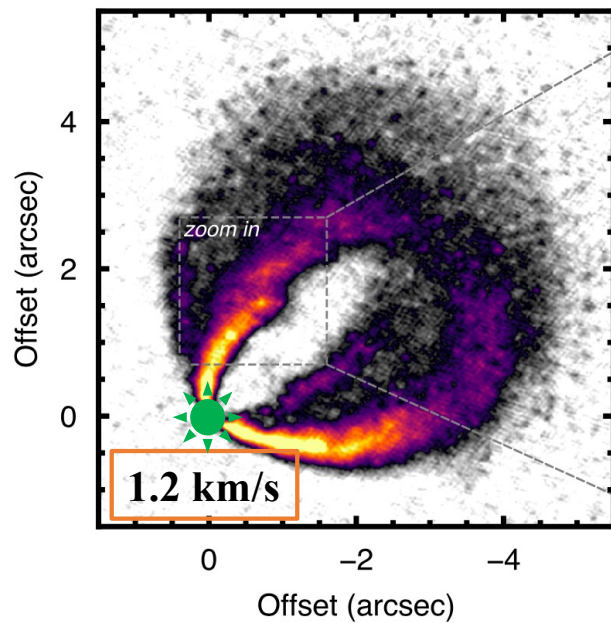


Muley + 21

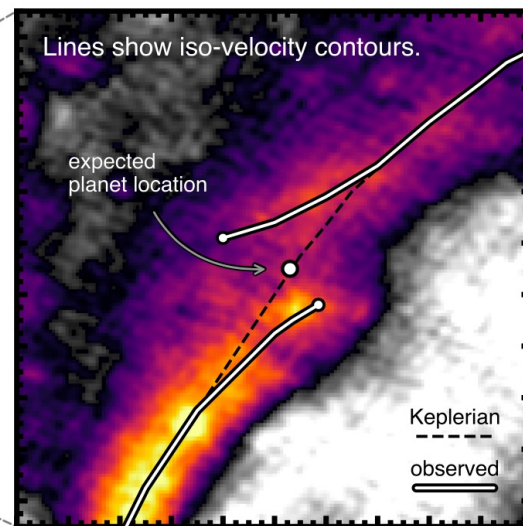
Kinematic Structures (HD 163296)

CO J=2-1 Emission Observation

Observation



Observation



Simulation

