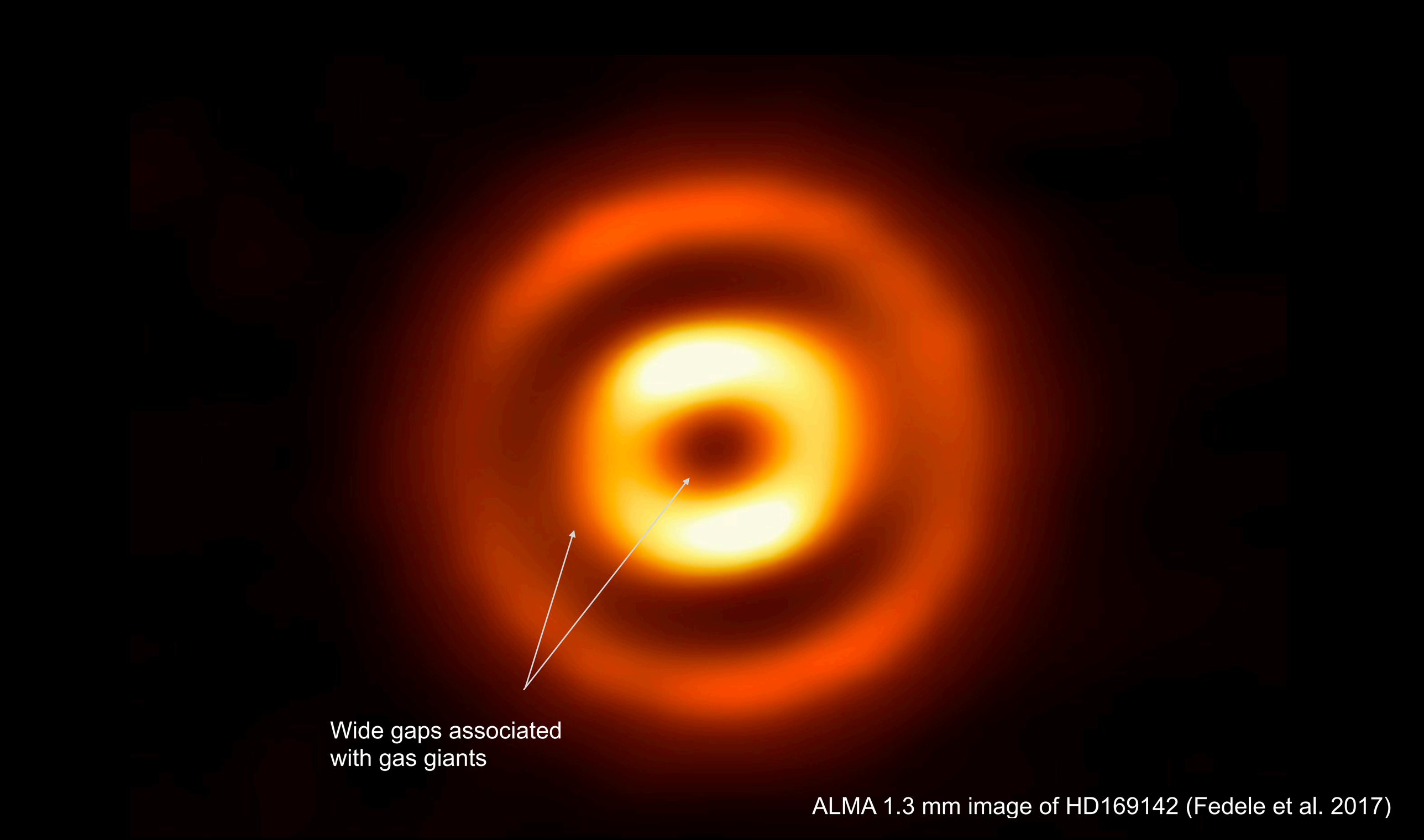
Protoplanet gets busted via dust continuum

#DustBusters #DustSubstructures #MiniNeptune #Migration #PlanetFormation2019

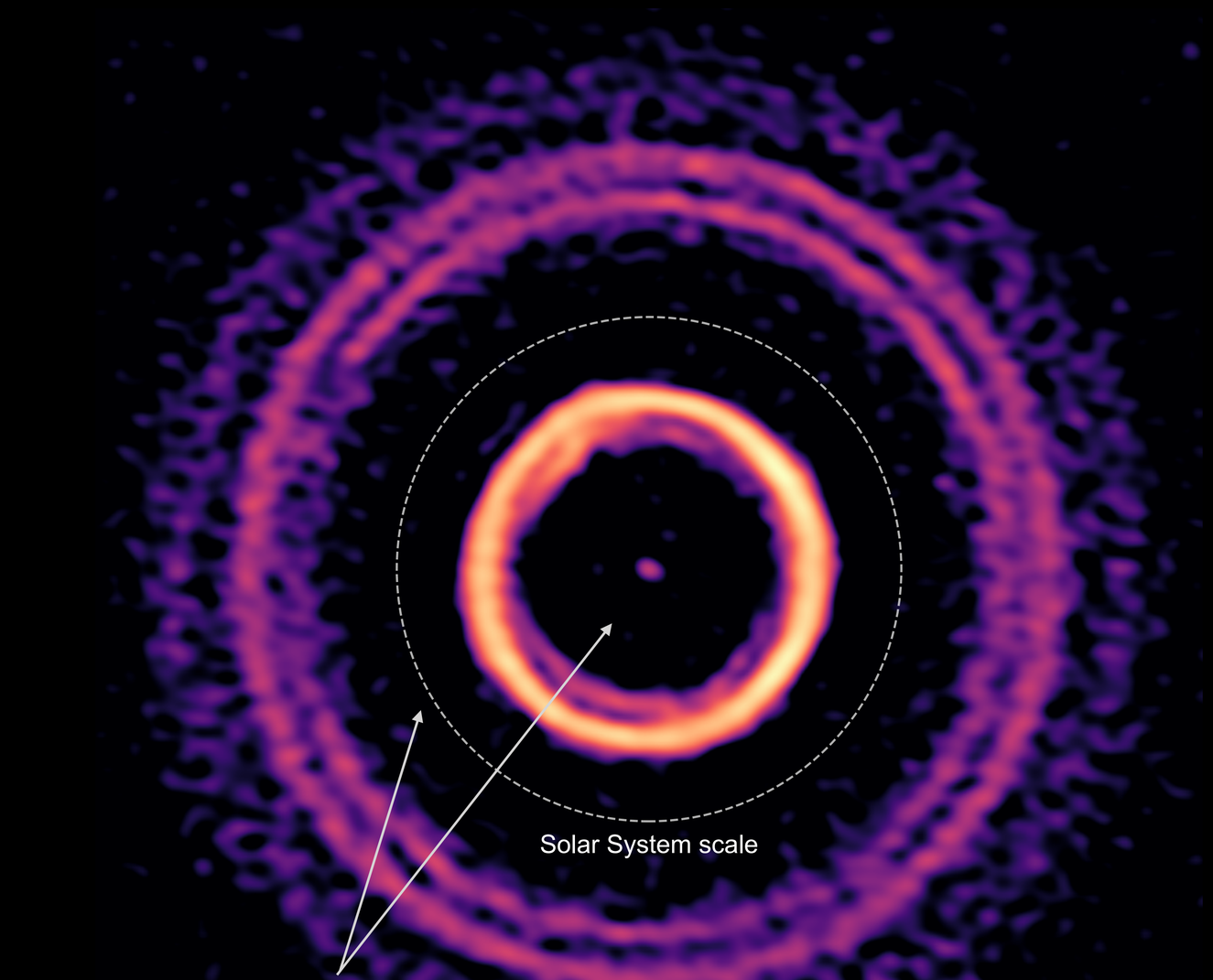
Sebastián Pérez
Great Barriers in Planet Formation
Palm Cove July 2019

UNIVERSIDAD DE SANTIAGO DE CHILE

In collaboration with: Simon Casassus, Robin Dong, Clement Baruteau, Sebastián Marino, Lucas Cieza, Pablo Benitez-Llambay, Alice Zurlo, Antonio Hales

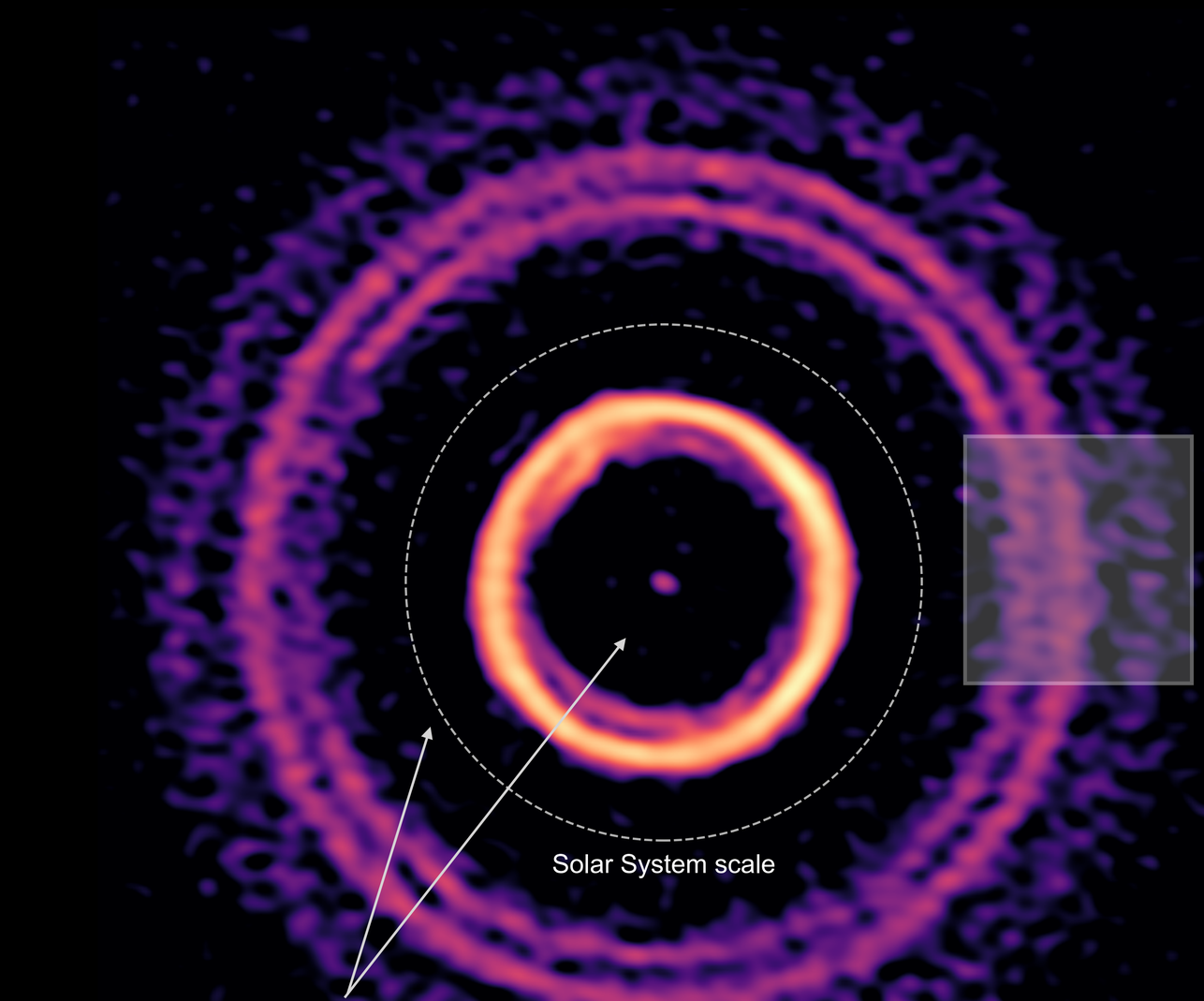


ALMA 1.3 mm image of HD169142 (Fedele et al. 2017)



Wide gaps associated
with gas giants

ALMA 1.3 mm image of HD169142 (Perez et al. 2019)
see also Enrique Macias' talk and recent paper



Fine rings and gaps
in the outer region

Wide gaps associated
with gas giants

ALMA 1.3 mm image of HD169142 (Perez et al. 2019)
see also Enrique Macias' talk and recent paper

b

B1

deconvolved widths:
B2 ~ 1.5 au
B3 ~ 1.8 au
B4 ~ 3.4 au

B2 B3 B4

Inner disk

Gap (D1)

Gap (D2)

D3

D4

Azimuthally averaged profile [mJy/beam]

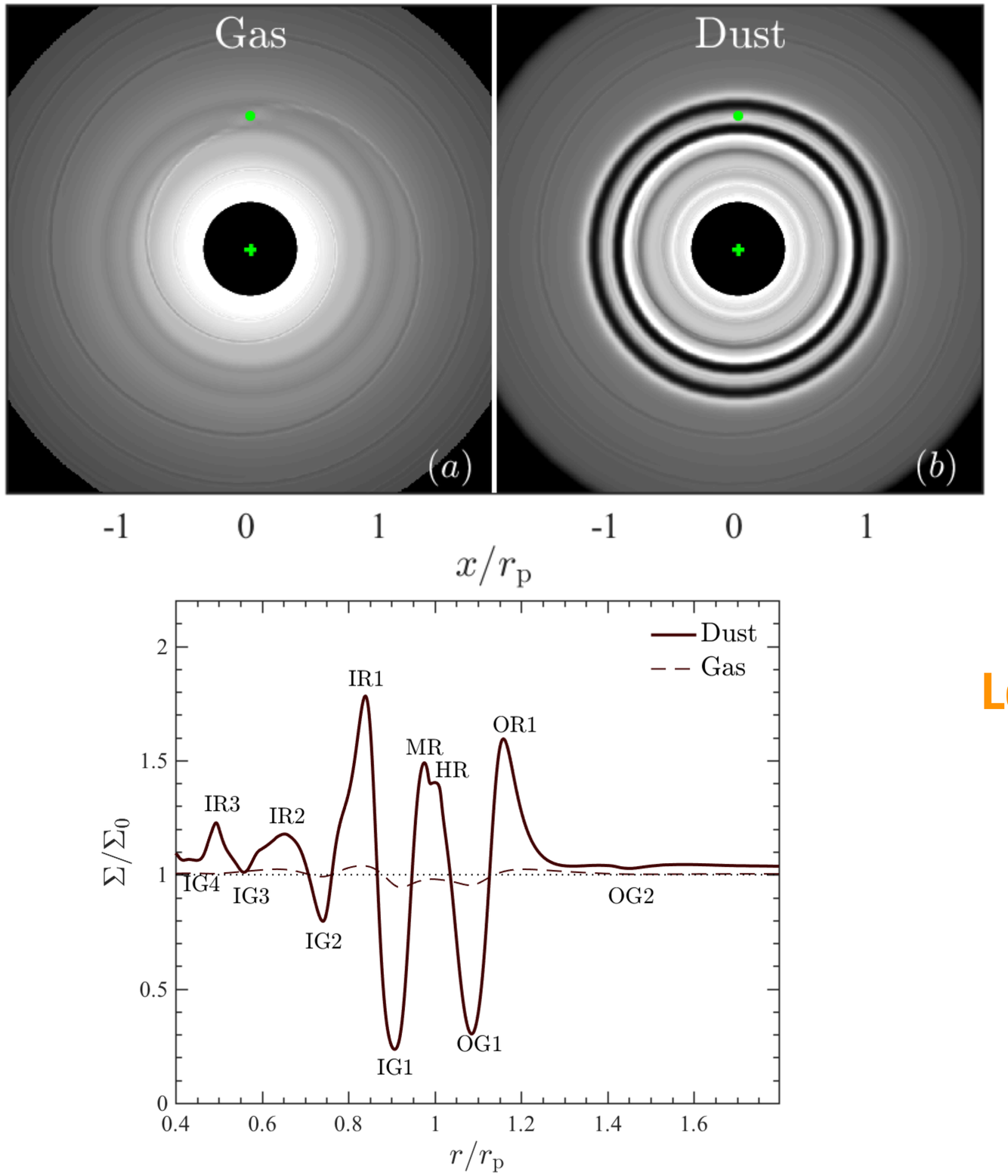
0.50

0.25

0.00

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

R [arcsec]



Two gaps, one planet

Dong et al. (2017, 2018)

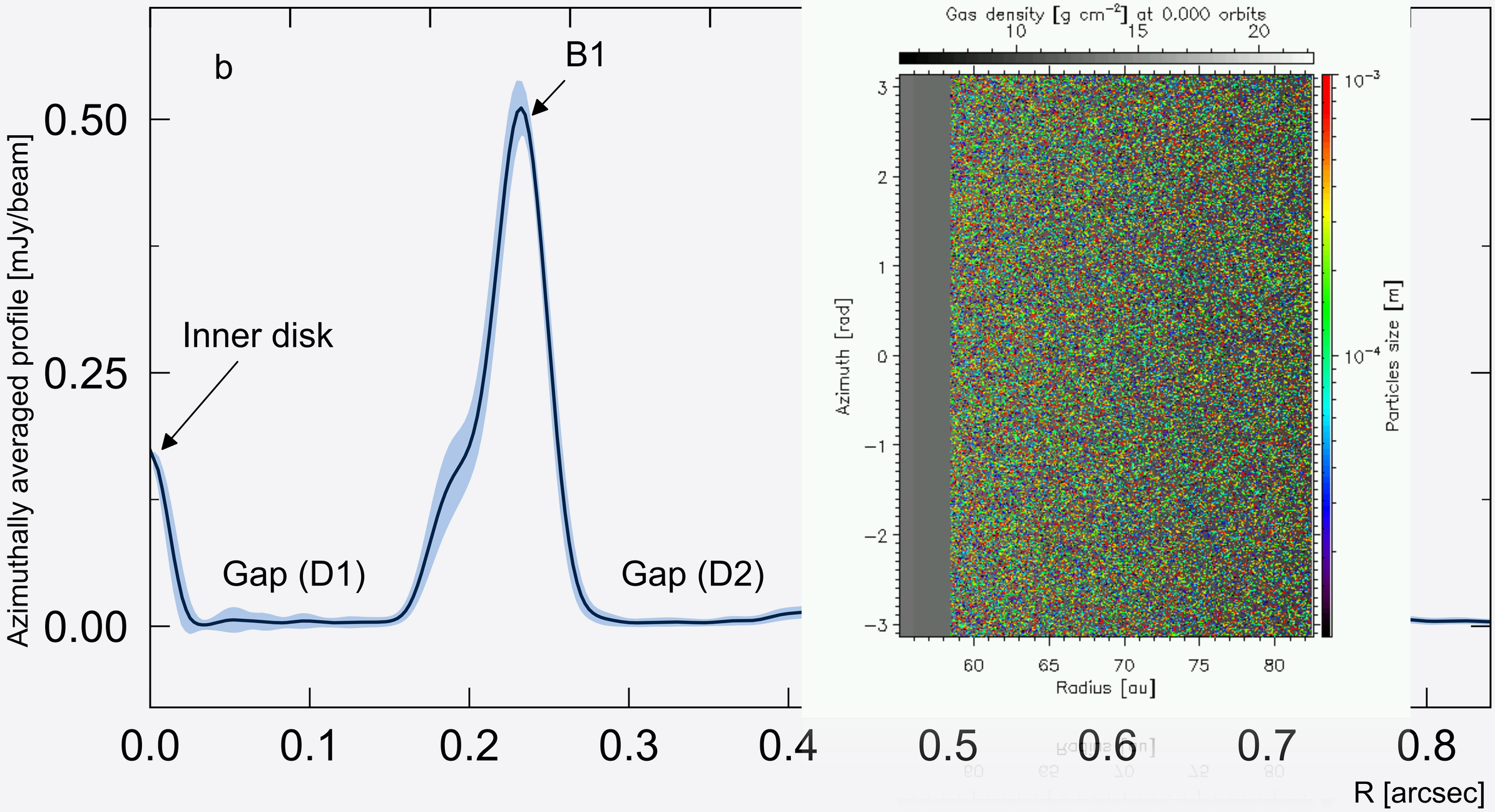
Goodman & Rafikov (2001)

Low viscosity disk:

$$\frac{r_{\rm OG1}-r_{\rm IG1}}{r_{\rm p}} \approx 2.9 \left(\frac{\gamma+1}{12/5}\frac{M_{\rm p}}{M_{\rm th}}\right)^{-2/5}\left(\frac{h}{r}\right)$$

Also: dependence on choice of EOS (Miranda & Rafikov 2019)

Dusty FARGO2D-ADSG simulation w/ Lagrangian particles (C. Baruteau's code)



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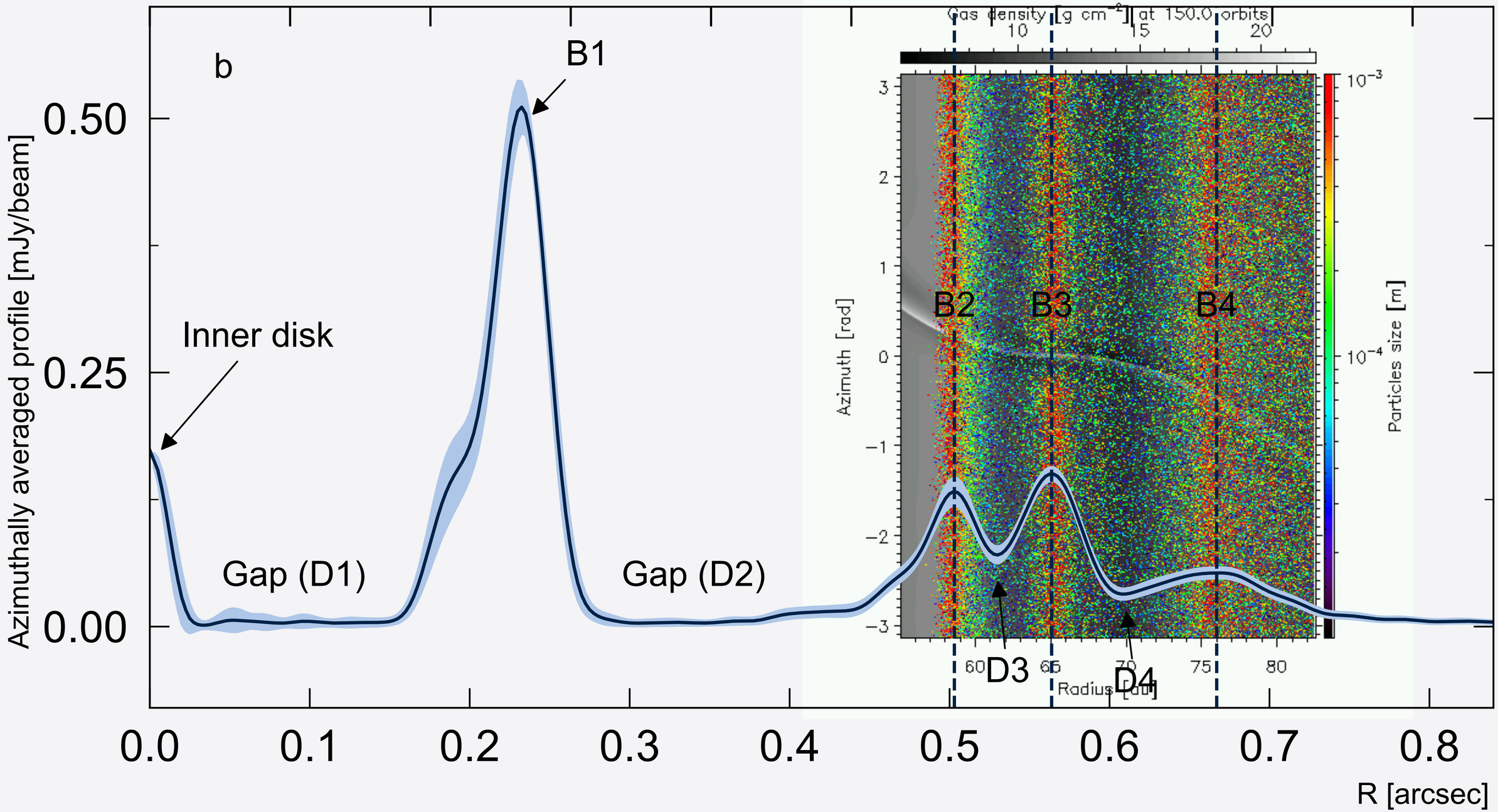

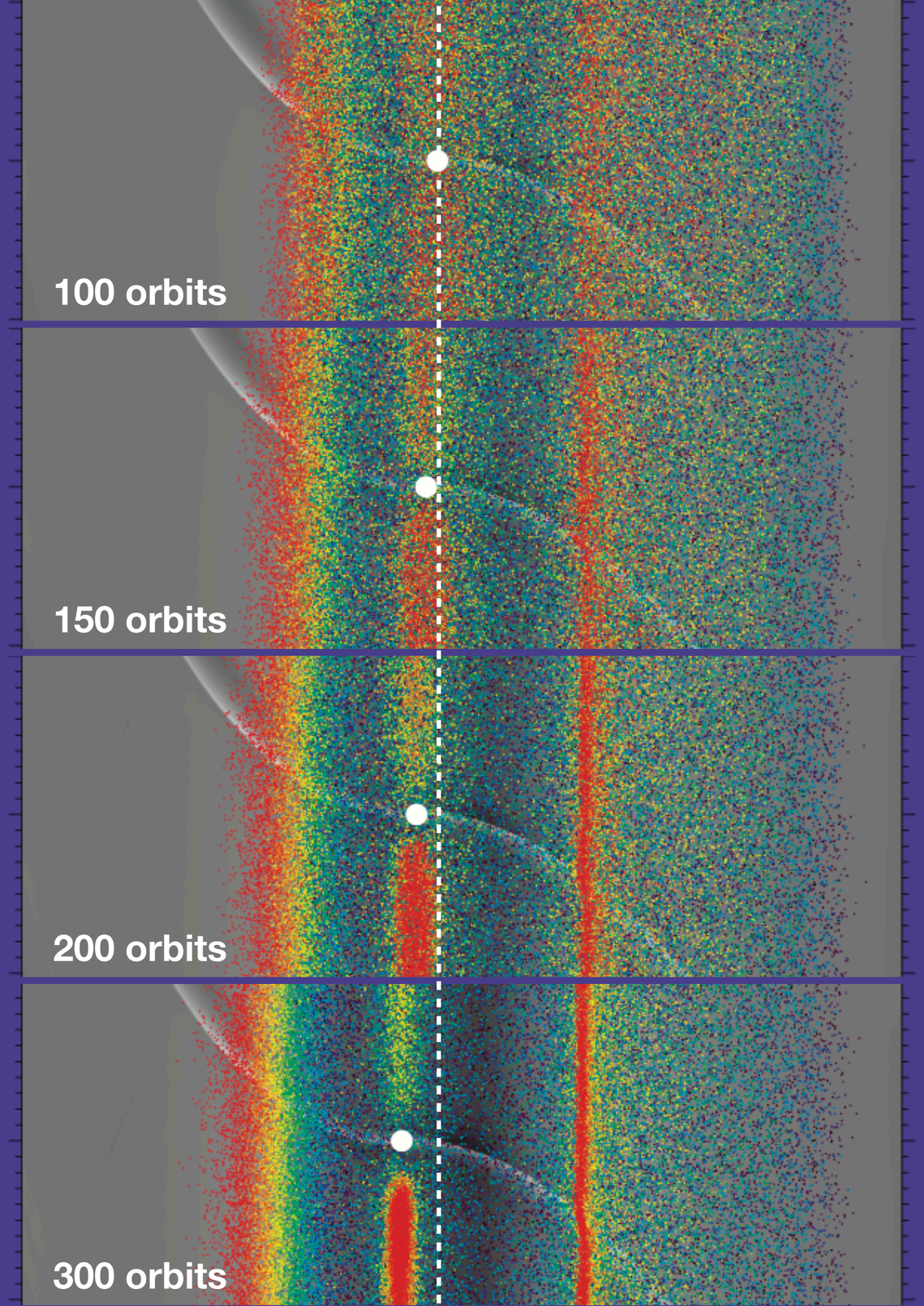

Locations of the rings (mutual separations) suggest the planet is migrating

~1 au / 10k years

ALMA observation

hydro+RT model

10x Earth
mass planet

hydro model

migrating 10x Earth mass planet

Outer regions in disks with cavities (a.k.a transition disks) can be fertile for planet formation.
HD169142: proof of concept to interpret the architecture of the outer regions of disks showing evidence of giant protoplanets, with low mass planet formation.

Perez, Casassus, Baruteau, Dong, Hales & Cieza (2019)

Protoplanet gets busted via gas kinematics

#PlanetDiscInteractions #KinkyKinematics #DopplerFlip #PlanetFormation2019

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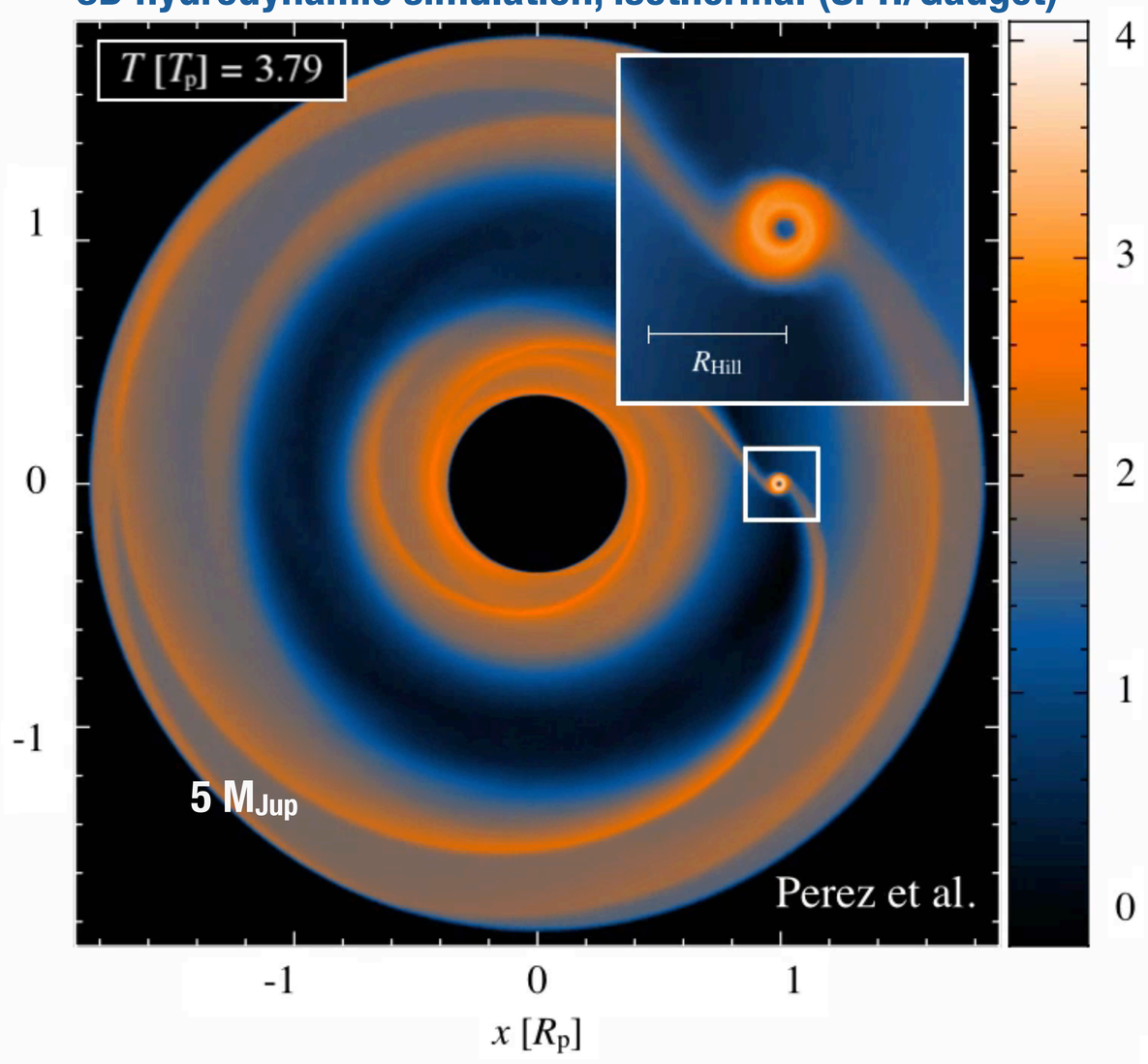
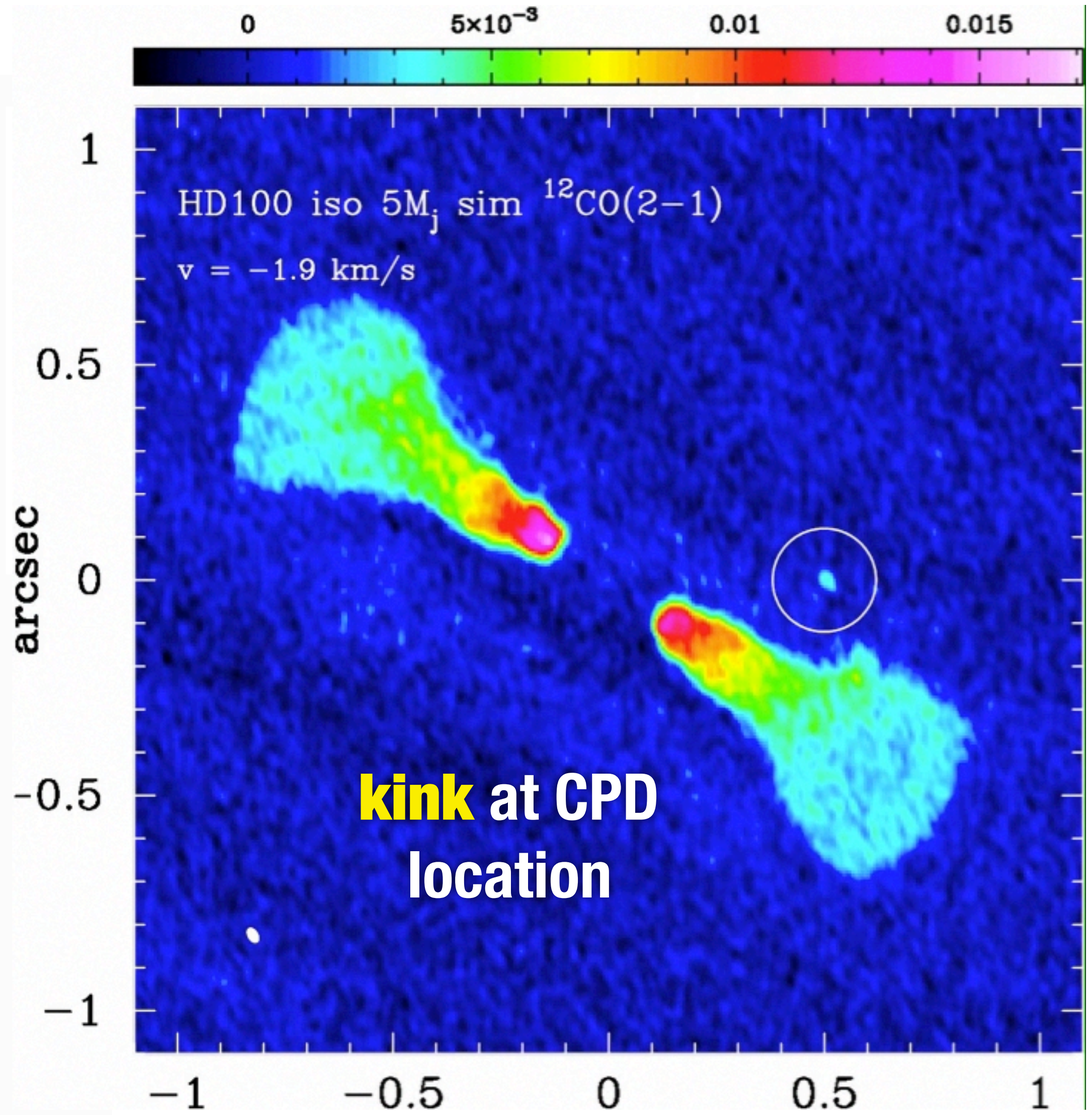
Circumplanetary disks via kinematics

3D hydrodynamic simulation, isothermal (SPH/Gadget)



^{12}CO gas prediction



Perez, Dunhill, Casassus et al. (2015) ApJL 811:L5

SPH2

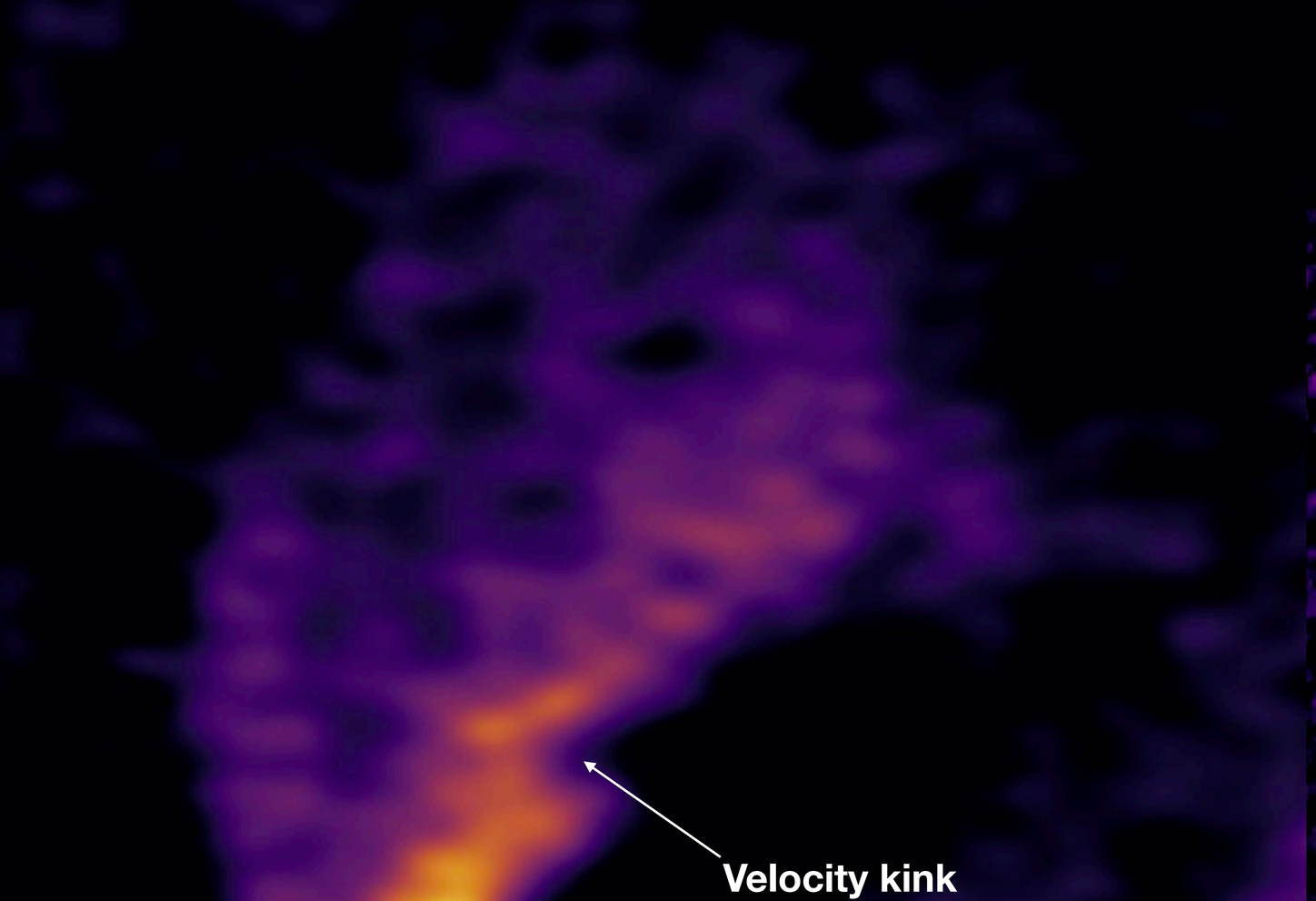
CPD dispersion

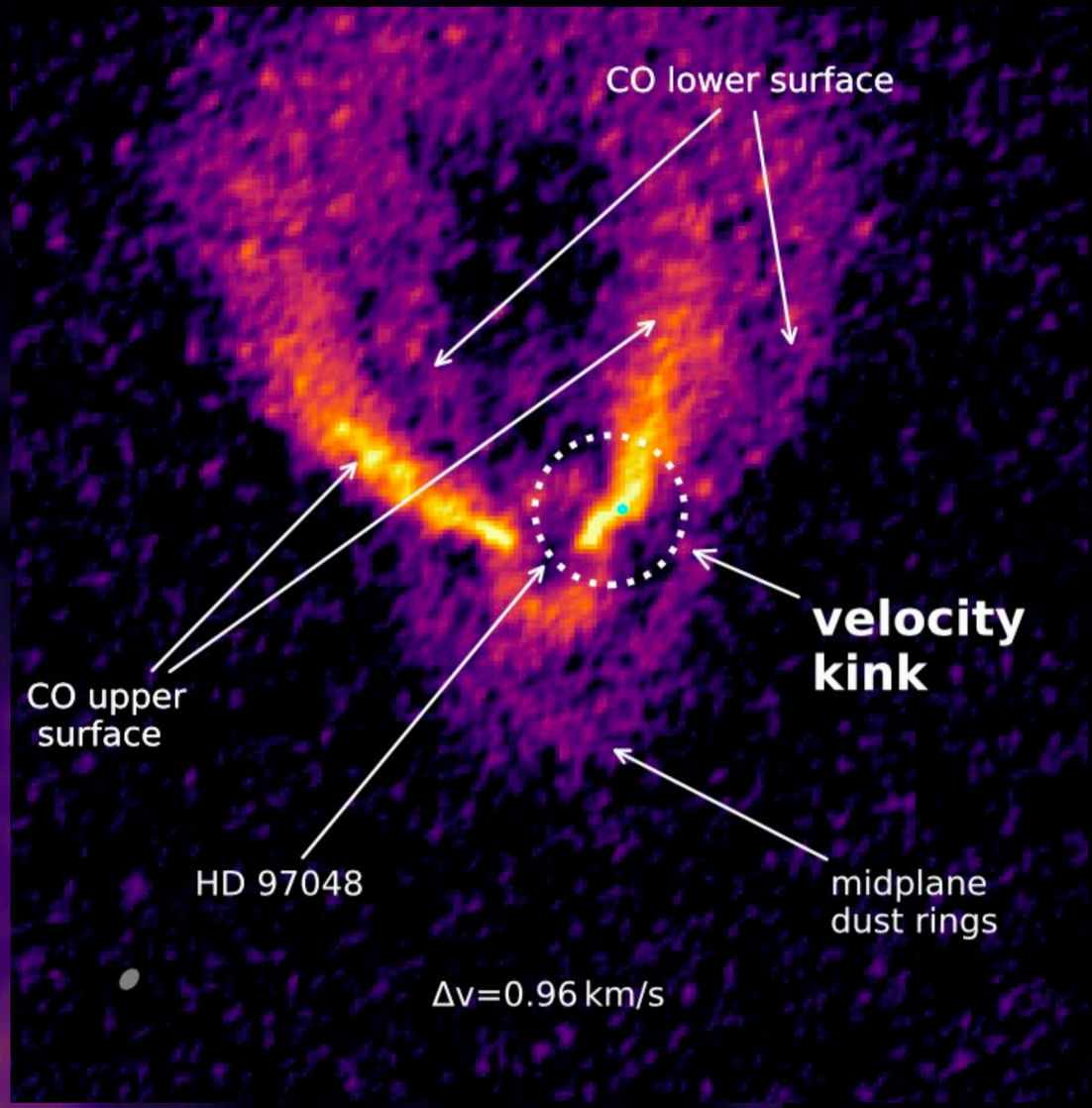
kink at CPD location

I. kink at the CPD location

II. local increase in velocity dispersion

Kinematic detections



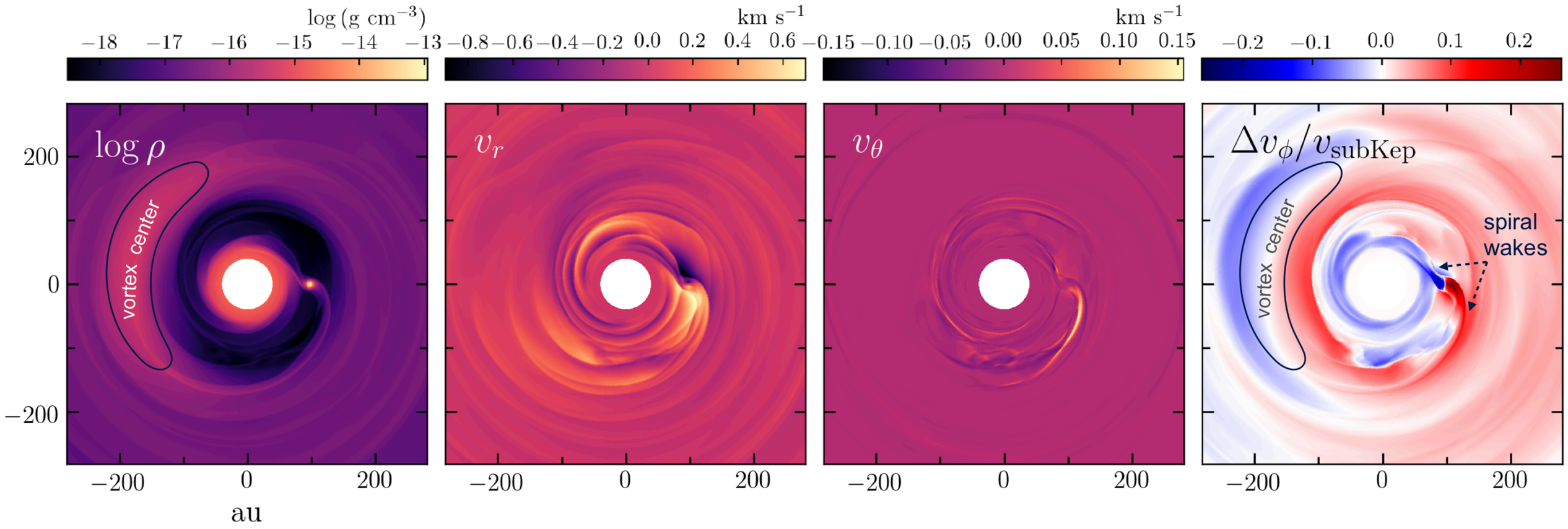


HD 97048 (Pinte et al. 2019)

HD 163296 (Pinte et al. 2018)

see Christophe Pinte's posters and Daniel Price's poster

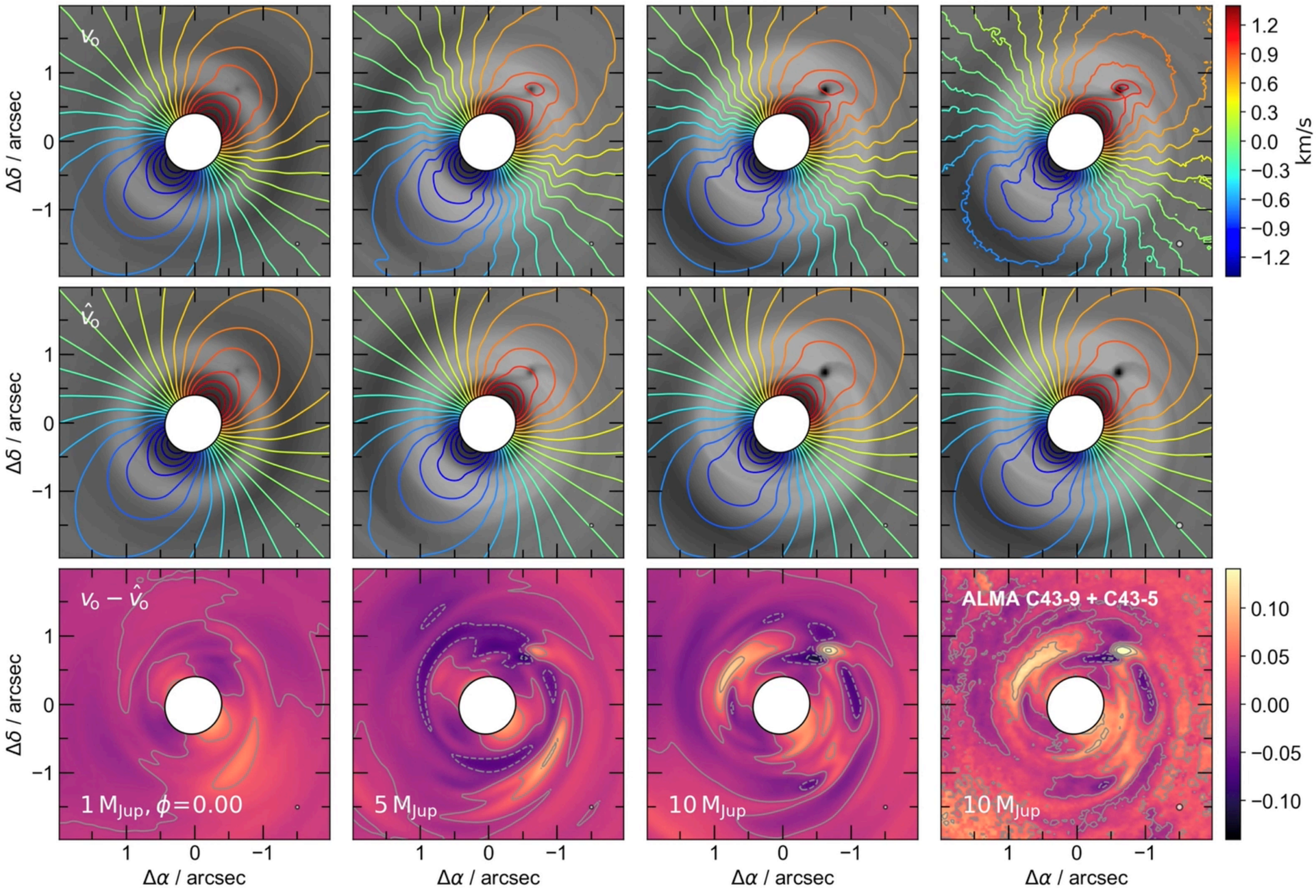
planet-disk interactions via kinematics

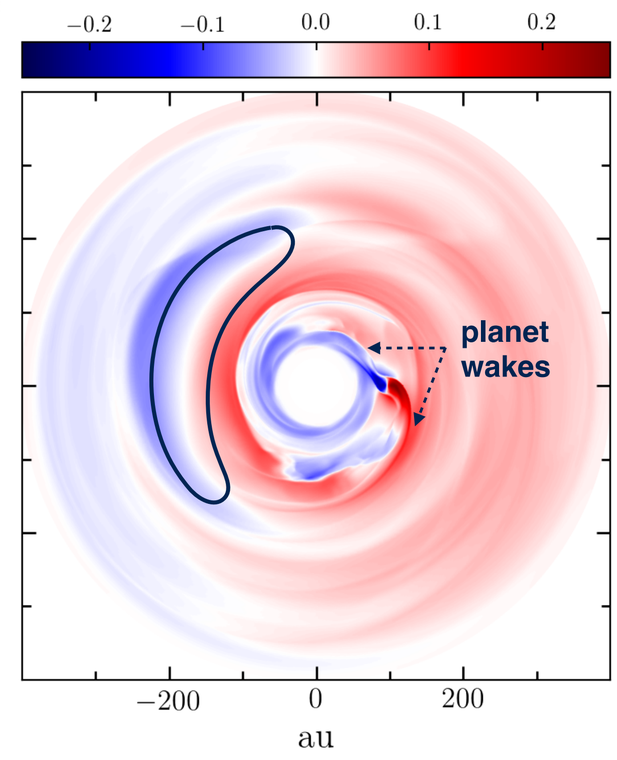


3D isothermal simulation, FARGO3D (GPU), 1000 orbits

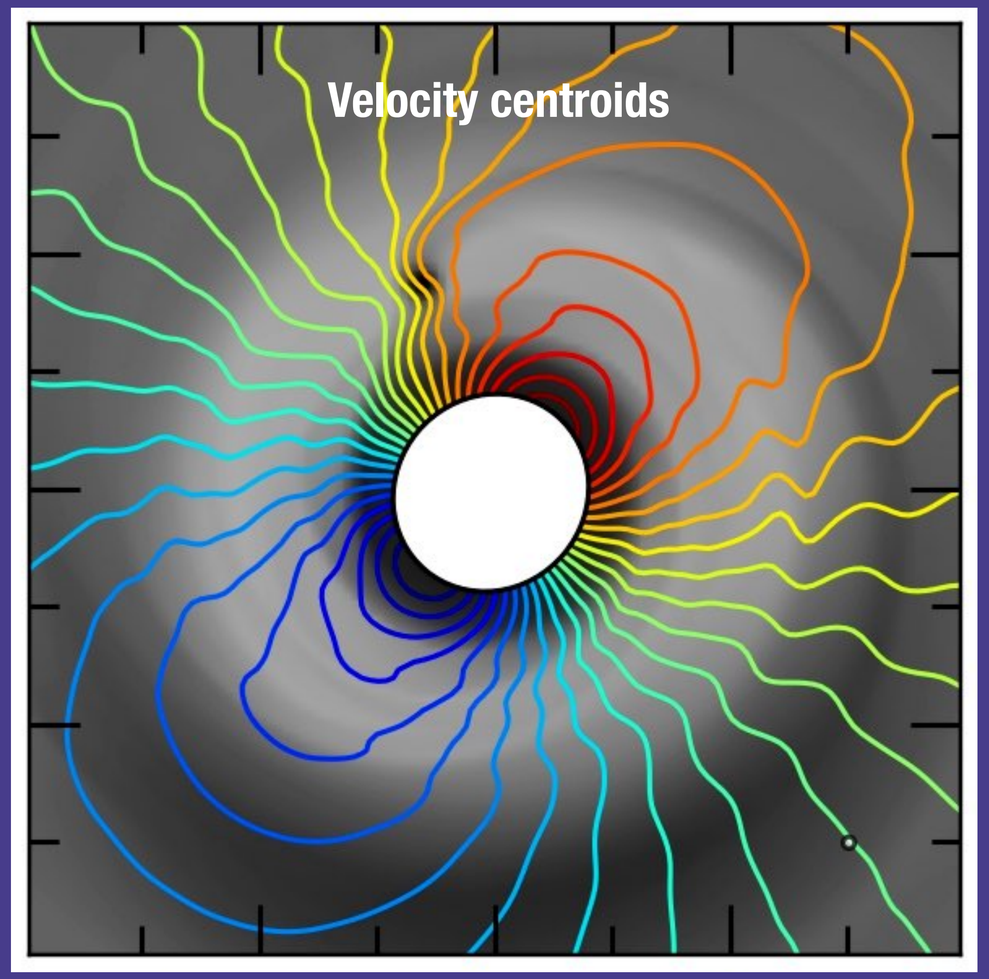
Perez, Casassus & Benitez-Llambay (2018)

planet-disk interactions via kinematics





Perez, Casassus
& Benitez-Llambay (2018)



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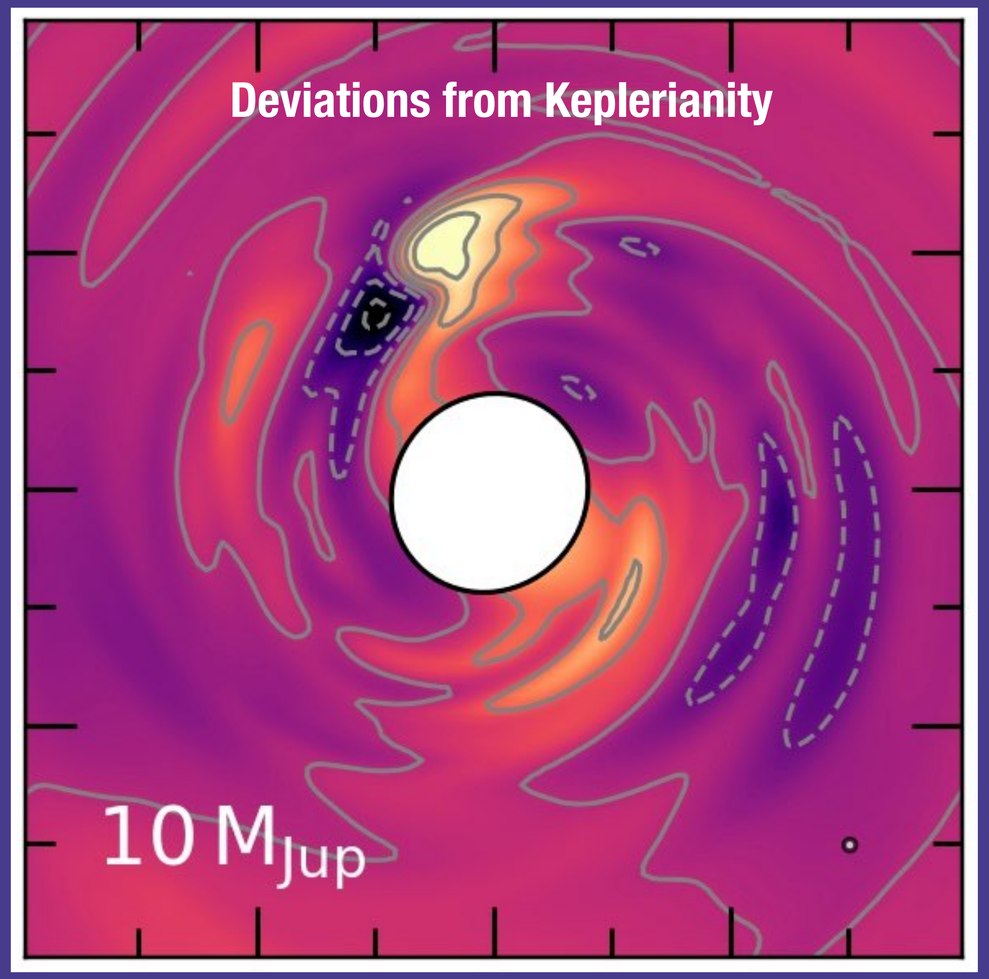
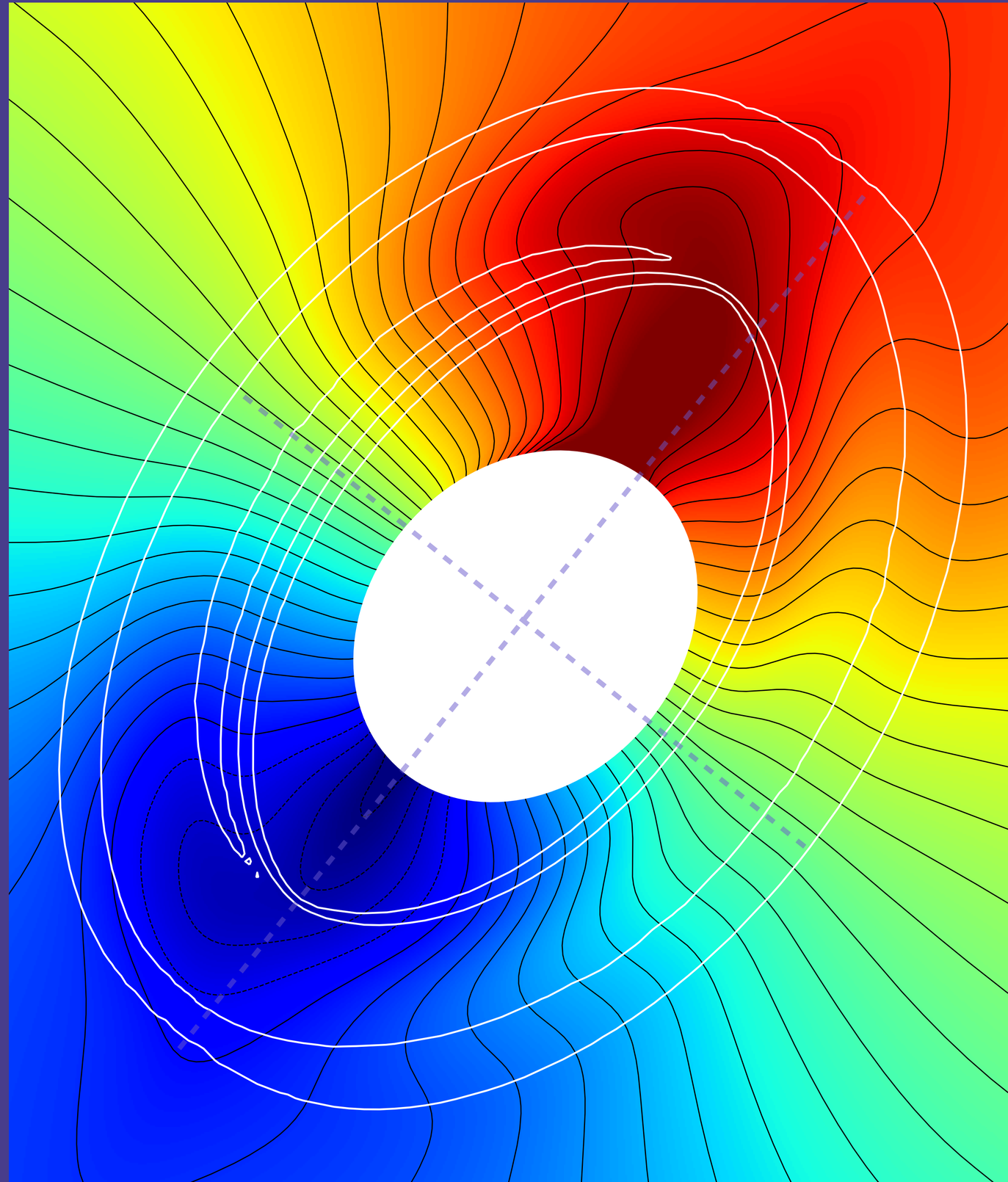


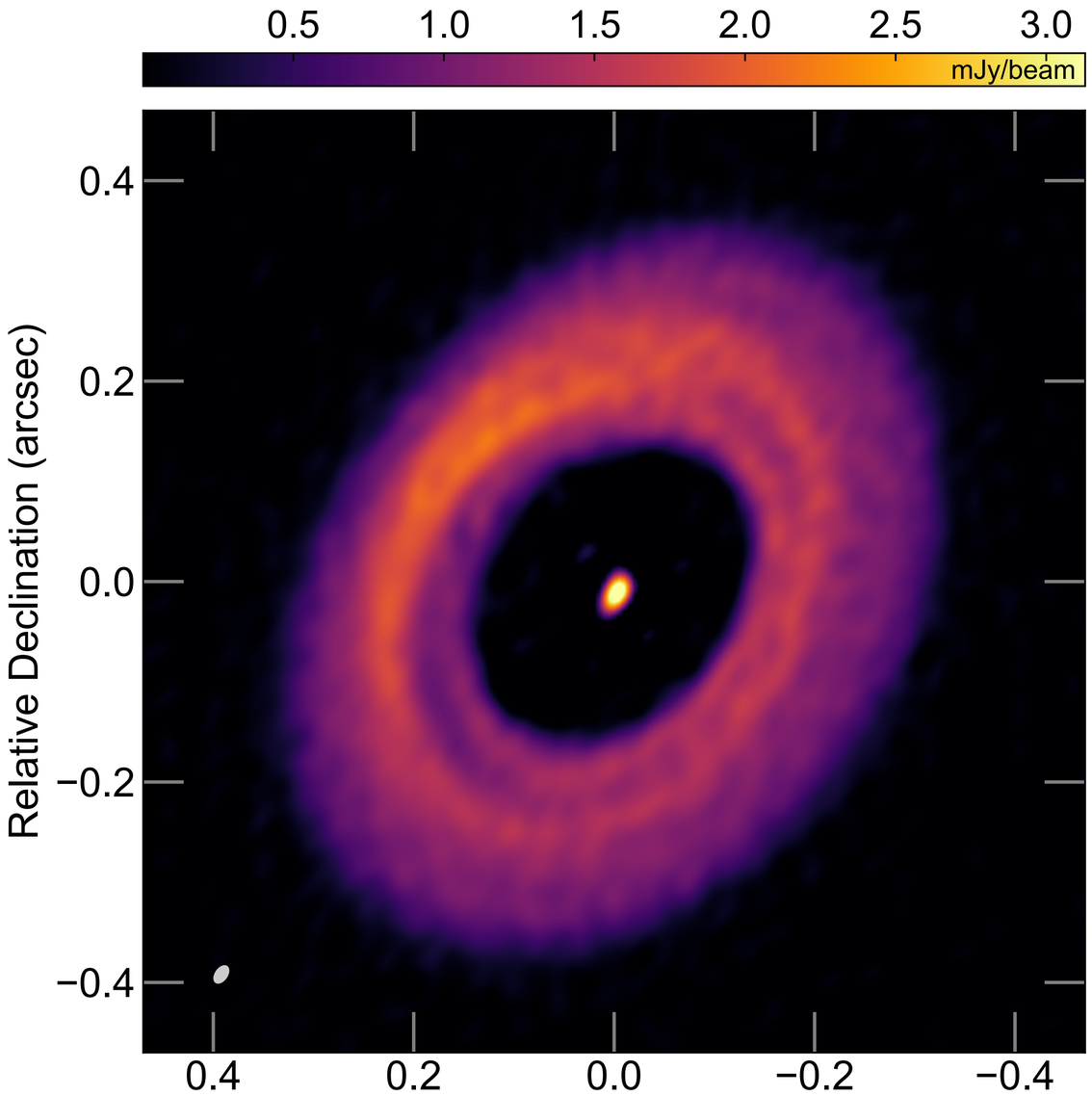
Perez, Casassus & Benitez-Llambay (2018)

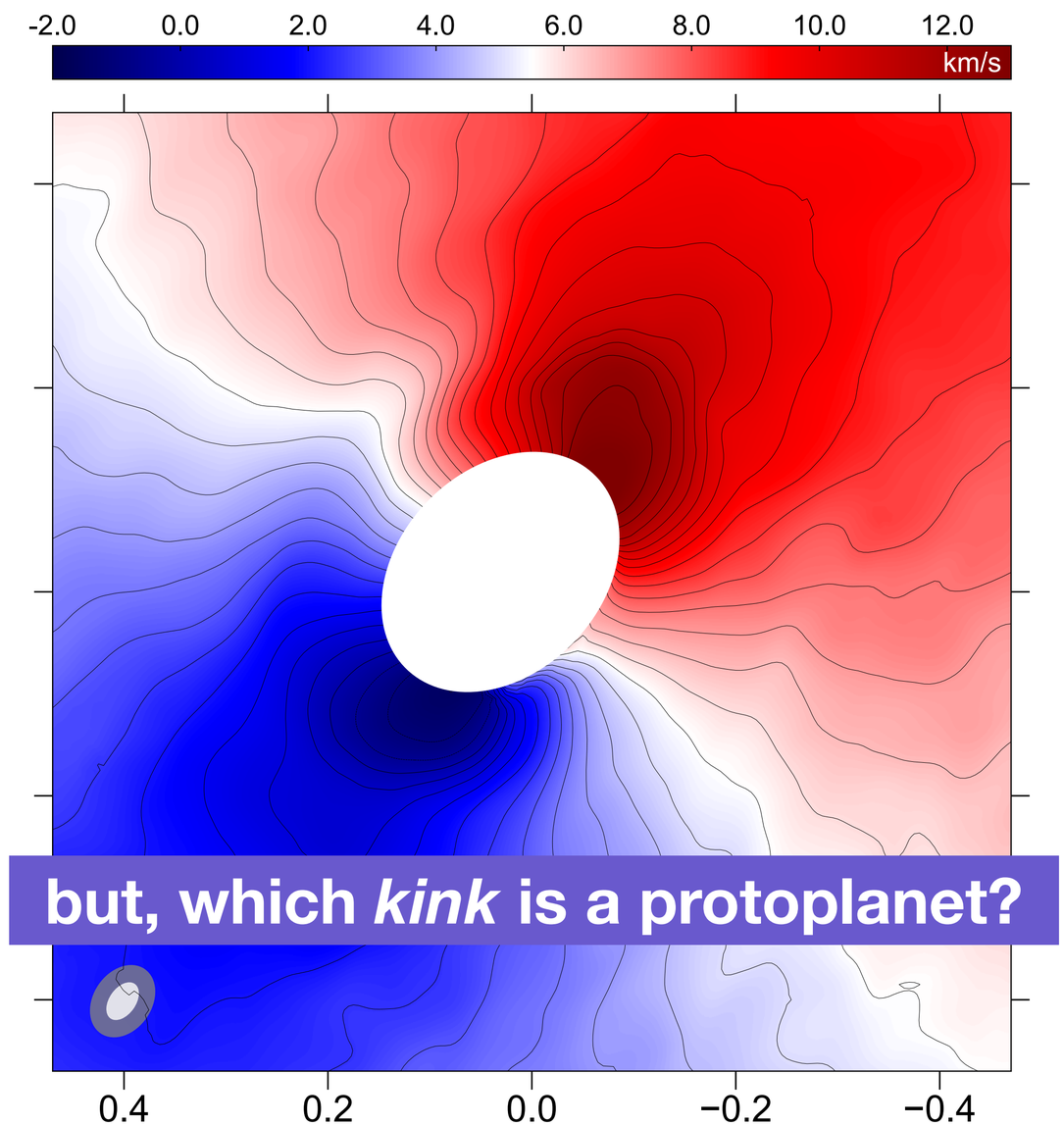
see also: moment 2 predictions in “Planet-induced Line Broadening in Gaps” by Dong, Liu & Fung (2019)
and vortex prediction by P. Huang et al. (2018)

simple parametric model
with optically thick
continuum ring



HD100546 with ALMA at 1.3 mm



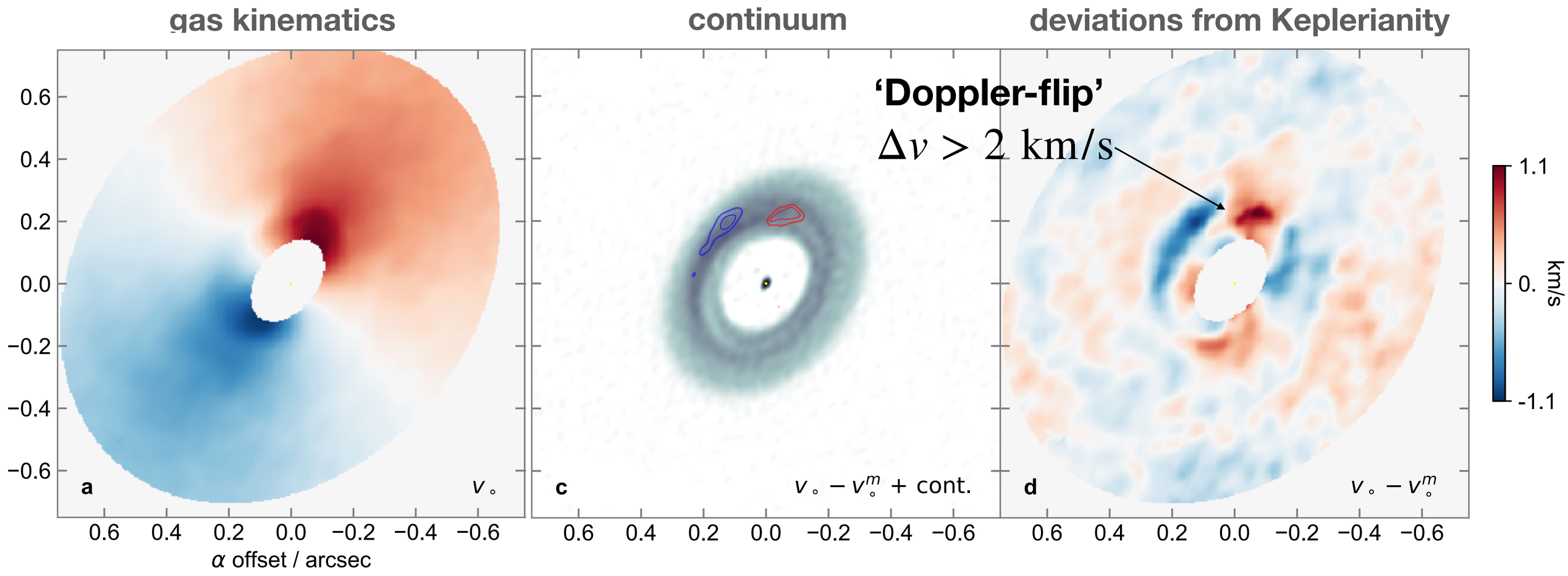


but, which *kink* is a protoplanet?

18x12 mas beam in continuum
70x50 mas beam in CO chans

Perez et al. 2019 *on ArXiv*

To find the CPD we need to subtract the ~Keplerian background (conical transform)



Needs high-fidelity line observations

Casassus & Perez (2019) *on ArXiv*

- ‘2 narrow gaps and 3 rings’ can be used to study planetary cores of a few Earth masses, as shown in HD169142 thanks to its isolated outer region:
  a migrating low mass planet can reproduce the rings
  #DustSubstructures #Migration #OnePlanetTwoGaps

- **kinematics** is a great way of detecting/characterising giant protoplanets.
  It requires high-fidelity: **kinks everywhere.** Probes larger scale planet-disk interactions #CPD #Vortices #Gaps #SpiralWakes #KinkyKinematics

- to pinpoint protoplanets location look for a **local sign reversal in the kinematic deviation (moment1-Keplerian) or** #DopplerFlip