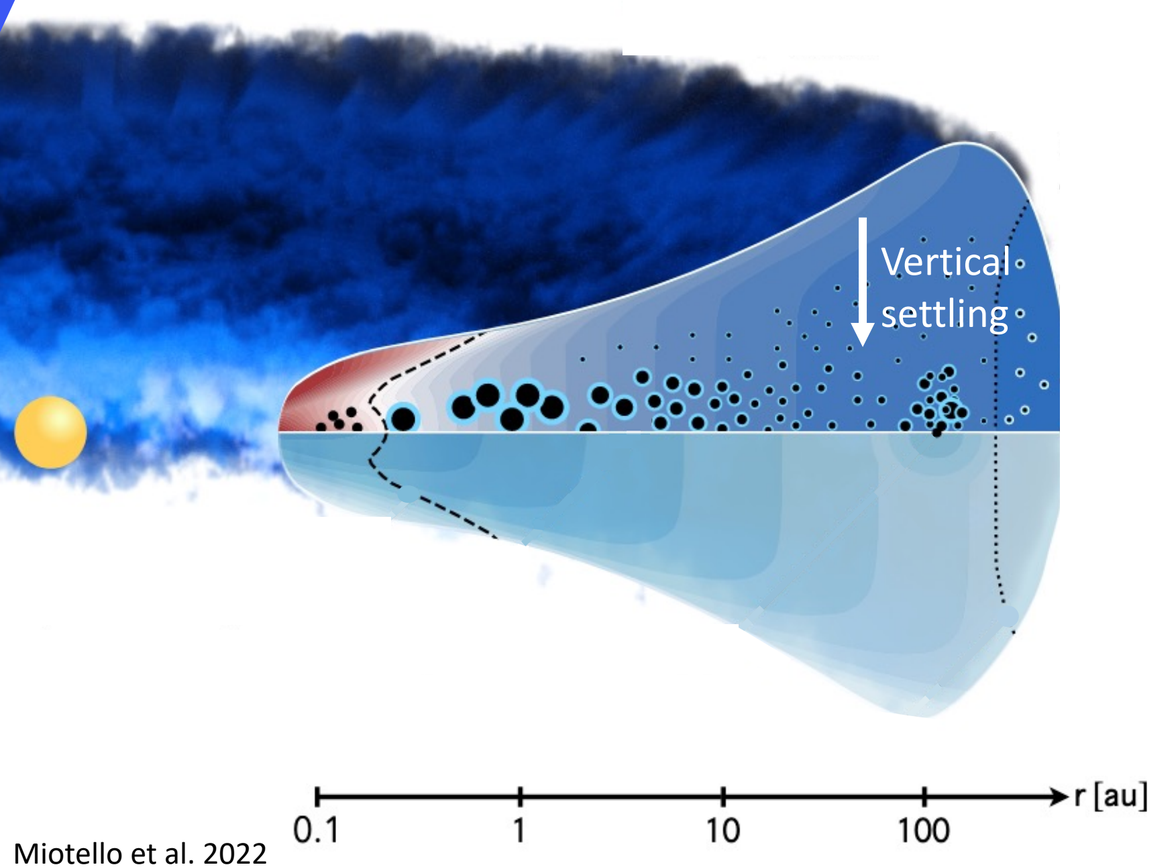
On the preferential locations for planet formation in protoplanetary disks

Marion Villenave – IPAG

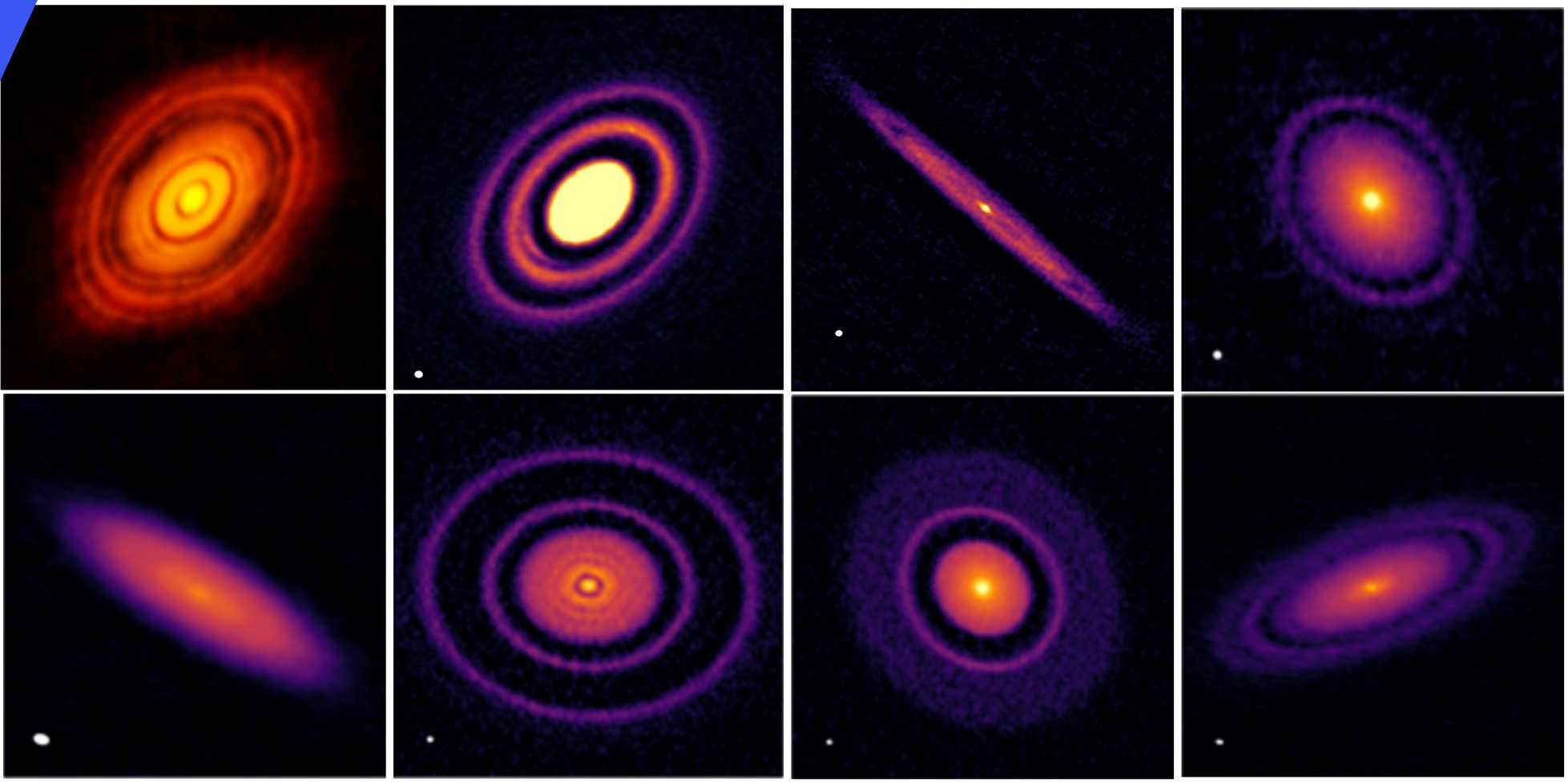
Dust vertical settling



Miotello et al. 2022

- **Vertical settling**
  - Dust rotates faster than the gas, and feels a head wind, leading to settling
  - Balance between **dust/gas coupling** St and **turbulence** α
  - Concentrates dust in the midplane – favorable for grain growth and planet formation

Previous measurement of dust vertical settling



- Mostly limited to one value in the disk

What is the radial variation of dust settling within disks ?

Pinte et al. 2016
Doi & Kataoka 2021
Villenave et al. 2022
Pizzati et al. 2023

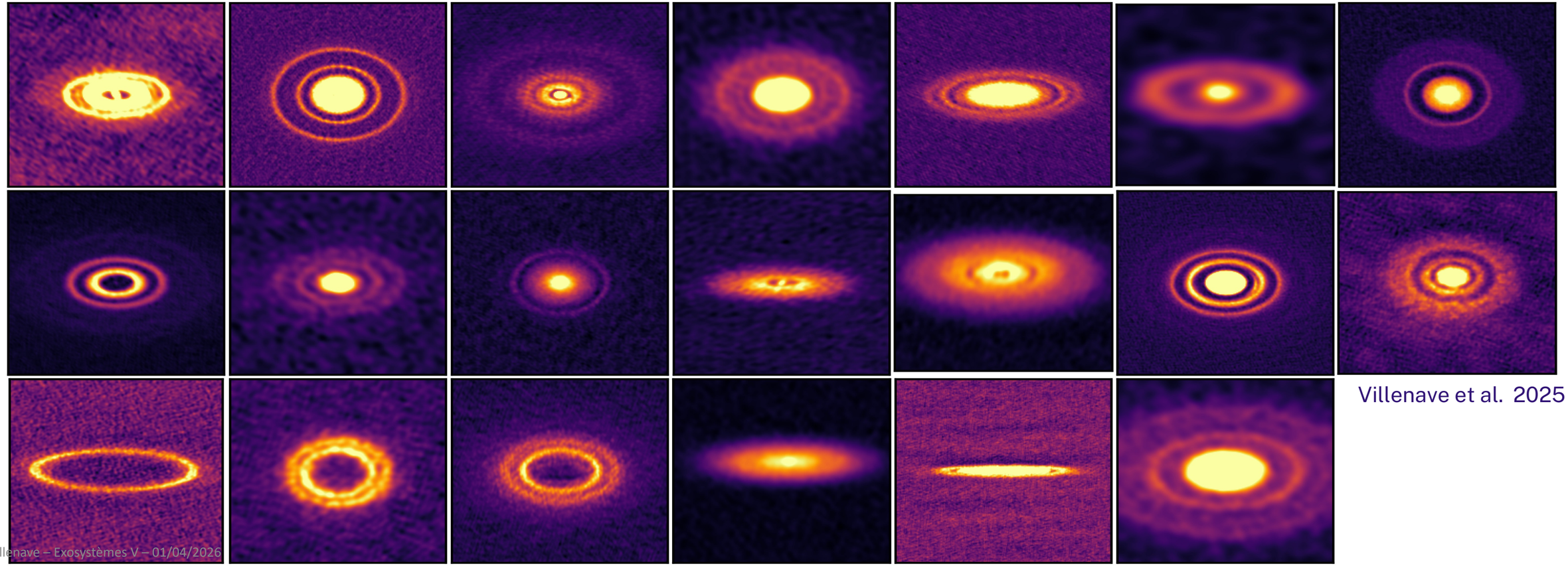
Sample of inclined disks with rings

Modeling strategy – 33 disks from the ALMA archive

- Reproducing the major axis profile of disks, for different dust height
- Then, compare the minor axis profiles to look for projection effects, for the different rings/gaps

- Dust grains: 0.01µm-3mm; Hg (100au) = 10au; Settling Fromang & Nelson (2009)

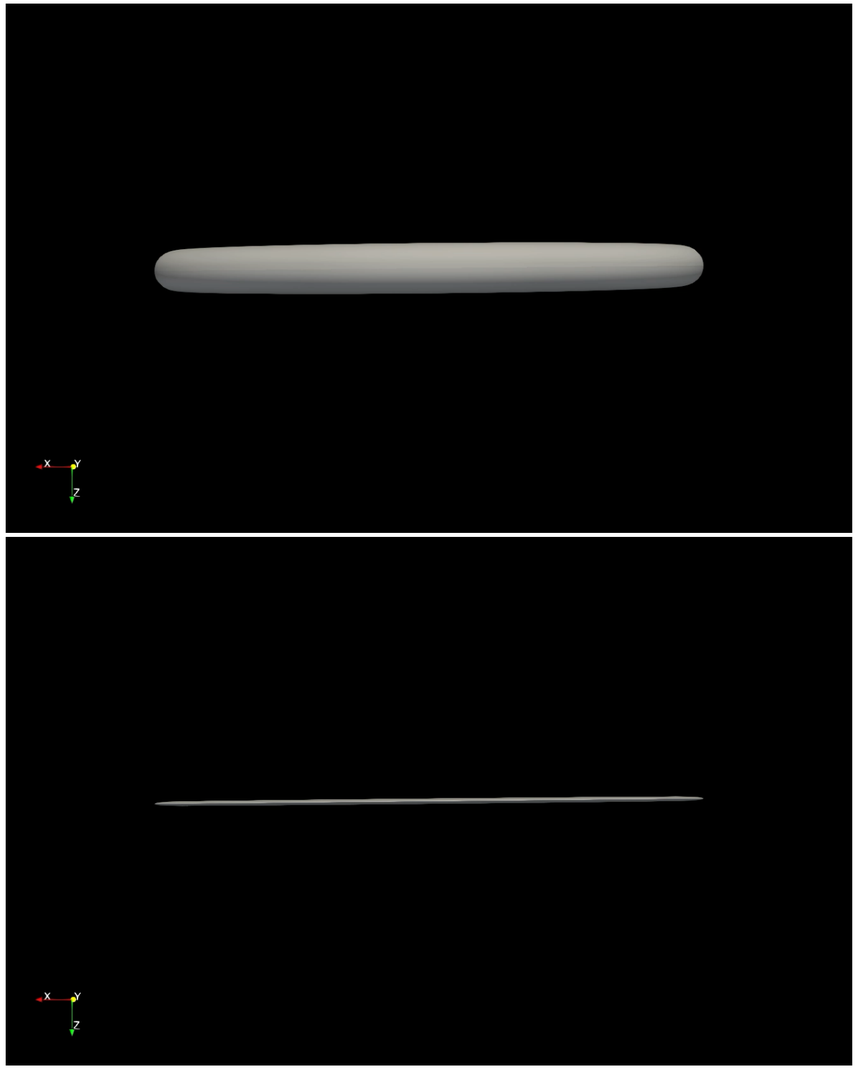
$$\rho(r, z, a) \propto \Sigma(r) \exp\left[-\frac{\Omega \tau_S(a)}{\tilde{D}} \left(e^{\frac{z^2}{2H_g^2}} - 1 \right) - \frac{z^2}{2H_g^2} \right]$$

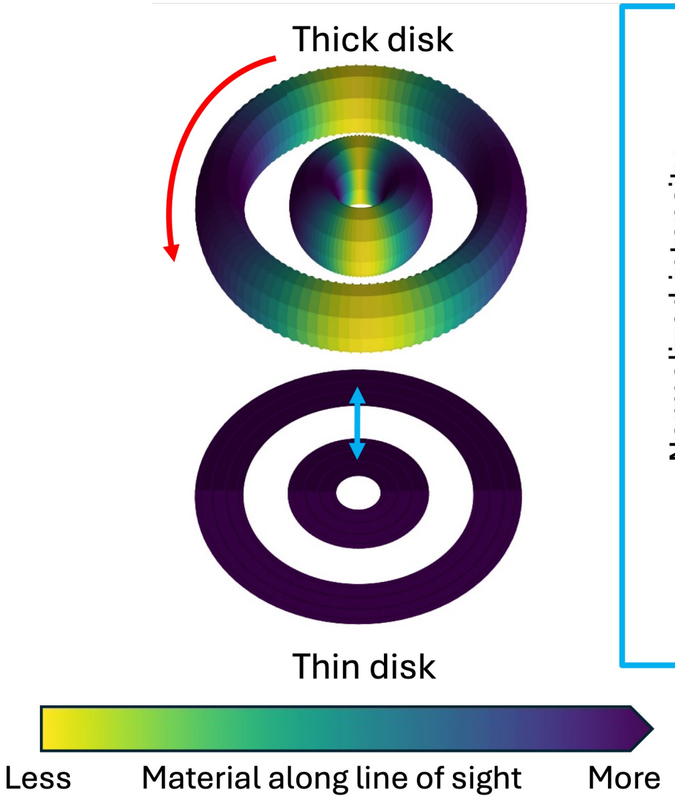


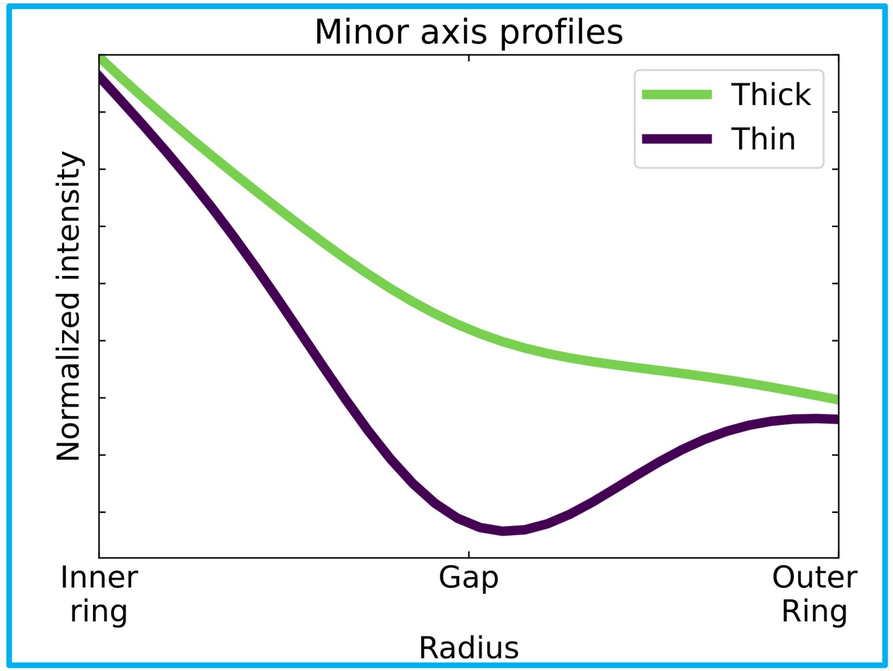
Villenave et al. 2025

Geometrical projection effects

Credits: G. Lesur



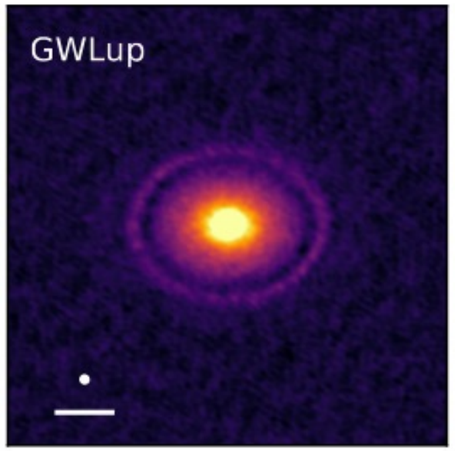


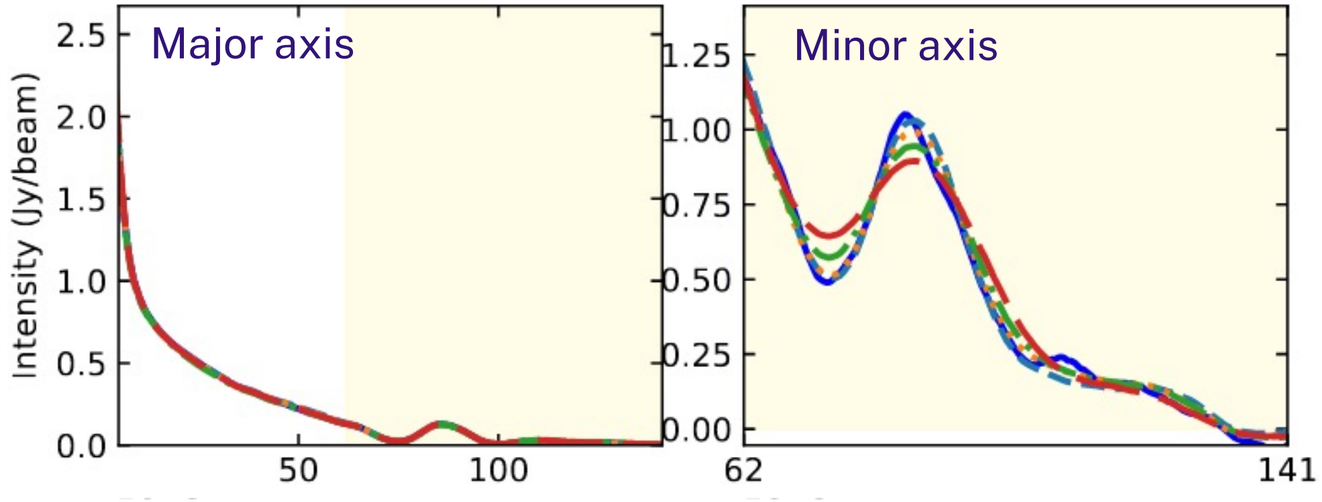


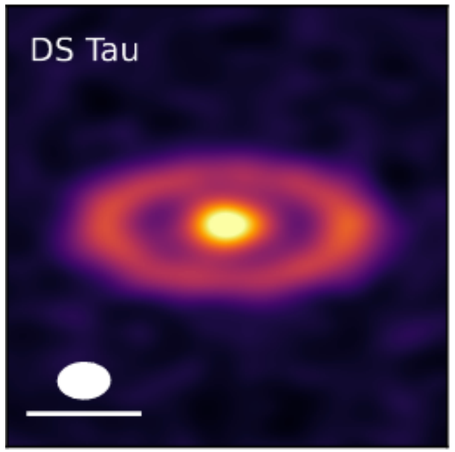
Upper limits

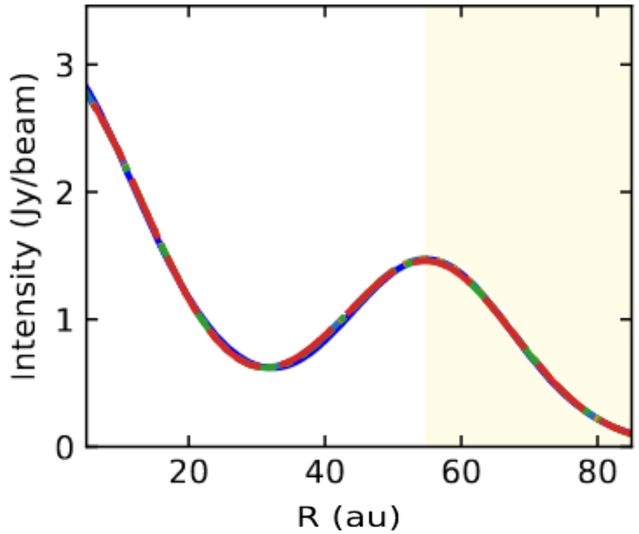
Results

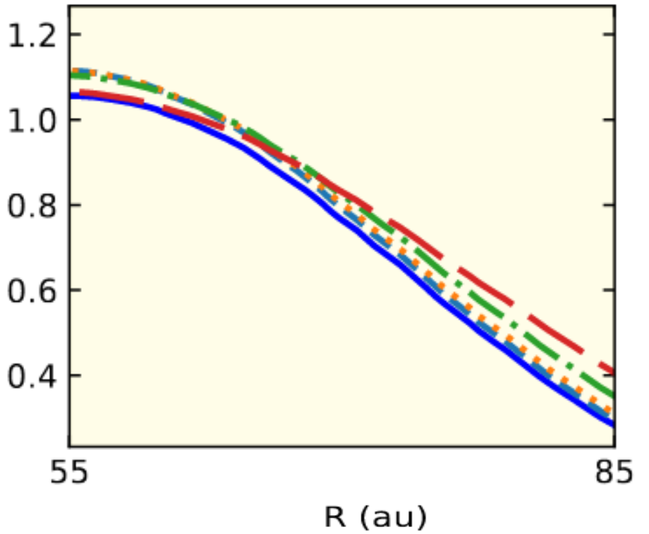
- 23/33 disks: **Upper limits to the dust height**

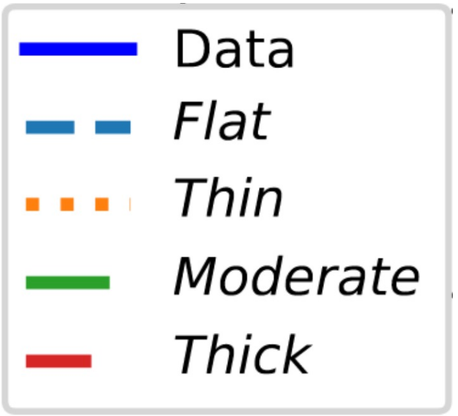








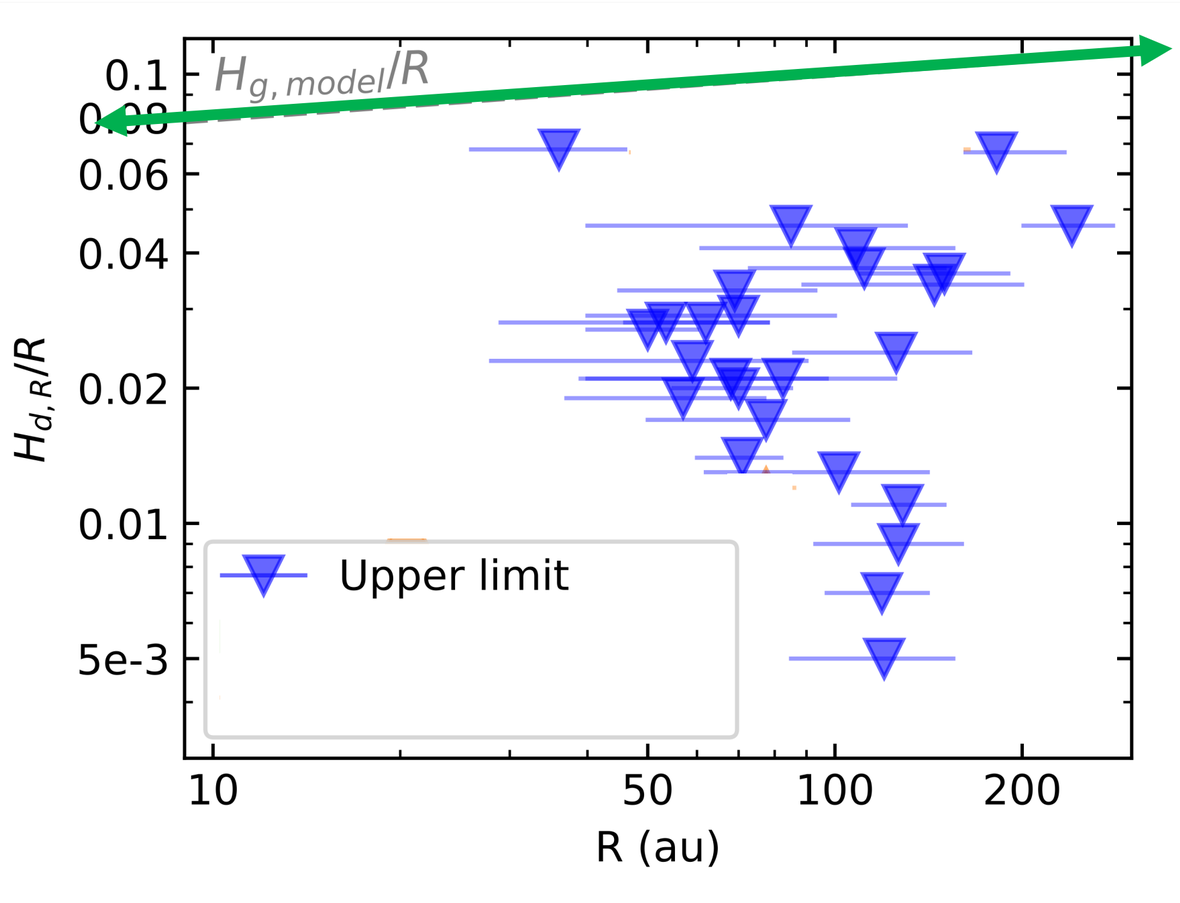




Upper limits

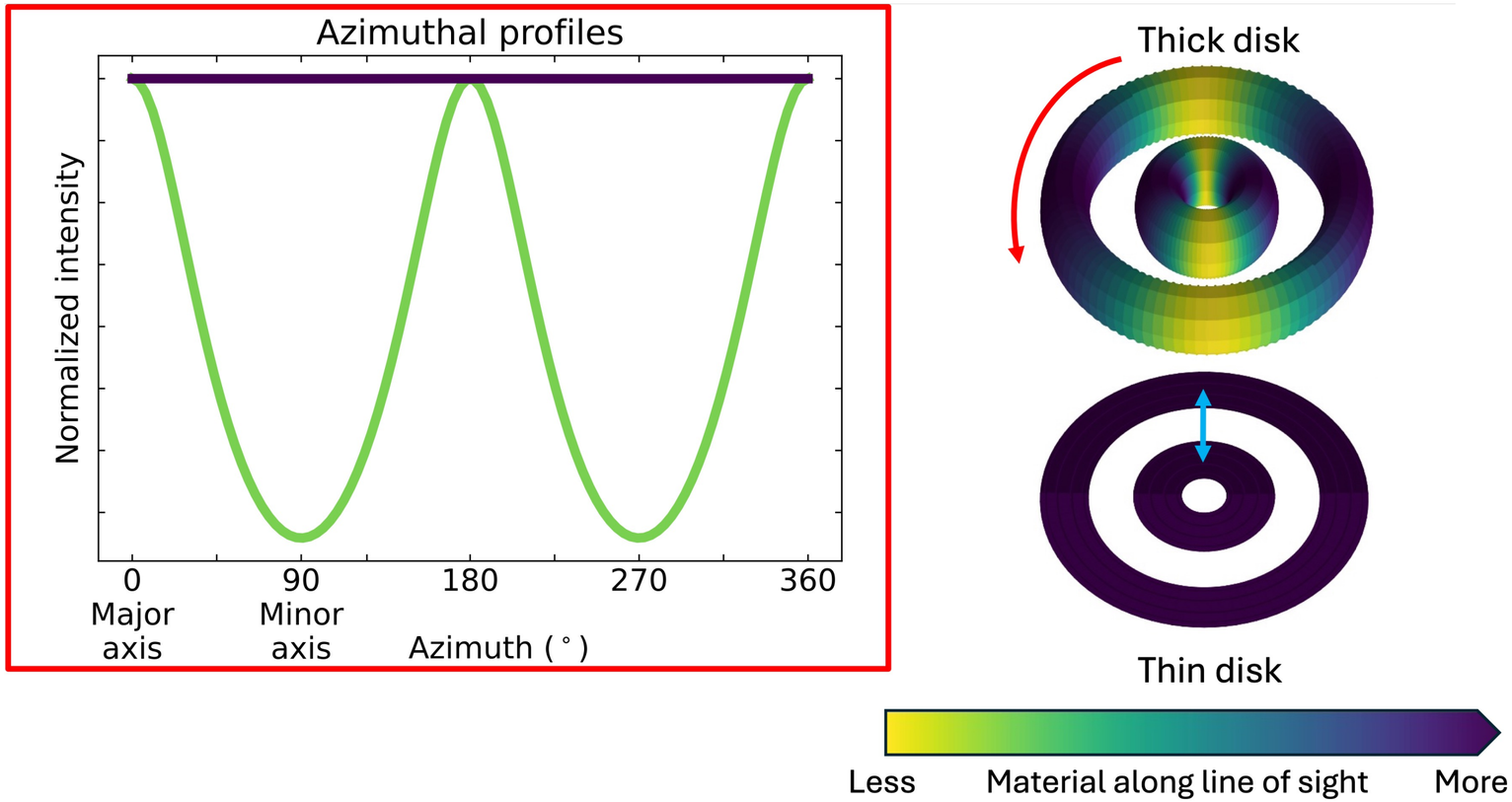
Results

- 10/33 disks: No constraints
- 23/33 disks: **Upper limits to the dust height**



Typical gas scale height

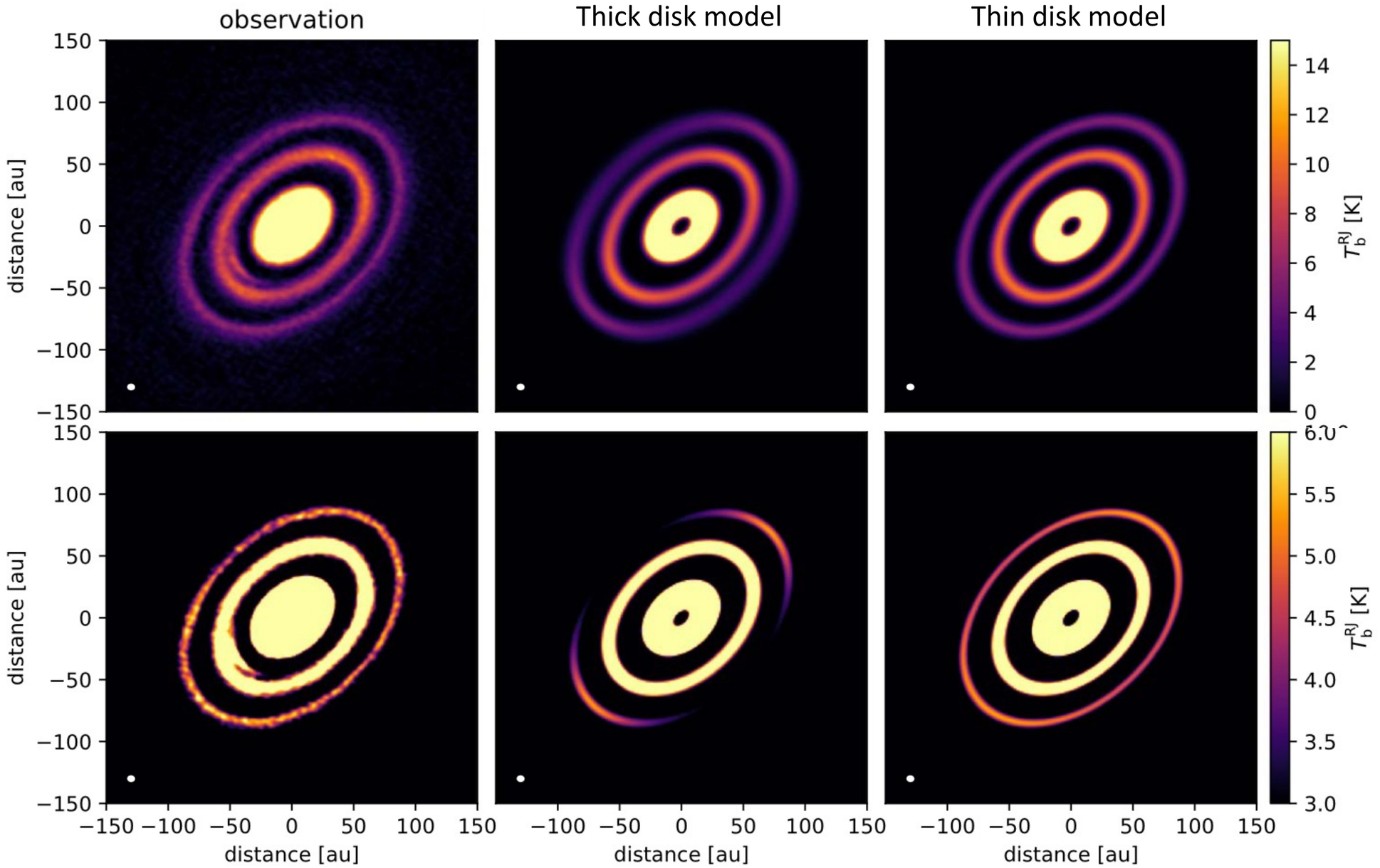
Using the line of sight to test for vertical thickness



Doi & Kataoka 2021
Villenave et al. 2025
Jiang et al. 2025

Using the line of sight to test for vertical thickness

- Inner ring = thick
- Outer ring = thin



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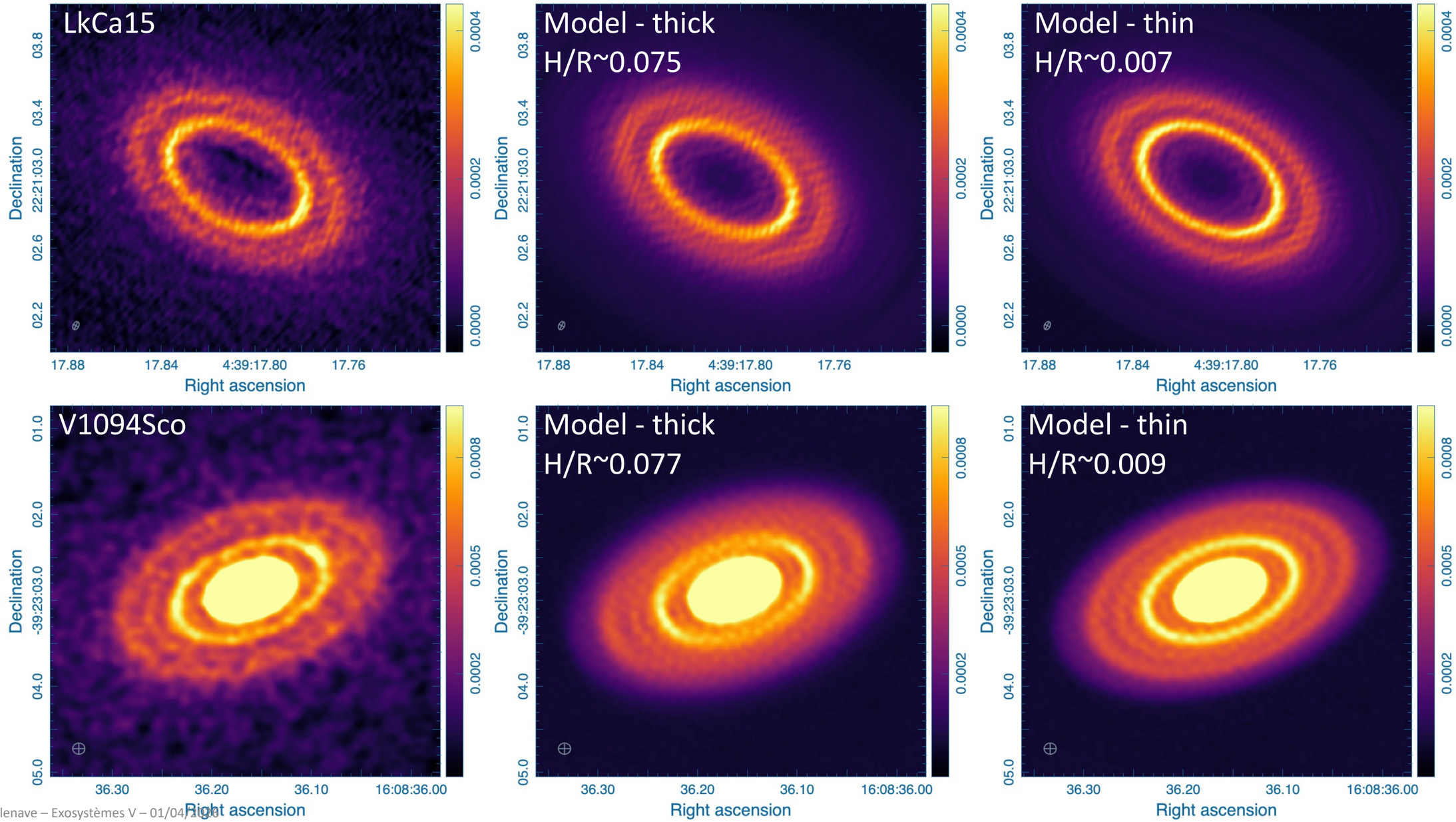
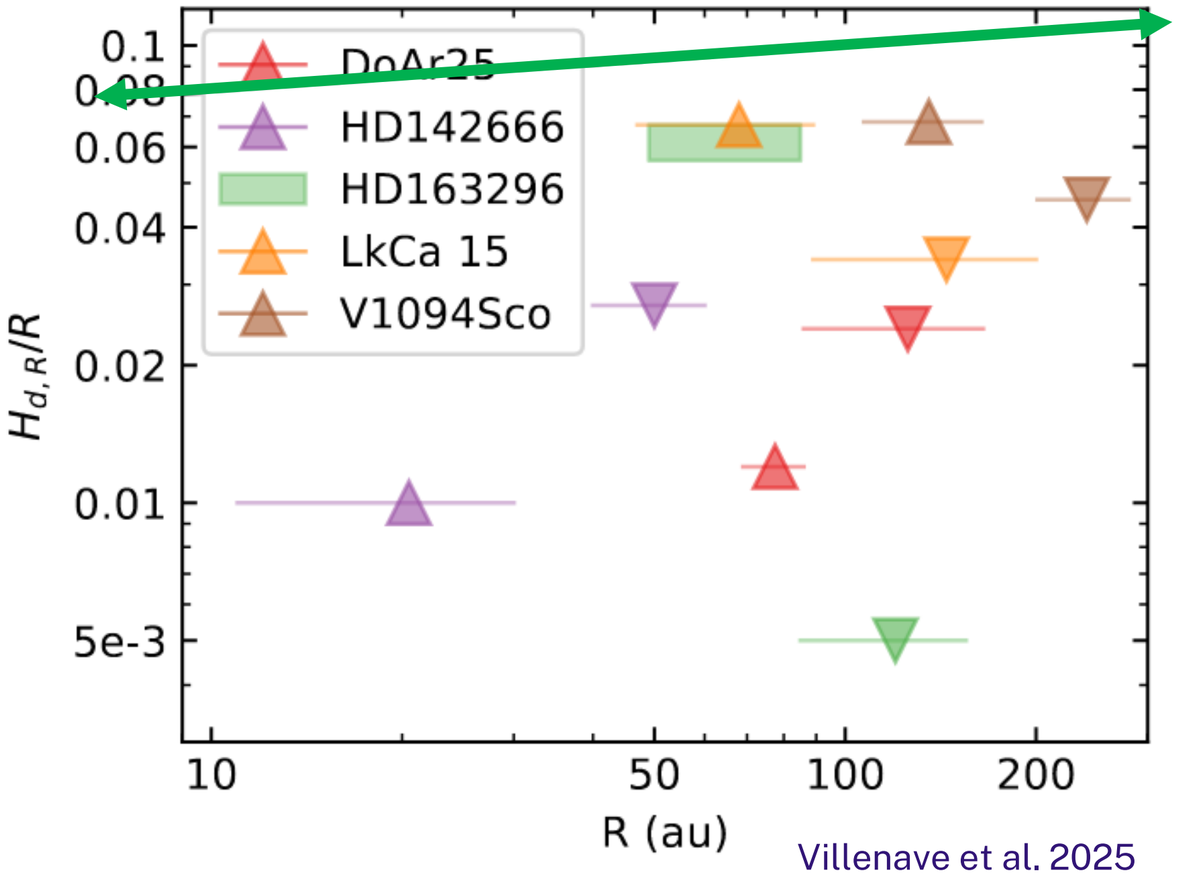


Villenave et al. 2025
See also Jiang et al. 2025

Systems with both an upper and a lower limit

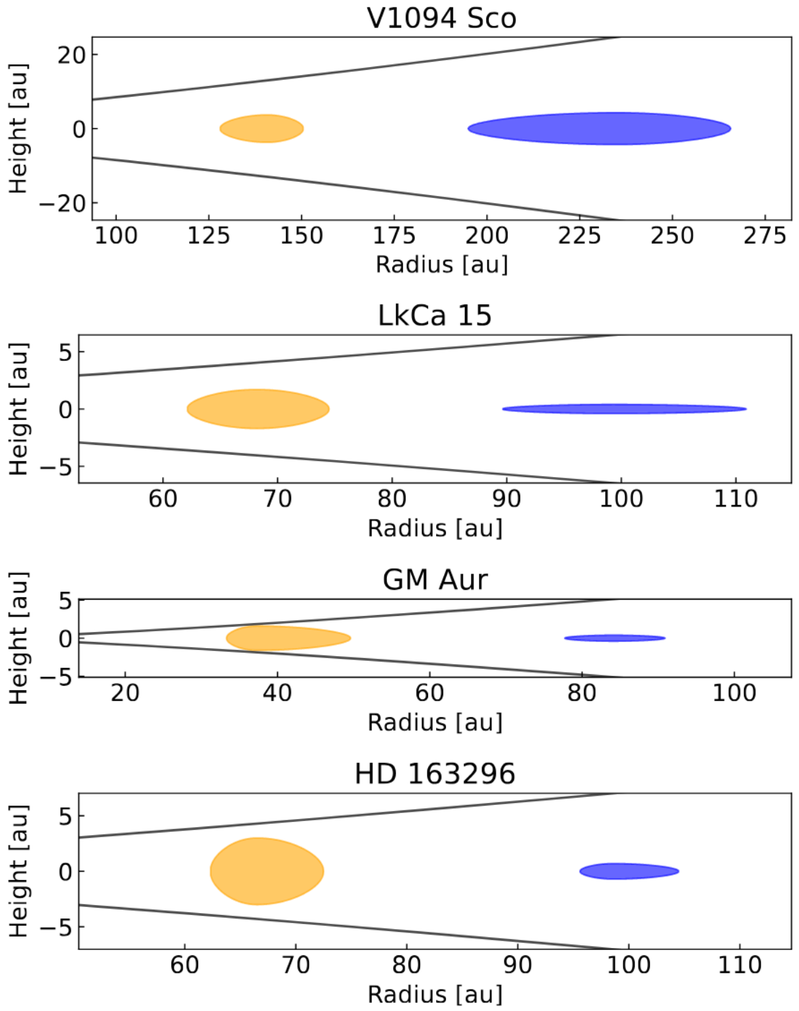
Results

- 18/23 disks: **Upper limits to the dust height**
- 5/23 disks: **Thick inner disk & Thin outer disk**



Typical gas scale height

Villenave et al. 2025



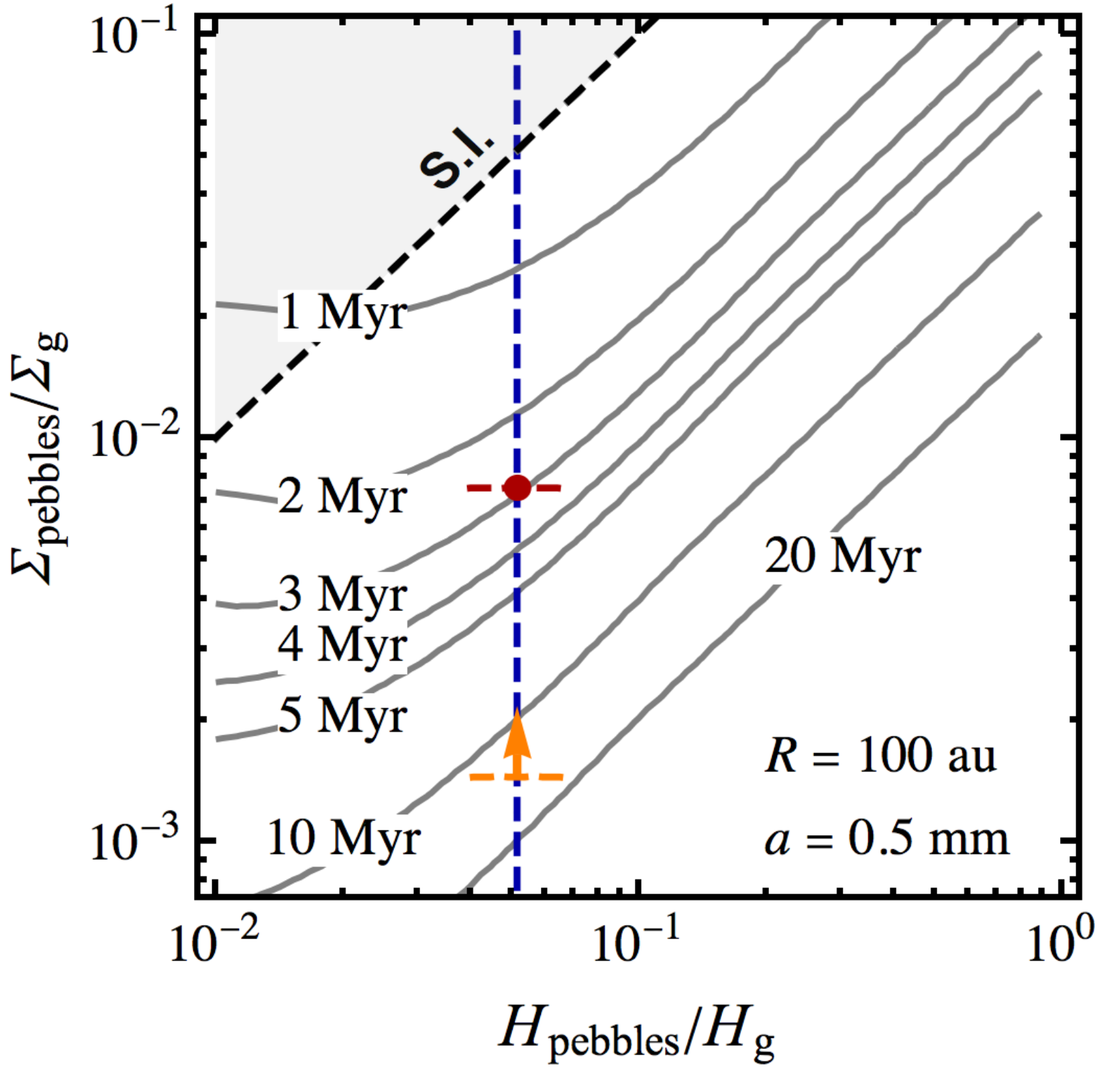
Jiang et al. 2025

Implications for wide-orbit planet formation

Pebble accretion in Oph163131

- A lunar embryo (0.01 M_E) can grow up to a 10M_E planet in less than 10 Myr at 100au from the central star
- A pebble scale height as constrained by the observations strongly promotes core growth
- In the full sample: faster growth in the outer disk than further in:
  e.g., AA Tau, HD163296, AS209

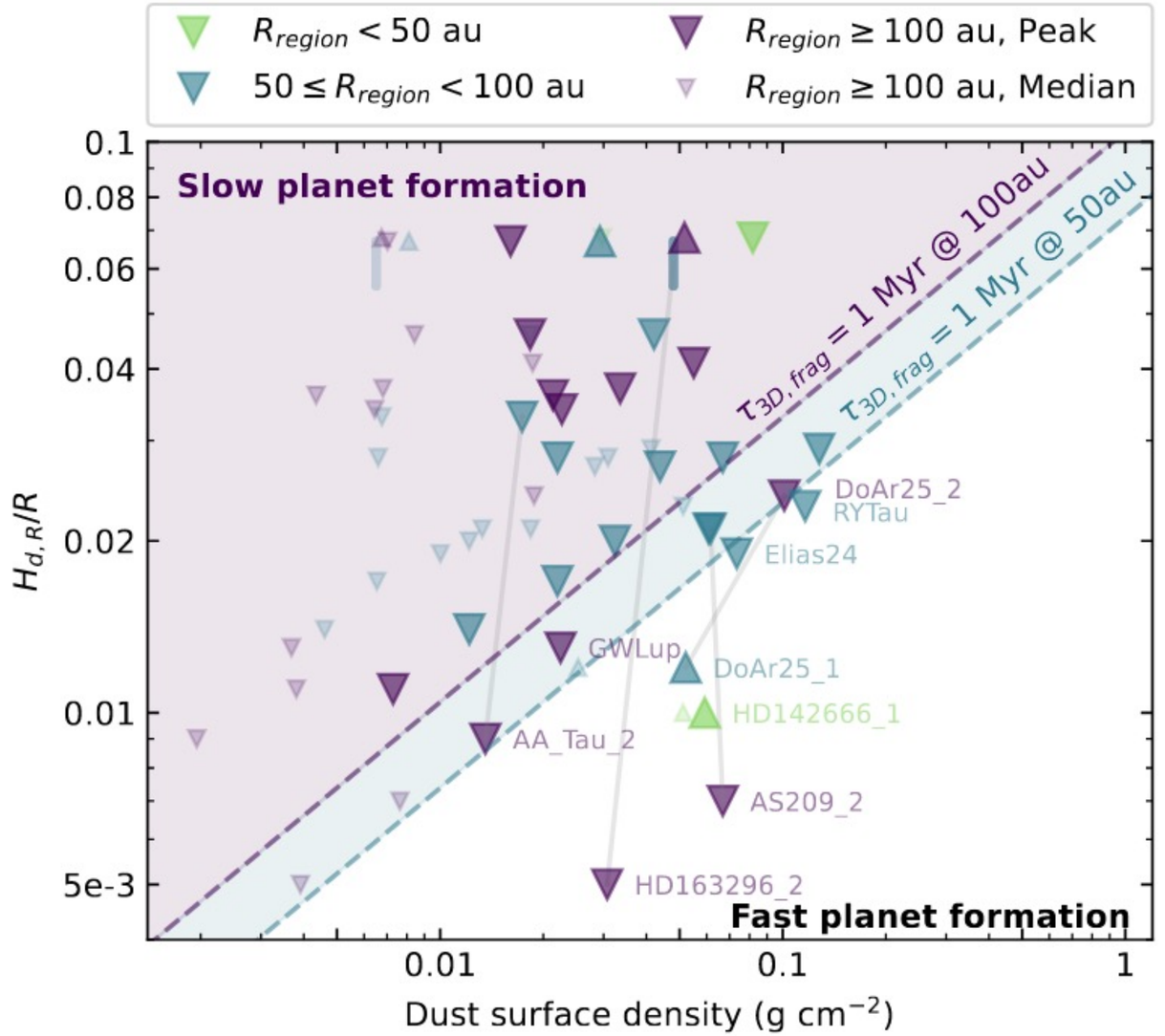
Villenave et. al 2022



Implications for wide-orbit planet formation

Pebble accretion in the large disk sample

- 2D vs 3D accretion regime
- Faster growth in the outer disk than further in: e.g., AA Tau, HD163296, AS209



Villenave et al. 2025

Summary

- **Vertical settling is efficient in disks**
  - 23/32 disks have upper limits to their dust thickness
  - 5/23 also have a thick inner ring (R~50-100au)

  - Planet formation faster in vertically sedimented regions
  - Planet formation might be more efficient in the outer regions of some systems

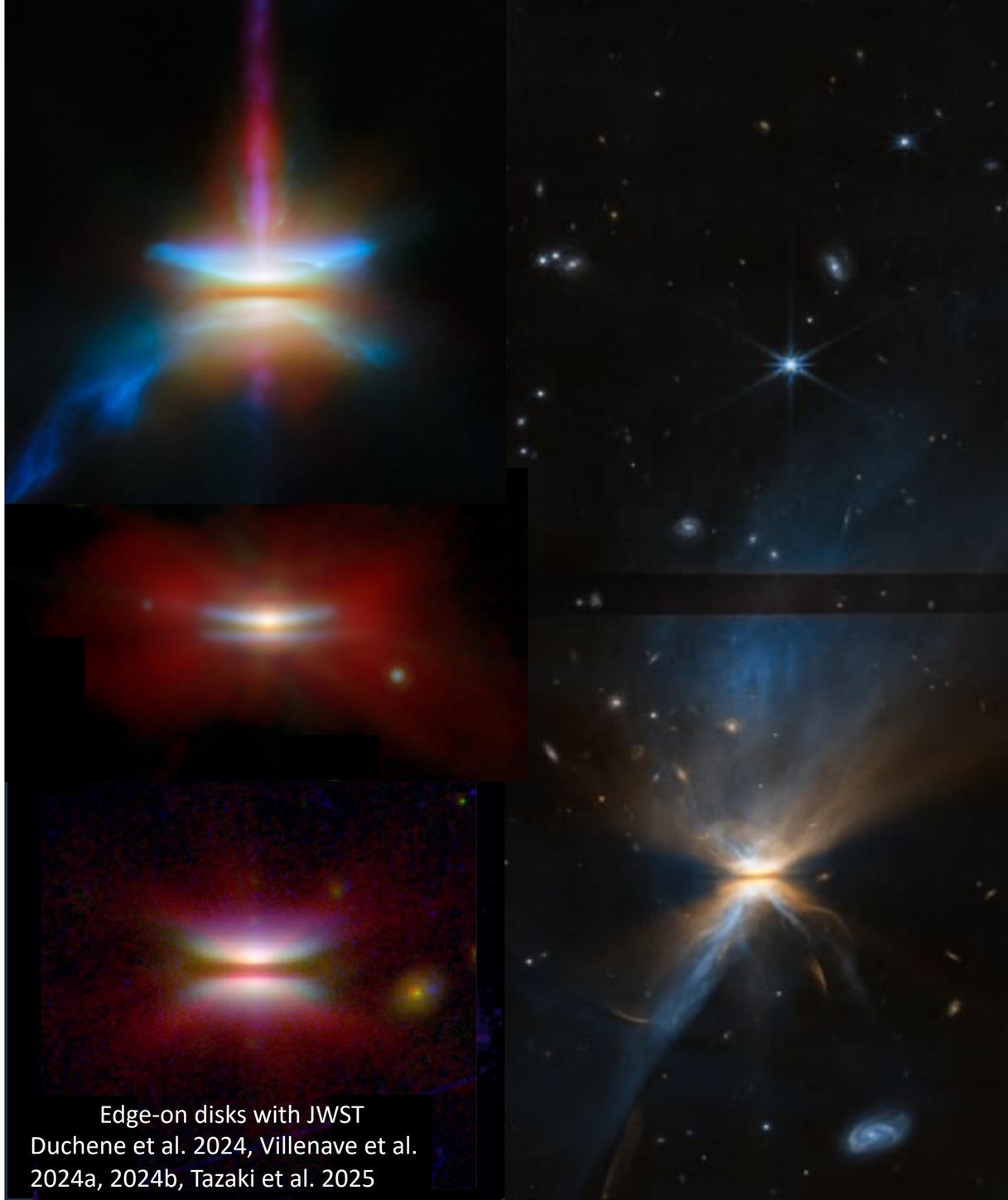
Atelier SF2A 2026 @ Grenoble

Mardi 26 juin, après midi

Les disques protoplanétaires à l'ère des grands instruments : quel rôle pour la communauté française ?

SOC : Benoit Tabone, Clément Baruteau, Jennifer Noble, M. Villenave

Deadline abstract : 10 avril

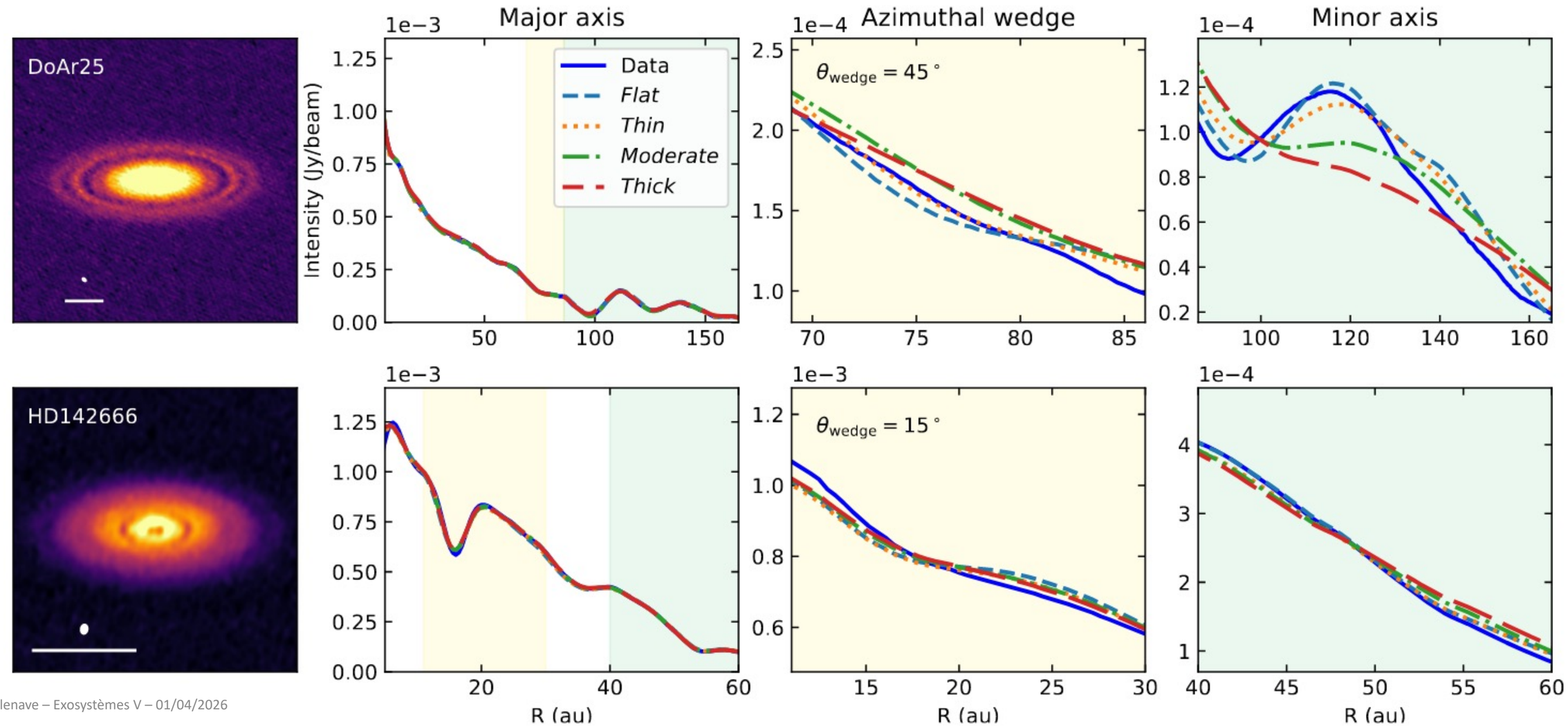


Edge-on disks with JWST
Duchene et al. 2024, Villenave et al. 2024a, 2024b, Tazaki et al. 2025

Systems with both an upper and a lower limit

Thicker inner disk than outer disk

- 2nd cut shows that blue/thin model still shows the gap too strongly -> too thin



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