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Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg

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How to halt inward migration of Giant planets.

Philippine Griveaud
Max Planck Institute for Astronomy
Heidelberg, Germany

Collaborators: Aurélien Crida, Elena Lega, Antoine C. Petit, Alessandro Morbidelli, Michiel Lambrechts, Myriam Benisty, Hubert Klahr

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Migration of **multiple** giant planets in **low viscosity** protoplanetary discs.

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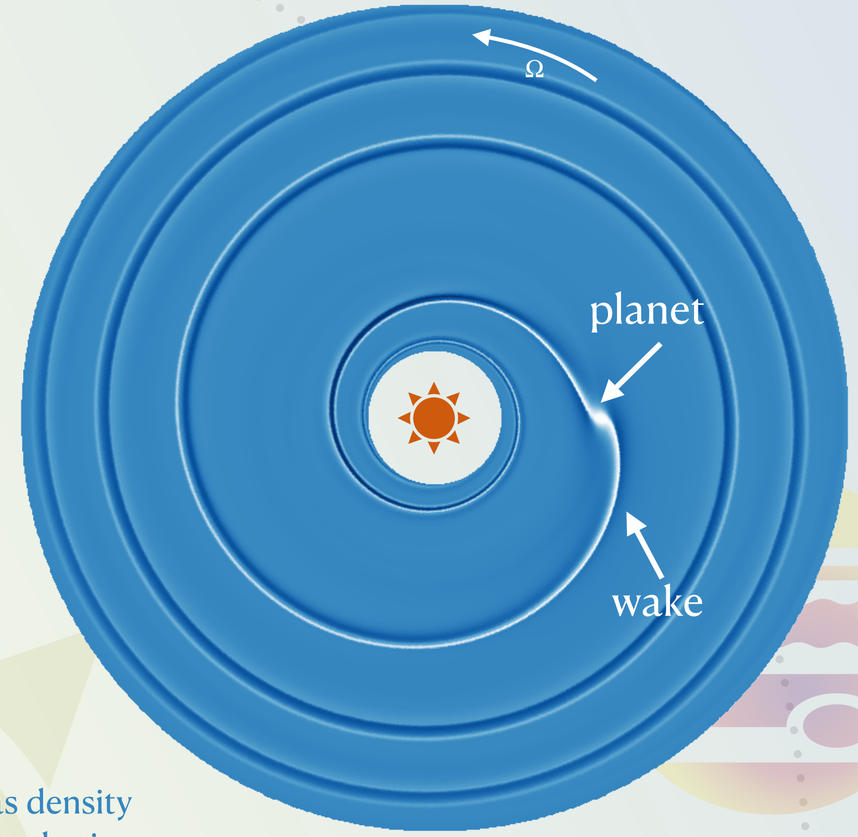
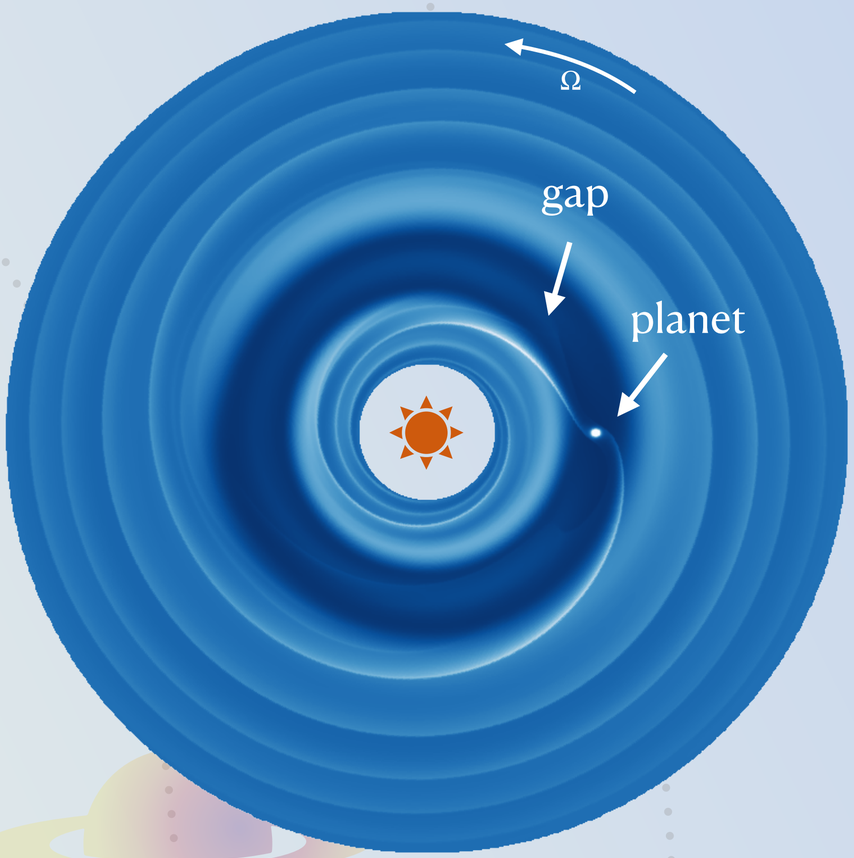
Planet-disc interactions

"Small" mass planet



gas density
perturbations

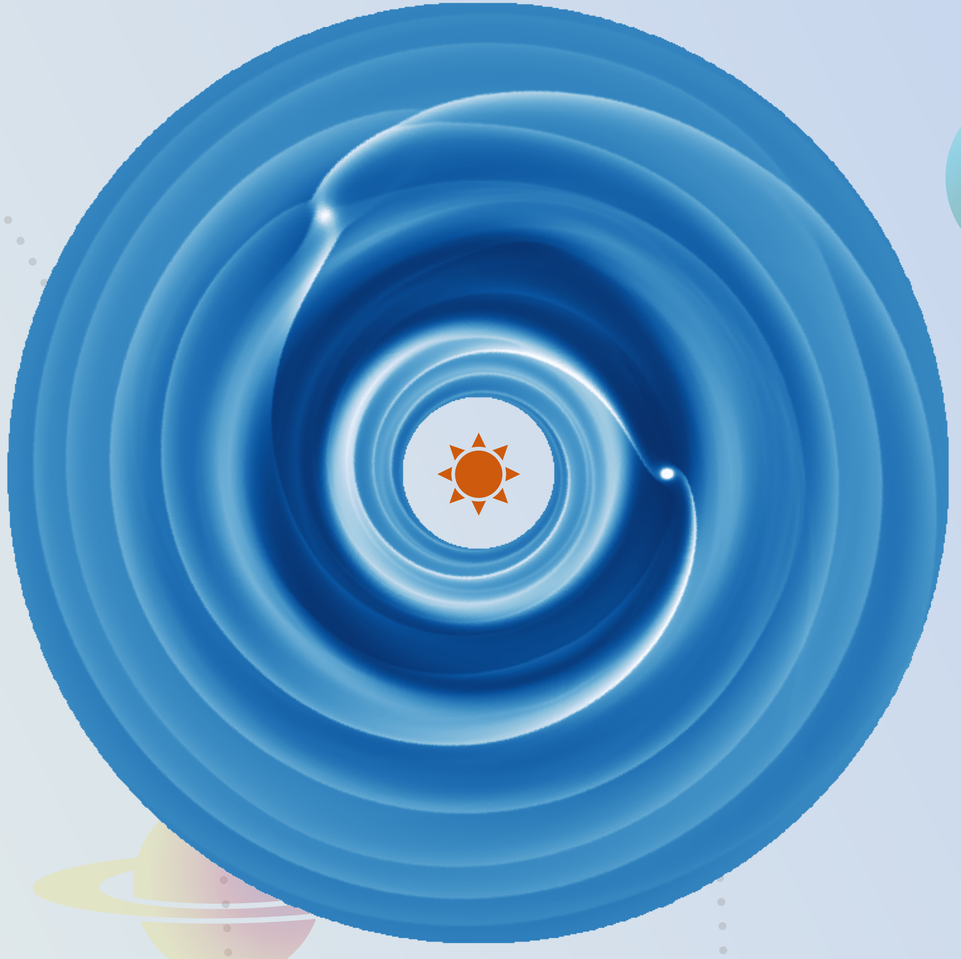
Giant planet



⇒ Single planets generally migrate inwards.

Planet-disc interactions

- Multi-planetary dynamics tends to **complicate** things.
- If convergent migration: planets **lock** into Mean Motion **Resonances** (MMR).
- Migration **cannot** be modeled with **simple** prescriptions anymore.



Change of paradigm in PPD modeling

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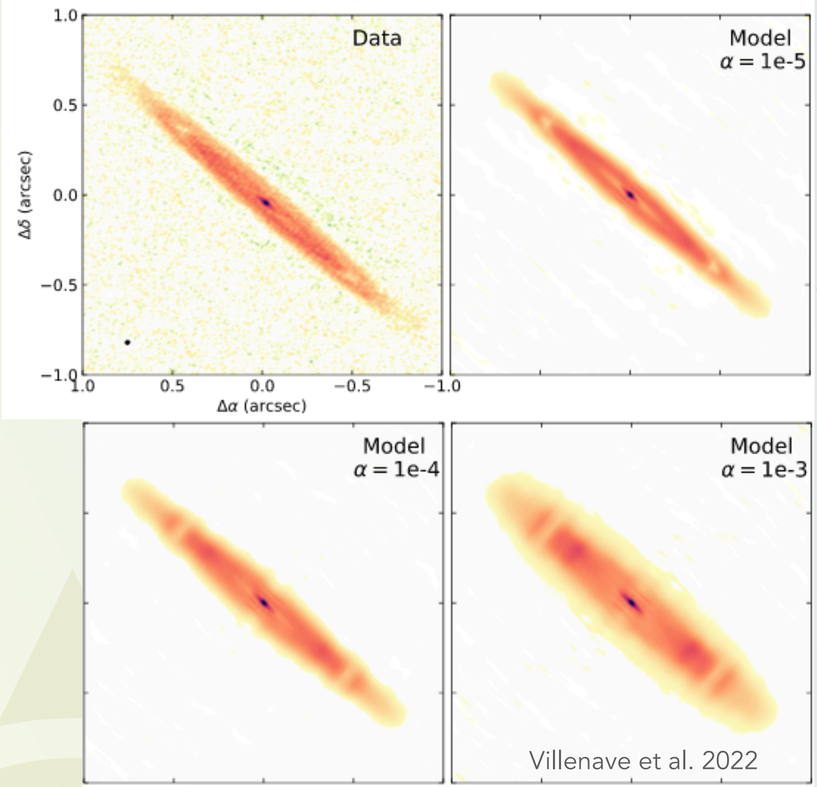
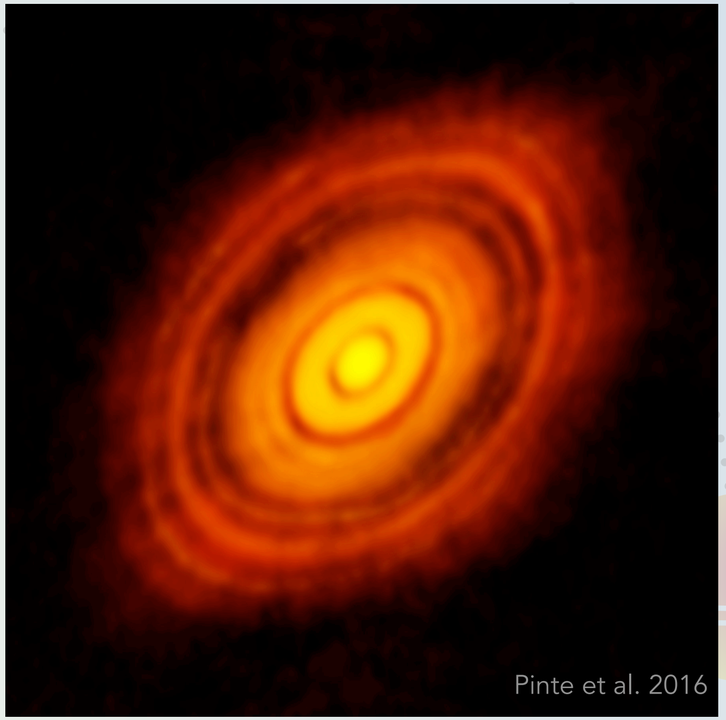


Villenave et al. 2022

HL TAU

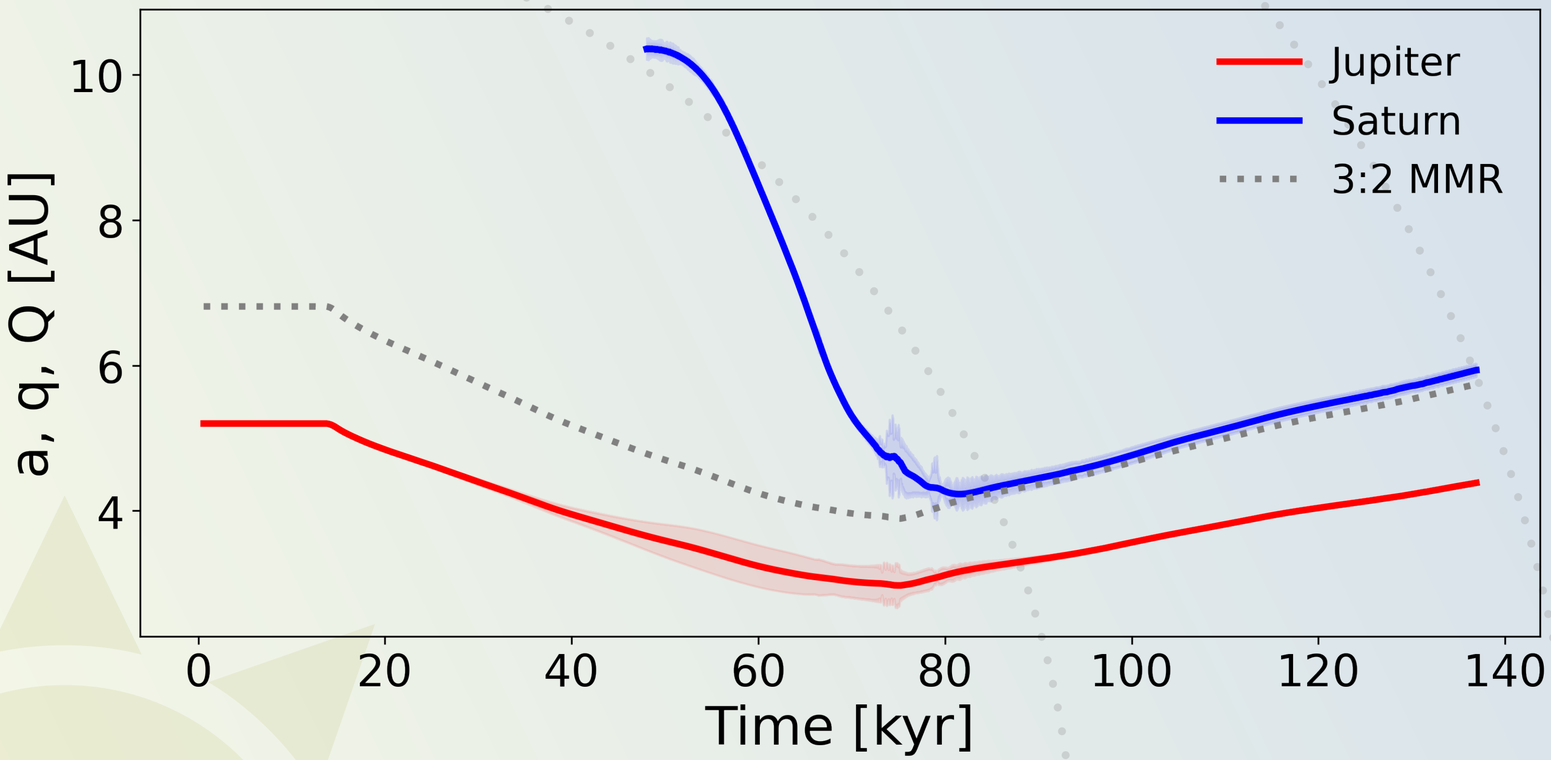


Pinte et al. 2016

- Accretion mechanism: viscosity driven → **disc winds**
- Mid-plane: from high turbulent → **dead zone**

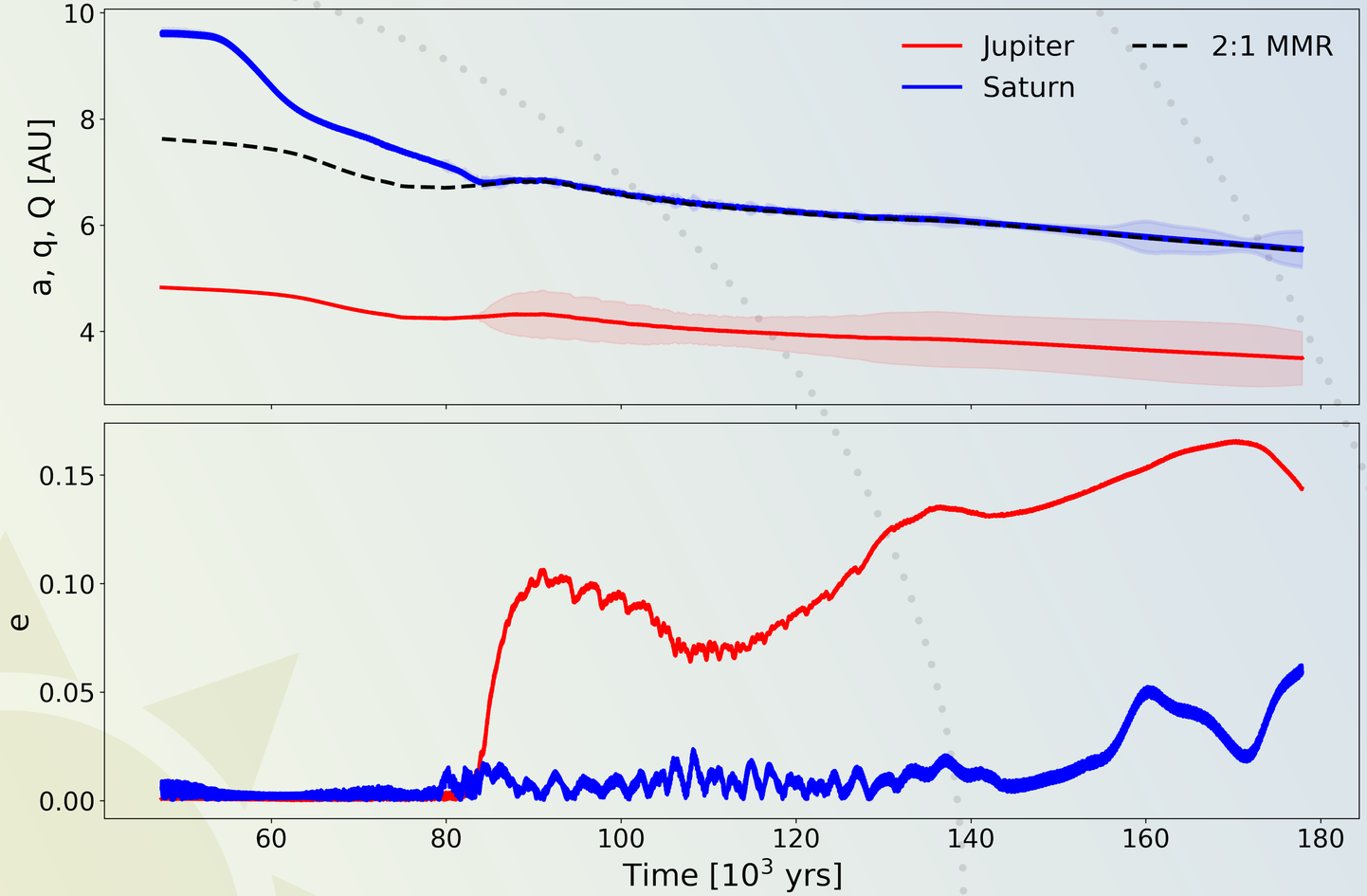
⇒ **Viscosity** parameter α: from $> 10^{-3} \rightarrow < 10^{-4}$

Classical Case: Jupiter & Saturn



- Classical result: **high** viscosity case ($\alpha = 10^{-3}$)
- Masset & Snellgrove (2001) Mechanism: outward migration in 3:2 MMR
- Great to explain **cold giants** population
- Origin of Grand Tack Scenario for Solar System Walsh et al. 2011

Pairs migrating in Low Viscosity



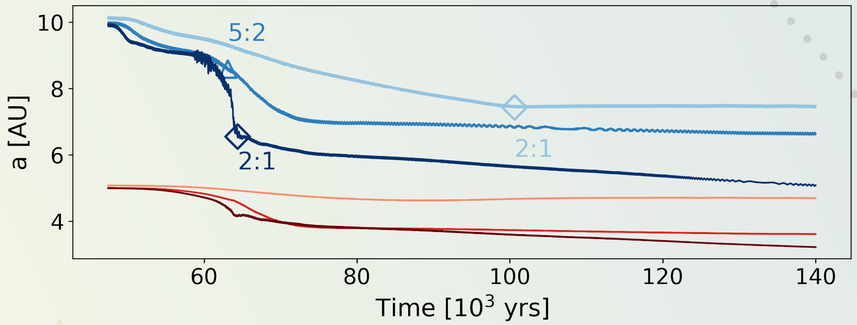
- **Low** viscosity $\alpha = 10^{-4}$
- Locking in 2:1 MMR
- **Slow inwards** migration
- High **eccentricity** of inner planet (even for more massive planet)

Griveaud et al. 2023

Pairs migrating in Low Viscosity

Throughout a wide parameter exploration

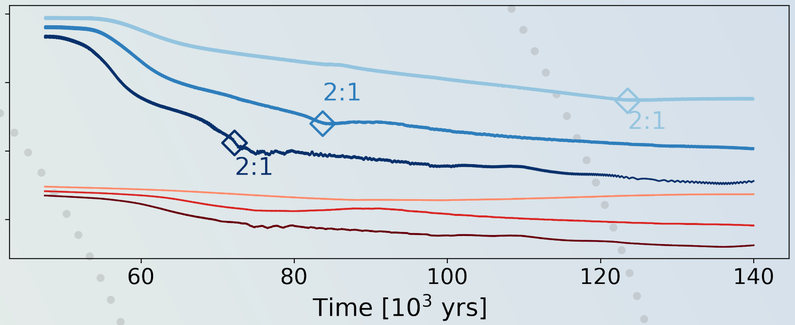
Thin disc,
varying density



$h = 0.035$

$\Sigma_0 = [1.61 \cdot 10^{-4}, 6.76 \cdot 10^{-4}, 2.8 \cdot 10^{-3}]$

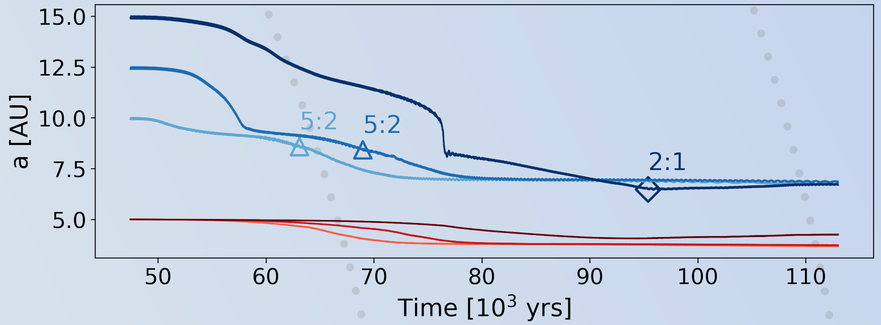
Thick disc,
varying density



$h = 0.05$

$\Sigma_0 = [1.61 \cdot 10^{-4}, 6.76 \cdot 10^{-4}, 2.8 \cdot 10^{-3}]$

Cold disc, varying
initial distance between planets



$h = 0.035,\ \Sigma_0 = 6.76 \cdot 10^{-4}$

$a_S/a_J = [2, 2.5, 3]$

⇒ Conclusion: 2:1 MMR is never crossed.

Also supported by semi-analytical study.

Griveaud et al. 2023

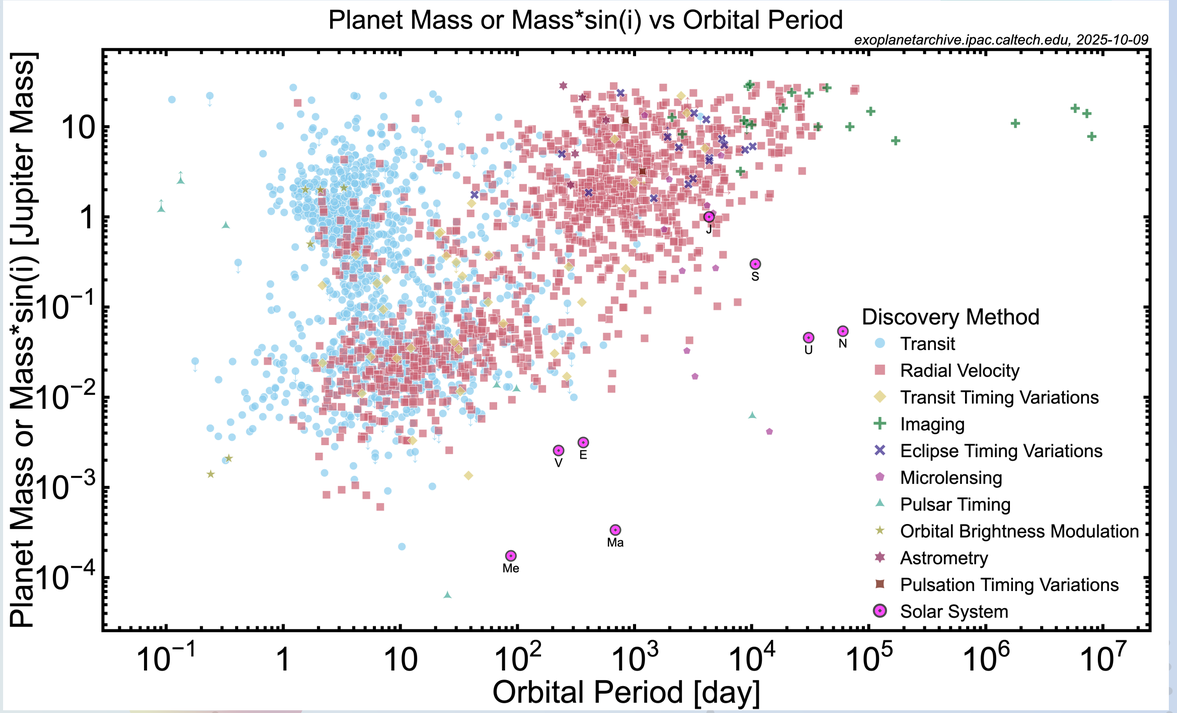
Mid-way conclusion

Griveaud et al. 2023

- **Low** viscosity discs **locks pairs** of giant planets are locked in **2:1 MMR** (*or higher)
- Migration is **slow** inwards or **stalled**
- Pair migrates **slower** than the **single** giant

  ⇒ Could explain “Warm Jupiters”

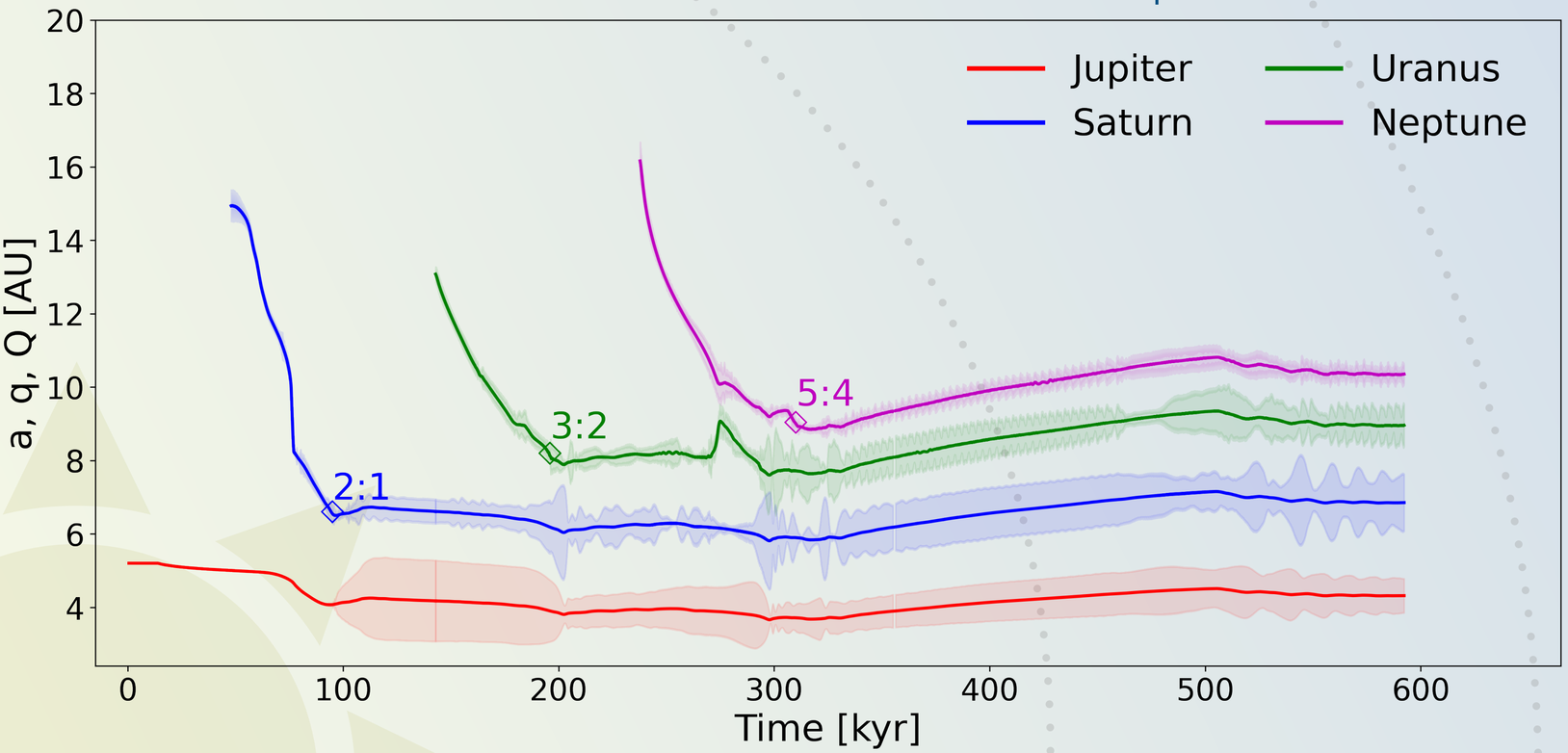
  Prediction: they should be in multiple systems
- Solar System: No Grand Tack scenario possible with Jupiter & Saturn

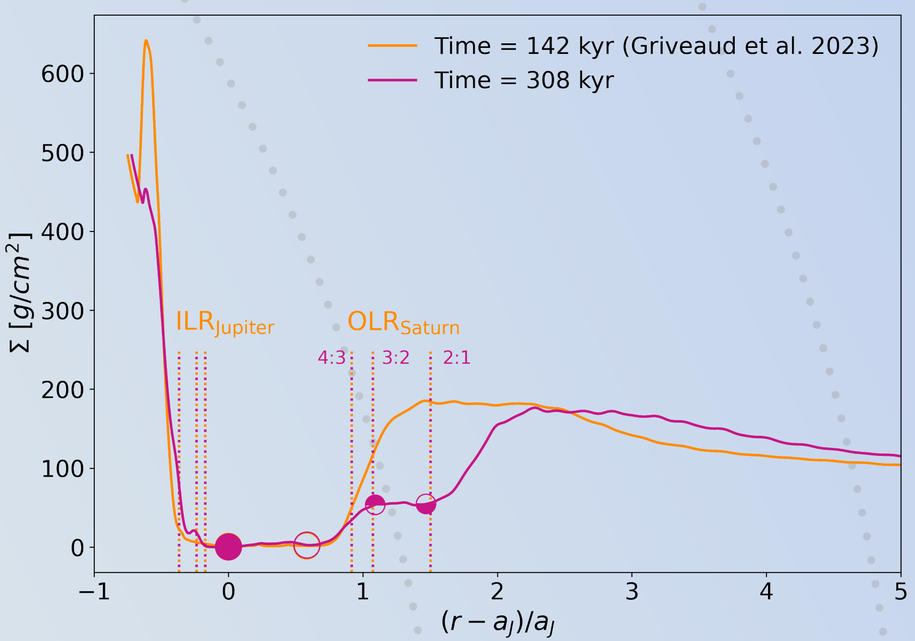


Solar System Scenario

- Adding some ice giants

* In a cold disc — aspect ratio $h = 0.035$

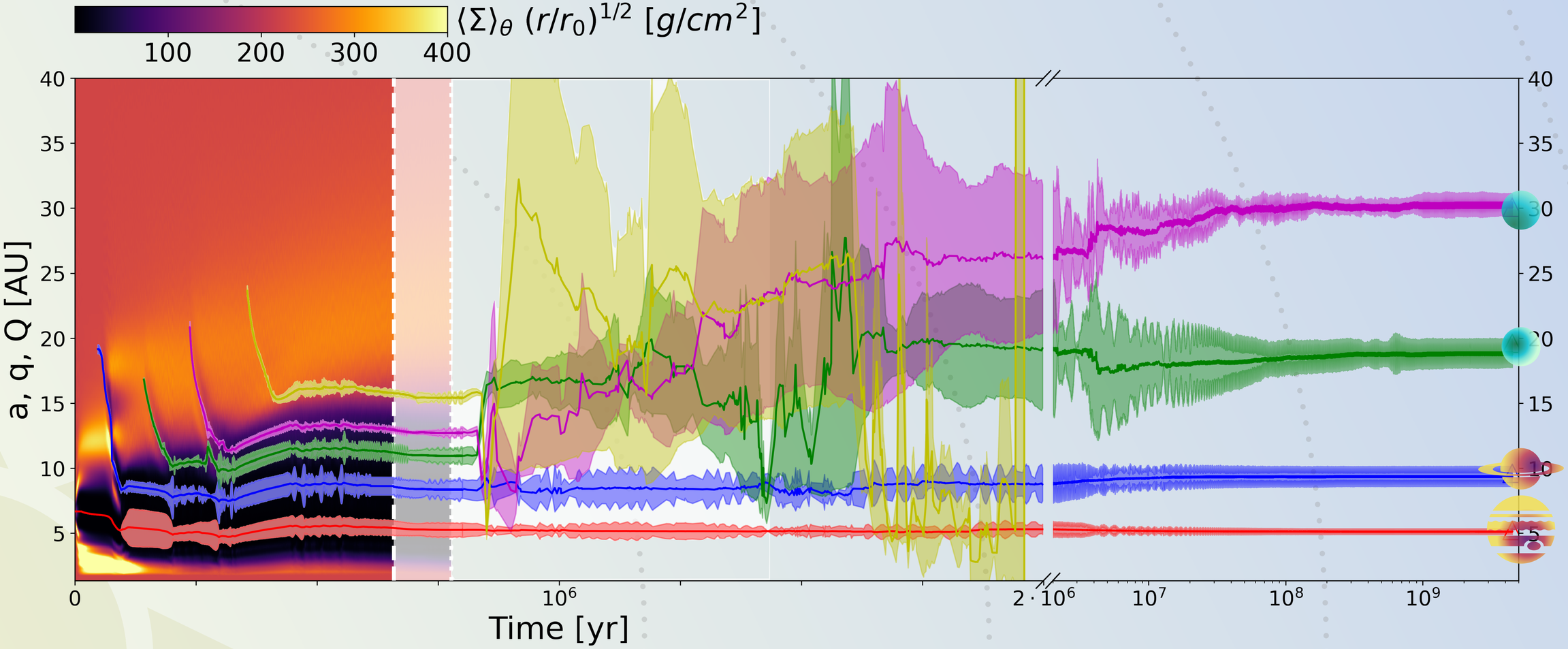




- Masset & Snellgrove mechanism with **2 pairs**
- **Outward** migration

Griveaud et al. **2024**

Solar System Scenario: From migration to Nice Model

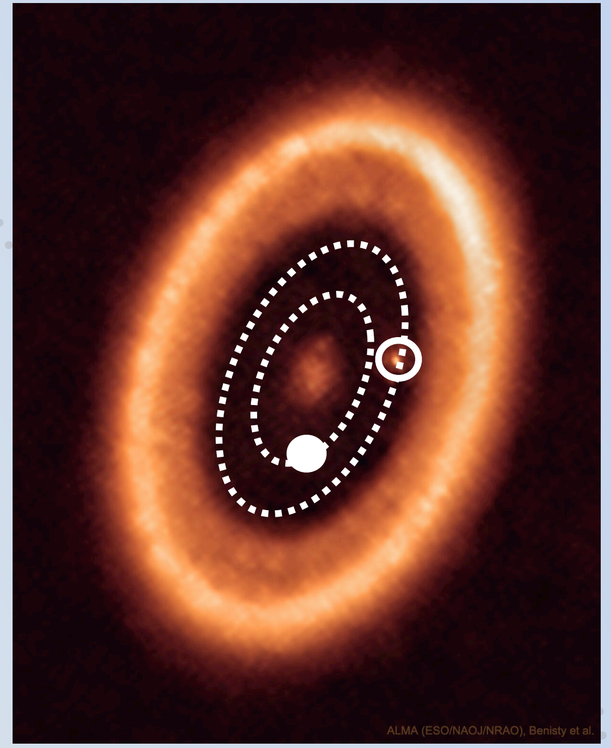


Griveaud et al. **2024**

Application to PDS70

- Only PPD with 2 Giants detected
- Planets: ~ few Jupiter Mass, seem to be in 2:1 MMR
- Observed features in dust emission, Hα, scattered light

⇒ Can PDS70 be a low viscosity disc?

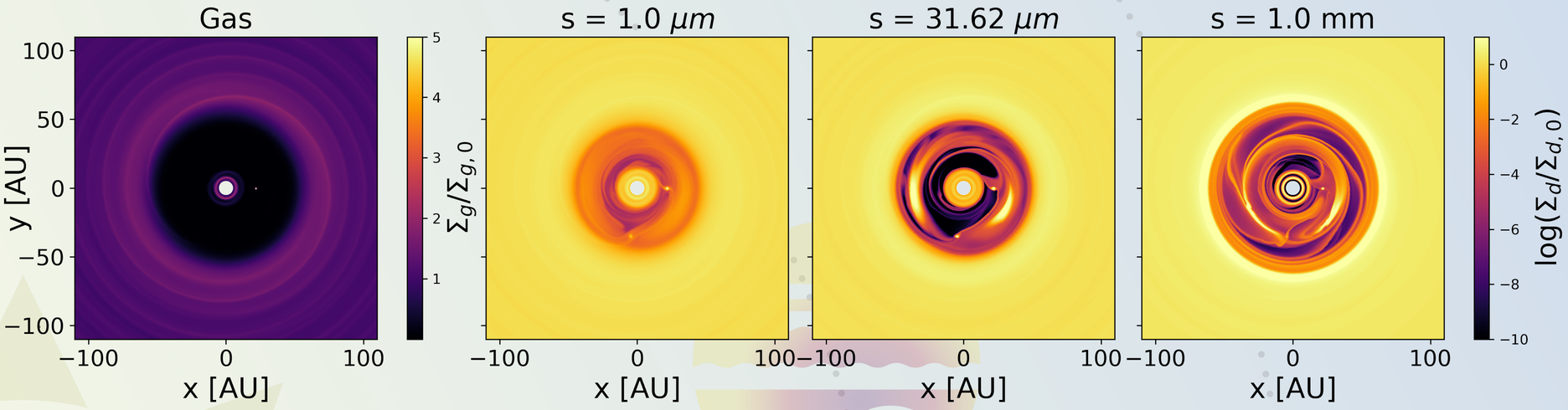


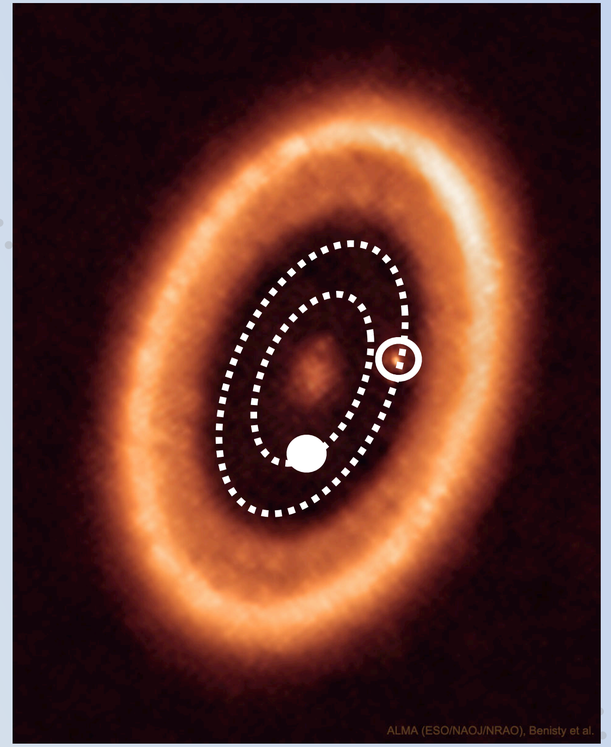
Benisty et al. 2021

Griveaud et al. in prep.

Application to PDS70

- Can low viscosity explain PDS70 ?





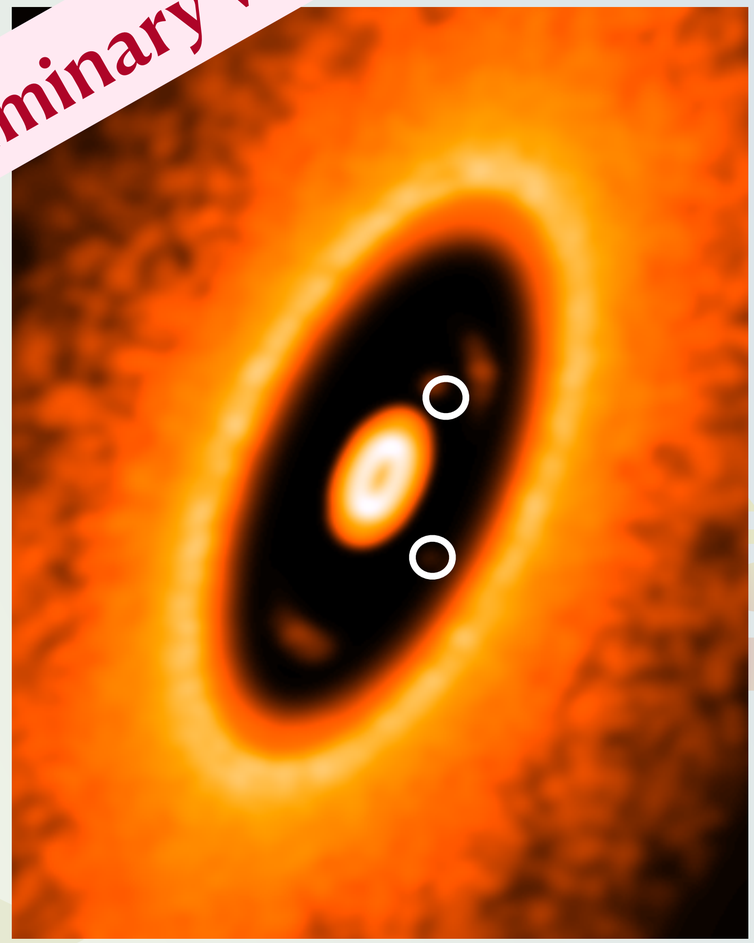
Benisty et al. 2021

Hydro-simulations of gas & dust with Fargo3d

Griveaud et al. in prep.

Application to PDS70

(Very) Preliminary work



Griveaud et al. in prep.

Benisty et al. 2021

Summary

- **Low** viscosity discs **locks pairs** of giant planets are locked in **2:1 MMR** (*or higher)

  Griveaud et al. 2023

- Migration is **slow** inwards or **stalled**

- Pair migrates **slower** than the **single** giant

  ⇒ Could explain “Warm Jupiters” — Prediction: they should be in multiple systems

- **Outward** migration is possible with **multiple** giants of **different** size

  Griveaud et al. 2024

- PDS70 is an *“ideal test bed of study of planet-disc interactions”* & confirm theories of Cold Giants formation and dynamics

  Bae et al. 2019