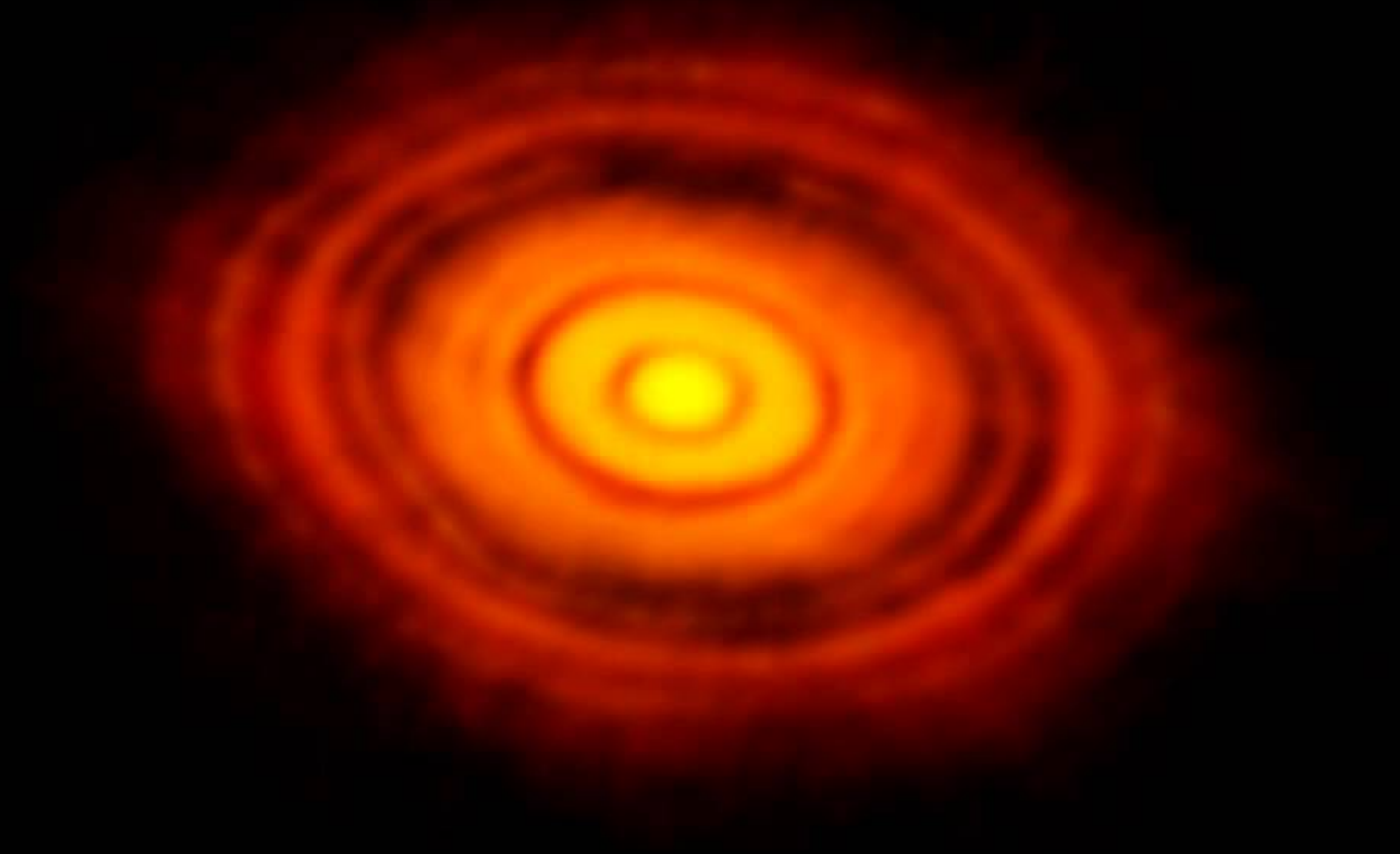
Why I don’t think that (most) rings are due to planets



Alessandro Morbidelli, CNRS, Observatoire de la Côte d’Azur, Nice, France

Why I don't think that (most) rings are due to planets

Content:
- Difficulties to form distant planets
- Counter arguments to main planetary claims
- Alternative mechanisms for ring formation
- Conclusions

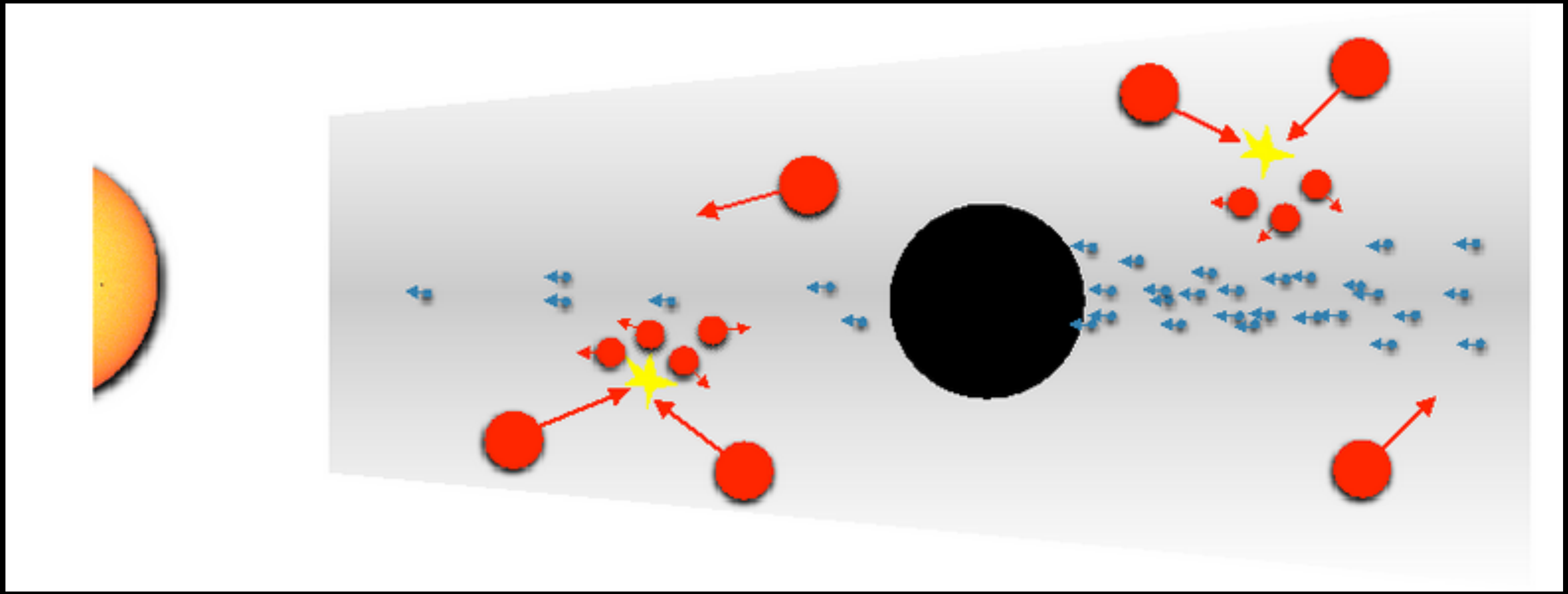
Alessandro Morbidelli, CNRS, Observatoire de la Côte d'Azur, Nice, France

Difficulties to form distant planets

I) core-accretion

Two ways to form planets:

- **Planetesimal accretion**
- **Pebble accretion**



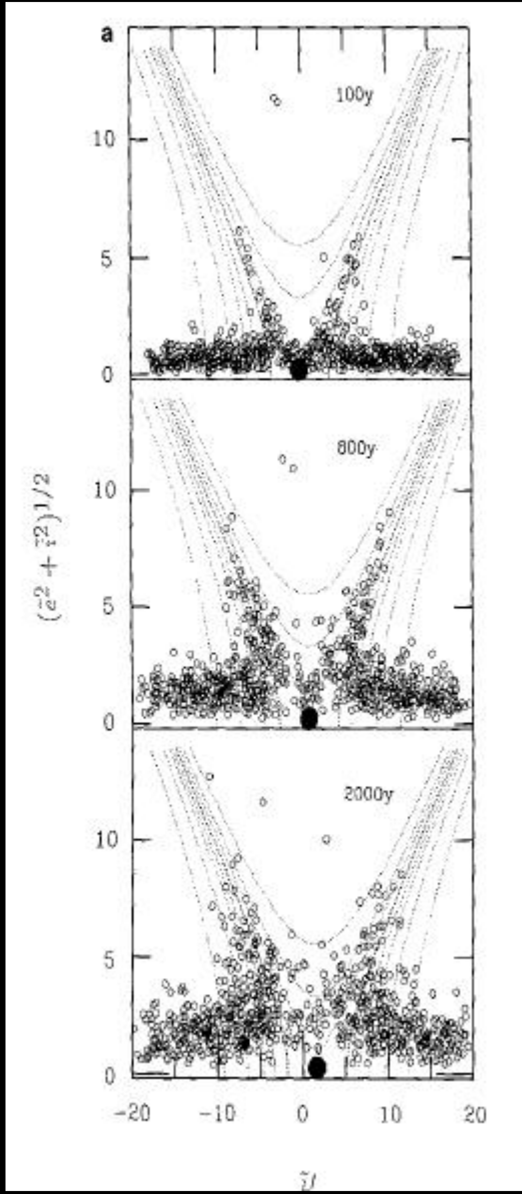
Scheme from *Alibert et al.*, 2018

Difficulties to form distant planets

Two ways to form planets by core-accretion :

- **Planetesimal accretion**

The efficiency depends on $\Sigma_{planetesimals}$, Ω (all decreasing as *r* increases) AND $\Theta = v_{esc}^2/v_{orb}^2$
For a given planet mass, Θ increases with r. When $\Theta>1$, dispersion wins over accretion



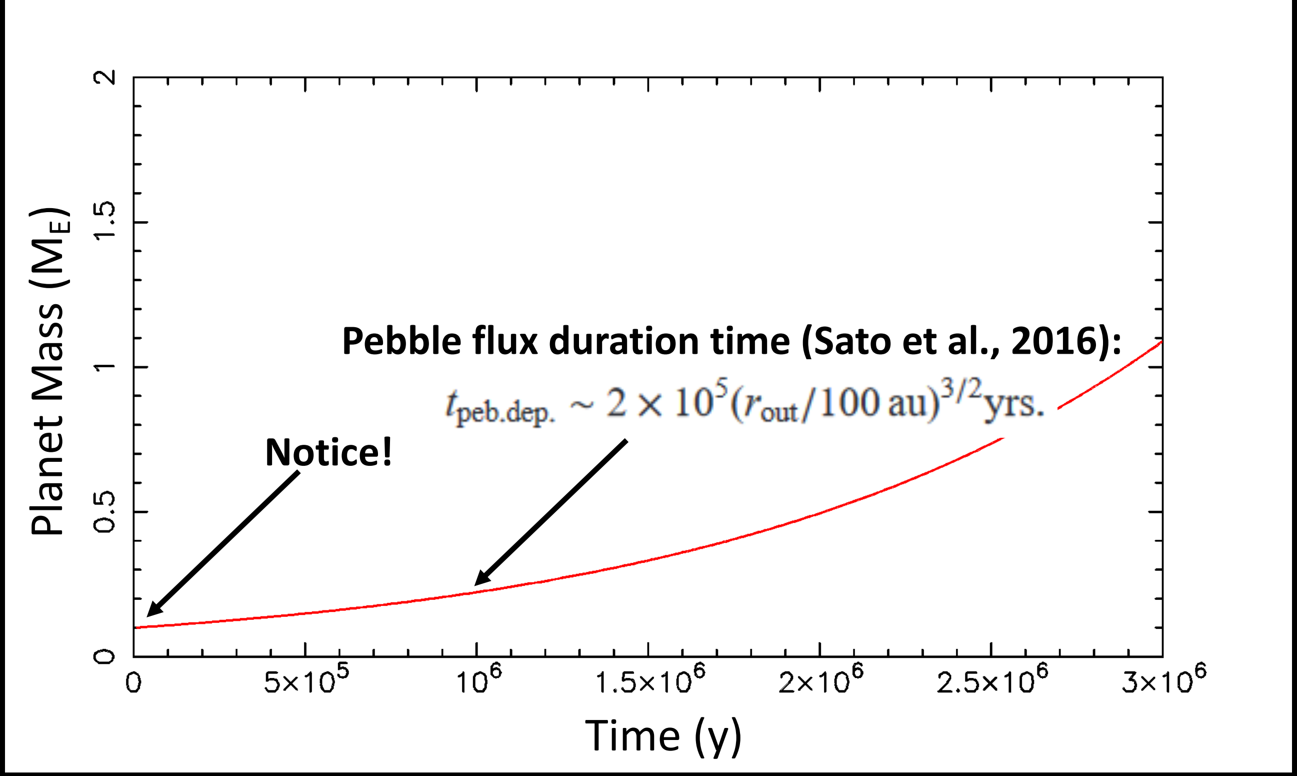
Ida and Makino, 1993

Difficulties to form distant planets

Two ways to form planets by core-accretion :

- **Pebble accretion**

The efficiency depends on $\Sigma_{pebbles}\,\Omega/h_{pebbles} \sim 1/r^{16/7}$



Peak density of Ring B77 in Dullemond et al. (2018):

$\Sigma_{pebbles}$ =0.2g/cm^2

r_0=75 AU

$h_{pebbles}$ =0.028

τ=3x10^{-3}

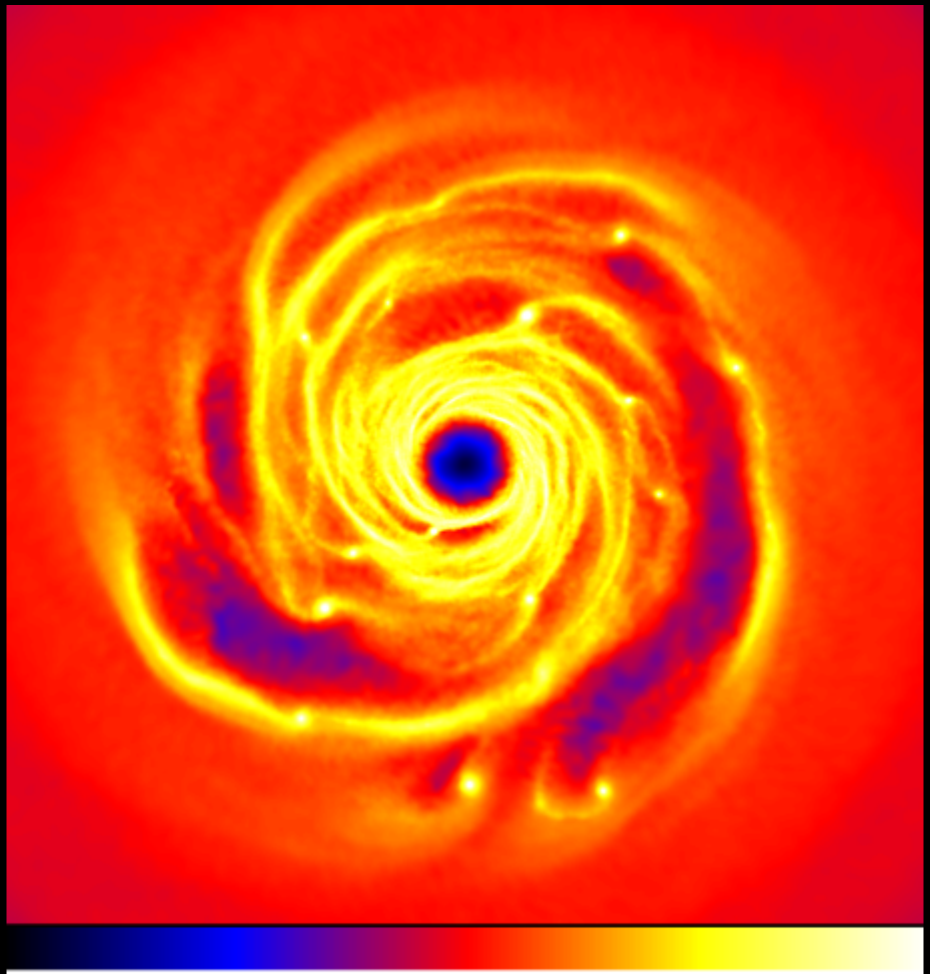
Much higher dust density needed than observed!

Morbidelli, 2020

Difficulties to form distant planets

II) gravitational instability

- Works preferentially at large distances provided that:
  - The disk is very massive: $\Sigma_{gas} > 30 g/cm^3$
  - The cooling time is very short: $< \frac{1}{2} P_{orb}$
- Forms giant planets (much more massive than usually invoked for the gaps, but more in line with those invoked in Pinte et al., 2020)
- If each gap were due to a super-Jupiter this would raise a number of problems, as discussed later

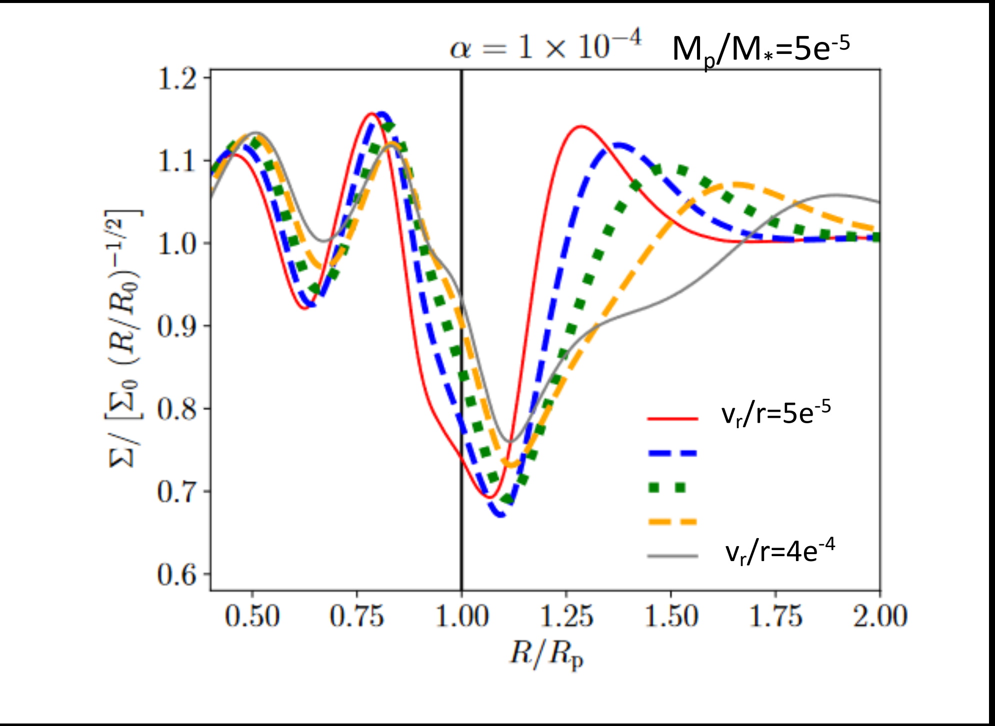


W.K.M. Rice, P.J. Armitage, M.R. Bate & I.A. Bonnell, *MNRAS*, 339, 1025 (2003)

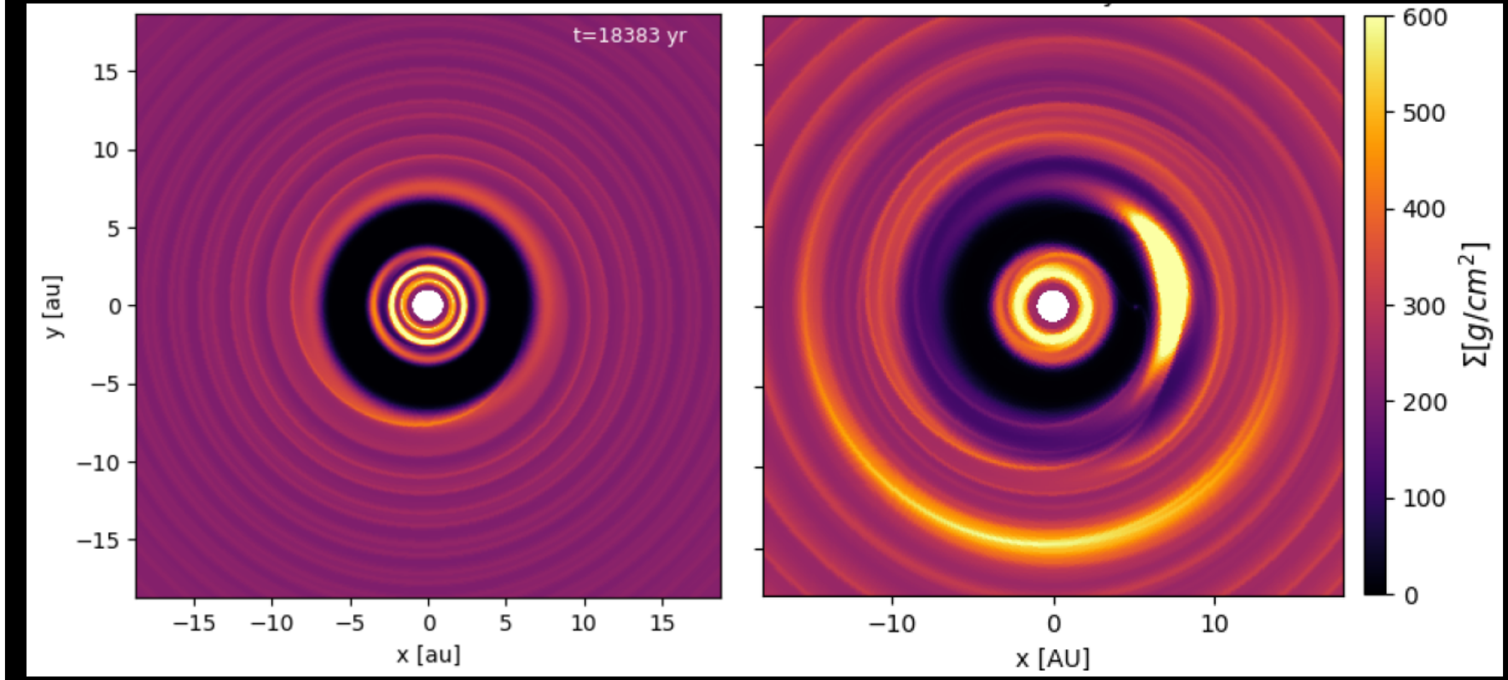
Counter arguments to main planetary claims

One planet – multiple gaps (Zhang et al., 2018):

Very appealing because of Occam razor.
Simulations are correct, but the multiple gap opening occurs only in 2D simulations and if the planet is kept of a fixed orbit.



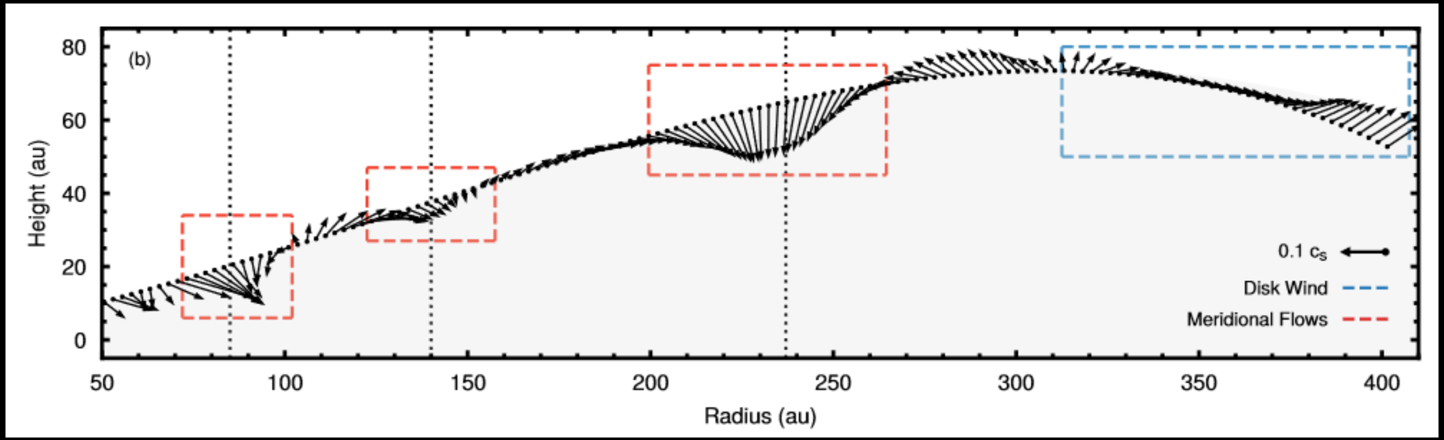
2D simulations with migration (Kanagawa et al., 2020)



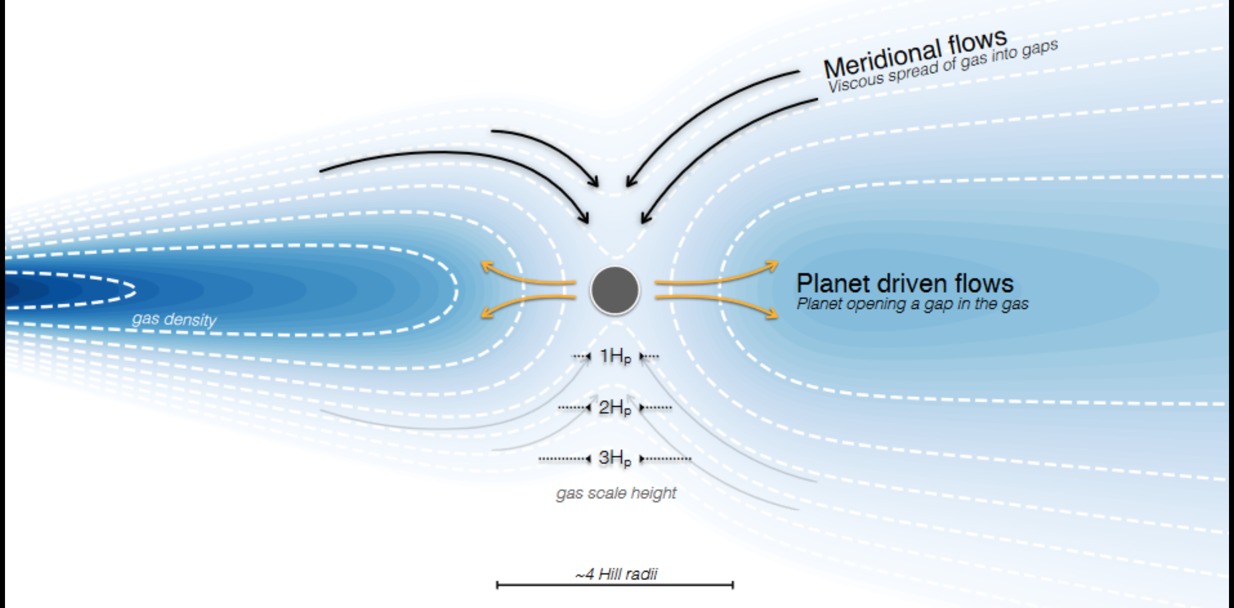
2D and 3D simulations of Jupiter on a fixed orbit in a disk (courtesy of R.P. Nelson and E. Lega)

Counter arguments to main planetary claims

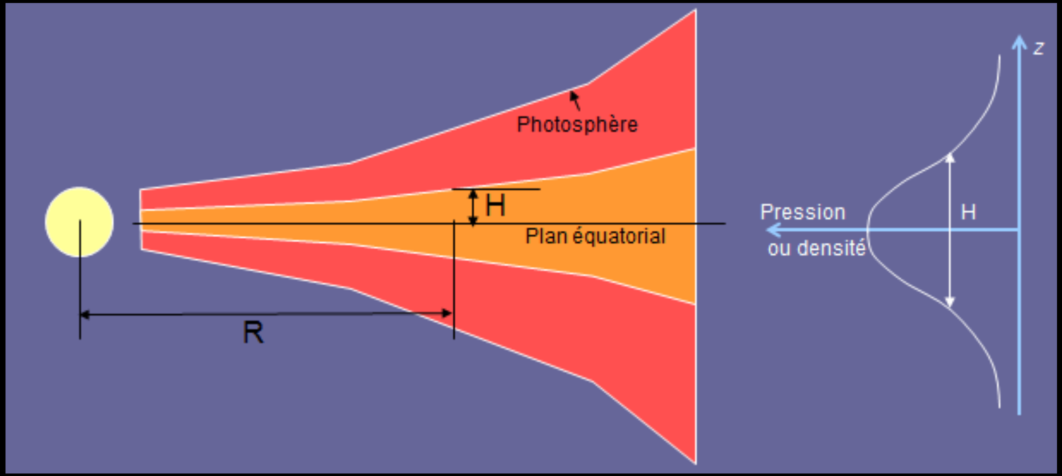
Meridional circulation in gaps (Teague et al., 2019):



Consistent with the expected gas circulation in planet-opened gaps



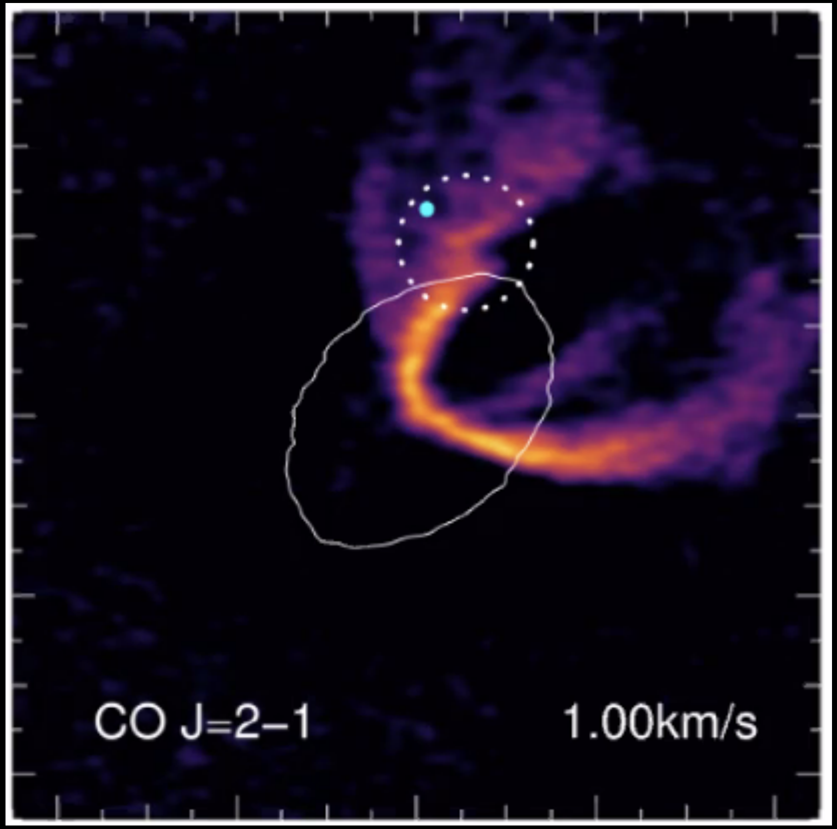
But, due to the vertical hydrostatic equilibrium…



…any mechanism removing gas preferentially from the midplane would induce a similar circulation

Counter arguments to main planetary claims

Velocity kinks (Pinte et al., 2020):



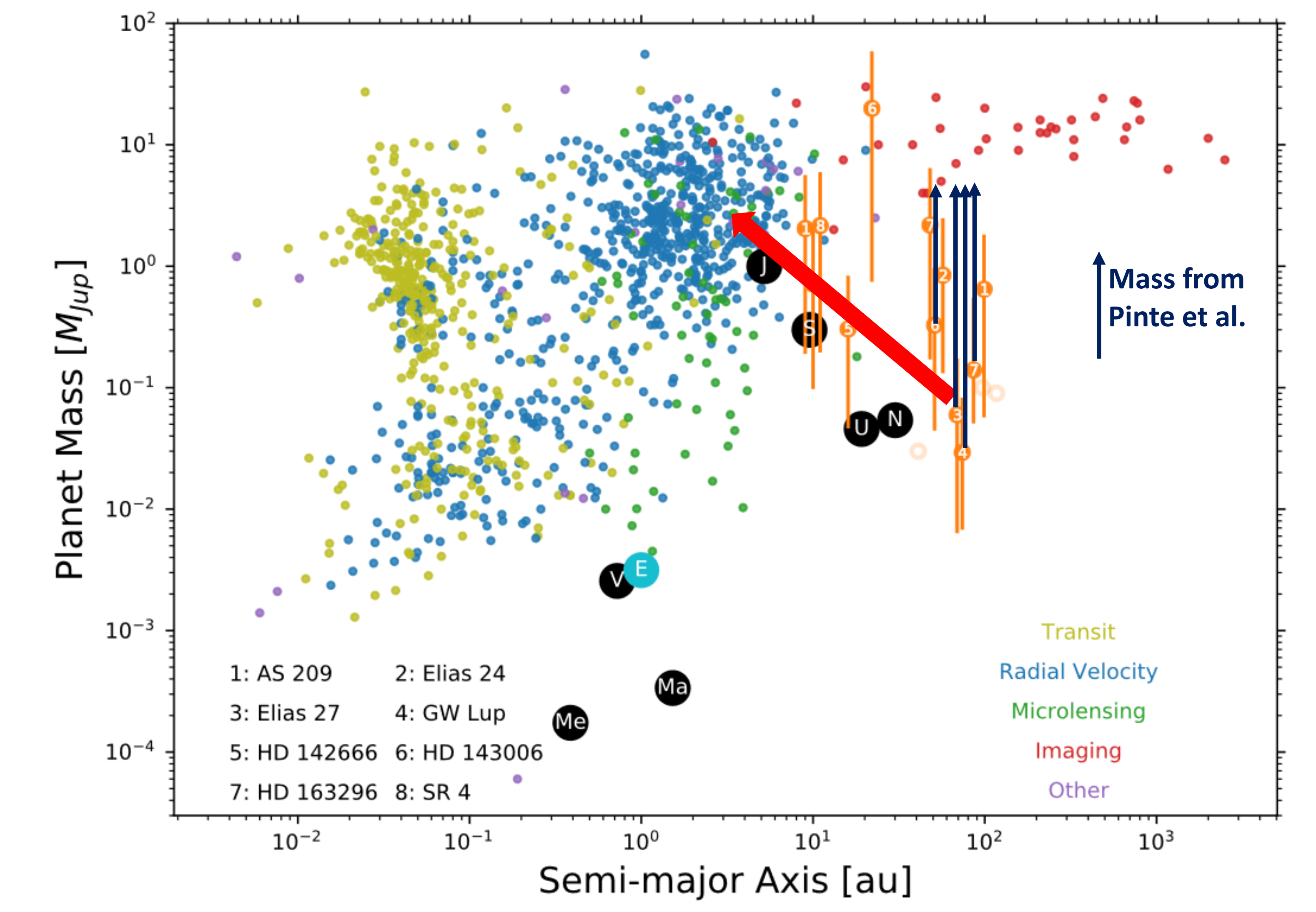
All of the candidate planets lie within a gap

But only 8 candidates out of 18 disks and many more rings

- If real, they imply planets with $M>M_{jupiter}$, much more massive than those deduced by looking at gap morphology/meridional circulation
- Unclear (to me) whether such massive planets would open gaps or cavities in the dust distribution.

Counter arguments to main planetary claims

If there are so many distant planets in disks, why are they so rare among main sequence stars?



Pinte et al. admit that there seem to be too many giant planets in disks than observed by direct imaging

It has been proposed that the gap-forming planets are "small" and they will grow and migrate to become the warm Jupiters detected in RV (Lodato , 2019)

But if this were true, we should see different ring structures in disks of different ages, which is not the case (e.g. HL Tau vs. TW Hya)

Zhang et al., 2018)

Alternative mechanisms for ring formation

Two kinds of processes proposed:

1. Snowline effects (dust growth and fragmentation)
2. Hydrodynamical effects.

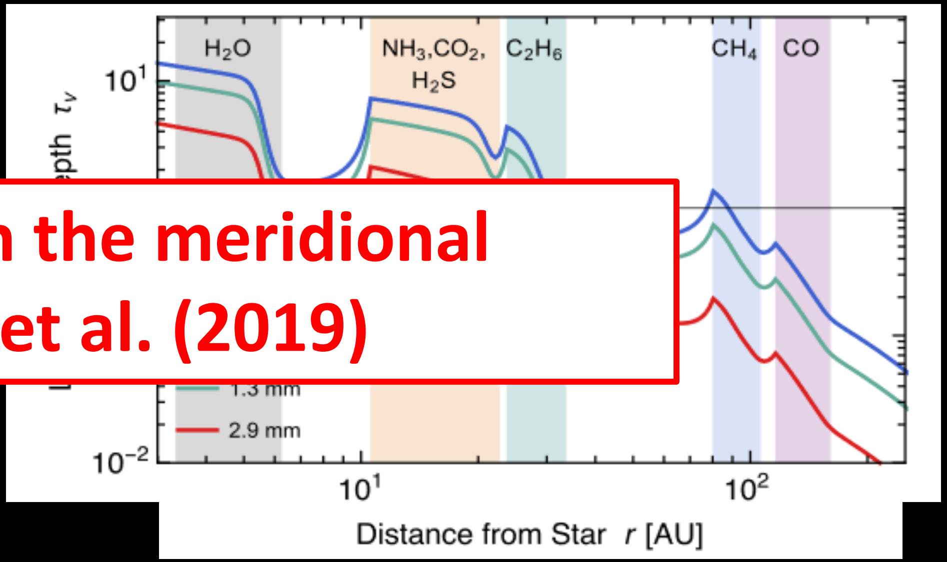
Alternative mechanisms for ring formation

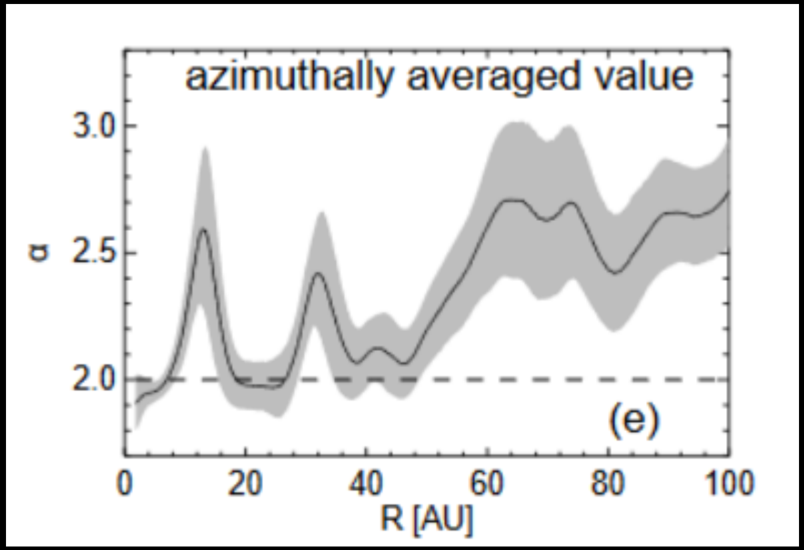
Two kinds of processes proposed:

1. **Snowline effects (dust growth and fragmentation)**

Okuzumi et al., 2016, propose that ice aggregates undergo sintering just beyond the corresponding condensation lines which make [...] behind the [...]

But opacity transitions cannot explain the meridional circulation of gas observed in Teague et al. (2019)





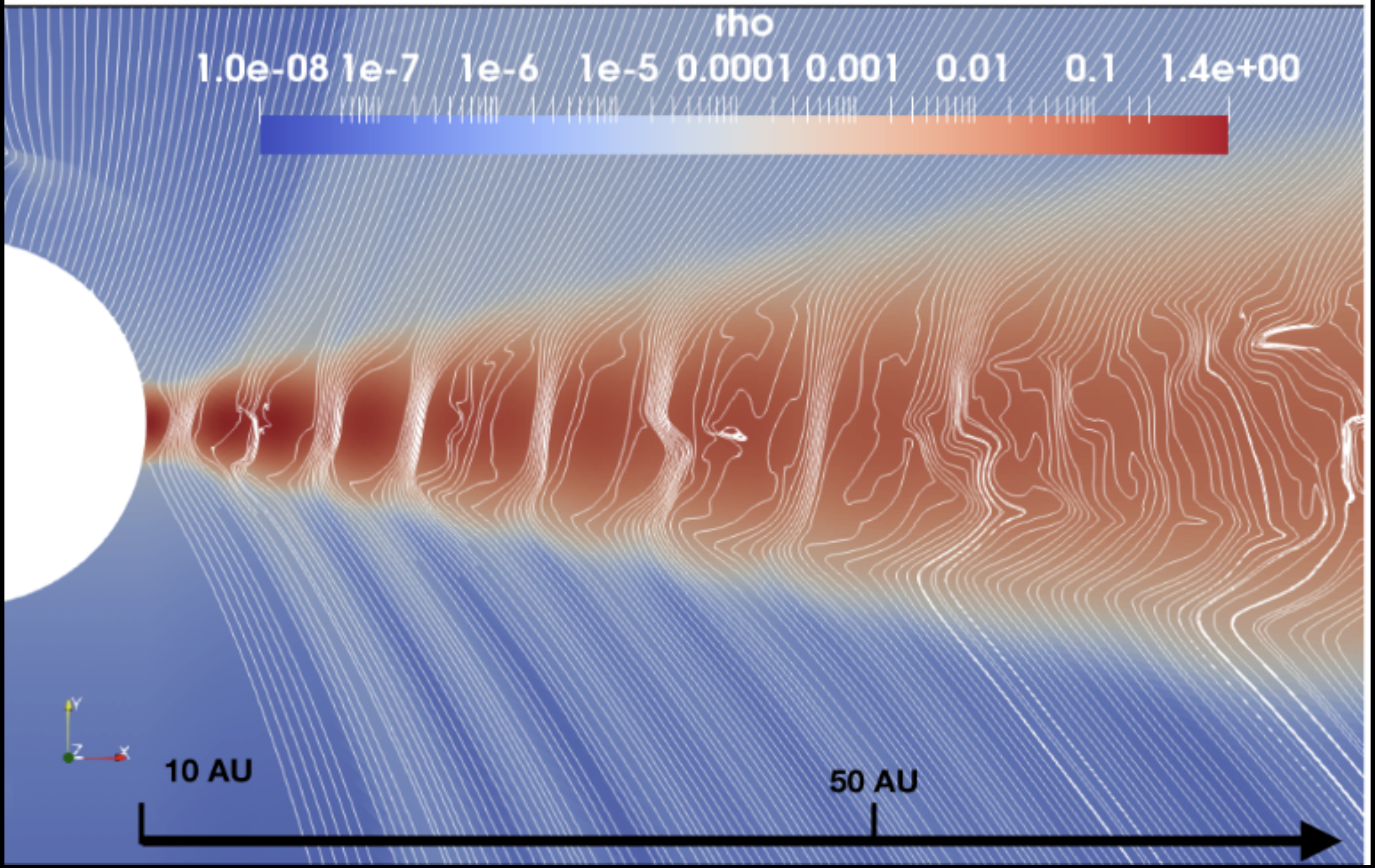
Zhang et al., 2015, find evidence in the spectral index for larger dust inside the gap (dust growth at the snowline?)

Alternative mechanisms for ring formation

Two kinds of processes proposed:

2. (M)Hydrodynamical effects.

MHD simulations (Riols et al., 2020 for the latest results) with no ideal effects show accumulation of magnetic field lines fragmenting the disk in radial zones

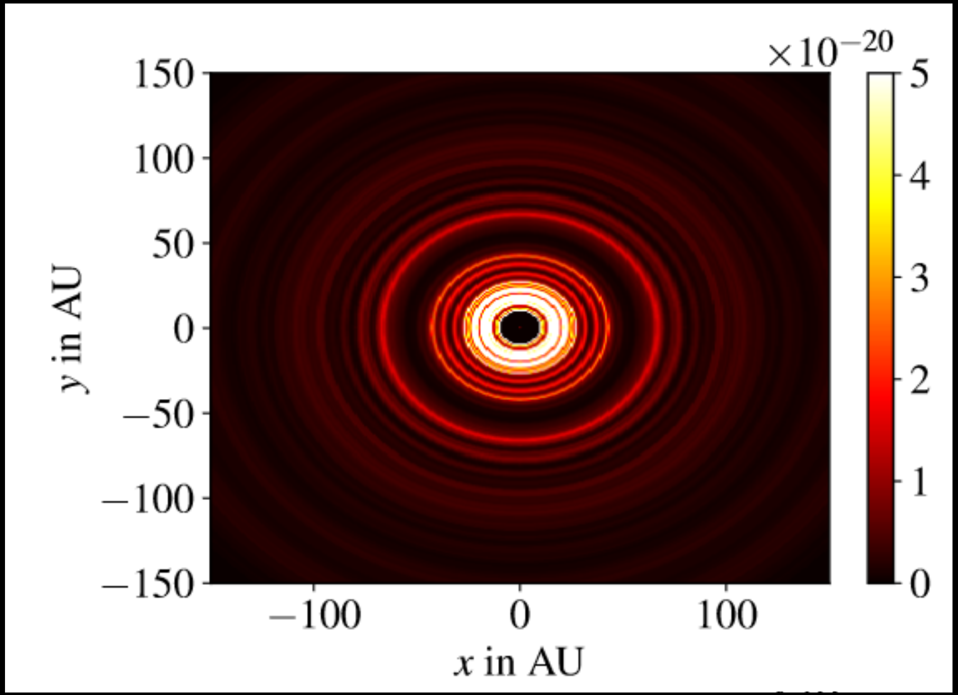


Alternative mechanisms for ring formation

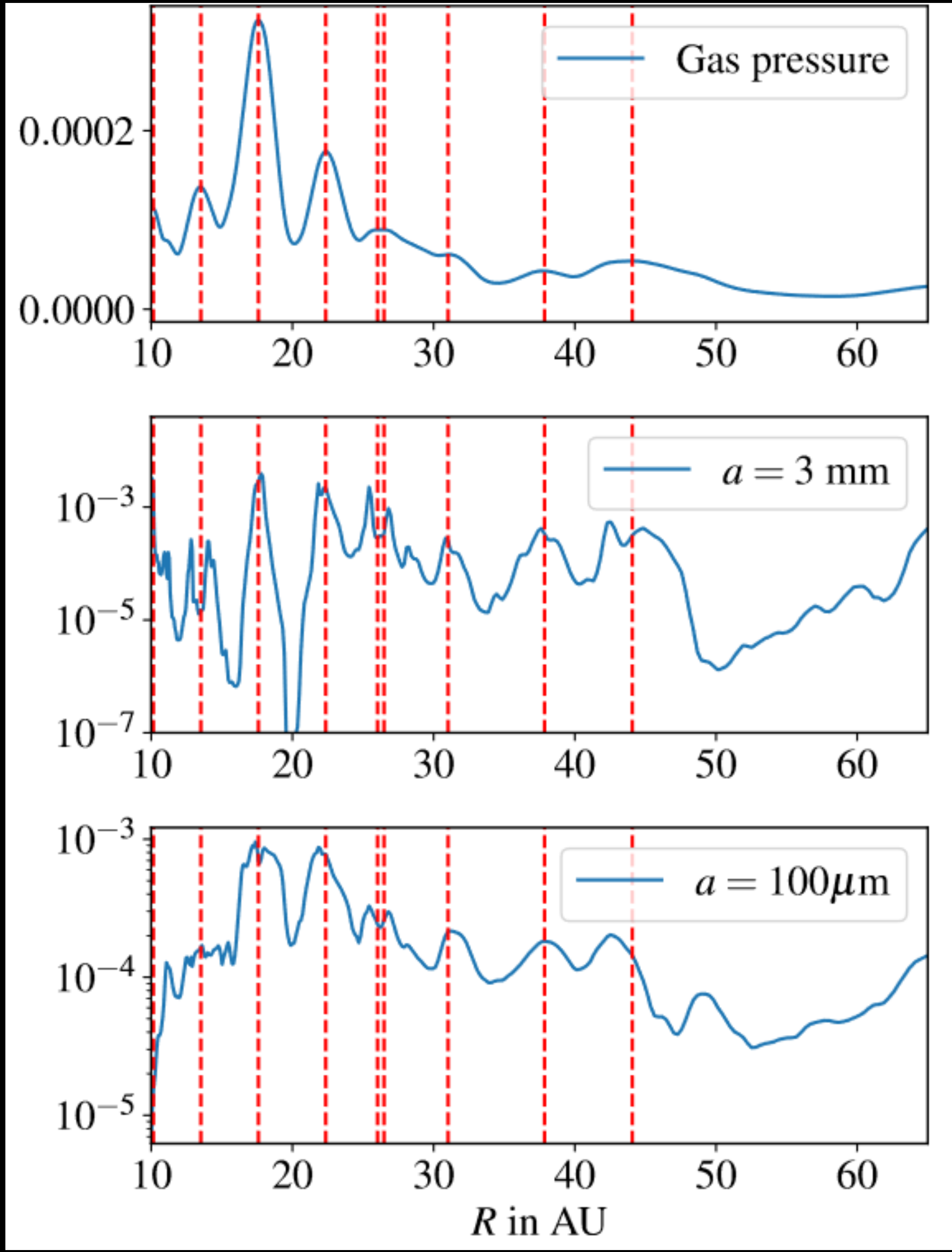
Two kinds of processes proposed:

2. (M)Hydrodynamical effects.

…this leads to pressure bumps, the accumulation of dust and opacity transitions that create rings in thermal emission images



Riols et al. (2020)

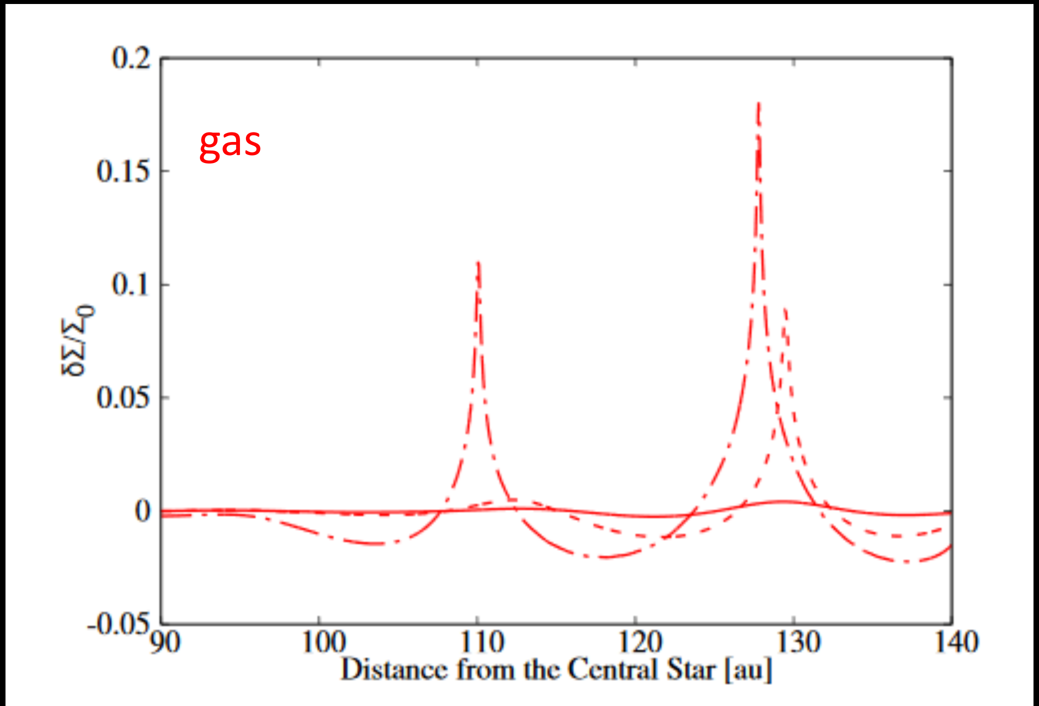


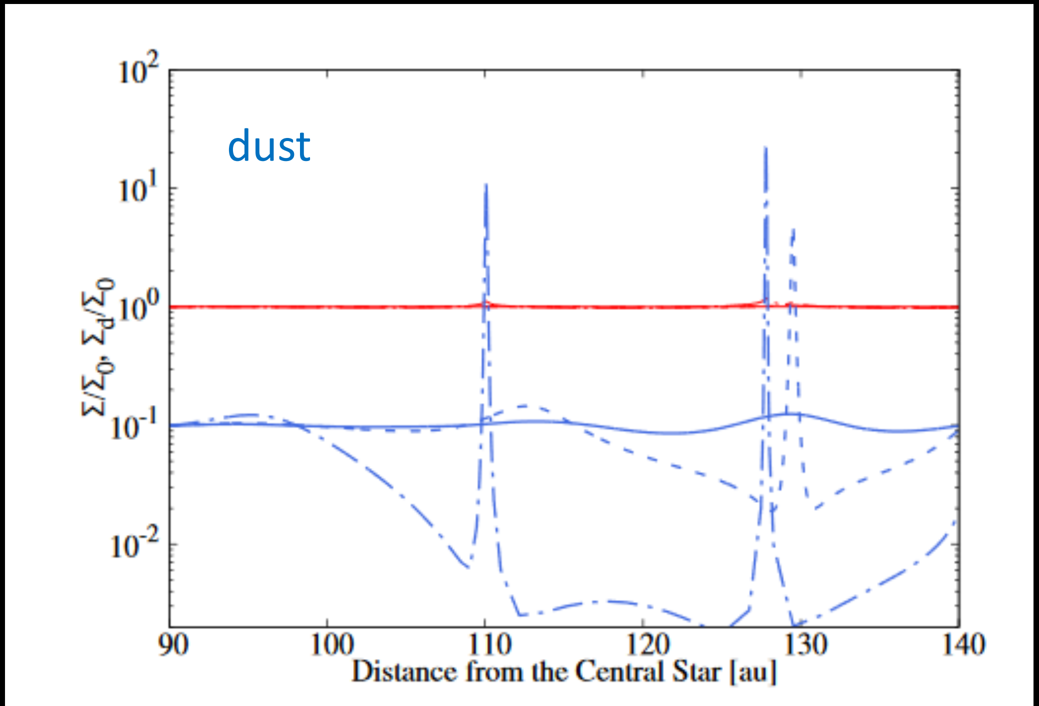
Alternative mechanisms for ring formation

Two kinds of processes proposed:

2. Hydrodynamical effects.

Two-component viscous gravitational instability (TVGI) – Tominaga et al., 2018, 2019
Instability derived from a combination of dust-gas friction and gas viscosity





CONCLUSIONS

- I am not saying that there are no planets in disks or that no gaps are due to planets
- Obviously when the HR 8799 formed it must have generated beautiful rings (or a giant cavity?)
- But I warn against the general association gap = planet
- The planets “deduced” by observing/modeling rings do not have the same status as those detected by RV, transit or even ML
- Let’s not fall into the temptation to declare that all gaps are due to planet (or that all planets are habitable), because in the long-run this will discredit our community