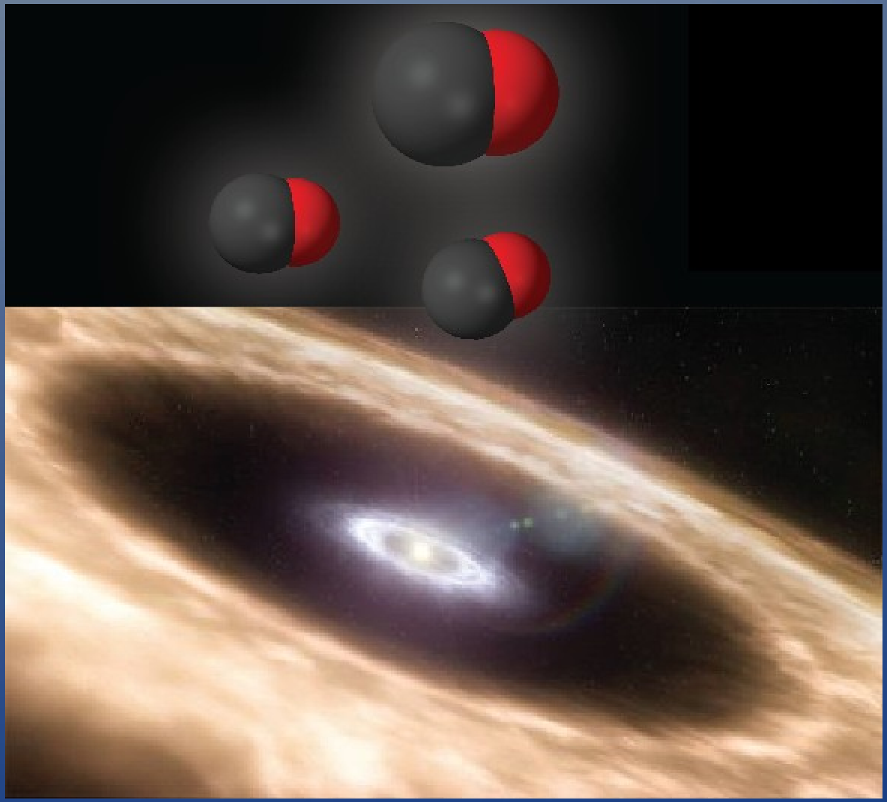
Planet formation in action

Resolved gas and dust images of a transitional disk and its cavity



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Ewine van Dishoeck, Simon Bruderer, Til Birnstiel, Paola Pinilla, Kees Dullemond, Tim van Kempen, Markus Schmalzl, Joanna Brown, Geoff Mathews, Gregory Herczeg, Vincent Geers

Leiden Observatory

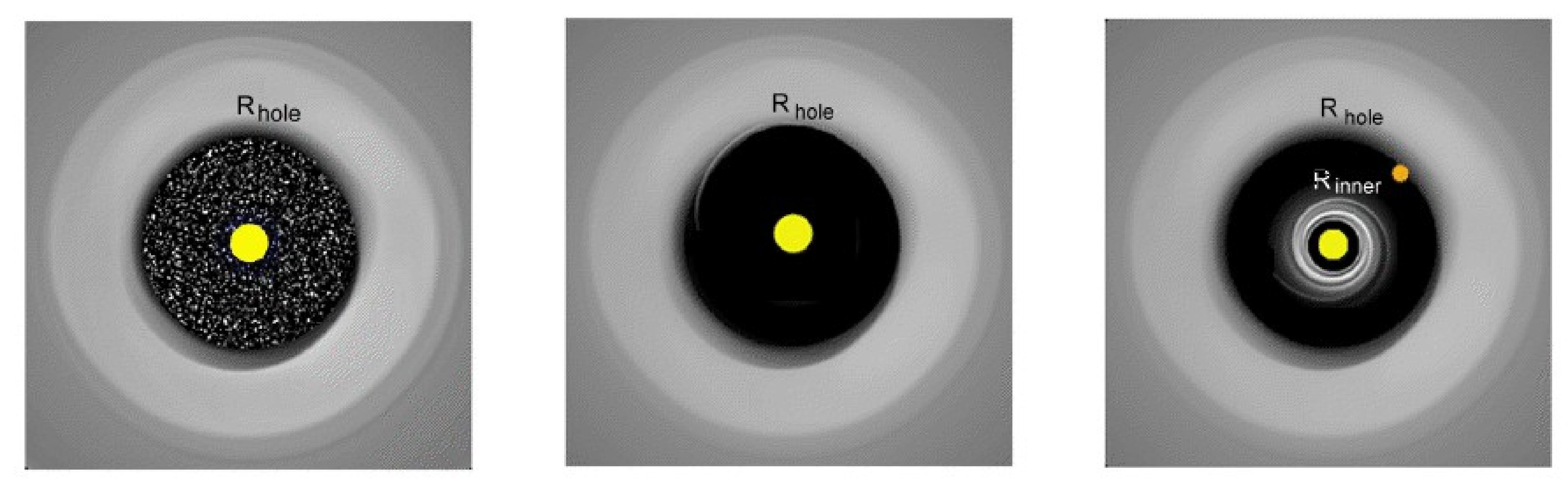
2013 Rocks!
12th April 2013

Sterrewacht Leiden

Transitional disks

- Dust hole: mechanisms

Grain growth | Photoevaporation | Stellar companion / Forming planet?



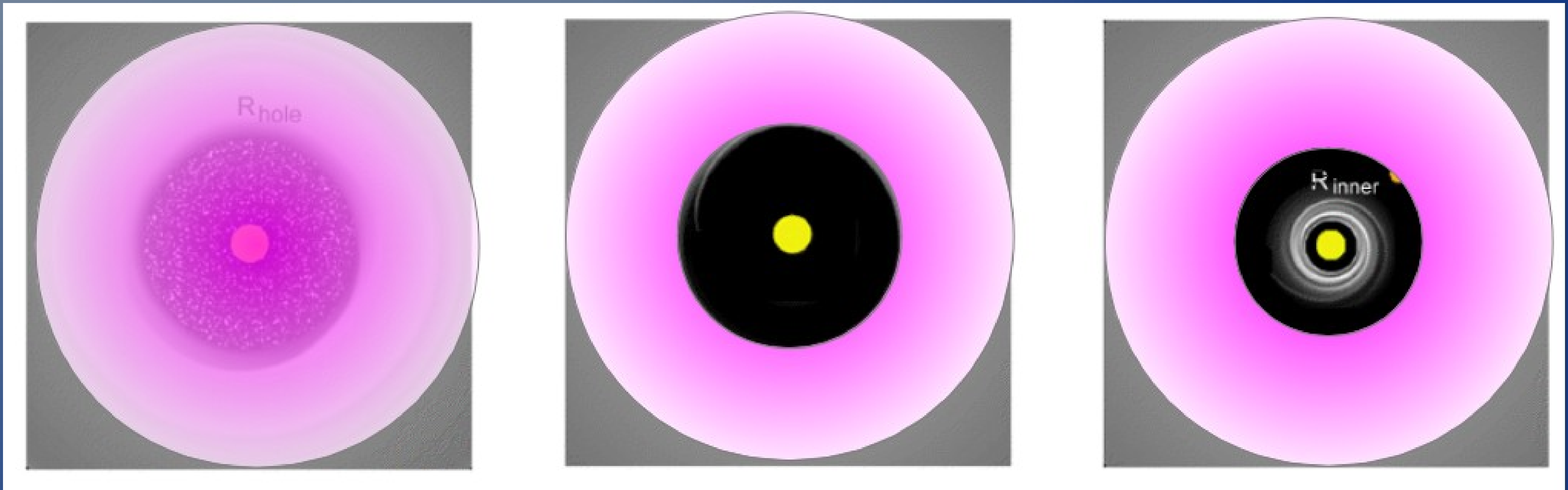
⇒ **What about the gas?**

Strom & Najita

Transitional disks

- Dust hole: mechanisms

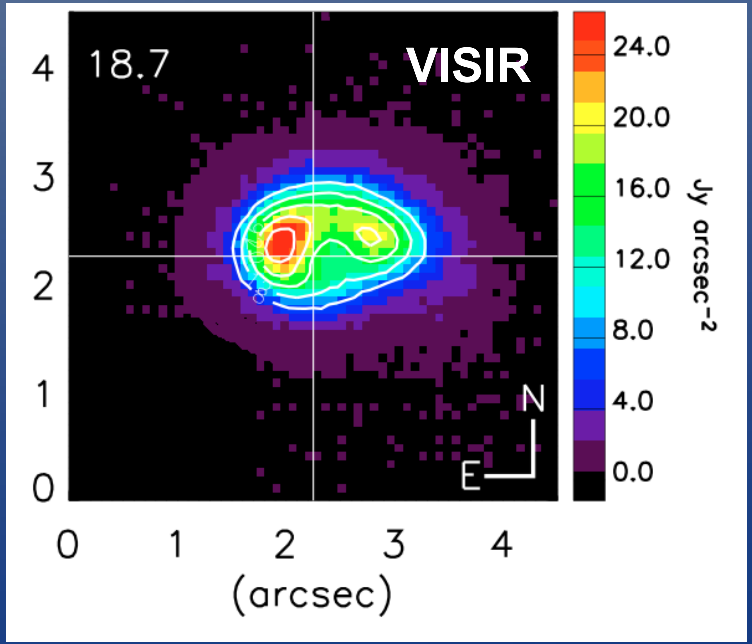
Grain growth — Photoevaporation — Stellar companion / Forming planet?

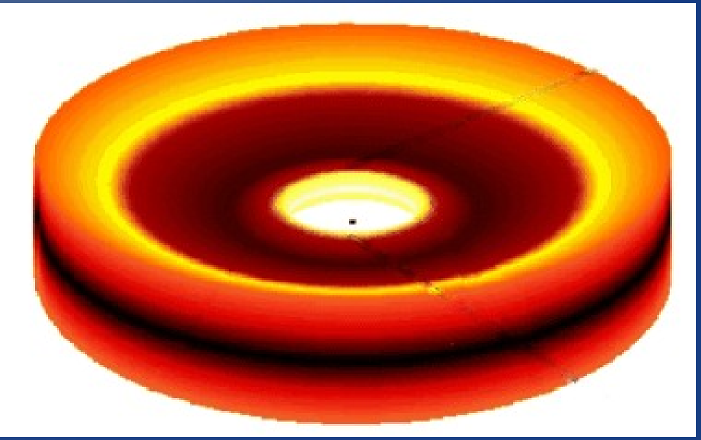


⇒ **Need to know the gas distribution and mass < 50 AU ⇒ ALMA**

Oph IRS 48

- Target Cycle 0: Oph IRS 48
- Dust ring (VISIR imaging) R_h=55 AU
- CO (v=1-0) gas hole (CRIRES) R_h=30 AU
- Ophiuchus (d~120 pc): 0.23” ⇔ R_b=14 AU





i = 48°

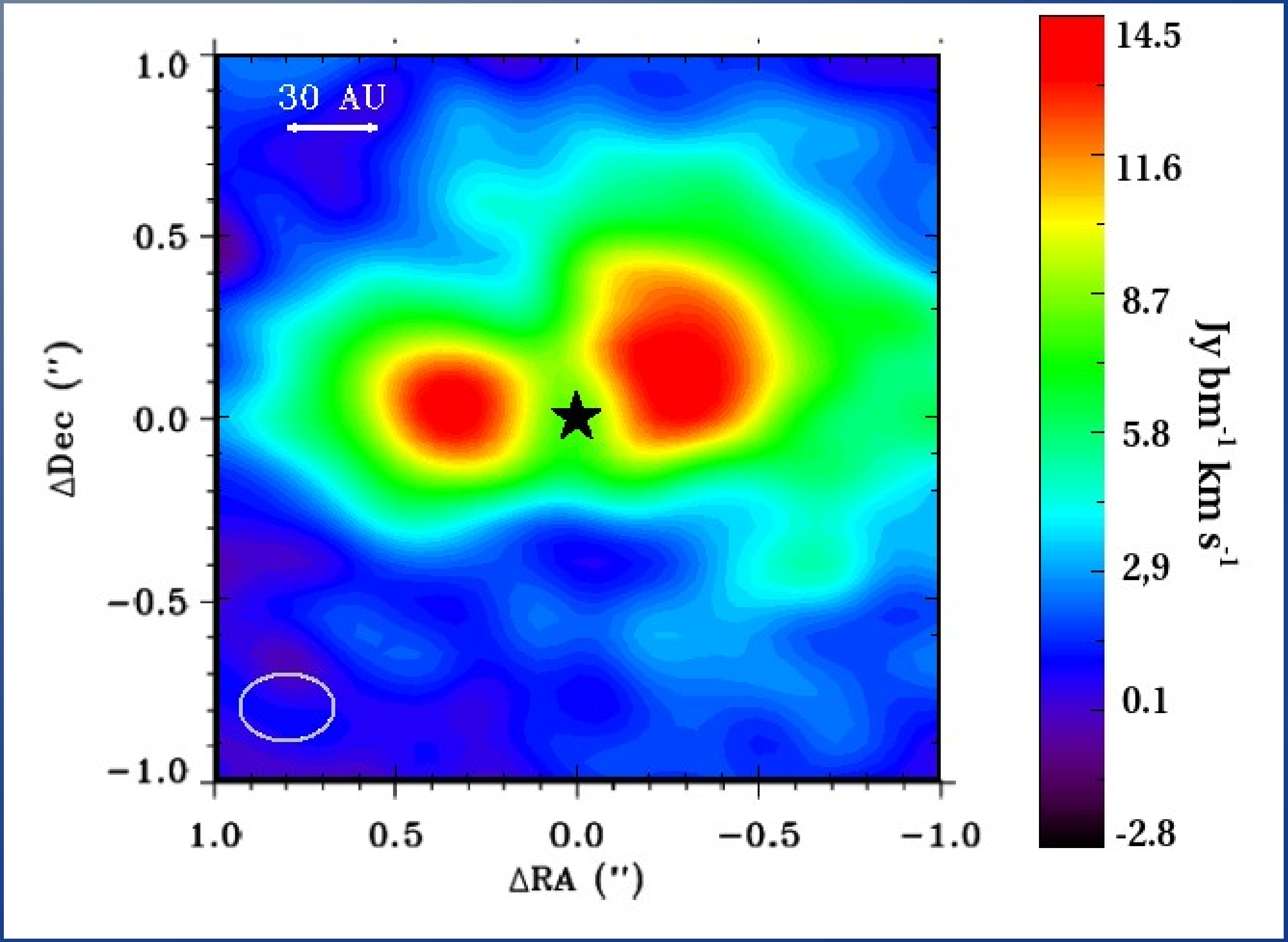
Geers et al. 2007
Brown et al. 2012

ALMA observations

- Band 9: spatial resolution ~0.23” (Extended)
- CO 6-5 and 690 GHz continuum
- 0.2 km s^{-1} channels
- Thanks to JAO and Dutch ARC node (Allegro) for support for observations and set-up, especially calibrators

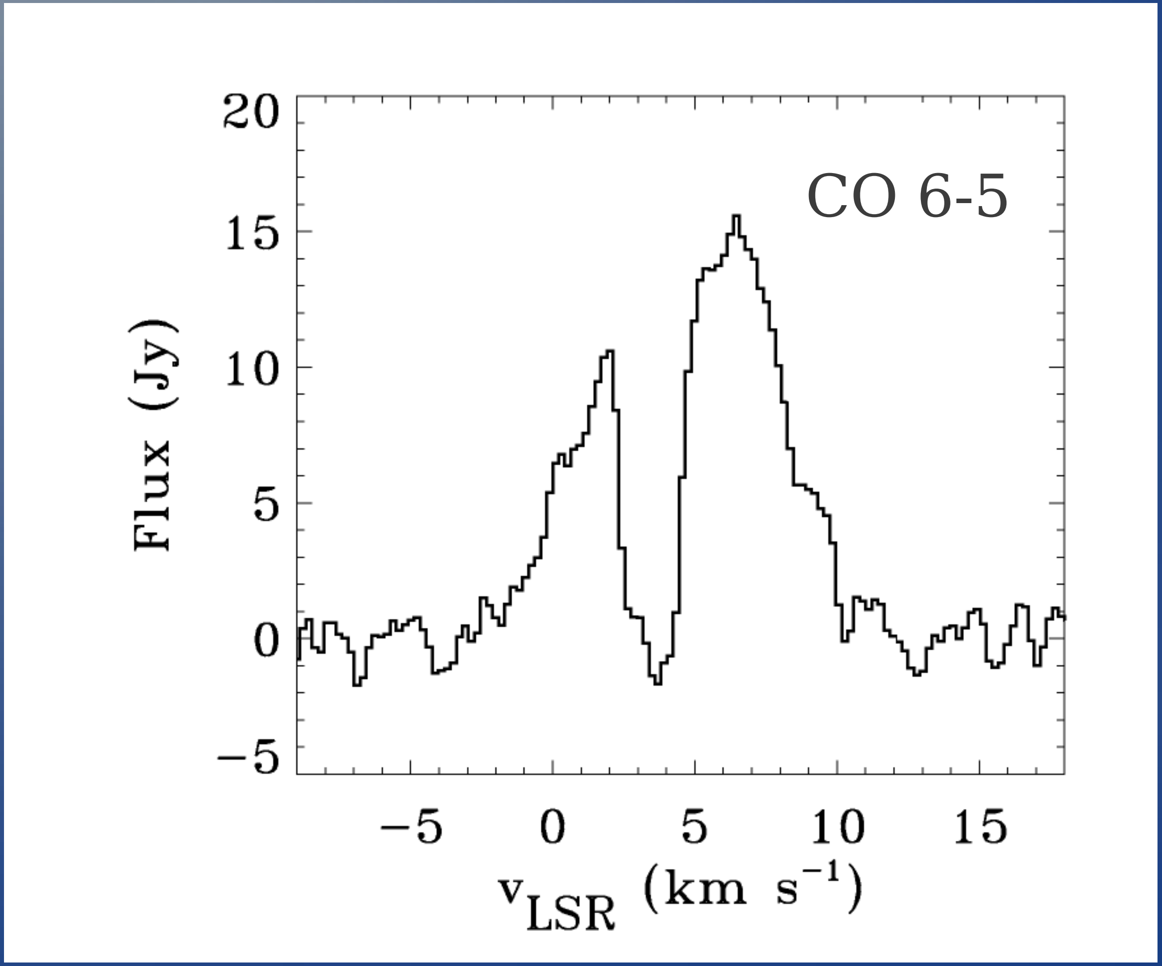
ALMA observations

- Data quality excellent at delivery
- Integrated ^{12}CO



ALMA observations

- Asymmetry: foreground absorption in ^{12}CO



ALMA observations

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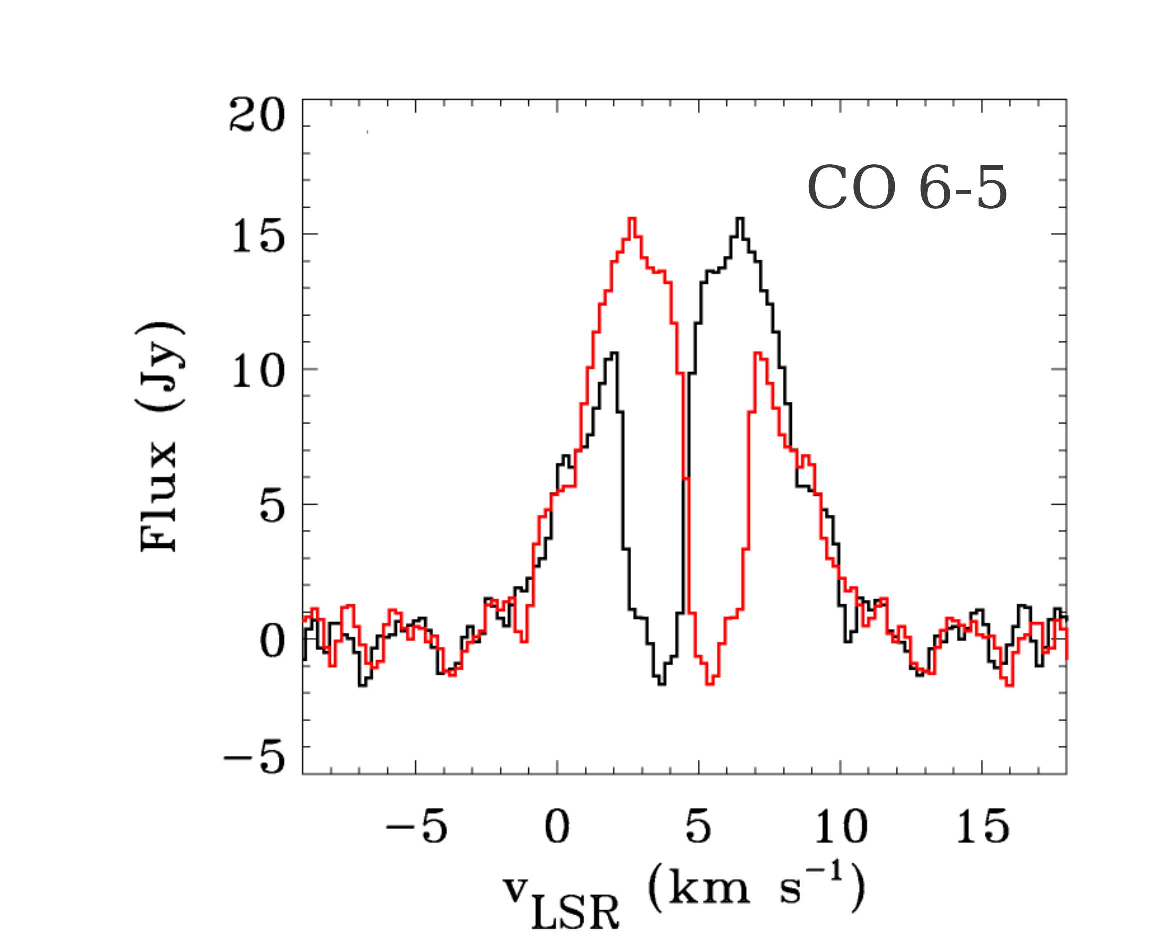
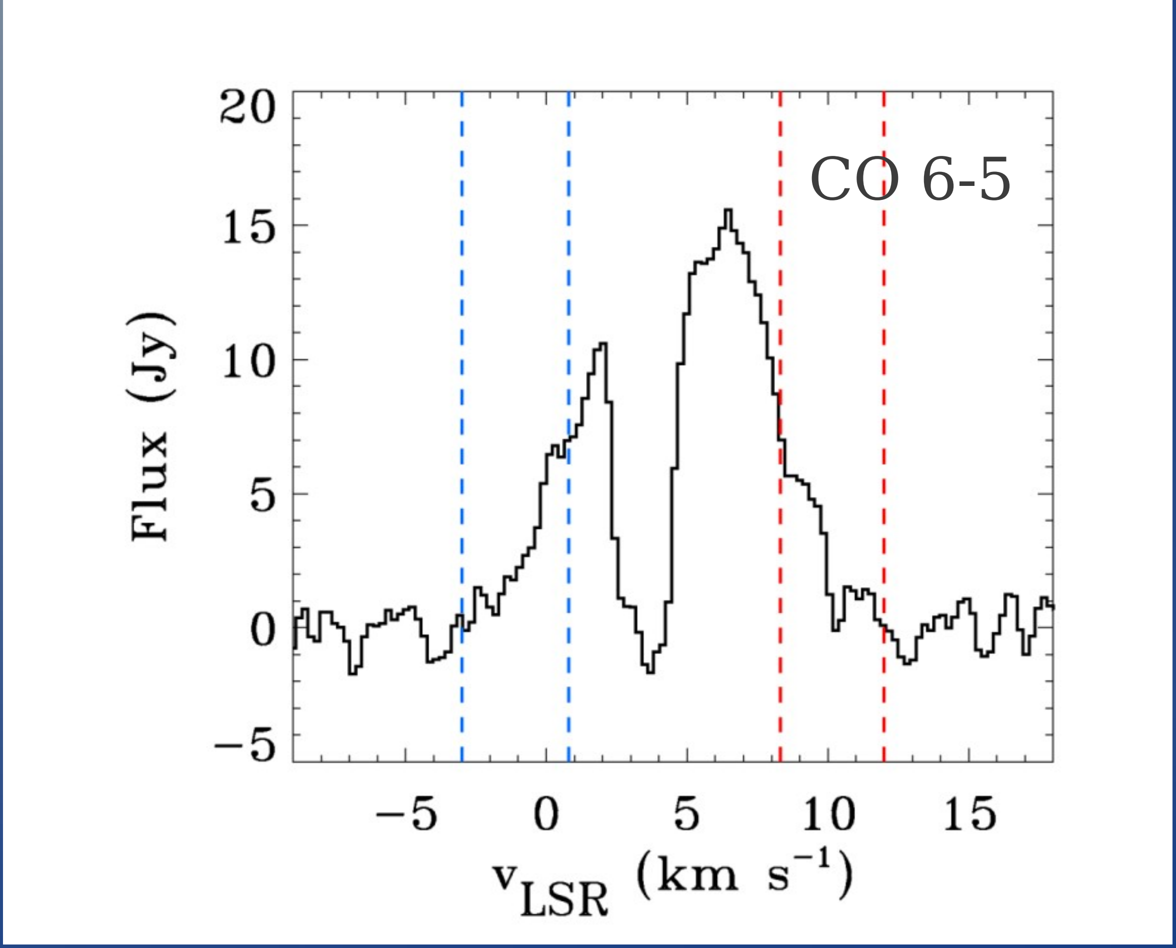


- Profile perfectly symmetric in line wings

ALMA observations

- Asymmetry: foreground absorption in ^{12}CO



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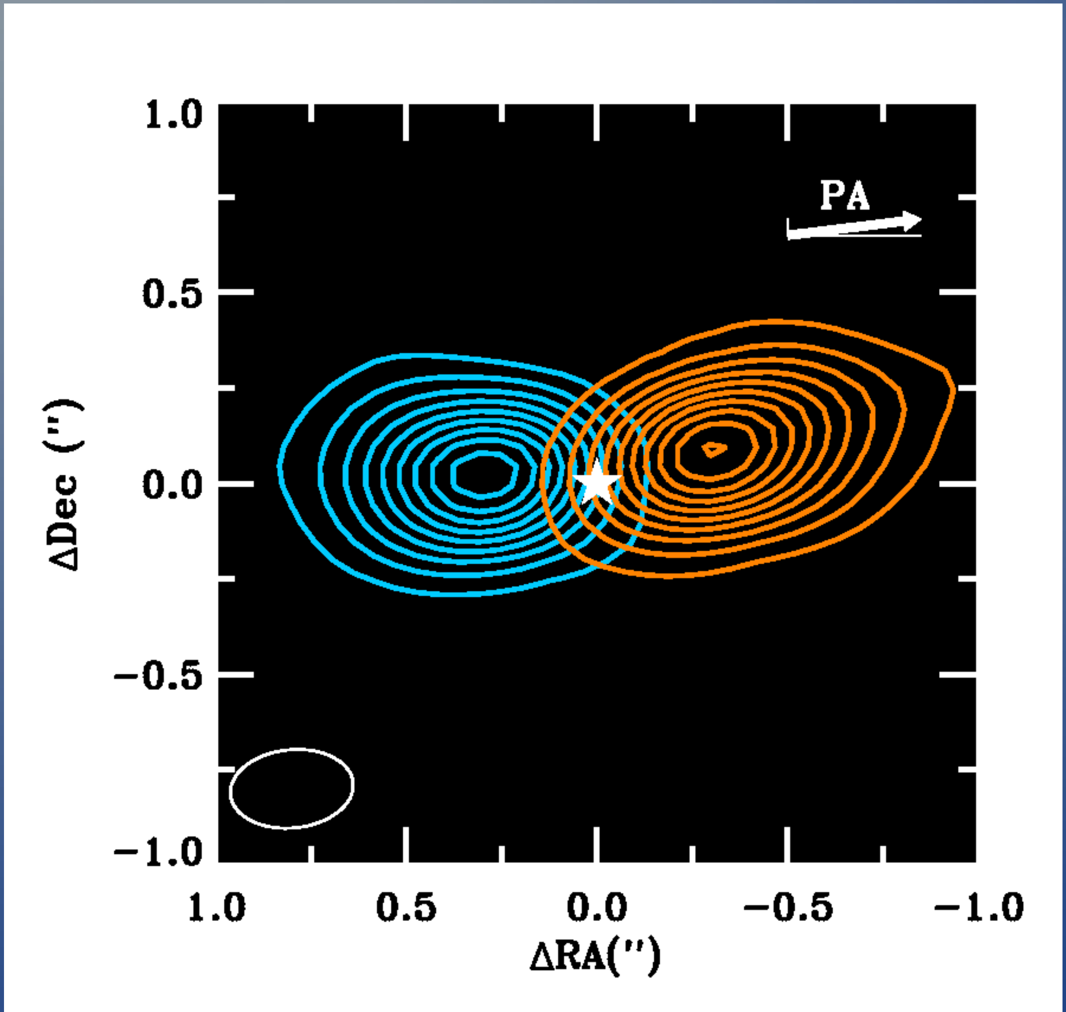
ALMA observations

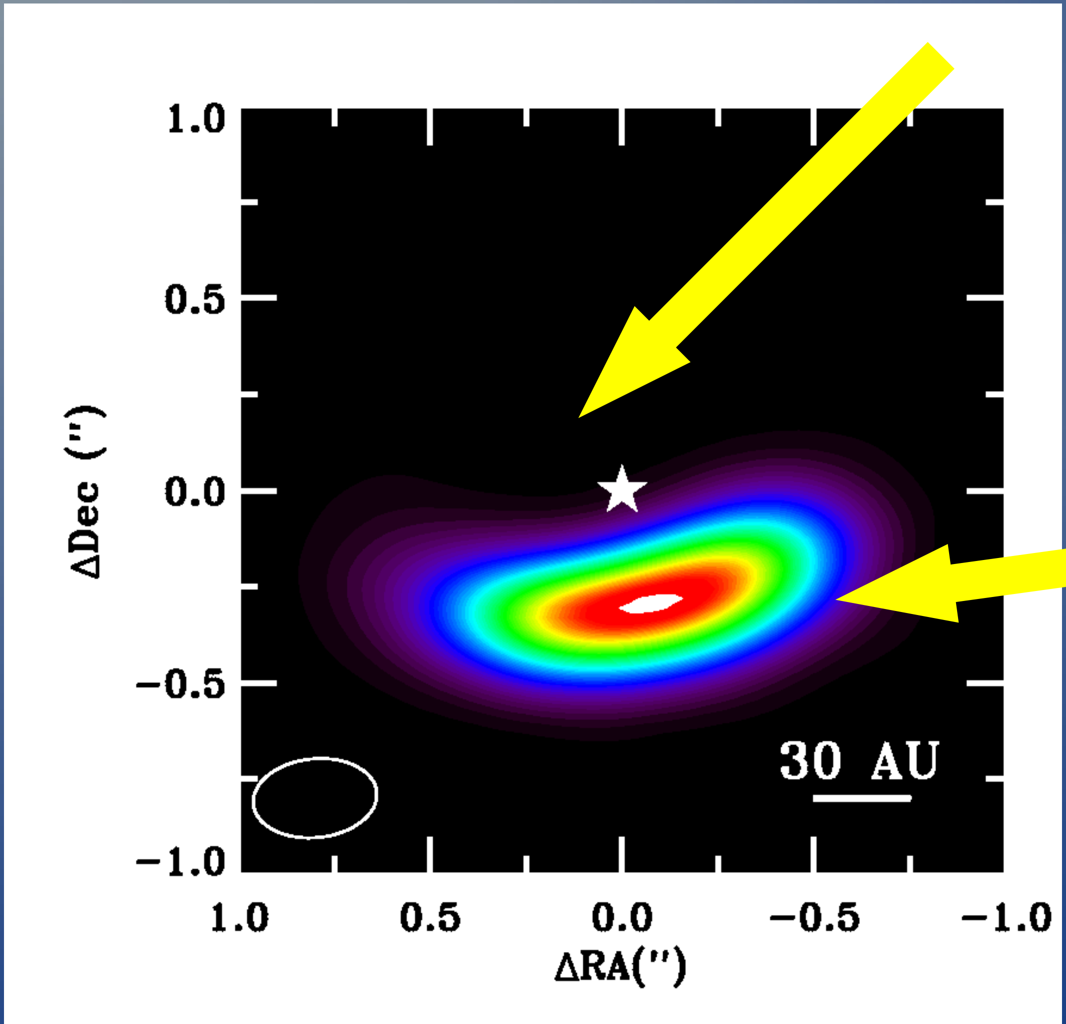


- Full gas disk
- Highest velocity channels consistent with gas hole with R_h=20 AU
- Gas hole decrease ~1000

- And what about the dust?

van der Marel et al. (in rev.)
Bruderer et al. (in prep.)
(Poster Bruderer P4)

A gigantic dust trap!



Missing dust

Continuum peak ~390σ!

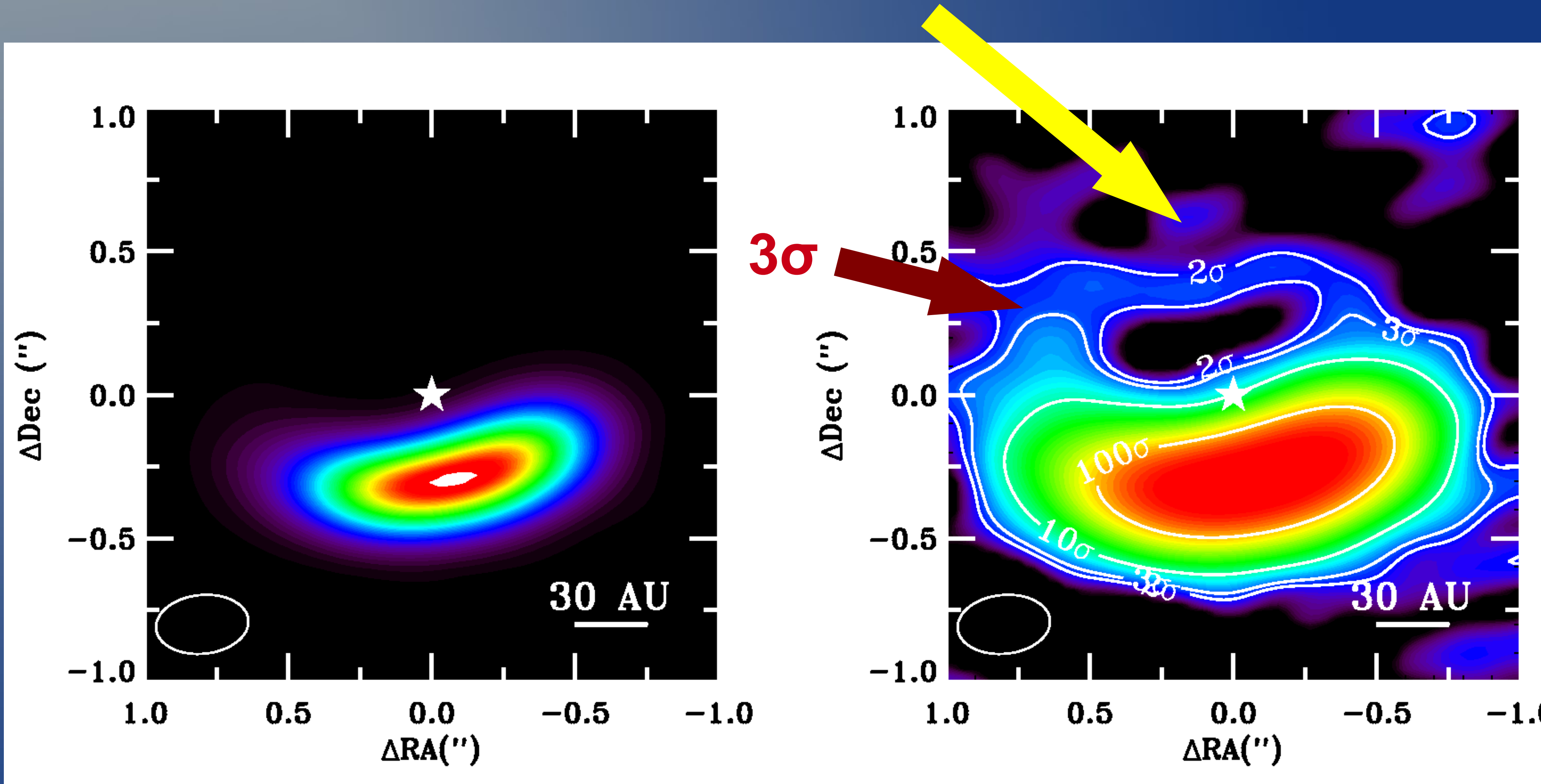
σ = 0.8 mJy/beam

van der Marel et al. (in rev.)

A gigantic dust trap!

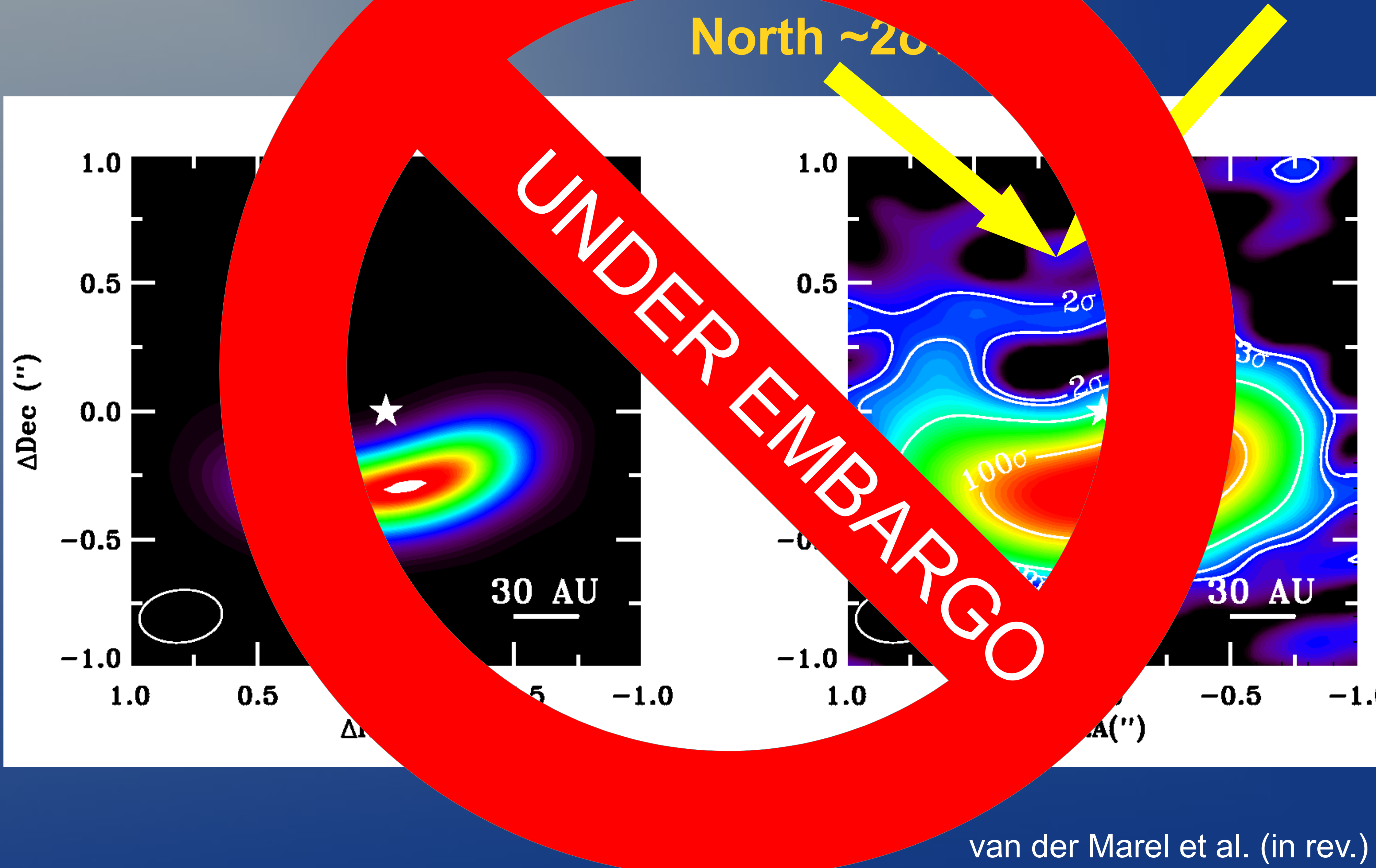
North ~2σ!

3σ



van der Marel et al. (in rev.)

A gi ap!



van der Marel et al. (in rev.)

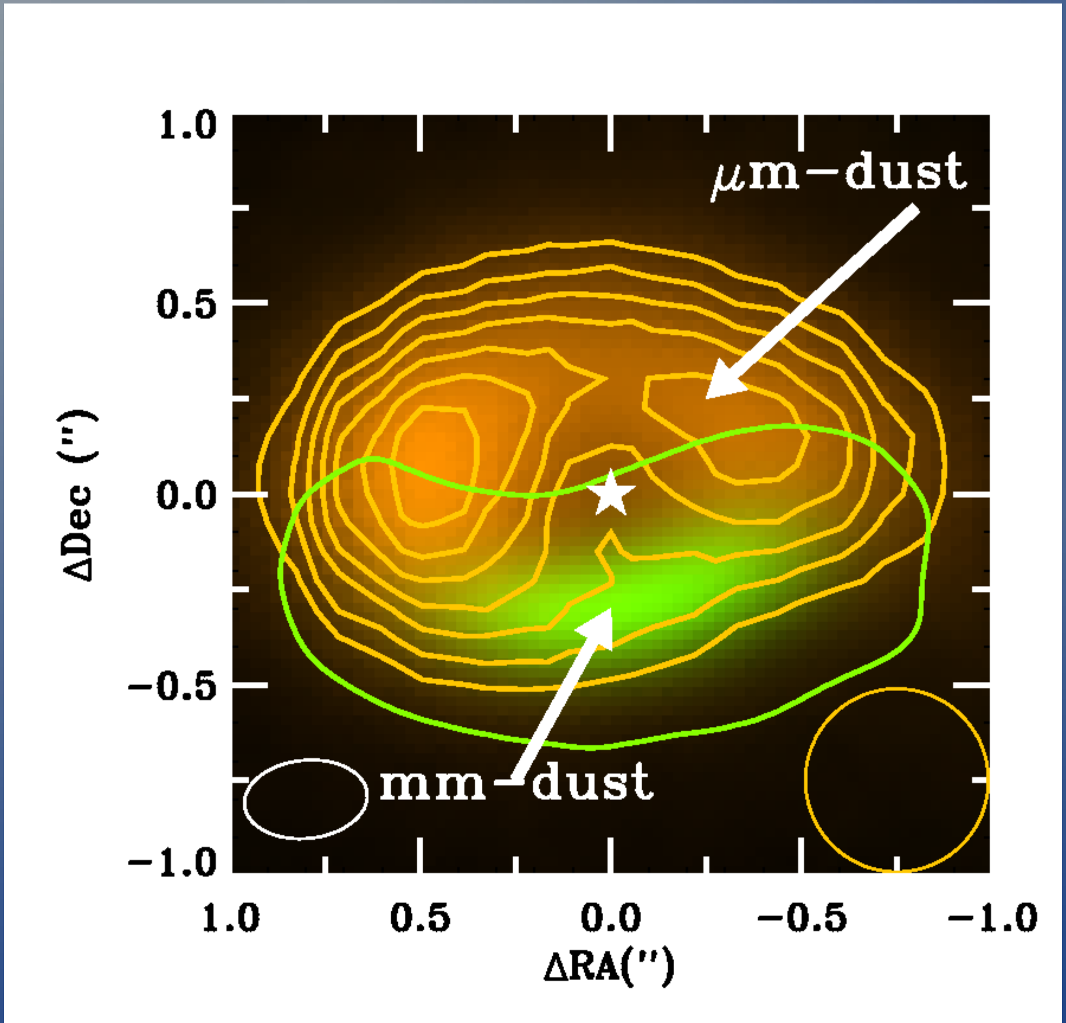
ALMA observations

- Dust ~ 45-80 AU extent
- Spectral slope = 2.7 (±0.25) (using SMA data 345 & 230 GHz)
- $\beta \sim 0.7 \Rightarrow$ large grains (>mm)
- $\tau \sim 0.4$ and $n(a) \sim a^{-3.5}$
- Dust mass mm grains: ~9 Earth masses (60 K)
- Growth up to planetesimal sizes possible

$F_\nu \sim \nu^{2+\beta}$

=> Kuiper Belt Object factory

Large vs small dust

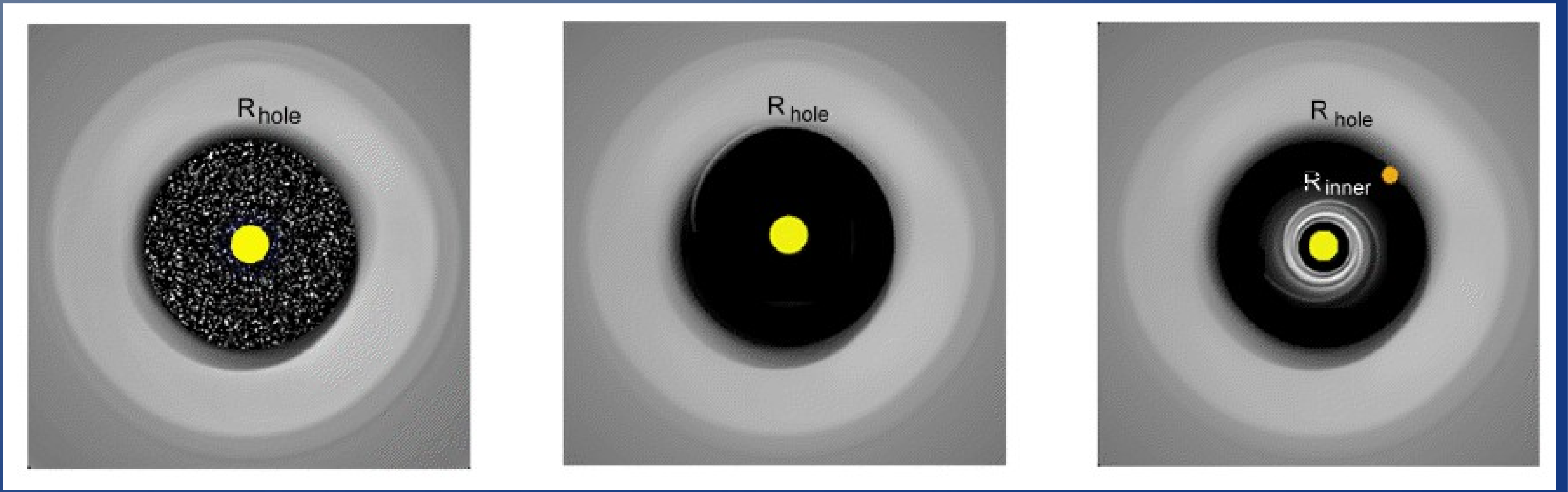


- Not only gas, but also small dust emission indicates a full ring
- Separation mm-dust and μm-dust

Transitional disks

- So which mechanism is responsible for hole?

Grain growth | Photoevaporation | Stellar companion / Forming planet?

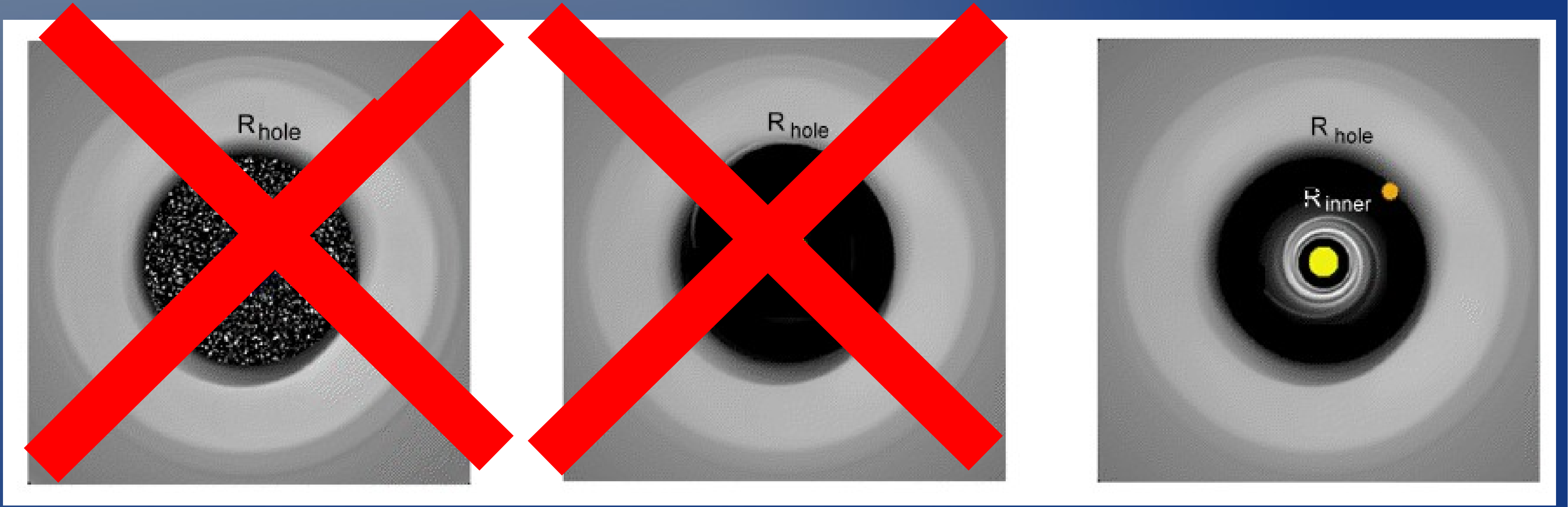


Strom & Najita

Transitional disks

- Separation large dust vs gas/small dust: radial ànd azimuthal

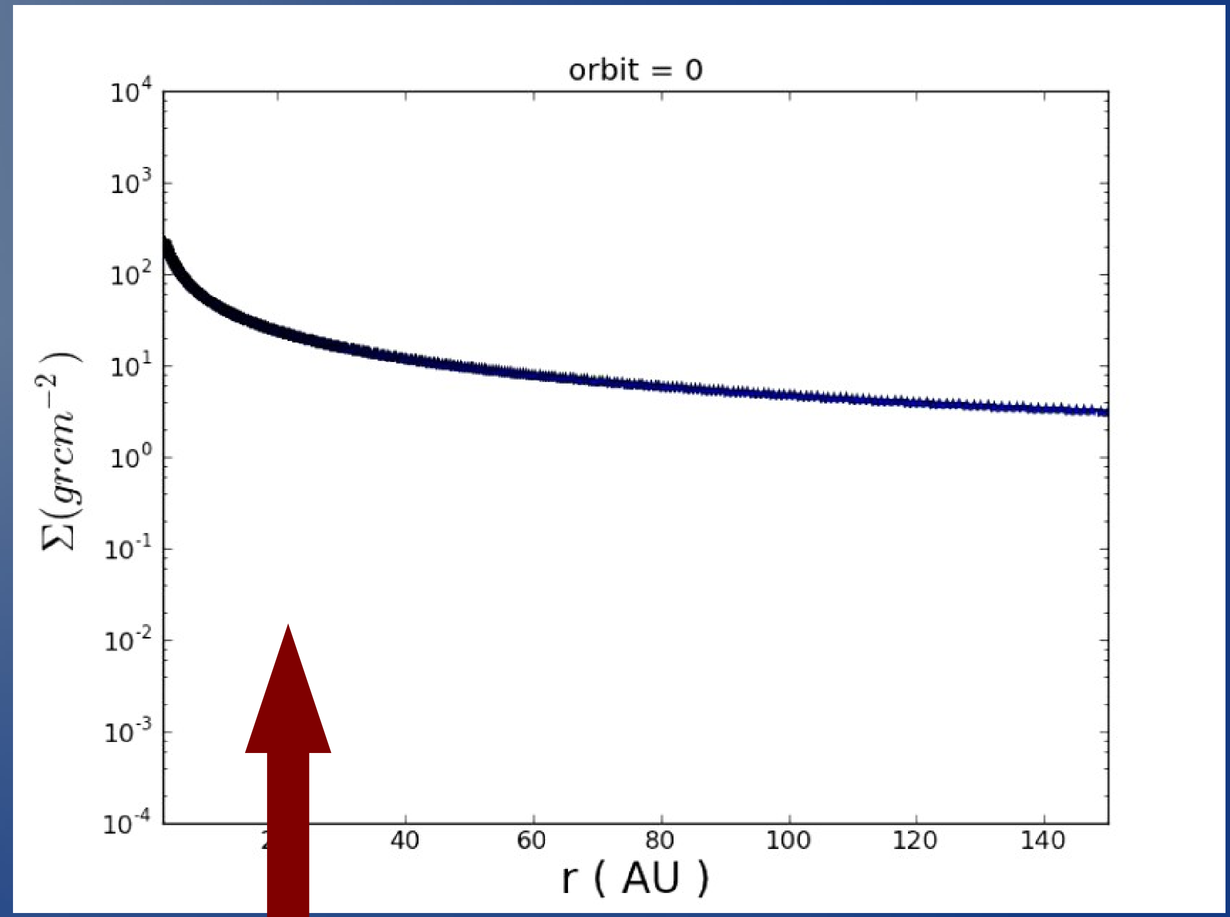
Grain growth | Photoevaporation | Stellar companion Forming planet?

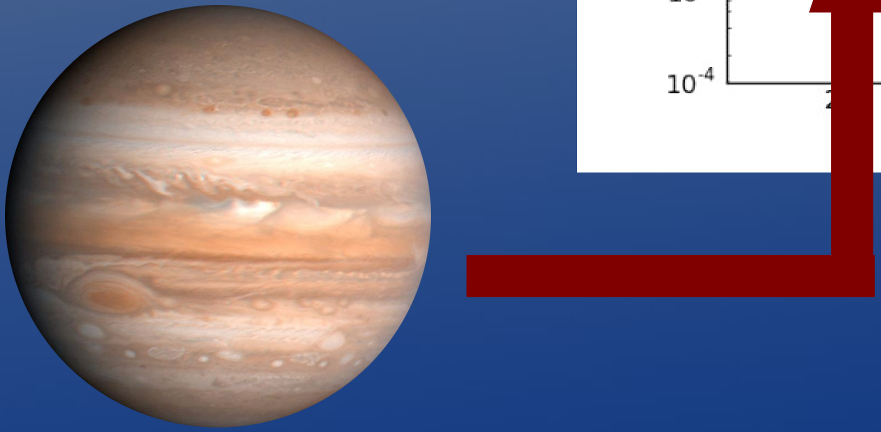


Strom & Najita

Dust trapping

- Companion generates a radial pressure bump in gas





Pinilla et al. 2012

Dust trapping

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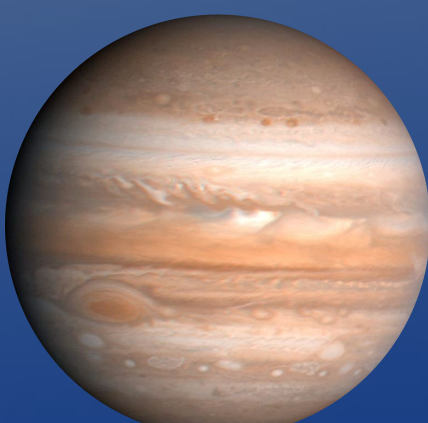
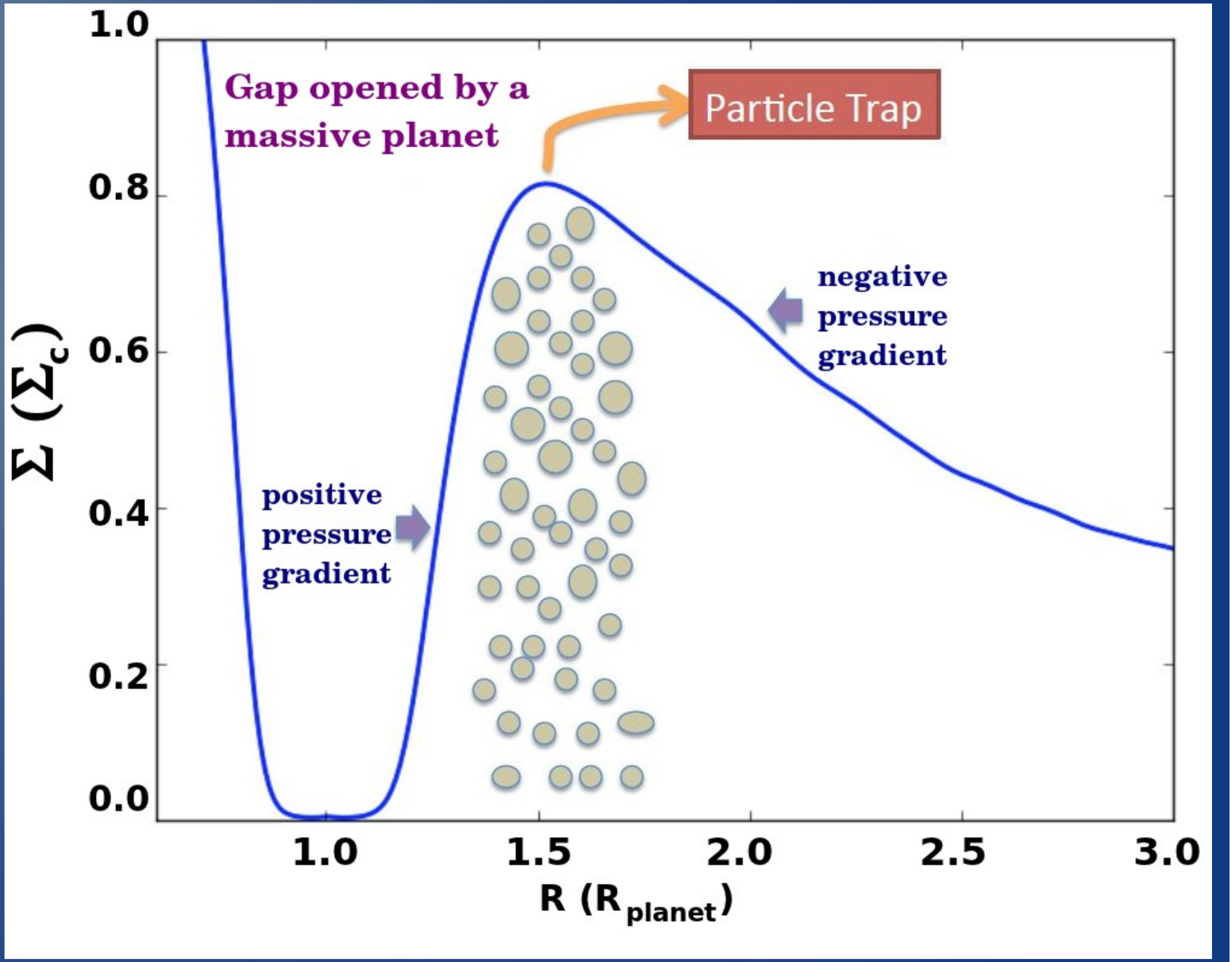


Pinilla et al. 2012

Dust trapping

- Companion generates a radial pressure bump in gas
- Large dust will be trapped and no longer migrates inward
- Dust hole much larger than gas hole ⇒ planet massive (>10 M_{Jup})



Pinilla et al. 2012
Talk Birnstiel

Dust trapping

- What is the origin of the azimuthal asymmetry?
- Massive companion
  $\Rightarrow$ pressure bump becomes Rossby unstable

Talks Birnstiel, Menard
Pinilla et al 2012
Birnstiel et al. 2013
Ataiee et al. 2013 (in press)

Dust trapping

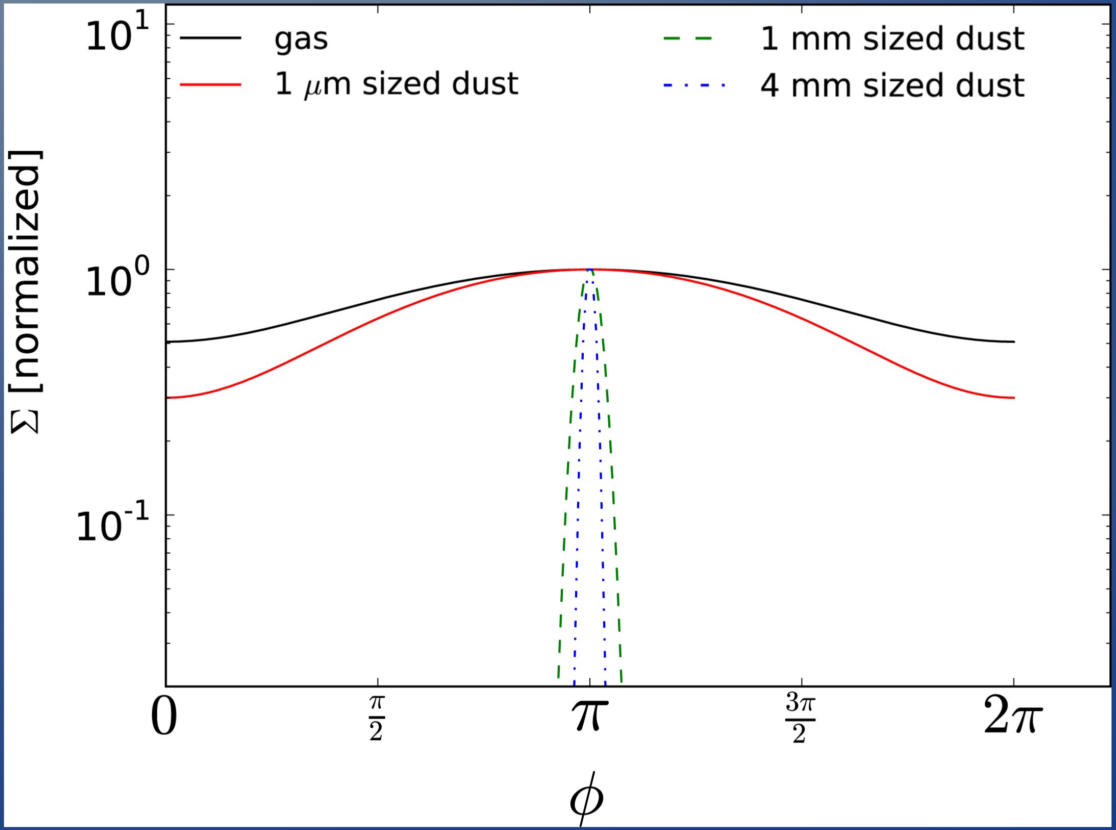
- What is the origin of the azimuthal asymmetry?
- Massive companion
  $\Rightarrow$ pressure bump becomes Rossby unstable:

long-lived vortex

Talks Birnstiel, Menard, Wolf
Pinilla et al 2012
Birnstiel et al. 2013
Ataiee et al. 2013 (in press)

Dust trapping

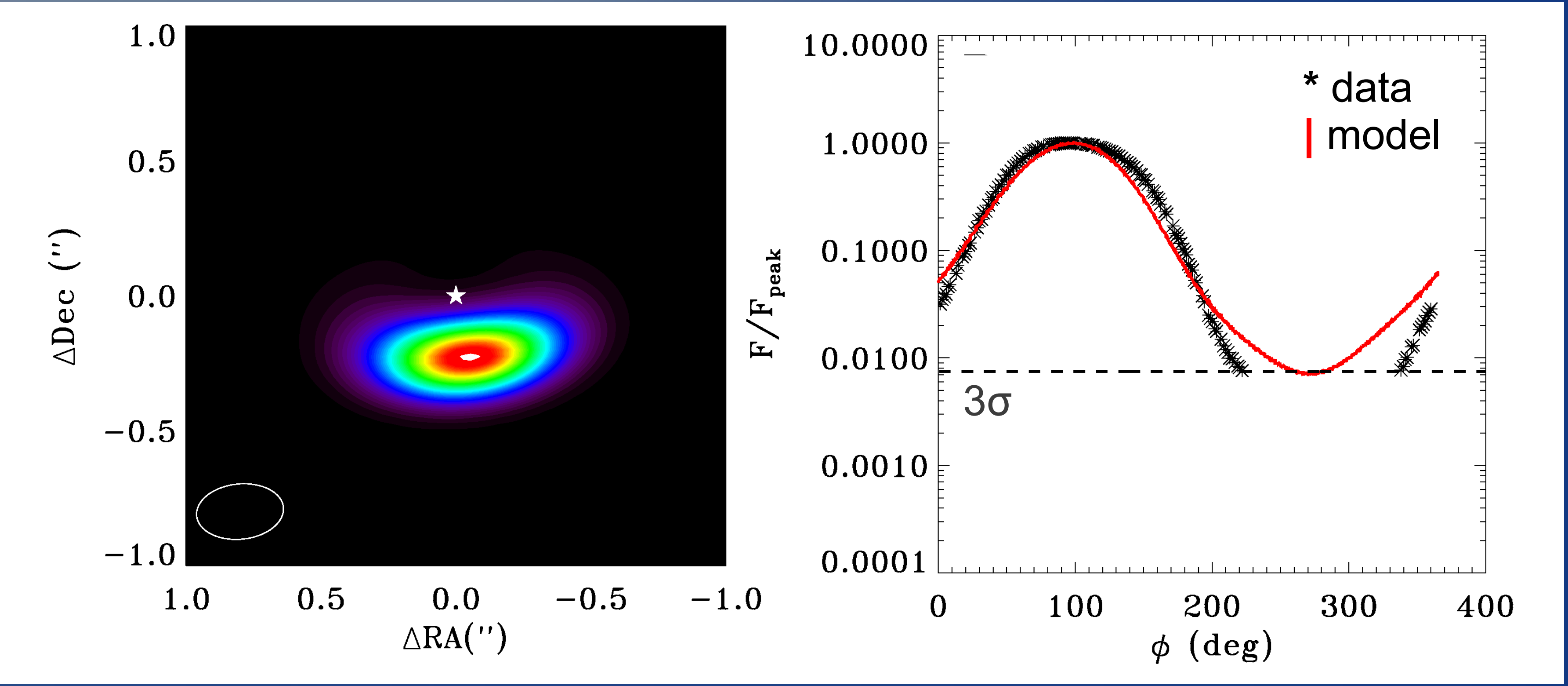
- Small gas asymmetry ⇔ large dust asymmetry



Talks Birnstiel, Menard
Birnstiel et al. 2013
Van der Marel et al. (in rev.)

Dust trapping

- Small gas asymmetry ⇔ large dust asymmetry
- Prediction: asymmetric dust trap



Birnstiel et al. 2013
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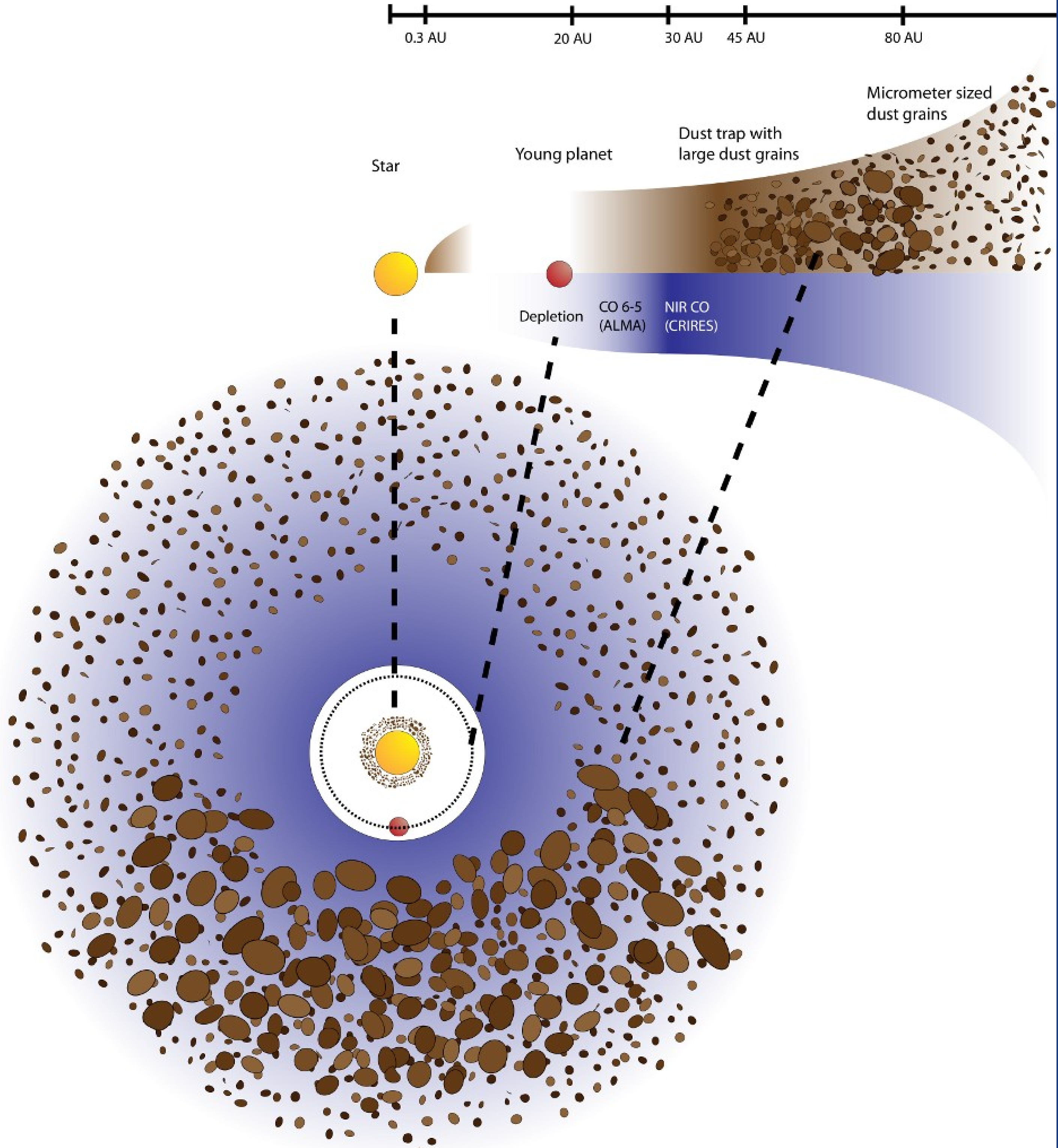

0.3 AU
20 AU
30 AU
45 AU
80 AU
Micrometer sized dust grains
Dust trap with large dust grains
Young planet
Star
Depletion
CO 6-5 (ALMA)
NIR CO (CRIRES)

Summary

- Data quality Band 9 excellent
- Gas/small dust: full Keplerian disk with small hole
- Dust: highly asymmetric, indicative of gigantic dust trap
- Scenario: gas pressure bump induced by massive companion traps large dust efficiently in radial and azimuthal direction
- Dust trap as KBO-factory similar to planet factory at smaller radii
- Observational evidence dust trap: a different view on planet formation and disk evolution models

- Is IRS 48 a special case?

  => ALMA will give the answer, need gas ànd dust

  => stay tuned for more transition disks in C0 and C1!

Thank you