Gas gaps and companions: the case of PDS70 and beyond

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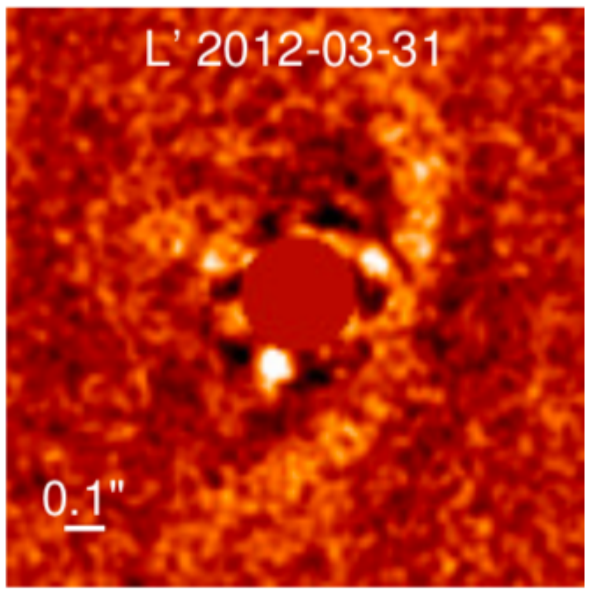
July 17th 2019
Disc-ussions Monash

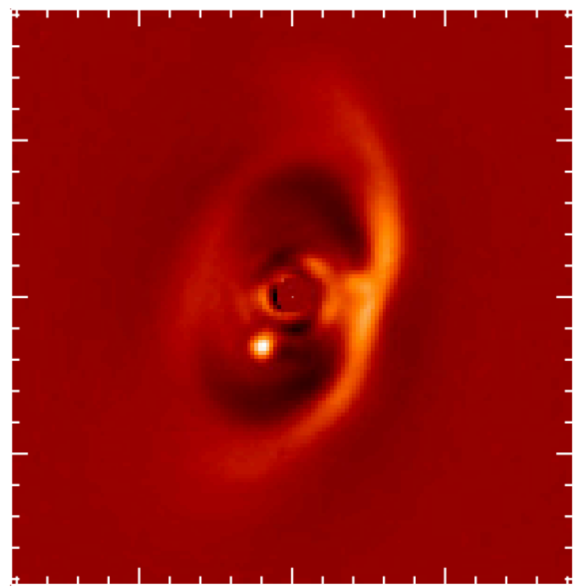
PDS70b (and c)

Keppler+2018



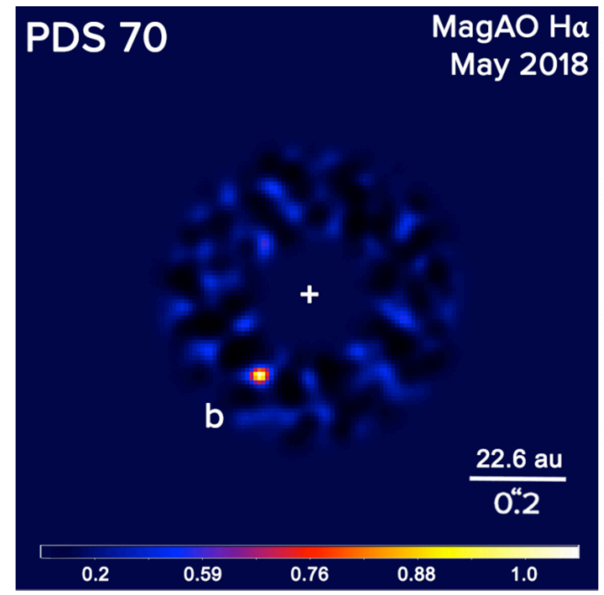
Detection point source PDS70b

Muller+2018



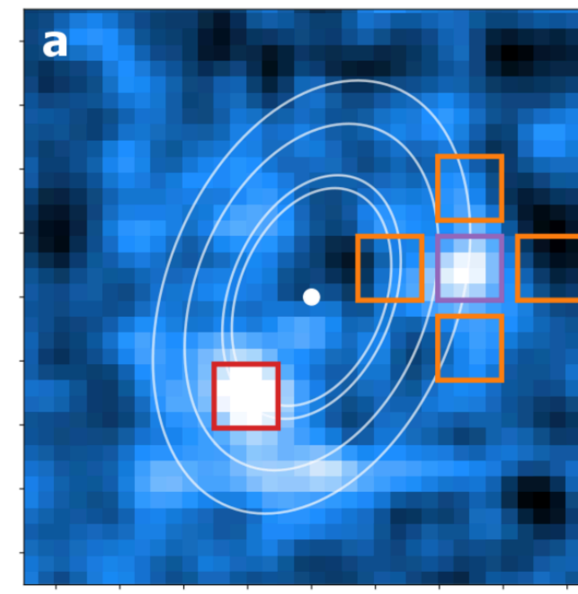
Constrain orbit to 22 au and mass to 2-17 M_{Jup}

Wagner+2018



Measure accretion rate PDS70b as 10^{-8} M_{Jup} yr^{-1}

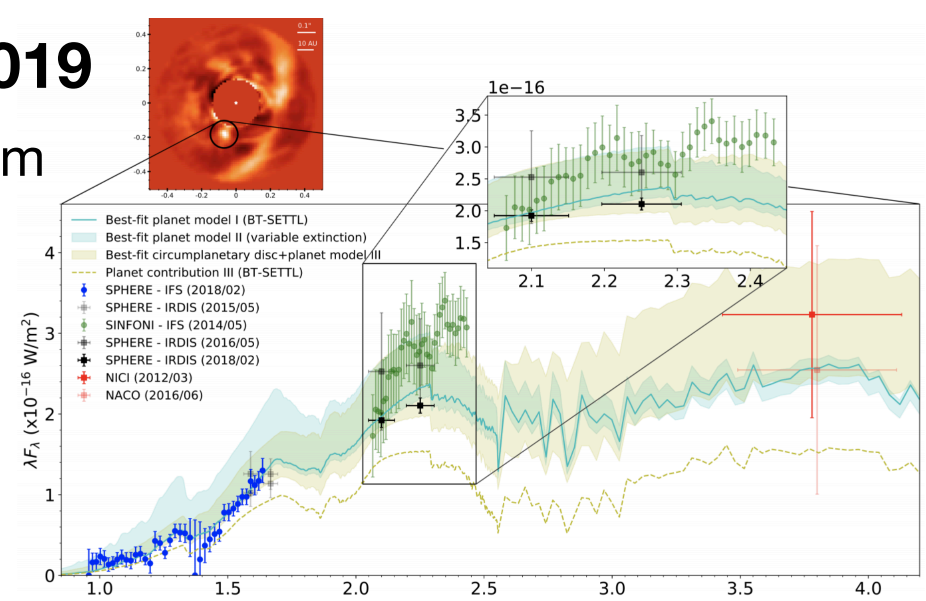
Van Haffert+2019



Detection PDS70b and c in H-alpha

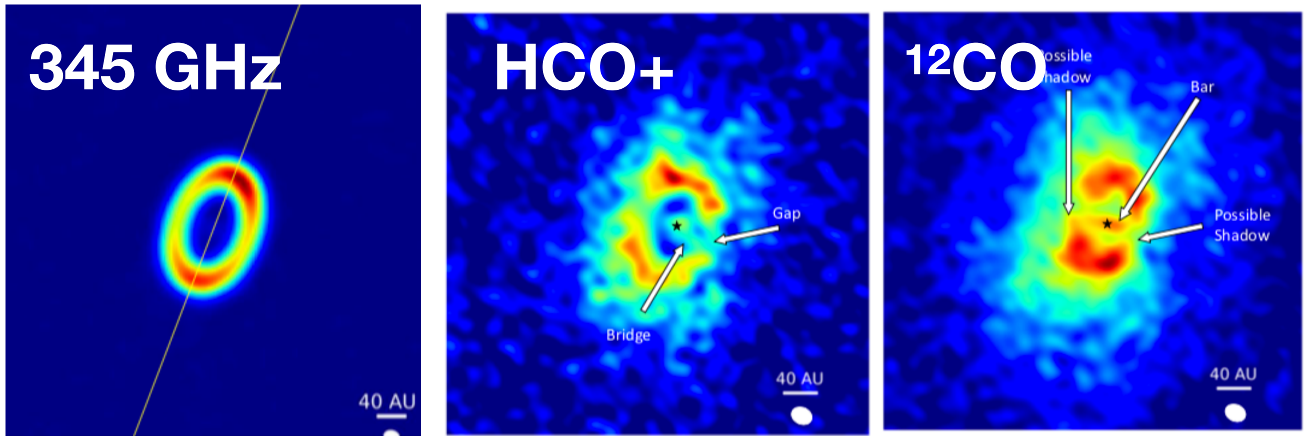
Christiaens+2019

Derived CPD from SED PDS70b



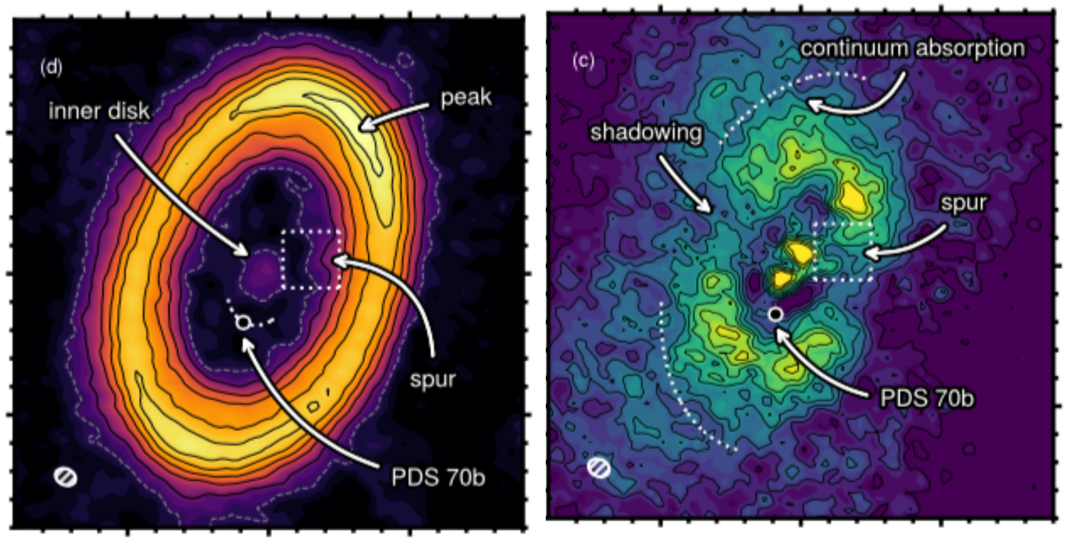
PDS70 disk

Long+2018 (0.2x0.15")



Dust gap between 15-60 au,
gas gap narrower than dust gap

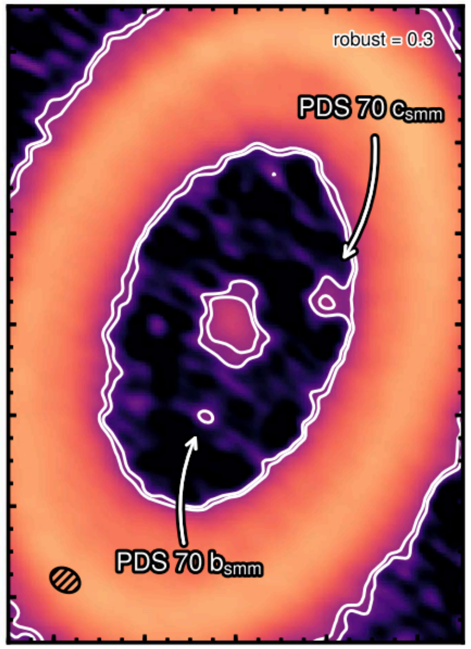
Keppler+2019 (0.07x0.05")



Dust ring at 74 au and 60 au, inner disk with bridge,
upper limit PDS70b CPD, spur PDS70c,
gas gap at ~22 au radius,
evidence non-Keplerian motion <0.8"

Isella+2019 (0.07x0.05")

PDS70c CPD
and dust detection ahead
of PDS70b



Major question (before PDS70c):
how to create dust ring at much larger radius than planet?

PDS70 model

- How to create dust gap >> planet orbit?
    - Eccentricity growth, facilitated by planetary accretion
- PEnGUIn (Fung+2015) 2D planet-disk interaction simulation, starting from an accreting planet core in a representative disk, run over the age of the system (~5 Myr)
- External eccentric Lindblad resonances are relevant for wide gaps (co-orbital Lindblad circularise orbit)

Muley et al. 2019

PDS70 model

- Equations:

$$\Sigma(r, \phi, t = 0) = \Sigma_0\left(\frac{r}{22 \text{ au}}\right)^{-1}$$

$$H \equiv h/r = 0.063(r/22 \text{ au})^{0.3}$$

$$\dot{\Sigma}_{\text{acc}}(r, \phi) = -\frac{\Sigma(r, \phi)}{k\ t_{\text{ff}}} = -\frac{\Sigma(r, \phi)}{10\sqrt{2r_{\text{acc}}^3/GM_p}}$$

- Initial planet: 23 au, 10 M_{Earth}, circular orbit

- Initial disk mass: ~5-25 M_{Jup} (Choice Σ_0)

- Boundaries 5-100 au

- 4.6 Myr: 39,000 orbits:
  => growth up to 2.5 M_{Jup} (q>0.003) => eccentricity starts!

Muley et al. 2019

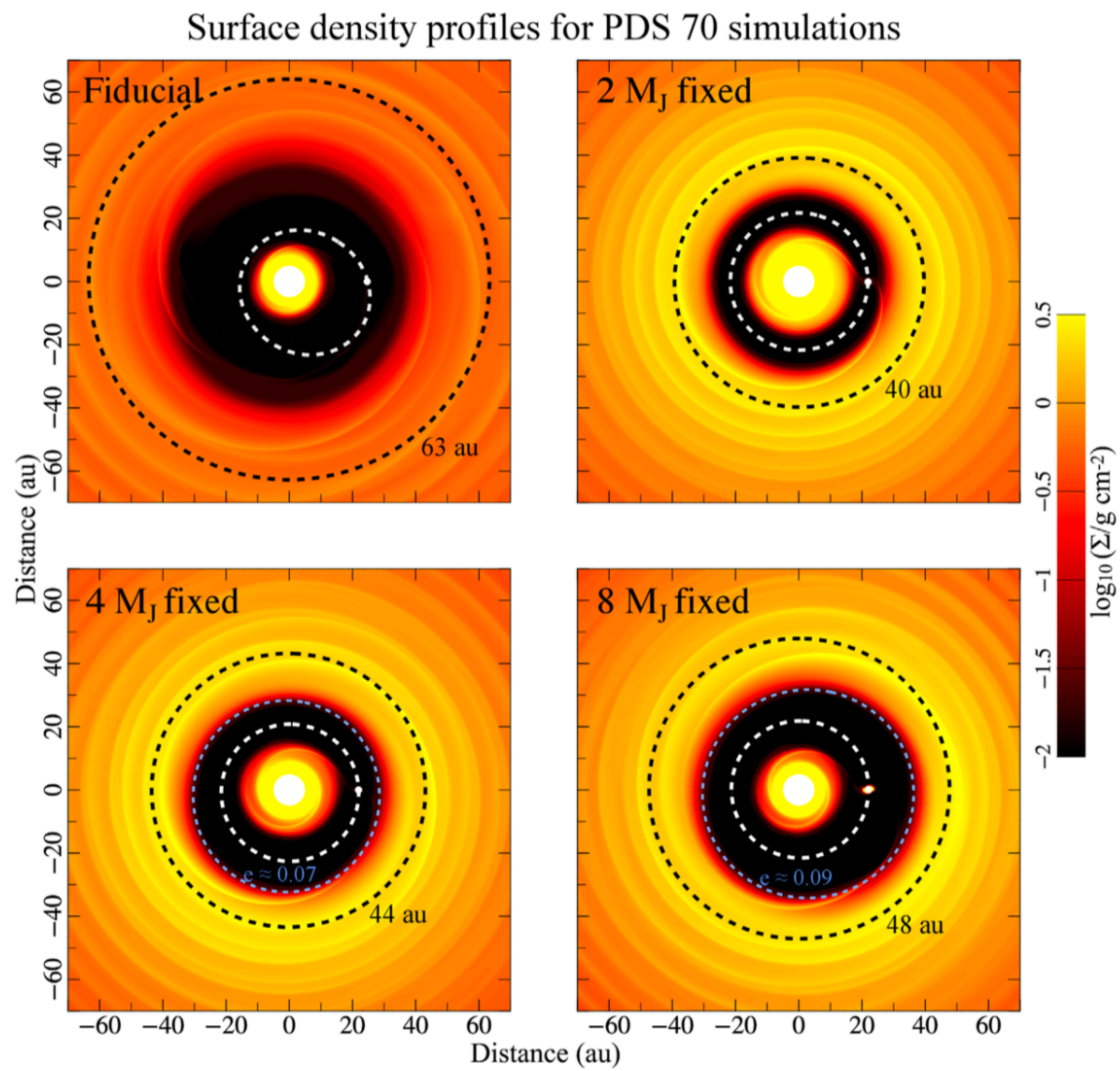
PDS70 model

Massive non-accreting planets on fixed orbits also induce eccentricity, but not a deep, wide gap such as seen in the observations!

=> Fast accreting planet required! (fiducial model)

Other constraints:

- Disk mass low/accretion high: limit migration
- Final gas surface density in gap <0.01 g cm^{-2} (^{12}CO opt. thin)
- No asymmetry (RWI) but wide gap: viscosity ~ 10^{-3}



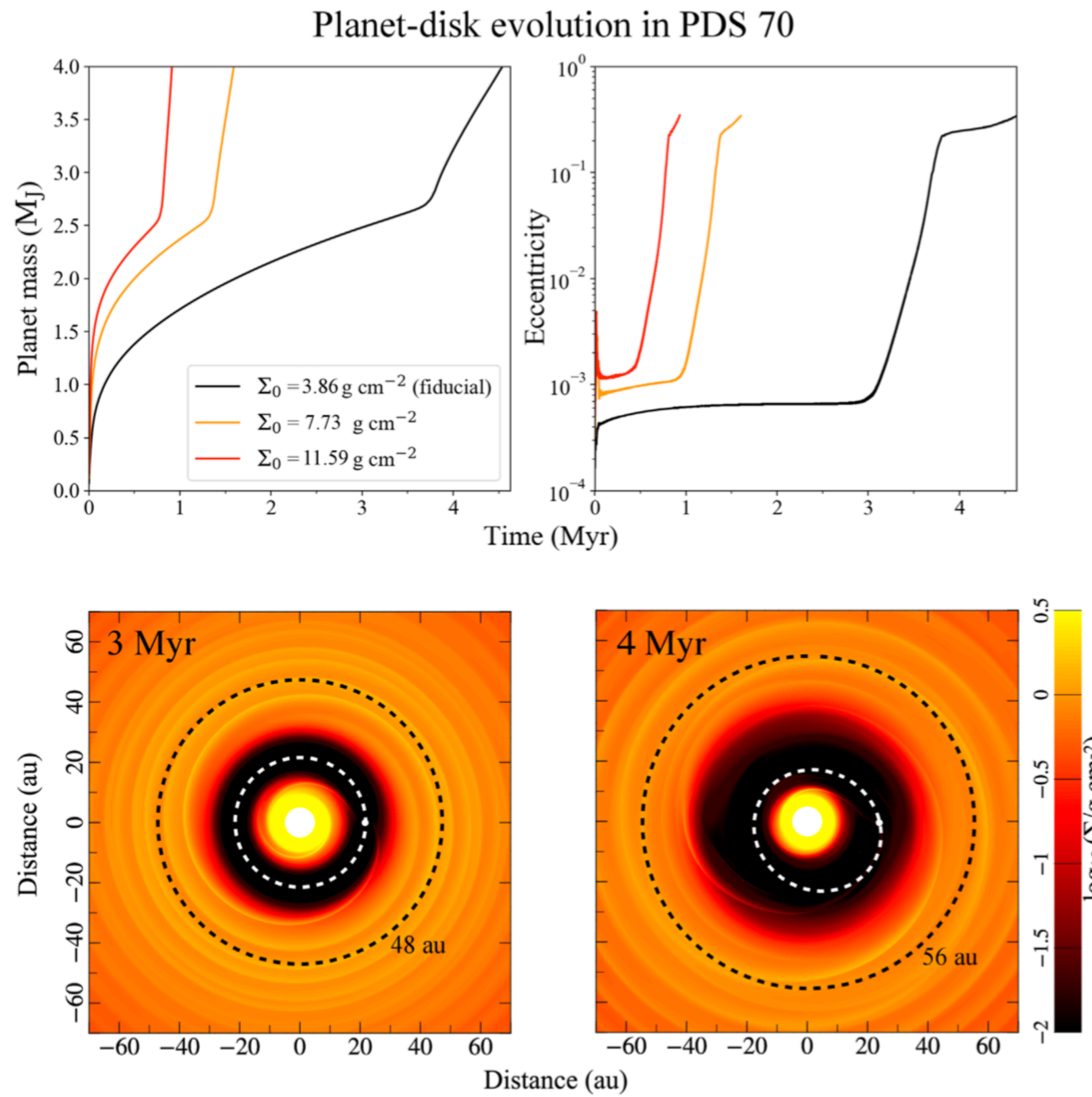
Muley et al. 2019

PDS70 model

Simulation:
eccentricity grows exponentially
when $M_p \sim 2.5\ M_{Jup}$
up to e~0.25.

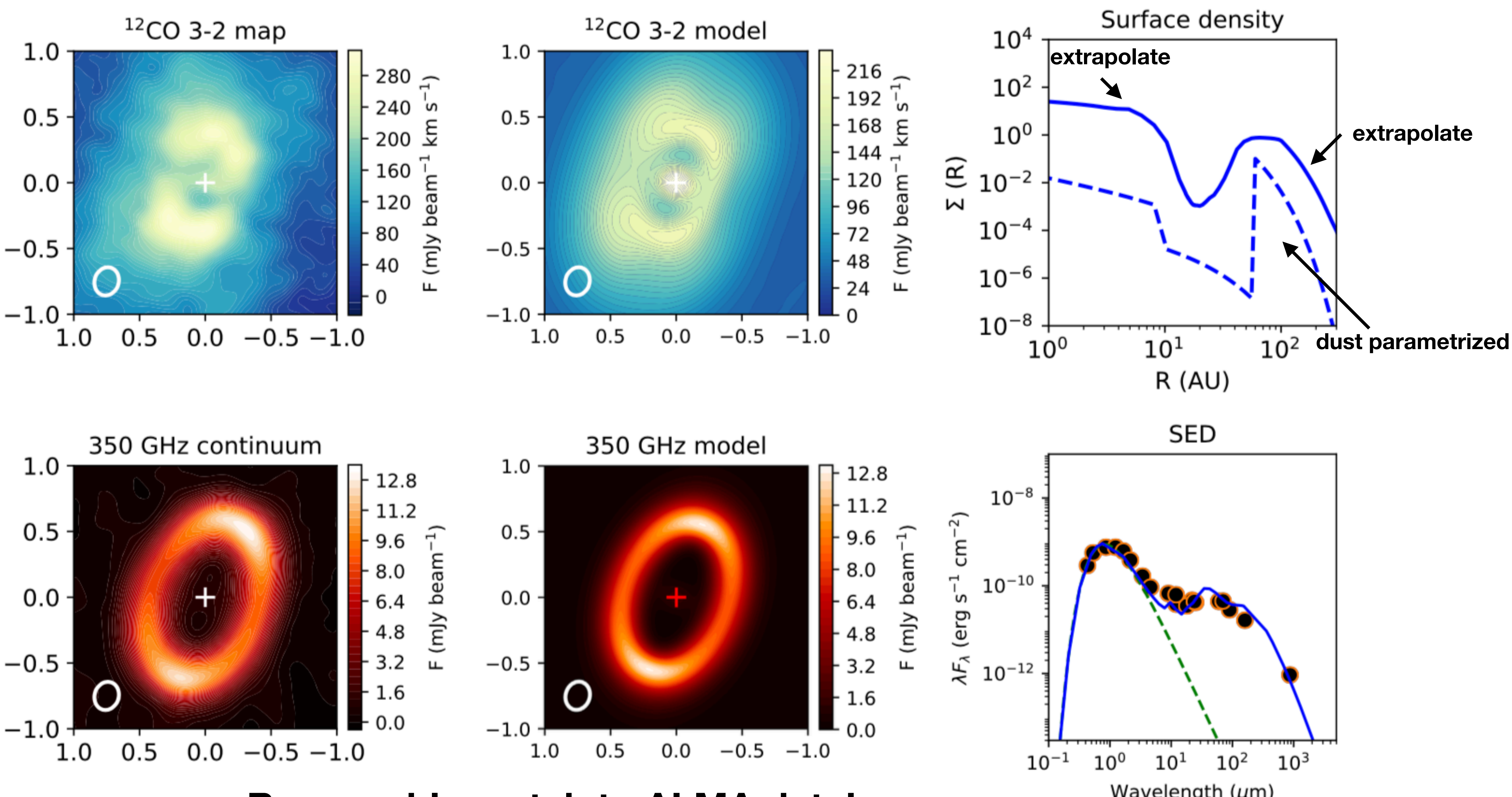
Orbital constraints Muller+2018:
0.0-0.27 68% confidence

Also, migration is halted at 22 au
due to disk feedback!



Muley et al. 2019

PDS70 model



Reasonable match to ALMA data!

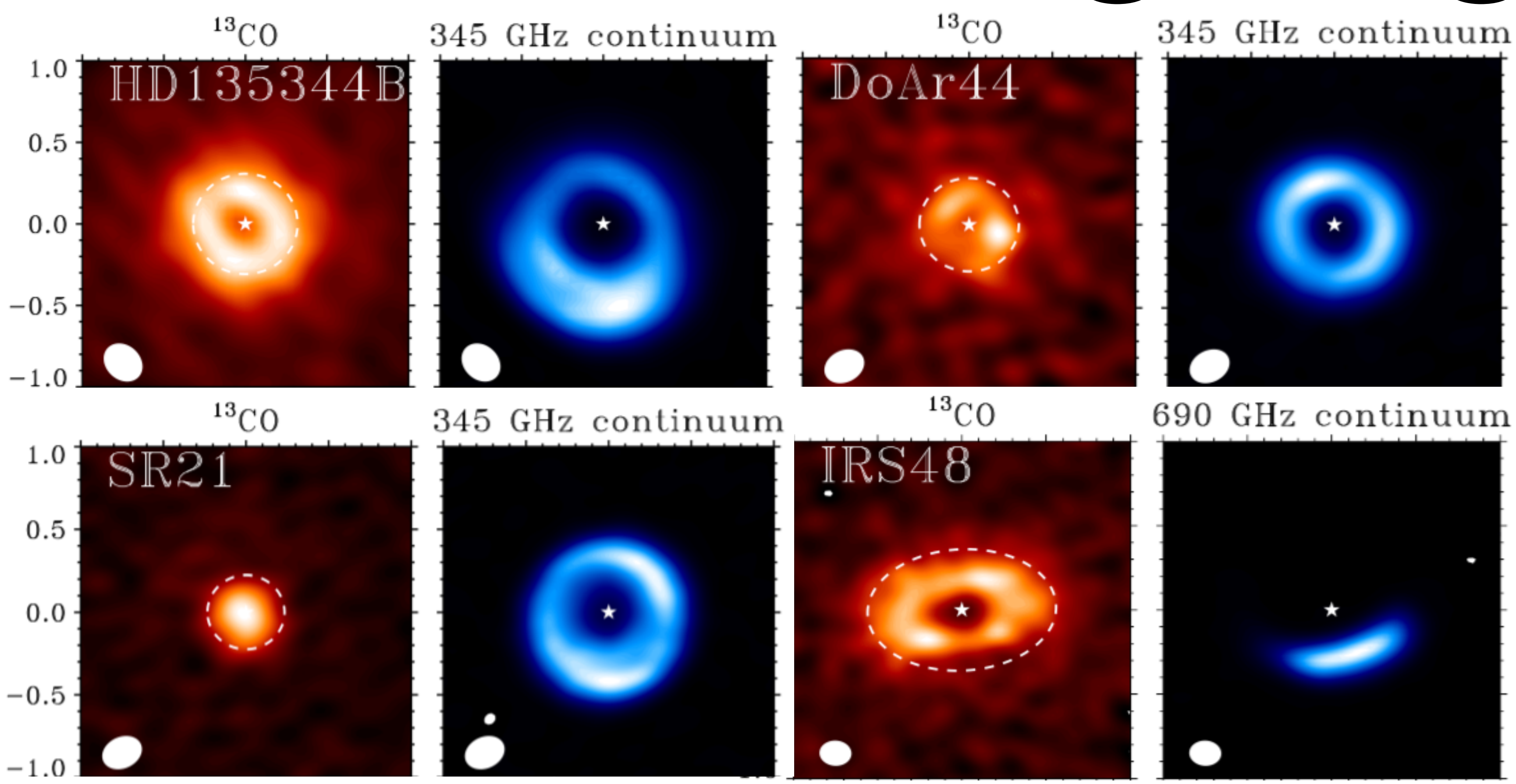
caveat: central ¹²CO emission in model too bright
=> Temperature? Boundary condition? Stellar accretion?

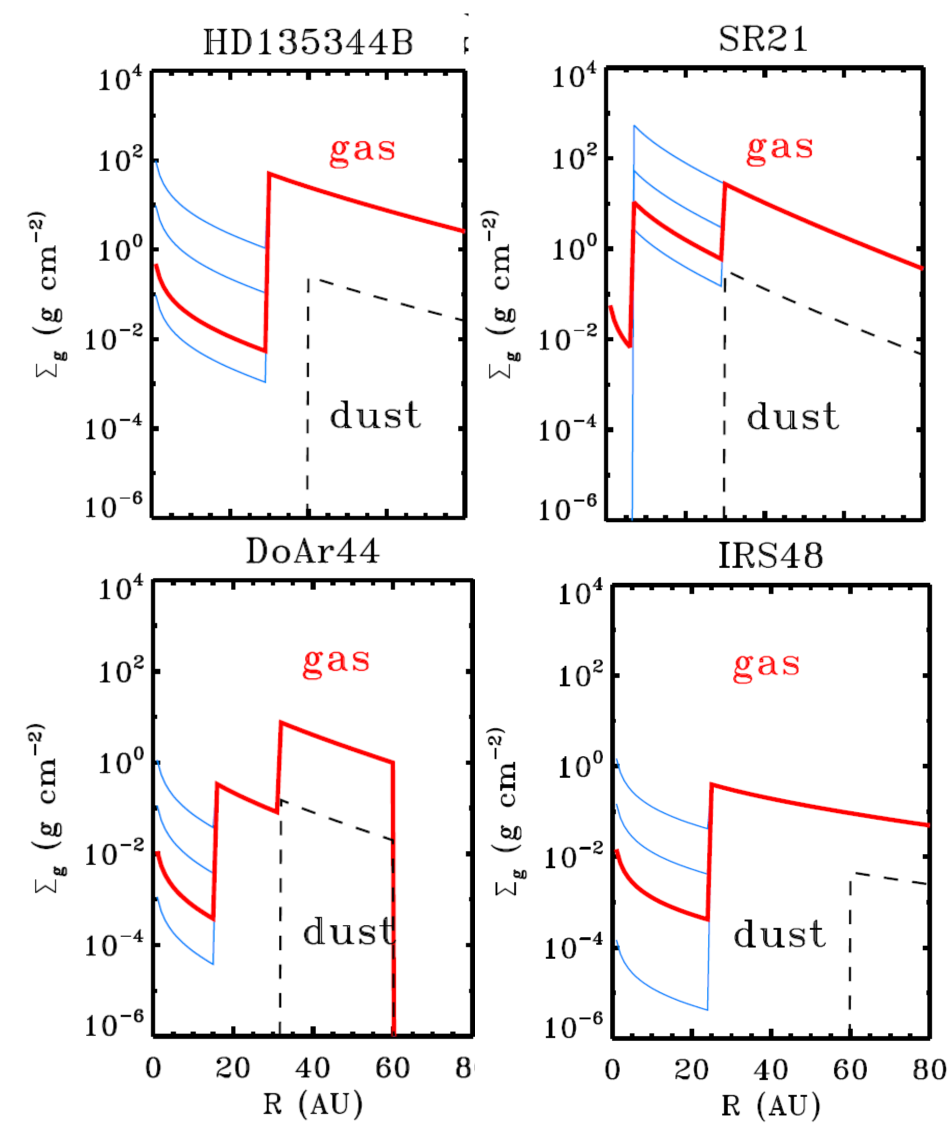
Muley et al. 2019

PDS70

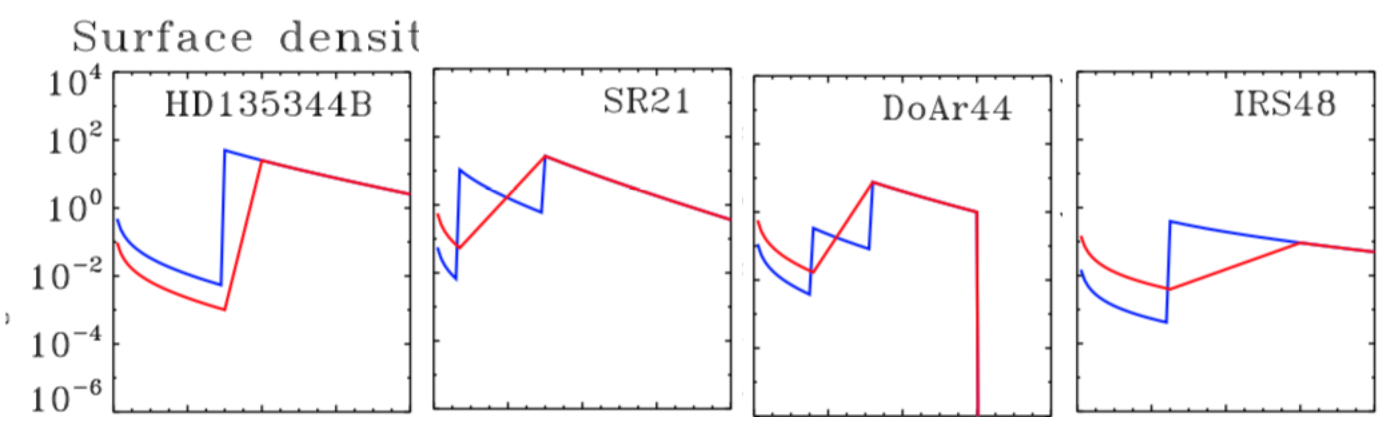
- Accreting planet in disk can induce eccentricity and limit migration: single planet sufficient for wide gap
- Strict constraints on disk mass, accretion rate and eccentricity planet orbit: special circumstances or every transition disk?
- Remaining questions:
  - PDS70c? Eccentricity growth not necessary? => Still sample case
  - Inner disk?
  - Observed eccentricity orbit?
  - Continue accretion until eccentricity saturates: in reality, heating and angular momentum of the CPD would limit accretion eventually
  - 3D vs 2D?

Other gas gaps





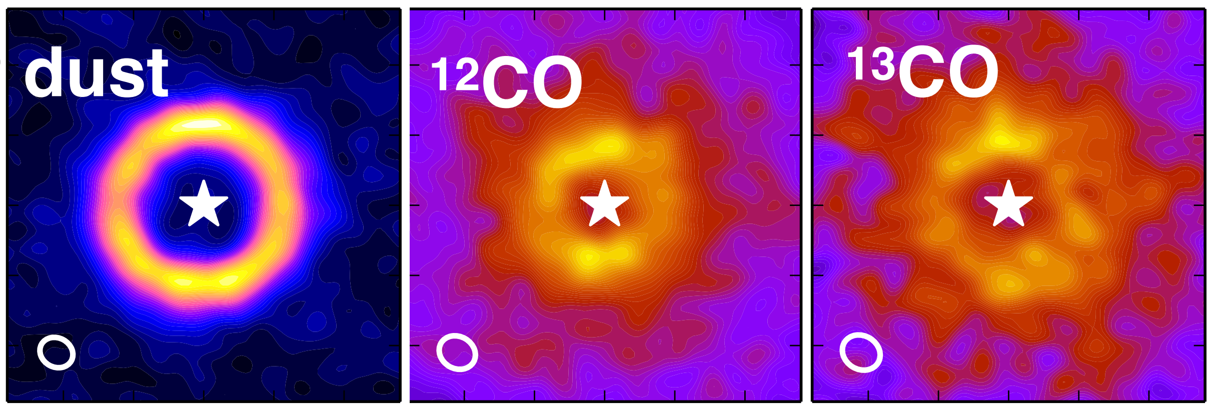
Disks can be equally well fit with a shallow slope



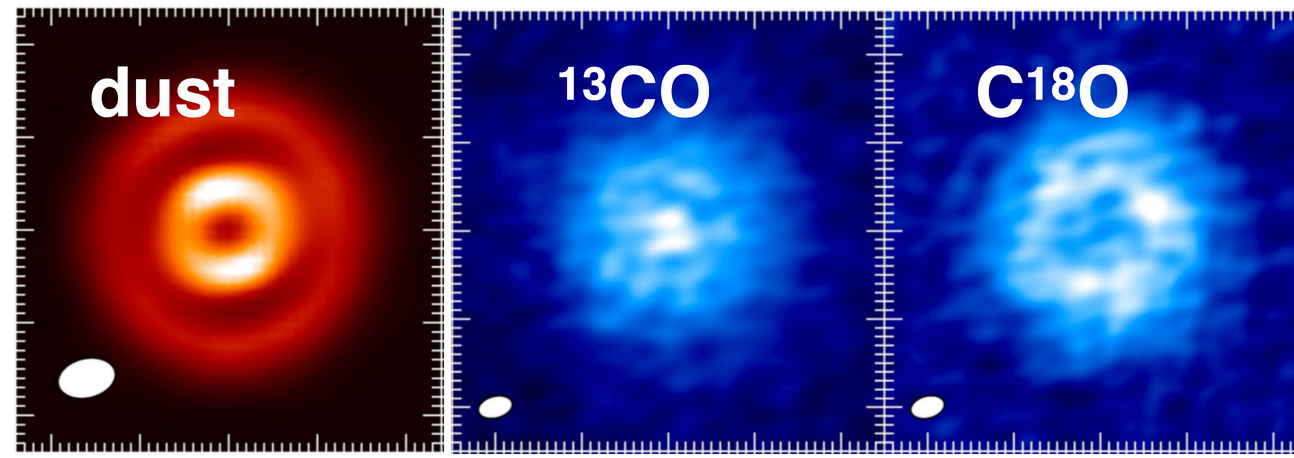
Van der Marel et al. 2016

Other gas gaps

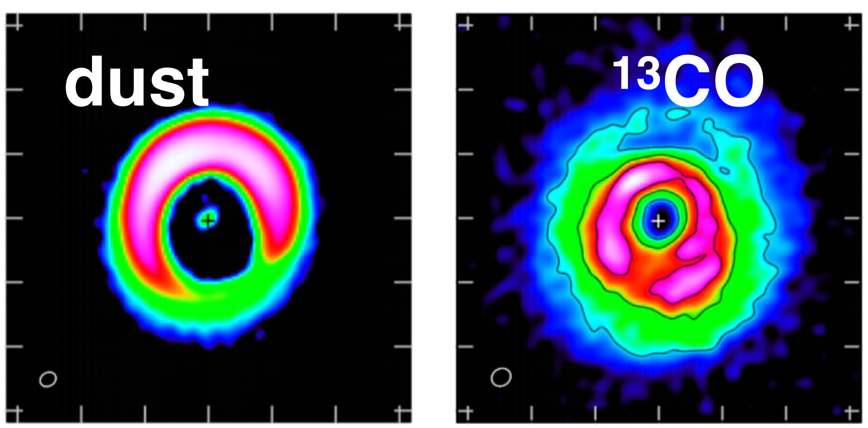
J1604-2130



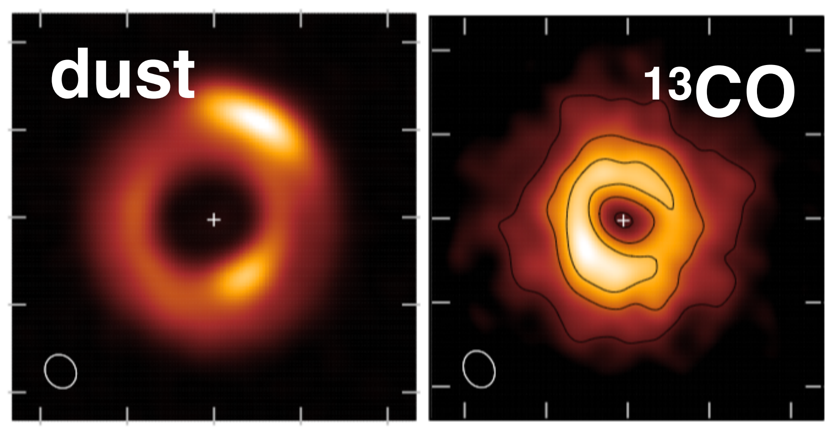
HD169142



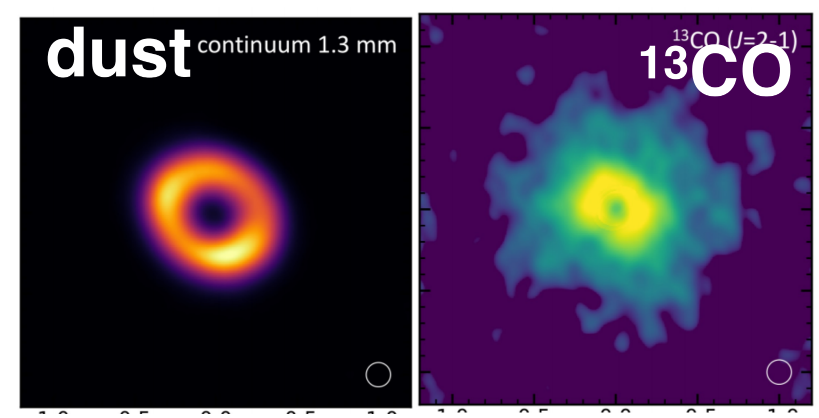
HD142527

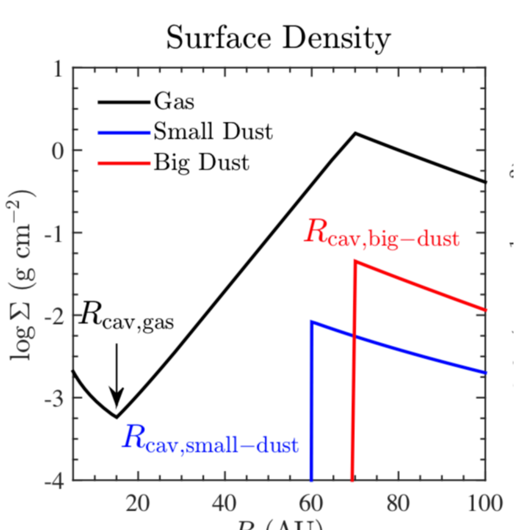


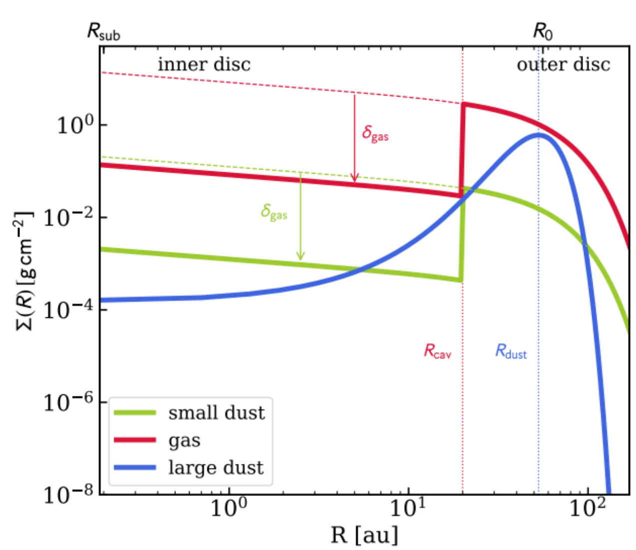
MWC758



CQ Tau







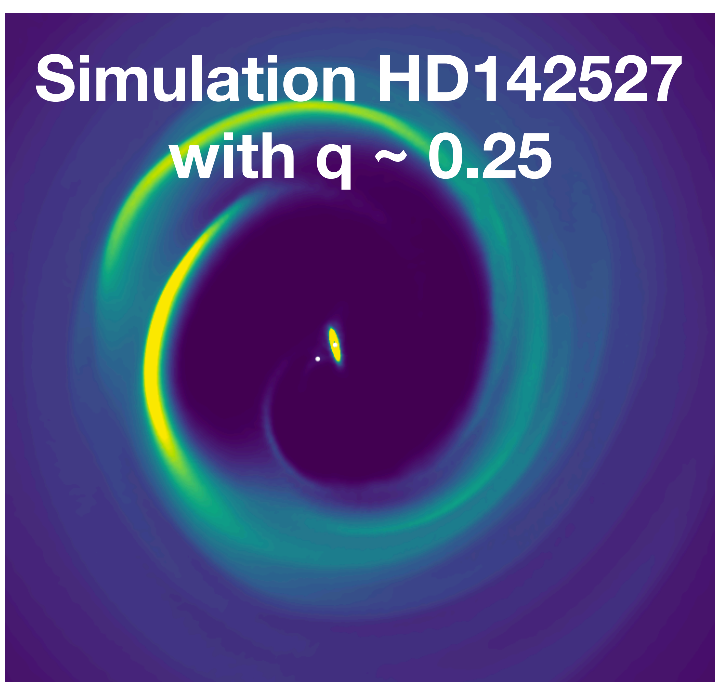
Dong, van der Marel et al. 2018
Fedele et al. 2017
Boehler et al. 2017, 2018
Gabellini et al. 2019

Other gas gaps

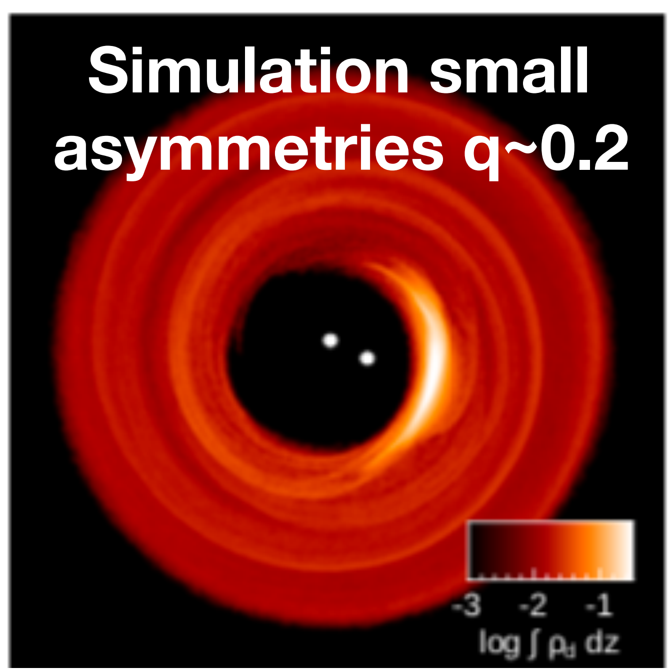
- What are companion masses?
  => Density drops ~10^2-10^4:
  even for $\alpha < 10^{-3}$, M_p ~ 5-10 M_{Jup} (van der Marel+2016)

$$\Sigma_{\rm gap}/\Sigma_0 = 4.7 \times 10^{-3} \left(\frac{q}{5 \times 10^{-3}}\right)^{-1} \left(\frac{\alpha}{10^{-2}}\right)^{1.26} \left(\frac{h/r}{0.05}\right)^{6.12}$$

- Evidence substellar companions? (>13 M_{Jup})

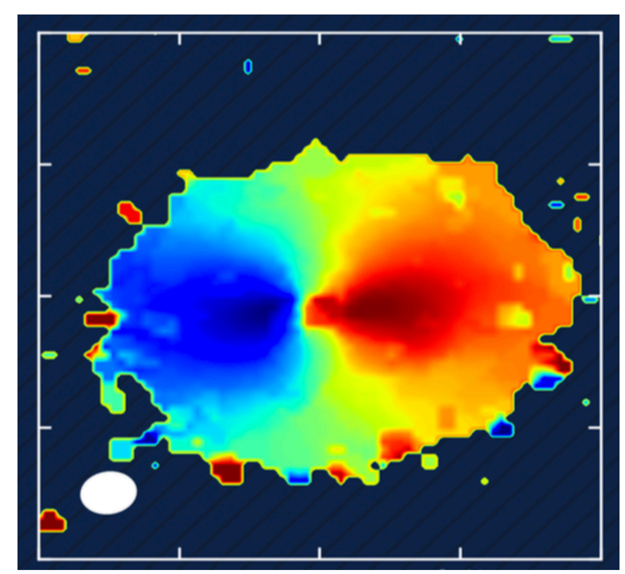


Price+2018



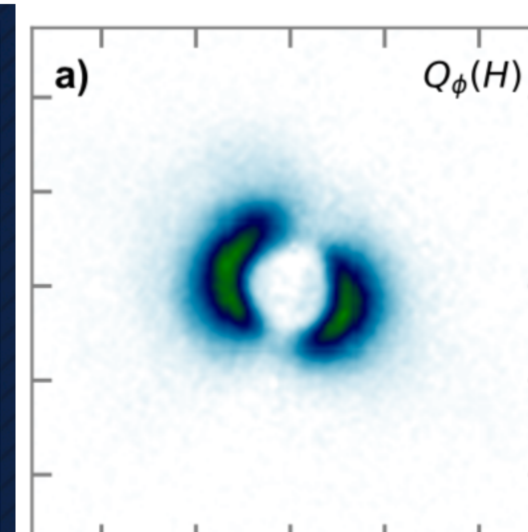
Ragusa+2016

Warp IRS48



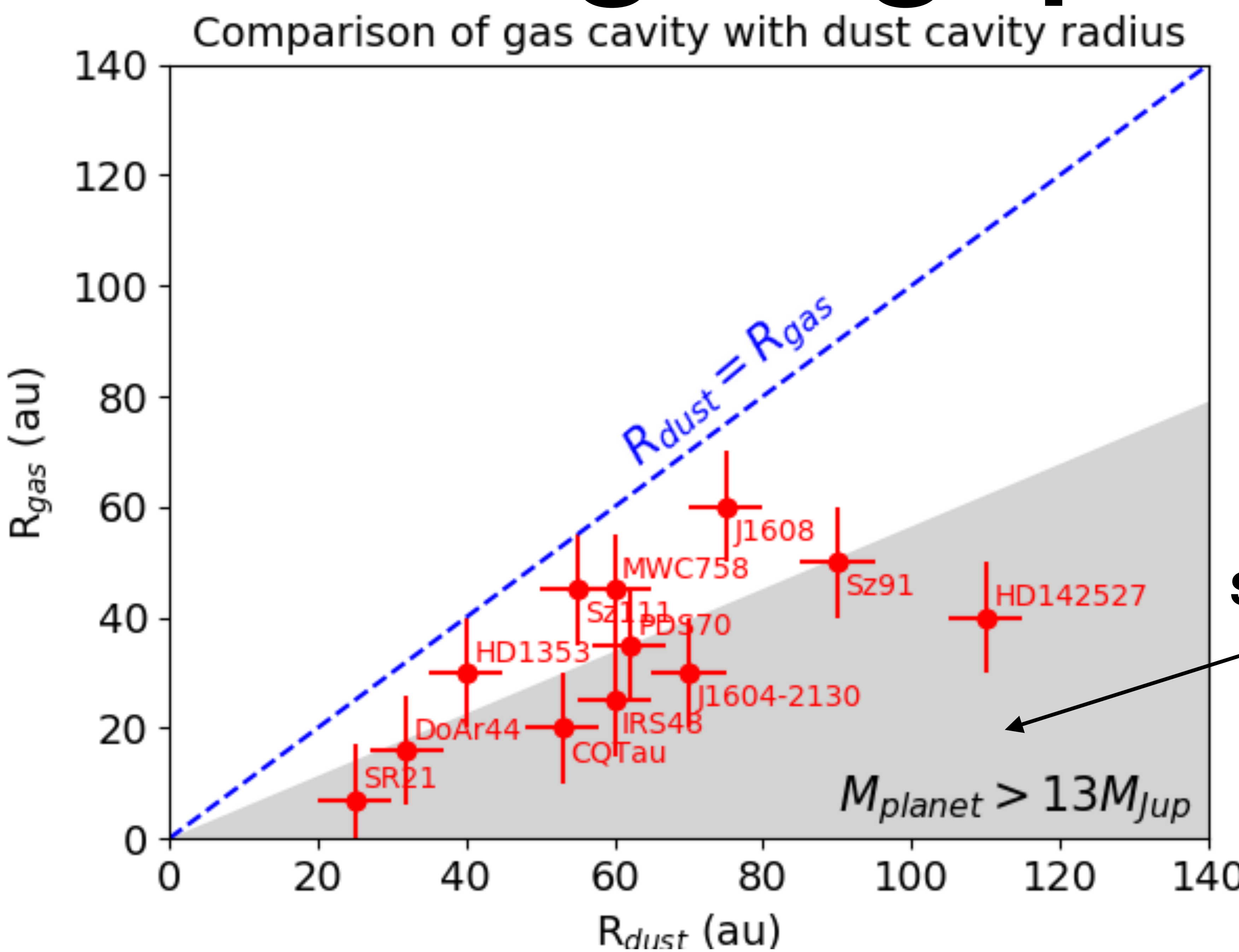
Calcino+subm.

Warp DoAr44



Casassus+2018

Other gas gaps

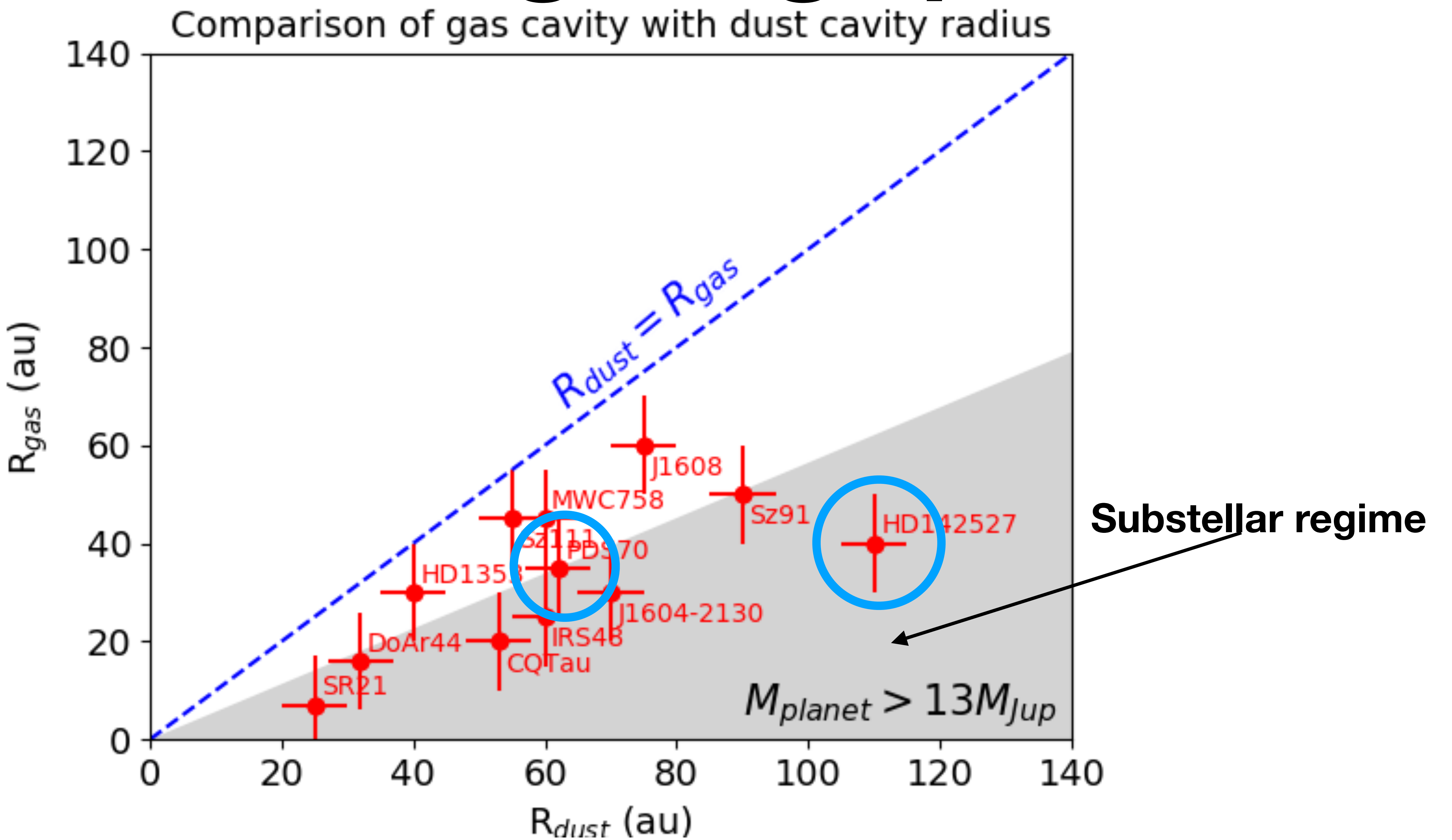


Substellar regime

Gas cavity radius < Dust cavity radius

Van der Marel et al. in prep.

Other gas gaps



Encircled: disks with known companion mass:

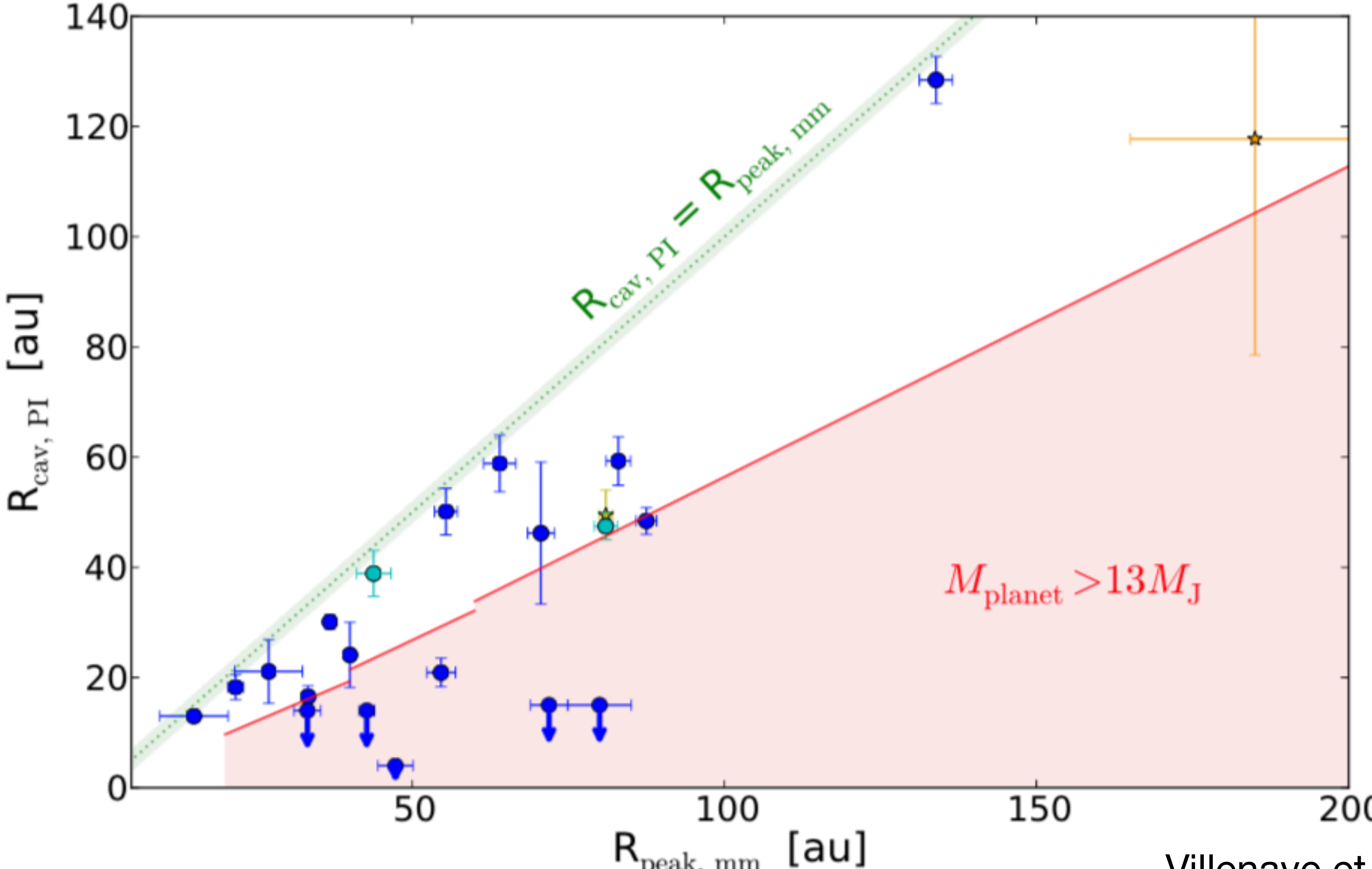
- **HD142527: 0.2-0.4 Mo (q~0.2)**
- **PDS70: 2-17 M_{Jup} (q~ 0.01)**

?

Van der Marel et al. in prep.

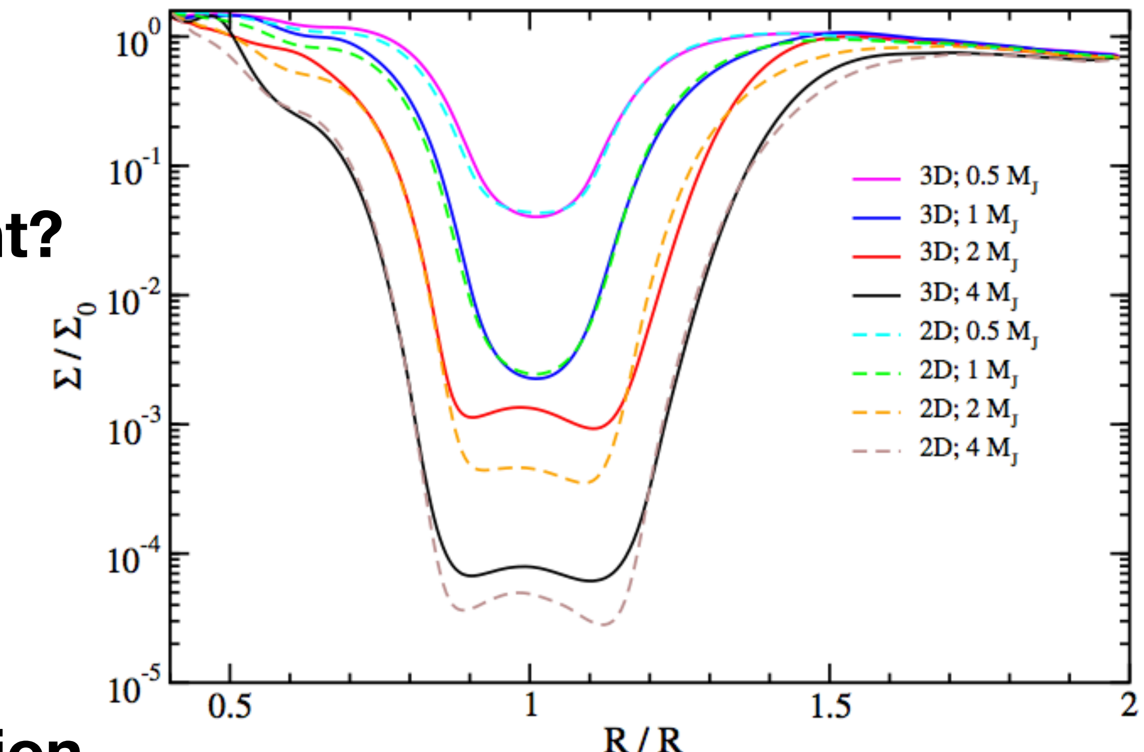
Small dust gaps

Results from scattered light



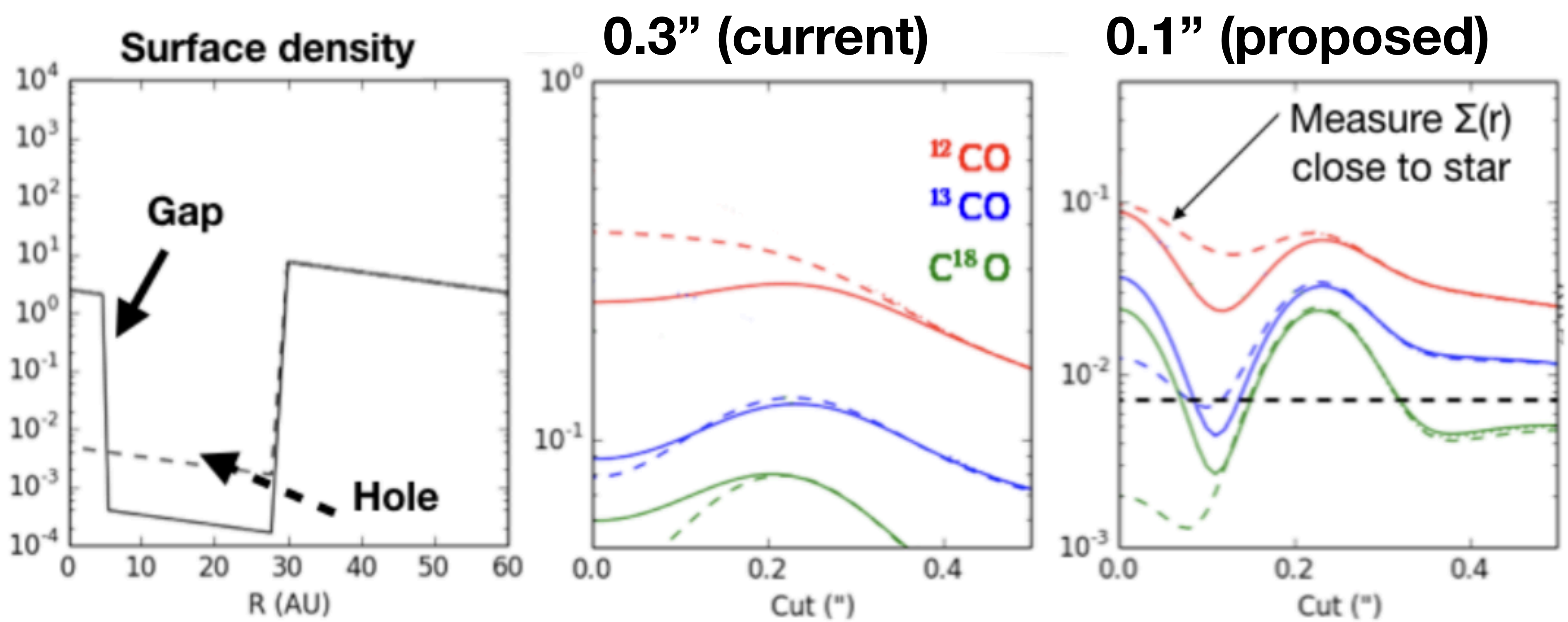
Villenave et al. 2019

Gas cavity = gas gap?



Actual planet gap: inner disk present?
=> also suggested by measured accretion rates

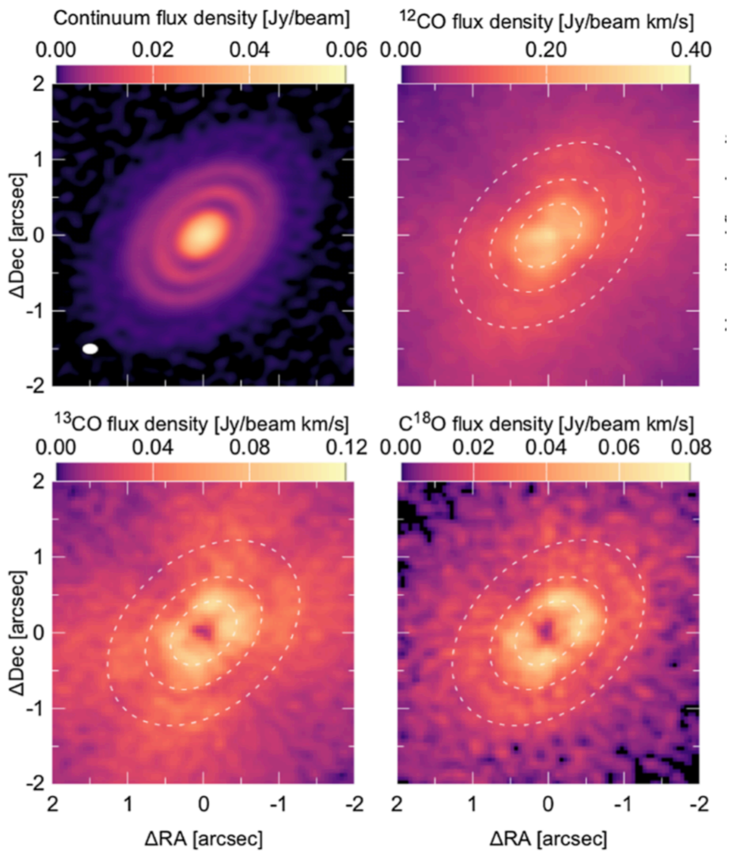
But many CO images limited by resolution….

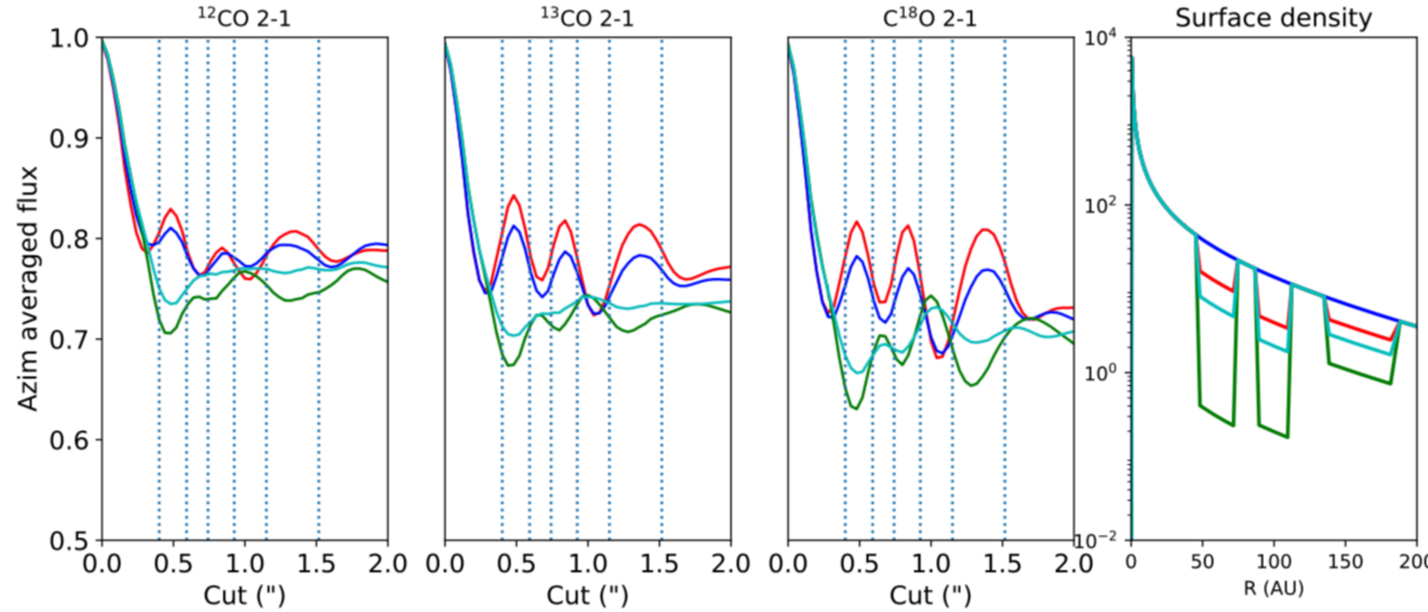


Plus, some temperature effect in ^{12}CO in models?

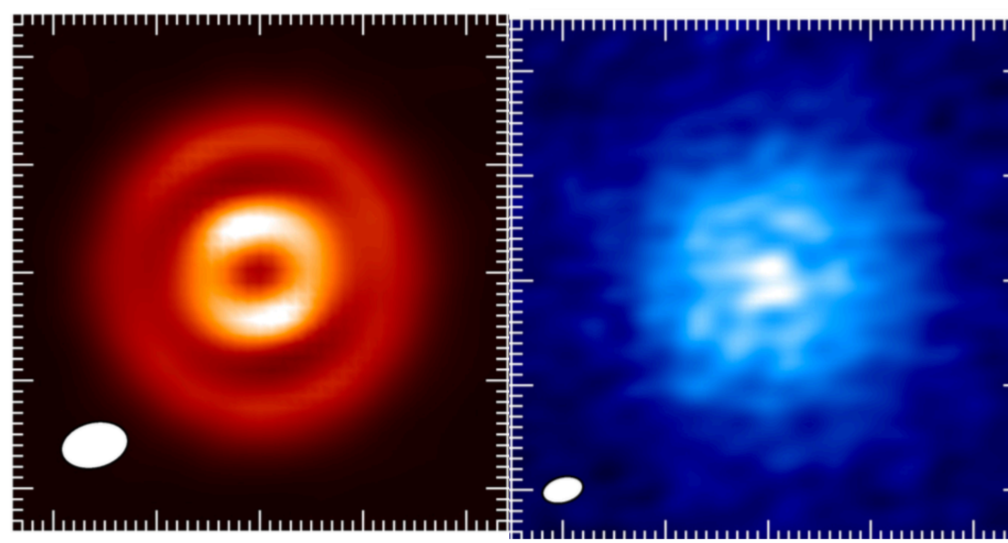
Narrow gas gaps

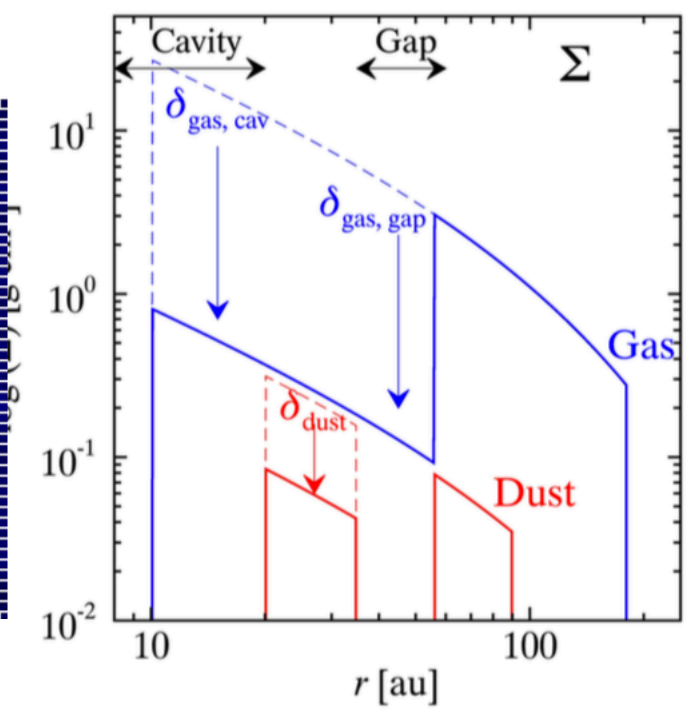
HD163296



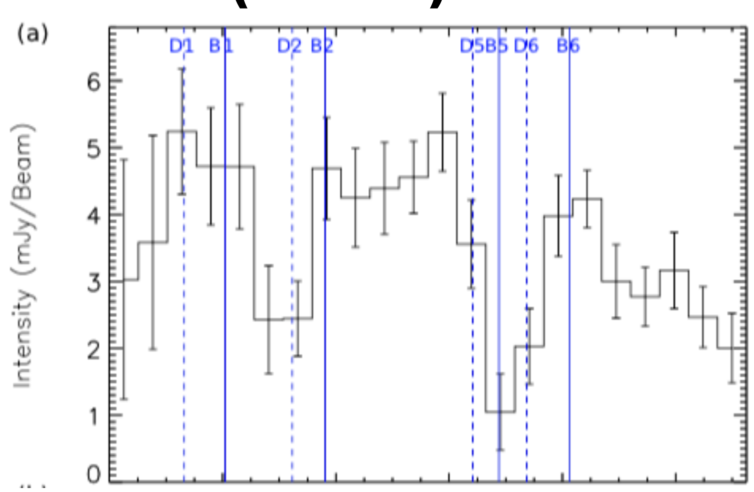


HD169142 (^{13}CO)





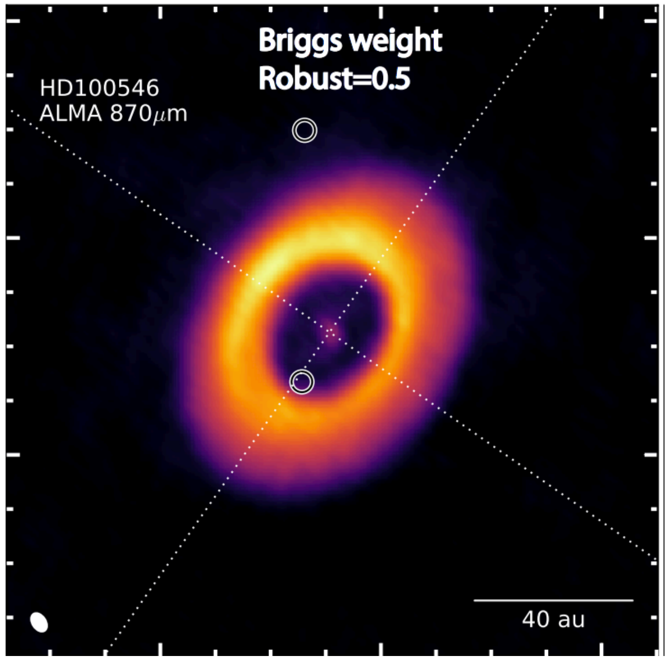
HL Tau (HCO+)



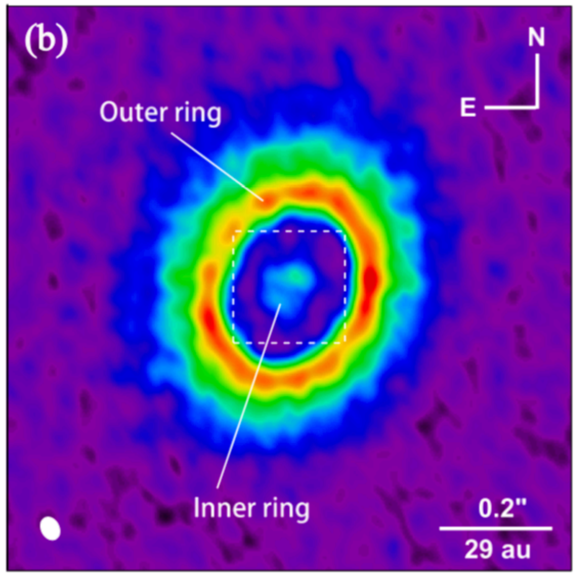
Yen et al. 2016
Fedele et al. 2017
Van der Marel et al. 2018b

Inner dust disk: gap?

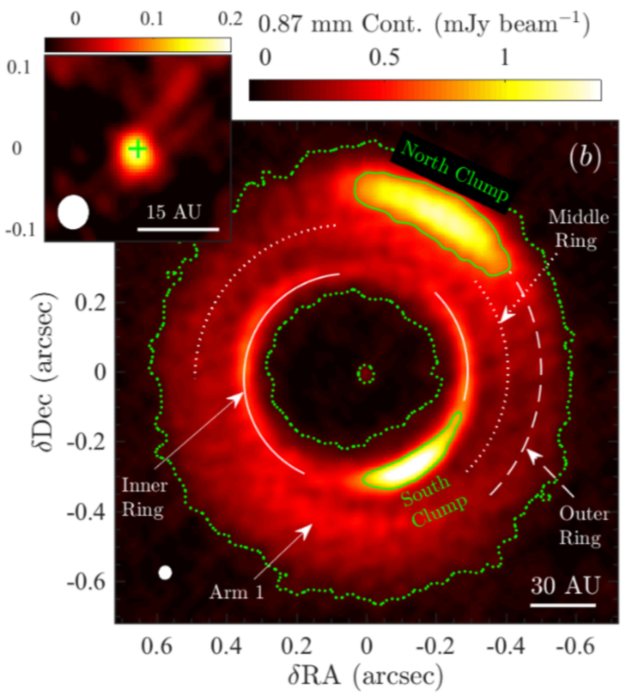
HD100546



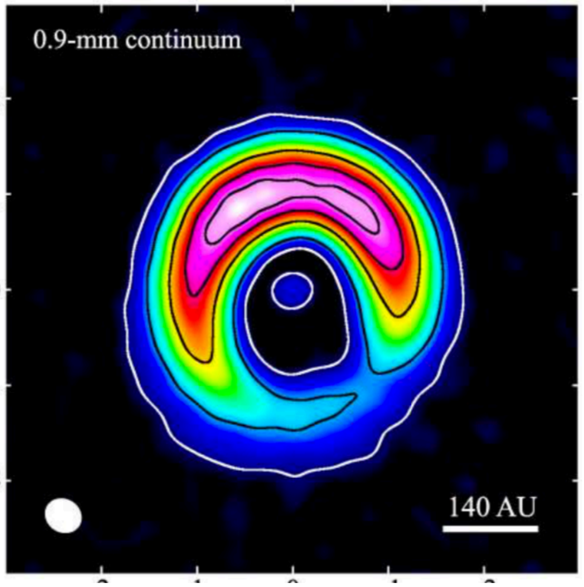
DM Tau



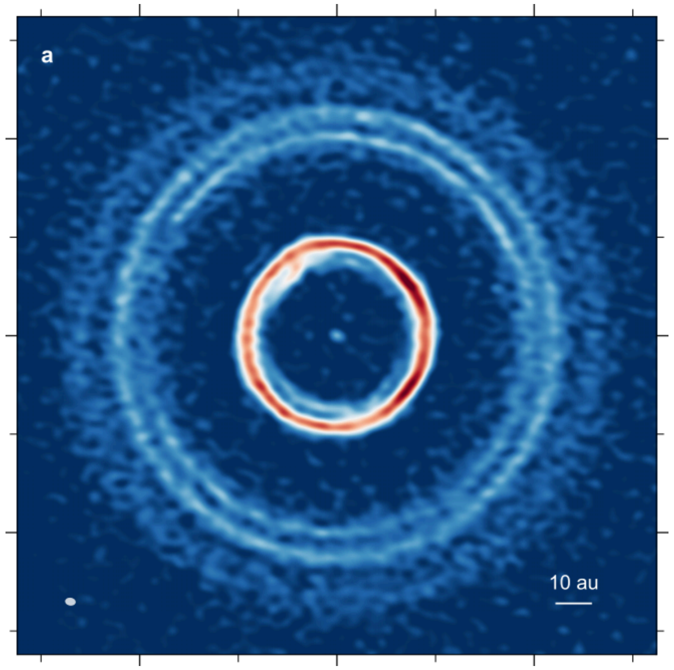
MWC758



HD142527



HD169142



Fukagawa et al. 2013
Pineda et al. 2018
Kudo et al. 2018
Dong et al. 2018
Perez et al. 2019

Inner dust disk: gap?

Depletion time scale: radial flows?

Francis & van der Marel in prep.

Summary

- An accreting Super-Jupiter in a low-mass disk becomes eccentric and opens a wide gap
- Ratios of gas gap vs dust gap suggest that some companions may be (sub)stellar: binarity?
- Higher resolution gas observations are essential to derive gas gap properties (depth, width)
- Inner disk observations may help to constrain gap and accretion properties