The gas mass in protoplanetary disks

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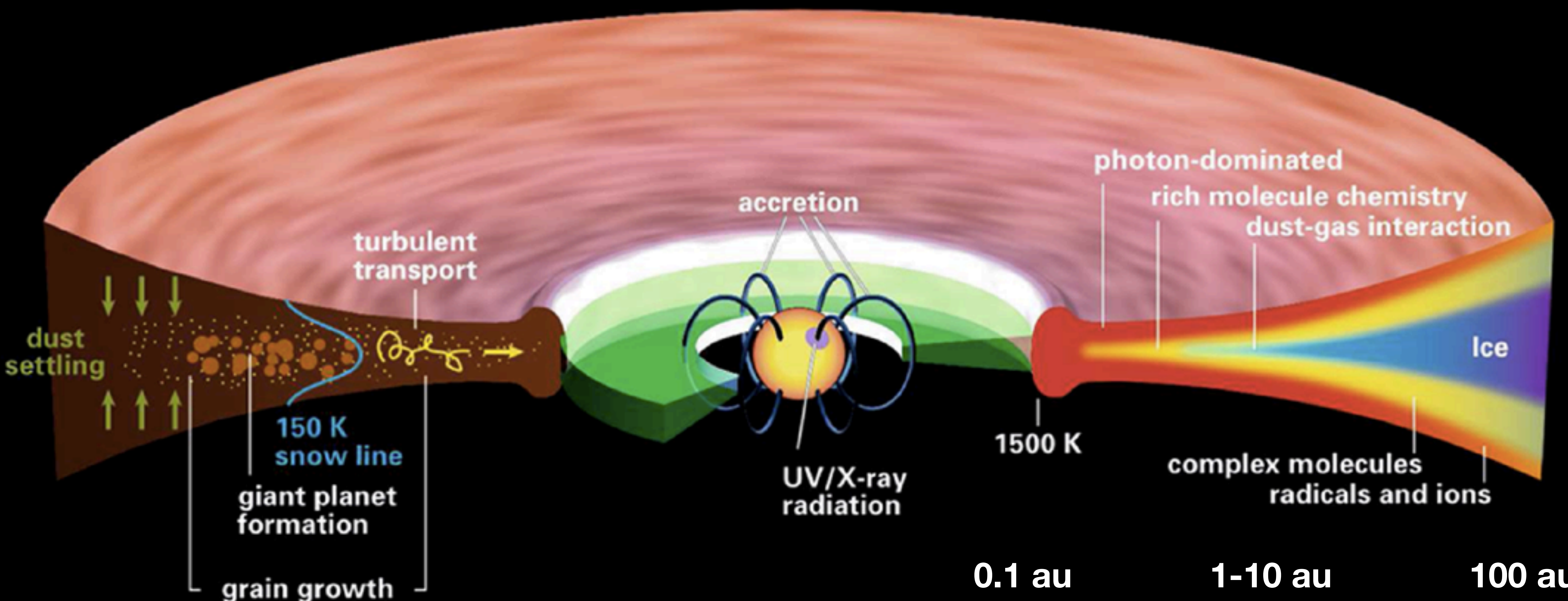
with **Leon Trapman**

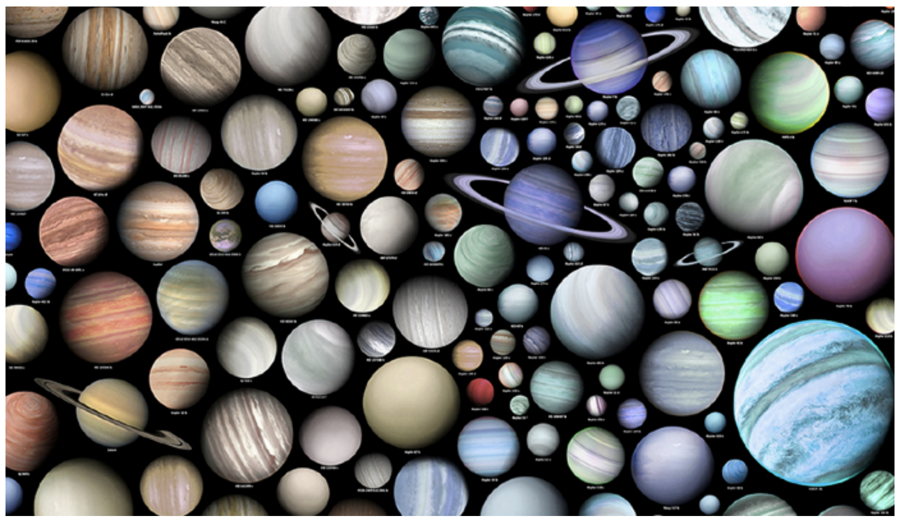
Where planets form



Henning & Semenov (2013)

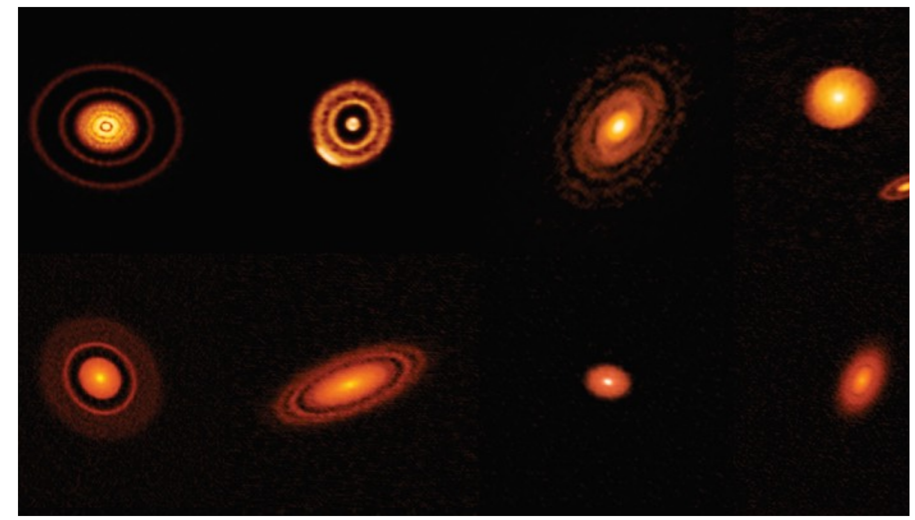
Why measure the gas mass?

The Golden Age of exoplanets



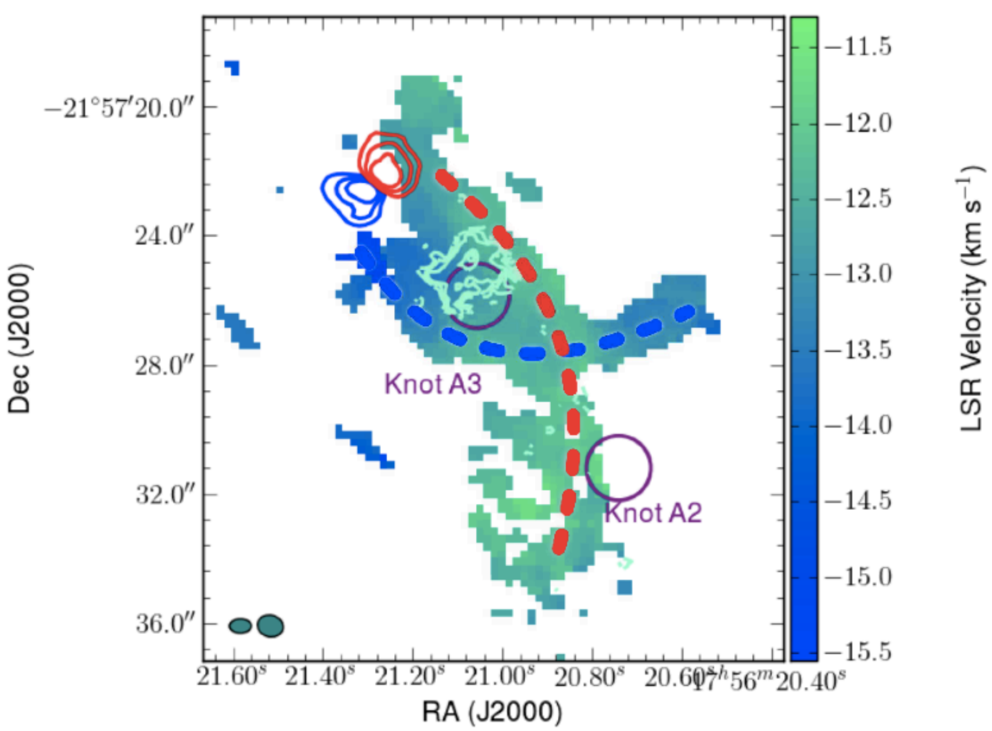
Martin Vargic; Time Magazine

Gas controls dust evolution: building cores, terrestrial planets



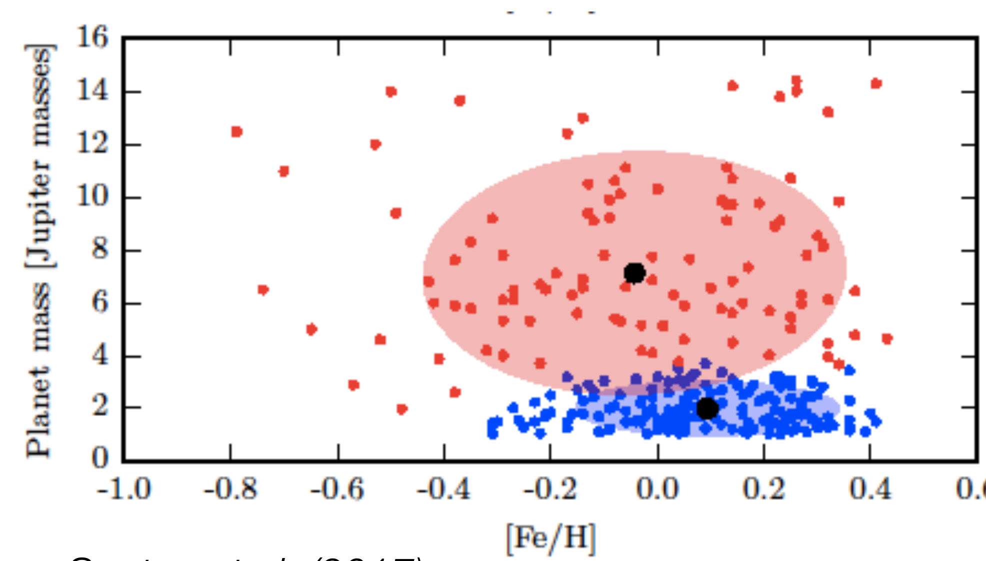
Andrews et al. (2018)

Disk evolution: accretion, winds



Klaassen et al. (2013)

Giant planets: core accretion vs gravitational instability



Santos et al. (2017)

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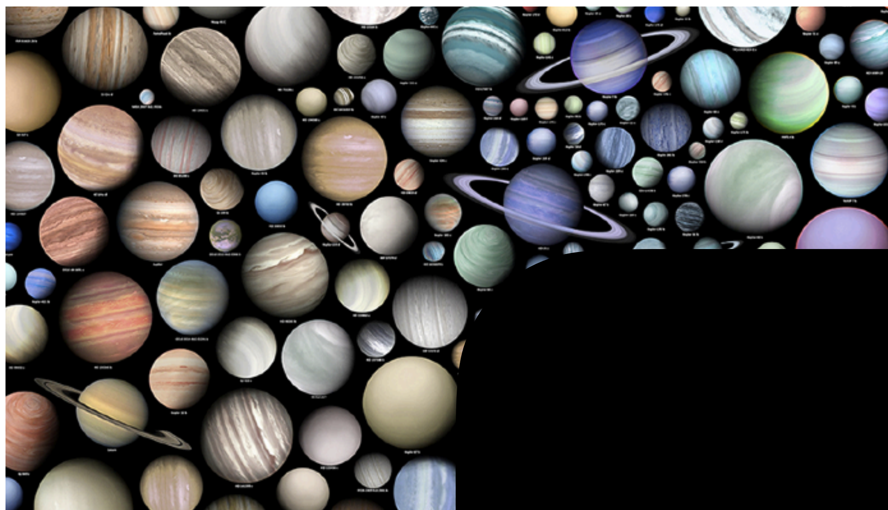
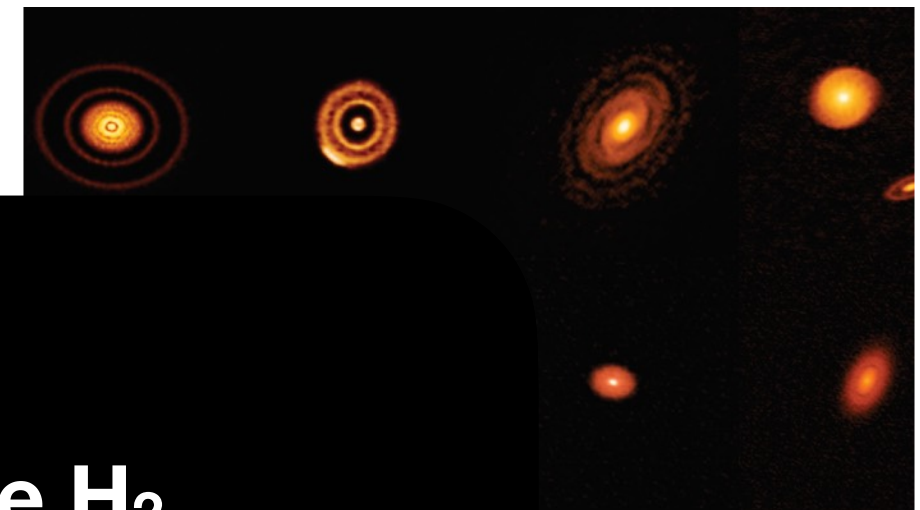
The Golden Age of exoplanets



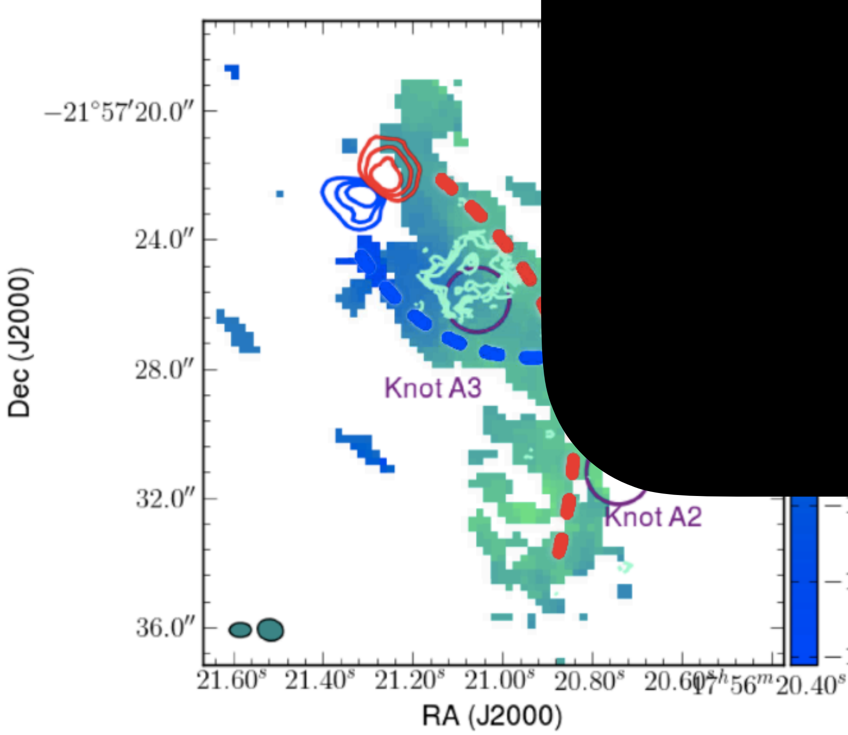
Martin Vargic; Time Mag

Gas controls dust evolution: building cores, terrestrial planets



Measuring the H_2 mass is a timely and key challenge

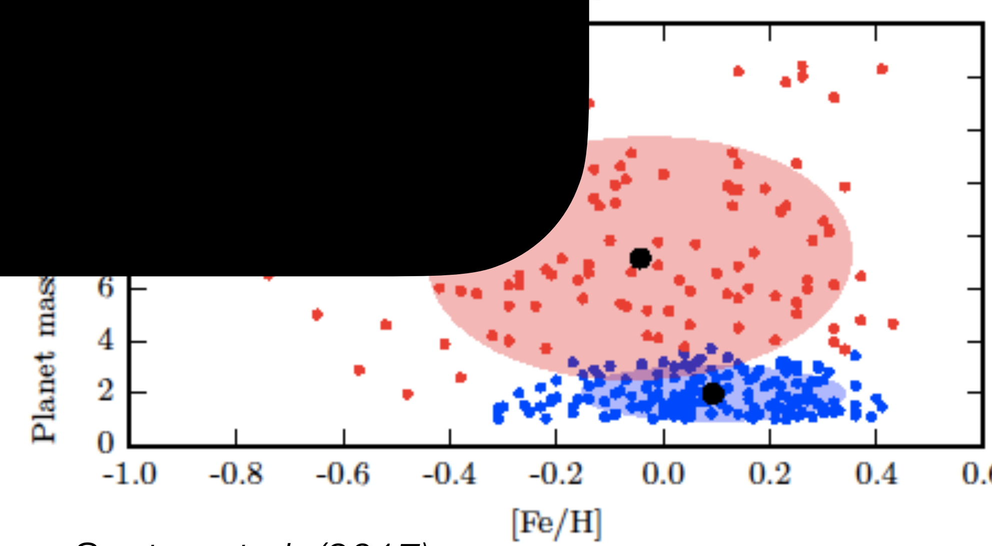
Disk evolution:



Klaassen et al. (2013)

accretion vs

ility



Santos et al. (2017)

H_2

is invisible at typical disk conditions

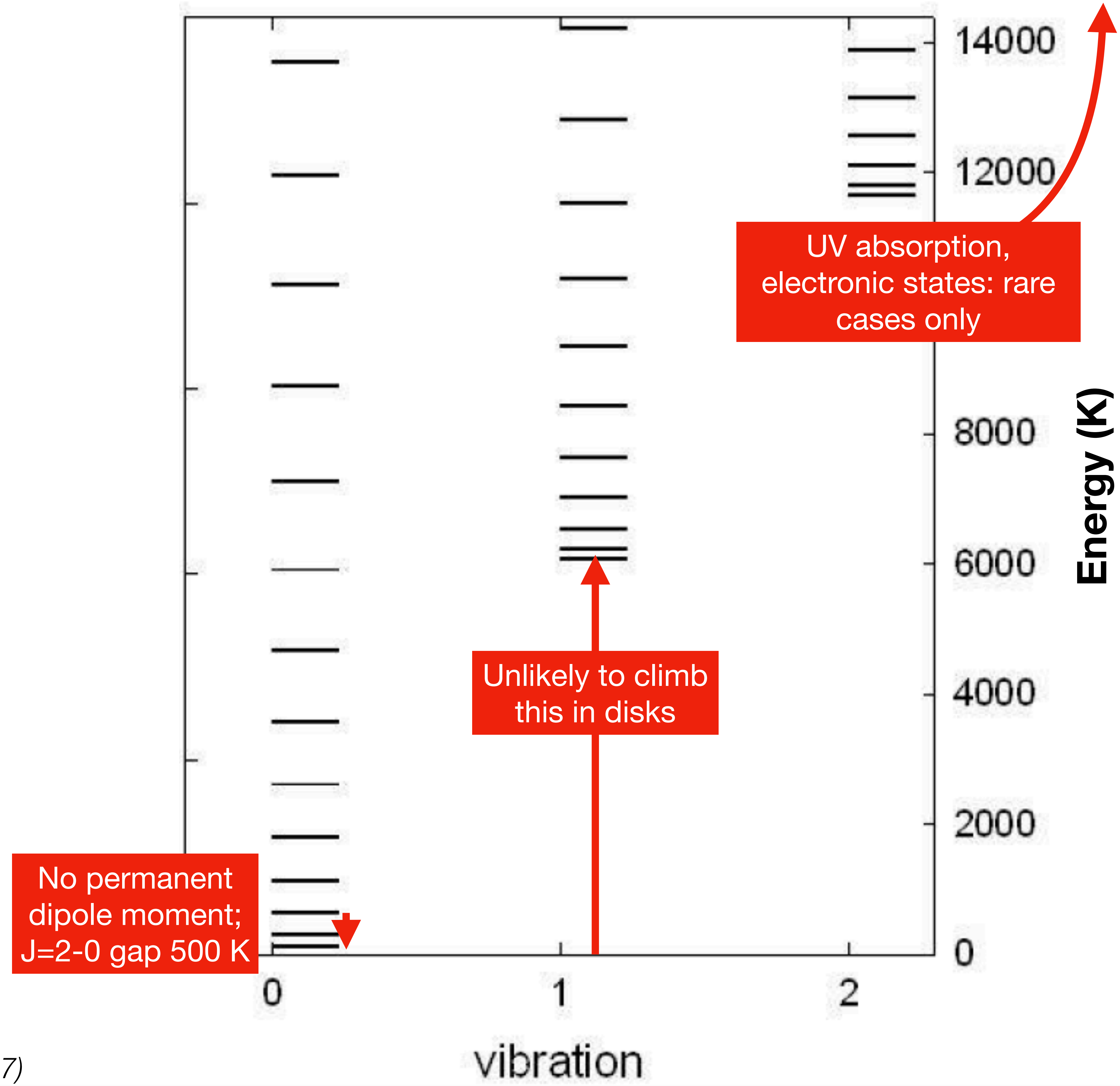
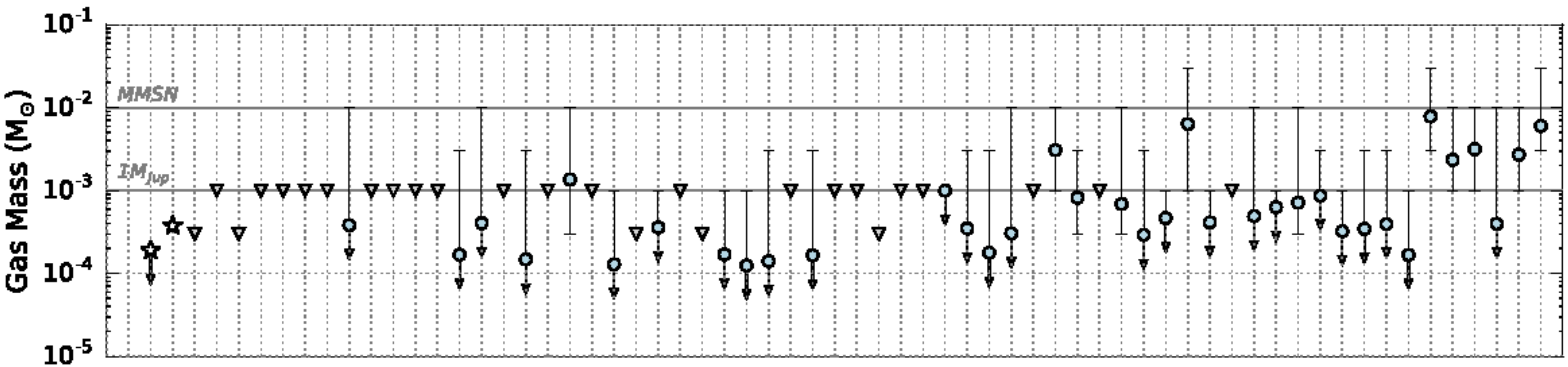


Figure: Shaw et al. (2007)

CO

is unreliable due to
physical & chemical
sequestration on
the midplane



Orders of magnitude uncertainty from the depletion of volatile elements

Favre et al. (2013); Kama et al. (2016); ***Ansdell et al. (2016)****; Miotello et al. (2017)*

Hydrogen deuteride

- Cosmic D/H = (2.0±0.1) x 10^{-5}
  Prodanovic et al. (2010); Linsky et al. (1998)

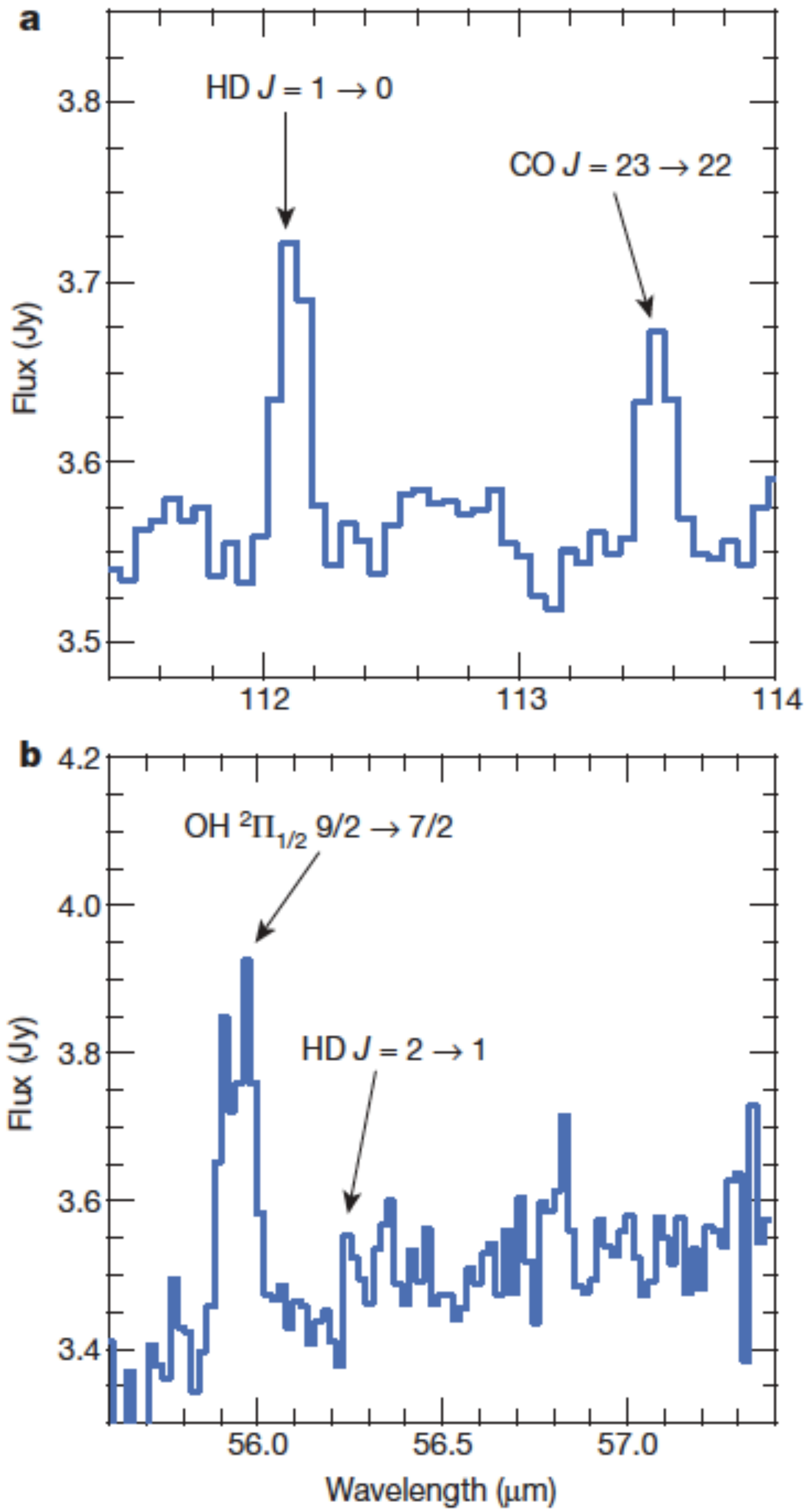
- HD/H_2 ~ (3-4)e-5 at disk conditions
  Bergin et al. (2013); Trapman et al. (2017)

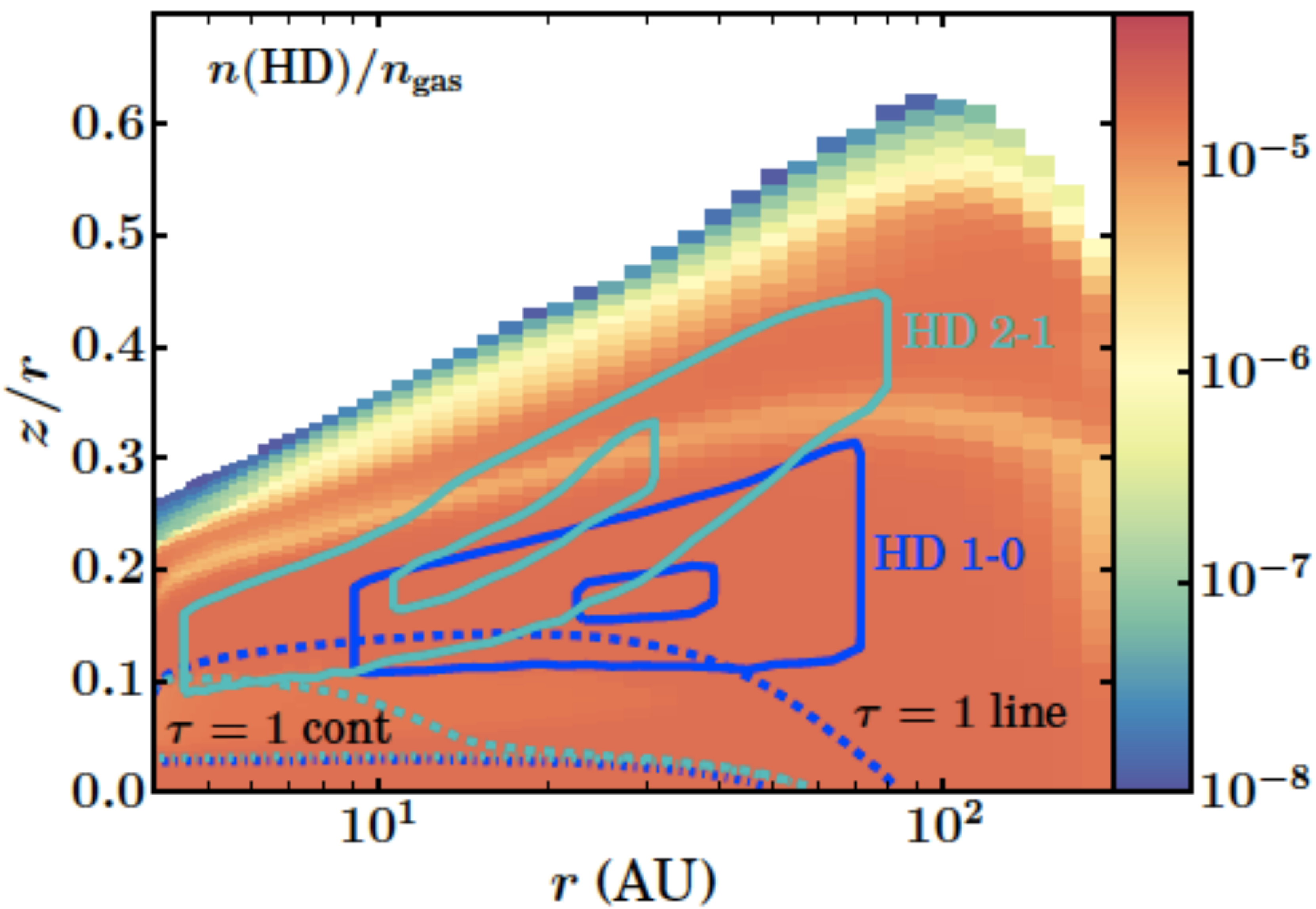
- Rotational J=1-0
  E = 128.5 K
  λ = 112 μm (impossible from ground)

- Best chemical proxy for H_2 mass in disks

HD emission in TW Hya

7h of *Herschel* integration time (Bergin+13)

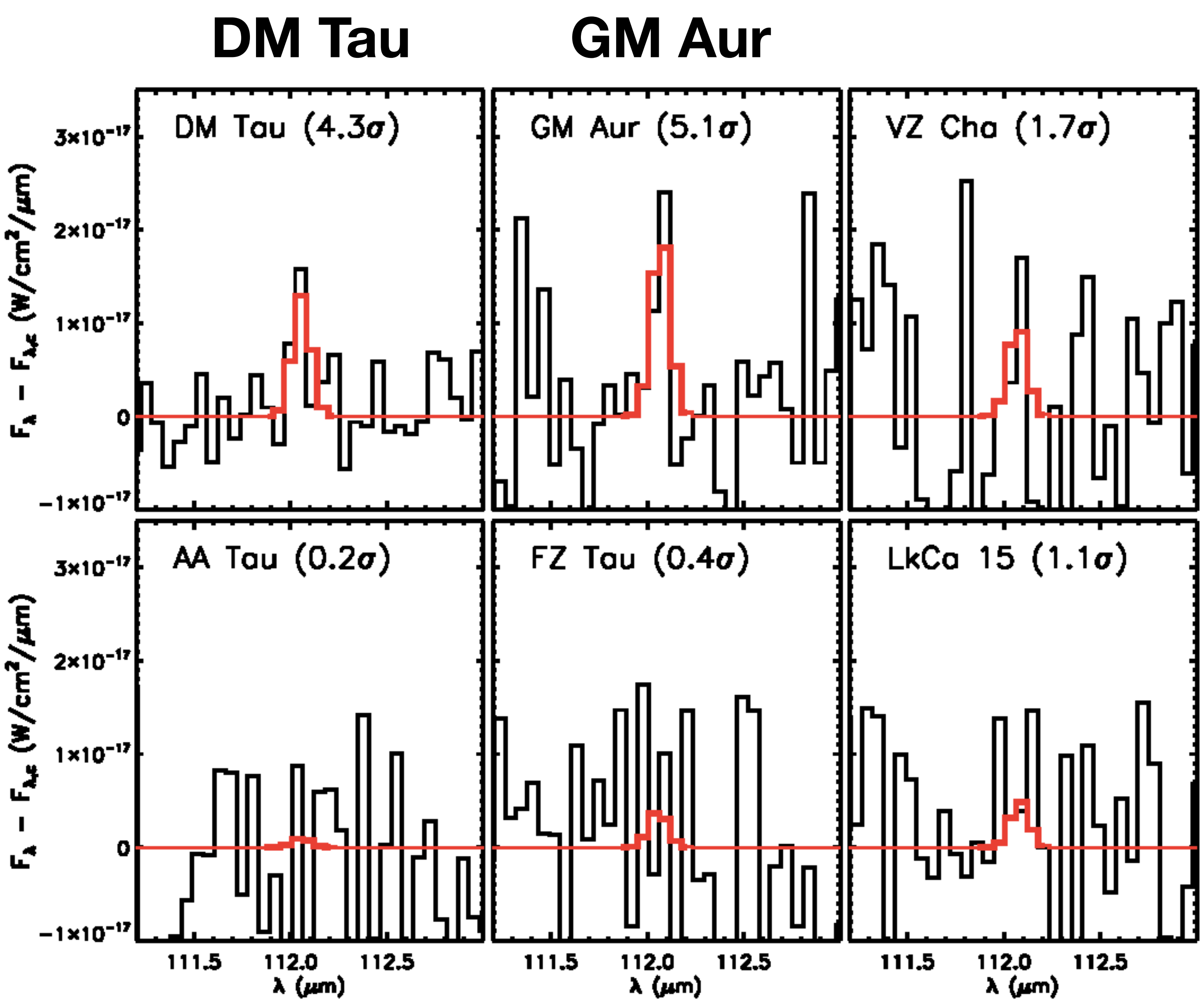




Bergin et al. (2013)

Trapman et al. (2017)

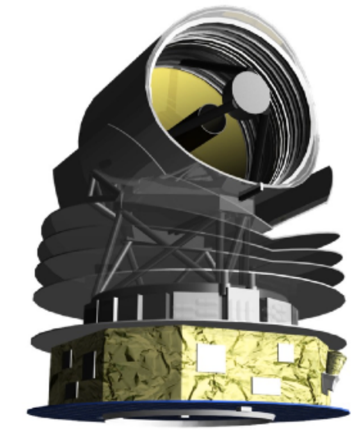
HD emission in DM Tau & GM Aur

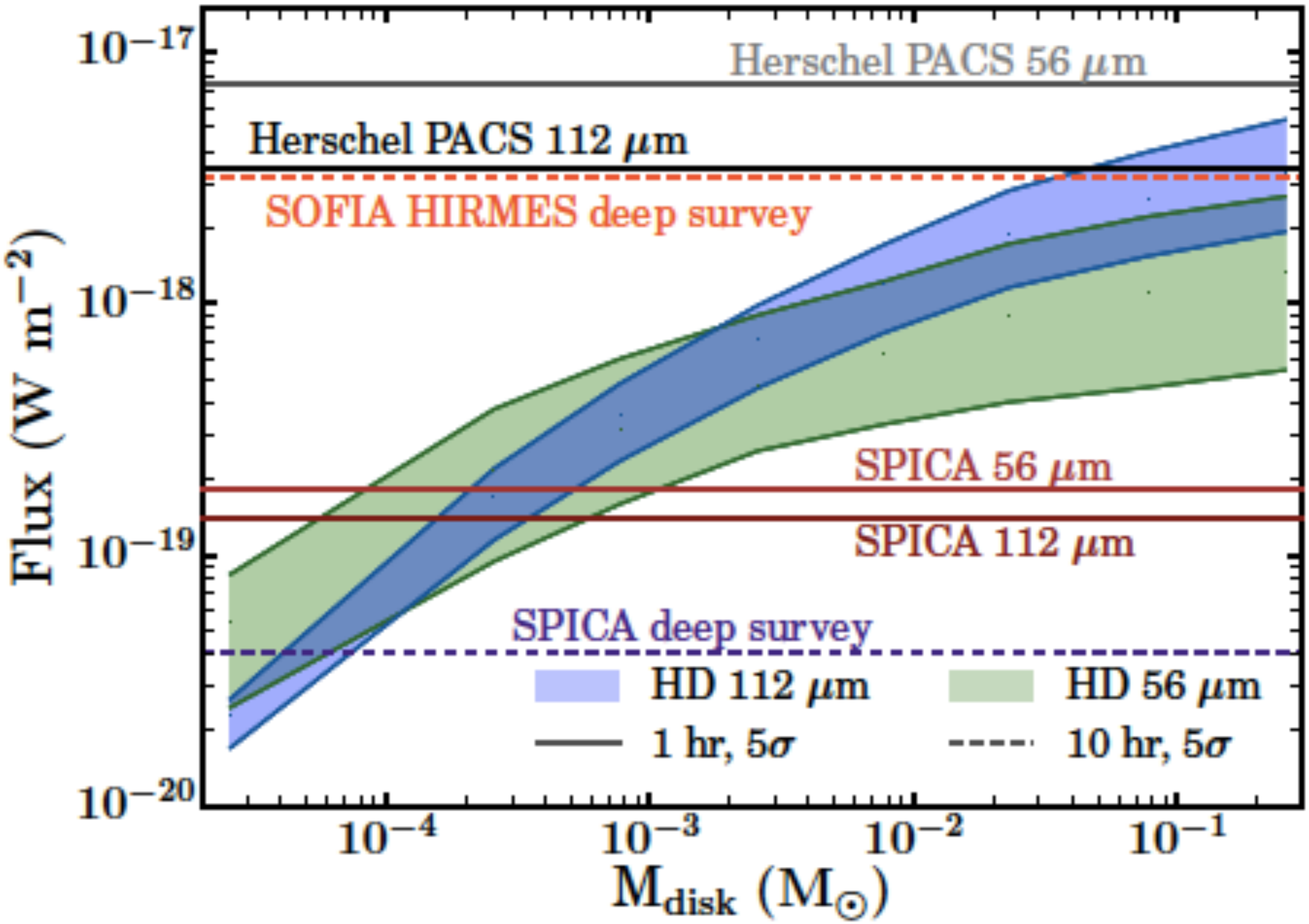


Disk	Mass (10^{-2} $M_\odot$)
TW Hya	6.0 - 9.0
DM Tau	1.0 - 4.7
GM Aur	2.5 - 20.4

Bergin et al. (2013); McClure et al. (2016); Trapman et al. (2017)

Herschel, SOFIA, SPICA

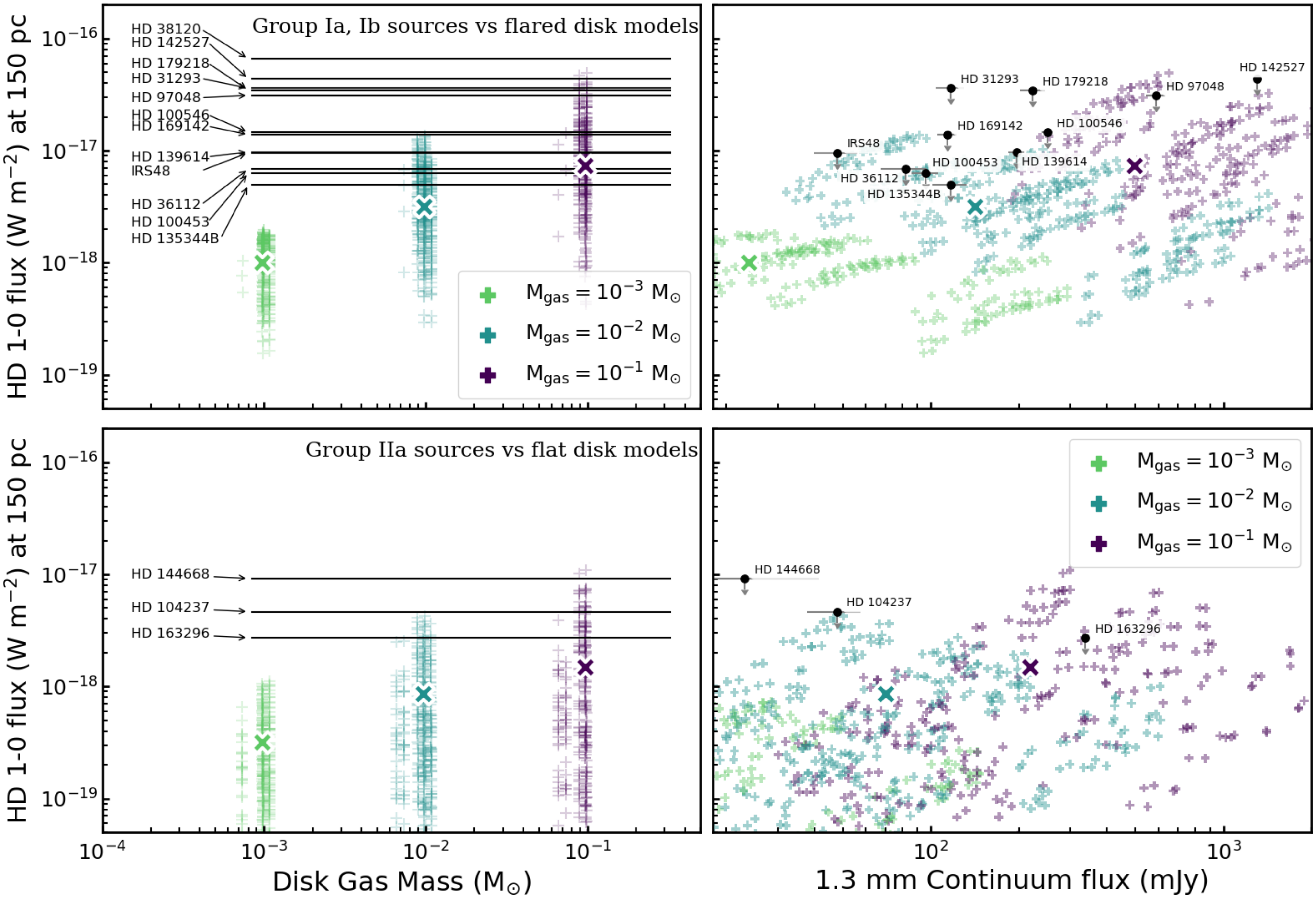




Trapman et al. (2017)

New constraints on 15 disks

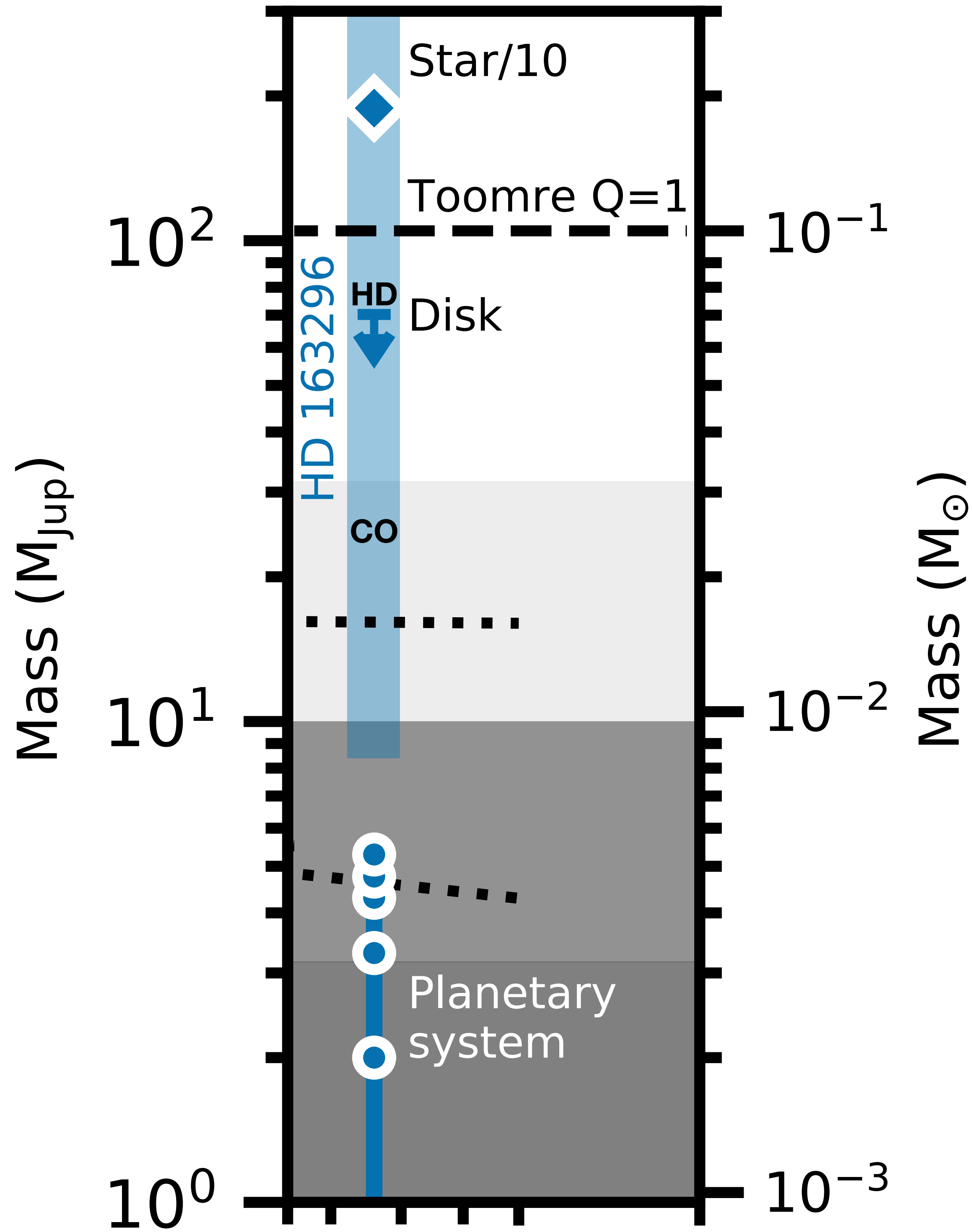
- *Herschel*/PACS archival data from DIGIT
  PI Neal Evans
- Detections of CO, OH, etc. published
  Fedele et al. (2013); Meeus et al. (2013)
- HD J=1-0 and 2-1 not detected, not analysed
- We investigate limits on Herbig Ae/Be disks (L_{*}~10-100 $L_{\odot}$)…
- …and use DALI for modelling
  Bruderer et al. (2012); Bruderer (2013); Trapman et al. (2017)



Kama, Trapman, et al. (2020)

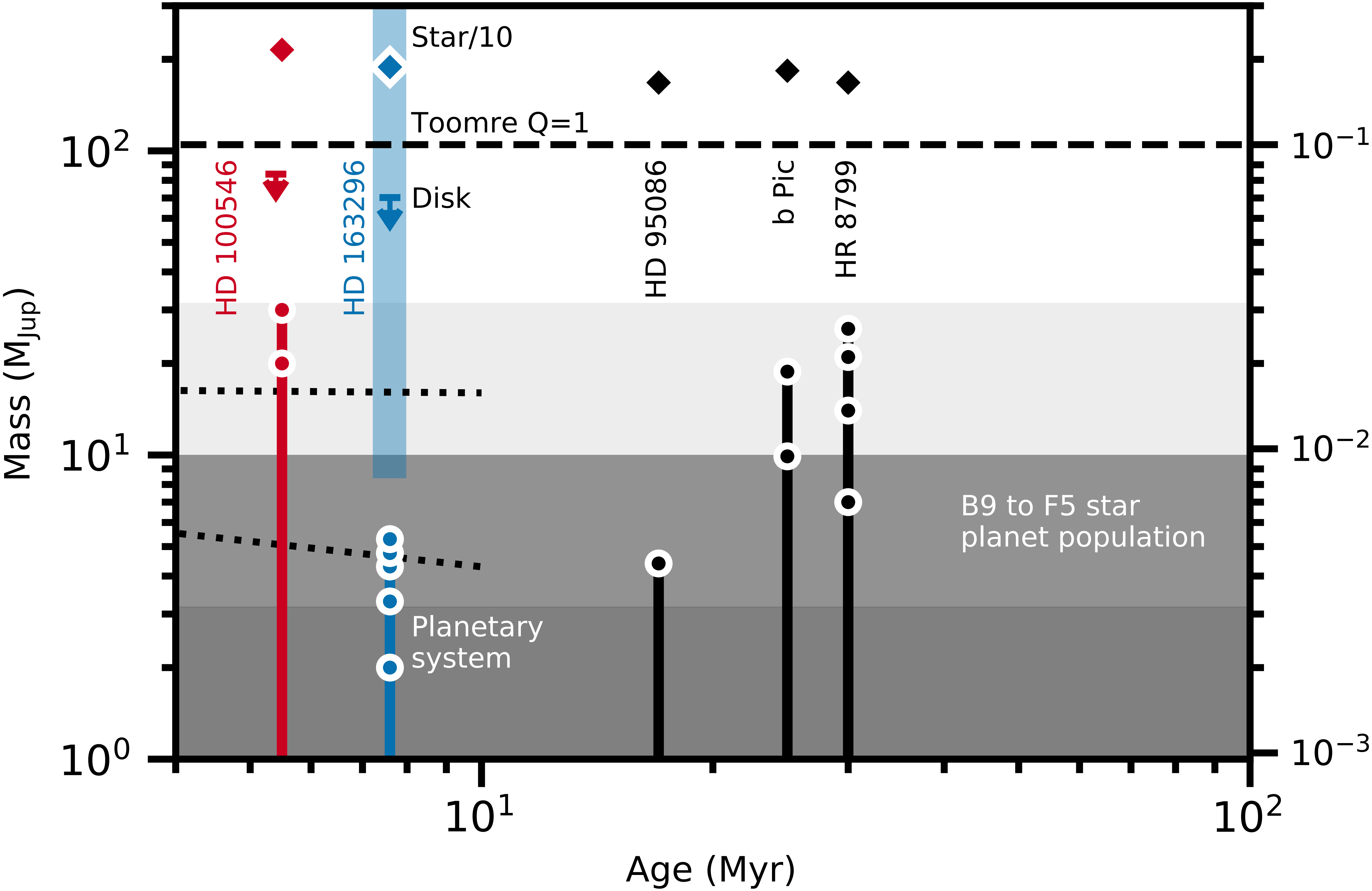
The disk around

HD 163296



Parameter	Value
γ	0.9
ψ	0.05
h_c	0.075
R_c	125 au
Σ_c R_{cav}	0.41 au
M_{gas}	6.7×10^{-2} $M_\odot$
M_{dust}	6.6×10^{-4} $M_\odot$
$\Delta_{g/d}$	100
f_{large}	0.9
χ	0.2
L_* ($L_\odot$)	37.7
i (°)	45
d (pc)	101 pc

Kama, Trapman, et al. (2020)



Kama, Trapman, et al. (2020)

HD: the best measure of disk mass

- **Pioneering HD detections**: TW Hya (7.5e-2 $M_\odot$; *Bergin+13*), DM Tau and GM Aur (2.9e-2 $M_\odot$ and 1.2e-1 $M_\odot$; *McClure+2016*)
- **HD upper limits**: $M_{gas} < 0.1\ M_\odot$ for 11 disks, stable to GI (*Kama+2020*)
  — HD 163296 disk < 0.067 $M_\odot$
  — HD 100546 disk < 0.08 $M_\odot$
- **Planets can reach 10-40% of the current disk gas mass** (*Kama+2020*)
- Supporting data (dust & CO) are in archives or can be obtained from the ground
- New data similar to *Herschel* on **HD 1-0** and 2-1 would be **unique and impactful** in planet formation studies: *disk evolution physics; planet build-up; anchor for chemical abundances*

HD is not the hero we deserve,
but the hero we need

Kama, Trapman, et al. (2020)
see also Trapman et al. (2017)