Reservoirs of Water in Protoplanetary Disks: a multi-wavelength view

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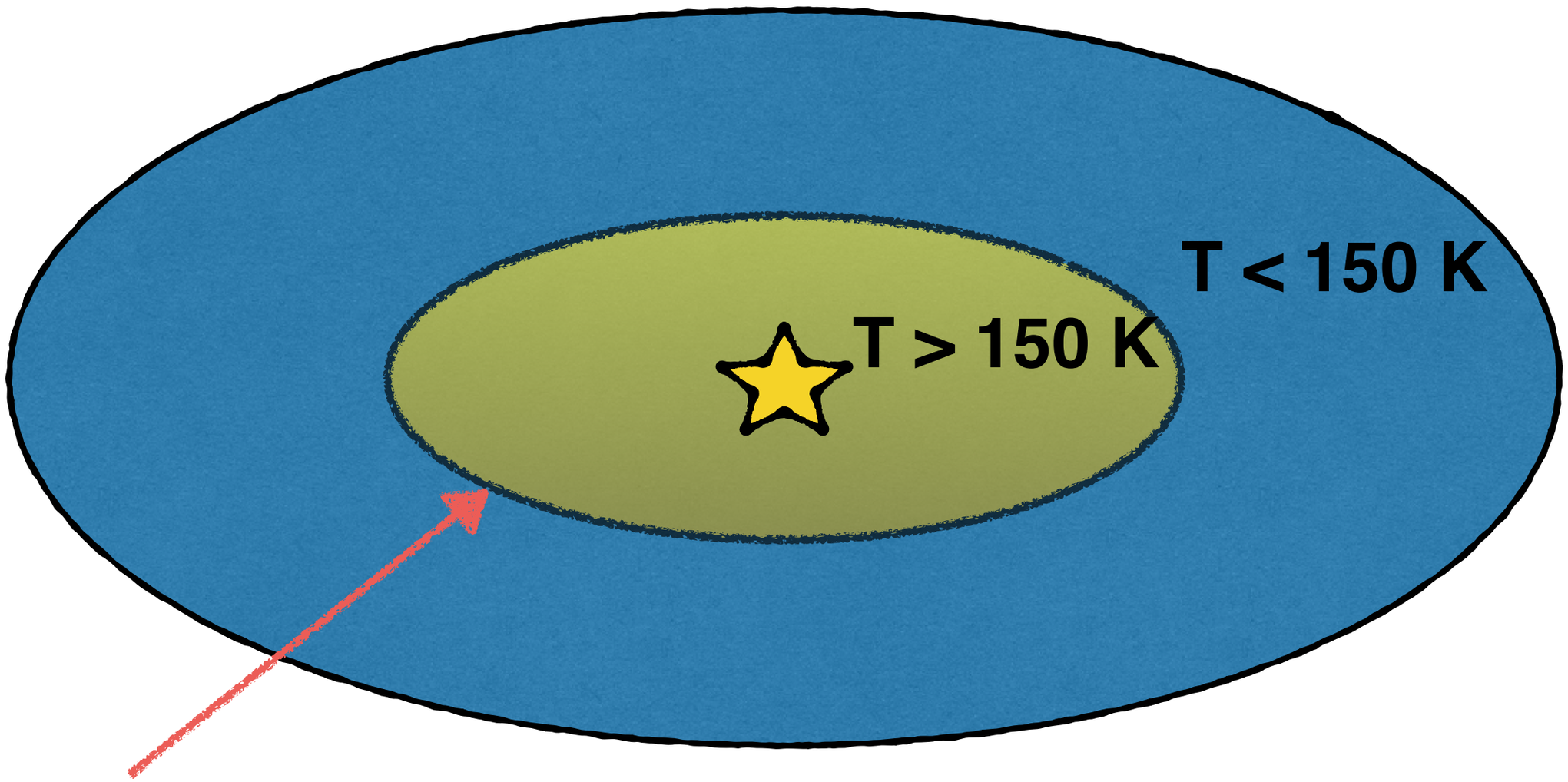
Outline

- Introduction
- H_2O in Disks: from Spitzer to Herschel
- H_2O abundance in HD 100546 & HD 163296
- Conclusions

Water in protoplanetary disks



H_2O phase transition gas —> solid

- Local enhancement of solid surface density
- Affects physical and chemical evolution

Water on Earth

- “Wet” formation (e.g., Drake ’05)

By adsorption of H_2O-vapor on dust grains. Accretion of hydrated silicates

- “Dry” formation (e.g.Morbidelli et al. ’00)

Water delivered from asteroids and comets after the planet has formed

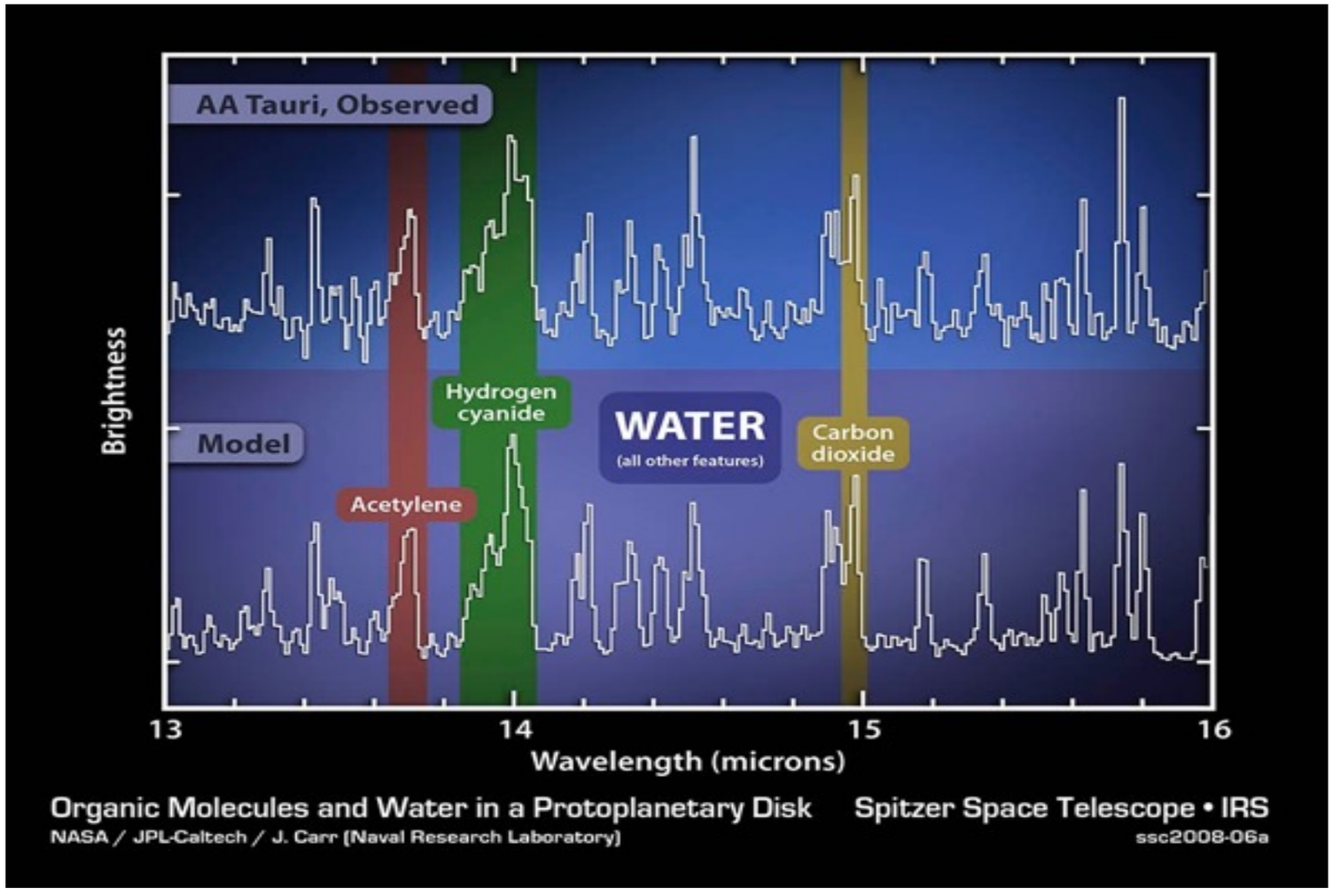
Where is H_2O in protoplanetary disks ?

Motivation

- What is the H_2O abundance in planet forming disks?
- How is H_2O distributed ?
- Are all disks the same ?

H_2O in disks:
a multi-wavelength view

Early results



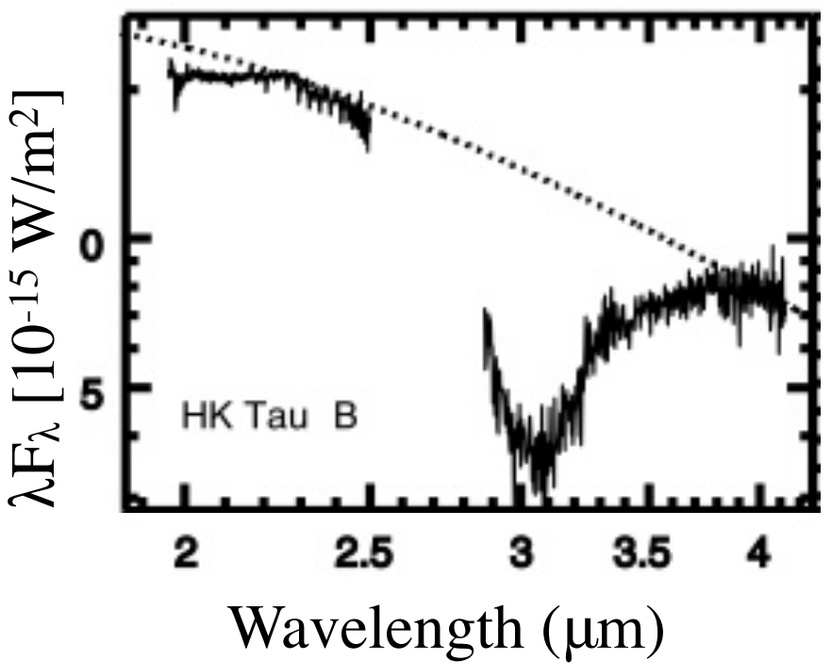
e.g.
Carr & Najita 2004, 2008
Salyk+ 2008
Mandell+ 2008
Pontoppidan+ 2010
Fedele+ 2011

e.g.
Glassgold+ 2009
Woitke+ 2009
Meijerink+ 2009
Bethell & Bergin 2010
Najita+ 2011
Adamkovics+ 2014
Antonellini+ 2015a,b

Abundant (~ 10^{17} cm^{-2}) H_2O in disks around Solar-like stars

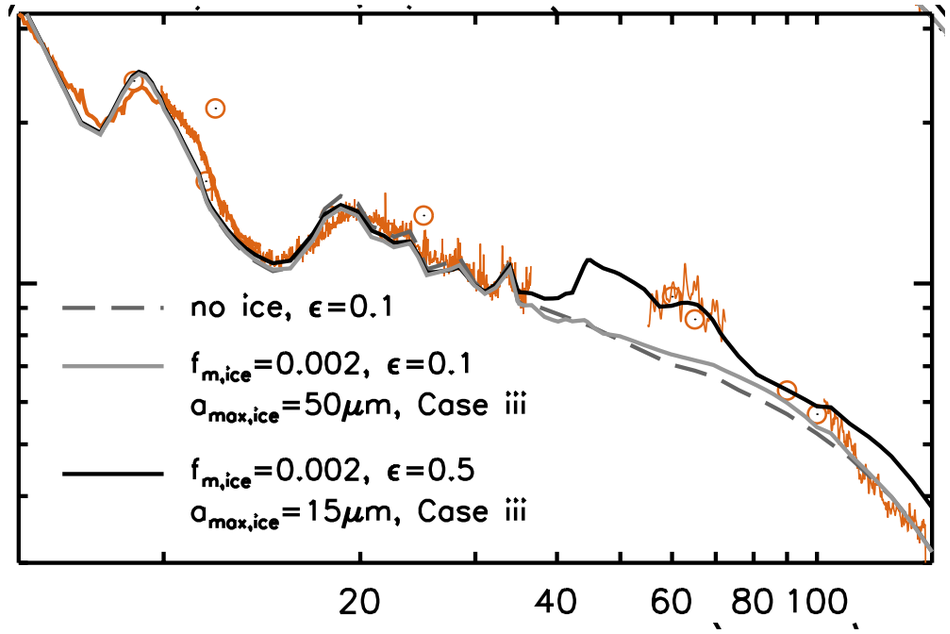
H_2O - ice

3 micron



Terada 2007
Honda 2009

60 micron

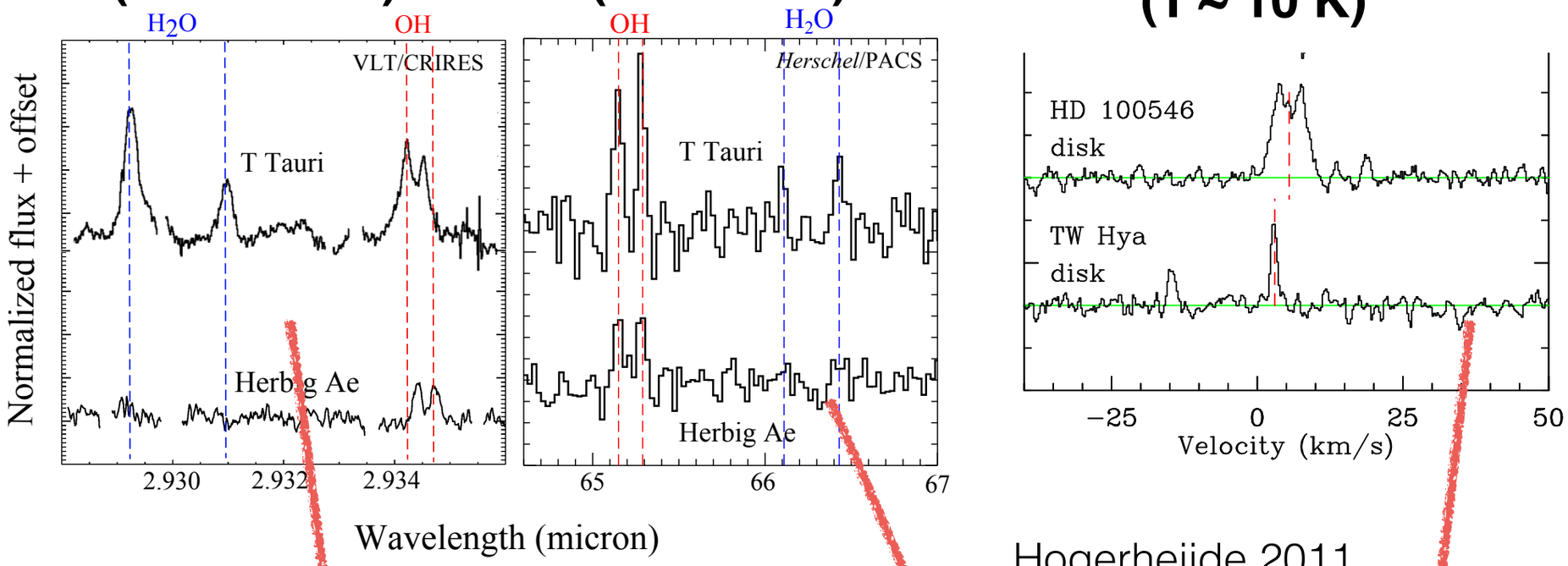


Malfait 1999
McClure 2012

3 micron (T ~ 1000 K)

50/200 micron (T ~ 100 K)

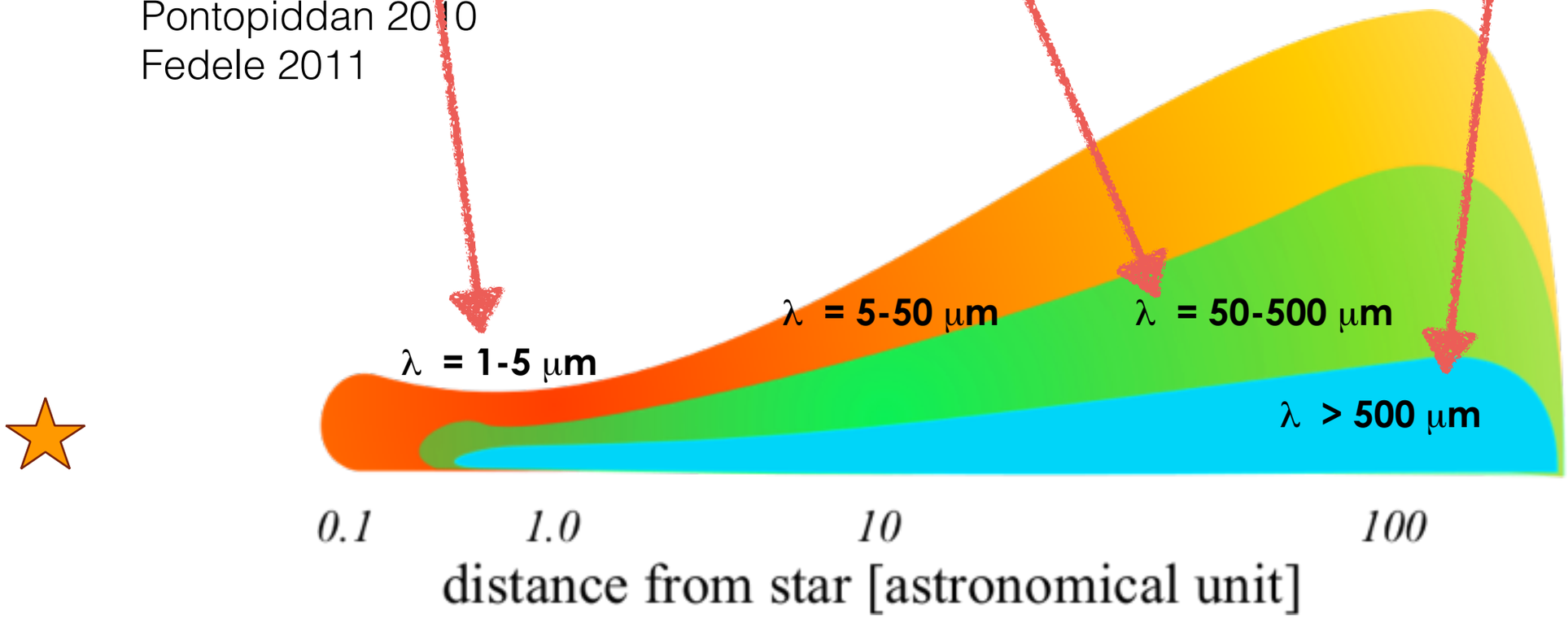
557 micron (T ~ 10 K)



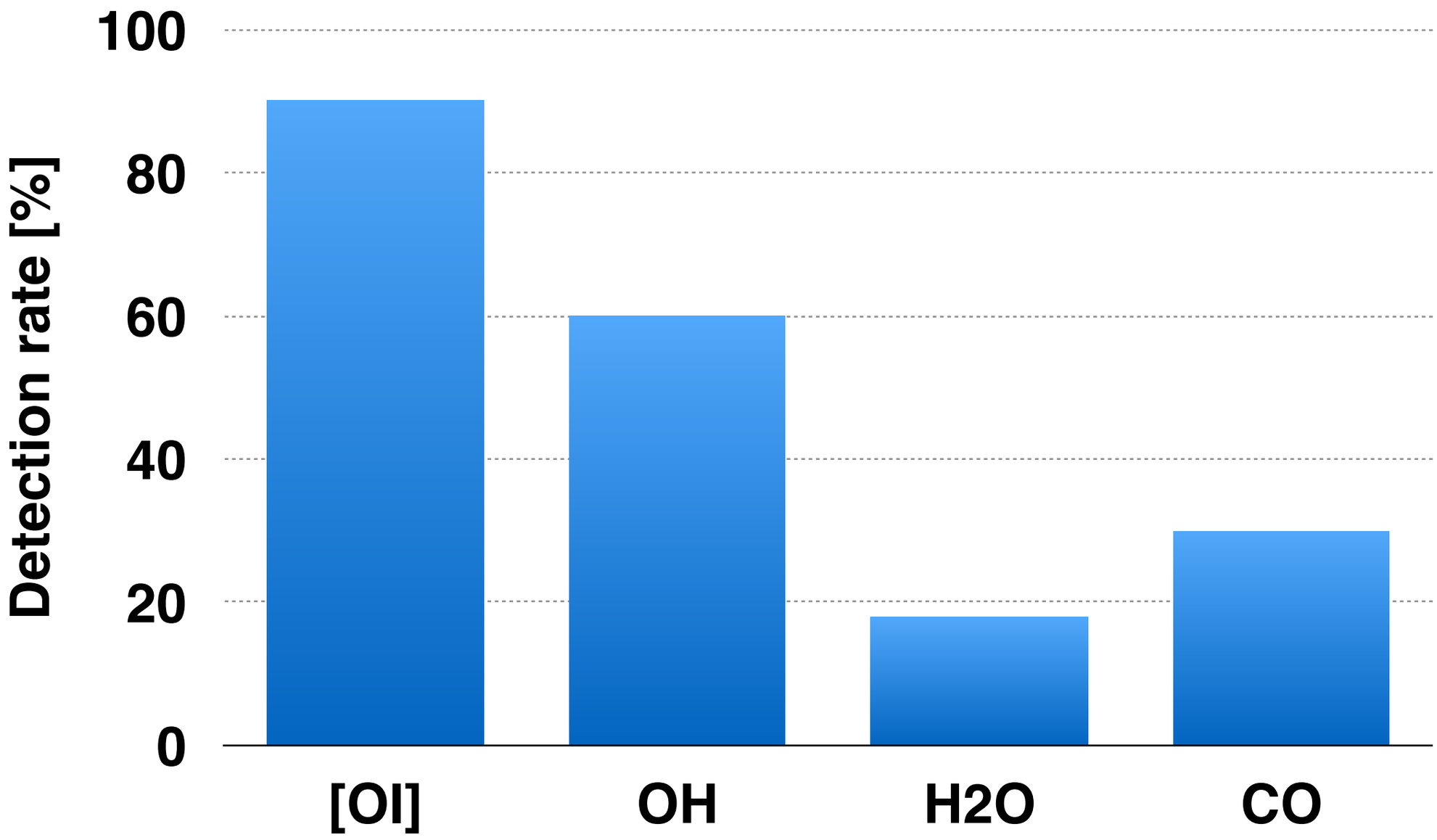
Hogerheijde 2011

e.g.,
Carr & Najita 2008
Pontopiddan 2010
Fedele 2011

e.g.,
Fedele 2012, 2013



Herschel/PACS detection rate

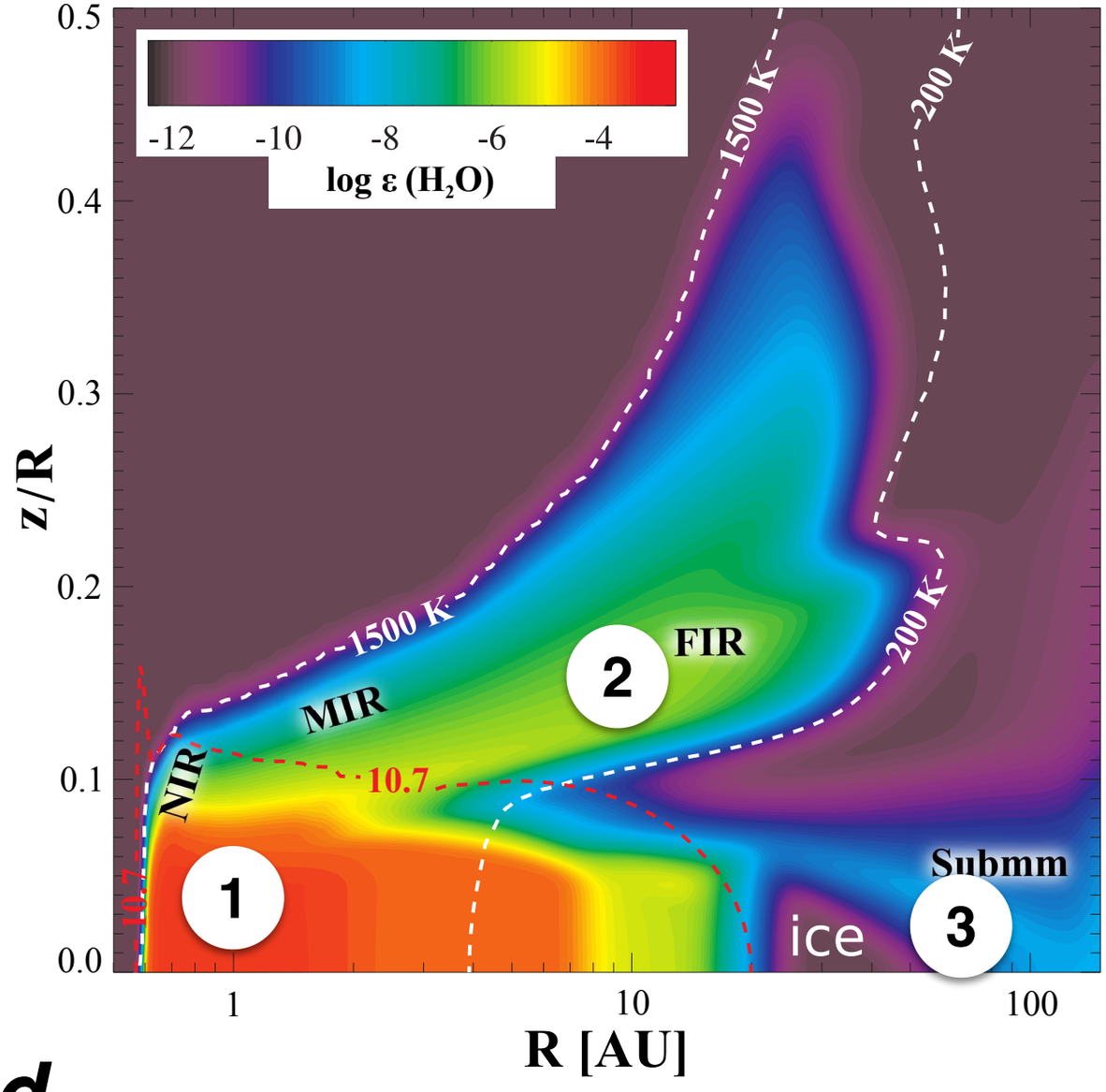


Water reservoirs in disks

r1
(hot) gas-phase

r2
gas-phase

r3
grain-surface
photodesorption

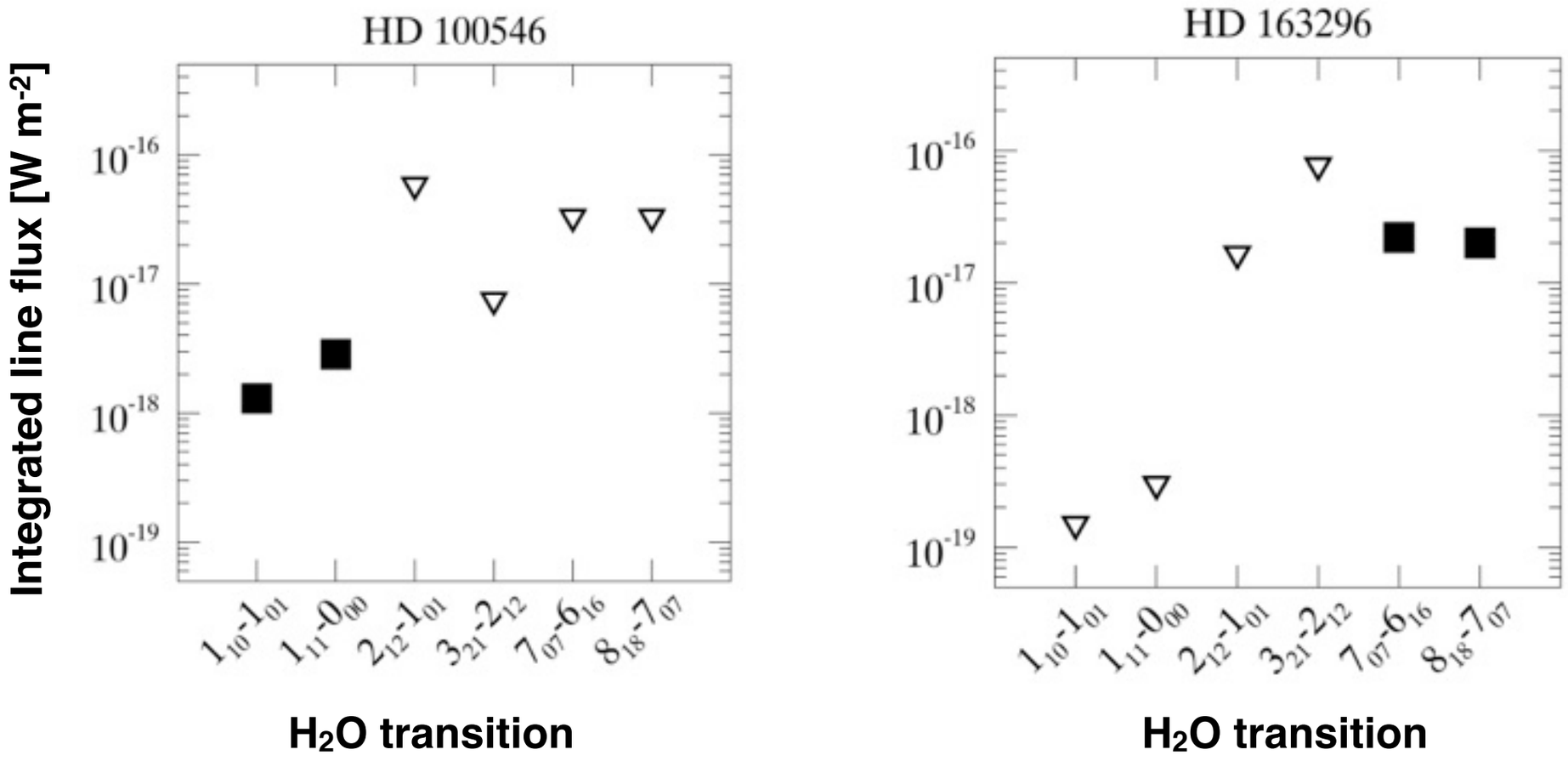


All reservoirs are detected

e.g.,Glassgold 2009; Woitke 2009; Walsh 2011
Bruderer 2012

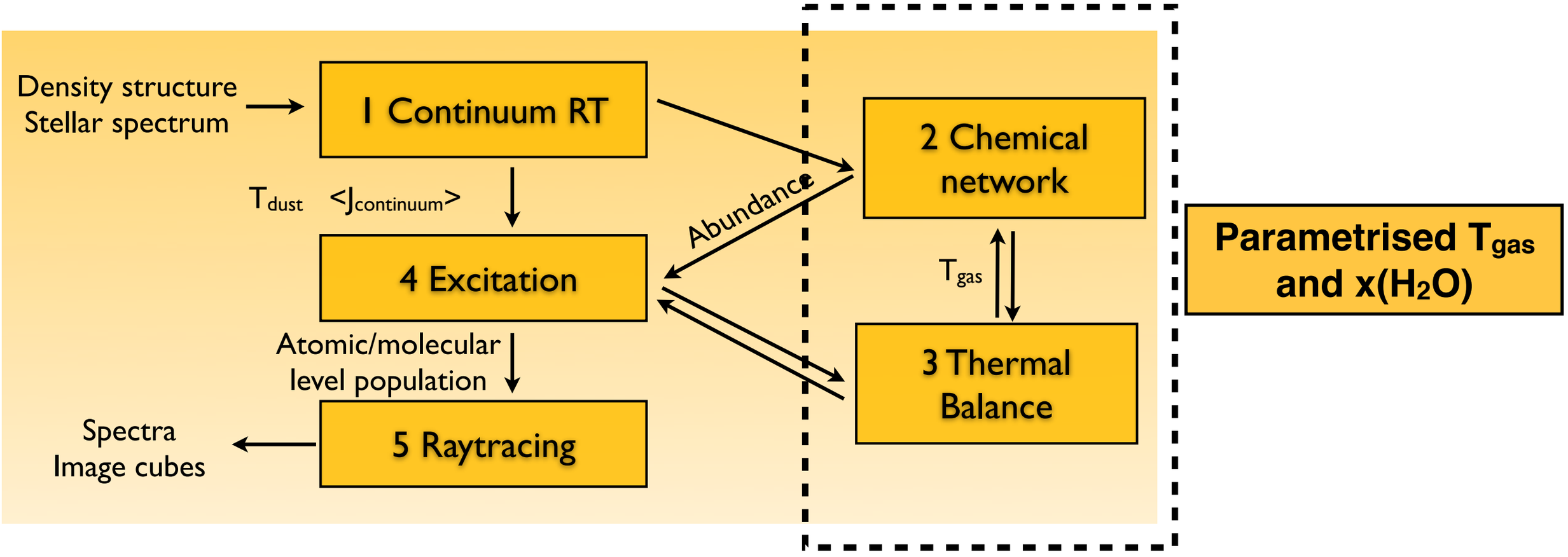
H_2O abundance distribution in HD 100546 and HD 163296

Transition	λ [μm]	E_{up} [K]	Int. flux [10^{-18} W m^{-2}]	
			HD 100546	HD 163296
$1_{10} - 1_{01}$	538.29	53	1.3 ± 0.1	< 0.15
$1_{11} - 0_{00}$	269.28	61	2.9 ± 0.2	< 0.30
$2_{12} - 1_{01}$	179.54	114	< 58.3	< 16.5
$3_{21} - 2_{12}$	75.38	305	< 7.5	< 77.0
$7_{07} - 6_{16}$	71.95	843	< 33.0	22.0 ± 5.0
$8_{18} - 7_{07}$	63.32	1070	< 33.0	20.0 ± 6.0



Fedele in prep

DALI - thermo-chemical code

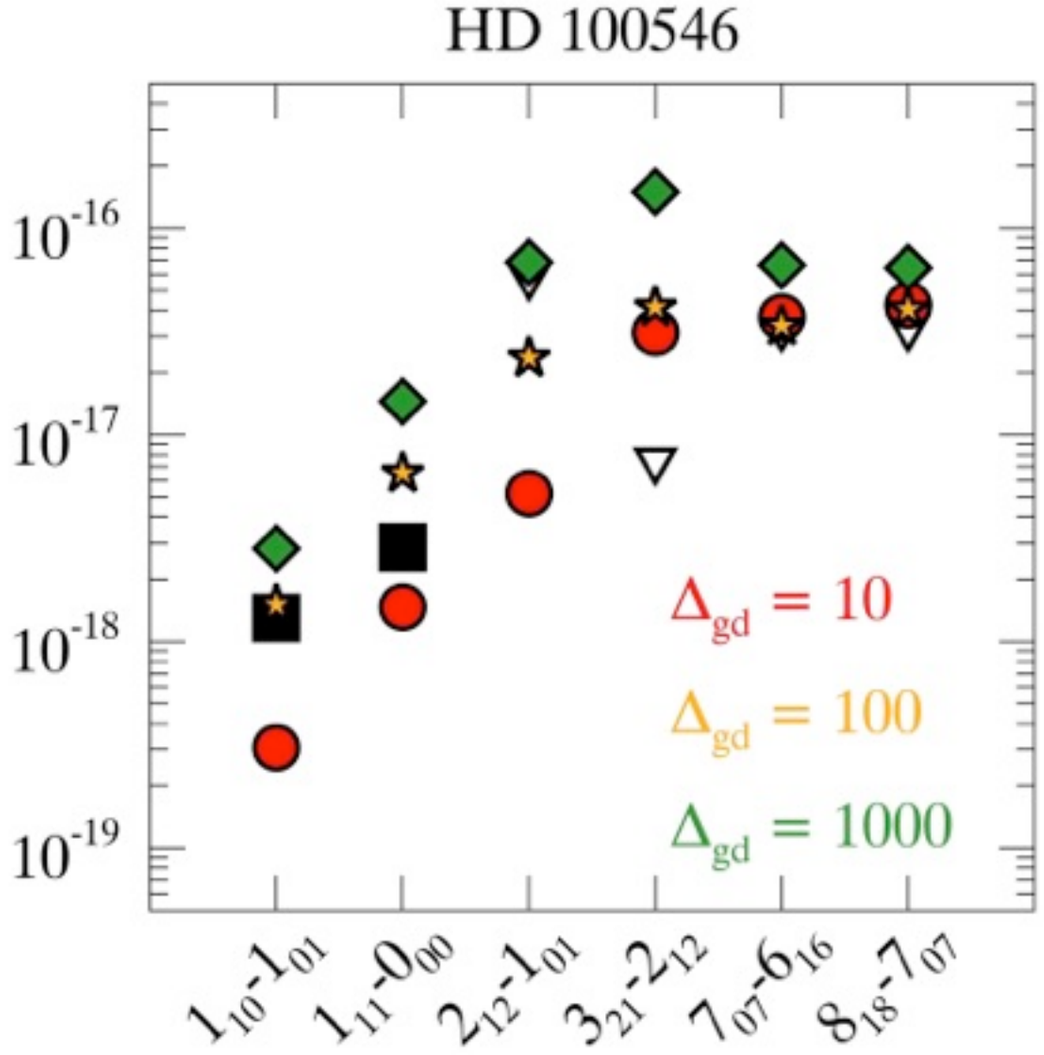


Bruderer 2012, 20013

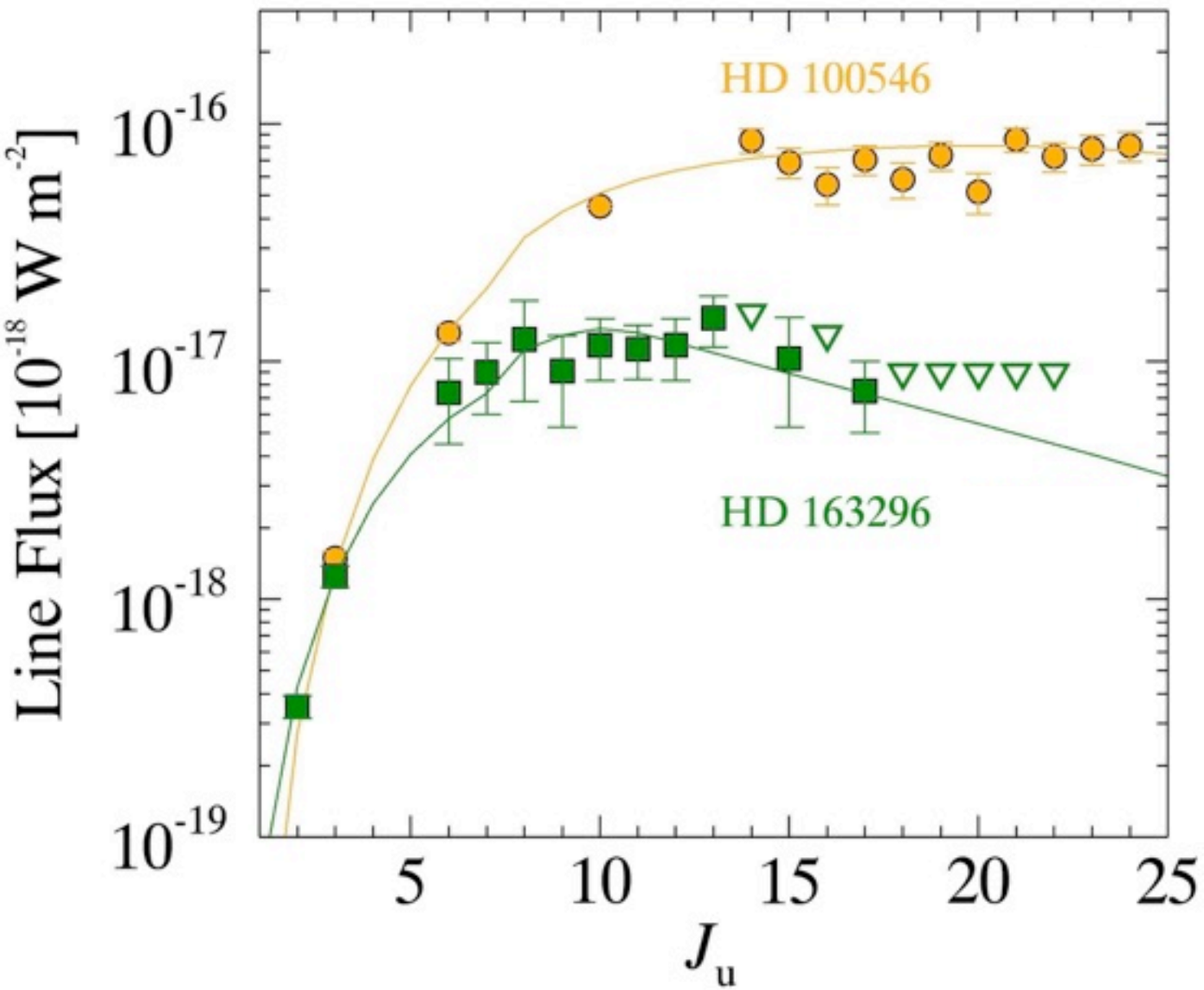
H_2O *vs* physical structure

- Gas mass
- Gas-to-Dust mass ratio

- Scale height
- Flaring angle
- …



Gas temperature constrained by CO rotational ladder



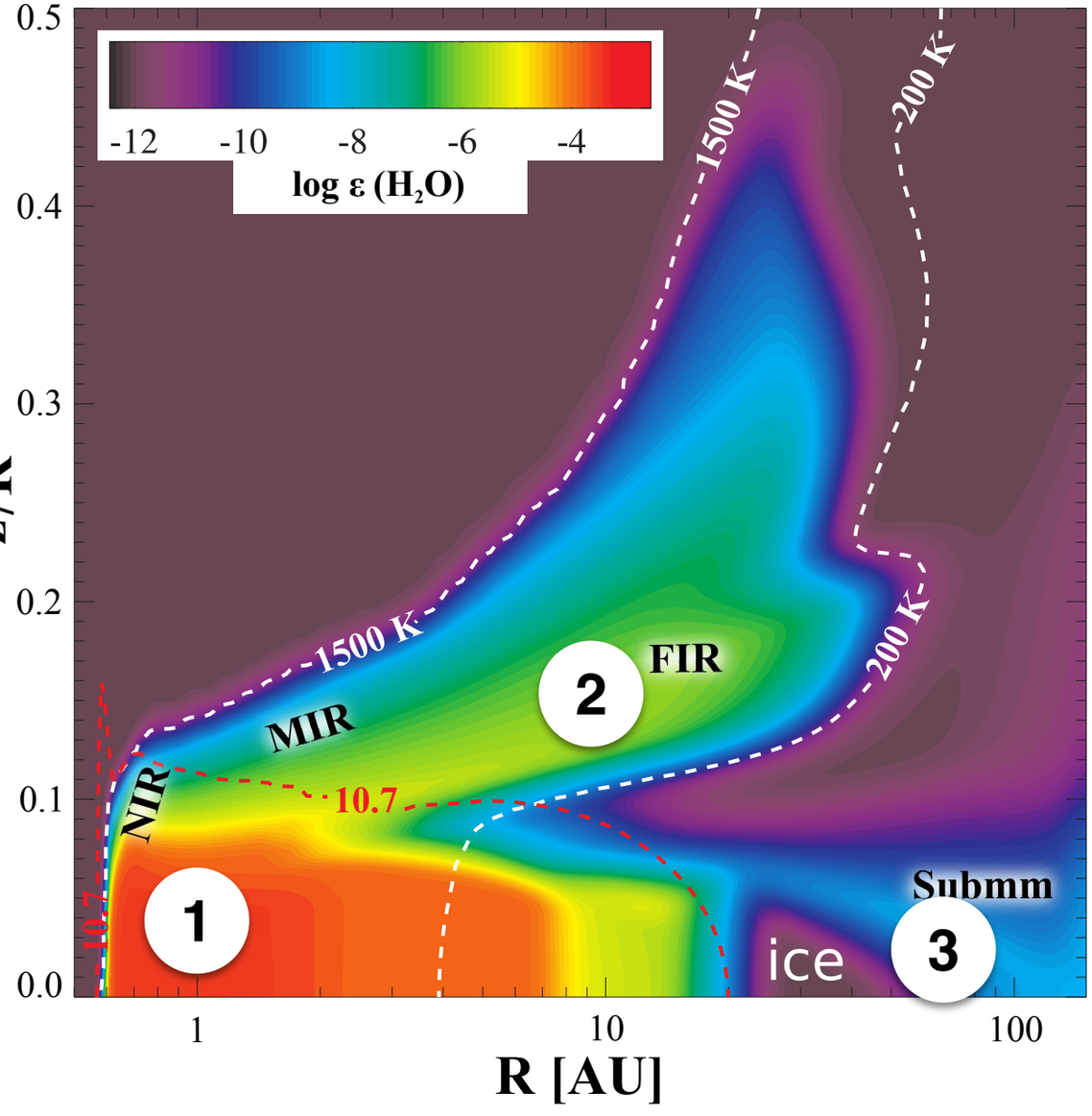
Fedele+ 2016

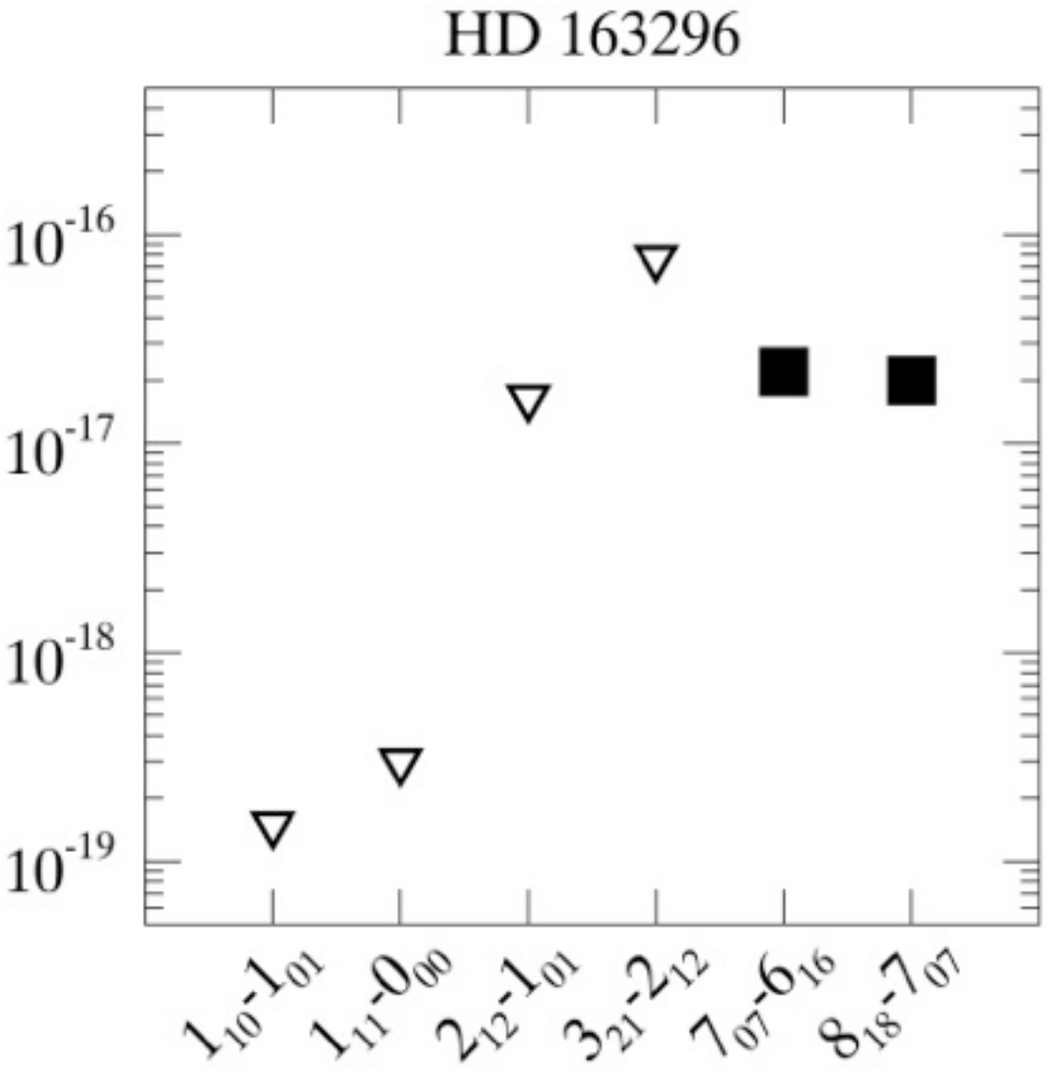
Tune H_2O abundance

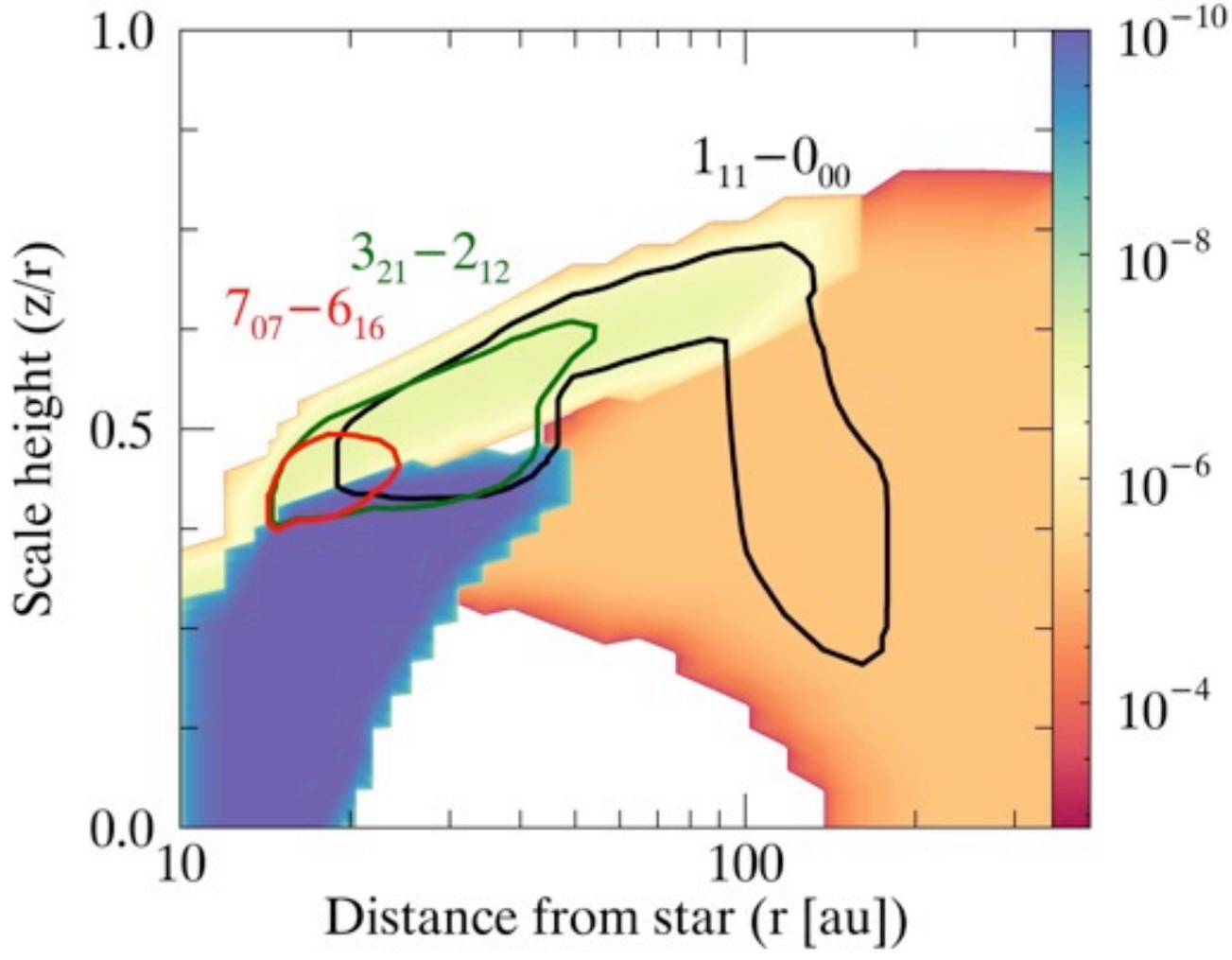
r1
T > 100 K, Av > 2 mag

r2
T > 250 K, Av > 0.5 mag

r3
T < 100 K, Av > 0.5 mag




HD 163296
10^{-16}
10^{-17}
10^{-18}
10^{-19}
1_{10}-1_{01}
1_{11}-0_{00}
2_{12}-1_{01}
3_{21}-2_{12}
7_{07}-6_{16}
8_{18}-7_{07}


1.0
0.5
0.0
Scale height (z/r)
10
100
Distance from star (r [au])
$1_{11}-0_{00}$
$3_{21}-2_{12}$
$7_{07}-6_{16}$
10^{-10}
10^{-8}
10^{-6}
10^{-4}

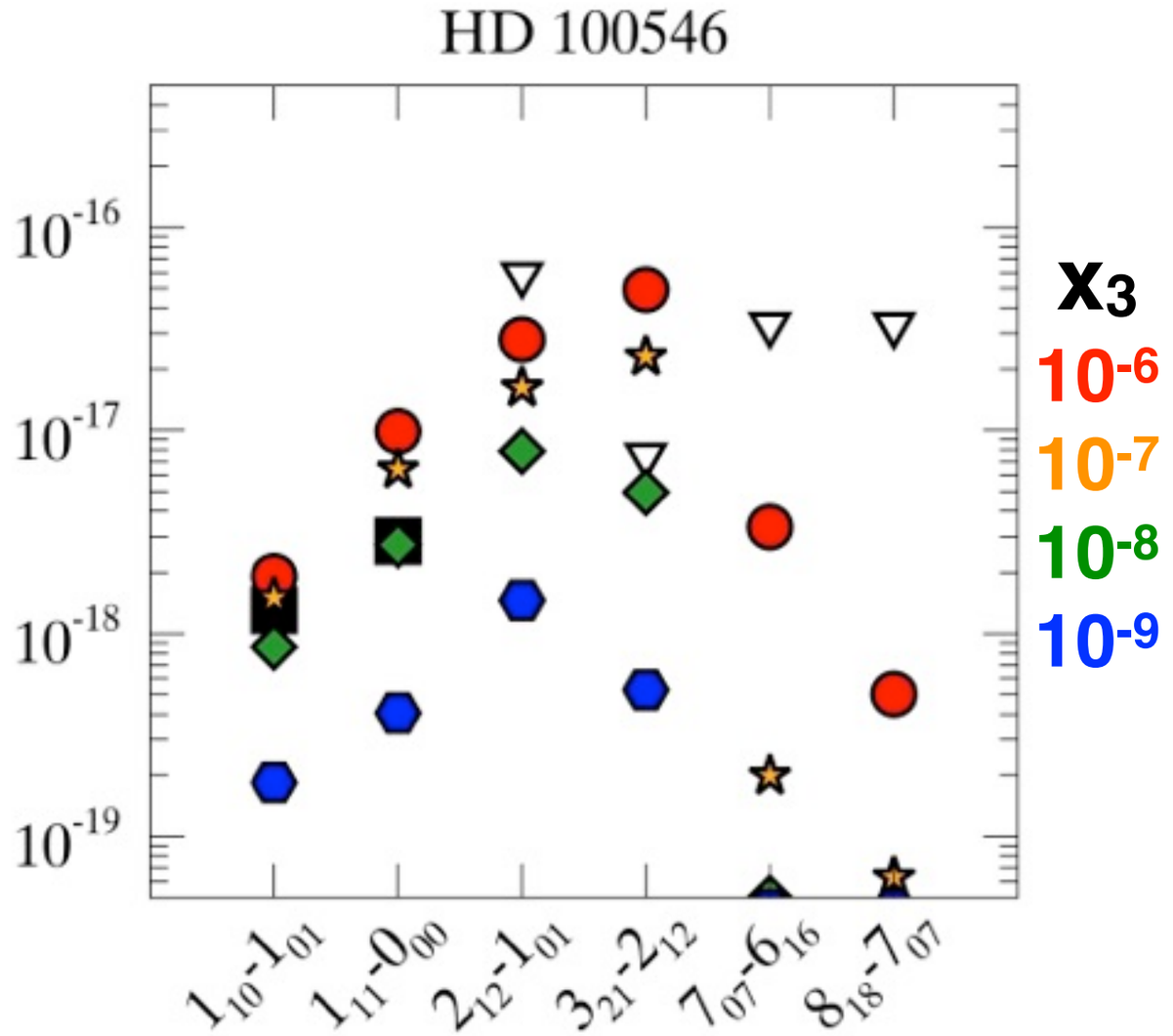
x(H_2O) in HD 100546

- **x1 < 10^{-8}**
- **x2 < 10^{-8}**
- **x3 = 10^{-8}**

H_2O mainly in outer disk (r > 20 au)

Photodissociation in inner disk

Photodesorption in outer disk



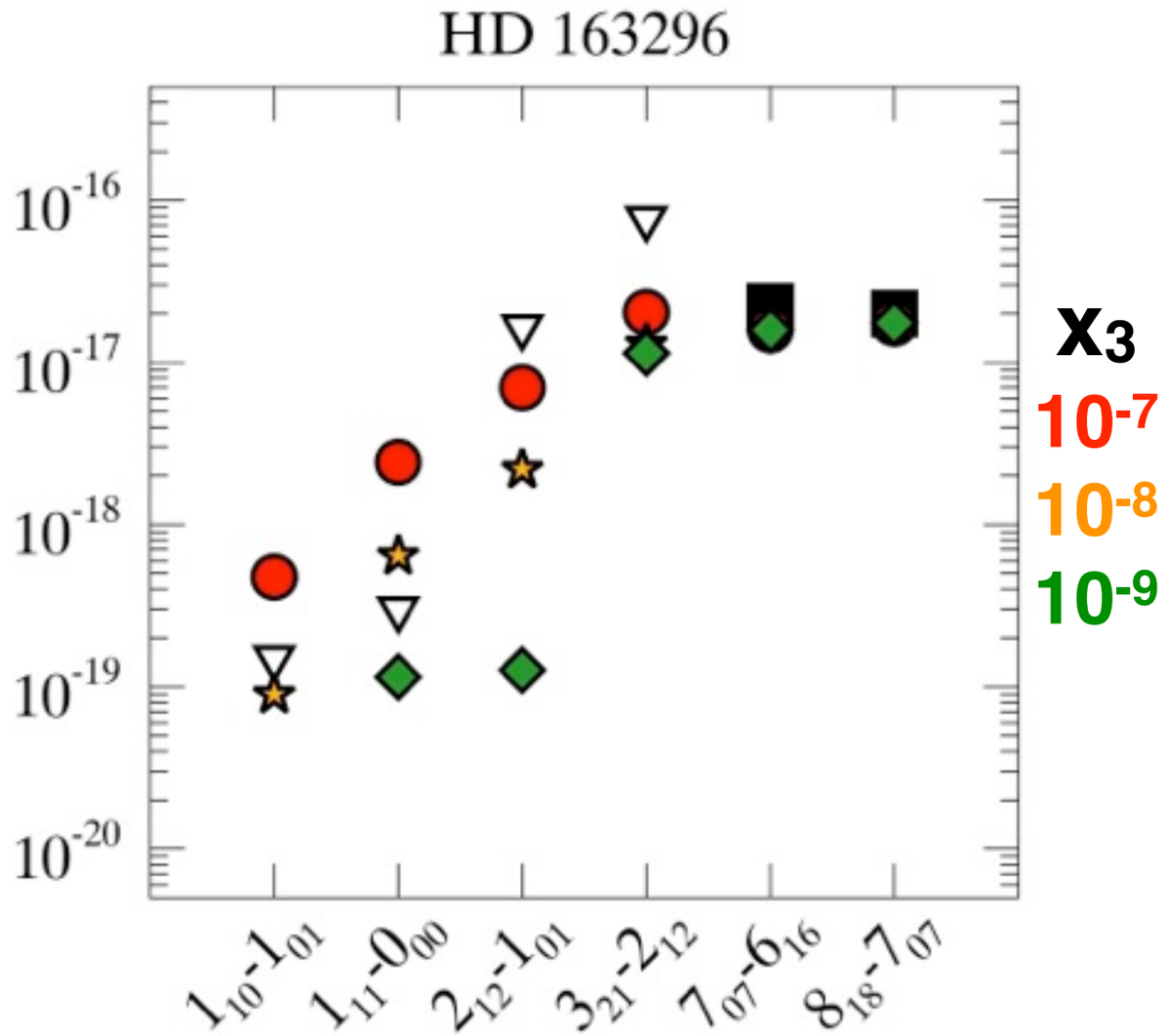
x(H_2O) in HD 163296

- **x1 = 10^{-5}**
- **x2 = 10^{-6}**
- **x3 = 10^{-9}**

H_2O mainly in inner disk (r < 20 au)

UV-shielded inner disk

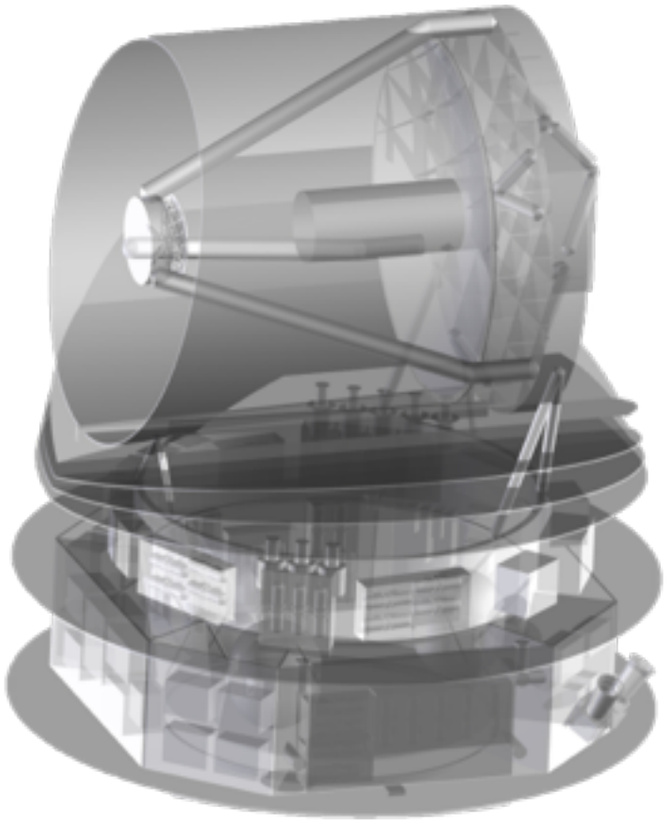
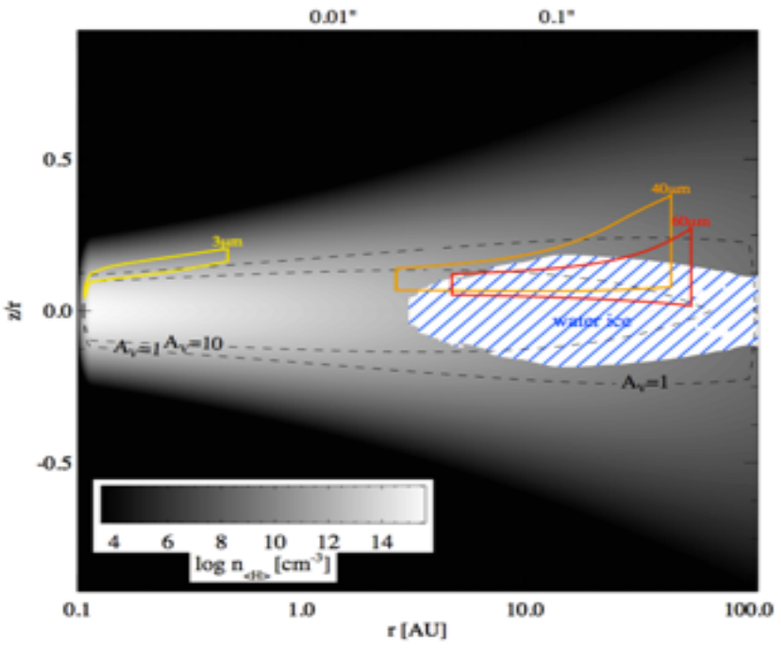
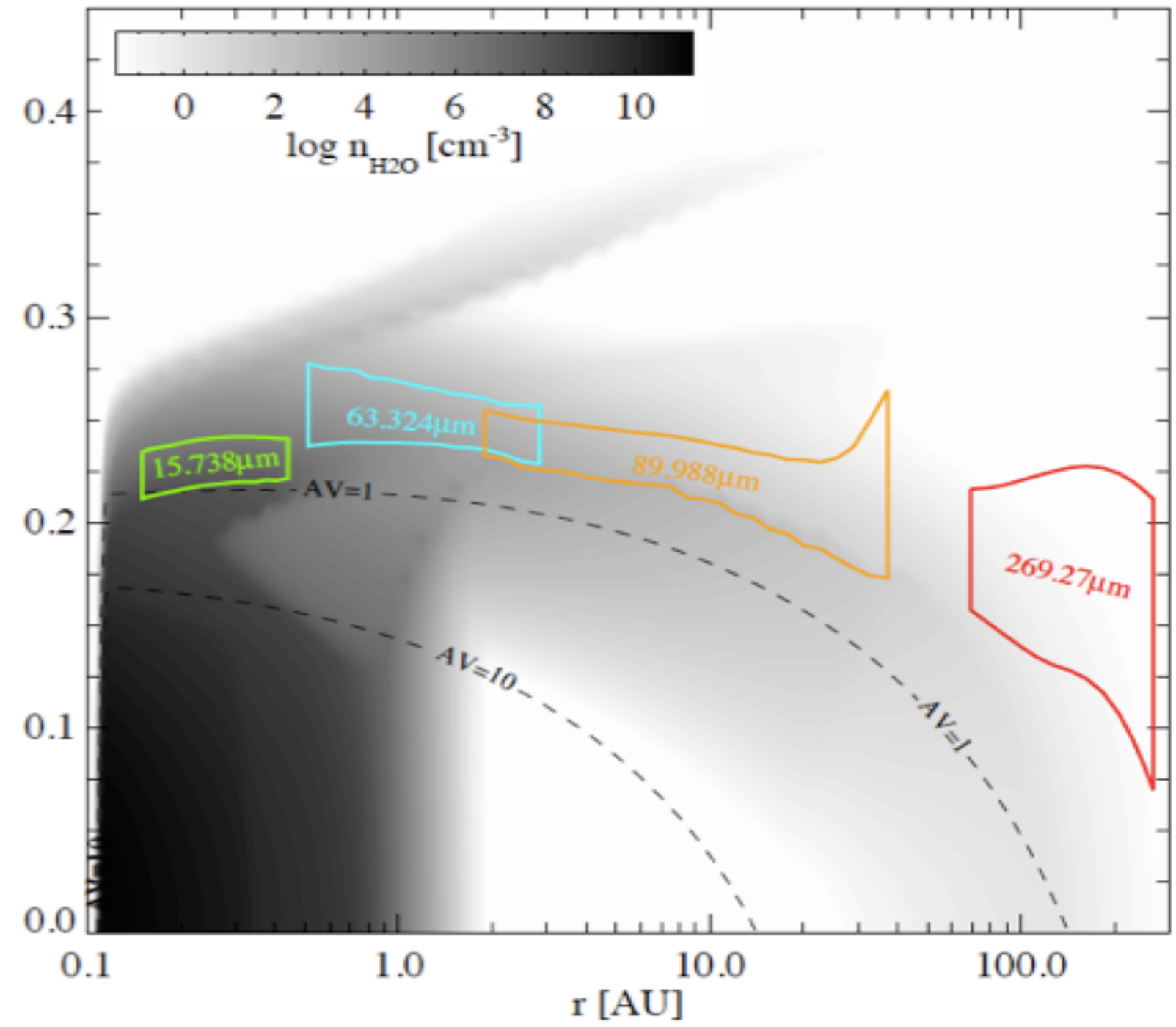
No photodesorption in outer disk



Conclusions

- All H_2O reservoirs in disks are detected
- Multiple-J analysis to map H_2O abundance structure
- $x(H_2O)$ varies from disk to disk

- 50-600 micron H_2O data on a few disks only
- Need for a new FIR cold telescope for warm/cold H_2O and ice

SPICA

The water trail: tracing the snow line