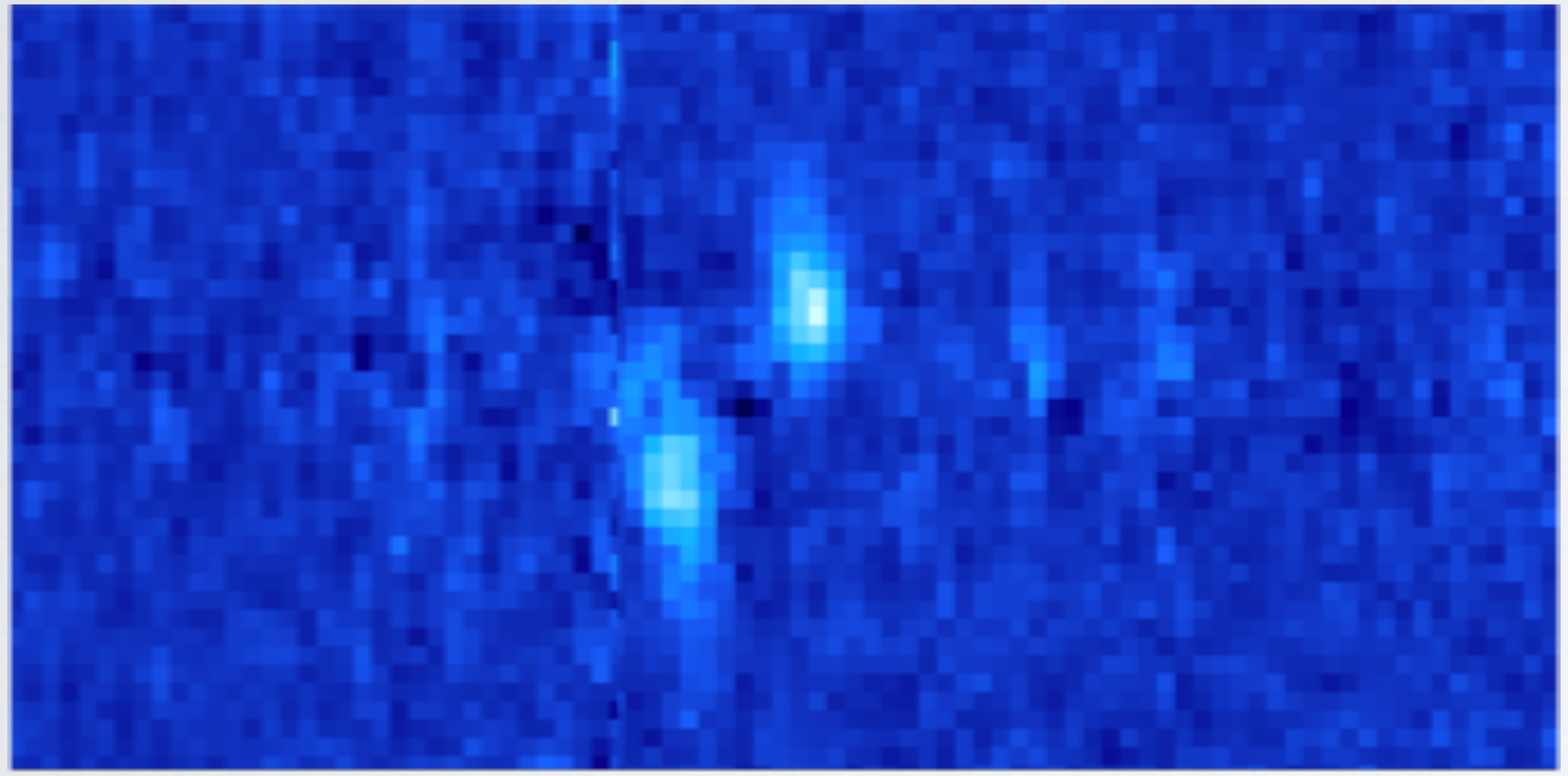
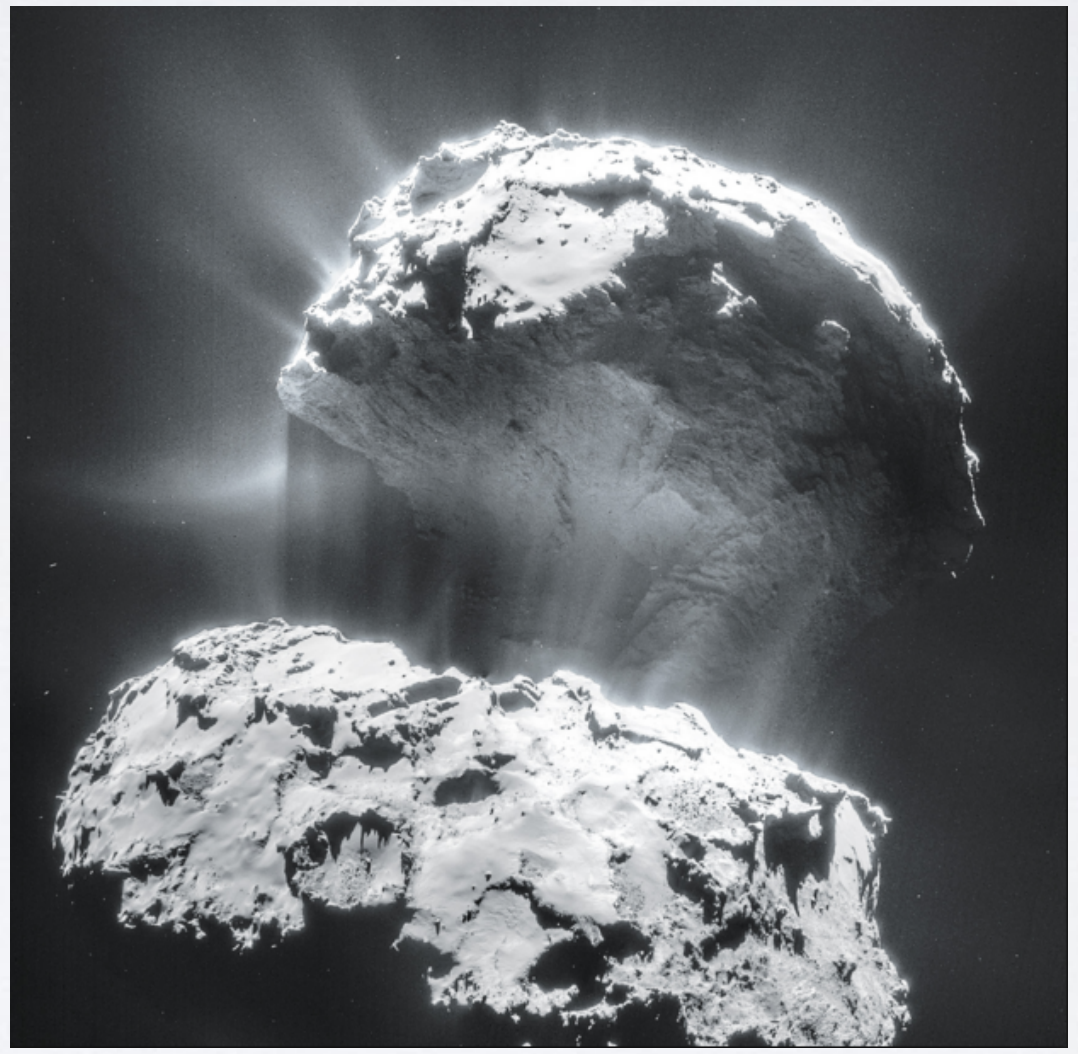
ORIGINS Space Telescope

OBSERVATIONS OF HYDRIDES IN DISKS





Klaus Pontoppidan
Space Telescope Science Institute

The Hydrides Toolbox, Paris, December 15, 2016

STScI | SPACE TELESCOPE SCIENCE INSTITUTE

HOW DID WE GET HERE?

"The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. We are made of star stuff." - Carl Sagan

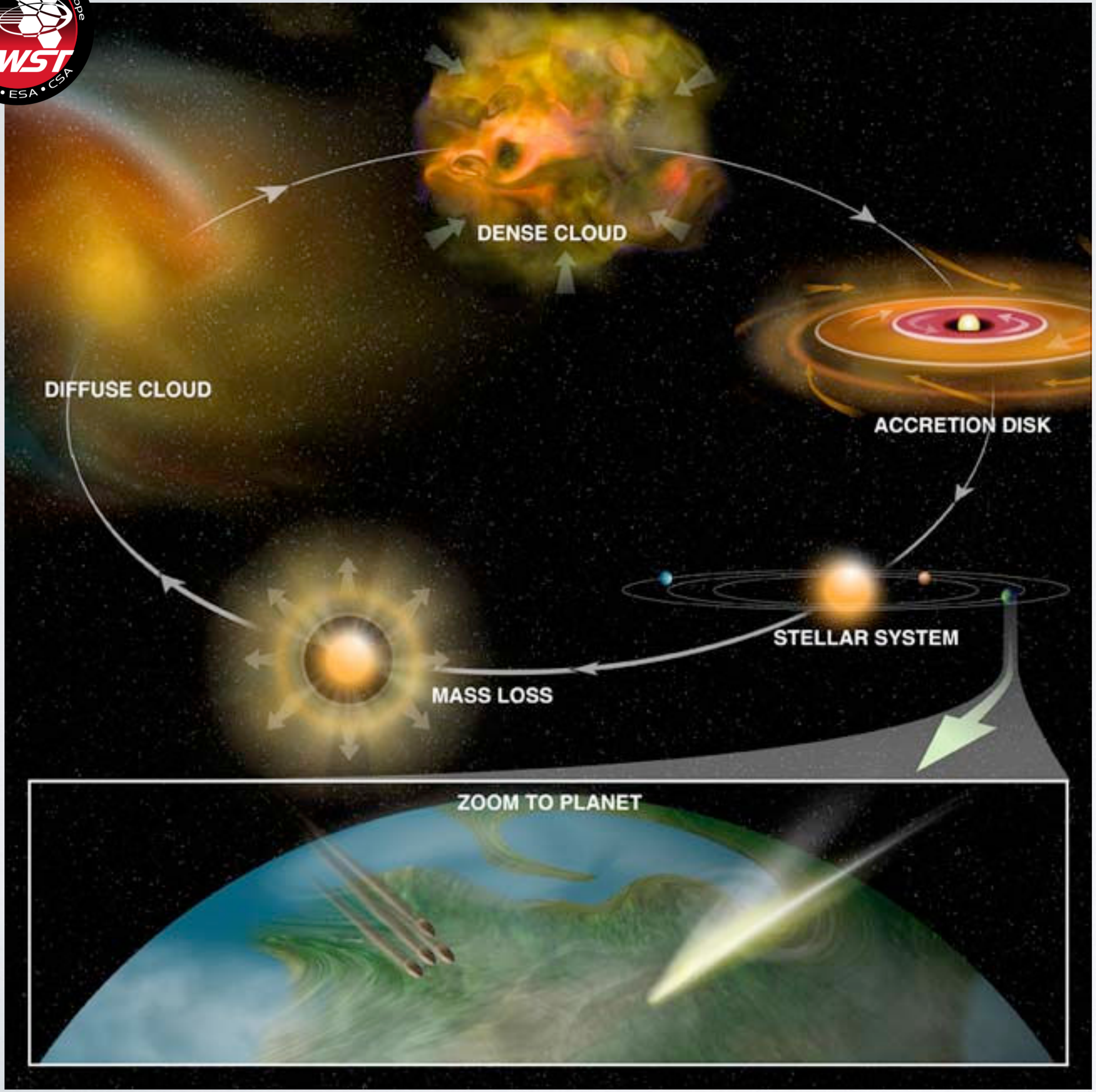
Bulk Carbon/Nitrogen ratios in habitable planets

Deuterium/Hydrogen ratios in the Earth vs. comets

^{14}Nitrogen/^{15}Nitrogen ratios in the Earth vs. comets/asteroids

^{16}Oxygen/^{18}Oxygen/^{17}Oxygen ratios

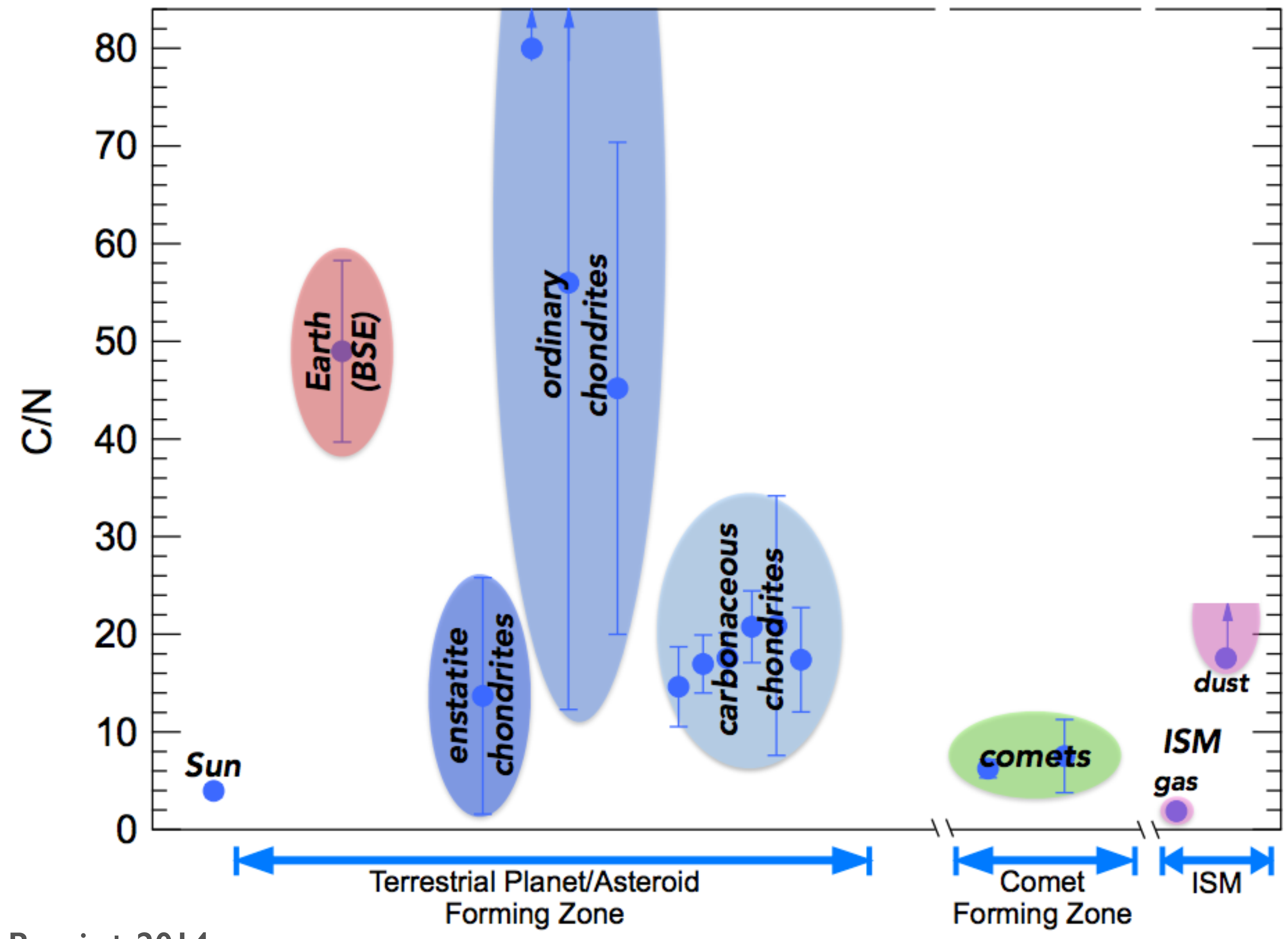
All related to the chemical evolution of molecular carriers of elements



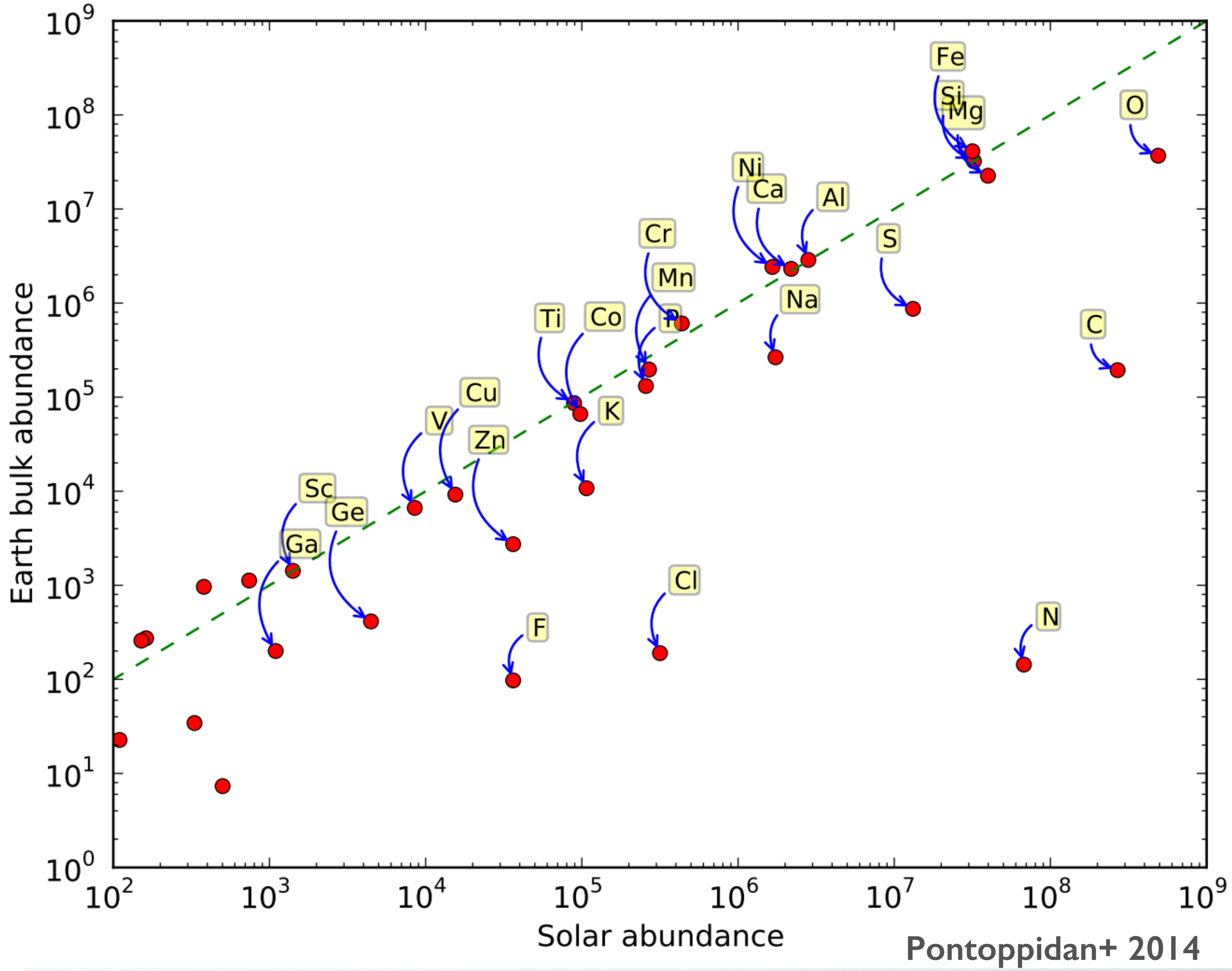
THE CLASSICAL INTERSTELLAR MATTER LIFE CYCLE

But how much of the chemistry is inherited?

DELIVERY OF CARBON, NITROGEN AND WATER TO TERRESTRIAL PLANETS

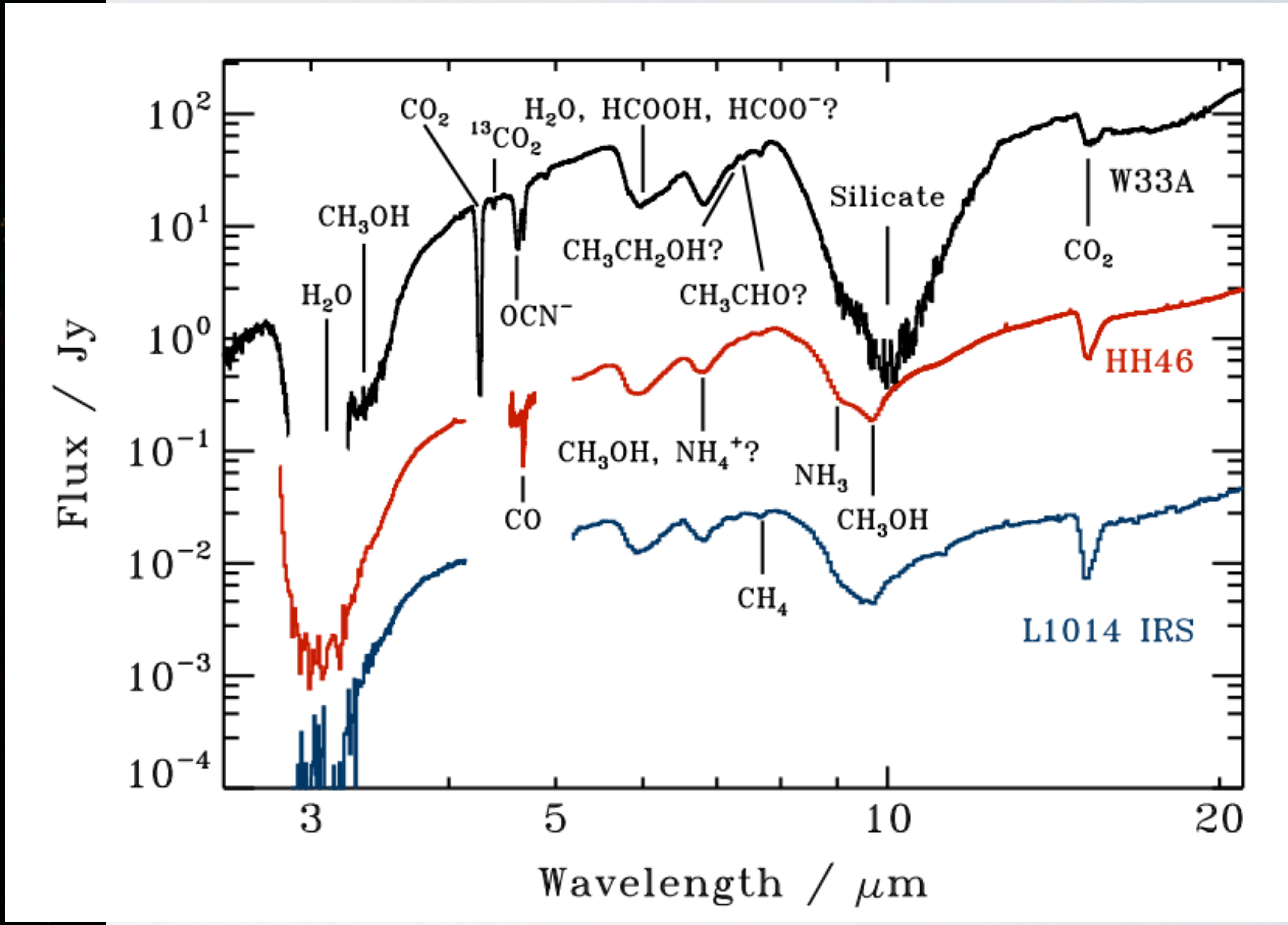


Bergin+ 2014



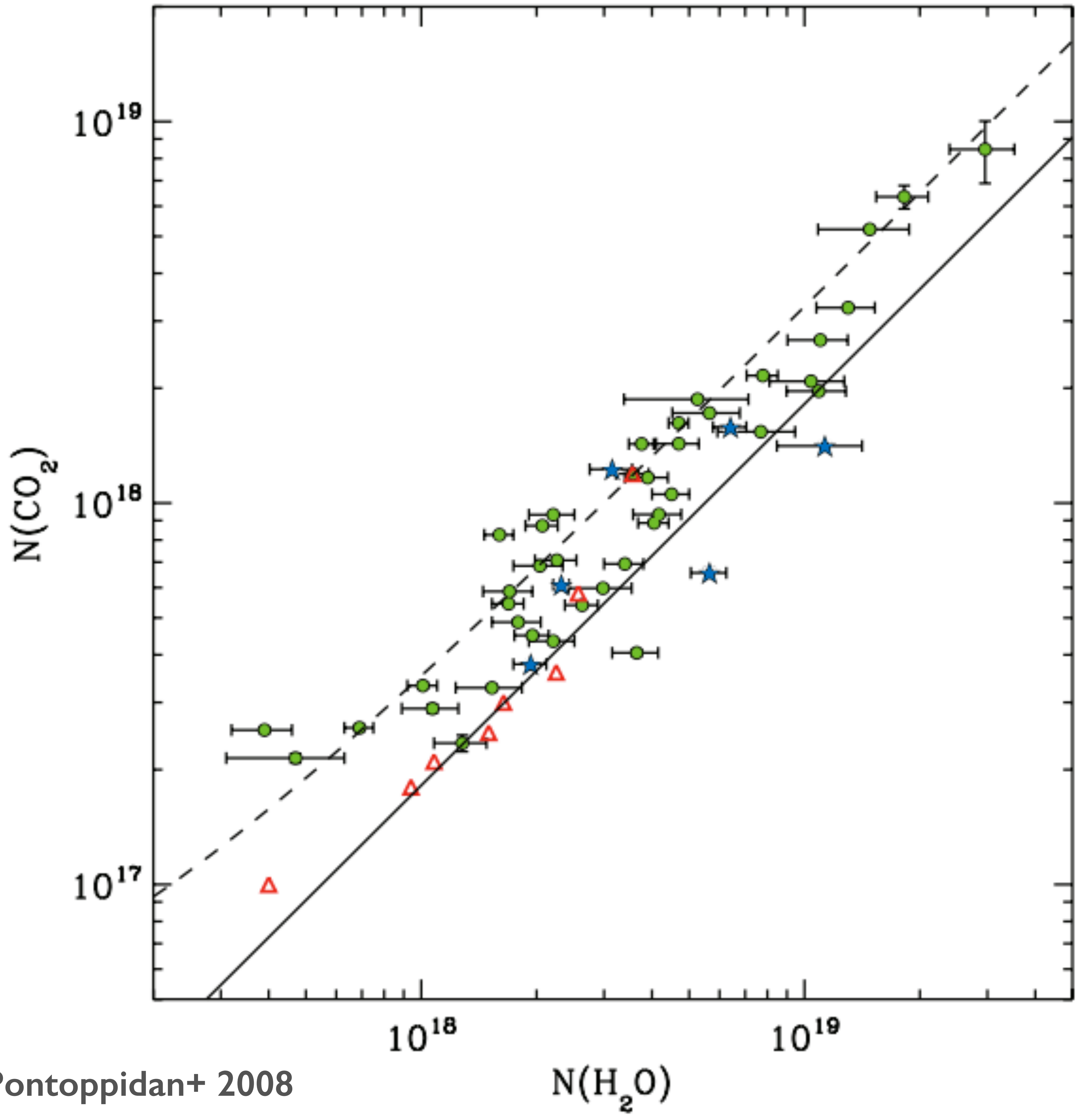
Pontoppidan+ 2014

Comparing to primordial molecules

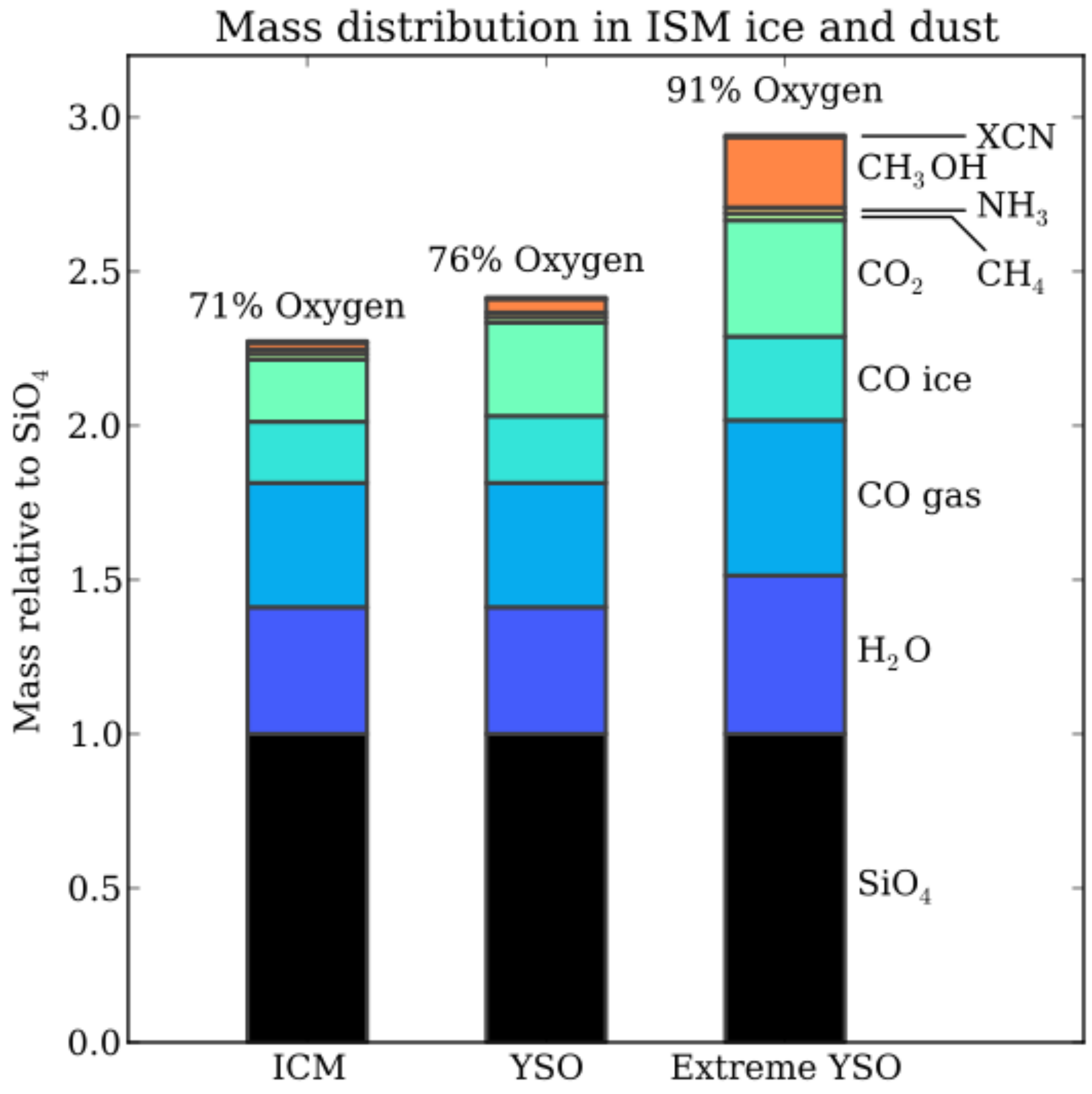


Boogert, Pontoppidan, Oberg, Bottinelli+

FINGERPRINTS OF COLD ICE CHEMISTRY

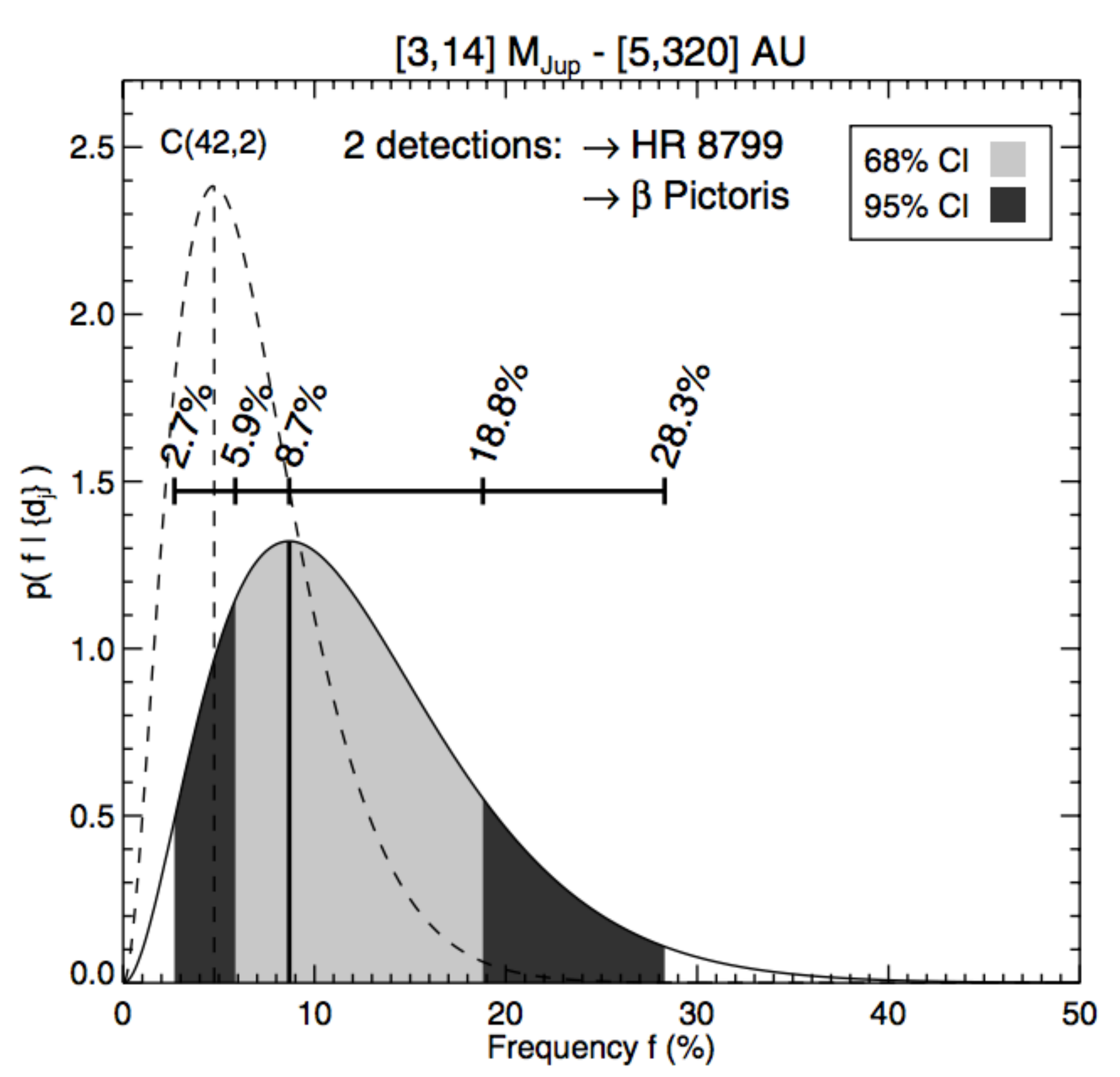


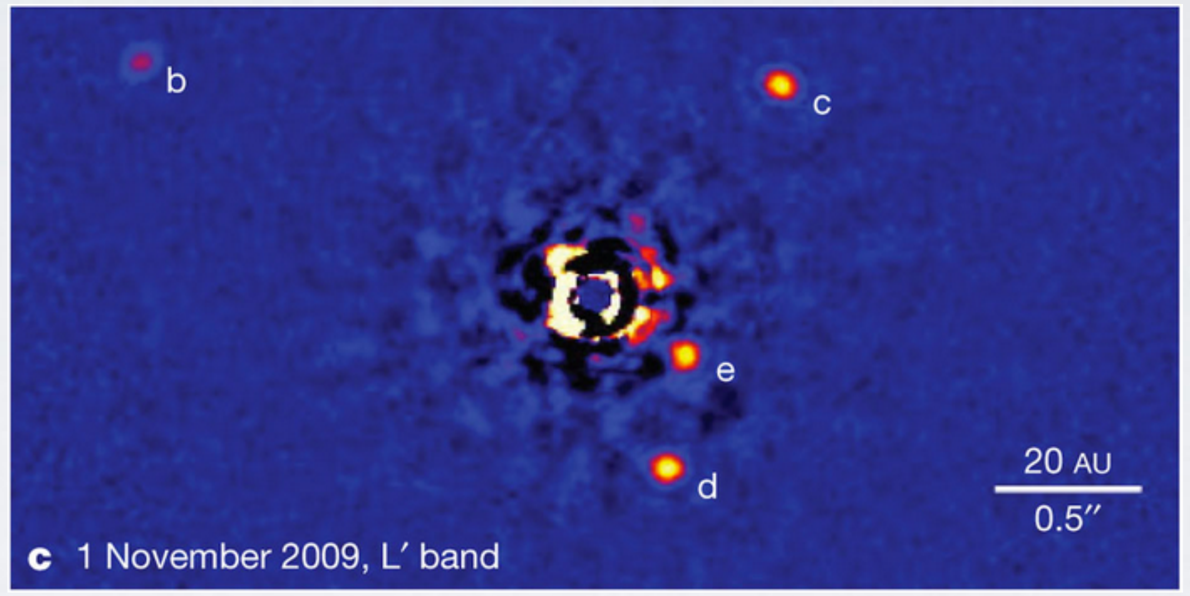
Pontoppidan+ 2008



Pontoppidan+ 2014

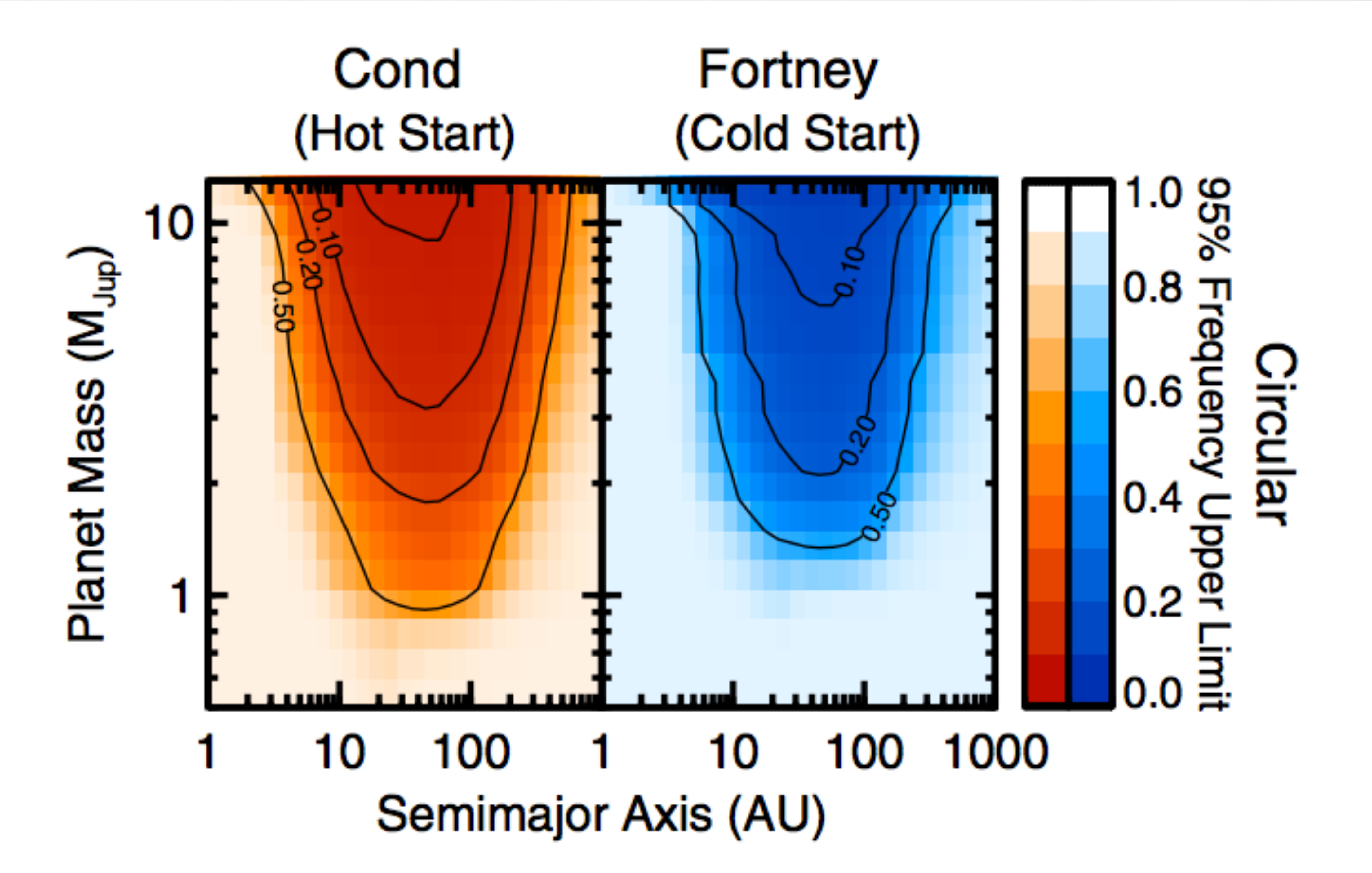
THE PLANET-FORMING REGION: GIANT PLANETS ARE RARE BEYOND 10 AU



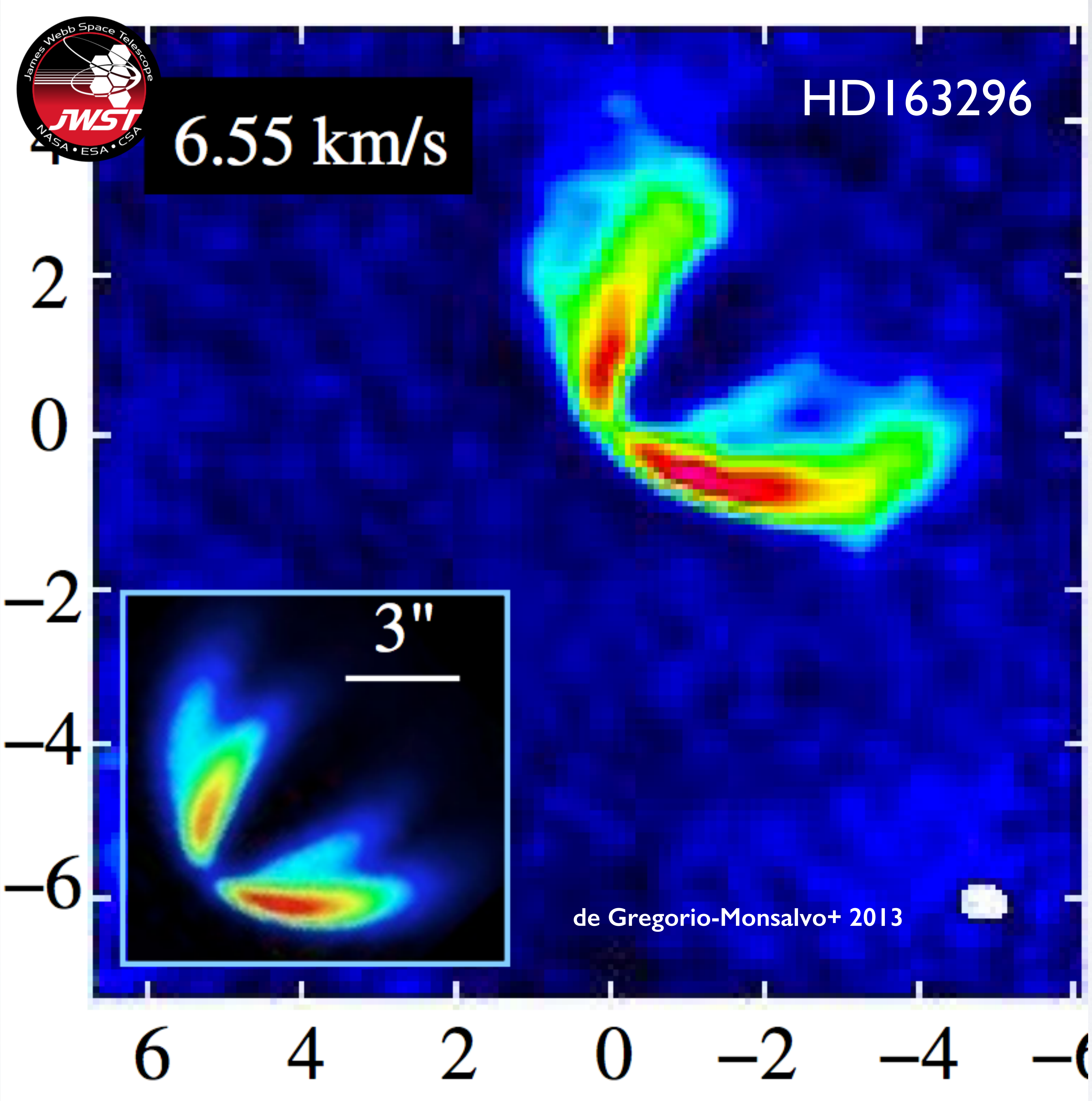


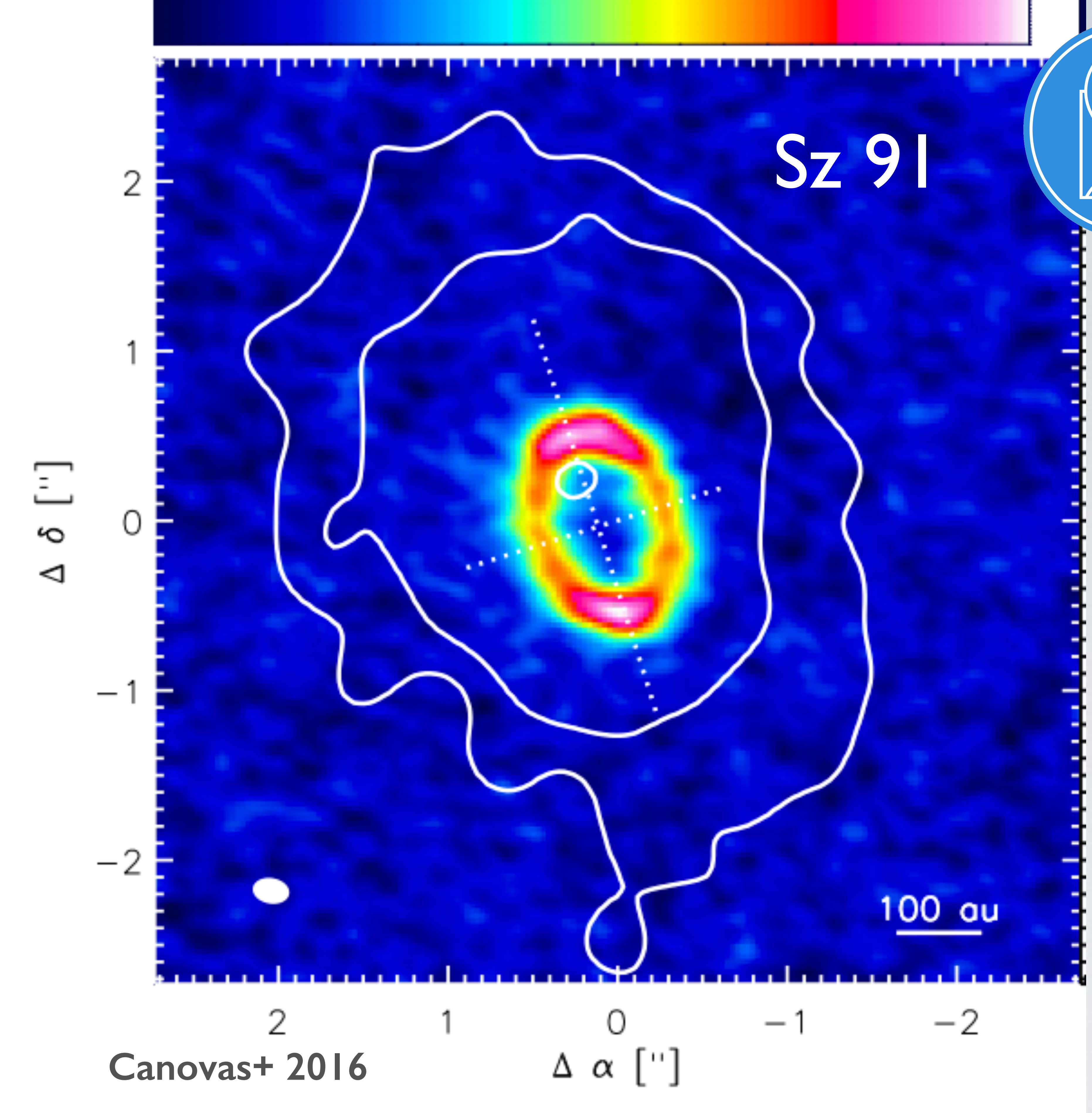
Limits from direct imaging surveys

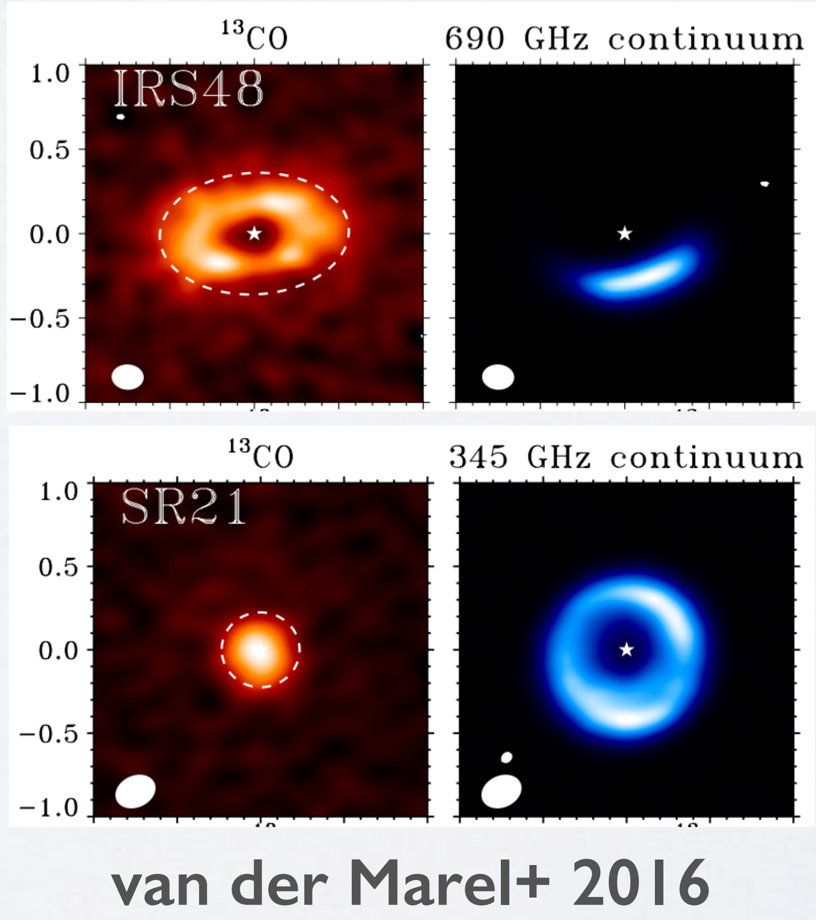
Marois+ 2010

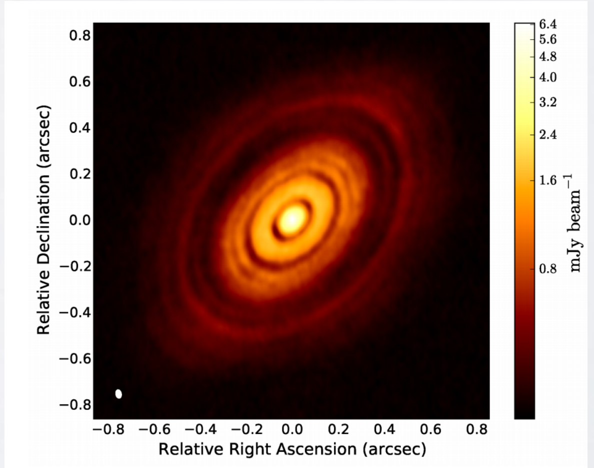


Bowler+ 2015





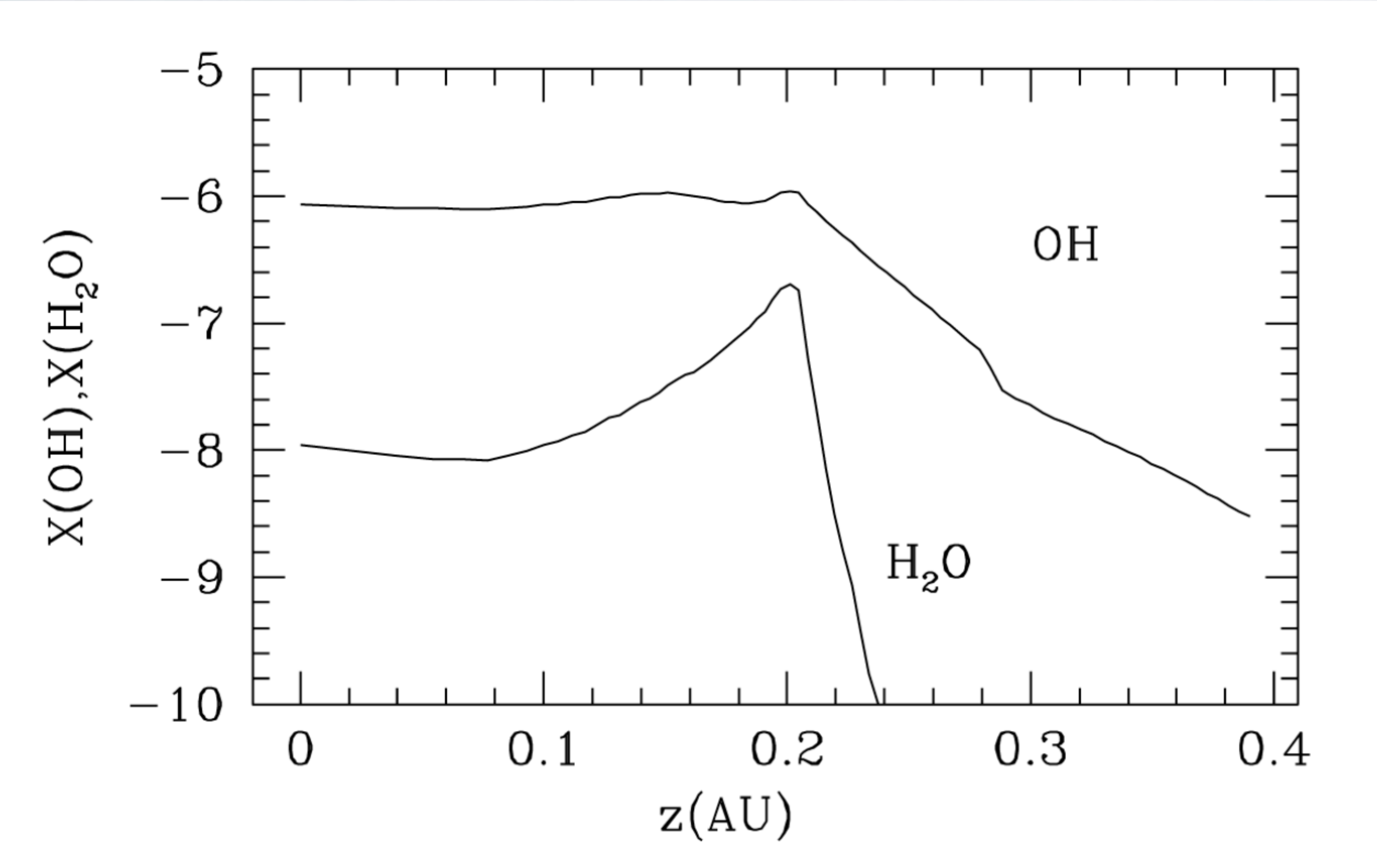




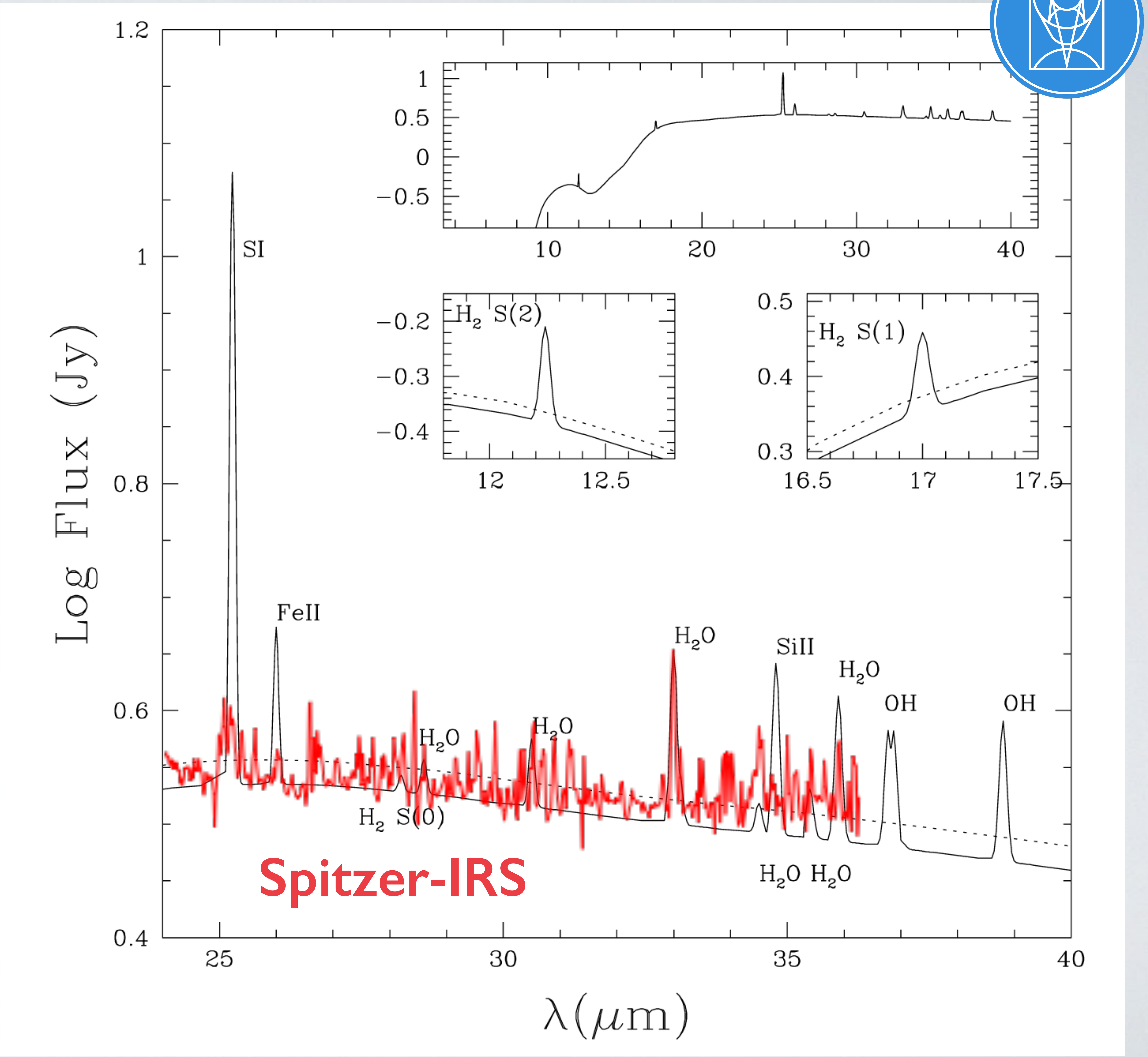
Planet-forming region
Radius=10 AU

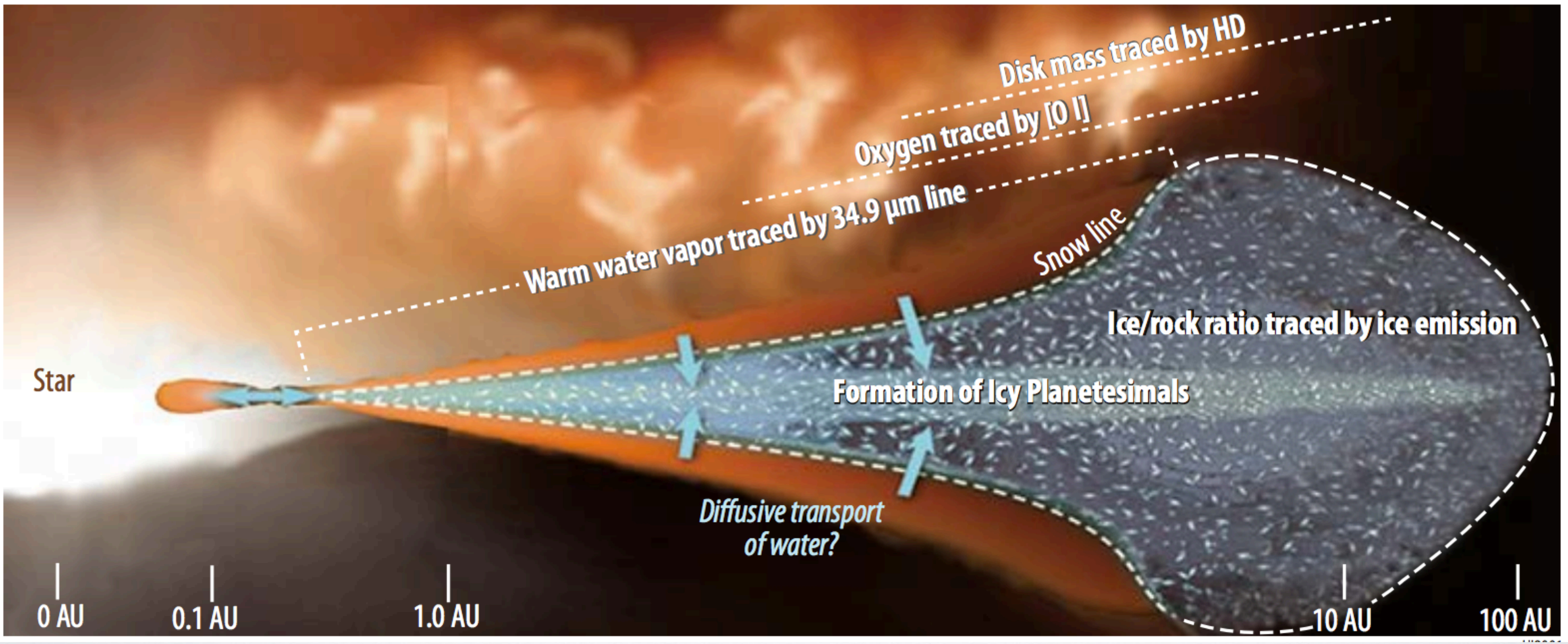
NEED FOR OBSERVATIONS OF DISK GAS

Pre-Spitzer chemical models of disks



Gorti & Hollenbach 2004





See talk by Ilse Cleeves!

MAJOR SURVEYS OF WATER VAPOR IN DISKS

TABLE 1
SUMMARY OF MAJOR WATER VAPOR SURVEYS IN PROTOPLANETARY DISKS.

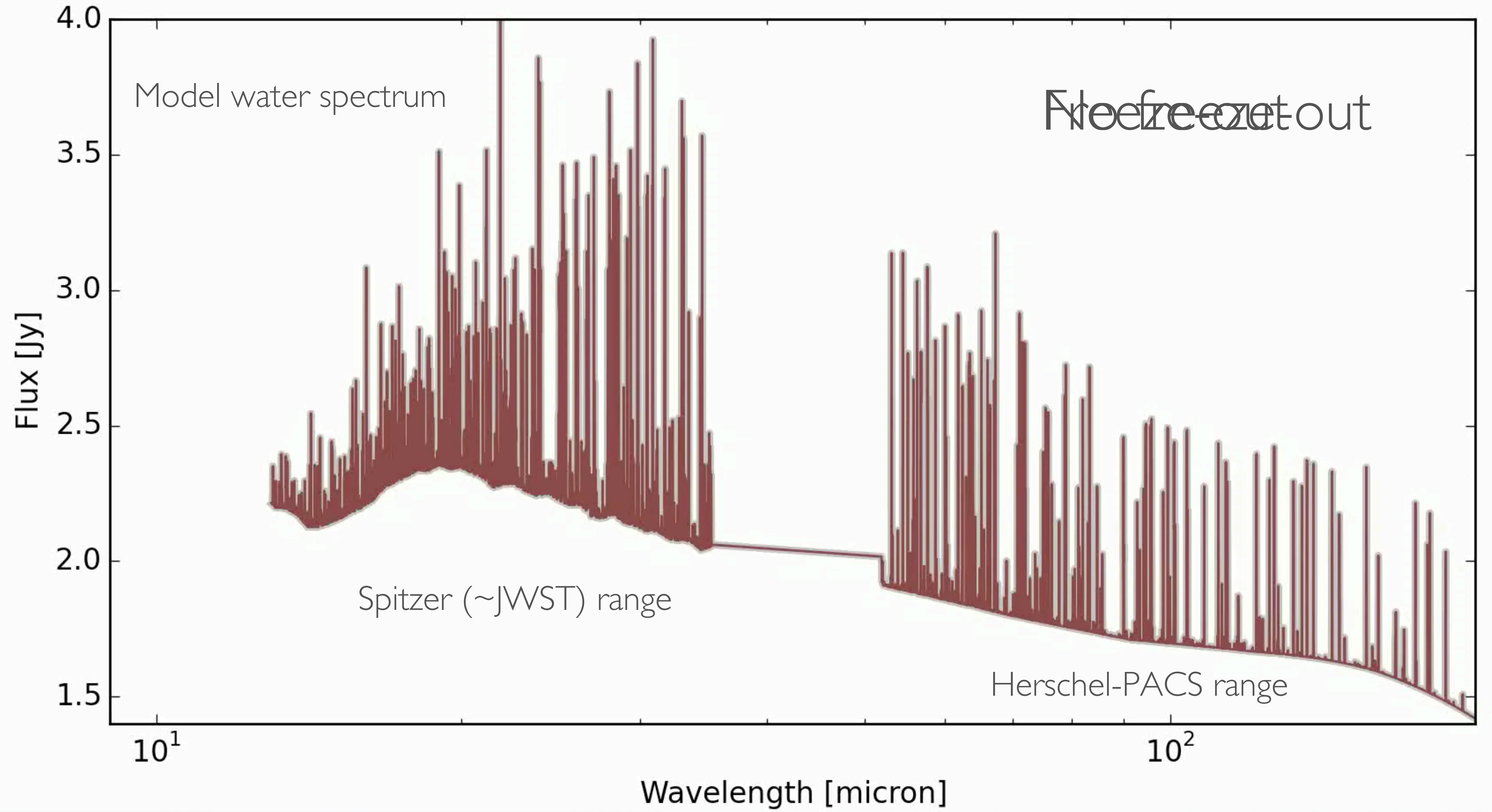
λ [μm]	Instr.	Resol.	# lines	E_u [K]	T_{ex} [K]	# disks	$M_\star < 0.2$	$0.2 < M_\star < 1.5$	$M_\star > 1.5$	Refs
							Detection fractions (and sample sizes)			
2.9–3	VLT-CRIRES	100,000	≈ 40	8000–10,000	900	≈ 40	N/A	58% (24)	11% (18)	this work, 1
					Sensitivity:		–	-15	-14.6	
10–37	*Spitzer*-IRS	700	≈ 200	700–6000	300-700	≈ 100	0% (5)	63–85% (64)	0–18% (27)	this work, 2
					Sensitivity:		-15.7	-14.8	-13.7	
55–200	*Herschel*-PACS	1000–5000	≈ 20	100–1400	100-300	≈ 120	0% (10)	15% (80)	15% (27)	3
					Sensitivity:		-14.6	-14.5	-14	

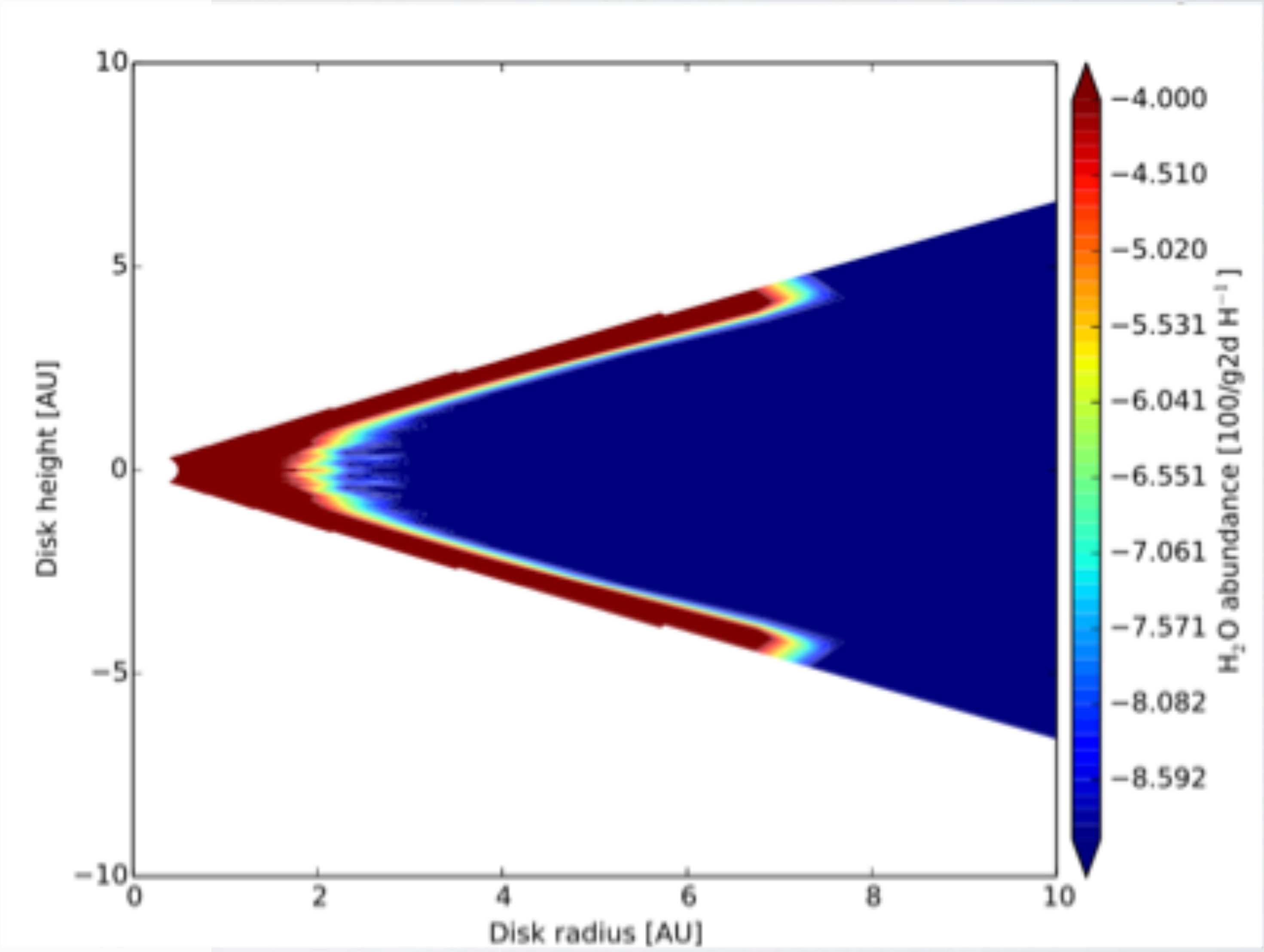
REFERENCES. — [1] Fedele et al. (2011); Mandell et al. (2012); [2] Pontoppidan et al. (2010a); Carr & Najita (2011); Salyk et al. (2011a); Pascucci et al. (2013); [3] Riviere-Marichalar et al. (2012, 2015); Meeus et al. (2012); Fedele et al. (2013); Blevins et al. (2016)

NOTE. — Detection fractions are reported in percentage, individual sample sizes in brackets, and log sensitivities in erg cm^{-2} s^{-1}, for three stellar mass bins as indicated.

Banzatti+ 2016

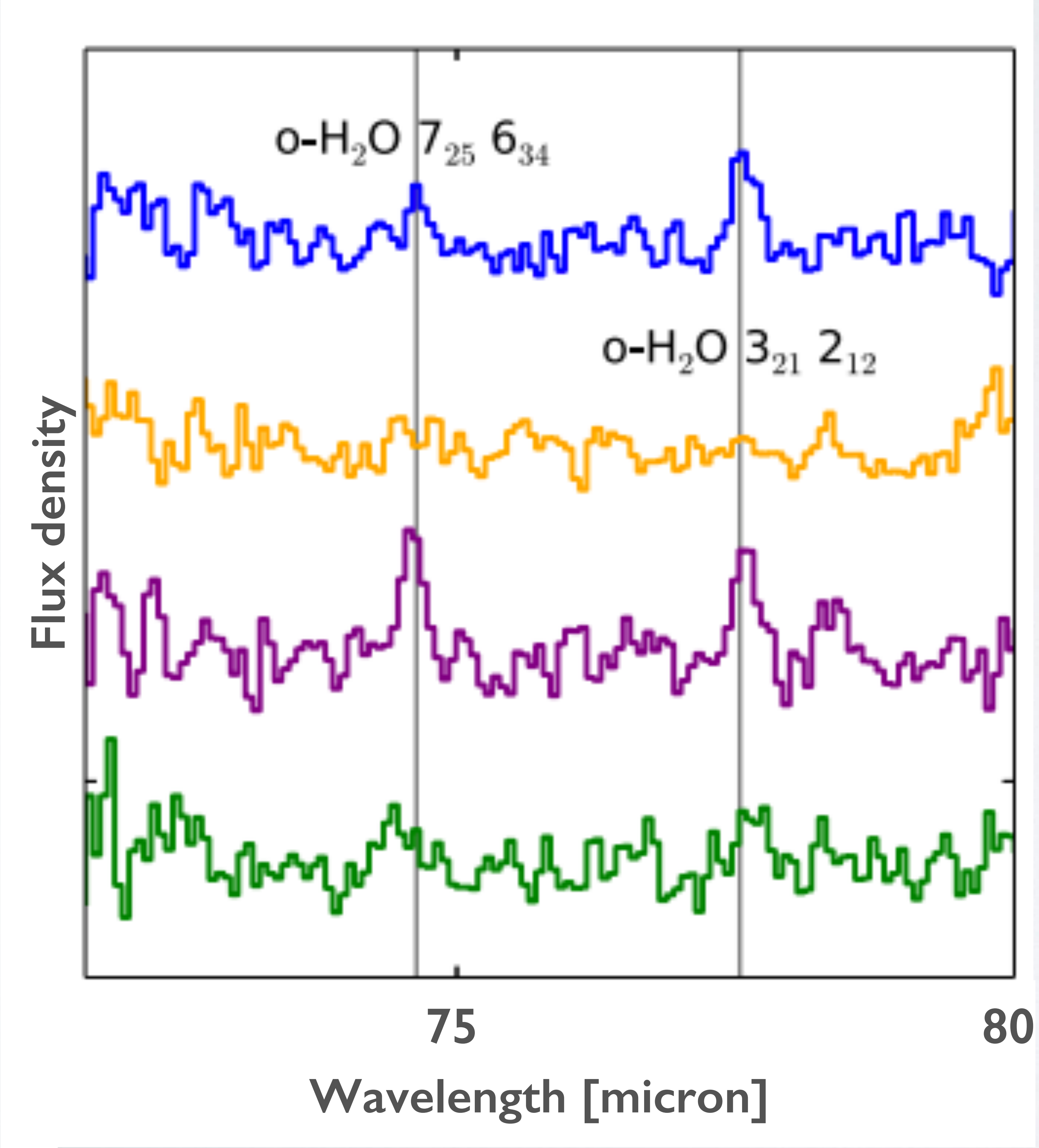
SPECTROSCOPIC EFFECTS OF A SNOW LINE

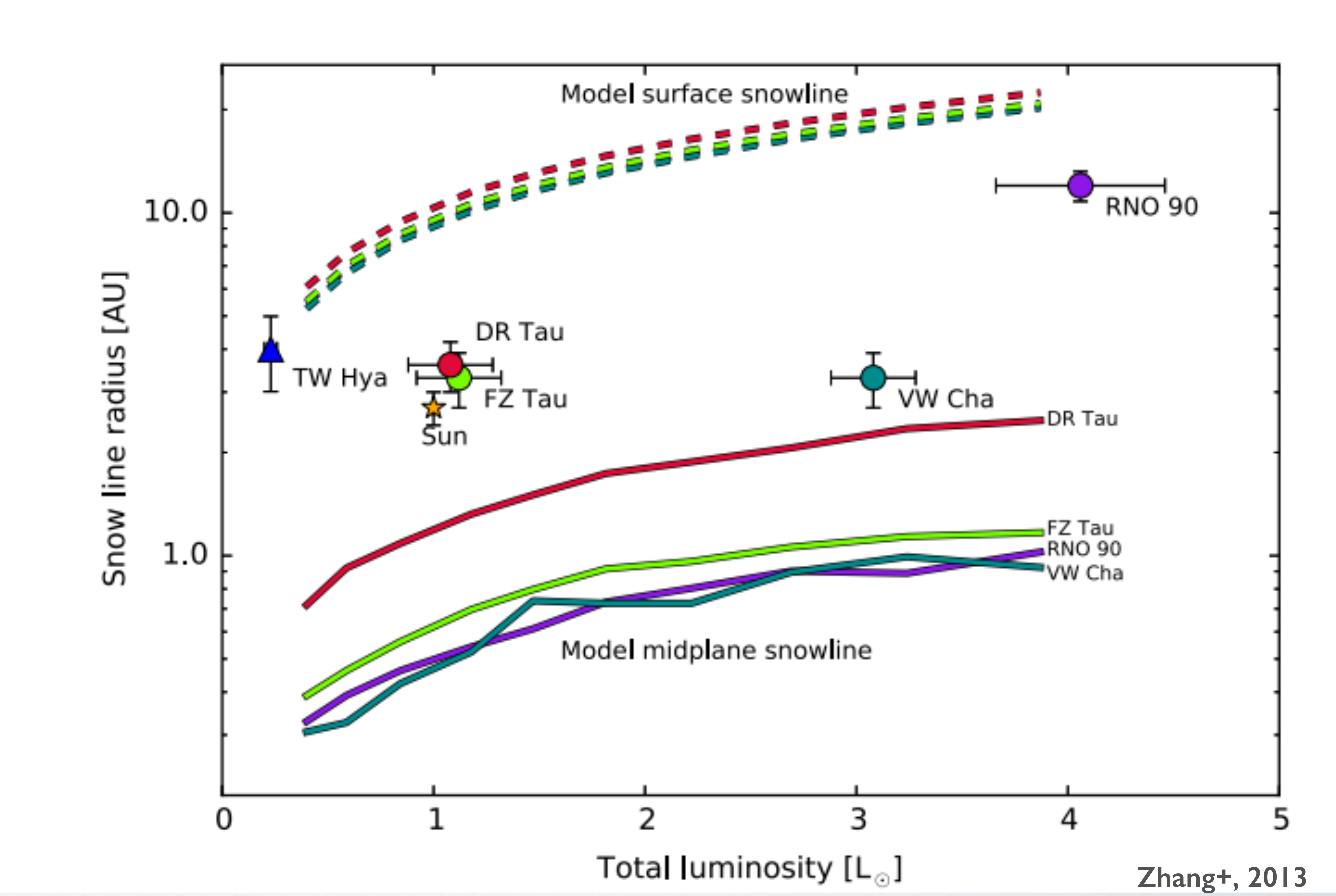




OST range

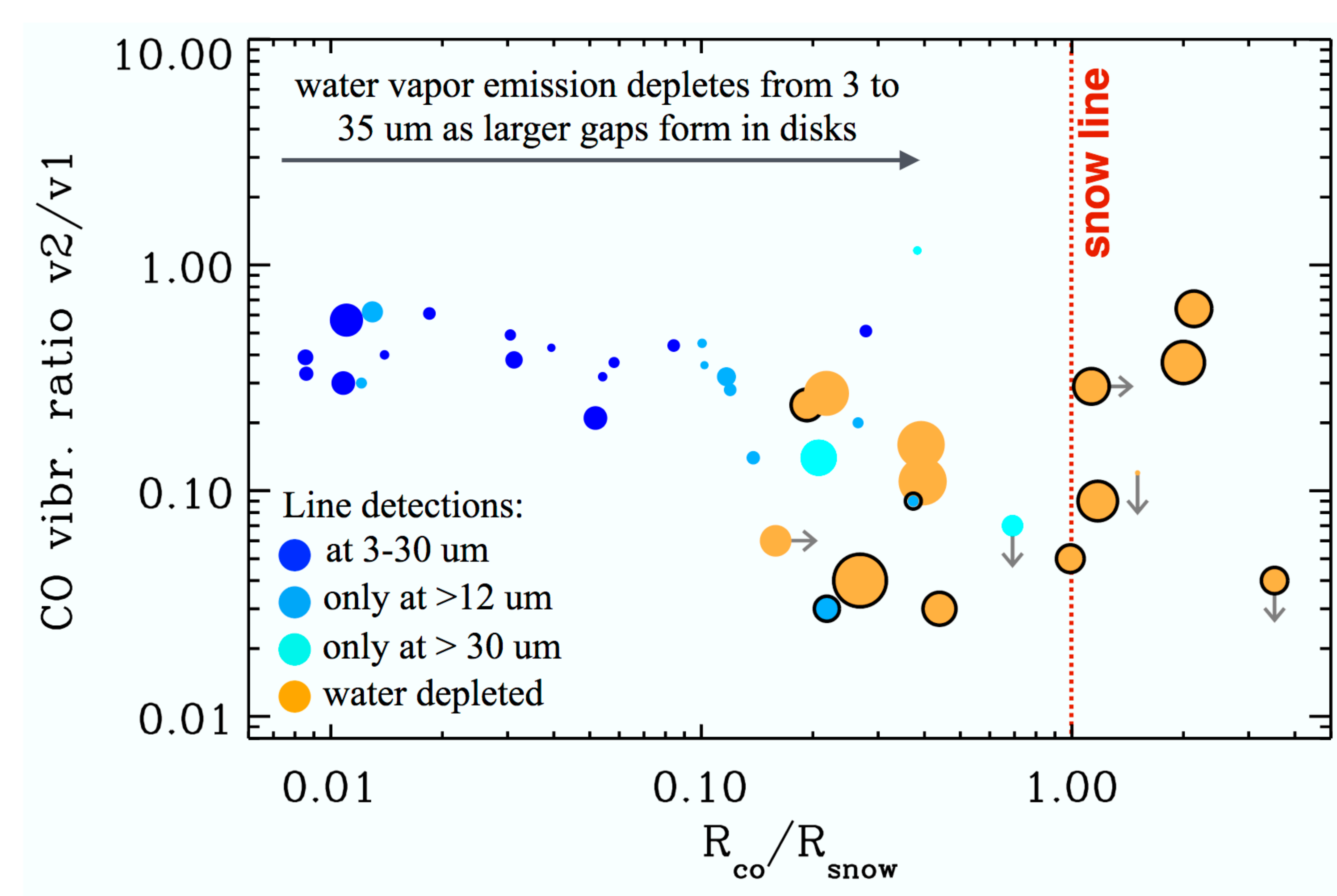
SPECTRAL DETECTIONS OF THE SNOW LINE





Zhang+, 2013
Blevins+ 2016

INSIDE-OUT DEPLETION OF WATER



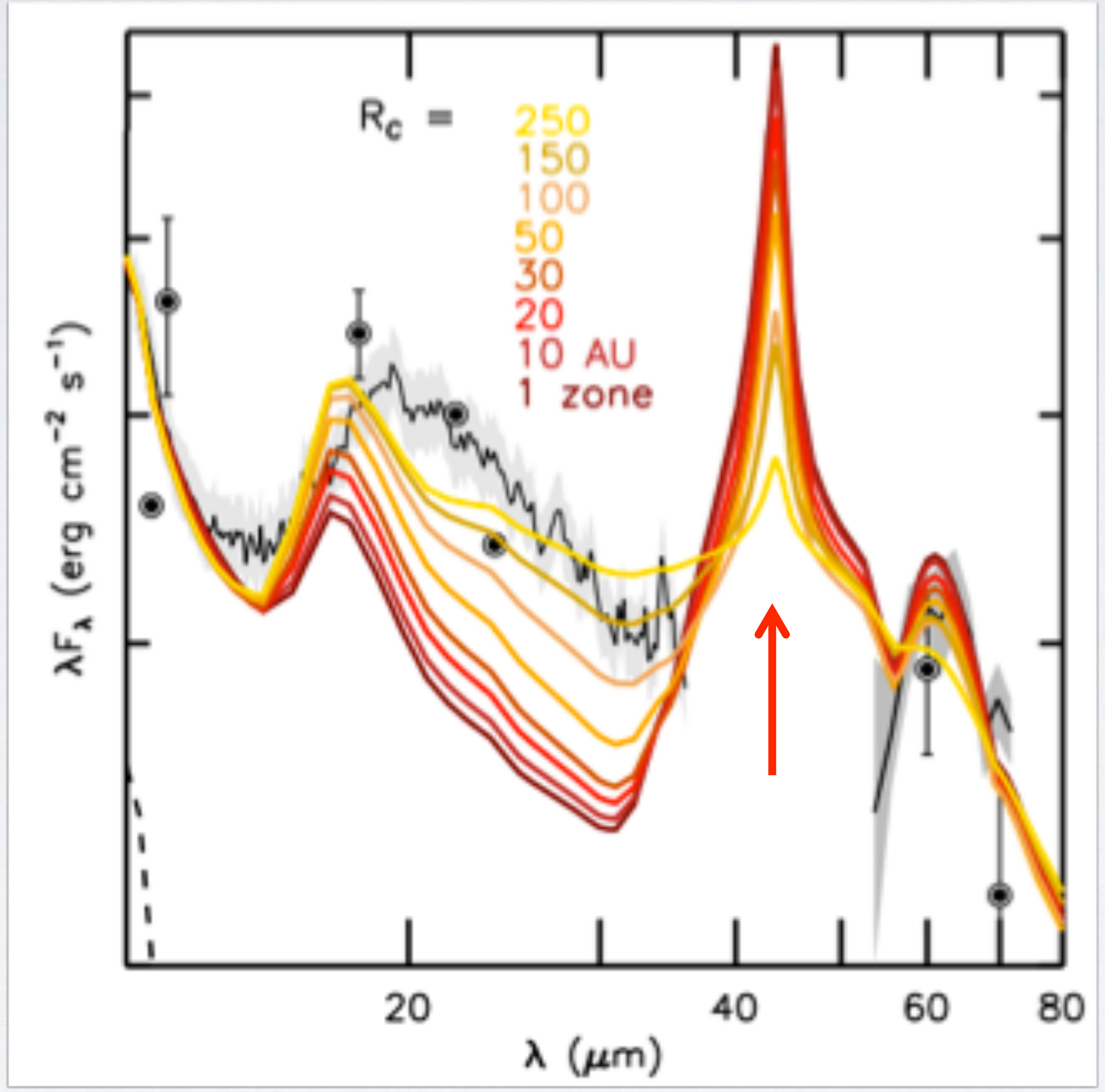
Banzatti+ 2016

MEASURING THE ICE MASS IN PROTOPLANETARY DISKS

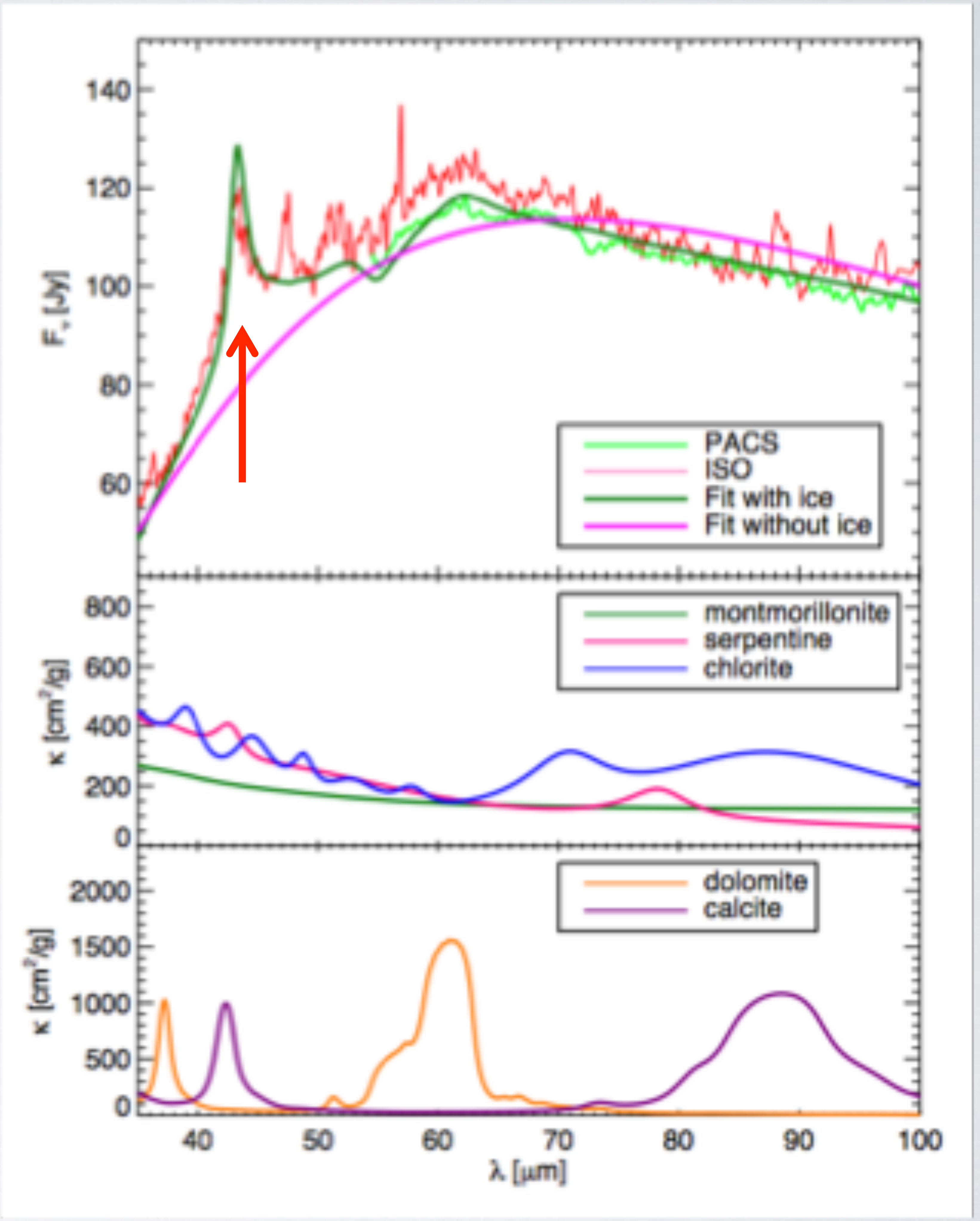
- The 43 micron emission band is the most sensitive tracer of bulk water ice in disks.
- OST will be sensitive enough to measure it across the stellar mass range, and from debris disks to protoplanetary disks out to several kpc.

HIRMES
HIgh Resolution Mid-infrarEd Spectrometer

ORIGINS
Space Telescope

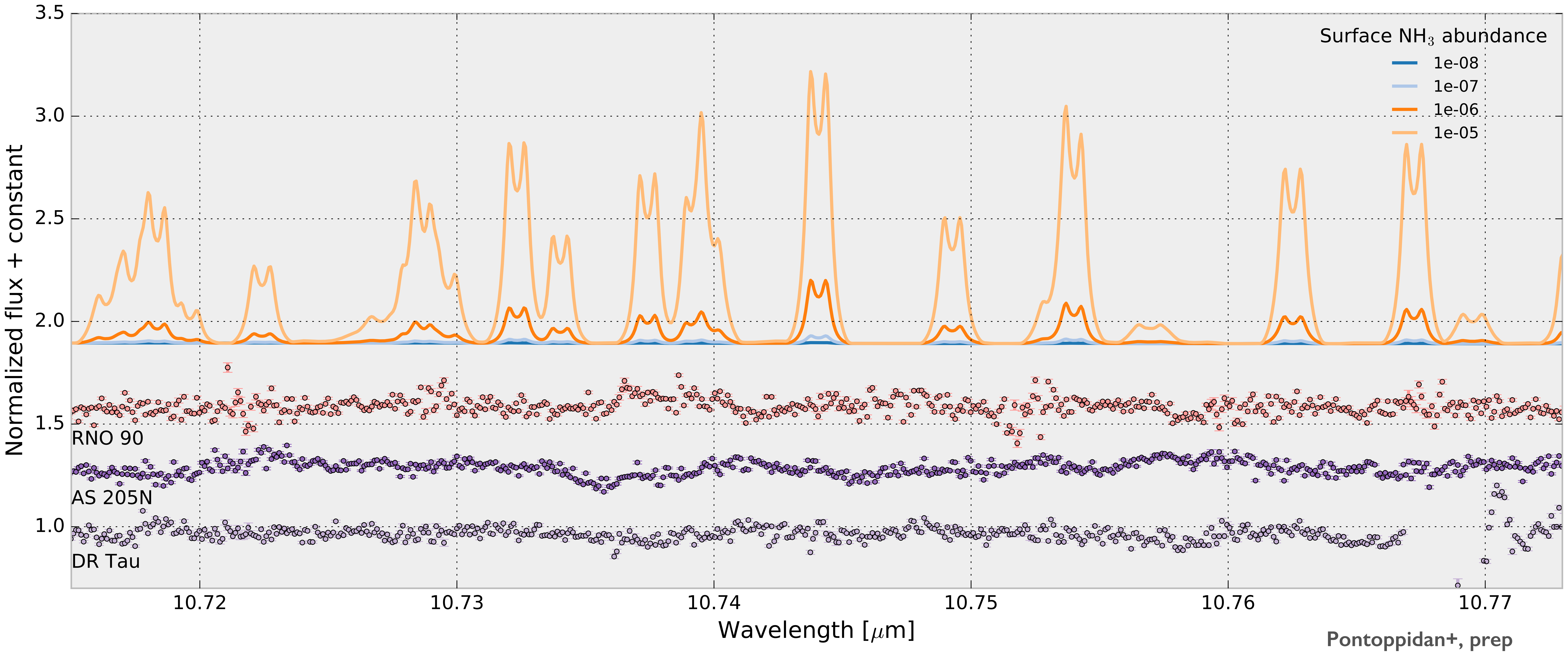


McClure+ 15



Min+ 16

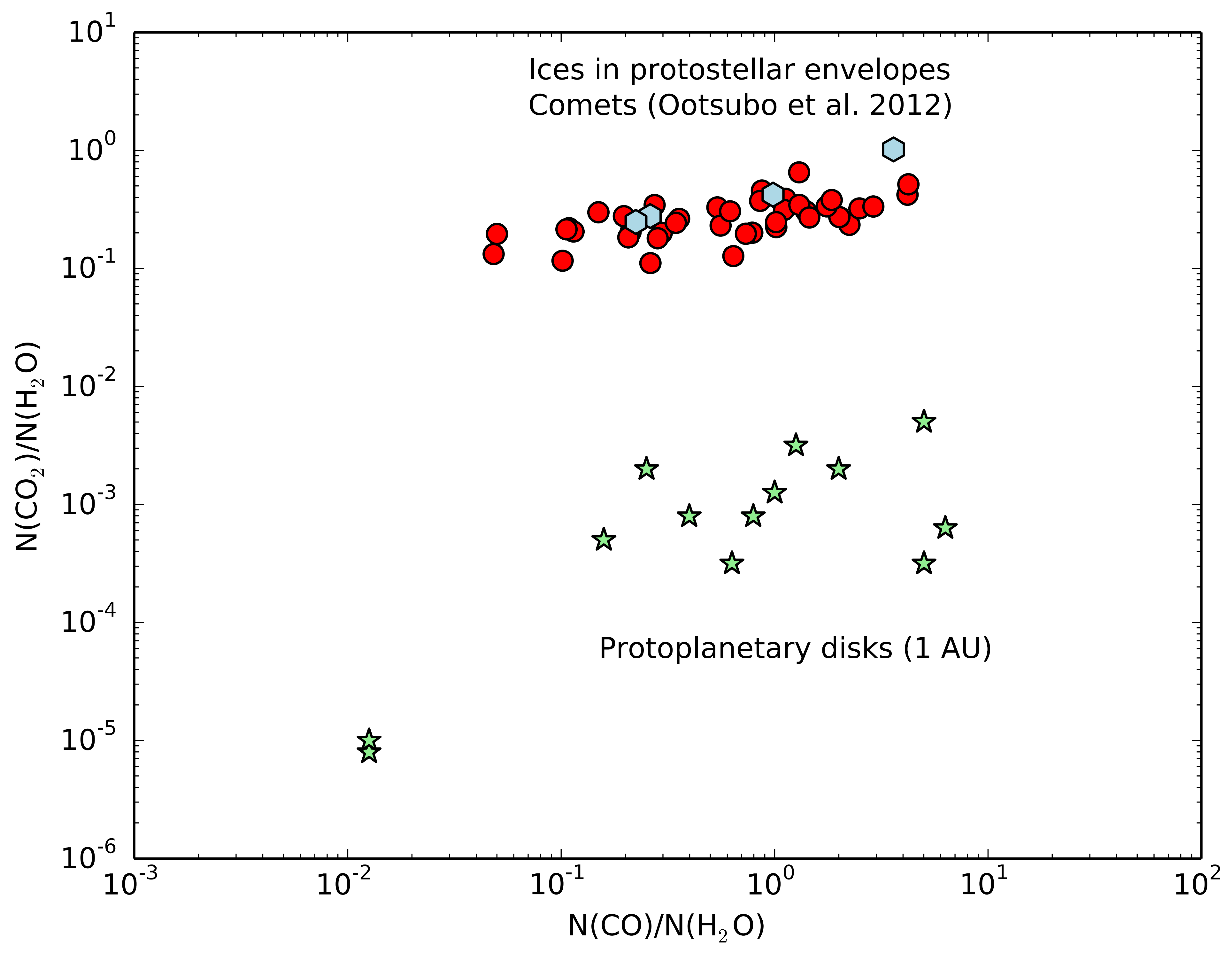
EVOLUTION OF CARBON AND NITROGEN RESERVOIRS



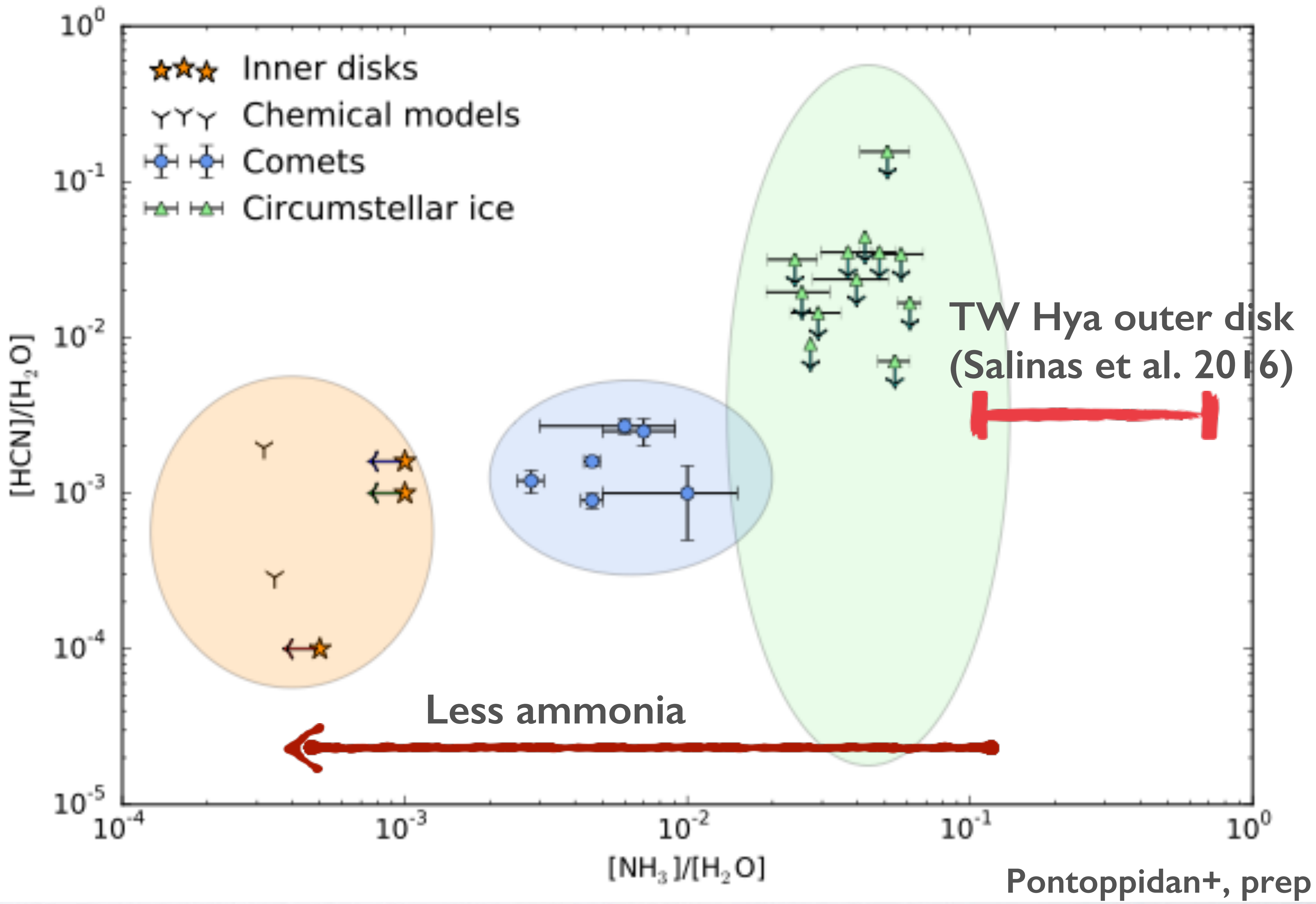
Pontoppidan+, prep

EVOLUTION OF CARBON AND NITROGEN RESERVOIRS

CO_2

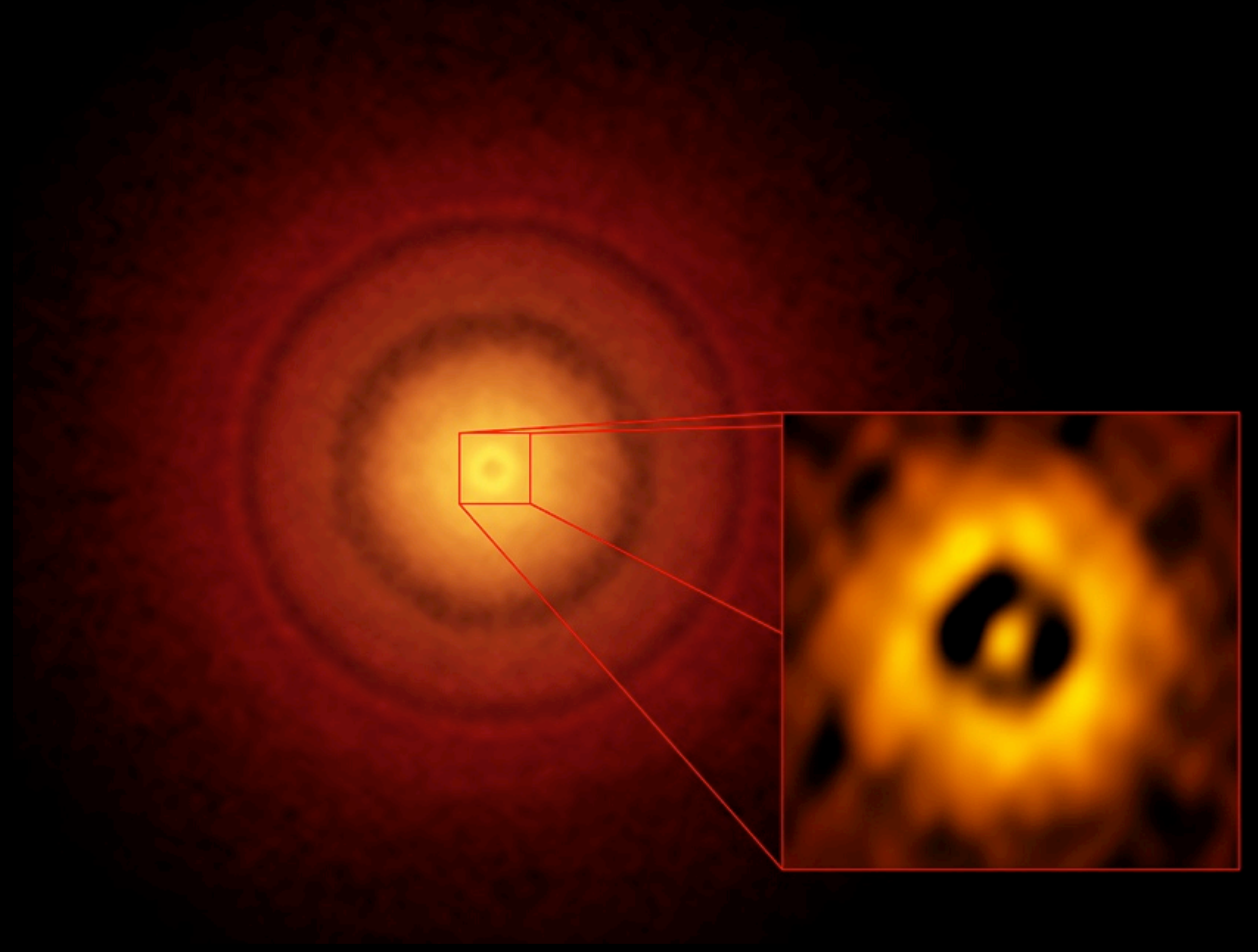


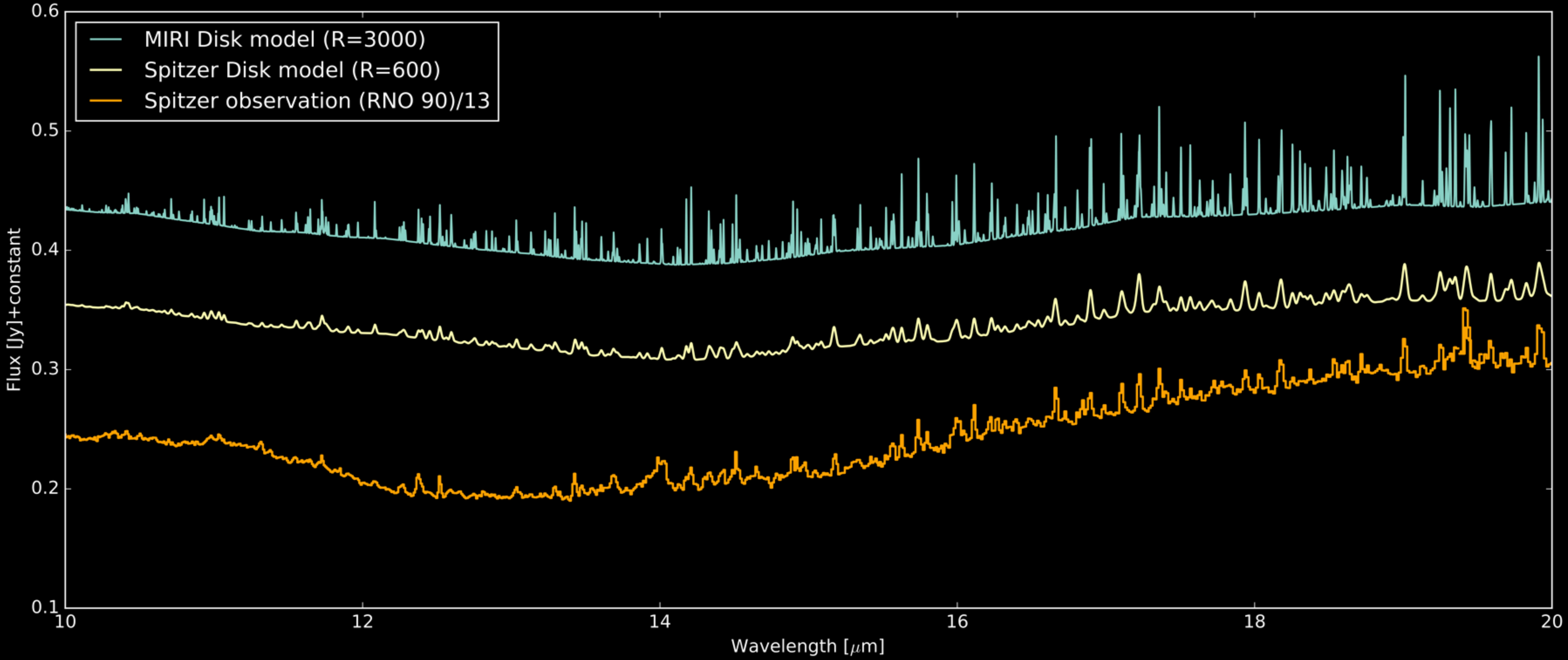
Ammonia

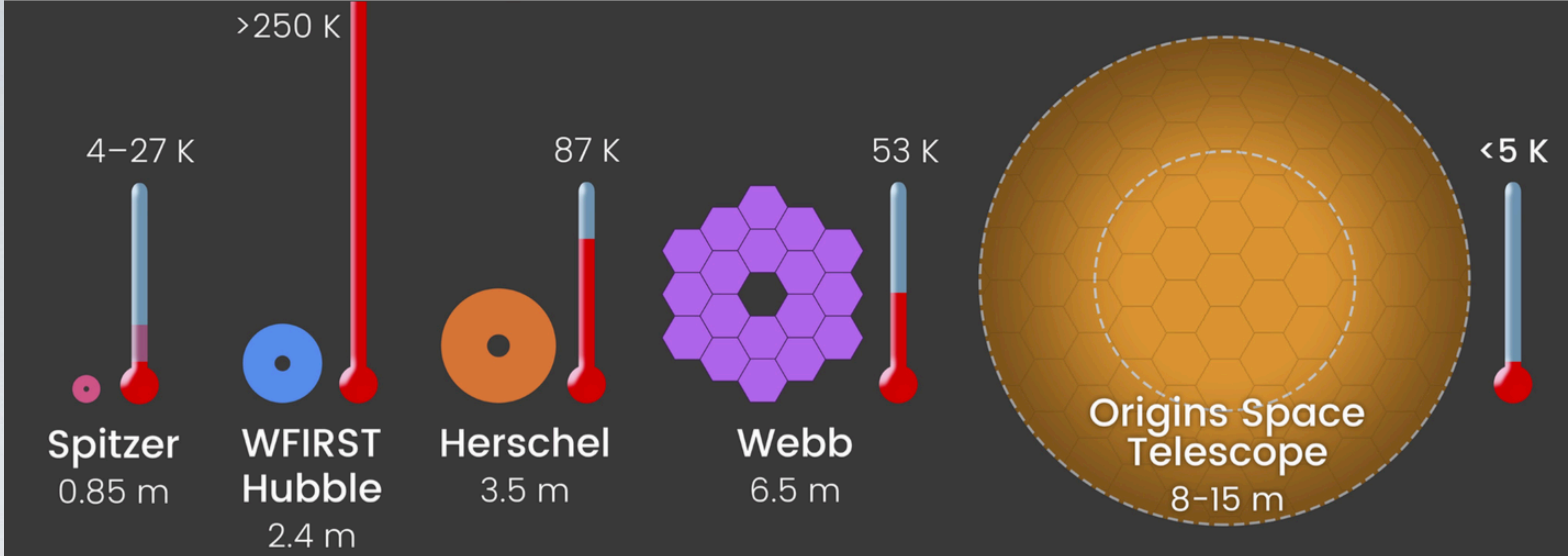


Pontoppidan+, prep

Water and organics in disks with JWST

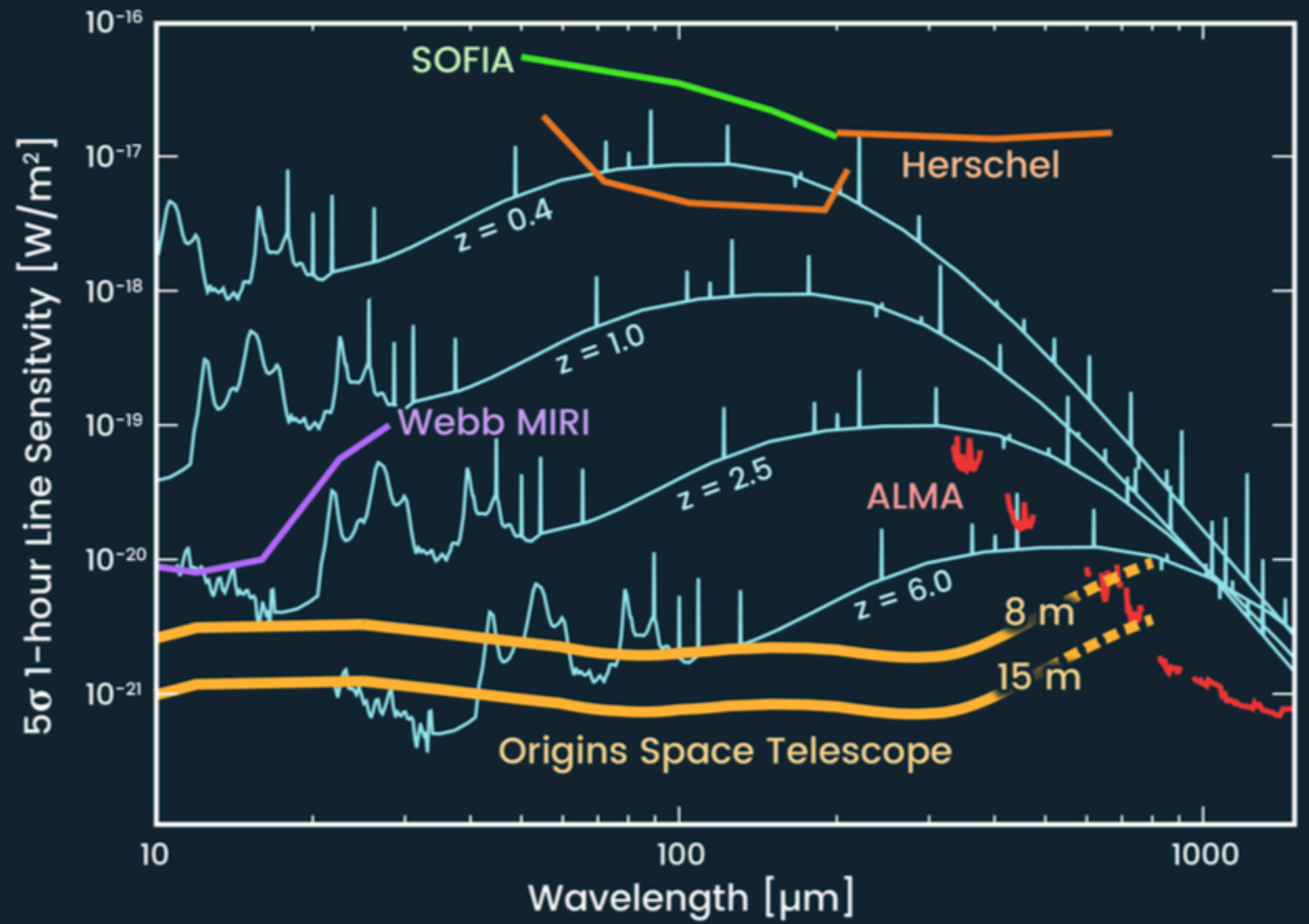






Actively-Cooled Large Aperture

Will attain sensitivities 100–1000x greater than any previous far-infrared telescope

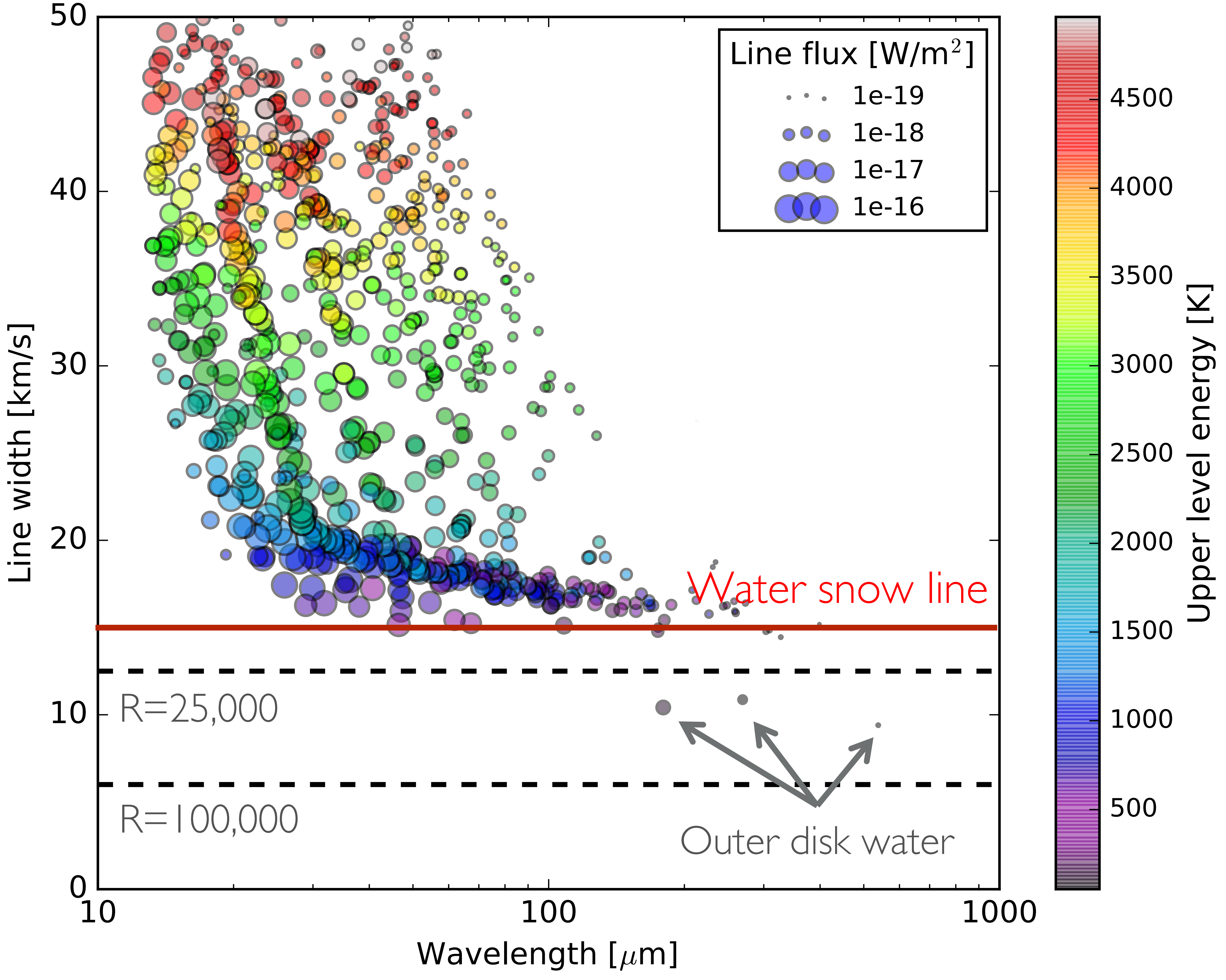


Unprecedented Sensitivity

ORIGINS
Space Telescope

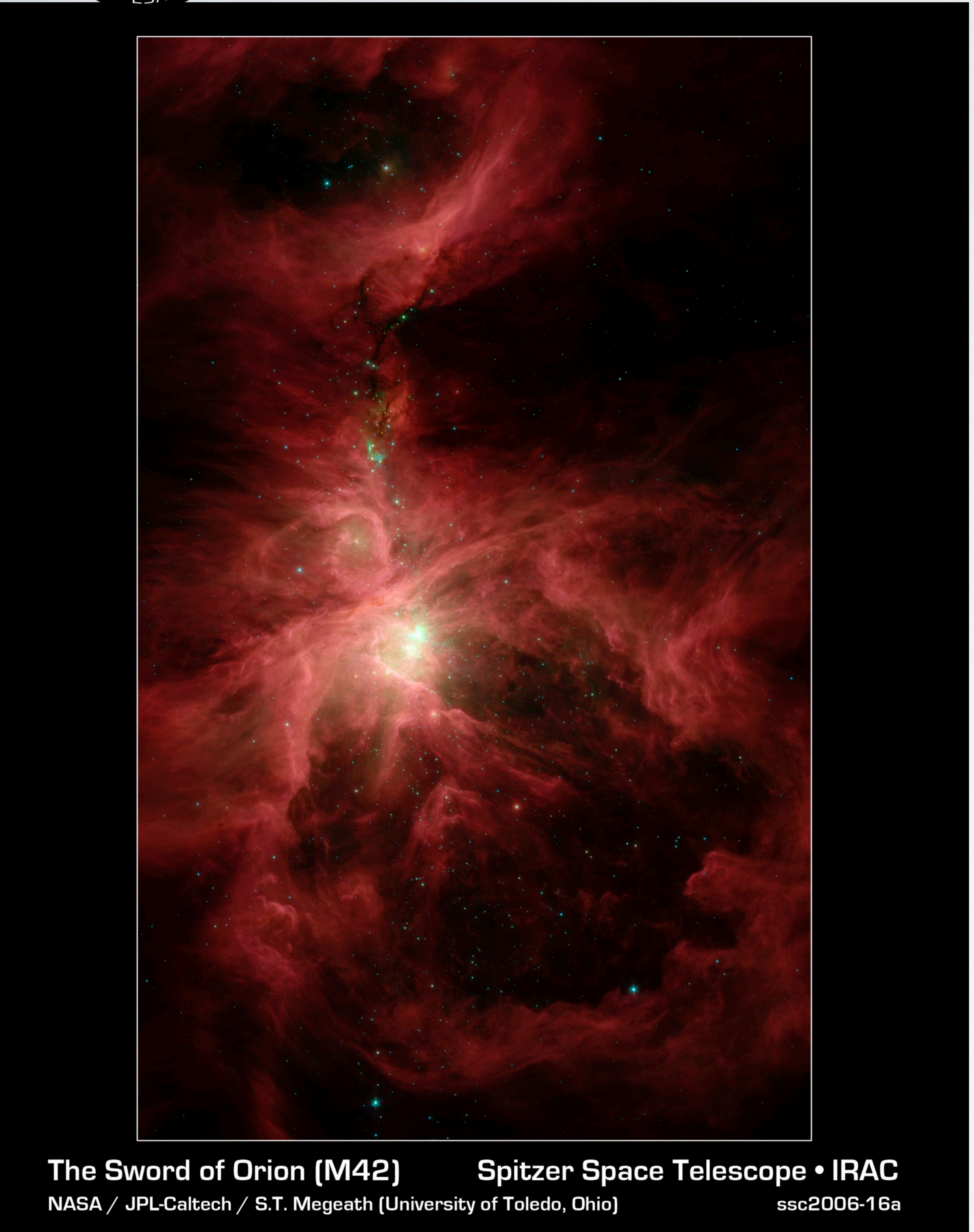
MEASURING WATER SNOW LINES WITH RESOLVED FIR SPECTROSCOPY

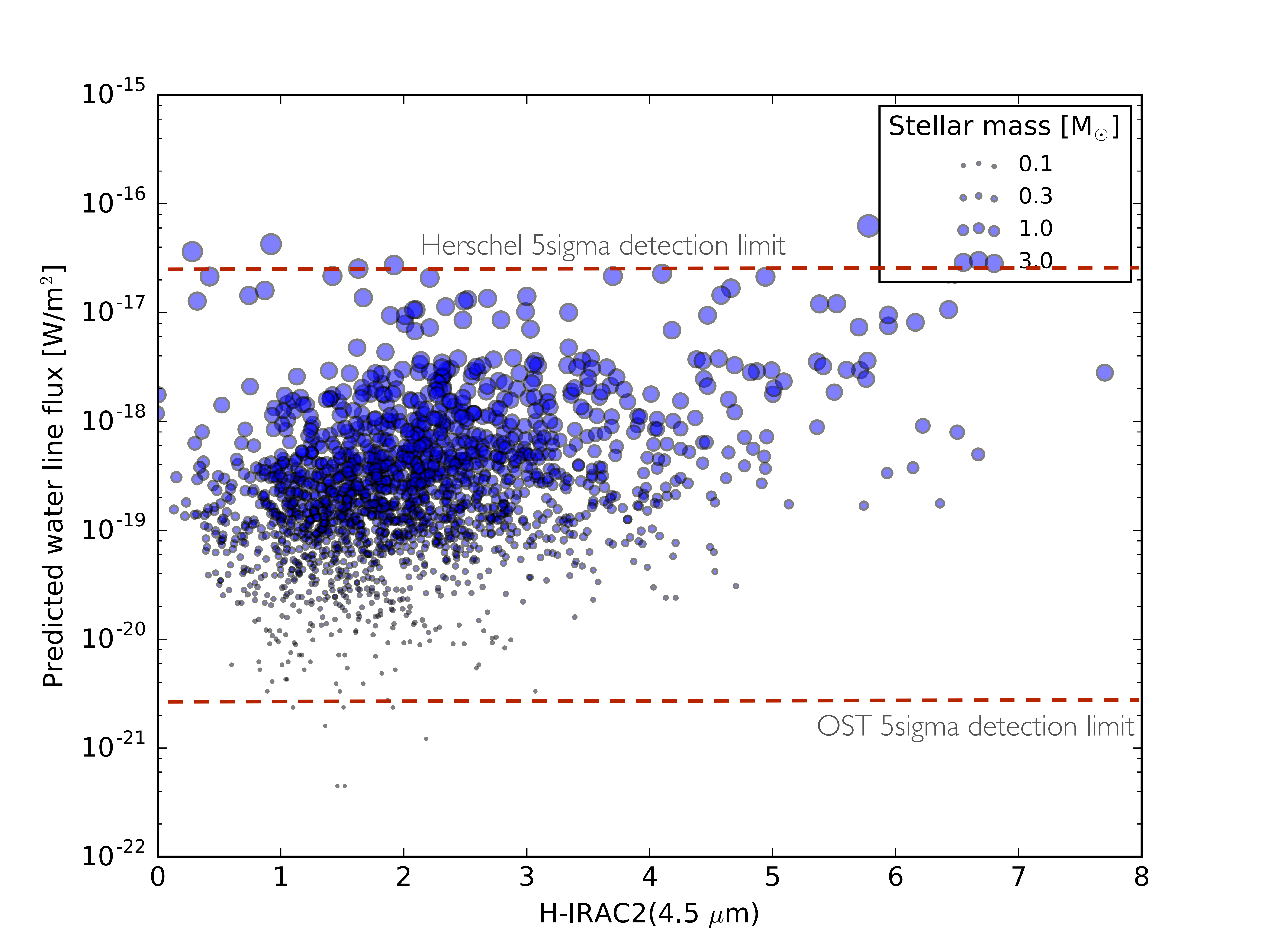
- Fluxes and widths of water lines from a typical protoplanetary disk
- Lines at 20-100 micron needed to trace region near snow line.
- Lines at 179-600 micron needed to trace water outside of snow line.
- Resolving powers of 25,000 needed to trace the snow line.
- Resolving powers of 50,000-100,000 needed to trace beyond the snow line.



ORIGINS Space Telescope

WATER IN 1000 SOLAR-NEBULA ANALOGS

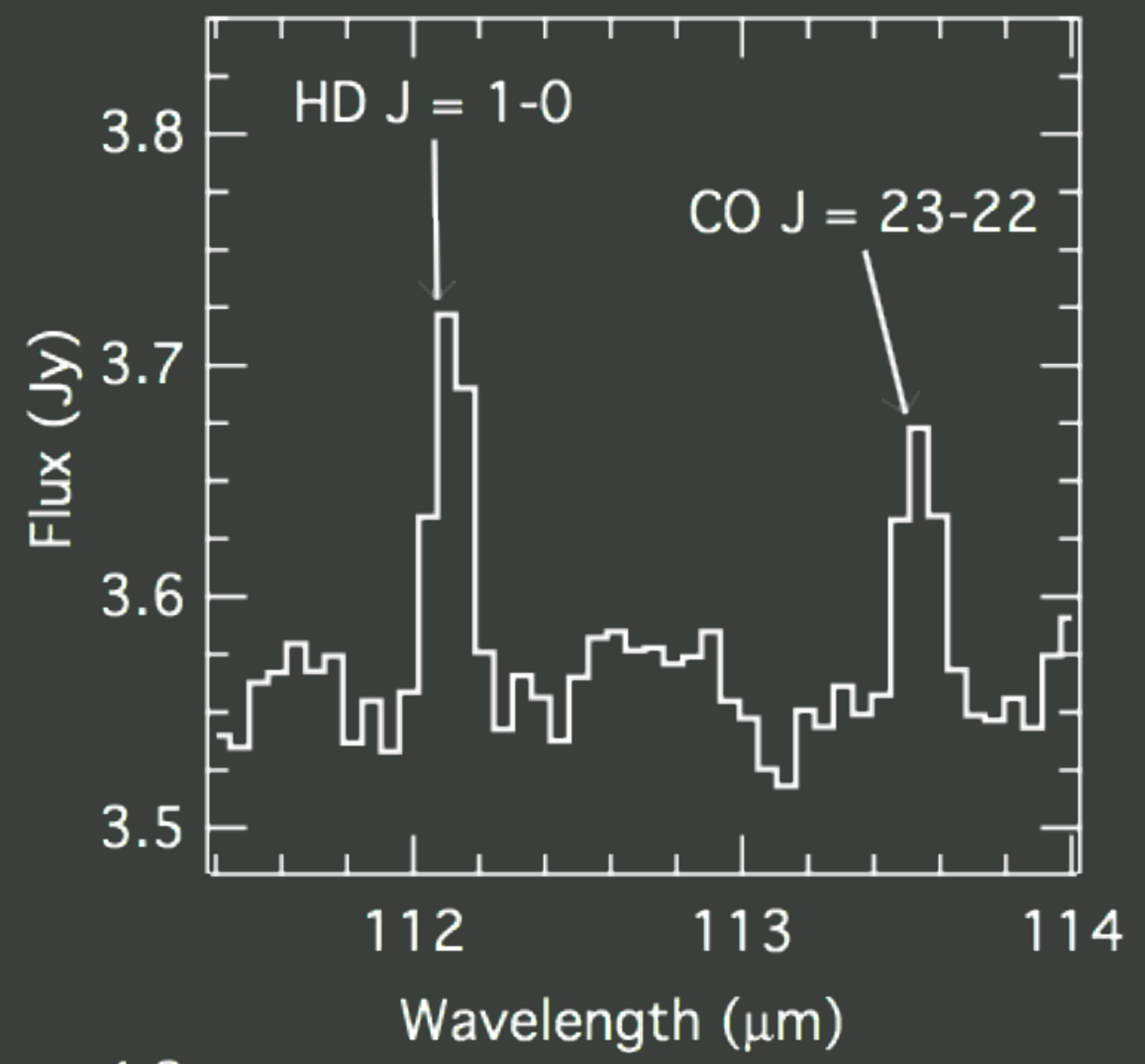


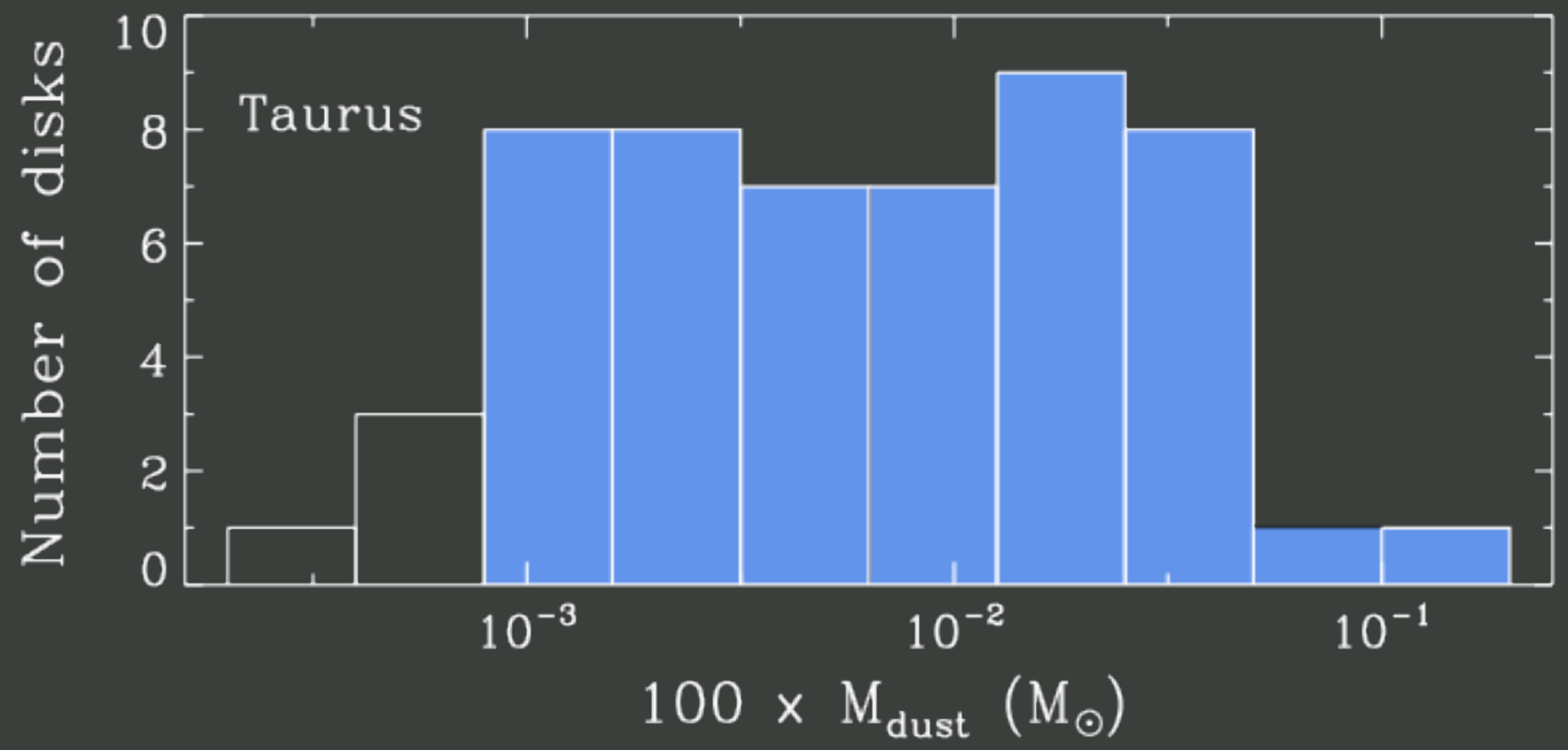


WHAT ARE PP DISK GAS MASSES?

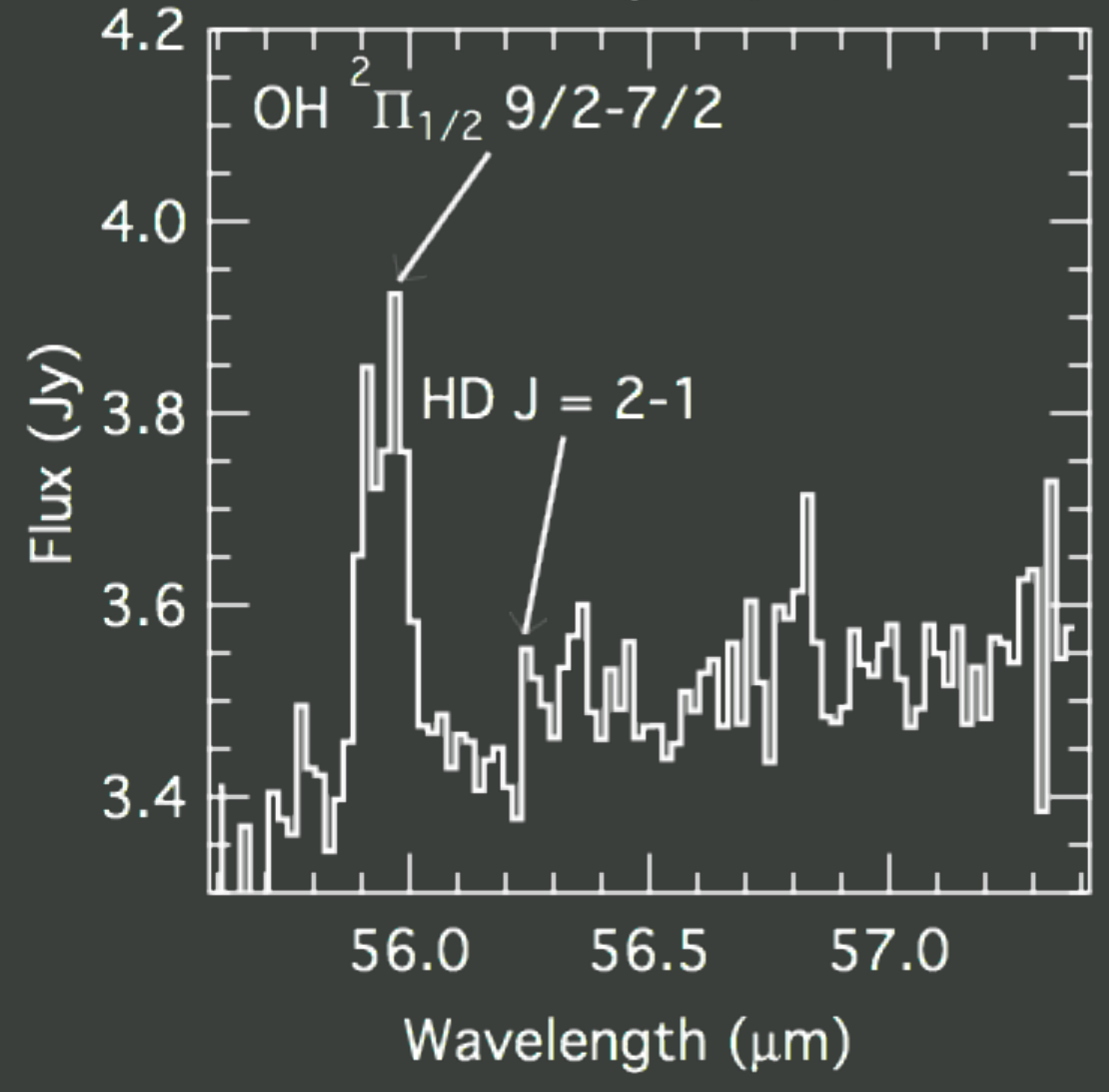
- ➡ HD is a million times more emissive than H_2 at T ~ 20 K.
- ➡ Atomic D/H ratio inside the local bubble is well characterized (~1.5 x 10^{-5})
- ➡ HD will follow H_2 in the gas

➡ TW Hya disk mass M_{disk} ~ 0.05 $M_\odot$





Williams and Cieza 2011



Bergin+ 2013

THE FUTURE OF PLANET-FORMING CHEMISTRY

- ALMA (0.1-1.0") — cold CO, HCN, N_2H+ and complex organic chemistry
- JWST (0.15-1.0") — warm H_2O, CO_2, HCN, CH_4, NH_3, …
- SOFIA-HIRMES (unresolved) — Sensitive spectrometer for 43 micron water ice+gas, HD and [OI]
- E-ELT METIS (0.03-1.0") — 3-5 micron R=100,000 IFU for warm CO imaging
- Origins Space Telescope (0.1-1.0) — 9-500 micron complete H_2O census, disk gas masses (HD), NH_3,...