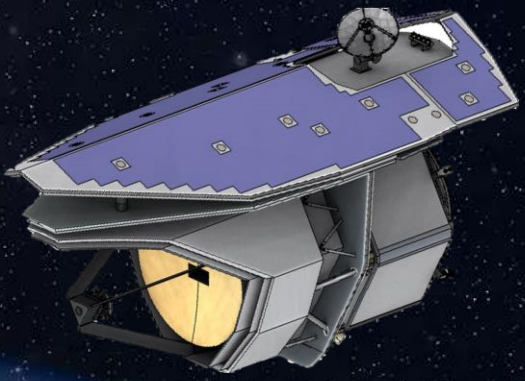
Beyond Water: Far-IR Observations of Planet Formation

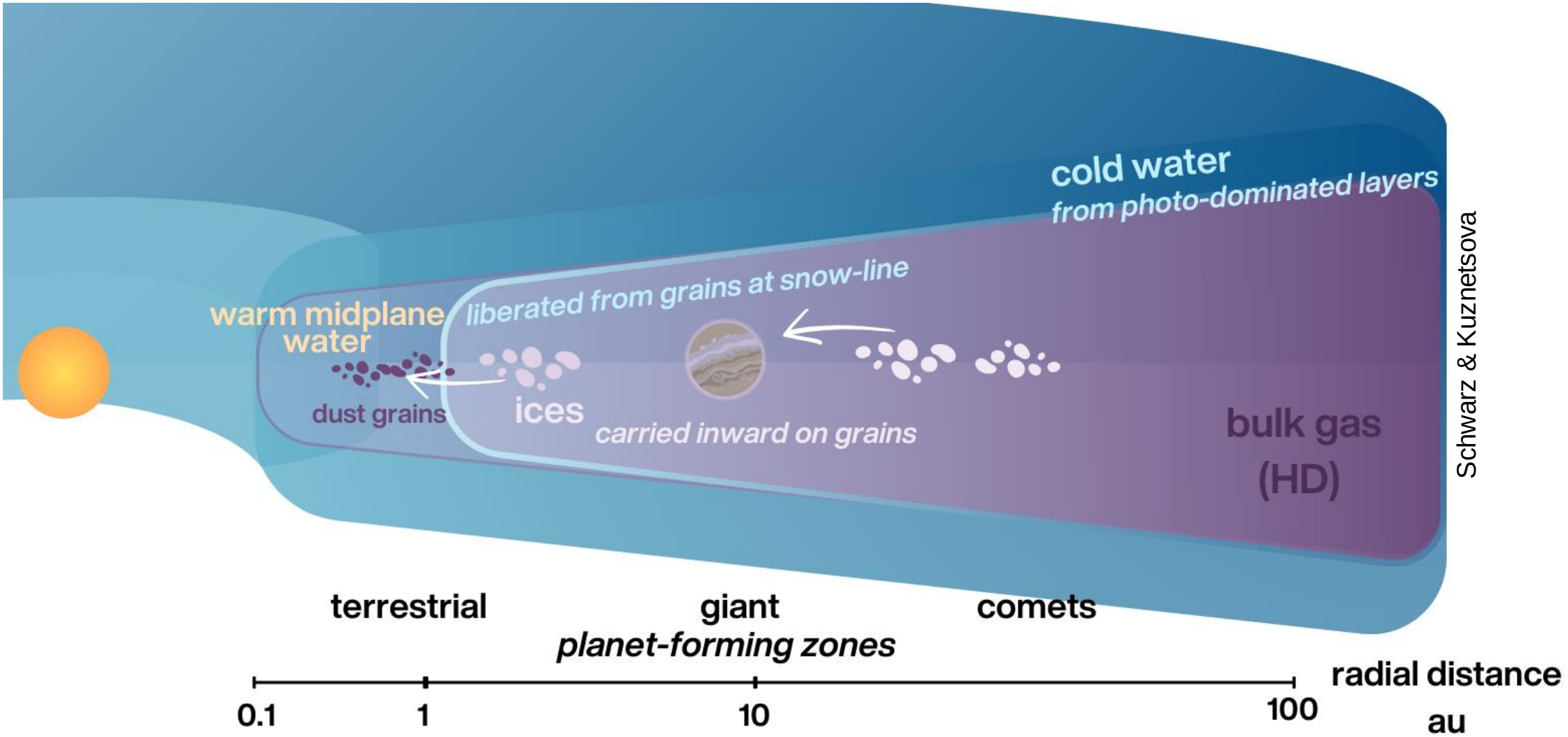


Kamber Schwarz
Max Planck Institute for Astronomy

The Building Blocks of Life

- Carbon Hydrogen Oxygen Nitrogen Sulfur CHONS!
  - Elements found in all life on Earth
  - Can form complex molecules in space
  - Jumpstart life?
  - Where are they when planets form?
  - FIR excellent for observing CHONS

Credit: NOVA “Finding Life Beyond Earth”



Schwarz & Kuznetsova

PRIMA PI program will obtain:

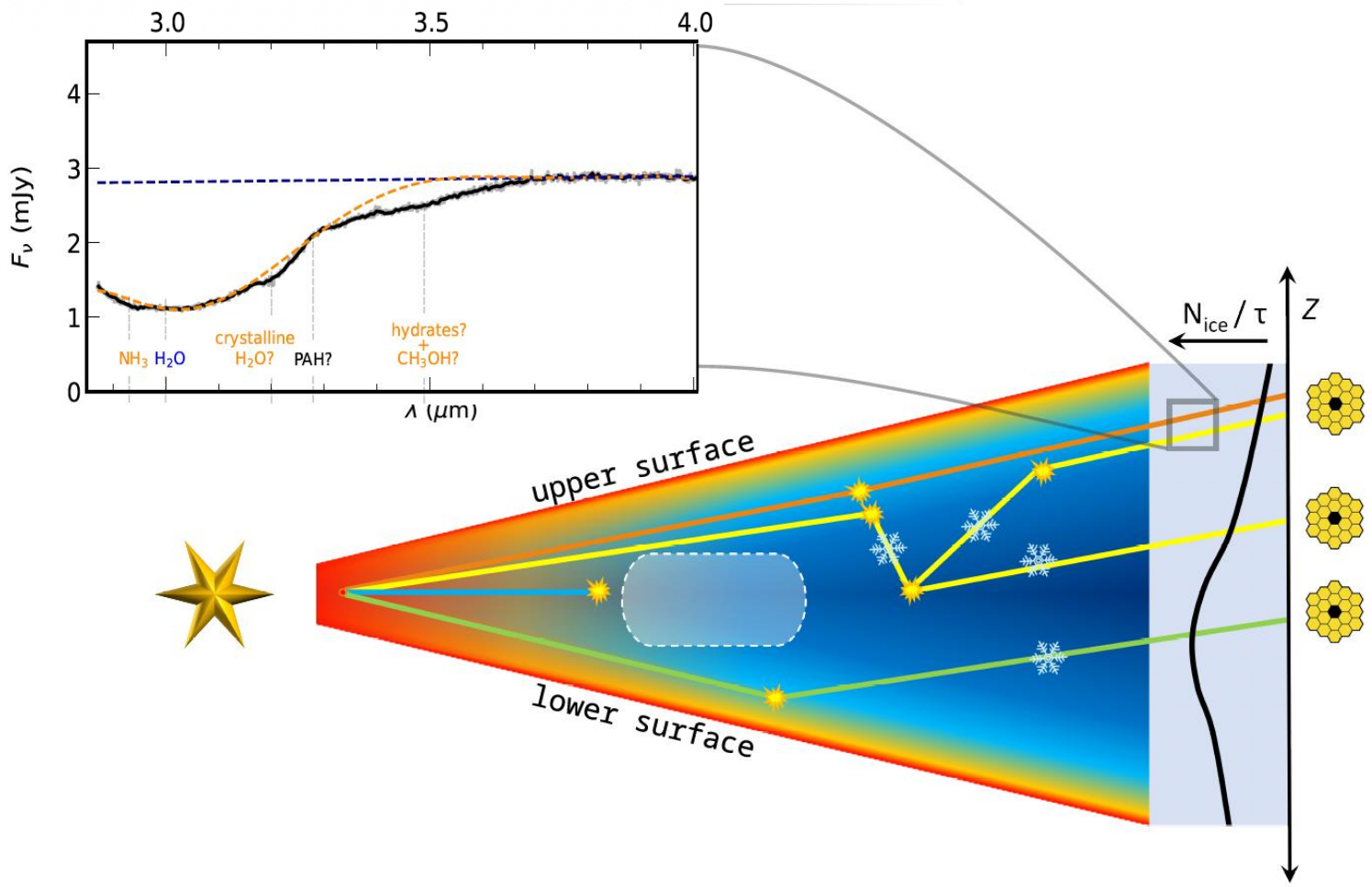
- Bulk hydrogen from HD 1-0
- Cold and warm water vapor

In 200 Disks down to 3 M_J

Most H_2O is in ices

- H_2O ice absorption with JWST NIRSpec
- Limited to edge-on disks
- Light scatters through the disk
- Primarily probe surface

➔Difficult to constrain abundance



Sturm+23d

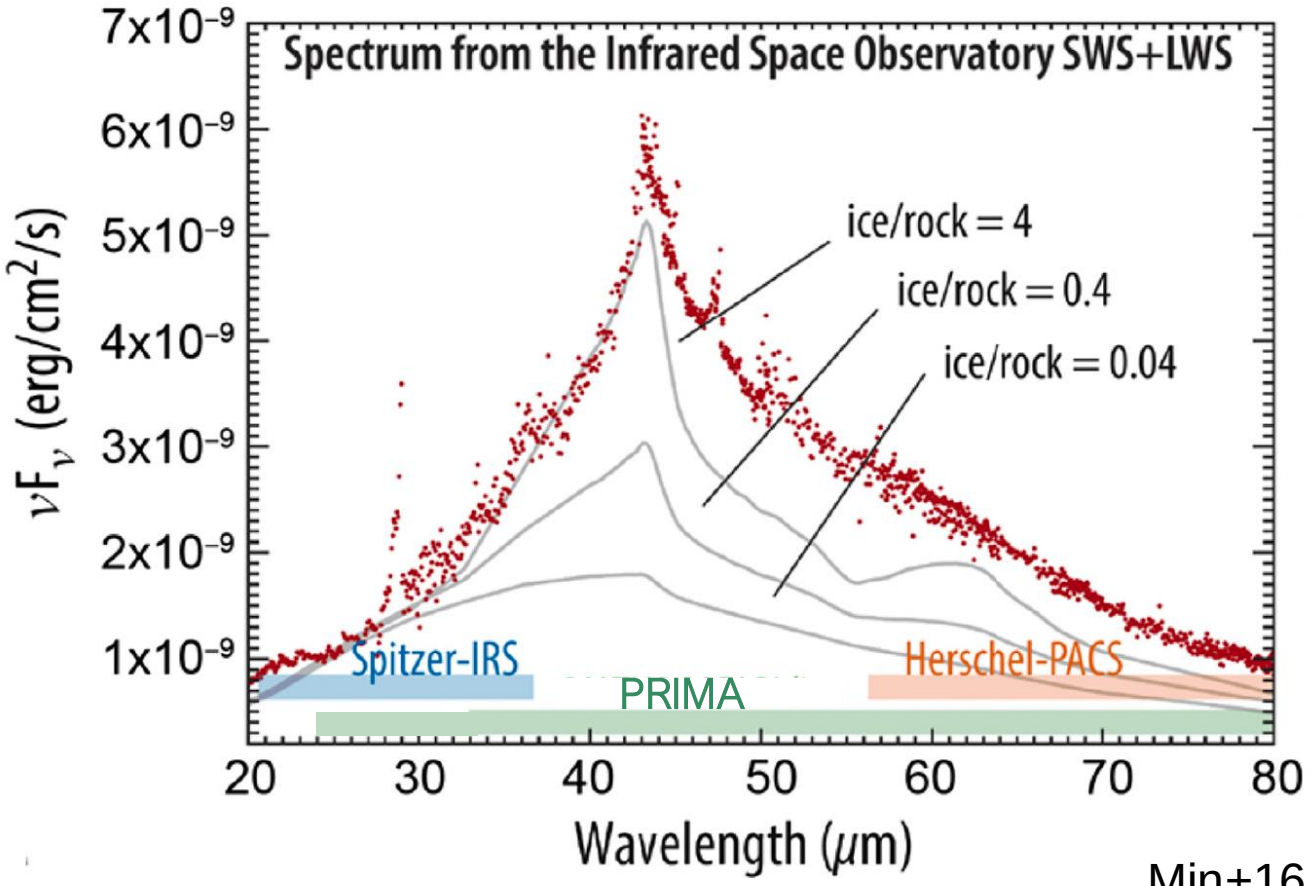
H_2O Ice Phonon Modes

- Lower optical depth in far-IR → Tracing bulk ice content
- Far-IR features in emission
  - ***Not dependent on viewing angle!***
- Get:
  - Local abundance
  - Temperature
  - Ice:silicate ratio

Wavelengths: 45 μm 63 μm

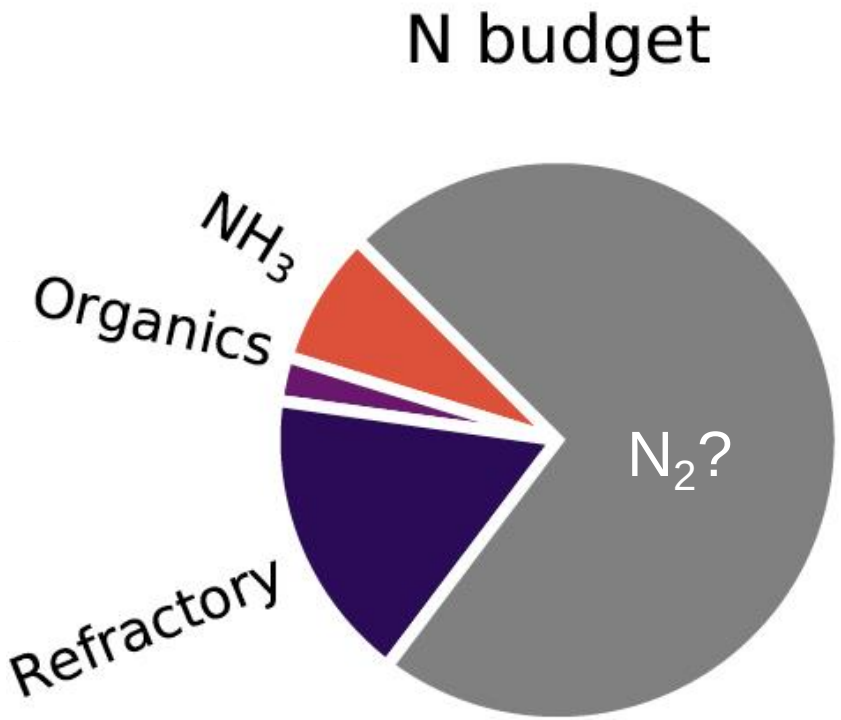
R: ~300

Sensitivity: ~0.3 mJy



Min+16

Nitrogen



Öberg & Bergin 21

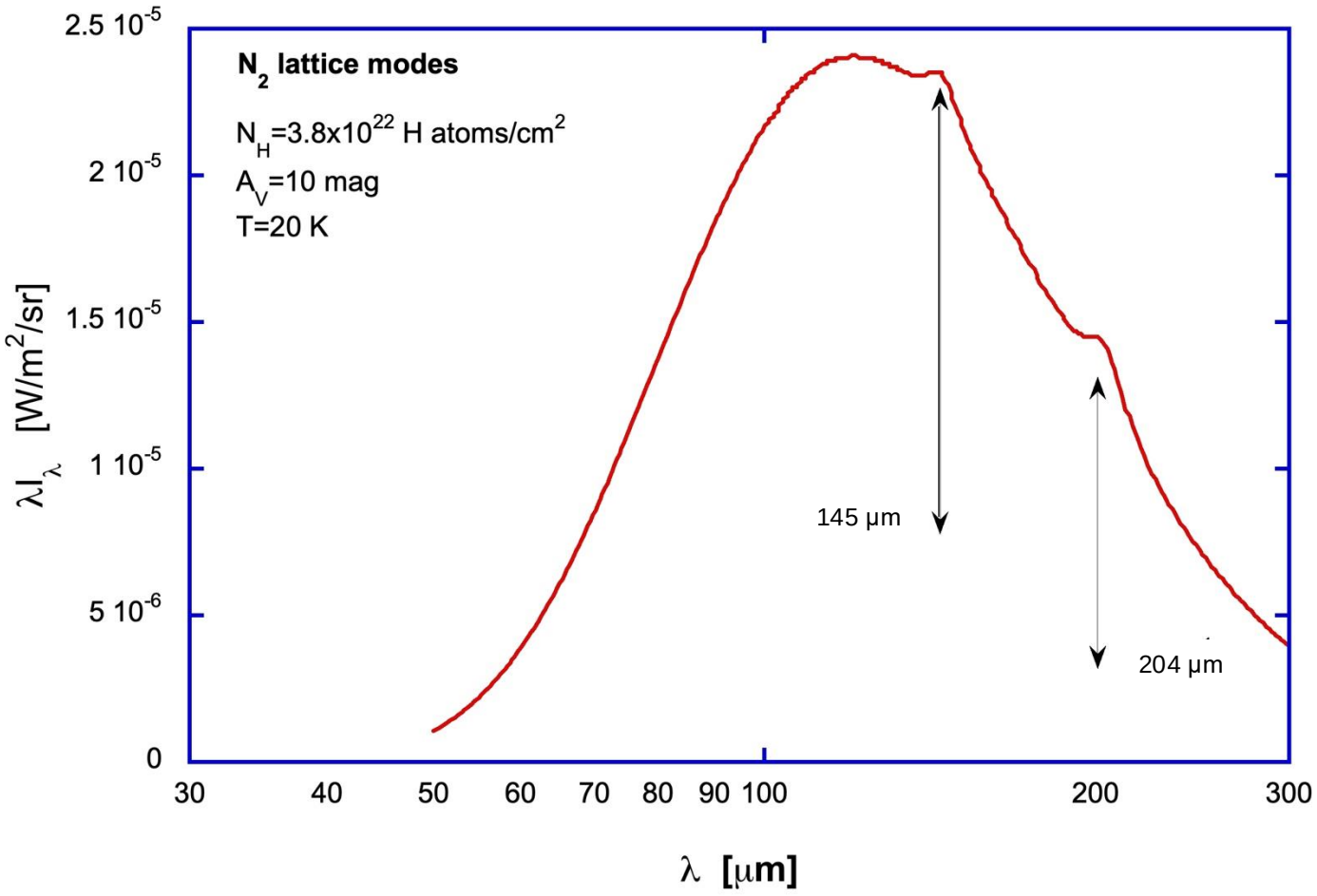
- Nitrogen largely unconstrained in disks
  - Likely in N_2 or NH_3 (Schwarz & Bergin 14, Krijt+23)
- N_2 has no dipole moment
- Difficult to observe

N_2 Ice Phonon Modes

- FIR *only* way access to N_2 ice

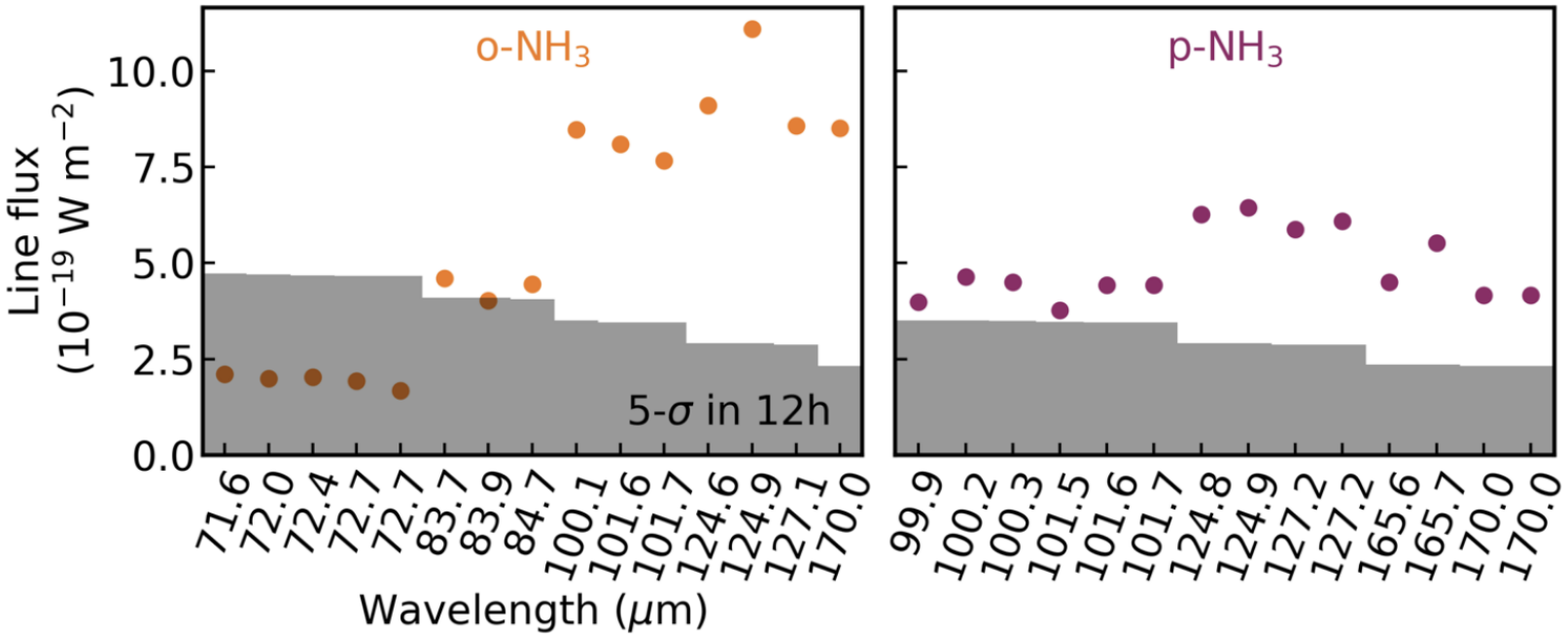
Wavelengths: 145 μm 204 μm

Sensitivity: 1% wrt continuum



NH_3

- 1 detection in an outer disk (Salinas+16)
- 1 detection in an inner disk (Najita+21)
- Multiple ortho & para lines observable with PRIMA!



Bergner+, GO Book

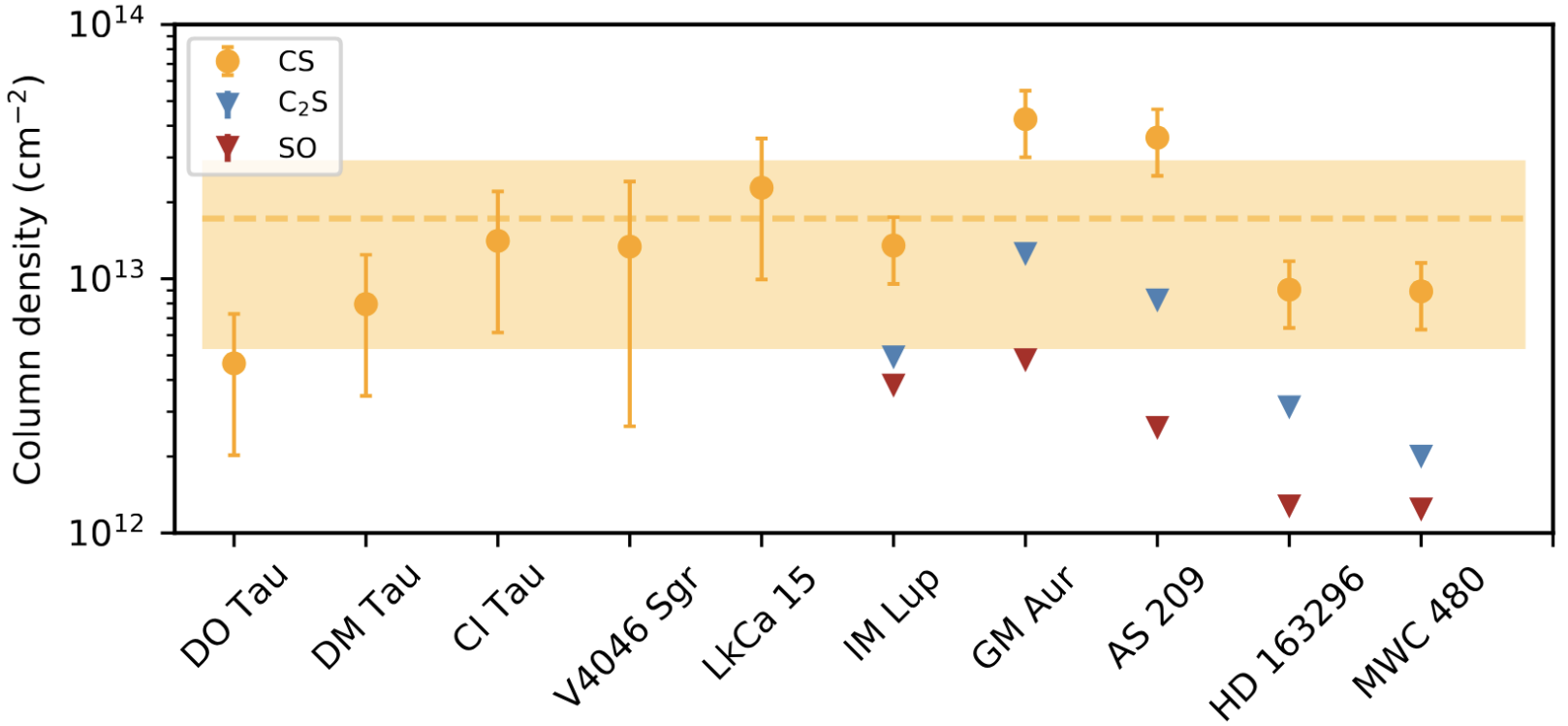
Wavelengths: 80 – 239 μm

R: 4400

Sensitivity: 45 mJy

Sulfur: The Big Unknown

- Likely carriers: H_2S, OCS, SO, SO_2 and CS (Keyte+24)
- Trace species CS is bright
- H_2S detected in 3 disks (Phuong+18, Rivière-Marichalar 21,22)
  - S carrier in comets
  - $1_{10} - 1_{01}$ line weaker than FIR lines
- Strong H_2S lines at 160.7 and 233.9 μm



Le Gal...KS+21

Measuring C, O, N, S in ices

H_2O, HCN, NH_3, N_2, H_2S, CO, CO_2, CH_3OH, H_2CO

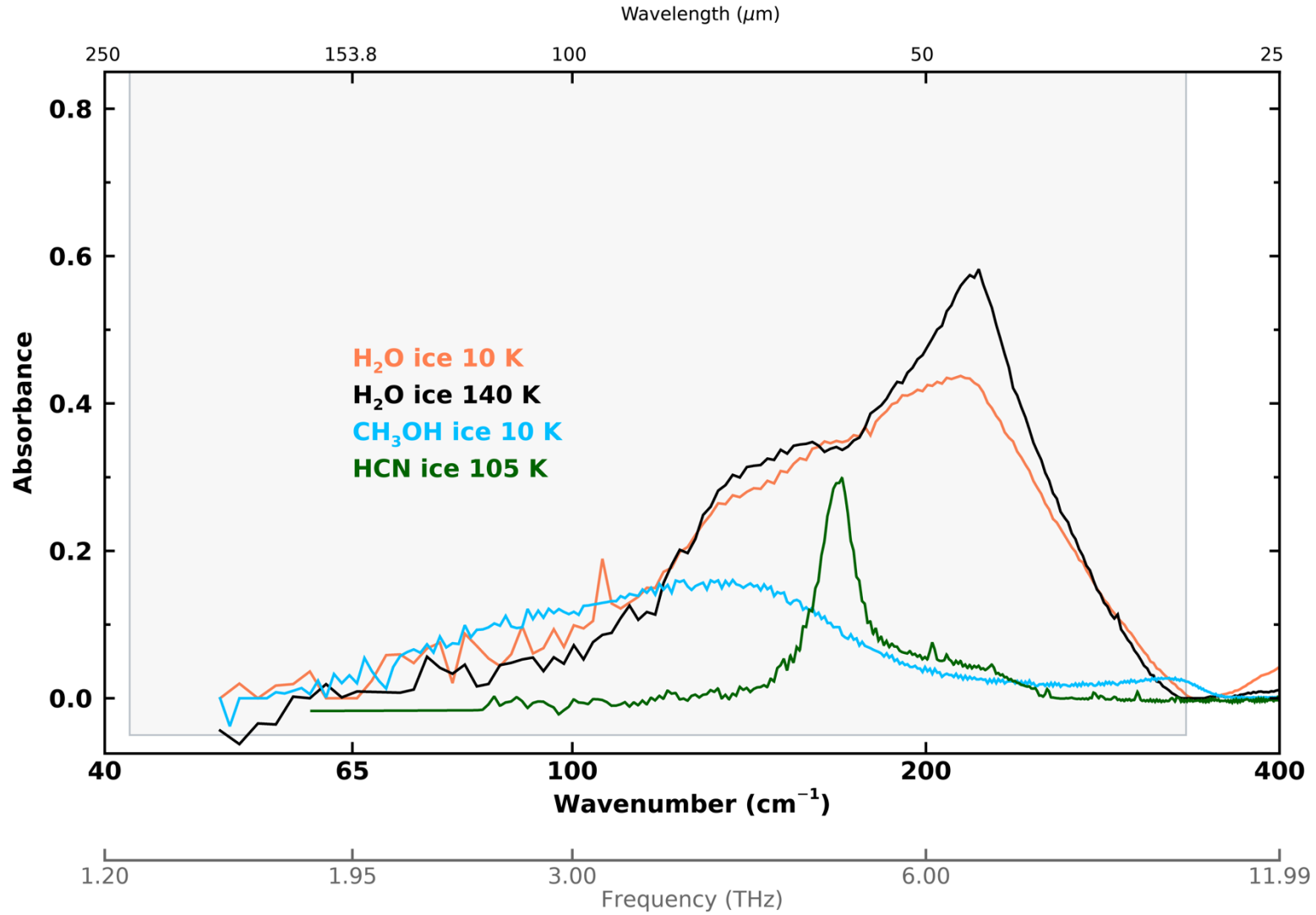
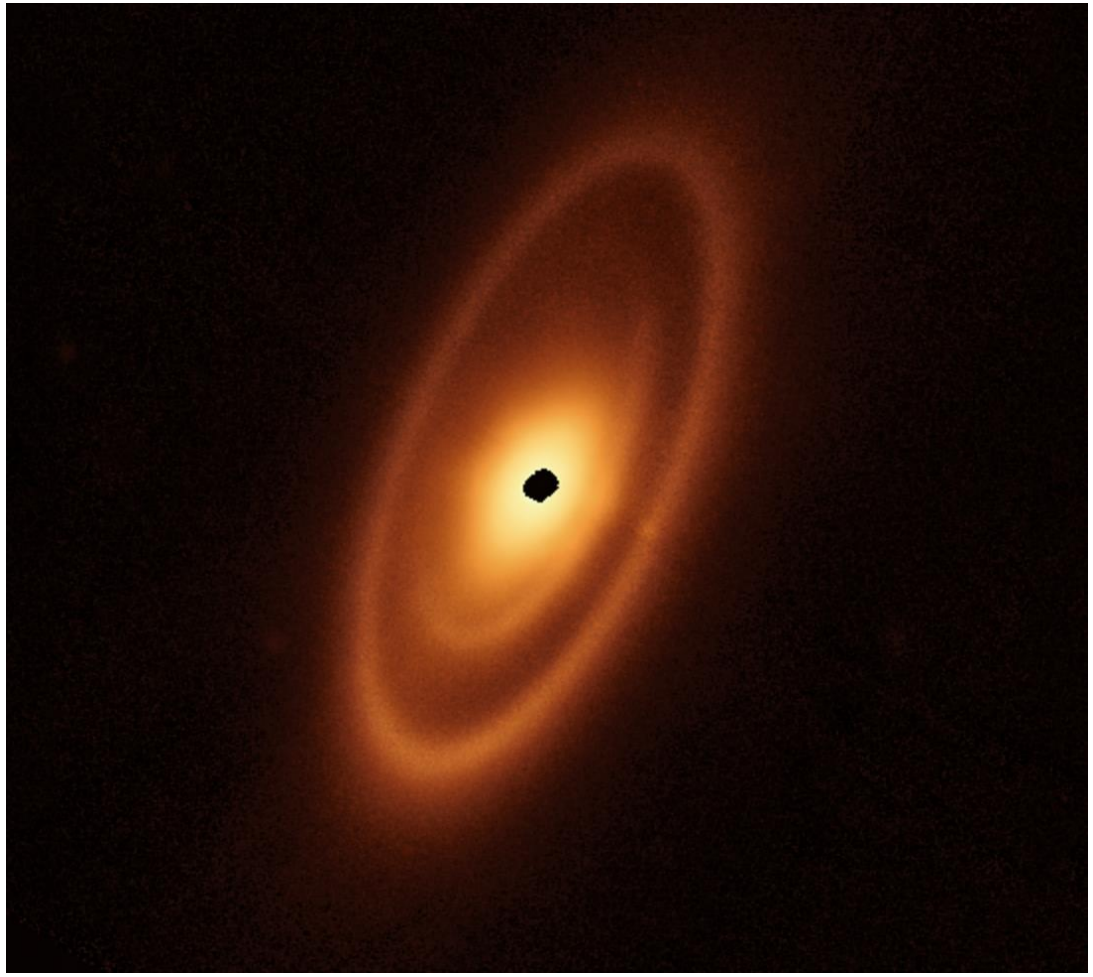


Image Credit:
Carrie Anderson

Debris Disks vs. The Solar System

- Debris disks – old(er) systems with dust belts generated by collisions
- Analogous to Kuiper Belt and Asteroid Belt
- Only see brightest disks
- Exo-Kuiper Belt T~50 K – blackbody peaks in the FIR!



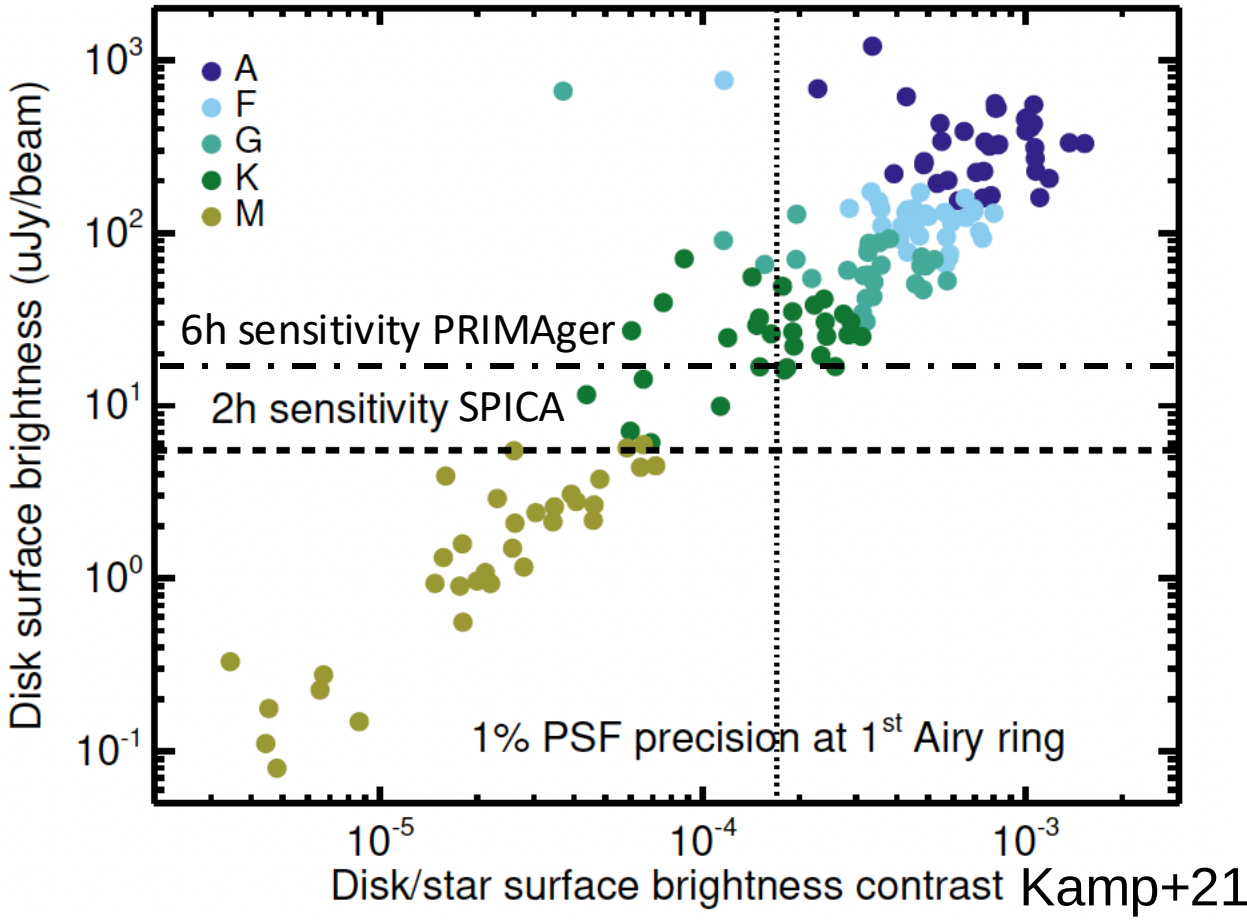
Gáspár+23

Deep Integrations on Debris Disks

- Emission from exo-Kuiper Belt peaks in FIR
  - No current detections
- Constrain frequency of exo-Kuiper Belts

Wavelength: 30-70 μm

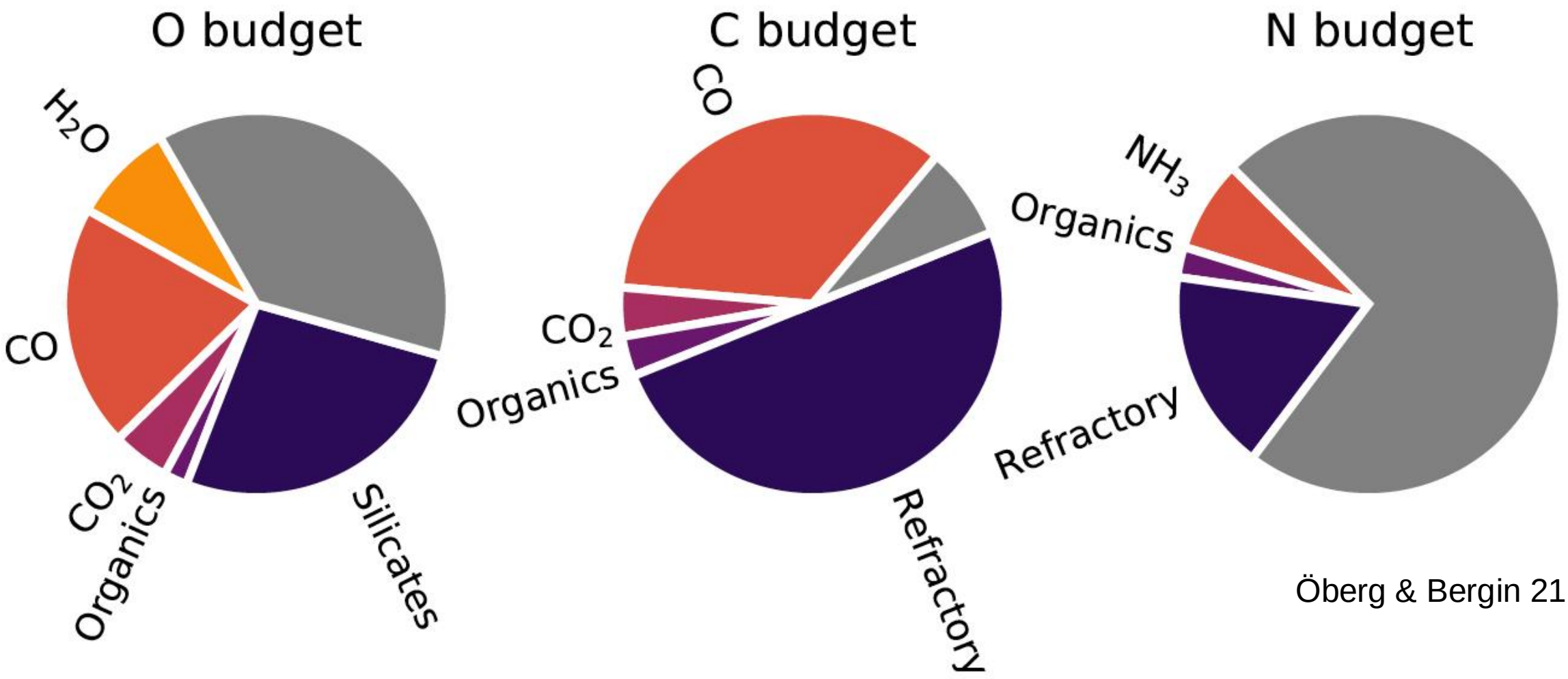
Sensitivity: 22 μJy/beam



FIR Observations of Disks: more than just H_2O!

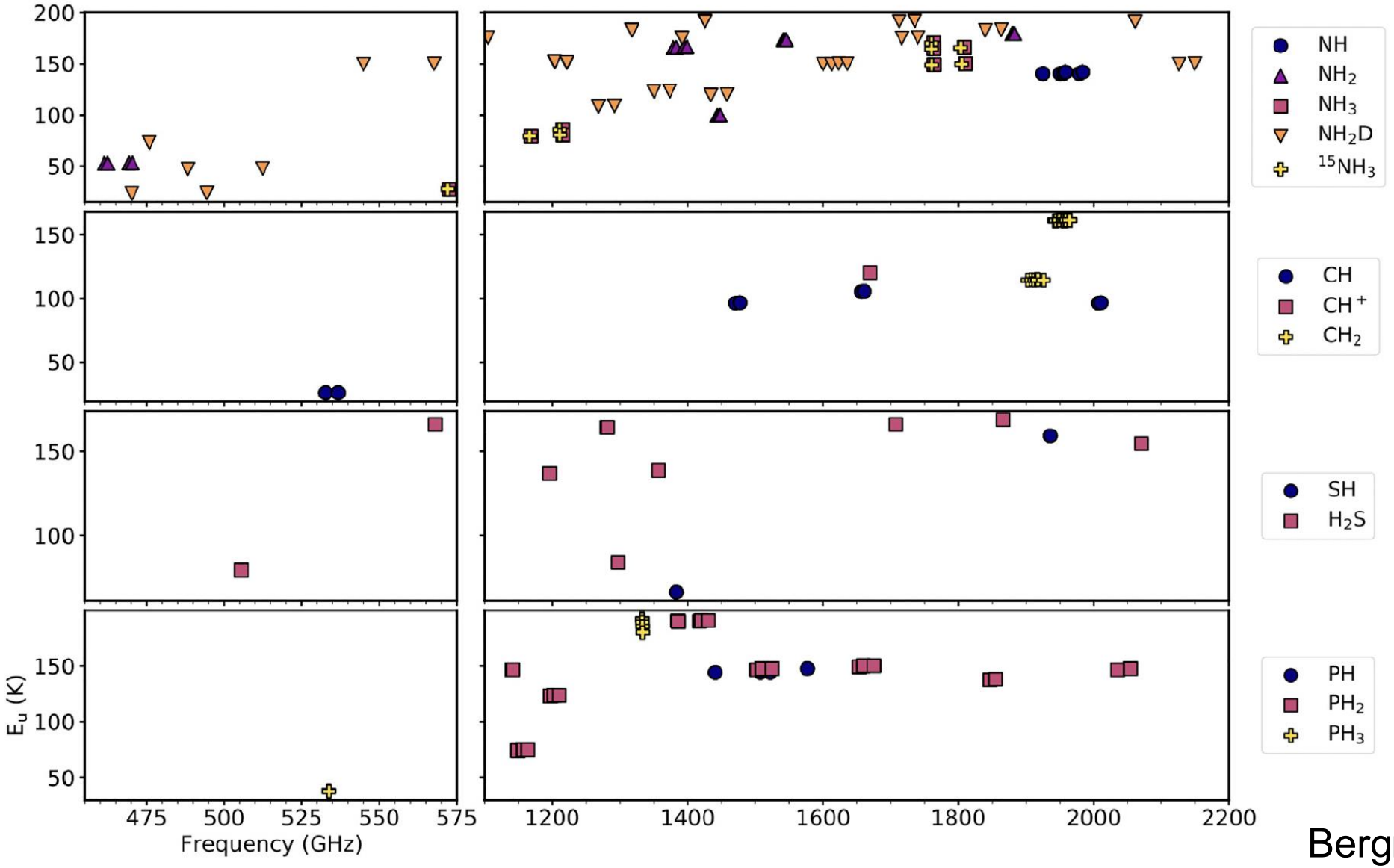
Observable	Wavelength (μm)	Frequency (THz)	R	Sensitivity
H_2O Ice	45 & 63	4.7 & 6.6	300	0.3 mJy
N_2 Ice	145 & 204	1.47 & 2.0	300	1% wrt continuum
NH_3 & H_2S Gas	107-524+	0.57-2.8	10^4	45 mJy
Exo-Kuiper Belts	30-70	4.3-10	10	22 μJy/beam

CNO at the Start of Star Formation



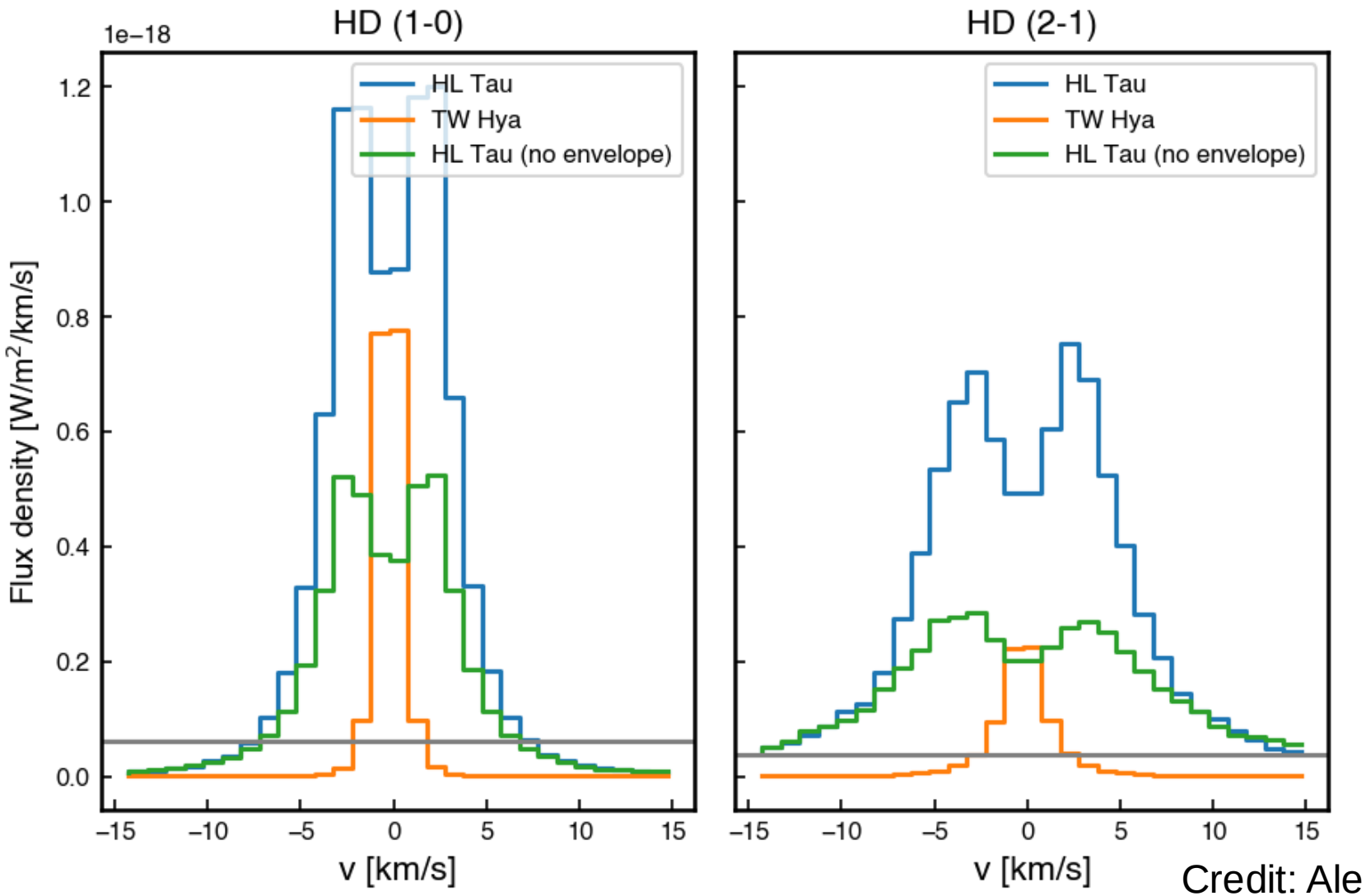
Öberg & Bergin 21

Phosphorous?



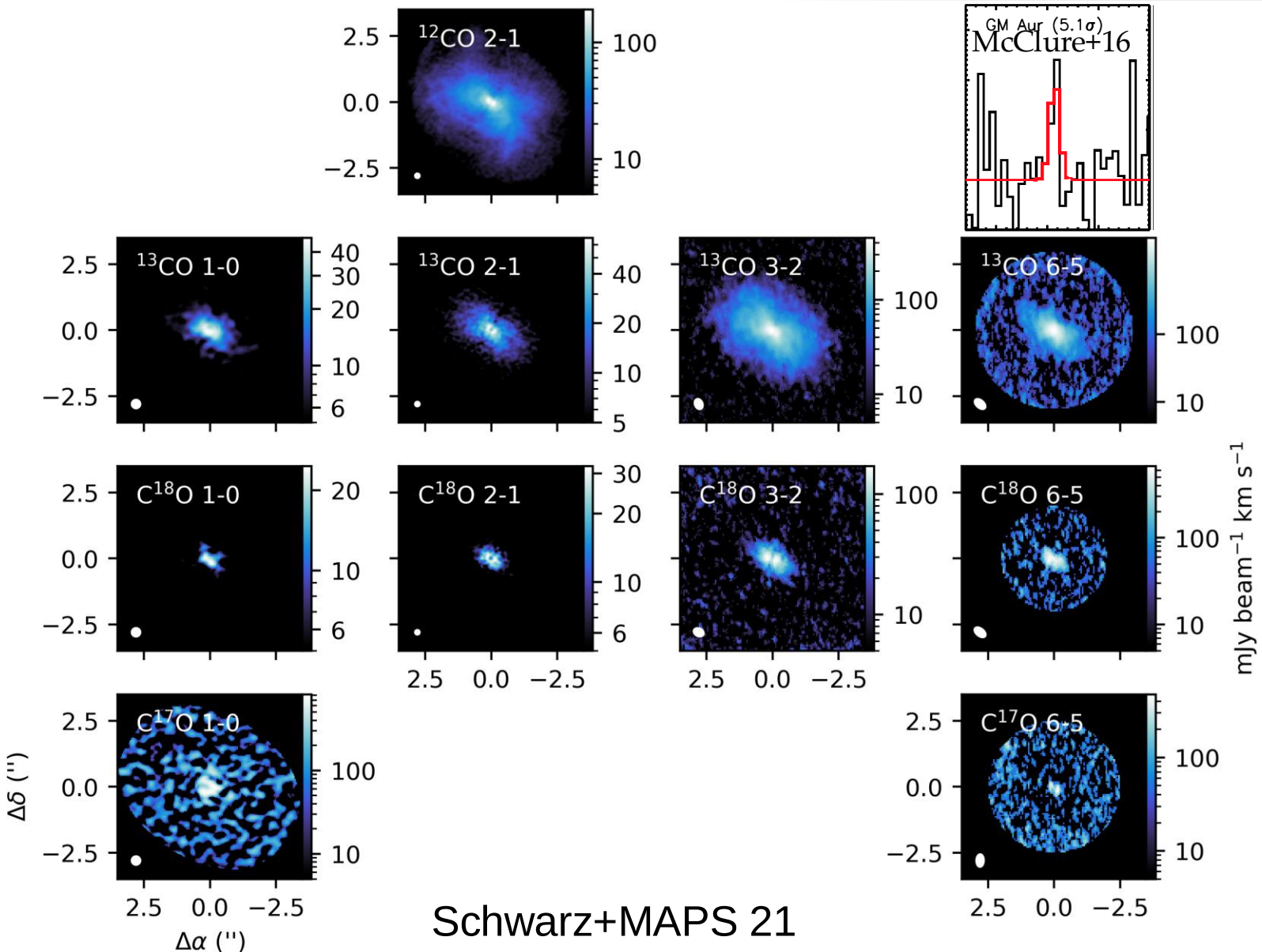
Bergner…KS+22

Disk+Envelope HD Models



Credit: Aleksandra Kuznetsova

CO and Gas Mass in GM Aur



Schwarz+MAPS 21

- Build disk model to reproduce HD Flux & 11 CO lines
- Goal: H_2, CO, & T_{gas} maps in 2D

Radial Intensity Profiles: Best Fit

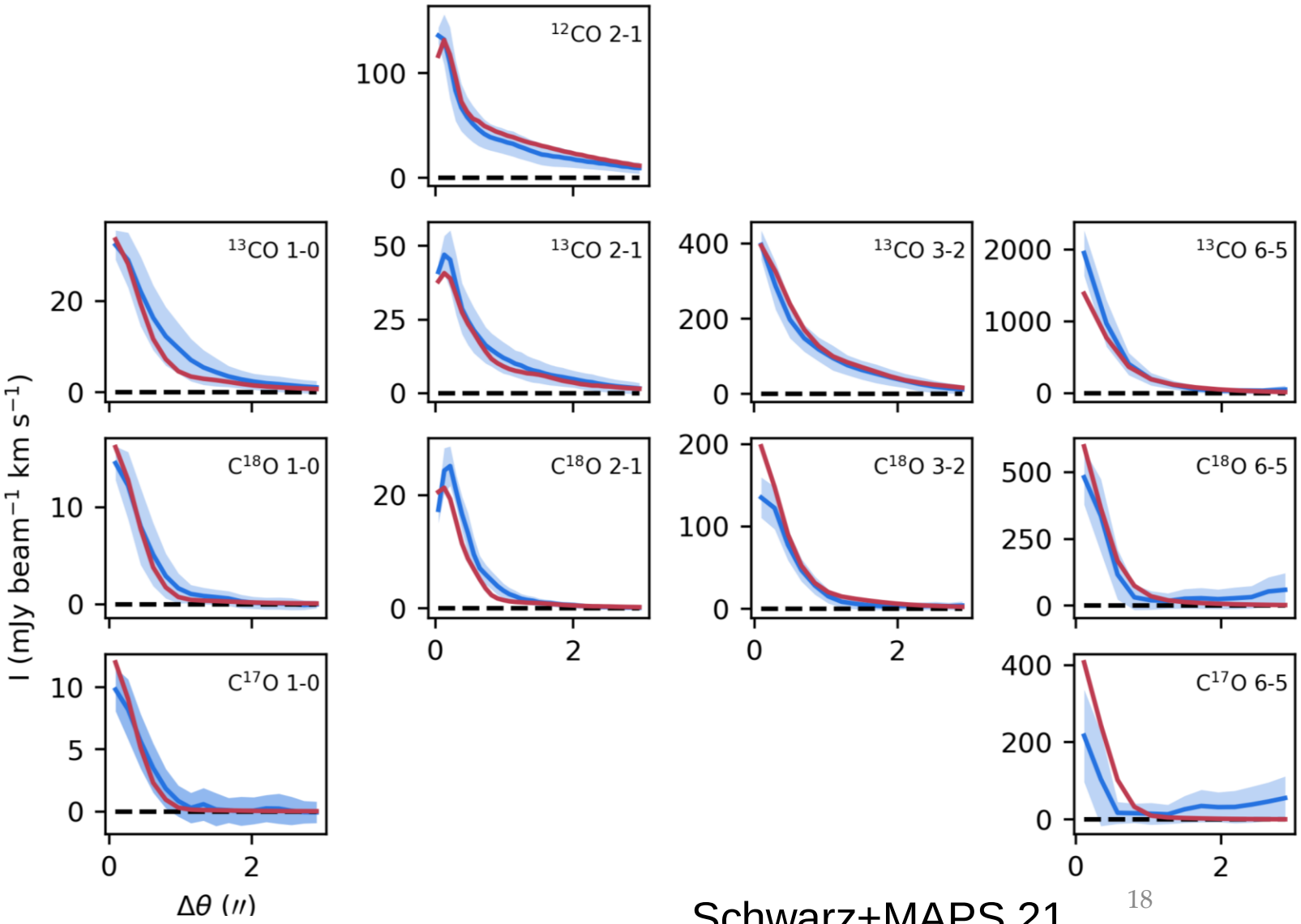
HD 1-0

Observed:

2.5±0.5e-18 W m^2

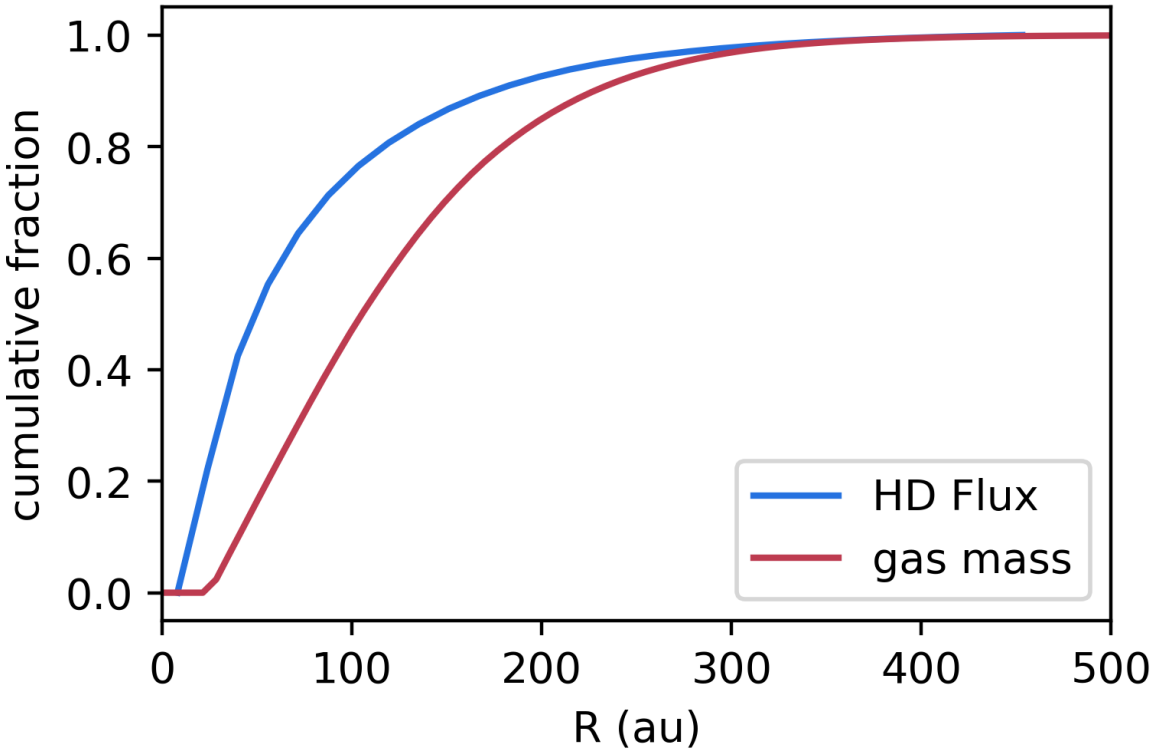
Modeled:

2.5e-18 W m^2



Schwarz+MAPS 21

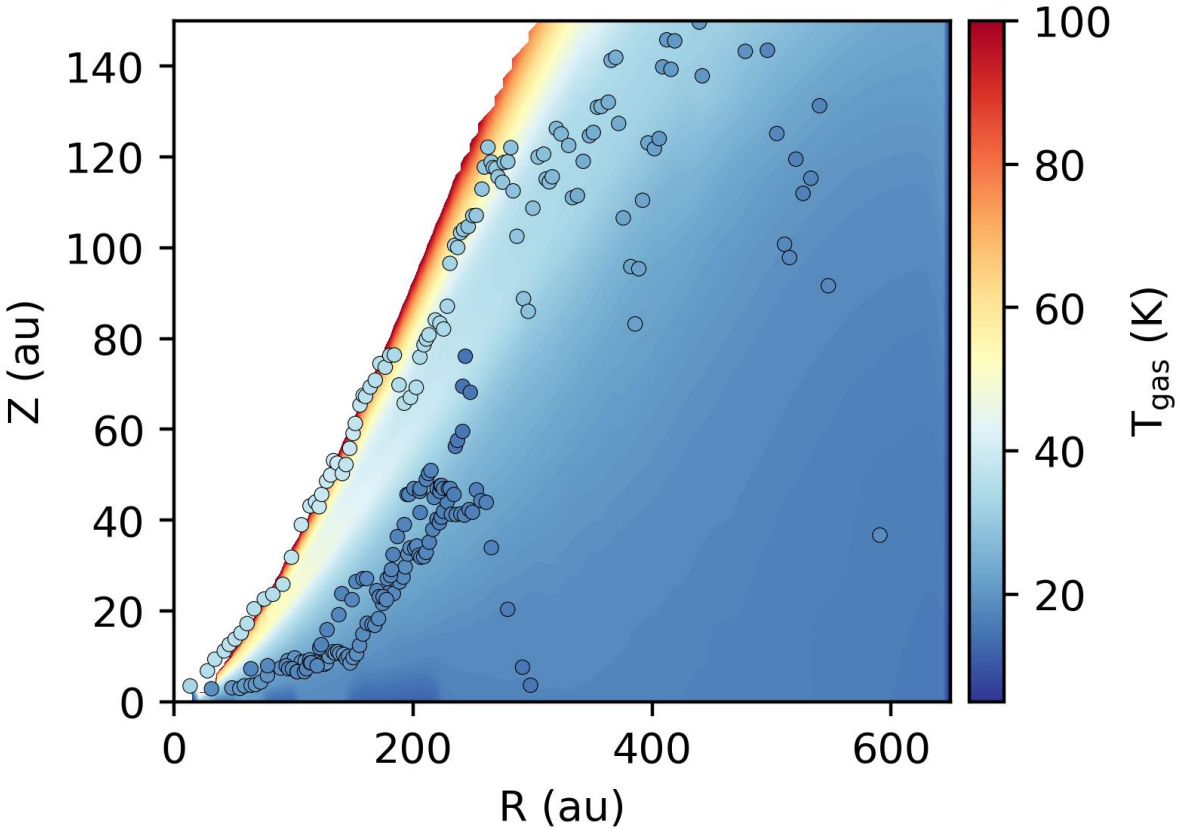
Results: Massive



Schwarz+MAPS 21

- $M_{disk} \sim 0.2\ M_{\odot}$
  - $M_{star} = 1.1\ M_{\odot}$
  - $M_{gas}/M_{dust} = 290$

Results: Cold



Schwarz+MAPS 21

- 32% of mass < 20 K
- Low T_{gas} to match CO line temperatures
  ➔ Need high M_{gas} to match HD flux