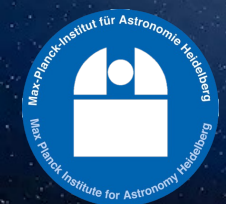


# Beyond Water: Far-IR Observations of Planet Formation



Kamber Schwarz, Carrie Anderson, Jennifer Bergner, Gordon Chin, Quentin Kral, Joan Najita, Peter Roelfsema, Xander Tielens, David Wilner, & Erick Young

# H<sub>2</sub>O Ice Phonon Modes

“How Are Potentially Habitable Environments Formed?” – Decadal E-Q3a

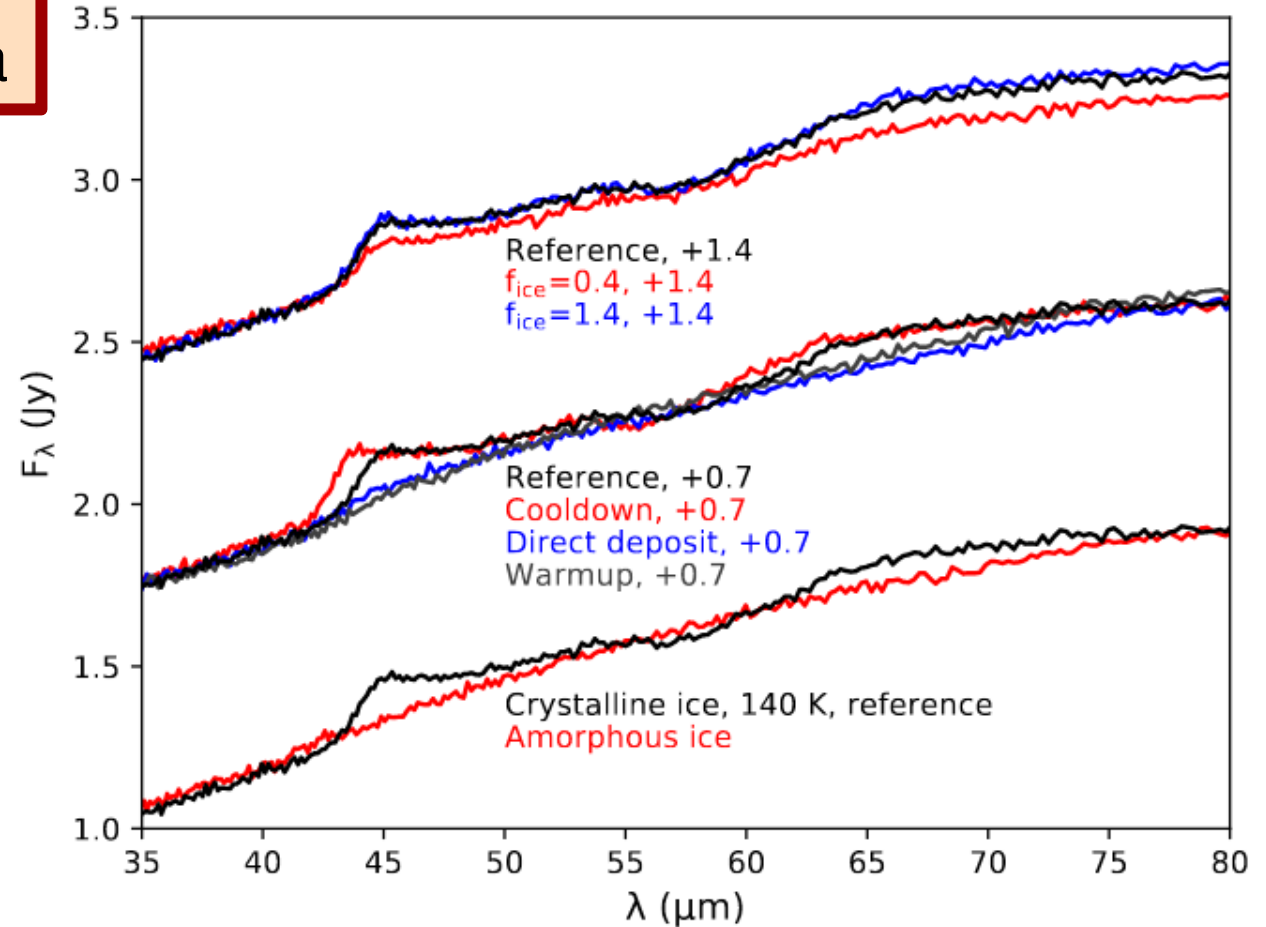
- Mid-IR ice features only probe surface (Sturm+23d)
  - Difficult to constrain abundance
- Lower optical depth in far-IR → Tracing bulk ice content
- Far-IR features in emission
  - **Not dependent on viewing angle!**

Wavelengths: 45  $\mu$ m 63  $\mu$ m

R: ~300

Sensitivity: ~0.3 mJy

Simulated 10 minute exposure w/ SAFARI



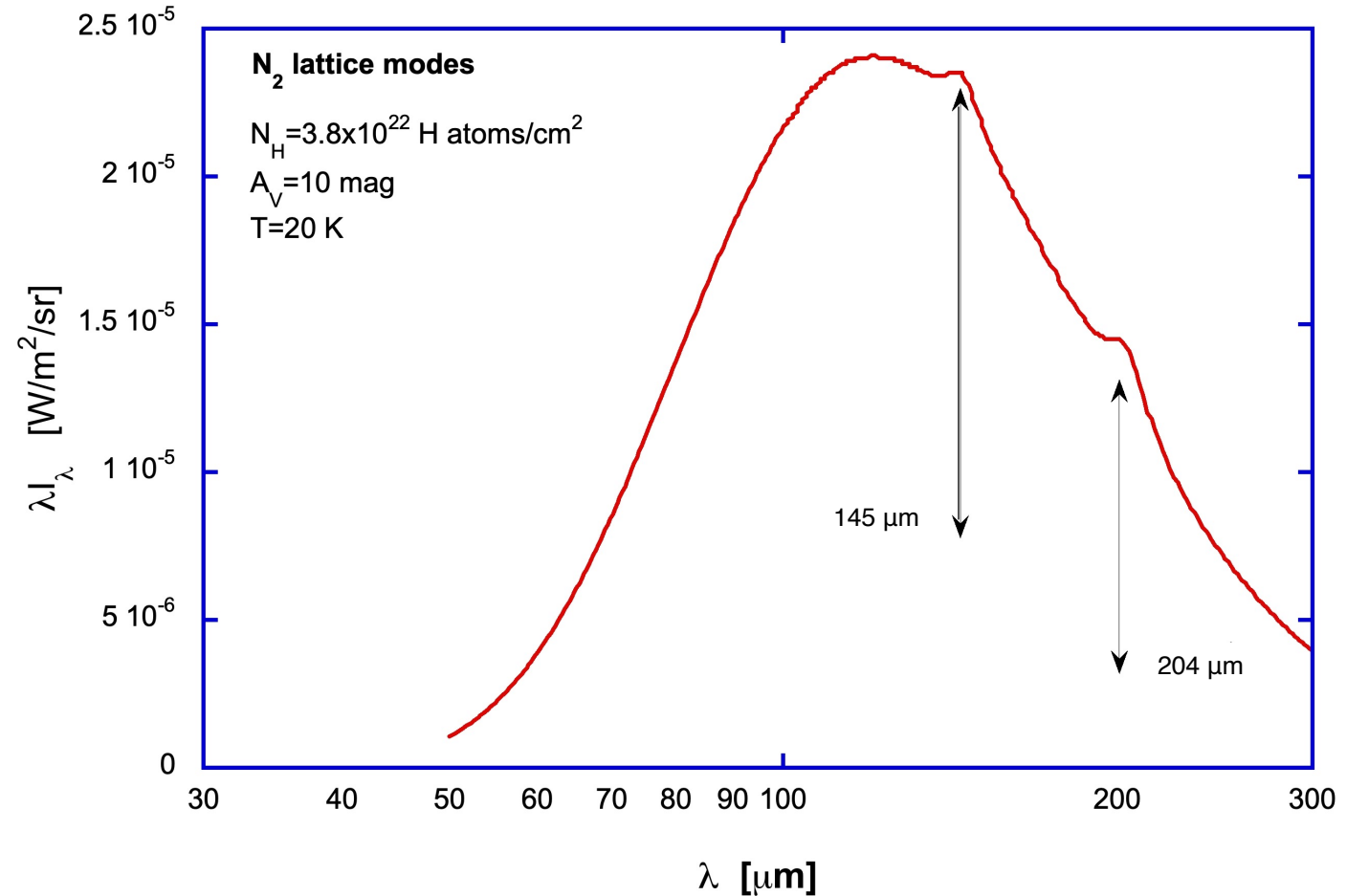
Kamp+18

# N<sub>2</sub> Ice Phonon Modes

- Nitrogen largely unconstrained in disks
  - Likely in N<sub>2</sub> or NH<sub>3</sub> (Schwarz & Bergin 14, Krijt+23)
- FIR *only* way access to N<sub>2</sub> ice

Wavelengths: 145  $\mu\text{m}$  204  $\mu\text{m}$

Sensitivity: 1% wrt continuum



# Measuring C, O, N, S in ices

H<sub>2</sub>O, HCN, NH<sub>3</sub>, N<sub>2</sub>, H<sub>2</sub>S, CO, CO<sub>2</sub>, CH<sub>3</sub>OH, H<sub>2</sub>CO

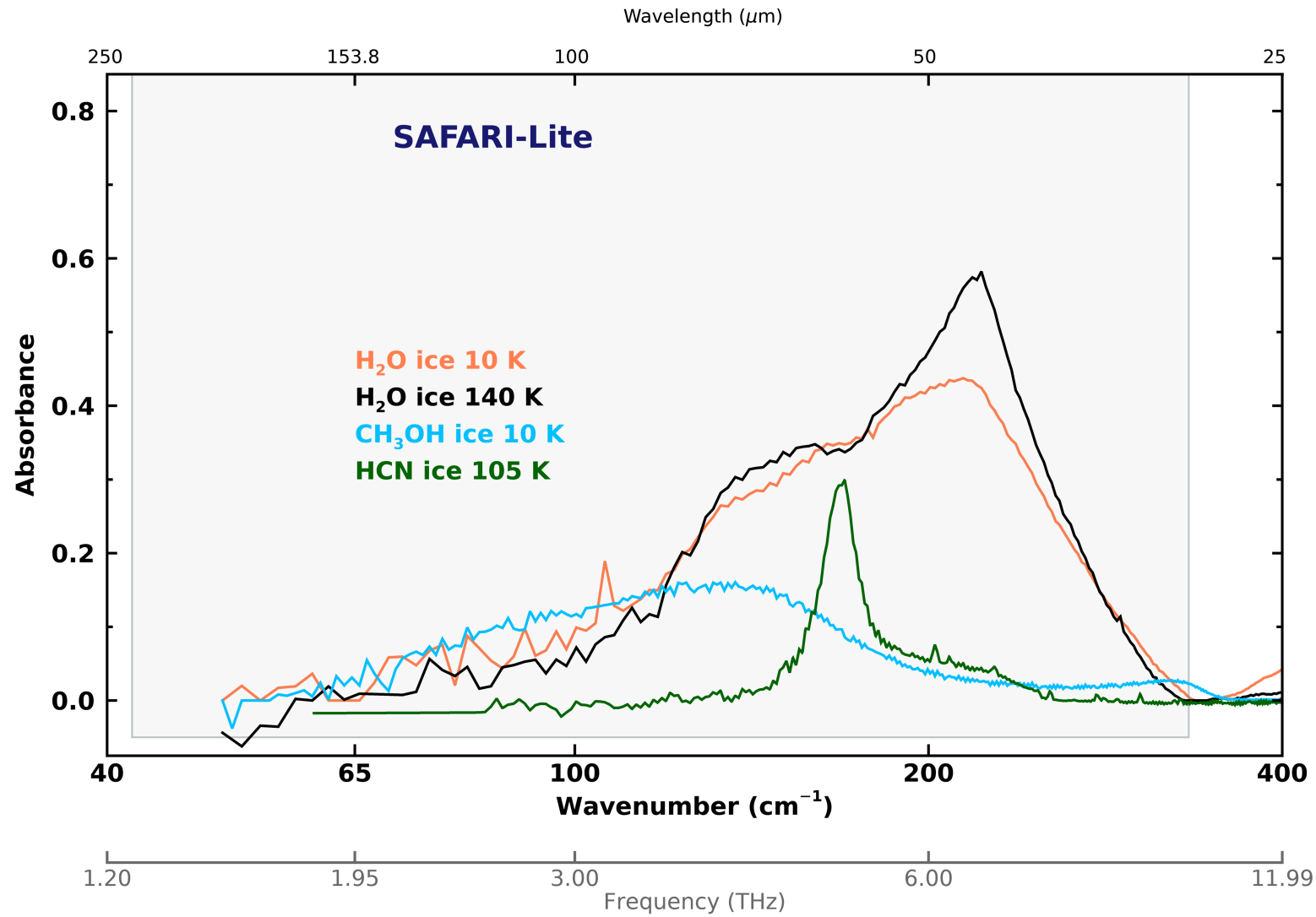


Image Credit:  
Carrie Anderson

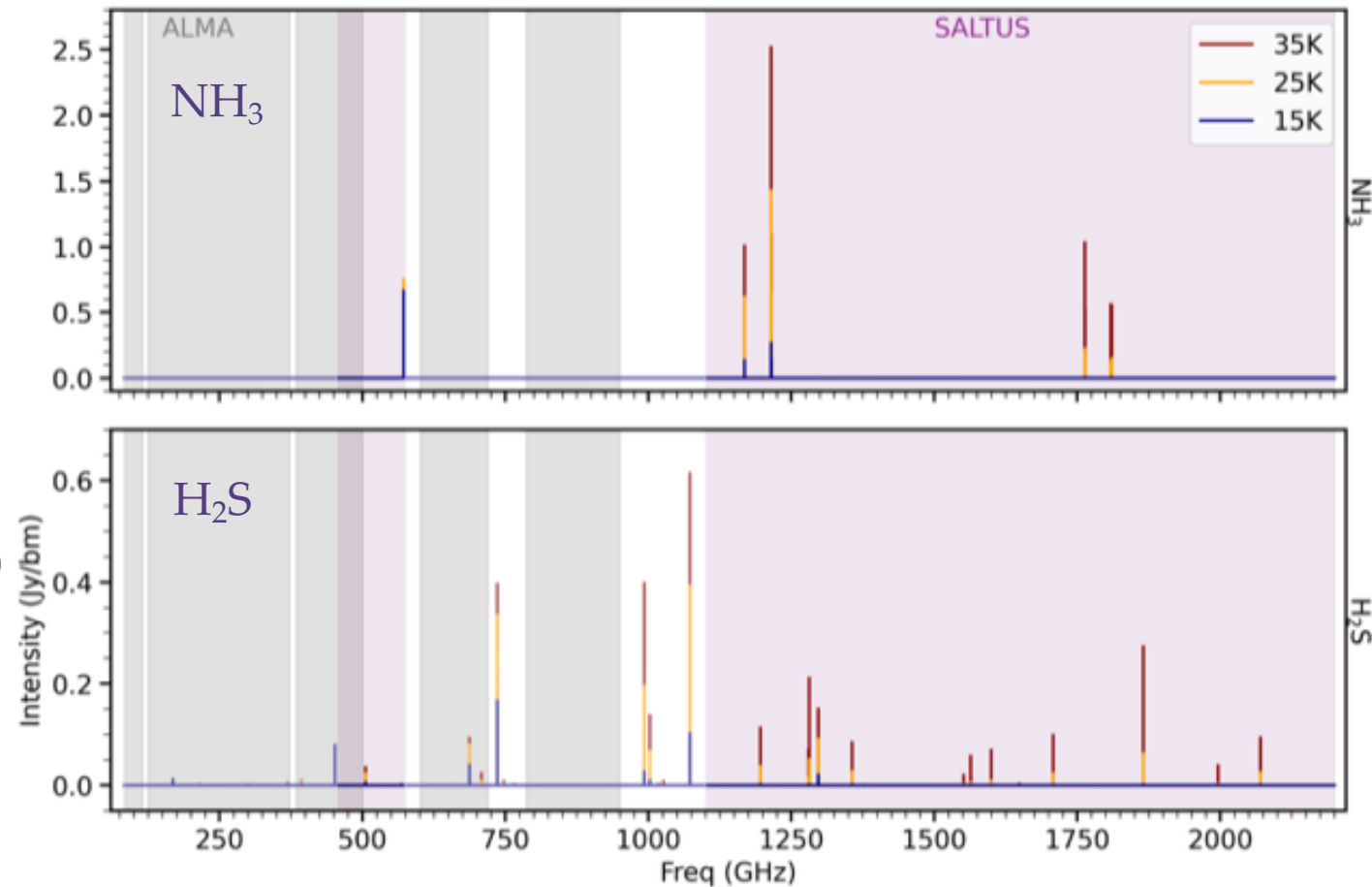
# Measuring Major O, N, S Carriers in Gas Disks

- Major volatiles: CHONS
  - Important for habitability
- Only 1 detection of  $\text{NH}_3$  gas in an outer disk (Salinas+16)
- O, N, & S distribution largely unknown
- Major carriers ( $\text{H}_2\text{O}$ ,  $\text{H}_2\text{S}$ ,  $\text{NH}_3$ ) require THz instrument to observe

Wavelengths: 170 – 524  $\mu\text{m}$

R:  $\sim 10^5$

Sensitivity: 45 mJy



# Organics in Protostellar Cores

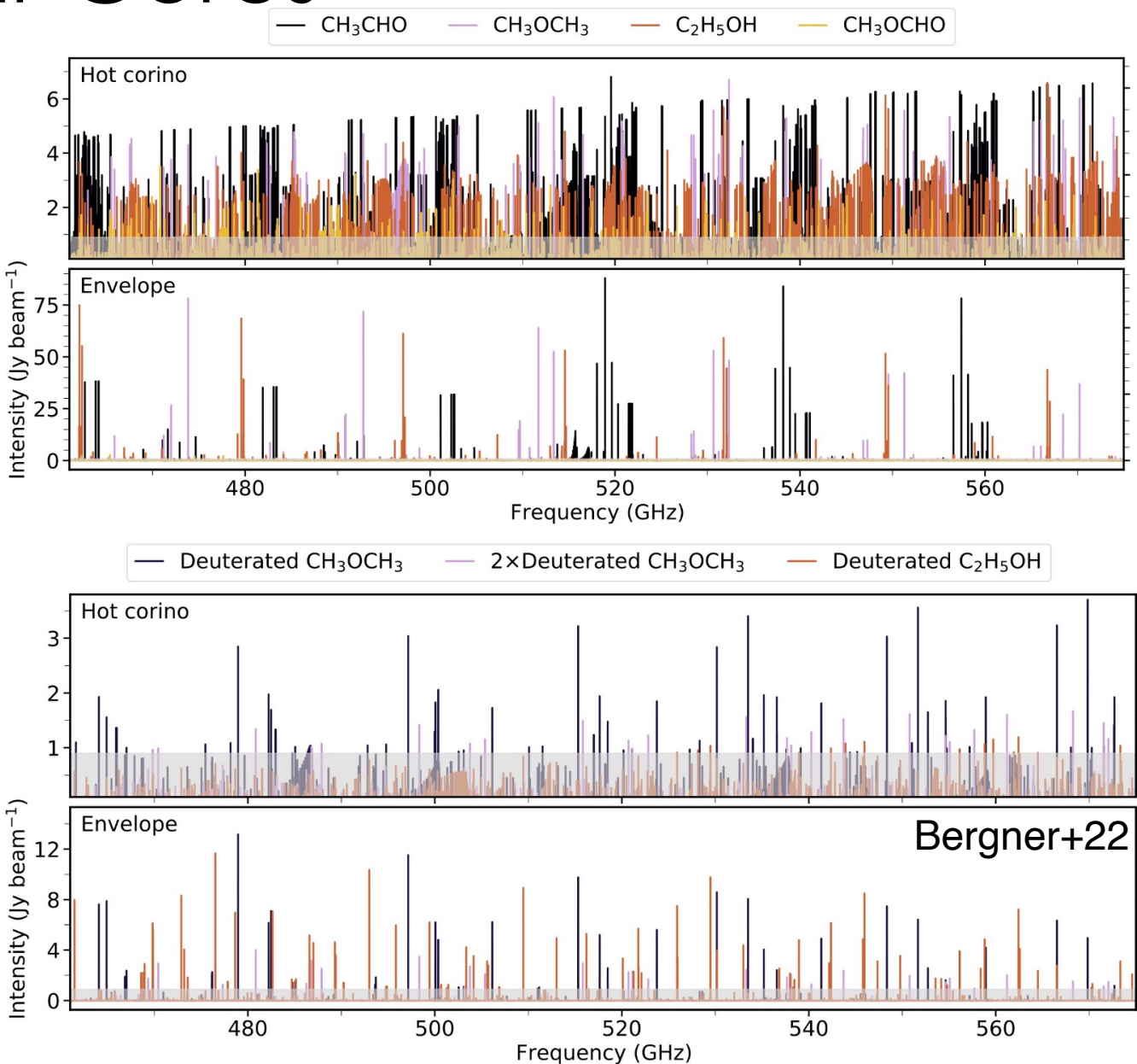
“What generates the observed chemical complexity of molecular gas?”  
– Decadal F-Q2c

- Emission from sublimated ices
- Isotopologue abundance traces formation
- Previous surveys suffer from beam dilution or resolve out emission

Wavelengths: 450-570  $\mu\text{m}$

R:  $\sim 10^5$

Sensitivity: 0.5 Jy



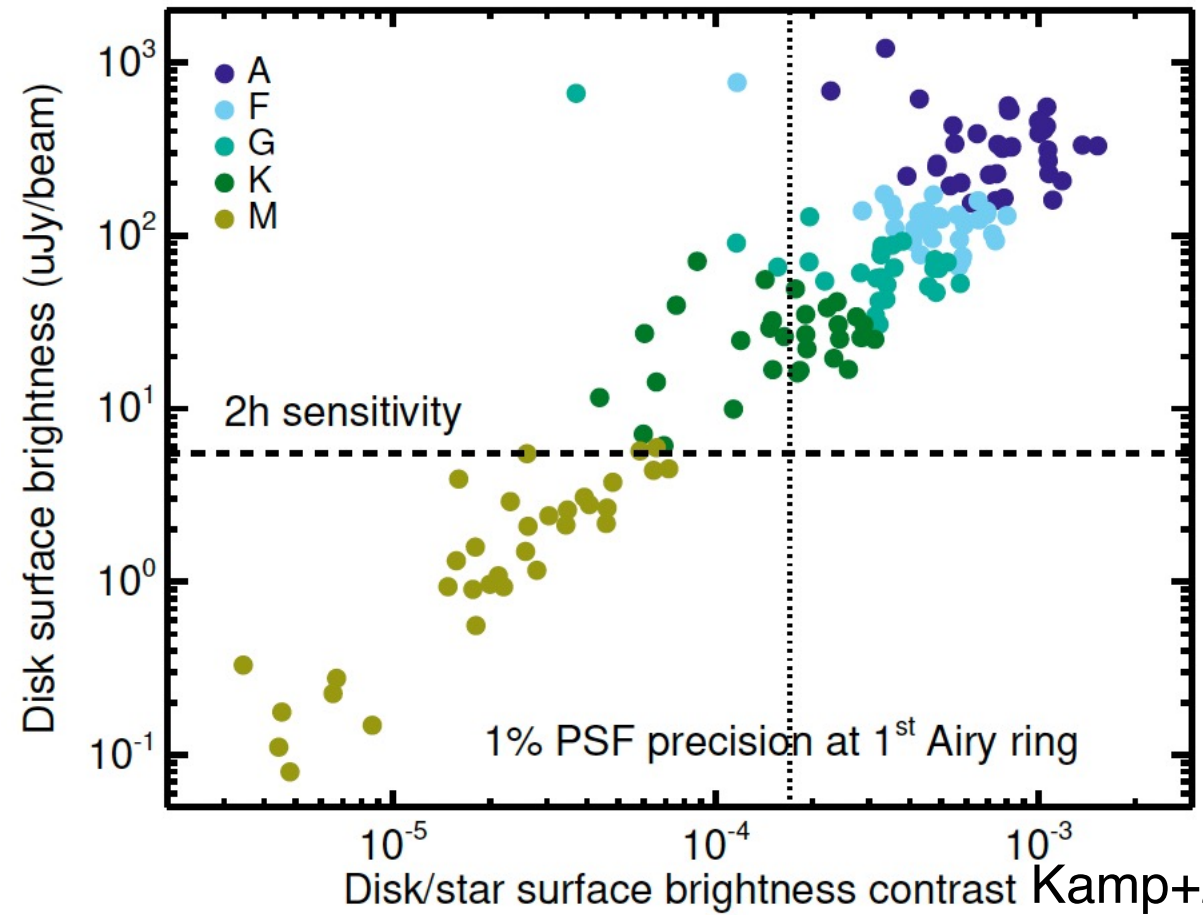
# Deep Integrations on Debris Disks

“How Does the Distribution of Dust and Small Bodies in Mature Systems Connect to the Current and Past Dynamical States Within Planetary Systems?”  
– 2020 Decadal E-Q1d

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

Wavelength: 30-70  $\mu\text{m}$

Sensitivity: 22  $\mu\text{Jy}/\text{beam}$



# FIR Observations of Disks: more than just H<sub>2</sub>O!

Observable	Wavelength ( $\mu\text{m}$ )	Frequency (THz)	R	Sensitivity
H <sub>2</sub> O Ice	45 & 63	4.7 & 6.6	300	0.3 mJy
N <sub>2</sub> Ice	145 & 204	1.47 & 2.0	300	1% wrt continuum
NH <sub>3</sub> Gas	107-524+	0.57-2.8	10 <sup>5</sup>	45 mJy
Protostar Organics	520-650	0.45-0.57	10 <sup>5</sup>	0.1 Jy
Exo-Kuiper Belts	30-70	4.3-10		22 $\mu\text{Jy}/\text{beam}$