#### The Far-Infrared A missing link in disk evolution, planet formation and earth-like planets

Klaus Pontoppidan Space Telescope Science Institute What if the Nitrogen were depleted by **6 orders of magnitude** <u>rather than</u>

5?

Volatiles depleted in the Earth are observable in the gas-phase



# A factor 2 in solid mass makes a difference in giant planet formation



Adapted from Pollack et al. 1996



#### Planet C/O ratios depend on disk chemistry



Oberg et al. 2011

#### Exoplanet WASP 12b may have C/O>~1



Madhusudhan et al. 2011

Protoplanetary disks are not monolithic objects, but systems with complex structure



# Inner disks around solar type stars are abundant in water and organics



Also, John Carr, Joan Najita, Colette Salyk, Ilaria Pascucci Astronomical facilities sensitive to water in protoplanetary disks



## Observability of water

Infrared water lines from protoplanetary disks



#### The FIR water lines uniquely trace >1 AU water.



### Observed H<sub>2</sub>O lines in disks



Hogerheijde et al. 2011 + Bergin

#### Current surface snow lines



But this is all there is (maybe 1 or 2 more).

#### The FIR can unique observe ice in emission



#### A handful of ice detections with Herschel



Min et al. 2015

#### FIR tracers of the disk gas mass HD vs [0|63]/[0|145]



Bergin et al. 2013

### High-J CO and the disk photosphere



### Requirements for a FIR mission

#### Unique space far-infrared tracers of protoplanetary disks "Killer" science cases

- Water ice in *emission* 42 micron
  - Possibly other ice species, but not yet demonstrated (CO<sub>2</sub>, CH<sub>3</sub>OH, ...).
- Water vapor tracing gas at 20-300 K 25-200 micron
  - Traces the surface snow line.
- HD 112 micron (1-0) + 56 micron (2-1)
  - Unique mass tracer (Bergin talk).
- Oxygen [OI] 63 micron + high-J rotational CO
  - Traces the disk's thermo-chemical energy balance, and possibly mass.

### Spatial tracers in the FIR



#### Current sensitivities are just out of range



#### Desired Measurement Capabilities

Parameter	Units	Value or Range
Wavelength range	μm	30-200 (must) 25-500 (goal)
Angular resolution	arcsec	0.5-5.0
Spectral resolution, ( $\lambda$ / $\Delta\lambda$ )	dimensionless	500 + 50,000 (ideal)
Continuum sensitivity	μJy	1,000 (1sig, minimum)
Spectral line sensitivity	10 <sup>.19</sup> W m <sup>.2</sup>	
Instantaneous FoV	arcmin	1 (>10 beams across for self-calibration)
Number of target fields	dimensionles s	100-1000
Field of Regard	sr	>2pi