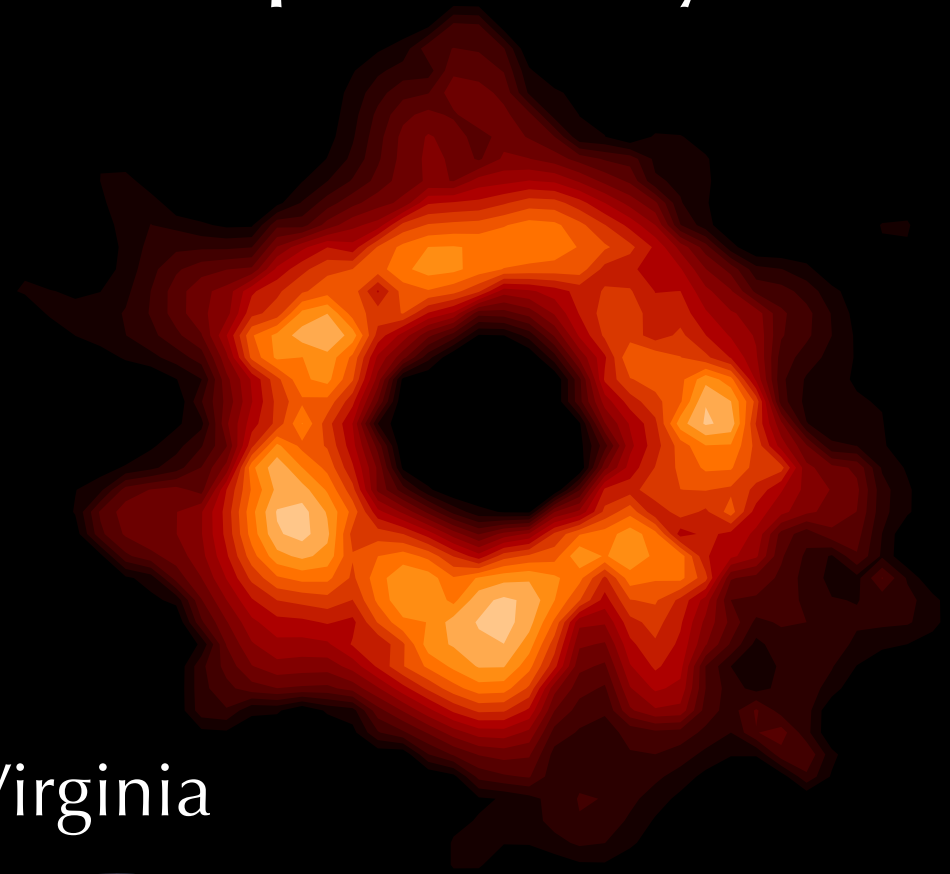
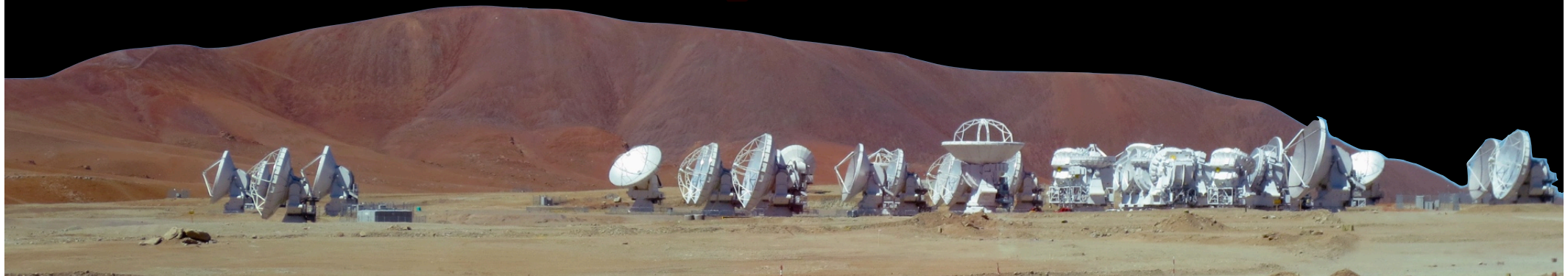
ALMA Band 2 Molecular Probes of Protoplanetary Disks

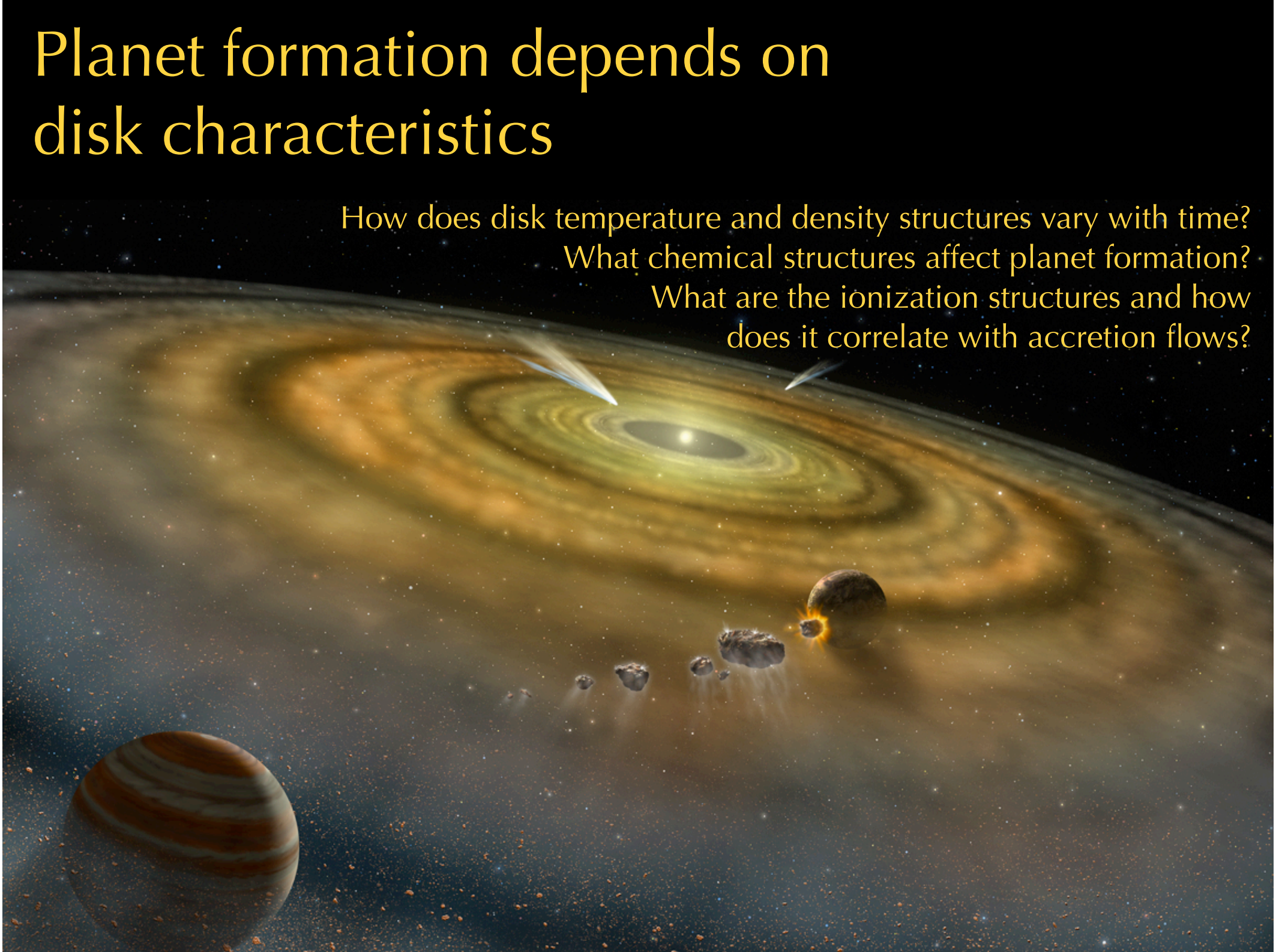


Karin Öberg

University of Virginia



Planet formation depends on disk characteristics



How does disk temperature and density structures vary with time?
What chemical structures affect planet formation?
What are the ionization structures and how does it correlate with accretion flows?

Molecules are probes of radiation, fractionation, ionization and freeze-out

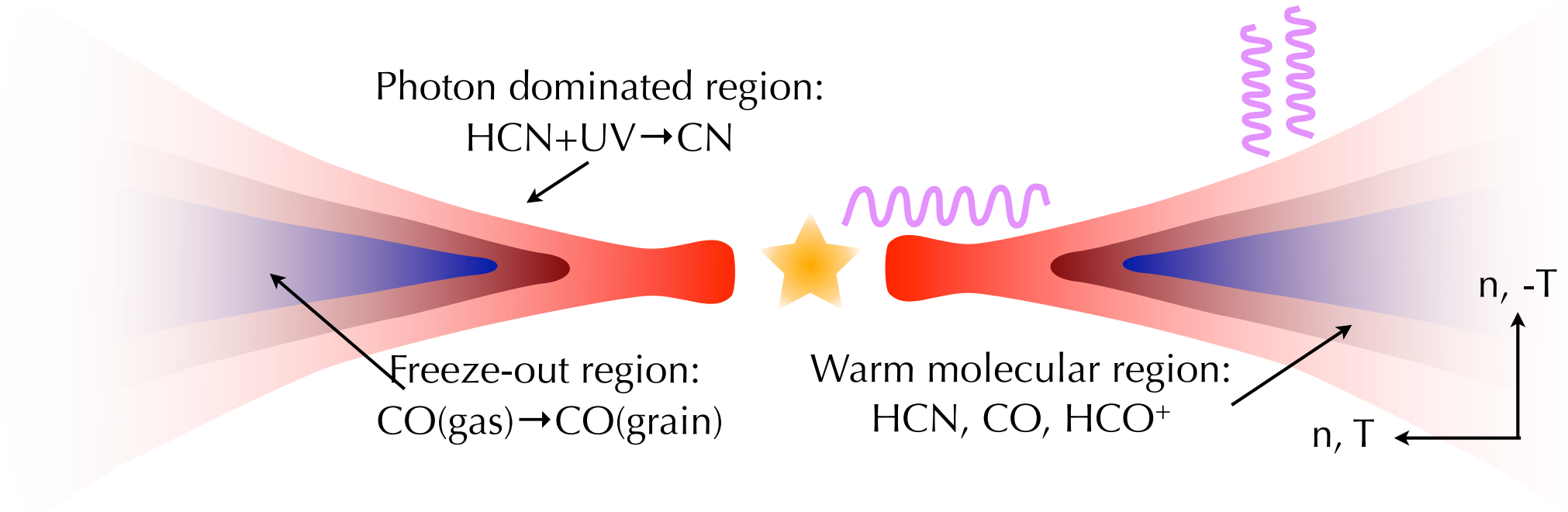
Disk structure and kinematics: CO, ^{13}CO, $C^{18}O$ (ubiquitous, simple chemistry)

UV flux and line vs. continuum: N_{CN}, and CN/HCN (Bergin et al. 2003)

Deuteration (thermal history): DCO^+/HCO^+, DCN/HCN (N_2D^+, D_2CO)

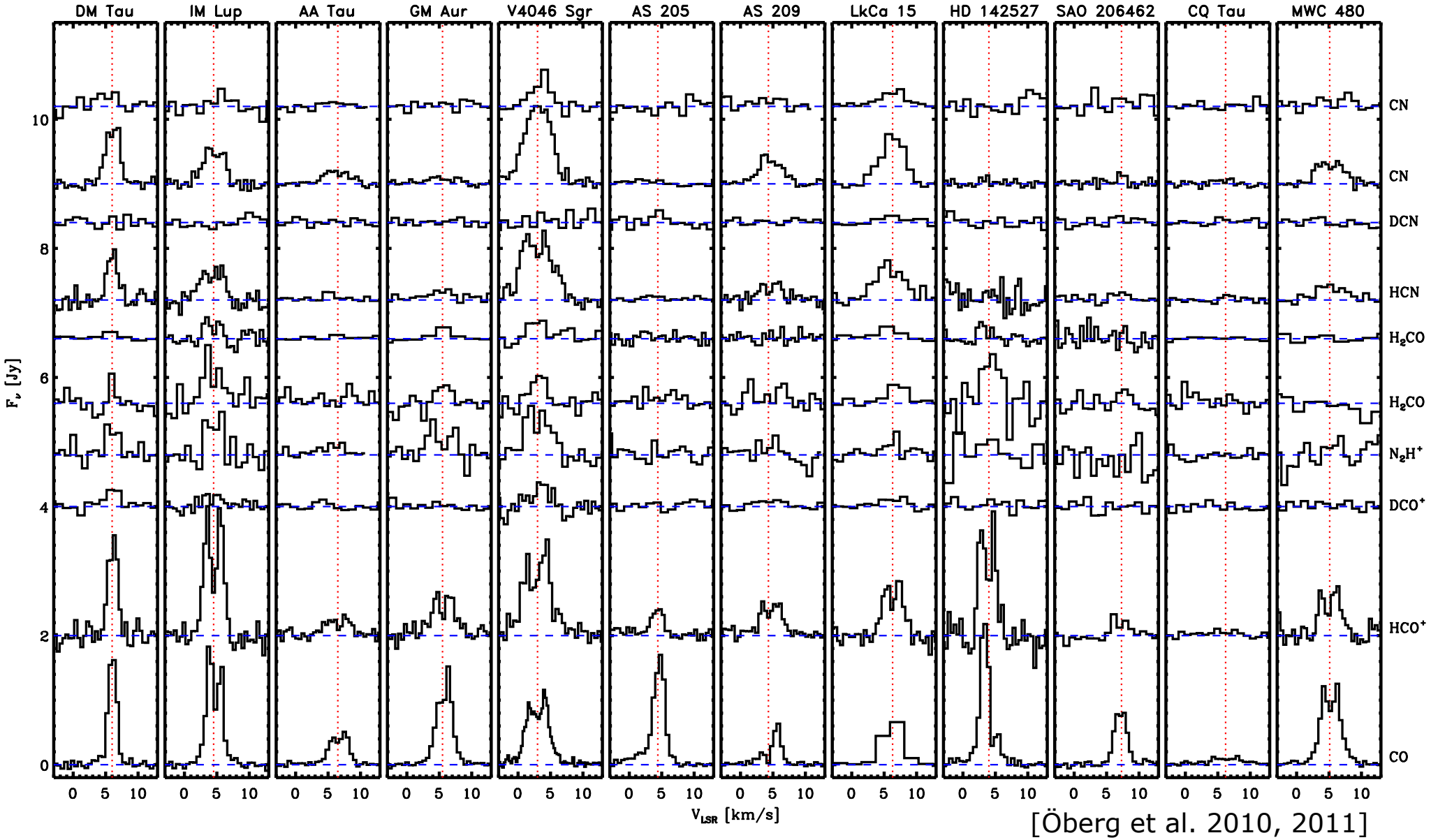
Ionization: HCO^+, DCO^+, N_2H^+, H_2D^+

CO freeze-out: N_2H^+, H_2CO



[Dutrey et al. 1997, Thi et al. 2004, Kastner et al. 2008, Dutrey et al. 2007, Qi et al. 2008, Henning et al. 2010]

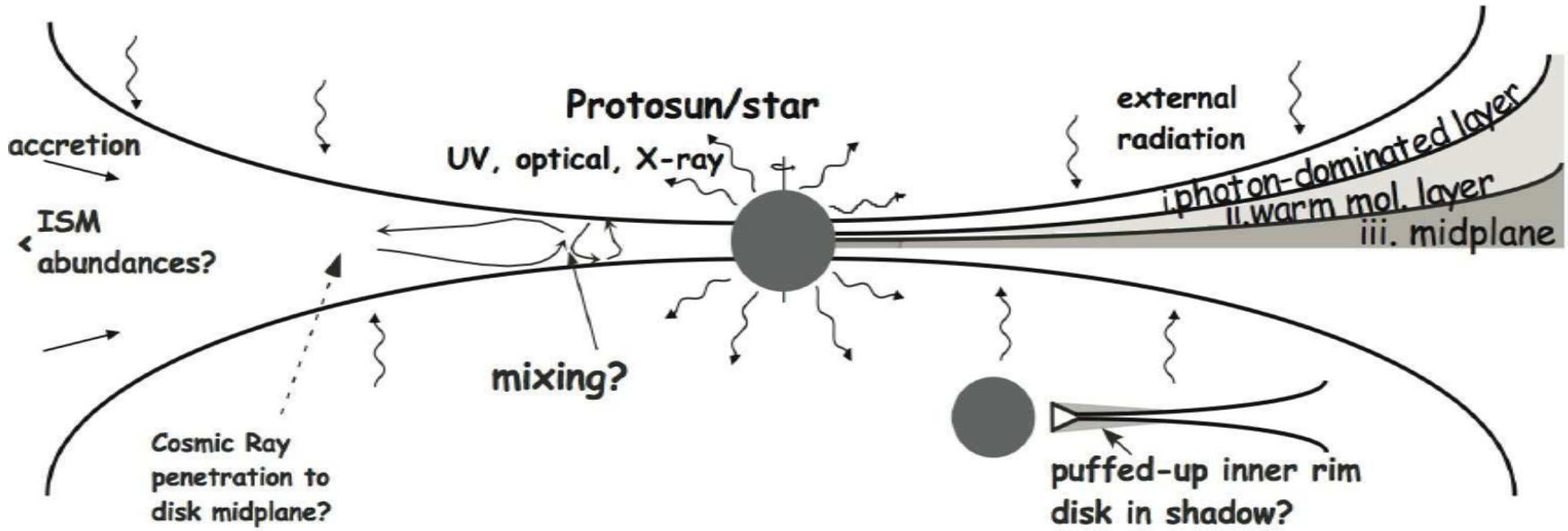
Disks are mainly observed in small molecules (at 1mm)



[Öberg et al. 2010, 2011]

3D disk structures requires spatially and spectrally resolved, multi-transitional studies

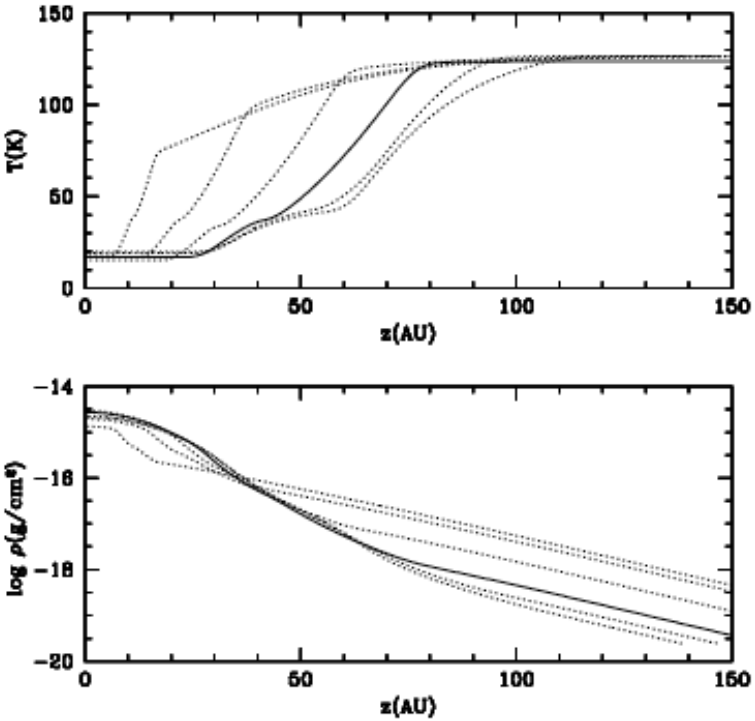
Vertical distributions are constrained by relative intensities of different lines

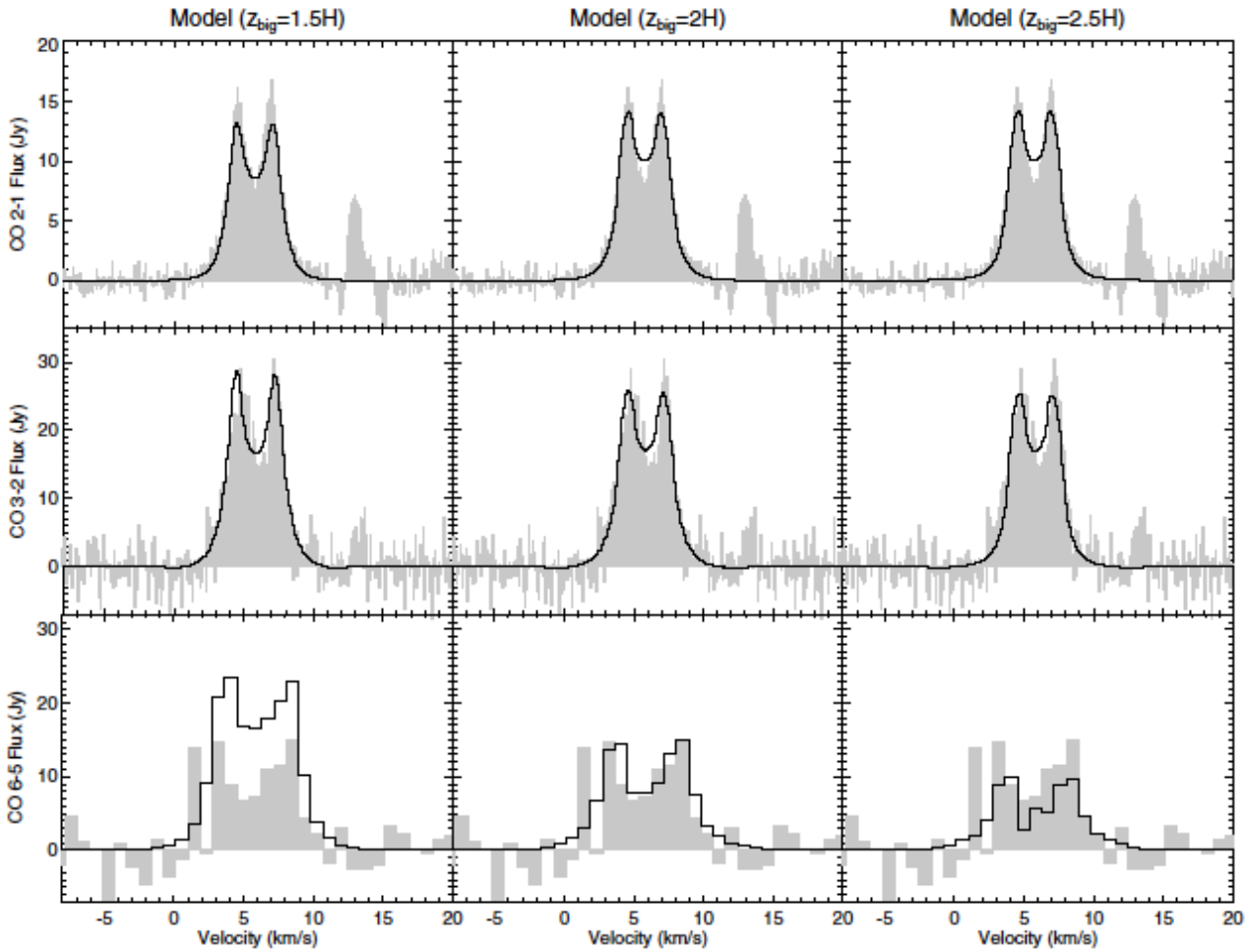


Radial distributions can be spatially resolved down to 10s of AU with ALMA

[Bergin et al. 2007]

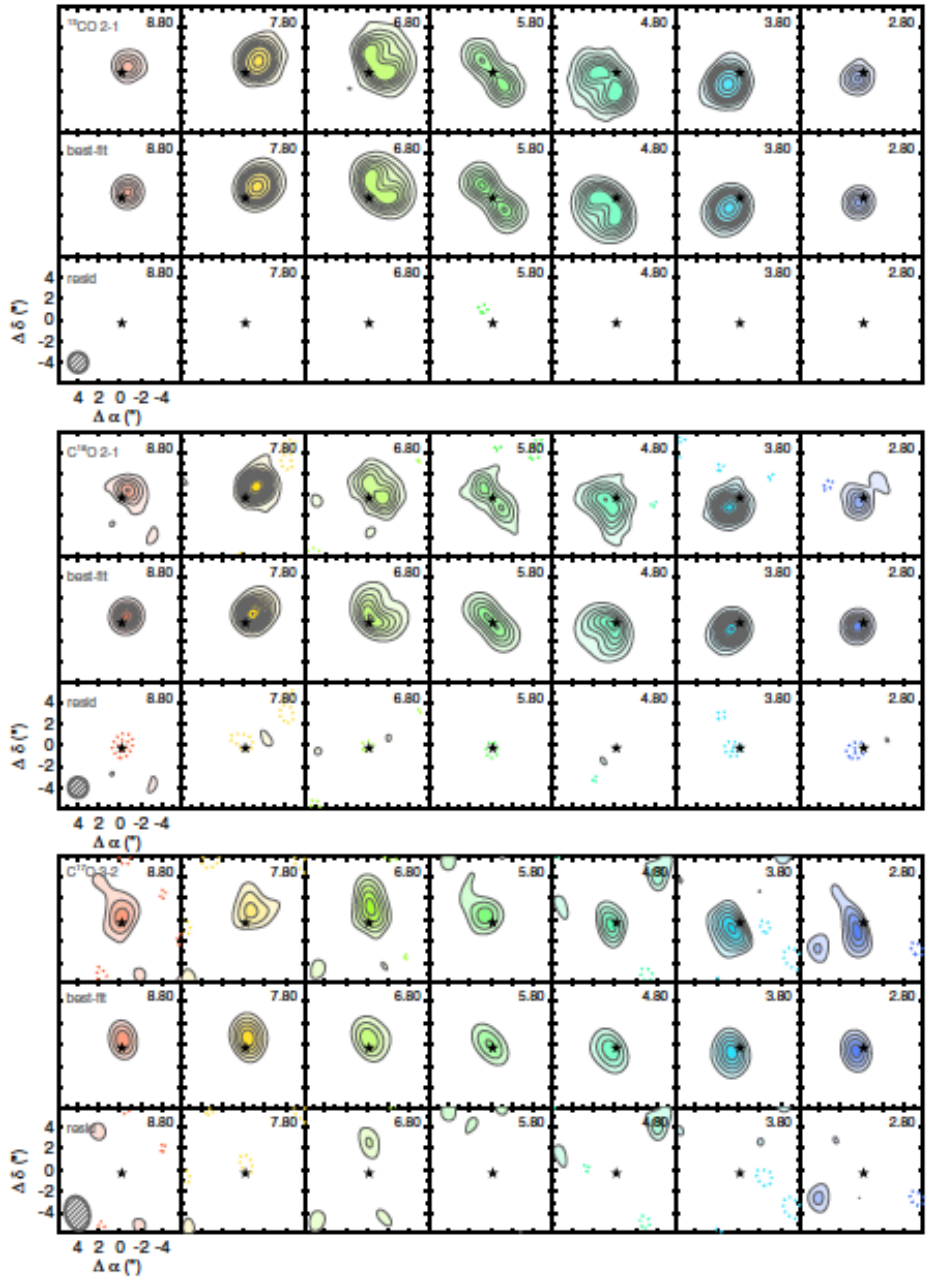
Vertical disk structure based on CO 6-5, 3-2, 2-1





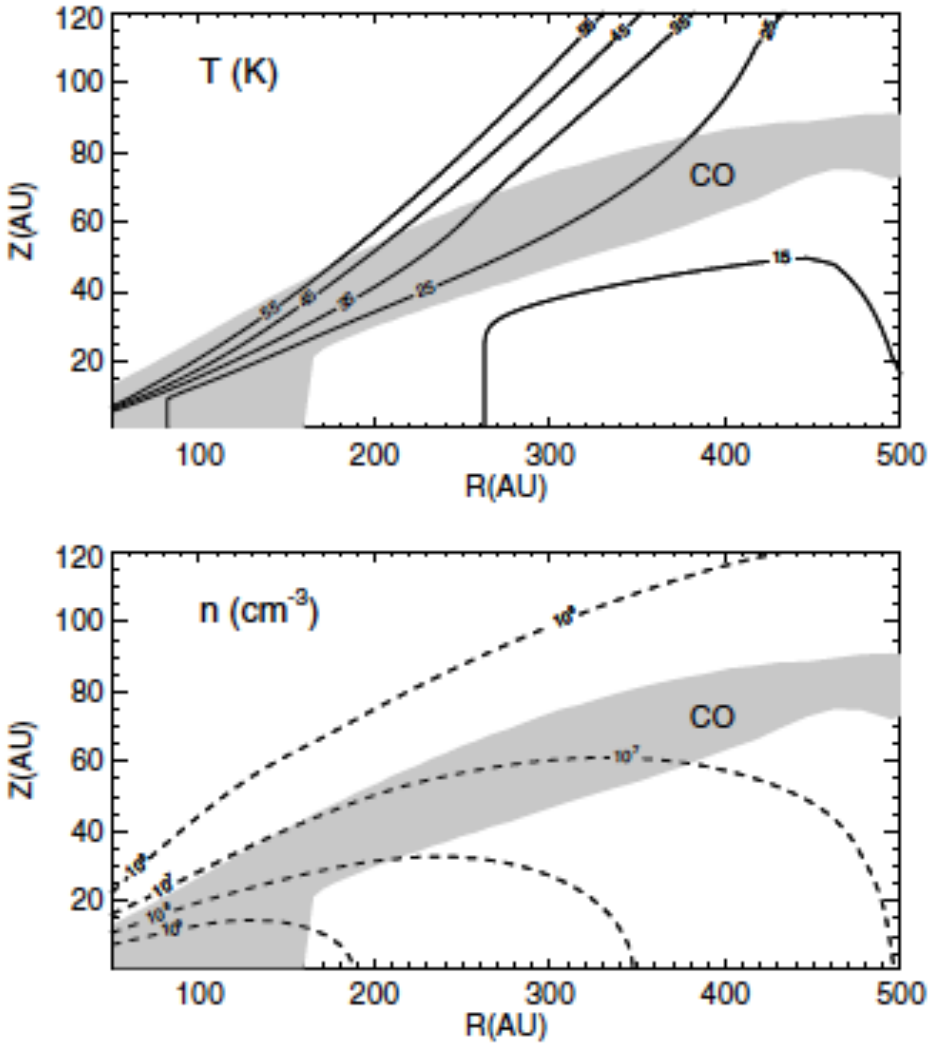
[Qi, d'Alesssio, Öberg et al. 2011]

Radial disk gas structure is based on resolved CO isotopologue observations



[Qi, d'Alesssio, Öberg et al. 2011]

2D disk gas structure around HD 163296

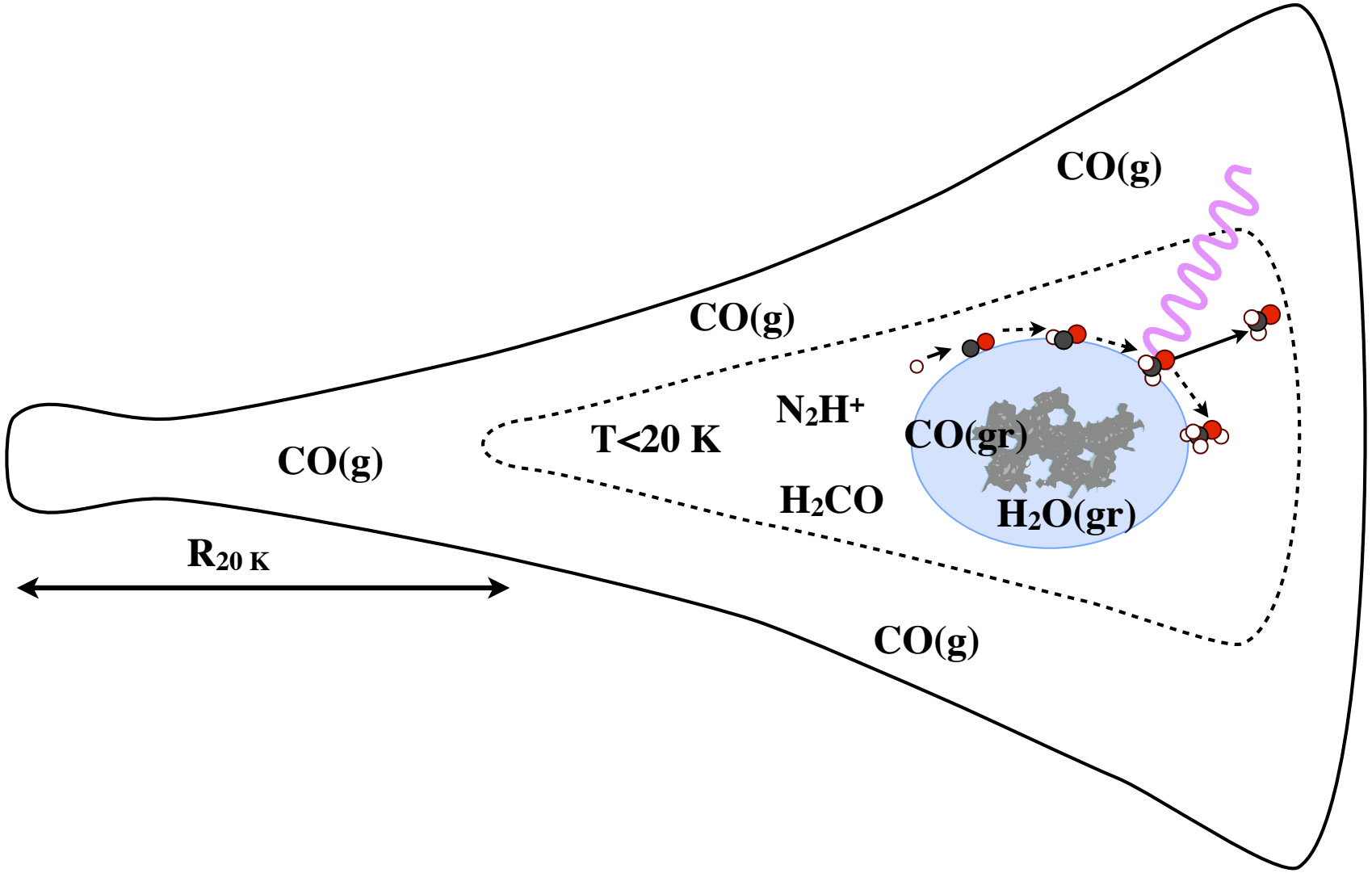


[Qi, d'Alesssio, Öberg et al. 2011]

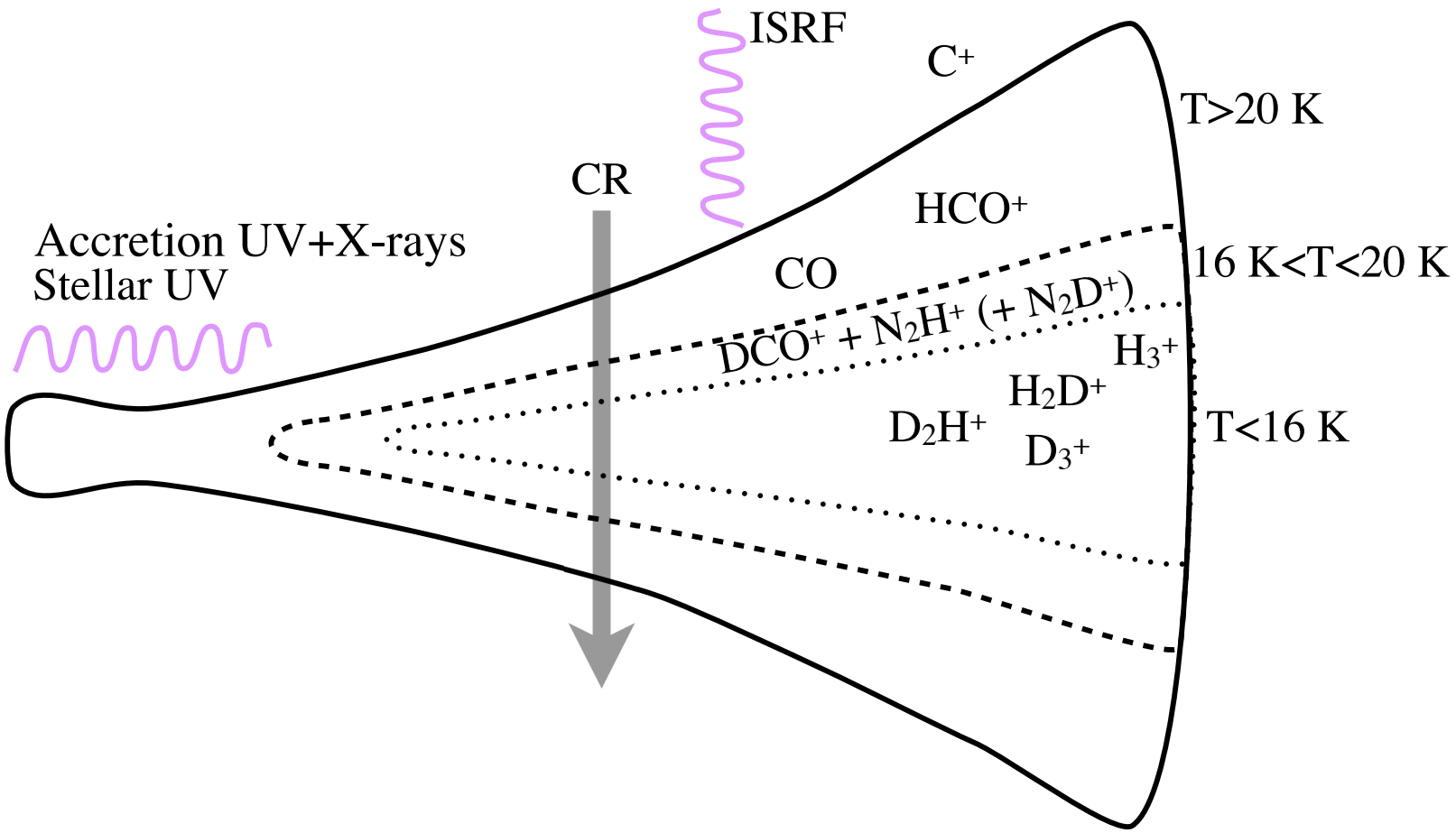
J=1-0 transitions are needed to constrain midplane distributions

Disk midplanes are cold
Best traced by lines with low energy levels
To constrain temperatures 1-0 and e.g. 3-2 transitions are needed (6-5 will typically not be populated)

Disk midplanes are characterized by deuterium fractionation, radiation attenuation and molecular freeze-out



Disk midplanes are characterized by deuterium fractionation, radiation attenuation and molecular freeze-out



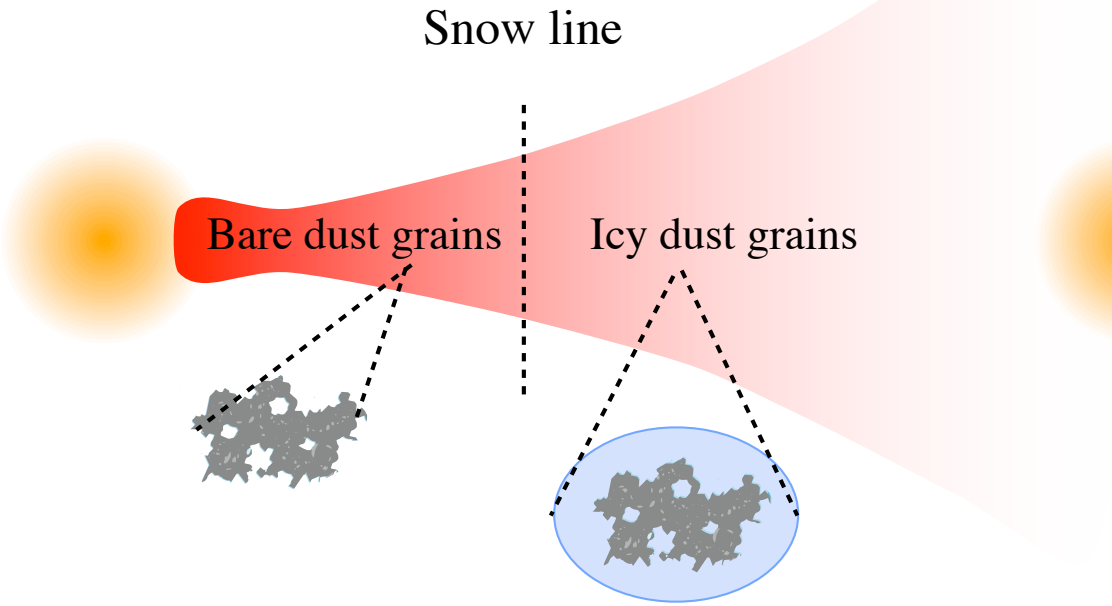
ALMA band 2 gives access to J=1-0 transitions of key molecules

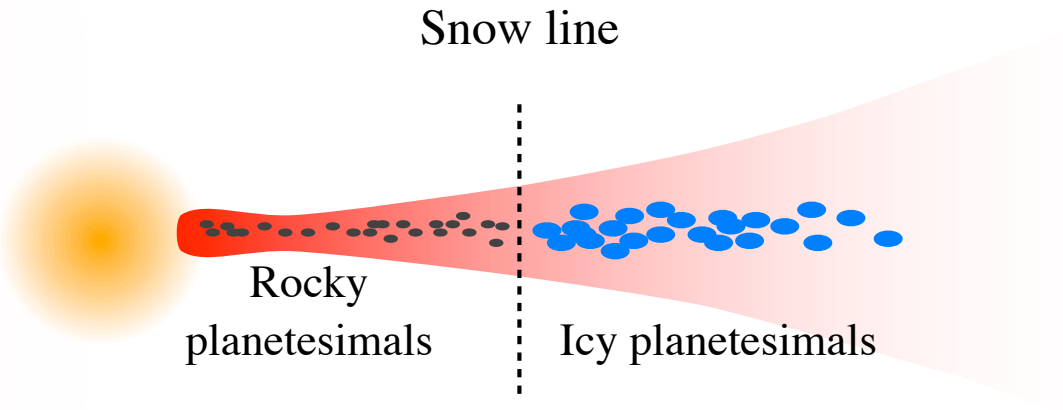
Ions: DCO^+, N_2D^+,
Deuterated molecules: DCO^+, C_2D, DCN, N_2D^+
Other isotopologues: $H_2{}^{13}CO$, $^{13}C_2H$, $H^{13}CO^+$, $HC^{18}O^+$, $H^{13}CN$, $HC^{15}N$
Small organics: H_2CO, C_2H

Specific research topics:

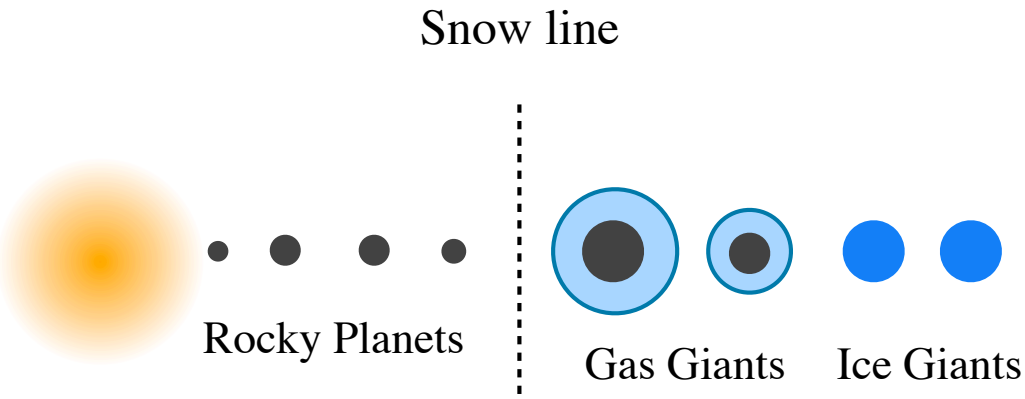
The locations of snowlines and their sharpness
Tracing deuterium fractionation throughout disks
Fractionation of heavier species
Ionization structures (dead zones)

Planet formation around the snow line



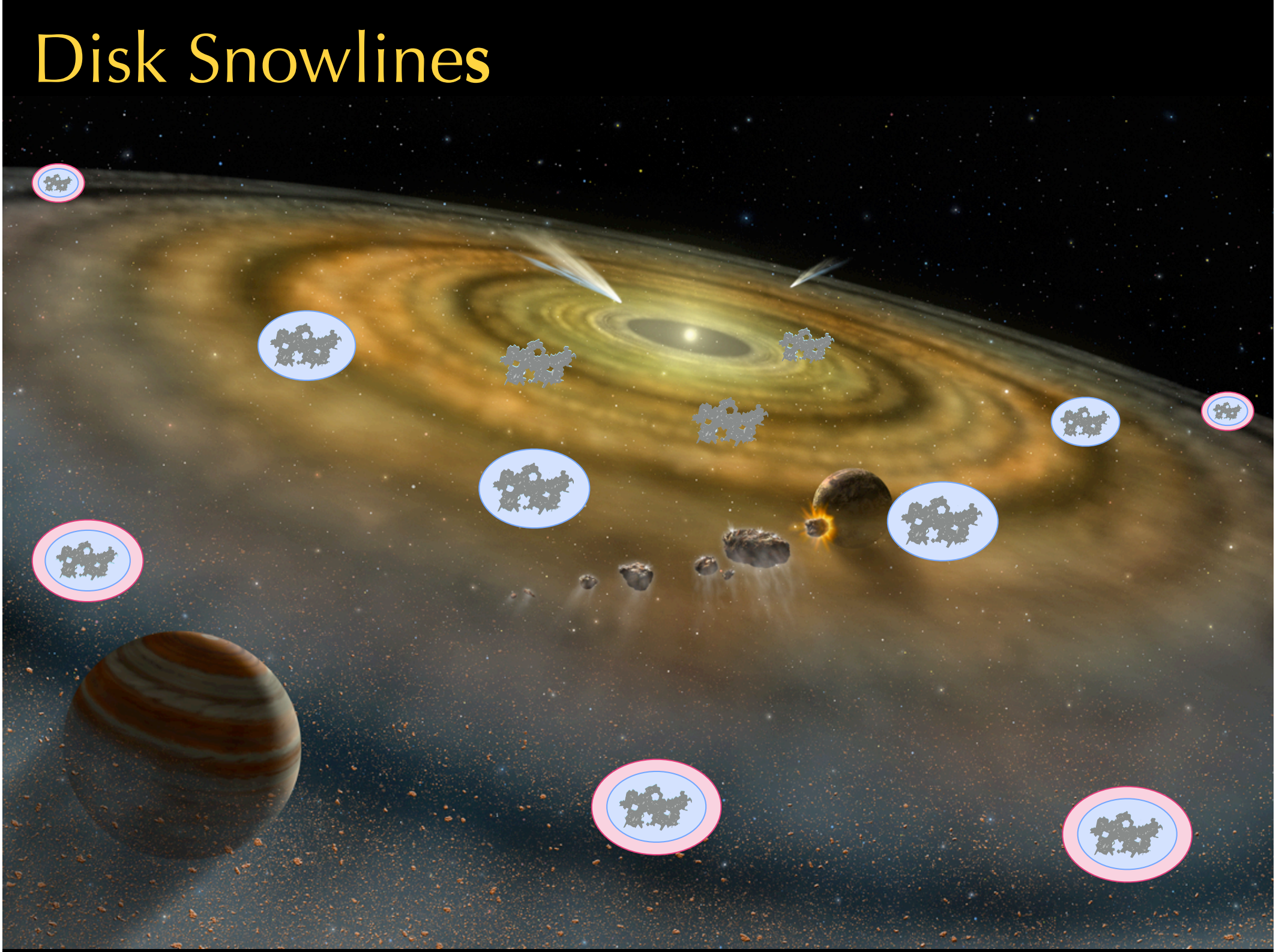


Affects planet formation efficiencies because: Icy grains are stickier than bare grains, grain column density increases, pressure traps etc.

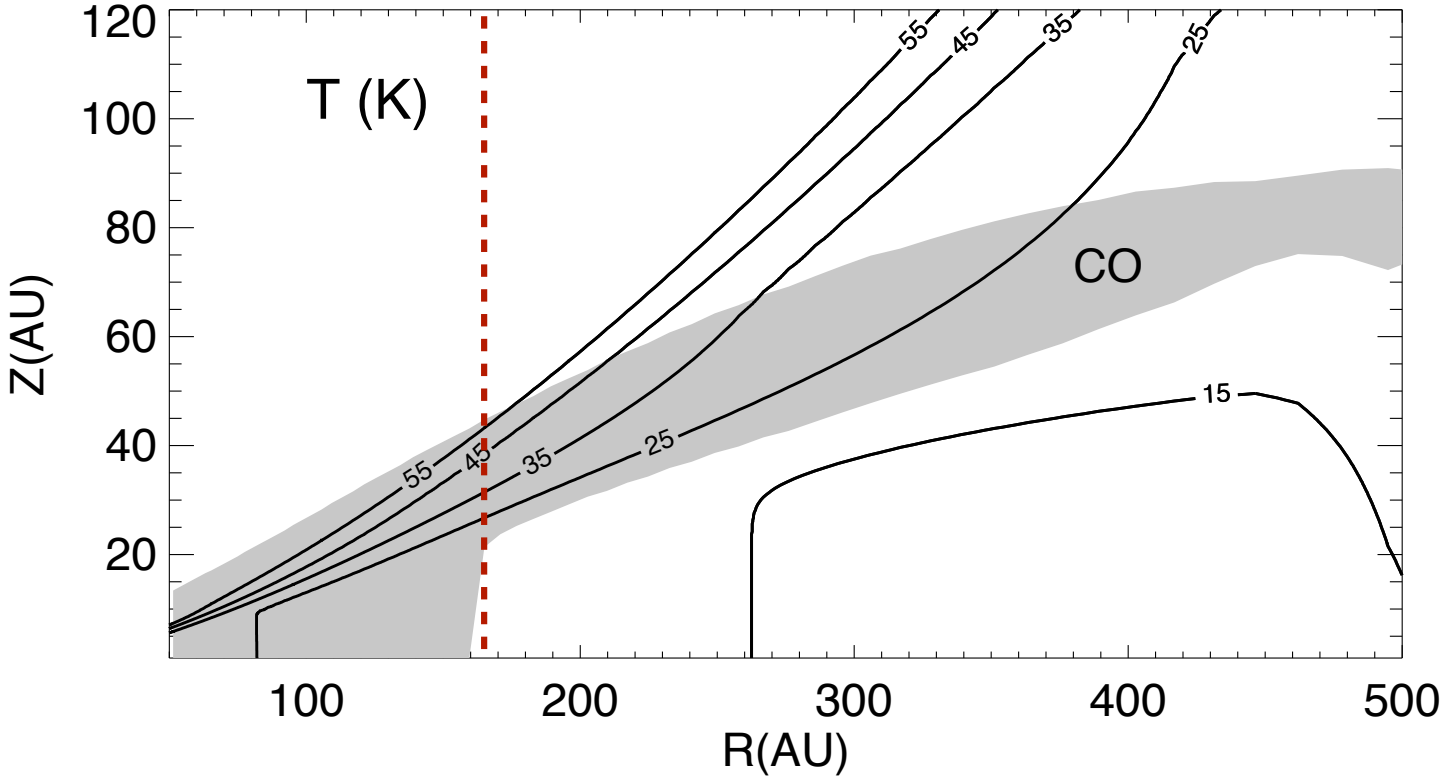


[e.g. Ciesla & Cuzzi 2006, Ros & Johansen 2013]

Disk Snowlines

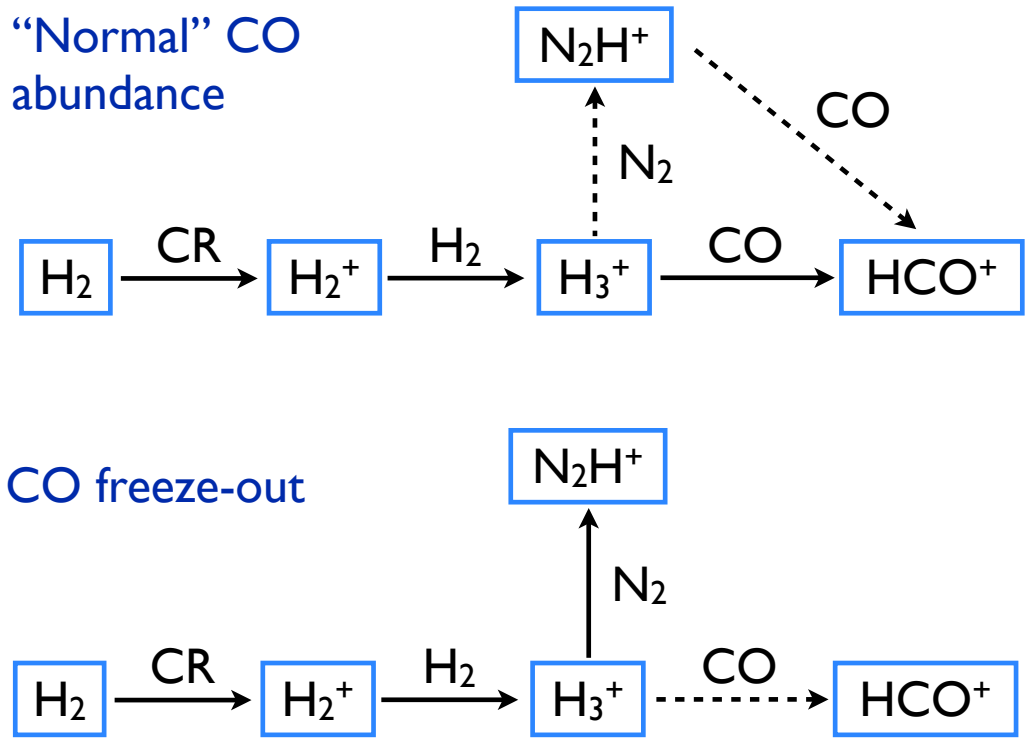


Observing (CO) Snow Lines / Snow Surfaces Limited by Disk Atmosphere

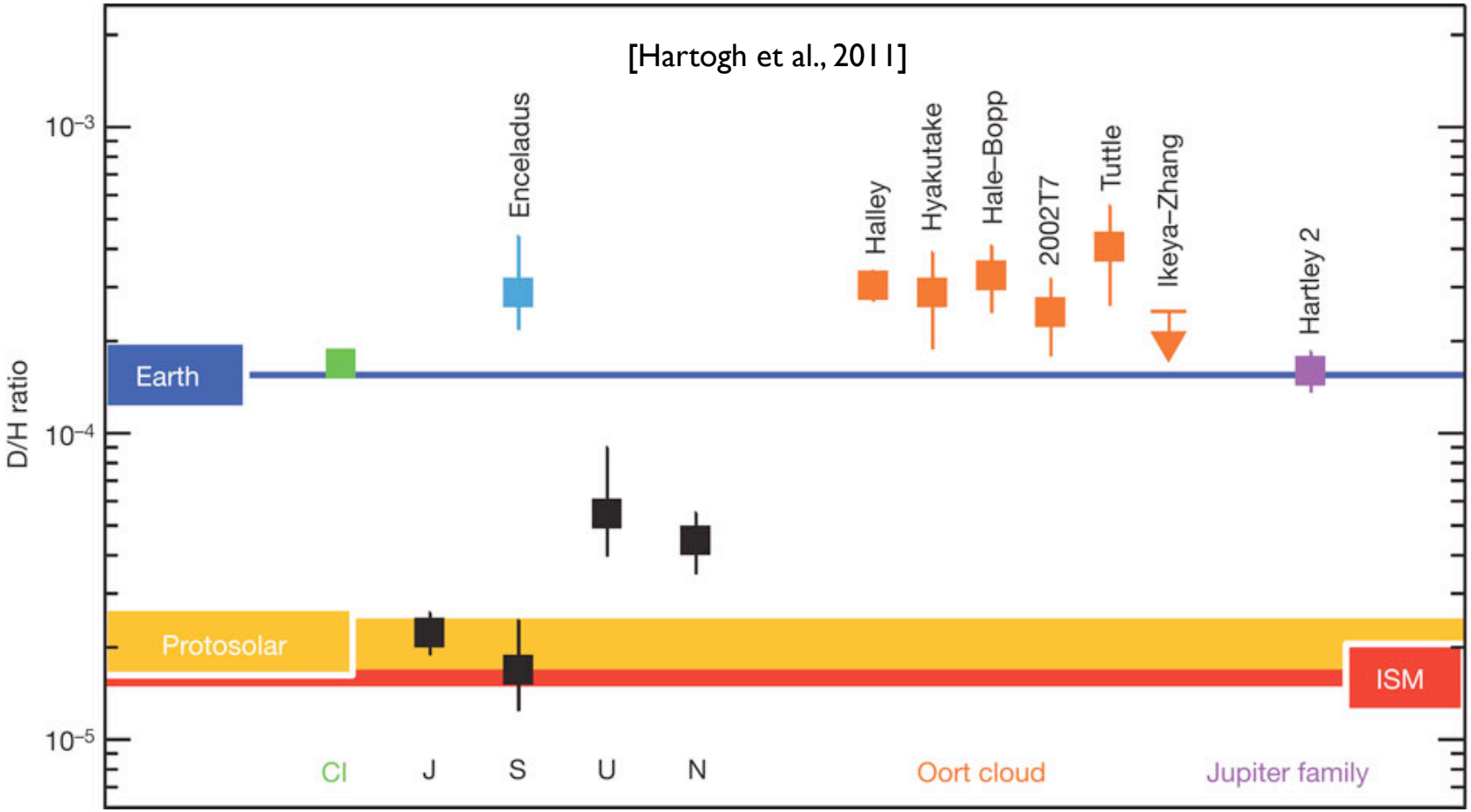


[Qi, d'Alesssio, Öberg et al. 2011]

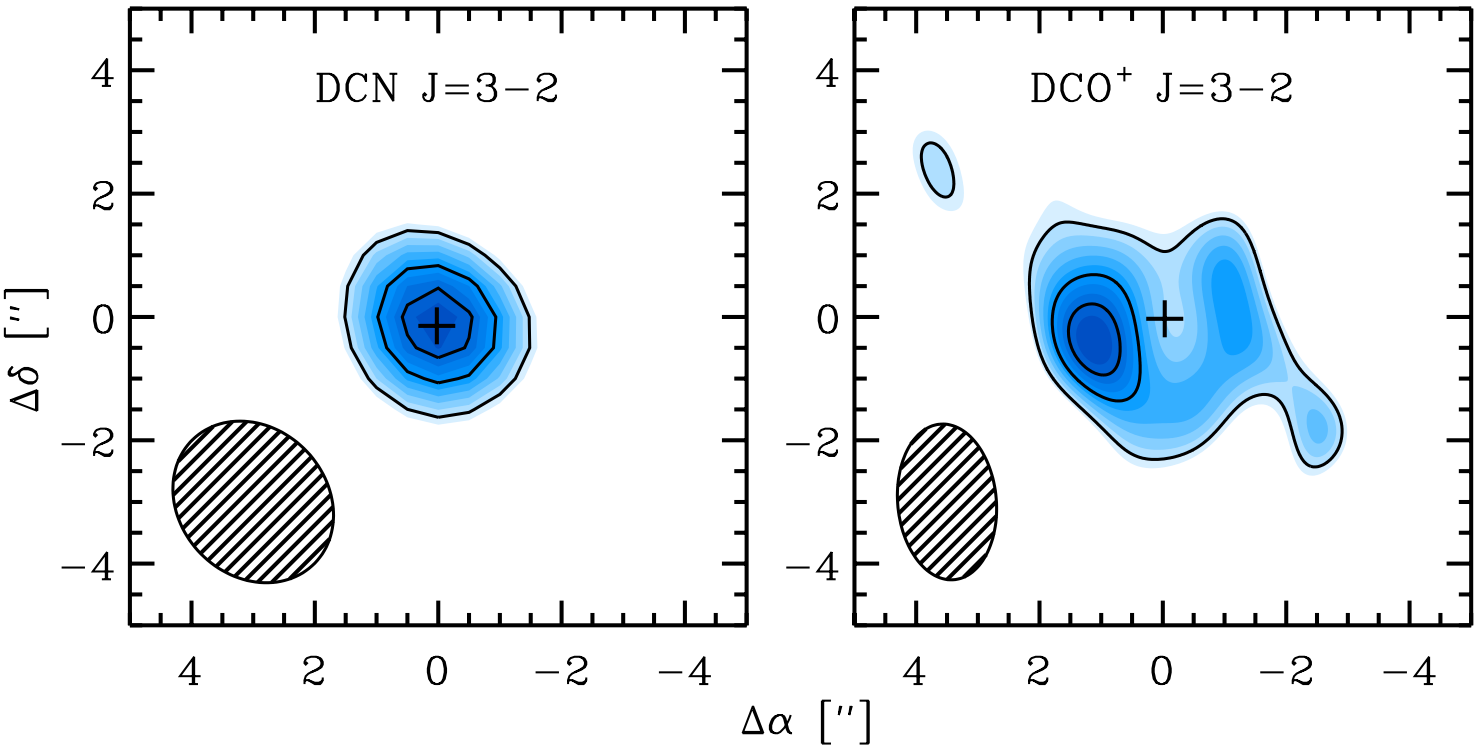
Tracing CO Snowlines with N_2H^+/N_2D^+



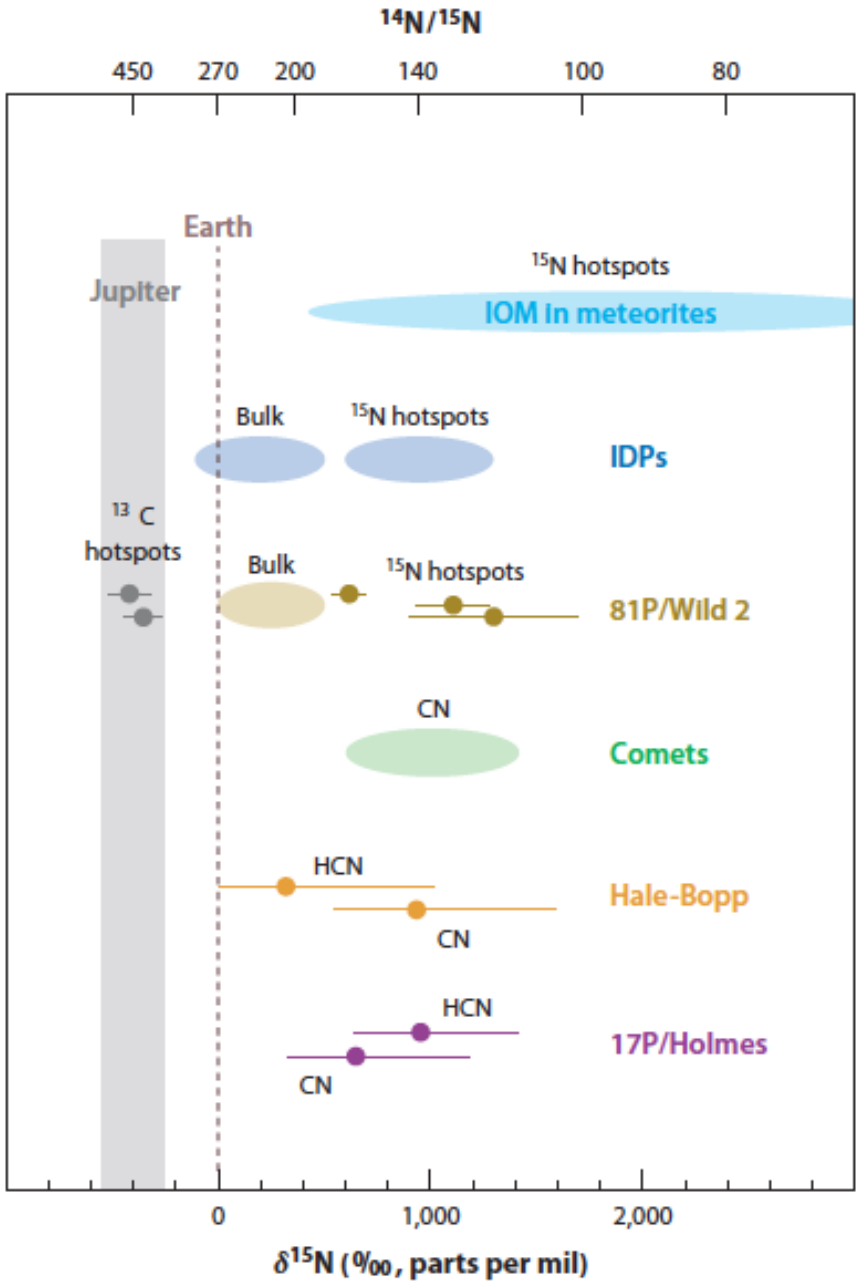
Deuterium fractionation traces origins of volatiles in disks



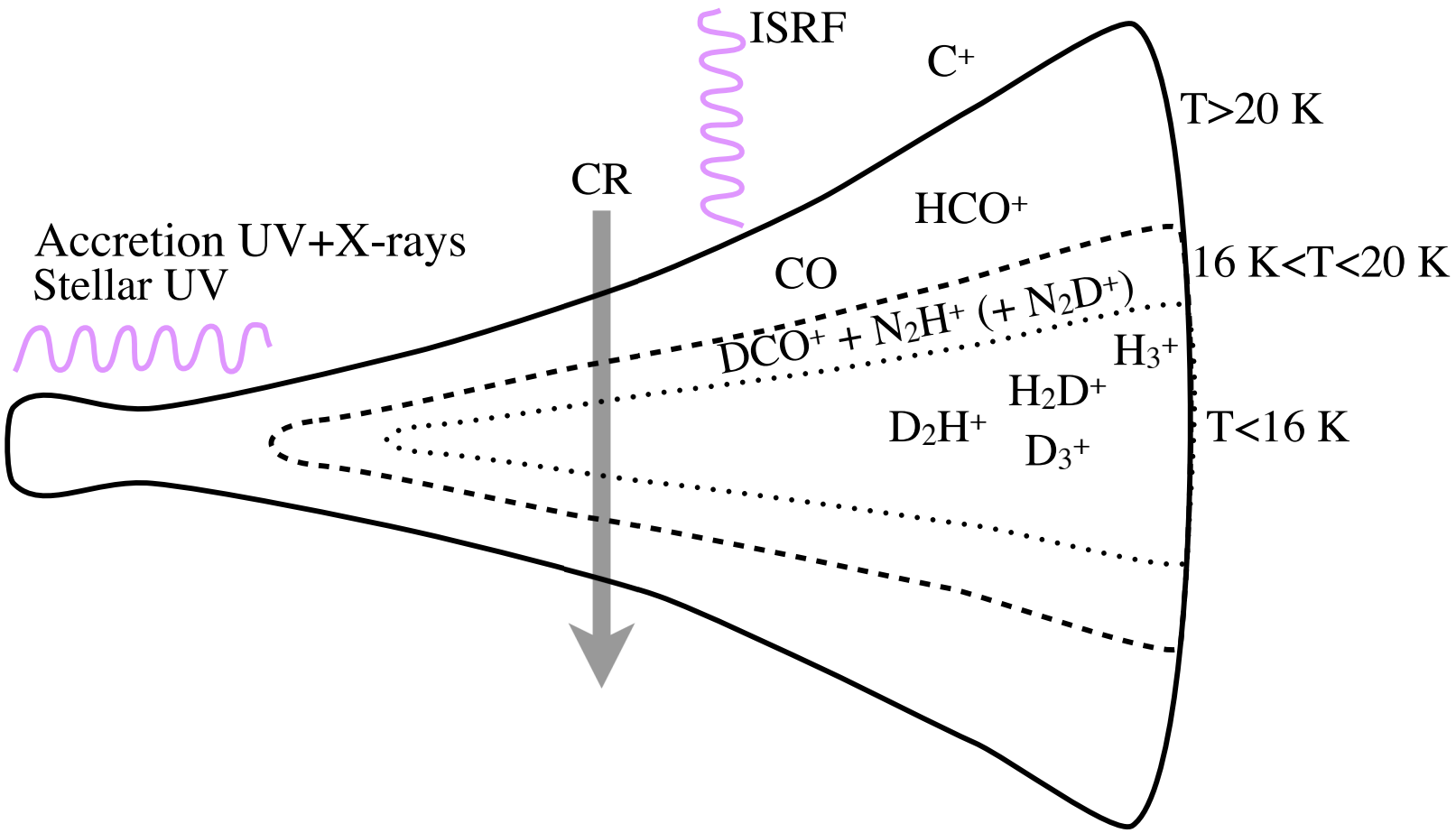
Deuterium fractionation as a function of disk radius and height



Isotopic fractionation in C, O and N



Searching for dead zones



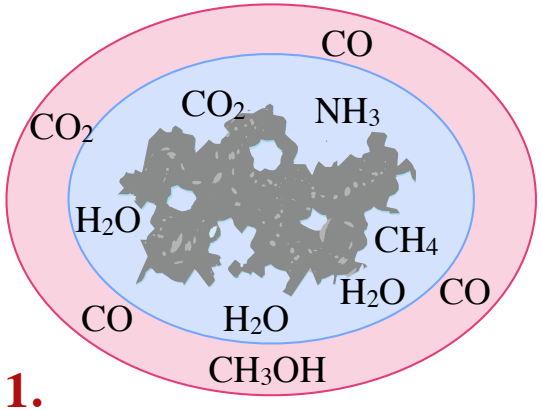
The need for J=1-0 molecular lines in disk midplane studies

Disk midplanes are the sites of planet formation, the main reservoirs of mass and probable sources of complex organics

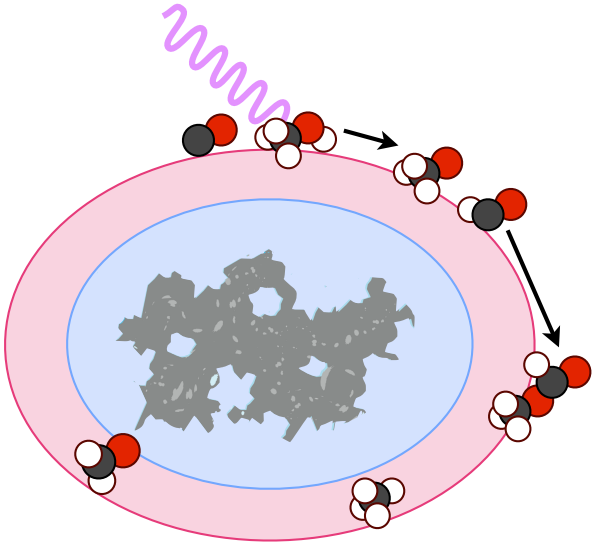
Disk midplanes are cold

To characterize disk midplanes requires access to range of low-energy lines of ions, deuterated molecules, isotopologues and organics

ALMA Band 2 is the only observatory that would provide spatially resolved observations of key J=1-0 lines.

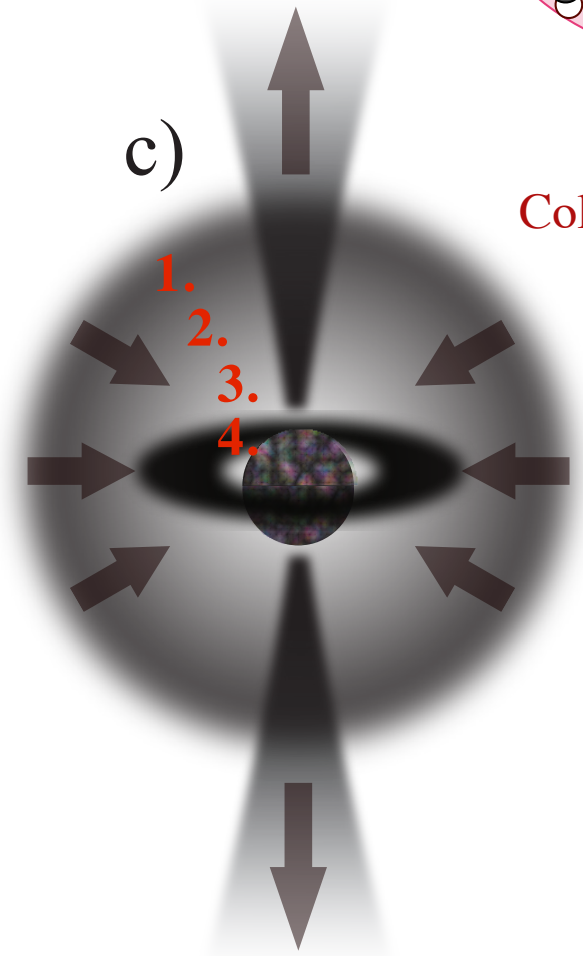


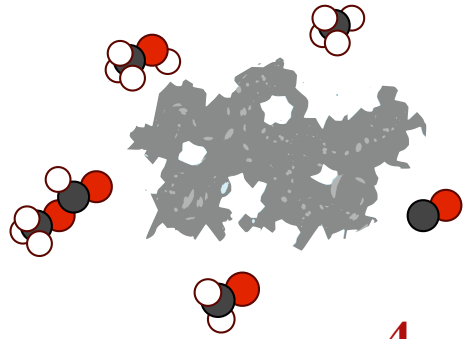
1.
Simple ice formation.



2.
Cold ice photochemistry.

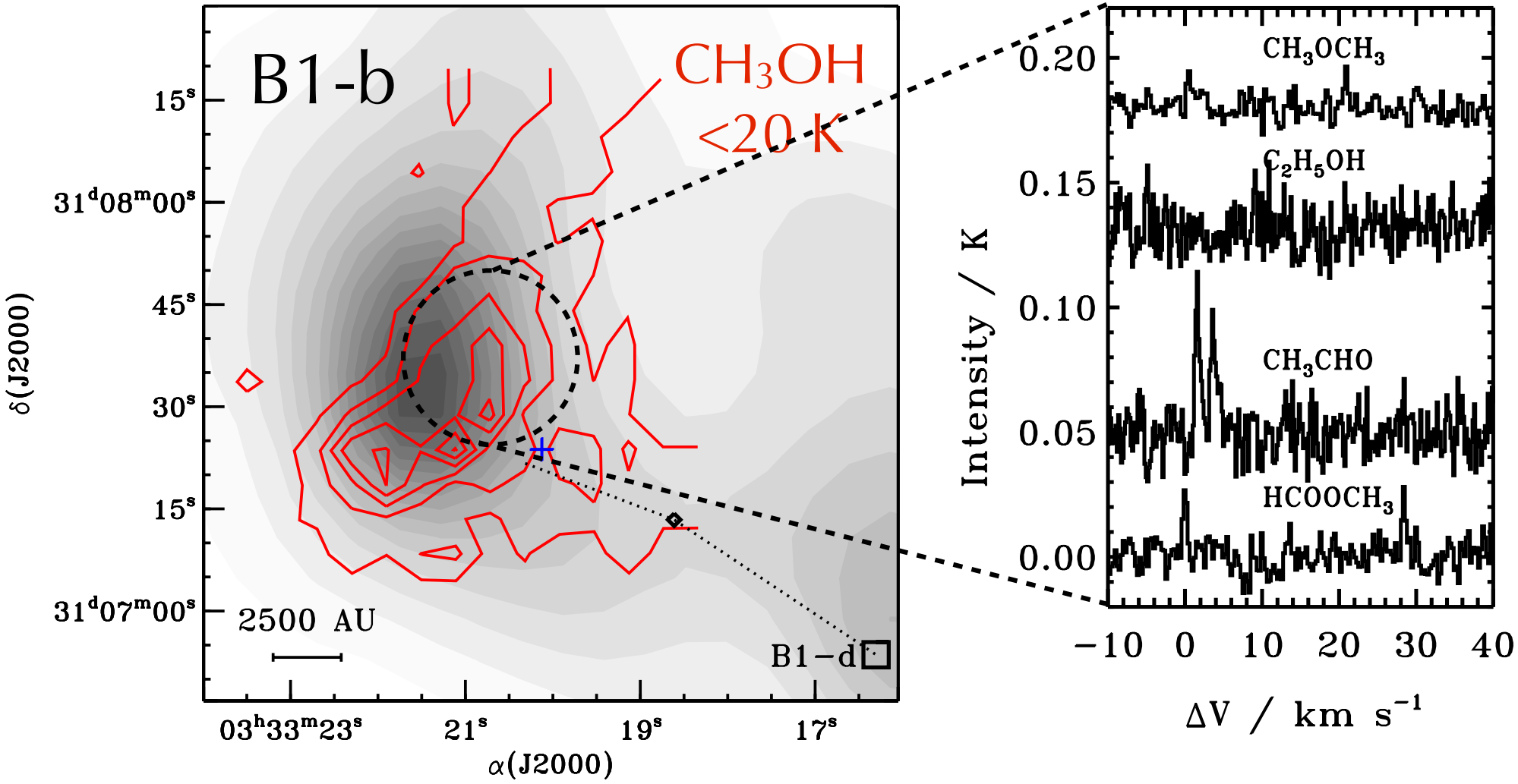
3.
Warm ice photochemistry and ice-specific desorption lines.





4.
Complete thermal ice evaporation.

Very Cold Complex Chemistry



[Öberg et al. 2010a, Bachmann et al. 2012]

Cold organic chemistry at 4 mm