Spatially Resolved Observations of Protoplanetary Disk Chemistry

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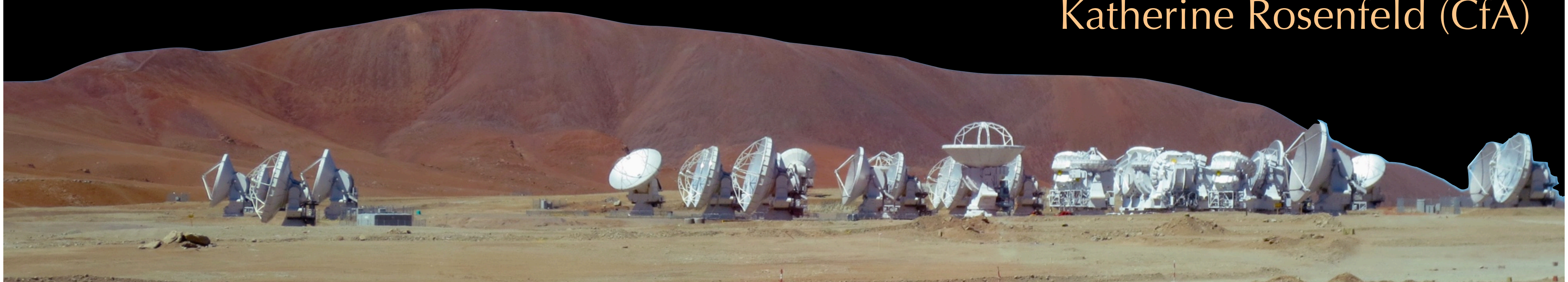
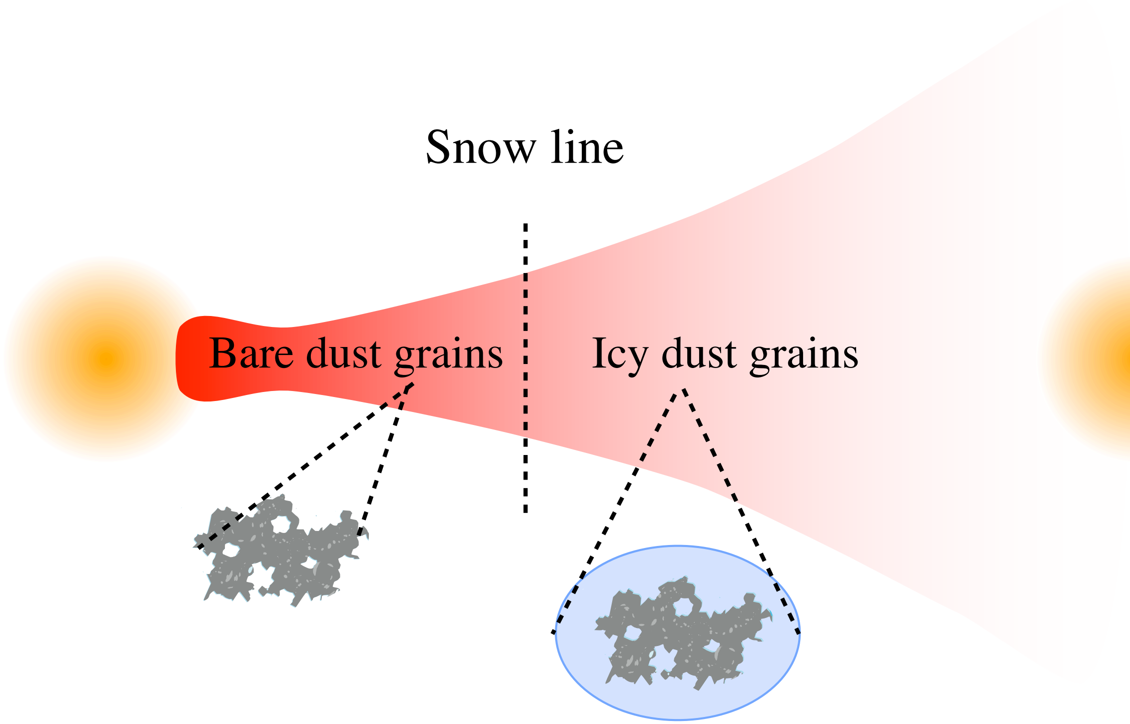
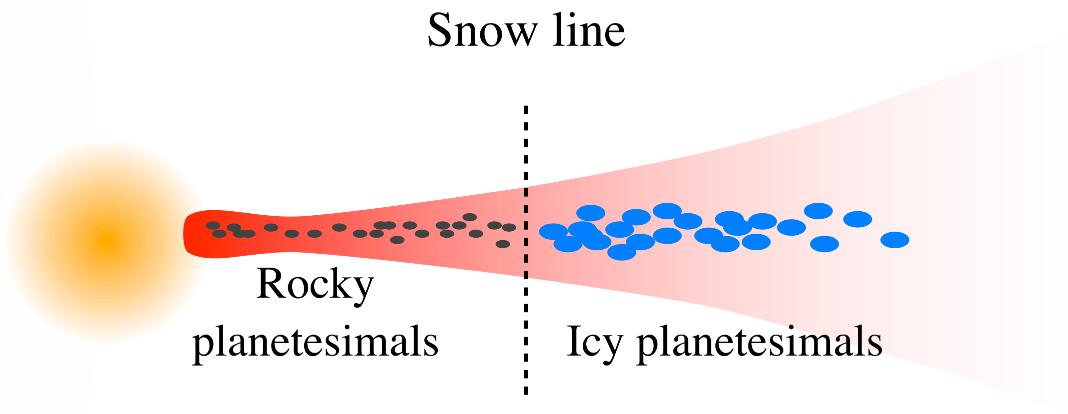


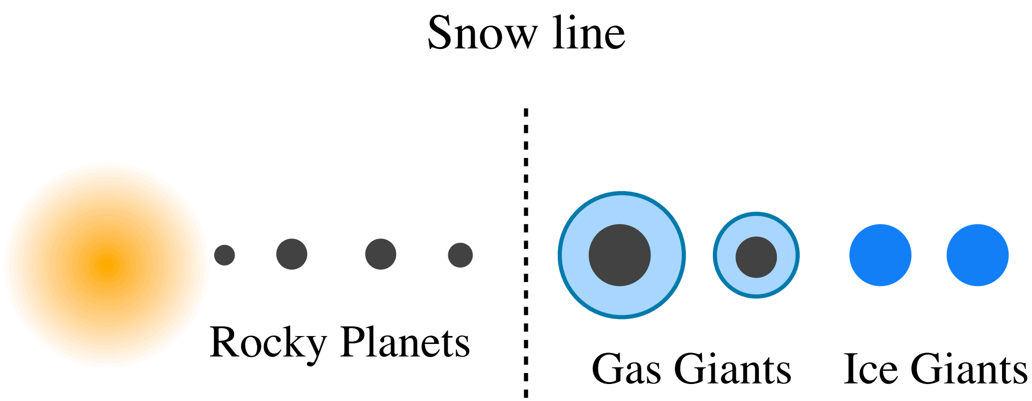
Planet formation around the snow line





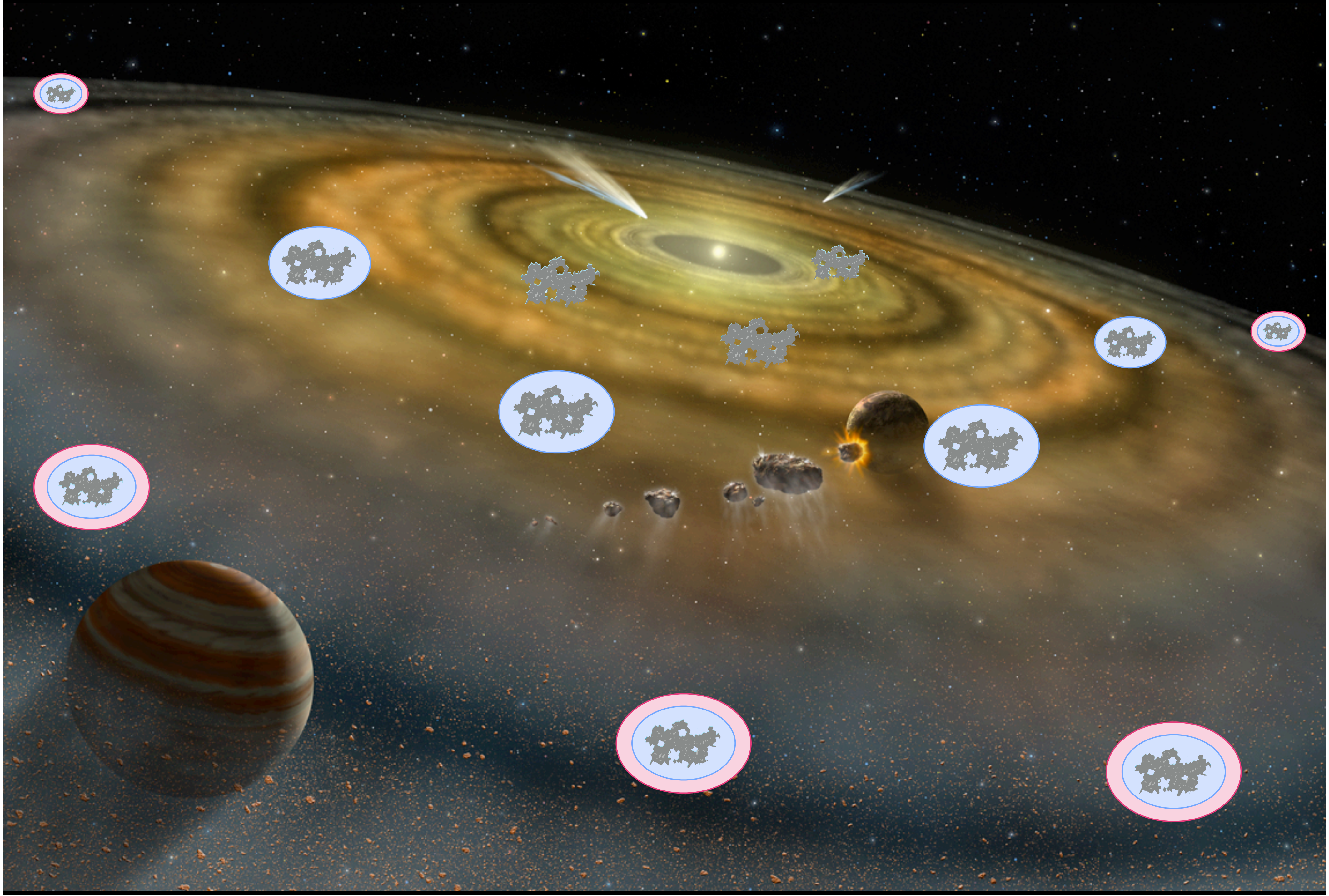
Affects planet formation efficiencies because: Icy grains are stickier than bare grains, grain column density increases, pressure traps etc.

Also affects the composition of forming planets

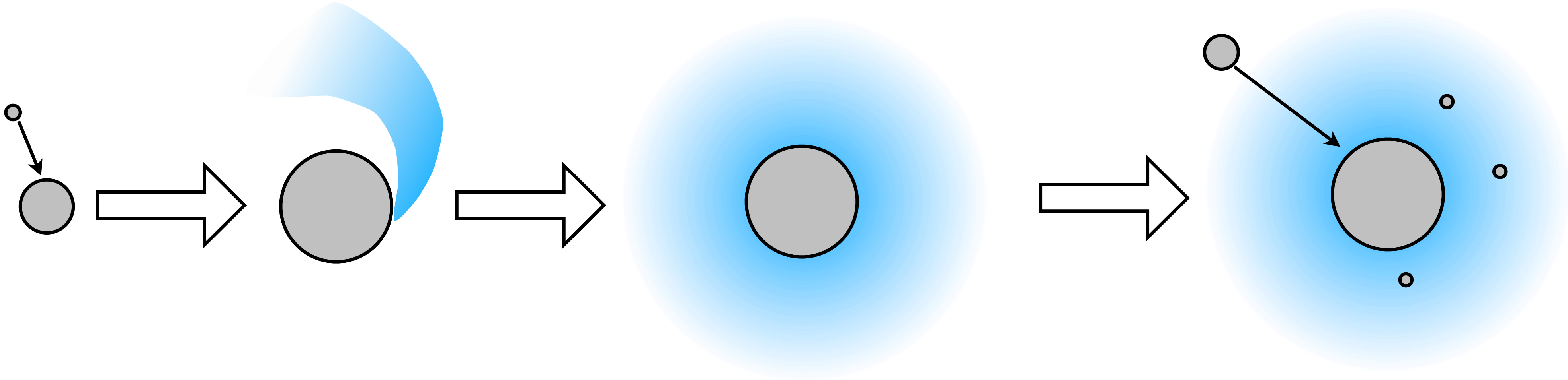


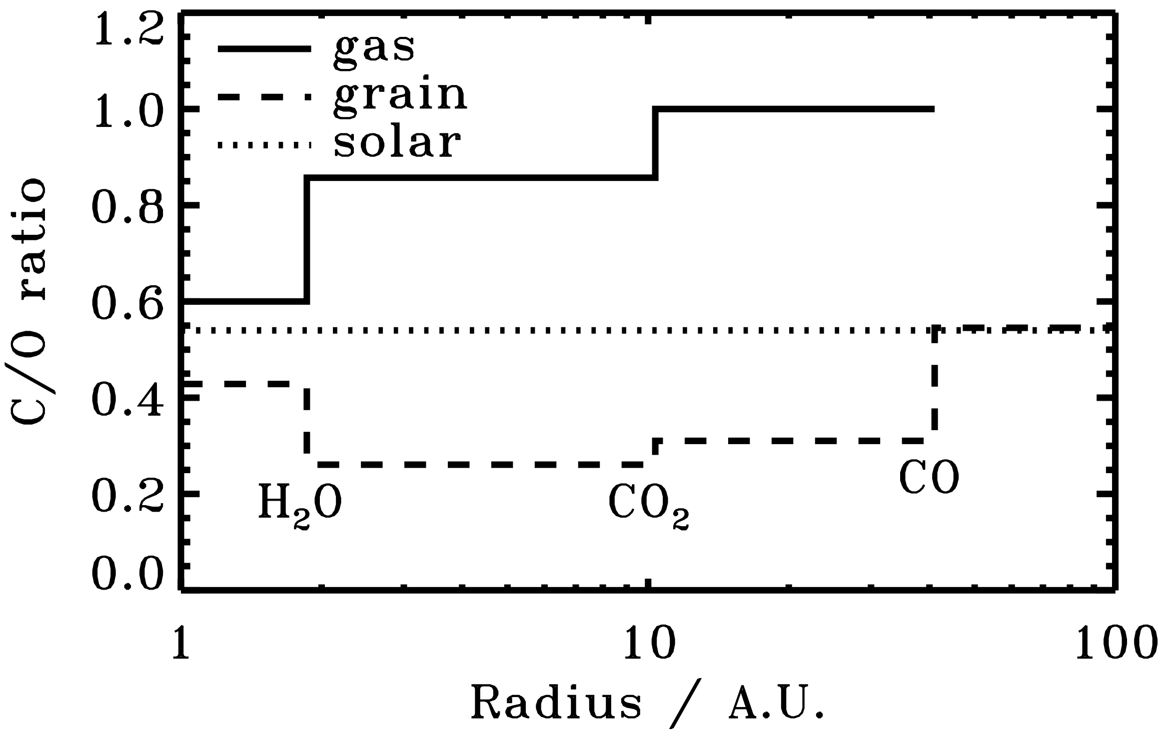
[e.g. Ciesla & Cuzzi 2006, Ros & Johansen 2013]

Disk Snowlines



The importance of the CO snowline I



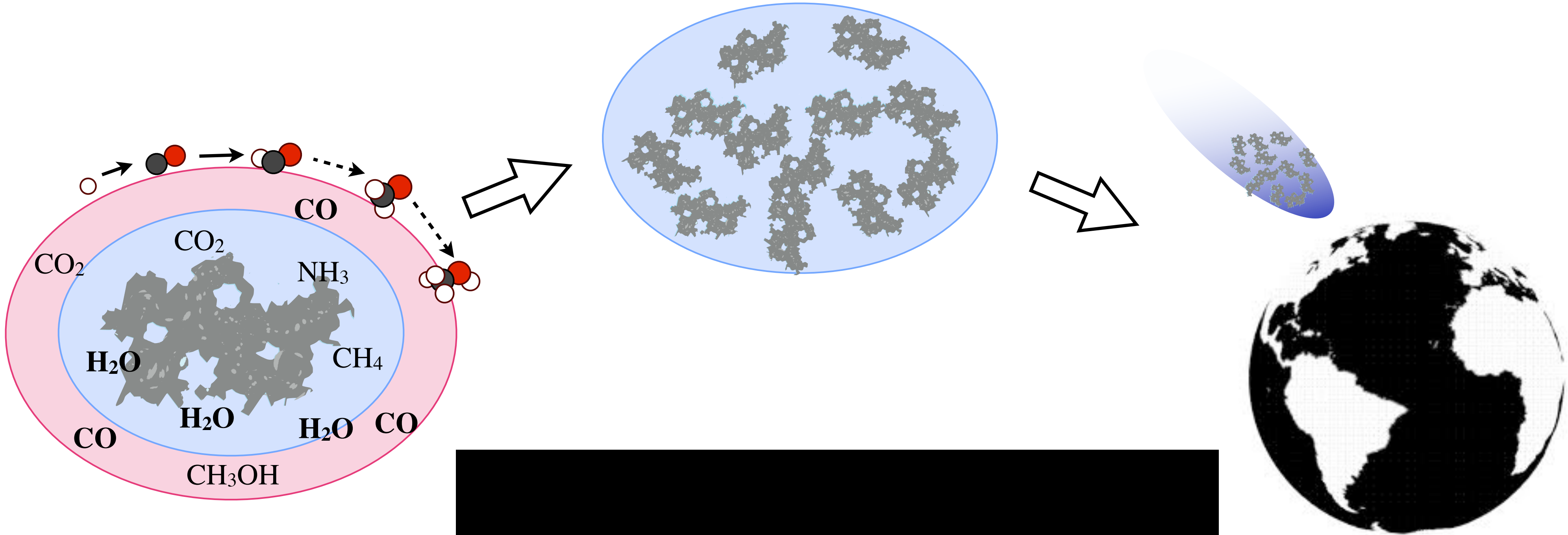


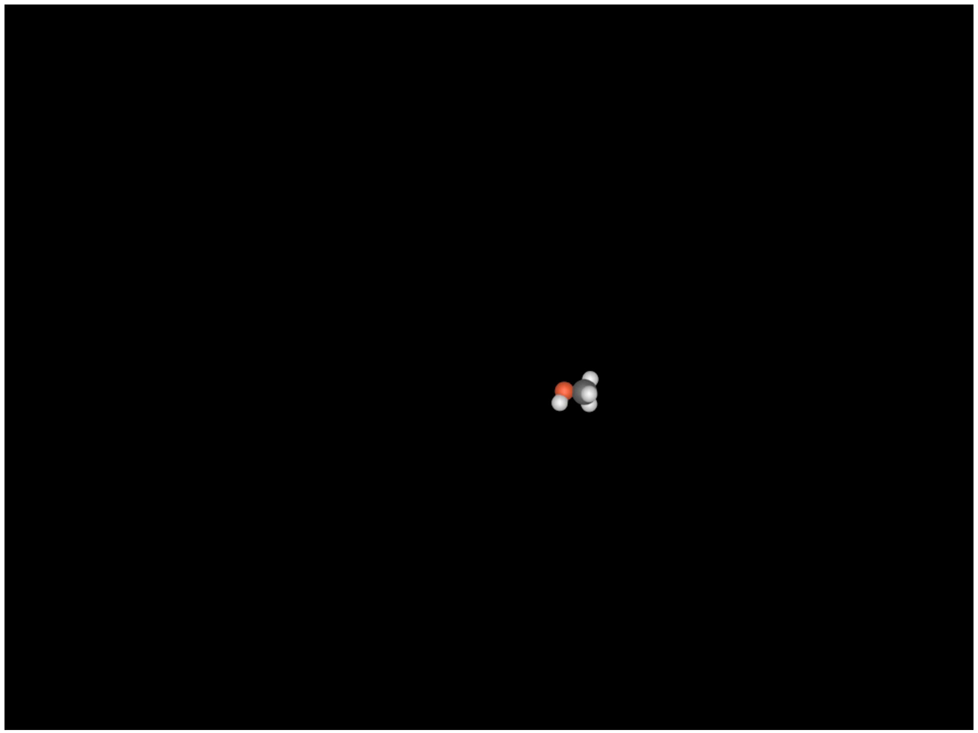
Assuming interstellar molecular abundances, the C/O ratio between the CO_2 and CO snowlines will be ~1.

If a gas giant accretes the core from solids and envelope from gas, C/O~1 in the atmosphere, assuming no planetesimal pollution or core dredging.

[Öberg, Murray-Clay & Bergin 2011b]

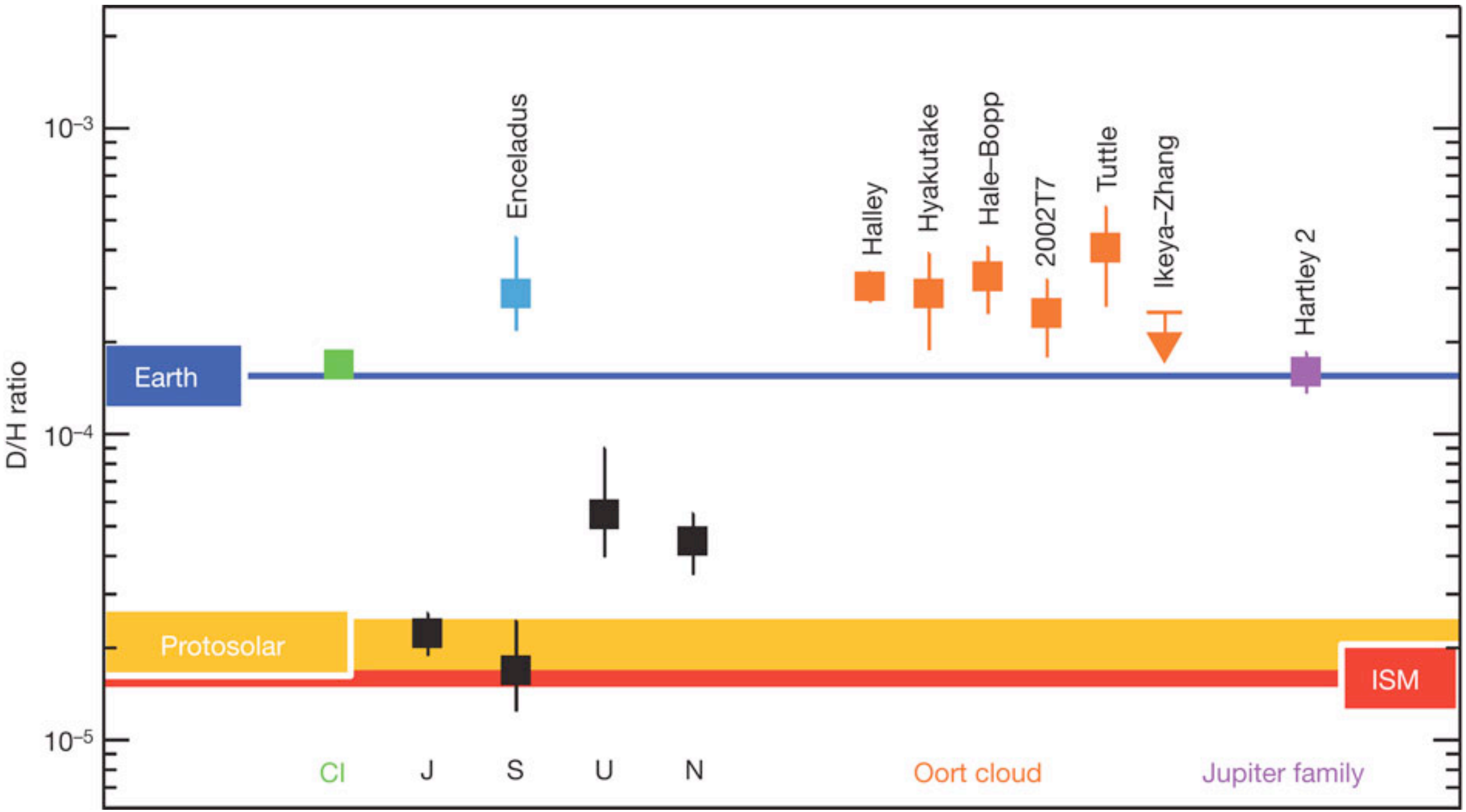
The importance of the CO snowline II





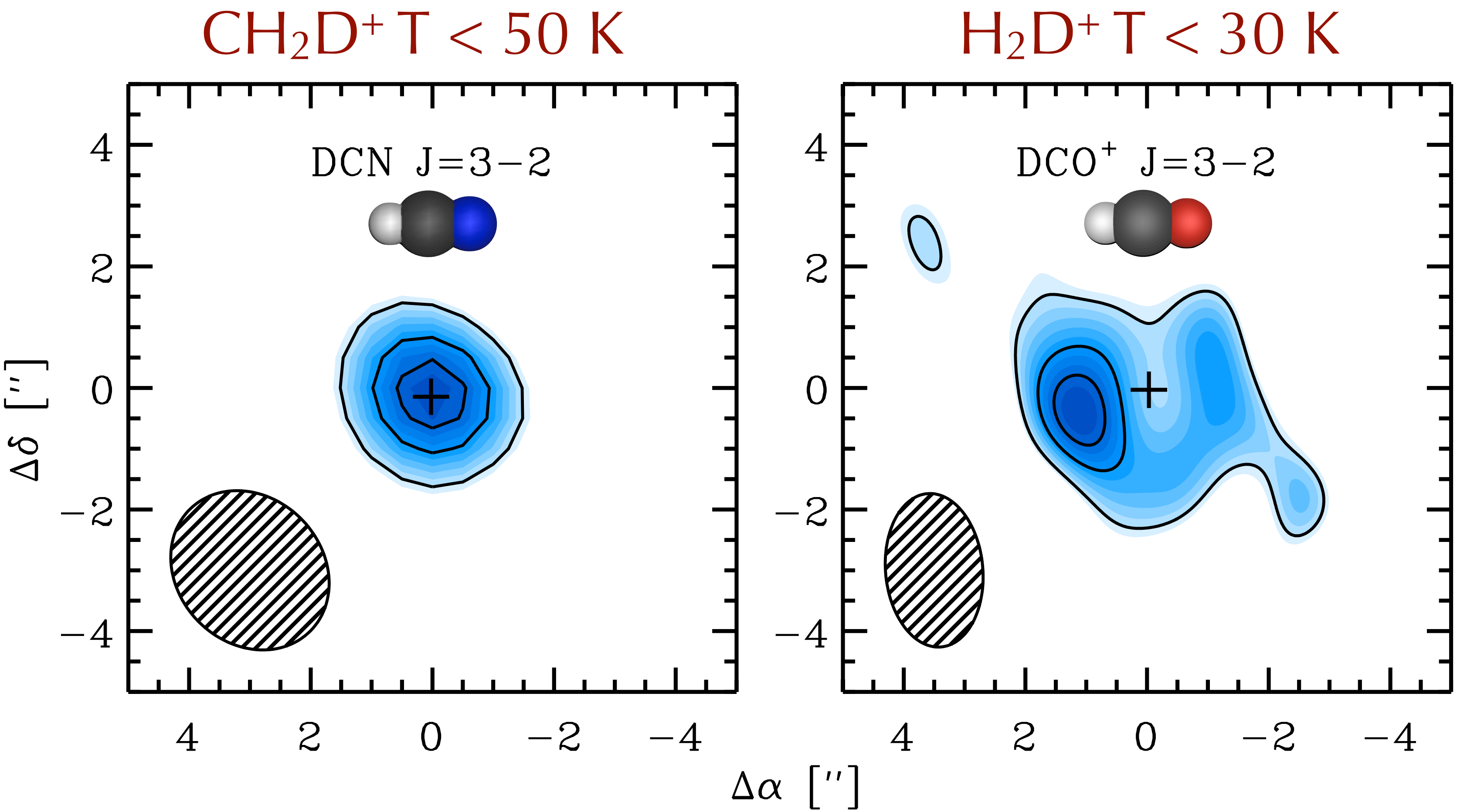
[Öberg, Garrod et al. 2009]

Delivery of volatiles to Earth from Comets



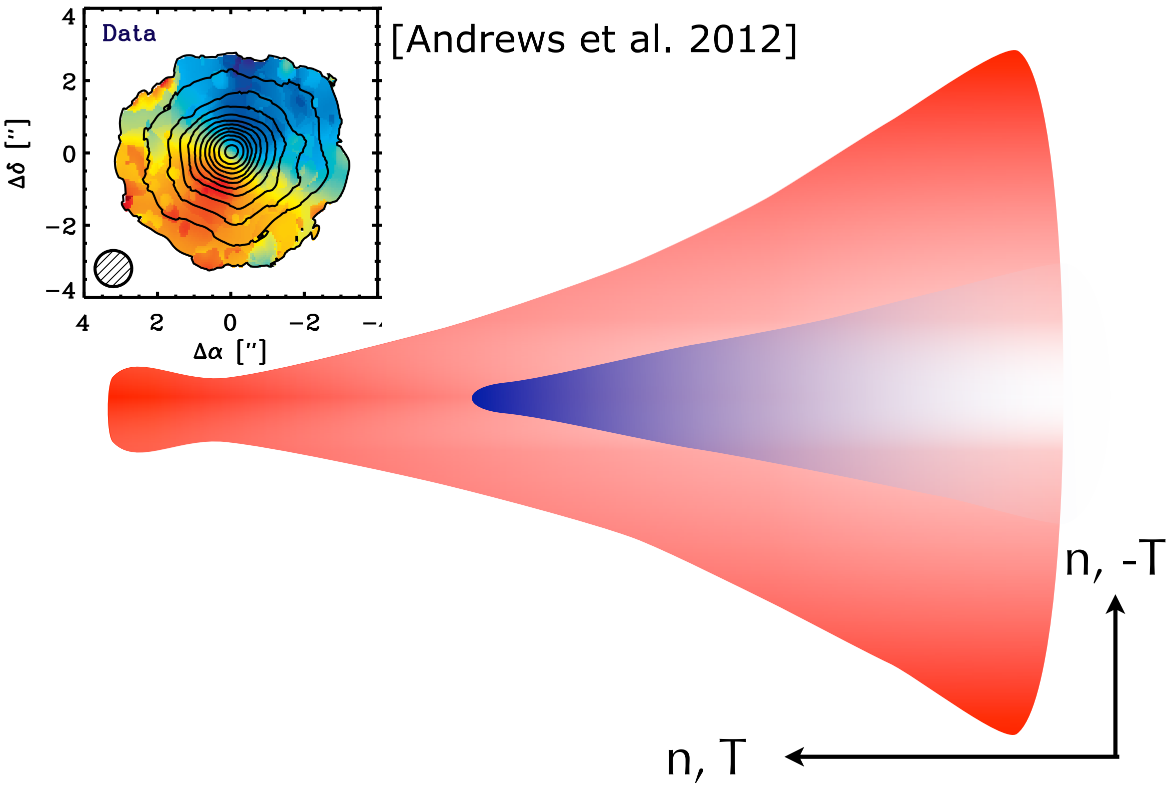
[Hartogh et al. 2011]

Deuterium Enrichment toward TW Hya



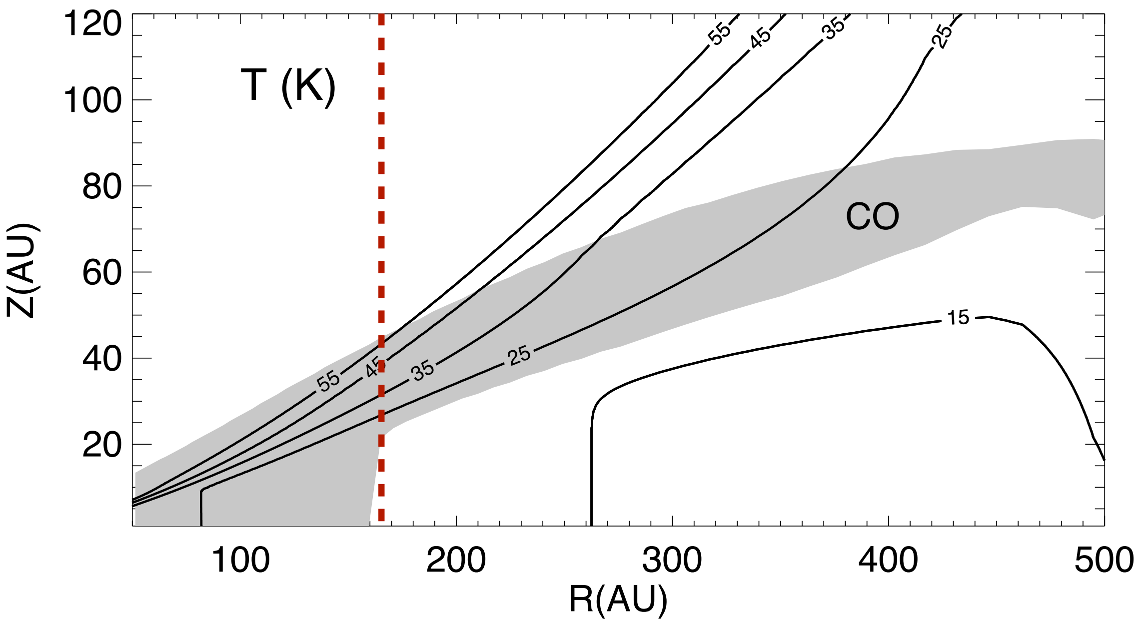
Deuterium enrichment occurs at a range of temperatures during planet formation!

[Qi et al. 2008, Öberg, Qi et al. 2012]



[Andrews et al. 2012]

Observing (CO) Snow Lines / Snow Surfaces



Multi-transitional CO data (J=2-1, 3-2, 6-5 and four isotopologues) required to constrain the CO temperature structure and snowline location towards HD 163296.

CO freeze-out outside of 170 AU, corresponding to a freeze-out temperature of ~19 K.

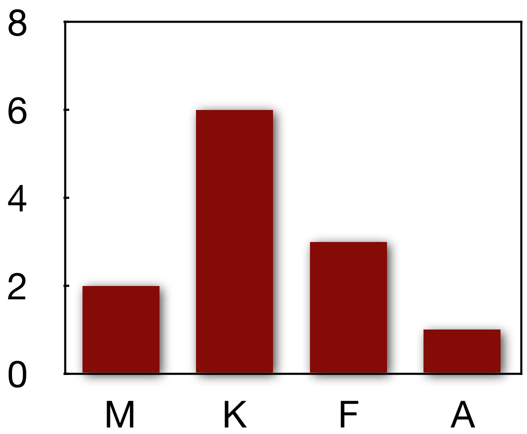
[Qi, d'Alesssio, Öberg et al. 2011]

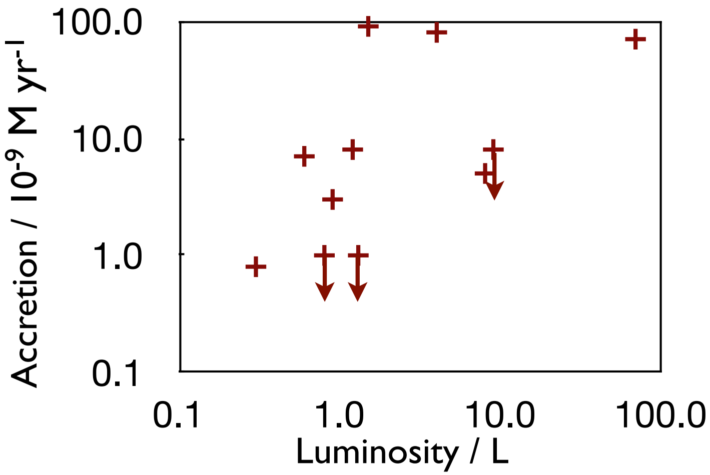
Disk Imaging Survey of Chemistry with the SMA

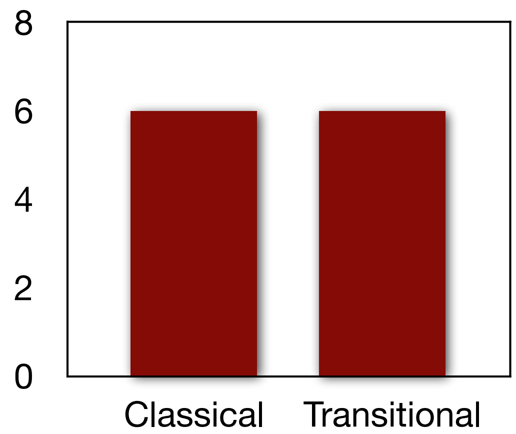
20 track survey of 10 molecular lines toward 12 protoplanetary disks:

CO 2-1, HCO^+ 3-2, DCO^+ 3-2, N_2H^+ 3-2, H_2CO 3-2, 4-3, HCN 3-2, DCN 3-2, CN 2-1

SMA compact configuration ~ 2-3″ resolution ~ 100-400 AU

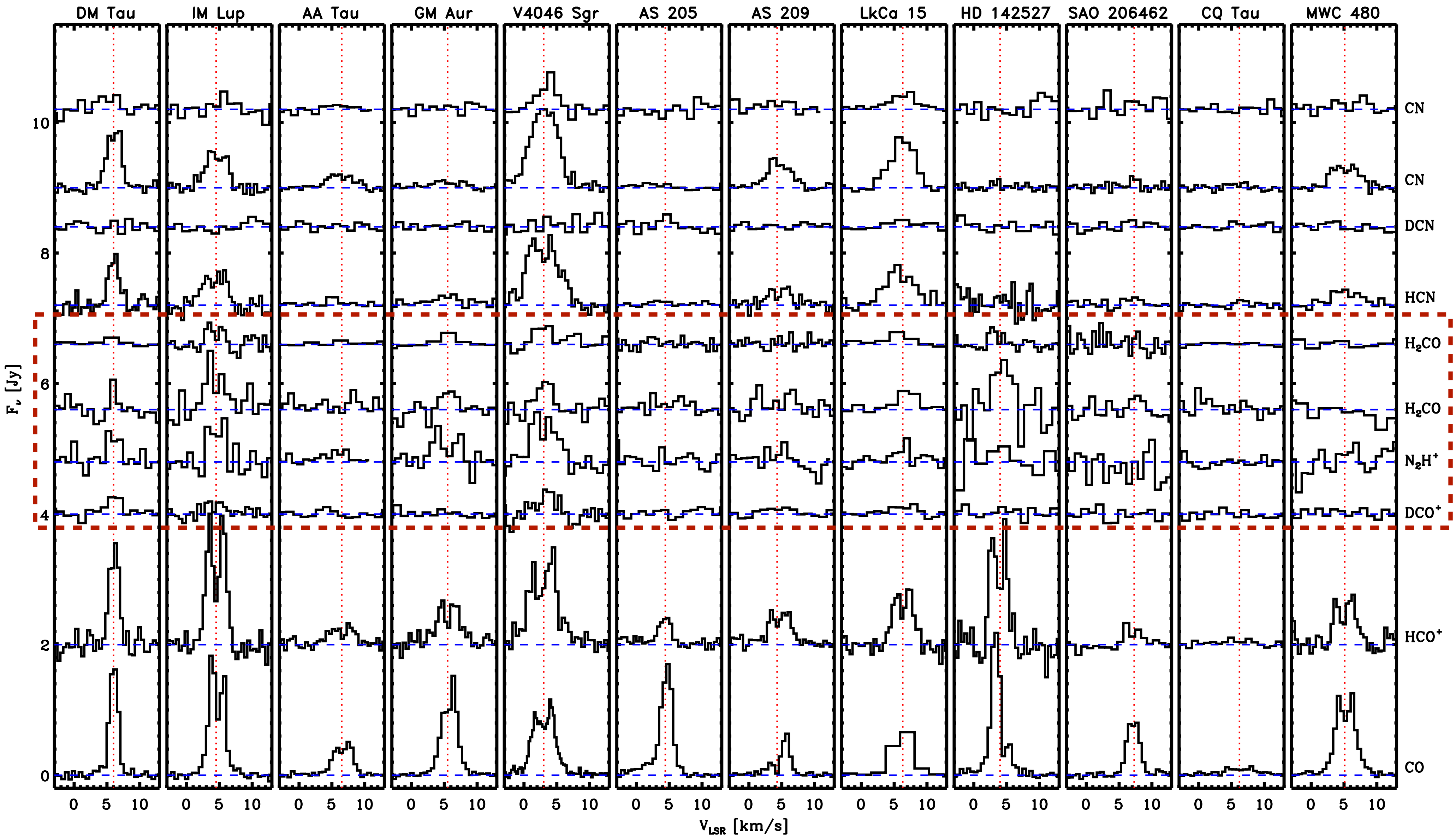






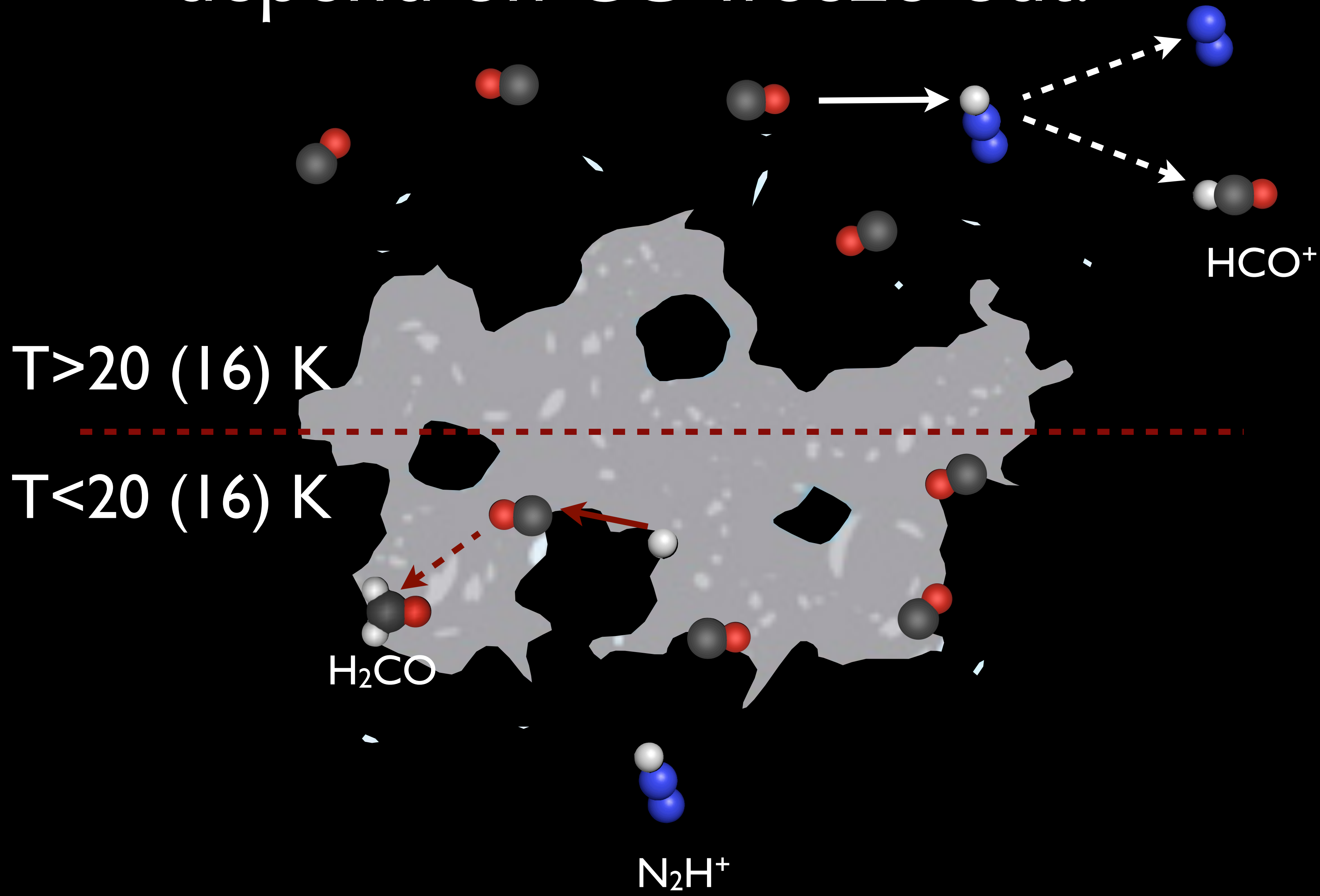
[PI: Öberg]

DiSCS Summary

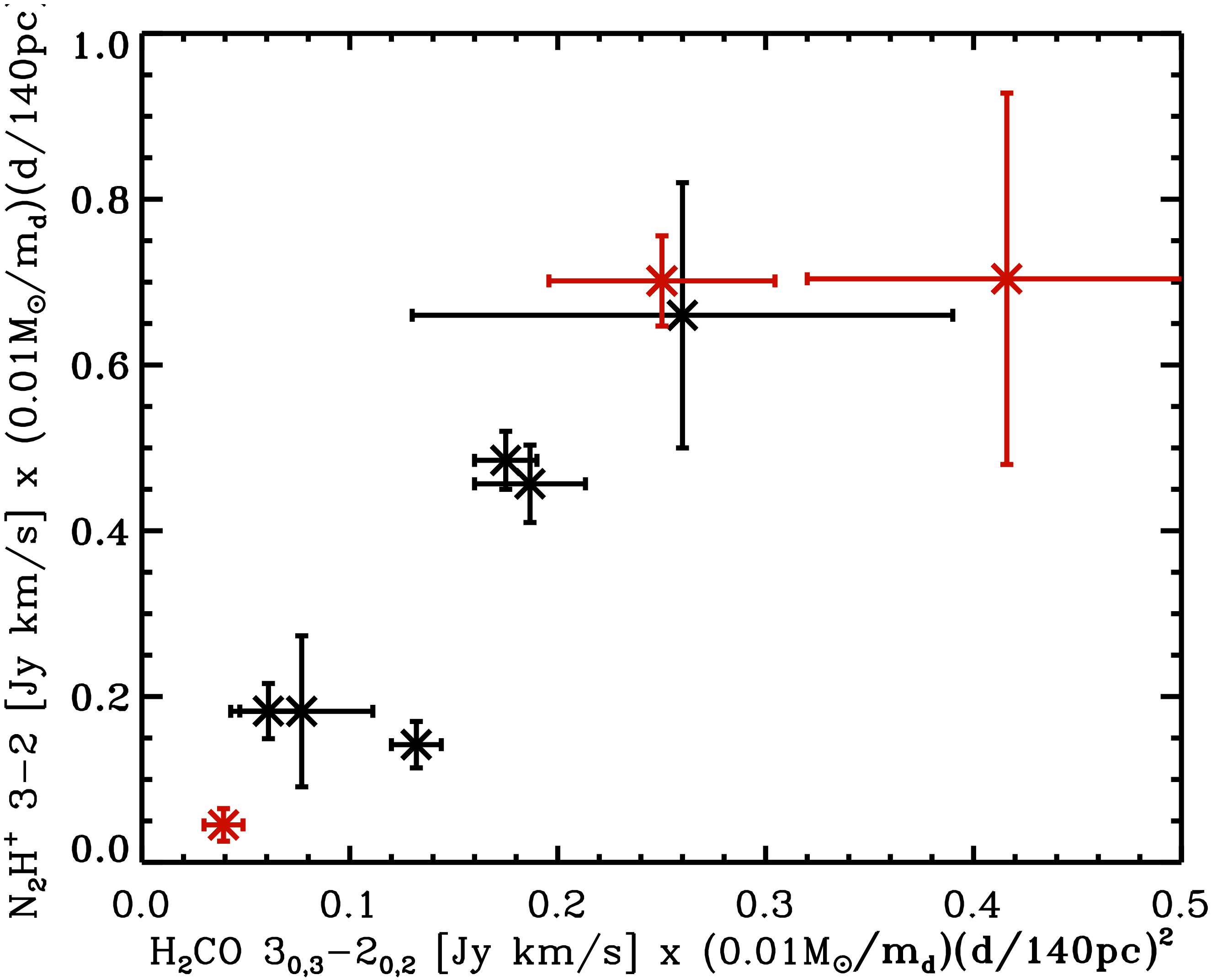


[Öberg, Qi et al. 2010, 2011]

H_2CO and N_2H^+ formation should both depend on CO freeze-out.



DiSCS: N_2H^+ vs. H_2CO Statistics



H_2CO proposed to form from hydrogenation of CO ice

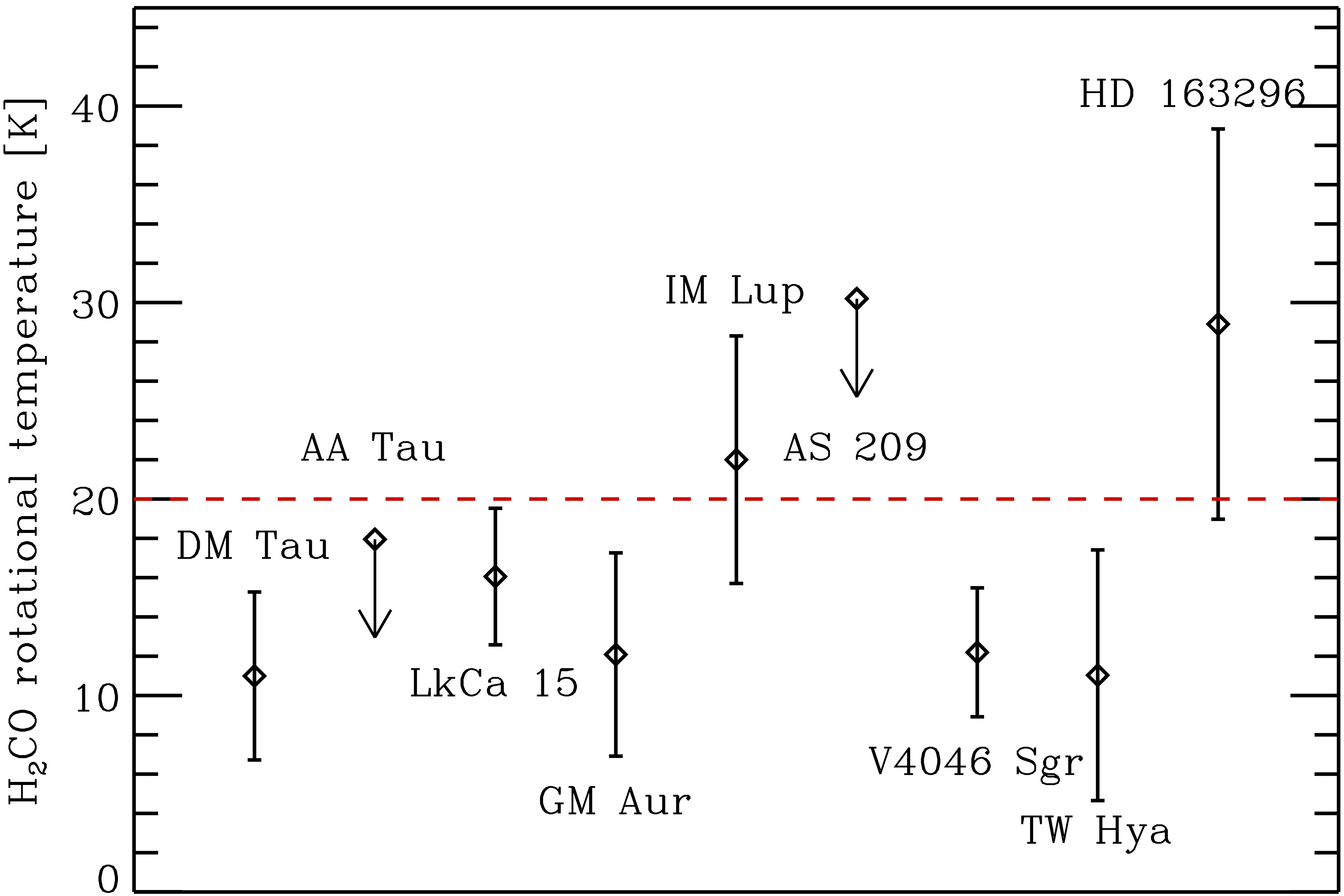
N_2H^+ is destroyed by gas-phase CO

Disk averaged N_2H^+ and H_2CO emission are strongly correlated

Consistent with that both molecules rely on CO freeze-out

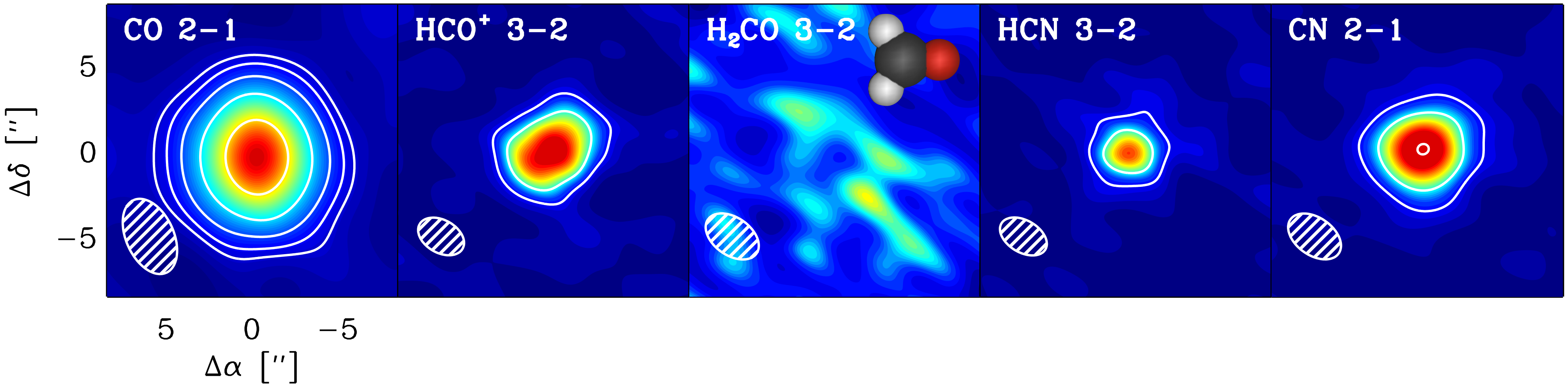
[Qi, Öberg et al. 2013a]

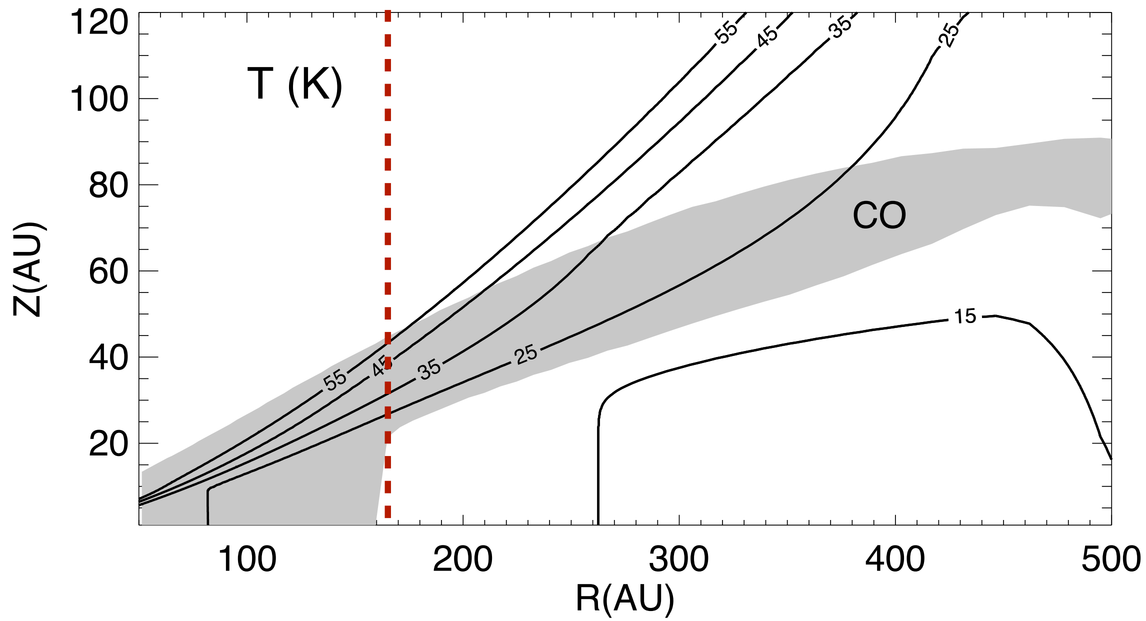
DiSCS: H_2CO Excitation Temperature



[Qi, Öberg et al. 2013a]

H_2CO and the CO snow line in HD 163296





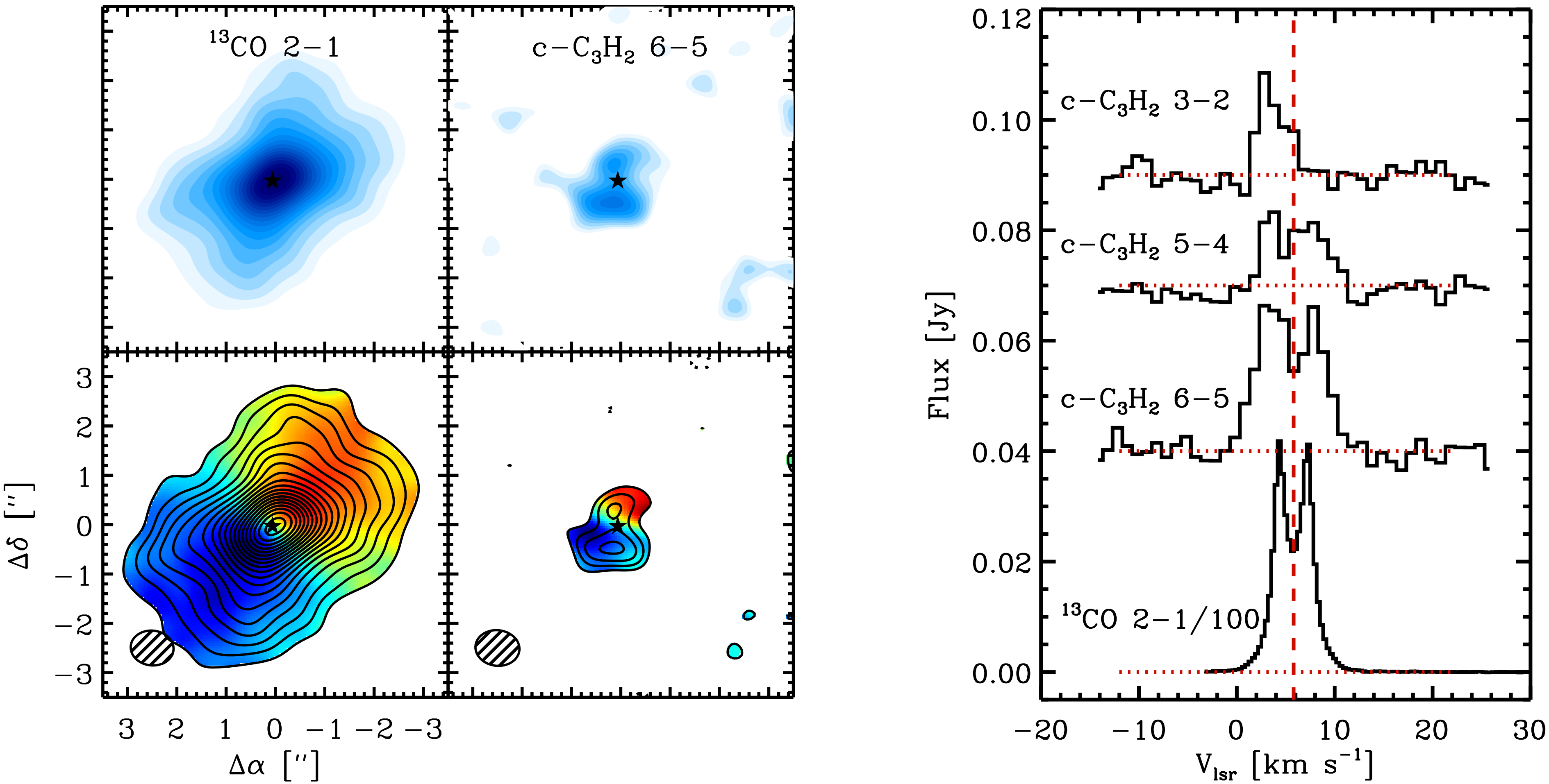
H_2CO `ring' radius consistent with CO snow line.

Conclusion supported by statistics from DiSCS sample.

Very low S/N...

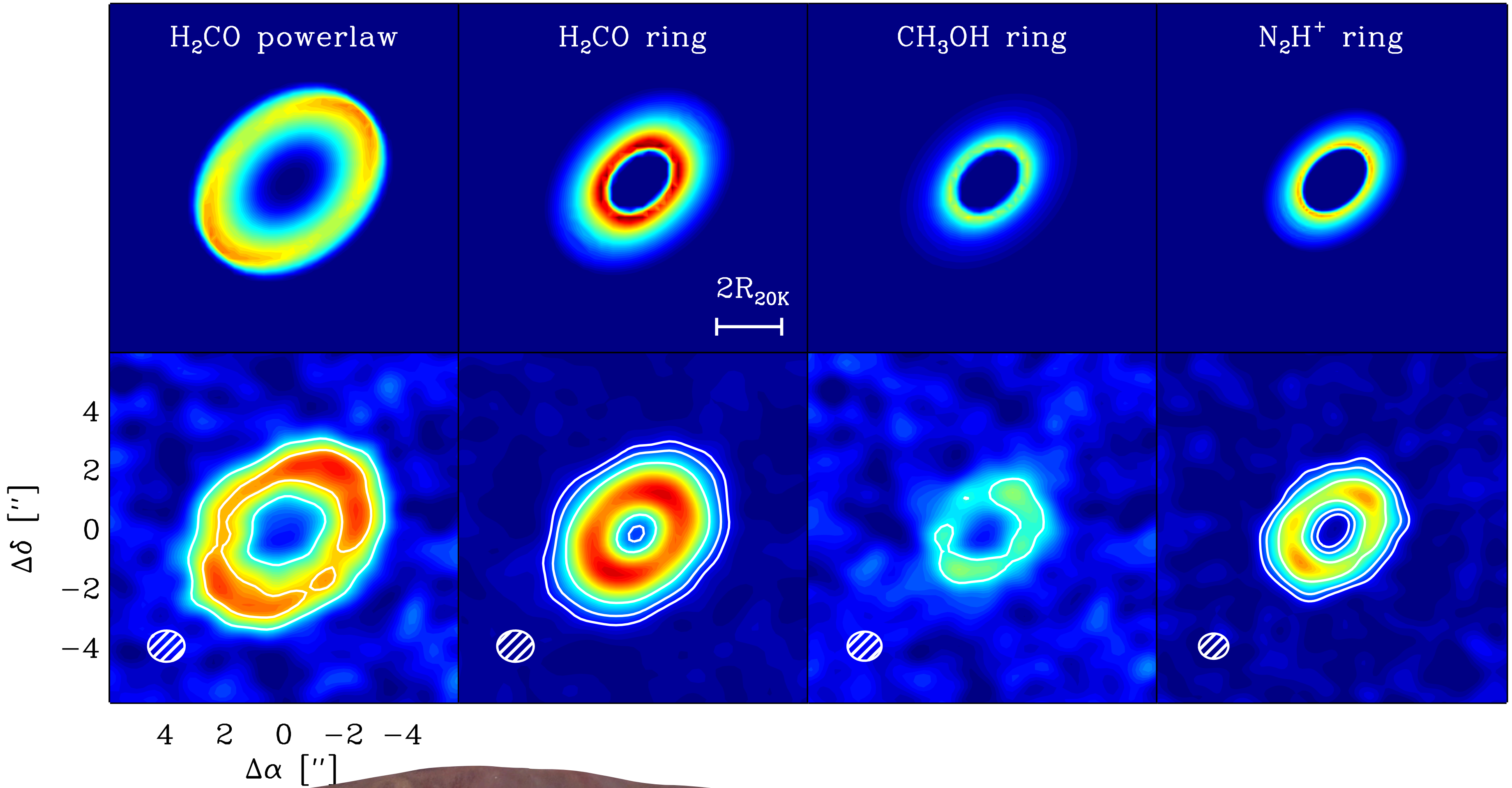
[Qi, Öberg et al. 2013a]

The ALMA revolution: c-C_3H_2



[Qi, Öberg et al. 2013b]

ALMA Simulations of Chemical Rings



[Qi, Öberg et al. 2013a]

N_2H^+ Towards TW Hya

Molecular Probes of Protoplanetary Disks

Disk chemistry depends on temperature, density and radiation structures, and the location of snowlines → large untapped potential for molecular probes.

ALMA will continue to improve sensitivity and resolution: already exquisite chemical imaging of protoplanetary disks!

Low-mass stars are likely more hospitable to prebiotic chemistry since CO snowlines and thus CH_3OH formation are closer to the planet-forming zone.