Chemical rings and their relation to planet formation

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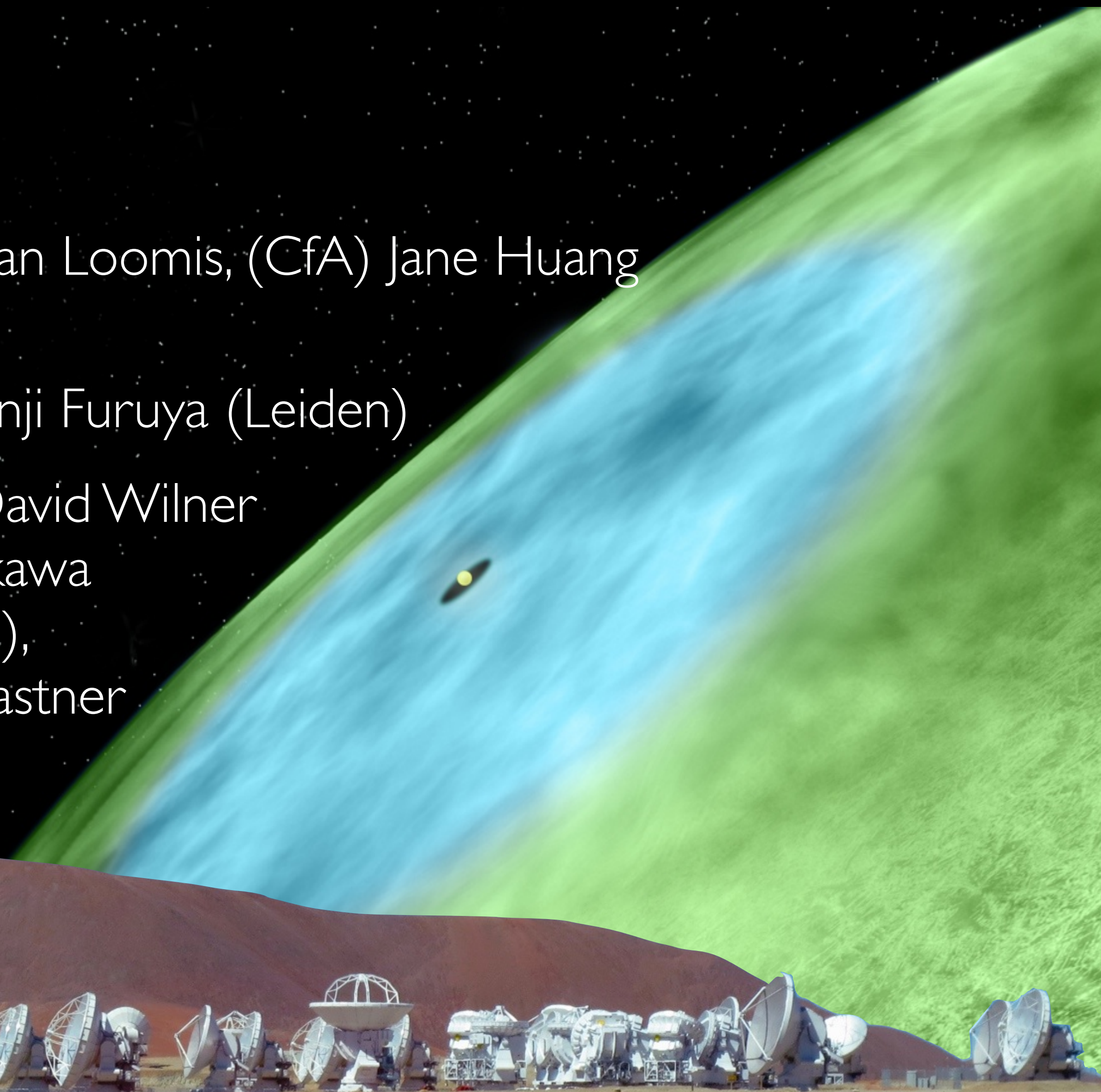
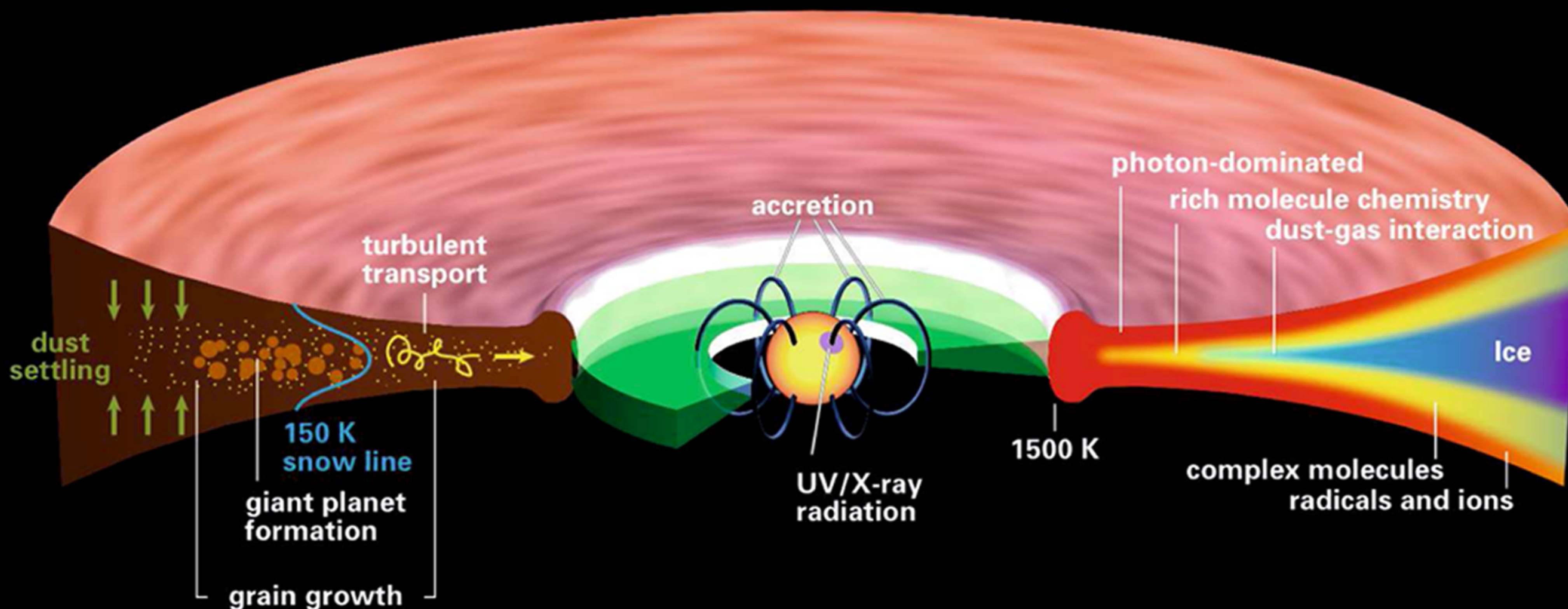


NASA Origins, Sloan Foundation, Simons Collaboration on the Origins of Life

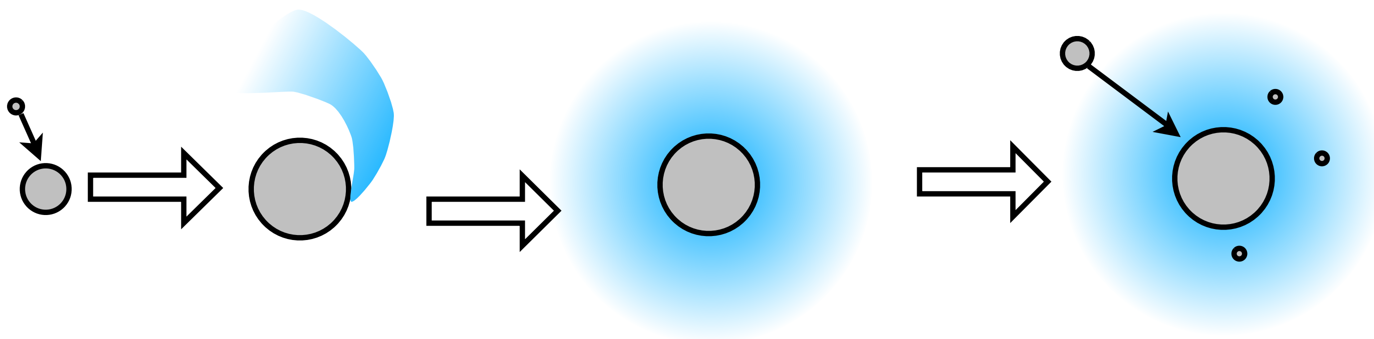
Protoplanetary disk chemistry: Temperature and radiation gradients should produce molecular rings



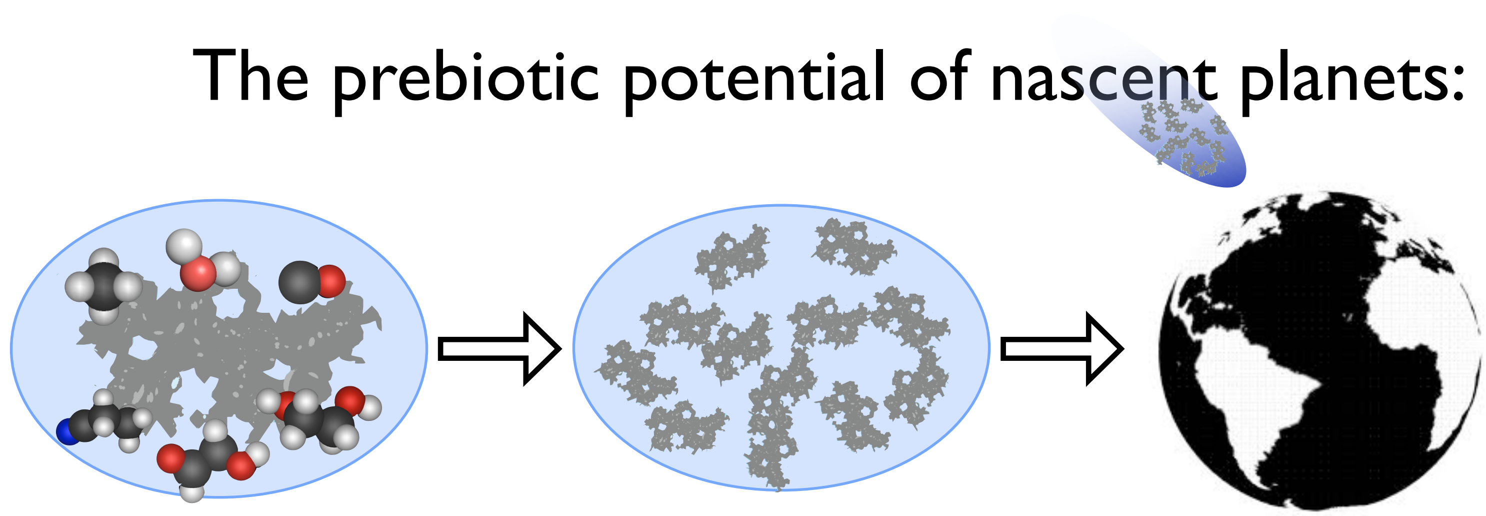
[Henning & Semenov 2014]

Importance of Disk Chemistry for Planets

Planet formation efficiencies and bulk compositions:



The prebiotic potential of nascent planets:



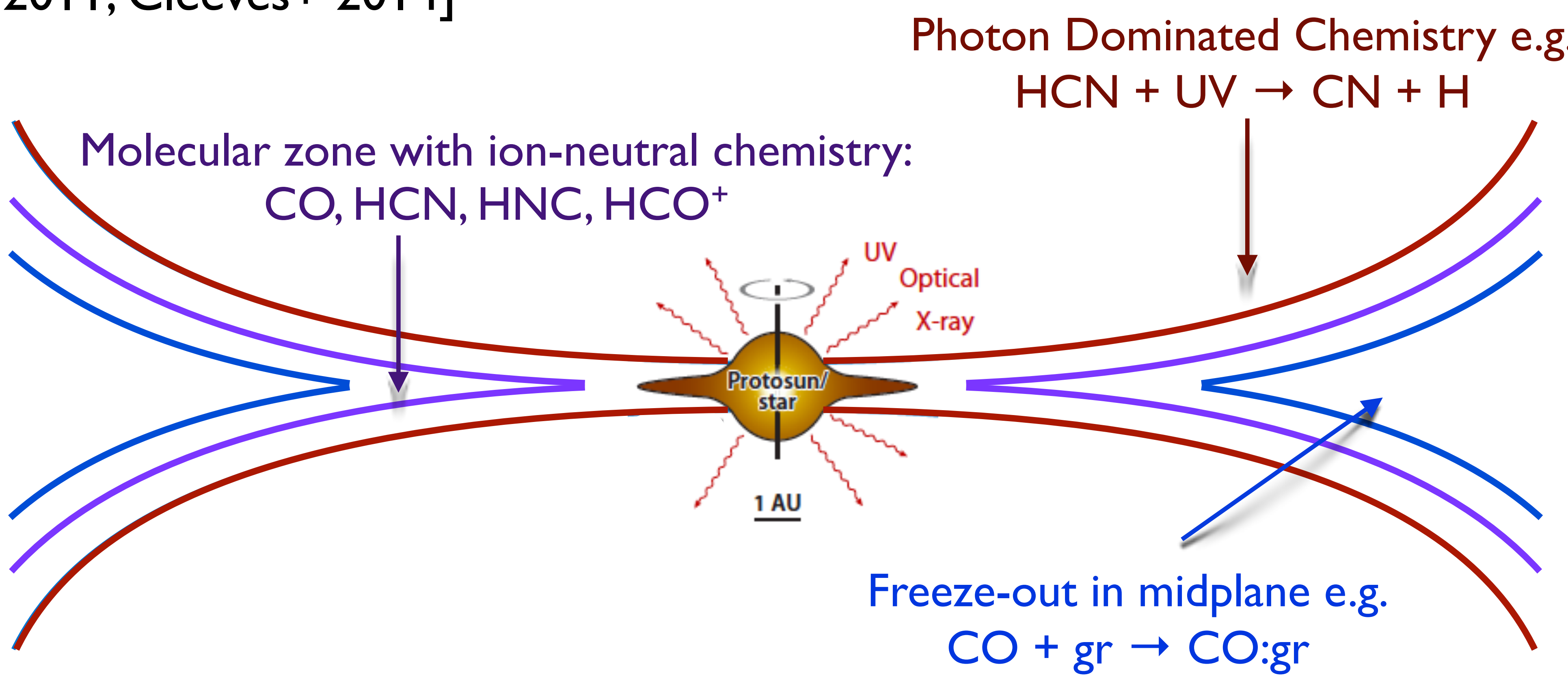
Probes of disk temperature, density, radiation and ionization

Molecular emission as tools to characterize disks

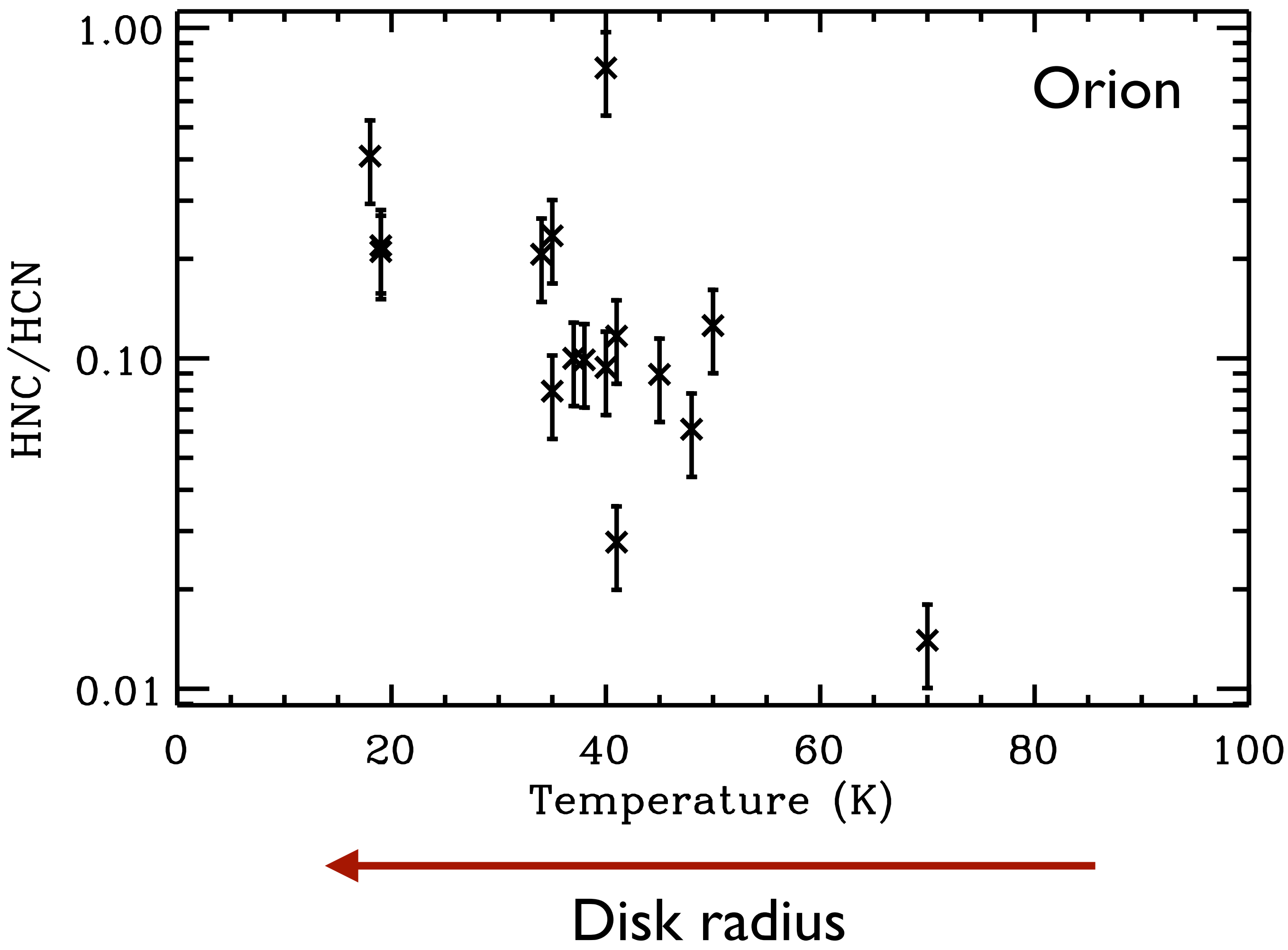
Temperature: HNC/HCN [Graninger+ in prep.]

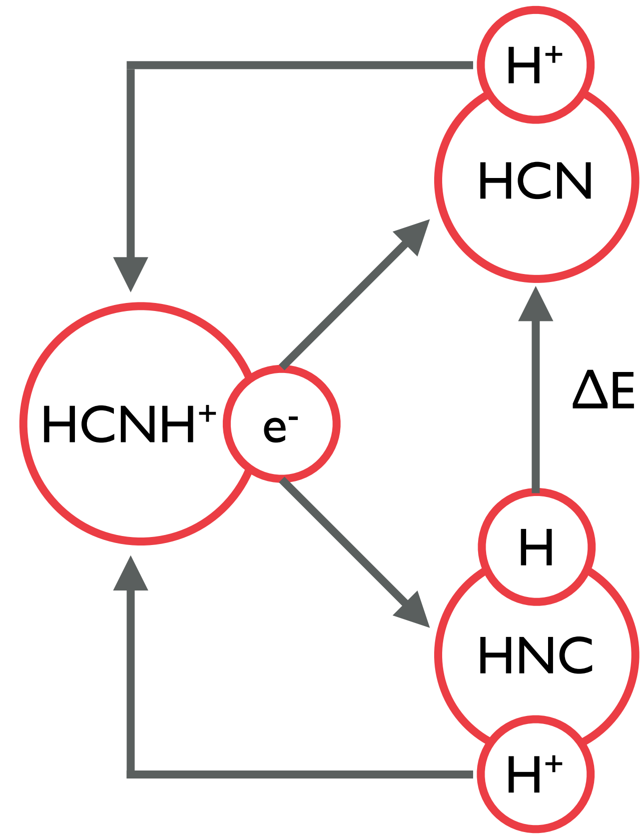
Radiation: CN/HCN [Guzman+ in prep.]

Ionization: HCO^+, $H^{13}CO^+$, DCO^+, N_2H^+, H_2D^+ [Öberg+ 2011, Chapillon+ 2011, Cleeves+ 2014]



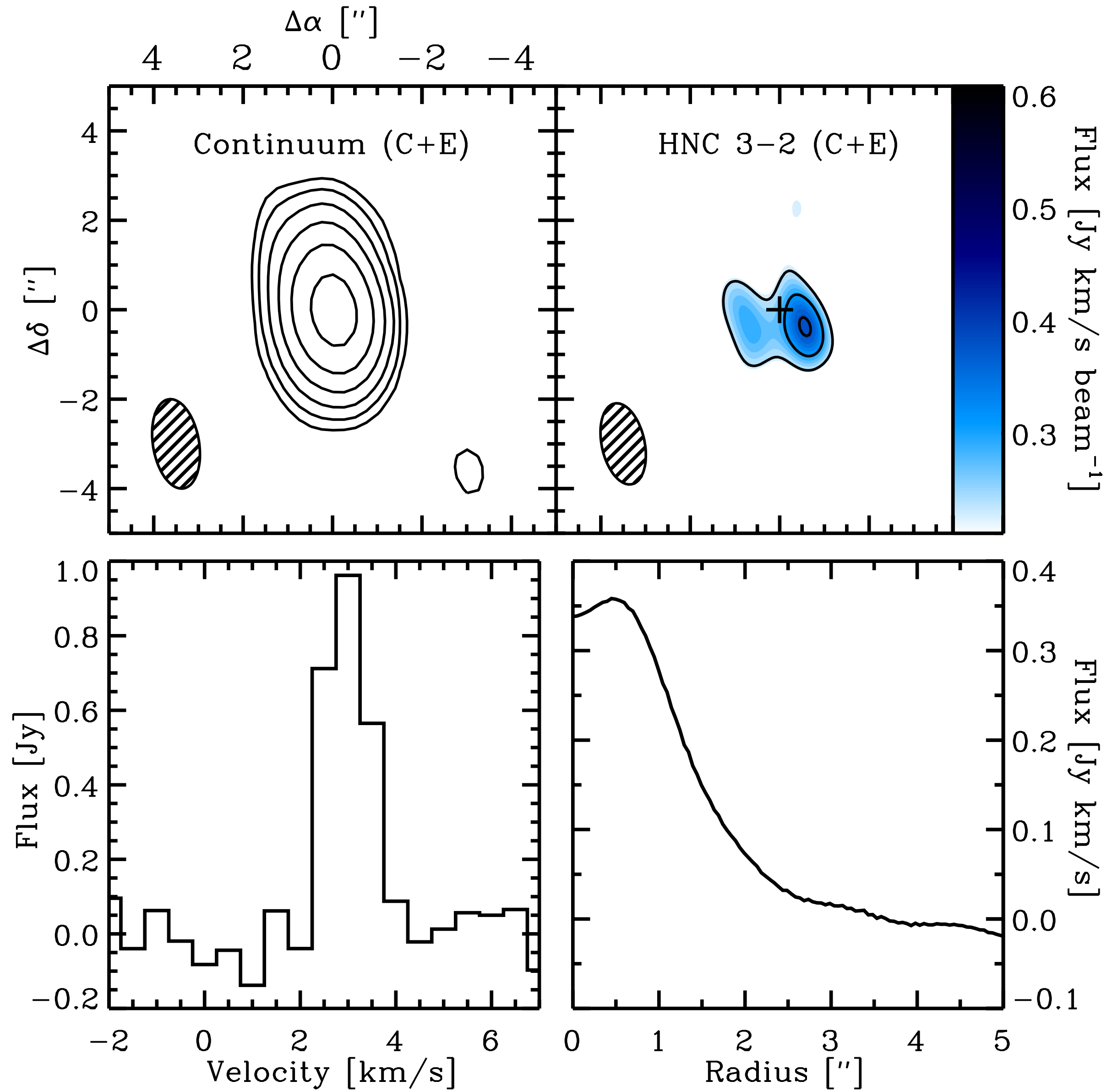
HNC/HCN: a thermometer?





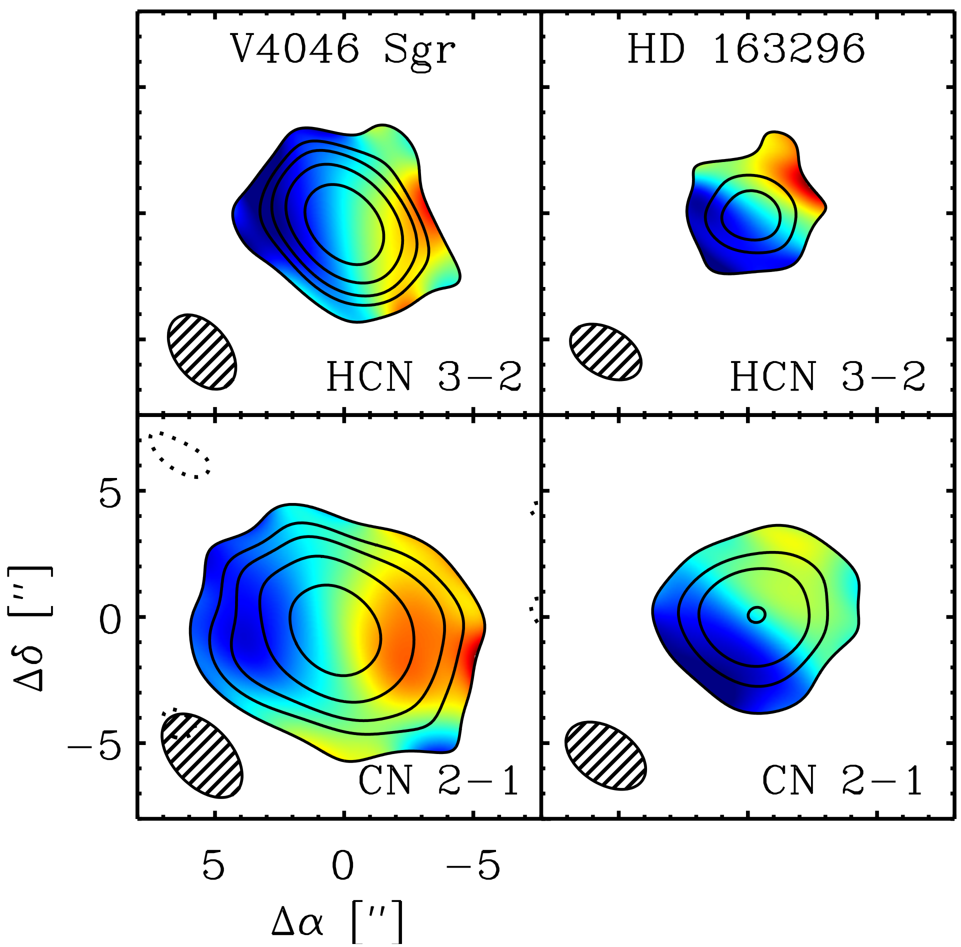
[Schilke+ 1992, Graninger+ 2013]

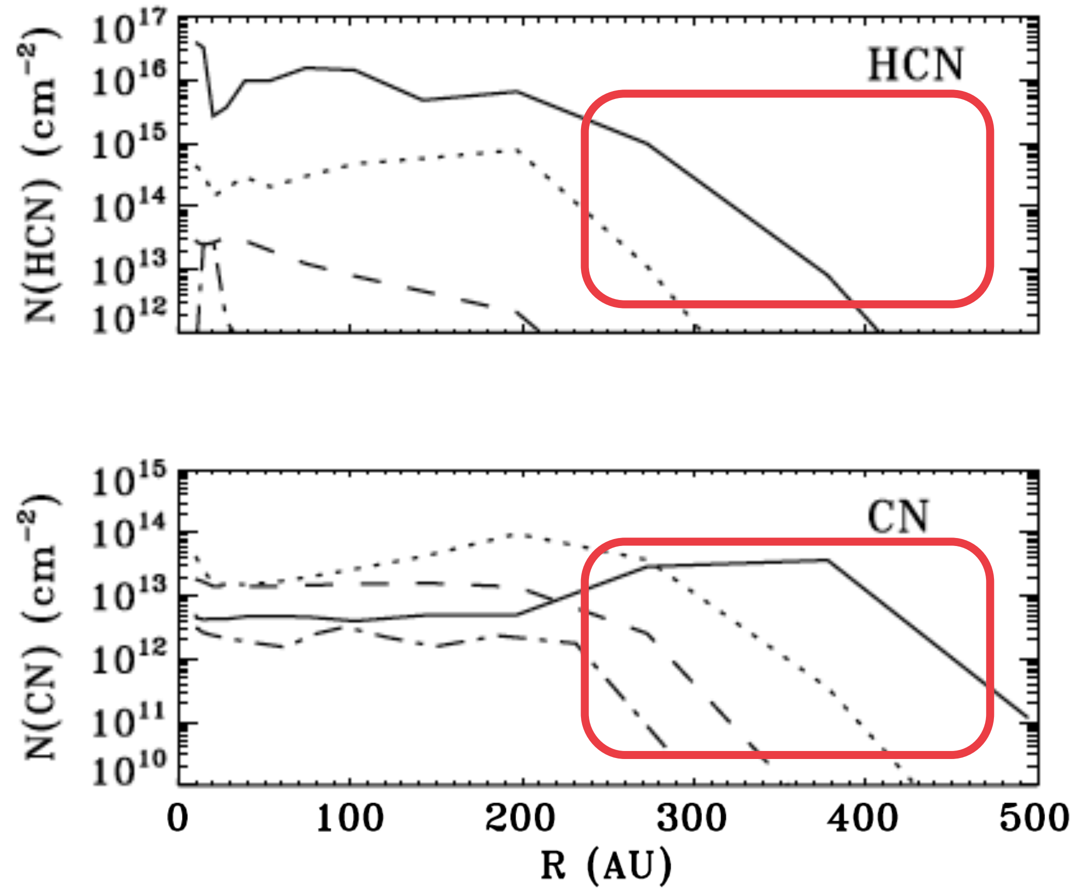
A HNC ring in TW Hya



[Graninger+ in prep.]

CN/HCN: a UV photonmeter?

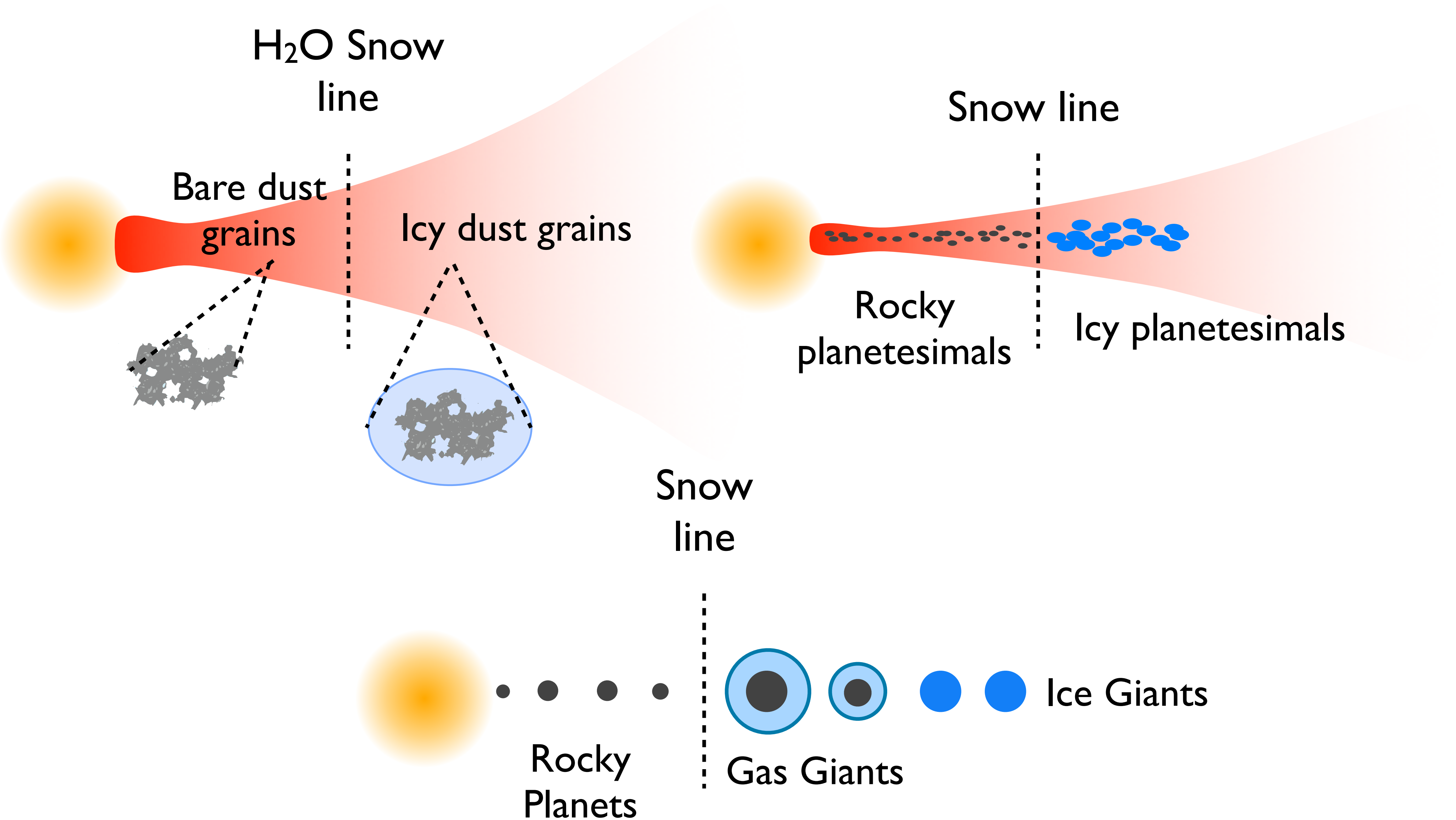




HCN + UV → CN + H

[Jonkheid+2007, Öberg, Qi+ 2011, Guzman+ in prep.]

The water snowline in the Solar Nebula



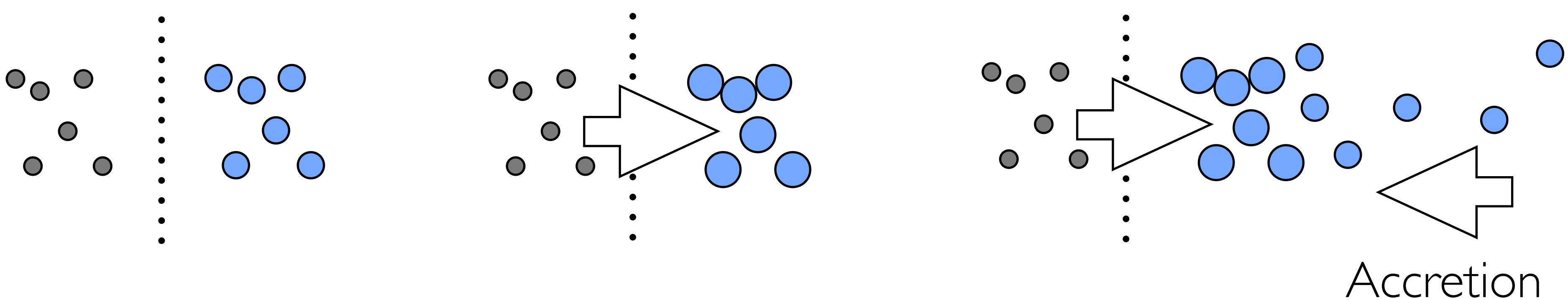
Icy grains should form planets faster

Icy grains are stickier than bare grains.

Volatile molecules (except for H_2) are ~2-3 times more abundant than silicate grains

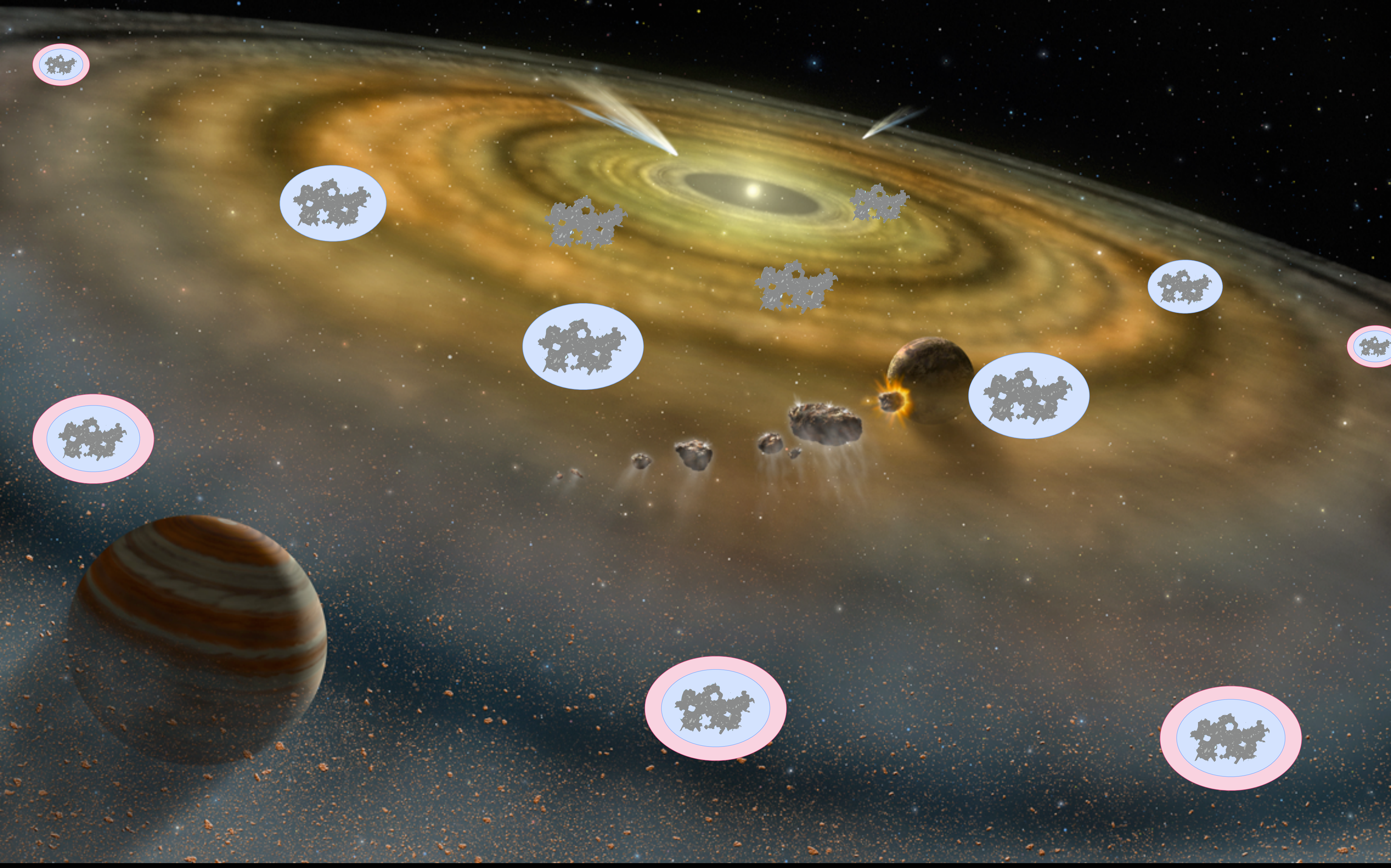
Pressure bumps may trap material around the snowline

Coldfinger effects: turbulence brings vapor into the cold regions where it gets trapped

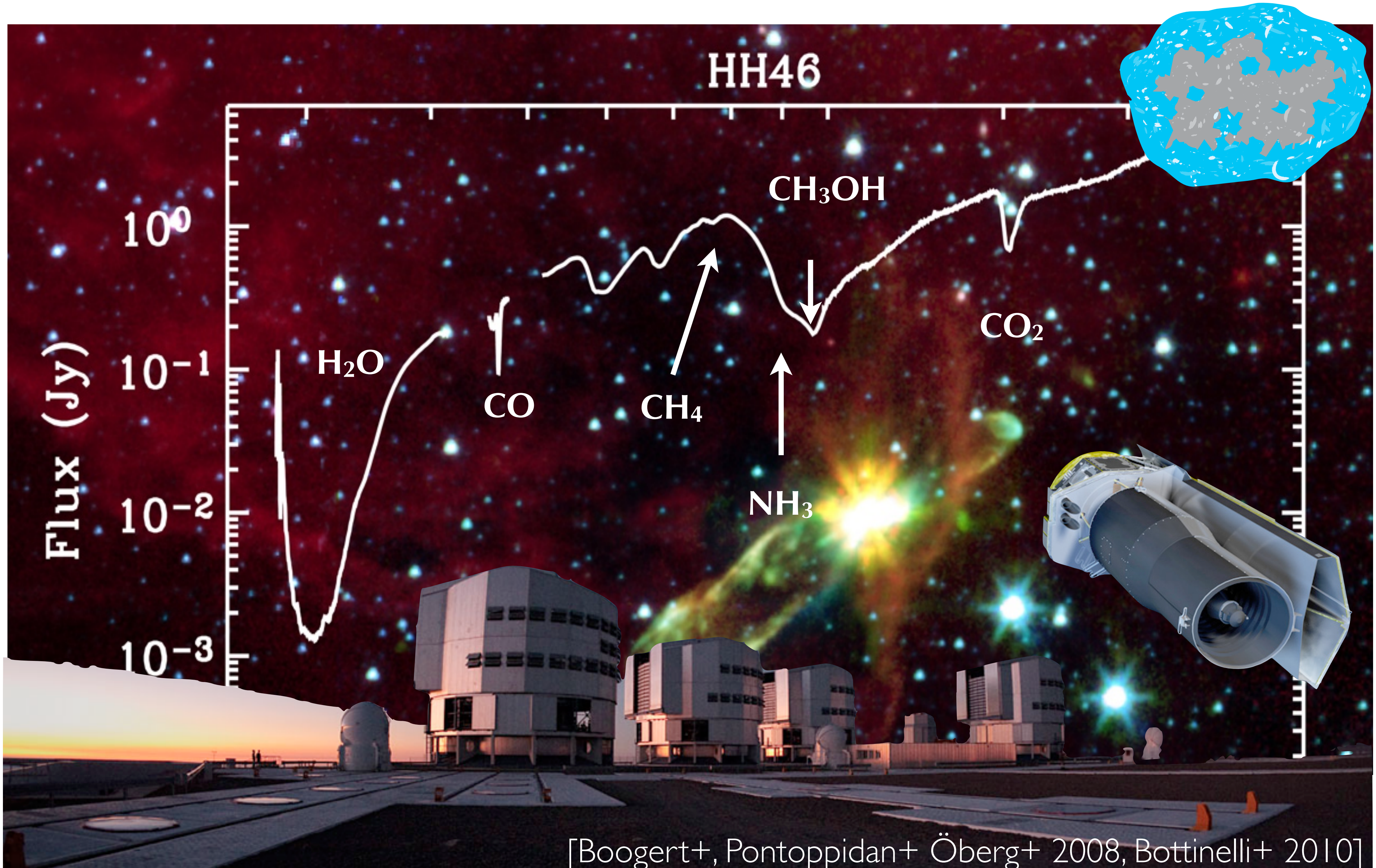


[e.g. Ciesla & Cuzzi 2006, Chiang+ 2010, Ros & Johansen 2013]

Expect a Series of Snowlines outside of the H_2O Snowline



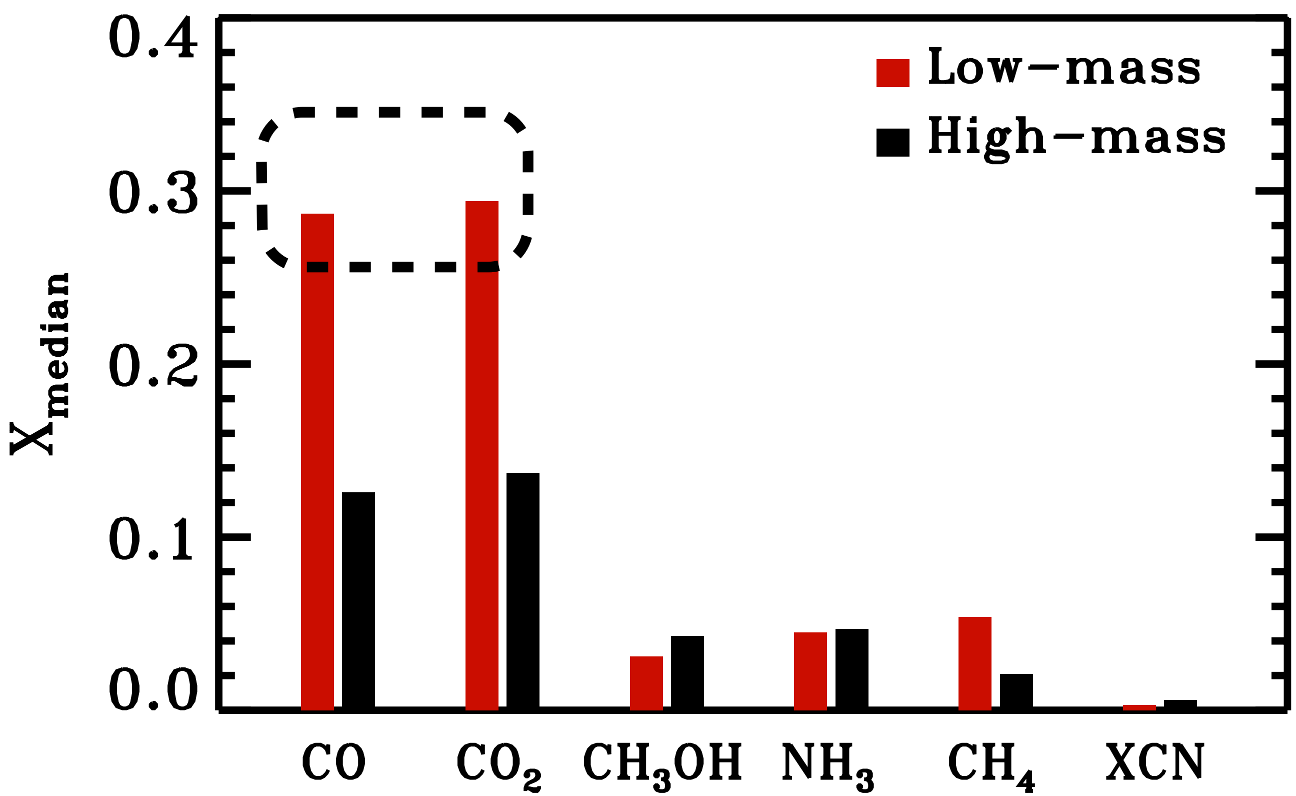
Infrared telescopes enable direct observations of interstellar ices



[Boogert+, Pontoppidan+ Öberg+ 2008, Bottinelli+ 2010]

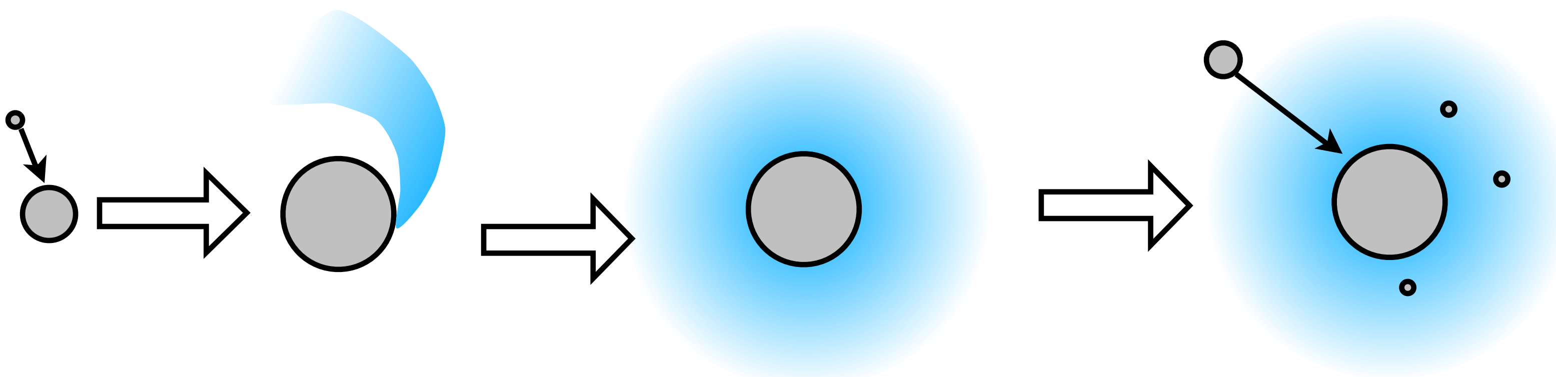
Protostellar Ice Compositions:

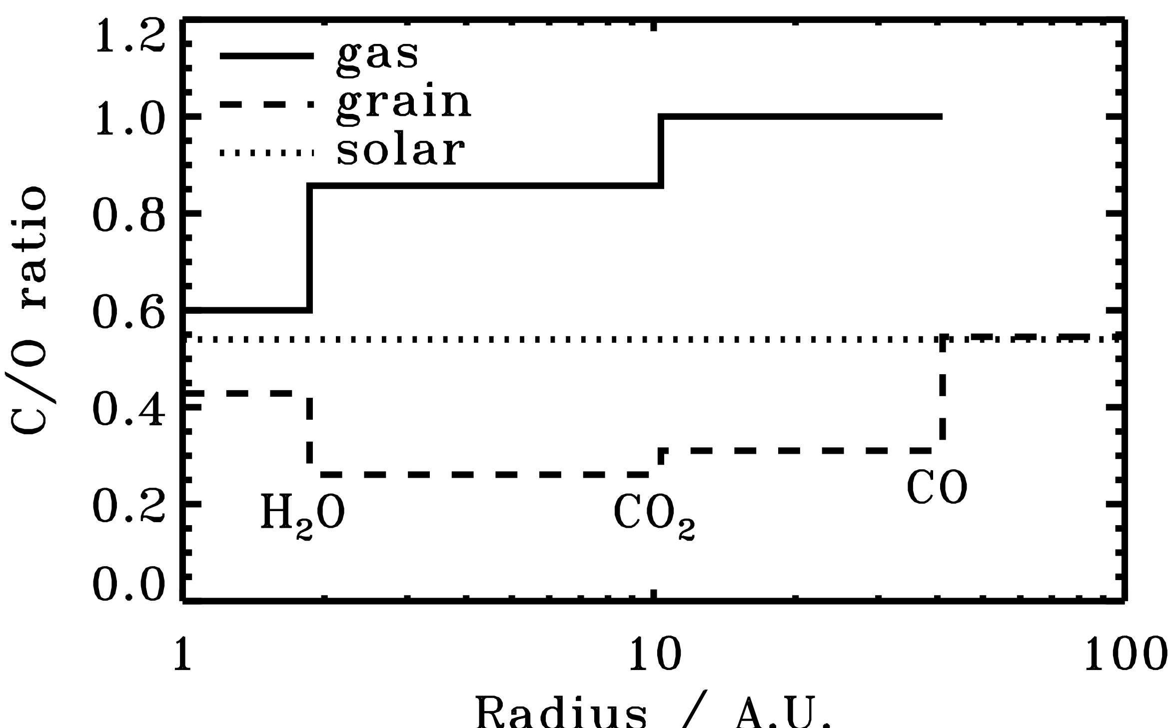
H_2O, CO, CO_2 and trace species



[Öberg+ 2011c]

Condensation lines change the gas-phase and solid elemental ratios



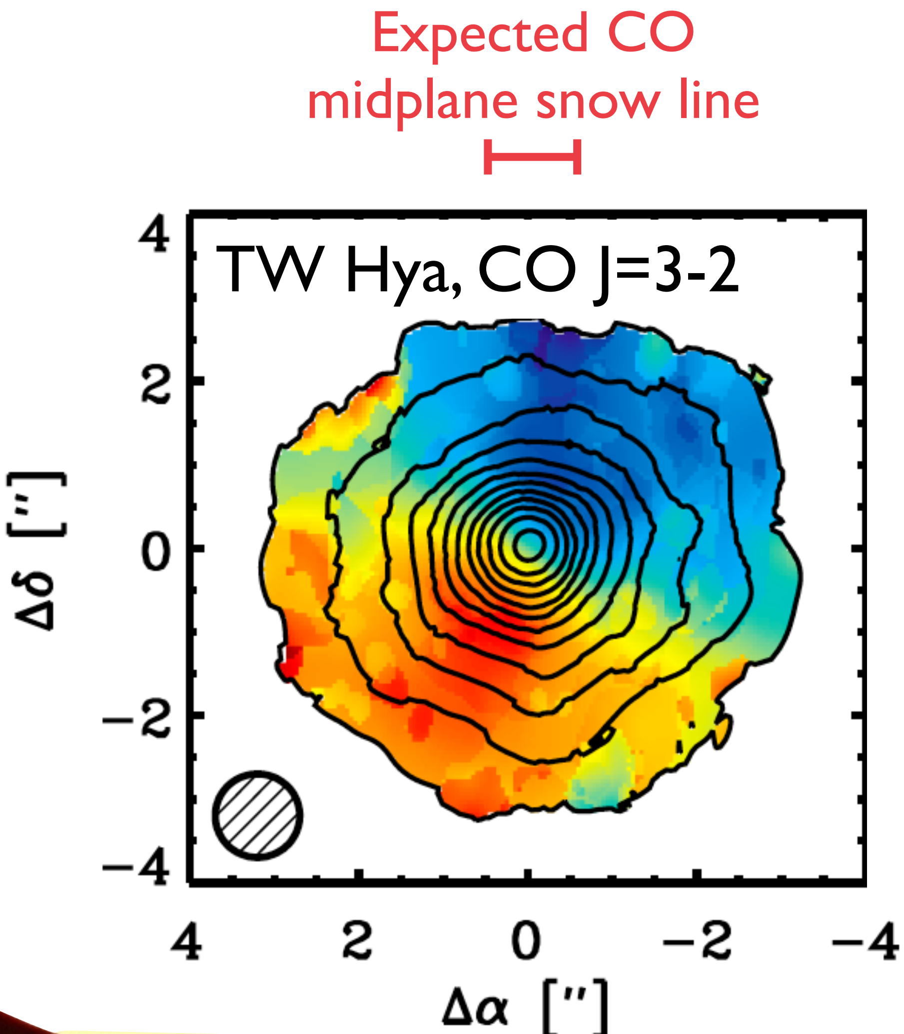


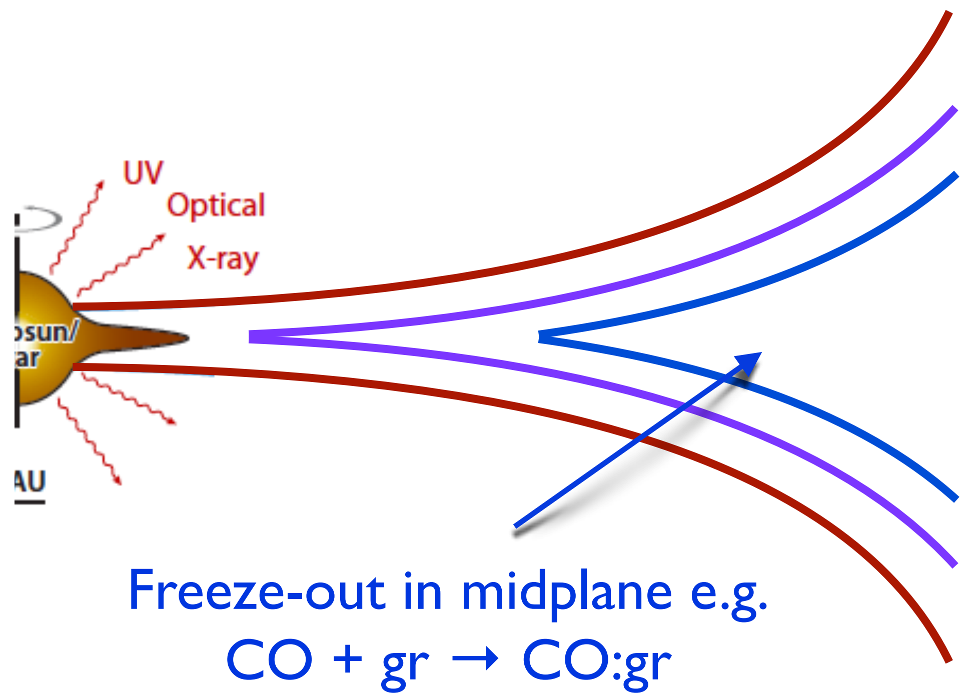
Assuming interstellar molecular abundances, C/O~1 between the CO_2 and CO snowlines.

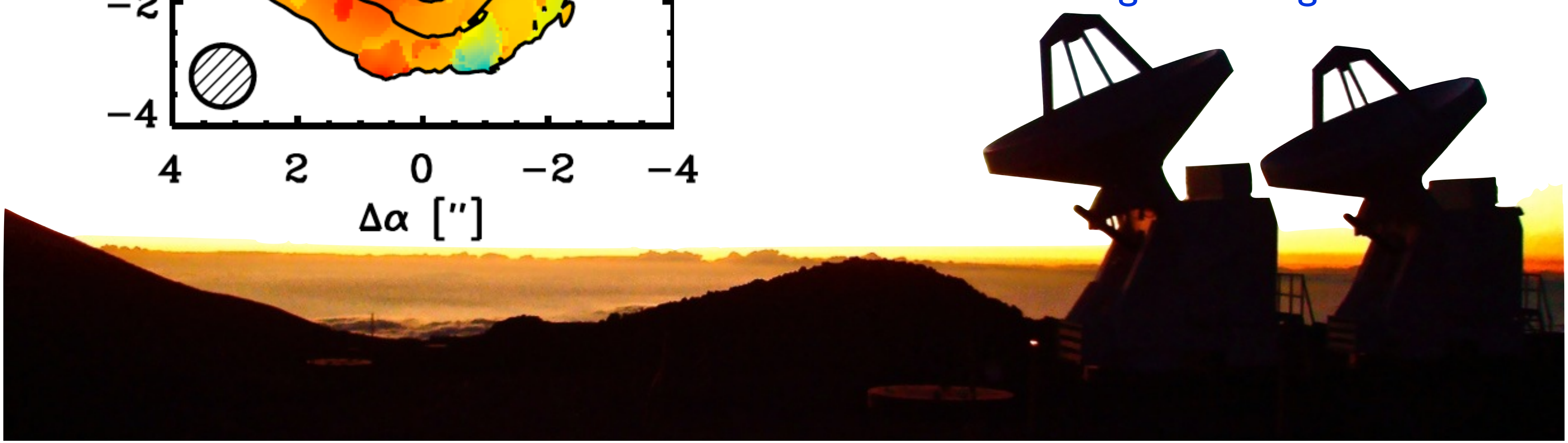
If a gas giant accretes the core from solids and envelope from gas, C/O~1 in the atmosphere, assuming no planetesimal pollution or core dredging.

[Öberg, Murray-Clay & Bergin 2011]

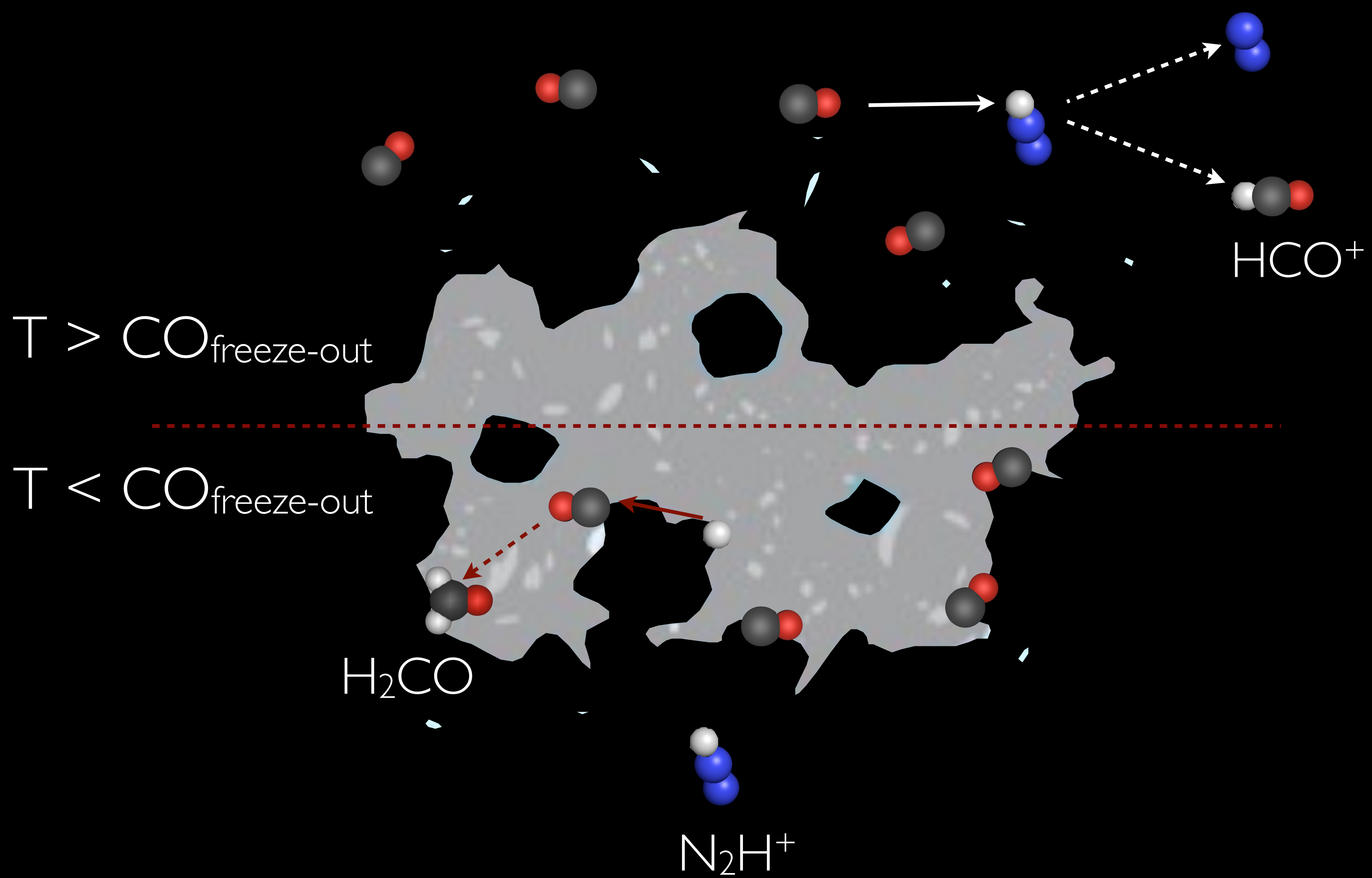
Direct (sub-)Millimeter Imaging of CO



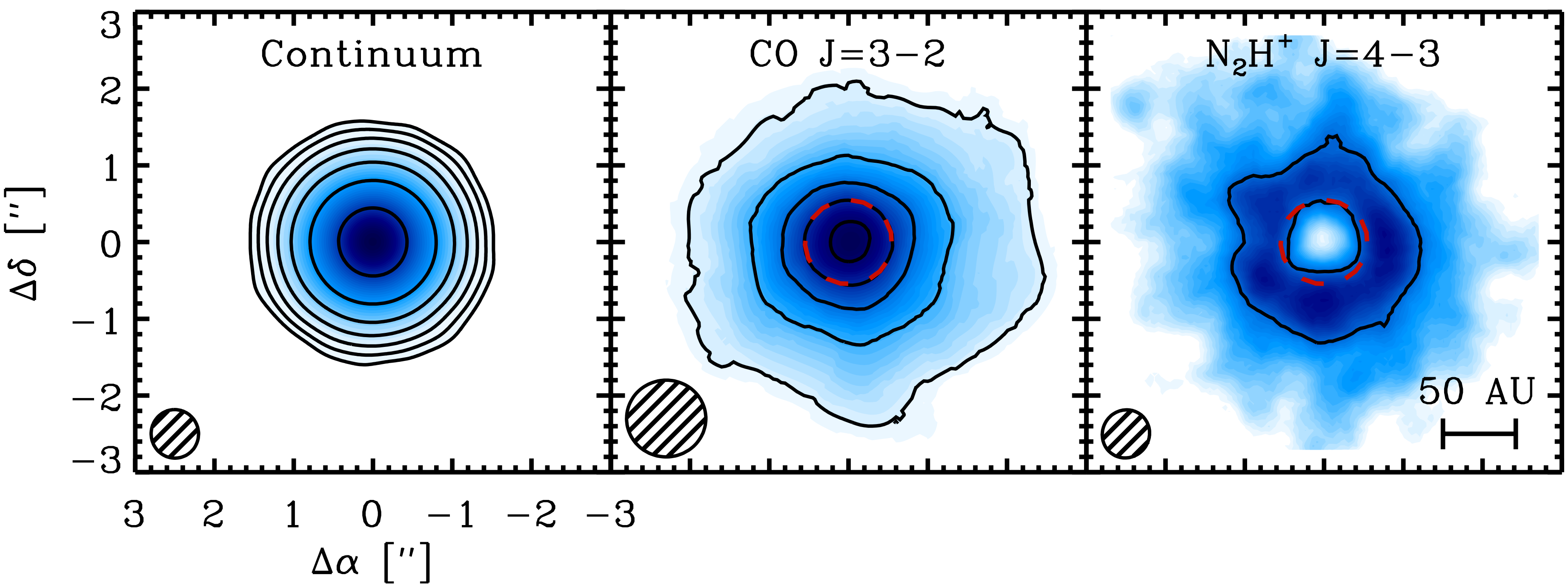




Chemical effects of CO freeze-out

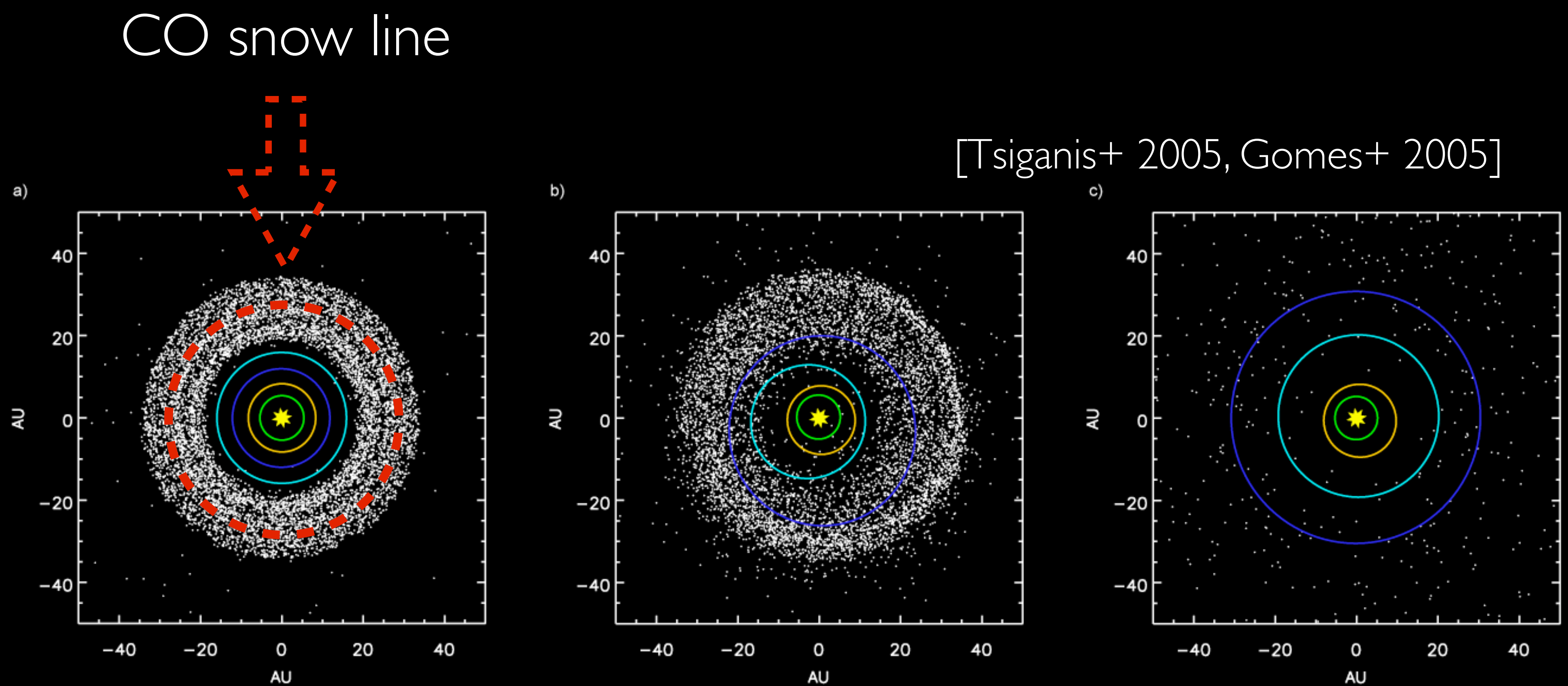


ALMA observations of the CO snowline



[Qi, Öberg+ 2013]

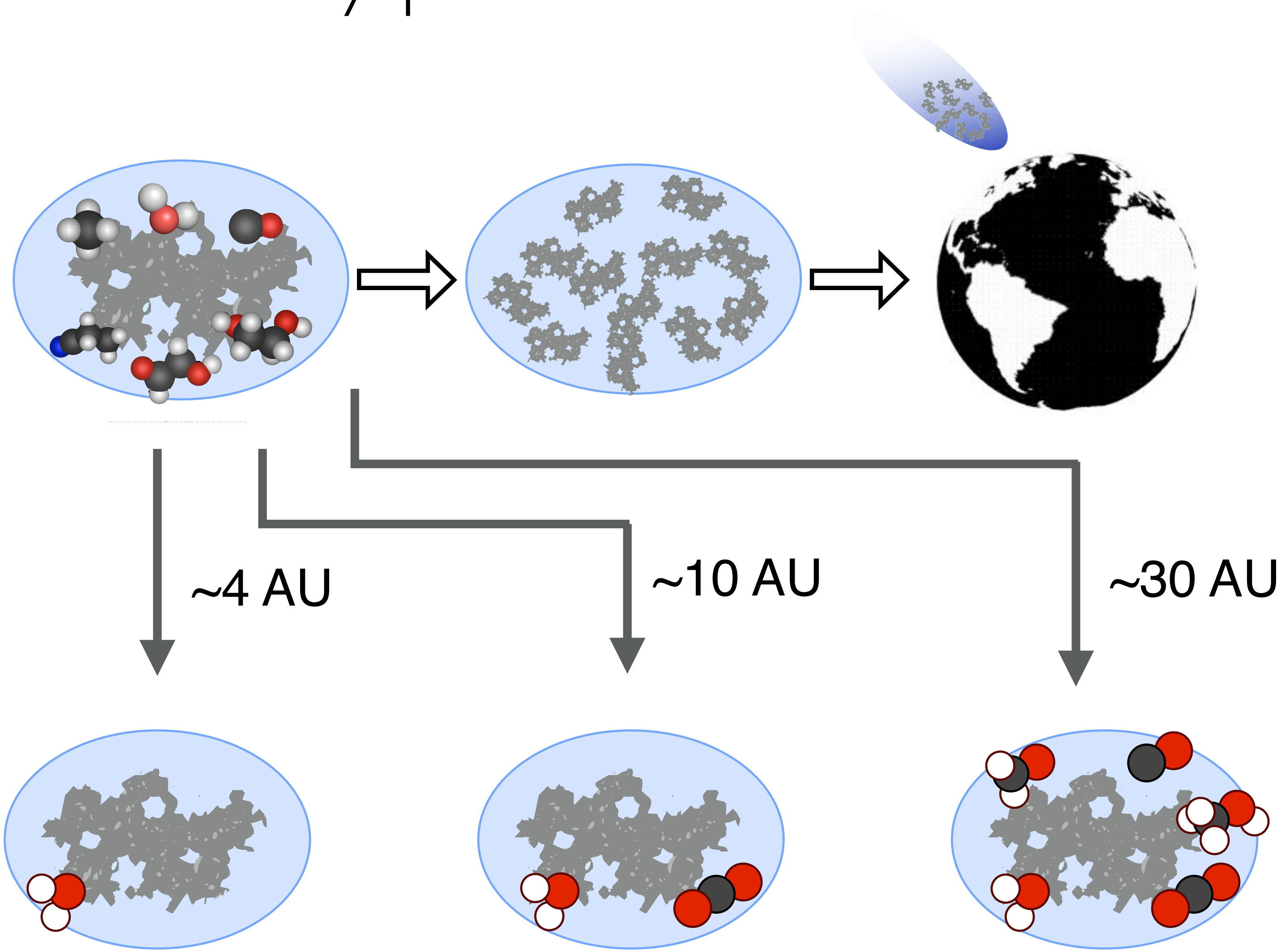
CO snow line radius implications for the Solar System



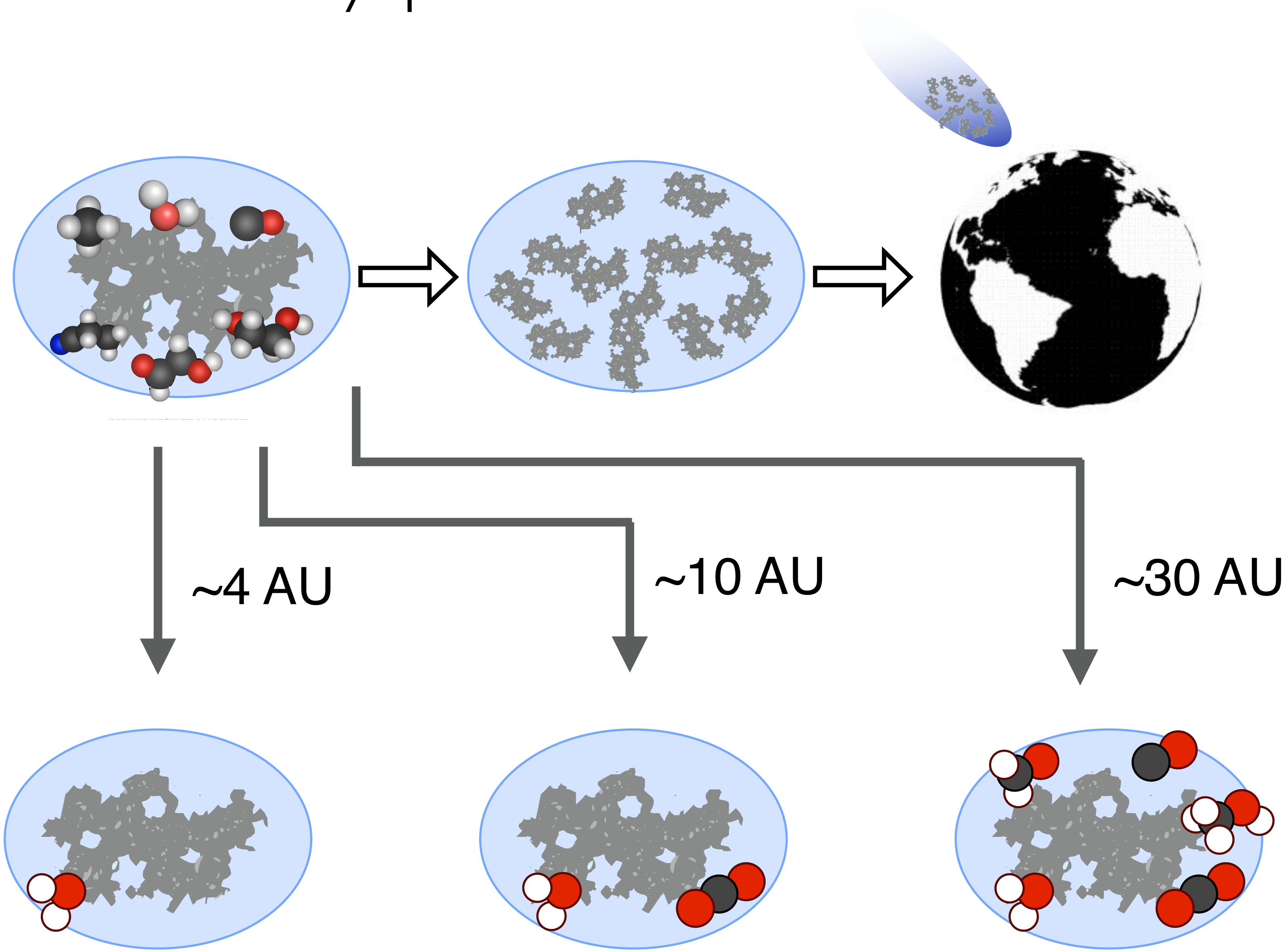
CO snow line is outside of Ice Giant formation zone according to Nice model

Some comets and Kuiper belt objects should have formed from CO-ice grains

Ice chemistry and delivery of volatile organic material to rocky planets

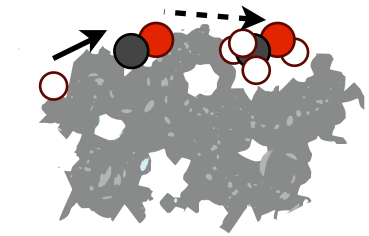


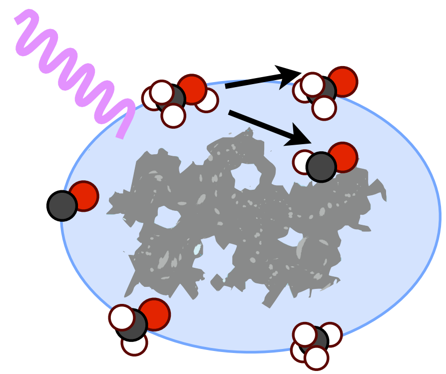
Ice chemistry and delivery of volatile organic material to rocky planets



Ice Chemistry

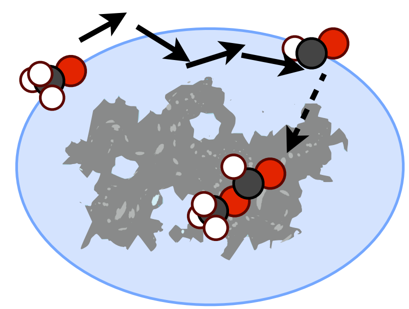
0. Grain surface atom addition reactions (10-20 K)



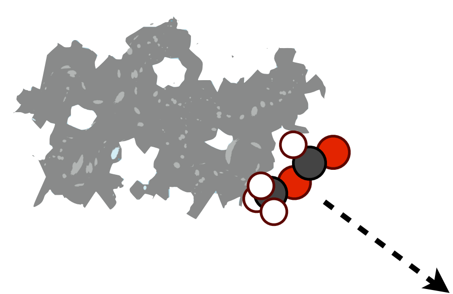


I. Ice dissociation (All T)

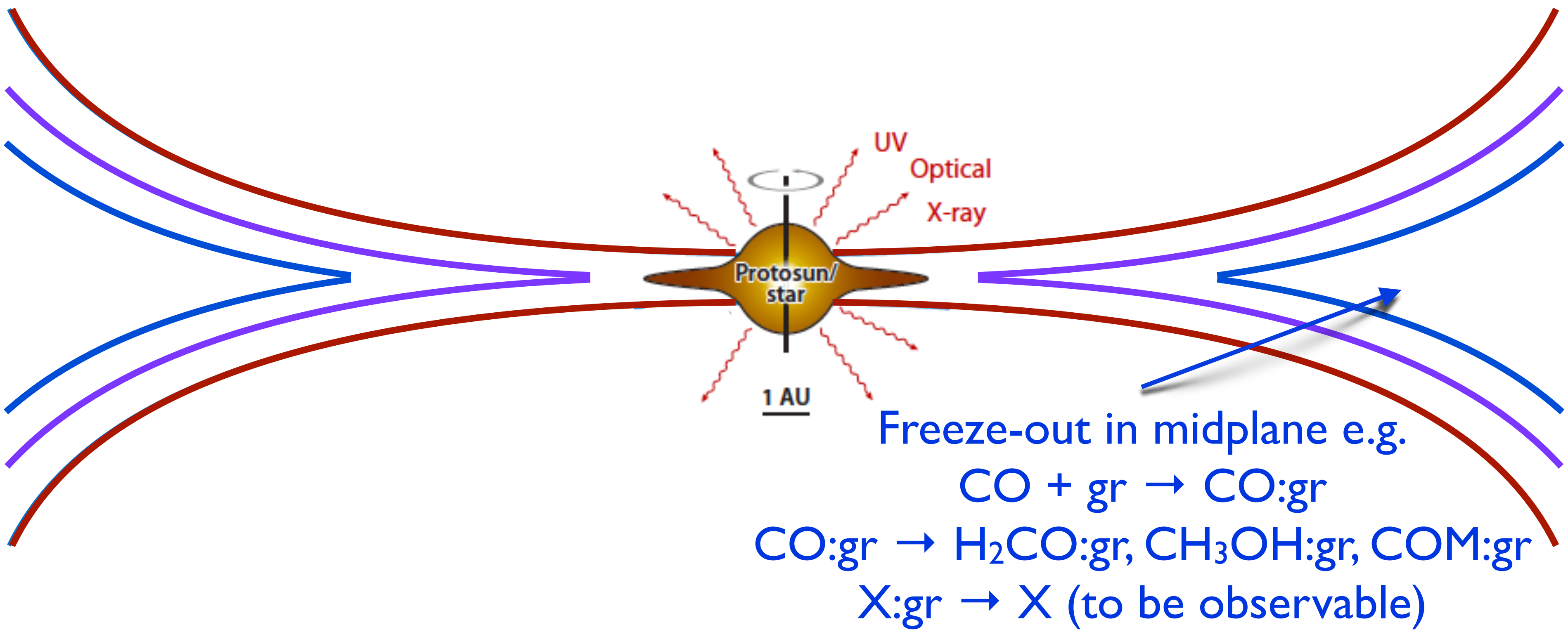
II. Radical diffusion + recombination (25+ K)



III. Ice desorption (10-200 K)

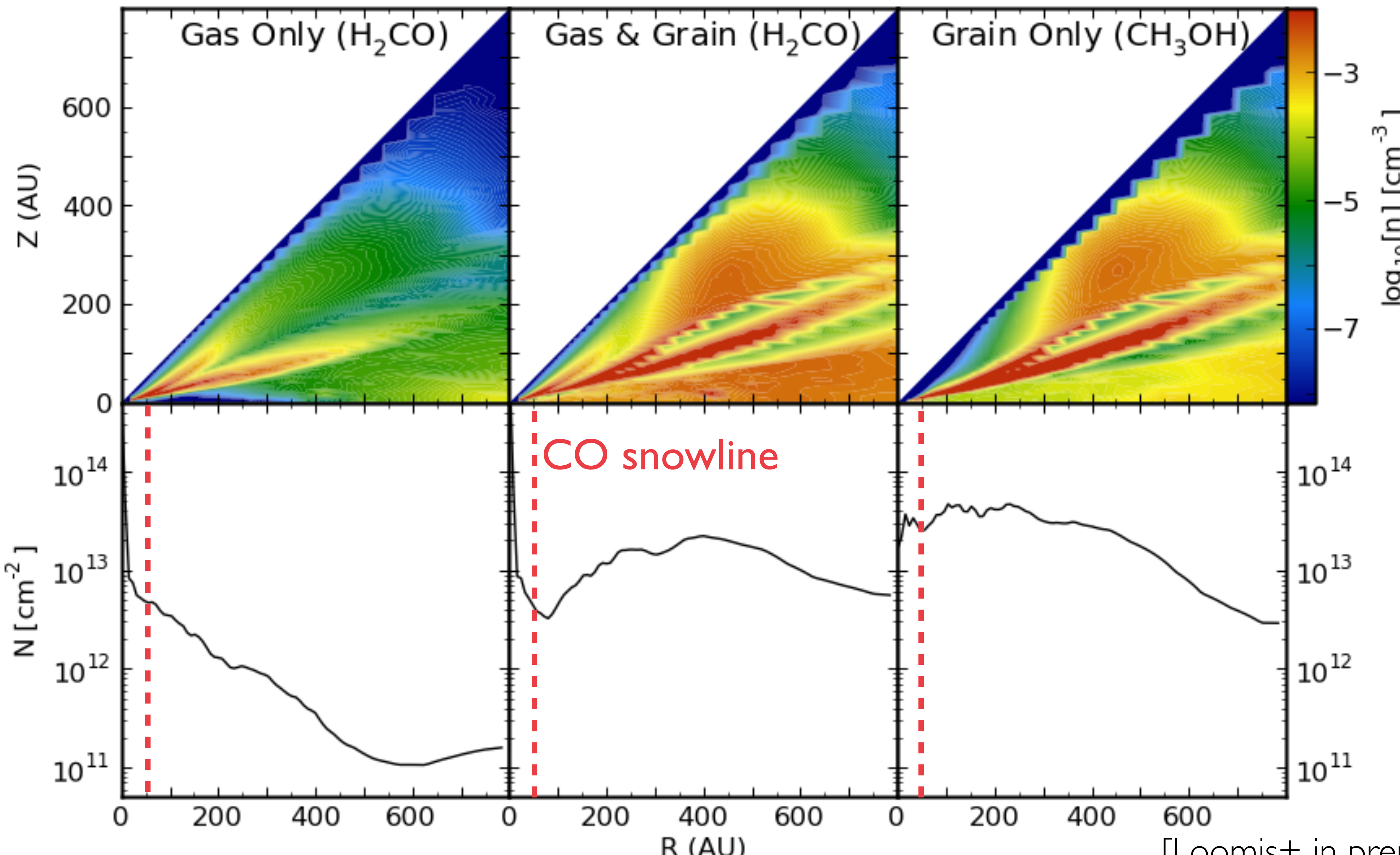


Direct constraints on organic ice chemistry in disks?



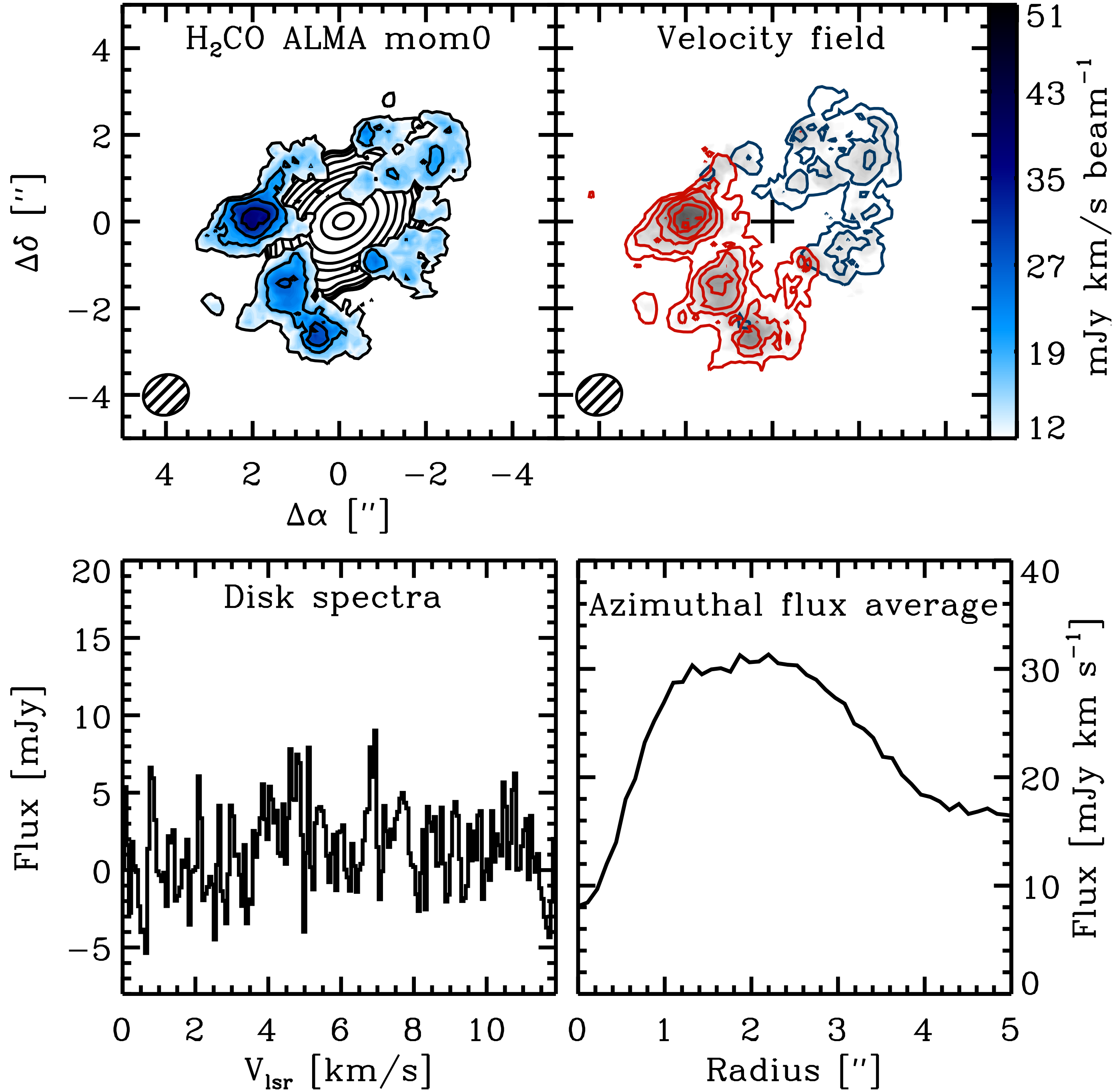
[after Bergin]

H_2CO model predictions suggest 'simple' test for chemical origin of observed molecules



[Loomis+ in prep.]

HD 163296 H_2CO with ALMA: It's ring!



[Öberg+ in prep.]

Chemical Rings and Planet Formation

Snowlines can regulate planet formation, and their locations can be probed with ALMA observations of trace molecules.

HNC, HCN, CN and molecular ions can probe disk temperature, radiation and ionization fields.

Deuterium fractionation can date volatiles and with ALMA we can probe it in situ in disks.

H_2CO in disks forms through ice chemistry → active organic ice formation during planet formation