The Role of Ice Compositions and Disk Dynamics for Snowlines and C/N/O Ratios in Active Disks

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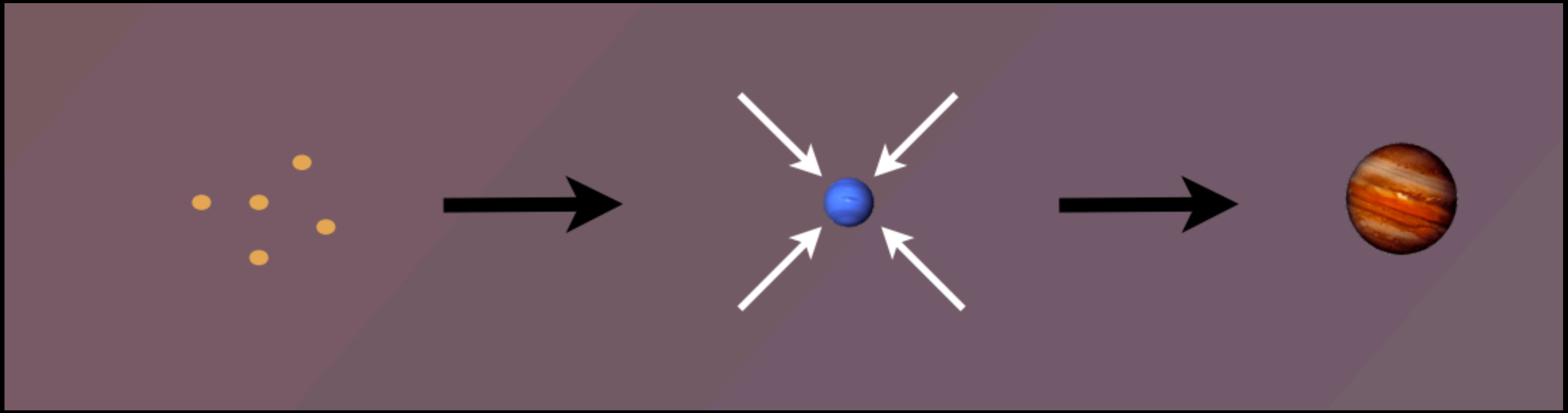
Fundamental Question

What composition will a formed giant planet have obtained?

Disk Compositions Regulate Planet Compositions



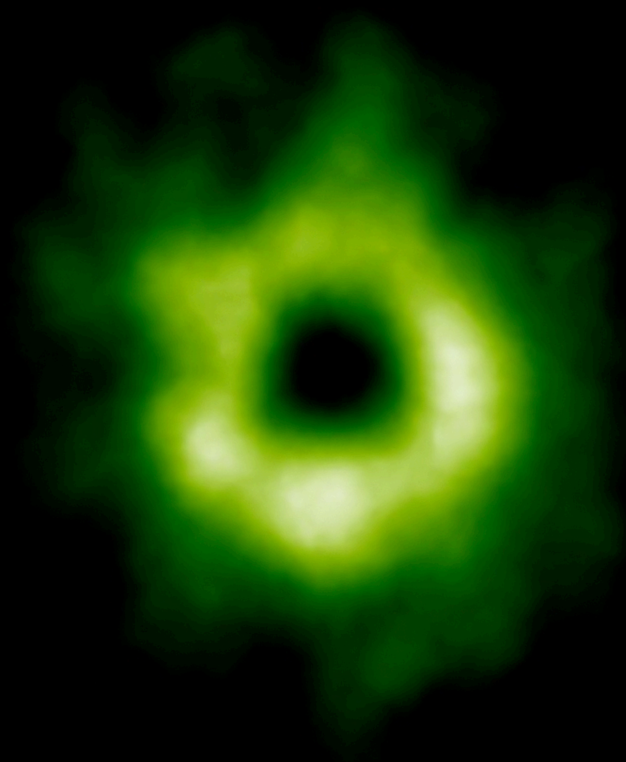
The composition of planets is determined by and tightly linked to the disk composition

BASIC IDEA

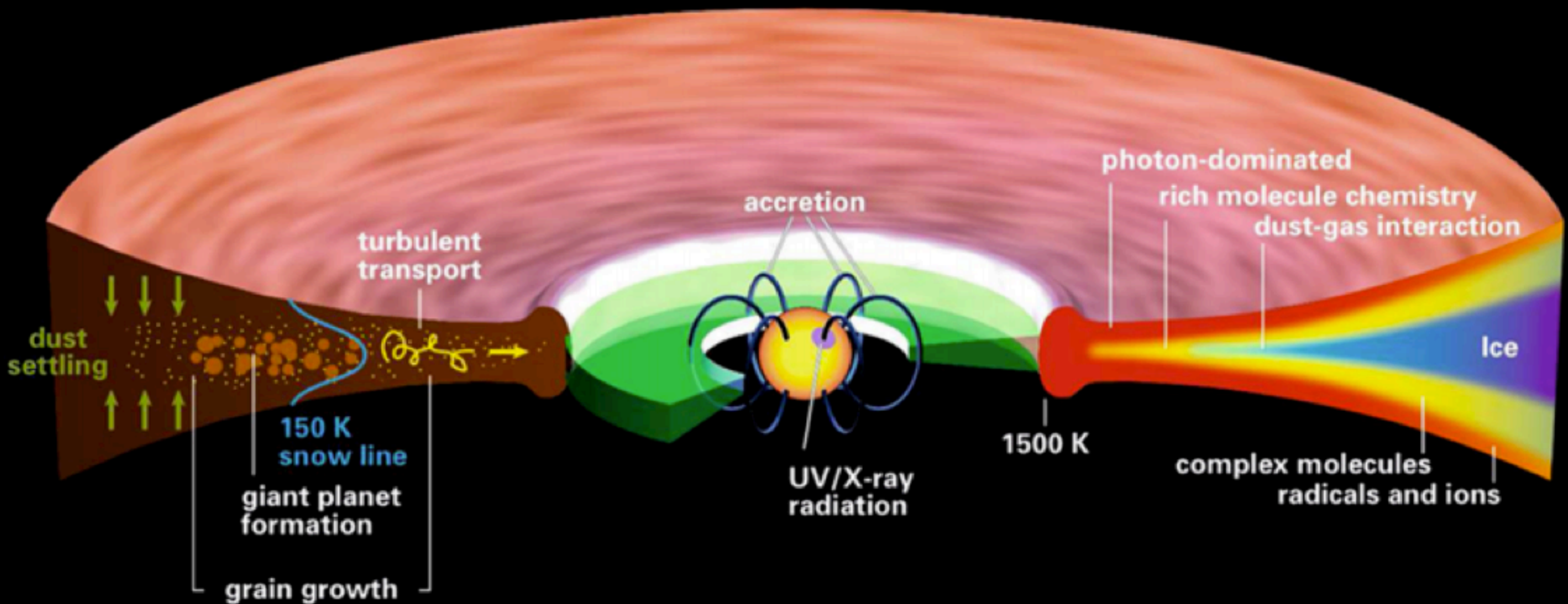
Understand the disk well enough to:

1. Predict what kind of planet compositions result from planet formation in different parts of the disk
2. Back-track the planet formation location based on the planet composition

Snowline Locations in Protoplanetary Disks and C/N/O ratios

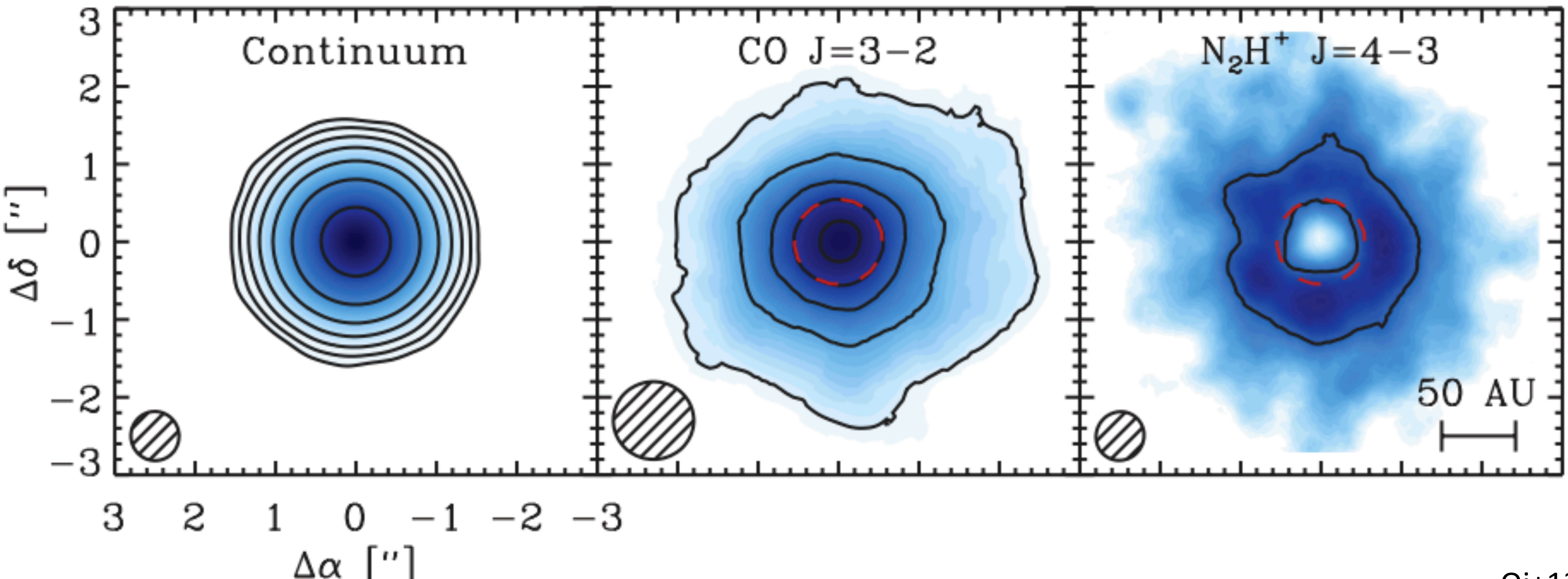


Disk structure is complex!



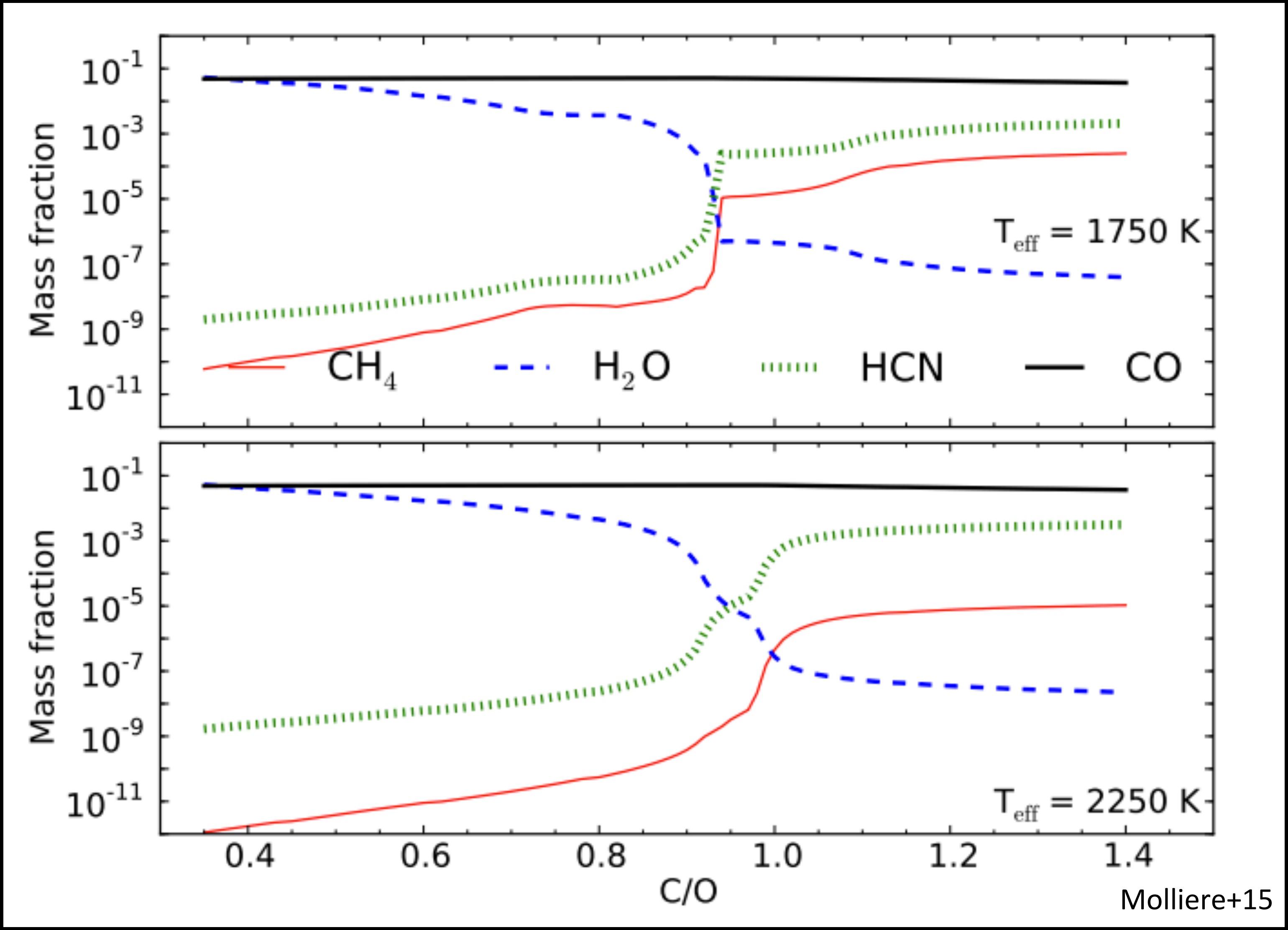
Henning&Semenov (2013)

Snowlines of volatile molecules have been detected in disks



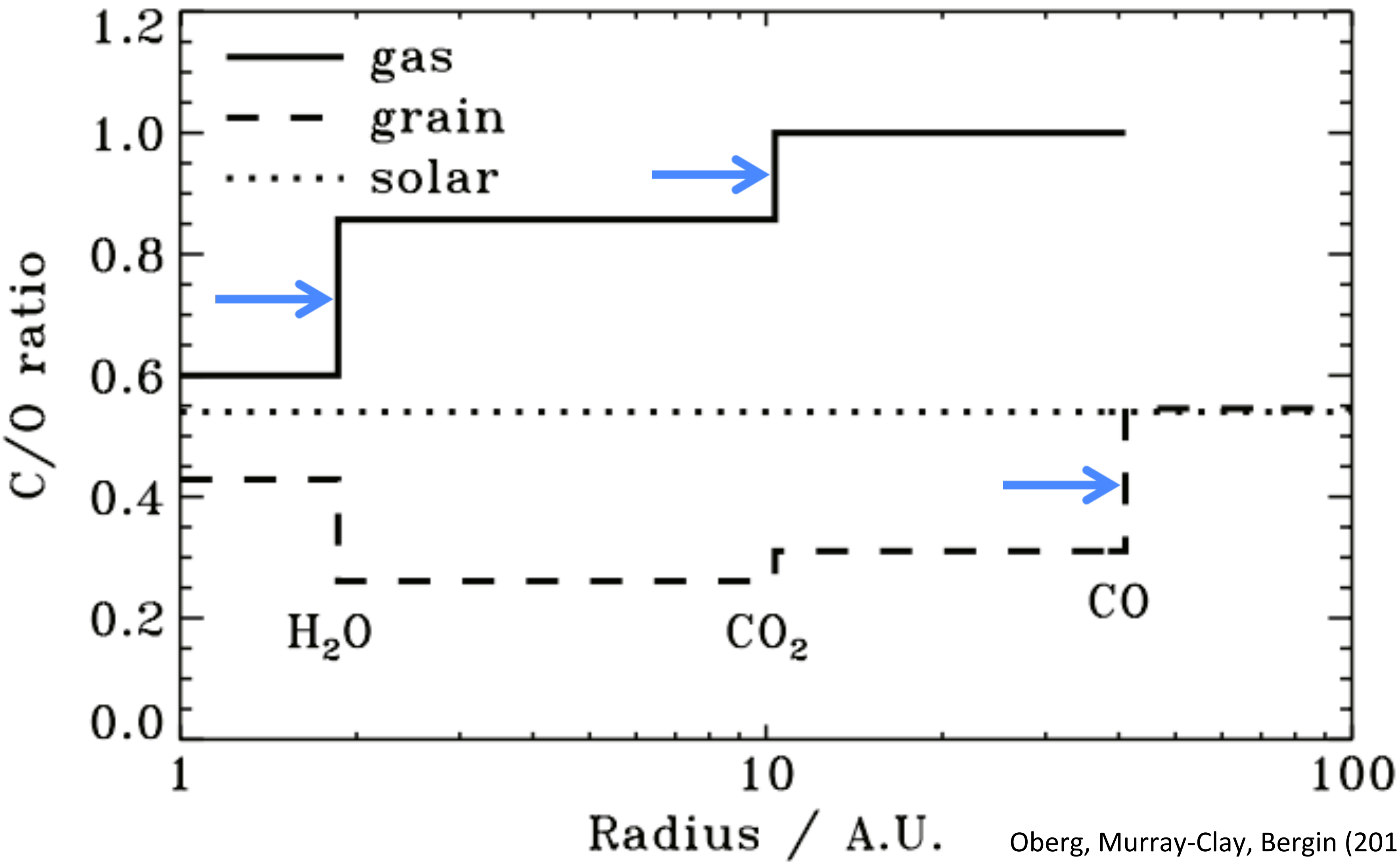
Qi+13

C/O ratio is an important signature of atmospheric chemistry



WHY Different C/O Ratios?

Possible explanation: main carriers of C and O, i.e. H_2O, CO_2 and CO, have different condensation temperatures => variations in the abundances of C and O in solids and gas between the snow lines of these volatiles

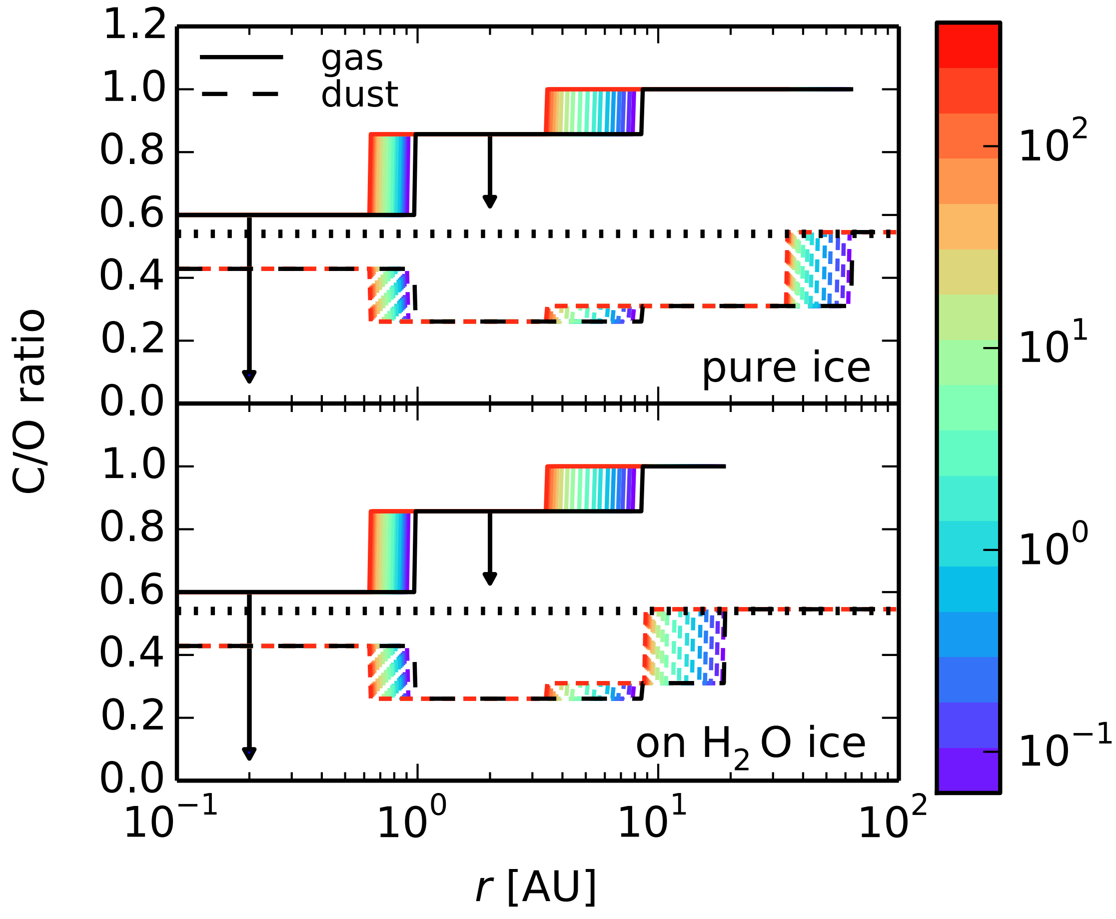


Oberg, Murray-Clay, Bergin (2011)

GOAL

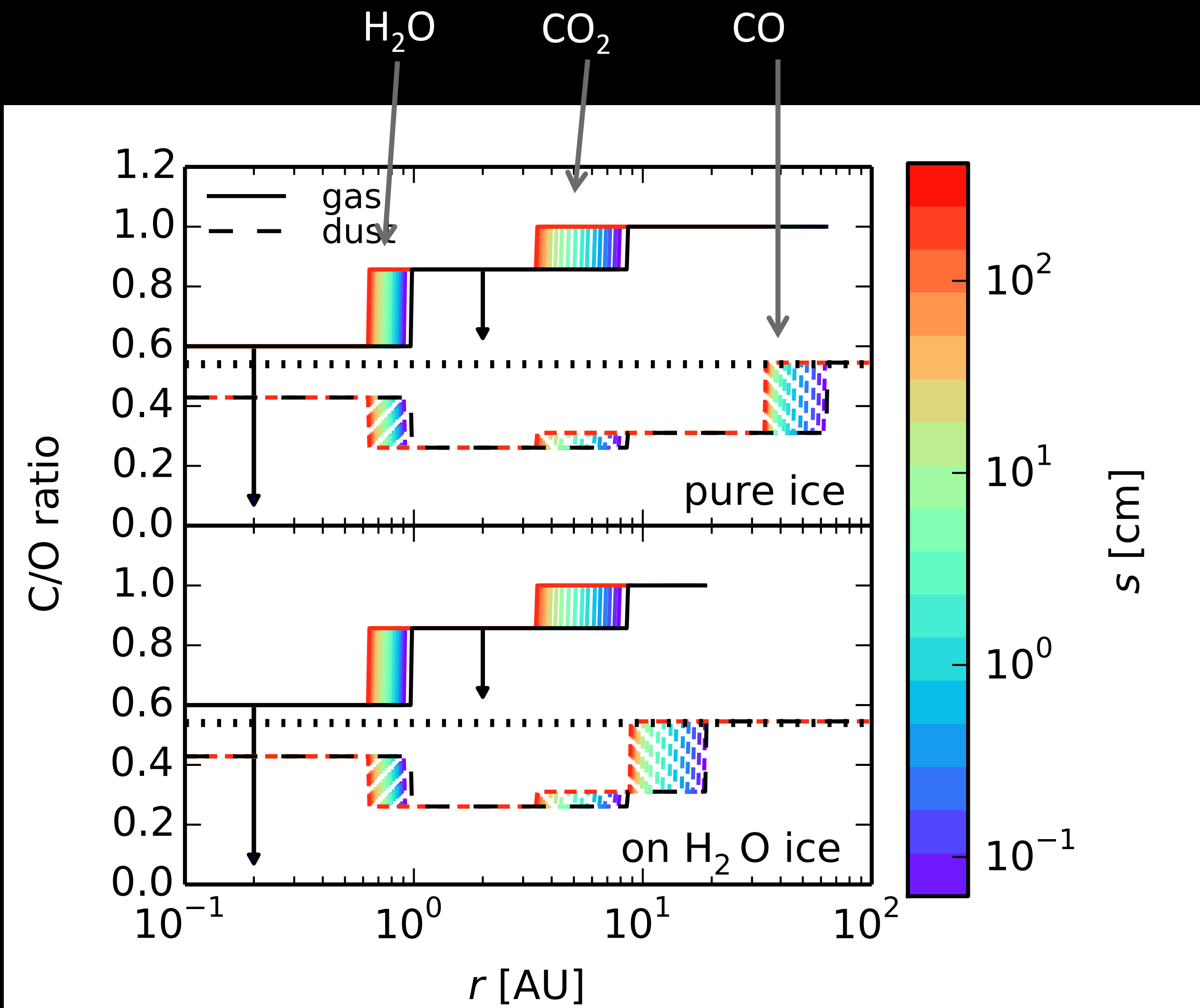
Understand how radial drift, gas accretion and ice morphology affect snowline locations, and thus the C/O ratio in gas and dust throughout the disk

Disk dynamics and ice morphology may change the CO snowline location by a factor of 7!



Piso, Pegues, Oberg (2016)

Disk dynamics and ice morphology may change the CO snowline location by a factor of 7!



Piso, Pegues, Oberg (2016)

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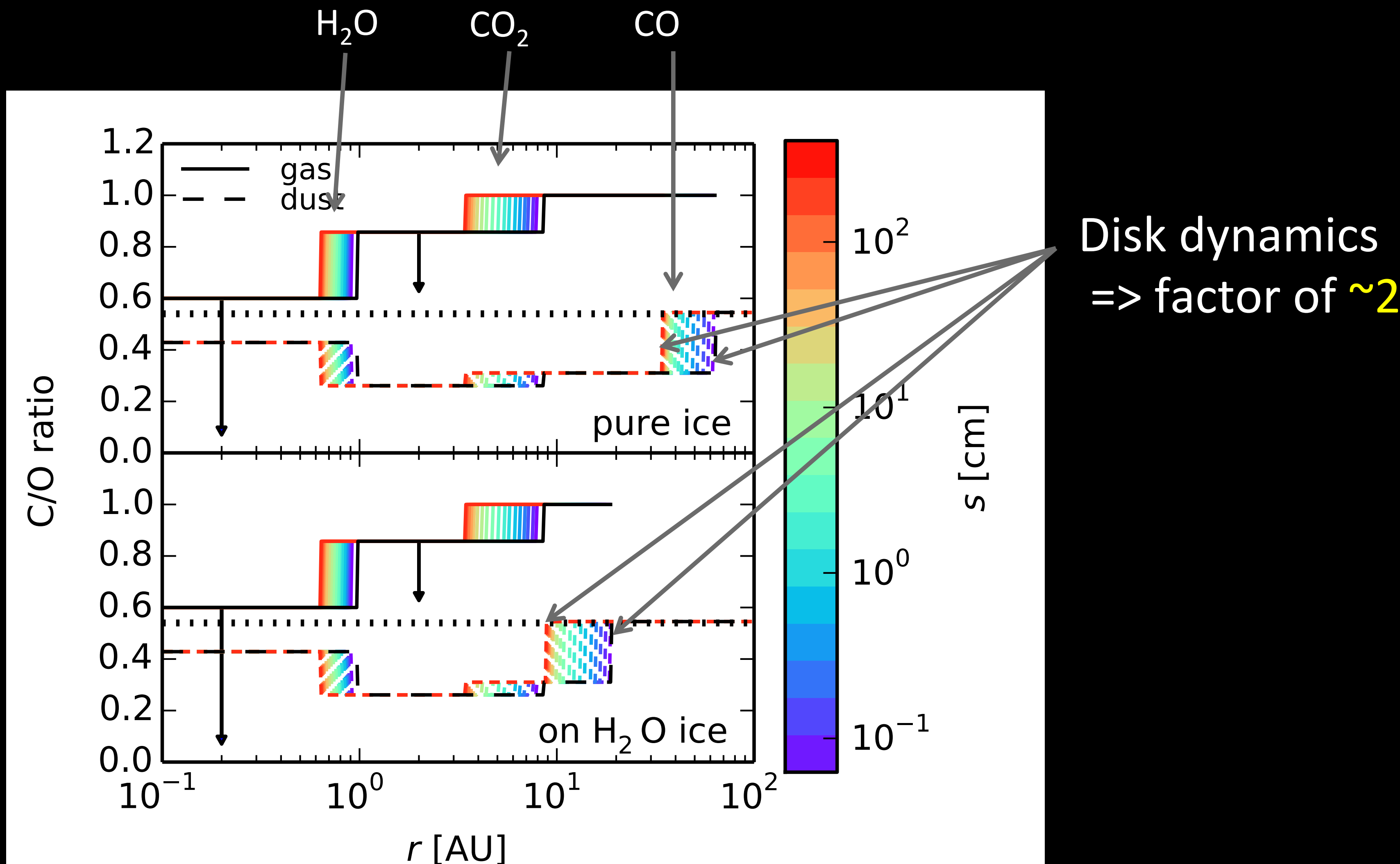

Piso, Pegues, Oberg (2016)

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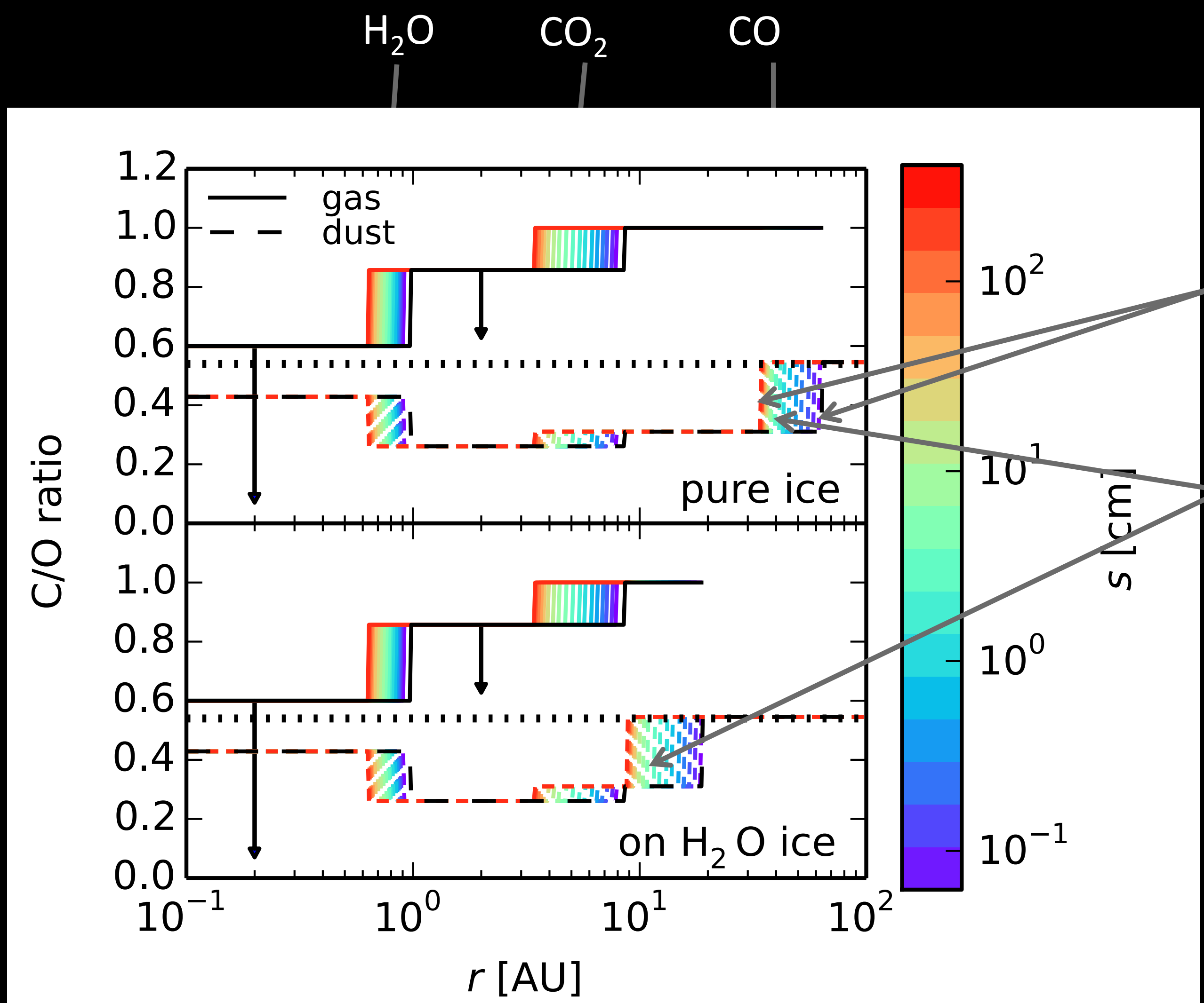
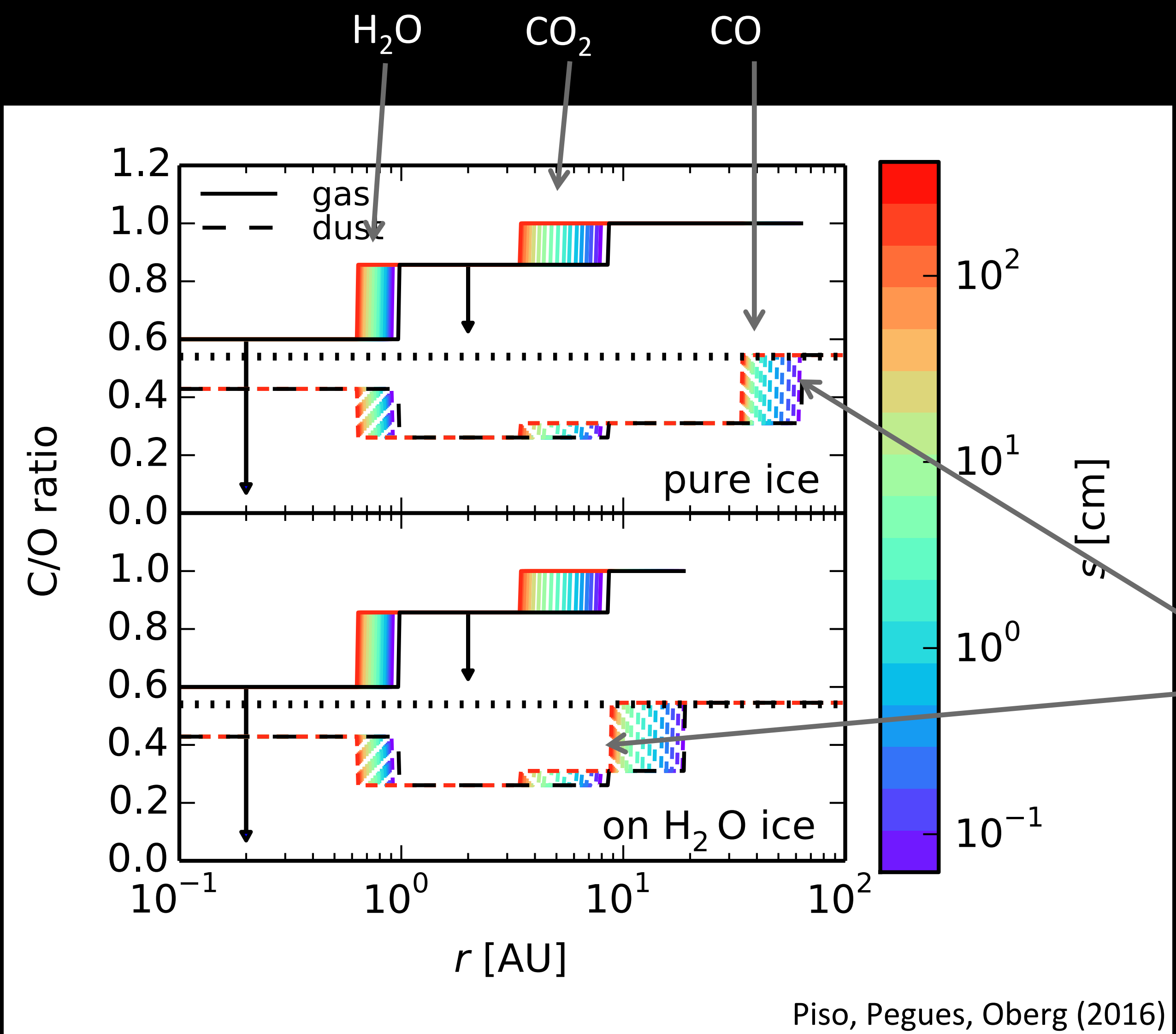


Piso, Pegues, Oberg (2016)

Disk dynamics
=> factor of ~2

Ice morphology
=> factor of ~3-4

Disk dynamics and ice morphology may change the CO snowline location by a factor of 7!

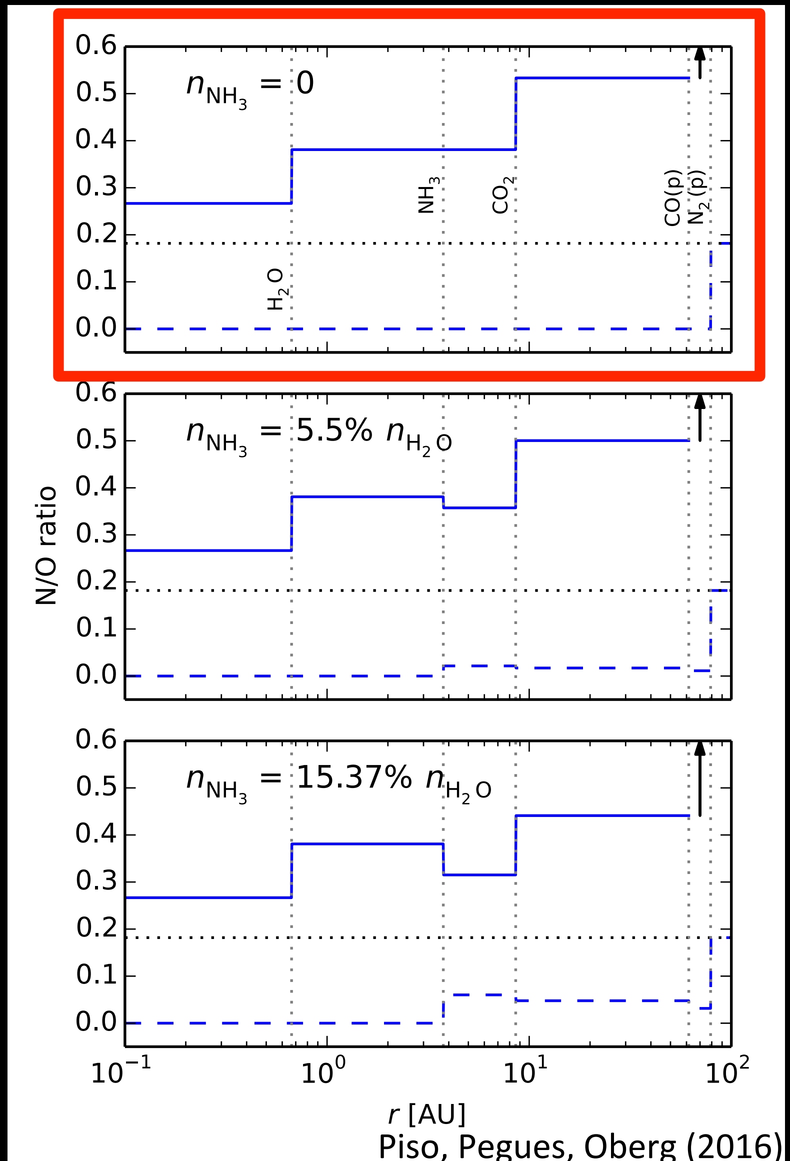


Disk dynamics
=> factor of ~2

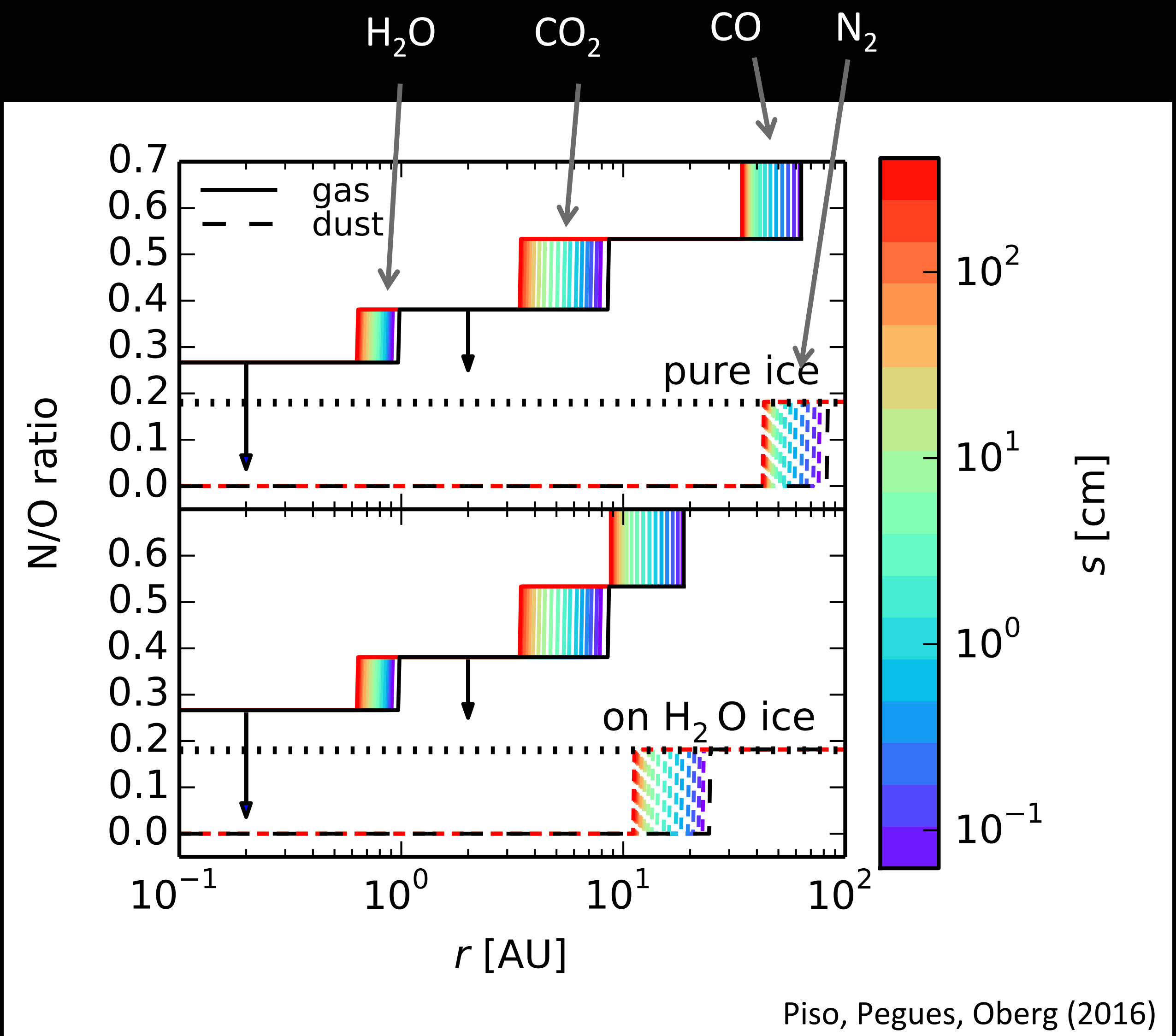
Ice morphology
=> factor of ~3-4

CO snowlines span 9-61 AU!

N/O ratios in static disks: highly enhanced gas N/O compared to the average value



Disk dynamics and ice morphology may change the N_2 snowline locations by a factor of 7!

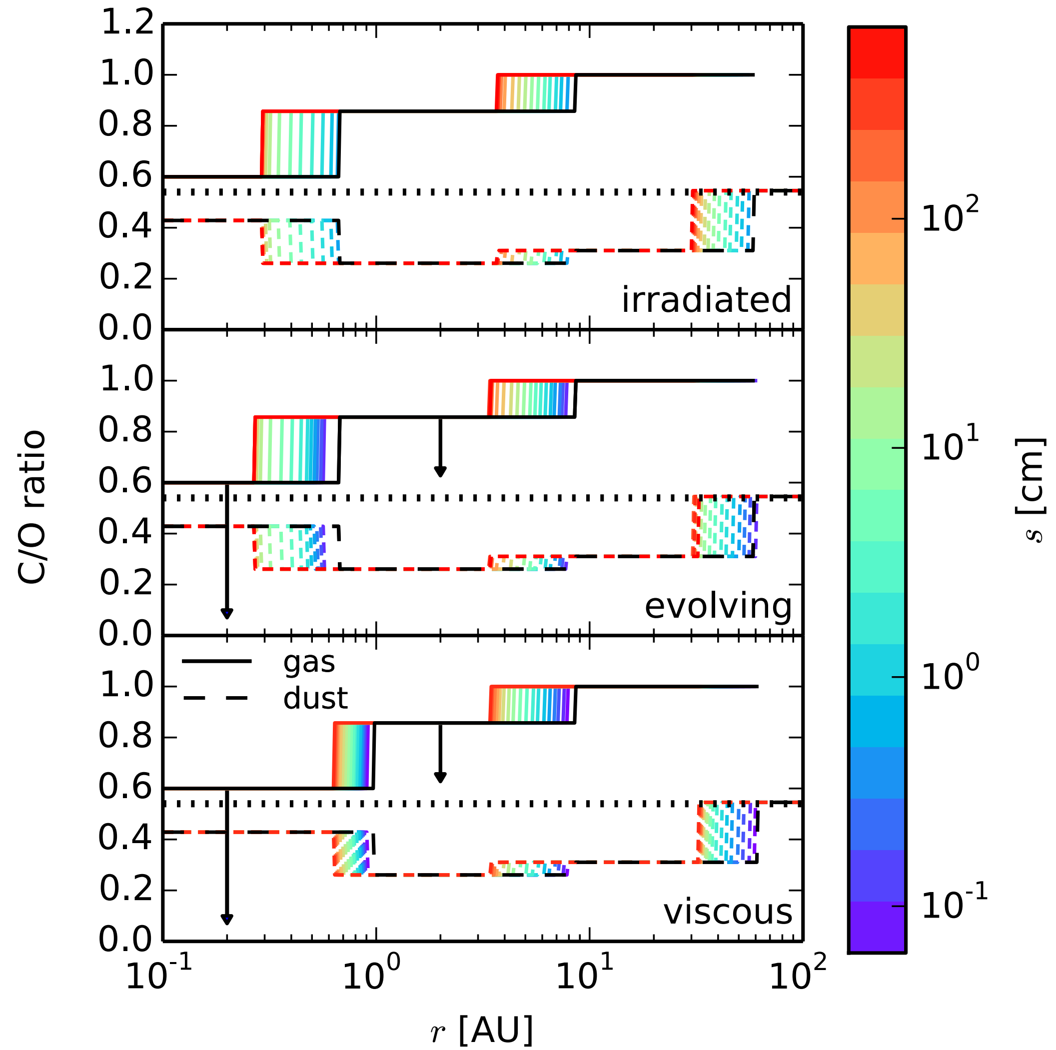


N_2 snowlines span 11-79 AU!

Takeaway point 1: Gas phase N/O ratios are highly enhanced throughout most of the disk compared to the average value, and more enhanced than the C/O ratio

Takeaway point 2: The locations of the CO and N_2 snowlines are highly uncertain and can span several tens of AU due to disk dynamics and ice morphology => observations are KEY

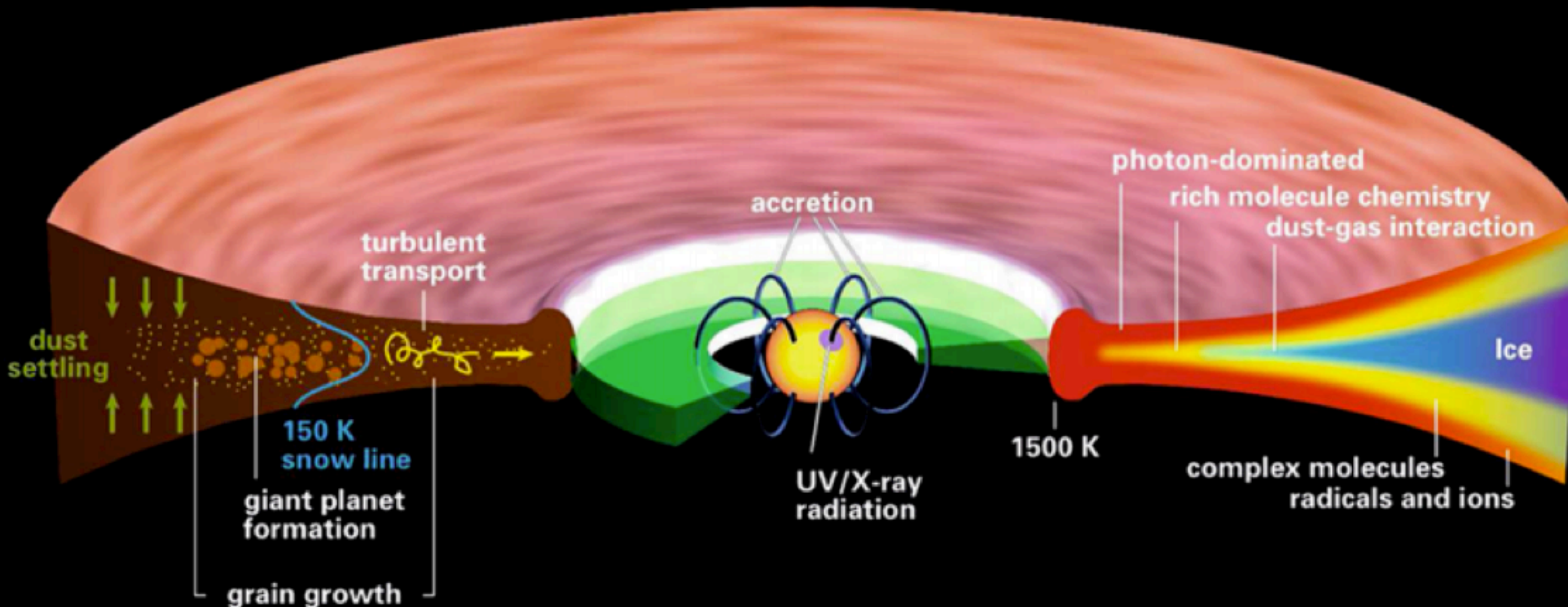
We determined upper limits for the C/O ratio across the disk



Piso, Oberg, Birnstiel, Murray-Clay (2015)

Gas Giants

NEXT STEPS



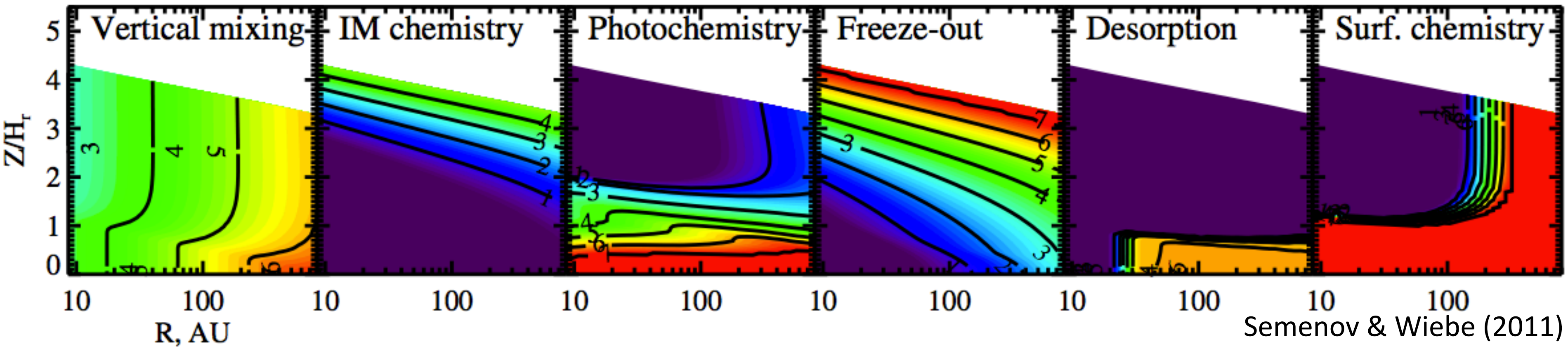
Henning&Semenov (2013)

Additional chemical and dynamical processes to be explored

Process	Effect
Radial drift	$\leftarrow$
Gas accretion	$\leftarrow$
Particle growth	$\rightarrow \leftarrow$
Turbulent diffusion	$\rightarrow \leftarrow$
Particle fragmentation	$\rightarrow \leftarrow$
Grain morphology	$\rightarrow$
Particle composition	$\rightarrow \leftarrow$
Disk gaps and holes	$\rightarrow$
Accretion rate evolution	$\rightarrow \leftarrow$
Stellar luminosity evolution	$\leftarrow$
Non-static chemistry	$\rightarrow \leftarrow$

Piso, Oberg, Birnstiel, Murray-Clay (2015)

Chemistry and Dynamics need to be coupled



Semenov & Wiebe (2011)

Fundamental Questions

1. Where in the disk can giant planets form?

    Piso & Youdin (2014)

    Piso, Youdin, & Murray-Clay (2015)

2. What compositions will the formed giant planets have obtained?

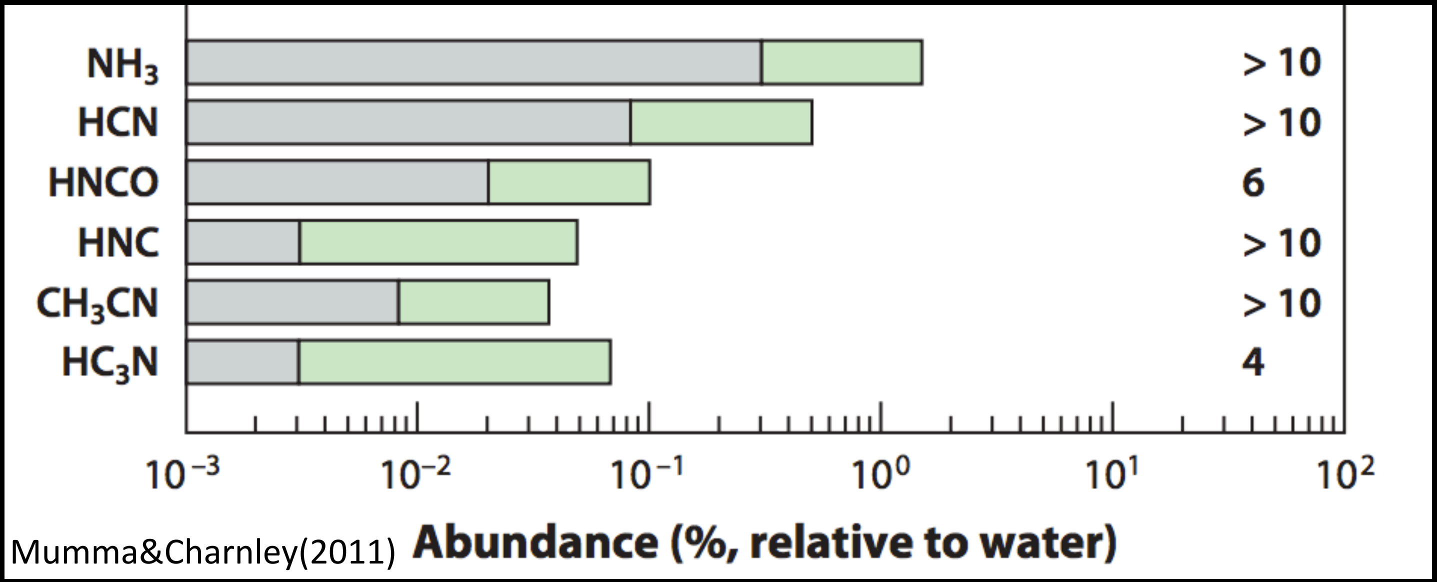
    Piso, Öberg, Birnstiel, & Murray-Clay (2015)

    Piso, Pegues, & Öberg (2016)

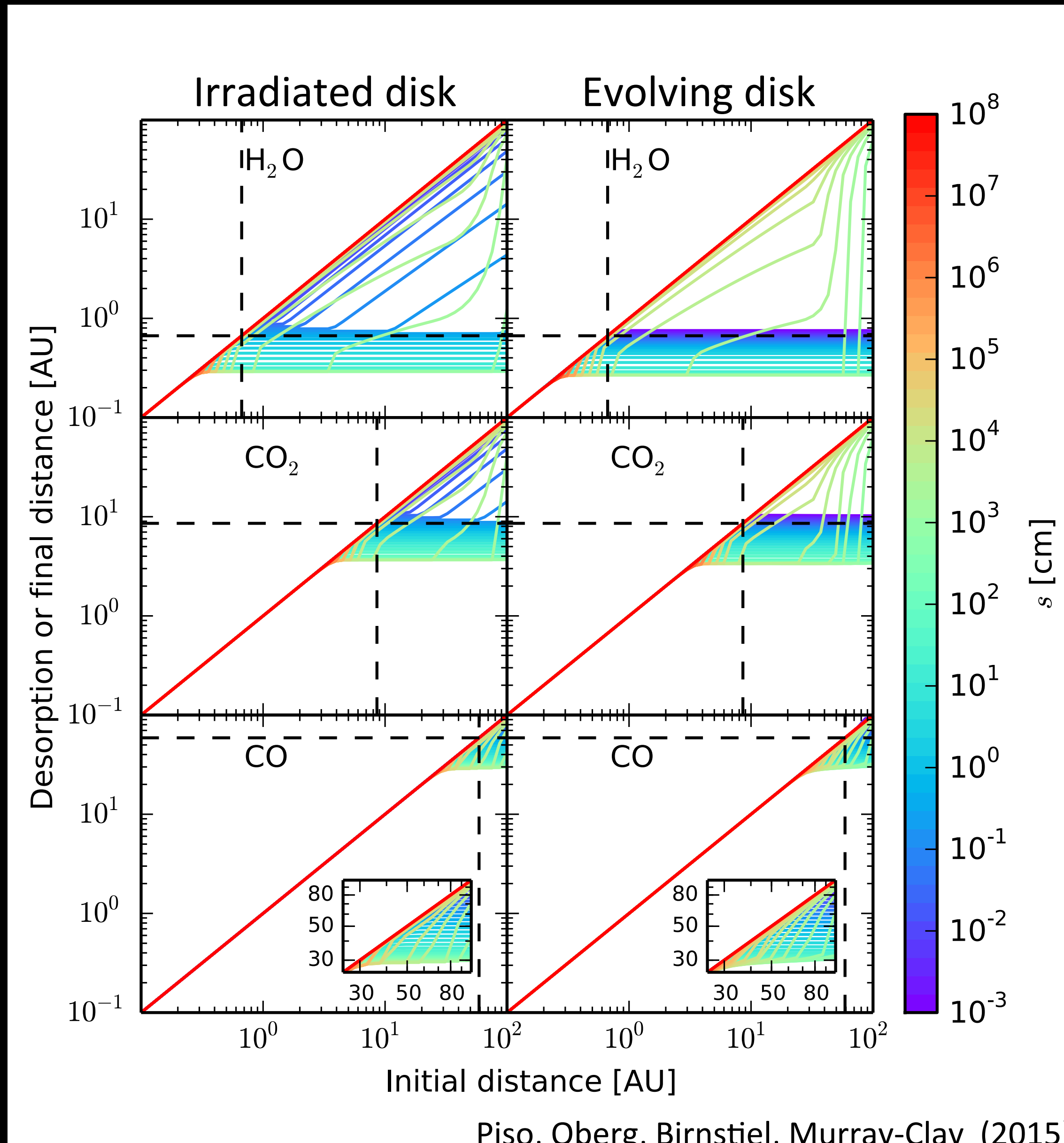
Nitrogen is important!

- Add nitrogen-bearing molecules – nitrogen highly abundant in the Solar System and in disks and primarily found as N_2
- Some N present in the form of NH_3

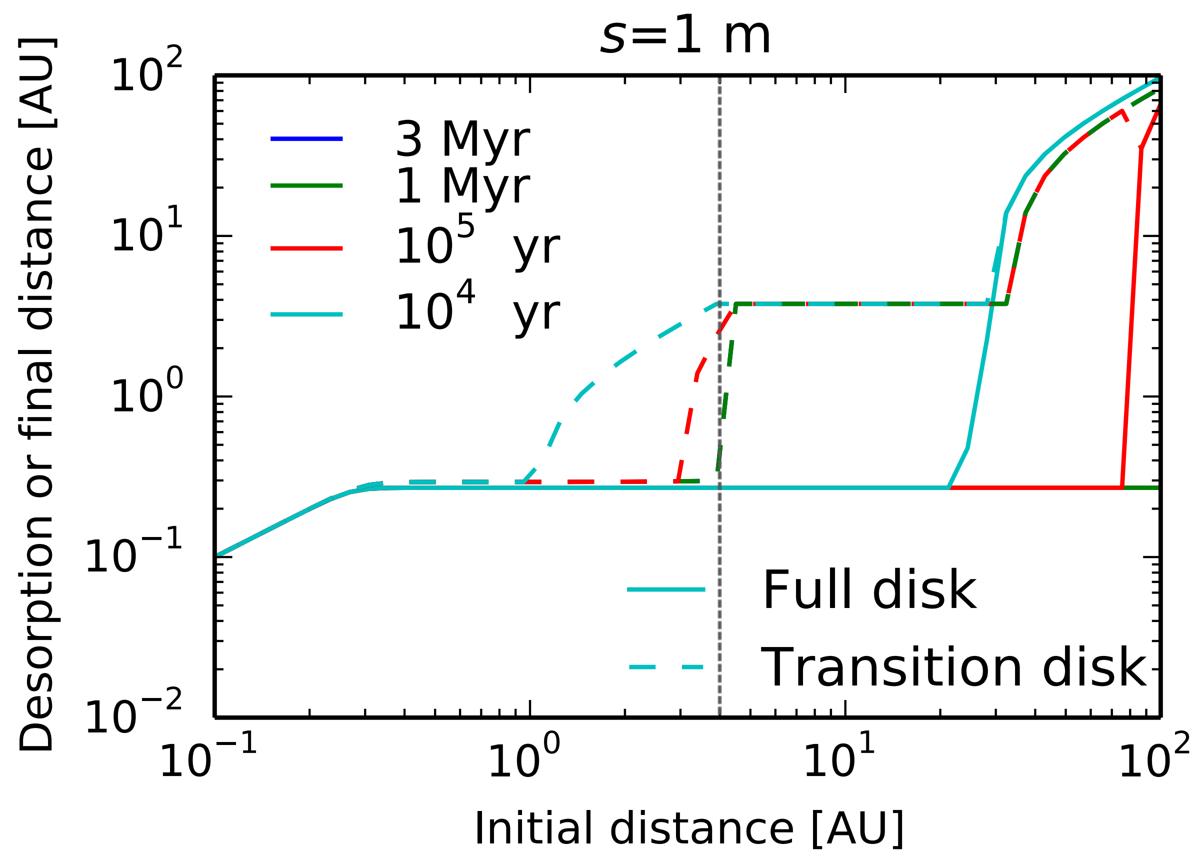
  => Use the median and maximum NH_3 abundances observed in protostellar cores from *Spitzer* c2d Legacy ice survey (Oberg et al. 2008, Oberg et al. 2011, etc.)



Radial drift affects snowline location



The desorption distance for transition disks agrees with observations



Piso, Oberg, Birnstiel, Murray-Clay (2015)