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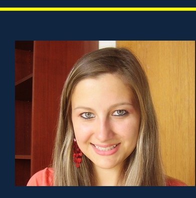

The Role of Ice Compositions and Disk Dynamics for Snowlines and the C/N/O Ratios in Active Disks

ABSTRACT

The elemental compositions of planets define their chemistry, and could potentially be used as beacons for their formation location if the elemental gas and grain ratios of planet birth environments, i.e. protoplanetary disks, are well understood. In disks, the ratios of volatile elements, such as C/O and N/O, are regulated by the abundance of the main C, N, O carriers, their ice binding environment, and the presence of snowlines of major volatiles at different distances from the central star. We explore the effects of disk dynamical processes and ice compositions on the snowline locations of the main C, O and N carriers, and the C/N/O ratios in gas and dust throughout the disk. The gas-phase N/O ratio enhancement in the outer disk (exterior to the H2O snowline) exceeds the C/O ratio enhancement for all reasonable volatile compositions. Ice compositions and disk dynamics individually change the snowline locations of CO and N_2 by a factor of 2-3, and when considered together the range of possible CO and N_2 snowline locations is ~10 - ~70 AU in a standard disk model. Observations that anchor snowline locations at different stages of planet formation are therefore key to develop C/N/O ratios as a probe of planet formation zones.

DISK COMPOSITIONS REGULATE PLANET COMPOSITIONS

WHAT

The composition of a giant planet atmosphere is determined by and tightly linked to the disk composition => AIM to 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 a planet's formation location based on the planet composition

HOW

Study the snowline locations of volatile molecules, some of which have been detected in disks.

Explore the effect of DISK DYNAMICS and ICE COMPOSITIONS on snowline locations and the C/N/O ratios in disks and planet atmospheres

VOLATILE SNOWLINES IN DISKS

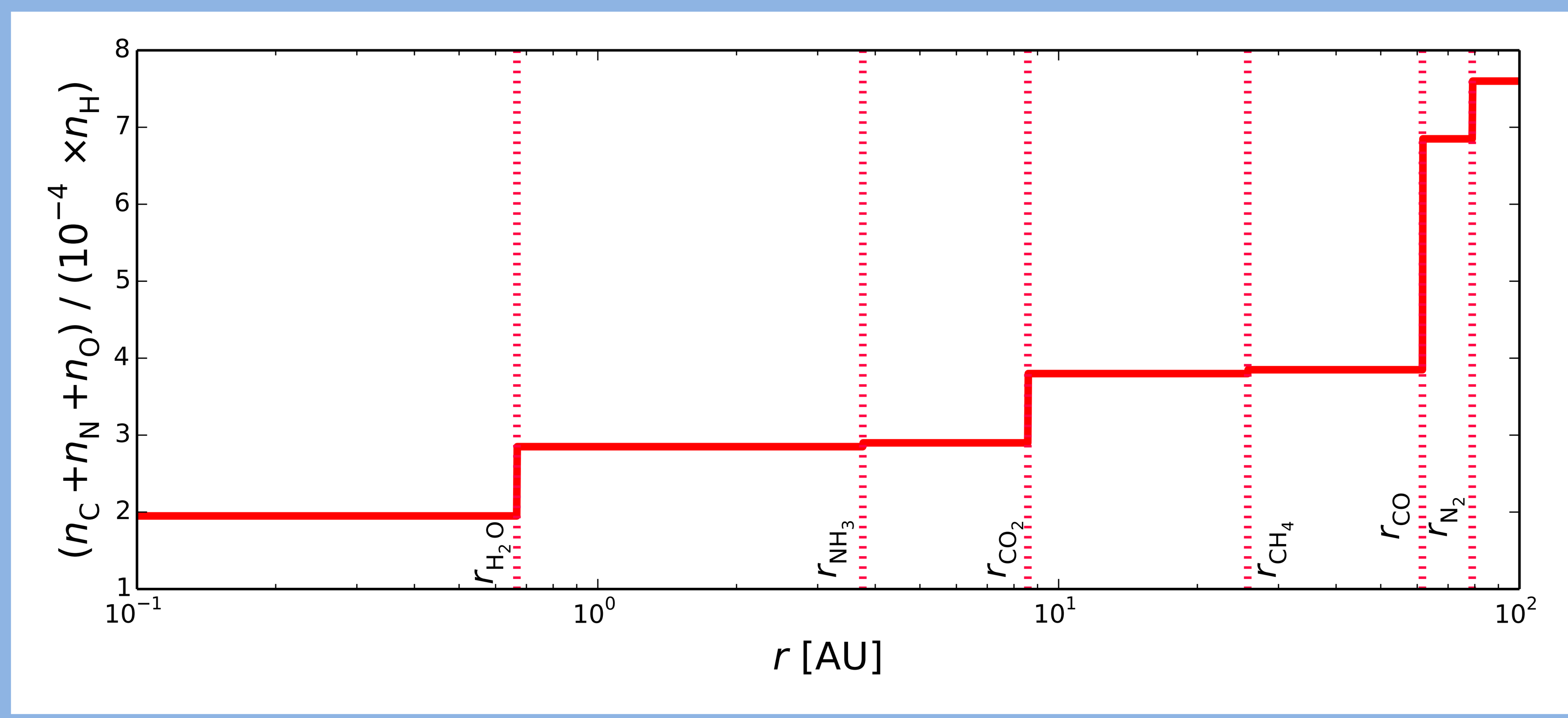

Fig. 1: The total carbon, nitrogen, and oxygen abundance in solids as a function of semimajor axis in a static disk. Relevant volatile snowlines are marked by the vertical dashed lines. The grain abundances are calculated as a function of the observed median CH_4 and NH_3 abundances in protostellar cores. The total grain abundance increases with semimajor axis as more and more species freeze out. Adapted from Piso et al. (2016)

C/O RATIO IS AN IMPORTANT SIGNATURE OF ATMOSPHERIC CHEMISTRY

Some observations suggest C/O ratios in exoplanet atmospheres different from the stellar value

POSSIBLE EXPLANATION

Main carries of C and O (H_2O, CO_2, CO) have different condensation temperatures => variations in the abundances of C and O in solids and in gas between volatile snowlines

Dynamical processes such as radial drift of solids and viscous gas accretion onto the central star may affect the distance at which particles of different sizes desorb, and therefore snowline locations

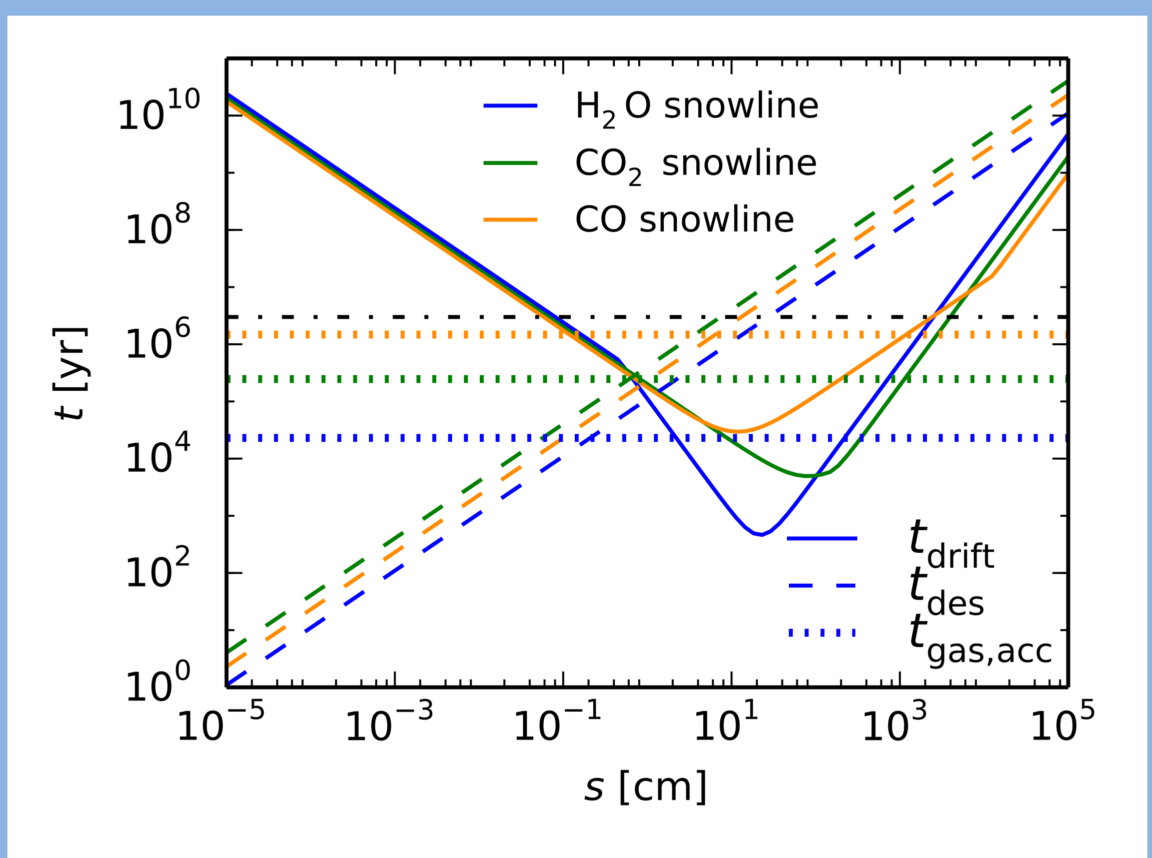

Fig. 2: Relevant timescales for dynamical effects in the desorption process. Radial drift and gas accretion affect desorption in the regions where their respective timescales, i.e., t_{drift} and $t_{gas,acc}$, are comparable to the desorption timescale t_{des}. From Piso et al. (2015b).

C/O RATIOS AND SNOWLINE LOCATIONS IN ACTIVE DISKS

Particles within a specific size range desorb at a fixed location in the disk that is only particle size dependent, on a very short timescale, and in a very narrow distance range => fixed, sharp snowlines

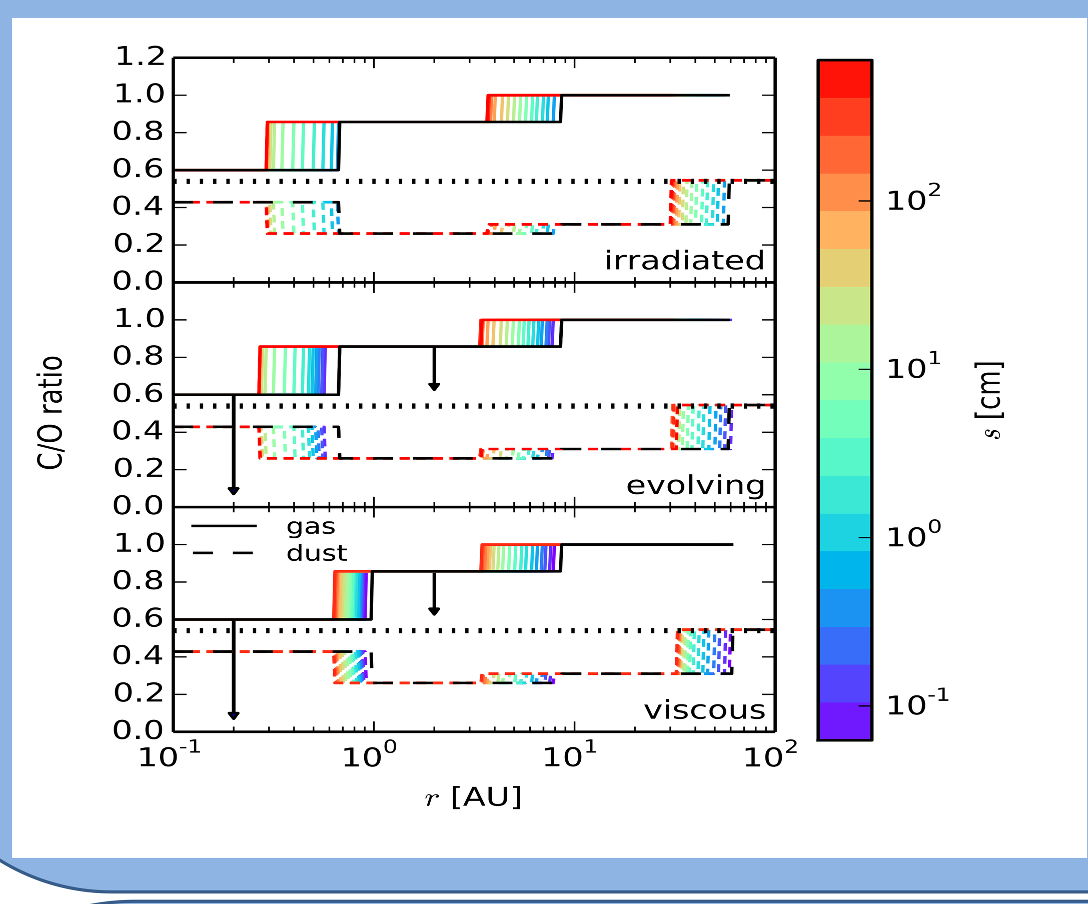

Fig. 3: . Estimated C/O ratios in gas and in dust for several disk models and a range of initial particle sizes as shown by the color bar. The black lines represent the C/O ratios in a static disk. The gas-phase C/O ratio is enhanced by a factor of 2 in the outer disk compared to the stellar value (dotted line). Disk dynamics move the snowlines inwards by up to a factor of ~2. From Piso et al. (2015b).

DISK DYNAMICS AND ICE COMPOSITIONS MAY CHANGE THE CO SNOWLINE LOCATION BY A FACTOR OF 7!

The CO binding energy is ~1.7 times larger if CO is in a water dominated environment rather than pure ice => binding environment changes the CO snowline locations

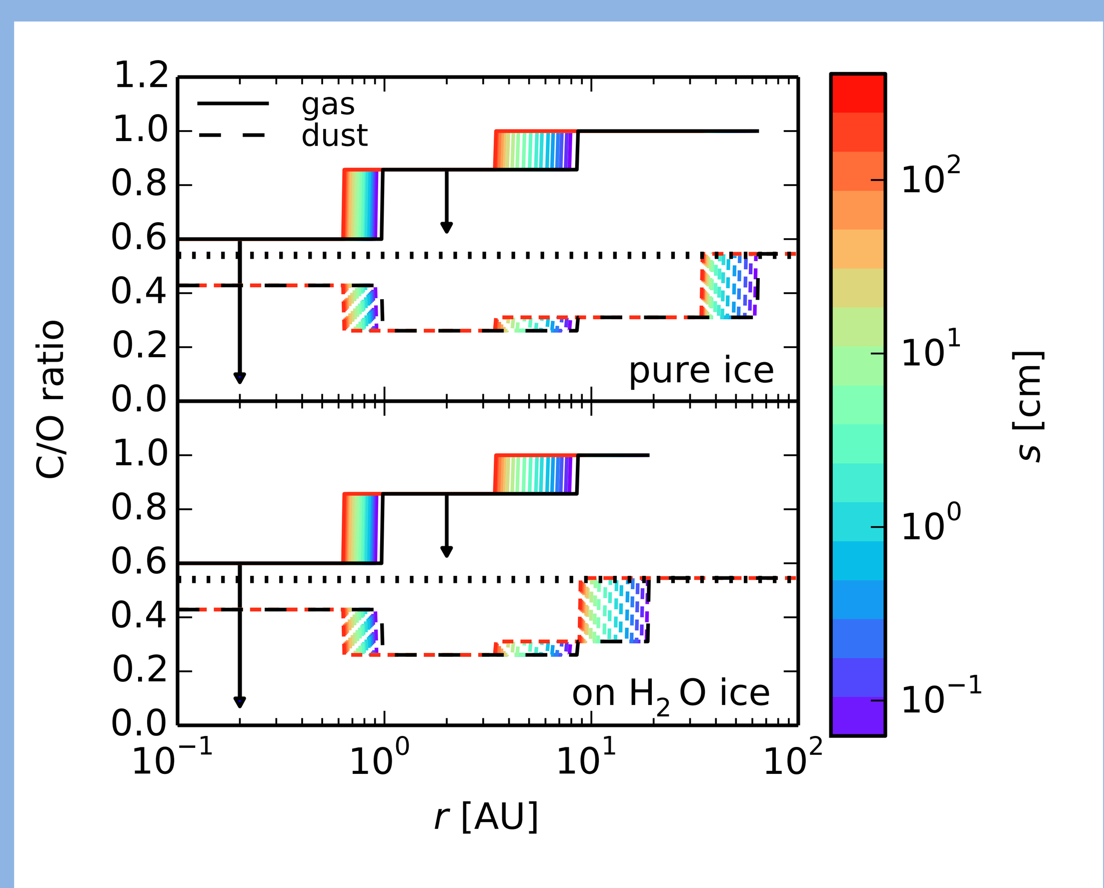

Fig. 4: C/O ratios and snowline locations in a viscous disk, with CO as pure ice (top panel) and in a water dominated environment (bottom panel). The CO snowline location may change by a factor of ~2 due to disk dynamics and by a factor of ~3-4 due to ice compositions. In our fiducial disk, the CO snowlines can span 9-61 AU. From Piso et al. (2016).

N/O RATIOS IN DISKS ARE HIGHLY ENHANCED

Can use N/O ratios in addition to C/O to further constrain disk and planet compositions

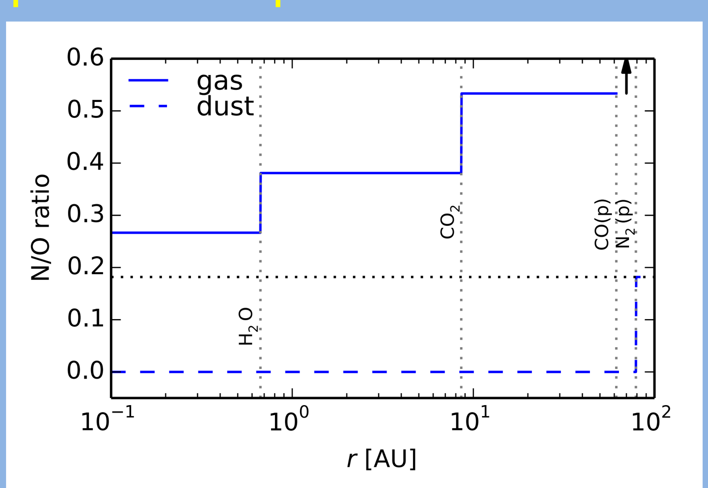

Fig. 5: The N/O ratio in gas (solid line) and dust (dashed line) in a static disk. We consider that all nitrogen is in N_2. The gas-phase N/O ratio is enhanced by a factor of 2 outside the H_2O snowline compared to the stellar value (dotted line), by a factor of 3 between the CO_2 and CO snowlines, and by many orders of magnitude between the CO and N_2 snowlines where oxygen gas is depleted. Adapted from Piso et al. (2015b).

CONCLUSIONS

Gas phase N/O ratios are highly enhanced throughout most of the disk, and more enhanced than the C/O ratio

The locations of the CO and N_2 snowlines are highly uncertain and can span several tens of AU => observations are KEY

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