

Referee Report

Global comment: This paper aims at discussing the influence of ice morphology and disk dynamics on the location of snowlines of main C-, N- and O- bearing species in protoplanetary disks. The authors use static and time-dependent disk models associated with desorption-drift models to depict the fate of ice particles in the disk and to derive the abundance profiles of C, N and O abundances in solids or in the gas phase as a function of the distance to the star. I recommend major revisions before considering the publication of this paper in The Astrophysical Journal. In its present shape, the manuscript poorly addresses the influence of the nature of the ices in the presented results, contrary to the goal announced in the title.

We thank the referee for a thoughtful and detailed report. The major comment was along the lines of clarifying and further explaining the effect of the nature of ices on snowline locations. First off, the word 'morphology' was a poor choice on our part, as the main focus of our paper is the composition of the icy particles, not the morphology of the water substrate. We thus removed morphology from the title as well as the main text, with one exception in the last paragraph of section 3.1 where we briefly discuss the different morphologies of the water ice substrate (amorphous vs. crystalline). Further changes are addressed in the responses below.

Detailed comments:

- Introduction:

1) Titan's atmospheric N₂ is not primordial and probably comes from primordial NH₃ accreted by the satellite (Atreya et al. 1978; Mandt et al. 2014).

We added this clarification in the text: "...although Titan's N₂ dominated atmospheric composition is not primordial but rather originates from primordial NH₃ accreted by the satellite (Atreya et al. 1978, Mandt et al. 2014)."

2) In the third paragraph, it is stated that N₂ was probably the dominant N₂ form in the protosolar nebula and that the N/O ratio may be enhanced in the outer disk. These statements are at odds with the mention of the N₂ detection in comet 67P/churyumov-Gerasimenko because the abundance of this molecule is very small in the comet.

We removed the reference to comet 67P in the introduction as we discuss the detection of N₂ and the low N₂/CO ratio in 67P in section 4.

3) Sentence "Because of the high volatility of N₂, the N/O ratio in the outer disk should be more enhanced than the C/O ratio..." This argument needs clarification. The equilibrium curves of pure N₂ and CO crystalline ices are very

close at nebular conditions. There might be just 2-3 K of difference at low pressure (Fray and Schmitt 2009).

We explained that the N/O ratio is more enhanced than the C/O ratio because nitrogen is primarily N₂, while carbon is carried by other species besides CO: “The larger N/O ratio enhancement is due to the fact that nitrogen is primarily carried by N₂, while carbon has other carriers besides CO. The N/O enhancement is most pronounced between the CO and N₂ snowlines, where the gas phase N/O ratio exceeds the stellar value by many orders of magnitude due to the depletion of oxygen gas in this region (see Section 3).”

4) There is no indication of the ice state in this section. I also found nothing in the manuscript. I think that it is a major issue because the results presented by the authors strongly depend on the type of material they consider. From the papers they mention, I found that the authors considered icy grains made of amorphous ice. This should be stated in the paper, as well the corresponding conditions enabling the existence of this type of ice in the disk.

We expanded the fourth paragraph of the introduction to address these concerns. We clarified what we mean by pure and water dominated ices. The CO and N₂ binding energies are larger in an amorphous porous water environment than in the amorphous compact case or the crystalline water ice case. The CO and N₂ binding energies are lower when they are pure ices than in all water dominated scenarios. We thus consider the pure and amorphous porous water dominated environments as these are the limiting cases (lowest and highest binding energies, respectively), and therefore they allow us to explore the range of distances at which ices with different compositions desorb. The conditions in which these types of ices can exist in the disk are discussed in the third paragraph of section 4.

- Section 2:

Eq. 2, please detail T_{irr}

We redefined T in equation 1 as T_{irr} and T in equation 2 as T_{visc}. We agree with the referee that our temperature notation in both equations as T was confusing.

- Section 3.1: This section should include results from different ice morphologies to make more sense. Two extreme cases should be considered: amorphous ice and crystalline ice. The clathrate case could be eventually discussed. All these ices present different condensation/sublimation temperatures and could potentially induce drastic changes of the C/N/O ratios in the disk.

As we note in the introduction, we explore the pure ices and amorphous porous water dominated ices because these are the limiting cases (lowest and highest binding energies). We restated this in section 3.1, i.e. that the results we present in Figure 1 are the extremes and therefore they show the full range of CO and N₂ snowline locations in different ice environments. We also quantified the variations in snowline locations for all cases: amorphous porous water ice, amorphous compact water ice, crystalline water ice, and CO and N₂ as pure ices. These updates are in the last paragraph of section 3.1

- Section 3.1: the different snowlines correspond to equilibriums between adsorption/desorption. What are the corresponding temperatures in the disk?

We added the corresponding disk temperatures next to the binding energy values.

- Section 3.2: "In this section we consider pure ices". What does it mean? What is the structure of these ices?

We clarified what we mean by pure ices at the beginning of the section, as well as in the introduction.

- Section 4: please explain what would be the influence of other transport mechanisms such as the "cold finger effect" detailed in Cyr et al. (1999) or Ali-Dib et al. (2014).

Added, and also noted that the influence of other transport mechanisms on snowline locations is described in more detailed in Piso et al. (2015): "Moreover, the diffusion of vapor across the snowlines following the cold finger effect (Stevenson & Lunine 1988, Cyr et al. 1988) will change the shape of the C/O and N/O curves and therefore the magnitude of the C/N/O ratios between different snowlines. The effect of dynamical processes on snowline locations is discussed in more detail in Paper I, Section 5.2."

- Section 5: Last paragraph "Recent measurements... in the gas phase". The N₂ (and Ar) depletion measured in 67P may not be a record of the primordial composition. These features may be also due to postformation processes such as radiogenic heating or devolatilization during the orbital history of the comet.

For both this comment and the next one, we note that the referee was referring to the last paragraph of section 4 -- section 5 was probably just a typo. We addressed this concern in the last paragraph of section 4: "However, it is also possible that the measured N₂ abundance in 67P may be due to post-formation processes such as radiogenic heating (Rubin et al. 2015) and thus may not reflect the comet's primordial composition."

- Section 5: Last paragraph "Theoretical models... more detailed modeling is needed". Recent models suggest that JFCs formed between 5 and >30 AU in the protosolar nebula. It is then difficult to rely any N₂ measurement in these bodies to the location of the N₂ snowline...

We address this concern in the last sentence section 4: "...as well as the uncertainty of the formation zone of Jupiter-family comets (anywhere between 5 and >30 AU; Pontoppidan et al. 2014),...".