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Origin of the high N_2/CO ratio in comet C/2016 R2 (PanSTARRS)

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Abstract

Recent observations of the long period comet C/2016 R2 (PanSTARRS) indicate an unusually high N_2/CO abundance ratio, typically larger than ~0.05, and at least 10 times higher than the one measured in 67P/Churyumov-Gerasimenko. Because N_2 is usually depleted in these bodies, the N_2/CO ratio measured in C/2016 R2 (PanSTARRS) suggests that its formation conditions in the protosolar nebula differ from those of the other comets. Here we show that this abundance ratio can be explained by C/2016 R2 (PanSTARRS)'s agglomeration from CO-dominated clathrates and N_2 pure condensate, provided that the water abundance was slightly supersolar (~1.3 x $(O/H_2)_{protosolar}$) in the protosolar nebula and that the formation temperature of cometary grains decreased down to ~22 K at least.

1. Introduction

Recent observations of the long period comet C/2016 R2 (PanSTARRS) (hereafter R2) indicate an unusually high N_2/CO ratio, a value estimated to range between 0.06 +/- 0.01 [1] and 0.08 [2] and at least 10 times higher than the one measured before perihelion in 67P/C-G. To explain the higher N_2/CO ratio measured in R2, [1,2] suggested that the comet agglomerated from amorphous ice formed at temperature below 24 K, allowing the adsorption of important quantities of N_2 compared to higher temperatures. At present, further laboratory experiments are needed to assess this hypothesis. [2] also speculated that N_2 could also exist in pure condensate form in the comet but did not detail the processes leading to the incorporation of this icy phase in the comet. An alternative scenario formulated by [2] is that R2 would be a fragment of the disruptive collision of a large Kuiper Belt object whose outer layers have been progressively enriched in ultravolatiles, due to radiogenic heating. Here we propose that the high N_2/CO ratio measured in R2 was acquired directly from the PSN at the formation epoch of R2's building blocks. We then show that either the comet agglomerated from a mixture of clathrates and pure condensates or from clathrates only, depending on i) the amount of crystalline water available for clathration, and ii) the PSN temperature at its formation location.

2. Model

Our model assumes the formation of a multiple guest (MG) clathrate in which the relative abundances of trapped guest species (here CO and N_2) are calculated following an approach based on classical statistical mechanics that relates the macroscopic thermodynamic properties of clathrates to the molecular structure and interaction energies [3,4].

Because half of protosolar carbon is expected to be used in organic compounds in the PSN, we assume that only the remaining half is in the form of CO. Assuming that 90% of protosolar nitrogen is in N_2 form, we derive a N_2/CO ratio of 2.66 x 10^{-1} in the initial gas phase of the PSN, based on the protosolar abundances [5]. In our model, clathrates form in the PSN as long as crystalline water is available. Once all the water budget has been used for clathration, the volatiles remaining in the gas phase form pure condensates at lower temperatures.

3. Results

Figure 1 represents the temperature dependence of the N_2/CO ratio in icy grains crystallized in the PSN, assuming an initial H_2O/H_2 ratio of 1.3 x $(O/H_2)_{protosolar}$, i.e. ~1.6 x 10^{-3}, in the gas phase of the disk. This value is 70% higher than the H_2O abundance derived from C and O protosolar values but allows for the quasi-full trapping of CO in clathrates at the expense of N_2. This trend shows that CO's propensity for trapping is much more important than that of N_2 when these two molecules coexist in the gas phase. N_2/CO ratios measured in several comets are also represented against the values calculated with our model. The upper values measured in 122P/1995 S1 (deVico) and C/1995 O1 (Hale-Bopp) correspond to N_2/CO ratios calculated in clathrates at temperatures of $\sim$25 and 29 K, respectively. The error bar associated with the N N_2/CO ratio measured in 67P/C-G matches our clathrate composition model at ~50-52 K. On the other hand, the N_2/CO ratio in R2 does not match the range of values in clathrates calculated at temperatures lower than 100 K in the PSN. Temperatures higher than 100 K are needed to enable this matching but the corresponding equilibrium pressures required for clathrate formation are higher than $\sim 10^{-3}$ bar, implying total gas pressures exceeding 10 bars. Such values for the total gas pressure are orders of magnitude too high beyond the snowline in the PSN. Alternatively, the N_2/CO ratio observed in R2 can be explained if the comet agglomerated from i) N_2 pure condensate crystallized at ~22 K or below, and from ii) CO-dominated clathrates formed at higher temperatures, probably in the range of those needed for the formation of the grains agglomerated by Hale-Bopp, deVico, or 67P/C-G. R2 would have then agglomerated from two distinct icy phases with different formation temperatures. The adopted value for the abundance of water (1.3 x $(O/H_2)_{protosolar}$) is key in this scenario. A lower abundance of water would imply that a fraction of CO has not been trapped in clathrates and remains available for condensation at lower temperature in the PSN. In this case, because of their very close crystallization temperatures, both the remaining CO and N_2 would become incorporated together as pure condensates in cometary grains. This would result in an increase of the N_2/CO ratio, potentially exceeding the value measured in R2, and reaching at most ~2.7 x 10^{-1}. This latter value derives from protosolar C and N if clathration never operated at the formation locations of these icy grains.

4. Conclusions

We have shown that the unusually high N_2/CO abundance ratio observed in R2 can be explained by the agglomeration of CO-dominated clathrates and N_2 pure condensate if the water abundance was ~1.3 x $(O/H2)_{protosolar}$ in the PSN, provided that the formation temperature of cometary grains decreased down to ~22 K at least.

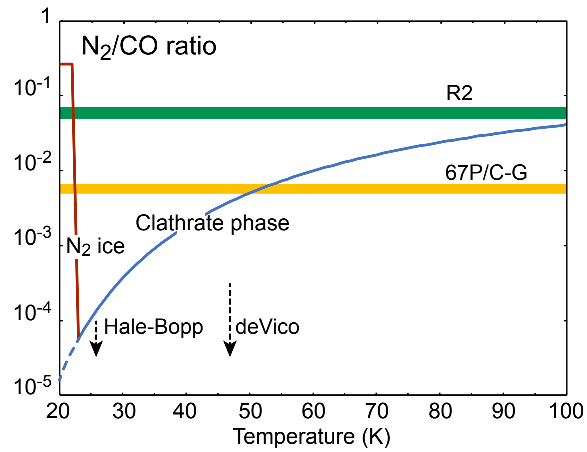

Fig. 1. N_2/CO ratio in cometary grains calculated as a function of the water abundance in the PSN for different formation temperatures. The green and orange horizontal bars represent the N_2/CO ratios measured in comets R2 and 67P/C-G, respectively. The two vertical dashed lines with arrows down correspond to upper limits of the N_2/CO ratio measured in 122P/1995 S1 (deVico) and C/1995 O1 (Hale-Bopp).

References

[1] Opitom, C., Hutsemékers, D., Jehin, E., et al. 2019, arXiv:1901.00657

[2] Biver, N., Bockelée-Morvan, D., Paubert, G., et al.\ 2018, A&A, 619, A127

[3] Lunine, J.I., & Stevenson, D.J. 1985, ApJS, 58, 493

[4] Mousis, O., Lunine, J.I., Picaud, S., & Cordier, D. 2010, Faraday Discussions, 147, 509

[5] Lodders, K., Palme, H., & Gail, H.-P. 2009, Landolt Börnstein, 712