EPSC Abstracts
Vol. 13, EPSC-DPS2019-2014-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

Entrapment of Volatiles in Amorphous Ice

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Abstract

Rosetta mission has provided many unexpected details into a comet's behavior. One of them is the detection of supervolatiles such as N_2, O_2, Ar, in addition to CO and CH_4 [Rubin, Altwegg et al. 2017]. This observation requires that either the comet 67P/Churyumov-Gerasimenko nucleus is extremely cold (<30 K) retaining the interstellar amorphous water-ice grains in which the supervolatiles are "*entrapped*" or these supervolatiles formed "*clathrates*" occupying the crystal lattice of crystalline water ice. Laboratory studies are conducted, but their interpretation is divided among the community. This talk will summarize and provide insight into new studies conducted at the Ice Spectroscopy Laboratory (ISL) of JPL.

1. Introduction

All the data we have so far about a comet's bulk composition is from the cometary outgassing – whether atomic, molecular, or particulate. Surface chemical composition is more certain now than the physical properties on the upper tens of centimeters to several meters of the crust. Below this "more thermally processed crust" it is expected that comets pristine/primordial material is kept unaltered for billions of years. Thus, the chemical composition and physical state of the nucleus plays critical role on the outgassing properties of comets.

The term "pristine/primordial" is also somewhat vague, as we still have very little understanding of how cometary nucleus is formed from a few micron-sized interstellar ice grains to millimeter-size protoplanetary disk grains (cometesimals) to meters-to-kilometers icy bodies that became Kuiper Belt Objects, Centaurs, and subsequently Comets. If the ice grains from interstellar stage are evaporated and recondensed during the protoplanetary stage into millimeter-size grains of crystalline ice the primordial nature starts from there onwards. If not, primordial material in comets can be traced all the way back to amorphous interstellar ice grains, which are far better understood.

Assuming that the ice grains of interstellar stage are unaltered, we will discuss what a comet's interior composition could be and how the Rosetta observations could be rationalized and where the potential disagreements could be.

2. Laboratory Experiments

We have conducted a series of experiments containing CO_2-rich ice doped with supervolatiles (CO and O_2) as well as H_2O-rich ice doped with the same super volatiles. Further, we conducted a mixed CO_2/H_2O ice with the same supervolatiles. Temperature-programmed-desorption (TPD) was monitored using Near- and Mid-Infrared Spectroscopy as well as Quadrupole Mass Spectrometry (QMS) simultaneously. These results will be presented and discussed in the context of the cometary nucleus interior composition.

3. Trapped vs. Clathrate

When an impurity, such as the supervolatile molecules, is trapped either in an amorphous ice matrix (with large voids for the mobility of the molecular species) or between the crystalline grain boundaries of polycrystalline ice, this phenomenon is called as "entrapment" [Levi, Sasselov et al. 2013]. In such cases, the supervolatile has two sublimation profiles. First, due to an excess supervolatile ice itself, resembling otherwise pure supervolatile ice sublimation and the second, a delayed sublimation at higher temperature due to being trapped in the host matrix (amorphous ice). Both these sublimations occur well below the sublimation temperature of the host ice matrix. On the other hand, if it is a clathrate or a hydrate (both have crystalline lattice), at least some fraction of supervolatiles should be subliming along with the host ice [Shin, Cha et al. 2017]. In all our studies, we have not observed any signatures for "clathrate formation" during the sublimation process.

4. Summary and Conclusions

Our laboratory studies that will be discussed indicate that a wide range of supervolatiles can easily be trapped in amorphous ice, which sublime at a wide range of temperatures, but well below the sublimation temperature of water-ice sublimation temperature. Based on these observations, we conclude that the cometary nucleus should be primordial with cold (<30 K) amorphous interstellar ice.

Acknowledgements

This work was funded partly by ROSETTA USA support and conducted at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.

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