NITROGEN AND NOBLE GASES IN COMETARY ICES FORMED AT 70K.

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Introduction: Laboratory investigations of volatile elements trapped in cometary ice analogues have the potential to provide important information on the origin and evolutionary history of comets [1], and their role as precursors to the rocky/terrestrial planet atmospheres [2]. Noble gases (Ar, Kr and Xe) and N_2, due to their inert nature and distinct condensation temperatures, constitute a unique cosmochemical thermometer, which can be used to infer the temperature of formation of cometary ices and thermal evolution within the solar system since their formation around 4.5 Ga. Historical studies on the capacity of amorphous water ices to trap and retain volatiles above their sublimation temperature [1,2] failed to predict the noble gas and nitrogen composition of comets, as measured in ice sublimating from comet 67P/Churyumov-Gerasimenko [3]. Here we further investigate the noble gas and nitrogen signature of cometary ice analogues using a newly designed experimental setup called EXCITING (Exploring Xenon in Cometary Ices by Trapping and Irradiating Noble Gases).

Experimental: We have developed an experimental setup to form cometary ice analogues from mixtures of water, nitrogen and noble gases [4]. The aim of this experiment is to better understand the elemental and isotopic behaviour of nitrogen and noble gases trapped in amorphous water ice, when ice is subject to conditions akin to those experienced by outer solar system bodies. In this experiment, we form amorphous water ice at temperatures ranging from 28K to 80K, at pressures ~10^{-8} mbar. Upon heating, water structure changes from amorphous to crystalline ice at around 140K, with the liberation of all guest volatiles that were initialy trapped within the structure of the amorphous ice. This corresponds to the gas phase in the coma of comets, where both trapped volatiles and sublimating water are present. In this experiment, gases released from the ice are analysed using a quadrupole mass spectrometer for their elemental abundances, and a static noble gas mass spectrometer (GV Instrument Helix MC) for their isotope composition.

Results and Discussion: We investigate the evolution of N_2/Ar/Kr/Xe in the ice analogues from their condensation temperature to their simultaneous release into the gaseous phase, and the potential for this trapping and release to fractionate the isotopic signature of trapped volatile species. We are able to reproduce comet 67P/C-G elemental Ar/Kr/Xe ratios from a solar-like initial composition with an ice deposition temperature of ~70K [4]. Additionally, high $N_2/^{36}Ar$ measured in comet 67P/C-G [3] is also replicated when the ice forms at this temperature (see Figure). These results suggest that cometary ice may have formed at 70K, which is higher than previous estimates of ~30K [5]. Nitrogen and noble gases released from the ice were also measured for their isotopic composition, but show only limited isotopic fractionation from their initial isotopic composition compared to the N [6] or Xe [7] anomalies found in comets. Taken together these results provide further constraints on the potential location (molecular cloud vs. protoplanetary disk) and composition of the formation environment of cometary ices. A possible origin of N and Xe isotopic anomalies is selective photo-dissociation (from self-shielding) of ^{15}N-^{14}N in the protoplanetary disk during the lifetime of the solar nebula, and inheritance of nucleosynthetic Xe anomalies from the parent molecular cloud.

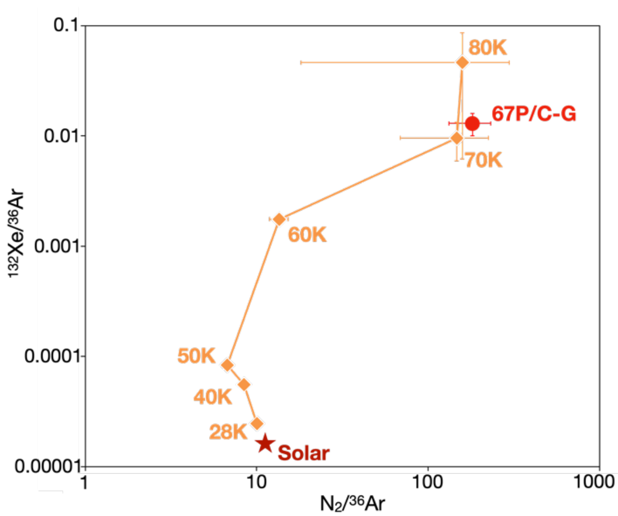

Figure: Composition of N_2/Ar/Xe in the cometary ice analogue formed in EXCITING as a function of the temperature of formation of the ice (28K-80K) starting from a solar composition.

References: [1] Bar-Nun A. and Kleinfeld I. (1989) *Icarus* 80:243-253. [2] Owen et al. 1992. *Nature* 358: 43-46. [3] Rubin et al. 2018 *Science advances* 4 [4] Almayrac et al. submitted to *The Astrophysical Journal* [5] Rubin et al. 2015 *Science* 348:232-235 [6] Altwegg et al. 2019 *Annual Review of Astronomy and Astrophysics* 57:113-155. [7] Marty et al. 2017 *Science* 356:1069-1072.