HELIUM ISOTOPES IN STARDUST COMETARY MATTER: A POSSIBLE RECORD OF THE EARLY EVOLUTION OF THE SOLAR SYSTEM. E. Füri and B. Marty, CRPG-CNRS, BP20, 54501 Vandoeuvre-lès-Nancy, France (efueri@crpg.cnrs-nancy.fr; bmarty@crpg.cnrs-nancy.fr)

Introduction: In order to decipher and understand the physical and chemical conditions in the protosolar nebula (PSN) from which the Sun and planets formed, a proxy for the primordial nebula composition is needed. Comets are considered the most primitive material in the Solar System [1], and knowledge of the noble gas composition of cometary matter is one of the last grand issues to be resolved in cosmochemistry. Noble gases are chemically inert and their abundances and isotope compositions can only be modified by physical processes (e.g., nuclear reactions, phase changes, and kinetic processes). Thus, the noble gases are exceptional tracers of contributions to comets from various Solar System volatile reservoirs, and of processing of matter in the nascent Solar System.

NASA's Stardust mission (Discovery Program) collected cometary dust particles from the coma of comet 81P/Wild 2. The cometary grains (<30 μm) were captured at 6.1 km/s in low-density silica aerogel tiles and returned to Earth in January 2006 [2]. These unique samples provided the first means to directly analyze the noble gas (He and Ne) composition of cometary matter [3].

Experimental method: For this study, a total of 16 aerogel fragments, including non-flight and flight 'blank' chips as well as cometary dust-bearing aerogel samples from particle impact tracks #41 (cell 2044) and #80 (cell 2092), were analyzed by CO_2 laser extraction-static mass spectrometry analysis at CRPG, Nancy. Individual aerogel fragments were heated for ~3 min by very slowly increasing the power of the CO_2 laser. The large blank aerogel chips could be safely heated; however, for the analyses of the significantly smaller aerogel fragments containing cometary dust, the sample pits of the laser chamber were covered with a ZnSe window in order to prevent the samples from jumping out of their pits. This method resulted in slightly increased ^{4}He blank levels (i.e., 5.27×10^{-11} cm^{3}STP) compared to blanks run without the ZnSe plate (i.e., 2.55×10^{-11} cm^{3}STP).

Results: Only one aerogel fragment without visible cometary particles (C2044,0,41,Slice 2) showed a helium concentration significantly higher than aerogel blank values (i.e., 23.7×10^{-11} cm^{3}STP). This sample records a ^{3}He/^{4}He ratio of $(3.57 \pm 0.49) \times 10^{-4}$, comparable to previous values of $(3.56 \pm 0.23) \times 10^{-4}$ [4] and $(4.9 \pm 0.4) \times 10^{-4}$ [5] observed in particle-free aerogel fragments from Track #41 (Figure 1). Notably, these ratios appear significantly higher than the helium isotope composition measured in two dust-bearing samples from the same track (i.e., $(2.47 \pm 0.34) \times 10^{-4}$ and $(2.92 \pm 0.26) \times 10^{-4}$ [3]).

Discussion: The He and Ne abundances of the majority of all analyzed aerogel fragments, i.e., 'blank' aerogel fragments extracted adjacent to impact tracks as well as aerogel containing visible cometary grains, are indistinguishable from procedural blanks [this study; 4-5]. However, the detection of significant helium excesses in several 'blank' aerogel fragments suggests that cometary gas has been implanted into some parts of the aerogel surrounding the particle impact Track #41.

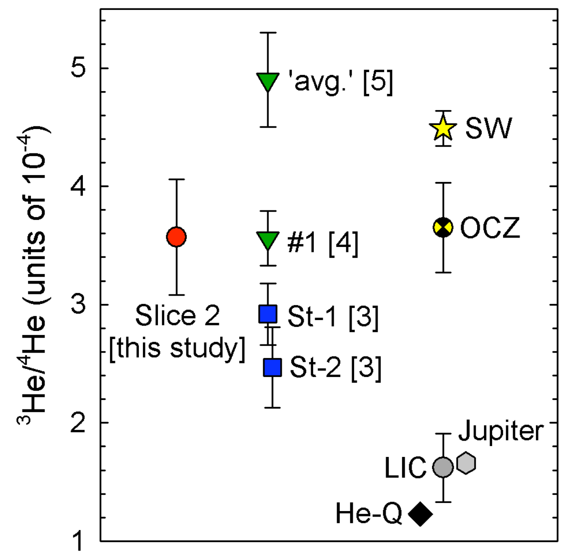

Figure 1: Helium isotope ratios (^{3}He/^{4}He) of Stardust samples from particle impact Track #41 [this study; 3-5] as well as of modern solar wind (SW; [6, 7]), the Sun's outer convective zone (OCZ; [9-11]), Jupiter's atmosphere [12], the local interstellar cloud (LIC; [13]), and He-Q [14]. The Jovian isotope signature is thought to represent the composition of the PSN.

While ^{3}He may be produced in-situ near the surface of a comet by nuclear spallation reactions, the lack of cosmogenic ^{21}Ne in previous analyses of Stardust samples showed that the high ^{3}He/^{4}He ratios can only be explained by the presence of a ^{3}He-rich volatile component [3]. Thus, the He isotope signature of the samples can in principle reveal when comets acquired their noble gas inventory, and from what volatile reservoir.

Modern solar wind (SW) shows a ^{3}He/^{4}He ratio of $(4.49 \pm 0.15) \times 10^{-4}$ [6, 7], and the constant isotope signature of SW-derived He trapped in lunar ilmenites of variable antiquity suggests that this ratio has not varied significantly over the past ~4 Gyr [8]. However, fractionation of the SW composition relative to the Sun's outer convective zone (OCZ), and modification of the OCZ relative to the original solar nebula must be considered when inferring the primordial nebula composition from SW-derived volatiles. The $^3He/^4He$ ratio of the present-day OCZ is inferred to be lower than that of the SW, and estimates range from ~(3.75 to 3.98) × 10^{-4} [9-11]. Furthermore, the early conversion of deuterium to ^3He significantly modified the initial solar $^3He/^4He$ ratio, i.e., the abundance of ^3He in the OCZ represents approximately the abundance of ^3He + D in the PSN. The He isotope signature of Jupiter's atmosphere ($^3He/^4He$ = (1.66 ± 0.05) × 10^{-4} [12]) is currently considered to be the best estimate for the composition of the PSN, before D-burning. Notably, the Jovian isotope signature is within the uncertainty identical to the helium isotope composition of the local interstellar cloud (LIC; 1.62 ± 0.29 × 10^{-4} [13]). Alternatively, the slightly lower $^3He/^4He$ ratio of (1.23 ± 0.02) × 10^{-4} of He-Q, a helium component observed in a carbonaceous carrier within primitive meteorites, may represent the PSN value [14].

Conclusions: Stardust samples record $^3He/^4He$ ratios of ~(2.5 to 4.9) × 10^{-4}. These values are significantly higher than the isotope composition inferred for the primordial nebula and fall between Jupiter and contemporary SW values, indicating that noble gases in comet 81P/Wild 2 originate from at least two volatile reservoirs. The high $^3He/^4He$ ratios observed by Palma et al. [4] are consistent with the presence of a SW-derived He component, erratically distributed within the aerogel surrounding impact Track #41. In contrast, the lower values of dust-bearing samples [5] require a contribution from a low-$^3He/^4He$ endmember in comet Wild 2, possibly indicating i) implantation of an 'ancient' SW component before D-burning was completed in the Sun, ii) the presence of the carbonaceous phase Q, or iii) incorporation of interstellar gas into comets or cometesimals. Therefore, it is possible that Stardust matter has recorded several snapshots of the early evolution of the Solar System.

Future work: In order to expand the limited noble gas data set, we will analyze additional research samples from the NASA Stardust sample collection. It is important to understand the 'erratic' distribution of noble gas excesses observed around the impact Track #41, and to compare the results from Track #41 with other impact tracks.

Additional information about comets is potentially recorded in UltraCarbonaceous Antarctic MicroMeteorites (UCAMMs). Since UCAMMs show numerous similarities with Stardust samples and are thus thought to be of cometary origin [15], analysis of their noble gas composition will allow us to further assess the variability of noble gas isotope compositions, abundances, and elemental ratios of different cometary samples, and to determine if the Stardust samples are representative of cometary matter in general.

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