The Search for Cometary Xenon – About Xenon Examinations in Interplanetary Dust Particles (IDPs), Antarctic Micrometeorites (AMMs) and Aerogel. H. Busemann[1,2], N. H. Spring[2], A. O'Mara[2], P. L. Clay[2], S.A. Crowther[2], J. D. Gilmour[2] and R. Wieler[1], [1]Dept. of Earth Sciences, ETH Zürich, Switzerland, busemann@erdw.ethz.ch, [2]SEAES, University of Manchester, UK.

Introduction:

Comets might be an important source for the replenishment of the volatile elements in the inner solar system after initial accretion and planetary differentiation. They may have brought water, organic matter (OM), and the noble gases to the terrestrial planets and their atmospheres [1-3]. The noble gases He-Xe in these secondary atmospheres and in the terrestrial mantle, possibly incorporated late during accretion (e.g. as "late veneer" [4]), cannot satisfyingly be explained by processing known meteoritic or solar components [e.g., 5,6], and a cometary origin has been suggested [2,3].

However, cometary noble gas compositions are largely unknown. The only laboratory study on cometary Wild 2 dust, sampled by NASA's Stardust mission, revealed the presence of Ne with a primordially trapped, meteoritic "Q"-like signature and abundant He, isotopically intermediate between Q and solar [7,8].

Another source of bona-fide cometary matter for study in the laboratory are interplanetary dust particles (IDPs) and Antarctic micrometeorites (AMMs). Due to their stochastic nature, a cometary origin for a single grain is difficult to prove. However, there is ample theoretical and experimental evidence that most chondritic-porous IDPs and C-rich AMMs are from comets [e.g., 9-13]. IDPs collected during targeted collections in particular dust streams can even be associated with known comets such as Grigg-Skjellerup or Schwassmann -Wachmann 3. Some of the IDPs from these collections are indeed particularly primitive [14,15].

The study of Xe in these samples, as in Wild 2 dust, is particularly insightful, as Xe has a large number of isotopes and the potentially cometary candidate components (Q-gas, solar wind, maybe fission- and ^{129}I-derived Xe) have characteristic signatures. Moreover, contributions from interfering cosmogenic Xe will, in contrast to He and Ne, be negligible. Also, the abundances of Xe originating from solar wind possibly incorporated during transfer in space will be comparably small, if the possibly organic carrier of most Xe in meteorites, the so-called phase Q [16], is also abundantly present in cometary matter.

The Xe study of both IDPs/AMMs and Wild 2 dust is hampered by their very small sizes (typically in the order of 10 – 100 µm diameter), which requires high-sensitivity mass spectrometry. We assess the origin of the IDPs analyzed in this work by various further analyses (SEM, IR & Raman spectroscopy and Secondary Ion Mass Spectrometry). Here we present these and correlated Xe results for a number of IDPs and AMMs.

Wild 2 dust grains were collected in aerogel, which strongly adsorbs noble gases from the atmosphere [17] rendering heating extraction for Xe as performed in [8] for He and Ne problematic. Here we present our results on a first initial etch experiment on (unflown), aerogel, showing the feasibility of the approach to separate Xe adsorbed on aerogel from potentially present cometary Xe.

Experimental:

IDPs were analyzed optically and by SEM with EDX, Carbon Raman and IR spectroscopy, and Secondary Ion Mass Spectrometry (NanoSIMS). We aim to assess a cometary origin based on physical appearance, mineralogy, the degree of order of the OM, the presence of H, C, N isotopically anomalous OM and characteristic functional groups, and to calculate presolar silicate and oxide abundances based on the areas of O-isotope anomalies [18-20]. Xenon in both AMMs and IDPs were analyzed with Manchester's high-sensitivity resonance-ionization mass spectro- meter RELAX [21]. The very low blank of ~1000-2000 atoms was still significant for many of the small (~10^{-8} - 10^{-7} g) IDPs and also many AMMs. Typically, the samples were extracted in 2-4 steps at increasing IR laser power.

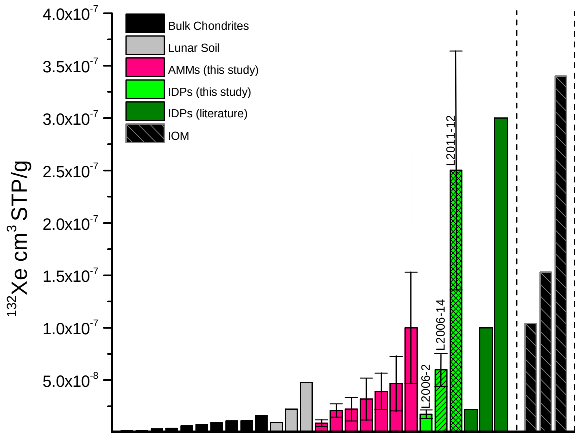

Fig. 1 Xe concentrations in IDPs and AMMs from this study compared with chondrites, lunar soil, IDPs from previous studies and IOM residues.

The all-Au and Pt "CSSE" (closed-system step etching) line developed at ETH Zurich [see, e.g., 16] was attached to Manchester's RELAX [21]. ~60 µg of aerogel had been baked at 85 ºC in UHV for several weeks and ~0.3 ml of conc. HF was used for the chemical, low temperature destruction.

Procedural Xe blanks were negligible. The acid Xe blanks were high and comparable to some of the etch steps but still negligible compared to the gas-rich etch steps and the totally released amount of ^{132}Xe.

Trapped Xe in IDPs and AMMs:
Three IDPs showed ^{132}Xe above the detection limit. Among them is an "ultra-carbonaceous" IDP with ~50 wt% C and a chondritic-porous IDP with high 12 wt% C. Both IDPs also show high presolar grain abundances and isotope anomalies in H and N, implying a possible cometary origin [12,15]. The isotopic composition is consistent with Q, air or solar wind. Xe concentrations range from 1.7 x 10^{-8} to 2.5 x 10^{-7} cm^3/g (Fig. 1). The general short lifetime of IDPs combined with their limited residence in the inner solar system and shielding within cluster particles exclude that these large concentrations originate from solar wind exposure, but suggest instead a primordially trapped origin. This is similar to the conclusion of an earlier study on 4 very small (2-4 µm) metal-rich IDPs that were extracted together [22]. The Xe concentrations in the AMMs are comparable with literature values [e.g., 23-24]. Inferring the ultra-carbonaceous IDP is composed of ~40 % OM that contains all Xe, the Xe concentration of the OM in the IDP is comparable to those found in residues such as e.g. CM2 Cold Bokkeveld [16]. Although at a sub-µg scale the IDPs show some heterogeneity, the results further suggest the Xe-Q carrier is relatively uniformly distributed amongst organic material in IDPs, AMMs and meteorites.

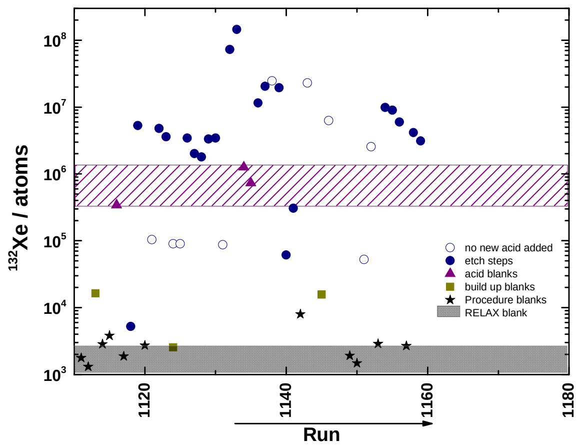

Fig. 2 Xe released during the etch run of 60 µg of aerogel compared to the RELAX, procedure, build-up and acid blanks.

Xenon in Aerogel:
We successfully released in total ~2.5 x 10^{-7} cm^3/g ^{132}Xe in 31 etch steps of very mild etching of aerogel (Fig. 2). The large concentration is the result of the huge surface area of ~20 cm x 20 cm for the 60 µg of aerogel. >90 % of the adsorbed terrestrial Xe was released in 2-15 min steps, mostly at -70 °C or 25 °C. In contrast, HF etching of SW-rich lunar samples releases <2 % of the trapped ^{4}He in the first 15 steps (in 8 - 40 min each, mostly at -22 to 0 °C [25]. The complete ^{4}He release is achieved only after many hours of etching at 25 °C [25]. Note that the SW-He is implanted only into the outer 10s of nm. SW-rich meteorites are etched by HF even more slowly: <2 % ^{4}He is released in the first 3-5 steps in 2h steps, mostly at 0 to 10 °C, and complete ^{4}He release is reached only after many days at 25 °C [25].

The amount released during etching is comparable with concentrations found earlier in aerogel [17] and in artificial Si smoke exposed during formation to Xe at high partial pressure [18]. However, phase Q is still 2 orders of magnitude richer in Xe, assuming it comprises of ~1 % of the OM-rich residue extracted from primitive meteorites [16]. Using the relative Ne/Xe trapping efficiency from the Si smoke [18] only a small fraction of the Ne found in the Stardust Wild 2 experiment [8] might be terrestrial. In conclusion, aerogel can be etched with HF in UHV (without any acid-related damage) and releases most Xe under very mild conditions, which suggests that the separation of cometary from adsorbed Xe is possible in an etch experiment of Wild 2 dust embedded in aerogel.

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