

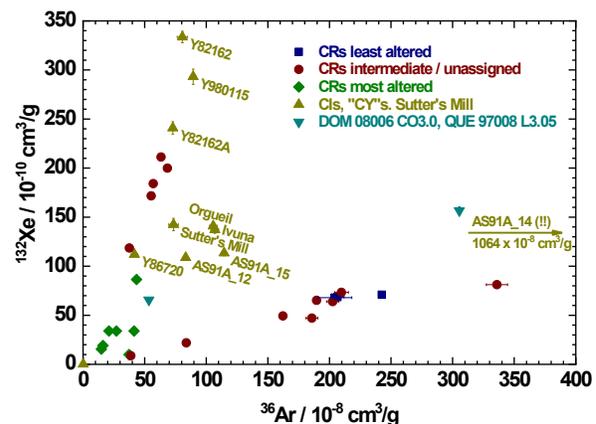
**NOBLE GASES AS IMPORTANT TRACERS FOR PROCESSES ON SMALL PLANETARY BODIES – A DETAILED LOOK AT THE CARBONACEOUS CHONDRITES.** H. Busemann and M. E. I. Riebe, Institute of Geochemistry and Petrology, ETH Zurich, Clausiusstrasse 25, CH-8092 Zürich, Switzerland (henner.busemann@erdw.ethz.ch).

**Introduction:** Noble gas analysis is essential to characterize and understand extraterrestrial materials. For two main groups of extraterrestrial materials noble gases play an important role in improving our understanding: (i) materials collected on/around the Earth (meteorites from the moon, Mars, asteroids and perhaps comets; asteroidal and cometary interplanetary dust particles and micrometeorites) and (ii) samples that have been, or are planned to be returned by space missions sampling asteroids (Hayabusa/II, OSIRIS-REx), the Moon (Apollo, Luna, Chang'e programs), Martian moons, the Sun (Genesis) and comets (Stardust).

By studying noble gases we can address a wide variety of essential scientific issues such as stellar nucleosynthesis and resulting primordial noble gas isotope anomalies, effects of the early active sun and accretion in the nebula, the timing of formation, impact and alteration events through gas retention ages, duration (and shielding) of exposure of materials on their parent bodies and in space, the alteration of primordially trapped noble gases during parent body alteration and the understanding of trapping mechanisms and carrier phases. Most of these processes are currently examined in our group. At the meeting, we will discuss processes that affected the primordially trapped noble gas contents in the various carbonaceous chondrite (CC) classes, which will be most relevant to the study and understanding of the C-rich asteroids Bennu and Ryugu.

**Experimental methods:** The noble gas laboratory at ETH Zurich examines extraterrestrial materials using a number of mass spectrometers and various extraction techniques. The latter cover all conventional techniques (IR laser stepwise heating [1,2], spatially resolved UV laser ablation, crushing and stepwise heating by fusion [3]) and the unique in-vacuum etching technique “CSSE” [4,5]. Mass spectrometers include the exceptional, custom built low-blank high-sensitivity instrument “Tom Dooley”, equipped with a compressor source that allows the detection of all He and Ne isotopes with significantly lower detection limits than commercial instruments [6], as well further single [3,5] and multi-collection instruments such as a new Nu instrument Noblesse with 5 Faraday/5 Multiplier configuration. The compressor source allows us to determine He and Ne concentrations and isotopic compositions even in small single grains. Recently we

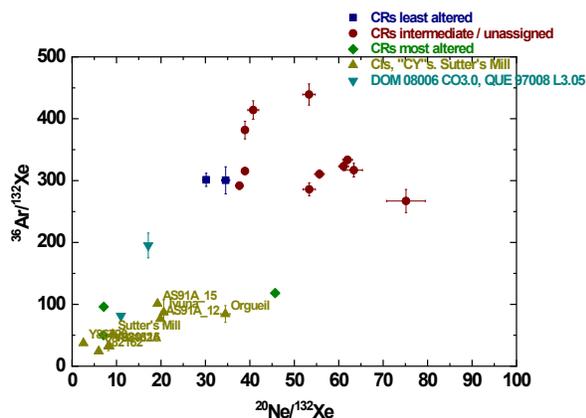
analyzed, e.g., hibonites bearing evidence for early solar activity [1], presolar grains showing their residence time in interstellar space [2] and single olivine grains returned by JAXA’s Hayabusa mission from LL type asteroid Itokawa to determine their exposure times to cosmic rays and solar wind [7,8] and fossil meteoritic chromite in sediments to reconstruct the fall of extraterrestrial material through time [9]. Online etching allowed us recently, e.g., to understand in detail the effects of aqueous alteration on presolar SiC and insoluble organic matter (IOM) and its noble gases on the Tagish Lake parent body [4], as well as the primordial noble gases in various acid soluble fractions of one of the least altered meteorites Miller Range (MIL) 090657 (CR) [10]. At the meeting we will mostly discuss data obtained by one temperature step (1700 °C) bulk extractions of carbonaceous chondrites. This data shows the effects of parent body aqueous alteration on potential carrier phases of a ubiquitous but poorly understood primordial noble gas component rich in Ar. In addition, we will combine this with recent results from the CSSE analysis of MIL 090657 [10], in which the Ar-rich component was analyzed directly.



**Fig. 1.** Trapped  $^{36}\text{Ar}$  and  $^{132}\text{Xe}$  concentrations in recently measured CCs (Y=Yamato, DOM=Dominion Range, QUE=Queen Alexandra Range [11], AS91A\_14=CI-type material from Almahata Sitta [12]). The least altered CR chondrites show significantly more abundant Ar than the other CRs. Trends towards increased  $^{132}\text{Xe}$  in CYs and likely CRs are strongly affected by terrestrial Xe contamination (up to 50 %, [13]).

**Results and Discussion:** The data presented here is part of a detailed program to examine a large number of carbonaceous chondrites of various classes to characterize their primordially trapped noble gas contents. The data will serve as a baseline for (i) a better understanding of the original distribution of trapped noble gases and their carriers (presolar grains, phase Q and potentially other acid-soluble minerals) in the nebula, (ii) the examination of the effects to noble gas concentrations and compositions of both aqueous and thermal alteration on the parent bodies, and finally (iii) modeling noble gases accreted by the terrestrial planets. So far, various CR, CM [14], CI, CY [13,15], CO [11] and ungrouped carbonaceous chondrites have been measured as well as CI type material recently found in fragments of Almahata Sitta [12]. Various conclusions can be drawn already from these studies:

The concentration of trapped Ar and likely Xe (corrected for terrestrial Xe) in CR chondrites is decreasing with increasing aqueous alteration experienced on the parent body (Fig. 1). This has been suggested earlier for CMs [16] and partly confirmed in a recent, more detailed study on CMs [14]. However, CM chondrites are complex rocks that are often brecciated and consist of lithologies of different petrologic type [17] which complicates the picture. Mineralogical studies by XRD on aliquots of the same samples are on the way to determine the exact petrologic type of the material analyzed for noble gases [10].



**Fig. 2.** Trapped  $^{36}\text{Ar}/^{132}\text{Xe}$  and  $^{20}\text{Ne}/^{132}\text{Xe}$  ratios in recently measured CCs. See Fig. 1 for details.

The CIs, CYs, Sutter's Mill and the most altered CR chondrites have significantly lower  $^{36}\text{Ar}$  concentrations as well as lower element ratios than CR chondrites with low to intermediate alteration (both figures). This suggests that at least one carrier of trapped  $^{36}\text{Ar}$  -and perhaps trapped  $^{20}\text{Ne}$  as well- is destroyed by aqueous alteration (CR3=>CR1). CR1s show concen-

trations and elemental ratios similar to the CIs and CYs which are also strongly aqueously altered. The Q (in IOM) / HL (in presolar diamond)-gas ratios remain largely unaltered in CRs. There is a tendency for Q and HL to be lost more readily than Ne-E during aqueous alteration of CR chondrites. The least altered CRs may contain 5x more Ar and 2x more Xe than CIs, and only ~20 % of all CRs contain solar wind.

Our results suggest that all CR, CI, CY, and C chondrites started with a similar inventory of trapped noble gases as the least altered CRs. This inventory was later modified by parent body aqueous alteration. Etching with various agents gives some hint for separate, yet unknown Ne and Ar carriers differently susceptible to water, acetic acid,  $\text{HNO}_3$ , HF, and HCl [10]. These carrier(s) could be amorphous silicates, and/or metal / metal-sulphide or other phases that were formed during nebula condensation or possibly associated with chondrule formation. Vogel et al. [18] indeed found an enrichment of Ar relative to Ne in metal-sulphide chondrule coatings formed during metal-silicate separation in molten chondrules. Such enrichment of (carbonaceous) phase Q expelled into the metal phase could perhaps explain the presence of high Ar concentrations.

**References:** [1] Kööp L. et al. (2018) *Nature Astron.*, 2, 709-713. [2] Heck P. R. et al. (in revision) *Proc. Nat. Acad. Science*. [3] Riebe M. E. I. et al. (2017) *Meteoritics & Planet. Sci.*, 52, 2353-2374. [4] Riebe M. E. I. et al. (in press) *Meteorit. & Planet. Sci.* [5] Busemann H. et al. (2000) *Meteorit. & Planet. Sci.*, 35, 949-973. [6] Baur H. (1999) *EOS Trans. AGU*, 46, F1118. [7] Busemann H. et al. (2015) *LPS, XLVI*, Abstract #2113. [8] Meier M. M. M. et al. (2014) *LPS, XLV*, Abstract #1247. [9] Schmitz B. et al. (2019) *Earth & Planet. Sci. Lett.*, 522, 234-243. [10] Krietsch D. et al. (2019) *82<sup>nd</sup> Ann. Meet. of the Meteorit. Soc. (LPI Contrib. No. 2157)*, Abstract #6296. [11] Davidson J. et al. (in press) *Geochim. Cosmochim. Acta*. [12] Goodrich C.A. et al. (in press) *Meteorit. & Planet. Sci.* [13] King A. J. et al. (in press) *Chemie Erde (Geochemistry)*. [14] Weimer D. et al. (2017) *80<sup>th</sup> Ann. Meet. of the Meteorit. Soc. (LPI Contrib. No. 1987)*, Abstract #6300. [15] Riebe M. E. I. et al. (2017) *Geochim. Cosmochim. Acta*, 205, 65-83. [16] Browning L.B. et al. (1996) *Geochim. Cosmochim. Acta*, 60, 2621-2633. [17] Bischoff A. et al. (2017) *80<sup>th</sup> Ann. Meet. of the Meteorit. Soc. (LPI Contrib. No. 1987)*, Abstract #6089. [18] Vogel N. et al. (2003) *Meteorit. & Planet. Sci.*, 38, 1399-1418.