NOBLE GASES IN CHASSIGNY AND THE MARTIAN INTERIOR. U. Ott[1,2] and S.P. Schwenzer[3], [1]Max-Planck Institute for Chemistry, Hahn-Meitner-Weg 1, 55128 Mainz, Germany; [2]Institute for Nuclear Chemistry (Atomki), Bem tér 18/C, 4026 Debrecen, Hungary; uli.ott@mpic.de; [3]EEES/STEM, The Open University, Milton Keynes, MK7 6AA, UK. (susanne.schwenzer@open.ac.uk).

Introduction: Heavy noble gases (Ar, Kr, Xe) in Chassigny have generally been assumed to represent the signature of the Martian interior, or, more specifically, the Martian mantle [e.g., 1]. Early work [*2*] suggested the presence of Xe with an isotopic composition similar to solar wind (SW), the presence of which was confirmed by [3] (Chass-S), who, in addition, identified another, "evolved", component (Chass-E) characterized by the addition of Xe from the fission of ^{244}Pu. A different result was recently obtained by Péron and Mukhopadhyay [4], who concluded that Kr and, with somewhat lesser certainty, also Xe in Chassigny and, by inference, the Martian mantle were "chondritic" in isotopic composition.

Critical comparison: For their interpretation, the authors of [4] quote and show in their figures data from previous work, but in the discussion and interpretation of the data they rely solely on their own results. While for Kr there is little previous useful analytical data (but see below), the situation is different for Xe. A comparison of their results with those for bulk Chassigny and an olivine separate in [3] indicates that Chassigny is not a homogeneous reservoir of Xe isotopes. At present, it is unclear which analyses are representative for Chassigny as a whole (and, therefore, the martian mantle).

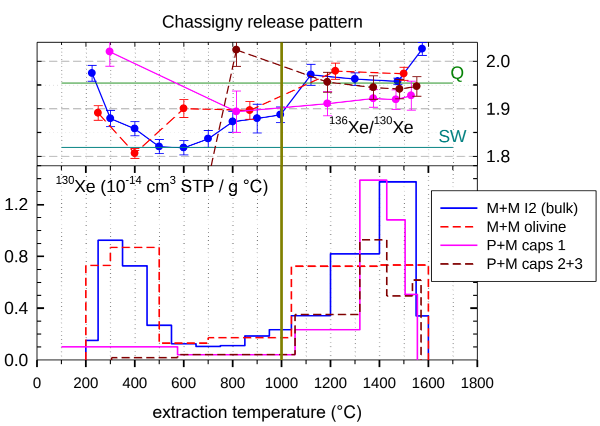

Fig. 1. The bottom section compares the release patterns for trapped ^{130}Xe in the analyses by Péron and Mukhopadhyay ("P+M"; [4]) and by Mathew and Marti ("M+M"; [3]). The amounts are normalized to the size of the temperature interval between successive extractions. The top part shows the corresponding ^{136}Xe/^{130}Xe ratios. The data have been corrected for cosmogenic contributions (see text).

Solar wind component. Fig. 1 compares, in the bottom part, the trapped (i.e., corrected for cosmogeic contributions) Xe release patterns, for the two samples from [3] and the two samples from [4]. Xe has the advantage that, in comparison to Kr, interfering cosmogenic contributions to the major isotopes are smaller and that differences between components that can be expected to be present are larger.

Two release peaks are apparent in the analyses of [3], one in the low-temperature regime (below 1000 °C) and another at high temperature, while the low-temperature part is missing in the analyses of [4]. Xe within the two peaks is distinct in isotopic composition, as shown in the top section of Fig. 1. At low temperature, ^{136}Xe/^{130}Xe ratios are close to the one in the solar wind [5], whereas the high-temperature part has a ratio similar to that of AVCC [6] and that in phase Q [7]. The component with the solar wind-like Xe is missing in the analyses of [4].

High-temperature component. Additional insight, with evidence for complexity in the high temperature observations as well, is apparent from looking at Fig. 2, which is a three-isotope plot of ^{132}Xe/^{130}Xe vs. ^{136}Xe/^{130}Xe. The data have been corrected for cosmogenic contributions following [8], with a (La+Ce+Nd)/Ba ratio ("REE/Ba" ratio) of 0.30 [9], where decomposition into trapped and cosmogenic is based on the ^{126}Xe/^{130}Xe ratio. The uncertainties in the cosmogenic ratios given by [8] have been propagated, together with a 50% uncertainty in the REE/Ba ratio. For extractions below 1000 °C (open symbols) solar wind was assumed for the trapped ^{126}Xe/^{130}Xe ratio, above 1000 °C (closed symbols) the ratio in Q was used. Since ^{126}Xe/^{130}Xe is almost equal in solar wind and Q (0.0252 vs. 0.0251), the resulting corrected ratios for the other isotopes are not sensitive to this choice.

All high temperature extractions from caps 2+3 [4] clump together, indicative of a single high temperature trapped component. Those from cap 1 also form a cluster, slightly offset, while the Xe composition of the martian mantle inferred by [4] plots intermediate between the two clusters. The low-temperature extractions of [3], on the other hand, which require little to no cosmogenic corrections, extend from there towards the SW composition. Like in case of [4], the high-temperature data points of [3] also form a cluster for each analyzed sample. The clustering of data points with both negligible and more significant cosmogenic contributions indicates reliability of the cosmogenic correction. Within each study, the differences are moderate, but the results from [3] and [4] are clearly distinct. The high-temperature extractions from [3] are consistent with a trapped composition that is either Q- or AVCC-like, but they are also consistent with a mixture of solar wind and fission Xe from ^{244}Pu. The latter explanation ("Chass-E") is that suggested by [3], but the alternatives are difficult to distinguish based on Xe data alone. In contrast, the high-temperature releases of [4], as well as the martian mantle composition inferred by [4], plot above AVCC/Q, at higher ^{132}Xe/^{130}Xe, close to a mixing line between solar wind and, surprisingly, (terrestrial) air. Interestingly, a similar composition had been reported in an abstract by [10], which is also included in Fig. 2 (labeled "O 83"). This result was discarded by [2], but in hindsight may have been real, given the data of [4].

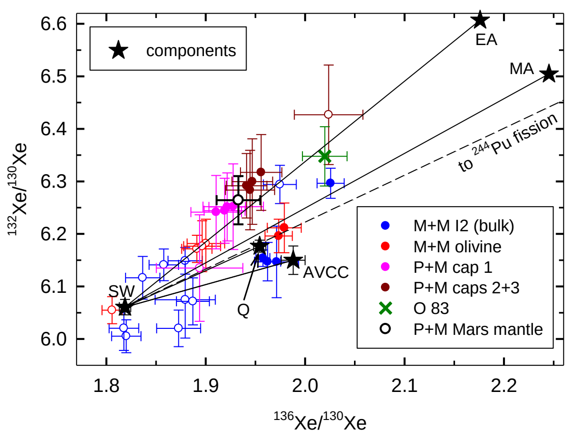

Fig. 2. Three isotope plot of ^{132}Xe/^{130}Xe vs. ^{136}Xe/^{130}Xe in analyses of Chassigny by Péron and Mukhopadhyay ("P+M"; [4]) and Mathew and Marti ("M+M"; [3]), as well as the Xe composition of the martian mantle ("Chassigny source") derived by [4]. Some low-temperature steps with little or undetectable Xe have been omitted. Also included is the analysis reported in [10] (labeled "O 83"). EA and MA designate terrestrial [11] and martian [12] atmosphere, SW is the solar wind composition [5], while and AVCC [6] and Q [7] are "planetary" trapped compositions observed in primitive meteorites.

The case of Kr. There are no literature data for comparison with [4] as detailed and precise as those of [3] for Xe. But it seems natural to expect that, had [3] analyzed also Kr, they would have found a low temperature peak in their samples, likely with SW-like composition, as for Xe. In fact, non-cosmogenic Kr in the analysis of [13], as evident in Fig. 1B of [4], has a composition virtually identical with SW. The measurement of [13] is a total extraction, but has small analytical errors. Surprisingly, [4] excluded it from further consideration because the study of [13] "was not targeted to determine the martian interior composition" [4]. This does not appear to be a valid reason.

Conclusions: Comparison of different analyses of Chassigny indicates that the meteorite is not a homogeneous reservoir of Kr and Xe isotopes, nor is it clear which phases of the complex geologic history the measurements – especially of bulk – might record [see e.g., 14]. This hinders conclusions about the noble gas reservoir of the Martian interior. A low-temperature SW-like component has been seen in some, but not all studies, while Xe released at higher temperature may either be "evolved SW" [3] or similar to "chondritic" (Q or AVCC) in composition. If the latter, the analyses of [3] are compatible with well-characterized "chondritic" Xe components, whereas those of [4] imply presence of a rather specific "chondritic-like" Xe component.

"Chondritic" vs. "solar". The terms "solar" and "solar wind" are often used indiscriminately by workers in the field, including the authors of [4]. The isotopic compositions of the solar wind do not equal those of the bulk Sun (and likely, by inference, those in the nebular gas), however. For He, Ne and Ar this has been demonstrated by [15] from analyses of SW captured by the Genesis mission. It is difficult to extrapolate the observations to Kr and Xe, but estimates in [16] suggest that "chondritic" and "bulk solar" being (almost) the same is within the range of possibilities. If so, the presence of "chondritic" Kr and Xe in Chassigny (and martian interior) [4] might not exclude acquisition of this component from the solar nebula, as an alternative to its acquisition via chondritic matter.

References: [1] Ott U. et al. (2019) in: "Volatiles in the Martian Crust" (eds. J. Filiberto, S.P. Schwenzer), pp. 35-70, Elsevier. [2] Ott U. (1988) *GCA, 52*, 1937-1948. [3] Mathew K.J. and Marti K. (2001) *JGR, E106*, 1401-1422. [4] Péron S. and Mukhopadhyay S. (2022) *Science, 377*, 320-324. [5] Meshik A. et al. (2015) *LPS XLVI*, Abstract #2640. [6] Swindle T.D. (1988) in: "Meteorites and the Early Solar System" (eds. J.F. Kerridge, M.S. Matthews), pp. 535-564. University of Arizona Press. [7] Busemann H. et al. (2000) *MAPS, 35*, 949-973. [8] Hohenberg C.M et al. (1981) *GCA, 45*, 1909-1915. [9] Lodders K. (1998) *MAPS, 33*, A183-A190. [10] Ott U. et al. (1983) *LPS XIV*, 586-587 (abstract). [11] Ozima M. and Podosek F. (2002) Noble Gas Geochemistry, Cambridge University Press. [12] Conrad P.G. et al. (2016) *EPSL, 454*, 1-9. [13] Eugster O. et al. (2002) *MAPS, 37*, 1345-1360. [14) McCubbin F.M. et al. (2013) *MAPS, 48*, 819-853. [15] Heber V.S. (2012) *ApJ, 759*, #121. [16] Ott U. (2014) *ChemErde-Geochemistry, 74*, 519-544.