NOBLE GASES IN MARTIAN METEORITES: A PUZZLE OF COMPONENTS, SOURCES, PATHWAYS AND SINKS. S. P. Schwenzer[1] and U. Ott[2] [1]The Open University, Walton Hall, Milton Keynes MK7 6AA, UK. susanne.schwenzer@open.ac.uk; [2]University of West Hungary, H-9700 Szombathely, Hungary.

Introduction: Noble gases have been measured in the Martian atmosphere by the Viking lander [1] and Curiosity rover [2], and in rock samples collected at Gale Crater by the Curiosity rover [3]. A second, important source of data on Martian noble gases stems from measurements of the Martian meteorites. In fact, noble gas measurements in melt glass pockets of shergottite EETA79001 provided the first data-based clear evidence that the source of the SNC meteorites is indeed Mars [4].

Martian reservoirs: Noble gases in Martian meteorites are usually a mixture of a variety of components. On Mars, atmosphere, interior and fractionated atmospheric components occur and specific isotopes are formed as radiogenic / nucleogenic products, including fission and spallation processes. In addition, during space travel cosmogenic isotopes are formed. Once on Earth, terrestrial atmosphere – elementally fractionated in most cases – adds to the picture. Here we will focus on the Martian components interior and atmosphere and investigate the complications inflicted by terrestrial atmospheric contamination.

Shergottites and the atmosphere. The noble gas composition of the Martian atmosphere was first measured in-situ by the Viking lander [1], and subsequently found in shock glass of EETA79001 [4]. Shergottite samples generally fall onto a trend between the atmospheric endmember and Martian interior (Fig. 1). Martian atmospheric heavy noble gases shown in this plot are characterized by a ^{84}Kr/^{132}Xe ratio of 20.5±2.5 and ^{129}Xe/^{132}Xe = 2.590±0.031 [see [9] for review]. The ^{40}Ar/^{36}Ar ratio was measured as 3000 by Viking [1], but suggested to be considerably lower (~1900) from EETA79001 measurements [10]. The Curiosity rover found 1900±300 [2].

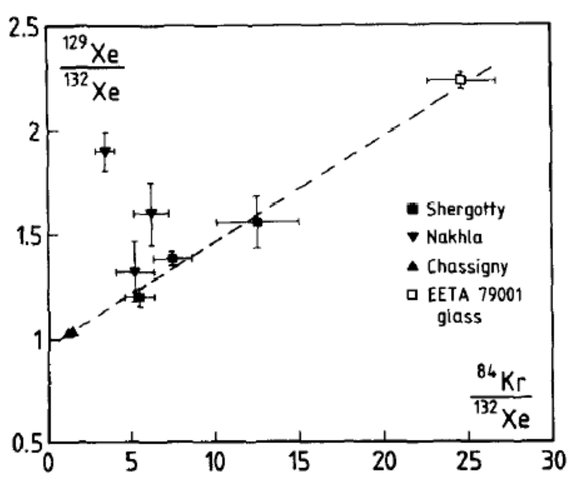

Figure 1. *^{129}Xe/^{132}Xe vs. ^{84}Kr/^{132}Xe plot from [5]. Plotted are high temperature steps of Shergotty, Nakhla and Chassigny measurements [5] and the composition of Martian atmosphere as found in EETA 79001 glass by [6].*

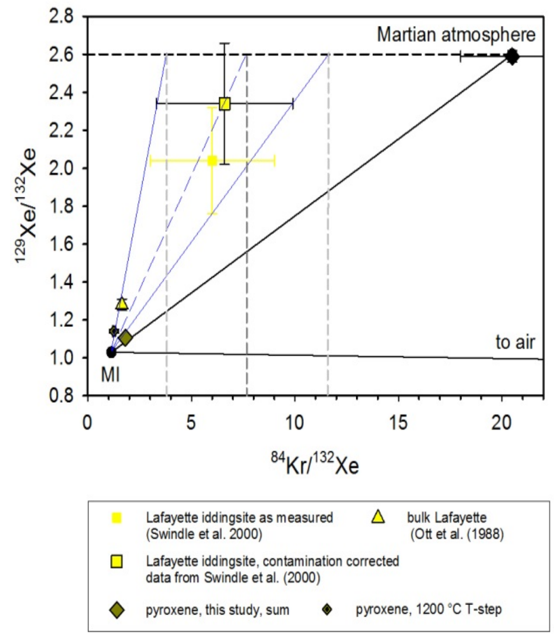

Figure 2. *^{129}Xe/^{132}Xe vs. ^{84}Kr/^{132}Xe in the nakhlite meteorite Lafayette, corrected for Earth atmosphere contamination. Martian atmosphere as measured by Viking[1] and in the EET 79001 meteorite [6], MI from [5]. Within uncertainties, the data suggest a mixture of interior component and elementally fractionated Martian atmosphere (EFM), with the latter having the ^{129}Xe/^{132}Xe ratio of the Martian atmosphere, and ^{84}Kr/^{132}Xe ~8. Data from [7] and [8].*

Chassigny and the interior. An interior component was first identified in Chassigny ([5]; Fig. 1), where it is characterized by a ^{84}Kr/^{132}Xe ratio of 1.14±0.06 and overall solar-wind like Xe, with ^{129}Xe/^{132}Xe = 1.03±0.02 [5]. [11] found the same solar like Xe (Chass-S) in Chassigny and ALH84001, along with an evolved Xe-component (Chass-E). Reported ^{40}Ar/^{36}Ar of the Martian interior spans a wide range between ~300 and 2000 [12-15], and the current assumption is that there are (at least) two interior components [e.g., 14].

Nakhlites and the fractionated atmospheric component. The nakhlite Martian meteorites contain a component with an elementally fractionated signature of the heavy noble gases compared to the atmosphere, but apparently having atmospheric isotopic composi-

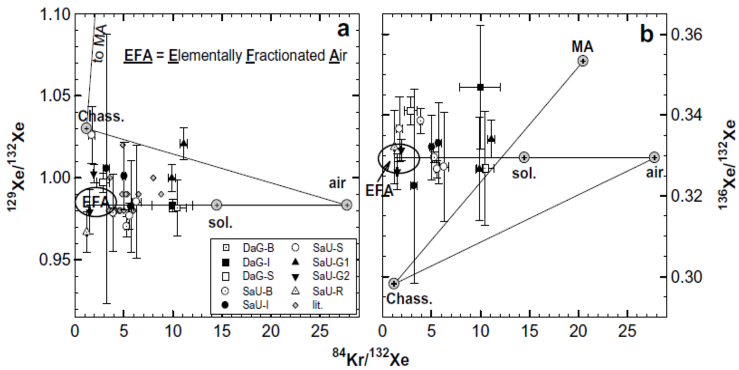

Figure 3. *Plot of isotopic ratios $^{129}Xe/^{132}Xe$ (a) and $^{136}Xe/^{132}Xe$ (b) vs. $^{84}Kr/^{132}Xe$ for ''low temperature" data (usually <1000 °C and/or with $^{129}Xe/^{132}Xe$ < 1.03) from hot desert Martian shergottites From [16] (their Fig. 3). For literature data and endmembers see [16] and references therein.*

tion. Fig. 2 shows data for the nakhlite meteorite Lafayette, corrected for contamination with air [17]: olivine with Martian alteration, bulk rock, and cleaned mineral separates. The corrected data fall (within uncertainty) on a mixing line between the Martian interior component (Chassigny) and a component with high ^{129}Xe/^{132}Xe and moderate ^{84}Kr/^{132}Xe. Assuming that the pure component has the atmospheric ^{129}Xe/^{132}Xe ratio of 2.6, then its ^{84}Kr/^{132}Xe ratio is ~8 [17], far lower than the Martian atmosphere value of 20.5 [9]. The origin of this component is under considerable debate [18-27], with hypotheses ranging from unfractionated incorporation of an (earlier) atmosphere with different composition to uptake of a sedimentary component into the magma and to elementally fractionated incorportion of atmosphere of Viking/shergottite composition during formation of the alteration minerals.

ALH84001 and NWA7034. Two of the Martian meteorites are dated as Noachian in age. ALH84001 is an orthopyroxenite [28], and NWA7034 is a crustal breccia [29]. Both meteorites contain a Martian atmospheric component, whereby elemental fractionation similar to the nakhlites has been found in ALH84001 [e.g., 11]. For NWA7034 the signatures measured so far are mostly resembling modern atmosphere, but could hint at a fractionated component, too [30]. If fractionated atmosphere were confirmed in NWA7034, then alteration - as observed in ALH84001 [28] and NWA7034 [29] - could be a common process introducing a fractionated Martian atmospheric component. However, this requires a more detailed study of NWA7034, especially clast and mineral separation.

EFA – terrestrial fractionated air: Many finds amongst the Martian meteorites show a low temperature step that plots close to the Martian interior component in plots of ^{129}Xe/^{132}Xe vs. ^{84}Kr/^{132}Kr or vs. ^{36}Ar/^{132}Xe [16](Fig. 3). This has been attributed to dominance of elementally fractionated terrestrial air (EFA). It has recently been shown that hot [16] and cold [31,32] desert finds contain variable, but usually significant, amounts of EFA. Unfortunately, EFA is also introduced during standard laboratory procedures such as etching and grinding, and may require degassing temperatures as high as 600 °C [34].

Open questions and useful spacecraft investigations: The two most important questions concerning the trapped components are: i) How homogeneous is the Martian interior? ii) What is the source and incorporation mechanism of elementally fractionated Martian atmosphere? The first calls for in depth meteorite studies, because mineral separation and stepwise heating enable access to the gases incorporated into minerals from the interior which have the highest degassing temperatures. In contrast, the atmospheric component is released at lower temperatures, and sited either in alteration phases or distributed on grain surfaces. This signature can be measured with current spacecraft technology, which would provide insight into atmosphere-surface-subsurface interaction and volatile pathways and sinks on Mars.

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