NOBLE GASES IN THE LL5 CHONDRITE CHELYABINSK. H. Busemann[1], E.R. Toth[1], P.L. Clay[1], J.D. Gilmour[1], M. Nottingham[1], I. Strashnov[2], R. Wieler[3], K. Nishiizumi[4] and R.H. Jones[5]. [1]SEAES, University of Manchester, Manchester M13 9PL, United Kingdom, (henner.busemann@manchester.ac.uk), [2]School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK, [3]ETH Zurich, Institute for Geochemistry and Petrology, 8092 Zurich, Switzerland, [4]Space Sciences Laboratory, University of California, Berkeley, CA 94720, USA. [5]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA.

Introduction: The fall of the LL5 chondrite Chelyabinsk in Russia in Feb. 2013 attracted significant attention, particularly because of the considerable damage caused, the well-documented bolide, and the large mass [1-5]. The pre-atmospheric diameter and mass of the meteoroid were ~19 m and ~12,000 tons, respectively [1,2]. Only some 0.01 % has been found on Earth; the largest piece of ~650 kg was recovered in Oct. 2013 from the ground of Lake Chebarkul [3]. Scientifically, Chelyabinsk is especially interesting, albeit being an “ordinary” type 5 LL chondrite, because the orbital parameters could be precisely determined, due to the abundant footage of the trajectory [1,2,4]. However, the large mass of the meteoroid renders the determination of the travel time in space difficult. This is important to assess potential parent asteroids. Many fragments of Chelyabinsk have been distributed since the fall, and a few have been analyzed for the presence of cosmogenic nuclides [1,6].

With this full noble gas characterization of Chelyabinsk we aim to determine (i) its element abundances and isotope compositions of He-Xe that will allow a comparison with the LL chondrite literature, (ii) its halogen contents, as part of our comprehensive study of halogens in primitive meteorites [7], (iii) its Ar-Ar systematics and potentially an age for a late reheating event on the parent body, (iv) the cosmic-ray exposure age, based on the ^{81}Kr-Kr system, and finally (v) potential differences between fragments recovered freshly after the fall and those from the lake, to assess the impact of terrestrial alteration and the location of the fragments in the meteoroid, assuming that the main mass resided in the centre of the meteoroid.

Table 1 Noble gas concentrations and isotopic ratios in Chelyabinsk.

	^{20}Ne 10^{-8} cm^3/g	^{20}Ne/^{22}Ne	^{21}Ne/^{22}Ne	^{84}Kr 10^{-10} cm^3/g
1700 °C	0.221±0.004	1.018±0.017	0.9121±0.0027	0.611±0.021
ReEx	n.d.			0.0564±0.0014
total	**0.221±0.004**	**1.018±0.017**	**0.9121±0.0027**	**0.667±0.021**

n.d. = not detected

Here, we discuss measurements on a fragment from the University of New Mexico [8] (“MB001” , original mass 66 g), comprising bulk noble gases (i) and initial Kr results (iv). Further data including more Kr isotope data (iv), the halogens content (ii) and the Ar-Ar systematics (iii) will be presented at the meeting.

Table 1 continued

	^{4}He 10^{-8} cm^3/g	^{3}He/^{4}He x 10000	^{36}Ar 10^{-8} cm^3/g	^{36}Ar/^{38}Ar	^{40}Ar/^{36}Ar
1700 °C	67.62±0.12	134.1±0.6	0.3759±0.0015	4.087±0.027	538±12
ReEx	n.d.		n.d.		
total	**67.62±0.12**	**134.1±0.6**	**0.3759±0.0015**	**4.087±0.027**	**538±12**

	^{78}Kr	^{80}Kr	^{82}Kr ^{84}Kr≡100	^{83}Kr	^{86}Kr
1700 °C	0.58±0.04	4.10±0.21	20.5±1.0	21.7±1.0	31.5±1.3
ReEx	0.62±0.17	4.3±0.6	20.4±1.6	20.1±1.8	29.5±1.2
total	**0.59±0.04**	**4.12±0.23**	**20.5±0.9**	**21.6±0.9**	**31.3±1.5**

Experimental: (i) Fragment “MB001g”, 240 mg, allocated to Manchester, showed the typical dark shock veins of metal-sulfides [8], partially crosscutting each other, brown patches, metal and was otherwise inconspicuous. The noble gases in a largely uncrushed piece (92.65 mg) were measured by pyrolysis in two ~1700°C steps at ETH Zurich (see, e.g., [9,10] for details). The “re-extraction” step was performed to verify complete extraction: 8 % of the total Kr and 3 % of Xe were released in the second step. He-Ar were completely released in the first step. Blank corrections were ≤1 % for He and ^{21,22}Ne, 4 % for Xe, ~10 % for ^{20}Ne, ^{40}Ar and 14-18 % for ^{36,38}Ar and Kr. Concentrations and isotope ratios are given in Table 1. (ii-iii) Six small aliquots of 0.4 – 3.3 mg were n-irradiated in the NRG reactor, Petten, The Netherlands, (neutron fluence ~2 × 10^{18} n/cm^2 for ~24h) for Cl, Br, I and Ar-Ar age determinations [7], by noble gas mass spectrometry with the Thermo Scientific Argus instrument, recently installed in Manchester. (iv) Two samples (5.37±0.01 and 12.00±0.03 mg) were measured with the high-sensitivity resonance ionization mass spectrometer “RIMSKI” in Manchester for Kr isotope abundances. The extraction followed the methods described in [11,12]. Only the larger sample yielded probable cosmogenic ^{81}Kr above the background. (v) Small fragments from the lake Chebarkul piece will be analyzed in identical ways as described above, as soon as they are made available.

Results: (i) The bulk He-Xe results are roughly consistent with Chelyabinsk being an LL5 chondrite. The trapped Ar concentration (~95 % of the measured ^{36}Ar), is below most values measured in LL5 and LL6 chondrites [13], whereas ^{84}Xe and ^{132}Xe concentrations are similar to previously reported values for falls and hot desert finds [14-15]. Unusually large absorption of Kr and Xe onto MB001 after the fall due to terrestrial weathering did not occur. The isotopic compositions of Kr and Xe are consistent with air or Q-gas compositions (Fig. 1), with the exception of a slightly elevated ^{83}Kr and a high ^{129}Xe/^{132}Xe ratio (see below).

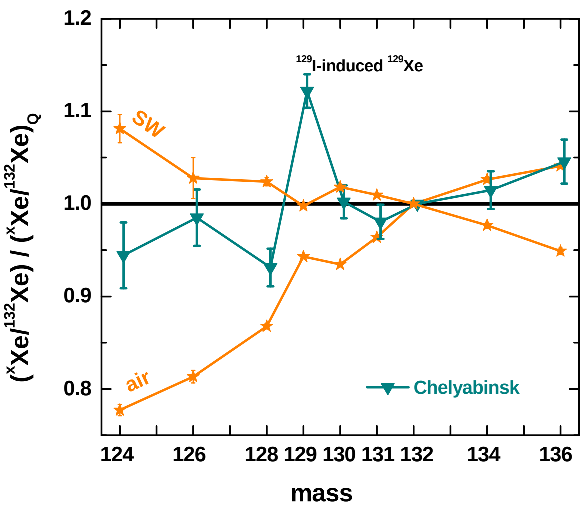

Fig. 1. The Xe isotopic composition in Chelyabinsk normalized to Q-Xe [10] and compared with solar wind and air.

^{3}He and Ne concentrations are low and nevertheless dominantly of cosmogenic origin. The lack of any solar wind signature in He and Ne excludes that this sample was in a regolith environment. Interestingly, the Chelyabinsk data point plots perfectly and centrally ((^{22}Ne/^{21}Ne)$_{cosm}$ ~ 1.089) on the so-called "Berne-line" in cosmogenic ^{3}He/^{21}Ne-^{22}Ne/^{21}Ne space [e.g., 16] indicating that He was not preferentially lost during atmospheric entry. The ^{4}He content in MB001 is nevertheless exceptionally low, compared to a typical radiogenic ^{4}He concentrations of ~1000-1500 × 10^{8} cm^{3}/g in LL chondrites, implying a major, rather recent gas loss on the parent body not accompanied by ^{3}He loss. A rather complete noble gas loss on the parent body early but after complete accretion can be excluded, because a ^{129}Xe/^{132}Xe ~1.17 indicates the presence of once live ^{129}I (half life 15.7 Ma) and at least partial retention since radiogenic ^{129}Xe accumulation.

While it is impossible to determine a proper ^{21}Ne exposure age without knowing the shielding conditions of our sample (the (^{22}Ne/^{21}Ne)$_{cosm}$ "shielding indicator does not give a unique depth), it is possible to compare a preliminary ^{36}Cl/^{21}Ne exposure age [6] with our first very preliminary result of our current RIMSKI study on two small aliquots of MB001. This appears to reveal the presence of ^{81}Kr (see Fig. 2). As the exposure age of Chelyabinsk is in any case short (consistent with low cosmogenic ^{3}He, ^{21}Ne, ^{38}Ar and a ^{36}Ar/^{38}Ar of ~4.1), the lack of abundant cosmogenic Kr isotopes (cf. Table 1) and the dominance of trapped Kr (albeit its low concentrations) hampers the determination of a precise ^{81}Kr-Kr age. Our current "best estimate" however is consistent with a short exposure to cosmic rays of <5 Ma, consistent with predictions of a "short exposure age" [2] and with the ^{36}Cl/^{10}Be exposure age of ~1.5 Ma given by [6].

Table 1 continued

	^{132}Xe 10^{-10} cm^3/g	^{124}Xe	^{126}Xe ^{132}Xe≡100	^{128}Xe
1700 °C	0.962±0.012	0.436±0.015	0.397±0.011	7.67±0.13
ReEx	0.049±0.006	0.17±0.10	0.50±0.11	7.1±0.7
total	**0.962±0.012**	**0.430±0.015**	**0.400±0.012**	**7.66±0.15**

	^{129}Xe	^{130}Xe	^{131}Xe ^{132}Xe≡100	^{134}Xe	^{136}Xe
1700C	117.3±1.7	16.23±0.23	80.3±1.2	38.5±0.7	33.1±0.7
ReEx	105±5	16.4±0.8	77±3	34.3±3.0	30.8±2.1
total	**117.0±2.1**	**16.23±0.29**	**80.3±1.5**	**38.4±0.8**	**33.1±0.8**

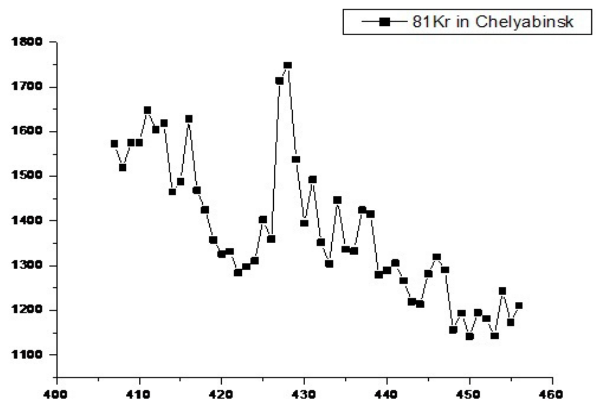

Fig. 2. ^{81}Kr detected with RIMSKI in 12 mg of Chelyabinsk (arbitrary units).

Acknowledgement: The work was made possible by the Paneth Meteorite Trust undergraduate internship program (E.R. Toth) and funding by STFC and ERC (P.L. Clay).

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