CRACKING THE ELEMENTAL GENETIC CODE OF THE ATMOSPHERIC NOBLE GASES: THE "MISSING" ^{36}ARGON AND ^{84}KRYPTON. M. Maurette, CSNSM, Bat. 104, 91406 Orsay−Campus, France, maurette@csnsm.in2p3.fr.

Introduction: Large unmelted micrometeorites with sizes ~100−200 µm, recovered from Greenland and Antarctica (AMMs), originate from the peak of the meteoroid mass distribution in space, which corresponds to MicroMeteoroids (***µMs***). We have argued that they dominantly fed the formation of the terrestrial atmosphere [1, 2], even though we could not decrypt the "mystery" of the noble gases (NGs) −as summarized in Ref. 3, p. 249). Recently, this scenario was further supported by the finding that the expected ***µMs*** burdens of S and Ir-group elements are similar to those locked in the primitive upper mantle (PUM). It is timely to look again at the NGs mystery in a ***µMs***- base atmosphere.

The meteoroid accretion equation: This equation predicts the total amount, **M**(A), of any species, **A**, delivered to the Earth by the micrometeoroid flux, since the formation of the Moon by a giant impactor, at t_0 ~ 4.44 Ga. It reads as:

$$\mathbf{M}(A) = \mathbf{A}\ (g/g) \times \Phi_{\mu Ms}(t_0)$$

where **A**(g/g) is the measured average concentration of a given species, **A**, in AMMs and $\Phi_{\mu Ms}(t_0)$ the integrated ***µMs*** mass flux accreted by the Earth since the formation of the Moon. In this ***Early MicroMeteoroid Accretion*** scenario (***EMMA***), the Moon forming impactor also blew off the intractable pre−lunar atmosphere. Section 4, in Ref. 2, outlines the most recent derivation of this formula, where $\Phi_{\mu Ms}(t_0)$ ~5.6×10^{24}g is deduced from both: (i) the Hartmann-Neukum "relative" lunar cratering rates, and; (ii) the contemporary mass flux of micrometeoroids, φ_0.

The value of φ_0 is a key parameter, which was derived from: (i) the mass flux of AMMs (7,300 tons yr^{-1}) directly inferred from their numbers and size distributions in known ~100 kg aliquots of snow collected at Dome C, in 2006 —this value obtained with the best statistics is still unpublished [4]; (ii) a correction factor that scales the efficiency of collection of a flat snow surface at Dome C (~40%), which is related to the Earth's obliquity [5]; (iii) the destruction of at least ~60% of the micrometeoroids upon atmospheric entry. The final value of φ_0 (~45,000 tons/yr), is similar to an estimate from ***µMs*** impact craters on LDEF [6].

Supports for *EMMA*: Let us compare the predicted **M**(A) values deduced from the measured concentrations of these species in AMMs to the observed values. Two groups of elements have been considered: (i) atmospheric species, Ne, N_2, H_2O, CO_2 [1], and; (ii) S and Ir−group elements (Ir, Os, Ru) in PUM [2, 7]. A "*misfit ratio*" (bold−italics), has been next attached to these species. For the first group, it scales as the ratios between the predicted to observed amounts, of about ***1.2*** (^{20}Ne), ***0.98*** (N_2), ***1.6*** (CO_2), ***0.40*** (H_2O). For Ne, N_2 and C the predicted amounts are spread within a factor 2 of the corresponding measured values, i.e., within the factor ~2 uncertainty of the accretion equation. This a good fit when going so far back in Hadean times with species that differ so much in both their properties and concentrations in ***µMs***. For the second group, the concentrations of S and Ir−group elements in AMMs have been reported in Refs. 8 and 9, respectively. I next assumed [1, 7] that their have been fully forwarded and locked into PUM, in accordance with the geochemical model of the "layered" mantle. This yields their predicted concentrations in PUM. Now, the *misfits* scales as the ratios of these meteoroid concentrations to the corresponding values measured in PUM: S ~ 254 ppm (Ref. 10, p. 1259) and, Ir ~3.5 ppb, Os ~ 3.9 ppb and Ru ~ 7.1 ppb [11]. The *misfits* are surprisingly small, i.e., good (especially for S and Ir), as they rank as: ***1.10*** (S), ***0.91*** (Ir), ***0.77*** (Os) and ***0.82*** (Ru).

NGs "reference" concentrations: By definition, they refer to the concentrations of ^{20}Ne, ^{36}Ar, ^{84}Kr and ^{132}Xe, which would have delivered the measured burden of each NG in the atmosphere. They are deduced just dividing these burdens by $\Phi_{\mu Ms}(t_0)$, and transforming the unit of g/g into cm^3 STP/g (cc/g). I next compare these values to the concentrations measured in: (i) 26 AMMs from Dome Fuji, Antarctica [12]; (ii) 31 unmelted micrometeorites collected in Greenland and Antarctica [13], and preselected by Chad Olinger and myself.

Figure 1 shows the 4 histograms of the distributions of the measured concentrations of NGs in the Dome Fuji AMMs reported by Osawa et al [14]. These histograms also include: (i) the reference concentrations (**red arrows**); (ii) the corresponding mean measured concentrations of Dome Fuji AMMs (**dark** arrows) as given in Ref. 14 (Table 3) for ^{36}Ar, ^{84}Kr, ^{132}Xe, but in Ref. 15 (Table 3) for ^{4}He and ^{20}Ne, now restricted to a subset of "unmelted" AMMs; (ii) The corresponding mean concentrations (**purple** arrows) inferred from Olinger's data for Ne and Ar, which rather well fit the corresponding Dome Fuji values. In this last work, 31 unmelted AMMs (i.e., excluding vesicular, scoriaceous, and "possibly" and/or or "partially" melted AMMs) among 73 analyzed particles could be selected for Ne, but only 4 for Ar (in Table B9). They had to further show: (i) weights ≥ 0.2 µg, measurable with a precise balance ("visual" estimates are banned); (ii) signals at ^{20}Ne and ^{22}Ne that are ≥ 3σ above blank level; (iii) solar Ne isotopic compositions.

Discussion and prospects:

Missing Ar and Kr in the micrometeoroid atmosphere. The red arrows in figure 1 show that the "virtual" NGs concentrations fits the corresponding observed values for ^{20}Ne and ^{132}Xe. However, they largely exceed the measured ^{36}Ar and ^{84}Kr values by a factor ~12−18x. Therefore, with ***EMMA***, the mystery of the "missing" Xe has vanished, but the now missing Ar and Kr had to be supplemented by "spikes" of Ar and Kr. Owen et al [16] reported that simulated cometary ices strongly adsorb Ar and Kr, relatively to Ne and Xe, at ≤ 50K. They suggested that the impacts of comets might have delivered spikes of Kr and Ar to an early atmosphere. Subsequently, Marty and Meibom [17] did model the effects of such spikes on a chondritic asteroid base atmosphere.

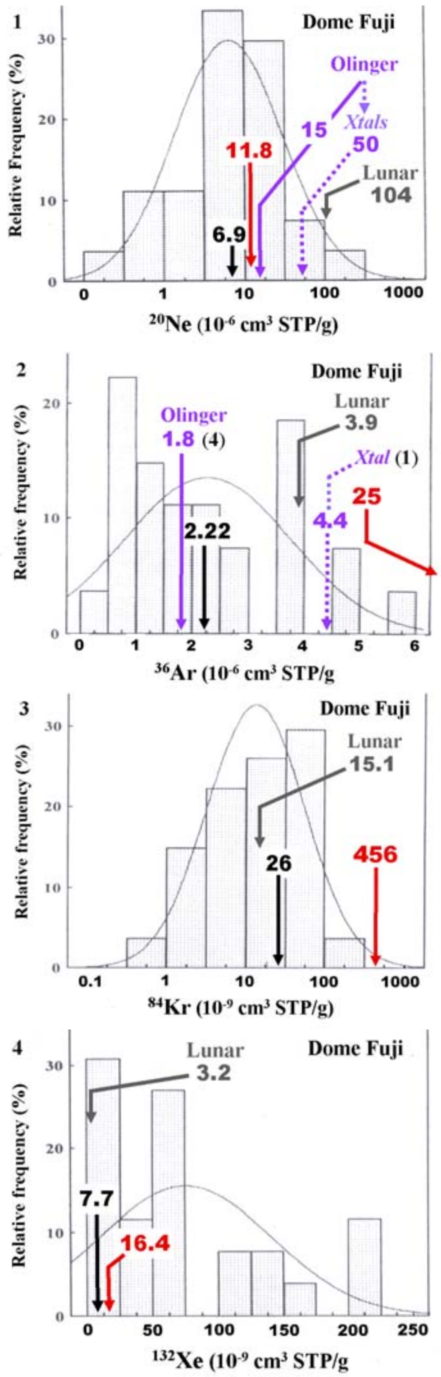

Figure 1. Histograms of the distributions of the concentrations of ^{20}Ne, ^{36}Ar, ^{84}Kr and ^{132}Xe measured in 26 Dome Fuji Antarctic micrometeorites (in cm^3 STP/g). Adapted from figures 1, 2 and 3 in Ref. 14.

This dual ***μMs***–comets model is strictly constrained by: (i) The D/H ratio of the terrestrial oceans (SMOW), which fits the AMMs value. This implies that the total mass of the "spiking" comets has to be ≤ 0.05x$\Phi_{\mu Ms}(t_0)$~ 3x10^{23} g, as to avoid increasing the SMOW value with heavy cometary waters; (ii) The observed Ne/N_2 ratio of the atmosphere, which also fits the AMMs values. Simultaneously, this excludes a base atmosphere released during the impacts of CI– or CM–types asteroids that would generate ≥100x smaller ratios (c.f., Ref. 1, p. 83).

Hazardous comparisons with solar NGs in IDPs and lunar soils. Intact particles with size ~100 µm are not found in the IDPs collection (i.e., when large "cluster" IDPs that fragment upon collection are disregarded). A comparison with lunar soils is more relevant in spite of difficulties, such as: (i) the accumulation and mineral retentivities of solar ions in ***µMs*** and the lunar regolith; (ii) the huge and confusing variety of lunar soil samples used for NGs studies.

"Bulk" lunar soils have to be disregarded, due to the complex NGs contributions of their glassy agglutinates. I did focus on a well defined size fraction (~100µm) of the most retentive mineral (ilmenite) investigated in Ref. 18. I also considered the ~5–fold lower specific mineral retentivities of Ne and Ar in olivine and pyroxene. They mostly compose the "crystalline–type" micrometeorites (***Xtals***), only identified in the Olinger's data (**purple dotted** arrows in Fig. 1). The extrapolated lunar NGs concentrations (**grey** arrows in Fig. 1) rather well fit the corresponding AMMs values, with the exception of Ne that only fits the higher ***Xtals*** value.

In a ***µMs*** base atmosphere the mystery of the "missing" ^{132}Xe [3] has been substituted by that of the "missing" ^{36}Ar and ^{84}Kr. Cometary impacts might have supplemented the Earth with the right amounts of Ar and Kr, without noticeably affecting the $^{20}Ne/N_2$ and D/H ratios of the terrestrial atmosphere and oceans, respectively.

References: [1] Maurette M. (2006) *Micrometeorites and the mysteries of our origins* (Springer: Berlin), 330p. [2] Maurette M. (2009) Forthcoming. Hydrous–Carbonaceous Meteoroids in the Hadean Aeon. *ASP Conf. Series.* [3] M.Ozima M. and Podosek F.A. (2002) *Noble gas Geochemistry* (Cambridge Univ. Press), pp. 1-286. [4] Duprat J. (2009) The Dome C Antarctic micrometeorites. Seminar at CSNSM. [5] Maurette M. (2008) *Meteoritics & Planet. Sci., 23*, Supp., A93. [6] Love S.G. and Brownlee D.E. (1993) *Science, 262*, 550-553. [7] Maurette M. (2009) *EPSC Abstract, 4,* EPSC2009-302. [8] Duprat et al. (2007) *Adv. Space Res., 39,* 605–6013. [9] Kurat G. et al (1994) *GCR, 58,* 3879-3904. [10] Morgan J.W. et al (2001) *Meteoritics & Planet. Sci. 36*, 1257-1275. [11] Becker H. et al (2006) GCA, 70, 4528-4550. [12] Osawa T. and Nagao K. (2002a) *Meteoritics & Planet. Sci. 37,* 911-936. [13] Olinger C.T. (1990) PhD thesis, Washington University, St Louis, pp. 1-222. [14] Osawa T. and Nagao K. (2002b) *Antarctic Meteorite Res., 15,* 165-177. [15] Osawa T. et al. (2003) *Meteoritics & Planet. Sci. 38,* 1627-1640. [16] Owen T. et al (1992) *Nature, 358,* 43-46. [17] Marty B. and Meibom (2007) *eEarth Discu., 2,* 99-113. [18] Eberhardt P. et al (1970) *Proc. Apollo 11 Lunar Sci. Conf, 2,* 1037-1070.

Acknowledgments: This discussion is rooted in the works of many colleagues, and the supports of IN2P3 and IPEV. I thanks K.Osawa and collaborators, for their decisive AMMs analyses, and G.Kurat and C.T. Olinger for their companionships in AMMs research and NGs adventures, respectively.