INDIGNEOUS LUNAR GASES FROM THE EARTH WIND – AN EXPERIMENTAL VERIFICATION.

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Introduction: Comparison of elemental and isotopic compositions of heavy noble gases in contemporary Solar Wind (SW) captured by Genesis NASA mission with SW accumulated in young (<100 Ma) and old (> 1 Ga) lunar soils delivered by Apollo missions reveals large variations of Kr/Xe ratios and small but statistically significant isotopic variations (Fig. 1). The ratio of the most abundant isotopes ^{84}Kr/^{132}Xe was determined to be 9.55 in the present SW [1]; it varies from 7 to10 in young lunar regolith and from 4 to 6 in the old regolith soils [2]. The question of whether these variations reflect secular changes in the SW composition or resulted from diffusional losses of more mobile Kr from old regolith soils is still open. Isotopic fractionation of SW-Kr suggests preferential SW-Kr losses; however, no corresponding fractionation of SW-Xe in lunar soils is observed (Fig. 1). Instead, Xe in the lunar regolith exhibits ~1.5% depletion in ^{134}Xe and ^{136}Xe relative to Genesis SW-Xe. A similar effect was observed in some lunar anorthosites [3,4]. This may indicate the presence of indigenous lunar Xe with isotopic structure that seems to be similar to hypothetical U-Xe [5], reportedly observed in the comet 67P/C-G [6]. When and how the 67P/C-G-type Xe has been delivered to the Moon is not clear. An intriguing possible mechanism of this delivery is an ancient Earth Wind [7].

Earth Wind (EW) hypothesis was originally proposed to explain the isotopic composition of lunar nitrogen [8,9]. The Moon Mineralogy Mapper on the Chandrayaan-1 mission revealed that hematite is apparently more prevalent on the near side of the Moon than the on the far side, suggesting that "*oxygen delivered from Earth's upper atmosphere could be the major oxidant that forms lunar hematite*" [10]. Biogenic oxygen was proposed to be delivered to the Moon by "*a wind of magnetosphere ions*" [11]. A recently proposed model suggests that "*the ancient lunar regolith has been exposed to a xenon-rich Earth-Wind*" [12]. The EW was likely stronger in the past before the Earth magnetic field had been established and the Earth's atmosphere was not shielded from ionizing UV radiation produced by the young Sun. Today we may expect EW only in the polar regions where the earth has ozone holes. Indeed, the NASA VISIONS-1 mission observed the outflow of oxygen ions from polar cusps (Fig. 2). According to the ESA Cluster mission, our planet is losing ~90 tons of material per day from the upper atmosphere. Our atmosphere is evidently leaking.

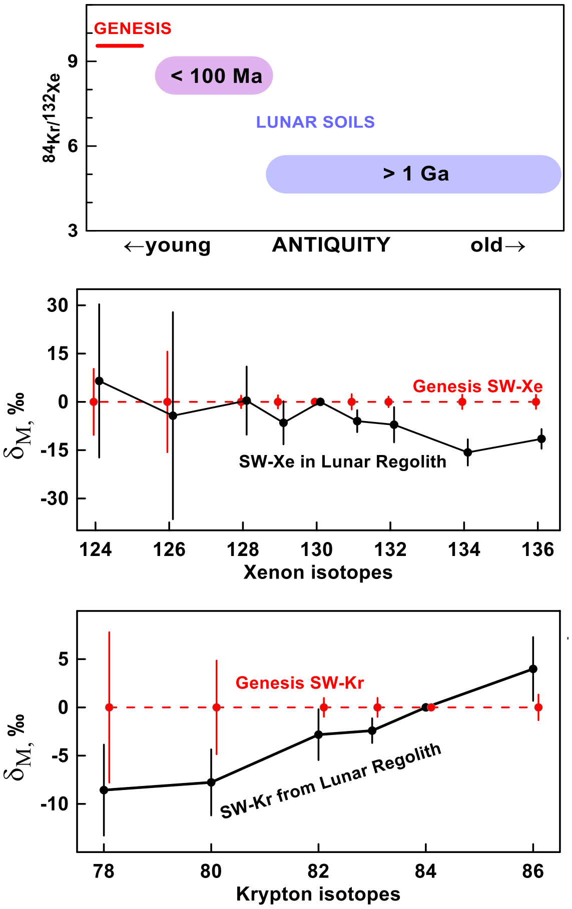

Figure 1. Heavy noble gases in lunar regolith [2, 13, 14]. δ_M are permil deviations from the SW Kr and Xe captured by Genesis [7].

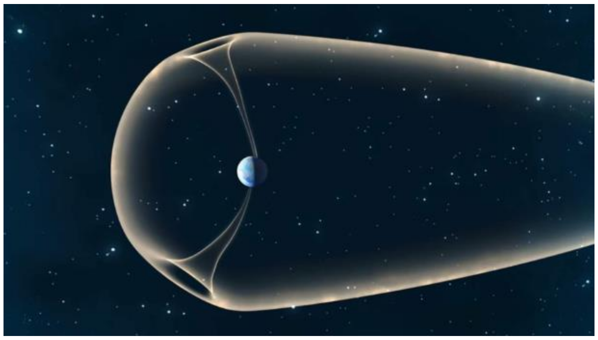

Figure 2. NASA VISIONS-1 mission observed and visualized outflows of oxygen ions from polar cusps. (NASA image).

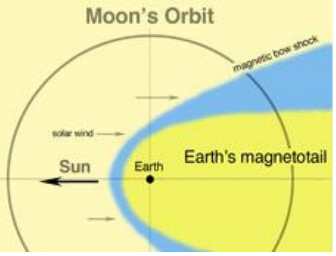

Figure 3. The moon spends about six days each month inside the Earth's magnetotail. (https://www.nasa.gov/images/content/222898main_orbit2_20080416_HI.jpg)

The Earth Wind hypothesis is gaining popularity, especially for oxygen. But there is no experimental evidence for or against EW noble gases delivered to the Moon. Analyses of the samples from the far side of the Moon, mostly shielded from the geomagnetic tail, would be an ideal test, but such a return mission is not feasible in the near future. Since VISIONS-1 measured oxygen (first ionization potential is 13.6 eV) leaking from the atmosphere, Xe (12.1 eV) should also be ionized and leak with better efficiency than Kr (14.0 eV), making Kr/Xe ratio in the polar cusps smaller than it is in the bulk stratosphere. In addition to estimating the strength of the current EW, studying the effects of elemental and isotopic fractionation of atmospheric gases in the polar stratosphere could potentially help us to understand the history of terrestrial atmosphere and, perhaps, the timing of the Earth's magnetic field formation.

Experimental. Our ongoing experiment is aimed at precise analyses of the noble gas composition in the ozone hole over Antarctica to estimate the upper limit of variations in noble gas composition escaping the stratosphere through the ozone hole. We designed, built, and successfully tested [15] the Balloon Air Sampler (BAS) device that captured air at different altitudes over Antarctica in the 2018/19 season [16] when it flew as a piggyback on a long-duration balloon-borne instrument SuperTIGER-2 (Super Trans-Iron Galactic Element Recorder [17]). BAS flew again in the 2019/2020 and worked as intended, but the sampling location (above the Ross Ice Shelf) was too far from the center of the ozone hole that was unusually small and asymmetrical in December 2019 (Fig. 4).

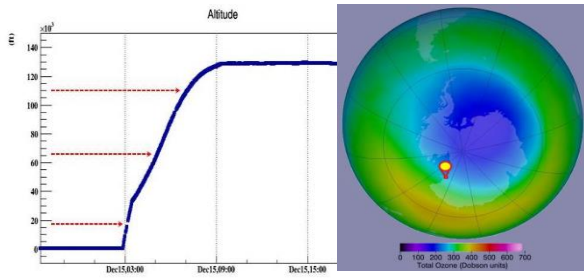

Figure 4. The altitudes (left) and location (right) of air sampling that took place in 2019/2020 season. The position of the ozone hole is shown in blue.

The current BAS device consists of three identical samplers activated by high precision absolute pressure sensors at designated altitudes. Each air sampler consists of a 200 $m\ell$ stainless steel cylinder welded to all metal ultra-high vacuum valves operated by gear motor actuators with torque limiters. The cylinders are internally electro-polished, cleaned (UHV protocol) and He leak checked at temperatures cycled from room to –60°C. The cylinders were pumped out to < 10^{-9} Torr using an oil-free pumping station, the valves were closed, and the inlet tubes were attached to the valve side ports with less than 0.1 $m\ell$ "dead" volume. To exclude potential mass-fractionation at sampling, especially at low stratospheric pressures and temperatures, we use four parallel 4" long .005" ID stainless steel capillaries. Each air inlet lasts 4 min. Valve opening or closing requires 2 minutes. BAS has been vigorously tested in laboratory at 1 Torr and –50°C. It will be recovered after flight and sent for high precision noble gas analyses to our laboratory [18]. The device is shown in Fig. 5.

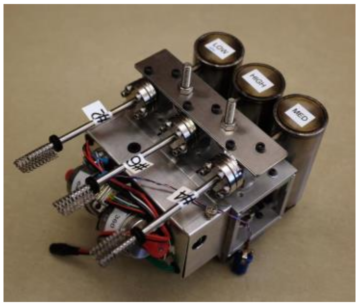

Figure 5. BAS (Balloon Air Sampler) fits into 1'×1'×1' enclosure, weighs 25 lbs., requires < 30W for air sampling and < 1W at standby. No power is needed after sampling.

We are looking forward to the next, decisive Antarctic balloon flight, whenever an opportunity arises.

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