The Moon Is a Harsh Chromatogram:
The Most Strategic Knowledge Gap (SKG) at the Lunar Surface

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INTRODUCTION:

In gas chromatography (GC), gas components become separated according to physical and chemical properties (e.g., size, polarity, mass) that affect the "retention" of the sample in its selected medium. In a similar fashion, gases from impact ejecta plumes or outgassing from the lunar interior waft their way across the lunar surface, intermingling with regolith grains through gas-surface interactions [1].

THE ISSUE:

Described as a "surface-bounded exosphere" (SBE) [2], the lunar atmosphere is so tenuous that each gas species can be treated independently of all others due to the lack of collisions between molecules. The "surface" which binds this exosphere is permeated by both endogenic and exogenic gas sources. For example, radiogenic ^{40}Ar, the long-lived decay daughter of ^{40}K ($\tau_{1/2}$=1.25x10^9 yr), is not found in the solar wind, but was detected in the lunar atmosphere at the Apollo 17 site by LACE [3], and from orbit by the LADEE (NMS) [4]. Solar wind-implanted ions contribute to most of the detected atmosphere at the lunar surface [5]. In a manner analogous to the principles of gas separation used in GC, "separation" must occur on a large scale between gas species evolving at the lunar surface, and the mobility of these gases is governed not only by extreme lunar temperature gradients, but also by complex gas-surface chemistry of activated regolith grains. Consequently, the survival time of gases evolving from a moonquake, impactor, or spacecraft engine plume is an unresolved question requiring future investigations into gas-grain interactions on the microscopic scale and how these are manifested in macroscopic signatures detectable to both *in situ* and remote sensors.

EMPIRICAL RESULTS:

1. **Apollo 11:** N_2 released from sample 10086 taken from near LM [6]
2. **Apollo 12:** No N_2 released from sample 12023 taken far from LM [6]
3. **Apollo 12 CCGE:** Measured large pressure background [7]
4. **Apollo 14 CCGE:** High background pressure fell over months [8]
5. **Apollo 15 CCGE:** High background pressure fell over months [9]
6. **Apollo 15 LOMSE:** Detection of lunar exosphere & co-orbiting H_2O [10]
7. **Apollo 16 LOMSE:** Detection of lunar exosphere & co-orbiting H_2O [11]
8. **Apollo 17 LACE:** Detection of lunar exosphere and ^{40}Ar [3]
9. **LCROSS:** Impactor released atomic & molecular volatiles [12]
10. **LADEE:** No gas signature of Chang'e-3 spacecraft detected [4]
11. **PREMISE:** CO_2 adsorption at room temperature in JSC-1A. No N_2 adsorption [1].
12. **REVISE:** CO_2 and O_2 adsorption at RT in 10084. No N_2 adsorption (Fig. 1).

ABBREVIATIONS:

CCGE: Cold Cathode Ion Gauge Experiment; **GC:** Gas Chromatography; **LACE:** Lunar Atmospheric Composition Experiment; **LADEE:** Lunar Atmosphere and Dust Environment Explorer; **LCROSS:** Lunar Crater Observation and Sensing Satellite; **LOMSE:** Lunar Orbital Mass Spectrometer Experiment; **LM:** Lunar Module; **NMS:** Neutral Mass Spectrometer; **PREMISE:** Polar Regolith Environment Molecular Impact Simulation Experiment; **REVISE:** Regolith Environment Volatile Impact Simulation Experiment

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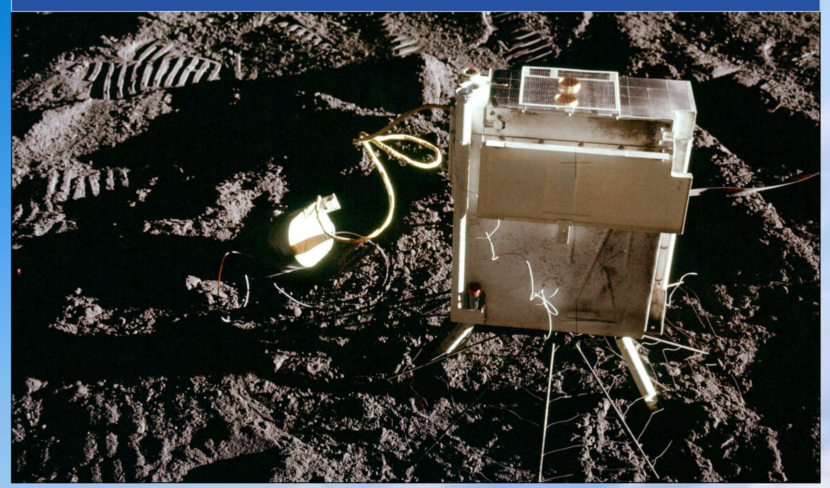
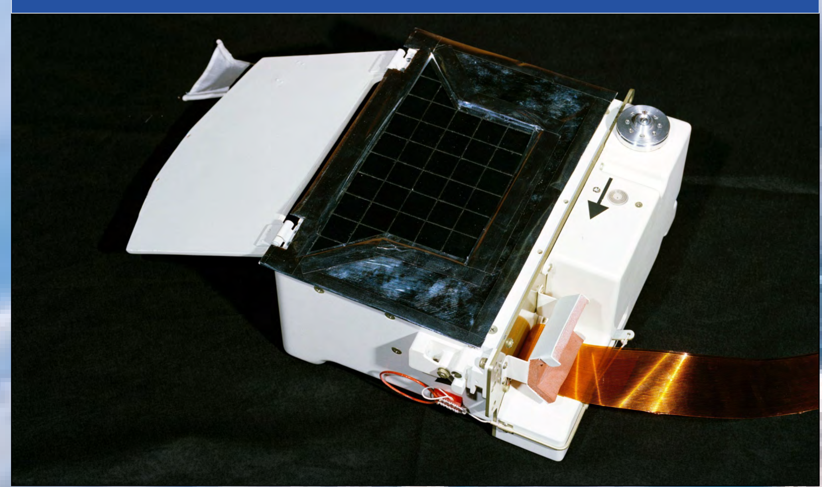
Apollo 11 LM

Apollo 12 CCGE



Apollo 17 LACE



LADEE Spacecraft

Chang'e-3 Spacecraft

EMPIRICAL RESULTS (continued):

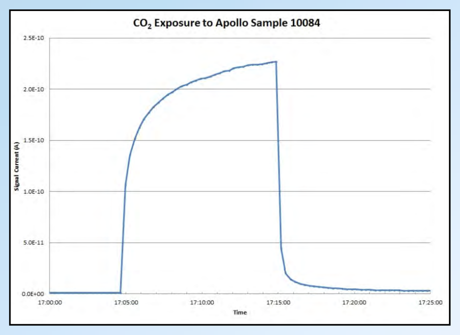
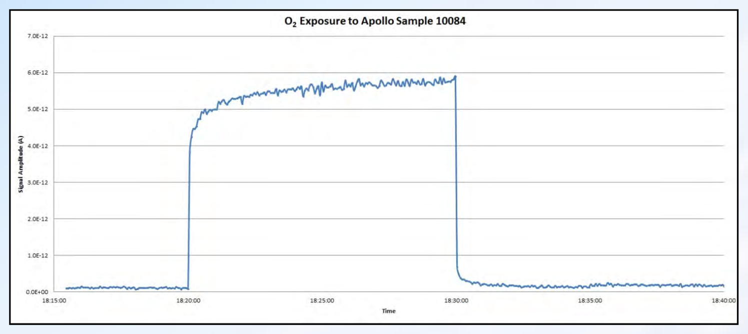
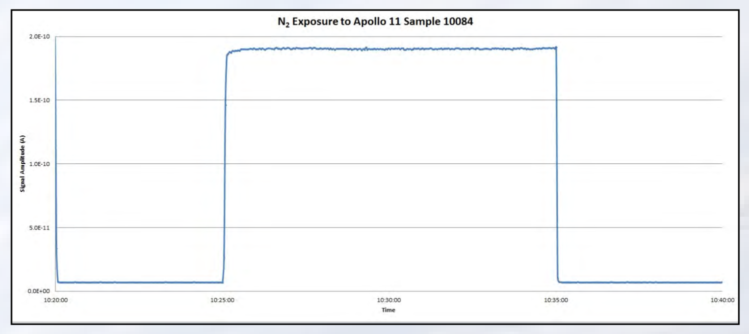


Figure 1. Exposures of Apollo 11 Sample 10084 to 600-second gas pulses of CO_2, O_2, and N_2. The CO_2 and O_2 exposures showed evidence of irreversible trapping at room temperature indicated by a sharper drop in the recovery signal than the rise to pressure maximum. (Maximum pressures were typically in the range of 1x10^{-8} Torr.) The square nature of the N_2 gas exposure pulse suggests little or no trapping of that molecule.





SUMMARY & KEY QUESTIONS:

Laboratory results suggest N_2 can become trapped in lunar regolith fines as observed in Apollo 11 sample 10086[6,13], which we have been unable to reproduce in Apollo 11 sample 10084 (Fig. 1). ***Does this not suggest either a novel trapping mechanism for nonreactive gases, or N_2 present at the lunar surface in a chemical form related to engine exhaust byproducts of nitrogen tetroxide (N_2O_4) & monomethyl hydrazine ($CH_3(NH)NH_2$)?***

It has been estimated that each Apollo mission temporarily doubled the mass of the lunar exosphere [14] due to the total quantity of gases produced by spacecraft engines. From lunar orbit, no signature of the Chinese Chang'e-3 spacecraft was observed by the LADEE NMS[4]. There were no reports of increased local pressure by the Apollo 15 and 16 LOMSE mass spectrometers[10,11] as they flew over their respective lunar modules (LMs) beneath. ***Do these results by orbiting mass spectrometers suggest possible local trapping of volatile gases near the sites of their surface sources?***

The Apollo 17 LACE detected the local lunar exosphere and its monotonic decline over the course of nine lunations[3]. ***While this decline in locally-measured pressure could represent the decay of a subsurface lunar outgassing event, could it not also suggest a decay in a local gas source triggered by disturbance of the local lunar subsurface by the 16,000 kg Apollo 17 LM?***

The LCROSS impact produced evidence[12] of gases in lunar cold traps such as CO_2, NH_3, and H_2O suggesting delivery of these gases at other latitudes in quantities sufficient to reach the lunar poles to become trapped. ***Does this not suggest significant inventories of volatiles have accumulated over the history of the Moon and represent an important (and vulnerable) record of the paleo-cosmic history of the inner solar system?***

CONCLUSION: The Moon is a harsh chromatogram that currently represents a major strategic knowledge gap (SKG) in our understanding of gas behavior at the lunar surface.

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