AN EXOGENIC ORIGIN FOR VOLATILES SAMPLED BY LCROSS: RELEVANCE TO VIPER. K.E. Mandt[1], O. Mousis[2], A. Bouquet[2], D. Hurley[1], A. Luspay-Kuti[1], L. Magana[1,3,4], K. Retherford[4,3], and the VIPER Science Team. [1]Johns Hopkins Applied Physics Laboratory, Laurel, MD (Kathleen.Mandt@jhuapl.edu), [2]Aix Marseille Univ, CNRS, CNES, LAM, Marseille, France, [3]Univ. of Texas at San Antonio, San Antonio, TX, [4]Southwest Research Institute, San Antonio, TX.

Introduction: The Moon is recognized as a cornerstone for understanding solar system history. Just as the impact history of the Moon helps us to understand the impact history of the Earth and other solar system bodies, the history of volatiles on the Moon can help us to constrain how volatiles were delivered to the Earth-Moon system.

The Moon's Permanently Shaded Regions (PSRs) are known to provide an environment well suited for long-term preservation of volatiles [1,2]. However, the exact abundance and composition of the volatiles present in the PSRs is poorly understood. The Lunar Crater Observation and Sensing Satellite (LCROSS) mission provided the greatest insight so far into the composition of volatiles beyond water ice [3,4]. This investigation, and future measurements by the Volatiles Investigating Polar Exploration Rover (VIPER) [5] can provide important insights into the origin and history of volatiles on the Moon and in the Earth-Moon system.

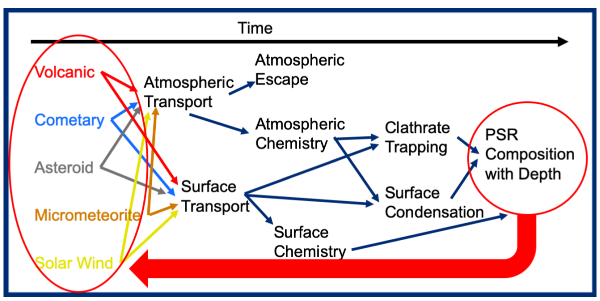

Figure 1 – Connecting the current composition of volatiles in the Lunar PSRs requires an understanding of the processes that took place between delivery of the volatiles and their sequestering.

Unraveling composition: The LCROSS mission impacted the Cabeus Crater PSR and determined the abundance of several species in the resulting plume based on observations by the LCROSS shepherding spacecraft in near ultraviolet, visible, and near infrared wavelengths [3]. Far ultraviolet measurements by the Lunar Reconnaissance Orbiter (LRO) Lyman Alpha Mapping Project (LAMP) determined the abundance of H_2, CO and several other species [4].

We illustrate in Fig. 1 the processes that need to be considered when connecting the current composition of volatiles on the Moon to the variety of possible sources. These potential sources include volcanic activity, impacts of comets, asteroids and micrometeoroids occurring over the history of the Moon, and water produced by the interaction of the solar wind with the Lunar surface. It is clear from this figure that determining the origin of any volatiles characterized by the LCROSS plume composition or future VIPER observations will be challenging.

We developed a method for constraining the source of volatiles by (1) using elemental composition to eliminate the processes in Fig. 1 that change molecular composition, and (2) evaluating whether the LCROSS observations were upper or lower limits relative to the sources if any fractionation of the elemental composition by these processes had occurred [6].

Determining the elemental composition of the volatiles in the regolith requires understanding how the volatiles are stored. If they are stored as condensed material, the volume of regolith from which any constituent was volatilized by the LCROSS impact depends on the volatility of the constituent. This means

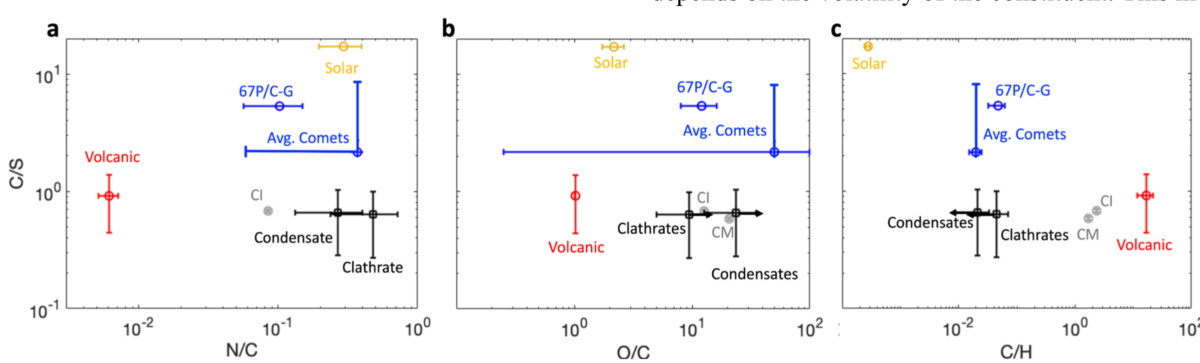

Figure 2 – Comparison of potential volatile source composition with the regolith volatile composition based on the LCROSS plume composition (black squares) assuming that the ices were store either as "Clathrates" or condensed onto regolith grains as "Condensates". Note that no single source can explain the LCROSS observations. Modeling is required to determine the mixture of sources and if fractionation took place.

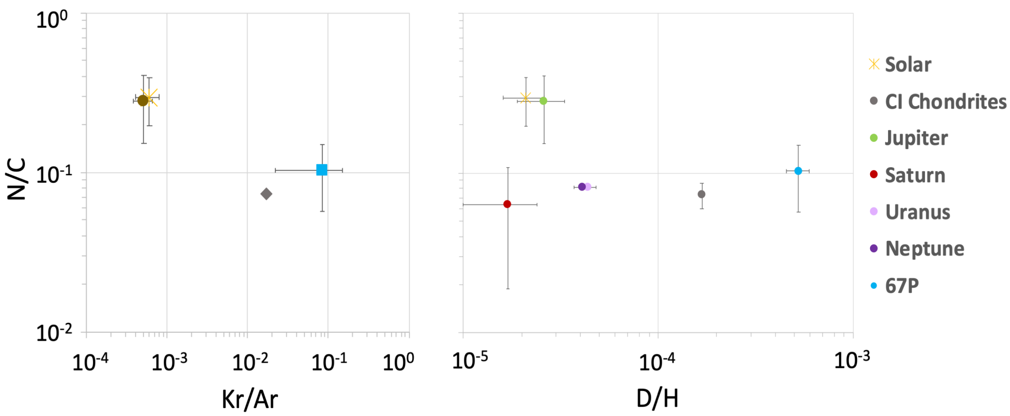

Figure 3 – Additional elemental composition measurements that serve as a powerful tool for determining volatile sources [based on data from 13]. Although we do not know these values for volcanic gas, any volatiles measured by MSolo that are traced back to volcanic sources could provide this information, helping us to learn more about the history of volatiles in the interior of the Moon. Furthermore, noble gas abundances have only been measured in one comet [8] and are critical for determining the composition of the building blocks of the giant planets, constraining where and how they formed [13]. If MSolo measures volatiles from cometary sources, the noble gas abundances can help determine if [8] is representative of most comets or not.

that the amount of highly volatile species in the plume, such as CO, may be inflated because they would be volatilized from a larger volume than the water. However, if the volatiles are stored in clathrates, the volatiles would all be released together upon destabilization of the clathrates. In this case, the plume composition represents the composition of the volatiles in the regolith. We show in Fig. 2 the elemental composition of the volatiles in the regolith for these two types of storage mechanisms.

We also show in Fig. 2 the elemental composition of potential source materials. Comet measurements are made in the coma and represent the icy component of comets. Here, H_2O is the most abundant molecule, with large abundances CO and CO_2 and trace amounts of C_2H_4, CH_4, CH_3OH, NH_3, H_2S, and SO_2 [7]. Volcanic gases tend to have large amounts of CO with some CO_2, H_2O, H_2S, and SO_2 [8,9,10]. Chondrites provide an analog for the composition of asteroids and micrometeoroids impacting the surface to deliver volatiles [11]. This also represents the refractory composition in comets.

As Fig. 2 shows, no single source can explain the LCROSS observations. We modeled combinations of sources and found that no combination could explain the LCROSS observations [6]. One or more of the processes shown in Fig. 1 must have fractionated the elemental composition of the volatiles. When we included fractionation, we found that (1) the volatiles could not have been stored as clathrates; (2) the lack of nitrogen in volcanic gas does not allow for any contribution from volcanic sources; and (3) the best explanation for the LCROSS observations is a combination of cometary ice and chondritic material [6].

How VIPER will advance volatile source studies: The VIPER Mass Spectrometer Observing Lunar Observations (MSolo) will provide the first ever in situ composition measurements of volatiles in ice stability regions of the Moon. In addition to observing the species found in the LCROSS plume, MSolo will be able to measure abundances of species that could not be measured remotely, like N_2, noble gases, and isotope ratios (see Fig. 3). The model described above for the LCROSS observations will be applied to VIPER MSolo measurements with the addition of more species to provide better constraints.

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