Integrating CAvity enhanced Raman Ultraviolet Spectrograph (ICARUS) instrument concept for Lunar Exploration

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Trace mineral trace species, mineral hydration states, and alterations of primary mineral phases including olivine and plagioclase feldspar help us interpret the history of the lunar surface, particularly the timing of delivery of volatiles. The LCROSS mission’s discovery of both water and hydrocarbon species in Cabeus crater highlights the potential role of the delivery of volatiles to the surface by comets and micrometeorites; subsequent modern-day transport of such volatiles is of great interest for in situ resource utilization applications. Measurements of the D/H ratio of ices in Permanently Shaded Regions (PSRs) are needed to understand the relative importance of key processes and sources. Landed missions in the coming decade will employ a variety of techniques to determine the ages and compositions of regions of interest to clarify the influence of the Late Heavy Bombardment, compared with ongoing impact processes as typified by soil properties.

Raman spectroscopy is well suited for these key mineralogical and volatile-isotope studies, and is rapidly advancing in readiness for planetary missions. The first Raman systems flown into deep space are set for the next Mars rovers from both NASA and ESA. Many Raman instruments currently in development for planetary studies utilize a confocal technique where the excitation laser is focused to a small spot on the sample. Our Integrating Cavity Raman Ultraviolet Spectrograph (ICARUS) instrument has a Deep-UV+VIS dual-laser Raman system capable of detecting complex molecular species, which will constrain mineral abundances, hydrated states, and volatile-isotopes in PSRs. Our integrating cavity technique enhances the Raman signal by up to 10^2-10^4 relative to the confocal approach, enabling sensitive measurements of trace species and isotopes. Cavity enhanced fluorescence has already demonstrated femtomolar level measurement sensitivity for urobilin in liquid water, benzo[a]pyrene at 700 nanomole sensitivity (e.g., ~180 ppb wt. in 1 g water-ice), and for bulk pyrene down to 37 nanomole (Bixler et al. 2015).

The integrating cavity material is made of high purity fumed silica, which is optimized for high total internal Deep-UV reflectance. Incorporating two lasers and a UV LED with three different excitation-emission pathways will allow us to definitively indentify the spectral fingerprints of individual constituents within a sample, which is crucial for studying mixed materials. Our fiber-fed multisource measurement approach removes fluorescence driven ambiguities from degenerate, non-unique signatures expected for the most interesting trace constituents, i.e., those best revealed by UV excitation. A TRL-4 cavity breadboard has been built and operated using internal SwRI funds, which we have used to analyze several lunar analog materials and compare them to their published mineralogies. We have also examined icy mixtures, and Apollo samples to determined their compositions.

Samples of 1 mm to 1 cm scale are measured in bulk across their surface areas once placed inside the cavity, avoiding the need for contextual imaging and limitations of spot-targeting approaches used in stand-off Raman systems. Notch filters are included to obtain low frequency phonon mode signatures of mineral hydration states. Customization of the instrument concept for a landed lunar platform is ongoing. We are working to develop a pneumatic system that will deliver samples to the cavity and clean the cavity between samples. The final instrument concept will be of sufficiently low mass, volume, and power to be compatible with inclusion on commercial lander systems.

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