Standoff Ultracompact µ-Raman Sensor (SUCR): Search for Polar Ices, Geology and Conduct Human Research

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1.0 Introduction

This white paper addresses the need to confirm the discovery of ice on Moon which would reveal a valuable resource that is important for long term human survival on the Lunar surface. Moon water could help astronauts explore the moon for a long period of time and enable future robotic precursor missions. NASA Deputy Administrator, Steven Clarke, Science Mission Directorate (SMD), said about ice in his recent statement, "We know the South Pole region contains ice and may be rich in other resources based on our observations from orbit, but, otherwise, it's a completely unexplored world".[1] Currently there is indirect evidence of water ice possibly present in permanently shadowed areas at the lunar poles, predicted through the remote sensing data of Clementine and the Lunar Prospector. The evidence of surface water ice in the polar regions by analyzing the data from the Lunar Orbiter Laser Altimeter (LOLA) and Diviner Lunar Radiometer Experiment (DLRE) has been discussed in ref. 2. A rapid response instrument is needed for characterizing south-pole region of the moon that provides a unique robotic exploration to examine the presence of frozen volatiles. A time-resolved active Raman spectroscopic technique could provide analysis of the polar ice distribution in the lunar surface as well as surface mineralogy of a large number of targets (e.g., quartz, feldspar, fluorite, marble, olivine, etc.) using a handheld standoff ultracompact µ-Raman (SUCR) sensor for localized investigation. The SUCR sensor developed under the PICASSO program[3] would also be a prime candidate for a robotic/lander mission with a focus on surface chemistry, geology, and lunar surface studies. The sensor will meet the following geological science objectives: determine the composition of mixed samples, including accurately measure mineralogy of the lunar surface, water ice, and evaluate other frozen volatiles and minerals. In this white paper, the SUCR instrument detection capabilities are tabulated in a lunar Science Traceability Matrix (STM) (Table 1).

Furthermore, standoff detection of biological, organic materials, as well as biomarkers suitable for astronauts' health monitoring in space are very important for human research to Moon and Mars. Presently, µ-Raman spectroscopy has been shown to be a powerful diagnostic tool for biomedical applications[4-5]**.** This paper focuses SUCR sensor on a biomedical study with the following capabilities: a. Portable and remote Raman measurements at several centimeters range (no sample collection); b. Predict, protect and preserve astronaut health during space exploration missions; c. Identified space radiation-induced biological damage; d. Detection of biomedical samples (e.g., urine, serum, etc.): light and dark conditions. As mentioned above, the biomedical samples will be evaluated in the lab using the SUCR sensor, which will be ready for astronauts' health monitoring in space in near future. This standoff SUCR system will have wide-ranging applications wherever human explorations to Moon and Mars. "**NASA Plans to send astronauts to Moon's unexplored South Pole by 2024**," by BGR, April 18, 2019, Tech, New York Post.

Table 1. The following table reports the science traceability matrix under Lunar Exploration Roadmap (Version 1.3, 2016): Lunar exploration roadmap, Objective, Investigation of the Lunar Lander mission flow into SUCR Measurement and a SUCR instrument characteristics, which serves as an example suite of instruments that could address the science investigations.

Lunar Exploration Roadmap	Objective	Investigation	SUCR Measurement	SUCR Characteristics
Sci-A-3: Characterize the environment and processes in lunar polar regions and in the lunar exosphere.	Understand the nature and transport of volatiles in permanent and near-permanent shadow.	Determine volatile concentrations and variation in space and time at a polar landing site	Quantify abundances of ices, adsorbates, organics, and alteration minerals	Standoff Ultracompact Micro-Raman Spectroscopy Spectral Range: <100 - 4500 cm^{-1} Spectral Resolution: 8 cm^{-1} (high frequency region) and 10 cm^{-1} (low frequency region) for 50 µm slit SNR: >5000 (on average)
Sci-A-4: Understand the dynamical evolution and space weathering of the regolith.	Understand the space weathering process and how it relates to composition and exposure	Determine source rock composition, impact glass composition and how they relate, us hydroxyl as a tracer	Quantify abundances and chemistries of major rock forming minerals, glasses, and hydroxyl	
Objective Sci-A-5: Understand lunar differentiation.	Determine range of compositions of crustal and mantle rocks and how they are related	Determine bedrock lithology in mare and highland region, and potential mantle outcrops	Quantify abundances and chemistries of major rock forming minerals	

2.0 Lunar South Pole: Regions of Interest

The Planetary Science Decadal Survey committee recommended the South Pole-Aitken Basin Sample Return mission as one of the priority New Frontiers missions identified in 2013.[6] The objective of this white paper is to address the lunar polar-regions for volatile materials and resources from a surface-based lander platform. The SUCR sensor mounted on a small lander platform can explore Moon's surface ice, water, carbon dioxide, methane, and minerals in order to understand how permanent shadow occur to very small crater sizes at very high latitudes as well as the possible large targets for investigation. The important advantage of SUCR over orbital passive remote sensing methods is that it will yield reliable results with high confidence level even in the presence of complex mixture of sample distributions on the lunar surface due to small area inspection. Time-resolved Raman and fluorescence spectroscopic techniques[7-8] can provide information about surface mineralogy as well as polar ices distributions. The SUCR system uses time-resolved fluorescence for detection of organics and phosphorescence for rare earth elements. Organics have been suggested to occur in permanent shadow at the Moon's poles, created from radiation processing of simple ices. Carbon compounds are important to in-situ resource utilization (ISRU) and the payload, SUCR sensor, could be a robotic/lander mission to Moon to search and find habitable locations. The other objectives of this white paper discuss NASA's broader lunar exploration goals, including human exploration and *in situ* resource utilization (ISRU), as well as lunar science for a small lander mission.

3.0 Study Geology and Biomarkers

This paper concentrates on a crewed mission to the Lunar South Pole to conduct multiple activities using the same handheld SUCR sensor, such as 1. Lunar surface characterization under Science Mission Division (SMD) and 2. Crew health monitoring in space under Human Exploration and Operations Mission Division (HEOMD). First, collection of lunar samples and use portable or handheld sensors to inspect and identify the collected samples without any need for sample preparation and manipulation. The crews can achieve real time information about the samples, whether they are water, ice, minerals, organic or biogenic materials embedded in the soil or on the surface. An investigation of samples is very critical to finding habitable regions for human exploration and extended stays on the lunar surface. Second, the crews can perform Raman spectroscopy measurements of biomarkers, e.g., urine, serum, and other biomedical specimens in monitoring crew-health using the handheld SUCR sensor after validating the system in the lab. This SUCR sensor will be ready to investigate and identify normal and abnormal biomarkers in urine, saliva, cells, and tissue on a real-time basis with rapid results in near future.

Summary:

This white paper addresses the human exploration to the lunar south pole and search for evidence of polar ices and geology to find habitable regions for human survival on Moon. Polar ices including water, carbon dioxide and methane that might occur on shadowed polar surfaces. Organics have been suggested to occur in permanent shadow at Moon's poles, created from radiation processing of simple ices. Carbon compounds are important to in situ resource utilization (ISRU). Evaluate the SUCR sensor's ability to characterize and identify samples (e.g., minerals, natural rocks, and soils, organic, and biomarkers) and astronauts' health monitoring in space. The SUCR sensor technology discussed in this white paper is applicable to a broad range of other landed planetary missions and directly addresses science questions raised in the National Research Council's Book, "*Vision and Voyages for Planetary Science in the Decade 2013-2022"*.[9]

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