REDEPLOYABLE SENSOR PROBE FOR *IN-SITU* LUNAR RESOURCE MAPPING FROM SMALL LANDERS.

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Mapping Lunar Resources: The use of *in-situ* resources in lunar regolith for production of propellant, life support, and construction (e.g. polar water ice, hydrogen, helium-3, and regolith minerals) will enable sustainable robotic and human space exploration and pave the way for commercialization of lunar exploration. Currently, the search for and characterization of resources on the Moon uses orbital datasets and local geological and geophysical surveys to map and characterize potential deposits. To develop efficient ISRU systems, it is essential to find, characterize, and map lunar resources *in-situ*, at local scales, using deployable, analytical payloads. We have developed a 3 kg, TRL4 scientific payload, MoonSHOT (Moon Subsurface Hydrogen Optical Tool), to characterize and map lunar resources from a small lander or rover (Figure 1).

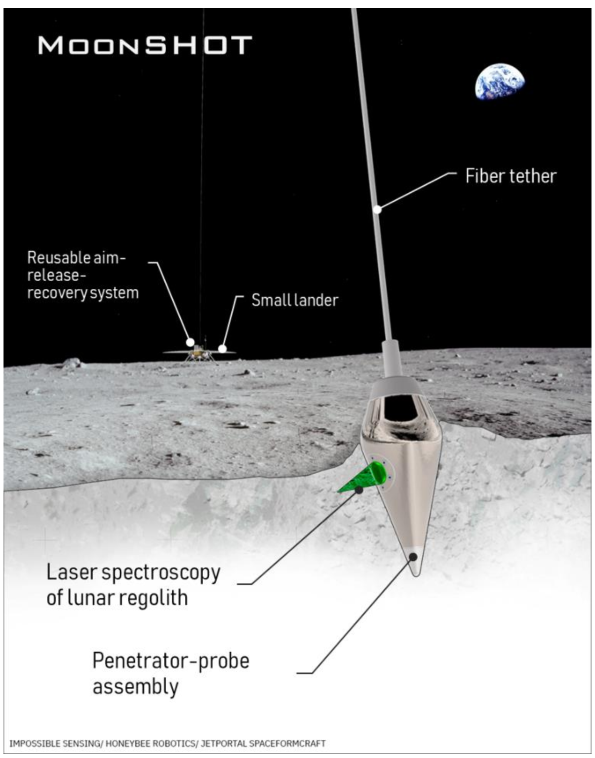

Figure 1: Artist's rendering of MoonSHOT analyzing lunar regolith. MoonSHOT gives mobility and high spatial remote sensing ability to a lander, thus effectively removing the need for rover and sampling devices. It performs *in-situ* analysis of minerals and volatiles using variable-length fiber probe. Probe is aimed at a target location and launched, analyses are conducted, and probe is recovered. This operation, repeated throughout the mission, maps resource composition (H, water and other volatiles, metals).

MoonSHOT Innovation: MoonSHOT is a next-generation ultra-compact laser spectroscopy system equipped with a fiber optic sensing probe that enables *in-situ* geochemical and mineralogical analysis and mapping of Moon surface and shallow-subsurface samples in a remote location without having to extract a sample and bring it to a spectrometer.

MoonSHOT's core unit, hosted inside the spacecraft, contains laser, spectrometer, and electronic modules. The core unit connects to a shielded fiber-optic umbilical and a reusable, gimbaled electro-mechanical spool. The fiber is terminated in a miniature optical probe that is inserted from either a lander or rover into the lunar regolith via a penetrator. Operationally, the concept of operation of MoonSHOT is to 1) aim and release/shoot the fiber-tethered penetrator into regolith up to 20 m away from the landed craft and down to 5 cm (these are baseline requirements and can be modified); 2) illuminate a sample to induce Raman scattering and LIBS; 3) collect and relay this light to the spectrometer, where spectral intensity and distribution are measured, recorded, and analyzed in real time to generate science measurements; and 4) reel in/recover the probe. Using this architecture, MoonSHOT can be repeatedly deployed and retrieved from a fixed lander or mobile rover (Figure 2).

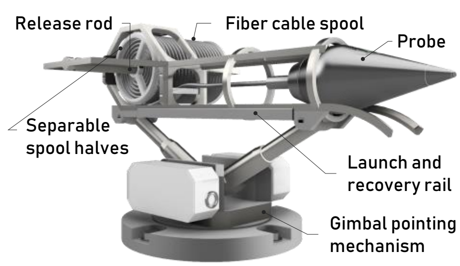

Figure 2: MoonSHOT utilizes a resettable hold-down release mechanism to accomplish multiple probe separation-launch-recovery cycles. The mechanism is integrated into electromechanical gimbal actuators as part of a launch restraint system. This system acts as a multi-axis pointing platform that facilitates targeting of specific locations for MoonSHOT analyses. All components have been used in spaceflight applications.

The scientific outcomes of MoonSHOT are rapid and unambiguous chemical and mineralogical characterization and mapping of surface and subsurface materials by integrating an innovative, miniature Raman+LIBS (laser-induced breakdown spectroscopy) probe with a penetrator. Thus, MoonSHOT will: (i) eliminate the need for drill-sample-analyze approaches, which are popular but scientifically limited and resource inefficient, (ii) provide evidence relevant to selecting sample sites that warrant additional investigations, (iii) be useful for selecting samples for eventual collection, and (iv) facilitate rapid assessments of subsurface processes with real-time *in-situ* monitoring.

MoonSHOT Performance: Figue 3 shows MoonSHOT current TRL4 system. We have tested component pieces with one another to demonstrate the ability of MoonSHOT's optical circuit to conduct remote *in-situ* Raman+LIBS measurements using our innovative optical design and probe- penetrator architecture. We used JSC-1 lunar regolith and samples of pure and mixed materials relevant to lunar exploration: olivine, pyroxene, plagioclase (near Ca-endmember anorthite), ilmenite, silica polymorphs, Fe,Ti,Cr oxides, sulfides, K-feldspar, hydrated phosphates (apatite), other igneous rocks. We developed a MoonSHOT probe assembly in which the spectroscopy probe is installed in a custom cone shape penetrator for testing.

Significance: Our innovative approach to lunar resource mapping delivers three game-changing advantages in lander/rover lunar exploration with MoonSHOT: a) unprecedented analytical capabilities – remote *in-situ* coregistered high-resolution Raman+LIBS mapping, b) minimization of the resources and complexity required to perform surface and shallow subsurface science analyses – no need for core sample and delivery systems, robotic arm movement between sample and onboard, and c) possibility for novel mission architectures – spatially distributed analysis capabilities can be achieved from a lander platform, thus removing the need for platform lateral mobility. These advantages cannot be overestimated: characterizing and mapping lunar surface and subsurface resources at small scale (10 to 100 m) is a key NASA Strategic Knowledge Gap but remains technologically challenging. Our MoonSHOT lunar exploration strategy is a game-changing improvement over the state of the art: it gives mobility and high spatial resolution remote sensing ability to a lander, thus effectively removing the need for rover and sampling devices.

MoonSHOT will advance lunar exploration by bringing first-time observational and analytical capabilities to small landers, MoonSHOT may also become a critical new instrument in missions highlighted by PSD: a) exploration missions to Venus, Moon, Mars, Europa, Titan, comets, and asteroids; b) sample return missions to Moon, Mars, comets, and asteroids.

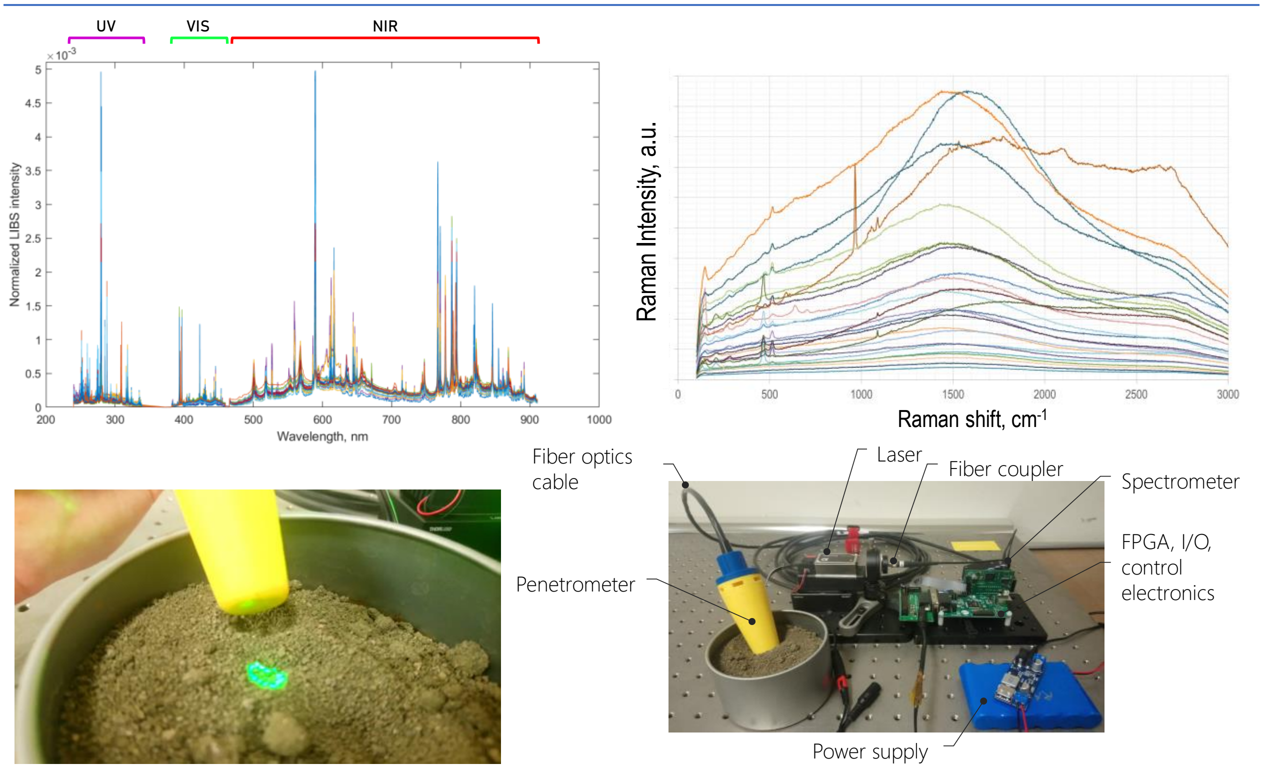

Figure 3: TRL4 MoonSHOT. The prototype uses COTS laser (Integrated Optics), spectrometer (Ibsen), fiber probe (InPhotonics), electronics (IMS/HBR), a mockup penetrator (HBR) that represent high-fidelity unit-level MoonSHOT components. We have tested this prototype to demonstrate remote, *in-situ* Raman and LIBS detection of mineral and elemental species relevant to lunar exploration. All other key subsystems are at TRL4+ already. The Raman spectra show orthoclase bands at 154, 282, 514, and 640 cm^{-1}, a quartz band at 465 cm^{-1}, calcite bands at 285, 714, and 1090 cm^{-1}. The LIBS spectra show variable amounts of Fe, Si, Ca, and K. Additional elements were analyzed (~ 35), but their emission peaks are not shown here for simplicity.