Brief Report
on
ISECG Lunar Polar Volatiles Virtual Workshop#3: Lunar Surface Prospecting Instruments

On July 6, 2016 the ISECG held its third virtual workshop on exploring and using lunar polar volatiles. The workshop focused on understanding the types of scientific instruments that would be useful in prospecting for water ice and other polar volatiles at the lunar poles. Approximately 50 participants from various countries met online for a 2-hour session, representing not only space agencies, but industry and academia as well. The participants included planetary scientists, students, engineers, mining professionals, and other space professionals. ESA/James Carpenter moderated presentations by five expert panelists and addressed questions from attendees, while others participated simultaneously by exchanging text comments in an associated chat forum. All the presentation materials and a recording of the event were posted to the ISECG volatiles website (http://lunarvolatiles.nasa.gov/).

<u>Overarching question:</u>

1. What instruments may be most valuable on the lunar surface to locate and characterize polar volatile deposits and determine their distribution, composition, abundance, etc?

<u>Panelists:</u>

Dr. Simeon Barber (The Open University, UK)
Dr. Valérie Ciarletti (LATMOS Laboratory, France)
Dr. Anthony Colaprete (NASA Ames Research Center, USA)
Dr. Richard Elphic (NASA Ames Research Center, USA)
Dr. Roger Weins (Los Alamos National Laboratory, USA)

<u>Findings:</u>

1. Lunar surface prospecting instruments work best when combined with other instruments to get a concurrent, comprehensive understanding of lunar polar volatiles. Any individual surface mission would greatly benefit from having several scientific instruments included in a science payload.

2. Neutron spectroscopy is an excellent method for surface-based prospecting to measure hydrogen concentrations in the lunar regolith. Neutron spectrometers have been successfully used from orbit at the Moon, Mars, and Mercury, and surface-based spectrometers would benefit from this flight-heritage. Surface-based neutron spectrometers can be built lightweight, robust, and simple, and can operate and

collect data while a rover is traversing. The National Space and Aeronautics Administration (NASA) Resource Prospector project has successfully field tested a rover-compatible neutron spectrometer in the Mojave Desert.

However, neutrons leaking from the lunar surface are created by interactions between galactic cosmic ray protons and nuclei in the lunar surface, and these interactions are limited to approximately the upper meter of the lunar regolith. Therefore, a surface-based neutron spectrometer will only measure hydrogen concentrations in the upper meter of the lunar regolith, similar to the orbital measurements.

3. Currently, it is unknown how well ground penetrating radar (GPR) will be able to detect water ice in the lunar subsurface. WISDOM, a GPR designed for the European Space Agency's (ESA) ExoMars rover, can only see subsurface structures greater than about 10 cm in size (in the vertical direction), but it can penetrate to depths of 5 to 10 meters. This means only large units of segregated ice, or ice lenses, 10s of cms in thickness can be detected, while individual ice crystals or small ice patches mixed in the lunar regolith at low wt. % will likely not be detected. However, if dry regolith/rock electrical properties can be well constrained, then broader average values of permittivity might be able to suggest whether there is ice or not. Synergistic measurements with a neutron spectrometer would significantly improve GPR interpretation in terms of ice content.

China successfully demonstrated the use of GPR on the lunar surface during the Chang'e-3 mission The lunar rover Yutu was equipped with a two channel (60 MHz and 500 MHz) lunar penetrating radar. Generally, lower frequency radar sounding reaches greater depths. For water ice prospecting in the shallow subsurface (< 10 m), high frequency radars like WISDOM's 0.3 to 3 GHz broadband UHF GPR will be needed to get fine resolution and detailed subsurface structure.

4. Mass spectrometry is very powerful for investigating the composition of a range of lunar polar volatile compounds and their origins. There is a wide range of instruments available, a wide range of supporting sampling tools, and a wide range of resource requirements needed for the different instruments. However, some of these resource requirements (i.e., mass, power, volume, data rates) are quite modest. Most lunar polar volatiles can be separated with unit mass separation (i.e., separating mass 18 from mass 19, from mass 20, etc.), which does not require much mass resolution or resolving power. resulting in less complex and less massive spectrometers. Isotope ratio measurements will be required to investigate the possible origins of the lunar polar volatiles (i.e., cometary, solar wind, asteroids, etc.)

Two mass spectrometer systems are in development for use in lunar polar exploration. The Luna 27 mission to the South Pole, a cooperative mission between the Russian Space Agency (RSA) and ESA, will include the ProSPA payload. ProSPA consists of a carousel of ovens, gas chromatograph, and an ion trap mass spectrometer based on flight hardware from the Rosetta Mission, and a stable isotope ratio mass spectrometer based on flight hardware from the Beagle 2 mission. NASA's Resource Prospector project includes the LAVA payload, a combination gas chromatograph and mass spectrometer. These systems require samples to be delivered to the instruments. Other mass spectrometers (i.e, ESA's LUVMI instrument) are being developed to sample the subsurface directly.

5. Near-infrared (NIR) spectroscopy is a proven technique, and has been successfully used at the Moon on several missions (M^3 on Chandrayaan-1; VIMS on Cassini, HRI-IR on Deep Impact, and NSP2 on LCROSS). NIR spectrometers have a small to modest mission footprint (i.e., low cost, mass, power, volume), and can be designed to detect a number of lunar polar volatiles (i.e., H_2O, NH_3, CO_2, CH_4, etc.). NIR spectrometers are rover compatible instruments, and can be used while the rover is traversing. Quick turn-around data analysis also allows for real-time critical decision making in rover traverse planning and scheduling other science instruments at sites with indications of high volatile abundance. NIR spectrometers can be sensitive to 0.5 wt. % water ice mixed in with the lunar regolith.

The RSA/ESA Luna 27 mission will be equipped with a Lunar Infrared Spectrometer (LIS), and the NASA Lunar Prospector project is being designed with the Near-Infrared Volatile Spectrometer System (NIRVSS).

6. Laser Induced Breakdown Spectroscopy (LIBS) has been discussed as a potential scientific method to investigate lunar polar volatiles. LIBS could be used in detecting water frost or other ices on the surface of the Moon (and also any drill cuttings brought to the surface from the subsurface) from a standoff distances of about 5 meters. Laboratory experiments conducted in vacuum with a lunar regolith simulant (JSC-1) mixed with 25 wt. % water ice showed a strong hydrogen peak at a standoff distance of 3 m, with extrapolated laboratory detection limits of about 1 wt. %. It is believed detection limits on the Moon, with optimized spectrometers, could reach 0.5 wt. % water ice. LIBS could be used in permanently shadowed regions (PSRs).

LIBS has been successfully demonstrated on Mars, with the ChemCam instrument on NASA's Curiosity rover (350,000 spectra on about 12,000 observation points as of July 6, 2016). ChemCam has been able to characterize the hydration of the martian regolith. While LIBS detects chemical elements only, a new instrument being developed for NASA's Mars 2020 rover, SuperCam, will combine LIBS with remote Raman and VIS-IR spectroscopy to also acquire mineralogical data.

7. Small, drill-integrated instruments such as down-hole neutron spectrometers and mass spectrometers are being investigated as a next-generation class of scientific instruments to detect lunar polar volatiles in the subsurface.