Handheld, Surface-Deployed or Rover-mounted Astronaut Instruments. Pamela E. Clark[1], Robert L. Staehle[1], David Bugby[1], Abigail Fraeman[1], Robert O. Green[1], R. Glenn Sellar[1], Stojan Madzunkov[1], Frank Maiwald[1], Nan Yu[1], Adrian Tang[1], Corey Cochrane[1], Craig Hardgrove[2], Michael Collier[3], Vassilis Angelopoulos[4], [1]Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, [2]Arizona State University, School of Earth and Space Exploration, Tempe, AZ 85287; [3]NASA/GSFC, 8800 Greenbelt Road, Greenbelt, MD 20771; [4]UCLA, Institute for Geophysics and Planetary Physics, Los Angeles, CA 90095. Email: pamela.e.clark@jpl.nasa.gov.

Purpose: We are developing a diverse set of compact instruments and instrument suites, as well as high performance adaptable packaging options suitable for a wide range of instruments designed as handheld, crew-deployed or rover-mounted devices to achieve high priority lunar surface science and exploration goals.

Surface Science Objectives: For the Moon, these objectives include determining the global distribution and origin, as well as resource inventory, for water and other potential in-situ resources at local-scale resolution; monitoring and modeling the nature of the radiation/charged particle /exosphere/micrometeorite/ surface/subsurface interactions constituting the lunar environment and impacting performance and health of the crew and their equipment; monitoring and modeling the lunar interior and constraining the Moon's history and origin.

Instrument Suites: The table below summarizes the target characteristics, including mass, power, and volume, of certain instruments of primary interest already under development via NASA DALI, CLPS/NPLP, GCT and SIMPLEx programs, supplemented by JPL internal funding, with more details, including crew involvement and operation, given below.

Physical and compositional properties of local terrains. We have Vis/IR cameras and spectrometers. For Artemis, these could include rover-mounted camera EECam [1] with filters for particular applications, IR (600 to 3600 nm) imaging spectrometers based on UCIS-Moon (DALI, polar rover) [2] or High-resolution Volatiles and Minerals Moon Mapper (HVM3, to be launched aboard the SIMPLEx Lunar Trailblazer) [3]. Handheld versions of the small instruments could easily be developed. The patterned filter microimager [4] described in an abstract submitted for this workshop by Clark, Sellars, and Wilson would be especially valuable as a handheld rock and regolith mineralogy and petrology assessment tool.

Exospheric species abundances. Our primary candidate would be the DALI-funded compact Quadrupole Ion Trap Mass Spectrometer (QITMS) which also includes a LETS radiation detector, known as the Lunar Cubesat Mass Spectrometer (LCMS) [5]. Its mass resolution of 1000 and range of 0.75 to 230 Da could make it suitable for detection of lunar neutral exospheric species. The astronauts could deploy this as part of an exosphere monitor network. If operated after crew departure, this instrument could quantify the fall-off in gas emissions from equipment left behind as "atmospheric" conditions return to the natural background. If surface-exposed volatiles are present, one would expect a diurnal signal could be detected through the lunar day and night, especially near local sunrise.

Internally generated and bombardment-induced seismic activity. Candidates include the Atomic Lunar Seismometer (ALS) being developed for DALI [6]. As in the case of the mass spectrometer, the astronauts could deploy this as part of a seismic monitor network.

Extended Resource Prospecting: Programmable mini-rovers could gather data along traverses in areas the astronauts identified as 'promising' in terms of potential resources, while astronauts continued to explore new places. A proposed water prospector package indicated in the table and described in an abstract submitted for this workshop by Staehle et al would characterize surface/subsurface water to a depth of 1 to 2 meters. The package would include one of the IR imagers described above to characterize surface 'signatures' along with ASU's mini Neutron Spectrometer to measure proton (by implication ice) abundance to a depth of at least one meter, and mini Ground Penetrating radar now under development at JPL, which would yield variations in dielectric constant (and by implication water ice) to a depth of a few meters with a resolution of 10 cm.

Astronaut-Deployed Stations: The astronauts could deploy monitoring stations as part of a spatially and temporally distributed network.

A water cycle monitoring station [7], would include one of the IR instruments and the miniNS described above to determine variations in components and forms of surface and subsurface water as a function of time of day, latitude, and terrain, as well as an instrument to monitor solar wind input (proton interactions with regolith) with an instrument like the proposed HALO Electrostatic Solar wind Analyzer (ESA) [8], and an instrument that would measure exospheric energetic neutrals produced from that interaction, such as the proposed HALO Energetic Neutral Analyzer ENA [8].

Measurements made by magnetometers deployed at locations on the Moon, supplemented by analogous measurements made by magnetometers already in cislunar space on a long-term basis (ARTEMIS) [9] could be used to derive temperature and compositional profiles of the interior which can then be used to model the structure and state of core and mantle. Compact fluxgate magnetometers are readily available, and vectorized magnetometers under development. We have considered a dual magnetometer package, with fluxgate magnetometer, such as the one flown on ELFIN [10], providing ongoing measurements throughout many diurnal cycles, and calibration provided by the more stable but more resource intensive vector helium magnetometer [11] used periodically.

Generic yet Reconfigurable Packaging: A major challenge for small packages, particularly on the lunar surface, is thermal packaging to protect the payload from the lengthy temperature extremes without the need for active control systems requiring power and thus significantly increasing mass and volume needed for batteries during lunar night. High performance thermal component packaging based on passive thermal design that will allow operation on at least limited duty cycle during lunar night is now being developed and tested through the STMD-funded Planetary and Lunar Environment Thermal Toolbox Elements (PALETTE) project [Bugby, et al.].

Cost estimates vary, and are highly dependent on instrument hosting interfaces, hardware class, and crew safety requirements.

References: [1] McKinney et al, 'Flexible camera architecture for generic space imaging applications', LPS CLIX, #2857, 2018; [2] Blaney et al, 'The ultra-compact imaging spectrometer (UCIS) in situ imaging spectroscopy for Mars, the Moon, and asteroids, LPS XLIII, #2593, 2012; [3] https://www.caltech.edu/about/news/nasa-selects-caltech-led-lunar-mission-finalist; [4] Nunez J., Farmer J., Sellar G., Allen C., 'Microscopic Imager: integrating microimaging with spectroscopy for the In-Situ Exploration of the Moon', LPS XLI , Abstract #1581, 2010; [5] Avice G. et al, 'High precision measurements of krypton and xenon isotopes with a new static mode quadrupole ion trap mass spectrometer, JAAS, 34, 2018; [6] Yu N. et al, https://www1.grc.nasa.gov/wp-content/uploads/Atomic-Lunar-Seismometer.pdf, 2019; [7] Clark P.E. et al, 'Global Lunar Organized Water In-Situ Network: Multiplatform concept for understanding the lunar water cycle', Annual LEAG Meeting #5024.pdf, 2019; [8] Stubbs T. et al, 'A heliophysical monitoring network for the near-surface lunar plasma and radiation environments', LPS XXXIX, #2467, 2008; [9] Angelopoulos V., 'The ARTEMIS mission', Space Science Reviews, 165, 3-25, 2011; [10] Strangeway R. et al, http://elfin-lomo.igpp.ucla.edu/?mag.shtml; and [11] Papalardo R. et al, 'The Europa multiple-flyby mission: synergistic science to investigate habitability', LPS XLVII, #2732, 2017.

Some Lunar Surface Instrument and Instrument Suite Candidate Characteristics

Instrument	Type	Mass	Power	Volume
UCIS-Moon	IR Imaging spectrometer 600-3600 nm	4 kg	20 W when operating,	4U
HVM3	IR Imaging spectrometer	12 kg	15 W	56 cm3
QITMS	Mass Spec	7 kg	24W when operating	8U
MMI	microimager	1 kg	5 W when operating	1U
miniGPR	Ground penetrating radar	1.5 kg	1W when operating	2U
miniNS	Neutron spectrometer	0.5 kg	5W when operating	1U
miniENA, miniESA	Electrostatic analyzer and energetic neutral analyzer	<1 kg each	1W each	1U each
Dual magnetometer	VHM and FGM	0.5 kg FGM, 2 kg VHM + booms	<1W FGM, 2.5 W VHM when operating	<0.5U FGM, 2U VHM
Mini water prospectors	Mini IR camera (filter), miniNS, miniGPR	3 kg	8W when operating	6U
water cycle monitoring stations	IR imager, miniESA, miniENA, miniNS	5 kg	2 W night, 9W day when operating	5U

Power when operating. Mass and volume assume high performance packaging but do not include radiators except for HVM3.