Compact Instruments and Instrument Suites for Future Small Satellite Opportunities in Cislunar Space and Beyond

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Note: This is predecisional information for planning purposes only.

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Current Context:

As part of the NASA Lunar Initiative, through programs such as SMD DALI, SIMPLEx, HEOMD CLPS/NPLP, STMD GCT, and now PRISM, as well as internal center funding,

NASA and collaborators have been developing diverse instruments, as well as high performance generic yet configurable packaging for the extreme environments,

Versions discussed here are cubesat/smallsat scale and suitable for orbital, stationary or mobile lunar surface platforms.

Instrument Suites:

Also presented here are examples of suites utilizing some of these instruments capable of delivering focused yet high priority measurements on mobile platforms.

NASA/JPL-Caltech

Relevant Lunar Surface Science Objectives:

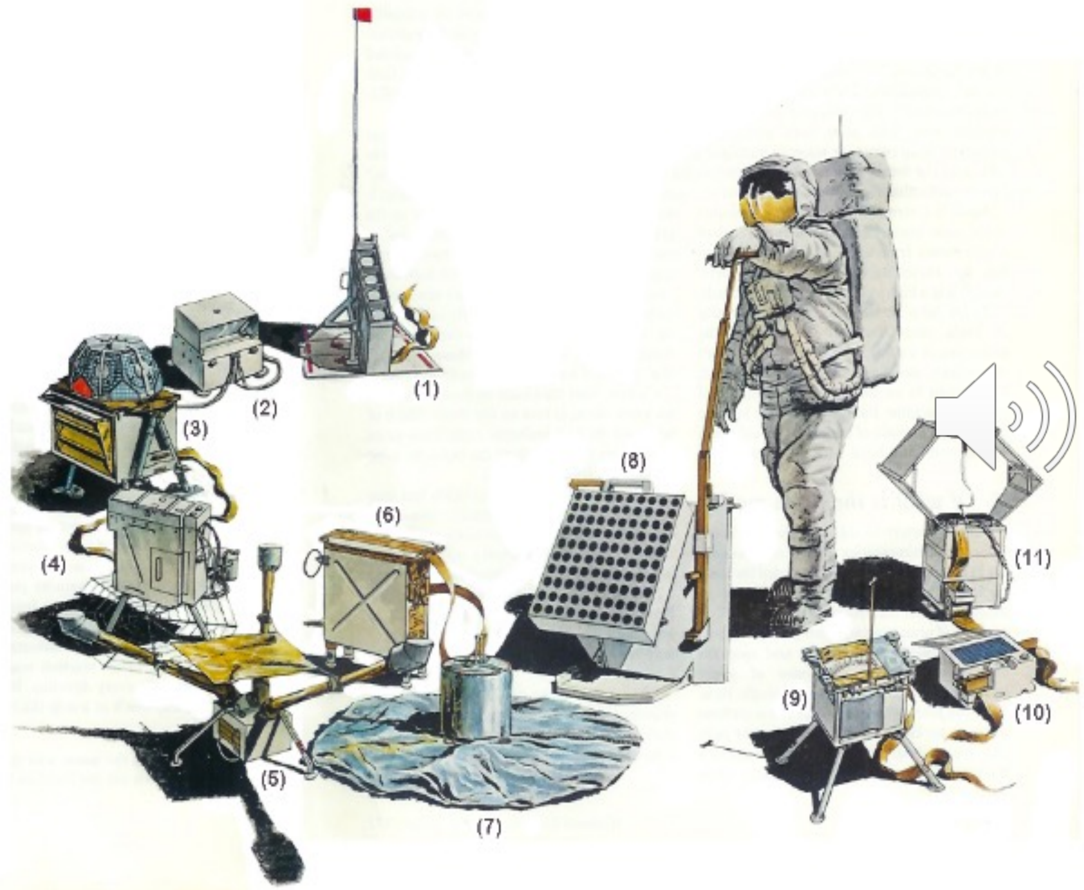
1) determining the global distribution and origin as well as inventory for water and other potential in-situ resources at local-scale resolution;

2) monitoring and modeling the range of radiation/charged particle/exosphere/micrometeorite/surface/subsurface interactions constituting the lunar environment, especially in areas around the morphological and illumination boundaries associated with persistently shadowed regions (PSRs);

3) monitoring and modeling the lunar interior to constrain the Moon's history and origin in areas likely to reveal lunar volcano-tectonic or bombardment history.

Planetary Decadal Survey	Measurement Context	Instruments	Compact Examples
Origin of and relationship between terrestrial planets, extrasolar systems Nebular/Accretion Processes, Early Solar System, Bulk compositions, volatile budgets, differentiation Crust/mantle/core materials, new rock types, robust sampling, Early planetary evolution, external processes, and origin and evolution of life	in situ isotopic, elemental, volatiles (molecular), mineralogical, textural, geochronological, regolith, rocks, 'new' sites, dealing with contamination. Reverse stratigraphy observed from mobile platforms.	X-ray spectrometer X-ray imaging Gamma-ray spectrometer Neutron spectrometer Active mass spec (LIBS, LAMS) Active Gamma-ray/Neutron Compact IR spectroscopy Compact IR imaging Compact active near IR imaging In Situ geochronology Mass spec w/ in situ chromatography	MIT REXIS JPL PIXL PSI GRAND U of A LunaHMap LANL ChemCam (JPL MSL) GSFC SINGR GSFC/JPL BIRCHES JPL UCIS, SILVIR JPL Lunar Flashlight JPL RbSr KAr concepts GSFC SAM; JPL QIT-MS
Internal processes involving volatiles, polar deposits Crust/mangle/core materials, interior structure, stratigraphic record, dynamics, heat loss	Deployable network interior characterizers, lander or rovers with special attention to past or current 'active' regions. Cryogenic sampling.	Compact Cameras Micro Imager Ground Penetrating Radar Magnetometer Seismometer Heat Flow Laser Reflector	JPL EECAM, JPL MMI JPL, Natl A&S Museum, GPR JPL/UCLA Fluxgate, VHS JPL SEIS, uSeismometer JPL ALGEP (Banerdt) JPL (Turyshev)
Surface Processes: regolith character and formation, impact processes		Geotechnical sensors (Mech, EM, thermal) Regolith particle analyzer	KSC MECA, SWRI DART COTS Microbrook Eyetech
Environmental processes: solar wind, plasma, IMF, micrometeoroid, radiation, exosphere interactions	Deployable environmental/ surface safety network monitoring surface dynamics	Mass Spectrometers Particle analyzers (ion/electron) Electric Field Instrument Dust Detector UV Spectrometer Radiation Detector	JPL QIT MS GSFC HALO, SIMS GSFC EPDA GSFC EPDA ARC LADEE UVS UNH DOSEN

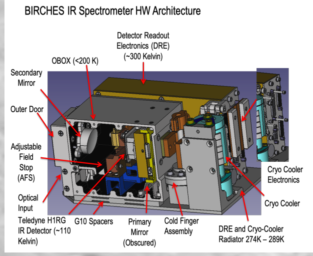
In Situ Science Time on the Moon

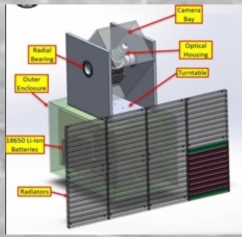


1) ASE Mortar Package Assembly
2) Heat Flow Experiment electronics box
3) Solar Wind Spectrometer
4) Suprathermal Ion Detector/Cold Cathode Ion Gauge
5) Lunar Surface Magnetometer
6) Charged Particle Lunar Environment
7) Passive Seismic Experiment
8) Laser Ranging Retroreflector
9) Lunar Ejecta and Meteorites Experiment
10) Lunar Atmospheric Composition Experiment
11) Lunar Surface Gravimeter

Properties of local surface

Cameras and Spectrometers, developed from orbital missions, portable/rover-mountable, capable of providing photogeological, geochemical, physical, and volatile data discretely (for individual rock or regolith) and contextually (for surrounding landscape).





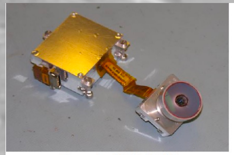


Figure 2 – MSL ECAM

Name/Acronym	Description	Measurements	Mass	Power	Vol
BIRCHES Broadband InfraRed Compact, High-resolution Exploration Spectrometer	IR point spectrometer with IVRS heritage (Teledyne H1RG 1 to 4 micron FPA, simple reflective optics, linear variable filter)	Distinguish water features by fully utilizing the three micron band as a function of time of day in same swaths from orbit	3 kg in 14 kg Lunar Ice Cube	15W peak	3U
NIRVSS Near InfraRed Volatile Spectrometer System [22]	dual point AOTF IR InGaAs and MCT detectors (with dual filament lamp) and visible CMOS spectral context (with LED sources) (SCI) spectrometer, as well as Longwave Calibration radiometer (LCS)	ground-pointing on rover, near or in PSRs, color signatures and IR absorption features Fe-bearing minerals; water related (1200-[illegible]000), ~1 mm spatial resolution, SCI 7 LEDs 340-940 nm, 0.25 mm resolution at 1 meter.	5 kg (minus thermal and batteries, with some mechanical packaging.	30 W peak	6U
SILVIR Surface Imaging of Lunar Volatiles in the InfraRed [23]	imaging HOTBIRD spectrometer and camera optics with cryocooler in 2.5 to 6.5 micron range with gimbal for large effective FOV	stationary platform 9 absorption bands from 2.5 to 6.5 microns representing and distinguishing OH and H2O, <cm to m scale resolution 180 x 90 degree maps of landing site as function of time of day	15 kg (with thermal, all packaging, and batteries)	27-47 W peak	12U
EECam Enhanced Engineering Camera [19]	Lunar version of Mars 2020 cameras	45 x 45 FOV, 4 mrad/pixel at 1 m, <<1 mm resolution. Selected Vis/NIR bandpass filter(s). Could add 'source' LEDs.	<1 kg	2.2 W	<1U

Multispectral MicroImager (handheld or rover arm)

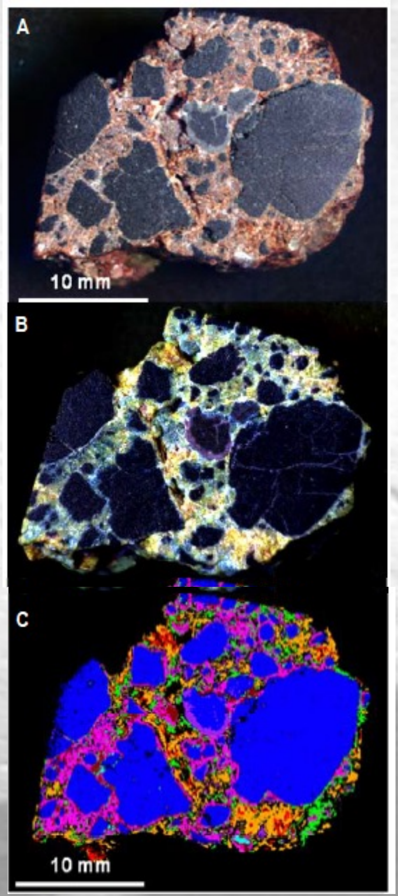
Description: Compact, low-cost Multispectral Microscopic Imager (MMI) to provide petrographic (microtextural) information on composition and color to reveal origin and history of sample.

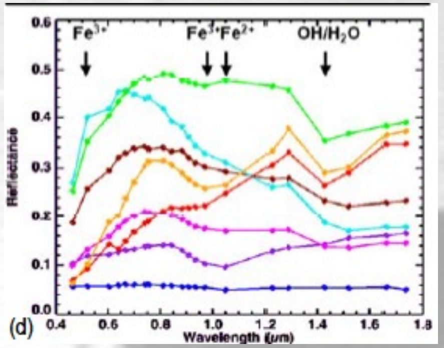
Measurement Advances: Spectrometric capabilities added to MER microscopic imagers (MI). Multiple bands and range (visible to near IR) extend ability to characterize mineralogy and allow more effective sample screening

Technology Advances: Advance MI to be rugged, portable instrument with built in sources (LEDs) with no moving parts to be mounted on rover or tripod.

Approach/Milestones, TRL 4 to 6
Build and test prototype based on field unit.

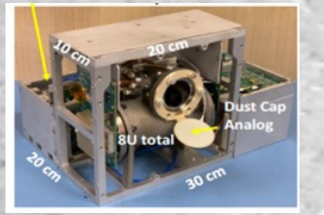
Team: Sellar, Farmer (ASU), Nunez (ASU)

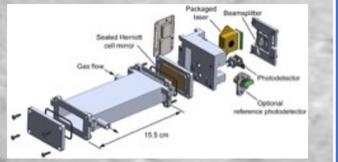




Left: MMI 25 x 30 mm subframes A. natural color composite, B. translated color composite, C. mineralogical map. Right top: reflectance spectra of end-member minerals mapped in C. Right bottom: Field unit.

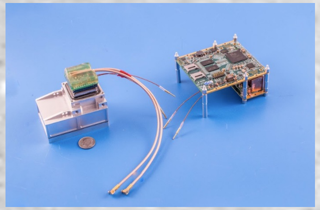
Exospheric species, Energetic Particles, and Dust. In Situ environmental instruments, all very compact, would establish the relationship between the exosphere, the regolith, and the surrounding plasma environment. Networked stations or mobile payloads would allow capture of environmentally or human activity induced spatial and temporal variations.

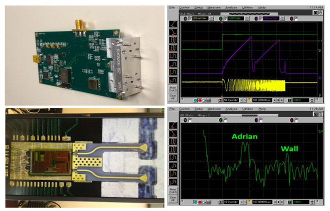


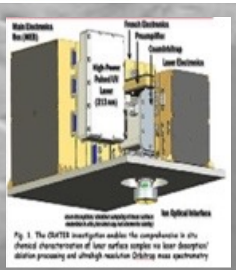


Name/Acronym	Description	Measurements	Mass	Power	Vol
Lunar Cubesat Mass Spec (LCMS) [31]	STMD GCT Quadrupole Ion Trap Mass Spec with LETS radiation sensor Freebie. World record sensitivity, mass resolution and precision for a compact MS	Mass range 0.75 to 230, mass res (FWHM) 1000 including H, H2, H3 isotopes, Ne, N2, O2, Ar, CH4, XO, XO2, noble gases, OH, H2O.	7 kg	7 to 24 W (peak)	6 U
Lunar In Situ Resource Analyzers (LIRA) [32]	tunable lasers (with sealed optical Herriot cell) tuned for monitoring trace water in ISRU related systems (propellant streams from hydrogen reduction systems or other)	Unique molecular absorption of water at 2.61 µm wavelength to measure low-ppm humidity in either pure O2 or H2 at relevant temperatures and pressures. Detection sensitivity < 3 ppmv H2O	<1 kg	TBD	150 cu cm cell plus about same volume additional components (300 cu cm)
Mini Electrostatic Analyzer (ESA) and Mini Energetic Neutral Analyzer (ENA) [33,34]	monitor solar wind input (proton interactions with regolith) with large FOV based on HALO [33] ACES design and ENA produced from that interaction based on FASTSAT design [34]	ENA: 10-5000 eV surface backscattered H flux. ESA: ion distributions 20-5000 eV with 12.5% energy resolution and 15 degree angular resolution	<1 kg each	1 W each	1 U each

Subsurface resources. Subsurface composition and structure (volatiles, element/mineral abundances) bulk characterization and/or profile to 1 meter, based on earlier orbital designs, tailored for surface applications

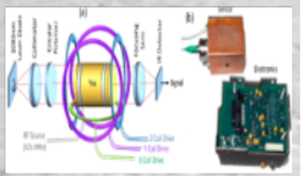






Name/Acronym	Description	Measurements	Mass	Power	Vol
Mini Neutron Spectrometer NS [26]	Modified version of LunaH-Map Neutron Spectrometer with state of art (high efficiency) CLYC detector	reductions in thermal neutron flux from subsurface due to greater abundance of protons to a depth of 1 meter implying presence of ice. To <500 ppm.	0.5 kg	5 W	<1 U (sensor plus processing)
Bulk Elemental Composition Analyzer BECA [27]	combined gamma-ray and neutron spectrometer w/ pulsed neutron generator (deuterium/tritium) technique established in oil well boreholes.	measurements of scattered gamma-ray lines characteristic of C, H, N, O, P, S, Si, Al, CA, Fe, Mg, B, Cl, Ti, Mn, Ni, Gd, V, Mn, K, U, Th to 30 cm, 1 meter area.	6 kg??	10w??	30 cm x 20 cm x 10 cm sensor plus electronics.
mini-Ground Penetrating Radar GPR [28]	Ground Penetrating Radar (mini-GPR) – wideband hybrid RF-digital radar developed by JPL team	measuring dielectric constant in subsurface profile with vertical resolution of 10 cm induced by variations in water/ice. No sample preparation.	1.5 kg	5 W	<2U (plus antenna)
Characterization of Regolith and Trace Economic Resources CRATER [29]	UV Laser-based ion trap (CosmOrbitrap) mass spec	cation (metal) and volatile compound abundances, 16 to 2000 Da, m/delta m 100,000 (very high) without need for sample processing	~12 kg	~150W peak	10 x 10 x 20

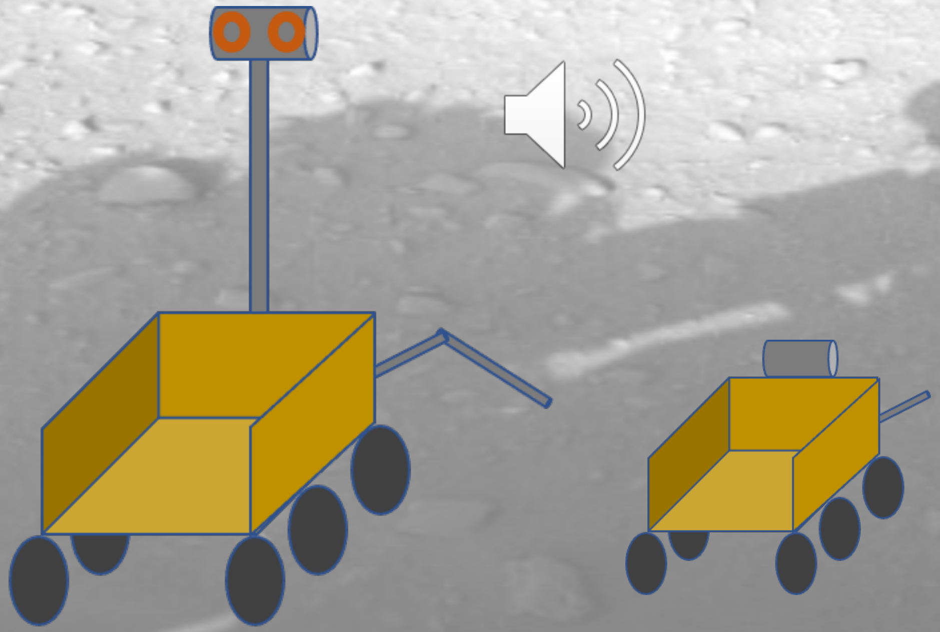
Deep Internal structure. Mobile platforms could enable deployment of seismometers at selected locations to characterize internal structure. In situ Magnetometer readings, could measure magnetic field variations induced by variations in the external field (IMF) if simultaneous measurements are taken by an external magnetometer). From these variations, interior temperature and compositional profiles could be derived and used to model the structure and state of core and mantle.



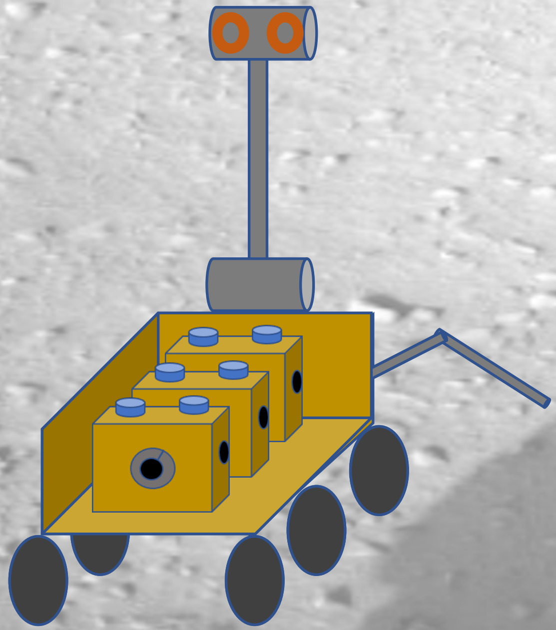
Name/Acronym	Description	Measurements	Mass	Power	Vol
Vector Helium Magnetometer [35]	Updated version of INSPIRE magnetometer	intensity of mag field along 3-axes in situ with sensitivity 20 pT/SQRT(Hz) and range +/- 100 to 100000 nT (body dependent)	3 kg plus batteries + small boom	3.5 W day, 4 W night.	<3U
Si/C Magnetometer [36]	new technology solid state self-calibrating magnetometer	intensity of mag field along 3-axes in situ with sensitivity <100 nT/SQRT(Hz) (currently, anticipating <1 nT) and range without need for calibration (self-calibrating, eliminating need for boom). Measure 1 vector (3 axes)/minute with 20 bits precision each axis, for 60 bits	<1 kg, no boom required.	3 W	~1U
Fluxgate Magnetometer [37]	modified version of ELFIN magnetometer	Intensity of mag field along 3-axes with sensitivity <10 pT/SQRT(Hz) at 1Hz, and range plus/minus 1000 nT. Include a second magnetometer at different distance along boom for characterization and removal of offending lander fields, but duty cycle second sensor as needed for characterization not required for routine operations.	<0.5 kg plus boom	2 W/sensor	~0.5U
SEIS SP Seismometer	Modified version of SEIS Short Period INSIGHT seismometer	ground acceleration, sensitivity < 5 x 10^{-9} m/(Sqrt(Hz)) between 0.1 and 10 Hz	<1 kg	2-4 W	~1U

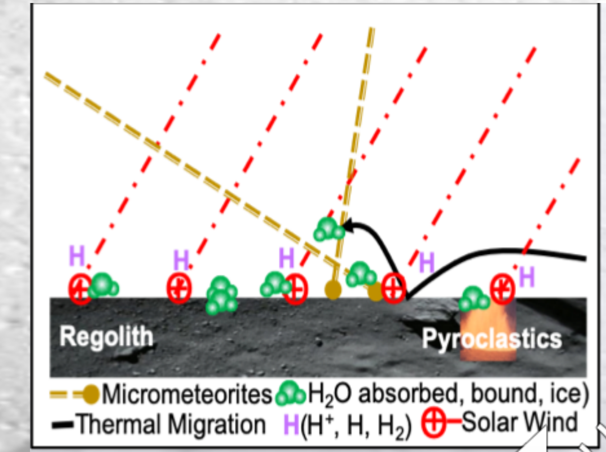
Mobile Instrument packages: We envision several compact mobile platforms capable of carrying payloads ranging from 10-20 kg (MER 180 kg rover with arm) to 5 to 10 kg (90 kg rover) utilizing instruments described above, with some potential compact additions.

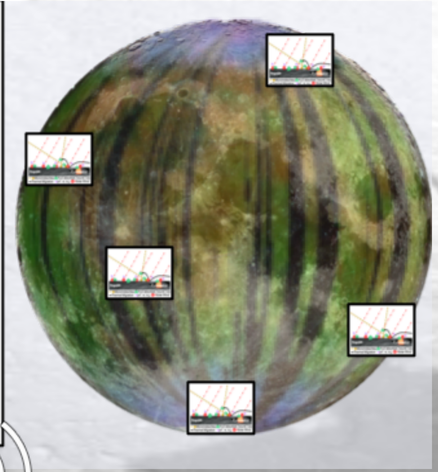
Surface Mobility, Physical and Electromagnetic Properties: Mechanical or Electromagnetic property meters for determining mechanical and electromagnetic properties could be embedded in rover tires for any mobile platform.



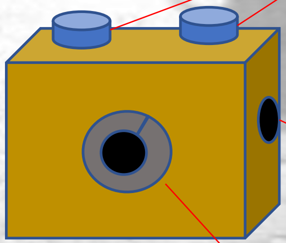
Deployed Stations: A mobile platform, robotic or with astronauts, could deploy interior or environmental monitoring stations to create a spatially and temporally distributed network for monitoring the charged particle interaction/water cycle, including solar wind, resulting energetic neutrals, OH and molecular water.





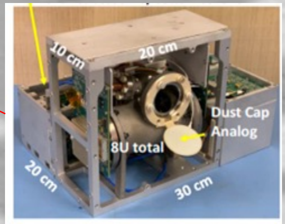


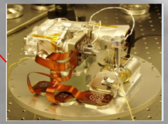
GLOWIN globally distributed ground network provides the basis for comprehensively modeling the lunar water cycle resulting from interactions between the environment, surface, and interior.



ESA/ENA

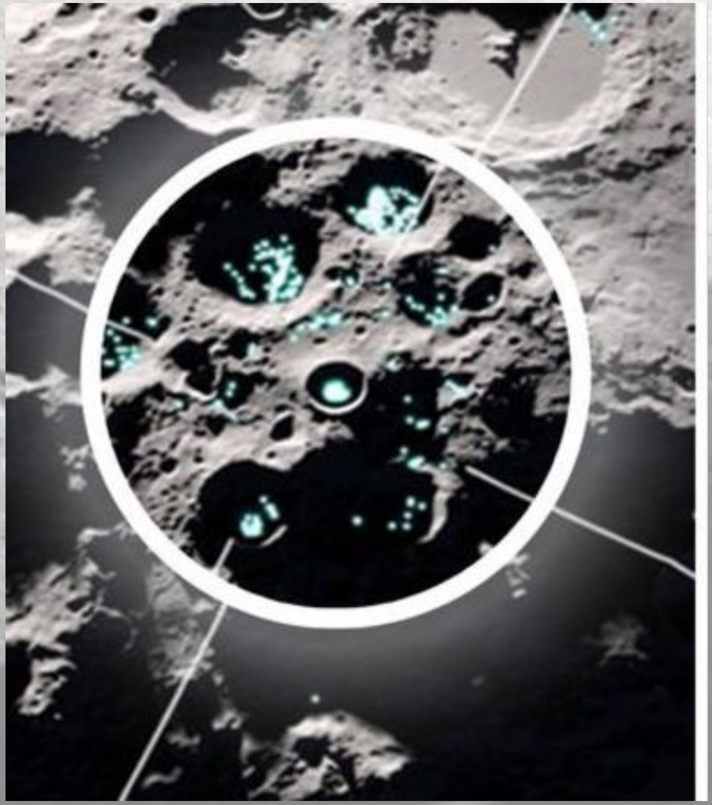
LCMS

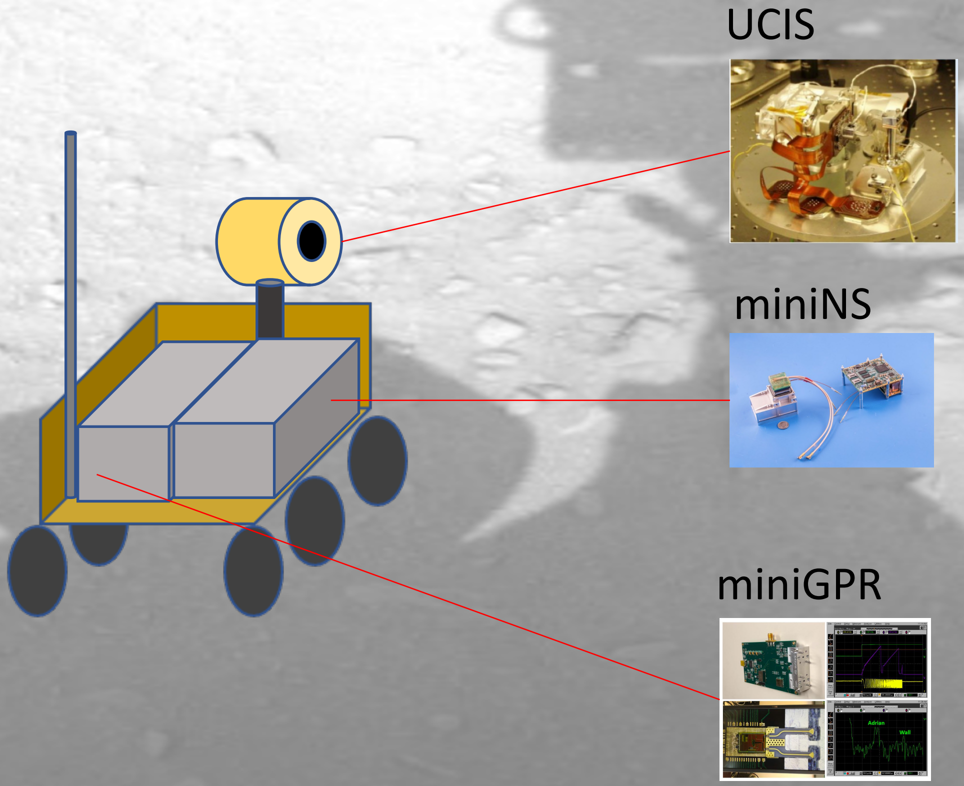




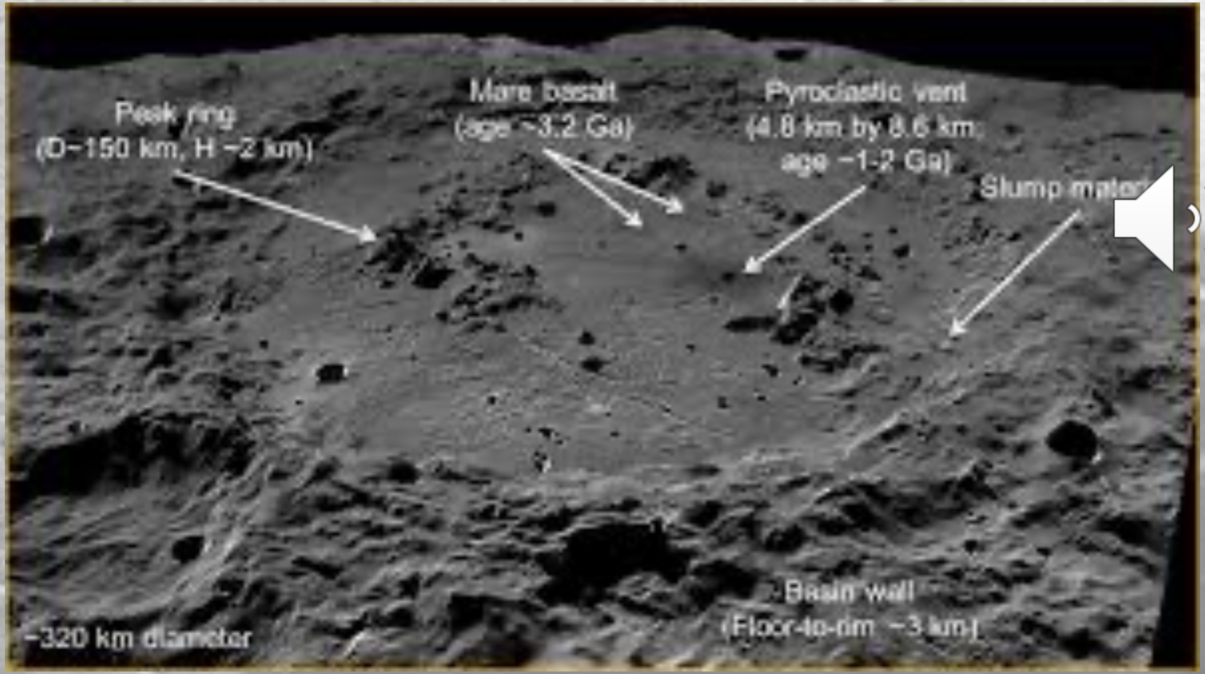
IR Spectrometer (UCIS)

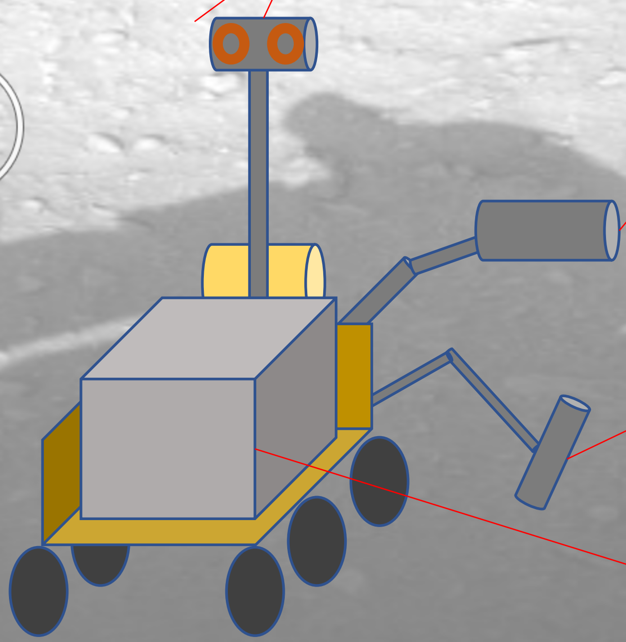
Water Prospector [6]: Smaller rover(s) with compact IR imager, neutron spectrometer and ground-penetrating radar could gather data on water distribution in the hundreds of ppm range in the first meter or more along traverses in areas identified from orbit as 'promising' in terms of water or other volatile resources.



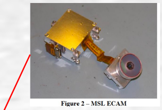


Terrain Character Mapper. Rover would allow geochemical and structural characterization of selected previously unexplored terrains, such as volcanically complex farside basin Schrodinger.

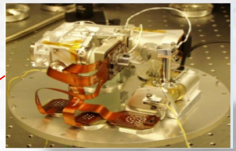




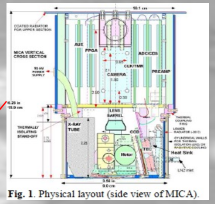
EECam



UCIS



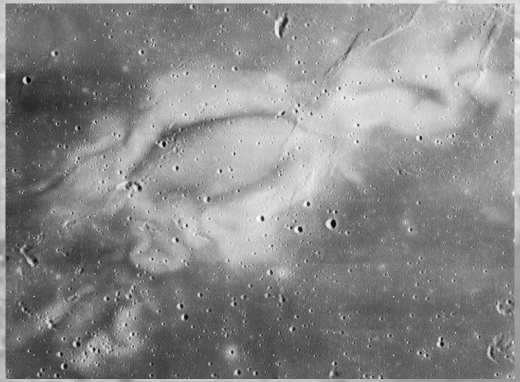
Combined XRF/XRD

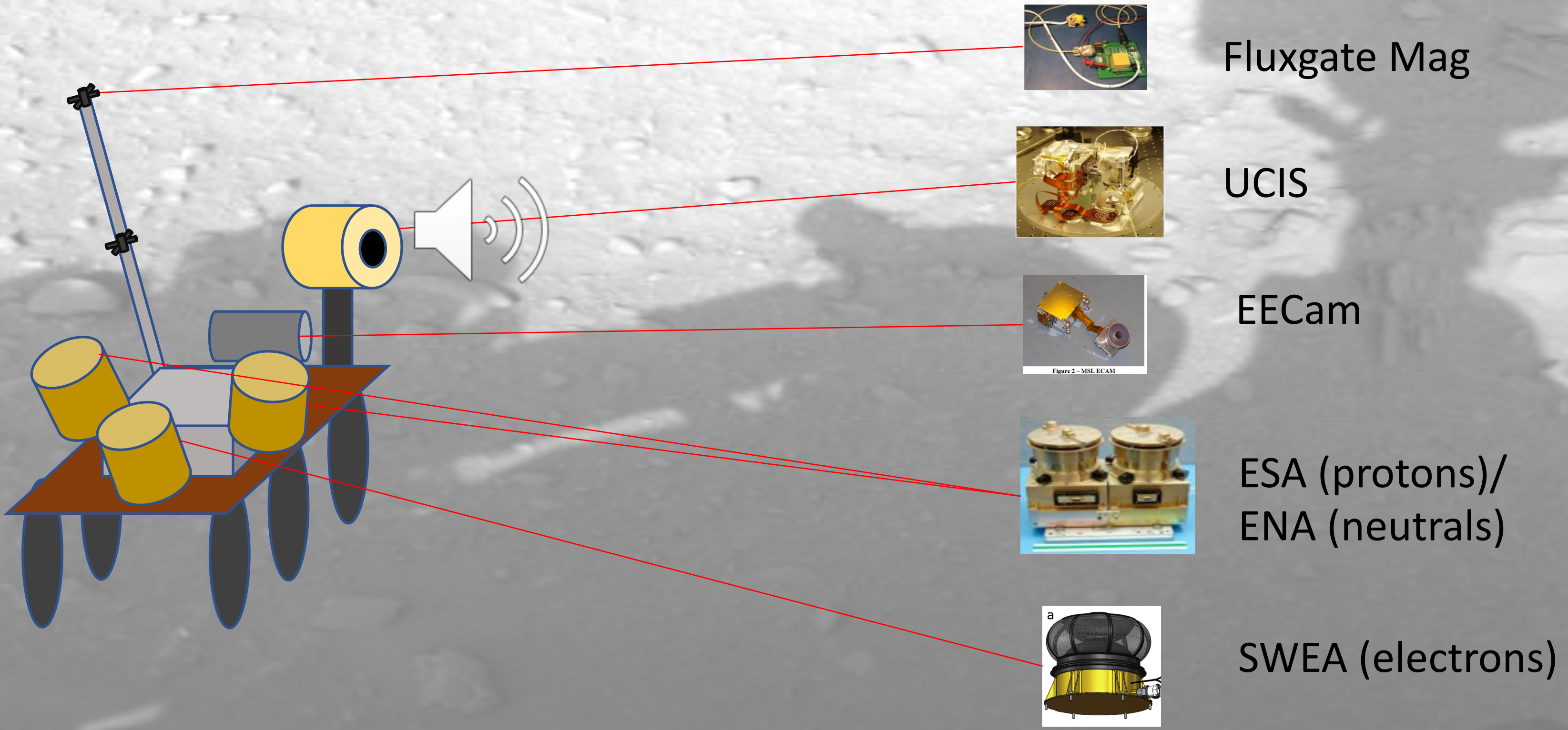


Multispectral Micro Imager

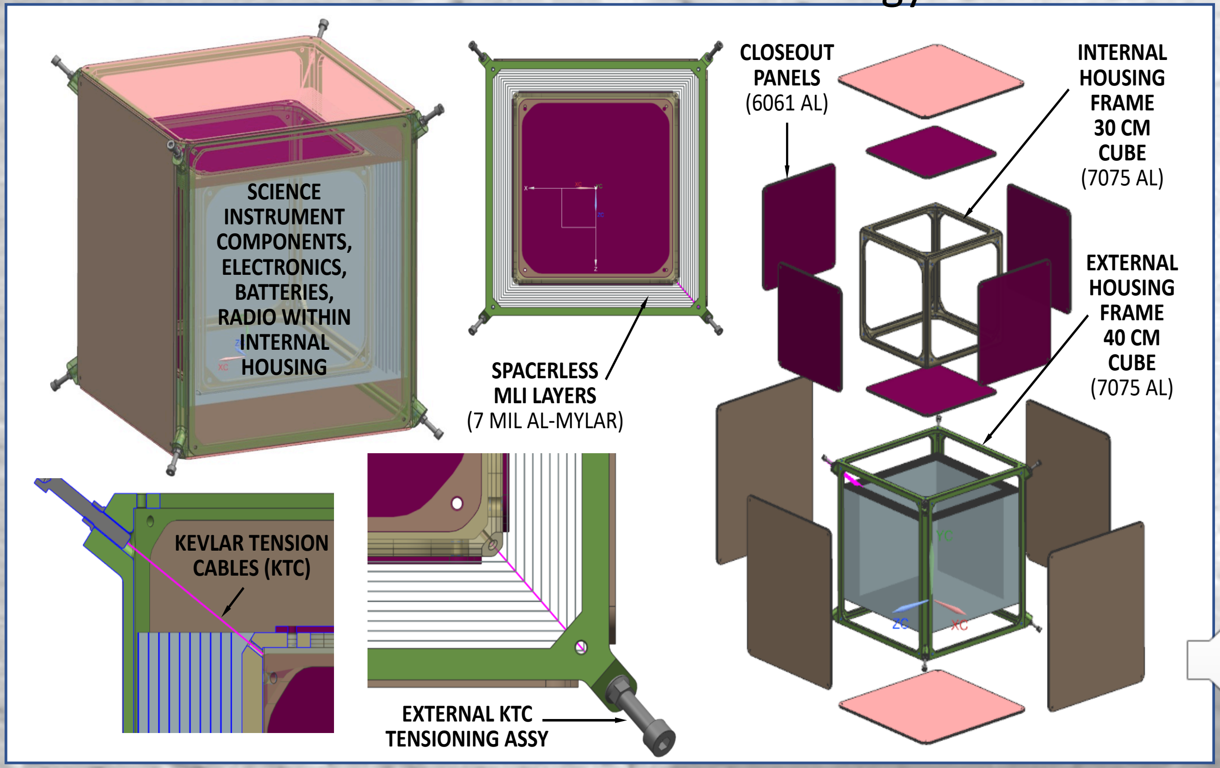
Bulk Elemental Composition Analyzer

Electromagnetic Anomaly Mapper. Rover(s) with in situ detectors could be used to determine the relationship between charged particles, exosphere, energetic neutrals, local fields and volatiles. A small rover with energetic particle, energetic neutral, magnetometer, also capable of visible and IR mapping could help to resolve the nature of magnetic swirl anomalies and their influence on space weathering.

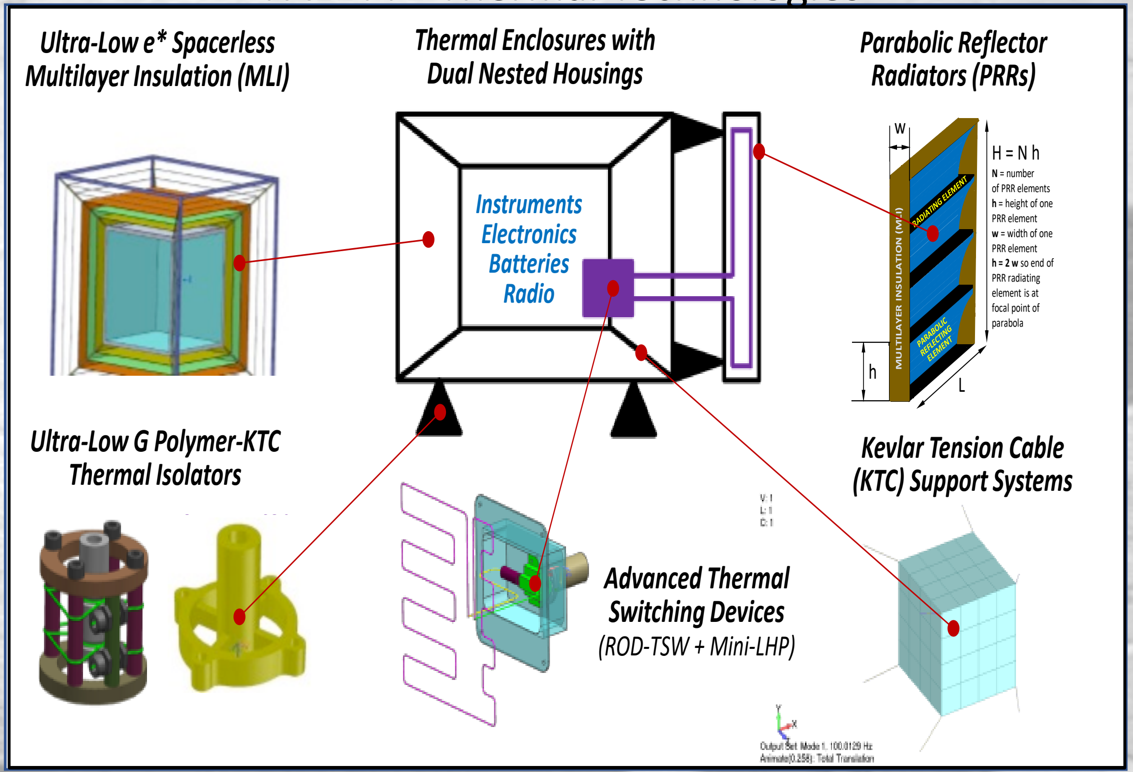




ARTEMIS-T-IA Enclosure Technology



PALETTE Thermal Technologies



Generic yet Reconfigurable Packaging [15]:

- A major challenge for small packages, particularly on the lunar surface, is thermal packaging to protect the payload from the lengthy temperature extremes conventionally requiring significantly increasing mass and volume needed for batteries during lunar night.
- High performance thermal component based packaging based on passive thermal design that will allow operation on at least limited duty cycle during lunar night with interfaces for lander power, comm, is now being developed and tested.
- Thermal packaging from ARTEMIS-T (JPL SR&TD) and PALETTE (NASA GCD) projects. Design uses advanced features described in the figures.

Summary:

The instruments NASA and collaborators have been developing, combined with high performance generic yet configurable packaging for the extreme environments, provide candidates for suites which could deliver focused yet high priority science measurements from mobile lunar surface platforms, as the several examples given here indicate.

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