EPSC Abstracts
Vol. 13, EPSC-DPS2019-1571-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

LUNAR "VOLATILE AND MINERALOGY MAPPING ORBITER (VMMO)" MISSION

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Introduction: The lunar CubeSat mission proposal called VMMO (Volatile & Mineralogy Mapping Orbiter) is among the two winners of the European Space Agency (ESA)'s SysNova Challenge on LUnar Cubesats for Exploration (LUCE) in 2018. VMMO has been developed by a multi-national team consisting of MPB Communications Inc, Surrey Space Centre, University of Winnipeg and Lens R&D.

The proposed mission aims to address several key aspects of future lunar exploration:

- *Lunar Resource Prospecting*: *Mapping the location of relevant in-situ resources and volatiles in sufficient quantities to be operationally useful (fuel, life-support) for future sustained surface missions.* The VMMO's primary science payload (Lunar Volatile and Mineralogy Mapper or LVMM) is a miniaturised laser instrument that would probe Shackleton Crater, adjacent to the South Pole, for measuring the abundance of water ice. It uses a dual-wavelength chemical lidar at 532 nm and 1560 nm at relatively high SNR to improve the sensitivity to small changes in the water/ice content of the regolith. Scanning a 10m-wide path, LVMM would take around 260 days to build a high-resolution map of water ice inside the 20 km-diameter crater. LVMM would also map lunar resources such as ilmenite ($TiFeO_3$) as it overflew sunlit regions, as well as monitoring the distribution of ice and other volatiles across darkened areas to gain understanding of how condensates migrate across the surface during the two-week lunar night.
- *Lunar Environment and Effects: Measuring radiation, lofted dust and diurnal temperatures in the cis-lunar environment to support planning for future manned missions.* A secondary radiation-detecting payload (Compact LunAr Ionizing Radiation Environment or CLAIRE) would build up a detailed model of the radiation environment for the benefit of follow-on mission hardware as well as human explorers.
- *Lunar Explorations Technology: Developing enabling technologies for beyond-LEO CubeSats.* VMMO adopts a low-cost 20kg 12U CubeSat design, incorporating beyond-LEO navigation methodology and sensor suite as well as qualification of key electronics for CubeSats in the cis-lunar environment. The laser payload offers a dual use to demonstrate high-bandwidth and 1560nm optical downlink to an existing optical ground station.

Mission Profile & Operation: VMMO has been designed for a potential flight opportunity within the Lunar Communications Pathfinder Mission currently being developed by Surrey Satellite Technology Ltd. (SSTL) and Goonhilly in partnership with ESA. The VMMO CubeSat would be injected by a mother spacecraft into a nominal high-eccentricity lunar orbit. It would then use its on-board propulsion to attain the desired operating lunar orbit.

The mission operation consists of the following sequence, as shown in Figure 1. After launch from Earth, the mission will take some time before the mother spacecraft Lunar Orbiter (LO) reaches its desired orbit around the Moon (approx. 15 days). The next step in the mission is to get from LO orbit to a Small Satellite (SS) release orbit at approximately 500 km altitude (approx. 15 days). At this point the VMMO will be released from SS orbit. Once released VMMO will perform de-tumbling and initial health monitoring prior to maneuvering into its final orbit (approx. 7 days). The maneuver length from the release orbit to VMMO final orbit is estimated to take 68 days using electrical propulsion. In the final orbit, VMMO will perform scientific measurements: Active, Passive and Radiation (approx. 260 days). Data transmission includes sending data to Earth via the LO relay or via a direct optical downlink. The total mission duration is expected to be approximately 1 year.

Spacecraft Design Overview: Figure 2 gives an preliminary overview of the VMMO 12U CubeSat, consisting of two payloads (LVMM and CLAIRE), three sets of deployable solar panels (one of them would be acting as a baffle for the LVMM payload), batteries, two electrical propulsion units, four reaction wheels with cold gas thrusters for momentum management, twelve attitude thruster nozzles, one star tracker, sun sensors, on-board computer and UHF and X-Band communication units and patch antennae.

The VMMO Cubesat will facilitate the selection and TRL advancement of low-cost microelectronics (FPGA, SRAM, PROM and flash memory, A/D, D/A, multiplexers and relevant analog and digital electronics) for beyond-LEO space applications. The CLAIRE Radiation Effects Test Board will assess the performance of a range of relevant commercial-off-the-shelf (COTS) electronic devices operating in a real lunar radiation environment by monitoring for single-event-effects and power consumption changes due to total-dose damage. This will allow direct correlations to be drawn between effects on the selected electronics test bed and the real measured environment. The VMMO Cubesat will develop and flight qualify in a relevant lunar orbit environment an altitude and orbit control system (AOCS) for semi-autonomous spacecraft operation beyond LEO. VMMO will also validate a hybrid electric/cold-gas propulsion subsystem to enable acquisition of the low-eccentricity frozen operating lunar orbit and de-spinning of the onboard reaction wheels.

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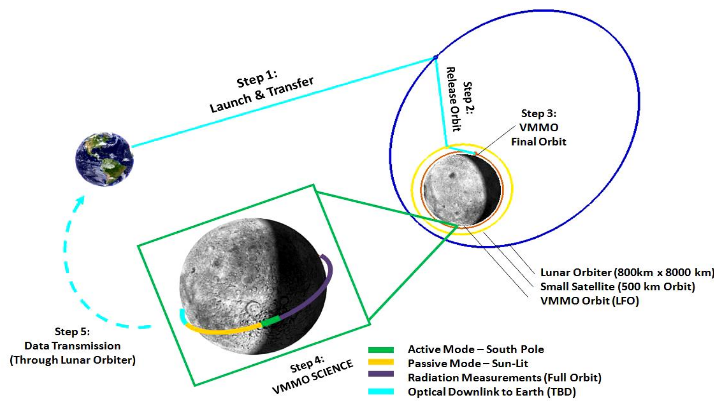

Fig 1: VMMO Mission Profile and Operation

Payload	**LVMM:** • Dual Band Laser Projection (532nm, 1560 nm) to detect Water/Ice presence at high resolution • Active Mode Res: 4 m x 44 m • Passive Mode Res: 20 m x 20 m **CLAIRE:** • Cis-Lunar Radiation Measurements
Structures	• 12 U Cubesat form factor (23 x 24 x 36 cm^3) • < 24 kg total launch mass • 12 U Dispenser compatible
Electric Propulsion	• 2x IFM Nano Thrusters (0.35 mN at 35 W, total impulse of 10,000 Ns) • ΔV up to 750 m/s
C&DH	• Radiation Tolerant LEON 3 system: Xilinx XCKU060, 512 SDRAM, 4 M SRAM and 64 M PROM
Power	• Deployable Solar Arrays (6 arrays with 18 cells per panel) providing up to ~123 W of power. • LiFePO4 batteries with 8 cells at 10 A-hr, providing up to 236 W-hr total energy.
Comms	• DSN and CCSDS Compliant X-Band Transponder • UHF Transceiver (Variant STRX UHF VHF)
ADCS	• 4x Reaction Wheels (RW3-006) Sinclair Interplanetary: Momentum 60 mNms, Torque 20 mNm at 0.12 Nms • ST-16RT2 star tracker (5 arcsec boresight RMS) • Lens R&D BiSon64-B sun sensors and SINPLEX IMU • Butane Cold Gas Thrusters, 12 nozzles, 70s Isp, 0.27 kg of propellant
Orbit	• Polar Lunar Frozen Orbit • Semi-major axis 1858 km, Eccentricity 0.043

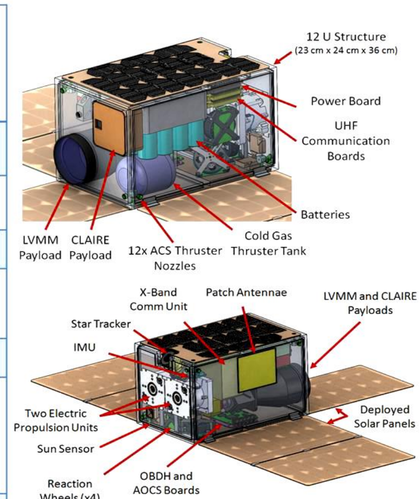

Fig 2: VMMO Spacecraft Preliminary Overview