Preliminary Lunar Science Drivers for *Lunar Mission One**

(*Contributors are listed at the end of the document)

1. Introduction

This document describes the top-level science drivers for *Lunar Mission One* (as envisaged in December 2014). It should be viewed as a 'living document' that will be revised in the light of further studies to be conducted after the Kickstarter funding phase. The science goals will be prioritized, and instruments selected, as the mission becomes better defined.

2. Landing site and science planning assumptions

It is assumed that a south polar site will be selected in an area of long-duration sunlight - a few hundred days with eclipse durations of less than 50-70 hours. The specific landing locality will be defined after a full study of potential landing sites based on work already performed for previous mission studies (e.g. ESA's proposed Lunar Lander [1]). All the proposed landing sites (e.g. Shackleton crater and Mons Malapert) lie on, or just within, the rim of the giant South Pole-Aitken (SPA) impact basin [2]. Scientifically, these south polar locations are of interest because the local regoliths may contain fragments of SPA impact melt (which could in principle be used to date the basin, a key event in lunar geological history), and fragments of lower crustal and/or mantle materials excavated by the basin. In addition, the detection and characterization of volatiles that may be retained in these cold polar regoliths is of both scientific, and possibly (in the longer term) practical, interest.

To a first approximation, the near-surface environment of potential polar landing sites are likely to be similar, with several metres of unconsolidated regolith, probably containing blocks of more competent materials, overlying more compacted highland 'mega-regolith'. However, the detailed geological record preserved in the near sub-surface at various candidate landing sites may be different. For example, Shackleton is a 20-km impact crater, and deposits close to the rim are likely derived from a depth of about 2 km below the pre-impact ground level, which forms an interior ring of SPA [2]. Mons Malapert, on the other hand, may be an outcrop of pre-SPA highland crust, possibly covered by SPA ejecta. Other potential landing sites will have other considerations. More work is therefore required to define the geological contexts, and likely sub-surface environments, of all the potential landing sites as part of a detailed site selection process.

The science case is largely predicated on studying samples retrieved from, and instruments placed within, a >20 m deep borehole at the landing site. The drilling technology itself, likely either 'wire-line' or 'coiled tubing', will be subject to detailed study once funding is secured (see references [3, 4] for some discussion of extraterrestrial drilling technologies). It is assumed that access will be available to samples from downhole drilling, with possible placement of instruments within the borehole. It is likely that the surface layer in the near vicinity of the lander will be contaminated with landing rocket exhaust, but samples may be uncontaminated once the drill has penetrated a few 10s cm into the surface (to be confirmed by future studies).

Primary mission science will be obtained mainly via the drill samples or emplacement of instruments within the borehole. It is assumed that a sub-set of samples from the drilling will be cached for a potential sample return mission that may follow at a later date. If there is sufficient mass budget available additional instruments may be deployed on the surface, for example to characterise the abundance and composition of volatiles in the local regolith.

3. Top-level science drivers for Lunar Mission One

A thorough, top-level, prioritisation of lunar science objectives is provided in the US National Research Council (NRC) Report on the *Scientific Context for Exploration of the Moon* (SCEM) [5] and this still represents a broad consensus in the science community on lunar science priorities. Based on this study, and on more recent reviews of the literature (e.g. [6,7] and references cited therein) the following science goals for *Lunar Mission One* are suggested. These will be further refined as mission planning proceeds (no order of priority is implied):

1. **Understand the geochemistry/mineralogy of the lunar crust**

    a. Determine the physical properties, geochemical and mineralogical composition of the landing site versus depth beneath the surface and determine if possible the extent and structure of the mega-regolith at the landing site (SCEM recommendations 2a, 3a, 3b, 3d, 3e, 7a, 7b, 7d, some partially).

    b. Attempt to identify fragments of deep crustal and/or mantle materials excavated by the SPA impact within the local regolith, and characterise their chemical composition and mineralogy (SCEM recommendations 2a, 2b, 3a, 3b, 3c, 3d).

2. **Characterize the impact history of the landing site and constrain the age of the SPA Basin**

    If feasible within the constraints of the payload, attempt to identify impact melt fragments in the local regolith and attempt to date these (e.g. by using the i*n situ* K-Ar method recently demonstrated by instruments on the Curiosity rover on Mars [8]). This may be able to constrain the impact history of the landing site, and possibly establish an approximate age for the South-Pole Aitken basin (SCEM recommendations 1a, 1b, 1c).

    It is recognized that accurate dating will require the return of samples to Earth. For this reason, *Lunar Mission One* will aim to characterise and cache appropriate samples for later collection and return to Earth to enable later accurate age dating and geochemical and isotopic analyses.

3. **Understand the diversity and origin of lunar polar volatiles**.

    Determine the volatile content (including OH/H_2O) of the local regolith, both at the surface and within drill samples (SCEM recommendations 4a, 4b, 4d, 4e, some partially).

4. **Constrain models of the lunar interior**

    a. By placing thermal sensors in the borehole measure the lunar heat flow. This will help characterise the thermal state of the interior at a locality far from the Apollo heat-flow measurements and elucidate the workings of the planetary heat engine (SCEM recommendation 2d).

    b. By placing a seismometer in the borehole use seismic signals generated by natural moonquakes and/or meteorite impacts to probe the structure of the lunar crust and mantle at a locality far from the Apollo seismic measurements. Such knowledge will shed light on the differentiation of the Moon and, when coupled with geochemical studies, may further constrain the bulk composition of the Moon (SCEM recommendations 2a, 2b, 2c).

c. In addition, subject to available payload mass and the planned cadence of future missions, *Lunar Mission One* could also act as a node for a future lunar geophysics network which would further inform our knowledge of the lunar interior.

5. **Characterize the lunar environment for future scientific exploitation and human exploration**

   Measure the environment at the site and characterise its radiation, seismic, dust and charging environment as well as the local exosphere (SCEM recommendations 8a, 8b). This will identify possible hazards to future human exploration and habitation. It will also help characterize the lunar environment in preparation for future scientific activities (e.g. astronomical observations and fundamental physics experiments).

6. **Identify resources for future human space exploration**

   Assess the potential for exploiting lunar resources for exploration and human habitation from the local mineralogy and volatiles (for context see reference [9] and references cited therein).

7. **Assess the potential of the lunar surface as a platform for astronomical observations**

   Conduct initial proof-of-concept studies for future low-frequency radio astronomy from the Moon, including measurements of extra-galactic and galactic sources, terrestrial emission, the lunar exosphere, and the effects of the lunar surface on radio propagation and communication. Additionally, investigate the possibilities for studying the Earth and its magnetosphere from the Moon.

8. **Science education**

   Although not strictly a science goal, the project will aim to maximise the outreach potential for science education during all phases of the mission.

4. Example payload

The following minimum model payload is indicative of one that would achieve the proposed science goals within a notional 30 kg allocation. At present this is purely conceptual but is based on instrumentation that has an appropriate level of technical maturity. It will be refined as a result of future studies.

- Descent Imager – part of landing system images of the landing site at various heights to place the landing site into the local context. Some other instruments required for navigation/landing (e.g. landing LIDAR) may also provide data of scientific value.

- Landing Site Imager – multi-spectral imaging mineralogy for landing site characterisation. If possible, obtaining images of Earth from the landing site will also be desirable for outreach purposes and for studies using the Earth as an analogue for habitable exoplanets.

- Infra-Red Imaging Spectrometer – to characterize the local mineralogy.

- X-ray Diffraction/X-ray Fluorescence (XRF)/Gamma-ray spectrometer/Densitometer – to determine elemental composition, mineralogy, trace elements and radio-nuclides. Note: It is important to ascertain the thermal conductivity (e.g. via density) of the rock to accurately determine heat flow (a densitometer could be incorporated within the drill).
- Raman-LIBS (Laser Induced Breakdown Spectrometer) – to determine elemental composition and mineralogy at the landing site and of drill samples.
- Neutron spectrometer – for the determination of hydrogen concentrations in the local regolith for comparison with orbital measurements.
- Mass Spectrometer – for determination of the chemical composition of sampled materials, especially of volatiles and (ideally) stable isotopes. This would give potential for K-Ar age dating (when combined with K data from XRF or LIBS [8]), and characterization of volatiles trapped in the regolith. Requires a sample handling system and a carousel of ovens.
- Seismometer – for determination of internal lunar structure and characterization of natural moonquakes (might also be used to monitor drilling activities). If a multi-year mission life proves possible this could become a contribution to a future lunar geophysics network.
- Heat Flow – to better characterize lunar thermal evolution; needs to measure temperature and thermal conductivity as a function of depth.
- Dust, radiation and charging package – to determine dust particle size and electrostatic charging; should also include radiation monitor.
- Sample imager – to image samples analysed by others to provide colour and context (may have microscope capability).
- Low-frequency (LF) radio-astronomy investigation package – to investigate the practicality of LF radio-astronomy from the Moon (interference environment, etc); possible radio-frequency beacon to aid future missions.
- Proof of concept Magnetosphere Imager.

The above list is not exclusive and other instruments may be possible. All will need to be reviewed as the project develops.

It is intended that a final payload selection will be made following a detailed study of science return, technical maturity, availability, accommodation (mass, power, telemetry, spatial), operational needs, risk and cost, and international exploration priorities. Each suggested payload instrument will be investigated and a number of potential architectures explored including a central control unit/data management unit and robotic arm or other instrument deployers around the periphery of the lander. Sample handling will be a key issue since this will impact the instrumentation that will study the recovered samples. Down-hole versus recovered sample studies will also be traded. The possibility of overwintering will be included in the study. This trade will lead to a strawman payload and accommodation which will form the basis of a preliminary design. Throughout this process an international science advisory group will provide essential support and establish scientific priorities.

A preliminary model payload which addresses these science goals is shown in the table below.

Table 1: *Lunar Mission One*: Example Instruments and Top-Level Science Goals

Instruments / Science Goals	Goal 1: Geochemistry & Mineralogy	Goal 2: Impact chronology (including SPA Basin Age)*	Goal 3: Volatiles	Goal 4: Internal Thermal	Goal 5: Environment (Dust, radiation, seismic surface conditions)	Goal 6: Resources	Goal 7: Radio-Astronomy/ Magnetosphere Studies	Goal 8: Science Education
Landing Site Imager					X	X		X
IR Spectrometer	X				X	X		
X-ray/Gamma-ray Spectrometer	X	X (v. approx age only*)	X (if low energy response)			X		
Raman-LIBS	X		X			X		
Mass Spectrometer	X	X (v. approx age only*)	X		X	X		
Neutron spectrometer	X		X					
Seismometer				X	X	X		
Heat Flow				X				
Dust, Radiation Charging Package					X	X		
Sample Imager	X		X			X		X
Radio-astronomy demo package							X	X
Magnetospheric Imager							X	X

*It is noted that *in situ* identification and subsequent age dating of SPA fragments will be extremely challenging and is an aspiration at this time. This science may have to be addressed via caching and later sample return.

References

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