LUNAR GEOPHYSICAL INSTRUMENT PACKAGE (LGIP) I – SCIENCE AND INSTRUMENTATION.

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Introduction: The return of humans to the Moon will occur 40+ years after the last astronaut left. While the Apollo missions set up individual instruments (as part of the Apollo Lunar Surface Experiments Package - ALSEP) to collect geophysical data, the small aerial distribution of the sites, coupled with the short term nature of some measurements and the fact that not all missions carried the same instruments, gave only a limited glimpse of the Moon's inner structure, composition, and thermal evolution. Several important unanswered questions remain: (1) What is the composition and size of the lunar core? (2) What is the internal structure of the whole Moon? (3) What is the thermal budget of the Moon and how has this impacted its evolution? (4) Did the early Moon have a dynamo and if so, when did it start and when did it stop? (5) What is the nature of ground movement in response to the large (body wave magnitude ≥5) Moonquakes that are known to occur [1]? (6) Are meteoroid impacts concentrated more in some areas on the Moon than others?

To answer these questions, it is necessary to make global lunar geophysical measurements over a long period of time (≥6 years) that at a minimum covers one lunar tidal cycle. This may be realized through the establishment of a global lunar geophysical network. To accomplish this in a timely and cost effective manner, it is likely that the next lunar geophysical network will be incrementally built up in a variety of locations, using a number of missions over a long period of time. A Planetary Instrument Design and Development Program (PIDDP) has recently been awarded to develop a small self-contained lunar Geophysical Instrument Package (LGIP) for use in a long lived lunar geophysical network. This contribution examines the instruments that comprise the proposed Lunar Geophysical Instrument Package (LGIP) as well as their science requirements. The actual probe design, power and concept of operations are the subject of a companion contribution [2]. While the impetus for this study comes from the limited knowledge of the lunar interior, the technology developed may be applied to other solid bodies in the solar system.

Instruments: The LGIP combines a seismometer, heat flow probe, and a surface magnetometer into an integrated suite of instruments that may be used on a robotic lander, or deployed robotically or by an astronaut as a stand alone geophysical probe. Each of the instruments considered for the LGIP is relatively mature and is a payload on a past, current or future planetary mission. Modifications to individual instruments to meet science measurement requirements and conform to a common probe architecture, are what form the basis of the LGIP study and will be outlined in this contribution.

Seismometer. The data returned from the Apollo missions showed the Moon to have a much lower seismic background noise relative to the Earth. In fact, it is likely that the background levels recorded were actually the noise limits of the instruments themselves rather than true seismic noise (likely below 10^{-10} $ms^{-2}/Hz^{1/2}$ on the vertical seismometer).

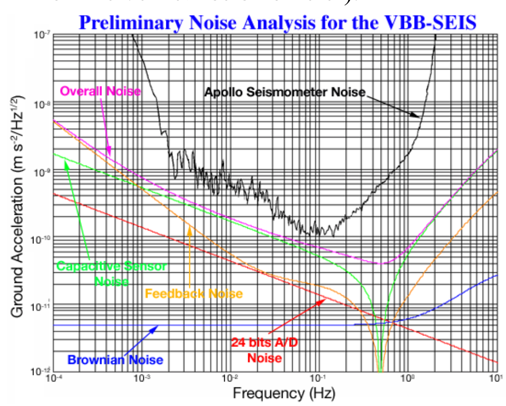

***Figure 1** – VBB-SEIS Preliminary Noise Analysis*

The LGIP uses a modified version of the very broad band seismometer (VBB-SEIS) developed by CNES (Centre National d'Etudes Spatiales) for the Mars Netlander mission [3] and selected for the ExoMars mission. The design for the Moon, studied by an ongoing R&D CNES program, is a spherical assembly, enclosing three Very Broad Band oblique seismometers to make a full 3 axis sensor. The sphere is thermally decoupled from the environment and also encloses a set of secondary sensors (temperature and inclination), used for both instrument management and scientific purposes. **Figure 1** shows noise profiles for both actual VBB-SEIS measurements and theoretical spectra based upon design. The instrument noise is already a factor of ~2 lower than the Apollo seismometer noise in flat mode. Much of the VBB-SEIS re-design effort in the CNES R&D study is to optimize and improve the noise levels until they are at least a factor of 10 lower than the seismometers used during Apollo.

The VBB-SEIS electronics also employ a 24 bit A/D converter as compared to 10 bits for Apollo. This increased resolution allows for greatly improved seismic monitoring, provides much better wave forms and increases the dynamic range of the instrument. All of these improvements will allow for the detection of more seismic events over a broader range of amplitudes and with greater resolution than was capable with Apollo. In addition, the power requirements of the VBB-SEIS seismometer are considerably lower at < 1 W (peak), versus 46 W (peak) for the Apollo seismometers.

Heat Flow Probe. Lunar heat flow was measured at locations along the rims of the Imbrium and Serenitatis impact basins on the Apollo 15 and 17 missions. Attempts to measure the Moon's heat flow in highland regions (Fra Mauro during Apollo 13, Cayley Plains during Apollo 16) were unsuccessful. Although the Apollo results provide a useful first step in assessing the Moon's thermal structure, important issues remain to be resolved. Future measurements should be obtained from the center of a mare basin, for several locations in the highlands (both nearside and farside), and for a location near the center of the PKT unit. Another desirable measurement is from the floor of the very deep South Pole-Aitken basin, where lower crust or possibly even mantle material is exposed at the Moon's surface. Combining measurements from all of these various geologic units will lead to a vastly improved knowledge of the Moon's thermal structure.

The proposed LGIP heat flow probe is based upon the thermal probe MUPUS-TP on ESA's Rosetta spacecraft [4] and the Heat Flow and Physical Properties Package (HP^3) instrument that is being developed for ExoMars mission [5], with some characteristics borrowed from the probes in the Japanese Lunar-A penetrator mission [6,7]**.** Perhaps the most important design consideration for the LGIP heat flow probe is that of deployment. To make effective measurements, the heat flow probe must be placed far from any artificial heat sources, such as the probe power supply or other instruments. The probes must also penetrate the lunar regolith by at least 150 cm (vertically). Various options, including self burrowing, penetrators or drilling are available. Heat probe deployment will depend largely upon how the LGIP itself is being used, e.g. as a payload on a robotic lander or as a stand-alone instrument package. A portion of this presentation outlines the trade space for heat flow probe deployment and design modifications that will be investigated during the LGIP study. Deployment options are discussed in more detail in a companion submission [8].

Magnetometer. The ALSEP deployed a 3-axis surface magnetometer in the same proximity as the seismometers and heat flow probes. The measurements, however, were obtained at locations that were not ideal for testing hypotheses about the origin of the lunar crustal magnetic field. Although correlative studies suggest that basin ejecta materials are the sources of many or most lunar magnetic anomalies, ground truth evidence is so far limited to just the Apollo 16 landing site, which did not coincide with a strong orbital anomaly. Moreover, the identit(ies) of lunar magnetizing fields remain uncertain. The next lunar geophysical network should deploy one or more geophysical stations at the surface sites of known strong magnetic anomalies, such as the Descartes mountains and the Reiner Gamma site.

The LGIP uses a MAGSON (www.magson.de) 3-component vector compensated Low Mass Fluxgate Sensor magnetometer instrument of the same type that is currently being flown on the ESA Rosetta mission [9]. This magnetometer has a very high technology readiness level (TRL), and requires no specific instrument development. The main focus of the magnetometer portion of the LGIP study is the integration with the package. Specifically, can this instrument easily be attached to and deployed with the VBB-SEIS seismometer, or will it require a separate packaging and deployment? Magnetometer integration considerations such as these are outlined in this contribution.

References: [1] Oberst J. and Nakamura Y., "A Seismic Risk For The Lunar Base," *Lunar Bases & Space Activities* **2**, 231-233, Lunar & Planetary Institute, Houston, 1992. [2] Weinberg J.D., Heshmatpour B. and Neal C.R., *LPSC Poster Abstract,* "Lunar Geophysical Instrument Package (LGIP) II – Power And Probe Development," 2008 (submitted). [3] Lognonné P., et al., "The NetLander Very Broad Band Seismometer", *Planet. Space Sci.* **48**, 1289-1302, 2000. [4] Marczewski W., et al., "Prelaunch Performance Evaluation of the Cometary Experiment MUPUS-TP," *JGR-Planets* **109**, E07S09, 2004. [5] Wieczorek M.A. et al., AGU Fall Meeting P43C-02, 2007. [6] Tanaka S., et al., "Development Of The Heat Flow Measurement System By The Lunar-A Penetrators," in **Moon And Mars**, edited, pp. 1825-1828, 1999. [7] Mizutani H., et al., "Lunar-A Mission: Goals and Status," in **Moon: Science, Exploration And Utilisation**, pp. 2315-2321, 2003. [8] Huang S., et al., *LPSC Poster Abstract,* "Three Deployment Options for the Heat Flow Component of the Long-Lived Lunar Geophysics Instrument Package," 2008 (submitted). [9] Auster H.U., et al., "ROMAP: Rosetta Magnetometer and Plasma Monitor," *Space Sci. Revs*., 2005.