LUNETTE: ESTABLISHING A LUNAR GEOPHYSICAL NETWORK WITHOUT NUCLEAR POWER THROUGH A DISCOVERY-CLASS MISSION.

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Introduction: The last decadal survey for the Planetary Sciences Division of the Science Mission Directorate [1] stated (pp. 62-63) as one of its lunar objectives "*Geophysical network science (seismic, heat flow) to determine internal structure, distribution of heat-producing elements, lateral and vertical heterogeneity of crust and mantle, and the possible existence of an iron-rich core. Geophysical network science would address how small planetary bodies differentiate, how the bulk composition of the Moon is related to the composition of Earth, and how planetary compositions are related to nebular condensation and planetary accretion processes.*" There was some confusion in this document because establishing such a geophysical network was classified both as a medium cost class mission (p. 176), and a small, Discovery class mission (pp. 61-62). The document further stated that Geophysical Network Science worthy of flight and accorded it a high priority. However, for reasons of mission sequencing, technological readiness, or budget, they did not make the final cut for the current decade. With the next decadal survey currently underway, it is important to note that a white paper in strong support of establishing a lunar geophysical network was submitted with an international authorship of over 85 scientists [2].

Following the Vision for Space Exploration [3] "The Scientific Context for the Exploration of the Moon" [4] designated understanding the structure and composition of the lunar interior (to provide fundamental information on the evolution of a differentiated planetary body) as the second highest priority lunar science concept that needed to be addressed. To this end, the Science Mission Directorate formulated the International Lunar Network (ILN) mission concept that enlisted international partners to enable the establishment of a geophysical network on the lunar surface. NASA would establish the first four "anchor nodes" in the 2018 time frame. These nodes are envisioned to use radioisotope power systems to allow operation of each node for at least 6 years. Each anchor node will contain a seismometer, magnetometer, laser retroreflector, and a heat flow probe [5] and will be distributed across the lunar surface to form a much more widespread network that the Apollo passive seismic, magnetometer, heat flow, and the Apollo and Luna laser retroreflector networks. (Fig. 1). It is planned that the four anchor nodes will be launched on an Atlas 5 launch vehicle and the cost is estimated to exceed that for a current New Frontiers mission.

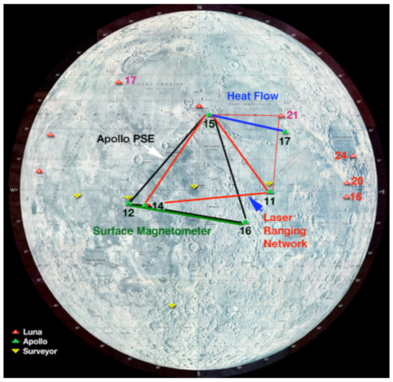

Figure 1: Landing sites on the Moon and geophysical networks established by the Apollo and Luna landings.

What we present here is an alternative to the ILN architecture that would deploy three geophysical nodes on the lunar surface that are widely spaced (3,000-5,000 km), but at a much lower cost (within a Discovery mission cap) [6,7]. This concept uses new power management technology to offer a non-nuclear alternative [5]. This mission will provide detailed information on the interior of the Moon through seismic, thermal, electromagnetic, and precision laser ranging measurements, and will substantially address the lunar interior science objectives set out in "The Scientific Context for the Exploration of the Moon" [4] and "The Final Report for the International Lunar Network Anchor Nodes Science Definition Team" [5].

Instrumentation: Each node will contain: a very broad band (VBB) seismometer that is at least an order of magnitude more sensitive over a wider frequency band than the seismometers used during Apollo; a short period (SP) seismometer; a heat flow probe, delivered via a self-penetrating "mole" device; a low-frequency electromagnetic sounding instrument, which will measure the electromagnetic properties of the outermost few hundred km of the Moon; and a corner-cube laser retroreflector for lunar laser ranging. These instruments will provide an enormous advance in our knowledge of the structure and processes of the lunar interior over that provided by Apollo-era data, allowing insights into the earliest history of the formation and evolution of the Moon.

The instruments that comprise the individual nodes are all optimized for low power operation and this mission will not rely on a radioisotope power supply. Improvements in solar energy and battery technology, along with an Event Timer Module which allows the lander to shut down its electronics for most of the lunar night, enables a solar/battery mission architecture with continuous instrument operation and a two-year nominal lifetime. The instruments have a combined mass of <12 kg, and the dry mass of each lander will be on the order of 100 kg, including solar panels, batteries, and communications. The most power hungry instrument is the heat flow "mole", which requires ~ 11 W during penetration and ~5-6 W during the active heating tests for thermal conductivity measurements. Normal operations of the mole only require 2.2 W. These activities can all be done during daylight. The nodes will operate during the lunar night in a low power mode where only systems required for data acquisition are powered. Timing reference will be maintains by a chip-scale atomic clock. Communications back to Earth will only occur during the lunar day so there is data storage on the order of 3-4 Gbits to enable continuous operations during the lunar night (up to 16 earth days). The direct-to-Earth link is S-band at 120 kbps to a DSN 34 m ground station.

Placement of the Stations: The three geophysical stations will be deployed on the lunar nearside akin to the sites outlined by Kiefer et al. [8]. The different instruments contained within each lander have slightly different landing site requirements:

Heat Flow: The heat flow probes should be deployed at least 100 km from any terrane boundaries (cf. [9]) and should not be deployed in the shadow of the lander.

Laser Ranging: The retroreflectors should be deployed towards the limbs of the Moon to dramatically improve the fidelity of measurements that suggest the lunar core is fluid and may extend top 20% of the lunar radius [10]. Such deployments will also enable better tests of gravitational physics and improvement of the lunar orbit determination. A larger north-south distribution would help determine fluid core moment and core-mantle boundary flattening, and help look for free wobble stimulation. A wider east-west distribution would help look for free longitude libration stimulation.

Electromagnetic Sounding (EMS): EMS requires measuring time variations in the surface magnetic field in regions without intrinsic magnetic anomalies. Because of the sensitivity of conductivity to both temperature and composition, measurements both inside and outside of the Procellarum-KREEP Terrane [9] are desirable.

Seismology: Examining the structure of the lunar crust, mantle, and core requires care in siting each Lunette lander and these requirements will drive the site selection. One of these sites should be antipodal to the A-33 farside nest and one will be placed closer to this source so as to detect seismic waves from a known source that have passed through and have not passed through the core of the Moon (Fig 2). This will allow the core of the Moon to be studied. One other site could be potentially Reiner Gamma, to examine the magnetic anomalies. More detailed modeling is required to properly define the landing sites.

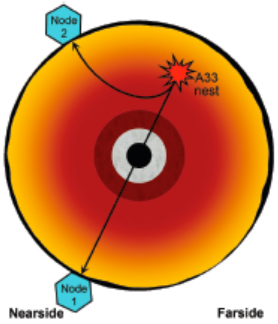

Figure 2: Example of geophysical station emplacement to take advantage of the known A-33 farside deep moonquake nest. Taken from [2].

Sites placed on the nearside will also take advantage of meteorite impacts that can be recorded so the exact time and location of the impact is known. This way, a known seismic source can be used to explore the interior of the Moon. See http://www.nasa.gov/offices/meo/home/index.html for more details.

The datasets taken by each instrument suite are complementary in nature in that they allow examination of the internal structure of the Moon in a number of different ways that collectively will greatly improve our understanding of lunar origin and evolution

International Collaboration: The only way this mission can fit within a Discovery mission cost cap is through international collaboration. Therefore, a multinational team has been put together with the VBB seismometer being contributed by a European consortium headed by France, along with Germany and Switzerland; the SP seismometer is being contributed by Japan, the heat flow probe is being contributed by Germany, with the laser retroreflector and EM sounding instruments being supplied by the USA.

References: [1] New Frontiers in the Solar System: An Integrated Strategy (2003) National Academies Press, Washington DC. [2] The Rationale for Deployment of a Long-Lived Geophysical Network on the Moon(http://www.lpi.usra.edu/decadal/leag/LunarGeophysicalNetwork.pdf) [3] The Vision for Space Exploration (2004) NASA (http://history.nasa.gov/sep.htm) [4] The Scientific Context for the Exploration of the Moon, Final Report. National Academies Press, 121 pp. [5] ILN Final Report: Science Definition Team for the ILN Anchor Nodes, NASA, 45 pp (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20090014121_2009013378.pdf. [6] Elliott J. & Alkalai L. (2008) *Proc. Internat. Astro. Congress*, **59**. [7] Elliott J. & Alkalai L. (2009) *Proc. Internat. Astro. Congress*, **60**. [8] Kiefer W.S. et al. (2010) Ground-Based Geophysics on the Moon Workshop abstract, Tempe Arizona. [9] Jolliff B.L. et al. (2000) *J. Geophys. Res.* **105**, 4197-4216. [10] Williams J.G. et al. (2006) *Adv. Space Res*. **37**, 67-71.