LUNETTE: A TWO-LANDER DISCOVERY-CLASS GEOPHYSICS MISSION TO THE MOON.

C. R. Neal[1], W. B. Banerdt[2], and L. Alkalai[2], and the Lunette Team. [1]Dept. of Civil Engineering & Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, neal.1@nd.edu; [2]Mail Stop 264-422, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109.
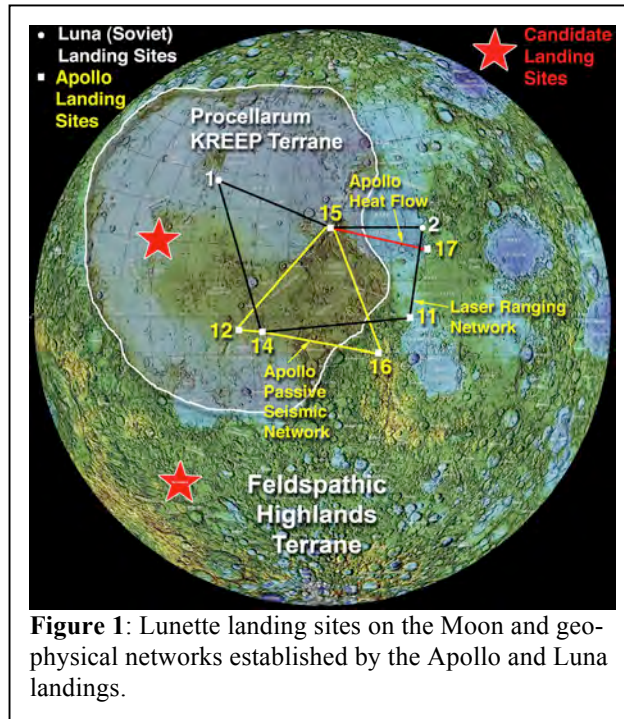

Figure 1: Lunette landing sites on the Moon and geophysical networks established by the Apollo and Luna landings.

Introduction: The document "The Scientific Context for the Exploration of the Moon" [1] 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 (web site) 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 [2] 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 New Frontiers mission. What we present here is an alternative to the ILN architecture that will still return the data required to understand the nature of the lunar interior and determine how the Moon evolved.

Mission Concept. Lunette is a solar-powered, four-year geophysical network mission to the Moon using two identical landers to achieve a Primary Goal of *Understanding the Early Stages of Terrestrial Planet Evolution*, as the Moon preserves a record of these early processes. The Mission has two Science Objectives 1) Understand the evolution and current state of the Moon; 2) Constrain the bulk composition of the Moon. Within these two objectives are four Science Investigations: 1) Determine **crust** thickness, stratification, and lateral variability; 2) Investigate **mantle** composition and chemical/physical stratification; 3) Investigate **core** size, state, and composition; 4) Investigate the workings of the **planetary heat engine.**

The two landers are launched on the same vehicle and separate once in Earth orbit. They make their way individually to the Moon and are landed and deployed sequentially at the beginning of subsequent lunar months. This concept uses new power management technology to offer a non-nuclear alternative [3, 4]. Both landers are solar powered, thus removing the need for expensive radioisotope power supplies and relieving stress on NASA's ever dwindling supply of ^{238}Pu. Notional landing sites are just south of the Aristarchus Plateau in the Procellarum KREEP Terrane (PKT) and within the Schickard Basin in the Feldspathic Highlands Terrane (FHT) (Fig. 1). The nominal mission length is 4 years from the deployment of the second lander.

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" [1] and "The Final Report for the International Lunar Network Anchor Nodes Science Definition Team" [2].

Instrumentation: Each lander will contain (Fig. 2): 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; two heat flow probes, each 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 the next generation of 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. All instruments are optimized for low power operation.
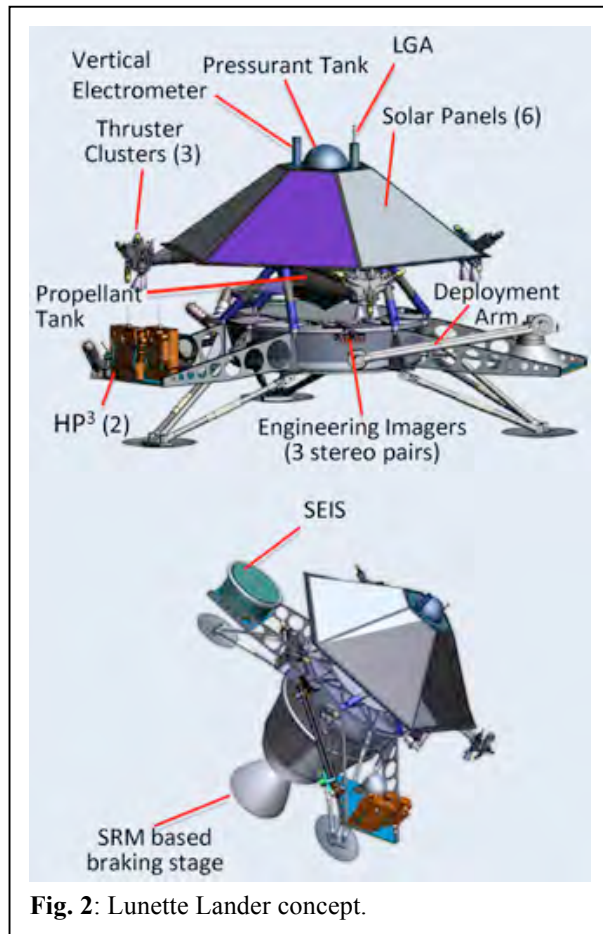

Fig. 2: Lunette Lander concept.

Improvements in solar energy and battery technology, along with an Event Timer Module 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 are all 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 two landers stations will be deployed on the lunar nearside well within terrane boundaries (Fig. 1). This was not done for Apollo. Lunette uses Apollo knowledge of deep moonquake nests and Earth-based nearside impact flash monitoring (IFM) to enable a 2-station mission to address this goal. IFM provides known seismic sources, allowing detailed seismic study of the lunar interior from a 2-station network, representing a major advance since Apollo. The instruments and support systems are designed to operate for much longer than four years and therefore could be integrated into any future international lunar geophysical network. Modeling undertaken demonstrates the feasibility of this approach for seismic data. Using the Apollo seismic record, the sensitivity and broadband nature of the seismometer is shown to be able to address the challenges of seismic scattering, low frequency seismology, detection of core phases (e.g. PKP, ScS), and meteoroid impact characterization to achieve the primary mission goal

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] The Scientific Context for the Exploration of the Moon, Final Report. National Academies Press, 121 pp. [2] 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. [3] J. Elliott and L. Alkalai, "Lunette: A Low-Cost Concept Enabling Multi-Lander Lunar Science and Exploration Missions," Proceedings of the 59th International Astronautical Congress, September 29th – October 30th, 2008, Glasgow, Scotland. [4] J. Elliott and L. Alkalai, "Lunette: A Network of Lunar Landers for In-Situ Geophysical Science," Proceedings of the 60th International Astronautical Congress, October 12-16, 2009, Korea.