A FUTURE MOON MISSION: THE LUNAR SEISMIC NETWORK.

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Introduction: The New Views of the Moon initiative has integrated remotely sensed and sample data in its approach to synthesizing lunar research over the last 30+ years. This integration has clearly demonstrated what we know and, maybe more importantly, what we don't know about the Moon. Most significantly, it has helped to formulate fundamental scientific questions about the Moon that still need to be addressed. In addition, the lessons learned from the study of the Moon provide an invaluable road map for our exploration of the inner planets of the solar system. The results of the New Views initiative highlight in explicit detail just how little we know about the nature of the lunar interior. While studies of the Moon have produced the magma ocean hypothesis [e.g., 1], this cannot be adequately tested until seismic data are obtained from around the Moon and the nature of the lunar interior is evaluated in detail. The existing Apollo seismic experiment data only provide us with clues about the interior of the Moon, primarily because the seismometers were set up in a relatively restricted area on the lunar nearside. Interpretations based on these limited data are ambiguous. For example, the presence of garnet in the lunar mantle has been proposed by several authors to accommodate higher velocities in the middle mantle (>500 km) [e.g., 2-4]. This has been supported by geochemical evidence from some mare samples [5]. However, Nakamura et al. [6] and Nakamura [7] suggested that increasing the proportion of Mg-rich olivine in the lunar mantle could accommodate the higher velocities. What has become apparent is the presence of a seismic discontinuity around 500 km, albeit somewhat heterogeneous in nature [8-10] and this has been interpreted as the maximum depth of LMO melting [7,11-13]. While innovative modeling approaches have refined the original data [e.g., 8-10], comprehensive and definitive interpretations of the lunar mantle remain elusive and fundamental questions regarding lunar origin, evolution, and structure still remain unanswered.

Science Drivers: The major questions we would want to answer with a Lunar seismic mission are: What is the structure and thickness of the crust on the lunar near and far sides? Are crustal structure changes gradational or are distinct domains present? Is garnet present in the middle and deep lunar mantle? Are nests producing periodic Moon-quakes present on the far side? Is the ~500 km discontinuity a moon-wide phenomenon (magmasphere vs. magma ocean)? What is the lunar core made of (sulfide, metal, ilmenite) and how extensive is it? Are the core and mantle completely solid or do plastic zones still persist?

The LUNAR-A Mission: The Japanese LUNAR-A mission is scheduled for launch in 2003 and will carry 2 penetrators, each containing heat sensors and 2 seismometers (5 times as sensitive as the Apollo seismometers) [14-17]. One will be deployed on the nearside (between the Apollo 12 & 14 landing sites) and one on the farside of the Moon, with data being stored in the penetrator before being transmitted to Earth via an orbiter that passes overhead every 15 days [14-17]. The seismic experiment of LUNAR-A is designed to examine internal structure and core size and will last for one year (battery life in the penetrators). However, because of the fact that there will be only two stations, this experiment will be limited to using only Moonquakes from previously located deep Moonquake nests for interior structure studies.

A Possible New Frontiers Mission: In building upon the Japanese LUNAR-A mission, a seismic network is proposed for the Moon. In this mission, it is envisaged that a minimum of 8 seismometers will be deployed around the Moon (an example of a lunar seismic network array is in Fig. 1) to cover the nearside, the farside and the polar regions. This configuration will gather data that will answer many of the questions that are driving this mission concept. An orbiting satellite will relay information back to Earth as it passes over each seismometer. The mission will last for a minimum of 2 years. This proposed mission is intended to build upon the results of LUNAR-A and it is hoped that it will be conducted in cooperation with other space agencies, thus maximizing the science return. Planning for implementing the lunar seismic network is still in the preliminary stages, but we hope that it will be community-driven with input helping to shape this into a highly successful, science mission to the Moon.

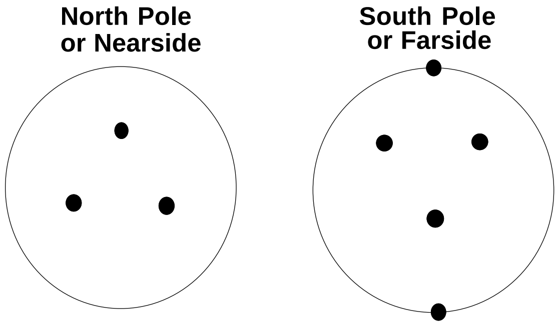

Figure 1: Schematic seismometer configuration for a lunar seismic network.

Problems to Overcome: While there are many problems that will be encountered in the successful implementation of the lunar seismic network, we perceive the major ones to be as follows: 1) Can the seismometers be made small enough yet sensitive enough to form a network over the Moon? 2) How can each seismometer be successfully deployed? 3) Communications — how can seismic events be recorded and the data be sent back to Earth? 4) What type of power supply is needed to ensure that data can be recorded for an extended period (i.e., >1 year)? 5) Can an orbiter be maintained for >2 years? 6) Can a substantial seismic network be deployed with one spacecraft or are several required? We are currently exploring answers to such questions.

Hardware: Microseismometers are available having been developed for the Mars Netlander mission weighing 100-200 g for each 3-axis instrument (e.g., Fig. 2). A conventional seismometer weighs up to 20 kg. While the sensitivity of these seismometers are currently 1-2 orders of magnitude less than the Apollo seismometers (albeit over a wider frequency band), we are examining the possibility of increasing sensitivity without significantly increasing the weight of the instrument. Similar silicon micro-machined structures have been successfully impact-tested in penetrator applications, but further tests are required in order to declare them mission ready .

The power required for continuous operation of the seismometer is a few hundred milliwatts. In order to ensure that this will be a long-term mission (i.e., longer than two years), the use of mini Radioisotope Thermoelectric Generators (RTGs) is being explored. At the time of writing this abstract, we are discussing the possibility with the Department of Energy of using an RTG that would generate about 1 watt maximum power. This would remove much of the opposition to using RTGs because it would not require the kilograms of radioactive material required for RTGs that were included in the Cassini mission. Further progress will be reported at the 34th Lunar and Planetary Science Conference.

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Figure 2: Diagram of a single-axis microseismometer sensor.