**THE LUNAR GEOPHYSICAL NETWORK MISSION.** C.R. Neal,[1] W.B. Banerdt[2], C. Beghein[3], P. Chi[3], D. Currie[4], S. Del'Agnello[5], I Garrick-Bethell[6], R. Grimm[7], M. Grott[8], H. Haviland[9], S. Kedar[2], S. Nagihara[10], M. Panning[2], N. Petro[11], N. Schmerr[4], M. Siegler[12], R. Weber[9], M. Wieczorek[13], and K. Zacny[14]. [1]University of Notre Dame (neal.1@nd.edu), [2]JPL-Caltech, [3]UCLA, [4]University of Maryland, College Park [5]Laboratori Nazionali di Frascati (LNF) dell'INFN, [6]UC Santa Cruz, [7]Southwest Research Institute, [8]German Aerospace Center, [9]NASA-MSFC, [10]Texas Tech Univ., [11]NASA-GSFC, [12]Planetary Science Institute, [13]Observatoire de la Côte d'Azur, Laboratoire Lagrange, [14]Honeybee Robotics.

**Introduction:** The Moon represents an end-member in the differentiation of rocky planetary bodies. Its small size (and, reduced heat budget) relative to planets means that the early stages of differentiation are recorded. By studying the lunar interior we can understand how more complex rocky planets initially differentiated. Despite the success of the (Early) Apollo Lunar Surface Experiment Package (EASEP/ ALSEP) [1-5], significant unresolved questions remain regarding the nature of the lunar interior. General models of the processes that contributed to the formation of the present-day lunar interior are currently being challenged (e.g., [6,7]). While lunar laser ranging [8] and reinterpretation of the Apollo Passive Seismic Experiment seismic data has led to identification of a lunar core [1], the latter has resulted in a wide range of seismic velocity structure models for the lunar crust and mantle [9-12]. This is partially due to the limited geographic covarge of the ALSEP stations, all of which were located in the low-to-mid-latitudes on the near side. In addition, the large geographic variation in crustal density, as revealed by the recently acquired GRAIL orbital mission, affects the crustal thickness estimates [13]. Deployment of a long-lived network of globablly distributed geophysical instruments would enable us to define the nature of the lunar interior in more detail and to explore the early stages of terrestrial planet evolution. For example, more detailed characterization of lateral and vertical heterogeneities within the lunar deep interior, will yield important information about mantle stratification that could have resulted from crystallization of the lunar magma ocean and any subsequent cumulate overturn [14]. Advancing our understanding of the Moon's interior is critical for addressing these and many other important lunar and Solar System science and exploration questions. Importantly, the Lunar Geophysical Network mission concept has been advanced in several NASA and National Academies documents [15-17] as a New Frontiers (NF) class mission. Here we present the current status of the planned response of the LGN team to the upcoming NF-5 AO, anticipated before the end of the current National Academies decade.

**Beyond Apollo:** A future LGN should learn from Apollo and be greatly enhanced in terms of the geographic coverage of the network and the geophysical measurement capabilities. The LGN station coverage should reach the polar and far side regions as well as the nearside. Each station should contain a minimum of a seismometer, heat flow probe, and electromagnetic sounding instrumentation as standard, plus a laser retroreflector for nearside stations.

*Seismometer*: the Apollo passive seismometer [18] consisted of three long period sensors (X, Y, Z, all with detection limits of 0.3nm at 0.004-2 Hz) and one short period sensor (Z with a detection limit of 0.3nm at 1 Hz). The seismometer for the LGN needs to have ≥4 sensors that have at least an order of magnitude better sensitivity than that used during Apollo and over a much broader frequency range (0.1 to >10 Hz).

*Heat Flow*: Heat flow was measured at the Apollo 15 and 17 sites and consisted of two probes ~11 m apart, with each probe consisting of two sections reaching 1.5-m and 2.4-m depths, respectively [19]. Measurements of absolute temperature were to ±0.05K. Thermal conductivity (0.009-0.014 W/mK) was determined for two depth intervals with ~15% accuracy from modeling the downward propagation of annual thermal waves [19]. The instrument used by LGN should be able to measure both temperature and thermal conductivity with 30- to 50-cm depth intervals down to 3 meters with a temperature difference uncertainty of better than 0.01K [16] with a 10% or better accuracy of the heat flow determination. Subsurface temperature measurements should be repeated frequently to monitor possible fluctuation of the regolith temperature distribution.

*Electromagnetic Sounding (EMS)*: Wideband magnetic fields were measured at the surface by Apollo 12, 15, and 16, and from orbit on Apollo 15 and 16. Electrical conductivity of the mantle was determined from the transfer function between Explorer 35 and Apollo 12, but suitable spatial and temporal overlaps for the transfer functions for the other stations, as well as data degradation, have limited the robustness of EMS [20]. A dense magnetometer network would enable EMS by gradiometry (geomagnetic depth sounding). Better yet, measurement of electric and magnetic fields (magnetotellurics) provides an independent conductivity profile at each site. Natural-field variations can be supplemented by artificial fields (transmitters) for better resolution of the upper mantle/lower crust.

*Lunar Laser Ranging*: The passive LLR is the only

Apollo experiment that is ongoing (Fig. 1). Laser retroreflectors were placed by the Apollo 11, 14 and 15 missions and the two Soviet Lunokhod rovers (Luna 17 and 21 missions) also carried retroreflectors. The restricted selenographical range of the existing LLR network (Fig. 1) means tidal librations are poorly constrained. The variations of pole direction, physical librations, and solid-body tidal distortions provide information about the Moon. Expansion of the network with the next generation of retroreflectors will constrain tidal librations. The new retroreflectors must support at least a factor of five improvement in the single shot ranging accuracy, which support millimeter accuracy for the LLR in oder to reduce uncertainty in the measurements.

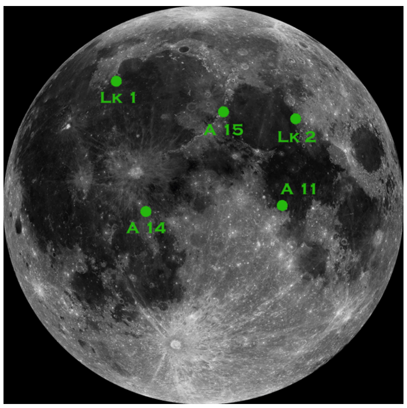

**Fig. 1**: Retroreflector locations for the current LLR network.

*Science*: Integrating datasets obtained by the LGN with orbital observations allows a comprehensive examination of the structure and composition of the lunar interior. For example, the heat flow probes yield crustal estimates. Combined with EMS, the temperature profile of the deep interior can be modeled along with mineralogy. The seismic and LLR data also yield structure and compositional information of the lunar interior. The high fidelity data would enhance the usefulness of the GRAIL and SELENE gravity data. The network must be globally distributed and last >5 years (longer than the entire Apollo network).

**Technology Development:** There are ongoing efforts within the United States to improve planetary seismometers (e.g., [21]), heat flow probes [22,23], and corner cube laser retroreflectors [24]. In terms of magnetometers and electrodes, the instruments are developed, but the deployment mechanism will need some refinement.

During the ILN effort some lander development was pursued at MSFC, but geophysical lander technology and instrument deployment still requires fine tuning. Gven the Commercial Lunar Payload Services (CLPS) program is now underway, this could be a vehicle to add nodes to the network.

Maybe the biggest issue is power supply. Ideally these LGN stations should have a minimum life of 10 years. The longer the time these stations are active, not only is the science return from the network improved, the greater the likelihood that more stations could be added by subsequent launches, either by international cooperation (i.e., as in ILN [16]), the United States, and/or commercial entities. Power becomes critical in enabling network longevity, thus also enabling the addition of stations to the network over time. Development of highly efficient nuclear power sources (e.g. $^{238}$Pu Radioistope Thermal Generators) with multi-decadal capabilities are enabling for creation of multi-station geophysical and other long-lived monitoring networks (e.g., space weathering, exosphere monitoring, etc.). Positive developments in these area are currently underway (e.g., [25]).

It is critical that the LGN be established prior to extended human lunar activity because we currently do not know the exact locations or causes of the shallow moonquakes – the largest magnitude seismic events recorded by Apollo (at least 1 event/year of magnitude ≥5; [26,27]). Recent work suggests they may be related to activity on lunar lobate scarps, which have been mapped globally [28]. Establishing infrastructure near shallow moonquake epicenters needs to be avoided. Establishment of the LGN would also address Objective Sci-A-1, LEAG Lunar Exploration Roadmap [29].

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