The Lunar Geophysical Network Mission

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Abstract

In 2007, the National Academies designated "understanding the structure & composition of the lunar interior" (to provide fundamental information on the evolution of a differentiated planetary body) as the second highest lunar science priority that

needed to be addressed. Here we present the current status of the planned response of the Lunar Geophysical Network (LGN) team to the upcoming New Frontiers-5 AO. The Moon represents an end-member in the differentiation of rocky planetary bodies. Its small size (and heat budget) means that the early stages of differentiation have been frozen in time. But despite the success of the Apollo Lunar Surface Experiment Package (ALSEP), significant unresolved questions remain regarding the nature of the lunar interior and tectonic activity. General models of the processes that formed the present-day lunar interior are currently being challenged. While reinterpretation of the Apollo seismic data has led to the identification of a lunar core, it has also produced a thinning of the nearside lunar crust from 60-65 km in 1974 to 30-38 km today. With regard to the deep mantle, Apollo seismic data have been used to infer the presence of garnet below ~500 km, but the same data have also been used to identify Mg-rich olivine. A long-lived global lunar geophysical network (seismometer, heat flow probe, magnetometer, laser retro-reflector) is essential to defining the nature of the lunar interior and exploring the early stages of terrestrial planet evolution, add tremendous value to the GRAIL and SELENE gravity data, and allow other nodes to be added over time (ie, deliver the International Lunar Network). Identification of lateral and vertical heterogeneities, if present within the Moon, will yield important information about the early presence of a global lunar magma ocean (LMO) as well as exploring LMO cumulate overturn. LGN would also provide new constraints on seismicity, including shallow moonquakes (the largest type identified by ALSEP with magnitudes between 5-6) that have been linked to young thrust fault scarps, suggesting current tectonic activity. 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, including protection of astronauts from the strong shallow moonquakes.

Establishing a Long-Lived, Global Lunar Geophysical Network
(aka ILN for the 21st Century)

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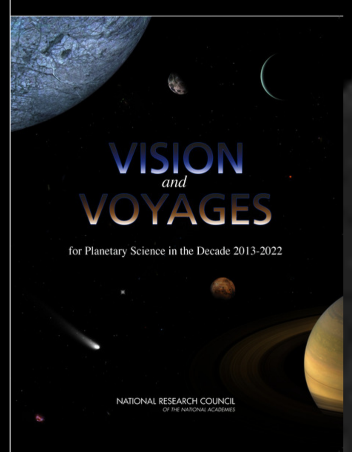


Lunar Geophysical Network (LGN) for a New Frontiers (NF)-class mission in the decade 2013-2022 [1], as part of the NF-5 call. *"This mission consists of several identical landers distributed across the lunar surface, each carrying instrumentation for geophysical studies. The primary science objectives are to characterize the Moon's internal structure, seismic activity, global heat flow budget, bulk composition, and magnetic field."*

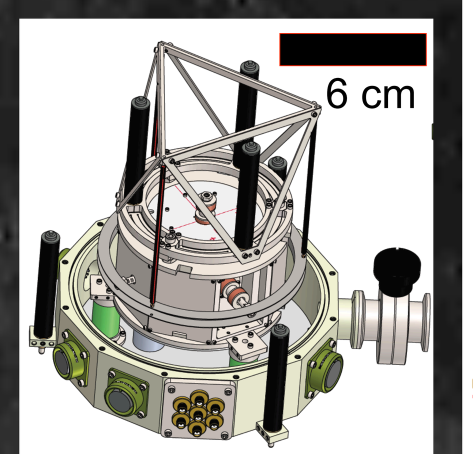
- Global distribution of multiple stations. Each station contains a seismometer, heat flow probe, electromagnetic sounder, laser retroreflector (lunar nearside).
- Each station must be long-lived (e.g., ≥10 years) to allow more stations to be integrated with the total network.
- Instruments must be better than Apollo.

Why Is LGN Important?

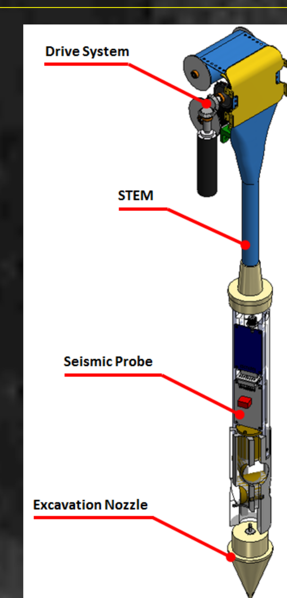
- **Lunar Science**
- **Solar System Science**
- **Informing Exploration**

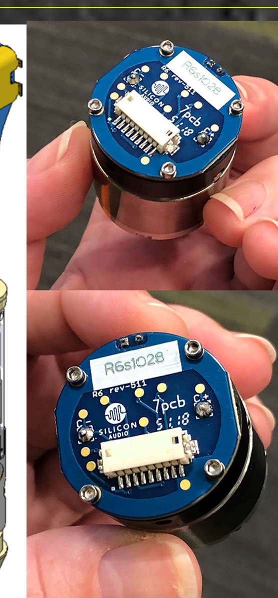
CORE INSTRUMENTS FOR EACH LANDER

Seismometers: ≥4 sensors; ≥1 order of magnitude better sensitivity than used during Apollo; broader frequency range (0.1 to >10 Hz). Robust to large thermal changes.



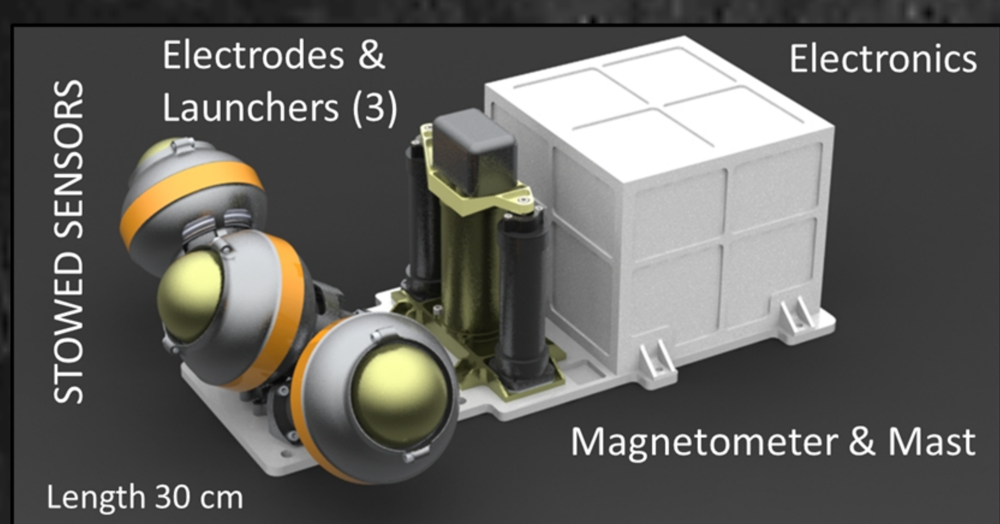
Planetary BroadBand Seismometer (PBBS) [3]



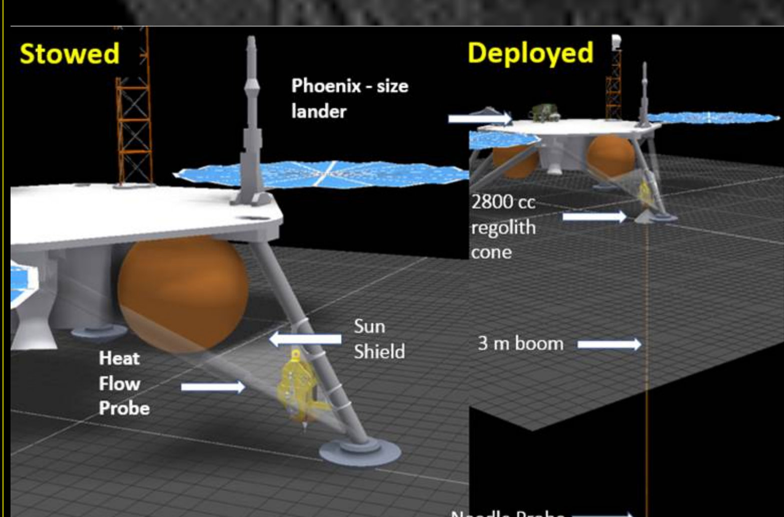


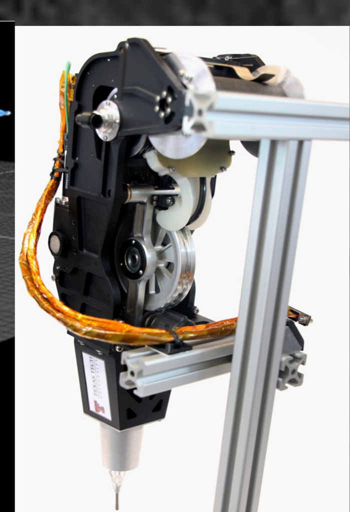
Several options exist at various TRLs. The InSight VBB (TRL 9), JAXA Geophone (TRL 8). Also the Silicon Audio Geophone [2] (next left figure) and the PBBS [3] (both TRL 4) are among others being considered.

Electrodes (green "pills") are spring-launched to ~14 m distance in an orthogonal pattern. Magnetometer extended on a mast (~2 m) provides noise standoff from the lander.



Electromagnetic Sounding (EMS)[@]: Measurement of electric and magnetic fields at each station yields an independent determination of conductivity structure (magnetotellurics) without an orbiter. Comparison of magnetic data between different stations (geomagnetic depth sounding) provides a complementary result.





Heat flow probe (~1.2 kg) sensor system stowed. Deployment using a pneumatic system. [2,4]

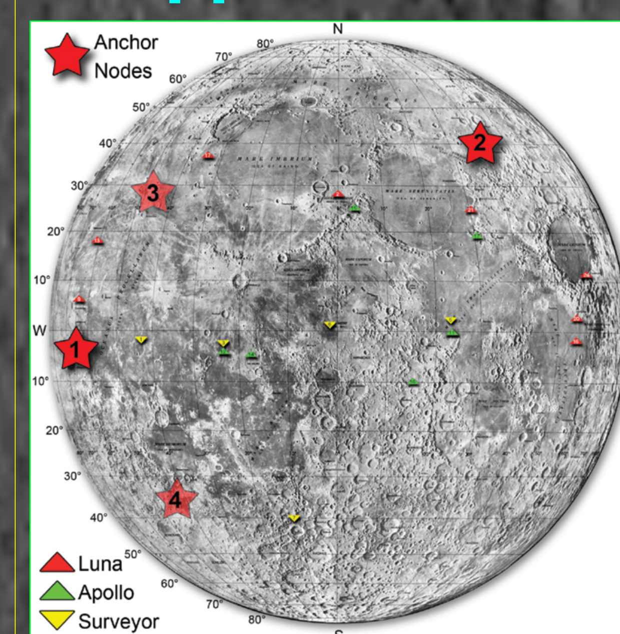
Heat Flow[@]: measure temperature every 20 cm to a depth ≥ 3 m (relative accuracy = 0.01K). Measurements every hour. Thermal conductivity determined at several intervals (e.g., every 50 cm).

Laser Ranging*: For the Moon, expansion of the network will better constrain tidal librations. New retroreflectors need to give at least a factor of two better return signal.

Total payload mass ~1.3 kg. Plus Earth pointing actuators [5]

*3 Instruments scheduled to fly on CLPS landers 2021; [@]Instrument scheduled to fly on CLPS lander in 2022.

ILN [6] Anchor Nodes

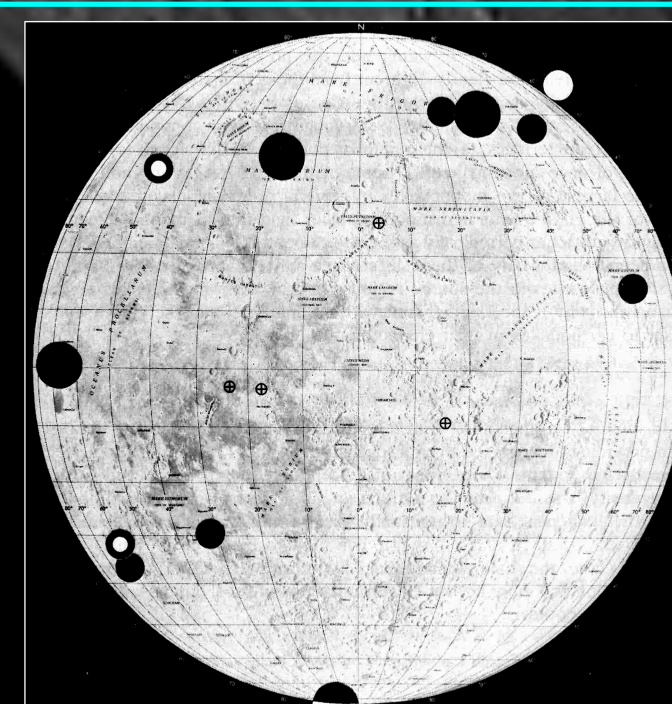


Lunar Science

- Heat flow combined with EMS data can derive the temperature profile of the deep interior in addition to mineralogy.
- Seismic and LLR data also yield structure & compositional information of the lunar interior (core to crust).
- LGN data will enhance the usefulness of the GRAIL and Selene gravity data.

Solar System/Astrophysical Science

- Laser ranging contributes to testing the general theory of relativity, inverse square law, & the Equivalence Principle.
- The Moon forms an end-member to understanding planetary body differentiation (smallest terrestrial planetary body, largest small body.
- LGN will record the current impact flux of the inner Solar System.



Informing Exploration

- Apollo recorded distinct "shallow moonquake" activity.
- Maximum ground motion for 10 minutes.
- 7 Shallow Moonquakes recorded with magnitude 5-6.
- One of these was in the South polar region [7].
- LGN will precisely locate and define the causesof Shallow moonquakes

References: [1] *Vision and Voyages for Planetary Science in the Decade 2013-2022*. National Academies Press. [2] Zacny K. et al. (2013) *EMP 111*, 47. [3] Chui T.C.P. et al. (2017) LPSC 48, abstract #1660. [4] Nagihara, S. et al. (2014) *Internat. Wksp. Instrumentation for Planetary Missions*, Abst. #1011. [5] Currie D. et al. (2013) *Nuc. Phys. B 243-244*, 218. [6] *ILN Final Report: Science Definition Team for the ILN Anchor Nodes*. NASA. [7] Nakamura Y. et al. (1974) *PLSC 5th*, 2883.