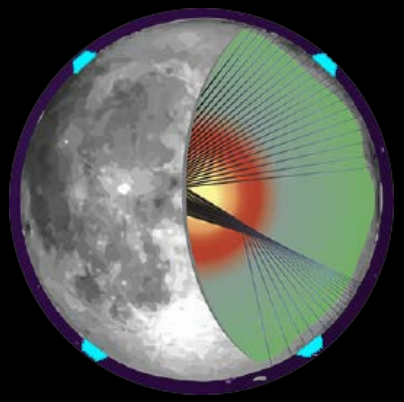
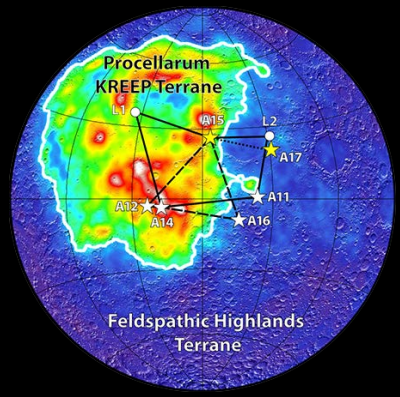


Lunar Geophysical Network

A High Priority Planetary Science Mission



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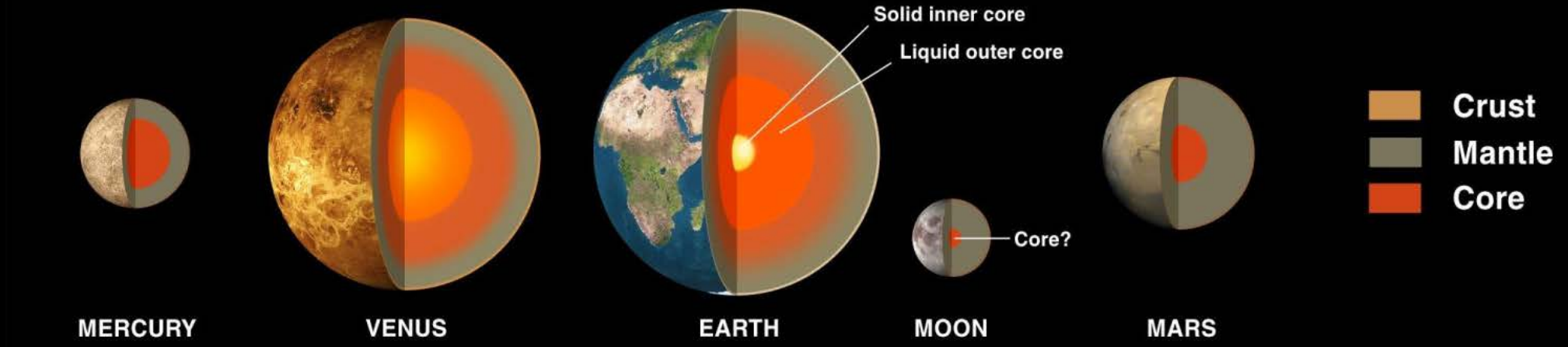
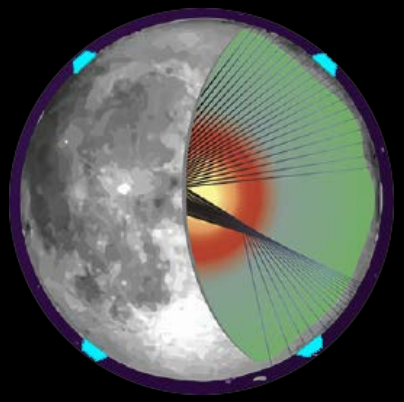
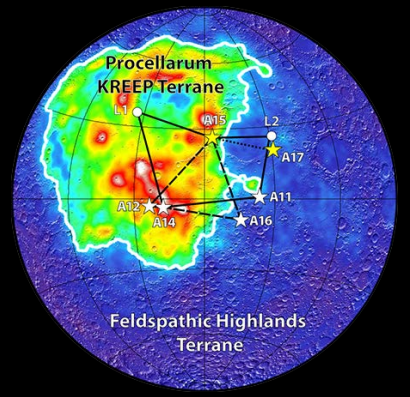


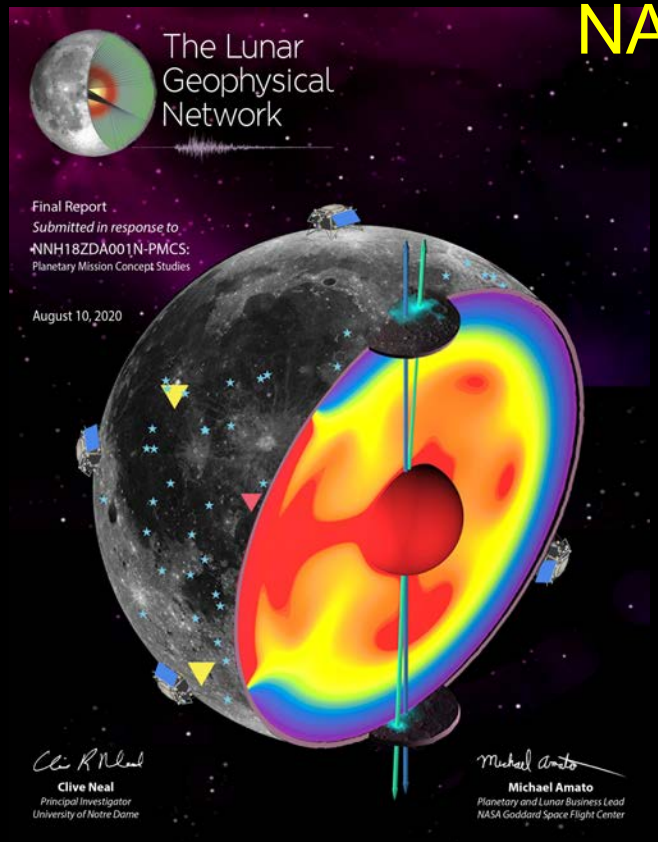


Lunar Geophysical Network

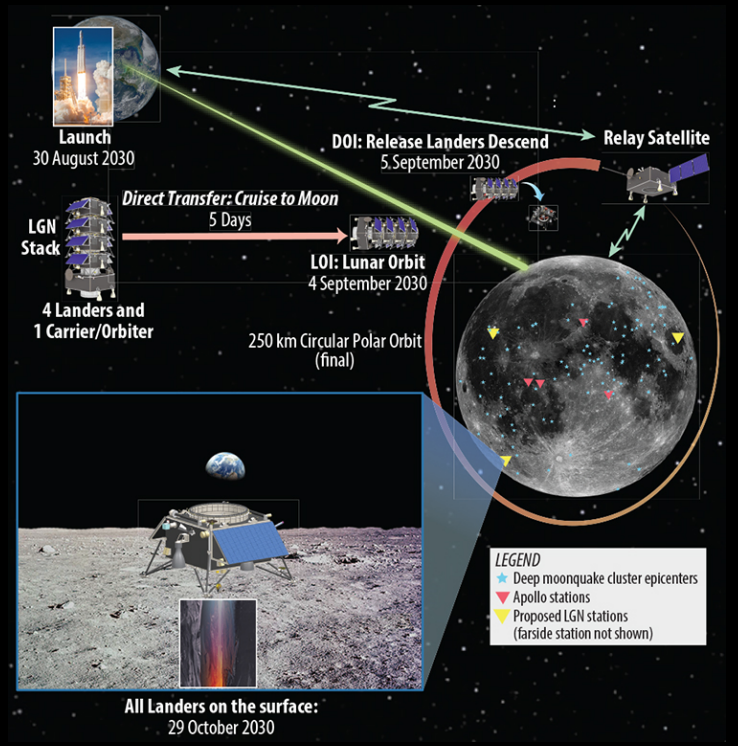


A High Priority Science Mission

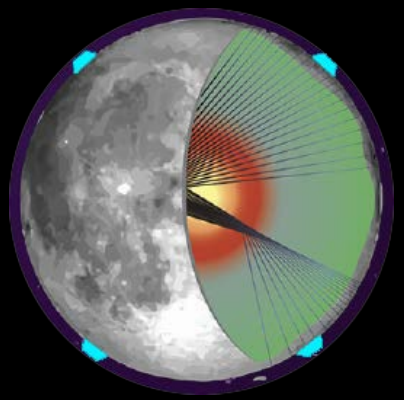
NASA-funded Planetary Mission Concept Study, 2019-2020



- A Lunar Geophysical Network mission under the New Frontiers program is feasible.
- Explored architectures that illustrate what types & limits of mission could fit in a New Frontiers cost cap.
- Highlighted specific trades/areas for future work that are needed in certain aspects of mission design, power, thermal management, lander design, communications, mass reduction.



https://science.nasa.gov/science-red/s3fs-public/atoms/files/Lunar%20Geophysical%20Network.pdf



Lunar Geophysical Network

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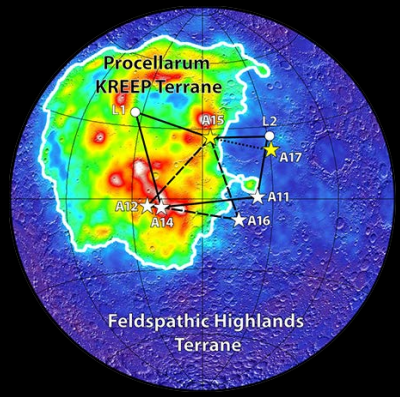
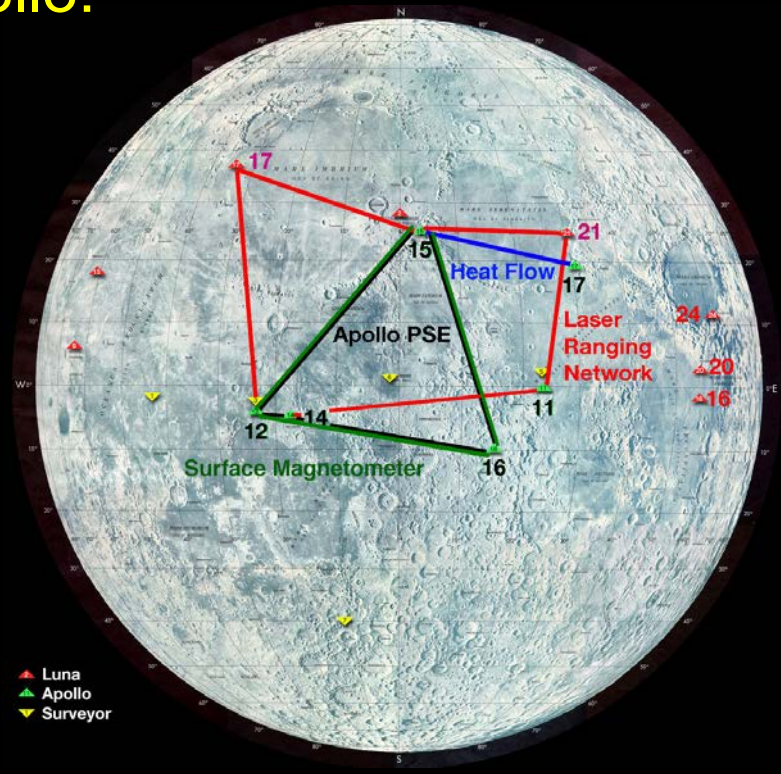
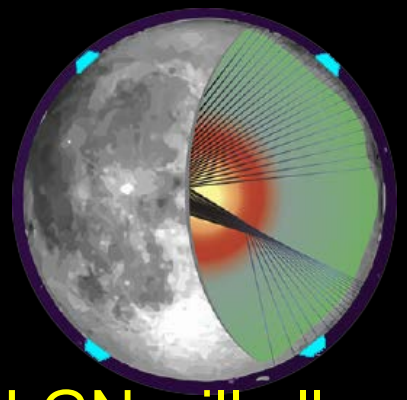


Significant science questions that remain unanswered by Apollo:

- How does the overall composition and structure of the Moon inform us about initial differentiation of terrestrial planets?
- What is the state, structure, and composition of the mantle and is it consistent with the lunar magma ocean hypothesis?
- What is the present heat budget and how could the Moon experience magmatism for >3 b.y.?
- What is the crust-mantle heterogeneity within and between different terranes?
- How did the lunar core form and could it have supported a global magnetosphere?
- What is the bulk composition of the Moon?





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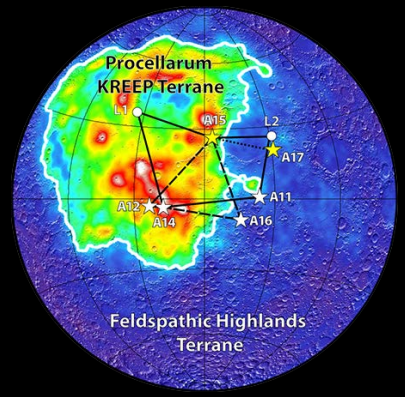
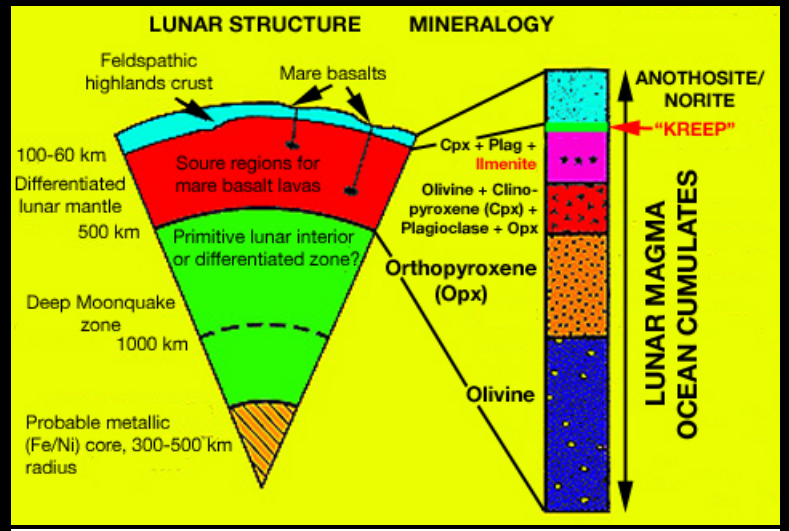
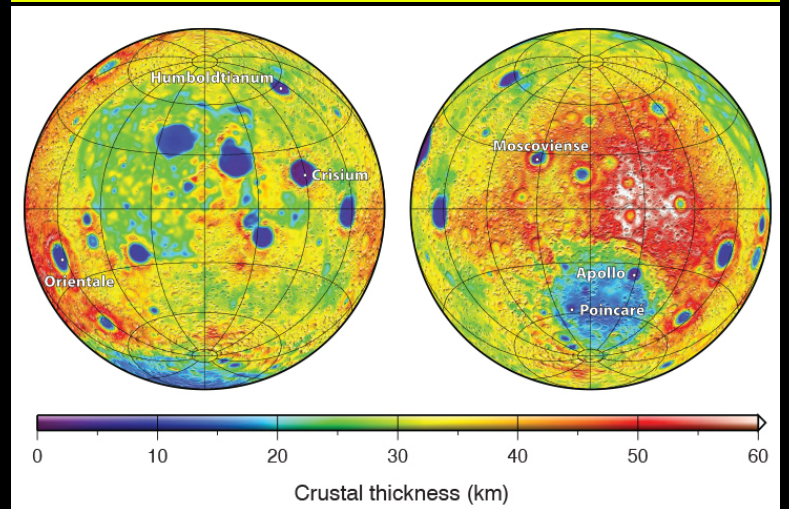
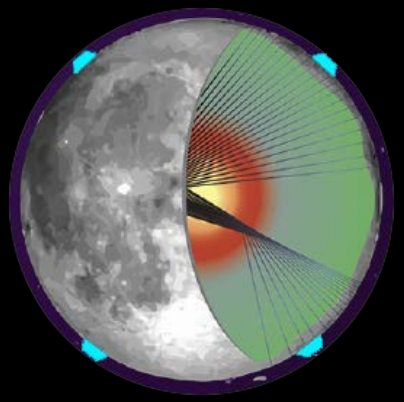


LGN will allow more intricate questions to be addressed:

- Do deep moonquakes occur on the farside of the Moon (Nakamura et al., 1982; Nakamura, 2005)?
- What is the mechanism for triggering deep moonquakes (Weber et al., 2009; Kawamura et al., 2017)?
- Are there global discontinuities in the mantle and do they relate to the lunar magma ocean (Nakamura et al., 1982; Lognonné et al., 2003)?
- Do different lunar terranes have unique heat flow budgets and what does this imply about the bulk geochemical composition of the Moon (Laneuville et al., 2018)?
- What is the lateral/vertical structure and composition as revealed by electrical conductivity (Hood et al., 1982; Grimm, 2013)?
- Do shallow moonquakes represent movement along thrust faults (Watters et al., 2019) that present a threat to future human infrastructure (Oberst and Nakamura, 1992)?







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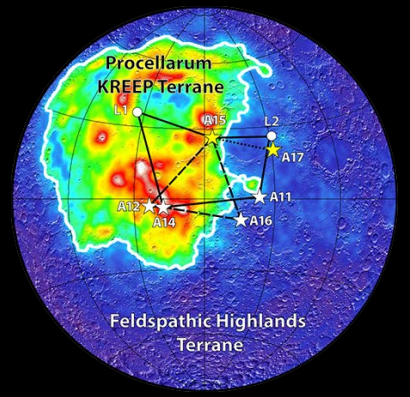
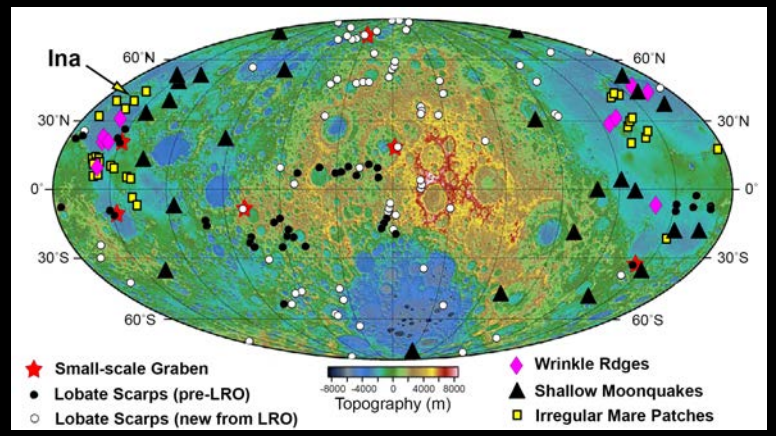


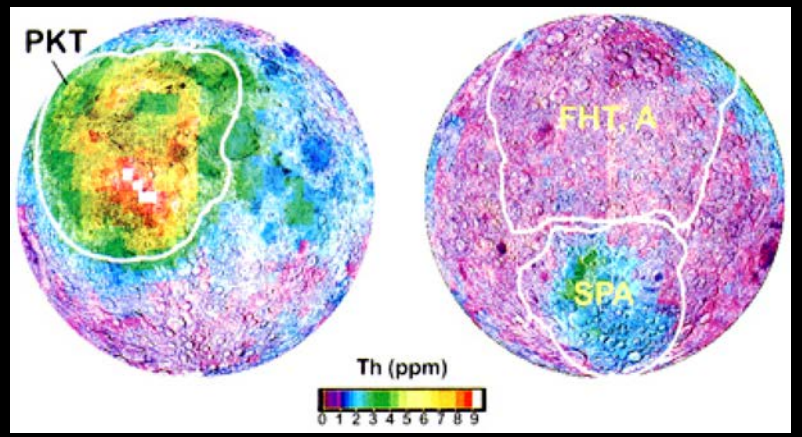
A High Priority Science Mission

Goal: To understand the initial stages of terrestrial planet evolution.

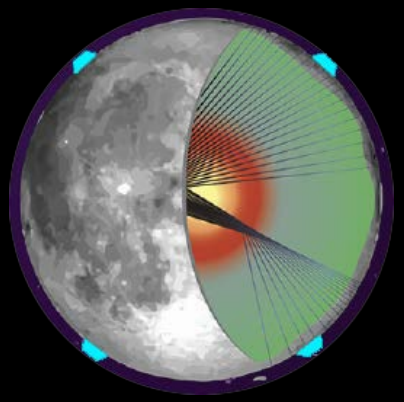
Objectives: Define the interior structure of the Moon.
Constrain the interior and bulk composition of the Moon.
Delineate the vertical and lateral heterogeneities within the interior of the Moon as they relate to surface features and terranes.
Evaluate the current seismo-tectonic activity of the Moon.



Watters et al. (2012) Nature Geosci.. 5, 181-185

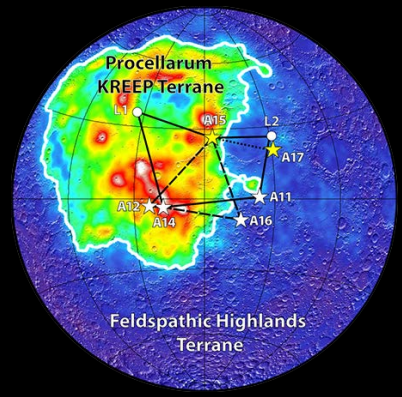


Jolliff et al. (2000) J. Geophys. Res. 105, 4197-4216



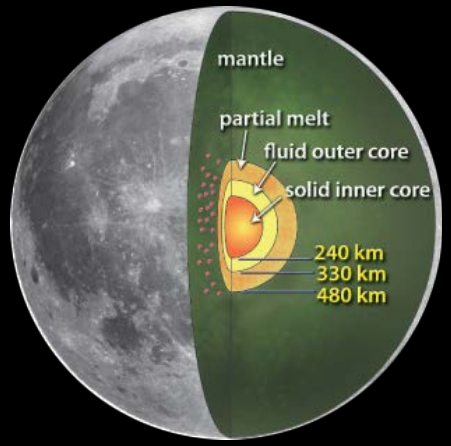
Lunar Geophysical Network

A High Priority Science Mission

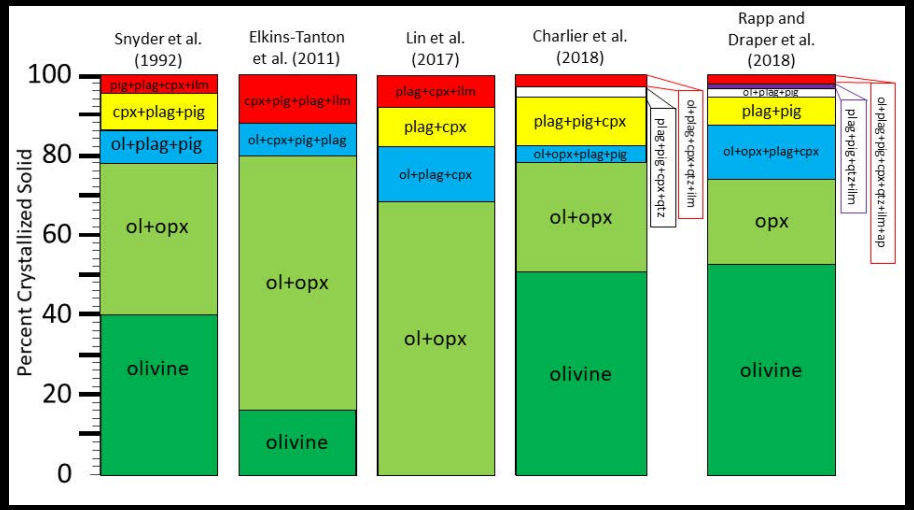


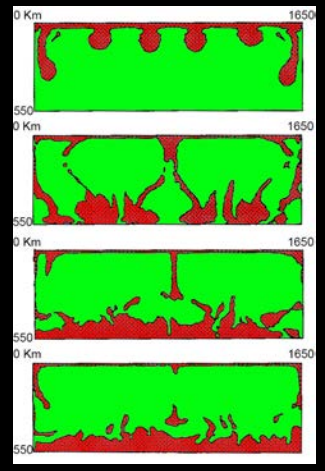
Investigations

- Determine the size, state, and composition of the lunar core.
- Determine the state and chemical/physical stratification in the lunar mantle.
- Determine the thickness of the lunar crust and characterize its vertical and lateral variability.
- Determine the thermal state of the lunar interior and elucidate the workings of the planetary heat engine.
- Monitor impacts on to the lunar surface as an aid to exploring the lunar interior.

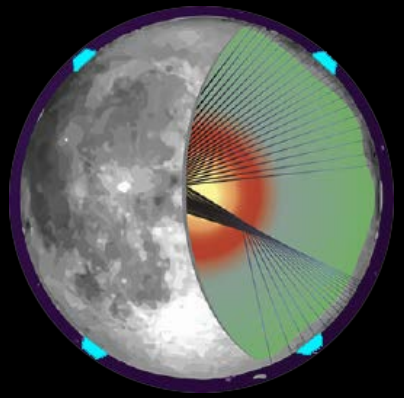


Weber et al. (2011) Science 331, 309-312





Spera (1992) GCA 56, 2253-2265



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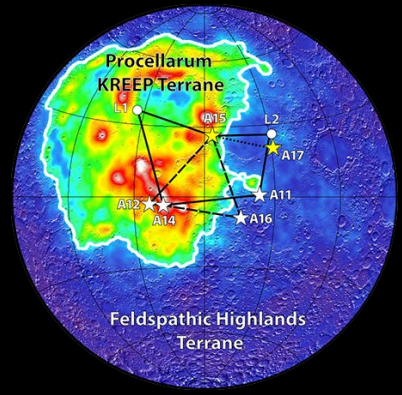


Secondary Goals

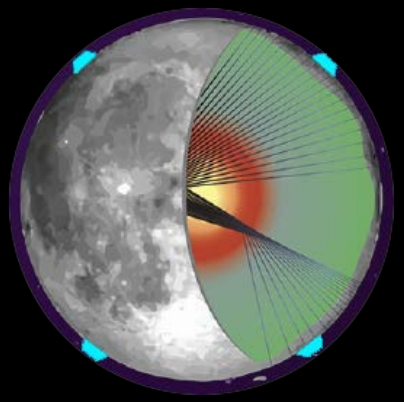
- Understand the current space environment.
- Provide the most sensitive available tests of current gravitational theories & General Relativity.

Secondary Objectives

- Characterize the present impact flux, and variations therein, on the Moon.
- Obtain fundamental data about the current lunar surface plasma environment.
- Characterize the fundamental aspects of gravitation and General Relativity as they relate to the fundamental aspects of Cosmology.

Secondary Investigations

- Monitor impacts on to the lunar surface as an aid to exploring the lunar interior.
- Characterize and monitor lunar surface plasma and its spatiotemporal input processes..
- Evaluate the deviations of motion of the center of mass of the Moon as compared to the predictions of General Relativity.
- Test of the possible rate of change of the gravitational constant *G*.



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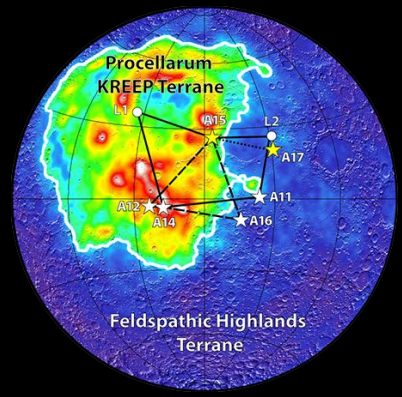


A High Priority Science Mission

Exploration Goals

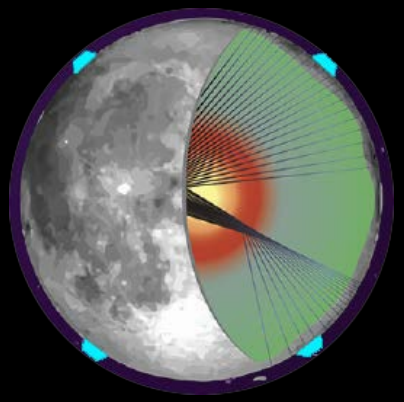
- Evaluate the risk to humans living and working on the Moon.
- Establish infrastructure to support missions to the Moon.

Exploration Objectives

- Characterize the present impact flux, and variations therein, on the Moon.
- Obtain fundamental data about the current lunar surface plasma environment.
- Quantify the risks to human habitats on the lunar surface from moonquakes.
- Support precision navigation for crewed and robotic missions on route to the Moon and in the lunar vicinity

Exploration Investigations

- Monitor impacts on to the lunar surface as an aid to exploring the lunar interior.
- Characterize and monitor lunar surface plasma and its spatiotemporal input processes..
- Define locations and magnitudes of shallow moonquakes.
- Use LLRs to aid navigation, cartography, and orientation relative to Earth.



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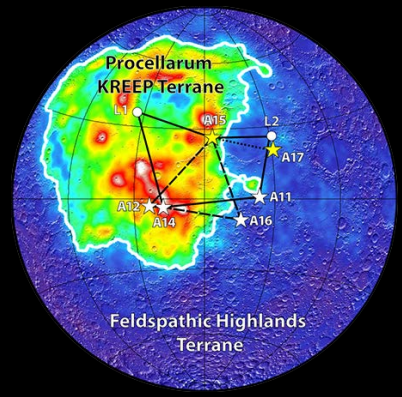

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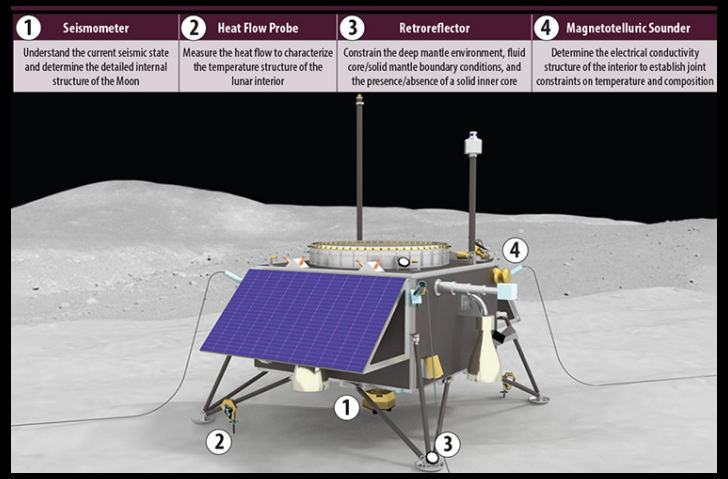


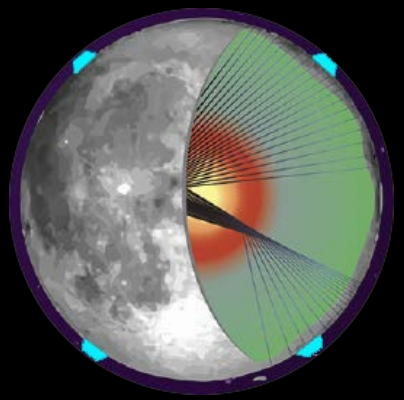
Per Lander Instruments

1. Seismometer: very broadband (1) and short period (3)
2. Heat Flow Probes (2) deployed from lander legs
3. Laser Retroreflectors (2): one on the deck and one on a lander leg
4. Magnetotelluric Sounder (1): Electrodes (4), Fluxgate Magnetometer (1), Search Coil Magnetometer (1), Ion Electrostatic Analyzer

	Mass			Average Power			Mission Data Volume
	CBE (kg)	% Cont.	MEV (kg)	CBE (W)	% Cont.	MEV (W)	For 6 Years (Gbits)
VBB/SP Seismometer	25	30	32.5	11	30	14.3	3,217
SP Seismometer (On Deck)	1	30	1.3	2	30	2.6	1,514
Silicon Audio/MEMS Seismometer	9.4	30	12.3	4.6	30	6.0	1,779
Heat Flow Probe (2)	14.2	30	18.5	12	30	15.6	284
Lunar Magnetotelluric Sounder Suite	6.1	30	7.9	8.6	30	11.2	11,353
Next Generation Lunar Retroreflector (2)	10	30	13.0	0.0	30	0.0	0
Close Range Imager (4), Panoramic Imager	9.8	30	12.7	25.8	30	33.5	1,779
Payload Totals	**76.5**	**30**	**99.5**	**64**	**30**	**83.2**	**19,926**

Mass and power estimates include instrument electronics and deployment systems as appropriate.

CBE: Current Best Estimate
MEV: Max. Expected Value



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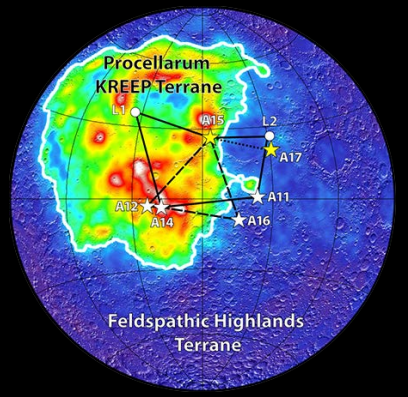
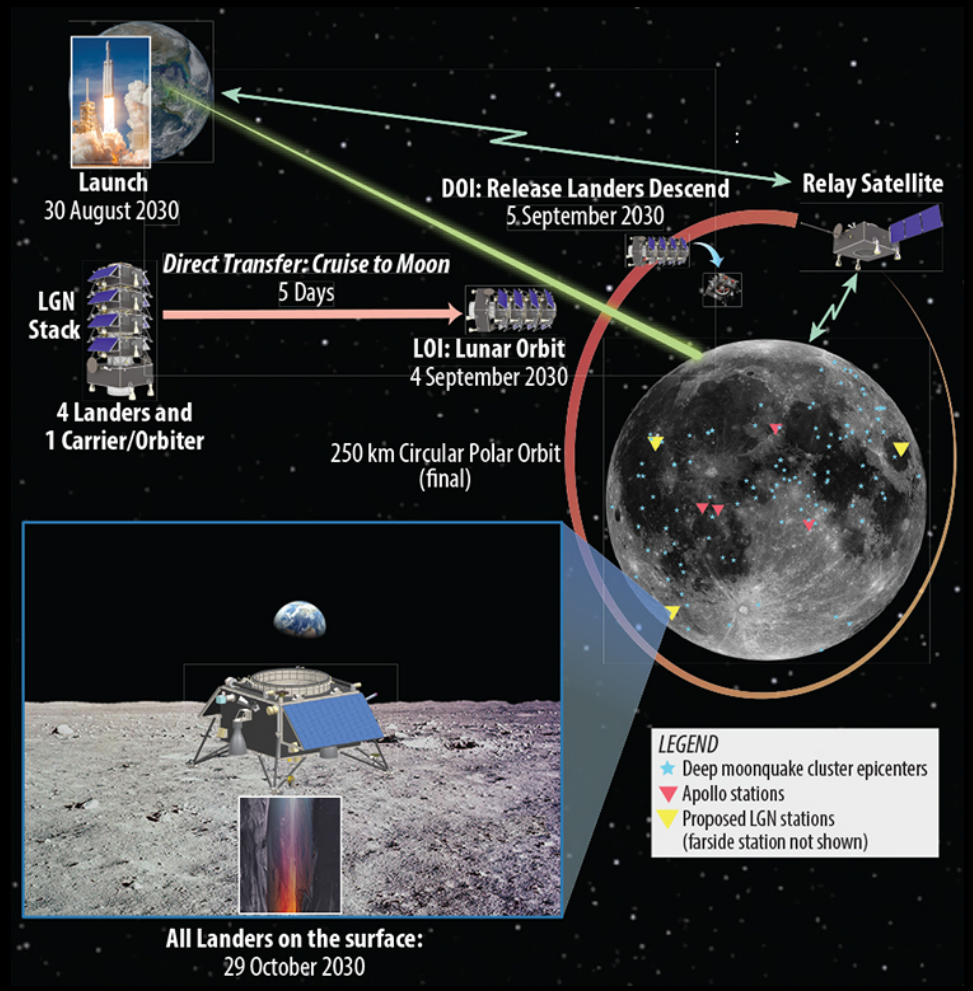
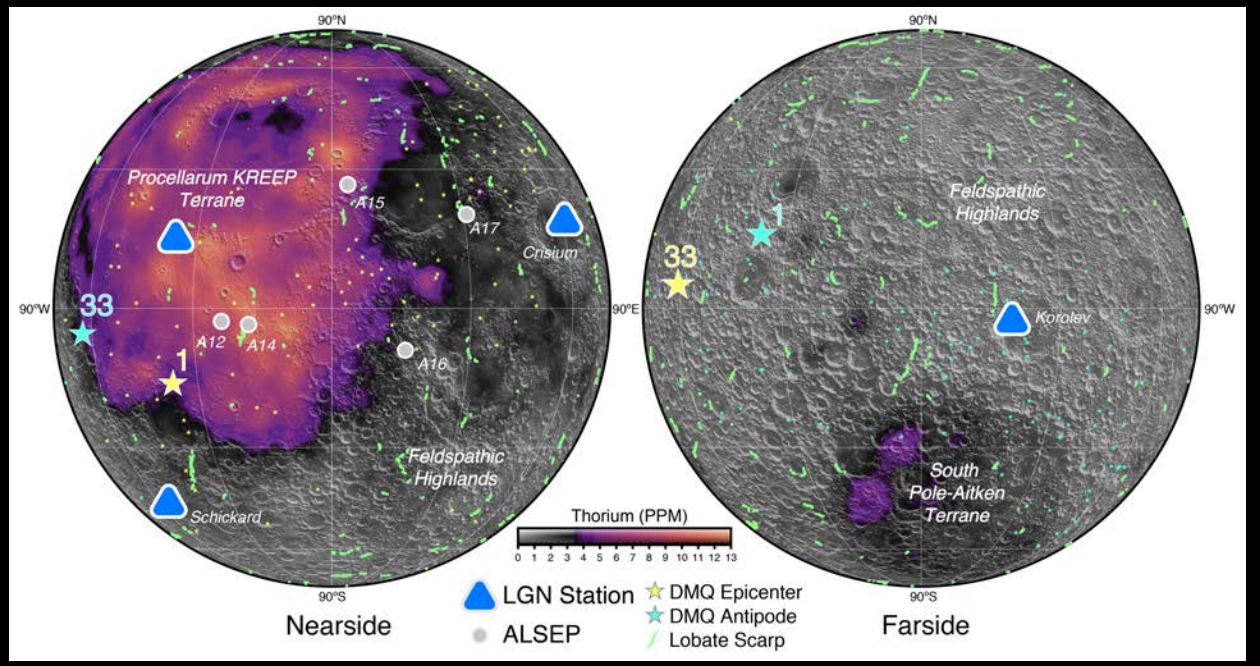
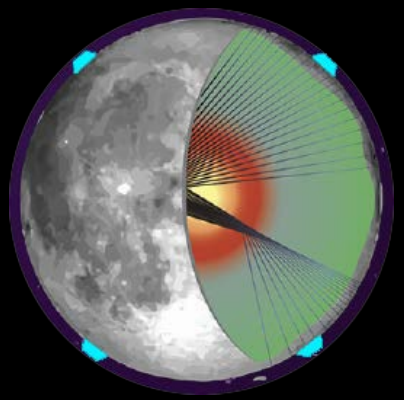




- 4 identical landers deployed globally.
- Communications satellite required for the far-side station.
- Sites chosen to maximize science return.





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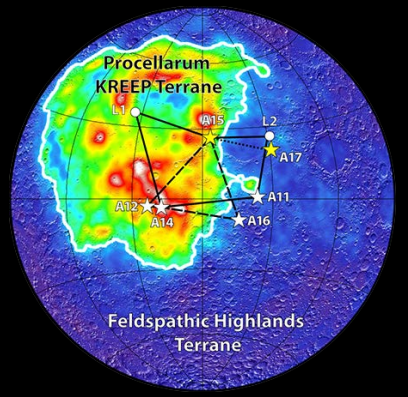
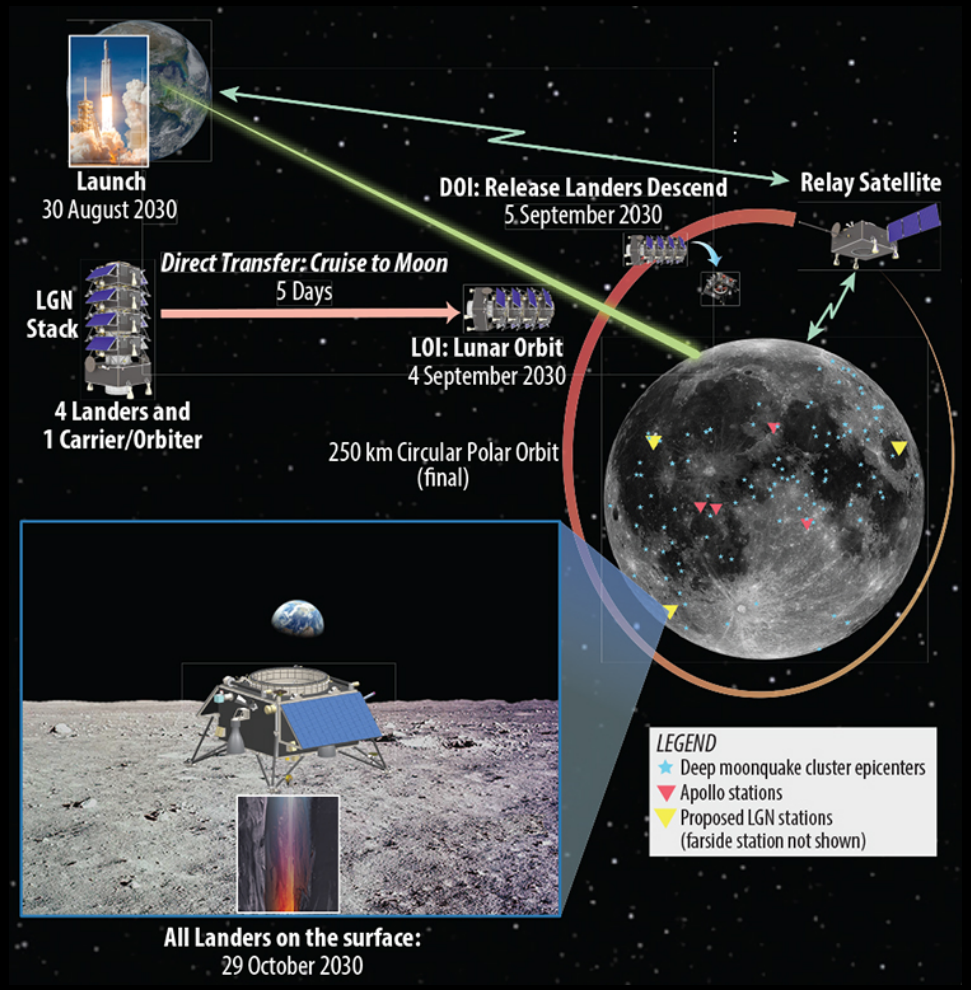
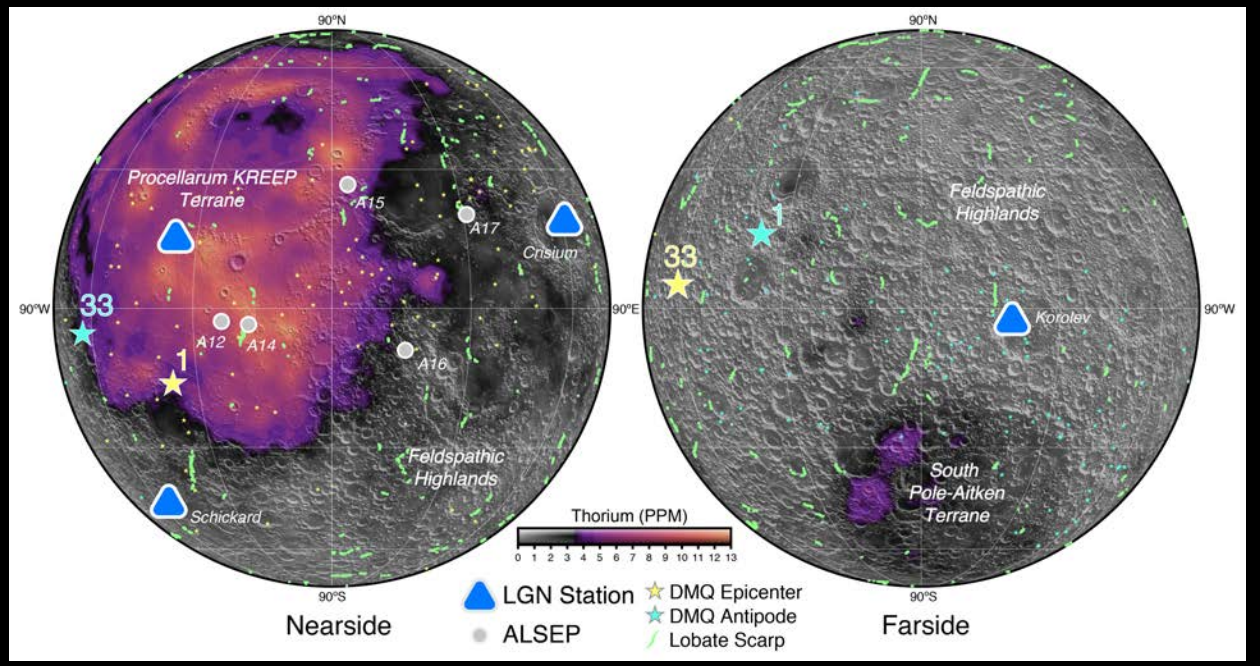
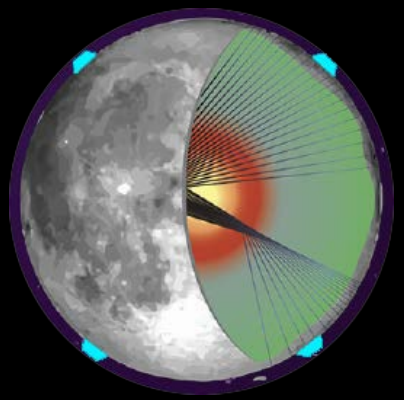




- Sequential deployment at lunar dawn.
- Operational at all times (including night) – 6 yr minimum.
- Communications only during sunlight.





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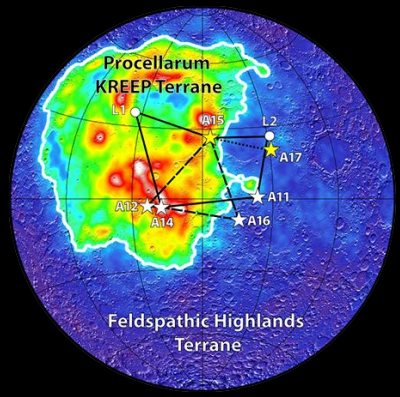
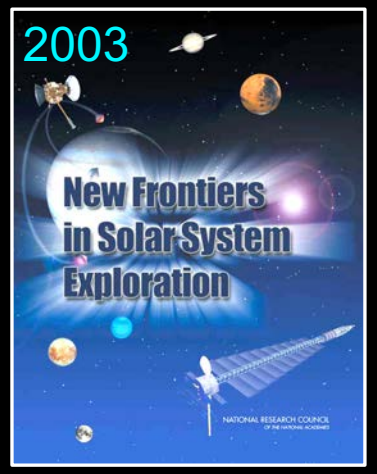
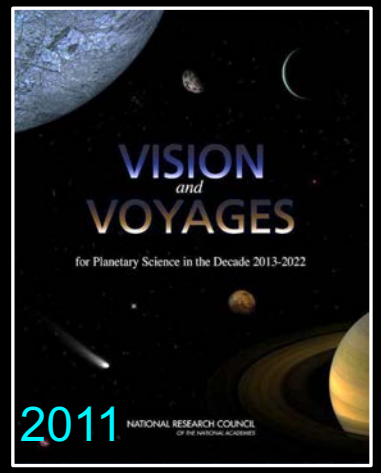
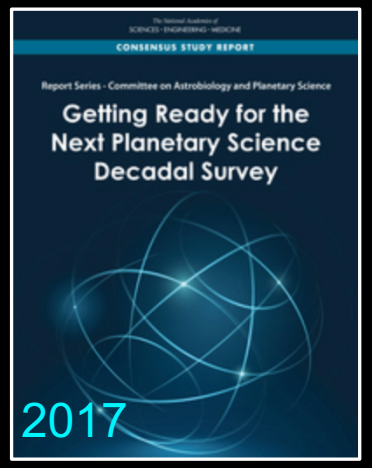
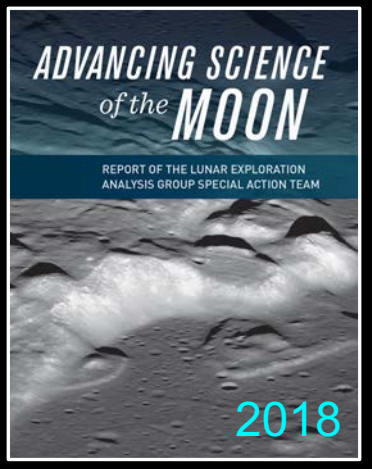
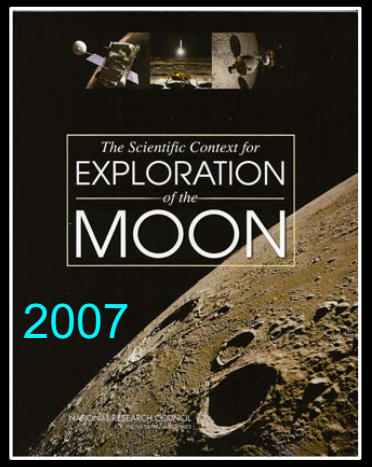


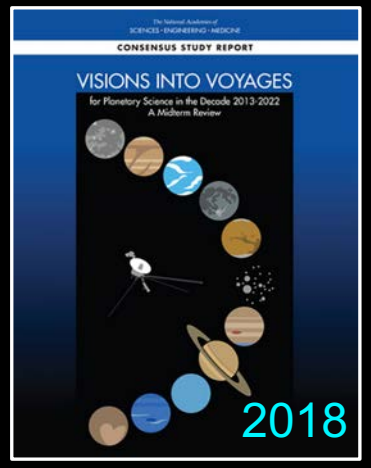


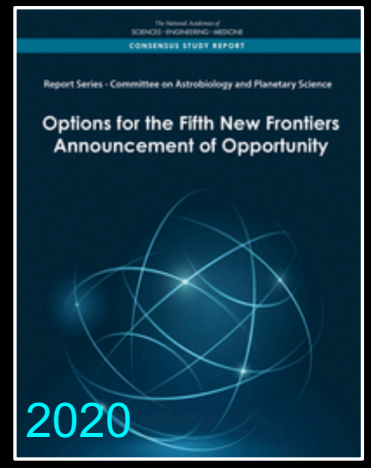


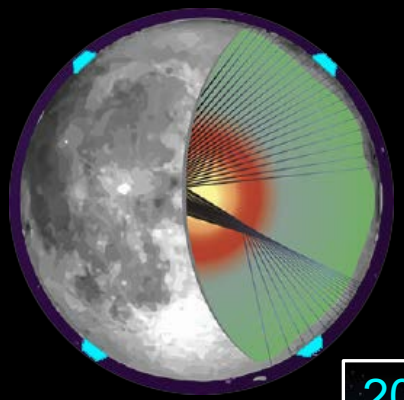




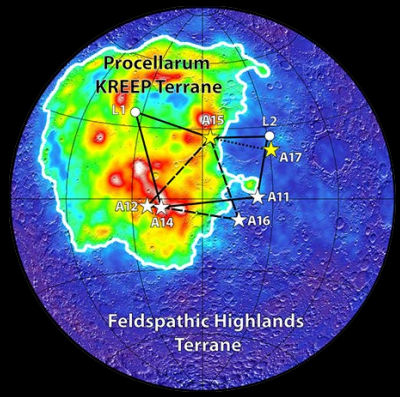








Lunar Geophysical Network



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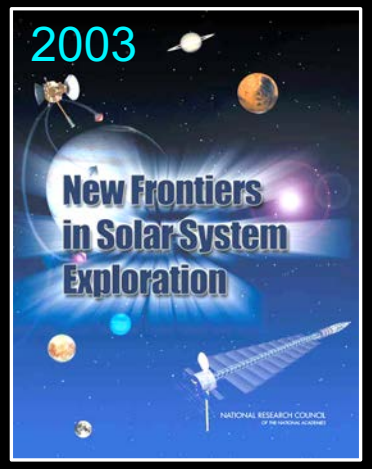
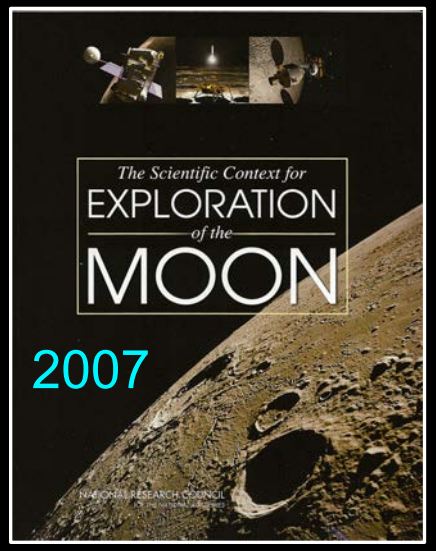


The structure & composition of the lunar interior provide fundamental information on the evolution of a differentiated planetary body.



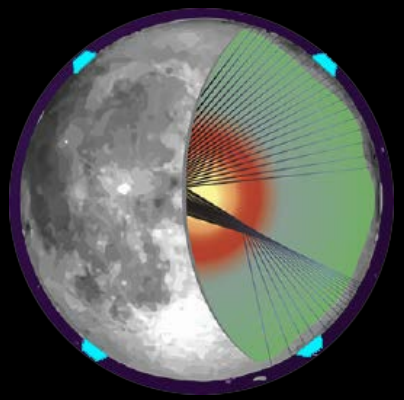
Goal 2a - Determine the thickness of the lunar crust, characterize its lateral variability on regional and global scales.

Goal 2b - Characterize the chemical/ physical stratification in the mantle, particularly the nature of the putative 500-km discontinuity and the composition of the lower mantle.

Goal 2c - Determine the size, composition, & state of the lunar core

Goal 2d - Characterize the thermal state of the interior & elucidate the workings of the planetary heat engine

Page 62: 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.



Lunar Geophysical Network

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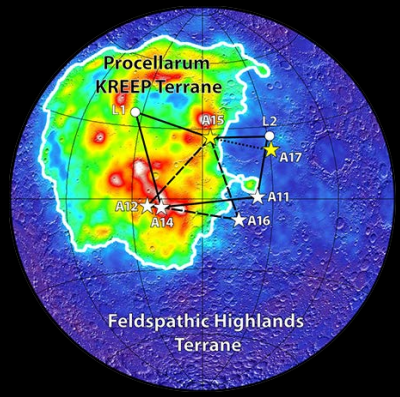
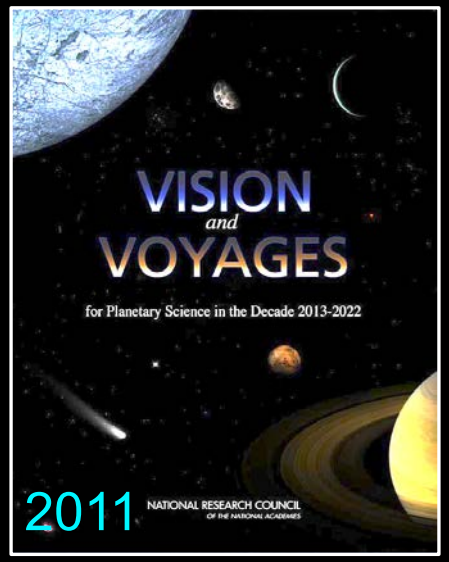




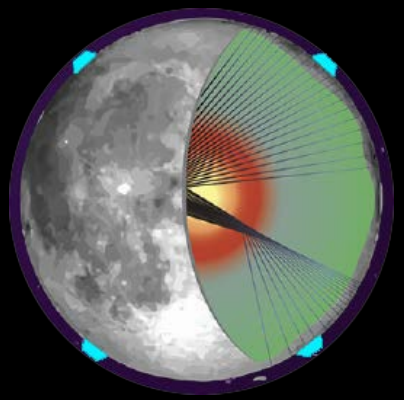
Page 15 [New Frontiers missions 2013-2022]: ***Lunar Geophysical Network*** - several identical landers distributed across the lunar surface, each carrying instrumentation for geophysical studies. The primary science objectives are to characterize the Moon's internal structure, seismic activity, global heat flow budget, bulk composition, and magnetic field

Objective Sci-A-5: Understand Lunar Differentiation.

Investigation-C: Determine the composition, structure, and variability of the crust.

Investigation-D: Determine the composition, structure, and variability of the mantle

Investigation-E: Determine size and composition of the core



Lunar Geophysical Network

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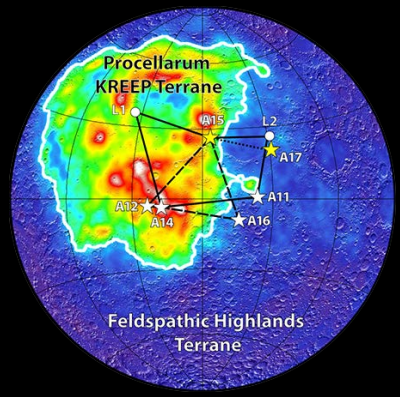
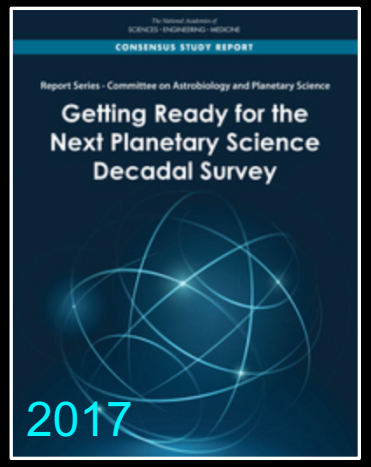
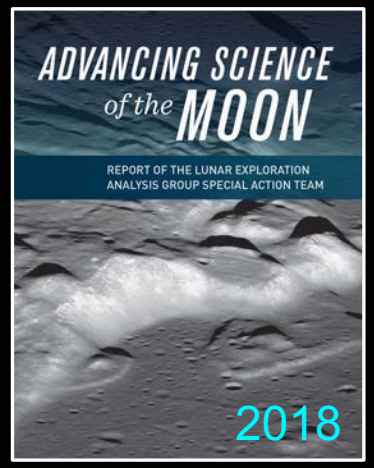
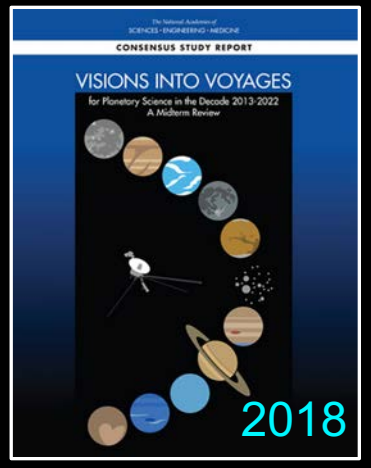




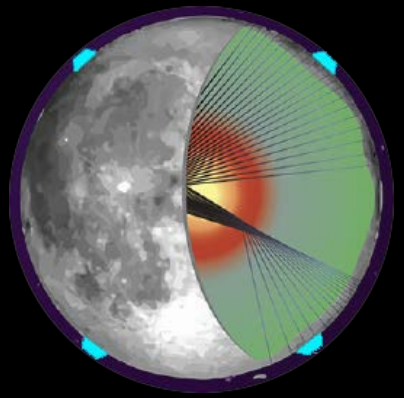
The technical feasibility of the ….. Lunar Geophysical Network (LGN), could be fruitfully reexamined.



Recommendations for addressing Concept 2 [emplacement of a simultaneous, globally distributed seismic & heat flow network and/or an expanded retroreflector network] in the 2007 NRC report remain valid



The committee believes that LGN still remains valid for New Frontiers 5.



Lunar Geophysical Network

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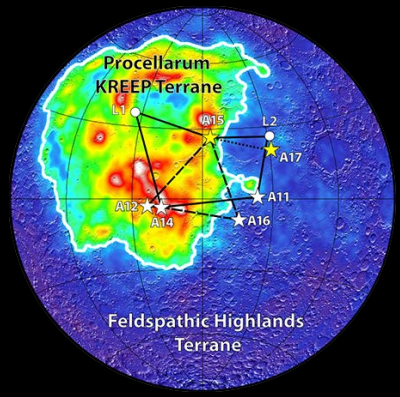
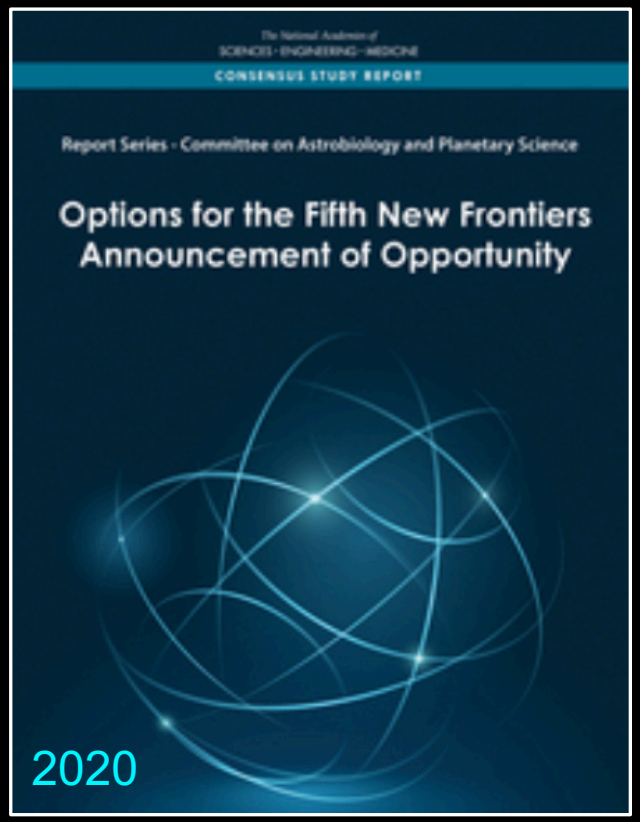
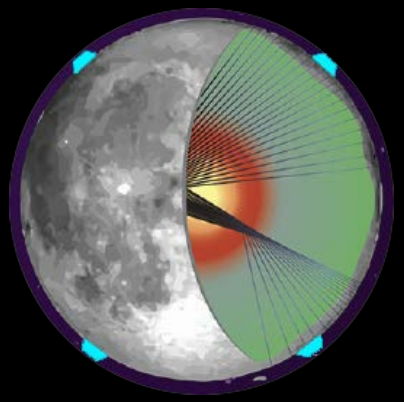




Finding: ***CLPS missions by their design*** (and current implementation approach) ***cannot replace the integrated New Frontiers–level science investigations of the LGN***. But, the CLPS program, if so utilized, represents a potentially important risk reduction mechanism for LGN instruments and technologies.

Finding: Scientific discoveries from lunar orbit or in terrestrial laboratories and technical advances in instrumentation since the 2011 decadal survey do not replace or obviate the need for the LGN.

Finding: ***The scientific rationale in V&V for the LGN has not changed, and if anything has become more compelling***, so reconsideration by NASA of inclusion of LGN in the NF5 target list is not warranted. Substantial investment in deployable geophysical instrumentation for the lunar surface over the past decade has made the scientific case for LGN more robust in the sense of being more achievable.



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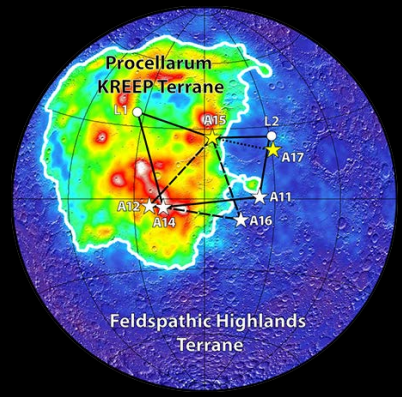
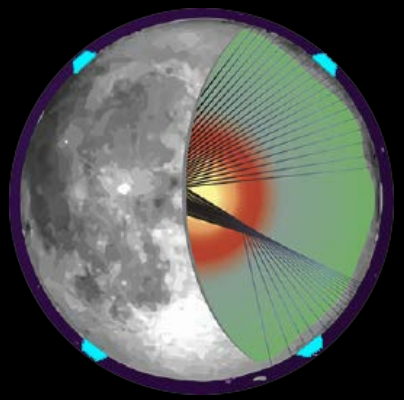
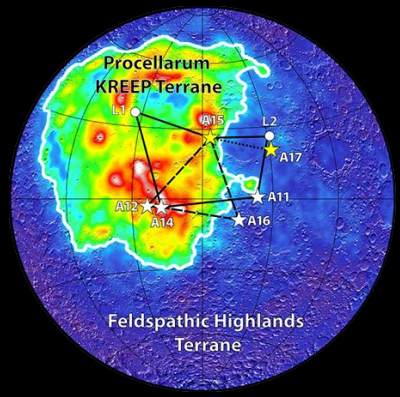


Current Decadal Survey - Relevant White Papers:

- The Scientific Rationale for the deployment of a Long-Lived Geophysical Network on the Moon – Weber et al. (47 signatories)
- Lunar Mission for the Decade 2023-2033 - Cohen et al. (distilled from the 2019 LEAG Annual Meeting; 9 signatories)
- Planetary Science Priorities for the Moon 2023-2032 – Jawin et al. (distilled from the 2019 LEAG Annual Meeting; 12 signatories)
- The Moon is a Special Place – Moriarty et al. (37 signatories)



Lunar Geophysical Network



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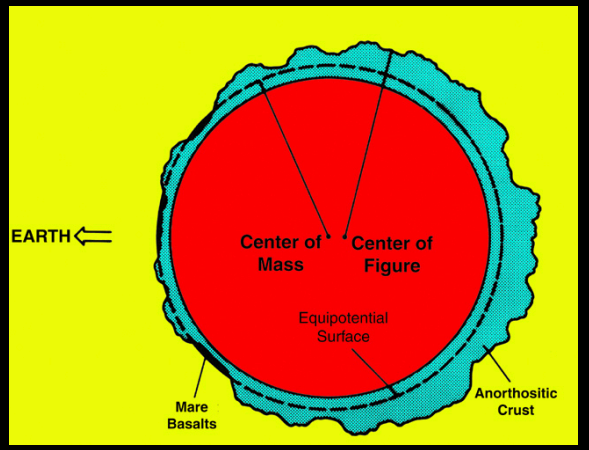
Summary: LGN will test fundamental concepts that underpin lunar science, but will also go beyond the Moon:

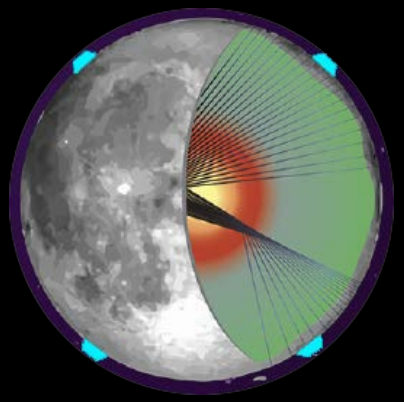
Lunar Science: Test the Lunar Magma Ocean Hypothesis
Constrain the Bulk Composition of the Moon
Investigate the lunar core dynamo hypothesis
Investigate the near-side, far-side crustal dichotomy



Solar System Science: Define the initial stages of terrestrial planetary body differentiation
Quantify the current impact flux of the inner solar system

Astrophysics: Provide constraints on Equivalence Principle, General Theory of Relativity

LGN data will enhance GRAIL mission data providing greater fidelity for gravity observations the the lunar interior, which are currently based upon Apollo seismic data.



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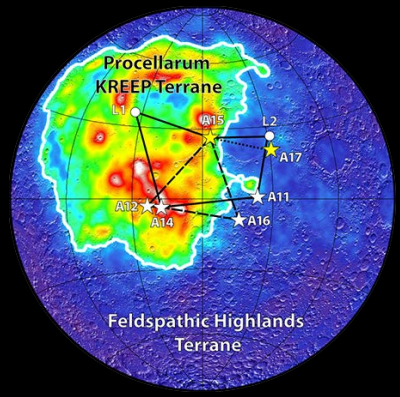
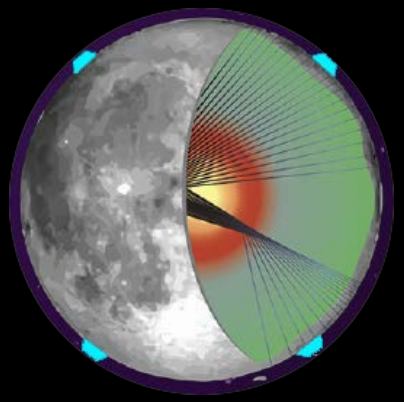


Questions?



Lunar Geophysical Network

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