LUNETTE – Establishing a Lunar Geophysical Network without Nuclear Power through a Discovery Class Mission

Clive R. Neal[1], W. Bruce Banerdt[2], Leon Alkalai[2], John O. Elliott[2], & the Lunette Team*

[1]Dept. Civil Eng. & Geological Sci., 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 (bruce.banerdt@jpl.nasa.gov; leon.alkalai@jpl.nasa.gov, john.o.elliott@jpl.nasa.gov)

MISSION OVERVIEW

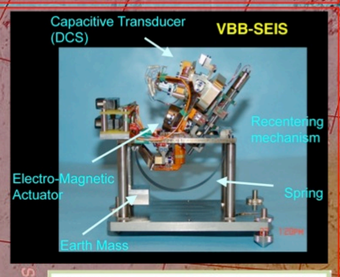
- Place three landers with identical instrumentation on the lunar near side well within distinct terranes (Feldspathic Highlands (FHT) – Schickard Crater; Procellarum KREEP (PKT) – Mare Insularum; MASCON – Mare Crisium).
- Nominal mission is for 2 years (minimum). Instruments operate during lunar day & night; comm. during lunar day only.
- **Science return must be better than Apollo.**

INSTRUMENTATION

SEISMOMETER

France: Very Broad Band (VBB) Seismometer

Japan: Short Period (SP) Seismometer

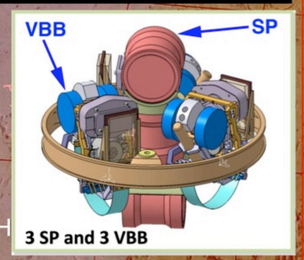


- Diameter : 185 mm
- Height : 195 mm
- Mass:
  - Sensors 2345g;
  - Electronics: 4020 g

Power < 1500 mW

VBB: <10^{-9} m s^{-2} $Hz^{-1/2}$ (10^{-3} - 10 Hz)

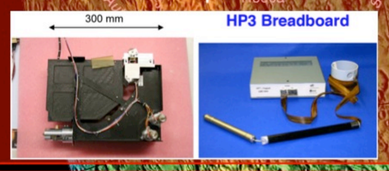
SP: < 5 x 10^{-8} m s^{-2} $Hz^{-1/2}$ (10^{-2} - 100 H

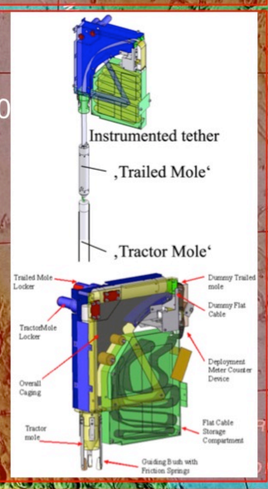


HEAT FLOW PROBE

Germany: HP3 Mole

- Dimensions (mm): 346 x 265 x 230
- Mass: 1726 g
- Hammering Power: 10.2 W
- Maximum Power Budget:
  - Active Heating Exp.: 6.0 W
  - Operation @ Depth: 2.6 W
  - HP3 Warm-up: 1.5 W





ELECTROMAGNETIC SOUNDING

USA: 4electrodes (E1-4) yield 3 components of E-field.

- E1-E3 = 3x9 cm spiked cylinders – ballistic.
- E4 = 3x20 cm cylinder.

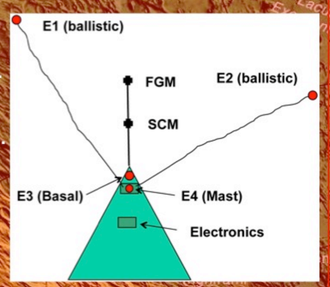
Fluxgate Magnetometer (FGM) = "low- freq" B-field.

Search-Coil Magnetometer (SCM) = "high-freq" B-field.

Heaters & temperature EM sensors.

Total Mass: 7400 g.

Max Power: 4.6 W.



LASER RETROREFLECTOR

USA: Corner Cubes

Total Mass: 5 kg

Corner cube dimensions:

- 170 mm diameter
- 104 mm edge length

Container dimensions:

- 222.5 mm diameter
- 190 mm high

Power: 0 W

Primary Science Goal: Understand the Structure, Composition, Evolution, & Current State of the Moon.

Primary Science Objectives:

- Use the Moon to explore the early stages of planetary differentiation.
- Constrain the structure, bulk composition, and origin of the Moon.
- Constrain the present day meteoroid flux on the lunar surface.

Primary Science Investigations:

- Determine the size, state, and composition of the core.
- Determine the state of & the chemical/physical stratification in the mantle.
- Determine the thickness of the crust & characterize its lateral variability.
- Determine the thermal state of the interior and elucidate the workings of the planetary heat engine.
- Characterize the present impact flux on the Moon.

Secondary Science Goals:

- Test fundamental gravitational physics models using the Earth-Moon System.
- Monitor high energy particle emissions.

Secondary Science Objectives:

- Test Equivalence Principle, Theory of Relativity, Gravitational Inverse Square Law.
- Possible detection of high energy particles and "strange quark matter" (SQM).

Secondary Science Investigations:

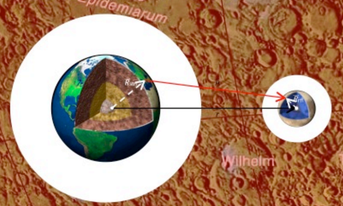
- High precision measurements of the Earth-Moon distance over time.
- Perturbations of the lunar orbit over time &relativistic precession of lunar orbit.
- Monitor EM (high energy particles) and seismic (SQM) data.

Measurement Objectives:

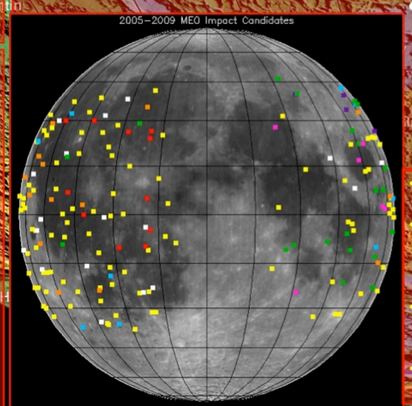
- Lunar seismicity in normal modes and identification of PKP, PcP, ScS signals;
- Correlation with impact flashes on lunar surface;
- Surface temperature (±0.1 K), magnetometers (<1 nT); electrometers (TBD);
- Heat Flow temperatures to ± 0.1K;
- Laser ranging deployed to ~1˚ of mean Earth; precision ~ 1 mm

GROUND-BASED SUPPORT

TELESCOPES

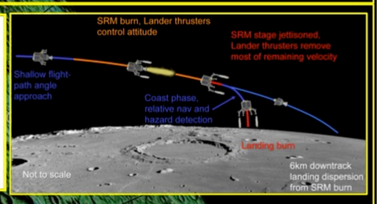


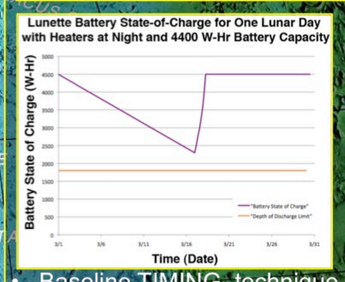
- Lunar laser ranging measurements from Earth-based telescopes allow resolutions to ~1 mm.
- Record meteoroid impact flashes and time stamp – gives known seismic sources that can be correlated with data recorded on each seismometer.
- Impact data coupled with seismic recordings can be used to model the crust and mantle structure and composition.



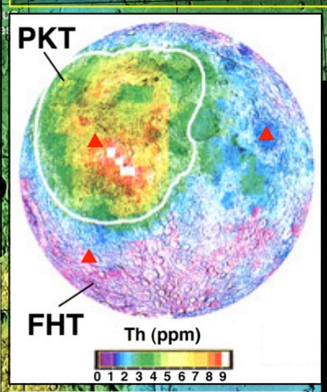
- Camera field of view is an ~20x15 arcminute rectangle. The Moon is 30 arcminutes in diameter.
- The camera is pointed at the nightside hemisphere centered on the equator and includes the lunar limb - polar regions and the central portion of the disk are not viewed.
- The asymmetry between the western (left or leading) and eastern hemispheres is real but is likely not simply caused by the Moon's motion.
- The various colors are approximate meteor shower associations.

OPERATIONS

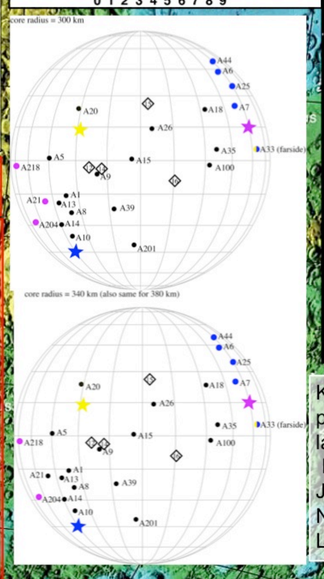




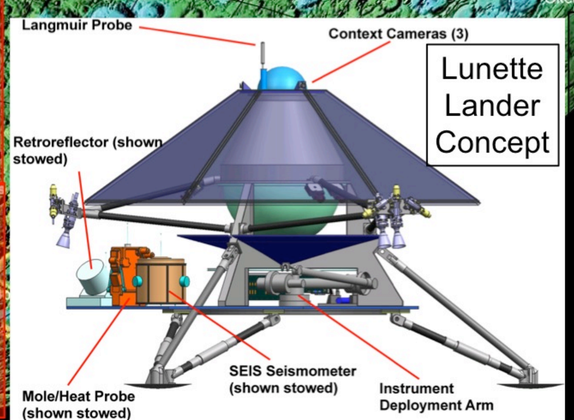
- Sequential landing reduces cost and risk.
- Lander power = solar arrays and battery: 4400 W hr Li-ion batteries (~41 kg).
- Fast recharge just after lunar dawn.
- All non-essential functions shut down over lunar night.
- Collect data from seismometer, electromagnetic, and heat flow instruments over Lunar night.
- Baseline TIMING technique is to use a Chip-Scale Atomic Clock (CSAC) to maintain sufficient time accuracy between stations (50 usec accuracy).
- To address data collection and timing during nighttime operation, an Event Timer Module (ETM) will be used as a stand-alone interface between critical instruments and the lander C&DH.



LUNETTE LANDING SITES



Known Deep Moonquake (DMQ) nests that would produce PKP ray paths (assuming different core radii) and their relation to the Lunette landing sites. Color coding relates the landing site to the DMQ nests. DMQ locations from Nakamura (2005, JGR 110 doi:10.1029/2004 JE002332). PKP travel times calculated using the velocity model of Nakamura (1983, JGR 88, 677-686). Using the velocity model of Lognonné et al. (2003, EPSL 211, 27-44) produces the same results.



***LUNETTE TEAM**

USA: Vassilis Angelopoulos (UCLA); Greg Delory (UC Berkeley); Matt Fouch (ASU) Bill Folkner (NASA-JPL); Robert Grimm (SwRI); Lon Hood (Univ. Arizona); Walter Kiefer (LPI); Paul Morgan (NAU); Yosio Nakamura (UT Austin); Sue Smrekar (NASA-JPL); Rob Suggs (NASA-MSFC); Mike Thorne (Univ. Utah); Slava Turyshev (NASA-JPL); Jim Tyburczy (ASU); Renee Weber (USGS); Jim Williams (NASA-JPL).

Canada: Catherine Johnson (UBC).

France: Raphael Garcia (SUPAERO); Jacques Laskar (IMCCE); Philippe Lognonné (IPGP, Paris); David Mimoun (Univ. Tolouse); Mark Wieczorek (IPGP, Paris); David Baratoux (Univ. Tolouse).

Germany: Ulrich Christensen (MPI); Walter Goetz (MPI); Matthias Grott (DLR); Joerg Knollenberg (DLR); Lutz Richter (DLR); Tilman Spohn (DLR).

Japan: Naoki Kobahashi (JAXA); Hiroaki Shiraishi (JAXA); Satoshi Tanaka (JAXA).

Switzerland: Lapo Boschi (ETH); Domenico Giardini (ETH).

TRACEABILITY. New Frontiers in the Solar System: An Integrated Strategy (2003) (pages 62-63) NRC. Scientific Context for the Exploration of the Moon (2007), NRC: 2nd highest priority = understanding the structure and composition of the lunar interior. Rationale for Deployment of a Long-Lived Geophysical Network on the Moon (2009): white paper submitted to the Inner Planets Panel of the Decadal Survey with > 85 co-authors. International Lunar Network Final Report: Science Definition team for the ILN Anchor Nodes (2009).