The International Lunar Network (ILN) is an initiative of 9 national space agencies to establish a set of robotic geophysical monitoring stations on the surface of the Moon.

- The ILN accomplishes high priority science by coordinating landed stations (nodes) from multiple space agencies.
- ILN nodes will fly a core set of instruments, plus additional passive, active, ISRU, or engineering experiments, as desired by each space agency.
- Contributions could include orbiter support, tracking, communications, and closely related science.

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The U.S. contribution to ILN is the Anchor Nodes Project

- NASA has been conducting an Anchor Nodes Science Definition Team and Engineering Pre-Phase A Study
- Two mission concepts were developed by MSFC/APL based on SMD direction:
  - Advanced Radioisotope Generator (ASRG) - $836M, $607M
  - Asteroid Science Observatory (ASO) - $650M

- Independent PA&E Technical, Cost, & Schedule Review is complete:
  - Project's costs & schedule estimates are reasonable for the mission concepts developed.
  - Decadal class lunar network science is a New Frontiers cost class of mission.

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Pre-Phase A Cost Estimates for U.S. Anchor Nodes have been validated through independent PA&E technical, schedule and cost review:
- Cost estimates of mission concepts and instruments are in-family with historic NASA planetary missions
- Cost analysis is traceable and contains supporting documentation and technical data

Due to the high cost of a Decadal class Anchor Nodes mission, lunar network science has been remanded to the Decadal Survey for prioritization.

Robotic Lunar Lander team is proceeding with risk reduction and technology development of the small lunar lander design:
- Lander designs are capable of supporting the selected SMD science mission based on results from Decadal Survey.

International Lunar Network Science
Barbara Cohen, ILN Project Scientist

Outline

- Scientific motivation
- Science Definition Team
  - Formulation and prioritization of science and measurement goals
  - Science baseline and floor definitions
- Science mission drivers
  - Number of Nodes
  - Day/Night Operations
  - Lifetime
  - Landing sites
  - Instrument payload
  - Launch data

Scientific Motivation

The Moon uniquely preserves a record of geologic processes of early planetary evolution
- The Moon is a terrestrial body – it formed and evolved in a similar manner to Earth, Mars, Mercury, Venus, and large asteroids
- The Moon is a differentiated body, with a layered internal structure (crust, mantle, and core)
- The Moon is an active body, experiencing thousands of deep moonquakes each year, releasing primordial heat, conducting electricity, and wobbling in its orbit

The goal of a Lunar Geophysical Network is to understand the interior structure and composition of the moon

Genesis of the Geophysical Network

A Geophysical Network is recommended in the Planetary Decadal Survey (2003), the Scientific Context for the Exploration of the Moon (2007), the NAC Workshop on Enabling Science in the Lunar Architecture (2007), and Opening New Frontiers in Space (2008) to include, at a minimum, seismic and heat flow sensors, and new laser ranging retroreflectors. Coordinated with those of other countries that are included in their space exploration strategies.

Lunar Interior Structure: The Theory

- Mars-sized body slammed into the proto-Earth at 4.56 Ga
- Moon formed out of hot crust/outer mantle component - lack of metal & volatiles
- Moon and Earth differentiated via igneous processes
  - Basaltic volcanism via mantle density overturn
  - Incompatible elements in KREEP layer
- Redistribution by impact processes
The complete Apollo seismic network (4 nodes) operated from April 22, 1972 to Sept. 30 1977. Penetrated ~800 km deep.

- The crust on near side is 30-40 km thick; far side is thicker (60 km). It has an anorthositic composition; lateral variations exist.
- Geochemical arguments hypothesize that the lunar mantle is layered and of a different composition than Earth's mantle.
- Magmatism was most active > 3 Ga, therefore heat flow in the mantle was higher then.

There is probably a small (250-350 km diameter) core.

The next generation of geophysical measurements is intended to directly detect a planetary core, to provide a framework for interior models, and to understand later variations within a planet. These objectives will substantially improve upon our current knowledge of planetary interiors.

**Many Unresolved Science Questions**

- There are many unresolved science questions about the interior of the Moon, its evolution, and implications for other planets.
  - **Lunar Core**
    - What is the thermal structure of the Moon? How does it vary with time?
    - How does the thermal structure of the Moon compare to that of Earth?
    - What is the thermal evolution of the Moon?
  - **Lunar Mantle**
    - What is the mineralogical composition of the lunar mantle?
    - How does the composition of the lunar mantle vary with depth?
    - What is the dynamic structure of the lunar mantle?
  - **Lunar Crust**
    - What is the thermal evolution of the lunar crust?
    - How does the thermal evolution of the lunar crust compare to that of Earth?
    - What is the dynamic structure of the lunar crust?
  - **The next generation of geophysical measurements** is intended to study detect a planetary core, to provide a framework for interior models, and to understand lateral variations within a planet. These objectives will substantially improve upon our current knowledge of planetary interiors.

**ILN Science Definition Team (SDT)**

- NASA HQ convened an independent Science Definition Team (SDT) to address the science uniquely enabled by a network, March 2008.

  - The clear focus of the SDT is to address what science is uniquely enabled by the synergy of a network, within the context provided by previous community-based activities.
  - Define and prioritize the scientific objectives for the ILN.
  - Define measurements required to address the scientific objectives.
  - Define instrumentation required to obtain the measurements.
  - Define criteria for selection of the initial two sites.
  - Identify technical challenges.
  - To the extent that there is still mass and power available for an additional instrument, a priority list of what measurements that instrument should provide.

**Science Baseline and Floor Definition**

- **Geophysical Network Science Baseline Mission**
  - Four stations, four instruments, concurrently active, lifetime of 6 years; two stations at geosynchronous altitude, one at ~20° of the Earth.
  - **Science Floor Mission**
    - Two stations, seismometer only, concurrently active, lifetime of 2+ years, stations placed relative to A33 moonquake nest hypocenter.
  - SDT defined graceful descopes between Baseline and Science Floor.
  - Instrument requirements, number and type of instruments, total lifetime, reduced power modes for nighttime operations, number of nodes.

  "Two nodes are insufficient for achieving major new lunar science. Therefore, the SDT strongly advocates a Network Science Baseline Mission, where two initial nodes are joined with at least two additional nodes to form a larger network for a combined 6-year minimum operational lifetime. SDT report p. 2.

  "NASA must continue its long-term partnership with the international community for the success of the entire International Lunar Network. SDT report p. 33."
Find the speed of seismic waves through the Moon — related to the material it is made of.

Need to simultaneously measure 4 independent pieces of information:
- Use three stations to triangulate the location of the moonquake
- Measure time for waves to reach a 4th sensor at a known distance
- Calculate the mean speed of waves
- The more independent stations, the more lateral variability can be investigated
- All four stations must be simultaneously and continuously operational (day and night)

Need to observe multiple seismic events
- Apollo gave us statistical information about frequency and cyclicity
- For network science baseline, need to capture information over a lunar tidal cycle (6 years) — longer baseline than Apollo, provides ~6 strong, shallow moonquakes
- For science floor (2 nodes), limited science objectives can be accomplished from deep moonquakes in a shorter time (2 years).
- Other experiments need two years or less - not drivers.

The more independent stations, the more lateral variability can be investigated.
- All four stations must be simultaneously and continuously operational (day and night)

Launch Date

Launch Date

Number of Nodes & Operations

International partners may well end up at a pole for their own exploration/research

Synthetic seismogram study will evaluate potential locations

Site selection should be done with full community input, plus constraints from engineering

4 Lander mission can go anytime

Notional Payloads

- Seismometry: Balancenaut (instruments, galvanometer)
- Heat Flow: Nasa1 (instruments, magnetometer)
- EPSE: Emco (instruments, magnetometer)
- Laser: EPL (instruments, RHEE
- Lander: NASA (instruments, Emco)

4 Lander mission can go anytime

 notions show do not include 20% mass and power margin carried at the system level
 any additional landing mass will be allocated to provide additional payload capacity. Lander designed for 4.5 science by accommodating instruments that can provide required measurements.
The goal of a Lunar Geophysical Network is to understand the interior structure and composition of the moon.

- A variety of geophysical and compositional analyses of the Moon will enable researchers to determine the internal structure and composition of a differentiated planetary body.
- The next generation of geophysical measurements have to substantially improve on our current knowledge in order to make significant advances in science.
- Lunar geophysical science drives severe mission implementation needs:
  - Sophisticated instrument payload
  - 4 simultaneously operating nodes
  - Continuous seismometer operations
  - Long lifetime (2-6 years)
  - Far side placement

ILN Anchor Node Pre-Phase A Major Activities

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ILN Anchor Node Lander Concept Evolution

Resulting Lander Options

- Both options are sized to perform ILN mission
- ASRG option has additional mass and power margin for growth on other payloads
- Solar-Battery option has significant total payload capacity for other Lunar mission

Mission Concept of Operations
ILN Anchor Nodes Current Status
Extended Pre-Phase A: Risk Reduction Activities

• Objective: Utilize extended formulation period to perform value-added work in an effort to reduce risk in the development and implementation phases of the project.

• Risk Reduction Activities Currently On-Going
  – Lunar Lander Test Bed: Hardware In the Loop (HWIL) testing with landing algorithms and thruster positions
  – Propulsion: thruster testing in relevant environment, pressure regulator valve
  – Power: battery testing
  – Thermal: WEB analysis
  – Structures: composite coupon testing, lander leg stability
  – Avionics: reduced mass and power avionics box with LEON3 processor
  – GN&C: landing algorithms
  – Mole testing at JPL: test mole in lunar regolith simulants
  – Seismograph task: analysis to inform the requirement for the number and location of sites

Lunar Lander Test Bed Overview

• Lunar Lander Robotic Exploration Test Bed initiated by MSFC
  – Provides a test environment for robotic lander test articles, components, algorithms, etc.
  – Implemented by Von Braun Center for Science and Innovation non-profit consortium
  – ILN anchor node project as first user has input into test bed requirement

• Development of MSFC cold gas test article
  – Test bed team developed platform requirements with input from ILN project
  – RFP for structure and propulsion systems released in December 2008
  – Structure and propulsion system contract awarded in January 2009
  – Structure and propulsion system delivered in May 2009
  – Avionics integration completed
  – Testarticle provides ILN-like thruster geometry and will implement a similar software environment for demonstrating takeoff GN&C control
  – Serves as a pathfinder for flight development in certain areas (e.g. IMU interface, IDM integration, etc.)

Test Status

• Completed attitude control test
  – Vehicle was sequenced and demonstrated the ability to rotate to and hold commanded orientations
  – Completed hardware-in-the-loop (HWIL) simulation testing
  – Conducted software and software in-the-loop (HWIL) simulation testing
  – Currently undergoing high performance pressure system check-out via HWIL simulation testing
  – Flight testing will commence once high pressure performance is verified

Next Generation

• Activities underway to develop "warm" gas test article to begin longer duration testing in August 2010

Lander Multi-mission capability – Quick Look

ILN Anchor Node lander design is extensible to other science mission objectives

Information is Preliminary
Summary

- Both ASRG and Solar-Battery options are sized to perform the ILN mission
- Four ASRG lander mission is New Frontiers cost class and independently reviewed by NASA PA&E
- Significant concept development work has been performed
  - Concept is mature and accounts for necessary ILN accommodations
  - Majority of design is based on existing technology
  - Risks have been identified and a comprehensive risk reduction effort is underway
    - Significant portion of these activities nominally would be completed during Phase A/Phase B
    - Expenditures now on risk reduction activities increase confidence in the design and reduces cost for Phase A and Phase B
    - Cost estimates provided in the cost presentation have not been credited for these activities
- Lander designs are capable of supporting the selected SMD science mission based on results from Decadal Survey