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 cradle support, tracking, communications, and closely related science.

To guide the ILN initiative, a non-binding “Statement of Intent” was signed on July 24, 2008, by Canada, France, Germany, India, Italy, Japan, Korea, the UK, and the U.S.

- Working Groups established for Core Instrumentation (WG1), Communications (WG2), Site Selection (WG3), and Enabling Technologies (WG4)
- White paper completed by WG2; white papers near complete for WG1 & WG4
- Site Selection working group not yet seated

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:

- The ASO Mission Concept
  - Cost Estimate: $836M
  - Delivery Date: 2013
  - Wet Mass: 6582 kg
  - Power: 128 W
  - Scientific Instruments: 4 (seismometer, heat flow, EM sounder, laser ranging)

- The ASRG Mission Concept
  - Cost Estimate: $650M
  - Delivery Date: 2013
  - Wet Mass: 798 kg
  - Power: 105 W

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.

FY2010 Lunar Quest Program Budget

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

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The complete Apollo seismic network (4 nodes) operated from April 22, 1972 to Sept. 30 1977. Penetrated ~800 km deep.

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.

There are many unresolved science questions about the interior of the Moon, its evolution, and implications for other planets.

Lunar Core:
- What is the internal structure? (Global and local)
- What is the internal composition? (e.g. iron, nickel, magnesium)
- What are the major processes? (e.g. convection)
- What is the thermal history?
- What is the heat flow? (Deep or shallow)

Lunar Mantle:
- What is the composition?
- What are the processes?
- What are the major ingredients? (e.g. iron, nickel, magnesium)

Lunar Crust:
- What is the thickness?
- What is the composition?
- What are the minor ingredients? (e.g. aluminum, silicon)

Lunar Geophysical Network Science Baseline Mission:
- Four stations, four instruments, concurrently active, lifetime of 6 years; farside coverage desirable, or nearside stations within ~20û of the limb

Science Floor Mission:
- Two stations, seismometer only, concurrently active, lifetime of 2+ years, stations placed relative to A33 moonquake nest hypocenter

The next generation of geophysical measurements have to improve on our current (largely Apollo-derived) knowledge:
- Solar seismology
- Heat flow
- Electromagnetic sounding
- Laser ranging

The goal of a Lunar Geophysical Network is to understand the interior structure and composition of the moon:
- Solar seismology
- Heat flow
- Electromagnetic sounding
- Laser ranging

The next generation of geophysical measurements have to improve on our current (largely Apollo-derived) knowledge:
- wider geographical placement
- more sensitive instrumentation
- longer baseline of observations

NASA HQ convened an independent Science Definition Team 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

Findings and recommendations reported to the Planetary Science Division Director and SMD AA July 2008; final report January 2009
- Science Definition Team: Joe Veverka, Barbara Cohen, Bruce Banerdt, Andrew Dombard, Linda Elkins-Tanton, Rob Grimm, Yasuo Nakamura, Clive Neal, Jeff Plescia, Sue Smrekar, Ben Weiss

Defined ILN science objectives ➔ derived mission objectives ➔ measurement and mission requirements

Geophysical Network Science Baseline Mission:
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Science Floor Mission:
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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 four 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 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.

Synthetic seismogram study will evaluate potential locations
Site selection should be done with full community input, plus constraints from engineering
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)
- Farside placement

## International Lunar Network Anchor Nodes

**Mission Design Concepts**

Brian Morse, Assistant Project Manager

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**ILN Anchor Node Pre-Phase A Major Activities**

<table>
<thead>
<tr>
<th>HQ SWD</th>
<th>CY08</th>
<th>CY09</th>
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<tbody>
<tr>
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</tbody>
</table>

**ILN Anchor Node Lander Concept Evolution**

**Mission Concept of Operations**

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**Resulting Lander Options**

<table>
<thead>
<tr>
<th>Lander Option</th>
<th>ASRG</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wet Mass (Cruise/Lander)</strong></td>
<td>1164/422</td>
</tr>
<tr>
<td><strong>Generic max Landed Payload Support Mass (kg)</strong></td>
<td>157</td>
</tr>
<tr>
<td><strong>Max Int. Payload Mass for ILN (kg)</strong></td>
<td>25</td>
</tr>
<tr>
<td><strong>Max Int. Payload Power for ILN (W)</strong></td>
<td>9,500 day/7,800 night</td>
</tr>
</tbody>
</table>

- 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 missions

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**Nodes**

- **Surface Operations**
- **Launch and Cruise**
- **Landing**

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**Legend**

- [Diagram of launch and cruise stages](#)
- [Diagram of landing and operations stages](#)

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**Notes**

- [Detailed explanation of mission components and stages](#)
**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 Ongoing**
  - Lunar Lander Test Bed: Hardware in the Loop (HWIL) testing with landing algorithms and thruster positions
  - Propulsion: thrusting testing in relevant environment, pressure regulator valve
  - Power: battery testing
  - Thermal: WES analysis
  - Structures: composite coupon testing, lander leg stability
  - Avionics: reduced mass and power avionics box with LEON3 processor
  - GN&C: landing algorithms
  - Mole testing @ JPL: test mole in lunar regolith simulant
  - 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
  - Test article provides ILN-like thruster geometry and will implement a similar software environment for demonstration of takeoff and landing (GN&C) functionality
  - Serves as a pathfinder for flight development in certain areas (e.g., IMU interface, cFE integration, etc.)

**Test Status**

- Completed attitude control test
  - Vehicle is sequenced and demonstrates the ability to rotate to and hold commanded orientations
  - Complete hardware-in-the-loop (HWIL) simulation testing

- Currently undergoing high pressure system/propulsion system test (HWIL simulations)

- Flight testing will commence this high pressure performance is verified

**Next Generation**

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

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**Lander Multi-Mission Capability – Quick Look**

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

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**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