Lunar Quest Program Contents

LRO Participating Scientists

LRO Science Mission

Robotic Lander Technology Development

Research & Analysis

Education & Outreach
Lunar Quest Program Status

• Program Objectives:
  – Conduct small to medium, high value robotic lunar science investigations
  – Re-invigorate the lunar science community
  – Facilitate the application of enhancing or enabling technologies to support flight missions
  – Enhance science opportunities in the implementation of the U.S. Space Exploration Policy

• Status
  – Required documentation in approval cycles (PCA and Program Plan)
  – Program Approval Review (PAR) is scheduled for December 8-11, 2009
    • Provides the agency with an independent (SRB) assessment of the readiness of the program to move into implementation.
    • Successful completion allows LADEE and future missions to be considered for confirmation review.
    • The official transition from formulation to implementation (KDP-1) scheduled for January 28, 2010
SMD plans include:

- Transition operations to SMD following 1 year Exploration mission, September 16, 2010.
- Providing funding for the LRO Principal Investigators, as well as for 24 Participating Scientists.
- Continue to fund scientists for up to three years.
- Senior Review scheduled for January, 2010
- Possible operations with a more robust pointing strategy in a different orbit (e.g. limb viewing, more coverage over lower latitudes, or in a more stable orbit for prolonged operations) to meet SMD objectives
- Delivering LRO data products to the Planetary Data System within six months for use by the scientific community.
Lunar Atmosphere and Dust Environment Explorer

Objectives
• Measure Lunar Dust
• Examine the Lunar atmosphere

Key parameters
• Launch in 2012
• Science Data Acquisition: 100 days

Spacecraft
• Type: Small Orbiter - Category III, Enhanced Class D
• Provider: ARC/GSFC

Instruments
• Science Instruments: NMS, UVS, and LDEX
• Technology Payload: Lunar Laser Communications Demo

Launch Vehicle: Minotaur IV+ launched from Wallops Flight Facility

Status
• In Phase B
• Preliminary design review scheduled for April, 2010
**LADEE Instrument Payload**

**Neutral Mass Spectrometer (NMS)**

*In situ* measurement of exospheric species

*P. Mahaffy*

*NASA GSFC*

150 Dalton range/unit mass resolution

**UV Spectrometer (UVS)**

LCROSS heritage

*A. Colaprete*

*NASA ARC*

Dust and exosphere measurements

**Lunar Dust EXperiment (LDEX)**

HEOS 2, Galileo, Ulysses and Cassini Heritage

*M. Horányi, LASP*

**Lunar Laser Com Demo (LLCD)**

Technology demonstration

*High Data Rate Optical Comm*

*D. Boroson*

*MIT-LL*

51-622 Mbps
What is… the International Lunar Network (ILN)?

- The ILN is an initiative of 9 national space agencies to coordinate robotic science on the surface of the Moon.
  - The ILN accomplishes high priority science by coordinating landed missions 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.

- 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)

- Initial Science Objectives: Geophysical Network Science

- Emerging New Science Focus: WG1 expanding consideration of science to other measurements to include, perhaps, volatiles and sample return.
What was... the U.S. Anchor Nodes Project?

• The U.S. contribution to ILN was a Pre-Phase A study of Geophysical Network Nodes

• NASA established a Science Definition Team (SDT) and has been conducting a Pre-Phase A engineering study

• Two mission concepts were developed by MSFC/APL based on SMD direction: 4-lander/ASRG & 2-lander/Solar

• Pre-Phase A Cost Estimates for U.S. Anchor Nodes have been validated through independent PA&E technical, cost, and schedule review (August 2009)

• Due to the establishment of the Decadal Survey this Pre-Phase A lunar network science is being considered by the Decadal Survey Inner Planets Panel for prioritization

• Lunar Lander Development Team is proceeding with risk reduction and technology development of a small lunar lander
  - Lander designs are capable of supporting a selected SMD science mission based on results from Decadal Survey

4-lander / ASRG Concept
Cost + Launch: $836M (FY10)
Lander mass: 260 kg
Power (day/night): 115/115 W

2-lander / Solar-Battery Concept
Cost + Launch: $607M (FY10)
Lander mass: 422 kg
Power (day/night): 56/26 W
Lunar Surface Science Risk Reduction

- **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: Warm Electronics Box and Radiator analysis
  - Structures: composite coupon testing, lander leg stability testing
  - 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
Robotic Lander Testbed: Incremental Development Approach for Flight Robotic Lander Design

• **Cold Gas Test Article (Operational)**
  - Completed in 9 months
  - Emulates Robotic Flight Lander design for thruster configuration in 1/6th gravity
  - Flight time of 10 seconds at 3,000 psi
  - Demonstrates autonomous controlled descent and attitude control
  - Utilizes compressed air for safety, operational simplicity, and multiple tests per day

• **Warm Gas Test Article (Summer 2010) adds to Cold Gas Test Article Functionality:**
  - Longer flight duration (approx. 1 min) and greater altitude for more complex testing
  - Utilizes Robotic Flight Lander design sensor suite, software environment, avionics components (processors), GN&C algorithms and ground control software
  - Serves as a pathfinder for flight lander design and development
  - Quick turn around time to allow multiple tests per day
  - Open to academia and private industry for technology testing

Test bed provides for autonomous closed loop control to demonstrate landing capability on airless bodies to build confidence and reduce overall risk.
LSSL Testbed 3m Cold Gas Hover and Descent Test
• NASA Lunar Science Institute

• Lunar Advanced Science and Exploration Research (LASER)
  – Approximately $3M in FY10, ~20-25 new awards expected
  – Competed through ROSES
  – Next call planned for January, 2010

• Additional elements:
  – Planetary Geology and Geophysics (~$1.8M across ~20 projects per year)
  – Cosmochemistry (~$2M across ~25 projects per year)
  – LRO Participating Scientists (FY10 $2.4M, 25 researchers)
  – Lunar Planetary Data System
  – Moon and Mars Analog Mission Activities (MMAMA)
Research & Analysis
NASA Lunar Science Institute (NLSI)

• Supplements and extends existing NASA lunar science programs
• Trains next generation of Lunar researchers and project managers
• Modeled after the NASA Astrobiology Institute
• Managed by Ames Research Center, work is distributed across centers, universities, other government agencies, and for-profit and non-profit research groups
• Provides quick-response capability to support Exploration needs
• Hosts annual Lunar Science Forum; works closely with LEAG
• 7 initial member research teams competitively selected through a NASA Cooperative Agreement Notice (CAN) funding 198 researchers total
  – Additional 3 international teams (Canada, Korea, UK) plus others in work
• Awards typically $1-2M each for 4 years
• Coordinates in-depth research efforts in lunar science to benefit scientific and exploration missions
Understanding the Formation and Bombardment History of the Moon  
PI: Bill Bottke - Southwest Research Institute

Impact Processes in the Origin and Evolution of the Moon: New Sample-driven Perspectives  
PI: David Kring, USRA/LPI

Dynamic Response of the Environment At the Moon (DREAM)  
PI: Bill Farrell, NASA Goddard Space Flight Center

Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS)  
PI: Mihaly Horanyi, University of Colorado – Boulder

The Moon as Cornerstone to the Terrestrial Planets: The Formative Years  
PI: Carle Pieters, Brown University

Scientific and Exploration Potential of the Lunar Poles  
PI: Ben Bussey, Johns Hopkins University

Lunar University Node for Astrophysics Research (LUNAR): Exploring the Cosmos from the Moon  
PI: Jack Burns, University of Colorado - Boulder
INTERNATIONAL AFFILIATE TEAMS

Canada
PI: Gordon “Oz” Osinski,
University of Western Ontario
Partnership signed July 2008

Korea
PI: IM Yong-Taek,
Korean Institute for Advanced Science & Technology (KAIST)
Partnership signed December 2008

United Kingdom
PI: Mahesh Anand,
Open University
Partnership signed January 2009
Lunar Science & Exploration Research (LASER)

2007/8: First Program Year (with ESMD) – $4.7M FY08 NEW Awards

2008/9: Second Program Year (SMD Alone) – $2.2M FY09 NEW Awards

2009/2010: Third Program Year $3M FY10 NEW Awards Expected

FY2009 Awards ($) by Review Group

- Dust; 20%
- Geochemistry; 17%
- Geophysics; 26%
- Geology; 9%
- Remote Sensing; 28%
- Remote Sensing; 28%

Average Grant Size ($K)

- 2007: 87
- 2008: 109

# Awarded

- 2007: 25
- 2008: 43

27-28% Awarded / Year

# Proposals

- 2007: 90
- 2008: 160

LASER Historical Trend

2008

2007
Lunar Science Education & Public Outreach

- Lunar Science EPO is distributed in Program, Mission, Research and EPO elements
- Lunar Quest Program Office, LRO (and GRAIL) have embedded EPO programs
- NLSI has EPO embedded in NLSI central and each individual team
- LASER researchers have won ROSES EPO supplements
- Lunar sample disks are distributed to educators
- SMD has several large Lunar EPOESS awards
Lunar Quest
Program update

Jim Adams
Planetary Science Division

November 16, 2009
Back Up
Lunar Science

ESMD – 1st year then PSD

Extended Themis Mission (Heliophysics)

Discovery mission

Wallops Launch on Minotaur V &

LaserCom Demo

Next Decadal
Flexible Lander Architecture
Payload Mass vs. Payload Power Comparison

Payload Mass (kg) vs. Payload Power Available (Watts)

1. Solar Lander
   Day Ops Only

2. ASRG on Solar/Battery Architecture
   Operate Day and/or Night
   Up to 6 year life

3. ASRG Hopper
   Operate Day and/or Night
   Up to 6 yr life

4. Solar/Battery Hopper, short night

5. Small Solar on ASRG architecture
   Operate Day Only

6. Solar/Battery ILN Mission
   Operate Day and Night
   6 year life

7. ASRG ILN Mission
   Operate Day and Night
   6 year life

8. Lunar Polar Volatiles Mission
   Operate Day and/or Night
   6 year life

Surveyor 3 – Reference
65 hour mission duration
### Solar-Battery Lander Design Concept

#### Power
- Solar Array Power for cruise & lunar day
- Secondary Batteries for lunar night
- Power System Electronics

#### Propulsion
- Bi-Propellant
- 100 lbf Descent DACS Engines (6)
- 6 lbf ACS DACS Engines (6)
- 2 Custom metal diaphragm tanks

#### Avionics
- Integrated Flight Computer and PDU

#### RF
- S-band
- 1 W RF transmit power
- Antenna coverage for nearside or farside operations

#### GN&C
- Star Tracker (dual)
- IMU
- Radar Altimeter
- Landing Cameras (2)

#### Structure
- Composite Primary Structure

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**Max Wet Mass**
- **1164 kg**

**Max Wet Mass**
- **422 kg**
## ASRG Lander Design Concept

| Power          | • ASRG Primary Power Source  
|                |   • Power System Electronics  
|                |   • Primary Batteries  
| Propulsion     | • Bi-Propellant  
|                |   • 100 lbf Descent DACS Engines (3)  
|                |   • 6 lbf ACS DACS Engines (6)  
|                |   • 2 Custom metal diaphragm tanks  
| Avionics       | • Integrated Flight Computer and PDU  
| RF             | • S-band  
|                |   • 1 W transmit power  
|                |   • Antenna coverage for nearside operations  
| GN&C           | • Star Trackers (Dual head)  
|                |   • IMU  
|                |   • Radar Altimeter  
|                |   • Landing Cameras (2)  
| Structure      | • Composite Primary Structure  

![Image of ASRG Lander Design Concept]

- **Maximum Wet Mass**
  - Cruise Configuration: 798 kg
  - Landed Configuration: 260 kg

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![Image of ASRG Lander Design Concept]

- **ASRG RF Antennas**
  - Maximum Mass 798 kg

![Image of ASRG Lander Design Concept]

- **Star SRM Adapter**
  - Maximum Wet Mass 260 kg
## Resulting Lander Options

<table>
<thead>
<tr>
<th>Lander Option</th>
<th>Solar/Battery</th>
<th>ASRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Mass (Cruise/Lander) (kg)</td>
<td>1164/422</td>
<td>796/260</td>
</tr>
<tr>
<td>Generic max Landed Payload/Support Mass (kg)</td>
<td>157</td>
<td>37</td>
</tr>
<tr>
<td>Max Inst. Payload Mass for ILN (kg)</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>Max Inst. Payload Power for ILN (W)</td>
<td>19.5 day/7.8 night</td>
<td>Up to 74 Configuration dependent</td>
</tr>
</tbody>
</table>
| Launch Options    | • 1 on Taurus II Falcon 9 B1  
• 2 on Falcon 9 B2*  
• 2 on Atlas V 401 with 952 kg excess capacity  
• 4 on Atlas V 531 | • 2 on Atlas V 401 with 1684 kg excess capacity  
• 4 on Atlas V 401*  
• Other LVs require RPS qual. |

Note: All mass and power figures include 30% growth margin

*Lander was sized for this launch configuration.*

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

- Low cost emphasis
- Achieve floor science
- Baseline science would depend on partners

Minotaur V
413 kg

- SmRPS
- Seismometer
- COTS Components

Falcon 9 B1
2000 kg

- 2X SmRPS
- Full Instruments
- COTS Components

Falcon 9 B2
2680 kg

- 2X SmRPS
- Full Instruments
- COTS Components

Atlas 401
3580 kg

- Solar/Battery
- Full Instruments
- Hard Lander/Penetrator

Atlas 531
5400 kg

Jan. – April 2009
- Anchor Nodes accomplishes baseline science
- Decadal Class Science Mission

- Inadequate Lift Performance
- Required 2 launches for Floor Science

- SmRPS design
- Immature
- Power margins low

April - Present
- Provide several options depending on available budget and priorities
- 2-4 Landers
- ASRG or Solar-Battery

- Small Launch Vehicles
  - Eliminated due to nuclear certification
- Small RPS eliminated due to lack of technical maturity

2X 2 LVs
Solar Battery Full Inst.

2X Solar Battery Full Inst.

4X Solar Battery Full Inst.

4X 4X
SmRPS Full Inst.
ASRG Full Inst.

2X Solar Battery Full Inst.

4X ASRG Full Inst.

4X Solar Battery Full Inst.