The Lunar Atmosphere and Dust Environment Explorer (LADEE): T-Minus One Year and Counting

R. C. Elphic  G. T. Delory  E. J. Grayzeck
A. Colaprete  M. Horanyi  P. Mahaffy  B. Hine
J. Salute  D. Boroson
LADEE
Lunar Atmosphere and Dust Environment Explorer

Objective
• Measure Putative Lunar Dust
• Examine the Tenuous Lunar Atmosphere

Key parameters
• Launch in mid-2013
• Science Data Acquisition: 100 days

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

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

Launch Vehicle: Minotaur V
Launch Site: Wallops Flight Facility
Lunar Exosphere – Measurements

Surface measurements: Ar and He

Earth-based measurements: Na and K

We know that Ar, He, Na and K exist in the exosphere.
Exosphere: Mysterious Variability

- Density varies month to month.
- Density appears to decrease between 1\textsuperscript{st} quarter and 3\textsuperscript{rd} quarter.
- Other species variable?
- Lunar helium variations (LRO/LAMP)

(Kagitani et al, *P&SS* 2010)

(Feldman et al, *Icarus*, 2012)
LADEE Tests Latest Dust Theory

Reanalysis of Apollo light scattering photos (Glenar et al., 2011)
LADEE Instrument Payloads

**Neutral Mass Spectrometer (NMS)**
- MSL/SAM Heritage
- \(SMD - directed\) instrument
- In situ measurement of exospheric species
- P. Mahaffy
- NASA GSFC
- 150 Dalton range/unit mass resolution

**UV Spectrometer (UVS)**
- LCROSS heritage
- \(SMD - directed\) instrument
- Dust and exosphere measurements
- A. Colaprete
- NASA ARC

**Lunar Dust EXperiment (LDEX)**
- HEOS 2, Galileo, Ulysses and Cassini Heritage
- \(SMD - Competed\) instrument
- M. Horányi
- LASP

**Lunar Laser Com Demo (LLCD)**
- Technology demonstration
- \(SOMD - directed\) instrument
- High Data Rate Optical Comm
- D. Boroson
- MIT-LL
- 51-622 Mbps
Minotaur V Launch Vehicle

- LADEE will be the first Minotaur V mission
- Based on the successful Minotaur IV
- Launch Site: Wallops Flight Facility
Trajectory

Mission Critical Events:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Type</th>
<th>Ground Station(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch Vehicle Separation</td>
<td>Mission Critical</td>
<td>TDRSS</td>
</tr>
<tr>
<td>Initial Safe-Mode Acquisition</td>
<td>Mission Critical with Time Constraint</td>
<td>HBK</td>
</tr>
<tr>
<td>Phasing Maneuvers: PM1, PM-2*, PM-3*</td>
<td>Mission Critical with Time Constraint</td>
<td>WS-1 or DSN</td>
</tr>
<tr>
<td>Lunar Orbit Insertion 1 (LOI-1)</td>
<td>Mission Critical with Time Constraint</td>
<td>WS-1 or DSN</td>
</tr>
<tr>
<td>LDEX Cover Deploy</td>
<td>Mission Critical</td>
<td>WS-1 or DSN</td>
</tr>
<tr>
<td>NMS Cover Deploy</td>
<td>Mission Critical</td>
<td>WS-1 or DSN</td>
</tr>
<tr>
<td>UVS Cover Deploy</td>
<td>Mission Critical</td>
<td>WS-1 or DSN</td>
</tr>
<tr>
<td>Contingency OMM Burns</td>
<td>Mission Critical</td>
<td>WS-1 or DSN</td>
</tr>
</tbody>
</table>

Mission Phase

1. Launch: Minotaur V Launch Vehicle
2. TLI: STAR 37 FM Upper Stage
3. TCM(s): Perigee/Apogee Bipropellant
4. LOI: Bipropellant
Commissioning Timeline of Activities

1. Circularize orbit in order to gain control of periselene placement over terminator
2. Lower periselene at altitude such that it degrades to 50 km at 40 days
3. Lower apospelene to circularize at 50 km orbit - begin Science Operations

Delta-V Profile (nom.)
- No maintenance needed (impact at infinity)
- Impact in 10-20 d
- Impact at 3 g

Delta-V Profile (cont.)
- 250 km Circular
- Decision to Lower Periselene to achieve low altitude passes
- Decision to lower Apospelene and start science phase
- Decision to Lower Periselene under contingency - variable within contingency period
- Lower Apospelene under contingency

Activities:
- Spacecraft Checkout
- Instrument Aliveness
- LLCD
- High-Altitude Sci. Checkout / Bus Activities
- Low Altitude Sci. Checkout
- Contingency
Science Operations

Day in the Life:
Science Operational Scenarios (>15% margin)

<table>
<thead>
<tr>
<th>Orbit #</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NMS1/LDEX</td>
</tr>
<tr>
<td>2</td>
<td>UVS1/LDEX</td>
</tr>
<tr>
<td>3</td>
<td>UVS2/LDEX</td>
</tr>
<tr>
<td>4</td>
<td>Comm</td>
</tr>
<tr>
<td>5</td>
<td>Comm</td>
</tr>
<tr>
<td>6</td>
<td>Power recov.</td>
</tr>
<tr>
<td>7</td>
<td>NMS1/LDEX</td>
</tr>
<tr>
<td>8</td>
<td>UVS1/LDEX</td>
</tr>
<tr>
<td>9</td>
<td>UVS2/LDEX</td>
</tr>
<tr>
<td>10</td>
<td>Margin orbit</td>
</tr>
<tr>
<td>11</td>
<td>Margin orbit</td>
</tr>
<tr>
<td>12</td>
<td>NMS2</td>
</tr>
<tr>
<td>13/1</td>
<td>NMS1/LDEX</td>
</tr>
</tbody>
</table>
Observatory Description

- Radiator Assembly
- Bus Module
- Payload Module
- Extension Modules
- Propulsion Module

LDEX
NMS
UVS
LLCD
Spacecraft integrated, rotated horizontal, and electrically integrated with Radiator Panel at Ames.
UVS Integrated onto LADEE

8-24-2012
NMS Integrated onto LADEE
LLCD Flight Components Still in Testing

Flight LLCD OM in Performance Tests
LADEE Critical & Near Critical Paths

<table>
<thead>
<tr>
<th>Task Name</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>LLCD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NMS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transponder</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LDEX</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UVS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Structures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiator Assembly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Integration &amp; Testing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P/L Integration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observatory Functional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Testing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observatory Environmental Testing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch Site Processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(WFF)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Encapsulation Through</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch Readiness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Launch Readiness Date</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(LRD)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mission Operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Key:
- Project Critical Path
- Near Critical Path (5d)
- Complete

Based on LADEE_IMS_v3_120831YNa

IMS Baseline – 7/9/12
IMS Status – 8/31/12
The case for a Controlled Lunar impact of the Herschel space observatory

Neil Bowles (Oxford)

On behalf of the Herschel Lunar Impact Consortium

01/11/2012
System Design Capitalizes on External Stimulation of Lunar Exosphere and Dust

Meteor Shower Flux and LADEE Launch Date

LADEE Launch

100 days
Final Notes

- LADEE should be at, or on the way to the Moon one year from now.
- Good company:
  - LRO/LAMP complementary measurements
  - ARTEMIS solar wind/plasma/EUV inputs
- Other external inputs
  - Herschel impact?
# Exosphere: Instrument Performance

<table>
<thead>
<tr>
<th>Species</th>
<th>UVS time to detect (s)</th>
<th># UVS Orbits</th>
<th>NMS time to detect (s)</th>
<th># NMS Orbits</th>
<th>PLRA Rqmt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>1 s</td>
<td>&lt;1</td>
<td>-</td>
<td>-</td>
<td>4.2.1.1</td>
</tr>
<tr>
<td>K</td>
<td>100 s</td>
<td>&lt;1</td>
<td>-</td>
<td>-</td>
<td>4.2.1.1</td>
</tr>
<tr>
<td>Ar</td>
<td>-</td>
<td>-</td>
<td>&lt;1 s</td>
<td>&lt;1</td>
<td>4.2.1.1</td>
</tr>
<tr>
<td>He</td>
<td>-</td>
<td>-</td>
<td>1 s</td>
<td>&lt;1</td>
<td>4.2.1.1</td>
</tr>
<tr>
<td>CH₄, O, OH, H₂O, CO, CO₂, S</td>
<td>1-1000 s</td>
<td>1</td>
<td>0.1 – 385 s</td>
<td>&lt;1</td>
<td>4.2.1.2</td>
</tr>
<tr>
<td>Si, Al, Mg, Ca, Ti, Fe</td>
<td>400 – 5000 s</td>
<td>~5</td>
<td>1000-2000 s</td>
<td>~3</td>
<td>4.2.1.2</td>
</tr>
<tr>
<td>Unknowns (species of opportunity)</td>
<td>180,000 s</td>
<td>60</td>
<td>60,000 - 120,000 s</td>
<td>60</td>
<td>4.2.1.3</td>
</tr>
</tbody>
</table>

- **UVS/NMS detect/lower limit in <5 orbits**

- **12 hrs – 30 days**

- **No temporal reqmt**
## Dust Detection: Instrument Performance

### 12 hrs – 30 days

<table>
<thead>
<tr>
<th>Dust population</th>
<th>UVS time to detect (s)</th>
<th># UVS Orbits</th>
<th>LDEX time to detect (s)</th>
<th># LDEX Orbits*</th>
<th>PLRA Rqmt</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;=1 μm</td>
<td>100 s</td>
<td>&lt;1</td>
<td>1000s</td>
<td>&lt;=3</td>
<td>4.2.1.4</td>
</tr>
<tr>
<td>100 nm – 1 μm</td>
<td>100 s</td>
<td>&lt;1</td>
<td>&lt;1 s</td>
<td>&lt;1</td>
<td>4.2.1.4</td>
</tr>
</tbody>
</table>

*SNR >= 3

- **UVS/LDEX** achieve dust measurement in \( \leq 3 \) orbits
Lunar Exosphere: A nearby *Surface Boundary Exosphere*. What is its composition, variability and structure?

Lunar Dust: Does electrostatic lofting of dust occur?

*Surveyor 7: 1968-023T06:21:37*
LADEE Guiding Principles

• The LADEE Mission is following a low-cost approach:
  • Accept single-string design with limited or no redundancy
    • Pursue functional backups instead
  • Avoid any new design
    • Use existing commercially available box-level components
    • Avoid any design changes to an existing commercially available design
  • Minimize complexity
    • No deployables or articulation
    • Simple safe mode
    • Launch Powered Off
  • Do not attempt to optimize the design for the mission if it violates the principles above
  • Accept the risk of minimum hardware spares
  • Minimize the risk of instrument development by keeping their delivery well ahead of critical path
  • Execute as cost-capped
Spacecraft Components - Internal

- Star Tracker Cameras
- SEPIA
- Top of Radiator
- LDEX
- Omni Antenna
- MG Antenna
- UVS
- IAU
- RWA x4
- Bottom of Radiator
- NMS
- Payload Module
- Propulsion Module
- LLST
- Transponder
- Battery
- IMU
- VDU
LADEE Assembly Levels

Component Level

Subsystem Level

Observatory Level

- Radiator Assembly
- Bus Module
- Payload Module
- Extension Modules
- Propulsion Module

Spacecraft Bus Level (Subsystem)