The Lunar Atmosphere and Dust Environment Explorer (LADEE): New Mission, Longstanding Questions

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LADEE Context & Motivation

  
  a. Make precise compositional measurements of the surface-bounded atmospheres of Mercury and the Moon and determine the relationship between ionospheres and magnetospheres,
  
  b. Quantify regolith processes on bodies with tenuous atmospheres.

- **Objective Sci-A-3 in the LEAG Roadmap (exosphere & dust)**

- **National Research Council (NRC) report, “Scientific Context for the Exploration of the Moon” (SCEM)**
Surface Boundary Exospheres (SBEs): most common type of atmosphere in the solar system…?

Evidence of dust motion on asteroids and the Moon....

Surveyor 7: 1968-023T06:21:37

Mercury
Moon
Europa & other Icy satellites
Io
Large Asteroids & KBOs
Itokawa
Eros
Lunar Exosphere - Measurements

Global model distribution of Ar-40 at 30 km and 50 km (provided by D. Hodges). Gas densities peak at the sunrise terminator, where desorption is greatest, > 4000/cc at 50 km.
Lunar Exosphere – Emissions

- Na, K resonant scattering emission from sunlight.
“Disappearing” Surficial H$_2$O and OH

- Chandrayaan-1 M$^3$, EPOXI and Cassini VIMS 3-$\mu$m observations.

- Presence of H$_2$O and OH in/on surface grains:
  - Signature deepest at high latitudes and off-noon local times.
  - Where do OH, H$_2$O go? Into exosphere? Polar cold traps?

Pieters et al *Science* 2009
Lunar Exosphere Transport

![Diagram of lunar exosphere transport with labels for shadowed and illuminated moon, processes like lost to space, recycle to lunar atmosphere, losses, cold trapping, sequester by regolith overturn, sources, and Lucey, P. G. (2009).]
Dynamic Lunar Dust

- Surveyor 7 images of lunar horizon glow (“LHG”)
- Prevailing theory: <10 um dust, ~150m away, ~1m high on sunset horizon

• Apollo surface experiment LEAM detected dust activity correlated with the lunar terminators

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Baseline Science-Instrument Traceability

**LEVEL 1**

4.2.1.1 Measure spatial and temporal variations of Ar, He, Na, and K. Temporal scales: 12 hours to 1 month. Resolve variations within $\pm 20^\circ$ of the terminator.

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**LEVEL 2**

Neutral/ion mass spectra

- $^{40}\text{Ar}$, He

UV/visible spectra

- SNR $> 5$ for resonant emission Na, K

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**LEVEL 3**

NMS

UVS

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4.2.1.2 Detect or establish new limits for selected species exogenic/volatiles (CH$_4$, O, OH, H$_2$O, CO, S), endogenic (regolith-derived refractory) (Si, Al, Mg, Ca, Ti, Fe)

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UV/visible spectra

- O, OH, H$_2$O, and Mg, Al, Si, Ca, Ti, Fe at SDT density limits, w/SNR $> 5$

Neutral/ion mass spectra

- CH$_4$, CO, H$_2$O, OH, S, and Fe, Al, Mg at SDT density limits

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4.2.1.3 Perform survey for other species … within mass range 2-150 Da, sensitivity of several particles/cc

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UV/visible spectra

- over passband

Neutral/ion mass spectra

- 2-150 Da with a sensitivity of several particles/cc.

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4.2.1.4 Detect or set new limits for spatial and size distribution of atmospheric dust: altitude range from 3 km up to 50 km, with a height resolution of 3 km, minimum detectable density of $10^{-4}$ grains/cc, 100 nm to at least 1 micrometer in diameter. Temporal and spatial scales of 4.2.1.1.

4.2.1.5 Measurements over 100 day mission life

UV/visible spectra
- Detect >100 nm grains n >$10^{-4}$/cc over 1.5 to 50 km altitude
  - Solar occultation observations
  - Limb sounding, scattered light

In situ spatial and size distribution for dust grains < 1um
- Detect existence of dust >100 nm
- Density $10^{-4}$/cc at 50 km

LEVEL 1

LEVEL 2

LEVEL 3

UVS

LDEX

NMS

LEVEL 1

LEVEL 2

LEVEL 3

UVS

LDEX

Operate instruments for 100 days in appropriate orbit
**Neutral Mass Spectrometer (NMS)**
MSL/SAM Heritage

*In situ* measurement of exospheric species

P. Mahaffy
NASA GSFC

- 150 Dalton range/unit mass resolution

**UV-Vis Spectrometer (UVS)**
LCROSS heritage

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
Measurements at ≤ 50 km altitude over the sunrise terminator are of high priority

Low altitude measurements desired throughout the orbit

Retrograde orbit (avoid sunlight into FOVs over sunrise terminator)

Orbit plane within ±20° of the equator (inclination 180 ± 20°)
LADEE Milestones –
Passed PDR: 7/20-23/2010
KDP-C: Approved for Phase C, 8/23/2010
CDR: 5/18/2011
Launch Readiness Date: 5/02/2013
Summary

• LADEE mission addresses longstanding questions outlined by the NRC and LEAG.

• Payload draws on high-heritage instruments.

• LADEE addresses a key issue raised by LCROSS, LRO, Chandrayaan-1 M³, EPOXI and Cassini VIMS surficial H₂O/OH measurements:
  – origin and transport of volatiles to polar cold traps.
End
Model of Lunar Dust and Na Emissions

Stubbs et al., Planet. & Space Sci. 2010
System Design Tailored to Meet Science Objectives (3)

Meteor Shower Flux and LADEE Launch Date

Impact rate of ~5-cm objects

~9.5 events/hr globally

100 days

LADEE Launch

Date
Lunar Dust – in Orbit?

Gene Cernan sketches from Apollo Command Module

- Eyewitness accounts of “streamers” from Apollo command module
- Too bright to be meteoritic ejecta
- Exosphere and/or high altitude (50 km) dust is one possibility
- Key goal if LADEE is to help resolve this open question
The Lunar Exosphere and Dust: Sources & Sinks

**Inputs:**
- Solar photons
- Solar Energetic Particles
- Solar wind
- Meteoric influx
- Large impacts

**Processes:**
- Impact vaporization
- Interior outgassing
- Chemical/thermal release
- Photon-stimulated desorption
- Sputtering

Dayside: UV-driven photoemission, +10s V

Nightside: electron-driven negative charging -1000s V