The Lunar Atmosphere and Dust Environment Explorer (LADEE). G. T. Delory[1,2], R. Elphic[1], T. Morgan[3], T. Colaprete[1], M. Horanyi[4], P. Mahaffy[5], B. Hine[1], and D. Boroson[6] [1]NASA Ames Research Center, Moffett Field, CA 94035-1000, [2]Space Sciences Laboratory, University of California, Berkeley CA 94720 gdelory@ssl.berkeley.edu, [3]Planetary Science Division, Science Mission Directorate, NASA, Washington, DC 20546, [4]NASA Goddard Space Flight Center, Greenbelt, MD, 20771 [5]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309, [6]Lincoln Laboratory, Massachusetts Institute of Technology, Lexington MA 02421

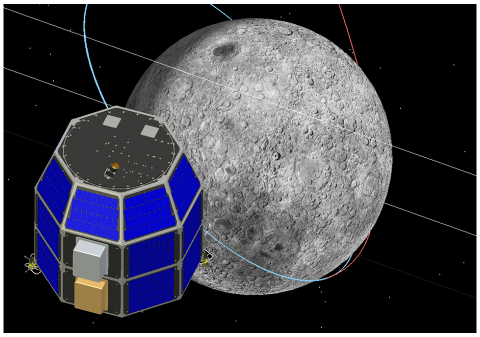


***Fig. 1:** LADEE modular spacecraft bus*

Introduction: The National Research Council report *The Scientific Context for Exploration of the Moon* (SCEM) lists studies of the pristine state of the lunar atmosphere and dust environment as one of eight major priorities for future lunar science missions. The Lunar Atmosphere and Dust Environment Explorer (LADEE) was developed to address this goal. LADEE is a low-cost lunar orbiter (Fig. 1) managed by the NASA Ames Research Center (ARC) in cooperation with the Goddard Space Flight Center (GSFC), and is designed to be compatible with light lift capability launch vehicles. LADEE is an important component in NASA's portfolio of near-term lunar missions, addressing both science and exploration objectives not covered by other U.S. or international efforts, and whose observations should be conducted before large scale human or robotic activities perturb the tenuous and fragile lunar atmosphere.

Science Goals: LADEE will (1) determine the composition of the lunar atmosphere and investigate the processes that control its distribution and variability, including sources, sinks, and surface interactions, and (2) characterize the lunar exospheric dust environment and measure any spatial and temporal variability and impacts on the lunar atmosphere. To accomplish these objectives, the LADEE instrument payload includes an Ultraviolet Spectrometer (UVS), a Neutral Mass Spectrometer (NMS), and the Lunar Dust Experiment (LDEX). A fourth instrument, the Lunar Laser Communication demonstration (LLCD), will test a high speed telemetry system from the Moon to the Earth.

The Lunar Exosphere. The lunar "atmosphere" is an exosphere, a tenuous, collisionless gas of neutral atoms (see [1, 2] for a complete review). Much of the exosphere is ultimately derived from the lunar regolith, although the solar wind and dust are also sources. A host of processes act to generate the exosphere from the lunar surface, including impact vaporization, photon-stimulated desorption by solar UV, sputtering by solar wind and magnetospheric plasmas, chemical and thermal release, and internal activity. Exospheric sink processes include Jeans (gravitational) escape, photoionization, chemical loss, and cold trapping. Species that are gravitationally bound undergo ballistic trajectories until captured again at the surface or lost to space. The dynamics of these processes are heavily species-dependent, and also influenced by the external environment, including impact rate, plasma conditions, and solar illumination. Thus the lunar exosphere is a dynamic system with multiple source and sink mechanisms, and these are currently poorly understood.

Decades of observations by the Apollo missions and ground-based telescopes have detected only a few species, including He, K, Na, Ar, and Rb [1-4] (Fig. 2). The density of these constituents is far less than the total exospheric gas pressure measured during Apollo, thus much of the lunar exosphere remains unexplored. If even a portion of the exosphere is representative of the composition of the regolith, many other species should be present; however intense searches have yielded only upper limits [5-7]. LADEE will detect new exospheric species and also confirm previous detections, studying the details of their temporal and spatial dynamics in order to understand their source and sink mechanisms. For elements that LADEE does not detect, new upper limits will be established.

Lunar Dust. Significant temporal and spatial variations of the lunar surface potential are known to occur due to charging from photo-emission and plasma currents, and range from ~+10V to –4 kV [8-10]. These variations in surface potentials may cause the electrostatic transport of dust, as suggested for other airless bodies [11]. Dust levitation almost certainly occurs within a few meters of the lunar surface, creating "lunar horizon glow" (LHG), as captured by Surveyor lander cameras [12] (Fig. 2). Observations from the Apollo command module imply the presence of a high-altitude component of lunar dust extending up to 100 km [12, 13]. Visible to the naked eye, these dust

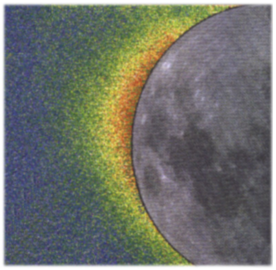
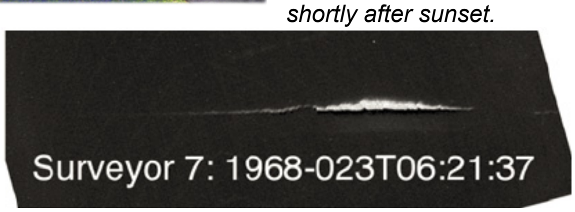


Fig. 2 *Left: Na exosphere detected by Potter & Morgan [15] using a solar coronograph to occult the illuminated surface of the Moon. Below: Surveyor 7 camera images of lunar horizon glow on the western horizon shortly after sunset.*



concentrations are too high to be explained by impact-related processes alone, leading to the concept of dust fountains [14], in which large surface potentials expected near the terminator regions ballistically loft smaller dust grains to high altitudes. Whether LHG results from dust or perhaps emission from the sodium exosphere remains an open question that LADEE will help resolve. If LHG is composed of dust, LADEE will determine the spatial and size distribution of the grains. Temporal and spatial correlations of dust activity with the terminator, geotail crossings, and solar events may yield details about specific mechanisms of dust lofting.

Instruments: The LADEE instrument payload consists of three science instruments (NMS, UVS, and LDEX) and the LLCD technology demonstration. The NMS is based on a similar instrument on CONTOUR and the Sample Analysis at Mars (SAM) instrument developed for the Mars Science Laboratory (MSL). The NMS uses a high sensitivity quadrupole mass spectrometer with a 150 Dalton range and unit mass resolution. The UVS is based on the Alice instrument developed for the Lunar Crater Observing and Sensing Satellite (LCROSS), modified to enable both limb-viewing and occultation modes with a spectral range of 230 to 815 nm. UVS will examine exospheric emissions and a broader continuum of forward or backward scattered light from dust down to ~10 nm in size. In occultation mode, UVS will study dust distributions down to ~300 m above the surface. The LDEX instrument is based on impact ionization dust detectors such as those flown on Cassini, capable of detecting small (<1 μm) and slow (~2 km/s) dust grains expected in lunar orbit. It will determine the mass of grains down to roughly 0.3 μm in size; smaller grains can be detected through the collective effects of many impacts. The LLCD system will transmit data at rates varying between 50-600 megabits/second during a dedicated testing period prior to nominal science operations. If successful, subsequent opportunities to download science data through the LLCD will be taken as resources allow.

Spacecraft and Mission: Exospheric and dust measurements are ideally conducted at low altitudes in an equatorial orbit. The nominal science orbit altitude is 50 km, which may vary depending on trades between mission duration and delta-V requirements. The orbit is retrograde to keep ram-viewing instruments (NMS, LDEX) out of sunlight during low altitude passes over the sunrise terminator, where exospheric and dust variability are expected to peak. The nominal mission duration is 100 days after a 30 day science checkout phase.

The LADEE spacecraft design is based on a modular bus concept developed at NASA ARC, utilizing stackable segments that can accommodate a variety of mission requirements. Each segment is composed of lightweight composite panels reinforced with aluminum and titanium structures. Major subsystems use commercial off-the-shelf (COTS) hardware to the extent possible, including a BroadReach command and data handling system. Either mono- or bi-propellant propulsion systems can be accommodated. The spacecraft is 3-axis stabilized and capable of accurate pointing for ram, limb, and occultation instrument modes.

LADEE has recently passed through the Mission Confirmation Review, with the Preliminary Design Review currently set to begin in late 2009. Launch is scheduled for late 2011 or early 2012 aboard a Minotaur V class launch vehicle. LADEE should arrive at the Moon during the ARTEMIS mission, enabling detailed correlations between lunar dust and exospheric activity with ambient plasma conditions, greatly enhancing the science return of both missions.

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