Ground-Based Lunar Meteoroid Impact Observations and the LADEE Mission

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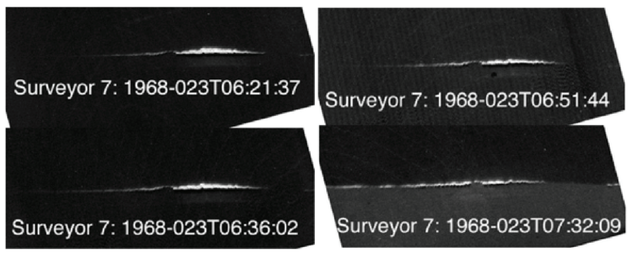
A Dusty Lunar Atmosphere

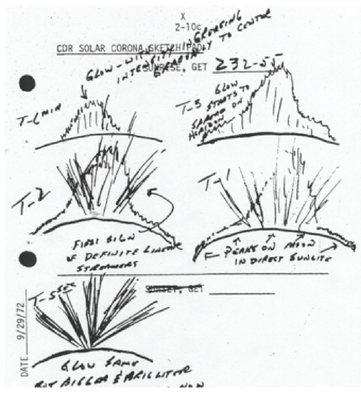
Early detections of the tenuous lunar exosphere were made on the lunar surface during the Apollo program using three cold cathode gauge experiments and the Lunar Atmosphere Composition Experiment mass spectrometer (Stern, 1999). The lunar atmosphere has also been found to contain an active dust component. Post-sunset images of the lunar horizon by Surveyors 5, 6, and 7 showed horizon glows that have been interpreted as electrostatically levitated dust with a scale height of < 1 meter (Rennilson and Criswell, 1974). Support for this interpretation came from the LEAM experiment deployed by Apollo 17 (Berg et al, 1976). Photographic and visual observations of sunrise streamers during Apollo 15 and 17 have been interpreted as dust lofted to scale heights of tens of kilometers (McCoy and Criswell, 1974), though it is possible that these observations might have been indicative of the then unknown Na/K lunar atmospheric emission (Zook et al, 1995). Possible mechanisms for lofting dust to such high altitudes included electrostatic levitation (Stubbs et al, 2005) and meteoroid impacts (Grün et al, 2011).



Surveyor lunar horizon glow images. (Credit: NASA)

Enhanced understanding of the lunar atmosphere resulted from Earth-based spectroscopic detection of Na/K emission from the lunar atmosphere (Potter and Morgan, 1988), the ability to image the lunar atmosphere from Earth (Smith et al, 2001; Wilson et al, 2003), and the discovery and monitoring of the Moon's sodium tail (Matta et al, 2009). Of particular interest was the observed enhancement of the Moon's sodium tail in association with the 1998 Leonid meteor shower (Wilson et al, 1999).

Meteoroid impacts have thus been implicated as potential sources for both the lunar atmosphere and lofted lunar dust.



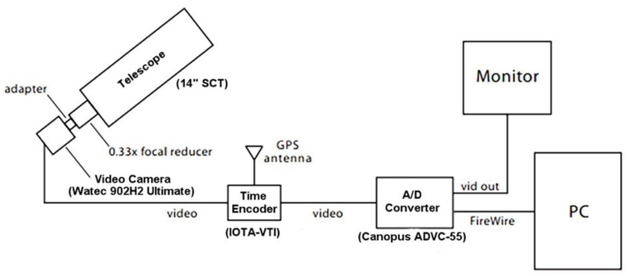
Sunsrise streamers sketched by Gene Cernan, Apollo 17 (Credit: NASA)

Lunar Meteoroid Impacts

For many years, observations of possible flashes on the lunar surface attributable to lunar meteoroid impacts were lumped in with a wide range of transient lunar phenomena that many experts regarded as having questionable veracity. However, the advent of low-light CCD video cameras and their application to astronomy resulted in the first scientifically confirmed recordings of lunar meteoroid impact flashes during the Leonid meteor storm of 1999 (Bellot Rubio et al, 2000). Since then, flashes from lunar meteoroid impacts are regularly recorded by professionals, particularly through NASA's Meteoroid Environment Office (http://www.nasa.gov/centers/marshall/news/lunar/index.html), as well as by amateurs, such as those participating in the Association of Lunar and Planetary Observers' Lunar Meteoritic Impact Search section (http://www.alpo-astronomy.org/). An analysis of the first 5 years of NASA's lunar impact data and the photometric calibration technique is described in Suggs et al., 2014

Equipment requirements for lunar meteoroid impact detection are fairly modest. A telescope of 20-35 cm aperture and approximately 1 meter focal length is optimal. This is typically coupled with a low-light CCD video camera, a GPS time inserter, an analog to digital converter, as well as a computer to store the resulting video files. Free software to find the flashes in the video files can be downloaded (http://www.gvarros.com/lunarscan15.zip).

Example of a Lunar Impact Monitoring System Configuration

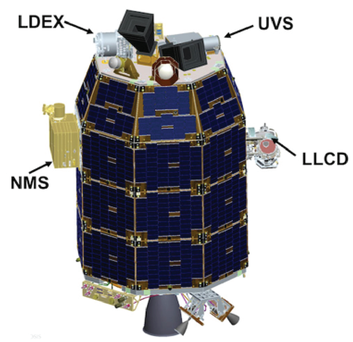


(Credit: NASA Meteoroid Environment Office)

LADEE and Lunar Meteoroid Impacts

NASA's Lunar Atmosphere and Dust Environment Explorer mission (LADEE) was a lunar orbiter designed to characterize the composition of the lunar atmosphere and investigate the processes that control its distribution and variability, including sources, sinks, and surface interactions. LADEE also measured the presence of dust in the lunar atmosphere and investigated the processes that contribute to its sources and variability. LADEE carried three scientific instruments, a neutral mass spectrometer, an ultraviolet-visible spectrometer, and the LDEX dust experiment, as well as a laser communications technology demonstration (Hine et al, 2010). LADEE was launched on September 7, 2013, 03:27 UTC; lunar orbital insertion occurred on October 6, 2013, 10:57 UTC; routine science observations began on November 10, 2013; the mission concluded with LADEE's impact on the far side of the Moon on April 18, 2014, ~04:30 UTC.

LADEE E/PO, science and project management realized that the mission provided an excellent opportunity for a coordinated campaign between the mission and ground-based observers, with the potential to look for correlations between observed impact events and changes detected by LADEE's science instruments. As part of this campaign, on December 5, 2013, NASA's Solar System Exploration Research Virtual Institute (SSERVI) conducted an online "Workshop Without Walls" for interested parties from around the world to outline the plans and procedures for making scientifically useful observations. This workshop brought together members of the LADEE mission, NASA Meteoroid Environment Office, the Association of Lunar and Planetary Observers, and a number of experienced impact observers. The workshop was recorded and archived by SSERVI to be used as a resource for continued professional-amateur collaborations in lunar meteoroid impact studies during and continuing beyond the LADEE mission. (http://sservi.nasa.gov/articles/lunar-meteoroid-impacts-and-ladee-mission-workshop/)



LADEE Spacecraft. (Credit: NASA)

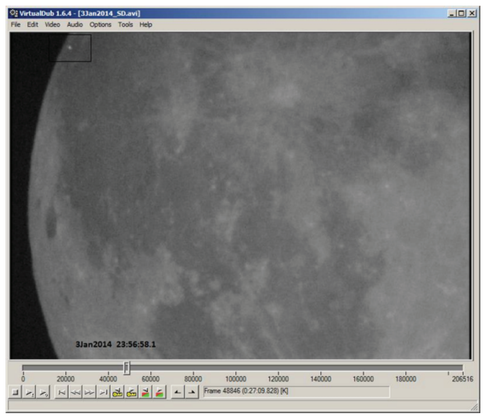
Results

Among the data collected by LADEE during the science phase of its mission is that of the presence of lunar dust aloft, along with changes in the dust's concentration, thought to be indicative of "flak" from meteoroid impacts (Elphic et al, 2014).

Ground-based impact observations are limited to the night side of the Moon and to dates that provide favorable lunar phase for such observations. Though the Moon encountered several meteor showers during the LADEE mission, none of these occurred at a phase particularly suited for ground-based observations. However, observations at advantageous phases were made with positive results (Table 1). Note that confirmed impacts were recorded in two or more telescopes while suspected impacts were visible in one telescope for multiple frames which ruled out cosmic ray noise or passing satellites.

Table 1 – Confirmed and Suspected Impacts Recorded LADEE Science Operations

UT Date/Time Observers	Lunar Lat/Lon	Comments and Observer Location
29 Nov 2013 10:49:23.6 ALaMO (Suggs)	11S, 76E	La Perouse area. Confirmed in two telescopes. (Alabama)
29 Nov 2013 10:53:08.3 ALaMO (Suggs)	17.5N, 40.5E	Franz area. Confirmed in two telescopes. (Alabama)
29 Nov 2013 11:07:24.3 ALaMO (Suggs)	3S, 76E	Gilbert area. Confirmed in two telescopes. (Alabama)
7, Dec 2013 19:31:06.6 Stefano Sposetti, Marco Iten	14S, 11W	Sporadic. In Mare Nubium, confirmed in two telescopes, 80 ms duration (Italy, Switzerland)
8 Dec 2013 19:15:58.6 Stefano Sposetti, Marco Iten	50S, 18W	Sporadic. Longomontanus crater border, confirmed in two telescopes 40 ms duration (Italy, Switzerland)
27 Dec 2013 10:42:20.2 ALaMO, New Mexico Skies (Suggs)	7.0S, 53.0E	East Mare Fecunditatis. Confirmed in three telescopes. (Alabama, New Mexico)
3 Jan 2014 23:56:58.1 ALaMO (R.J. Suggs)	19.0N, 73.0W	Possible Quadrantid. Struve B area. Confirmed in two telescopes. (Alabama)
4 Jan 2014 23:49:57 George Varros	1.0N, 11.6W	Suspected but not confirmed by ALaMO. Quadrantid? Flash seen on single video field, brightness distribution matches a star more than a cosmic ray impact. (Maryland)
5 Jan 2014 00:12:26 George Varros	15.3S, 25.5E	Suspected. Sporadic? Inside crater Cyrillus F, faint single-frame event with stellar brightness profile. (Maryland)
5 Jan 2014 00:31:35 George Varros	15.5S, 20.6E	Suspected. Sporadic? Faint single-frame event with stellar brightness profile. (Maryland)
7 Jan 2014 05:17:02.7 New Mexico Skies (Kingery)	10.0N, 13.0W	Suspected. Stadius area. Four frames. (New Mexico)
7 Jan 2014 18:19:31.0 Stefano Sposetti, Marco Iten	19.5N, 15.5W	Sporadic. In Mare Imbrium, confirmed in two telescopes, 20 ms duration. (Italy, Switzerland)
26 Jan 2014, 11:32:09.0 New Mexico Skies (Kingery)	22.0N, 17.5E	Bessel area. Confirmed in 2 telescopes. Four frames. (Alabama, New Mexico)
6 Mar 2014 02:48:44.05 New Mexico Skies (Suggs)	5.0S, 42W	Suspected. Flamsteed area. Two frames and multiple pixels. (New Mexico)



Meteoroid impact on Jan 3, 2014 (Ronnie J. Suggs, NASA Meteoroid Environment Office)

Preliminary analyses have yet to correlate any of the LADEE "flak" events with any of the observed impacts. This is not surprising, as the possible impacts detected by LADEE were not constrained to occur in the limited areas of the lunar surface accessible to ground-based observation, and the impacts observed from the Earth were not constrained to occur when LADEE was overhead with instruments on. However, the campaign was a success in that the campaign yielded geographic and temporal coverage that expanded upon and supplemented that which was provided by the Automated Lunar and Meteor Observatory (ALaMO) and New Mexico Skies Observatory operated by NASA's Meteoroid Environment Office. Another indicator of success for this effort is the establishment of a new student program of lunar meteoroid impact research at Prairie View A&M University, a Historically Black College/University (Cudnik and Rahman, 2014).

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