GROUND BASED OBSERVATIONS OF LUNAR METEORS IN SUPPORT OF THE LADEE MISSION: A STATUS UPDATE. B. M. Cudnik[1] and B. H. Day[2], [1]Department of Chemistry and Physics, Prairie View A&M University, P.O. Box 519, MS 2230, Prairie View, TX 77446, bmcudnik@pvamu.edu; [2]NASA Ames Research Center, Mail Stop 17-1, Bldg. 17, Rm. 112, P.O. Box 1, Moffet Field, CA 94035-000, brian.h.day@nasa.gov.

Introduction: What was once thought a spurious phenomenon with little scientific evidence, a form of Transient Lunar Phenomena, point flashes from lunar meteoroid impacts are now a relatively commonly observed phenomena as shown by the many confirmed observations by both professional and amateur groups. In addition to the natural phenomena, several artificial impacts of spacecraft on the moon over the last fifteen years have yielded valuable information on the physics of impacts as well as evidence of sub-surface water ice. Now a coordinated effort between NASA and ground-based observers is underway to assist in the scientific efforts of a satellite launched last year, the Lunar Atmosphere and Dust Environment Explorer (LADEE).

LADEE is currently in the science phase of its mission, collecting data from low lunar orbit (20 – 100 km altitude). Among the data collected is that of the presence of lunar dust aloft, along with changes in this concentration (Figure 1, next page shows, in graphical form, how this works), thought to be the "flak" from meteoroid impacts [1]. The lunar environment provides an excellent laboratory to study phenomena related to hypervelocity impacts, and correlation between observed impacts and changes in dust concentration have the potential to contribute valuable information on the physics of hypervelocity impacts. This provides high-velocity results that are currently beyond the reach of capabilities of ground-based high velocity collision laboratories.

Collaboration between the LADEE mission personnel and ground based observers equipped for the task is already proving to be a fruitful example of professional-amateur collaborations; there is still a significant need for observers to assist in this effort.

Examples of Recent Confirmed Lunar Meteoroid Flash Observations: For over eight years now the Meteoroid Environment Office of NASA-Marshall Space Flight Center have been monitoring the moon for impact flashes and have documented over 300 events. One notable event was an impact that occurred on March 17, 2013, one of the brightest yet observed, and the first to be unambiguously connected to a very fresh crater imaged by the Lunar Reconnaissance Orbiter. In addition to these events, several well-equipped amateurs have documented impact events confirmed by remote observers: a possible alpha-Capricornid on August 1, 2013, and two likely Geminid impacts on December 7 and December 8, 2013.

Recent ground-based observations. Several teams of observers continue to monitor the moon on a regular basis in addition to the NASA Team. The Swiss-Italian team, led by Stefano Sposetti and Rafaello Lena, has observed several confirmed impact events since August. One analyzed in detail was a faint, magnitude 8.3 event recorded by four telescopes and detectors at 2:21:55UT on 1 August 2013 in Switzerland and Italy. The team estimates this to display a luminous efficiency between 2×10^{-3} and 2×10^{-2}, caused by a 6 to 12 cm diameter meteoroid likely from the alpha Capricornid stream, which may have produced a 3 to 7 m diameter crater [2].

Two additional impacts are reported by the same team: 19:31:06.6 7 December 2013, and 19:15:58.6 8 December 2013 [3]. The first was observed by two well-separated observers, with one of the observers noting the appearance of the flash being a bright point, lasting four video frames or about 80 ms. The second flash, nearly 24 hours later, was also recorded by two observers, but was fainter and lasted about 40 ms. No photometry was performed on the images to estimate the magnitude of either flash at the time of this writing. The two flashes may be derived from objects that are possibly members of the Geminid meteoroid stream which was building toward a December 13 peak at the time of these observations.

The Youngest Crater Yet Seen. The Lunar Reconnaissance Orbiter has imaged a months old crater at the site of the March 17, 2013 bright impact flash. The impactor struck the moon at an estimated 25 km/sec and generated a crater 18-m across, complete with its own fresh ejecta blanket and central peak. The crater is prominent in an "after" image (the "before" image was taken in February 2012) taken by LRO. Image pairs like these made in proximity to confirmed ground-based meteor flashes could provide additional valuable information on the physics of high-speed impacts by correlating each flash with very fresh craters.

LADEE and Ground-based Observations: Yet another probable impact event was observed at 11:07:24.3UT on 29 November 2013 by the NASA Meteoroid Environment Office team. This event may have produced a measurable change in the dust environment at LADEE's altitude, the first of what is hoped to be several such episodes. The impact appears very faint on the video frame where it displays its maximum brightness (though it was very close to the limb), but it

is possibly energetic enough to loft dust to the elevation of the orbit of the spacecraft. It occurred near the lunar equator, within the latitude range of the flight path of LADEE which is on a 22 degree inclined orbit. Ground-based video observations of the moon in search of impacts like this one will focus on the lunar equator and low latitudes (on the dark part the moon well away from the sunlit part), where the spacecraft will be monitoring for changes in the dust concentration in its low-inclination orbit (Figure 1).

In addition to detections caused by natural events, measurements looking for changes due to artificial events are being carried out as the opportunities arise. For example, before and after the landing of the Chinese Chang'e 3 spacecraft on December 14th. LADEE searched for changes in the gas and dust content of the lunar exosphere. Some of the gas species looked for include H_2O, N_2, CO, CO_2, perhaps OH, as well as propulsion products for unsymmetrical Dimethyl Hydrazine and N_2O_4[1]. However, the orbiting spacecraft never got any closer than 1,300 km (800 miles) to the landing site within an hour after the landing and detected no change in the lunar exosphere. This null result provides valuable information as to the extent that lunar dust migrates after a perturbation of known energy (i.e. the landing thrusters of Chan'e 3 which stirred up dust for less than 15 seconds) [4].

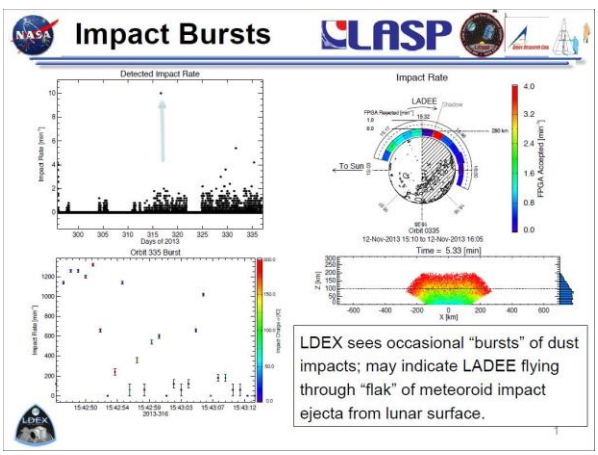

Figure 1. Charts and graphics from Elphic's LADEE workshop presentation showing possible changes in dust concentrations aloft ("Impact Bursts"), which could be the ejecta from unobserved and observed impact events.

On 5 December 2013, NASA Ames Research Center hosted an online conference, LADEE Mission Workshop without Walls, for interested parties from around the world to outline the plans and procedures for making scientifically useful observations. This workshop featured a mission status report, information on where to submit observations, how to make observations, and what equipment is most useful to make observations with, and the importance of obtaining comparison / standard stars for flux / magnitude determination. Individuals and teams experienced in the process of flux calibration will do such work on observers' images; it will be up to the observers to provide the recordings of the reference stars to be used in the analysis.

The workshop was videotaped and made available to those who would like to re-watch it or were not able to view it the first time when it was streaming live. This event served as a type of training exercise to prepare interested observers to make observations that will best support the LADEE results. This workshop in its entirety can be viewed by anyone interested in doing so by going to the following URL: http://connect.arc.nasa.gov/p4zpsnm6weh/.

Conclusion: With the LADEE mission well underway, ground-based observations of the moon by individuals, groups, and schools around the world using low light video cameras affixed to medium sized telescopes (8- to 14-inch range) continue to monitor the moon for impact flashes. Any recorded flashes will be reported and analyzed to determine their magnitude and to correlate them with any changes in the lunar exosphere as measured by LADEE. This work will continue for at least the 100 day science phase of the mission (which takes it through the early part of March, 2014), and likely beyond. Even after the conclusion of the mission, interested observers are encouraged to continue efforts to monitor the moon for meteoroid impacts in an ongoing effort to understand the nature and frequency of these enigmatic events.

References: [1] Elphic R. "LADEE Science Status", LADEE Mission Online Workshop, 5 December 2013. [2] Lena R., Manna A. and Sposetti S. (2013) *Selenology Today* 33, 4. [3] Sposetti S. (2013) Private Communication. *Meteoritics & Planet. Sci., 32,* A74. [4] http://www.nasa.gov/content/ladee-project-scientist-update-intial-observations-of-chang-e-3-landing/