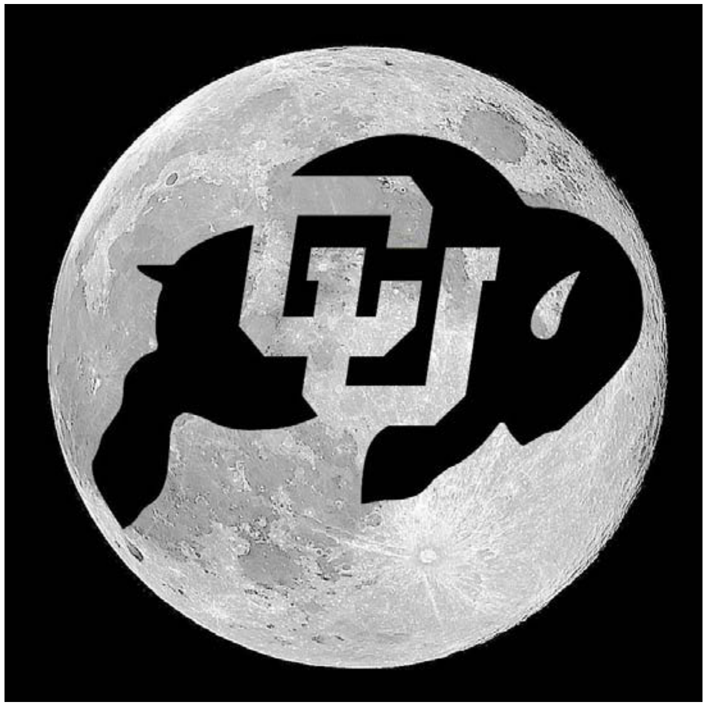
6. NASA Lunar Science Institute:
Colorado Center for Lunar Dust and Atmospheric Studies



Report for Year 1-3

4/15/2009 – 4/14/2012

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6.1 EXECUTIVE SUMMARY

The Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS) is focused on: a) experimental and theoretical investigations of dusty plasma and impact processes; b) the development of new instrument concepts for future in situ dust and plasma measurements on the surface and in orbit about the Moon; and c) a complementary program of education and community development. CCLDAS addresses basic physical and applied lunar science questions, including the long-term usability of mechanical and optical devices on the Moon. CCLDAS is supporting the development of the Lunar Dust Experiment (LDEX), an in situ impact dust detector to be flown on the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission scheduled to be launched in 2013.

CCLDAS is a truly interdisciplinary program with researchers, faculty and students from four academic departments at the University of Colorado: Physics, Aerospace Engineering, Civil and Environmental Engineering, and Astrophysical and Planetary Sciences. CCLDAS includes partners at NASA's Johnson Space Center, two small businesses in Boulder, Colorado: Tech-X and Zybek, and no-cost international partners from Germany and Belgium. Our co-investigators represent a wide spectrum in career stages from young assistant professors to leading scientists from the Apollo era.

Our **experimental research program** involves a series of small-scale (< 30 cm) tabletop experiments housed in the Dusty Plasma Laboratory (DPL), and also a large-scale (> 1 m) experimental setup, which includes the development of a 3 MV electrostatic dust accelerator for impact studies, housed in the Lunar Environment and Impact Laboratory (LEIL). LEIL is the cornerstone of our experimental setups, capable of simulating the lunar surface environment, including variable plasma conditions, solar wind, UV radiation, and dust impacts on a dusty regolith surface. The facility is now available for the testing and calibration of plasma and dust instruments, including LDEX for the LADEE mission (**Figure 6.1**).

Figure 6.1. The start of the construction of the CCLDAS dust accelerator at the end of 2009 (left), and the completed facility after recording of our first dust signal in April 2011 (middle). The first recorded dust signal from an in-beam charge pickup-tube detector (right). A time-lapse video of the arrival of the 3MV Pelletron in January 2011, is available online at http://lasp.colorado.edu/ccldas/multimedia.html.

Theoretical and modeling studies complement the DPL and LEIL work by addressing the properties of the UV-generated plasma sheath and its interaction with the solar wind plasma flow, and the role of 3D topography in the possible formation of dust ponds, which have been clearly identified in images returned by the NEAR mission on its final approach to the asteroid Eros.

The **development of new instrumentation concepts** includes the laboratory fabrication and test of the Electrostatic Lunar Dust Experiment (ELDA), capable of detecting slow-moving (< 100 m/s) dust particles, and a Dust Telescope (DT), which is a combination of a dust trajectory sensor, and a chemical composition analyzer to measure hypervelocity (>> km/s) interplanetary and interstellar dust impacts on the lunar surface.

The University committed two new faculty lines to CCLDAS in order to further strengthen the pool of expertise in lunar sciences and to initiate and teach new lunar science courses. The search for new faculty was successfully completed in 2010, resulting the hiring of Drs. David Brain in the Astrophysical and Planetary Sciences Department, and Sascha Kempf in the Department of Physics.

Our research goals remain focused on the processes involved with the atmosphere and dust environment of the Moon accessible for scientific study while the environment remains in a pristine state, one of the high priority science concepts (#8) identified by the National Research Council [The Scientific Context for Exploration of the Moon, NRC, 2007 (SCEM)]. CCLDAS research is directed towards the SCEM science goals:

(8a) Determine the global density, composition, and time variability of the fragile lunar atmosphere before it is perturbed by further human activity.

(8b) Determine the size, charge, and spatial distribution of electrostatically transported dust grains and assess their likely effects on lunar exploration and lunar-based astronomy.

(8c) Use the time-variable release rate of atmospheric species such as 40Ar and radon to learn more about the inner workings of the lunar interior.

The 'Heliospheric Science and the Moon' survey [Report to the NASA Advisory Council Heliospheric Subcommittee, 9/2007] identified the need to characterize and understand the interaction of dust and plasma on the surface of the Moon and in the lunar exosphere.

CCLDAS strongly supports future human exploration as the understanding of the dusty plasma processes can provide a scientific basis for finding effective and economical dust hazard mitigation strategies. The lunar surface will remain a difficult working environment for humans, and a challenging place to maintain the long-term use of optical and mechanical devices due to dust, UV, and plasma effects.

CCLDAS is active in the training the of the next generation of multidisciplinary lunar scientists involving graduate, undergraduate and even high school students in our science and engineering project, involving students from a number of departments across different colleges within the university, including the Physics, Astrophysical and Planetary Sciences, Aerospace, and Civil Engineering.

6.2 PROJECTS

6.2.1 Lunar Environment and Impact Laboratory (LEIL)

6.2.1.1 Overview

A major part of the CCLDAS experimental program is the development of a 3 MV dust accelerator at the new Lunar Environment and Impact Laboratory (LEIL). The objective of the LEIL facility is to accelerate micron-sized grains, which provide a unique research tool to generate high-velocity dust impacts, closely reproducing the effects of micrometeoroid impacts onto the lunar surface. The LEIL facility, including the accelerator itself and the accompanying target chambers, has been developed to simulate the lunar surface environment, including variable plasma conditions, solar wind, UV radiation, and dust impacts (**Figure 6.2.1**).

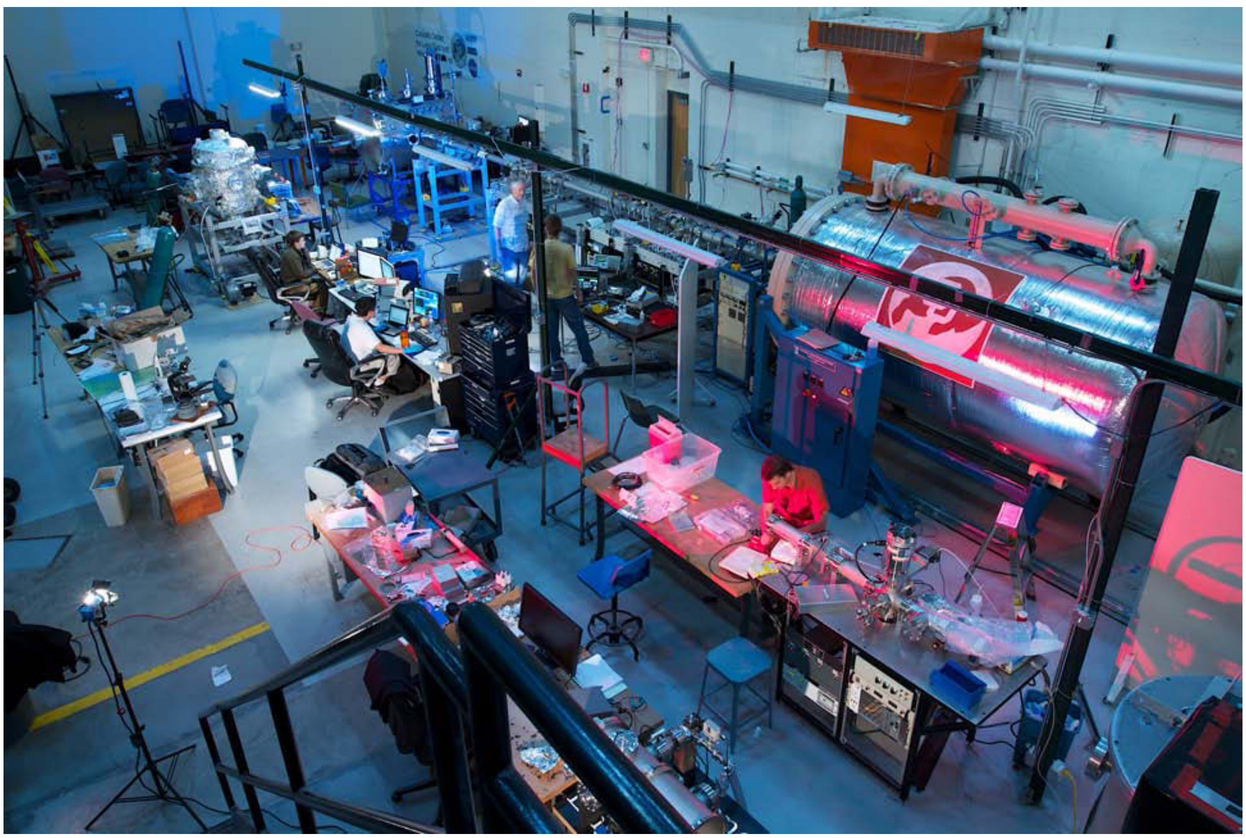


Figure 6.2.1. 3 MV dust accelerator installed at the CCLDAS Lunar Environment and Impact Laboratory. The accelerator is used to simulate the effects of dust impacts with speeds >> 10 km/s for micron sized projectiles. The facility is also used to test and calibrate plasma and dust instruments, including the Lunar Dust EXperiment (LDEX) for the LADEE mission. The facility is now operational and available for the lunar community for impact studies.

6.2.1.2 Site preparation

The LEIL facility is housed in the high-bay of the University of Colorado Nuclear Physics Laboratory, which previously housed a cyclotron accelerator. During this period we have completed the transformation of this space into a working accelerator facility, complete with two working dust accelerators: one 3 MV main beam and a smaller, 20 kV accelerator for component testing (**Figure 6.2.2**). This has included site modifications (power, water, air, etc.) as well as the installation of the Pelletron high-voltage generator and the complete beam line and target chambers. The accelerator is now operational with a fully-loaded schedule of ongoing experiments. Technical details are described in the following several subsections.

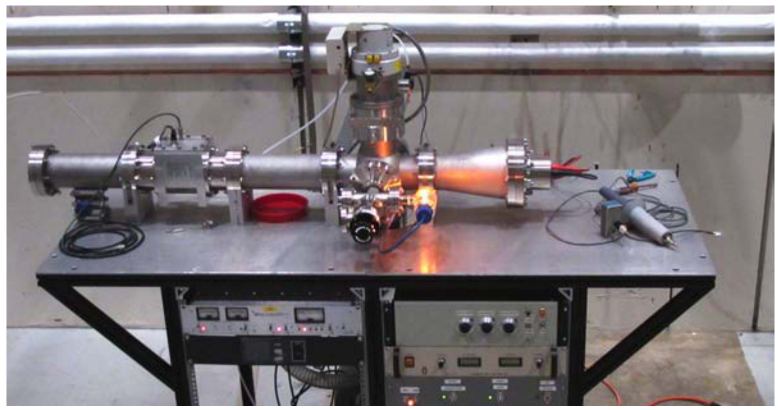


Figure 6.2.2. 20 kV "mini-accelerator" for use in component testing and dust-source preparation.

Beyond the high-bay experimental hall, our team of faculty members, postdocs, graduate and undergraduate students, and technical support personnel have occupied a suite of 14 offices, a "sample preparation lab" as well as a meeting room equipped with a video-conferencing system for remote meeting participation. To facilitate cross-coupling of the various classes of experiments within CCLDAS, several smaller-scale experiments have been moved to share the large high-bay space with the accelerator.

6.2.1.3 Accelerator components and performance

A dust source (**Figure 6.2.3**) mounted inside the Pelletron injects highly charged dust particles for acceleration. Two interchangeable dust sources have been fabricated and tested, enabling one to be used for the preparation of new source particles on the small accelerator while the other is in use in the Pelletron. After the particles exit the dust source, they pass through an "Einzel-type" electrostatic focusing lens. The Einzel lens forms a near-field beam waist, and the diverging beam is then collimated by the focusing effect of the fringing fields at the entrance to the 3 MV acceleration column. The Einzel lens and beam focusing properties have been fully modeled by our team using the SIMION software package, and verified against the actual performance of the accelerator (**Figure 6.2.4**).

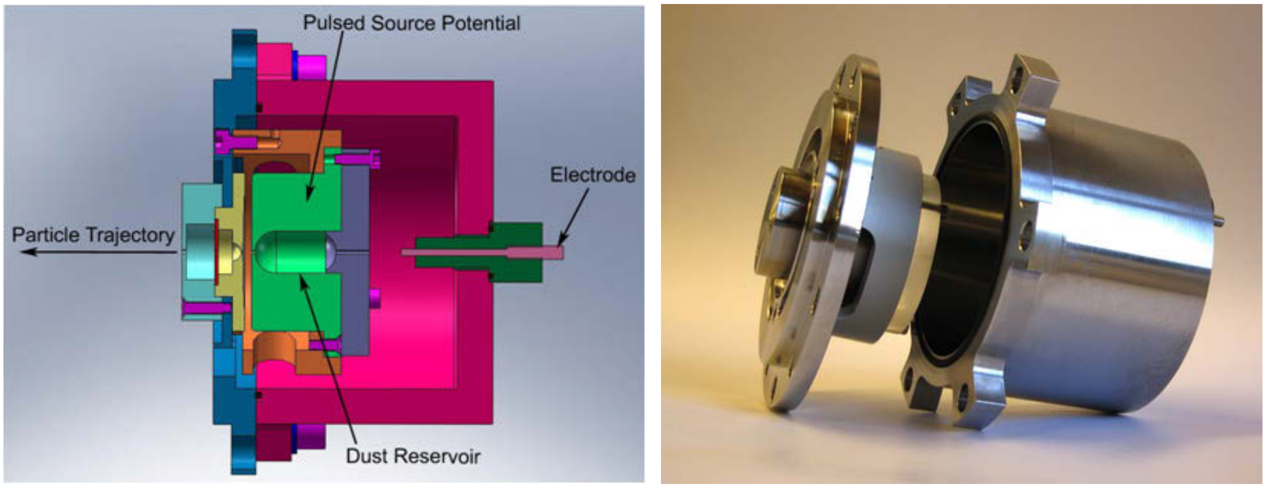


Figure 6.2.3. The design of the dust source that enables the injection of highly charged dust particles for acceleration (*left*) with photo of the working dust source (*right*).

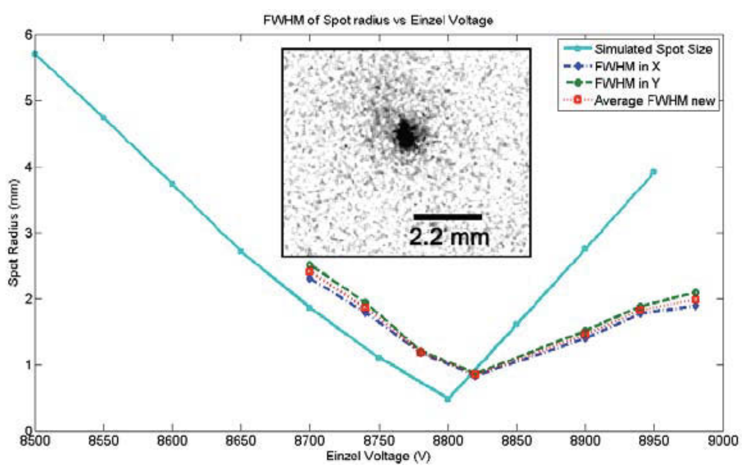


Figure 6.2.4. Plot of beam spot size vs. Einzel lens focusing voltage, both simulated (solid) and measured (dotted). Inset shows an image of the focused beam.

After acceleration, the particles are sent through a beam steerer and series of pick-up detectors (**Figure 6.2.5**) for the initial determination of the charge, mass and velocity. A particle selection unit (PSU) utilizes a set of high-voltage deflection plates to reject particles outside the desired mass and velocity range from entering the experimental chamber. A final pick-up detector confirms the particle's arrival. A total of five detectors have been fabricated and are currently in use. Four of these are used on the main Pelletron beam, and one on the small 20 kV accelerator. The detectors make use of high-gain charge-sensitive amplifiers to record the particle charge, which can be detected down to levels of 6000 electrons.

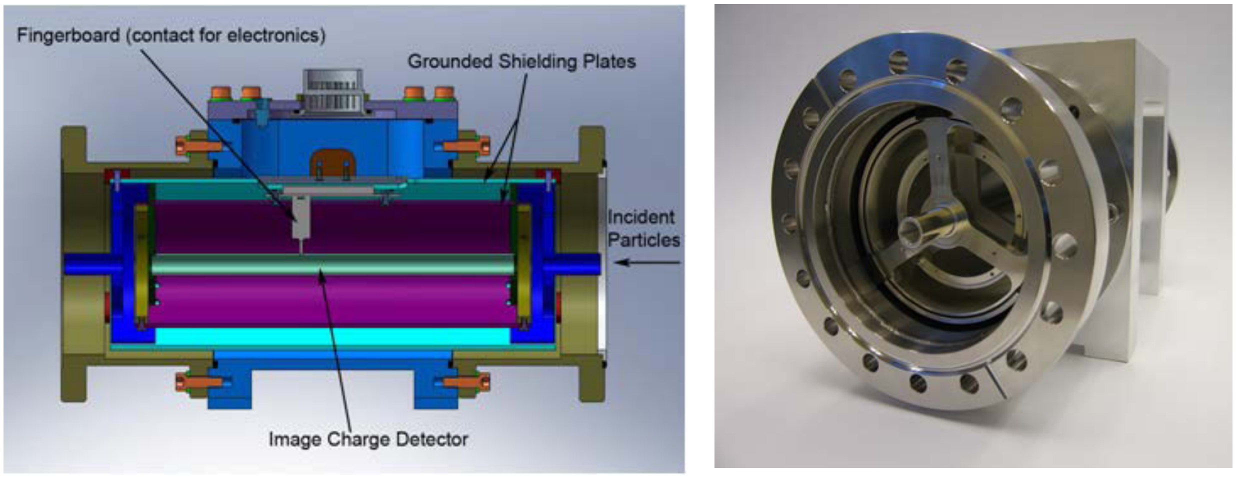


Figure 6.2.5. The design of an 'in-line' dust detector to measure the charge and the velocity of a dust particle (*left*) with a photo of a working detector (*right*), for in-flight selection of a desired dust mass and velocity.

The PSU is composed of a series of fast logic units and pulse-stretching circuits, enabling the user to select specific particle characteristics in flight for admission to the target chamber. Additionally, we are already well into the development of a "second generation" PSU, based on FPGA technology. For this we are implementing fast filtering of the weakest signals to enable extremely low charge levels to be selected with the PSU. The FPGA-based PSU has been fully fabricated and demonstrated on the benchtop with real (pre-recorded) dust signals, and we are now in the process of integrating it into the main accelerator system.

In order to facilitate the real-time monitoring of the dust beam, and to open the possibility of performing single-impact studies in the future, we have designed, fabricated, and tested a dust-beam position sensor (**Figure 6.2.6**). The sensor detects particles passing through orthogonal grids of wires by measuring the charge induced on each wire, in a similar manner to the Dust Trajectory Sensor (DTS) instrument. The ensemble of signals from the wires is processed in real time, providing individual particle position information to within 0.05 mm and collective beam profiles as they accumulate.

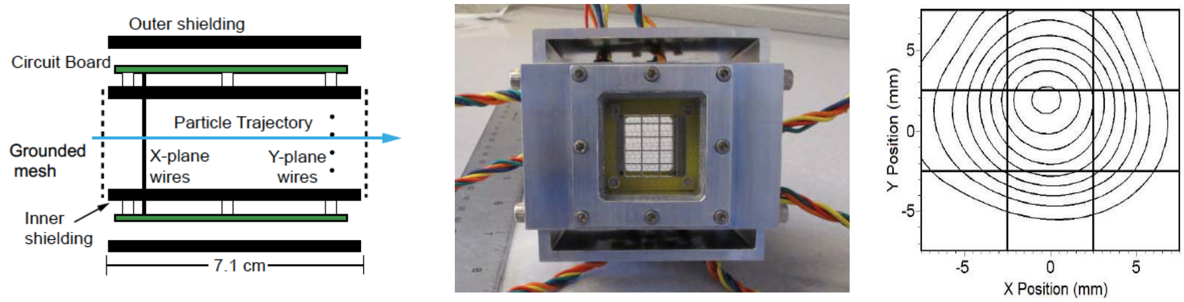


Figure 6.2.6. Schematic (left) and photograph (center) of dust-beam position sensor. Individual particle positions are determined in real time to within 0.05 mm. An example of an accumulated beam profile from the unfocused 20 kV accelerator is shown at right.

The CCLDAS dust accelerator has been operational since April 2011. Dust particles with diameters ranging from 0.5-2.5 μm have been accelerated to velocities of 1-45 km/s. **Figure 6.2.7** shows a velocity vs. mass plot of particles detected from the accelerator during a typical run. Several lines are plotted indicating physical or electronic limits of the accelerator. These limits depend on the terminal voltage of the accelerator and threshold of the detection electronics, and are set by the ion field-emission limit (i.e. maximum charge) of particles of a given size, maximum acceleration energy, and minimum detectable charge. We reiterate that as the noise-floor is reduced with the use of more advanced digital filtering techniques, such as those employed in the FPGA-based PSU, we will enable the detection, selection, and experimental use of increasingly faster particles.

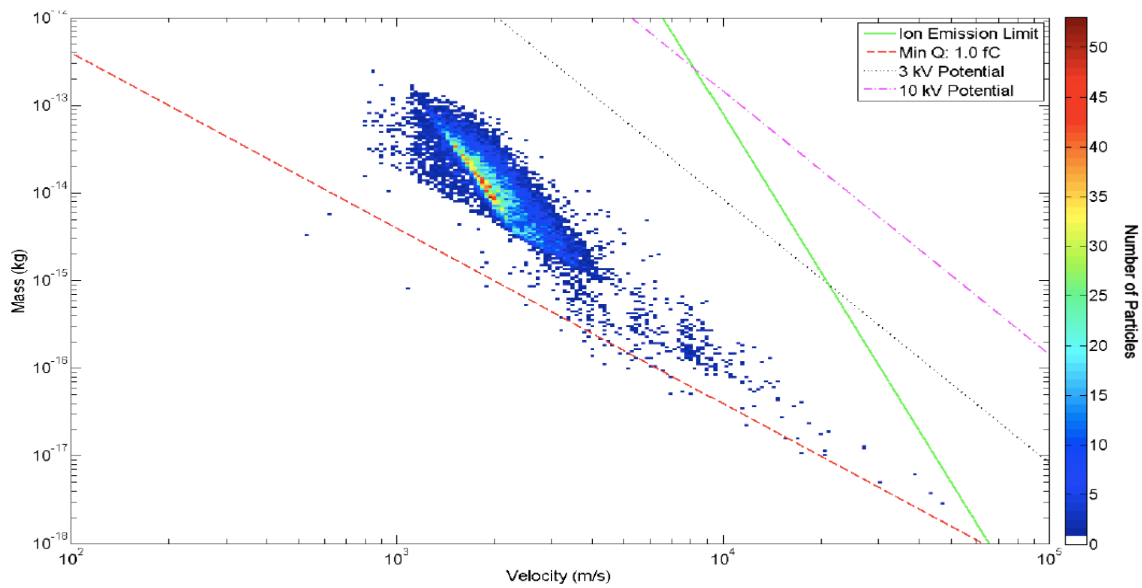


Figure 6.2.7. Density distribution of velocity and mass of particles in the CCLDAS dust accelerator during a typical run. Lines indicate various physical limits of the acceleration process.

6.2.1.4 Primary and ultra-high vacuum impact chambers

For most experiments, the LEIL makes use of a vacuum chamber 48 inches in diameter and 60 inches long that houses a series of versatile, movable internal structures and an array of diagnostic tools (**Figure 6.2.8**). This chamber serves as the "workhorse" chamber for impact studies and instrument calibration tests, among others. Targets can be illuminated by up to 12 excimer UV lamps emitting at 170 nm to create the photoelectron sheath that is created on the Moon by solar illumination. The facility will recreate to the extent possible the lunar plasma environment to investigate dust levitation, transport, and adhesion. Manipulators can be used to find how robotic activity disperses dust and how the mobilized dust adheres to various surfaces.

The LEIL also makes use of a second, smaller vacuum chamber for sensitive detection of impact products, e.g. ejecta, gas, plasma, etc. (**Figure 6.2.8**). This chamber is housed on a movable stand, so that it can be inserted or removed from the main beam line upstream from the large primary chamber. The small chamber will be differentially pumped (with respect to the beamline) to achieve UHV conditions, necessary for the expected levels of impact products. The UHV chamber was delivered in April 2011. Ultrahigh vacuum (< 2 x 10^{-10} torr) was successfully demonstrated after baking. The first experiment in this chamber, a fast, miniature ion gauge for observation of impact-generated neutrals, began development in late 2011. The experimental apparatus is complete and is undergoing testing prior to beginning experimental runs with the CCLDAS dust accelerator.

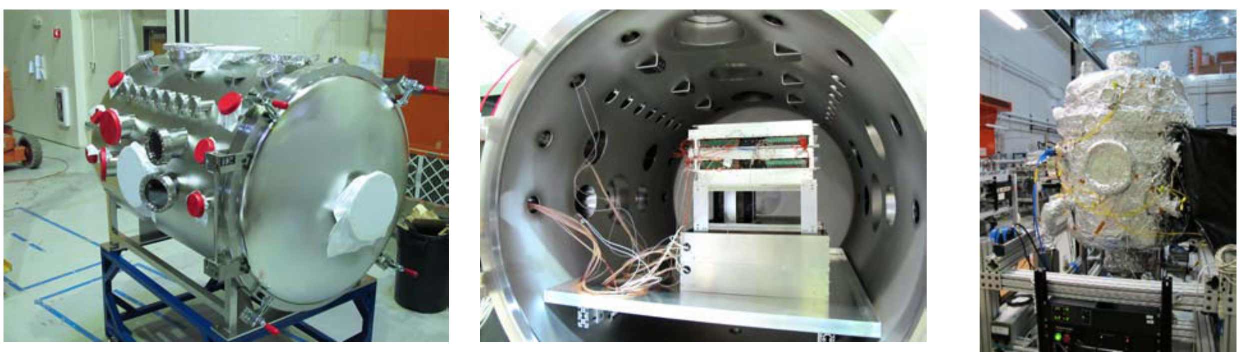


Figure 6.2.8. The Lunar Environment and Impact Laboratory PRIMARY chamber exterior (left) and interior (middle) housing a dust-trajectory instrument for testing. This impact chamber will house UV, electron, and ion sources to simulate the variable plasma conditions on the lunar surface, and actS as a target chamber for the dust accelerator. The UHV (right) chamber, is designed for experiments of impact products, where ultra-high vacuum conditions are required.

6.2.1.5 Experimental impact studies

During the first few months of operation, the accelerator has been used for a number of initial experiments. In one run, for example, a sample of 7 μm thick aluminized mylar foil was placed into the beamline to assess the possibility of using thin foils as a secondary ejecta detector for micrometeorite impacts (**Figure 6.2.9**). This experiment is part of an ongoing series to characterize the relationship between thin films, impactor characteristics, and the resulting cratering and/or penetration details. This study has immediate applicability to polyvinylidene fluoride (PVDF) as a dust detector, and may lead to fundamental improvements to our understanding of PVDF detector signals.

Silicon Nitride windows from the Solar Probe Plus mission were studied in the accelerator to assess the damage from hypervelocity impacts. These windows are extremely thin, and there is a concern that hypervelocity dust penetrations can lead to damage that propagates along the surface. In the initial tests, this did not occur, and follow-up tests will be carried out in the future.

In another experiment, several samples of fused silica were placed into the beamline in order to characterize the damage from micrometeorites on lunar retroreflectors. The resultant craters were imaged using a scanning electron microscope (SEM), showing craters approximately 0.7-3 μm in diameter. Future work includes determining the depth of the craters and whether the flakes are chemically similar to the coating of the sample. This is also part of an ongoing study to determine materials and their applicability as barriers to micro-particles. Samples of carbon, stainless steel, tungsten, and molybdenum have also been exposed the dust beam for this purpose.

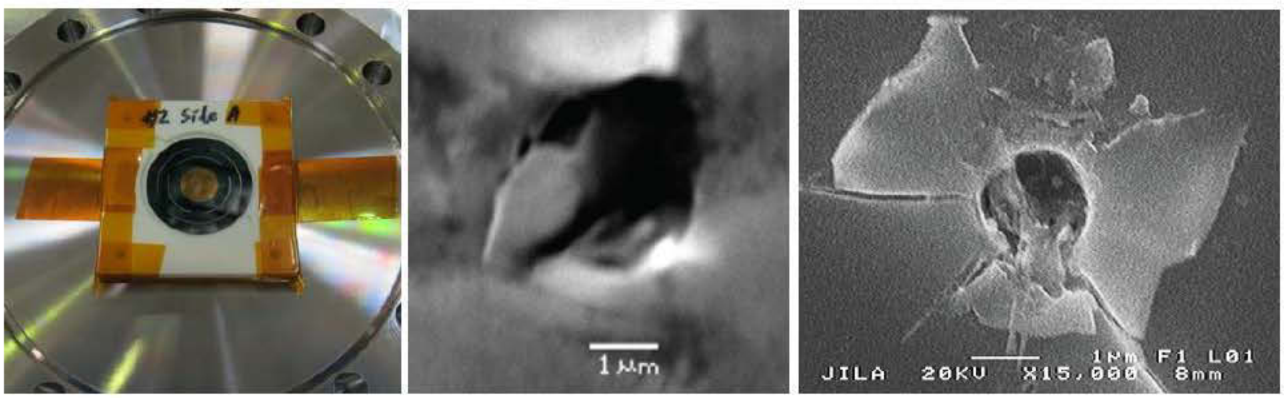


Figure 6.2.9. Images of various experiments from the initial accelerator runs. On the left is a foil sample from Solar Probe Plus. The center photograph shows the penetration damage at high magnification. Micrometeoroid damage to a fused quartz retroreflector sample is shown at right.

6.2.1.6 Investigation of impact-generated light flash

One well-known effect of hypervelocity dust impacts is the generation of a brief (100-200 microsecond) flash of light in the visible part of the spectrum. Impact-generated light flash has been observed in natural contexts, including meteoroid impacts on the Moon, and in the laboratory by Eichhorn (1970s) and others. The light is believed to originate from the plasma cloud formed as a result of the dust impact on a solid surface. Laboratory experiments revealed strong scaling of the light energy with particle velocity ($E \sim v^3$ to v^4), and an apparent blackbody spectrum, although the physics that governs the flash and velocity scaling remains obscure.

To further investigate this phenomenon, experiments were carried out at the CCLDAS dust accelerator in early 2012 to measure properties of the light flash using photomultiplier tubes. The principle goals of the experiment were (1) to reproduce the scaling effect in light energy and intensity with velocity as observed by Eichhorn and others, (2) to measure the time evolution of the observed blackbody temperature for a large ensemble of impacts, and (3) to investigate scaling of the temperature over a wide range of velocities and masses.

To measure the impact flash, iron and iron oxide dust particles were fired at a tungsten foil target, surrounded by an array of photomultiplier tubes. The particles ranged in speed from 1 km/sec to 40 km/sec, as well as several decades in mass, resulting in a total ensemble of about 1000 recorded light flashes. Each phototube could be optionally be equipped with a narrowband interference filter, to permit the simultaneous recording of light intensity versus time at a variety of wavelengths. **Figure 6.2.10** shows typical time traces recorded in this fashion; (left) wavelength-integrated light intensity versus time, demonstrating the complex nature of the flash's time evolution, and (right) time evolution of the light observed through three narrowband filters at various locations in the visible spectrum. Observations made at multiple wavelengths, as a function of time, permits reconstruction of the source's blackbody curve at multiple times, to investigate time variation in temperature. This work is expected to result in at least one peer-reviewed publication to be submitted in the March-April 2012 timeframe.

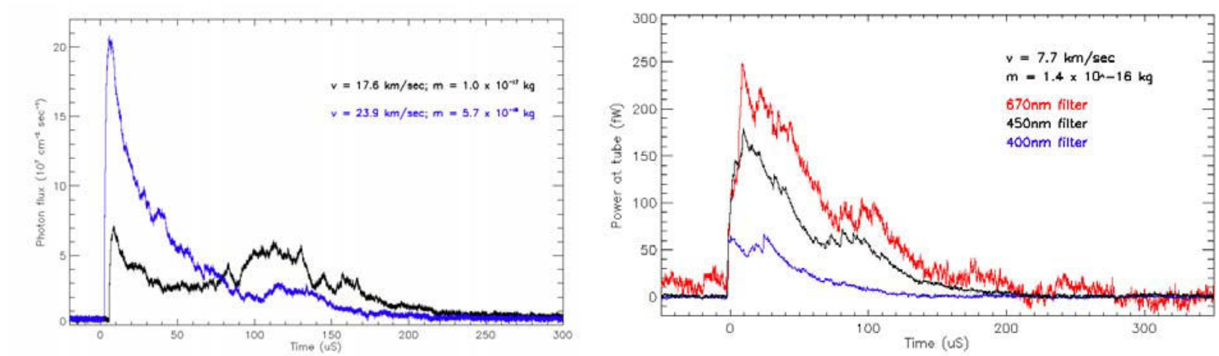


Figure 6.2.10. (Left) Wavelength-integrated photon flux observed at a distance of 10cm from impact location. Two particles are shown, to demonstrate the variability of the flash on a particle-by-particle basis. (Right) Power versus time observed simultaneously in three 40nm wavelength bands centered at 670nm, 450nm and 400nm, for a single 7.7 km/s dust particle.

6.2.2 Dusty Plasma Laboratory (DPL)

In addition to the suite of experiments taking place in the LEIL facility, a number of small-scale, rapid turn-around experiments are being conducted at the Dusty Plasma Laboratory on the main University of Colorado campus. The DPL facility uses several various-sized vacuum chambers, along with a standard suite of plasma diagnostic tools, to analyze and interpret various environments relevant to the lunar near-surface plasma environment. These experiments have focused on demonstrating and investigating the "basic physics" of the lunar plasma environment and associated dust dynamics, and are described below.

6.2.2.1 Dust transport

When the Moon enters the plasma sheet of the earth, high-energy electron fluxes are incident upon the lunar surface. Some regions are in the shadow of these fluxes due to topographic features. In an experiment designed to mimic these conditions, large electric fields were found at similar shadow boundaries created by electron beams incident upon an obstacle in the laboratory (**Figure 6.2.11**). Potentials on the beam-illuminated surface follow beam energies and were negative relative to potentials on the shadowed surface. Charged dust particles in the beam-illuminated region were observed to move into the shadow due to these electric fields (**Figure 6.2.11**). The oblique incidence of the electron fluxes upon craters can lead some portions of the crater surface exposed to illumination and leave other portions in the shadow. Dust particles on the slopes of craters can thus experience large electric fields and transport downhill to fill the bottom of the craters. This mechanism may contribute to the formation of dust ponds, such as those observed by the NEAR-Shoemaker spacecraft at 433 Eros, and might be at work on the lunar surface as well. In the laboratory, we used electron fluxes with energies up to 90 eV to bombard an insulating half-pipe (**Figure 6.2.12**). An angle of incidence was chosen so that the impact occurred on far side of the slope and left the bottom and the nearside slope in shadow. Dust particles on the beam-illuminated slope moved down along the surface toward the bottom of the half-pipe and hopped to the bottom as well, while particles on the shadowed slope remained at rest (**Figure 6.2.12**).

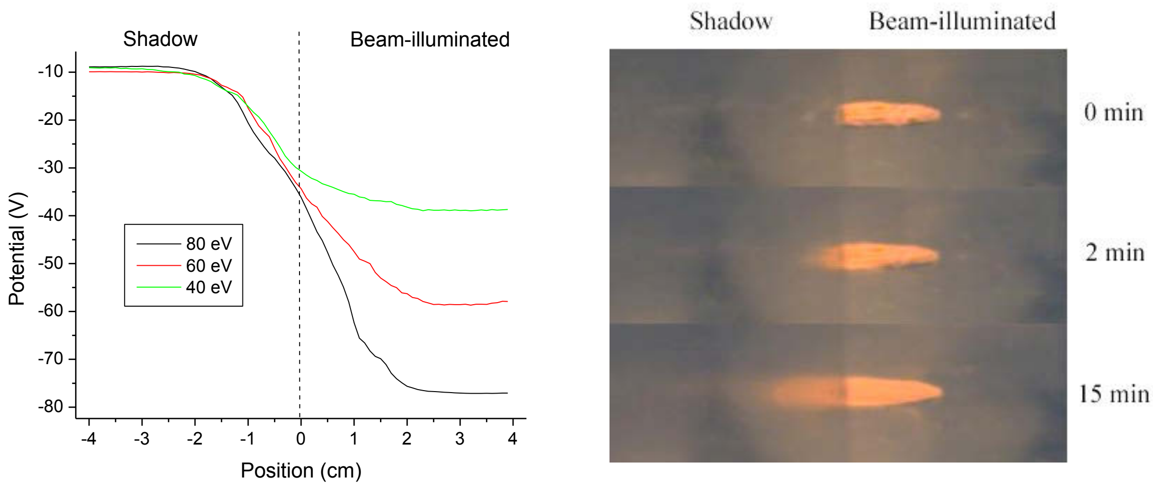


Figure 6.2.11. Potential distributions measured 1mm above the surface across the beam/shadow boundary with three energies (left). Images showing dust transport into shadow with the beam energy at 80eV. The labels indicate the time elapsed after turning on the beam (right).

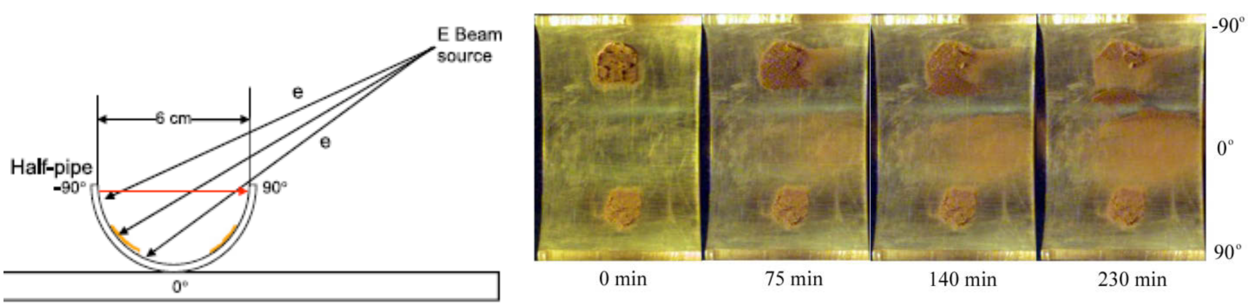


Figure 6.2.12. Experimental configuration for dust transport in a half-pipe (left). Two dust patches are in orange color. Images of dust transport in the half-pipe with the beam energy at 80 eV. The labels indicate the time elapsed after turning on the beam (right).

6.2.2.2 Electric fields near craters

Lunar craters have a variety of sizes relative to ambient plasma shielding distance (Debye length). The electric potential distributions in these craters can be significantly different. Experiments were performed with a hemispherical shape crater in the center of a thick insulating disc in laboratory plasmas to investigate the role of the crater size in shaping the electric fields near the surface. The size of the crater remained fixed in these experiments, and the plasma shielding distance (S) was changed by adjusting the plasma density. When the sheath S is smaller than the radius of the crater R, a barrier-like potential structure is observed to form between the central crater and the wall due to the expansion of the plasma into the crater (**Figure 6.2.13**). When the sheath is larger than the radius of the crater, the potential distribution in the crater becomes more homogenous because the plasma is shielded out from the crater (**Figure 6.2.13**). Due to the topography of the crater and the plasma shielding effects, the electric fields near the bottom of the crater are relatively small. This result may cause charged dust particles transported into depressions to become trapped, possibly forming the dust ponds as observed on asteroid 433 Eros.

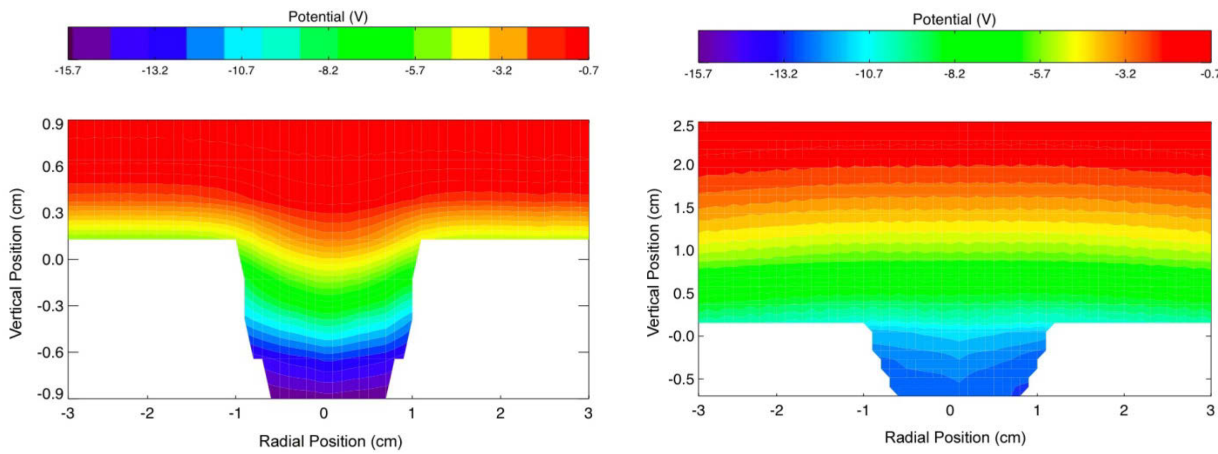


Figure 6.2.13. The measured potential contours in/out of a crater with a plasma shielding distance smaller S < R (left) and larger than the radius of the crater S > R (right).

6.2.2.3 Magnetic field effects on plasma sheaths

Fundamental studies of the effects of the crustal-like magnetic fields on surface charging and the sheath profiles have begun in the laboratory. The magnetic fields are created by a permanent magnet placed below an insulating surface (**Figure 6.2.14**). Preliminary results show that the surface charging and the sheath above the surface are largely dependent on the local magnetic field properties. A non-monotonic sheath was seen for the first time in the presence of a magnetic field (**Figure 6.2.15**). The gyro-radii for the electrons and ions are < 1 mm and ~ several cm, respectively; therefore, the electrons are thus more magnetized and trapped by the magnetic fields above the surface but the less magnetized ions can still reach the surface, leading to a positively charged surface. Horizontal scans 1 mm above the surface show a complex potential pattern along the magnetic field lines (**Figure 6.2.15**).

6.2.2.4 Characteristics and diagnostics of a photoelectron sheath

Immediately above the lunar surface is a sheath of photoelectrons with a density much greater than the electron density in the solar wind. In order to better understand the plasma environment of the lunar surface, we constructed an experiment with intense ultraviolet sources to create a sheath of photoelectrons above a surface. Initial studies have been done with metallic surfaces having known surface potentials in order to develop diagnostic probes and to aid in developing methods for interpreting probe data. A second series of experiments is planned for the summer of 2012 in which lunar regolith simulants will be placed on the metallic surfaces.

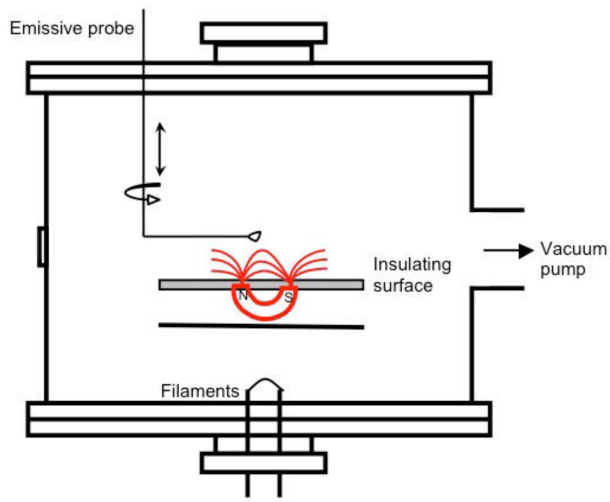


Figure 6.2.14. Magnetic field configuration in a small plasma chamber.

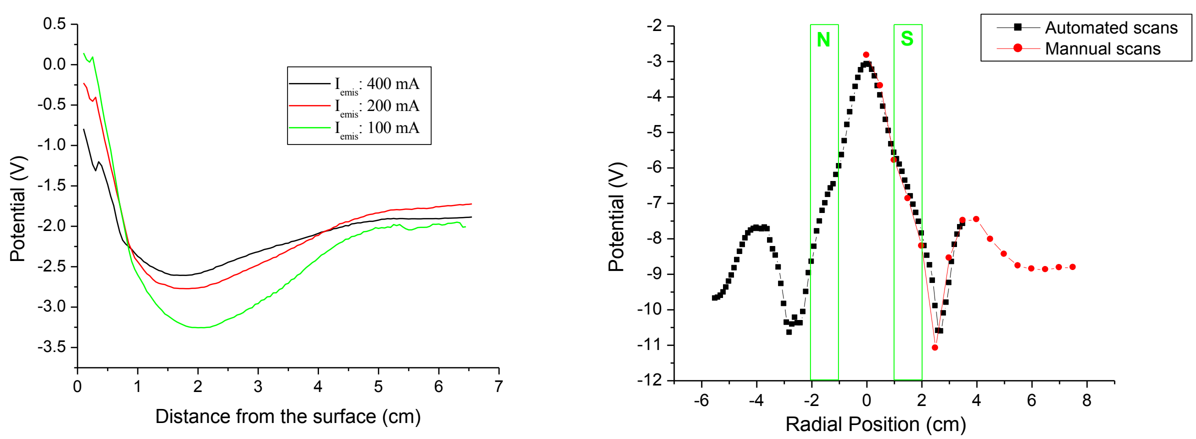


Figure 6.2.15. Vertical potential profiles above the surface in the magnetic fields exhibiting non-monotonic behavior (left). Horizontal potential profile along the magnetic field lines (right).

The UV sheath experiments are carried out in a 200-liter cylindrical vacuum chamber that is 62 cm in diameter and 82 cm tall (**Figure 6.2.16**). The chamber has ports at the top for mounting up to 10 xenon excimer lamps that deliver intense UV at 170 nm (~7 eV photon energy). The emitting surface is a zirconium disk 50 cm in diameter, and 7.6 cm above the disk is a stainless steel mesh. The grid provides a surface of constant potential that aids in data analysis and in comparisons of data with results from simulation codes with idealized boundary conditions. The measurement tools include (1) a small surface of Zr foil with known photoemission coefficients for calibration of the light intensity, (2) a cylindrical Langmuir probe for measuring the electron density and distribution function, and (3) an emissive probe for measurements of the space potential above the surface.

Figure 6.2.17 shows the photocurrent density as a function of distance from the top of the chamber with one and two lamps operating. These data show that current densities of order 1 μA/cm^2 are easily achieved above a metallic surface.

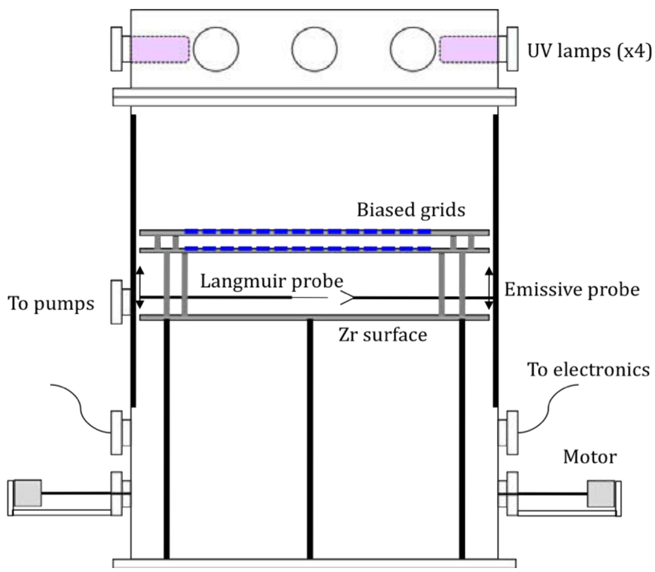
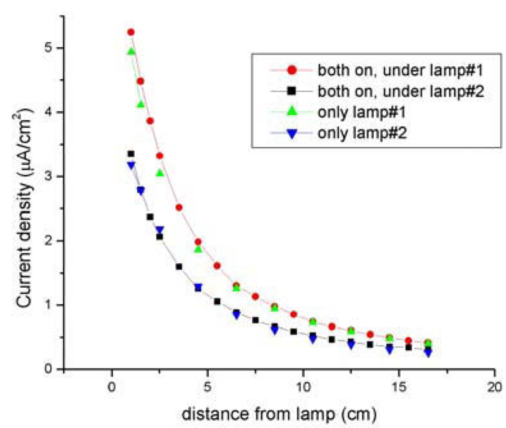


Figure 6.2.16. The photoemission experiments are conducted in a vacuum chamber having UV sources at 170 nm. Initial work is done with a 50 cm dia. Zr surface that is beneath grids that are biased to define planar potential surfaces. The photoelectron plasma is measured by a Langmuir probe and the electrostatic potential is mapped by the emissive probe. The grids are biased to repel spurious electrons from the chamber walls.

This photoemission current density is greater than at the lunar surface (~ 0.4 μA/cm^2) so that we can have a sufficiently small Debye shielding distance (<10 cm) in our experiment to observe sheath effects. The sheath must have a Debye length smaller than the characteristic dimensions of the experiment. Using 4 out of 10 lamps, the Debye length for our photoelectron layer is about 4 cm, which is significantly smaller than the transverse dimensions (~50 cm) of the emitting surface.

Figure 6.2.17. Plot of photoemission from a Zr surface as a function of distance from one and two UV lamps. The photoemission at a typical working distance is of order 1 microamp/cm^2. Photoemission from the lunar surface is about 0.4 nanoamps/cm^2.



Extensive sets of data have been taken with the Langmuir probe that give the photoelectron density and temperature and with the emissive probe that give the potential profile between the emitting surface and the grid. Here we highlight one Langmuir probe dataset showing how it may be used to find the potential of the lunar surface relative to an instrument package. The probe is attractive to electrons when biased positively and repels electrons when biased negatively. The electron distribution is often near-Maxwellian; thus, the current falls exponentially with bias when the probe is negative. The current increases algebraically when the probe is positive. Thus there is a peak in the first derivative when the probe is at the plasma potential. For a probe above the lunar surface emitting photoelectrons, we conjectured that the photoelectrons have a plasma potential corresponding to the potential of the lunar surface. We have verified this conjecture in the data in **Figure 6.2.18**. Probe sweeps are taken above the Zr surface with different bias voltages on the surface. The first derivative of the probe sweep moves to more positive potential as the surface is made more positive. The data show that the peak in the first derivative is an accurate measure of the potential of the emitting surface. This remains true over a range of bias voltages from -20 V to +10 V as shown in **Figure 6.2.18**.

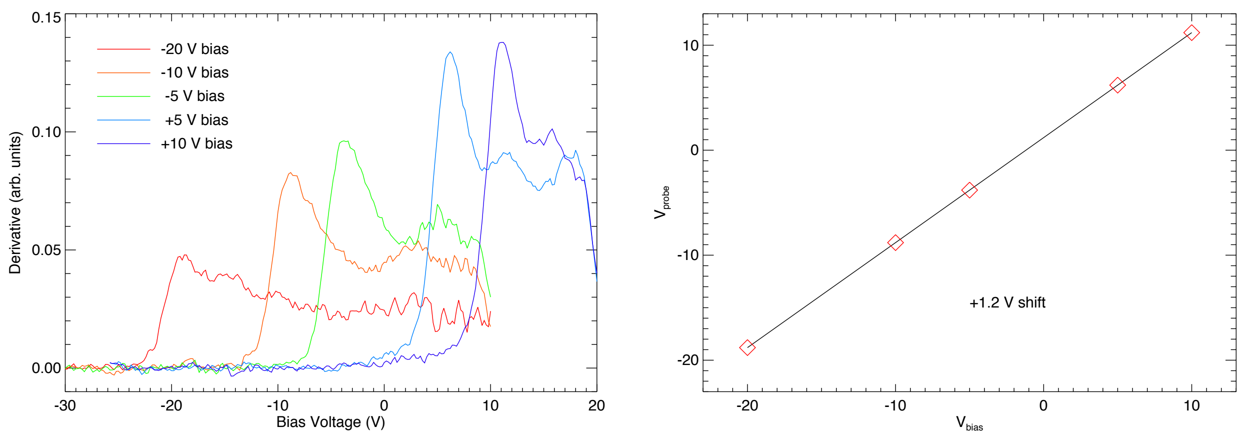


Figure 6.2.18. The first derivative of Langmuir I-V characteristic for a probe above a photoemitting surface having an adjustable bias potential. The peak in the first derivative occurs at more positive voltages as the photoemitting surface is made more positive (left). Location of the peak in the derivative of the Langmuir probe I-V characteristic plotted against the potential of the photoemitting surface. The data show that the peak follows the surface bias potential with and offset of about one volt (right).

The photoelectron sheath experiments will continue with surfaces that are partially and totally covered with granular materials. These materials will include conductors, insulators such as cerium oxide with high photoelectron emission, and simulated lunar surface regoliths. Transport of dust will be studied by photographing the change in appearance of surfaces that are partially covered with a dust that has a high visual contrast with the underlying material. Faraday cup collectors will be used to determine the charge on individual grains that are set in motion by electrostatic forces. Data from the Apollo missions showed that dust on the Moon was more mobile near sunrise and sunset, hence these experiments will include a light baffle to create a surface with a gradient in illumination.

6.2.3 Instrument Development

6.2.3.1 Langmuir Probes for the Lunar Surface (LPLUS)

CCLDAS and its industry partner United Launch Alliance (ULA) co-funded a student instrument development project in the Aerospace Engineering Sciences (AES) Department of the University of Colorado. The ASEN 4018/4028 class was a two-semester course covering the entire instrument development process, ending in the summer of 2010. The course was structured and run as a NASA hardware-project, including the standard milestones: Preliminary Design Review (PDR) and Critical Design Review (CDR). The instrument requirements were derived from a carefully assembled set of science and measurement requirements.

In addition to funding this project, CCLDAS has been involved in educating students in the technical challenges of future lunar missions. The development resulted in a fully tested (TRL = 4) laboratory prototype of the LPLUS instrument, which consists of one 3 m and two 2 m long deployable booms (**Figure 6.2.19**). Course credit for the work was given to group of seven undergraduate AES students: A. Berg, K. Hahn, T. Hanson, L. Martinez, R. Mayerle, M. Siegers, S. Valdez.

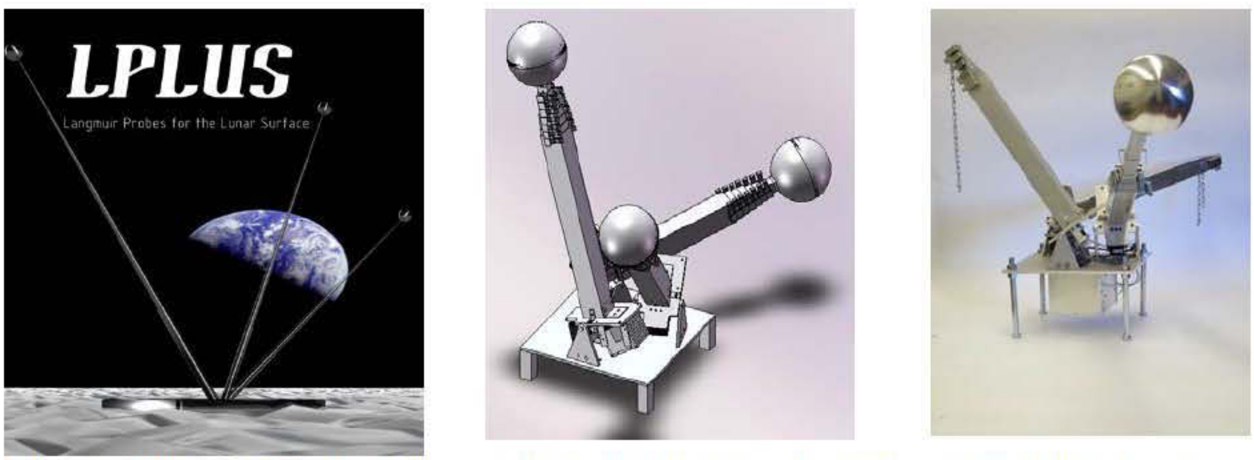


Figure 6.2.19. The LPLUS logo developed by the students (left), CAD drawings of the LPLUS deployable boom structure (middle), and the prototype machined, built and tested by students (right).

6.2.3.2 LPLUS Laboratory Model

A scaled-down version of the LPLUS has been constructed and is undergoing testing in a simulated lunar surface environment including UV illumination and low-density plasma. (**Figure 6.2.20**). Probe sweep measurements showed that the UV generated photoelectron plasma has a wide electron energy distribution that was likely caused by contamination of the plasma chamber surface. A liner with pristine graphite coating has been designed and is currently under construction.

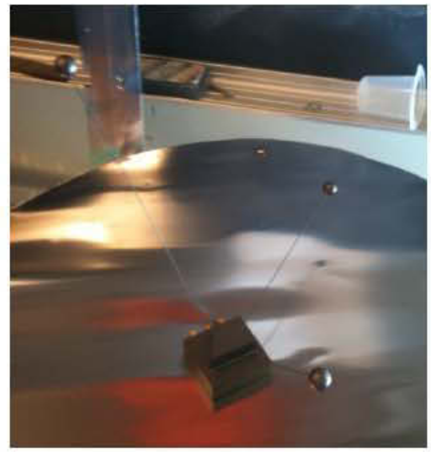


Figure 6.2.20. The scaled-down LPLUS⁻ instrument with its 3 small spherical probes attached.

6.2.3.3 Electrostatic Lunar Dust Analyzer (ELDA)

The detection of low-velocity (<< 1 km/s) micron sized dust particles using standard dust detection technologies is difficult due to the low kinetic energy and momentum they possess. A feasible detection principle is through the charge the particles carry. A laboratory prototype instrument using this approach has been developed and tested to TRL = 4 (Technical Readiness Level). ELDA was initially funded by NASA Planetary Instrument Definition and Development Program (PIDDP). As part of the CCLDAS instrument development effort, the ELDA instrument development continues for increasing its TRL level by testing and calibrating it in a relevant environment.

The ELDA operation concept is based on measuring the induced charge from a passing-through dust particle on an array of wire electrodes, as shown on **Figure 6.2.21**. The electrodes are arranged into four planes with alternating orientation that allows measurement of the two components of the particles velocity vector, while the third component is calculated from the relative timing of the signals. The masses of the particles are determined after bending their trajectory using a set of electrodes biased to high potentials. The trajectory is thus measured twice, before an after the induced bend. ELDA employs wire electrodes as their low capacitance allows the best noise performance and thus the highest sensitivity.

A vacuum-compatible version of the ELDA has been constructed and equipped with low-noise Charge Sensitive Amplifiers (CSAs) (**Figure 6.2.22**). The setup has been tested in the Lunar Environment and Impact (LEIL) chamber by dropping charged dust particles into ELDA and measuring their velocity vector and mass. The trajectories are calculated by fitting a family of modeled detector response curves to the measured signals.

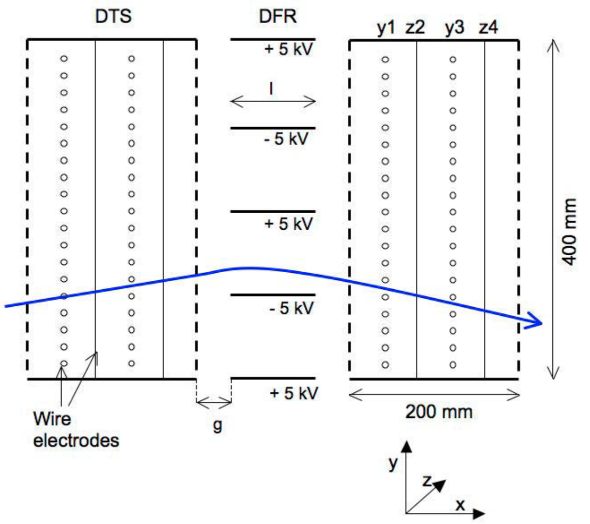


Figure 6.2.21. The schematics of the ELDA instrument. The charged dust particle flies through two sets of wire electrodes (Dust Trajectory Sensors, or DTSs) before and after its trajectory is bent. Each wire electrode is connected to a separate front-end electronics.

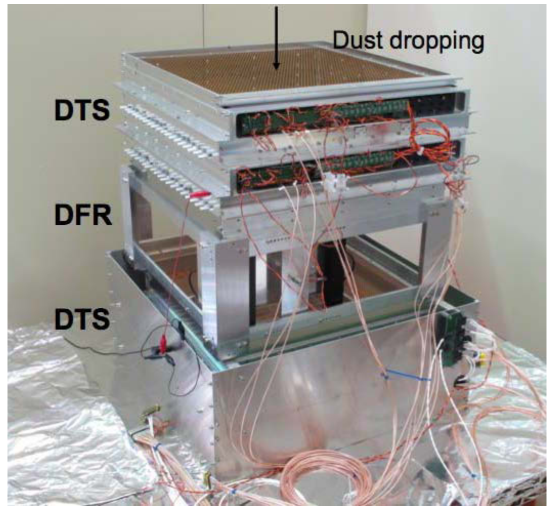


Figure 6.2.22. The vacuum compatible laboratory version ELDA. Dust particles are dropped into the instrument from above.

6.2.3.4 Instrument development supported by CCLDAS

The dust accelerator facility has been developed as part of CCLDAS to also enable the development, testing, and calibration of instruments for NASA projects with relevance to lunar science. We have kept the full beamline and primary impact chamber exceptionally clean by using only oil-free pumps (including all forepumps) to maintain vacuum, enabling the future development of ultrasensitive instruments capable of measuring the chemical and isotopic composition of dust particles in space.

The Lunar Dust EXperiment (LDEX) is a dust detector instrument to be launched in May, 2013, onboard the Lunar Atmosphere and Dust Environment Explorer (LADEE) to map the distribution of dust around the Moon. The preliminary testing and calibration of LDEX has been performed at the dust accelerator facility in operation at the Max Planck Institute for Nuclear Physics, Germany. The final testing of the LDEX flight model is now performed at the CCLDAS dust accelerator (**Figure 6.2.23**).

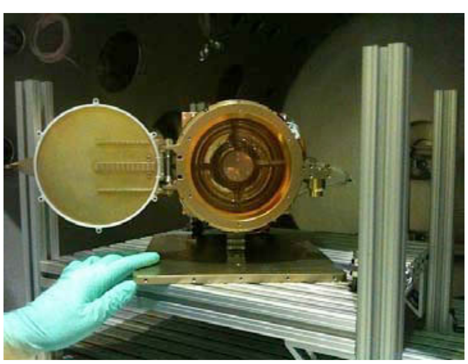


Figure 6.2.23 The flight model of the Lunar Dust Experiment (LDEX) instrument in the LEIL chamber for testing and calibration at the CCLDAS dust accelerator in February 2012.

The Nano-Dust Analyzer (NDA) is an instrument development project funded by NASA's Heliospheric Physics program to develop an instrument capable of detection and chemical analysis of nanometer sized dust particles originating from the inner solar system and accelerated to hundreds of km/s by the solar wind. The plasma-wave antennas of both STEREO spacecraft have observed nano-dust particles, and if the flux measurements turn out to be correct, the high velocity nano-dust particles will be the most populous impactors on the lunar surface. The NDA instrument is currently under design/fabrication, and its first testing at the CCLDAS dust accelerator is anticipated in the Fall of 2012.

6.2.3.5 E-Parallel-B Analyzer

A proposal was submitted under the Planetary Instrument Definition and Development program (PIDDP) in August of 2011, for development of a novel instrument for analysis of ions from the thin lunar atmosphere incident on the lunar surface. The instrument would use a diagnostic technique derived from the plasma fusion community, in combination with a high-resolution, space-validated sensor technology (**Figure 6.2.24**) to record the energy and momentum of every ion entering the device. The proposed instrument development would be carried out at CCLDAS and support an additional full-time graduate student.

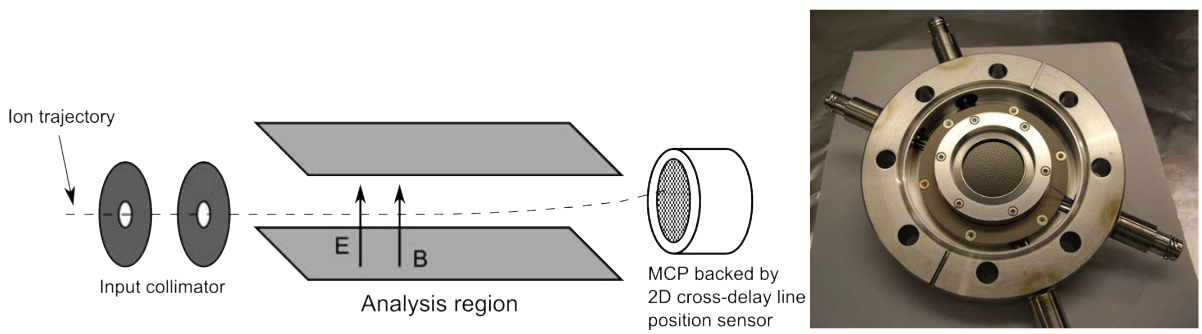


Figure 6.2.24. A schematic of the proposed E-Parallel-B instrument (left), and the microchannel plate/cross-delay-line (MCP-XDL) sensor which serves as the readout (right).

6.2.4 ARTEMIS Data Analysis

The Acceleration, Reconnection, Turbulence, and Electrodynamics of the Moon's Interaction with the Sun (ARTEMIS) mission consists of two spacecraft redeployed to lunar orbit from NASA's five spacecraft Time History of Events and Macro-scale Interactions during Substorms (THEMIS) heliophysics mission designed to study the processes that lead to terrestrial aurora. ARTEMIS returns information about the vector magnetic and electric field (and related waves) and suprathermal charged particles from a lunar orbit with altitudes ranging from ~20 km up to ~11 lunar radii, making the dual spacecraft mission well-suited to establish the context in which lunar dust charges and moves. We have pursued ARTEMIS analysis in two areas:

6.2.4.1 Lunar Magnetic Anomaly Effects

We have undertaken analysis of ARTEMIS measurements in the vicinity of magnetic anomalies to explore how the anomalies interact with their environment. To date we have focused on low altitude (< 100 km) passes near anomalies, of which there have been ~19 since the two probes arrived in lunar orbit in the summer of 2011 (**Figure 6.2.25**).

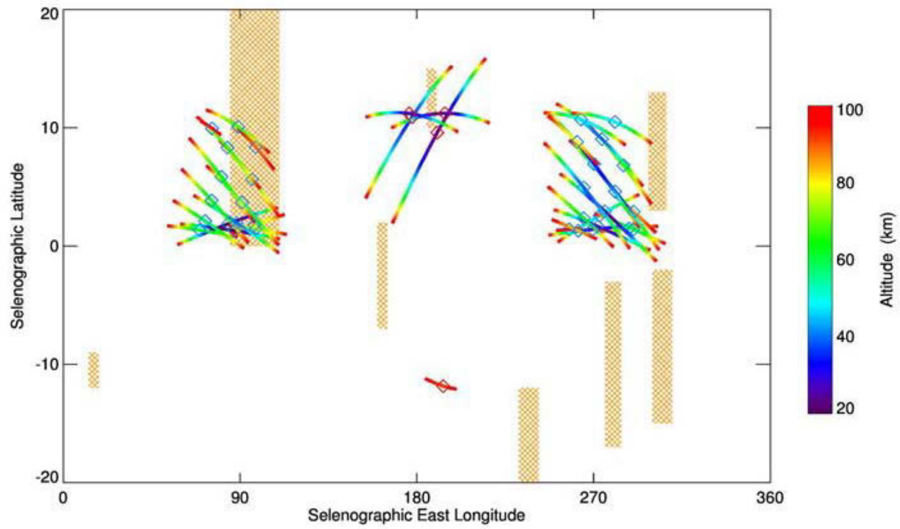


Figure 6.2.25.

Selenographic map of the ground-tracks of ARTEMIS orbits passing below 100 km altitude. Ground tracks are color coded according to altitude, and show the periapsis location as an open diamond. Lunar magnetic anomaly locations are indicated by orange shading.

We have investigated three very low altitude (20-40 km) passes in particular, and identified a number of interesting features, including (**Figure 6.2.26**) low energy reflected ions, narrow reflected ion features with pitch angle dispersion, a highly variable reflected electron population (not shown), and ubiquitous wave activity. The wave activity is particularly interesting, and among the three events shows variable wave activity at frequencies below the local proton gyrofrequency and differences in magnetic field oscillations before and after closest approach (though the nature of the differences varies from orbit to orbit). High frequency electrostatic waves appear to be correlated with lower frequency electromagnetic waves measured by the search coil magnetometer for all three events. Results from our study of anomaly influences were presented at the 2011 Fall AGU meeting. Over the coming year we plan to continue analysis of more low altitude anomaly passes, and investigate the mechanisms responsible for the various wave signatures.

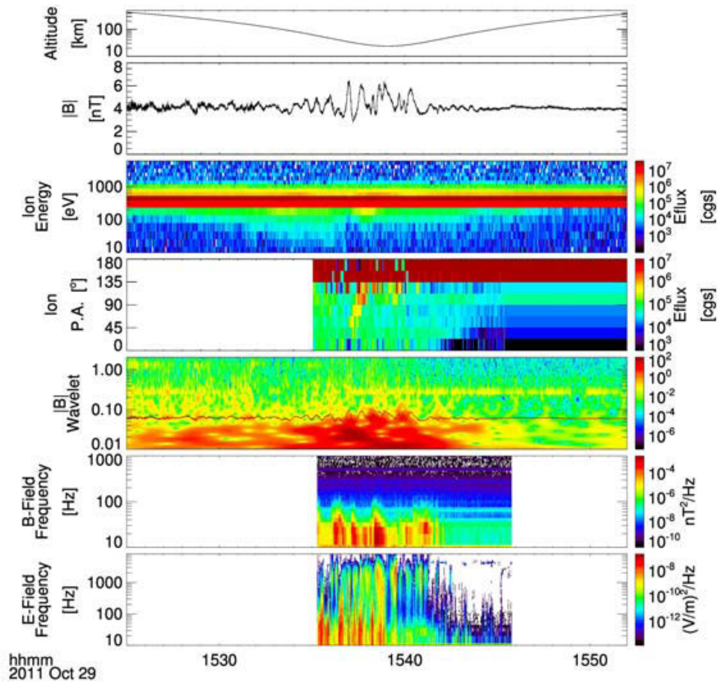


Figure 6.2.26. Time-series of ARTEMIS observations in a magnetic anomaly region. Panels show (from top to bottom): spacecraft altitude, magnetic field amplitude, ion energy fluxes, ion pitch angle, and three panels showing magnetic and electric field power as a function of frequency. The influence of the anomaly is evident in every panel.

6.2.4.2 Lunar Wake Study

Our team is using ARTEMIS to study the shape of the lunar plasma wake, including its variation in response to changes in the solar wind. As the strength of the solar wind varies the wake should shrink or grow, and the wake is expected to have asymmetries corresponding to the solar wind convection electric field or the perturbing effects of crustal magnetic fields at the lunar surface. Using many crossings of the wake boundary by the ARTEMIS probes we are experimentally determining the shape and variability of the boundary to the wake by correlating the position of its outer boundary with solar wind parameters and the orientation of the Moon. Our results will establish for the first time the response of the wake boundary to external conditions, and they can be compared to the results of several simulations currently being developed by other teams. Furthermore, our results can help to constrain how quickly and via what processes solar wind plasma fills the vacuum behind the Moon. This study is being pursued as a graduate student project.

After validating our analysis approach with several wake crossings, we identified all periods for which the ARTEMIS probes passed behind the Moon since arriving in lunar orbit. We are now in the process of examining each candidate wake crossing by hand, and identifying the location of the outer boundary to the wake using ion measurements. Once a database of wake crossings has been constructed we will determine how the location of the wake varies with solar wind drivers, lunar orientation, and location of the spacecraft behind the Moon – thereby establishing the shape and variability of the wake. We are also investigating plasma structures observed near the center of the lunar wake (e.g. ions near 17:10 in **Figure 6.2.27**). Our preliminary work has uncovered previously unreported wake plasma structures that don not fit cleanly with current explanations for access of plasma to the central portions of the lunar wake. In the coming year we will construct an event list and classification for central wake plasma structures.

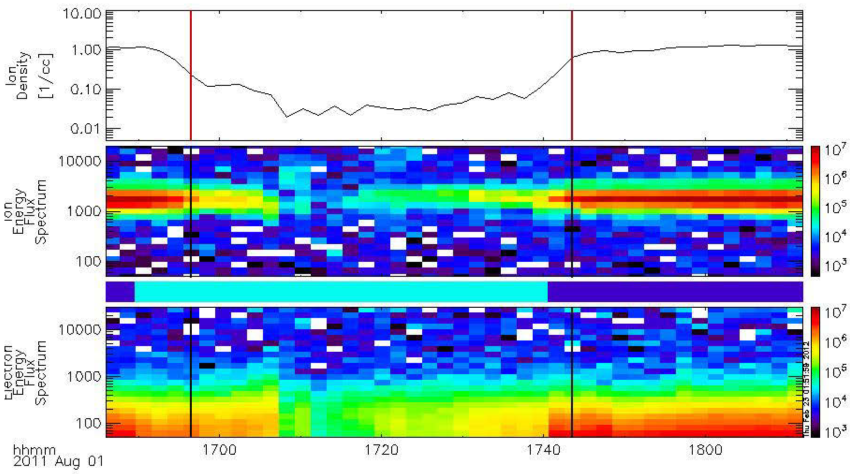


Figure 6.2.27 Time-series of ARTEMIS observations of the lunar wake. Panels from top to bottom show ion density, ion fluxes, and electron fluxes. The entry and exit from the wake are identified from the ion density measurements and the spectrogram of ion fluxes. Plasma is also seen in the central wake at ~17:10.

6.2.5 NJSC Light Gas Gun Laboratory

CCLDAS is partnered with the the Experimental Impact Laboratory (EIL) at the NASA Johnson Space Center to expand the scope of possible impact experiments and instrument development studies. EIL is a facility dedicated almost exclusively to planetary-science research. In rare cases, such as the investigation immediately following the Columbia disaster, EIL personnel and capabilities have supported impact and vacuum testing of spacecraft hardware. The EIL is part of the Astromaterials Research Office (Code KR) of the Astromaterials Research and Exploration Science Directorate (ARES). Scientific and technical support is provided by Jacobs Technology and their subcontractors. The EIL comprises a machine shop and other equipment supporting three separate and distinct ballistic ranges: the flat-plate accelerator (FPA), the two-stage light-gas gun (LGG), and the vertical gun.

1. The FPA is a horizontally mounted, powder-propellant gun used primarily for shock-recovery experiments, in which samples are subjected to predetermined shock stresses, recovered, and analyzed. It uses interchangeable barrels with bores of 20, 25, and 40-mm diameter.
2. The horizontally mounted LGG uses a gunpowder-driven piston to compress gaseous hydrogen, which is used as the working gas to accelerate < 5-mm projectiles to speeds as high as 8 km/s, although speeds below 7 km /s are more typical and less stressful on the equipment.
3. The vertical gun is another powder-propellant accelerator, oriented to shoot vertically downward, permitting experiments using granular and liquid targets. It also uses a variety of interchangeable barrels; those used most often have 6-mm and 7.62-mm bores. Depending on the projectile mass, operational speeds from the vertical gun range up to ~2.8 km/s. The impact chamber of the vertical gun is a surplus environmental test chamber from the Apollo era, with a built-in refrigeration system that can maintain a chamber temperature of -20°C, thus permitting experiments using cold targets, including H_2O ice.

The Experimental Impact Laboratory has gone through an extended non-operational period from April 2008 through late 2010. Installation of a new vacuum plumbing was completed in February 2011, at which time it also passed its leak test by a factor-of-two margin (**Figure 6.2.28**). After more than two years of repair activity, operational shots with the vertical gun resumed in mid 2011, including a campaign for CCLDAS (**Figure 6.2.28**). In this experiment, PVDF foils were bombarded with dust with diameters ranging from 3-30 µm, at velocities between 2-3 km/s. This augments the parameter space accessible to the CCLDAS dust accelerator, which reaches higher velocity but smaller maximum particle size. This is part of a comprehensive study of cratering properties of PVDF, which define its usability as a dust detection instrument. The light gas gun is expected to be ready for active experiments in late spring of 2012, and a CCLDAS campaign is planned early in that run.

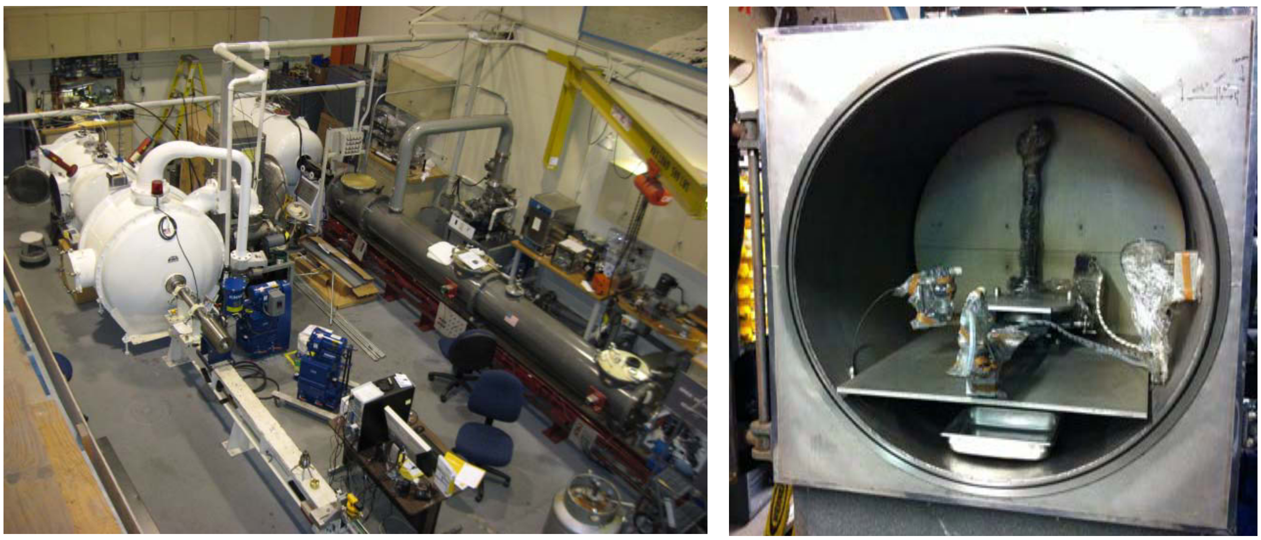


Figure 6.2.28. The NJSC flat plate gun and light-gas gun (left image, white and gray, respectively) after installation of the new vacuum plumbing. Vent lines for pumps have been installed and pneumatic lines have been completed. CCLDAS foil samples installed in the Vertical Gun target chamber (right).

6.2.6 Tech-X: Large Scale Computational Modeling

Over the past years, the local small company Tech-X has been working with CCLDAS on two main lunar dust environment simulation scenarios: The first was related to the plasma sheath formation and the resulting electrostatic fields in complex settings like a lunar crater. One of the main questions was to investigate the effect of varying angle of UV/solar wind incidence onto the crater and the effect on the resulting fields. To our knowledge, these simulations were the first fully 3D kinetic simulations of the lunar plasma environment in complex geometries. The resulting field patterns were then used by our collaborators at CCLDAS to investigate the transport of a dust particle in the electrostatic field. The second set of simulations was to reproduce experiments of a simpler setup consisting of a plate with a circular dimple and to directly compare the simulation results to the measured data. Each of these is described below.

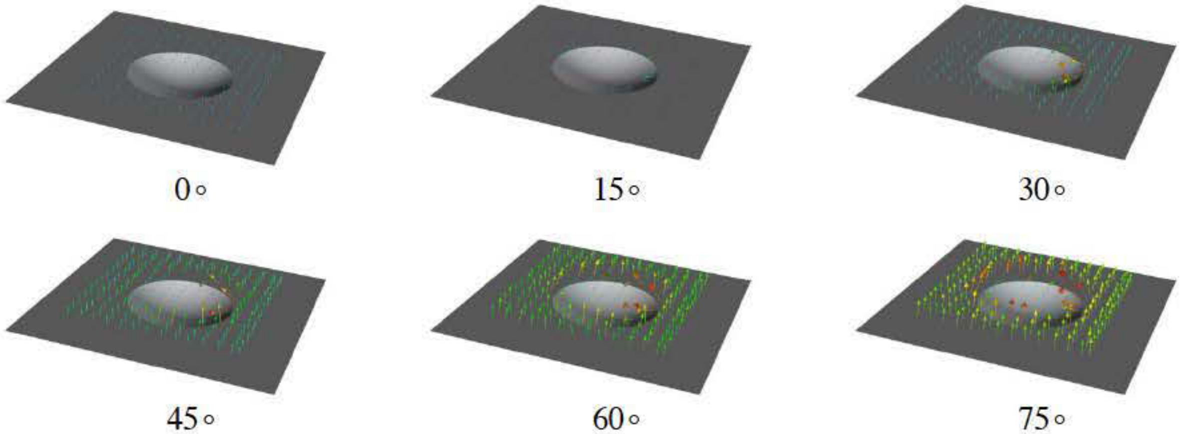
6.2.6.1 Simulations of the plasma environment of a lunar crater

The goal of this technical activity was to extend the simulations, designed during the first year of the project, to the simulations of the plasma environment in realistic lunar crater. The crater was modeled as a capped parabola on the flat lunar surface. The crater is assumed to be a perfect dielectric, resulting in immobile charge being accumulated on the crater surface. Photo-emission is represented as a particle source emitting electrons at a rate dependent on the angle between the incident solar radiation and the local surface normal. The incident solar wind is modeled as an electron/proton plasma with parameters commonly found in the solar wind. We performed simulations at various angles of incidence. These simulations were usually run in parallel on 64 cores of an in-house cluster at Tech-X. Each simulation performed 10000 time-steps in about 8 hours and produced a data output of 10 GB. Each simulation ran on a grid of 150x150x150 cells and used ~10^7 particles. In order to validate the results, we performed a range of simulations at varying grid resolution and varying particle densities.

The main finding from these simulations was the complex structure of electric field at the crater surface. Both the magnitude and the amplitude of the electric field have a strong dependence on the angle of solar incidence (**Figure 6.2.29**). These small-scale intense electric fields are expected to have profound effects on the motion of mobilized small charged dust grains (**Figure 6.2.30**). It is worth pointing out several key results of the simulations. During the sunrise or sunset, when the solar wind is parallel to the crater surface, neither photons nor solar ions penetrate into the crater; however, thermal solar electrons can enter the crater. These electrons charge the crater surface negatively and lead to a negative surface potential. Electric field lines are directed towards the crater surface. In the complementary case, when the sun is at the zenith, we observe the expected formation of a plasma sheath with positive surface potential and electric field lines pointing away from the surface. We also observe an increase in the electric field strength at the crater rim. The next steps in this project are to introduce small objects like a rock into the crater simulations to break the symmetry and observe the effect on the plasma environment. Most of these simulations can be performed with relatively small modifications to the existing simulation setups. Finally, we conducted a study of the dependence of the plasma sheath near the crater on the external magnetic field. The magnetic field strength varied from 2.5 to 250 nT, corresponding to typical conditions on the lunar surface. However, no effect on the plasma sheath has been observed, most likely due to the significant difference between the Larmor radius for charged particles in such magnetic fields (kilometer scale) and the plasma sheath length (meter scale).

6.2.6.2 Simulation Support of Small-scale Laboratory Experiments

In these simulations, a dielectric plate with hemispherical dimple is immersed in a plasma to imitate the experimental setup discussed in section 6.2.2.2. In the experiment, measurements of the potential above the dimple showed the formation of a sheath. The goal of the simulations is to reproduce the sheath measurements. One of the main challenges in setting up these simulations is the large size of the experimental setup and the limited domain size for the simulations. This requires an appropriate setup of boundary conditions in the simulations. In order to prevent charge build up at the domain boundaries, we therefore decided to use reflecting boundaries for the outer walls. However, due to the absorption of some of the plasma on the dimple surface, we needed to introduce additional plasma into the system. The simulation results match qualitatively well with the measurements.



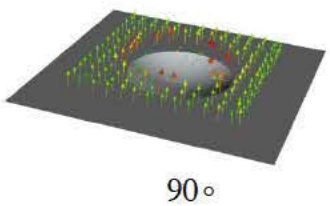


Figure 6.2.29. Distribution of electric field on the crater surface for different angles of solar incidence (0 and 90 degrees correspond to solar wind parallel and normal to crater surface).

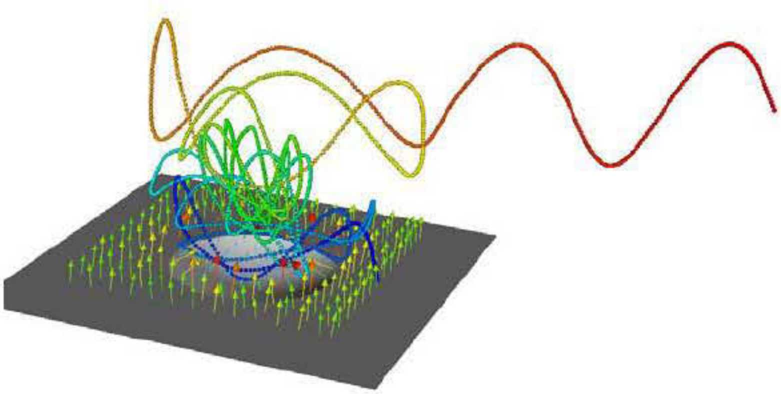


Figure 6.2.30. Dust particle trajectory above a crater. The grain starts at right (red points), oscillating stably above the lunar surface. As the grain enters the region above the crater at later times (yellow to blue points), the grain is trapped by the near-surface electric fields. Eventually, the grain comes to rest on the surface inside the crater.

6.2.7 Zybek Lunar Simulant Material Development

CCLDAS small local business partner Zybek Advanced Products, Inc. (ZAP) developed a complete industrial-scale process to manufacture lunar simulants (**Figure 6.2.31**). The lunar simulants range from bulk excavation-grade regolith simulants to precise, chemically and physically-correct dust components for medical and chemical process testing. The process uses remotely-coupled plasmas that thermally react the feed stock components. The plasma thermal reaction production options include manufacturing of: synthetic minerals, bulk-glass, glass spheres, and agglutinates. The remote-coupling provides a very high energy density and temperatures that do not require electrically conductive materials. The material produced from the plasma process is then milled in a newly-developed, Aerodynamic Impact Reactor. The AIR mill breaks the solid particles into the desired size and shape ranges. Currently, ZAP is completing is the production of approximately 20 metric ton of JSC-equivalent lunar simulant. The feedstock for this material was procured from the Merriam Crater, which was the same location used to supply the scientific community with JSC-1A.

Figure 6.2.31. The plasma torch setup at Zybek for the manufacturing of custom-made lunar simulants.

6.2.7.1 Synthetic Mineral Manufacturing

To produce lunar simulant components for NASA and the USGS, Zybek has developed a process for creating synthetic minerals from commercially available oxides. ZAP has produced several synthetic minerals, including: Sapphire, ruby, anorthite, augite, pigeonite, and enstatite, using commercially-available batch ingredients (i.e., CaO, Al_2O_3, SiO_2). The batch ingredients are combined in solid form and then brought to molten temperatures by the proprietary remotely-coupled arc plasmas. The cooling then controlled to promote crystal growth or quenched to produce glass. Current production capability is multi-ton per day.

6.2.7.2 Aerodynamic Impact Mill

ZAP's AIR mill has been upgraded to allow continuous production of ~ 1 ton material lots. The size and shape analysis shows the final material is jagged and has a high aspect ratio (**Figure 6.2.32**). This differs significantly from traditional mills that use mechanical grinding techniques to reduce particulate size. To ensure the material is split accurately into the individual containers, a 1-ton splitter has been fabricated. The splitter divides a 1-ton lot into 35 containers at approximately 1 cm per layer. This ensures each container is equally sampled from the bulk lot.

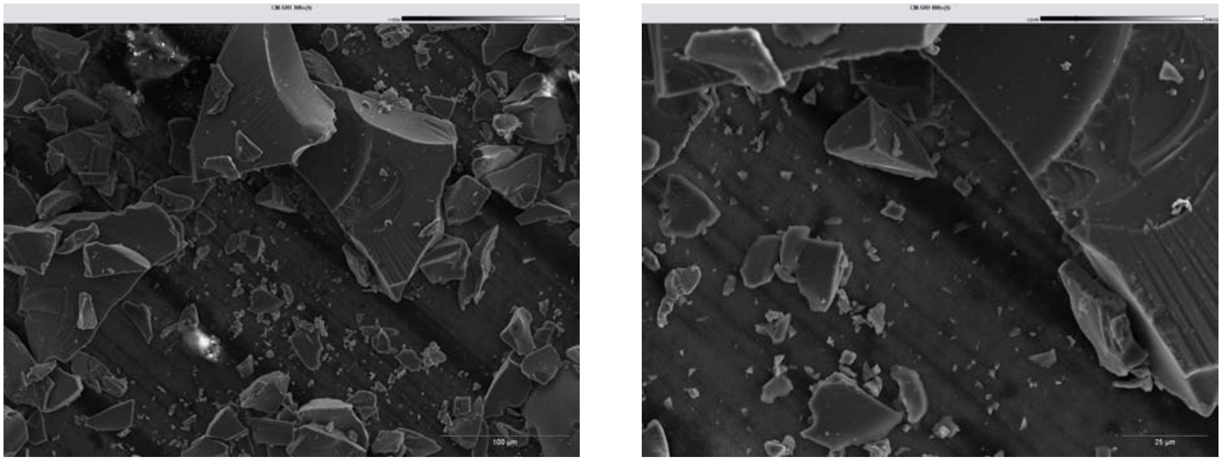


Figure 6.2.32. Glass particles produced in the Aerodynamic Impact Mill at ZAP.

6.3 INTER-TEAM COLLABORATIONS

6.3.1 DREAM and CCLDAS

Andrew Poppe and Mihaly Horanyi (CCLDAS) worked with Jasper Halekas, Greg Delory, and Bill Farrell (DREAM) on the analysis and interpretation of observations made by Lunar Prospector (LP) of the lunar surface potential in both the terrestrial plasma sheet and the solar wind. The Electron Reflectometer on LP reported large negative surface potential over the lit side of the Moon, contradicting all theoretical expectations. Recently developed theoretical and simulation models suggest the formation of non-monotonic potential structures above the dayside lunar surface with a large negative potential minimum above the surface, while still maintaining a positive charge density of the surface, offering a long-awaited theory to explain the LP findings. Andrew completed his PhD in 2011, and now is a Post Doc with the DREAM Team at UC Berkeley.

6.3.2 LUNAR and CCLDAS

Doug Curry (LUNAR) is leading an effort to develop a new generation of corner-cube retro-reflectors for laser ranging. He has brought sample reflectors to the CCLDAS dust accelerator to investigate the effects of hypervelocity dust impacts on the optical properties of the sample. This early experiment will be followed up with a systematic study of crater forming impacts on optical devices.

6.3.3 Brown U. Team and CCLDAS

Initial experiments to investigate space weathering due to dust impact are scheduled in the spring of 2012. Basalt samples will be exposed to hyper-velocity (> 1 km/s) iron dust impacts to identify changes in their reflectance spectra. If successful, a follow up series experiments of will be planned to use different dust compositions, and to establish a scaling between the number of dust impacts per unit surface area and the geologic exposure time.

6.3.4 International Partners

CCLDAS closely collaborates with the dust group at the Max-Planck-Institute for Nuclear Physics, Heidelberg (MPI-K), and the University of Stuttgart, Germany, both members of the German Lunar Science Institute. CCLDAS greatly benefited from these collaborations in the development of our dust accelerator facility. We are establishing a common data management system for dust impact studies, and plan on scheduling parallel complementary experiments. We have an active exchange program for postdocs and researchers, and initiated establishing a student exchange program that will also include formal class work, in addition to involvement in our experimental programs. Dr. Anna Mocker (U. of Stuttgart) is a visiting scholar at CCLDAS for the period of 8/2011 - 12/2012. CCLDAS graduate student Anthony Shu (supported by NLSI) spent 3 weeks at the MPI-K dust accelerator. Initiated by CCLDAS and the Institute for Space Systems, the University of Colorado and the University of Stuttgart signed a Memorandum of Understanding to set the framework for collaborations in lunar and space research.

6.4. EDUCATION, PUBLIC OUTREACH, AND PROFESSIONAL COMMUNITY DEVELOPMENT

Beginning in October 2010, E/PO management was transferred to the new LASP Office of Communications & Outreach manager, Stephanie Renfrow, following the departure of the previous lead, Dr. Emily Cobabe-Ammann. As part of this transition, Renfrow revisited the existing E/PO plan to include updates of programming elements and costs.

6.4.1 Journalist Workshop

NASA has traditionally identified activities that promote the education of the general public as part of E/PO and those that involve journalists and the media as part of Public Affairs. However, over the last several years, there has been recognition that in the interest of "full spectrum science communication," journalists, who deliver more than 85% of the science news and content to the general public, may be legitimately seen as an audience for E/PO activities. The goal of these activities is not to promote a specific story, event, or theme, but instead to broaden and deepen journalists' understanding of space science and to promote increased communication and understanding among journalists, scientists and educators. It is in our interest to have journalists competently well-informed and captured by the excitement of space sciences and exploration.

The May 2010 journalist workshop carried on a 5-year legacy of media professional development workshops by Dr. Emily CoBabe-Ammann, the CCLDAS E/PO lead through October 2010. The program was attended by 11 nationally recognized journalists and six scientists, as well as an astronaut. Seven areas were covered:

Bill Bottke	SWRI Boulder	NLSI/CLOE	Bombardment History of the Moon
Steven Moijzis	CU Boulder	NLSI/CLOE	The missing history of the Moon
Jasper Halekas	UC Berkeley	NLSI/DREAM	The lunar space plasma environment
Mihaly Horanyi	CU Boulder	NLSI/CCLDAS	Moon: A Dusty Plasma Laboratory
Benjamin Weiss	MIT	NLSI/Brown-MIT	The Possibility of a Lunar Core
Alan Stern	SWRI Boulder	NLSI/CCLDAS	The Future of Lunar Science
Jeff Ashby	Blue Origins		The Future of Lunar Exploration

These workshops, starting in 2011, have been picked up as an NLSI core activity. The first of the NLSI/CCLDAS media workshops set the groundwork for workshops to come. We are focusing on three themes: 1) The current state of our understanding of the Moon system, 2) How we can use the Moon as a place to conduct natural experiments, and 3) Discussion of the direction of lunar exploration, both within NASA and within the commercial space industry.

6.4.2 Lunar Graduate Conference (LunGradCon 2010/2011)

The Lunar Graduate Conference (LunGradCon), modeled after the highly successful Astrobiology Graduate Conference (AbGradCon), was initiated by members of CCLDAS and has been held in July, 2010 and July, 2011. Adrienne Dove and Andrew Poppe were the lead organizers the first year, working with Amy Fagan (a graduate student working with Clive Neal at Notre Dame), and Catherine Neish (a postdoc working with Ben Bussey at the Applied Physics Laboratory). The 2011 organizing committee was comprised of Adrienne Dove, Heidi Fuqua (a graduate student working with Imke dePater at the University of California, Berkeley), Alicia Muirhead (a graduate student at the University of Colorado), and Georgiana Kramer (a postdoc working with David Kring at the Lunar and Planetary Institute/CLSE).

The purpose of LunGradCon is to enhance the professional development of graduate students and early postdoctoral researchers by providing an opportunity to present and discuss scientific research in an environment of their peers. For the first two years, LunGradCon has been held as a one-day conference in conjunction with the NLSI Lunar Science Forum at the NASA Ames Research Center. Activities include an invited overview talk on each of the NLSI's three main research areas (OF the Moon, ON the Moon, and FROM the Moon), submitted oral presentations from graduate students and postdoctoral researchers, and networking opportunities with established member of the lunar science community and NLSI.

In each of the first two years of LunGradCon, there have been 20-25 attendees, with about 15 of those presenting submitted talks (**Figure 6.4.1**). Each speaker received feedback forms from the other participants in order to improve on their presentation techniques. Participants also provided feedback on the conference as a whole in order to evaluate the content and provide suggestions for improvement in following years. Overall, the feedback has been extremely positive. Students commented that they appreciated the "low-stress" environment, which gave them a chance to improve their speaking ability and confidence. Additionally, many of the graduate students formed connections with students in other fields and at other universities and institutions, which will help to strengthen their future careers in lunar science. LunGradCon 2012 is already in the planning stages, and will likely be in a 1.5-day format, with additional activities including an invited speaker and a tour of NASA Ames Research Center to be added to the schedule. More information is available online about LunGradCon 2012 at: http://lasp.colorado.edu/ccldas/lgc2012/.

Figure 6.4.1. Attendees of LunGradCon 2010 (left) and 2011 (right).

6.4.3 Lunar Science Summer School

Seeing an opportunity to leverage the diverse research experience of the Lunar Science Institutes, we have begun planning a Lunar Science Summer School for graduate students. We are testing the concept in the summer of 2012 as a one-day meeting connected to LunarGradCon, before the annual Lunar Science Forum. The goal of the summer school is to provide global context for graduate students pursuing research in any area of lunar science, by exposing them in a quasi-academic environment (e.g. tutorials) to one area of lunar research (e.g. plasma interactions) or one multi-disciplinary problem in lunar science (e.g. regolith redistribution). If our proposed effort in 2012 is successful then we will pursue the summer school concept on an annual basis – perhaps coupling a summer meeting of participating graduate students with a semester-long remote participation seminar that culminates in the meeting and small group projects.

6.4.4 International Observe the Moon Night (InOMN 2010/2011)

Saturday, September 18, 2010, marked the first annual International Observe the Moon Night. InOMN is an outreach event created to get the public interested in the Moon, give them a chance to look through telescopes and learn about the Moon, and see how exciting current lunar research can be. Adrienne Dove organized a CCLDAS event at the Courthouse Lawn on the Pearl Street Mall in downtown Boulder, CO (**Figure 6.4.2**). Many CCLDAS members were in attendance, including professors, researchers, and graduate and undergraduate students; other graduate students from CU helped out at the event, as well. Two homemade reflecting telescopes (with 15" and 17" primary mirrors) were set up on the lawn and aimed at the Moon and at Jupiter (which nicely had the four Galilean moons in full view) throughout the night. At least 200 people stopped by and "oohed" and "ahhed" as they peered through the eyepieces; for many it was their first time looking at the Moon through a telescope. We had a small telescope building activity for kids, led by CCLDAS graduate students, and a couple of other hands-on activities. A slide show of Moon facts was running for most of the evening, and Kim Ennico of NASA Ames presented a short talk on the LCROSS mission. The reception from the public was fantastic - we considered the event a great success.

Figure 6.4.2. On September 18, 2010, in downtown Boulder, a line of people gazed at the Moon with their homemade telescopes, most of which were built by K-12 students, but enjoyed by all ages!

Saturday, October 8, 2011 marked the second annual International Observe the Moon Night (**Figure 6.4.3**) Because of the success of the first InOMN, an event was again organized on the Courthouse Lawn in downtown Boulder. Many representatives of CCLDAS were at the event, including researchers and graduate and undergraduate students. Because of the unfortunately rainy and cold weather, the large telescopes used the previous year could not be set up, although we were able set up a small portable telescope for a brief window. We were still able to attract some attention to our table of handouts and activities, which included helping kids (of all ages!) build small telescopes that they could take home with them. Although the crowd was smaller, the volunteers and people who did stop by were excited about the event, and are looking forward to clear skies next year! More images for these events are available online at http://lasp.colorado.edu/ccldas/gallery.html.

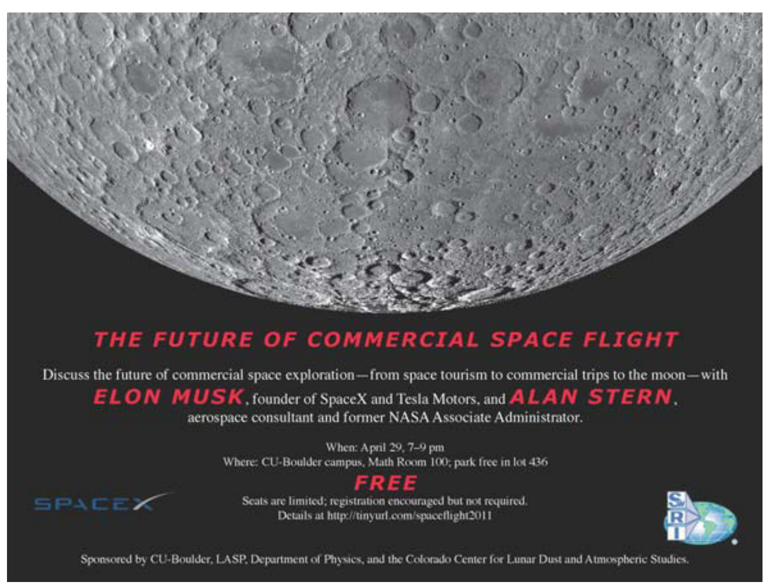
Figure 6.4.3 Ms. Adrienne Dove helps a group of girls assemble their handheld telescopes, which have CCLDAS and InOMN stickers.

6.4.5 Public Talks

1. Dust in Space – What can we learn from it?
   Z. Sternovsky, LASP public lecture, May 5, 2010.
2. Mysterious Moving Moon Dust.
   M. Horanyi, 365 days of Astronomy Podcast on November 23, 2010.
3. CU scientist and Vice Chancellor for Research Stein Sture made presentations at Boulder Valley School District's Platt Middle School on Nov. 5, 2010, to give two lectures on the same day to different classes on science and engineering research. Each presentation involved a full class period and included work in CCLDAS and science in general.

6.4.6 Public Symposia

On April 29, 2011, we coordinated our first of two CCLDAS public symposia. The topic of the symposium, "The Future of Commercial Space Flight," was selected because it is an exciting and timely subject pertaining to lunar science and lunar exploration. The symposium featured nationally known entrepreneur Elon Musk, as well as former NASA Associate Administrator and CCLDAS member Alan Stern. In anticipation of the popularity of the event, we offered free online tickets for attendees who wanted to reserve their spots ahead of the event. By April 15th, the



reservation system was "sold out" at the room capacity of 420 seats, with a long waiting list. The audience, primarily CU students and members of the Front Range community, enjoyed the event so much that our speakers received a standing ovation at the close of the event. We archived the video online; as of January 24, 2012, the archived video has had 218 views on Ustream and 680 views on YouTube—thus, the symposium has continued to reach audiences well after the in-person event ended (www.youtube.com/watch?v=ZQcZ9pKsliQ). Our next public symposium is slated for spring 2013; planning has not yet begun for this event, but we aim for a similar reach and focus on up-and-coming topics.

6.4.7 CCLDAS Supported Courses and Student Development

CCLDAS research involves both undergraduate and graduate students. Our experimental students learn to maintain and use vacuum systems, computerized data acquisition, and all of them have taken a week-long machining class to learn how to safely use power tools, including our on-site Bridgeport milling machine.

1. *Graduate Planetary Seminar* (2010): CCLDAS, in partnership with the Lunar University Network for Astrophysical Research (LUNAR) at the University of Colorado and the Center for Lunar Evolution and Origin (CLOE) at the Southwest Research Institute, offered a graduate seminar class in lunar science during the Spring 2010 semester. The seminar covered all three main aspects of NASA's Lunar Science Institute: Of the Moon, On the Moon and From the Moon.

2. *Graduate Planetary Seminar* (2011): CCLDAS members Z. Sternovsky and M. Horanyi organized a graduate level seminar class about spacecraft instrumentation.

3. *Graduate Plasma Physics*: The Physics Department at the University of Colorado offers a yearly graduate course in plasma physics. The PHYS 5150 now includes a section on dusty plasma physics problems of the lunar surface, and was taught by CCLDAS members M. Horanyi (Spring 2010), and S. Robertson (Spring 2011).

4. *Aerospace Engineering Senior Project*: ASEN 4018/4028 was a two-semester course covering the entire instrument development process, ending in the summer of 2010. The course was structured and run as a NASA hardware-project.

6.4.8 Professional Community Development—Media Training Workshops

For fall of 2012, we are planning three half-day workshops for graduate students and early-career scientists. The workshops will be facilitated by LASP and CCLDAS team members. The workshops will invite participants from other NLSI teams as well as participating CU departments and institutions. The topics we will cover are: a) Introduction to today's media; b) Learning from the experts: A panel with media-savvy scientists; and c) What do they want? A panel with the media.

6.4.9 Online Presence

In addition to public talks and symposia, CCLDAS also maintains a robust online presence in order to connect with the public through "new media", including:

1. Webpages: http://lasp.colorado.edu/ccldas/
2. Student Blog: http://ccldas.blogspot.com/
3. Flickr: www.flickr.com/photos/ccldas/
4. Webcam: http://dustcam.colorado.edu

6.5. PUBLICATIONS

CCLDAS organized the LDAP-2010 workshop "Lunar, Dust, and Atmosphere: The Next Steps" (http://lpa2010.colorado.edu/). The meeting was a forum to discuss our current understanding of the lunar surface and atmosphere, and share results from past and still ongoing missions. It focused on the open science questions, the status of our modeling and laboratory experimental capabilities, required measurements, and instrument capabilities for future investigations on orbit, or to be deployed on the lunar surface. The special issue of Planetary and Space Sciences (Volume 59, Issue 14) titled "Lunar Dust, Atmopshere, and Plasma: The Next Steps" has been published in November 2011. A follow-up meeting DAP-2012 "Dust, Atmosphere and Plasma: Moon and Small Bodies" will take place in Boulder in June 6-8, 2012, in Boulder, Colorado.

6.5.1 Publications in Refereed Journals

(*** joint NLSI Team Publication; student author)

1. X. Wang, M. Horanyi, S. Robertson, Experiments on dust transport in plasma to investigate the origin of the lunar horizon glow, J. Geophys. Res., 114, Issue A5, CiteID A05103, 2009.
2. D. James, V. Hoxie, M. Horanyi, Polyvinylidene Fluoride Dust Detector Response to Particle Impacts, Rev. Sci. Instruments, **81**, 034501, 2010.
3. A. Poppe, M. Horanyi, Simulations of the Photoelectron Sheath and Dust Levitation on the Lunar Surface, J. Geophys. Res. **115**, A08106, doi:10.1029/2010JA015286, 2010.
4. S. Auer, G. Lawrence, E. Grün, H. Henkel, S. Kempf, R. Srama, Z. Sternovsky, A self-triggered dust trajectory sensor, Nucl. Instrum. and Meth. A, doi:10.1016/j.nima.2010.06.091, 2010.
5. A. Poppe, B. Jacobsmeyer, D. James, M. Horanyi, Simulation of Polyvinylidene Fluoride Detector Response to Hypervelocity Particle Impact, Nucl. Instr. Meth. A, **622**, 583-587, 2010.
6. X. Wang, M. Horanyi, S. Robertson, Investigation of dust transport on the lunar surface in a laboratory plasma with an electron beam, J. Geophys. Res., **115**, A11102, doi:10.1029/2010JA015465, 2010.
7. M. Horányi, O. Havnes, G.E. Morfill, Dusty plasmas in the solar system, in: Complex and Dusty Plasmas: From Laboratory to Space, Edited by Vladimir E. Fortov and Gregor

E. Morfill. Published by CRC Press/Taylor & Francis, Boca Raton 2010. ISBN: 9781420083118, p.291
8. A. Poppe, J. S. Halekas, and M. Horanyi, Negative potentials above the day-side lunar surface in the terrestrial plasma sheet: evidence of non-monotonic potentials, Geophys. Res. Lett., **38**, L02103, 2011. ***
9. X. Wang, M. Horanyi, S. Robertson, Dust transport near electron beam impact and shadow boundaries , Planetary and Space Science, 59, 791-1794, 2011.
10. E. Grun, M. Horanyi, and Z. Sternovsky, The Lunar Dust Environment, Planetary and Space Science 59, 1672-1680, 2011.
11. F. Postberg, E. Grun, M. Horanyi, S. Kempf, H. Kruger, R. Srama, Z. Sternovsky, and M. Trieloff, Compositional Mapping of Moon Surfaces by Mass Spectrometry of Dust Ejecta, Planetary and Space Science, 1815-1825, 2011.
12. N. Duncan, Z. Sternovsky, E. Grun, S. Auer, M. Horanyi, K. Drake, J. Xie, G. Lawrence, D. Hansen, The Electrostatic Lunar Dust Analyzer (ELDA) for the detection and trajectory measurement of slow dust particles on the lunar surface, Planetary and Space Science 59, 1446-1454, 2011. ***
13. M. Horanyi, A. Stern, Lunar dust, atmosphere and plasma: The next steps, Planetary and Space Science 59, 1671, 2011.
14. J. Xie, Z. Sternovsky, E. Grun, S. Auer, N. Duncan, K. Drake, H. Le, M. Horanyi, and R. Srama, Dust Trajectory Sensor: Accuracy and data analysis, Review of Scientific Instruments 82, 105104 (doi: 10.1063/1.3646528), 2011. ***
15. X. Wang, M. Horanyi and S. Robertson, Dust Transport on a Surface in Plasma, IEEE Transactions on Plasma Science 39, 2730, 2011.
16. A. Dove, G. Devaud, X. Wang, M. Crowder, A. Lawitzke and C. Haley, Mitigation of lunar dust adhesion by surface modification, Planet. Space Sci., 59, 1784, 2011.
17. Z. Sternovsky, E. Grun, K. Drake, J. Xie, M. Horanyi, R. Srama, S. Kempf, F. Postberg, A. Mocker, S. Auer, H. Kruger, Novel Instrument for Dust Astronomy: Dust Telescope, Aerospace Conference, 2011 IEEE, 1-8, , doi: 10.1109/AERO.2011.5747300 , 2011.
18. Kempf, S., Srama, R., Grün, E., Mocker, A., Postberg, F., Hillier, J. K., Horanyi, M., et al. Linear high resolution dust mass spectrometer for a mission to the Galilean satellites. Planetary and Space Science. doi:10.1016/j.pss.2011.12.019, 2011.
19. A. Mocker, S. Bugiel, S. Auer, G. Baust, A. Colette, K. Drake, K. Fiege, E. Grün, F. Heckmann, S. Helfert, J. Hillier, S. Kempf, G. Matt, T. Mellert, T. Munsat, K. Otto, F. Postberg, H. Röser, A. Shu, Z. Sternovsky, R. Srama, A 2 MV Van de Graaff accelerator as a tool for planetary and impact physics research, Review of Scientific Instruments, 82, 095111-095111-8, 2011.
20. E. Grun, Z. Sternovsky, M. Horanyi, V. Hoxie, S. Robertson, J. Xie, S. Auer, M. Landgraf, F. Postberg, R. Srama, N. Starkey, J. Hillier, M. C. Price, I. A. Franchi, P. Tsou, A. Westphal, Z. Gainsforth, Active Cosmic Dust Collector, Planet. Space Sci. 60, 261-273, 2012.

6.5.2 Refereed Publications in Review

1. Nicholas B. Childs, Anthony Shu, Andrew Collette, Keith Drake, Mihaly Horanyi, Measuring the Speed of Hypervelocity Dust Particles, American Journal of Physics, submitted, 2011
2. J. S. Halekas, A. Poppe, G.T. Delory, W.M. Farrell, M. Horanyi, Solar Wind Electron Interaction with the Dayside Lunar Surface and Crustal Magnetic Fields: Evidence for Precursor Effects, Earth, Moon and Planets, submitted, 2011. ***
3. H.-W Hsu, M. Horanyi, Ballistic motion of dust particles in the Lunar Roving Vehicle dust trails, American Journal of Physics, submitted, 2011
4. A. Collette, S. Robertson, An Ion Analyzer for the Lunar Surface with E Parallel to B, Advances in Space Research, submitted, 2011.
5. Anthony Shu, Andrew Collette, Keith Drake, Eberhard Gruen, Mihaly Horanyi, Sascha Kempf, Anna Mocker, Tobin Munsat, Paige Northway, Ralf Srama, Zoltan Sternovsky, and Evan Thomas, The 3 MV Hypervelocity Dust Accelerator at the Colorado Center for Lunar Dust and Atmospheric Studies, Review of Scientific Instruments, submitted, 2012.
6. Paige Northway, Siegfried Auer, Keith Drake, Mihaly Horanyi, Anna Mocker, Tobin Munsat, Evan Thomas, Anthony Shu, Zoltan Sternovsky, and Jianfeng Xie, Beamline position sensing by charge induction, Review of Scientific Instruments, submitted, 2012.

6.6. CONFERENCE PAPERS

Total number of conference papers, extended abstracts, poster and oral presentations: 49 (http://lasp.colorado.edu/ccldas/publications.html)

6.6.1 Published Conference Proceedings and Abstracts

1. T. Munsat, Z. Sternovsky, S. Robertson, E. Grun, M. Horanyi, Lunar Dust TransportPackage, 41st Lunar and Planetary Science Conference (2010), Abstract #2538
2. T. Delory, R. C. Elphic, A. Colaprete, P. Mahaffy, M. Horanyi, The LADEE Mission: The Next Step After the Discovery of Water on the Moon, 41st Lunar and Planetary Science Conference (2010), Abstract #2459
3. A. Dove, S. Dickson, S. Robertson, Z. Sternovsky, X. Wang, M. Horanyi, Characterization of a UV-generated Photoelectron Sheath, 41st Lunar and Planetary Science Conference (2010), Abstract #2406
4. A.R. Poppe, M. Horanyi, Simulations of the Lunar Photoelectron Sheath and Associated Dust Grain Levitation Equilibria, 41st Lunar and Planetary Science Conference (2010), Abstract #1218
5. P A. Likhanskii, A. Poppe, M. Piquette, P. Messmer and M. Horanyi, Plasma Sheath at the Lunar Craters: from Sunrise to Sunset, 42nd Lunar and Planetary Science Conference (2011), Abstract # 2285
6. M. Horanyi, Z. Sternovsky, E. Grun, S. Kempf, R. Srama, F. Postberg, LDEX+ Lunar Dust Experiment with Chemical Analysis Capability to Search for Water, 42nd Lunar and Planetary Science Conference (2011), Abstract #1656

7. A. Dove, S. Robertson, X. Wang, A. Poppe, Z. Sternovsky, and M. Horanyi, Characterization of a Laboratory Simulated Lunar Photoelectron Sheath, 42nd Lunar and Planetary Science Conference (2011), Abstract #2650
8. Horanyi, M., Munsat, T., Sternovsky, Z., Kempf, S., Colette, A., Wang, X., Robertson, S., Mocker, A., Grun, E., NASA Lunar Science Institute: Colorado Center for Lunar Dust and Atmospheric Studies, Annual Meeting of the Lunar Exploration Analysis Group, (2011) LPI Contribution No. 1646.
9. X. Wang, S. Robertson, and M. Horanyi, Dust charging and transport on surfaces, Dusty/Complex Plasmas: Basic and Interdisciplinary Research, Sixth International Conference on the Physics of Dusty Plasmas, Garmisch-Partenkirchen, Germany, 2011.
10. C.D. Neish, S. Besse, G. Kramer, W. Farrell, C. Pieters, M. Horanyi, Y. Pendleton, Virtual Swirls: Highlights from NLSI's First Workshop Without Walls, 42nd Lunar and Planetary Science Conference (2011), Abstract #2034
11. Z. Sternovsky, S. Auer, K. Drake, E. Grun, M. Horanyi, H. Le, R. Srama, and J. Xie, Frontiers in in-situ cosmic dust detection and analysis, Dusty/Complex Plasmas: Basic and Interdisciplinary Research, Sixth International Conference on the Physics of Dusty Plasmas, Garmisch-Partenkirchen, Germany, 2011.
12. M. Horanyi, A. Collette, K. Drake, E. Grun, S. Kempf, T. Munsat, S. Robertson, A. Shu, Z. Sternovsky, and X. Wang, The dust accelerator facility of the Colorado Center for Lunar Dust and Atmospheric Studies, Dusty/Complex Plasmas: Basic and Interdisciplinary Research, Sixth International Conference on the Physics of Dusty Plasmas, Garmisch-Partenkirchen, Germany, 2011.
13. Adrienne Dove, Scott Robertson, Mihaly Horanyi, Andrew Poppe, and Xu Wang, Operation of a Langmuir probe in a photoelectron plasma, Dusty/Complex Plasmas: Basic and Interdisciplinary Research, Sixth International Conference on the Physics of Dusty Plasmas, Garmisch-Partenkirchen, Germany, 2011.
14. Munsat T., Collette A., Drake K., Grun E., Horanyi M., Kempf S., Mocker A., Northway P., Robertson S., Shu A., Sternovsky Z., Thomas E., The Dust Accelerator Facility of the Colorado Center for Lunar Dust and Atmospheric Studies, 43rd Lunar and Planetary Science Conference (2012), Abstract #2730
15. Dove A., Poppe A., Fagan A. L., Neish C., Fuqua H., Kramer G., Szalay J., Horanyi M. LunGradCon: The Lunar Graduate Student Conference, 43rd Lunar and Planetary Science Conference (2012), Abstract #2713
16. Horanyi M., Sternovsky Z., Lankton M., James D., Szalay J., Drake K., Shu A., Colette A., Gruen E., Kempf S., Srama R., Mocker A., The Dust Environment of the Moon: Expectations for the Lunar Dust Experiment (LDEX) The Lunar Graduate Student Conference, 43rd Lunar and Planetary Science Conference (2012), Abstract #2635
17. Collette A., Horanyi M., Drake K., Mocker A., Sternovsky Z., Munsat T., Cintala M., Experimental Investigation of Light Flash from Hypervelocity Impacts, 43rd Lunar and Planetary Science Conference (2012), Abstract #2793
18. Szalay J. R. , Horanyi M., Modeling Dust Clouds on the Moon, 43rd Lunar and Planetary Science Conference (2012), Abstract #1796
19. Stern S. A., Gladstone G. R., Horanyi M., Kutter B., Goldstein D. B., Tapley M., Synthetic Lunar Atmosphere Experiments and Base Resupply Mission Concept , 43rd Lunar and Planetary Science Conference (2012), Abstract #1008
20. Dove A., Robertson S., Wang X., Horanyi M., Surface Effects on Photoelectron Sheath Characteristics 43rd Lunar and Planetary Science Conference (2012), Abstract #2421

6.6.2 Colloquia, invited talks, and NLSI Seminars

1. INVITED TALK: 'Dusty Plasmas on the Lunar Surface, and the new Lunar Science Center at CU', T. Munsat, seminar presented to the Colorado REU program, July 7, 2009
2. INVITED TALK: 'Dusty plasma studies at the University of Colorado Lunar Science Center', T. Munsat, International Workshop on Frontiers in Space and Fusion Energy Sciences (Tainan, Taiwan), December 3, 2009
3. COLLOQUIUM: 'CCLDAS Colorado Center for Lunar Dust and Atmospheric Studies, Z. Sternovsky, Max-Planck Institute for Nuclear Physics, December, 2009.
4. INVITED TALK: 'A Short History of Dust Accelerators', T. Munsat, 21st International Conference on the Application of Accelerators in Research and Industry (Fort Worth Texas), Aug. 8-13, 2010
5. INVITED TALK: 'In Situ Measurements of Interplanetary and Interstellar Dust', M. Horanyi, UC Irvine, CA (03/2010)
6. INVITED TALK: 'Charged dust in the Solar System: Direct and Indirect Evidence', M. Horanyi, AAS, Miami, FL (5/2010)
7. INVITED TALK: 'Plasma Physics of the Lunar Surface', M. Horanyi, ICTP, Trieste, Italy (7/2010)
8. INVITED TALK: 'The Lunar Surface: A Dusty Plasma Laboratory', Robotic Science From the Moon: Gravitational Physics, Heliophysics and Cosmology, T. Munsat, (10/2010), Boulder, CO
9. INVITED TALK: 'Investigation of near-surface lunar dust transport in the laboratory', Z. Sternovsky, 38th COSPAR Scientific Assembly, 18 – 25 July 2010, Bremen, Germany
10. NLSI SEMINAR: 'The lunar surface: a dusty plasma laboratory', Z. Sternovsky, NLSI Director's Virtual Seminar Series, November 8, 2010
11. NLSI SEMINAR: "Plasma physics of the lunar surface", A. Poppe, NLSI Director's Virtual Seminar Series, May 18, 2010
12. INVITED TALK: 'The 3MV Dust Accelerator at the Colorado Center for Lunar Dust and Atmospheric Studies', T. Munsat, POSTECH University plasma physics seminar (Pohang, Korea), September 21, 2011
13. INVITED TALK: 'Revisiting the Moon: detection and analysis of lunar dust', Z. Sternovsky, Department of Meteorology, Stockholm University, Stockholm, Sweden, Sep 26, 2011.
14. INVITED TALK: 'Frontiers in in-situ cosmic dust detection and analysis', Z. Sternovsky, 6th International Conference on the Physics of Dust Plasmas, Garmish-Partenkirchen, Germany, May 16-20, 2011
15. COLLOQUIUM: 'Dust detection in space', Z. Sternovsky, PhD Research School organized by the University of Oslo, Andoya Rocket Range, Norway, Oct. 5, 2011
16. COLLOQUIUM: 'Physics of the Lunar Surface', M. Horanyi, Colorado State University, Colorado Springs, CO (9/2011)
17. NLSI Workshop Without Walls, Laboratory investigations of the lunar electrical environment, Lunar Swirls, Xu Wang, September 7, 2011
18. INIVTED TALK: 'Solar wind plasma and UV effects on Surfaces in Space', M. Horanyi, AGU (12/2011)
19. INVITED TALK: 'Impact ionization spectra of cosmic dust analogues', S. Kempf, AGU (12/2011)

6.6.3 Undergraduate Conference at LPSC Presentations (2011/2012)

1. Electrostatic Effects on Dust Transport in the Lunar Plasma Environment.
   M. Piquette, A. Poppe, M. Horanyi, P. Messmer, and A. Lihkanskii (2011)
2. Beam Line Focusing and Alignment for a New Dust Particle Accelerator,
   Northway P., Auer S., Drake K., Grün E., Horányi M., Munsat T., Thomas E., Shu A. (2011)
3. Dust Detection for a Lunar Dust Accelerator,
   Thomas E., Shu A., Collette A., Drake K, Munsat T., Horányi M., Sternovsky Z. (2011)
4. Dust Transport in the Lunar Plasma Environment.
   M. Piquette, A. Poppe, M. Horanyi, P. Messmer, and A. Lihkanski (2012)

6.7. NEW FACULTY, POST.DOCS, STUDENTS

6.7.1 New Faculty

Completing a highly competitive search process in 2010 CCLDAS was successful to fill two new faculty lines at the University of Colorado.

1) In May 2011 Sascha Kempf joined CCLDAS, moving from the Max-Planck-Institute for Nuclear Physics in Heidelberg, Germany. His contributions to CCLDAS are focused on dust and plasma instrument development for surface application, and preparations for the data analysis and interpretation for LDEX measurements onboard the LADEE mission. Sascha is rostered in the Physics Department.

2) In July 2011 David Brain joined the CCLDAS team, moving from the University of California Berkeley to the University of Colorado. His contributions to CCLDAS include analysis of spacecraft data from the Moon (jointly supported by the ARTEMIS mission), and pursuit of a CCLDAS-led outreach activity. David is rostered in the Department of Astrophysical and Planetary Sciences.

6.7.2 Post. Docs.

Andrew Colette	Impact plasma experiments, UHV chamber
Anna Mocker	Ion mass spectrometry using TOF techniques (supported by DLR, Germany)

6.7.3 Students

Graduate Students	**Project**
Addrienne Dove	Photoelectron sheath experiments
Andrew Poppe (graduated, 2011)	Theory and modeling (Post.Doc. with the NLSI DREAM Team at UC Berkeley)
Anthony Shu	LEIL Impact phenomena
Jamey Szalay	LDEX Theory support
Jianfeng Xie	ELDA Theory support
Christine Hartzell	Dust adhesion theory/experiments
Evan Thomas	FPGA Design for particle selection
Summer Graduate Interns	
Alex Belt (NC State Univ.)	Particle selection unit electronics
Nick Childs (Montana State U.)	Impact experiments
Undergraduate Students	
Christopher Anaya	Light-flash experiments
Nicholaus Beaty	Detector electronics
Spencer LeBlanc (graduated, 2011)	Beam line design/assembly
Shannon Dickson	DPL diagnostics
Huy Le	ELDA
Spenser Burrows	Accelerator HV electronics
Nicole Duncan (graduated, 2011)	Detector Electronics Design (grad. student with the NLSI DREAM Team at UCB)
Paige Northway (graduated, 2011)	Position sensors and beam focusing
Marcus Piquette	VORPAL modeling
Tyler Wingfield	PSU design
Hemal Semwal	Beam-line assembly
Todd Strong	Tribo-electric charging experiments
Michael Wagner (graduated)	HV optical switching
High School Students	
Jordan Stern (Niwot HS)	Detector electronics development
Nick Boschert (Broomfield HS)	Monochromator refurbishing

6.7.4 Student Awards

1) CCLDAS graduate student Andrew Poppe has received AGU's Outstanding Student Paper Award from the December 2010 meeting for his work on simulations of the photoelectron sheath on the lunar surface. His paper, "Non-monotonic potentials above the lunar surface: implications for electron reflectometry measurements" was presented in the planetary science section of the meeting and is accompanied by a publication in Geophysical Research Letters entitled, "Negative potentials above the dayside lunar surface in the terrestrial plasma sheet: evidence of non-monotonic potentials." (GRL 38, L02103, 2011)

2) CCLDAS undergraduate student Marcus Piquette has been awarded a 2011-2012 Achievement Rewards for College Scientists (ARCS) Scholarship. He currently works with M. Horanyi on simulations of the photoelectron sheath and dust dynamics on the lunar surface. Information about the ARCS Scholarship: http://www.arcsfoundation.org/.

3) Nick Boschert (Broomfield High School) was awarded first place in the Physics category in the "40th Roche Boulder Valley Regional Science Fair" in February 2012, with his project titled "Monochrometer, Repair and Recalibration." Nick worked on this project guided by Andrew Colette at CCLDAS.