National Aeronautics and Space Administration

YEARS 1-3 ***EXECUTIVE SUMMARY***

Colorado Center for Lunar Dust and Atmospheric Studies (CCLDAS)

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NASA LUNAR SCIENCE INSTITUTE

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 1**).

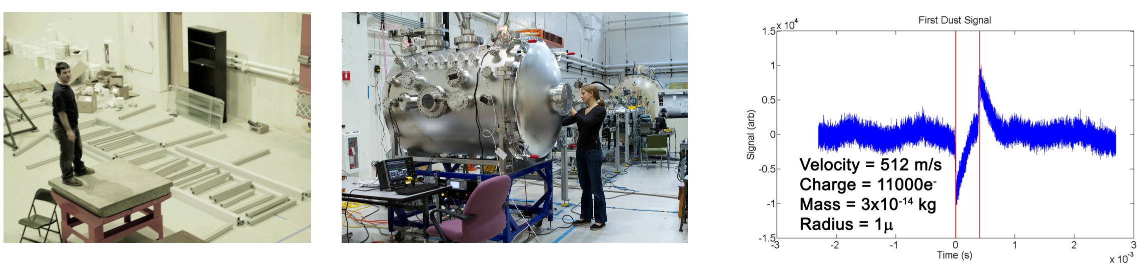

Figure 1. The start of the construction of the CCLDAS dust accelerator at the end of 2009 (left), and the completed facility after recording of our first dust signal in April 2011 (middle). The first recorded dust signal from an in-beam charge pickup-tube detector (right). A time-lapse video of the arrival 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.

Lunar Environment and Impact Laboratory (LEIL)

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 2 and 3.**).

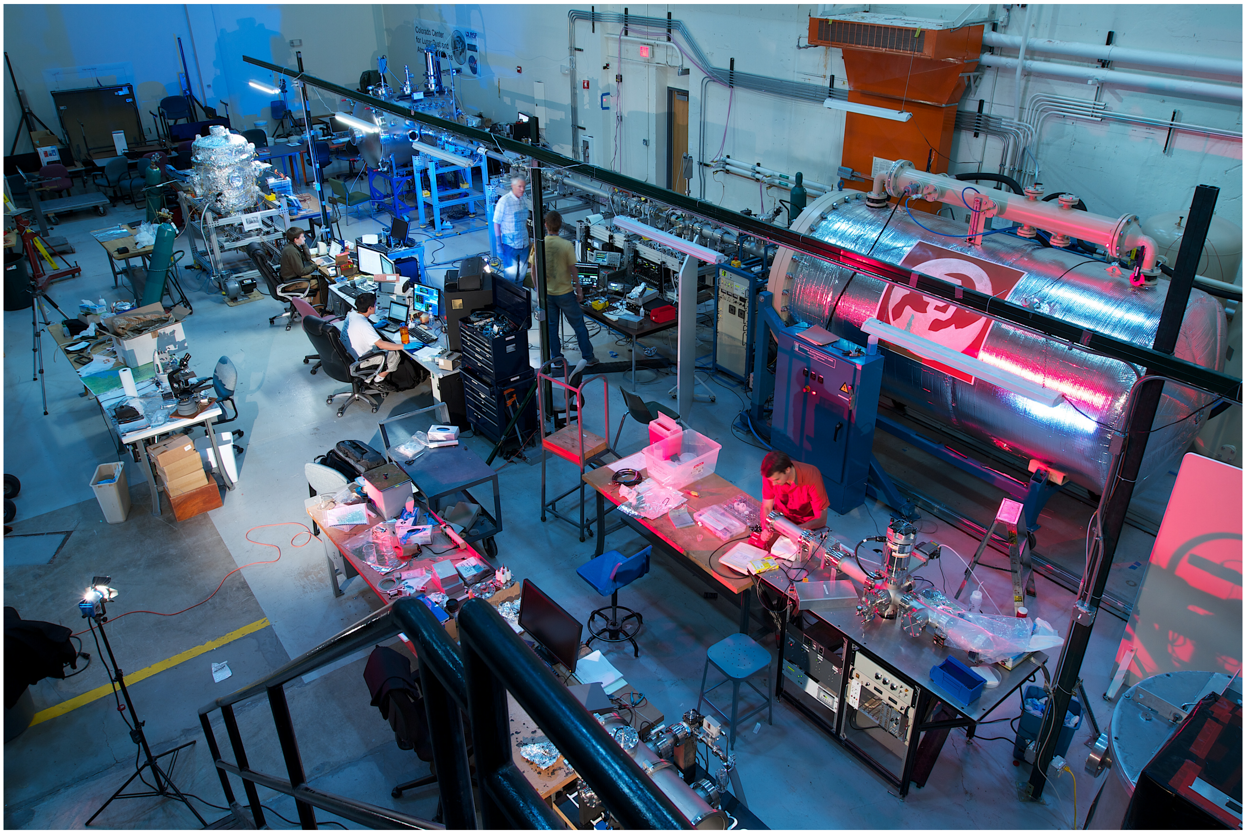

Figure 2. 3 MV dust accelerator installed at the CCLDAS Lunar Environment and Impact Laboratory. The accelerator is used to simulate the effects of dust impacts with speeds >> 10 km/s for micron sized projectiles. The facility is also used to test and calibrate plasma and dust instruments, including the Lunar Dust EXperiment (LDEX) for the LADEE mission. The facility is now operational and available for the lunar community for impact studies.

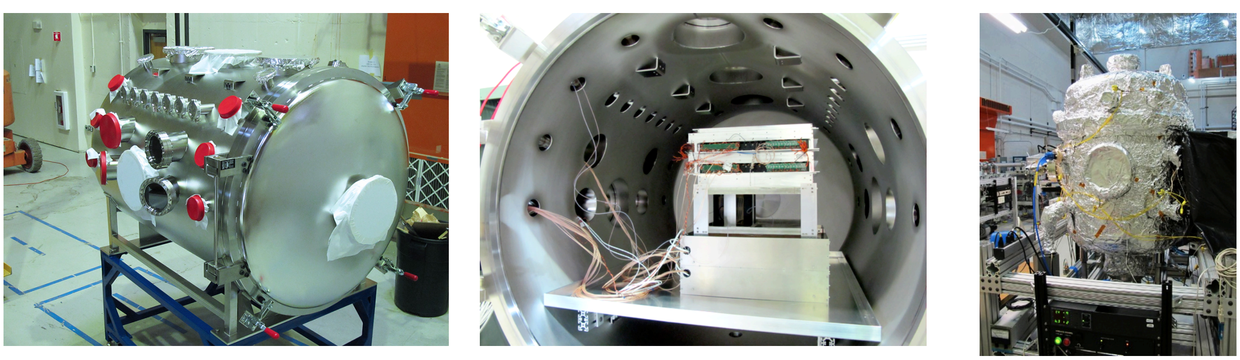

Figure 3. The Lunar Environment and Impact Laboratory PRIMARY chamber exterior (left) and interior (middle) housing a dust-trajectory instrument for testing. This impact chamber will house UV, electron, and ion sources to simulate the variable plasma conditions on the lunar surface, and acts as a target chamber for the dust accelerator. The UHV (right) chamber, is designed for experiments of impact products, where ultra-high vacuum conditions are required.

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 3**). 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.

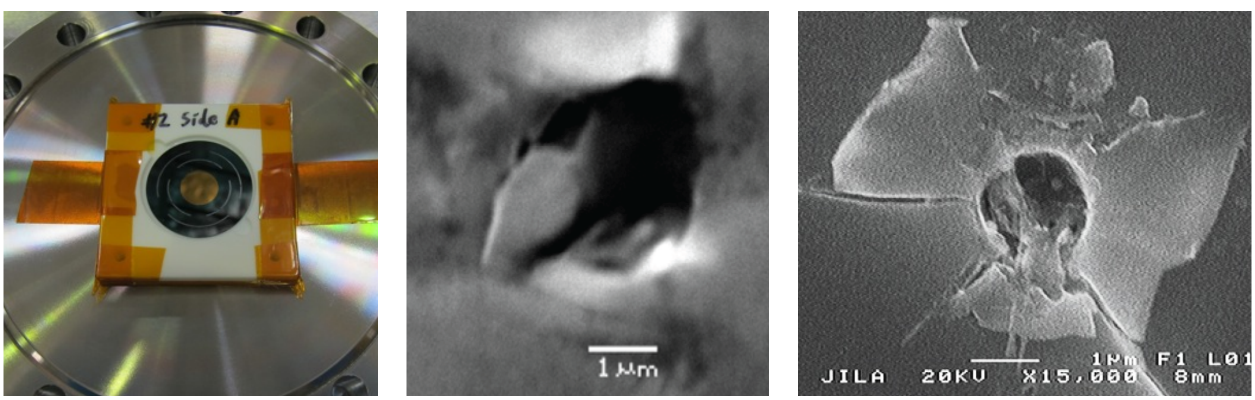

Figure 3. Images of various experiments from the initial accelerator runs. On the left is a foil sample from Solar Probe Plus. The center photograph shows the penetration damage at high magnification. Micrometeoroid damage to a fused quartz retroreflector sample is shown at right.

INTER-TEAM COLLABORATIONS

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..

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.

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.

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.

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