Trajectory Measurements on the Colorado Dust Accelerator Using a Dual Dust Coordinate Sensor

Name:	William Goode
Research Advisor:	Prof. Tobin Munsat
Research Field:	Dusty Plasmas
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Abstract

The Dust Coordinate Sensor (DCS) is a dual detector instrument located on the beamline of the 3 MV hypervelocity Dust Accelerator at the Institute for Modeling Plasma, Atmospheres and Cosmic Dust (IMPACT) at the University of Colorado, Boulder. This instrument measures the three-dimensional trajectories of charged, hypervelocity (3-8 km/s), micron-sized dust particles while in flight by utilizing the image charge on grids of wire electrodes. The position measurements are matched by timestamp with separate measurements of charge and velocity for each launched dust particle. By measuring the trajectories, the points of impact coordinates on a target can be pinpointed to within a fraction of a millimeter. This new capability also provides opportunities for profiling the particle beam.

Prospectus

The Dust Coordinate Sensor (DCS) was developed for use on the 3 MV electrostatic hypervelocity dust accelerator at the Institute for Modeling Plasma, Atmospheres and Cosmic Dust (IMPACT) at the University of Colorado, Boulder. Installed at two locations along the beamline, approximately 4m apart, this new instrument is capable of detecting the three-dimensional trajectories of each dust particle in flight. Micro-crater studies have been done in the recent past with limited knowledge of impactor characteristics using averages and size ranges [15]. The emphasis of this thesis will be the development of the data acquisition and analysis process using the dual detector configuration. The implementation of this new instrument will enable micro-crater studies using ono-to-one correspondence between each crater and impactor for the first time using particle trajectories. By measuring the velocity, charge, and trajectories of particles with known material properties, it is possible to characterize both the dust particle beam itself along with target impacts with increased precision.

Each of the two DCS instruments utilize induction charge on wire electrodes by a passing charged dust particle (See Figure 1). These wire electrodes are arranged into two planes of four wire electrodes, orthogonal to direction of flight, running vertical in the first plane and horizontal in the second plane [11]. While the particle is within a wire plane, it induces an image charge on each of the four wires. The ratio of the peak magnitude of the induced charge between the four wires depends on the particle's position within the plane. The vertical wire plane measurements are used to determine the x-position while the horizontal wire plane is used for the y-position. Each wire electrode is connected to a charge sensitive amplifier (CSA) so that the induced charge can be measured as a peak voltage on 16 different channels.

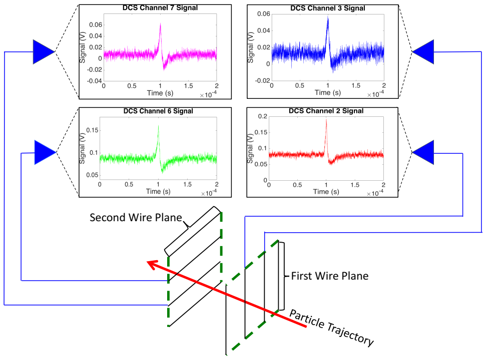

Figure 1: A particle passes through the DCS wire planes inducing an image charge on each wire. The CSA voltage waveforms for the inner two wires of each plane is shown.

The position-dependent ratios of induced charge on each of the eight wires were used to create a series of lookup tables using a COULOMB software simulation [11]. This table contains each x-y coordinate within the 12 X 12 mm^2 area covered by the wire planes with corresponding normalized peak values of induced charge on each wire with 0.5 mm resolution. This lookup table is used by an interpolation software routine in order to determine the best match between measured peak values and corresponding x-y coordinates at the location of each DCS instrument.

Data acquisition and analysis software has been developed for the purpose of utilizing the dual configuration of DCS enabling particle trajectory measurements. For data acquisition, DCS utilizes analogue to digital converter data acquisition cards (DAQs) for each of the 16 channels (eight per detector). Each DAQ is triggered externally by the accelerator's field programable gate array (FPGA). The FPGA tracks data acquired by the accelerators three separate image charge detectors [16]. The data from these detectors provide velocity (using time of flight) and total charge of individual particles. Once a particle fitting preselected parameters is detected, the FPGA sends a pulse signal to allow the particle to enter the target chamber. This pulse is also sent to the DCS DAQs in order to trigger at the appropriate time. The transient waveform data from DCS are matched by timestamp with corresponding data from the image charge detectors for each particle. Once the waveforms from both the DCS and image charge detectors are processed, data consisting of particle characteristics (e.g. mass and velocity) are paired with x-y coordinates at two locations on the beamline. We now have three-dimensional trajectories for individual particles.

At this point, DCS has measured hundreds of particle trajectories with matching image charge detector data. The aggregate results have been consistent with physical expectations so far. However, since we wish to locate particle impacts on a target with the best precision possible, the accuracy of DCS must be evaluated for individual particles. One way of achieving this is to use a backlight silver mirror target. While firing a few particles (up to one or two dozen), a video camera captures the impact locations indicated by light spots appearing at a time corresponding to a particle impact. A slow impact rate is used so as to allow for rough time matching with minimal uncertainty. The image if impact locations can be directly compared with trajectory plotted locations in order to determine error. I am currently comparing a recent set of backlit mirror impact data with DCS trajectory data. The results so far are promising. However, the software routine used to calculate minimum uncertainty for each position measurement needs improvement. Once this is done, the overall accuracy of DCS will be well characterized.

Using the best quality measurements, the uncertainty may be sufficiently reduced to allow locating individual impact craters utilizing the scanning electron microscope (SEM). This, along with the matched image charge detector data, would achieve the goal of providing one-to-one correspondence between impact craters and impactor characteristics. It is required that we know the location of each DCS detector and the target itself in relation to a common axis along the beamline. A reliable method for placing a target, such as a mirror, in alignment with beamline needs to be developed. Once we are able to reliably locate impact craters, we will begin characterizing them. The relation between impact crater and impactor characteristics will be analyzed and compared to previous studies. The overall goal is to improve upon experimental testing of previously used cratering scaling models, such as the ones used by Poppe et al [15], as well as to provide new beam profiling techniques for electrostatic dust accelerators.

References

[1] Siegfried Auer. Two high resolution velocity vector analyzers for cosmic dust particles. *Review of Scientific Instruments*, 46(2):127–135, 1975.

[2] Siegfried Auer, Eberhard Grün, Sascha Kempf, Ralf Srama, André Srowig, Zoltan Sternovsky, and Valentin Tschernjawski. Characteristics of a dust trajectory sensor. *Rev Sci Instrum*, 79(8):084501, Aug 2008.

[3] Siegfried Auer, George Lawrence, Eberhard Gruen, Hartmut Henkel, Sascha Kempf, Ralf Srama, and Zoltan Sternovsky. A self-triggered dust trajectory sensor. *Nucl. Instrum. Methods Phys. Res. Sect. A-Accel. Spectrom. Dect. Assoc. Equip.*, 622(1):74–82, October 2010.

[4] B.-K. Dalmann, E. Grün, J. Kissel, and H. Dietzel. The ion-composition of the plasma produced by impacts of fast dust particles. *Planetary and Space Science*, 25(2):135 – 147, 1977.

[5] H. Dietzel, G. Neukum, and P. Rauser. Micrometeoroid simulation studies on metal targets. *Journal of Geophysical Research*, 77(8):1375–1395, 1972.

[6] N. Duncan, Z. Sternovsky, E. Gruen, S. Auer, M. Horanyi, K. Drake, J. Xie, G. Lawrence, D. Hansen, and H. Le. The electrostatic lunar dust analyzer (ELDA) for the detection and trajectory measurement of slow-moving dust particles from the lunar surface. *Planet Space Sci.*, 59(13):1446–1454, October 2011.

[7] M. Horanyi, V. Hoxie, D. James, A. Poppe, C. Bryant, B. Grogan, B. Lamprecht, J. Mack, F. Bagenal, S. Batiste, N. Bunch, T. Chanthawanich, F. Christensen, M. Colgan, T. Dunn, G. Drake, A. Fernandez, T. Finley, G. Holland, A. Jenkins, C. Krauss, E. Krauss, O. Krauss, M. Lankton, C. Mitchell, M. Neeland, T. Reese, K. Rash, G. Tate, C. Vaudrin, and J. Westfall. The student dust counter on the new horizons mission. *Space Sci. Rev.*, 140(1-4):387–402, October 2008.

[8] M. Horanyi, Z. Sternovsky, M. Lankton, C. Dumont, S. Gagnard, D. Gathright, E. Gruen, D. Hansen, D. James, S. Kempf, B. Lamprecht, R. Srama, J. R. Szalay, and G. Wright. The lunar dust experiment (LDEX) onboard the lunar atmosphere and dust environment explorer (LADEE) mission. *Space Sci. Rev.*, 185(1-4):93–113, December 2014.

[9] M. Lambert. Hypervelocity impacts and damage laws. *Advances in Space Research*, 19(2):369 – 378, 1997. Space Debris.

[10] Andrew Oakleigh Nelson, Richard Dee, Murthy S. Gudipati, Mihály Horányi, David James, Sascha Kempf, Tobin Munsat, Zoltán Sternovsky, and Zach Ulibarri. New experimental capability to investigate the hypervelocity micrometeoroid bombardment of cryogenic surfaces. *Review of Scientific Instruments*, 87(2):024502, 2016.

[11] Paige Northway, Siegfried Auer, Keith Drake, Mihaly Horanyi, Anna Mocker, Tobin Munsat, Anthony Shu, Zoltan Sternovsky, Evan Thomas, and Jianfeng Xie. Characteristics of a new dust coordinate sensor. *Meas. Sci. Technol.*, 23(10), October 2012.

[12] Katharina A. Otto, Ralf Srama, Siegfried Auer, Sebastian Bugiel, Eberhard GrÃŒn, Sascha Kempf, and Jianfeng Xie. Application and calibration of a simple position detector for a dust accelerator. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 729:841 – 848, 2013.

[13] Andrew Poppe, Brian Jacobsmeyer, David James, and Mihály Horányi. Simulation of polyvinylidene fluoride detector response to hypervelocity particle impact. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 622(3):583 – 587, 2010.

[14] T See, M Albrooks, D Atkinson, and C Simon. Meteoroid and debris impact features documented on the long duration exposure facility. Technical report, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION HOUSTON TX LYNDON B JOHNSON SPACE CENTER, 1990.

[15] A. J. Shu. *Microcratering in Polyvinylidene Fluoride.* PhD thesis, University of Colorado at Boulder, 2015.

[16] Anthony Shu, Andrew Collette, Keith Drake, Eberhard Grün, Mihály Horányi, Sascha Kempf, Anna Mocker, Tobin Munsat, Paige Northway, Ralf Srama, Zoltán Sternovsky, and Evan Thomas. 3 MV hypervelocity dust accelerator at the colorado center for lunar dust and atmospheric studies. *Rev Sci Instrum*, 83(7):075108, Jul 2012.

[17] R. Srama, T. J. Ahrens, N. Altobelli, S. Auer, J. G. Bradley, M. Burton, V. V. Dikarev, T. Economou, H. Fechtig, M. Gorlich, M. Grande, A. Graps, E. Grun, O. Havnes, S. Helfert, M. Horanyi, E. Igenbergs, E. K. Jessberger, T. V. Johnson, S. Kempf, A. V. Krivov, H. Kruger, A. Mocker-Ahlreep, G. Moragas-Klostermeyer, P. Lamy, M. Landgraf, D. Linkert, G. Linkert, F. Lura, J. A. M. McDonnell, D. Mohlmann, G. E. Morfill, M. Muller, M. Roy, G. Schafer, G. Schlotzhauer, G. H. Schwehm, F. Spahn, M. Stubig, J. Svestka, V. Tschernjawski, A. J. Tuzzolino, R. Wasch, and H. A. Zook. The Cassini cosmic dust analyzer. *Space Sci. Rev.*, 114(1-4):465–518, 2004.

[18] J Xie, Z Sternovsky, E Grün, S Auer, N Duncan, K Drake, H Le, M Horanyi, and R Srama. Dust trajectory sensor: accuracy and data analysis. *Rev Sci Instrum*, 82(10):105104, Oct 2011.

Timeline

5-15 Sep 2017	Develop uncertainty calculations for position measurements.
NLT 1 Oct 2017	Finalize DCS instrument paper and submit.
1 Oct 2017	Begin writing honors thesis using DCS measurements.
1-15 Oct 2017	Write instrument operation chapter.
15-31 Oct 2017	Write error analysis chapter.
1-15 Nov 2017	Write instrument performance chapter.
15 Nov - 15 Dec 2017	Develop DCS hardware improvement concepts.
Jan 2018	Develop cratering experiments.
Feb 2018	Acquire cratering data on accelerator (Write thesis introduction).
1-15 March 2018	Finalize thesis chapters.
Apr 2018	Submit and defend thesis.