Lunar Swirls and Plasma Magnetic Field Interaction in the Laboratory. M. Dropmann[1,2], R. Laufer[1,2], G. Herdrich[2,1], L.S. Matthews[1], T.W. Hyde[1], [1]Center for Astrophysics, Space Physics and Engineering Research (CASPER), Baylor University, One Bear Place 97310, Waco, TX-76798-7310, [2]Institute of Space Systems (IRS), Universität Stuttgart, Raumfahrtzentrum Baden-Württemberg, Pfaffenwaldring 29, 70569 Stuttgart, Germany.

Introduction: At the Center for Astrophysics, Space Physics and Engineering Research (CASPER) at Baylor University, Texas, a GEC reference cell has been used to conduct experiments investigating magnetic field plasma surface interactions. The results of these experiments shall be used to help understand the formation of lunar swirls which are known to be located close to regions of magnetic anomalies. Strong crustal magnetic fields can influence the lunar plasma environment by separating charges and thus creating electric fields. This in turn can alter the incoming solar wind flux and dust transport processes. Experiments have been conducted to map electric forces in a plasma close to a magnet using dust as a probe. These experiments were conducted in preparation for future experiments within flowing plasma, representing the solar wind, which will be accomplished using the inductively heated plasma generator (IPG6-B) developed in close collaboration with the Institute of Space Systems (IRS), University of Stuttgart, Germany.

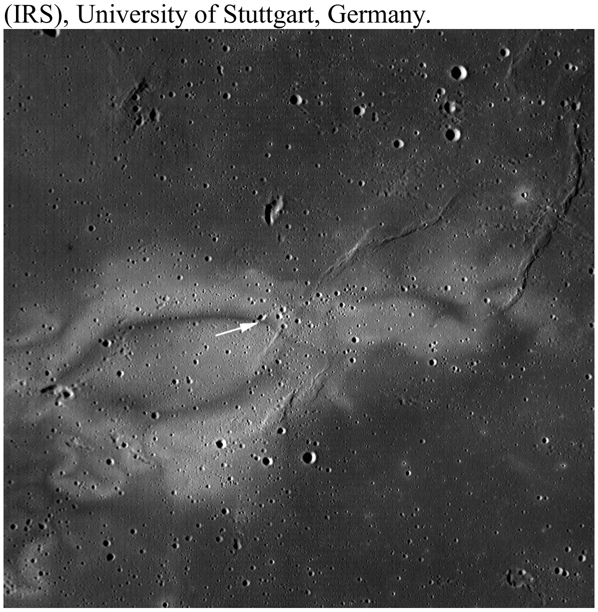

Figure 1. A lunar swirl known as the Reiner-Gamma-Formation. Image credit: NASA/GSFC/Arizona State University.

Lunar Swirls: Across various locations, the lunar surface exhibits light colored sinusoidally shaped patterns which appear unconnected to any geometrical feature such as craters, valleys or mountains. Although these albedo patterns, named lunar swirls, are well known [1] there is yet no consensus concerning their formation. One example of a lunar swirl is the Reiner-Gamma-Formation shown in figure 1.

To date, all swirls have been found in regions of strong crustal magnetic fields. Thus, it appears likely that these fields may be involved in their formation process. Magnetic fields which have a strength of more than 100 nT can interact with the lunar plasma environment, which is mostly fed by the solar wind. In this case, electrons are magnetized by the field and can not penetrate the field lines while ions remain unmagnetized and can enter the field. The resulting space charge regions formed are responsible for the formation of electric fields, which can shield the surface partially from the solar wind flux. This may alter the surface maturation speed and darkening. Additionally dust, for example the dust lifted from the surface as observed during the Apollo era [2], can be influenced by these fields and transported across the surface. This process provides a mechanism for fine grain dust transport, allowing such dust to accumulate in certain regions and change the surface albedo. Other theories of swirl formation persist, for example the cometary impact theory [3].

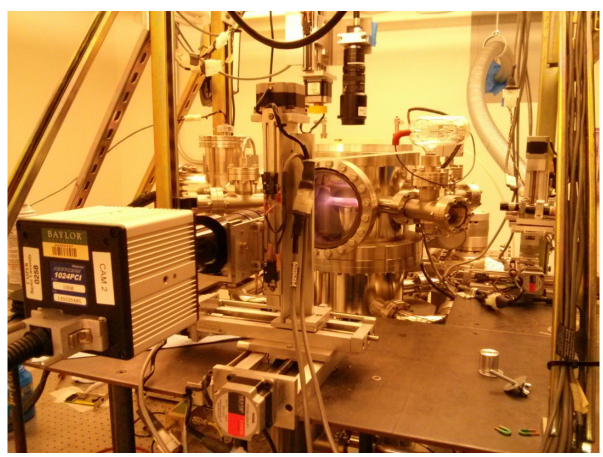

Figure 2. GEC-Reference cell in operation with Argon plasma.

Experiment: The interaction of magnetic fields with plasma in connection with lunar swirls has previously been investigated by Bamford [4] and Wang [5]. Here a new approach to determine the resulting electric fields is introduced. In order to investigate the magnetic field plasma surface interaction near the lunar surface, the problem has been scaled to fit into a laboratory experiment. While scaling the problem it is important to insure that the laboratory plasma employed is collision-less and has magnetized electrons and unmagnetized ions as is the case in the lunar environment.

Experimental Setup. An Argon plasma is created in a GEC reference cell (figure 2). A cylindrical neodymium magnet with 6.35mm diameter and length is placed on the lower electrode to represent the lunar magnetic anomaly. To represent the non-conductive lunar surface, a glass plate is placed above this magnet. For diagnostic purposes 8.89µm melamine formaldehyde (MF) particles are dropped into the plasma. These particles are illuminated with a laser fan and the trajectories recorded using a high speed camera running at 1000 fps. As the particles charge negatively in the plasma they are subject to forces caused by the resulting electric fields in the plasma.

Data Analysis. Based on the video data the particle trajectories are determined. By calculating the first and second derivative of the particle location the speed and acceleration in both the x and y direction can be determined. The acceleration can then be used as a diagnostic for the electric force. For proper measurement, other significant forces like gravity, friction and interparticle forces must also be considered in the analysis as well. Unfortunately even after eliminating all disturbing forces, it is not easily possible to determine the electric field strength as the particle charge is not well known and can vary based on location in the plasma. In this case, OML theory [6] is used in order to address this problem.

Results: The results shown in figure 3 indicate the horizontal forces on the dust particles caused by the influence of the magnetic field. To obtain this result, a reference experiment without a magnet was also conducted. The results measured without magnetic field are then subtracted from those with magnetic field. As a result only the influence of the magnetic field is shown. As no correlation of speed and acceleration could be found it is assumed the friction component of the force can be neglected. However, accelerations caused by electrostatic inter particle forces are found to be significant and have not been subtracted from the data. This leads to an additional force that accelerates the particles away from the center line.

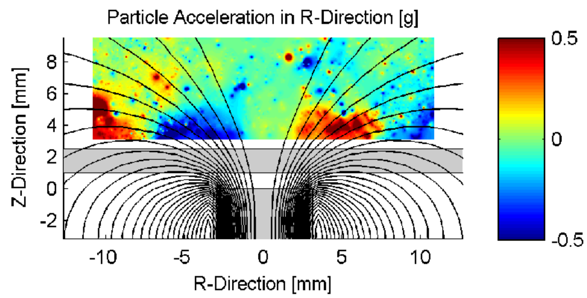

Figure 3. Electrostatic acceleration in radial direction.

The data shows that a force exists that pushes the dust particles away from the center indicating a more negative potential in the center. In a region about 7 mm from the center the direction of the force changes leading to a focusing of dust particles. Thus the potential in this region must be more positive, becoming more negative again when going further outwards. Applying this knowledge to the lunar environment, this mechanism would allow dust to be transported into preferred regions leading to an altered surface appearance.

Outlook/IPG6-B: In the near future further experiments are planned with magnetic fields under various angles as is the case for the lunar environment. Also planned is the use of the inductively heated plasma generator IPG6-B. This plasma generator has been established in close collaboration with the Institute of Space Systems, University of Stuttgart, Germany. The plasma generator can produce a plasma jet (plasma streaming) which provides a better equivalent for the streaming solar wind in the lunar environment.

References:

[1] Blewett D. et al. (2011) *JGR, 116,* E02002. [2] Colwell J. et al. (2007) Rev. Geophys.*, 45,* 2005RG000184. [3] Starukhina L.V. and Shkuratov Y. G. (2004) Icarus, 167, 136-147. [4] Bamford R. et al. (2012) PRL, 109, 081101. [5] Wang X. et al. (2013) GRL, 40, 1686-1690. [6] Fortov V. E. et al. (2004) Physics-Uspekhi, 47(5), 447-492.