LABORATORY EXAMINATION OF THE ELECTRON AVALANCHE AND BREAKDOWN OF THE MARTIAN ATMOSPHERE. W. M. Farrell[1.] J. L. McLain[2.], M. R. Collier[1.], J. W. Keller[1.], T. L. Jackson[1.], and G. T. Delory[3]; 1. NASA/Goddard Space Flight Center, Greenbelt MD (william.m.farrell@nasa.gov); 2. University of Maryland, College Park, MD; 3. University of California, Berkeley, CA

Abstract: Viking era laboratory experiments show that mixing tribo-charged grains in a low pressure CO_2 gas can form a discharge that glows, indicating the presence of an excited electron population that persists over many seconds. Based on these early experiments [1], it has been predicted that Martian dust devils and storms may also contain a plasma and new plasma chemical species as a result of dust grain tribo-charging [2]. In this work, we examine the possible breakdown in a Mars's-like atmosphere under controlled circumstances. We conclude that in a Mars-like low pressure CO_2 atmosphere and expected E-fields, the electron current remain in a dark 'Townsend' discharge where the electron density is exponentially growing with applied E.

Laboratory Measurements: In order to quantify the atmospheric currents generated under a driving E-field in a low pressure CO_2 gas, we performed a systematic laboratory study of the breakdown process. In an analogy to thunderstorms, the triboelectric process in dust devils tends to charge smaller dust (< 20 microns) negative but leave larger sand grains (~100 microns) and the surface positive. Vertical winds in the storm then transport and separate the charged grains, lofting the negatively charged light dust to high altitudes relative to the larger sand grains and the surface. In terrestrial dust devils, large E-fields have been reported to develop by this electrical generation process [2].

In a simplified description, the charge concentration centers in the convective feature can be thought of as a charged capacitor plate containing -Q at high altitudes and +Q at the surface, and having a triboelectric generated E-field between the plates (i.e., behaves like a dipole and can be sensed externally from the feature). To simulate this effect in the laboratory, an electrostatic plate system has been placed in a CO_2-rich environment at low pressure to simulate the conditions on the surface of Mars.

Figure 1 shows inside the chamber containing the parallel plates where the E-field is generated. The chamber has the ability to maintain vacuum to 10^{-8} Torr but in our Mars applications that level of vacuum is not required. All experiments are run for a CO_2 gas at 5 Torr. Ambient air is removed to a level of ~ 0.1 Torr and then ultra-high purity grade CO_2 gas is leaked into the chamber to obtain an ultimate pressure of 5 Torr.

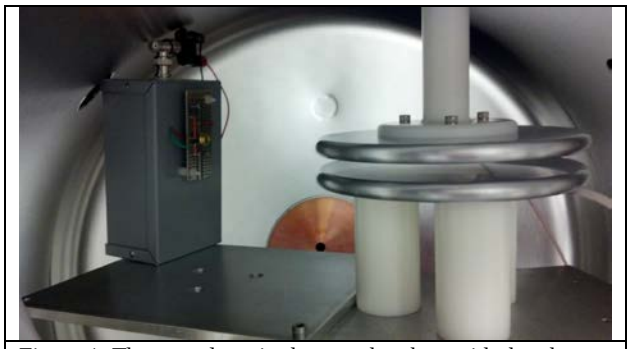

Figure 1. The two plates in the test chamber, with the photo-diode board assembly located to the left.

Two circular parallel plates of 7 cm radius form the capacitor that can be separated from ~0.1 cm to ~7 cm via an computer-controlled manipulator, allowing plate separation to be set without having to break vacuum. A UV photo-diode is used to stimulate a low level of electron emission to initiate the electron avalanche. A voltage drop across a resistor in series with the plate capacitor provides an indication of the plate-created atmospheric current.

Early Results. Figure 2 shows a plot of measured (a) current and (b) equivalent electron conductivity as a function of driving E-field between the plates. The value of E is V/d, where V is the voltage applied to the plates from a high voltage power supply and d is the plate separation. We make special note that the effective conductivity shown in (b) is J_e/E. At relatively small E values, the effective conductivity is the ambient (bulk) isotropic conductivity, $\sigma = J_e/E$. However, as E increases, the electron avalanche initiates an exponential growth in electron density and electron drift speeds increase, the avalanche current becomes directional along E, and the conductivity is then that of the σ_{zz} element in the conductivity tensor. This increase in E field-aligned electron conductivity creates a subtle but important effect in applications to grain charging: Past studies have viewed the electron avalanche as an effective increase in bulk conductivity, but it is actually an electron beam flowing along the E direction.

As evident in Figure 2, there are three separate current regimes:

1) For E-fields below about 25 kV/m, the current varies linearly with E-field, $J = \sigma E$, behaving like a nominal atmosphere of conductivity near ~ 10^{-12} S/m.

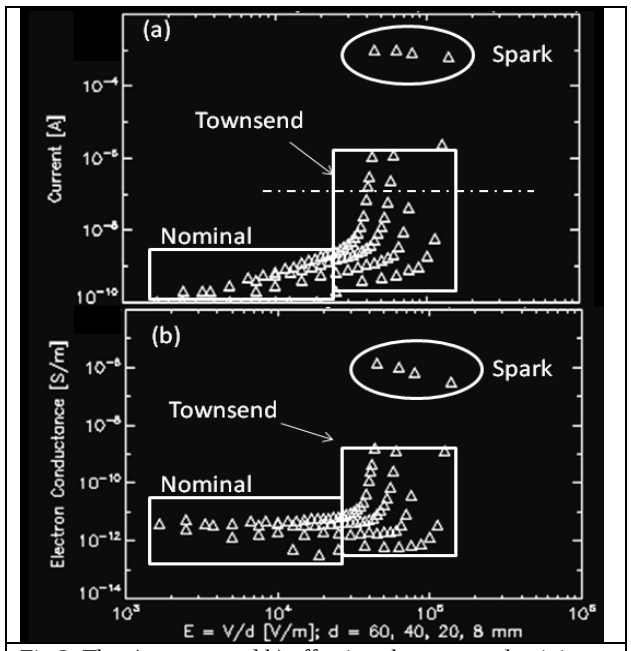

Fig 2. The a) current and b) effective electron conductivity as a function of E-field for plate separations (from left to right in the figure) of 60, 40, 20, and 8 mm.

2) Between 25 and 100 kV/m and for currents below ~1 μA, the gas is undergoing an electron avalanche process, where the electron density is exponentially increasing with driving E-field. This portion of the curve is commonly called the 'Townsend' discharge, with the atmospheric conductivity increasing exponentially with E. This 'dark' discharge, having no obvious illumination, occurs preceding a spark discharge [3]. In the electron avalanche, the electron density increases as $n = n_o \exp(\alpha(E)d)$, where $\alpha(E) = \alpha_o \exp(-E_o/E)$. The quantities α_o and E_o for a low pressure CO_2 gas can be derived [2] or found in texts on the subject (e.g., Table 6.1 in [4]) The electron conductivity in Figure 2b is no longer directly proportional to E in the Townsend discharge regime, but instead displays the obvious exponential increase with E (i.e., the effective conductivity along E is now $\sigma \sim n_o \exp(\alpha(E)d)\, e\mu$, where μ is the electron mobility). The ions, on the other hand, are not as easily accelerated along E, with their relative drift speeds in proportion to their mass.

3) At a threshold electric field (which differed for each value of plate separation distance, d), the currents make an abrupt increase by over a factor of 100, to initiate an observable spark discharge in the chamber. These discharges typically are found with currents exceeding ~ 0.1 mA, and the increase or jump in current at the threshold E is nearly a factor of 100 (note the clear 'gap' in measurement values from 10^{-5} to 10^{-3} Ampere levels, from 'Townsend' to 'spark' discharges, in Figure 2a).

We should note that the term 'spark' discharge is a misnomer: Even at currents at 10's of μA in between the plates, the electron density is still very low, near 1 part in 1-10 billion of the neutral gas density. Hence the gas is still very weakly ionized. As such, this is not a filamentary discharge in the same sense of terrestrial lightning, where the gas is very hot and ~100% ionized.

Conclusion: Typical dust devil tribo-electric currents found at Earth and expected for Mars are illustrated by the dotted line in Figure 2a. We find that for typical dust devil charging currents, we should not expect the dust devil feature to initiate a spark discharge. However, enhanced electrification and electron avalanche should be expected to be driven in the system. Specifically, the dust devil is expected to be in the dark discharge 'Townsend' regime, with electron densities exponentially growing with increasing E.

We also find that the current densities generated in the Townsend discharge are not capable of short-circuiting a tribo-charging dust devil (having charging currents at J_c ~10 μA/m^2). For the most part, the currents in the electron avalanche will remain below J_c. However, as the E-field increases, the elecrtron current, J_e will become comparable to J_c and in doing so will limit the E-field growth, dE/dt, (but not shut itself off or quench).

References. [1] Eden HF and B Vonnegut, (1973). Electrical breakdown cause by dust motion in low pressure atmospheres: Consideration for Mars, *Science*, 180, 962. Mills, AA, (1977). Dust cloud and frictional generation of glow discharges on Mars, *Nature*, 268, 614. [2] Delory, GT et al. (2006), Oxidant Enhancement in Martian Dust Devils and Storms: Storm Electric Fields and Electron Dissociative Attachment, *Astrobiology*, 6, 451. Jackson, T. L., and W. M. Farrell (2006), Electrostatic fields in dust devils: An analog to Mars, IEEE Trans. Geosci. Remote Sens., 44(10), 2942– 2949, doi:10.1109/TGRS.2006.875785. [3] Llwellyn-Jones, F. (1966), *Ionization and breakdown in gases*, Chapman and Hall, London. [4] Brown, S. C. (1966), Introduction to electrical discharges in gases, Wiley and Sons, NY.