Abstract. Lightning is expected to occur on Mars within dust devils and dust storms, which are likely to discharge in the low pressure carbon dioxide environment. Despite this, radio emissions from Martian lightning have not yet been conclusively observed by remote sensing, nor have there been any in situ measurements of Martian atmospheric electricity. We report laboratory experiments to simulate Martian electrical discharges and measure the radio emissions from them, to facilitate searches of Martian lightning from spacecraft data. Voltage transients were observed in a tank in which Martian analogue simulant was allowed to become triboelectrically charged, and then fall to a sensing electrode. A plausible explanation for our results is that electrical discharges have taken place, caused by charge separation on differently sized particles as predicted by theory. Unlike in previous reports, we have been able to detect discharges without adding glass microballoons to the Martian analogue dust to facilitate the charging, although the addition of glass microballoons did enhance the transient rate.

1. Introduction
Lightning has long been studied on Earth and more recently has been observed on other planets throughout the Solar System. Lightning is expected to occur on Mars because of triboelectrification within regional-scale dust storms and localised dust devils [1]. Terrestrial dust devils become highly electrically charged, up to ~100kV m$^{-1}$ [2], and based on the Paschen curve for 10mbar CO$_2$, discharges are expected from Martian dust devils at ~20kV m$^{-1}$. Martian lightning is expected to play a role in the production of trace organic molecules that may be important for biological processes [3]. Despite this clear scientific significance, there have never been any electrical measurements in the Martian atmosphere, and neither do we know of any forthcoming missions carrying relevant instrumentation. We are therefore investigating techniques for remote sensing of radio emissions generated by Martian electrical discharges. This has been attempted previously, but with no conclusive results [2]-[5]. Our work is in two parts, laboratory experiments to characterise the optical and electrical signals expected, and analysis of spacecraft data to search for electromagnetic signals emitted from the Martian atmosphere.
2. Laboratory simulations of the Martian atmosphere

2.1. Experiment
We have set up a laboratory experiment intended to generate and detect electrical discharges in a Martian analogue atmosphere, based on [6]. The experiment uses a cylindrical Perspex tank approximately 1m long of diameter 0.25m. In the top of the tank there is a funnel sealed by a plunger, which is accessible from outside the tank. The funnel is filled with 500g JSC Mars-1 Martian regolith simulant [7], (baked to remove adsorbed water) and the tank is evacuated and filled with 7-9 mbar CO₂. The plunger is then released and the dust falls to the bottom of the tank through another inverted funnel. The top metal plate is electrically grounded, and the voltage on the bottom metal plate is measured with a Keithley 2000 DMM, with the voltage logged to a PC via an IEEE-488 interface. The hole between the funnels, through which the dust falls, is 2.5cm diameter, wide enough for most of the falling dust to pass through without touching it. This ensures the majority of the dust charging occurs purely from dust-to-dust contact, although there will be some charging from the dust touching the funnel walls. The tank is mounted on a support frame so that after each dust drop it can be rotated to reload the funnel, Figure 1.

Figure 1 Martian analogue experiment, showing dust loaded before a drop. The CO₂ line was disconnected before a dust drop and subsequent rotation of the tank to reload the dust.

In [6] discharges in the dust were detected, by spikes in the voltage recorded at the sensing plate, and also visually when in a dark room. However, discharges only occurred when the JSC Mars-1 simulant was mixed with glass microballoons, implying that the potentials generated by dropping Mars simulant dust alone were not adequate for discharges.

2.2. Results
In total 22 dust drops were carried out for which data were recorded, 13 drops with dust only, and 9 drops with dust plus microballoons. The results were repeatable, with examples shown in Figure 2. All dust drops, activated by pressing down the plunger to release the dust, took place after 100s logging to record the background noise level of the system, ±1V. The dust drops (Figure 2(a)) show a sharp positive peak of ~12V, followed by a few ~2-4V negative spikes, then a slow smooth decay of the voltage. The results with microballoons (Figure 2(b)) are different, always commencing with a
negative transient of ~10V which then appears to be effectively neutralised by numerous bipolar spikes.

The positive transient on releasing the Martian analogue dust is consistent with the larger size fraction, which is expected to become positively charged with respect to the smaller particles [8], arriving at the bottom of the tank first. The smaller dust particles are expected to be negatively charged and settle slowly, which explains the gentle decay of the positive voltage in Figure 2(a). The negative spikes in Figure 2(a) are too large to be caused by any single particle (which would have to be very large, and therefore would be expected to be positive in any case), and are well above the system noise level. Figure 2(b) shows many more transients, but with no overall decay, as in 2(a). The differences between Figure 2(a) and (b) and the previous observations of discharges when microballoons were added suggests that the spikes are discharges caused by charge separation between the falling particles.

![Figure 2 Typical dust drop results at 9mbar (a) ~490g dust only, representative of 12 out of 13 drops (b) ~250g dust with ~230g microballoons, representative of 8 out of 9 drops.](image)

The differences between Figure 2(a) and (b) can be explained by considering that the glass microballoons are higher in the triboelectric series than the JSC Mars-1 simulant (which is located between stainless steel and Teflon [9]), and therefore likely to charge positively with respect to the dust. Firstly, this implies that the Martian analogue dust is likely to become negatively charged when the microballoons are present, causing negative initial transients, as the larger dust particles fall to the sensing electrode first, Figure 2(b). Secondly, the minimum electric field for a gaseous electrical discharge $V_{crit}$ for a material of ionization energy $E_i$ and with mean free path $\lambda$ is given in [10] as

$$V_{crit} = 2 \left( \frac{E_i}{e\lambda} \right)$$  \hspace{1cm} (1)$$

Since the glass microballoons reduce the mean radius of the particle distribution, this will increase the mean free path and reduce $V_{crit}$, increasing the likelihood of discharges in the glass microballoon mix compared to the dust only case. Although quantitative estimates are difficult without accurate measurements of the particle size distribution, this is consistent with the observations.

These results are broadly consistent with [6], although we observe voltage spikes in our dust-only drops as well as the glass microballoon-dust mixture. Unlike [6] however, a faint purple glow was only seen in one of the dust only cases, but this could have been because the experiments were carried
out in a well-lit room. Electrical discharges still remain the most plausible explanation for the voltage spikes seen.

3. Detecting radio emissions from Martian electrostatic discharges

The presence of electrical discharge on Mars has been inferred from an observed increase in the non-thermal microwave emission during a Martian dust storm [3], but no evidence of electrical discharge associated with dust storms was observed when examining the background radio noise between 4.0 and 5.5 MHz in data from the MARSIS instrument onboard the Mars-Express spacecraft [4]. Although the MARSIS instrument would easily detect lightning discharges of similar intensity to those found on Earth [4] this does not rule out the possibility of discharges that emit a signature at lower frequencies (such as sprites) [11] or much higher frequencies (such as coronal discharge) [5], which we may have observed in our laboratory experiments.

4. Conclusions

Our results suggest that electrical discharges have been observed in Martian analogue dust in a simulated Martian atmosphere of 9mbar CO₂. The effects observed are consistent with the theory of triboelectric particle charging, for example, the number of discharges observed increases when glass microballoons are added to the mixture. Future experiments will be carried out in a dark room, to facilitate optical detection, and with a radio spectrum analyzer to characterize the discharges. Radio observation of corona discharges will enable targeted spacecraft observations to be made.

References

[1] Aplin K L 2006 Atmospheric electrification in the Solar System Surv. Geophys. 27, 1, 63-108
[2] Jackson T L and Farrell W M 2006, Electrostatic fields in dust devils: an analog to Mars, IEEE Trans. Geoscience Remote Sensing, 44, 10, 2942-2949
[3] Ruf C, Renno N, Kok J, Bandelier E, Sander M, Gross S, Skjerve L, and Cantor B 2009 Emission of non-thermal microwave radiation by a Martian dust storm Geophys. Res. Lett, 36, L13202
[4] Gurnett D, Morgan DD, Granroth L J, Cantor B A, Farrell W M and Espley J R 2010, Non-detection of impulsive radio signals from lightning in Martian dust storms using the radar receiver on the Mars Express spacecraft, Geophys. Res. Letts. 37, L17802
[5] Zarka P, Farrell W M, Fischer G and Konovalenko A, 2008 Ground- and space-based radio observations of planetary lightning Space Sci Revs. 137, 1-4, 257-269
[6] Krauss C E, Horanyi M and Robertson S 2003 Experimental evidence for electrostatic discharging of dust near the surface of Mars New. J. Phys 5, 70.1-70.9
[7] Allen C, Morris R, Lindstrom D, Lindstrom M, and Lockwood J 1997 Lunar and Planetary Institute Sci. Conf. Abs., 28, 27.
[8] Lacks D and Levandovsky A 2007 Effect of particle size distribution on the polarity of triboelectric charging in granular insulator systems J. Electrostatics 65, 2, 117-112
[9] Sharma M, Clark D W, Srirama P K and Mazumder M K 2008, Tribocharging characteristics of the Mars dust simulant (JSC Mars-1) IEEE Trans. Industry Apps., 44, 1, 32-38
[10] Treumann R A, Klos Z and Parrot M, 2008 Physics of electric discharges in atmospheric gases, Space Sci. Revs. 137, 1-4, 133-148
[11] Farrell W M, Kaiser M, Desch M, Houser J, Cummer S, Wilt D and Landis G 1999 Detecting electrical activity from Martian dust storms J. Geophys. Res., 104, 3795–3801