EPSC Abstracts
Vol. 6, EPSC-DPS2011-1229, 2011
EPSC-DPS Joint Meeting 2011

Atmospheric Electricity on Mars

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Abstract

The atmosphere of Mars is one compelling example in our solar system that should possess active electrical processes, where dust storms are known to occur on local, regional, and global scales. Laboratory experiments and simulations all indicate that these events are expected to generate substantial quasi-static electric fields via triboelectric (i.e., frictional) charging, perhaps up to the breakdown potential of the Martian atmosphere. However current observations of potential electrical activity on Mars from both ground-based and orbital platforms have yielded conflicting results. If present, significant atmospheric electricity could be an important source of atmospheric chemistry on Mars, and thus impact our understanding of the evolution of the atmosphere and its past or present astrobiological potential. Here we review the current state of understanding regarding atmospheric electricity on Mars, and discuss its implications pending the results of future measurements.

1. Introduction

Nearly every laboratory experiment or observation of naturally occurring dust motion reveals the presence of electric fields caused by some charging mechanism, which is usually triboelectric in nature. Terrestrial dust devils routinely produce electric fields in excess of 20 kV/m, and can support charge concentrations up to 10^6 electrons/cm^3 [5, 6]. Relatively simple experiments readily demonstrate manifestations of triboelectric phenomena under conditions similar to Mars, where the Paschen breakdown voltage in the thin atmosphere is estimated to be ~20 kV/m. Eden & Vonnegut [3] agitated dry sand in a CO_2 gas at low atmospheric pressures similar to Mars, and observed a visible glow accompanied by discrete, filamentary discharges, presumably caused by triboelectrification of individual grains. Laboratory experiments are ongoing to this day and may continue shed light on mechanisms of dust charging in the Martian environment [13, 16], although in general the physics of the triboelectric process remains mysterious even for typical terrestrial materials [7], which many times rely on the empirically derived triboelectric series for quantification.

Most models describing dust electrification on Mars assume simple charging mechanisms that are related to triboelectric processes and terrestrial analogies. Models by Melnik and Parrot [12] and Farrell et al., [5] indicate the presence of large scale electrification in Martian dust storms and devils that can reach the breakdown value (Figure 1). Additional work has examined charging processes in the saltation layer, where high (>20 kV/m) electric fields can also be developed [8, 9].

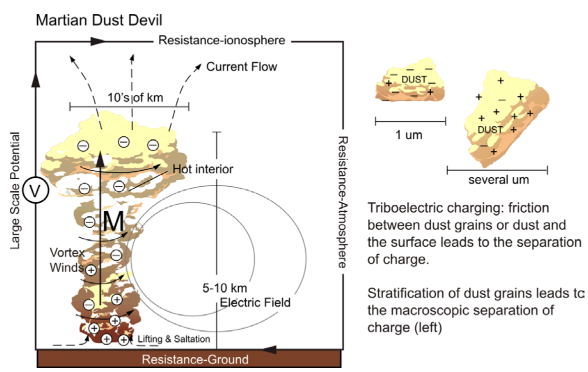

Figure 1: A simple model of a dust devil on Mars where charge stratification generates electric fields

2. Observations

Despite decades of observations from Earth, orbital spacecraft or landers, direct evidence of any large scale atmospheric electrical processes on Mars remains scant or contradictory. In a novel experiment, Ruf et al [15] utilized a Deep Space Network (DSN) antenna to detect emissions from Mars in the micro-wave band during a dust storm. A non-thermal component of this radiation was detected, which could be generated by electrified dust. Furthermore, modulations in these emissions were interpreted to result from Schumann resonances, indicating the presence of lightning. However observations from the MARSIS sounder aboard the Mars Express spacecraft have failed to detect any confirmed emissions in the 4-5 MHz band during known dust activity despite over five years of operations. At present these results are irreconcilable, and will likely only be settled by future observations.

3. Implications

While current observations are contradictory, it is likely the form rather than the presence of atmospheric electricity on Mars that is under debate. Whereas large scale discharges such as lightning may or may not be present, the lofting of significant amounts of dust is likely to sustain electric fields. The presence of these fields can energize the plentiful supply of ambient electrons present in the highly conducting Martian atmosphere. The resulting electron swarm can then dissociate key trace species such as water vapor, and produce precursors to the formation of oxidants such as hydrogen peroxide [1, 2], which may be important to understand from the perspective of habitability. More recently, the discovery of trace amounts of methane have re-ignited the debate regarding the presence of any form of life on Mars [10, 14]. Understanding the sources and sinks of this important trace species is critical in order to interpret its origin; however the highly spatial and temporal variations of methane on Mars cannot be explained by any currently known process [11]. Electrochemical effects have been shown to break down methane at rates far in excess of photo-chemical or other processes and may help explain the observed variability [4].

4. Summary and Conclusions

We are at a unique point in our understanding of atmospheric electricity on Mars. While all laboratory data and simulations indicate that substantial electrification should be present, current observations are contradictory at best, and will only be resolved through future observations. The Mars Atmosphere and Volatile EvolutioN (MAVEN) mission will carry a wave receiver to Mars in 2013-14, which may carry on the work of MARSIS in attempting to discern emissions produced by dust storms. The Mars Science Laboratory may also detect the chemical effects of charged dust on Mars. The detection or non-detection of atmospheric electricity on Mars has important implications for our understanding of chemical processes and is thus a subject of extreme interest for these future missions.

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