The Electrostatic Environments of Mars and the Moon

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Abstract. The electrical activity present in the environment near the surfaces of Mars and the moon has very different origins and presents a challenge to manned and robotic planetary exploration missions. Mars is covered with a layer of dust that has been redistributed throughout the entire planet by global dust storms. Dust, levitated by these storms as well as by the frequent dust devils, is expected to be electrostatically charged due to the multiple grain collisions in the dust-laden atmosphere. Dust covering the surface of the moon is expected to be electrostatically charged due to the solar wind, cosmic rays, and the solar radiation itself through the photoelectric effect. Electrostatically charged dust has a large tendency to adhere to surfaces. NASA's Mars exploration rovers have shown that atmospheric dust falling on solar panels can decrease their efficiency to the point of rendering the rover unusable. And as the Apollo missions to the moon showed, lunar dust adhesion can hinder manned and unmanned lunar exploration activities. Taking advantage of the electrical activity on both planetary system bodies, dust removal technologies are now being developed that use electrostatic and dielectrophoretic forces to produce controlled dust motion. This paper presents a short review of the theoretical and semiempirical models that have been developed for the lunar and Martian electrical environments.

1. Introduction

Mars and the Earth's moon have very different surface and atmospheric environments, as can be seen in Tables 1 and 2. They, however, have one thing in common: their surfaces are covered with a relatively homogeneous layer of dust. This surface dust dominates the electrostatic environment of Mars and plays an important role in that of the moon.

Table 1. Physical Properties of Mars and the Moon

	Mars	**Moon**
Orbit Inclination	23° 19'	6° 41'
Orbital Period	24 h 37 min	27.3 d
Diameter	6796 km	3476 km
Mass	0.64×10^{24} kg	7.35×10^{22} kg
Density	3.94 g/cm^3	3.36 g/cm^3
Surface gravity	0.379 g	0.167 g
Surface temperature	-140° to 20°C	-170° to 130°C

Table 2. Atmospheric Properties of Mars and the Moon

	Mars		**Moon**	
Surface pressure (mbar)	5 to 10		1×10^{-12}	
Composition	**Gas**	**%**	**Gas**	**%**
	CO_2	95	Ar	79.2
	N_2	2.7	He	19.8
	Ar	1.6	O	1
	O_2	0.15	Na	Trace
	H_2O	0.03	H	Trace

These electrostatic environments are far from being fully understood. The desire for their study goes beyond scientific inquiry. Human and robotic exploration missions to both bodies require a good understanding of this environment to avoid failures and mishaps.

2. Lunar and Martian Electrostatic Environments

2.1. The Moon

At 10^{-12} mbar, the lunar atmosphere is extremely rarefied and its influence in the electrostatic environment near the surface of the moon is negligible. This environment is instead controlled by the flux of photons and ions from the solar wind, cosmic rays, and galactic cosmic rays. The lunar surface is composed of rocks and granular material with grains and dust particles ranging in size from a few centimeters down to a few nanometers. This granular material is expected to be electrostatically charged due to the incident plasma and to the UV from the sun, which releases photoelectrons from the surface of the material.

The plasma and photon fluxes bathing the moon produce a complex electrostatic environment. On the sunlit side, photoelectric charging by solar UV photons dominates. The emission of photoelectrons leaves the surface positively charged to a potential of about 5 to 10 V [1]. On the dark side, plasma electrons dominate and the surface becomes negatively charged to a negative potential or the order of the electron temperature, about -50 to -100 V [2]. The moon is essentially a charged body in a plasma, creating a screening effect in the plasma with a characteristic distance or Debye length of the order of meters on the lunar dayside and of the order of kilometers on the dark side. A Debye sheath is then formed around the moon which reaches a meter or so on the dayside and several kilometers on the nightside [3,4]. The nightside Debye sheath, dominated by photoelectrons, is usually called the photoelectron sheath.

Lunar surface potentials depend greatly on changes in the solar wind and cosmic rays, which affect the plasma environment. When the moon crosses the Earth's plasma, negative surface potentials can reach several kV. Surface potentials reaching -5 kV were observed by Lunar Prospector during periods of intense solar activity [5].

In our airless moon, it would seem likely that the dust on its surface be relatively static. However, the complex electrostatic environment just described affects dust behavior in unexpected ways. There appears to be evidence of dust levitation and dust transport on the moon. This issue has been controversial since it was first raised during the Apollo missions [6]. A horizon glow was reported by Apollo astronauts [7] (Fig. 1). This glow has been interpreted as evidence of transient dust clouds above the lunar surface that could reach several km above the surface. Observations with the lunar Surveyor spacecraft [8] and the Lunar Ejecta and Meteorites Experiment (LEAM) on Apollo 17 indicated the presence of dust clouds [9]. Although no theoretical model satisfactorily explains the phenomenon, it has been suggested that electrostatic charging of the lunar surface due to exposure to charged particles from the solar wind as well as UV radiation could result in the levitation and transport of dust particles [10].

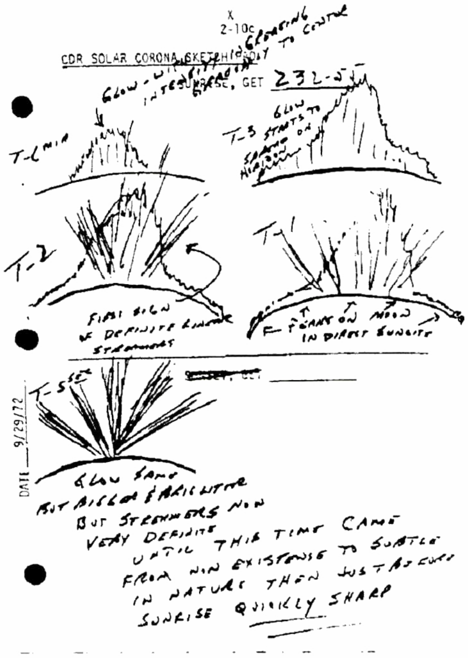

Figure 1. Sketches done from orbit by Apollo astronauts showing streamers reaching up to 100 km from the surface. [Courtesy NASA]

2.2. Mars

2.2.1 *Particle Size Distribution in the Martian Atmosphere*

The surface of Mars is covered with a layer of dust that has been somewhat homogenized by planet-wide dust storms. These dust storms, which have wind velocities up to 32 m/s, have been observed to last for several months (Fig. 2) [11]. Dust devils up to 10 km high were detected during the 1997 Mars Pathfinder mission with daily frequency. NASA's Mars rover Spirit has photographed dozens of dust devils from its location inside the red planet's Gusev Crater (Fig. 3). Opportunity, the mission's second rover, had not been able to capture an image of a dust devil until this past July, six years after its arrival on Mars. Its location, on Meridiani Planum, is not as dusty. NASA's Phoenix Mars Lander also photographed dust devils in the Martian arctic during its 2008 mission.

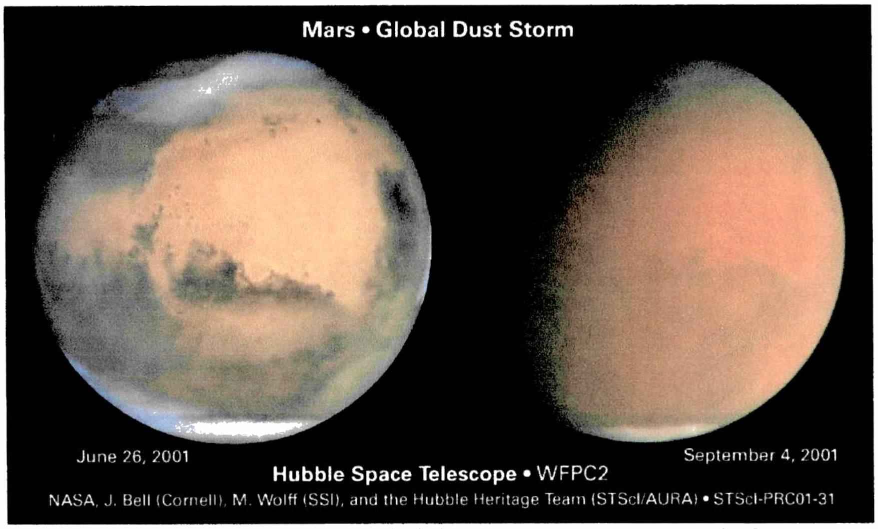

Figure 2. A Martian global dust storm [Courtesy NASA].

These storms, along with the frequent dust devils, carry dust particles that are uplifted into the thin atmosphere of the planet. The actual mechanism that uplifts dust into the atmosphere is still nor clearly understood. From the knowledge of the terrestrial mechanism, it has been proposed that saltation aided by dust devils and the presence of electric fields may uplift dust [12, 13]. From optical data using instruments on orbiting spacecraft and on landers, estimates of the size distribution of dust particles in the atmosphere have been made. These measurements yield a value for particle diameter of 1.5 ± 0.2 μm. However, the size distribution of atmospheric dust changes with the presence of dust devils and dust storms, as one would expect. At the peak of the 2001 global dust storm depicted in Figure 2, particle diameters derived from data from the Thermal Emission Spectrometer on board the Mars Global Surveyor orbiting spacecraft ranged from 2 to 5 μm [14].

Figure 3. A dust devil photographed by the Sprit rover the 488 day of the mission [Courtesy NASA]

Using measurements by the Microscopic Imager (MI) on the Mars Exploration Rovers, Landis et al seem to find evidence for a three-component particle distribution for atmospheric dust: *Atmospheric dust* suspended for long periods of time, with diameters in the 2 to 4 μm; *settled dust* raised into the atmosphere by wind and dust devils, with diameters in the 10μm and under range; and *saltating particles*, with diameters greater than 80 μm, that move due to saltation [15].

Particle size distribution data for the Martian soil has been obtained by the Mars Exploration Rovers Spirit and Opportunity at the locations that the two craft have visited. These values are however somewhat skewed because the instrument used to measure them, the Microscopic Imager, has a resolution of 31 μm per pixel, which limits the detection of very small particle sizes. The MI on Spirit has recently completed measurements of the soil on Scamander Crater, obtaining average particle sizes of 220 μm [16].

2.2.2 *Atmospheric electric fields*

Stationary surface sand and dust on Mars may be electrostatically charged due to incident UV radiation reaching the surface. Although the total integrated UV flux over 200-400 nm is comparable to Earth's, shorter wavelengths contribute a larger proportion of this flux [17]. Contact charging may also occur due to collisions between wind-blown dust particles and stationary surface particulate matter.

There is experimental evidence that collisions due to dust motion can result in electrostatic charging of dust particles. In the early 1970s, Eden and Vonnegut observed a glow as well as filamentary discharges as a container with sand was shaken under Martian atmospheric conditions [18]. Shortly after, Mills suggested that triboelectrically produced glow discharges in the Martian atmosphere might explain the apparent absence of carbonaceous matter on the planet [19]. More recently, we were able to observe glow discharges caused by collisions of Mars simuant dust particles under atmospheric conditions mimicking those of Mars and showed that these discharges altered known organics on Mars simulant dust [20]. Fabian et al and Krauss et al designed experiments to demonstrate that the vertical motion of dust is sufficient for this charging mechanism to produce strong electric fields capable of creating electrical discharges in a low-pressure CO_2 atmosphere [21, 22]. They were able to detect discharges both visually and electronically and measured the discharge frequencies and intensities. The range of pressures required to efficiently produce these discharges was also examined, demonstrating that electrical discharges can occur under conditions expected on the Martian surface. Additionally, a simple theoretical model has been created to constrain the parameters involved in the dust charging experiment. Their model supports the ideas developed in their experiment. Similar theoretical calculations had been performed earlier by Melnik and Parrot [23].

Accurate determinations of the charge and particle size distribution for particles in the Martian atmosphere could be obtained when dedicated instrumentation is flown on a future mission. With that in mind, our laboratory, in collaboration with the University of Arkansas, developed a Dust Particle Analyzer instrument that is capable of determining the electrostatic charge and the aerodynamic diameter of dust particles in the Martian atmosphere [24]. Aerodynamic diameters and electrostatic charge values of Martian simulant dust particles in a vacuum chamber at simulated Martian atmospheric conditions are shown in Fig. 4.

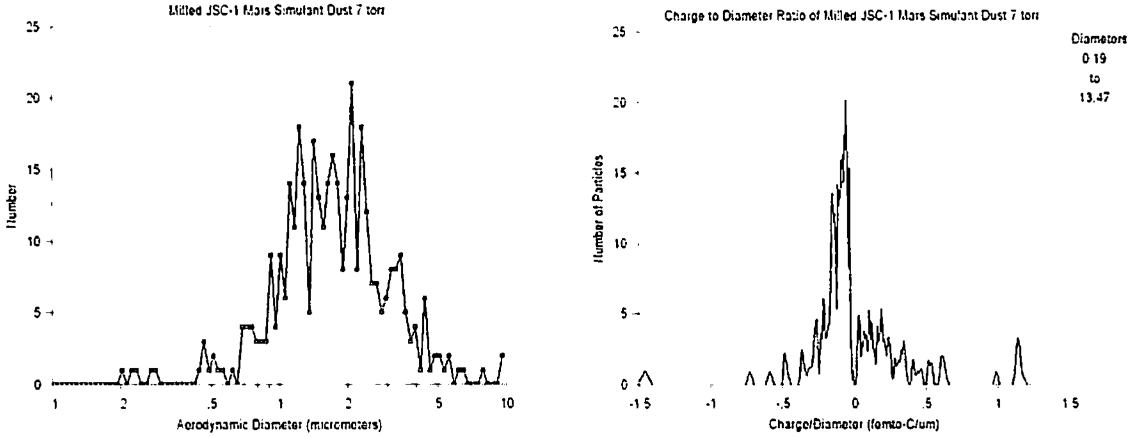

Figure 4. Aerodynamic diameter and charge of Martian simulant dust particles measured with NASA's Dust Particle Analyzer under simulated Martian atmospheric conditions.

3. Challenges and Possibilities for Exploration Missions

The complex electrostatic environments of Mars and the moon present challenges for human and robotic exploration. On both surfaces, dust can deposit on the surfaces of solar cells, equipment, thermal radiators, and other hardware likely to be used in exploration missions. Lunar dust is expected to be electrostatically charged by the incident plasma and by the solar UV. Dust in the Martian atmosphere is also expected to be charged by dust collisions in dust devils and dust storms.

The presence of electrostatically charged dust on Mars and the moon also presents opportunities to enable exploration missions. Our laboratory has been developing a dust mitigation technology that takes advantage of these electrostatic environments [25-27]. The Electrodynamic Dust Shield, a system based on the generation of changing non-uniform electric fields able to accelerate charged dust particles with the dielctropheric force, has proven to be extremely efficient at clearing dust at lunar and Martian environmental conditions. Inclusion of this technology along with other instrumentation for the accurate measurements needed will enhance and enable future missions.

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