PROSPECTING FOR NEAR-SURFACE H$_2$O ON MARS WITH DIELECTRIC SPECTROSCOPY. David E. Stillman, and Robert E. Grimm, Dept. of Space Studies, Southwest Research Institute, Boulder, Colorado, 80302 (dstillman@boulder.swri.edu)

Introduction. MEPAG has identified In-Situ Resource Utilization as a priority for a manned mission to Mars. Martian subsurface ice could be used to reduce mission costs by allowing the crew to use the ice to make ascent fuel, water, and oxygen. Large amounts of subsurface ice are likely trapped within the top 3m of the martian regolith at latitudes poleward of possibly 30°[1-3], but certainly 45°[4]. Here, we describe how a geophysical surface sounding technique, known as dielectric spectroscopy (DS), can quantify the volume percentage (v%) of ice and adsorbed water in the top 3m of the martian regolith. This directly addresses goal 1 of Challenge Area 1. DS measures the frequency-dependence (1 mHz – 10 kHz) of the electrical properties of the subsurface with position and depth. Each electrical spectrum can be deconvolved to quantify the v% of ice or adsorbed water.

Ice on Mars. Both polar layered deposits possess large amounts of ice. At latitudes poleward of 50° the neutron spectrometer indicates average ice concentrations of ~40 v% in the top 10s of cms of the regolith [5]. Polygonal terrain is found poleward of 30°, which probably formed due to thermal cracking of an ice-rich mantling unit [2]. Phoenix landed in polygonal terrain at a latitude of 68° and found ice-bonded regolith at a depth of 4.25 cm and uncovered segregated ice [6]. Recent impact craters have excavated a layer of segregated ice that seems to be ~0.5 – 2.5m under the surface at latitudes >43° [4]. Radar indicates that large amounts of massive ice can also be found in lobate debris aprons that range from latitudes of 30° – 60° [1,7] At southern latitudes between 32° – 48° recurring slope lineae [3] (likely liquid water flows that recur each year once the temperature exceeds -23°C) indicate that subsurface ice could be slowly melting. The neutron spectrometer also indicates ~8 mass% hydrogen in equatorial regions such as Meridiani Planum within 10s of cms of the surface [5]. DS could be used to determine if this hydrogen is in the form of relic ice and/or adsorbed water, although it is most likely in the form of hydrated minerals, similar to jarosite KFe$_3$(OH)$_6$(SO$_4$)$_2$.

Dielectric Spectroscopy. Induced polarization, precursor to DS, measures the resistive-dielectric properties of the earth and has been employed for nearly a century to explore for minerals and groundwater and to characterize subsurface geology. DS was created about 30 years ago, and now encompasses multiple frequencies from 1 mHz – 10 kHz [e.g., 8]. The first DS planetary instruments have flown on Huygens, Phoenix, and the Rosetta lander. These instruments lack the bandwidth and depth of penetration of terrestrial DS. This requires larger electrode arrays, high-impedance (~10 TΩ), low-capacitance (~1 pF) coupling, and mitigation of coherent noise such as leakage and eddy currents using buffering, shielding, and guarding of electrodes.

DS works by injecting current I into the ground via two electrodes and then measuring the magnitude and phase of the voltage V response with two other electrodes (Fig. 1). The frequency of the injected current is varied over the bandwidth of the instrument. Electrical properties are derived at each frequency from the impedance (V/I) and electrode geometry. The geometry (not frequency) controls the subsurface depth of investigation with larger electrode spacing allowing for deeper penetration [e.g., 9]. The depth of investigation is ~1/3 the largest electrode separation.

The electrodes can be accommodated in lander legs, rover wheels, a robotic arm, or in a ballistically deployed string (Fig. 1). Our present efforts are aimed toward the design of a transmitter and receiver requiring a few kilograms and a few watts, plus electrodes.
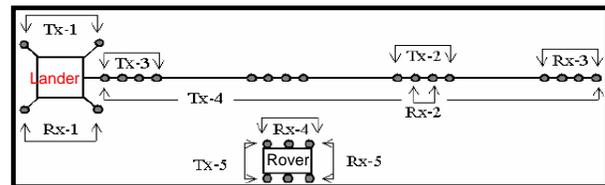
Figure 1. Schematic layouts for electrodes. Tx = transmitter or I electrodes, Rx = receiver or V electrodes. (Tx-1; Rx-1) Electrodes on static lander footpads. (Tx-2; Rx-2) Closely spaced electrodes on ballistically deployed string for shallow subsurface investigation. (Tx-3; Rx-3) Widely spaced electrodes for deeper investigation. (Tx-4; Rx-4) Large transmitter dipole on lander and short dipole on rover (wheel base) for deep investigation. (Tx-5; Rx-5) Rover-only short dipoles for mobile, shallow investigation.

Electrical properties. The electrical properties of all materials can be represented by a parallel circuit with three paths: 1. a resistor, which represents the DC conductivity of the material, 2. a capacitor, which represents the high-frequency permittivity of the material, and 3. a capacitor and resistor in series, which represents the jump in permittivity at the relaxation frequency (maximum change between the low and high frequency permittivity) of the material. On Earth, liquid water dominates the electrical properties at low frequencies and its low resistance shorts out path 2 and 3. Even in terrestrial permafrost areas with high-

surface areas the conductivity of the unfrozen water dominates paths 2 and 3. At cold martian temperatures the conductive path is significantly reduced at DS frequencies allowing measurement of a full dielectric spectrum or paths 2 and 3.

Up to 5 dielectric relaxations are created when H_2O is in a regolith below 0^oC [10]. One relaxation is due to ice, 3 are due to adsorbed water (although 2 of these only occur in high-surface area (>1 m^2/g) materials), and 1 due to conductive pathways being cutoff.

Protonic point defects create a unique dielectric relaxation in ice that varies from a relative permittivity of 3.1 at high frequency to over 120 at typical martian temperatures. The relaxation frequency at martian temperatures could vary between 1 – 1000 Hz depending on the concentration of Cl^- and H^+ in the ice lattice. The v% of ice in a low-surface area mineral follows a simple mixing power law, as v% is a function of the permittivity at low frequency [10,11]. In low surface area minerals and dry low-loss minerals (not ilmenite) even 1 v% of ice is easily distinguishable in the lab (Fig 2) [10,12]. In minerals that possess frequency dependence the minimum detection limit is a function of how lossy they are, but is generally <5 v%. This is because ice has a strong sharp relaxation compared to the broad relaxations indicated by minerals at cold temperatures.

JSC Mars-1 is a martian spectral analog [13]. It has a large H_2O surface area of ~105 m^2/g [14], compared to the Viking measurement of 18 m^2/g [15]. Therefore, we use this as a worse case scenario. Given its high-surface area the first ~9 v% of H_2O goes into three monolayers of adsorbed water. Therefore, no ice is detected because no ice exists. However, the monolayers of adsorbed water possess a strong signature that is different from ice (Fig 2). It creates two relaxations: one with a higher relaxation frequency and one that is lower. The relaxation frequencies appear to be correlated with v% of adsorbed water as the low-frequency permittivity remains constant. We were able to use the first form of DS that was sent to Mars (the single frequency permittivity probe that was part of TECP onboard Phoenix) to determine that the increase in permittivity at night was caused by 3 monolayers of water adsorbing onto a regolith that was radiation damaged with a surface area of ~1 m^2/g [16]. Also, the high-frequency adsorbed water relaxation creates radar attenuation and is likely the reason radar does not penetrate into polygonal terrain [17]. The ice relaxation frequency is still detected in high-surface area minerals, but quantifying the amount is more difficult as the adsorbed water relaxations on either side of the ice relaxation complicate the picture (Fig 2).

We currently just received funding to quantify the amount of adsorbed water in a regolith. This is certainly possible as many humidity sensors including the one that flew to Mars on TECP measured the changes in permittivity at a single frequency caused by adsorbed water which is related to relative humidity.

References. [1] Holt, J., et al. (2008) Science, 322, 1235-1238. [2] Levy, J., et al. (2009) *JGR, 114*, E01007. [3] McEwen, A., (2011) *Science, 333*, 740-743. [4] Bynre S., (2009) Science, 325, 1674-1676. [5] Feldman et al. (2008) *JGR, 108(E9)* 5130. [6] Mellon, M., et al. (2009) *JGR, 144*, E00E07. [7] Plaut, J., (2009) *GRL, 36*, L02203. [8] Grimm R.E. (2005) *J. Environ. Eng. Geophys.,10*, 351-364. [9] Hamelin M. et al. (2003) *JGR, 108*, 8045. [10] Stillman, D. et al. (2010) *J. Phys. Chem. B, 114*, 6065. [11] Grimm, R., and D. Stillman (2011) *LPSC* 2550. [12] Seshardi, S., et al. (2008) *Astrobio, 8*, 781-792. [13] Allen, C. et al. (1997) *LPSC* 1797. [14] Pommeral et al. (2009) *Icarus, 204*, 114-136. [15] Ballou, E.V., et al. *Nature, 271*, 644-645. [16] Stillman D., and R. Grimm (2011) *JGR, 116,* E09005. [17] Stillman D., and R. Grimm (2011) *JGR, 116,* E03001.
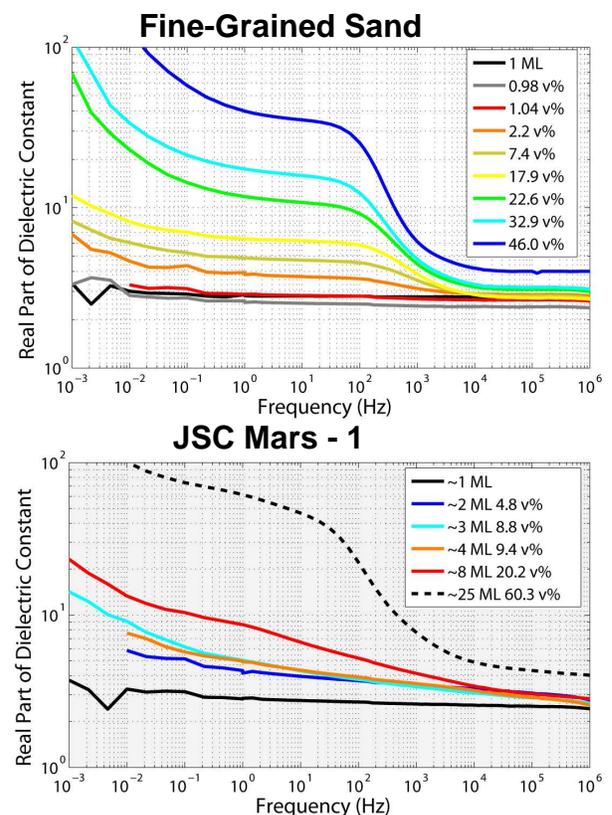
Fig. 2. Dielectric spectra at -85˚C as functions of H_2O volume for a (**top**) sand and (**bottom**) JSC Mars-1 with ice only occurring when the number of monolayers (ML) is >3. Ice relaxation (sharp slope at a few hundred Hz) is evident in sand down to ~1% H_2O, but is only clearly evident in JSC Mars-1 at 60v%. At 4 and 8 MLs, the ice relaxation is blurred by the nearby adsorbed water relaxations.