MEASUREMENTS OF THE ELECTRICAL PROPERTIES OF NEW PLANETARY SOIL SIMULANTS

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Introduction: In the last few decades, radar sensing has become one of the most important means of exploring the physical properties and compositions of planetary surfaces. Groundbreaking discoveries range from widespread near-pure subsurface ice on Mars discovered by orbital subsurface sounding radars [1-3], to the inverted gradient of high porosity icy regolith in the interior of comet 67P/C-G, observed by the CONSERT bi-static radar [4]. These milestones in planetary science led to a variety of radar instruments being included in recent and upcoming missions. These include two ground penetrating radars (GPR) for Mars – RIMFAX [5] on NASA's Perseverance rover and WISDOM [6] on ESA's Rosalind Franklin rover – and two remote sensing radars – RIME and REASON [7] – going to the Jupiter system aboard ESA's JUICE and NASA's Europa Clipper missions respectively. A common objective shared by these instruments is that of characterizing the water and ice on the surface and subsurface of Mars, Europa, Ganymede and Callisto.

In essence, these instruments function by measuring the strength and time delay of the return of a microwave signal previously emitted toward the surface. Both of these quantities depend on the complex relative dielectric permittivity of the target material ($\varepsilon_r = \varepsilon_r' - i\varepsilon_r''$), with the real part affecting the time, and the imaginary part, the strength of the wave as it travels through the material. As these properties depend strongly on the composition, porosity and temperature of the target material, studies of the relationship between the latter parameters and permittivity are crucial to interpret radar observations, or to predict what future instruments will observe. These studies can be performed in the laboratory by measuring the effects that planetary analog soils, ices, and their mixtures can have on a microwave signal, and then quantifying this effect as empirical "mixing models" that relate permittivity to composition, temperature, etc. As better analogs are created, mixing models can be improved to more closely approximate radar measurements.

As an example, the discovery of subsurface excess ice (up to 75% pure) on Mars was interpreted thanks to a three-phase model that relates the real part of the permittivity (ε_r') of mixtures of silicate sand, air (pores), and saline water to the proportions of each component in the mixture[3,4,8]. Subsequent measurements using purpose-built Mars analog soil JSC-Mars 1 [9] resulted in an improved model that interpreted the upper limit of excess ice to be 85% by volume [10].

Here, we present initial results of measurements of the electrical properties of two new planetary analog soils: one for Mars (MGS-1; [11]), and one for comets (Cophylab; [12]). We summarise the instrumentation and capabilities of the University of Bern's Electrical Properties of Planetary Simulants and Ices Laboratory (EPSSIL), which was used to make the measurements and was designed specifically for these purposes.

Methods: The University of Bern's IceLab has a history of leading laboratory simulations of remote sensing instruments to provide ground truth for observations [13]. EPPSIL was developed within the IceLab to simulate the radar response of aqueous and granular samples relevant to planetary surfaces. The instrument suite includes a He pycnometer to measure material densities, a sonic sifter for fine-sieving of granular samples, and a 2-port Vector Network Analyzer (VNA) that measures the scattering of EM waves through samples with a tool called EpsiMu [14].

EpsiMu consists of a conical coaxial cell that connects to the VNA, and is furnished with a central cylindrical sample holder. The samples are held by two PTFE dielectric walls. The VNA can operate at frequencies between 1 MHz and 20 GHz. A schematic of the setup is in Fig. 1, and a full description in [15].

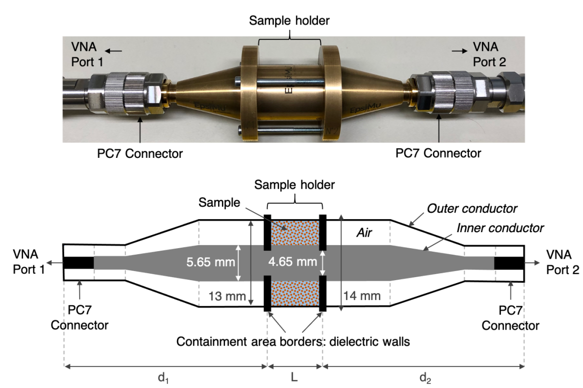

Fig. 1. Schematic of the EpsiMu/VNA-based setup for the measurement of electrical properties.

To prepare a measurement, the cylindrical sample holder is first filled with the sample, after which the EpsiMu coaxial cell is assembled and connected to the VNA. To achieve different porosities of the samples in the holder, the sample is compressed throughout the filling process with varying degrees of pressure. Bulk densities and porosities (derived with material densities measured with the He pycnometer) are calculated once the holder (of known volume) is filled. The VNA measures the complex reflection and transmission scattering parameters of the sample, which are then used to derive the real and imaginary parts of the permittivity and permeability. For this step, we have used both the

Nicolson-Ross-Weir procedure [NRW; 16] and the Baker-Jarvis procedure [BJar; 17].

Both of the samples we present here show little variability of ε_r with frequency in the frequency ranges relevant to radar remote sensing, as dielectric relaxations occur at much lower frequencies. Thus, for each sample, the average ε_r between these frequencies is calculated and taken as representative of the sample.

Results:

Mars: The MARSIS [1] and SHARAD [2] remote radars currently in orbit around Mars have central frequencies of 5 and 20 MHz respectively, and the future GPRs will operate at 150–1200 MHz [5] and at 0.5–3 GHz [6]. We evaluated the dielectric response of the new Mars Global Simulant (MGS-1; [9]) between 3 MHz and 3 GHz. This simulant was modeled after windblown dust at the Rocknest site characterized by the Curiosity rover, and is the most representative analog of a "global average" of Martian regolith. An advantage of MGS-1 is its high proportion of grains <10 µm, as it is the finest, airborne dust (<5 µm) that is most likely entrained in the icy deposits of the Martian polar caps and mid-latitudes, which are major targets of radar studies. We thus sieved a bulk sample of MGS-1 into seven grain size distributions (GSD) that were measured individually, and evaluated the permittivity differences between the fine and large samples. The results for ε_r' (Fig. 2) show that: (1) Average ε_r' matches the expected value (~ 3) given the known composition of MGS-1, and is similar to that of JSC-Mars 1, and (2) though permittivity appears to decrease with grain size, this, expectedly, also correlates to an increase in porosity. The latter is a result of difficulties in achieving low porosities with the smaller GSDs.

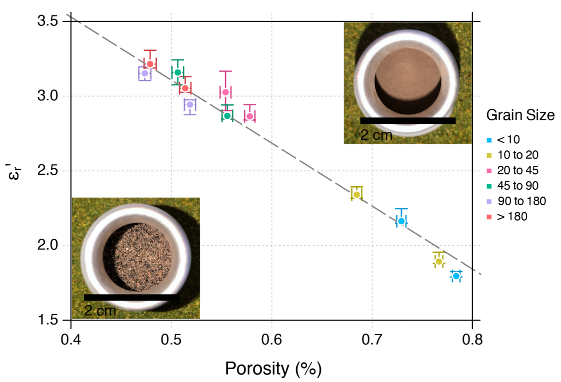

Fig. 2. Variation of the ε_r' of MGS-1 by average grain size and porosity. Top right inset: MGS-1 silt (grains <45 µm). Bottom left inset: MGS-1 sand (grains >180 µm).

Comets: A new cometary analog soil is currently being developed as part of a collaboration to investigate the physics of cometary processes in the laboratory [10]. The composition of this analog is based on studies of many physical properties observed in the regolith of comets, particularly 67P. The two phases selected were fine-grained Juniper charcoal (JC; <100 µm), representing the darker organic material; and ultra-fine-grained silicon dioxide (SiO2; <5 µm), representing the silicate component. We measured the electric permittivity of the potential analogs at many proportions of SiO_2 to aid in discerning the most representative mixture (Fig. 3). The frequency range selected was 80 MHz–3GHz. Studies by the Arecibo radio-observatory (2.38 GHz [18]) and the CONSERT bi-static radar on Rosetta (90 MHz [4]) place the range of values of ε_r' of the cometary nucleus between 1.25 and 2.1. CONSERT detected the lower values in this range in the deepest parts of the cometary nucleus, indicating increasing porosity with depth [2]. Furthermore, CONSERT measurements predict a nucleus porosity between 75–85%, with up to 40% water ice present. With these considerations, the mixtures with 60–80% SiO_2 are the best analogs for cometary soil from a radar perspective.

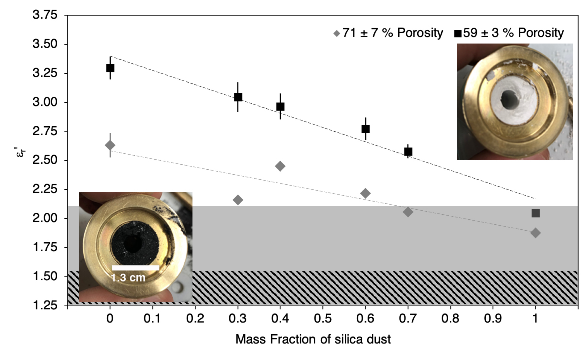

Fig. 3. Variation of the ε_r' of a new cometary dust analog based on mixtures of SiO_2 and charcoal [10]. The gray shaded area corresponds to the range of ε_r' measured for 67P, and the striped area corresponds to ε_r' of highly porous water ice. Insets: end member phases in the EpsiMu sample holder.

Future Work: For MGS-1, we plan to 1) measure a larger porosity range to discern between the effects of grain size and porosity; 2) measure the finest grain size channel at <5 µm, representative of aerosol dust; and 3) measure mixtures with salts and water at low temperatures to evaluate the radar response of aqueous brines. The cometary analog will also be mixed with water ice, in order to achieve fully representative measurements of cometary nucleus material. Finally, we will test saline ices independently of a silicate analog, to begin investigations of the radar response of materials relevant to Europa and other icy satellites.

References: [1] Picardi et al. 2004, PSS 52 [2] Seu et al. 2007, JGR 112 [3] Bramson et al. 2015, GRL, 42 [4] Kofman et al. 2020, MNRAS 497 [5] Hamran et al. 2015, IEEE [6] Ciarletti et al. 2017, Astrobio. 17 [7] Aglyamov et al. 2017, Icarus 281 [8] Stillman et al. 2010, J. Phys. Chem. B, 114 [9] Allen et al. 1998, EOS, 79 [10] Brouet et al. 2019, Icarus 321 [11] Cannon et al. 2019, Icarus 317 [12] Lethuillier et al., 2021 (in prep.) [13] Pommerol et al., 2019, Spac. Sci. Rev. 215. [14] Ba & Sabouroux 2010, Microw. Opt. Tech. Lett. 52 [15] Brouet et al., 2015, A&A 583 [16] Georget et al. 2014, C. R. Phys. 15 [17] Baker-Jarvis et al. 1990, Microw. Inst. Meas. 38.