Preliminary electromagnetic characterization of different lunar soil analogues.

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Introduction: Understanding the origin, age and distribution of water ice in the subsurface of the lunar polar and sub-polar regions requires the use of in-situ geophysical methods capable to measure depth, lateral and vertical extent, physical distribution (i.e., mixed in the regolith or as lens/layers of pure ice) and volume of the ice. Among all geophysical techniques, Ground Penetrating Radar (GPR) is by far the most suitable method for planetary shallow subsurface exploration, as it does not require any direct and permanent contact between the antennas and the surface, it is light, non-destructive, has a low power consumption and can easily operate on board a rover. The Moon is particularly suitable for such type of exploration due to the general low attenuation of the radar signal in the regolith which allows to reach a large depth [1]. In future unmanned and human missions this technique will be largely employed, therefore it is of paramount importance to understand the radar response in several types of Moon soils. In this work we perform dielectric measurements of four different lunar analogues as a function of temperature, density, oxide contents and porosity to evaluate the GPR performance in different soil conditions.

Lunar analogues samples

The certified lunar soil simulants used in this work are produced by Exolith Lab and replicate the two main geological terrains present on the Moon: lunar highlands and lunar maria. The acronyms LHS-1, LHS-1D refer to Highlands while LMS-1 and LMS-1D to Maria. These simulants are granular samples, and their principal differences are on oxide contents and grain sizes. Some details can be found in Tab.(1) and Tab.(2).

	LHS-1	**LHS-1D**
Particles size range	$< 0.04\mu m - 400\ \mu m$	$< 0.04\mu m - 35\mu m$
Anorthosite (Wt %)	74.4	74.4
Glass-rich basalt (Wt %)	24.7	24.7
Ilmenite (Wt %)	0.4	0.4
Olivine (Wt %)	0.3	0.3
Pyroxene (Wt %)	0.2	0.2

Table 1 Data sheet for lunar analogue LHS-1 and LHS-1D

	LMS-1	**LMS-1D**
Particles size range	$< 0.04\mu m - 300\ \mu m$	$0\mu m - 30\ \mu m$
Anorthosite (Wt %)	19.8	19.8
Glass-rich basalt (Wt %)	32.0	32.0
Ilmenite (Wt %)	4.3	4.3
Olivine (Wt %)	11.1	11.1
Pyroxene (Wt %)	32.8	32.8

Table 2 Data sheet for lunar analogue LMS-1 and LMS-1D

Experimental set-up

The measurements were performed in the facility operating at the Mathematics and Physics Department of Roma Tre University that has been designed to measure the electromagnetic properties of different type of simulants of the surfaces of the Solar System bodies. The data were acquired in the frequency range 20 Hz - 1 MHz by a LCR meter (Agilent HP4284A) and then repeated in the 75 kHz - 30 MHz range using a second LCR meter (Agilent HP4285A) capable to cover a wider spectrum of frequencies. Each measure was replicated, following the same procedure and maintaining the same physical parameters such as room temperature, equal sample mass inserted in the cell and compaction grade, to verify the reproducibility of the measurements. Before each experimental run, the sample was dried in a vacuum oven (SalvisLab) at 378 K for 24 hours to eliminate any residual water which would strongly affect the measurement. Then, the sample was inserted into the parallel plates cell and left inside to cool down to room temperature before starting the measure.

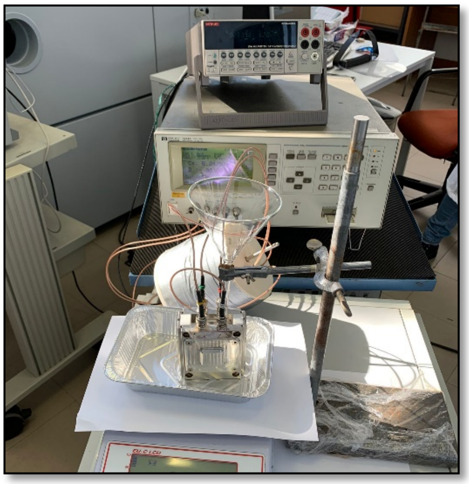

Figure 1:Experimental set-up: Impedance Analyzer HP4284A connects to the capacitive cell filled with the lunar analogues.

Results

The plots reported in Fig.2 show the trend of the real and imaginary parts of the four samples as a function of frequency for a fixed (room) temperature. Data refer to the acquisitions performed with the two different LCR meters. As shown in Fig.2, the real part of permittivity of all samples is substantially constant above about 10^4 Hz, and the values at 1 MHz range between 1.5 to 3.5. Conversely, the imaginary parts of all samples decrease as the frequency increases. Fig.3 illustrates the measurement reproducibility: M1 and M2 represent two independent measurements of the same sample. Both plots of the real and imaginary parts are very similar, confirming the reliability of the measurement procedure.

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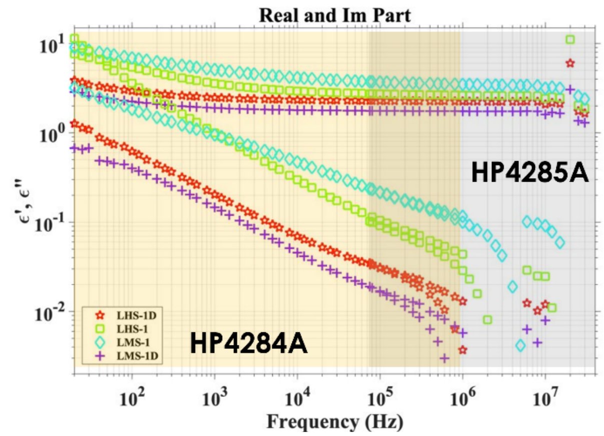

Figure 2: A comparison of the real and imaginary part of the complex dielectric permittivity measured at room temperature as function of frequency

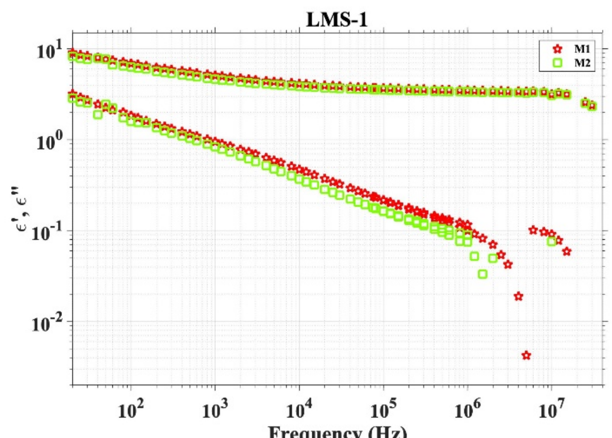

Figure 3: A comparison of the real and imaginary part of the complex dielectric permittivity of the two measurements on the same LMS-1 sample

In the future, we intend to perform new measurements to investigate the effect of the oxide content, the grain sizes and the sample compaction on the complex dielectric permittivity; moreover we will run new tests in a large range of temperature (100K – 450K).

References: **[1]** Li, Chunlai, et al. "The Moon's far-side shallow subsurface structure unveiled by Chang'E-4 Lunar Penetrating Radar." *Science advances* 6.9 (2020): eaay6898.