BROADBAND PERMITTIVITY MEASUREMENTS ON POROUS PLANETARY SOIL SIMULANTS, IN RELATION WITH THE ROSETTA MISSION.
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Introduction: The European Rosetta Space Agency's spacecraft has been orbiting the nucleus of comet 67P/Churyumov-Gerasimenko (hereafter 67P) since Aug. 2014 and has successfully landed Philae module on it in Nov. 2014. Among the numerous instruments carrying by Rosetta and Philae, MIRO (Microwave Instrument for the Rosetta Orbiter) [1], a radiometer composed of a millimeter receiver and a submillimeter receiver with center-band frequencies equal to 190 GHz and 560 GHz, respectively, is dedicated to the measurements of the subsurface and surface brightness temperatures. These values depend not only on the thermal properties but also on the complex relative permittivity ε (hereafter permittivity) of the material material which itself depends on frequency, bulk density/porosity, composition and temperature [2]. The real part of the permittivity ε' is related to the ability of material to store energy, while the imaginary part ε'' describes losses in the material. Considering the low bulk density of 67P (of around 450 kg.m^{-3} [3]) and the suspected presence of a dust mantle in many areas of the nucleus [4], investigations on the permittivity of porous granular samples are needed in order to support the interpretation of MIRO data but also of other microwave experiments involved in the Rosetta mission e.g. CONSERT (COmet Nucleus Sounding Experiment by Radiowave Transmission), a penetrating radar for tomography working at 90 MHz [5][6].

Experimental approach: We have developed a programme of permittivity measurements on porous granular samples over a frequency range of more than 3 orders of magnitude (50 MHz to 6 GHz and 190 GHz) under laboratory conditions (temperature of about 300K). Previous measurements had been performed on porous samples of volcanic origin as a first approximation of the high porosity of cometary dust: Etna volcanic ash and JSC Mars-1 Martian soil simulant [7]. Here we present new results obtained on JSC1A lunar soil simulant and ashes from Etna. The latter mostly consist of dark and basaltic porous grains and tiny crystallized grains, with a mineralogical composition dominated by silicates. The samples were split into several sub-samples with different size ranges covering a few to 500 µm (cf. Table 1). Bulk densities of the sub-samples have been measured before each measurement by determining the mass and volume of the sample holder thereby providing a mean bulk density ρ for each sub-sample. A moisture analyzer was used to dry and to estimate the volumetric moisture content of all the sub-samples (found to be in the 0.1-0.6% range) before any measurements between 50 MHz and 6 GHz. Also, the sub-samples were dried in a heater for 24h at 373K before any measurements at 190 GHz.

Between 50 MHz and 6 GHz, ε' and ε'' have been measured with a coaxial cell connected to a vector network analyzer (VNA) and equipped with a sample holder that can contain any kind of non-gaseous material: solids, powdered materials and liquids. The scattering parameters of the cell are measured and then are used to determine ε' and ε'' via the modified Nicholson-Ross method (see [8] for more details).

At 190 GHz, measurements have been done with a quasi-optical bench mounted in transmission, with two corrugated horns as emitting and receiving antennas, connected to a VNA. The free space transmission coefficient of the millimeter signal generated by the VNA is measured in phase and amplitude. By placing the sample at a Gaussian beam waist within the system, phase rotation and amplitude damping of the signal within a narrow frequency range allow one to determine ε' and ε'', respectively (see [7] for more details).

Measurements results: The results shown in Fig. 1 highlight dispersive behaviors of ε' normalized by the bulk density for the finest sub-samples between 50 MHz and 190 GHz. These frequencies encompass frequencies of interest for CONSERT (for which ε'' is within the 0.01-0.09 range for all sub-samples). The single-relaxation Debye model [2] fits relatively well the global behavior of ε' over the frequency range, thus validating the experimental setups and the measurements obtained from 50 MHz to 6 GHz and at 190 GHz (cf. Table 2). The dispersive behavior of ε' and results obtained for ε'' will be discussed longer in a forthcoming paper. Fig. 2 shows ε' as a function of the bulk density at 80 MHz, 110 MHz and 190 GHz. Results confirm, as a first approximation, that ε' decreases quasi-linearly with the decreasing bulk density at any frequency, as expected by the mixing formulae (described e.g. in [2]).

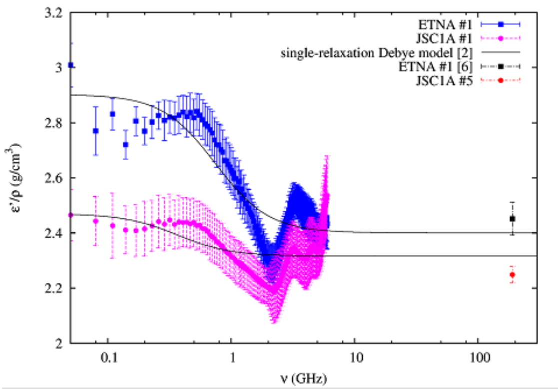

Fig. 1: Real part of the permittivity ε' normalized by the bulk density ρ, as measured for Etna sub-sample #1 and JSC1A sub-sample #5 fitted by a single-relaxation Debye model.

Table 1: Real part ε' and standard deviation $\sigma_{\varepsilon'}$ of permittivity for Etna and JSC1A sub-samples at 80 and 110 MHz; φ and ρ are respectively the mean particle size and bulk density of the sub-samples, with σ_φ and σ_ρ their respective standard deviations.

				80 MHz	110 MHz
	#	$\varphi \pm \sigma_\varphi$ (μm)	$\rho \pm \sigma_\rho$ (kg/m^{-3})	$\varepsilon' \pm \sigma_{\varepsilon'}$	$\varepsilon' \pm \sigma_{\varepsilon'}$
ETNA	1	36±15	1085±14	3.33±0.09	3.41±0.06
	2	115±35	1236±10	3.21±0.10	3.53±0.08
	3	283±67	1190±15	3.19±0.10	3.43±0.06
	4	506±60	1207±13	3.14±0.11	3.43±0.07
JSC1A	5	24±9	1285±8	3.36±0.09	3.37±0.12
	6	74±28	1395±6	3.69±0.10	3.67±0.09
	7	164±21	1237±22	3.48±0.05	3.45±0.05
	8	248±39	1228±11	3.28±0.06	3.49±0.05
	9	347±43	1166±8	3.39±0.04	3.41±0.06
	10	544±59	1103±27	3.20±0.13	3.18±0.13

Table 2: Real ε' and imaginary ε'' parts of permittivity at 190 GHz for JSC1A sub-samples, with $\sigma_{\varepsilon'}$ and $\sigma_{\varepsilon''}$ their respective standard deviations.

ν = 190 GHz	#	$\rho \pm \sigma_\rho$ (kg/m^{-3})	$\varepsilon' \pm \sigma_{\varepsilon'}$	$\varepsilon'' \pm \sigma_{\varepsilon''}$
JSC1A	5	1285 ± 8	2.89 ± 0.03	0.051 ± 0.016
	6	1395 ± 6	3.17 ± 0.04	0.065 ± 0.013
	7	1237 ± 22	2.93 ± 0.04	0.065 ± 0.012

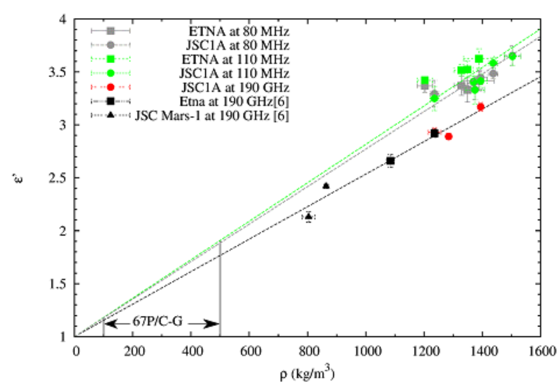

Fig. 2: Real part of the permittivity ε' as a function of the bulk density of the Etna and JSC1A sub-samples at 80 MHz, 110 MHz and 190 GHz (cf. Tables 1 and 2). Measurements previously obtained for JSC Mars-1 sub-samples at 190 GHz are also indicated [6].

Taking into account temperature variations expected for 67P [9] and the linear decrease of the permittivity with the temperature measured by [10] on JSC1A sample, these results provide an estimation of ε' and ε'' for a surface of 67P covered by a free-ice dust mantle at the frequencies of MIRO and CONSERT: ε' is likely to be in the 1.1–1.8 range; ε'' is likely to be below 0.05.

Future works: Similar measurements are foreseen in the current year on porous analogues of interest for planetary and cometary surfaces: i.e. powdered chondrites and ice/dust mixtures. Other frequency bands of measurements will be also investigated with the coaxial cell, and at submillimeter wavelengths with the quasi-optical bench. Efforts to set up these experiments in an environmentally controlled chamber will be made.

References: [1]Gulkis S. et al. (2007) *Space Sci. Rev.*, *128*, 561–597. [2]Ulaby F.T. and Long D. (2014) The University Michigan Press. [3]Sierks H. et al. (2015), *in prep*. [4]Thomas N. et al. (2015), *in prep*. [5]Kofman W. et al. (2007) *Space Sci. Rev.*, *128*, 413-432. [6]Heggy E. et al. (2012) *Icarus*, *221*, 925-939. [7]Brouet Y. et al. (2014) *PSS*, *103*, 143-152. [8]Georget E. et al (2014) *C. R. Physique*, *15*, 448–457. [9]De Sanctis M.C. et al. (2005), *A&A*, *444*, 605–614. [10]Calla O.P.N. and Rathore I.S. (2012), *Adv. Space Res.*, *50*, 1607–1614.

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