VOLUMETRIC GHZ RADAR FREQUENCY LOSS TANGENTS OF APOLLO 17 VERY HIGH TITANIUM BASALTS: IMPLICATIONS FOR ARTEMIS. J. B. Garvin[1], R. Rincon[1], M. Desphande[1], Justin Jones[1], Stephen Lebair[1] & R. Lempicki[1]; [1]NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD 20771 (james.b.garvin@nasa.gov; cell: 301-646-4369)

Introduction: Non-destructive volumetric (3D) evaluation measurements of *very high titanium* (VHT) basalts on the Moon offer insights into their formation, emplacement, and modification [1-4, 6-7]. Given their high Fe-Ti oxide concentrations (8-14 vol. % [8]), they are frequently considered both as a scientific and human exploration resource, with direct relevance to the ARTEMIS program. As part of our work with the micrometeorite cratering on lunar basalts we conducted micro-Computed Tomography (micro-CT) imaging of metal-oxide distributions in Apollo 17 sample **71035,52** (4.72 g) in comparison with simple multi-rotational 1-1.7 GHz dielectric permittivity measurements. Our aim has been to evaluate the intrinsic volumetric anisotropy of GHz dielectric properties of such materials on the Moon and derive meaningful values for their *loss tangents* as constraints on radar scattering models (RSMs) we have developed [5] for polarimetric Synthetic Aperture Radar (SAR) sensing of the Moon; e.g., from the DF-SAR on ISRO's *Chandrayaan-2* orbiter [10,12]. Ultimately, orbital SAR-based detection of VHT basalts, as a potential local resource, will be possible depending on radar sensitivity (NES*0*) and geologic context. Extending GHz dielectric permittivity analyses from bulk estimates to 3D (directional) measurements will improve RSMs of the Moon for a better assessment of radar subsurface detection of high-value materials including *ilmenite* [11] and *water ice* [12].

Here we describe the first correlation of micro-CT results for sample **71035,52** ($\leq$ 25%) with multi-pose dielectric tensor measurements at L-band (1 to 1.7 GHz) using a newly developed approach that permits multi-angle "CT-style" measurements of parameters such as the *loss tangent* and the *Real* part of the permittivity at key radar frequencies [1,3,4,6,11].

APPROACH: We configured an L-band **W**aveguide together with a **P**NA measuring system as part of a forward **M**odelling (***WPM***) approach for estimating the dielectric permittivity of an arbitrary sample**.** This *WPM* method relies on independent measurements of the 3D "shape" of the sample (via micro-CT) so that forward modelling can effectively constrain the *Re* and *Im* parts of the dielectric permittivity and permit estimation of the *loss tangent*. Remote sensing and laboratory measurements of the dielectric properties of the lunar regolith since the 1970s indicate that a typical *loss tangent* is ~ 0.005 [4], with values as high as 0.014 for Apollo 17 samples [1,3]. Similar values are also observed for Mars at GHz frequencies. Such low values are important in RSMs and allow for depths of penetration to 5-10 m in low-roughness settings to enable detection of buried water ice layers. Here we have used a simple rotational *WPM* approach (in contrast with typical cavity-resonance perturbation methods) to analyze the *loss tangents* within a VHT basalt sample (**71035,52**) in comparison to other lunar samples such as impact melt breccias (e.g., **14304,342**). With a noise floor sensitivity as low as -70 dB, our measurements for small (4-8 g) Apollo samples permit analysis of dielectric anisotropy within such materials via simple rotation, of direct value in side-looking radar RSMs for the Moon and Mars [5, 12].

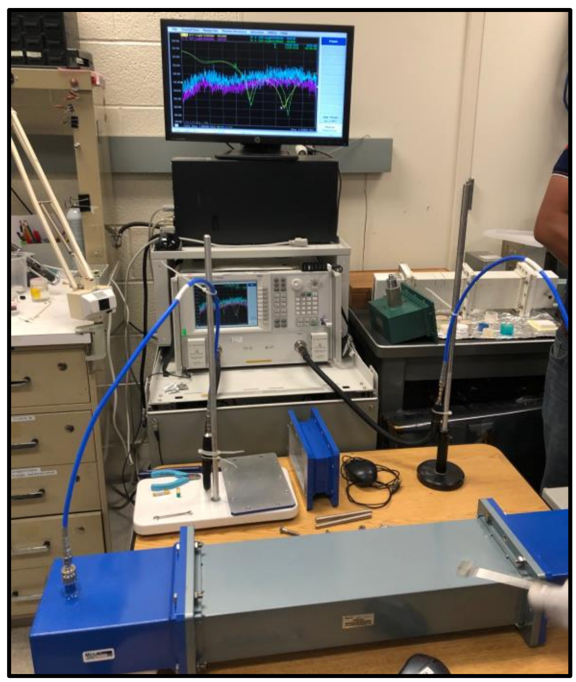

Figure 1: *L-band waveguide with PNA and sample within (WPM) for multi-rotation dielectric property measurements of Apollo samples (NASA GSFC).*

MEASUREMENTS: GSFC's micro-CT was used to produce ~8 μm/voxel x-ray CT data for **71035,52**, and segmentation analysis isolated the approximate volume % of *ilmenite* (and other metal-oxides) as ~20-25 %, larger than petrographic assessments (13%) [8]. **Fig. 2a** illustrates the micro-CT data for the 4.7g sample from which 3D shape files were derived (**Fig. 2b**). This VHT vesicular basalt (Type 1B) was chipped from a 0.5m boulder at Apollo 17 Station 1A, and displays skeletal ilmenite [2, 7-8]. Additional analysis using nano-CT methods is underway to refine first-order assessment of the ilmenite within the sample for electrical properties relevance (*see* [11]).

***Diel. Perm. at 1 to 1.7 GHz**:* Initially 4 poses were used to capture the 3D anisotropy of the VHT basalt sample. We plan to increase the number of poses to ~ 50 to analyze the bulk dielectric tensor across all relevant orientations. From these initial orientations, organized as basis vectors to span the sample volume (**Fig. 2b**), we were able to quantify large variations in the *loss tan*gent, with values ranging from 0.15 to 0.40, and a mean of 0.23. Such loss tangents are nearly 100 times those typical of lunar regolith, as per extant literature [1,3,4]. Bulk estimates of *loss tangents* for high titanium basalts have previously been reported at MHz frequencies [3,11], suggesting values as high at 0.18, but never up to 0.40. **Fig. 2** illustrates the measured *loss tangent* values for **71035,52** at the initial orientations. Comparisons with Apollo 14 sample **14304,342** suggest that the wide range of elevated *loss tangents* for **71035,52** are very significant (by a factor of ~25). Thus, suitably sensitive SAR instruments can detect deposits of TiO_2 rich materials (as at Apollo 17) based on simple polarimetric signatures as a means for isolating upper-surface resources (for oxygen) in scientific context to depths up to ~ 30 cm [5, 10, 12].

Summary: New GHz radar frequency measurements of the dielectric properties for a classic Apollo 17 VHT basalt (**Fig. 2**) reveal a high level of directional anisotropy, with *loss tangents* ranging from 0.15 to 0.40, which are many times larger than typical lunar materials (most of which are $\leq$ 0.010). Using these values, the model-based depths of penetration into the lunar surface at such loss tangents will be limited to 14-30 cm, even at L-band [5]. However, VHT-basalt surfaces that are spatially extensive enough should be detectable based on their SAR polarization signatures, such as those at the well-studied Apollo 17 site. In this way, localized patches of high TiO_2 materials can be mapped with high spatial resolution orbital SAR instruments of benefit to ARTEMIS and related lunar exploration activities. Sub-meter resolution orbital SAR imaging of the Moon could build on these preliminary results to rapidly detect small-scale patches of VHT basalts (or other metal-oxide rich materials) which could be used as resources in support of sustainable crew operations [6,12].

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Figure 2: *GHz frequency Waveguide-PNA-modelling approach for measuring multi-orientation diel. Permittivity (such as loss tangent) for Apollo sample* **71035,52** *(and others). We measured the anisotropy of loss tangents in this Apollo 17 VHT sample via 4 orientations* **(b,c),** *relative to typical lunar rocks listed in Lunar Sourcebook) [1] and in Olhoeft &Strangway) [3].*