DIELECTRIC PROPERTIES OF CHONDRITES AND THEIR IMPLICATION IN RADAR SOUNDING OF ASTEROID INTERIORS. E. Heggy[1], E. Asphaug[2], R. Carley[3], A. Safaeinili[4], and K. Righter[5]; [1]Lunar and Planetary Institute, Houston, TX, 77058-1113, USA (heggy@lpi.usra.edu); [2]University of California, Santa Cruz, CA, 95064, USA; [3]University of Cambridge, Cambridge, UK; [4]Jet Propulsion Laboratory, Pasadena, CA, 91109, USA; [5]NASA Johnson Space Center, Houston, TX, 77058-3696, USA.

Introduction: Over the past decades, radar remote sensing techniques have provided new insights into the surface and subsurface properties of the Earth, Moon, Venus, Mars, and Titan. Its demonstrated surface and subsurface imaging capabilities and mature spatialization techniques make it one of the most prominent techniques for exploring the interior of asteroids and providing a first insight into their geophysical properties, including volumetric images of the interior that assess their three-dimensional distribution of complex dielectric properties that reflect their structural, mechanical, and compositional variations. Such information is crucial for understanding the evolution of those objects as well as the potential hazard associated with any potential collision with other bodies of the solar system. The success of these radar investigations (as well as our understanding of the data acquired by earlier Earth-based radar observations) is strongly dependent on how the mineralogy, temperature, and porosity of the local environment affect the interaction of the radar wave with the surface and its propagation vector in the subsurface. Unfortunately, we have yet to characterize much of the potential parametric space associated with any of these planetary bodies. This research addresses this deficiency by determining the electromagnetic properties of a broad range of asteroid-like materials, mainly chondritic meteorite materials.

Experimental Approach: The radar penetration depth in geological materials for a given frequency can be constrained by quantifying the total signal loss affecting the radar wave during its propagation through the subsurface. Total signal loss can be summarized as the sum of individual losses from the surface reflection, geometrical spreading, electromagnetic attenuation, and scattering [1]. The amplitude of each loss mechanism is frequency and target dependent. At low frequencies (e.g., 1–50 MHz) the electromagnetic attenuation dominates the total signal losses and hence defines the penetration capabilities of a sounding experiment [2]. The electromagnetic properties in this study case is defined in term of the knowledge of the dielectric constant of the different units constituting the asteroid body and its evolution in term of the composition, density, and temperature variations among the structure. However, the parametric space associated with these dielectric properties has yet to be explored. In a first step toward addressing this deficiency we experimentally measured the electromagnetic properties of a broad range of dry meteoritic samples, mostly ordinary chondrites (LL5, L5, H5, and mesosiderites) inferred to have a good compositional analogy to asteroid material as observed from spectral observations [3,4]. Measurements were performed at room temperature using alternative current impedance techniques to evaluate the dielectric constant, represented by a complex variable ($\varepsilon^{/}$-i $\varepsilon^{//}$).

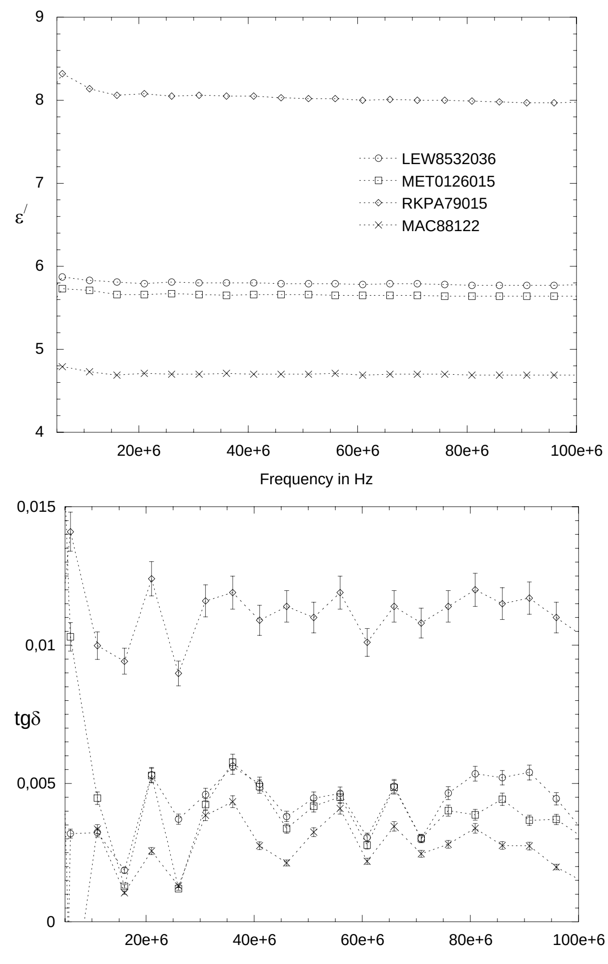

Fig. 1: Dielectric constant (upper) and the loss tangent (bottom) for dry chondritic samples in the frequency band 5–100 MHz at room temperature.

Measurements were made in the frequency range 1 MHz to 3 GHz with the dielectric cell connected to a high-precision impedance analyzer connected to a guarded coaxial capacitive cell designed to avoid fieldedge effects, which tend to reduce measurement accuracy. The use of guarded electrodes also prevents large reading errors in the lower limit of the frequency band where error exceeds 3%. Figure 1 summarizes some of the measurement results in the frequency band from 5 to 100 MHz for four chondrite samples: MAC 88122 (LL5), MET 0126015 (L5), LEW 8532036 (H5), and RKPA 79015 (mesosiderite) that are mineralogically and petrophysically characterized and curated in the Johnson Space Center meteorite database. We can clearly observe that the dielectric properties follow very closely the meteoritic classification with an increase of the dielectric constant as a function of the iron oxide enrichment of each meteorite class. The observed frequency dependence is very weak, suggesting a non-dispersive behavior for the chondrites. The real part of the dielectric constant is confined between ~4.6 and 5.8 for our samples with the exception of the mesosiderite, which contains a much higher amount of iron oxides than the other three samples and has a real value of ~8 at 20 MHz. While LL5, L5, and H5 samples can be viewed as representative of the outer layers of an asteroid [3], mesosiderites can be assumed as an analog to the denser metallic core material of an asteroid. The loss tangent values (bottom of Fig. 1), which are defined as the ratio between the imaginary and real part of the dielectric constant, are representative of the amount of signal losses in the radar wave [5] as they penetrate the asteroid outer layer to its central part. We can clearly note that chondrites have a very low loss tangent with an average value ~ 0.003 at 20 MHz for the LL5, L5, and H5 samples. This implies that such materials are very favorable to radar penetration.

In a first attempt to quantify this penetration depth using the laboratory experimental results, we calculated the theoretical two-way losses, α_{thl}, in dB/m and the associated theoretical penetration depth, δ_{thl}, in meters using a simple propagation model [equations (A) and (B), which do not consider scattering or magnetic losses] that integrates the dielectric constant and the loss tangent of the investigated materials as shown in Fig. 1. Hence for a given frequency, *f*, the radar losses and penetration depth are only a function of the permittivity as defined by equations (A) and (B):

$$\alpha_{thl} = 40 \times \frac{2\pi f}{c} \sqrt{\frac{\varepsilon'}{2}\left[\sqrt{1+(tg\delta)^2} - 1\right]} \quad \text{(A)}; \qquad \delta_{thl} = \frac{dB_{\max}}{\alpha_{thl}} \quad \text{(B)}$$

Figure 2 shows the evolution of the radar penetration as the function of the frequency for the average dielectric constant of 4.8 and loss tangent of 0.003 cited above for LL5, L5, and H5 samples as investigated in this preliminary study. The propagation model suggests that penetration depths of ~1000 m can be achieved at 20 MHz for an orbital sounder having a dynamic range of 60 dB.

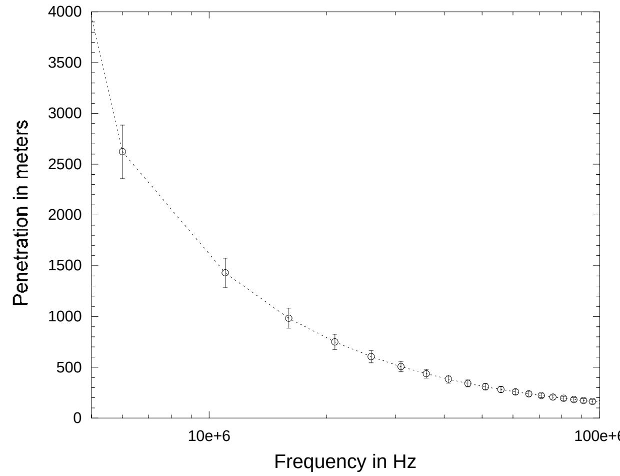

Fig 2: Penetration depth as a function of the frequency for an average asteroid represented by a typical chondritic sample.

It should be noted that the results in Fig. 1 are expected to vary significantly as the geophysical condition of temperature and density change the dielectric constant [6] and hence affect the penetration depth as can be deduced from equations (A) and (B). More parametric measurements are being performed by our team to quantify the effect of low temperatures and low density (inferred as a closer case to the asteroid environment) on the dielectric properties of asteroid analog materials (i.e., chondrites). Primary results suggest that both conditions cited above tend to decrease the dielectric constant and the loss tangent, which in turn improves the radar penetration depth capabilities.

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