EXPLAINING BRIGHT RADAR REFLECTIONS IN THE MARTIAN SPLD WITHOUT LIQUID WATER.

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Introduction: Recent discoveries of anomalously bright radar reflections below the Mars South Polar Layered Deposits (SPLD) have sparked new speculation that liquid water may be present below the ice cap [1][2][3]. These reflections, discovered in radar data acquired by the Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS), are far too powerful to be caused by a return from a simple boundary between water ice and other dry geologic materials. Instead, they are more consistent with reflections from damp materials or even something akin to the subsurface ponds and lakes sometimes found beneath Earth's ice sheets [4][5].

While this possibility is exciting, it is also difficult to confirm. Through thermal modeling, it was shown that without something akin to a recently emplaced magma chamber present beneath the surface, the heat requirements simply cannot be met [6]. In addition, the location of the bright reflections does not seem to match any likely lake locations based on the inferred hydraulic potential beneath the SPLD [7].

In light of these inconsistencies, it is necessary to consider alternative hypotheses for the observed radar returns. Previous work involving data from the Shallow Radar (SHARAD) instrument has shown that radar reflections in layered deposits can be greatly affected by constructive and destructive interference [8][9][10]. Herein, we use a one-dimensional radar sounding model to show that interference patterns can produce reflections consistent with those observed by MARSIS without the need for any liquid water, using only materials already known to be present in the SPLD.

Modeling Methods: Our one-dimensional model is similar in principle to that used by previous MARSIS and SHARAD studies [1][11]. We start by constructing a synthetic stratigraphy, which consists of an arbitrary number of semi-infinite layers between two half-spaces. The top half-space represents the atmosphere, while the bottom represents the bedrock beneath the SPLD. Each layer is assigned a complex permittivity, and each intermediate layer is assigned a thickness. We then calculate the total effective reflectivity of the model stratigraphy for each frequency sampled by MARSIS (see figure 1). This reflectivity is then multiplied by a synthetic chirp in frequency space mimicking the signal transmitted by MARSIS. We then multiply by the complex conjugate of the "transmitted" signal in order to simulate the standard pulse compression processing applied to MARSIS. The resulting signal is then brought into the time domain through a Fast Fourier Transform, where it approximates a processed MARSIS waveform. The main difference between our model and previous models is that instead of using a recursive method to calculate the effective reflectivity of the model stratigraphy, we use the so-called "matrix method" [12]. This change has no impact on our final results.

In order to test the hypothesis that thin layer interference could cause anomalously bright reflections we tested a number of different scenarios. Typically, these scenarios consisted of inserting one or more thin layers of CO2 ice or basaltic rock near the base of the model stratigraphy. Massive deposits of CO2 ice are known to exist in the SPLD [13][14] and recent evidence suggests that the basal unit of the NPLD includes many alternating deposits of water ice and basaltic material, implying that both scenarios are plausible [15]. We experimented with many different layer thicknesses and separations producing a wide range of results. After simulating a given model stratigraphy, we compared our results to real MARSIS echoes and calculated the effective permittivity one would retrieve under the (erroneous) assumption of a single simple interface. Because permittivity is related to material composition, this procedure allows us to determine if we can produce reflections similar to those caused by liquid water while using only dry materials.

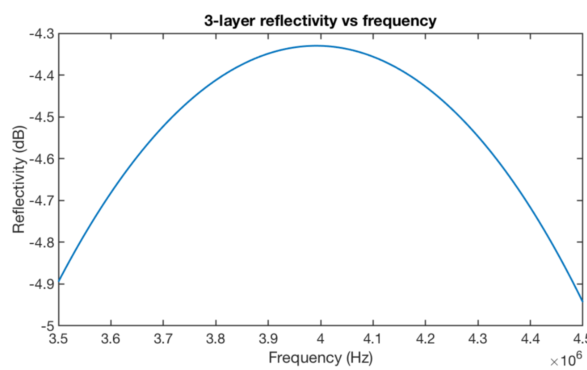

Figure 1: Reflectivity as a function of frequency for two 12 m CO2 ice layers separated by 12 m of pure water ice and bounded by water ice half-spaces, calculated using the matrix method [12].

Results: We are able to reproduce strong reflections comparable to those observed by MARSIS using multiple subsurface layering scenarios. Figure 2 shows an example of a simulated waveform for a stratigraphy consisting of two 12 m layers of CO_2 ice separated by 12 m of dusty water ice, all of which sit below 1.4 km of dusty water ice and above a basaltic bedrock. This simulated waveform closely matches a real MARSIS waveform taken from the region containing most bright reflections.

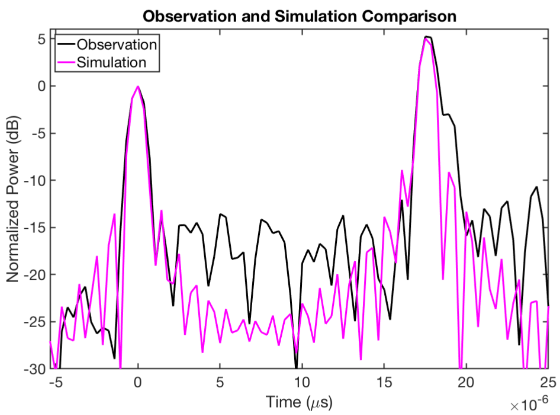

Figure 2: Comparison of a simulated (pink) and real (black) MARSIS waveform. Only the basal reflection was simulated, no attempt was made to recreate other layers.

In this simulation, the basal reflection is approximately 5.1 dB brighter than the surface reflection. Using a simple inversion method [16] we can convert the ratio between the subsurface and surface reflection power into an effective permittivity. The effective permittivity for this model stratigraphy is approximately 55, which matches some of the highest permittivity estimates derived in previous work [1][2][3]. For context, dry materials rarely have a permittivity above 15, and pure liquid water has a permittivity near 80. These results show that it is entirely possible to create extremely bright reflections without invoking the presence of liquid water.

It is important to be clear that we do not know what types of layers are in fact present at the base of the SPLD, and cannot rule out the possibility of liquid water. The purpose of this work is to provide a valid and plausible alternate hypothesis. The model stratigraphy simulated in figure 2 is just one possibility, and our results are quite sensitive to the chosen layer thickness and separation, as well as the number of layers used.

There is additional evidence, however, supporting the importance of interference between layer boundaries in determining reflectivity. This type of interference has already been observed by SHARAD in the NPLD [10], and we know that layering at the required scales is present within the SPLD. We can also compare MARSIS observations taken at different center frequencies. If bright reflections are caused by damp material or liquid water, we would not expect to see differences in reflectivity at different center frequencies. If interferences are contributing to reflectivity, those interferences will be stronger or weaker at different frequencies, and we should see a corresponding change in the observations. Indeed, observations show variable basal reflectivity between different frequencies, and it is not clear that such variability can be entirely explained by differences in attenuation between the surface and base of the deposits.

Given this supporting evidence, along with our simulation results and the inconsistencies with thermal and hydraulic modeling, we believe that the anomalously bright reflections at the base of the SPLD can be more readily explained as the result of normal layering, rather than invoking the presence of liquid water.

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