FREQUENCY DISPERSION OF THE MARTIAN SURFACE REFLECTIVITY BY MARSIS.

C. Grima[1], W. Kofman[2,3], A. Hérique[2] and P. Beck[2]. [1]Institute for Geophysics, University of Texas at Austin, TX, USA, (cyril.grima@utexas.edu), [2]Univ. Grenoble Alpes, CNRS, CNES, IPAG, 38000 Grenoble, France, [3]Centrum Badan Kosmicznych Polskiej Akademii Nauk (CBK PAN), PL-00–716 Warsaw, Bartycka 18A, Poland.

Aim. We are investigating the frequency dispersion of the radar surface return from the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) [1]. We provide preliminary observations at planetary scale. Their translation into hypotheses for the physical property of the surface and the near-surface will be discussed.

Background. Radar sounders are active instruments transmitting and recording back bursts of radio signals that are scattered by geologic discountinuities along the propagation path, the first being the surface. There are various physical properties of a planetary surface that modulate the strength of the radar return (reflectivity) [2]. Among them, some have dispersive properties, i.e., their impact on reflectivity varies with the frequency of the impinging signal. For example, losses due to roughness will generally fade with decreasing frequency [3, 2]. Conversely, the reflected strength over a given conductive material increases with decreasing frequencies [4, 5]. Furthermore, the presence of a superficial layer thinner than the vertical resolution of the radar system [6] is also responsible for a dispersive reflectivity that is dependent on the ratio between the radar wavelength and the overburden thickness [6].

Data. MARSIS is a multi-frequency radar sounder on board the European Space Agency's Mars Express spacecraft [1]. It transmits 1-MHz-wide chirped signals (150 m vertical resolution in void) centered at 3, 4, and 5 MHz (resp, 100-m, 75-m, and 60-m wavelength). Only two of those frequency bands are used at the same time, depending on the instrument acquisition plan. Our preliminary study uses the dataset processed by [7] and also used by [2], spanning 3 years of early observation. It is derived from the MARSIS Experiment Data Record (EDR) using the Subsurface Sounding mode 3 (SS3). The SS3 mode does not do multi-look processing (non-coherent sum of the echoes), so that the optimal along-track sampling is preserved and unpredictable gain variations from higher processing levels is avoided [8]. These data are each filtered in three Doppler bands corresponding to the fore, nadir and aft directions with respect to the spacecraft motion. We consider the surface echo that is the stronger among those three bands to ensure it corresponds to the first scattering center. The dataset is also corrected from the ionosphere distortion to gather back the energy of the surface echo in a single temporal resolution cell [7]. Preliminary results are presented on Fig.1.

Relative Calibration. The relative gain between each frequency channel is unknown, challenging any attempt to investigate the dispersivity of the signals. To partially by-pass this issue, we consider two ad-hoc relative calibrations (C) that we speculate to be approximate end-members between which lies the true relative calibration values. (C1) A value of 0 dB is assigned at each frequency to the mean reflectivity of an intermediate flat plateau at the South Polar Layered Deposit (SPLD) (Fig.1.Left). This region is located between 81.5–84.5°S and 180–200°E. It is used as a reference for number of reflectometry investigations with a usual assumption to be made of a homogeneous media with a flat surface [7, 3, 9], thereby with no frequency dispersion expected. (C2) A value of 0 dB is assigned to the median of the reflectivity distribution of each frequency (Fig.1.Right). With this calibration C2, the 3-MHz frequency has the strongest reflectivity at the SPLD, followed narrowly by the 5-MHz and 4-MHz reflectivity, weaker by 0.4 dB and 1.2 dB, respectively.

Observations and Discussion With the C1 calibration, the 4-MHz reflectivity (the middle frequency of the MARSIS bands) is often stronger (greenish colours on Fig.1 maps). This cannot result from a global roughness regime or widespread conductive material because those would produce a monotonic reflectivity response with frequency. It remains the possibility of a global and specific sequence of layering in the near-surface that could produce this frequency-dependence response, although such a steady layering through terrains of various ages and origins appears a priori unlikely. Testing this later hypothesis would provide clues on whether or not the SPLD reflectivity can indeed be assumed as a non-dispersive media, with implications for past and future reflectometry investigations.

With C2, the distribution of the frequency-dependence of the reflectivity planet-wide is naturally more balanced. The mid-latitude cratered plateaus in the South tend to have a weaker 5-MHz reflectivity (yellowish colours on Fig.1 maps), as expected for a rough terrain. This trend, however, disappears further South ($< 20 - 30°$) where larger decakilometric-scale roughness derived from altimetry has been reported to falter [10], a hypothetical sign of the roughness threshold beyond which MARSIS is truly responsive.

In the northern plains, one prominent feature is independent on the calibration scheme. Above $45°$, the lower 3-MHz reflectivity steadily decreases with latitude

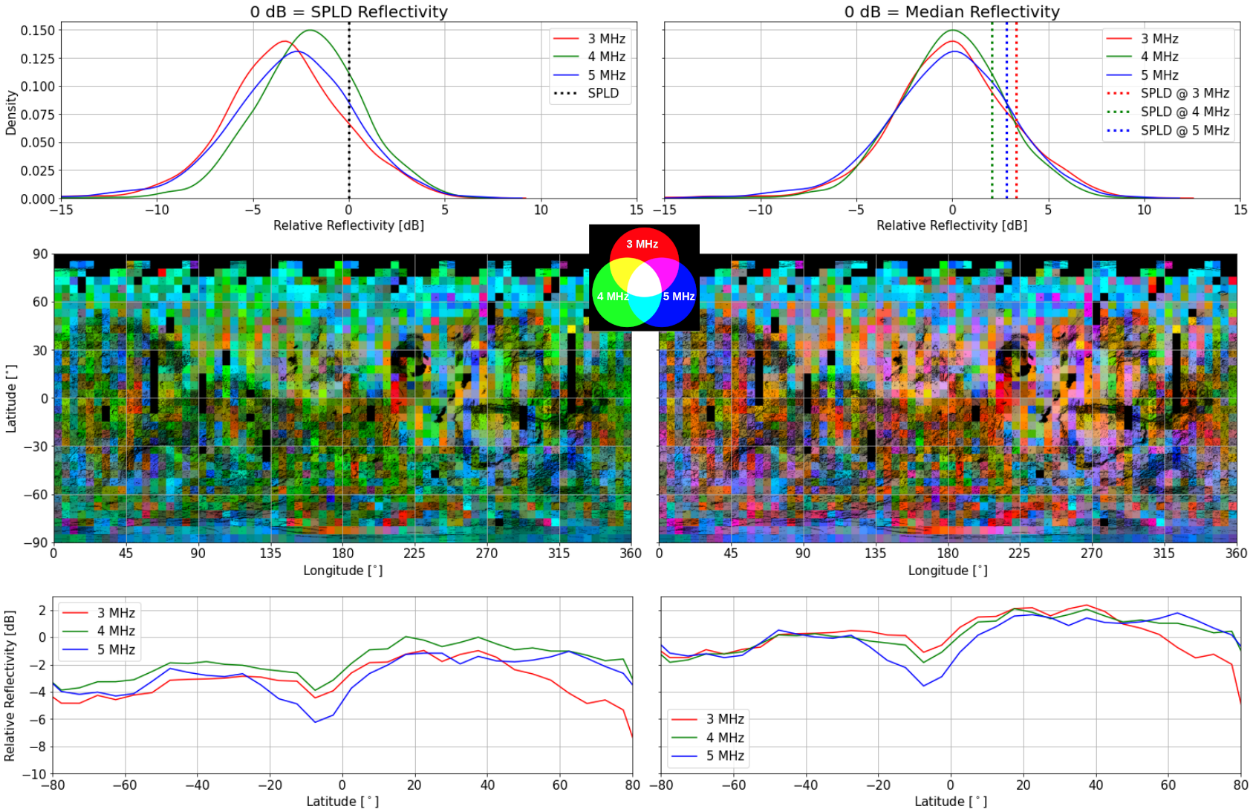

Figure 1: MARSIS surface reflectivity at 3 MHz (red), 4 MHz (green), and 5 MHz (blue) relatively calibrated to the reflectivity at the SPLD (left column), or the median reflectivity at each frequency (right column). (Top row) Density distribution of the reflectivity. (Middle row) Composite RGB image obtained by additive mixing of the colored associated to each frequency. Brighter shades denote a more reflective surface. Data are averaged within 5° × 5° spatial bins. (Bottom row) Average reflectivity per latitude.

to reach a deficit to 2-4 dB below the other frequencies at the SPLD margin. This trend is observed at every longitude. The outer limit of this feature mimics in extent, but precedes in latitude, the increase in water equivalent hydrogen (WEH) contained in the first meter of the ground [11]. We hypothesize this to be due the presence of the ice table within the MARSIS vertical resolution (< 150 m) and altering the reflectivity by signal interference. An alternative hypothesis is an ionospheric correction bias that could affect preferentially one frequency, although such a bias should also be visible in the South if the observed solar zenith angle is equally distributed between the two hemispheres.

Ongoing work for testing some of the hypotheses introduced above will be presented at the conference.

References: **[1]** G. Picardi et al., *Science* 310.5756 (2005), pp. 1925–8. **[2]** C. Grima et al., *Geophysical Research Letters* (in press). **[3]** C. Grima et al., *Icarus* 220.1 (2012), pp. 84–99. **[4]** S. M. Tulaczyk and N. T. Foley, *The Cryosphere* 14.12 (2020), pp. 4495–4506. **[5]** C. J. Bierson et al., *Geophysical Research Letters* 48.13 (2021). **[6]** J. Mouginot et al., *Icarus* 201 (2009), p. 454. **[7]** J. Mouginot et al., *Icarus* 210 (2010), p. 612. **[8]** N. S. Arnold et al., *Journal of Geophysical Research: Planets* 124.8 (2019), pp. 2101–2116. **[9]** R. Orosei et al., *Science* (2018). **[10]** M. A. Kreslavsky and J. W. Head, *Journal of Geophysical Research: Planets* 105.E11 (2000), pp. 26695–26711. **[11]** J. T. Wilson et al., *Icarus* 299 (2018), pp. 148–160.