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► **To cite this version:**

Emile Brighi, Valérie Ciarletti, Alice Le Gall, François-Wandrille de Lamberterie, Yann Herve, et al..  
Identifying heterogeneity sizes in the subsurface with WISDOM, the GPR of the ExoMars mission.  
Europlanet Science Congress 2022, Sep 2022, Granada, Spain. pp.EPSC2022-55, 10.5194/epsc2022-  
55 . insu-03752781

**HAL Id: insu-03752781**

**<https://insu.hal.science/insu-03752781>**

Submitted on 17 Aug 2022

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## Identifying heterogeneity sizes in the subsurface with WISDOM, the GPR of the ExoMars mission

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The WISDOM (Water Ice Subsurface Deposits On Mars) ground penetrating radar (GPR) (2)(3) has been specifically designed for the ExoMars (ESA/ROSCOSMOS) Rosalind Franklin rover to investigate the first meters below the surface of Oxia Planum in order to understand the geological context of the landing site and to provide guidance for sample collection by the drill.

The detection of clear buried interfaces or resolvable large reflecting structures might be the most rewarding features a GPR can reveal. Nevertheless, the shallow subsurface of some locations in Oxia Planum may be such as WISDOM radargrams would be difficult to interpret because of the lack of clearly identifiable structures. In particular, this will be the case if the subsurface consists in a heterogeneous medium including a large density of scattering structures of dimension commensurate with WISDOM wavelengths of operation. Such scattering structures could be indicative of local changes in porosity or composition ; their characterisation is of interest as it provides information about the geological history and processes in the investigated area. This work proposes and tests a method to statistically estimate the typical size and, possibly shape, of buried scatterers and to retrieve their permittivity contrast with the surrounding material from WISDOM radargrams.

### ▪ WISDOM, GPR of the ExoMars mission

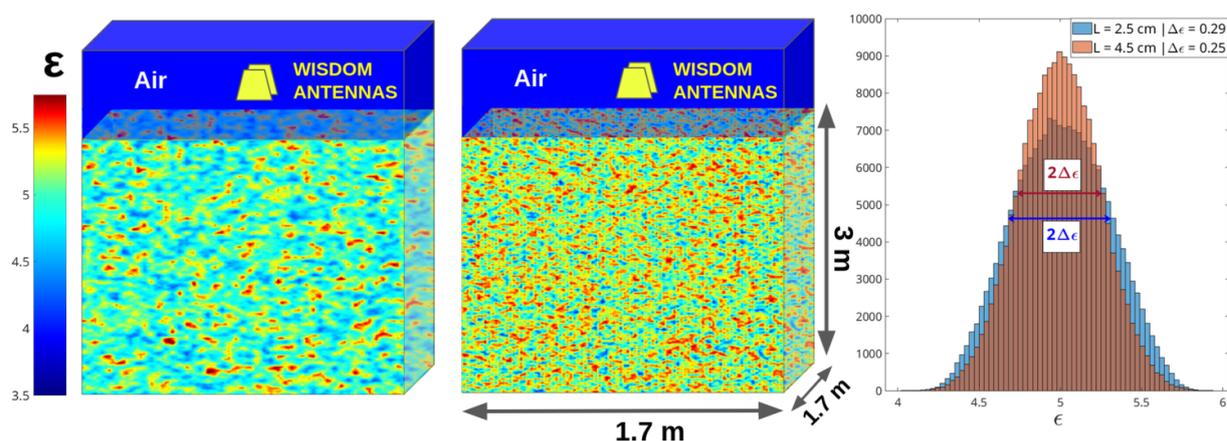
The WISDOM instrument is a step-frequency radar operating in a broad frequency bandwidth (0.5-3 GHz) corresponding to wavelength values ranging from 5 cm to 27 cm (for a relative permittivity value of 5), that ensures a vertical resolution better than 3 cm in the subsurface (1). WISDOM is also a polarimetric GPR. Thanks to its antenna system, it can acquire data in four polarization configurations (6) which allows an in-depth analysis of the received echoes for a better characterization of the shape and orientation of any buried reflector. These characteristics make WISDOM an instrument very well suited to the quantitative analysis of small-scale heterogeneities in the subsurface.

### ▪ Method

For this study, we have conducted numerical simulations with the code TEMSI-FD (4), which solves Maxwell equation using the Finite-Difference Time-Domain (FDTD) method. TEMSI-FD can simulate the propagation of WISDOM electromagnetic waves in realistic environments.

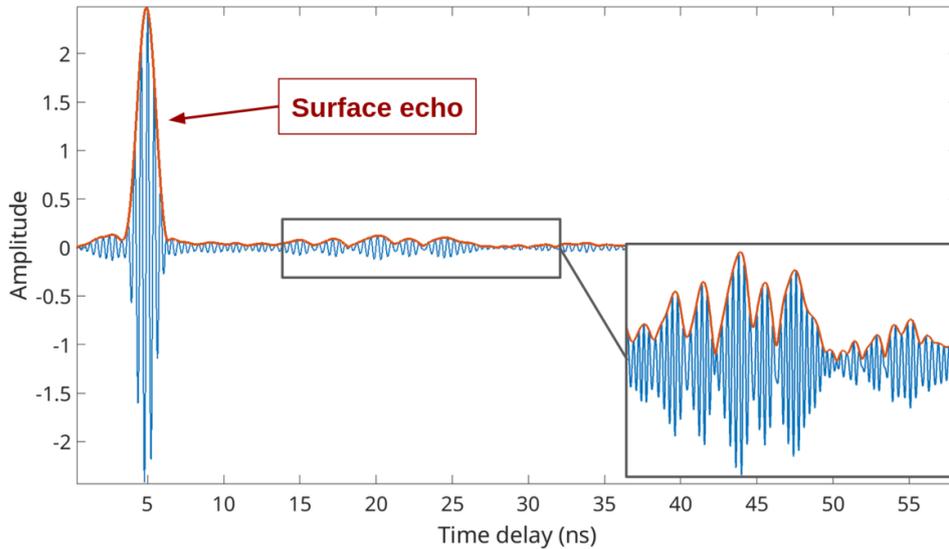
For the purpose of our study, we have considered subsurfaces embedding heterogeneities of fractal properties. These latter were generated by the diamond-square splitting technique implemented in the TEMSI-FD code. The resulting medium is characterized by 3 parameters : its mean relative permittivity mean, the standard deviation of its permittivity and the typical size of the heterogeneities  $L$ .

For a given set of these parameters, a number of subsurface volumes were generated in order to be able to perform meaningful statistical averages. Fig. 1 shows two examples of modeled subsurfaces with different  $L$  values and somewhat similar distributions of permittivity (right).



**Fig. 1.** : Simulated box configuration for a given fractal heterogeneous subsurface with  $L = 4.5$  cm (left box) and  $L = 2.5$ cm (middle box). Associated statistical distributions of permittivity values (right).

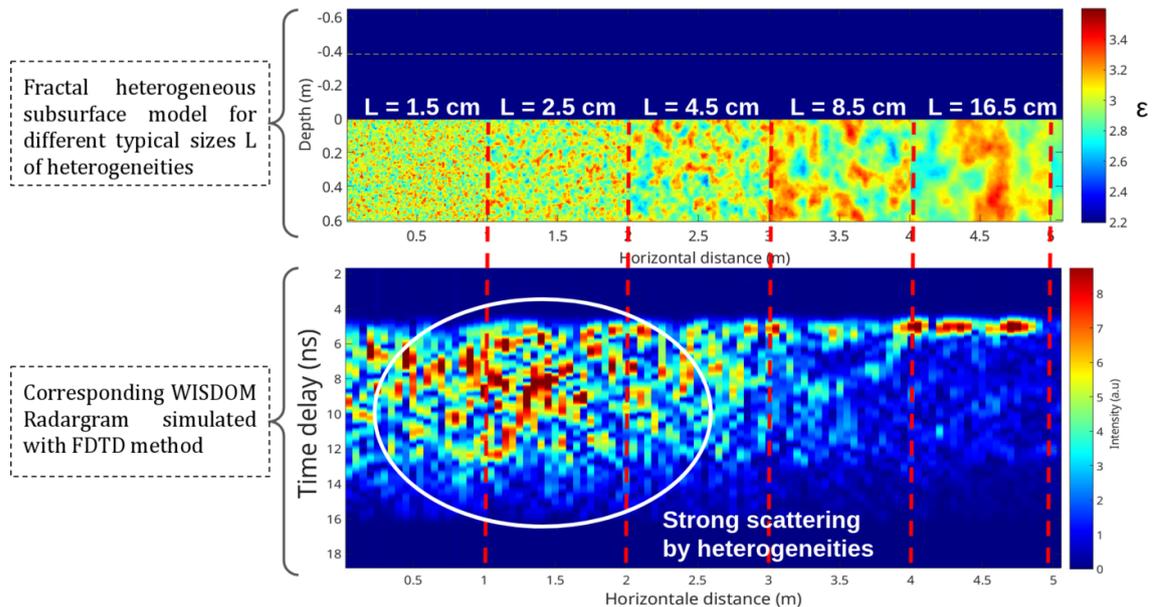
TEMSI-FD is used to simulate realistic WISDOM data for the study. The antennas and the transmitted signal are accurately modelled in order to reproduce as reliably as possible WISDOM operations over heterogenous media such as the ones displayed in Fig. 1. The orientation of the transmitting and receiving antennas can be changed to simulate the different polarimetric configurations. For one location of the radar, a single sounding provides the received amplitude as a function of the two-ways propagation time (Fig. 2). The mean of the signal envelope (red curve on Fig. 2) is computed to quantify volume scattering by heterogeneities (not considering the surface echo). Combining several soundings acquired at different radar location along a profile produces a radargram (Fig 3).



**Fig. 2:** Example of a simulated sounding. The surface echo is clearly visible as the strongest and earliest signal, followed by weaker signals back-scattered by heterogeneities.

▪ **Results and preliminary analysis**

Fig 3 shows that volume scattering mostly occurs for L values ranging between 1.5 and 4.5 cm, with a maximum around 2.5 cm. Beyond 4.5 cm, no volume scattering is noticeable because the fractal heterogeneities can be regarded as individual reflectors at WISDOM wavelengths.

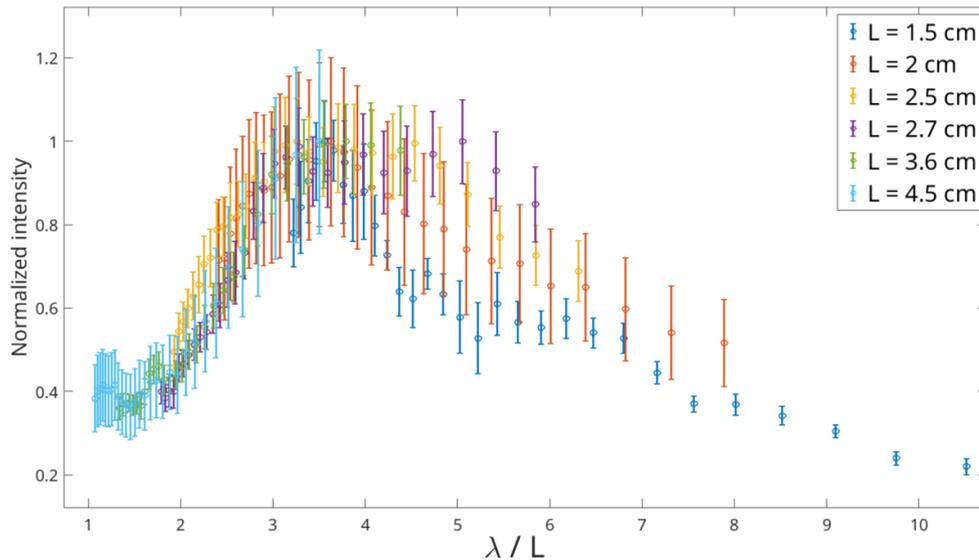


**Fig. 3:** Simulated WISDOM radargram obtained on fractal heterogeneous subsurface of different L values.

The broad frequency bandwidth of WISDOM allows to study the scattering process by sub-frequency band to estimate the typical size of the structures. The whole frequency domain is analyzed using 30 sliding sub-bands of 400 MHz width (to keep a sufficient temporal resolution), each being characterized by a mean wavelength  $\lambda = c / \sqrt{\epsilon_{mean}} f_{mean}$  where  $f_{mean}$  is the mean frequency for

the sub-band and  $c$  the celerity of light in vacuum.

Fig 4 synthesizes the results obtained for  $L$  values ranging from 1.5 to 4.5 cm; the error bars correspond to the standard deviation computed over 60 soundings. The results clearly show a maximum of scattering intensity for a wavelength  $\lambda \approx 3.5 L$  regardless the value of  $L$ . This implies that, in principle, WISDOM data can be used to determine the size of heterogeneities within 1.7 cm and 10 cm in a porous subsurface ( $\epsilon = 3$ ) and within 1.0 cm and 5.7 cm in a compacted one (permittivity around 8). During the presentation, we will further discuss the validation and the implications of such a method of analysis which will be applied to terrestrial data acquired in a Martian analog, namely the Atacama desert (5). We highlight that the present work and proposed method can be readily adapted to other GPR operating from a planetary surface.



**Fig. 4:** Back-scattered intensity as a function of  $\lambda/L$ . The error bars correspond to the standard deviation computed over 60 soundings.

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