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The WISDOM GPR on board the ESA's ExoMars Rosalind Franklin Rover – Focus on tools developed for a quantitative data interpretation

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Introduction

The ExoMars Rosalind Franklin Rover exobiology mission is now scheduled to launch in 2028 to search for traces of past or present life in the shallow subsurface of Oxia Planum [1],[2]. The Rover is equipped with a drill capable of taking samples up to 2 m deep where organic molecules and possible biosignatures are likely to be preserved. The WISDOM GPR was designed specifically for the mission's objectives [3],[4]: it will provide images of the Martian subsurface down to a few meters which will contribute, together with the other instruments of the payload, to the understanding of the geological context of the landing site. The article focuses on the signal and data processing tools that have been developed, validated on simulated data and eventually implemented in the pipeline that will be used for the interpretation of Martian data. Applications to experimental data collected during field campaigns will be presented.

The WISDOM instrument

Two GPRs (RIMFAX on board the Perseverance rover (NASA) [5] and RoSPR on board the Zhurong rover (CNSA) [6]) operated on Mars, have demonstrated the potential of GPRs to provide, in a non-destructive way, first-hand information about the subsurface, which is essential for a comprehensive understanding of the geological context of the investigated area. WISDOM has been designed to image the Martian subsurface down to at least 2-3 meters with a few-centimeter vertical resolution, which is required to be consistent with the size of the core samples that will be collected by the ExoMars Rosalind Franklin Rover drill. WISDOM is a polarimetric, step-frequency GPR operating in the frequency domain over an ultra wide band from 500 MHz to 3 GHz.

The WISDOM FM has been thoroughly characterized end-to-end [7] in the laboratory and also once accommodated on the Rosalind Franklin rover in order to document the interactions between the rover structure and the radar radiation pattern, and take them into account in order to avoid possible misinterpretations of the future Martian data.

On Mars, while the rover is moving at the surface, WISDOM will perform electromagnetic soundings, typically every 10 cm in order to automatically produce radargrams (i.e. images of the subsurface

showing, along the rover track, the amplitude of the radar signals back-scattered by permittivity contrasts in the subsurface as a function of the propagation delay). Since WISDOM operates in the frequency-domain, an Inverse Fourier Transform (IFT) needs to be applied to the frequency domain data to obtain the response in time-domain, which provides the subsurface images. In order to specify the depth of any structure detected in the Oxia Planum subsurface, the measured propagation delays must be converted to depths, which requires an estimated value of the average subsurface permittivity.

A number of algorithms have been used to develop tools to process the data and produce the data products that will allow to maximize the scientific return of the instrument and of the mission.

Data processing

As previously mentioned, WISDOM operates in the frequency-domain and a number of processing techniques are directly applied on the raw data before IFT: free space removal to suppress parasitic signals (electronic coupling, antenna crosstalk, multiple reflections on the rover body, etc), windowing to reduce sidelobe contribution and whitening for spectrum frequency-dependent compensation [7].

Eventually, the Bandwidth Extrapolation (BWE) technique has been implemented to enhance WISDOM radargrams vertical resolution [8] by a factor of up to 3. Recently, we released the first open-source BWE software, as a Python library named « PyBWE » [9]. (see Oudart et al. submitted to MITM13 EPSC 2024)

Clear buried interfaces or resolvable large reflecting structures are easily interpretable features in radargrams. However, radargrams most often show diffuse scattering indicative of the presence of heterogeneities that could be pyroclastic, sedimentary or ejecta deposits. Their typical size as well as their shape provide constraints about the origin and transport of materials and therefore about the chronology of geological events. We have thus developed a method to statistically estimate the typical size of buried scatterers [10]. The method requires data produced by ultra-wideband GPR since it relies on the analysis by narrow frequency sub-bands. Based on numerical simulation, we demonstrated that the size L of the scatterers can be estimated from the wave length value λ that triggers the maximum of volume scattering ($L \sim \lambda/5$). (see Brighi et al. submitted to TP2 EPSC 2024). For a permittivity value of 5 in the subsurface, the WISDOM data could thus be used to estimate the dimensions of the heterogeneities in the range of 0.9-4.2 cm.

Since, one of WISDOM's objectives is to detect potential buried rocks that could jeopardize drilling activities, we have developed an automated tool for detecting hyperbolic signatures in radargrams [11]. It allows locating the scatterers and also obtaining an estimate of the soil permittivity value (which must be known to convert the measured arrival times into distances). The tool is based on the Hough transform and takes into account the refraction at the surface and therefore applies to all planetary GPRs, such as WISDOM, whose antennas are located a few decimeters above the surface.

Future work will be dedicated to the more time-consuming algorithms that cannot be run in real time but will enable deeper data interpretation (for example, by comprehensively exploiting WISDOM's polarimetric capability).

[1] Vago et al. (2017), *Astrobiology*, 17 (6-7). [2] Fawdon et al. (2024), *Journal of Maps*, 2024, 20 (1) [3] Ciarletti et al. (2011), *Proceedings of the IEEE*, vol. 99, no. 99 . [4] Ciarletti et al. (2017), *Astrobiology* 17 (6-7) [5] Hamran et al. (2022), *Mars. Sci. Adv.* 8 [6] Zhou et al. (2020), *Physics* 4 [7] Hervé et al. (2019), *Planetary and Space Science*, 189, pp.104939 [8] Oudart et al. (2022) *Planetary and Space Science*, 224, pp.105606 [9] Oudart et al., 2024 (in review), *Journal of Open Source Software* [10] Brighi et al. (in review), *Planetary and Space Science*. [11] Oudart et al. (2021) *Planetary & Space Science* 197, pp.105173.