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Analysis of the Martian subsurface from the observation of the Rover Subsurface Penetrating Radar (RoSPR) onboard Tianwen-1

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Introduction

China's first Mars exploration mission, Tianwen-1, was successfully launched on 23rd July 2020. The mission included an orbiter, a lander, and the Zhurong rover. Zhurong landed on Mars in the southern part of Utopia Planitia (109.925°E, 25.066°N) on 15th May 2021 and then conducted unprecedented *in-situ* observations with several instruments, including a ground-penetrating radar (GPR) called Rover Subsurface Penetrating Radar (RoSPR) (Liu et al., 2023). The radar (Fig. 1) aimed at probing the subsurface at the Zhurong landing site and searching for buried water ice. Utopia Planitia is well known for showing different ice-related landforms (Séjourné et al., 2019). To achieve this goal, RoSPR was equipped with two channels: a high-frequency channel providing high-resolution (5 cm, when permittivity is 3) full-polarization radargram of the shallow subsurface (first 10 meters) and a low-frequency channel capable of penetrating the Martian subsurface down to a depth of ~100 meters with a 1-meter vertical resolution.

In-situ GPR observation can reveal the structure and permittivity distribution along the cross-section drawn by the rover's traverse. The subsurface structure is interpreted from the radar profile, which intuitively shows the location of subsurface reflectors, such as buried craters, aeolian deposits, and icy beds. Permittivity is a complex parameter describing the electromagnetic properties of materials. It mainly depends on composition and porosity. Its real part and imaginary part respectively control the wave velocity and signal attenuation rate in the Martian subsurface.

Data and Methods

We use all the 5893 dual-channel radar traces collected by RoSPR during the 325 solar days on Mars. The traverse of the radar is shown in Fig. 2. Those observations covered ~1840 meters with an elevation variation of ~10 meters from the Zhurong landing site southward. Data from ground experiments of RoSPR on glaciers on Earth are also used to provide a comparison between the RoSPR data acquired on different sites.

In addition to conventional RoSPR data treatments, advanced data processing methods are deployed to better reveal subsurface structure. In particular, we adopt a background matrix method (Rashed and Harbi, 2014) which statistically removes the systematic clutters. Blind deconvolution methods of the radar B-scan are also tested to address and eliminate the ringing effect that commonly exists. In addition, the bandwidth extrapolation technique designed for range resolution enhancement (Oudart et al., 2021) will be applied to further provide clarity among different buried objects.

Preliminary Results and Ongoing Work

To estimate the Martian soil permittivity, we applied a hyperbola fitting method which accounts for the antenna's height (Wang et al. 2021, Oudart et al., 2022), and a centroid frequency shift method (Quan et Harris, 1997) which uses the real-time spectrum of dual-channel RoSPR data to maximize the accuracy (Fig. 3). Loss tangent estimation also reveals upper bounds of ~ 0.008 and ~ 0.022 for the first 10 meters and 40 meters, respectively.

The low-frequency B-scan, as shown in Fig. 4, reveals buried structures and indistinct reflectors in deeper regions. The variation of the B-scan and loss tangent value along the depth implies varied composition at the landing site. The ongoing work focuses on refining data processing techniques to improve the clarity of subsurface imaging and provide robust interpretation and geological analysis.

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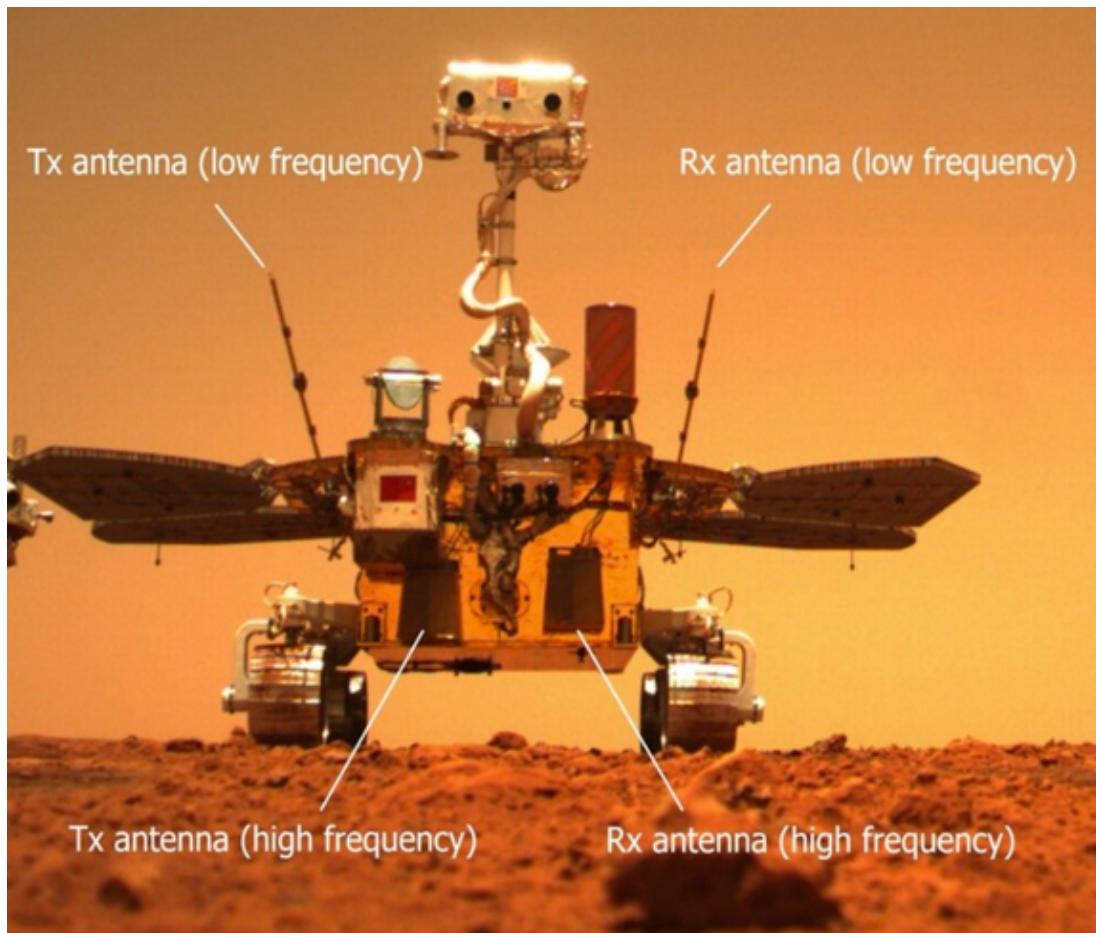


Fig. 1 The dual-channel RoSPR onboard Zhurong rover. The low-frequency monopole antennas are mounted in the front of the rover. The high-frequency Vivaldi antennas are tied to the rover's body.

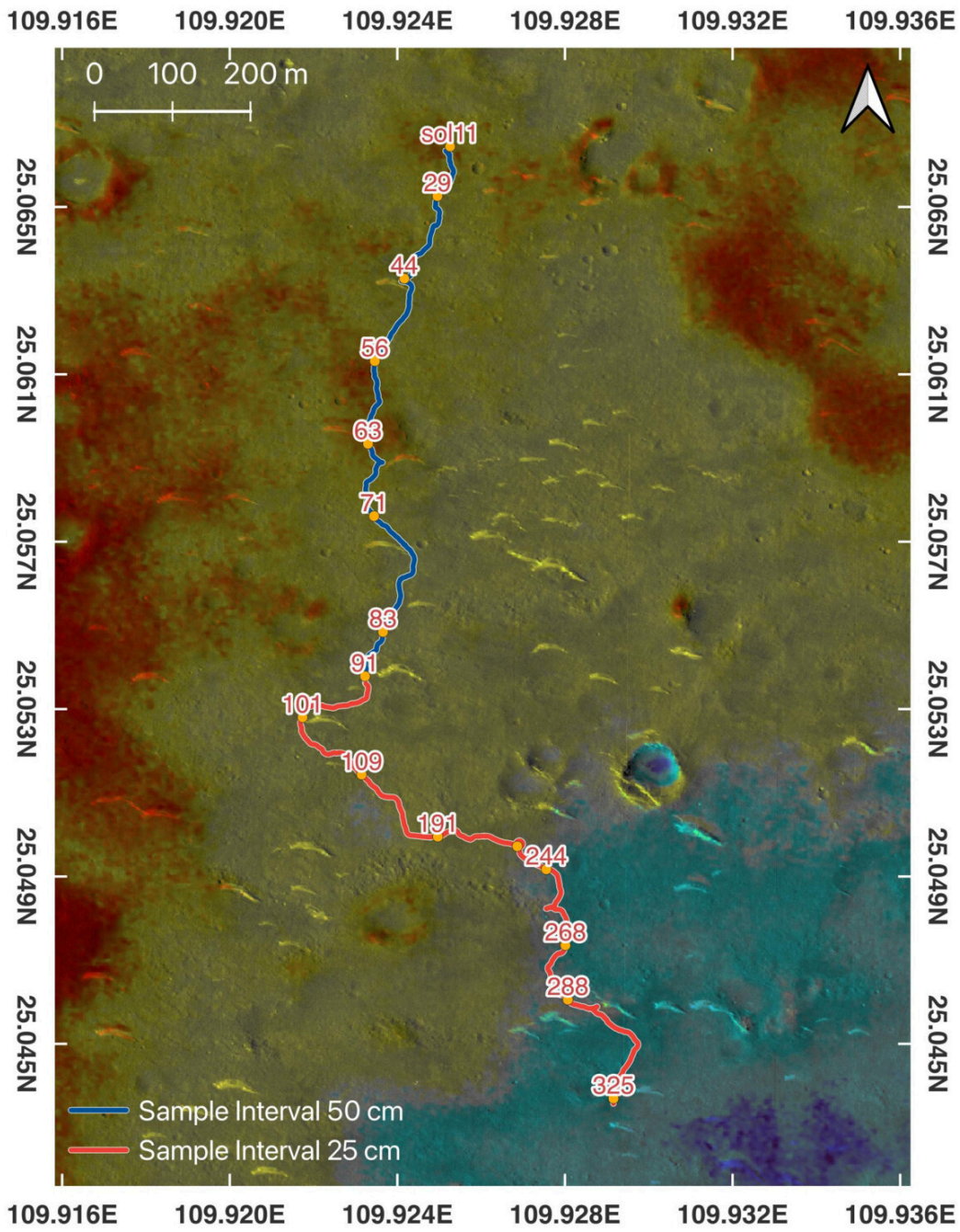


Fig. 2 The traverse of Zhurong rover and the elevation at the landing site.

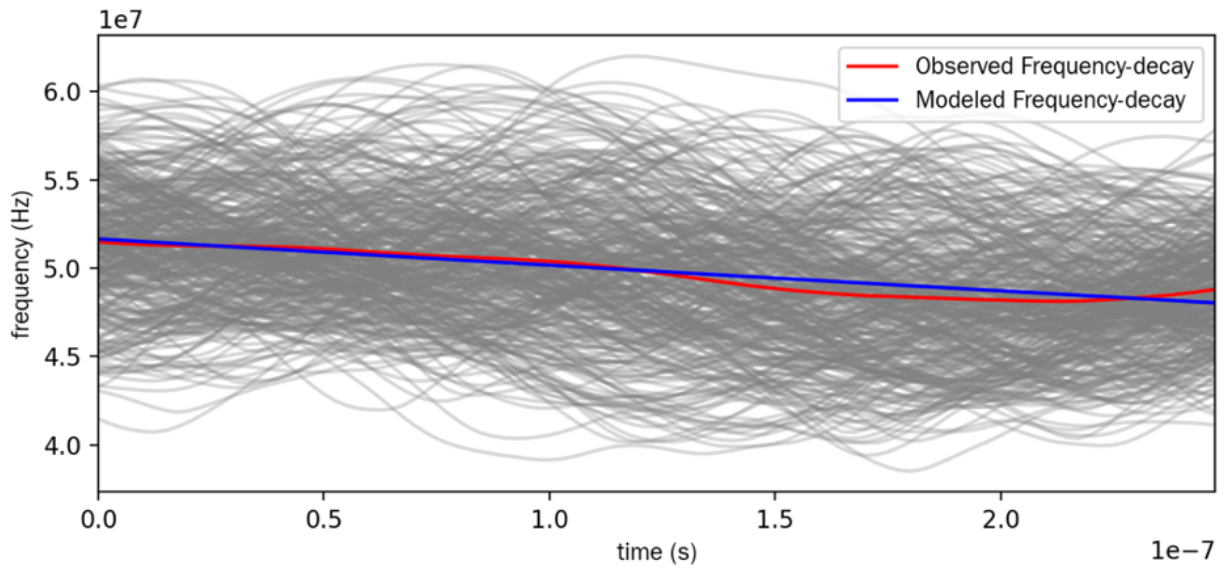


Fig. 3 The loss tangent estimation via RoSPR low-frequency data. The figure demonstrates the centroid frequency decay versus time delay relationship, calculated from 160 traces of Low-frequency channel data ranging from ~ 300 to ~ 550 ns.

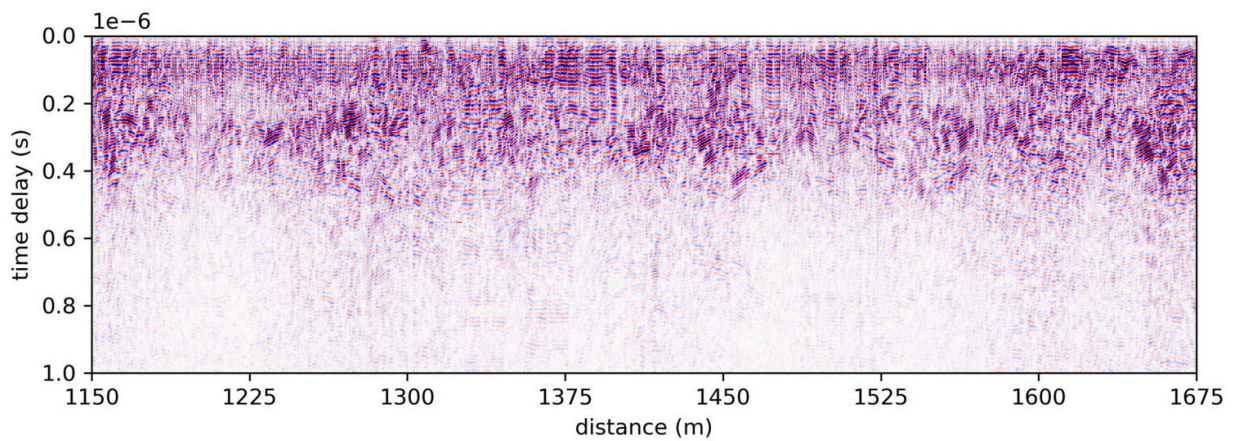


Fig. 4 RoSPR low-frequency B-scan section from sol 112 to sol 288.