PERFORMANCE EVALUATION OF LUNAR REGOLITH PENETRATING RADAR ONBOARD THE LANDER OF CHANG'E-5 BASED ON RESULTS OF GROUND EXPERIMENTS AND SIMULATIONS.

Yuan Xiao,[1,2,3] Yan Su,[1,2] Jianqing Feng,[1,2] Shun Dai,[1,2] Shuguo Xing,[1,2] and Chunlai Li[1,2], [1]National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China, (xiaoy@nao.cas.cn), [2] Key Laboratory of Lunar and Deep Space Exploration, Chinese Academy of Sciences, Beijing 100012, China, [3] University of Chinese Academy of Sciences, Beijing 100049, China.

Introduction: Knowledge of the subsurface stratigraphic and tectonic features is necessary to understand the origin and evolution of a planet, and the planetary subsurface stratigraphy can be scanned by a Ground Penetrating Radar (GPR) or radar sounder onboard a spacecraft. The Lunar Penetrating Radar (LPR) onboard the Yutu Rover of Chang'e-3 (CE-3) probed the lunar regolith layer and the underlying basalt units [1, 2]. After the successful soft landing of CE-3, China will implement Chang'e-5 (CE-5) mission as the beginning of the third phase (sample return phase) of the Chinese Lunar Exploration Program (CLEP), the main task of which is to launch the automatic lunar surface sample collector, collect lunar regolith sample, and return to the Earth [3]. One of the scientific payloads of CE-5 lander is the Lunar Regolith Penetrating Radar (LRPR), which is a high-resolution lunar regolith penetrating radar. The LRPR has the ability to detect the depth and structure of the lunar regolith, and provide important information for the drilling and sampling process as well. The difference between the LRPR and the LPR is that the LRPR is an unmovable antenna array mounted on the lander of CE-5, while the LPR is a movable radar mounted on the rover of CE-3. This study focuses on performance evaluation of the LRPR of CE-5, based on ground experiments and echo simulations.

Ground Experiments: The main objective of the ground experiments is to test the basic operations of the system, evaluate the performance of the prototype system of the LRPR, and identify any problems that might be encountered during on-orbit operation in the future.

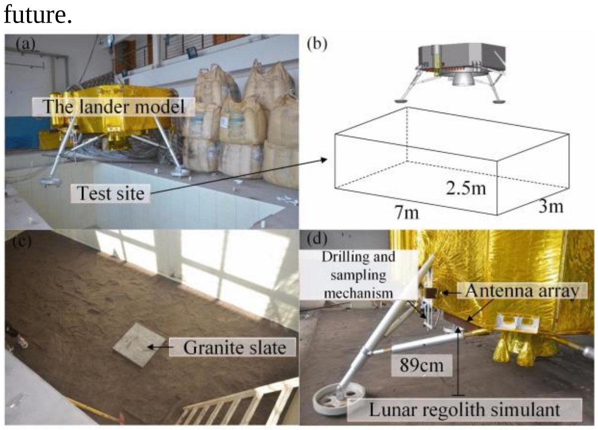

Fig. 1: Photographs of the test site and the setup of the ground experiments.

A pool filled with lunar regolith simulant is built to meet the requirements of the experiments, the dimensions of which are 7m×3m×2.5m, as shown in Fig. 1. The LRPR prototype is mounted on a 1:1 model of the CE-5 lander, which is 89 cm above the surface of the lunar regolith simulant. The lunar regolith simulant is made out of tephra, whose electromagnetic characteristics are very close to those of lunar regolith. The testing targets of the experiments are granite slates, polytetrafluoroethylene (PTEF) plate, metallic balls, and basalt blocks, which are buried in the lunar regolith simulant at predetermined depths.

Identification of blocky objects and plate-like objects: One of the main objectives of the ground experiments is to test the ability of the LRPR to identify blocky objects and plate-like objects.

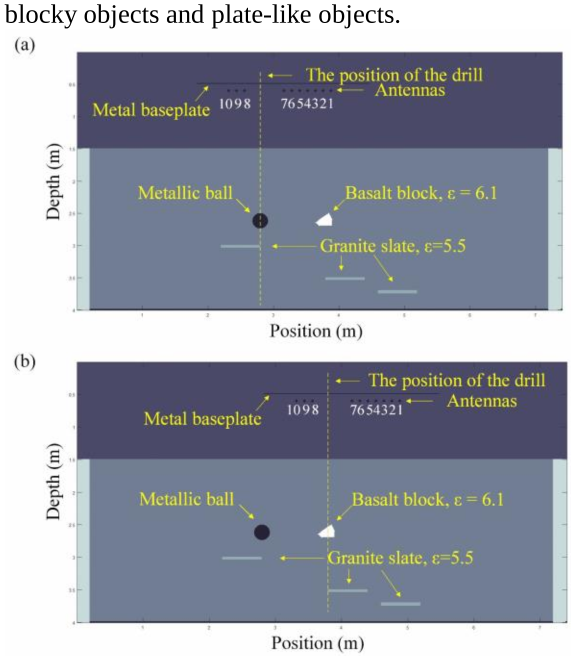

Fig. 2: Model of the simulation of detecting blocky objects buried in the lunar regolith simulant. (a) The metallic ball is under the drill. (b) The basalt block is under the drill.

In the experiment, a metallic ball and a basalt block with the dielectric constant of 6.1 are buried in the lunar regolith simulant at the depth of 1 m. The diameter of the metallic ball is 24cm, and the basalt block is of similar size. 3 granite slates with the dielectric constant of 5.5 are buried in the lunar regolith simulant, at the depth of 1.5 m, 2 m, and 2.2 m. The drilling and sampling mechanism points at the center of the metallic ball and basalt block respectively. A metal sheet is placed at the bottom of the lunar regolith simulant to test the depth detection ability of the LRPR..

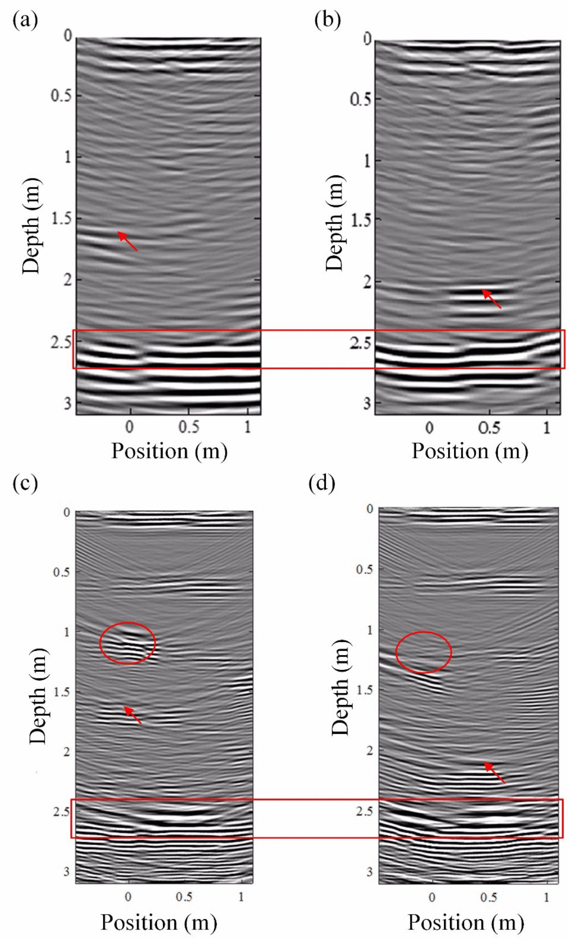

Fig. 3: (a) Processed image of experimental data of the metallic ball under the drill. (b) Processed image of experimental data of the basalt block under the drill. (c) Processed image of simulated data of the metallic ball under the drill. (d) Processed image of simulated data of the basalt block under the drill.

The processed experimental data and simulated data are shown in Fig. 3. The metallic ball and the basalt block can be identified from the simulated data rather than the experimental data. Therefore, the blocky objects with diameters less than 24 cm cannot be identified by the LRPR in practical application. The two granite slates at the depth of 1.5 m and 2 m can be identified clearly in the migrated images of both the experimental and the simulated data. Moreover, the strong reflection at the depth of 2.5 m is caused by the metal sheet at the bottom of the site, as shown in the boxes in Fig. 3.

The interference from the metal baseplate of the lander: A certain interference on the recognition of target objects caused by the metal baseplate of the lander of CE-5 is found from the experimental data. In order to estimate the interference, and correctly identify real targets, non-target, the two conditions with and without the metal baseplate are simulated. There are no buried targets in either case. The results indicate that interference signals are mainly caused by the multiple reflections of the electromagnetic wave among the metal baseplate of the lander, the metal sheet at the bottom of the experimental site and the concrete walls. Moreover, the strong reflection at the depth of 2.5 m is caused by the metal sheet at the bottom of the site.

The imaging effect of dense antenna array: In this experiment, the imaging results of objects under the drilling and sampling mechanism and objects under dense antennas as compared. The targets are three plates buried in the lunar regolith simulant. A PTEF plate is buried at the depth of 1 m, and one meter apart is another PTEF plate superimposed on a granite slate. Firstly, data are collected with the drill pointing to the center of the two superimposed plates. Next, data are collected when the two superimposed plates are under the dense antennas. The two superimposed plates can be identified, while the boundary between them cannot be identified. The results indicate that the imaging effect of dense antennas is better than other positions.

Summary: According to multiple sets of experimental and simulated data, the plate-like objects buried in lunar regolith simulant within 2.5 meters can be identified clearly, and their depths and horizontal positions can also be easily obtained from processed images. However, the blocks with diameters less than 24 cm cannot be recognized, so it is difficult to identify blocky objects for the LRPR. The results indicate that the identification ability is directly related to the radar reflection section of the target, the burial depth and the interferences. The imaging effect of the location under the dense antennas is better than that of other positions.

Acknowledgements: The authors thank the Ground Application System of Lunar Exploration, National Astronomical Observatories (NAOC), and Institute of Electronics, Chinese Academy of Sciences, for providing the ground experimental data of the LRPR. This work was supported by the National Natural Science Foundation of China (Grant no. 41403054) and NAOC through Grant no. Y734061V01.

References: [1] Y. Su. et al. (2014) *RAA*, *14*, 1623-1632. [2] L. Xiao. et al. (2015) *Science*, *347*, 1226-1229. [3] L. Xu. and Z. Y. Ouyang. (2014) *CJSS*, *34*, 525-534.