Introduction about the Preliminary Radio Science Experiment in Chinese Lunar Landing Mission Chang'E-3

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Abstract

Radio science experiments have been involved in all of the Chinese lunar missions with different research objectives. In Chang'E-3 landing mission, a 3-way open loop lunar radio phase ranging and Doppler technique was suggested and tested. This technique is modified and updated from early multi-channel one-way Doppler deep space tracking technique developed for Chinese Mars mission Yinghuo-1. In the 1st preliminary experiments, we obtained 1sps continuous phase ranging data before and after the successful landing period, with a resolution of 0.5 millimeter or better. This method, called Lunar Radio Phase Ranging (LRPR) can be a new space geodetic technique to measure the station position, earth tide and rotation, lunar orbit, tide and liberation, by means of independent observation, or to work together with Lunar Laser Ranging. Also, it can be used in future Mars mission.

1. Introduction

The radio tracking data in lunar and planetary missions can be directly applied for scientific investigation. The variations of phase and of amplitude of the radio carrier wave signal linked between the spacecraft and the ground tracking antenna are used to deduce the planetary atmospheric and ionospheric structure, planetary gravity field, mass, ring, ephemeris, and even to test the general relativity. The radio science experiments have been arranged and merged in to most of the lunar and deep space missions. So do the Chang'E lunar missions. In Chang'E-1 mission, the USB radio ranging and Doppler data have been used to improve the lunar gravity field together with the VLBI data. In Chang'E-2 mission, the same kinds of data have been used to navigate the satellite flying to the L2 point, and then to the asteroid. In Chang'E mission, the link wave changed from S-band to X-band for improved downlink data transferring requirement, and to reduce the ionospheric effect in satellite tracking. Also, DOR tone signals are coherently designed with carrier wave for Delta-DOR VLBI tracking. This kind of designation gives us a unique chance to develop lunar radio ranging technique.

The radio sciences have been developed step by step in Chinese lunar missions. In Chang'E-1 lunar orbiting mission, we developed and realized a method of real-time tracking and monitoring the s/c flying status. Also, by using the tracking data, we improved the lunar gravity field successfully. In Chang'E-2 mission, deep space DOR/VLBI tracking method was realized, and an open-loop 3-way Doppler tracking technique was also tested. Chang'E-3 is a lunar surface landing mission. We are using the planetary radio science receiver developed in Chang'E-2 and YH-1 mission to measure the distance variation between the tracking station-lander-VLBI site by means of 3 way phase tracking. This LRPR technique can over the disadvantages of the LLR methods: cannot operate during full moon, new moon, bad site weather period. And only a few sites can do LLR. For LRPR, it can be operated during all time theoretically. The high precise ranging data can be used in many research areas.

2. Chang'E-3 mission

After the successful lunar orbiting missions of Chang'E-1/2, China launched the Chang'E-3 lunar landing and rover mission at the end of 2013. Launching mass of the Chang'E-3 is ~3.7 ton, lander mass is ~1.2 ton, rover mass is 120kg with scientific payloads of 20 kg. Some important key techniques were realized, including lunar soft landing, lunar surface rover exploration and surviving over lunar night, deep space communications and remote control operation, rocket directly launched into the earth-moon transfer orbit and other key technologies. The real-time radio altimeter and laser altimeter system onboard the spacecraft platform were applied to support the autonomous soft landing operation. This mission is the key one of Chinese lunar landing exploration phase. Figure 1 shows the configuration of landing mode and rover mode.

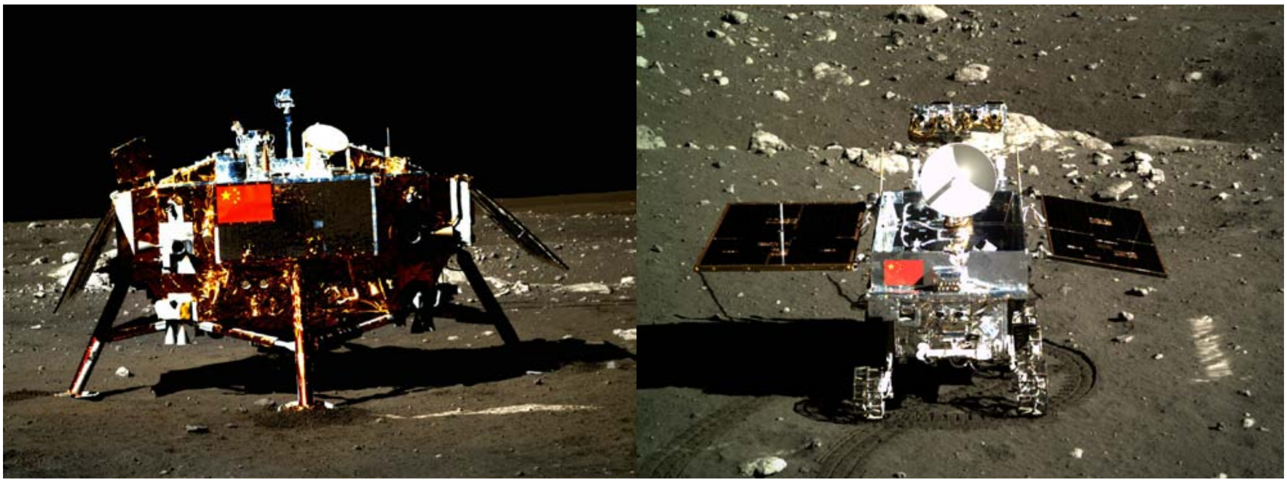

Figure 1. Chang'E -3 mission: lander (Left) and rover (right). (Follow Xinhua News)

Chang'E-3 is realizing the 2nd phase of Chinese lunar scientific exploration projects. Together with the various in-situ optical observations around the landing sites, the mission carried 4 kinds of radio science experiments, which cover the various lunar scientific disciplines as well as lunar surface radio astronomy studies. The key payloads onboard the lander and rover include the near ultraviolet telescope, extreme ultraviolet cameras, ground penetrating radar, very low frequency radio spectrum analyzer, which have not been used in earlier lunar landing missions. Optical spectrometer, Alpha Paticle X-ray spectrometer and Gama Ray spectrometer is also used. The mission is using extreme ultraviolet camera to observe the sun activity and geomagnetic disturbances on geo-space plasma layer of extreme ultraviolet radiation, studying space weather in the plasma layer role in the process; the mission also carries the first time lunar base optical astronomical observations. Most importantly, the topography, landforms and geological structure has been explored in detail.

3. Radio Sciences in Chang'E 3

Three kinds of radio science experiments have been planned in Chang'E 3 landing missions: 1) HF and VHF duel-band penetrator radar on the rovers; 2) same-beam X-band VLBI for precise positioning of rover; 3) precise radio phase ranging for lunar rotation and dynamics.

HF and VHF duel-band penetrating radar: the radar has center frequencies at 30MHz and 50MHz with bandwidth of 15MHz for each, linear polarized antenna to study the subsurface structure of landing area. In the mission LRS of SELENE/KAGUYA project, Japanese researchers obtained the lunar subsurface structure of 5~10 KM deep with resolution of dozens meters, where the igneous lunar basalt filling at mare area was firstly measured with the maximum thickness of 500~600 meters. Lunar regolith and lunar crust subsurface of shallower than 3km will be firstly studied by using the duel-band GPR on the rover with very high resolution. The thickness of regolith of the soft landing area will be measured .

Same beam VLBI tracking: Two VLBI beacon transmitters with high stable oscillators are installed on the Chang'E 3/4 landers and the rovers separately. Beacons will transmit X band DOR wave or single carrier wave back to the Earth. The Chinese VLBI network and the new developed Chinese deep space tracking station will observe the DOR signal from two beacons simultaneously by the main lobe of each antenna. In the differential DOR observables, the effects due to the tracking station, the atmosphere and the ionosphere of the earth, as well as the effects due to the lunar rotation, tides and liberation can be cancelled dramatically. Then, the high precise relative position of the rover to the lander of the same mission will be obtained at each observation point of the rover. Based on a simulation results, the precision of relative positioning can reach about 10m or higher.

Lunar Radio Phase Ranging: Since early Luna and Apollo missions set 5 optical corner reflector systems on the surface of the Moon, Lunar laser ranging have been played key role on measuring the lunar rotation, Physical liberation and surface solid tides. However, the bad weather on laser site, the full Moon and new Moon phase may block the optical observation. Similar to Luna-Glob landers, together with the VLBI radio beacons, the radio transponders are also set on the Chang'E-3/4. Transponder will receive the uplink S/X band radio wave transmitted from the two newly constructed Chinese deep space stations, where the high quality hydrogen maser atomic clocks have been used as local time and frequency standard. The clocks between VLBI stations and deep space stations can be synchronized to UTC standard within 20 nanoseconds using satellite common view methods. In the near future there will be a plan to improve this accuracy to 5 nanoseconds or better, as the level of other deep space network around world. Radio science receivers have been developed by updating the multi-channel open loop Doppler receiver developed for VLBI and Doppler tracking in Yinghuo-1 and Phobos-Glob Martian missions. This experiment will improve the study of lunar dynamics, by means of measuring the lunar physical liberations precisely together with LLR data. Above method may be used in the next Chinese Martian mission.

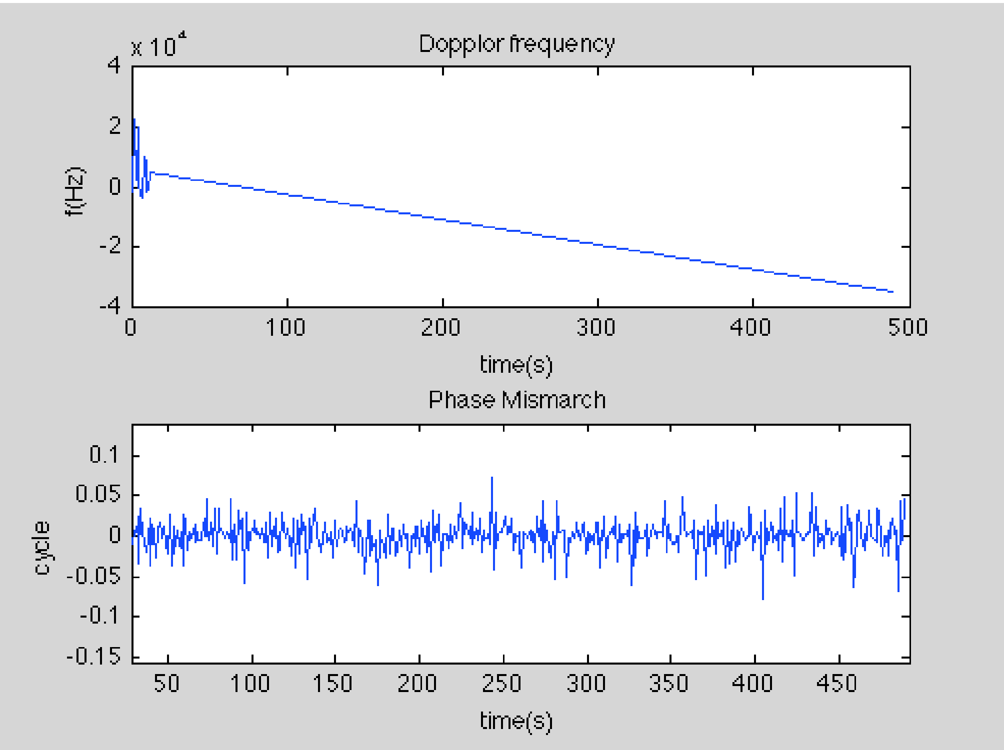

Figure 2. Chang'E -3 main carrier LRPR results: Doppler (above) and phase noise (low).

4. Preliminary LRPR Result

During and after the Chang'E-3 landing period, 4 channel 1sps LRPR we obtained by using the planetary radio science receiver set at Kunming VLBI station, during the preliminary LRPR experiment. Total tracking period was about 100 minutes, with about 45 minute data after landing. Here only the results from main carrier wave signal are shown in this paper. Both of data types of three way Doppler and Phase ranging were obtained. The phase resolution has a noise RMS about 0.0189 circle, corresponding to a ranging resolution of 0.68 mm at X band. See Figure 2. This resolution is better than current LLR result of several mm to 1~2 cm.

Our data was obtained just after landing, the vibration of S/C platform due to firing the engine during landing period can be clearly seen in the phase data. The Figure 3 shows many harmonic waves of the vibrations many due to different parts of the S/C. The main vibration period is about 20 seconds. The spectra of at least 5 groups of vibrations can be identified, with amplitudes various from 0.002 circle through 0.034 circle, corresponding to 0.07mm through 1.35mm. The landing zone is rock area with less soft soil, the decay of the S/C vibration may have a long time in a space without air. Due to the main carrier and DOR tone have not been transmitted till we prepare the paper, we still have not chance to check the current vibration situation.

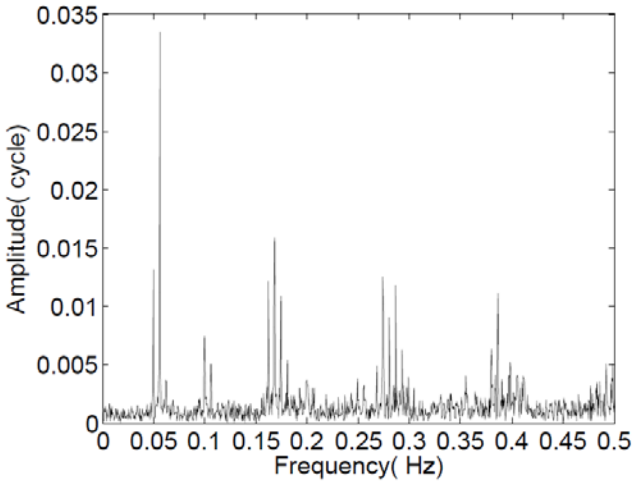

Figure 3. Vibration harmonic waves of Chang'E-3 platform after landing.

The high resolution LRPR technique was tested during the landing period. Different from LLR techniques, most of the VLBI station, especially the small antenna VLBI station and S/C tracking station can join the open loop LRPR observations, with will give a very nice observation geometry to improve the final resolution. We plan to use the technique to measure the lunar movement and dynamics as well as the geodynamics in the Chang'E-3 extended mission period, after its nominal mission period. The method can also be used in future lunar mission and mars mission. And, a new kind of space technique starts, beside VLBI, SLR/LLR, DORIS.

5. Acknowledgments

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