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Investigations of In Situ Lunar Geodetic Experiments in Japan for the Study of the Interior of the Moon

H. Araki (1), S. Sasaki (1), H. Hanada (1), H. Noda (1), H. Kunimori (2), F. Kikuchi (1), K. Matsumoto (1), T. Iwata (3), N. Kawano (1,4), K. Funazaki (5), and RISE Group (Researches In SElenodesy, NAOJ)
(1) National Astronomical Observatory of Japan, Ohshu, Japan, (2) The National Institute of Communication and Technology, Koganei, Japan, (3) The Institute of Space and Astronautical Science, Sagamihara, Japan, (4) Shanghai Astronomical Observatory, China, (5) Department of Mechanical Engineering, Iwate University, Morioka, Japan
(arakih@miz.nao.ac.jp / Fax: +81-197-22-7120)

Abstract

Measurements of physical and free librations of lunar rotation are important because they provide information of the physical state of the lunar interior. For example, we can discuss if the lunar core is molten from the amplitudes of libration terms. Previously only passive LLR (Lunar Laser Ranging) using CCR (corner cube reflectors) has been applied for the detailed study of lunar librations. As for candidate instruments for SELENE-II (forthcoming lunar landing mission by JAXA), we propose precise measurements of lunar rotation by ILOM (In-situ Lunar Orientation Measurement) and IVLBI (Inverse-VLBI) in addition to LLR.

1. Introduction

The precise measurement of the rotation of planets is one of techniques to obtain the information of the internal structure of planets [1]. As for candidate instruments for SELENE-II (forthcoming lunar landing mission by JAXA), we propose detailed measurements of lunar rotation by ILOM (In-situ Lunar Orientation Measurement) [2][3], LLR (Lunar Laser Ranging)[1] and IVLBI (Inverse-VLBI) [4]. Here we are proposing ILOM and Inverse-VLBI in addition to LLR. Inverse-VLBI is useful also for precise gravity measurements.

2. ILOM (In-situ Lunar Orientation Measurement)

The ILOM (In-situ Lunar Orientation Measurement) is an experiment to measure the lunar physical librations in situ on the Moon with a small telescope, which tracks stars [2][3]. Since ILOM on the Moon does not use the distance between the Earth and the Moon, the effect of orbital motion is clearly separated from the observed data of lunar rotation. This is the advantage of ILOM over LLR. The ILOM will observe the lunar physical and free librations from the lunar surface with an accuracy of 1 millisecond of arc. If ILOM telescope is put on the lunar polar region, it can detect spiral trajectories of the stars. Theoretical study in relation to the interior structure is being developed by Petrova et al. [5]. We have been developing BBM model of ILOM at Iwate University (Figure 1). This BBM was made for the tests of controllability and optical characteristics. Since the lunar surface is covered with regolith, the precise attitude control of ILOM PZT telescope is inevitable after its deployment on the lunar surface. Even in the case that ILOM would be installed inside the lander, the attitude control should be necessary.

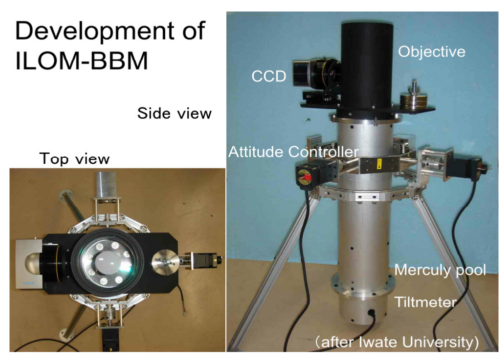

Figure 1: BBM of ILOM model. Attitude control system is attached to the outside of the telescope tube. Optical tests with CCD and light sources are performed using this model.

3. LLR (Lunar Laser Ranging)

The Lunar Laser Ranging (LLR) is the method to measure the distance between the Earth and the Moon. For more than 40 years since the Apollo and the Lunokhod mission placed retro-reflectors on the Moon, LLR produced data on the lunar rotation as well as the lunar orbital evolution. On the basis of LLR data, the state of lunar interior is discussed. [1]. We are proposing a new LLR on board SELENE-II. Instead of conventional corner cube reflector (CCR) array, we are planning to use a larger single reflector. This has an advantage over the conventional CCR array, because a single cube should have smaller distance variation within the reflector upon monthly libration of the lunar rotation. We also aim to place a new reflector should be somewhere in the southern hemisphere on the nearside Moon (Figure 2). Then in combination with a powerful A15 CCR, latitudinal component of lunar libration and its dissipation can be measured precisely.

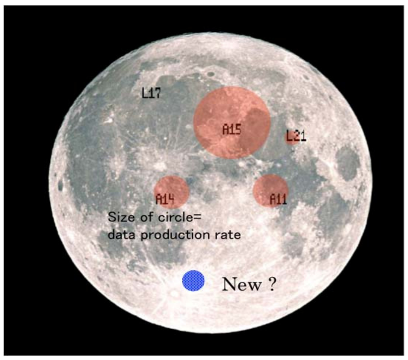

Figure 2: Previous LLR reflector positions and a possible new LLR location in the southern hemisphere.

4. Inverse VLBI

Very long baseline interferometry (VLBI) is conventionally used for precise positioning of radio source. Radio signal transmitted from radio source, such as a quasar, is received at two separate ground VLBI stations. In Japanese KAGUYA (SELENE) mission, multi-frequency VLBI observations (S/X bands) are used for the precise orbital determination of satellites in order to increase the accuracy of lunar gravity field. In the case of inverse VLBI, an artificial radio source is loaded on lunar and planetary vehicle, such as orbiter and lander, and radio signals transmitted from vehicle are received at a ground VLBI station [4]. These signals are cross-correlated and the difference of propagation times from vehicles to the ground station is measured. The desired accuracy of the measurement is predicted to several tens to several pico second. Currently SELENE-II will have only one lander equipped with a rover (Figure 3). If a radio source should be on board the rover moving as far as 100 km, rotation change information could be obtained from the difference of the propagation time between the lander and rover. However, thermal control for overnight survival of electronics would be very difficult for the rover. Therefore, we should seek a possibility of simultaneous observation between SELENE-II lander and another lander in the framework of recently discussed ILN (International Lunar Network).

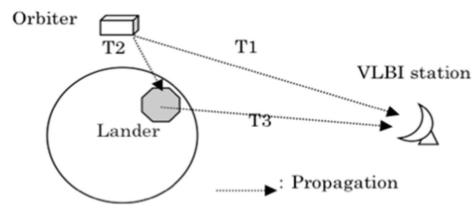

Figure 3: The principle of inverse VLBI in the case of an orbiter and a lander.

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