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VLBI Observation of SELENE (KAGUYA) by VERA and an International Network

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Abstract. SELENE (KAGUYA) is a Japanese lunar mission which was successfully launched from the Tanegashima Space Center on Sep. 14, 2007. KAGUYA consists of the main orbiter, and two small free-flying sub-satellites, called Rstar (OKINA) and Vstar (OUNA). We are observing OKINA and OUNA using differential VLBI observations with the aim of improving the lunar gravity field model. Our observations will particularly improve the accuracy to which the low degree gravitational harmonics and the gravity field near the limb can be measured, and when combined with Doppler measurements will enable three-dimensional information to be extracted. Differential VLBI will be used to accurately measure the trajectories of the satellites, both with the Japanese VERA (VLBI Exploration of Radio Astrometry) telescopes and an array including the international VLBI stations, Shanghai, Urumqi (China), Hobart (Australia), and Wettzell (Germany).

We are using multi-frequency VLBI to determine the angular distance between OKINA and OUNA using three frequencies in S-band, (2212, 2218 and 2287 MHz), and one in X-band, (8456 MHz). Two periods of international observations, each of one month in duration, with the participation of VERA and the international stations, (in addition to the normal observations by VERA only) are planned for the one year mission period. We are able to measure the phase delay to an accuracy of better than 0.17 rad (10 deg) in X-band in these observations.

1. Introduction

The Japanese lunar explorer SELENE (SElenological and Engineering Explorer) or Kaguya which was launched on Sep. 14, 2007, makes precise observations of the gravitational field of the Moon utilizing both 4-way Doppler observations through a relay satellite (RSAT experiment), and differential VLBI observations of two satellites (VRAD experiment), as well as through the 13 other scientific instruments that are part of the mission [1]. The purpose of these observations is to address the inadequacies in existing data, and hence obtain a highly accurate lunar gravity model. This paper describes the scientific objectives, new technical developments, mission plan, and initial results of VLBI observations of Kaguya.

2. VLBI Observations of Kaguya

VLBI observations are carried out by the Japanese domestic VERA network (4 stations) [2] on a regular basis (8 hours/day, 3 days/week during the mission period of one year), and 2-way and 4-way Doppler measurements are also conducted by the Usuda Station of JAXA (Japan Aerospace Exploration Agency). Since the accuracy of VLBI positioning depends on baseline length, observations with long baselines are desirable. Currently the Shanghai and Urumqi (China), Hobart (Australia), and Wettzell (Germany) stations participate in the international observations to improve the lunar gravity field model through precise orbit determination of Okina and Ouna.

Fig. 1 shows how the VLBI observations contribute to the improvement of the lunar gravity field model [3]. There are three cases: where all the possible Kaguya spacecraft tracking data are included, where VLBI observation is not included, and LP100J. The accuracy of all the coefficients included in the model will be improved by combining VLBI with 2-way and 4-way Doppler measurements. Here we have accounted for the effect of VLBI data on determining the precise orbit of Okina, which is a reference for the 4-way Doppler measurements. By including VLBI data, the coefficients of degrees less than the 33rd harmonic will be improved by about a factor of 2, with the best improvement in the 2nd degree coefficient by a factor 2.6. If through proper force modeling we are able to achieve an arc length of Okina and Ouna longer than 1 day the final accuracy of the Kaguya gravity field will be one order of magnitude better than that of LP100J below approximately degree 30.

VRAD (differential VLBI RADio sources) are on-board two sub-satellites, Okina and Ouna, and are used for differential VLBI observations of the trajectories of the satellites with VERA and the international network. We will apply

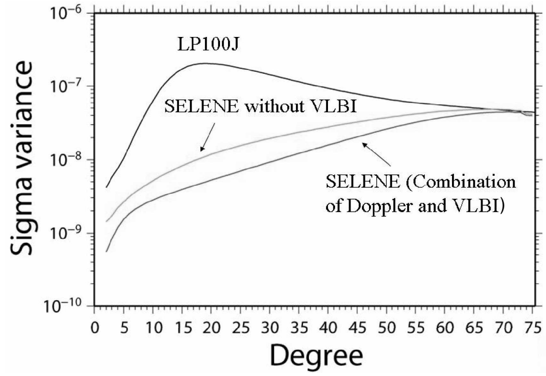

Figure 1. Anticipated coefficient sigma degree variances are shown for the following three cases; LP100J, Kaguya without VLBI observations, Kaguya with VLBI

a multi-frequency VLBI method to measurements of the angular distances between two radio sources in Okina and Ouna using three frequencies in S-band, 2212, 2218 and 2287 MHz, and one in X-band, 8456 MHz [4]. The phase delay will be measured with an accuracy of better than 0.17 radians (10 deg) in X-band, which is equivalent to positioning accuracy of about 20 cm on the Moon with the VLBI network with a baseline length of 2000 km. Kikuchi [5] has shown that the cycle ambiguity can be resolved by combining the same beam VLBI method and the multi frequency VLBI method. In the same beam VLBI method, a ground antenna sees two objects simultaneously when the angular distance between them is less than the angular dimensions of the main beam of the antenna. Liu et al. [6] measured the S-band phase characteristics of the Mizusawa 20 m telescope, one of the VERA network antennas, and confirmed that the phase deviation is smaller than 0.06 rad (3.4 deg).

The international VLBI campaigns for Kaguya are one month long each and take place twice during the 1-year mission period. The basic idea of observation scheduling is to conduct VLBI observations when the orbital plane is in "face-on" configuration in order to add more powerful constraints on orbit determination, which compensates for the loss of line-of-sight sensitivity coming from 2-way Doppler measurements. The "face-on" configuration will take place twice a month and we conduct a 4-day "core observation" for each fortnightly observation chance. The contribution from VLBI is also important to precisely determine the orbit of Okina which serves as a reference for 4-way Doppler observation, playing an important role mainly in "edge-on" configuration. Therefore it is highly desirable to extend the VLBI observation times to the period other than "face-on" configuration, which we refer to as "extended observations".

3. Initial Results

VLBI observations commenced on Nov. 5, 2007 after the initial checkout of Okina and Ouna. In addition to regular VLBI observations using the VERA network, the first international VLBI observations were carried out in Jan. 2008. We had many opportunities to utilize the same-beam VLBI method during the period and have confirmed that the cycle ambiguity of the differential phase delay (DPD) in multi-frequency VLBI (MFV) method can be solved by the same-beam VLBI method. The error of DPD is smaller than 2 ps in a 30 s integration interval (Fig. 2). If the baseline is assumed to be 2000 km, 2 ps corresponds to position sensitivities of 12 cm near the Moon.

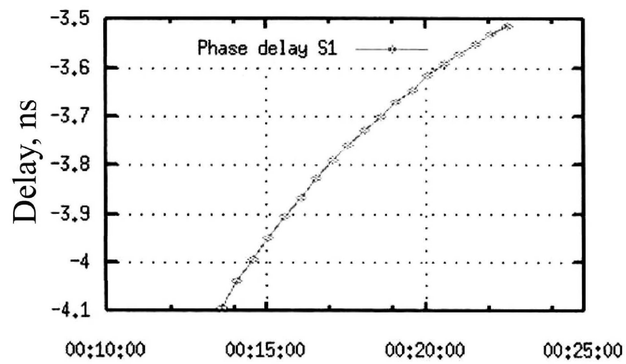

Figure 2. A result of estimation of differential phase delay of S1 for the baseline between Ishigaki and Iriki

4. Summary

We have succeeded in making VLBI observations of Okina/Ouna with VERA and the international network, and confirmed that the receiving, the tracking, and the recording system work well, and that the signals from Okina/Ouna are normal. We have succeeded in correlation of signals from Okina/Ouna, and confirmed that the signals have a S/N high enough to allow resolution of cycle ambiguity with our multi frequency VLBI method. We have succeeded in obtaining phase delays with an accuracy of several in S-band.

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