SLR return analysis for ASTRO-G

Ryo Nakamura (1), **Takahiro Inoue** (1), **Shinichi Nakamura** (1), **Keisuke Yoshihara** (1), **Hiroshi Takeuchi** (1), **Hiroo Kunimori** (2) , **Toshimichi Otsubo** (3)

(1) Japan Aerospace Exploration Agency
(2) National Institute of Information and Communications Technology
(3) Hitotsubashi University

nakamura.ryoh@jaxa.jp / Fax: +81-29-868-2990

Abstract

The next-generation space radio telescope, Astro-G, which is planned to be launched in 2012 and injected into a highly elliptical orbit with an apogee height of 25000km and a perigee height of 1000 km, has a requirement of orbit determination accuracy higher than 10cm using GPS and SLR. The SLR role is a precise orbit determination (POD) especially near the apogee. The SLR data are expected to have considerably time variation not only because of a laser retro reflector array (LRRA) on a moving gimbal, but also because of an observation mode called phase referencing observations. The expected returns from Astro-G are simulated and proper bin sizes and editing methods for making QLNPs are studied.

Introduction

ASTRO-G is a next-generation space radio telescope designed to reveal phenomena such as the relativistic phenomena in the space around super-massive black holes at the centers of galaxies [Tsuboi08]. The satellite will be launched by H2A rocket from Tanegashima Space Center in 2012 and injected into an elliptical orbit with an apogee height of 25000km and a perigee height of 1000 km. The observation project is known as VSOP-2, which is extending the successes of VSOP/HALCA project (1997-2005). HALCA demonstrated successfully the technologies required for the space very-long-baseline interferometry (VLBI). In the VSOP-2 project, observation bands will be shifted to higher (up to 43GHz) frequencies compared to the VSOP. The project features direct imaging observation of astronomical phenomena with a level of high-spatial resolution (40 micro arc sec. at its best) never achieved before. In order to successfully conduct a phase referencing observation, one of the observation modes in which the antenna points to a target radio source and a calibration source in a switching manner, a precise orbit determination (POD) is required [Asaki08][Otsubo06]. The accuracy requirement is at least 10 cm. In order to achieve the orbit determination accuracy, the satellite will carry a GPS receiver and a laser retro-reflector array (LRRA) for SLR.

Satellite Overview

Astro-G satellite image is shown in Figure 1. The satellite will be equipped with a 9.6-metre large deployable antenna and 8, 22, 43 GHz band receivers. Astro-G will be injected to an elliptical orbit parameters of which are listed in Table. 1. The apogee height is 25000km, higher than the altitude of GPS satellites. The higher frequency observation and high altitude of the satellite's apogee enable an observation with higher resolution. The angular resolution will be 0.040 milliarcsec. at 43GHz, 10 times better than the VSOP's 0.4 milli arc sec. at 5GHz. For the POD, Astro-G will carry a multi-frequency GPS receiver. Because of its apogee altitude (25000km) higher than that of GPS satellites, however, only1-2 GPS satellites can be used for the orbit determination at the apogee (See Figure 2), which results in degradation of the orbit determination accuracy. Therefore, Astro-G will also carry a LRRA for SLR, mounted next to a Ka-band link antenna that is steerable independent of the satellite body.

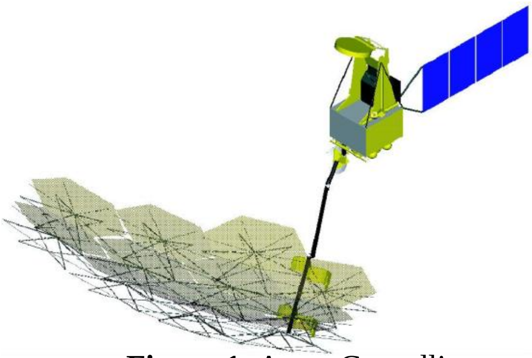


Figure 1. Astro-G satellite

Table 1. Orbital Parameters of Astro-G

Apogee altitude	25000km
Perigee altitude	1000km
Inclination	31deg
Eccentricity	0.62
Precession of AOP	+258deg/year
Precession of LAN	-167deg/year
Orbital period	7.45hour

Figure 2. Number of visible GPS satellites

Laser Retro-Reflector Array

Figure 3 shows a preliminary design of a LRRA for Astro-G. The LRRA consists of two parts. One is a center area, which has a pyramid shape for supporting wide range of laser incident angle at low altitudes. Another part is a surrounding area composed of flat corner cubes for increasing effective aperture area at high altitude. The corner cubes of center area are 28mm in diameter, coated on the back faces and 30deg-slanted. The corner cubes of surrounding area are 28mm (inner ring) or 38mm (outer ring) in diameter, uncoated on back faces and not slanted. As shown in Figure 4, the LRRA is mounted next to Ka-band link antenna, because no specific plane of Astro-G always directs to the Earth. Therefore, the LRRA position and attitude (pointing direction) is synchronized with those of the Ka-band link antenna. Phase referencing observation, one of the observation modes of Astro-G, causes a attitude oscillation, which results in a fluctuation of position and attitude of Ka-band link antenna. Therefore, the LRRA position and pointing direction is varied because of Phase referencing observations, and the SLR observations (residuals or O-C) is time-varying as a result.

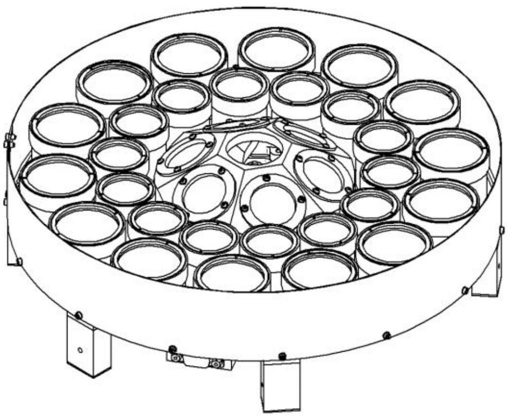


Figure 3. Preliminary design of LRRA for Astro-G

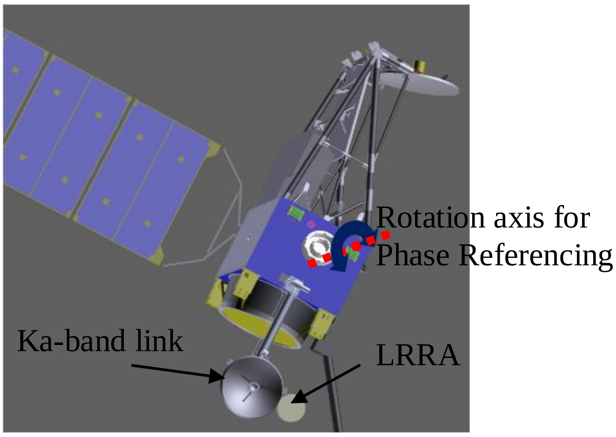


Figure 4. Position of LRRA and Ka-band link antenna

Phase Referencing Observations

In the VSOP-2 project, phase referencing observations are proposed for mitigating the phase fluctuation due to the Earth's atmosphere, because observations are made not only by Astro-G, a space telescope, but also by terrestrial telescopes. As shown in Figure 5, in phase referencing observations, telescopes are alternately pointed toward a target source and a calibrator. One cycle of the typical phase referencing observations consists of 58 cycles of small (about 3-deg) switching and one cycle of large (about 10-deg) switching. One cycle is represented as steps 1-7 as shown in Table 2.

Table 2. One cycle of a typical phase referencing observation

Step	Operation
1	Observation of a target (15sec)
2	Attitude change to a calibrator (15sec,3deg)
3	Observation of the calibrator (15sec)
4	Attitude change to the target (15sec,3deg)
Steps 1-4 are repeated 58 times.	
5	Attitude change to a calibrator (45sec,10deg)
6	Observation of the calibrator (45sec)
7	Attitude change to the target (45sec,10deg)

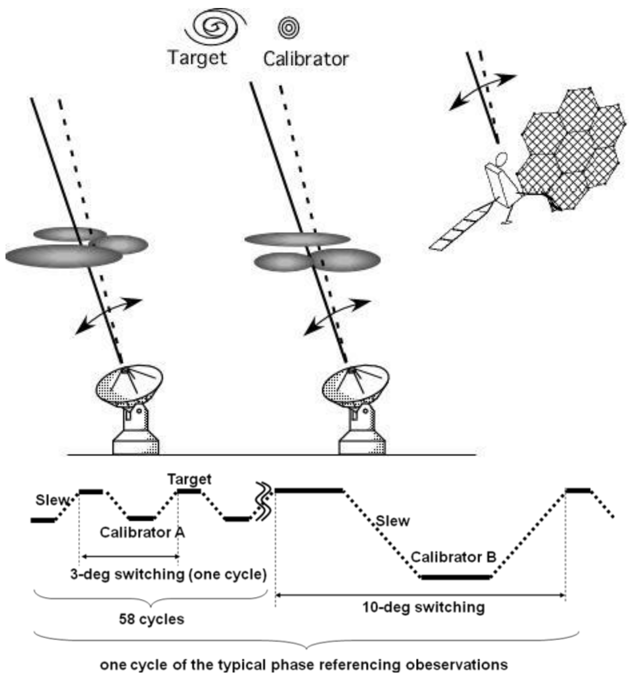


Figure 5. Schematic representation of phase referencing observation in VSOP-2 project

Simulated Return Pattern

As mentioned in section 3, the SLR observations (residuals or O-C) is time-varying due to the phase referencing observations. We simulated SLR return (residuals or O-C) patterns expected to be received at GMSL and YARL. The simulations were done for four cases (two for altitudes change and two for rotation axis (see Figure 4) direction change). Ka-band link antenna is assumed to be directed to the center of the Earth. Figure 6 shows the simulated return pattern for 3-deg switching. Figure 7 shows the simulated return for 3-deg and 10-deg switching.

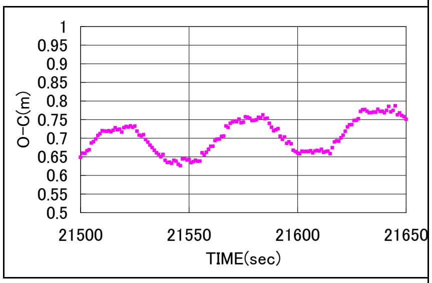
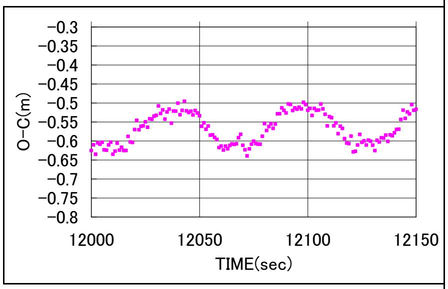
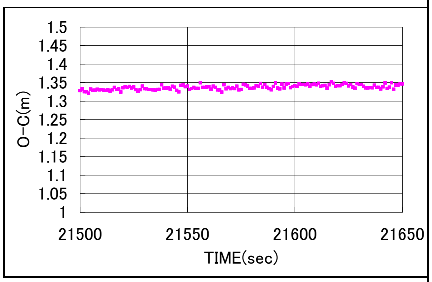
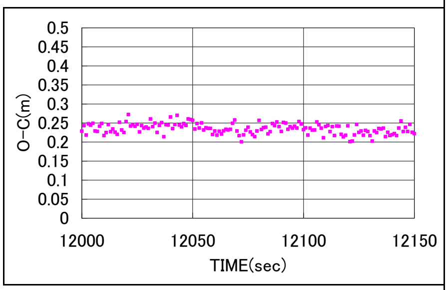
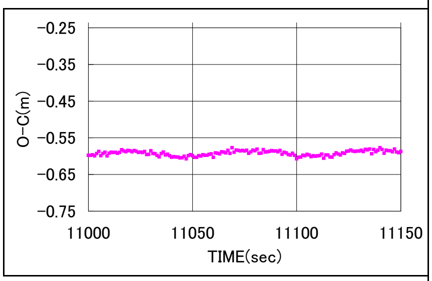
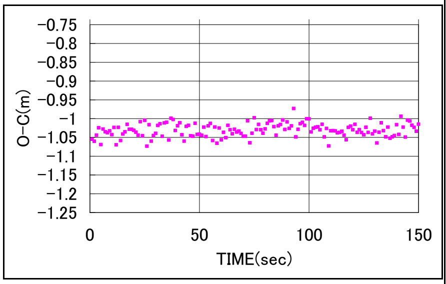
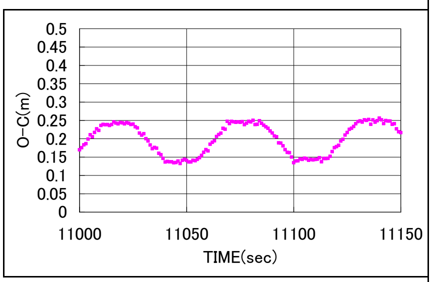
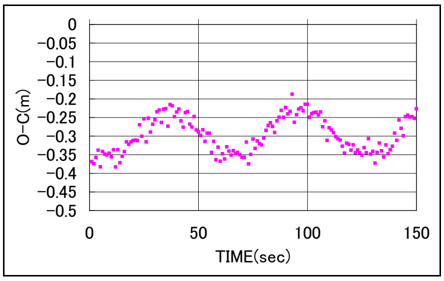
Atitude	Rtation axis direction	GMSL	YARL
1000km	Stellite's radial direction		
	Stellite's along track direction		
Apogee (25000km)	Stellite's radial direction		
	Stellite's along track direction		

Figure 6. Simulated return pattern for 3-deg switching

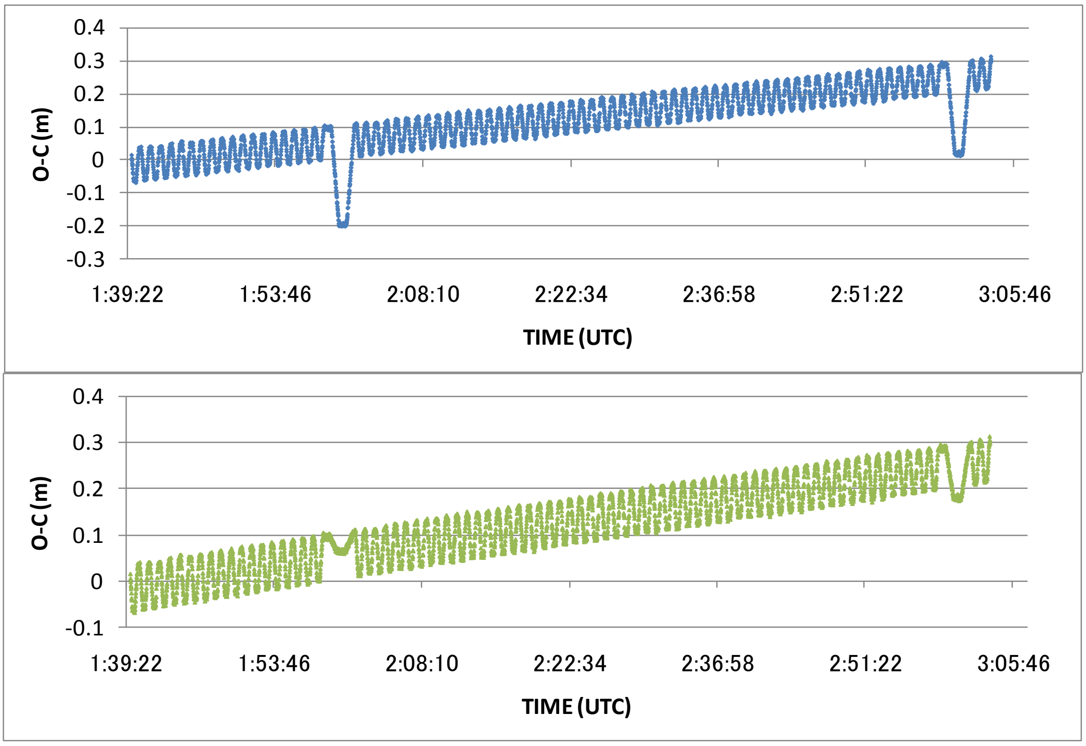


Figure 7. Simulated return pattern for 3-deg and 10-deg switching
(10-deg switching sometimes causes a spike (above) and sometimes not (below).)

Required Data Handling

As is obvious from the simulation result, the observation data from Astro-G requires careful handling. There are two concerns about the data handling. The first one is regarding a bin size of a QLNP. If a large bin size (for example, 15sec) is used, the fluctuation of the LRRA position caused by the phase referencing observation cannot be observed. This works against the POD. Smaller bin size is preferable, so that we can identify the data variation due to the phase referencing operation. In practice, we can choose a 5-sec bin size for Astro-G's QLNP. Another option is to send full rate data. In that case, however, large volumes of data such as data from kHz ranging stations will be another issue. The second concern is regarding a data screening criteria. If tight rejection criteria are applied to the data like shown in the Figure 6 (above), QLNP may have some bias as a result. Figure 8 shows a result of an iterative 2.5-sigma rejection. Triangular plots represent the rejected data after four iteration. At the upper parts of the fluctuation, the data at the above edge are rejected, which results in a downward bias of the QLNP. Similarly, at the lower parts of the fluctuation, the data at the below edge are rejected, which results in an upward bias of the QLNP. These biases also lead to degradation of the orbit determination. In order to avoid the normal point biases caused by data rejection, loose data screening criteria or manual data rejection is mandatory. Even if we are going to take an option of full rate data transmission, since noise reduction should be done on each site, the loose data screening criteria or manual data reduction with these characteristics in mind are of high importance.

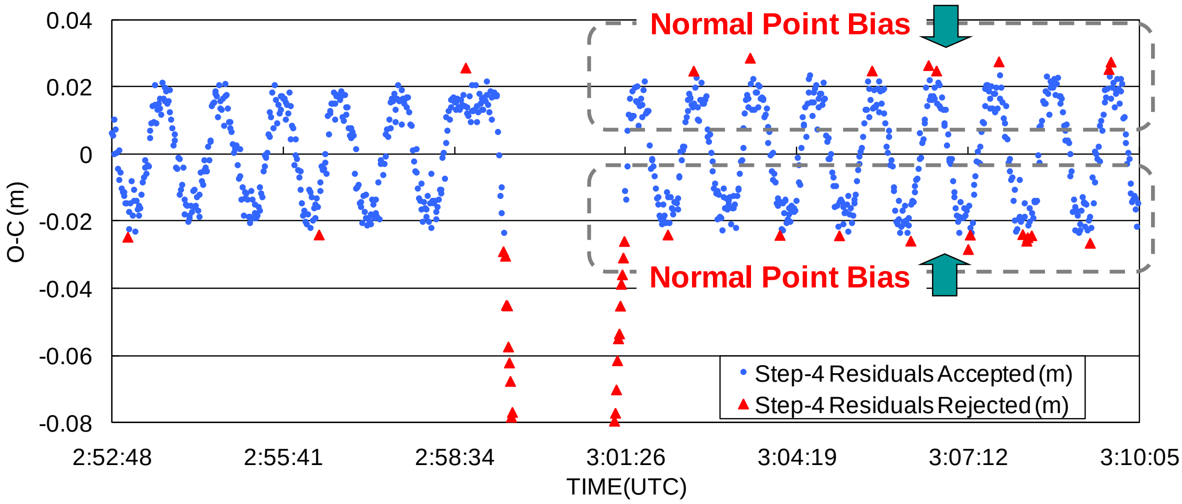


Figure 8. Result of Data Screening (After Iterative 2.5-sigma rejection)

Summary

A POD (10cm accuracy) is required for mission success of Astro-G, which is a space radio telescope and a successor of HALCA. One of the advanced observation modes of Astro-G is a phase referencing observations. SLR observations (O-C) are time-varying, because the position and pointing direction of LRRA (mounted next to Ka antenna) are varied due to the phase referencing observations. QLNP with 5 sec bin size is required for observing fluctuation of the LRRA position and pointing direction. Transmission of full rate data is another consideration. In order to avoid the normal point bias caused by data rejection, a loose data screening criteria or a manual data rejection is mandatory.

References

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