
Possibility of Laser Ranging Support For The Next-Generation Space VLBI Mission, Astro-G

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Introduction

Space VLBI (Very Long Baseline Interferometry) missions enable us to extend the baseline length beyond the diameter of the Earth and, as a result, to obtain more precise images of astronomical radio sources. Following the first successful space VLBI mission, HALCA (Hirabayashi, et al., 1998), which launched in 1997 and finished in 2005, JAXA (Japan Aerospace Exploration Agency) approved the next-generation space VLBI satellite called ASTRO-G (Hirabayashi, 2005) in 2006. It is scheduled to be launched in 2012. This new satellite, with a 9.6-metre mesh antenna, will receive high frequency radio signals up to 43 GHz and enhance the resolution of images by approximately 10 times than the former mission. It is expected to provide high-resolution imaging of active galactic nuclei, motion in galactic star forming regions, observations of extragalactic water masers, and so on.

The space VLBI satellite observes stellar objects in collaboration with ground VLBI network. One of the observation modes is called phase compensation observation. That is, the VLBI antenna switches the pointing direction by 2 or 3 degrees every minute to see a target object and a reference object. This makes it possible to compensate the atmospheric delay for ground VLBI stations. In this observation mode, very precise orbits up to a few cm precision are required throughout the trajectory.

Its orbit is highly elliptic. With an eccentricity of 0.62, its altitude varies from 1000 km (perigee) to 25000 km (apogee). The orbital period is about 7.5 hours and the inclination is set to 31 degrees. In contrast to spherical geodetic satellites, the area-mass ratio is large and its shape is very complicated. Therefore, it will experience large and complicated perturbation forces mainly due to solar radiation pressure. Although the cm-order orbit determination for near-circular orbits is nowadays fairly common, that for such an elliptic orbit is a highly challenging problem. We

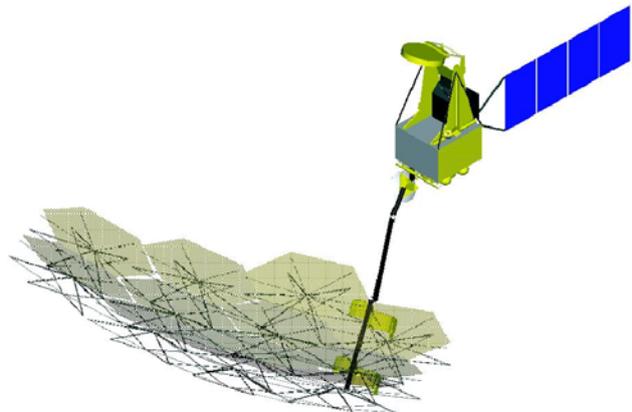


Figure 1. ASTRO-G satellite.

are currently investigating possible instruments for high-precision orbit determination. This paper deals a quick-look, first-step simulation of GPS and SLR data.

Possible instruments for precise orbit determination

In the following discussions, we assume these virtual orbital elements of ASTRO-G:

Epoch: 0h UT, 26 Apr 2004
Semimajor axis: 19378 km
Eccentricity: 0.6193
Inclination: 31 deg
Longitude of ascending node: 0 deg
Argument of perigee: 0 deg
True anomaly: 0 deg

After several experiments since 1990's, an onboard GPS receiver is found to be useful for precise orbit determination of low earth orbit (LEO) satellites, and the number of LEO satellites carrying this instrument is rapidly increasing.

We currently consider GPS receiver(s) as the primary instrument for precise orbit measurement. The apogee of ASTRO-G is 25000 km of altitude which is higher than the GPS satellites (20000 km). The beam divergence of GPS microwave signal is almost the size of the earth, so it gets out of the main lobe of the GPS signal (~ 20 degrees for L1 frequency) as its altitude gets high (~ typically a few thousand km).

The number of 'visible' GPS satellites on track was plotted in Fig. 2 using the true GPS constellation on the day. The bottom graph is the geocentric distance of the ASTRO-G satellite. This graph covers 15 hours, almost 2 revolution periods. The 'visibility' is defined so that the ASTRO-G satellite is within the 20-degree beam divergence and it is out of the Earth's shadow. First, assuming a single GPS receiver that always points away from the geocentre, the 'visible' number of GPS satellites is the dotted (blue) line in the top graph. Only when it is close to the perigee, one hour per the 7.5 hours period, it can see more than four satellites. Then, we simulated multiple receivers which provide no limit in terms of direction. The result is plotted as the solid (red) line in the top graph. With the contribution from GPS satellites that locate opposite side of the earth, the 'visible' number increases. Even away from the perigee, a few GPS satellites can be visible, but the number is far less than four in most cases.

In order to overcome this situation, we need to look into the possibility of the use of sidelobe GPS signal. Also, other GNSS satellites like GLONASS and GALILEO are also possible to improve the situation. Nevertheless, we stick to the above condition (solid red line) for the rest of this paper.

In these circumstances, laser ranging seems to play an important role for precise orbits. We have not looked into the specifications, but the reflector array size should be similar to that of GPS or GLONASS satellites. Other possibilities, such as an accelerometer or VLBI delay measurements, are also being considered, but not included in this paper.

Quick-look POD simulations

We simulated the following data set for the 15 hours in Fig. 2:

- GPS: every 30 seconds, pseudorange and carrier phase, L1 and L2 frequency (assumed observation error = 10 cm for carrier phase, and 3 m for pseudorange)
- SLR: normal points every 120 seconds (assumed observation error = 6 cm)

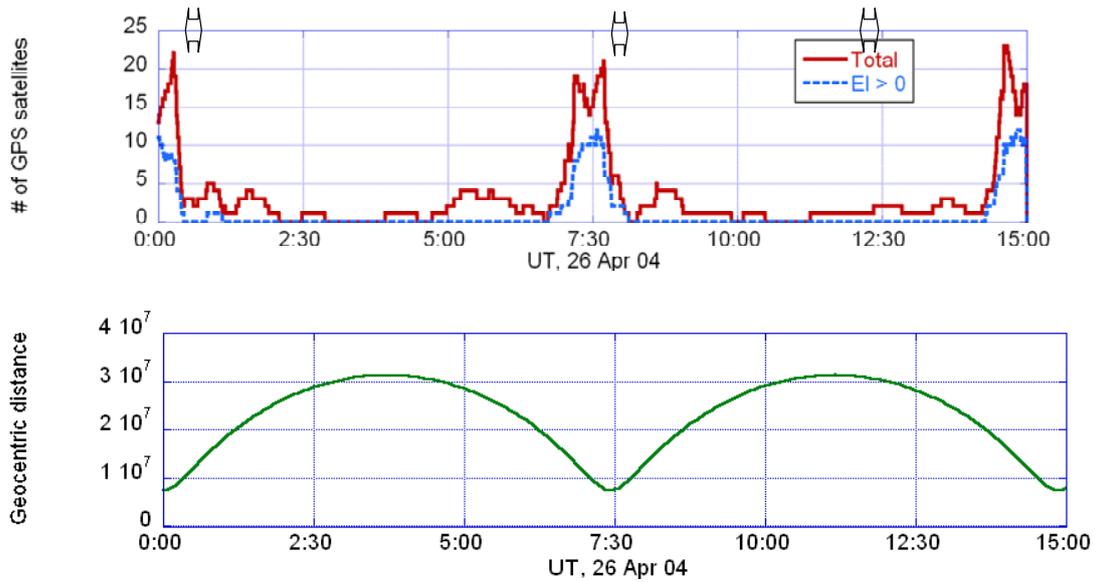


Figure 2. Number of visible GPS satellites (top) and geocentric distance (bottom) of ASTRO-G simulated orbit. The three two-headed arrows are the duration of assumed SLR observations.

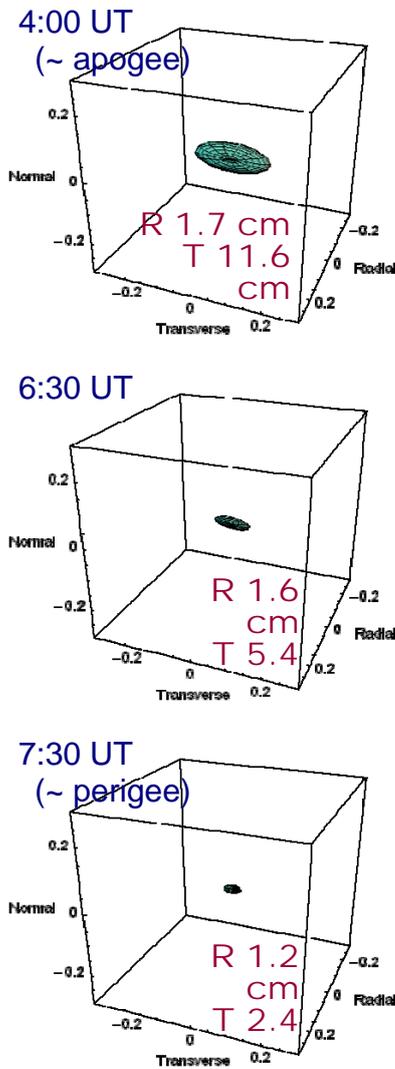


Figure 3. Error ellipsoids for the GPS-only case.

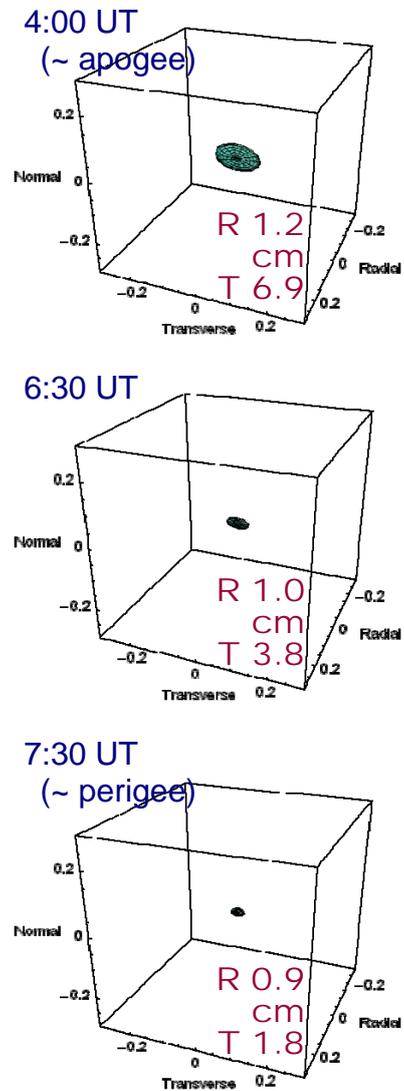


Figure 4. Error ellipsoids for the GPS+SLR case.

The orbital parameters, six elements, constant along-track acceleration and once-per-rev along-track acceleration, are estimated at 4:00 (close to the apogee), 6:30 and 7:30 (close to the perigee), instead of the starting time (0:00) of the arc. The clock offsets at each epoch and the ambiguities of ion-free GPS carrier phase are also solved for. We look into the covariance matrix of the orbit positional solution to obtain the estimation error. The covariance matrices given in the XYZ inertial coordinate system are then converted to the RTN satellite-fixed system, that is, in Radial, Transverse and Normal direction.

We firstly simulated the GPS data only. The ellipsoidal bodies in Fig. 3 show the size of three-dimensional errors for the three epochs. The error in the transverse component (= along-track component at the apogee and the perigee) is dominant in all cases. As expected, the ellipsoid gets larger around the apogee where GPS signal is merely detected.

Then we added the SLR data, the three 30-minute passes shown in Fig. 2, to the GPS data. The ellipsoids are shown in Fig. 4. It is obviously seen that the errors in the transverse and radial components are significantly reduced by the addition of the small amount of SLR data. Although we cannot expect dense tracking from the SLR network, this result suggests the SLR data will significantly contribute to the improvement of the orbit of ASTRO-G.

Discussions for future studies

The precise orbit monitoring instrument for the ASTRO-G satellite is being investigated. SLR observations will significantly improve the orbit compared to the GPS-only case. With further analyses we need to consider the details on the instruments such as the number and arrangement of GPS antennas and SLR retroreflectors.

The International Laser Ranging Service (ILRS) had a small experience of highly elliptic orbit satellite in the LRE (Laser Ranging Equipment) test mission launched to a geostationary transfer orbit in 2001 (Otsubo, et al., 2002). If the satellite actually carries retroreflectors for SLR, we would like to ask the ILRS stations to adapt their tracking system to highly elliptic orbits.

Due to the complicated shape of the satellite and the large area-per-mass ratio, this satellite is to experience largely complicated perturbation forces from solar radiation pressure that is about 100 times of LAGEOS. Therefore, along with the orbit measurement instruments discussed in this paper, the establishment of a precise force model is also essential for the precise orbit determination of this satellite.

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