SLR Return Analysis for Astro-G

- Laser Retro-Reflector Array and Simulated Return Pattern -

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Overview of Astro-G

- ASTRO-G is a next-generation space radio telescope designed to reveal fascinating phenomena such as the relativistic phenomena in the space around super-massive black holes at the centers of galaxies.

- The VSOP-2/ASTRO-G project is extending the successes of VSOP/HALCA project (1997-2005).

- HALCA demonstrated successfully the technologies required for the space very-long-baseline interferometry (VLBI).

Overview of Astro-G

- **Launch Rocket:H2A (from tanegashima)**
- **Launch epoch:TBD**
- **Orbit**

Apogee height	25000Km
Perigee height	1000Km
Inclination	31°
Orbital period	7.5 h
$\dot{\Omega}$	-167° / year
$\dot{\omega}$	258° / year

Orbit determination accuracy (1σ) and Scientific targets (ISAS Doi,Asaki 2007)

- **Orbit accuracy(1σ) ＞30 cm**
  - On-source observation (Continuum, Galactic masers)
- **Orbit accuracy(1σ) ＜30 cm**
  - **Phase referencing observations in X-band (8.4 GHz)**
- **Orbit accuracy(1σ) ＜6 cm**
  - **Phase referencing observations in K-band (22GHz)**
  - Determination of the Hubble constant by on-source observations of Megamasers in 22GHz.

Orbit determination accuracy (1σ) and Scientific targets (ISAS Doi,Asaki 2007)

- **Orbit accuracy(1σ) < 6 cm**
  - **Phase referencing observations in Q-band (43GHz)**
  - 10% accuracy of distance measurements by parallax, almost everywhere in our Galaxy

Target is 3cm accuracy
(requirement is 10cm)

Precise Orbit Determination
using GPS receiver data and SLR

GPS visibility from Astro-G

- GPS's altitude(20000Km) is lower than the apogee altitude of Astro-G (25000km).
- Only1-2 GPS satellites can be used at the apogee.

→SLR is important

Number of visible GPS satellites (Otsubo,2006)

Laser Retro-Reflector Array for Astro-G

Center area : To support wide range of incident angles

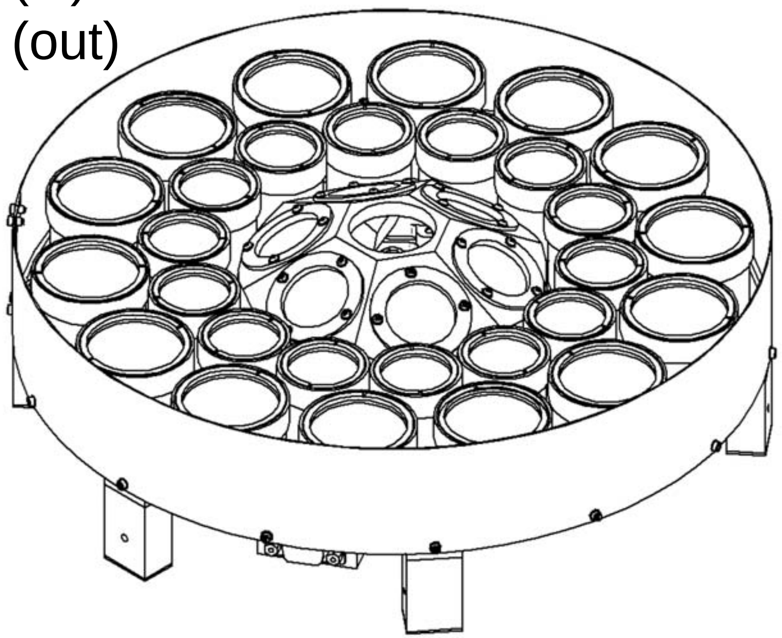
Pyramid-shaped array for **low altitudes**

corner cube : r = 14mm (ϕ = 28mm)
coated on back face
30deg slanted
Dihedral Angle = 2.5”

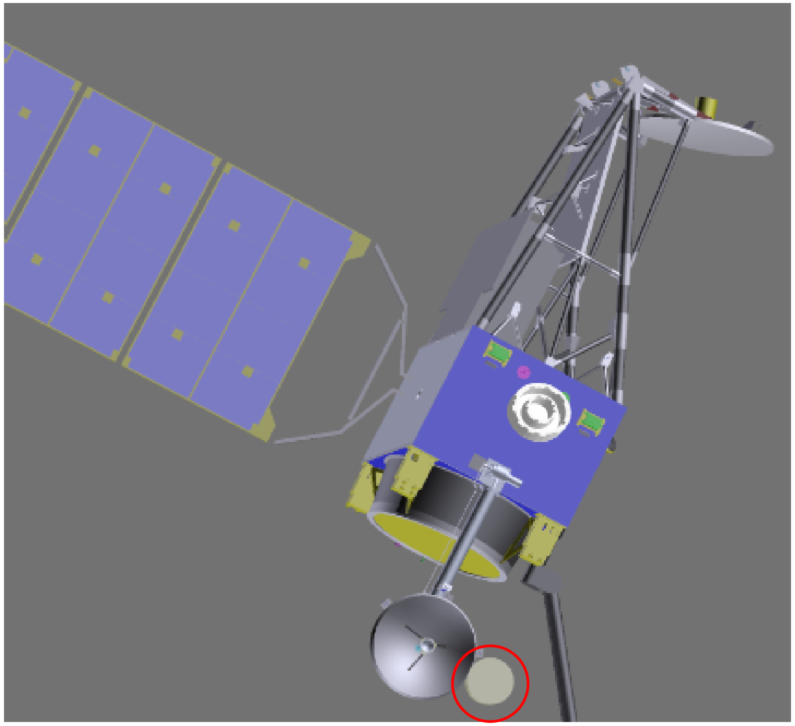
Surrounding area : To increase effective aperture area

Flat array composed of inner (in) and outer (out) ring for **high altitudes**

corner cube : r = 14mm (ϕ = 28mm) (in)
r = 19mm (ϕ = 38mm) (out)
uncoated on back face
no-slant
Dihedral Angle = 0.75”



Laser Retro-Reflector Array for Astro-G



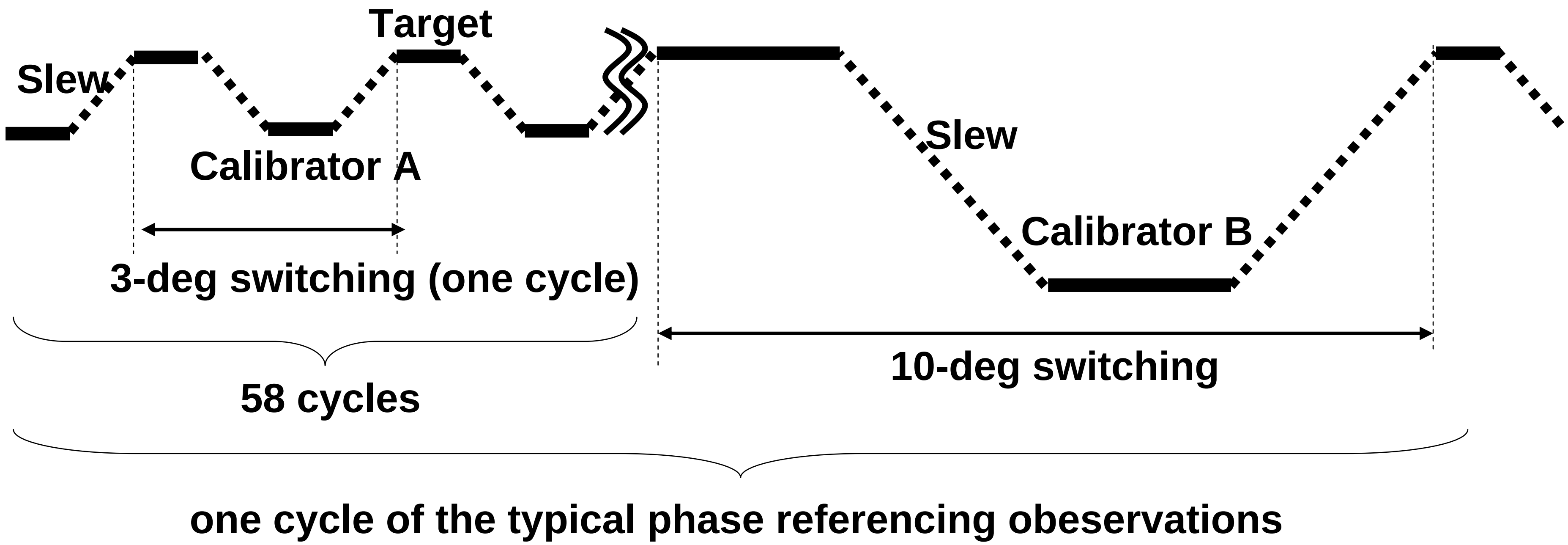
- Mounted next to Ka antenna
  (fixed to Ka antenna)

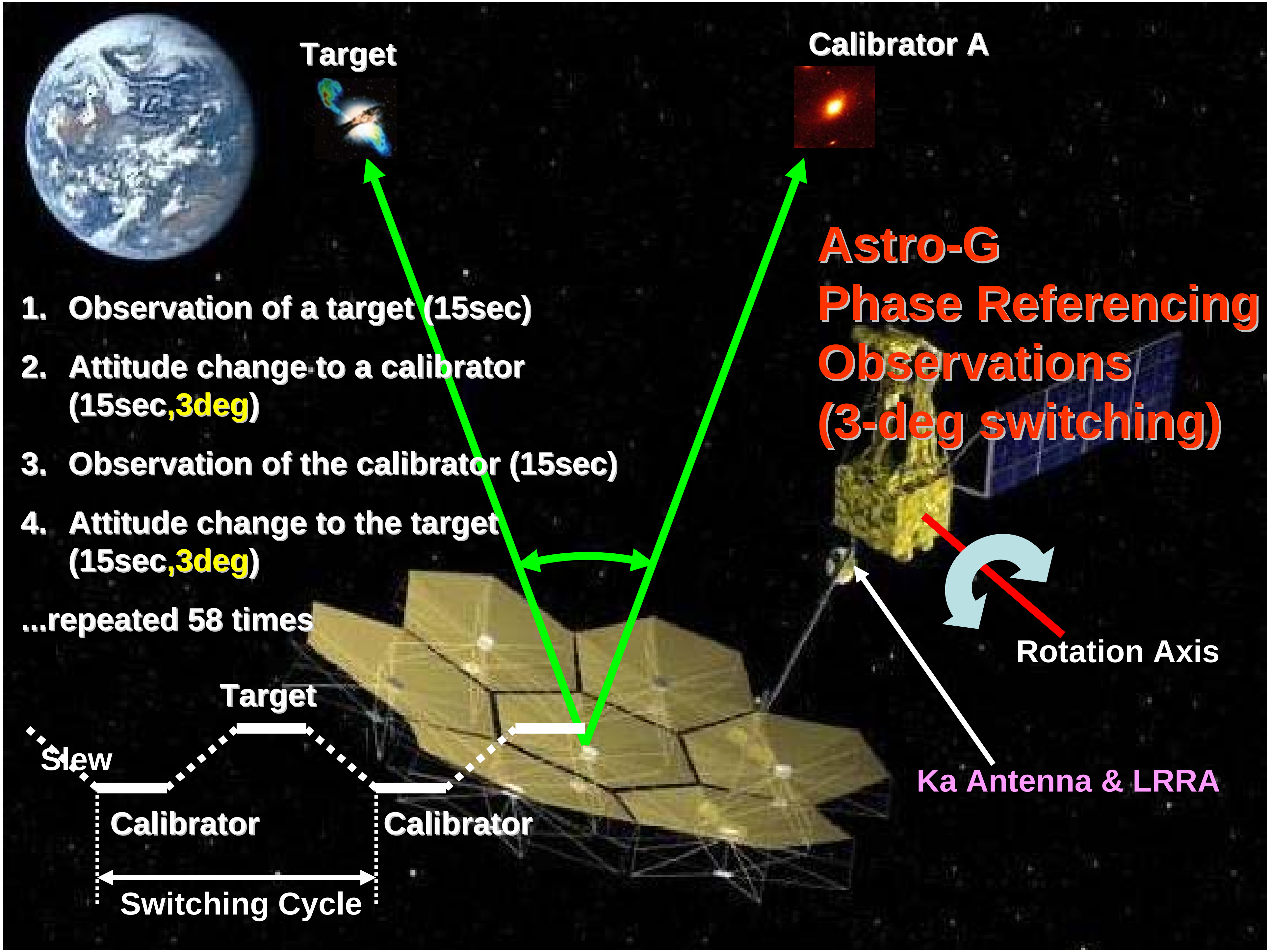
→LRRA position and attitude (pointing direction) is synchronized with those of Ka antenna.

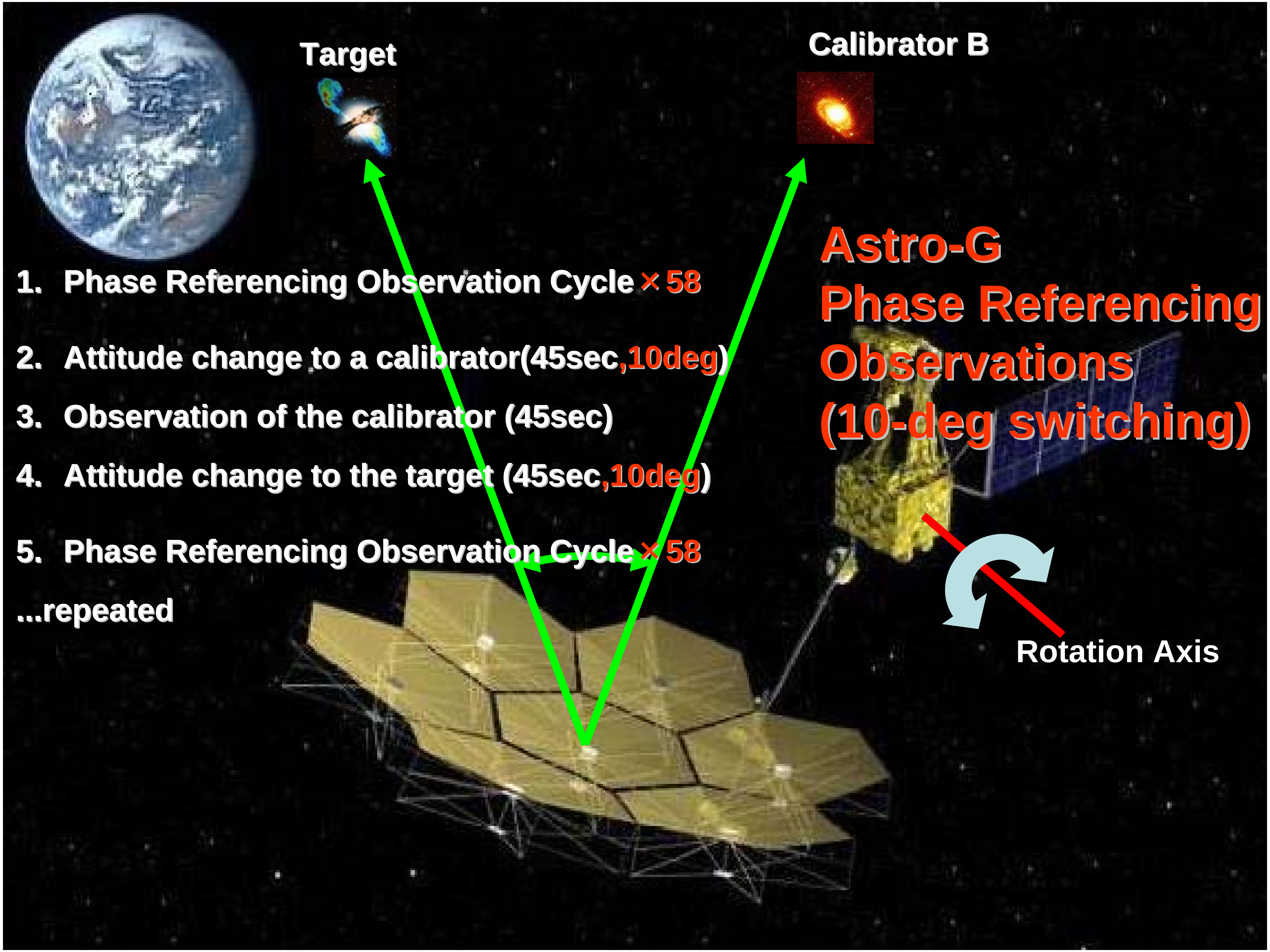
LRRA position and pointing direction is varied because of Phase referencing observations.

Phase Referencing Observations

- One cycle of the typical phase referencing observations consists of 58 cycles of 3-deg switching and one cycle of 10-deg switching.



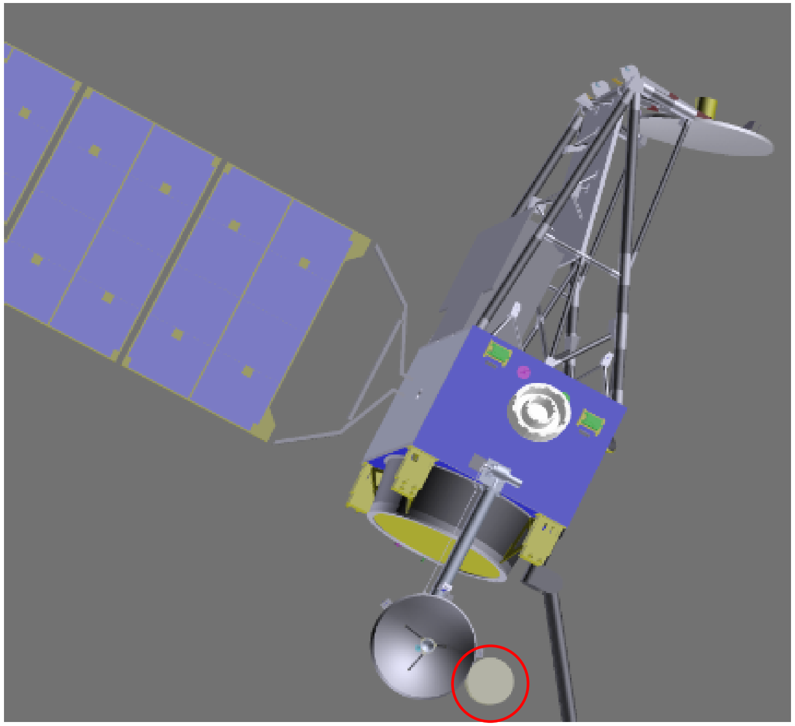

Target
Calibrator A
Astro-G
Phase Referencing
Observations
(3-deg switching)
1. Observation of a target (15sec)
2. Attitude change to a calibrator (15sec,3deg)
3. Observation of the calibrator (15sec)
4. Attitude change to the target (15sec,3deg)
...repeated 58 times
Rotation Axis
Target
Slew
Calibrator
Calibrator
Switching Cycle
Ka Antenna & LRRA


Target
Calibrator B
Astro-G
Phase Referencing
Observations
(10-deg switching)
1. Phase Referencing Observation Cycle × 58
2. Attitude change to a calibrator(45sec,10deg)
3. Observation of the calibrator (45sec)
4. Attitude change to the target (45sec,10deg)
5. Phase Referencing Observation Cycle × 58
...repeated
Rotation Axis

Laser Retro-Reflector Array for Astro-G

- Mounted next to Ka antenna
  (fixed to Ka antenna)

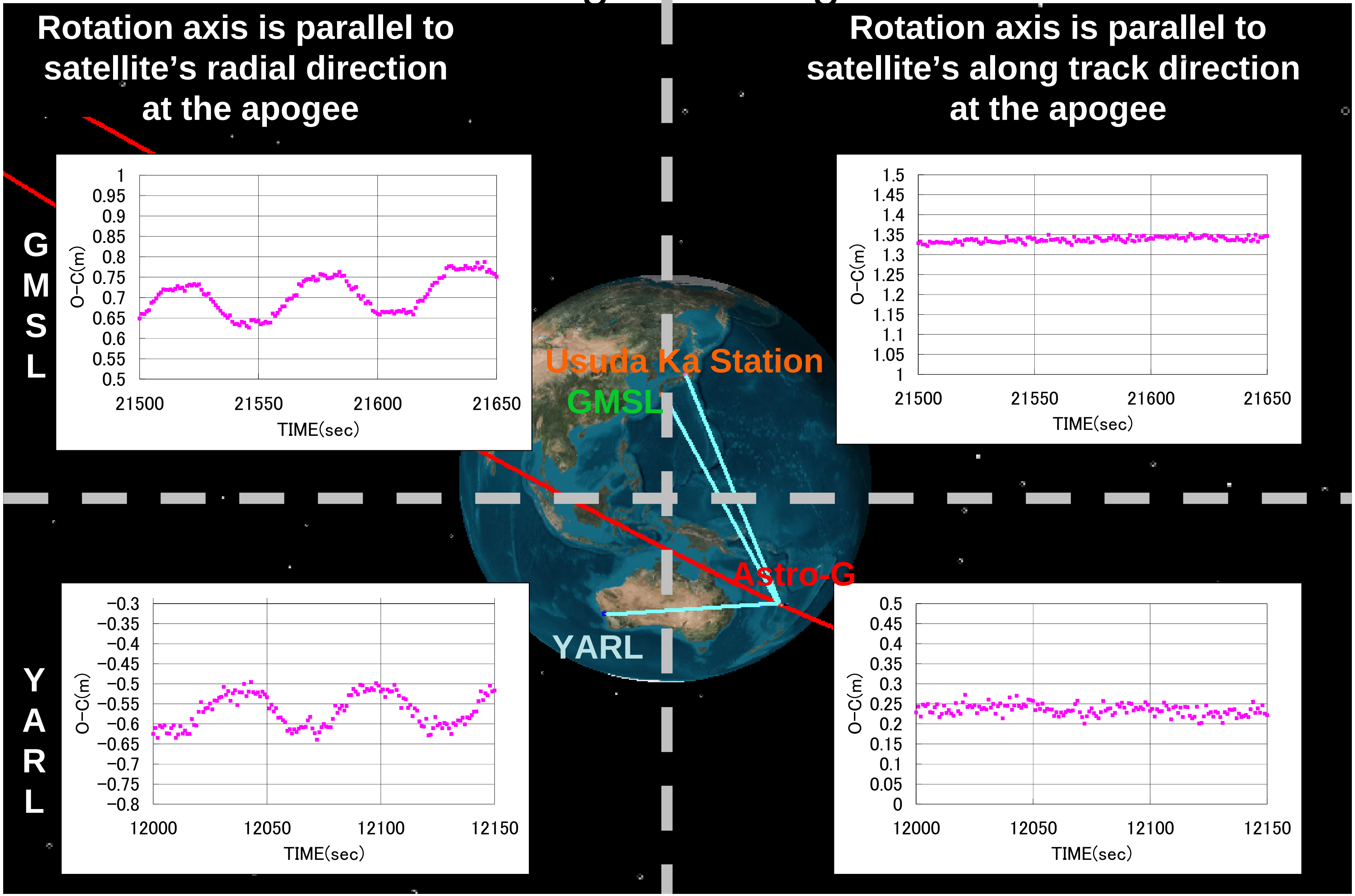
→LRRA position and attitude
  (pointing direction) is synchronized
  with those of Ka antenna.



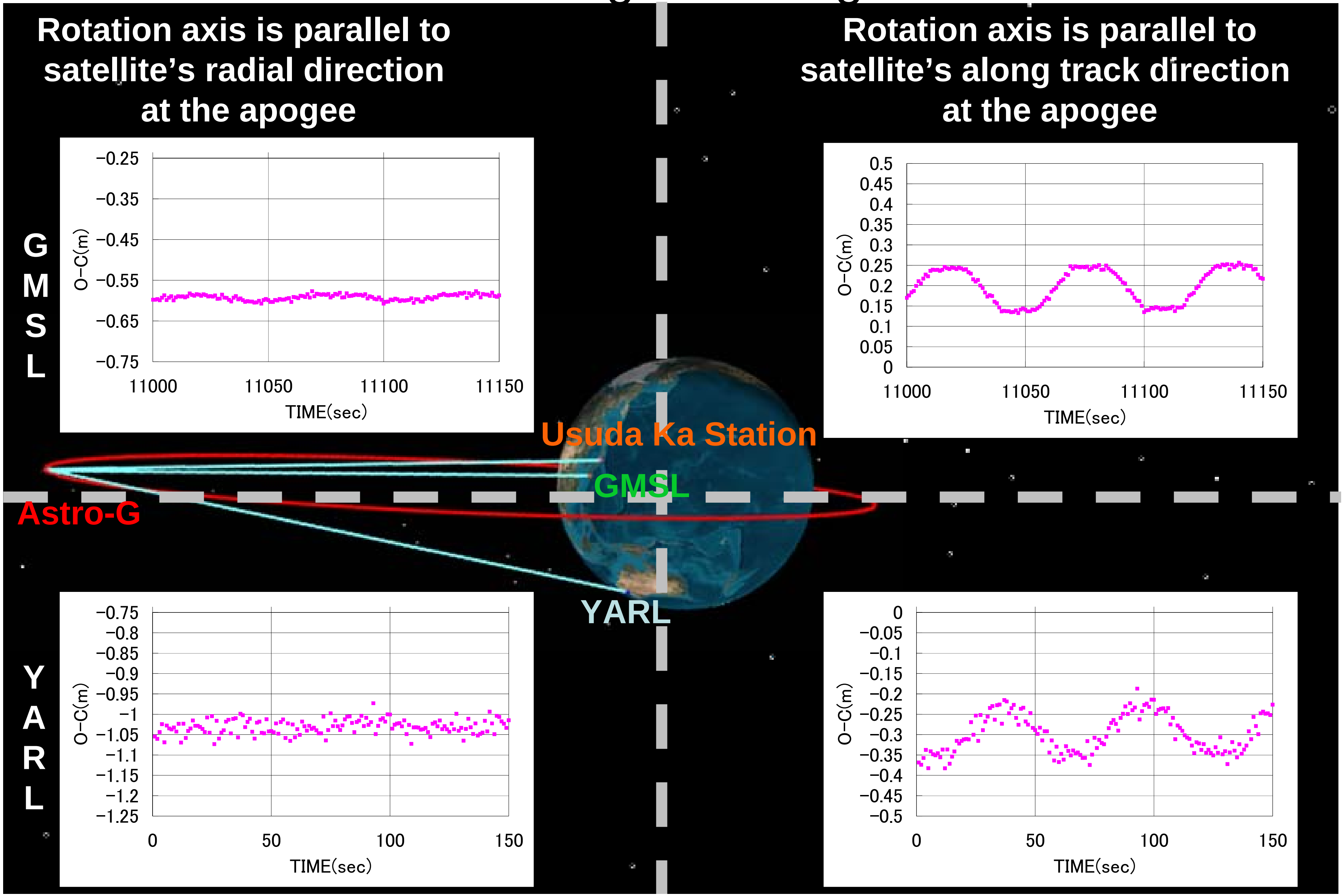
LRRA positon and pointing direction is varied because of Phase referencing observations.

SLR observations (O-C) is time-varying!!

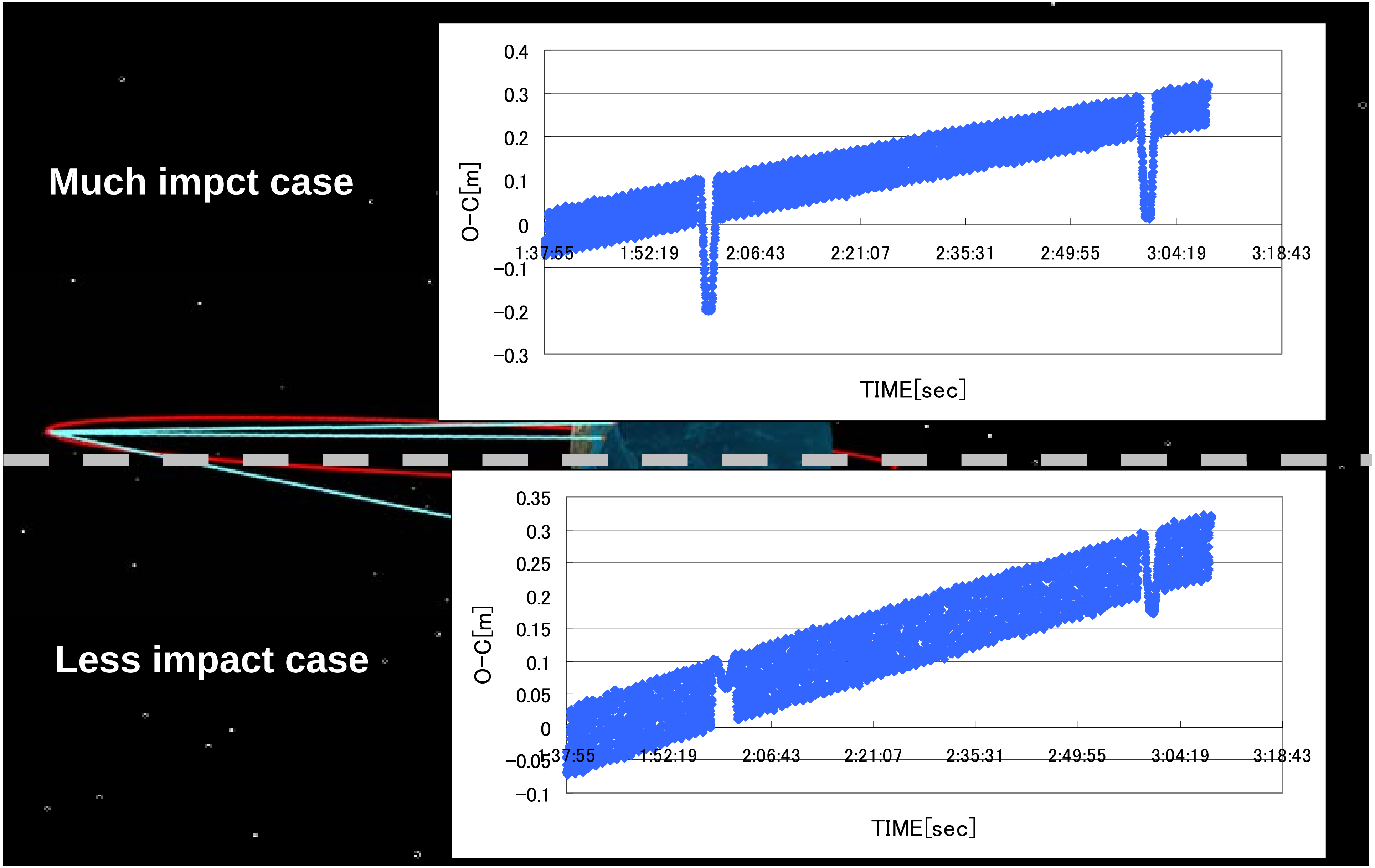
simulated SLR return pattern (altitude～10000km) ~3deg switching~



simulated SLR return pattern (apogee)
~3-deg switching~



simulated SLR return pattern
~3-deg swithicng and10-deg switching~



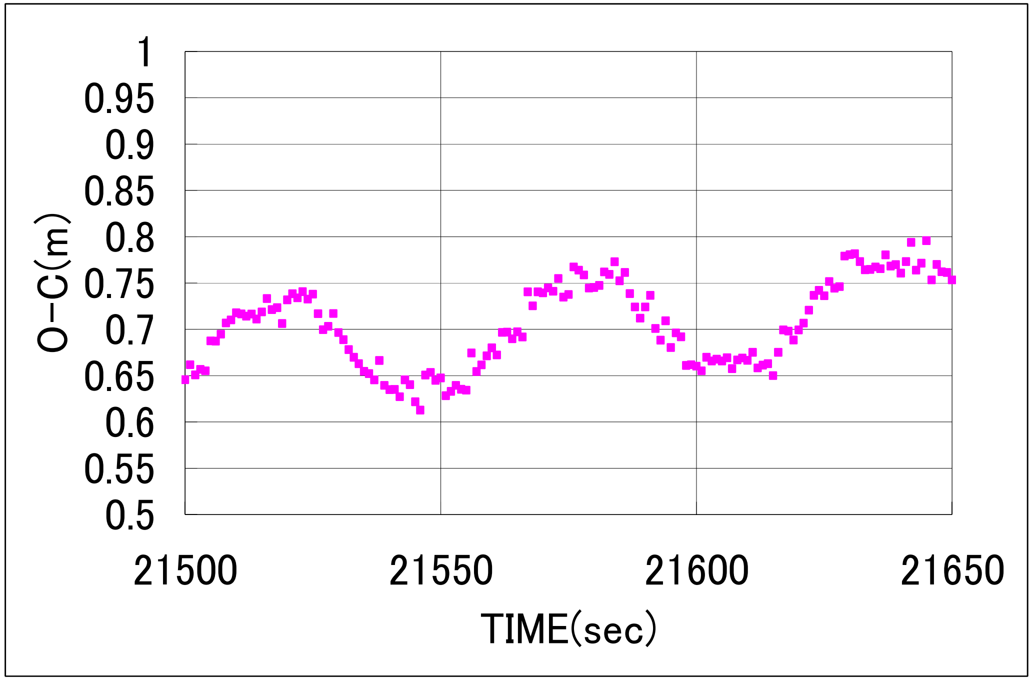
Two Request

- Normal handling of the time-varying observations results in ...
  - The fluctuation of LRRA position caused by the phase referencing observation can't be observed.
  - The normal points may have some bais.

- **Small bin size for QLNP**
- **Loose data screening**

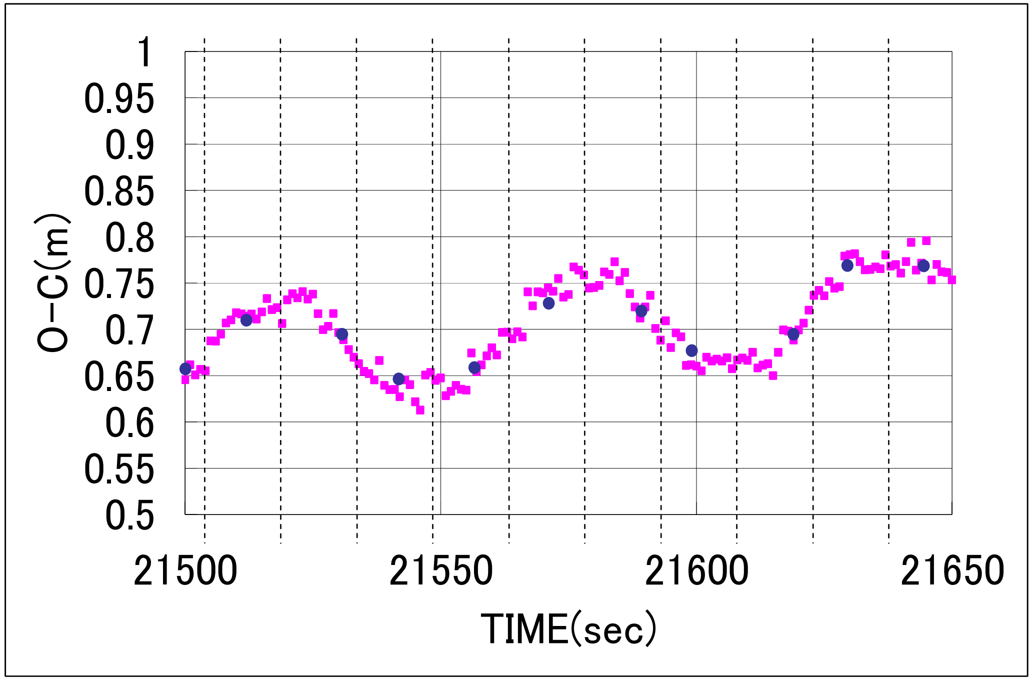
Bin size of QLNP

- Observation of Fluctuation caused by Phase Referencing Observations for 3cm orbit determination accuracy



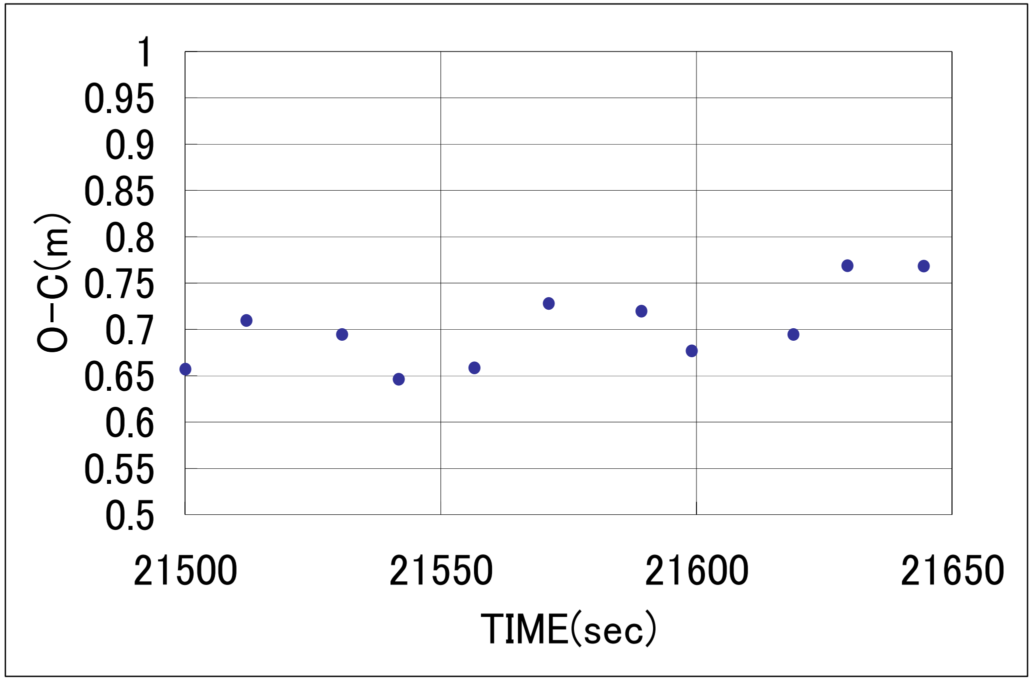
Bin size of QLNP

- Observation of Fluctuation caused by Phase Referencing Observations for 3cm orbit determination accuracy



Bin size of QLNP

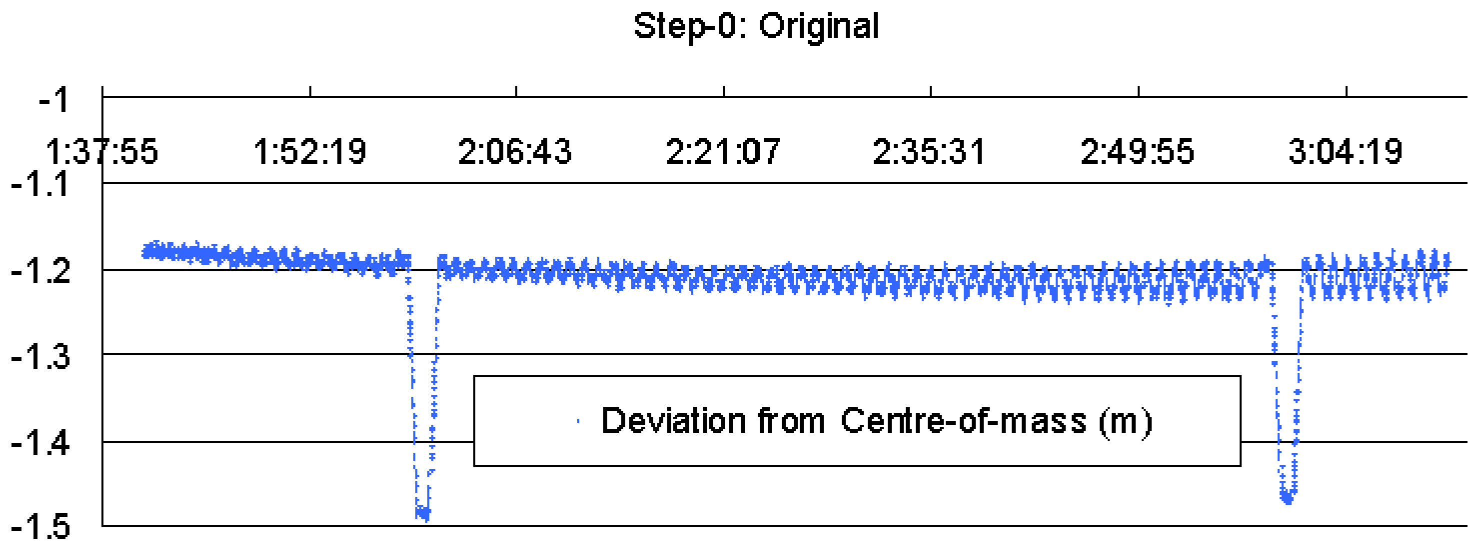
- Observation of Fluctuation caused by Phase Referencing Observations for 3cm orbit determination accuracy



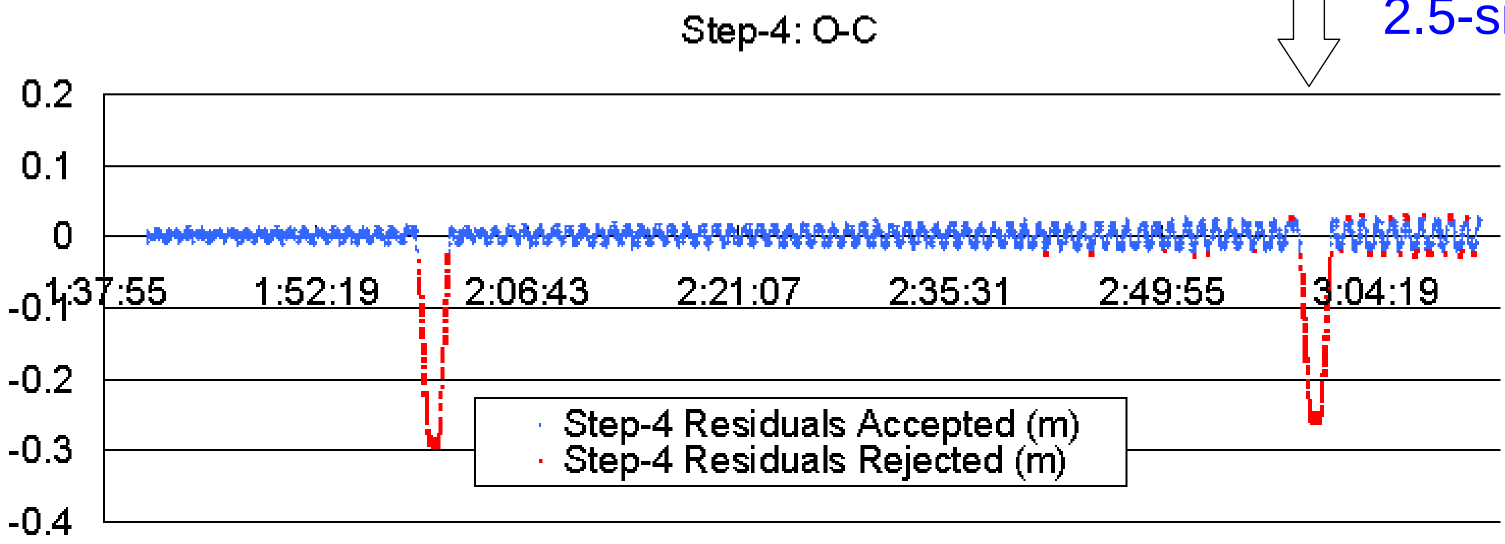
QLNP with 15 sec bin size is not enough

QLNP with 5 sec bin size is required

Data Screening

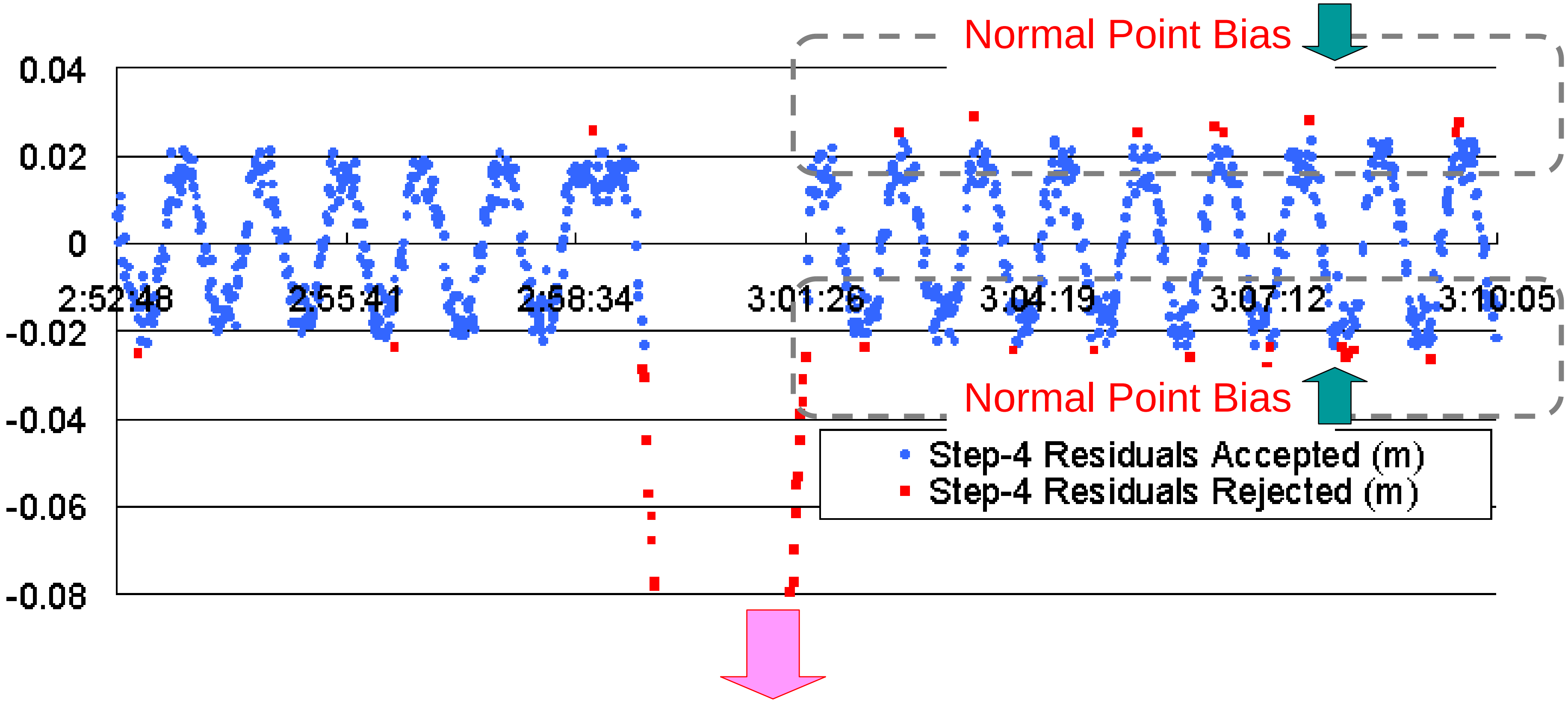


Iterative (4-fold)
2.5-sigma rejection



Data Screening

After Iterative 2.5-sigma rejection



Don't apply tight rejection criteria.
Loose or manual screening preferable.

Summary

- Precise orbit determination (3cm accuracy) is required for mission success of Astro-G, which is a space radio telescope and a successor of HALCA.
- Astro-G performs Phase referencing observations.
- SLR observations (O-C) is time-varying, because position and pointing direction of LRRA (mounted next to Ka antenna) is varied due to the phase referencing observations.
- QLNP with 5 sec bin size is required for observing fluctuation of LRRA position and pointing direction.
- In order to avoid the data rejection, loose data screening criteria is preferable.