SECTION III: RETROREFLECTOR ARRAY INFORMATION:

A prerequisite for accurate reduction of laser range observations is a complete set of pre-launch parameters that define the characteristics and location of the LRA on the satellite. The set of parameters should include a general description of the array, including references to any ground-tests that may have been carried out, array manufacturer and whether the array type has been used in previous satellite missions. So the following information is requested:

Retroreflector Primary Contact Information:

Name: Zhang Zhongping

Organization and Position: Shanghai Astronomical Observatory,Chinese Academy of Sciences. Professor

Address: No.80,Nandan Road,Xuhui,Shanghai,P.R,China

Phone No.: 86-21-64696290

E-mail Address: zzp@shao.ac.cn

Array type:

○ Single reflector ○ Spherical ◉ Hemispherical/Pyramid ○ Planar

○ other (specify: ________________)

Attach a diagram or photograph of the satellite that shows the position of the LRA, at the end of this document.

☒ Attached

Attach a diagram or photograph of the whole LRA at the end of this document.

◉ Attached ○ Same as above, Not attached (acceptable only for a cannonball satellite)

Array manufacturer:

Shanghai Astronomical Observatory,Chinese Academy of Sciences

Link (URL and/or reference) to any ground-tests that were carried out on the array:

none

Has the LRA design and/or type of cubes been used previously?

◉ No ○ Yes (List the mission(s): ________________)

For accurate orbital analysis it is essential that full information is available in order that the 3-dimensional position of the satellite center of mass may be referred to the location in space at which the laser range measurements are made. To achieve this, the 3-D location of the LRA phase center must be specified in a satellite-body-fixed reference frame with respect to the satellite's mass center. In practice this means that the following parameters must be available at 1 mm accuracy or better.

Define the satellite-body-fixed XYZ coordinates (i.e. origin and axes) on the spacecraft:
(specify) (add a diagram in the attachment)

The origin of satellite-body-fixed coordinates is located at mass center, the +Xb axis points to the front end of the TG-2, the +Zb axis points toward the bottom, and the +Yb axis completes the right-handed system. see Attachment --Appendix 3

Relate the satellite-body-fixed XYZ coordinates to a Celestial/Terrestrial/Solar Reference Frame including the attitude control policy:
(specify) (add a diagram in the attachment)

see Attachment --Appendix 4

The 3-D location of the satellite's mass center in satellite-body-fixed XYZ coordinates is:

- (●) Always fixed at (0, 0, 0)
- ( ) Always fixed at (__________, __________, __________) in mm
- ( ) Time-varying by approximately (__________) mm during the mission lifetime.
  Will a time-variable table of the mass center location be available on the web?
  ( ) No ( ) Yes (URL: __________________________)

The 3-D location (or time-variable range) of the phase center of the LRA in the satellite-body-fixed XYZ coordinates:

(215.9, -4.5, 1658.6) in mm

The following information on the corner cubes must also be supplied.

The XYZ coordinates referred to in the following are given in:

- ( ) Satellite-body-fixed system (same as above)
- (●) LRA-fixed system (specify below)

(specify the origin and orientation) (add a diagram in the attachment)

The origin is the spherical center point of LRA. Xr-axis: parallel to Xb Zr-axis: parallel to Zb Yr-axis: completing the right-handed orthogonal system see Attachment --Appendix 5

List the position (XYZ) of the center of the front face of each corner cube, and the orientation (two angles or normal vector) and the clocking (horizontal rotation) angle of each corner cube. Note that the angles should be clearly defined.

- ○ Attached at the end of this document
- ◉ Listed here (acceptable for small number (10 or fewer) of corner cubes)

(specify) (add a diagram in the attachment)

see Attachment--Appendix 6: the position of each corner cube

Is the corner cube recessed in its container (i.e. can the container obscure a part of the corner cube)?

○ No ◉ Yes (specify below)

(specify) (add a diagram)

see Attachment--Appendix 7: CCR in the house

The size of each corner cube: Diameter (33.2) mm Height (24) mm

The material from which the cubes are manufactured (e.g. quartz):

quartz

The refractive index of the cube material

= 1.461 for wavelength $\lambda = 0.532$ micron

= see Attachment--Appendix 8: Refractive index and dispersion as a function of wavelength λ (micron):

The group refractive index of the cube material, as a function of wavelength λ (micron):

= 1.485 for wavelength $\lambda = 0.532$ micron

= 1.462@1064nm as a function of wavelength λ (micron):

Dihedral angle offset(s) and manufacturing tolerance (in arcseconds):
1.5+/-0.3aresec

Radius of curvature of front surfaces of cubes:

- [x] Not applied
- [ ] Yes (specify: ____________________)

Flatness of cubes' surfaces:
0.1 wavelength

Back-face coating:

- [ ] Uncoated
- [x] Coated (specify the material: Coated with silver)

Other comments on LRA:

(specify) (add a reference to a study of the optical response simulation/measurement if available) (add a diagram if applicable)

Except for the above LRA for SLR tracking of TG-2, one set of laser radar retro-reflector array (LRRA) using for the lidar rendezvous and docking is also available on TG-2 spacecraft. Due to its large size, the ground stations will also receive the laser echoes from LRRA when SLR tracking. So some requirements are needed for SLR data post-preprocessing. Detailed requirements can be seen from the attachment--Appendix 9: Other comments on LRA.

Attachments of ILRS SLR Mission Support Request Form for TG-2

Appendix 1: A diagram of the satellite that shows the position of the LRA

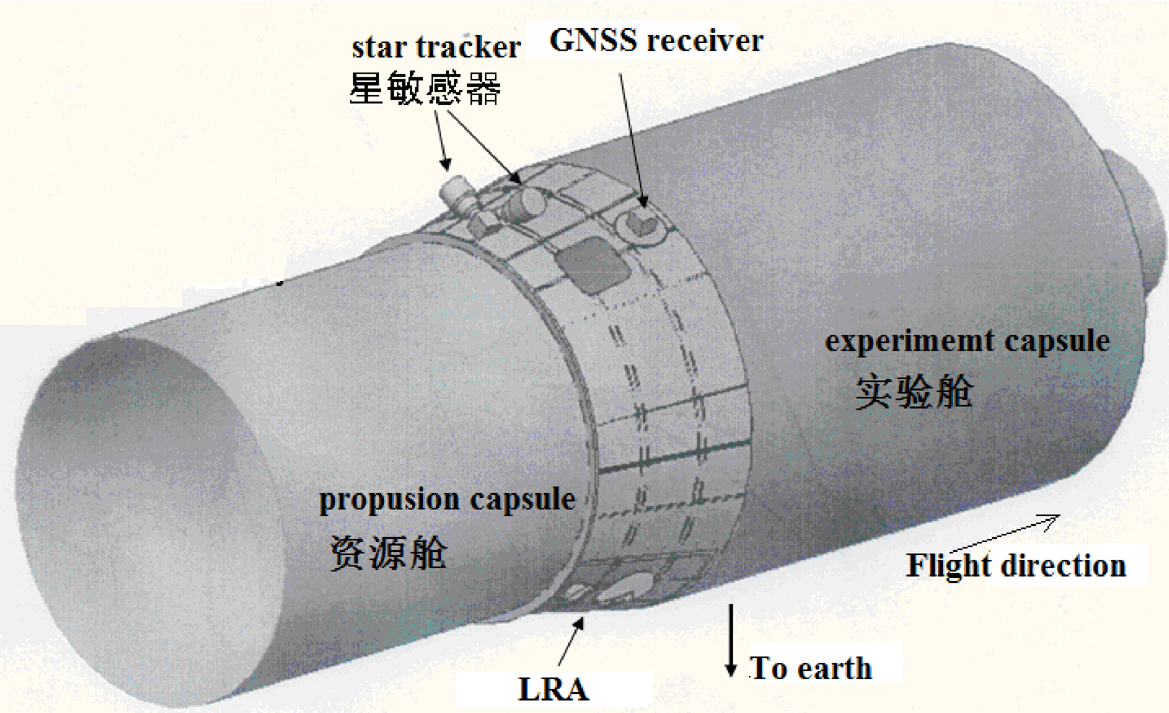

Fig.1 LRA on the TG-2 spacecraft

Appendix 2: A diagram of the LRA

Fig.2 LRA for SLR to TG-2

Appendix 3: Define the satellite-body-fixed XYZ coordinates (i.e. origin and axes) on the spacecraft

The origin of satellite-body-fixed coordinates is located at mass center, as shown in the Fig.3, the $+X_b$ axis points to the front end of TG-2, the $+Z_b$ axis points toward the bottom, and the $+Y_b$ axis completes the right-handed system.

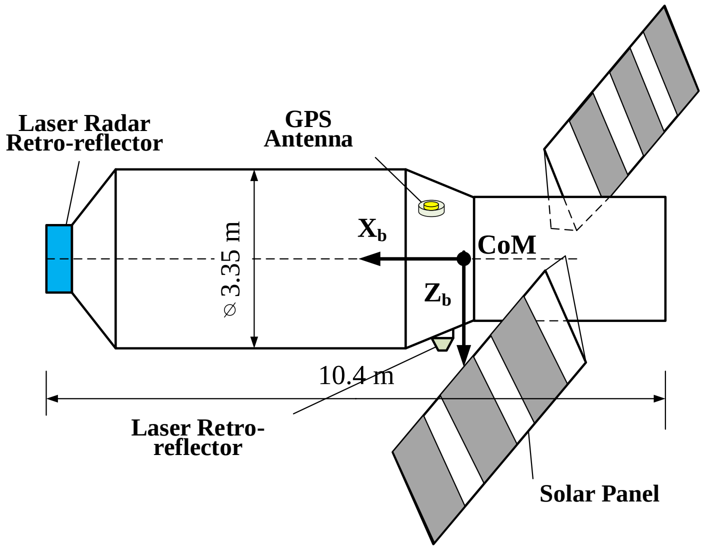

Fig.3 the satellite-body-fixed XYZ coordinates on the spacecraft

Appendix 4: Relate the satellite-body-fixed XYZ coordinates to a Celestial/Terrestrial/Solar Reference Frame including the attitude control policy

The transformation is divided into two steps:

1) **The transformation between the satellite-body-fixed coordinates ($O_bX_bY_bZ_b$) and the orbital coordinates ($O_oX_oY_oZ_o$)**

The origin of satellite-body-fixed coordinates is located at mass center, the $+X_o$ axis points to the flight direction of TG-2, the $+Z_o$ axis points toward nadir, and the $+Y_o$ axis completes the right-handed system.

The transformation is given by:

$$\begin{bmatrix} X_b \\ Y_b \\ Z_b \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & \sin\varphi \\ 0 & -\sin\varphi & \cos\varphi \end{bmatrix} \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X_o \\ Y_o \\ Z_o \end{bmatrix}$$

where ψ, φ, and θ are yaw, roll, and pitch angles relative to the $O_oX_oY_oZ_o$. If the TG-2 is in the attitude mode of three-axis Earth-pointing stabilization, the two coordinates coincide with each other.

2) The transformation between the orbital coordinates ($O_oX_oY_oZ_o$) and the Terrestrial Reference Frame ($O_tX_tY_tZ_t$)

The elements of the $O_oX_oY_oZ_o$ to the $O_tX_tY_tZ_t$ are given by:

$$\boldsymbol{u}_x = \boldsymbol{u}_y \times \boldsymbol{u}_z$$

$$\boldsymbol{u}_y = \frac{\boldsymbol{v} \times \boldsymbol{r}}{|\boldsymbol{v} \times \boldsymbol{r}|}$$

$$\boldsymbol{u}_z = \frac{-\boldsymbol{r}}{|\boldsymbol{r}|}$$

where $\boldsymbol{r}$ and $\boldsymbol{v}$ are position and velocity of TG-2 that are expressed in the $O_tX_tY_tZ_t$, thus the transformation is given by:

$$\begin{bmatrix} X_t \\ Y_t \\ Z_t \end{bmatrix} = \begin{bmatrix} \boldsymbol{u}_x & \boldsymbol{u}_y & \boldsymbol{u}_z \end{bmatrix} \begin{bmatrix} X_o \\ Y_o \\ Z_o \end{bmatrix}$$

Appendix 5: LRA-fixed system

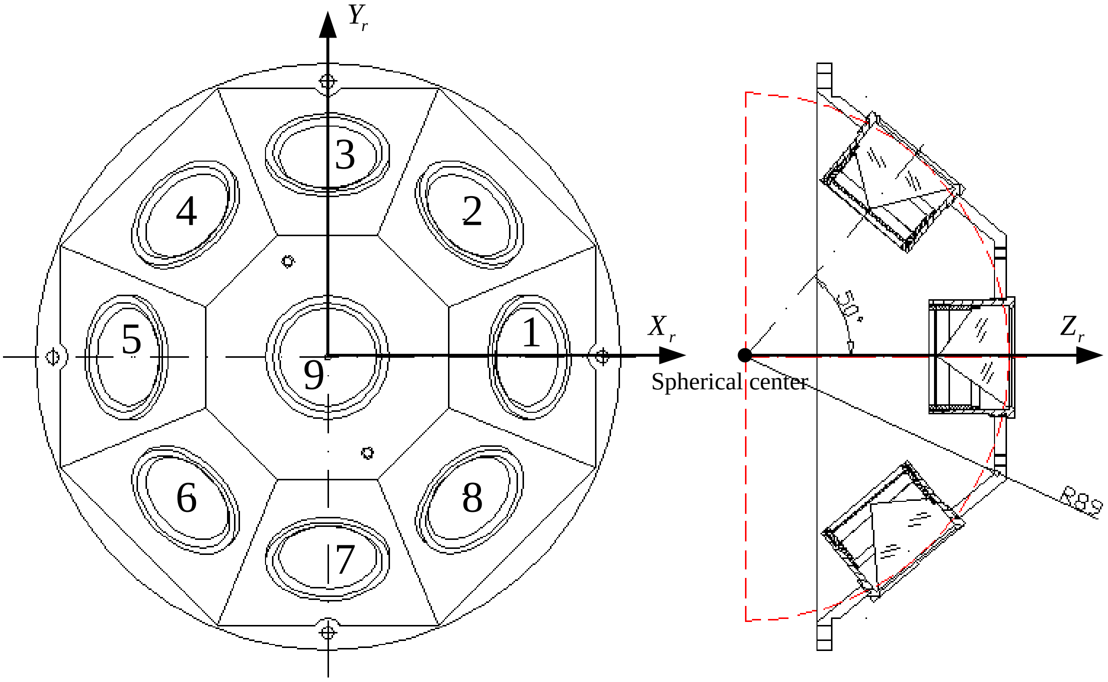

Fig.4 The structural profile of LRA for TG-2

The origin is the spherical center point of LRA.

X_r-axis: parallel to X_b

Z_r-axis: parallel to Z_b

Y_r-axis: completing the right-handed orthogonal system

Appendix 6: the position of each corner cube

The spherical center point (reference point) of LRA is (215.9, -4.5, 1611.3) mm--in the satellite-body-fixed $X_bY_bZ_b$ coordinates.

The range correction of LRA from spherical center is 47.3 mm.

The LRA reference point is spherical center point of LRA. The position of the center of the front face of each corner cube is as following --in the LRA-fixed $X_rY_rZ_r$ coordinates (Fig.4):

No.1 (68.18, 0, 57.21) mm, No.2 (48.21, 48.21, 57.21) mm, No.3 (0, 68.18, 57.21) mm,

No.4 (-48.21, 48.21, 57.21) mm, No.5 (-68.18, 0, 57.21) mm, No.6 (-48.21, -48.21, 57.21) mm,

No.7 (0, -68.18, 57.21) mm, No.8 (48.21, -48.21, 57.21) mm, No.9 (0, 0, 89) mm

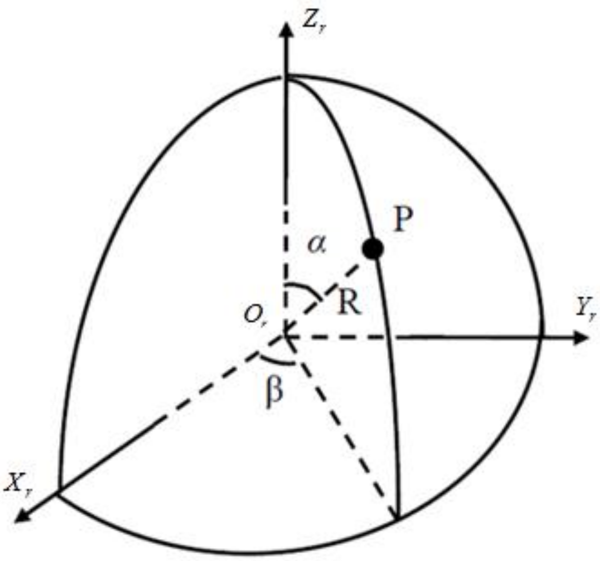

Fig.5 The definition of the orientation (α, β) of each cube **P** with spherical coordinates

The definition of the orientation (α, β) of each cube with spherical coordinates as following (Fig.5):

No.1 (50°, 0°), No.2 (50°, 45°), No.3 (50°, 90°),

No.4 (50°, 135°), No.5 (50°, 180°), No.6 (50°, 225°),

No.7 (50°, 270°), No.8 (50°, 315°), No.9 (0°, 0°)

Appendix 7: CCR in the house

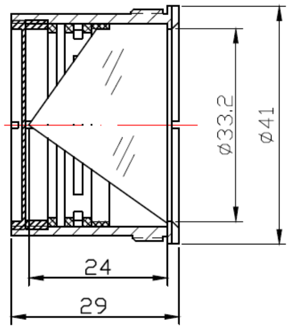

Fig.6 CCR in the house

Appendix 8: Refractive index and dispersion

Refractive Index and Dispersion:

Conditions: 22 °C, 760 mm Hg, N_2

Wavelength [Vacuum] [nm]	Refractive Index[2] n	Thermal Coefficient $\Delta n/\Delta T$[3] [ppm/C]	Polynomial Dispersion Equation Constants[1], 22 °C	
1128.950	1.448866	9.6	A_0	2.104025406E+00
1014.260 n_t	1.450241	9.6	A_1	-1.456000330E-04
852.344 n_s	1.452463	9.7	A_2	-9.049135390E-03
706.714 n_r	1.455144	9.9	A_3	8.801830992E-03
656.454 n_C	1.456364	9.9	A_4	8.435237228E-05
632.990	1.457016	10.0	A_5	1.681656789E-06
587.725 n_d	1.458461	10.1	A_6	-1.675425449E-08
546.227 n_e	1.460076	10.2	A_7	8.326602461E-10
486.269 n_F	1.463123	10.4		
435.957 n_g	1.466691	10.6	Sellmeier Dispersion Equation Constants[2], 22 °C	
404.770 n_h	1.469615	10.8	A_1	0.68374049400
365.119 n_i	1.474539	11.2	A_2	0.42032361300
334.244	1.479764	11.6	A_3	0.58502748000
312.657	1.484493	12.0		
253.728	1.505522	13.9	B_1	0.00460352869
228.872	1.521154	15.5	B_2	0.01339688560
214.506	1.533722	17.0	B_3	64.49327320000
206.266	1.542665	18.1		
194.227	1.558918	20.3	$\Delta n/\Delta T$ Dispersion Equation Constants[3], 20-25 °C	
184.950	1.575017	22.7	C_0	9.390590
			C_1	0.235290
			C_2	-1.318560E-03
			C_3	3.028870E-04
			Other Optical Properties	
			nF'-nC'	0.006797
			Stress Coefficient	35.0 nm/cm MPa
			Abbe Constants:	
			V_e	67.6
			V_d	67.8

*1 Polynomial Equation: $n^2 = A_0 + A_1\lambda^4 + A_2\lambda^2 + A_3\lambda^{-2} + A_4\lambda^{-4} + A_5\lambda^{-6} + A_6\lambda^{-8} + A_7\lambda^{-10}$ with λ in μm

*2 Sellmeier Equation: $n^2-1 = A_1\lambda^2/(\lambda^2 - B_1) + A_2\lambda^2/(\lambda^2 - B_2) + A_3\lambda^2/(\lambda^2 - B_3)$ with λ in μm

*3 Δn/ΔT Equation: $\Delta n/\Delta T\ [ppm/C] = C_0 + C_1\lambda^{-2} + C_2\lambda^{-4} + C_3\lambda^{-6}$ with λ in μm

The above dispersion equations for SiO_2 were fit to the refractive indices of 20 wavelengths from 1129 nm to 185 nm.

Appendix 9: Other comments on LRA----Requirements of SLR data post-preprocessing

For implementing laser rendezvous radar of TG-2 spacecraft, there is one set of laser radar retro-reflector array (LRRA) on TG-2 for space rendezvous and docking. Fig.7 shows the picture of laser radar retro-reflector array. Fig.8 shows the schematic diagram of the relative position of LRA and LRRA on TG-2 spacecraft with the distance of about 6 meters.

Fig.7 Laser radar retro-reflector array (LRRA) for TG-2 spacecraft

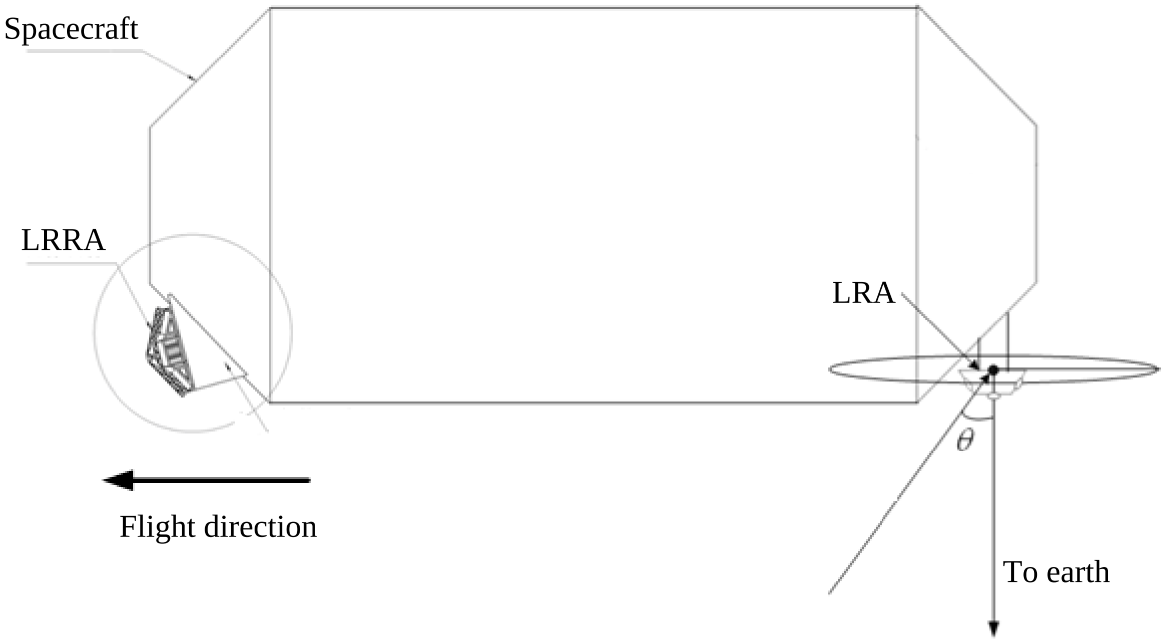

Fig.8 The relative installed position of LRA and LRRA on TG-2 spacecraft

Despite of the normal of LRRA pointing to flight direction, it will also reflect the laser signal from the ground. According to analysis results, the ground station will receive returns from LRRA and LRA at the same time within the about 2/3 of one flight pass. The characteristics of laser signals from LRRA and LRA are following: 1) the intensity of laser signal from LRAA is higher than that of LRA and the precision of laser data from LRRA is worse than that of LRA because of its large array size. 2) The laser signal from LRRA will be disappeared when descending pass arc and ones from LRA will exist in the total pass arc. Fig.9 shows the characteristics of laser return signal from LRRA and LRA when data post-preprocessing.

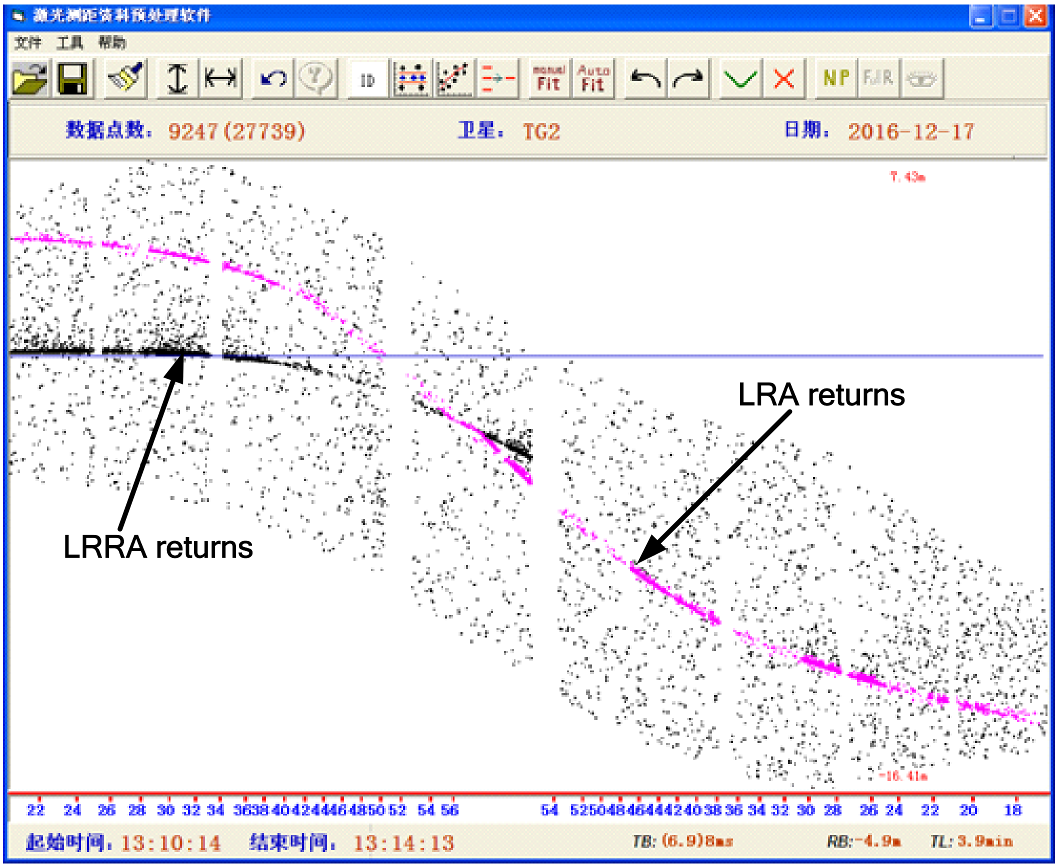

Fig.10 SLR residual plots of TG-2

For implementing the orbit determination of TG-2, the laser signal from LRA should be retained to produce CRD files and the ones from the LRRA should be removed. For distinguishing the laser return signal from LRRA and LRA, the SLR stations should track the total pass of TG-2 with the best efforts.