Space Debris Laser Ranging at Yunnan Observatories

Li Yuqiang，Li Zhulian，Li Rongwang，Fu Honglin，Zhai Dongsheng，Xiong Yaoheng

Yunnan Observatories, Chinese Academy of Sciences, Kunming, 650216，*China*

Abstract: In recent years, with the continuous increase of space activities, space debris is also becoming more and more. Spacecraft in orbit are being threatened by space debris, so many countries have developed detection techniques for space debris, and the diffuse reflection laser ranging of space debris is a new technology. The research progresses of space debris laser ranging at several stations in the world are introduced. The first diffuse reflection laser ranging echo of space debris was received successfully in June 2010 at Yunnan observatories. The structure of the systems and the key techniques for space debris laser ranging at Yunnan Observatories are described. At the beginning of 2011, the experiment of space debris laser ranging is carried out again. The precision of space debris laser ranging is given in this paper. At last, the applications of space debris laser ranging are discussed, such as space debris orbit improvement and preliminary scale determination of space debris.

Key words：Measurements; Space Debris; Satellites Laser Ranging; Diffuse Reflection

1. Introduction

The first satellite, Sputnik 1, was launched in 1957. Currently, the United States Space Surveillance Network (SSN) catalogs, tracks, and maintains orbits on over 16300 objects larger than about 10 cm in diameter. Unfortunately, active spacecraft are only a small percentage of this population. The rest of the tracked population is space debris or ''space junk'' consisting of expended rocket bodies, dead payloads, bits and pieces from satellite launches, and fragments from satellite breakups (Johnson et al., 2001). The image below (NASA image) shows the space debris distribution at LEO around the Earth.
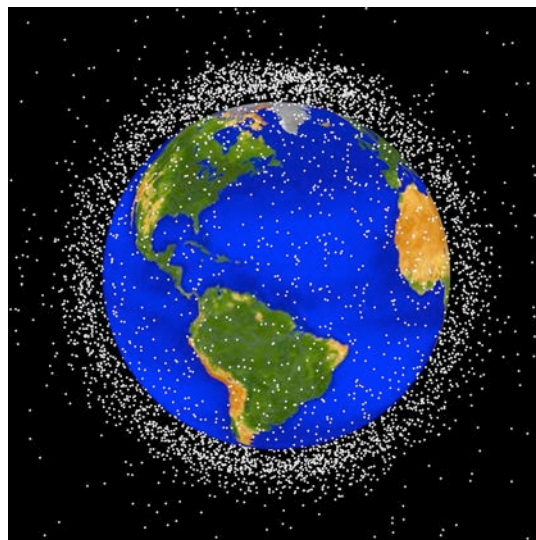
**Figure 1:** Image of space debris distribution around the Earth at LEO

Space debris generated by more than 50 years of space activities pose a risk for operational spacecraft, which can collide in a catastrophic manner with either another large object (e.g., an upper stage rocket body) or with a smaller fragment generated by a previous collision or by a previous explosion of a large object (Andrew et al., 2009).

Measurements of near-Earth space debris are accomplished by conducting ground-based and

space-based observations of the space debris environment. Optical telescopes and radar are tools used to obtain a more complete picture of the Space debris environment.

Satellite Laser Ranging (SLR) measures the time intervals required for pulses emitted by a laser transmitter to travel to a satellite and return to the transmitting site. The "range", or distance between the satellite and the observing site, is approximately equal to one half of the two-way travel time multiplied by the speed of light. In routine SLR, satellites are equipped with specially designed reflectors to return the incoming laser pulse back to the transmitting site. But space debris has no reflectors, so the echo photons are few or none. As an important space country, we should develop some new techniques to detect space debris, and improve the capability of apprehension of the collision of space debris.

Laser tracking is inherently accurate, and laser link equations allow scaling of laser tracking systems to track small space debris. The Stromlo SLR system was upgraded for debris tracking during 2001/2002. Results were obtained for space debris objects down to 10 cm in size (Ben Greene, 2002). The result shown in Figure 2 appears very similar to normal SLR residual plots, except the residual scale here is much larger. This difference is very significant, since it conveys a sense of the poor quality of a priori orbital elements available for debris objects.
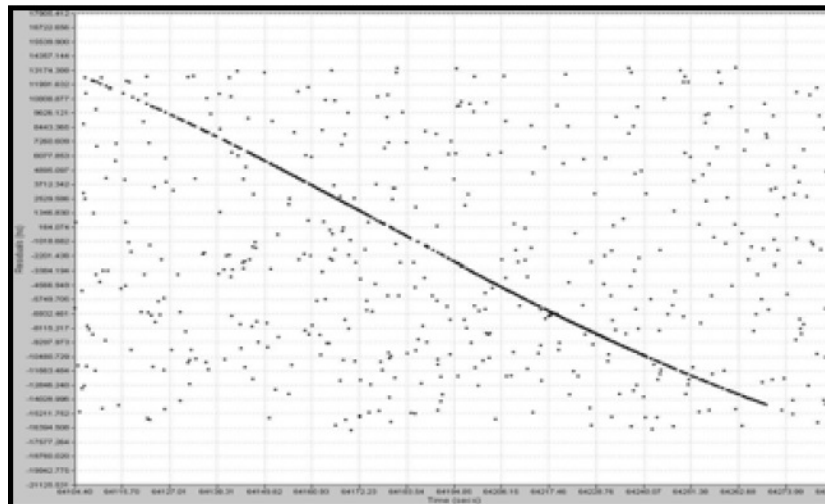
Figure 2: Laser track of 15 cm object at 1,250 km. [X = elapsed time. Y= range residual]

The laser returns from the un-cooperative targets have been obtained at the Shanghai SLR station in July 2008. These targets are the discarded Soviet and US rockets with the ID 1987-38B and 2007-006G, respectively. It is shown from the experiment that the return signals from the targets with the range of 900 km were quite strong. Further experiment for more distant and smaller targets is under way (Yang, et al., 2008).

In June 2010, some space debris have been obtained at Yunnan Observatory, this paper will introduce the results of the experiment for space debris diffuse reflection laser ranging and its application.

2. Space Debris Laser Ranging System
2.1 The high power laser

Because the space debris are un-cooperative targets, there are only a few photons returned from the targets, which maybe received tens of thousands of laser photons. In order to get more

photons returned successfully, a high power laser is used for the experiment of the space debris diffuse reflection laser ranging. The below image is the outer view of the laser, and the parameters of the laser are as follows:


Figure 3: Outer view of Nd: YAG laser

Wavelength： 532nm
Pulse energy：4.5J
Repetition： 10Hz
Pulse width：~10ns
Divergence：<0.5mrad
Beam diameter：20mm

2.2 The control system

After the installation of the new laser, we built the control and ranging interfaces and software for the experiment. The control system for the diffuse reflection space debris laser ranging is shown as Figure 4. The receive/transmit rotating mirror generates a synchrony signal to the control computer, then the computer will give a fire command to the laser, which will generate a laser beam to start a measurement. The PIN detector detects the transmitting laser signal and sends to the control computer the SR620 time interval. After they received the transmitting laser signal, the SR620 begins to count simultaneously and the computer computes the C-SPAD gating time and gives it to C-SPAD detector immediately. When the C-SPAD detects the echo signal, the SR620 stops count simultaneously, and a round-trip measurement is over.
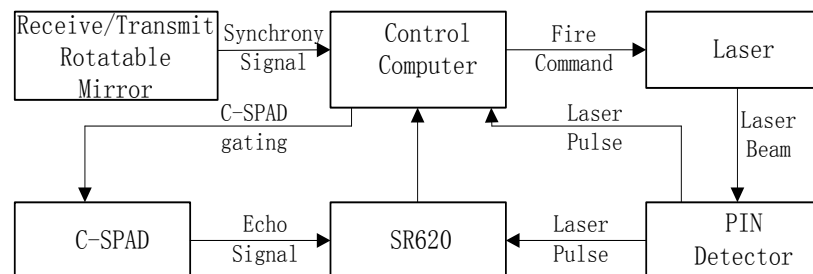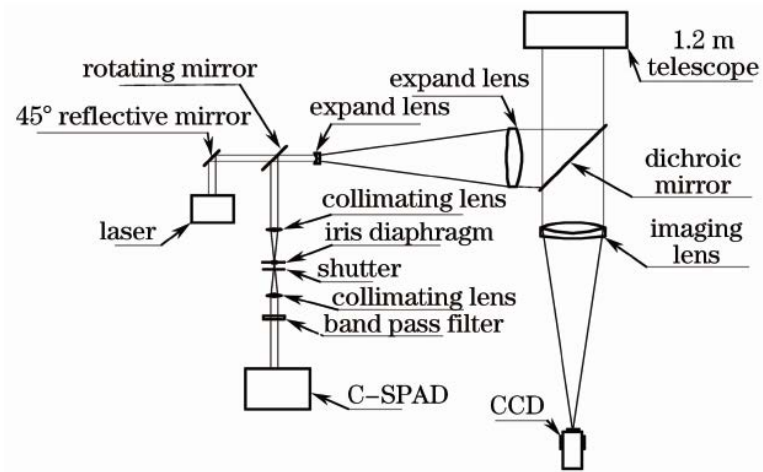

Figure 4: Control system of diffuse reflection of space debris laser ranging

2.3 The optical path

Fig.5 shows the optical path of our laser ranging system. A 1.2m telescope is used as both the

transmit and the receive instrument. Both the primary mirror and the second mirror are parabolic. The telescope has a 1.1m effective aperture, its pointing accuracy is ±1-2″(R.M.S), field of view is 3′ and the tracking accuracy is 3″.


Figure 5: Light system of diffuse reflection laser ranging

3. Results of the experiment of Space Debris Laser Ranging

The laser returns from space debris have been obtained at Yunnan Observatory in June 2010, and we did a second experiment from January to February 2011. These targets are the discarded rockets bodies. The residuals (O-C) of two targets, which are space debris 23769 and 25400, are shown in Figure 6 and 7. The well-regulated plots, which can be in line are the echo signal, and the ruleless plots are the observation noise (Li, 2011).
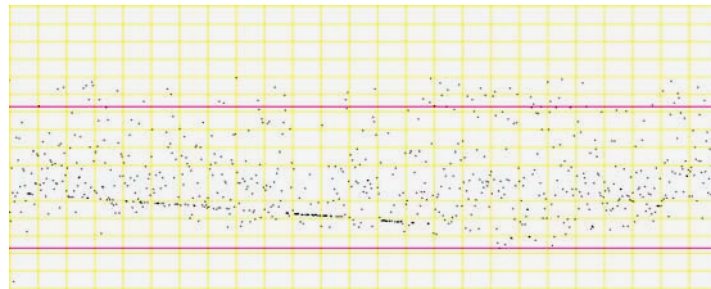
Figure 6: Echo of diffuse reflection Laser ranging of space debris 23769
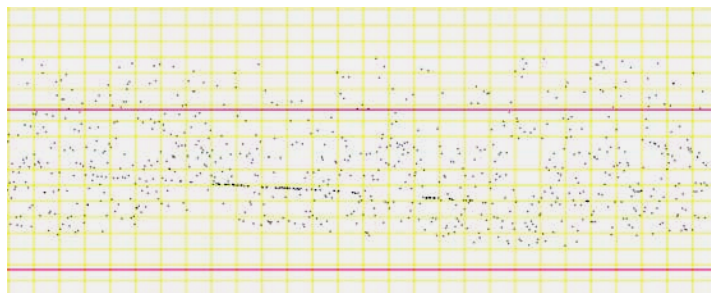
Figure 7: Echo of diffuse reflection Laser ranging of space debris 25400

Table 1 shows the results of the space debris diffuse reflection laser ranging from January to

February 2011. The information about the space debris, that we chose for the experiment, are shown on Table 1, such as their size and range, and table 1 also gives the echo number and ranging precision. The first list means SSN catalogue number of space debris; the echo number means effective data; the precision of the range data is through a screen processing firstly, then using a 3σ rule to do data filtering.

Table 1: the results of space debris diffuse reflection Laser Ranging

| Objects	Date	Time interval	Perigee /km	Apogee /km	Size /m	Range /km	Echo	Precision /cm
17590	0124	21:42:52-21:47:03	832.1	842.3	10.4×3.9	965~1625	42	199.3
10517	0124	22:03:05-22:05:33	477.4	1784.0	6.4×2.0	841~1489	73	79.3
17590	0125	21:28:40-21:31:08	832.1	842.3	10.4×3.9	1146~1824	75	245.3
27387	0125	22:29:46-22:32:10	750.9	796.4	10.0×2.5	1086~1256	32	198.0
25400	0126	12:39:44-12:43:32	801.3	814.9	10.4×3.9	1171~1616	76	243.1
18403	0127	12:46:15-12:49:18	934.9	1020.0	6.0×2.4	1162~1741	31	91.2
24809	0130	12:03:39-12:09:48	654.8	1652.0	5.9×2.4	1240~1960	36	118.9
10793	0130	12:16:18-12:20:20	568.1	1926.0	6.0×1.4	977~1858	39	122.5
23769	0130	12:36:03-12:40:02	358.3	850.8	5.9×2.4	827~1187	104	126.8
23769	0205	11:59:19-12:01:26	358.3	850.8	5.9×2.4	860~1233	60	53.5
18586	0206	12:24:08-12:29:41	757.0	787.0	6.0×2.4	867~1567	64	73.3
20509	0208	11:42:21-11:44:46	948.2	1013.0	6.0×2.4	1001~1520	57	89.5
18313	0208	12:48:12-12:53:02	942.0	956.0	2.6×2.2	1048~1473	39	60.9
29713	0208	12:56:20-12:59:43	610.2	651.4	4.0×2.0	787~1533	56	114.0

4. Applications

a) preliminary determination of the size of the space debris

In the experiment of space debris laser ranging, all space debris are rocket bodies that are cylindrical, so the size means length and diameter. Figure 8 shows the statistics of the relationship between the precision and length of the rocket bodies, and Figure 9 shows the statistics of the relationship between the precision and the area, which is the length multiplied by the diameter of the rocket bodies. It is inferred from the data of table 1 that the magnitude of the error can respond to the space debris size. The errors of range are bigger, the size of the space debris are bigger. In this way, we maybe can make a preliminary determination of some unknown space debris size, however, the distance of the space debris would be another factor in the range error. Further experiment for more distant and smaller targets is under way. By then, we can use more observations to resolve this problem.
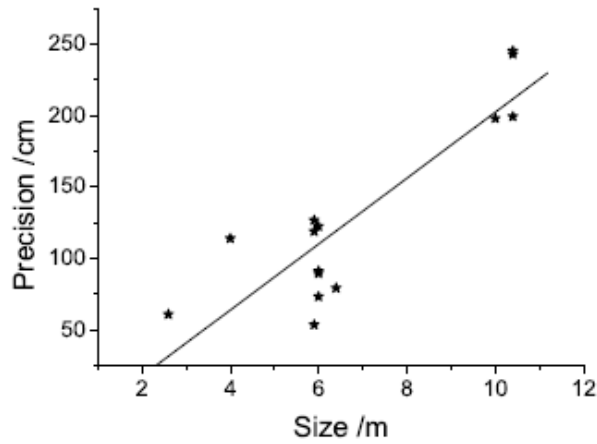
Figure 8: the relations between precision and size of space debris
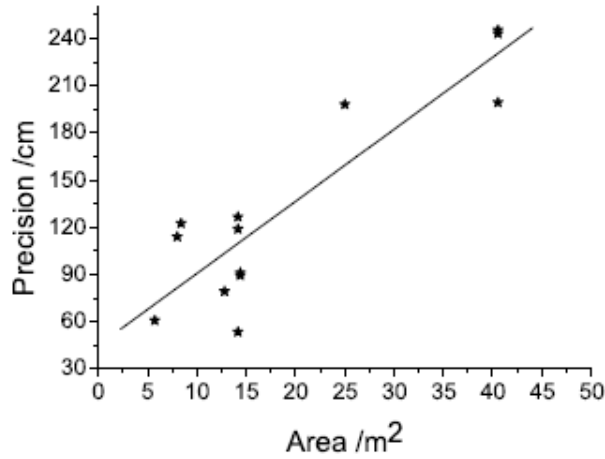
Figure 9: the relations between precision and area of space debris

4.2 orbit improvement

A purported benefit of the laser technique is the rapid determination of accurate orbits and elements. It is known that it is impossible to do precision orbit determination only using rigid single SLR data within a single pass. Though the Earth is rotating, the entity station should be regarded as a rigid station when the observation period is short (Liu, 2000). Fortunately, in the process of space debris laser ranging, besides recording the time of transit of the laser beam between the station and the space debris, it can also record the telescope's direction at the laser fire epoch, which is the angle data.

In data processing，an accurate object orbit is determined with global SLR data, which is considered as the "true" orbit. After that, the use of the "true" orbit, according to a single station SLR data time series, simulates Azimuth/Elevation of the object with Gaussian noises of 3″. Just use the simulated data to determine the orbit, labeled as AE. Synthesize these two data to determine the orbit, labeled as AE-LR. The orbit elements of Ajisai at epoch (January 22, 2009, 0h UTC) are as follows (Li R.W.,2010):

Semi-major axis	a: 7871412.436 m
Eccentricity	e: 0.0016666

Inclination			i: 49.9751 deg		
Argument of perigee			ω: 173.6875 deg		
Right ascension of the ascending node			Ω: 248.3578 deg		
Mean anomaly			M: 11.0983 deg		

Synthesizing these two types of data, range and angle direction, precision orbit determination is possible. The solution is stable and credible. And the precision of the determined orbit much exceeds the orbit determined by using Azimuth/Elevation. It takes full advantage of the high precision SLR data, and breaks the limit of impossibility to do precision orbit determination only using single SLR data within a single pass. Table 2 gives the results of orbit determination.

Table 2 results of orbit determination with simulation data

	AE	AE-LR		AE	AE-LR
δR (m)	-52.83	2.19	δa (m)	-98.21	4.55
δT (m)	-5226.03	260.11	δe (10^{-6})	-6.88	0.33
δN (m)	15.37	-2.58	δi (as)	-0.32	-0.08
$\delta \overset{g}{R}$ (m/s)	4.653	-0.235	$\delta \omega$ (as)	1247.27	-10.21
$\delta \overset{g}{T}$ (m/s)	0.008	0.000	$\delta \Omega$ (as)	0.49	-0.10
$\delta \overset{g}{N}$ (m/s)	0.010	0.003	δM (as)	-1379.7	17.02

5. Summary

Space debris is a major problem for all space-faring nations. Reliable and accurate measurements of space debris are a fundamental requirement for any effort towards debris collision avoidance. Space debris diffuse reflection laser ranging has been developed at Yunnan Observatory. The precision of range is about 50~250 cm. It is inferred that the error of space debris diffuse reflection laser ranging can preliminarily determined some unknown space debris size. Meanwhile, the observation of space debris laser ranging can be used for orbit improvement, and the precision of the determined orbit much exceeds the orbit determined by using Azimuth/Elevation.

Further experiment for more distant and smaller targets is under way.

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