Research in Astron. Astrophys. **2012** Vol. **12** No. **2**, 212–218
http://www.raa-journal.org *http://www.iop.org/journals/raa*

***R**esearch in*
***A**stronomy and*
***A**strophysics*

The use of laser ranging to measure space debris

Zhong-Ping Zhang[1,2], Fu-Min Yang[1], Hai-Feng Zhang[1], Zhi-Bo Wu[1,2], Ju-Ping Chen[1,2], Pu Li[1] and Wen-Dong Meng[1]

[1] Shanghai Astronomical Observatory, Chinese Academy of Sciences, Shanghai 200030, China; *zzp@shao.ac.cn*
[2] Key Laboratory of Space Object and Debris Observation, Chinese Academy of Science, Nanjing 210008, China

Received 2011 May 19; accepted 2011 August 24

Abstract Space debris is a major problem for all the nations that are currently active in space. Adopting high-precision measuring techniques will help produce a reliable and accurate catalog for space debris and collision avoidance. Laser ranging is a kind of real-time measuring technology with high precision for space debris observation. The first space-debris laser-ranging experiment in China was performed at the Shanghai Observatory in July 2008 with a ranging precision of about 60–80 cm. The experimental results showed that the return signals from the targets with a range of 900 km were quite strong, with a power of 40W (2J at 20 Hz) using a 10ns pulse width laser at 532 nm wavelength. The performance of the preliminary laser ranging system and the observed results in 2008 and 2010 are also introduced.

Key words: astrometry — catalogs — space debris — laser ranging — observation

1 INTRODUCTION

China has launched many spacecraft and has produced some space debris since the 1970s. It is also one of the members of the IADC (Inter-Agency Space Debris Coordination Committee). It is therefore necessary for China to pay great attention to efforts to reduce possible damage from space debris in cooperation with the international community, and to develop types of high precision measuring techniques for the reliable and accurate cataloging of the space debris. Laser ranging is a kind of real-time measuring technology with high precision for space-debris observation. In October 2002, Ben Greene presented a report named “Laser Tracking of Space Debris” at the 13th International Laser Ranging Workshop, and announced that it was possible to track space debris with a size of 15 cm at a distance of 1250 km by using the aperture of a 76 cm telescope and a high-power laser (Greene et al. 2002).

In recent years only a few countries have conducted research on space-debris laser-ranging technology. The laser ranging to space debris project at the Shanghai Astronomical Observatory in China is supported by the Chinese Space Agency. A preliminary experimental laser ranging system for space debris at the Shanghai Satellite Laser Ranging (SLR) station with the aperture of a 60 cm telescope was set up in 2006. The major goal of the system was to develop key techniques for laser ranging to space debris. After testing and upgrading, we obtained some of the laser returns from a discarded Soviet rocket (catalog number 17912) and a US rocket (catalog number 30778) in July

2008 with a range of more than 900 km and the power of a 40W laser made by a domestic institute. After that, in 2010, the experimental system was improved and several passes of laser ranging to space debris were obtained at a precision of 50–70 cm. The maximized range of the targets is up to 1200 km with a 10W laser imported from the US.

The preliminary experimental system, the measuring results and the data analysis are given in this paper.

2 THE PERFORMANCE OF THE LASER-RANGING SYSTEM

The experiment was carried out at the SLR station of the Shanghai Astronomical Observatory, Chinese Academy of Sciences.

Figure 1 shows the structure of the space-debris laser-ranging system, including orbit prediction, control system, high power laser, laser-beam transmitting system, telescope mount tracking system, high-precision timing system, return detection and receiving system.

Figure 2 shows the observation house, the tracking telescope and electronics room. The satellites equipped with retro-reflectors are routinely measured at the station. The apertures of the receiving telescope and transmitter are 60 and 21 cm, respectively. The mount is of Alt-Azimuth type, and is directly driven by motors. The pointing accuracy of the telescope after star calibration is about $5''$.

One of the key instruments for the experiment, a high-power Nd: YAG laser, was built by the North China Research Institute of Electro-Optics (NCRIEO) in Beijing. The parameters of the laser are as follows: 2J per pulse, 10 ns pulse width, 0.6 mrad divergence, 20 Hz repetition rate and 40W mean power at 532 nm wavelength.

Figure 3 shows the block diagram of the 40W Nd: YAG laser, and Figure 4 shows the photograph, inner view and laser beam through the transmitter to the sky.

There are 10 Nd: YAG rods in total in the laser system. The output from the oscillator with two laser rods inside is divided into two beams, and then goes to amplifier units 1 and 2, respectively. The outputs from the two sets of amplifier units pass the frequency doublers, and then combine into one beam for ranging.

The detector and time interval instruments adopted are the same as in the routine SLR operation. Due to space debris of irregular shape and laser pulse-width, the measurement of space debris is lower than the routine SLR. The single-photon avalanche diode detector with single-photon sensitivity and 30 ps timing precision was provided by the Czech Technical University. The event timer (Model A032-ET) for time interval measurement with 10 ps timing precision was made by Riga University, Latvia (Artyukh 2001; Artyukh et al. 2008).

3 RETURN ANALYSIS DETECTED BY THE LASER-RADAR EQUATION

The returned signal strength expected from a 2 m diameter target located 800 km away can be roughly estimated by the following equation (Degnan 1993)

$$n_0 = \frac{\lambda \eta_{\mathrm{q}}}{hc} \times \frac{E_t A_{\mathrm{r}} \rho S \cos\theta}{\pi {\theta_{\mathrm{t}}}^2 R^4} \times T^2 \times K_{\mathrm{t}} \times K_{\mathrm{r}} \times \alpha, \tag{1}$$

where n_0 is the average number of photoelectrons received by the detector; λ is the wavelength of the laser, 532 nm; η_{q} is the quantum efficiency of the detector, 0.2; h is the Planck constant, $6.6260693 \times 10^{-34}\,\mathrm{J \cdot s}$; c is the light speed, 299792458 m s^{-1}; E_t is the energy of the laser pulse, 2J; A_{r} is the effective area of the receiving telescope, 0.251m^2; ρ is the reflectivity of the target surface, 0.16; and S is the effective reflective area of the target. The equivalent radius is 1 m, $S = \pi r^2$; $\cos\theta$, suppose the targets are spherical, $\cos\theta = 1$; θ_{t} is the divergence of the laser beam from the telescope, 12 arcsec; R is the range of the targets, 800 km; T is the atmospheric transmission, $T = 0.6$ at an elevation of 30°; K_{t} is the efficiency of transmitting optics, 0.6; K_{r} is the efficiency of receiving optics, 0.6; α is the attenuation factor mainly caused by atmospheric effects, 13 dB.

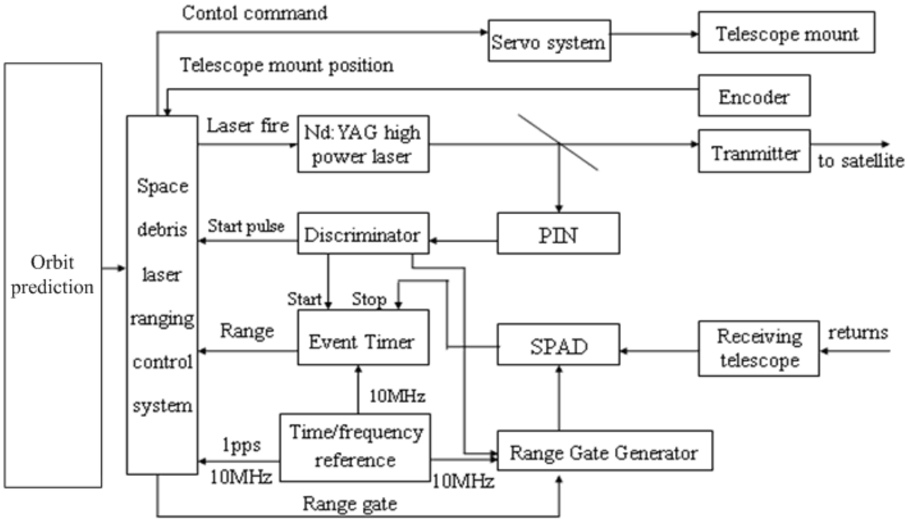


Fig. 1 Structure of the space-debris laser-ranging system.

Fig. 2 Shanghai SLR station, telescope and electronics control room.

We found

$$n_0 = 0.13\,(\text{photoelectrons})\,.$$

The probability of detection by the C-SPAD detector with a single-photon sensitivity can be estimated by

$$P = 1 - \mathrm{e}^{-n_0} = 1 - \mathrm{e}^{-0.13} = 0.12\,. \qquad (2)$$

So, theoretically, we might get 12 returns in the observation time interval, each of 5 s with the 20 Hz laser.

4 OBSERVATIONAL RESULTS FROM THE SPACE DEBRIS AT THE SHANGHAI OBSERVATORY

After the installation of the 40W power laser, we built the control and ranging interfaces and software for the experiment. In July 2008, we firstly obtained some laser returns from the space debris which were discarded Soviet and US rockets with catalog numbers 17912 (639×611 km) and 30778 (541×499 km), respectively. The range residuals ($O - C$) via the elapsed time for three passes are shown in Figure 5, and the ranging precision is from 60 to 80 cm. In Figure 5, the horizontal axis is the elapsed time from the beginning of tracking and the vertical axis is the range residuals $O - C$

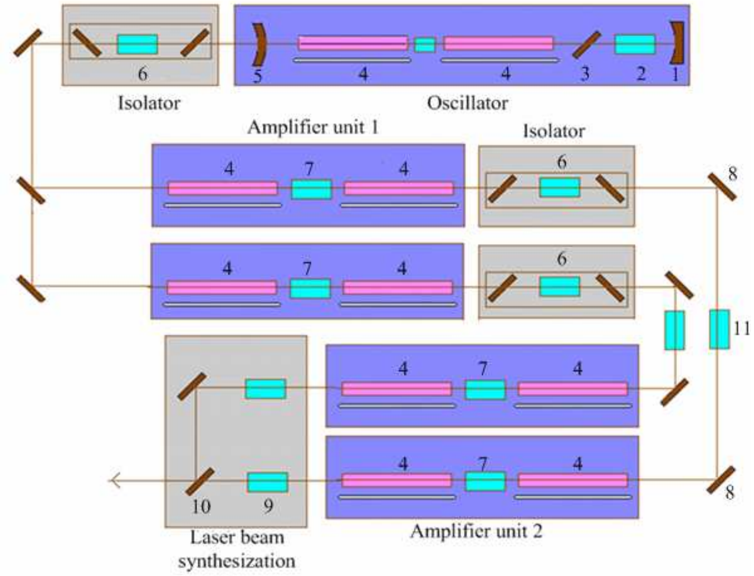


Fig. 3 Diagram of the 40W Nd:YAG laser (2J in 532 nm, 20 Hz). 1: HR mirror; 2: E-Q Switch; 3: Polarizer; 4: YAG rod; 5: Output mirror; 6: Isolator; 7: Compensator; 8: Reflection mirror; 9: Frequency doubler; 10: Optical coupler; 11: Image lens.

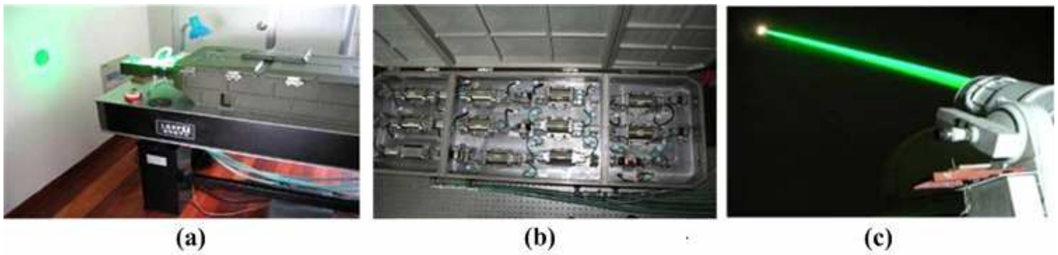

(a) (b) (c)

Fig. 4 A photograph of the inner view and laser beam of the 40W laser. (a) Photo of the 40W laser; (b) Inner view of the 40W laser; (c) Laser firing to the sky.

between the observed and predicted values. The central points in the line are the laser returns, and the other points are noise from the detector and the background.

Figure 6 shows the range variations for each pass; the horizontal axis is the seconds of the day and the vertical axis is the range of the space debris. The maximum range obtained in the measurement was 936 km.

Figure 7 shows the laser-return statistics in 5 s bins from ID 17912 on 2008 July 7. The horizontal axis is time binning in 5 s and the vertical axis is the number of returns obtained. The laser return rate is about 7%. It is shown that about 10 to 14 returns in several 5 s intervals were obtained when the telescope’s tracking was good, and this roughly coincides with the theoretical estimation of returned signal strength.

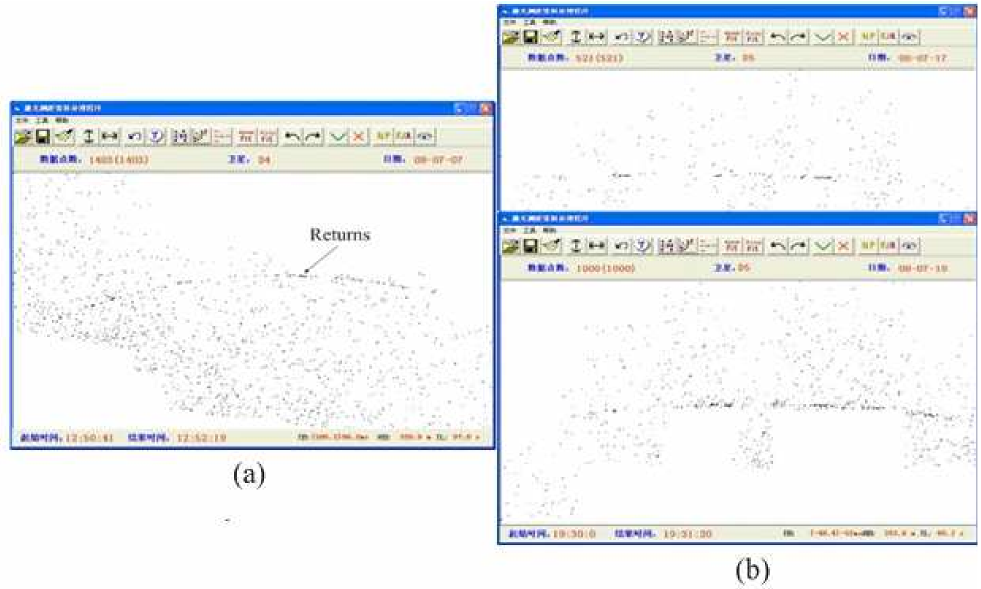


Fig. 5 Laser returns from the space debris. (a) The discarded Soviet rocket (ID: 17912) on July, 2008; (b) the discarded US rocket (ID: 30778) on July 17/18, 2008.

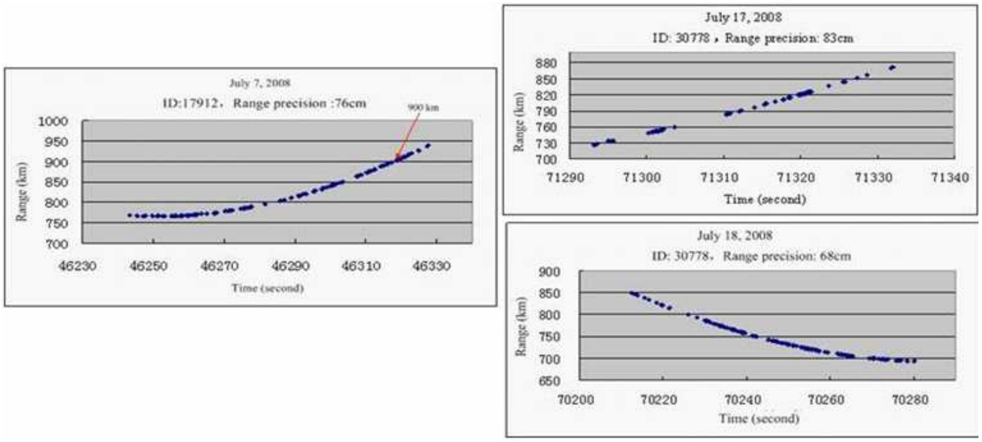


Fig. 6 Obtained ranging data of the space debris.

In 2010 the Shanghai SLR station updated the experimental system for space-debris laser ranging, including adopting a better, more stable high-power laser (1J at 10 Hz, output 10W at 532 nm wavelength). This improved the servo-tracking system, enabled automatic adjustment of the multi-step range gate and applied two line elements to predict the orbit with an accuracy of less than 1 km. The capacity of the experimental system of laser ranging to space debris was therefore obviously improved. Figure 8 shows the servo-tracking performance of the telescope mount, and the tracking precision is less than 1″.

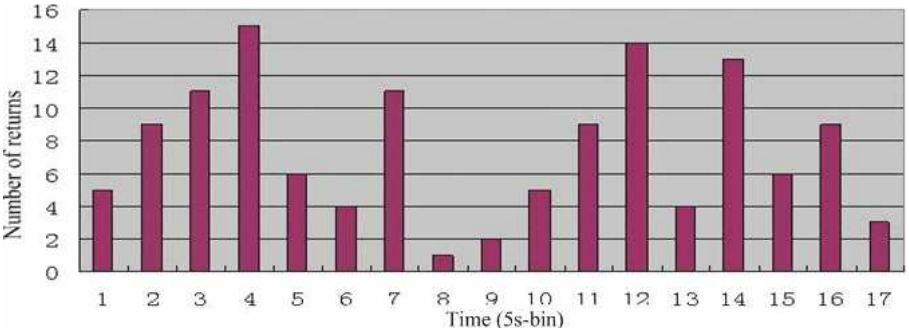


Fig. 7 Laser-return statistics (5 s time-interval bin) on 2008 July 7.

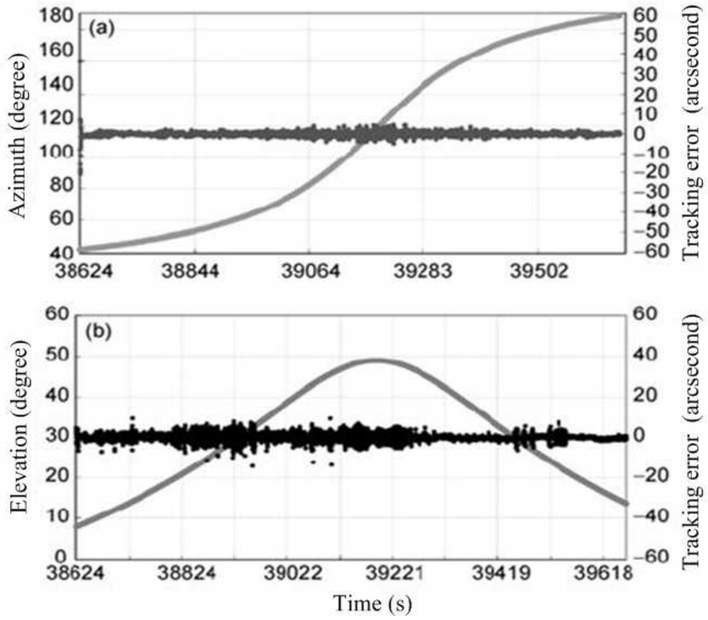
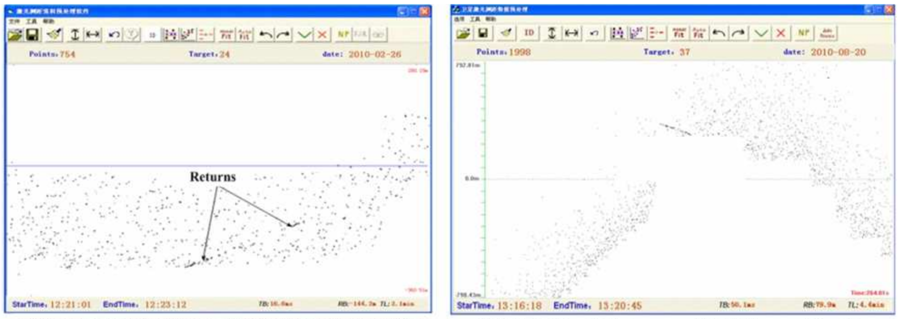


Fig. 8 Tracking performance of the telescope mount.

Figure 9 shows some of the measuring results obtained by the 10W laser. The range measured is from 800 to 1200 km, and the ranging precision is from 50 to 80 cm. Most returns are up to more than 150 points within 66 s, and the return rate is about 23%. It can be seen that the ability of the ranging system by using the 10W laser is improved compared to the one using the 40W laser.

The above measuring results show that the experimental system for space-debris laser ranging, established by the Shanghai Astronomical Observatory, realized its preliminary goal and had the ability to track large-scale, low-orbit space debris by laser technology. Although some improved methods were adopted, laser ranging of space debris is still difficult, mainly because of the power of the laser, the accuracy of predicting the orbit, the uncertainty of the reflective characteristics on the surface and the size of the space debris. So more advanced methods should be developed to further the research into this kind of technology.



Points: 754 Target: 24 date: 2010-02-26

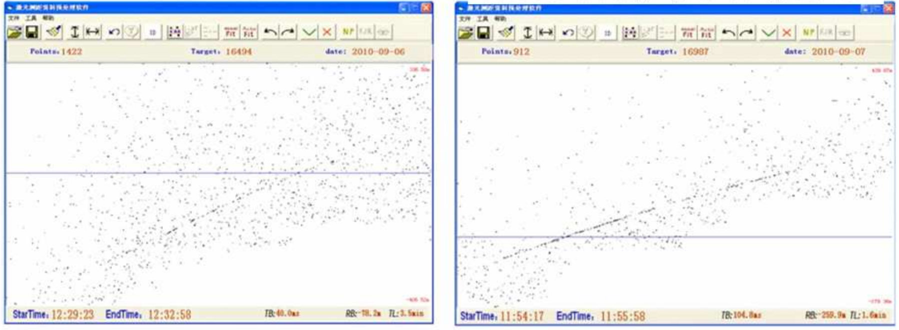
StarTime: 12:21:01 EndTime: 12:23:12 TB:16.0ns RB:-144.2m TL:2.1min

Points: 1998 Target: 37 date: 2010-08-20

StarTime: 13:16:18 EndTime: 13:20:45 TB:50.1ns RB:79.9m TL:4.4min

2010-03-26 Iridium satellite, range: 750-800km, precision: 60cm

2010-08-20 US rocket body, range: 950-1010km, precision: 65cm



Points: 1422 Target: 16494 date: 2010-09-06

StarTime: 12:29:23 EndTime: 12:32:58 TB:40.0ns RB:-18.2m TL:3.5min

Points: 912 Target: 16987 date: 2010-09-07

StarTime: 11:54:17 EndTime: 11:55:58 TB:104.8ns RB:-259.9m TL:1.6min

2010-09-06 Russia rocket body, range: 1100-1200km, precision: 80cm

2010-09-07 Russia rocket body, range: 840-1100km, precision: 58cm

Fig. 9 Some of the measuring results from the 10W laser in 2010.

5 CONCLUSIONS

The laser ranging to space debris experiment was successfully performed at the Shanghai Observatory in China in July 2008, and several passes of the laser ranging of space debris were obtained. It is shown from the experiment that the return signals from the targets with a range of 900 km were quite strong. This verified the high-accuracy method of the real-time laser-determined orbital elements and explored a wide range of Chinese satellite laser-ranging technology. Through improving the preliminary laser-ranging system, more passes and more distant space debris were observed. However, due to the existence of many influencing factors, the measuring success rate is very low. So further experimental research for the laser ranging of space debris should enable the observation of more distant and smaller targets, and increase the ability of routine space debris laser tracking.

Acknowledgements This research is supported by the Chinese Space Agency and the Instrument Developing Project of the Chinese Academy of Sciences (Grant No. 2920100701). We would like to thank Dr. Josef Kolbl of the Deggendorf University of Applied Sciences, Germany, for his comments and suggestions for the estimate of return signal strength.

References

Artyukh, Y. 2001, Automatic Control and Computer Sciences, 35, 11

Artyukh, Y., Bespalko, V., Boole, E., & Vedin, V. 2008, in Proc. 16th International Workshop on Laser Ranging, 16, 398

Degnan, J. 1993, AGU Geodynamics Series, 25, 133

Green, B., Yuo, G., Chris, M., et al. 2002, in Proc. 13th International on Laser Ranging Workshop, 13, 198