Progress of Laser Measurement to Space Debris at Shanghai SLR Station

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Abstract

Shanghai SLR station has been developing the technology of laser measurement to space debris since 2008. According to characteristics of laser echoes from space debris and the experiences of practical measuring activities, the improvements of laser system, laser detector and spectrum filter are performed for laser measurement to space debris and the achievements have been made with hundreds of passes of laser data from space debris at the distance between 500km and 2900km with Radar Cross Section (RCS) of >10m^2 to <0.5m^2. The laser measurement to space debris with the near infrared wavelength laser signal and multi-receiving telescopes are also developed in order to make the better performance of laser ranging to space debris.

1. Introduction

With development of global space technology, more and more spacecrafts are launched into space and lots of debris orbiting the Earth is produced. Space debris has become the vital factors threatening the safety of active spacecrafts on orbit for all space-faring nations in recent decade years.

High precise measurement and accurate catalogue for space debris are required for debris surveillance and collision avoidance. Accurate position determination of space debris is governed on the availability of precise tracking data.

Among the techniques of observing space debris, Debris Laser Ranging (DLR) is one which directly measure the distance between space target and ground station with the precision of better than 1 m, higher one or two orders of magnitude than that of microwave radar and optical-electrical telescope.

Development and realization of its application in the debris observation will be significant for increasing the ability of debris surveillance.

With the development of Chinese space technology, Chang'e project (Lunar Explorations), Beidou Navigation system, Manned space flight (Space Station) and others, China is becoming the major space-active country in the world.

Fig.1 Development of Chinese space activities and efforts made on the reduction of debris

As the member of IADC, the attention on the development of debris observing techniques also paid for the reliable and accurate catalogue of space debris. Shanghai Astronomical Observatory, one of the important observatory in China, is the first one to develop DLR in China while performing the measurement to ILRS satellites and also made the great efforts to promote the DLR technology.

2. Major development of debris laser ranging system

1) Laser system

At the initial research stage of DLR technology at Shanghai SLR station before the year of 2012, 20Hz/10Hz high energy laser systems were used and some measuring results were obtained. Due to high energy per shot pulse, the stability of laser system is not maintainable.

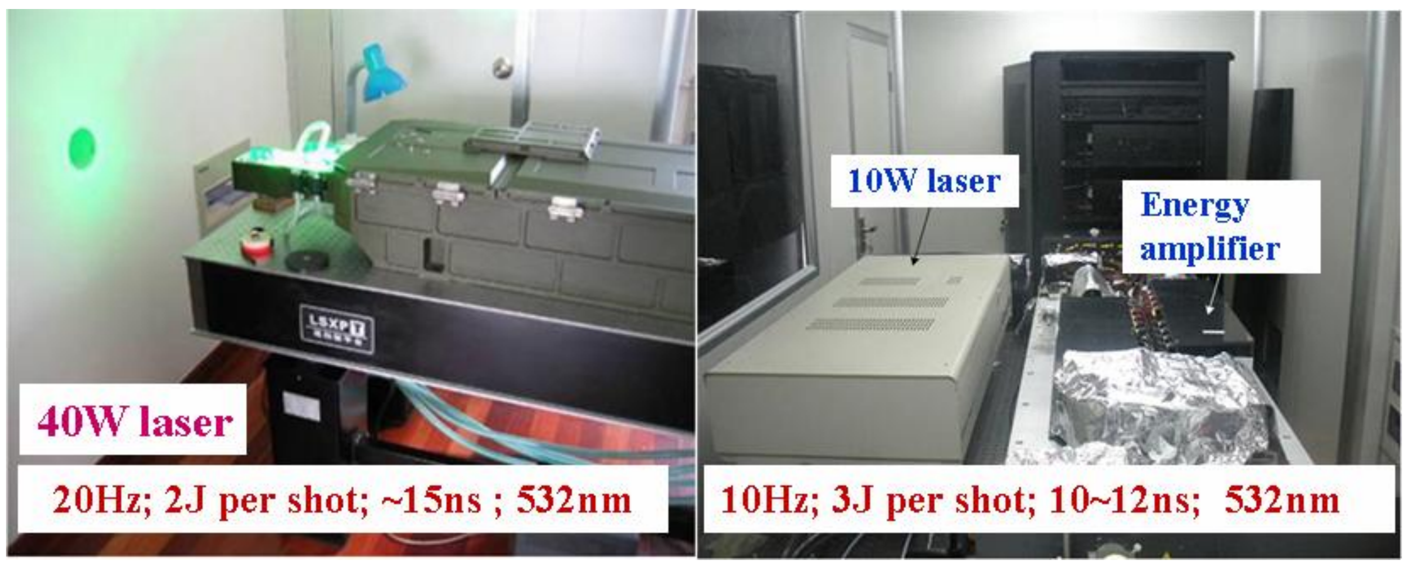
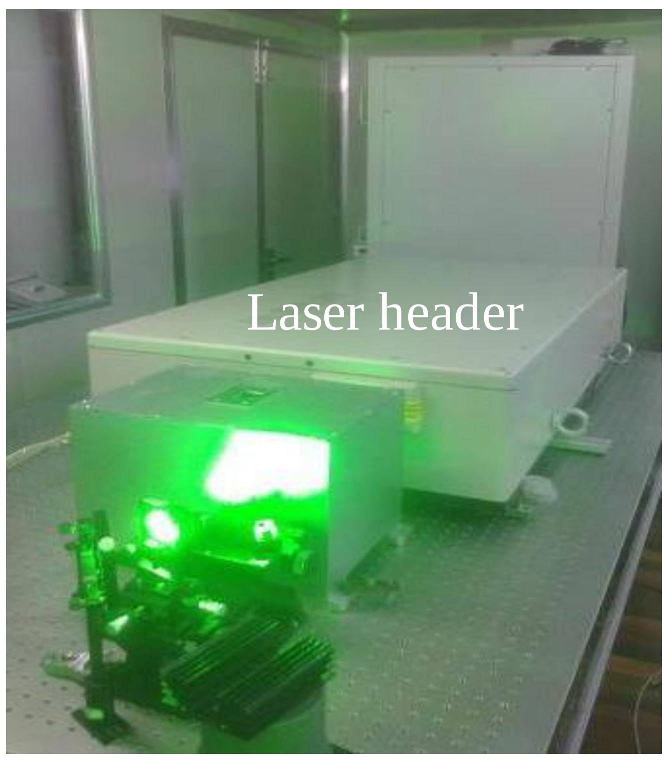


Fig.2 High pulse energy laser system with 20Hz/10Hz repetition rate

For high power laser system and better stability of system, high repetition rate with low pulse energy are feasible. In 2013, one set of demonstrated laser system with 200Hz, 50W, 532nm was installed at Shanghai SLR station and firstly applied in the observation of debris with high repetition rate in China and the experiments of laser measurement to space debris were also performed.

In 2014, one set of the dedicated laser system with 200Hz @ 60W, 8ns, 532nm was set up at Shanghai SLR station as the laser system for routine ranging to debris.

- Power: ~60W
- Frequency: 200Hz
- Pulse width: <8ns
- Wavelength: 532nm
- Beam M^2: <3.5
- Divergence: 0.5mrad



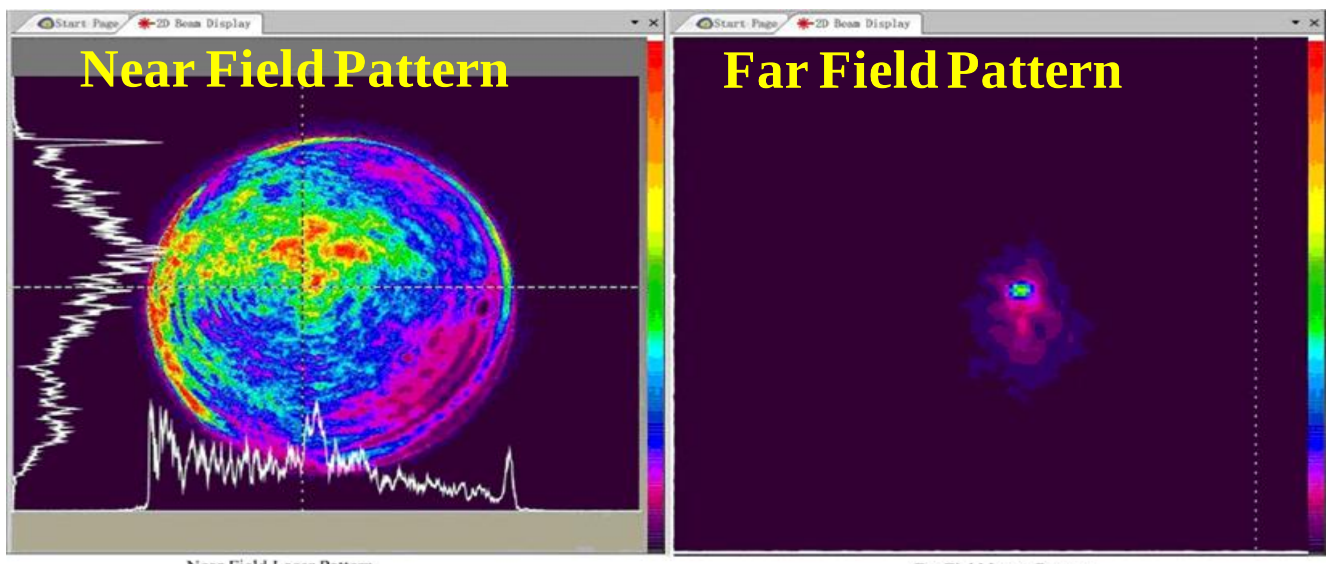
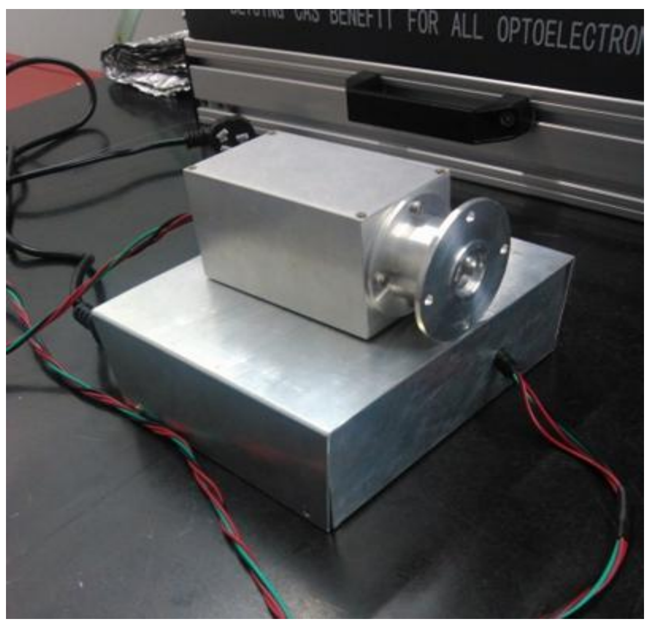


Fig.3 The dedicated high power laser system

2) Laser photon detector

For increasing the ability of measuring debris, especially for farther and smaller size ones, it is vital to reduce the level of noise detection and obtain laser returns with high ratio of signal to noise.



Cooperation with domestic university, the demonstrated APD detector was developed with specification of 500um chip size, 50% detecting efficiency and dark noise 10kHz and firstly applied in the debris laser ranging in China. The good measuring performance are acquired while using the demonstrated 200Hz high power laser system in 2013-2014.

The dedicated APD detector with the similar performance and the interface of C-SPAD was also developed and applied in debris laser ranging with the dedicated 200Hz high power laser system in 2015-2016.

3) Telescope Tracking System

The laser echoes received by the ground station has the relation with telescope tracking performance.

For debris laser measurement, the requirement of telescope tracking precision is at the level better than arc-seconds.

Updating the telescope tracking encoder by adopting the Reinshaw production with the resolution of 0.01 acr-second and developing the relevant the electro-circuit.

Optimizing the PID arithmetic and servo control to realize the tracking precision of better than 1 acr-second for tracking debris.

Fig.4 The telescope tracking system

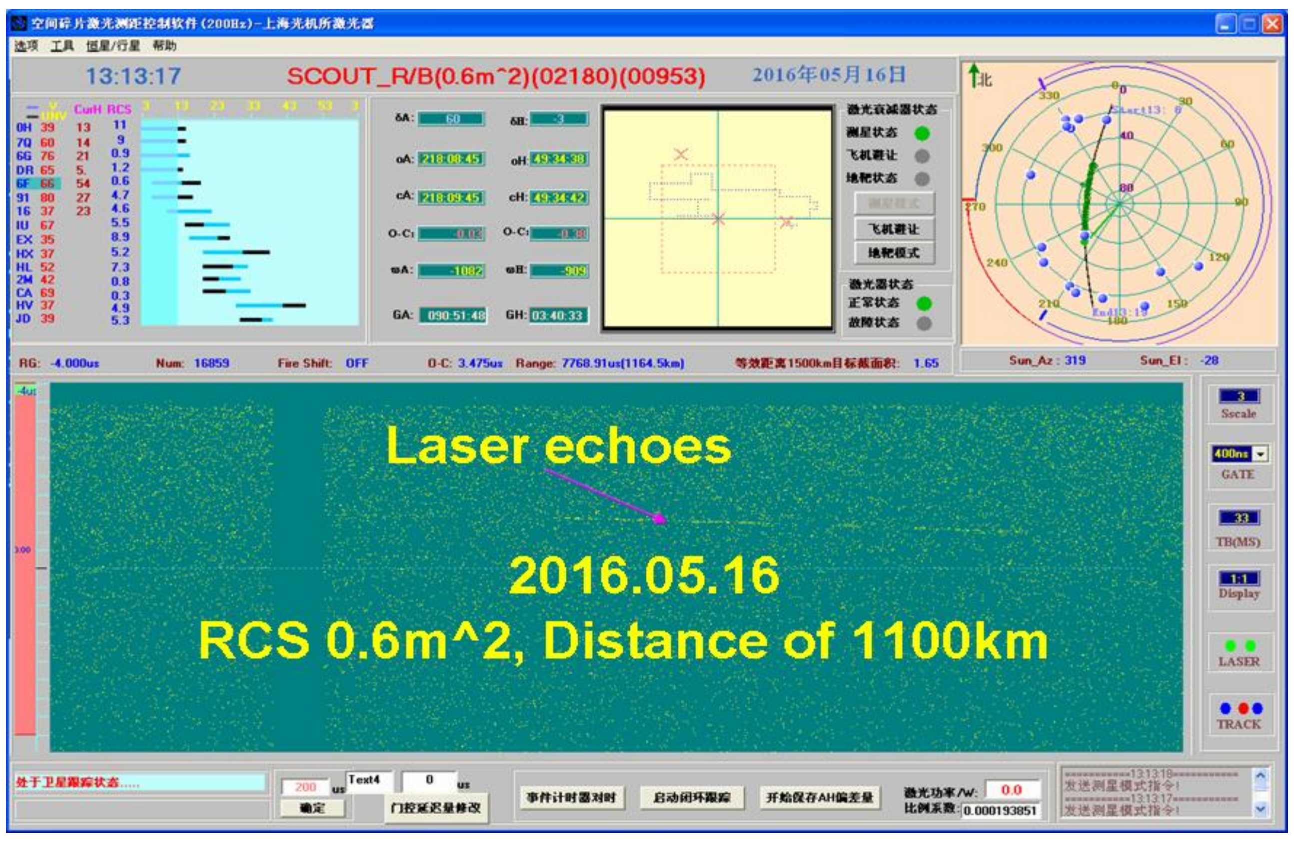
3. Results of laser measurement to space debris

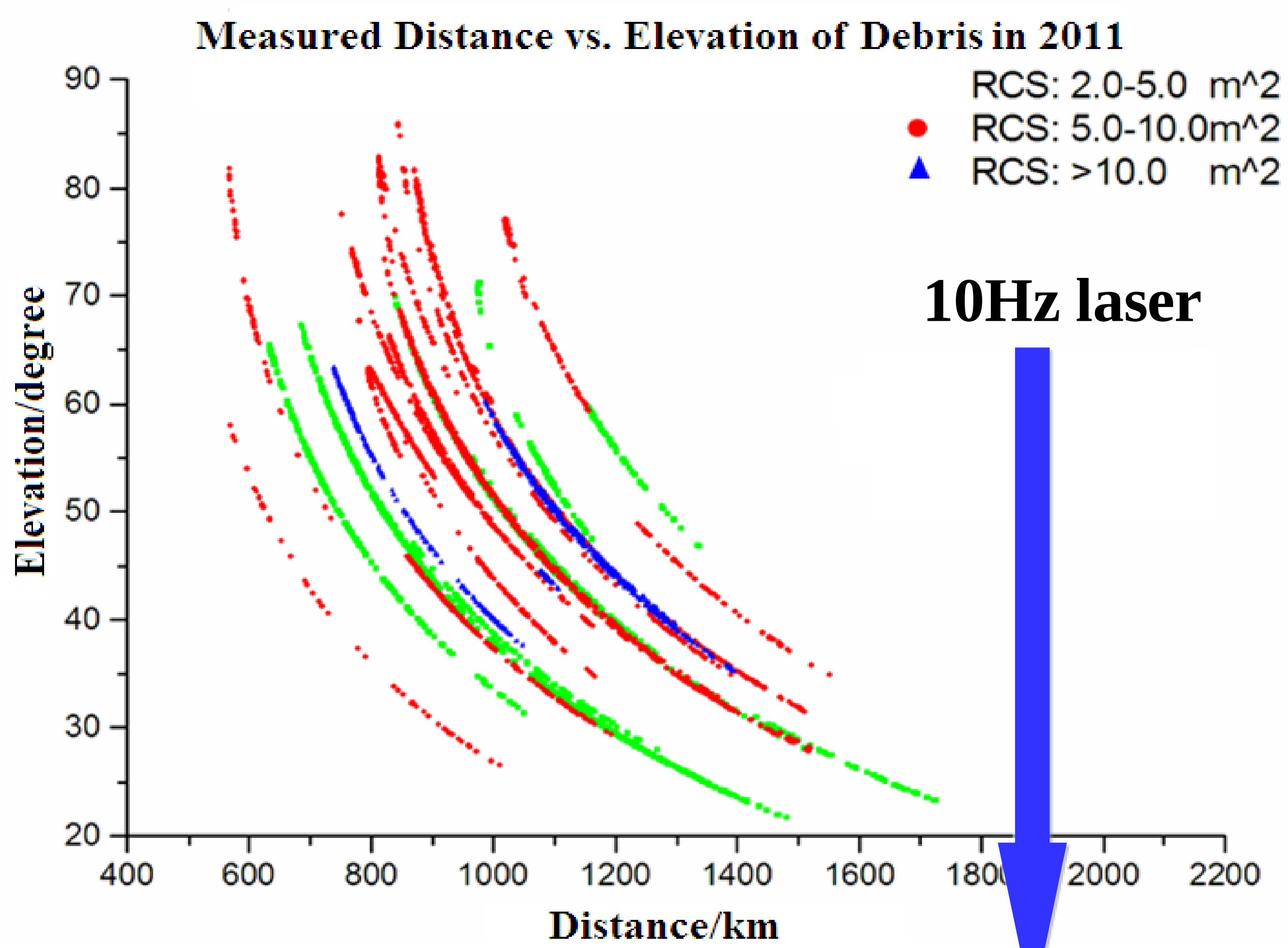
Selection of more than seven hundreds of targets from the cataloged space targets, mainly rocket body, unused satellites, broken targets.

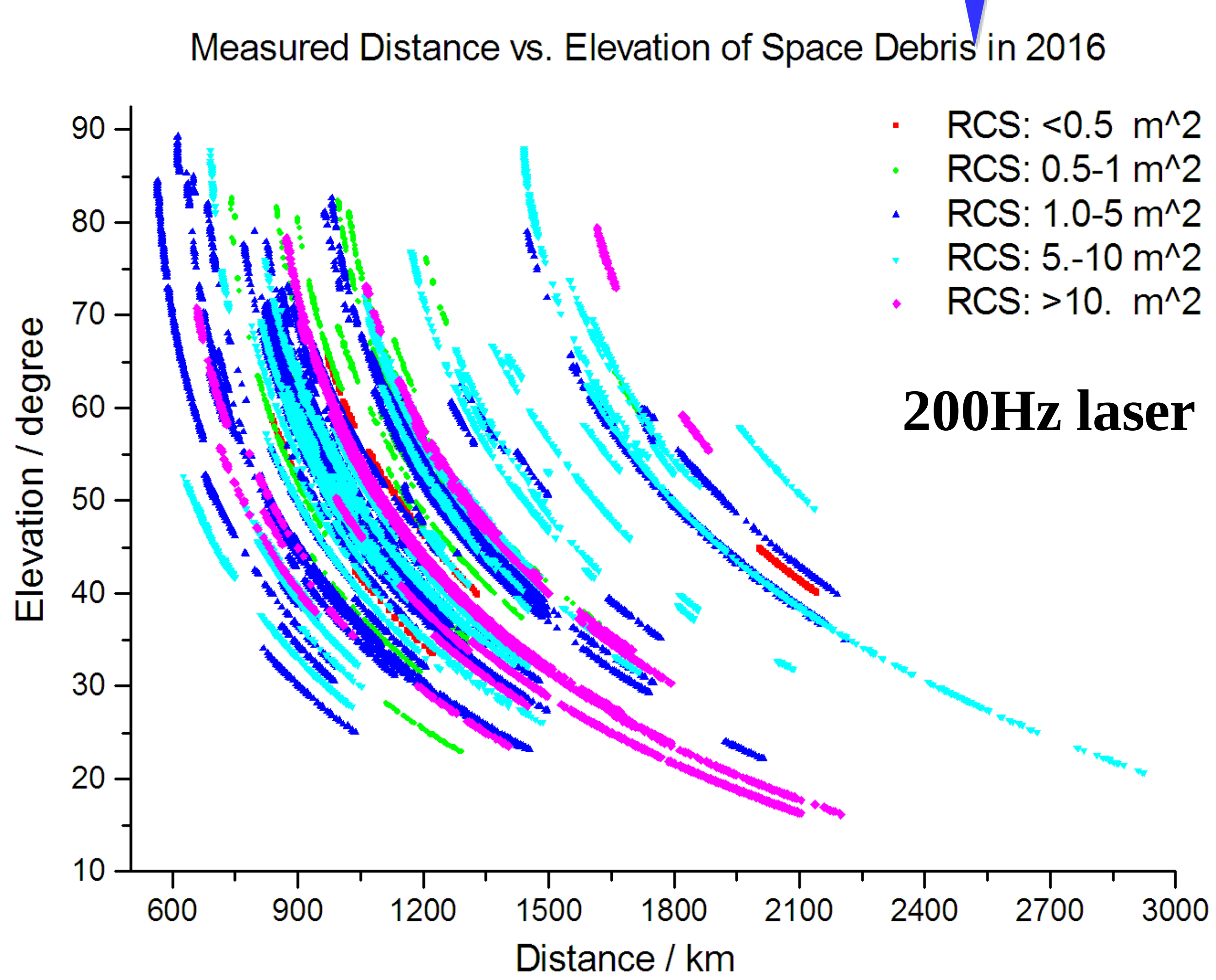
Through using APD detector and narrow band spectrum filter, the range gate can enlarged to the level of kilo-meters and TLE orbit can be used for tacking debris.

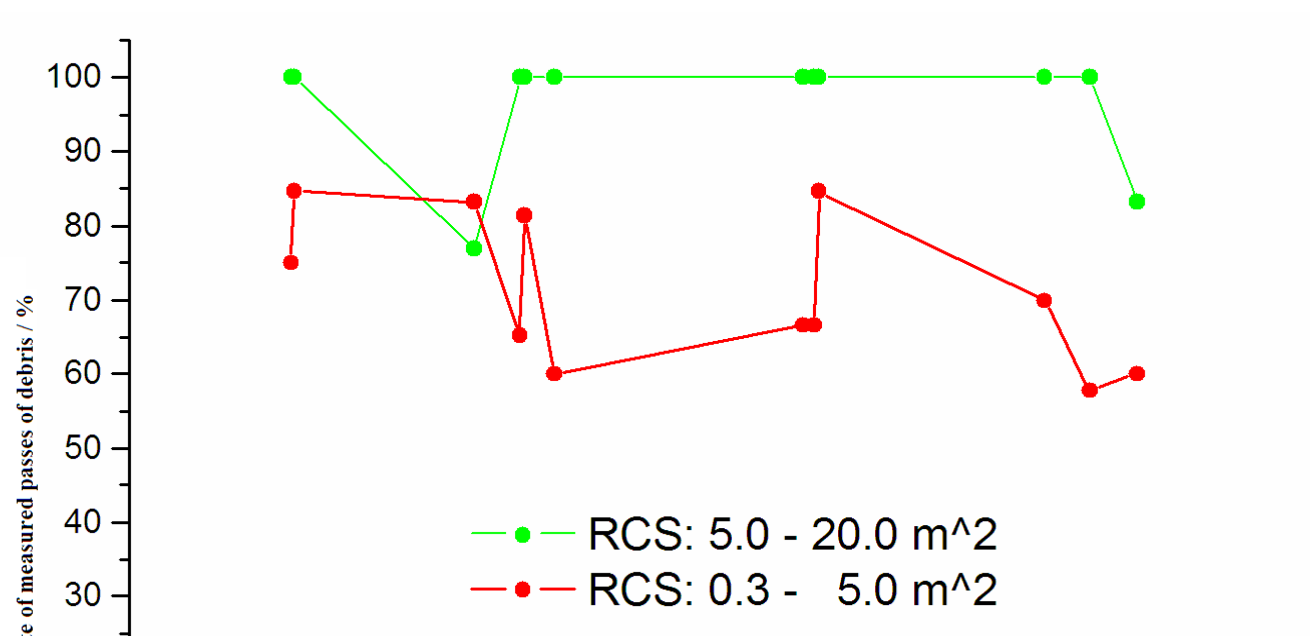
Fig.5 Shanghai SLR station and telescope

The routine laser measurement to debris has been realized from 2015. Hundreds of debris and more than five hundreds of passes of laser data have been obtained



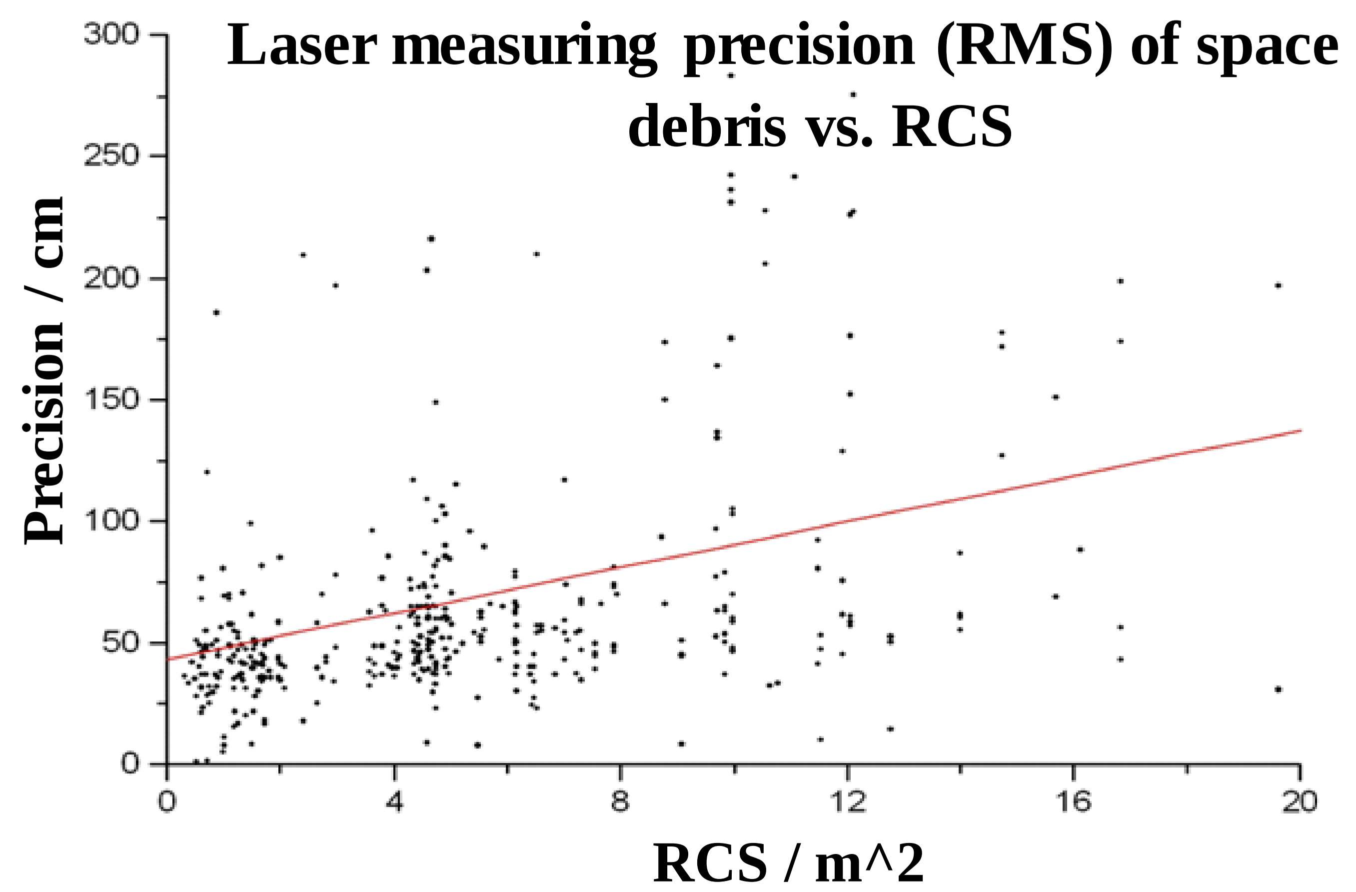




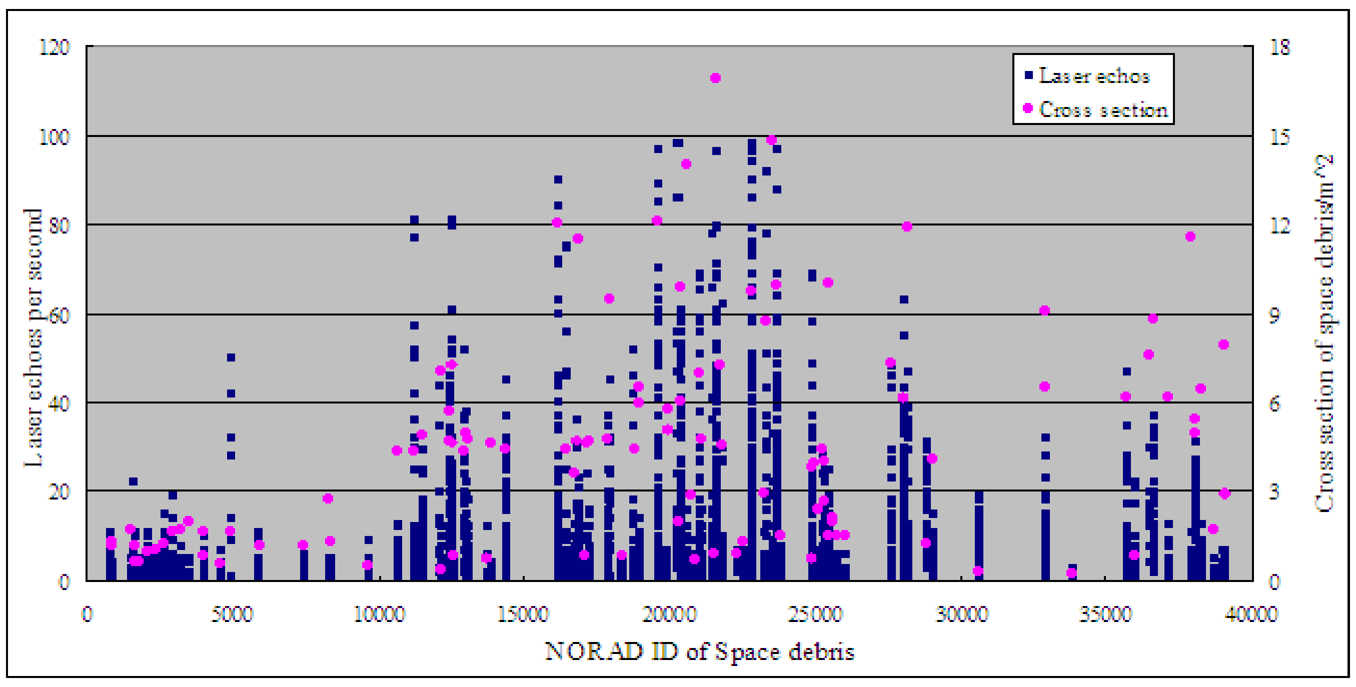


Success rate of measured passes of debris

- **Size of debris: 2m^2 → 0.3m^2;**
- **Max. distance :1700km → 2900km;**
- **Success rate of measured passes:**
  ~100%(RCS >5),
  >60%(RCS <5).

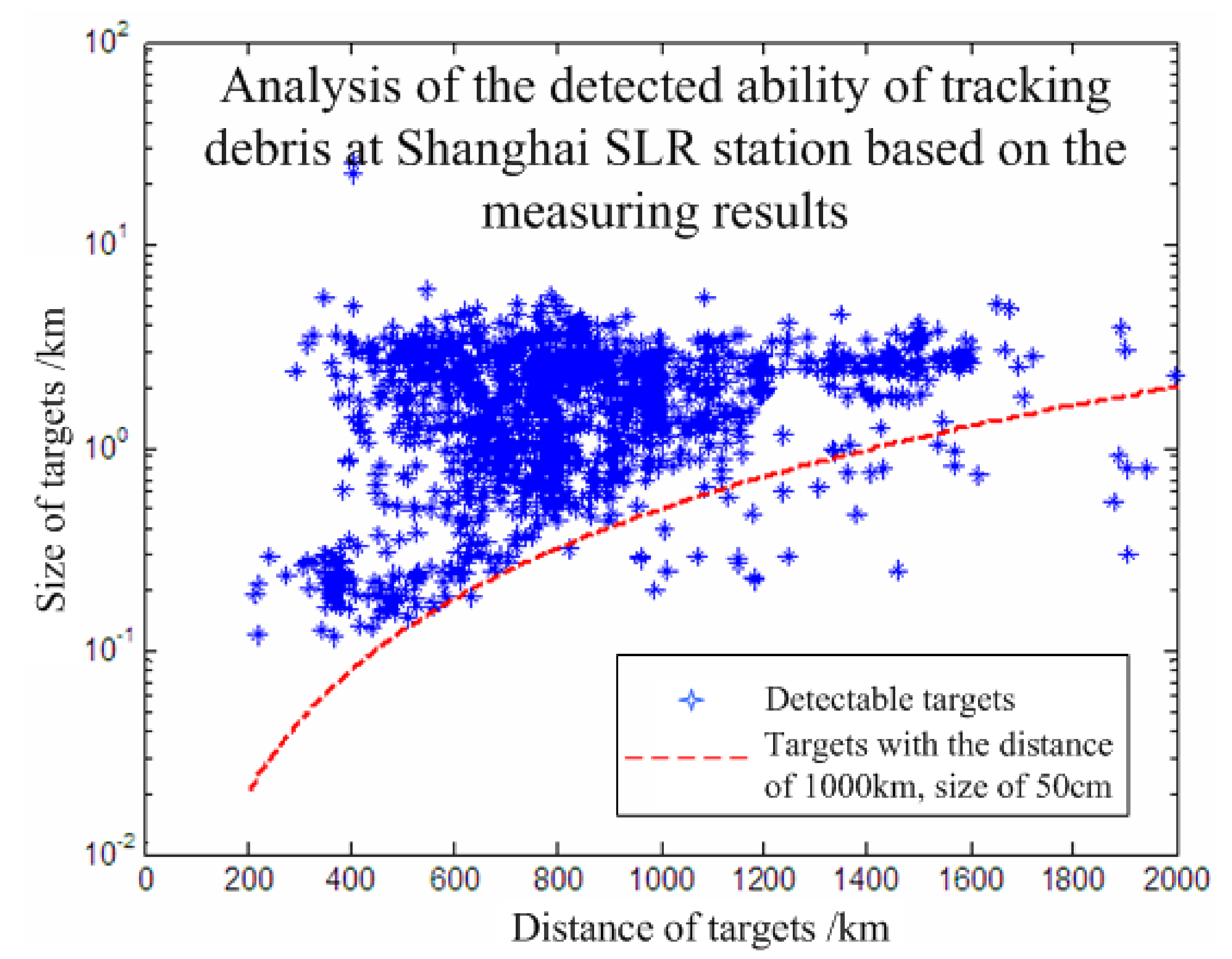


- **RMS<1m for RCS < 8m^2;**
- **Larger size → larger RMS.**



Statistic of laser echo per one second vs. RCS of debris

- **For large size of debris, echo rate is up to 50%; Small size ones <5%;**
- **Some exceptions, maybe have relation with material of debris and worth investigating on the debris type according to laser echoes.**



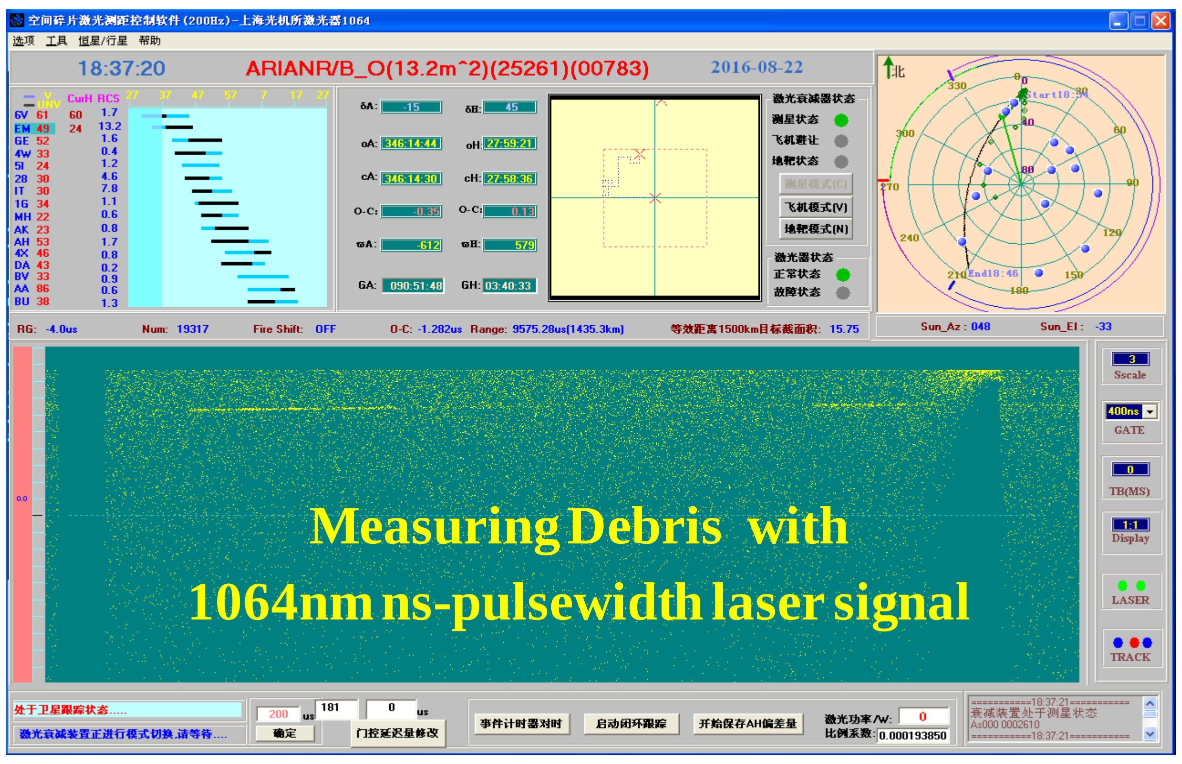
4. New technical development and experiments

To increase the ability of debris laser ranging system, the developments of new techniques and relevant experiments have been performed.

1) 1064nm laser ranging to space targets

Increasing the output power is the major advantage by using 1064nm laser signal. The experiments of 1064nm laser measurement to satellites and debris are performed by using the infrared CCD and InGaAs laser detector based on the kHz ps-pulsewidth laser system and 200Hz ns-pulsewidth laser system.

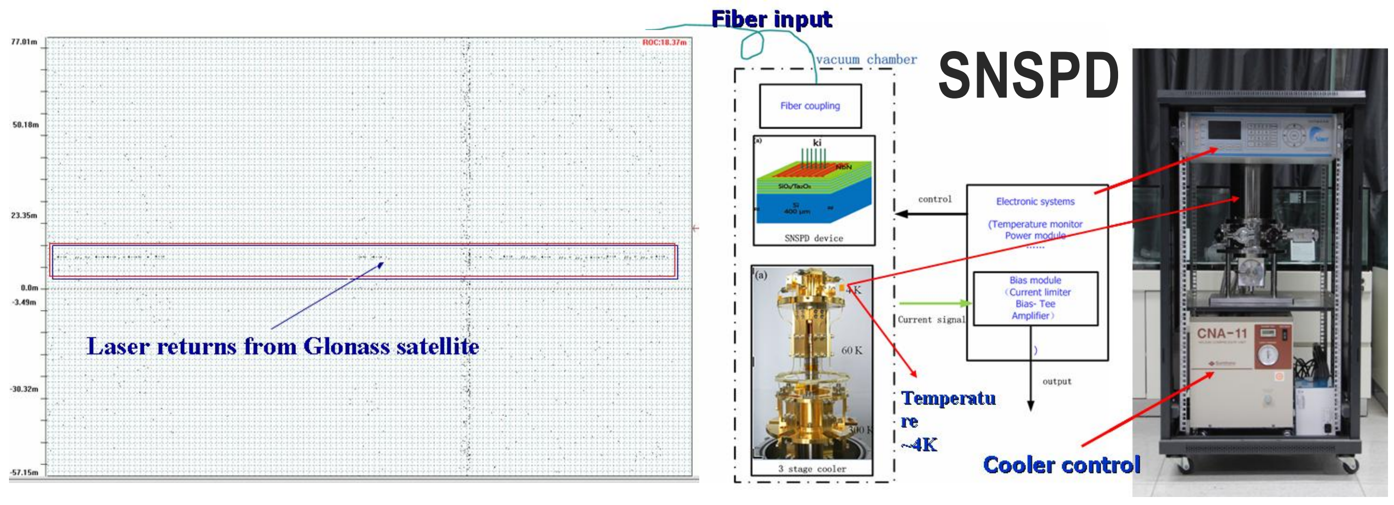
InGaAs laser detector



2) SNSPD laser ranging to satellite

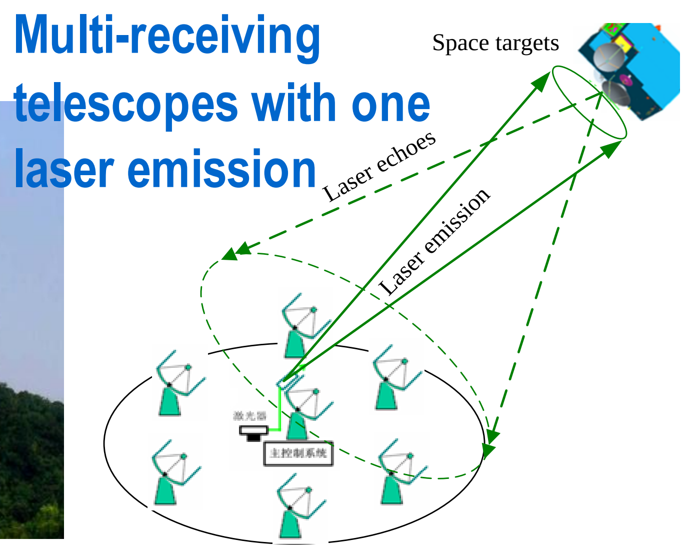
SNSPD detector with the good performance for detecting laser signal will become the next generation of laser photon detector in the field of SLR measurement.

Cooperation with Shanghai Institute of Microsystem and Information Technology (SIMIT), the first version for 532nm laser detection is developed and applied in SLR measurement.

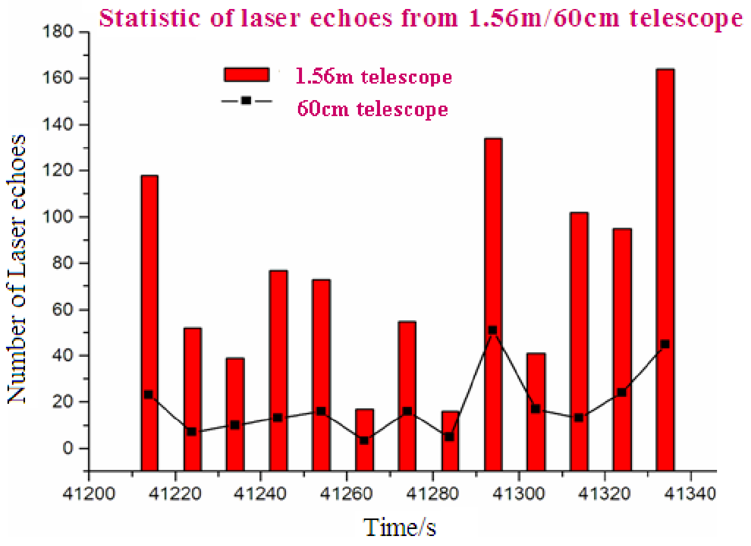


3) Multi-telescopes to receive laser signal

The demonstrating experimental system based on the 60cm SLR system and 1.56m telescope at the distance of ~50m was established to verify the feasibility of multi-telescopes to receive laser signal.



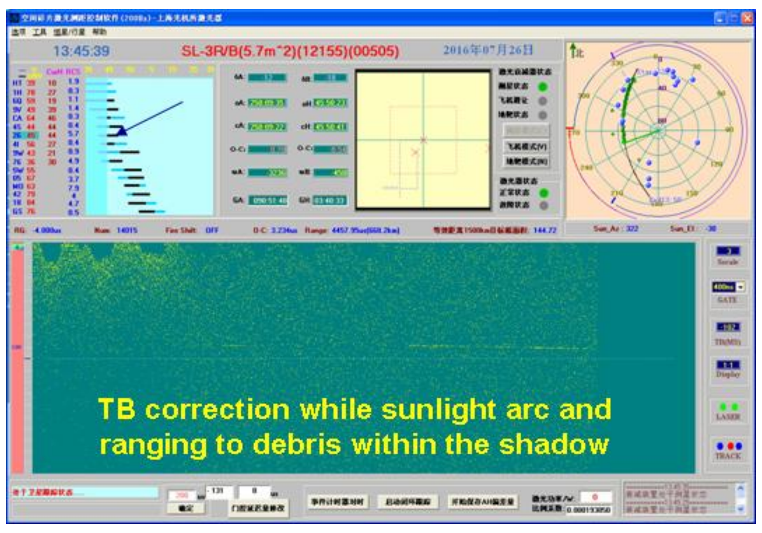
Number of laser echoes from 1.56m/60cm telescopes are higher 3~4 times than that of 60cm and present the advantages of multi-telescopes.

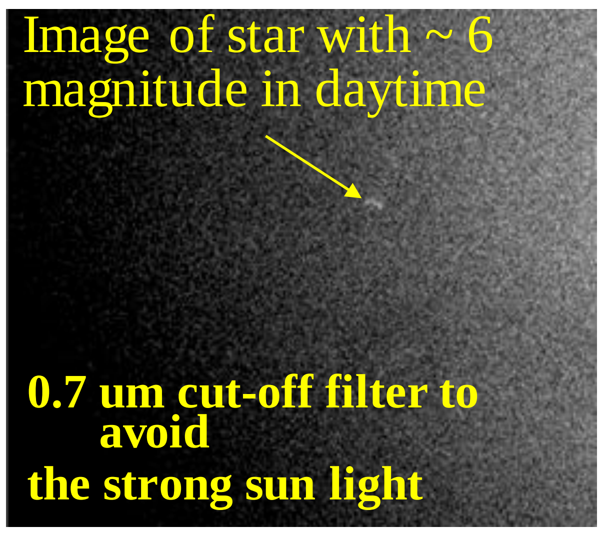


4) Laser Tracking Debris in the shadow and day time

The research on laser tracking debris in the shadow and day time are also preliminary start up. According to the variable of azimuth and elevation offset for the sunlight debris, the time bias of TLE orbit are corrected and applied to the pass arc within the shadow.

Development of daylight imaging the space targets by using cut-off filter and EMCCD in order to obtain the accurate guide.





The images of debris are also acquired in daytime for tracking guide and try to daylight laser ranging to debris.

5. Summary

Through upgrading and development of DLR system and solving the key points, the routine DLR measurements has been realized and lots of laser data are obtained. It can be as a kind of high precise measuring techniques for space debris surveillance.

For continuously developing DLR technology, the new techniques and experiments are also investigated and implemented. And DLR will be one of important work for Shanghai SLR station while laser ranging to ILRS satellites.