Progress and Observation of Space Debris Laser Ranging at Shanghai SLR station

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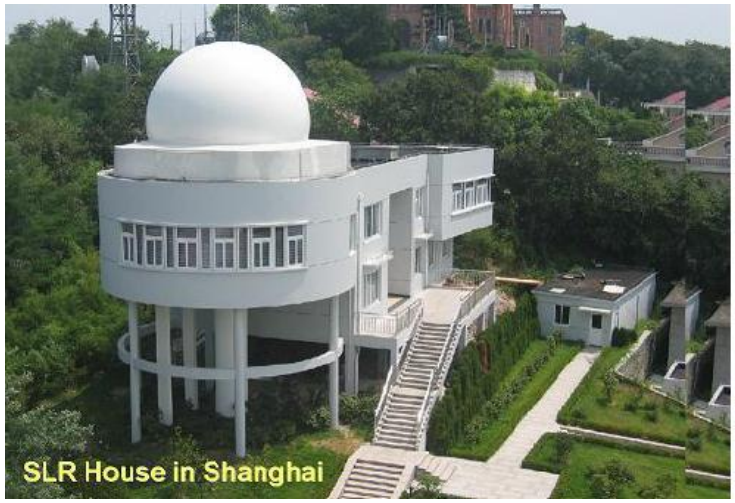
1、Introduction

- **Since 2006, under the support of National Projects, Shanghai Astronomical Observatory firstly in China have begun to research on the technology of Laser Ranging to space debris.**
- **From July 2008, the space debris laser ranging system was established with lamp pumping laser and data from space debris were obtained.**


SLR House in Shanghai


60cm SLR telescope

1、Introduction

- **Limited to the power and beam quality of laser system, difficult to observe objects with longer distance and small size.**
- **Need to adopt more stable, high power of laser system with good beam quality.**
- **For lamp pumping laser with low repetition rate, increasing its power makes pulse energy enlarged.**

Disadvantage:

- **Making optical components more damageable.**
- **Performances of laser become the major problems.**

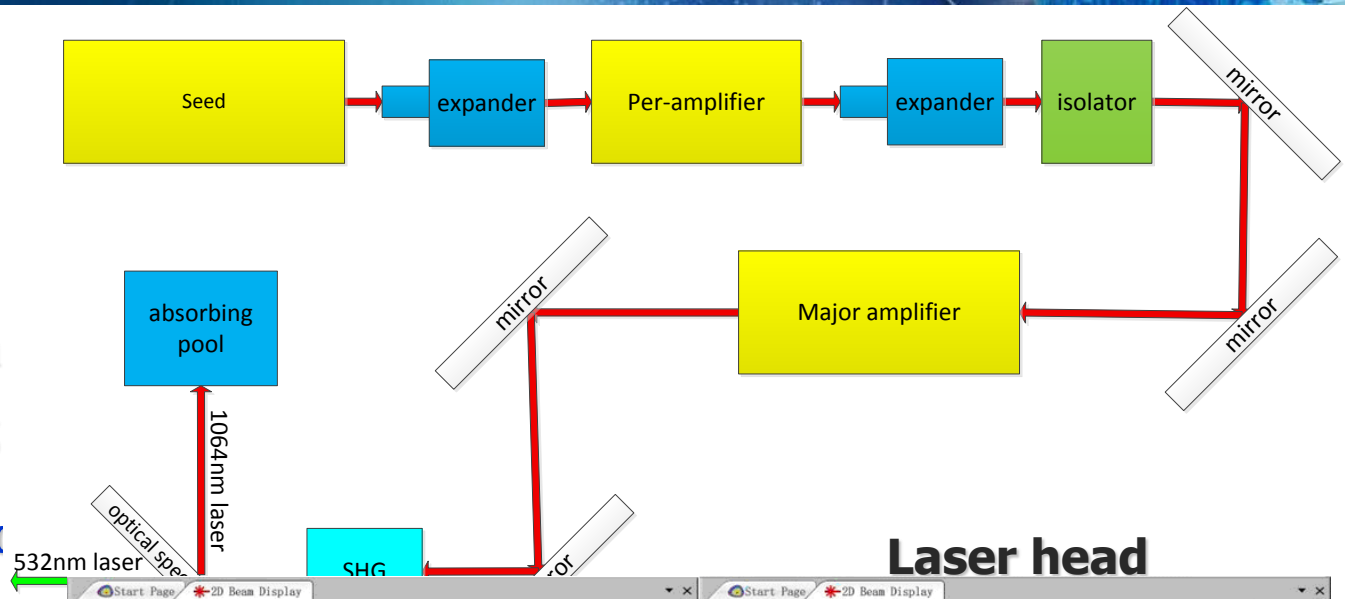
The diode pumping laser with high repetition rate becomes a good choose.

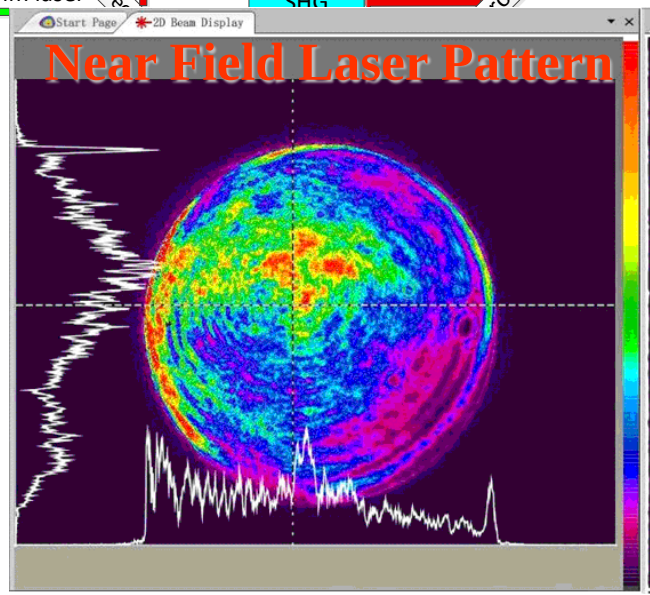
2、 Upgraded system and measurement to space debris ranging

- **At the beginning of 2013, Shanghai SLR station used the demo laser system with diode pumping of 50W@532nm at the frequency of 200Hz to perform laser tracking space debris.**
- **Development of low dark noise APD detector for laser return detection with high repetition rate.**
- **Adopting the narrow bandwidth spectrum filter with high efficiency to reduce the sky noise.**

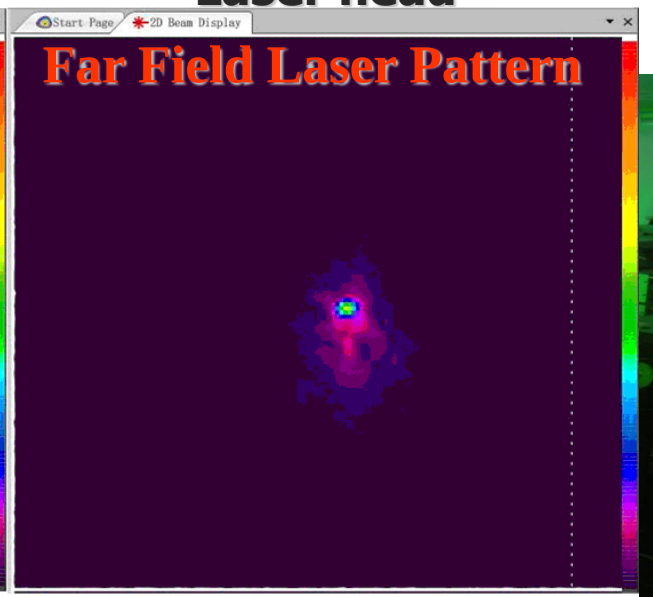
Laser system with 200Hz repetition rate

- Power: ~50W
- Frequency: 200Hz
- Pulse width: 11ns
- Wavelength: 532nm
- Beam quality: M^2~5
- Divergence: 0.5mrad





Near Field Laser Pattern



Far Field Laser Pattern

Made by China Academy of Engineering Physics

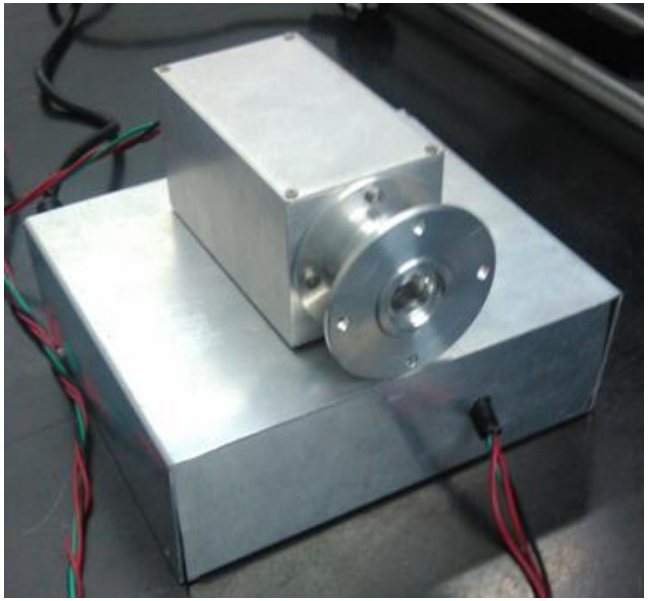
APD detector with high efficiency/low noise

- **Except for high power laser system, the other two key problems for laser measurement to space debris:**
  - **Not good precision of orbit prediction to make RGG control difficultly.**
  - **Noise from sky and objects, especially for high repetition rate.**

- **Reducing the level of noise detection to make large scale of RGG adjustment and obtaining laser returns with high S/N for farther distance and smaller size space debris.**

APD detector with high efficiency/low noise

- Cooperation with one domestic university, the breadboard APD detector is developed and used for laser measurement to space debris.
  - Diameter of Chip: 500um;
  - Dark noise: <10kHz;
  - QE: 40%@532nm



- Its stability needs further improvements.
- Narrow bandwidth spectrum filter to reduce the level of sky noise.
  - Center wavelength: 532nm; Bandwidth: ±1.0nm; Efficiency: >90%

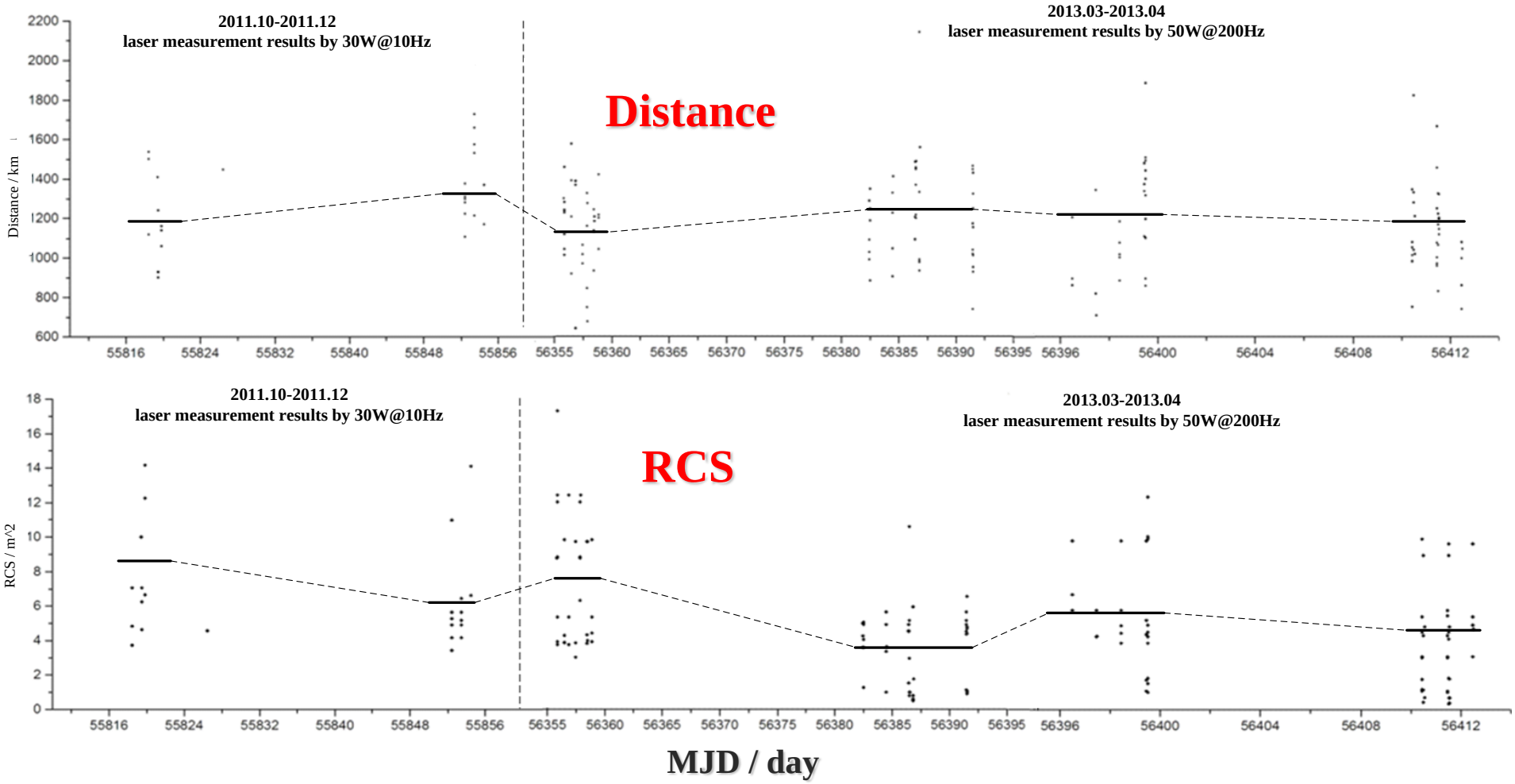
Results of laser measurement to space debris with 200Hz laser system

- After making modifications for laser ranging system, the measurement to space debris were performed during March and April in 2013.
- More than 110 objects (Rocket body, Iridium, Radar Cal. Obj, Debris) with 160 passes of laser data were obtained.
- The most 16 passes one night obtained and the longest distance is more than 2100km and the min. cross section (RCS) is 0.5 m^2 and measurement success rate >80%.
- And several objects is measured with multi passes in consecutive days to meet the requirements of orbit processing and analysis.

Results of laser tracking space debris on April 2, 2013

No.	ID.	Len. of Pass /min	RCS /m^2	Ranging /km	Returns	Precision /cm
1	11112	1.24	4.96	1178 ~1495	435	72.13
2	4237	4.09	1.02	1045 ~1465	177	59.34
3	23815	1.78	1.55	840 ~1096	181	53.46
4	17160	2.88	4.57	1011 ~1212	493	88.86
5	18749	2.39	4.59	655 ~1098	1025	66.71
6	2825	1.18	5.21	1154 ~1496	487	72.19
7	7737	2.56	2.99	1204 ~1456	61	99.32
8	8744	2.66	2.98	1067 ~1206	266	47.9
9	22699	1.77	0.8	883 ~1224	77	47.12
10	19120	3.23	10.72	875 ~1375	3753	57.42
11	1389	1.79	1	1245 ~1498	234	49.19
12	29956	4.09	0.51	966 ~ 1340	65	51.61
13	10246	2.26	0.82	566 ~ 937	300	55.92
14	1433	0.63	0.6	864 ~ 995	33	37.42
15	19910	6.11	6	1773 ~2160	118	72.87
16	13493	4.03	1.78	1259 ~1571	207	66.62

The comparison of laser measurement to space debris by the 10Hz and 200Hz laser system



3、Preliminary orbit analysis by laser data

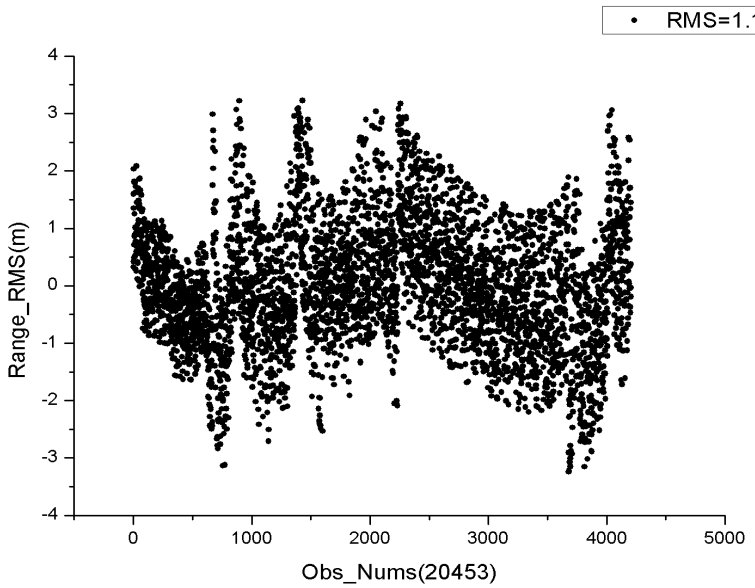
NORAD ID	Start Time (UTC)	Arc Section (s)	Actual sampling Time (s)	Echoes	Average sampling rate (per sec)	Range (km)
20453	03-04 11:49:08	77	72	669	9	3
	03-05 10:38:06	209	197	1629	8	
	03-05 12:21:57	101	99	1443	15	
	03-06 11:12:27	131	105	557	5	
28222	03-02 21:06:44	98	89	6010	68	571～1287
	03-03 21:06:39	30	30	893	30	
	03-04 21:07:55	104	98	3583	37	
11574	03-02 21:22:30	96	81	312	4	855～1317
	03-03 20:40:30	221	198	652	3	
	03-05 21:02:01	177	170	1638	10	
23705	03-03 11:04:27	257	65	101	2	871～1588
	03-05 21:23:26	31	27	101	4	
16182	03-02 21:16:29	228	218	2615	12	1248～1317
	03-04 20:45:24	149	148	2410	16	

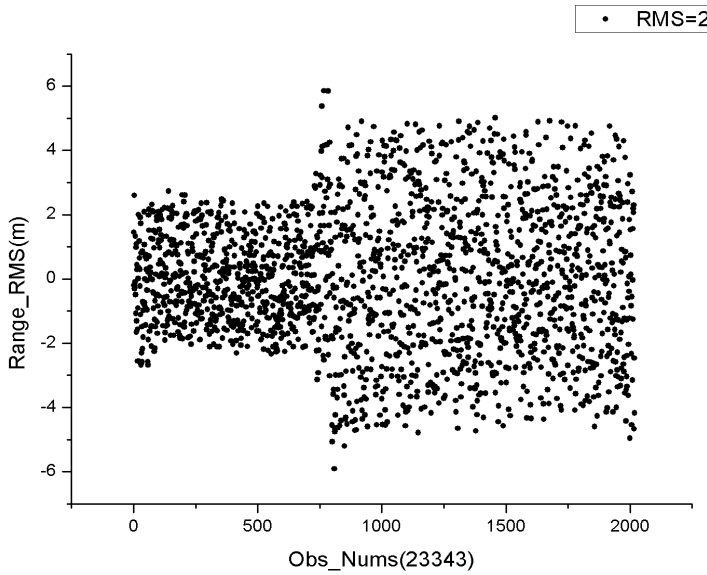
Objects and measurement data during 2-6,March

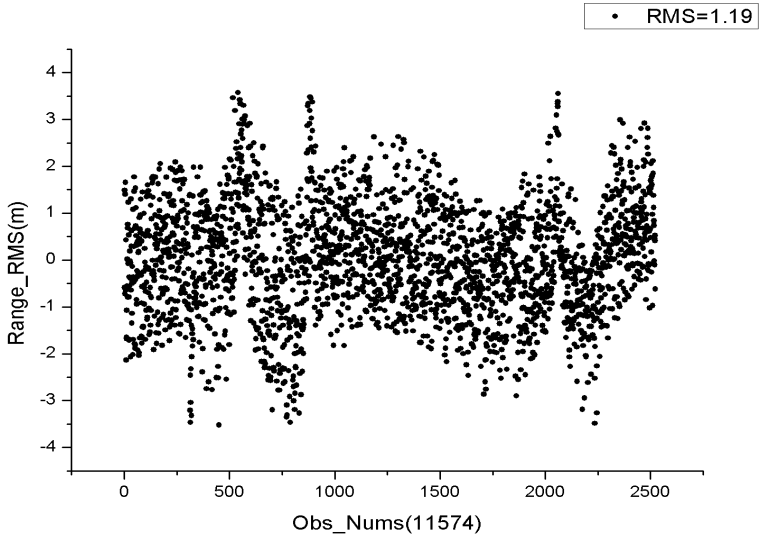
Method of Orbit Determination (OD)

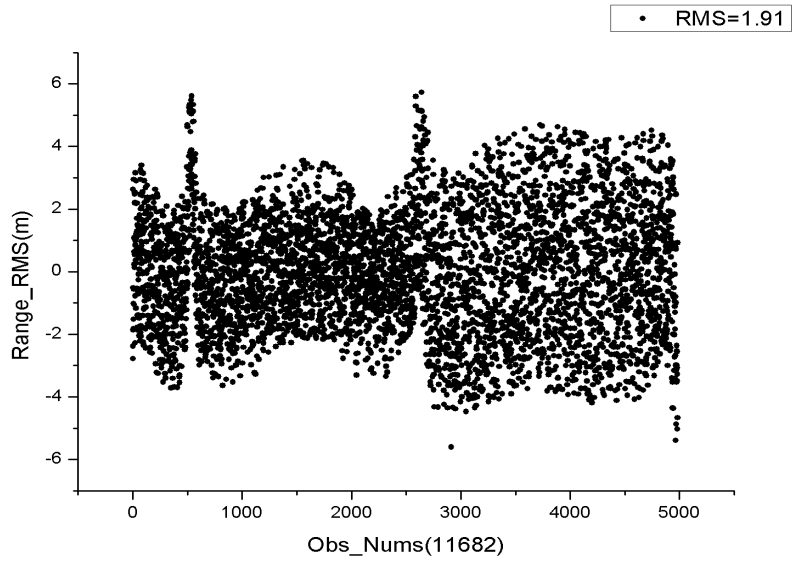
- For objects (20453,23343,11574, 16182), the orbit determination by laser data can be convergent when data processing.
- The range residual is about 1-2 meters, lower than laser measuring RMS (60-80cm).

Range residual, rms:1-2m









Evaluation of OD Precision

- Using method of orbit overlap data process to assess the accuracy of Orbit Determination(OD) by laser data.
- The object, NORAD ID 20453, have 4 consecutive passes in three days to meet the requirement of OD.

NORAD ID	Start Time (UTC)	Arc Section (s)	Actual sampling time (s)	Echoes	Average sampling rate (per sec)	Range (km)
20453	03-04 11:49:08	77	72	669	9	777～1179
	03-05 10:38:06	209	197	1629	8	
	03-05 12:21:57	101	99	1443	15	
	03-06 11:12:27	131	105	557	5	

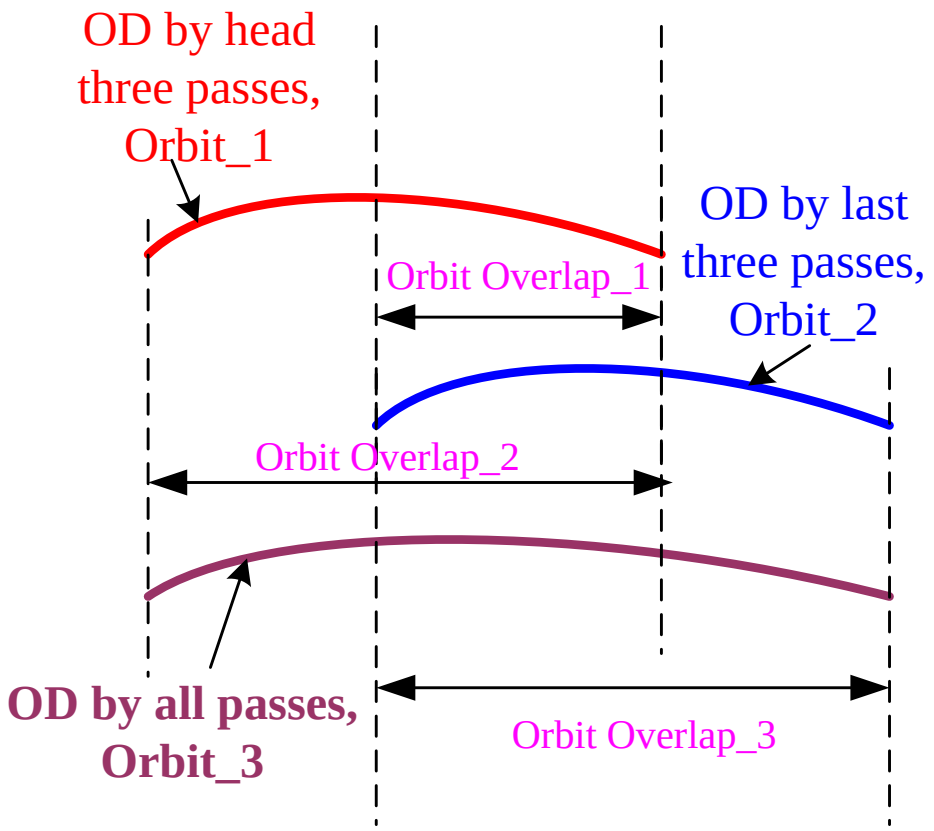
- **The 4 consecutive passes of laser data can produce three orbits (Orbit_1, Orbit_2, Orbit_3).**

- **The three orbit overlaps will be presented:**

  Orbit Overlap_1,

  Orbit Overlap_2,

  Orbit Overlap_3



Results of orbit bias with method of orbit overlap

Comparison with the orbit derived from the ahead three passe of laser data, the last three ones and the all passes.

No.	Start Time (UTC)	Num of Passes	Length of OD/day	Length of overlap/day	Orbit bias /m			
					R	T	N	3D
1	03-04 11:49:08	3	1.5	1.0	7.13	31.16	17.41	36.41
2	03-05 10:38:06	3	1.5					

Orbit Overlap_1

No.	Start Time (UTC)	No. of Passe	Length of data (s)	Length of OD /day	Orbit bias /m			
					R	T	N	3D
1	03-04 11:49:08	3	77+209+101	1.5	11.72	39.45	17.98	44.92
2	03-05 10:38:06	3	209+101+131	1.5	4.64	12.39	0.96	13.27

Orbit Overlap_3

Orbit Overlap_2

The precision of orbit produced by laser data from the single station is less than 50m.

Results of orbit prediction by measurement data

- For object (NORAD ID 20453, total 4 passes of laser data), using the ahead three passes of laser data to produce the orbit.
- Then using the orbit to predict the next 12 hours, covering the forth pass of laser data.
- The comparison of range predicted and measured, the error less than 300m.

Orbit determination			The laser data for comparison	Range residual (O-C) /m	
laser data (UTC)	Length of orbit (day)	Length of predictions (day)		Mean	RMS
03-04 11:49:08 03-05 10:38:06 03-05 12:21:57	1.5	0.5	03-06 11:12:27-11:14:38	229.98	177.92

- The above results are only given by one object, needing more objects to further validate it.

4、Summary

- **Firstly applying high rep. rate laser (diode pumped, 200Hz, 50W) to track space debris in China and measuring ability improved greatly (min. RCS 0.5m^2 measurable, max. distance >2100km);**
- **More than 110 objects with 160 passes of laser data obtained in two month test and average laser returns per pass have increased obviously;**
- **The breadboard APD detector has been developed and used for the measurement to space debris and needed further improvements.**
- **Using multi consecutive passes of laser data from a single station, the precision of orbit determination for space debris is less than 50 m.**
- **The orbit prediction by laser data from the single station is at the precision of less than 300m for 12 hour.**


Thank you!