Pulse repetition frequency of 10Hz~1MHz industrial picosecond laser and applications to SLR and DLR

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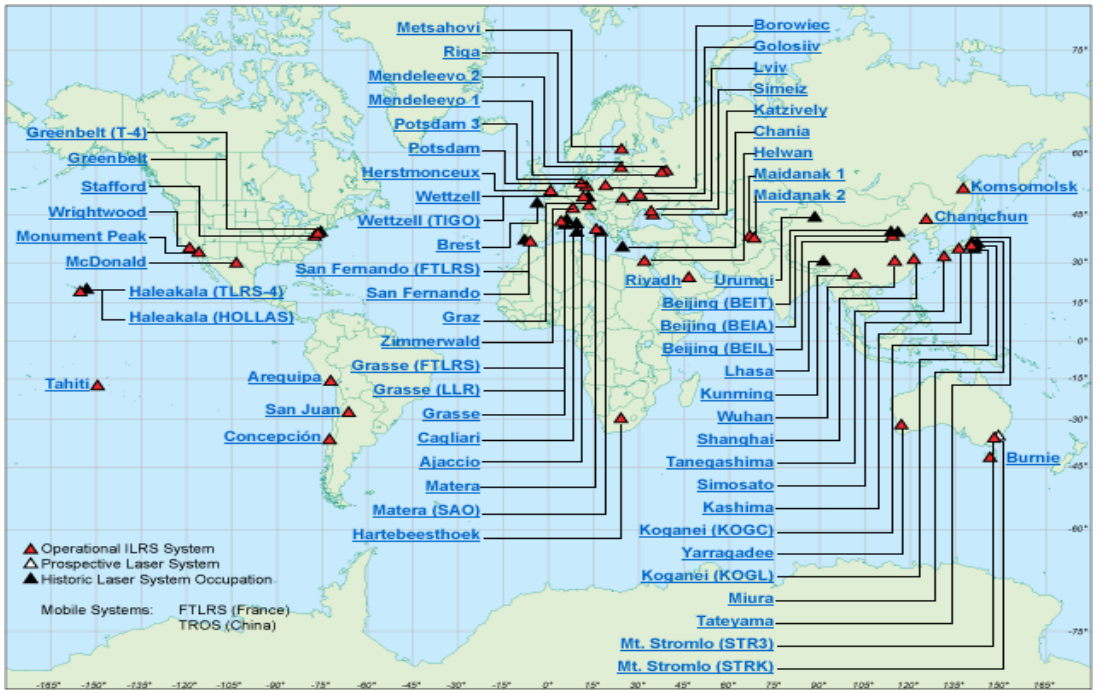
4 Summary

1. Motivation

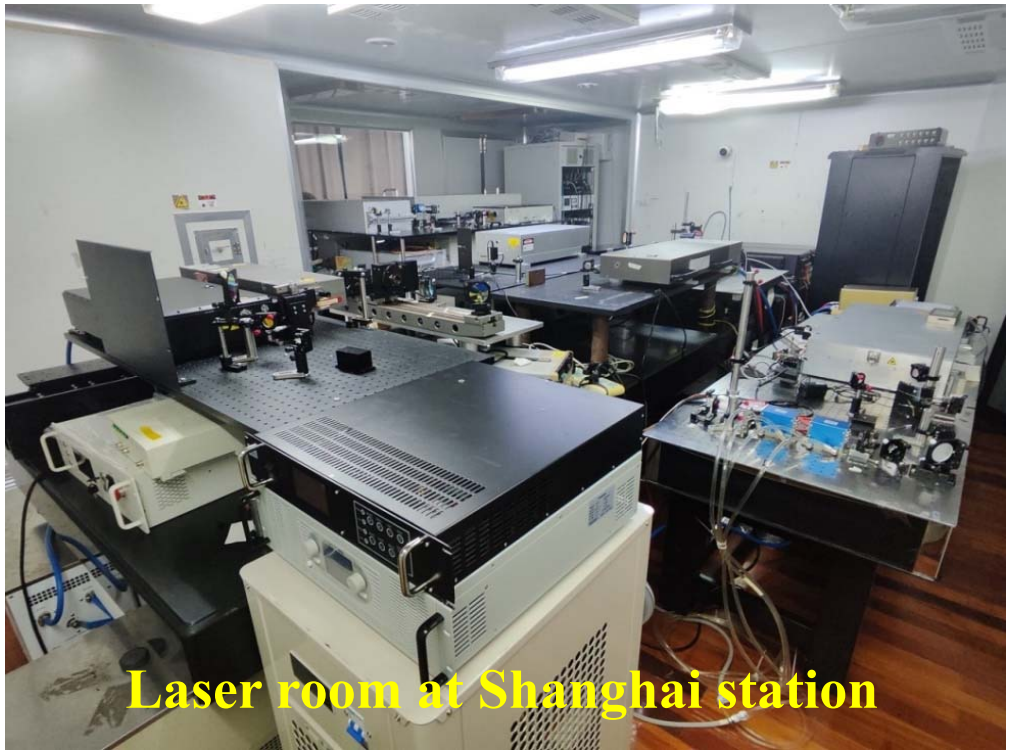
- The number of SLR system is no more than 50 in ILRS network.
- The laser unit is an important component in SLR system and its specifications are also different for different stations.

- The laser unit is commonly customized by the dedicated laser company and its number for SLR station is a little.
- So, the alone designed for required laser should be done and of course the cost is high and the maintainability should be specially paid an attention to.



1. Motivation

- Normally one SLR station has two or three or more laser units for different purposes, such as 532nm output, 1064nm output, kHz/10kHz/ 100kHz SLR, debris tracking, LTT measurements etc.
- And the laser transmission path in the laser room should be switched in those laser unit.
- Sometime the routine SLR path is easily influenced.
- In addition, the space of laser room is also very limited.
- So the idea that one laser unit can be used for multifunctions is proposed.

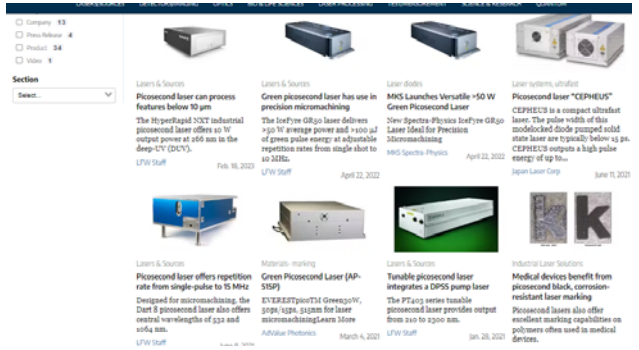


Laser room at Shanghai station

1. Motivation

- **One laser unit** can mostly meet the measurements of high-precision satellites and debris, and other purposes, Is it feasible?

- **After investigating the different mode of laser unit, the industrial-level one is put into attentions by us.**
- **The industrial-level laser unit has the advantages of productization, well-design, low cost, good stability and maintenance.**



- **So, collaboration with a laser company, Shanghai station use one type of industrial-level laser unit for testing.**

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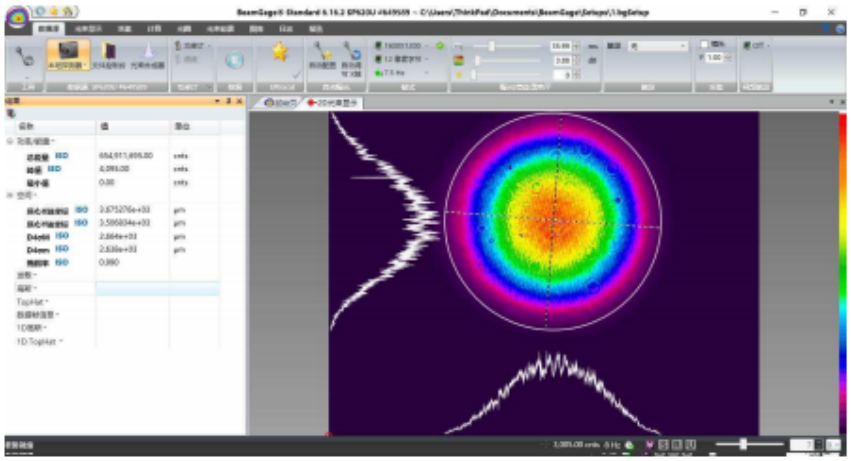
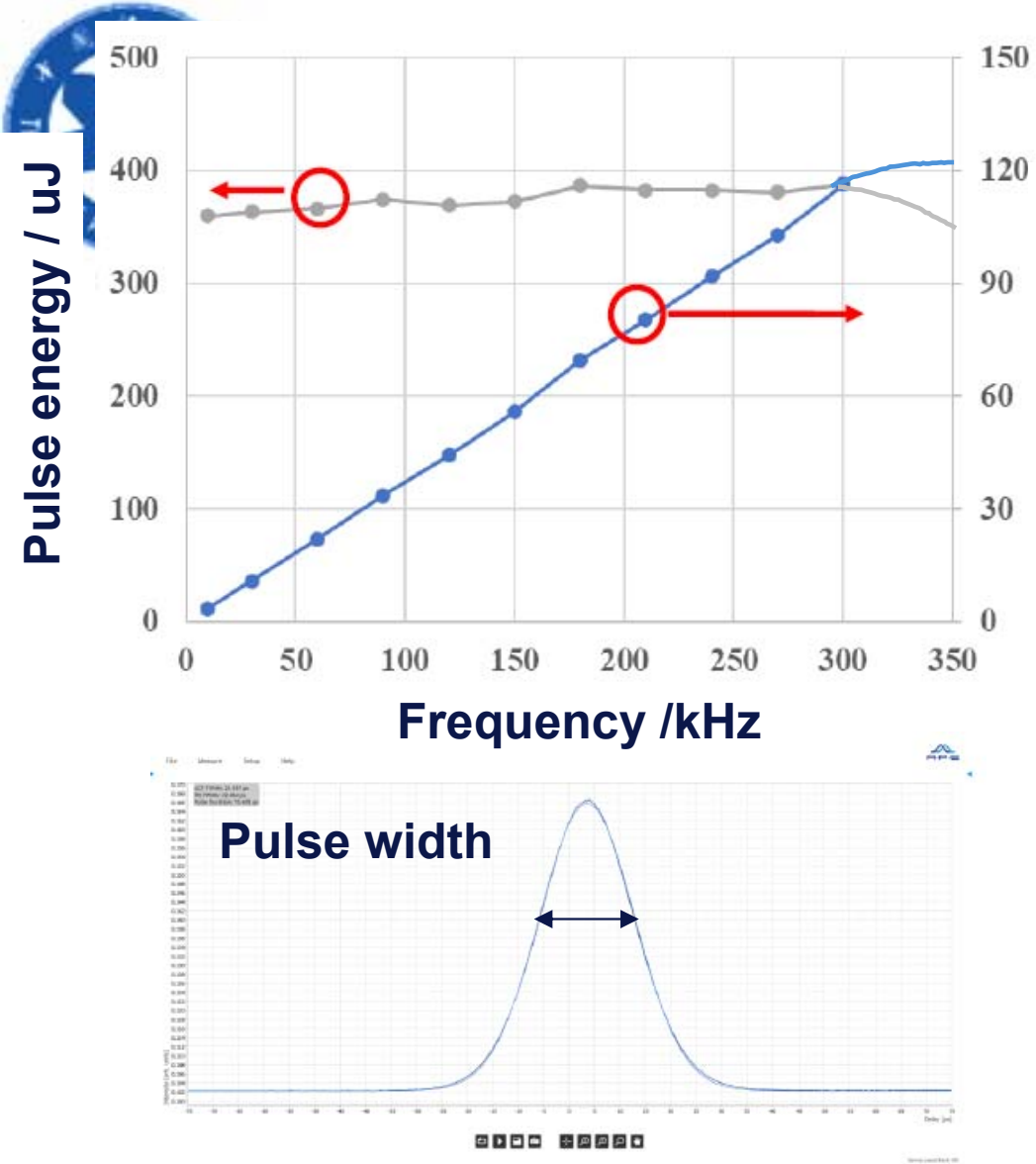
2. Industrial picosecond laser

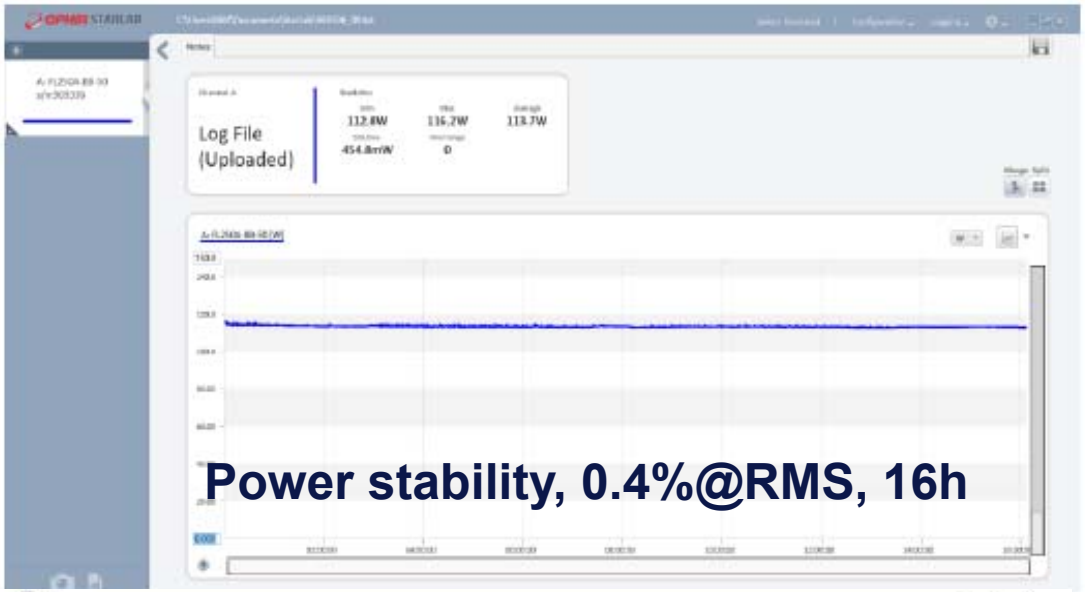
- **A set of industrial-level laser unit from superwave company installed in Shanghai in Nov. 2023**



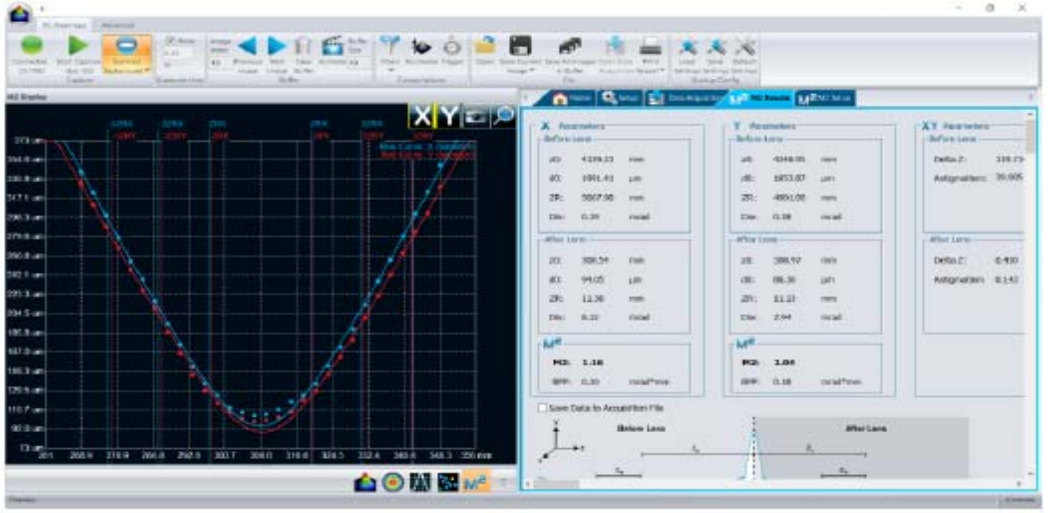
序号	Item		Request	Results
1	working current			12.0A-11.3A-11.7A-8.7A
2	wavelength		532 nm	532 nm&1064 nm
3	frequency		300-1000 kHz	10-1000 kHz
4	Max. power		90 W@532 nm	116.4 W@532 nm
5	Max. energy		300 μJ@532 nm	388 μJ
6	Power stability (RMS@14 hours)		< 1.00 %	0.40 %
7	光束质量 M^2	M^2x	< 1.30	1.16
		M^2y		1.04
8	Divergence	θx	< 0.80 mrad	0.39 mrad
		θy		0.38 mrad
9	Size of beam (出光口 60 cm 处)		2.0 mm±0.5 mm	2.29 mm
10	近场光斑圆度（4σ）		> 90 %	99.0 %
11	远场光斑圆度（4σ）		> 90 %	96.4 %
12	Pulse width		~10 ps	15.6 ps

> 380uJ, ~15ps, 532nm/1064 output





脉冲宽度：15.6 ps@高斯拟合



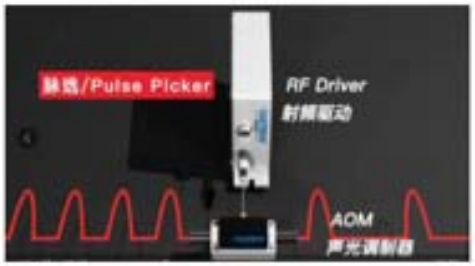
光束质量 M^2 ： $M^2x=1.16$ / $M^2y=1.04$

发散角：$\theta x=0.39$ mrad / $\theta y=0.38$ mrad

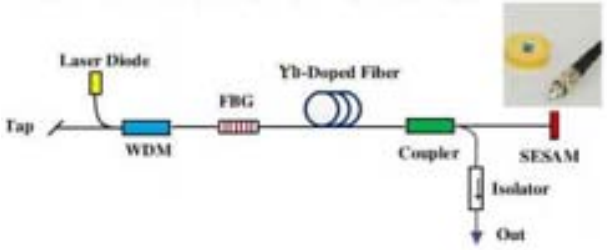
2. Industrial picosecond laser

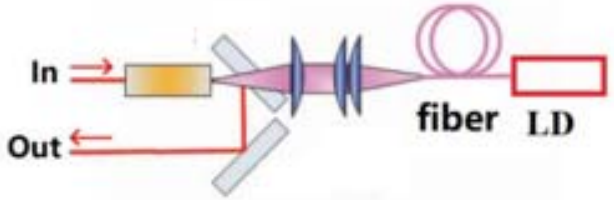
The working mode of traveling wave amplification

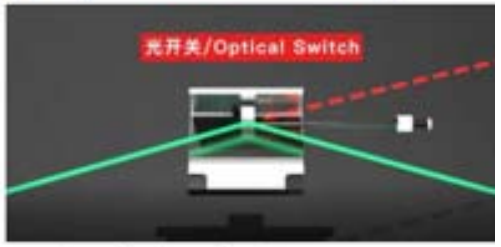
SUPERWAVE



picosecond seed → Pulse picker → Traveling wave amplification1 → Traveling wave amplification2 → optical switch →







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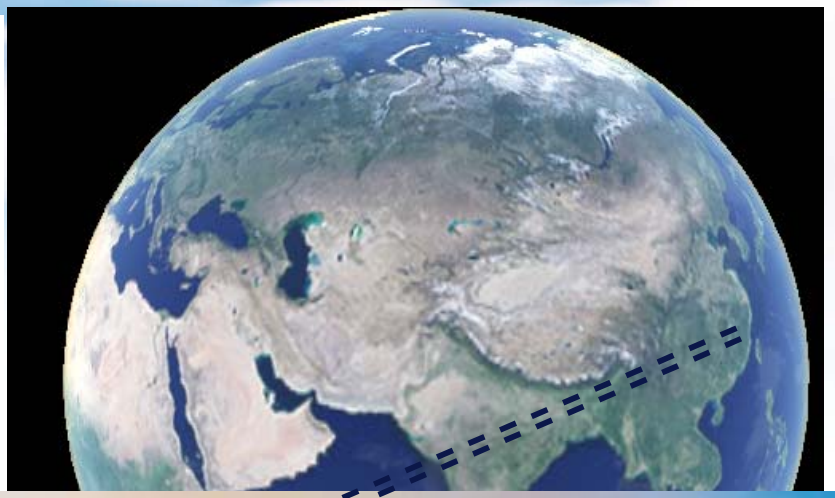
3. Applied in laser ranging

- SLR station is at SheShan mountain ,Shanghai, with altitude of 100m,
- It's an part of Chinese Academy of Sciences, the Latitude is 31.0961 ° N and the Longitude is 121.1866° E.

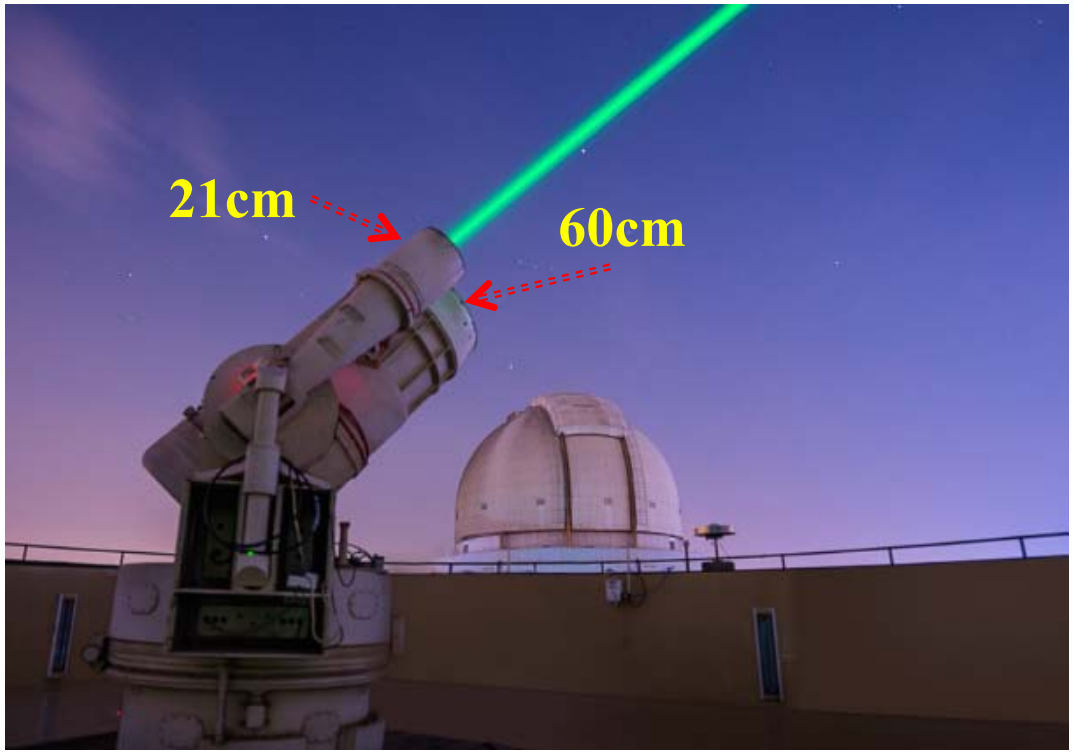
Shanghai - China

Site Code: SHA2
Station #: 7821
DOMES #: 21605S010
31.0961 N, 121.1866 E



3. Applied in laser ranging

- **Shanghai SLR station**



Main specifications of station

Items	60cm telescope
Receiving telescope	R-C system
Tracking mount	Altazimuth
Focus length	5.2m
Diameter of secondary mirror	0.2m
Efficiency of receiving optical system	~60% @532nm
Efficiency of laser detector	SPAD, 20%@532nm
FOV of detection	~135″
Tracking precision (RMS)	~1″
Timing system	A033 Event Timer
Time and Frequency source	Symmetricom@XLi
Efficiency of laser transmitting system	~65% @532nm
Diameter of laser transmitting telescope	21cm
Divergence of laser signal	8~10″

3. Applied in laser ranging

■ 5kHz SLR system

- The frequency of this laser can be adjusted easily for 10-1MHz.
- The day and night SLR measurements with 5kHz are implemented based on the current SLR system.
- For daylight SLR, due to low energy the laser beam is difficult to be monitored for 5kHz, so, increasing the working frequency to 20kHz through control unit to adjust the laser beam pointing. And after that, the working frequency is back to 5kHz.

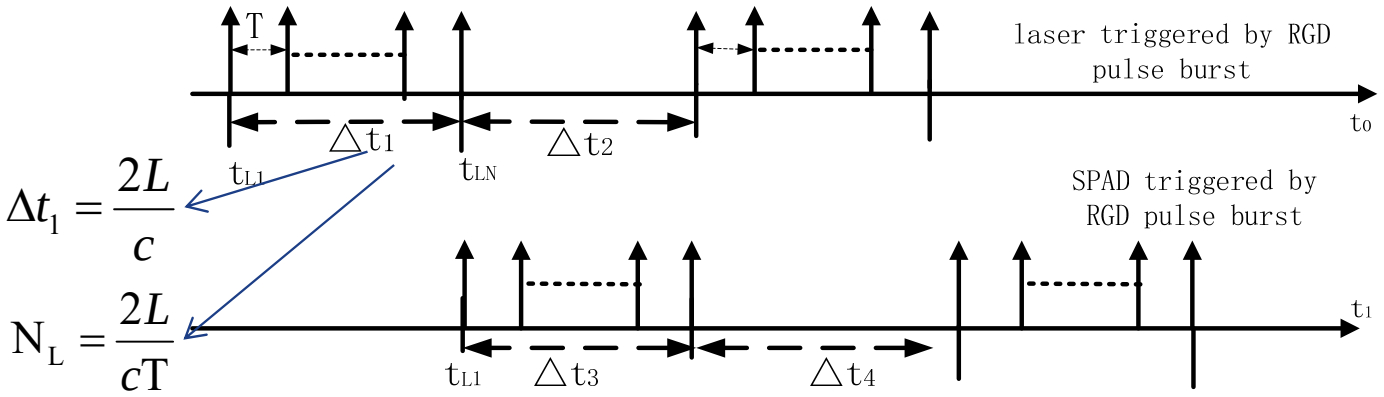
- **Calibration RMS:~ 2 mm because of 15ps pulse width**
- **Ranging precision of satellites are also increased, for GEO satellite, up to 2mm.**

3. Applied in laser ranging

■ 100kHz SLR system

1) Laser atmospheric backscatter noise is one problem for 100kHz SLR
2) And the high dark counts rate is also problem for high repetition rate.

- For solving the laser atmospheric backscatter noise, the method of switching of laser fire and gate signal output is adopted.



$$\Delta t_1 = \frac{2L}{c}$$

$$N_L = \frac{2L}{cT}$$

$$T_L = \Delta t_1 + \Delta t_2 = \frac{4L}{c}$$

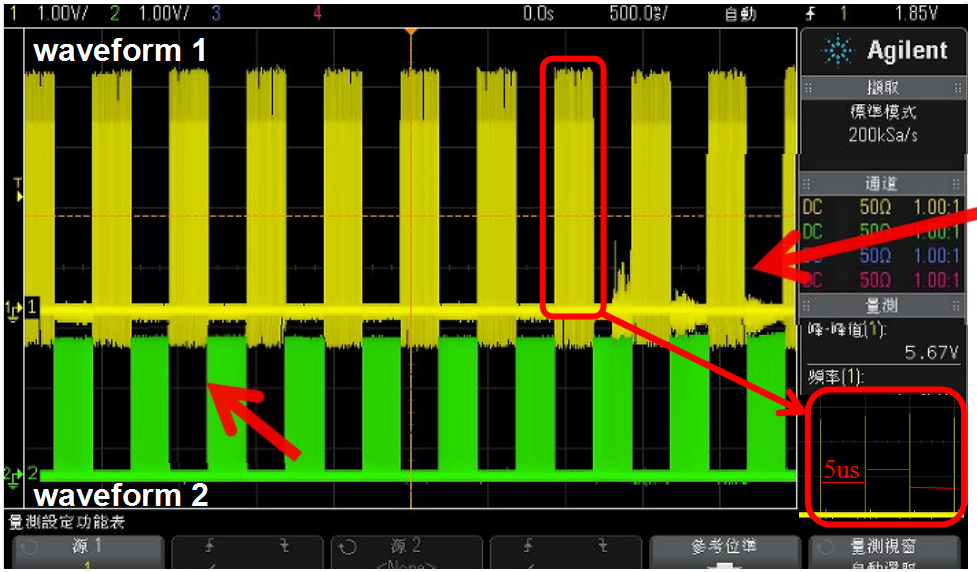
3. Applied in laser ranging

■ 100kHz SLR system

- Our group develops the FPGA RGG generator for switching laser fire and gate signal. For 100kHz rate, the timer interval of fire signal and gate signal is 5us.
- The time period of switching fire and gate is from the predict range of satellite.

Fire

Gate



- RGG generator base on FPGA
- Predict range is input to FPGA unit through RS232 interface per one second

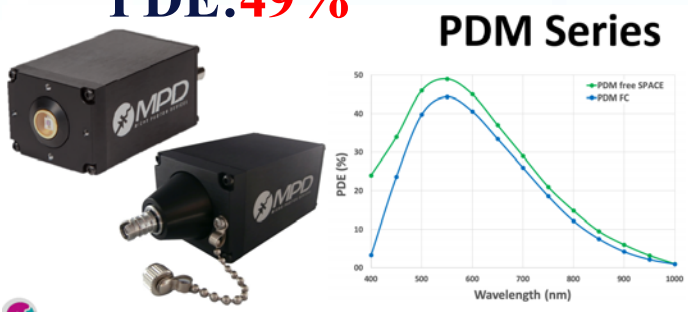
3. Applied in laser ranging

■ 100kHz SLR system

For solving the high dark count rate for APD and SPAD, the MPD detector is used.

- Receiving len for detector is installed by our group to make the best receiving ability.
- The mode of free running within the gate width.
- For the 100kHz, the max. length of gate width is 5us.
- The low time walk for MPD.

PDE:49%



High Photon Detection Efficiency
up to 49% @ 550nm

Best-in class Timing Accuracy
Typ. **35 ps** FWHM

Low Dark Count Rate
as low as **1 cps**, depending on detector diameter

High performance uniformity
across detector area

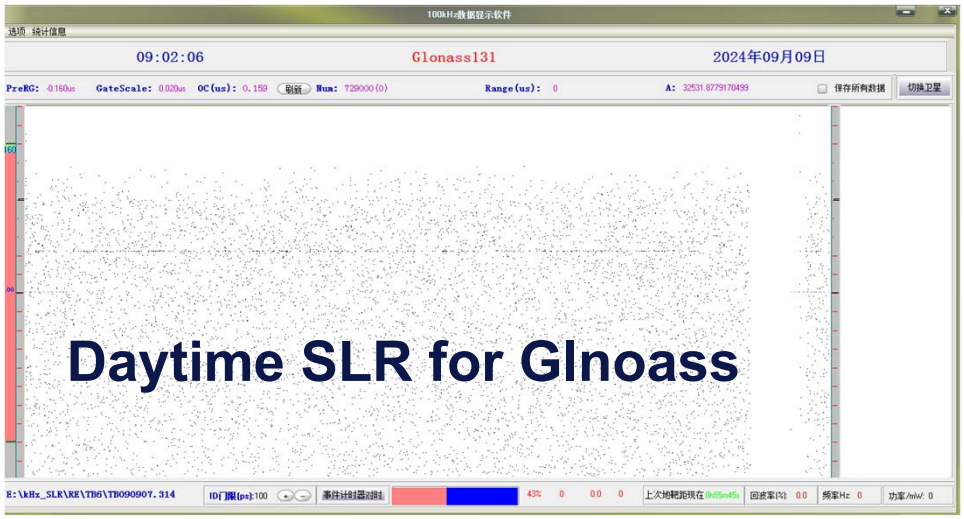
3. Applied in laser ranging

■ 100kHz SLR system

- A033-usb version is used for recording the start and stop epoch.
- Updating software at the aspects of fast processing of start and stop echoes, real-time residual display, post-processing, etc.

3. Applied in laser ranging

- **SLR measurement(100kHz):**
  - **LEO, Lageos, MEO, GEO satellites, day and night.**
  - **The amount of laser data is over over 10 millions for LEO satellites, increasing several magnitude order.**

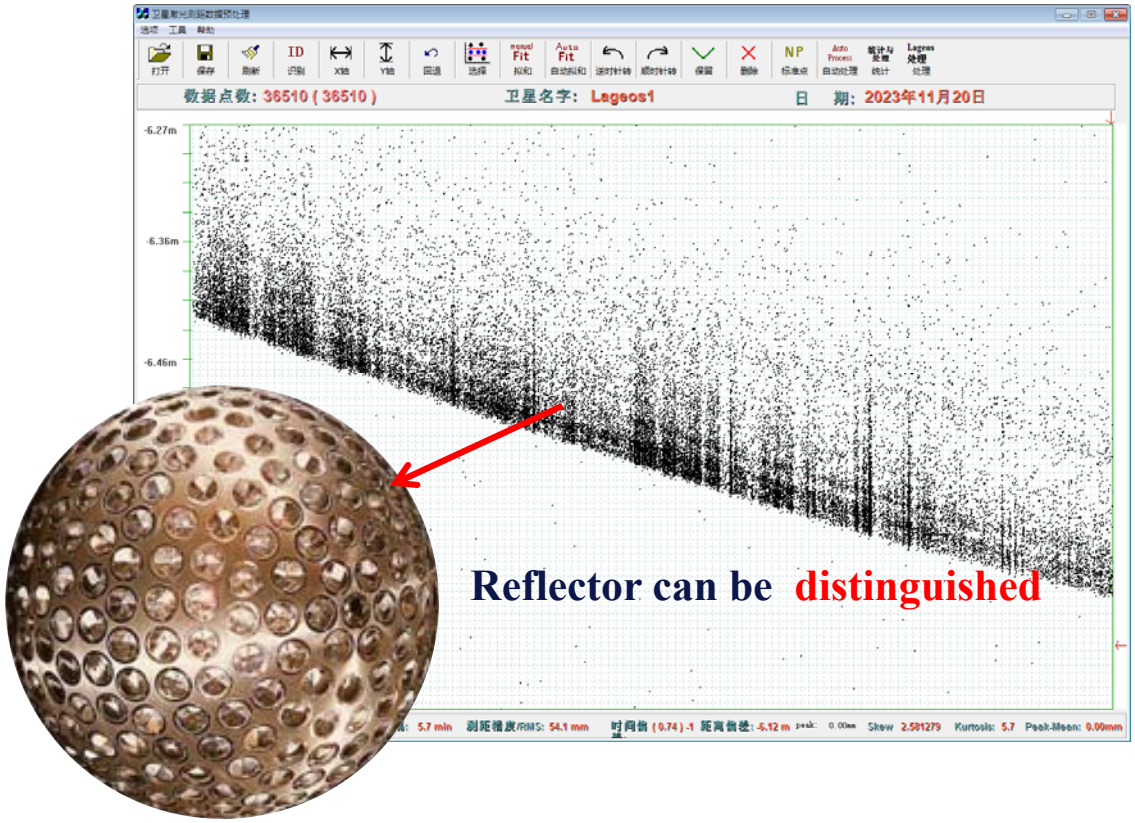


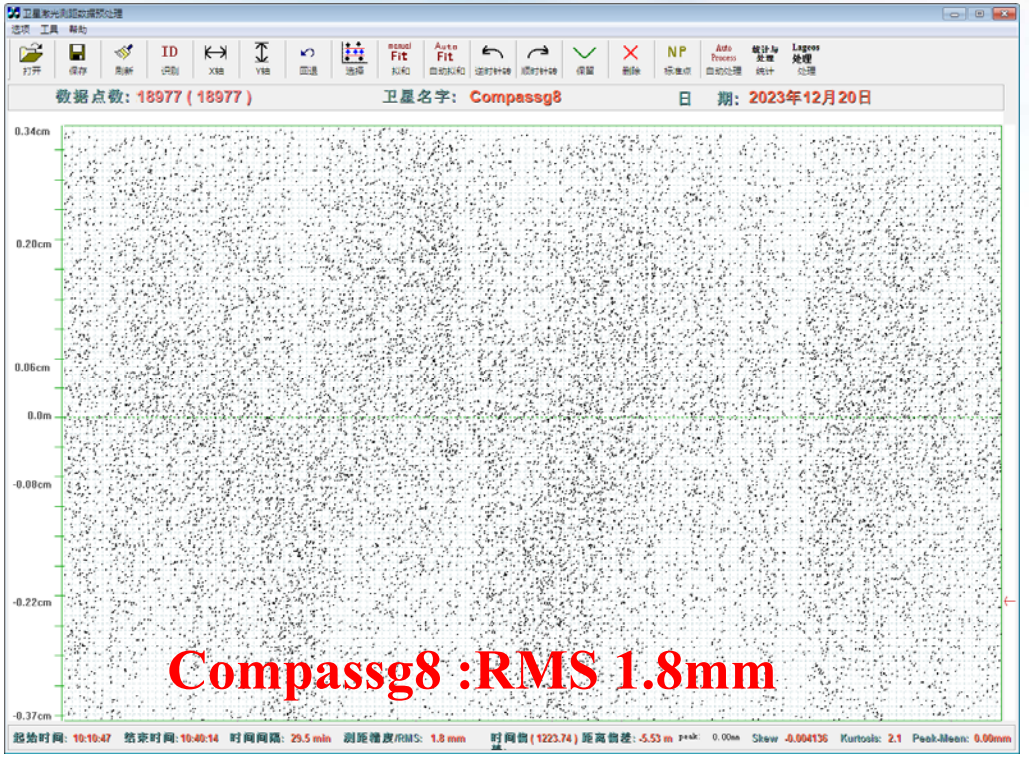
- The laser data are processed by SHAO-POD software and the range bias is normal.

date(YMD)	STime	ETime	SateName	Points	RMS /cm
2024-05-28	13:01:29	13:13:29	compassg8	126291	0.31
2024-05-28	13:37:03	13:38:13	starlette	233941	0.83
2024-05-28	13:14:03	13:17:09	irnsslj	494	1.33
2024-05-28	12:28:58	12:31:25	glonass127	74524	2.45
2024-05-28	12:42:28	12:56:40	beidou3ml9	218015	1.04
2024-05-28	13:23:25	13:31:38	beidou3m5	23203	0.59
2024-05-28	13:32:59	13:36:34	glonassl16	925	1.88
2024-05-28	13:39:31	13:45:37	beidou3i02	6162	0.74
2024-05-28	13:49:06	13:58:15	beidou3ml8	6600	1.23
2024-05-28	12:40:11	12:41:19	stella	92819	0.26
2024-05-28	12:40:11	12:41:18	stella	83078	0.33
2024-08-24	11:27:32	11:33:37	galileo103	5587	1.16
2024-08-31	11:59:00	12:02:21	starlette	238632	0.30
2024-08-31	12:03:19	12:09:14	stella	9999999	0.57
2024-08-31	12:10:00	12:12:35	lares2	12272	0.45
2024-08-31	12:36:02	12:58:38	galileo215	4532	1.66
2024-08-31	12:44:35	13:09:51	lageos1	745132	0.52
2024-08-31	12:59:36	13:02:59	glonass131	1800	2.94
2024-08-31	13:10:35	13:13:16	hy2d	97698	0.80
2024-08-31	13:17:38	13:32:45	lageos2	11494	0.51
2024-08-31	13:35:20	13:45:02	galileo201	9229	0.89
2024-08-31	13:55:34	14:01:05	beidou3m6	141262	0.81
2024-08-31	14:02:31	14:05:55	beaconc	9999999	2.56
2024-08-31	14:07:00	14:21:56	beidou3i02	35924	0.42
2024-08-31	14:26:49	14:31:54	beidou3m22	22311	0.99
2024-08-31	14:33:47	14:43:00	compassi5	1667	1.20
2024-08-31	14:43:52	14:53:04	beidou3ml1	6199	1.44
2024-08-31	14:57:13	15:02:51	lares	2227	0.52
2024-08-31	13:51:35	13:52:32	starlette	96028	0.34
2024-09-06	11:49:02	11:55:26	beidou3i02	69783	0.67
2024-09-06	12:14:08	12:20:19	beidou3ml1	70978	1.01
2024-09-06	12:27:26	12:35:47	galileo218	3981	0.99
2024-09-06	12:36:36	12:42:29	qzs2	152	0.48
2024-09-06	12:45:07	12:55:39	galileo201	19733	0.74
2024-09-06	12:04:59	12:09:13	starlette	1705938	0.71
2024-09-06	11:38:24	12:11:28	lageos1	462489	0.44
2024-09-09	09:15:44	09:18:03	beidou3m24	2178	1.12
2024-09-09	10:16:47	10:25:01	irnsslj	13621	1.16
2024-09-09	09:24:57	09:25:39	starlette	603592	0.49
2024-09-09	10:07:36	10:10:03	lares2	33671	0.37

3. Applied in laser ranging

- High precision and large amount of laser data for investaging satellite signature.

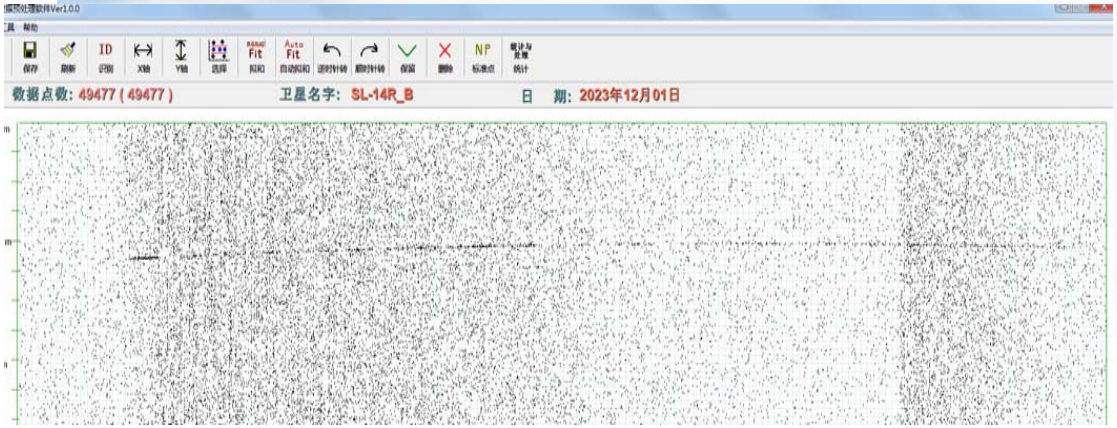




3. Applied in laser ranging

- **DLR measurements(100kHz, the same laser, detector):**
  - Distance of more than 1000km, RCS of >4 m^2, ranging precision of sub-meters.
  - max. distance:1294km, and the smallest cross section (RCS): 4.5m^2.

  Problems:
  - low pulse energy lowing signal-noise-ratio;
  - Bad orbit prediction case the OC residual crossing the frequency interval (5us).



ID	name	RMS(cm)	Maxranging(km)	minranging(km)	RCS(m2)
27561	RUBIN3_SL-	172.9	738	735	6.41
16182	SL-16R_B	235.2	1294	1161	12.05
19650	SL-16R_B	359.5	930	896	5.03
40058	PSLV R/B	71.15	1134.8	910	5. 6
28809	OICETS	0.61	972	863	1. 7
12586	SL-3_R_B	54.58	763	528	7.2
20466	SL-14R_B	103.7	1123	1020	4.5
37215	CZ-4C R/B	47.1	698	694	8.3
23447	SL-14 R/B	588.6	1044.9	887.7	6. 1

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- At Shanghai SLR station, the validations of industrial picosecond laser used for SLR and DLR are performed by using one system.
- The quality of SLR laser data evaluated by POD software is normally.
- Through using this laser unit, one system has the good performance of SLR and laser frequency of kHz to hundred's kHz.
- Due to the convenience of changing the working frequency, the dedicated experiments can be implemented.
- However, for DLR the low pulse energy makes the lower signal-noise-ratio and we will continue to collaboration with the laser company to increase pulse energy.


Thanks for your attentions!