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Lunar Laser Ranging Research and Experiment at Yunnan Observatories

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3 Youth Innovation Promotion Association (YIPA), CAS

Outline

1. Introduction
2. LLR System
3. LLR Observations
4. Summary

Introduction

Photoelectrons

$$n_{pe} = \eta_q \left(E_T \frac{\lambda}{hc} \right) \eta_t G_t \sigma \left(\frac{1}{4\pi R^2} \right)^2 A_r \eta_r T_a^2 T_e^2$$

$$\sim \frac{1}{R^4} E_T \lambda \cdot G_t \cdot A_r \cdot \eta_t \eta_r$$

reciprocal ratio to the 4-power of range

direct ratio to the energy of laser, wavelength, area of receiver, optical efficiency of transmitting and receiving path, transmitter gain

Degnan, John J, 1993lri..workU....D

LLR system of Yunnan Observatories

① Optical System

② Control System

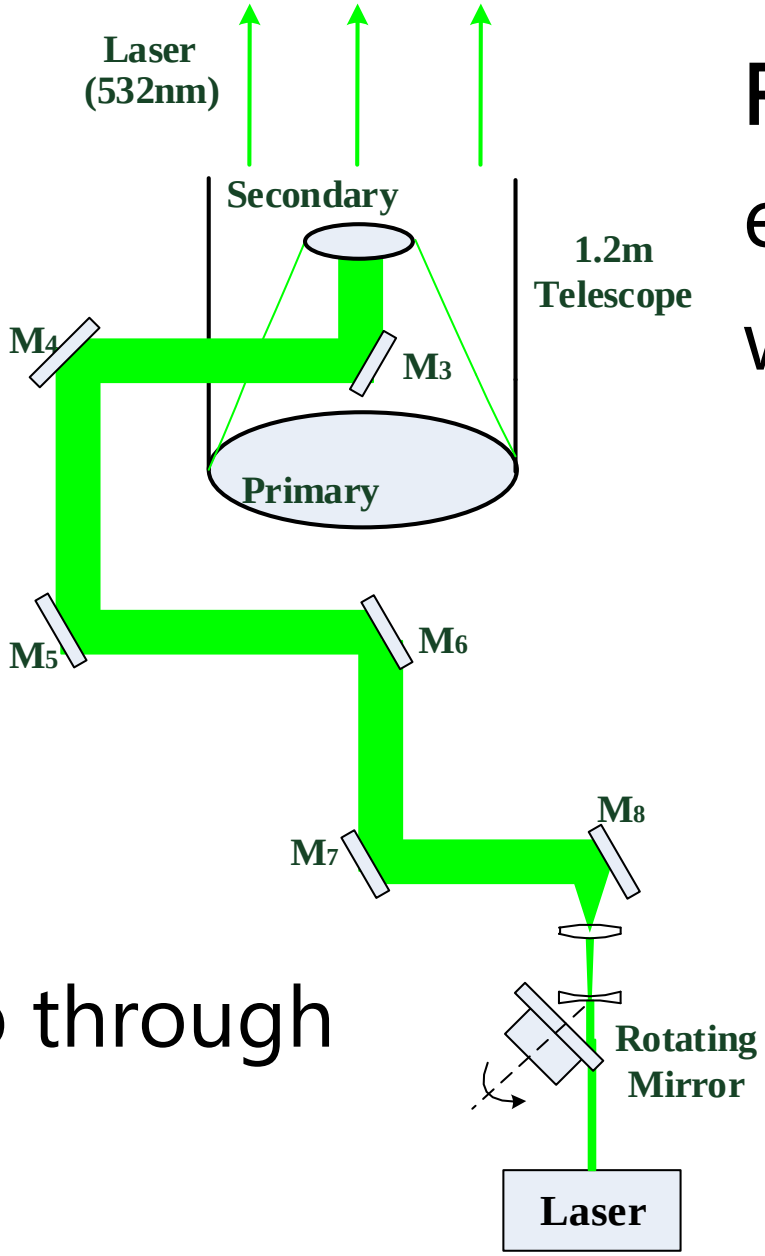
Telescope(upgraded)

Parameter name	Value	Units
Effective aperture	1060	mm
Primary mirror focal length	1800	mm
Secondary mirror focal length	-240	mm
Pointing accuracy	＜1	"
Accuracy-ensured tracking speed - Azimuth	0.004-3	°/s
Accuracy-ensured tracking speed - Altitude	0.004-1	°/s
Max angular velocity - Azimuth	6	°/s

Better servo

Sponsored by Bureau of Facility Support and Budget CAS

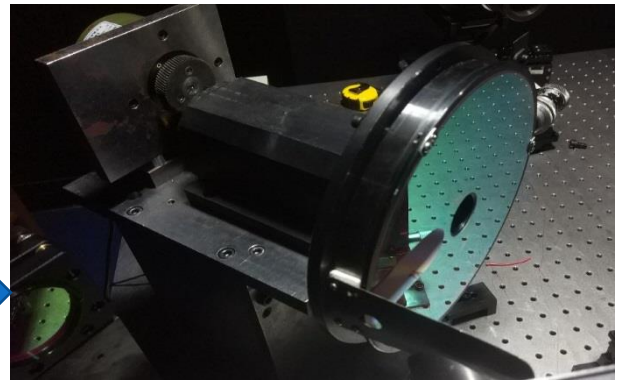
Laser Transmitting Optical Path



Replaced new mirrors except primary mirror with **high reflectivity**.

optics efficency

go through

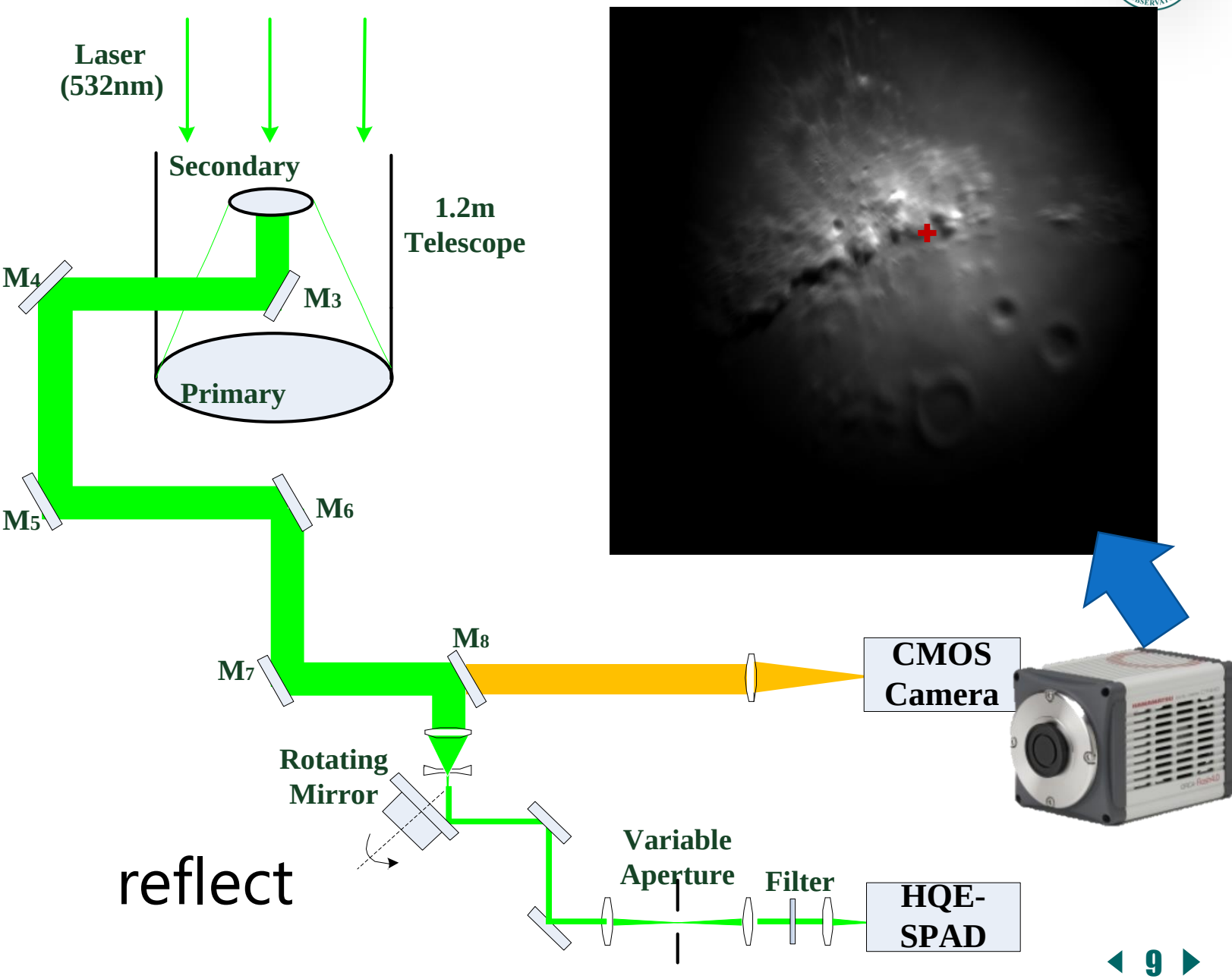


The Laser

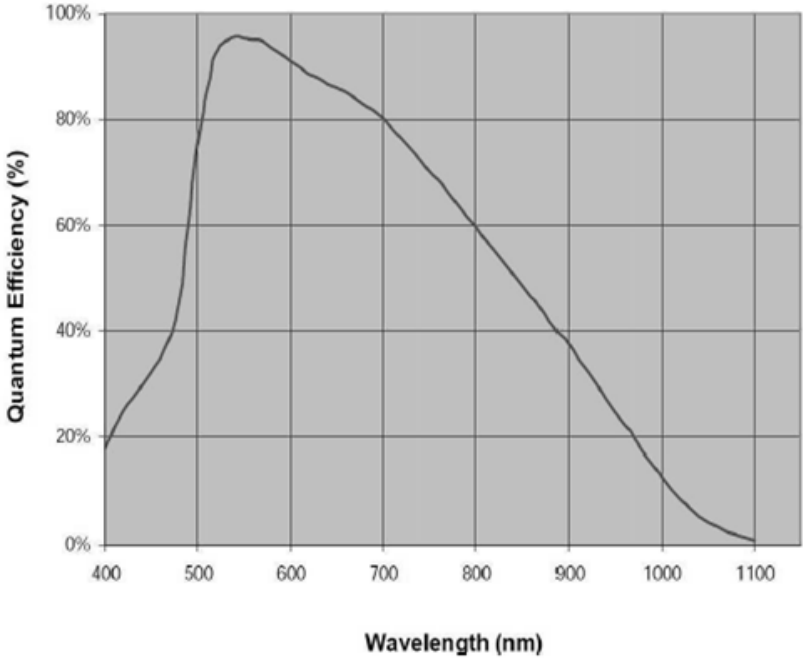
Parameter name	Value	Units
Wavelength	532	nm
Pulse Energy	3.0	J
Repetition Rate	10	Hz
Pulse Width	10	ns
Divergence Angle	0.5	mrad
Beam Diameter	22	mm

optimized: small divergence

Receiving Optical Path

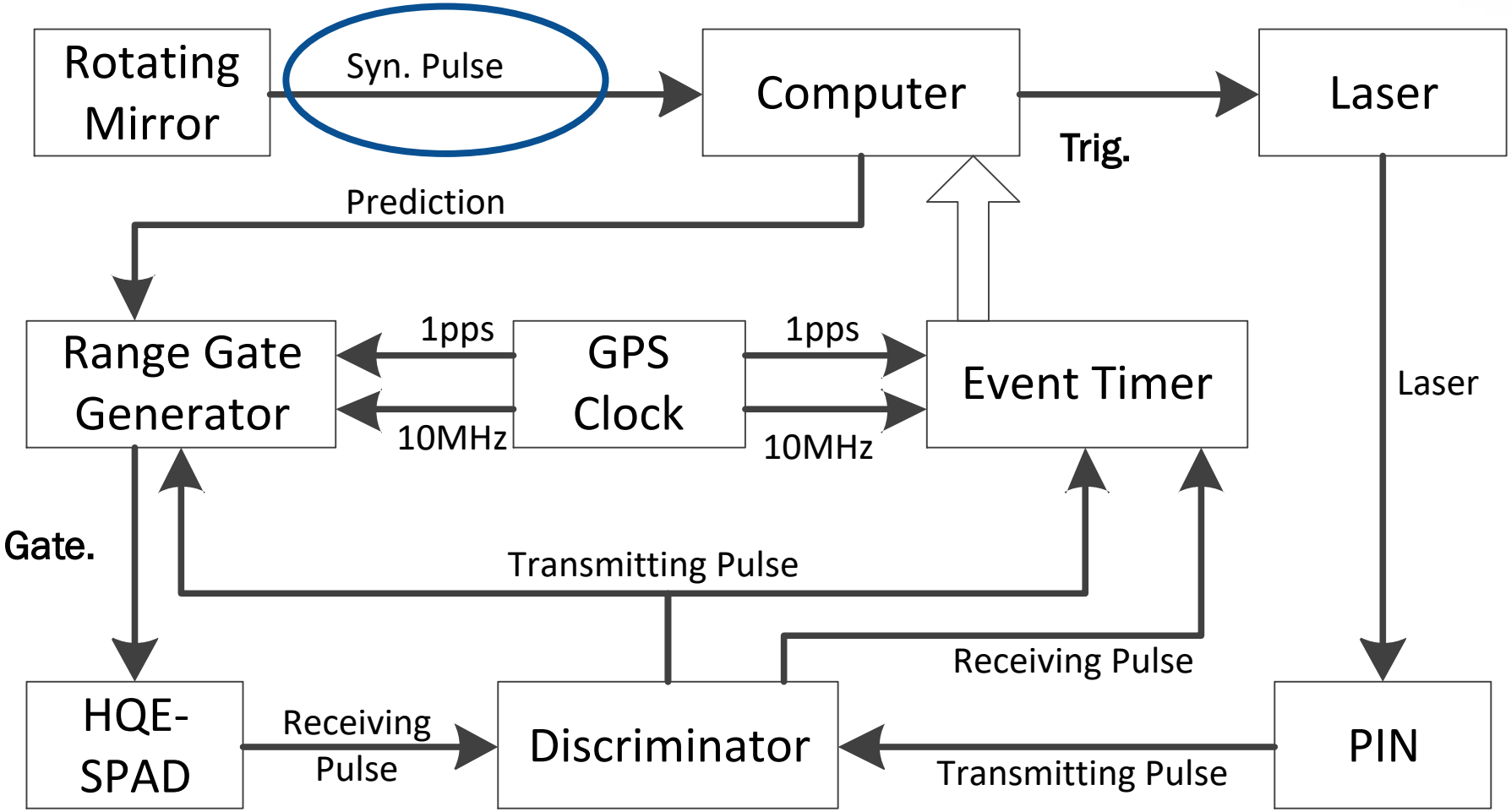


HQE-SPAD

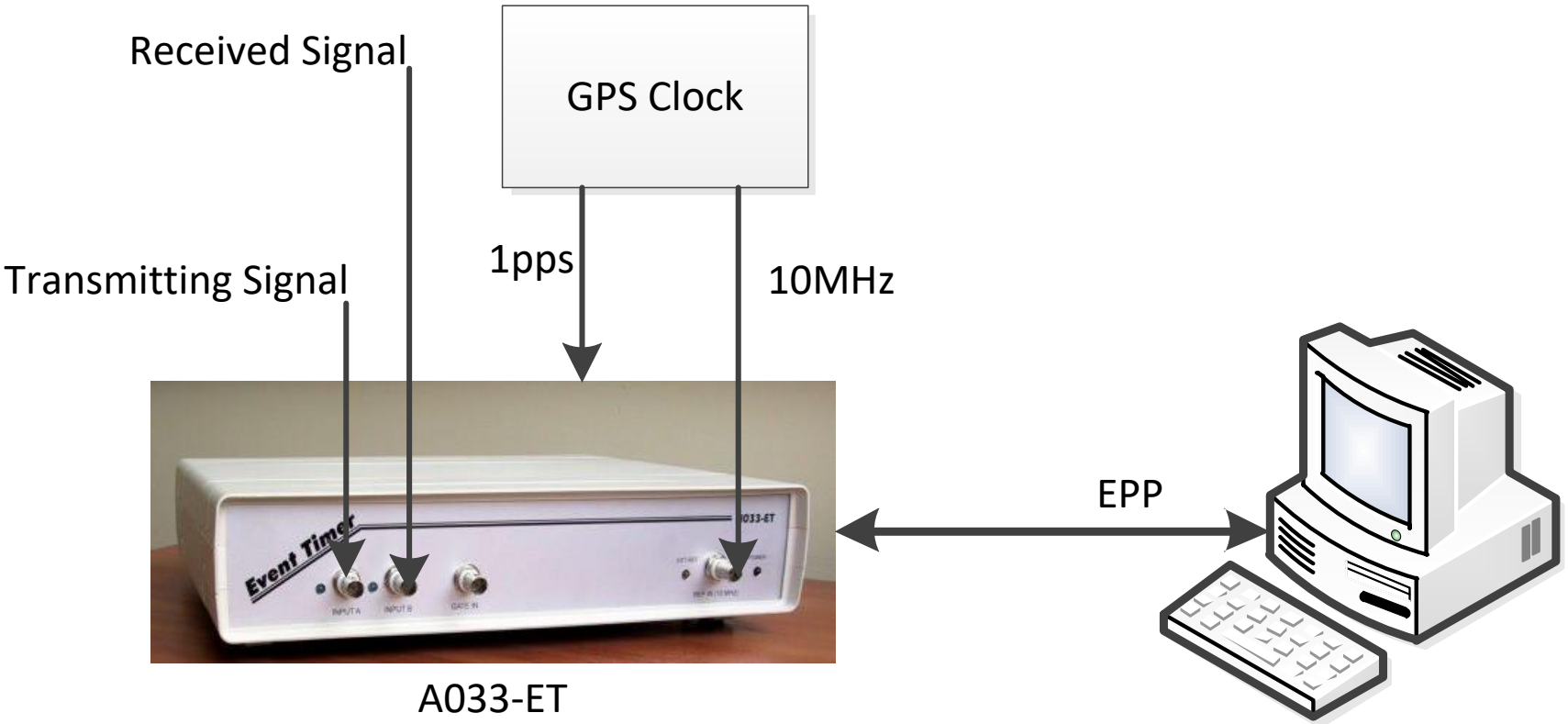


Parameter name	Value
Photosensitive Area Diameter	500μm
Quantum Efficiency (@532nm)	**> 60%**
Dark Count (@1kHz)	**15**
Recovery Time	50ns
Time Jitter	160ps

Ranging Control System



Data Collection



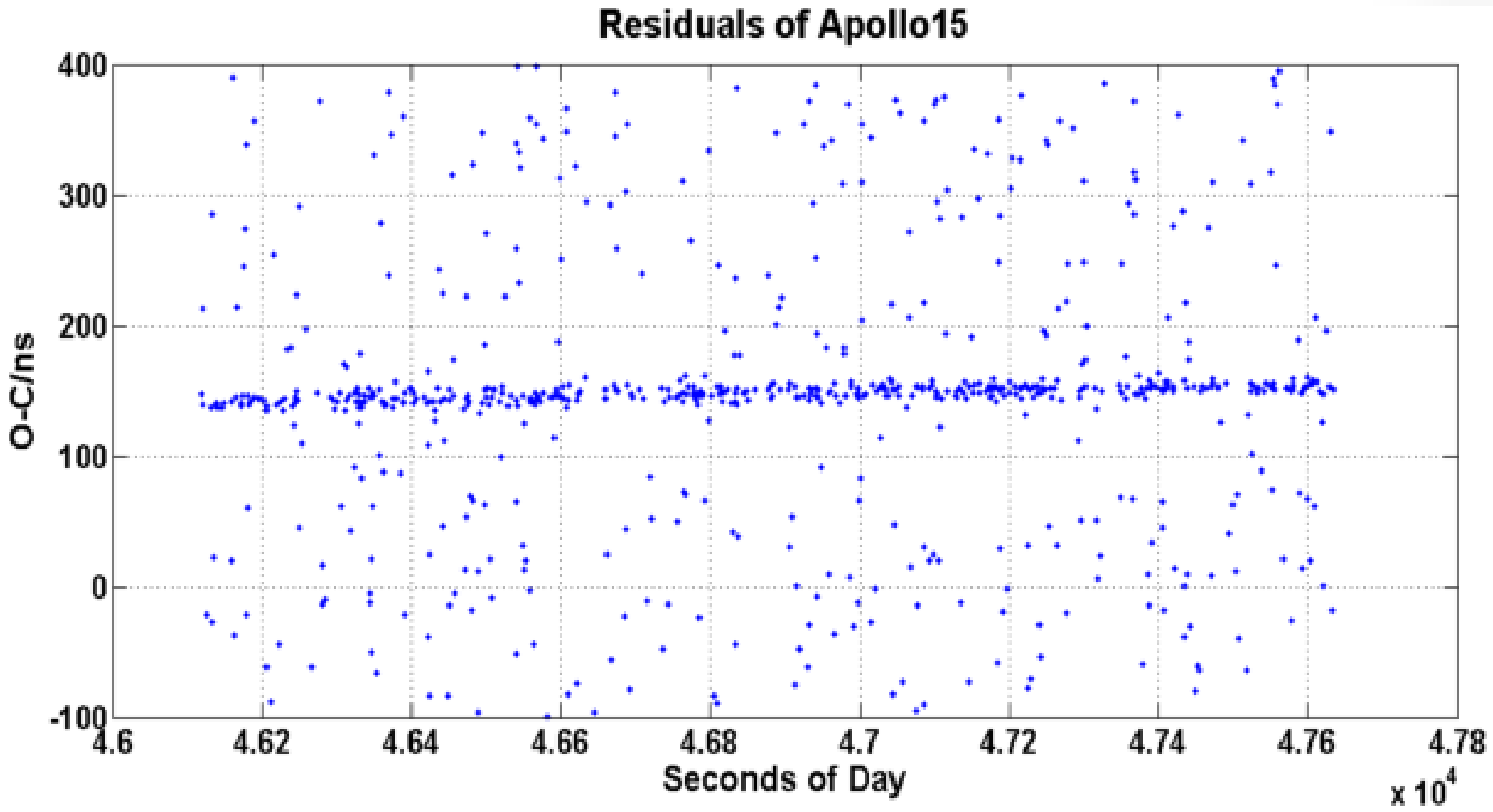
EvenTech

LLR Observations

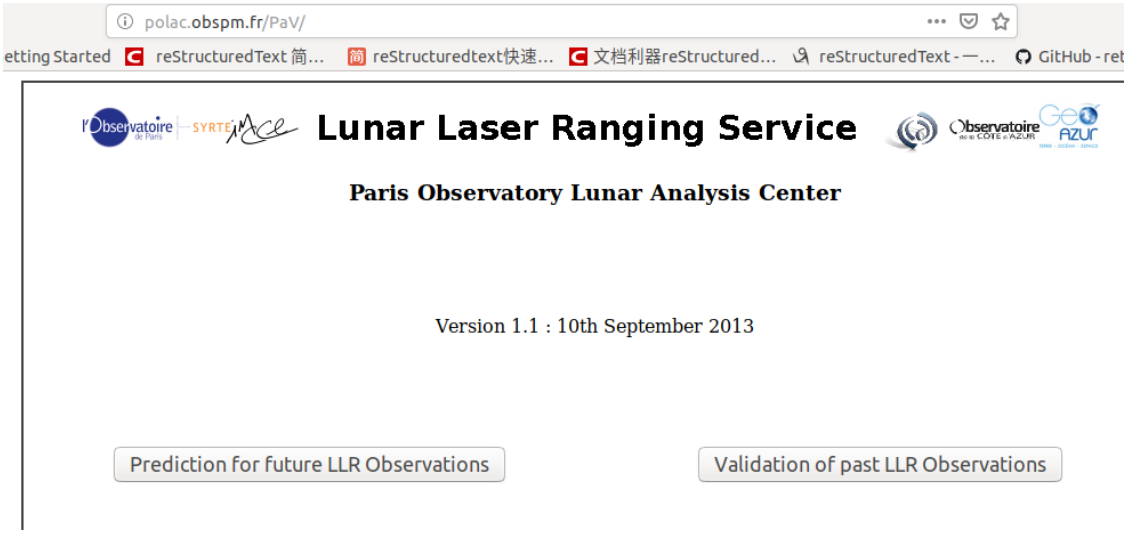
① Observations

② Signal Recognition

Residuals of Apollo-15



Data Verification



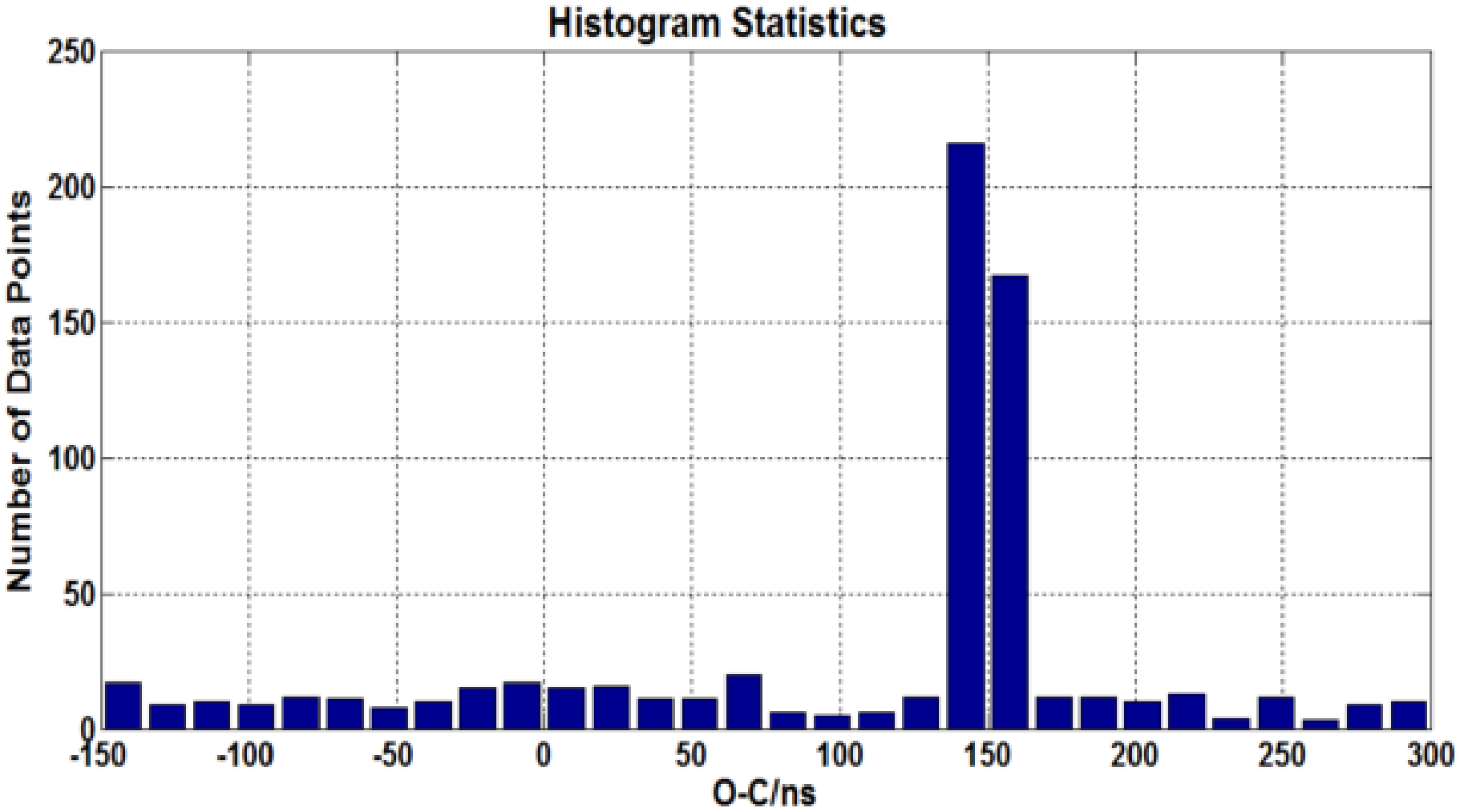
http://polac.obspm.fr/PaV/

- Results of the Normal Points

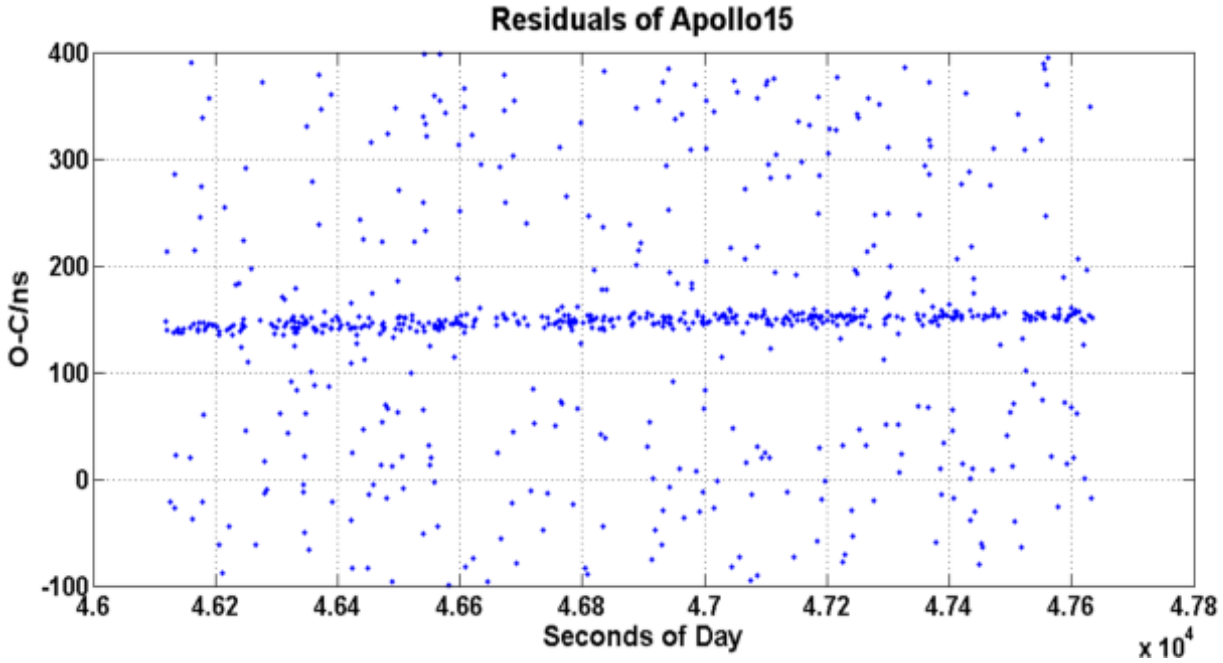
```
Normal Points : 00035
Valid         : 00031
Wrong (***)   : 00004     Limit:      1.000 m

R0 Apollo 11  : 00003     Bias:      -0.053 m      -0.352 ns      St.dev. :      0.752 m      5.020 ns
R2 Apollo 14  : 00005     Bias:      -0.219 m      -1.459 ns      St.dev. :      0.375 m      2.505 ns
R3 Apollo 15  : 00023     Bias:      -0.303 m      -2.023 ns      St.dev. :      0.329 m      2.197 ns
   Global     : 00031     Bias:      -0.265 m      -1.770 ns      St.dev. :      0.405 m      2.700 ns
```

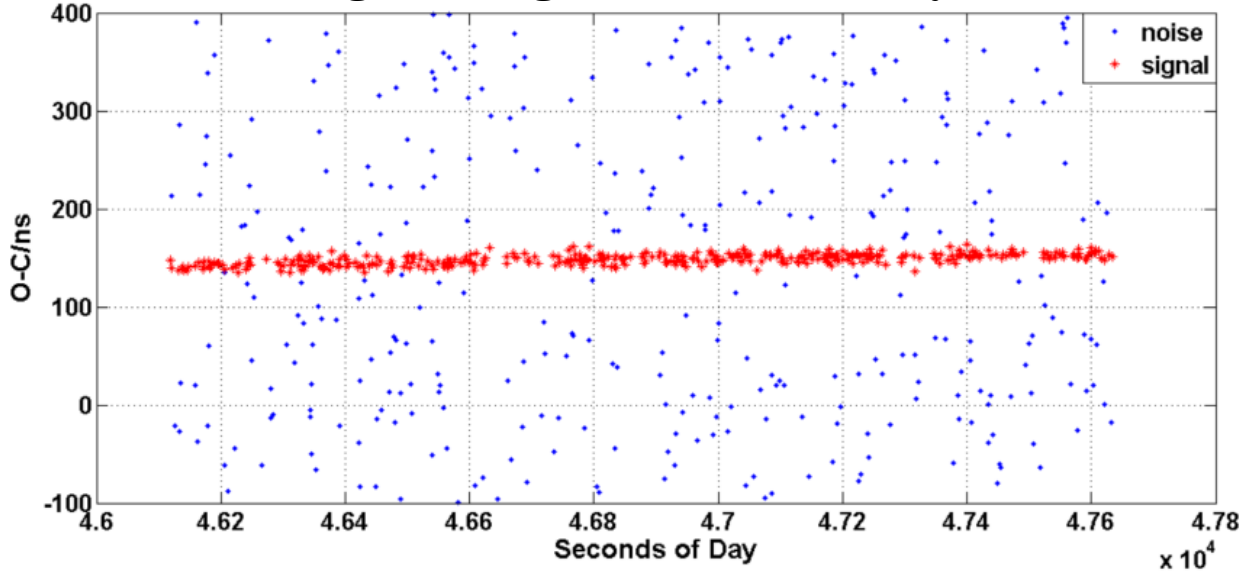
Signal Recognition



Signal Recognition



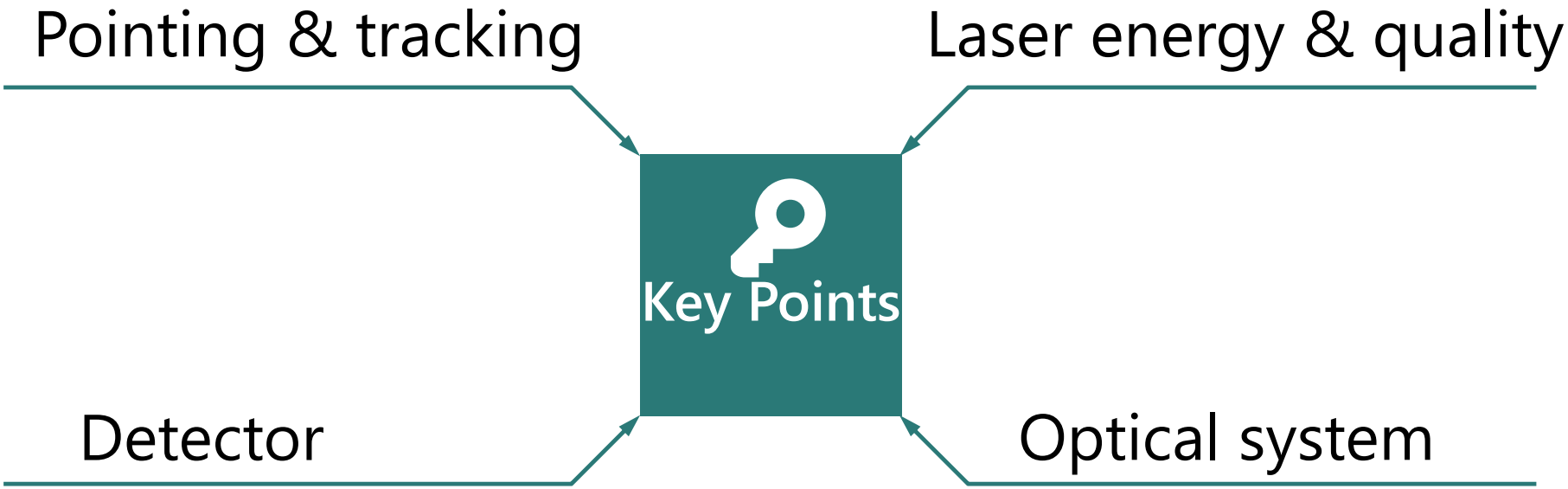
signal recognition automatically



LLR Data statistics

Date	A-15	A-11	A-14	Luna17
2018/01	12	3	4	0
2018/02	10	0	0	0
2018/03	3	0	1	0
2019/03	6	0	0	0
2019/04	1	0	0	0
2019/06	14	1	1	2
Total	46	4	6	2

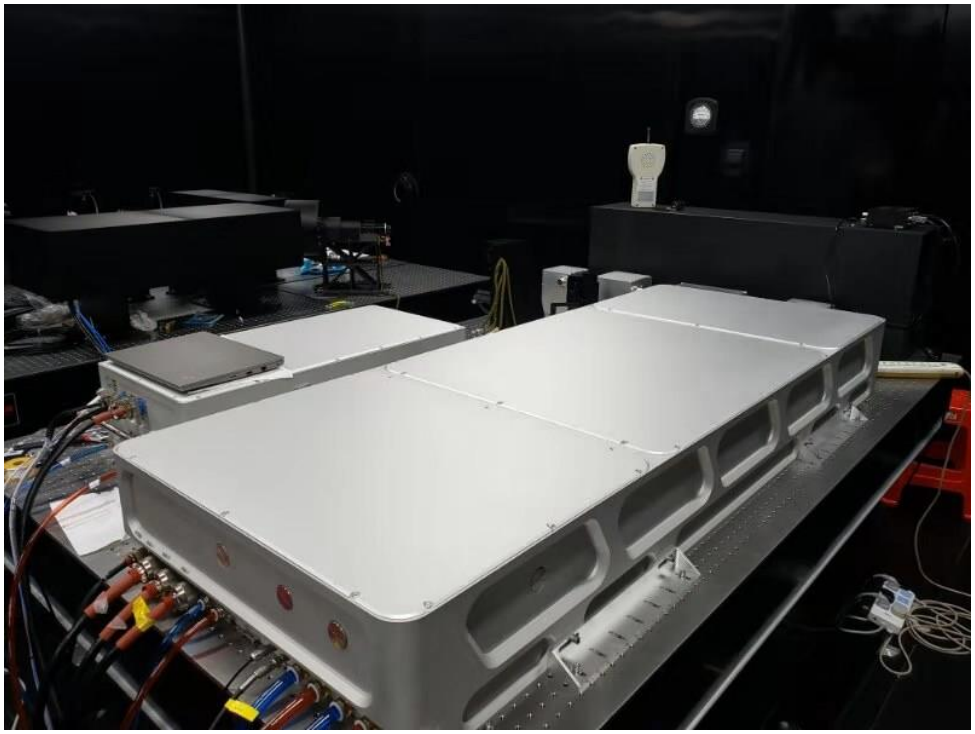
Summary



We got 58 NPs of LLR.

Next Step: focus on precision

Outlook



Made in China
Aerospace Information Research Institute, CAS

Wavelength: 1064nm
Repetition frequency : 100Hz
Pulse energy: 320mJ
Pulse width: 65ps
optical quality: M^2 2.4

The laser is scheduled to be installed at the Yunnan Observatories next year.

Acknowledgments

We all wish to thanks：

- **Paris Observatory Lunar Analysis Center** for providing predications, validations service, and many helps.

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Thanks for your attention

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