21st International Workshop on Laser Ranging

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Development on Lunar Laser Ranging at Yunnan Observatories

Xiong Y[1], Li R[1,2], Li Y[1,2], Li Z[1,2], Zhai D[1,2], Fu H, Tang R, Pi X , Zhang H

1 Yunnan Observatories, CAS, Kunming Yunnan, China

2 Key Laboratory of Space Object and Debris Observation, CAS

Outline

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

Introduction

Photoelectrons

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

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

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

LLR system of Yunnan Observatories

① Optical System

② Control System

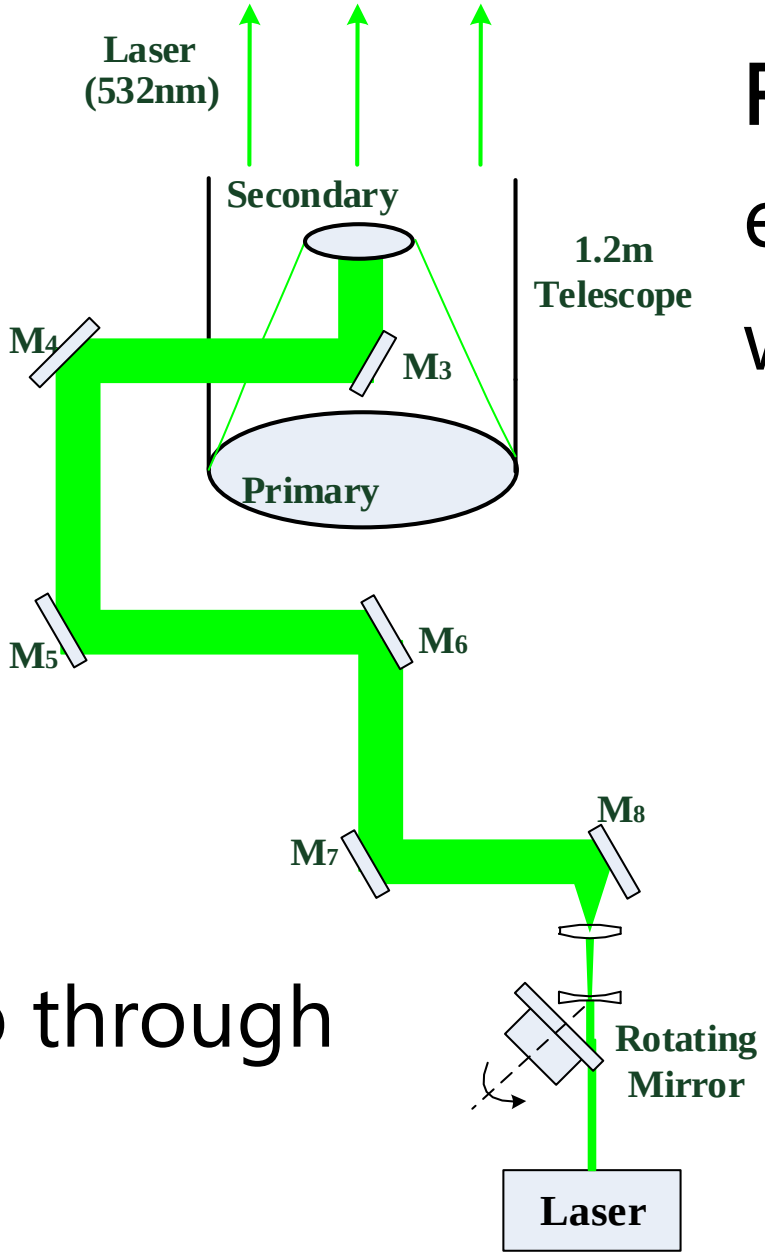
Telescope(upgraded)

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

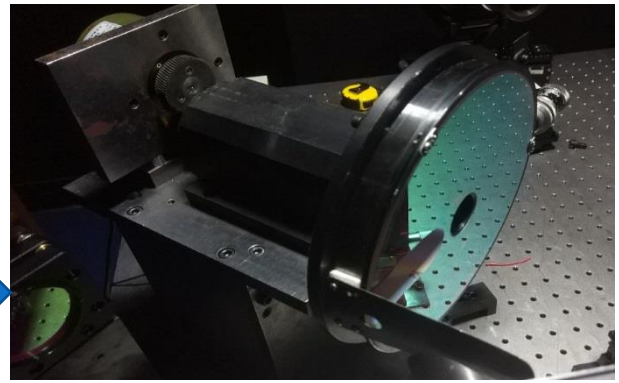
Laser Transmitting Optical Path



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

optics efficency

go through

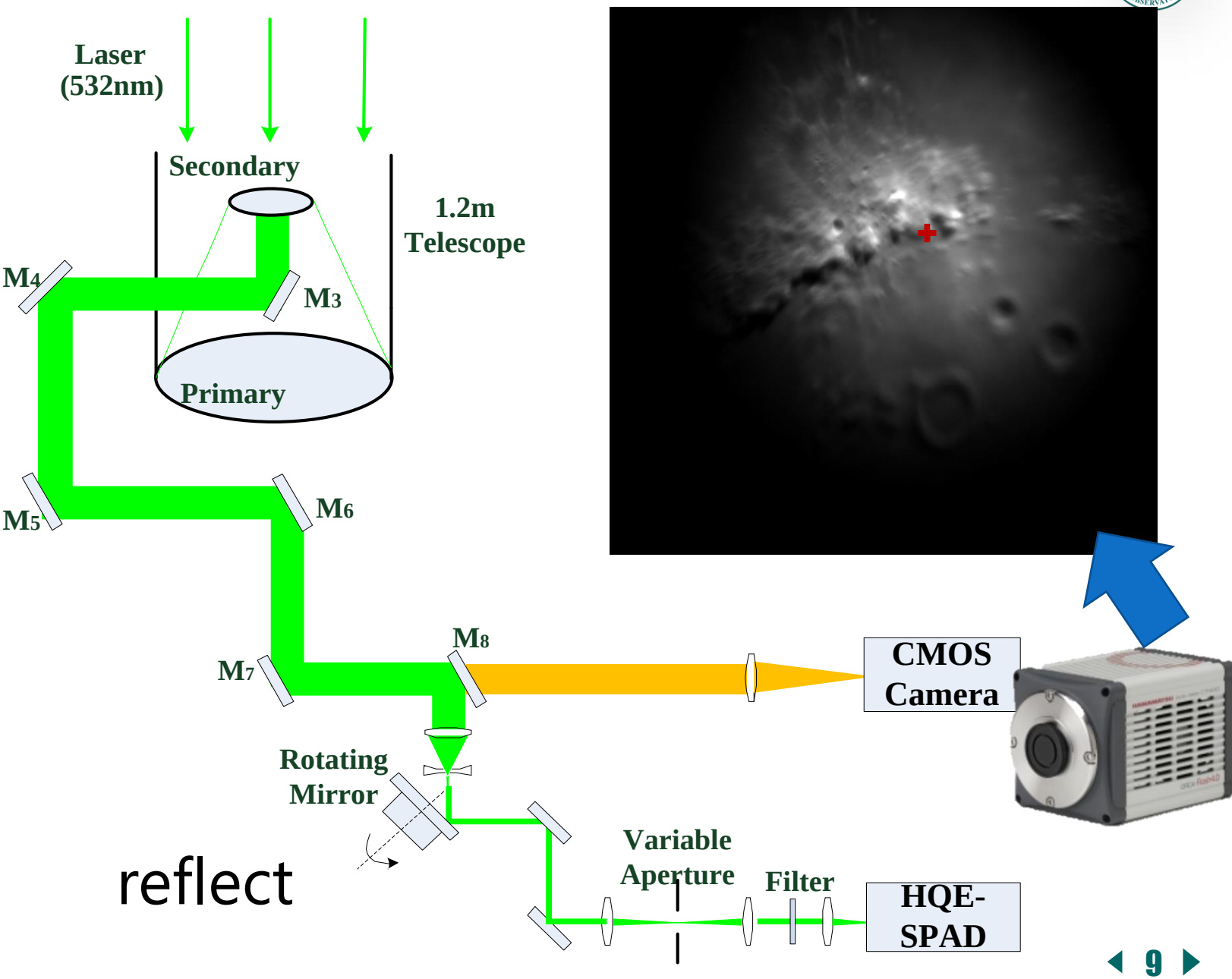


The Laser

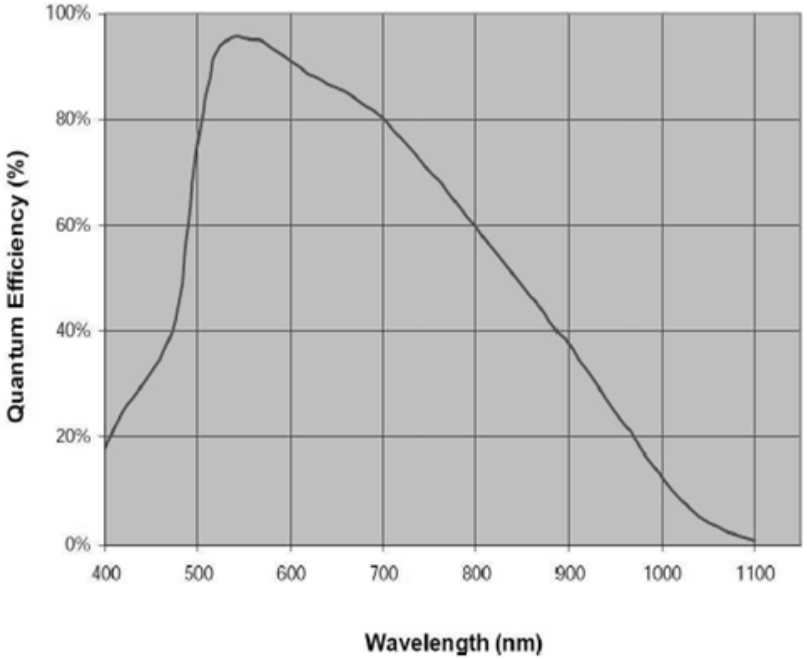
Parameter name	Value	Units
Wavelength	532	nm
Pulse Energy	3.0	J
Repetition Rate	10	Hz
Pulse Width	10	ns
Divergence Angle	0.5	mrad
Beam Diameter	22	mm

optimized: small divergence

Receiving Optical Path

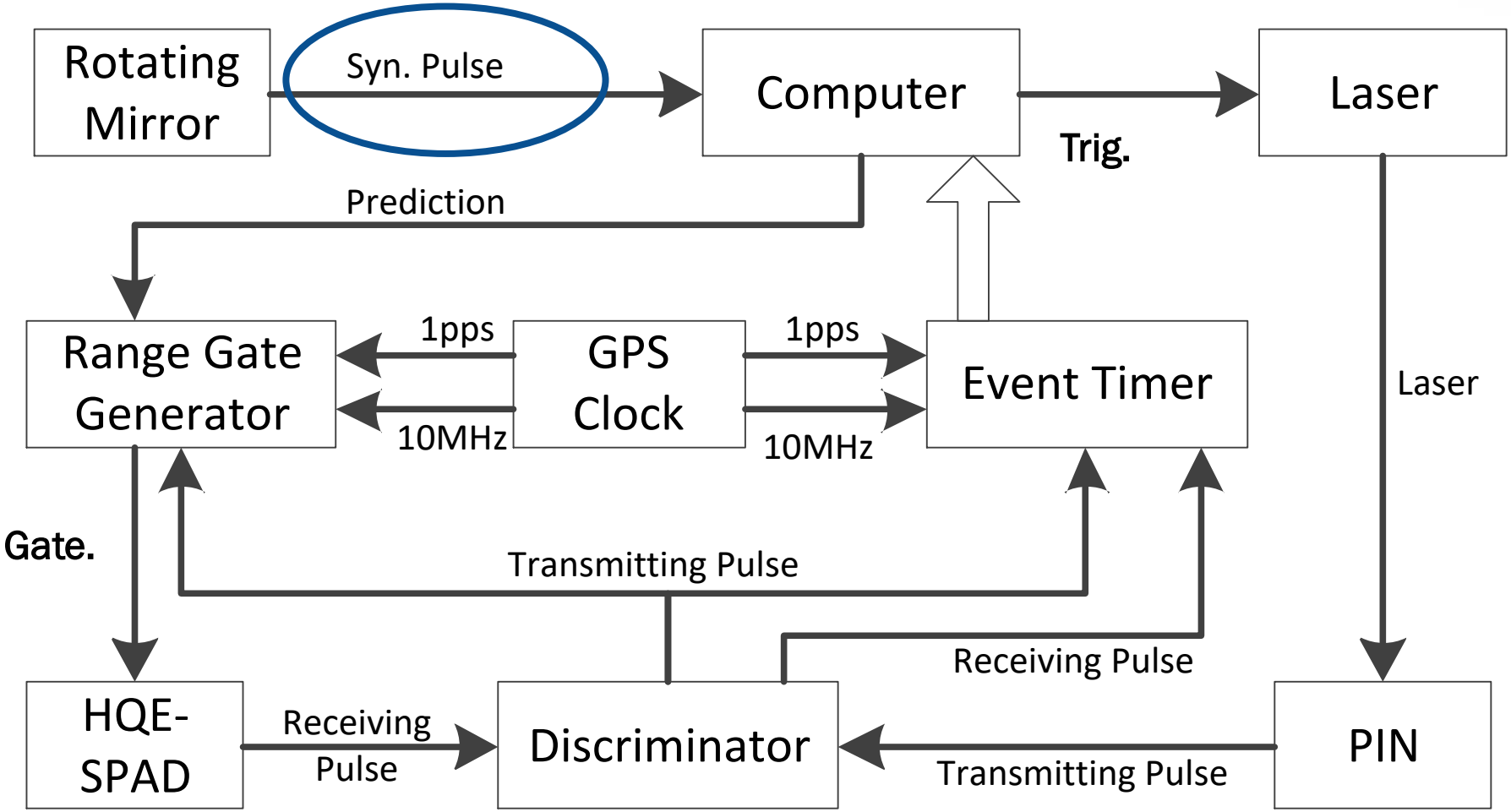


HQE-SPAD

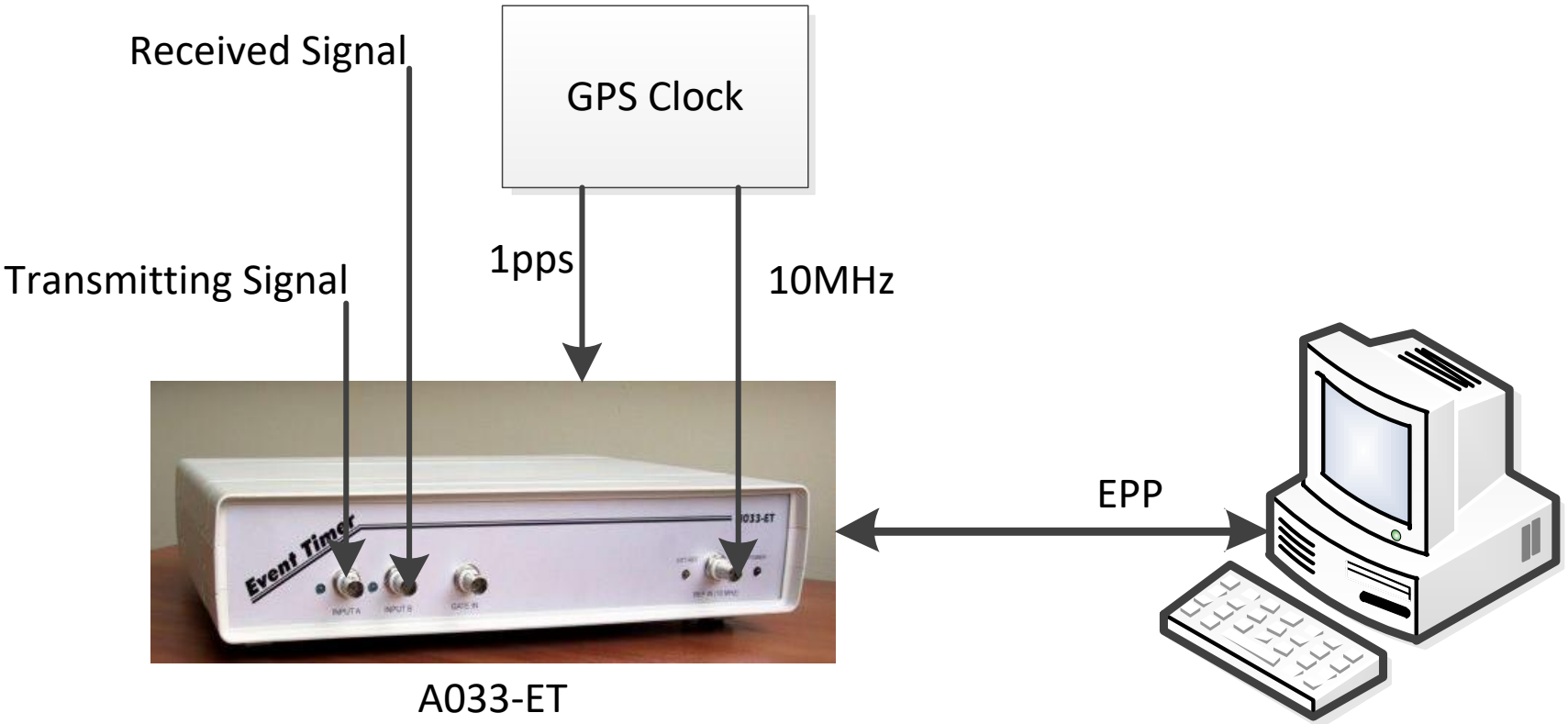


Parameter name	Value
Photosensitive Area Diameter	500μm
Quantum Efficiency (@532nm)	**> 60%**
Dark Count (@1kHz)	**15**
Recovery Time	50ns
Time Jitter	160ps

Ranging Control System



Data Collection



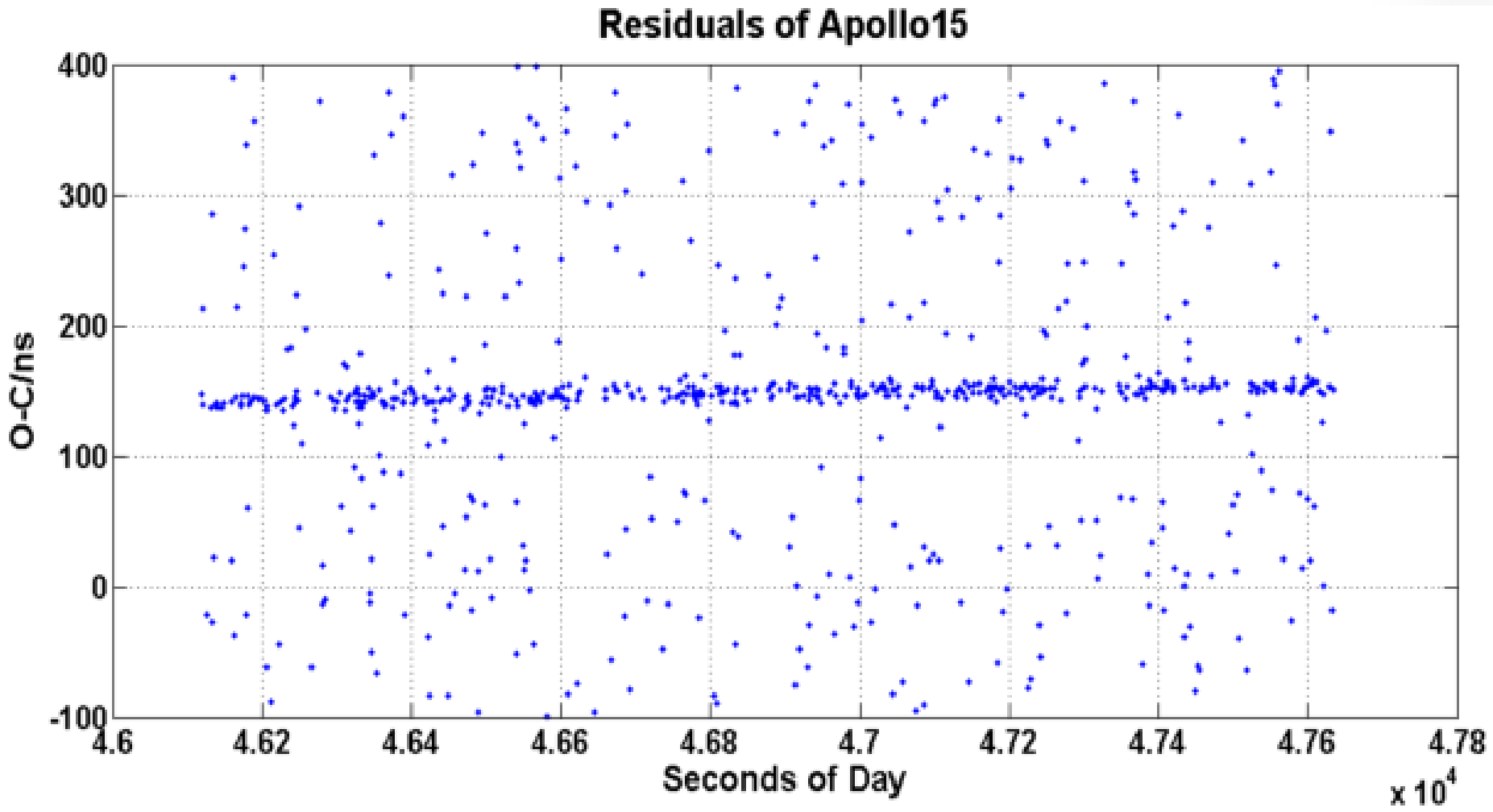
EvenTech

LLR Observations

① Observations

② Signal Recognition

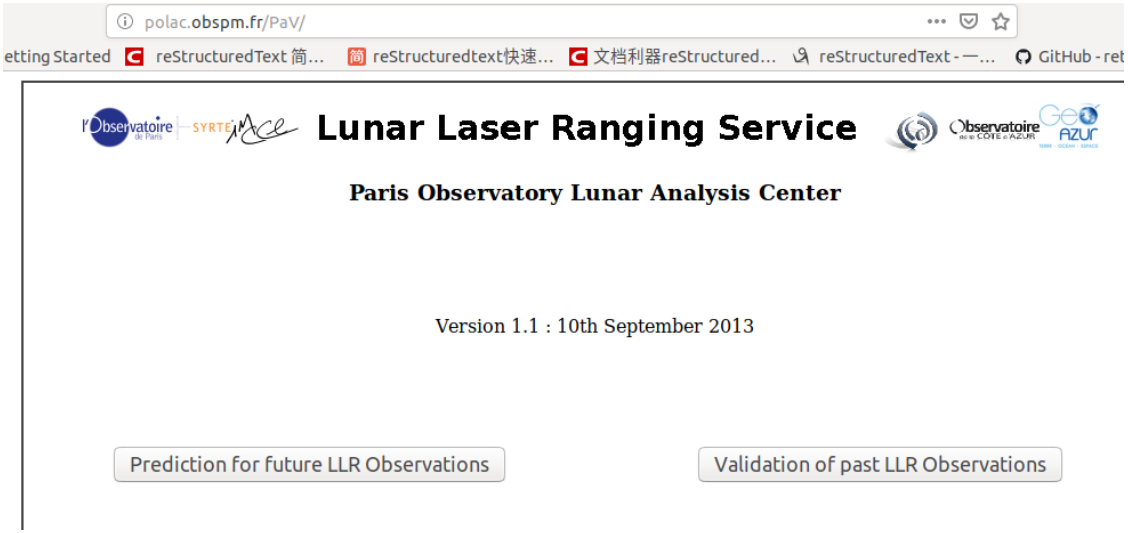
Residuals of Apollo-15



LLR Data List

Date	A-15	A-11	A-14	Daily Total
2018/1/22	3	0	0	3
2018/1/23	3	2	1	6
2018/1/24	1	0	1	2
2018/1/26	3	1	2	6
2018/1/27	1	0	0	1
2018/1/28	1	0	0	1
2018/2/20	1	0	0	1
2018/2/21	2	0	0	2
2018/2/22	3	0	0	3
2018/2/23	1	0	0	1
2018/2/24	2	0	0	2
2018/2/25	1	0	1	2
2018/3/23	2	0	0	2
2018/3/24	2	0	1	3
Total	26	3	6	35

Data Verification

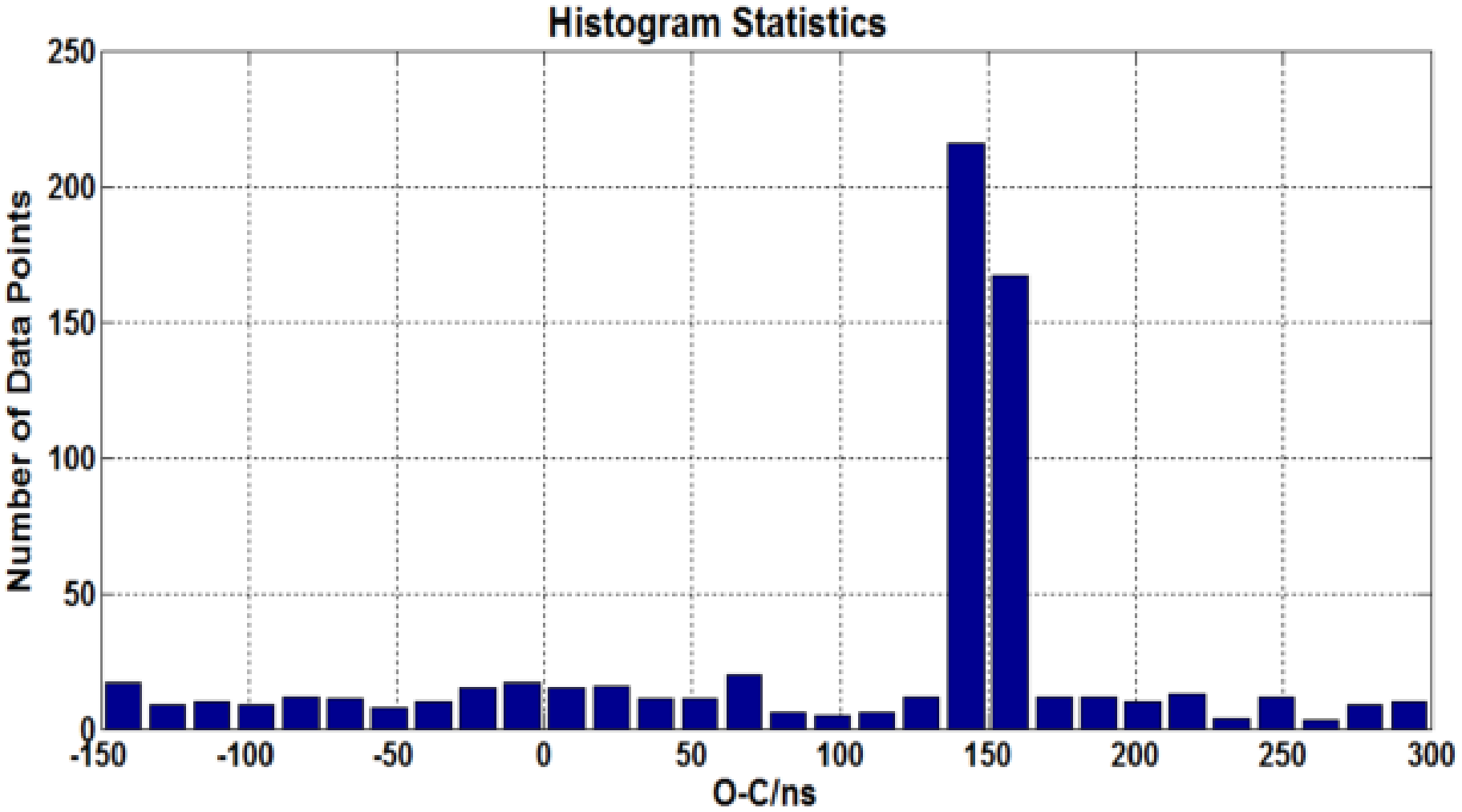


http://polac.obspm.fr/PaV/

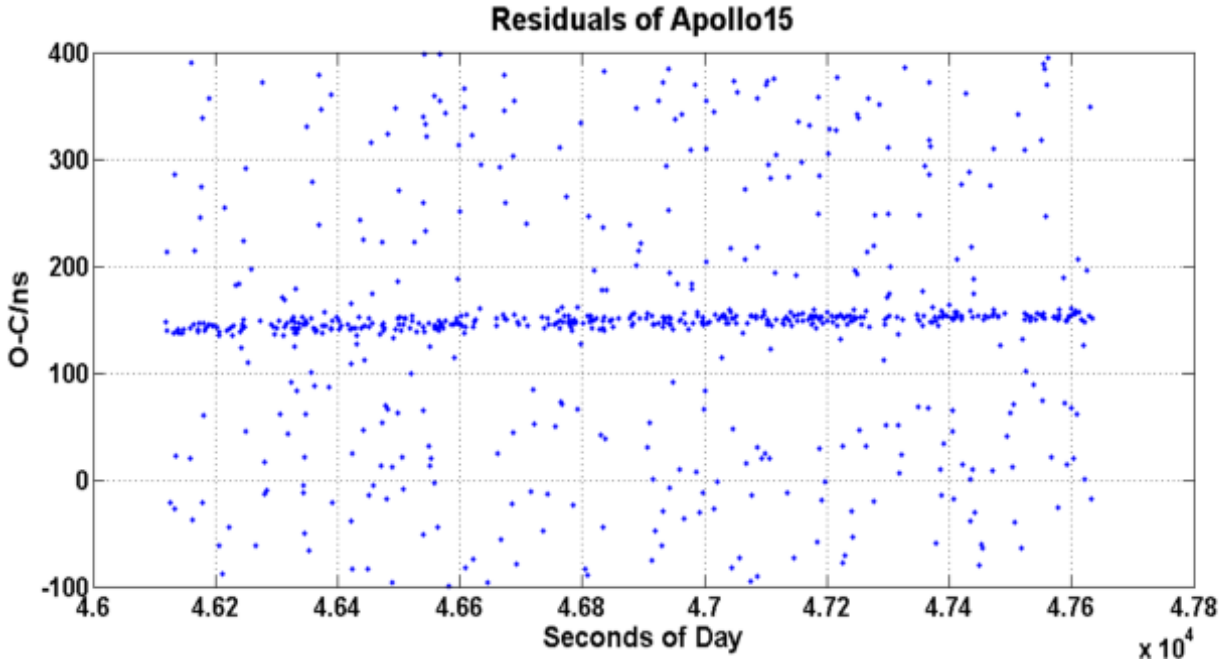
- Results of the Normal Points

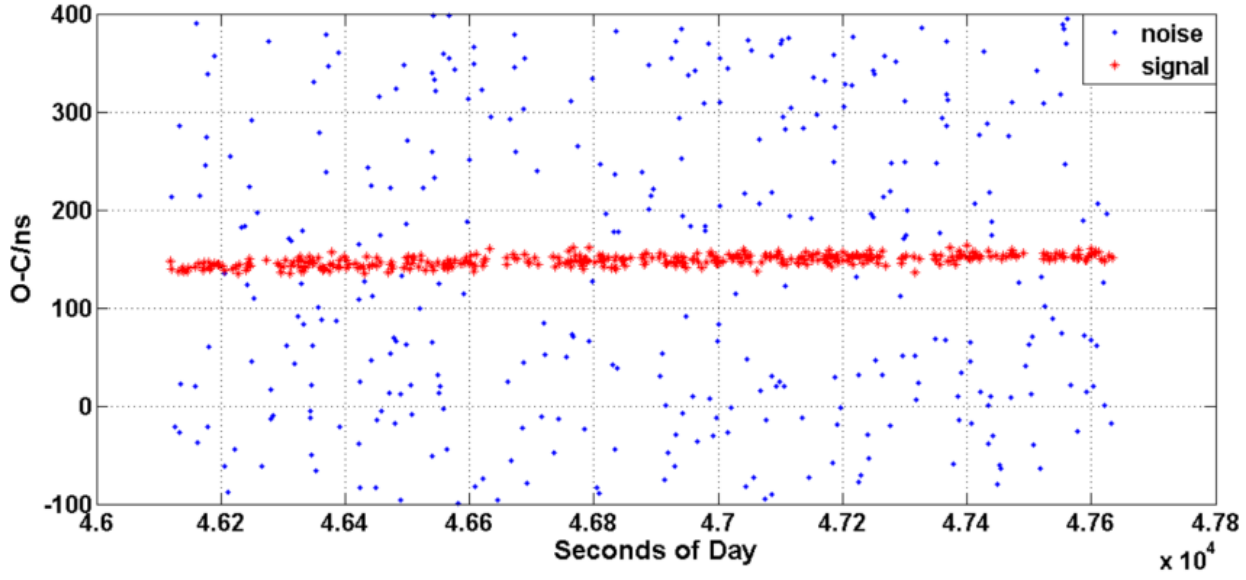
```
Normal Points : 00035
Valid         : 00031
Wrong (***)   : 00004     Limit:      1.000 m

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

Signal Recognition

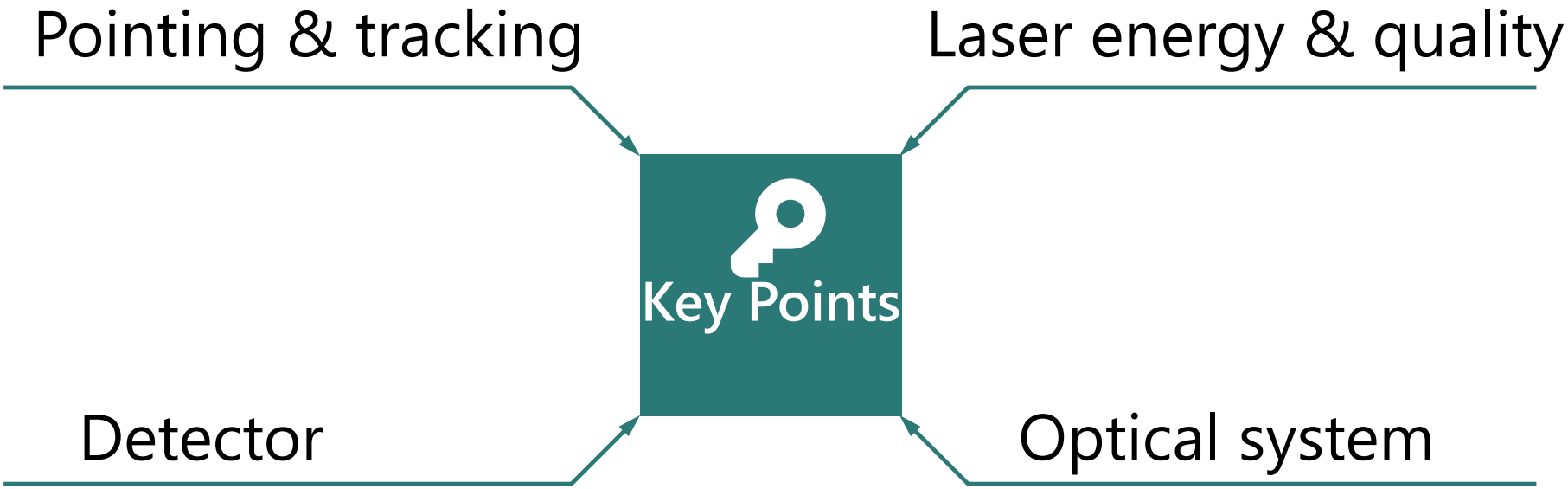


Signal Recognition





Summary



We got 35 NPs of LLR.

Next Step: focus on precision

Acknowledgments

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Thanks for your attention

Li R (lirw@ynao.ac.cn)

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