Federal Agency for
Cartography and Geodesy

Observations from LEO orbit up to the moon

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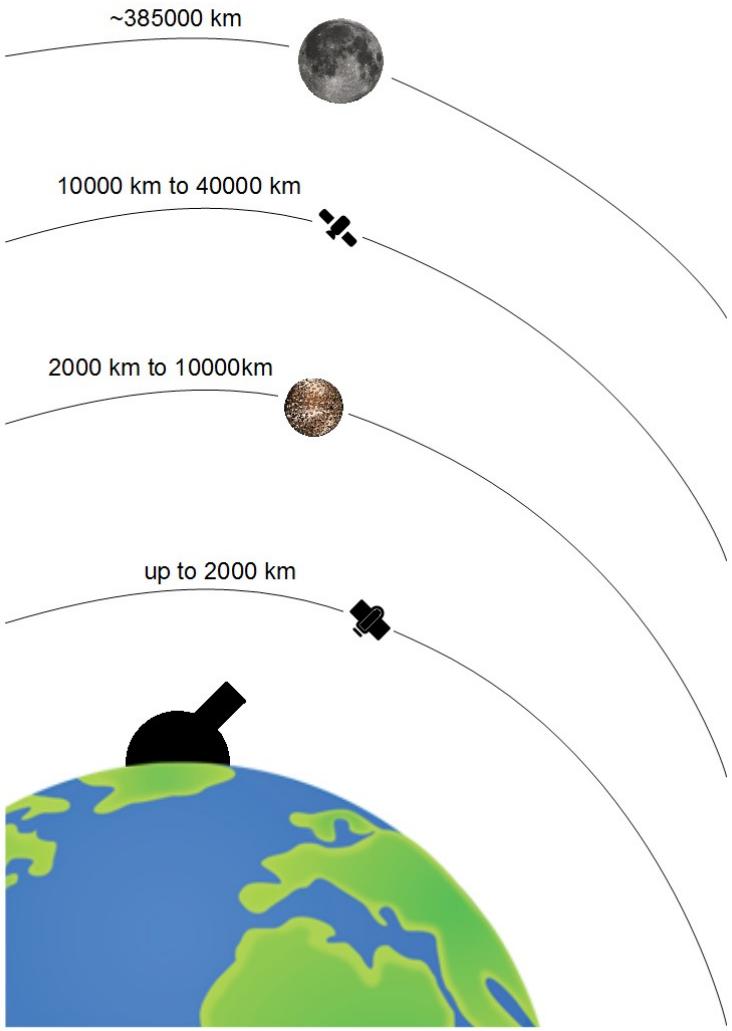
Situation
- link budget -

$$Number_{photoelectrons} \propto \frac{Cross\ Section}{Distance^4}$$

$$\frac{N_{pe,max}}{N_{pe,min}} \sim 1e^9$$



→ Two operating modes (from/to GEO):

1. High repetition rate
2. “eye-safe”
3. High energy mode
4. (LLR, Debris)

„eye-safe“
- requirements -

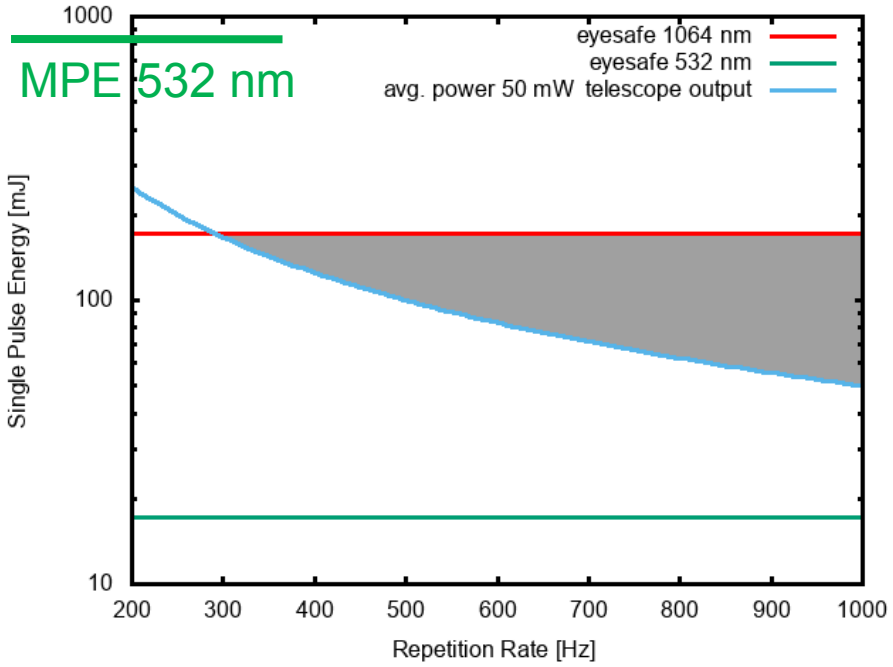
- **IEC 60825-1:2014 → Class 1 („eye-safe“):**

1064 nm : 7,7e-8 J @ 5 cm, 10 ps → ~170 µJ (WLRS)

532 nm : 7,7e-7 J @ 5 cm, 10 ps → ~ 17 µJ (WLRS)

- Min. req. NIR Power:
  ~ 0,1 W (link budget)
- Limited in max.

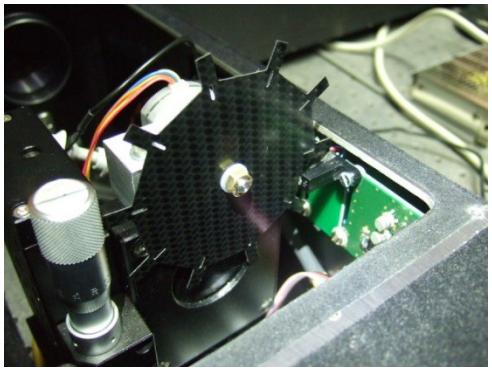
rep.-rate: 400 Hz
(rt-cal & regen. Amp.)

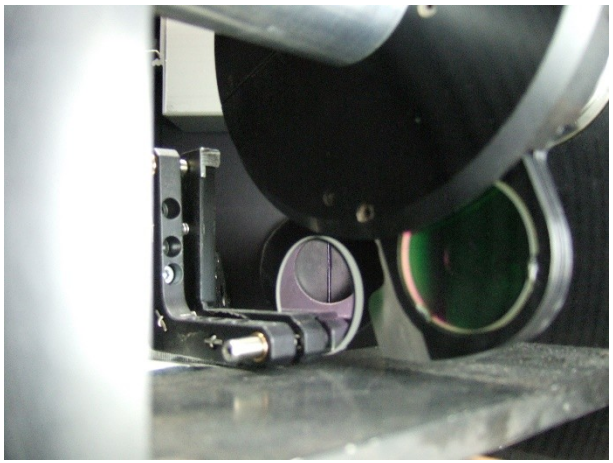


→ Single Pulse Energy of 170 µJ @ 400 Hz optimum

T/R Switch
- principle -

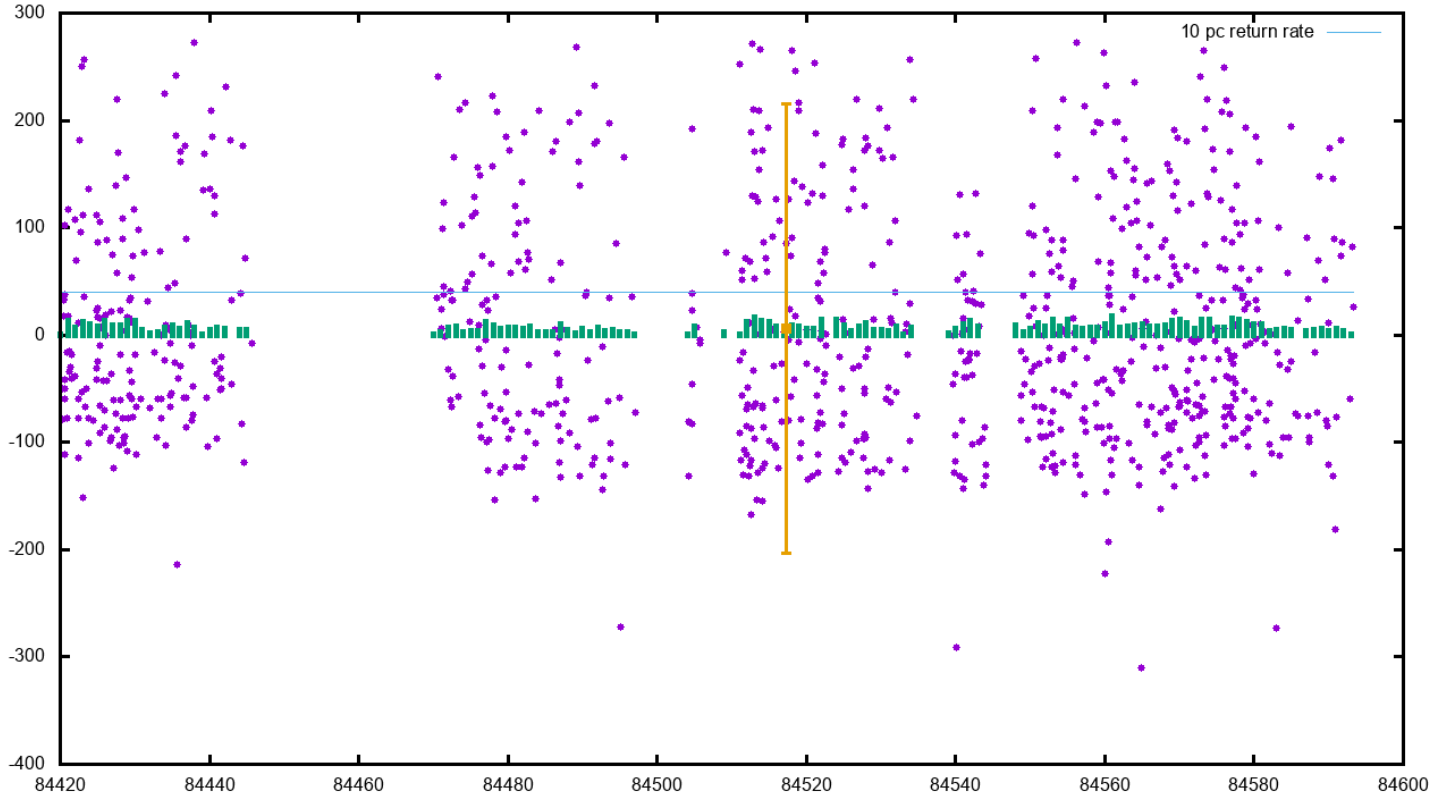
- Alternatively: **rotating mirror** or **polarizer & beam block**





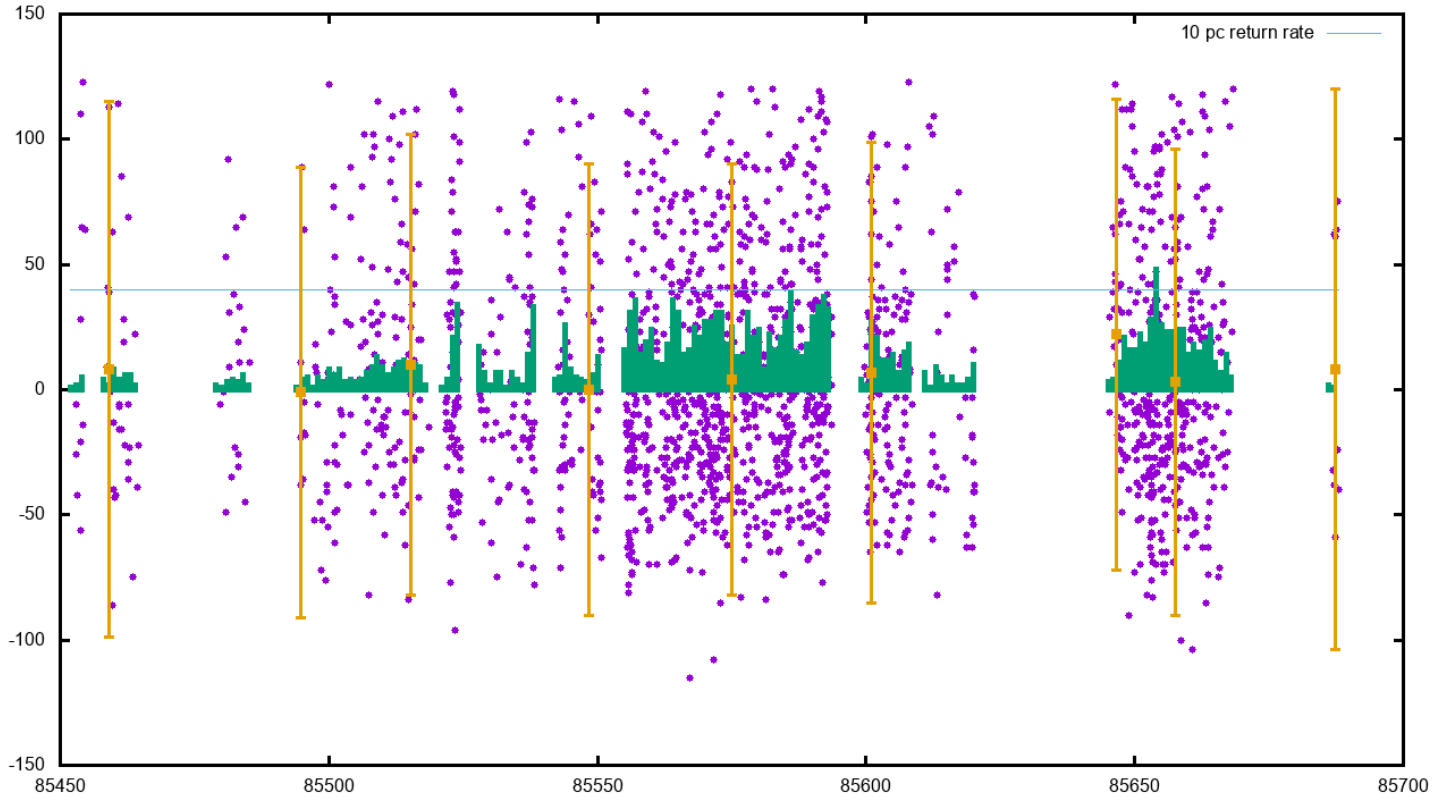
Polarizer & Beam Block
- 1064 nm „eye-safe“ -

- Etalon passage < 25 degree in elevation
- 1000 returns in 180 seconds



Polarizer & Beam Block
- 532 nm „eye-safe“ -

- Lares passage



- Permanent operation in high repetition rate mode planned with upcoming system automation

LLR Signal / Noise

Detection Efficiency (SPAD) PGA-080u-1064TOT (now ARGO)	~50% @ 1064
Aperture	0,75 m
Pulse Energy (dual pulse)	75 mJ & 60 mJ
Wavelength	1.064 nm
Transmit & Receive Efficiency	???
Transmit Gain	???
Field of View	10 arcsec
Spectral Filter Width	0,35 nm
Range Gate	~100 ns before
Optical Alignment	???
Target Signature	???

signal

noise

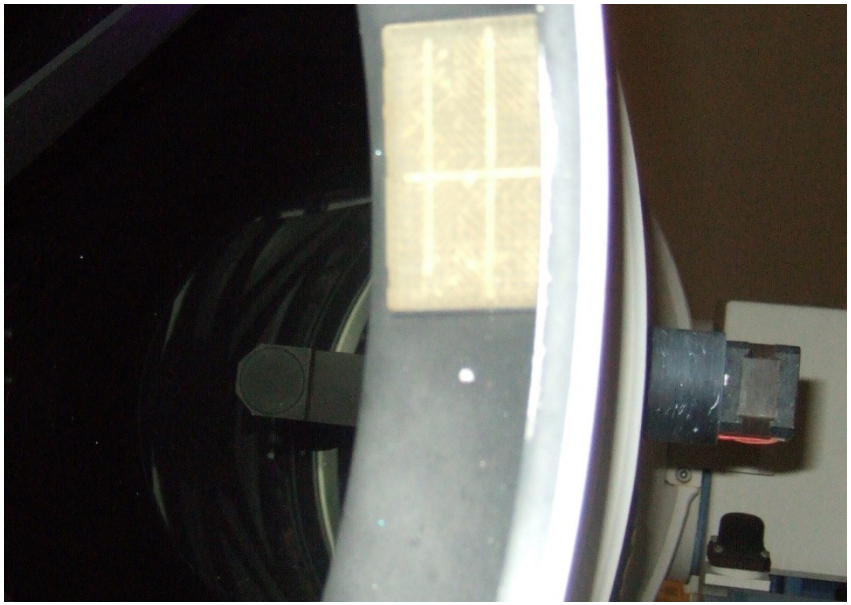
→ optimum condition: Expected N_{pe} ~ 0.2 %

Optical Alignment

- Prior to each Lunar observation

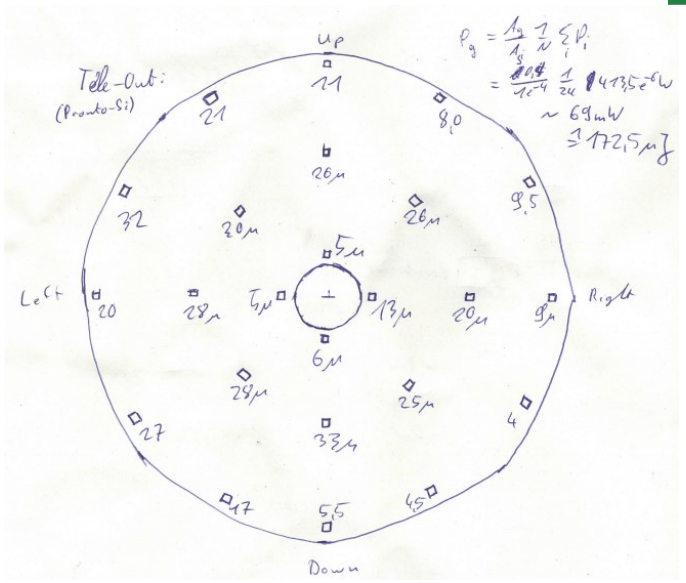
→ adjust the optical axis to ~ 1 arcsec

- Piezo actuator for laser beam steering installed, FoV adjustment pending
- Remote control of telescope retros

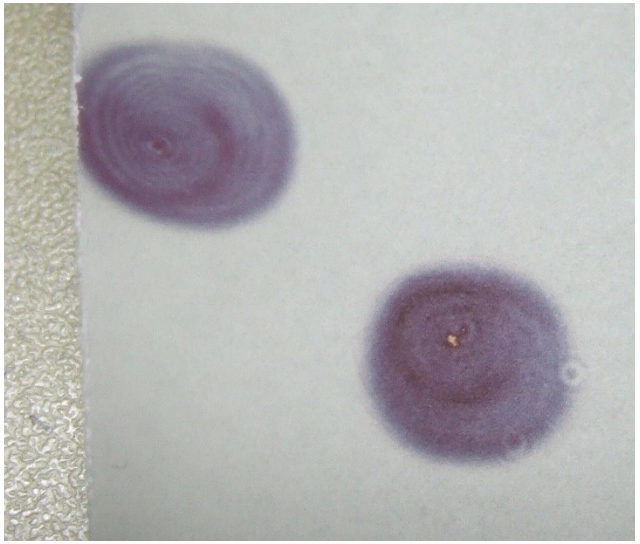


Transmit & Receive Efficiency

- Take samples @ different positions of the beam path
- Averaging @ positions with large beam diameter

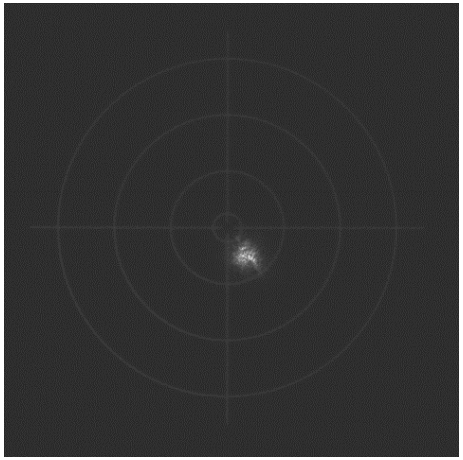


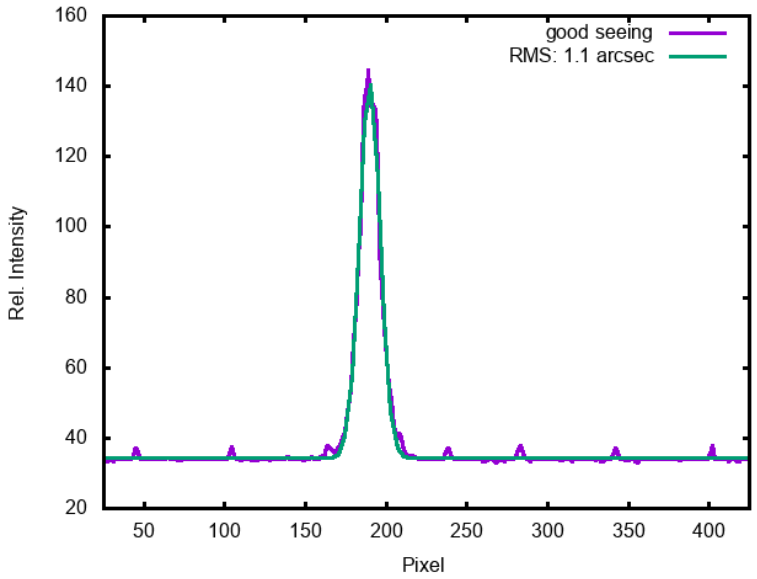
Position	Loss in Percent
Before T/R	10,8
After T/R	22,8
After 5 x Expander	36,4
@ Telescope Output	76,7



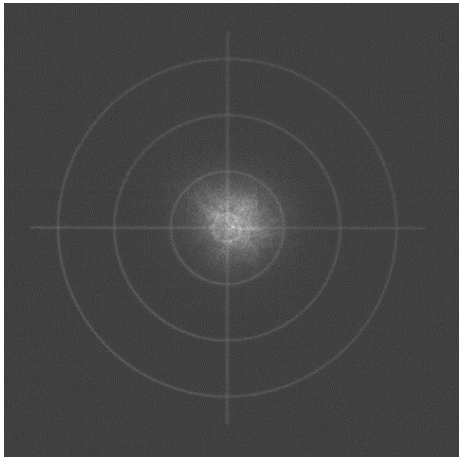
Transmit Gain
- seeing -

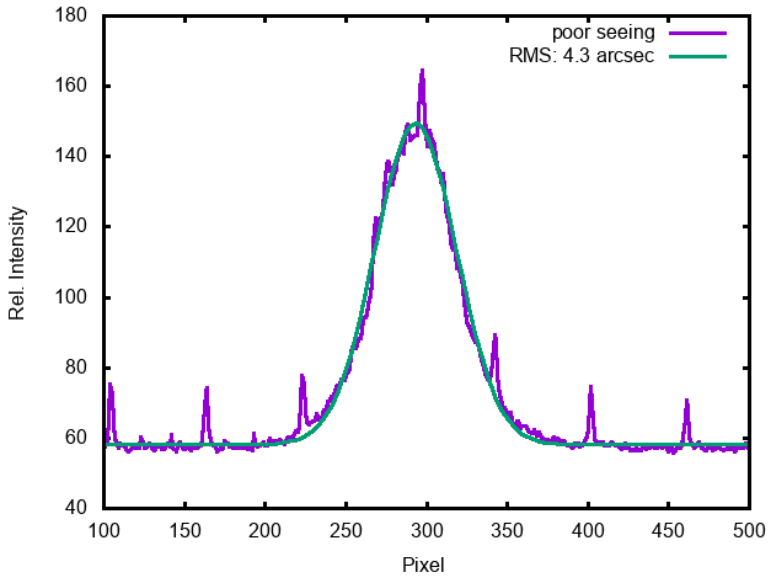
Night of 2018_09_29





Night of 2018_09_28

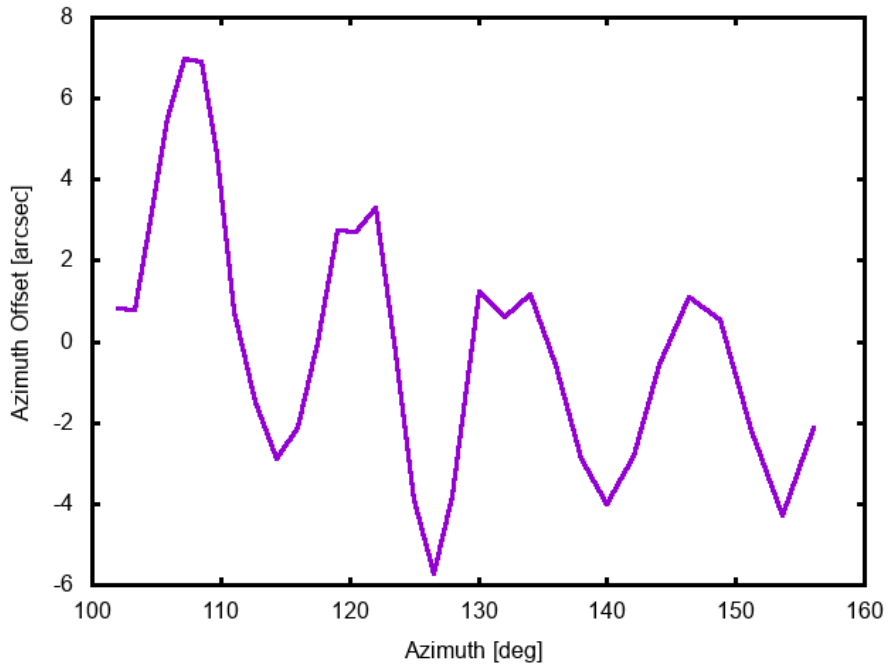




Transmit Gain
- telescope pointing -

- After renewing the telescope drives

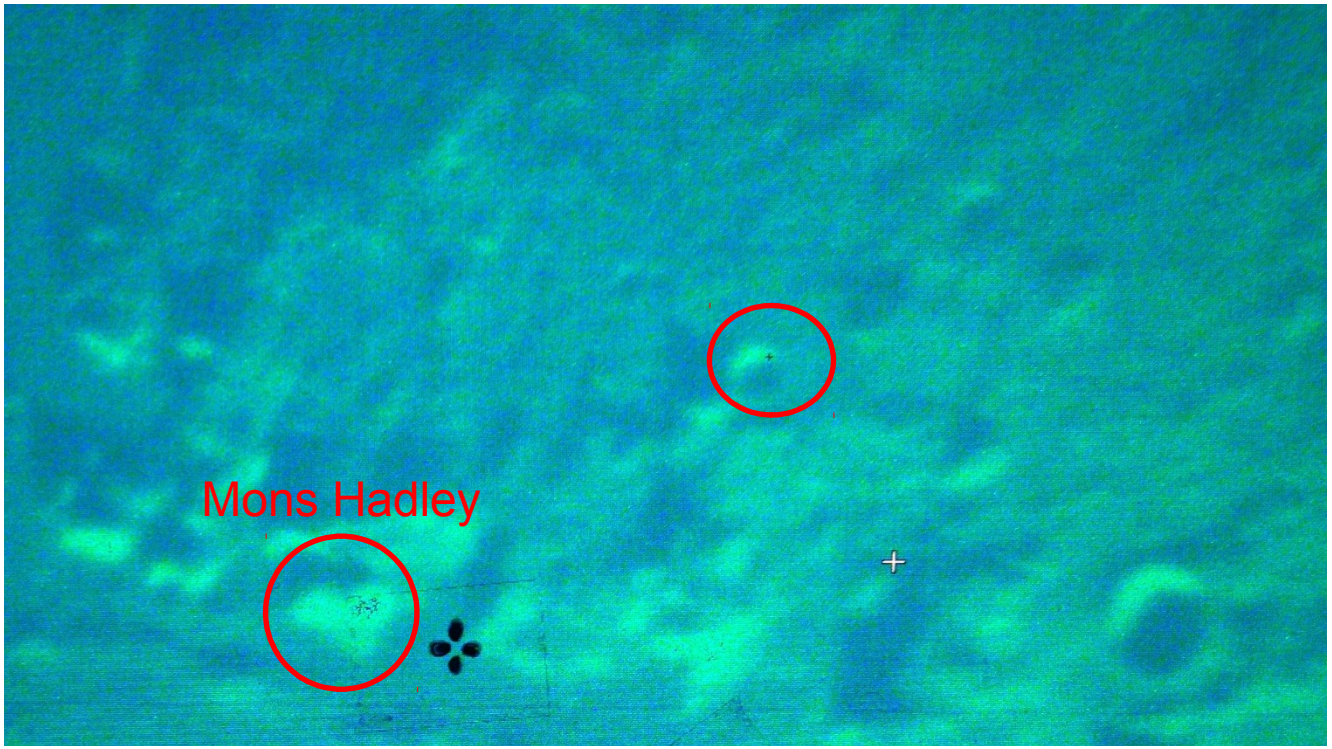
→ Telescope tracking error detected (LLR showstopper)



Workaround needed

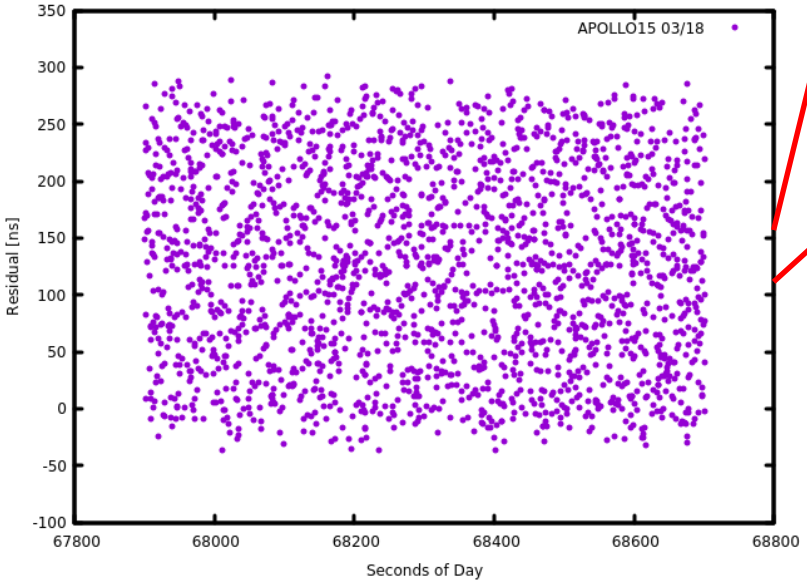
Interactive Tracking
- example APOLLO 15 -

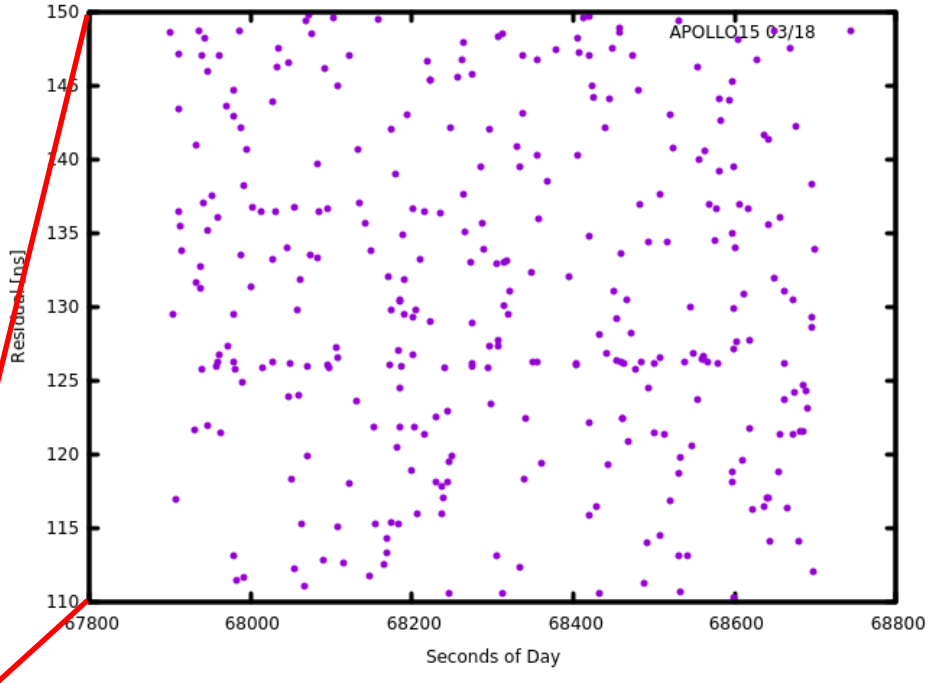
1. Crater referencing (many Thanks to OCA team!!!)
2. Reflector tracking & definition of reference
3. Interactive telescope positioning

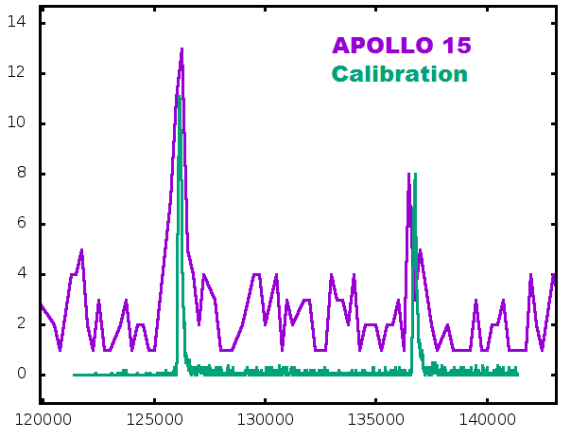


LLR
- first light after many years -

- Apollo 15, March/2018
- Usually signal is visible after post-processing only

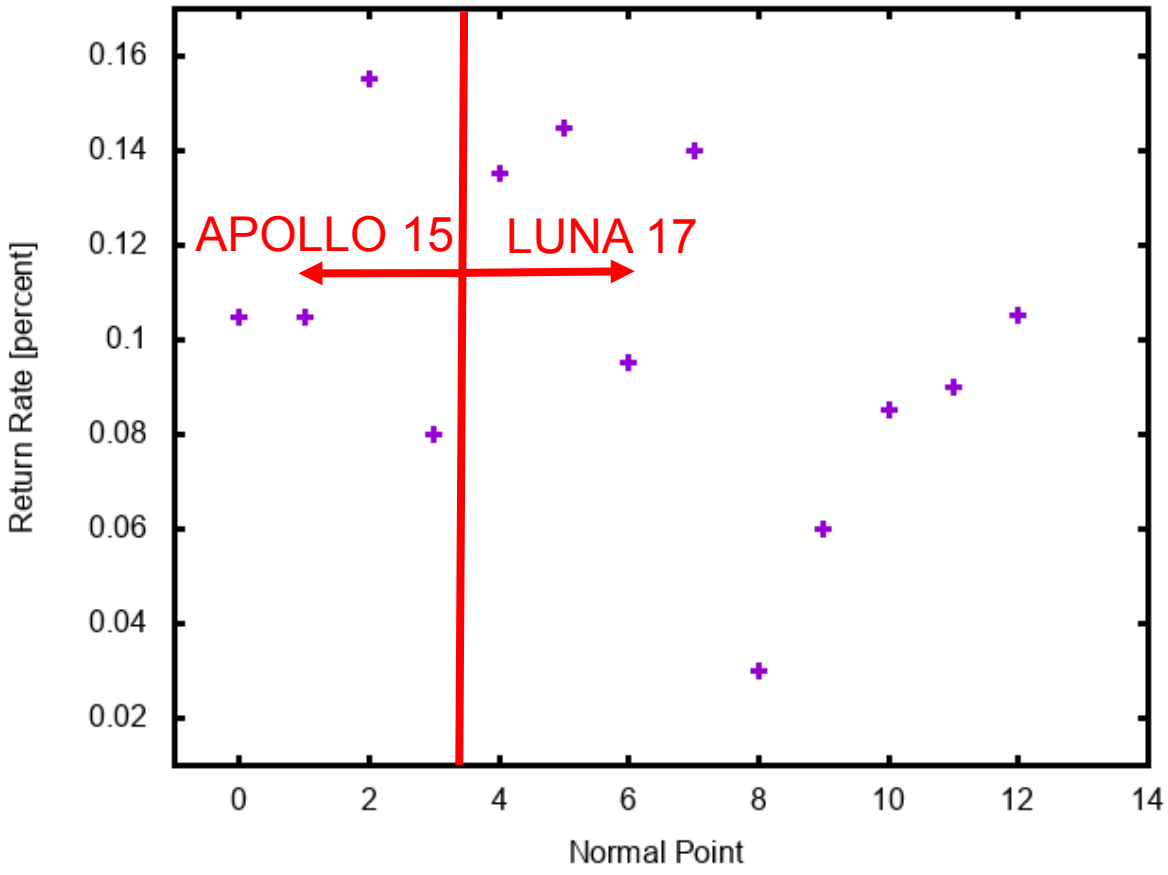






LLR
- link budget -

- Calculate Return Rate per Normal Point
- Optimum: ~0.2 Percent



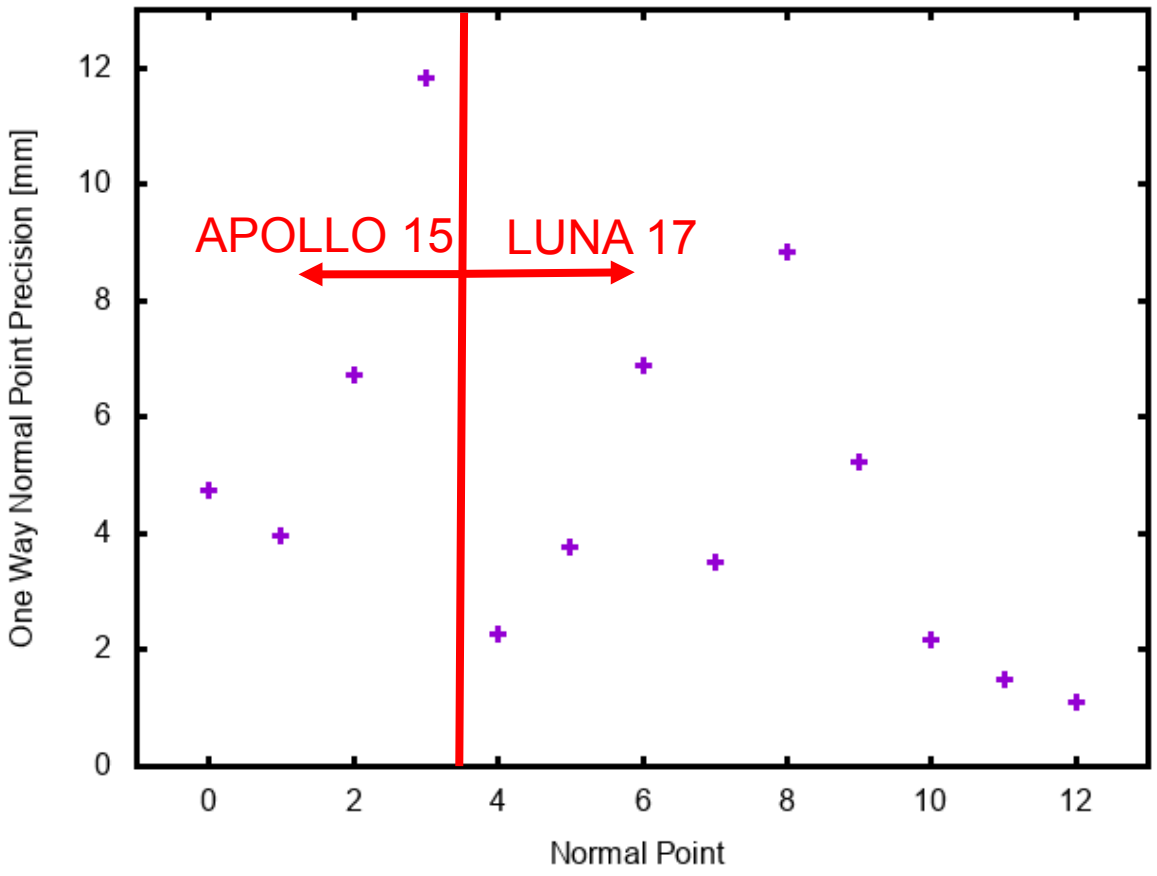
LLR
- phase & time of day -

- Lunokhod 17 daytime ranging

Date	Moon Illumination	Max. Sun Elevation	Avg. Moon Elevation	Distance Sun-Moon
2018_08_05	45%	18 degree	53 degree	~112 degree
2018_08_06	34%	33 degree	55 degree	~55 degree
2018_09_06	16%	17 degree	57 degree	~53 degree

LLR
- data precision -

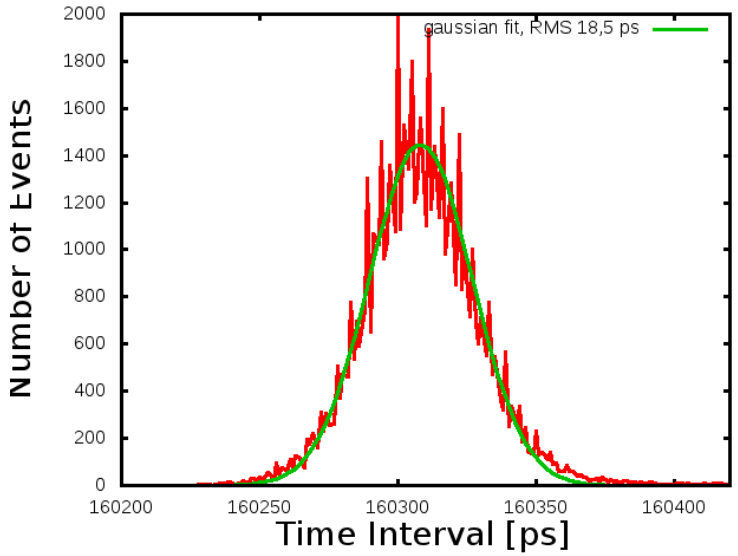
$$Precision = \frac{Single\ Shot\ RMS}{\sqrt{Number\ of\ Echos}}$$

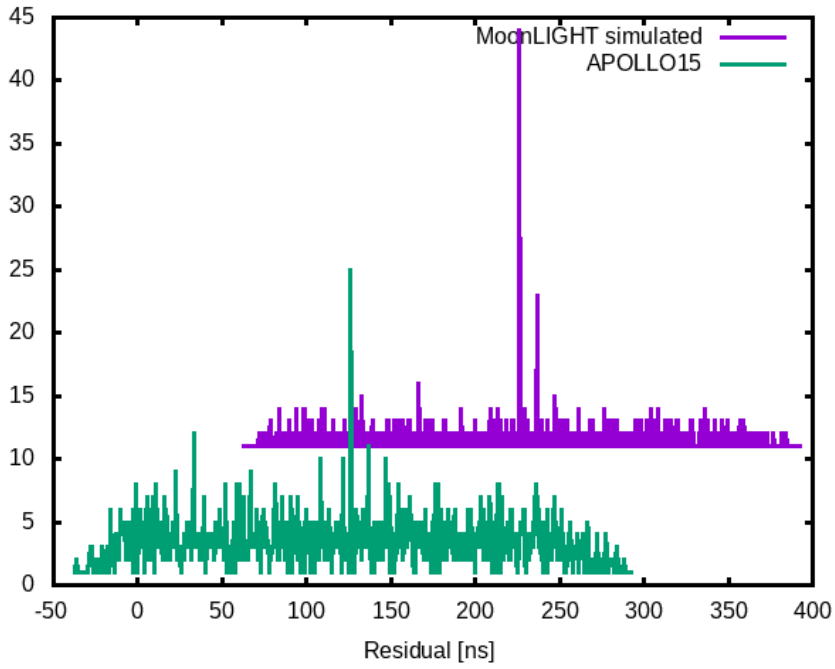


LLR
- target signature -

- Simulated MoonLIGHT echos
- WLRS single shot RMS ~ 3 mm (10 ps Laser)

→ S/N also improves by about factor 2 (narrow Filter)

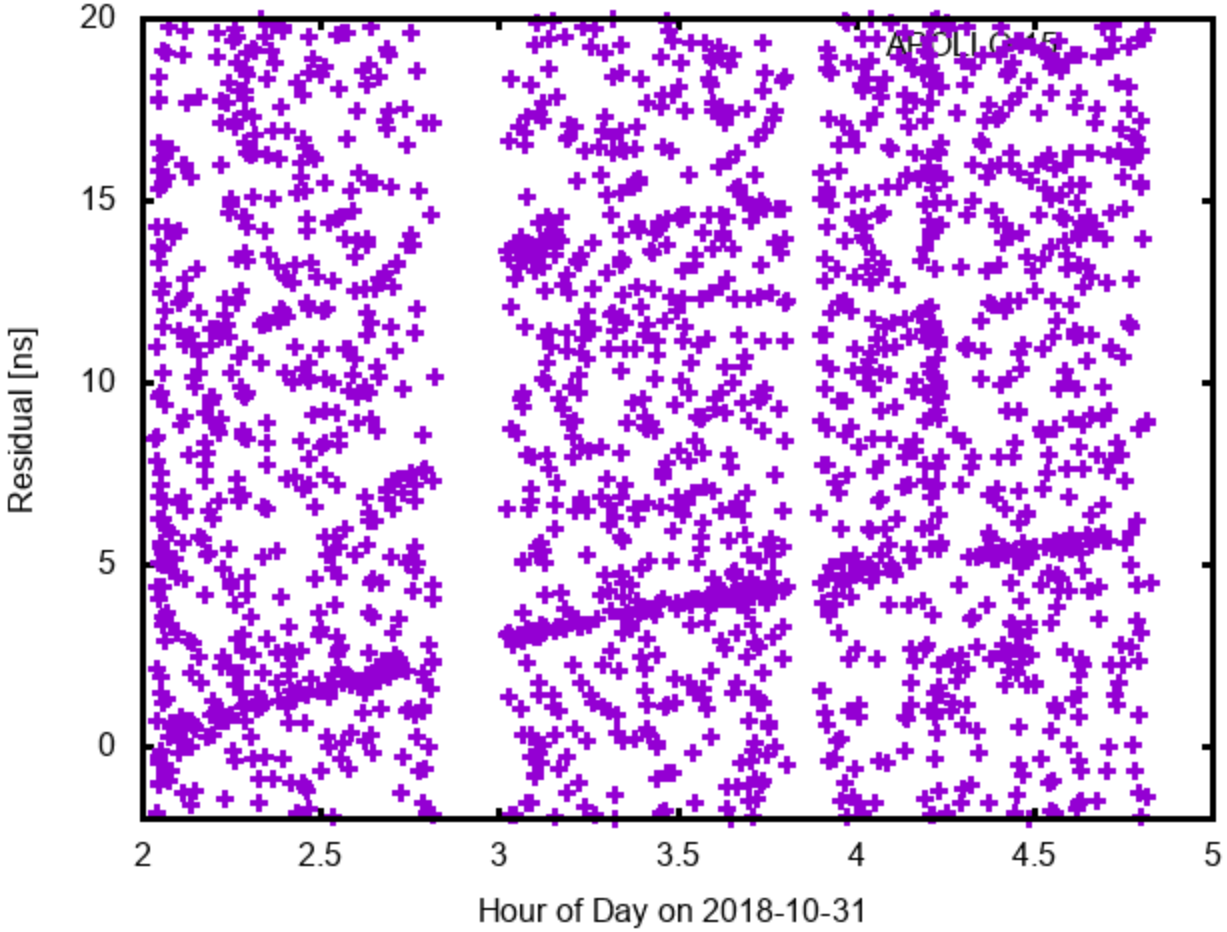




Conclusion

- SLR-Systems with 1 m class telescopes allow for eyesafe SLR with capability of ranging all ILRS satellites @ a wavelength of 1064 nm

- LLR with laser pulse width of only 10 ps shown
- With improved target signature single shot RMS < 5 mm feasible
- Further optimization planned (T/R efficiency, Beam Profile, Adaptive Optics, …)


APOLLO
Residual [ns]
20
15
10
5
0
2
2.5
3
3.5
4
4.5
5
Hour of Day on 2018-10-31