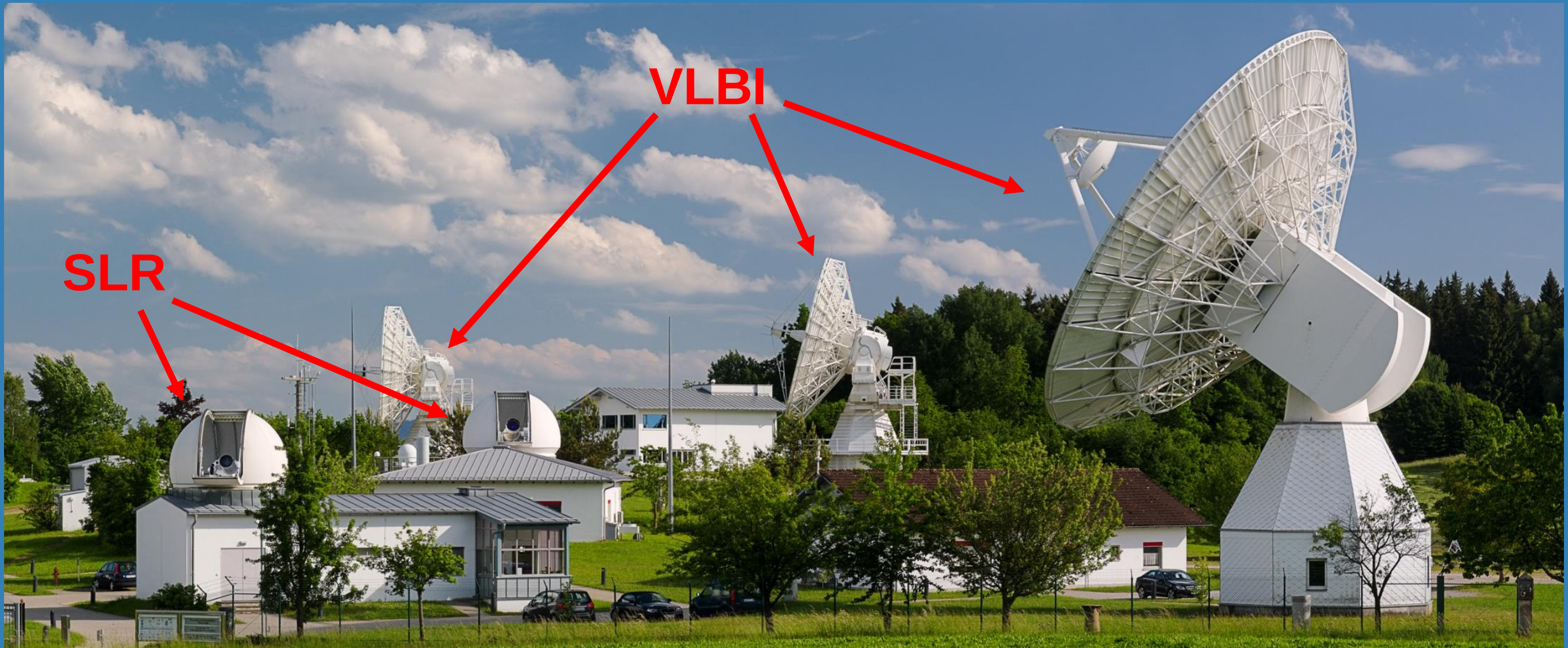
Bundesamt für
Kartographie und Geodäsie

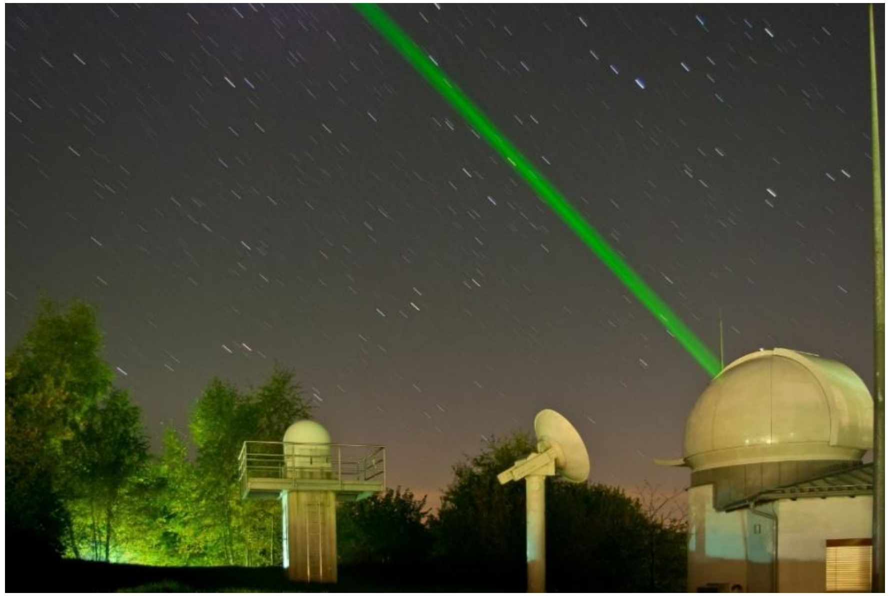
BKG
Wir geben Orientierung.

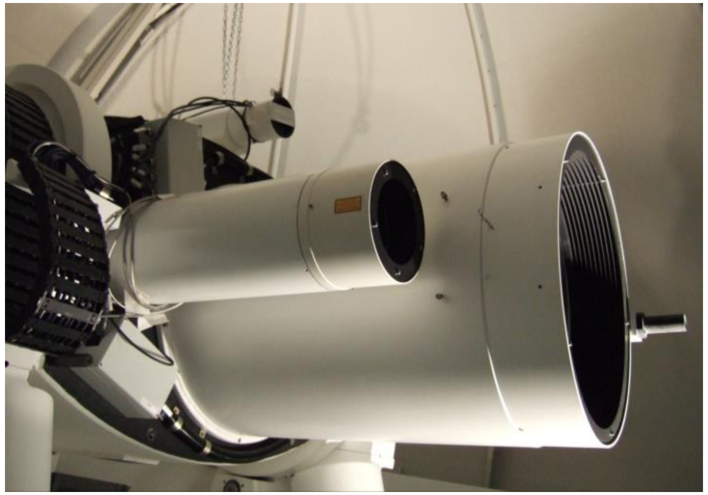
Lunar Laser Ranging at the WLRS

Johann Eckl, Geodetic Observatory Wettzell



Laser Ranging Systems





Wettzell Laser Ranging System (WLRS, 1990)

- 75 cm monostatic telescope
  - Identical beam path for transmit/receive
  - Pointing accuracy of optical axes 0,5 “
- Nd:YAG pulse laser
  - 532 nm (green) or 1064 nm (NIR)
  - Pulse width 10 ps (3 mm)
  - 667 pulses per second (20 for LLR)
- Observations
  - Satellites (all heights)
  - **Lunar Laser Ranging**, Space Debris Ranging
  - Scientific projects, e. g. Time Transfer

Satellite Observing System Wettzell (SOS-W, 2014)

- 16 cm / 50 cm bistatic telescope
- Ti:SAP pulse laser
  - 425 nm (blue) or 850 nm (NIR)
  - 1000 pulses per second (1 kHz)
- Observations
  - Satellites (all heights)

WLRS
- lunar laser ranging -

SCOPE

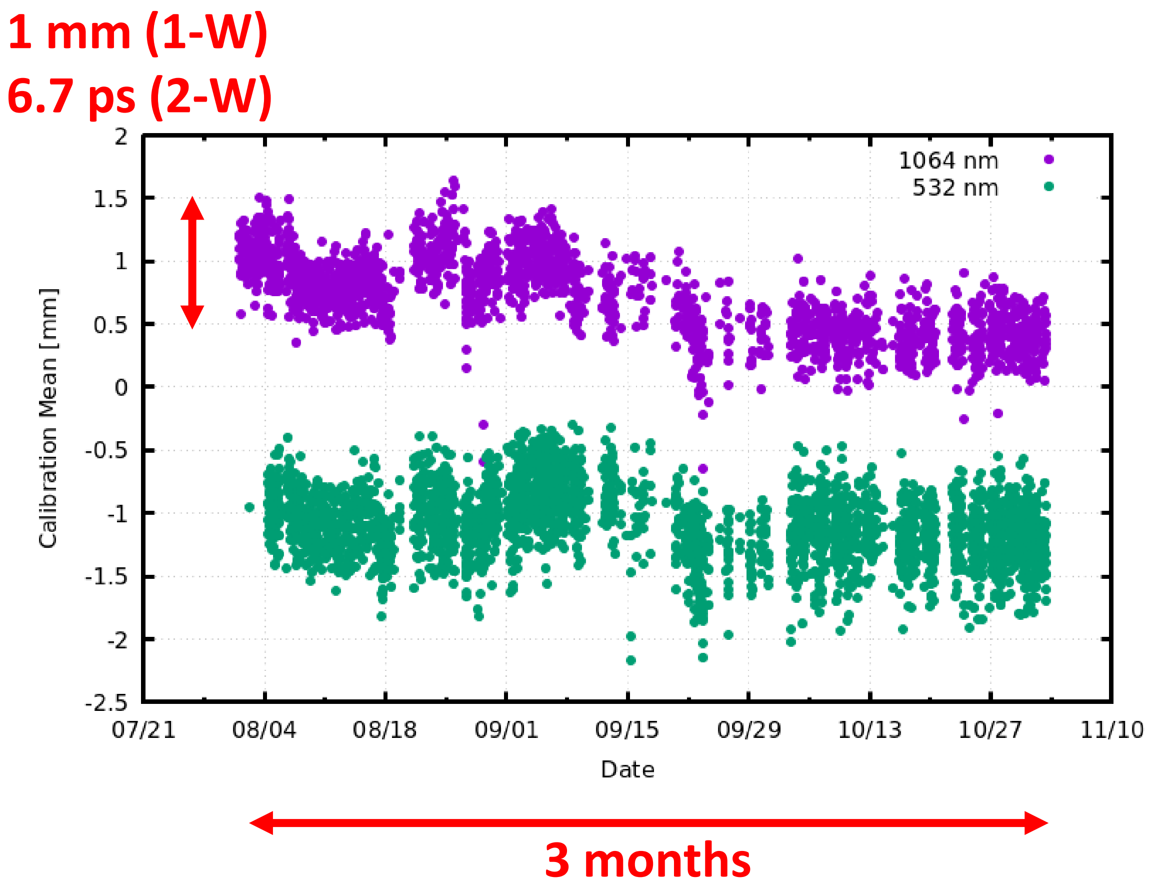
- Good connection to reference frames
- T&F system, good representation of SI second (3 Masers, CS clocks)
- Well defined SLR reference point
  - Station coordinates & velocity (ITRF)
  - Local tie network (system calibration, range bias)
- 10 ps Laser pulse, intrinsic precision < 4 mm RMS
- Good intrinsic system stability, Calibration mean
- Daytime LLR possible

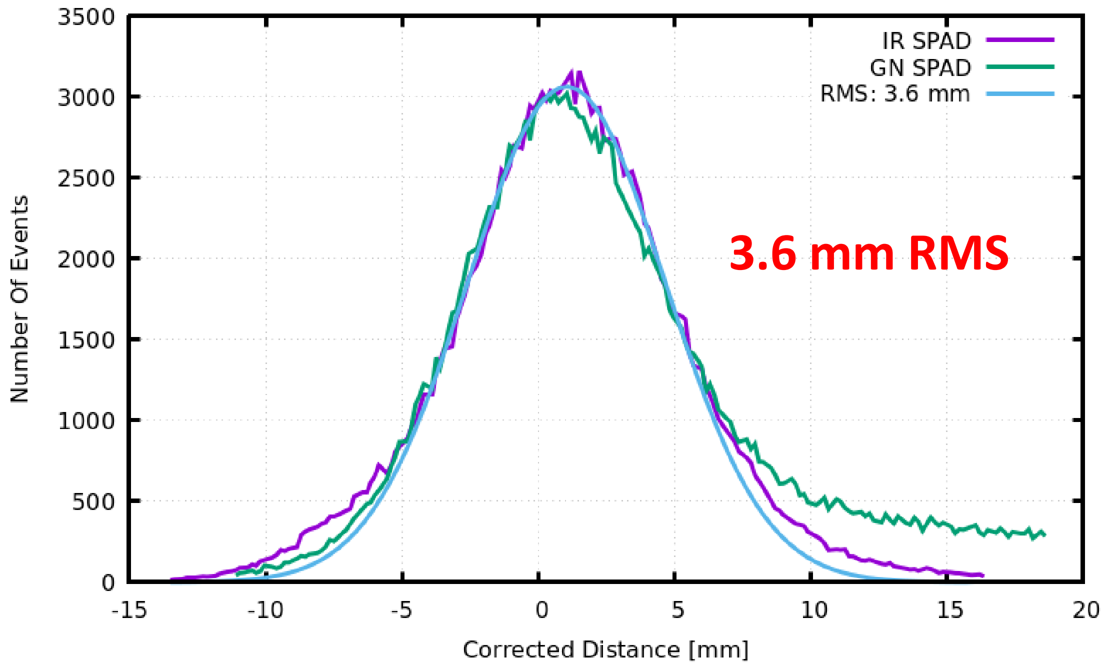
LIMITATION

- Elevation > ~55 deg
- No blind tracking (also full moon difficult)
- No reflector switching possible
- Calm atmosphere
- Clear conditions, of course…

WLRS
- system calibration -

- Measurement to target with known distance to eliminate delay variations in electronics, cables, … & determine system constant (absolute measurement)





Lunar Laser Ranging
- link budget -

$$\textit{Received Number of Photoelectrons}$$
$$\propto \textit{Telescope Aperture} * \textit{Pulse Energy} * \textbf{Detection Efficiency} * \textbf{Wavelength}$$
$$* \textbf{Transmit Gain} * \textbf{Reflector Cross Section}$$

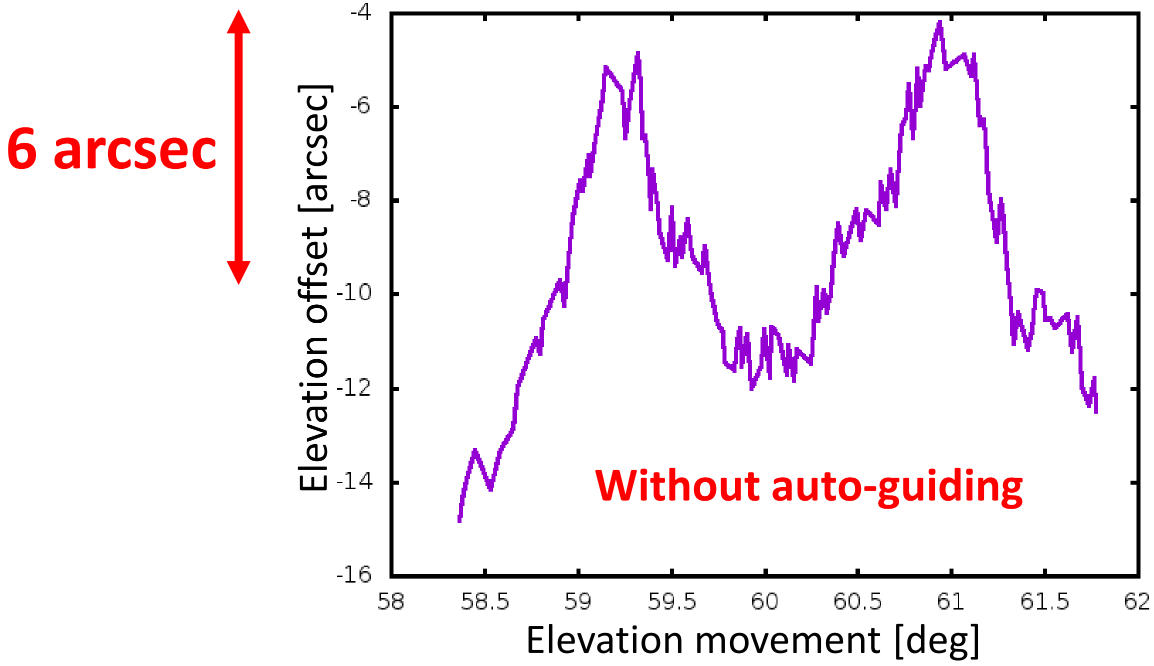
Transmit Gain is function of pointing precision & atmospheric condition

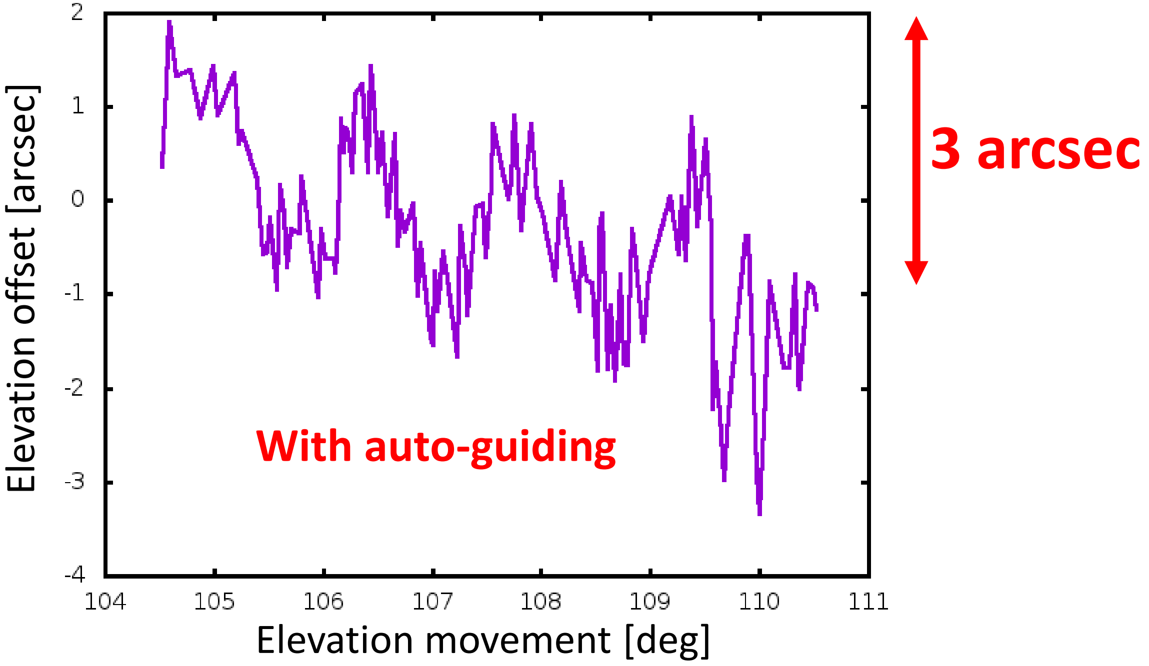
	APOLLO	Grasse MeO	Matera MLRO	WLRS
Telescope Aperture [m]	3.5	1.54	1.5	0.75
Laser Pulse Energy [J]	0.115	0.3 (0.2)	0.1	0.07 & 0.04
Detection Efficiency [%]	30	20 (20)	15	30
Wavelength [nm]	0.532	1.064 (0.532)	0.532	1.064
Elevation [m]	2788	1323	540	665

- WLRS link budget more than one order of magnitude below best performing LLR systems.
- Considering just number of photons, Ranging @ 1064 nm provides ~ factor 4 gain in signal strength.

WLRS
- telescope tracking issue -

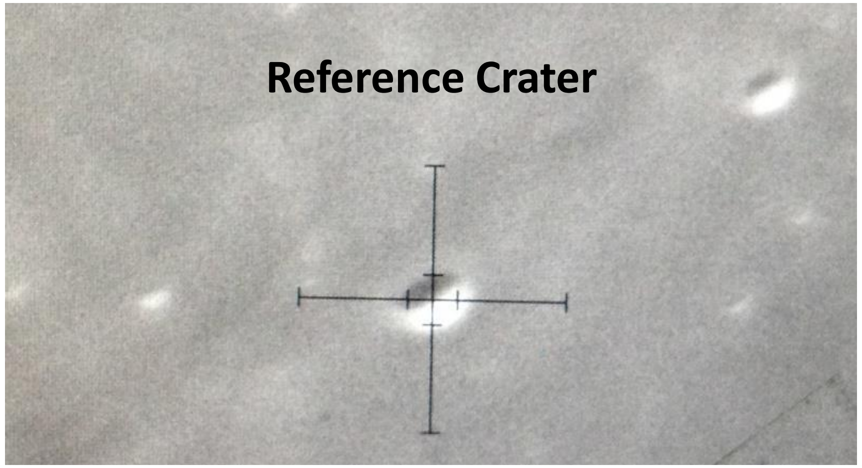
- Tracking error discovered (caused by worm gear)
- Workaround needed
- Camera assisted automatic guiding
- Tracking performance verified by star tracking → Residual RMS error < 1 arcsec

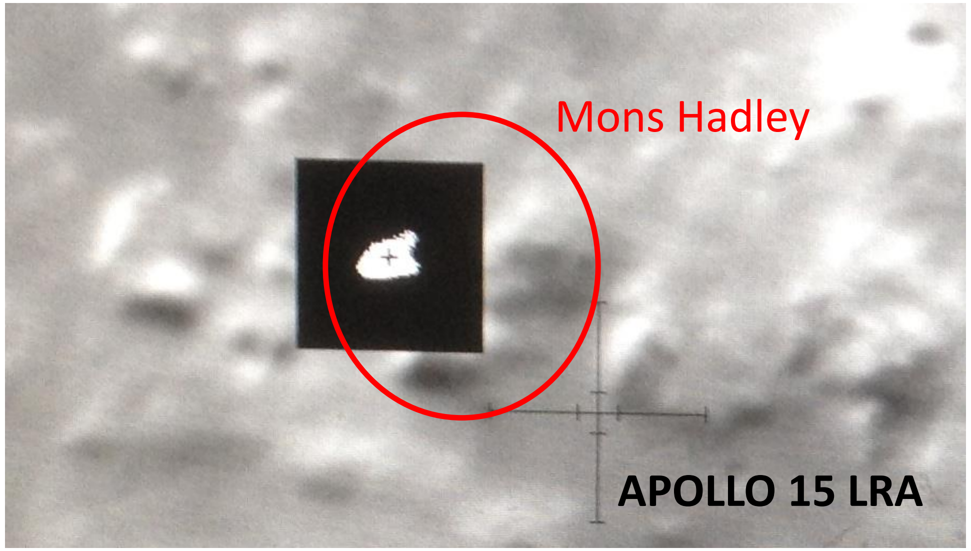




Lunar Laser Ranging
- tracking procedure -

1. Crater referencing (many Thanks to OCA team!!!)
2. Reflector tracking & definition of a reference
3. Automatic telescope guiding wrt defined reference

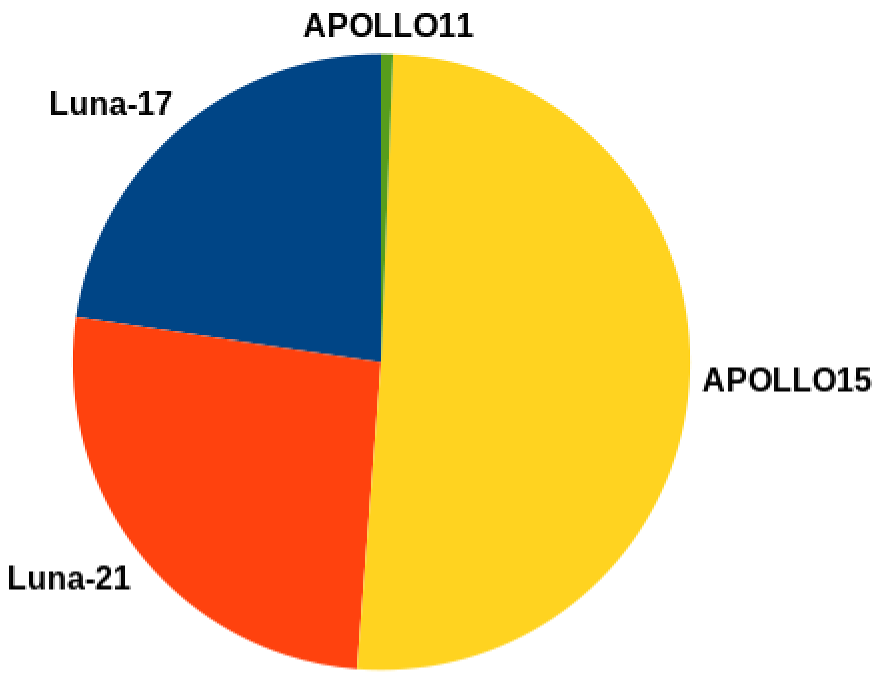


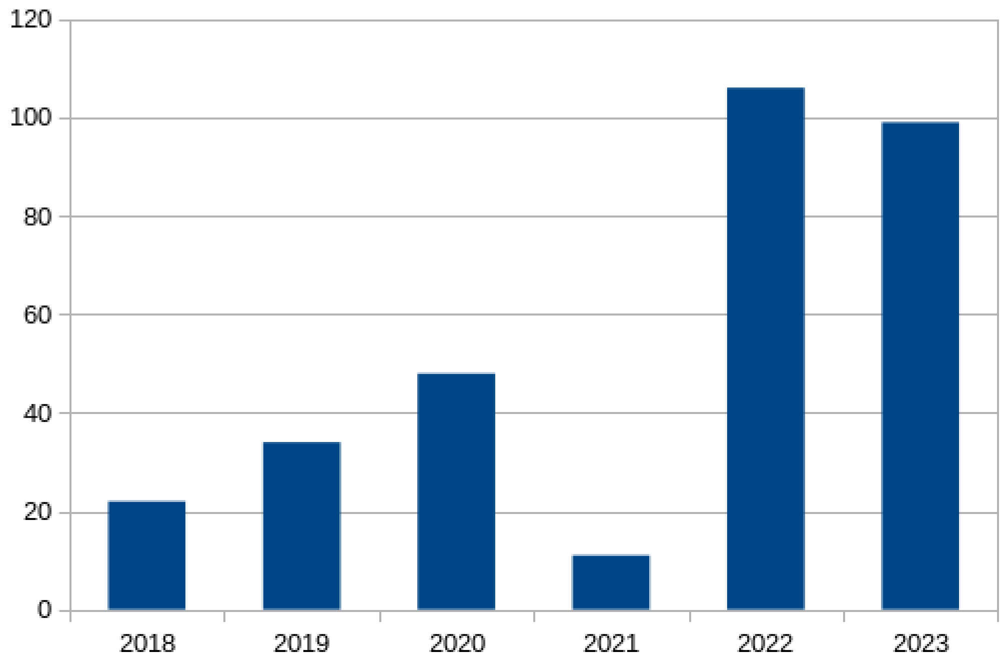


-> first lunar echoes since many years in 2018 -> start of timeline

Lunar Laser Ranging
- measurements so far … -

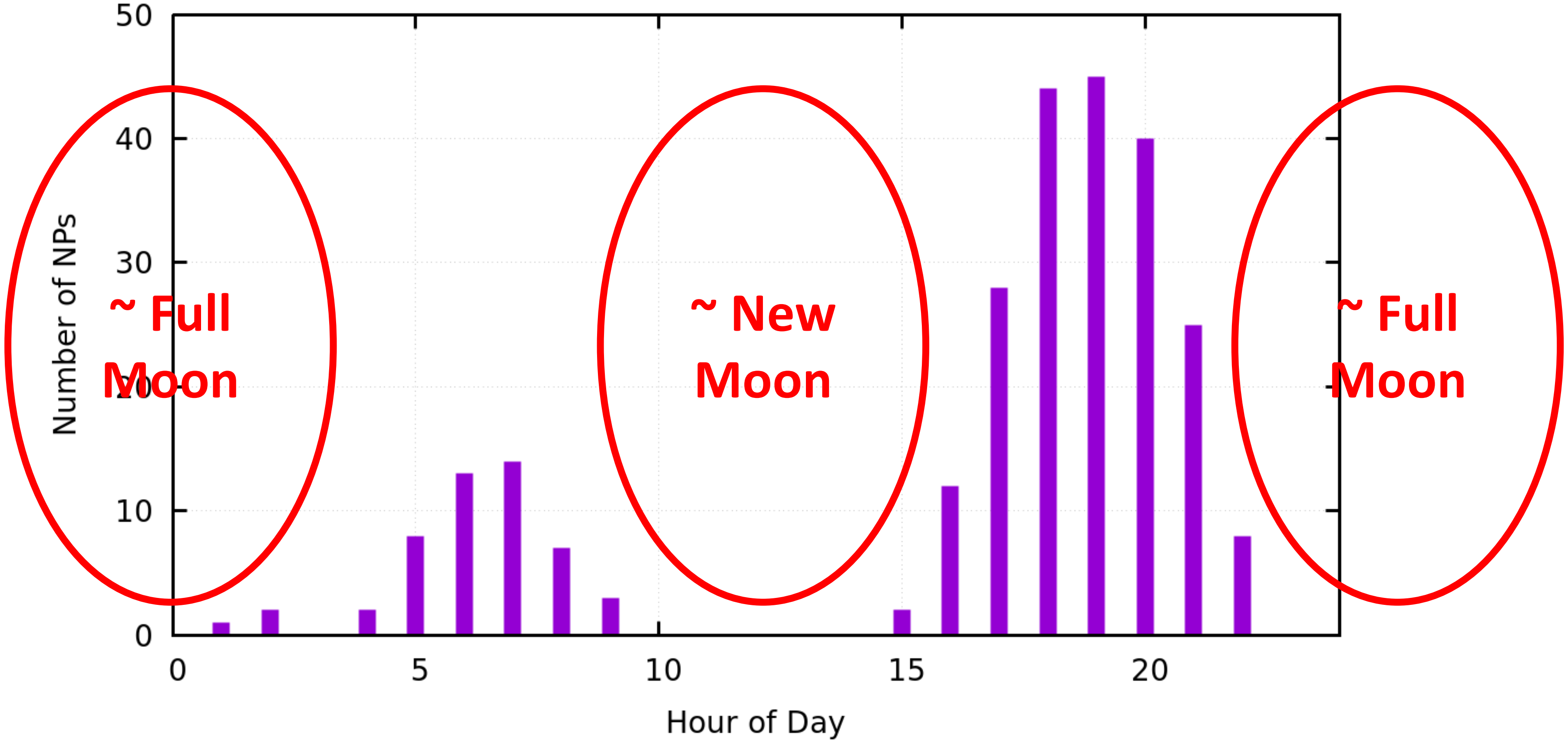
- Target distribution depending mostly on visibility of tracking reference point
- Steady rise of number of „Normal-Points“ since start in 2018





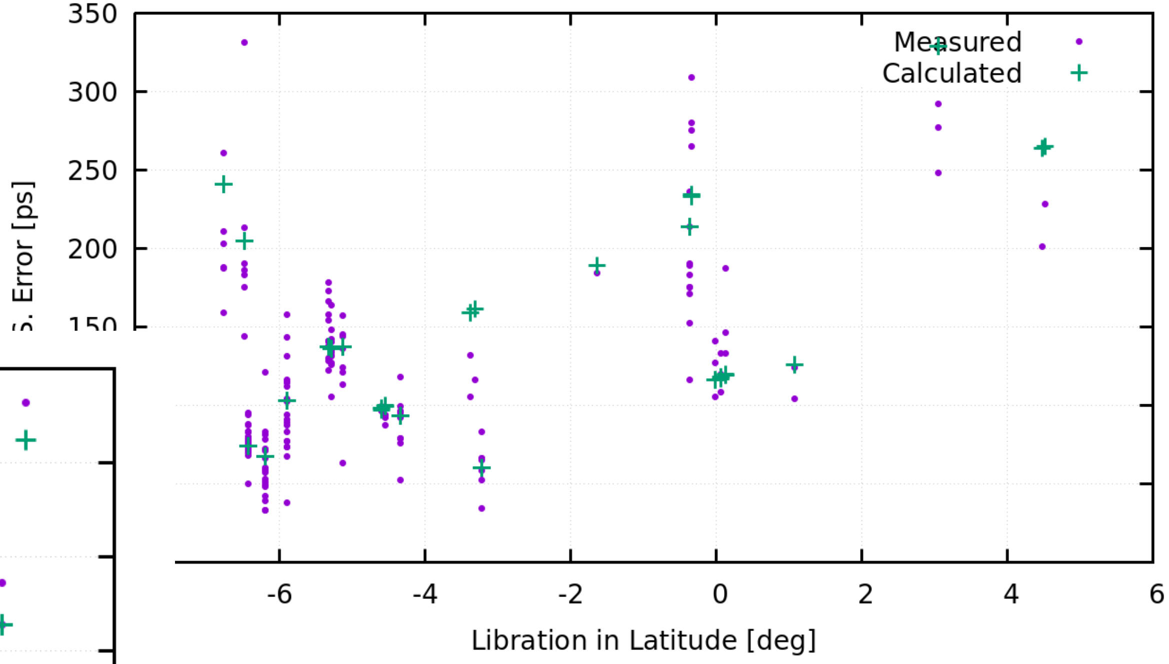
Lunar Laser Ranging
- hour of day -

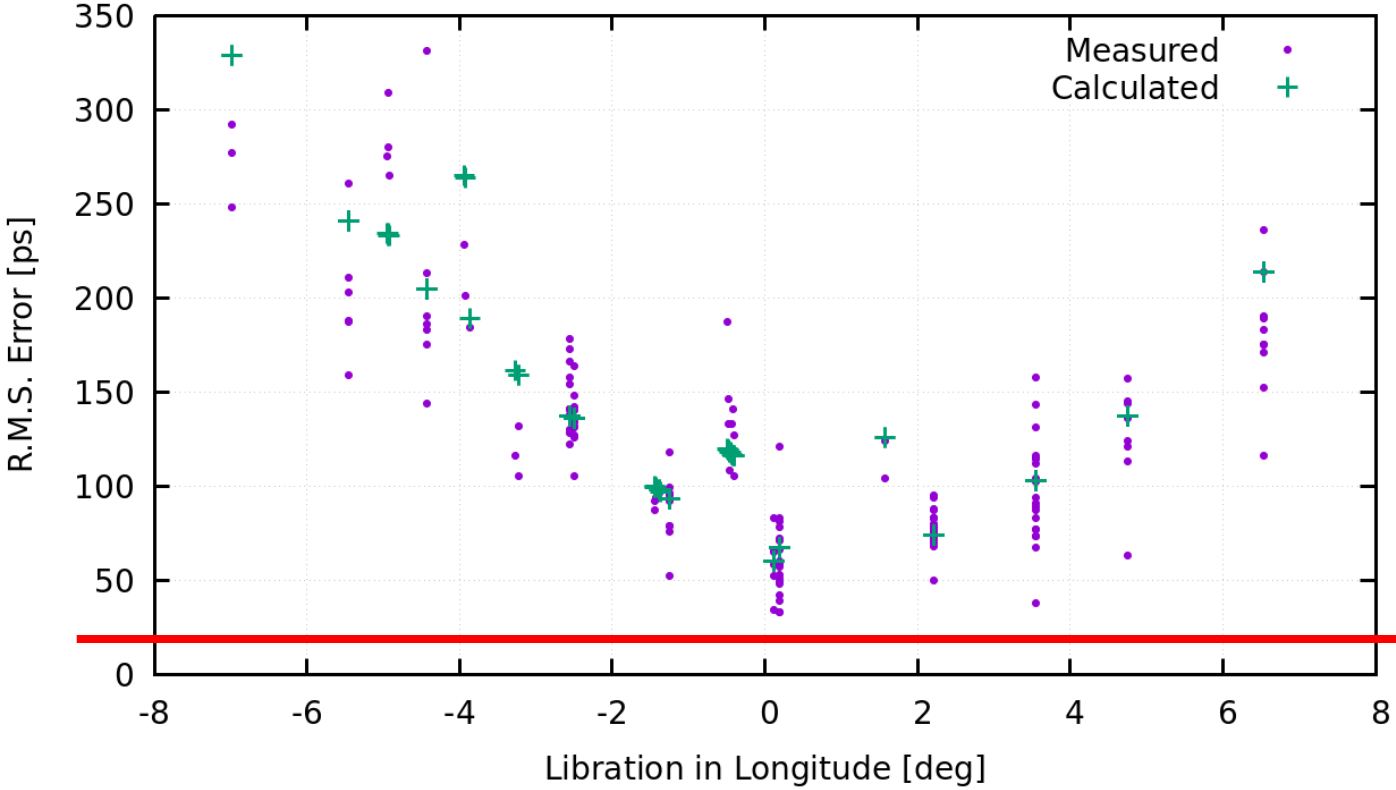
- Daytime ranging uncritical
- Due to Elevation > 55 deg → hour of day represents ~ lunar phase



Lunar Laser Ranging
- APOLLO 15 LRA Target Signature -

- Simple rectangular reflector model, tilted with libration
- Found reflector offset pointing of -1.1 lon & 4.3 lat deg wrt WLRS position, when adjusting the data



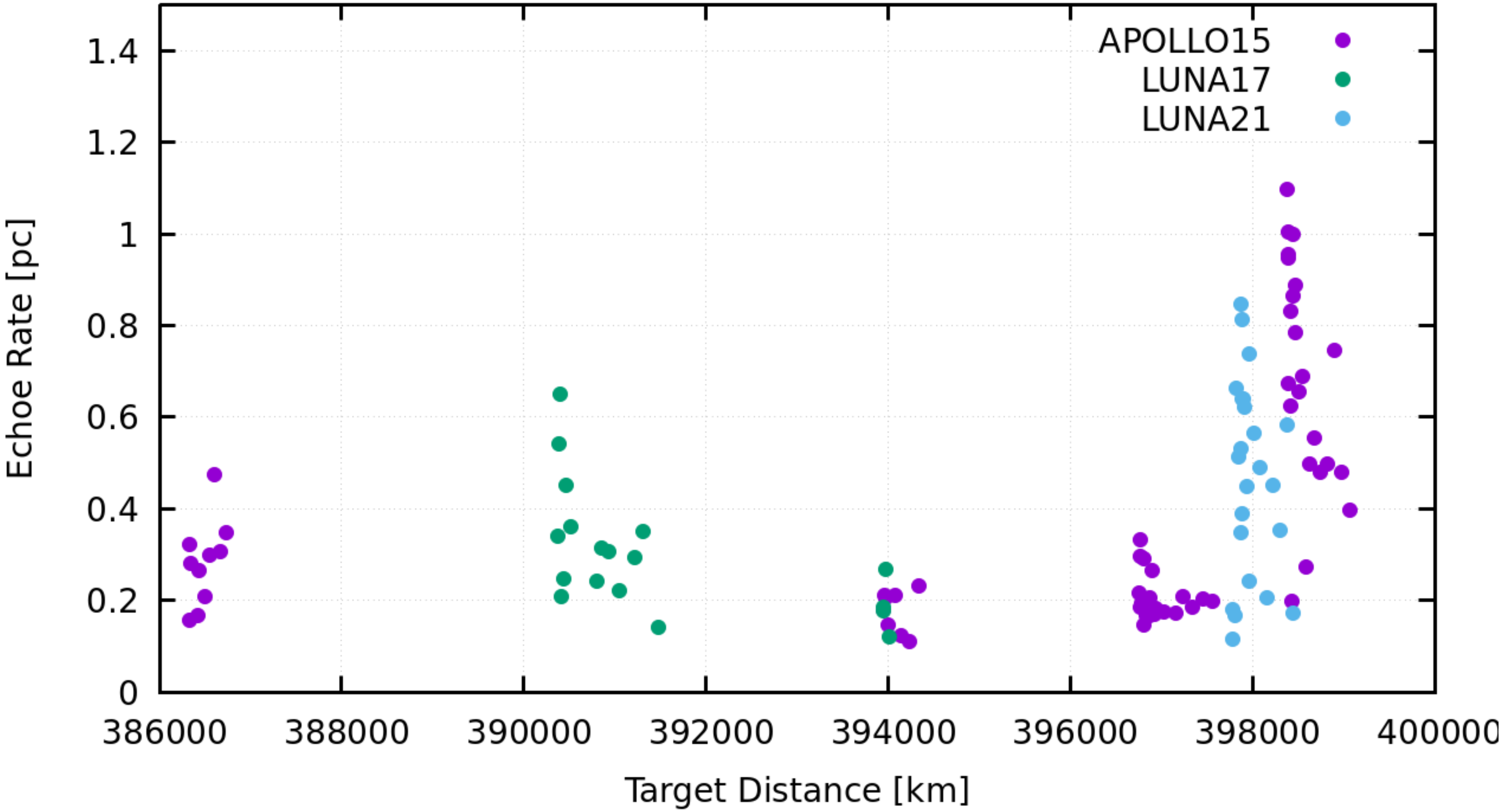


- Method for quality control (good indicator for systematic error)

→ Time correlated single photon counting

WLRS intrinsic timing precision

Lunar Laser Ranging
- echoe rates in 2023 -

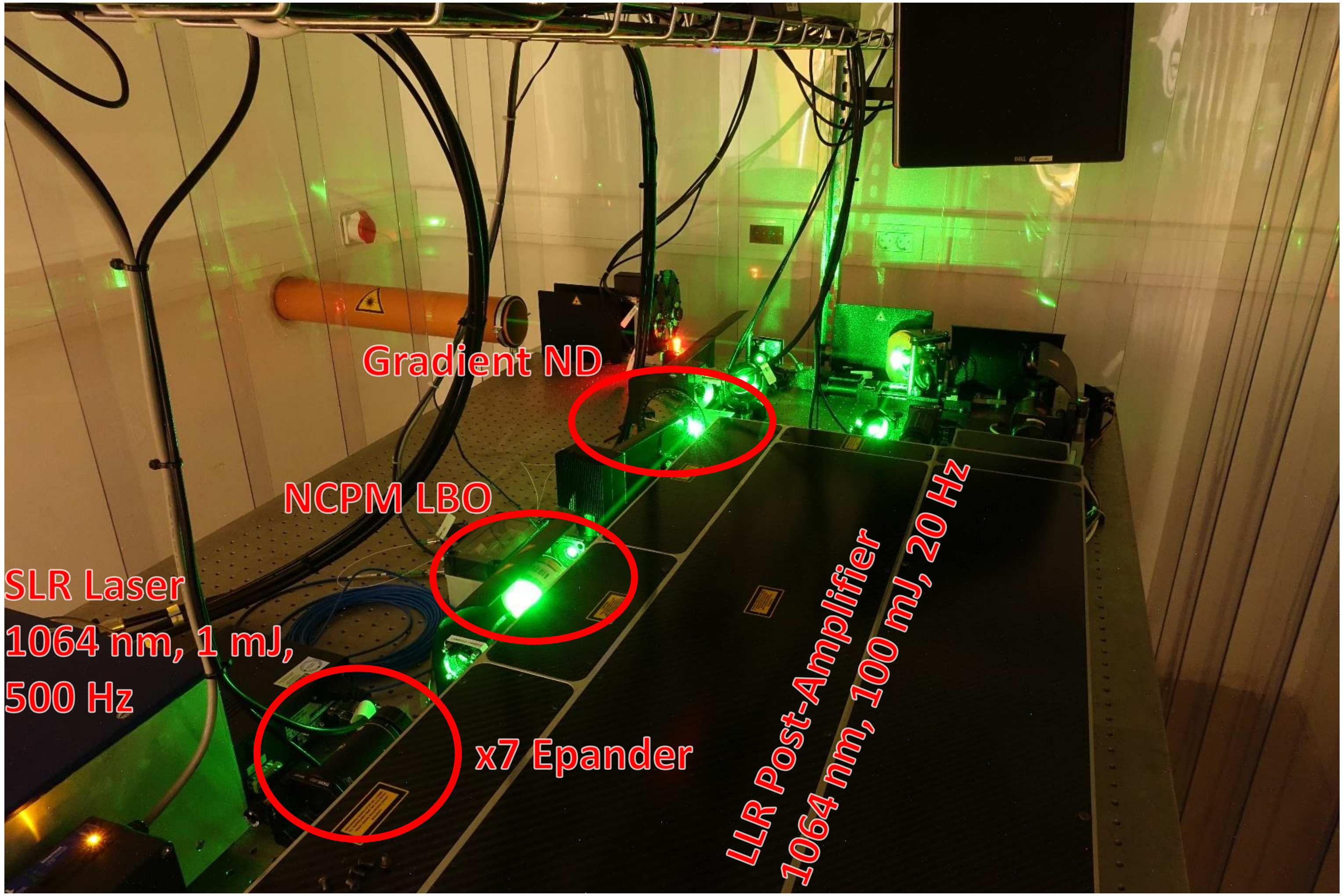


- Rates from 1 echoe in 5 … 50 seconds!

→ NO signal strength optimisation possible!!!

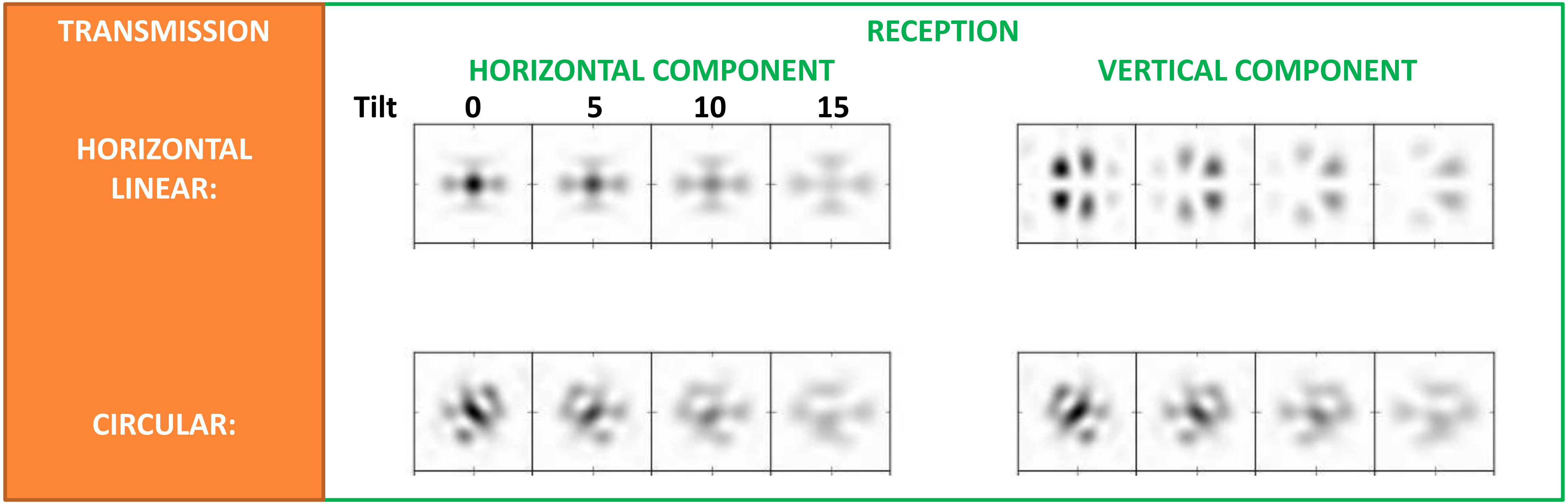
Outlook
- currently ongoing system upgrade -

- GOAL:
  „real-time“ feedback:
  1 echoe per second
- Laser post amplifier upgrade to 250 Hz
- Average power >10 W (now: ~ 2.2 W)
- But:
  - **Reduced single pulse energy**
  - **polarisation dependent T/R switch neccessary**



Outlook
- uncoated CCR polarisation dependence -

- Transmission of linear or circular polarised light possible..



FROM: Polarization and far-field diffraction patterns of total internal reflection corner cubes, T. W. Murphy and S. D. Goodrow

- Reception of horizontal or vertical component possible (not both!)
- CIRCULAR: Energy in main lobe is split in both components → USE LINEAR!

Further Outlook & Conclusion

- Fortunately had some money during the last years:
  - Guide star laser
  - Deformable mirror
- GOALS: blind tracking capability & reduce minimum possible elevation

Conclusion:

- LLR timeline started in 2018
- Can not compete with LLR partner stations in terms of amount of data
- Focus on best possible precision and accuracy in combination with connection to reference frames & clocks (SI second)
- With ongoing/upcoming upgrades: Support new Missions with improved CCR!

Thank you for your attention!