POLARIMETRIC SATELLITE LASER RANGING

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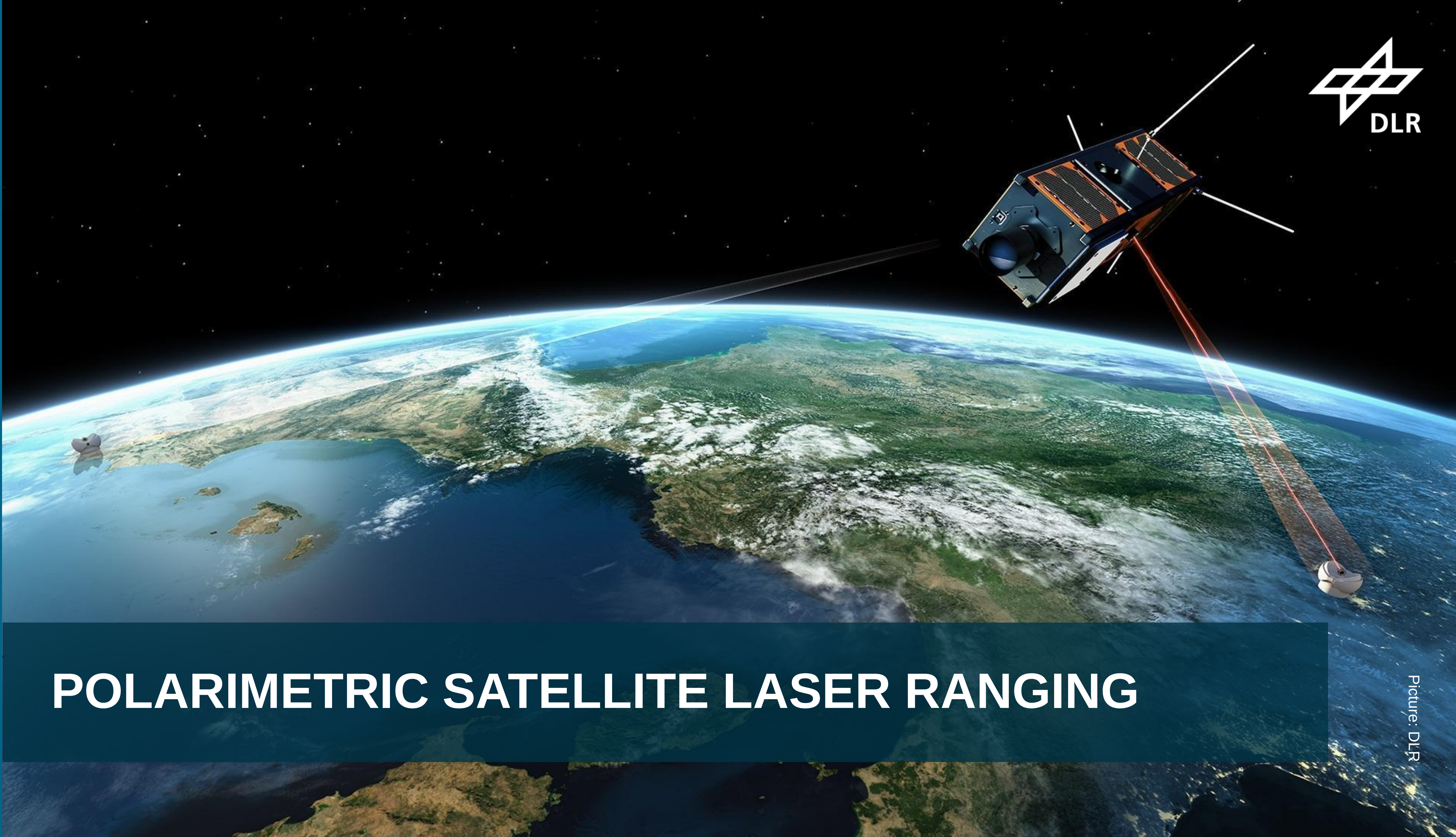
DLR



POLARIMETRIC SATELLITE LASER RANGING

Picture: DLR

GOOD MEMORIES

- ILRS workshop (Stuttgart, 2019)

Motivation: Retroreflectors for space traffic management

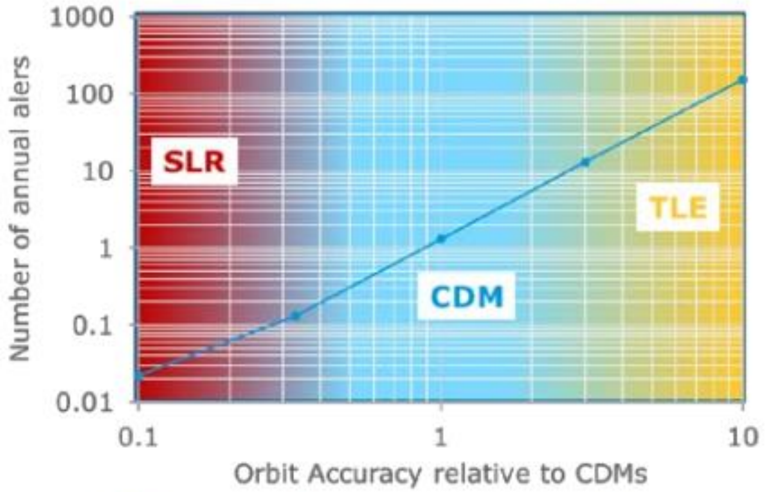


Figure 3: Number of alerts in a year for a LEO spacecrat (safety sphere with 4.5m radius) as a function of the orbit data quality, for a risk threshold corresponding to 90% risk reduction

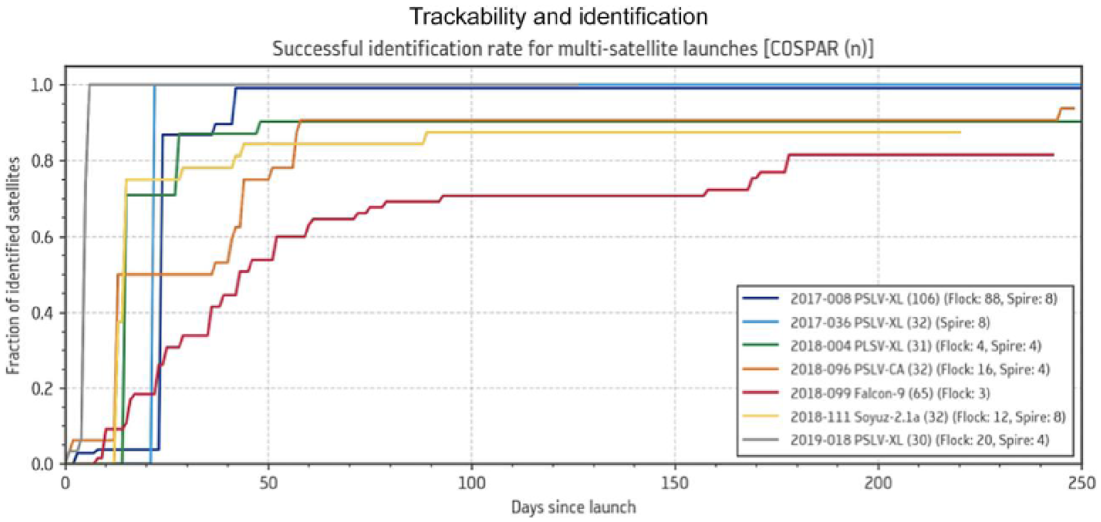
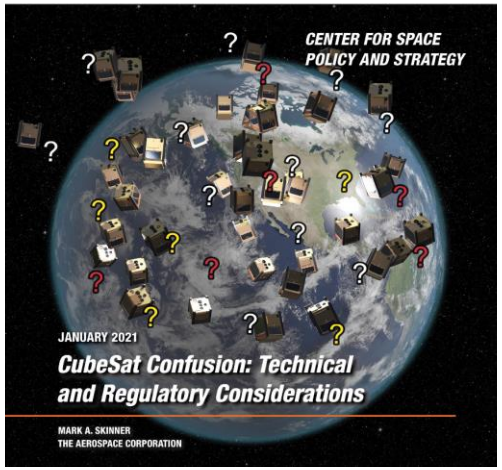


Figure 1: It can take weeks to months to identify most of the object launches, and in some cases 10 percent to 20 percent may never be identified, even after six months or more. Image used with permission of ESA.

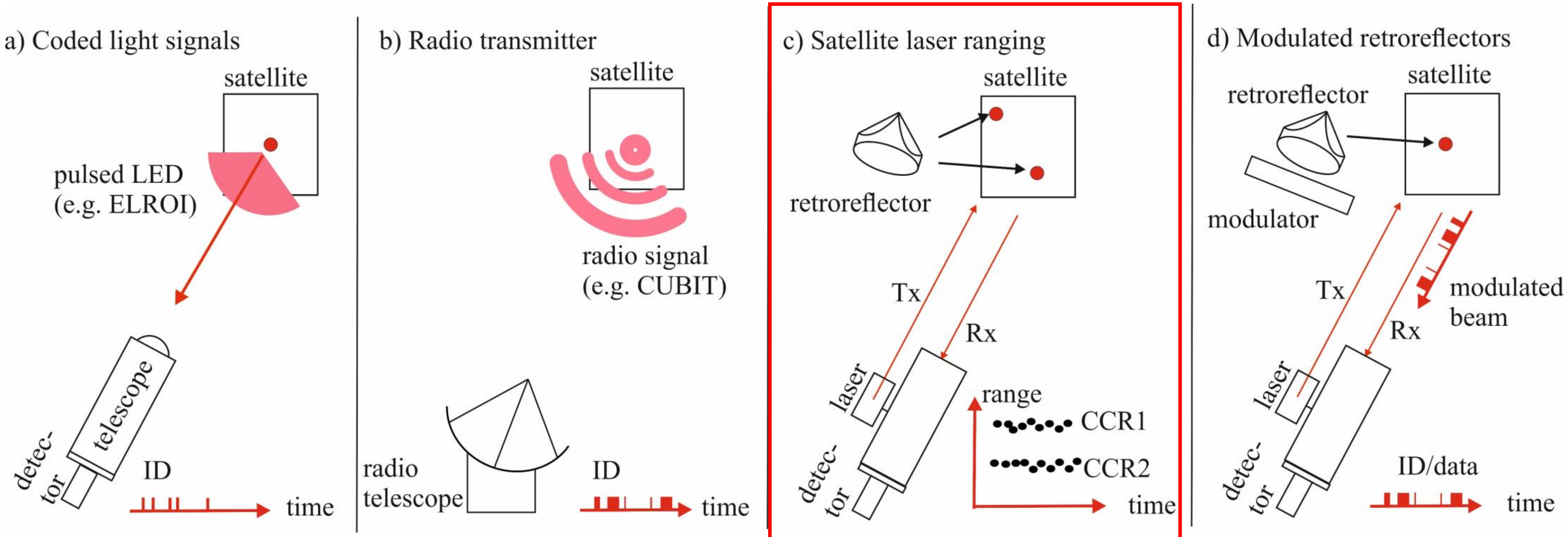
- Increasing number of objects in LEO
- 580 collision avoidance maneuvers per year (99% false alters)
- Number of false alters can be reduced by precise tracking (SLR) → satellites need retroreflectors

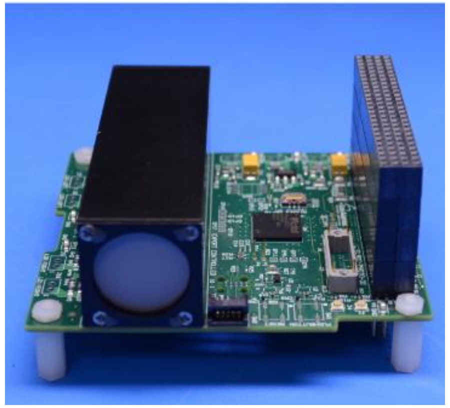
- Ideally, satellites should also be identified, especially after cluster launches of CubeSats

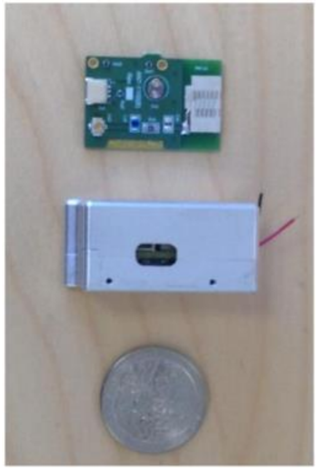
H.Krag et. Al., „Ground-based laser for tracking and remediation – An Architectural view“, 69th International Astronautical Congress, 2018.



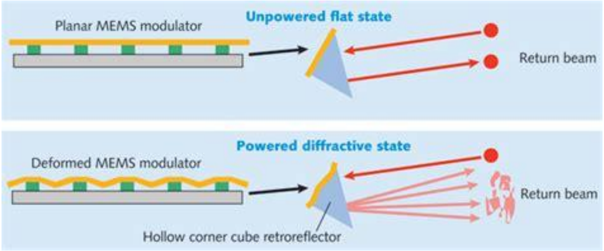
Ideas to identify satellites





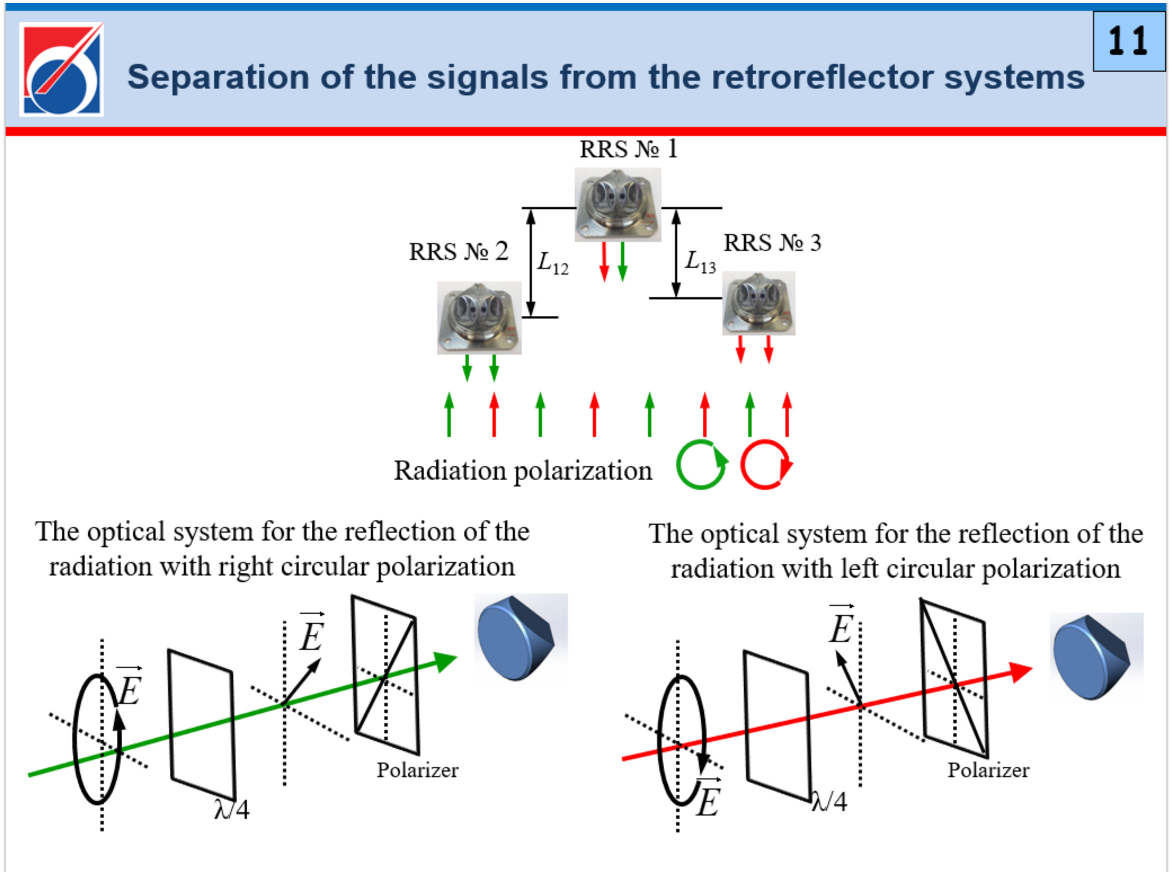


How to increase the number of IDs?



Ideas to identify satellites

- How to code an ID into retroreflectors?
  Ideas: Color, Intensity, Polarization
- Use of polarization has been suggested to determine the coordinates of SC moving parts: Useful to identify satellites?



A.S. Akentyev et. al., „Retroreflector complexes to determinate the coordinates of SC moving parts“, 21st International Workshop of Laser ranging, 2018.

Concept

- Measurement of 4 intensities:

$$
\begin{aligned}
I_1 &= I(T_x = RC, R_x = RC) \\
I_2 &= I(T_x = RC, R_x = LC) \\
I_3 &= I(T_x = LC, R_x = RC) \\
I_4 &= I(T_x = LC, R_x = LC)
\end{aligned}
$$

$$I_a = I_1 + I_2$$

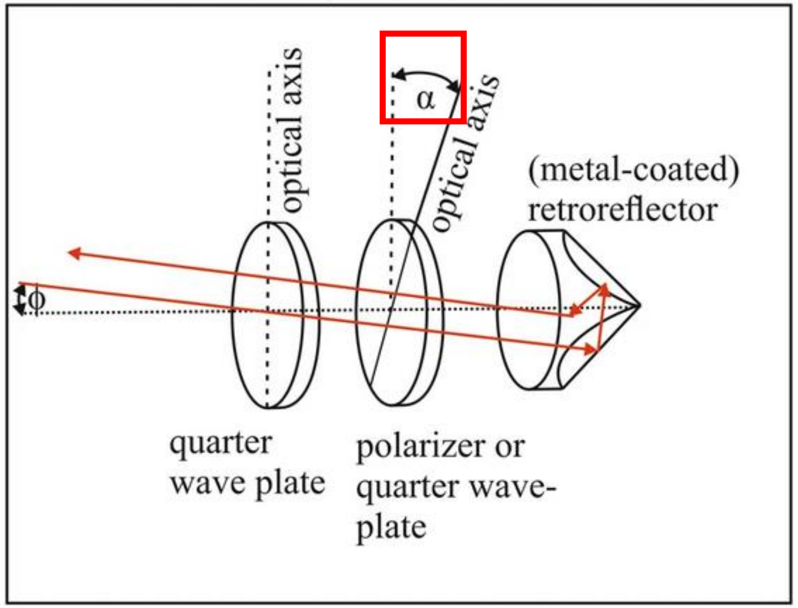
$$I_b = I_3 + I_4$$

- Definition of “symmetry parameters”:

$$P_1 = \frac{I_a - I_b}{I_a + I_b}, \quad P_2 = \frac{I_1 - I_2}{I_1 + I_2}, \quad P_3 = \frac{I_3 - I_4}{I_3 + I_4}$$

- Definition of different retroreflector assemblies with different symmetry parameters; these can be calculated (Mueller calculus):

retroreflector assembly



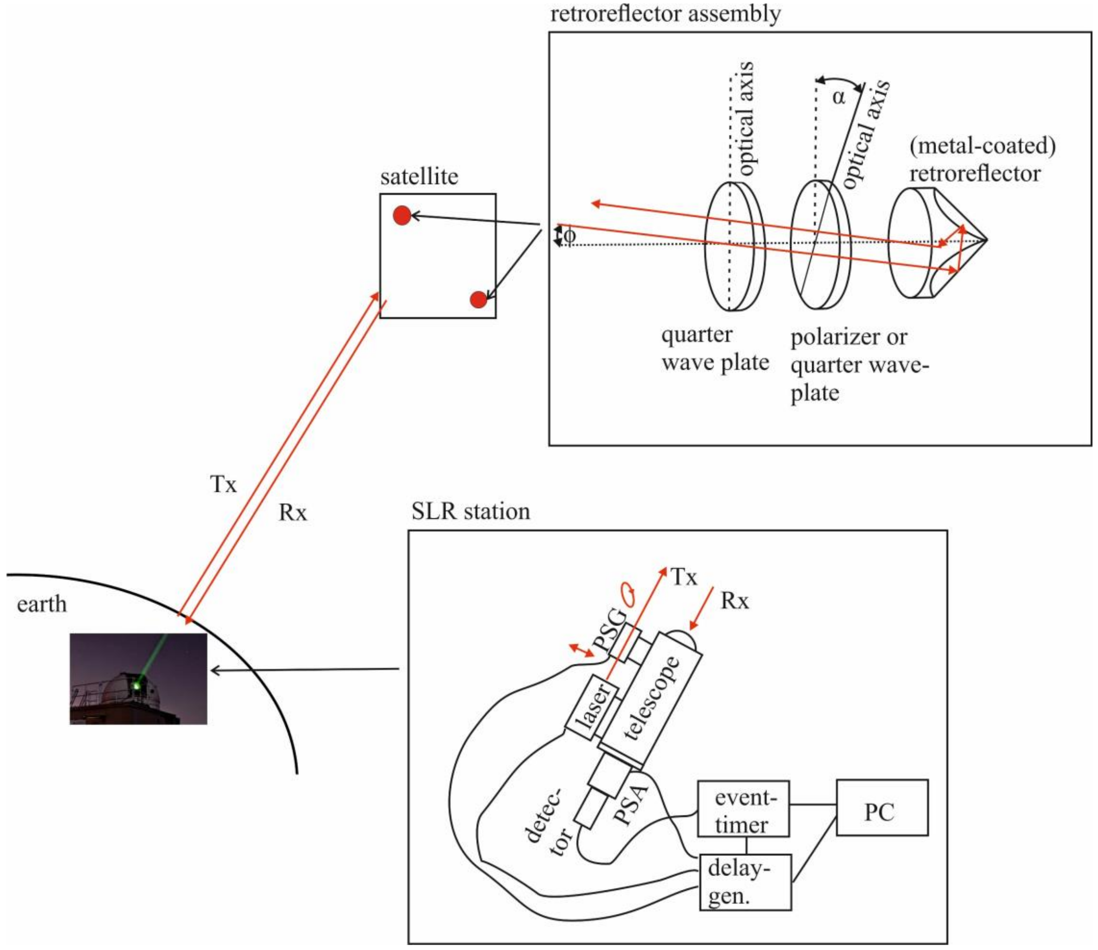
Concept: Emission and detection of right-circular (RC) and left-circular (LC) polarized light

Table 1 Calculated symmetry parameters for different retroreflector assemblies.

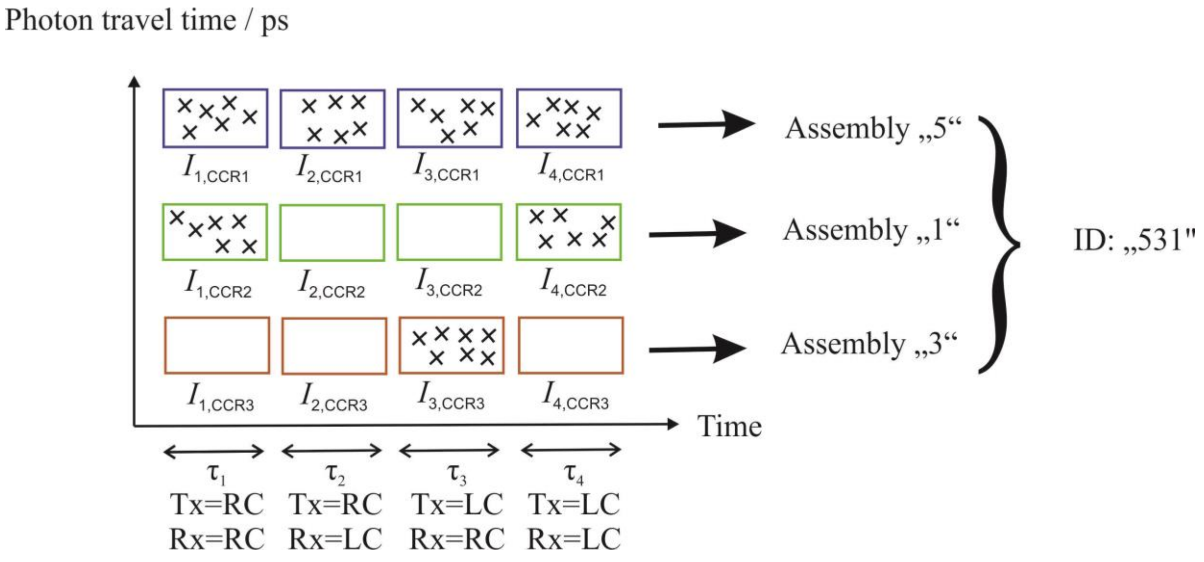
Assembly	Design[a]	α	P_1	P_2	P_3	Intensities
1[b]	A	0°	0	1	−1	$(I_1 = I_4) > 0;\ I_2 = I_3 = 0$
2	A	45°	0	−1	1	$I_1 = I_4 = 0;\ (I_2 = I_3) > 0$
3	B	−45°	−1	$\lim_{\alpha \to -45°} P_2(\alpha) = 1$	1	$I_1 = I_4 = I_2 = 0;\ I_3 > 0$
4	B	−15°	−0.5	0.5	0.5	$I_3 > (I_1 = I_4) > I_2$
5	B	0°	0	0	0	$I_1 = I_2 = I_3 = I_4$
6	B	15°	0.5	−0.5	−0.5	$I_2 > (I_1 = I_4) > I_3$
7	B	45°	1	−1	$\lim_{\alpha \to 45°} P_2(\alpha) = -1$	$I_1 = I_4 = I_3 = 0;\ I_2 > 0$

[a]Design A uses two quarter wave plates whereas design B uses a quarter wave plate and a polarizer mounted to the front face of the retroreflector.
[b]Assembly 1 has the same symmetry parameters as a metal-coated retroreflector without additional polarization optics.

Concept



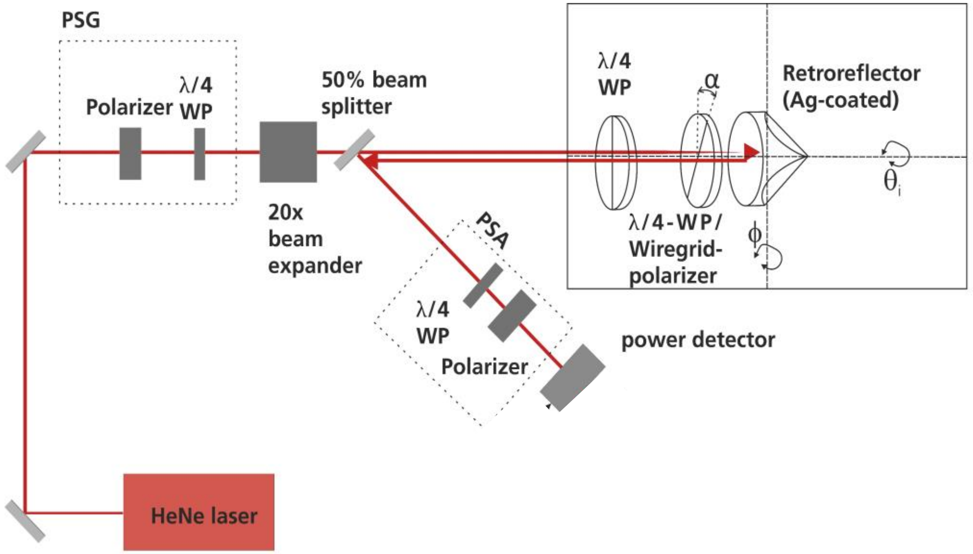
A satellite can carry more than 1 retroreflector.
Signal can be resolved via photon travel time.

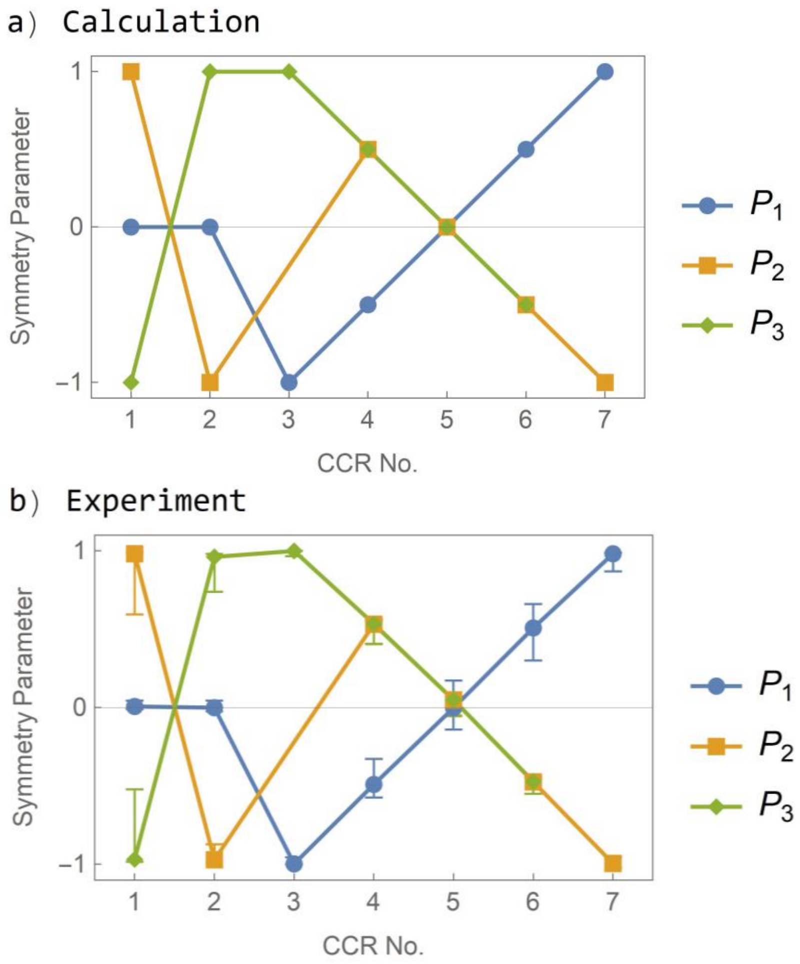


For $k = 3$ CCRs and $n = 7$ different assemblies, we would get $\binom{n+k-1}{k} = 84$ IDs.

Laboratory tests

Test 1: Measurement of total intensity

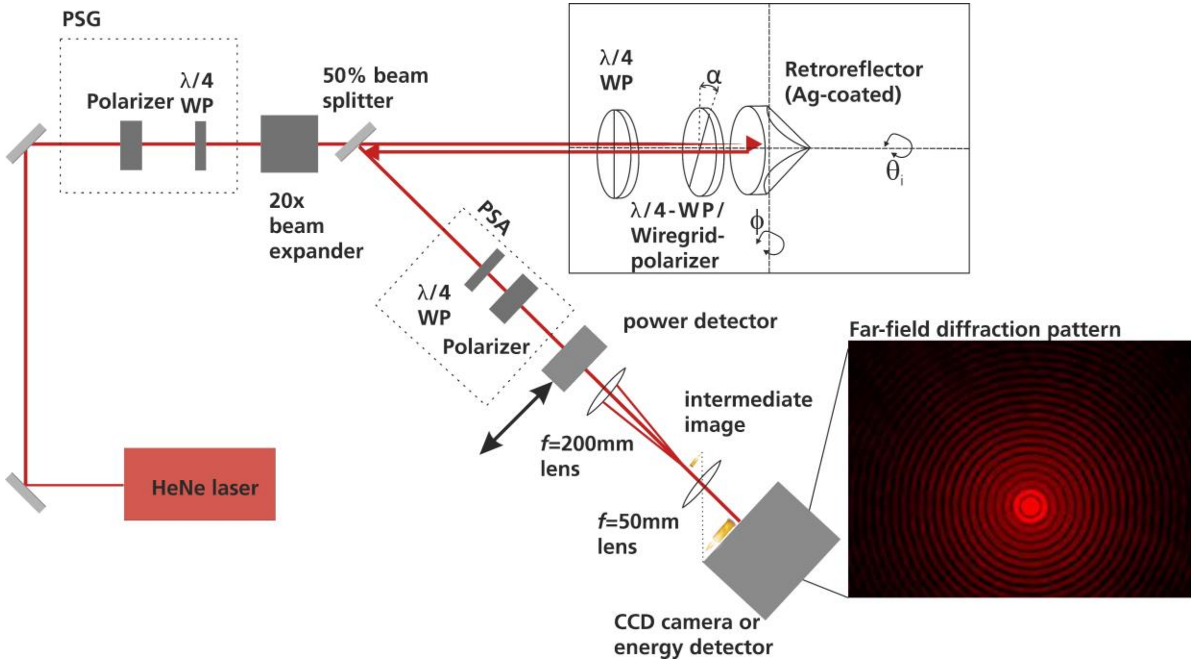




The error bars describe the variation of the symmetry parameter for different incidence angles (θ_i and ϕ)

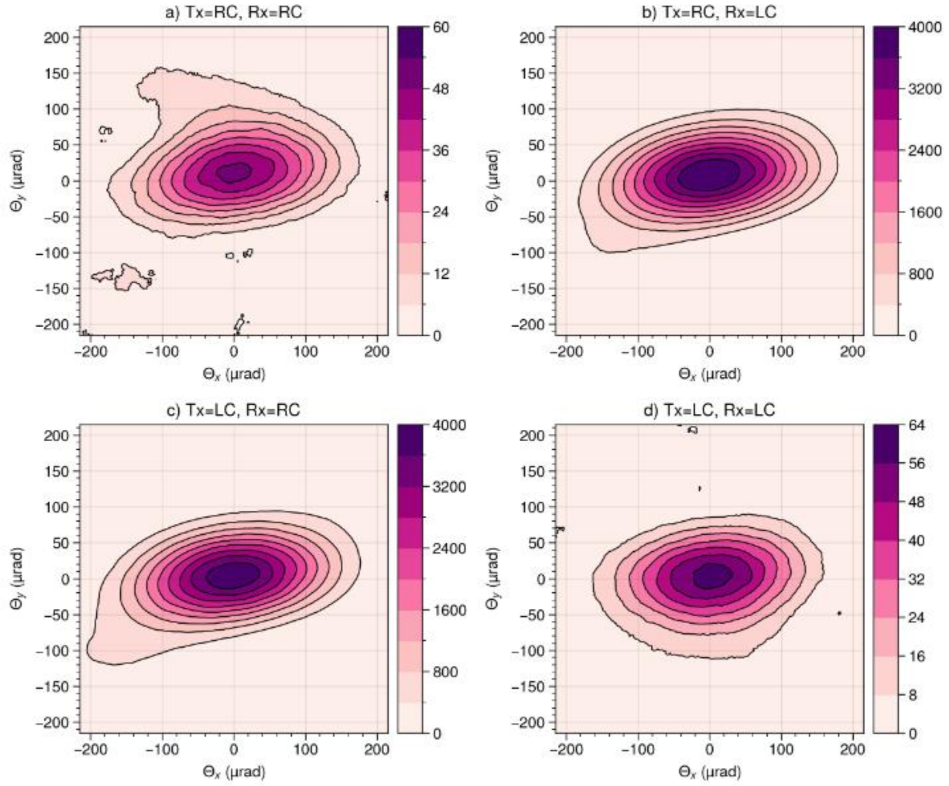
Laboratory tests

Test 2: Measurement of polarization-dependent diffraction patterns



Polarimetric measurements and space qualification of polarization optics: Moritz Vogel
Moritz.Vogel@dlr.de

Example: Far-field diffraction patterns (FFDPs) of assembly 2 at an incidence angle of $\phi = 30°$.



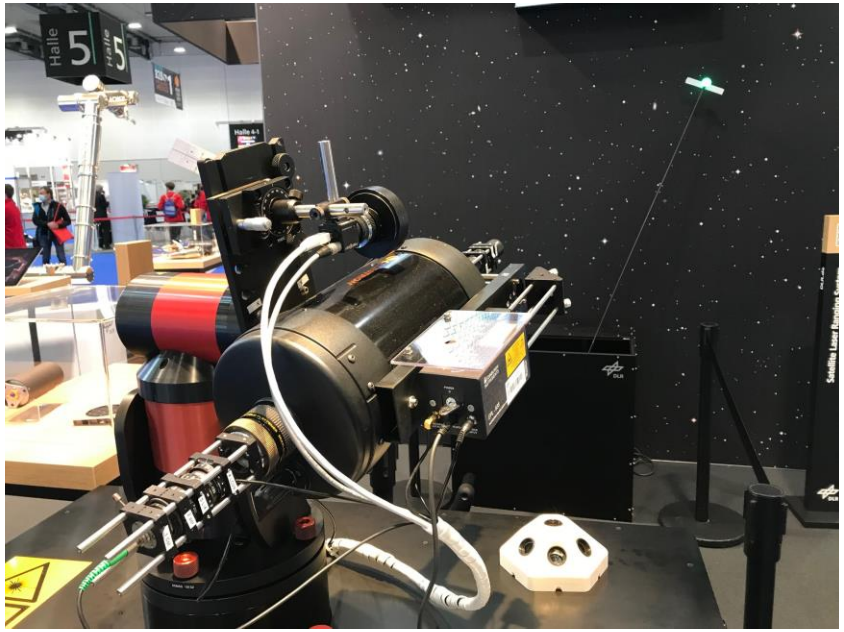
Measurement of symmetry parameters in the diffracted beam appears feasible.

Laboratory tests

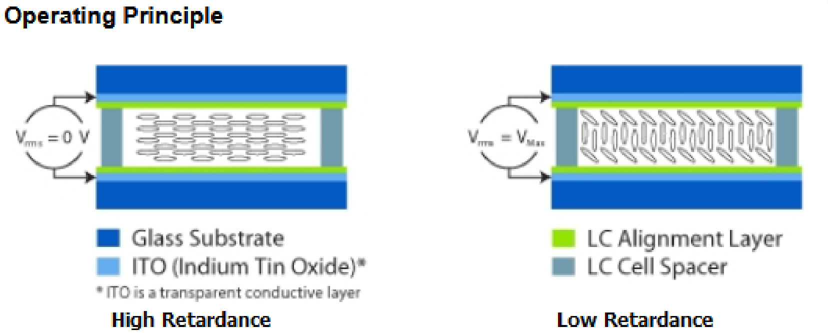
Test 3: How to generate/detect RC and LC polarized light?

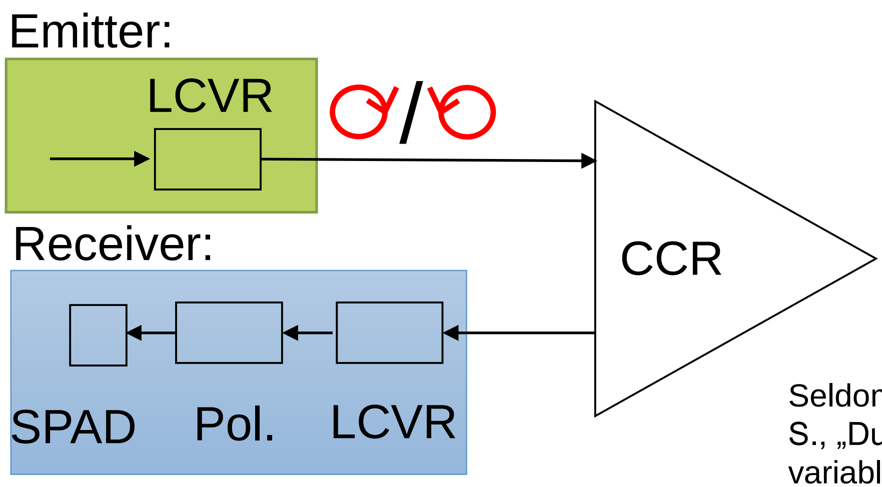
PhD topic: Felicitas Niebler
Felicitas.Niebler@dlr.de

Initial idea: Switching liquid crystal variable retarders (LCVRs)



Polarimetric SLR demonstrator





+ easy to integrate into SLR systems
- LCVRs need to be calibrated and temperature stabilized
- Undefined polarization state during switching time
- LCVR on detector needs to be switched later than on the emitter (photon travel time)

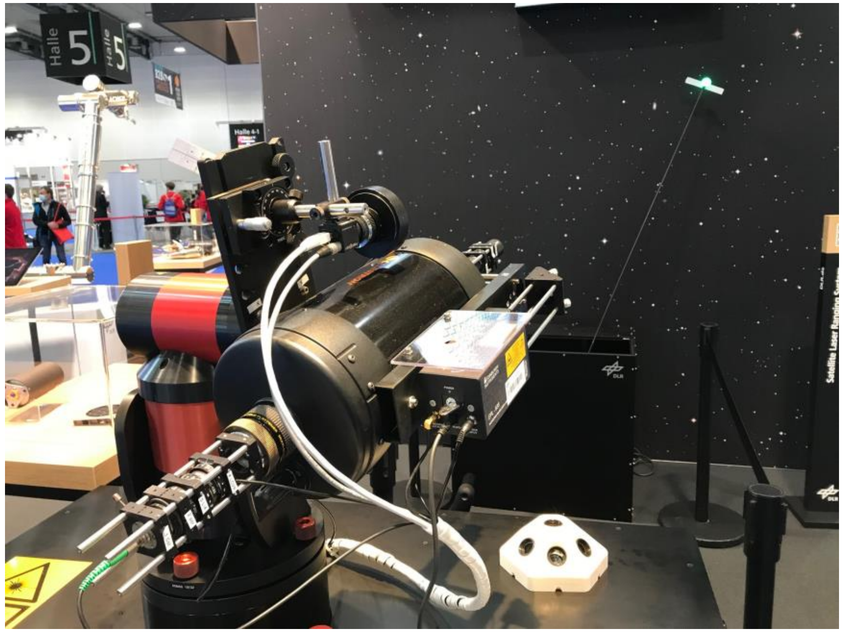
Seldomridge, N. L., Shaw, J. A. & Repasky, K. S., „Dual-polarization lidar usinga liquid crystal variable retarder“, Opt. Eng. 45, 1–10 (2006)

Laboratory tests

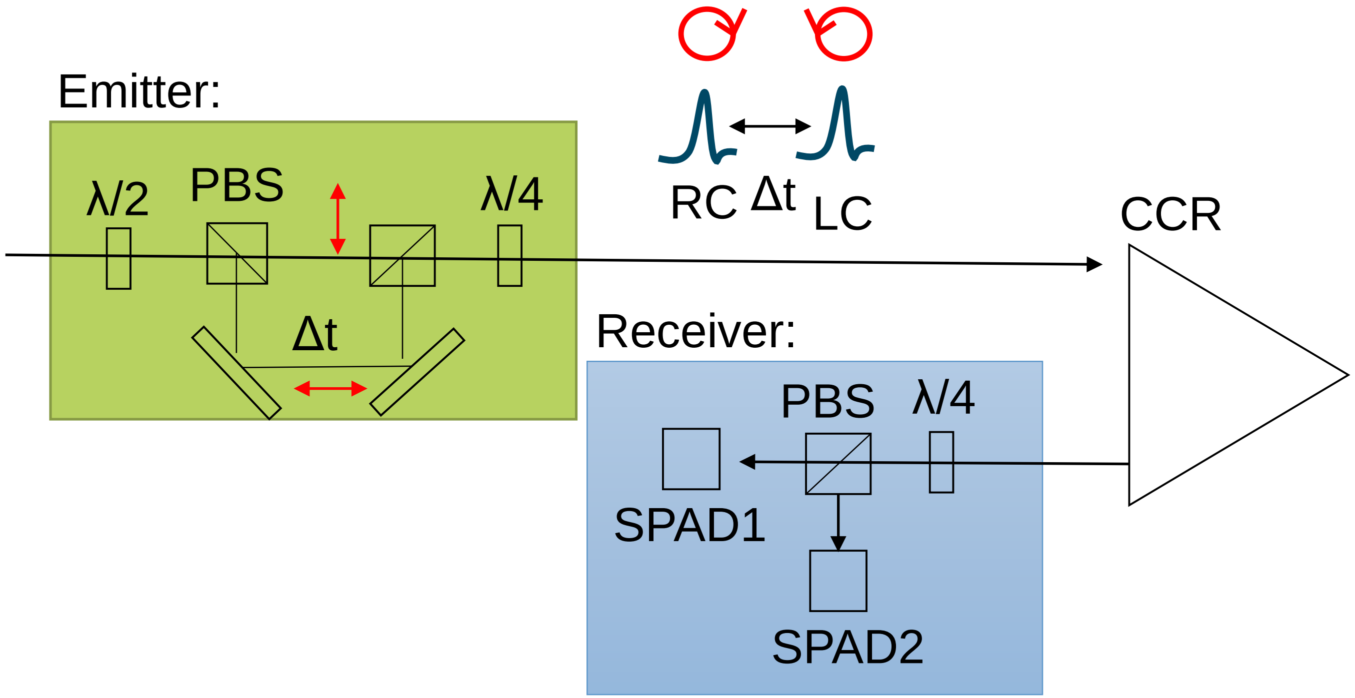
Test 3: How to generate/detect RC and LC polarized light?

PhD topic: Felicitas Niebler
Felicitas.Niebler@dlr.de

Optimized design: Double pulses generated via polarizing beam splitters (PBS)



Polarimetric SLR demonstrator



- Delay line in emitter required (difficult to align?)
- Less energy in single laser pulse due to double pulse generation

+ no switching times → more photons
+ no calibration, temperature stabilization

Conclusions

DLR

- We are investigating polarimetric SLR to allow for a simultaneous orbit determination and identification of satellites.

- Questions to ILRS community:
  - Polarimetric SLR targets space traffic management (STM). Any ideas for applications in space geodesy? Attitude dependent center of mass correction?
  - Can a demonstration mission be tracked by the ILRS?

- Questions to industry:
  - Opinion on commercialization of the technology once demonstrated in a space mission?

The presented results have been made possible by great team work with:
Felicitas Niebler, Daniel Hampf, Wolfgang Riede, Moritz Vogel, Paul Wagner (now at DLR Institute of Communication and Navigation), Ewan Schafer (now at Lumi Space, UK), Paul Allenspacher (now retired), Bernhard Heidenreich, DLR Technical workshops

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engineering

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Check for updates

https://doi.org/10.1038/s44172-022-00003-w OPEN

Space object identification via polarimetric satellite laser ranging

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