S3LA - THE SINGLE-PHOTON COUNTING LASER ALTIMETER FOR THE SER3NE MISSION TO THE MOON

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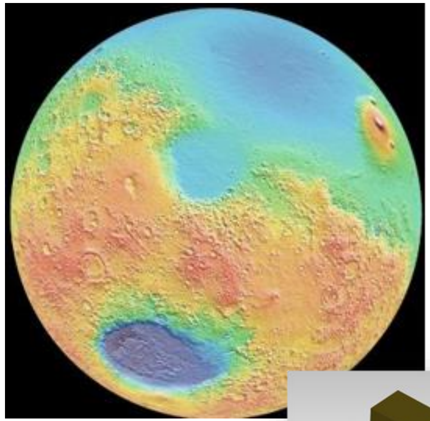
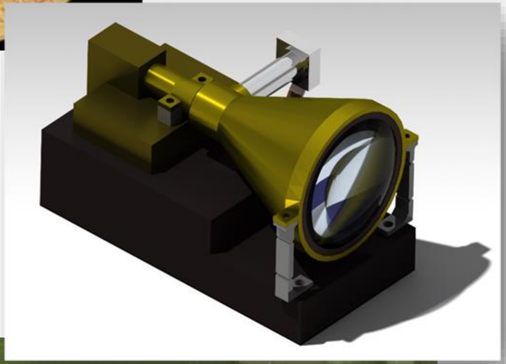
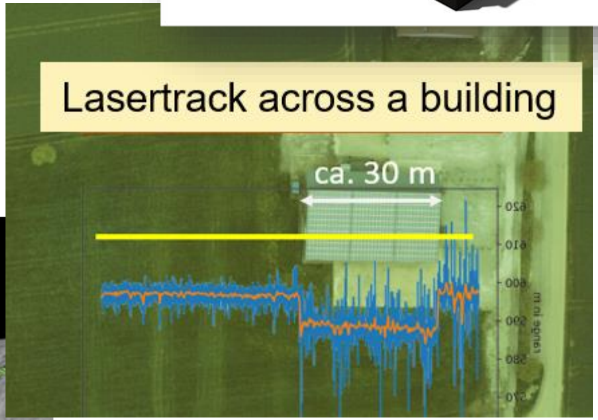
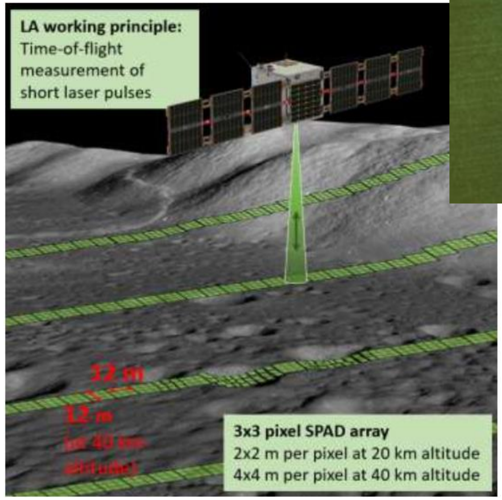
Outline

- Laser Altimeter in Planetary Research
- Single-photon Counting Laser Altimeter
- S3LA Instrument
- Flight Campaign with a S3LA Breadboard
- Outlook







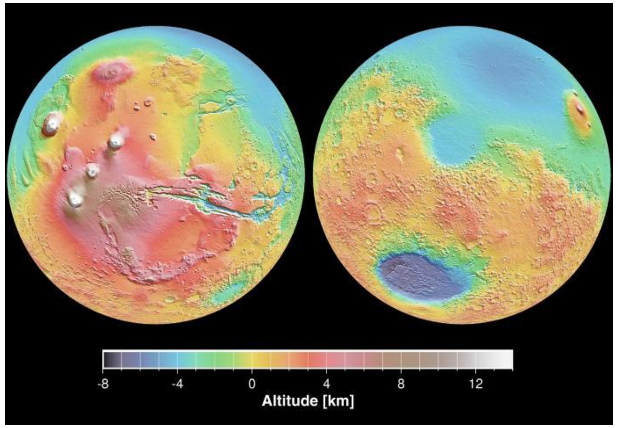


Science Objectives of Laser Altimeter in Planetary Research

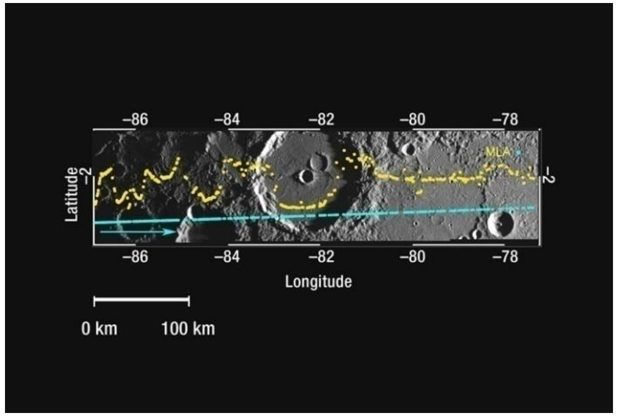
Geology:
- Regional and local **height profiles** for morphological characterization of surface features
- Targeted **investigations of specific regions** (e.g., cryo-volcanic regions, permanently shadowed craters)
- **Surface properties** (local slopes, roughness, albedo)

Geophysics:
- **Tidal deformation**: periodic variations of surface deformation
- Global and regional **topography** for interpretation of gravity field measurements
- Cross-over analysis to improve orbit determination

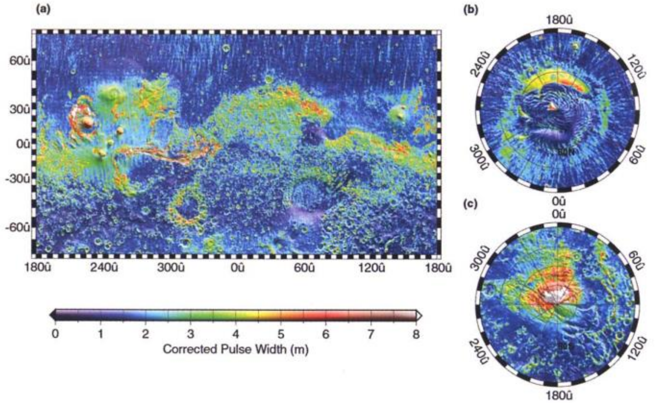
Geodesy:
- Radius, global **shape** and rotational state
- Establishing reference systems



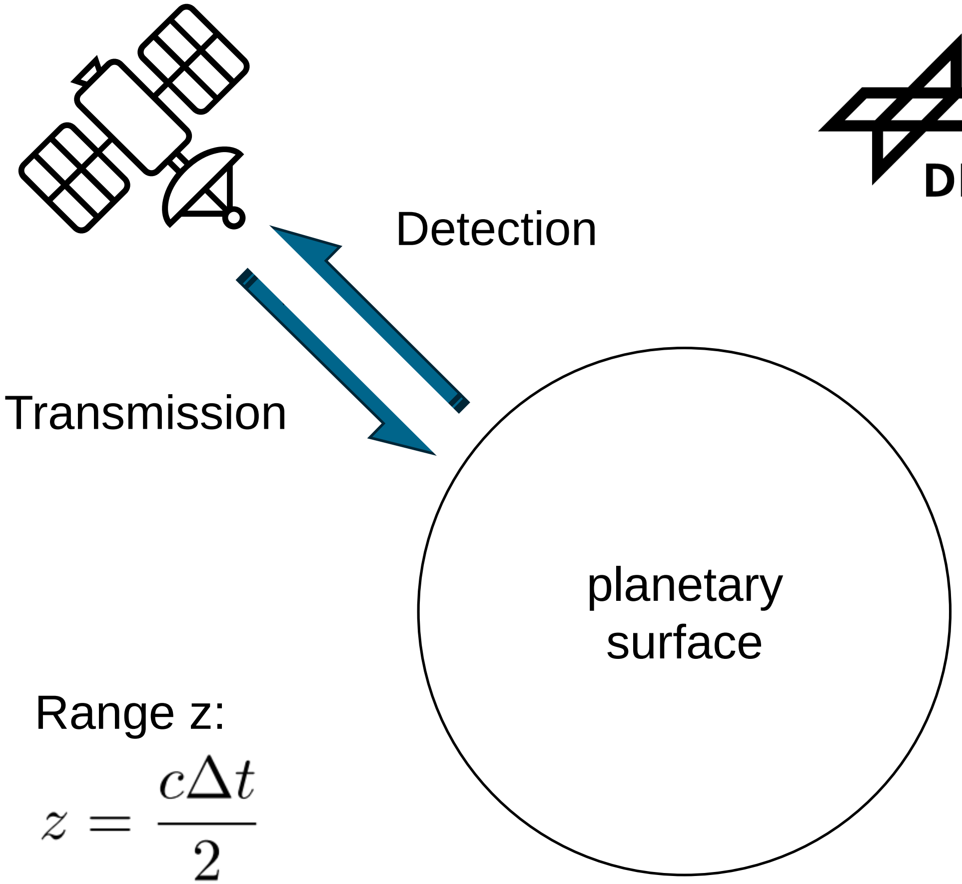
Global Topography of Mars (MOLA)



Mercury (MLA): Laser ground-track and range measurements.



Laser Altimeter Working Principle



1. a laser source sends light pulses to the target
2. the pulses hit the surface, reflect back to the instrument
3. a photonic detector detects the signal

This happens many times per second (Hz to kHz)

Range z:

$$z = \frac{c\Delta t}{2}$$

Data product is topography, albedo etc. of planetary surfaces, measured from distances up to 1000 km with a range accuracy of <10 cm.
1000 km is like from Berlin to London

Number of received photons N_{ph}:

$$N_{\mathrm{ph}} = \frac{E_T \xi_T \xi_R a d_T^2 T_A^2 Q_e}{4R^2 h\nu}$$

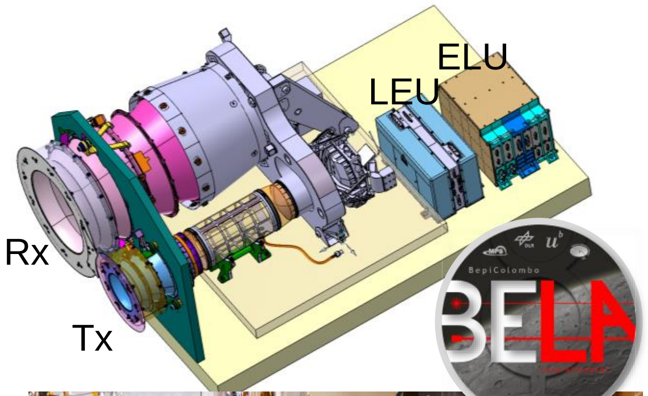
N_{ph} is the number of photons in the reflected pulse, E_T is the energy of the emitted laser pulse, ξ_T and ξ_R are the losses in the transmitter and receiver optics, a is the fraction of emitted power reflected at the surface (the albedo), d_{2T} is the diameter of the receiver optics, T_A is the fractional loss of optical power through attenuation in the atmosphere (if present), Q_e is the quantum efficiency of the sensor, R is the range to target, $v = c/\lambda$ is the frequency of the laser light (λ is the wavelength) and h is the Planck constant.

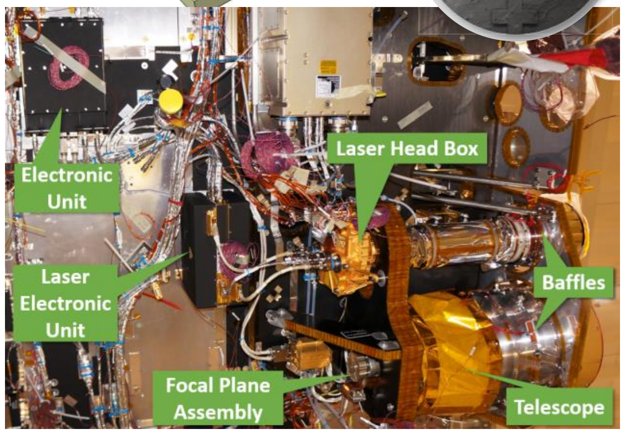
Classical Laser Altimeter

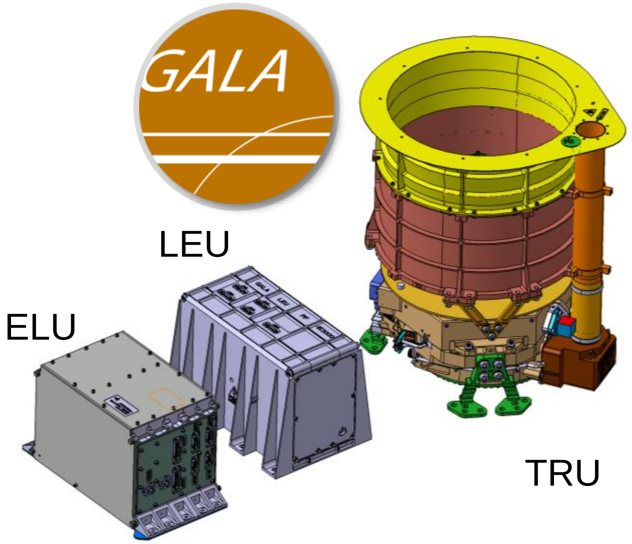
- “Classical” in terms of “<u>not</u> single-photon counting”, but some hundreds of photons in the reflected pulse
- Examples: Apollo (Moon), MOLA (Mars), LOLA (Moon), MLA (Mercury), **BELA** (Mercury), **GALA** (Jupiter’s Icy Moons)

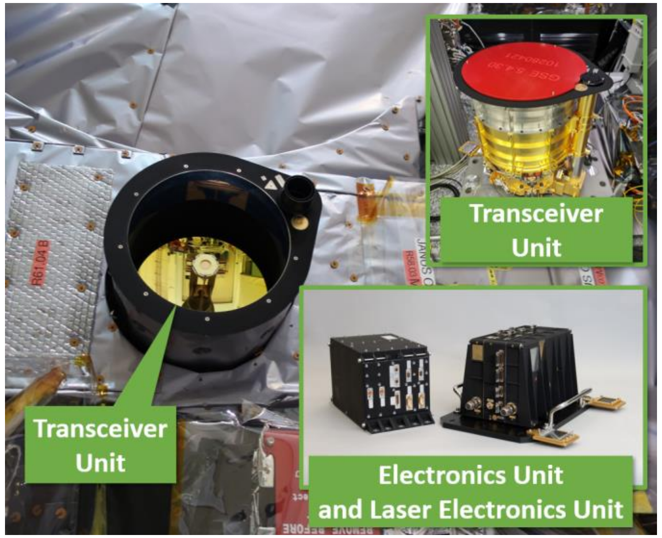
Instrument Parameter	BELA	GALA
Pulse Energy [mJ]	50	17
Pulse Repetition Rate [Hz]	10	30
Telescope Diameter [cm]	25	20
Mass [kg]	15	25
Electrical Power [W]	43	50
Detector (APD) in linear detection mode, digital waveform analysis, needs 700 to 1000 photons		

→ **Powerful, but heavy, large and expensive**









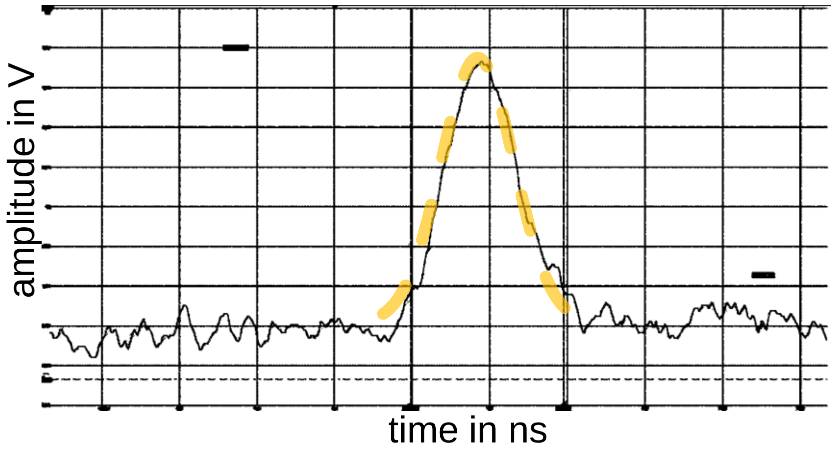
Single-photon counting APD (SPAD) for SPC LA

The basic link budget equation (see before) applies, but statistical mathematics becomes relevant for the detection of the single photons

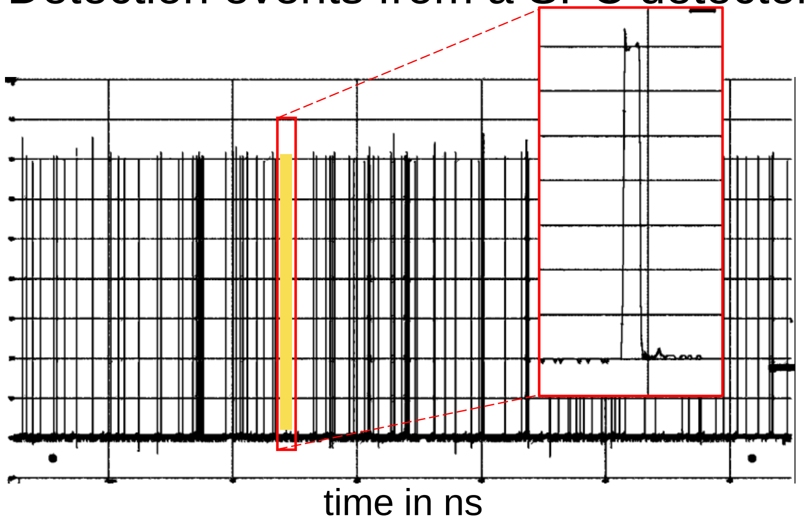
Technical prerequisites for a miniaturized instrument:

- SPAD array:
  - timestamping logic (100 ps) on the detector chip (ASIC)
  - very short deadtimes (< 3 ns)
- Narrow optical bandpass filter (< 0.15 nm) for reduction of straylight
- Compact & tunable laser
- Combined Transmitter-Receiver optics

Pulse shape in classical laser altimeter

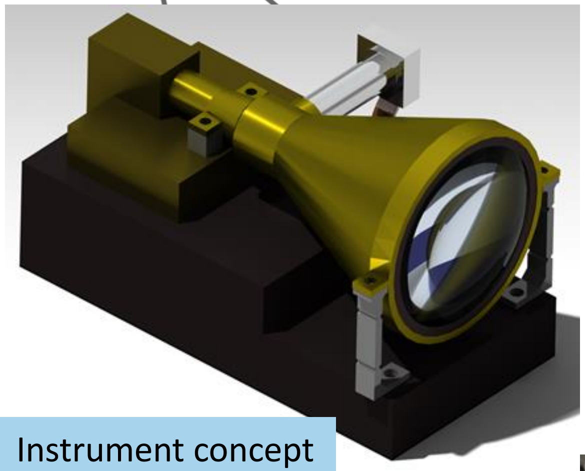


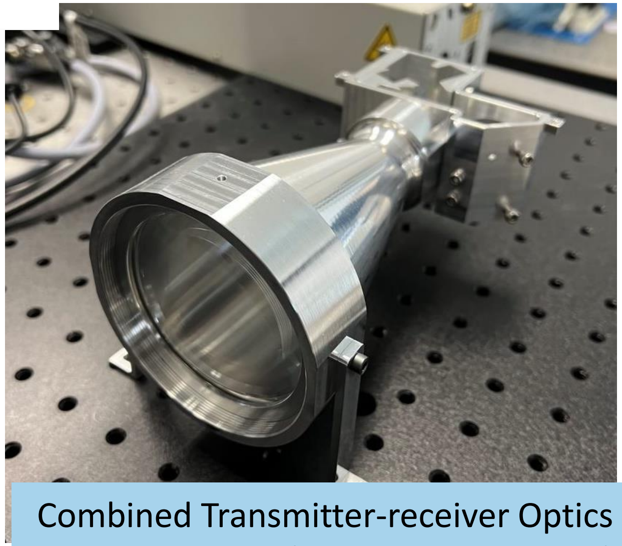
Detection events from a SPC detector

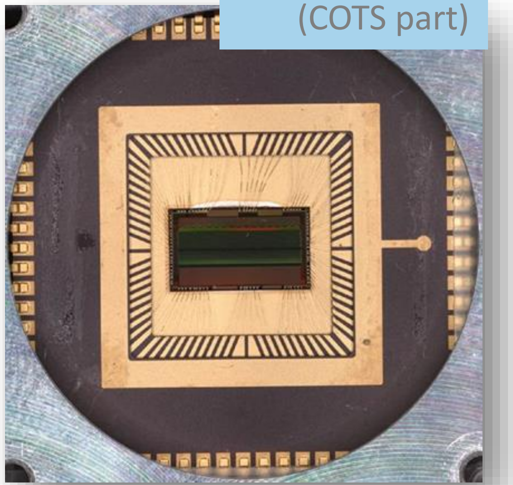


S3LA
the SER3NE Laser Altimeter

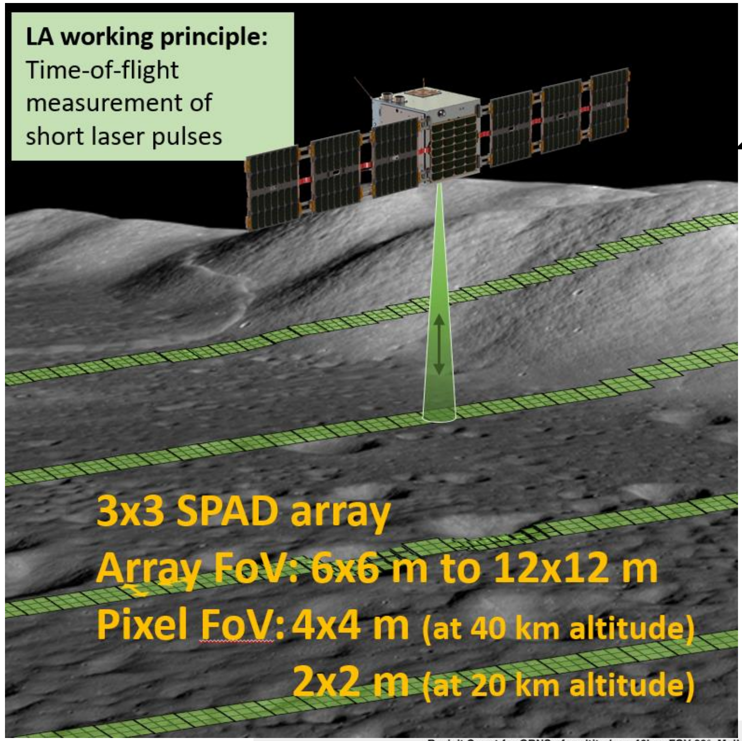
- SER3NE is a mission to Moon, 20-200 km orbit, with NIR spectrometer, gamma-ray and neutron spectrometer and the laser altimeter
- Currently in an **ESA Pre-Phase A**
- S3LA is active between 20 and 40 km altitude
- Main performance parameters:
  - 3x3 pixel SPAD detector array
  - 5 cm measurement accuracy
  - 2 to 4 m horizontal resolution
  - Laser pulse energy 0.5 to 2 mJ at 200 to 425 Hz repetition rate, dependent on altitude
  - 3.6 kg and 20 W
  - full digital signal processing


Instrument concept


Combined Transmitter-receiver Optics (Cubesat-compatible)


Detector array (COTS part)

S3LA
the SER3NE Laser Altimeter



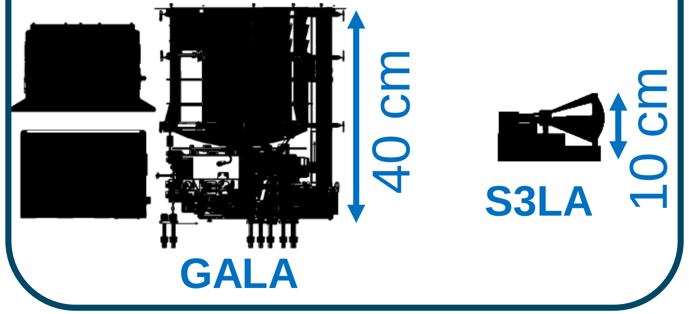
Primary Instrument Science Goals:

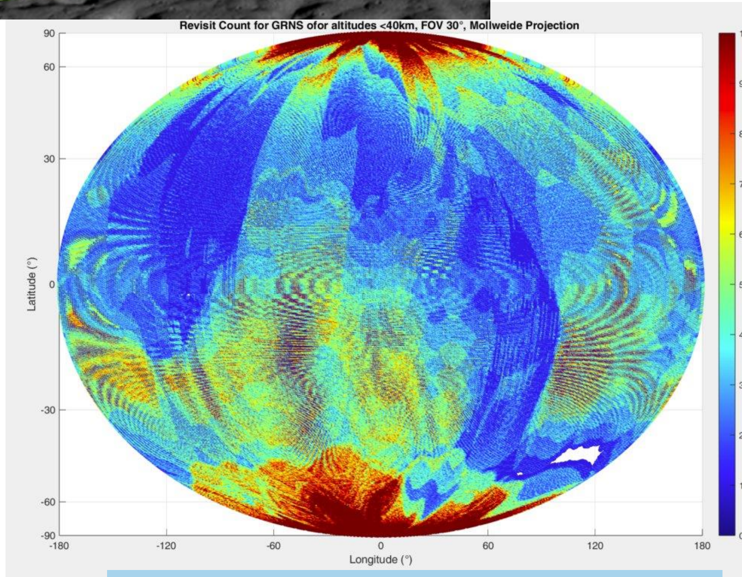
- High-resolution topography at potential landing sites, craters, permanently shadowed regions
- Improve and complement existing data
- Context for other instruments, navigation support

Earth-based
Lunar Laser Ranging:
S3LA shall receive & timestamp laser pulses from Earth for a better orbit determination

Example: LOLA Laser Ranging

Dimensions comparison:
(although not quite fair)

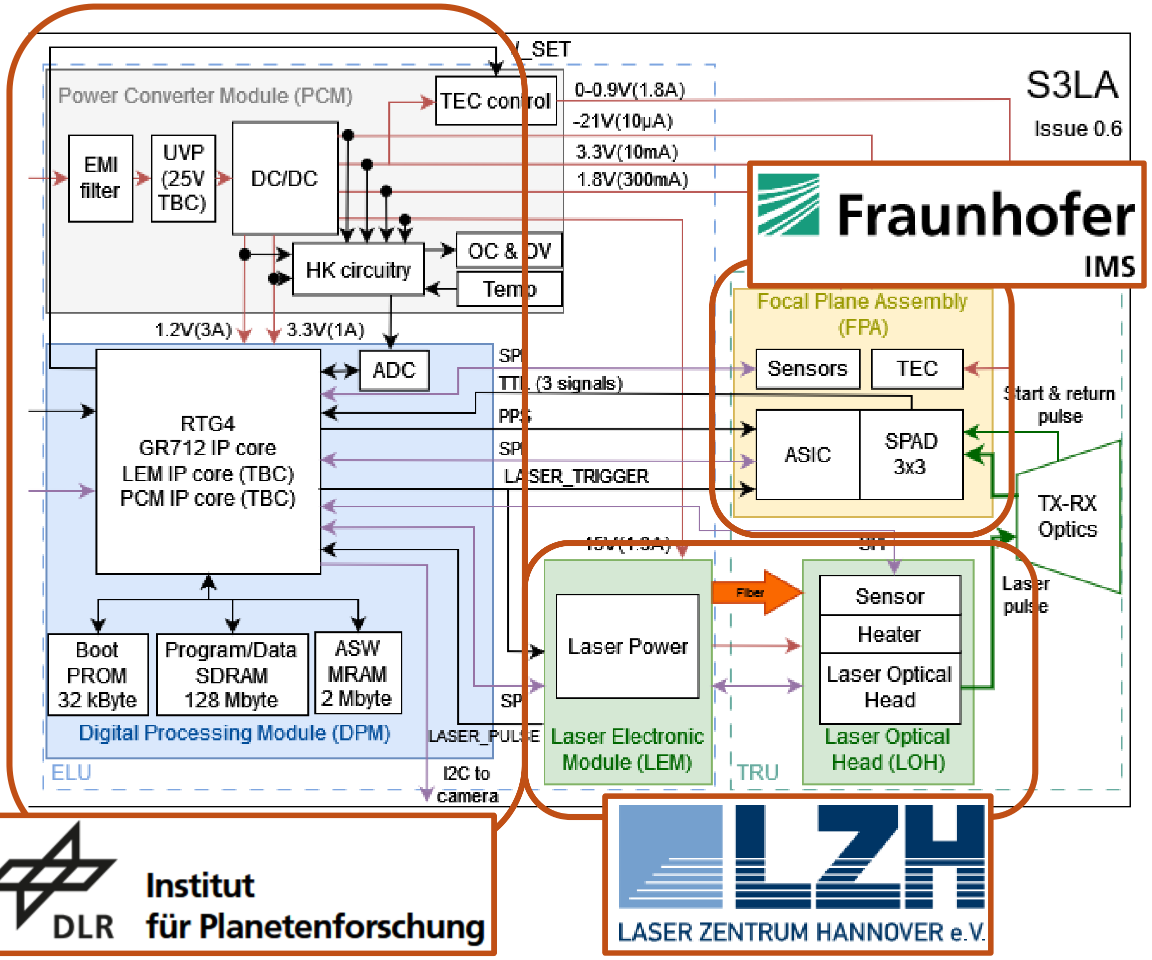




Coverage for altitudes <40 km
(but large crosstrack gaps at equator)

S3LA Consortium

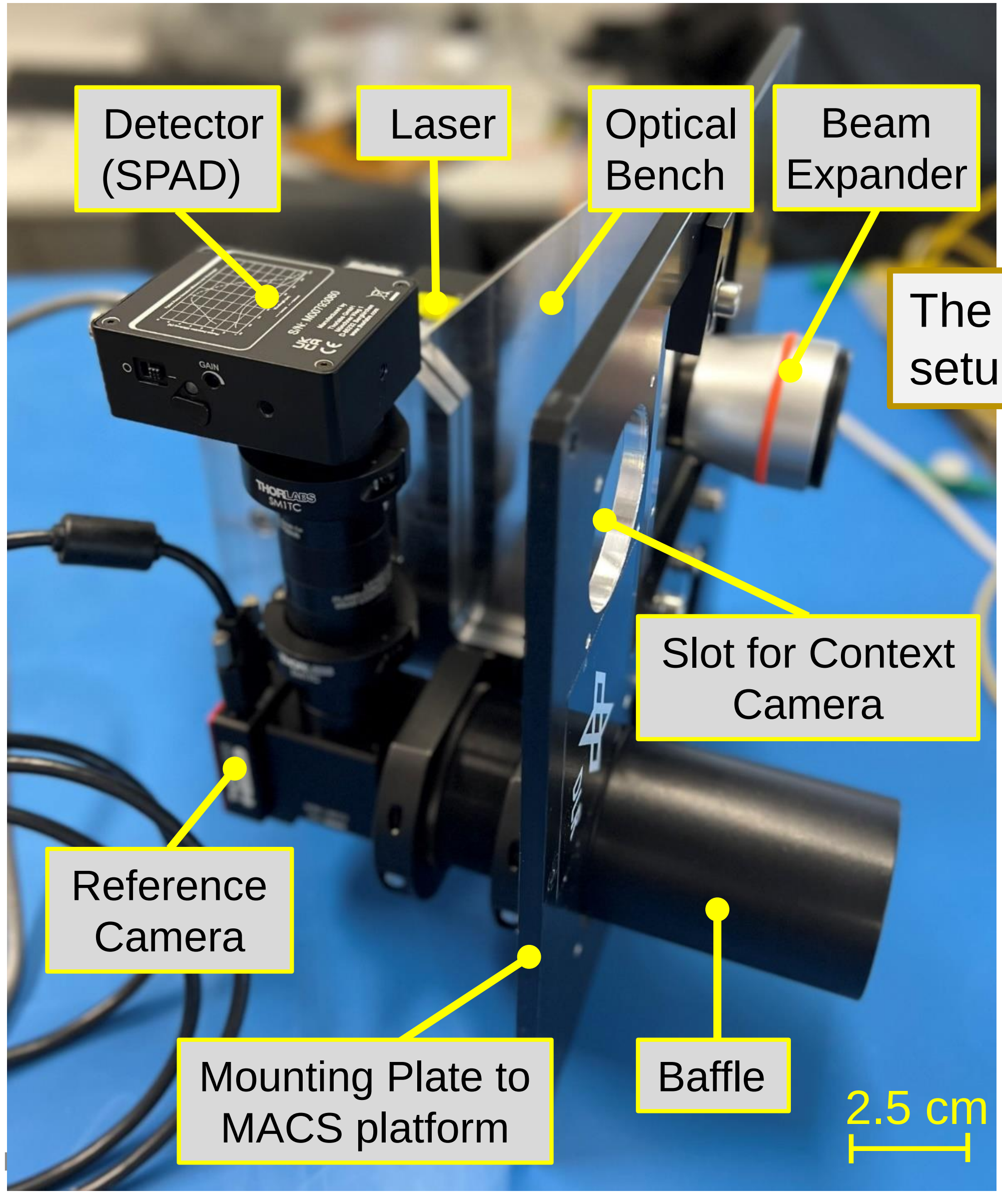
- DLR: Instrument lead, system responsibility, Main electronics,
  optics, science, data analysis
- Fraunhofer Institute for Microelectronic Circuits and Systems (IMS) Detector array with timestamping
- Laser Zentrum Hannover: Laser system



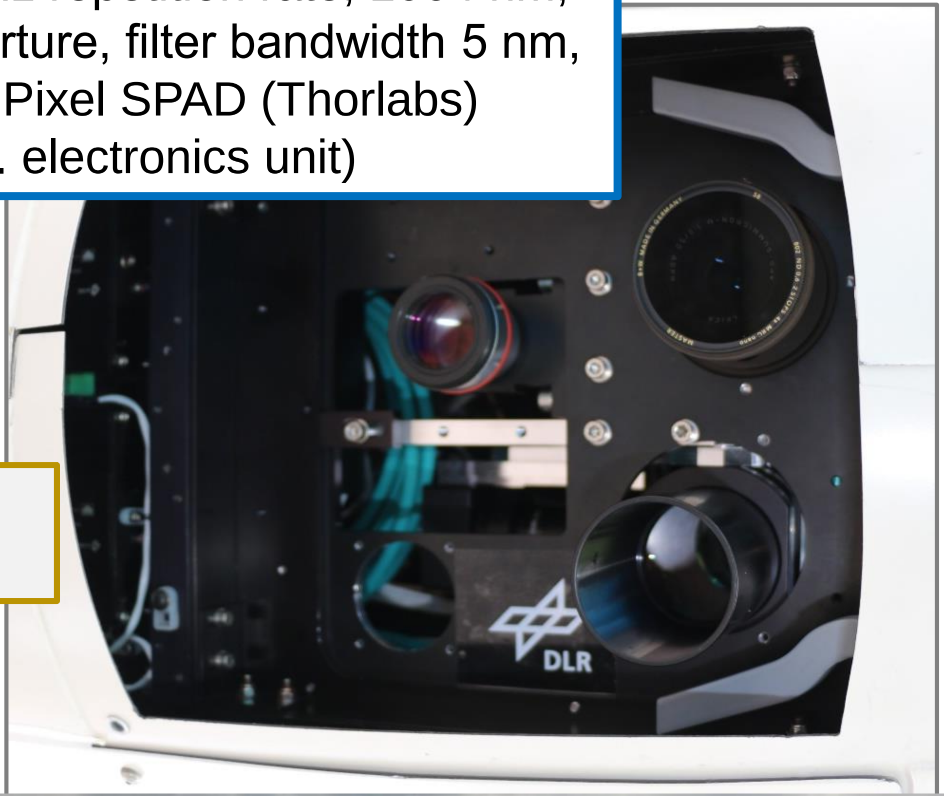
- ➢ National value creation and development of new technologies
- ➢ Several technology transfer options identified

Flight campaign with a SPC laser altimeter breadboard

Laser: 5 µJ, 5 kHz repetition rate, 1064 nm,
Receiver: 2” aperture, filter bandwidth 5 nm,
Detector: Single Pixel SPAD (Thorlabs)
Mass: 4 kg (excl. electronics unit)



The breadboard setup



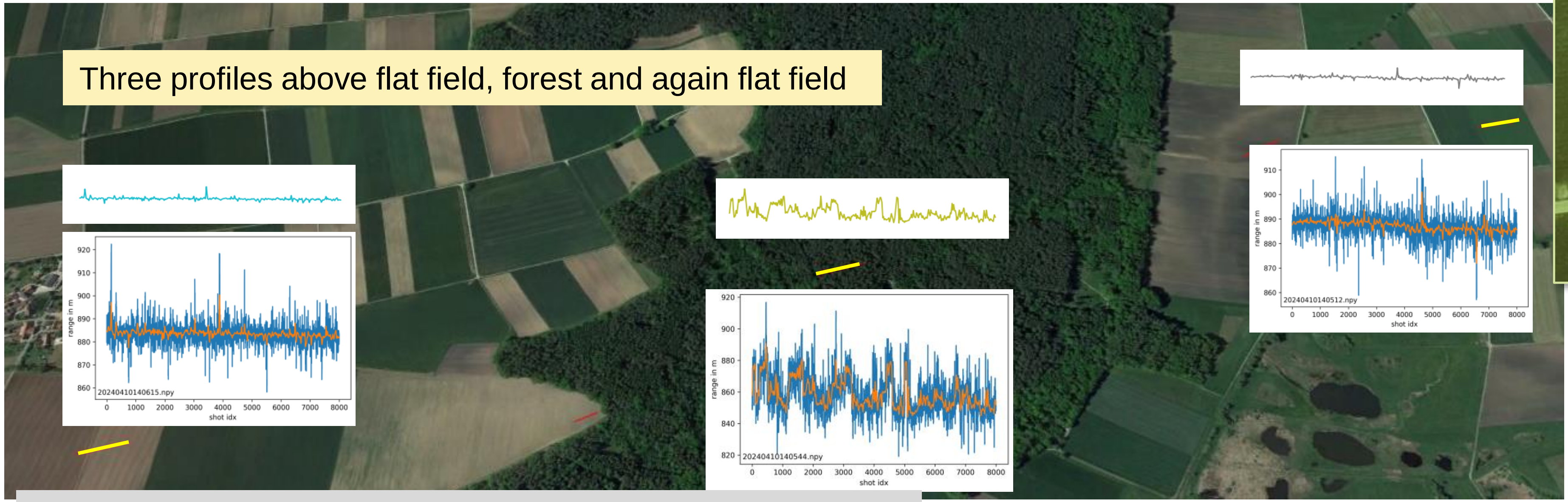
Mounted into the wingpod

The motor glider is taxiing to take-off

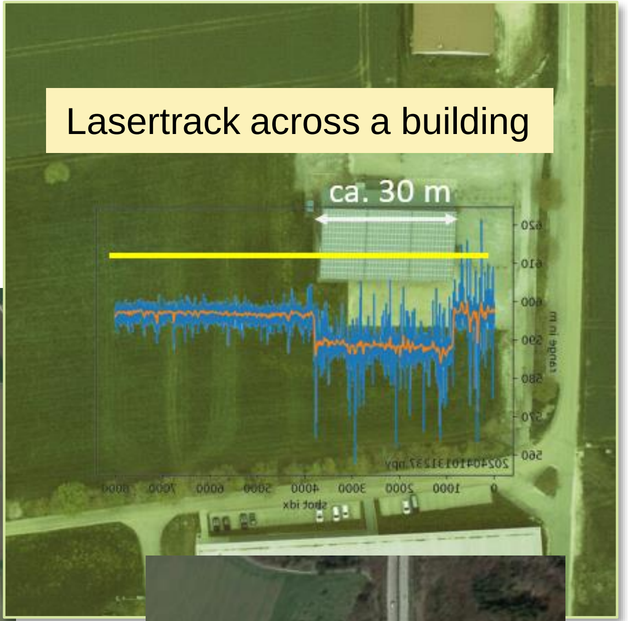
Flight campaign with a SPC laser altimeter breadboard

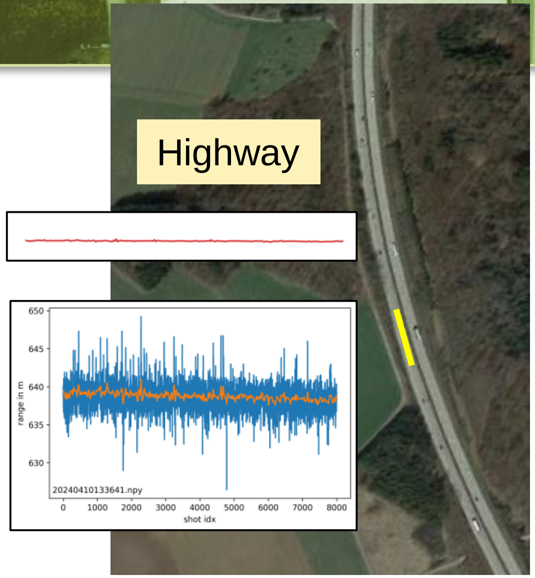
Some examples of the obtained data sets:

(due to storage and data transfer limitations, sections of 1.6 s length were recorded, see yellow lines)



Blue: event with highest probability, Orange: Gaussian filter





Further Miniaturization for use on lander, rover, helicopter

The instrument concept allows for further miniaturization:

- **Lander:** surface surveillance before landing and GNC support during landing
- **Rover**: 360° surveillance, range < 500 m, instrument volume < 5x5x20 cm^3
- **Helicopter or drone:** highly customized, even less mass/power/volume, but same SPAD array and functional principle
- **GNC**: navigation support during docking or for swarms

Outlook

- With S3LA, we can refine and amend existing lunar data sets with the goal of future exploration
- Finish the ESA Pre-phase A study and maybe start phase A/B1 in November
- Increase TRL & maturity
  - by further design work,
  - by testing with breadboards and prototypes
  - with further flight campaigns using a more representative instrument

Thank you for your attention!

Imprint

Topic: **S3LA - the single-photon counting laser altimeter for the SER3NE mission to the Moon**

Date: 2025-05-05

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Institute: DLR Institute of Space Research

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