DEMONSTRATION BREADBOARD OF A MINIATURIZED SINGLE PHOTON DETECTION LASER ALTIMETER FOR SMALL SATELLITE APPLICATIONS

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Sunday, July 14, 2024, 15:30-15:45 (15 min)

B: Space Studies of the Earth-Moon System, Planets, and Small Bodies of the Solar System

B0.2: Instrumentation for Planetary Exploration

DLR

Outline

- Introduction

Principle and Instruments

- Miniaturization

Goal and Rationale

- Demonstrator

COTS design and Testing

- Flight Campaign

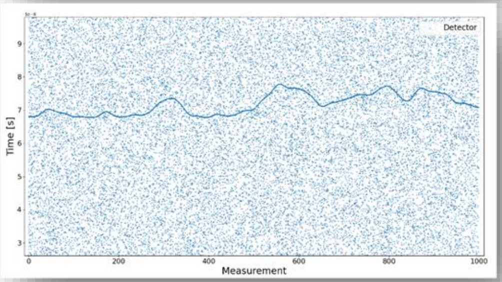
Ranging Profiles

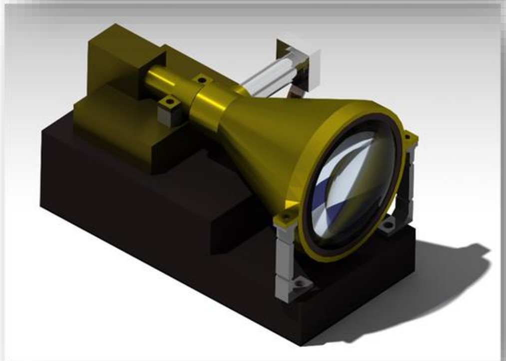
- Data Evaluation

Algorithm

- Outlook

Improvements and Small Satellite

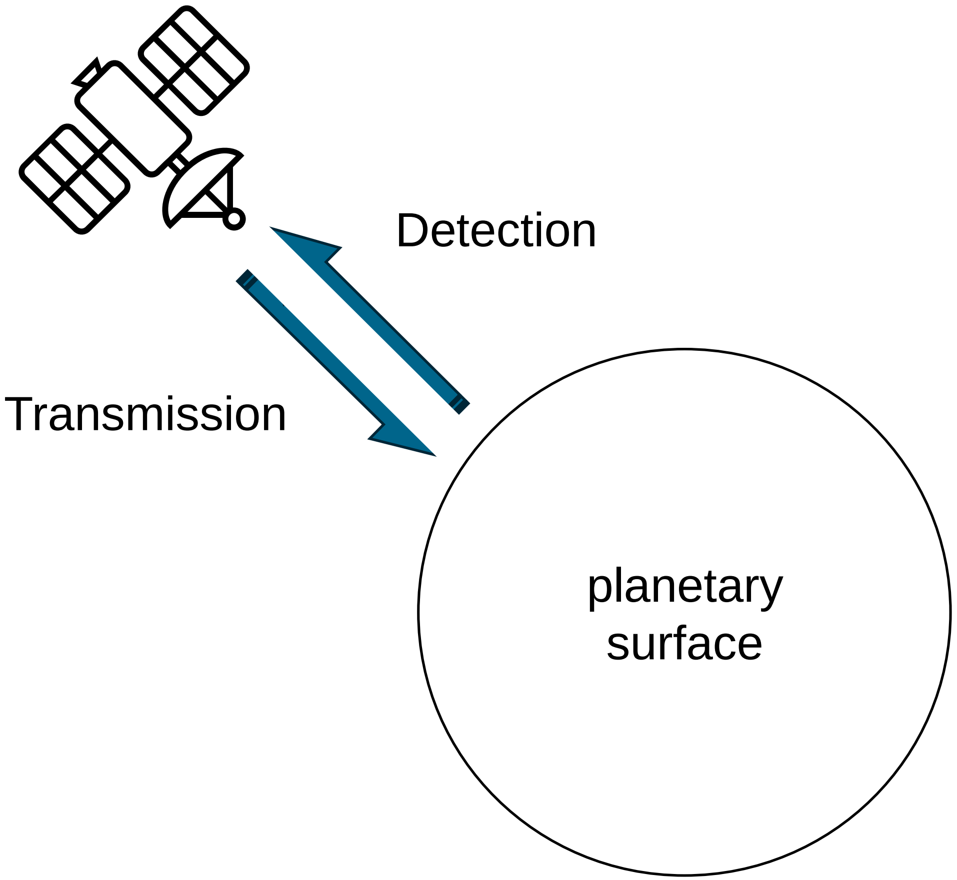




Introduction: Laser Altimeter Principle

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

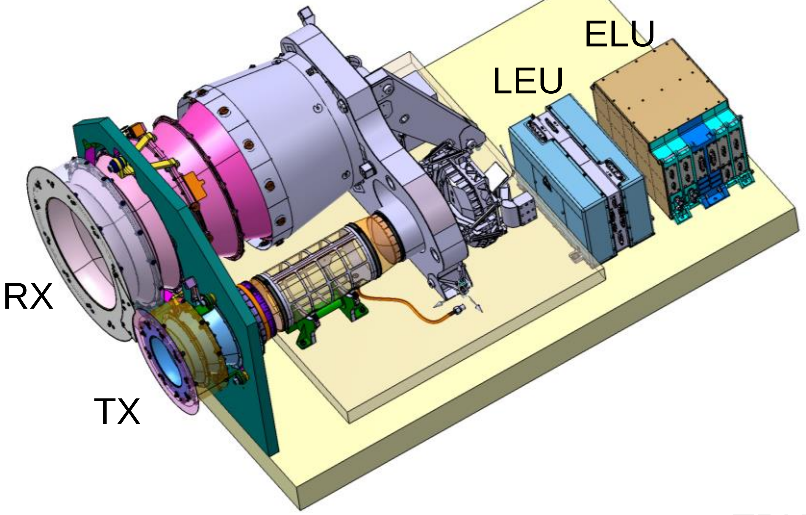
- from the signal information about the surface can be obtained:
  - time of flight (ToF) → topography
  - pulse width → slope and roughness
  - received energy → albedo



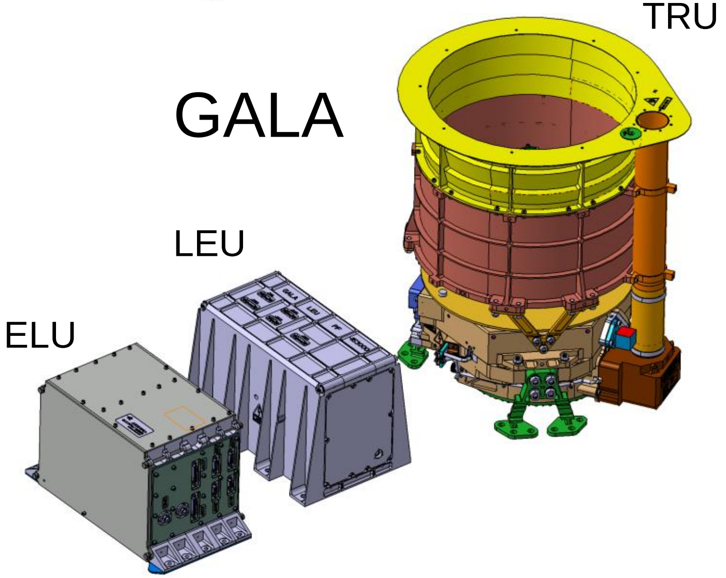
Introduction: Classical Instruments

- BELA / GALA are classical laser altimeters
  - diode-laser pumped Nd:YAG lasers
  - 50 / 17 mJ pulse energy
  - 10 / 30 Hz repitition rate
  - 25 / 20 cm telescope diameter
  - 15 / 25 kg mass
  - 50 W power
  - Avalanche Photodiode in linear detection mode
- ➢ powerful instruments for creating absolutely calibrated digital terrain maps of planetary surfaces from distances up to 1000 km
- ➢ BUT: heavy, large and costly

BELA

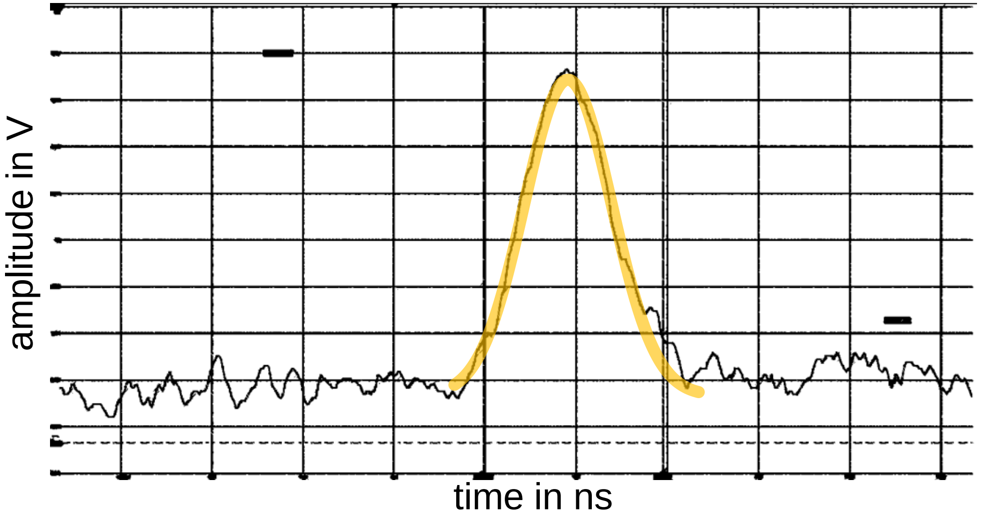


GALA

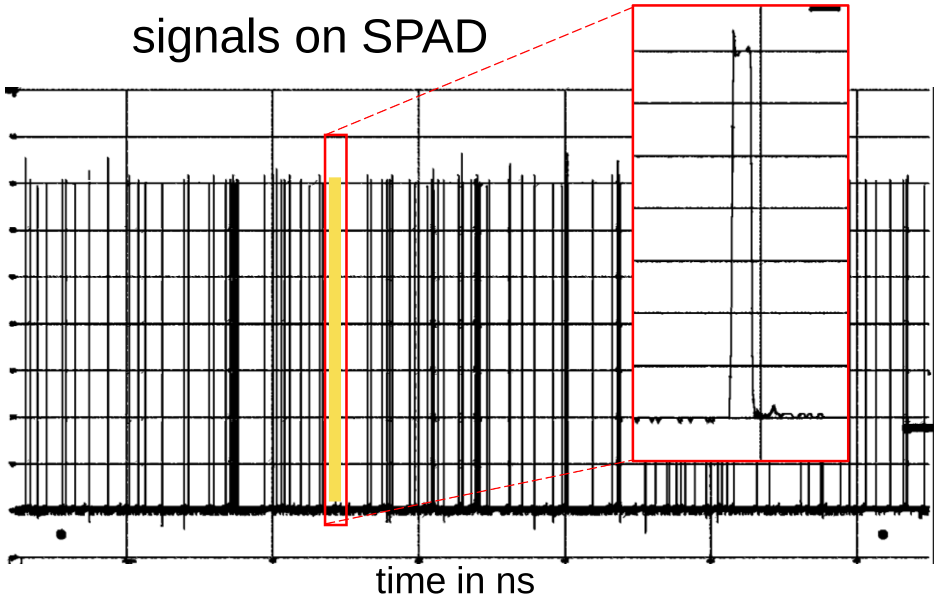


Introduction: Detection schemes

return pulse classical



signals on SPAD

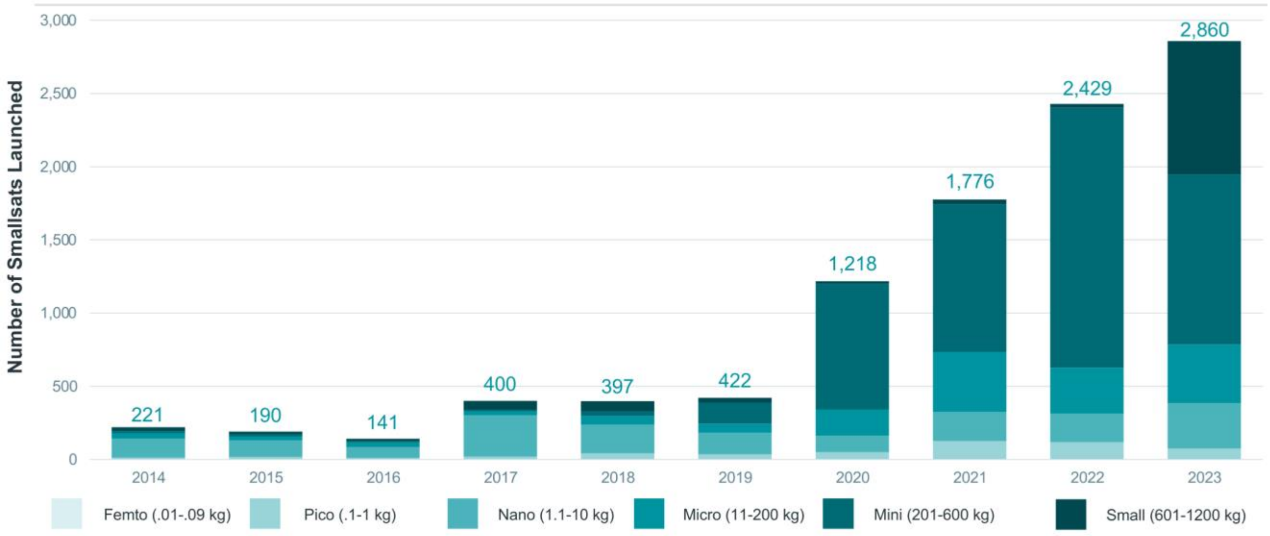


- APD, in linear mode and determination of TOF from temporal pulse shape (threshold /fitting)
- some 100 photons are needed

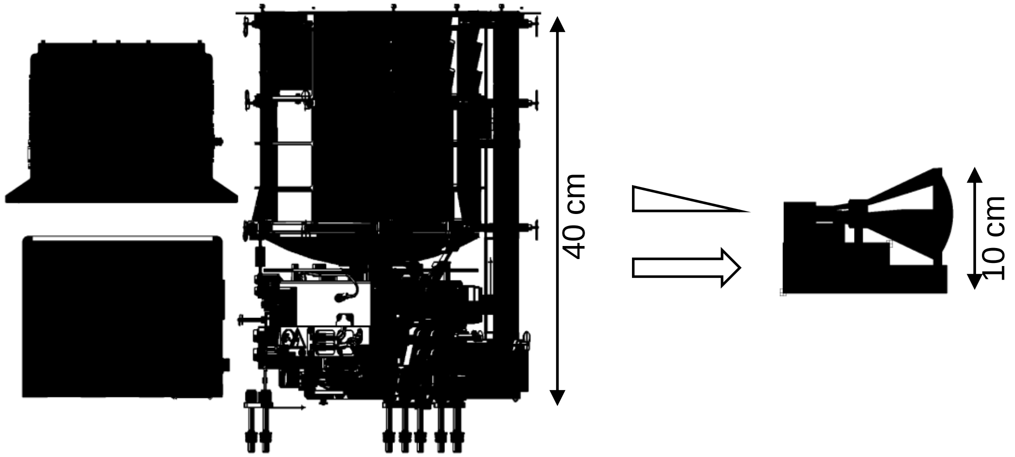
- SPAD, filtering and statistical methods to separate signal events from noise/background events and determination of TOF
- single photons are sufficient

Miniaturization

- trend for miniaturization and small satellites applications
- need for SWAP reductions in Laser Altimeters
- GOAL: derive the time-of-flight information from only a few photons → **Single Photon Detection**
    - implementation of a SPAD module as detector (multi pixel detector)
    - implementation of a transceiver design
    - use of a high quality laser beam with low divergence
    - tightly limiting the field-of-view of the telescope
    - narrow spectral filtering
    - effective filtering and statistical algorithms

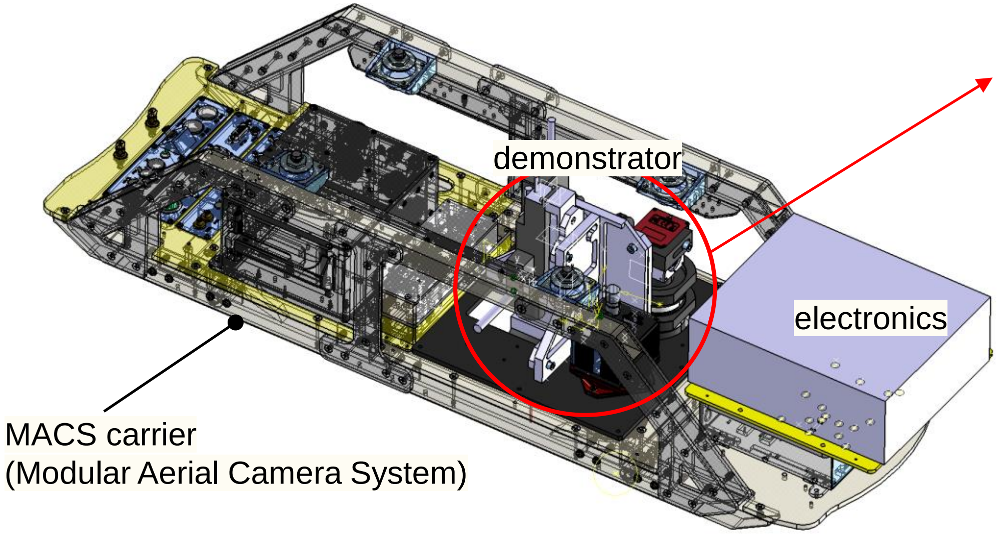


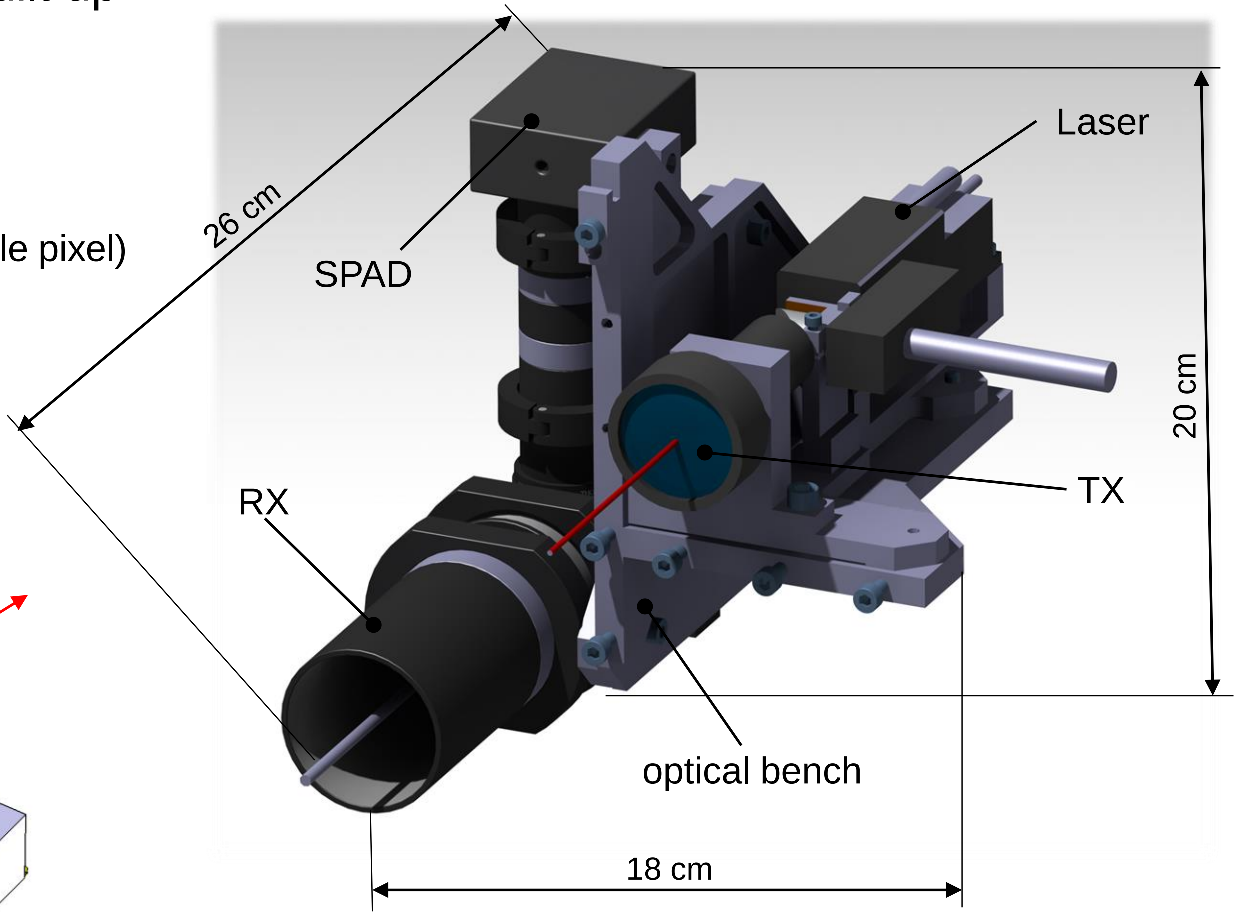
credits: Bryce Tech



Demonstrator: Description

- to test and optimize the complete development and data processing chain a demonstrator was built up with COTS parts
  - µ-chip laser 5 µJ with 5 kHz, 1064 nm, 1 ns
  - Single Photon Detector SPDMA from Thorlabs (single pixel)
  - 2“ receiver telescope, F/L 100 mm
  - band pass filter 1064 nm, bandwidth 5 nm
  - size ~26 x 20 x 18 cm³
  - mass 4 kg (excl. electronics unit)

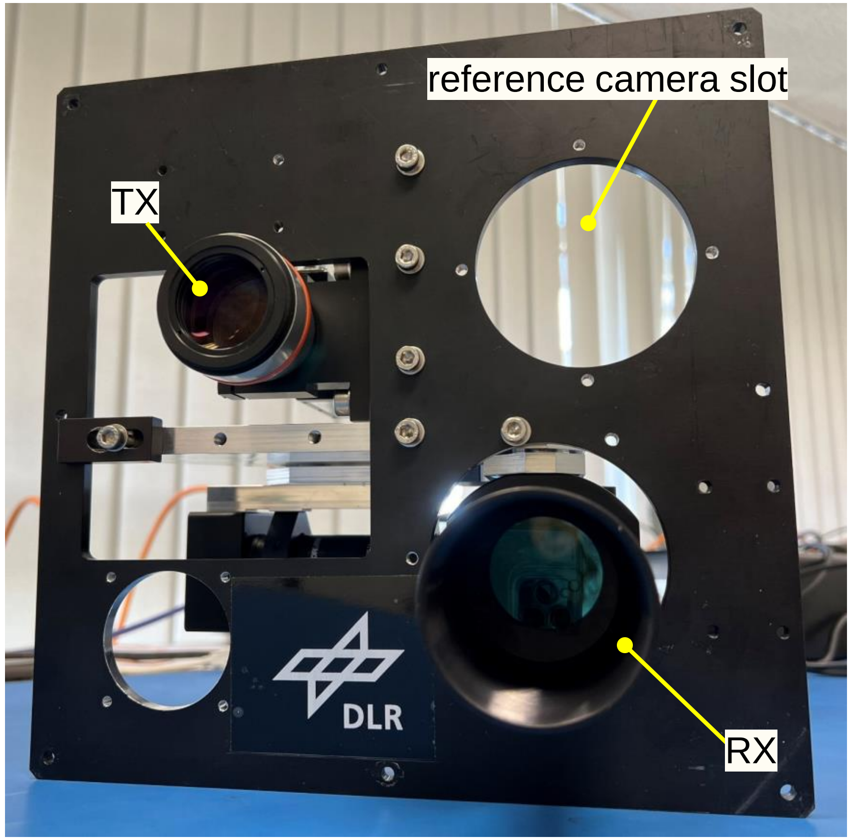


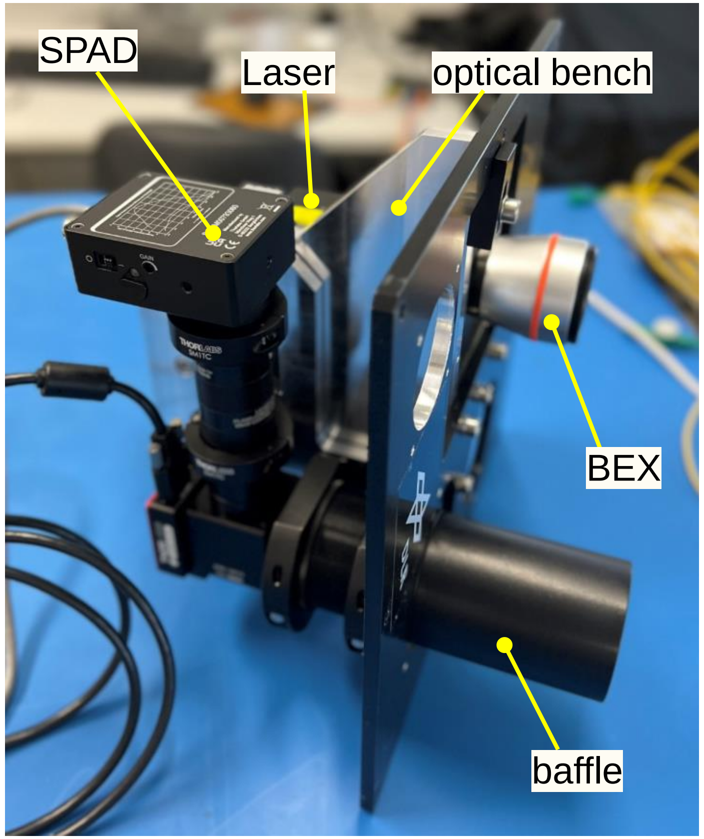


Single Photon Detection Laser Altimeter **Demonstrator**

Demonstrator: Integration

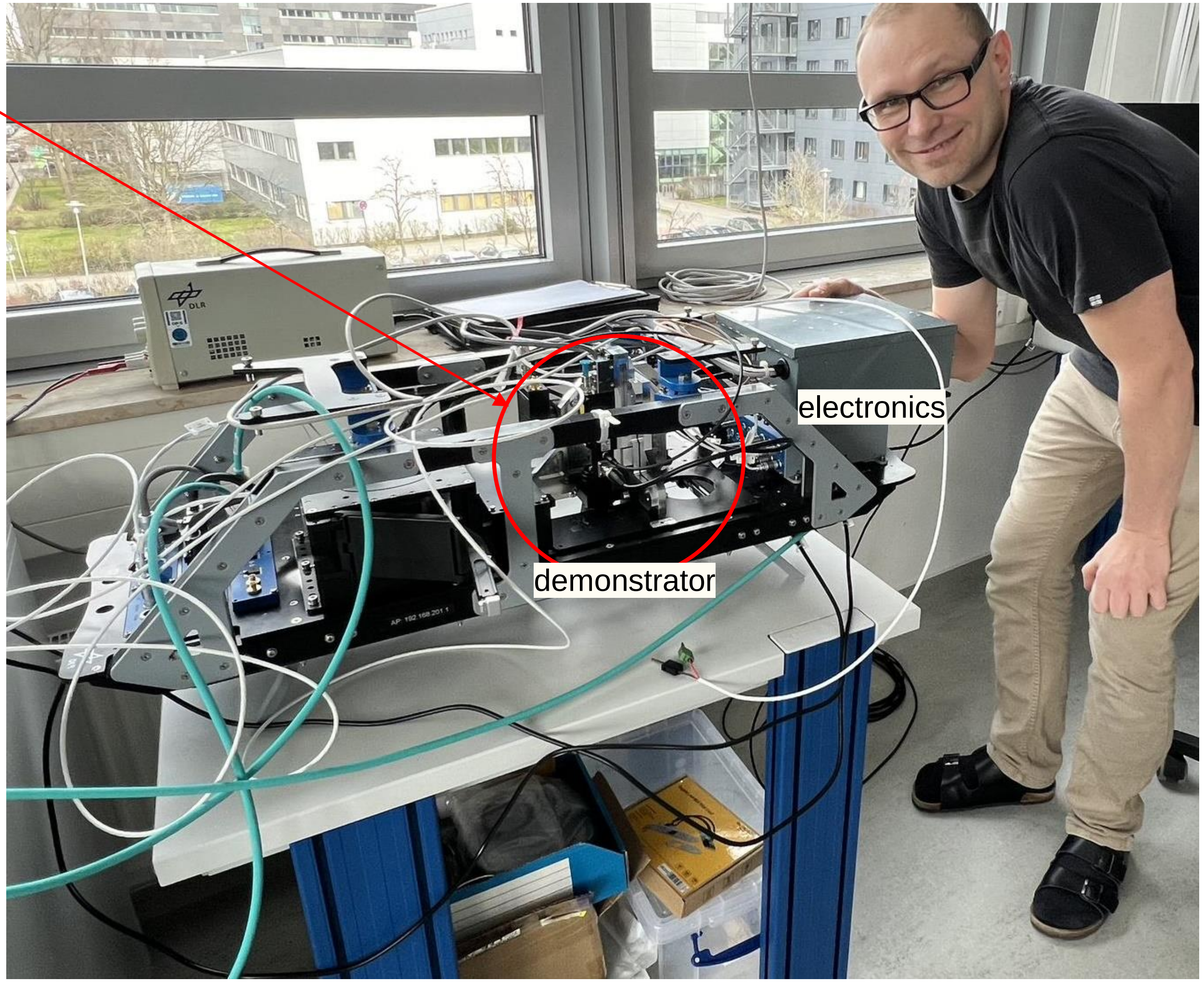
- demonstrator as built and mounted to adapter plate for MACS integration





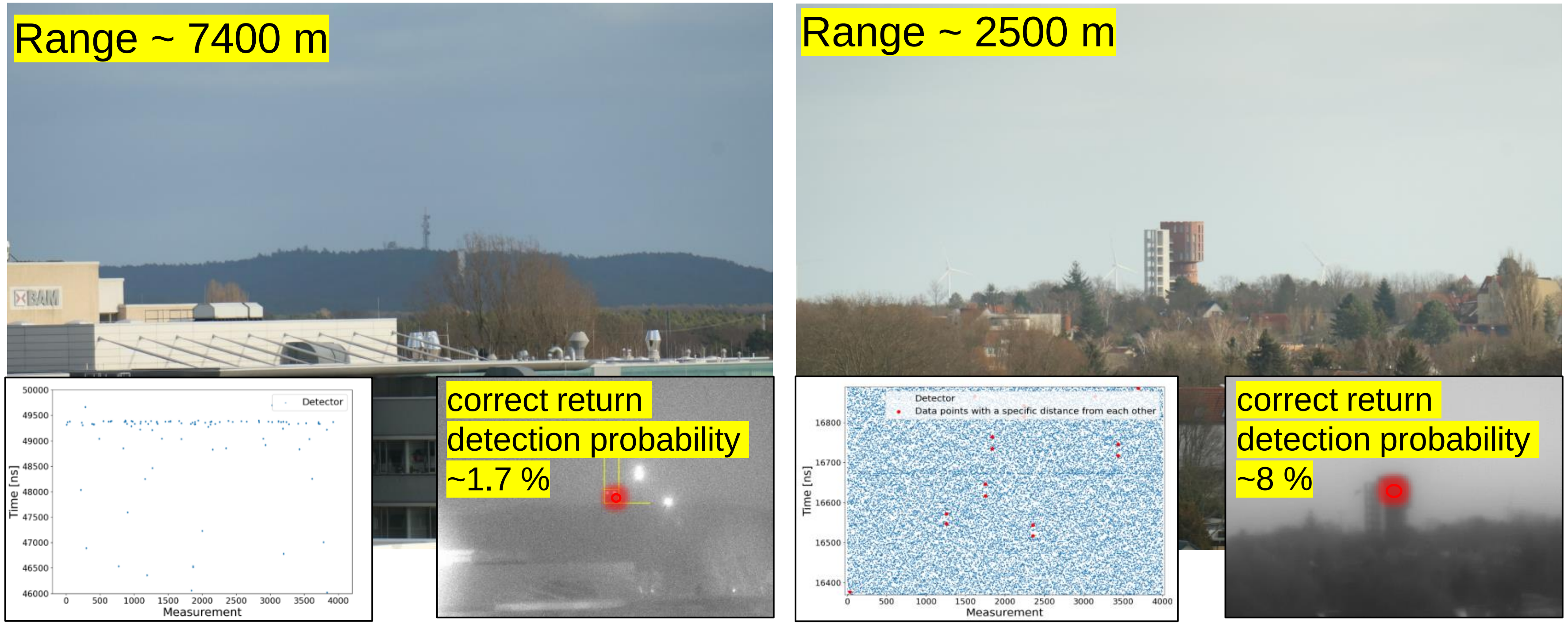
Demonstrator: Fitcheck to MACS

- demonstrator setup integrated in MACS carrier
- 28 VDC power supply by airplane generator
- control and data storage via raspberry Pi
- data acquisition with USB oscilloscope
- storage on micro-SD card
- commanding from cockpit with tablet PC connected via ethernet
- logging of GPS position and attitude from IMU (inertial measurement unit)



Demonstrator: Laboratory Tests

- demonstrator was tested in field over distances up to 7.4 km
- pointing at known targets was achieved by the help of the reference camera in the RX path
- different illumination (clear sky, haze, cloudy, day, night) were tested
- ranging resulted in a signal detection in about ~8 % of the shots at 2500 m; ~1.7 % at 7500 m

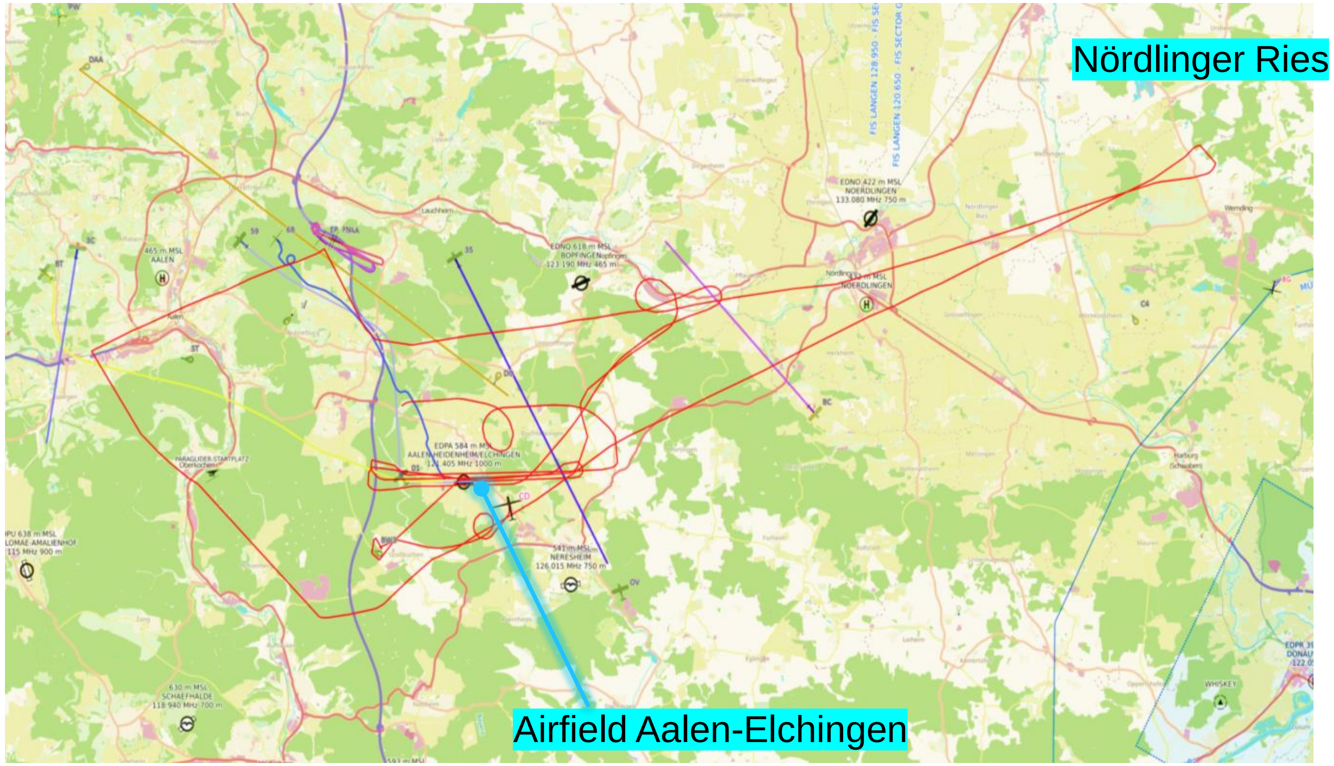


Ranging in static in field conditions. Left: ranging on 7.5 km distant target during night. Noise is minimized. Right: ranging on 2.5 km distant target during daytime.

Flight Campaign: Key Data

- 10 April 2024
- Airfield Aalen-Elchingen (80 km east of Stuttgart)
- 85 min flight time
- max. flight altitude ~1000 m due to low hanging clouds (airplane is capable > 8000 m)
- several flyovers over the airfield, big loop to Nördlinger Ries
- flight over forests, fields, towns and highways
- 166 profiles with 8000 shots each were recorded → 1,328,000 shots in total
- each shot contains about 750 events during the range gate duration of 50 µs

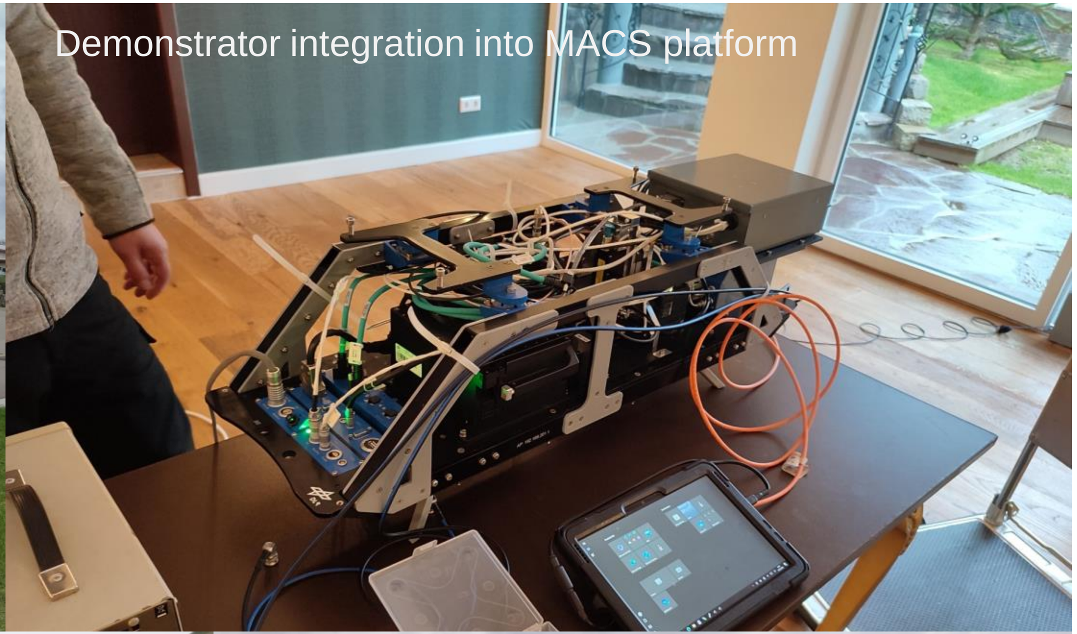
➢ **the instrument worked as expected**



indicated in red is the flight route on the 10 April 2024

Flight Campaign: Impressions


Motorglider Stemme S10-VTX


Demonstrator integration into MACS platform

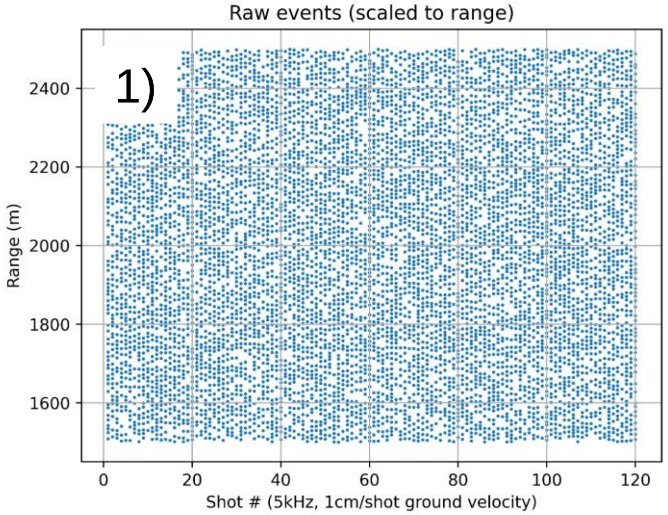

view from below

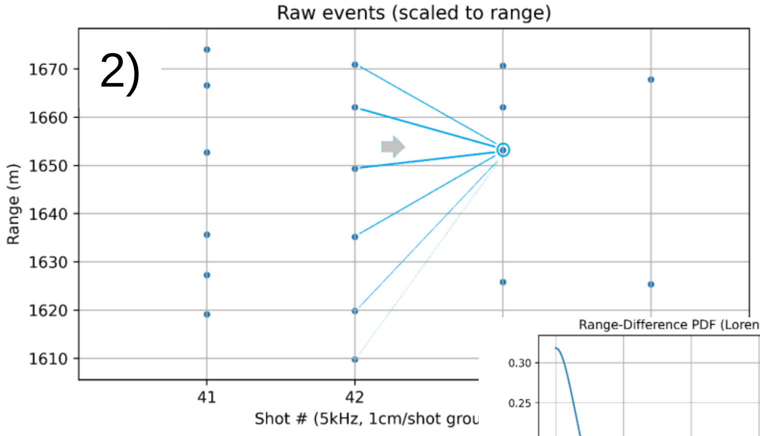

last function test before flight

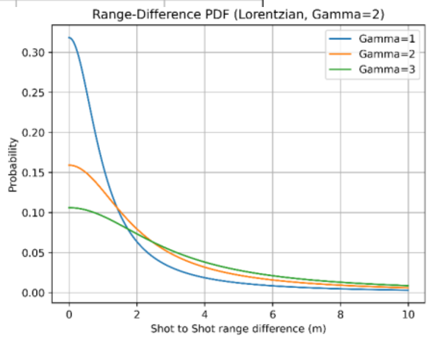

taxiing to runway

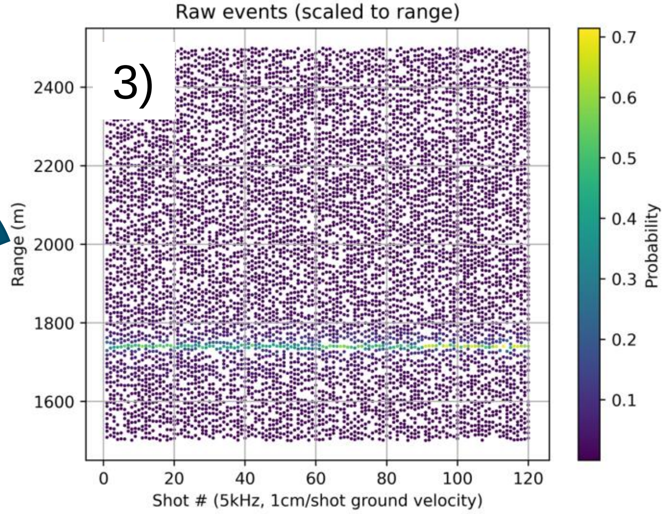
Data evaluation

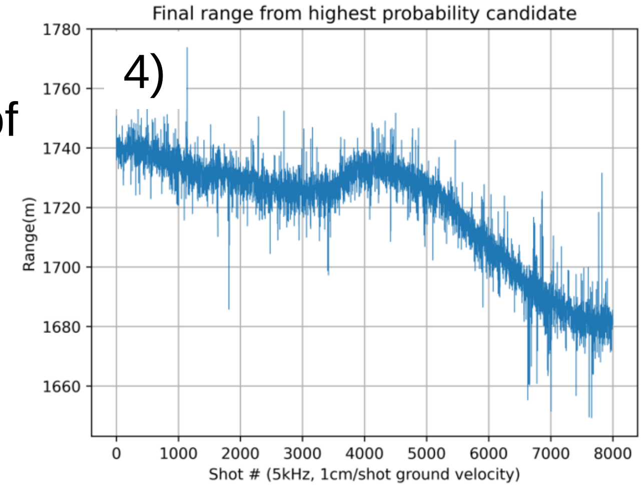
- signal and noise events are looking identical
- algorithm to find the most probable signal events
- first approach: Bayesian interference method
- Later: Coincidence filtering with SPAD array, i.e. identification of signal events by their occurrence in a narrow time window





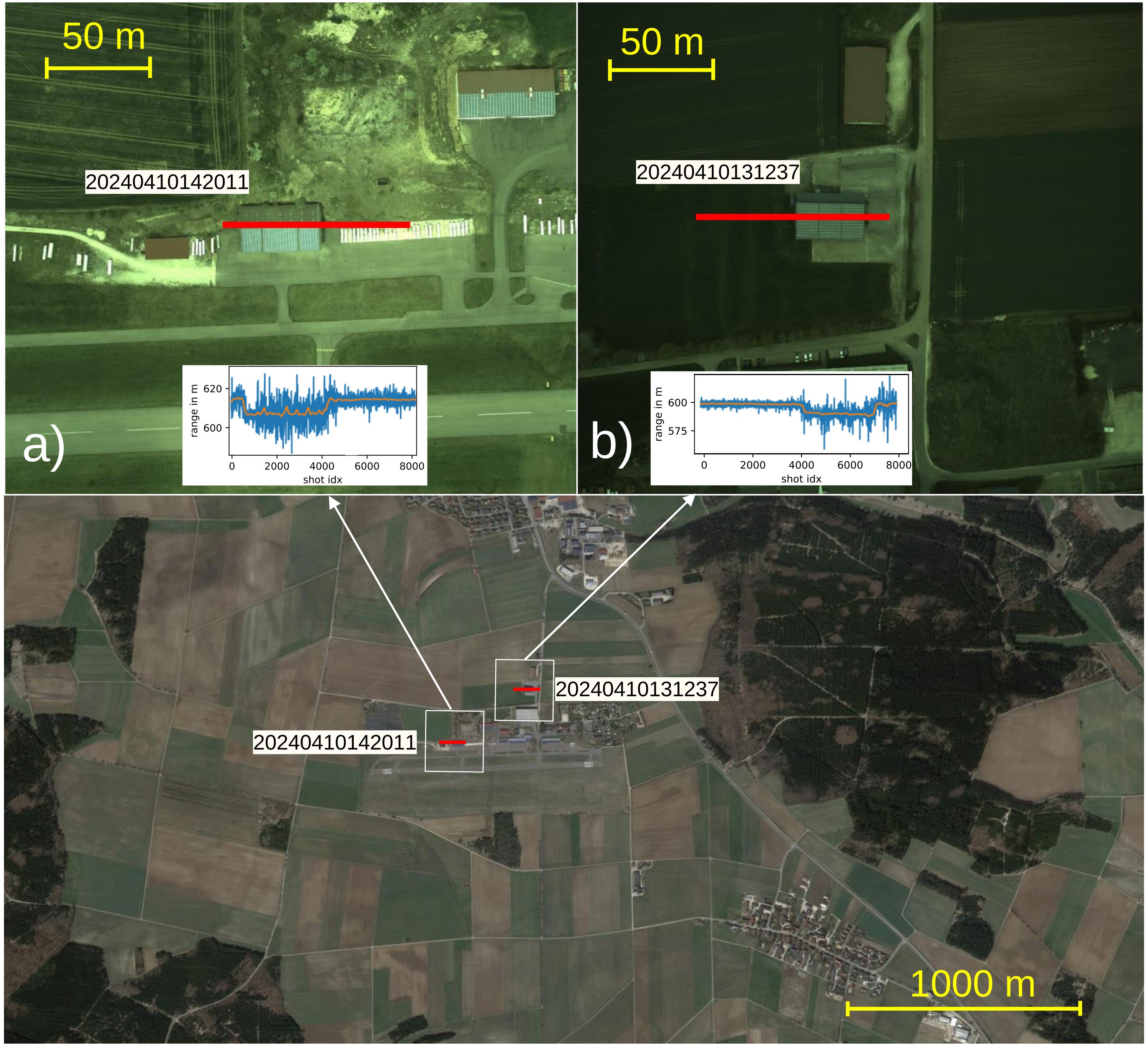






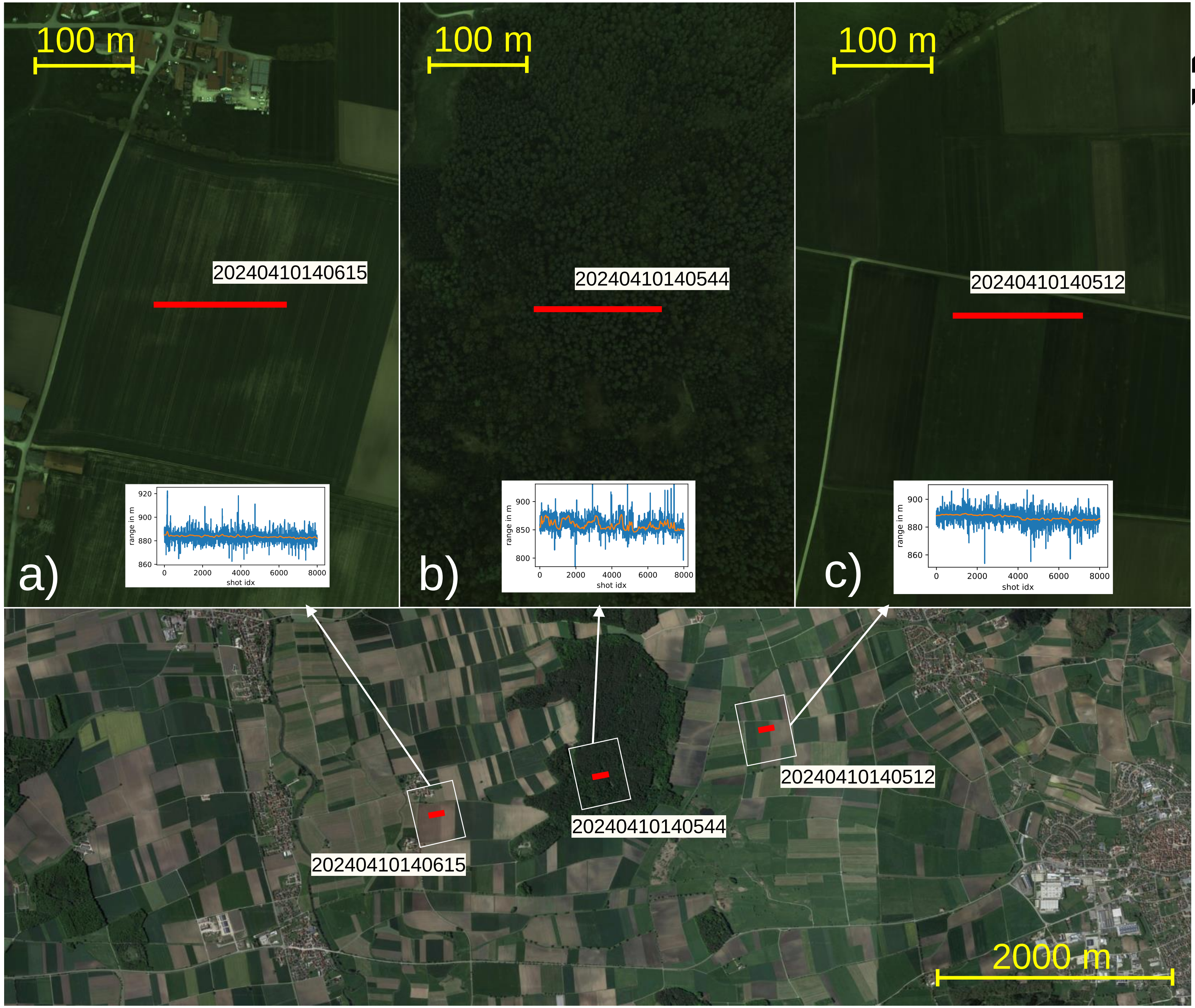
Data evaluation: Example Profiles

- for reference purposes besides taking camera images, the flight route was over buildings
- these could be clearly identified in the ranging profiles



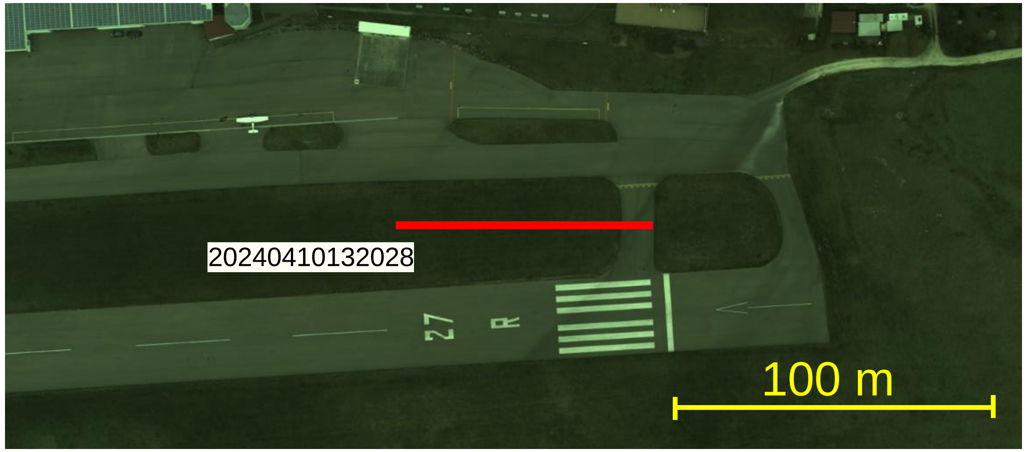
Data evaluation: Example Profiles

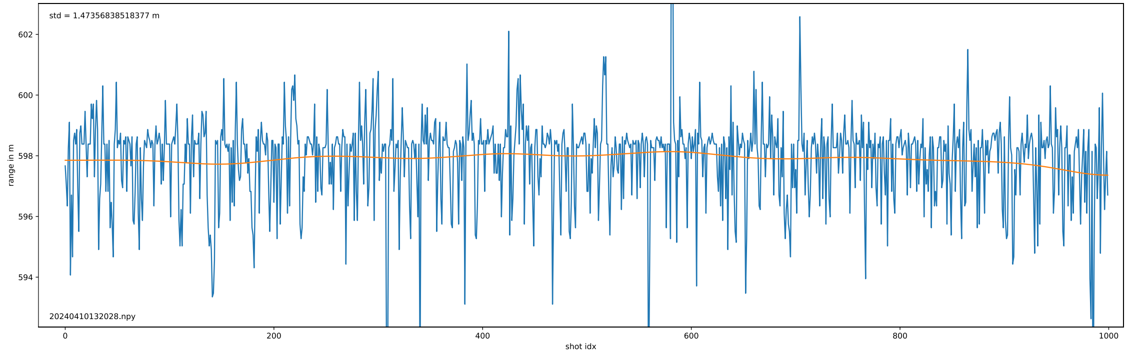
- also different landscapes were measured
- here forests and fields



Data evaluation: Reference track

- example track of a flat topography → airfield
- standard deviation of 1000 consecutive pulses is about 1.47 m
- this is much more than the sampling interval of 0.8 ns ~ 0.12 m
  - BUT: background rate of about 15/µs (every ~ 70 ns)
  - low QE of detector at 1064 nm of ~0.3 %
- improvements are currently being implemented
- the absolute accuracy is currently being evaluated by combining data from the flight's GPS, IMU (inertial measurement unit), and high-quality DTM (digital terrain model)





Outlook: Transceiver design

- mass and volume saving with transceiver design
- prototype is being built up in house

potential manufacturers of main sub-assemblies shall fulfill following criteria:

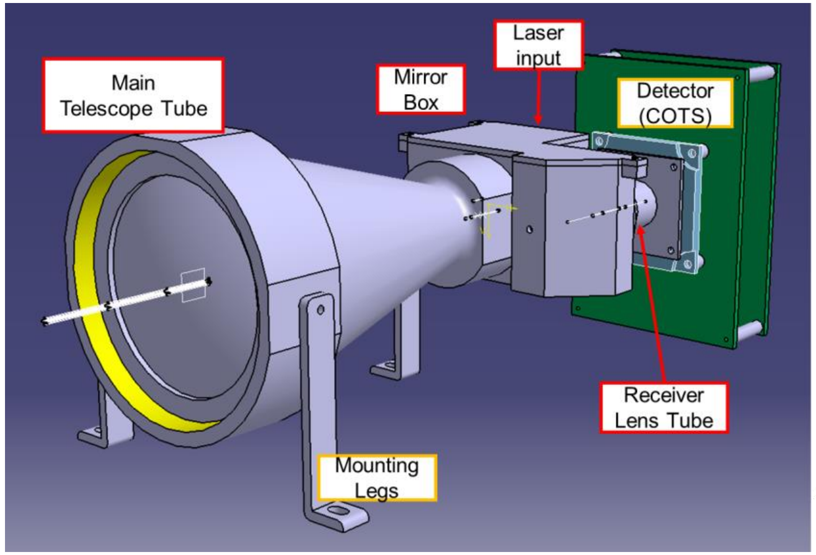
  - their technology is suitable for the instrument
  - they have experience in space projects
  - they are open for a future cooperation

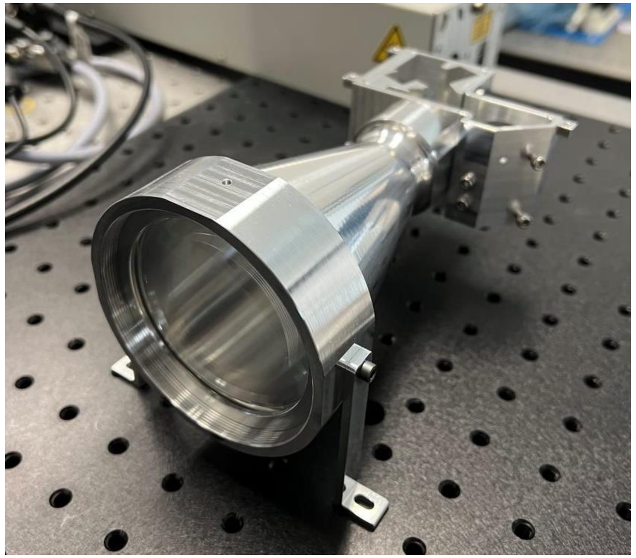
- for the laser:
  - Laserzentrum Hannover (LZH)

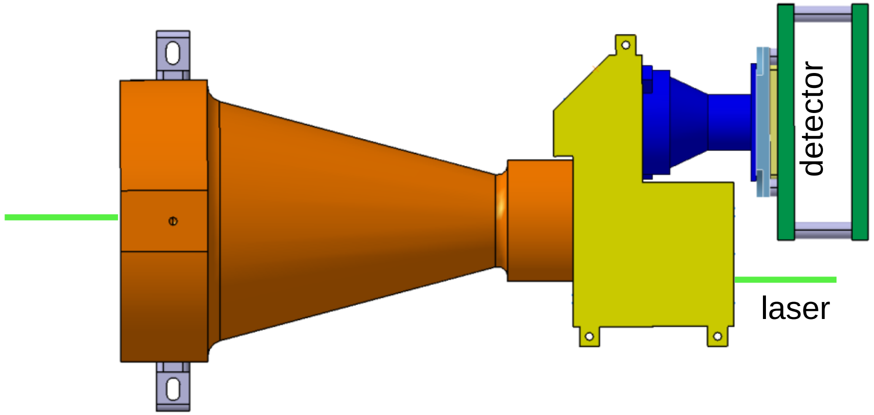
  → compact design available

- for the SPAD array:
  - Fraunhofer IMS, Duisburg

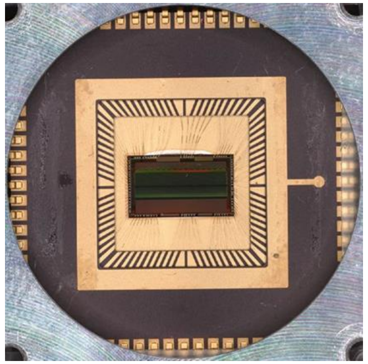
  →SpadEye 2 in house





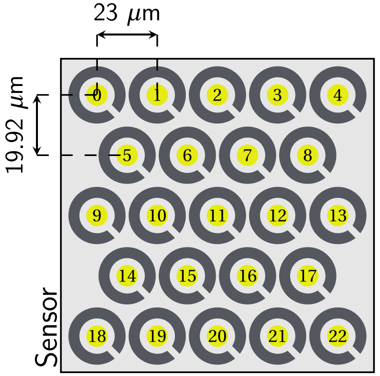


SpadEye2



Credits: Fraunhofer IMS

SPAD23

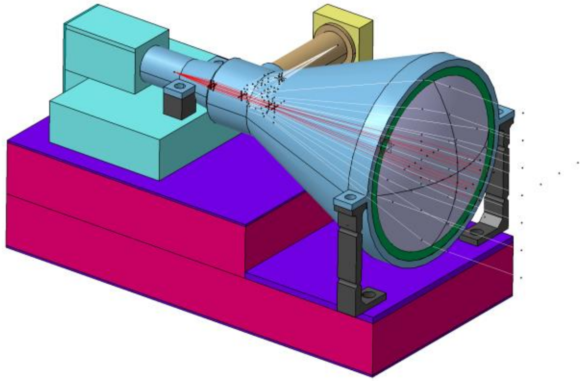


Credits: Pi Imaging

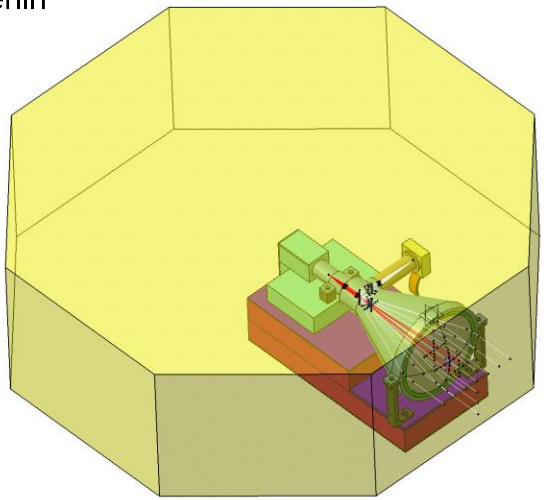
Outlook: SWAP estimation and platform

- design allows integration into existing small satellite platforms
- e.g. on TUBiX20 platform from TU Berlin: 27 satellites in mission

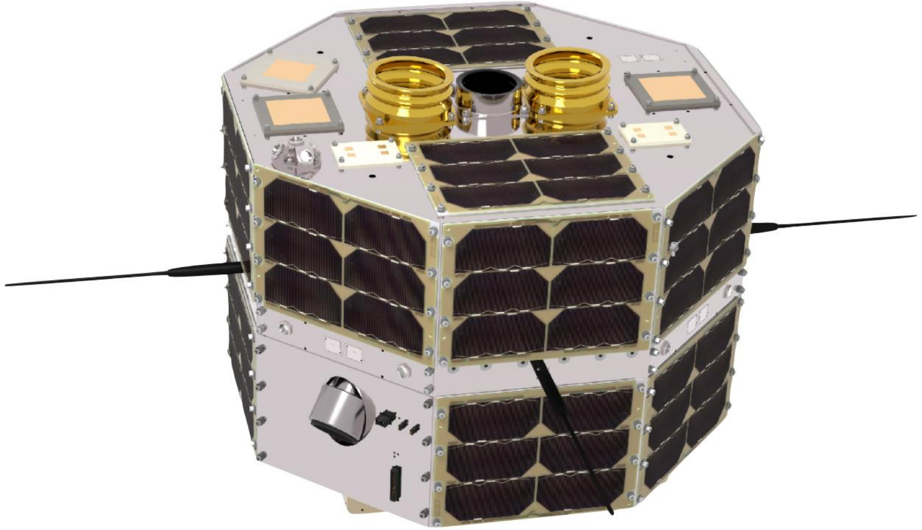
Single Photon Laser Altimeter



TUBiX20 – modular microsatellite platform by TU Berlin



Specifications	**TUBIN (TUBiX20)**	**Single Photon Laser Altimeter**
Size / Mass	22.6 kg	2.4 kg
Payload Volume	10.5 dm³	3 dm³
Power	>35 W (peak solar)- Body mounted solar panels	27 W



Example: TUBIN (credits: TU Berlin)

Outlook: Next Flight Campaign September

- next flight campaign will be in September 2024 with combined TX-RX optics, detector array and improved instrument control
- flight altitudes over 1000 m and up to 6000 m are planned
- use of SPADeye2 array with coincident detection (1 pixel → > 8 pixels)
- wavelength (1064 nm → 532 nm)
- narrow bandpass filter (5 nm → <0.2 nm)
- narrow RX field of view further (5 mrad → < 1 mrad)
- reduce laser beam divergence (0.5 mrad → 0.3 mrad)
- longer profile data acquisition (1.6 s → some minutes)

THANK YOU! QUESTION?