MINIATURIZED LASER ALTIMETER FOR SMALL SATELLITE APPLICATIONS

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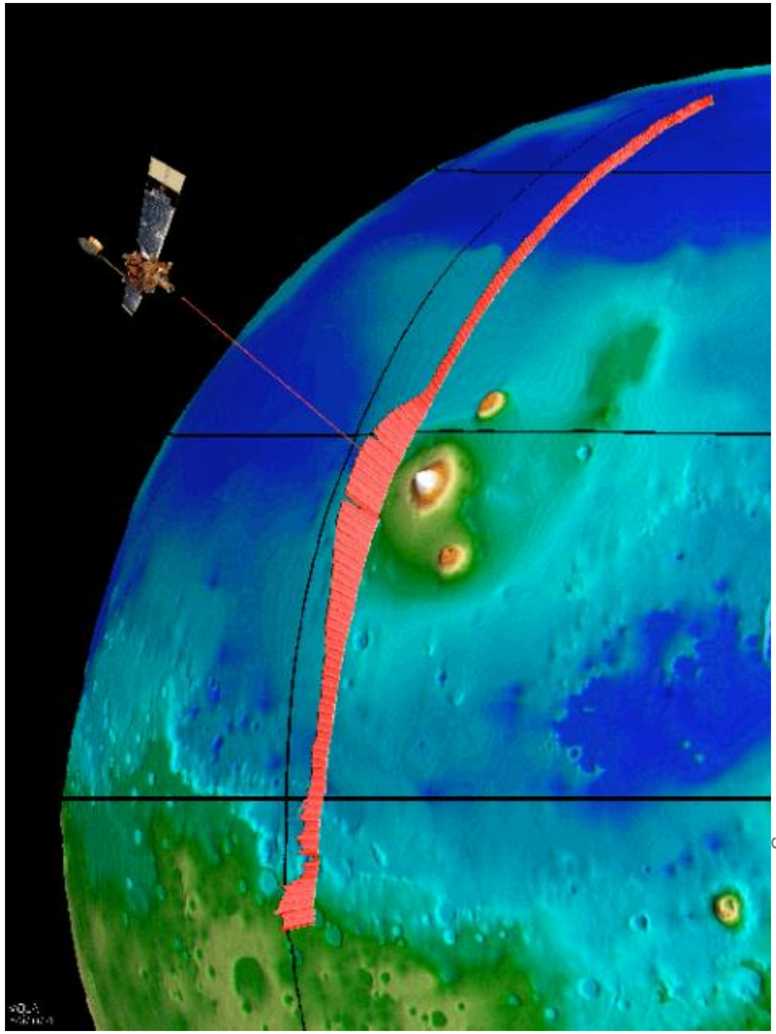
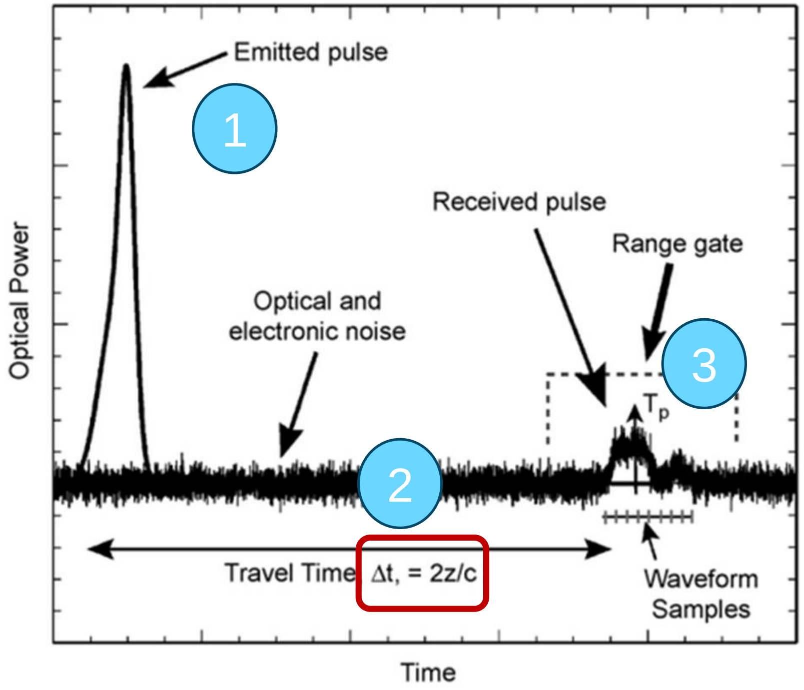


Image: MOLA Team

Laser Altimeter Working Principle

- With a laser altimeter, one can measure the distance/altitude above an object or surface.
- The instrument emits a short laser pulse, detects the reflected pulse and calculates the time of flight resp. the distance.
- A laser altimeter consist of three main elements:
  - Transmitter: pulsed laser
  - Receiver: telescope, optics and detector
  - Electronics for analysis of the reflected pulse and instrument control



After Bufteon et al., 1989

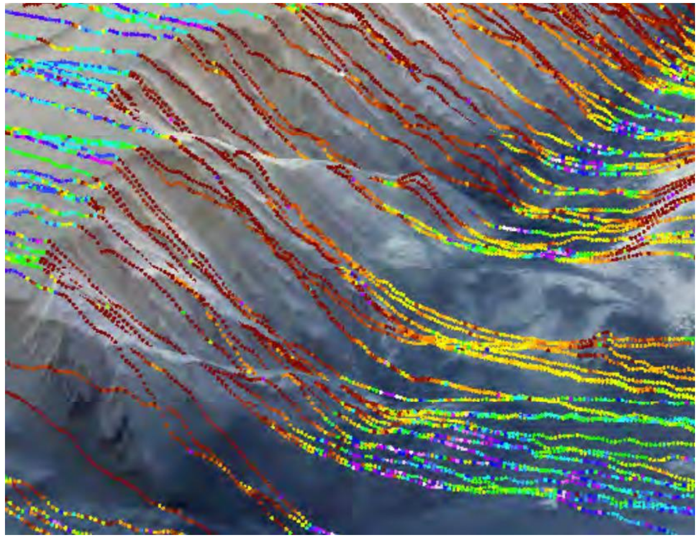
Link budget equation:

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

- N_{ph} number of photons in the reflected pulse
- E_T is 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_T^2 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,
- λ is wavelength and
- h is the Planck constant.

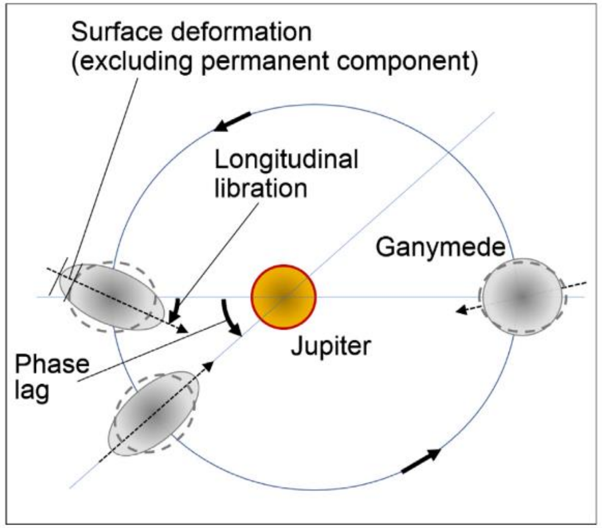
Laser Altimetry in Planetary Research

- Laser altimetry is used in planetary research for
  - Topography: craters, ridges, slopes, roughness, reflectance etc.
  - Surface deformation (tidal amplitudes)
  - Global reference model
- Laser altimeter data is combined with data from other instruments like cameras, spectrometers, magnetometer, gravimeter etc.



MOLA Team/DLR

Laser altimeter data (from MOLA) superposed with camera data (from HRSC)
Color codes: green & blue: small pulse spread; red: large pulse spread



Enya et all, 2022

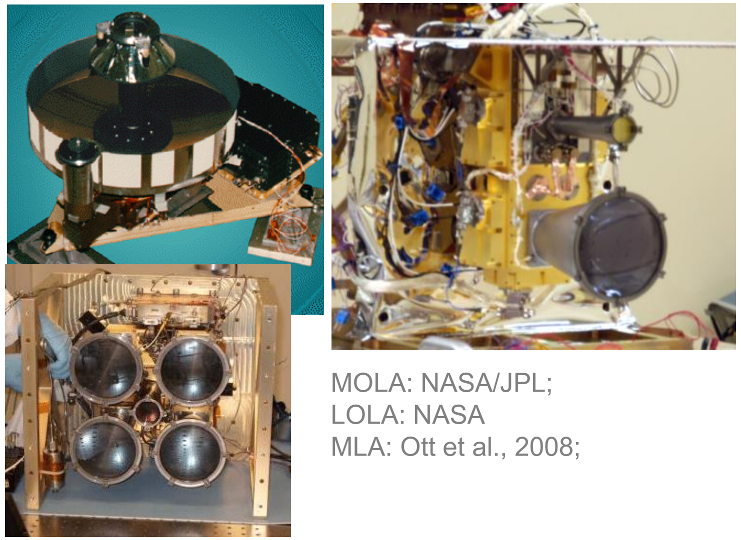
Surface deformation, phase lag and longitudinal libration

- Laser altimetry helps to understand the evolution and the current state of a planetary body

Classical Laser Altimeters

Numerous missions in our Solar System are equipped with laser altimeters

MOLA on Mars Orbiter LOLA on Lunar Orbiter MLA on MESSENGER	BELA on BepiColombo (to Mercury, launched in 2018) with strong DLR contribution	GALA on JUICE (to Ganymede, launched in 2023) with DLR as consortium lead



MOLA: NASA/JPL;
LOLA: NASA
MLA: Ott et al., 2008;

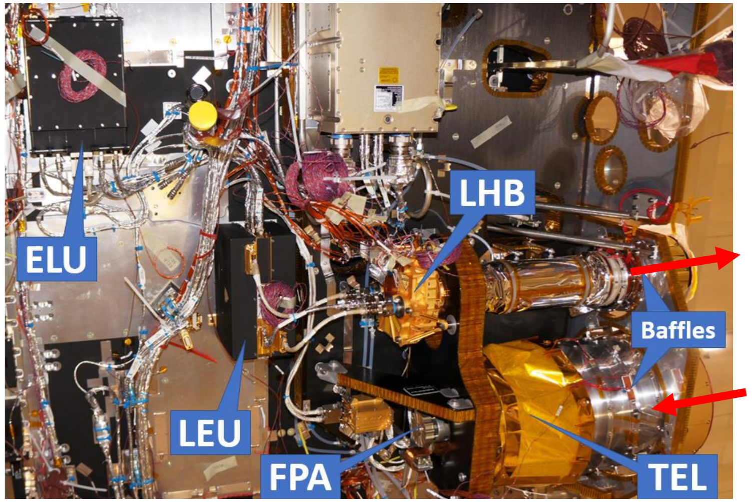


Image: DLR

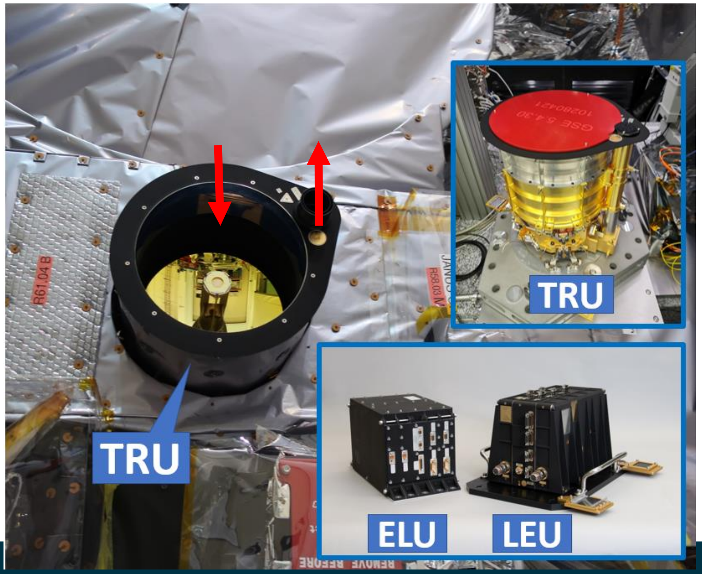


Image: DLR, Hensoldt Optronics

- These laser altimeters need a lot of resources on the spacecraft:
  Mass (BELA: 15 kg, GALA: 23 kg)   Power (30 W resp. 50 W)   Volume (100 l resp. 60 l)

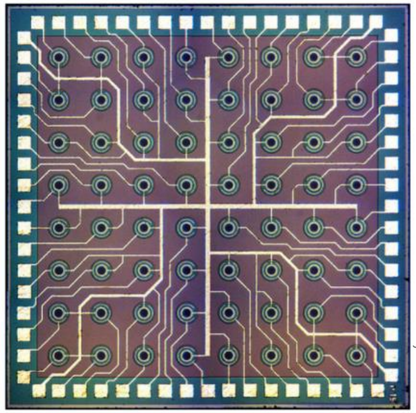
Single-Photon Counting Laser Altimeters (1/3)

- The previously mentioned laser altimeters work with detectors which need a return signal consisting of a <u>few hundreds</u> photons at least.

→ Use a more sensitive detector, e. g. a <u>single</u> photon counting detector.

- Several single photon counting techniques do exist, we will focus on single-photon avalanche diodes (SPAD).
- The output signal of a SPAD is not an analogue waveform anymore, but already digital TTL-like (high/low).

Image: EFys



8x8 pixel SPAD array

Ceccarelli et al., 2017

- A new detector technology requires less strong return signal - and less strong transmitter laser pulses

Single-Photon Counting Laser Altimeters (2/3)

The main assemblies:

- Microchip laser or diode laser
- Combined transmitter-receiver optics
- Single-photon counting detector array (multi-pixel)
- Electronic: one FPGA for data processing, instrument control, data transfer

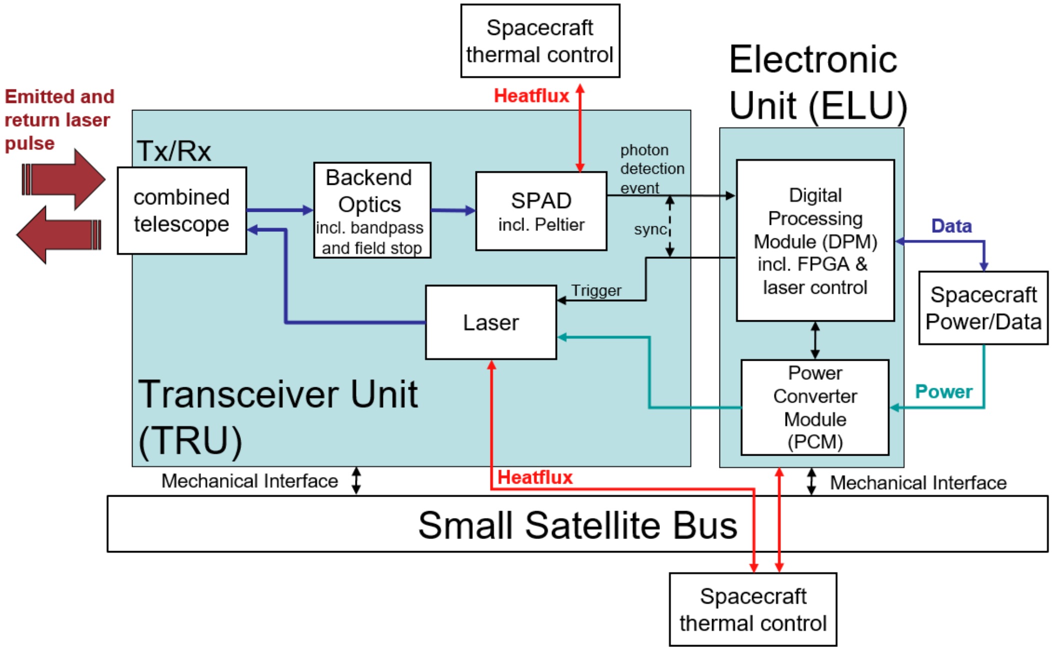


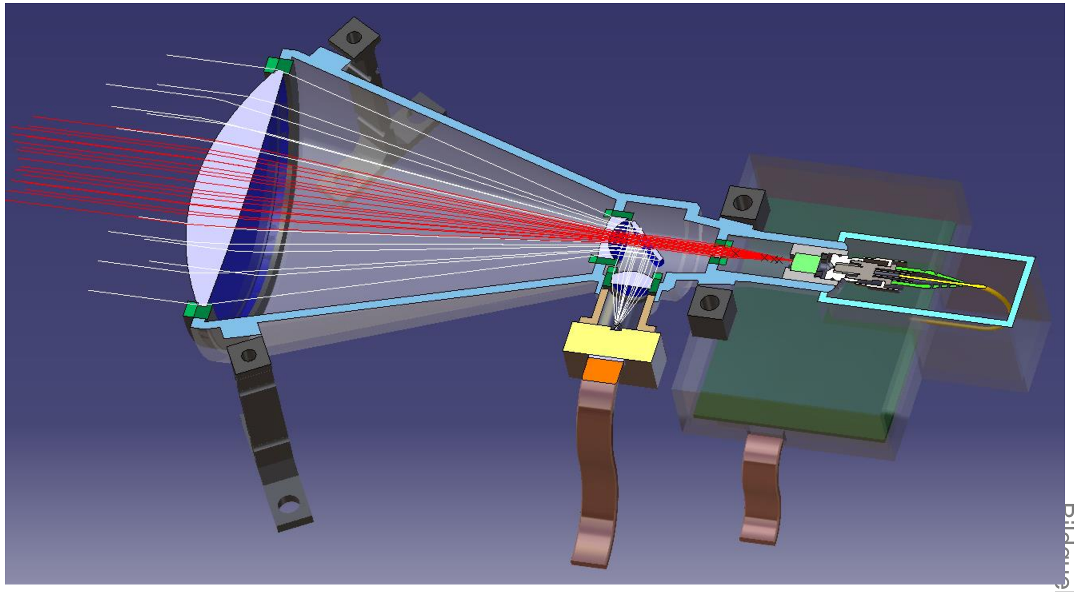
Image: DLR

- Every part of the instrument can be miniaturized due to the more sensitive detector

Single-Photon Counting Laser Altimeters (3/3)

For a potential mission to Moon,
basic instrument parameters are set to…

- Orbit altitude: 70 km (max)
- Laser pulse energy: 2 mJ
- Laser pulse repetition rate: 30 to 50 Hz
- Telescope diameter: 8 cm
- Detector: 2x2 pixel array



… and a design and resource numbers are derived.

Parameter	GALA	SPC LA
Mass	23 kg	**5 kg**
Power	50 W	**20 W**
Volume	60 l	**5 l**

The instrument design is more compact and much less resources are needed w.r.t to classical laser altimeters.

Experimental Results and Science Performance

- The instrument development is parallel on hardware and simulations. New findings are immediately verified and tested in the lab.
- In the lab, a SPC detector is fed with very weak laser pulses, e. g. generating less than 5 signal photons or detection events.
- Mathematical simulations concerning quantum efficiency, detection probabilities, time-of-flight measurement and detection schemes are verified.

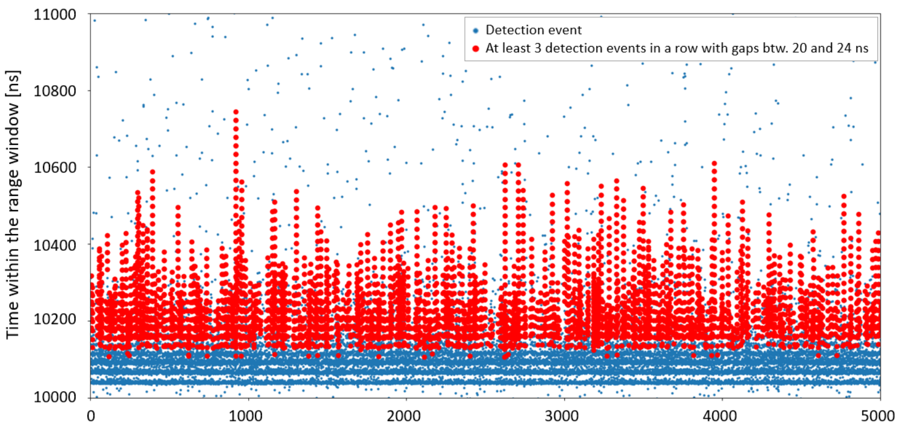


Image: DLR

A pulse of 80 ns length and approx. 5 signal photons is detected three times (blue lines) by a detector with 25 ns death time.

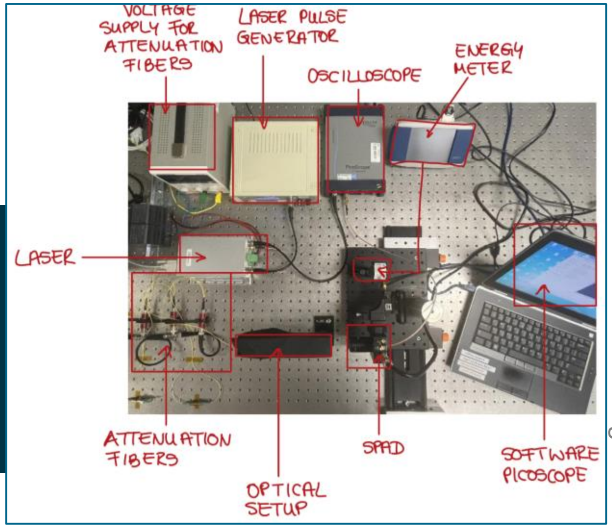


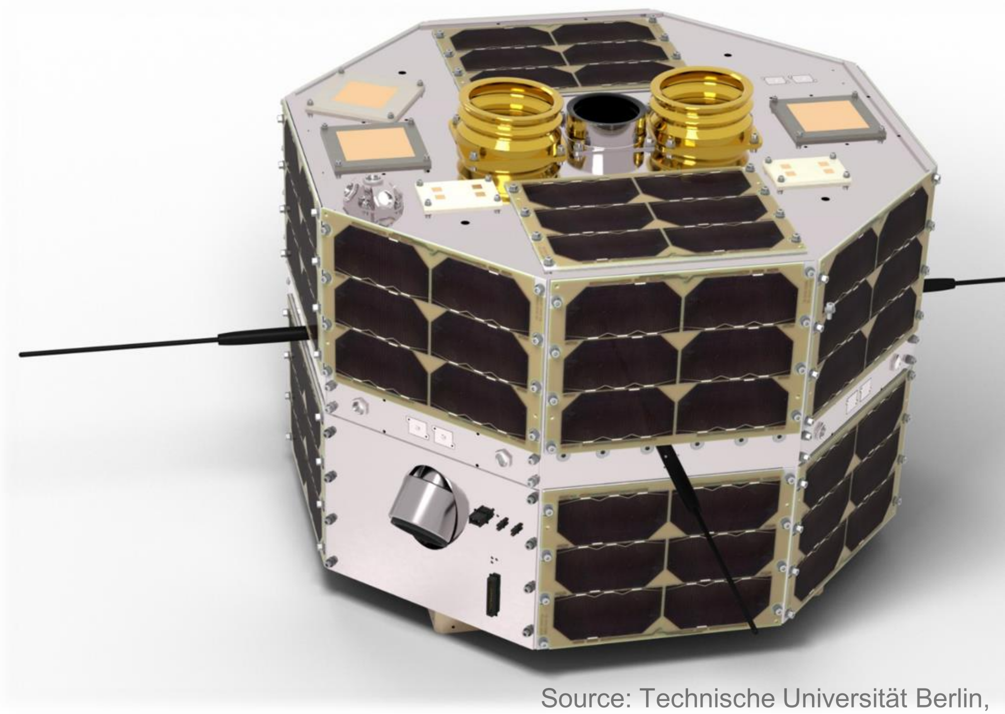
Image: DLR

- We demonstrate the working principle of the single-photon counting laser altimeter and validate the relevant performance parameters.

Microsatellite Mission Studies (1/2)
Low Earth Orbit

- In-Orbit Demonstration (IOD) utilizing TUBiX20 microsatellite platform
  - Highly modular, easy adaption to mission parameter
  - 5 to 25 kg payload mass
  - 25 to 60 W continuous payload power supply

- Flight proven platform
  - Low cost, low risk
  - high pointing accuracy of 0.1° (3-sigma)

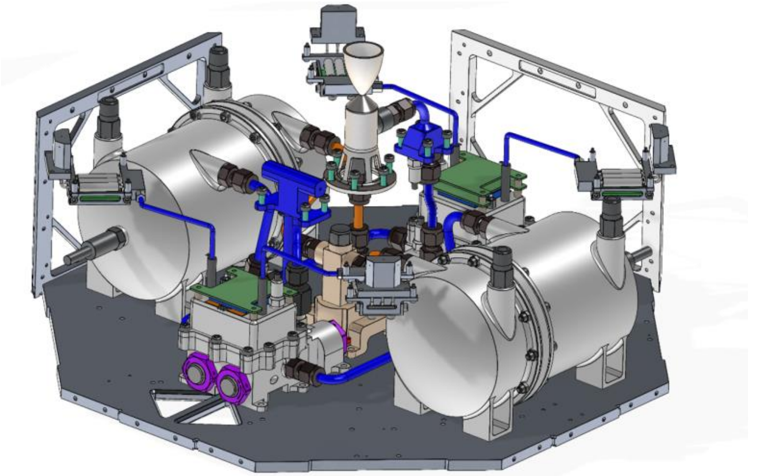


Source: Technische Universität Berlin, Chair of Space Technology

- Low cost, low risk, flight heritage
- Less favorable use case
  → high noise outside eclipse, high altitude

Microsatellite Mission Studies (2/2)
Lunar Orbit

- Much more favourable for instrument demonstration
  - Less signal noise & lower altitude
    → better return signal and temporal & spatial coverage
- Utilizing ongoing TUBiX20 developments
  - Propulsion system and non-magnetic attitude control
  - Radiation hard (COTS) electronics
  - Higher ressource budgets for payloads
    → Qualify TUBiX20 for missions beyond LEO



Source: Technische Universität Berlin,
Chair of Space Technology

- Additional challenges to overcome for microsatellites
  → Lunar orbit determination and control
  → Communication with Earth

Future Work

- Improve design and simulations of the instrument
- Select the most relevant parts (laser, detector, FPGA, optics etc.)
- Establish representative (elegant) breadboards for space-qualification on ground
- Develop TUBiX20 platform for use beyond LEO
- Improve autonomous platform operation

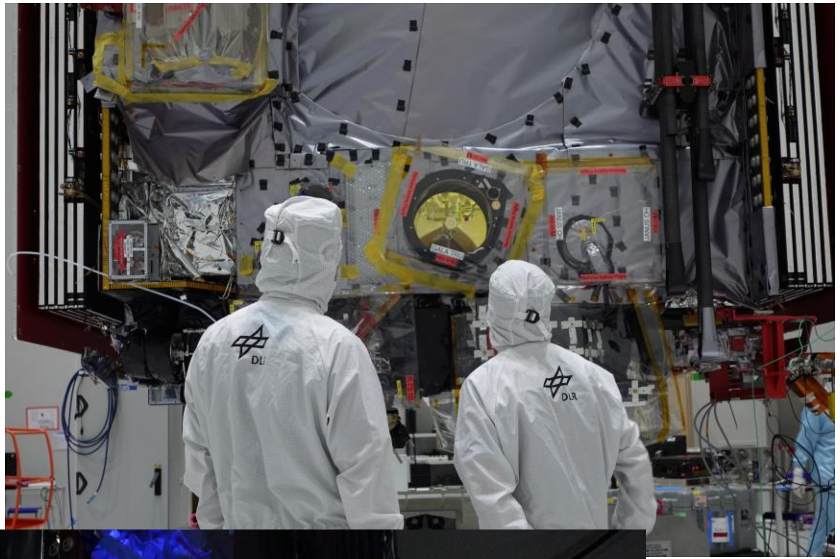
- Our goal is the space-qualification of the instrument and the platform.

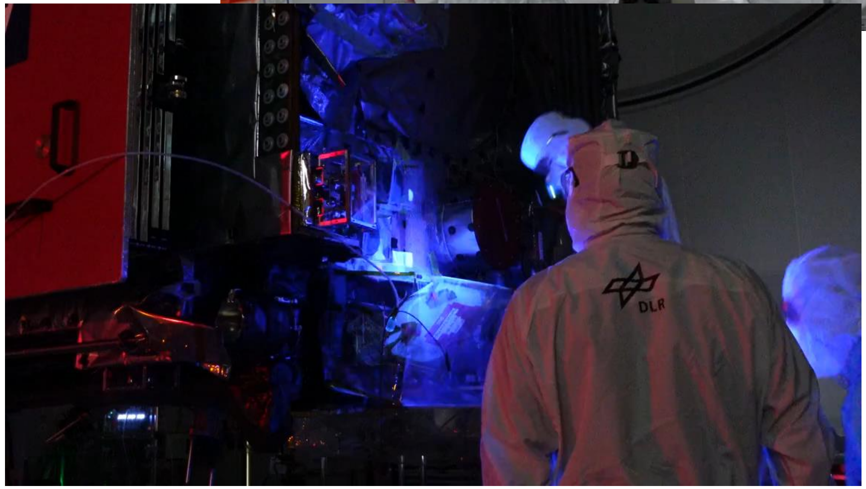
Summary

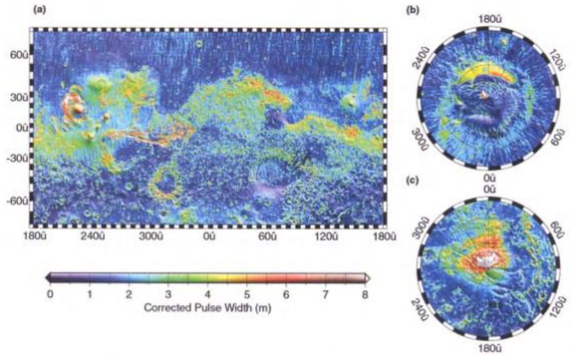
- Based on our heritage in planetary laser altimetry and small satellite systems, we develop a new instrument and satellite generation
- For the instrument, first resource budgets are available and science performance is verified by lab tests
- Combined with a small satellite platform with improved designs for propulsion system and attitude control, a technology demonstrator mission to the Moon is the obvious next step
- Lunar IOD of instrument and platform is more challenging but much more useful

- Single-photon counting laser altimetry is the next generation of laser altimeters in space
- A small satellite platform is the perfect fit for a such an miniaturized instrument

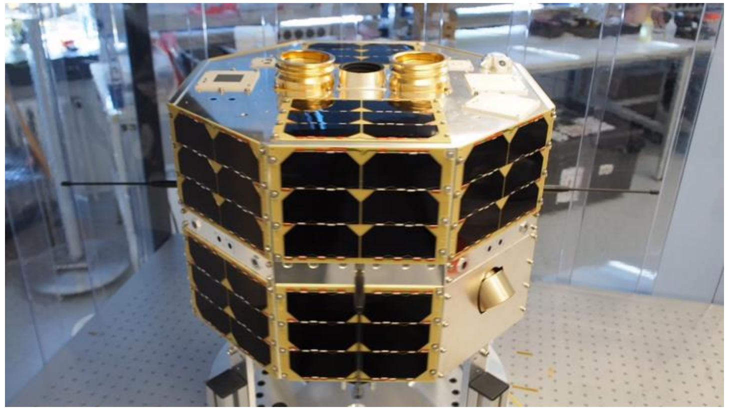
Thank you for your attention!







- Smith et al. (1999)



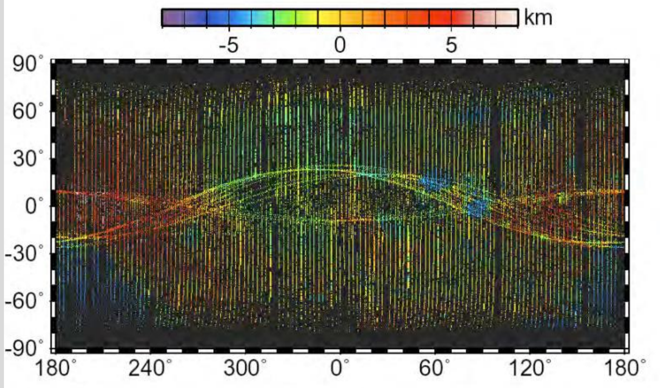


Figure 3. Lunar topographic coverage from Apollo orbiters and Clementine [*Smith et al.*, 1997].