# PROGRESS ON (LASER-)OPTICAL TECHNOLOGIES AND RETROREFLECTORS FOR SPACE TRAFFIC MANAGEMENT

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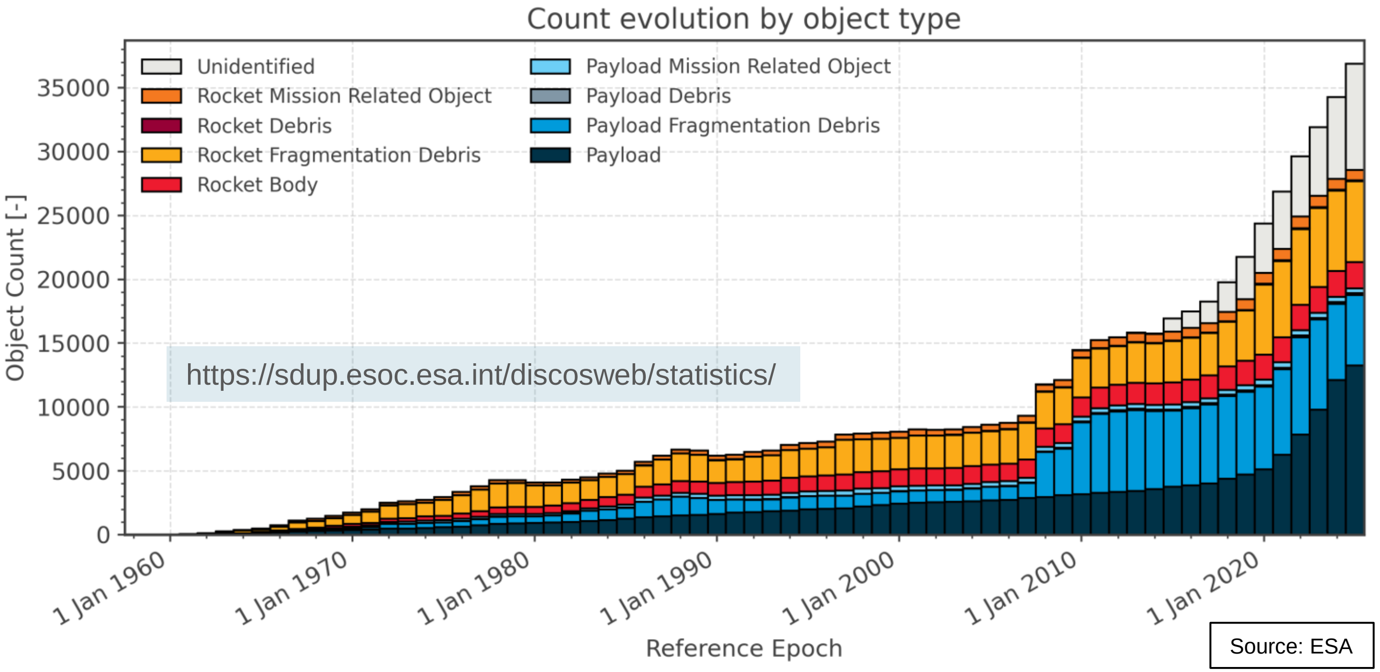
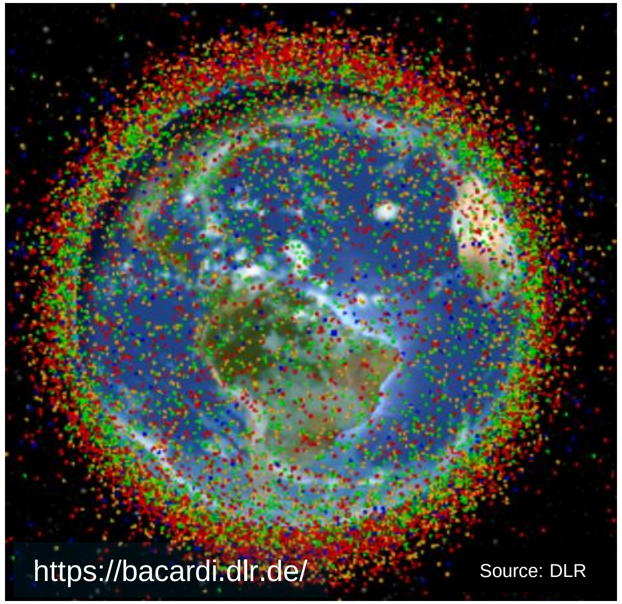
# Actual and future challenges in orbit environment




Source: ESA



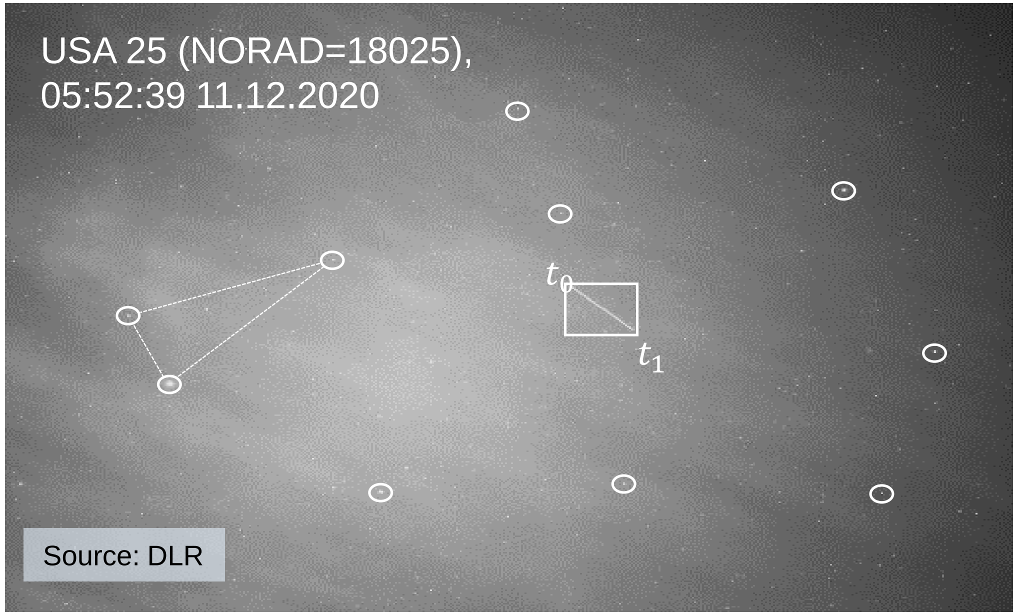

- Space is getting continuously more crowded (actual population in LEO: 11266 operational satellites and 12000 debris objects / defunct satellites - ESA space environment statistics 07/2024)

- Number of threatening encounters of objects in space increases: https://celestrak.org/SOCRATES/

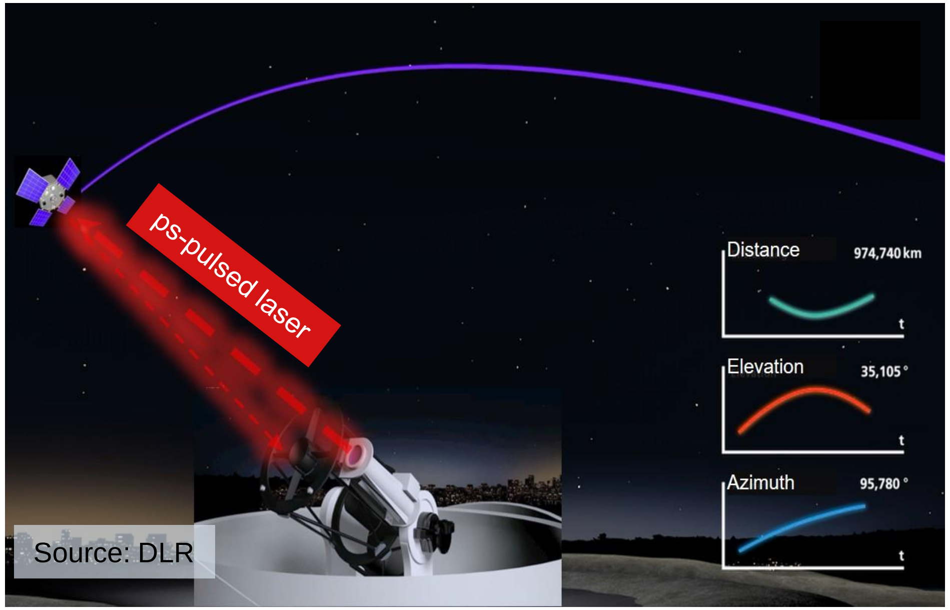
# (Laser-)optical technologies in space traffic management

DLR develops laser and passive optical sensors for detection and orbit determination with a focus on

- transportable
- low SWaP values (size, weight and power)
- high accuracy

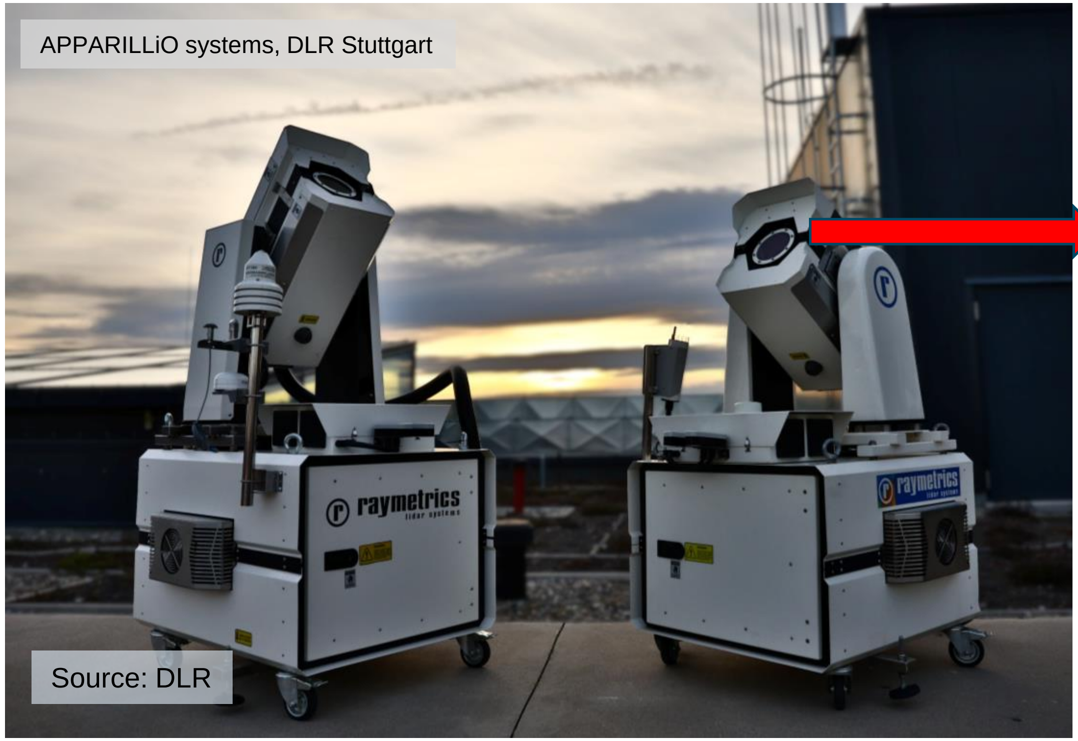



Passive optical detection of sun-illuminated space objects for (initial) orbit determination and catalogue maintenance

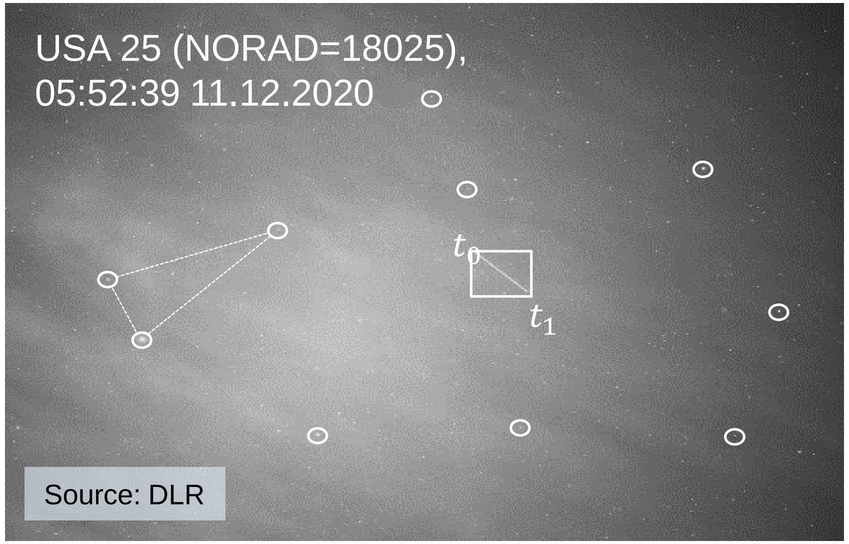



Satellite laser ranging (SLR) for precise orbit determination in case of conjunction warnings
→ large potential to reduce the number of necessary collision avoidance maneuvers

# Progress on passive optical detection of LEO space objects





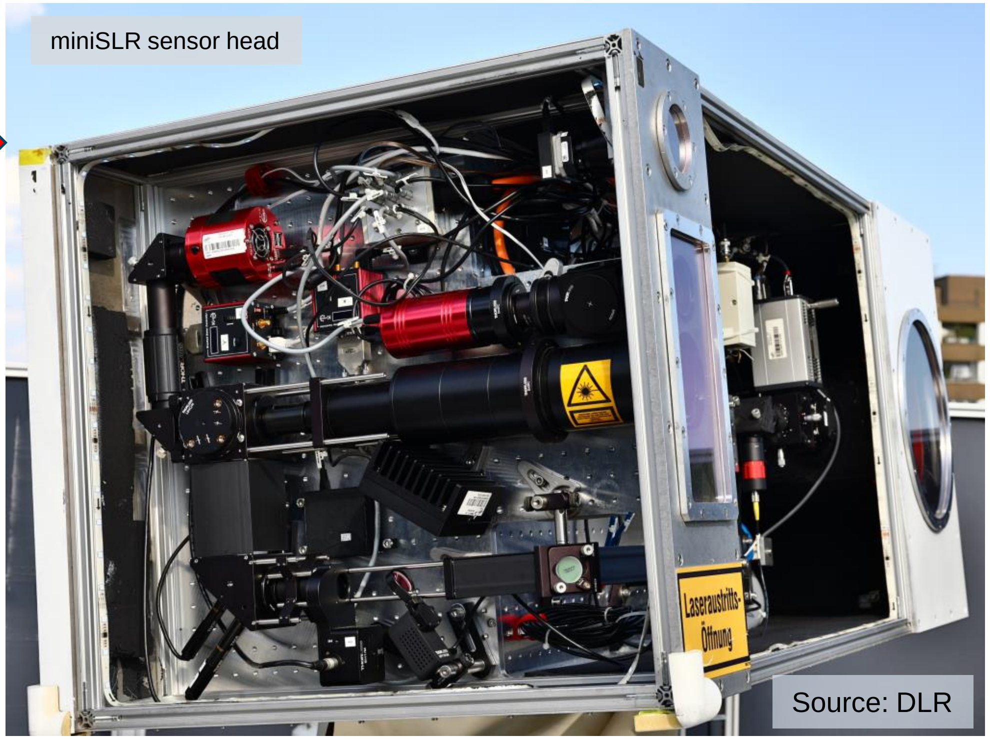



- APPARILLiO is a fully autonomous and transportable staring system for LEO object detection
- Novel laboratory calibration method precise timing during image acquisition.
- This greatly improves the accuracy of the sensor, particularly for LEO objects with high angular velocities with respect to the staring sensor.

R. Rosok et al., „Method for improving the positional accuracy in passive optical detection of space objects“ , Appl. Opt. 63, 18 (2024)

# Progress on SLR ground station development


miniSLR system, DLR Stuttgart




miniSLR sensor head

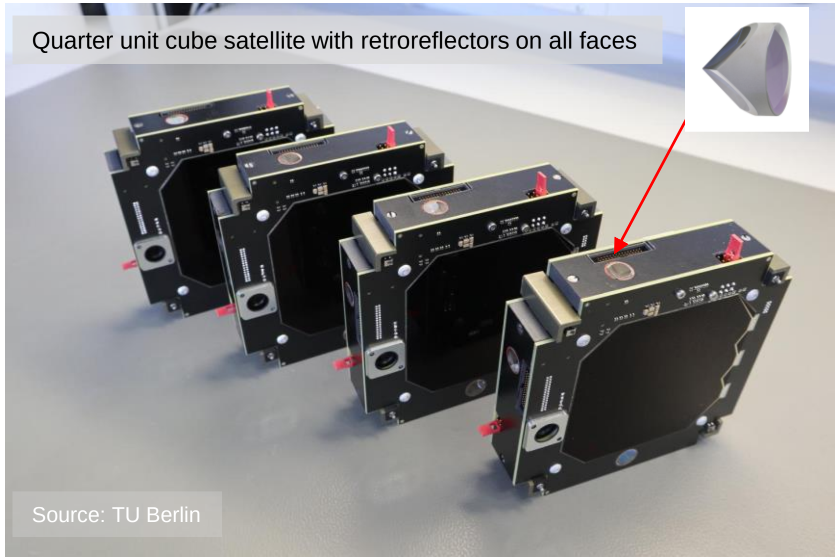
Source: DLR

- miniSLR is a 600 kg, transportable, small area footprint (< 3 $m^2$) SLR station
- Miniaturization is possible via a design without a dome and using a compact laser source with low pulse energy (85 µJ) & high repetition rate (50 kHz)
- Evaluation campaign shows that the miniSLR systems can compete with larger SLR stations in terms of a accuracy (7.4 mm rms pass range bias) and precision (4.0 mm rms ).
- SLR stations now available as turn key systems

D. Hampf et al., „The miniSLR: a low-budget, high-performance satellite laser ranging ground station", J. Geod. 98, 8 (2024).

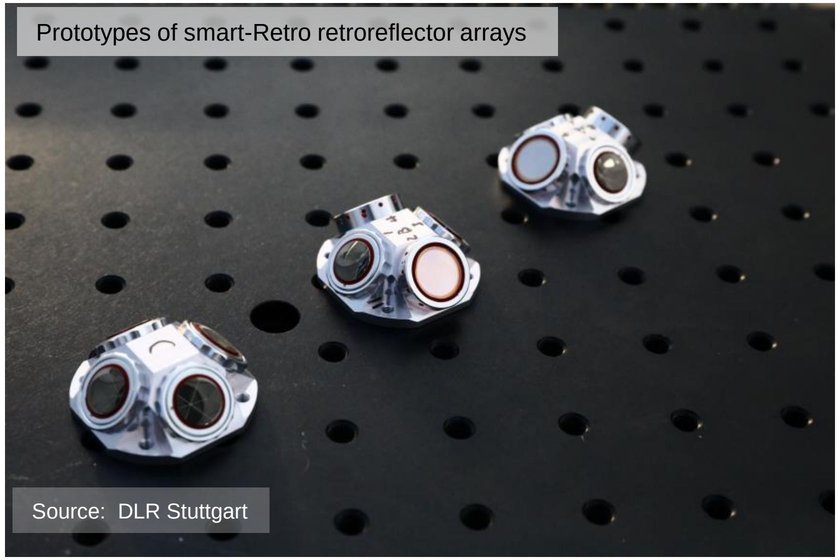
# Retroreflectors for space traffic management

- Retroreflectors greatly increase the return signal in laser ranging. They are small, low cost and can easily be integrated into all satellites including CubeSats.
- DLR develops an optical tagging (smart-Retro) technology for polarimetric discrimination of satellites using the polarization of light
- A website with a list of satellites equipped with retroreflectors and supporting laser ranging is currently being developed for scientific purposes (cooperation between DLR and the Institute of Air Law, Space Law and Cyber Law in Cologne, Germany)



Quarter unit cube satellite with retroreflectors on all faces

Source: TU Berlin



Prototypes of smart-Retro retroreflector arrays

Source:  DLR Stuttgart

# Conclusions and outlook

- Passive and laser-optical technologies have great potential for space traffic management in densely populated orbits

- Technological innovations
  - A laboratory calibration method increases the accuracy of passive optical detection of space objects
  - Successful design of compact and transportable SLR stations
  - Polarimetric satellite laser ranging for the identification of satellites, e.g. after cluster launches

- Retroreflectors on satellites may facilitate laser ranging and laser-based orbit determination for efficient planning/avoidance of conjunction maneuvers. This supports the implementation of LTS Guideline B.2 on enhancing orbital accuracy, particularly for small spacecraft.

# THANK YOU VERY MUCH

Picture: DLR

# Selection of related literature


- R. Rosok et al., „Method for improving the positional accuracy in passive optical detection of space objects“, Appl. Opt. 63, 18 (2024), https://doi.org/10.1364/AO.526011
- D. Hampf et al., „The miniSLR: a low-budget, high-performance satellite laser ranging ground station”, J. Geod. 98, 8 (2024), https://doi.org/10.1007/s00190-023-01814-1
- D. Hampf et al., „A path towards low-cost, high-accuracy orbital object monitoring”, Proc. 8th European Conference on Space Debris Darmstadt, Germany, 20–23 April 2021, SDC8-paper251.pdf
- M.A. Skinner: CubeSat Confusion: Technical and Regulatory Considerations, The Aerospace Corporation, 2021, https://aeropace.org/sites/default/files/2021-01/Skinner_CubeSatConfusion_20210107.pdf
- N. Bartels et al., „Space object identification via polarimetric satellite laser ranging“, Commun. Eng. 1, 5 (2022), https://www.nature.com/articles/s44172-022-00003-w
- W. Riede et al., “Satellite retroreflectors and laser ranging for space traffic management”, UN COPUOS 2023 - Session of the Scientific and Technical Subcommittee, Vienna, Austria (2023).
- United Nations Office for Outer Space Affairs (UNOOSA), “Guidelines for the long-term sustainability of outer space activities of the committee on the peaceful uses of outer space”, V21-00374, United Nations (2021).