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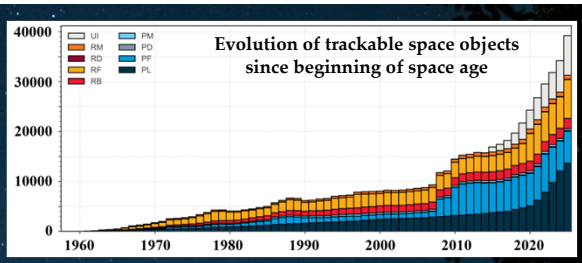
SATELLITE LASER RANGING

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S. Schneider, B. Süßer-Rechberger, N. Trummer, P. Wang

MORE ABOUT US

LUSTBÜHEL OBSERVATORY, GRAZ

- Millimeter precision laser-based range measurements
- Satellite Laser Ranging & Space Debris Laser Ranging
- Single-photon light curves
- Machine Learning Classification
- Laser and detection packages





SATELLITE LASER RANGING - SLR

- **Laser:** 0.8 Watt, 2 Kilohertz, 10 picosecond pulse duration
- **Reflection principle:** Corner Cube Retroreflectors (CCR)
- **Targets:** > 150 satellites (geodetic, scientific, navigation)
- **Target size:** ≥ 1 corner cube retroreflector (1 cm)
- **Range:** < 36,000 km; **Orbit:** low Earth, geostationary
- **Precision:** 3 mm; **Time of flight:** 0.002 - 0.25 seconds

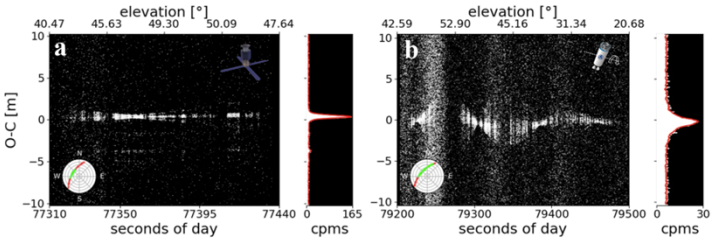
SATELLITE LASER RANGING: FIELD OF USE

- Highly precise orbit predictions, up to sub-centimeter precision
- Independent & passive technique, cross-technique validation
- International Terrestrial Reference Frame (ITRF)
- Earth center of mass, Earth gravitational field
- Environmental satellites: oceanic motion, topography, ice masses

MEGAHERTZ SDLR - COMBINING TECHNIQUES

Using a laser with a repetition rate of up to 1 Megahertz, the strengths of both satellite laser ranging (mm-precision) and space debris laser ranging (power, targets without reflectors) were combined in a single system. This leads to improved precision in both regimes without the need of switching the measurement setup.

Up to 250,000 successful measurements per second improve the normal point precision to satellites to the µm-level. To space debris, fine details of different reflecting surfaces of space debris and a rotation can be distinguished. A split setup, separating transmit and receive, allows for avoiding atmospheric backscatter, thereby doubling the effective power with MHz systems.



Space debris laser ranging residuals [m] using the MHz laser system to a) COSMOS 2082 and b) SL-14 rocket body. Fine details of the individual reflecting surfaces are visible for COSMOS. A rotation of 170 sec indicates a tumbling motion around the principle axis of inertia for the SL-14 rocket body.

Besides improving the technology and lowering the entry threshold for stations to contribute debris measurements, a network of space debris laser ranging capable stations is a prerequisite for future high precision orbit determination, collision avoidance or removal missions. The SLR group is also building laser and detection packages for space agencies or research institutions worldwide (e.g. ESA, EU, JAXA, TU Berlin, ASI).

Steindorfer et al. 2025, Nature Communications.

SPACE DEBRIS LASER RANGING - SDLR

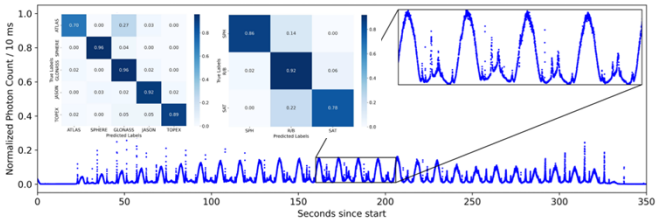
- **Laser:** 16 Watt, 200 Hertz, 3 nanosecond pulse duration
- **Reflection principle:** Diffuse reflection from whole object
- **Targets:** > 300 space debris objects (rocket bodies, defunct satellites)
- **Target size:** > 1 m, depending on reflection characteristics
- **Range:** < 2,500 km; **Orbit:** low Earth
- **Precision:** < 1 m; **Time of flight:** 0.002 - 0.02 seconds

SPACE DEBRIS: FACTS AND STATISTICS

- Definition: Human-made space objects without function
- Reasons: Collisions, fragmentation, anti-satellite tests
- Satellites: 13,000 operational - 3,500 defunct
- Catalogued debris: 40,000 objects > 10 cm 1.2 Million > 1 cm
- Velocity: up to 7 km/s, Mass: > 15,000 t

MACHINE LEARNING - DEBRIS CLASSIFICATION

At Graz SLR station Single Photon Avalanche Diode (SPAD) detectors are used to measure the temporal variation of sunlight reflections of orbiting objects with temporal resolutions down to the microsecond-level. IWF's SPARC catalogue hosts more than 6,000 light curves of 700 different satellites and space debris. As space objects can start to rotate at the end of their lifetime, targets show unique reflection signatures.



Light curve of the defunct satellite Topex/Poseidon (T_{rot} = 10 sec). Upper left: Confusion matrices / machine learning classification (1 = 100 % success rate).

Machine learning techniques were utilized to perform classification tasks of space debris targets. An accuracy of up to 90% was reached by using feature extraction techniques as preprocessing for target classification.

Trummer et al. 2025, Acta Astronautica.

GALILEO ATTITUDE DETERMINATION

Due to its unique precision, Satellite Laser Ranging allows to identify individual retro reflectors on orbiting targets, even if they are mounted in close proximity. On Galileo satellites up to 84 reflectors are mounted on a panel in a hexagonal pattern. At specific orientations along the orbit, the reflectors on the panel align in a way that multiple reflectors appear at equal range. Those millimeter range differences were measured and the incident angle of the laser beam on the satellite is calculated up to 0.1° accuracy. Furthermore, an improvement of the normal point precision was achieved, correcting an irregular reflection distribution of the panel.

Steindorfer et al. 2024, GPS Solutions.

2025
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