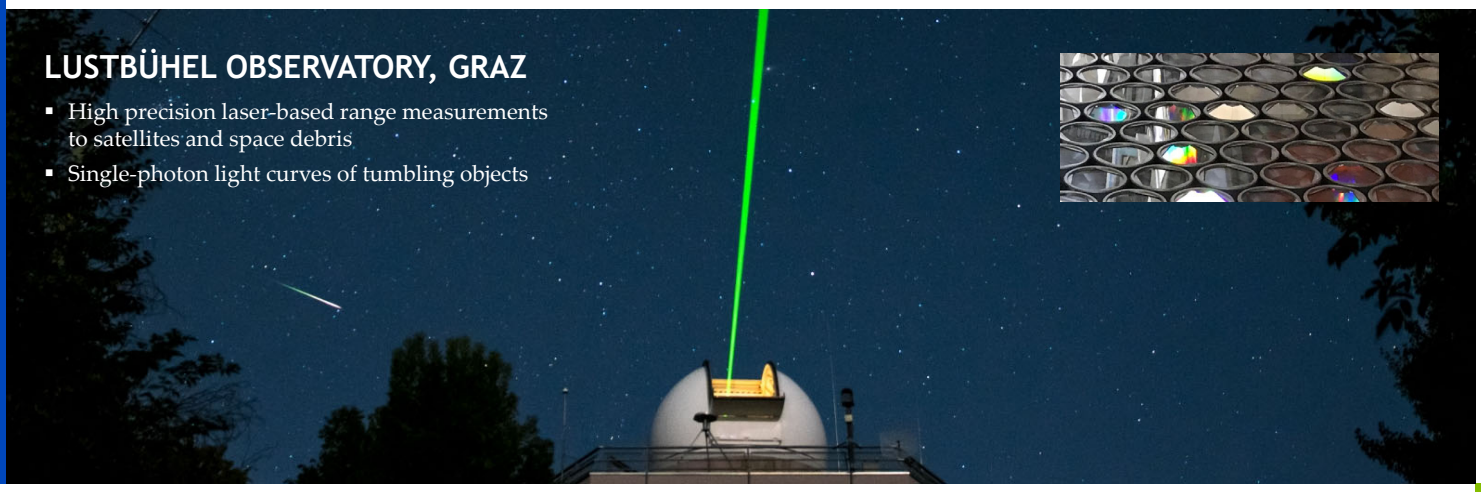
ÖAW IWF

SATELLITE LASER RANGING

Michael Steindorfer, D. Fauland, Ch. Graf, A. Gratzer, F. Koidl, O. Posch, S. Schneider, R. Stieninger, N. Trummer, P. Wang

MORE ABOUT US



LUSTBÜHEL OBSERVATORY, GRAZ

- High precision laser-based range measurements to satellites and space debris
- Single-photon light curves of tumbling objects

SATELLITE LASER RANGING - SLR

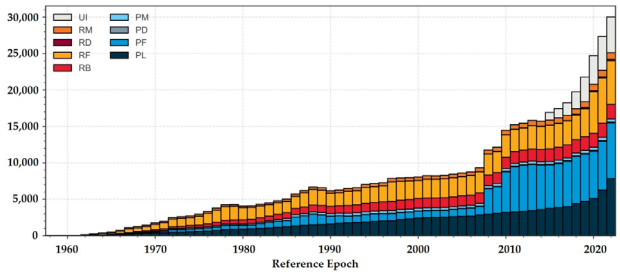
- **Laser:** 0.8 Watt, 2 Kilohertz, 10 picosecond pulse duration
- **Reflection principle:** Corner Cube Retroreflectors (CCR)
- **Targets:** > 150 satellites (geodetic, scientific, navigation)
- **Target size:** > 1 corner cube retroreflector (1 cm)
- **Range:** < 36,000 km; **Orbit:** low Earth, geostationary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

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 (defunct satellites, rocket bodies)
- **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

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
- Relativistic effects: frame dragging, gravitational redshift



Evolution of trackable space objects since beginning of space age

SPACE DEBRIS: FACTS AND STATISTICS

- Definition: Human-made objects without function
- Reasons: Collisions, fragmentation, anti-satellite tests
- Satellites: 7,000 operational - 2,500 defunct
- Catalogued debris: 30,000 > 10 cm
- Smaller objects: 1 Million > 1 cm; 130 Million > 1 mm
- Velocity: up to 7 km/s, Mass: > 10,000 t

Space debris population with a size larger than 1 millimeter

SPIN PERIOD AND ATTITUDE DETERMINATION

TUMBLING MOTION CHARACTERIZATION - RIGID BODY IN SPACE

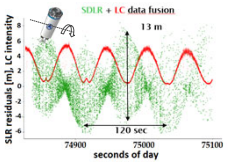
- Tumbling motion: Rotation of uncontrolled space objects
- Reasons: Solar radiation pressure, collisions, fragmentation, outgassing
- Rotation axis: Spin period, angular momentum w.r.t. reference frame

DATA FUSION: 3 OBSERVATION TECHNIQUES, DIFFERENT STRENGTHS

- SLR: Range variations of CCRs
- SDLR: Range variation; size, shape, center of mass
- Single photon light curves: Reflected sunlight, surface feature detection
- Huge database: >10,000 passes, machine learning, data fusion

SLR AND LIGHT CURVE SIMULATIONS

- Copernicus: Design of backup CCRs
- Attitude determination validation
- Debris removal, re-entry analysis



ATTITUDE DETERMINATION

- Galileo: Attitude and laser beam incident angle determination [5]
- Topex: Correlation rotational behavior - solar radiation pressure
- Ajisai: Characterization of defects of individual mirrors

KEY TECHNOLOGY AND SCIENCE

LASER AND DETECTION PACKAGES

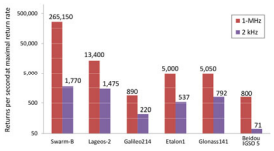
- Modular laser ranging packages for new SLR stations
- CAD, optical simulations, fabrication, assembly
- IWF technology for: ESA, JAXA, EU, ASI, TU Berlin, Yebes

RESEARCH TOPICS AND COOPERATIONS

- Daylight space debris laser ranging: Increase of observation time [1]
- Stare and Chase: Debris laser ranging of a-priori unknown targets [2]
- Quantum key distribution: Lustbühel as one of three ground stations [3]
- Bistatic SDLR: Detection of Graz debris photons within Europe

MEGAHERTZ SATELLITE LASER RANGING

- > 250,000 return photons per second [4]
- High resolution satellite signature
- Improved data precision, big data



HIGHLIGHT PUBLICATIONS

1) Steindorfer et al., Daylight space debris laser ranging, Nature Communications, 2020
2) Steindorfer et al., Stare and chase of space debris targets using real-time derived pointing data, Advances in Space Research, 2017
3) Liao et al. Satellite-relayed intercontinental quantum network, Physical Review Letters, 2019
4) Wang et al., Megahertz repetition rate satellite laser ranging demonstration at Graz observatory, Optics Letters, 2021
5) Steindorfer et al., Attitude determination of Galileo satellites using high-resolution kHz SLR, Journal of Geodesy, 2019

IWF — INSTITUT FÜR WELTRAUMFORSCHUNG, WWW.OEAW.AC.AT/IWF, MICHAEL.STEINDORFER@OEAW.AC.AT