


Laser Ranging to Space Debris from Graz Laser Station

Georg Kirchner and Franz Koidl, Graz

Abstract

The Satellite Laser Ranging (SLR) station Graz is measuring distances to satellites – equipped with retro-reflectors – with an accuracy of a few millimetres, since several years. In addition, in 2012 we started to measure also distances to space debris – e.g. old rocket bodies, which are NOT equipped with retro-reflectors ('non-cooperative targets'). In several experimental sessions, we have tracked some hundred passes of about 60 objects of different sizes, in distances between 500 km and up to 3000 km. In 2013, Graz started with 'multi-static' laser ranging: While Graz ranged to the debris target, other European SLR stations – synchronized to the Graz laser shots – detected the diffusely reflected Graz photons, thus adding one-way measurements (from target to the stations).

Keywords: Space Debris, Laser Ranging

Kurzfassung

Die 'Satellite Laser Ranging (SLR)' Station Graz misst die Entfernung zu Satelliten, die mit Retro-Reflektoren ausgestattet sind, mit einer Genauigkeit von 2 bis 3 mm. Zusätzlich begannen wir 2012 auch die Entfernungen zu Weltraumschrott zu messen – z.B. zu alten Raketenstufen, die NICHT mit Retro-Reflektoren ausgestattet sind. In mehreren Experimental-Sessions von jeweils etwa 2 Stunden wurden über 200 Durchgänge von insgesamt mehr als 60 Objekten verschiedener Größen in Entfernungen zwischen 500 km und mehr als 3000 km gemessen.

Schlüsselwörter: Weltraumschrott, Laser Ranging

1. Introduction

The Satellite Laser Ranging (SLR) station Graz is located at the Observatory Lustbühel, on a hill close to and about 150 m above the city of Graz (Figure 1). It uses a 2 kHz laser (400 µJ per shot @ 532 nm, 10 ps pulse duration) to measure distances to satellites, which are equipped with retro-reflectors; the accuracy is a few millimetres. The 2 kHz repetition rate allows to apply statistics to form very accurate Normal Points, which can reach an ultimate resolution of about 0.2 mm. Calculating a best-fit orbit using SLR data of about 40 stations distributed around the world, shows the excellent accuracy of the Graz SLR station (Figure 2).

Fig. 1: Observatory Graz-Lustbühel: SLR Dome, SLR telescope

2. The Space Debris Problem

2.1 General space debris information

Space debris is created by rocket bodies, upper stage engines, decommissioned satellites, and fragmentation due to break-ups, collisions, explosions of non-empty fuel tanks etc. The number of space debris objects is increasing rapidly, and within a few years it could reach a run-away point in the most populated LEO orbits between 800 km and 1200 km, where the number of debris items constantly increases due to progressively unavoidable collisions. This scenario is called the *Kessler Syndrome* [1] and is predicted with high probability even for the very unlikely case that all future launches are stopped.

Pieces of space debris – travelling at high speeds of about 8 km/s in crowded orbits - pose increasing hazards to manned and unmanned space flights and space operations. There have been already several collisions in space, some with minor consequences (Jason-1, March 2002) [2], some catastrophic (Iridium33 collision with Cosmos 2251 in 2009), and some even intentionally generated: China destroyed 2007 its own aging Fengyun-1C weather satellite during an anti-satellite rocket test, increasing the total number of radar traceable debris objects by 22 %.

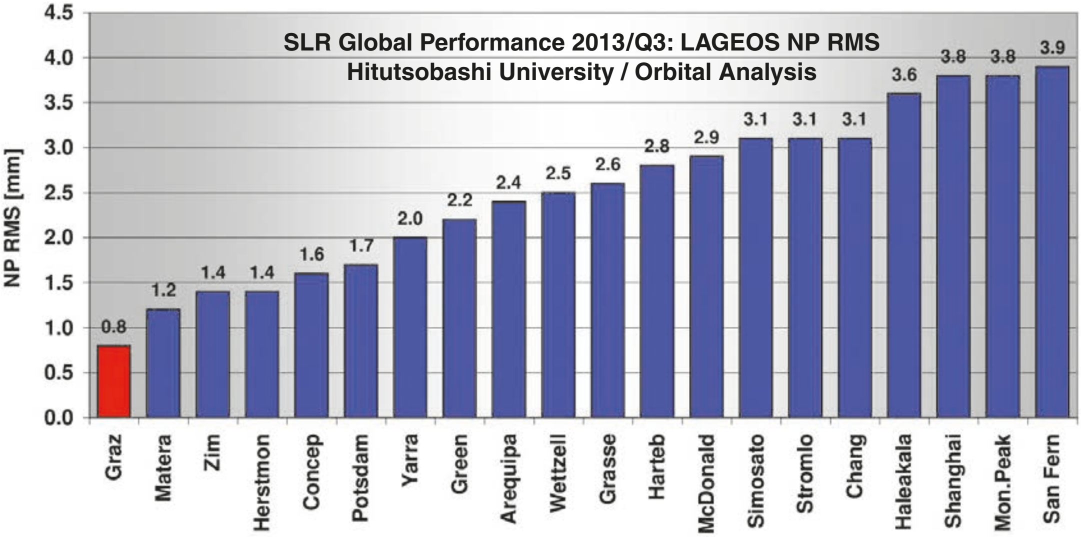

Fig. 2: SLR Graz delivers very accurate Normal Points of satellite LAGEOS

The estimated number of space debris objects down to a size of about 1 cm is already in the order of about 600,000. While particles smaller than about 1 cm can be mitigated by proper shielding of spacecrafts, collisions with larger objects are most likely catastrophic due to the high kinetic energy involved at relative propagation velocities above 8 km/s. To avoid collisions, spacecraft manoeuvres are required, which are costly in terms of available propellant. Threats from space debris have caused already 16 collision avoidance manoeuvres of the ISS since October 1999 [2].

2.2 Determination of space debris orbits

Space debris orbits are determined mainly by tracking with big radar systems, like the U.S. Space Surveillance Network, and the TIRA (Tracking and Imaging RAdar) near Bonn (Fraunhofer Institute), or by passive optical tracking with telescopes [3], [4]. The radar systems usually operate in 'staring mode': The radar dish pointing remains fixed and all objects passing within the radar beam are recorded.

Passive optical methods usually work in a similar way: Telescopes observe the sky and record accurate tracks of sunlit objects with cameras; this method has additional limitations by needing clear weather and darkness at the observing site, and the objects to be sunlit.

While these well established methods are effective, and have taken the main burden of space debris orbit determination, their nominal accuracy is relatively low, and the resulting orbit predictions may have offsets of up to a kilometre or more [10]. The accuracy can be increased only with repeated measurements focussed on selected targets; this is costly and time consuming. Inaccurate orbits are a problem for proper scheduling of collision avoidance manoeuvres - any unnecessary manoeuvre is a waste of limited propellant – and also for ambitious plans aiming for the removal of space debris from orbit by laser ablation [5], [6].

3. Laser Ranging to space debris targets

3.1 Laser Ranging to space debris from a single Satellite Laser Ranging station: Graz

An evolving method to improve space debris orbit predictions uses high energy laser pulses, fired to space debris objects, detecting the diffusely reflected photons and measuring the time-of-flight to determine the distance. The results reported up to now used kW lasers [7], or more recently a 2 J/20 Hz laser [8], or a 2 J/10 Hz laser at the lunar laser ranging station in Grasse / France [9]. At the satellite laser ranging (SLR) station Graz, the first laser ranging measurements to debris objects started in 2012 [10], using a diode-pumped laser (on loan from DLR Stuttgart) with 1 kHz repetition rate, with a relatively low energy of 25 mJ per pulse, and 10 ns pulse width.

This first laser was replaced in 2013 by a flash lamp pumped laser (also on loan from DLR

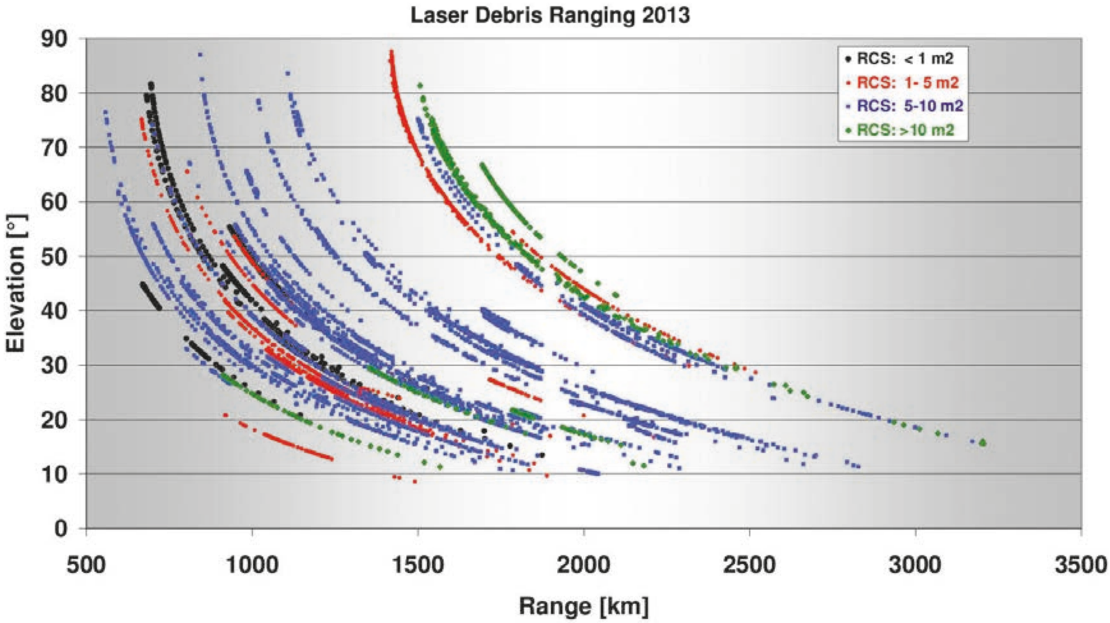

Fig. 3: SLR Graz: Laser Ranging to Space Debris Objects in 2013: > 200 Passes, about 60 different objects, 13 sessions; up to 3000 km distance

Stuttgart) with 99.9 Hz maximum repetition rate, 200 mJ per pulse and 3 ns pulse width. Both lasers operated at 532 nm, the most common wavelength used for satellite laser ranging, and were successfully used to measure distances of up to about 3000 km to larger targets with several m^2 Radar Cross Section (RCS), and to smaller targets (down to 0.3 m^2 RCS) at shorter distances (Figure 3)

3.2 Multi-Static Laser Ranging to space debris

We extended this basic concept by including multiple SLR stations into the measurement process, in order to achieve Multi-Static Laser Ranging to space debris objects. One station (called the 'active' station ⇒ Graz) fires laser pulses to the object and detects the diffusely reflected photons measuring the time-of-flight. Additional stations ('passive' stations) track the same target with their telescopes without firing their own laser, and detect diffusely reflected photons of the active station (Figures 4 and 5).

The 'passive' stations have to be synchronized to the 'active' station Graz; that means they have to know the Graz firing epochs to significantly better than 1 µs. This was achieved by pre-defining all Graz firing epochs in advance, with an accuracy of < 100 ns; to make this as simple as possible, we selected an accurate 80 Hz laser repetition rate, which is repeated within each one-second period; the offset of the first firing epoch from the 1 pps was published to the passive stations in advance for each session.

These 'passive' stations measure pseudo-ranges, because of the unknown clock offsets between the active and each passive station. These measurements are only quasi-simultaneous since the small percentage of laser shots that generate an echo at the Graz SLR will mostly correspond to different laser fire times as those

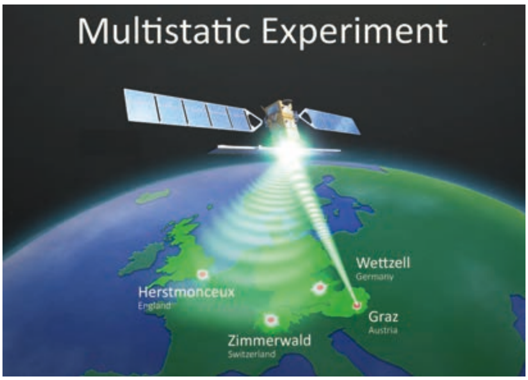

Fig. 4: Graz fired laser pulses to debris targets passing over Middle Europe; the photons - diffusely reflected from the debris targets - were detected at 4 SLR stations: Graz; Zimmerwald (600 km); Wettzell (400 km); Herstmonceux (1200 km); Graphics: Peter Ruzek/ AIUB

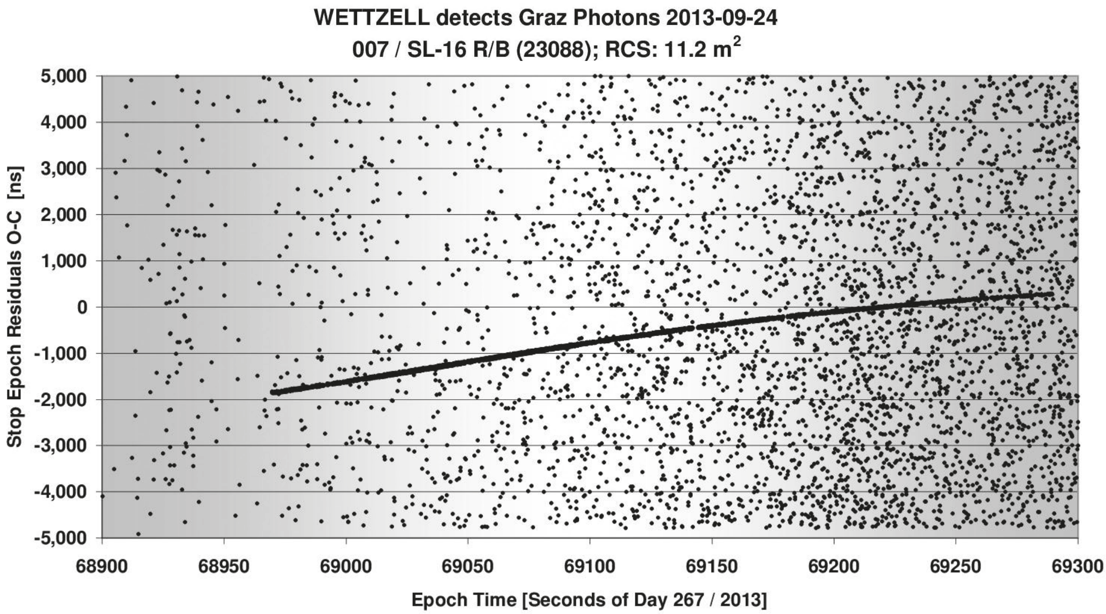

Fig. 5: Graz photons, diffusely reflected from an old rocket body (NORAD 23088; 11 m² RCS (Radar Cross Section), in an 850 km orbit) and detected at the SLR station Wettzell; shown are the residuals, ZERO is the predicted time-of-flight (Graz – Target – Wettzell)

laser shots generating echoes at each individual passive station.

The main goal of the here described technique is to generate a significantly more precise orbit prediction for a selected target which is accurate to 10–20 arc seconds for the next 24 or 48 hours and to do so in a significantly shorter time of approximately 3 hours (2 revolutions of the target around the Earth). First results indicate a possible 10 times improvement [11] when using multi-static laser ranging data.

4. Conclusion, outlook, future plans

Synchronizing the SLR stations at Zimmerwald, Wettzell and Herstmonceux to the Graz laser firing times, these three 'passive' stations could detect the laser pulses from Graz, diffusely reflected from space debris targets. The Graz laser fired at a wavelength of 532 nm pulses with 80 Hz, 200 mJ per pulse and 3 ns pulse width.

Using one uplink and several quasi-simultaneous downlink trajectories, multi-static laser ranging to space debris targets has demonstrated the prerequisites for a more accurate orbit determination (10–20 arc seconds for the next 24 or 48 hours) in significantly shorter time (24 hours) needing fewer passes (e.g. 2).

The 4 SLR stations – including Graz – involved in the experiment are located in 4 different weather zones; this reduces heavily the probability for acceptable laser ranging conditions at all sites. As a consequence, only during 1 out of 9 sessions we obtained triple ranges (Graz, Zimmerwald and Wettzell). During the other 8 sessions, we had acceptable laser ranging conditions only in Graz and one of the 'passive' stations: Weather simply was the main limitation for successful multi-static sessions in the optical regime. However, there are several possible ways to improve this:

- More participating *'passive'* (receive-only) stations: Potsdam, Borowiec, Riga, Grasse and Matera have already expressed their interest
- Increase the number of *'active'* stations (transmitting strong laser pulses): This is more limited because more expansive equipment (high energy laser) is necessary. This method could however resolve the time scale differences (or clock offset) issue: Two stations both firing and receiving not only their own echoes, but also echoes from the other transmitting station, corresponds to the conditions of asynchronous transponder operations [12]
- Adding a few receive-only stations within e.g. 200 km of a transmitting station:
  - It is more likely to have consistent weather conditions within shorter distances;

- These stations could be much cheaper than a complete SLR station (no laser, no Coudé optical feeding path)
- Remote-controlled / automatic; no costs for operators; no laser / aircraft problems etc.

Even with the present configuration, the existing pool of SLR stations in Europe, linked within the EUROLAS sub-network of the ILRS, already offers a unique opportunity to perform such multi-static laser ranging to space debris.

Future plans include measurements with at least 3 or 4 stations simultaneously, which assumes that more European SLR stations will become available for this purpose. These measurements will establish how fast and how well the initial orbit prediction accuracy can be improved using a minimum number of acquisitions.

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Contacts

Dr. Georg Kirchner, Observatory Lustbuehel, Lustbuehelstrasse 46, A-8042 Graz, Austria.
E-Mail: Georg.Kirchner@oeaw.ac.at

Ing. Franz Koidl, Observatory Lustbuehel, Lustbuehelstrasse 46, A-8042 Graz, Austria.
E-Mail: Franz.Koidl@oeaw.ac.at