THE FUTURE OF SPACE DEBRIS LASER RANGING TOWARDS HIGH PRECISION MHZ DAYLIGHT SPACE DEBRIS LASER RANGING?

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ABSTRACT

The satellite laser ranging (SLR) station in Graz is involved in many different activities related to space debris laser ranging (SDLR). This paper gives an overview over the most important achievements of the last years including simultaneous space debris laser ranging and single photon light curves detection, stare & chase, multistatic space debris laser ranging or daylight space debris laser ranging. Furthermore, first test results with a Megahertz laser are presented.

1 MULTISTATIC SDLR

When an (active) SDLR station fires high power laser pulses to space debris targets, diffusely reflected light is distributed across Europe and can be detected by other (passive) SDLR stations using single-photon avalanche detectors. Such “bi-static” or “multi-static” measurements are conducted in Graz since 2013 with multiple stations around Europe (Wettzell, Zimmerwald, Potsdam, Herstmonceux or Stuttgart).

Graz uses a space debris laser to fire laser pulses with 200 Hz / 16 Watt to selected space debris targets. The receiving station’s detector and software needs to be synchronized to the laser pulse of the active SDLR station by calculating the predicted arrival time of the reflected photons.

A unique experiment took place in 2016 within the framework of the ESA GSTP study “Accurate Orbit Determination of Space Debris with Laser Tracking / Tasking”.

SLR station Graz was able to send and receive their own green photons while simultaneously detecting Wettzell’s infrared photons. At the same time Wettzell was also detecting their own infrared photons. In addition to that Stuttgart was able to detect Wettzell’s infrared photons (Table 1).

In 2015 [1] it was shown that the orbit calculated from 3 bistatic passes can reach similar accuracy as compared to 10 SDLR passes of 6 different monostatic SLR stations.

Table 1. Summary of the experiments conducted in 2016 together with Wettzell and Stuttgart. C1-C6 highlight the different experiment configurations. A coloured X indicates successful participation transmitting (trans) and receiving (rec) in different wavelengths 532 nm (green) and 1064 nm (red).

Conf.	Graz		Wettzell		Stuttgart	
	trans.	*rec.*	*trans.*	*rec.*	*trans.*	*rec.*
C1			X	X		
C2			X	X		X
C3		X	X	X		
C4		X	X	X		X
C5	X	X	X	X		
C6	X	X / X	X	X		

2 SDLR & LIGHT CURVES

For selected targets, simultaneous to SLR and SDLR light curves are recorded by gathering the reflected sunlight of satellites or debris with a single photon avalanche diode detector at wavelengths different to 532 nm. Space debris laser ranging gives an indication of the size of the object, also reflecting the rotational behaviour.

Figure 1 shows the results to an upper stage of the long march 3B rocket body (NORAD ID: 38253) which re-entered into Earth’s atmosphere in August 2017.

The rocket body is rotating and a rotation period of approx. 120 s can be estimated from analysing the data.

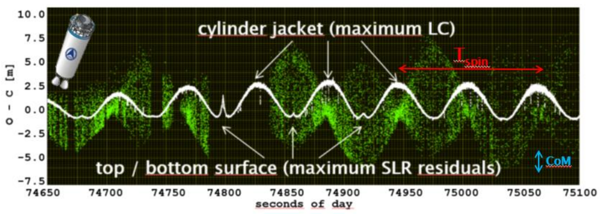

Figure 1. Space debris laser ranging range residuals (green, in meters) and light curve measurements (white, proportional to the number of single photon returns within 10 ms intervals) vs. the seconds of day.

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The maximum offset of the SLR range residuals is approximately 12 m, which corresponds well to the rocket body dimensions (12.38 m length, 3 m diameter). This also implies that at that time the cylinder symmetry axis is oriented close to the line of sight of the observer. Furthermore, the SLR residual maxima are aligned with the small and sharp light curve peaks. These arise from the reflection of the sunlight on the top/bottom surface of the rocket body.

At the minimal SLR residuals the light curve shows a broad reflection maximum. These light curve peaks are related to sunlight reflections of the cylinder jacket. The cylinder symmetry axis is hence lying within a plane normal to the line of sight of the observer.

3 STARE & CHASE

'Stare & Chase' is a method to track and range to space debris targets of which no a priori orbit information is available by optically determining the pointing direction to these targets [2].

An analogue astronomy camera is equipped with a commercial off-the-shelf 50 mm objective monitoring a field of view of approximately 7° of the sky. The camera system is piggyback mounted on our SLR telescope and roughly aligned with the optical axis. The telescope is then moved to an arbitrary position 'staring' into the sky and displaying stars up to 9th order magnitude. From the stellar background utilizing a plate solving algorithm the equatorial pointing direction of the camera center is determined with an accuracy of approx. 15 arc seconds.

Once a sunlit space debris object passes through the field of view (Figure 2) its equatorial coordinates and the current time are stored. From the pointing information a CPF orbit prediction file is generated and used to immediately track the satellite within the same pass. The process from the first detection of the satellite until successful tracking can be completed within less than 2 minutes.

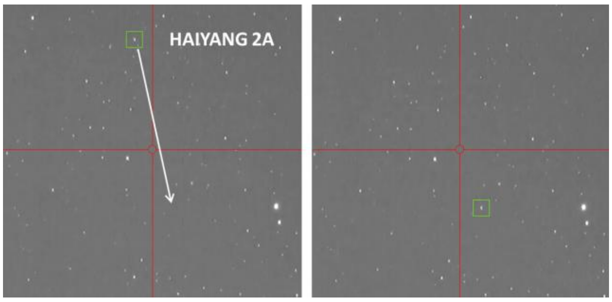

Figure 2. Detection of the Haiyang 2A satellite moving through the field of view of the 'Stare and Chase' camera system.

As soon as tracking is established the SLR system starts 'chasing' the target with a high power (20W/100Hz) space debris laser. Space debris laser ranging to several cooperative and uncooperative (without retroreflectors) targets was successfully achieved using the 'Stare & Chase' predictions.

4 DAYLIGHT SDLR

Orbit predictions of space debris objects based on Two Line Elements (TLE) are usually only accurate to within a few hundred meters. To reduce the time searching for space debris objects, before starting the actual SDLR search routine, space debris objects are centered within the field of view of the SLR station. The object has to be optically detected with an additional telescope using a larger field of view.

To extend the observation times of space debris laser ranging to full daylight it is hence necessary to visualize such targets against the blue sky background. An 8-inch Schmidt Cassegrain telescope was piggyback mounted on top of the SLR receive telescope. A CMOS camera in combination with a 780 nm edge filter (to reduce daytime sky light) was used to visualize stars and rocket bodies (Figure 3, Figure 4), calculate biases and to center them in the field of view.

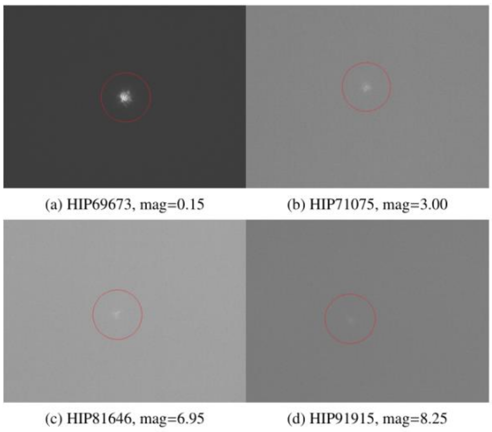

Figure 3. Detection of stars of the Hipparchos catalogue during daylight up to a minimal stellar magnitude of 8.25.

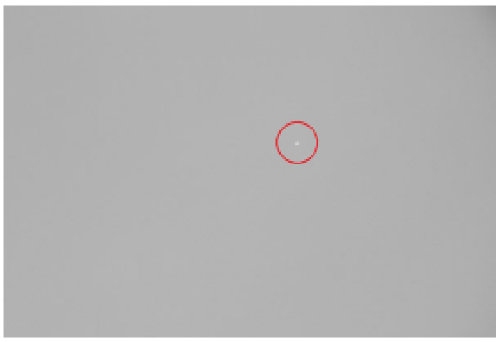

Figure 4. Detection of an upper stage SL-12 rocket body (NORAD 15772) during daylight.

So far space debris laser ranging was only possible close to the terminator period, while it is already dark at the SLR station and the object is illuminated by sunlight. Graz SLR station presented that SDLR is possible to to space debris during daylight as well [3]. Returns from four different upper stage rocket bodies were achieved up to a maximum sun elevation of 38°. An example of the residuals to an SL-16 rocket body is shown in Figure 5.

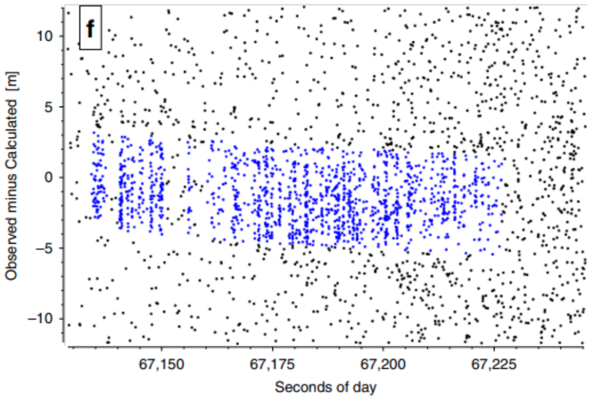

Figure 5. Daylight space debris laser ranging Observed-Minus-Calculated results to an SL-16 upper stage rocket body (NORAD ID: 22803). Identified returns are highlighted in blue. Range difference of up to 8 m give an indication of the size of the rocket body.

5 MHZ LASER RANGING

In the recent 20 years the kHz SLR technology has been practiced widely in International Laser Ranging Service (ILRS) network. Ultra-high repetition rate laser ranging (up to MHz) is the next promising strategy for future SLR [4]. The increased repetition rates with low pulse width (<10 ps) and low pulse energy can significantly improve the performance of SLR in terms of data density, accuracy, precision and stability to further enhance its unique contribution to the International Terrestrial Reference Frame.

In July 2020 the SLR station Graz demonstrated 1-MHz SLR using a laser with a very low pulse energy of ~7.8 µJ. Targets from low earth orbits up to inclined geosynchronous orbits were successfully tracked - during night-time up to a maximum slant range of 38,000 km. Among those a maximum return rate of up to 53% was achieved, equivalent to 265,000 returns per second for the satellite Swarm-B. Compared to the conventional 2 kHz SLR system in Graz, the 1-MHz SLR system leads to significantly increased return rates in all orbital regimes (Fig. X). According to the ILRS normal point (NP) algorithm, this will improve the precision of the final NP results in view of statistical errors. Consequently, it could also lead to an increased temporal resolution for distinguishing individual retro-reflector cubes, analysing the spin rate, spin axis motion, signature and attitude of satellites and space debris objects.

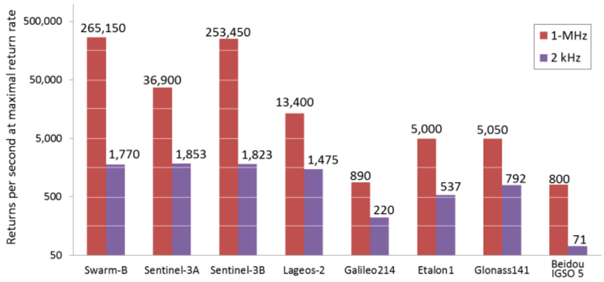

Figure 6. Comparison of the returns per second of the Graz 2 kHz system (in the year 2020) and the 1-MHz demonstration in different orbits from Low Earth Orbit up to Inclined Geosynchronous Orbit.

The used MHz laser system allows laser powers of up to 40 Watt, which encourages us to do tests to space debris targets with this picosecond pulse length laser as soon as our new MHz system is in regular operation.

6 REFERENCES

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