SLR/LLR/Time Transfer Experimentes @WLRS

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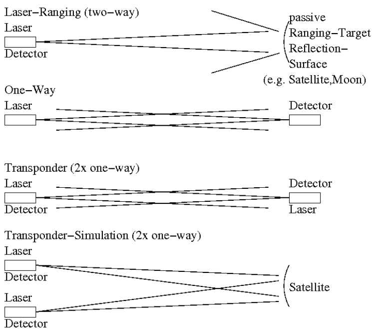
Concepts and Motivation

Contrary to the usual SLR, the following combinations of laser pulse transfers are possible:

Unidirectional: The transmitting laser beam bypasses only one distance to the target, the receiving detector; for this so-called one-way technique, the outgoing and incoming time of the laser pulse is measured at the ground and at the target, the satellite, respectively.

Bi-directional: In both directions working one-way techniques can be operated in principle asynchronously, but they can also be synchronised (so-called transponder).

SLR is a two-way technique because the transmitting laser beam has to travel to the satellite and back again to the receiving detector; for this technique, only one site is equipped with active components; the ranging target is passive.



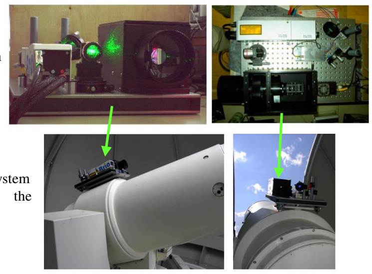
For the one-way techniques, the bypassing distance is smaller and the intensity reduction of the beam is much lesser due to the lack of the sub-optimal reflection at the satellite. Therefore, for the one-way techniques the laser pulses are much easier to detect. Of course, for the one-way techniques and transponder systems respectively, both sites must be active. The goal of such laser pulse transfers is in particular the bypassing of interplanetary distances because the technical limits of one-way techniques exceed in principle the limits of two-way techniques.

Beside the classical ranging, the applications should be the time transfer and finally the more broadband communication from the earth to spacecrafts. The feasibility of such technical systems is possible because the pulse lasers are enough powerful, the detectors are enough sensitive (single-photon mode), the time measurement can be performed very precise and such complete systems, amongst others it's weight and it's geometrical dimensions, can be put onto satellites/spacecrafts. Before the realisation of such missions, the operation has to be demonstrated using simulation experiments. In this regard at the WLRS, some experiments have been carried out.

Altimetry and Transponder Ground-Simulation-Experiment

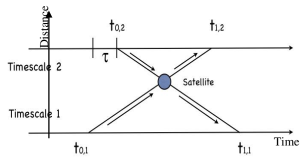
For the transponder application on both sites of a transmit-receive-link, a transmitting laser and a receiving detector exists. Instead of a real transponder module using a laser-detector-eventtimer system on-board of a satellite, a transponder simulation is applied here. The missing transponder module at the satellite is replaced here by a small auxiliary SLR system at the ground alongside the WLRS. As the real transponder module, the auxiliary system has the fewer powerful laser and the lesser receiving aperture.

Auxiliary-SLR-System



Auxiliary-SLR-System mounted onto the WLRS-telescope

In order to obtain the temporal synchronisation of the laser pulse of the first SLR system with the detector gate the second SLR system and vice versa for the synchronous transponder mode, the WLRS has been interconnected with the auxiliary system accordingly (electrically across). The different possible measurement arrangements of the SLR systems and transponder modes respectively were measured and validated (Schreiber et al./2009).



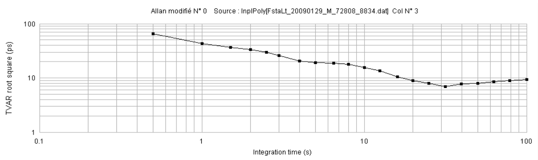
Achievable One-Way Transponder Distances (theoretical estimate):

0.44 AU using the auxiliary SLR system,
4 AU typical value of the WLRS,
110 AU marginal maximal using the WLRS.
(40 AU for comparison: Pluto-Sun)

Time Transfer by Laser Link/T2L2 (operated by France)

Beside the usual SLR tracking of the satellite Jason-2, additionally at the satellite, the stop time/epoch is measured. For this, the satellite has a detector and an event timer on-board. At the WLRS, the start laser pulse is measured at best time and frequency stability, evaluated and transferred to the data centres using the maximum time resolution.

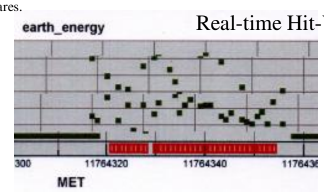
"Time stability, measured by T2L2 on one pass of the SLR station of Wettzell, Germany (H-Maser), compared to the on-board DORIS USO (quartz) : ***40ps@1s and 7ps@30s***. For integrated times >30 s : limit due to DORIS with : 5ps@30s and 10ps@100s." (Exertier/2009)

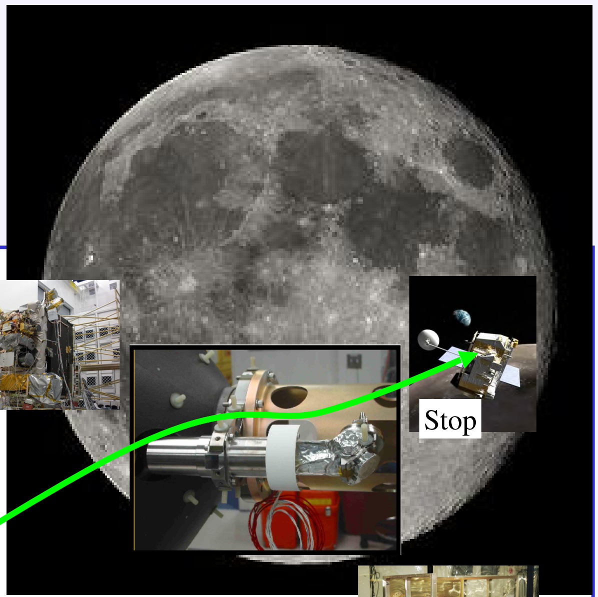


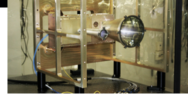
Tracking of the Lunar Reconnaissance Orbiter/LRO-LR (operated by NASA)

The goal is to hit the detector of the around the moon orbiting spacecraft using the WLRS laser and telescope. The detector at the spacecraft is very sensitive and is armed for 8ms every cycle of 28Hz. For the experiment the WLRS hardware was to be adapted in the following way: The laser pulse is generated asynchronously using 9.3Hz instead of the 28Hz of the open gate at the LRO. The pulse cycle duration can be changed by 0.5ms per impulse in order to hit the LRO gate. The telescope pointing errors were minimised by applying the mount model, verifying the software and analysing the results of high earth orbit satellites. The power of the laser was increased again to 90mJ. The beam divergence was adapted again and again (1"..330" half angle). Due to security reasons, a NASA controlled laser interlock was implemented. This one-way mode and, for this, the data evaluation were enabled in the involved WLRS softwares.

Real-time Hit-Window

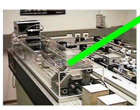






LRO-Tracking: For this experiment, the principle difficulty is in fact to hit the detector window of the moon orbiter, and that both geometrically and temporally. For this, for the tracking, the pulse frequency and the telescope pointing is varied. The NASA obtains the detector hit event data via a LRO RF downlink. Via the internet, latter can be illustrated in a real-time hit-window at the WLRS and serve as feedback for the multi-dimensional tracking iteration. The handicaps weather, moon constellation, NASA schedules, technics and system errors made the experiment drastically more difficult.

Start



WLRS

LRO data evaluation: After the tracking, the WLRS start events are send to the NASA that processes the LRO detector hit events. Because the laser pulse of the WLRS is not frequency synchronous to the detector time-window, the hits drift within the gate (right picture: see lines having a gradient). At the end of 2009, the WLRS had the first ***two hit-passages*** of 16 and 20 minutes on LRO. Therewith, the time transfer to a moon spacecraft was realised in principle.