HISTORY OF THE LASER OBSERVATIONS AT ZIMMERWALD

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Abstract: *In 1971 first tests with a ruby laser built by the Institute of Applied Physics of the University of Bern mounted along the tube of the Schmidt Cassegrain telescope were performed. The success was very limited, but first instrumental experience in the field of SLR observations could be acquired. Nowadays Zimmerwald is one of the most productive stations worldwide in terms of number of observed satellite passes and delivered normal points. A historical overview of the technical developments, in particular the various telescopes and laser systems used for the SLR observations, will be presented.*

The Zimmerwald Observatory

The Zimmerwald Observatory was built 1955/1956. In the first three years optical observations were performed using a small Schmidt Camera (25 cm aperture, 104 cm focal length). Since 1959 the larger Schmidt Camera (40 cm aperture, 104 cm focal length) as well as a Cassegrain telescope (60 cm aperture, 13 m focal length), both fixed to the same equatorial mount, were at disposal. First optical observations of active and passive geodetic satellites (GEOS, Explorer, Pageos and Echo) were performed with the Schmidt Camera in 1965. Due to the extremely time-consuming evaluation of the photographic plates, the photographic observation technique was abandoned and a new observation technique was introduced: The *Satellite Laser Ranging* (SLR).

60cm Cassegrain/Schmidt Telescope

In 1971 first tests with a ruby laser built by the Institute of Applied Physics (IAP) of the University of Bern mounted along the tube of the astronomical telescope, using the Cassegrain telescope as receiver, were performed. The success was very limited, but first instrumental experience in the field of SLR observations during the ISAGEX campaign could be acquired. D1D, BEC, D1C and GEO2 were the most important targets.

50 cm Cassegrain Telescope

1974-1983: The satellite observatory Zimmerwald (an annex to the existing observatory with a new dome) was constructed in collaboration with the IAP. The telescope was designed and mostly built in-house. It consisted of a Cassegrain receiving telescope of 50 cm aperture and a separate transmitting Galilei telescope. Two laser systems were installed, a Ruby laser for SLR purposes and a Rhodamin laser for the illumination of satellites in case of optical observations. The energy per pulse of the 1 Hz ruby laser was in the range of 3 -5 joules, the pulse length between 15 -20 ns. A Grundig FA 42 S TV-Camera mounted in the primary focus of the receiving telescope allowed the observations of objects up to magnitude 9.5. A RCA 7265 photomultiplier was used as detector, and the light travelling time was measured by an “Eldorado 796” counter. A receiver of the so-called HGB 75kHz signal of the Swiss time reference system ensured determination of the epoch to within 20 usec.

In autumn 1978 first successful ranging with the ruby laser was carried out, about 120 echos in 8 passages of GEOS 1 and GEOS 3 could be measured. In 1979, the first major upgrade of the telescope control took place. The former manual control of the telescope was replaced by a computer-controlled system using a PDP 11/40 system. From August to October 1980, the station took part in the SHORT MERIT campaign by observing passes of GEOS-C and STARLETTE satellites. The single shot rms error was of the order of 60 to 100 cm. The station took also part in WEDOC and EDOREF campaigns.

1983-1995: Starting in 1983, the ruby giant pulse laser system was replaced by a new 10 Hz Neodyme:YAG laser system manufactured by Quantel (model 402 DP). Optics, electronic components, software and ranging accuracy were significantly improved. The station frequency standard was a model B1326 oven-controlled crystal oscillator by OSCILLOQUARTZ SA. Its phase was controlled by a LORAN-C receiver and permitted an epoch registration accuracy of about 10 us in real time and of 1 us after post processing. Either an EMI GENCOM D341B photomultiplier or a HAMAMATSU R1244 tandem microchannel plate was used as detector. The upgrade of the laser system provided the possibility to range the satellites on a routine basis. On 15th May 1984, the first successful ranges to LAGEOS were obtained. The station joined the MERIT campaign by observing the geodynamical satellites LAGEOS, STARLETTE and BEACON-C.

In the following years the laser ranging system was enhanced continually. In 1986 a HP5370A time interval counter was installed. Tests were carried out with a new microchannel plate Hamamatsu R1294J detector. About one year later the passive mode locking of the laser was changed to the more reliable active/passive mode locking system, yielding a more stable cadence and output energy of the laser pulses. The laser delivered now from 5 mJ to 40 mJ per pulse, the frequency was raised from 5 Hz to 10 Hz, and the pulse length was in the range of 160 ps. In May 1987 the installation of the new station computer, VAX Station 2, was initiated. The new system replaced the old PDP-11/40. Starting from 1988, observations were performed 7 nights per week by the staff of the observatory and three students. 1989 first echos of the ETALON satellite could be detected. The Loran-C timing receiver used for the real-time control of the station clock was replaced in 1991 by the 1 PPS signal of the permanent GPS receiver. The collaboration with the Federal Office of Topography (swisstopo) was significantly intensified. Since 1992 the engineers of swisstopo have participated in the operation of the laser station. In 1993 a commercial, small boat radar has been fixed on a separate 2-axes mount. It was driven in parallel to the laser telescope to check the presence of aircrafts near the laser beam. Table 1 gives an overview of the laser and receiver systems used at the 50cm Cassegrain telescope from 1978 to 1995.

Due to difficult and unstable axis alignments between the transmitting and receiving telescope and the limited tracking accuracy it was not possible to narrow the field of view enough for daylight tracking. The energy budget of the whole system did not allow ranging to high-orbit targets such as GPS and GLONASS satellites. In May 1995 the old satellite laser ranging telescope and its dome were dismounted, the Nd:YAG laser system and much of the control electronics removed.

	1978-1983	1983-1995
Laser		
Type	Ruby	Nd:YAG, passive mode locking Since 1987: active/passive mode locking
Manufacturer / Model	Institute of Applied Physics, University Bern	Quantel 402 DP
Wavelength	694 nm	532 nm
Frequency	1 Hz	10 Hz
Pulse Energy	3 – 5 J	125 mJ @ 532 nm
Pulse Width	15 -20 nsec	160 ps
Echo detection		
Type	PMT (RCA 7265)	PMT (EMI GENCOM D341B) MCP (Hamamatsu R1244) MCP (Hamamatsu R1249J)
Time of Flight	Interval (Eldorado 796)	Interval (since1986 HP5370A)
Epoch Timing	Quartz controlled by HGB (similar to DCF77)	Quartz controlled by LORAN-C, Since 1991 by GPS
Ranging accuracy	60 – 100 cm	< 10 cm

Table 1: Laser and receiver systems used at the 50cm Cassegrain telescope (1978 – 1995)

1 m ZIMLAT Telescope

1995 – 2008: In July 1995 the installation of the new 1-meter Zimmerwald Laser and Astrometry Telescope (ZIMLAT) was started. The telescope has been built by Telas, a joint venture of Aerospatiale Cannes and Framatome, France. For the first time a Titanium-Sapphire laser was introduced into an SLR tracking system. The repetition rate of the laser was 10 Hz, the pulse length 100 ps, and the energy per pulse about 80 mJ. A HAMAMATSU H 6533 photomultiplier was used as detector at 423 nm. Day- and nighttime observations to all LEO and MEO satellites equipped with retroreflectors (including the GPS and GLONASS navigation satellites) were now possible and routinely performed. On 19th December 1996, first ranges to LAGEOS could be collected, the regular SLR observations started by mid-1997. The first ranges to a GPS satellite (GPS-35) were measured on 16th July 1997. On 14th August 2002, the first two color ranging measurements were delivered to the analysis centers of the International Laser Ranging Service (ILRS). A HAMAMATSU H 7422P-50 photomultiplier was used as detector at 846 nm. Starting from 2003, a compensated SPAD was used as detector at 423 nm instead of the old photomultiplier.

Since 2008: In spring 2008 the Titanium-Sapphire laser was replaced by a new 100 Hz Neodyme:YAG laser system. Table 2 provides a summary of the laser and receiver systems used at the 1 m ZIMLAT telescope since 1996. On 7th April 2008 first successful ranging to LAGEOS was carried out, since 19th April the system operates on a routine basis 365 days per year and 24 hours per day in case of good weather conditions. On 20th July 2009, Zimmerwald was the first European station which successfully sent laser pulses to the Lunar Reconnaissance Orbiter

(LRO). 5 years later, another remarkable success was reported by the ILRS, namely the first simultaneous ranging to LRO between a European (Zimmerwald) and an American station (Greenbelt) on 15th September 2014. Since summer 2010 the complete GLONASS constellation is ranged from Zimmerwald. On March 2012 the Graz and Zimmerwald SLR stations successfully conducted the first ever so called 'bistatic' laser ranging to a non-cooperative target. On 28th March 2012 the Zimmerwald SLR station for the very first time successfully detected and time-tagged photons sent by a powerful laser at the Graz SLR station and diffusely reflected by the body of the European ENVISAT spacecraft. About one year later (18th June 2013) photons reflected by a space debris object (upper stage CZ-2C) with a considerably smaller cross section than ENVISAT could be detected.

	1996-2008	Since 2008
Laser		
Type	Titanium-Sapphire	Nd:YAG
Manufacturer / Model	Thales	Thales
Wavelength	423 & 846 nm	532 nm
Frequency	10 Hz	100 Hz
Pulse Energy	100 mJ @ 846 nm 40 mJ @ 423 nm	24 mJ @ 1064 nm 10 mJ @ 532 nm
Pulse Width	100 ps @ 423 nm	58 ps @ 532 nm
Echo detection		
Type	PMT / CSPAD	CSPAD
Time of Flight	Interval counter (Stanford)	Event timer (Riga)
Epoch Timing	Quartz controlled by GPS	Quartz controlled by GPS

Table 2: Laser and receiver systems used at the 1 m ZIMLAT telescope (since 1996)

Since 2006 Zimmerwald is one of the 4 most productive stations worldwide in terms of number of observed satellite passes and delivered normal points. Thanks to the steadily increasing automation of the observations the number of passes raised from about 100 passes per month in 1998 up to more than 1000 passes in 2014.

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