Section 8:

ILRS Network

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Overview

The ILRS coordinates activities for an international network of Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) stations. The network represents a global consortium of stations that range to ILRS-approved targets for science and engineering applications. The stations are required to follow established ILRS policies and procedures, including maintenance of system site logs and adherence to tracking priorities and restrictions. To facilitate operations and communications, the network is divided into sub-networks by generalized geographic region:

- European Laser (EUROLAS) network
- National Aeronautics and Space Administration (NASA) network
- Western Pacific Laser Tracking Network (WPLTN)

LLR is currently performed at stations in Grasse/France, Matera/Italy, Wettzell/Germany, and Apache Point NM/USA.

Although the general configuration of the ranging stations is similar, they have been developed by different institutions over time, and represent different approaches in technology, operation, and maintenance. ILRS network systems range from legacy technology long proven through many years of operation to newer technologies with enhanced capability.

The ILRS itself does not fund the establishment or operation of ranging stations. Stations are typically associated with a host nation space or scientific research program, and are frequently located adjacent to other observatory or measurement systems.

Laser ranging stations may be a member of the ILRS network as an operational station providing data are submitted in the proper format and are of sufficient data quality to achieve IAG related objectives. Engineering stations are those that perform engineering or development work that may be of interest to the ILRS in its IAG or other science or engineering activities, or if the station is in process with the objective of supporting the ILRS in its IAG or other science objectives.

Stations must adhere to the ILRS guidelines and follow established procedures to maintain their operational status in the ILRS network. These guidelines were reviewed and documented on the ILRS website:

- Range to satellites that have been authorized by the ILRS and maintained on the ILRS website;
- Adhere to the ILRS restricted tracking procedures and only range to restricted missions when explicitly approved by the ILRS and the mission;
- Maintain site logs and configuration files, ensuring content is current;
- Maintain aircraft avoidance and other ILRS safety procedures;
- Adhere to the ILRS data product delivery requirements;
- Strive to produce the highest quality SLR measurement by:
    - Eliminating systematic errors;
    - Carrying out regular system delay calibrations;

- Regularly surveying the site reference markers and inter-technique site ties;
- Investigating and responding promptly to ILRS notifications and communications regarding data quality issues.

Stations in the ILRS network may support other science and engineering activities, but must adhere to the ILRS safety requirements above.

Stations in the ILRS Network

The stations in the ILRS network range to a constellation of approved satellites as approved by the ILRS Governing Board. Stations transmit their data on an hourly or daily basis to ILRS Operations Centers for final archive at the ILRS Data Centers. The tracking data produced by the ILRS network stations are regularly and continuously analyzed by the ILRS Analysis Centers to generate official ILRS products. The ILRS network during the 2016-2019 timeframe is shown in Figure 8-1; lists of stations (current, engineering, closed/inactive, and future) in the ILRS network are maintained on the ILRS website at: *https://ilrs.gsfc.nasa.gov/network/stations/index.html*.

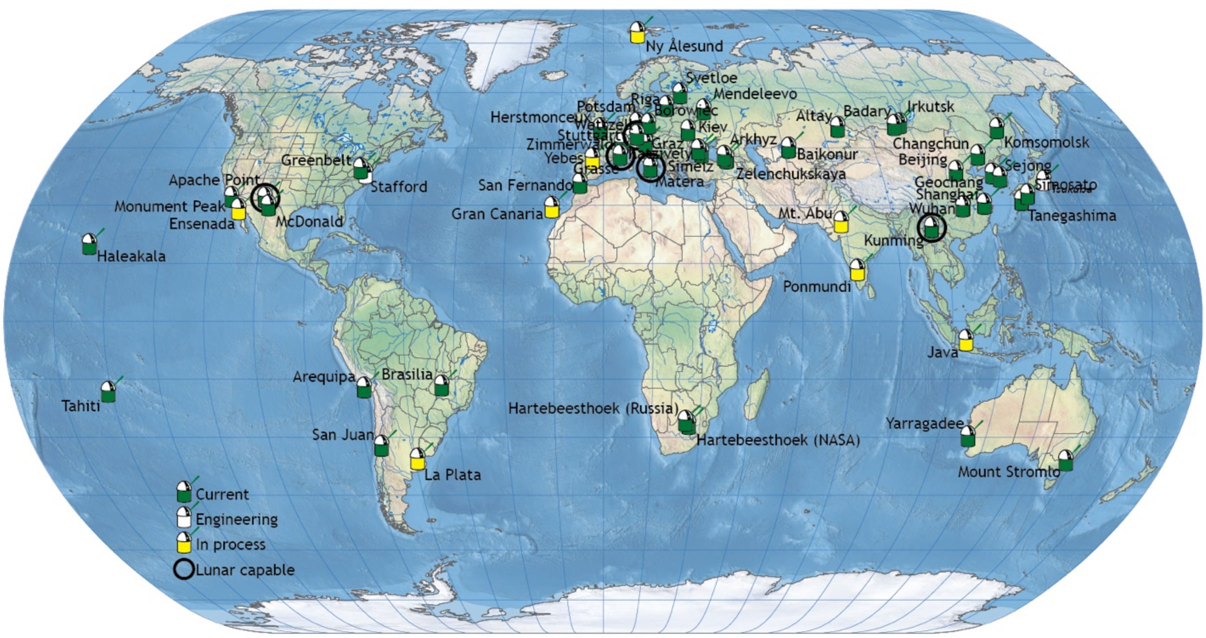

Figure 8-1. The ILRS network during the 2016-2019 timeframe.

During the 2016-2019 period, 43 stations regularly tracked 151 satellites, generating over 7.25M normal points from over 708K passes. Figure 8-2 and 8-3 plot the number of passes per station with the number of tracking days; Table 8-1 presents various tracking statistics for the reporting period. The geodetic satellites (i.e., LAGEOS and LARES) are a top priority for the network, however GNSS satellites are now playing a large role in SLR tracking.

As can be seen in these charts and table, there is a large divergence in the station performance across the ILRS network. In recent years, nearly half of the stations in the ILRS network achieved the 3500 passes/year minimum guideline. Low data yield in some cases has been due to station upgrades or technical issues, and thus the ILRS anticipates increased performance in the future. Unfortunately, stations with low performance levels contribute very little to the ILRS derived products which are incorporated into the ITRF.

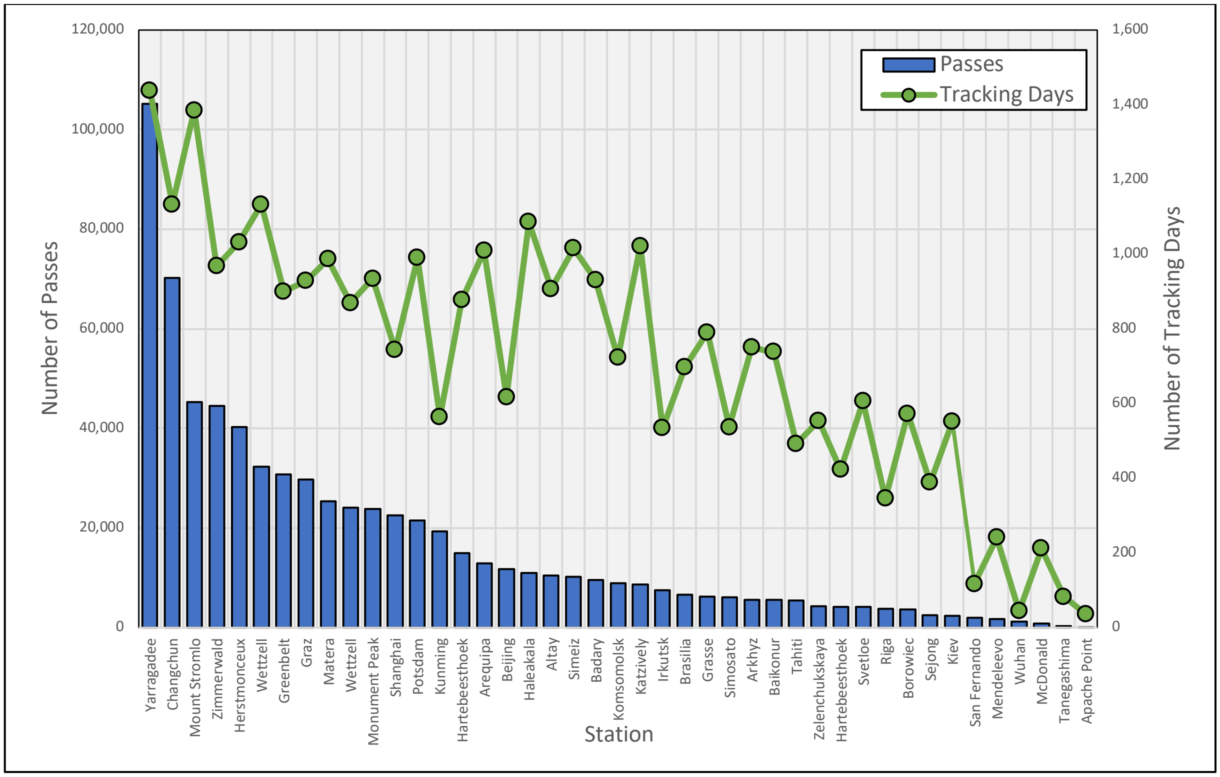

Figure 8-2. SLR pass and tracking days figures for 2016-2019.

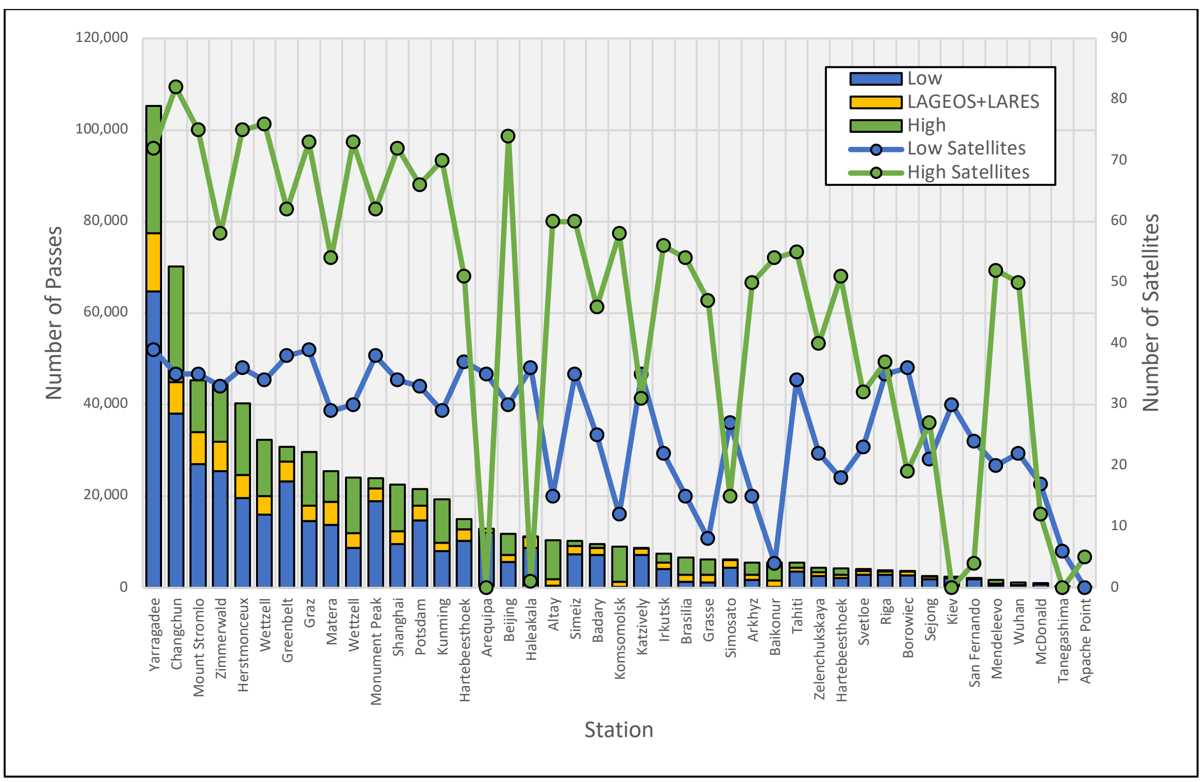

Figure 8-3. SLR pass total figures for 2016-2019.

Table 8-1. ILRS network pass totals (01-Jan-2016 through 31-Dec-2019)

Site Name	Sta.	Code	Start	End	Passes	NPTs	Satellites
Altay	1879	ALTL	160101	191228	10,415	44,440	78
Apache Point	7045	APOL	160103	161125	131	259	5
Arequipa	7403	AREL	160104	191231	12,892	129,109	38
Arkhyz	1886	ARKL	160111	191231	5,546	28,915	68
Badary	1890	BADL	160101	191226	9,541	80,406	74
Baikonur	1887	BAIL	160411	191224	5,538	21,857	61
Beijing	7249	BEIL	160301	191228	11,774	72,950	107
Borowiec	7811	BORL	160203	191231	3,674	55,615	58
Brasilia	7407	BRAL	160102	191230	6,613	23,708	72
Changchun	7237	CHAL	160101	191231	70,185	507,103	120
Golosiiv	1824	GLSL	160103	191220	2,444	19,889	33
Grasse	7845	GRSM	160107	191230	6,220	72,905	58
Graz	7839	GRZL	160101	191229	29,721	366,045	116
Greenbelt	7105	GODL	160104	191231	30,783	485,897	103
Haleakala	7119	HA4T	160101	191231	11,035	160,404	40
Hartebeesthoek (NASA)	7501	HARL	160105	191218	14,945	190,538	91
Hartebeesthoek (Sazhen-TM)	7503	HRTL	170324	191215	4,239	33,383	72
Herstmonceux	7840	HERL	160103	191230	40,312	371,437	114
Irkutsk	1891	IRKL	160122	191225	7,507	49,592	81
Katzively	1893	KTZL	160101	191230	8,679	89,754	69
Komsomolsk-na-Amure	1868	KOML	160101	191230	8,915	37,677	73
Kunming	7819	KUN2	170123	191230	19,290	131,094	102
Matera	7941	MATM	160101	191231	25,412	234,327	87
McDonald	7080	MDOL	160113	181026	885	6,064	32
Mendeleevo	1874	MDVS	160121	191125	1,773	18,710	75
Monument Peak	7110	MONL	160108	191231	23,897	366,779	103
Mount Stromlo	7825	STL3	160101	191231	45,244	467,322	113
Potsdam	7841	POT3	160103	191230	21,506	274,190	103
Riga	1884	RIGL	160404	191219	3,794	60,417	76
San Fernando	7824	SFEL	160108	191230	2,049	19,502	31
Sejong	7394	SEJL	160111	191125	2,499	29,785	52
Shanghai	7821	SHA2	160102	191231	22,565	149,558	109
Simeiz	1873	SIML	160111	191228	10,184	95,602	98
Simosato	7838	SISL	160104	191225	6,100	91,488	45
Svetloe	1888	SVEL	160101	191231	4,125	30,292	58
Tahiti	7124	THTL	160113	190530	5,451	71,975	92
Tanegashima	7358	GMSL	160419	191212	361	2,616	9
Wettzell (SOS-W)	7827	SOSW	160108	191230	24,094	151,047	106
Wettzell (WLRS)	8834	WETL	160102	191230	32,346	221,556	113
Wuhan	7396	JFNL	180929	191213	1,169	7,228	75
Yarragadee	7090	YARL	160101	191231	105,230	1,406,264	114
Zelenchukskaya	1889	ZELL	160102	190726	4,364	32,167	65
Zimmerwald	7810	ZIML	160321	191231	44,549	540,432	95
Totals	43 sta.				707,996	7,250,298	151

An Eye to the Future of the ILRS Network

The many new SLR systems in process and undergoing upgrade will significantly enhance the productivity and geographical coverage of the ILRS network. New and upgraded systems typically include higher repetition rates, increased accuracy, more automation, and state-of-the-art electronics and signal detection. Some of the recently reported network developments include:

- The BKG SLR system from Concepción has been relocated to La Plata, Argentina, and is being upgraded as part of the new Argentine-German Geodetic Observatory (AGGO) Core site. The SLR is going through its final stages of setup and is expected to be operational by late 2020 or early 2021.
- The National Astronomical Observatories of China (NAOC), Chinese Academy of Sciences (CAS) is upgrading their system in San Juan, Argentina in cooperation with the Felix Aguilar Astronomical Observatory, San Juan National University; the system is scheduled to be back in operation by early 2021.
- The Finnish Geospatial Research Institute, National Land Survey (FGI) is constructing a new SLR system at the Metsähovi Geodetic Research Station; the system is scheduled to be in operation in early 2021 as a future GGOS Core Site.
- NASA is building new generation SLR systems for deployment at: (1) Ny Ålesund, Norway (with the Norwegian Mapping Authority) a part of the new Ny Ålesund Core Site, (2) McDonald Observatory in Texas as part of the new McDonald Core Site, and (3) Hawaii as part of the Hawaii Core Site. Installations are planned for staging over the next five to six years.
- The ROSCOSMOS network is planning new systems in Ensenada, Mexico; Grand Canaria, Spain; Java, Indonesia; and other possible sites; these will be the new Tochka systems; deployment is planned over the next five to six years.
- ISRO is building new SLR stations in Mt. Abu and Ponmundi in India; these stations are planned for operation by 2022.
- The Yebes Observatory (IGN, National Geographic Institute) is designing and building the Yebes LAser RAnging (YLARA) Station. The location has been selected and work is underway. First light is expected in 2023 and routine operations in the 2024 timeframe. The site will join the two VLBI antennas, GNSS receiver, and gravimetry techniques, also operational in site, to form a Core station.
- The Geospatial Information Authority of Japan (GSI) is planning a new station for Tsukuba, Japan, in close proximity to the new VLBI station in Ishioka.

With these activities underway, the ILRS anticipates considerable improvement in network data quantity, quality and geographic coverage over the next 5 to 6 years.

ILRS Station Reports

Altay, Russia

Author: *Natalia Parkhomenko*
Responsible JC "RPC "PSI"

System: ALTL/1879
Location: Altay Territory, t. Zmeinogorsk, Russia
Latitude: 51.2°N, Longitude: 82.3°E, Elevation: 270m

Station Operations

The Altay station (ALTL/1879) is housed in the Altay Optic-Laser Center (AOLC), 300 km southwest of the city of Barnaul, 20 km to the north of town Zmeinogorsk. The NOLS TTI SLR station started operations on September 15, 2004.

Station staff strives to work on a 12/7 basis, focusing as a first priority on targets of Russian interest (e.g., GLONASS, photometry) and then on the ILRS priority list.

Figure 8-4. Location of facilities in Altay, Russia.

Figure 8-5. SLR system at Altay, Russia.

System Improvements

- Completed work to optimize algorithms and software related to the search and tracking of satellites, as well as the detection of a signal reflected from the LRA on the satellite.
- Developed and implemented a program for visualization/display of spacecraft flight paths.
- Modified the Diaphragm Switching Unit to increase the wear resistance of the field diaphragm positioning mechanism.

Current Challenges and Future Plans

Any problems with hardware and software are resolved quickly through remote consultations, and, if necessary, a specialist from PSI can visit the SLR station.

Future plans to improve the Altay SLR system include:

- Development and implementation of digital cameras with a permeability of at least 12 magnitude to replace the TV cameras that have outlived their life.
- Development and implementation of a laser with a pulse duration of not more than 60 ps.
- Development of software for calculating normal points directly at the station in order to reduce data access time for users.

Station Personnel

- Person 1: Manager of the NOLS TTI system
- Person 2: NOLS TTI operator
- Person 3: NOLS TTI operator
- Person 4: NOLS TTI operator

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Arequipa, Peru

Author: *Raul Yanyachi/Universidad Nacional de San Agustín de Arequipa*
Responsible Agency: Universidad Nacional de San Agustín de Arequipa

System: AREL/7403
Location: Observatory of Characato at University San Agustin, Arequipa
Latitude: 16.4657° S, Longitude: 71.4930° W, Elevation: 2489.05 m

Station Overview

Figure 8-6. TLRS-3 NASA station in Arequipa, with DORIS antenna in foreground and the Chachani and Misti volcanoes in the background.

The TLRS-3 NASA station is located in the Observatory of Characato at University San Agustin, Arequipa, Peru. The station continued operations during 2017 and 2018.

Figure 8-7. Panoramic views of the Arequipa site.

Station Operations

In 2017, Arequipa performed with three-shift operations (24 hours) for five days a week; a fourth shift during weekend nights (12 hours coverage) began in April 2018.

TLRS-3 tracks low orbiting satellites during the day and night with good results. Mid-altitude orbiting satellites such as LAGEOS-1 and -2 have better results during nighttime operations. TLRS-3 does not track high orbiting satellites. Figures 8-8 and 8-9 below show normal point and pass totals for 2017 and 2018.

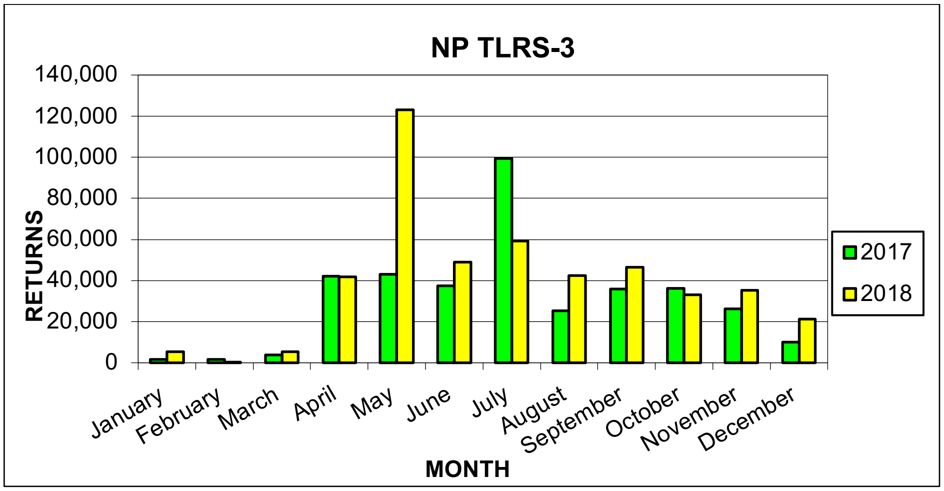

Figure 8-8. TLRS-3 normal point statistics for 2017 and 2018.

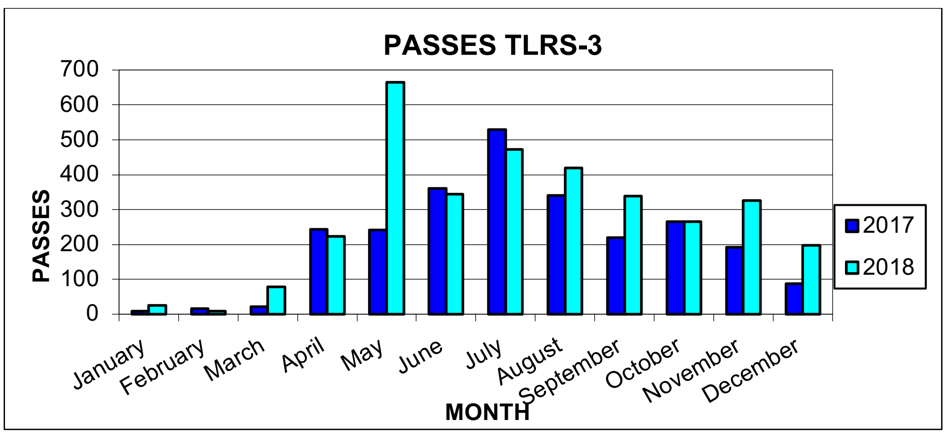

Figure 8-9. TLRS-3 pass statistics for 2017 and 2018.

System Improvements

The staff performed some important changes to the system in 2016:

- Replaced two motors in the mount (one for azimuth and other for elevation)
- Upgraded the RCC
- Removed time code generator
- Added new event timer
- Installed new MET-4

At the end of 2016, NASA engineers replaced the old T/R switch with a static T/R switch and installed a new scope. During 2017 and 2018, the system tracked LAGEOS-1 and -2 to validate the event timer installation.

Significant Events

In 2016, David McCormick, the NASA SLR Manager, and Claudia Carabajal from GSFC visited Arequipa to meet UNSA's new administration staff and discuss the continued operations of the TLRS-3 station.

During the 2016-2018 time period, the station commemorated the "Day of Astronomy" with an "Open Door" visit to the Observatory, welcoming visits from students and neighbors. The station staff participated in events related to the lunar eclipse in January 2019, sponsoring several courses at IAAPP and the station, covering such topics as space geodesy techniques, use of cluster, processing satellite imagery, GAMIT software use, and others.

Figure 8-10. UNSA Rector, David McCormick, and Claudia Carabajal during a site visit in 2016.

On April 29, 2019 Stephen Merkowitz, Rivers Lamb, and Claudia Carabajal visited the station and UNSA to discuss with UNSA's authorities the terms for renewing the agreement between their institutions for an additional five years. They signed a letter of intention, which will be validated with a new agreement. Merkowitz, Raul Yanyachi, and Carabajal gave several presentations ("NASA Space Geodesy Project", "Observatory the Characato Activities", and "ICESat-2 Mission") in the UNSA Paraninfo (Figure 8-11). Merkowitz also participated in interviews with local TV, radio, and newspapers (Figure 8-12).

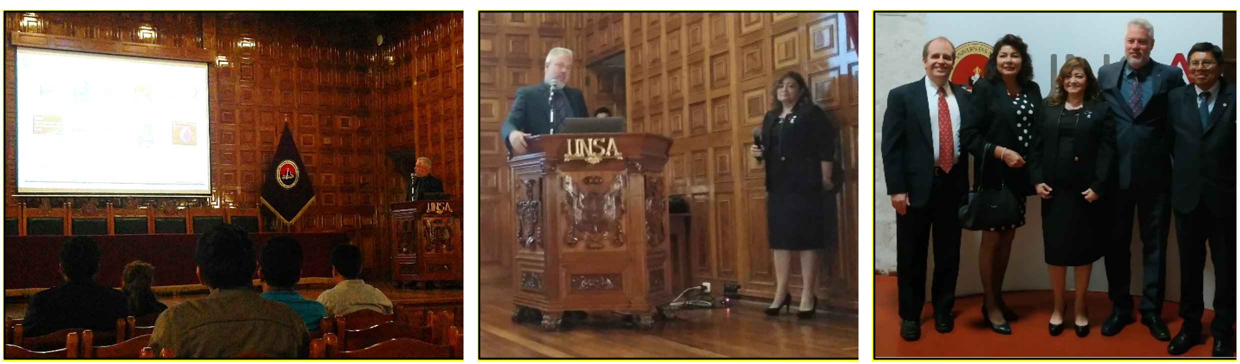

Figure 8-11. Stephen Merkowitz, Claudia Carabajal, and Raul Yanyachi during the presentation at UNSA Paraninfo in April 2019.

Many visitors from local schools and universities toured the TLRS-3, with presentations by station personnel.

Figure 8-12. Rivers Lamb and Stephen Merkowitz during their interviews in Arequipa in April 2019.

Co-located Systems

UNAVCO provided a new GNSS choke ring antenna in April 2018 that is connected to the JAVAD GPS/GNSS receiver, as well as a new UPS for the equipment.

Figure 8-12. GNSS antenna installation at site.

IGN/CNES sent a new GNSS receiver (Polar 5x Septentrio) to support their REGINA project. In addition, IGN and CNES provided new equipment and a backup battery for the DORIS installation at Arequipa.

UNSA continued to host the Cluster SGI in the dark room of SAO-2 building office. The IAAPP-UNSA continued maintenance of the SAO-2 building at the station which is equipped with computers for use as a classroom and data processing center, a communication room equipped with VNA, spectrum analyzer, and signal generator for measuring antenna parameters and performing general training. A new air conditioner and network equipment were also installed in this building.

Personnel

The crew at TLRS-3 consists of:

- Dr. Raul Yanyachi, station manager
- Jorge Valverde, Manuel Yanyachi (until 2017), Mariano Gomez, senior observers
- Marco Higueras, Kevynn Rodriguez, associate senior observers (since 2018)
- Alex Sanabria, junior observer
- Christian Levita (since 2017) and Julver Galindo (since 2018), training observers
- Janet Caceres, administrative assistant
- Wilberto Cañari, maintenance assistant

Figure 8-14. TLRS-3 personnel with David McCormick/NASA (2016).

Figure 8-15. TLRS-3 personnel with Rivers Lamb/NASA (2019).

Current Challenges and Future Plans

The staff plans to implement a 10pps tracking capability and start processing GNSS and SLR data with a new scientific software package.

Contacts

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Arkhyz, Russia

Author: *Natalia Parkhomenko*
Responsible JC "RPC "PSI"

System: ARKL/1886
Location: Arkhyz vil., Karachay-Cherkess Republic, Russia
Latitude: 43.6500°N, Longitude: 41.4333°E, Elevation: 2077m

Station Operations

The Arkhyz station (ARKL/1886) is housed in the Northern Caucasus. The Sazhen-TM SLR station started operations in 2006.

Station staff strives to work on a 12/7 basis, focusing as a first priority on targets of Russian interest (e.g., GLONASS) and then on the ILRS priority list.

Figure 8-16. Left to right: Old and new Sazhen-TM systems located at Arkhyz, Russia.

System Improvements

- Developed and implemented a program for visualization/display of spacecraft flight paths.
- Modified the diaphragm switching unit to increase the wear resistance of the field diaphragm positioning mechanism.
- Installed and tested the second Sazhen-TM SLR system.

Current Challenges and Future Plans

Any problems with hardware and software are resolved quickly through remote consultations, and, if necessary, a specialist from PSI can visit the SLR station. There is no laser for the second Sazhen-TM system.

Future plans to improve the Arkhyz SLR system include:

- Development and implementation of digital cameras with a permeability of at least 12 magnitude to replace the TV cameras that have outlived their life.
- Development and implementation of a laser with a pulse duration of not more than 60 ps.
- Development of software for calculating normal points directly at the station in order to reduce data access time for users.

Station Personnel

- Person 1: Manager of the Sazhen-TM system
- Person 2: Sazhen-TM operator
- Person 3: Sazhen-TM operator

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Badary, Russia

Authors: *Iskander Gayazov, Viktor Mitryaev*
Responsible Agency: Institute of Applied Astronomy (IAA RAS)

System: BADL/1890
Location: Republic of Buryatia, Russian Federation
Latitude: 51.7700°N, Longitude: 102.2354°E, Elevation: 803 m

Station Operations

The Badary SLR station (BADL/1890) is located in Badary (Republic of Buryatia, Russian Federation) at one of three observatories in the "Quasar-KVO" VLBI network. The observatory is a co-location site with two radio telescopes (RT-32 and RT-13), "Sazhen-TM" SLR system, GNSS receiver, DORIS antenna, and water vapor radiometer. The SLR system has day and night cameras and a holographic filter (0,1 nm bandpass) which allows for all day operations. In spite of a relatively small aperture telescope (25 cm) and low pulse energy (2,5 mJ), the laser system is capable of conducting observations of satellites with orbits up to 40000 km.

Figure 8-17. "Sazhen-TM" SLR system (left) and the laboratory equipment of the laser system (right).

Figure 8-18. GNSS antenna, DORIS antenna and RT-32 radiotelescope.

System Improvements

In 2018, new star calibration software was installed at the station. This software allows the staff to make angular corrections automatically and improves tracking capabilities enormously, especially in the daytime.

Current Challenges and Future Plans

The main problem is the obsolescence of the laser emitter of the system. This leads to the need to repair the laser every few years. The current laser has a pulse width worse than 300 ps. This is the main reason for the current level of single shot RMS (3-4 cm). The main task for the future is to modernize the system and improve the RMS up to 1 cm. To reach this goal, a replacement of the laser with new equipment is in planning stages, which has a ~50 ps pulse width. The next step is to replace the time interval counter and to increase the repetition rate from 300 Hz up to 600 Hz. These plans are expected to be implemented after 2020.

Station Personnel

The laser system at the observatory is maintained by a staff of operators, who work in shifts (two operators per shift). All operators are capable to carry out both VLBI and SLR observations even if they occur at the same time. The observation results are sent via network transmission to the processing center at IAA (Saint-Petersburg). There, the data are processed and sent to EDC and other users. Repairs of the system and overall operation are conducted by the lead engineer Viktor Mitryaev.

The station operators are as follows:

- Anna Zhiritskaya
- Olesya Alakova
- Veronika Lysakova
- Oksana Plotnikova
- Olga Slepkova
- Dmitry Zadrutski
- Tatiana Kotlova
- Aleksander Sorokovikov

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Baikonur, Kazakhstan

Author: *Natalia Parkhomenko*
Responsible JC "RPC "PSI"

System: BAIL/1887
Location: Baikonur, Kyzylorda region, Kazakhstan
Latitude: 45.7046°N, Longitude: 63.3422°E, Elevation: 98.3m

Station Operations

The Baikonur SLR system is located in the territory of the Baikonur cosmodrome. The Sazhen-TOS station started operations in 2006.

Station staff strives to work on 8/7 basis, focusing as a first priority on targets of Russian interest (e.g., GLONASS) and then on the ILRS priority list.

Figure 8-19. SLR system located in Baikonur, Kazakhstan.

System Improvements

- Developed and implemented a program for visualization/display of spacecraft flight paths.
- Modified the Diaphragm Switching Unit to increase the wear resistance of the field diaphragm positioning mechanism.

Current Challenges and Future Plans

Any problems with hardware and software are resolved quickly through remote consultations, and, if necessary, a specialist from PSI can visit the SLR station.

Future plans to improve the SLR system Baikonur:

- Development and implementation of digital cameras with a permeability of at least 12 magnitude to replace the TV cameras that have outlived their life.
- Development and implementation of a laser with a pulse duration of not more than 60 ps.
- Development of software for calculating normal points directly at the station in order to reduce data access time for users.

Station Personnel

- Person 1: Manager of the Sazhen-TOS system
- Person 2: Sazhen-TOS operator
- Person 3: Sazhen-TOS operator

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Borowiec, Poland

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Responsible Agency: Centrum Badań Kosmicznych Polskiej Akademii Nauk (CBK PAN) – Space Research Centre of the Polish Academy of Sciences (SRC PAS)

System: BORL/7811
Location: Astrogeodynamic Observatory Borowiec
Latitude: 52.2770° N, Longitude: 17.0746° E, Elevation: 123.4 m

Station Operations

The SLR station in Borowiec (site acronym BORL, station number 7811) is an active station in the ILRS network, located near Poznan, Poland. The station performs nighttime tracking all-year round including weekends.

Figure 8-20. The Borowiec system building.

System Improvements

Recent system developments at Borowiec include:

- Observations of active satellites (LEO-MEO regime) and space debris (including cooperative and uncooperative targets) from LEO regime by means of two independent laser modules (ps and ns)
- ADS-B monitoring
- Additionally, new format of laser data TDM (Tracking Data Message, recommended standard CCSDS 503.0-B-1, *https://public.ccsds.org/Pubs/503x0b1c1.pdf*)

The main problems for the system are the limited range of measurements (up to 23000km) and the inability to perform daylight tracking.

Current Challenges and Future Plans

The current technical challenges and future plans for the station over the next two years include:

- Day tracking (2020)
- Tracking 24/7 (2020)
- Installation of event timer (2019)
- Measurements in the range from 300 up to 40000km (2019)
- New detection system (2020)

Station Personnel

The Borowiec station staff members are as follows:

- Dr. Paweł Lejba, manager
- Dr. Eng. Tomasz Suchodolski, main engineer
- MSc. Piotr Michałek, technician-observer
- Stanisław Zapaśnik, technician-observer
- MSc. Jacek Bartoszak, supporting technician
- Prof. Stanisław Schillak, supporting mentor

Figure 8-20. Borowiec station staff (left to right): Pawel Lejba, Tomasz Suchodolski, Jacek Bartoszak, Piotr Michalek, Stanislaw Zapasnik.

Contact

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Brasilia, Brazil

Authors: *Natalia Parkhomenko, Geovany A. Borges, Renato A. Borges*
Responsible JC "RPC "PSI"/University of Brasilia (UnB)

System: BRAL/7407
Location: Brasilia, Brazil
Latitude: 15.7731°S, Longitude: 47.8653°W, Elevation: 1029.24m

Station Operations

The Brasilia station (BRAL/7407), a Russian Sazhen-TM SLR system, is located at the Campus Universitário Darcy Ribeiro, Asa Norte, Brasilia-DF, CEP: 70.910-900, Brazil. The construction of the Sazhen-TM station started during 2014 and the first ranging session took place in May 2014. In August 2018, the International Laser Ranging Service (ILRS) accepted the station as a contributing system to the ILRS network.

The station staff strives to work on a 24/7 basis, focusing, as a first priority, on targets of Russian interest (e.g., GLONASS) followed by satellites on the ILRS priority list.

Figure 8-22. SLR system in Brasilia, Brazil.

System Improvements

Work was done to optimize software algorithms related to the search and tracking of spacecraft, the detection of a signal reflected from the spacecraft, as well as for visualization/display of spacecraft flight paths.

Current Challenges and Future Plans

Various system hardware issues were experienced along these years of operation, negatively impacting the data yield. Nevertheless, these problems have been solved ensuring the station is in excellent working order with a high level of functionality.

Some future plans include:

- Improvement of the system of drying of optical surfaces of lenses.
- Improvement of the diaphragm switching unit to improve the wear resistance of the field diaphragm positioning mechanism.
- Development and implementation of digital cameras with a permeability of at least 12 magnitude to replace the TV cameras that have outlived their life.
- Development and implementation of a laser with a pulse duration of no more than 60 ps.

Figure 8-23. SLR telescope and operations room at Brasilia, Brazil.

Station Personnel

- Geovany A. Borges: Coordinator of the Sazhen-TM system and group
- Renato A. Borges: Vice-Coordinator of the Sazhen-TM system and group
- Francisco Assis Lima: Sazhen-TM technical support
- Luis Fernando Dias Pinheiro Soares: Sazhen-TM operator
- Raniere Rodrigues de Oliveira: Sazhen-TM operator
- Rogério Rocha Peixoto: Sazhen-TM operator
- Justino Cardoso Mendonça: Sazhen-TM operator
- Carlos Antônio de Aquino Bezerra: Sazhen-TM operator
- Maria Eliene Ferreira Linhares Côrtes: Sazhen-TM operator
- Silvério Alan Lima da Silva: Sazhen-TM operator

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Changchun, China

Authors: *Han Xingwei, Dong Xue, Liang Zhipeng*
Responsible Agency: Changchun observatory of National Astronomical Observatory, Chinese Academy of Sciences

System: CHAL/7237
Location: JIngyuetan Park xishan Changchun, P.R. China
Latitude: 43.7905° N, Longitude: 125.4434° E, Elevation: 274.9 m

Station Operations

Hours of operation: Weekdays: 24 hours
Status of station: Operational

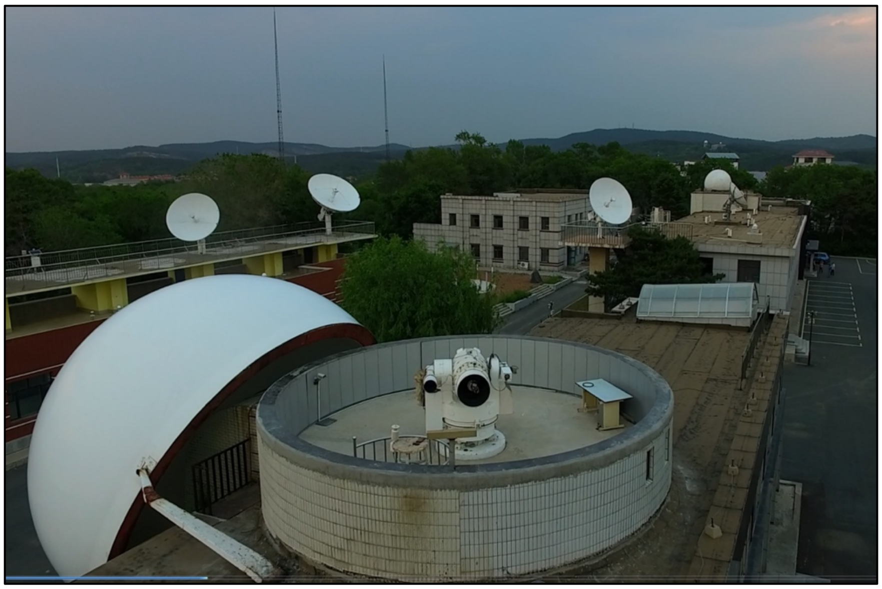

Figure 8-24. Changchun laser ranging station.

System Improvements

- Space debris laser ranging with a 60mJ @532nm/500Hz laser
- Improvement of daylight ranging to GNSS
- Improvement in data quality of Changchun high repetition rate laser ranging system
- A thermostatic housing for C-SPAD was installed to keep the temperature around detector stable, so as to avoid temperature drift effect for system delay.

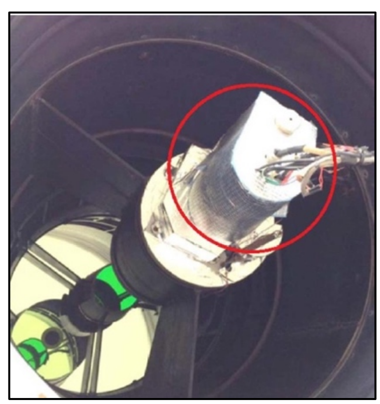

Figure 8-25. Thermostatic housing for C-SPAD.

Current Challenges and Future Plans

- Space debris laser ranging with 1064nm laser
- Light curve detection with SPAD detectors
- Improvement in data quality of Changchun
- Automation of the SLR observations

Station Personnel

- Fan Cunbo: Group leader, scientist
- Han Xingwei: Group leader, scientist, project management
- Dong Xue: Software, scientist, project management
- Song Qingli: Laser, engineer, station operations
- Liang Zhipeng: Engineer, scientist, data analysis
- An Ning: Engineer, scientist
- Wen Guanyu: Optics, scientist
- Gao Jian: Electronic, scientist
- Zhao Guohai: Mechanical, observations
- Zhang Haitao: Engineer, observations

Figure 8-26. Changchun SLR station staff.

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Email: *Dongx@cho.ac.cn*
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Geochang, Republic of Korea

Author: *Hyung-Chul Lim*
Responsible Agency: Korea Astronomy and Space Science Institute (KASI)

System: GEOL/7395
Location Mt. Gamak, Geochang-gun, Gyeongsangnam-do, Republic of Korea
Latitude: 35.5902° N, Longitude: 127.9201° E, Elevation: 934.063 m

Station Operations


Figure 8-27. Geochang SOLT station.

The Korea Astronomy and Space Science Institute has been developing the space optical and laser tracking (SOLT) system for space geodesy, space situational awareness, and Korean space missions. The SOLT system was established on Mt. Gamak at Geochang county, about 950 m high above sea level to improve the quality of satellite images achieved from the adaptive optics, which consists of satellite laser ranging (SLR), adaptive optics (AO), and debris laser tracking (DLT) systems. The SLR and AO system had been developed in the end of 2017 but the SLR system is still in the experimental stage due to the unstable laser system in terms of pulse energy. The DLT system is designed to provide angular measurements as well as range data of space debris because of the high tracking accuracy of the telescope, which is currently under development.

System Improvements

The Geochang system has the common coudé optical path using a 100 cm telescope, which is designed to be capable of laser ranging up to geosynchronous Earth orbit satellites with a laser retroreflector array, space objects imaging brighter than magnitude 10, and laser tracking low Earth orbit space debris of uncooperative targets. For the realization of multiple functions in a novel configuration, the Geochang system employs a switching mirror that is installed inside the telescope pedestal and feeds the beam path to each system (i.e., SLR, AO, and DLT).

The laser system consists of four modules: mode-locked laser oscillator, regenerative amplifier, power amplifier, and second harmonic generation. The laser has 15 mJ of pulse energy and 9 ps of pulse width. The laser beam size is expanded 21 times by two beam expanders in the transmitting optics and 3 times in the telescope. The clear apertures are 100 and 25 cm for the primary mirror and secondary mirror, respectively. The telescope focus is automatically controlled with 10 µm accuracy against the thermal expansion of telescope based on the temperature measurement of the optical tube assembly (OTA) and compensation by the primary/secondary mirror spacing. The tracking mount has a large hollow shaft for the optical beam path of 30 cm diameter, which is of the alt-azimuth type. It is required to be controlled fast and accurately to track LEO space debris, even at an altitude of 200 km. The tracking mount moves very fast with the slew rate of 30 degree/sec for azimuth and 15 degree/sec for elevation and acceleration of 10 degree/sec^2 for azimuth and 5 degree/sec^2 for elevation. To realize this requirement, two arc motors with a maximum torque of 3,900 Nm for azimuth and 1,068 Nm for elevation were specifically developed and implemented.

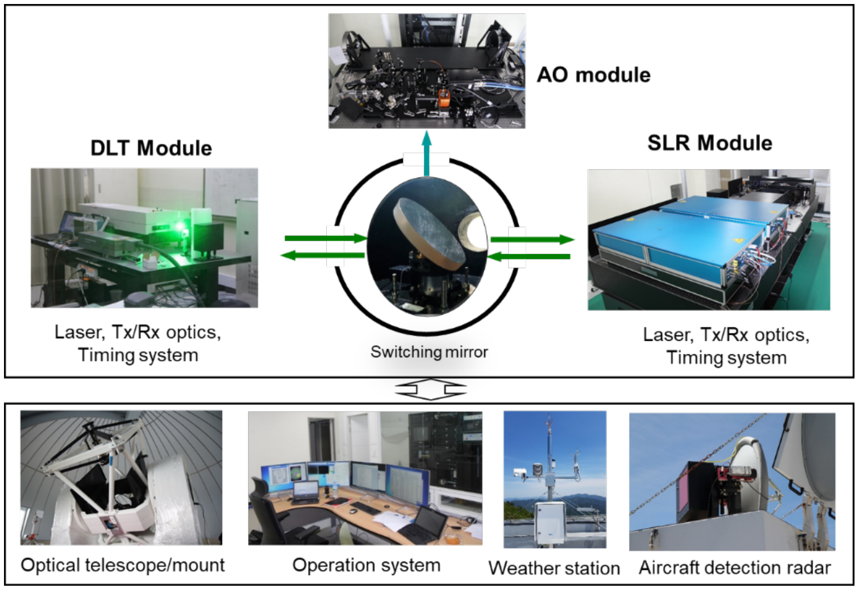

Figure 8-28. Configuration of the Geochang station.

Current Challenges and Future Plans

The single-shot precision of the Geochang SLR system was 3.6 mm for the ground target, 5.3 mm for the Starlette satellite, and 7.1 mm for the LAGEOS-2 satellite, on August 2018. But the SLR system has a fatal problem that the laser energy decreases rapidly as time goes on. After the problem is fixed, it is expected that the Geochang station plays an important role in Korean space missions as well as ILRS tracking network.

Station Personnel

- Mansoo Choi (Project Manager)
- Seung-Yeol Yu (Optical Engineer)
- Eunseo Park (Scientist of Data Processing)
- Ki-Pyoung Sung (Software Engineer)

Contact

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Golosiiv, Ukraine

Author: *Mykhaylo Medvedskyy*
Responsible Agency: Main Astronomical Observatory of NAS of Ukraine

System: GLSL/1824
Location: Kyiv, Ukraine
Latitude: 50.3633° N, Longitude: 30.4961° E, Elevation: 212.9 m

Station Operations

The station is located in Kiev on the Eurasian plate. Observations are carried out only in the nighttime during the year. The station was active during 2016-2019. In particular, during 2019, the station operated normally where a total of 878 successful observation sessions were performed, of which 72 were to the LAGEOS satellites.

System Improvements

The accuracy of a single measurement in the initial period was 8 cm. In 2018, a full upgrade of the station's hardware and the subsequent station software upgrade began and continued during 2019.

Hardware:

- Developed a time gate generator for the epoch timer with a time resolution of 40 ns, which includes:
  - GPS receiver + ATmega8
  - UTC clock with a scale resolution of 40 ns
  - Two frequency multipliers: input 5MHz, output 10MHz and 50 MHz + frequency distributors
  - 1pps generator
  - Time gate generator (40 ns step)
  - PC communication microcontroller using COM-port
  - High-speed START and STOP signal control logic
- Installed in the system event timer A033.
- Installed a fully upgraded dome control system (electric motor and control electronics).
- Fabricated and installed an automatic weather station into the system.
- Installed new rubidium frequency standard.
- Designed and created a lidar model, including software, based on a laser station. A distinctive feature is the ability to determine the intensity of the backscattering of a laser pulse at distances from some meters to tens of kilometers with the possibility of accumulating results. The spatial resolution is 15m.
- Developed a prototype of an automatic meteorological station with associated software. Characteristics of the developed meteorological station are as follows: measurement accuracy: temperature ± 0.2C, relative humidity ± 1%, atmospheric pressure ± 0.2MB; data update period 10 seconds.
- Automated the calibration process, which allowed to improve the stability and absolute accuracy of measurements.

Software:

- Created software to work with the new time gate generator and event timer A033. New software works under OS Windows. The whole complex includes 5 PCs, which are interconnected by a local network.
- Developed software for detecting aircraft using a sdr-rtl receiver. However, this software is not yet included in the station system.

The modernization made it possible to significantly reduce the time between the end of the observation and sending the results to the EDC. Now this time is a few minutes.

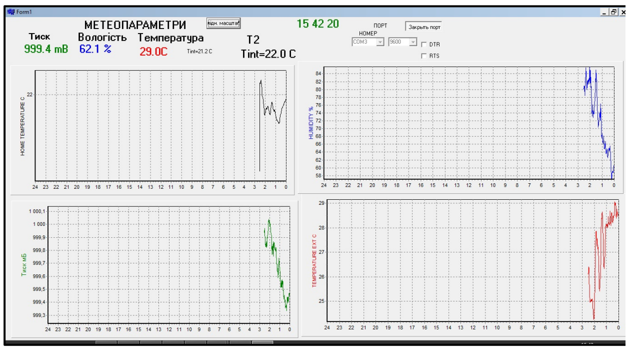

Figure 8-29. Golosiiv weather station screen.

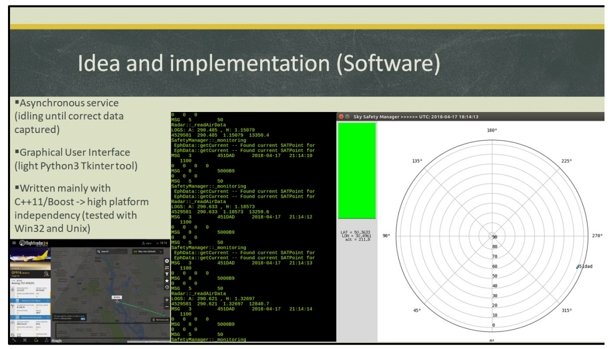

Figure 8-30. System screen shots showing recently developed software.

Main problems:

- Low measurement accuracy associated with the use of slow PMT.
- Poor quality mechanics of the telescope practically does not allow for the observation of invisible satellites.
- Poor quality of the telescope main mirror coating. There is no possibility to update the mirror coating.

Current Challenges and Future Plans

- Create new software for telescope control running Windows OS
- Design and manufacture a receiving channel using SPAD receivers
- Upgrade software that will allow observation of high satellites

Station Personnel

The Golosiiv station staff consists of three people:

- Mykhaylo Medvedskyy: Station management, development and manufacture of electronic modules, software development, including software for microcontrollers, making observations.
- Viktor Pap: Software development, making observations.
- Yurij Hluschenko: Development of electronic modules, making observations.

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Grasse, France

Authors: *Clément Courde, Julien Chabé, Hervé Mariey*
Responsible Agency: Observatoire de la Côte d'Azur (OCA)/CNRS-Geoazur

System: GRSM/7845
Location: Observatoire de la Côte d'Azur, 2130 Route de l'Observatoire, 06460 Caussols, FRANCE
Latitude: 43.7546° N, Longitude: 6.9216° E, Elevation: 1323.1 m

Station Operations

The Grasse MeO (GRSM 7845) SLR system is located in the Grasse highlands, on the Calern site of the Observatoire de la Côte d'Azur (OCA).

Figure 8-31. The Grasse laser ranging station.

The hours of operation at Grasse are 5 of 7 days per week, 24 hours per day (3 8-hour shifts): one operator during the day, one operator during the first part of the night, one operator during the second part of the night).

The Grasse SLR system operations are divided into four main tasks: maintenance, service, research and development, and SLR/LLR observations. The system's target priorities are as follow:

- LLR to the five retroreflectors on the Moon (Apollo II, 14, 15, and Luna 17, 21)
- Geodetics satellites (LAGEOS-1, -2, LARES, Stella, Ajisai, Etalon-1, -2)
- GNSS constellations (Galileo, GLONASS, Compass)

System Improvements

Highlights:

- Time Transfer by Laser Link (T2L2)
- IR detection for LLR observation
- Optical telecommunication (with CNES, NICT, NASA, DLR)
- Two-way laser ranging on LRO (NASA, OP-SYRTE)

System developments:

- High count rate laser ranging
- Improvement of the station settings with impact on the LLR results

Current Challenges and Future Plans

The strategy of the team is oriented over three main tasks:

- The improvement of the metrological performances of the instrument in order to reach a millimetric accuracy. Two technical challenges are led: the laser ranging at high repetition rate and at two colors in single photon mode; the development and the use of optical telecommunications for the geodesy and the time transfer.
- The automation of the SLR observations: aircraft safety, thermal imagery for the cloud cover.
- The support for the development of a new SLR station in Tahiti, French Polynesia.

Future plans:

- Participation in the ACES-ELT experiment.

Station Personnel

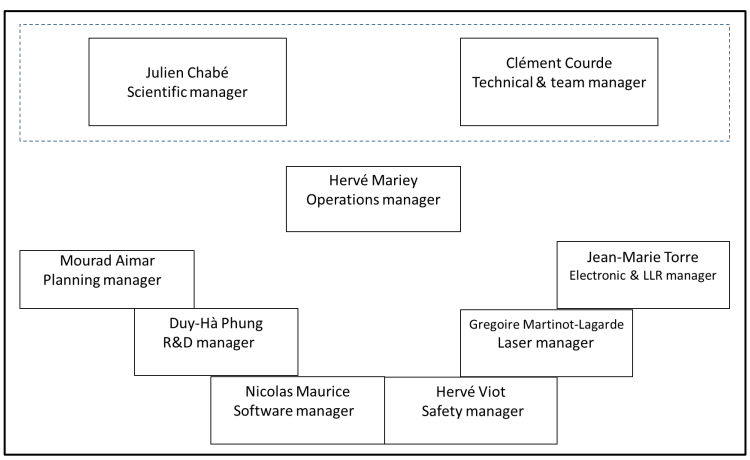

Figure 8-32. Station personnel supporting Grasse operations; staff also includes one non-permanent staff member, Julien Scariot.

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Graz, Austria

Author: *Michael Steindorfer*
Responsible Agency: Space Research Institute, Austrian Academy of Sciences

System: GRZL/7839
Location: Lustbühelstraße 46, 8042 Graz, Austria
Latitude: 47.0678° N, Longitude: 15.4942° E, Elevation: 495 m

Station Operations

Hours of operation: Weekdays: 24 hours
Status of station: Operational

Figure 8-33. Nighttime operations at the Graz Austria SLR station ranging.

System Improvements

- Space debris laser ranging
- Laser ranging up to geostationary orbit using a μJ laser
- Attitude determination of Galileo satellites
- Laser ranging without Coudé path
- Light curve detection with SPAD detectors
- Simultaneous space debris laser ranging and light curve detection to upper stage rocket bodies
- Stare and chase, pointing determination, orbit calculation and space debris laser ranging within one pass
- Design and development of laser package and detector package for ESA SLR station Tenerife

Current Challenges and Future Plans

- Space debris laser ranging during daylight
- MHz laser ranging
- ps laser ranging to space debris and cooperative targets, with one laser for both operation modes

Station Personnel

- Georg Kirchner: group leader, scientist, project management
- Michael Steindorfer: post-doc, scientist, project management
- Franz Koidl: engineer, scientist, station operations
- Peiyuan Wang: engineer, scientist, data analysis
- Reinhard Stieninger: engineer, daylight observations
- Christian Graf: daylight observations

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Greenbelt MD, USA

Author: *Maceo Blount*
Responsible Agency: NASA GSFC

System: GODL/7105
Location: Greenbelt, MD, USA
Latitude: 39.0206° N, Longitude: 76.82770° W, Elevation: 19.184 m

Figure 8-34. MOBLAS-7 located at GGAO in Greenbelt MD.

Station Operations

The MOBLAS-7 station is located at the Goddard Geophysical and Astronomical Observatory (GGAO), NASA GSFC in Greenbelt, Maryland. The station is operational, with three shifts, 24 hours a day, five days a week. The station staff also assists the NASA engineering section in testing and upgrades for the NASA SLR tracking network.

System Improvements

- Installed the event timer (ETM) into the system in July 2016 improving the RMS by 2mm; the rate was also increased on LAGEOS from 5pps to 10pps.
- Supported the testing/verification of additional ETM systems being implemented throughout the NASA network.
- Installed a modified Laser Ranging Control (LRC) board for 10pps tracking of HEO satellites.
- Upgraded the processor computer to CentOS 6 to comply with IT security standards.
- Installed the GLM Sacher laser and a fiber optic cable to track the GOES-16 and -17 satellites for the NOAA-NASA Geostationary Operation Environmental Satellite-R (GOES-R) Series Campaign in the fall of 2017 and 2018. MOBLAS-7 and MOBLAS-4 simultaneous tracked GOES-16 and -17; the mission gave both system certificates and accolades for an outstanding campaign.
- Modified the location and height of the MET-4 sensor in line with the telescope elevation and away from the trailer for accurate meteorological data.

- Completed harmonic drive modification/upgrade in the radar as part of a Laser Hazard Reduction System (LHRS) improvement. Additional processes and procedures were put in place to ensure the radar is always aligned with the telescope.

Current Challenges and Future Plans

MOBLAS-7 staff will continue to assist the engineering section in keeping the other stations in the NASA network operational until the SGSLR systems are deployed. The Greenbelt station also plans to enter into a new campaign for the GOES-16 and -17 satellites in the fall of 2019.

Challenges faced by the station are mainly due to the ability to maintain operability of obsolete parts and equipment; however sustaining engineering is taking on multiple efforts to procure, test, and evaluate replacement solutions, such as:

- Low signal loss and more durable PMT cables.
- Stanford Research Systems FS740 to replace the XL-DC.
- Laser Power Supply and Start Diode replacements.
- Improvement of heating, air, and ventilation system.
- Procurement of spare tachometer generator and brush-rings.

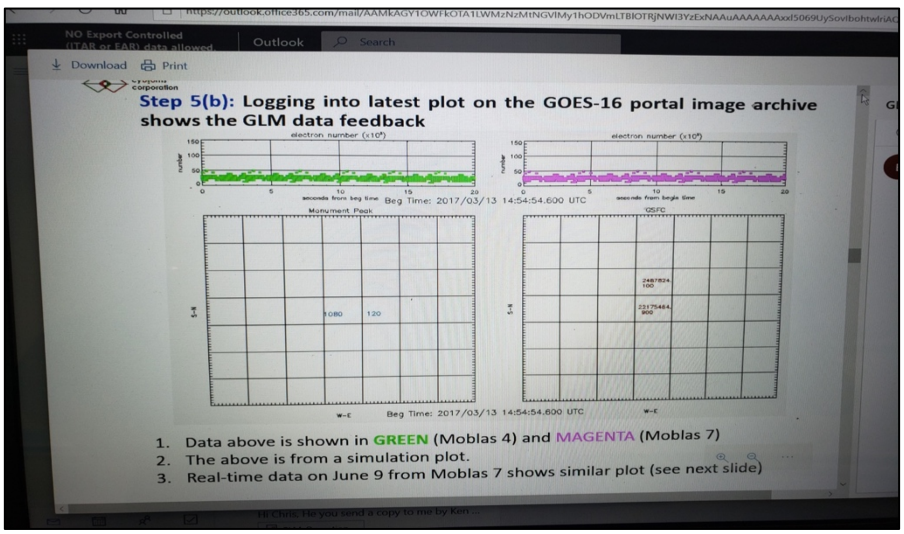

Figure 8-35. GLM support from the Greenbelt SLR station.

Station Personnel

Figure 8-36. MOBLAS-7 staff (left to right): Maceo Blount; Tushar Ulja, Paul Beckwith.

The crew members track over fifty satellites during operational shifts. In addition, they perform preventive and regular maintenance of the station during the work week. The station staff members are:

- Paul Beckwith, station operator
- Tushar Ujla, station operator
- Maceo Blount, station supervisor, operations, and engineering support team
- Ken Tribble, engineering technician/operator
- Dennis Chase, lead engineer
- Jason Laing, data operations lead
- Christopher Szwec, SLR project manager

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Haleakala HI, USA

Author: *Daniel O'Gara*
Responsible Agency: University of Hawai`i Institute for Astronomy

System: HA4T/7119
Location: Haleakala, Maui, HI, USA
Latitude: 20.7068° N, Longitude: 156.2568° W, Elevation: 3056.272 m

Station Operations

TLRS-4 is located near the summit of Haleakala on the island of Maui in the state of Hawai`i, USA. The TLRS-4 system is operated by the University of Hawai`i Institute for Astronomy under contract to NASA GSFC, and is part of the NASA Space Geodesy Network.

Tracking operations are scheduled seven days a week. There are two crews that each work 4x10 hour shifts per week for a total of eight shifts per week. Because TLRS-4 does not have an on-site radar, each crew is comprised of an observatory operator and a plane spotter. Shift start times are gradually moved over a four-week interval so that start times will move from 06:30 a.m. to 02:15 p.m. HST.

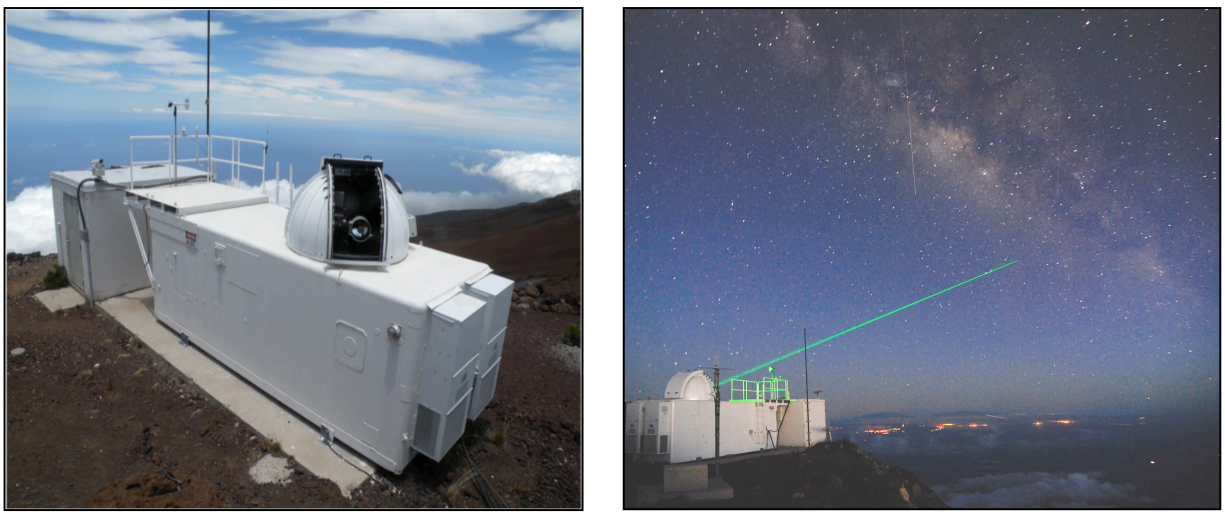

Figure 8-37. Photos of TLRS-4 system at Haleakala, HI.

System Improvements

- System accuracy was improved significantly over the last few years with the installation of a new time of flight measurement device. A Cybioms Event Timer replaced the HP5370B Time Interval Unit (TIU) on October 19, 2017. Calibration RMS improved from an average of 5.0 mm using the TIU to 2.6 mm using the Event Timer. LAGEOS-1/-2 RMS improved from an average of 10.8 mm to 8.6 mm. (See plots in Figure 8-38).
- The laser chiller was moved from inside TLRS-4 to an adjacent cinder block building, with operations restarting on June 7, 2017 after a one-day move and installation. Moving the chiller out of the TLRS-4 facility has helped us to maintain a stable interior temperature that has made for more stable laser operations. As a side benefit, the noise level inside the TLRS-4 trailer has been greatly reduced.

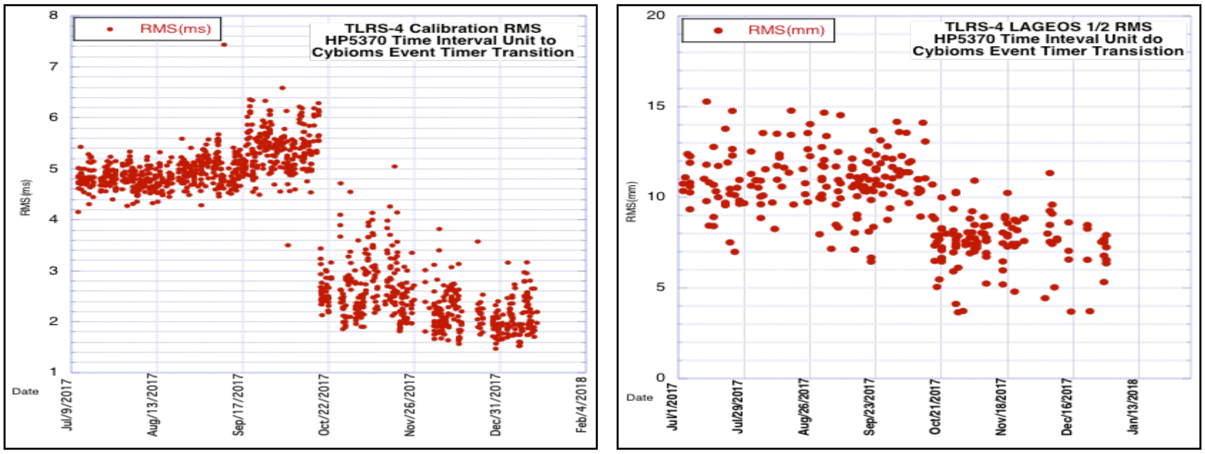

Figure 8-38. Improvements in TLRS-4 calibration and LAGEOS-1/-2 RMS after installation of event timer.

Current Challenges and Future Plans

Haleakala is planned to host an SGSLR station in the near future. To that end, multiple high performance GNSS receivers on Haleakala (and the VLBI station at Koke`e Park, Kauai) have been installed over the last two years in order to test precise site tie measurements between the two islands.

Station Personnel

Figure 8-39. Haleakala station personnel (left to right): Dan O'Gara, station manager/operations; Craig Foreman, laser technician/observatory foreman/operations; Jake Kamibayashi/electronics technician/operations; Rob Ratkowski, plane spotter/laser Ranging Safety; James Petruzzi, plane spotter/laser ranging safety.

Contact

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Website: *http://www.ifa.hawaii.edu/*

Hartebeesthoek, South Africa (MOBLAS-6)

Authors*: Willy Moralo, Roelf Botha*
Responsible Agency: SARAO/NASA GSFC/Peraton

System: HARL/7501
Location: Hartebeesthoek, South Africa
Latitude: 25.8897° S, Longitude: 27.6861° E, Elevation: 1406.822 m

Station Operations

The Hartebeesthoek (HARL 7501) NASA MOBLAS-6 system is located at the South African Radio Astronomy Observatory (SARAO), Hartebeesthoek facility, in near proximity to the 26-meter VLBI antenna, the HRAO GNSS reference station, and the Sazhen-TM SLR system. It has been in operation since 2000.

Station operation hours: 24hours 5 days a week and 16 hours 2 days a week.

System Improvements

Improvements:

- System slip rings replaced
- Timing system upgraded
- System air condition repaired
- System water chiller repaired

Problems:

- System radar has intermittent issues
- System MPACS (servo system is old and regularly causes problems)
- System will benefit from a better receive package (PMT tube)
- Day-time tracking is very difficult

Current Challenges and Future Plans

Current technical challenges:

- Servo system needs to be upgraded or charged for better pointing and accuracy
- Daylight tracking is almost impossible due to a poor receive package (low signal-to-noise ratio)
- System Radar need repairs
- System air conditioner are shutting down during hot summertime

Future plans for the station over the next two years,

- Upgrade servo system or replace them
- Negotiations are in process on how to improve our receive package (similar to MOBLAS-5)
- Peraton engineering personnel is visiting the station during July 2019
- Day-time camera upgrade planned
- Considering moving operations over to 24/7 pattern

Station Personnel

List of station personnel:

- Roelof Botha: Manager, Geodesy
- William Moralo: Operations supervisor
- Tshepo Makate: Technical operator
- Klaas Ramaoka: Technical operator
- Tshiamo Motlele: Technical operator

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Email: *willy@hartrao.ac.za*
Phone: +27 12 301 3100
Fax: +27 12 301 3300
Website: *http://www.hartrao.ac.za*

Hartebeesthoek, South Africa (Sazhen-TM)

Authors: *Roelf Botha, Andrey Pavlov*
Responsible Agency: JC "RPC "PSI"/SARAO Geodesy Programme

System: HRTL/7503
Location: Hartebeesthoek, South Africa
Latitude: 25.8892° S, Longitude: 27.6861° E, Elevation: 1413.999 m

Station Operations

The Hartebeesthoek HRTL 7503 station, a Russian Sazhen-TM SLR system, is located at the South African Radio Astronomy Observatory (SARAO), Hartebeesthoek facility, in near proximity to the 26-meter VLBI antenna, the HRAO GNSS reference station and the MOBLAS-6 SLR system (Figure 8-39). The construction of the Sazhen-TM station started in 2016 and first light was achieved on the evening of December 16, 2016. During 2017, the station started operations with a small staff complement and reached full operational status (with a full staff complement) by May 2018. On May 03, 2018 the ILRS accepted the station as a contributing system to the ILRS network.

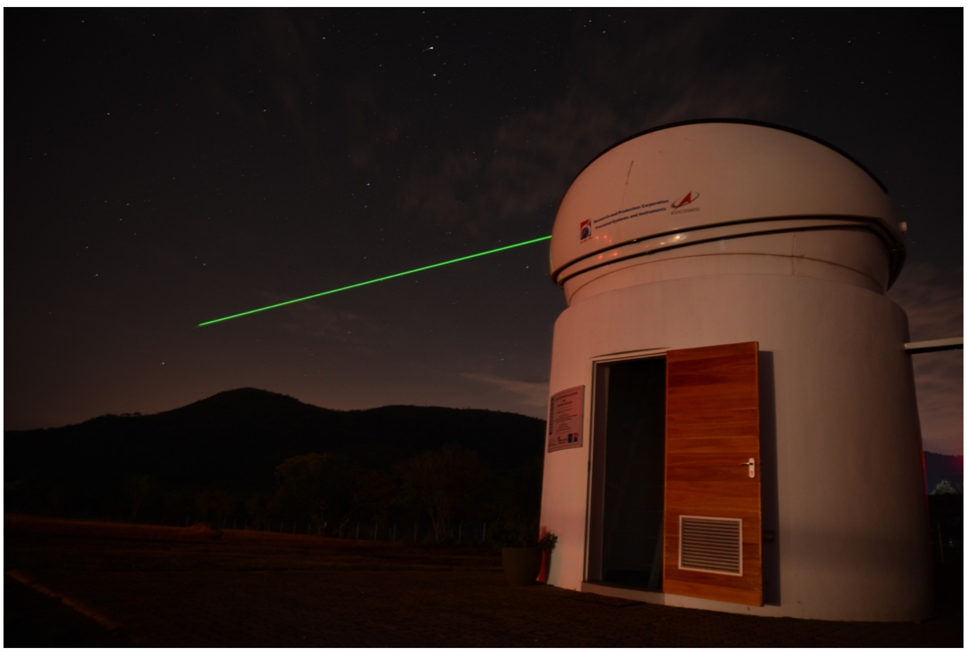

Figure 8-40: The Russian QOS "Sazhen-TM" in operation at the Hartebeesthoek facility of SARAO (photo credit: Jacoline Schoonees/DIRCO).

We endeavor to operate the station on a 24/7 basis, focusing as a first priority on targets of Russian interest (e.g., GLONASS) and then on the ILRS priority list.

System Improvements

Various system hardware issues were experienced from May through September 2018, negatively impacting the data yield. All problems were resolved by December 2018 and the station had a high level of functionality since that time. Regular software updates and improvements related to search, tracking and detection algorithms have been implemented.

Current Challenges and Future Plans

No serious technical challenges have been experienced and smaller issues are now usually resolved within a few days. We aim to have 24/7 operations until at least the end of 2020, without any major system or operational changes. Plans to improve the telescope dehumidification system by the end of 2019 are underway. The possibility of developing a new laser for QOS "Sazhen-TM" with a pulse duration of 45-60 ps (currently 300 ps) is currently under consideration.

Station Personnel

- Roelf Botha: Manager of the Sazhen-TM system and group
- Modibe Modiba: Sazhen-TM operator and team coordinator
- Caiphus Phale: Sazhen-TM operator
- Lionel Moralo: Sazhen-TM operator
- Adila Wamisho: Project PhD student and Sazhen-TM operator
- Vacant position: Sazhen-TM operator

Figure 8-41: The QOS "Sazhen-TM" team at Hartebeesthoek: (from left to right) Adila Wamisho, Caiphus Phale, Modibe Modiba and Lionel Moralo.

Contacts

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Address:	Farm 502JQ Hartebeesthoek	Fax:	+27 12 301 3300
	Krugersdorp	Website:	*http://www.hartrao.ac.za*
	SOUTH AFRICA		

Current Challenges and Future Plans

No serious technical challenges have been experienced and smaller issues are now usually resolved within a few days. We aim to have 24/7 operations until at least the end of 2020, without any major system or operational changes. Plans to improve the telescope dehumidification system by the end of 2019 are underway. The possibility of developing a new laser for QOS "Sazhen-TM" with a pulse duration of 45-60 ps (currently 300 ps) is currently under consideration.

Station Personnel

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- Lionel Moralo: Sazhen-TM operator
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Figure 8-41: The QOS "Sazhen-TM" team at Hartebeesthoek: (from left to right) Adila Wamisho, Caiphus Phale, Modibe Modiba and Lionel Moralo.

Contacts

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	Krugersdorp	Website:	*http://www.hartrao.ac.za*
	SOUTH AFRICA		

Herstmonceux, United Kingdom

Author: *Matthew Wilkinson, Robert Sherwood*
Responsible Agency: British Geological Survey

System: HERL/7840
Location: NERC Space Geodesy Facility, Herstmonceux, UK
Latitude: 50.8674° N, Longitude: 0.3361° E, Elevation: 75 m

Station Operations

The Space Geodesy Facility, Herstmonceux operates a prolific SLR system that is capable of supporting the full ILRS target list. The laser fires 1mJ, 10ps pulses at a rate of 1kHz, which are transferred to the emitter telescope through a coudé path of dielectric mirrors. The bi-static, azimuth-altitude, *Cassegrain, 50cm* telescope, tracks the target and directs the returning signal to a telescope-mounted SPAD detector. A narrowband filter is used to enable daytime observations and a variable neutral density filter is controlled to keep to low, single-photon levels of return rate. Two single-observer shifts are set every day, a day and a night duty, according to the satellite schedule. In-sky safety is ensured with an active radar, ADS-B tracking and the observer positioned alongside the telescope, all of which can inhibit the laser. The SGF also operates a number of GNSS receivers and absolute gravimeters.

Following a Strategic Review, NERC concluded that it shall continue to support the SGF and that it will be reclassified under the National Capability National Public Good funding stream from April 2018 and no longer be part of NERC's Services & Facilities portfolio. The SGF is now part of and managed by the British Geological Survey (BGS).

System Improvements

The performance of the kHz laser has been very good since the design upgrade in 2014, both in terms of energy output and reliability over time. This enabled routine high altitude GNSS satellite tracking in the day and fast inter-leaving between passes at night. Performance in the day was further boosted by the replacement of a daylight blocking filter in the receive path in 2015 and of the narrowband filter in 2018. However, the improvement from the new narrowband filter was not as great as expected and it is possible that the spectral laser line width is broader than this filter. The time required to produce a good normal point is significantly reduced with kHz, allowing for more frequent switching between satellite targets. An example plot showing this inter-leaving over two days is plotted right.

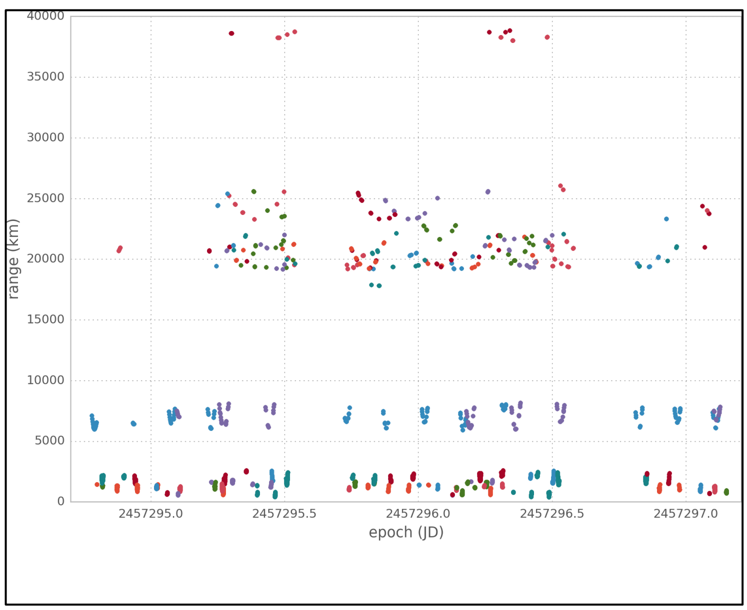

Figure 8-42. Pass interleaving using the kHz laser at Herstmonceux.

An A033-ET event timer from EvenTech was installed in 2014 to run in parallel with the HxET timer, which was constructed from two Thales Systems timing modules and a clock module. The new device is performing well and could become the future primary SLR timer. Using automatic, real-time track detection, the reduction method from this range data will be redeveloped for automation.

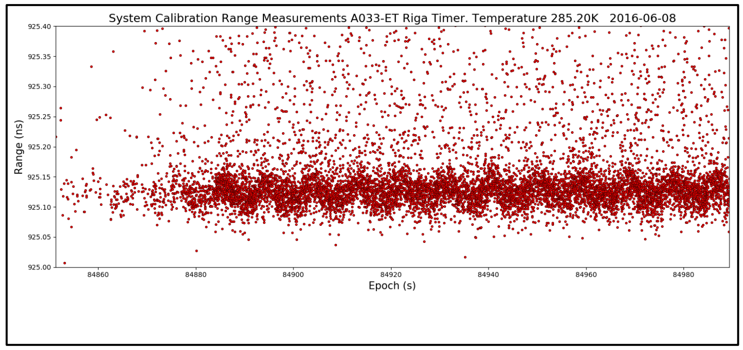

Figure 8-43. System calibration range measurements using A033-ET.

In 2016, a small, but visible, instability appeared in the laser range residuals, with an amplitude of approximately 1cm and a period of about 9 seconds, an example is plotted right. The source of this instability was found to be within the kHz laser itself. A service visit from the manufacturer was able to reduce this effect. The cause was later found to be a restricted flow of the cooling water through the laser bed, which required chemical cleaning.

In order to control the output polarization, a half-wave plate was placed outside the laser bed, which can be rotated using a stepper motor connected to a Raspberry Pi. By modelling the polarization orientation through the coudé path for all telescope positions, the linear polarized laser light can be fixed and switched by 90 degrees at the telescope emitter on command.

The SGF conducts regular height surveying using a Lecia DNA03 barcode level, with instrumental accuracy of 0.3mm. This is to assess the long-term stability of the SGF site and the stability of the inter-technique site ties. The results have shown good, sub-mm height stability and some variation at the ±1mm level in the monument for the HERS GNSS antenna. A site survey was carried out in 2017 to update the inter-technique site tie vectors between the telescope axis intersection invariant point and the reference markers on the SGF GNSS sites (HERS, HERT and HERO) and the absolute gravimeter floor studs. Included in the survey was the distance from the SLR telescope reference to the centre of retro-reflecting targets for terrestrial calibration of the SLR system delay. Agreement for this target was found at the polarization level with those from the previous survey carried out in 2008 by IGN. A newly constructed target pictured above right, with a well-defined reference point, was adopted as the primary SLR calibration target in 2018.

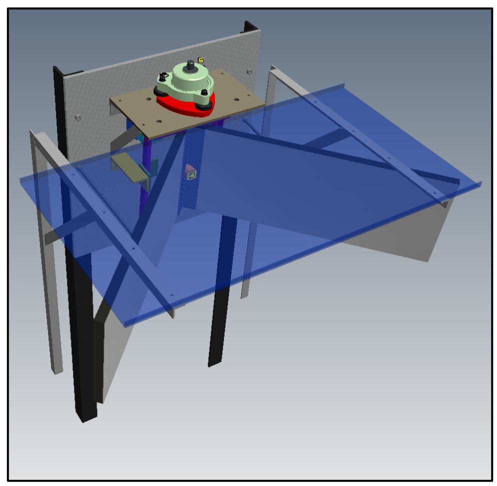
Figure 8-44. Diagram of new calibration target.

An active radar that tracks with the SLR telescope, an ADS-B receiver and the observer all switch off the laser beam should an aircraft approach the direction of fire. In addition to this, the advantages of an active camera system are being explored. Additionally, predictions for the International Space Station (ISS) were added to the ADS-B listen2planes TCP/IP server so that it will be treated like an aircraft and the laser will be inhibited if it approaches the beam.

A software program called orbitNP.py was released to the ILRS community in 2018, which originates from FORTRAN code used at the SGF that was translated into PYTHON. It reads full-rate data files, or raw epoch-range data, along with a corresponding CPF orbit prediction file to produce flattened range residuals by solving for time bias and range bias. The residuals are plotted for inspection and normal points are formed.

Future Plans

An assessment of what can be achieved with an optical camera aircraft detection system will continue as it is developed and tested. This will include day and night conditions as well as clear and partially cloudy skies. The advantages of colour images will also be explored.

Extraction of SLR returns from raw range data files recorded by the A033-ET Riga Event Timer are to be automated and this will be closely assessed for reliability.

The ability to control the polarization orientation at the telescope emitter will allow us to explore any impact on range measurements or return signal strength. This may lead to the installation of a quarter wave plate to produce circular polarization, which will be checked through the coudé path.

Station Personnel

Figure 8-45. SGF Herstmonceux team: Toby Shoobridge, Matthew Wilkinson, Dr. Graham Appleby, Victoria Smith, Robert Sherwood, Christopher Potter, José Rodríguez (left to right).

The SGF team is made up of seven personnel: Dr. Graham Appleby, Robert Sherwood, Christopher Potter, José Rodríguez, Toby Shoobridge, Victoria Smith, and Matthew Wilkinson. Six cover the observing schedule and within the team there is the required expertise in mechanical, software, electrical and optical engineering. Graham Appleby retired as head of the group in 2019, but will continue his involvement in the work of the SGF and its geodetic activities as a BGS Honorary Research Associate.

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Fax: +44 (0) 1323 833 929
Website: *http://sgf.rgo.ac.uk*

Irkutsk, Russia

Author: *Valery A. Emelyanov*
Responsible Agency: East-Siberian Branch of FSUE "VNIIFTRI"

System: IRKL/1891
Location: 57 Borodina st., Irkutsk, 664056, Russia,
Latitude: 52.2191°N, Longitude: 104.3164°E, Elevation: 505.62m

Station Operations

The SLR station in Irkutsk (ILRS code IRKL, station number 1891) is one of the two laser stations in the ILRS network (along with MDVS), administered by the FSUE "VNIIFTRI" (Mendeleevo). The station is located on the outskirts of the Irkutsk city. The distance from Lake Baikal is 70 km, the distance from the reservoir on the Angara River is 500 m. The weather in Irkutsk can range from 10°C to 20°C (night)/20°C to 35°C (day) in the summer and -15°C to -35°C (night)/-5°C to -30°C (day) during the winter. There are typically up to 150 clear nights during the year.

Irkutsk station operates in both day and night and is capable of tracking all satellites on the ILRS priority list. The system can operate in a temperature range of -25°C to 30°C.

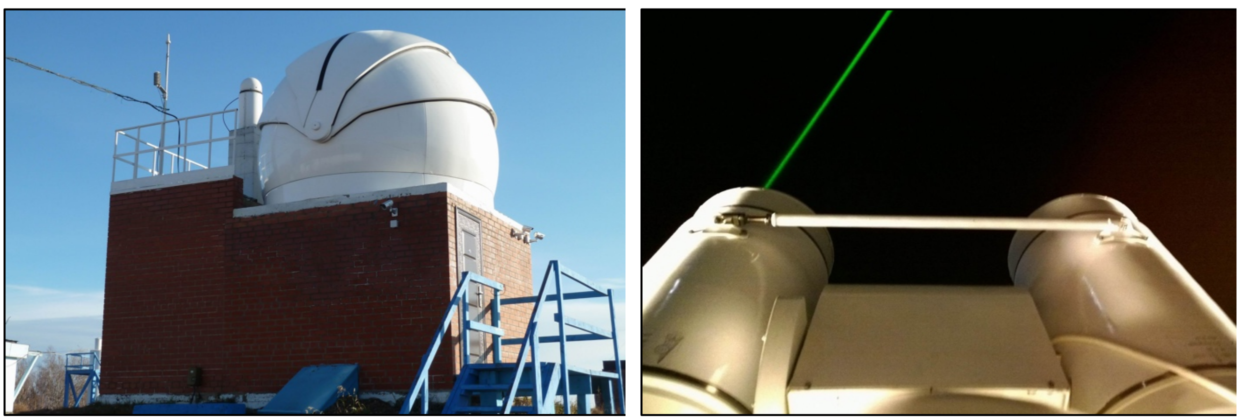

Figure 8-46. Daylight (left) and nighttime (right) observations at the Irkutsk laser station.

System Improvements

System characteristics:

- Name of the system: "Sazhen-TM"
- System manufacturer: OJC "RPC "PSI""
- Type of radiating- and TV-telescope: Gregorian
- Mirror aperture: 0.25 m
- Mount type: alt-azimuth
- Pulse repetition frequency: 300 Hz
- Pulse duration: 250 ps
- Laser type: ND: YAG
- Primary/secondary wavelength: 1064/532 nm
- Maximum output energy: 2.5 mJ
- Laser system resource: 10^9 pulses (~930 hours)

Established programs for laser observations are updated several times during the year.

Current Challenges and Future Plans

Every two years it is necessary to partially or completely replace the laser emitter due to the exhaustion of its resource.

Over the next year, the next generation of the "Tochka"-type laser station starting with sub-millimeter measurement accuracy is expected.

Station Personnel

Ten staff members are responsible for Mendeleevo station operations:

- Galina I. Modestova, head of department (station general management)
- Valery A. Emelyanov, responsible for the station operation (organizational, technical and software issues solution, observations)
- Victor V. Kaplenko, responsible for the station technical condition (technical issues solution, observations)
- Irina N. Bobrik, observer
- Andrey A. Chigvintsev, observer
- Elena P. Gladkevich, observer
- Pavel N. Modestov, observer
- Elena N. Myasnikova, observer
- Sergey I. Raschotin, observer
- Irina G. Tarlyuk, observer

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Fax: +77-(3952)-46-83-03
Email: *eva@vniiftri-irk.ru*
Website: *http://www.vniiftri.ru*

Katzively and Simeiz, Crimea

Authors: *A.I. Dmytrotsa, I. Artemov, U. Martyshin, D. Neyachenko, A. Polyakov*
Responsible Agency: Crimean Astrophysical Observatory RAS (CrAO RAS)

System: KTZL/1893
Location: Katzively, Crimea
Latitude: 44.3932° N, Longitude: 33.9701° E, Elevation: 68.7 m

System: SIML/1873
Location: Simeiz, Crimea
Latitude: 44.4128° N, Longitude: 33.9931° E, Elevation: 361.20 m

Station Operations

The Simeiz station has been systematically operating since 1991. Currently, we observe low and high satellites at night.

Despite the fact that we have the oldest laser (operating since 1990), the station operates stably, and shows good results. Thanks to the enthusiasm and consistent modernization, the distance gradually increases the number of observations, without loss of accuracy.

As can be seen from the Global Report Cards from ILRS, the number of observations increases from year to year and approaches baseline, and the RMS has improved to about 12 mm.

Table 8-2. Summary of results for Simeiz from ILRS report cards (2016-2018).

	Passes				Normal Points				Minutes of	RMS		
Year	LEO	LAGEOS	High	Total	LEO	LAGEOS	High	Total	Data	Cal.	Star.	LAG.
2016	1324	230	89	1643	14922	1573	422	16917	12241		13.6	16.9
2017	1881	245	176	2302	21329	1582	846	23757	15174	25.9	11.0	11.6
2018	2313	286	377	2976	25369	1578	1605	28552	14672	20.8	12.0	13.6
2019	2018	234	273	2525	19841	1198	1200	22239	11124	17.3	11.8	16.2

By accessing the EUROLAS Data Center (EDC) service and making a selection of stations in the territory of the former USSR, you can see that the Simeiz station started from eighth place in 2016 and took first place in 2019, as shown in Tables 8-3 through 8-6).

Table 8-3. Pass totals from former USSR stations (2016).

N	Name	Total/Bad	LAGEOS	GNSS	LEO
1	1879-Altay	2754/0	271	2227	256
2	1868-Komsomolsk	2580/0	253	2169	158
3	1887-Baikanur	2162/0	450	1589	123
4	***1893-Katzively***	***2019/0***	***287***	***76***	***1656***
5	1890-Badary	1870/0	104	77	1689
6	1886-Arkhyz	1766/0	276	1013	477
7	1891-Irkutsk	1674/0	264	573	837
8	**1873-Simeiz**	**1666/1**	**235**	**91**	**1340**
9	1888-Svetloe	1514/0	240	108	1166
10	1889-Zelenchuk	1186/0	226	291	669
11	1884-Riga	1053/4	134	65	854
12	1824-Golosiiv	550/3	34	0	516
13	1874-Mendeleevo2	516/0	111	248	157

Table 8-4. Pass totals from former USSR stations (2017).

N	Name	Total/Bad	LAGEOS	GNSS	LEO
1	1879-Altay	3223/7	286	2653	284
2	1890-Badary	3017/12	172	147	2698
3	**1873-Simeiz**	**2354/4**	**253**	**184**	**1917**
4	1868-Komsomolsk	2341/1	157	2025	159
5	***1893-Katzively***	***2104/0***	***180***	***86***	***1838***
…	…	…	…	…	…
13	1888-Svetloe	256/0	8	15	233

Table 8-5. Pass totals from former USSR stations (2018).

N	Name	Total/Bad	LAGEOS	GNSS	LEO
1	**1873-Simeiz**	**3046/0**	**295**	**396**	**2355**
2	1891-Irkutsk	2744/1	334	849	1561
3	1879-Altay	2412/3	254	2019	139
4	***1893-Katzively***	***2262/3***	***210***	***9***	***2043***
5	1868-Komsomolsk	2215/0	210	1928	77
…	…	…	…	…	…
13	1874-Mendeleevo2	518/2	87	298	133

Table 8-6. Pass totals from former USSR stations (2019).

N	Name	Total/Bad	LAGEOS	GNSS	LEO
1	**1873-Simeiz**	**3169/27**	**322**	**413**	**2434**
2	1890-Badary	2928/313	520	499	1909
3	***1893-Katzively***	***2326/36***	***232***	***4***	***2090***
4	1879-Altay	2106/39	215	1772	119
5	1891-Irkutsk	2029/641	157	413	1459
…	…	…	…	…	…
13	1874-Mendeleevo2	280/32	72	132	76

As you can see, our station took first places in 2018 and 2019. Our second station, Katzively (1893), has been in the top five in 2016-2019 years.

System Improvements

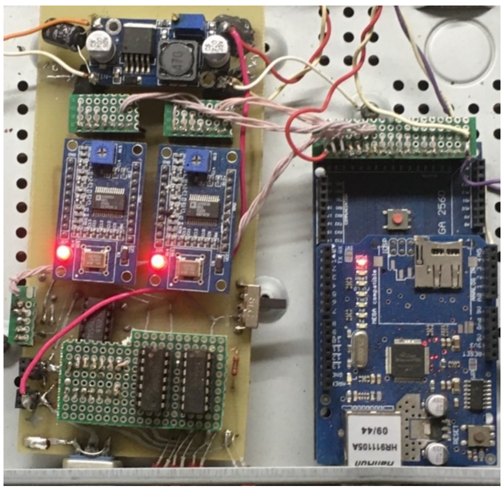

Figure 8-47. Replacement control board.

Despite these good results, the old laser does not make it possible to significantly increase the number of observations and normal points.

According to our plans, it is necessary to unload the control computer, update the equipment control boards and make them computer independent.

The main improvement over this period was the replacement of the engine control board (Figure 8-47). Previously, the board stood inside the computer, used the IDE protocol, now the control is implemented on the Arduino plate, and one controlled via Ethernet. The frequency for azimuth and altitude engines is generated by two frequency generators with an accuracy of 1Hz.

Current Challenges and Future Plans

On April 28, 2016, Moscow State University successfully launched the satellite “Lomonosov” from the new cosmodrome “Vostochnyi”, located in the Far East Siberia, during the first launch. The main goal of this project is to study extreme processes in the space, such as Ultra High Energy Cosmic Rays, Transient Luminous Events, Gamma Ray Bursts, variations of the radiation environment, and to test the space segment of optical monitoring of potentially dangerous space objects.

In 2016-2017, our station participated in the ground support of the TUS instrument, on the Lomonosov satellite. To do this, it was necessary to create an ultraviolet laser, and to illuminate the satellite at the right time, for calibrating the TUS detector.

We also took part in the support of RadioAstron satellite. But from a distance more then 200,000 km, where sessions of laser ranging were usually conducted, we did not receive a reliable number of measurements.

To further improve our station, it is necessary to unload the control computer, update the equipment control boards and make them computer independent. Next in line is a time recording board and a board for working with angular encoders.

The second important part of the job is software improvement. Firstly, we need to upgrade programs to meet the new requirements in version 2 of both the CPF and CRD format standards. Secondly, with the change and addition of new equipment. To do this, we use client-server technology, where each item of equipment is managed in a separate service.

Summary

Despite the oldest laser, our station and, especially the team, show great potential. I hope that further modernization will allow us to occupy a worthy place among the laser ranging stations.

Our station took first places in 2018 and 2019. Our second station in Katzively (1893) has been in the top five in 2016-2019 years.

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Komsomolsk-na-Amure, Russia

Author: *Natalia Parkhomenko*
Responsible Agency: JC "RPC "PSI"

System: KOML/1868
Location: Komsomolsk-on-Amur, Khabarovsk Territory, Russia
Latitude: 50.69461°N, Longitude: 136.74383°E, Elevation: 269.4027m

Station Operations

The KOML 1868, a Russian Sazhen-C SLR, is located at the Solnechny district of the Khabarovsk Territory. The construction of the Sazhen-C station started during 1992. In the mid-1990s, the SLR station Komsomolsk-on-Amur began laser ranging sessions (ERS-1,2 and other) for the benefit of the satellite laser ranging community, which was organized in 1998 at ILRS.

The station staff strives to work on a 8/7 basis, focusing as a first priority on targets of Russian interest (e.g., GLONASS) and then on the ILRS priority list.

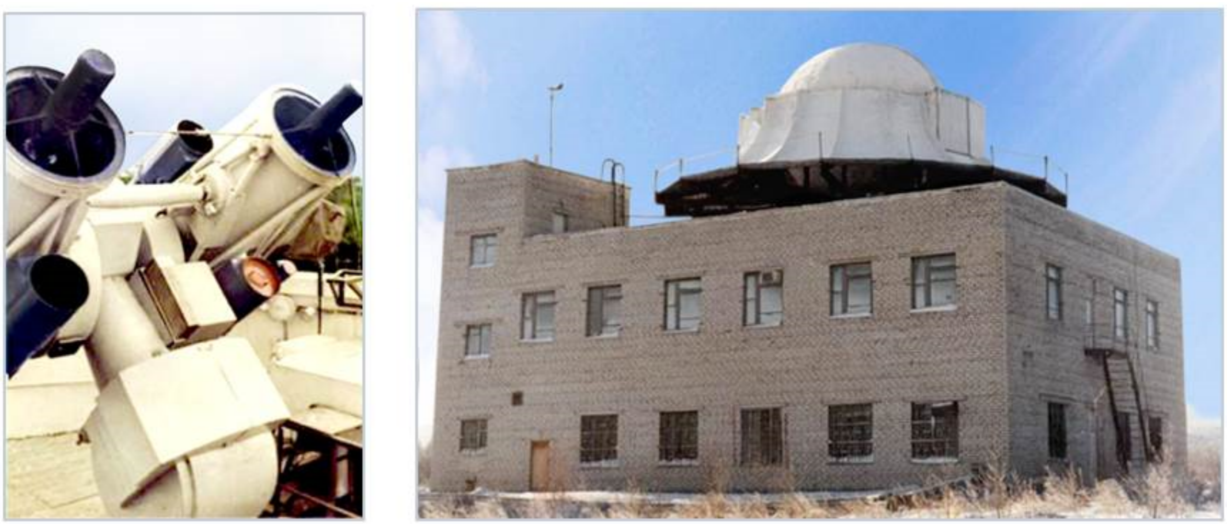

Figure 8-48. SLR system and facility located in Komsomolsk, Russia.

System Improvements

- Work was done to optimize algorithms and software related to the search and tracking of satellite, as well as the detection of a signal reflected from LRA on satellite.
- Developed and implemented a program for visualization/display of spacecraft flight paths.
- Modified the Diaphragm Switching Unit to increase the wear resistance of the field diaphragm positioning mechanism.

Current Challenges and Future Plans

Any problems with hardware and software are resolved quickly through remote consultations, and, if necessary, a specialist from PSI can visit the SLR station.

Future plans to improve the SLR system Komsomolsk-on-Amur:

- Development and implementation of digital cameras with a permeability of at least 12magnitude to replace the TV cameras that have outlived their life.
- Development and implementation of a laser with a pulse duration of not more than 60 ps.
- Development of software for calculating normal points directly at the station in order to reduce data access time for users.

Station Personnel

- Person 1: Manager of the Sazhen-C system
- Person 2: Sazhen-C operator
- Person 3: Sazhen-C operator

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Kunming, China

Author: *Yuqiang Li*
Responsible Yunnan Observatory, CAS

System: KUNL/7820
Location: Kunming, Yunnan Province, China
Latitude: 25.0298°N, Longitude: 102.7977°E, Elevation: 1987.05m

Introduction

The Satellite Laser Ranging (SLR) station of the Yunnan Observatories lies in the eastern region of Kunming. The main observational facilities for laser ranging are the 1.2m telescope and the 53cm binocular. Currently, the 1.2m telescope is the primary experimental platform for Debris Laser Ranging (DLR) and Lunar Laser Ranging (LLR), while the 53cm binocular is designated for routine SLR missions. Both are operated by the Applied Astronomy Group (AAG) of Yunnan Observatories, Chinese Academy of Sciences.

Figure 8-49. The 1.2m Telescope and the 53cm Binocular.

In order to improve system performance and to satisfy the increasing needs for more ranging experiments, the observational systems were upgraded in 2016. The retrofit period lasted from August to the following January. Since then, routine SLR responsibilities were passed to the 53cm binocular.

With its routine SLR duty transferred, the 1.2m telescope can be fully devoted to DLR and LLR research. Equipped with new detectors, sampling devices and laser generators, the 1.2m telescope was capable of carrying out ranging experiments on space debris in 2016, and successfully received echo signals from the lunar retroreflector Apollo 15 in 2018, being the first system in China to achieve LLR.

The 53cm binocular is located about 30m distant from the 1.2m telescope; it has a separated optical-path structure. In 2017, SLR data from the 53cm binocular was uploaded to the EUROLAS Data Center (EDC), and passed the validation process later in November.

Overview of Satellite Laser Ranging Activities

Earlier, SLR was carried out intermittently at the 1.2m telescope, but most of the time was occupied by other research. Meanwhile, AAG members felt that the observational resources were too limited to perform so many ranging experiments, and started to deploy the new SLR system at the 53cm binocular. SLR data from the 1.2m telescope (station ID: 7820) was suspended in 2017, while the 53cm binocular was acknowledged later as “Station 7819” and its SLR data have been validated ever since.

The 53cm binocular transmits 532nm laser with 1kHz rate, each laser pulse is 25ps in width and 0.5mJ in energy. A single photon avalanche diode (SPAD) and A033-type event timer are applied.

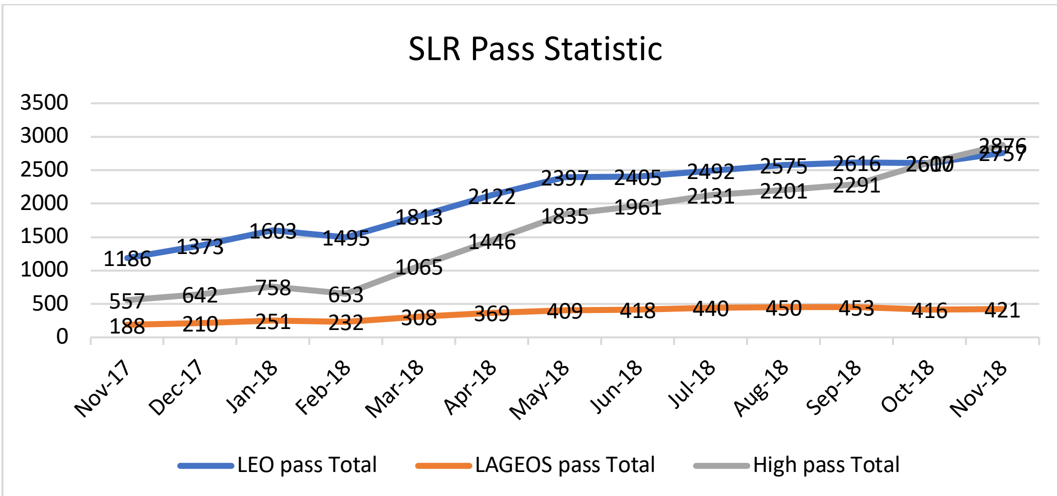

Figure 8-50. SLR passes statistics at Kunming.

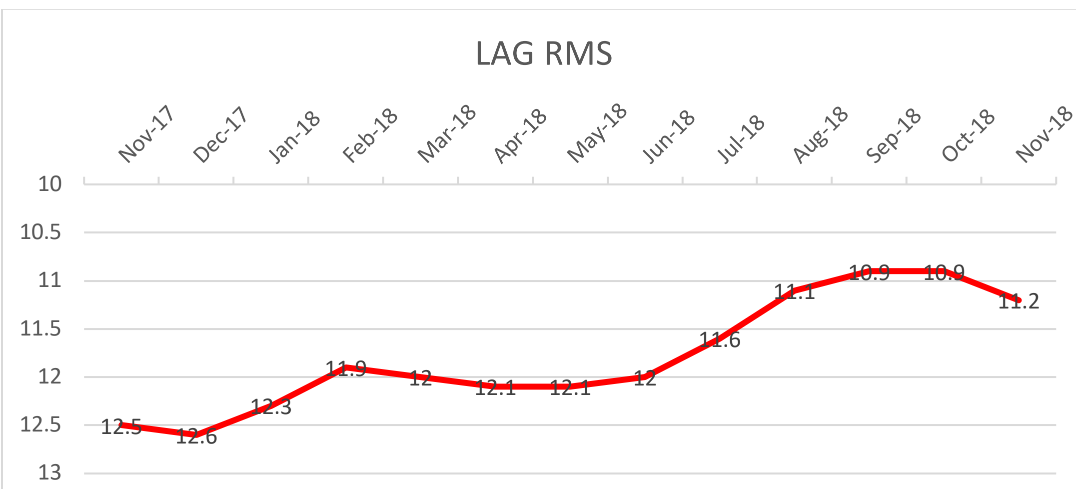

Figure 8-51. Average single-shot LAGEOS RMS (in millimeters).

As shown in Figure 8-50, the ranged pass by the binocular increased gradually, and the total pass number reached 6054 by 2018. Single-shot LAGEOS RMS values were more precise, from 12.5mm to 11.2mm, shown in Figure 8-51.

Overview of Debris Laser Ranging

DLR experiments were firstly carried out in the early 2010s, and new technologies such as a superconducting nano-wire single photon detector (SNSPD) high-speed event timer were gradually introduced into the ranging system since 2015.

A 1kHz 1064nm laser along with visible 532nm laser were transmitted from the 53cm binocular, while echo signals were received by both 1.2m telescope and 53cm binocular. A "Single-Transmitting and Dual-Receiving" ranging pattern was established for DLR research. The laser transmitting indicating signal was sent to the telescope side using fiber transferring technique. At the binocular's receiving end, the detector was SPAD-type for 532nm laser echo and the event timer was A033-series, while the telescope-side used SNSPD array for 1064nm laser echo detection and GT668-type event timer for multi-channel sampling.

In early 2016, the system was capable of ranging meter-size debris at 837km. After the retrofit, during the experimental period from March to May in 2017, the system collected a total of 208 passes on debris targets. Calsphere 1 and 2 were detected during that time, which were about 1000km distant and their radar cross section (RCS) were at the 0.04m^2-level.

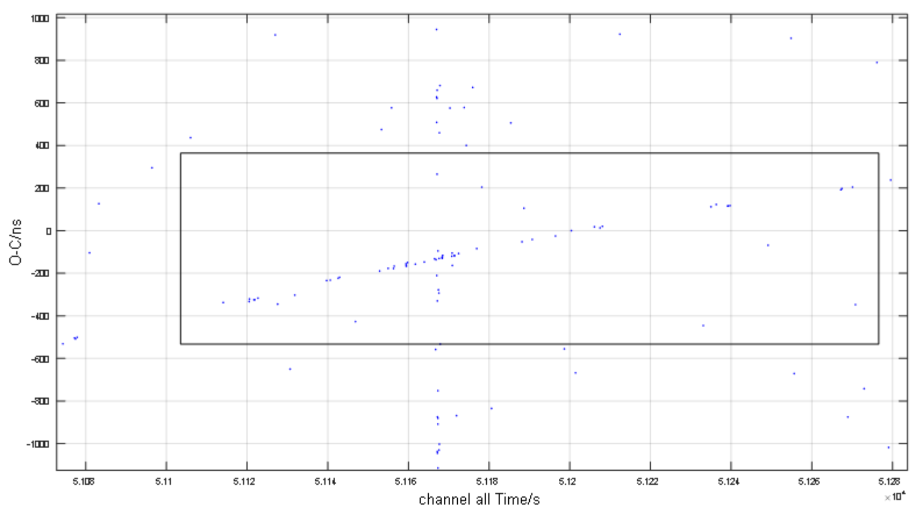

Figure 8-52. Echo signal of Calsphere 2.

Further improvements were introduced into the system in 2018, the software was upgraded. With 200W laser energy, the echo from the debris 12445 was detected, which had the range of about 6000km with its RCS of 18.25m^2, shown in Figure 8-53.

Today, "the 53cm binocular transmitting and the 1.2m telescope receiving" pattern is mostly used in DLR experiments. Based on array detection and a multi-channel sampling technique, new data processing software was implemented. With further ranging technology research and the application of SNSPD, the system is now more precise and more efficient in DLR studies.

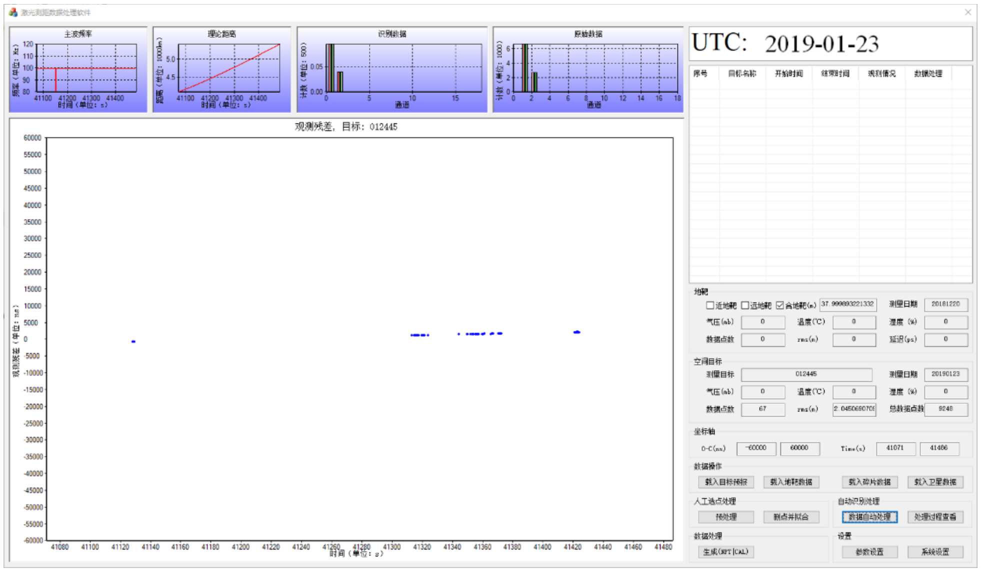

Figure 8-53. Echo signal of debris 12445.

Overview of Lunar Laser Ranging

The LLR system was established based on the retrofitted 1.2m telescope, in which common optical path was applied for high-precision pointing. 532nm laser (10ns pulse-width, 3.3J/pulse) of 10Hz rate were implemented, together with an exclusive range gate generator, high quantum-efficiency (HQE) SPAD and the A033 event timer, the system was finally prepared by November 2017.

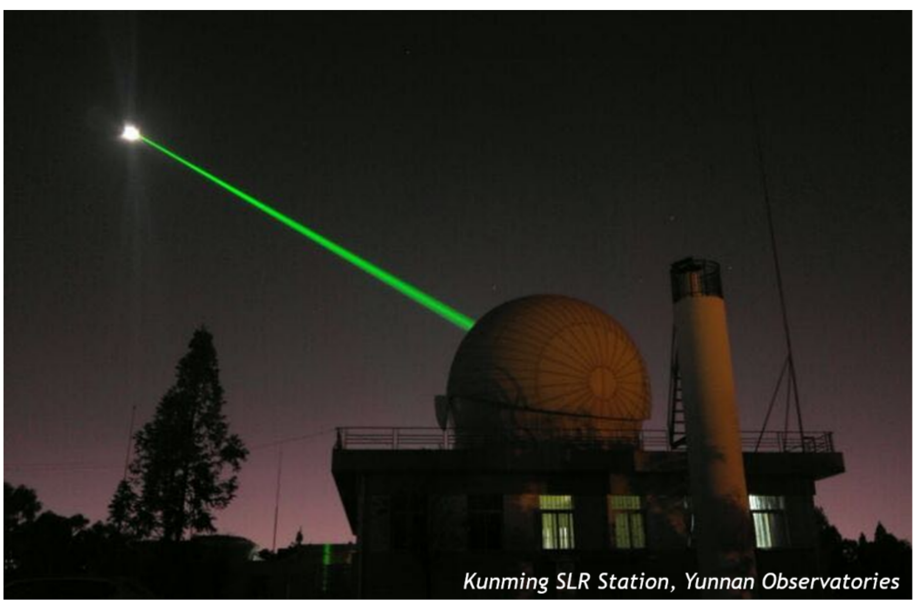

Figure 8-54. Pointing laser to the Moon.

On the night of Jan. 22, 2018, the first sign of echoes from Apollo 15 appeared. Computation and validation were carried out at once. Data were also uploaded to Lunar Laser Ranging Service developed by Paris Observatory Lunar Analysis Center for validation, and the results were exciting.

```
00056  2019/06/09  14h 08m 25s7525608   Apollo 15    Kunming           -0.064 m        -0.428 ns
00057  2019/06/09  14h 42m 54s0177808   Apollo 15    Kunming           -0.166 m        -1.106 ns
00058  2019/06/11  14h 46m 14s8770908   Apollo 15    Kunming            0.011 m         0.077 ns

Normal Points : 00058
Valid         : 00055
Wrong (***)   : 00003     Limit:      1.000 m

R0 Apollo 11   : 00004     Bias:     -0.004 m     -0.028 ns    St. dev. :     0.657 m      4.384 ns
R1 Lunokhod 1  : 00002     Bias:      0.390 m      2.599 ns    St. dev. :     0.190 m      1.268 ns
R2 Apollo 14   : 00006     Bias:     -0.151 m     -1.005 ns    St. dev. :     0.376 m      2.508 ns
R3 Apollo 15   : 00043     Bias:     -0.147 m     -0.982 ns    St. dev. :     0.363 m      2.420 ns
   Global      : 00055     Bias:     -0.118 m     -0.785 ns    St. dev. :     0.403 m      2.686 ns
```

Figure 8-55. Validation results.

The real-time data showed that the distance between the Apollo-15 retroreflector and Kunming station was 385823.433km to 387119.600km, during 21:25 to 22:31, Jan. 22, 2018. In the following days, echoes from Apollo-15, Apollo-14, and Apollo-11 were detected one after another, totally 35 passes with general accuracy better than 1m.

Summary

In recent years, the Kunming station has made great effort in developing SLR technologies and has achieved considerable progress. In 2016, the primary SLR duty was transferred from the 1.2m telescope to the 53cm binocular. After the retrofit, the telescope has been mainly used for DLR and LLR research, while the binocular is serving routine SLR activities. The LLR system was developed in 2017 and in the next year LLR achieved ranging success. As of today, the station keeps improving its research in related technologies for future laser ranging development.

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Matera, Italy

Author: *Giuseppe Bianco (ASI), Daniele Dequal (ASI), Giuseppe Nicoletti (e-GEOS)*
Responsible Agency: Italian Space Agency (ASI)

System: MATM/7941
Latitude: 40.6486°N, Longitude: 16.7046°E, Elevation: 536.9m

Station Operations

The Matera Laser Ranging Observatory (MLRO) is operational since 2000 and has been conceived to be a multipurpose state-of-the-art observatory capable of supporting a variety of experiments. Equipped with a 1.5 meter telescope, its main mission is the laser ranging to artificial satellites and Moon but is more and more involved in quantum communication experiments.

Figure 8-56. MLRO system in operation.

During the years 2016-2019 the MLRO station has been in routine, full time (24/7) operations, with the exception of two months in 2016 (June-July) and two months in 2019 (June-July) for the primary mirror recoating. The Figure 8-57 below represents the weekly number of passes observed by MLRO in the four years of this report.

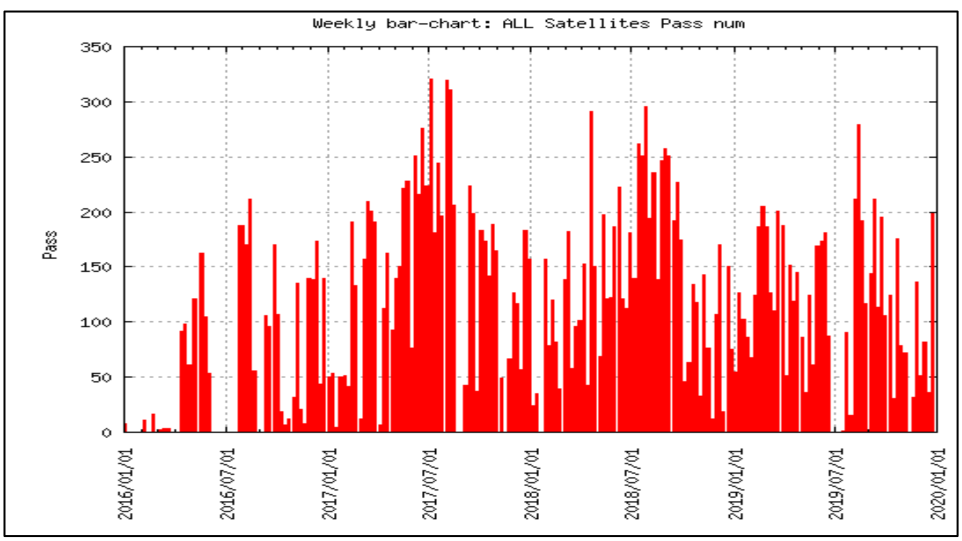

Figure 8-57. The monthly number of passes observed by MLRO in the past three years.

A small amount of data was acquired at the beginning of 2016 due to a failure of the telescope controller.

The average single-shot LAGEOS RMS, in millimeters, during the last quarter of 2019, is plotted in the following graph (Figure 8-58) as reported in the ILRS Global Performance Report Card.

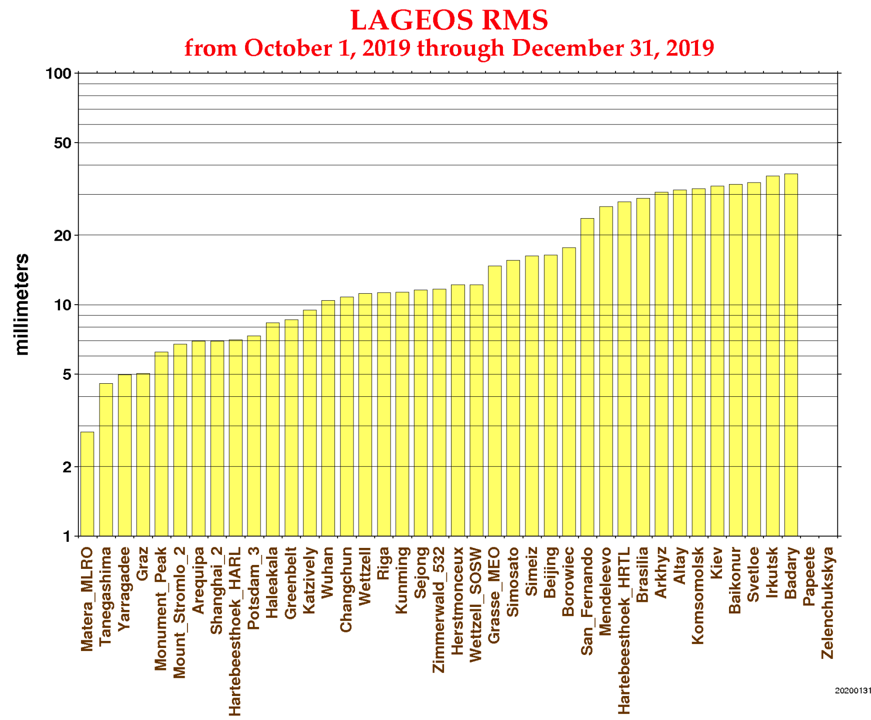

Figure 8-58. The LAGEOS RMS values for MLRO during 2019.

The acquisition of lunar data was improved with the replacement of the photomultiplier. The new Hamamatsu proved to be more efficient and the number of lunar observations per normal point is continuously increasing, as reported in the Figure 8-59. The tracking is performed during the first and last moon quarter for a couple of hours each night.

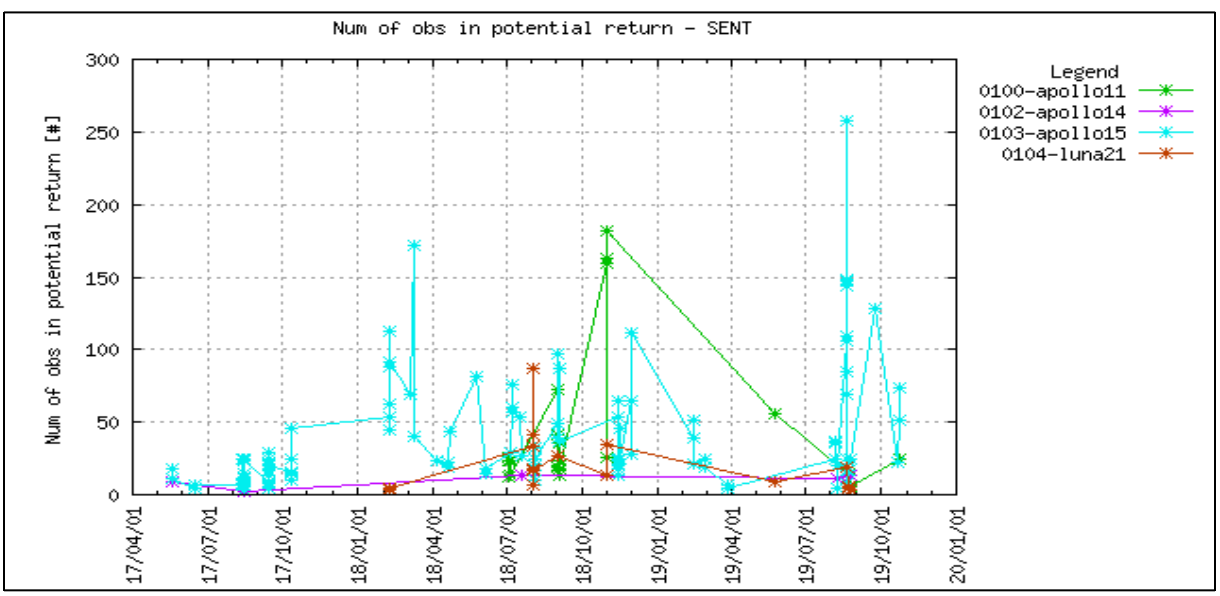

Figure 8-59. MLRO LLR observations (2017-2019).

System Improvements

- 2016: an upgraded state of the art servo-control system replaced the original Contraves Telescope control system, the installation was completed by Cybioms Corporation March 2016.
- 2016: MLRO is based on a 1.5-meter diameter Cassegrain telescope which was built in 1995. The primary mirror had a UV-enhanced coating with a very high reflectivity; however, after 20 years, it had degraded significantly and a new coating had become necessary. The recoating was completed in July2016.
- 2017: in December 2017 the Photek PMT was replaced with an Hamamatsu PMT.
- 2018 -2019 : Coudé path mirrors replacement from M7 to M2.
- 2019 : In June primary mirror re-coating due coating degradation.

Current Challenges and Future Plans

MLRO has been used for more than a decade to perform studies in the field of satellite quantum communication. The activities done so far exploited passive satellite equipped with retroreflector. In order to realize a high efficiency quantum-key-distribution (QKD) ground station, MLRO is undergoing an upgrade of telescope mirrors as well as detection apparatus. The station is now ready to receive quantum signals from the Chinese satellite Micius, and further upgrades will make it the reference national ground station for the in orbit validation of a QKD payload, founded by ASI. Upgrades will include new mirrors coating, an adaptive optics system and superconducting nanowires detectors.

MLRO is considered a national asset to be used for Space Surveillance and Tracking. Preliminary test demonstrated the capability of MLRO to track debris equipped with retro-reflectors, such as the rocket body CZ-2C R/B, However, its involvement in ILRS experiment and ESA projects stated that the system is not currently qualified to track uncooperative targets. The system low repetition rate (10Hz) revealed to be a big gap and the MLRO will undergo an upgrade.

MLRO will be improved with the update of the HW platform and the installation of the SW on the new platform, in order to preserve the current functionalities and support new features. Obsolete parts will be replaced with COTS subsystem, whenever possible.

Station Personnel

The Italian Space Agency is the owner of the Observatory and is the decision making body. The operations are performed by e-GEOS S.p.A. (formerly Telespazio) since the very beginning in the 80’s. A shift of ten people is running all the geodetic operations at the Space geodesy Center (SLR/LLR, VLBI, GNSS, gravimeter). The SLR/LLR operations and maintenance are coordinated by the SLR operation manager and a team of engineers is supporting preventive and corrective maintenance.

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McDonald TX, USA

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Location: McDonald Observatory, near Fort Davis, TX
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Station Operations

For the period in question (2016-2019), the McDonald Laser Ranging Station (MLRS) has been virtually non-operational (see below).

Figure 8-60. McDonald Laser Ranging Station (MLRS).

System Improvements

From the mid-1980's through the first decade of the 21st century, the MLRS provided more than 25 years of nearly flawless operation. During most of that time, the MLRS was one of the few laser ranging stations in the world that routinely ranged to the Moon and was one of the better, steady data producers. Sadly, for the past 10 years or so, the MLRS has been in a spiraling decline, principally due to a steadily deteriorating MCP/PMT. Because of budgetary reasons, the MLRS had not been a participant in the general NASA network-wide MCP/MPT upgrade that occurred about 5 years ago. The decline was exacerbated by the retirement of the sole, remaining laser technician, on August 31, 2015. This left MLRS with only a single observer and no skilled laser technician. Unfortunately, a laser upgrade in the summer of 2015 did not ameliorate the steady loss of sensitivity of the MCP/PMT.

In the spring of 2019, the MLRS received a replacement MCP/PMT. Working with T. Oldham and other NASA personnel, Wiant and Ricklefs worked to bring the MLRS back to its former operating condition. Regrettably, before much progress could be made, a severe lightning strike occurred on September 12, 2019 that seriously affected many of the instruments at the Observatory and dealt a fatal blow to the MLRS system. With the upcoming installation of SGSLR at McDonald, NASA decided to abandon any further attempts to resurrect MLRS; and the system was subsequently shut down permanently.

Figure 8-61. MGO VLBI antenna.

Figure 8-62. MGO gravimeter hut.

Current Challenges and Future Plans

As a part of the present NASA contract, a “new” McDonald Geodetic Observatory (MGO) is under construction. Combining artificial satellite laser ranging (SLR), very long baseline interferometry (VLBI), and the Global Navigation Satellite System (GNSS), plus associated local position monitoring at a single installation, the MGO will join other similar geodetic observatories around the world in facilitating the study of the Earth’s shape, gravity and rotation.

Supplementing NASA’s equipment investment, the University of Texas at Austin has contributed a GWR superconducting gravimeter (SG) as a permanent part of MGO. This makes MGO similar to most multi-technique geodetic observatories in Europe and elsewhere, which also operate an SG in addition to SLR, VLBI and GNSS equipment. The SG hut is now in place on the ‘guest pad’ on Mt. Fowlkes, and the SG was moved there in late September 2019. The VLBI passed its Site Acceptance Test in February 2019; and a piezometer was installed in October 2019 to measure groundwater pressure/flow near the gravimeter hut.

Burke Fort, John Ries, Randall Ricklefs, Peter Shelus (left to right)

Figure 8-63. MLRS station personnel.

Station Personnel

During 2016-2019, the following personnel have supported activities at MGO:

- Peter J. Shelus – MGO Principal Investigator (now retired)
- Srinivas V. Bettadpur – Original MGO Co-Principal Investigator
- Burke O. Fort – MGO Project Manager (now Co-Principal Investigator)
- Jerry R. Wiant – Station Engineer (now retired)
- Eusebio "Chevo" Terrazas – VLBI Operations Support Technician (OST)
- Randall R. Ricklefs – Software Engineer
- John C. Ries – SLR Data Quality Control (now Co-Principal Investigator)
- Anthony Garcia – Observer (no longer at MGO)

Rachel Green – Technical Staff Assistant (no longer at MGO)Contact

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Mendeleevo, Russia

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Station Operations

The Mendeleevo station (ILRS code MDVS, station number 1874) is one of the two ILRS network laser stations (along with Irkutsk/IRKL), administered by the FSUE “VNIIFTRI”. Federal State Unitary Enterprise (FSUE) “National Research Institute for Physical-Technical and Radio Engineering Measurements” (VNIIFTRI) is subordinated to Federal Agency on technical regulation and metrology of Russia, has the status of the State scientific metrological center and is one of the main Centers of the State standards of Russia. At present, VNIIFTRI supports and improves 38 State standards, 19 secondary standards, 23 rigs of highest accuracy, over 120 working standards and calibration rigs for various fields of measurement. VNIIFTRI performs the duties of the Main metrological center of the State service of time, frequency and the Earth rotation parameters determination (SSTF). The institute has been engaged of satellites laser ranging since the 70s of the last century. The third generation of equipment is currently in operations at the Mendeleevo station; the system is capable of both day and nighttime tracking all satellites on the ILRS priority list. The system can operate in a temperature range of -25°C to 30°C.

The station is located on the outskirts of the Moscow city. The weather in Mendeleevo can range from 10°C to 20°C (night)/20°C to 35°C (day) in the summer and -5°C to -35°C (night)/-5°C to -30°C (day) during the winter. There are typically up to 150 clear nights during the year.

Figure 64. Daylight (left) and nighttime (right) observations at the Mendeleevo laser station.

System characteristics:

- System name: “Sazhen-TM”
- System manufacturer: OJC “RPC “PSI”“
- Type of radiating- and TV-telescope: Gregorian
- Mirror aperture: 0.25 m
- Mount type: alt-azimuth
- Pulse repetition frequency: 300 Hz

- Pulse duration: 250 ps
- Laser type: ND: YAG
- Primary/secondary wavelength: 1064/532 nm
- Maximum output energy: 2.5 mJ
- Laser system resource: 10^9 pulses (~930 hours)

Established programs for laser observations are updated several times during the year.

System Improvements

New technical solutions, measurement and calibration techniques are being implemented at the Mendeleevo station; these modifications are also being implemented at other existing stations of the network. Some of these decisions have become part of the next-generation station.

Current Challenges and Future Plans

Every two years it is necessary to partially or completely replace the laser emitter due to the exhaustion of its resource.

Over the next year, the next generation of the “Tochka”-type laser station starting with sub-millimeter measurement accuracy is expected.

Station Personnel

Ten staff members are responsible for Mendeleevo station operations, including:

- Sergey L. Pasynok, head of EOP department of VNIIFTRI
- Igor Yu. Ignatenko, head of laser ranging service of FSUE “VNIIFTRI,” scientific and methodological guidance, responsible for the station operation (organizational, technical and software issues solution, observations)
- Efim N. Tsyba, scientific researcher of VNIIFTRI, development of the SLR and LLR processing software, development of the methods of parameter estimation
- Vacheslav S. Ivanov, responsible for the station technical condition (technical issues solution, observations)
- Vasiliy R. Schlegel, scientific researcher of VNIIFTRI, technical and software issues solution, observations
- Aleksey E. Drozdov, student of the Physics Faculty of Moscow State University, our concern for the future, observations.

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Monument Peak CA, USA

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Responsible Agency: NASA GSFC

System: MONL/7110
Location: Monument Peak
Latitude: 32.8917° N, Longitude: 116.4227° W, Elevation: 1842.177 m

Station Operations

The MOBLAS-4 system, located at Monument Peak, CA, operates 16 hours per day (06:00 a.m. to 10:00 p.m. local time), five days per week. The station is operational for all scheduled satellites.

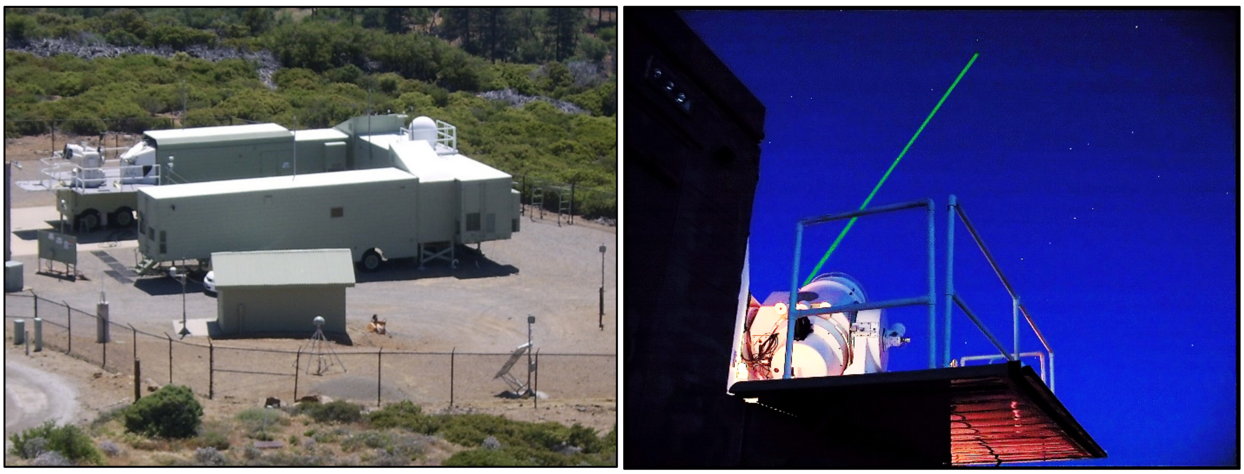

Figure 8-65. NASA SLR station located in Monument Peak, CA.

System Improvements

- The Geostationary Lightning Mapper (GLM) equipment was installed at Monument Peak on June 17, 2017 in support of NASA's participation in a GOES-R experiment. Tracking with the GLM started on September 17, 2018.
- In 2019, the Event Timer Module (ETM) officially replaced the TIU as the primary data measurement system after test data were reviewed and approved by the ILRS Analysis Standing Committee (ASC).
- Completed harmonic drive modification/upgrade in the radar as part of a Laser Hazard Reduction System (LHRS) improvement. Additional processes and procedures were put in place to ensure the radar is always aligned with the telescope.

Current Challenges and Future Plans

- The station plans to continue tracking all satellites for the ILRS and GLM projects.
- Sustainment of obsolete parts and equipment is becoming more difficult, however sustaining engineering is taking on multiple efforts to procure, test, and evaluate replacement solutions.
  - Low signal loss and more durable PMT cables.
  - Stanford Research Systems FS740 to replace the XL-DC.
  - Laser Power Supply and Start Diode replacements.
  - Improvement of heating, air, and ventilation system.
  - Procurement of spare tachometer generator and brush-rings.

Station Personnel

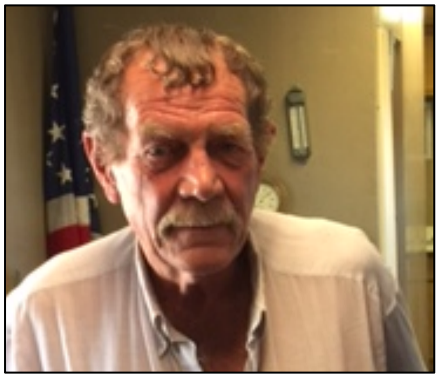 

Figure-8 66. MOBLAS 4 Ted Doroski and Ron Sebeny.

The crew members track over fifty satellites during operational shifts. In addition, they perform preventive and regular maintenance of the station during the work week. The station staff members are:

- Ted Doroski: Engineering Technician, Operator
- Ron Sebeny: Station Manager, Operations & Engineering Support Team
- Ken Tribble, Engineering Technician/Operator
- Dennis Chase, Lead Engineer
- Jason Laing, Data Operations Lead
- Christopher Szwec, SLR Project Manager

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Responsible Agency: Geoscience Australia

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Station Operations

The Mt. Stromlo Space Research Centre is a fundamental space geodesy site that currently consists of a high precision satellite laser ranging (SLR) station based on a 1m aperture telescope, and an experimental facility based on a 1.8m aperture telescope. The site is also supported by IGS GPS and IGLOS GLONASS receivers, IDS DORIS beacon, and a comprehensive local tie network.

SLR

Since November 2015, the Mt. Stromlo SLR station has been operated by EOS Space Systems Pty Ltd under contract to Geoscience Australia.

The station has operated continuously throughout this period and remains one of the most productive stations in the ILRS network. Figure 8-67 shows the productivity that has been achieved during 2016-18 in terms of number of passes of low earth orbit (LEO), high earth orbit (HEO/GEO) and LAGEOS satellites.

Routine 24/7 operations were performed autonomously and often unmanned. The sealed telescope enclosure, shown in the Figure 8-68 is one of the aspects of the station that allows such a high level of automation.

GNSS

The two IGS sites at Mt. Stromlo (STR1 and STR2) continue to provide a variety of GNSS data products, including a 1 Hz real-time data stream. A third GNSS antenna/receiver installed at the observatory on the northwest pillar is capable of tracking the Galileo satellites along with GPS and GLONASS, and is providing a 1 Hz real-time stream to the Cooperative Network for GIOVE Observation (CONGO) project.

Since Q1 2016, the Mt. Stromlo station incorporates a new monitoring station to support tracking of the Chinese Beidou satellite constellation.

Local Tie Survey

A full local tie survey was completed in September 2018 including the connection to the new GPS mount. A report detailing the survey is in preparation.

Gravimetry

As part of the AuScope gravity program the Reynolds dome at Mt. Stromlo was refurbished into a dedicated absolute gravity comparison facility for four instruments. The super-conducting gravimeter continues to operate, with frequent calibration from AuScope’s FG5 237 gravimeter. Continuing observations from this gravimeter extend the vertical gravity monitoring series at Mt. Stromlo.

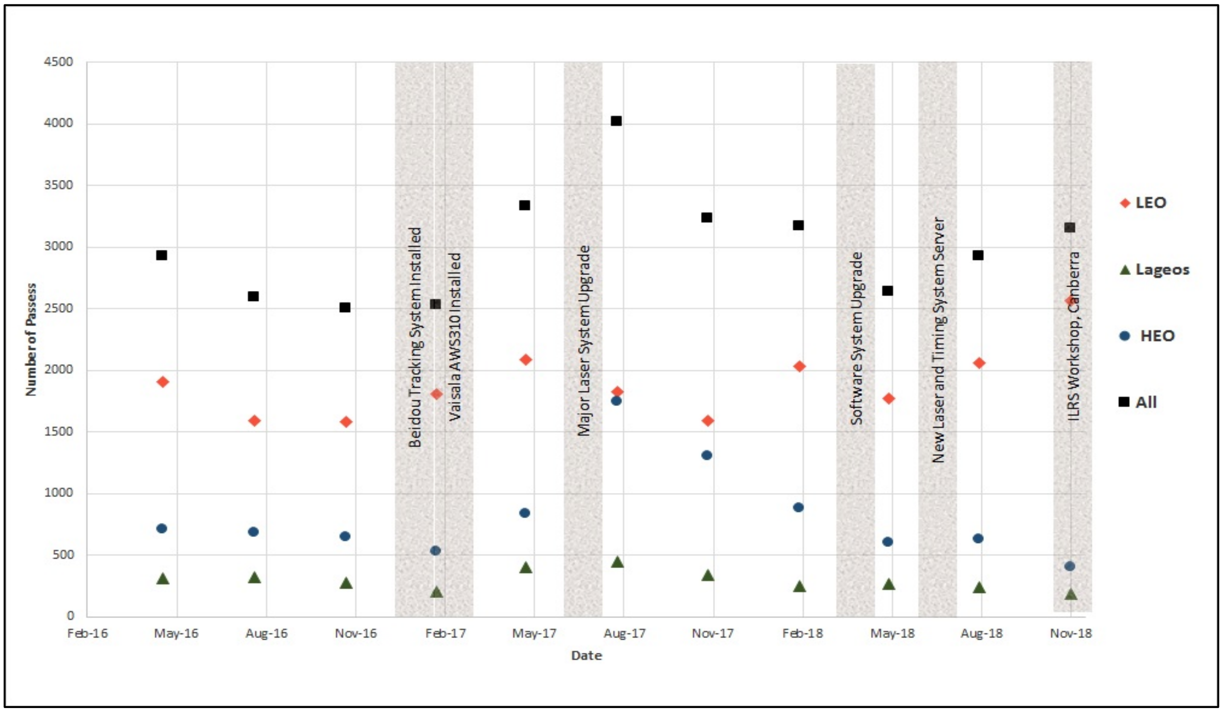

Figure 8-67. Productivity at Mt. Stromlo during 2016-2018, identifying major events.

Station Personnel

Staffing levels during 2016-2018 has typically required attendance of one person during normal business hours and occasional remote monitoring at other times. These duties were shared between Dr Christopher Moore (station manager) and operational support provided by Mr. Jonathan Poonpol and more recently by Mr. Babak Soltanfar. Given that EOS Space Systems provides SLR services under contract from Geoscience Australia, Mr. Mark Blundell also provides contract management services.

Figure 8-68. Mt. Stromlo SRC and EOS Space Systems staff, Mark Blundell (left) and Christopher Moore (right).

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Potsdam, Germany

Author: *Sven Bauer*
Responsible Agency: GFZ Potsdam

System: POT3/7841
Location: Potsdam, Brandenburg, Germany
Latitude: 52.3830° N, Longitude: 13.0614° E, Elevation: 123.5 m

Station Operations

Daytime and nighttime operation whenever there is good weather and actually somebody available for observations. However, retiring staff is continuously reducing the personnel, which reduces the station performance.

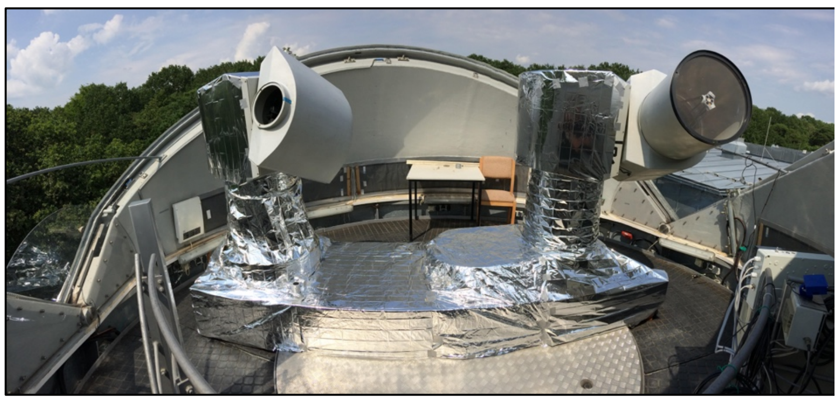

Figure 8-69. Potsdam laser installation (photo credit S. Bauer).

System Improvements

- HighQ laser system upgrade which increased the pulse energy and reduced the pulse length,
- Finally, successfully integration of an MPD SPAD in the system which reduced the measurement RMS (down to 2.5 mm one-way e.g., for Swarm), increased the signal return rate (GLONASS e.g., 1000 echos in 10 min before, now 10000 echos) and stabilized the station system delay due to less variation and sensitivity to external effects,
- Software updates improving station operation towards automation, in-sky and laser safety as well as hardware and system control,
- Establishment of the time bias service for analysis and comparison of prediction providers and quality as well as prediction of time bias values for various targets for the ILRS community.

Current Challenges and Future Plans

- Fully automated station operation during nighttime.

Station Personnel

- Sven Bauer/GFZ: Station manager
- Jens Steinborn/Digos Potsdam GmbH: IT and station operation and system software development (contracted)
- Andre Kloth/Digos Potsdam GmbH: IT and station operation and system software development (contracted)
- Stefan Weisheit/GFZ: Electronics and observer
- Martin König/GFZ: Electronics and observer
- Marcel Ludwig/GFZ: Mechanics and observer
- Students (one to two): Observer

Contact

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Riga, Latvia

Author: *Kalvis Salmins, Jorge del Pino*
Responsible Agency: Institute of Astronomy, University of Latvia

System: RIGL/1884
Location: Riga, Latvia
Latitude: 56.948551° N, Longitude: 24.059075° E, Elevation: 31.3367 m

Station Operations

The Riga SLR station (1884, RIGL) is situated at the University Botanical Garden in Riga, Latvia and now operates during night and twilight, seven days a week. The number of clear nights is on average 120 nights per year with a low season during October through January. The system tracks all the satellites up to the GLONASS/Galileo orbits. Due to the event timer RTS 2006 software design, range is currently limited to 25,500 km.

After two quarantine periods (data released on 2016-04-16 and 2017-02-01) the station was validated and operational since 2017-02-01. Segmented tracking, fast switching between satellites, and simultaneous TerraSAR-X/TanDEM-X tracking are now implemented and used on a regular basis, improving the station productivity.

Figure 8-70. Riga station view: The SLR system, GNSS antenna, new local network markers (lower right, top right and near the GNSS antenna) and groundwater monitoring well (yellow circle). Between the SLR and the lower right marker is the old AFU-75 satellite photo camera shed.

The total number of passes and normal points for the 2016-2019 period are: LAGEOS/LARES 748/7547, HEO 225/1165, LEO 3013/47955 and non-ILRS targets (TOPEX/Poseidon, ADEOS-2, Oicets) 276/4960.

The total observing nights where: 119 (2016), 100 (2017), 123 (2018) and 94 (2019).

Two hardware breakdowns occurred during 2017 (and documented in SLRMail messages 2455 and 2456) and affected the system operation, reducing the tracking output. Notable results during the 2016-2019 reporting period are as follows. Riga was the first station to observe an SNET satellite (SNET-4 on 2018/04/12 at 21:57 UTC) and the second station to report passes of GRACE-FO-1 and -2 after Potsdam (2018/05/24 at 21:54 UTC). In October 2017, The Riga staff hosted the 2017 ILRS Technical Workshop "Improving ILRS Performance to Meet Future GGOS Requirements".

The SLR station is co-located with the IGS GNSS station RIGA00LVA as well with a gravimetric site with regular relative gravity and groundwater level measurements complemented by a visiting absolute gravimeter.

System Improvements

A full description of the system improvements for 2016-2019 can be found in the posters presented at the two International Workshops on Laser Ranging (Potsdam 2016, "SLR Station Riga Status Report" and Canberra 2018, "SLR Station Riga Status Report 2018") as well as other posters or presentations during the same period.

SLR telescope building:

- External building walls and rolling roof pillars repaired.
- New utility power lines, UPS system and security light system.
- A new temperature control system in the laser room.

SLR system hardware:

- Primary and secondary telescope mirrors replaced and full optical system alignment.
- The telescope power and data cables replaced in 2017.
- The new Hamamatsu APD module C5658 (start channel) and a Hamamatsu H11901-20 PMT + Hamamatsu C5594 Amplifier (stop channel) installed.
- The new fiber optics internal calibration system installed and calibrated.
- A new narrow field camera Andor iXon Ultra 888 was installed in December 2019.
- Four cameras in operation: All-Sky, wide field and narrow field for visual tracking, and IR webcam to monitor the telescope movement.
- A Calibration/Tracking configuration switch, doubling as the laser beam emergency blocker.
- A remote controlled PMT filter selection with 3 IF + 2 ND.
- The TS/ATIC (Time Selector/Amplitude to Time Interval Converter), for improved signal processing electronics is operational since the last quarter of 2019.
- The Sky clarity sensor Aurora Cloud Sensor III with rain and snow alarm.
- A new backup meteorological station Vaisala PTU300. The pressure sensors on the primary WXT510 and PTU300 stations were recalibrated against the Potsdam SLR absolute barometer.
- The height difference between the meteorological station Vaisala WXT510 and the SLR and GPS reference points was remeasured.
- Three new local network reference points.
- A Raspberry PI-based temperature monitoring system at the laser and control rooms.
- All station software, except the DOS legacy programs controlling the telescope, has been ported to run under Windows 10.
- Since January 1st, 2018, the sky clarity is permanently monitored in cooperation with the Metsähovi SLR team in order to evaluate the long term local and simultaneous cloudiness statistics. (see the Stuttgart 2019 poster "Continuous Sky Clarity Monitoring at Riga and Metsähovi: January 2018 - June 2019").

In development:

- The computer-controlled beam divergence unit.
- The upgraded detector enclosure for optical, thermal and EMI protection of the detector.

Current Challenges and Future Plans

Current challenges:

- To increase daylight tracking time
- Event timer software upgrade

Near future plans are:

- Build a new detector unit
- New telescope control system
- New event timer
- Better thermal insulation for telescope and equipment compartments

Station Personnel

- Kalvis Salmins: Station manager, researcher
- Jorge del Pino: Researcher
- Janis Kaulins: Researcher, joined late 2018
- Aivis Meijers: SLR operator, technician
- Janis Sarkovskis: SLR operator
- Igors Abakumovs: SLR operator

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San Fernando, Spain

Author: *Manuel Catalán*
Responsible Agency: Real Instituto y Observatorio de la Armada

System: SFEL/7823
Location: Spain
Latitude: 36.4650° N, Longitude: 6.2055° W, Elevation: 98.177 m

Figure 8-71. San Fernando SLR station during laser operations.

Station Operations

Station tracking statistics from 2016 to 2019 are shown in Table 8-7 below. During 2016, the programmed observations of the daily routine of tracking artificial satellites continued. We included in our routine inactive satellites (collaborative objects) as was proposed as a goal in the Research Project entitled "Contribution of the Laser Station for monitoring of artificial satellites of the ROA.

Table 8-7 reflects the performance of the system throughout every year (2016-2019). It includes both active satellites with retroreflectors, and inactive collaborative objects.

Normal operations were performed from January to June 2017. Our tracking efficiency was low in 2018 as we were mainly involved in technical achievements. In 2018 from March 22th to April 1st, we participated in a campaign especially devoted to the reentry of the Chinese space station Tiangong-1.

Return echoes were first achieved on January 16, 2019 with the EKSPLA PL2251 PS laser. Between February 17 and March 20, 2019, we participated in SST survey campaign corresponding to the 20/2017 NEG Archive (DPEERT/DERT) in collaboration with CDTI and the European Union.

In early June 2019 we worked with the ILRS Analysis Standing Committee to re-join the ILRS network. From then until the end of December our data were under quarantine, performing an intensive campaign specially focused on the LAGEOS-1, LAGEOS-2, and LARES satellites. On November 27, 2019 we were informed that the station passed the evaluation phase, and that it was accepted again as member of the ILRS network.

Table 8-7. Tracking statistics for the San Fernando station (2016-2019).

	2016				2017				2018			2019		
Mon.	LEO	LAG.	HEO	Inactive collab. objects	LEO	LAG.	HEO	Inactive collab. objects	LEO	LAG.	Space Debris	LEO	LAG.	Space Debris
Jan.	99	3	2	1	53	4	0	0	0	0	2	38	3	46
Feb.	0	0	0	0	27	0	0	5	0	0	0	40	2	50
Mar.	9	0	0	0	96	0	0	9	0	0	0	55	12	59
Apr.	159	4	4	6	40	4	4	12	2	4	33	24	0	45
May	191	0	0	23	121	0	0	19	41	14	166	67	18	47
Jun.	340	3	0	39	101	3	0	13	37	10	80	65	7	35
Jul.	231	0	0	45					7	3	74	17	11	86
Aug.	291	26	0	43					13	10	39	141	23	85
Sep.	102	2	1	14					25	0	85	49	35	19
Oct.	65	2	0	29					30	5	46	12	51	0
Nov.	19	0	0	8					15	1	26	33	23	0
Dec.	64	0	0	20					40	3	60	30	5	0

System Improvements

Along 2016 it was noted a progressive deterioration in the state of various components, with the corresponding lost in performance. Likewise, between January and February 2016, mirrors were re-coated. In the month of April 2017, we checked the optical components to prepare the station for an SST evaluation campaign that finally took place in the month of June. Once this campaign ended, the laser bench was dismantled. We received a new laser bench (EKSPLA NL317 NS) in July 2017. This laser bench was specially prepared for tracking non-collaborative objects. Between August to December, 2017, a series of severe modifications were carried out aimed to integrate the new laser bank. Finally, in November 2017, first echoes were obtained from non-collaborative objects. In December 2017 we received the new laser bench. It was an EKSPLA PL2251 PS. This laser bench was conceived to fulfil normal active satellite tracking under ILRS rules.

During 2018, actions continued to improve and update the laser tracking system on non-collaborative objects. This leads to building new software to control the new laser bench. Likewise, air safety control software was developed. We included OCR readers that provided azimuth and elevation data, as well as sound alarms indicating the presence of aircraft into a pre-set safety sector at both sides of the laser beam while shooting. During the first semester, actions were carried out to put into operation the new picosecond laser bank. In March 2018, after a period of abnormal behavior the SPAD sensor is disassembled and sent to the Graz Observatory to be repaired. We received it once repaired on the 20th of that month.

On February 26, 2019, a new SAP-500 sensor was received. It was specific for space debris detection. A major issue affected the station from June to December. Our C-SPAD didn't work properly. The signal to command the reception of photons was not received properly. As the issue remained and was not solved we started developing a new system based on Programmable Logic Technology (FPGA board). On December 23, 2019, this new system became operative.

Figure 8-72. The laser bench installed at the San Fernando SLR station.

Current Challenges and Future Plans

Our main goal for the 2017-2019 period was to put into operation the new picosecond laser bench and join again the ILRS activities. Next we plan to change the telescope mount, including new absolute encoders. This will allow us to achieve 2 arc seconds as angular precision. This process was intended to start throughout the year 2020. Due to the current circumstances (COVID-19) the start remains uncertain.

Station Personnel

- Manuel Catalán, Head of Geophysics Department (mcatalan@roa.es)
- Manuel Sánchez-Piedra Head of SLR station (msanpie@roa.es)
- Manuel Larrán, hardware and operations team (mlarran@roa.es)
- Jesús Marín, hardware and operations team (jesusmarin@roa.es)
- Luis Cortina, hardware (lmcortina@roa.es)
- Jesús Relinque, software engineer (jrelinque@roa.es)
- Angel Vera, software engineer (avera@roa.es)
- Franco della Prugna, collaborator (fdellap@gmail.com)

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	San Fernando (Cádiz)		
	SPAIN		

Sejong, Republic of Korea

Author: *Hyung-Chul Lim*
Responsible Agency: Korea Astronomy and Space Science Institute

System: SEJL/7394
Location: Sejong, Republic of Korea
Latitude: 36.52099° N, Longitude: 127.302913° W, Elevation: 176.415 m

Station Operations

The Korea Astronomy and Space Science Institute has been operating the Sejong station since 2015 for the researches of space geodesy, geophysics and precise orbit determination. The Sejong station, the first SLR station in Korea, is located at Sejong city, administrative capital of Korea, for establishing the core station of Global Geodetic Observing System (GGOS). It had been continuously operated for 24 hours until the middle of 2018, but now is being operated only for night due to the limited budget of station operation.

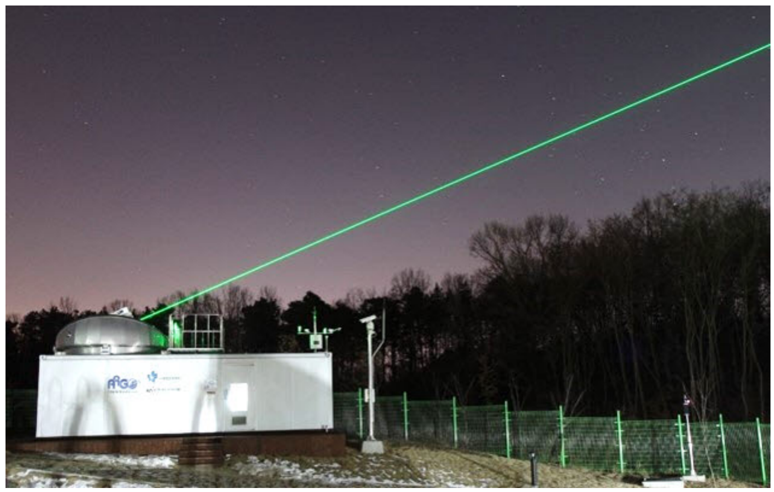

Figure 8-73. Sejong SLR system.

System Improvements

The SLR system is designed to enable kHz laser ranging in both daytime and nighttime tracking of satellites at altitudes between 300 km to 25,000 km. It has a bi-static optical path employing the 40 cm receiving and 10cm transmitting telescopes, and its repetition rate is 5 kHz to research the satellite spin dynamics.

The RGL-532 model of Photonics Industries (USA) is used for the laser system, which is an Nd:YAG pulse laser: 532nm, 2.5 mJ/pulse, 50 ns pulse width, 5 kHz repetition rate, 0.56 mrad far-filed divergence in full angle, 1.26 M2. The optoelectronic controller generates a laser fire command and the range gate (RG) for C-SPAD activity based on the predicted TOF, which is implemented by the field programming gate array (FPGA) board for a fast functional operation. But in the case of ground calibration, it generates a laser fire command and the RG directly without any information of time-of-flight (TOF) because the stop pulse arrives at the C-SPAD preceding the RG signals due to the short distance of the ground target. The SLR system uses the A033-ET model as an event timer which records the epochs of start and stop signals and then puts them into buffer for the implementation of kHz laser ranging.

The laser safety issue is very important in Korea. So, the SLR system uses a radar to provide a means of detecting aircrafts before they intersect a transmitting laser beam which can damage eyes of pilots. The radar pedestal is slaved and bore sighted to the laser-transmitting telescope. If the radar detects aircrafts or it is not synchronized with telescope direction, it sends a signal to the laser system to block the transmitting laser beam.

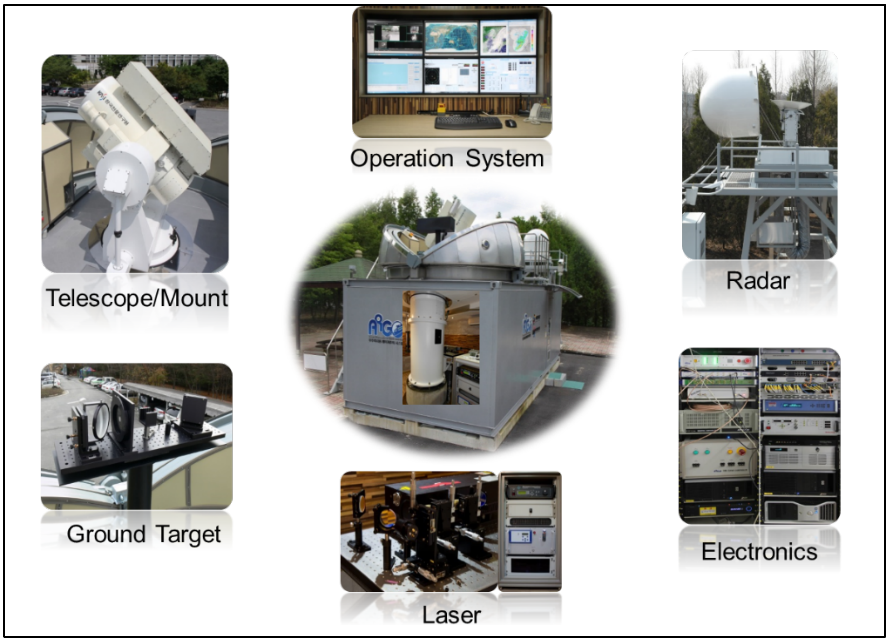

Figure 8-74. Configuration of subsystems of the Sejong SLR system.

Current Challenges and Future Plans

The Sejong station is the member of ILRS tracking network as well as the core station of GGOS which consists of Very Long Baseline Interferometry (VLBI), Global Navigation Satellite System (GNSS) and SLR system. The VLBI system has a 22m Cassegrain antenna, a hydrogen maser atomic clock and a four-channel receiver using 2, 8, 22 and 43 GHz frequencies. There are a lot of survey monuments and pillars inside the core station. So, the local tie survey will be completed in 2020 and then the survey results will be released for a contribution to the International Terrestrial Reference Frame (ITRF).

Station Personnel

- Mansoo Choi (Project Manager)
- Seung-Yeol Yu (Optical Engineer)
- Eunseo Park (Scientist of Data Processing)
- Ki-Pyoung Sung (Software Engineer)

Contact

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	REPUBLIC OF KOREA		

Shanghai, China

Author: *Shanghai Astronomical Observatory's SLR Staff*
Responsible Agency: Shanghai Astronomical Observatory, Chinese Academy of Sciences

System: SHA2/7821
Location: Mount Sheshan, Shanghai, China
Latitude: 31.0961° N, Longitude: 121.1866° E, Elevation: 99.961 m

Station Operations

The Shanghai SLR station is located at the top of Western Sheshan mount in the city of Shanghai, China, close to the Sheshan Church. The Shanghai SLR station operates about 20 hours per day (during clear skies), routinely performing 1 kHz SLR measurements. The total passes are over 5000 for tracking LEO, LAGEOS, MEO, and GEO satellites during the 2016-2018 time period with ranging precision on LAGEOS and Starlette at about 7-8mm. The technologies of space debris laser ranging, infrared SLR measurements, and laser time transfer are also developed by using the standard SLR system.

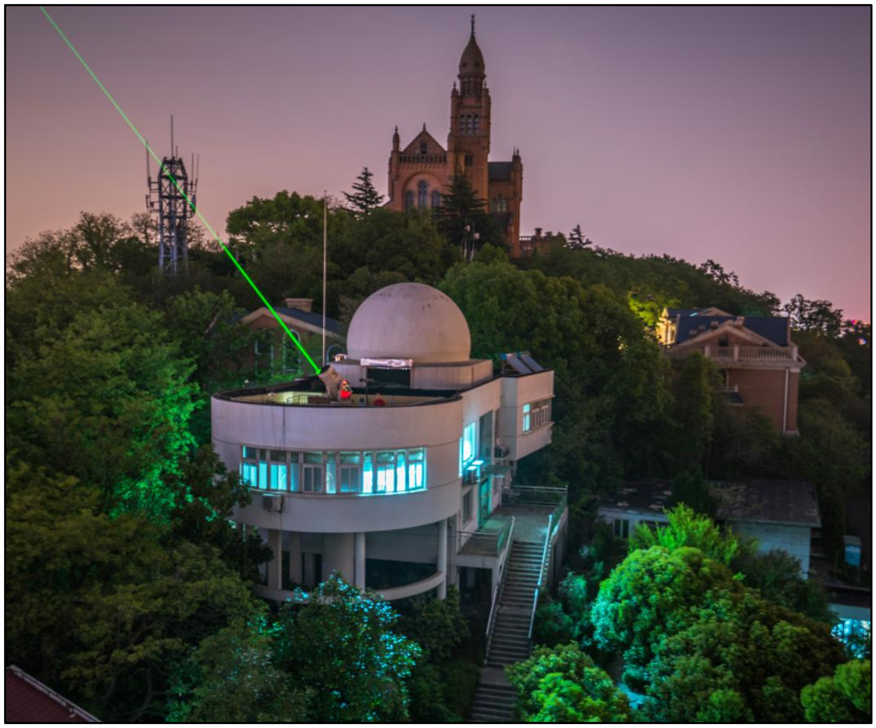

Figure 8-75. Shanghai Astronomical Observatory's SLR system.

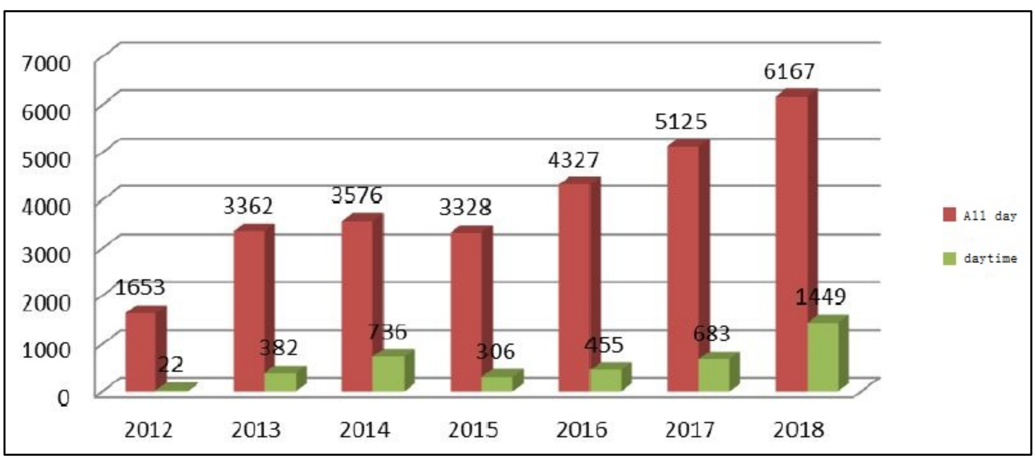

Figure 8-76. Observation statistics from the Shanghai SLR system since 2012.

System Improvements

- Improvements of data quality of ranging to the LAGEOS satellites: The long-term stability, short-term stability, and normal point accuracy have been improved from more than 10mm, 20mm and 2.0mm to less than 5mm, 10mm and 1.0mm by updating the SLR system, such as the shift of timing device into the clean room, changing the signal cables, and calibration.

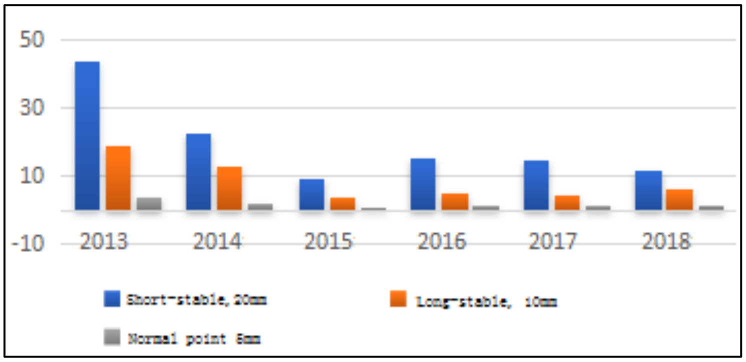

Figure 8-77. LAGEOS satellite's stability at Shanghai astronomical observatory's SLR since 2013.

- 4kHz repetition rate SLR measurements: Updating range gate generator and laser system with repetition rate of 4kHz, power of 3W of wavelength of 532nm; 4kHz SLR measurements are performed to improve the amount of laser data and precision of the normal points.
- Pico-second-laser tracking space debris: The pico-second laser tracking of space debris targets was achieved with a 4.2W double-pulse 532 nm pico-second laser at the pulse repetition frequency of 1kHz; compared with the nanosecond laser system, the advantages of pico-second laser signal are apparent in the aspect of laser divergence, far field pattern, and atmospheric effect.
- Bilateral SLR measurements to space debris: Through solving the synchronization of range gate and timing system between two SLR telescopes with the distance of 2.5km, the bilateral SLR measurements with similar two systems of 60cm telescopes to space debris was performed with the measured range of more than 1000km.
- Infrared SLR to space debris: Updating the high power laser system with the output of 1064nm laser signal, the infrared SLR to space debris was successfully realized by using the infrared detectors and laser beam guiding camera.
- Transportable cabin-based SLR system: One set of transportable cabin-based SLR systems with 60cm aperture telescope which is under development in Shanghai SLR station during 2018-2020, including the transportable cabin, tracking telescope mount, laser system and SLR control system; the potential working sites will be located in the northwestern China in the 2020.
- Development of new generation of Laser Time Transfer: The project of Laser Time Transfer (LTT) in the Chinese space station is underway in order to implement LTT measurements between ground and space station. The LTT payload is being developed by the Shanghai SLR station; the design of the detector and timer, the optical design are preliminary tested.

Current Challenges and Future Plans

In the next two years, Shanghai Astronomical Observatory's SLR station are planning to do the following activities:

- Routine SLR measurements with 1064nm wavelength with high precision
- Two color (1064nm/532nm) SLR measurements

- Developments of automated SLR measurements
- Space debris laser ranging with large energy of burst pulses pico-second laser system at 1 kHz

Station Personnel

- Zhongping Zhang: Director of SLR station
- Zhibo Wu: Manager, electronic
- Juping Chen: Electronic, system
- Haifeng Zhang: Data processing, software
- Pu Li: Mechanical
- MingLiang Long: Laser, optics
- Huarong Deng: Optics, system
- Yan Li: Software, mechanical

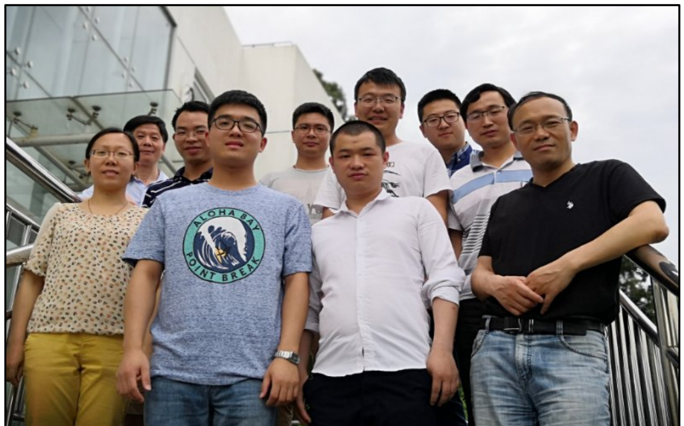

Figure 8-78. Shanghai SLR station staff and graduate student.

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System: SISL/7838
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Station Operations

The Shimosato Hydrographic Observatory (SHO) is located in the south of Kii Peninsula, central Japan, the southernmost part of the Honshu Island (the main island in Japan). Satellite laser ranging observations are routinely performed for 15-18 hours every day from 00:00 UTC (09:00 in JST) with 30-ps laser pulse (wavelength of 532 nm) oscillating at 1 kHz (at a maximum) at 3 mJ output. Recently, the Shimosato system has had difficulty with daytime observations.

Figure 8-79. Simosato laser ranging station.

System Improvements

In the SHO, the laser system, as well as the associated equipment and control unit, were updated in the October through December 2018 timeframe, i.e., from a flash-lamp-pumped YAG to a diode-pumped YAG.

Current Challenges and Future Plans

It is necessary to improve the laser ranging accuracy at the station, which is, of course, an important and common issue at all stations. It is also needed to solve the above-mentioned issue related to the difficulty in daytime ranging in our station.

Station Personnel

- Noritsune Seo: Chief
- Hidekazu Inoshiro: Deputy Chief
- Tomohiro Kinugasa: Staff member
- Masahito Nakanishi: Staff member

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Stuttgart, Germany

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Responsible Agency: German Aerospace Center (DLR) e.V.

System: UROL/7816
Location: Stuttgart, Germany
Latitude: 48.7824° N, Longitude: 09.1964° E, Elevation: 399 m

Figure 8-80. Twilight inside the dome at UROL.

Station Operations

The Uhlandshöhe Research Observatory (UROL) is operated by the Space Debris/SSA research group of the German Aerospace Centre's Institute for Technical Physics. The site was built as a test-site for space debris research, and this objective led to the development of the UROL SLR station.

UROL is located on a hill, only a few 100 meters from Stuttgart's main train station. The site is leased by DLR from the 'Schwäbische Sternwarte e.V.' amateur astronomy club, which has had a presence there since 1922, when the tower and dome (now a listed building) was constructed.

2016 – 2018 was a very eventful period for UROL. The station achieved first returns in December 2015 and joined the ILRS as an Engineering Station in 2017. Although, there are currently no routine SLR operations at UROL, the station is operated on a campaign by campaign basis.

Because tracking is performed closed-loop, using a tracking camera, the station is limited to night-time operations only. UROL is capable of SLR to LEO and GNSS, but not lunar ranging.

System Improvements

The station operates at 1060.8 nm and is unique in the ILRS in using an optical fiber, rather than a coudé path to couple the laser to the transmitter.

Fiber-coupling has resulted in a reduced cost and complexity system which is easier to maintain and upgrade[1]. A drawback of the current configuration at UROL is that long duration pulses (10 ns) are required to reduce the peak power density sufficiently to avoid damage to the optical fiber. The divergence of the transmitter is also relatively large, owing to the use of a multi-mode fiber.

The result of this is that UROL has relatively poor single shot accuracy of around 60 cm, and return ratios of around 0.1% for LAGEOS. To compensate for the low single shot accuracy, the system uses very high repetition rate and in 2018 DLR began operating the station at 100 kHz.

At these high repetition rates conventional pulse collision avoidance becomes difficult, and so the station is operated in ‘Burst Mode’, where the laser is gated into bursts which are one time-of-flight long. This results in an effective pulse repetition rate which is approximately half of the laser’s true pulse repetition frequency. UROL currently operates at 200 kHz pulse repetition frequency (100 kHz effective).

The increased performance at 100 kHz allows UROL to measure LAGEOS normal points with precision on the order of 10mm, and led to UROL’s first successful ranging to GNSS in 2018.[2]

For reference, the parameters of UROL’s laser as of 2018 (JenOptik JenLas fiber ns 70) are shown below:

Center wavelength:	1060.8 nm
Spectral Bandwidth (FWHM):	4 nm
Pulse energy (at laser):	80 µJ
Pulse energy (at transmitter):	50 µJ
Pulse duration:	10 ns
Repetition rate:	200 kHz (100 kHz effective)

In 2016, DLR developed “Orbital Objects Observation Software (OOOS)”, a cross-platform, modular and hardware-independent control software and user interface written in Python 2.7 (with some supporting functions in C) [3]. The project was ported to Python 3 and made open source in 2018.

Current Challenges and Future Plans

The choice of single photon detectors which are sensitive to 1060.8 nm light is limited. The IDQ400 detector used at UROL has a relatively small detector size of 80 µm which results in a small field of view for the detector. This field of view is smaller than the blind-pointing accuracy of the system, which is why UROL is currently not capable of blind-tracking, and by extension not capable of ranging during daylight.

Improved fiber coupling: The limitations of the optical fiber, mentioned in the previous section, are by no means hard limits for fiber-coupled SLR. The divergence of the transmitter would be greatly improved by coupling into a single-mode, rather than multi-mode optical fiber. The peak-power limit, which necessitates long duration pulses, could similarly be improved through the use of a hollow core fiber or LMA (large mode area) fibers.

In principle the repetition rate of the laser can also be increased further, before range ambiguity effects become significant. The JenLas laser can operate at repetition rates up to 1 MHz and we intend to

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[1] Hampf, Sproll, Wagner et al. (2016). First successful satellite laser ranging with a fibre-based transmitter. Advances in Space Research. 58. 10.1016/j.asr.2016.05.020.

[2] Hampf, Schafer, Sproll et al: Satellite Laser Ranging at 100 kHz pulse repetition rate, CEAS Space Journal (2019).

[3] Hampf, Sproll, Hasenohr (2017) OOOS: A hardware-independent SLR control system. ILRS Technical Workshop, 02.-05. Oct. 2017, Riga

investigate extremely high repetition rates, where the ambiguity problem can be tackled by using chirped pulses. This will likely only become feasible when the fiber is improved to allow higher power.

DLR is currently experimenting with fiber coupled detector(s) which will allow for more complex & heavier instruments with no loss of tracking performance.

Improved aircraft safety: A considerable amount of work is being carried out to ensure the safe operation of lasers in open airspace. UROL is located only 11 km from STR international airport. This, combined with UROL's proximity to the city center, results in aircraft frequently flying low, close to the station, making laser safety critically important.

There is an increasing probability that UROL may be decommissioned within the next two years. The lease on the site will expire in 2020, and we are therefore winding down station operations. The technology developed for UROL and lessons learned are being applied to DLR's 3 new SLR projects: miniSLR, STAR-C, and MS-LART.

Station Personnel

- Ewan Schafer: Station manager
- Daniel Hampf
- Paul Wagner
- Wolfgang Riede: Head of department

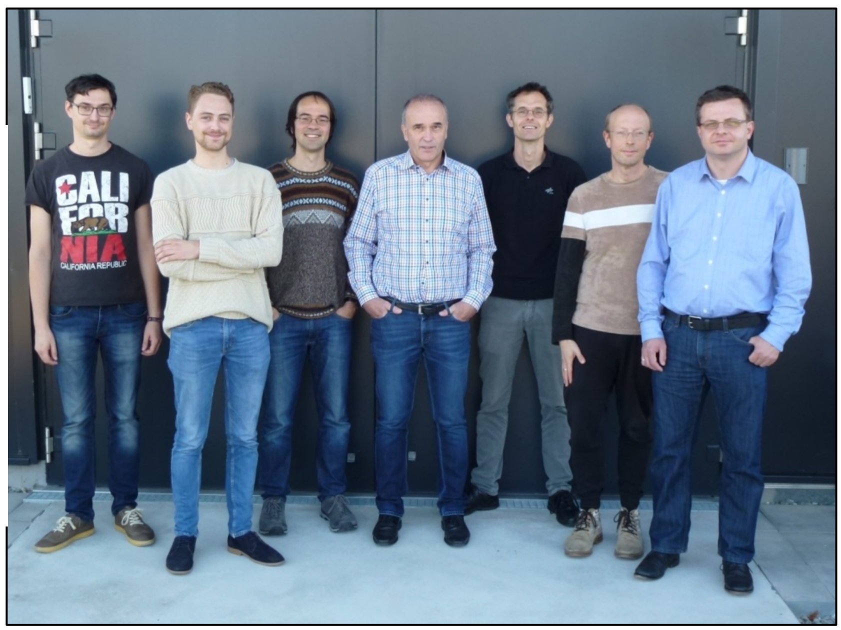

Figure 8-81. The staff of the Institute for Technical Physics, Active Optical Systems, SSA/Space Debris Research Group.

From left to right: Paul Wagner, Ewan Schafer, Daniel Hampf, Wolfgang Riede, Jens Rodmann, Stefan Scharring, Gerd Wagner

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Svetloe, Russia

Authors: *Iskander Gayazov, Viktor Mitryaev*
Responsible Agency: Institute of Applied Astronomy (IAA RAS)

System: SVEL/1888
Location: Svetloe, Leningradskaya District, Russian Federation
Latitude: 60.5332°N, Longitude: 29.7805°E, Elevation: 69 m

Station Operations

The Svetloe SLR station (SVEL/1888) is located in the Leningradskaya region near Saint Petersburg at one of three observatories of the "Quasar-KVO" VLBI network. The observatory is a co-location site with two radio telescopes (RT-32 and RT-13), "Sazhen-TM" SLR system, GNSS receivers, and a water vapor radiometer. The SLR system has day and night cameras and holographic filter (0,1 nm bandpass) which allows all day functioning. In spite of a relatively small aperture of the telescope (25 cm) and low pulse energy (2,5 mJ), the laser system is capable of conduct observations of satellites with the orbits up to 40000 km.

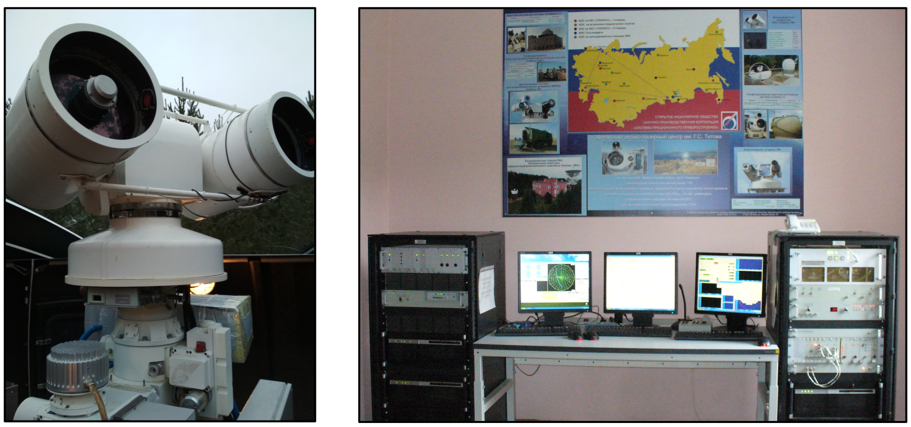

Figure 8-82. "Sazhen-TM" laser system (left) and the laboratory equipment of the system (right).

Figure 8-83. The SLR system building (left) and VGOS antenna of RT-13 radiotelescope (right).

System Improvements

In 2018 new star calibration software was installed at the station. This software allows staff to make angular corrections automatically and improves tracking capabilities enormously, in daytime especially.

Current Challenges and Future Plans

The main problem is the obsolescence of the laser emitter of the system. This leads to the need to repair the laser every few years. The current laser has a pulse width worse than 300 ps. This is the main reason for the current level of single shot RMS (3-4 cm). The main task for the future is to modernize the system and improve the RMS up to 1 cm. To reach this goal the replacement of the laser with new equipment which has a ~50 ps pulse width is planned. The next step is to replace the time interval counter and to increase the repetition rate from 300 Hz up to 600 Hz. These plans are expected to be implemented after 2020.

Station Personnel

The laser system at the observatory is maintained by the staff of operators, who work in shifts (two operators per shift). All operators are capable to carry out both VLBI and SLR observations even if they occur at the same time. The observation results are sent via network transmission to the processing center at IAA (Saint-Petersburg). There ,the data are processed and sent to EDC and other users. Repairs of the system and overall operation are conducted by the lead engineer Viktor Mitryaev.

The station operators are as follows:

- Victoria Baikova
- Olga Isaenko
- Vera Kirillova
- Natalia Slobozhaninova
- Julia Shumilova
- Olga Gribova
- Maria Kirillova
- Oksana Kuzmina
- Tatiana Oiya

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Tahiti, French Polynesia

Author: *Yannick Vota*
Responsible Agency: Université de la Polynésie Française

System: THTL/7124
Location: Tahiti, French Polynesia
Latitude: 17° 34’ 36.6’’ S, Longitude: 149° 36’ 22.3’’ W, Elevation: 99 m

Figure 8-84. The MOBLAS-8 system located in Tahiti, French Polynesia.

Station Operations

The station operates 16 hours/day, 4 days/week.

System Improvements

1. Two Harmonic Drives EC-1890B were installed in the radar and the resolver core nuts were secured with blue Loctite. The radar was aligned and verified using a recently installed cell tower and a peak on the distant island of Moorea. The alignment was verified by tracking one ferry boat and by tracking two groups of balloons carrying aluminum foil reflectors. No airplanes were tracked above twenty degrees, since no airplanes fly directly over the island and airport. Commercial airplanes landing and taking off never exceed the twenty degree elevation limit set for laser tracking.
2. Dual Power Amplifier EC-1559B was installed and verified operational.
3. MET-4 Meteorological System was relocated from the side of the Tracking Trailer and away from the Chiller exhaust and heat of the trailer. The new location is an extended pole on the back fence. The height of the barometer sensor was maintained to the center of the tracking mount.

4. ARSU Repair (Mantis 1075) The Amplified Receive Selection Unit (ARSU) was repaired by changing two cards and an amplifier module. The amplified mode was verified by performing valid amplified calibrations.
5. Encoders: The two system encoders and one spare were rebuilt with non-corrosive integrated circuits and verified in the Mount Position and Control System (MPACS).
6. Cable Arm: Since a lot of paint was missing from the cable arm . It was painted flat black to reduce the laser reflections when performing tracking operations. Brackets were installed on the cable arm to hold the cables.
7. Receive Cable: The bad receive cable was replaced and this reduced calibration RMS from 6.8 to 5.6 millimeters. The station has two additional spare receive cables in stock.
8. Installed the Event Timer EC-1169B and verified the input signals to the Event Timer (ETM) and Event Timer Computer (ETC). During verification a software error indicated a timing board failure in the ETC computer.

Station Personnel

Figure 8-85. Tahiti station personnel: (left to right), Jean-Pierre Barriot (station manager), Yannick Vota, Youri Verschelle, James Levreault (technicians).

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Tanegashima, Japan

Authors: *Shinichi Nakamura, Takehiro Matsumoto, Takushi Sakamoto, Kazuhiro Yoshikawa*
Responsible Agency: Flight Dynamics Team, JAXA

System: GMSL/7358
Location: Tanegashima, Japan
Latitude: 30.5565° N, Longitude: 131.0154° E, Elevation: 141.0967 m

Station Operations

The Tanegashima SLR station is located southwest of Japan and operated by remote control from Tsukuba Space Center. The system has been operated since April 1, 2004, and is capable of ranging to various satellites from LEO to GEO.

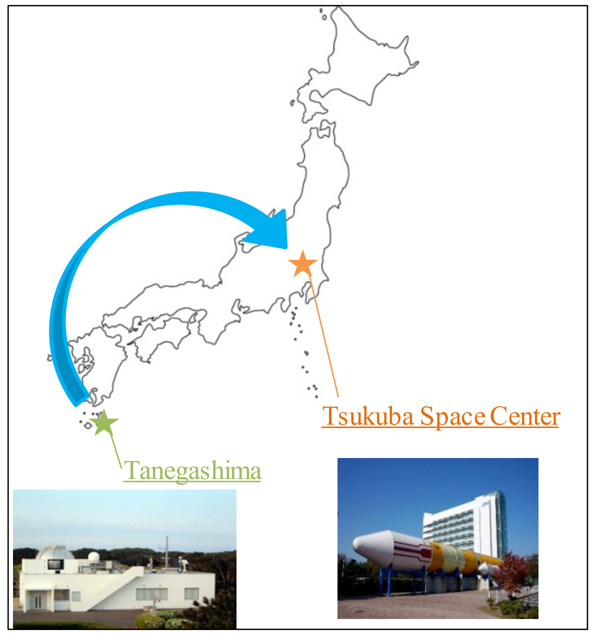

Figure 8-86. Tanegashima SLR station.

System Improvements

In 2012, due to SLR system problems, the Tanegashima station fell into the category of a “quarantine” station. After that, the station was used for tracking satellites, especially LAGEOS-1, LAGEOS-2, and LARES. During 2016-2018, the station was intensively tracking those satellites. However, another mechanical issue (failure of the focus mechanism of the telescope), prevented the station from returning to the operational station category. After the problem was fixed in July 2017, the station once again became capable of obtaining ranging data efficiently. In 2016, the station acquired 20, 5, and 19 passes of LAGEOS-1, -2, and LARES respectively. In 2017, the number improved to 16, 28, and 30. Unfortunately, due to the bad weather conditions, the Tanegashima station has not returned to the normal, operational category yet. Currently, Tanegashima station is still tracking those satellites, and its main focus now is to track QZSS to support the Japanese government by submitting CRD by email.

Current Challenges and Future Plans

In October 2017, a challenge to track space debris with high orbit mode, that is, 250mJ, 10Hz, 250 ps pulse width, was conducted several times. We succeeded in tracking space debris a few times, and the RMS of residuals (O-C) was 1 – 2 [m]. It was found that it is not so easy to track space debris because of the weak return rate and the bad accuracy of the orbital prediction.

From the middle of 2018, JAXA started developing a new SLR station where recent trends in SLR community such as kHz ranging, equipment downsizing, and 1064 nm wavelength will be introduced. The new SLR station will be built at the Tsukuba Space Center, where the weather conditions are much better than that of Tanegashima. The bid was finished in December 2018, and we are now in the design phase. According to the master schedule, the new station will start operating in April 2021, when the Advanced Land Observing Satellite 4 (ALOS-4) requires precise orbit determination.

Station Personnel

In 2019, our Flight Dynamics Team at JAXA, consisting of a manager and five energetic staff members, will take over the research and maintenance of SLR from the Network and Communications Team. We will do our best to meet ILRS expectations.

Figure 8-87. Tanegashima SLR station staff, left to right: Takushi Sakamoto, Takehiro Matsumoto, Yuki Akiyama, Shinichi Nakamura, and Kazuhiro Yoshikawa.

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	Space Tracking and Communications Center		
	JAPAN		

TROS Mobile System, China

Authors: *SLR Group*
Responsible Agency: Institute of Seismology, China Earthquake Administration, Xinjiang Astronomical Observatory , Chinese Academy of Sciences

Station Operations

Supported by the Crustal Movement Observation Network of China (CMONOC), the Institute of Seismology, China Earthquake Administration (ISCEA) reached a cooperation agreement with Xinjiang Astronomical Observatory, Chinese Academy of Sciences (XAO, CAS), to establish a SLR site in XAO with TROS1000 under the coordination of Chinese SLR network.

TROS1000 is a 1-m-diameter mobile Satellite Laser Ranging (SLR) system with a damping system for transportation and a detachment support system for observations (see Figures 8-88 and 8-89).

On August 29, 2019, TROS1000 set out from Xianning, Hubei Province, crossed about 3400km, passing through five provinces of Hubei, Shanxi, Ningxia, Gansu and Xinjiang. After a seven day journey, overcame various road conditions, TROS1000 reached Nanshan Observatory of XAO.

On September 19, 2019, TROS1000 successfully carried out the first day of observations, respectively observing high, medium and low orbit satellites, which is also the first time to obtain kHz mobile SLR data in Western China. As of October 13, 2019, the total number of observation quantities is 123 passes, including 69 passes of LEO satellite, 22 passes of LAGEOS satellite, 32 passes of HEO satellite. The effective observation days were 14 days, The maximum observation passes per day was 18 passes. The single accuracy of LEO satellite is better than 15mm, that of LAGEOS is better than 15mm, and that of HEO satellite is better than 20mm.

Figure 8-88. TROS1000 measurement.

Figure 8-89. TROS1000 system.

Station Personnel

Figure 8-90 shows the crew of TROS1000.

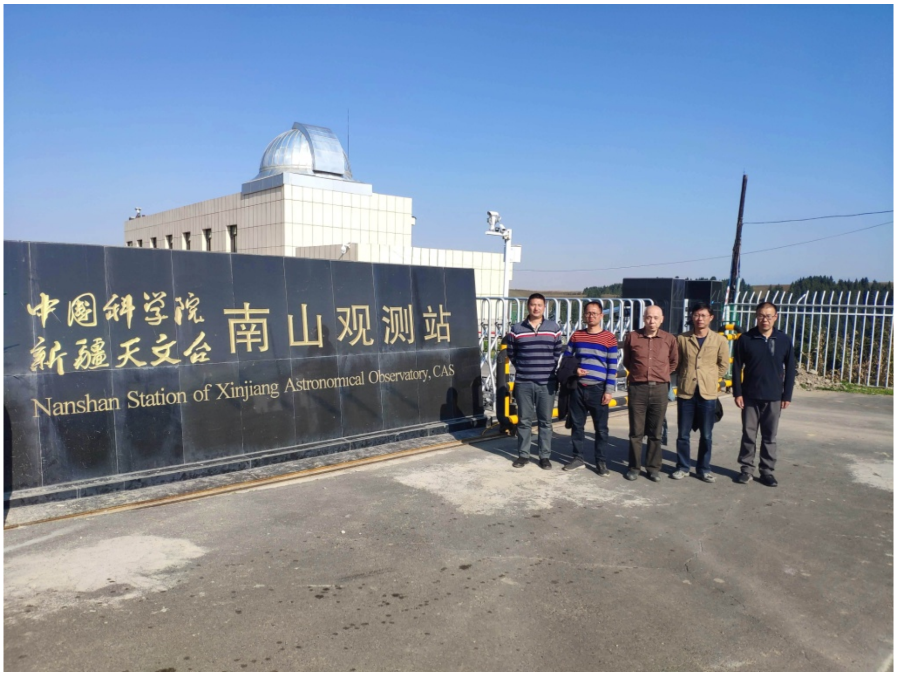

Figure 8-90. The crew of TROS1000.

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Wettzell, Germany (WLRS and SOS-W)

Author: *Johann Eckl, Stefan Riepl*
Responsible Agency: Federal Agency for Cartography and Geodesy (BKG)

System: WLRS/8834 and SOS-W/7827
Location: Wettzell, Germany
Latitude: 49.1449402° N, Longitude: 12.8781000° E, Elevation: 663.174m

Station Operations

The Geodetic Observatory Wettzell is a fundamental station that operates all four major geodetic techniques, namely SLR, VLBI, GNSS, and DORIS. SLR is carried out by two independent system, the WLRS (Wettzell Laser Ranging System) and the SOS-W (Satellite Observing System-Wettzell). Wettzell is located in the south-east of Germany, in the Bavarian Forest. The WLRS, as well as the SOS-W system, are fully dedicated to geodetic observations. Therefore, Satellite Laser Ranging measurements are performed on a 24/7 basis, whenever the weather permits. Observations are conducted from the laser team with support from colleagues from other disciplines at the Geodetic Observatory Wettzell and student observers.

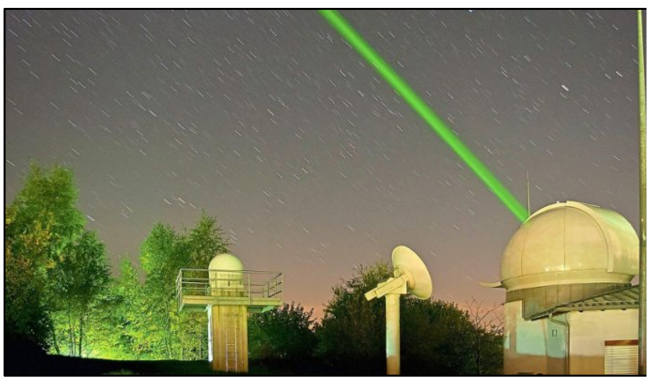

Figure 8-91. WLRS operating at night.

Figure 8-92. SOS-W laser dome.

WLRS: After two years with a moderate number of passages in 2016 and 2017, during 2018 a new passage record with 9516 passages could be obtained due to exceptionally good weather. In 2018 successful Lunar Laser Ranging (LLR) tests were also conducted in the near-infrared. From 2018 on LLR is also considered as a permanent task in the schedule of the WLRS. Due to the poor atmospheric condition at Wettzell, typically the air is rather wet and turbulent in this area, LLR is performed at an elevation of the Moon, above 50 degree only.

SOS-W: During the report period 2016 to 2018 the SOS-W, situated in Wettzell and co-located with WLRS and RTW (VLBI), was operated in 12/7 mode predominantly during the night. After the last issues concerning the telescope transmit optics were resolved in 2015, the system was running stable throughout the reporting period, with an exception of the summer 2017, where an issue occurred with the azimuth drive gear box, which required a modification of the lubrication concept. Investigations on how to resolve that issue in a permanent manner are still ongoing today.

System Improvements

SOS-W: Since November of 2016 the SOS-W operates exclusively in autonomous mode, i.e., the SLR system performs automatic scheduling and interleaving based on an algorithm, which was demonstrated at the 2017 ILRS Technical Workshop in Riga. As the primary in sky laser safety system is still a work in progress, operations are restricted to nighttime only. But the impact of switching to autonomous mode can be clearly seen by the improved data yield obtained from a better efficiency, due to the kHz- repetition rate operations.

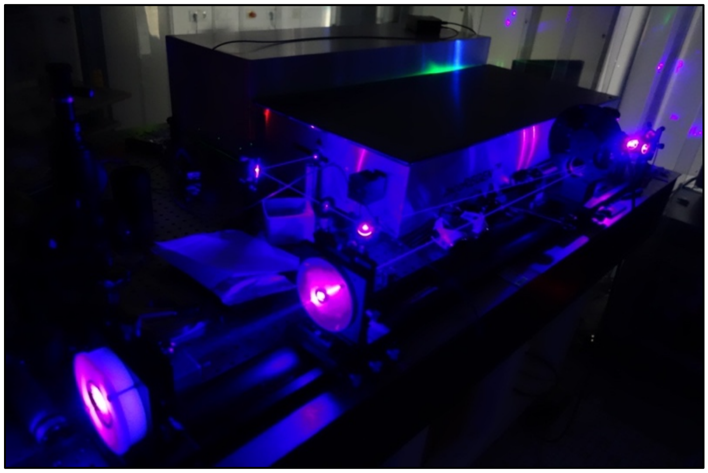

Figure 8-93. Operations of the Ti:Saph laser of the SOS-W.

WLRS: Because the radar-system of the WLRS developed performance issues over the years and because it was not compliant with the VLBI receivers of the TWIN radio-telescopes at the GOW, a new In-Sky-Safety concept was developed. The new safety system consists of sensors optimized for object detection at large and short distances. The primary in-sky-safety method for large distances is a real-time data stream of aircraft positions from the radar network of air traffic control in the region around Wettzell. This method is supported by an ADS-B receiver for redundancy. For short distances, an infrared camera for detecting hot objects in front of the cold atmospheric background was installed as the primary system. All safety methods support each other in a cooperative way on short as well as on long distances.

In 2016, our contribution to the ESA GSTP Project "Accurate orbit determination of space debris with laser tracking/tasking," which was conducted together with the colleagues from Technical University Munich, DLR Stuttgart, Observatory Graz, and ESA Darmstadt, could be finished successfully. The result was a demonstration of the capability of ranging debris targets in diverse configurations like single station, bistatic, multi-static, and with multiple laser wavelengths involved.

In 2017, ranging tests to the ISS were made in preparation of the ELT time transfer experiment. The goal was to identify spurious reflections from other retro-reflectors installed on the ISS. It was found that an additional algorithm is required to discriminate between spurious returns and the true ELT echoes.

In 2018, returns from the lunar retro-reflectors were detected, a long time since the last attempts by the system in the early 90s. The signal strength was close to the expected theoretical value. Usually about 20 to 30 lunar echoes are obtained in a 15 minute observation interval. Since the single shot precision of the WLRS is well below 5 mm, this is, in principle, sufficient to achieve a normal point precision close to or even below 1 millimeter. Unfortunately, the lunar libration causes the lunar reflectors to tilt and as a result to spread the single shot precision of the WLRS – a zero signature target on the Moon would be a great improvement.

Current Challenges and Future Plans

SOS-W: Due to the co-located operations of two laser systems at one site, the work is concentrating on the definition and implementation of a combined in-sky-laser-safety concept. This task includes the commissioning of an infrared camera based safety system, with the capability of detecting aircraft at a distance of up to 50km. Results obtained so far are very promising and operability of the system is expected in 2019. Apart from that, as the SOS-W is designed to support two color laser ranging, a second detector will be installed permanently, permitting two color observations at least to LEO satellite missions.

WLRS: Just recently the WLRS was upgraded to a high repetition rate system, now ranging at 400 Hz on a mono-static telescope. For that purpose, the software and hardware interacting with the DASSAULT event-timing modules had to be rebuilt. Since the WLRS is a mono-static system, a new T/R switch had to be installed in addition. The WLRS can now be operated in a high energy mode for lunar laser ranging or debris ranging and a low energy mode at a repetition rate of up to 400 Hz for all ILRS targets. The system now routinely operates at a wavelength of 1064 nm with the option to operate at 532 nm, if required. Since the energy density at the telescope output is eye-safe at 1064 nm in the low energy mode, eye-safe operation will be possible in the future when safe switching between the operating modes is implemented.

Increasing the repetition rate of the WLRS was the first step towards an autonomous operation of the system. A big effort is now made to finish the work on the new controlling software that allows for autonomous operation of the WLRS.

The LLR capability of the WLRS is still not at the final limit. Additional technical improvements will be implemented to increase the data yield. These may include the use of adaptive optics, the implementation of a wide field of view guiding camera and an optimization of the laser post amplifier. Further improvement is expected when a still existing small scale pointing issue of the telescope is resolved.

Since the ELT mission is intended to start in 2020, the WLRS, as the primary optical ground segment, is currently upgraded to support the mission. This upgrade includes the generation of the “start-epoch” at the sub-picosecond level, the synchronization of the laser fire epochs, and the approval the required laser safety implementation.

Station Personnel

- Torben Schüler: Head of the Geodetic Observatory Wettzell
- Ulrich Schreiber: group leader “Optical Technologies”
- Günther Herold: chief engineer, SLR operations (secondary contact)
- Stefan Riepl: SOS-W system manager (optics, hardware, software, and development) primary contact
- Johann Eckl: WLRS system manager (optics, hardware, software, and development) primary contact
- Theo Bachem: IT expert, system monitoring
- Andreas Leidig: software with focus on in-sky-safety and operating system
- Swetlana Mähler: local ties
- Observer support from other groups of the GOW and student observers

Contact

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Wuhan, China

Author: *Jie Zhang, Bobi Peng, Xinghua Hao, Chongchong Zhou*
Responsible Agency: Innovation Academy for Precision Measurement Science and Technology, CAS

System: JFNL/7396
Location: Wuhan, China
Latitude: 49.1449402° N, Longitude: 12.8781000° E, Elevation: 663.174m

Introduction

Satellite laser ranging (SLR) is widely recognized as the highest accuracy technology in the field of modern space ranging, and the measurement precision and accuracy can reach a millimeter order of magnitude. The Wuhan SLR station at the Institute of Geodesy and Geophysics, Chinese Academy of Sciences (CAS) started to work in satellite laser ranging from the end of the 1970s, building the 60cm SLR telescope (WUHL, 7231). It is the one of the earliest institutes which performs research in satellite laser ranging technology and analyzes laser ranging data in China. In the middle of the 1990s, the Wuhan SLR station was moved to the Jiufeng hill at the east side of Wuhan city. Part of the hardware and controlling algorithm was updated at the end of the 1990s, and the performance reached the accuracy of a third generation SLR system. The accuracy of the 60cm SLR telescope reached 1cm to several centimeters.

The Wuhan SLR station began to build a new 1m aperture SLR telescope (JFNL, 7396) in 2015 to replace the old 60cm SLR telescope (WUHL, 7231). The new 1m aperture SLR telescope obtained its first ranging data on September 29, 2018; the system was able to range to all SLR satellites listed on ILRS website. The new system has worked normally since July 02, 2019. The pointing accuracy is less than 2 arc second after corrections were applied to the pointing model, and the tracking accuracy is less than 0.3 arc second (RMS value of O-C).The target calibration accuracy is less than 7mm, and the single shot ranging accuracy for LAGEOS observations is less than 11mm.

Figure 8-94. 60cm (7231, left) and 1m (7396, right) telescope at Wuhan SLR station.

System Operations and Improvements

The 1m aperture SLR system consists of 1m aperture telescope, mount, servo-controlling module, laser transmitting and receiving module, time and frequency module, event counter and computer controlling module, and the block diagram of the SLR system is shown in Figure 8-95. The satellite orbit prediction and laser ranging data processing are carried out in a computer control module. C-SPAD with the performances of single photon detecting sensitivity, high quantum efficiency, time drift compensation and time resolution is used to detect echoes and generate “STOP” signal of event counter. The Latvia A033 event counter is used to measure the time interval between the laser launching moment and photon echoes receiving moment. In order to realize daytime ranging in future, the narrow-band optical filter and powerful light protector will be added in conventional echoes receiving system.

The key parameters of the new 1m aperture SLR system is described as following:

- Laser: 532nm, 1.0mj @ 1kHz
- Event timer: A033, 10ps precision
- Target: ground target with 2 diffuse aluminum sheet, installed on telescope
- Detector: C-SPAD, 25ps jitter, 20% Quantum Efficiency

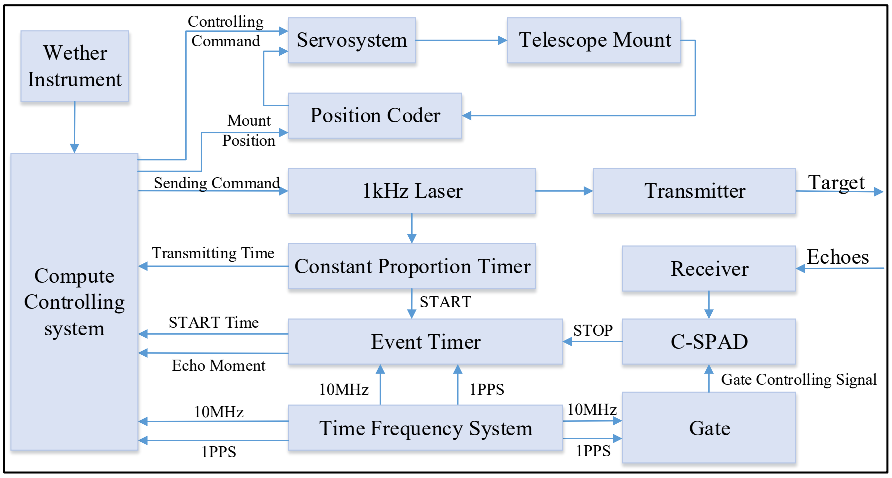

Figure 8-95. The block program of the new SLR system with 1 aperture telescope.

The ranging control software has many functions, including telescope controlling, data identification, pointing tuning, and ranging satellite selection and so on. The software is designed by the Shanghai SLR station, and shown in Figure 8-96. In addition, the post processing software is used to fit ranging data, generate CRD files (normal point and full-rate data) and analyze statistic parameters (range and time bias, rms, skew, etc.).

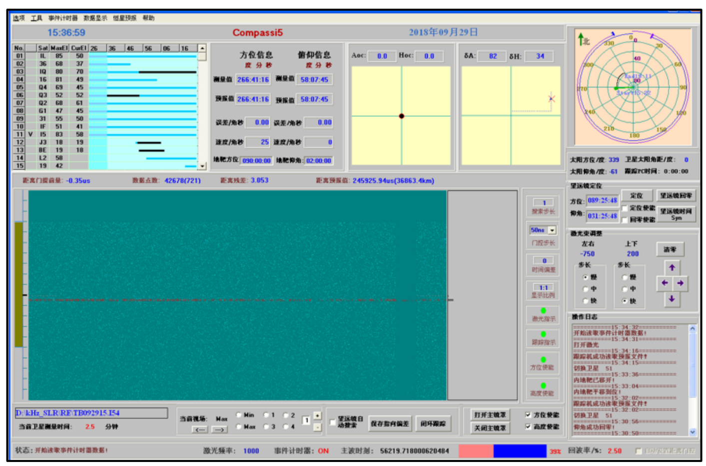

Figure 8-96. The controlling software of Wuhan SLR station.

Observation Results

Figure 8-97 shows the latest observation pass statistics from 2019-04-01 to 2020-03-31 for global SLR stations issued by International Laser Ranging Service (ILRS). The figure shows that the Wuhan SLR station obtained 1353 passes, including 528 low satellite passes, 171 LAGEOS satellite passes, 13 high satellite passes, and 641 global navigation satellite system (GNSS) satellite passes. In this year, the Wuhan SLR station obtained more ranging passes to reach the ILRS baseline of 3500 passes. Figure 8-98 shows that the accuracy of Wuhan SLR station is 10.3mm, and the target calibration accuracy is 6.6mm in this period.

Conclusion

The 1m aperture SLR system had successfully ranged to satellites on September 29, 2018. The system performs routine operations and has submitted laser ranging data to the ILRS data centers since July, 2019. Its performance has reached the baseline of LAGEOS NP RMS and short term stability. However, the problem is a reduced amount of observation passes for Wuhan SLR station. In order to reach the baseline of 3500 passes, the Wuhan SLR station will employ two full time observers this year.

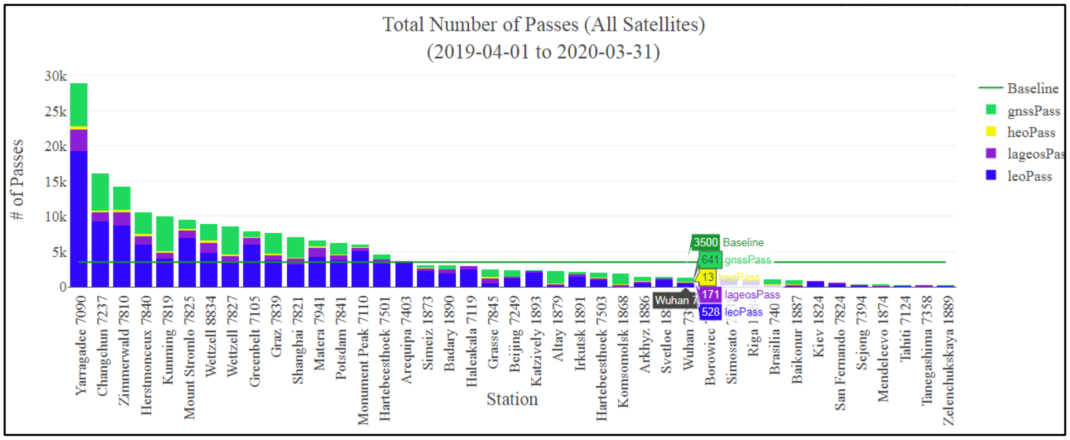

Figure 8-97. Observation passes statistics for global SLR stations.

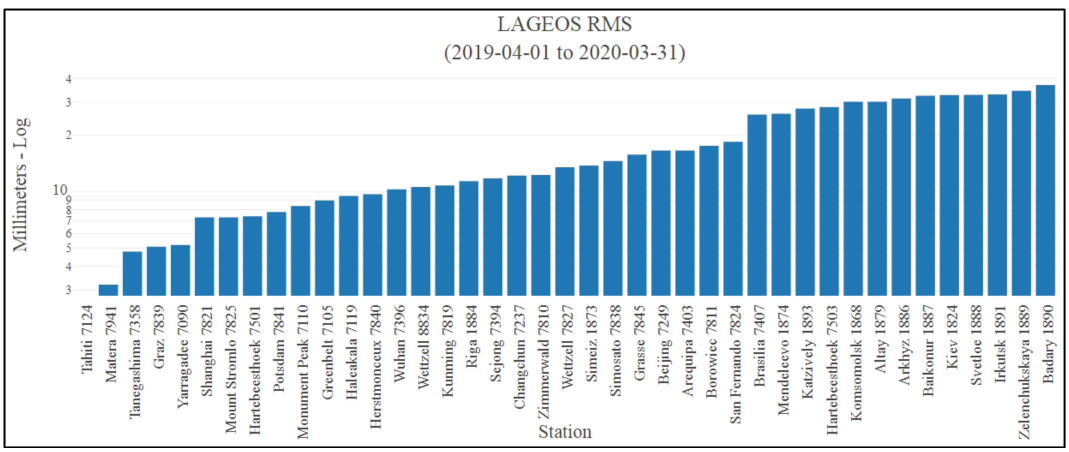

Figure 8-98. Ranging accuracy of LAGEOS satellite for global SLR stations.

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Yarragadee, Australia

Author: *Randall Carman*
Responsible Agency: NASA GSFC/Geoscience Australia

System: YARL/7090
Location: Yarragadee, Western Australia
Latitude: 29.0464° S, Longitude: 115.3467° E, Elevation: 244 m

Station Operations

The MOBLAS-5 system continues operations on a 24x7 basis as part of the Yarragadee Geodetic Observatory. The staff operates the system 12 hour, 4 days on 4 off non-rotating shifts.

The system is performing well and has maintained their position as the premier site for SLR data collection over the reporting period.

The staff also continue to operate the AUSCOPE 12m VLBI antenna in partnership with the University of Tasmania and host Geoscience Australia's GNSS CORs receivers (3+1). The site also includes a DORIS beacon and has hosted GA's FG5 absolute gravimeter three times during 2016-2019.

Figure 8-99. The Yarragadee Geodetic Observatory showing MOBLAS-5 vans with improved safety access, VLBI 12m antenna and two SAR calibration CRs.

System Improvements

The implementation of the NASA/SLR event timer in September 2017, greatly improving the single shot RMS, has been the biggest upgrade in the reporting period. Personnel have also installed safer access stairways to both the MOMS (75cm telescope), platform and instrument van.

During 2016, staff also installed a site-wide 200kVA UPS. This along with their automatic standby generator, means all equipment is much better protected from power outages and transients.

In 2018 Geoscience Australia installed two trihedral Corner Reflectors for SAR calibration.

Current Challenges and Future Plans

Some of the NASA/SLR provided operating software has become seriously limiting due to the greatly increased number of targets. NASA/SLR are working hard to upgrade the operating software but in the meantime the staff continues to develop workarounds to optimize tracking efficiencies. Link margins continue to decrease, most likely due to ageing optic coatings in the transmit and receive paths.

Personnel can already control the SLR system semi-remotely and they continue to work towards being able to operate the system completely remotely and/or semi-autonomously.

NASA/SLR are moving to a full implementation of the event timer whereby the system can operate at 10Hz for all targets.

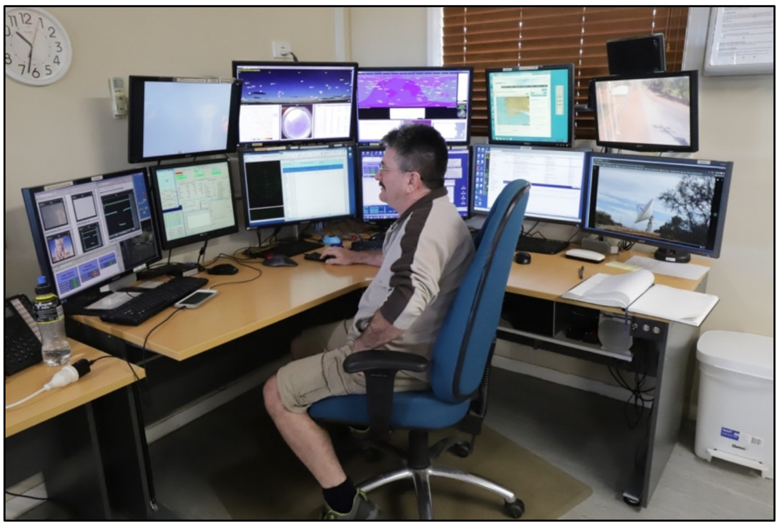

Figure 8-100. The current semi-remote operations console.

Station Personnel

In 2018 Geoscience Australia approved the increase in observatory staff from 6 to 7 and Mr. Sandy Jones was hired to fill the new role of Assistant Station Manager. This addition has greatly improved the ability to cover station staffing when the observers or manager are on leave.

Station staff:

- Randall Carman: Station manager
- Sandy Jones: Assistant station manager
- Peter Bargewell, Dave Essers, John Colley, Michael Wilson: Operations team
- Jack Paff: Facilities manager

Figure 8-101. Yarragadee Geodetic Observatory staff (left to right: Peter Bargewell, Michael Wilson, Dave Essers, John Colley, Sandy Jones, Jack Paff, and Randall Carman).

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Zelenchukskaya, Russia

Authors: *Iskander Gayazov, Viktor Mitryaev*
Responsible Agency: Institute of Applied Astronomy (IAA RAS)

System: ZELL/1889
Location: Zelenchukskaya, Karachaevo-Cherkesskaya Republic, Russian Federation
Latitude: 43.7887°N, Longitude: 41.5654°E, Elevation: 1155 m

Station Operations

The Zelenchukskaya SLR station (ZELL, 1889) is located in Karachaevo-Cherkesskaya Republic (Russian Federation) at one of three observatories of the “Quasar-KVO” VLBI network. The observatory is a co-location site with two radio telescopes (RT-32 and RT-13), “Sazhen-TM” SLR system, GNSS receivers, and a water vapor radiometer. The SLR system has both day and night cameras and a holographic filter (0,1 nm bandpass) which allows for all day functioning. In spite of a relatively small aperture of the telescope (25 cm) and low pulse energy (2,5 mJ), the laser system is capable to conduct observations of satellites with the orbits up to 40000 km.

Figure 8-102. “Sazhen-TM” laser system against the background of RT-32 radiotelescope (left) and the laboratory equipment of the laser system (right).

System Improvements

In 2018 new star calibration software was installed at the station. This software allows the staff to make angular corrections automatically and improves tracking capabilities enormously, especially in the daytime.

Current Challenges and Future Plans

The main problem is the obsolescence of the system’s laser emitter. This leads to the need to repair the laser every few years. The current laser has a pulse width worse than 300 ps. This is the main reason for the current level of single shot RMS (3-4 cm). The main task for the future is to modernize the system and improve the RMS up to 1 cm. To reach this goal the replacement of the laser by new equipment with a ~50 ps pulse width is planned. The next step is to replace the time interval counter and to increase the repetition rate from 300 Hz up to 600 Hz. These plans are expected to be implemented after 2020.

Station Personnel

The laser system at the observatory is maintained by the staff of operators, who work in shifts (two operators per shift). All operators are capable to carry out both VLBI and SLR observations even if they occur at the same time. The observation results are sent via network transmission to the processing center at IAA (Saint-Petersburg). There ,the data are processed and sent to EDC and other users. Repairs of the system and overall operation are conducted by the lead engineer Viktor Mitryaev.

The station operators are as follows:

- Andrey Shatilov
- Pavel Kisilev
- Victor Kononenko
- Militina Lysenkova
- Aleksander Ptitsin
- Nikolai Dzuba
- Galina Kravchenko
- Anastasiya Markelova
- Oleg Pervakov
- Nataliya Zabavskaya
- Evgeny Kvashnin

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Zimmerwald, Switzerland

Authors: *Emiliano Cordelli, Pierre Lauber, Thomas Schildknecht*
Responsible Agency: Astronomical Institute University of Bern (AIUB)

System: ZIML/7810
Location: Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald, Waldhof 2-4, 3086 Zimmerwald, Switzerland
Latitude: 48.8772° N, Longitude: 7.4652° E, Elevation: 951.2m

Station Operations

A total of 3,942 passes, resulting in 54,625 normal points, and 661.82 hours of observations were acquired in 2016. In 2017, the performances increased to 11,038 passes, 141,705 normal points and 1618.1 hours, while in 2018 we reached 15,989 passes, 200,619 normal points and 1792.98 hours.

The poor performance in 2016 and in the beginning of 2017 was due to technical issues that started in December 2015 with the laser double pass amplifier failing, which was first repaired, then we were obliged to use it at lower gain (summer 2016), and finally needed to be replaced in February 2017.

Since March 2017, the station is running normally and the team is striving for the improvement of the station efficiency and measurement accuracy. The ZIMLAT telescope is shared during nighttime between SLR operations, didactical activities, space debris, and classical astronomical observations.

Figure 8-103. Swiss Optical Ground Station and Geodynamics Observatory Zimmerwald today.

System Improvements

In order to speed up the acquisition of difficult targets, like newly launched satellite, the SLR system has been equipped with a night-tracking camera. A first analysis after the camera integration has shown an improvement of the station efficiency. The camera, which is used for correcting the pointing of the telescope in real time, allows us to track LEO and MEO defunct satellites with poor predictions with our SLR system. The main outcomes of the tracking are the angular positions of the object in the sky (azimuth and elevation), its distance, and its brightness. All these measurements are acquired synchronously with the timing accuracy provided by the SLR system and can be used for both, the attitude, and the orbit determination of space debris.

In the frame of the European Laser Time Transfer (ELT) project, we carried out a calibration session together with the University of Prague. The calibration campaign has been performed in order to determine one-way calibration constants, which are relevant for this experiment being sensitive to one-way delays. Significant one-way internal system calibration delays can now be expressed by ELT calibration constants and can in future be determined more easily using simple reproducible experiments without external calibration efforts.

To achieve a highly stable local time and frequency, a maser has been installed.

To improve the UTC time scale precision from 100 ns to 15 ns, an additional GPS-receiver has been procured and integrated. The receiver is embedded into the station time system in such a way that the previously determined calibration constants should be preserved.

With the newly installed GPS-receiver and a time interval counter, the local time derived from the maser is now measured against UTC (GPS) with a precision of 1 ns instead of 30 ns. SLR measurements provided to the ILRS are now tagged with epochs at 15 ns precision.

Because the ZIMLAT SLR telescope optics are also prepared for infrared, it was possible to host a quantum mechanics experiment of the Institute of Applied Physics of the University Bern (IAP). The experiment uses an infrared CW laser to produce entangled photons and was setup at the station as a starting point for the use of entangled photons in free space. The photon source was installed in the coudé path and a retro reflector mounted at 659m distance from the telescope.

Current Challenges and Future Plans

The main challenges for the next two years are:

- SLR System/s: evaluation and replacement of the current 100Hz system with a kHz laser. At the same time, we should be able to shorten the laser pulse width by a factor of 6 to about 10ps, which should improve the single shot measurements accuracy. The kHz system will also improve the station performance in terms of number of observed passes. The existing dome of the SLR system will be replaced by a new one to improve the safety of operations.
- Evaluation and implementation of a space debris laser system.
- Develop and adapt the current laser observation software to be compatible with the new kHz and space debris laser systems.
- Tracking camera: implement an automated closed loop to steer the telescope using images acquired by the tracking camera; develop a tool to improve the ephemeris with the acquired measurements from the tracking camera; extend the use of the tracking camera to daytime.
- ELT experiment: adapt the current laser triggering software in order to consider the changing light travel time to the ISS.
- Quantum Mechanics experiment: perform coincidence tests at the telescope using the installed retroreflector. Extend this experiment to LEO satellites.