16th International Workshop on Laser Ranging, Poznan Poland
Workshop Summary

The Committee on Space and Satellite Research of the Polish Academy of Sciences, the Space Research Centre of the Polish Acadame of Sciences, the Adam Mickiewicz University in Poznań and the ILRS hosted the 16th International Workshop on Laser Ranging in Poznań, Poland, October 13-17, 2008. The theme of the workshop was "SLR – The Next Generation". The Web site *http://www.astro.amu.edu.pl/ILRS_Workshop_2008/index.php* provides information about the workshop; proceedings and session summaries can also be found on the Web at *http://cddis.gsfc.nasa.gov/lw16/*.

Over 140 people from 19 countries participated in the workshop, which included oral and poster presentations on scientific achievements, applications and future requirements, system hardware and software, operations, advanced systems, and analysis. ILRS working group and Governing Board meetings and the ILRS General Assembly were held in conjunction with the workshop. The local organizers also entertained the delegates with a reception and banquet and tours of the Borowiec laser station and Poznan city.

The workshop brought together an exceptional group of researchers who provided reports on the spectrum of science investigations being supported by Satellite and Lunar Laser Ranging (SLR and LLR) and Laser Altimetry. The three sessions comprising this portion of the meeting, containing over twenty oral presentations and three posters, covered a wide range of activities. These sessions where structured as follows.

The first science session focused on the reference frame, positioning SLR stations with high precision within this frame, and time variations in the gravity field, which both perturb the SLR satellite orbits and cause changes of the location of the geocenter with respect to the polyhedron realized by the geographic distribution of the SLR stations. The legacy of SLR over the 1970s and 1980s where it alone provided precise Earth orientation information and through the 1990s for monitoring changes in the longest wavelengths of the gravity field were described. Also presented were results showing the SLR contribution to the International Terrestrial Reference Frame (ITRF) both in terms of providing scale and in monitoring geocenter motion. New missions, like GRACE, which now provide far more detailed information on mass flux within the Earth's system, were also discussed with regard to improving SLR orbit accuracies.

Session two focused on orbit determination capabilities, analyses, and new applications for SLR including support for upcoming Lunar Reconnaissance Orbiter (LRO) mission. This session also discussed various highly interesting investigations made possible through the availability of detailed topographic mapping capabilities delivered by laser altimeters and the Lunar Laser Ranging acquired on the moon. SLR remains one of the surest ways to provide precision orbits in its own right, and for independent orbit verification for solutions produced by GPS and DORIS. A laser transponder being deployed on LRO will provide significantly improved orbits for this lunar orbiter enhancing mission science objectives. The second half of this session focused on the outstanding results for both Earth and Planetary applications, made possible with laser altimetry. Excellent papers were presented on ICESat, the MOLA system flown on Mars

Global Surveyor (MGS), and a survey of applications including NEAR, MESSENGER, and LRO.

The third science session highlighted SLR and LLR contributions to planetary and lunar geophysics, fundamental physics (e.g. the Lens Thirring effect, the geophysical properties of the moon deduced from LLR) and the upcoming LARES experiment. SLR and LLR, given the long time history and stability of these systems, have made significant contributions to the study of fundamental physics in the field of General Relativity.

The science presentations at this workshop both individually and in total, were some of the most comprehensive ever presented within the ILRS Workshop framework. These papers clearly demonstrated the continuing role that SLR, LLR, and laser altimetry has in furthering our understanding of the dynamics ongoing in the Earth and its terrestrial-like planetary companions.

The session "The Role of Satellite Laser Ranging in the Global Geodetic Observing System" highlighted the central role that SLR plays within GGOS. The opening presentation summarized the main contributions of SLR to the three pillars of geodesy for GGOS with examples of the state-of-the-art in the definition of the origin and scale of the ITRF, the long history of SLR series of EOP, the longest of all space techniques, and mass load variations from long wavelength harmonics time series derived from SLR, with comparisons to other techniques (GRACE, GPS, hydrology, etc.). Efforts on a new ILRS product, daily delivery of fresh EOP estimates, show the product can be used to constraint the EOP forecasting process of the NEOS service of IERS. Other presentations highlighted the intercomparison and combination of SLR with other geodetic techniques. ESA's efforts to harmonize the reduction of GNSS and SLR data with a common analysis package would be an important contribution to GGOS for a combined and consistent estimation of geophysical parameters. Comparison between GPS- and SLR-derived time series of coordinates over a period of eleven years were shown, where the results indicated the general consistency of the results at the few millimeter level. This work demonstrated how well the two techniques compare at sites with data of exceptional quality, and how they can be used to identify problems in either technique when they are co-located and properly and accurately surveyed. Results of optimization studies in designing the future global geodetic networks that will support GGOS, focusing on the role of SLR and the possible products to be delivered, were shown. This presentation stressed the stringent requirements of GGOS and how the synergy of the geodetic techniques will meet this challenge. A poster illustrating the global map of the four networks of the space techniques as they exist today was shown. A second poster showed an example of how ILRS can make use of the Virtual Observatory on the web, following the example of astronomy.

The Network and Station Performance session covered three main topics: data quality control (at stations and at analysis centers), models, and the network in general. Presentations on data quality control reported on efforts to reach and maintain the highest data quality through the use of other on-site geodetic techniques (GNSS, absolute gravity), co-location, automation, and software monitoring development in cooperation with data analysts, engineers, and station operators. Data quality control at Analysis Centers included an overview of the routine quality control system for the ILRS global network is provided by the Hitotsubashi University, which is available via web, ftp and email. Results from the re-processing of data from selected missions

using the most accurate orbit models and the latest ITRF (SLRF2005) were shown; the analysis has been used in development of a new model, LPOD2005. A presentation summarizing an ILRS proposal to IERS for modification of the analysis standards related to the products contributing to the establishment of future ITRF solutions. Analysis of the correlation between the TRF datum and the ILRS network geometry was shown with the goal to explain the discontinuity in the SLR scale. Difficulties in tracking the future TanDEM-X mission were discussed with possible remedies for the various types of stations in the ILRS network.

There was significantly more activity in the Lunar Laser Ranging (LLR) and Interplanetary Laser Ranging session this year. A presentation on reference frames for lunar ranging analysis emphasized the need to avoid confusing gauge-dependent terms and physical effects. Two years of APOLLO operation has showed high photon rates and evidence for one-millimeter performance. There were also presentations on recent efforts to understand Earth orientation using 38 years of LLR data and the science that would be attainable with the next-generation (large) corner cubes on the lunar surface. There were several talks on one-way ranging to the lunar reconnaissance orbiter (LRO), focusing on technical parameters/capabilities, pointing strategies and verification, and scheduling and predictions. Preparations for the LRO experiment are taking place at the McDonald Observatory, where most of the software preparation is already completed. There was also a presentation on the science deliverables one may achieve through interplanetary laser ranging, including the successful ranging to the MESSENGER and Mars Orbiter, as well as plans for LRO. Posters were displayed on displayed pertaining to using LLR for Celestial pole determination, and the minimum duration necessary for sea level rise determination.

In the High Repetition Systems Session, the five-year success of the Graz station with two kHz laser operation was reviewed. Other stations including Herstmonceux, Zimmerwald, TIGO, NGSLR, several Chinese stations, a Russian system, and the Potsdam station have or are switching to higher repetition rate laser. New control systems for higher repetition rate lasers have been developed and implemented; most kHz stations are now using now Riga event timer. With the benefit of kHz ranging, several new results and additional areas of study are underway including very accurate satellite spin determination, fast optical response retrieving, mm resolution accuracy from cm targets like LAGEOS and AJISAI, LIDAR applications, seeing measurements, and kHz ranging to a Mars transponder. The SLR future is talking "kHz".

The Session on Lasers, Detectors and Timers included a review on commercially available kHz diode pumped lasers, and descriptions of a new high voltage Pockels cell driver for kHz SLR lasers, a new saturable absorber for laser transmitters, and a promising narrow-band holographic filters for ranging receivers. A new version of the Riga timer with improved resolution was introduced along with a presentation in the integration of Riga timers into Chinese SLR systems. The design for a commonly used TDC chips for high-speed event timers was presented as were the design and construction of compact event timing and laser fire control device for one-way laser ranging and a new, sub-picosecond timing device. A new photon counting detectors for future space missions was also presented.

Several themes ran through the Software and Automation Session; major topics included software modularity and robustness, automation, and remote access to geodetic systems. Also

discussed were automated processing of SLR data. CRD file creation, handling, and analysis, SLR predictions, and innovations in telescope pointing. Finally, a topic that has gained importance in the software industry, XML, has been applied to SLR station processing at Stromlo and Riga.

In New and Upgraded Stations, Extended Facilities, the Chinese network stations are being modernized with kHz lasers, event timers, CSPADS, and gravimeters. The Chinese TROS transportable system is in operational in The Republic of Korea to support the ARGO project. In France, the new MEO station is operational on both satellites and the Moon, and the mobile FTLRS system has been upgraded with Dassaults event timers for T2L2 project. The Herstmonceux station is testing a new kHz ranging laser and now has an absolute gravimeter operating on site. The Borowiec station has undergone major upgrading, and upgrades on the Simeiz and Katzively stations are underway. In South America, San Juan SLR station continues to perform exceptionally well and the TIGO system at Concepcion is operational again after delicate optical replacements.

In the session on Operational Issues and New Missions, several reports were given on new missions. Several current and upcoming European missions with retroreflectors including ERS-2, GOCE, and SWARM are focused on Earth sensing and technology applications. SOHLA-1, to be launched in early 2009 by JAXA for a demonstration of small, low cost technical payloads; since the spacecraft will be spinning, it will pose a tracking challenge since access to the retroreflector array will only last a few seconds in every few minute revolution period. Astro-G, a space borne VLBI antenna, is planned for launch in 2012; the highly elliptical orbit and bi-modal, switching operation of the antenna; will also limit normal points to very short intervals and require some special data handling procedures. The Precision Expandable Radar Calibration Satellite being planned by NRL for calibrating radars and studying drag and electromagnetic conditions in orbit will carry over 1000 retroreflectors distributed inside and outside of a spherical deployable frame. Consideration for an Optical Link for the ACES Mission was discussed along with concepts for resolving the range biases in one-way ranging experiments and a novel application of SPADs using no optics. An IR camera and aircraft radio detection beacon using a patched antenna array offers promise of new aircraft detection safety systems for laser ranging. The implementation of the Consolidated Laser Ranging Format is underway with full implementation later in 2009. Moblas 8 returned to operations. Posters included some historical SLR information, a status on the ILRS website update, and the upcoming ANDE mission scheduled for May 2009.

Papers presented during the Targets, Signatures, and Biases session covered retro-reflector array design and optical response functions. The continuing development of new missions that will require laser tracking support is evident, as is the ongoing and welcome dialogue between mission engineers and the laser community in developing the best array solutions to maximize the effectiveness of the tracking. Work on retro array design and chamber testing was shown, with particular emphasis on concepts for the next generation GPS satellites. A presentation described experimental results to determine pulse energy levels leaving the telescope as a function of its attitude and initial pulse polarization. Presentations were also given describing the laser arrays on the GEO and MEO elements of the emerging Chinese COMPASS GNSS and on the HEO two-satellite STSAT-2 technology mission. An optical response simulation was

described for the proposed HEO VLBI mission ASTRO-G, which very interestingly will see the ILRS supporting an astrophysics mission.

In the session on Advanced Systems and Techniques: Transponders, Altimeters, and Time Transfer, Altimeters, papers were presented on the development of simulators for planetary exploration and present and future airborne photonic 3D-imaging. Transponder topics included transponder simulations using artificial satellites preliminary hardware designs to demonstrate the feasibility of Mars links. Papers were given on time transfer including first data from T2L2 and some preliminary results from the Chinese LTT experiment and a discussion on One-Way System Calibration Techniques. Other talks included an update on the Russian SLR program including the release of some of the data, a paper on ranging to uncooperative targets in China, and SLR engineering activities at Riga including new developments in their epoch timer work.