21st International Workshop on Laser Ranging
Workshop Summary

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The Space Environment Research Centre (SERC) and the ILRS hosted the 21st International Workshop on Laser Ranging at the John Curtin School of Medical Research, Australian National University in Canberra, Australia during the week of November 05-08, 2018. SERC was established to combine government, university, and industry resources to apply new optical technology toward the problem of space debris, including information and direct intervention. Their research supports improvements in debris orbit predictions that allow active satellites to maneuver in time to avoid space debris collision. As such, SERC is, in general, very interested in laser ranging.

The theme of the workshop "Laser Ranging for Sustainable Millimeter Geoscience" afforded presentations on a wide range of topics highlighting SLR contributions to research. The workshop consisted of nine oral sessions with posters for each session. The session topics were:

- SLR Contribution to Global Geodetic Observing System – A 2020 Perspective
- Improvements in the SLR Product Quality and Precise Orbit Determination
- Satellite Missions and Techniques for Geodetic Applications
- Characteristics of Retroreflector Arrays
- Sources of Systematic Errors
- Network Operations and Site Upgrades
- Developments in SLR Techniques and Technologies
- Developments in Software and Automation
- Lunar Laser Ranging and Deep Space Missions

In addition to the main oral sessions, the workshop dedicated significant program time to poster sessions. Poster submissions were requested for each session theme. Furthermore, posters which provided updates on station activities were strongly encouraged. The workshop once again included a station operations or "clinic" session where ILRS experts met in small groups of station engineers and operators to provide solutions to common station problems, information to maintain station stability, and guidelines for interacting with the analysts in determining station biases. These station clinics were well received and attended by workshop participants.

Over 175 registrants from 23 countries participated in the four-day laser ranging workshop. It was followed by a one-day International Workshop on Space Debris Management on November 09; 20 additional attendees, mainly from Australia, participated.

Participants in the 21st International Workshop on Laser Ranging, Canberra Australia, November 2018. *(Photo credit: Exclusive Images, Canberra, Australia)*

The workshop program included 80 oral presentations and over 60 posters; 25 oral presentations and 15 posters were given at the Space Debris Workshop. All abstracts, presentations, posters, and summary papers from both workshops are available within the Program section of the workshop's proceedings website: *https://cddis.nasa.gov/lw21*. Additional information, such as meeting summaries, photos, and the full program booklet are available through this website.

Dr. Thomas Herring gave the keynote presentation "Contributions of SLR for the Next Decade" *(Photo credit: Exclusive Images, Canberra, Australia)*

Professor Thomas Herring, Massachusetts Institute of Technology, Cambridge, MA gave the invited keynote talk to open the workshop. Professor Herring's presentation highlighted the important synergy of SLR with the other space geodesy techniques, and ways of drawing out small systematic issues through careful scrutiny of the SLR data.

The four-day workshop program was organized into nine oral sessions, and two poster sessions focused on the oral session topics. A brief summary of these sessions:

- Session 1, "SLR Contribution to the Global Geodetic Observing System – A 2020 Perspective" covered SLR contributions to GGOS and inter-technique comparisons and synergies between SLR and other space geodetic techniques including the role of local ground surveys.

- Session 2, “Improvements in the SLR Product Quality and Precise Orbit Determination” dealt with estimation and monitoring of systematic errors, improved center of mass correction on geodetic satellites, advances in geophysical modeling, SLR synergy with GNSS, and SLR improvements in the terrestrial reference frame.
- Session 3, “Satellite Missions and Techniques for Geodetic Applications” discussed some of today`s many SLR applications including: validation and QC support for GNSS, spacecraft engineering tests, laser time transfer, spacecraft attitude determination, reflector panel resolution performance, new methods of gravity field estimation, and new application through the use of constellations of nano-satellites.
- Session 4, “Network Operations and Site Upgrades” included plans for new stations, upgrades and new technology at existing stations, overall network performance, and review of updates to ILRS procedures.
- Session 5, “Sources of Systematic Errors”, stressed the challenge of the 1-mm accuracy for GGOS and demonstrated that the identification and characterization of system biases now underway, is an essential step toward achieving this goal; some new analytic and modeling techniques for reducing range biases and the introduction of automated processing with data discrimination procedures are already being implemented at some stations.
- Session 6, “Characteristics of Retroreflector Arrays”, reviewed new developments in retroreflector arrays, including new targets already being tracked and those in planning or testing for future missions, including new compact retroreflector arrays that will reduce ranging RMS.
- Session 7, “Development of Software and Automation”, discussed the move toward fuller automation, including software development in scheduling, visualization, data processing, and station performance assessment.
- Session 8, “Developments in SLR Techniques and Technologies”, focused on new technologies to improve performance, and help standardize and simplify SLR/LLR systems, and potentially reduce systems costs, and the use of existing technologies for new SLR applications such as laser communication and space debris monitoring.
- Session 9, “Lunar Laser Ranging and Deep Space Missions”, reviewed recent progress in Lunar Laser Ranging and lunar reflector technology; interest is growing in lunar ranging and the science resulting from these measurements with more stations being planned.

Workshop organizers allocated one afternoon during the week to station “clinics”, allowing station operations staff (and anyone else with interest in the topics covered) to meet in small groups with experts in the engineering and data analysis areas. The clinics primarily benefited station representatives although others attendees were encouraged to participate. The topics covered in the clinic sessions were:

- Data quality
- Data productivity
- System accuracy/biases
- ILRS procedures
- Web tools and software
- Calibration and ground targets

These sessions were intended to be two-way conversations between topic experts and station contacts; material was prepared and distributed prior to the workshop to allow these representatives to gather

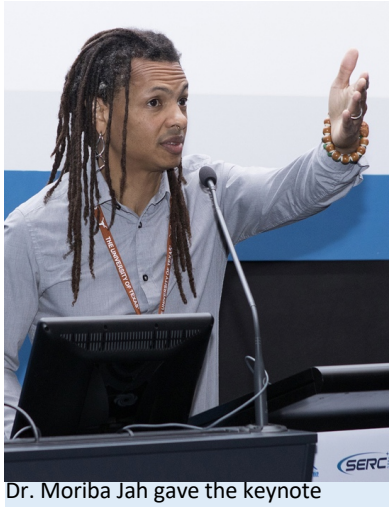
any questions prior to the workshop. Six small group clinics provided solutions to common station problems, information on maintaining station configuration stability, overview of new tools available, and guidelines for interacting with the analysts in determining station biases.

One issue that stimulated discussion was the SLR policy in tracking GNSS satellites. The ILRS routinely prioritizes satellite targets by altitude (LEO through geosynchronous), with occasional adjustments to enhance tracking on new satellites, typically with active systems aboard. Within the GNSS regime, several satellites may be given high priority at the request of the constellations to provide better pass coverage (3 pass segments) for special directed applications. Of the remaining GNSS satellites (currently ~ 60), a subset is identified for non-prioritized tracking on "as time permits" basis. The ILRS will work with the IGS and the contacts from the GNSS constellations for their inputs.

The 21st International Workshop on Laser Ranging concluded with a general discussion on the format of the workshop, planning for future workshops, and improvements to the clinic content and organization. In addition, the attendees put forth several resolutions:

- The IGS:
  - Requests that ILRS instruct stations to track the non-prioritized GNSS satellites in a low density (1 pass segment), randomized manner, where each station can freely select a set of GNSS satellites for tracking on a weekly basis, and in that way, get an orbital sampling of many GNSS satellites.
  - Requests that the remaining GNSS satellites be left in a randomized tracking pool;
  - Encourages development/installation of SLR stations in the Asia-Pacific region and the transition to kHz laser systems thus enabling shorter normal point duration.
- The ILRS:
  - Suggests that GNSS satellite tracking would be helped by giving stations some general selection criteria to encourage a satellite mix;
  - Suggests that relegating all the remaining GNSS satellites (~60) to a lower active tracking priority might lead to very sparse coverage, and that it might be wise to reduce this pool to ~30 well-selected satellites to avoid an imbalance of tracking among the constellations and to recognize the difference in day-night visibilities.
- The participants acknowledged the great success of the 21st International Workshop on Laser Ranging and thanked SERC and the local organizers for their exhaustive efforts and meticulous organization that enabled this successful workshop.

The last day of the week was devoted to a separate event, the International Workshop on Space Debris Management, which has synergy with new ILRS applications. Associate Professor Moriba Jah, University of Texas at Austin gave the opening keynote presentation to the International Workshop on Space Debris Management. This interesting talk covered the global importance of developing a capability to predict, quantify, and assess the behavior of objects in space and ideas for identification, location prediction/modeling, and quantification of space objects.



Dr. Moriba Jah gave the keynote presentation "Towards Quantifiable Resident Space Object Activity and Behavior Prediction, Identification, Quantification, and Assessment" for the International Workshop on Space Debris Management *(Photo credit: Exclusive Images, Canberra, Australia)*

Participants in the Space Debris Workshop, Canberra Australia, November 2018. *(Photo credit: Exclusive Images, Canberra Australia)*

The workshop's local organizing committee not only assisted in the preparation of an excellent program, but handled all logistics at the venue and arranged several excellent social events. The Wednesday workshop banquet took place at the National Arboretum, surrounded by forests of rare and endangered trees from not only Australia but around the world; attendees explored the grounds and were treated

View of Canberra from the National Arboretum. *(Photo credit: Carey Noll/ILRS Central Bureau, NASA GSFC)*

Mt. Stromlo Satellite Laser Ranging Observatory *(Photo credit: Exclusive Images, Canberra Australia)*

to a beautiful landscape complete with double rainbow. On the final day of the week, participants were given a tour of the EOS Space Research Centre (including the telescope facility) at Mt. Stromlo, which consists of operational and lab facilities for SLR and space debris tracking. The site also includes a state-of-the-art ground survey monitoring system with some locally built survey/ground baseline monitoring hardware. The local hosts concluded the tour with a barbeque dinner on the grounds of Mt. Stromlo with local kangaroos in attendance.

Once again, this International Workshop on Laser Ranging was another successful assembly of experts in the global laser ranging scientific community. The community looks forward to the next opportunity to meet, the 22nd International Workshop on Laser Ranging, which is planned for the 2020 timeframe in Kunming China.