International Laser Ranging Service (ILRS)

http://ilrs.gsfc.nasa.gov

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Overview

The ILRS is the international source that provides Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation data and data products for scientific and engineering programs with the main focus on Earth and Lunar applications. The basic observables are the precise two-way time-of-flight of ultrashort laser pulses from ground stations to retroreflector arrays on satellites and the Moon and the one-way time-of-flight measurements to space-borne receivers (transponder). These data sets are made available to the community through the CDDIS and the EDC archives, and are also used by the ILRS to generate fundamental data products, including: accurate satellite ephemerides, Earth orientation parameters, three-dimensional coordinates and velocities of the ILRS tracking stations, time-varying geocenter coordinates, static and time-varying coefficients of the Earth's gravity field, fundamental physical constants, lunar ephemerides and librations, and lunar orientation parameters.

SLR is one of the four space geodetic techniques (along with VLBI, GNSS and DORIS) whose observations are the basis for the development of the International Terrestrial Reference Frame, which is maintained by the IERS. SLR defines the origin of the reference frame, the Earth center-of-mass and along with VLBI, its scale. The ILRS generates daily a standard product of station positions and Earth orientation based on the analysis of the data collected over the previous seven days, for submission to the IERS, and produces LAGEOS/LARES combination solutions for maintenance and improvement of the International Terrestrial Reference Frame (ITRF). The latest requirement is to improve the reference frame to an accuracy of 1 mm accuracy and 0.1 mm/year stability, a factor of 10 – 20 improvement over the current product. To address this requirement, the SLR community will need to significantly improve the quantity and quality of ranging to the geodetic constellation (LAGEOS-1, LAGEOS-2, and LARES) to support the definition of the reference frame, and to the GNSS constellations to support the global distribution of the reference frame.

The ILRS participates in the Global Geodetic Observing System (GGOS) organized under the IAG to integrate and help coordinate the Service activities.

ILRS Structure

The ILRS Organization (see Figure 1) includes the following permanent components:

- Tracking Stations organized into Subnetworks
- Operations Centers
- Global and Regional Data Centers
- Analysis and Associate Analysis Centers
- Central Bureau
- Working Groups

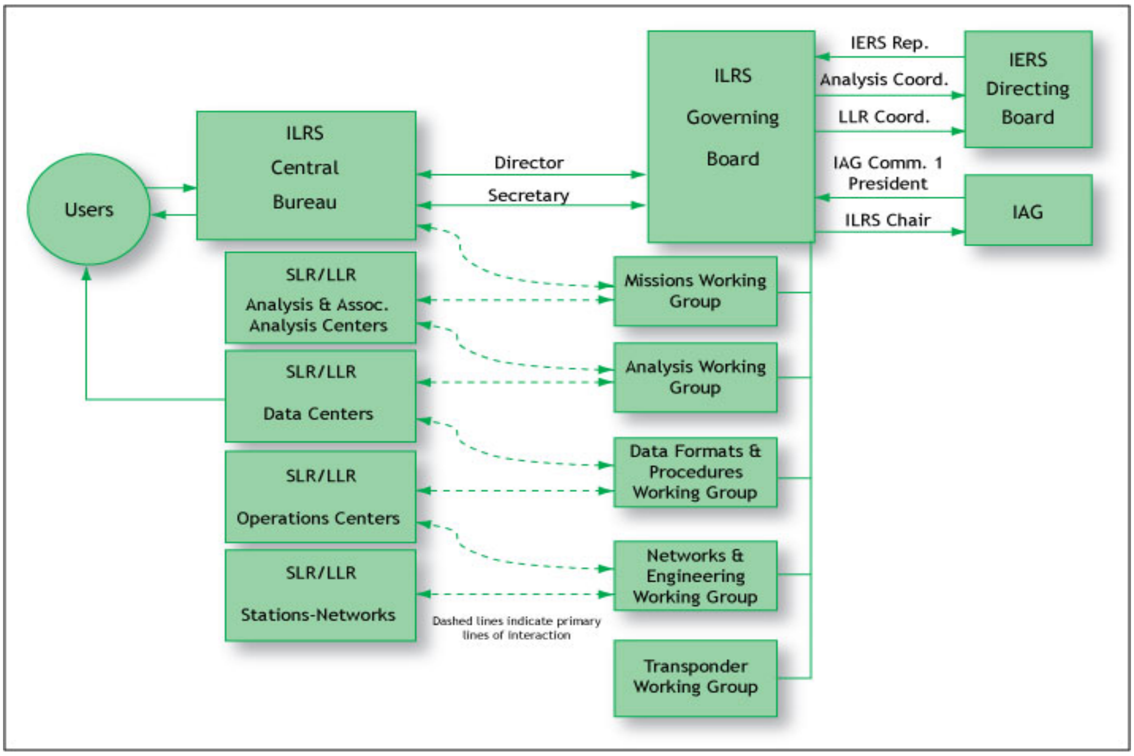

Figure 1. The organization of the International Laser Ranging Service (ILRS).

The role of these components and their inter-relationship is presented on the ILRS website (*http://ilrs.gsfc.nasa.gov/about/organization/index.html*).

The Governing Board (GB) is responsible for the general direction of the service. It defines official ILRS policy and products, determines satellite-tracking priorities, develops standards and procedures, and interacts with other services and organizations. The members of the current Governing Board, selected and elected for a two year term, are listed in Table 1. The election process for the next Board is underway; the new Board will formally take office at the 18th International Workshop on Laser Ranging in Japan, November 2013.

Within the GB, permanent (Standing) or temporary (Ad-Hoc) Working Groups (WG) carry out policy formulation for the ILRS. The WGs are intended to provide the expertise necessary to make technical decisions, to plan programmatic courses of action, and are responsible for reviewing and approving the content of technical and scientific databases maintained by the Central Bureau. All GB members serve on at least one of the five WGs, led by a Coordinator and Deputy Coordinator (see Table 1). The WGs continue to attract talented people from the general ILRS membership who contributed greatly to the success of these efforts.

Table 1. ILRS Governing Board (as of July 2013)

Tonie van Dam	Ex-Officio, President of IAG Commission 1	Luxembourg
Michael Pearlman	Ex-Officio, Director, ILRS Central Bureau	USA
Carey Noll	Ex-Officio, Secretary, ILRS Central Bureau	USA
Bob Schutz	Appointed, IERS Representative to ILRS	USA
Giuseppe Bianco	Appointed, EUROLAS	Italy
Francis Pierron	Appointed, EUROLAS	France
David McCormick	Appointed, NASA	USA
Jan McGarry	Appointed, NASA	USA
Wu Bin	Appointed, WPLTN	China
Hiroo Kunimori	Appointed, WPLTN	Japan
Vincenza Luceri	Elected, Analysis Representative, Analysis Working Group Deputy Coordinator	Italy
Erricos C. Pavlis	Elected, Analysis Representative, Analysis Working Group Coordinator	USA
Horst Mueller	Elected, Data Centers Rep., Data Formats and Procedures WG Coordinator	Germany
Jürgen Müller	Elected, Lunar Representative	Germany
Graham Appleby	Elected, At-Large, Missions Working Group Coordinator, Governing Board Chair	UK
Georg Kirchner	Elected, At-Large, Networks and Engineering Working Group Coordinator	Austria

Data Products

The ILRS products consist of SINEX files of weekly-averaged station coordinates and daily Earth Orientation Parameters (x-pole, y-pole and excess length-of-day, LOD) estimated from 7-day arcs of SLR tracking of the two LAGEOS and two Etalon satellites. As of May 1, 2012, the weekly analysis product is no longer the official ILRS Analysis product (thence reserved for Pilot Project use only), replaced by the same type of analysis performed on a DAILY basis by sliding the 7-day period covered by the arc by one day forward every day. This allows the ILRS to respond to two main users of its products: the ITRS Combination Centers and the IERS EOP Prediction Service at USNO. The former requires a single analysis per week, the latter however requires as "fresh" EOP estimates as possible, which the "sliding" daily analysis readily provides. Two types of products are distributed for each 7-day period: a loosely constrained estimation of coordinates and EOP and an EOP solution, derived from the previous one and constrained to an ITRF, currently ITRF2008. Official ILRS Analysis Centers (AC) and Combination Centers (CC) generate these products with individual and combined solutions respectively. Both the individual and combined solutions follow strict standards agreed upon within the ILRS Analysis Working Group (AWG) to provide high quality products consistent with the IERS Conventions. This description refers to the status as of July 2013. Each official ILRS solution is obtained through the combination of solutions submitted by the official ILRS Analysis Centers:

ASI, Agenzia Spaziale Italiana
BKG, Bundesamt für Kartographie und Geodäsie
DGFI, Deutsches Geodätisches Forschungsinstitut
ESA, European Space Agency
GA, Geosciences Australia (up until the end of 2012)
GFZ, GeoForschungsZentrum Potsdam

GRGS, Observatoire de Cote d'Azur
JCET, Joint Center for Earth Systems Technology and Goddard Space Flight Center
NSGF, NERC Space Geodesy Facility

These ACs have been certified through a benchmark process developed and adopted by the AWG. The official Primary Combination Center (ASI) and the official Backup Combination Center (JCET) follow strict timelines for these routinely provided products.

In addition to operational products, solutions obtained from re-analysis have been provided covering the period back to 1983 in support of ITRF development. The ILRS products are available, via ftp from the official ILRS Data Centers CDDIS/NASA Goddard (*ftp://cddis.gsfc.nasa.gov/*) and EDC/DGFI (*ftp://ftp.dgfi.badw-muenchen.de*).

The individual ILRS AC and CC contributions as well as the combinations are monitored on a daily basis in graphical and statistical presentation of these time series through a dedicated website hosted by the JCET AC at *http://geodesy.jcet.umbc.edu/ALL_PLOTS/*.

The main focus of the Analysis WG activities over this period was the improvement of modeling used in the reduction of the SLR data and generation of the official products. In particular, all ACs made major efforts to comply with the adopted analysis standards and the IERS Conventions 2010. Since the delivery of the ILRS contribution to ITRF2008, the AWG has launched an ongoing set of Pilot Projects to test, evaluate and adopt new models and practices that will limit or mitigate the effect of systematic errors in the ILRS data. Part of this effort was the development, evaluation and adoption of a new model for the application of the "center-of-mass" (CoM) offset corrections for the LAGEOS and Etalon target satellites. The new model developed by the Signal Processing Study Group (G. Appleby and T. Otsubo) is a further enhancement of the one made available in 2010. The latest version considers not only the specific geometry of the target satellites, but also the variable mode of operations at each specific ground station tracking system. This makes the model station-dependent and time-dependent at the same time. The model will be adopted after the evaluation of the test period during the summer of 2013. It is crucial to have this model applied before the AWG efforts turn to the estimation of systematic errors in general. This is a task to be completed prior to the reanalysis for the development of the ILRS contribution to ITRF2013 by early 2014. During the reporting period the ILRS adopted a new data format (CRD) and starting on May 1, 2012, the AWG switched to the use of the new format. At the same time, the official analysis product of the ILRS was changed to the DAILY analysis product, based on the data from the immediate prior seven days. Over the past three years, the daily product was generated on an experimental basis, primarily for use by the IERS EOP Prediction Service at USNO. ILRS thus provided USNO with an as fresh as possible SLR-derived EOP product. Once accepted by USNO, the more frequent series were adopted as the official positioning and EOP product of the ILRS. Work is now underway to complete the test phase of an additional official ILRS product, the precision orbital files for the LAGEOS and Etalon satellites. As far as the LLR analysis activities, a new service has been instituted via a web application, where one can obtain predictions for LLR observations at a specific site and they can also have their LLR data checked for validity, prior to submitting them to the Data Centers for archival. Currently, the LLR group are in the process of developing a unique data set of all available LLR data in the newly adopted CRD format, in order to better serve the community and to conform with the ILRS standards.

Satellite Laser Ranging

ILRS Network

The present ILRS network includes over forty stations in 23 countries (see Figure 2). During the last two years, new Russians stations joined the Network in Arkhyz, Zelenchukskaya, Svetloe, and Badary, filling in a very important geographic gap. SLR and LLR data are again flowing from the new MEO station at Grasse, France. A new SLR station is currently in Sejong, Korea and two new stations are under construction in India. New SLR stations are also being planned for Metsahovi (Finland) and Ny Alesund (Norway). Large gaps are still very prominent in Africa and South America and discussions are underway with several groups on the hope of addressing this shortcoming.

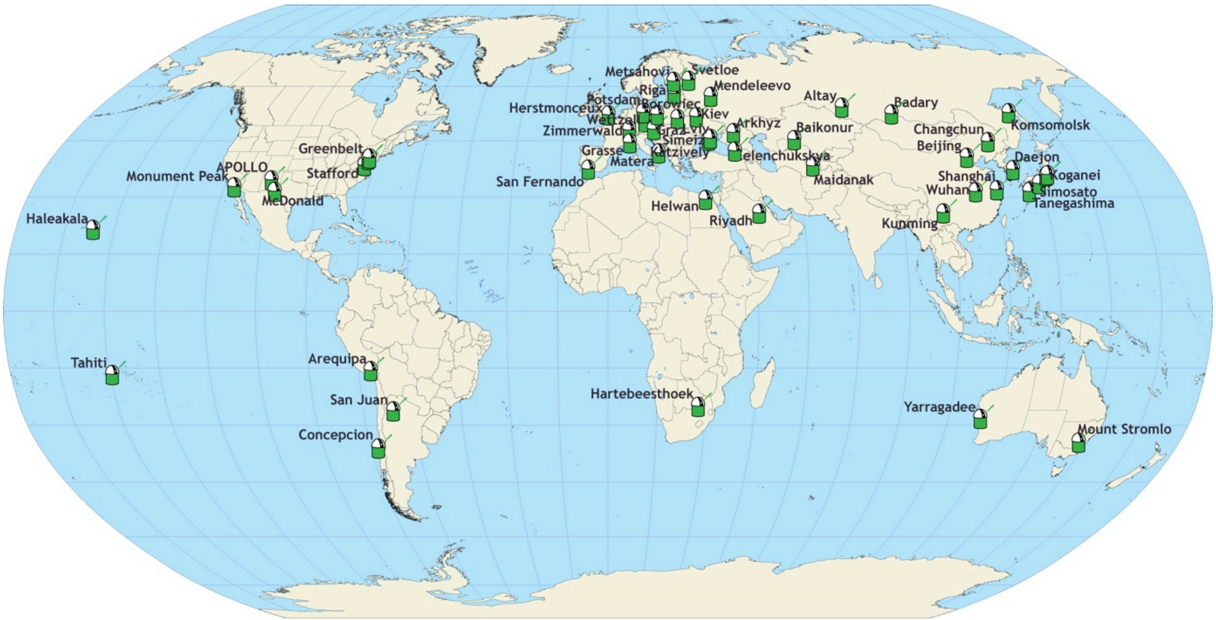

Figure 2. ILRS network (as of July 2013).

Stations designated as operational have met the minimum ILRS qualification for data quantity and quality. Several stations dominated the network with the Yarragadee, Changchun, Zimmerwald and Mt. Stromlo stations being the strongest performers. In general, stations continue to improve performance. During the twelve-month period from April 2012 to March 2013, 22 stations met the ILRS minimum requirement for total numbers of passes tracked (see Figure 3). The San Juan station performance continues to be impressive as does Wettzell, Matera, Goddard and Graz. In addition to San Juan, the rest of the Chinese SLR network continues its very strong support for the ILRS network. The improved orbital coverage over the Pacific region should have a very fundamental impact on our ILRS data products.

Several stations are operating with kHz lasers and fast detectors allowing then to be much more productive with pass interleaving. Some have demonstrated mm precision normal points, a fundamental step toward addressing the new reference frame requirements.

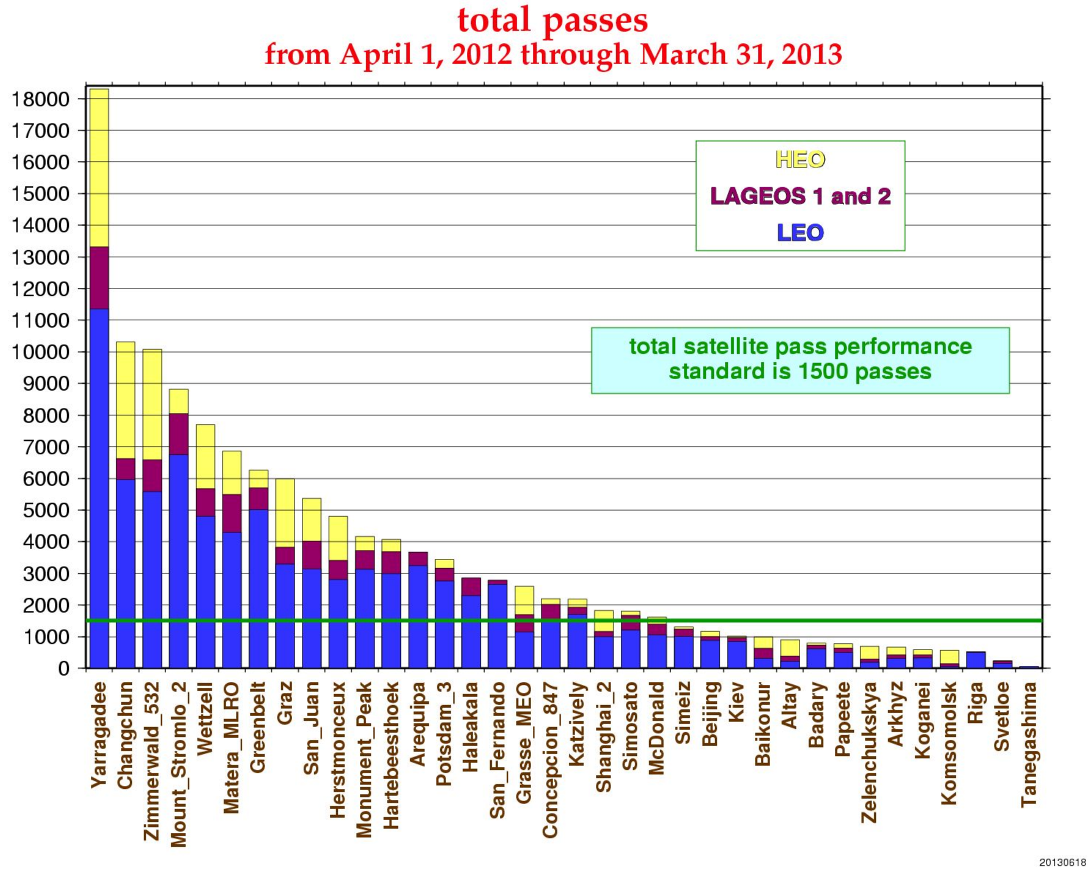

Figure 3. ILRS network performance (total passes).

Satellite Missions

The ILRS is currently tracking 40 artificial satellites including passive geodetic (geodynamics) satellites, Earth remote sensing satellites, navigation satellites, and engineering missions (see Figure 4). The stations with lunar capability are also tracking the lunar reflectors. In response to tandem missions (e.g., GRACE-A/-B, TanDEM-X/TerraSAR) and general overlapping schedules, many stations are tracking satellites with interleaving procedures.

The ILRS assigns satellite priorities in an attempt to maximize data yield on the full satellite complex while at the same time placing greatest emphasis on the most immediate data needs. Priorities provide guidelines for the network stations, but stations may occasionally deviate from the priorities to support regional activities or national initiatives and to expand tracking coverage in regions with multiple stations. Tracking priorities are set by the Governing Board, based on application to the Central Bureau and recommendation of the Missions Working Group (see *http://ilrs.gsfc.nasa.gov/missions/mission_operations/priorities/index.html*).

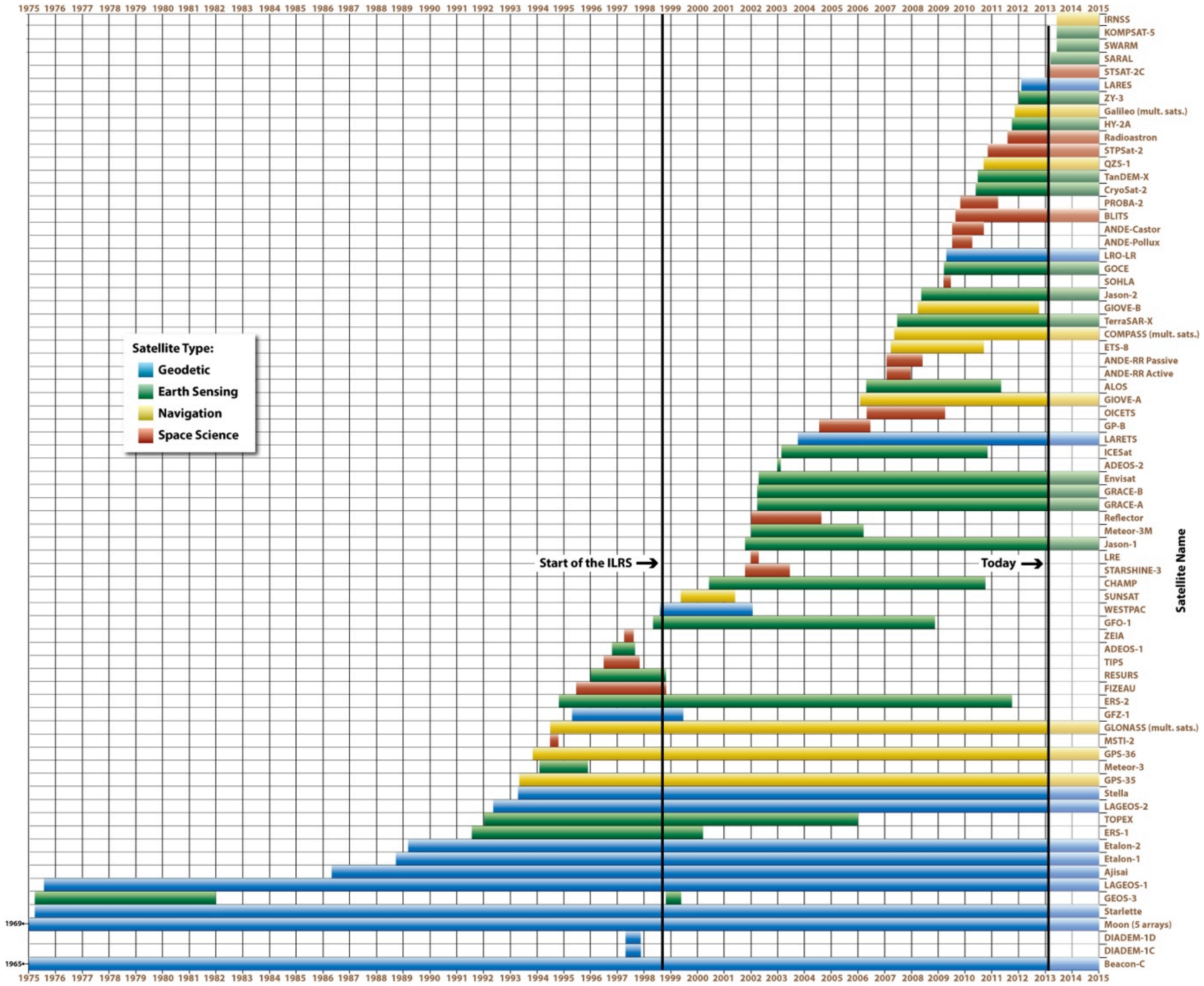

Figure 4. The past, current and future tracking roster for the ILRS network.

Missions are added to the ILRS tracking roster as new satellites are launched and as new requirements are adopted. Missions for completed programs are deleted from the ILRS (see Figure 4). Notable recent losses include the altimeter missions Envisat (ESA) and Jason-1 (NASA/CNES), after over ten years of ILRS support for each fully-operational mission. The ILRS continues to track Envisat to provide ephemerides and orientation data to help with trajectory/safety planning.

During this reporting period, LARES was added to the geodetic satellite constellation to support the reference frame and relativity studies. Several new satellites were added in Geosynchronous, Inclined geosynchronous and MEO orbits). The ILRS tracking roster presently includes six GLONASS satellites (102, 109, 110, 118, 129, 130), four Compass (G1, I3, I5, M3) and four Galileo satellites (101, 102, 103, 104). Following discussions at the ILRS Technical Workshop, Satellite, Lunar and Planetary Laser Ranging: Characterizing the Space Segment," in Frascati, Italy in November 2012, and elsewhere, several stations routinely track segments of passes of all 24 active GLONASS satellites. The newer "high" satellites are using retroreflector arrays that satisfy the ILRS standard. As a result stations are having greater success with daylight ranging.

The tracking approval process begins with the submission of a Missions Support Request Form, which is accessible through the ILRS website (*http://ilrs.gsfc.nasa.gov/docs/2009/ilrsmsr_0901.pdf*).

The form provides the ILRS with the following information: a description of the mission objectives, mission requirements, responsible individuals and contact information, timeline, satellite subsystems, and details of the retroreflector array and its placement on the satellite. This form also outlines the early stages of intensive support that may be required during the initial orbital acquisition and stabilization and spacecraft checkout phases. A list of upcoming space missions that have requested ILRS tracking support is summarized in Table 2 along with their sponsors, intended application, and projected launch dates.

Table 2. Recently Launched and Upcoming Missions (as of July 2013)

Satellite Name	Sponsor	Purpose	Launch Date
Recently Launched			
Compass (5 satellites)	Chinese Defense Ministry	Positioning, navigation, timing	2007-2012
Galileo (4 satellites)	ESA	Positioning, navigation, timing	2011-2012
LARES	ASI/ESA	Geodesy, relativity	Feb-2012
SARAL	CNES/ISRO	Earth observation	Feb-2013
STPSat-2	AFRL	Spacecraft development	Nov-2010
STSAT-2C	Mest/KAIST	Spacecraft development	Jan-2013
Approved by ILRS for Future SLR Tracking			
IRNSS	ISRO	Positioning, navigation, timing	Jul-2013
KOMPSAT-5	KARI,	Earth observation	Aug-2013
SWARM	ESA	Earth observation	Dec-2013
Future Satellites with Retroreflectors			
ANDE-3	NRL	Atmospheric density determination	Dec-2013
GPS-III	U.S. DoD, DoT	Positioning, navigation, timing	TBD
HY-2B	CNES, CNSA	Earth observation	2012
HY-2C	CNES, CNSA	Earth observation	2015
HY-2D	CNES, CNSA	Earth observation	2019
ICESat-2	NASA	Ice sheet mass balance, sea level	2016
Jason-3	NASA, CNES, Eumetsat, NOAA	Oceanography, climate change	2015
Sentinel-3A and -3B	ESA (GMES)	Oceanography	2014
SWOT	NASA, CNES	SAR altimeter	2016

Since several remote sensing missions have suffered failures in their active tracking systems or have required in-flight recalibration, the ILRS has encouraged new missions with high precision orbit requirements to include retroreflectors as a fail-safe backup tracking system, to improve or strengthen overall orbit precision, and to provide important intercomparison and calibration data with onboard microwave navigation systems.

The ILRS network has been involved in one-way ranging and time transfer programs. The first time transfer experiment T2L2 continues to demonstrate improved time transfer capabilities with the Jason-2 satellite; to date, time transfer to an accuracy of 100 ps has been demonstrated with potential of greater accuracy as the data analysis continues. A second time transfer proposal (ELT) utilizing a laser link for the atomic clock ensemble in space (ACES) mission on the ISS has progressed to the point that it is ready to be accepted for the baseline design of ACES. The ILRS actively supports the Lunar Reconnaissance Orbiter, where one-way laser ranging from a subset of the ILRS

Network is being used to improve the orbit determination for the laser altimeter and surface positioning. Approximately a dozen ground stations have supported one-way ranging to LRO. The network has just past 3000 hours of tracking. Ground-based hardware simulations for planning and designing for laser transponder have been also been carried out by several groups looking forward to interplanetary ranging.

Lunar Laser Ranging (LLR) Network

The LLR results are considered among the most important science return of the Apollo era. Currently, four active Lunar Laser Ranging (LLR) sites track the Moon routinely: the McDonald Observatory in Texas, USA, the Observatoire de la Côte d' Azur, France, the APOLLO site in New Mexico, USA and the Matera Laser Ranging station in Italy. The German Geodetic Observatory at Wettzell is still working on its system hoping to soon join the LLR tracking network. The measurement statistics of 2012 (Figure 5) exemplarily shows that about one third of the data have been collected at the APOLLO site, almost 60% of the data at the French site near Grasse.

Figure 6 illustrates the 2012 statistics for the observed reflectors, where - thanks to APOLLO and the upgraded French system - a much better coverage of all reflectors could be achieved than in the previous years. Figure 7 shows the entire LLR data set 1970-2012, indicating the amount of data collected by each of the active LLR sites in each year. It is about 17,700 normal points in total. A steady increase of LLR NP in the last years is obvious. Current LLR data are collected, archived and distributed under the auspices of ILRS. All former and current LLR data are electronically accessible through the CDDIS in Greenbelt, Maryland.

LLR data analysis is mainly carried out by four major LLR analysis centers: Jet Propulsion Laboratory (JPL), Pasadena, USA; Center for Astrophysics (CfA), Cambridge, USA; Paris Observatory Lunar Analysis Center (POLAC), Paris, France; Institute of Geodesy (IfE), University of Hannover, Germany.

One general objective is to achieve the mm level of accuracy for LLR data analysis. To meet this challenge, all elements of the tracking process have to be modeled at appropriate (relativistic) approximation, i.e., the orbits of the major bodies of the solar system, the rotation and deformation of Earth and Moon, the signal propagation, but also the involved reference and time systems. LLR remains one of the best tools to test General Relativity in the solar system. It allows for constraining gravitational physics parameters related to the strong equivalence principle, geodetic precession, preferred-frame effects, the time variability of the gravitational constant and others.

The four analysis centers have started a comparison initiative to mutually improve the various codes. Additionally from 2010 until 2012, an ISSI (International Space Science Institute, Berne, Switzerland) workshop series has been run dedicated to "Theory and model for the new generation of the Lunar Laser Ranging data", where experts from various disciplines discussed future challenges in LLR observation, modeling and analysis.

At the Observatoire de Paris, an "assisting tool" has been developed to support lunar tracking by providing predictions of future LLR observations as well as a validation of past LLR normal points. This tool and further information can be accessed via the ILRS website (*http://ilrs.gsfc.nasa.gov/science/scienceContributions/lunar.html*).

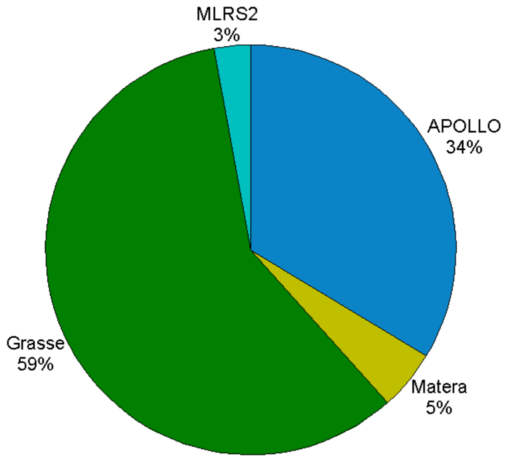

Figure 5. Observatory statistics in 2012.

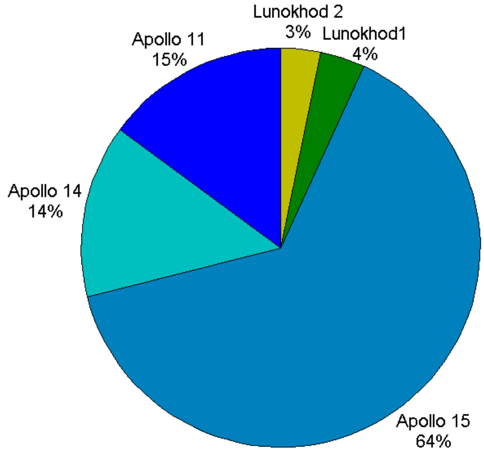

Figure 6. Reflector statistics in 2012.

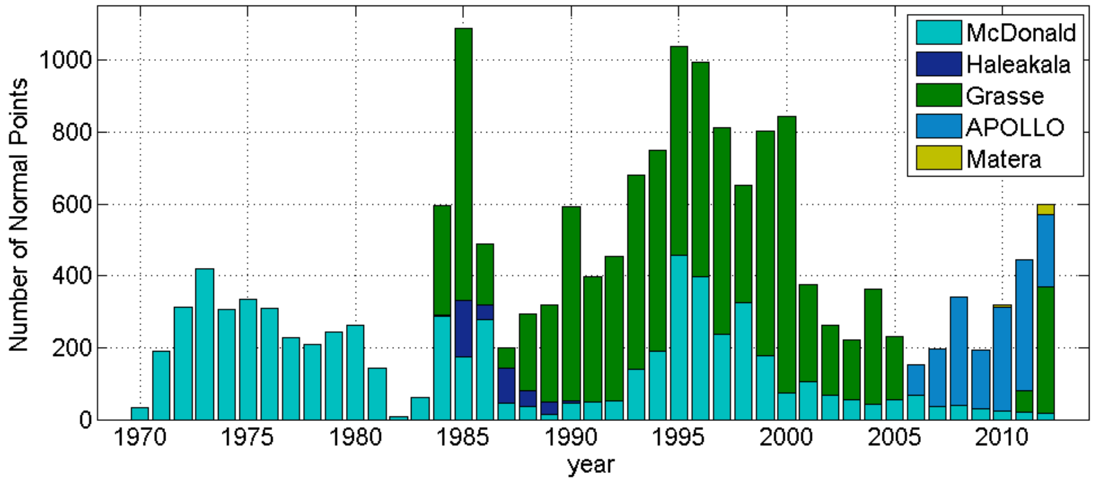

Figure 7. Data yield of the global LLR network of stations (up to 2012).

Recent Activities

In April 2013, the ILRS was accepted as a network member of the International Council for Science (ICSU) World Data System (WDS). The WDS strives to enable open and long-term access to multidisciplinary scientific data, data services, products and information. The WDS works to ensure long-term stewardship of data and data services to a global scientific user community. The ILRS is a network member of the WDS, representing its two data centers and coordinating their activities within the WDS.

ILRS Meetings

The ILRS organizes regular meetings of the Governing Board, General Assembly and working groups. These meetings are typically held in conjunction with ILRS workshops, such as the fall technical workshops (oriented toward SLR practitioners) or the biannual International Workshop on Laser Ranging. A summary of recent and planned ILRS meetings is shown in Table 3. Minutes and presentations from these meetings are available from the ILRS website (*http://ilrs.gsfc.nasa.gov/about/reports/meeting_reports.html*).

The ILRS also conducts meetings of the Central Bureau on a monthly basis. These meetings review network stations and support for upcoming missions as well as coordinate support of upcoming missions, monitoring and managing the ILRS infrastructure, and future directions and activities, such as the implementation of the new ILRS website.

Table 3. Recent ILRS Meetings (as of July 2013)

Timeframe	Location	Meeting
May 2011	Bad Kötzting, Germany	17th International Workshop on Laser Ranging ILRS Governing Board meeting ILRS Working Group meetings ILRS General Assembly
September 2011	Zurich, Switzerland	ILRS Analysis Working Group meeting
December 2011	San Francisco CA, USA	ILRS Governing Board meeting
April 2012	Vienna, Austria	ILRS Governing Board meeting ILRS Working Group meetings
November 2012	Frascati, Italy	ILRS Technical Workshop "Satellite, Lunar, and Planetary Laser Ranging: Characterizing the Space Segment" ILRS Governing Board meeting ILRS Working Group meetings
April 2013	Vienna, Austria	ILRS Analysis Working Group meeting
November 2013	Fujiyoshida, Japan	18th International Workshop on Laser Ranging ILRS Governing Board meeting ILRS Working Group meetings ILRS General Assembly

The ILRS Technical Workshop 2012: "Satellite, Lunar and Planetary Laser Ranging: characterizing the space segment" was held at the Frascati National Laboratories of the INFN-LNF, Frascati, Italy on November 5-9, 2012, in conjunction with a one-day Workshop on "ASI-INFN ETRUSCO-2 Project of Technological Development and Test of SLR Payloads for GNSS Satellites." The meeting focused on the laser ranging space segment including retroreflector arrays for Earth orbiting satellites and the moon, with special attention to the expanding role of ranging to GNSS and geosynchronous satellites. Topics also included receivers in space for time transfer experiments (T2L2), one-way ranging to lunar orbiters (LRO) and interplanetary spacecraft (MLA, MOLA), and data relay systems.

The next International Laser Ranging Workshop will be held in Fujiyoshida Japan, November 11-15, 2013. The theme of the 18th workshop will be "Pursuing Ultimate Accuracy and Creating New Synergies." An important topic for this workshop will be maximizing accuracy in the network with the intent of enhancing the potential for laser ranging by including activities in relevant fields.

Publications

Detailed reports from past meetings can be found on the ILRS website. ILRS Biannual Reports summarize activities within the service over the period since the previous release. They are available as hard copy from the CB or online at the ILRS website. The ILRS published the 2009-2010 ILRS Report in late 2012. This latest volume is the fifth published report for the ILRS and concentrated on achievements and work in progress rather than ILRS organizational elements.

In October 2012, the ILRS Central Bureau implemented a new design for the ILRS website, *http://ilrs.gsfc.nasa.gov*. The redesign process allowed for a review of the organization of the site and its contents, ensuring information was made current and remained useful to the laser ranging community.

ILRS Analysis Center reports and inputs are used by the Central Bureau for review of station performance and to provide feedback to the stations when necessary. Special weekly reports on on-going campaigns are issued by email. The CB also generates quarterly Performance Report Cards and posts them on the ILRS website. The Report Cards evaluate data quantity, data quality, and operational compliance for each tracking station relative to ILRS minimum performance standards. These results include independent assessments of station performance from several of the ILRS analysis/associate analysis centers. The statistics are presented in tabular form by station and sorted by total passes in descending order. Plots of data volume (passes, normal points, and minutes of data) and RMS (LAGEOS, Starlette, calibration) are created from this information and available on the ILRS website. Plots, updated frequently, of multiple satellite normal point RMS and number of full-rate points per normal point as a function of local time and range have been added to the ILRS website station pages.