Section 6:

Mission Support

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Responsible Agency: ILRS Central Bureau

Overview

By the end of 2019, the ILRS routinely tracked nearly 120 satellites, over three times the number the service supported at its start in 1998 (Figure 6-1).

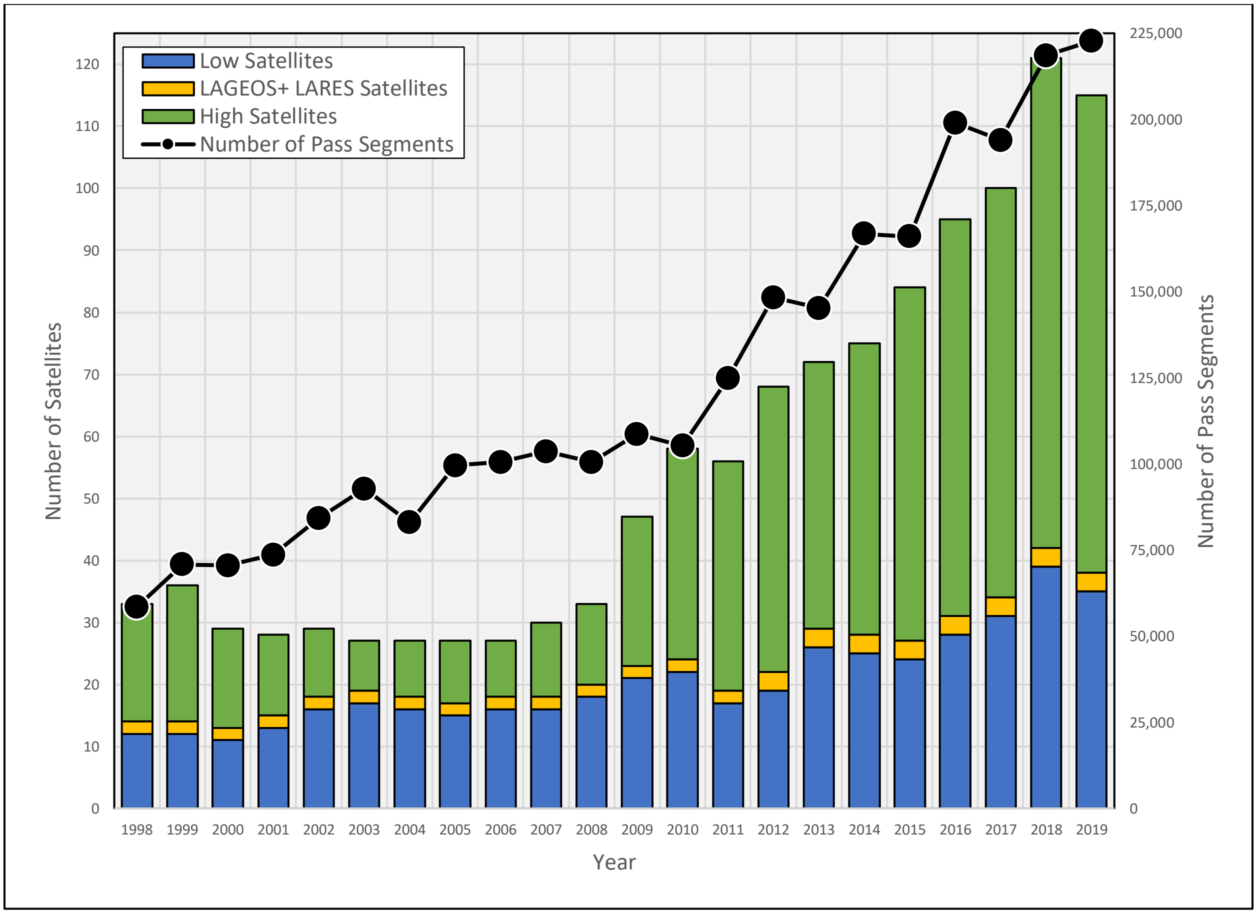

Figure 6-1. The number of missions supported through the years has continued to increase, mainly due to the increase in the number of GNSS satellites equipped with retroreflector arrays.

Stations in the ILRS network range to artificial satellites and the Moon; these satellites fall into four major categories:

- Geodetic
- Altimetric
- Space navigation and positioning (i.e., GNSS)
- Special/engineering

Examples of satellites in these categories are shown in Figure 6-2.

Geodetic satellites are dedicated, long-lived, passive retroreflector satellites, used in defining and improving the International Terrestrial Reference Frame (ITRF). These satellites include LAGEOS, LAGEOS-2, Etalon-1 and -2, and LARES. This application requires frequent and long-term tracking.

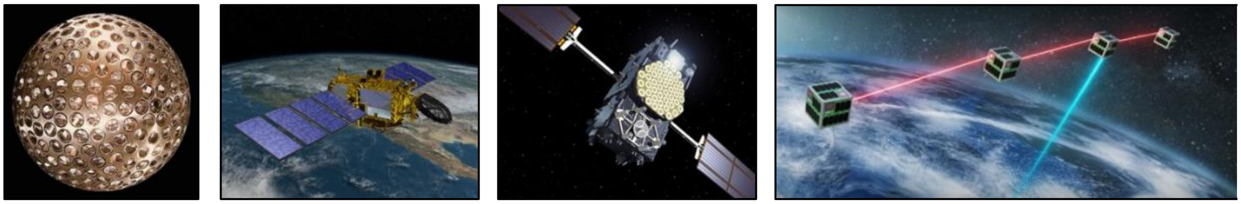

Figure 6-2. Some satellite missions currently supported by the ILRS; left to right: LAGEOS-1 (credit: NASA), Jason-3 (credit: NASA), a Galileo satellite (credit: ESA), SNET constellation (credit: TU Berlin).

Altimeter satellites, with typical life-times of 7 – 12 years, take measurements that allow us to better understand: the dynamics of sea surface topography, sea level, wave height determination, global ocean circulation, ice sheet thickness and topography, and land surface topography including biomass estimation. SLR is one of the techniques that provides Precision Orbit Determination (POD) and a means to calibrate and validate the altimeter instruments.

Space navigation and positioning satellites using microwave measurements give us precise geodetic positioning on the Earth for a wide range of applications and precise navigation in space. Laser tracking provides an independent means of calibrating the performance of these systems, further defining satellite force models, and directly tying their orbits into the SLR reference frame with its well-defined geocenter and vertical scale height.

Special or engineering satellites usually have unique, short-term scientific or engineering goals, such as testing the performance of new retroreflector designs, studying in-orbit satellite dynamics, or intercontinental time transfer experiments.

This section of the 2016-2019 ILRS report provides a summary of current, past, and future missions tracked by stations in the ILRS network as well as dedicated campaigns supported during the 2016-2019 timeframe.

Current Missions

In the 2016 to 2019 time period, the ILRS supported 139 distinct artificial satellite satellites and lunar reflectors in the categories listed above. A summary of the network tracking during this three-year period is shown in Figure 6-3; tracking totals by station can be found in figures in Section 8 (ILRS Network). As can be seen from the charts, the ILRS has a wide range of performance among the stations.

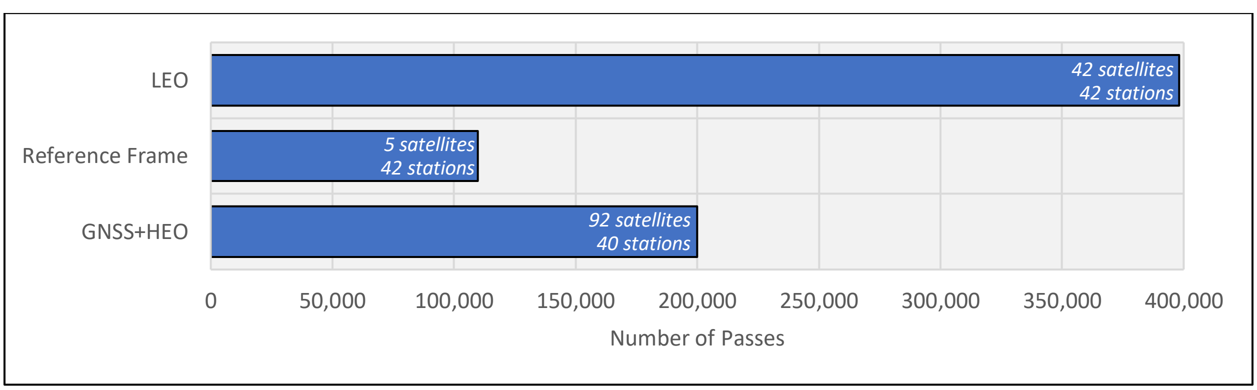

Figure 6-3. Satellite support by stations in the ILRS network in 2016-2019.

Lunar Targets

Stations in the ILRS network with lunar capability also tracked the five reflector arrays on the Moon. The measurement distribution w.r.t. of the reflectors is still dominated by the Apollo 15 reflector, but its impact was reduced to 69% (see Figure 6-4). When looking at the statistics between 2016 and 2018 (Figure 6-4) the distribution between the smaller reflectors was evened out and the Apollo 15 reflector has a share of only 39%. It should be noted, for the Apache Point APOLLO station, only the total number of normal points is approximately known; no normal points after 2016 were distributed up to now and could not be included in Figures 6-4 and 6-5.

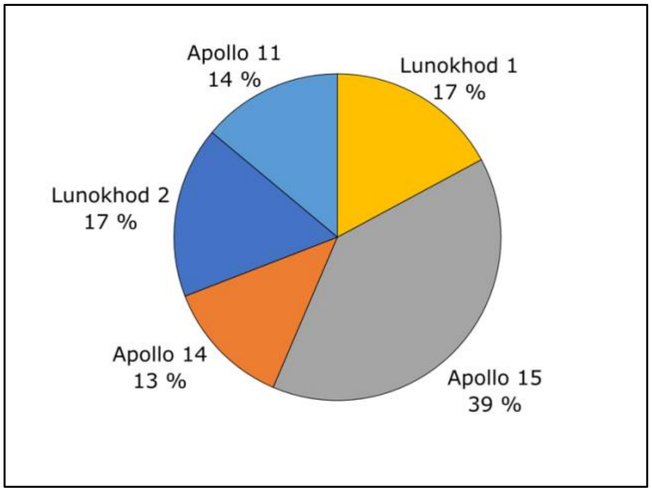

Figure 6-4. Lunar target statistics (1970-2018) by reflector array.

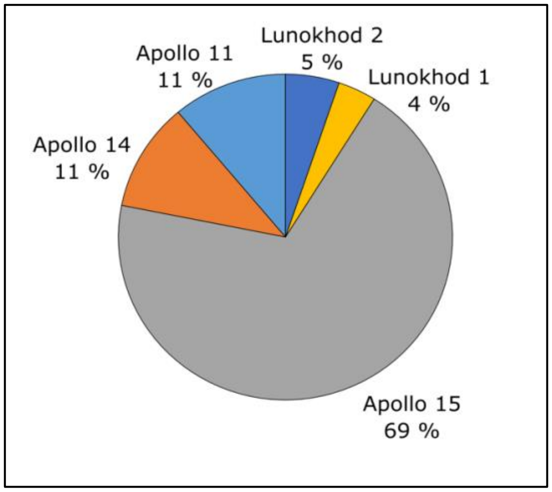

Figure 6-5. Lunar target statistics (2016-2018) by reflector array.

Processing Requests for Mission Support

The ILRS supports scientific and engineering research applications and programs; the service's primary emphasis, however, is the support of the IAG's Global Geodetic Observing System (GGOS) and the geodetic satellites that form the basis for the maintenance and improvement of the International Terrestrial Frame (ITRF). At the end of 2019, the ILRS network ranged to more than 120 satellites; missions continue to submit additional requests for tracking support. The ILRS reviews new Mission Support Requests (MSRs) on the basis of laser tracking need and the likelihood of mission success. Although the ILRS tries to accommodate all new tracking requests, the submission of a request does not guarantee ILRS support.

New requests for ILRS tracking support must be submitted to the ILRS Central Bureau, reviewed by the Missions Standing Committee (MSC), and following MSC recommendation, approved by the Governing Board.

Mission contacts must submit new requests, using the Mission Support Request Form available on the ILRS website, to the ILRS Central Bureau at least six months prior to launch or when the mission expects tracking support to begin. The MSR must include contact information, objective of the mission and its need for laser tracking support, satellite and retroreflector information, and a mission concurrence signature page. Following a positive review by the MSC, the CB submits the MSR to the Governing Board for final approval.

Once tracking support is approved, the ILRS Central Bureau works with the new missions to establish the level of tracking, the schedule, the points of contact, and the channels of communication.

Some satellites requesting ILRS support must (or can) only be tracked by laser ranging under certain constraints or conditions. These “restricted tracking” missions include satellites equipped with: 1) sensors that could be damaged if illuminated by a laser beam, 2) corner cubes that may not be visible under certain geometric conditions, or 3) detectors that only can handle a certain level of power produced by an SLR station. In order to support these missions, the ILRS, through the CB and MSC, must develop mission-specific procedures for restricting SLR tracking; this process often takes considerable time, coordination, and interaction between the CB, the MSC, the mission, and the stations. The ILRS CB and MSC must ensure that the mission requirements are met in a safe manner and that all participating stations range to the satellite following established guidelines. The ILRS CB works with these missions by providing station configuration information for their review. The CB also interacts with the stations, coordinating how and under what conditions they can range to the satellite. Examples of recent restricted tracking missions include the Sentinel-3 satellites and ICESat-2.

Recent Developments in Mission Support

The ILRS acknowledges the 40th anniversary of the launch of LAGEOS (May 04, 1976) and the 30th anniversary of the launch of Ajisai (August 13, 1986) during this reporting period; both satellites continue to satisfy investigator requirements in solid Earth dynamics and reference frame evolution. In addition, NASA celebrated the 50th anniversary of the first Moon landing on July 20, 1969 where astronauts installed retroreflector arrays and thus the birth of Lunar Laser Ranging.

New Mission Support Request Form

The ILRS Missions Standing Committee (MSC), in conjunction with the CB, developed an update to the ILRS Mission Support Request form. The new form includes additional fields needed by the ILRS to assess the mission requirements for future ILRS tracking support. The form is easier to fill out and read; some additional questions were added while obsolete, previously requested information has been removed. The new mission support Request Form, along with mission support guidelines, are available on the ILRS website at: *https://ilrs.cddis.eosdis.nasa.gov/missions/mission_support/new_mission_support.html.*

Guidelines for New Mission Support

The ILRS CB has been working with the MSC to clarify and strengthen the guidelines for missions requesting tracking support. In addition to the review of a complete Mission Support Request Form, some of the questions being considered are:

- Does SLR provide a unique capability that other tracking systems cannot? Is SLR the primary or secondary tracking technique? Can the tracking requirement be met by another technique?
- What added value will SLR data provide to the data products?
- Has the mission sufficiently quantified its tracking requirement (accuracy, data volume, coverage, etc.)?
- Does the mission have a vulnerable payload aboard that will require special tracking procedures?
- What is the procurement source of the retroreflector array(s)? Does the design include accommodation for the velocity aberration?
- Has the signal link budget been estimated either through comparison with spacecraft already tracked by SLR or through the link equation?

- Have provisions been made to provide reliable predictions in the required format? Has this source tested their predictions or are there plans to do such testing?

The ILRS MSC and CB addressed these questions and developed clear guidelines that would need to be considered when reviewing future mission support requests. The guidelines are now posted on the ILRS website: *https://ilrs.gsfc.nasa.gov/missions/mission_support/new_mission_support.html*.

Revised GNSS Tracking Strategy

The ILRS has been working with the IGS and other interested parties to develop and finalize a GNSS tracking strategy that would satisfy both mission and user requirements. For some applications, users want denser tracking on a few satellites. For other applications, users want some tracking on the full complex of GNSS satellites, even if that tracking is sparse. In addition, there are also requests for focused campaigns, in particular, for tracking GNSS satellites while going through Earth shadow to study the effects of radiation pressure. We presently have over 60 GNSS satellites (GLONASS, Galileo, BeiDou) on the ILRS roster. More will be added in the near future. The total could reach nearly 100 when GPS is added in the 2024 timeframe.

The ILRS implemented the new strategy for laser ranging to GNSS targets in 2019. These tracking guidelines for the stations were published on the ILRS website at: *https://ilrs.gsfc.nasa.gov/missions/GNSS_Tracking_Strategy_2019.html*. The main points that the ILRS has agreed to implement are as follows:

- GNSS tracking will continue to be prioritized with the other ILRS satellites by the standard ILRS priority scheme (by altitude and inclination);
- Four GNSS satellites will be identified by each constellation (Galileo, GLONASS, and BeiDou) for intensive tracking, with three sectors (at least 2 normal points each) spaced widely apart over the pass. If stations cannot obtain three sectors they should try to get two sectors. These four satellites per constellation would be selected by the constellation and would have the highest priority among the GNSS satellites.
- All of the remaining GNSS satellites would be tracked by the stations on an as time available basis; selection of targets should be determined by the stations for data yield, but stations are asked to try to diversify among all three constellations because we need some data on all three.
- Special tracking campaigns will be scheduled as time permits, to support special studies.
- Stations will be urged to set their tracking schedules to support all of the GNSS constellations.

Contacts for the GLONASS, Galileo, and BeiDou missions selected four primary, high priority satellites that were incorporated into the ILRS priority list.

New Missions (2016-2019)

During the 2016-2019 time period, the missions listed in Table 6-1 where accepted by the ILRS and tracking support began shortly after launch. A total of 11 missions totaling 15 satellite targets were reviewed by the Missions Standing Committee, approved by the ILRS Governing Board, and added to the ILRS priority list. Due to instrument vulnerabilities, SLR ranging to the Sentinel-3A and -3B and ICESat-2 satellites is restricted to a subset of stations approved by the mission and the CB. These stations obtain satellite predictions directly from the mission facilities.

Table 6-1. New satellite missions supported by the ILRS starting in 2016-2019.

Mission	Launch Date	Sponsor	Application	ILRS Support
Jason-3	17-Jan-2016	NASA, CNES, Eumetsat, NOAA	Oceanography	POD
Sentinel-3A Sentinel-3B	16-Feb-2016 25-Apr-2018	ESA, Eumetsat	Marine observation	POD
Geo-IK-2	04-Jun-2016	JSC ISS Russia	Earth remote sensing	POD
Tiangong-2	15-Sep-2016	CMSE China	Manned spaceflight	POD
TechnoSat	14-Jul-2017	TU Berlin Germany	Engineering	Engineering
SNET (4 satellites)	01-Feb-2018	TU Berlin, Germany	Engineering	Engineering
PAZ	22-Feb-2018	HISDESAT	Weather prediction	POD
GRACE-FO (2 satellites)	22-May-2018	NASA, GFZ	Gravity field	POD
ICESat-2	15-Sep-2018	NASA	Ice sheet monitoring	POD
LightSail-2	02-Aug-2019	The Planetary Society	Engineering	POD

Past Missions (2016-2019)

During 2016-2019 time period, the ILRS support for the missions, listed in Table 6-2, was no longer required.

Table 6-2. Missions completed for ILRS tracking support in 2016-2019.

Mission	Start/End Date	Sponsor	Application	ILRS Support
BLITS-M*	27-Dec-2019	Roscosmos, JC "RPC "PSI"	Calibration of SLR stations	POD
GRACE	Mar-2002 – Apr-2018	NASA/GFZ	Gravity field	POD
Jason-2	Jun-2008 – Oct-2019	NASA, ESA, EUMETSAT, NOAA	Remote sensing	POD
LightSail-2	Aug – Sep 2019	The Planetary Society	Engineering	POD
Lomonosov	Sep – Dec-2019	Moscow State University	Atmosphere research	POD
PN-1A	Nov-2015 – Feb-2018	BAAC	Engineering	POD
SpinSat	Dec-2014 – Mar-2017	NRL	Atmospheric density	POD
STSAT-2C	Mar-2013 – Aug-2019	MEST, KAIST	Spacecraft development	POD
Tiangong-2	Aug-2018 – Jan-2019	CMSE China	Manned spaceflight	POD

*Note: BLITS-M experienced a launch failure and never achieved its target orbit.

Special Tracking Campaigns (2016-2019)

The ILRS CB organizes special dedicated campaigns to provide more intensive or increased tracking on select missions. During 2016-2019, the ILRS conducted three major campaigns as discussed below. Several other mission-specific campaigns for concentrated tracking on single satellites were also conducted during this time period, e.g., QZS satellites, IRNSS-1B, etc.

GREAT: Galileo gravitational Redshift test with Eccentric sATellites

At the 2015 ILRS Technical Workshop in Matera Italy, colleagues with the Center of Applied Space Technology and Microgravity (ZARM) at Bremen University, Germany and the Systèmes de Référence Temps-Espace (SYRTE) laboratory, France agreed on an experiment to test the gravitational redshift by conducting an SLR tracking campaign on Galileo-201 and -202. Due to technical difficulties at launch, the satellites did not reach their intended orbits, but they were eventually maneuvered into eccentric/elliptical orbits, which induced periodic modulations of the gravitational redshifts. The on-board atomic clocks allowed for a long-term assessment in the variation of the redshift and for a determination of the accumulated relativistic effects. In conjunction with the IGS Multi-GNSS Experiment (MGEX) orbit products, SLR data were used to characterize the radial orbit errors. The ILRS supported the GREAT experiment from May 01, 2016 through April 07, 2017. During the campaign, ILRS stations were asked to concentrate tracking on Galileo-201 and -202 during the first seven days of every month for one year, tracking Galileo-201 more intensively. Stations were asked to take one or two normal points (5 minutes in duration) every fifty minutes over the pass. More information on the experiment is available on the ILRS website: *https://ilrs.gsfc.nasa.gov/missions/GREAT_exp.html*.

Results *(Javier Ventura-Traveset, ESA/ESAC)*

Europe's Galileo satellites 5 and 6 (Galileo-201 and -202), provided a historic service to the physics community worldwide by enabling the most accurate measurement ever of the gravitational redshift and thus of local position invariance, an integral part of the Einstein equivalence principle. For this ESA launched a dedicated research activity with two independent research groups, led respectively by the SYRTE Observatoire de PARIS-PSL (*https://syrte.obspm.fr/*) in France and Germany's ZARM Center of Applied Space Technology and Microgravity (*https://zarm.uni-bremen.de/en/*), coordinated by ESA's Galileo Navigation Science Office.

In support to these tests, a specific ILRS campaign took place during the years 2016-2017, which allowed us to very precisely the radial one-way residuals with respect to the modelled orbit solution of the two Galileo satellites, allowing, in turn, to quantify the systematics due to the orbital modelling in order to obtain a robust error budget.

As a result of these tests, an improvement of the gravitational redshift by a factor of 5 was achieved, providing, to our knowledge the first reported improvement since more than 40 years of the NASA Gravity probe A (1976) equivalent test. The support from the ILRS proved essential for this achievement.

Scientific References:

S. Hermann et al. "Test of the gravitational redshift with Galileo satellites in an eccentric orbit," *Physical Review Letters, Vol. 121, Iss. 23, p. 231102, 7 December 2018.*

P. Delva et al. "A gravitational redshift test using eccentric Galileo satellites" *Physical Review Letters, Vol. 121, Iss. 23, p. 231101, 7 December 2018*

LARGE: LAser Ranging to GNSS s/c Experiment

The ILRS established the LAser Ranging to GNSS s/c Experiment (LARGE) Study Group in 2013 to help expand the GNSS tracking coverage by the ILRS network. The GNSS satellite constellations with retroreflector arrays of main interest are those constellations with global coverage, including GLONASS, BeiDou, Galileo, and future GPS.

SLR tracking of GNSS satellites has been a network challenge, which will only become more demanding as additional satellites are launched in each constellation, and as the GPS-III retroreflector satellites join the roster in the middle of the next decade. Over the last few years, the ILRS has received differing requests from both the GNSS providers and users for SLR tracking support; some requesting intensive tracking on a few GNSS satellites and others requesting sparse tracking on as many GNSS satellites as possible. Intensive tracking was characterized by three tracking segments of at least two normal points each, with the segments taken during the ascending, middle, and descending regions of the pass. Sparse tracking was at the level of one segment per pass.

In 2018, the ILRS conducted two LARGE tracking campaigns, to examine how the service might combine the two options and address the needs of both communities. In the first campaign (February 15 through May 15, 2018), each GNSS constellation identified four primary and four secondary satellites for intensive tracking. In the second campaign (August 01 through October 31, 2018) the Galileo and Compass/BeiDou constellations selected eight satellites each for high priority tracking; GLONASS chose to identify only four. Since only four satellites were designated for GLONASS, the stations were instructed to try to obtain as many passes on these satellites as possible. Predictions for all the other satellites in each constellation were issued, and thus stations could continue to track these satellites on a non-interference basis with the LEO, LAGEOS, and selected GNSS satellites at higher priority. The designated LARGE GNSS satellites were interleaved on the priority list to try to give each constellation an equal chance of tracking.

The campaigns demonstrated that the network could expand SLR tracking coverage, even operating under the mixed mode strategy, but there was an imbalance in the tracking coverage for the three constellations and that further, more detailed instructions to the stations for effective tracking of GNSS satellites would be necessary. Additional observations about the campaign can be found in the monthly reports from both 2018 LARGE campaigns available on the ILRS website at:

https://ilrs.gsfc.nasa.gov/science/ILRS_LARGE_sg/LARGE_activities/LARGE_activities.html

These tests were the basis for the initial tests of new tracking strategies tried by the ILRS. Other strategies are under discussion with the IGS.

Etalon Campaign

The Etalon data contribution to the reference frame is still very sparse and yet holds potential for improvement in the determination of Earth Orientation Parameters (EOPs). The Analysis Standing Committee (ASC) requested that the ILRS organize a tracking campaign in 2019 to increase data volume on Etalon-1 and -2. During the three-month campaign, held February 15 through May 15, stations were asked to obtain at least one pass per day on each of the two satellites, with NPs on the ascending, middle and descending portions of the pass, with three normal points per segment.

The stations have been able to strengthen their ability to track GNSS altitudes, leading us to believe that a reasonable improvement in Etalon data can be achieved with some increase in effort. The ILRS ACs analyzed the results from the actual data analysis of the Etalon campaign period, focusing on the EOP improvement. Data from the same timeframe in 2018 were reanalyzed in order to have results compared to exactly the same IERS C04 series. The results showed that the additional Etalon data makes a significant difference, bringing the ILRS EOP product a lot closer to the "final" IERS series (which is ~90% a GNSS product). The campaign summary report is available on the ILRS website (*https://ilrs.gsfc.nasa.gov/docs/2019/Etalon_1and2_2019_Campaign.pdf*). The ILRS Analysis Coordinators have requested that the network do their best to increase their collection of Etalon data on a permanent basis.

Future Plans

New Missions

New mission support requests were received and approved by the ILRS for several missions in the near future, as summarized in Table 6-3 below.

Table 6-3. New satellite missions approved for ILRS tracking support in 2019 and beyond.

Mission	Planned Launch	Sponsor	Application	ILRS Support
Astrocast*	01-Apr-2019	ETH Zurich and Astrocast SA	Positioning	POD
COSMIC-2	25-Jun-2019	UCAR	Atmospheric research	GNSS orbit validation
ELSA-d	Nov-2020	Astroscale	Engineering research	POD
LARES-2	Fall 2020	ASI	Positioning, geodesy	POD
NISAR	2021	NASA/JPL, ISRO	Earth observation	POD

*Note: Select stations tracked the two Astrocast Precursor satellites in 2019 as per request of mission; general tracking by entire ILRS network has not yet been activated.

By the middle of the next decade, the ILRS anticipates the emergence of the new GNSS constellations (e.g., GPS-III) to be included in the ILRS tracking roster.

In the next few years, a new generation of more accurate and efficient lunar reflectors are expected to be deployed on the lunar surface. LLR again has shown a strong capability to test Einstein's relativity theory and to improve the limits for a number of relativistic parameters. In addition, lunar science and many quantities of the Earth-Moon dynamics are being widely be studied. As a next step, the ILRS is planning a new structure (e.g., a working group or standing committee) to support LLR within the ILRS and to link all LLR contributors, from observatories to science.

GNSS Eclipse Campaign

Solar radiation pressure is a significant surface force on GNSS satellites. Special campaigns have been requested by ESA to track GNSS satellites as they approach solar eclipse conditions to see the effect on the satellite orbits. Intensive tracking will be scheduled over the course of several days at a time and might involve a couple of satellites at a time. The first campaign will be scheduled for 2019.