International Laser Ranging Service

ILRS: Current Status and Future Trends

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ILRS Central Bureau

Implementation of the Global Geodetic Reference Frame (GGRF) in Latin America
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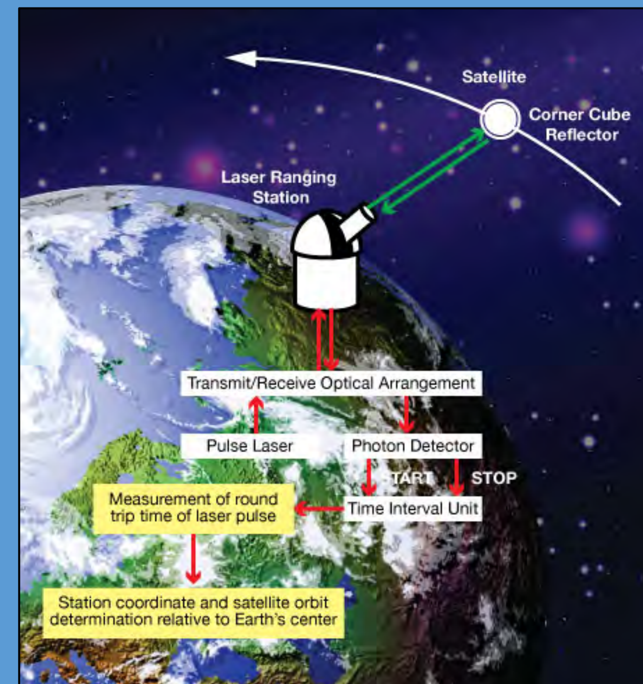
Buenos Aires, Argentina

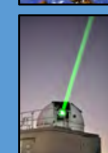
Outline

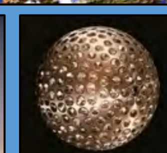
- Introduction
- SLR overview
- Current trends
- Network
- Mission support
- Infrastructure
- Conclusion

SLR and LLR

- Satellite Laser Ranging and Lunar Laser Ranging
- Space Segment:
  - Satellites equipped with corner cube reflectors
  - 100+ satellites (including the Moon)
- Ground Segment:
  - Short-pulse laser transmitter
  - ~40 sites tracking
- Observable:
  - Two-way range measurement to the satellite
- Characteristics:
  - Passive space segment
  - “Simple” range measurement
  - Only optical system in the space geodetic complex







SLR: satellite laser ranging

ILRS

- Satellite Laser Ranging directly measures the range between the ground station and the satellite using very short laser pulses, corrected for refraction, satellite center of mass, and the internal delay of the ranging machine.

$$R = \Delta t \times c/2 - R_{atm} + R_{c/m} + R_{cal}$$

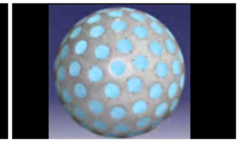
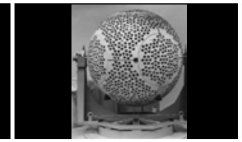
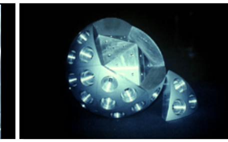
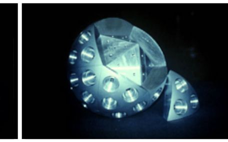
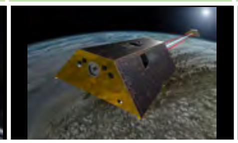
- State of the art is sub millimeter precision average measurements (normal points) with centimeter level accuracies
- SLR systems can track satellites from 300 km to 22,000+ km in day & night; some track the arrays on the Moon
- Each station tracks independently but a network of stations an be scheduled together (set priorities) to optimize tracking
- Requires only a passive retroreflector on the satellite

→ *Unambiguous centimeter accuracy orbits*
Long-term stable time series

SLR science and applications

- Measurements
  - Precision orbit determination (POD)
  - Time series of station positions and velocity
- Products
  - Terrestrial reference frame (center of mass and scale)
  - Improve understanding of the dynamics and modeling of GNSS orbits (one of our major users)
  - Calibration and validation of ocean and ice altimetry missions
  - Static and time-varying gravity field (low order/degree terms)
  - Plate tectonics and crustal deformation
  - Earth orientation and rotation (polar motion, length of day)
  - Total Earth mass distribution
  - Space science – satellite dynamics, etc.
  - Relativity and lunar science

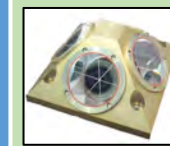
SLR satellite constellation: examples

Geodetic							
Satellite	LAGEOS-1	LAGEOS-2	LARES	Etalon-1/-2	Ajisai	Starlette	Stella
Inclination	109.8°	52.6°	69.5°	64.9°	50°	50°	98.6°
Perigee (km)	5,860	5,620	1,460	19,120	1,490	810	800
LEO							
Satellite	Jason-3	ICESat-2	GRACE-FO	Sentinel-3A/-3B	SWARM	SARAL	TerraSAR-X
Inclination	66°	92°	89°	98.65°	92°	98.55°	97.44°
Perigee (km)	1,336	496	500	814.5	720	814	514
HEO/ GNSS							
Constellation	GLONASS	Galileo	BeiDou	QZSS	IRNSS	GPS-III (future)	
Inclination	65°	56°	55.5°	45°	29°	55°	
Perigee (km)	19,140	23,220	42,161	32,00	42,164	~12,550	

Retroreflector arrays

ILRS

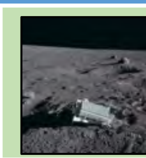
- Arrays for GNSS satellites
  - "ILRS Standard Specification for GNSS Satellites": effective area of 100 million square meters
  - Adaptation of the GNSS standard to synchronous satellites (e.g., IRNSS, BeiDou, QZSS)
  - Improved station quality may allow lower quality, less expensive corner cubes to be used
  - Investigation of specialized designs for increase cross-section
- Arrays for LEO satellites
  - "Pyramid" type arrays (e.g., Lomonosov) are lightweight, inexpensive, and have the required accuracy (0.5 mm)
  - Common use of the GFZ array, nearly COTS
  - Particular design depends upon the satellites altitude and tracking requirement
- Geodetic satellites
  - New array designs for LEO spherical satellites to reduce cost and improve performance
  - BLITS-M type satellites have minimal target error
- Large cornercubes (lunar ranging)
- Hollow cubes for LLR


GRACE


Jason

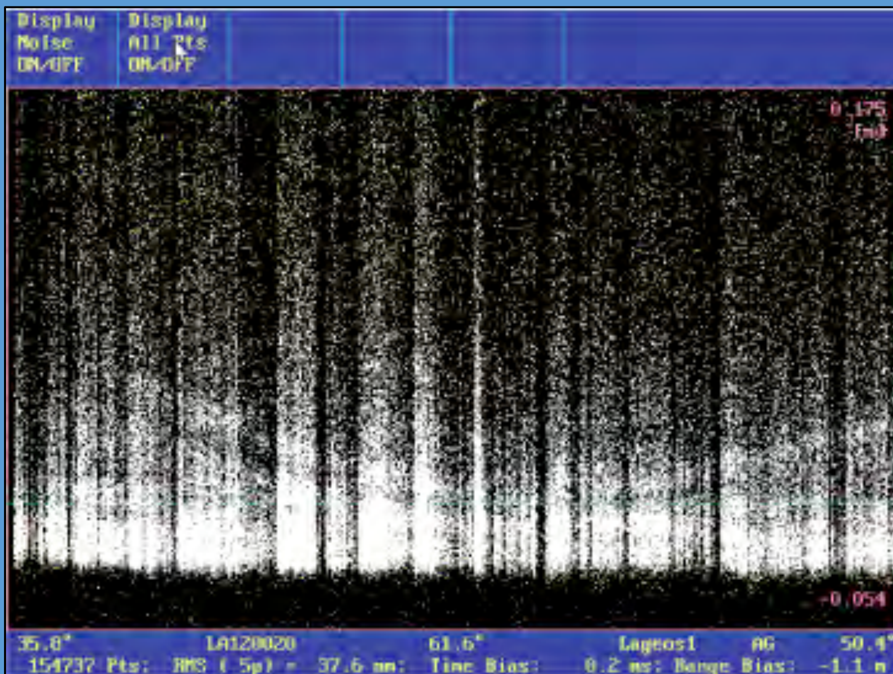

Blits


BeiDou

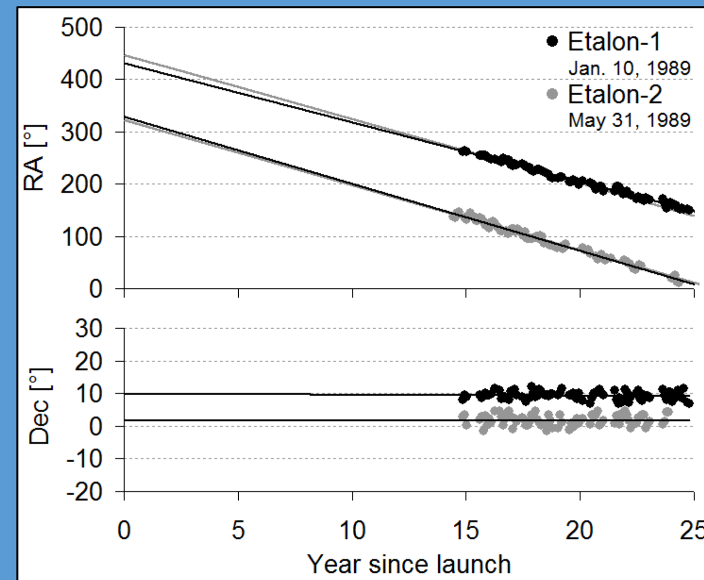

Lunar


LAGEOS

High repetition-rate systems

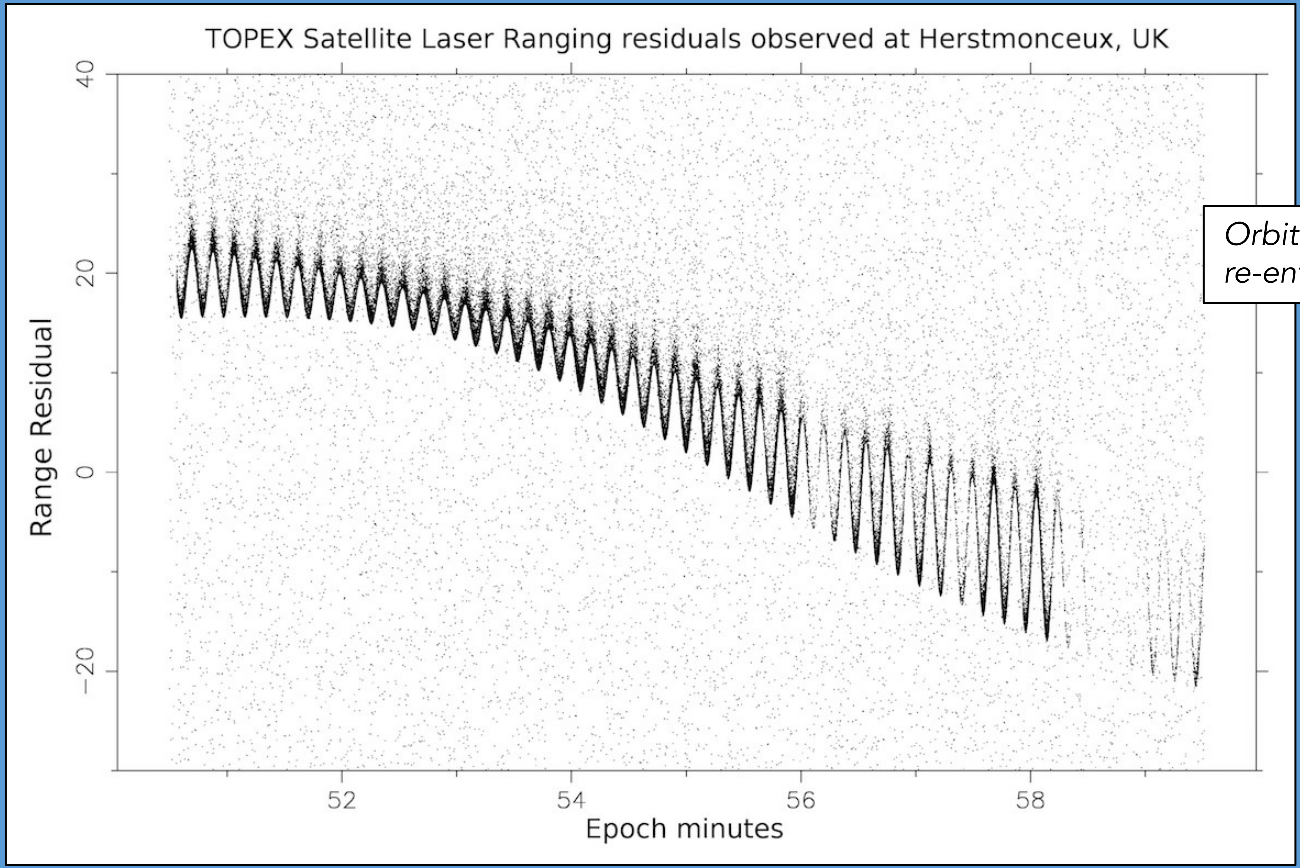


- High repetition rate, short pulse lasers allow us to see retroreflector array details



- Leading to impressive diagnostics of satellite attitude
  - Most of the geodetic spheres have had spin vectors measured as functions of time:
  - e.g., D. Kucharski et al, Etalon-1 and -2, *ASR* 2014

Space debris: TOPEX/Poseidon



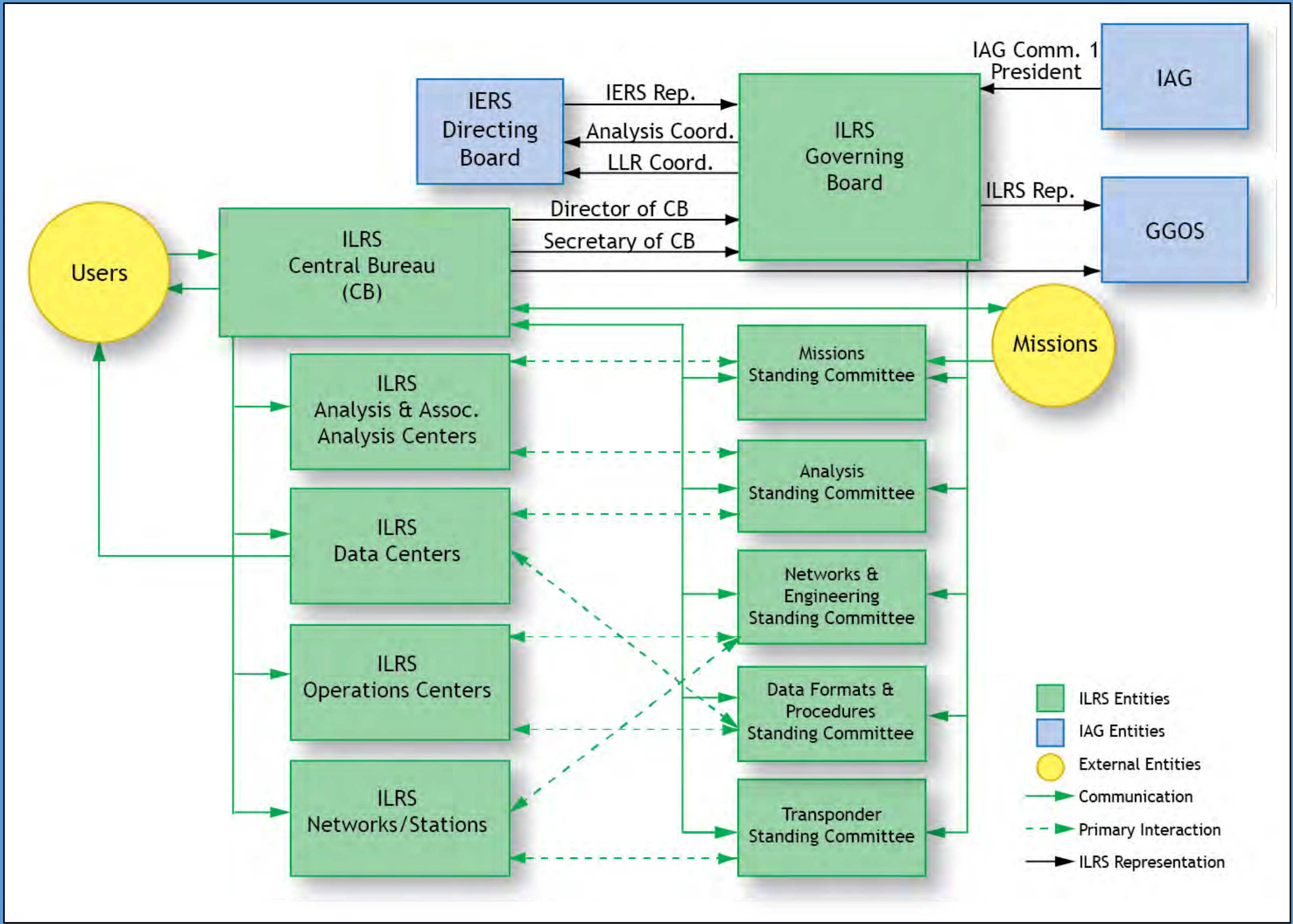
Orbital monitoring and re-entry forecast

The ILRS mission

- Laser ranging activities are organized under the International Laser Ranging Service (ILRS) which **provides global satellite and lunar laser ranging data and their derived data products to support research in geodesy, geophysics, Lunar science, and fundamental physics.** This includes data products that are fundamental to the International Terrestrial Reference Frame (ITRF), which is established and maintained by the International Earth Rotation and Reference Systems Service (IERS).

- The ILRS is one of the space geodetic services of the International Association of Geodesy (IAG) and is a member of the IAG's Global Geodetic Observing System (GGOS). The Services, **under the umbrella of GGOS, provide the geodetic infrastructure necessary for monitoring global change in the Earth system** *(Beutler and Rummel, 2012)*.

ILRS organization



Governing board: 2019-2020

- Ex-officio/appointed positions:
  - Director of the Central Bureau – **Mike Pearlman**
  - Secretary of the Central Bureau – **Carey Noll**
  - Representative of IAG Commission 1 – **Urs Hugentobler**
  - IERS Representative – **Daniela Thaller**
- Elected positions:
  - EUROLAS Network Representatives – **Pippo Bianco, Georg Kirchner**
  - NASA Network Representatives – **Jan McGarry, Stephen Merkowitz**
  - WPLTN Representatives – **James Bennett, Zhang Zhongping**
  - Data Center Representative – **Christian Schwatke**
  - LLR Representative – **Jean-Marie Torre**
  - Analysis Representatives – **Cinzia Luceri, Erricos Pavlis**
  - At-Large Representatives – **Toshi Otsubo (Chair), Matt Wilkinson**
- Appointed by the Governing Board:
  - **Ulli Schreiber**
  - **Krzysztof Sośnica**

18 members serving on the ILRS Governing Board which took office on January 01, 2019

International Workshops on Laser Ranging

- International Workshops on Laser Ranging typically held every two years
  - Program includes sessions on science, infrastructure, operations, technology, software, and mission design
  - Presentations, proceedings, summaries available on ILRS website
  - Clinics focus on small group interactions with station personnel
  - 21st International Workshop on Laser Ranging held in Canberra, Australia, November 2018
  - Theme: "Laser Ranging for Sustainable Millimeter Geoscience"

Number	Year	Location
1st	1973	Lagonissi, Greece
2nd	1975	Prague, Czechoslovakia
3rd	1978	Lagonissi, Greece
4th	1981	Austin, TX, USA
5th	1984	Herstmonceux, UK
6th	1986	Antibes, France
7th	1989	Matera, Italy
8th	1992	Annapolis, MD, USA
9th	1994	Canberra, Australia
10th	1996	Shanghai, China
11th	1998	Deggendorf, Germany
12th	2000	Matera, Italy
13th	2002	Washington, D.C., USA
14th	2004	San Fernando, Spain
15th	2006	Canberra, Australia
16th	2008	Poznan, Poland
17th	2011	Bad Koetzting, Germany
18th	2013	Fujiyoshida, Japan
19th	2014	Annapolis, MD, USA
20th	2016	Potsdam, Germany
21st	2018	Canberra, Australia
22nd	2020	Kunming, China

Over 150 participants in the 21st International Workshop on Laser Ranging, Canberra Australia https://cddis.nasa.gov/lw21/

ILRS Technical Workshops

- ILRS also organizes smaller, focused workshops in years between the International Workshops on Laser Ranging
  - Next technical workshop will be held in Stuttgart, Germany, October 21-25, 2019
  - Theme: "*Laser ranging: To improve economy, performance, and adoption for new applications*"
  - 2019 workshop will be proceeded by a one-day "SLR School" providing tutorials on SLR and the ILRS

Topic	Year	Location
SLR System Calibration Issues	September 1999	Florence, Italy
Working Toward the Full Potential of the SLR Capability	October 2003	Kötzting, Germany
Observations Toward mm Accuracy	October 2005	Eastbourne, UK
Challenges for Laser Ranging in the 21st Century	September 2007	Grasse, France
SLR Tracking of GNSS Constellations	September 2009	Metsovo, Greece
Satellite, Lunar and Planetary Laser Ranging: Characterizing the Space Segment	November 2012	Frascati, Italy
Network Performance and Future Expectations for ILRS Support of GNSS, Time Transfer, and Space Debris Tracking	October 2015	Matera, Italy
Improving ILRS Performance to Meet Future GGOS Requirements	October 2017	Riga, Latvia
Laser ranging: To improve economy, performance, and adoption for new applications	October 2019	Stuttgart, Germany

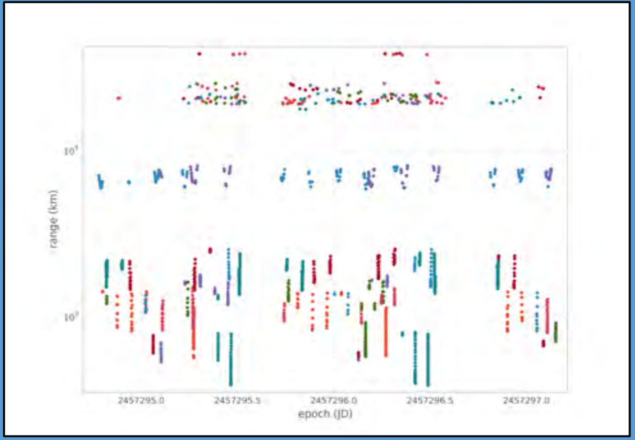
Journal of Geodesy
Special Issue on Laser Ranging

30+ papers submitted;
18 papers published online;
4 papers in final review stage.

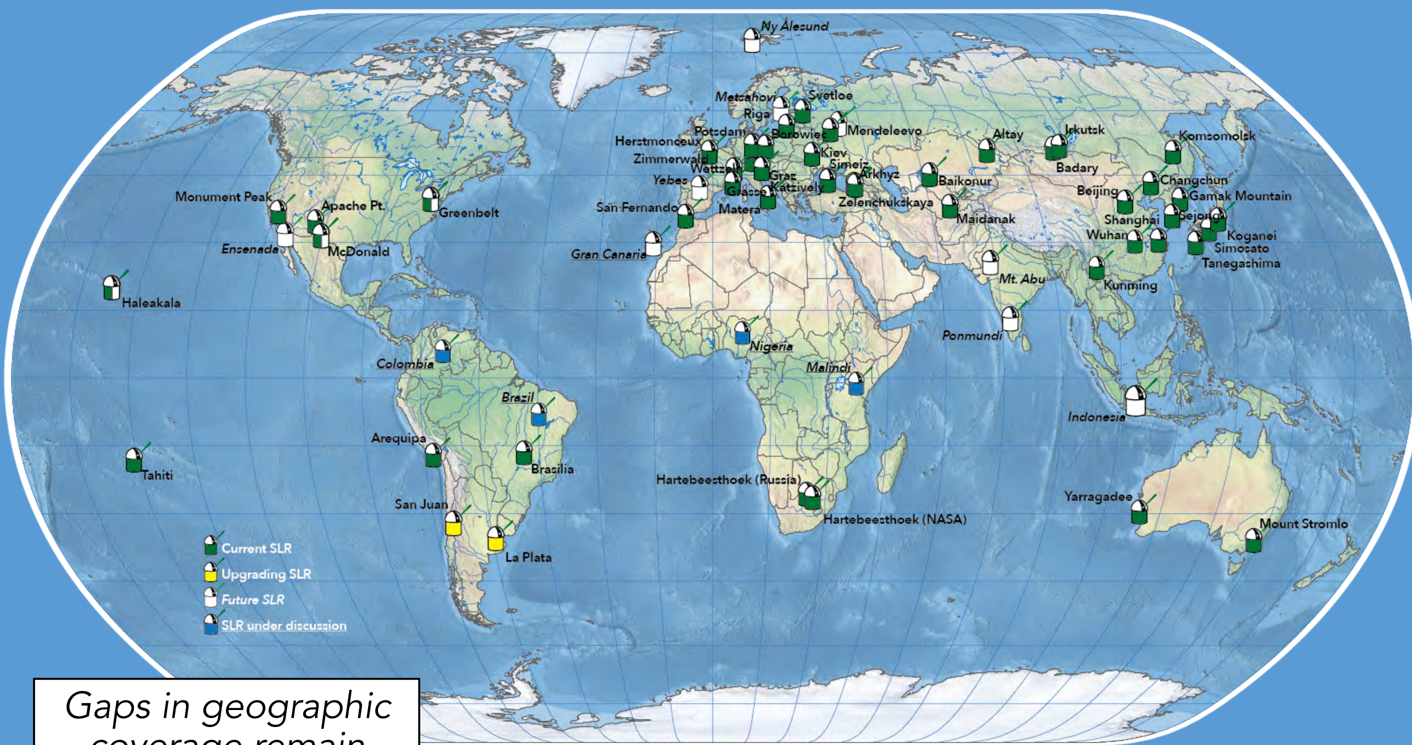
- The ILRS: Approaching twenty years and planning for the future
- Geodetic Satellites: A High Accuracy Positioning Tool
- Satellite Laser Ranging to Low Earth Orbiters - Orbit and Network Validation
- Version of a glass retroreflector satellite with a sub-millimeter "target error"
- Laser and Radio Tracking for Planetary Science Missions - A Comparison
- Assessment of the impact of one-way laser ranging on orbit determination of the Lunar Reconnaissance Orbiter
- Overview of Applications of Satellite Laser Ranging and Laser Time Transfer in BeiDou Navigation Satellite System
- Lunar Laser Ranging - A Tool for General Relativity, Lunar Geophysics and Earth Science
- NASA's Satellite Laser Ranging Systems for the 21st Century
- Time and laser ranging: A window of opportunity for geodesy, navigation and metrology
- The Next Generation of Satellite Laser Ranging Systems
- Rapid Response Quality Control Service for the Laser Ranging Tracking Network
- Solar orbital thermo-optical characterization of an innovative GNSS retroreflector array
- Operating two SLR Systems at the Geodetic Observatory Wettzell - from local survey to space ties
- Future SLR station networks in the framework of simulated multi-technique terrestrial reference frames
- Information Resources Supporting Scientific Research for the International Laser Ranging Service
- Modernizing and Expanding the NASA Space Geodesy Network to Meet Future Geodetic Requirements
- Time Bias Service: Analysis and Monitoring of Satellite Orbit Prediction Quality

Current trends

- SLR systems: lower energy, higher repetition rates (kHz)
- Single photon sensitive detectors (geodetic satellites)
- Shorter normal point intervals (take data more quickly) and faster slewing for increased pass interleaving
- Interleaving of satellite passes
- Real-time data evaluation for real-time decision making
- Automated to autonomous operation with remote access
- Stations with two SLR systems to help address the workload (e.g., Hartebeesthoek)
- Environmental monitoring and awareness
- for instrument integrity and safety
- Real-time network communication and information sharing among stations



ILRS network



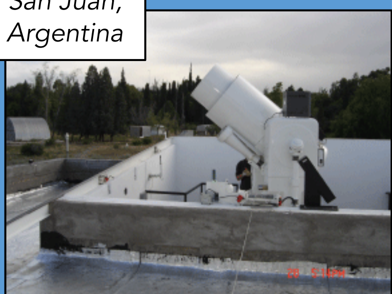
Gaps in geographic coverage remain

- BKG AGGO continuing setup at La Plata Observatory (Argentina)
- Russians implementing co-location concept in their own network to expand temporal coverage of satellites
- New stations underway:
  - Russia: Ensenada (Mexico), Java (Indonesia), Canary Islands (Spain)
  - NASA/NASA affiliated: McDonald, Halekala (USA), and Ny Ålesund (NMA, Norway)
  - Others: Metsahovi (Finland), Mt. Abu and Ponmundi (India), and Yebes (Spain)
- Upgrades underway at some stations

Space geodesy in South America

Arequipa, Peru

San Juan, Argentina



O'Higgins, Antarctica

Sazhen-TM, Brasilia, Brazil

Fortaleza, Brazil

AGGO, Argentina

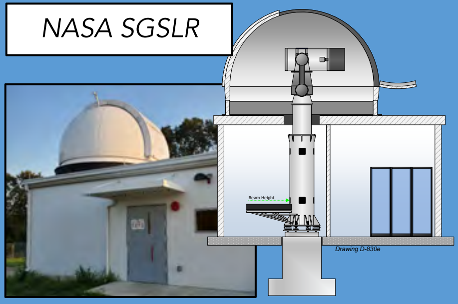
Station activity over the next few years

Site	Type	Agency	Time Frame
La Plata, Argentina	Upgraded core site	BKG, Germany	2019 – 2020
San Juan, Argentina	Upgraded SLR system	NAOC, China	2019 – 2020
Metsahovi, Finland	New SLR system	FGRI, Finland	2019 – 2020
Greenbelt, MD, USA	Replacement core site	NASA, USA	2019 – 2020
Haleakala, HI, USA	Replacement core site	NASA, USA	2019 – 2020
McDonald, TX, USA	Replacement core site	NASA, USA	2019 – 2020
Ny Ålesund, Norway	New core site	NMA, Norway/NASA, USA	2019 – 2020
Ensenada, Mexico	New SLR site	IPIE, Russian Federation	2020
Java, Indonesia	New SLR site	IPIE, Russian Federation	2020
Gran Canaria, Spain	New SLR in core site	IPIE, Russian Federation	2020
Mt Abu, India	New SLR site	ISRO, India	2019 – 2020
Ponmundi, India	New SLR site	ISRO, India	2019 – 2020
Yebes, Spain	New SLR site	IGS, Spain	2022


Tochka, Mendeleevo, Russia


Sazhen-TM, Brasilia, Brazil


Wuhan, China

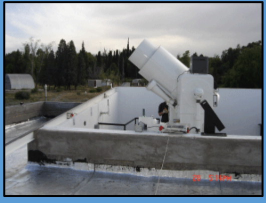


NASA SGSLR

ISRO, India

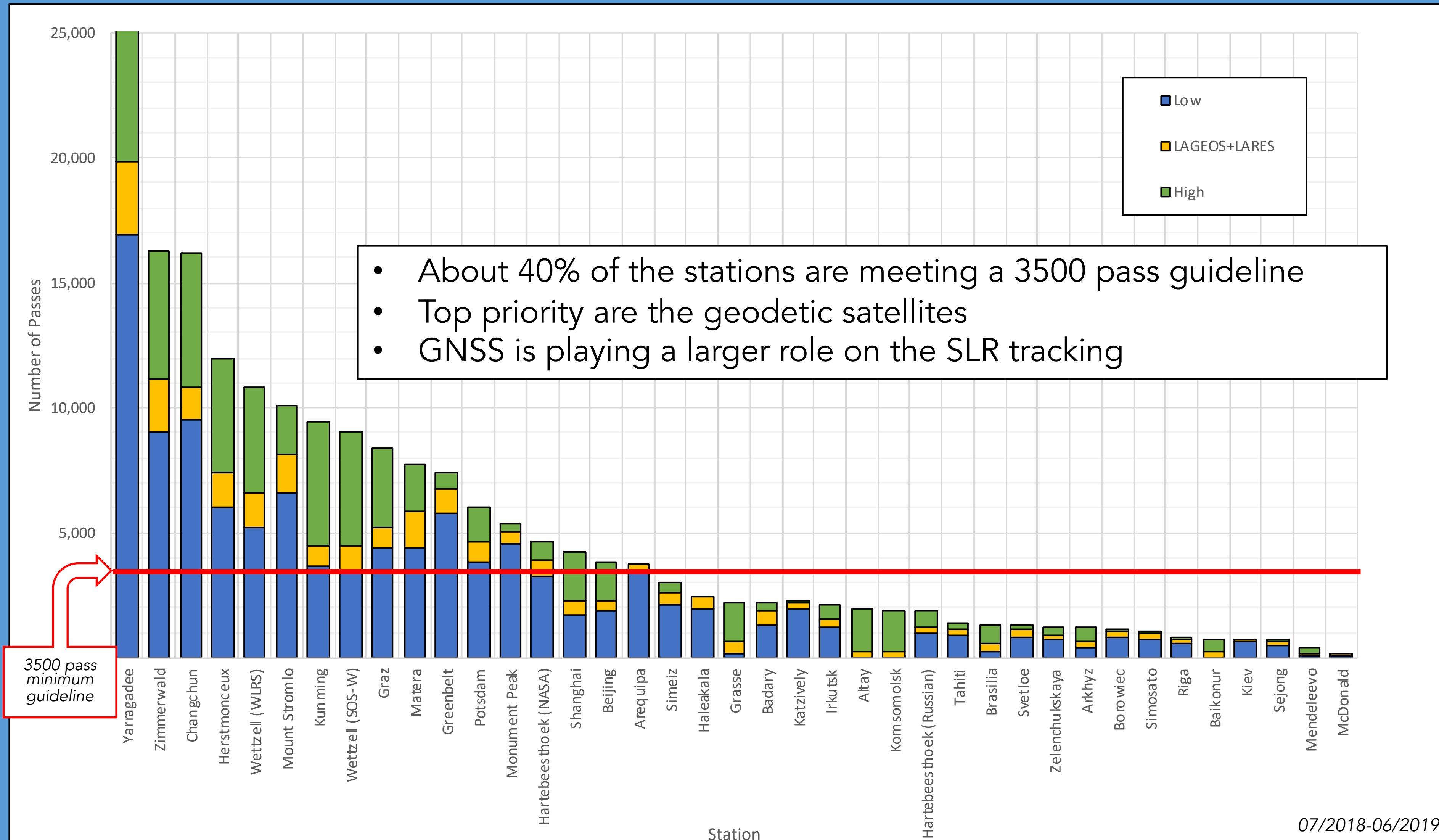
Metsähovi, Finland

Ny Ålesund, Norway



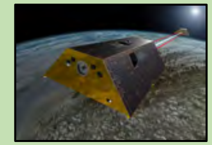
San Juan, Argentina

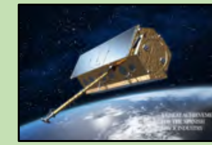
Station performance: passes



Highlights: missions

- Network routinely tracked 110+ satellites in 2019
- Recent additions to the ILRS priority list:
  - S-NET (4 cubesats/testing inter-satellite communication)
  - Sentinel-3B (altimeter mission/restricted tracking)
  - GRACE-FO (2 satellites/gravity measurements)
  - PAZ (SAR mission)
  - ICESat-2 (laser altimetry mission/restricted tracking)
  - Beidou-3M (4 GNSS satellites)
  - GNSS (Galileo, GLONASS, IRNSS)
  - LightSail-2 (solar sail)
- Future missions:
  - Astrocast Precursor (2 cubesats/engineering testing)
  - Additional GNSS: BeiDou/Compass, Galileo, etc.
  - COSMIC-2, HY-2C, SWOT, NISAR
- <u>More requests for restricted tracking, which is time consuming to implement</u>

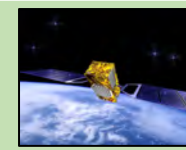

GRACE-FO

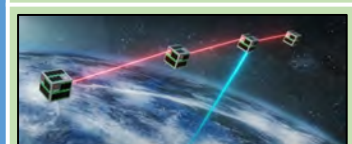

PAZ


Sentinel-3B


ICESat-2


Beidou


Galileo


S-NET


Astrocast


COSMIC-2


NISAR

Analysis activities (ASC)

- Working on the development of the ITRF2020 series; production starts in late 2019
- Currently we are testing new models for gravity, tides, TVG, and target signature (CoM) models, and the inclusion of LARES data
- New operational approach to handling error sources in our current modeling standards
  - Allowance for estimation of systematic errors simultaneously with all other parameters to eliminate biases in station positions (mainly height)
  - Improved corrections in the current model for the Center of Mass (CoM) target signatures; such errors can affect the SLR-VLBI scale difference at the 0.25 ppb level
- Next steps
  - Low degree/low order gravity field terms (data product)
  - Include LARES satellite to the operational data products and ITRF2020
  - Add atmospheric loading to the operational data products (at the observation level)

Issues & challenges

- Many geographic gaps, primarily in Latin America, Africa, and Oceania
- Mix of new and old technologies, levels of financial support, weather
- Lack of standardization in system hardware and operations
- Data quality issues (efforts underway to detect and reduce systematics)
- Number of target satellites continues to increase as new missions use SLR for orbit determination and other applications (110+ satellites)