Recent progress in the International Laser Ranging Service (ILRS)

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With contributions from many others:
Toshimichi Otsubo, Mathis Blossfeld, Clément Courde, Ulrich Schreiber, Michael Steindorfer, Beatriz Vaquero, Shinichi Nakamura, Andrea Di Mira, Michael Haefner, Gro Grinde

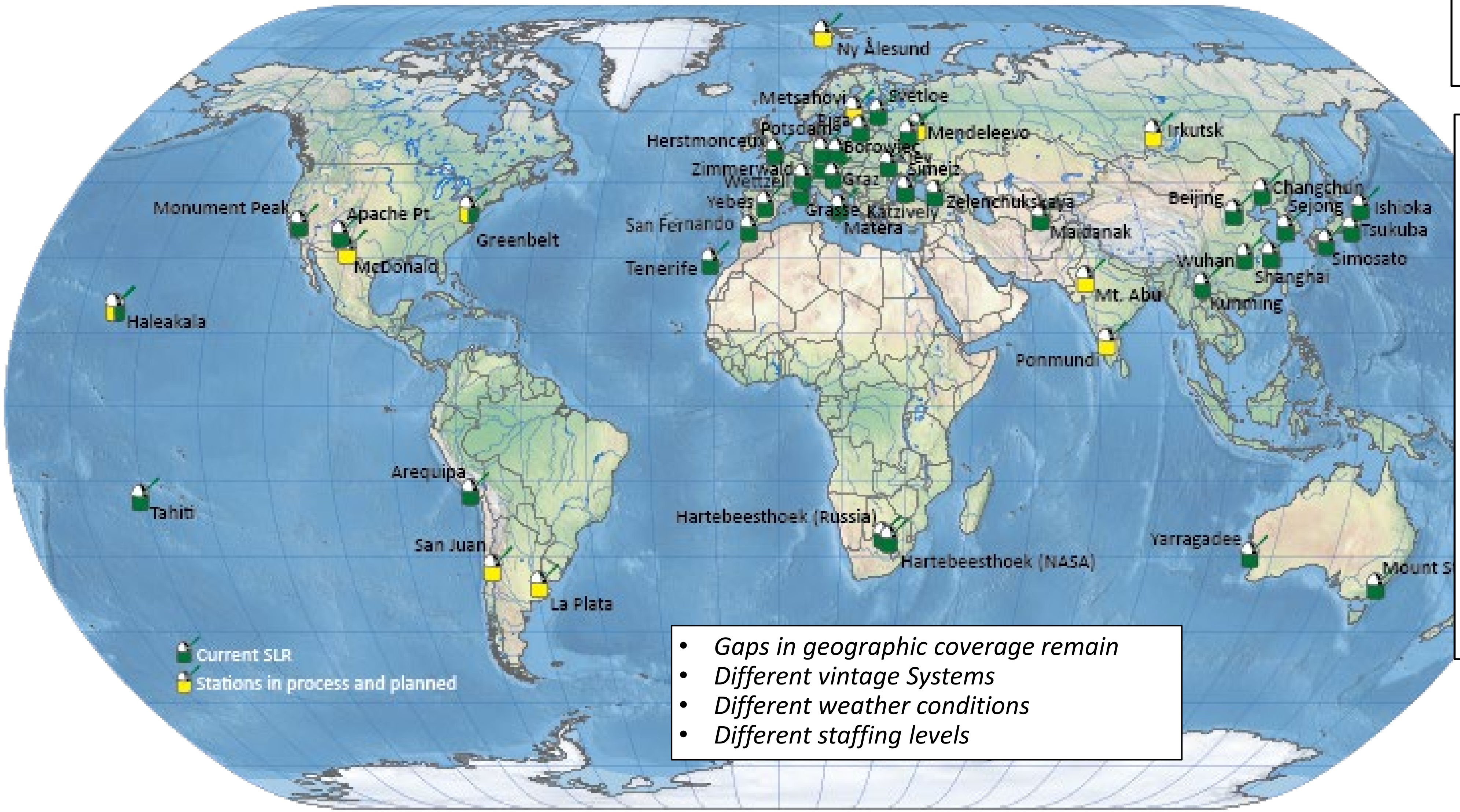
23rd International Workshop on Laser Ranging (IWLR)

October 20th-26th, 2024

Kunming, China

ILRS – Network

Current and Planned ILRS Network



- *Gaps in geographic coverage remain*
- *Different vintage Systems*
- *Different weather conditions*
- *Different staffing levels*

New Stations (2023-2024)
Yebes, Spain
Ishioka, Japan

Future Stations (2024-2027)
La Plata, Argentina
San Juan, Argentina
Metsähovi, Finland
McDonald, TX, USA
Ny Ålesund, Norway
Mt Abu, India
Ponmundi, India
Irkutsk (Tochka), Russia
Mendeleevo (Tochka), Russia

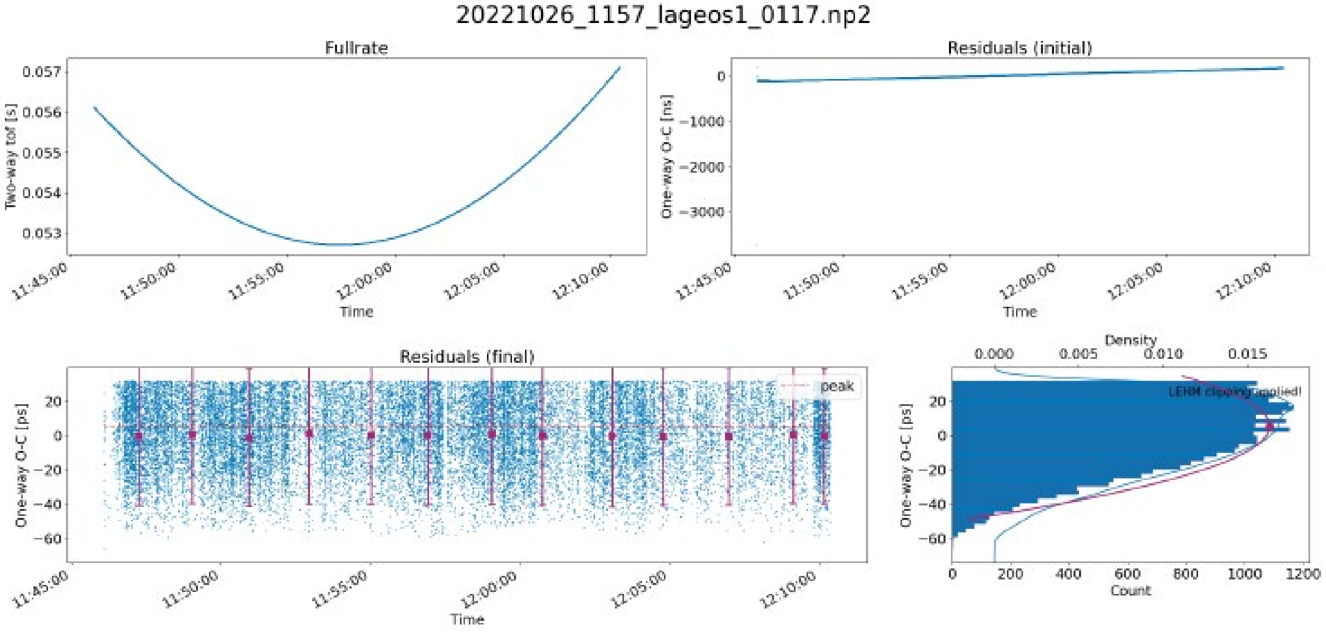
Other stations are undergoing significant upgrades

ILRS – Network

- JAXA developed a new SLR station in the Tsukuba Space Center (7306, Ibaraki, Japan), it has been operating since June 2023. Ranging precision is less than 1 cm for LAGEOS, it has recently passed quarantine.
- Mt. Stromlo (7825, Australia) has been qualified after some repair/upgrade.
- Yebes (7217, Spain) has recently passed quarantine.
- Ishioka (Japan) has ranged to SARAL in December 2023 and Starlett in September 2024.
- Several new stations in process. Irkutsk and Mendeleevo are candidates for the new Russian Tochka station.
- Ny-Ålesund, Norway SLR station will be installed between the two VLBI telescopes. The dome was installed in April 2022, and the gimbal and telescope in February 2024. Operations are planned for early 2026.
- San Fernando Station upgrade is underway; operations are expected to resume in early 2025.
- Matera will have a new laser and is expected to be operational in 2026.
- ILRS CB is beginning to evaluate ‘Station Survey and Plans’ results sent from the first group of 10 underperforming stations to better understand their operational challenges.

Tsukuba, Japan SLR Station

- JAXA developed a new SLR station in the Tsukuba Space Center (Ibaraki, Japan)
- Tsukuba station has been operating since June 2023
- Ranging precision is less than 1 cm for LAGEOS



Satellite: LAGEOS-1

RMS: 6.04 mm

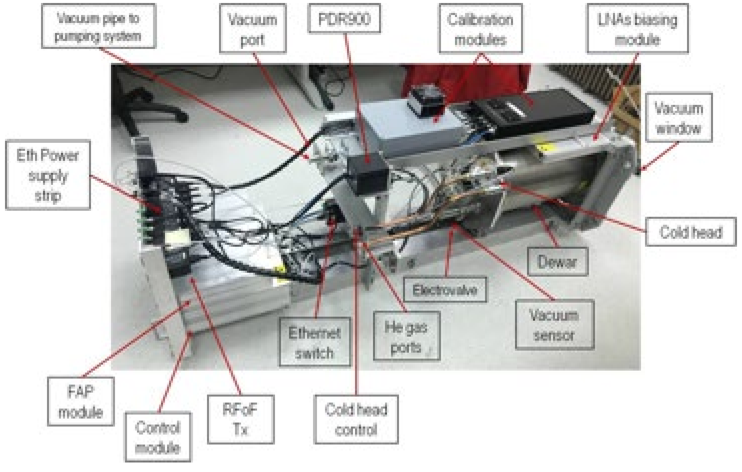
Shinichi Nakamura, JAXA

Yebes Observatory as GGOS Core Site

Bea Vaquero

Yebes VGOS RT Performance

- **First observation, November 2014, tri-band receiver (S-X-Ka)**
- **Broad band (2-14 GHz) observations: Yebes participates since the start of operations in June 2016 (Westford, GGAO, Wettzell, Yebes, KPGO)**
- **Since 2020, regular observations biweekly**
- **Other projects: VGOS-R&D, EU-VGOS, VGYG (Intensive), Fringe-Test support for new stations**



2 - 14 GHz VGOS geodetic receiver (by Yebes Obs.)

YEBL Station (SLR)

- **Geodetic observations (ILRS) + Space debris (future)**
- **Telescope assembly: 70 cm mirror, 3 Nasmyth foci, beam pointing accuracy ≤3”, high slew rate 12°/s Az and El**
- **Two configurations: piggy-back for SLR + Coudé path for other experiments**
- **Two color capability: 532/1062 nm, 7/8.5 ps, 1 kHz**
- **Under ILRS quarantine process**

Omni-SLR@Ishioka

Concepts

- Compact
- Low-cost
- Multi-purpose

Core institutes

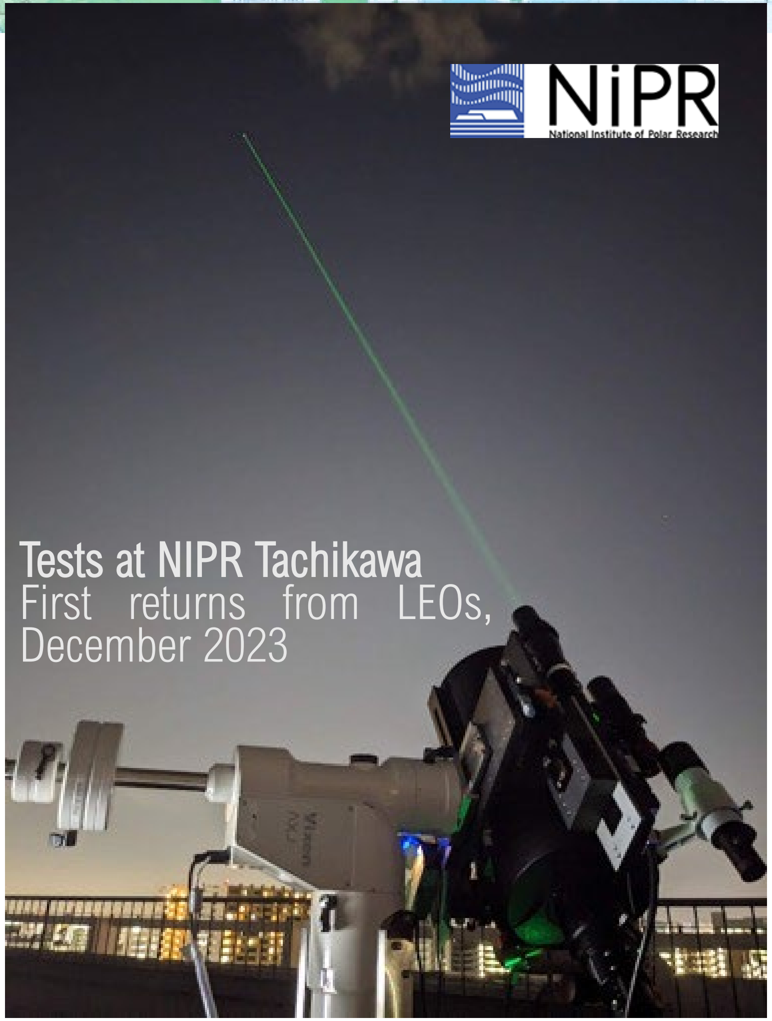
Hitotsubashi University

The University of Tokyo

NAOJ National Astronomical Observatory of Japan

being supported by other institutes and companies.

Toshimichi Otsubo



1 ns, 10 kHz, 6 microJ CryLAS laser; Vixen AXJ mount; 20 cm RX telescope; Hamamatsu MPPC SPAD module; Swabian Time Tagger event timer, etc

Approved as an engineering station of ILRS with the CDP Pad Number “7317”.

Plans and Visions

- To function as an SLR station.
- To evaluate its quality and stability.
- To be collocated with VLBI, GNSS, etc.
- To explore applications (T&F, communications, etc).
- To test it at Syowa@Antarctica (early 2027?)
- To expand the worldwide SLR network.
- To change the role of SLR.

Ny-Ålesund, Norway – Core Site

The site at 79° North is equipped with two VLBI telescopes, currently contributing to both legacy and VGOS VLBI sessions.

Between the two VLBI telescopes, there will be installed a SLR. The dome was installed in April 2022, and the gimbal and telescope in February 2024. Operations are planned for early 2026.

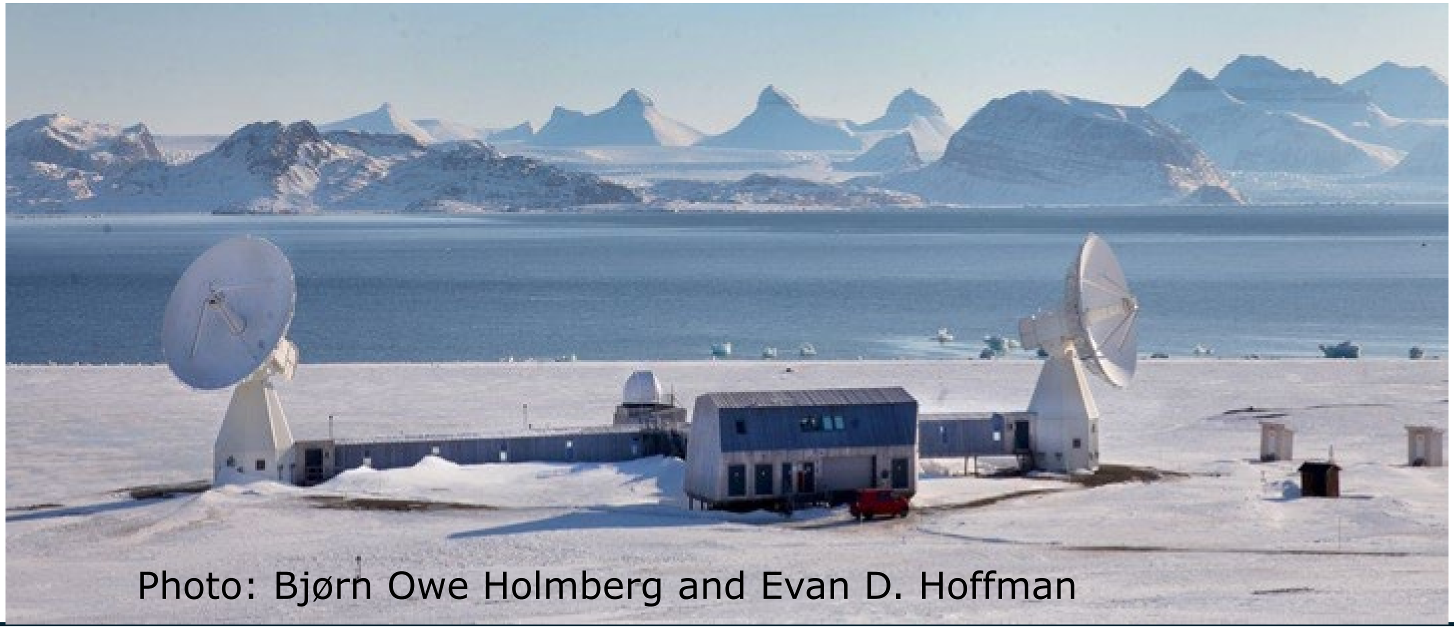


Photo: Bjørn Owe Holmberg and Evan D. Hoffman

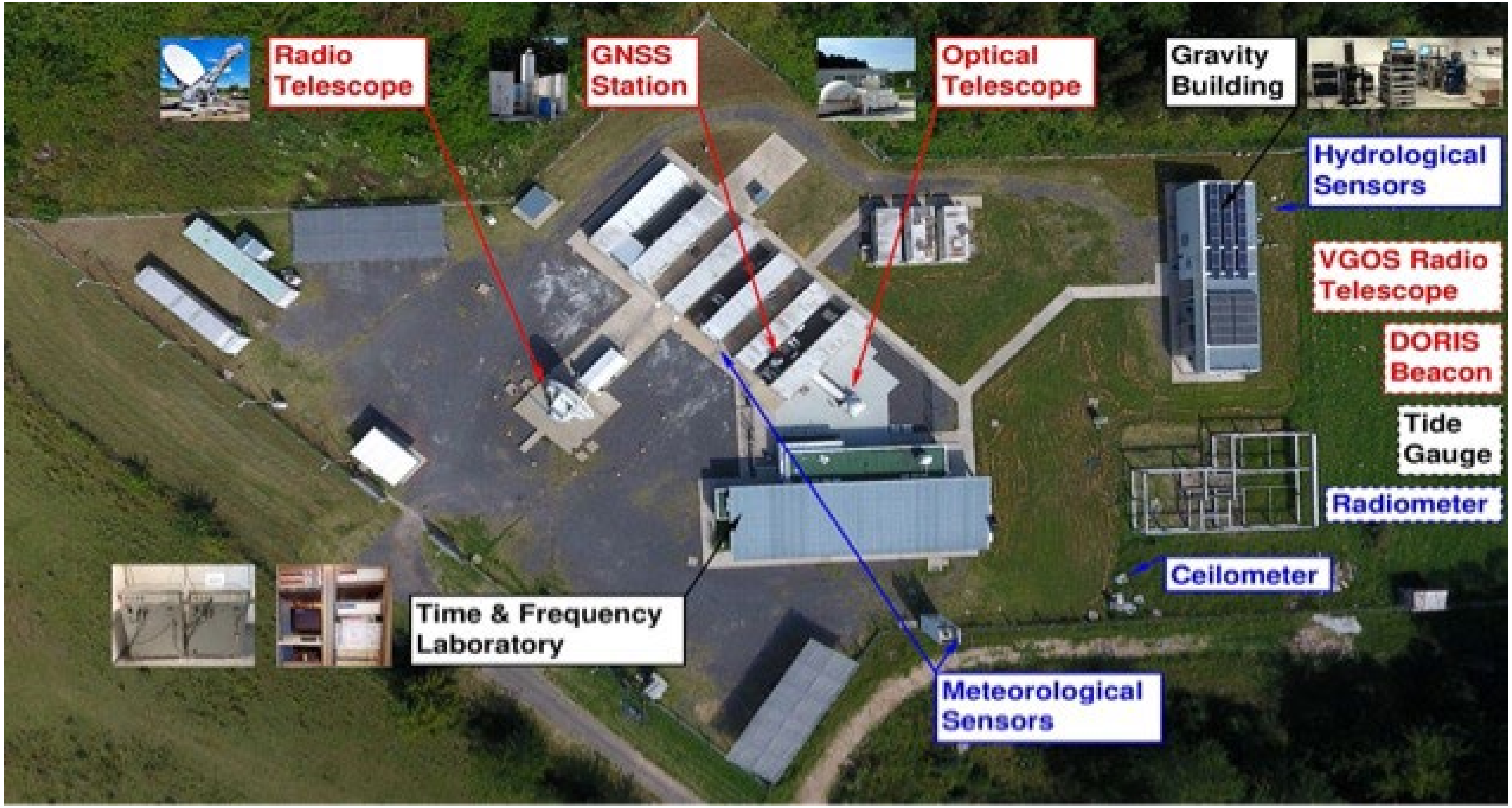
Key specifications:

Wavelength	*532 nm*
Pulse energy	*2.5 mJ*
Pulse width	*50 ps*
Repetition rate	*2 kHz*
Telescope	*Cassegrain 50 cm Coude path*
Aircraft detection	*Airport tower switch and ADS-B*

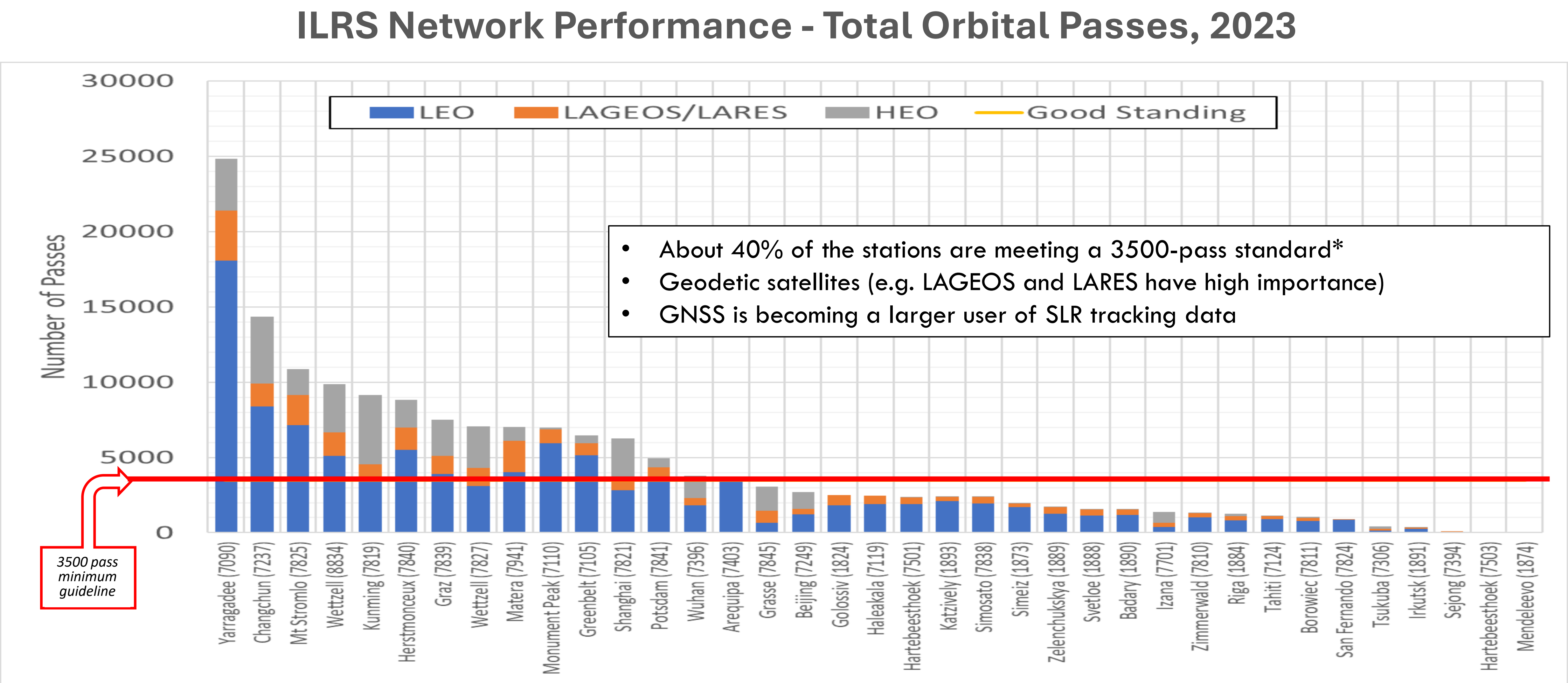
Kartverket

Gro Grinde

La Plata Station – SLR Upgrade Underway -Core Site



Stations Performance: Passes 2023

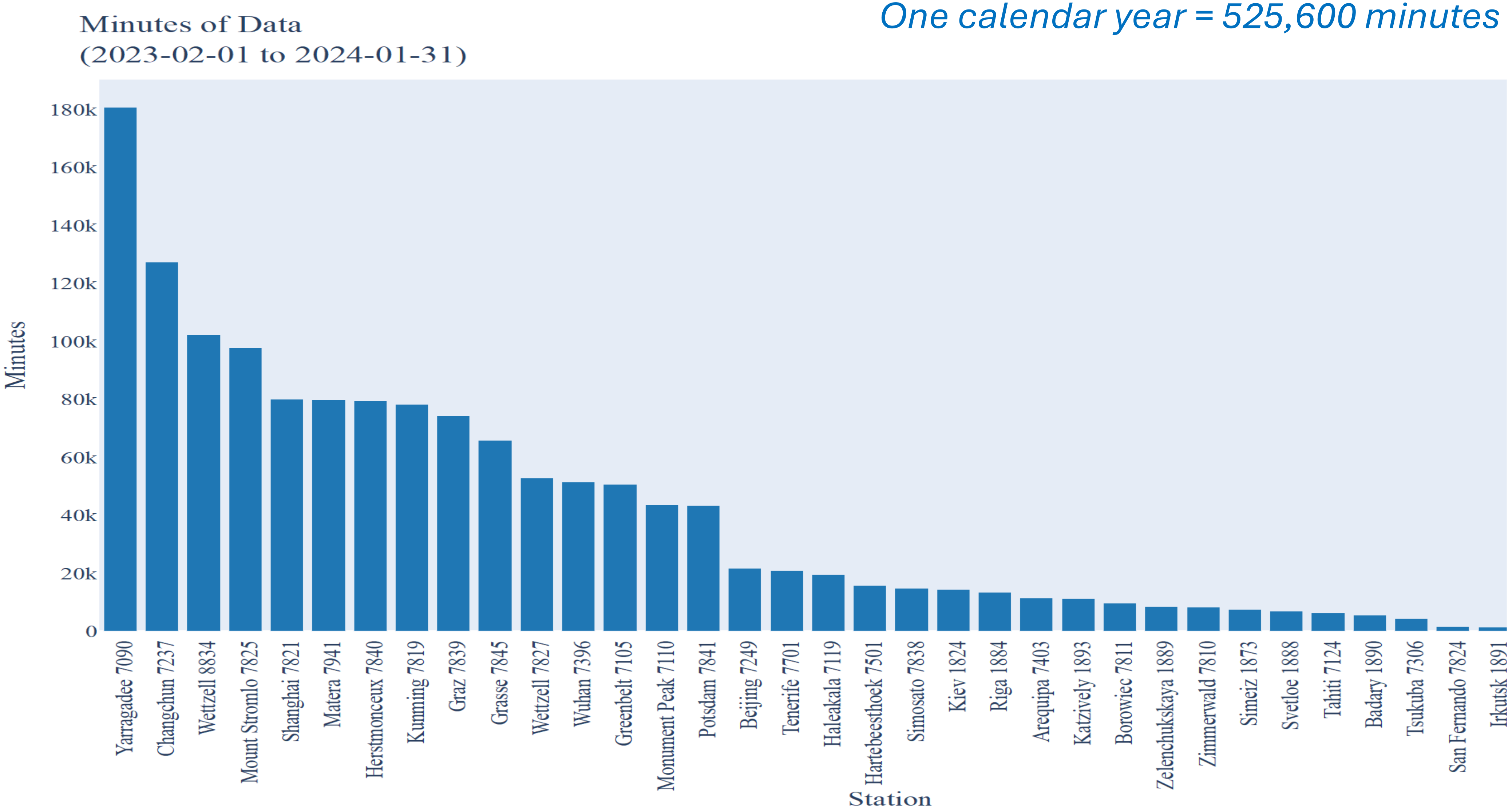


- About 40% of the stations are meeting a 3500-pass standard*
- Geodetic satellites (e.g. LAGEOS and LARES have high importance)
- GNSS is becoming a larger user of SLR tracking data

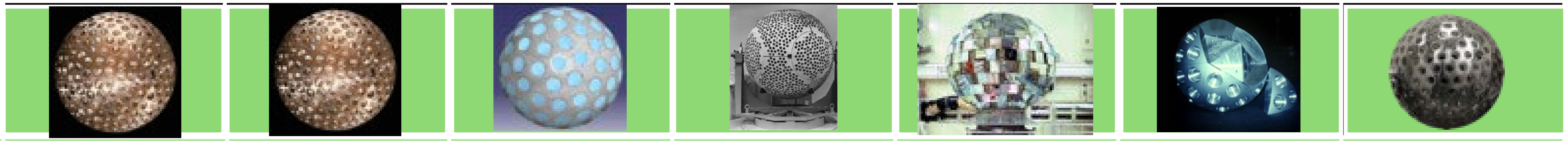
**Station Performance Requirements currently under review*

➢Network Performance in minutes (2023):

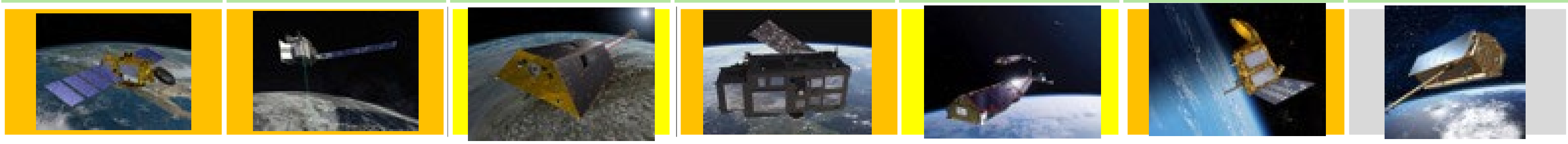
One calendar year = 525,600 minutes



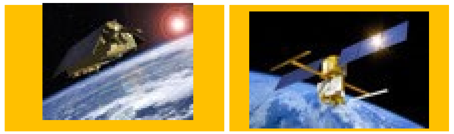
SLR Satellite Constellation: examples



Satellite	LAGEOS-1	LAGEOS-2	LARES	Etalon-1/-2	Ajisai	Starlette/Stella	LARES-2
Inclination	109.8°	52.6°	69.5°	64.9°	50°	50° / 98.6°	70.16°
Perigee (km)	5,860	5,620	1,460	19,120	1,490	810/800	5,899



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



Satellite	Sentinel-6A	SWOT
Inclination	66.042°	77.6°
Perigee (km)	1,339	850

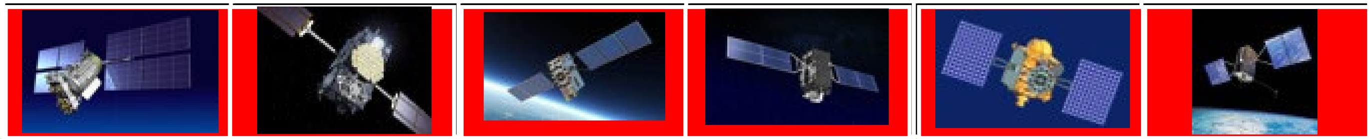
Geodetic

Altimetry

Geomagnetism and Gravity

GNSS

SAR



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	32,000	42,164	~12,550

New SLR Missions Support Exciting Space Applications

Mission	Sponsor/Country	Application	Launch date
MSS-1A	Macau University of Science and Technology/China	High precision surveying of the Earth's geomagnetic and space environment with emphasis on lower latitude regions	May 21, 2023 No updates
HTV-X	JAXA/Japan	Transporting cargoes to the International Space Stations (ISS). Verifying the GPS orbits. Verifying JAXA developed SLR retroreflector Mt. FUJI on orbit.	TBD - 2025
NANO-FF 1/2*	Technical University of Berlin/Germany	Nanosatellites in Formation Flight (2U-CubeSats), to accurately monitor their relative positions, close proximity operations.	November 29, 2023 No updates
e-kagaku-1*	The e-kagaku Association of Global Science and Education/Japan	Student education, fostering space engineers of next generation. Data transmission and tracking for satellite systems. Demonstrating SLR using JAXA developed mini-Mt. FUJI retroreflectors.	Delayed to 2025
ALOS-4	JAXA/Japan	InSAR and AIS Observing and monitoring disaster-hit areas, forests, sea-ice, and monitoring infrastructure displacement. Satellite checkout taking longer than expected. Tracking campaign to start mid-November.	June 30th, 2024

**Student Involvement in designing, building, and data analysis*

ILRS – Missions

- The JAXA ALOS-4 advanced Earth observation satellite, launched on June 30th, 2024 will be supported by ILRS with restricted tracking. The satellite will be observing the Earth's surface using its onboard phased array type L-band synthetic aperture radar (SAR). Tracking campaign planned for early November 2024.
- Launch of the Ekagaku-1 satellite has been delayed to 2025.
- New lunar retroreflectors on NASA's Commercial Lunar Payload Services (CLPS) and Artemis missions are being prepared for deployment over the next few years. The Next Generation Lunar Retroreflector NGLR is anticipated to be on the Moon in early 2025; its ILRS support request is being reviewed.
- QZS-5/6/7 from JAXA missions will be requiring support from the ILRS. Satellites have slightly different features and parameters than the other QZS satellites in the constellation. QZS-6 MSRF received being evaluated.
- JAXA has been developing a Precision Orbit Determination (POD) algorithm called "Precise Point Positioning (PPP) in Space" that realizes real-time PPP in orbit using MADOCA-PPP transmitted from the QZSS L6E signal. They plan to demonstrate this mission on the QPS-SAR satellite, a LEO small-satellite, in 2025. The mission is targeting centimeter-level orbit determination and requires a high precision reference and will be seeking tracking support from the ILRS.

ILRS – Missions (cont.)

- WESTPAC tracking campaign is underway by selected stations (lead by the NEWG). WESTPAC may be resurrected if it is deemed useful for the geodetic constellation.
- ESA GENESIS Mission co-locates in space all four of the Space Geodesy measurement techniques currently used for ITRF. Clément Courde (Observatoire de la Côte d'Azur, Nice, France) is the Chair of Satellite Laser Ranging Working Group (SLR WG); Mathis Blossfeld (TUM, Germany) is the Deputy. Missions, Networks and Engineering, Data Format & Procedures, Analysis Standing Commeetties and ILRS CB members participate in the SLR WG. The first meeting to define requirements was held early in September 2024. Follow up meetings will continue discussions on requirements and simulations to support them.
- "Missions Tracking Reports" were requested from selected LEO missions supported. All currently under review by the ILRS. The intention here is to begin developing summary reports for general distribution.

ILRS – Missions (cont.)

- Lunar Laser Ranging and Transponder activities: there are 6 lunar ranging Analysis Centers. Lunar ranging Stations include: Apollo (USA), Grasse (France), Matera (Italy), Wettzell (Germany) and stations in progress in China, Russian, and South Africa.

  5 reflectors on the Moon and new reflectors in a near future (2024-2025) on the Moon & on orbiter:

  - NASA-NGLR-1&2
  - ESA-MoonLIGHT & Lunar Pathfinder
  - CNSA-Tiandu-1 & CAS-1

Science and application with Transponders:

Ongoing:

- CSS-LTT (2022, underway) 2-way asynchronous

Upcoming:

- ACES-ELT: European Laser Timing (ELT) experiment, part of the ESA's Atomic Clock Ensemble in Space (ACES) mission, launch in early 2025.
- LTT on CAS-1

SLR Tracking Campaign to Galileo Satellites

➢ Galileo for Science Campaign underway, focused on elliptical orbit satellites (201 and 202). New Galileo -225 and -227 added to ILRS roster.

G4S_2.0 in a nutshell

Funded by the **Italian Space Agency (ASI)**, aims to perform a set of measurements in the field of **gravitation** with the **Galileo** satellites of the **Full Operational Capability (FOC)** constellation, taking advantage of the accuracy of the on-board atomic clocks and, in particular, of **GSAT0201** and **GSAT0202** by exploiting their relatively high eccentricity (≅0.16). **The campaign will last a total of two years.**

Main goals of the G4S_2.0 project:

- A new measurement of gravitational red shift
- A measurement of relativistic precessions on the two satellites in eccentric orbit
- Constraints on Dark Matter in the Milky Way
- Relativistic Positioning System
- Development of new models for non-gravitational forces
- Development of a new accelerometer concept for a next generation of Galileo satellites

Research Institutes Involved:

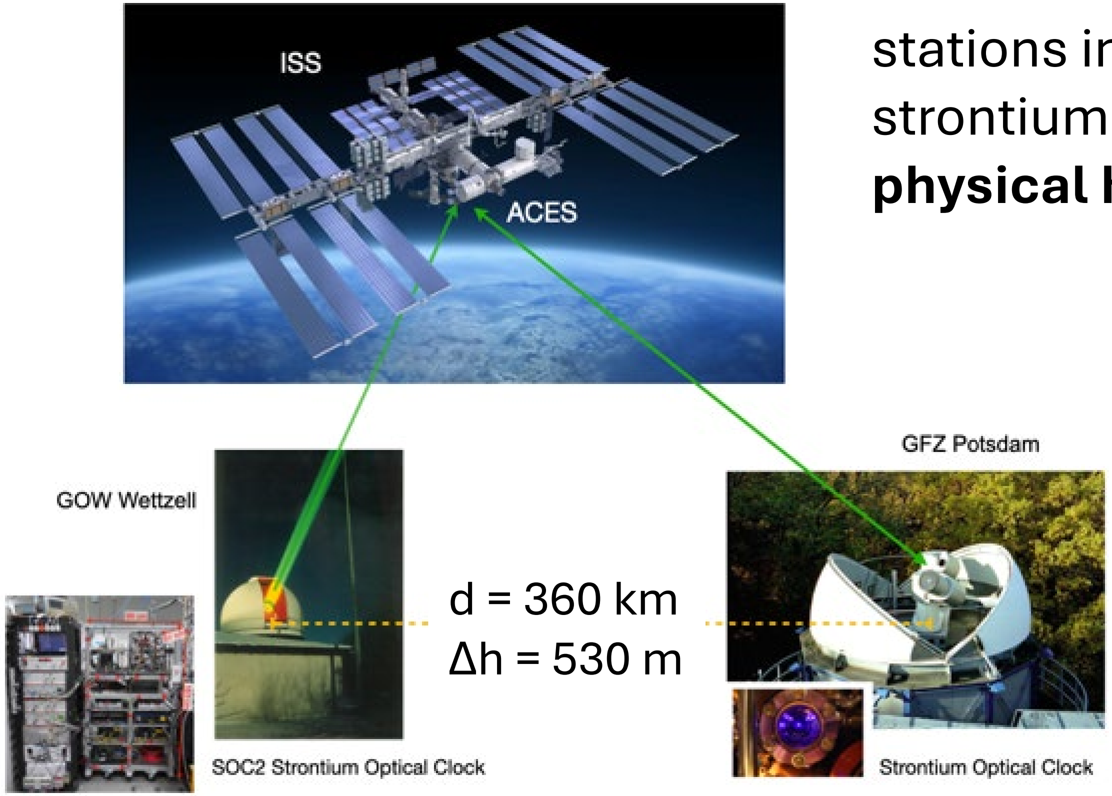
- **ASI-CGS** (Center for Space Geodesy) in Matera
- Istituto di Astrofisica e Planetologia Spaziali (**IAPS/INAF**) in Roma
- Osservatorio Astronomico di Torino (**OATO/INAF**) in Torino
- Politecnico (**POLITO**) in Torino

Refer to the Project furnished SLR Campaign Website

Galileo For Science 2.0 is here.

Common View Optical Time Transfer via a Free Space Link to the ACES H Maser in Orbit demonstrates Relativistic Geodesy

Linking two fully characterized optical clocks at different locations with SLR (Einstein Synchronization) provides height differences



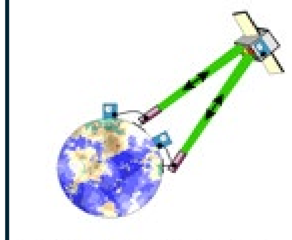
There is a funded proof of concept project, where the SLR stations in Wettzell and Potsdam are each tied to an optical strontium lattice clock, **demonstrating the feasibility of a physical height system.**

By performing repeated clock comparisons over several days, we expect to recover the height differences of 530 m between the clocks from the gravitational effect of general relativity on the clock transitions in common view.

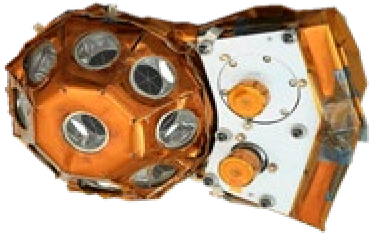
Additional experiments including the Grasse and other stations are planned for non-common view time transfer.

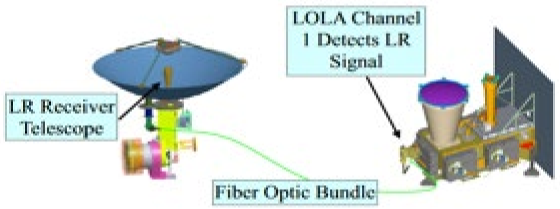
Optical Time Transfer makes distributed timescales highly coherent, which leads to reduced systematic errors

Transponders



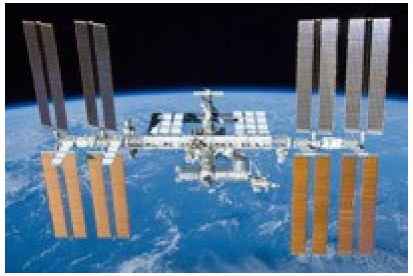
Common view configuration





Past :
- LASSO (1989-1992) 2way asynchronous
- Messenger (2005) 2x1way asynchronous
- MOLA-MGS (2005) 1way
- T2L2 (2008-2018) 2way asynchronous
- LRO (2009-2014) 1way

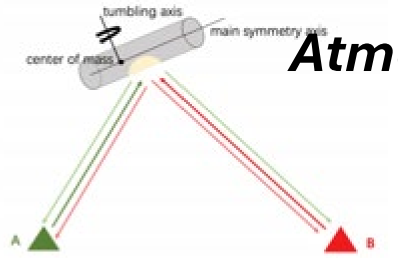
On-going :
- Hayabusa2 (2015;2020) 1way ; 2x 1way synchronous
- CSS-LTT (2022, underway) 2way asynchronous



Up-coming :
- ACES-ELT : launch in early 2025
- LTT on CAS-1

On-going tests on passive retroreflector

- Ground to ground time transfer with diffuse reflections (2021 space debris)



Science and application with Transponder

Time & frequency transfer and clock synchronization between ground & space

Interplanetary laser ranging

Fundamental physics
- Einstein's gravitational redshift
- Time variations of fundamental constants
- Dark matter searches

Chronometric geodesy

Atmospheric propagation delay

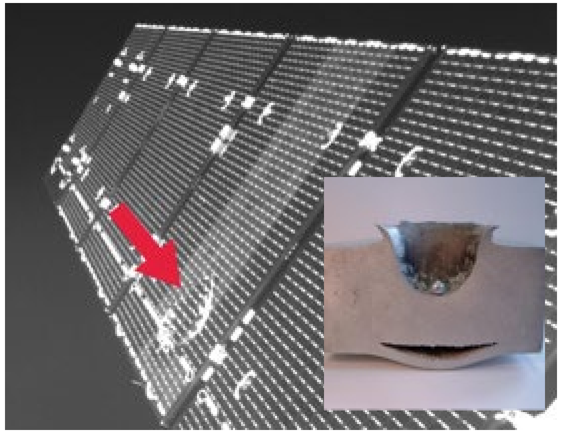
Laser communication

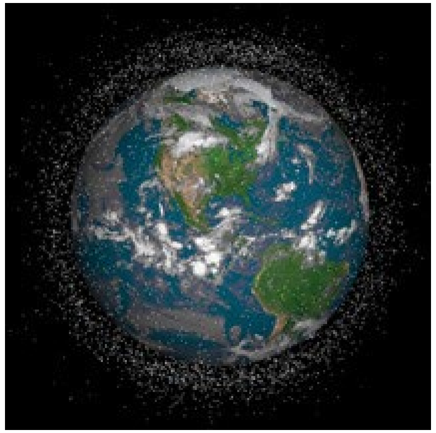
Navigation

Space Debris (Current) Overview

SPACE DEBRIS Numbers (ESA)		TYPES & Origins
> 6,500 lauches	Since 1957	Rocket bodies
9,000 / 2,500 satellites	active / inactive	Fragments
36,500 objects	Size: > 10 cm	Explosion
1,000,000 objects	Size: > 1 cm	Anti satellite missions
>100,000,000 objects	Size: > 1 mm	Collisions (2009, Iridium, Kosmos)
Velocity	~7 km / sec	Toolbags (ISS, 2008)
Impact	Ø < 1 cm --> 20 cm crater	Heat shield (ISS, 2017)

Credits: ESA, 2016





Major Accomplishments - SLR

Recent improvements in the ILRS ASC operational products:

- **New operational products**
  - v180 → daily TRF+EOP product (satellites used: LAGEOS-1/-2, ETALON-1/-2; 1 day latency) → used for USNO Bulletin A
  - v80 → weekly TRF+EOP product (9 days latency)
  - v80(orb) → weekly orbit product (9 days latency)
  - v280/v320 → weekly Station Systematic Error Monitoring SSEM-X (range bias) product (9 days latency) → used for Data Handling File (DHF) updates

- **ILRS contribution to ITRF2020 update**

  Mid-March 2024, the ILRS ASC provided the ILRS contribution to the ITRF2020 update (v85).
  - Solutions are based on v180/v80 model setups.
  - Solutions cover the time span 2021.0 until 2024.0.

- **Inclusion of LARES-2 in the operational ASC products**
  - Currently, long-term mean range biases to update ILRS DHF are operationally computed (v320).
  - Soon, we will start a test series of v180/v80 including LARES-2 as the 5th geodetic satellite.

- **Update of SLRF2020 and new stations**
  - The SLRF2020 will be updated soon with refined and new coordinates.

Deutsches Geodätisches Forschungsinstitut (DGFI-TUM) | Technische Universität München

Major Accomplishments - SLR

- Publication of the SLRF2020 (SLR-based ITRF2020-like global TRF solution).

- Publication/update of the ILRS Data Handling File (DHF) together with an update of the target signature model for geodetic spheres. This is a really important step forward, linking the technical developments done at the stations to the scientific analysis of SLR observations. It is absolutely beneficial for the quality of the ASC products in general.

- Low costs SLR systems are being developed by private enterprises (DiGOS) and various Universities; potential for expansion of the current SLR network.

ILRS – News and Events

News:

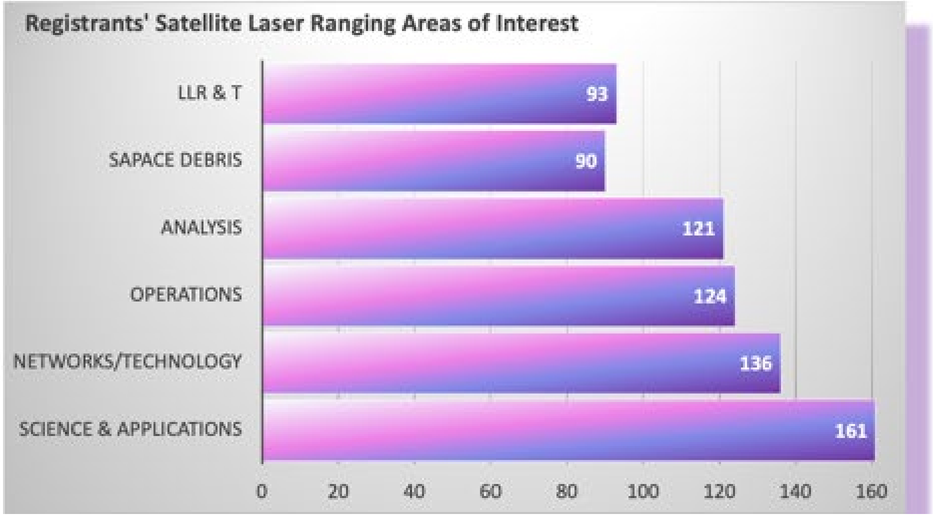
- Contributed to the IAG Geodesist Handbook (July 2024).
- ILRS GB news: Krzysztof Sośnica (Institute of Geodesy and Geoinformatics, Wrocław University of Environmental and Life Sciences, Poland) is a new appointed member of the ILRS GB (Representative of IAG Commission 1); we thank Urs Hugentobler (Technische Universität München, Germany) for his service to the ILRS.

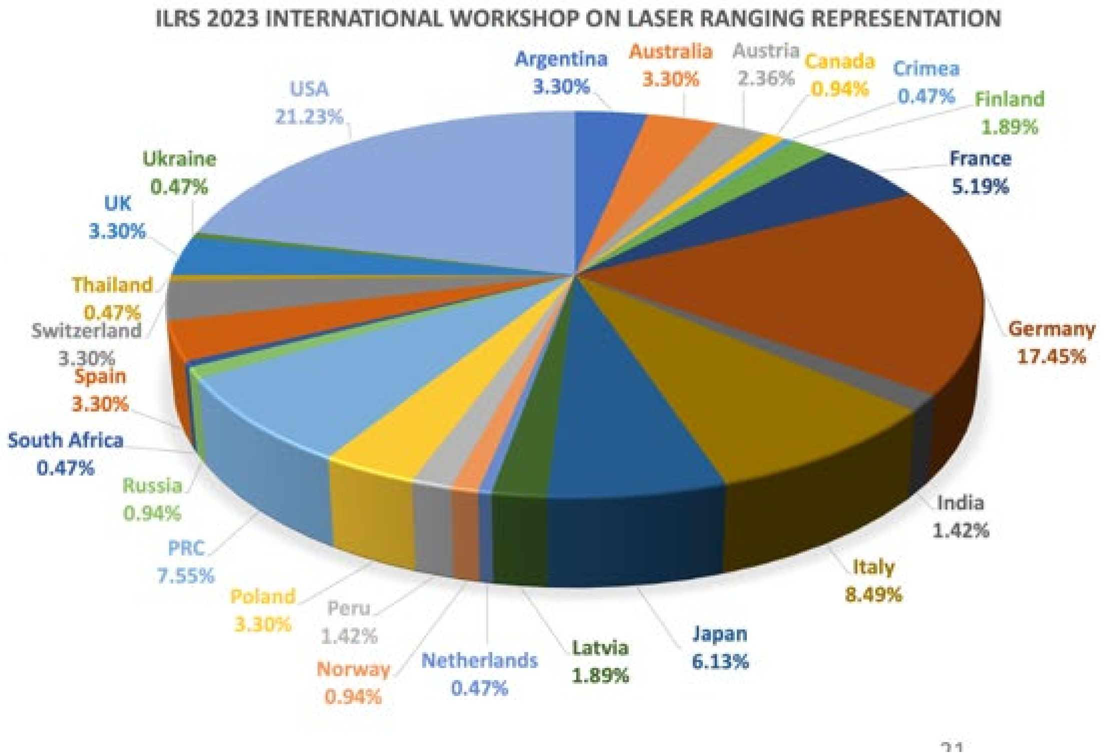
Events:

- Hosted the Virtual 2023 International Workshop on Laser Ranging (IWLR) during the week of October 16th-20th, 2023 (https://ilrs.gsfc.nasa.gov/lw23/index.html). Sessions on Missions & Applications, New technology/Systems and Operations, Analysis, Lunar Laser Ranging (LLR) and Space Debris were attended by more than 200 participants from 25 countries.
- The 23rd International Workshop on Laser Ranging (IWLR) will be hosted in Kunming, China, during the week of October 20th-26th, 2024 (https://23rdworkshop.casconf.cn/).
- The ILRS Specialized Workshop will be hosted in Arequipa, Peru, in 2025, dates TBD.
- The Argentinean CONICET and German BKG (AGGO) in Argentina are possible hosts for 24th IWLR in 2026.It will be proposed at the 23rd IWLR in Kunming, China. CONICET offered the venue in the center of Buenos Aires, the Argentine capital.

ILRS – Events: Virtual Workshops

Registrants:
25 Countries
213+ Participants
More than 100 participants per Session…





Thank you!

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