Satellite Laser Retroreflectors for GNSS Satellites: ILRS Standard

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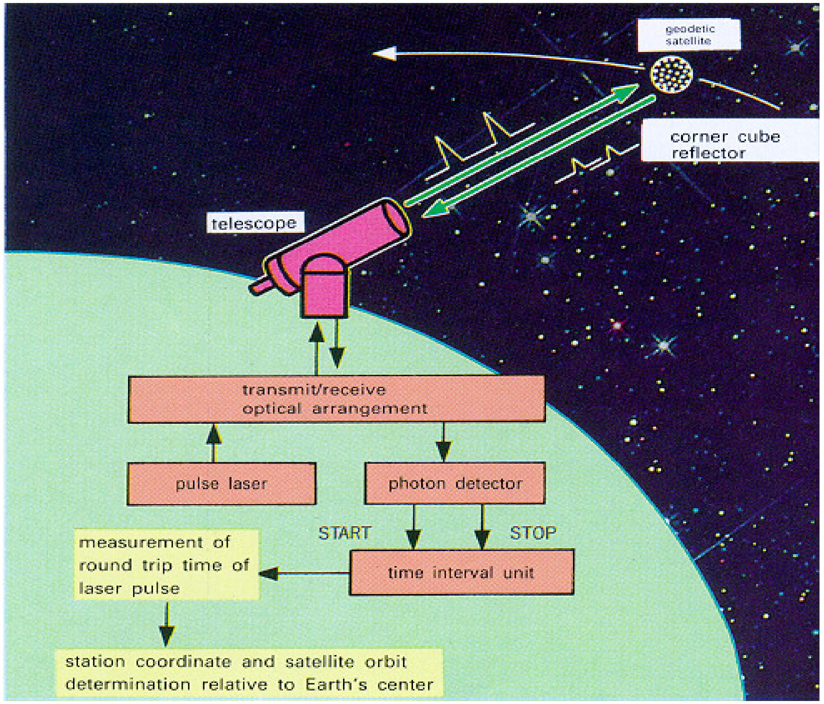
Satellite Laser Ranging Technique

Precise range measurement between an SLR ground station and a retroreflector-equipped satellite using ultrashort laser pulses corrected for refraction, satellite center of mass, and the internal delay of the ranging machine.

- Simple range measurement
- Space segment is passive
- Simple refraction model
- Night / Day Operation
- Near real-time global data availability
- Satellite altitudes from 400 km to 20,000 km (e.g. GPS/GLONASS), and the Moon
- Cm satellite Orbit Accuracy
- Able to see small changes by looking at long time series



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

SLR Science and Applications

- Measurements
  - Precision Orbit Determination (POD)
  - Time History of Station Positions and Motions
- Products
  - Terrestrial Reference Frame (Center of Mass and Scale)
  - Precision Orbits and Calibration of Altimetry Missions (Oceans, Ice)
  - Plate Tectonics and Crustal Deformation
  - Static and Time-varying Gravity Field
  - Earth Orientation and Rotation (Polar Motion, length of day)
  - Total Earth Mass Distribution
  - Space Science - Tether Dynamics, etc.
  - Lunar Science and Relativity
- More than 60 Space Missions Supported since 1970
- Four Missions Rescued in the Last Decade

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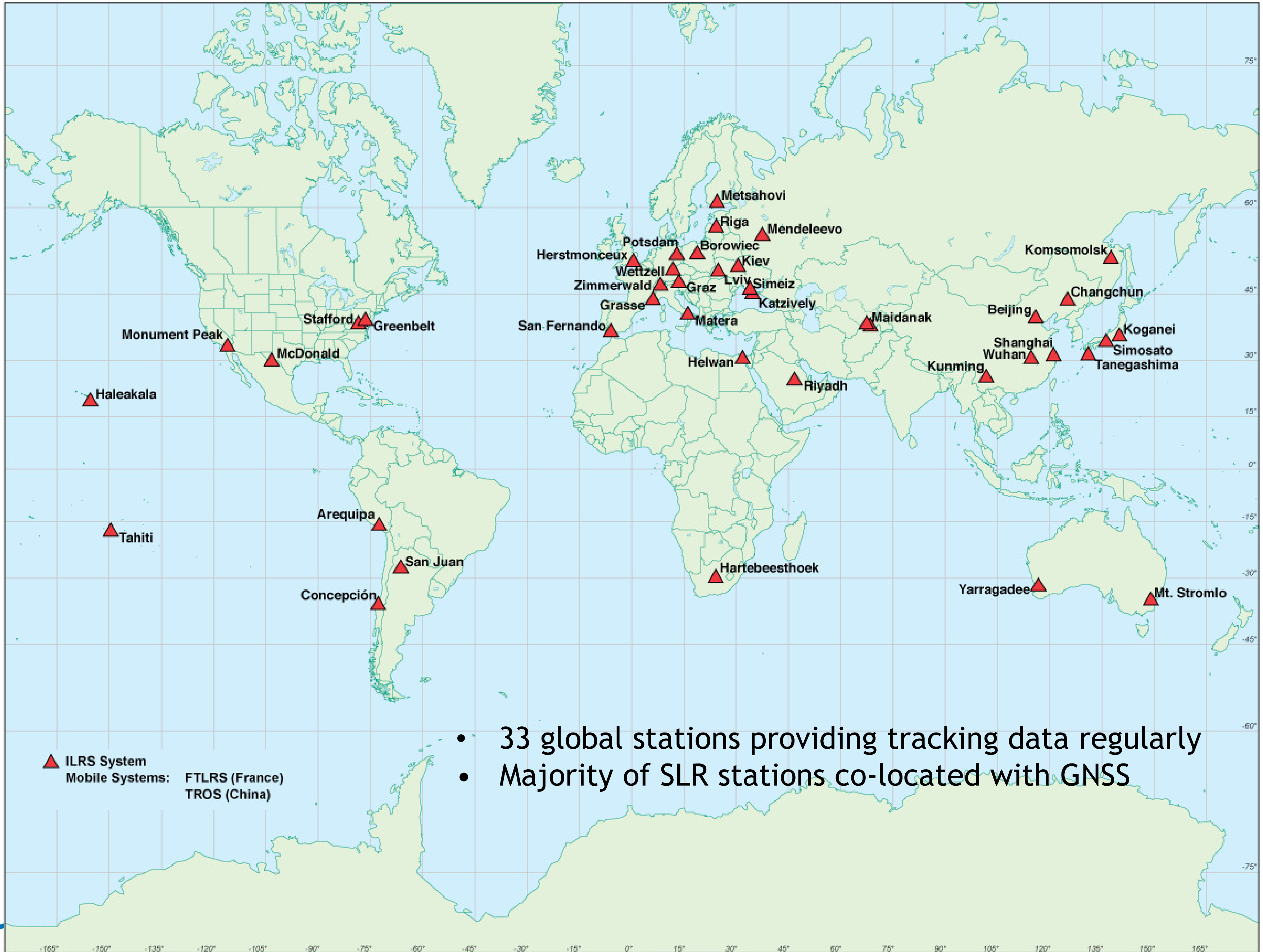
Need for SLR measurements on the GNSS Constellations

- Geoscience
  - Improve the Terrestrial Reference Frame (colocation in space)
    - Basis on which we measure global change over space, time, and evolving technology
    - Relies on colocation measurements with different technologies –GNSS, VLBI, SLR, DORIS, ----
    - Most stringent requirements - ocean surface, ice budget
  - Improve LEO POD
    - Altimeter satellites
- GNSS World
  - Provide independent Quality Assurance: - The GNSS orbit accuracy cannot be directly validated from the GNSS data itself;
  - Assure interoperability amongst GPS, GLONASS, Galileo, COMPASS --
  - Insure realization of WGS84 reference frame is consistent with ITRF
  - SLR is NOT required for use in routine / operational RF derived orbit and clock products

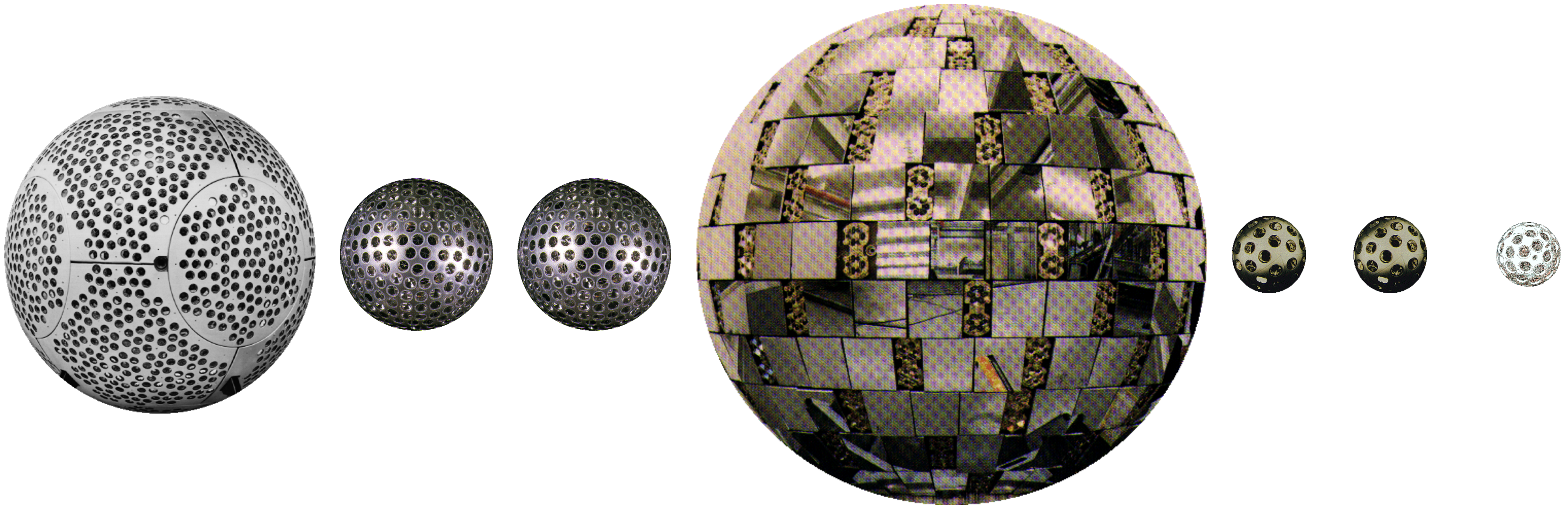
ILRS Network



- 33 global stations providing tracking data regularly
- Majority of SLR stations co-located with GNSS

Sample of SLR Satellite Constellation

(Geodetic Satellites)



	Etalon-I & -II	LAGEOS-1	LAGEOS-2	Ajisai	Starlette	Stella	GFZ-1
Inclination	64.8°	109.8°	52.6°	50°	50°	98.6°	51.6°
Perigee ht. (km)	19,120	5,860	5,620	1,490	810	800	396
Diameter (cm)	129.4	60	60	215	24	24	20
Mass (kg)	1415	407	405.4	685	47.3	47.3	20.6

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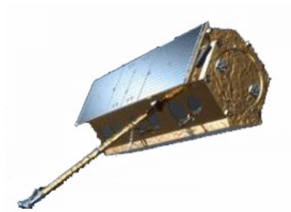
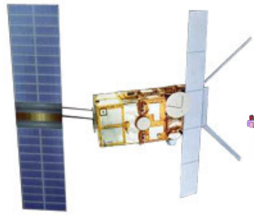
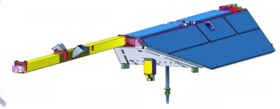
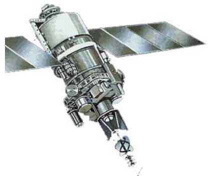
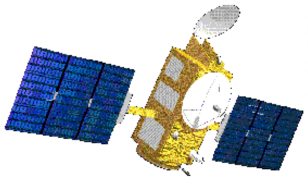
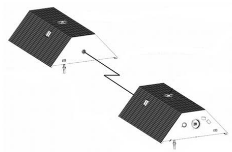
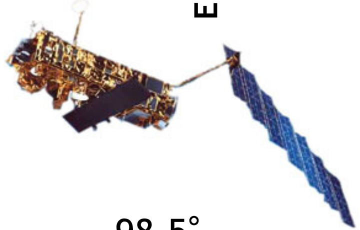
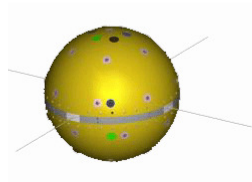
Sample of SLR Satellite Constellation

(POD Support)



	GFO-1	ERS-1	Terra-SAR-X	ERS-2	CHAMP
Inclination	64°	98.5°	66°	98.6°	87.27°
Perigee ht. (km)	19,140	780	1,350	800	474
Mass (kg)	1,400	2,400	2,400	2,516	400

	Meteor-3M	Jason-1	GRACE	Envisat	ANDE
Inclination	99.64°	66°	89°	98.5°	90°
Perigee ht. (km)	1,019	1,336	450	800	650
Mass (kg)	5,500	500	432/sat.	8,211	3,334

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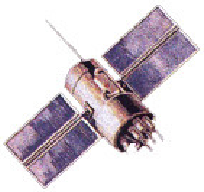
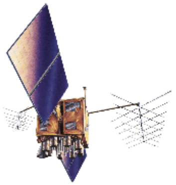
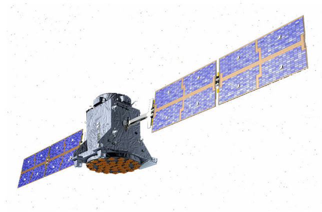
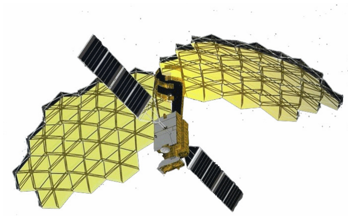
Sample of SLR Satellite Constellation
(HEO)

	GLONASS	GPS	COMPASS	GIOVE	ETS-8
					
Inclination	64°	55°	55.5°	56°	0°
Perigee ht. (km)	19,140	20,100	21,500	23,920	36,000
Mass (kg)	1,400	930	1,000	600	2800

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Retroreflector Arrays on MEO and HEO Satellites

Satellite	Altitude (MM)	Effective Cross Section (Million Sq Meters)	Relative Return Signal Strength	
			Zenith	45 degrees
Lageos1/2 *	5.8	15	1.0	1.0
Etalon1/2 *	19	55	.032	.044
GLONASS	19	80	.046	.065
GPS 35/36	20	20	.009	.012
COMPASS	21.5	80	.028	.041
GIOVE-A **	23.9	45	.010	.015
ETS-8 ***	36	140	.0063	.010

* Sphere ** Galileo Test Satellite *** Synchronous

Problem: Not enough return signal from the GNSS satellites

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ILRS Retroreflector Standards for GNSS Satellites

- Retroreflector payloads for GNSS satellites in the neighborhood 20,000 km altitude should have a minimum "effective cross-section" of 100 million sq. meters (5 times that of GPS-35 and -36)
- Retroreflector payloads for GNSS satellites in higher or lower orbits should have a minimum "effective cross-section" scaled to compensate for the R**4 increase or decrease in signal strength
- The parameters necessary for the precise definition of the vectors between the effective reflection plane, the radiometric antenna phase center and the center of mass of the spacecraft should be specified and maintained with an accuracy better than 0.1 ppb.

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Current SLR Ranging to GNSS Satellites

- Current tracking operation
  - Operations include 8 GNSS satellites

    (GPS 35 and 36; GLONASS 99, 102, and 109; GIOVE - A and - B; and *COMPASS)*
  - Satellite priorities set according to satellite altitude;
  - Five minute Normal Points; 3 Normal Points to a segment;
  - Three segments per pass (ascending, middle, descending);
  - Data transmitted after each pass;
  - The data is available on the website within an hour or two;

- GPS Campaign 2008 (March 25 - May 31)
  - Collected 261 passes from 18 stations (33 passes per week)
  - Five major contributors

- Retroreflector Arrays
  - GPS,GLONASS, and GIOVE all have arrays based on similar design
  - COMPASS has a newer design - initial ranging experience indicates

    considerably stronger return signal

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ILRS Operations Plan for GNSS Satellites

- Assumptions:
  - **Satellites carry the enhanced array (factor of 5 increase in effective cross section);**
  - **Precise Center of Mass information including the change with fuel consumption required for all spacecraft;**
  - **Upgraded SLR stations/increased ranging efficiency**
    - **KHz ranging**
    - **improved detectors**
    - **increased automation/autonomous tracking**

- SLR Tasking Requirements
  - **Tasking schedule well agreed upon in advance**
  - **One strategy for all of the GNSS satellites**
  - **Observation Spans fixed to Engineering Goals and TRF requirements**
  - **Measurements driven by the ability to achieve a Normal Points**
  - **SLR sites include local ties to GNSS**

- Still plenty of SLR Network Tracking Capacity Left

Concepts for an Operational GNSS Plan

- Support GPS, Galileo, GLONASS, and COMPASS;
- Greater emphasis on daylight ranging;
- Decrease Normal Point intervals to increasing tracking capacity;
- Data available on the website shortly after each pass;
- Possible GNSS tracking strategy
  - Subset selected for long-term tracking to support the TRF
  - Satellites rotated for engineering tests, maybe
    - one satellite per orbital plane per system at a time;
    - 60-day tracking cycles set to cover all satellites within a 12 month period;
- Flexible tracking strategies; organized in cooperation with the agencies involved and the requirements for the ITRF;
- The network can be segmented to track different satellites;
- ILRS analysts will do the analysis on all of the GNSS data and make the results available;

ILRS Security Agreement

ILRS authorization to track any satellites is constituted and governed by an approved Mission Support Request Form. All SLR stations within the International Laser Ranging Service agree to:

- range only to satellites for which they have approval from the ILRS or the satellite owner;
- adhere to any applicable ILRS Restricted Tracking Procedures including:
  - station by station authorization;
  - time and viewing angle constraints;
  - power constraints;
  - go/no-go switch.

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