International Laser Ranging Service

Satellite Laser Ranging (SLR) and the International Laser Ranging Service (ILRS)

http://ilrs.gsfc.nasa.gov/index.html

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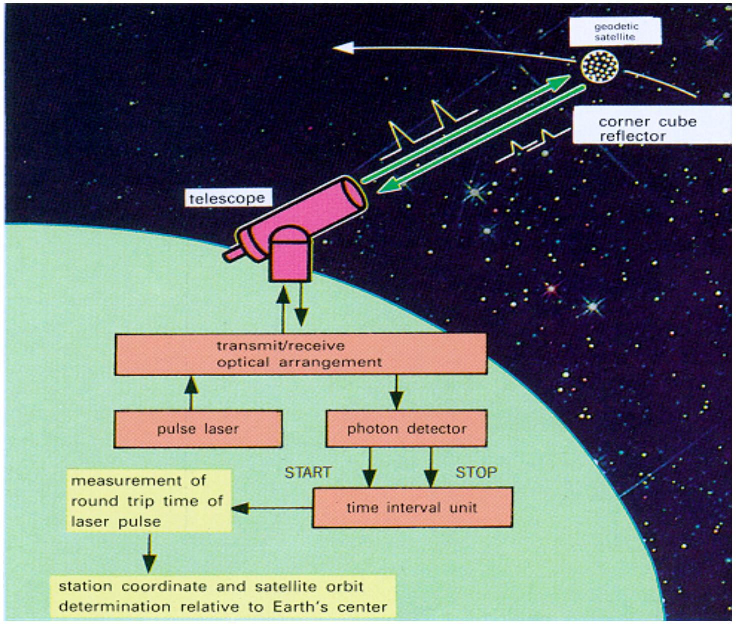
Satellite Laser Ranging Technique

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 (Not on GNSS)
- Near real-time global data availability
- Satellite altitudes from 400 km to synchronous satellites, and the Moon
- Cm satellite Orbit Accuracy
- Able to see small changes by looking at long time series



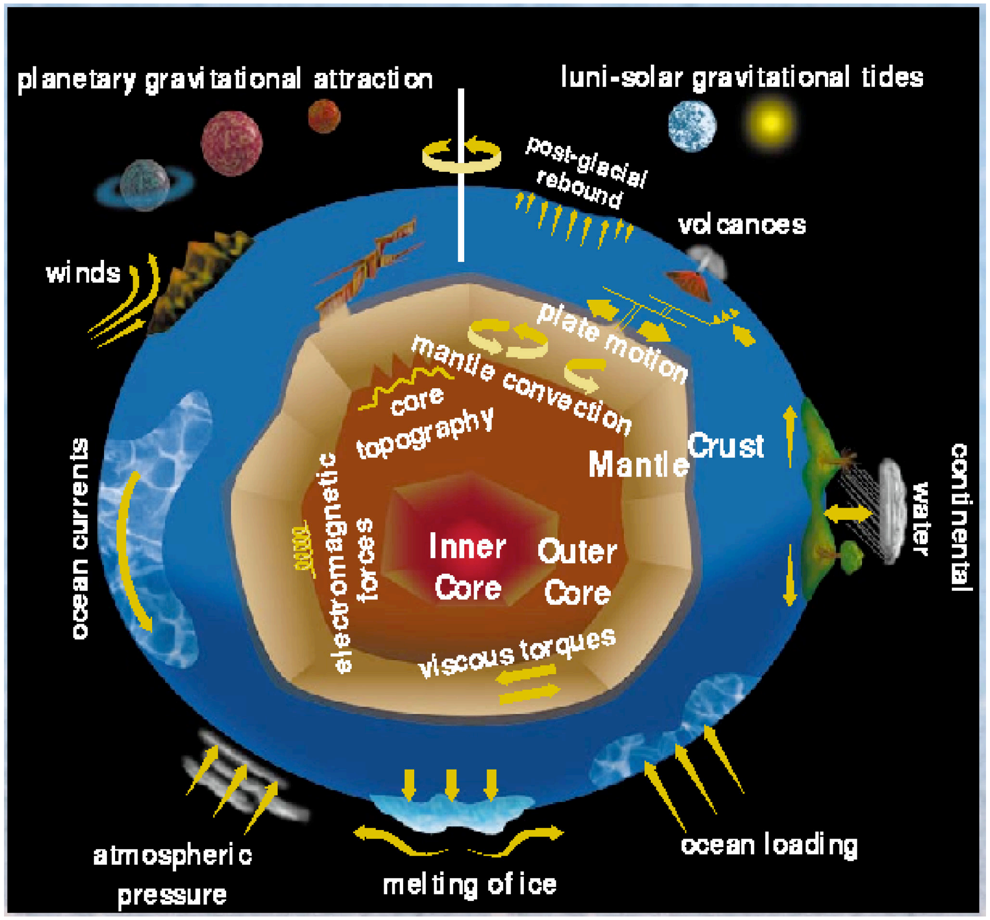
- Unambiguous centimeter accuracy orbits
- Long-term stable time series

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)
  - Plate Tectonics and Crustal Deformation
  - Static and Time-varying Gravity Field
  - Earth Orientation and Rotation (Polar Motion, length of day)
  - Orbits and Calibration of Altimetry Missions (Oceans, Ice)
  - Earth Mass Distribution
  - Space Science - Tether Dynamics, etc.
  - Relativity Measurements and Lunar Science
- More than 60 Space Missions Supported since 1970
- Five Missions Rescued in the Last Decade

Some people think the Earth looks like this:

But – really it looks like this:



Terrestrial Reference Frame (TRF)

- <u>Provides the stable coordinate system that allows us to measure change (link measurements) over space, time and evolving technologies</u>.
- An accurate, stable set of station positions and velocities.
- Foundation for virtually all space-based and ground-based metric observations of the Earth.
- Established and maintained by the global space geodetic networks.
- Network measurements must be precise, continuous, and worldwide.
- Must be robust, reliable, geographically distributed
  - proper density over the continents and oceans
  - interconnected by co-location of different observing techniques
- Most stringent requirement: Measuring sea level rise requires accuracy of 1.0 mm and a stability of 0.1 mm/yr.

Complex of Co-located Space Geodesy Instruments

International Laser Ranging Service

for development and maintenance of the reference frame

SLR/LLR

VLBI

GPS

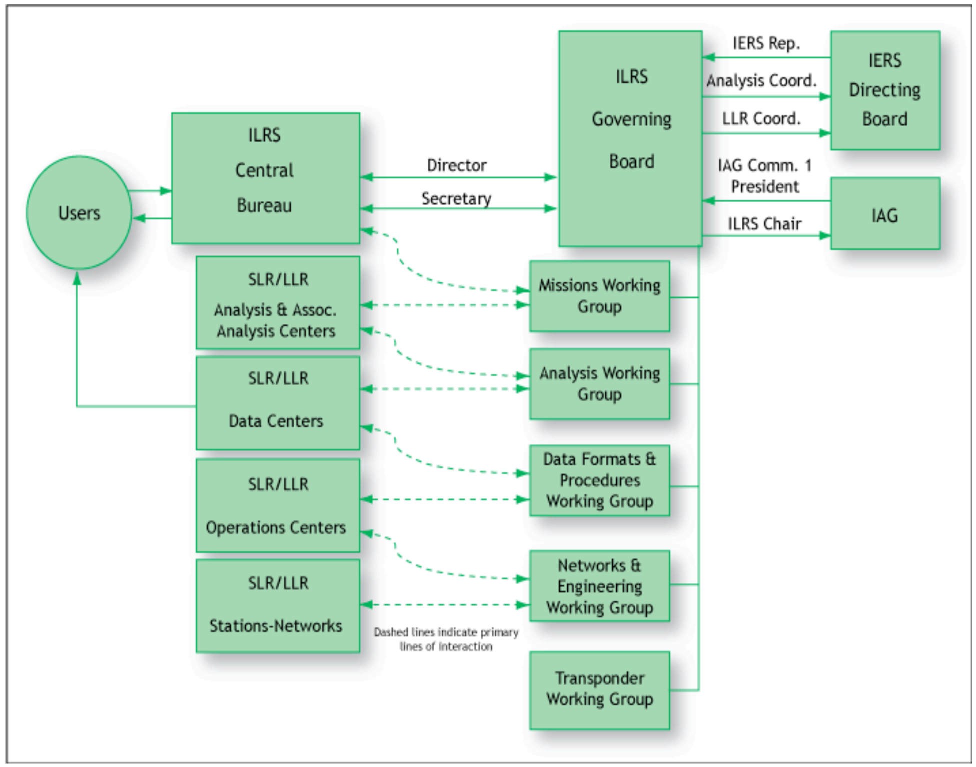
DORIS

International Laser Ranging Service

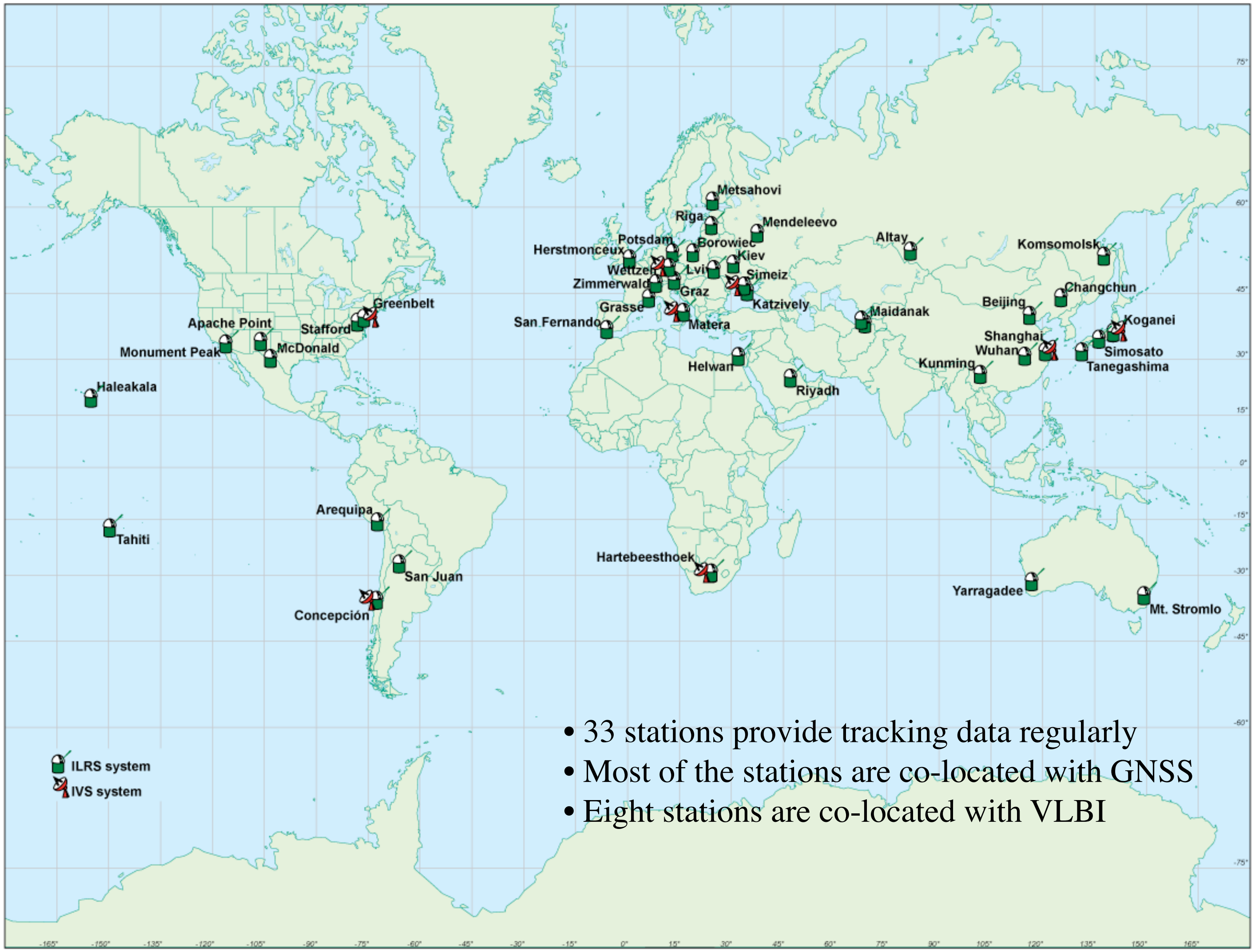
Established in 1998 as a service under the International Association of Geodesy (IAG)

The ILRS:

- Collects, merges, analyzes, archives and distributes satellite and lunar laser ranging data to satisfy user needs
- Encourages the application of new technologies to enhance the quality, quantity, and cost effectiveness of its data products
- Produces standard products for the scientific and applications communities
- Includes 75 agencies in 26 countries

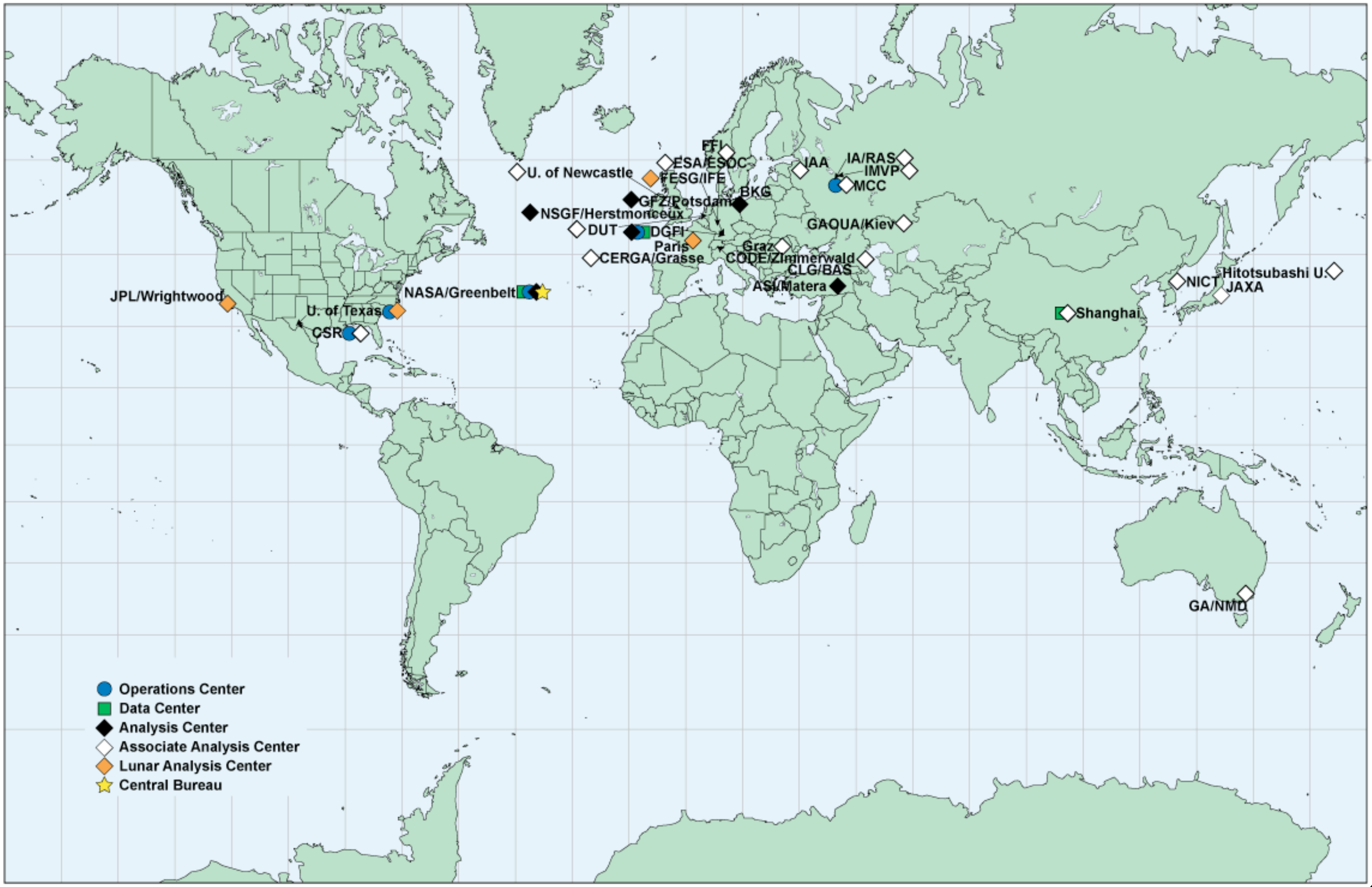


ILRS Network



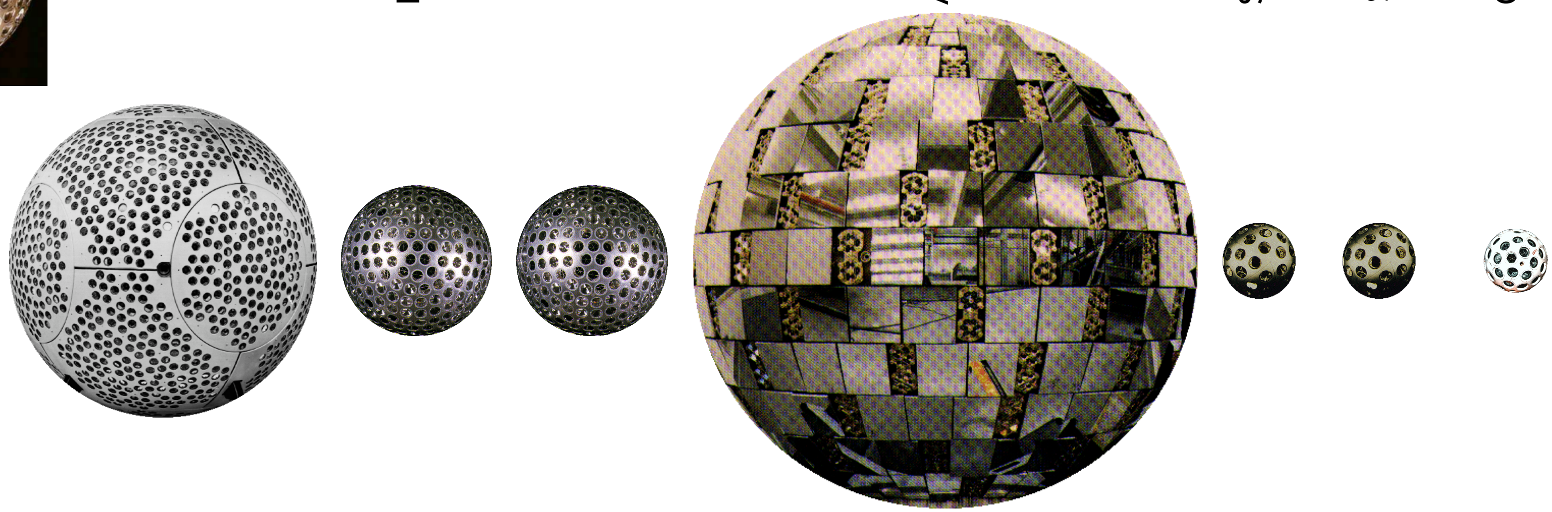
- 33 stations provide tracking data regularly
- Most of the stations are co-located with GNSS
- Eight stations are co-located with VLBI

Other ILRS Components



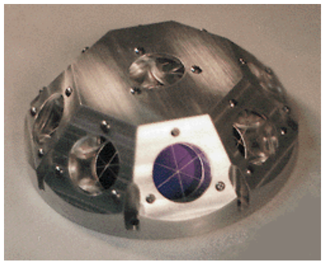
Selected SLR Stations Around the World

Sample of SLR Satellite Constellation
(Geodetic Satellites)

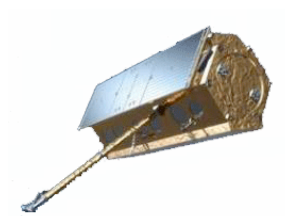
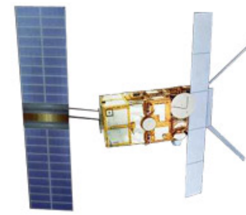


	Etalon-I & -II	LAGEOS-1	LAGEOS-2	Ajisai	Starlette	Stella	GFZ-1
Inclination	64.8°	109.8°	52.6°	50°	50°	98.6°	51.6°
Perigee ht. (km)	19,120	5,860	5,620	1,490	810	800	396
Diameter (cm)	129.4	60	60	215	24	24	20
Mass (kg)	1415	407	405.4	685	47.3	47.3	20.6

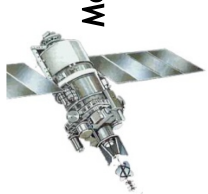
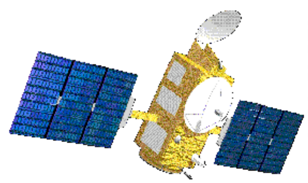
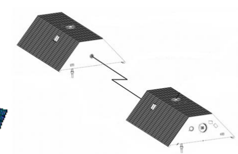
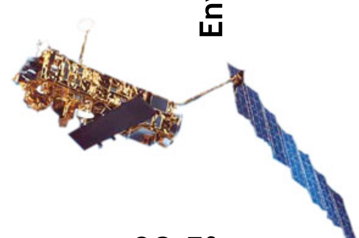
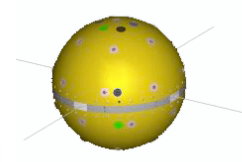
Sample of SLR Satellite Constellation





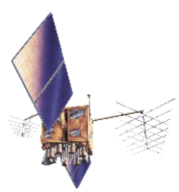
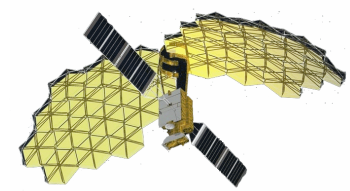




	GFO-1	ERS-1	Terra-SAR-X	ERS-2	CHAMP
Inclination	**108°**	**98.5°**	**97.4°**	**98.5°**	**87.27°**
Perigee ht. (km)	**800**	**780**	**514**	**785**	**474**
Mass (kg)	**300**	**2,400**	**1,230**	**2,516**	**400**

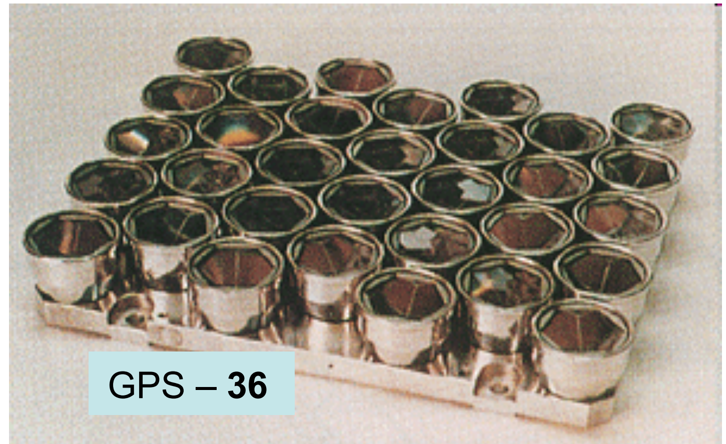






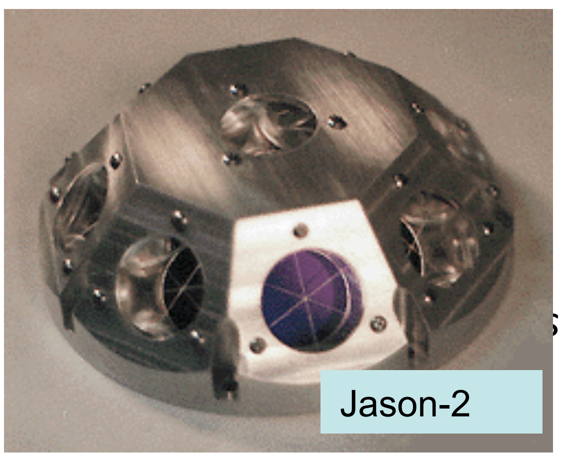
	Meteor-3M	Jason-1	GRACE	Envisat	ANDE-RR
Inclination	**99.64°**	**66°**	**89°**	**98.5°**	**51.6°**
Perigee ht. (km)	**1,012**	**1,336**	**450**	**796**	**250**
Mass (kg)	**2.477**	**500**	**432/sat.**	**8,211**	**50**

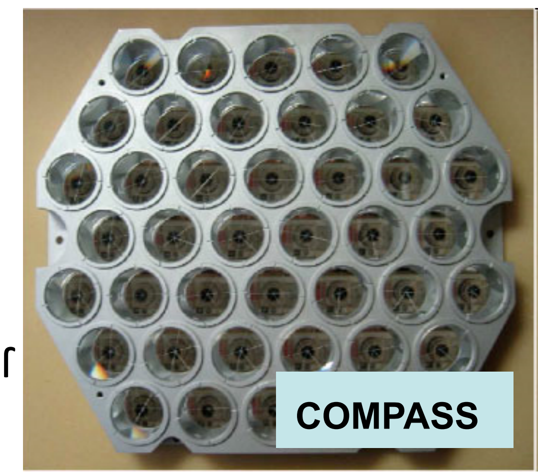
Sample of SLR Satellite Constellation
(HEO)

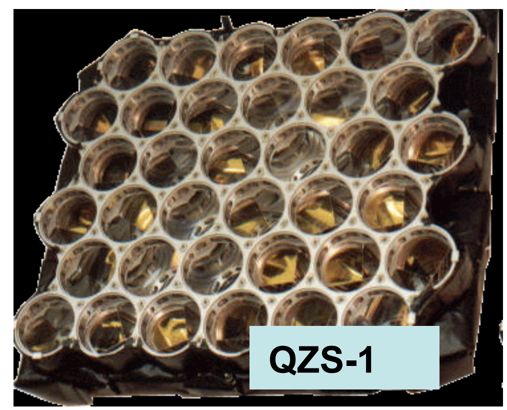
	GLONASS	GPS	COMPASS	GIOVE	ETS-8
					
Inclination	65°	64.8°	55.5°	56°	0°
Perigee ht. (km)	19,140	20,195	21,500	23,920	36,000
Mass (kg)	1,400	930	2,200	600	2,800
Retro array	3 (many)	1 (2)	1	2	1


LAGEOS

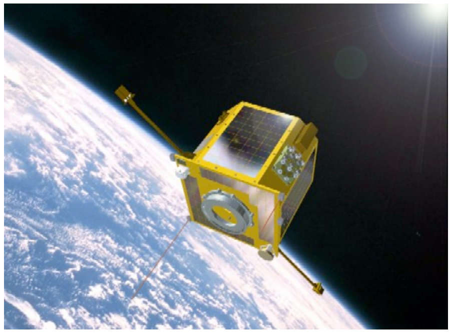

GPS – 36


Jason-2


COMPASS


QZS-1

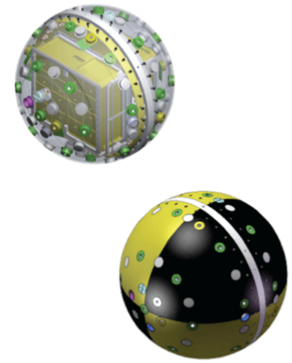
Missions for 2009 - 2010



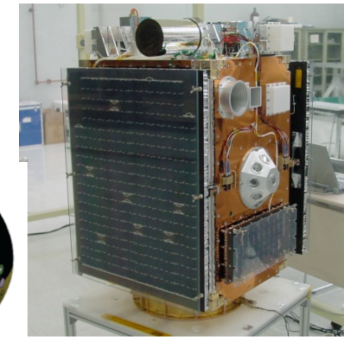
SOHLA
JAXA/Japan

GOCE
ESA

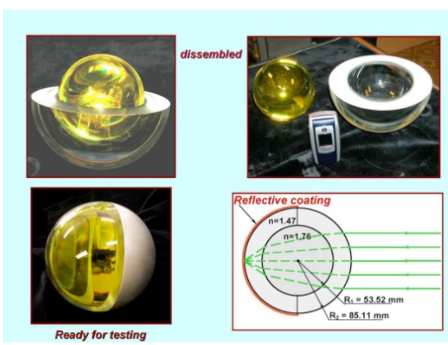
LRO
NASA/USA



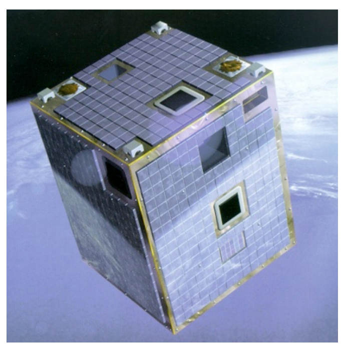
ANDE
NRL/USA



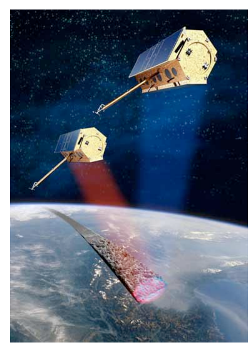
STSAT-2
KASI/Korea



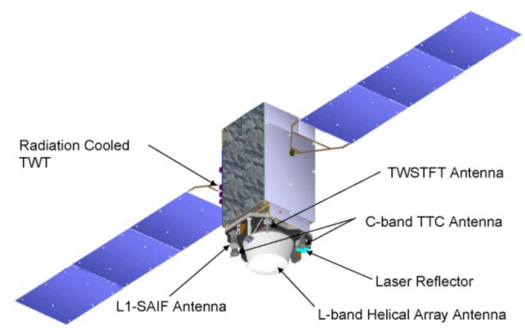
BLITS
IPIE/Russia



PROBA-2
ESA

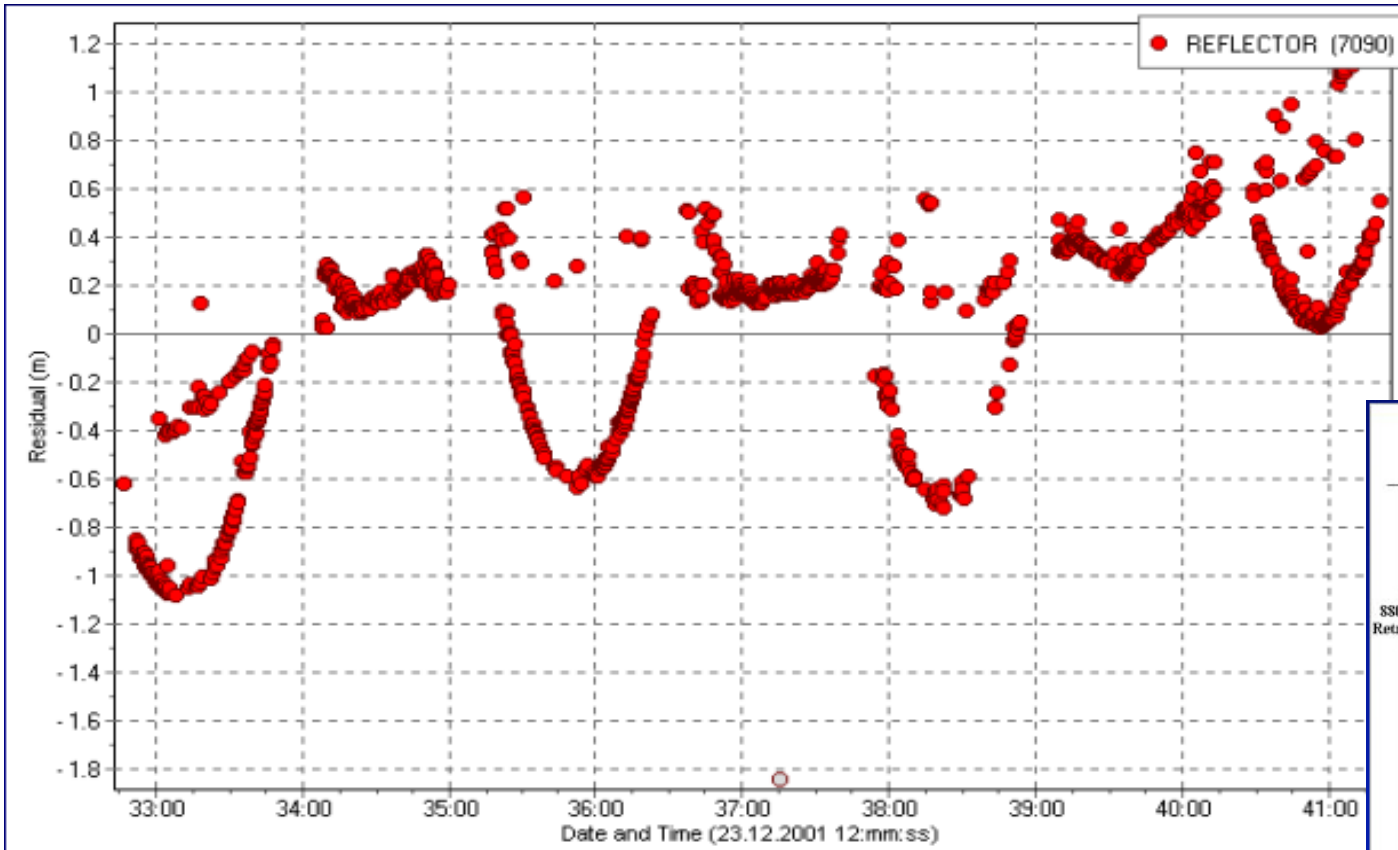


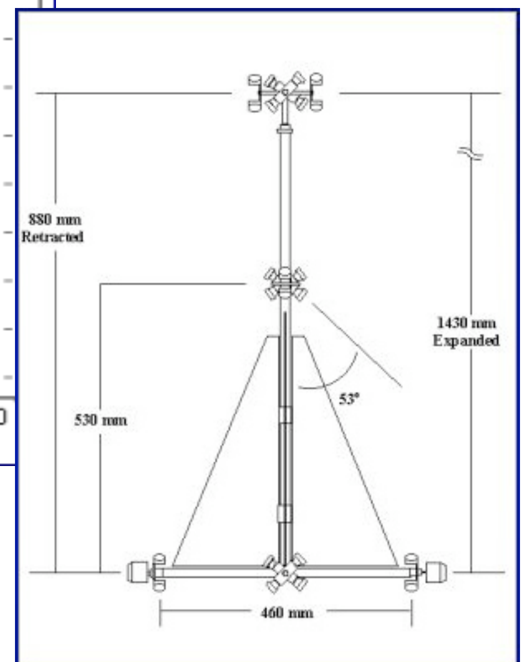
TanDEM-X
DLR, GFZ/Germany



QZS-1
JAXA/Japan

Reflector Satellite





SLR Biases

- Stanford Counter
  - non-linear effects – few to 15 mm;
  - calibration has limited success;
  - some ITRF reanalysis work based on engineering information has improved situation; table to be published and being used in the ITRF;
  - not a full or ideal solution;
  - most stations are upgrading their counter systems;
- Better system calibration major effort in the ILRS
  - ground surveys;
  - ground target;
  - array properties.

The Next Generation SLR Systems

The next generation systems will operate with:

- higher repetition rate (100 Hz to 2 kHz) lasers to increase data yield and improve normal point precision;
- photon-counting detectors to reduce the emitted laser energies by orders of magnitude and reduce optical hazards on the ground and at aircraft (some are totally eye-safe);
- multi-stop event timers with few ps resolutions to improve low energy performance in a high solar-noise environment; and
- considerably more automation to permit remote and even autonomous operation;
- More frequent survey vector measurements.

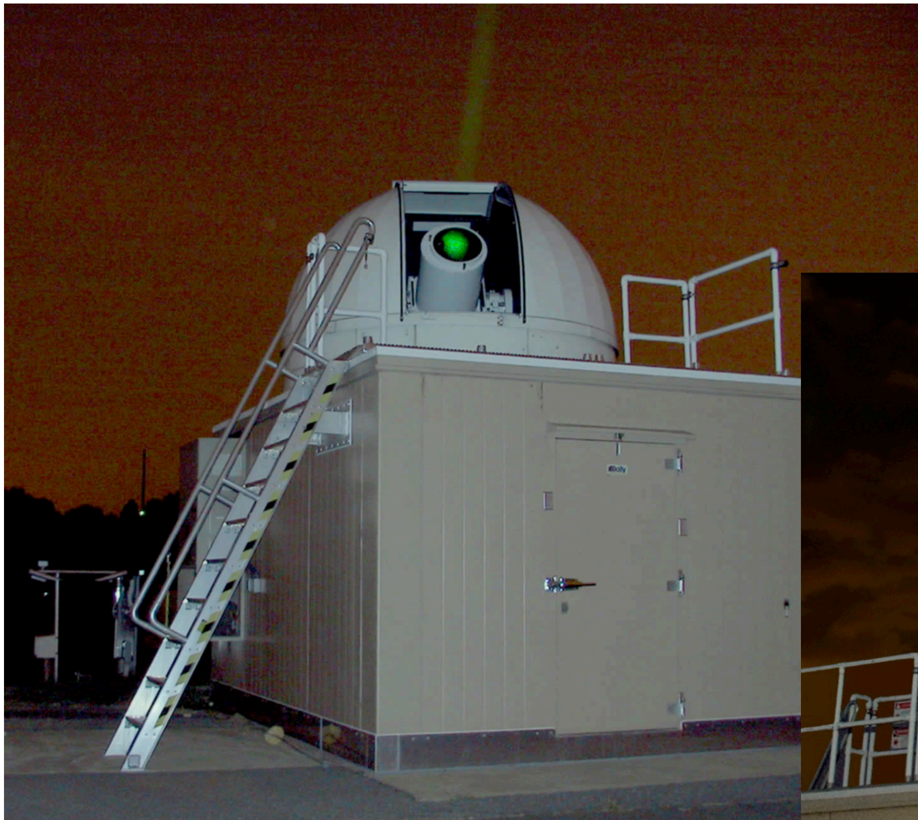
Many systems will operate at single photon levels with

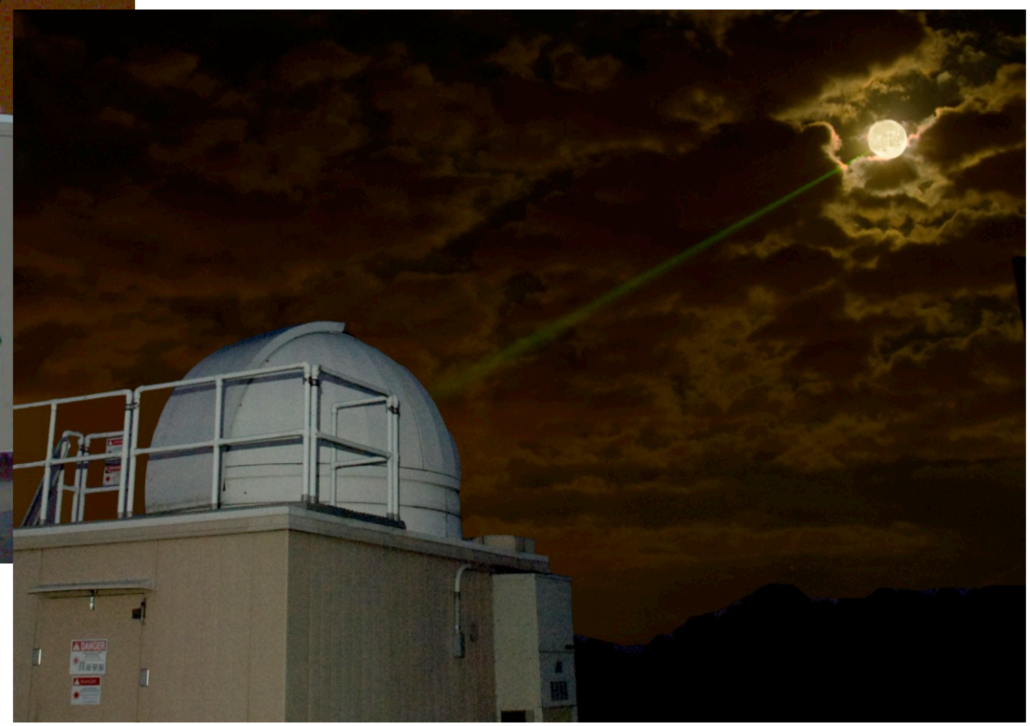
- Single Photon Avalanche Diode (SPAD) detectors or
- MicroChannel Plate PhotoMultiplier Tubes (MCP/PMIs).

Some systems are experimenting with two-wavelength operations to test atmospheric refraction models and/or to provide unambiguous calibration of the atmospheric delay.

NASA New Generation SLR System (NGSLR)

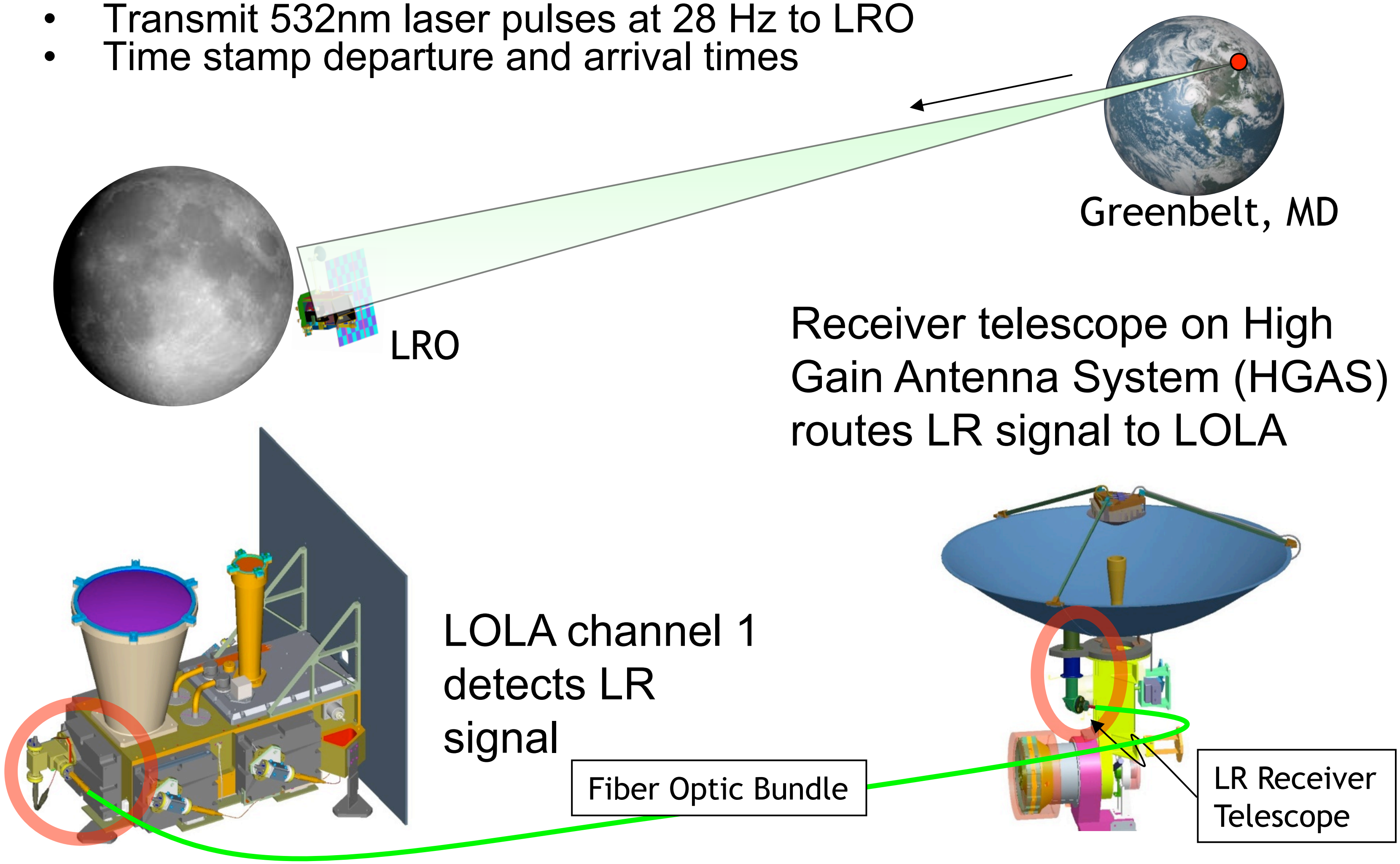
NASA Goddard Space Flight Center





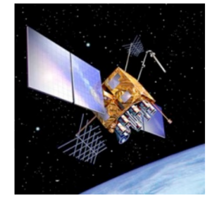
Lunar Orbiter Laser Ranging

- Transmit 532nm laser pulses at 28 Hz to LRO
- Time stamp departure and arrival times



GPS-35/36 Tracking Campaign

(25-Mar-2008 through 26-May-2008)

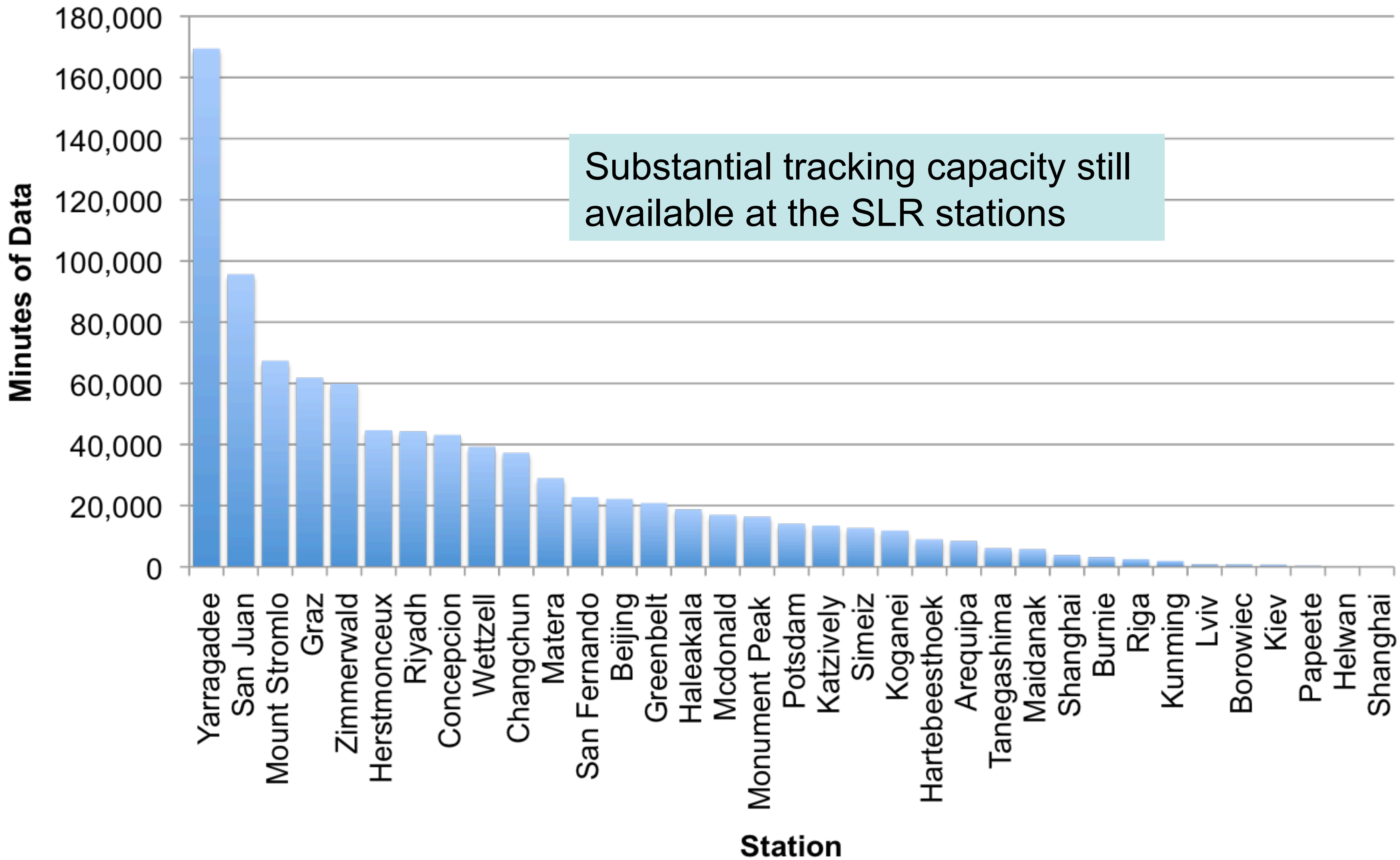


Site Name	Station #	No. Passes	No. Normal Points
Beijing	7249	1	3
Changchun	7237	2	8
Graz	7839	28	251
Greenbelt	7105	2	4
Herstmonceux	7840	23	77
Katzively	1893	1	6
Koganei	7308	2	9
Matera	7941	1	6
McDonald	7080	10	42
Monument Peak	7110	4	9
Mount Stromlo	7825	11	40
Riyadh	7832	20	99
San Juan	7406	60	375
Simeiz	1873	2	50
Tanegashima	7358	29	149
Wettzell	8834	18	79
Yarragadee	7090	70	267
Zimmerwald	7810	15	61
Totals:	18 stations	299	1535

33 Passes/week

ILRS Network Tracking

01-Jul-2007 through 30-Jun-2008



SLR Tracking on GNSS

Current Situation:

We currently track satellites in the GLONASS (3), GPS (2/1), GIOVE/Galileo (2), and COMPASS (1) Complexes, but data is sparse and night-time only

What do we need?

- How many satellites within a constellation should be tracked?
- How often (temporal distribution?)
- Do we need continuous tracking or are campaigns adequate?
- Should we cycling through the constellation, the orbital planes?
- How many satellites at a time?
- How many passes per day, per week, per month etc?
- Daytime tracking?
- By how many stations? ("As many as possible" is not good enough...).
- Distribution of observations within the pass? Precision? Accuracy? Maximum latency (e.g., is near-realtime requested?)

A Possible Plan for Multiple GNSS Tracking

- 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;
  - Many network stations will be using enhanced systems (e.g. KHz ranging, improved detection,) in the 2013 timeframe for improved performance on weak targets;
  - Increased automation and data interleaving procedures at the field stations will increase ranging efficiency;
- Concepts for an Operational HEO Plan:
  - Support GPS, Galileo, GLONASS,COMPASS, QZSS and possibly others;
  - Pointing predictions based on on-board GNSS data and SLR data for improved pointing particularly in daylight using real-time communication;
  - Decrease Normal Point intervals (from 5 minutes) as data volume increases, thereby increasing tracking capacity;
  - Three segments per pass (ascending, middle, descending);
  - Data available for analysis immediately after each pass;
  - Network tracking roster organized for at least 16 GNSS satellites at a time (at least one satellite per orbital plane per system);
  - Tracking cycles set for 30 – 60 days (to cover all satellites within a 12 month period);
  - Greater stress on daylight tracking;
  - Flexible tracking strategies; organized in cooperation with the agencies involved and the requirements for the ITRF;

We invite you to visit our website @

http://ilrs.gsfc.nasa.gov/index.html