

The International Laser Ranging Service; Past, Present and Future

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The International Laser Ranging Service; Past, Present and Future Abstract



The paper will review the role and the history of the ILRS, highlighting many of the changes that we have seen in the network, the technology, the missions (and associated support of science areas), the analysis, the procedures, the retroreflector arrays, and operations over the tenure of the Service. The institution of the ILRS Service brought about changes that have led to improved operations, expanded collaboration between isolated international groups, provided a conduit for information and idea exchanges, eliminated redundancy and unwarranted duplication of efforts, streamlined the collection, quality control and archival of all data and products, and eventually resulted in considerable improvement in the quality and quantity of SLR/LLR-based data products. Despite the unquestionable growth over the past two decades, there is still a lot of room for improvement and expansion, so this presentation will discuss the path forward that we foresee for laser ranging and the issues and obstacles that we will need to address and overcome in the near future. While the focus is on our technique—laser ranging, we also need to recognize the importance of co-location with the other geodetic techniques that will be essential as data product requirements become more stringent and as we attract new customers.

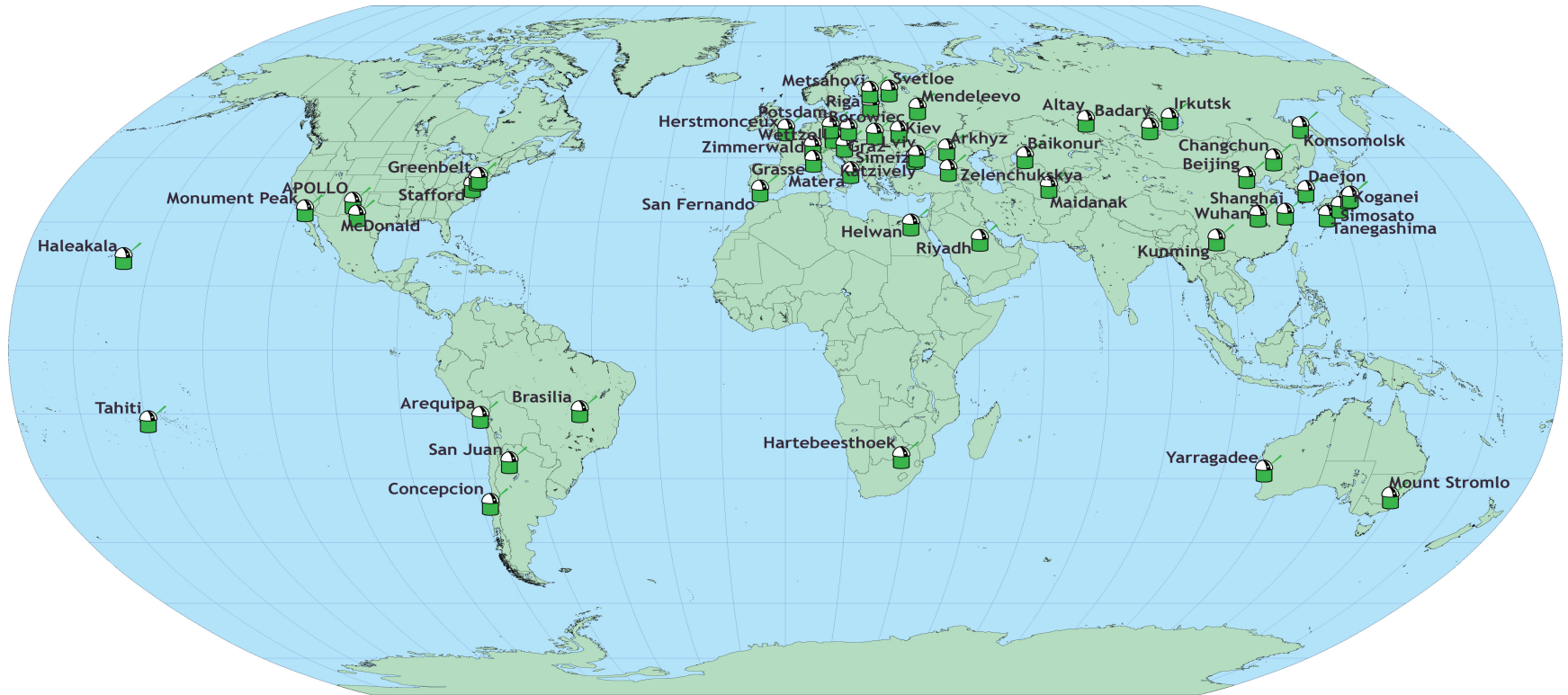
The Role of the ILRS

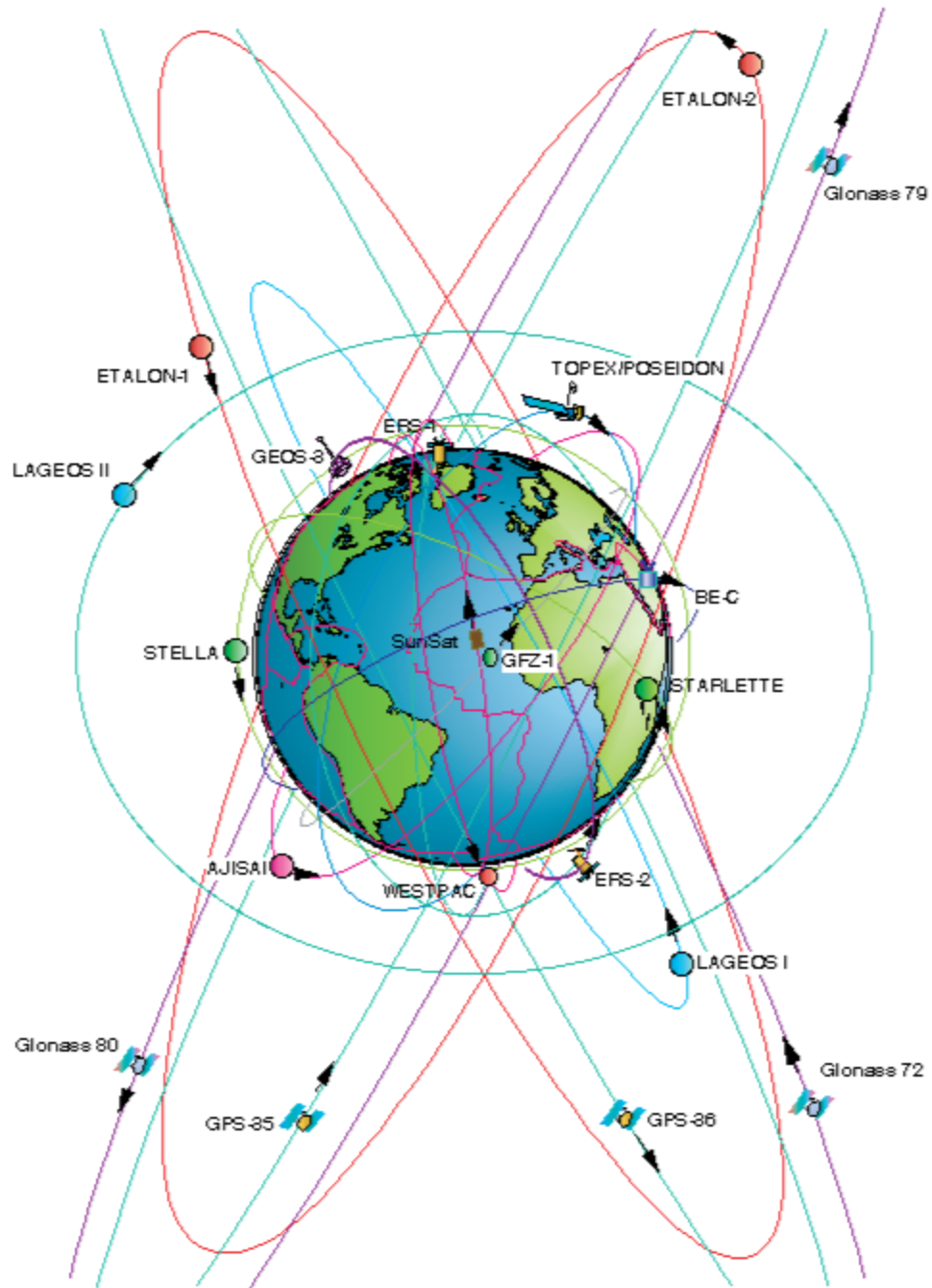
- The International Laser Ranging Service (ILRS) provides global satellite and lunar laser ranging data and their related products to support geodetic and geophysical research activities as well as IERS products important to the maintenance of an accurate International Terrestrial Reference Frame (ITRF).
- The service develops the necessary global standards/specifications and encourages international adherence to its conventions.
- The ILRS is one of the space geodetic services of the International Association of Geodesy (IAG) and is a participant in the Global Geodetic Observing System (GGOS).
- The ILRS collects, merges, archives and distributes Satellite Laser Ranging (SLR) and Lunar Laser Ranging (LLR) observation data sets of sufficient accuracy to satisfy the objectives of a wide range of scientific, engineering, and operational applications and experimentation.
- The ILRS organizes and coordinates the activities of laser ranging community

Where we came from...

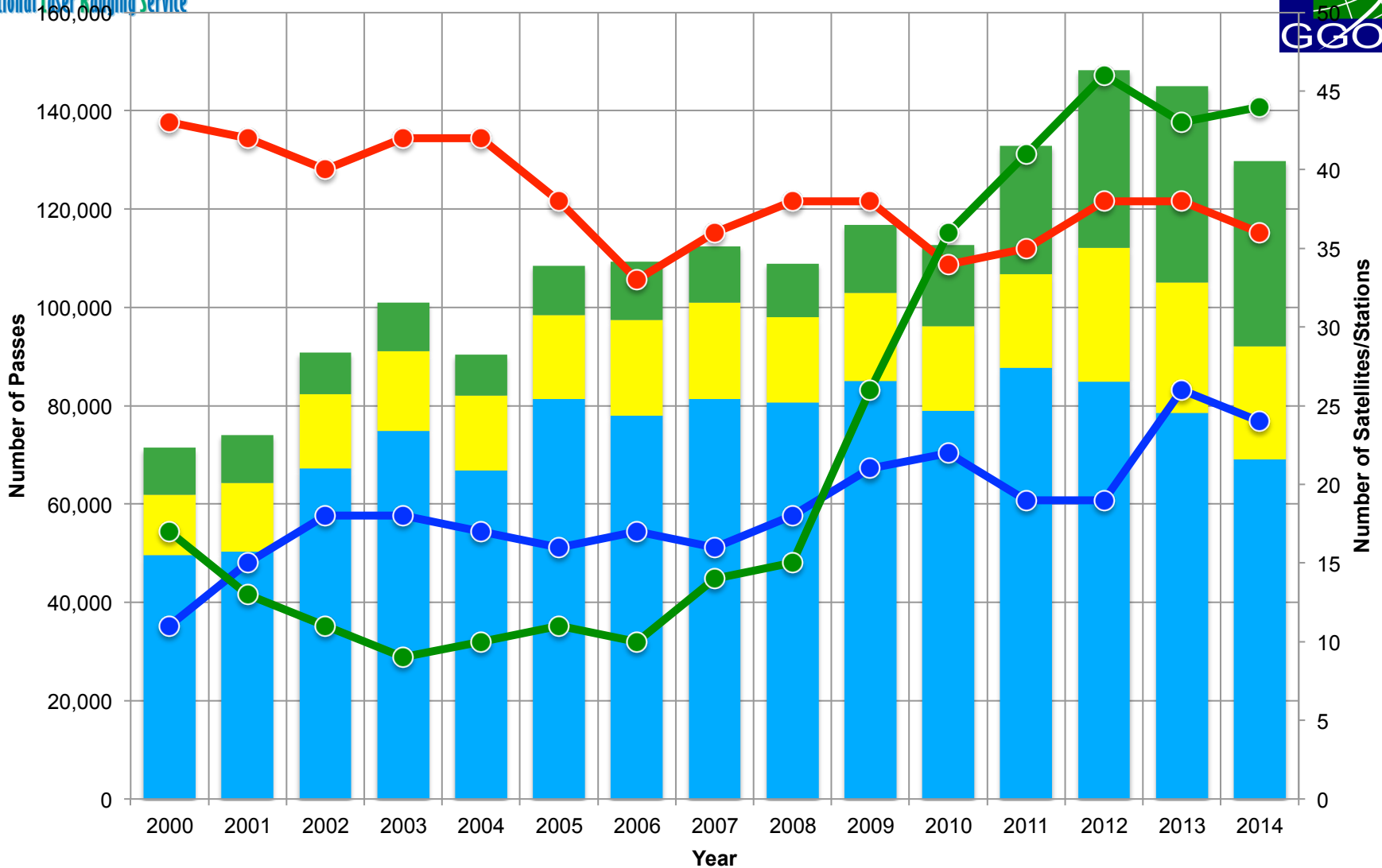
- 1980's: SLR coordination performed by Commission for coordination of Space Techniques for geodesy and Geodynamics (CSTG)
- 1995: Gerhard Beutler, CSTG president, called for proposals of participation in an International Laser Tracking Network, modeled on the success of the International GPS Service.
- June 1997: Draft ILRS Terms of Reference were presented and approved at the CSTG General Assembly in Maratea, Italy
- Fall 1997: John Degnan (CSTG SLR/LLR Subcommittee Chair) and Bob Schutz (SLR Representative to IERS Directing Board) drafted a Joint CSTG/IERS Call for Participation in the ILRS
- April 1998: Proposals reviewed and the approved responses presented at the CSTG SLR/LLR Subcommittee General Assembly in Nice, France
- September 1998: Final CSTG SLR/LLR Subcommittee General Assembly and first ILRS General Assembly held in conjunction with the 11th International Workshop on Laser Ranging in Deggendorf, Germany; Degnan officially disbanded the CSTG Satellite and Laser Ranging Subcommittee and replaced it with the new International Laser Ranging Service. John became the first chair of newly-formed ILRS Governing Board.

ILRS Network Today

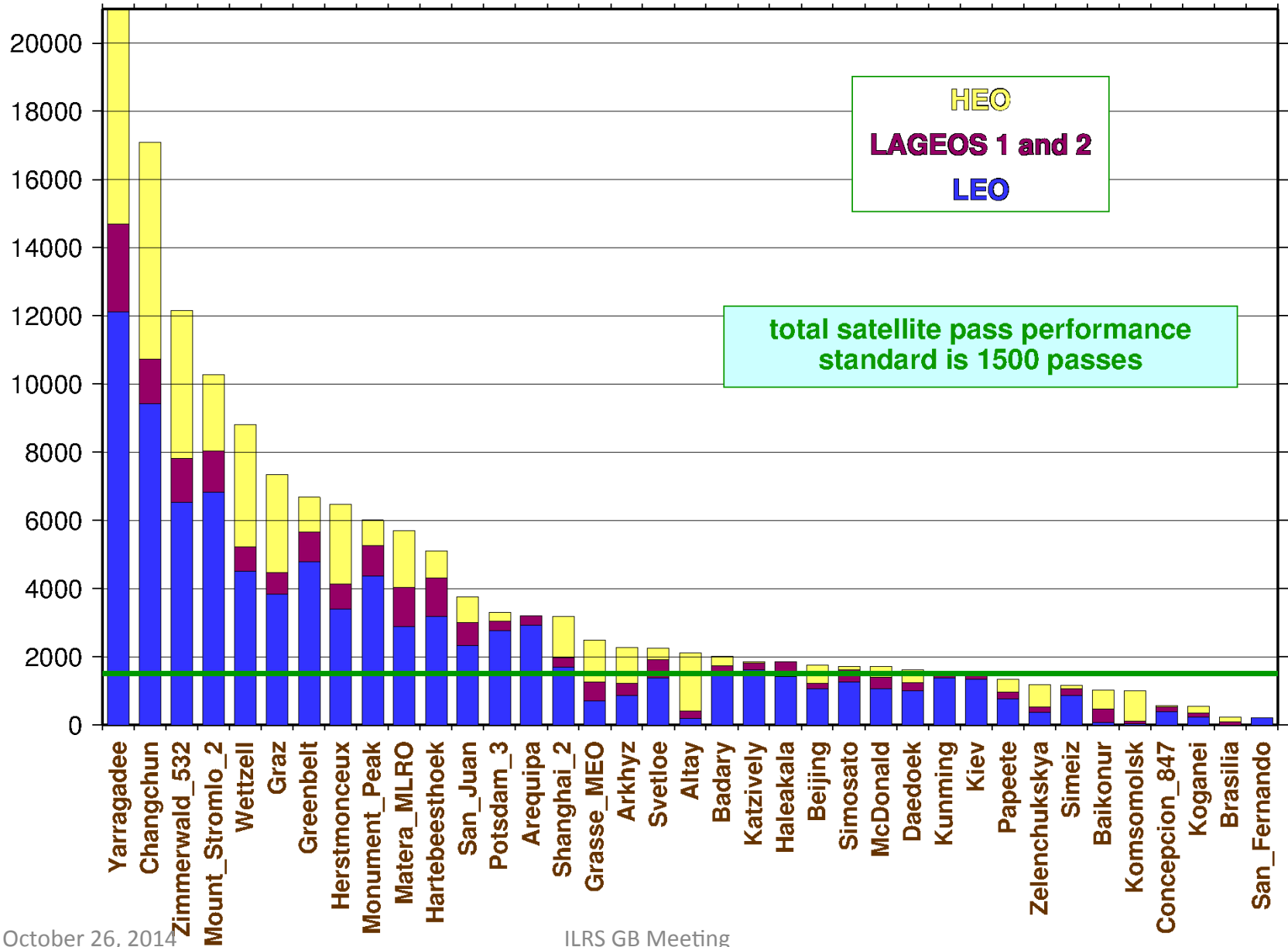




Annual Data Yield

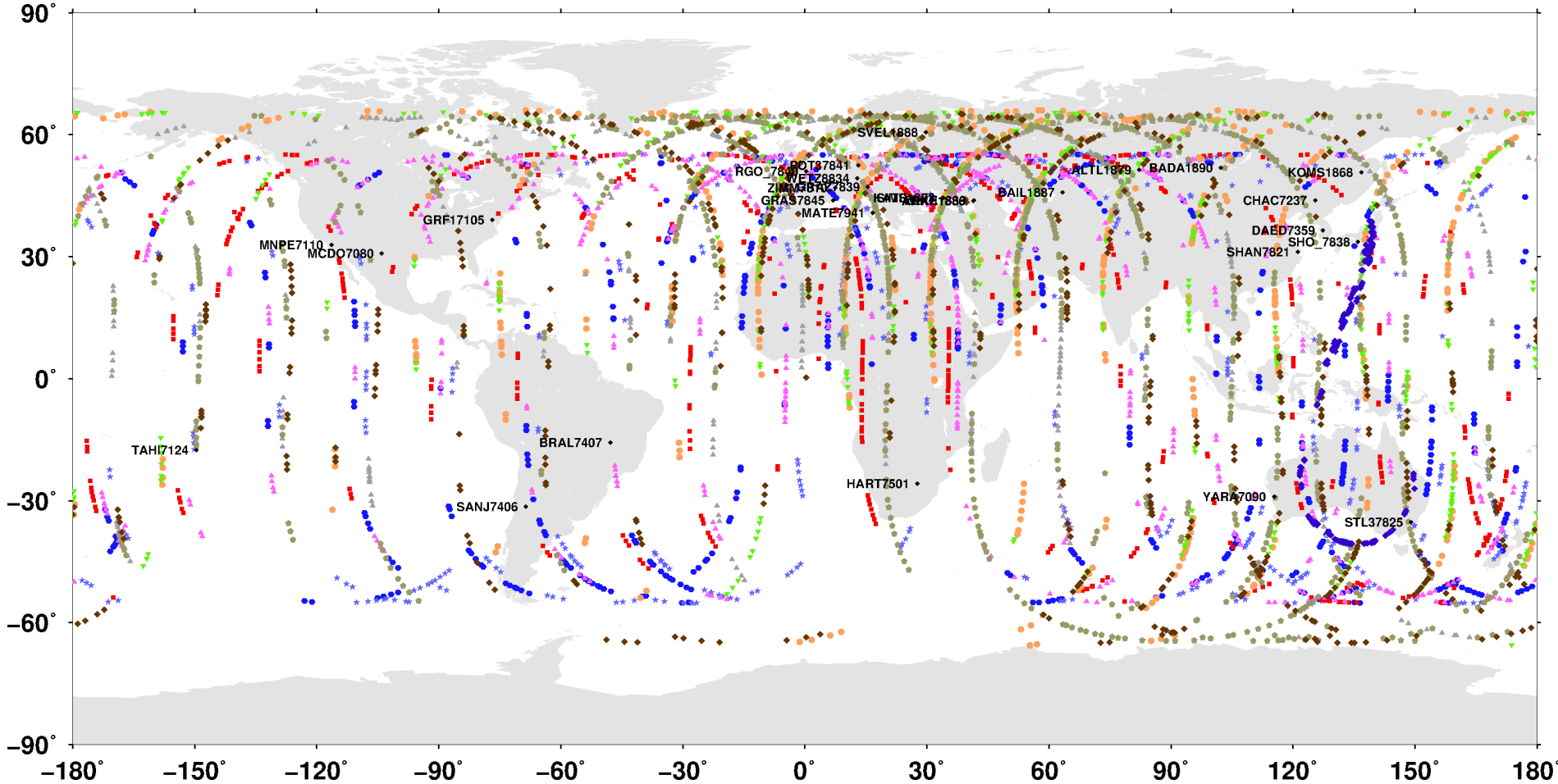


total passes from October 1, 2013 through September 30, 2014



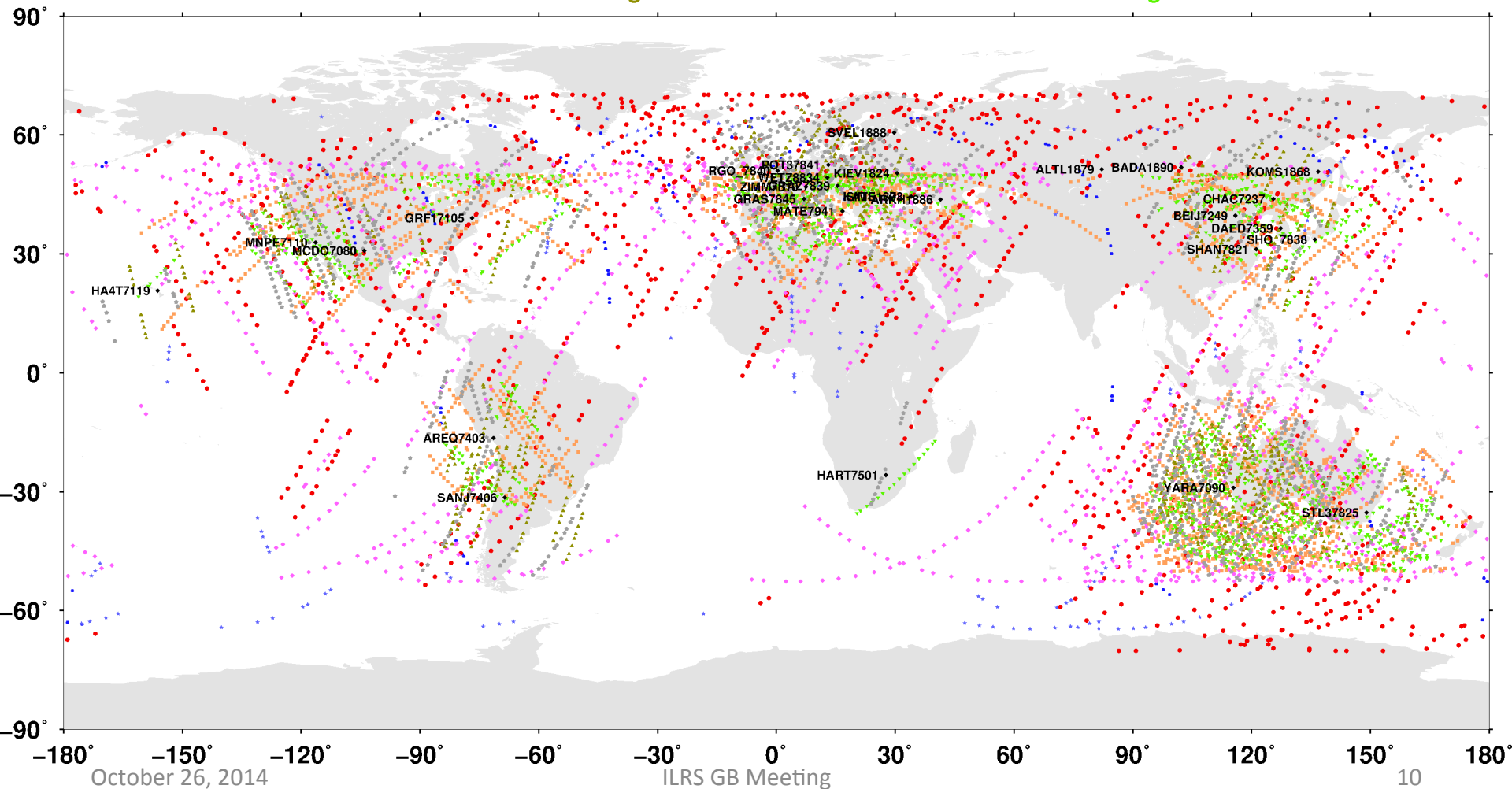
GNSS SLR data from 20140910 through 20141009 1200 UTC

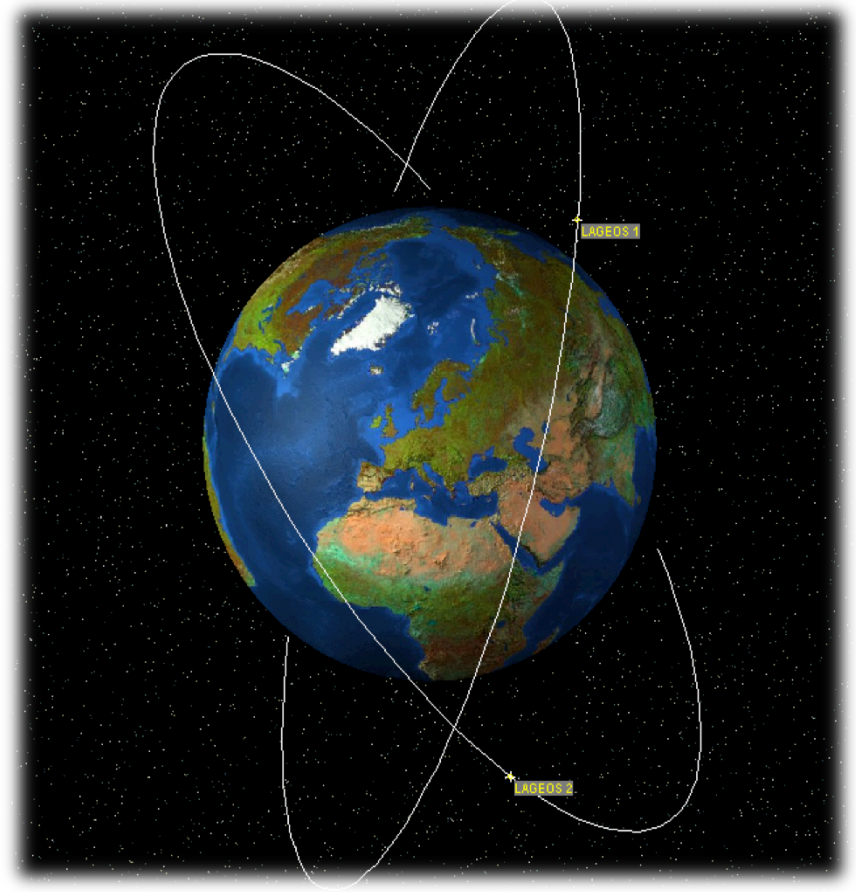
- galileo101 516 pts
- ★ galileo102 426 pts
- galileo103 561 pts
- ▲ galileo104 683 pts
- glonass102 575 pts
- ▼ glonass109 523 pts
- glonass111 0 pts
- ▲ glonass118 700 pts
- ◆ glonass129 1013 pts
- ◆ glonass130 647 pts
- giovea 0 pts
- ◆ qzs1 158 pts



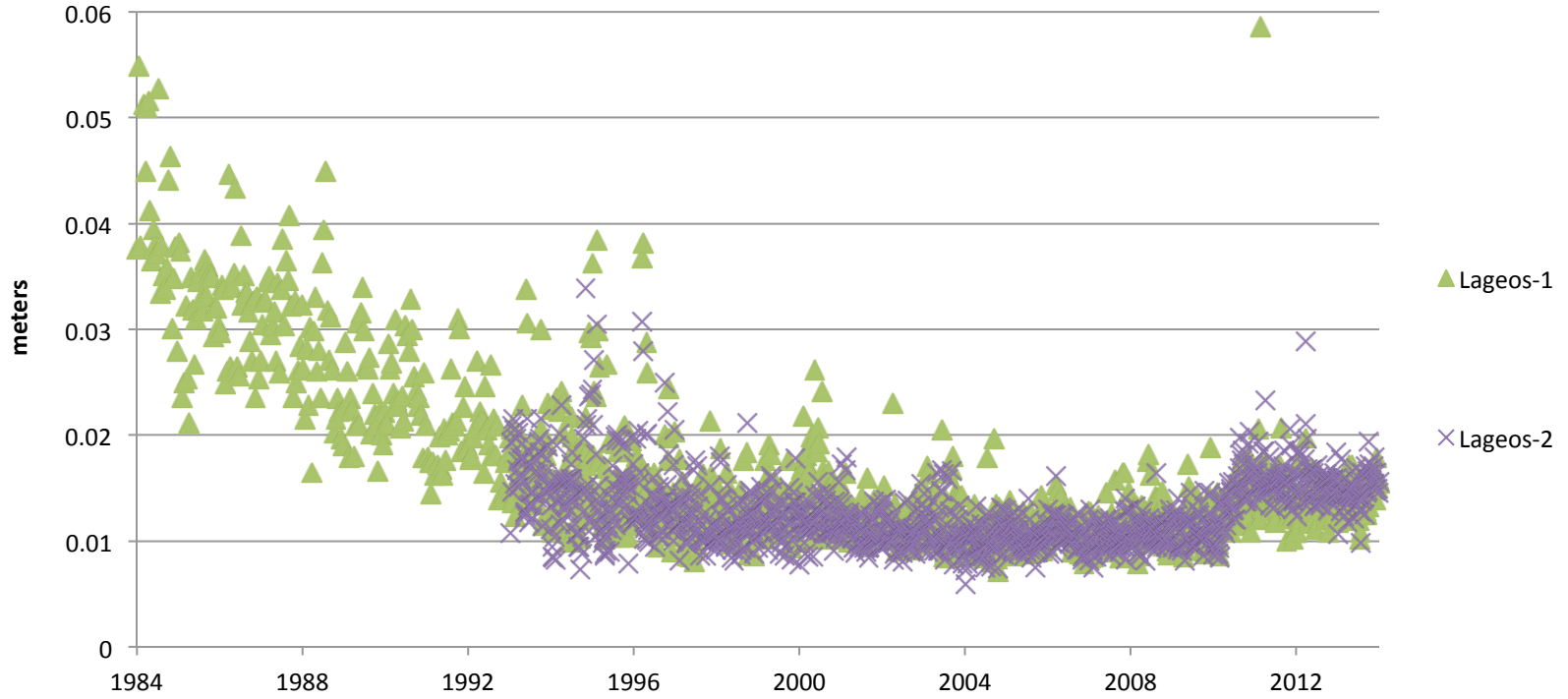
SLR data from 20141019 through 20141026 1200 UTC

- ETALON-1 19120 km 64.9 deg ★ ETALON-2 19120 km 65.5 deg ▼ AJISAI 1492 km 50 deg
- LAGEOS-1 5895 km 109 deg ◆ LAGEOS-2 5785 km 52 deg ◆ LARES 1450 km 69.5 deg
- STARLETTE 953 km 50 deg ▲ STELLA 795 km 99 deg

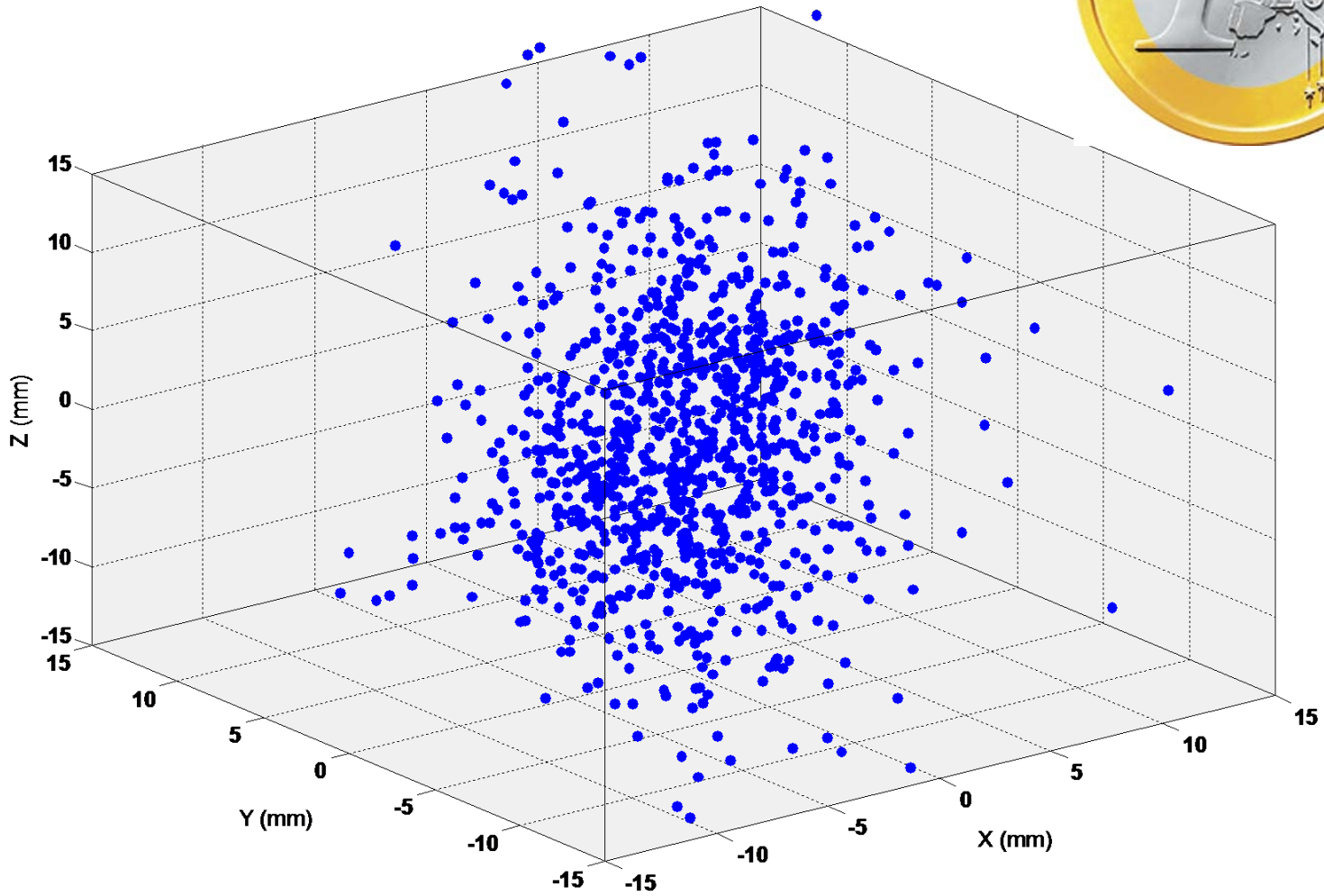




ARC Residual WRMS

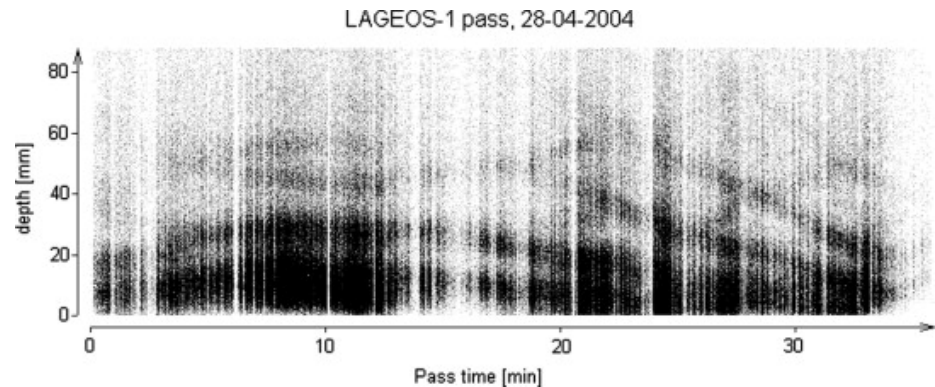


ILRSA 1993-2012 weekly geocenter vs ITRF2008 origin



Changes Since Inception Technology

- Lasers
 - High repetition rate lasers (100 – Khz rates)
 - Several stations have moved to higher rep rate (China, Russia, Europe)
 - faster satellite acquisition;
 - more rapid data accumulation; better populated NP's (now practical to get 1000 FR points per NP)
 - Narrower pulse widths (10 – 30 ps)
 - greater precision; precision has historically followed pulse width



Changes Since Inception Technology

- Timing systems; general move away from TIU to epoch timing systems
 - improved accuracy;
 - accommodate the multi-pulses-in-flight condition (high repetition rate) operation
- New detectors with higher quantum efficiency and faster response times
- GNSS steered timing and better oscillators or better network epoch synchronization
- Automation and remote operations
 - reducing need for manpower
 - autonomous operation for periods of time (e.g. Zimmerwald, Stromlo)

Changes Since Inception Analysis

- Strong Analysis Working Group organization under the guidance of Ron Noomen, Erricos Pavlis, and Cinzia Luceri;
- Great efforts toward harmonizing our analysis activities;
- Validation QC procedure for applicants applying to become an ILRS Analysis Center;
- Combination Centers established to QC and combine separate AC contributions into integrated and validated ILRS Data products (station positions, EOP, orbits);
- Uniformly adopted models for standardization of the analysis procedures;
- More consistent procedures across ACs as “configuration control” for much stronger ILRS data products.

Changes Since Inception Procedures

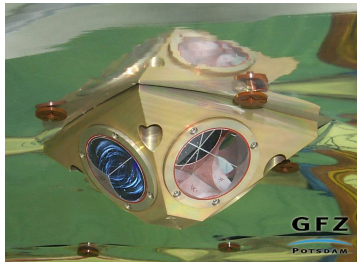
- A rapid and standardized station-reporting procedure so data issues can be quickly detected and diagnosed;
- New procedures for better definition of NP's on Lageos and more efficient and productive use of stations' time;
- Site logs for a permanent record of site evolution and history change logs for quick dissemination of station activities that may affect the data, users, etc.
- Wide use of web services to disseminate information amongst stations, operations centers, data centers, analysts, users and the community in general;
- Communication started among field stations to circulate tracking status in near real time to help stations set their priorities and Tracking schedules (EUROSTAT);

Changes Since Inception

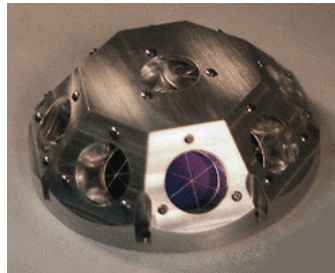
Retroreflector Arrays

- Common use of the “pyramid OR GFZ arrays” for LEO satellites – nearly COTS; particular design depends upon the satellites altitude and tracking requirement;
- Issue of ILRS Standard Specification for GNSS satellites of effective area of 100 million square meters;
- Adaptation of the GNSS standard to Synchronous satellites;
 - IRNSS constellation, Beidou (Compass), QZS

Champ



Jason

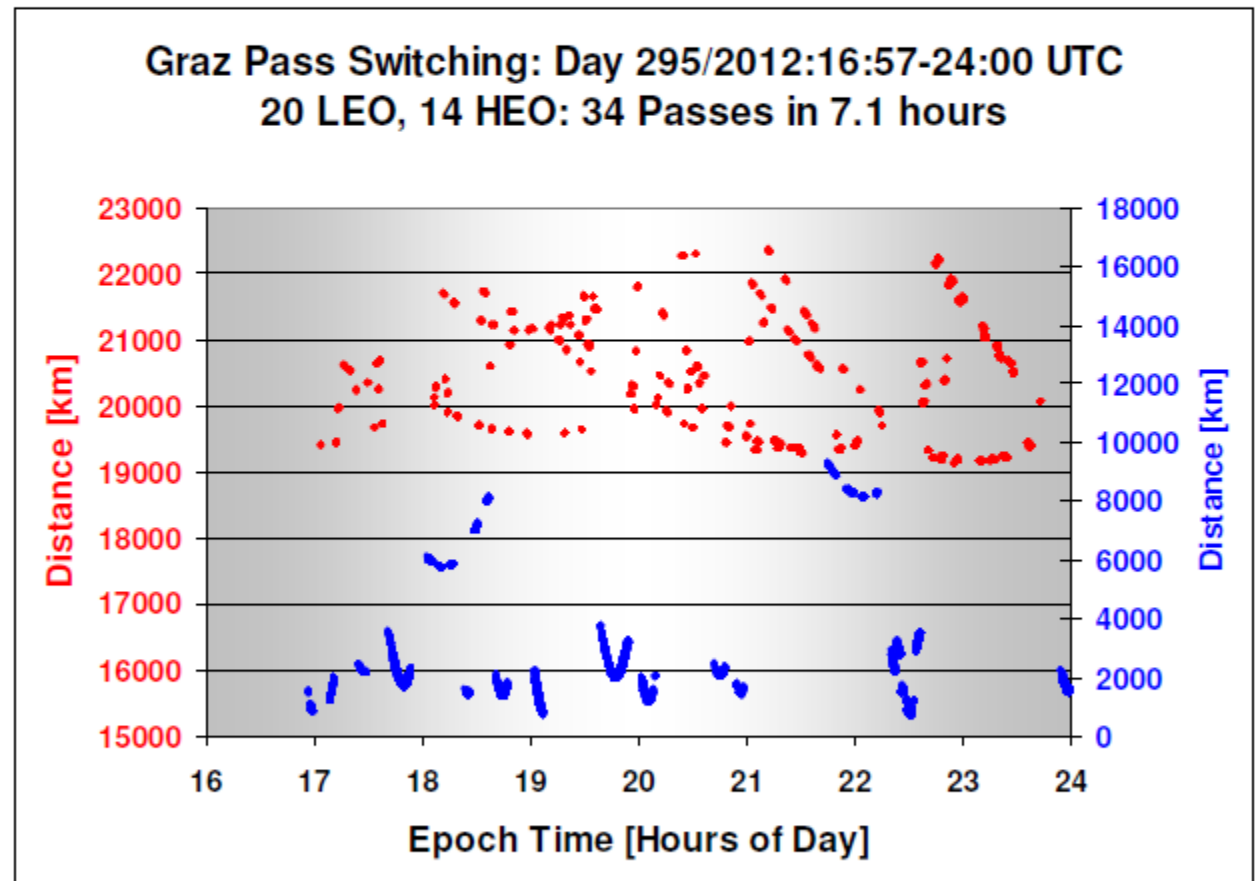


Beidou



Changes Since Inception Operations

- Improved daylight ranging
- Pass interleaving techniques to expand coverage
- Web-based centralized control systems to protect laser vulnerable satellites (example ICESat)

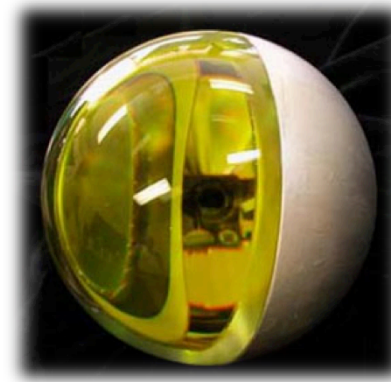


Path Forward

- Several initiatives under way to expand the Network; most notably Russia, China and the US that will help fill some of the the geographic gaps
- New individual stations in process: Ny Alesund, Metsahovi will help increase coverage at northern latitudes; talk being given in Japan regarding benefit of an SLR site in Antarctica;
- Expanded use of the newer technologies at the stations to move from legacy to new technology status
- Need more on-site tools for real-time performance assessment allowing systems to make real-time operational decisions
- Need more on-site tools to check for systematic errors and to apply diagnostic procedures to respond quickly
- More use of interactive communication on networks status to share experience and diagnostics

Path Forward (Continued)

- New applications using optical transponders for greater range;
- Beyond ILRS Scope, some stations are also supporting tracking debris: a new Study Group on Space Debris has just been approved by the GB
- Some station are supporting Quantum Communication experiments (MLRO, Graz, ?) – see presentation by P. Villoresi in Session 7 later today
- Alternative target designs to minimize signature



One-Way Earth-to-Mars Transponder Experiment

(September 2005)

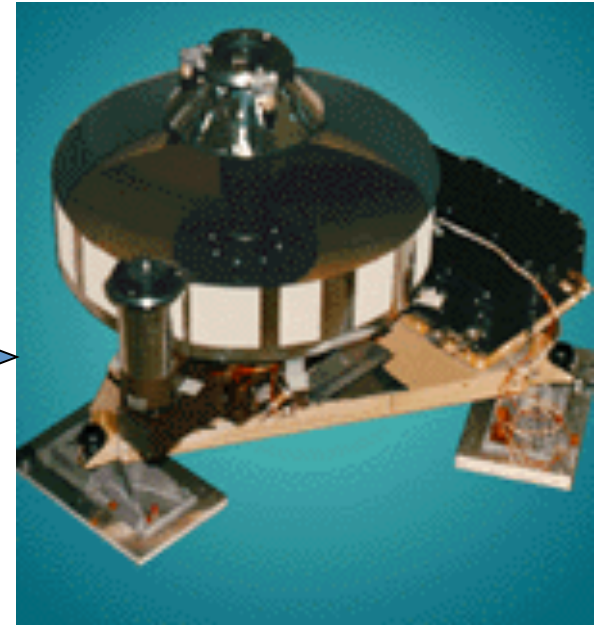


GSFC 1.2 Meter Telescope



80 Million Km!

~500 laser pulses
observed at Mars!



Mars Orbiter Laser Altimeter (MOLA)

Ground Station

Xiaoli Sun Jan McGarry Tom
Zagwodzki John Degnan

Science/Analysis/Spacecraft

David Smith Maria Zuber
Greg Neumann Jim Abshire

LRO Laser Ranging

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

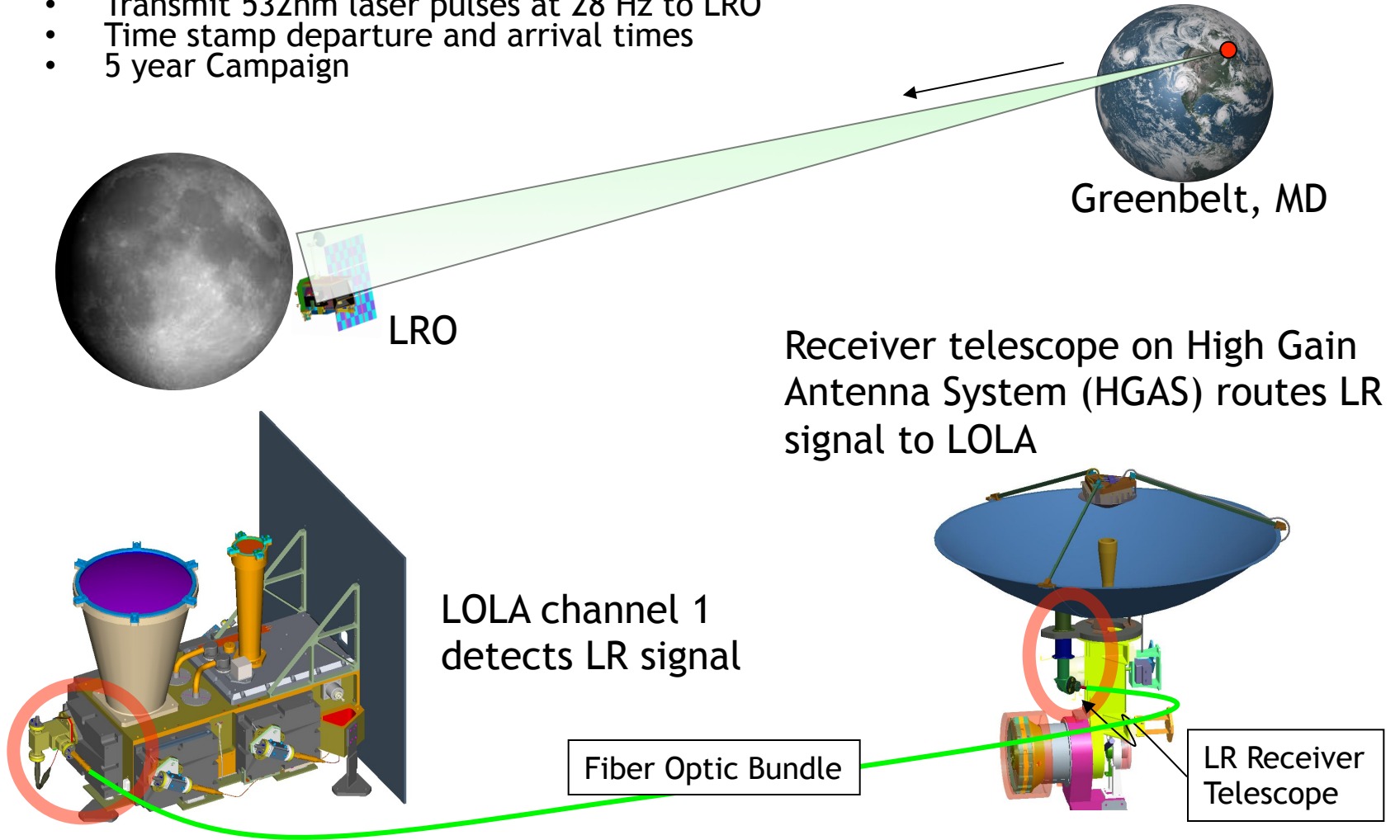


Table 1 | Main 2007 tests of the general theory of relativity

Phenomenon or principle tested	Method and 2007 experimental limit
Weak equivalence principle (test-particles fall with the same acceleration; this is at the foundations of geometrical (metric) theories of gravitation)	Laboratory experiments (accuracy of the order of 10^{-13}) Lunar laser ranging (accuracy of the order of 10^{-13})
Strong equivalence principle (this is at the foundations of the general theory of relativity)	Lunar laser ranging (accuracy of less than 10^{-3})
Gravitational time dilation or gravitational redshift (relative slowing down of clocks near a mass)	Gravity Probe A (with a clock on the ground and one on a rocket; accuracy of the order of 10^{-4})
Deflection of photons' path and travel time-delay of electromagnetic waves, or Shapiro time-delay, by a mass	VLBI (accuracy of the order of 2×10^{-4}) Cassini spacecraft tracking (accuracy of the order of 10^{-5})
Perihelion advance of Mercury	Mercury radar ranging (accuracy of the order of 10^{-3})
Periastron advance, time dilation, time delay, rate of change of the orbital period (accurately explained by the loss of energy due to the emission of gravitational waves from a binary system) and other relativistic parameters (these effects are characterized by strong gravitational field inside a pulsar)	Binary pulsar PSR1913+16 Other binary pulsars
Lense-Thirring effect, or frame-dragging of a gyroscope by the spin of a body	LAGEOS and LAGEOS2 laser ranging (accuracy of the order of 10^{-4}) Gravity Probe B (it might be detected by further GP-B data analysis)
Geodetic precession, or de Sitter effect (dragging of a gyroscope due to its motion in a static gravitational field)	Lunar laser ranging (accuracy of the order of 6×10^{-3}) Gravity Probe B (accuracy of the order of 1.5×10^{-2} ; it should be improved by further Gravity Probe B data analysis) Binary pulsars

For a detailed description see refs 7, 8 and 3; for an update see ref. 9.

Issues

- The lack of a “central design” for a “next generation SLR” system raises the cost, creates some compatibility issues (although minor) in data applications, and above all, makes the availability of any spare parts an almost unique issue per site or sub-network of sites;
- Mix of legacy and modern technologies and lack of standards in hardware will have an effect the data for a long time
- Filling the remaining geographic gaps will require many more partnerships and lots more resources;
- Co-locating SLR systems with VLBI; recognize that the two systems do not have the same site constraints – weather, RF problems, etc, so some compromises will be required if the total global network is to be realized;
- System biases still plague us at some stations; proper calibration and testing equipment and procedures need to be designed and implemented at all stations;
- Like the other techniques, we need standard procedures for site ties with proper modeling to instrument reference point.

Network evolution

