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Current Trends in Satellite Laser Ranging

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Laser Ranging

- In the era of the Global Geodetic Observing System (GGOS), high-quality multi-technique sites are crucial:

- The space-observational Services, the **IDS**, **IGS**, **ILRS** and **IVS** together supply the data and products to meet the GGOS Mission;

- Major goals are determination and maintenance of the terrestrial reference frame and determination and monitoring of the Earth's gravity field;

- Realised via inter-technique site ties and combination of analysis products (site position, velocity, Earth orientation) and tracking support for gravity missions

- For ITRF 2008:
  - geodetic laser ranging provided geo-centre and scale;
  - geodetic VLBI provided scale

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:

  - **Including weekly combined station coordinate solutions and daily EOPs from its Analysis Centres**

- Includes 75 agencies in 26 countries
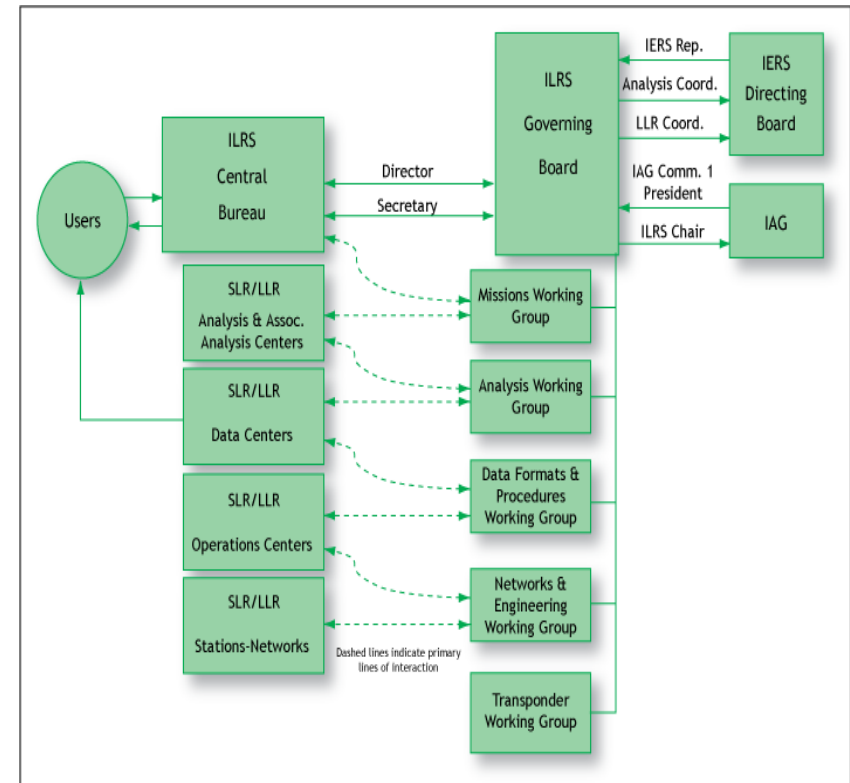
Satellite Laser Ranging Technique

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 synchronous satellites, and the Moon
- Satellite Orbit Accuracy ~1cm
- Able to see small changes by looking at long time series
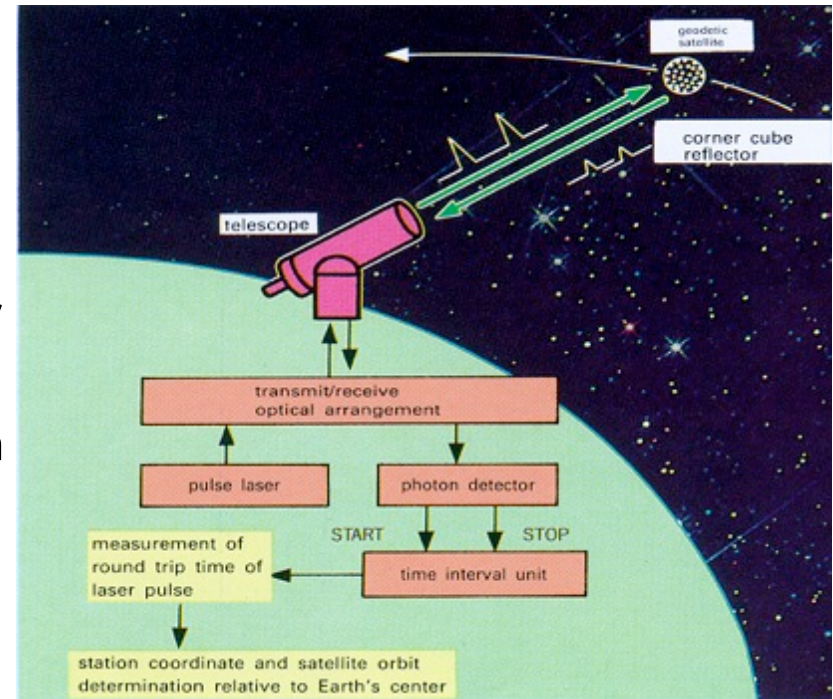
- Unambiguous centimeter accuracy orbits
- Long-term stable time series

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)
    - Total 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 Two Decades

ILRS Tracking Network

~30 global stations provide tracking data regularly
Most of the SLR stations co-located with GNSS; some also with VLBI, DORIS, and Gravity measurements
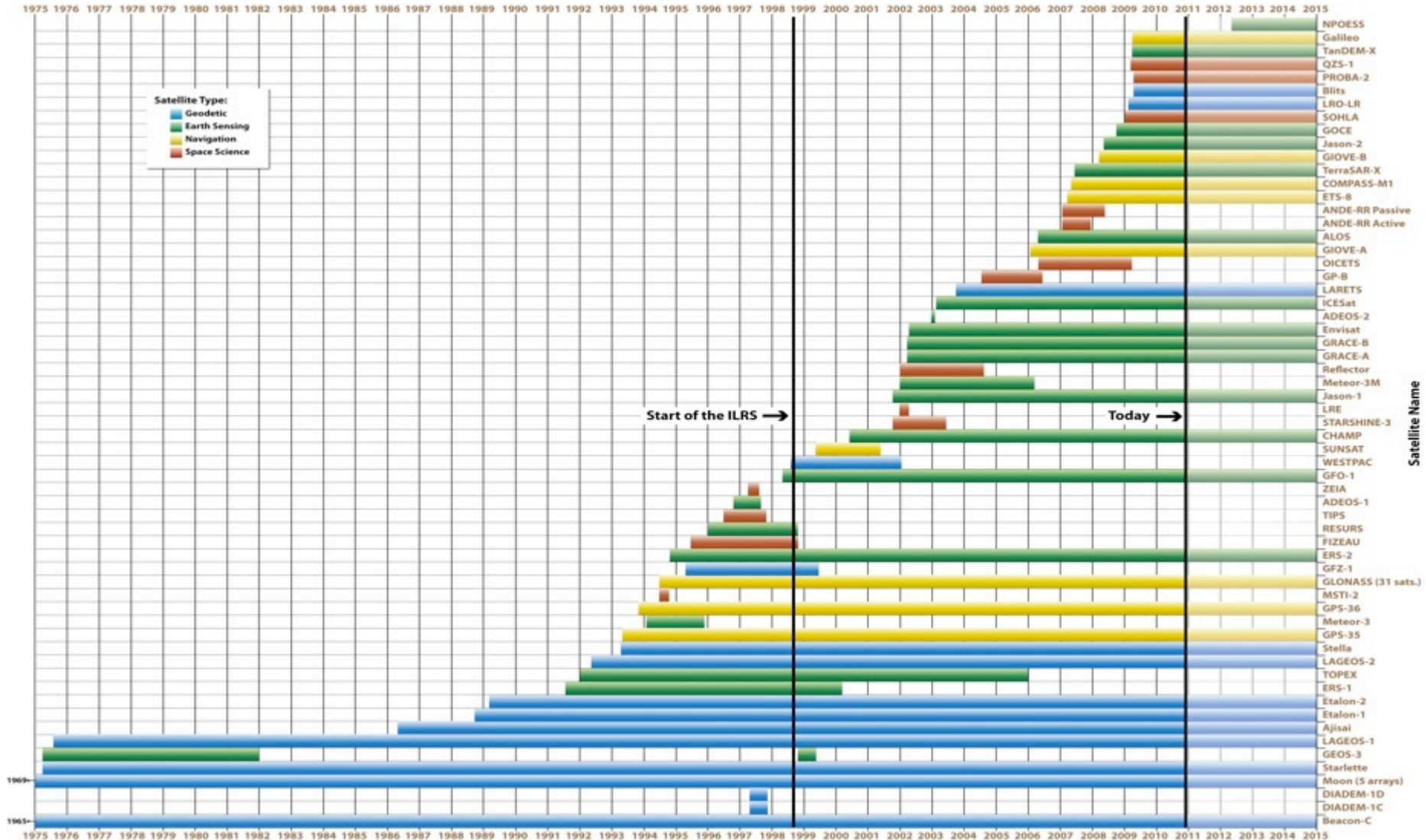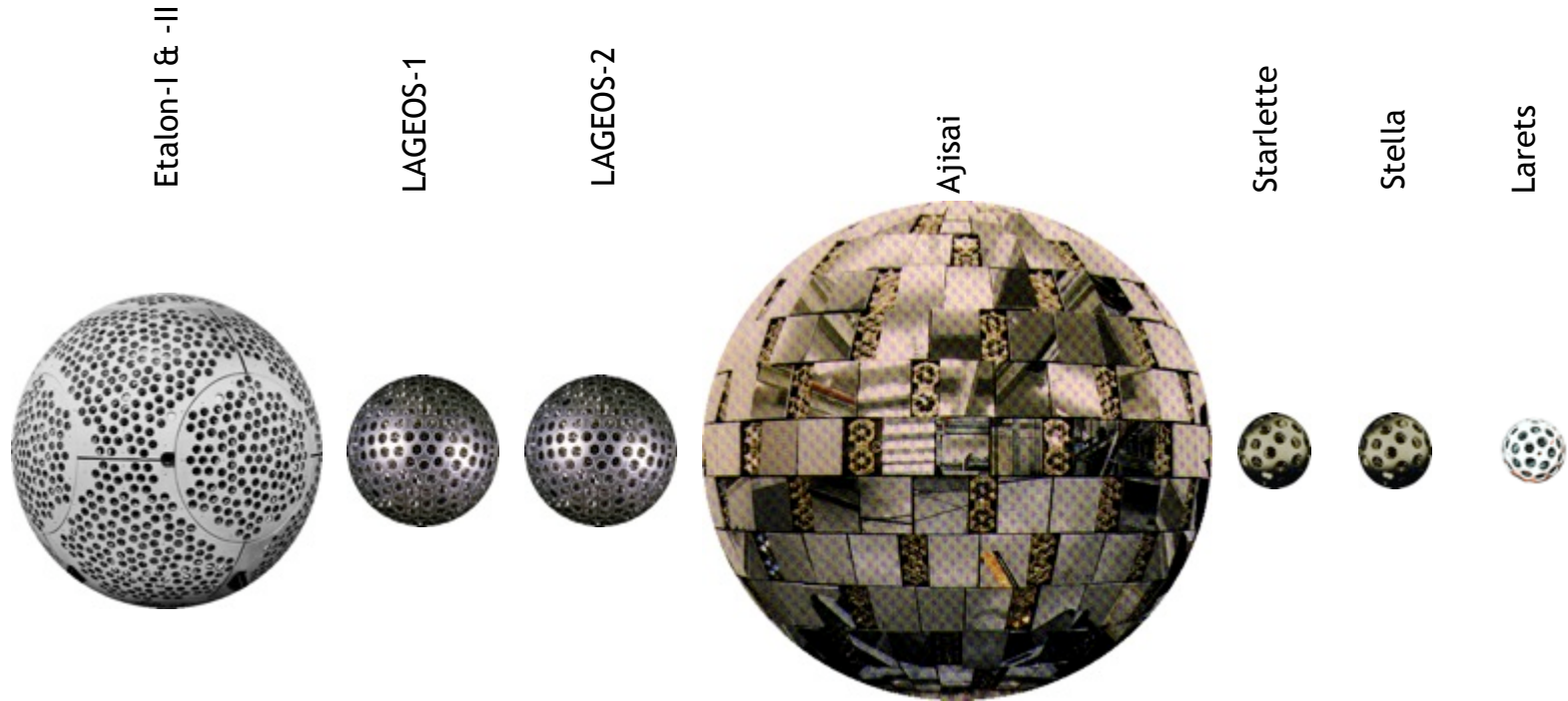
Selected SLR Stations Around the World

Missions supported by the ILRS

# Sample of SLR Satellite Constellation
(Geodetic Satellites)

	Etalon-I & -II	LAGEOS-1	LAGEOS-2	Ajisai	Starlette	Stella	Larets
Inclination	64.8°	109.8°	52.6°	50°	50°	98.6°	98.2°
Perigee ht. (km)	19,120	5,860	5,620	1,490	810	800	691
Diameter (cm)	129.4	60	60	215	24	24	20
Mass (kg)	1415	407	405.4	685	47.3	47.3	23.3

The Geodetic Reference Frame Requirement

Measurement of sea level
change is one of the
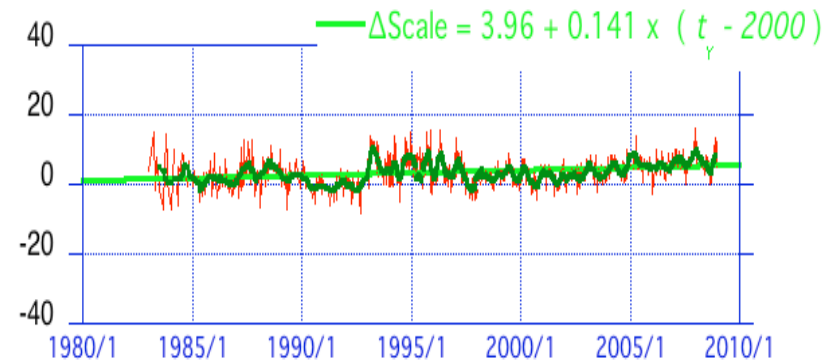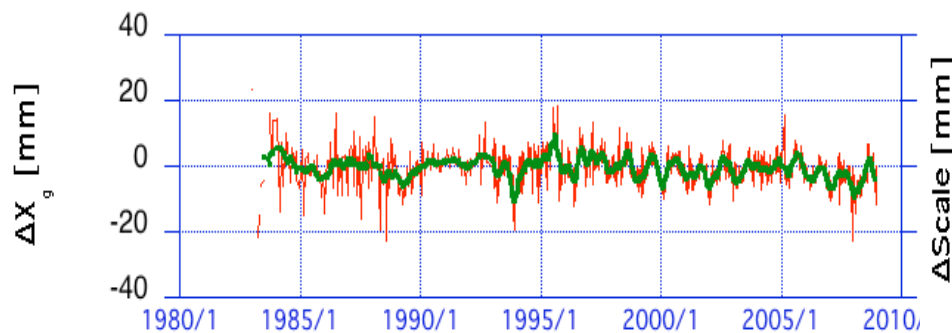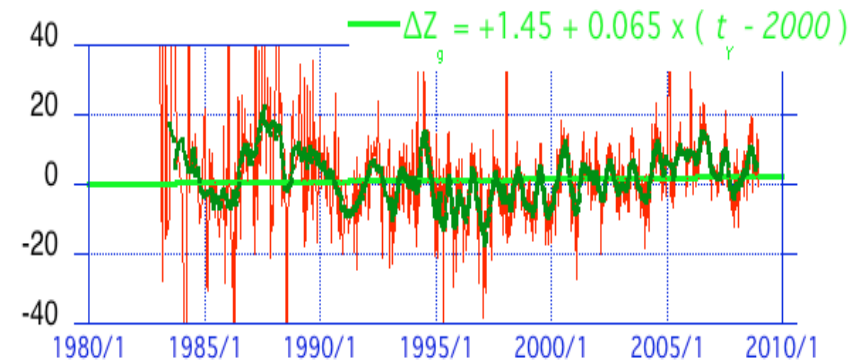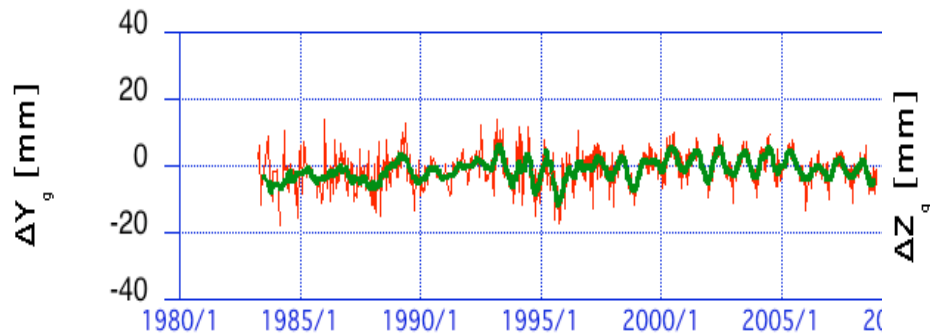primary science drivers
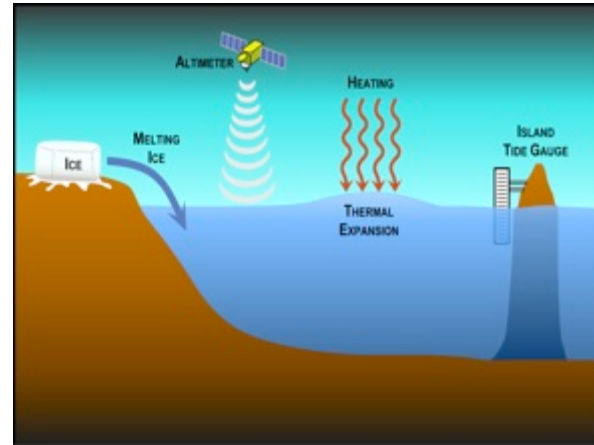
<1 mm reference frame accuracy

< 0.1 mm/yr stability

i.e. a factor of 10-20 improvement over current ITRF performance as
demonstrated by SLR results for ITRF2008 Origin and Scale variations:
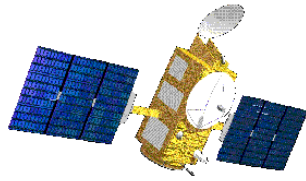
ITRF2008 Origin and Scale Variations from SLR

$$\Delta Z_g = +1.45 + 0.065 \times (t_Y - 2000)$$
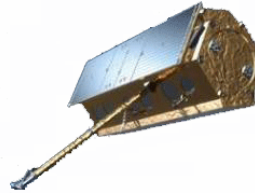
$$\Delta Scale = 3.96 + 0.141 \times (t_Y - 2000)$$

Sample of SLR Satellite Constellation
(Support for Precise Orbit Determination)

	Jason-2	**Terra-SAR-X/ TanDEM-X**	**ERS-2**
Inclination	66°	97.4°	98.5°
Perigee ht. (km)	1,336	514	785
Mass (kg)	300	1,230	2,516
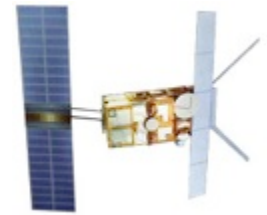
	GOCE	**GRACE**	**Envisat**
Inclination	96.7°	89°	98.5°
Perigee ht. (km)	295	450	796
Mass (kg)	1050	432/sat.	8,211

6/15/11

12
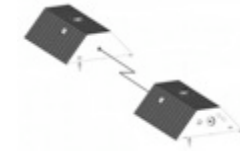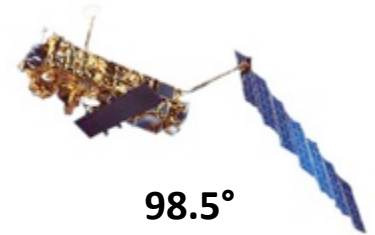
Growing Need for SLR measurements on the GNSS Constellations

- **Geoscience**
  - Improve the Terrestrial Reference Frame (colocation in space)

  - Improve LEO POD via GNSS tracking of SLR-calibrated GNSS orbits
    - 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
- **GNSS Support** is set to become more demanding, with GALILEO, GPS...

GNSS Satellite Constellation
(High Earth Orbit)
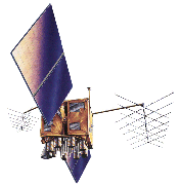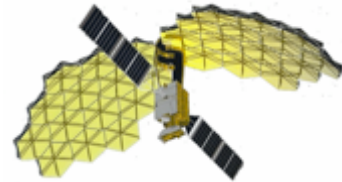

	GLONASS	GPS	COMPASS	GIOVE	ETS-8
Inclination	65°	64.8°	55.5°	56°	0°
Perigee ht. (km)	19,140	20,195	21,500	23,920	36,000
Mass (kg)	1,400	930	2,200	600	2,800
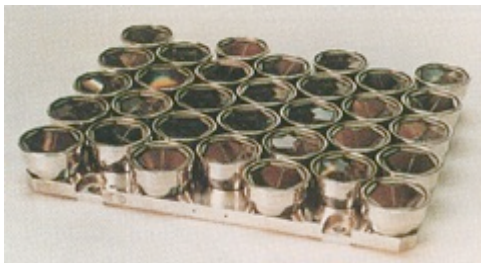
GNSS laser ranging

- Particularly challenging for stations because of distance:
  - Up to 24,000 km for GIOVE/ GALILEO
- Imperative that laser reflector arrays have sufficient radar cross-section to support day/ night ranging
- ILRS recommendation to LRA industry:100×10^6 m^2
- Collaboration with array Test Facility in Frascati
  - Potential for development of novel arrays

What technology/modelling developments are on-going within the current ILRS Network

- To address this need for improvement and to expand the technique into new applications:

- 2 kHz operation:
    - to increase data yield and hence normal-point precision
    - improve efficiency of satellite interleaving
    - new science from attitude-monitoring
- Eye-safe operations and auto tracking
- Automation (unattended operation)
- Event timers with near-pico-sec resolution
- Evaluation of hardware-induced observational error
- Improved modelling of satellite mass-centre corrections
- **Some examples**:

High repetition-rate, automation
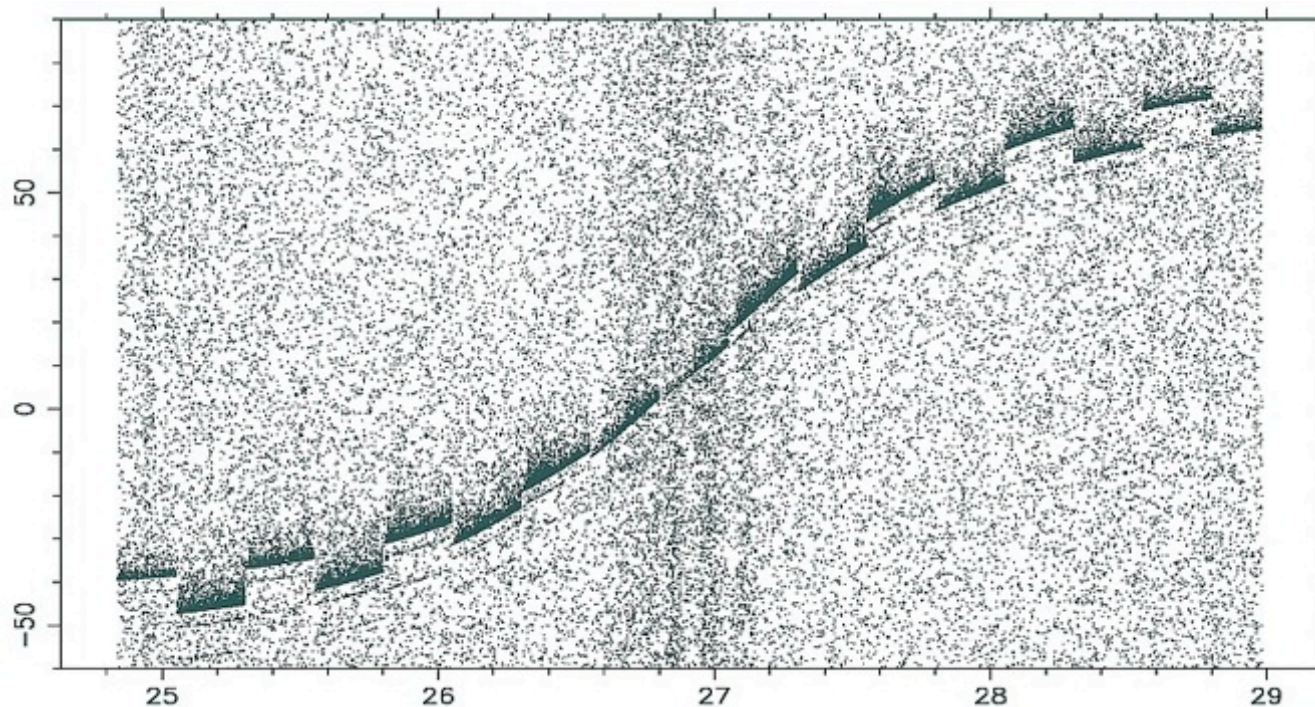

- Prototype Automated SLR System at NASA Goddard Space Flight Center;

- some other ILRS stations have upgraded to kHz repetition rates:

- Improved ranging precision through need to upgrade event timers

- Other benefits:

Experiment to obtain 1mm precision per NP

Observing on April 14th with kHz
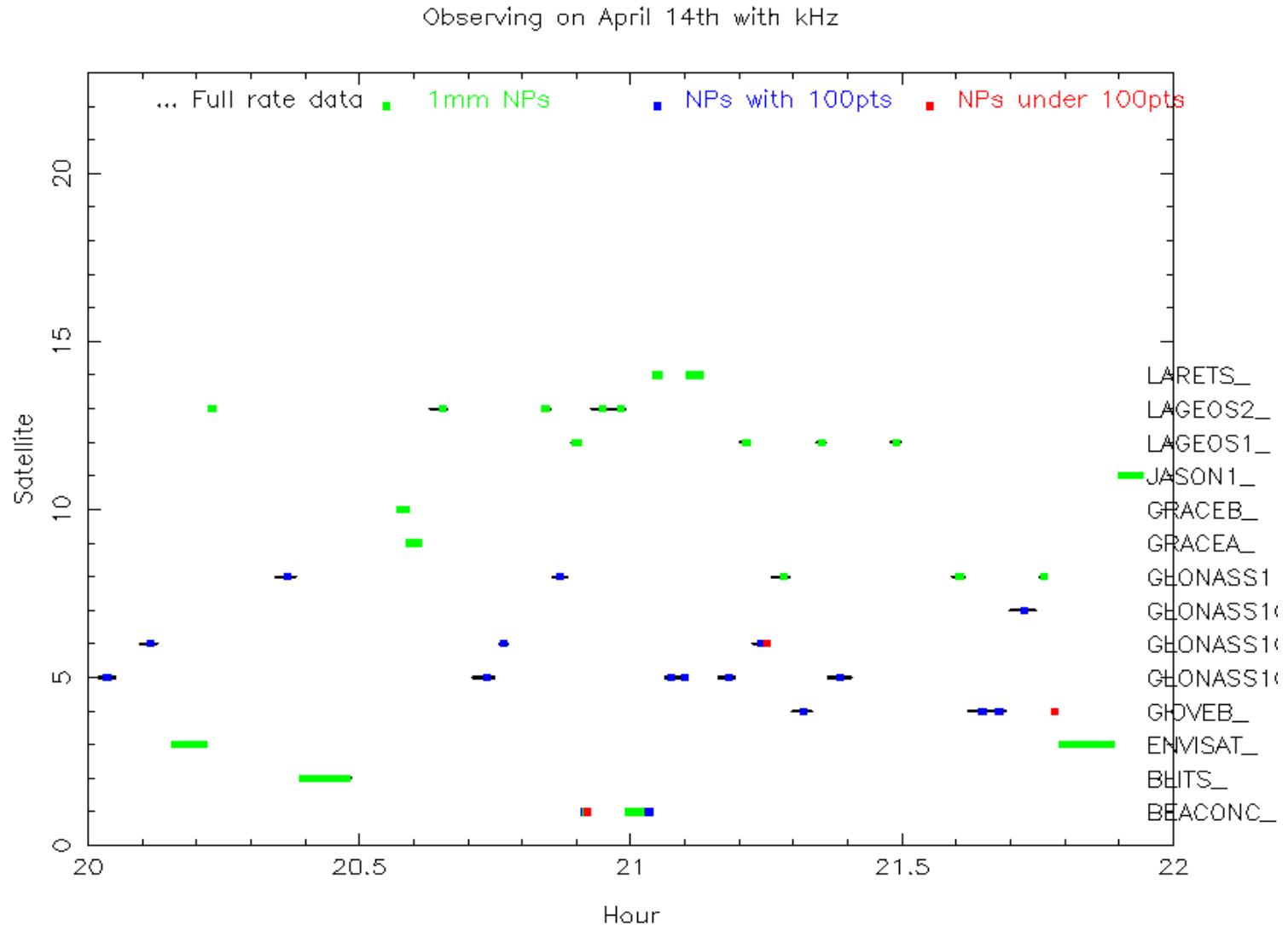
Very rapid switching between TanDEM-X and TerraSAR-X

Ranging accuracy

- Even more important than rapid acquisition and pass-interleaving is range accuracy, especially for the geodetic satellites;

- Dependent upon:
  - Ranging system technology – time of flight measurement, laser pulse-length
  - Accuracy of survey to calibration board
  - Ability to model accurately the **centre-of-mass** corrections for a non-homogeneous network:

Range data quality assessment by ILRS - single-shot precision

LAGEOS RMS
from July 1, 2010 through September 30, 2010
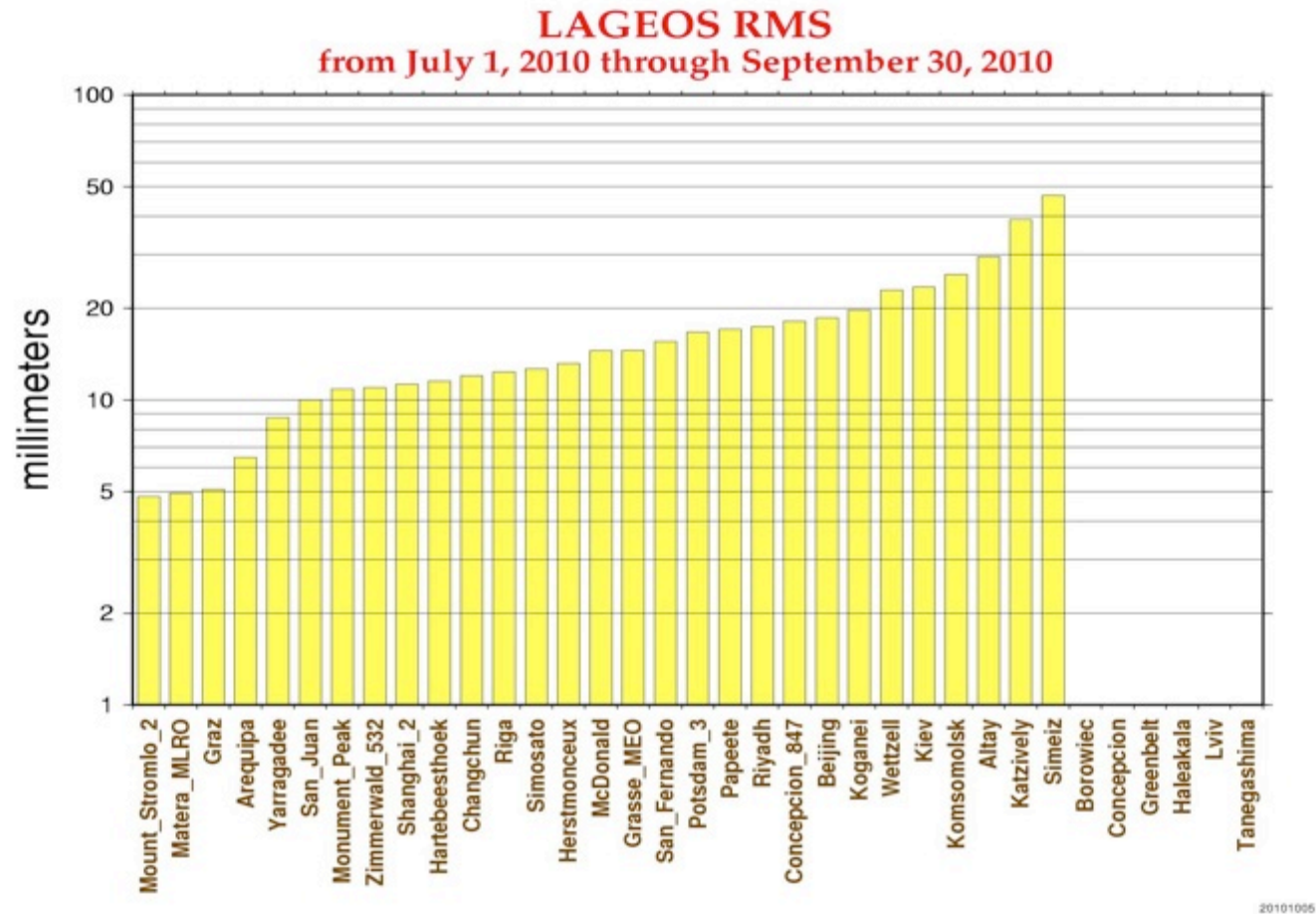
Magnitude of CoM effect
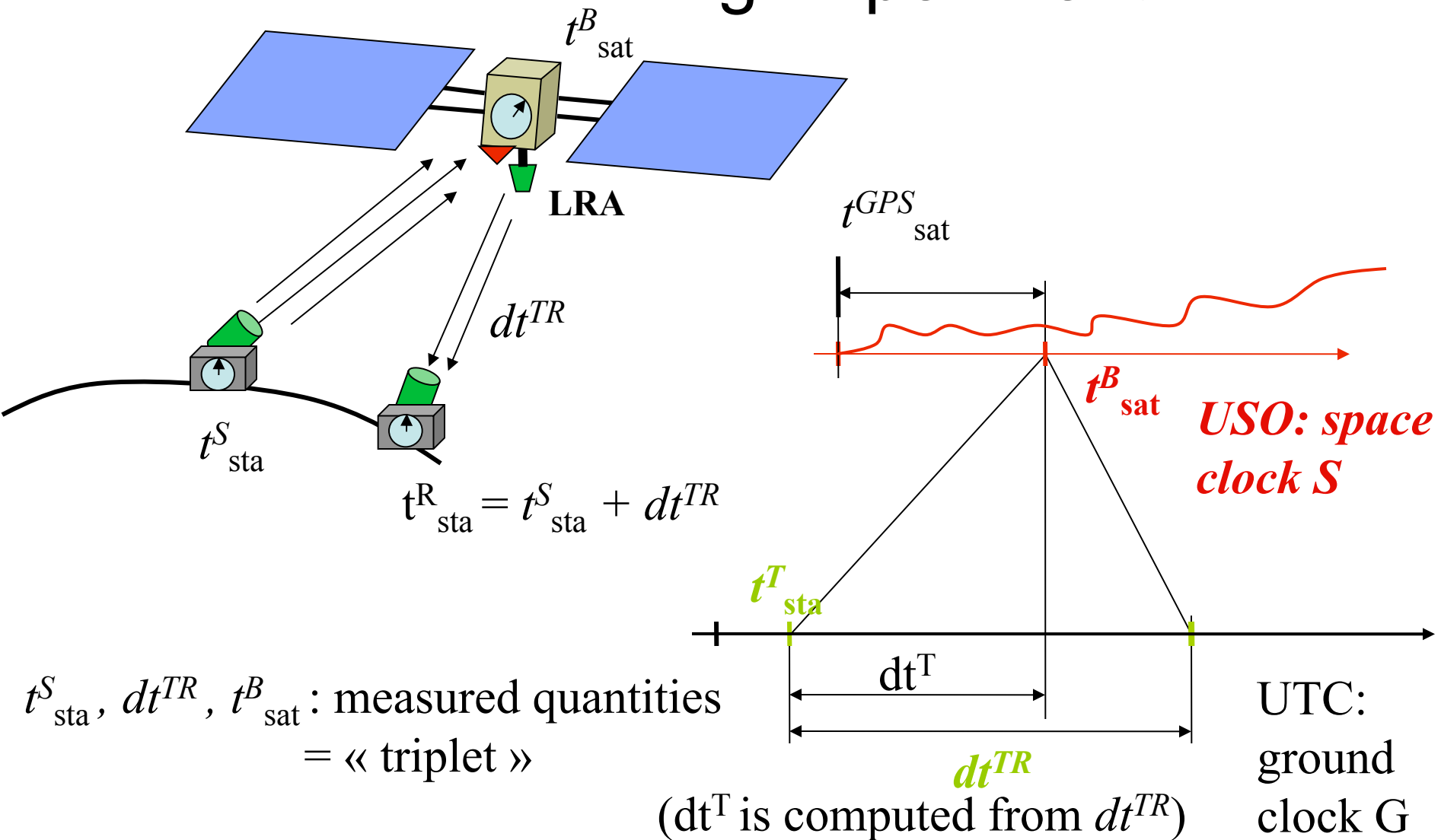
- Depending upon the stations' technology, there is a range of appropriate CoM values;

- For LAGEOS the total range is **~6mm**

- For ETALON the total range is **~5cm**

- Note that station technology is also **time-dependent**

- We have developed a table of CoM corrections
  - station- and time-dependent.

- Will be tested and used in next re-analysis.

New applications

- Especially for the more versatile SLR stations, a number of novel missions:

- Time Transfer by Laser Link (T2L2, CNES)
- Lunar Reconnaissance Orbiter (LRO, NASA)

  – Stations with high-accuracy clocks and frequency standards (H-maser) particularly valuable to the missions

T2L2 Timing Experiment

t^B_{sat}

LRA

dt^{TR}

t^S_{sta}

$\text{t}^R_{sta} = t^S_{sta} + dt^{TR}$

t^{GPS}_{sat}

t^B_{sat}

USO: space clock S

t^T_{sta}

dt^T

dt^{TR}

UTC: ground clock G

t^S_{sta} , dt^{TR} , t^B_{sat} : measured quantities = « triplet »

(dt^T is computed from dt^{TR})

$$X_A = (t_S + t_R)/2 - t_B + \tau_{Relativity} + \tau_{Atmosphere} + \tau_{Instrument}$$

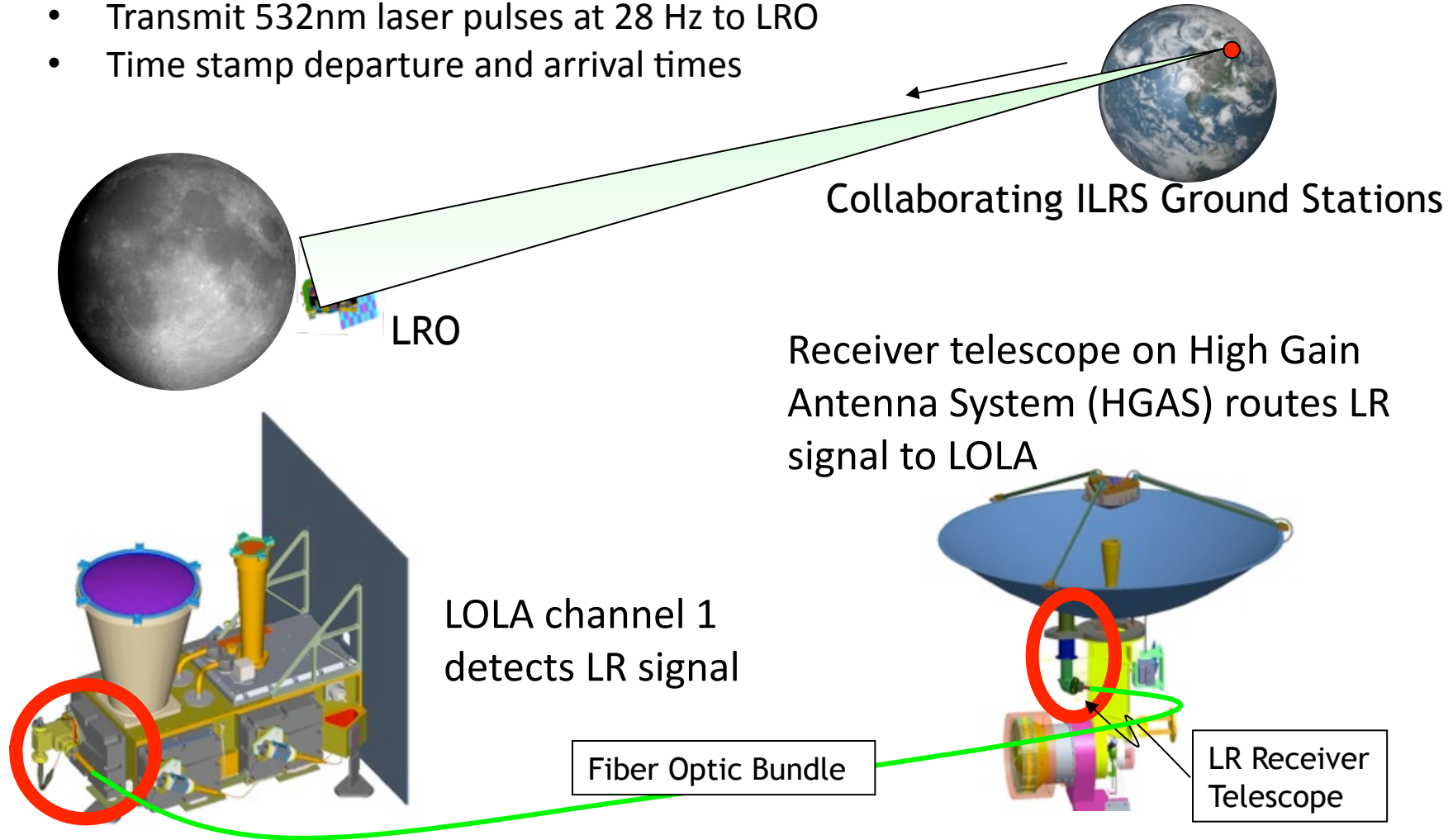# Two-station time-transfer at ~200ps level of precision.

Date : 20101119   Station #1 : 7845   Station #2 : 7840. 5-minute common data
(Samain, *et al*. CNES, OCA)
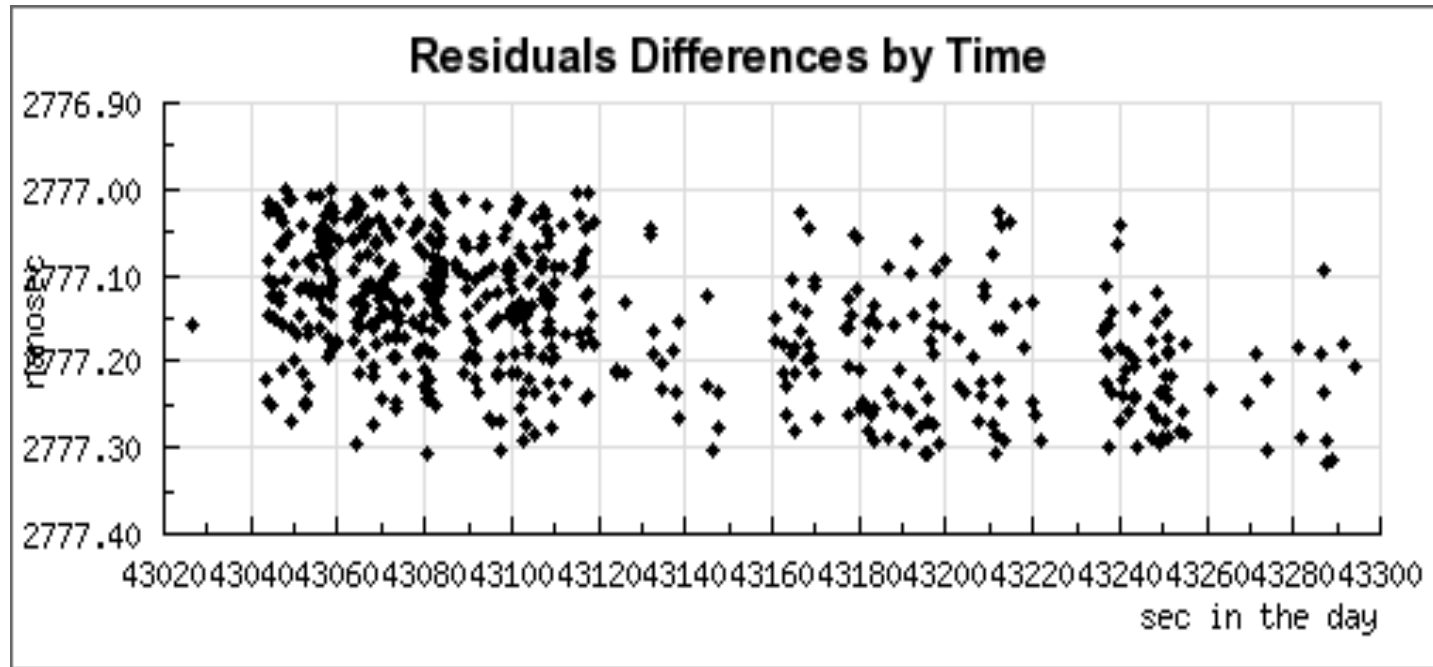
LRO Laser Ranging

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

Collaborating ILRS Ground Stations

LRO

Receiver telescope on High Gain Antenna System (HGAS) routes LR signal to LOLA

LOLA channel 1 detects LR signal

Fiber Optic Bundle

LR Receiver Telescope

LRO Ranging progress

- Some 750 hours of 'ranging' from up to seven ILRS stations

- Recently a number of simultaneous tracking sessions by 2 and 3 stations:
  - NGSLR, McDonald and Monument Peak

- Agreements between the stations and NASA being extended for further two years

LRO Ranging: 3-station simultaneous tracking in LRO range window

Events in Earth Window
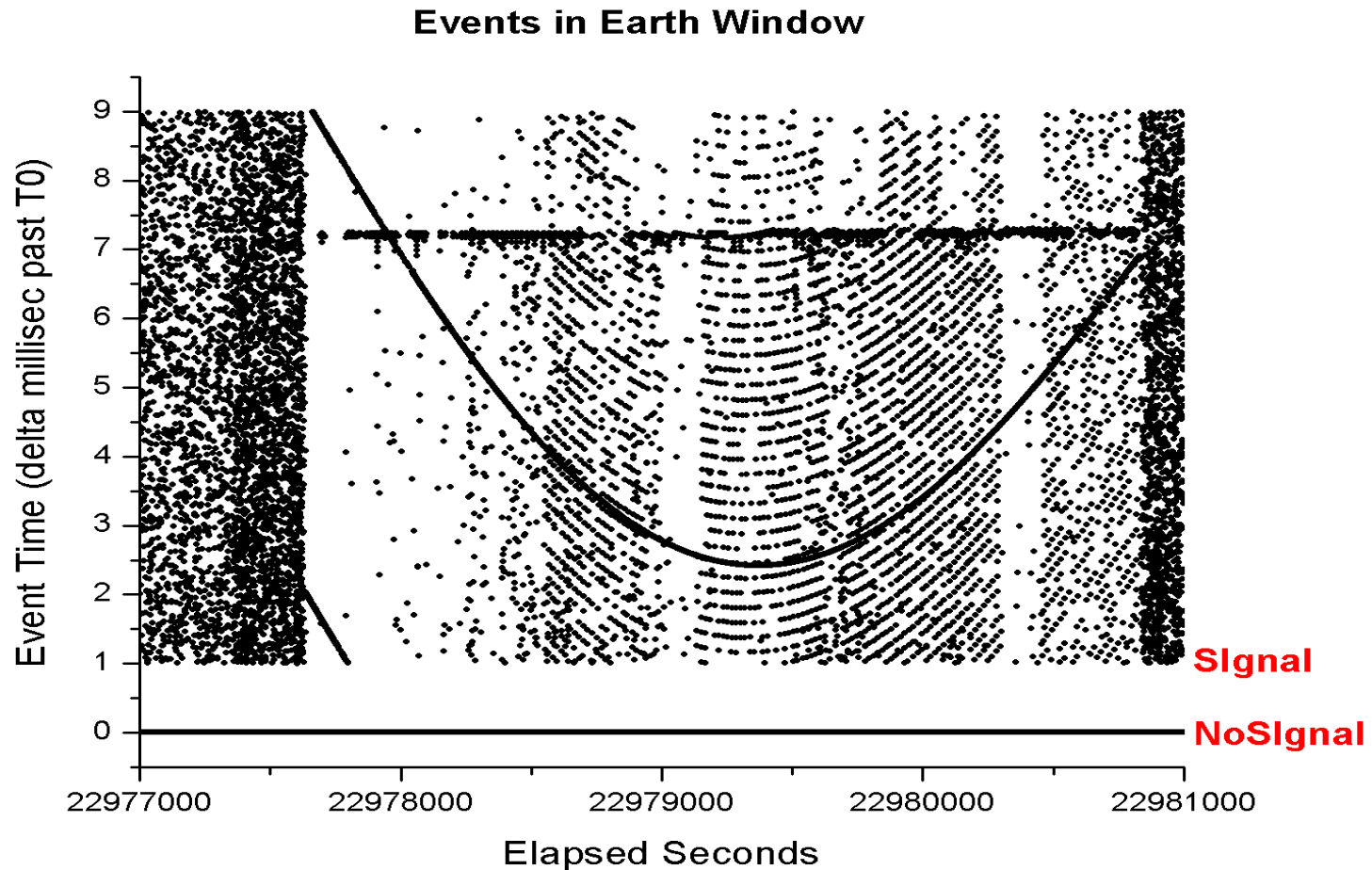
Summary

- ILRS organisationally effective
- Open to new challenges and missions:
    - Continuing need to improve data quality;
    - Upgrade ageing systems;
    - Improve geographic distribution
    - Effective support for transponder missions
        - T2L2, LRO, future Mars/Phobos/Deimos probe
- Improving Lunar Ranging capability, but yet to become routine for stations