Satellite Laser Ranging
and Rules of the Road for the International Laser Ranging Service

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

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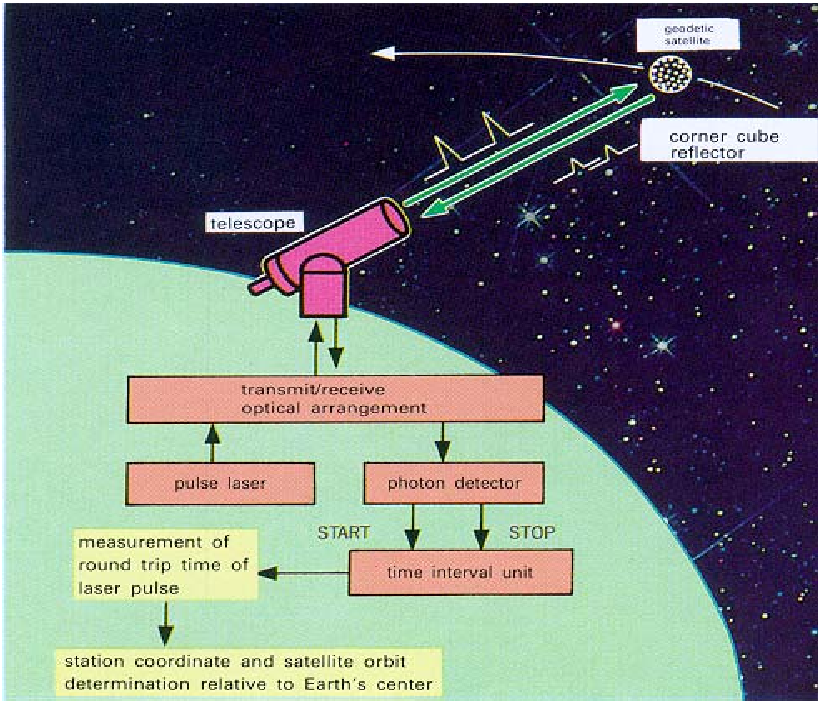
Satellite Laser Ranging Technique

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
- 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

International Laser Ranging Service

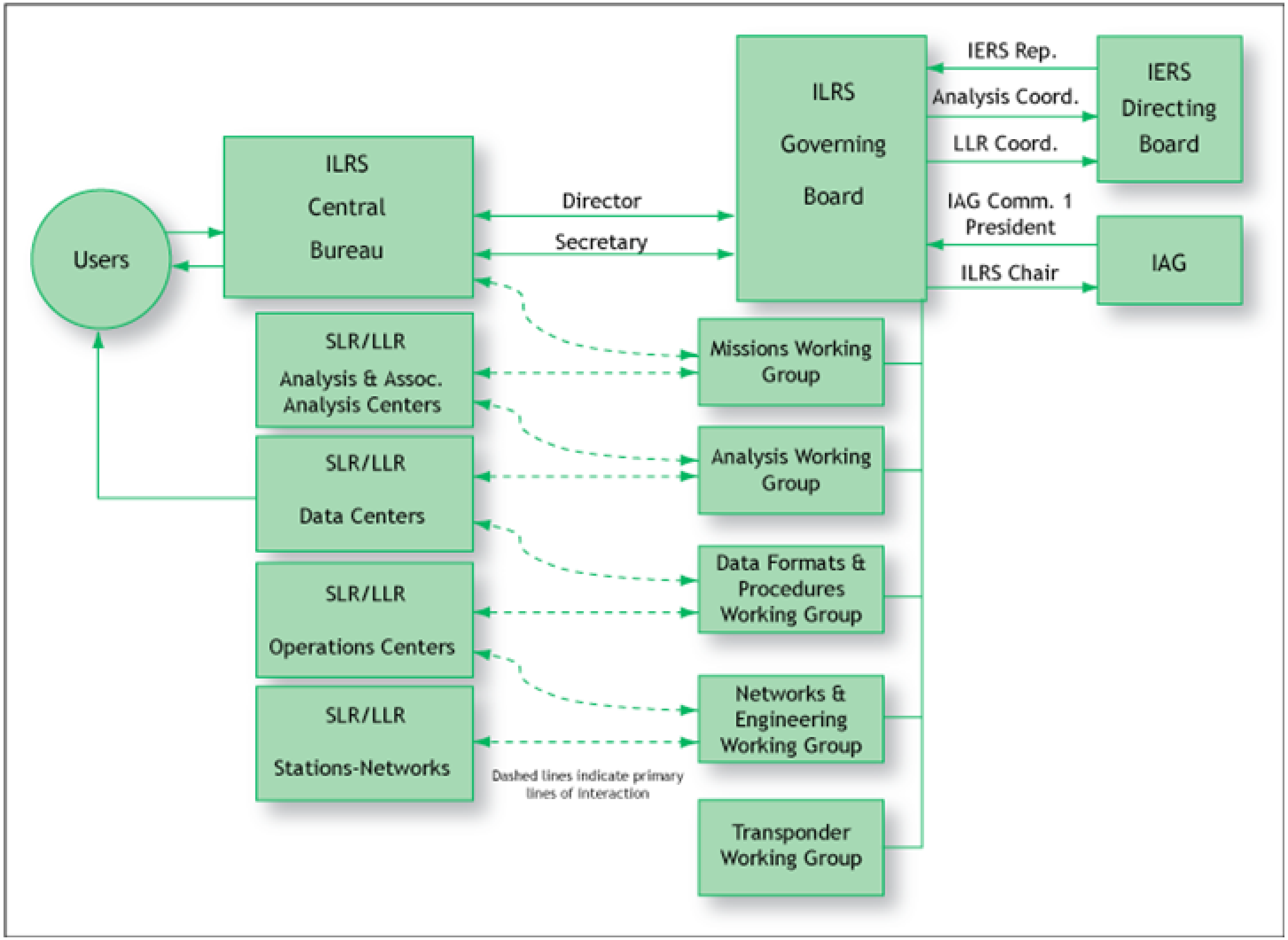
SLR Science and Applications

- 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
- Four Missions Rescued in the Last Decade

International Laser Ranging Service (ILRS)

- Established in 1998 as a service under the International Association of Geodesy (IAG)
- ILRS collects, merges, analyzes, archives and distributes satellite and lunar laser ranging data to satisfy a variety of scientific, engineering, and operational needs and encourages the application of new technologies to enhance the quality, quantity, and cost effectiveness of its data products
- Components
  - Tracking Stations and Subnetworks
  - Operations Centers
  - Global and Regional Data Centers
  - Analysis and Associate Analysis Centers
  - Central Bureau
- ILRS produces standard products for the scientific and applications communities
- ILRS includes 75 agencies in 26 countries

ILRS Organization



International Laser Ranging Service

Complex of Space Geodesy instruments

for development and maintenance of the reference frame

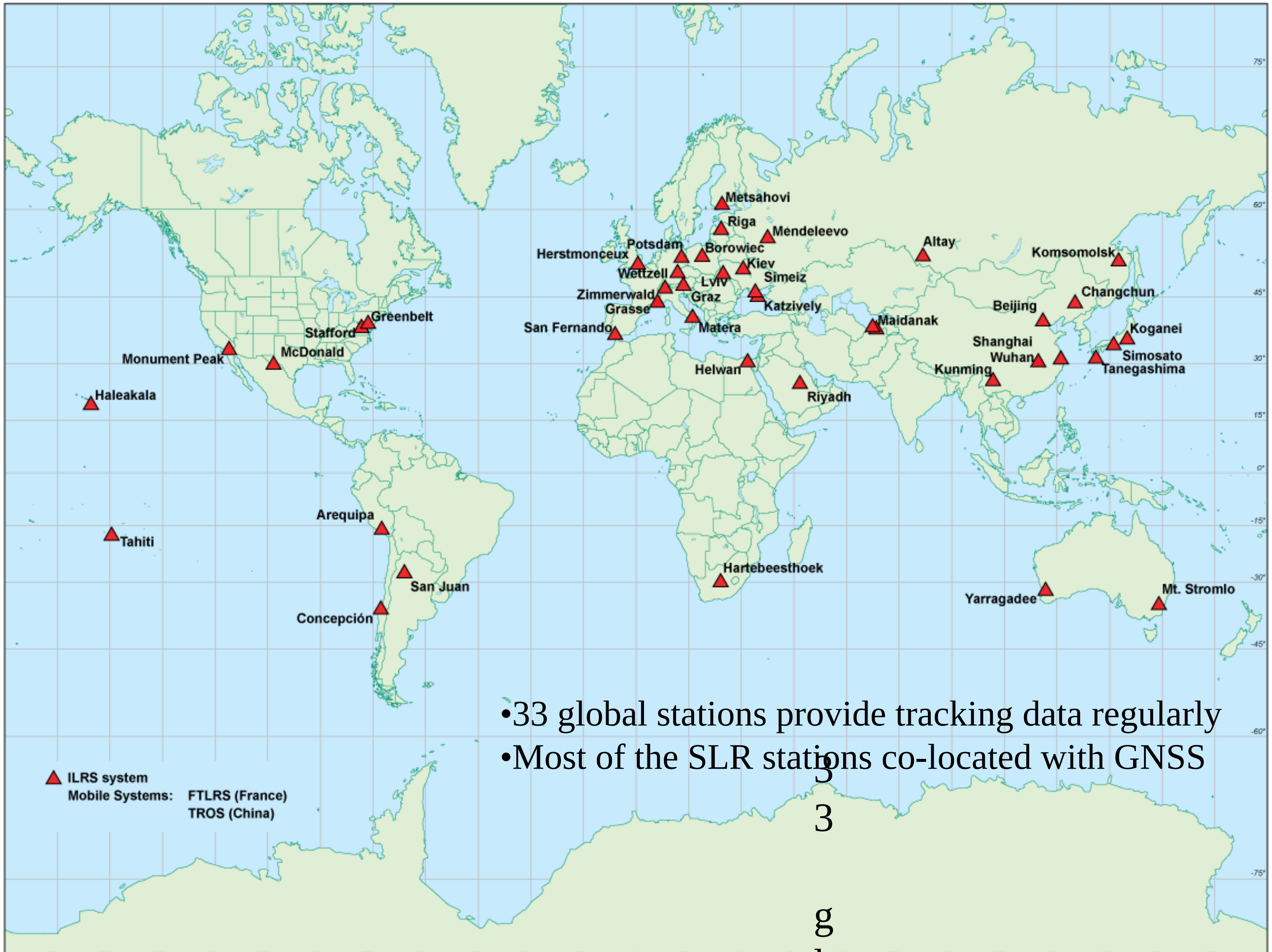
SLR/LLR

VLBI

GPS

DORIS

ILRS Network

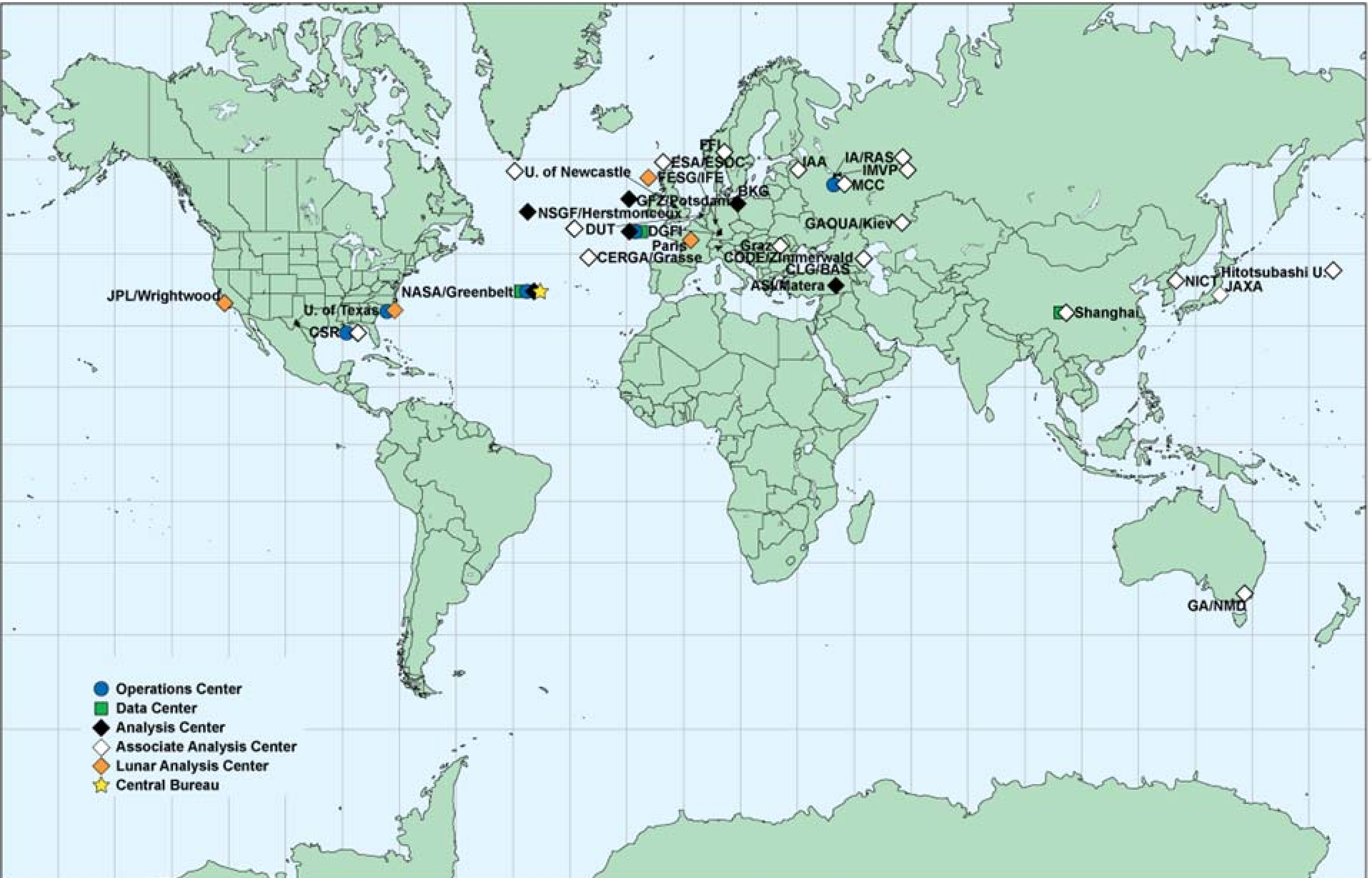


- 33 global stations provide tracking data regularly
- Most of the SLR stations co-located with GNSS

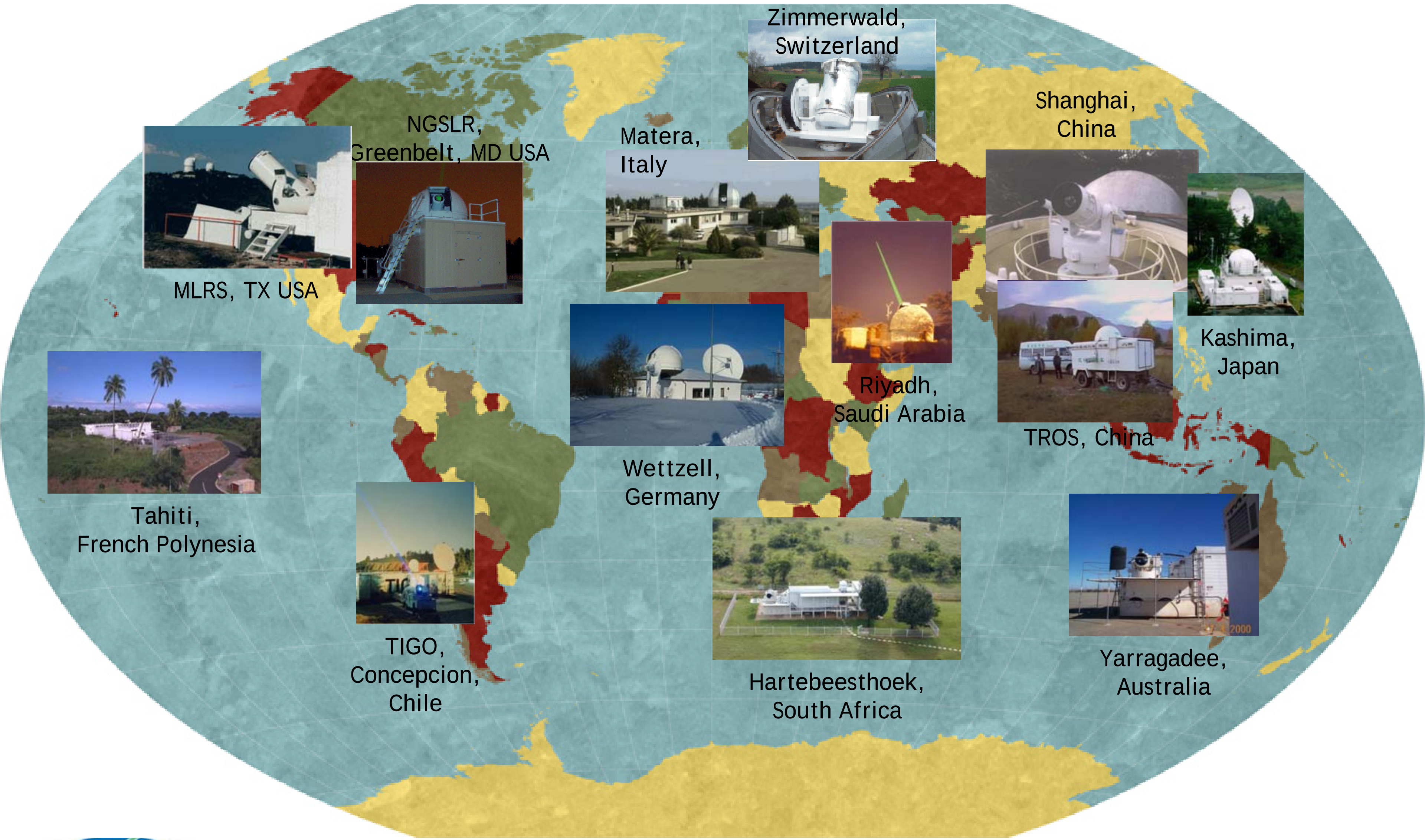
3
3

g
l
o
b

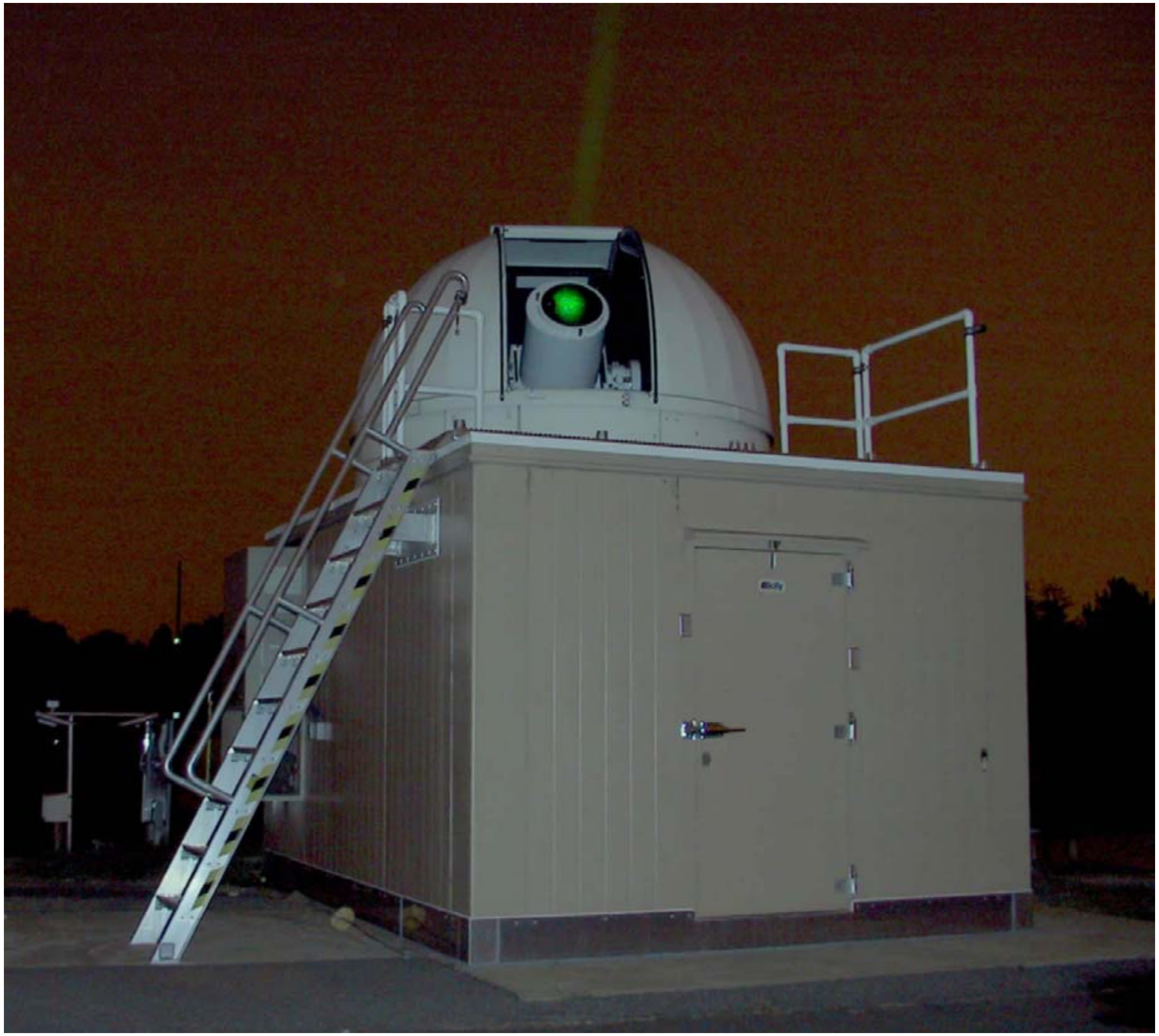
Other ILRS Components



Selected SLR Stations Around the World



NASA New Generation SLR System



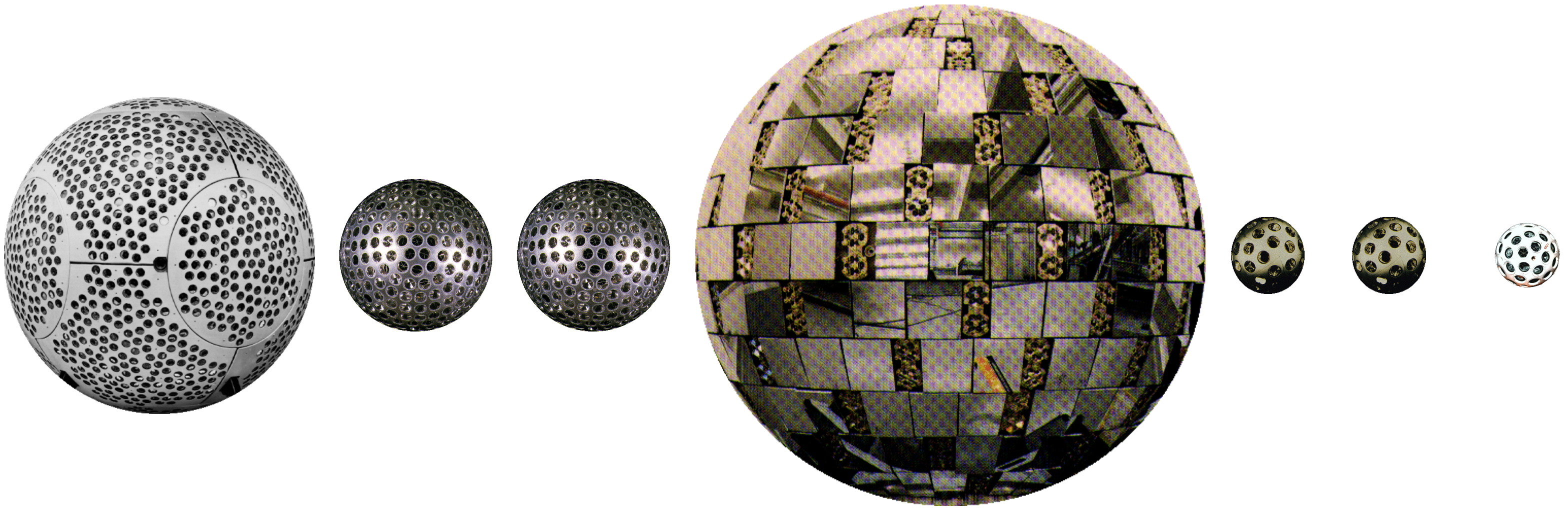
NASA's Next Generation SLR (NGSLR), GGAO, Greenbelt, MD

Technology Developments

- 2 kHz operation to increase data yield and improve interleaving
- Eye-safe operations and auto tracking
- Automation (unattended operation)
- Event timers with near-ps resolution
- Web-based restricted tracking to protect optically vulnerable satellites (ICESat, ALOS, etc.)
- Two wavelength experiments to test refraction models
- Experiments continue to demonstrate optical transponders for interplanetary ranging
  - Transponder experiment to Messenger (24.3 million km) was a two-way demonstration that resulted in a range precision of less than 20 cm.
  - Mars Global Surveyor MOLA experiment (over 80 million km link) was a one-way demonstration due to an inoperative laser at Mars.

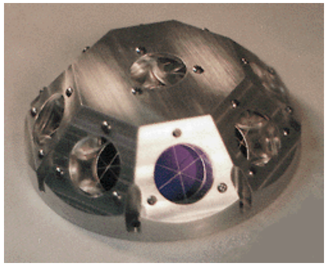
Sample of SLR Satellite Constellation

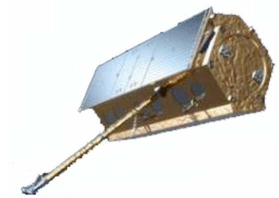
(Geodetic Satellites)

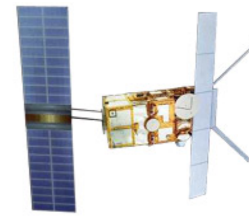


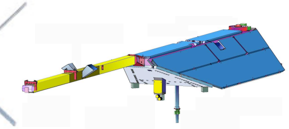
	Etalon-I & -II	LAGEOS-1	LAGEOS-2	Ajisai	Starlette	Stella	GFZ-1
Inclination	64.8°	109.8°	52.6°	50°	50°	98.6°	51.6°
Perigee ht. (km)	19,120	5,860	5,620	1,490	810	800	396
Diameter (cm)	129.4	60	60	215	24	24	20
Mass (kg)	1415	407	405.4	685	47.3	47.3	20.6

Sample of SLR Satellite Constellation

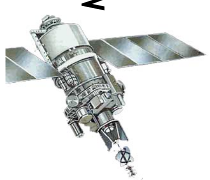


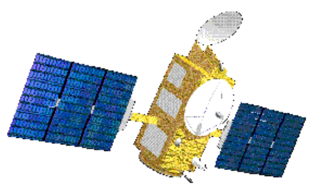


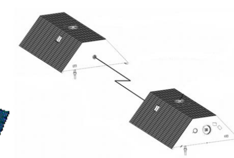


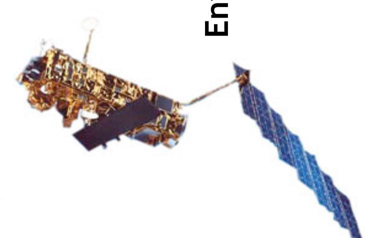


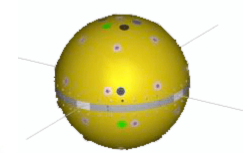
	GFO-1	ERS-1	Terra-SAR-X	ERS-2	CHAMP
Inclination	**108°**	**98.5°**	**97.4°**	**98.5°**	**87.27°**
Perigee ht. (km)	**800**	**780**	**514**	**785**	**474**
Mass (kg)	**300**	**2,400**	**1,230**	**2,516**	**400**





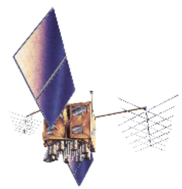
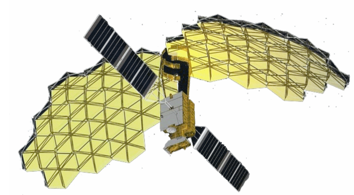


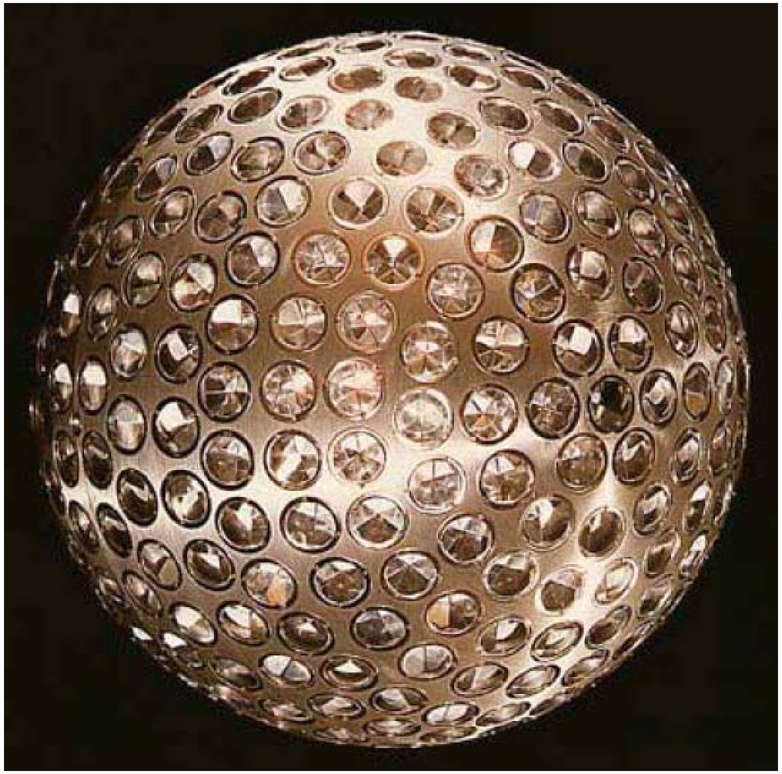




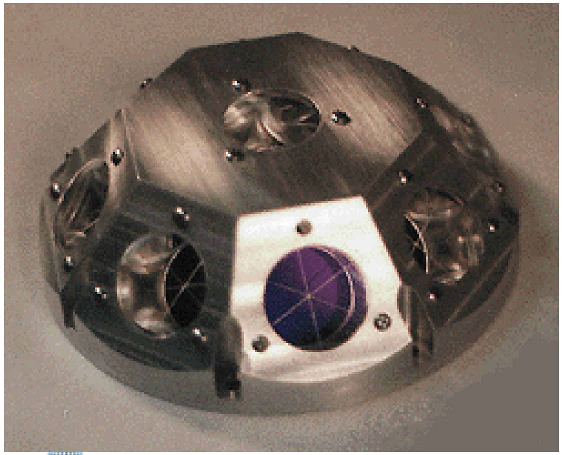
	Meteor-3M	Jason-1	GRACE	Envisat	ANDE-RR
Inclination	**99.64°**	**66°**	**89°**	**98.5°**	**51.6°**
Perigee ht. (km)	**1,012**	**1,336**	**450**	**796**	**250**
Mass (kg)	**2.477**	**500**	**432/sat.**	**8,211**	**50**

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



LAGEOS



Jason-2

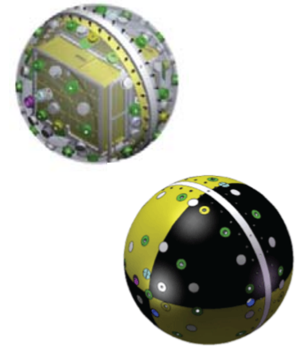
International Laser Ranging Service

Missions for 2009

SOHLA
JAXA/Japan
January 2009

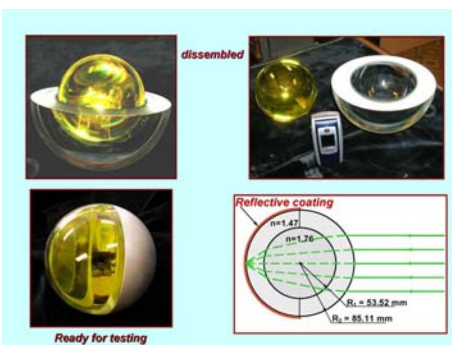
GOCE
ESA
March 2009

LRO
NASA/USA
April 2009

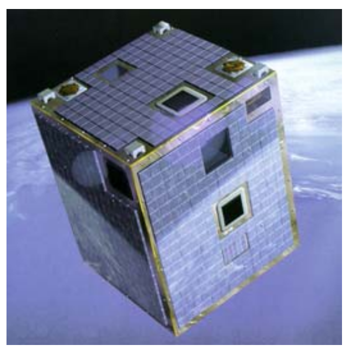


ANDE
NRL/USA
June 2009

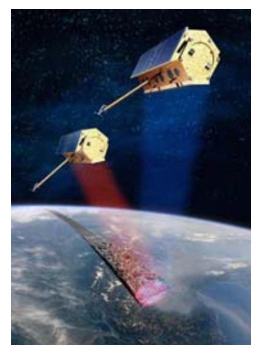
STSAT-2
KASI/Korea
Mid-2009



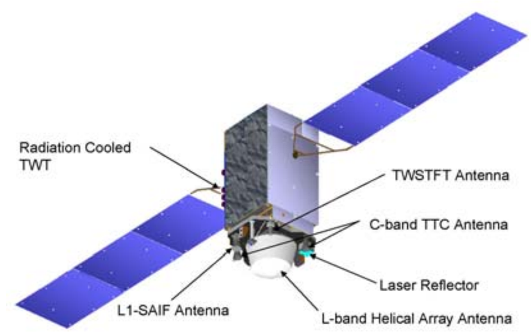
BLITS
IPIE/Russia
June 2009



PROBA-2
ESA
Mid-2009



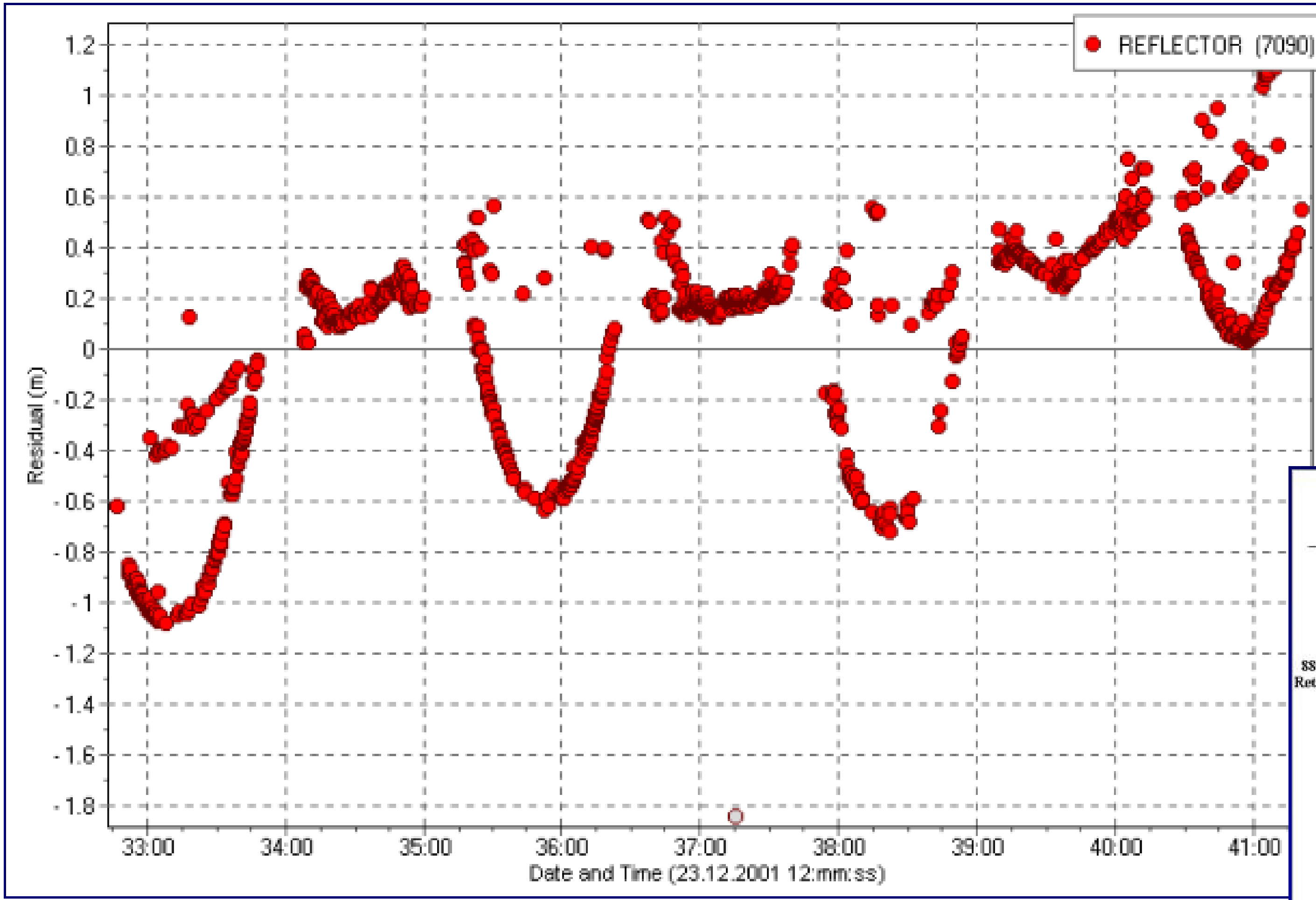
TanDEM-X
DLR, GFZ/Germany
2009

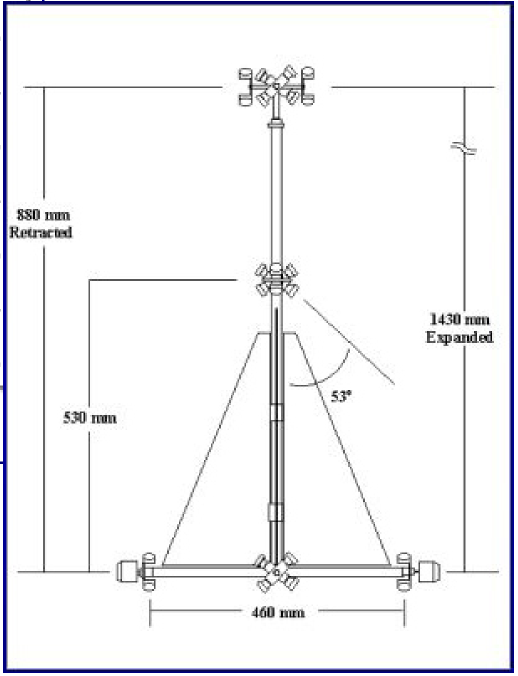


QZS-1
JAXA/Japan
2009

International Laser Ranging Service

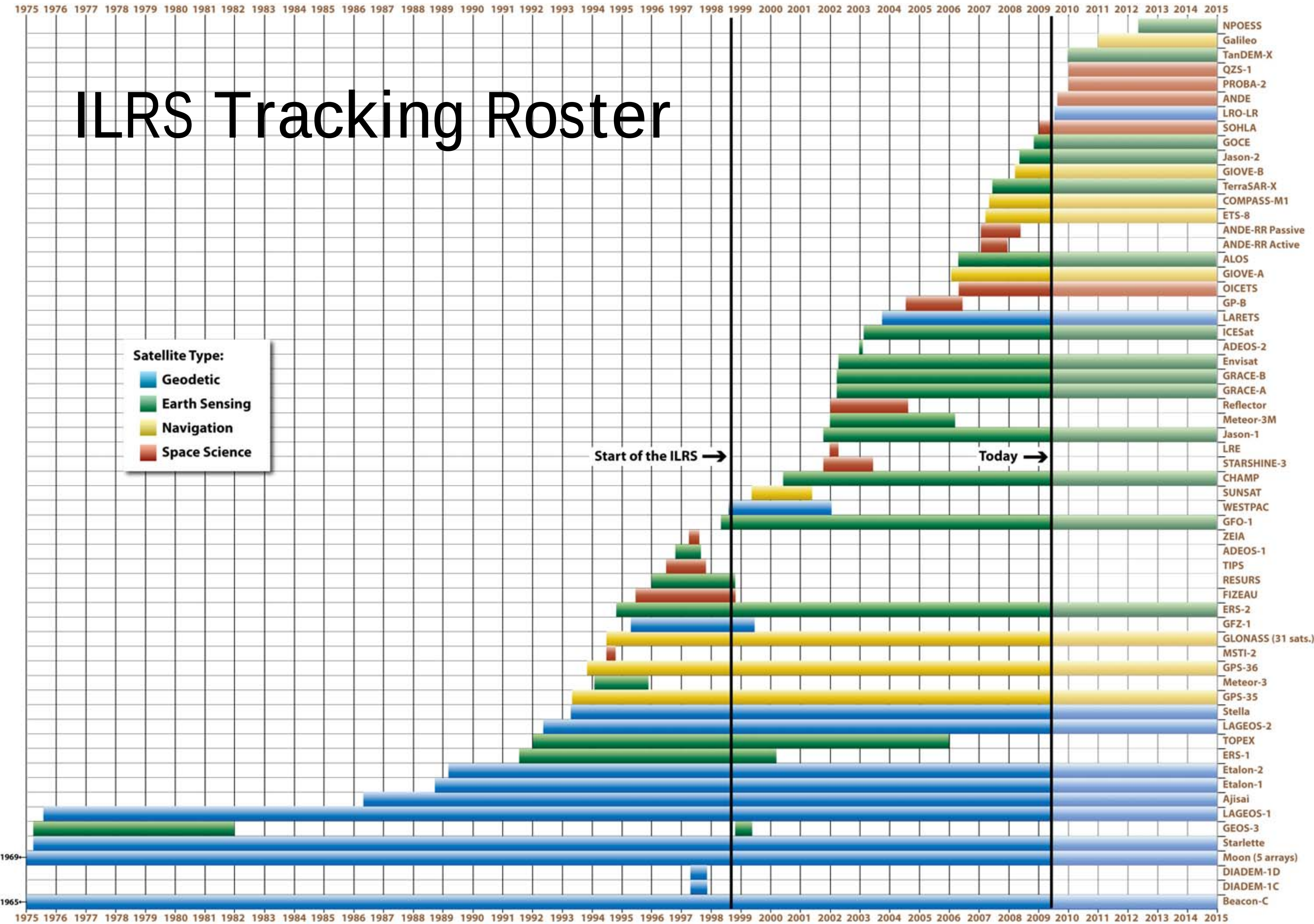
Reflector Satellite





International Laser Ranging Service

ILRS Tracking Roster



Mission Requirements

- Submit Mission Support Request Form;
- Approval from the Missions Working Group and the Governing Board
  - Science and technology available to the community
  - Tracking requirements and practicality
- Regular updates through launch and insertion
- Predictions in ILRS format
- In orbit updates
- Periodic reports on mission status and progress, data requirements, and data fulfillment

Station Requirements

- Submit Site and System Information Form (Station characteristics)
- Approved by the Governing Board
- Format compatibility
- Inform the ILRS of programmed station downtime and station modifications and configuration changes
- Proper site survey
- Requirements for Operational Status (Data volume, accuracy, latency, etc.)
- Participation in ILRS activities – Biannual Report, Workshops, etc.

International Laser Ranging Service

Aircraft Safety

- Radars
- Link to Air Traffic Control
- Visual spotters
- Optical detection systems
- Eye-safe laser systems
- Low energy – high repetition rate laser

ILRS Restricted Tracking

ILRS authorization to track ILRS-approved satellites is constituted and governed by an approved Mission Support Request Form;

All SLR stations within the International Laser Ranging Service agree to adhere to any applicable ILRS Restricted Tracking Procedures including:

- station by station authorization;
- time and viewing angle constraints;
- energy/power constraints;
- go/no-go switch.

International Laser Ranging Service

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**

International Laser Ranging Service

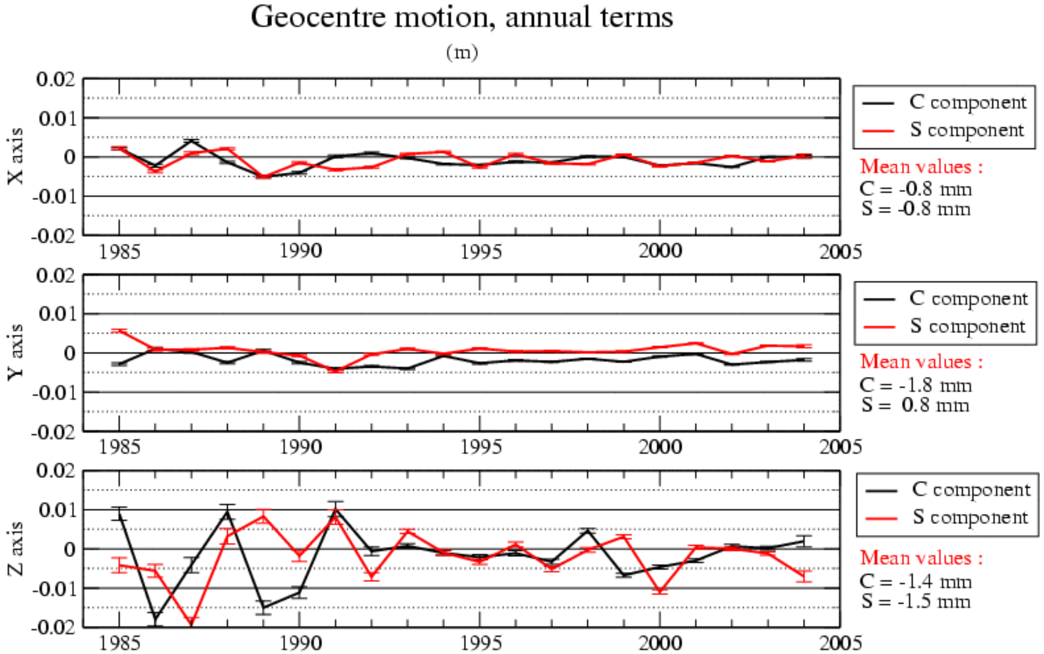
Current SLR Ranging to GNSS Satellites

- **Operations include 8 GNSS satellites**

  (GPS 35 and 36; GLONASS 102, 109 and 115; GIOVE – A and – B; and *COMPASS)*
- **Satellite priorities set according to satellite altitude;**
- **Track 5 minute segments at various points along the pass;**
- **Data transmitted after each pass;**
- **The data is available on the website within an hour or two;**
- **Plenty of spare SLR tracking capacity**

International Laser Ranging Service

Geocenter Motion



Mean annual terms amount to :

1.2 mm in X, with a minimum in February
2.0 mm in Y, with a minimum in December
1.8 mm in Z, with a minimum in February

corresponding to a winter loading centred on Siberia

- mm-level Geodesy requires understanding of the reference frame and its distortions to acute levels of precision.
- Shown here is the change in the origin of the crust-fixed frame w.r.t. the center of mass due to non tidal mass transport in the atmospheric and hydrospheric systems.

International Laser Ranging Service

One-Way Earth-to-Mars Transponder Experiment
(September 2005)

80 Million Km!

~500 laser pulses observed at Mars!

GSFC 1.2 Meter Telescope

Mars Orbiter Laser Altimeter (MOLA)

<u>Ground Station</u>

Xiaoli Sun   Jan McGarry
Tom Zagwodzki   John Degnan

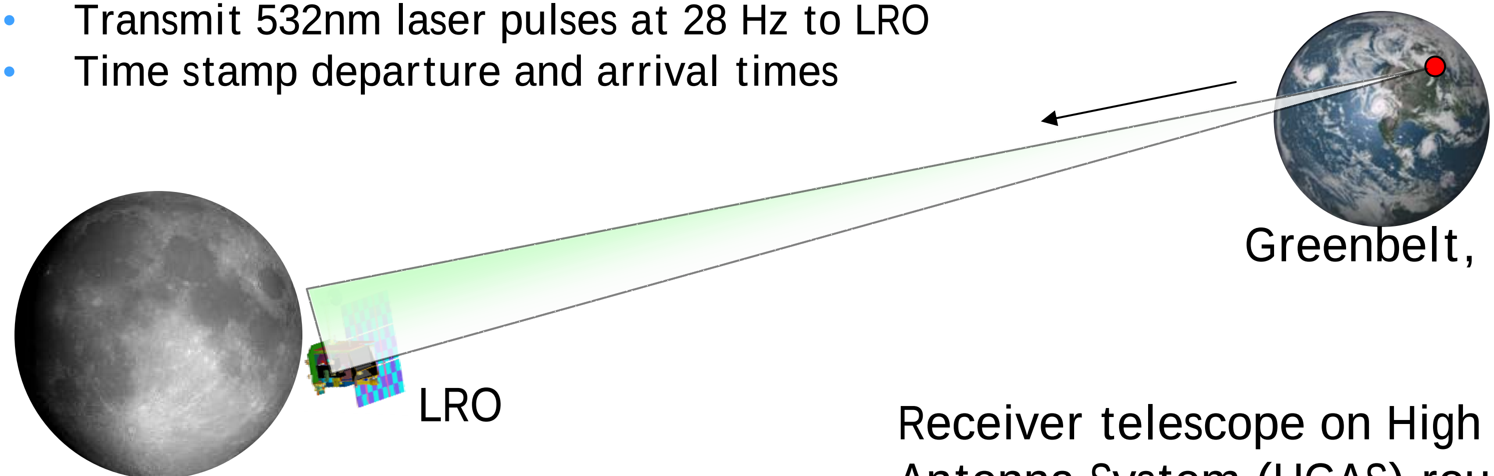
<u>Science/Analysis/Spacecraft</u>

David Smith   Maria Zuber
Greg Neumann   Jim Abshire

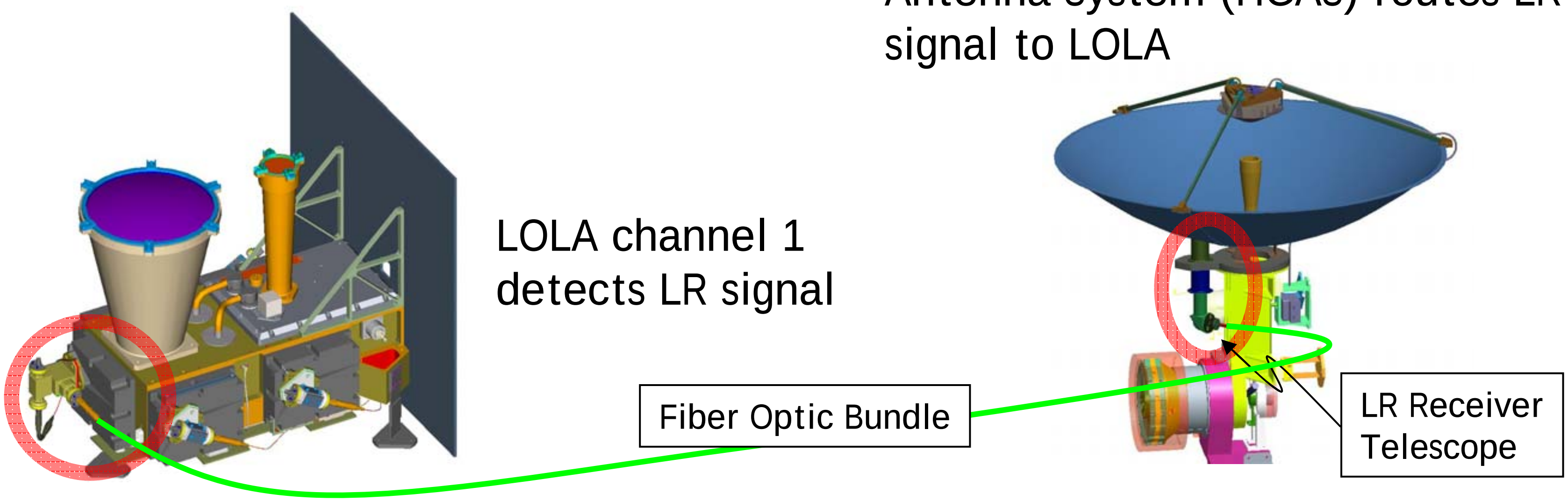
International Laser Ranging Service

LRO Laser Ranging

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



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



International Laser Ranging Service

Some Transponder Applications

- **Solar System Science**
  - Solar Physics: gravity field, internal mass distribution and rotation
  - Lunar ephemeredes and librations
  - Planetary ephemeredes
  - Mass distribution within the asteroid belt
- **General Relativity**
  - Tests of relativity and constraints on its metrics Precession of Mercury's perihelion
    - Constraints on the magnitude of G-dot (1×10^{-12} from LLR)
    - Gravitational and velocity effects on spacecraft clocks
    - Shapiro Time Delay
- **Lunar and Planetary Mission Operations**
  - Spacecraft ranging
  - Calibration/validation/backup for DSN microwave tracking
  - Subnanosecond transfer of GPS time to interplanetary spacecraft for improved synchronization of Earth/spacecraft operations
  - Independent self-locking beacon for collocated laser communications systems (e.g., NASA's Mars Laser Communications Demonstration)

International Laser Ranging Service

We invite you to visit our website @

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