International Technical Laser Workshop 2012 (ITLW-12)

"Satellite, Lunar and Planetary Laser Ranging: Characterizing the Space Segment"

(Monday, Tuesday, Thursday, and Friday)

in conjunction with the

Workshop on"ASI-INFN ETRUSCO-2 Project of Technological Development on SLR Payloads of GNSS

(Wednesday)

Frascati National Laboratories of the INFN-LNF, Frascati (Rome), Italy

Special Thanks

Local Organizing Committee (LOC)

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International Laser Ranging Service (ILRS)
http://ilrs.gsfc.nasa.gov/

- International organization (federation) that coordinates international laser ranging activities to satellites and the moon, and maybe beyond?
- Organized under the IAG
- Includes field stations, analysis centers, data centers, engineering centers, etc
- Sets standards, communications, data flow and services, etc.
- Includes ~ 35 ground stations not tracking ~ 45 satellites and increasing steadily!
- Satellites are added to the roster as new satellites and requirements are added, and satellites are deleted as programs come to an end

Global Geodetic Observing System (GGOS)

Established by the International Association of Geodesy to:

Provide the observations needed to monitor, map and understand changes in the Earth's shape, rotation and mass distribution.

Provide the global frame of reference that is the fundamental backbone for measuring and consistently interpreting key global change processes and for many other scientific and societal applications.

Benefit science and society by providing the foundation upon which advances in Earth and planetary system science and applications are built.

Special Welcome from: Dr.-Ing. Hansjoerg Kutterer/BKG
Chair of GGOS

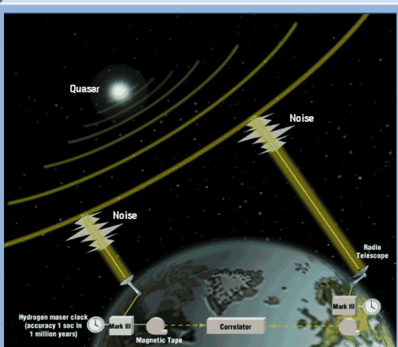
GGOS – observation techniques / products (1)

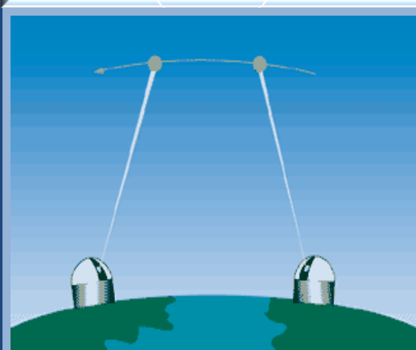
International Terrestrial Reference Frame (ITRFxx)

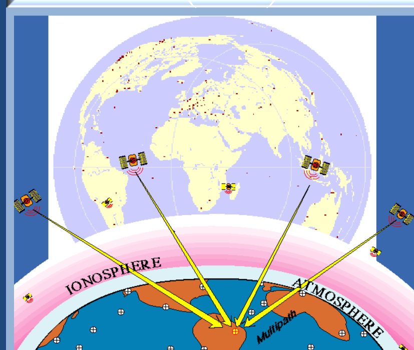
International Earth Rotation and Reference Systems Service (IERS)

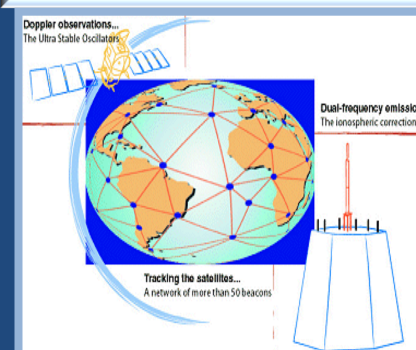
Radio source positions, precise GNSS orbits and clocks,
Earth orientation parameters (EOP), station coordinates and velocities

Very Long Baseline Interferometry (IVS)	Satellite Laser Ranging (ILRS)	Global Navigation Satellite Systems (IGS)	Doppler Orbit Determination and Radiopositioning Integrated on Satellite (IDS)









In memory of Steve Klosko

On August 6, 2012, our colleague Steve Klosko passed away surrounded by family and loved ones. We will greatly miss his immense contributions to the field of satellite laser ranging, space geodesy, and other scientific research areas.

We recognize his lifelong dedication to the SLR technique and Space Geodesy

Session 1: Introduction
Agenda

9:00 – 9:05	Welcome to ITLW-12	Mike Pearlman
9:05 – 9:20	Welcome from the ILRS Program Overview and Expectations	Graham Appleby
9:20 – 9:30	Welcome to LNF and Administrative	Simone Dell'Agnello
9:30 – 10:00	Historical Overview and Path to Present Day Requirements	Mike Pearlman
10:00 – 10:30	Laser Ranging: Scientific Accomplishments of the Past and Requirements for the Future	Erricos Pavlis

COFFEE BREAK (10:30-11:00)

11:00 – 11:30.	A Tutorial on Retroreflectors and Arrays for SLR	John Degnan

Historical Overview and Path to Present Day Requirements

Michael Pearlman

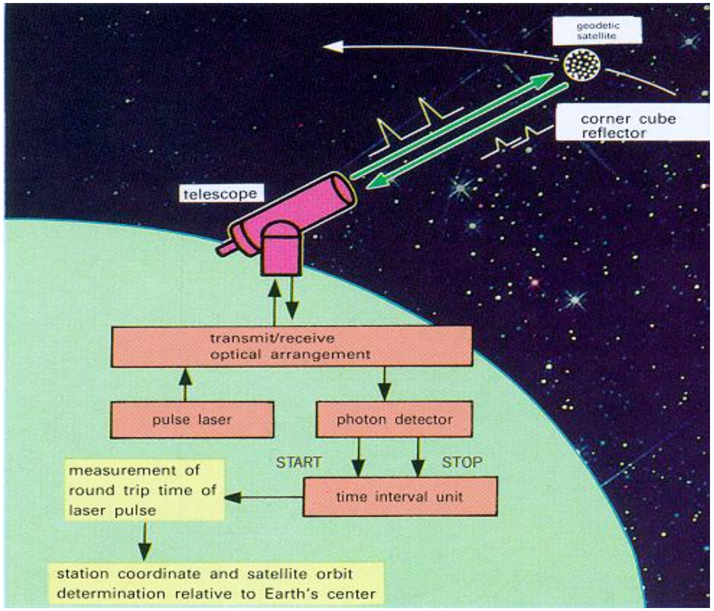
Harvard-Smithsonian Center for Astrophysics
Cambridge MA USA
mpearlman@cfa.harvard.edu

Workshop on Satellite, Lunar, and Planetary Laser Ranging:
Characterizing the Space Segment
Frascati, Italy
November 5 - 9, 2012

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

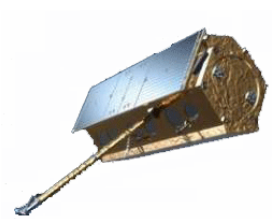
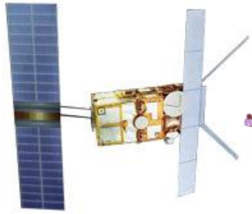


- Only Space Geodesy Technique that measures range directly
- Unambiguous centimeter accuracy orbits
- Long-term stable time series

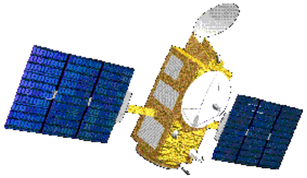
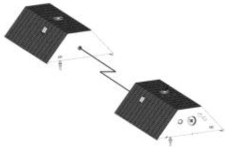
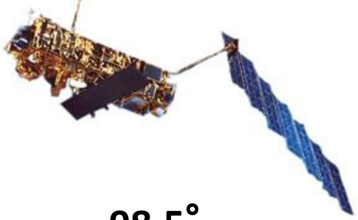
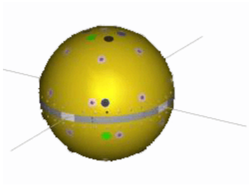
Sample of SLR Satellite Constellation

(Support for Precise Orbit Determination -POD)




	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

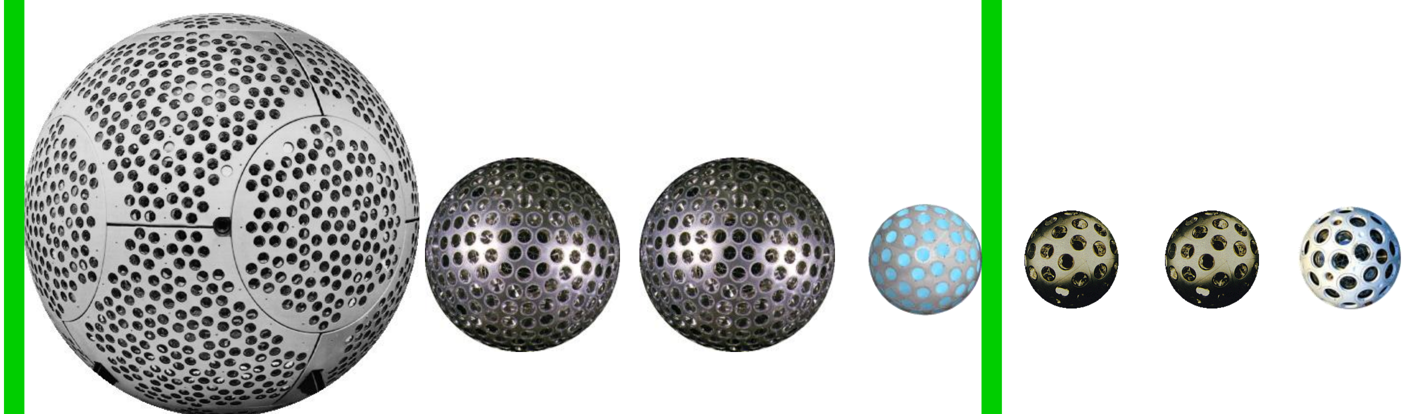






	Meteor-3M	Jason-2	GRACE	Envisat	ANDE-RR
Inclination	99.64°	66°	89°	98.5°	51.6°
Perigee ht. (km)	1,012	1,336	450	796	250
Mass (kg)	2.477	500	432/sat.	8,211	50

Sample of SLR Satellite Constellation

(Geodetic Satellites)

ITRF Constellation

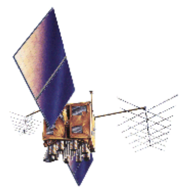


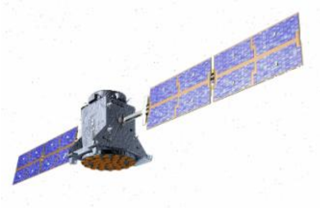
	Etalon-I & -II	LAGEOS-1	LAGEOS-2	LARES	Starlette	Stella	Larets
Inclination	64.8°	109.9°	52.6°	69.5°	50°	98.6°	98.2°
Perigee ht. (km)	19,120	5,860	5,620	1450	810	800	691
Diameter (cm)	129.4	60	60	36	24	24	24
Mass (kg)	1415	407	405.4	387	47.3	47.3	23.3

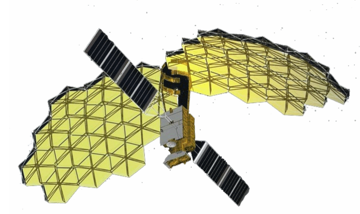
LARES $_{A/m}$ = 0.36 x LAGEOS

Sample of SLR Satellite Constellation

(High Earth Orbit)



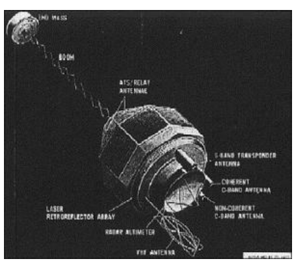




	GLONASS	GPS	COMPASS	Galileo	ETS-8
Inclination	65˚	64.8˚	55.5˚	56˚	0˚
Perigee ht. (km)	19,140	20,195	21,500	23,920	36,000
Mass (kg)	1,400	930	2,200	600	2,800

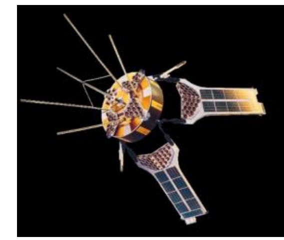
Laser Ranging – Early Days

Beacon B/C



GEOS 1/2/3

- Nearing the 50th Anniversary of Laser Ranging
- First Event at GSFC in 1964
- Big challenge: hitting the satellite
- Visual Tracking – Sun illuminated
- Major application – systems inter-comparison
  - Flashing lights for Cameras, Doppler, GRARR, C band, S Band, interferometer, etc
- Second application – Geodesy
  - Size and shape of the Earth
  - Fiducial network of stations
  - Gravity Field
- 1- meter accuracy
- Coated cubes – as much cross section as possible
- Basis for several early multi-technique international campaigns
  - ISAGEX, EPSOC, etc
- Early Earth models

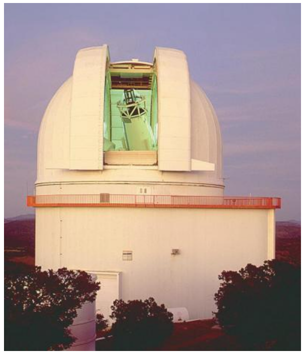


Diademe 1/2

PEOLE

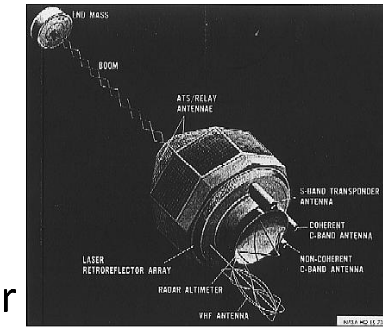
Lunar Ranging

- Big breakthrough came in 1969 with Lunar Ranging
- Apollo 11 landing and the lunar array; follow-on missions
- Landing of the Lunakhod Array
- Carefully designed arrays with uncoated cubes
- Ranging from McDonald Observatory and the
  Crimean Observatory
- Dedicated, high level team, international team

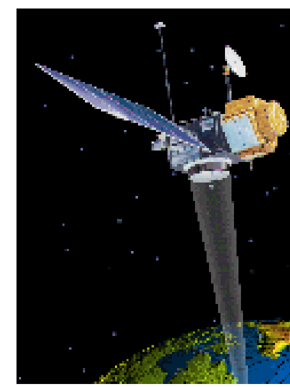


Early Altimeter Satellites

- GEOS-3
  - Whole suite of tracking systems
  - New Systems aboard including
    - Radar Altimeter for ocean surface topography
    - ATS – Relay Link for satellite to satellite tracking
  - SLR for POD and calibration; ring array around the altimeter
  - Accuracy – 10 cm.
  - New Products: Sea Surface topography, Gravity Field

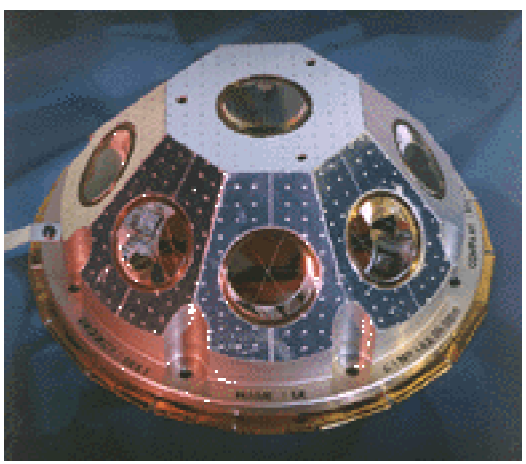


- TOPEX/Poseidon
  - Several altimeters aboard (NASA & CNES) plus GPS
  - Retro ring configuration; very complicated analysis
  - SLR Supported POD and calibration
  - Late in the mission GPS failed and SLR was the only POD



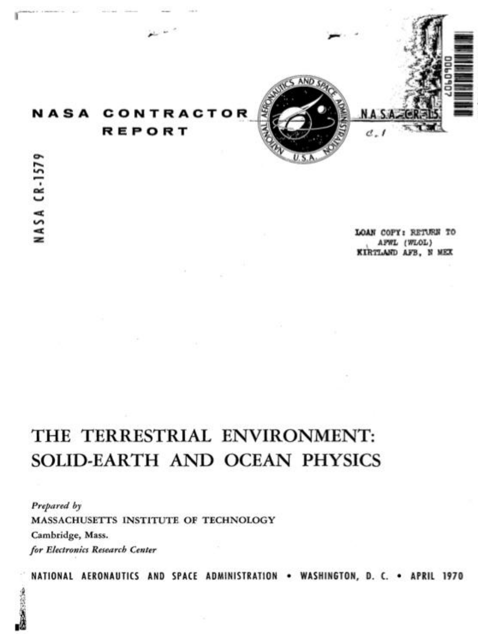
Expanded Suite of Altimeter and Ocean Sensing Satellites

- ERS-1/2, Jason-1/2, ENVISAT, ICESat, Cryosat, etc
- Use more compact Array design to limit the number of cubes illuminated and better define the C/M correction
- Orbital accuracy of couple of cm with a combination of tracking techniques



Williamstown Conference (1969)

- Path forward using space geodesy to study the Earth and ocean environment
- Chaired by Bill Kaula
- Attended by a wide community of technical specialists and program people
- Words like “motion, dynamics, topography, change, etc”
- Early mention of high m/a, passive, spherical satellites
- Early mention of cm accuracy satellite ranging (George Weiffenbach)
- Cm accuracy certainly discussed earlier in the Lunar Ranging Community


NASA CONTRACTOR REPORT

NASA CR-1579

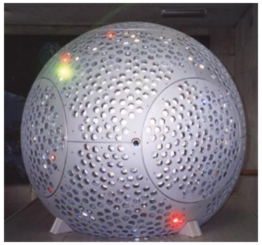
LOAN COPY: RETURN TO
AFWL (WLOL)
KIRTLAND AFB, N MEX

THE TERRESTRIAL ENVIRONMENT:
SOLID-EARTH AND OCEAN PHYSICS

Prepared by
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge, Mass.
for Electronics Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1970

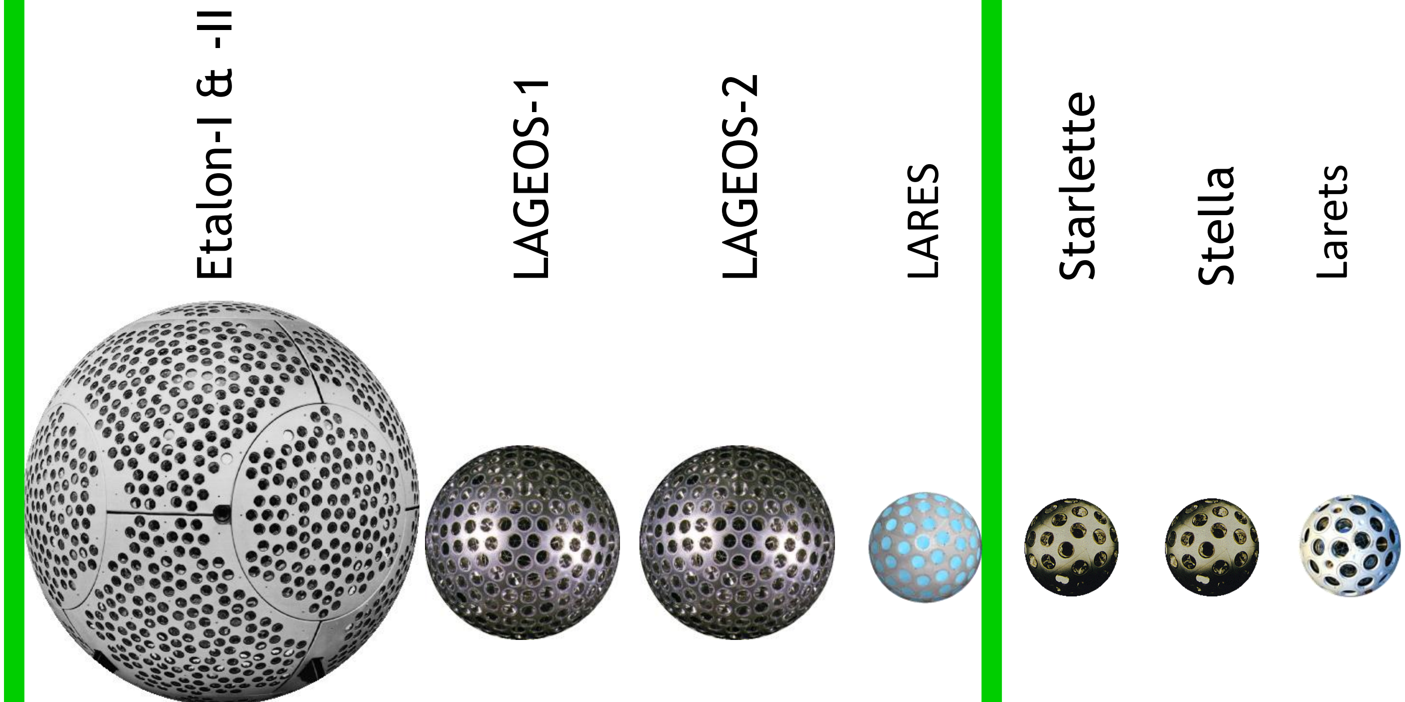
Geodetic Satellites



- Passive, spherical, large m/a ratio, covered with retroreflectors, stable orbit
- Cannonball Concept emerged after Williamstown
  - 8000 lb ball with a Uranium core
  - Designed as backup payload for the Saturn emergency launch vehicle for the Skylab mission;
  - The emergency was not needed
- LAGEOS concept was developed for a Delta launch
  - First use of uncoated cubes in artificial satellties
  - Lageos 1 built by NASA; launched in 1976
  - Lageos 2 built by ASI; launched in 1992
  - Application for geodynamics
- First Geodetic satellite launched by CNES
  - Starlette in 1975
  - Stella in 1993
  - Geodynamics and refinement of the low order/low degree terms in the gravity field
- High satellites added to the Geodynamics Complex with Etalon
  - Etalon 1/2 launched by the Russian Space Agency in 1989
- Additional low altitude satellite added to the Geodynamics Constellation with LARETS launched in 2003
- Additional mid-level satellite added to the Complex with LARES

Sample of SLR Satellite Constellation
(Geodetic Satellites)

ITRF Constellation



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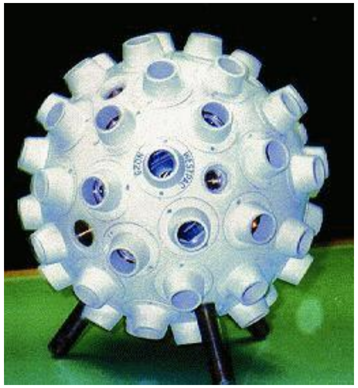
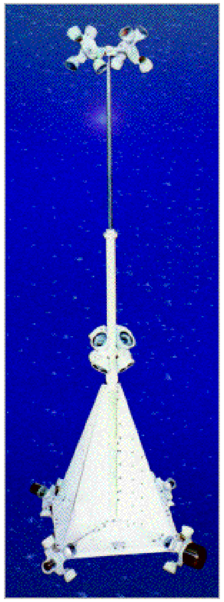
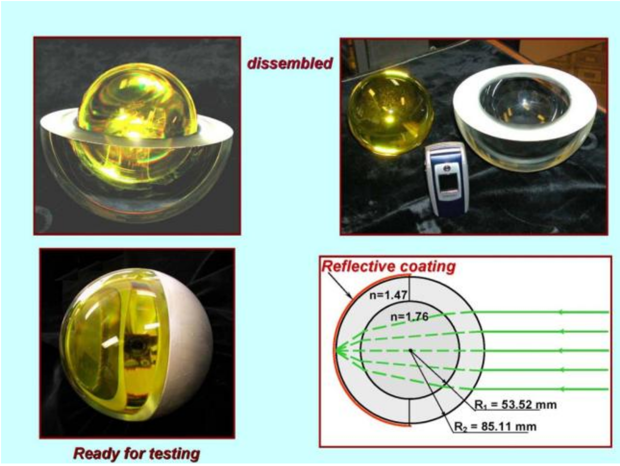
Novel Mission Designs



Westpac



Reflector

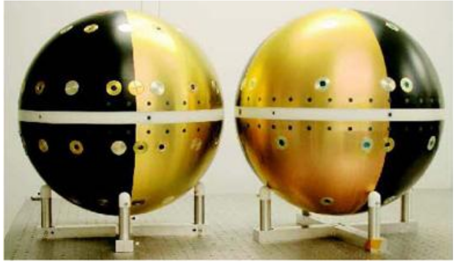


BLITS

TIPS

GFZ-1

AJISAi



ANDE

Applications of Laser Ranging

Earth Science:

- Fundamental data for the Reference Frame (Earth Center of Mass, Scale)
- Centimeter Accuracy Orbits
- 3-D station positions and velocities
- Calibrate and validate microwave and laser altimeters for ocean, ice, and terrestrial topography measurements (mass distribution and transfer)
- Calibrate and validate microwave navigation systems (e.g. GNSS)
- Static and time-varying components of the gravity field, and calibration of gravity field missions
- Fundamental constants (e.g. Gm) and general relativity
- Time transfer measurements (Earth to Earth and Earth to space)

Lunar Science and Fundamental Constants

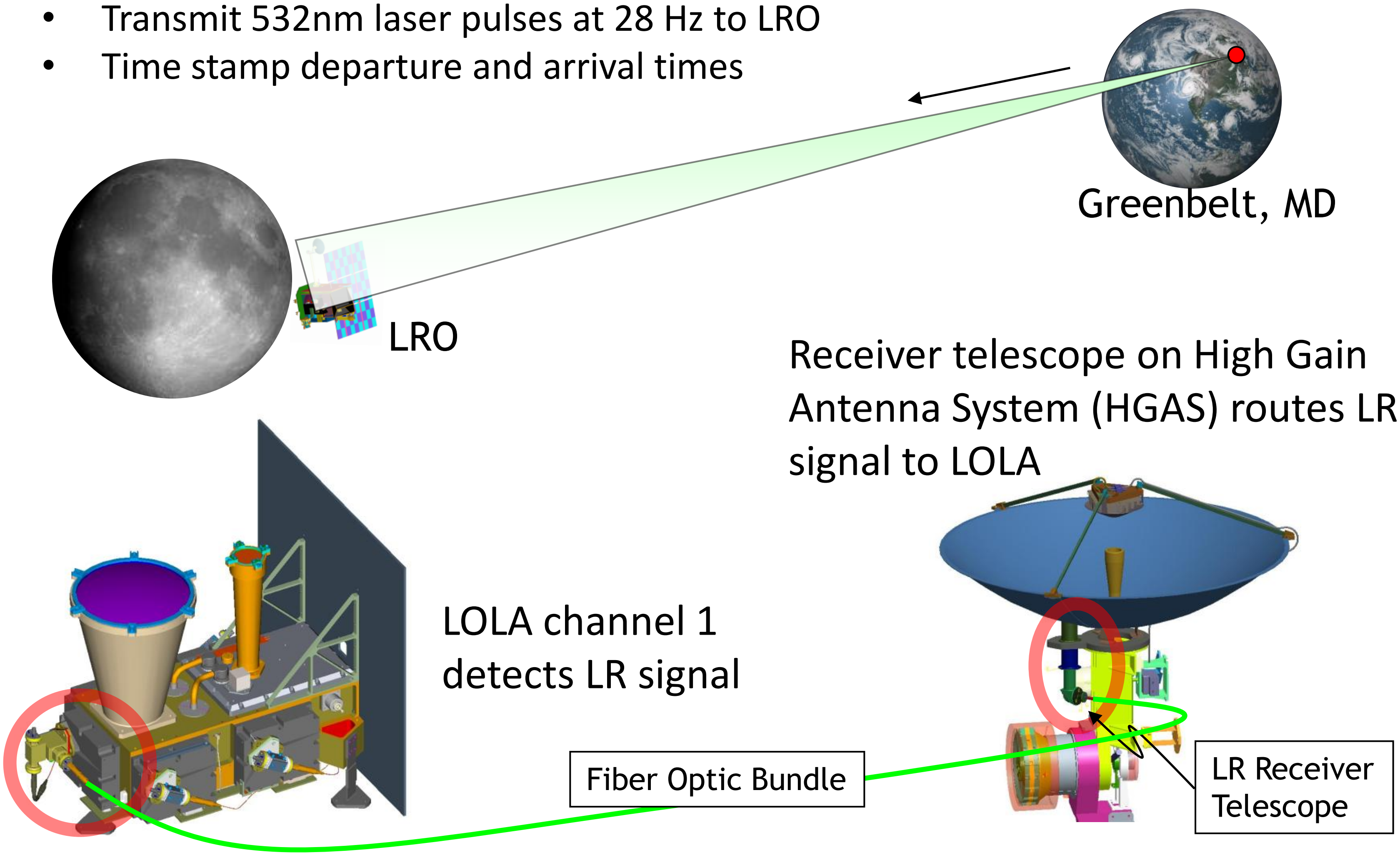
- Centimeter accuracy lunar ephemerides
- Lunar librations (variations from uniform rotation)
- Lunar tidal displacements and mass distribution
- Secular deceleration due to tidal dissipation in Earth's oceans – Measurement of G(ME + MM)
- GLONASS, DORIS, PRARE)
- Studies of Strong Equivalence Principle
- Solar System Reference Frame (LLR)
- Dynamic equinox Obliquity of the Ecliptic Precession constant

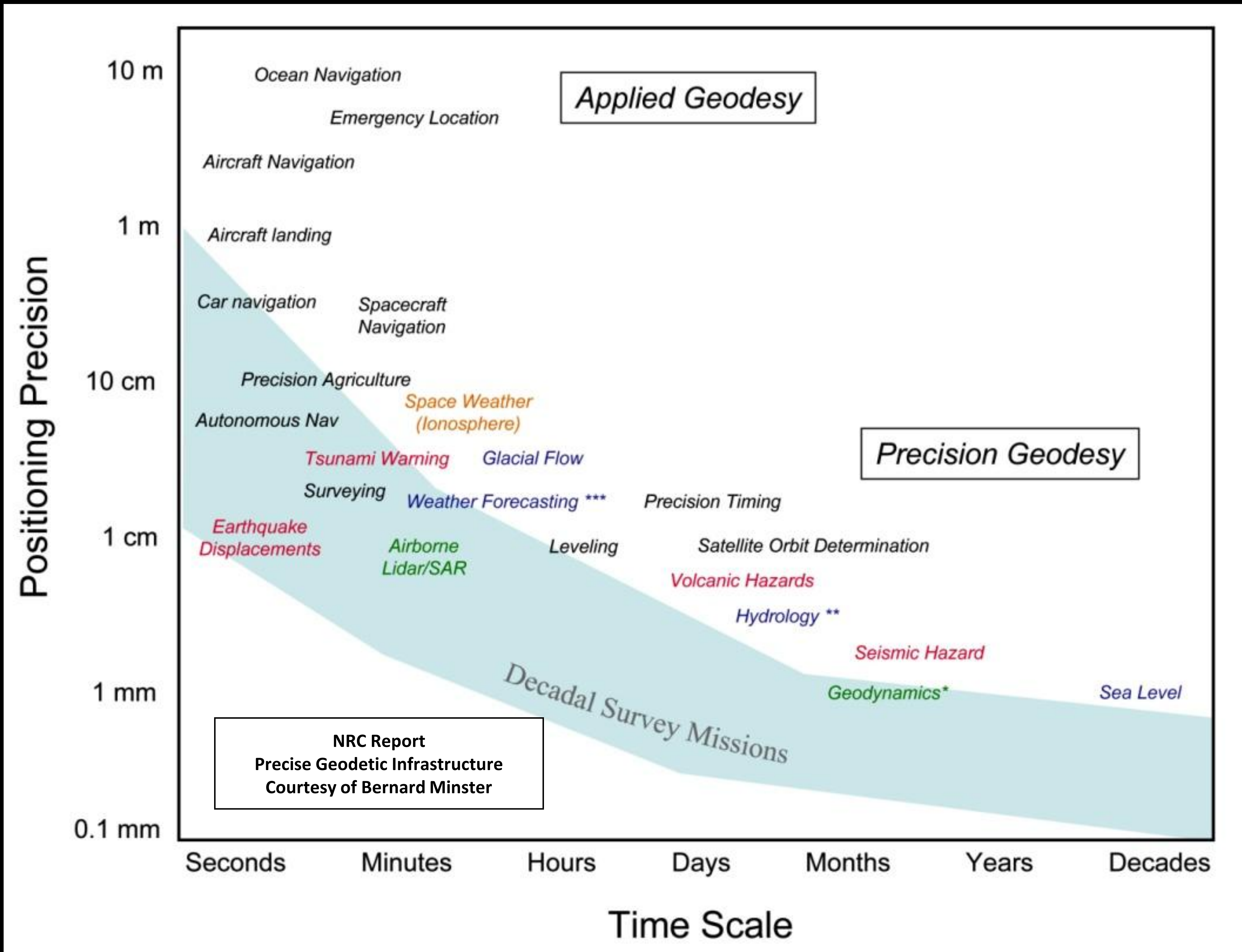
Receivers and Transponders in Space

- Time transfer measurements (Earth to Earth and Earth to space)
- Lunar positioning and gravity field
- Planetary Science (interplanetary tracking)

LRO Laser Ranging

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

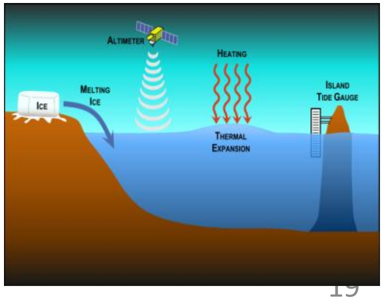




Courtesy of Bernard Minster
http://dels.nas.edu/Report/Precise-Geodetic-Infrastructure-National-Requirements/12954

International Terrestrial Reference Frame (ITRF)

- Provides the stable coordinate system that allows us to measure change (link measurements) over space, time and evolving technologies.
- 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, robust, reliable, and geographically distributed (worldwide).
- Network measurements interconnected by co-location of the different observing techniques at CORE SITES.



Global Geodetic Observing System (GGOS)

IAG Bylaws 1(d)

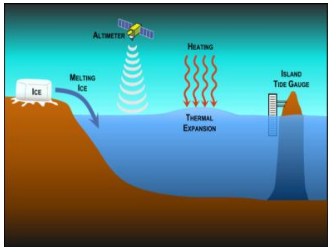
“The Global Geodetic Observing System is an element of the IAG that works with the IAG components to provide the <u>geodetic infrastructure</u> necessary for monitoring the Earth system and global change research.”

The vision of GGOS is

“Advancing our understanding of the dynamic Earth system by quantifying our planet’s changes in space and time.”

Major Item: *<u>Provide the infrastructure to maintain and improve the reference frame to meet future needs</u>*

The International Terrestrial Reference Frame is established by the Global Space Geodesy Networks



Requirement (Source GGOS 2020):

<1 mm reference frame accuracy

< 0.1 mm/yr stability

– Measurement of sea level is the primary driver

– Improvement over current ITRF performance by a factor of 10-20.

Means of providing the reference frame:

- Global Network of co-located VLBI/SLR/GNSS/DORIS CORE SITES;
- Dense network of GNSS ground stations to distribute the reference frame globally to the users

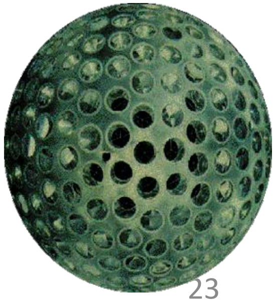
Requirement: Users anywhere on the Earth can position their measurements in the reference frame at any time

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 be specified and maintained with an accuracy sufficient to support GGOS objectives.

Current Trends in Satellite Laser Ranging

- Higher pulse repetition rate (0.1 – 2 KHz) for faster data acquisition;
- Smaller, faster slewing telescope for more rapid target acquisition and pass interleaving;
- Ranging from LEO to GNSS;
- Ranging to Space-born receivers
- More accurate pointing for link efficiency;
- Narrower laser pulse width for greater precision;
- New detection systems for greater accuracy;
- More automation for economy (24/7);
- Greater temporal and spatial filtering for improved signal to noise conditions;
- Modular construction and more off the shelf components for lower fabrication/operations/maintenance cost;



Questions on our Geodetic Satellites

- Can our current geodetic satellites support mm accuracy ranging? Do our products get sufficient unbiased data averaging to reduce the satellite contribution to <1 mm.
- Does the slowdown in rotation degrade the ranging results?
- How do we calibrate the satellites on the ground and model their evolution in space?