International Laser Ranging Service and its support for GGOS and Earth Sciences

Michael Pearlman[1], Carey Noll[2], Jan McGarry[2], Werner Gurtner[3], and Erricos Pavlis[4]

1*Harvard-Smithsonian Center for Astrophysics*
2*NASA Goddard Space Flight Center*
3*Astronomical Institute of Bern*
4*Joint Center for Earth Systems Technology, University of Maryland, Baltimore County*

***with a very extensive use of charts and inputs provided by many other people**

IAG Services: Backbone of GGOS

Geometry

IERS:	International Earth Rotation and Reference Systems Service
IGS:	International GNSS Service
IVS:	International VLBI Service
ILRS:	International Laser Ranging Service
IDS:	International DORIS Service

Gravimetry

IGFS:	International Gravity Field Service
BGI:	Bureau Gravimetrique International
IGeS:	International Geoid Service
ICET:	International Center for Earth Tides
ICGEM:	International Center for Global Earth Models

Ocean

PSMSL:	Permanent Service for Mean Sea Level
IAS:	International Altimetry Service (in preparation)

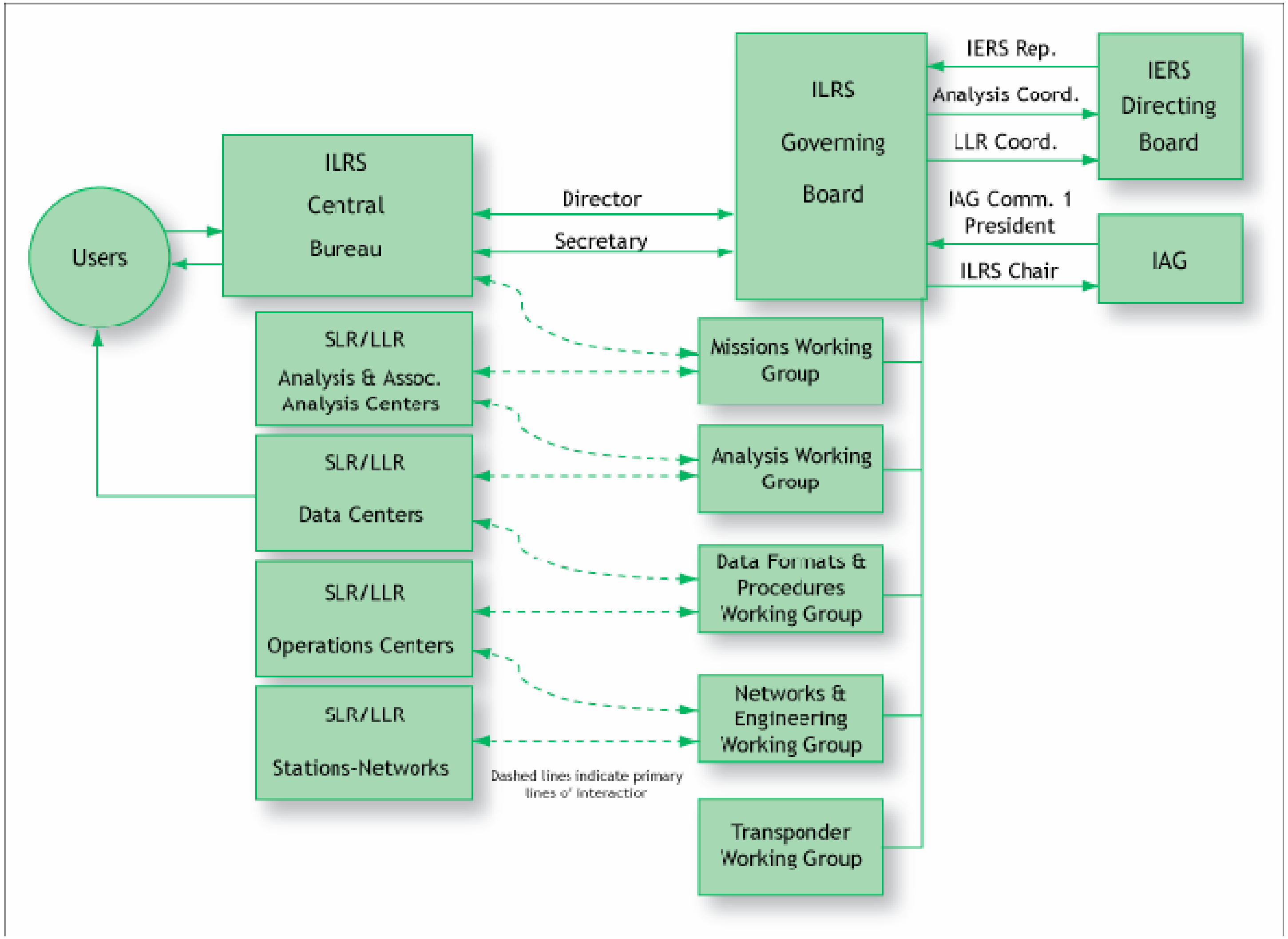
Std

BIPM:	Bureau International des Poids et Mesures
IBS:	IAG Bibliographic Service

International Laser Ranging Service

- Established in 1998 as a Service of the International Association of Geodesy (IAG)
- Collects, merges, analyzes, archives and distributes satellite and lunar laser ranging data to satisfy a variety of scientific, engineering, and operational 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
- Basic component of GGOS

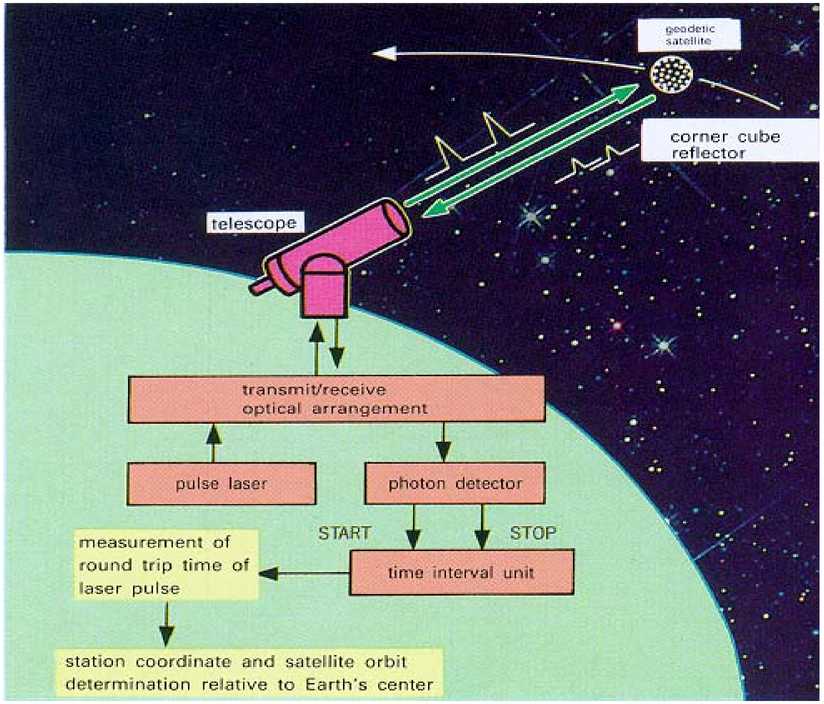
ILRS Organization



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 GNSS, 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
- User Products
  - Weekly solutions of station positions and EOP (for IERS)
  - Static and time-varying coefficients of the Earth's gravity field
  - Time varying Earth center-of-mass and scale (Terrestrial Reference Frame)
  - Accurate satellite ephemerides
- Applications
  - Realization of the Terrestrial Reference Frame (Earth center of mass and scale)
  - Calibration and validation of altimetry missions (ocean and ice)
  - Plate Tectonics and Crustal Deformation
  - Earth Mass Distribution
  - Relativity (Lageos, GP-B) and picosecond global timing (T2L2)
  - Non-conservative force modeling (Atmospheric modeling)
  - Satellite dynamics (tether satellites)
- More than 60 Space Missions Supported since 1970
- Four Missions Rescued in the Last Decade

LLR Science and Applications

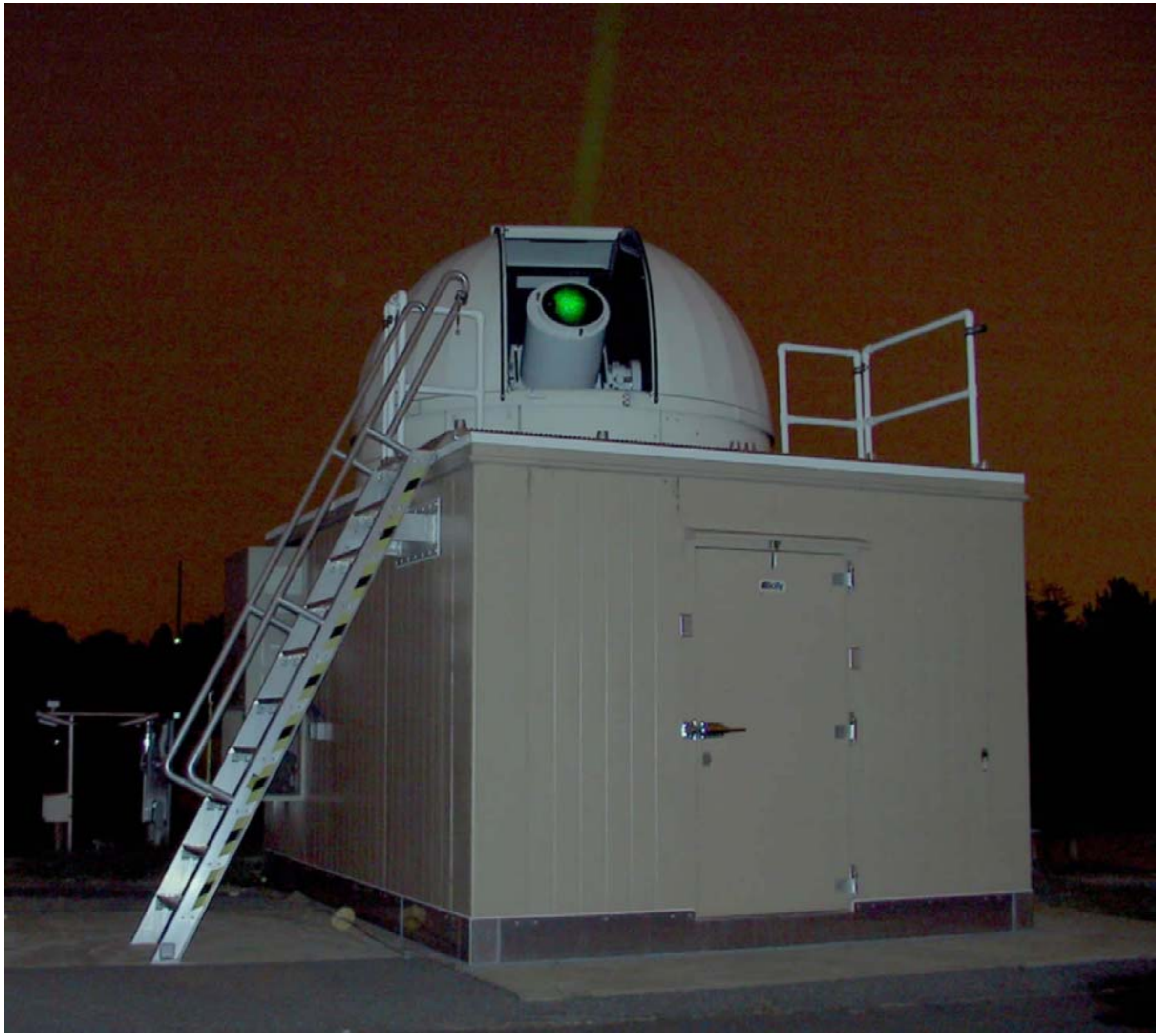
- Measurements
  - Motion of the lunar reflectors in space
- Applications
  - Lunar ephemerides
  - Relativity studies (Equivalence Principle, Robert-Walker b parameter)
  - Time rate of change of the gravitational constant?
  - Rotational dissipation
  - Nature of the lunar core-mantle boundary
  - Librations and stimulating mechanisms
  - Solar system ties to the Celestial Reference Frame

ILRS Network

- 30+ global stations providing tracking data regularly
- Majority of SLR stations co-located with GNSS

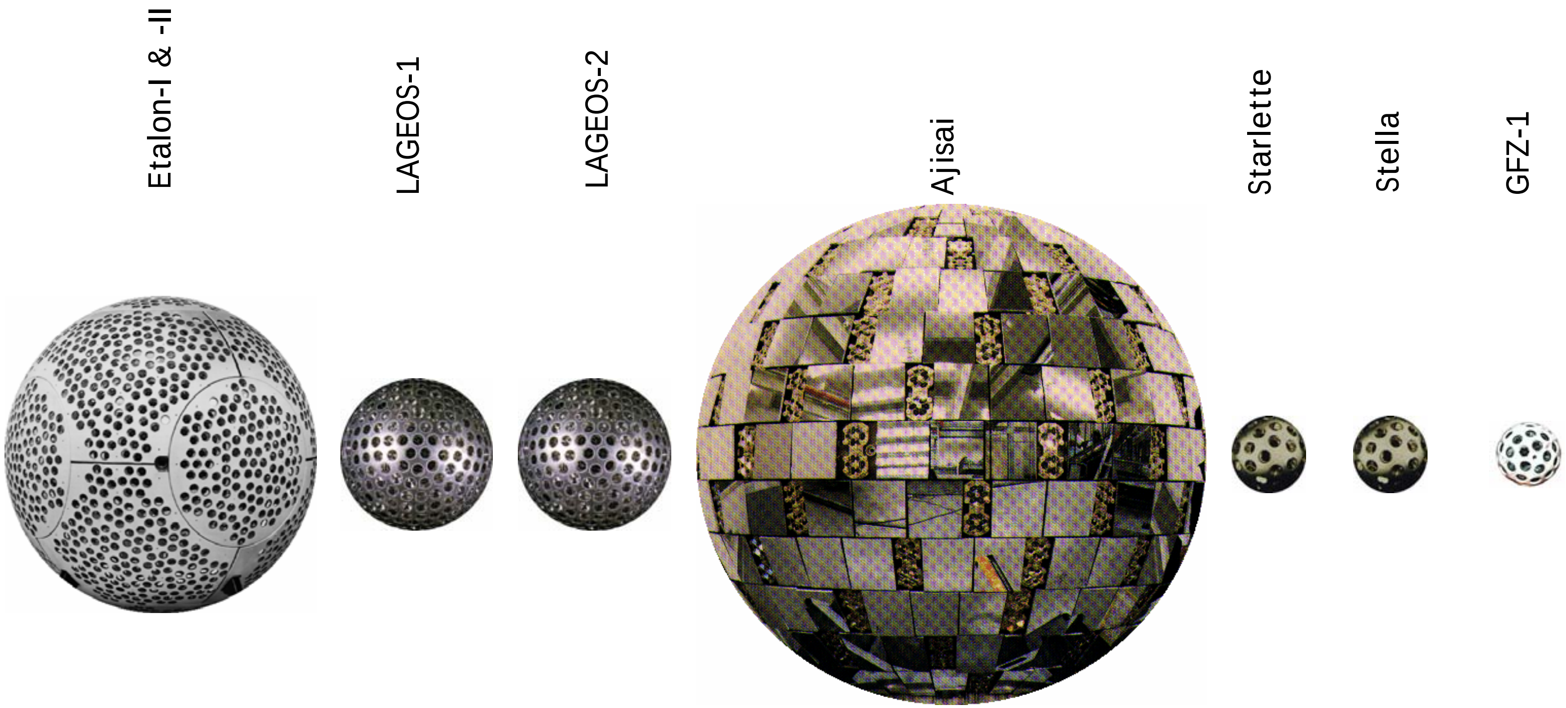
Selected SLR Stations Around the World

NASA SLR System under development



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

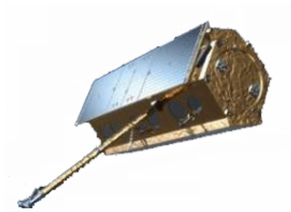
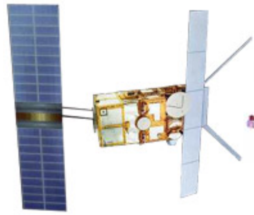
Sample of SLR Satellite Constellation
(Geodetic Satellites)

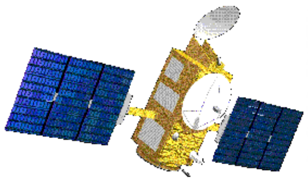
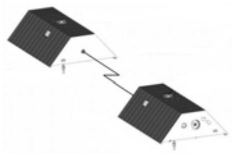
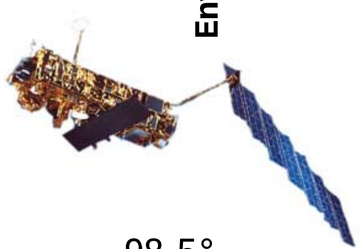
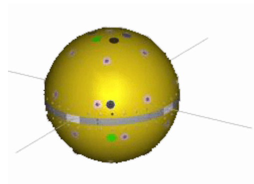


Inclination	64.8°	109.8°	52.6°	50°	50°	98.6°	51.6°
Perigee ht. (km)	19,120	5,860	5,620	1,490	810	800	396
Diameter (cm)	129.4	60	60	215	24	24	20
Mass (kg)	1415	407	405.4	685	47.3	47.3	20.6

Sample of SLR Satellite Constellation

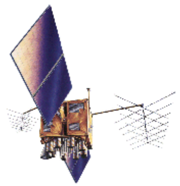
(POD Support)

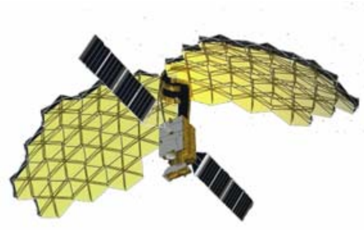
	GFO-1	ERS-1	Terra-SAR-X	ERS-2	CHAMP
					
Inclination	64°	98.5°	66°	98.6°	87.27°
Perigee ht. (km)	19,140	780	1,350	800	474
Mass (kg)	1,400	2,400	2,400	2,516	400

	Meteor-3M	Jason-1	GRACE	Envisat	ANDE
					
Inclination	99.64°	66°	89°	98.5°	90°
Perigee ht. (km)	1,019	1,336	450	800	650
Mass (kg)	5,500	500	432/sat.	8,211	3,334

Sample of SLR Satellite Constellation

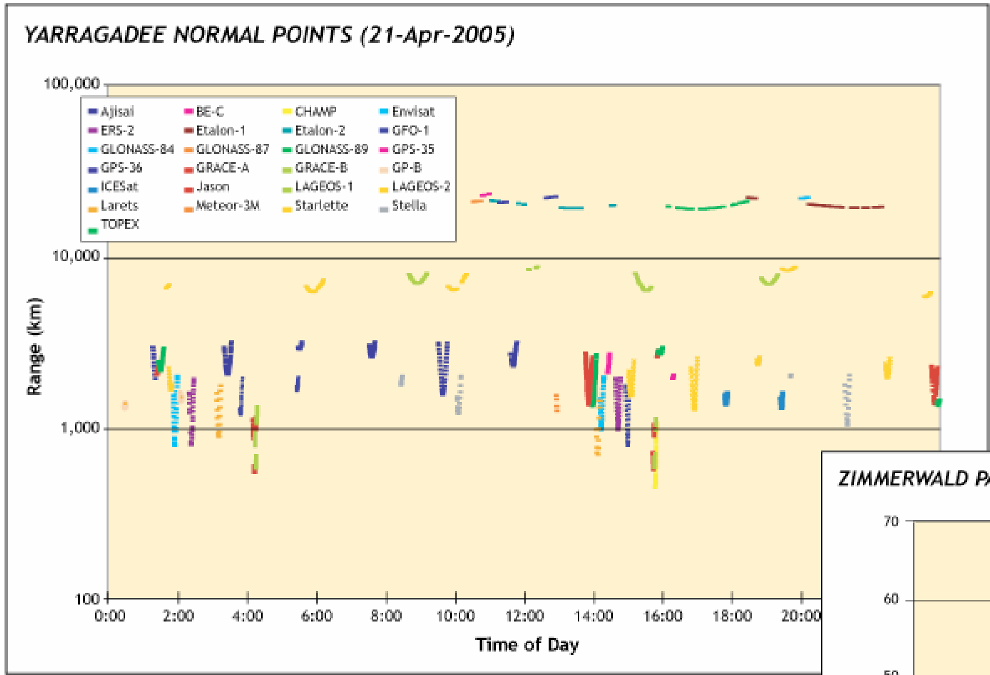
(HEO)

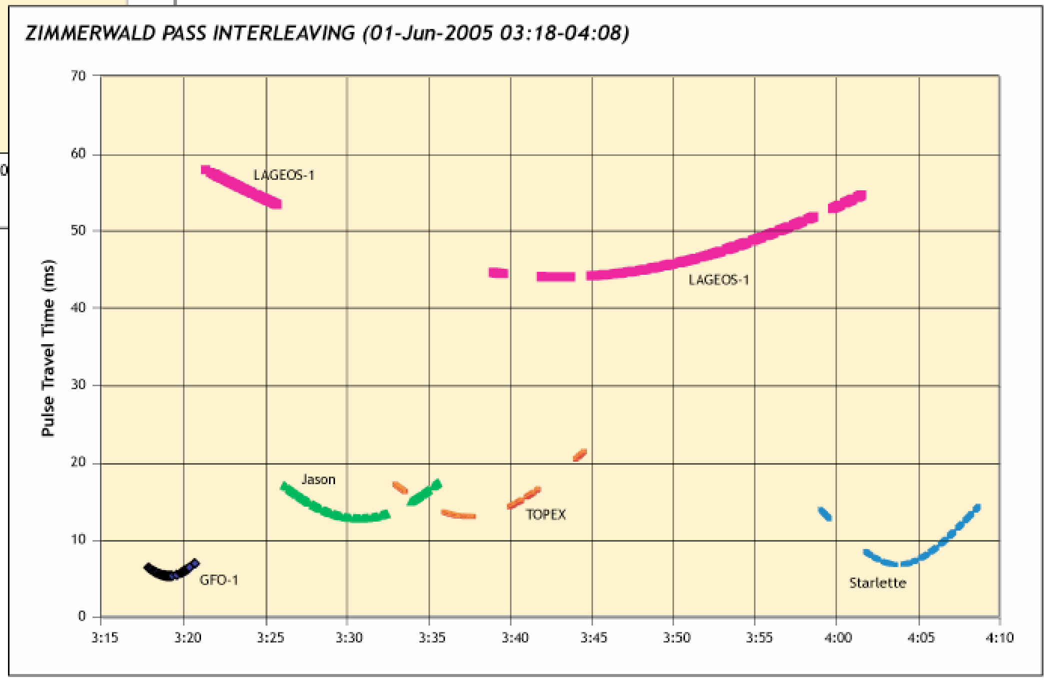




	GLONASS	GPS	GIOVE-A	ETS-8
Inclination	64°	55°	56°	0°
Perigee ht. (km)	19,140	20,100	23,920	36,000
Mass (kg)	1,400	930	600	2800

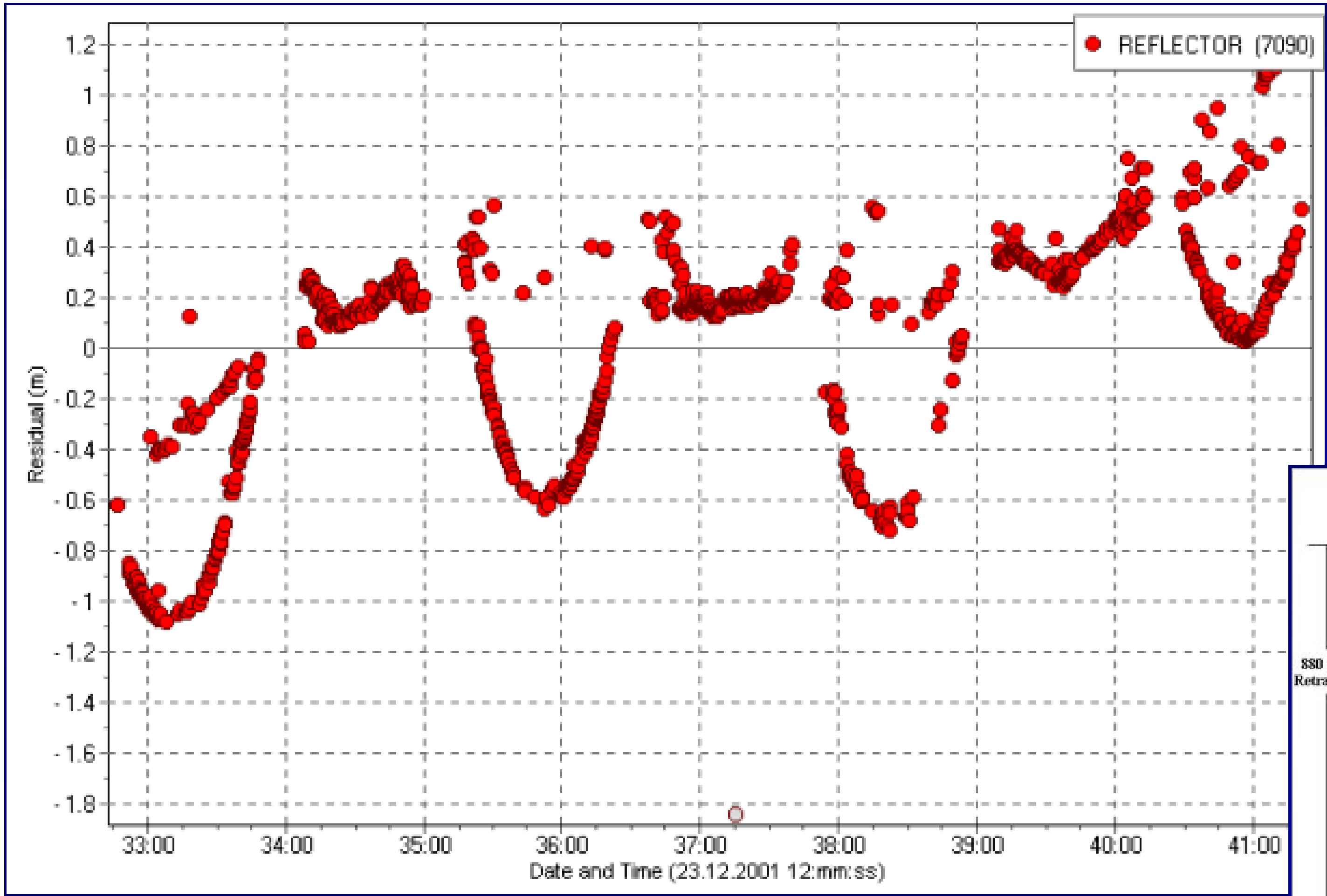
Pass Interleaving

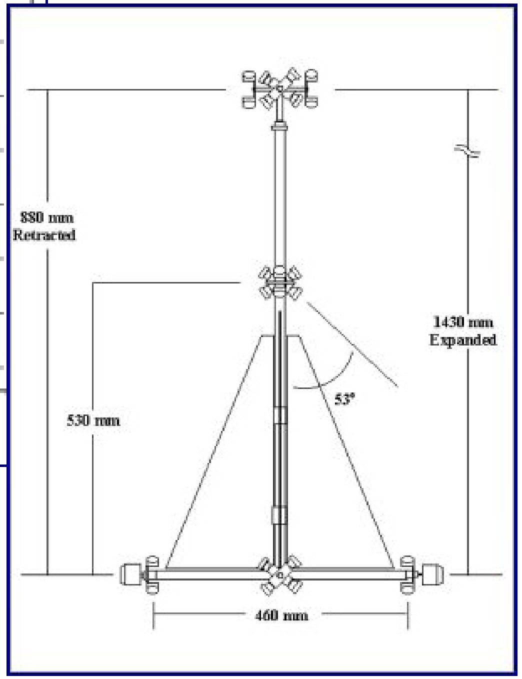




Pass interleaving allows stations to track satellites that are simultaneously visible

Reflector Satellite

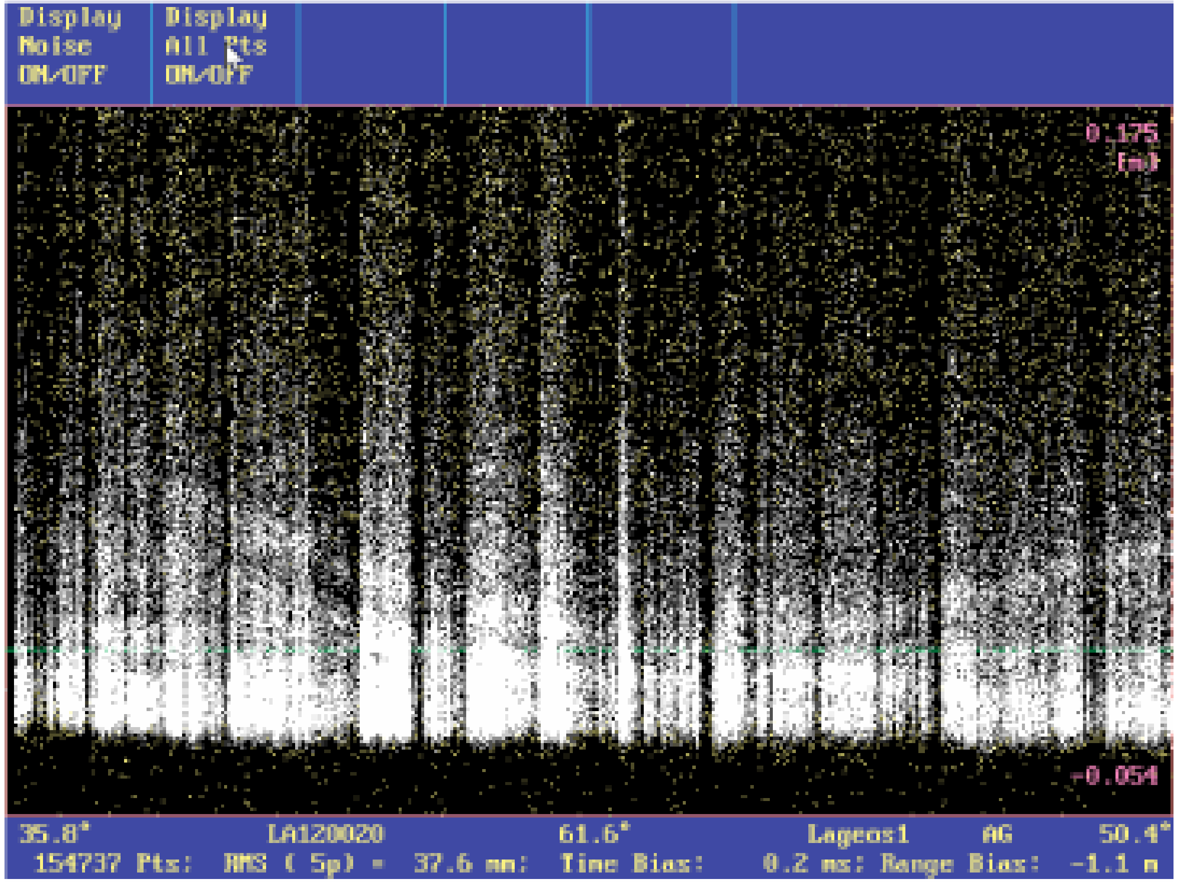




Technology Developments

- 2 kHz operation to increase data yield and improve interleaving
- Eye-safe operations and auto tracking
- 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.

LAGEOS Pass from Graz Station

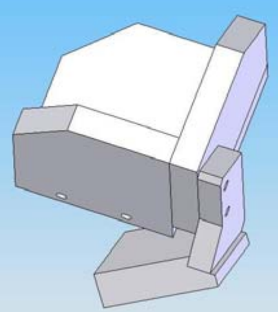


High repetition rate, short pulse lasers allow us to see retroreflector array details

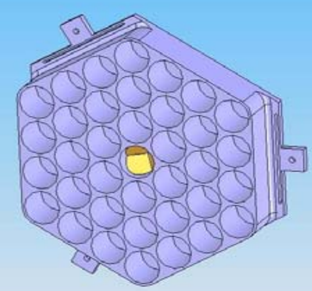
Retroreflector Technology

- GNSS retroreflector activities
  - Dialog underway with relevant agencies on the importance of including reflectors on GPS-III satellites
  - Specification document for GNSS array created for Governing Board consideration
  - Study underway at GSFC on hollow cube technology in collaboration with a newly-established testing facility (Laboratori Nazionali di Frascati, LNF, Italy)
- Several stations now ranging to ETS-8 in synchronous orbit

Single hollow cube



Hollow cube array configuration



Analysis Activities

- ILRS "official products" (station coordinates and EOP) issued weekly
- Eight ILRS Analysis Centers contribute to the official products:
  - ASI, Agenzia Spaziale Italiana
  - BKG, Bundesamt für Kartographie und Geodäsie
  - DGFI, Deutsches Geodätisches Forschungsinstitut
  - GA, Geosciences Australia
  - GFZ, GeoForschungsZentrum Potsdam
  - JCET, Joint Center for Earth Systems Technology
  - NSGF, NERC Space Geodesy Facility
  - GRGS/Observatoire de la Cote d'Azur
- Combination and Combination Back-up Centers at ASI and DGFI compute the combination products and furnish them to the IERS
- Time series of weekly solutions is provided to the IERS for the development of the ITRF (ITRF 2005)
- Analysis of early LAGEOS (1976-1993) data underway for ILRS product submission to the next reference frame
- New products for geodetic satellites under development

Some Transponder Applications

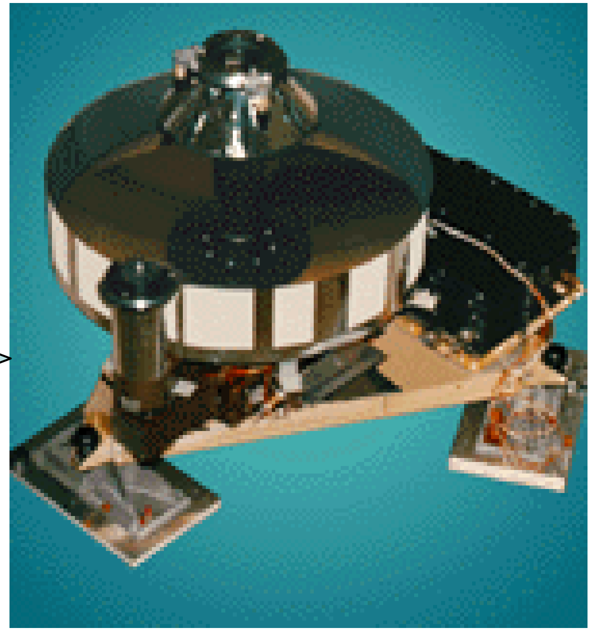
- **Solar System Science**
  - Solar Physics: gravity field, internal mass distribution and rotation
  - Lunar ephemeredes and librations
  - Planetary ephemeredes
  - Mass distribution within the asteroid belt
- **General Relativity**
  - Tests of relativity and constraints on the metrics Precession 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)

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>

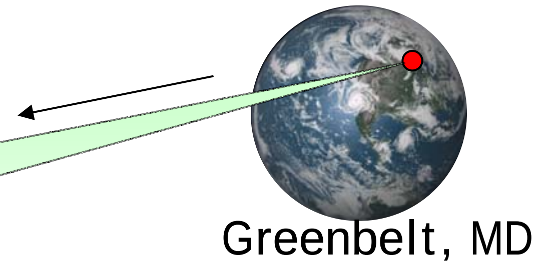
Xiaoli Sun	Jan McGarry
Tom Zagwodzki	John Degnan

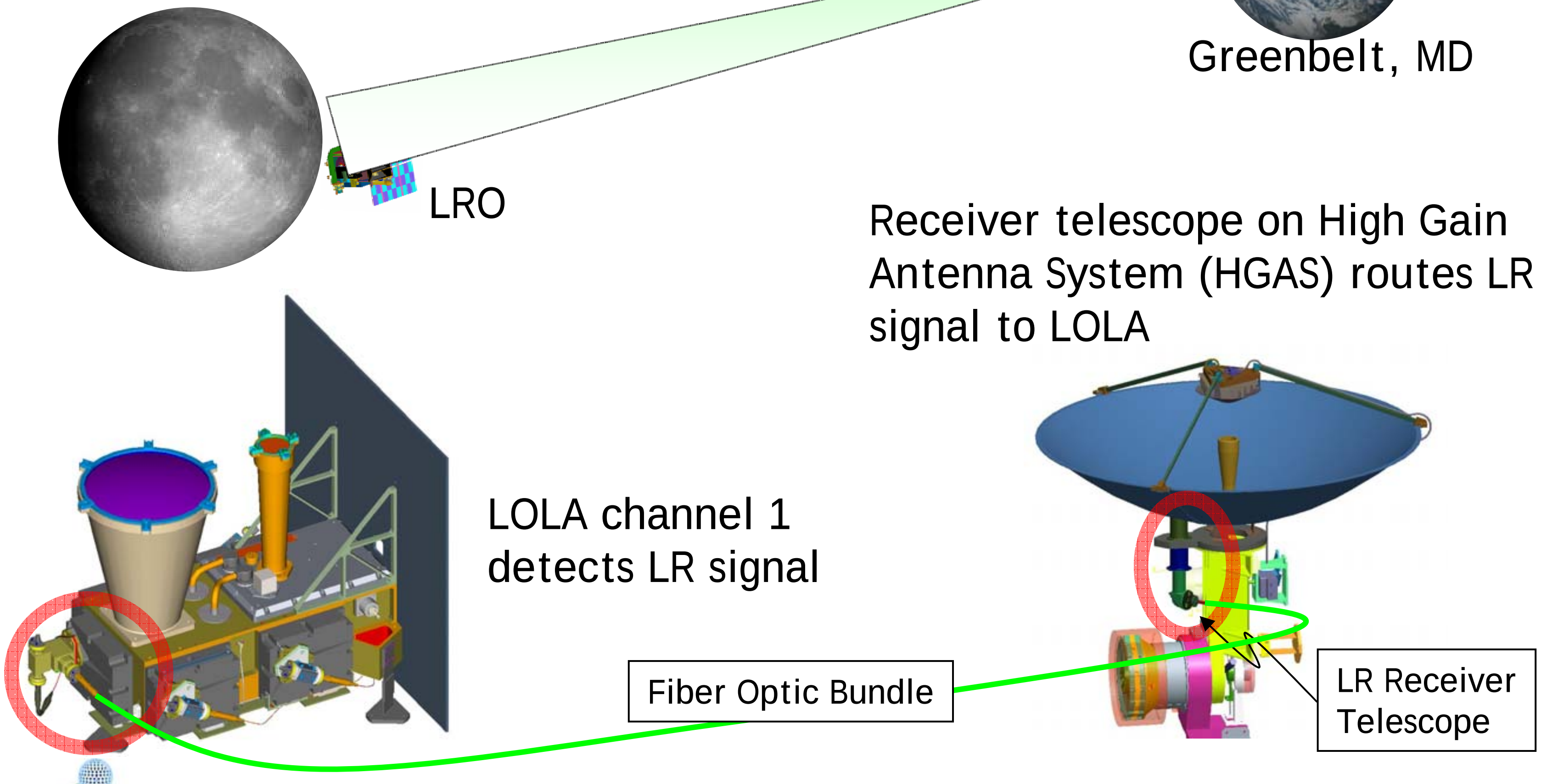
<u>Science/Analysis/Spacecraft</u>

David Smith	Maria Zuber
Greg Neumann	Jim Abshire

LRO Laser Ranging

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





Gravity changes from SLR showing long-wavelength water redistribution

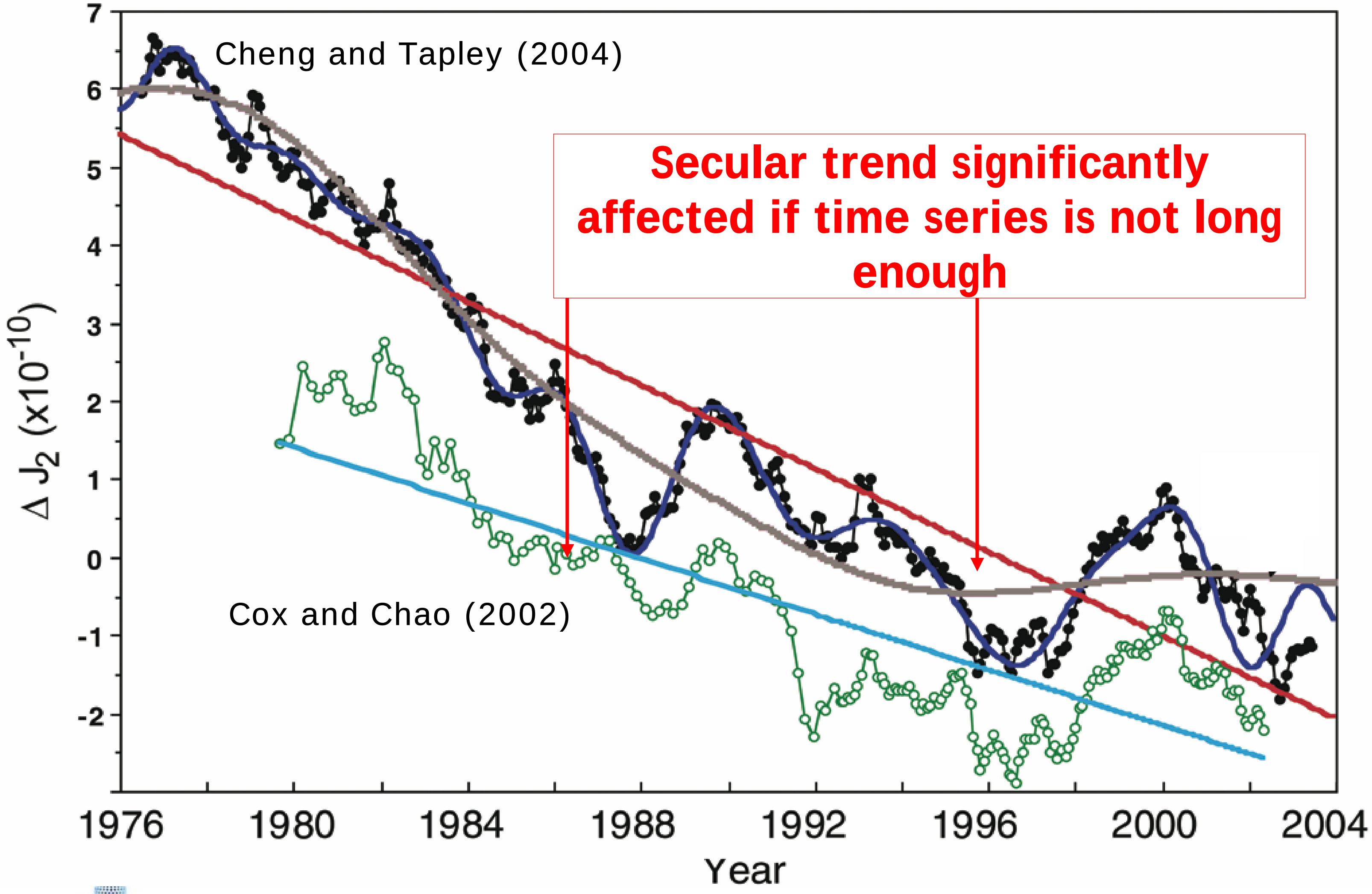
Large interannual variations related to strong El-Niño-Southern Oscillation (ENSO) events

seasonal variation only

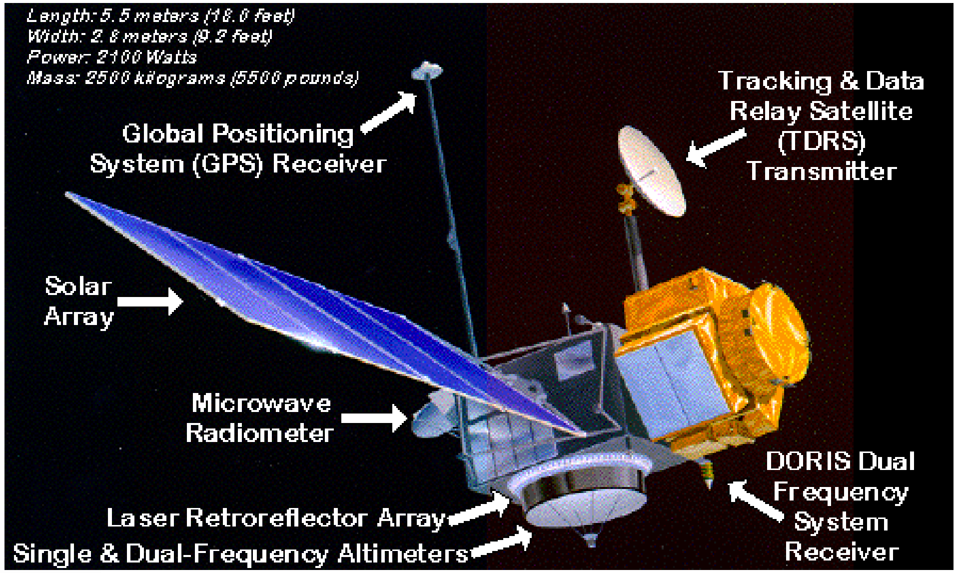
From Cheng and Tapley (2004)

Seasonal variation from mass redistribution in atmosphere, ocean and continental water

Multi-year gravity changes from SLR (seasonal variation removed)



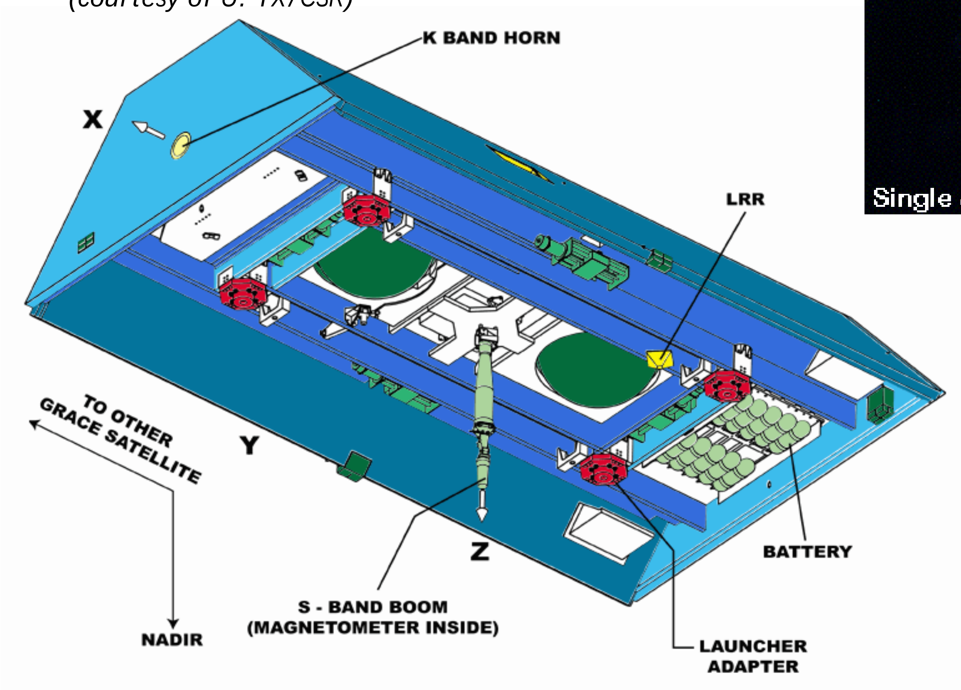
Example Satellite Configurations



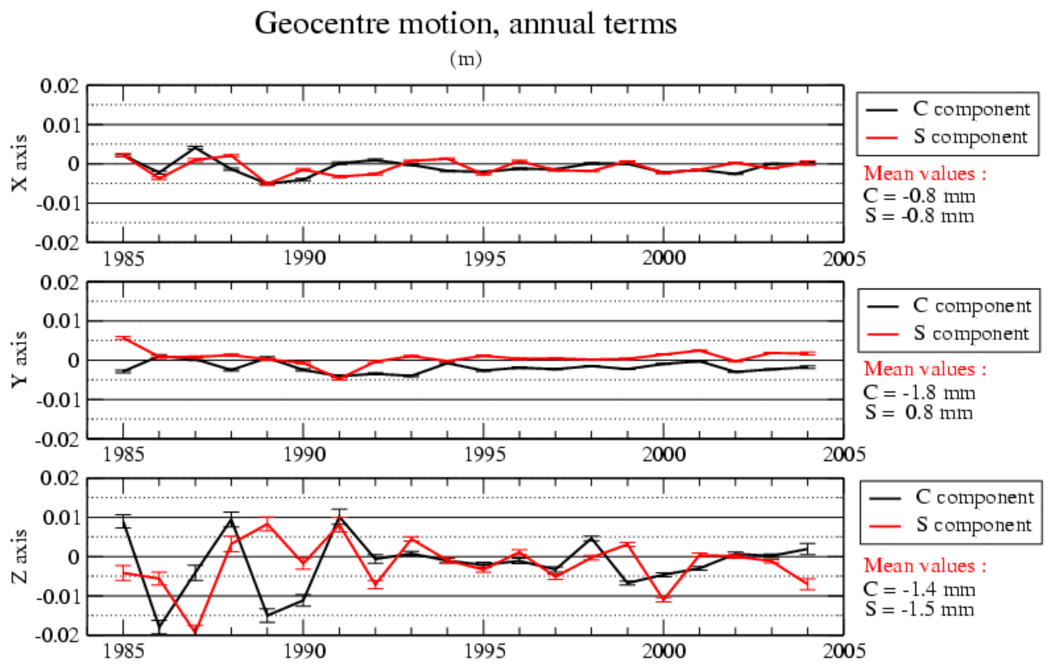
TOPEX/Poseidon

GRACE

(courtesy of U. TX/CSR)



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.