



A Brief History of Satellite Laser Ranging: 1964 – present*

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With special thanks to John Degnan for additional background information and slides.

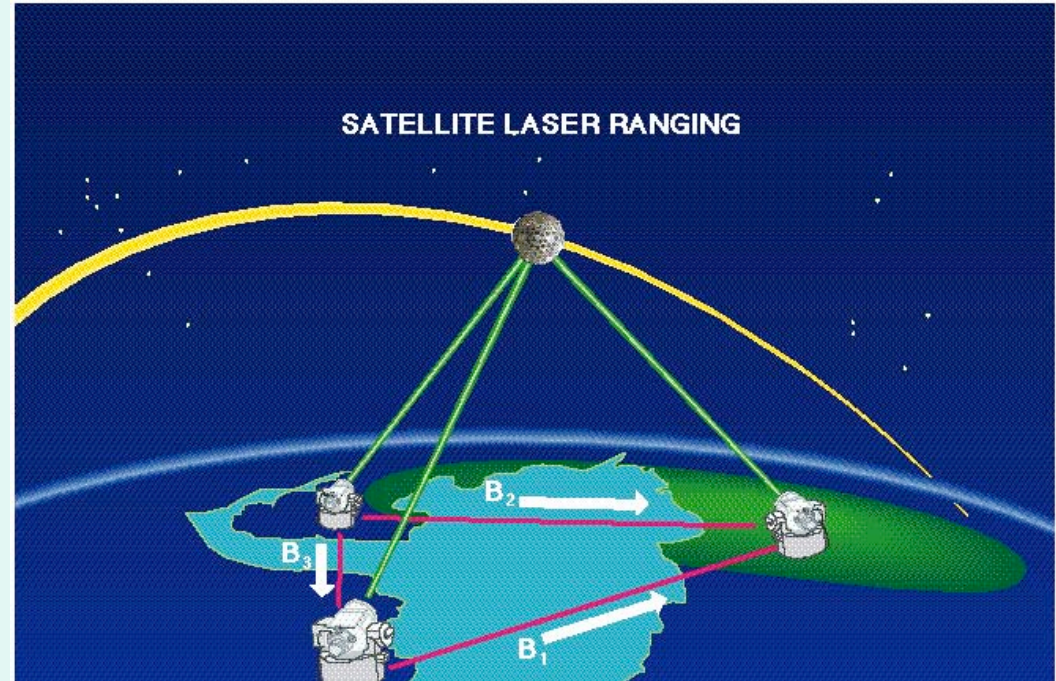
*** From the GSFC perspective!**



Satellite Laser Ranging Technique

Observable: The precise measurement of the roundtrip time-of-flight of an ultrashort (< 500 psec) laser pulse between an SLR ground station and a retroreflector- equipped satellite which is then corrected for atmospheric refraction using ground-based meteorological sensors.

- **Unambiguous time-of-flight measurement**
- **1 to 2 mm normal point precision**
- **Passive space segment (reflector)**
- **Simple refraction model**
- **Night / Day Operation**
- **Near real-time global data availability**
- **Satellite altitudes from 400 km to 20,000 km (GPS, GLONASS) and the Moon**
- **Centimeter accuracy satellite orbits**
 - ~ 1-2 cm (LAGEOS) & ~2-3 cm (GPS)

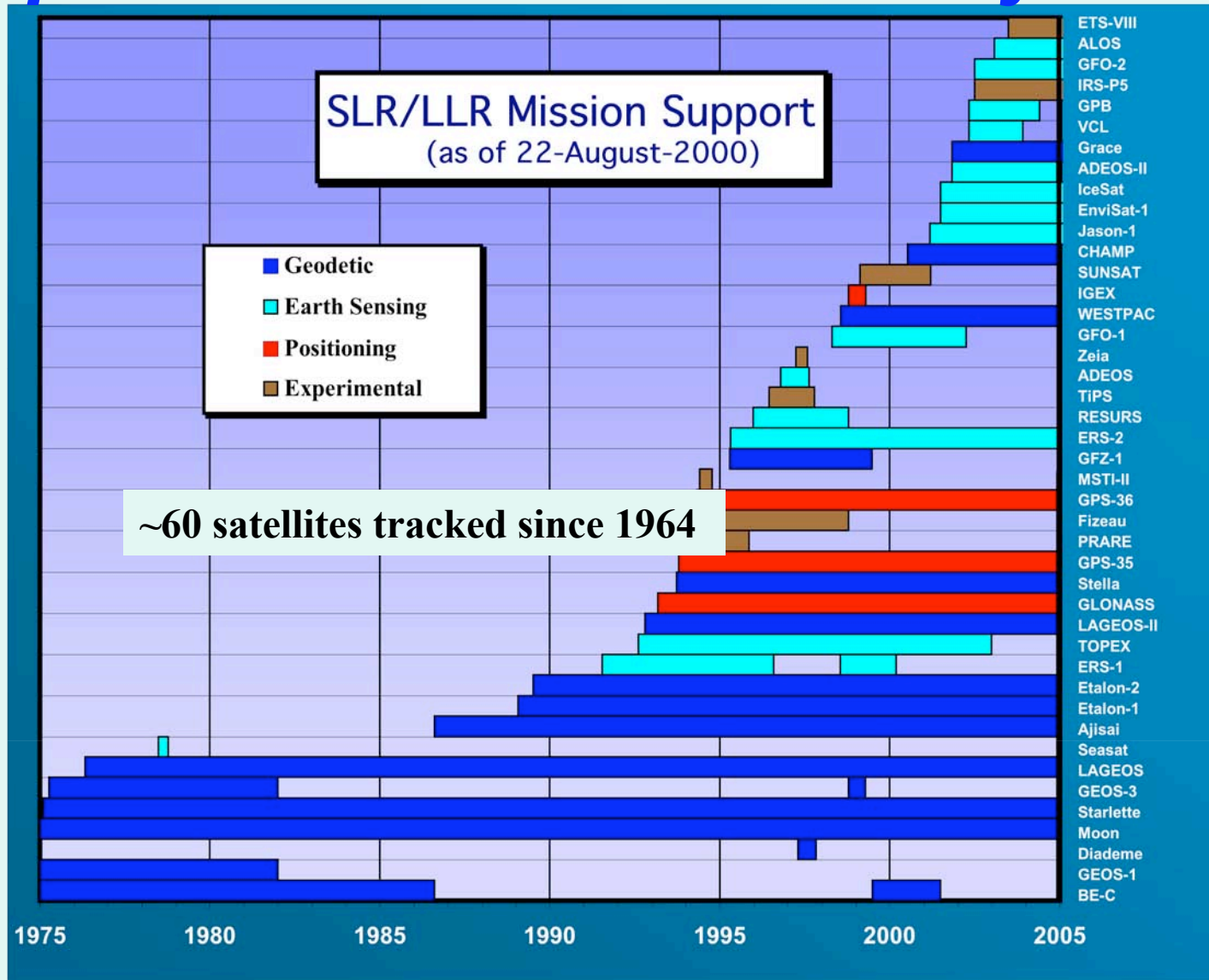


Science Applications of Satellite and Lunar Laser Ranging

- **Earth Gravity Field**
 - Static medium to long wavelength components
 - Time variation in long wavelength components
 - Mass motions within the solid Earth, oceans, and atmosphere
- **Lunar Physics (LLR)**
 - Centimeter accuracy lunar ephemerides
 - Lunar librations (variations from uniform rotation)
 - Lunar tidal displacements
 - Lunar mass distribution
 - Secular deceleration due to tidal dissipation in Earth's oceans
 - Measurement of $G(M_E + M_M)$
- **General Relativity**
 - Test/evaluate competing theories
 - Support atomic clock experiments in aircraft and spacecraft
 - Verify Equivalence Principle
 - Constrain β parameter in the Robertson-Walker Metric
 - Constrain time rate of change in G
- **Future Applications**
 - Global time transfer to 50 psec to support science, high data rate link synchronization, etc (French L2T2 Experiment)
 - Two-way interplanetary ranging and time transfer for Solar System Science and improved General Relativity Experiments (Asynchronous Laser Transponders)
- **Terrestrial Reference Frame (SLR)**
 - Geocenter motion
 - Scale (GM)
 - 3-D station positions and velocities (>50)
- **Solar System Reference Frame (LLR)**
 - Dynamic equinox
 - Obliquity of the Ecliptic
 - Precession constant
- **Earth Orientation Parameters (EOP)**
 - Polar motion
 - Length of Day (LOD)
 - High frequency UT1
- **Centimeter Accuracy Orbits**
 - Test/calibrate microwave navigation techniques (e.g., GPS, GLONASS, DORIS, PRARE)
 - Support microwave and laser altimetry missions (e.g., TOPEX/Poseidon, ERS 1&2, GFO-1, JASON, GLAS, VCL)
 - Support gravity missions (e.g. CHAMP, GRACE, Gravity Probe B)
- **Geodynamics**
 - Tectonic plate motion
 - Regional crustal deformation



Space Missions Tracked by SLR



SLR Retro-Reflector Array (RRA): GPS 35,36

32 cubes – each 28mm

Aluminum coated reflective surfaces

Array shape: planar square

Array size: 239 x 194 x 37 mm

Array mass: 1.27 kg



Retro-Reflector Array (RRA): JASON (GFO, ADEOS-II)

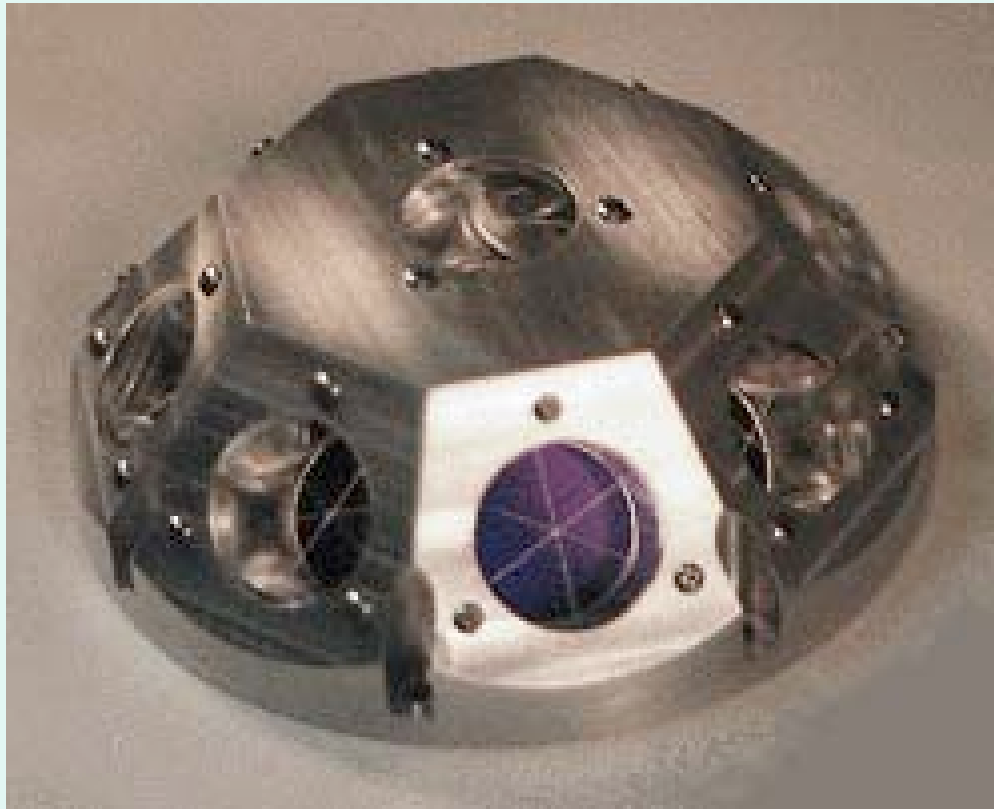
9 cubes – each 32 mm - 1 nadir pointing and 8 on sides

Research grade radiation resistant suprasil quartz, silver coated

Array shape: hemispherical

Array size: 16cm diameter

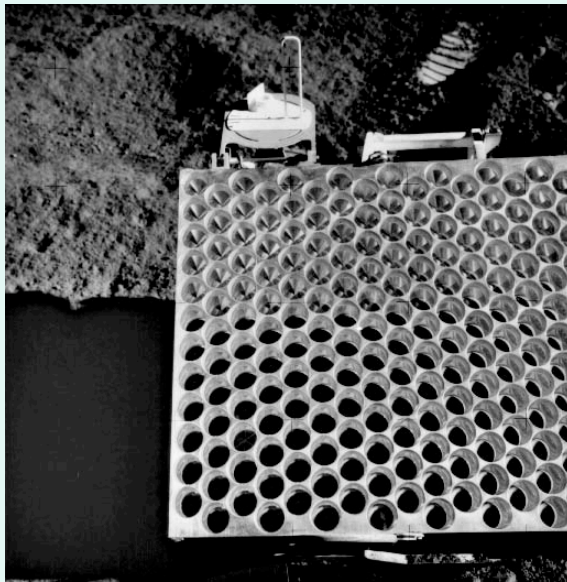
Array mass: 731 gm



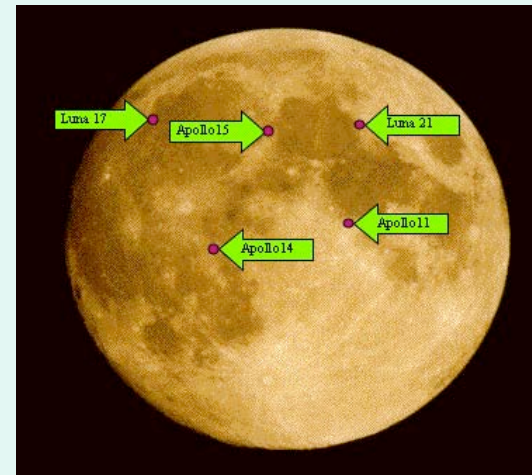
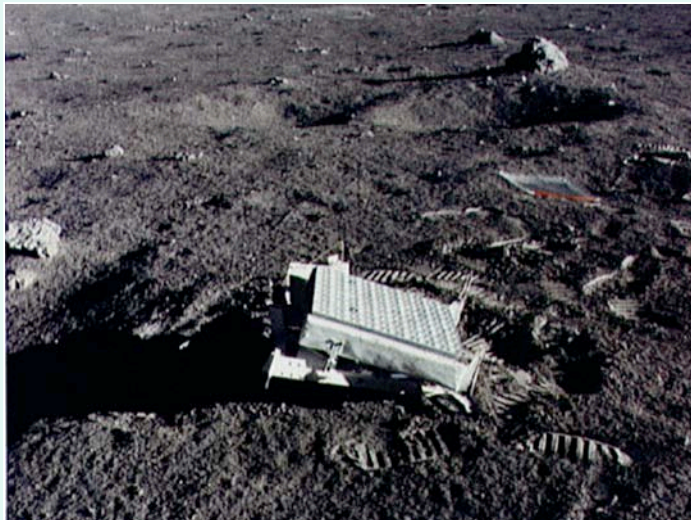
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Lunar Laser Ranging (LLR) to retro-reflectors

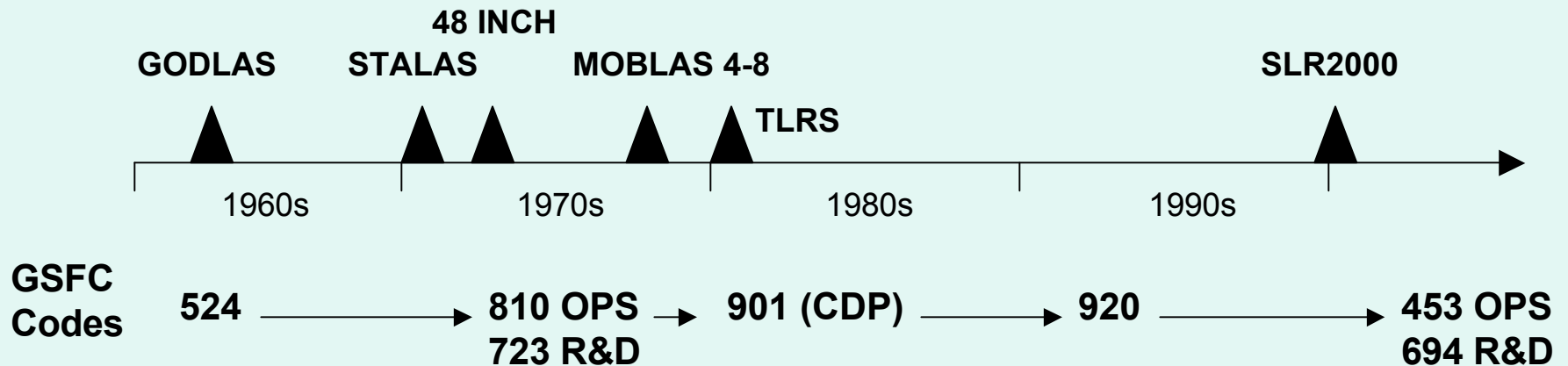


- There are 5 retro-reflectors arrays: 3 Apollo and 2 Luna.
- Apollo RRA's have 3.8 cm cubes. Apollo 11 & 14 have 100, Apollo 15 has 300.
- Regularly tracked by only a few stations. NASA funded University of Texas (MLRS) has successfully ranged continuously since 1970s. Ranges are accurate to a few centimeters.





SLR at GSFC



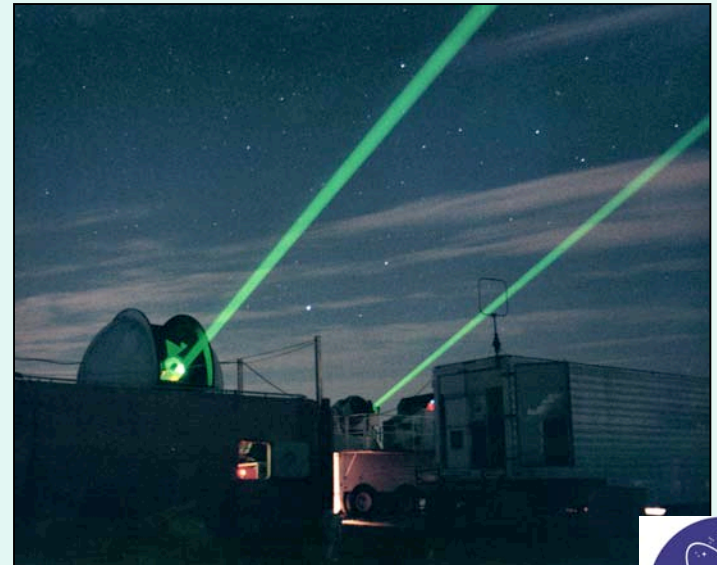
GSFC invented and developed Satellite Laser Ranging and continues to advance SLR R&D, however, there have been many contributors to SLR over the years, including SAO & U.Texas in U.S. and many international groups.



NASA/GSFC Satellite Laser Ranging (SLR) Network

GSFC Firsts (a 40+ year history!)

- **1964:** First successful demonstration of SLR to Beacon Explorer 22-B satellite at GSFC (3 m ranging)
- **1968-1976:** NASA, CNES, and SAO SLR systems carried out first meter level global geodetic and gravity field measurements using reflectors on remote sensing satellites
- **1969:** NASA Apollo 11 mission places first retroreflector array on Moon to begin international Lunar Laser Ranging (LLR) effort.
- **1975-1976:** CNES and NASA launched first passive satellites dedicated to SLR (Starlette and LAGEOS) to begin modern space geodetic era
- **1975-1979:** NASA builds up SLR network for POD support of GEOSAT and SEASAT ocean altimetric missions (10 - 20 cm ranging).
- **1979-1993:** NASA Crustal Dynamics Project (CDP) provides focus for further technology development (1 cm ranging) and international cooperation in defining contemporary tectonic plate motions, regional crustal deformation, Earth Orientation Parameters, Earth gravity field etc.
- **1992-present:** Various US and European remote sensing missions (e.g. ERS-1 & 2, TOPEX/Poseidon, GFO) rely heavily on centimeter orbits provided by SLR. NASA provides the world's data most precise data and until budget cuts in 2003, provided half of the global SLR data.
- **1998-present:** GSFC selected as the Central Bureau (CB) for the new International Laser Ranging Service (ILRS). The CB is responsible for overseeing global operations of 40 international stations providing cm-accuracy orbits for 20 artificial satellites (and the Moon) and ensuring that all ILRS stations, operations, data, and analysis centers adhere to ILRS standards.



Goddard Geophysical and Astronomical Observatory (GGAO) formerly Goddard Optical Research Facility (GORF)

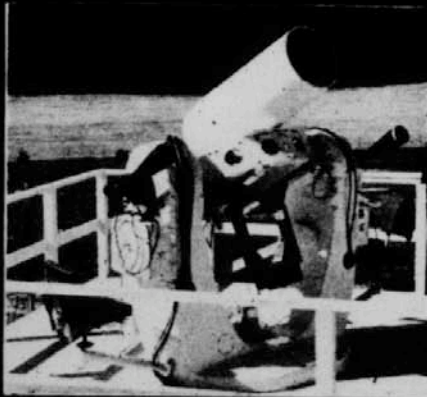


- Located ~ 3 miles from GSFC in middle of BARC on Springfield Road.
- Home to MOBLAS-7, 48" telescope, VLBI MV3, GPS, and numerous other facilities and experiments.
- GGAO has been the site of all NASA SLR system development, testing and collocations. The Italian MLRO system, the Saudi SALRO, and other ILRS systems have also been developed and tested at site.



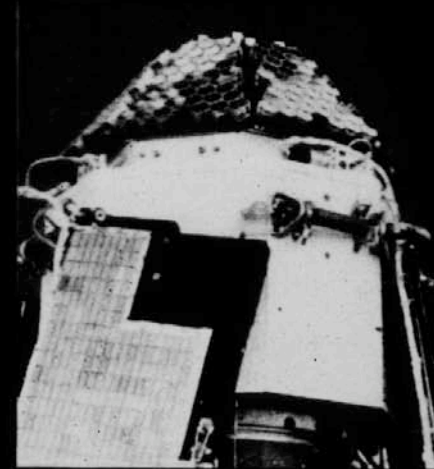
**GSFC records first SLR returns ever on Oct 31, 1964
(GSFC team lead by Henry Plotkin)**

SATELLITE LASER RANGING - 1964



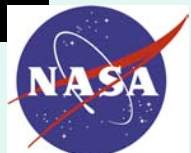
**TRANSMITTING LASER AND
RECEIVING TELESCOPE,
MOUNTED ON A MODIFIED
NIKE-AJAX RADAR PEDESTAL.**

GODLAS



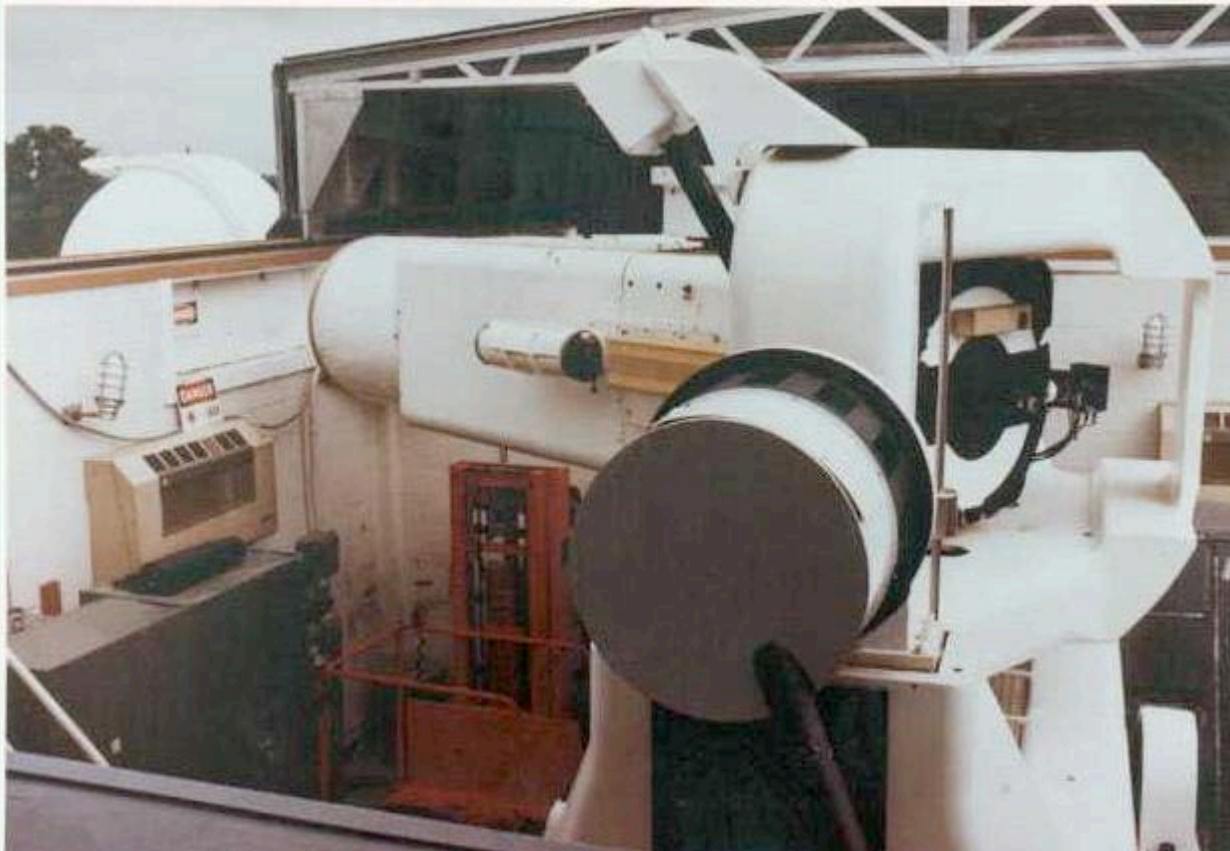
**THE BEACON EXPLORER-B
SATELLITE WITH ARRAY OF
CUBE-CORNER REFLECTORS.**

**BE-B: first satellite with
retro-reflectors**

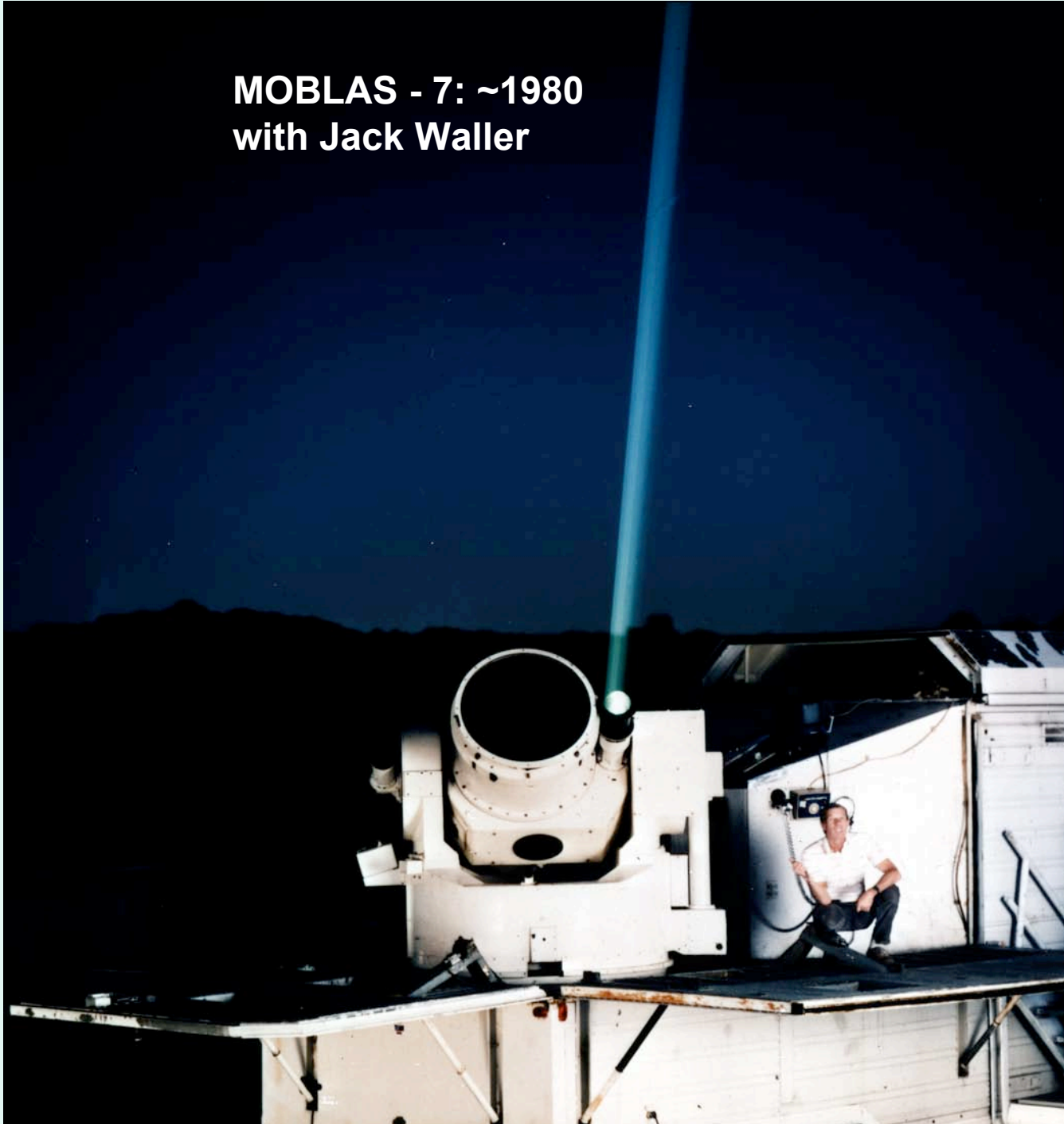


STALAS

- Developed in early 1970s as a “stationary laser” system at GORF.
- X-Y mount with 61cm (24”) telescope.
- Initial system had 1 Hz ruby (694nm) laser.



MOBLAS - 7: ~1980 with Jack Waller



-Systems built in 1978
by Contraves
(telescope & mount),
and BFEC
(electronics).

- 76 cm (30") diameter
telescope.

- Laser (now): 5Hz,
532nm, 100mJ.

-5 systems, all still
operating, now
located in:

California (Mon.Peak)
Australia
South Africa
Maryland (GGAO)
Tahiti.



48 Inch Telescope Facility at GGAO





48" Telescope Facility (aka 1.2 m Telescope) Located at GGAO

- **Built in 1973-74 by Kollmorgen Corporation as multi-user facility**
- **Arcsecond precision tracking**
- **R&D Facility used by many groups:**
 - Field testing of bread board for optical heterodyne spectrometers in 1970s & 1980s (M.Mumma & colleagues)
 - Automated guiding and two-color refractometry (D. Currie/UMd, D. Wellnitz/UMd): 1970s.
 - Lunar laser ranging test facility (C. Alley/UMd): 1980s.
 - Comparison of one way propagation times of laser pulses (East-West vs West-East) by C. Alley and R. Nelson in 1983.
 - Single and two-color satellite laser ranging test bed (Zagwodzki, Degnan, McGarry): 1980s & 1990s.
 - **MLA Earthlink Calibration Experiment: May 2005.**

and many others...



Code 723 was the GSFC Laser (& SLR) R&D Group in the 1970s and 1980s



Code 723: ~1985

Who are these people and why do they look so young?

NASA's next Generation of SLR stations: SLR2000

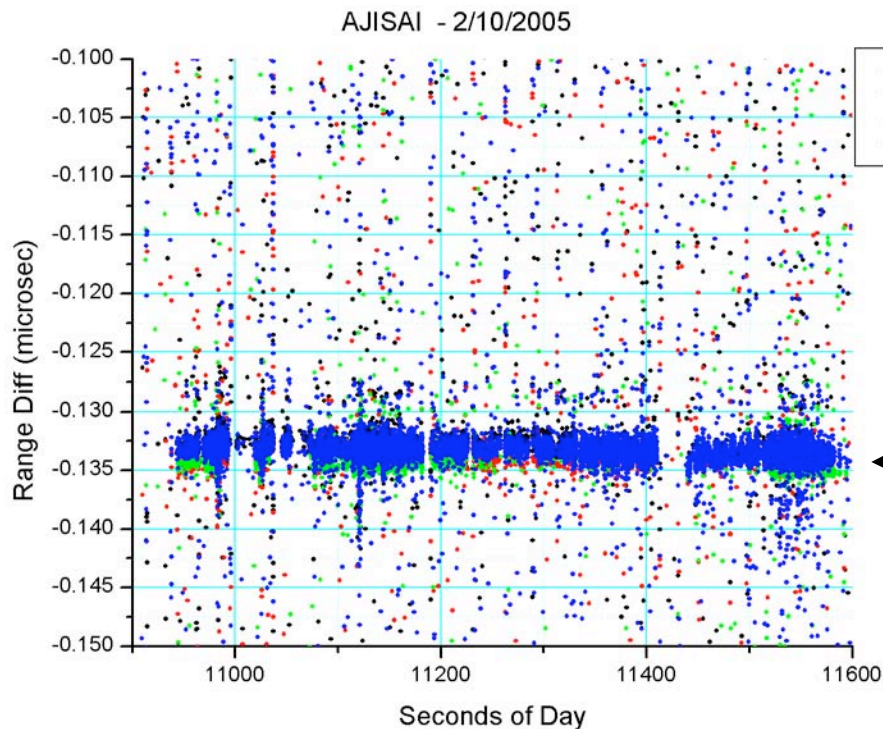


Prototype at GGAO: ~2002



SLR2000 Prototype at GGAO

- SLR2000 was concept developed by John Degnan in the 1990s, with many innovative ideas requiring R&D efforts.
- System designed in the mid 1990s, development began in late 1990s. Technical development is now in code 694 (SLR OPS is in code 453).
- Currently tracking LEO satellites. Nearing the completion of major technical challenges. Expect to have a working semi-automated system by end of this year.



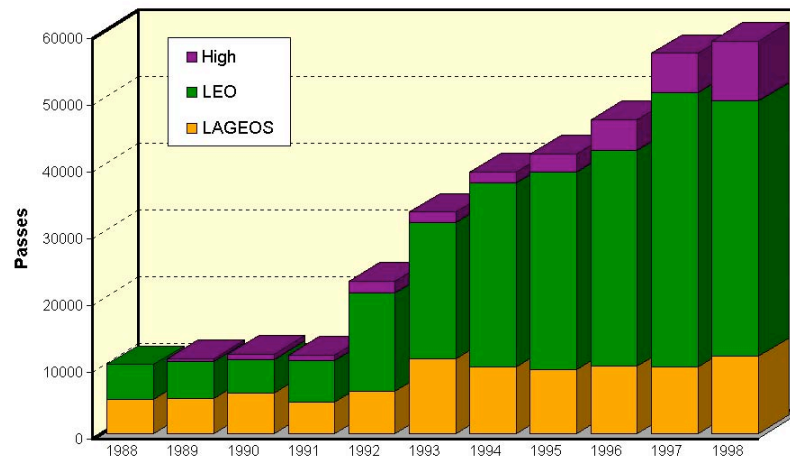
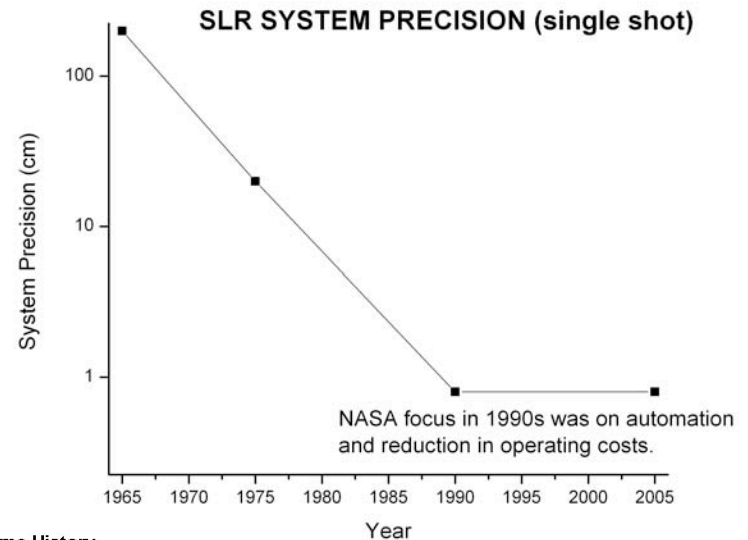
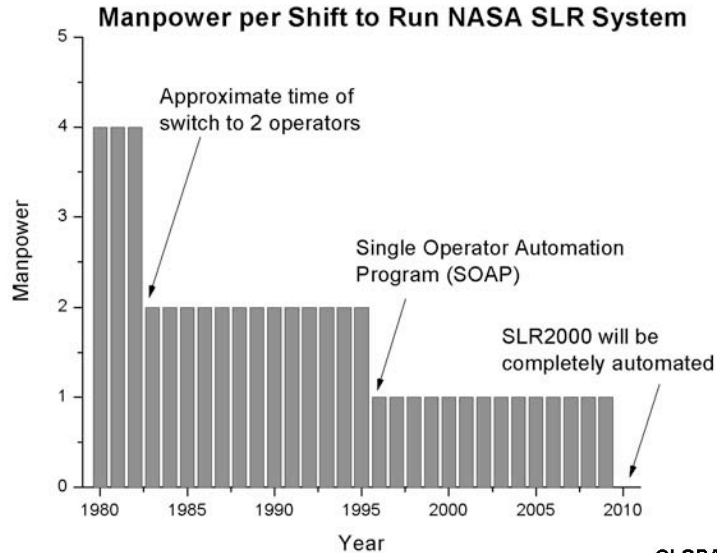
OMC ranging plot

NASA plans to build 12 new SLR systems (contracted out) and will replace all of its existing SLR Network with systems using technology developed on this prototype.



SLR TRENDS

SLR Precision has improved from meter to sub-cm level.
NASA operating costs have decreased (reductions in manpower).
And global data volume has been increasing.





NASA SLR is part of the International Laser Ranging Service (ILRS)

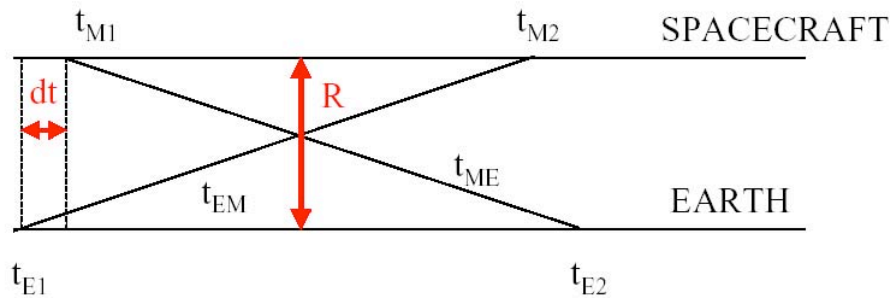
The International Laser Ranging Service (ILRS) began in 1998 and provides global satellite and lunar laser ranging data and their related products **to support geodetic and geophysical research activities as well as IERS products important to the maintenance of an accurate International Terrestrial Reference 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](http://www.iau.org/science/geodesy/iaag/) (IAG).

GSFC has been chosen to run the **Central Bureau** of the ILRS. The Central Bureau is responsible for overseeing global operations of 40 international stations



INTERNATIONAL LASER RANGING SERVICE (ILRS) NETWORK





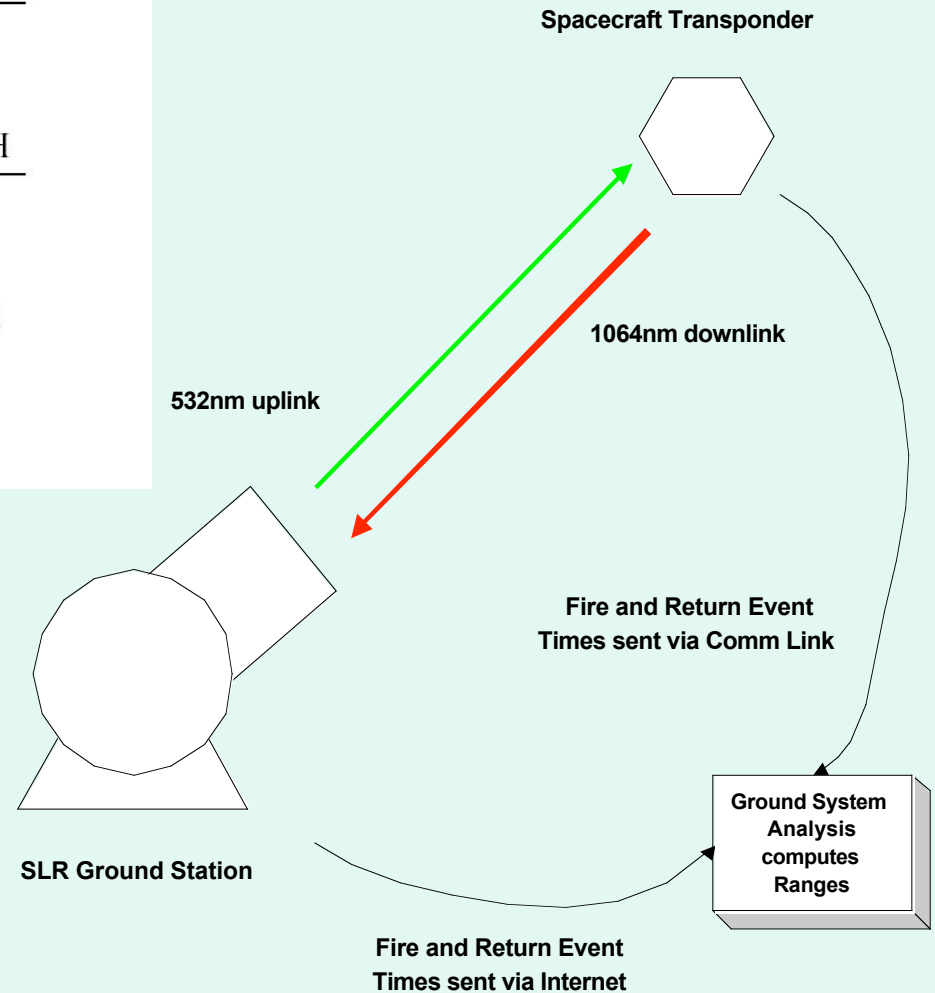
Range $R = c(t_{ME} + t_{EM})/2 = c [(t_{E2} - t_{E1}) + (t_{M2} - t_{M1})]/2$

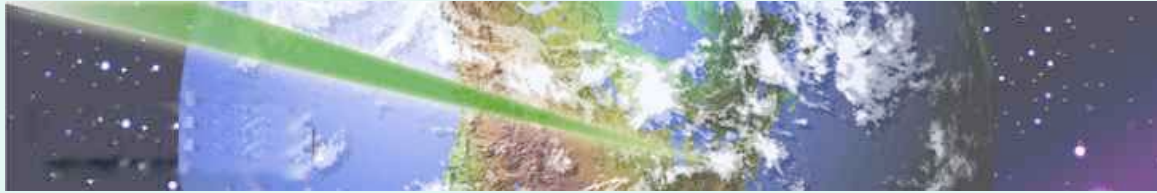
Clock Offset $dt = [(t_{E2} - t_{E1}) - (t_{M2} - t_{M1})]/[2(1 + R/c)]$

The Future of Laser Ranging: Asynchronous Transponders

$1/R^2$ signal loss for transponders,
 $1/R^4$ signal loss for RRA ranging.

Transponders are the only viable option
for ranging to planetary distances.





For further information on the History of Satellite Laser Ranging, see:

“Thirty Years of Satellite Laser Ranging”, John Degnan, Keynote Speech, Proceedings of the Ninth International Workshop on Laser Ranging Instrumentation, Canberra, Australia, November 7-11, 1994.