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Session 1
Historical Overview and Path to Present Day Requirements
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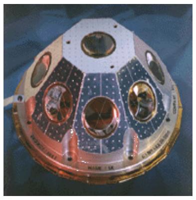
Satellite and Lunar Laser Ranging provide precise range measurements between a ground station and a retroreflector-equipped satellite or the moon using ultra short laser pulses corrected for refraction, satellite center of mass, and the internal delay of the ranging machine. Laser ranging is the only Space Geodesy Technique that measures range directly. It provides unambiguous centimeter accuracy orbits and long-term stable time series to accurately discern orbital signatures from geophysical effects.

The first laser ranging to satellites took place from NASA GSFC in October 1965 on NASA's Beacon-B satellite, which had been equipped with an array of back-coated cornercubes. Over the next several years, arrays were placed on the NASA Beacon-C, Geos-1, and Geos-2 satellites and the Diademe-1, Diademe-2, and PEOLE satellites launched by CNES. Ground networks included stations operated by NASA, CNES, and the Smithsonian Astrophysics Observatory (SAO). Early SLR activities supported inter-comparisons and verification of radio and camera tracking techniques; SLR tracking was working toward the meter level of accuracy. A second application was space geodesy: including size and shape of the Earth and gravity field. The combination of SLR with the other techniques were the basis for some of the early programs and campaigns including NGSP, ISAGEX and EPSOC that led to early Earth models such as the Smithsonian Standard Earth and the Goddard Earth Model. With ranging goals at the meter level, satellite configurations focused less on signal accuracy and more on getting enough return signal back; as such they often had had large arrays.

Lunar Laser Ranging (LLR) had long been in the conceptual stage through planning and organizing by scientists such as Professors Robert Dicke and Carroll Alley. Success came with the array landed by Apollo 11 in July 1969 and the ranging from the McDonald Observatory shortly thereafter. The array was the first use of uncoated cornercubes. Over the next few years, additional lunar arrays were placed on the lunar surface by Apollo 14 and 15, and on the Russian Lunakhod. Envisioned in the long-term were cm accuracy measurements to study the dynamics of the moon and measurement of fundamental constants.

Geos-3, launched in 1975 was the first geodetic mission with a radar altimeter aboard to measure the topography of the ocean surface to study ocean dynamics and gravity field (geoid); mapping accuracy was about 50 cm. SLR was part of the POD systems and provided altimeter calibration, sought to the 10 cm level. The array of coated cornercubes was placed in a ring around the radar altimeter dish. A similar array was placed on Seasat, launched in 1978 with a more advanced radar altimeter. The mission was short-lived, but demonstrated advances in altimetry and SLR calibration. TOPEX-Poseidon was launched in 1992, with two improved altimeters and a suite of tracking techniques including an SLR and GPS. Although sub-decimeter accuracy was the goal, the array was still placed on a ring around the altimeter dish. The ring shaped array with masking and other constraints ended up being a nuisance and considerable analysis and modeling was required to extract sub-decimeter accuracy. The mission was very successful and SLR ended up being the only high accuracy tracking technique available in the final year of the mission. Recognizing the need for more accurate ranging data on subsequent altimeter missions, the community implemented more compact arrays on ERS-1, ERS-2, Jason-1,



Jason-2, Envisat, ICESat, CryoSat, and other missions. With a combination of tracking techniques, orbital accuracies on LEO satellites were now at the 1-2 cm level. Several array designs of similar configuration that limit the reflection to one or two cubes are now available to support cm level tracking.

The path toward using SLR for studies of Earth dynamics was well articulated in the Williamstown Conference, “The Terrestrial Environment: Solid-Earth and Ocean Physics” at the Williamstown Conference in 1969. The conference, chaired by Professor Bill Kaula, drew a large audience of participants from the geosciences community and issued its report filled with works like dynamics, motion, topography, change, etc. One of many concepts discussed at the meeting was a high mass-to-area, passive, spherical satellite, covered with retroreflectors for studies of Earth dynamics at cm accuracies. The first proposal (Weiffenbach et al.) was an 8000-pound sphere with a uranium core designed as a backup payload for the Skylab emergency rescue vehicle. The vehicle was never built, and sights refocused to the more practical LAGEOS design. The first geodetic satellite was Starlette, launched in 1975 by CNES for geodynamics and gravity field refinement. This satellite posed a serious challenge during acquisition; the weather was very cloudy and it took several weeks and lots of searching by the SAO Baker Nunn Camera network to secure a prediction quality orbit. A sister satellite, Stella was launched in 1993.

The LAGEOS-1, built by NASA, was launched in 1976; LAGEOS-2, built by ASI, was launched in 1992. The LAGEOS cornercubes were uncoated to limit the responding cubes and to reduce the width of the satellites signature. The Russians launched the higher Etalon satellites in 1989, and LARES was added to the geodetic satellites in 2012. The LAGOES, Etalon, and LARES satellites form the current satellite constellation used for the modeling and refinement of the reference frame, which is now at the cm level.

Laser ranging has now expanded its realm to include time transfer experiments (T2L2), one-way ranging to lunar orbiters (LRO) and interplanetary spacecraft (MLA, MOLA), data relay (Mona Lisa picture), and ranging to higher satellites in GNSS and geosynchronous orbits.

The Global Geodetic Observing Systems (GGOS) was established by the International Association of Geodesy (IAG) to provide the geodetic infrastructure necessary for monitoring the Earth systems and global change. The most stringent requirement is the improvement of the reference frame to support mm accuracy measurements and 0.1mm/year stability. The primary driver for these requirements is ocean dynamics, but many other disciplines follow closely behind. The IAG Services, now components of GGOS, are gearing up for this next generation challenge.

To meet these challenges, current trends in laser ranging include: higher repetition rates for faster data acquisition; faster slewing rates for more rapid target acquisition and satellite interleaving; more accurate pointing for link efficiency; narrower laser pulses for greater precision; new detection systems for greater accuracy; greater temporal, spatial, and spectral filtering for improved noise conditions; and more modular and off-the-shelf components for lower fabrication, operations, maintenance costs. Satellite designs are focusing on narrower, better-defined return signal pulse shapes for more accurate satellite center of mass offsets values.