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SCF_Lab
Satellite/Lunar/GNSS
laser ranging and altimetry
Characterization **F**acilities **Lab**oratory

SCF_Lab is located in Frascati, Italy, at walking distance from ESA-ESRIN

http://www.lnf.infn.it/esperimenti/etrusco/

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Partners and National Collaborations:

ASI-Centro di Geodesia Spaziale

Ministry of Defense & Aeronautica Militare Italiana

International Collaborations:

International Laser Ranging Service

NASA-GSFC

NASA-SSERVI

ESA

Univ. of Maryland at College Park

Member of ILRS and Host of:

International Technical Laser Workshop 2012 (ITLW-12) on

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

November 5-9, 2012

In conjunction with a one-day Workshop

"ASI-INFN ETRUSCO-2 Project of Technological Development and Test of SLR Payloads for GNSS Satellites "

November 7, 2012
Frascati National Laboratories of the INFN
Frascati (Rome), Italy

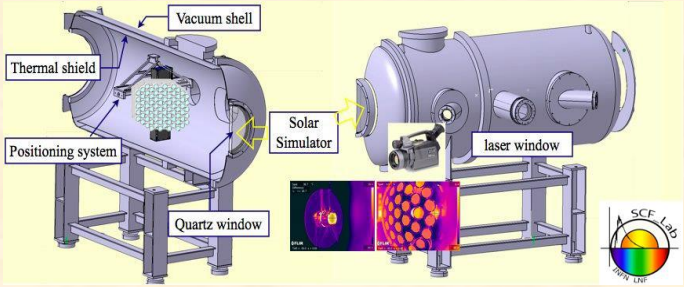
ETRUSCO R&D PROGRAM

(Extra Terrestrial Ranging to Unified Satellite Constellations)

- Background: continuation of ETRUSCO interdisciplinary R&D project of INFN (2006-09), dedicated to the characterization of Satellite Laser Ranging (SLR) of Corner Cube Retroreflectors (CCRs) for the Global Navigation Satellite System (GNSS).
- ETRUSCO2: Project of technological development (2010-13) in response to a nation-wide call by ASI in 2007. Main goal: development and SCF-Test of GNSS Retroreflector Arrays, targeted to Galileo & GPS-3 and open to other GNSS.

SCF: a Unique and Unprecedented OGSE (Optical Ground Support Equipment)

Our key to experimental innovation is the concurrent measurement and modeling of the optical Far Field Diffraction Pattern (FFDP) and the temperature distribution of SLR payloads under space conditions accurately simulated in the laboratory, produced with a close-match solar simulator. The SCF (Satellite/lunar/GNSS laser ranging and altimetry Characterization Facility) is a set of specialized instruments that allow us to recreate a realistic space environment around the tested CCRs and the simultaneous monitoring of temperature variations of the tested payloads and of the optical performance, in terms of FFDP and wavefront Interferogram. This new industry-standard space test is called SCF-Test, a background intellectual property of INFN [1].
The SCF is very versatile for its large number of measurement ports (side and back), very long horizontal translations and capabilities for lunar laser ranging (LLR) and laser altimetry CCR payloads.



Schematic view of SCF cryostat with: IR picture of the LAGEOS Sector, IR camera and SCF_LAB logo.

Front and rear view of SCF cryostat. The optical instrumentation is in the black enclosure.

ETRUSCO-2 Work Program

- Definition of an improved and enhanced "**SCF-Test/Revision-ETRUSCO-2**"
  - Implementation of advanced and innovative operational procedures for the test of the "*GNSS Critical Orbit*" (**GCO**) developed for Galileo IOV [2]
  - Integration of the Wavefront Fizeau Interferometer (**WFI**)

- Design and construction of a 2nd OGSE optimized for GNSS constellations: **SCF-G**
  - Inherits from SCF, partly built by INFN.
  - INFN part includes: state-of-art WFI insensitive to vibrations and air turbulence; 2nd, new Solar Simulator (SS)

- Integration of SCF-G with SCF_Lab infrastructure.

- Reduced-size prototype GNSS Retroreflector Array built with Hollow technology (**GRA-H**) according to INFN Guidelines
  - Inherits from R&D done with GSFC
  - 7 hollow CCRs, 6 on a ring and one in the center
  - Characterized with SCF and thermo-structural modeling

- Full-size prototype GNSS Retroreflector Array (**GRA**) for Galileo & GPS-3 built according to INFN Guidelines
  - Inherits from LAGEOS
  - 55 CCRs of solid retroreflector technology
  - Characterized with the SCF-G according to the new SCF-Test/Revision-ETRUSCO-2

- Space geodesy study on the SLR of GNSS and gravitational redshift study with the SLR of Galileo with ASI-GCS

SCF-G: 2nd OGSE Facility for GNSS

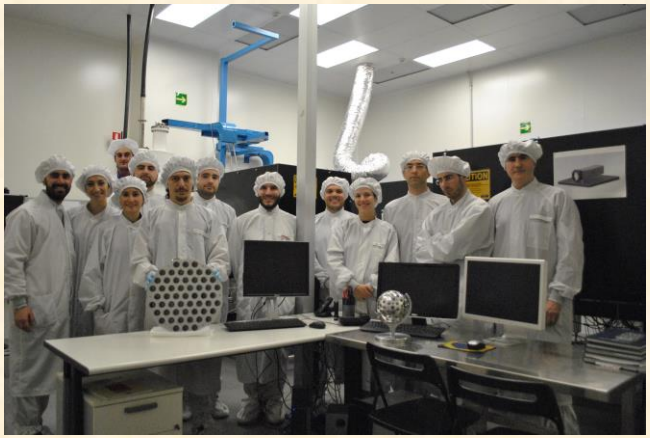
Based on the experience made with the SCF, we designed and built the "Satellite laser ranging Characterization Facility optimized for Galileo and GPS-3", SCF-G, which is operative in the same Clean Room infrastructure of INFN, the SCF_Lab.

Front and rear view of the SCF-G cryostat.

In 2011, in order to provide a dedicated infrastructure, INFN-LNF has completed the construction of a new Clean Room of class 10,000 (ISO 7) of about 85 m^2, kept at an isothermal temperature of about 21°C, which hosts both OGSEs.

SCF_Lab ISO 7 Clean Room.

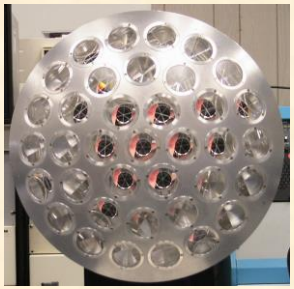
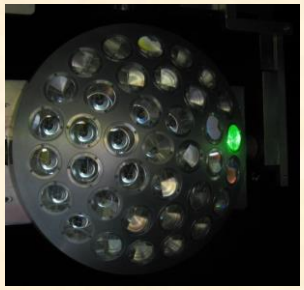
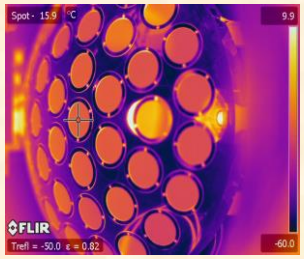
The primary goal of these unique OGSEs is to provide critical diagnostic, optimization and validation tools for SLR to all GNSS programs. The capability will allow us to optimize GRA (GNSS laser Retroreflector Arrays) designs to maximize ranging efficiency, to improve signal-to-noise conditions in daylight, to provide pre-launch validation of retroreflector performance under space conditions accurately simulated in the laboratory, as well as to characterize 'as-built' payloads.

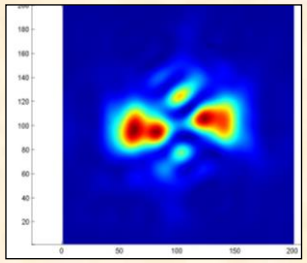


Some members of the SCF_Lab Team.

LAGEOS Sector

Uncoated retroreflectors are deployed on the SLR standard reference payload of the ILRS: LAGEOS (LAser GEOdynamics Satellite). Similarly, the uncoated Apollo CCRs are the standard reference for LLR. Uncoated retroreflectors with a properly insulated mounting (like Apollo and LAGEOS) can minimize thermal degradation and significantly increase optical performance and, thus, they are emerging as the recommended design for GNSS satellites. Therefore, in order to "calibrate" our SCF-Test, in 2009 we tested an engineering model of the LAGEOS satellite, given to us on loan by NASA-GSFC. LAGEOS is a satellite designed by NASA and launched in 1976. It is a passive sphere with a diameter of 60 cm, mainly made of Aluminum, covered by 426 uncoated CCRs. Since its launch, the satellite has provided important information on Earth's shape, gravitational field and tectonic plate movements, but, most important, due to its high mass-to-area ratio and the stability of the orbit, it gives a reference for the Earth's center of mass (geocenter), along with other cannonball SLR targets.

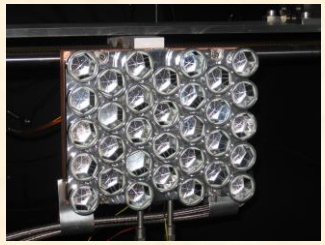
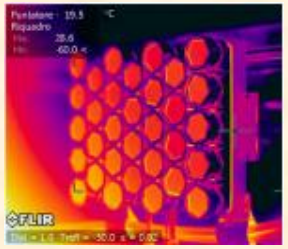






LAGEOS Sector: at GSFC (top left); in the SCF, temperature-controlled by an interface Cu plate, with laser illuminating one CCR (top right); IR thermogram (bottom left); CCR FFDP in velocity aberration plane in microrad units (bottom right).

GPS-2 Laser Retroreflector Array (LRA)

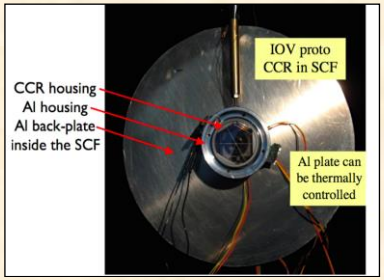
A flight model LRA of the GPS-2 constellation was given on loan by the University of Maryland to INFN-LNF for SCF-Testing and to measure its nominal optical ('lidar') cross section [1]. It is a rectangular array of 32 CCRs positioned on an aluminum tray of 239 mm length, 194 mm width and 1.27 kg weight.

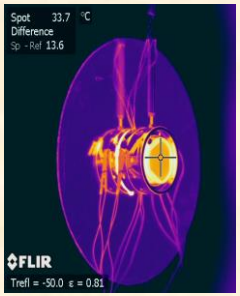



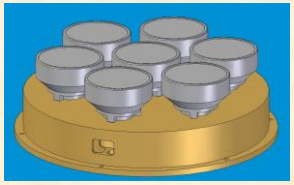
Third GPS flight array inside the SCF (left) and an IR thermogram taken during Solar Simulator illumination (right).

Galileo IOV Retroreflector

In 2010 INFN performed an extensive SCF-Test campaign requested by ESA on a prototype Galileo IOV retroreflector. This is a fused silica uncoated CCR, deployed in planar arrays of 84 units.

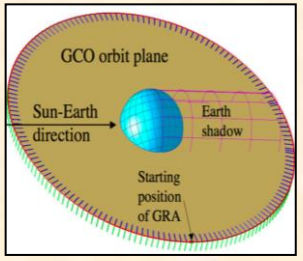


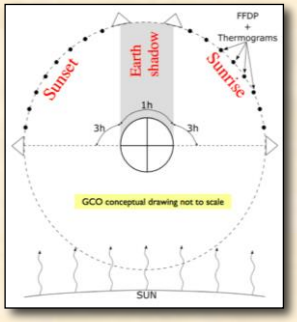


Galileo IOV CCR: front view (bottom left); setup inside SCF for GCO test (top left); IR thermogram (top left). IOV engineering model LRA built by LNF for further SCF-Testing (bottom right).

We refined the SCF-Test introducing the GCO (GNSS Critical Orbit). Galileo satellites have a quasi-circular orbit with orbital period of about 14 hrs. We simulated half of the orbit, from the moment in which sunrays rise above the CCR front face until they fall on the other side for about 7 hrs. SCF-Test results are in [2].



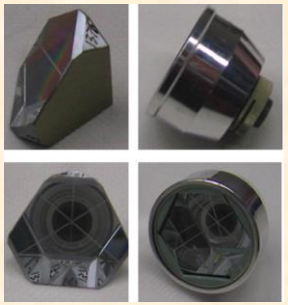
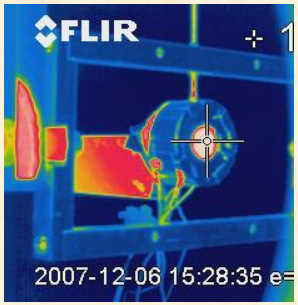


GNSS Critical Orbit (GCO) in space (left); GCO SCF-Test concept with measurement sequence & Solar Simulator illumination (right).

GLONASS Retroreflector

In 2007 and 2008 we SCF-Tested retroreflectors originally adopted by GLONASS. They are Al back-coated CCRs, with hexagonal front face inscribed in a circle of ~26mm in diameter. The CCR is inserted into a polished Aluminum housing screwed into the Aluminum baseplate of the LRA. LRAs of the 32 GLONASS-type CCRs (identical to the flight LRA characterized at the SCF_Lab) were deployed on the GPS-35 and GPS-36 satellites. GLONASS LRAs were deployed also on GIOVE-A and GIOVE-B.

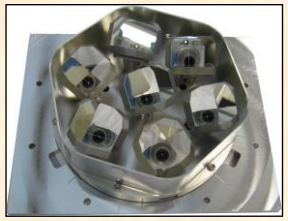
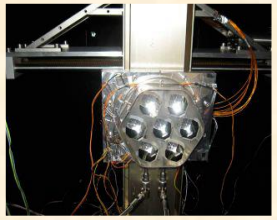
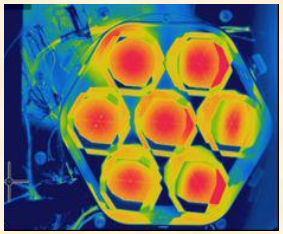
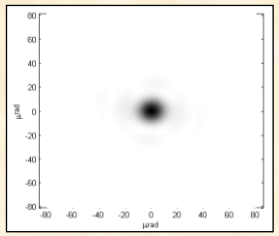
SCF-Test results reported in [1] have shown that GLONASS suffers severe degradation of the optical performance when operated in space conditions. From GLONASS-115, this Al back-coated CCR has been abandoned by modern GNSS (including Galileo IOV) in favor of uncoated CCRs.

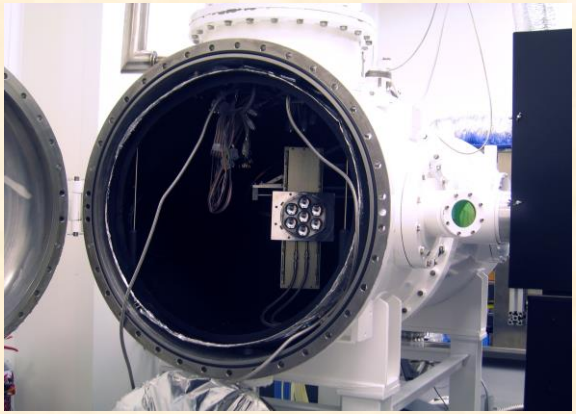
Old generation GLONASS/GPS/GIOVE CCR: bare and mounted in its Al housing (left); IR thermogram during SS illumination (right).

GRA-H

To verify the readiness of hollow retroreflectors for LRAs, we designed and built the GRA-H as a reduced-size prototype made of 7 hollow CCRs of 38.1 mm (1.5") of optical clear aperture, purchased from PLX, Inc. Due to ITAR restrictions, only CCRs with zero values of the dihedral angle offsets were available for the ETRUSCO-2 project. All CCRs have reflecting faces made of a Pyrex substrate coated with a high reflectivity film. Two sets of retroreflectors were procured, with Aluminum and Silver coatings. An Invar foot mount holds one of the reflecting faces onto which the others are glued. The GRA-H has been extensively characterized with the SCF and the results reported at the ITLW-12 and ETRUSCO-2 workshops.

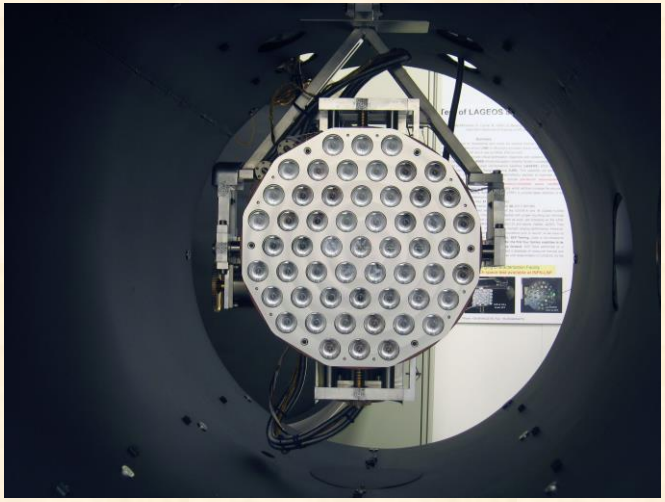
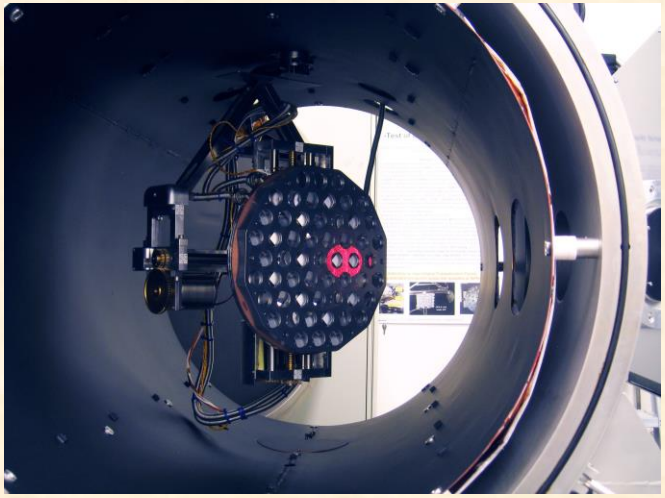
GRA-H fully assembled (top left), inside the SCF with PT100 temperature probe on each retroreflector (top right); IR picture during SS illumination (bottom left); FFDP of one of its CCRs.



GRA-H installed on the roto-translation positioning and thermal control system in the SCF (IR window in green color on the right).

GRA

Since the performance of the GRA-H hollow retroreflectors was not found satisfactory, as foreseen by the ETRUSCO-2 project guidelines, we designed and built the GRA using the consolidated fused silica retroreflector technology space-qualified first with Apollo LRAs and later with LAGEOS. Some of the criteria used in the GRA design are the ones endorsed by ILRS and reported in [1].

GRA (with the majority of its CCRs mounted) installed on the roto-translation positioning and thermal control system inside the SCF-G (top); GRA CCRs illuminated by external laser interrogation beam (bottom).

The GRA will be characterized with the SCF-G, according to the procedures foreseen by the SCF-Test/Revision-ETRUSCO-2, which include investigation of the GRA optical performance and thermal behavior along the GNSS Critical Orbit, under exposure to the Solar Simulator illumination. The GRA optical performance will be assessed in terms of FFDPs and of WFIs of its retroreflectors. The thermal behavior will be determined with IR thermometry and contact probes.

Milestones and Background Intellectual Properties

- 2005-06: Approval of ETRUSCO by INFN-LNF/INFN-CSN5 (**Commissione Scientifica Nazionale 5**), construction of SCF
- 2006-07: Development of SCF-Test
- 2007-08: SCF-Test of GPS-2, GLONASS and GIOVE
- 2008: Formal industrial optical acceptance test of 110 flight LARES CCRs for ASI (in isothermal conditions; no SCF-Test)
- 2009: SCF-Test of the NASA-GSFC LAGEOS Sector
- 2010: SCF-Test of the NASA-GSFC hollow CCR.

First-ever SCF-Tests of

- ***GPS-2*** retroreflector array flight model property of UMD
- ***GLONASS*** and Galileo's GIOVE-A and -B CCR prototypes
- ***LAGEOS Sector*** engineering model property of NASA-GSFC
- ***Hollow*** retroreflector prototype provided by GSFC
- ***Galileo IOV*** retroreflector prototype property of ESA
- ***MoonLIGHT*** New generation LLR retroreflector developed for NASA (led by UMD) and for INFN (led by LNF: MoonLIGHT-ILN of INFN-CSN5 and MoonLIGHT-2 of INFN-CSN2). The latter includes development of a laser altimetry CCR (INRRI) and of a specialized SCF-Test at 1064 nm for laser ranging and altimetry to solar system moon and Mars (**SCF-Test/Revision-IR**)

Other Main Projects

- ***ETRUSCO-GMES*** (CSN5 experiment on Copernicus (formerly GMNES) EU flagship program dedicated to Earth Observation
- ***G-CALIMES*** Defense-INFN project on Unification of Galileo and Italian constellations for radar mapping of Earth surface. Continuation and major extension of ETRUSCO program with development of space & ground geometrodynamics networks
- ***AUGUSTUS*** Italy-USA, MAECI bilateral project of the Research area "Marine and Earth Sciences" and study on applications of innovative ground segment devices for EO, GMES and geodesy.

Main References

[1] Dell'Agnello, S., et al, *Creation of the new industry-standard space test of laser retroreflectors for the GNSS and LAGEOS*, J. Adv. Space Res. 47 (2011) 822–842. Galileo Special Issue on *Scientific Applications of Galileo and other Global Navigation Satellite Systems – II*, March 1, 2011, pub. Proc. of "2rd International Colloquium – Scientific and Fundamental Aspects of the Galileo Programme", Padua, September 2009. See also: http://ilrs.gsfc.nasa.gov/about/reports/other_publications.html.

[2] S. Dell'Agnello et al., *ETRUSCO-2, an ASI-INFN Project for the development and SCF-Test of GNSS laser retroreflector arrays*, ESA proceedings of ESA "3rd International Colloquium – Scientific and Fundamental Aspects of the Galileo Programme", Copenhagen, Aug. 31 - Sep. 2, 2011. See also: http://ilrs.gsfc.nasa.gov/missions/satellite_missions/current_missions/ga01_reflector.html.