The INFN-LNF Space Climatic Facility for LARES and ETRUSCO

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Abstract

The construction of the LNF Space Climatic Facility (SCF) started in Frascati, Italy, in 2006. The initial purpose was to study the thermal thrusts (TTs) of LAGEOS I/II satellites and to perform the full space-climatic and laser-optical characterization of the new LARES laser-ranged test mass. In late 2004 the construction of LARES was proposed to INFN, which then gave the scientific approval of the LARES experiment in November 2006.

The modular and evolutionary design of the SCF turned out to be well suited to characterize the thermal and optical performance of retro-reflector CCR arrays deployed on GNSS constellations. For this purpose, the groups of INFN-LNF, Rome-Tor Vergata plus R. Vittori in 2006 proposed to INFN a new experiment, ETRUSCO ("Extra Terrestrial Ranging to Unified Satellite COnstellations"). ETRUSCO was approved by INFN in October 2006. This paper describes the SCF and the first preliminary measurements and thermal simulations.

The SCF Apparatus

A schematic view of the SCF is shown in Fig. 1. The steel cryostat is approximately 2 m length by 1 m diameter. Inside this vacuum shell the shield, black painted with the high emissivity paint Aeroglaze® 306, is cooled down to 77 K by forced LNF2 flow. When the SCF is cold, the vacuum is typically 10^{-6} - 10^{-5} mbar.

The thermal input loads are provided by a Solar Simulator (SS) and an infrared (IR) Earth Simulator (ES). The SS is located outside, behind a quartz window (36 cm diameter, 4 cm thickness), which is transparent to the solar radiation up to 3000 nm. The ES located inside, is an Al black-painted disk (diam. 300 mm) held at 254 K by thermo coolers (TECs). A support fixture on the ceiling holds the prototype in front of the simulators. The distance of prototype from the ES is such to provide the CCRs with the same viewing angle in orbit (~60^{o} for LAGEOS). A Germanium window on the right side of the SCF allows for the acquisition of thermograms of the prototypes with an IR digital camera.

The SS (www.ts-space.co.uk) gives a 40 cm diameter beam with close spectral match to the AM0 standard of 1 Sun in space (1366.1 W/m^2), with a uniformity better than ± 5% over an area of 35 cm diameter. The spectrum is formed from the output of two sources, namely an HMI arc lamp (UV-V), together with a tungsten filament lamp (Red-IR). The quartz halogen lamp (with the tungsten filament) has a power of 12 KW, while the metal halide lamp has 6 KW power. These two sources are filtered such that when the two beams are combined with a beam splitter/filter mirror, the resulting spectrum is a good match to AM0 in the range 400–1800 nm. The spectrum has also been measured also from λ = 1500 nm up to 3000 nm and found to be in reasonable agreement with the AM0 over this extended range. The absolute scale of the SS intensity is established by exposing the beam to a reference device, the *solarimeter*, which is a standard www.epply.com thermopile.

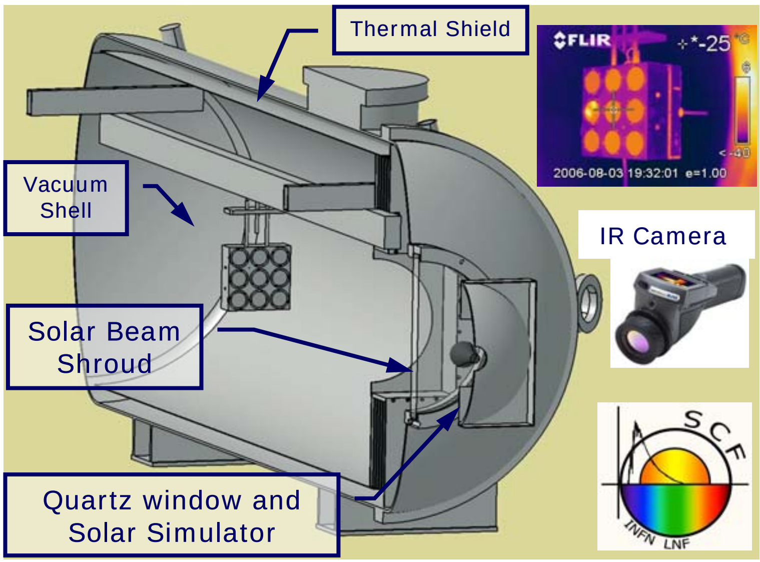

***Figure 1**: The LNF Space Climatic Facility with a retro-reflector array inside.*

The temperature DAQ system consists of an IR camera for non-invasive, high spatial granularity measurements and class-A PT100 RTDs with 4-wire readout. The IR camera is a ThermaCAM® EX320 by http://www.flir.com. The camera focal plane array detector is an un-cooled Vanadium Oxide micro-bolometer with spectral range 7.5 ÷ 13 μm. This camera has a true, built-in 320 x 240 pixel array, field of view/min focus distance 25° x 19° / 0.3 m and thermal sensitivity 80 mK. Since the EX320 factory accuracy is 2 K, the PT100s will be used for cross calibration. The PT100s are certified to have an accuracy of 0.1 – 0.3 K between 273 K and 373 K, which has been checked with a reference thermometer of absolute scale accuracy < 0.1 K, in a range appropriate for LAGEOS. The PT100s are also used below 250 K, outside the working range of the IR camera.

***Figure 2**: The 3×3 LAGEOS matrix built at LNF and the CCR assembly components.*

Thermal Characterization of LAGEOS Retro-reflectors

The thermal relaxation time of LAGEOS and LARES CCRs, τ_{CCR}, has never been measured in realistic climatic conditions. Computations vary by 300%. The goal for LARES and LAGEOS is to measure τ_{CCR} at ≤10% accuracy. This will make the error on the measurement of the Lense-Thirring effect due to thermal perturbations negligible (permil level; [1] and references therein). A prototype called “3×3 matrix” has been built by LNF to measure directly τ_{CCR} and the time relaxation constant of the retainer Al rings (see fig. 2).

The program of measurements to be done on LAGEOS prototypes is described in [1] and will not be repeated here. The Aluminium base of this prototype has been held at constant temperature by the TECs (for example T(Al) = 298 K), in order to simulate the average temperature of LAGEOS, while the CCR assembly components experience the SS and ES thermal loads in varying climatic configuration. Note that the baseline LARES design uses the same type of LAGEOS CCRs.

The SCF includes thermal software for simulation and parametric design of spacecrafts and/or components. LNF is using the following package from http://www.crtech.com/: Thermal Desktop, the CAD-based geometric thermal modeler, RadCad, the radiation analysis module and orbital simulator, Sinda-Fluint, the solver. With this software, we estimated the overall TTs on LAGEOS during the eclipse due to the Earth shadow (see ref. [1]). With the SCF a preliminary thermal measurement with the ES as the only thermal input has been performed. The measured steady-state temperature of the CCR shows a fair match with the simulated thermal model of the 3×3 matrix (see fig. 3). It should be pointed out, however, that this preliminary test has been carried out with a non-optimized configuration of the screws and retainer rings (in terms of the materials used and of the torque applied to the screws) and that the temperature scale of IR camera was not fully calibrated. Once the thermal model will have been tuned to the final data it can be used for the complete thermal analysis of the LAGEOS satellites (and for the parametric design of LARES).

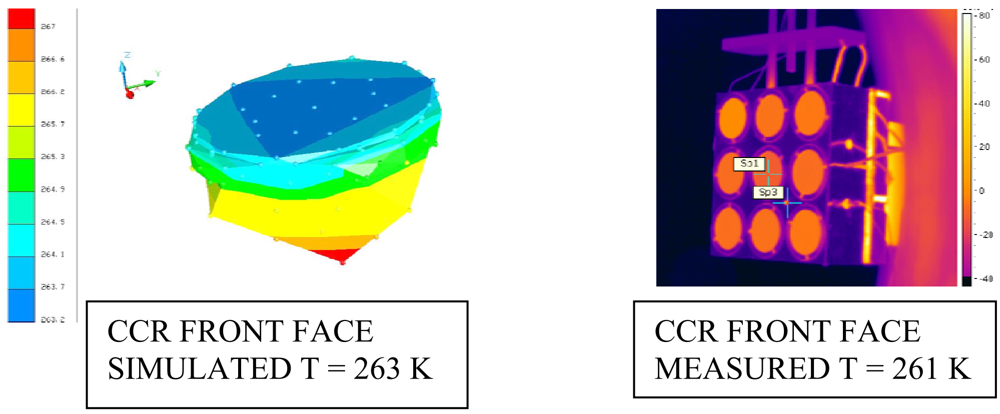

Figure 3*: Comparison of the steady state CCR temperature measured with the SCF (ES only) and modelled with the thermal software, in a specific test configuration.*

Figure 4 shows the result of another preliminary in-air test at STP conditions, which was performed with the SS as main thermal load (at 75% of the nominal intensity). This was done mainly to exercise the whole system during a maintenance period of the SCF.

The SCF is now being upgraded with one optical-quality fused silica window to measure the far field diffraction patterns (FFDPs) of CCRs inside the SCF in realistic space conditions. Integrated thermal and optical tests will be performed on the CCRs of the LAGEOS “sector” prototype of NASA-GSFC (fig. 5). The finish of its Al surface is believed to be highly emissive (20% - and it will be measured) like for LAGEOS I. The sector contains 37 CCRs of good optical quality (in terms of the accuracy of the dihedral angle offsets) with an outer diameter of 34 cm, well within the diameter of the SS beam.

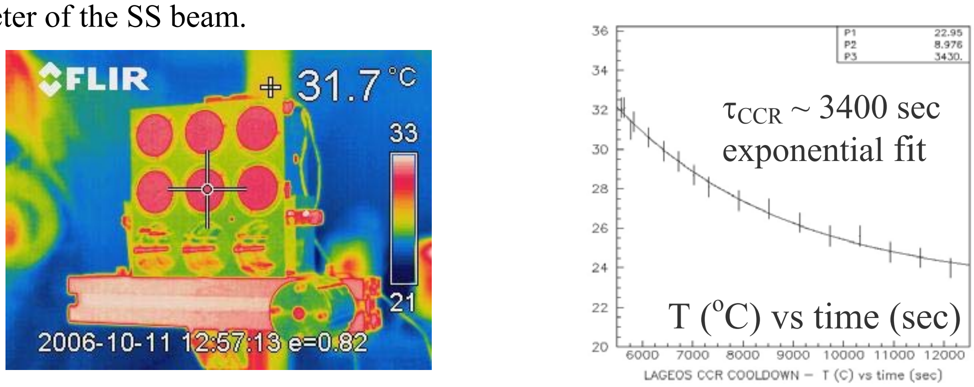

Figure 4: *Cool-down curve of a LAGEOS CCR in-air and STP conditions.*

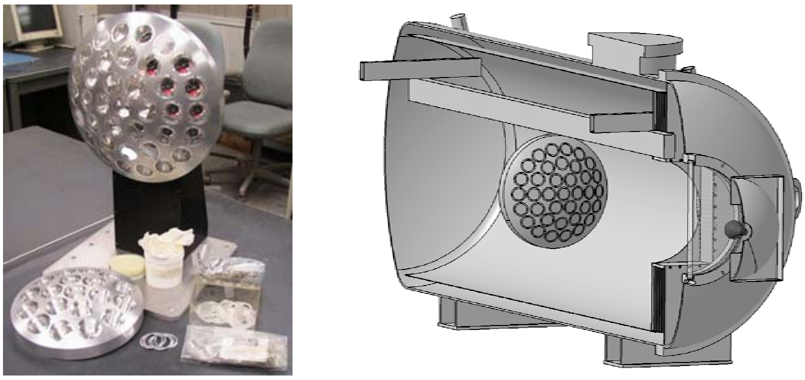

Figure 5: *Engineering model of LAGEOS (circa 1992) property of NASA-GSFC. This LAGEOS sector is now at LNF for thermal and optical testing at the SCF.*

ETRUSCO (ExtraTerrestrial Ranging to Unified Satellite COnstellations)

The “unification” refers to the addition of laser ranging to the standard microwave ranging of GNSS satellites. Our aim is to perform a complete thermal and laser optical characterization of different CCR arrays used for existing and future GNSS constellations.

A preliminary in-air and STP test of a flight model of the third CCR array to be deployed on a satellite of the GPS block II has been done at LNF. This so-called “GPS3” array is identical to the ones installed on the GPS 35 and 36 satellites in orbit and is property of the University of Maryland (C. O. Alley et al). The three arrays have been manufactured in Russia. Mechanical drawings for its correct modelling have been provided courtesy of V. Vassiliev of the IPIE, Moscow. The GPS3 is currently at LNF, under a special agreement between NASA-GSFC, UMD and INFN-LNF. to be tested at the SCF. A preliminary test was done with the SS as main thermal load (at 75% of the nominal intensity). Two thermograms are shown in Fig. 6.

Figure 7 shows the thermal behaviour of the GPS3 as measured with the IR camera. A space-climatic test will follow in 2007, under the supervision of D. G. Currie of UMD.

Far Field Diffraction Pattern Measurement

The optical circuit for FFPD measurements at STP conditions is shown in fig. 8. The laser beam profiler is a Spiricon CCD camera. Tests are now performed at STP; final one will be performed with the CCR array in SCF.

Figure 9 shows how the SCF is now being upgraded with one optical-quality fused silica window to measure the far field diffraction patterns (FFDPs) of CCRs inside the SCF.

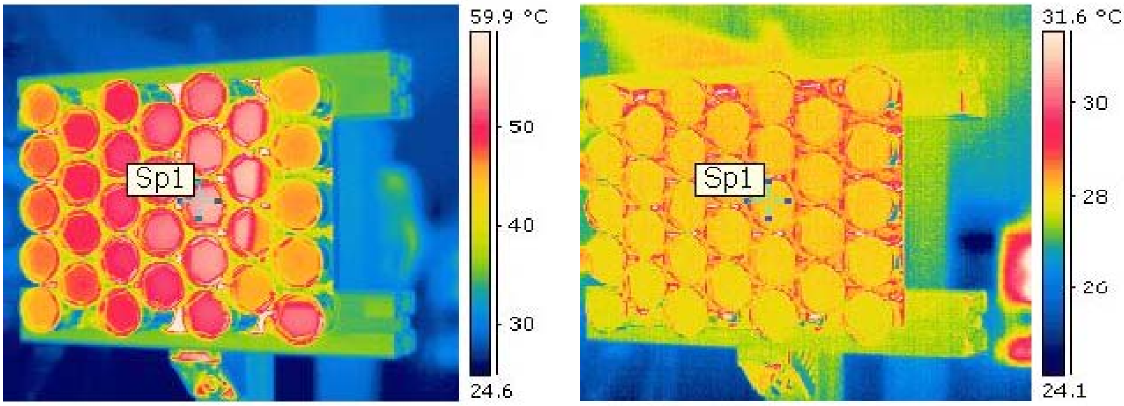

***Figure 6**: Warmest and coolest conditions of the GPS3 retro-reflectors in the LNF STP test.*

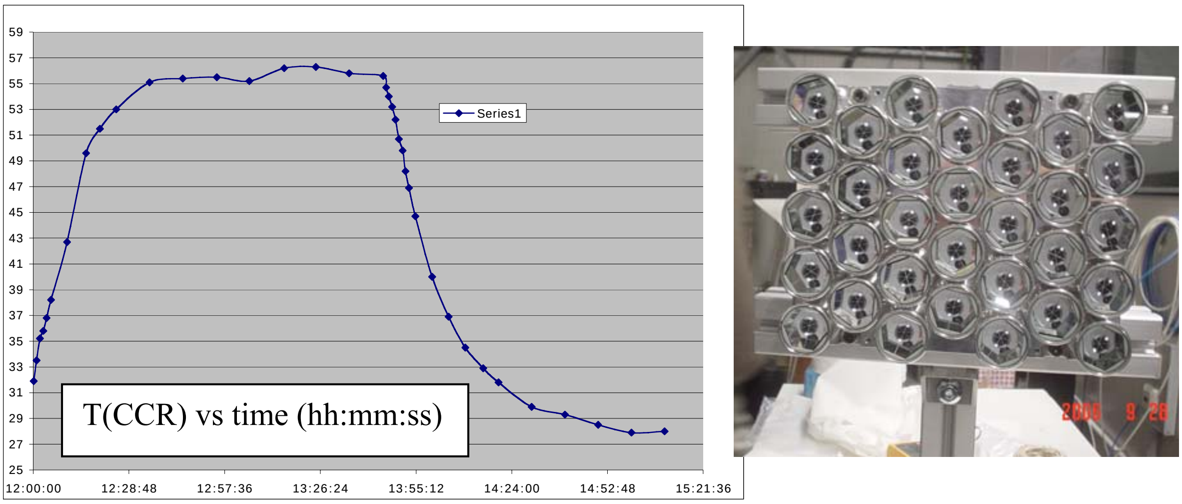

***Figure 7**: Warm-up and cool-down curves of the GPS3, in-ar and at STP at LNF.*

Each CCR will be first exposed to the Sun and the Earth simulators and its thermogram taken by the IR camera from the 45^{o} window. Then, the CCR will be moved in front of the optical window to be exposed to the laser beam and its FFPD recorded (see fig. 10).

Conclusions

At the end of 2006 the SCF has become a permanent, small-size, experimental apparatus of INFN-LNF. The collaboration with ILRS has been very fruitful. Two approved INFN experiments are based for a significant part on the SCF operation: the by-now consolidated LARES mission and the new ETRUSCO experiment. The current upgrade of the SCF, consisting of the integration of the thermal and the laser-optical tests has been funded by INFN, and by LNF, explicitly for ETRUSCO. This funding includes an additional, dedicated optical table to be installed next to the SCF. It does not include the mechanical system(s) for the automated positioning of all the CCRs in the SCF climatic conditions. An endorsement of this work and its scientific motivations by ILRS would be very useful for fund-raising (outside ILRS) and the fulfilment of the ultimate ETRUSCO goals.

References

[1] *Probing Gravity in NEO with High-Accuracy Laser-Ranged Test Masses*, A. Bosco et al, Report INFN-LNF-06-24(P): http://www.lnf.infn.it/sis/preprint/pdf/LNF-06-24(P).pdf. Presented by S. Dell'Agnello at the "Quantum to Cosmos" NASA Int. Workshop, Warrenton (VA), USA, May 2006; to be published in a special issue of Int. Jour. Mod. Phys. D.

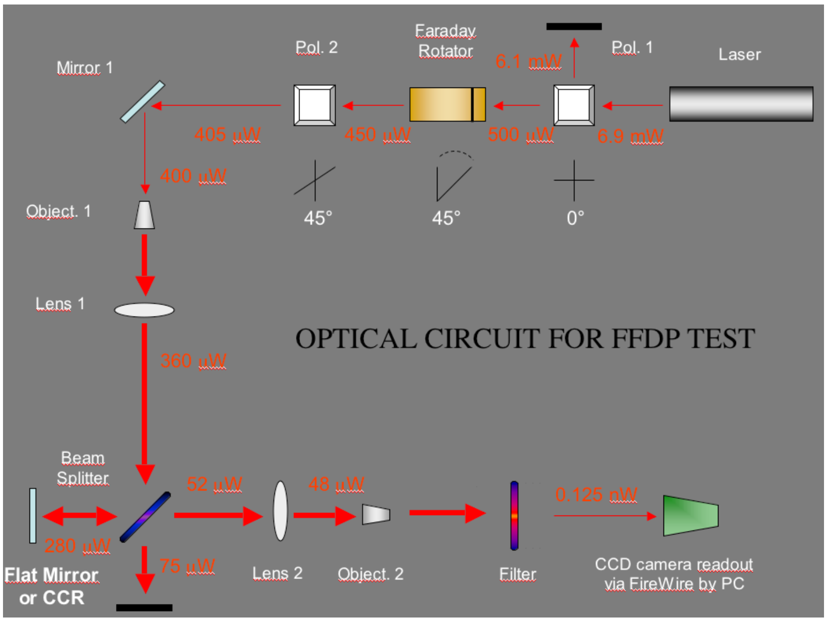

***Figure 8**: Layout of the optical circuit for the FFDP measurement.*

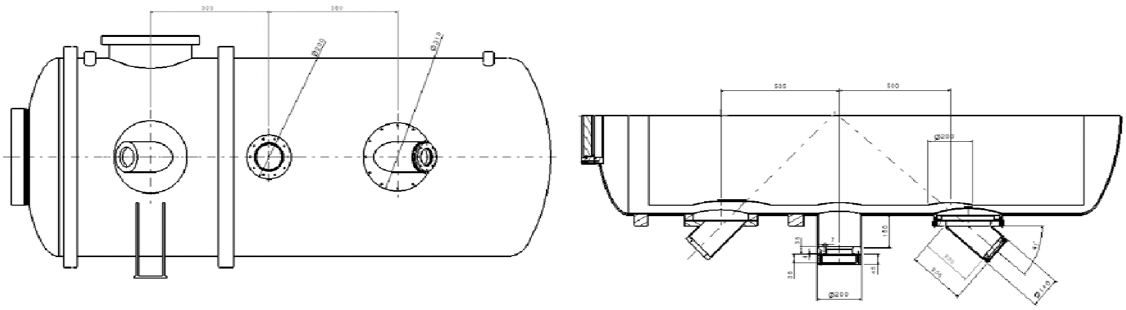

***Figure 9**: Left/central/right windows: IR thermometry, FFDPs and a spare.*

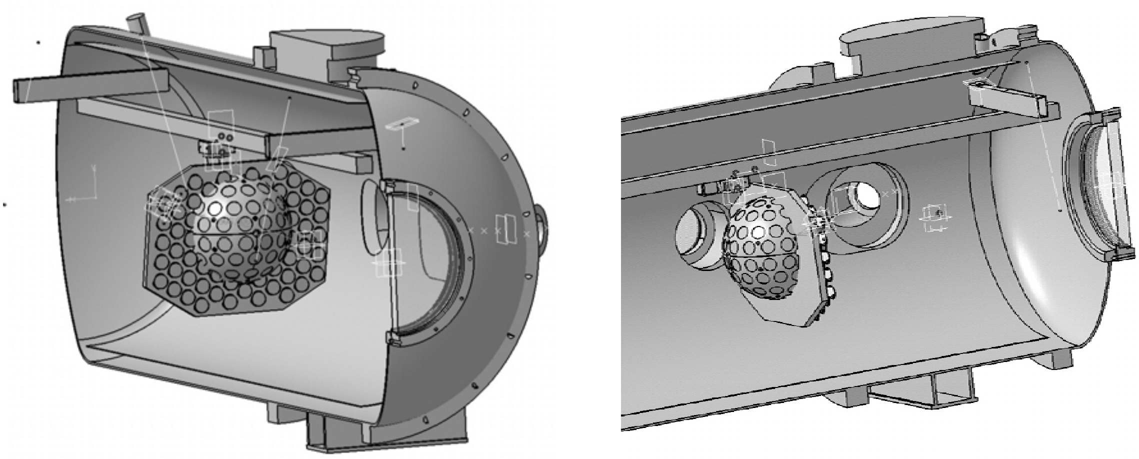

***Figure 10**: The baseline LARES and a GNSS retro-reflector*
array in the upgraded SCF.