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The INFN-LNF Space Climatic Facility

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Abstract

The Space Climatic Facility (SCF) is an experimental apparatus built in 2006 at the Frascati National Laboratory of INFN to study the thermal thrusts acting on the LAGEOS I and II satellites and to perform integrated thermal and optical characterization of retroreflector (CCR) arrays for laser ranging. The latter include the new LARES satellite, whose main scientific goal is to improve the measurement accuracy of the frame dragging of the Earth (Lense-Thirring effect) predicted by General Relativity and reach a relative accuracy of the order of 1%. The SCF is also devoted to make the same tests on CCR arrays deployed on GNSS constellations (especially on GALILEO) within an approved INFN experiment, ETRUSCO. The SCF is a cylindrical cryostat where a realistic space environment is established in terms of pressure (10^{-6}–10^{-7} mbar), temperature (down to 77 K) and e.m. radiation (Sun simulator and infrared Earth simulator). Thermal simulations are well advanced and laser-optical simulations are making good progress.

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1 Introduction

The LAGEOS/LARES program is addressing the significant issue of thermal Non Gravitational Perturbations (NGP), with two main goals: climatically characterize LAGEOS prototypes to reduce NGP errors on the determination of frame dragging, design a new mission and build a fully characterized satellite, which avoids as much as possible the weaknesses of LAGEOS and is capable of reaching 1% accuracy on the Lense-Thirring effect [1]. The SCF has been designed to measure the CCR thermal relaxation time of the, τ_{CCR}, at $\leq 10\%$ accuracy. In 2006 an engineering prototype of LAGEOS I (a polar sector built in 1992) was sent to LNF by NASA-GSFC for an SCF test. In September 2007 INFN gave the final approval of the LARES experiment.

The SCF turned out to be well suited to characterize the thermal and laser-ranging performance of CCR arrays deployed on GNSS, like the existing US GPS-2, the imminent European GALILEO and the future GPS-3. For each CCR of the arrays, the characterization will include the measurement of the thermo-optical parameters (emissivity, ϵ, and reflectivity, ρ), τ_{CCR} and the variation of the laser far field diffraction pattern (FFDP) in a realistic space environment. This SCF-test will improve the long-term stability and the accuracy of the determination of the GALILEO orbits down to ≤ 1 cm [2].

2 The Space Climatic Facility

The SCF is a cylindrical cryostat (1 m diameter, 2 m length) where a realistic space environment is established in terms of pressure, temperature and e.m. radiation (solar constant and Earth infrared emission). During the measurements a copper shield, black painted with a high emissivity paint, is cooled down with liquid nitrogen to $T = 77K$ and the vacuum is typically $10^{-7} \div 10^{-6}$ mbar. A side Germanium window allows for taking thermograms of the prototypes with an infrared (IR) digital camera [3]. Recently we added a fused silica window (deformations of transmitted wavefront $< \lambda/10$) for FFDP measurements in the space environment.

3 Thermal Measurements and Simulations

The IR camera measures temperatures of external components only. For the camera calibration and for internal componnents we use a 2nd temperature acquisition system made of National Instrument compact Fieldpoints and PT100/PT1000 probes.

Thermal SCF tests have been made on August 30th 2007 using a LAGEOS prototype built at LNF: an aluminum block with 9 CCRs, arranged in a 3x3 matrix[3]. On the top-left

CCR temperature sensors have been glued to monitor the temperatures of all the mounting rings. The aluminum block is kept at ~ 300K, the LAGEOS average temperature in space, with a series of 4 Thermo Electric Coolers (Peltier cells), driven by a Electrondynamics TCM controller. Measurements were performed with only the Solar Simulator turned on for three hours in front of the prototype; data were also taken for the next three hours during the cooling phase. The results are presented in Fig. 1 and 2. These tests,

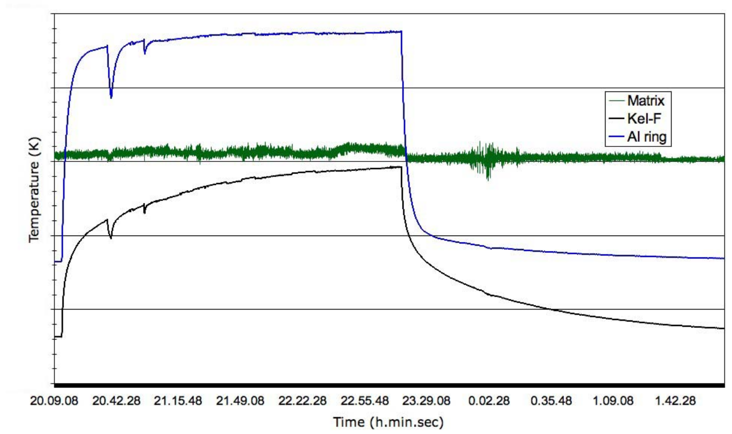

Figure 1: Measurement of the T variation of the CCR assembly parts using the PT100 sensors.

never performed before, gave important preliminary results:

- Al retainer rings have a significantly smaller temperature variation than expected from all previous calculations [4,5].
- τ_{CCR} is longer than expected.

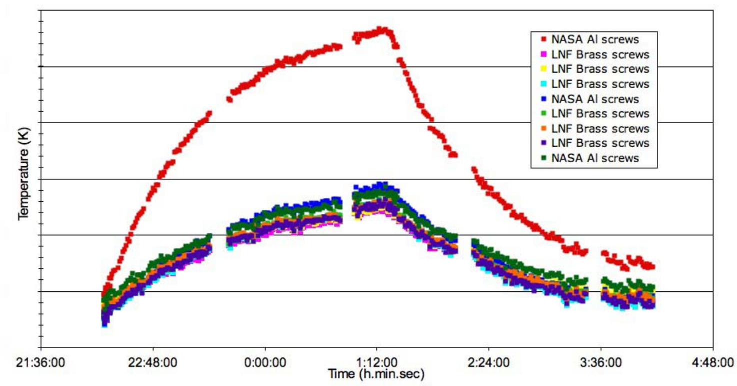

Figure 2: Measurement of the T variation of all CCR top surfaces using the IR camera.

As we expected, the sensors glued on the CCR destroy locally its Total Internal Reflection and cause a higher temperature variation (red line in Fig. 2). τ_{CCR} will be estimated using the other 8 unperturbed CCRs (with no PT100s glued on). Data taken from Figure 2 were used to make simulations of thermal thrusts of a simplified 3D model of LAGEOS during fully simulated orbits using Thermal Desktop and Sinda Fluint (by Cullimore & Ring Tech.). Results presented in Fig. 3 show good qualitative agreement with previous calculations[5], while the absolute values of the thrusts are lower than in [5]. New full-blown 3d models of LAGEOS and LARES are nearing completion.

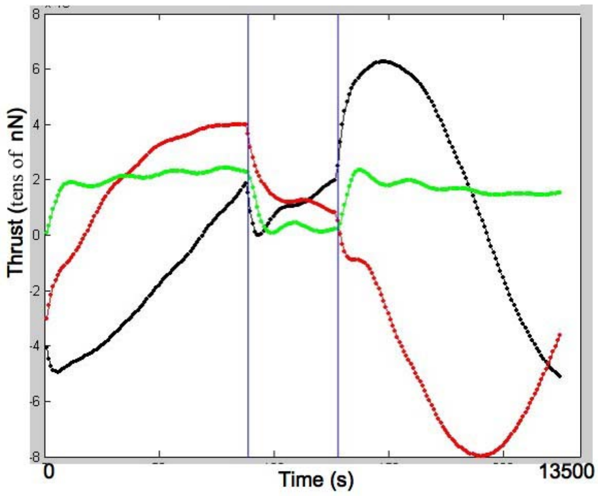

Figure 3: Thermal thrusts acting on LAGEOS in an orbit of Jan. 1, 2000.

4 Optical Measurements and Simulations

Laser ranging performances depend on the absolute angular size and intensity of CCRs FFDPs. The angular size is important for the phenomenon of the *Velocity Aberration*, due to the relative motion between the satellite and the LR station. Simulations have been performed with CodeV (by Optical Research Associates), an optical CAD modeling software used for the optimization, analysis and toleracing of optical systems. The FFPD measured for a LAGEOS-type CCR with 0 arcsec dihedral angle offset, with one edge up and for a normal horizontally polarized laser beam is shown in Fig. 4 along with the simulated pattern. The measured CCR belongs to the GSFC polar sector. A CCR with 0 arcsec dihedral offset has most of the energy concentrated in the center; an increase in angle offset causes the zone of higher energy to move towards external radii. To correct for the LAGEOS velocity aberration an offset of 1.25 $\pm$ 0.5 arcsec was used. For LARES satellite an offset of 1.5 $\pm$ 0.5 arcsec has been chosen due to the lower altitude. Figure

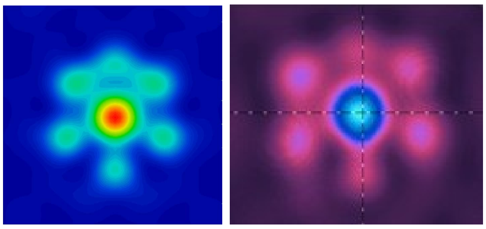

Figure 4: FFDP of an uncoated CCR with 0 arcsec angle offset. laser beam with $\lambda = 632.8$ nm. Plot size is $\pm 50\,\mu$rad. (Simulated pattern, measured pattern)

5 shows the simulated FFDP of a single LARES CCR, the simulated coherent pattern of the whole LARES (preliminary) and a simulated incoherent FFDP of the whole LARES.

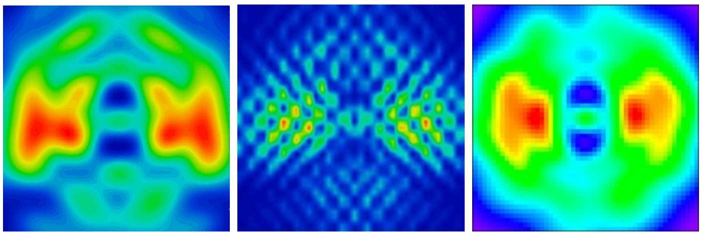

Figure 5: FFDP of a LARES under a normal horizontally polarized laser beam with $\lambda = 632.8$ nm. Plot size is $\pm 50\,\mu$rad

5 Conclusions

We are currently working on the SCF-test of the *flight model* of the GPS-2 CCRs array. The SCF-test of the LAGEOS polar sector will then follow. Integrated thermal and laser tests are now possible thanks to the new prototype positioning system (rotation+tilt) and to the 2nd optical table and FFDP circuit set-up next to the cryostat.

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