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ETRUSCO:

Extra Terrestrial Ranging to Unified Satellite COnstellations

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ABSTRACT

We describe the basic goals of the ETRUSCO experiment and the work done in 2006, together with our international collaborators, which led to the approval of the proposal by the INFN-CSNV in October 2006.

Some of the 2007 funds were made available in November 2006 and were used to buy optical instrumentation. In 2007 the LNF Satellite laser ranging Characterization Facility (SCF) has been upgraded to perform integrated laser ranging tests and thermal measurements (SCF-Test) of the planar retro-reflector arrays installed on the satellites of GNSS constellations. This will be done in a realistic environment, which simulates the orbital conditions of the GPS-2 (USA), GLONASS (Russia), and soon GALILEO (EU), at altitudes of about 20000-23000 Km.

The year 2007 has been devoted to the SCF-Test of a *prototype model* of a retro-reflector deployed on the two of GPS-2 satellites, on the GLONASS constellation and on GIOVE-A and GIOVE-B, the prototypes of GALILEO. This SCF-Test has been successful and data analysis is well underway. The experimental work at the SCF will also be compared to software models of the thermal, structural, orbital and optical behavior of the prototypes. Detailed thermal models of the LAGEOS-type retro-reflectors have already been built and checked with SCF measurements. Work is in progress to develop these models also for the GNSS.

The year 2008 is dedicated to the SCF-Test of a *flight model* of a retro-reflector array to be deployed on one of the next GPS-2 satellites.

The long-term goal of ETRUSCO is to perform at LNF the SCF-Test the larger and more important GALILEO laser retro-reflector arrays. Planning and provisions to reach this goal are well underway: in fact, INFN-LNF is participating to a call for tender for the "Support to the Coordination of the European GALILEO Simulation and Testing Infrastructure", issued by the Galileo Supervisory Authority, in the context of FP7-GALILEO. The result of the tender is due by October 2008.

1 Introduction

A Satellite laser ranging Characterization Facility (SCF) has been built at INFN-LNF (Frascati, Italy) in 2006. The SCF is described in detail in ref. 1) and 2). The initial purpose of the SCF was to study the non-gravitational perturbations on the LAGEOS and LARES satellites, used for precision Space Geodesy measurements and tests of General Relativity.

The modular and evolutionary design of the SCF turned out to be well suited to characterize the thermal and laser-ranging performance of cube-corner retro-reflector (CCR) arrays deployed on GNSS[1] constellations, like the existing US GPS-2, the imminent European GALILEO and the future GPS-3. The integration of satellite laser ranging (SLR) with the standard microwave ranging (MWR) to improve the satellite navigation capabilites has become another SCF goal.

With minor upgrades, the SCF can also test the laser-ranging performance of spherical test masses in the outer Solar System for DSGP (Deep Space Gravity Probe), which is a satellite formation of an active spacecraft and a few masses laser-tracked by the active spacecraft. DSGP is being conceived to accurately study the Pioneer effect (ie, deviations from the $1/r^2$ gravity force law) and to perform important (inter)planetary science investigations. For this purpose, the groups of INFN-LNF, Rome-Tor Vergata, plus R. Vittori[2] in 2006 proposed to INFN a new experiment, ETRUSCO (Extra Terrestrial Ranging to Unified Satellite COnstellations). ETRUSCO was approved by INFN in October 2006, with the recommentation to focus the activity on GNSS applications. The R&D for DSGP will be reconsidered at a later stage. We describe the first preliminary thermal measurements on a $flight$ model of CCR array to be deployed soon on the GPS-2 constellation and the upgrade of the SCF to perform simultaneous thermal and laser-ranging tests.

2 Extra Terrestrial Ranging to Unified Satellite COnstellations

A space-climatic characterization of the detailed thermal properties and of the laser ranging response of the GALILEO CCR arrays (SCF-Test) will strongly enhance the integration ("unification") of SLR with MWR. For each CCR fo the array, the characterization will include the measurement of the thermo-optical parameters (emissivity and reflectivity), the thermal relaxation time and the variation of the laser far field diffraction pattern in a realistic space environment. This will be done with the arrays inside the SCF, exposed to simulators of the Sun and Earth illuminations. Since SLR gives a fundamental contribution to the definition of the Earth center of mass and of the absolute scale of length, this test program will improve the accuracy and long-term stability of the determination of the GALIELO orbits. The ultimate satellite positioning accuracy that can be reached is less than 1 cm. This in turn will propagate to the final end used on the Earth and all civil and commercial services provided by GALILEO will benefit from it. Since the large-scale deployment of SLR on GALILEO will be a world-first in GNSS, it is of the utmost importance that a full-fledged space-climatic characterization is performed. The experience of SLR with GPS-2 (two satellites) and GLONASS was a test more than a mission critical deployment. Over several years, these few satellites have indicated how crucial the proposed characterization is and how difficult it is to model climatic effects without experimental measurements. A third CCR array exists, which will be deployed soon on a satellite of current GPS-2 constellation. This array is property of the University of Maryland (UMD, College Park, MD, USA) and is now at INFN-LNF for space climatic tests, following a special agreement with NASA-GSFC, IRLS[3] and UMD (C. O. Alley, D. G. Currie). Testing this third array is very important because the previous

[1] Global Navigation Satellite System.
[2] Italian Air Force and European Astronaut Corps.
[3] International Laser Ranging Service

identical versions of the arrays when tracked with lasers show significant periods of low light returns. Climatic tests and simulations are important to assure that no failures occur in GALILEO, in the long term and with a large multiplicity of satellites. The Frascati SCF offers the unique possibility to understand in detail the effects of the severe space environment on the many years of expected lifetime of the CCR arrays of GALILEO. In addition, the proposed test program can help keep GALILEO competitive with the next generation of GPS-3 (about 2011-2012), which might take advantage of proposed innovative retro-reflectors, like the hollow type, as opposed to the traditional solid, fused-silica reflectors used by GLONASS, GPS-2 and GALILEO.

3 The "GPS3" Array

This so-called GPS3 array is identical to the ones installed on the GPS-35 and GPS-36 satellites in orbit. The three arrays have been manufactured in Russia. Mechanical drawings for its correct modelling have been provided courtesy of V. P. Vasiliev of the Russian IPIE (Institute for Precision Instrument Engineering of the Federal Space Agency of Russia, Moscow). Since this is a *flight* model, in 2006 it was decided not to start with a full test in the harsh SCF environment. Figure 1 shows a photo of the GPS3 and the warm-up and cool-down curve of a central retro-reflector, measured with a digital infrared camera. This preliminary test was conducted with the Solar simulator as the main thermal load, at 75% of its nominal intensity. An SCF-Test in the SCF will follow in 2008, under the supervision of D. G. Currie of UMD.

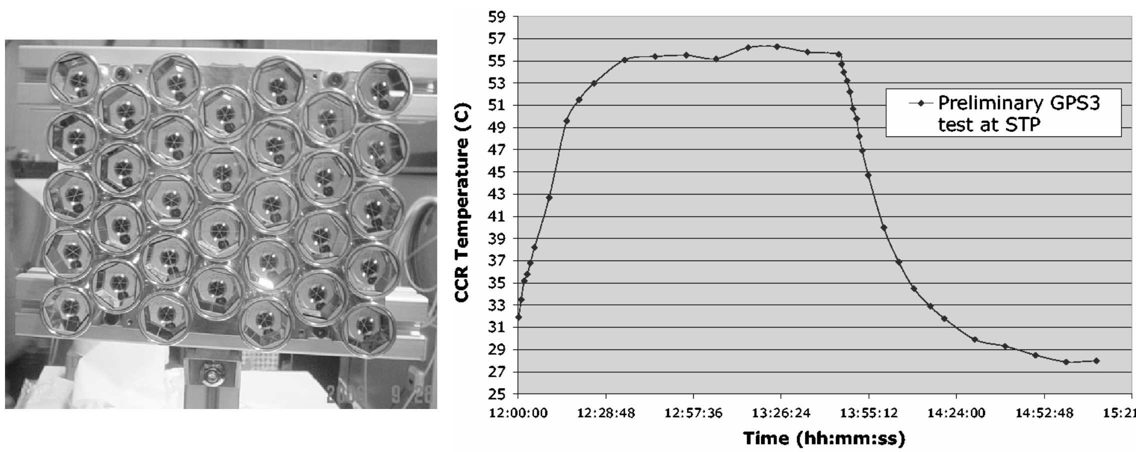

Figure 1: Left: the GPS3. Right: warm-up and cooldown curve of the GPS3 at STP.

4 Far Field Diffraction Pattern (FFDP) Measurement

The most basic test of the SLR performance, is the measurement of FFDPs. The optical circuit for FFDP measurements with CCRs is shown in fig. 2. The laser beam profiler (by Spiricon) uses a PtGrey CCD 2 MPix camera, readout via Firewire by a PC. These tests are currently done in STP conditions to check the optical instrumentation, but final tests will be performed with the CCR array in the SCF. Figure 3 shows a preliminary measurement of an FFDP of a flat mirror, in place of the CCR. Optical flats like this with known reflectivity will be used as a normalization to determine the absolute intensity of the SLR return to Earth from the CCR under test.

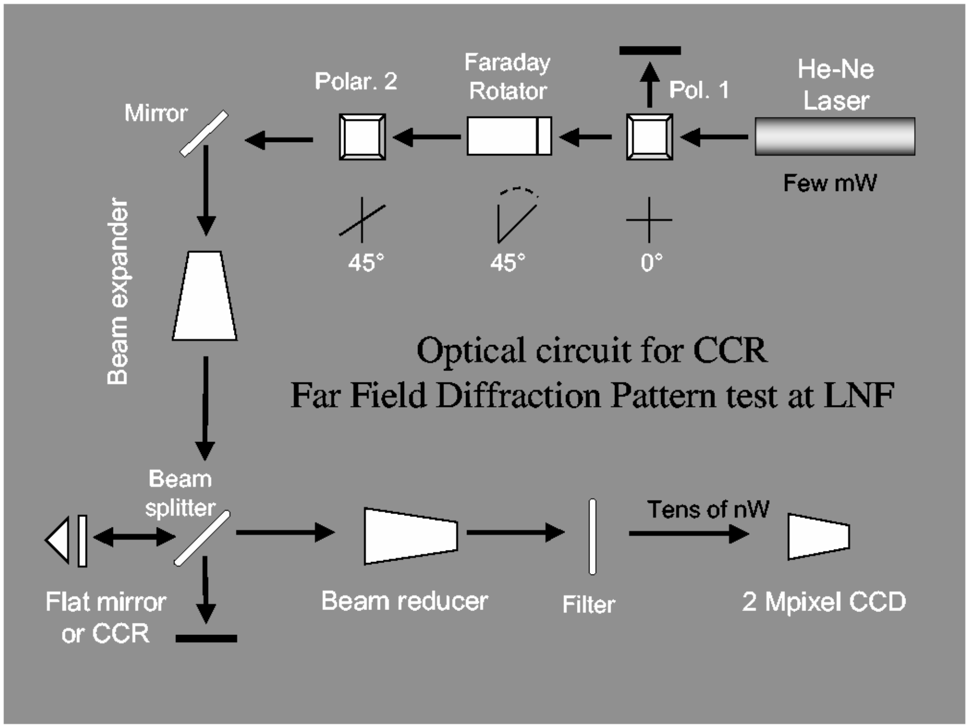

Figure 2: Scheme of the optical circuit for the FFDP measurement at LNF.

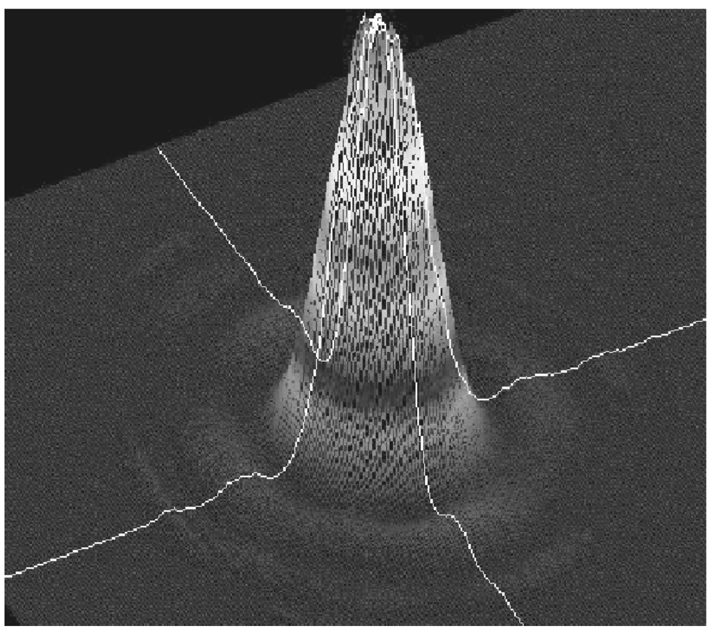

Figure 3: FFPD measured for a flat optical mirror.

5 SCF Upgrade

The upgraded SCF is shown in fig. 4: the existing left window for the IR camera, the new central window for FFDPs and the new right spare window. Each CCR will be first exposed to the Sun and the Earth simulators and its thermogram taken. Then, the CCR will be moved in front of the *central* window to take its FFPD.

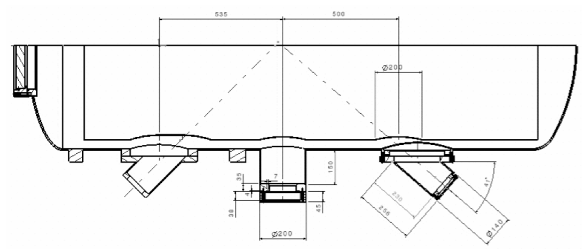

Figure 4: Upgraded SCF, top view: Sun enters left.

The upgraded SCF cryostat is show in fig. 5. The movement of prototypes inside the SCF is achieved with a system located outside, through the new top flange.

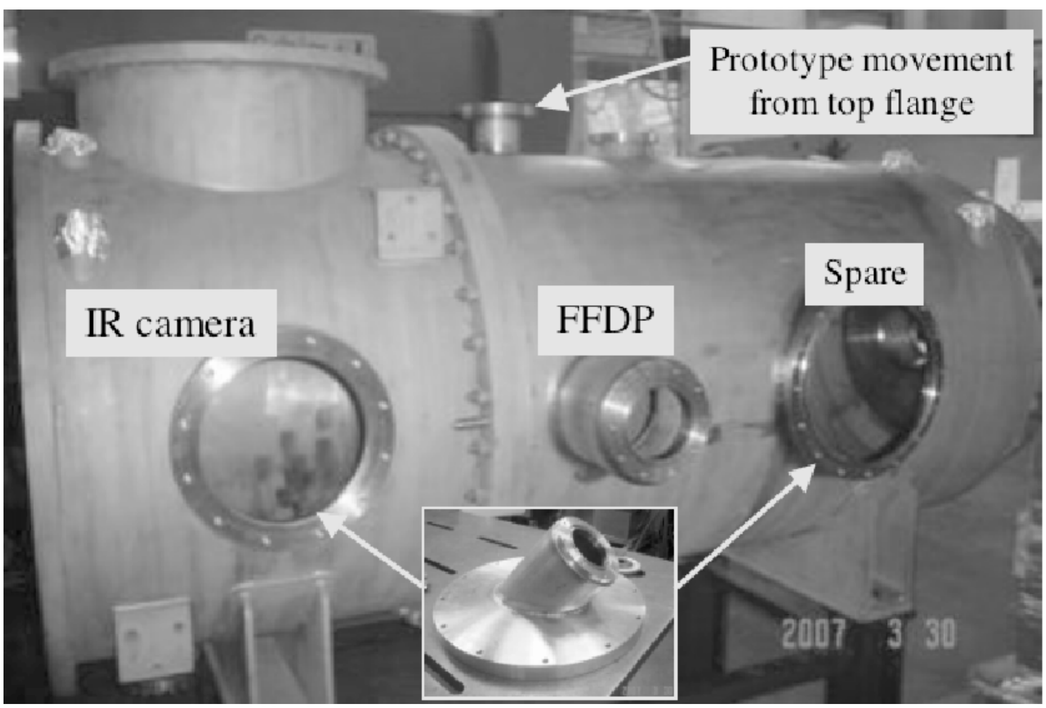

Figure 5: Photo of the upgraded SCF cryostat.

6 Simulation Software

SCF measurements are complemented by simulations done with commercial software [3) 1)]:

- Autocad INVENTOR for mechanical drawings and ANSYS for Finite Element. Meshing is done with great detail and in a complete *parametric* way for model portability, modularity and debugging.
- Space-climatic simulations are handled by THERMAL DESKTOP (geometric thermal modeler) + RADCAD (radiation analysis) + SINDA-Fluint (solver) + orbital simulator, by $C\&R - Tech$ (`www.crtech.com`). This consists of thermal modelization coupled to satellite attitude and orbital motion in the whole Solar System. Models are tuned to the SCF data.
- CODEV, by Optical Research Associates (`www.opticalres.com`) to analyze the FFDPs.

7 Conclusions

In September 2006 the SCF has become a permanent, small-size, experimental apparatus of INFN-LNF. During the last two years the collaboration of LNF with ILRS has been very fruitful. The current upgrade of the SCF, consisting of the integration of the thermal and the laser-ranging tests has been funded by INFN, and by LNF, explicitly for GNSS studies. An additional, dedicated optical table is now in place and is operated next to the SCF, when alternating among exposure to the heat simulators, IR thermography and laser ranging. At the end of 2006, LNF has become member of the "Signal Processing" Working Group of the IRLS.

In the beginning of 2008 a positioning has been designed and purchased by the LNF group to perform SCF-Tests of GNSS planar arrays. This mechanics of this system has been custommized for the GPS3 array. This positioning system is currently under commissioning.

References

1. *Probing Gravity in Near Earth Orbits with high-accuracy laser-ranged test masses*, A. Bosco, C. Cantone, S. Dell'Agnello, G. O. Delle Monache *et al*, Int. Jour. Mod. Phys. D, Vol. 16, N. 11 (1-15).
2. G. Bellettini et al, LNF Report LNF-06-26(IR).
3. A. Bosco, Thesis, Univ. of Rome Tor Vergata, 2006, LNF Report LNF-06/32(T).