TESTING FUNDAMENTAL PHYSICS WITH SATELLITE LASER RANGING: PERSPECTIVES AND GOALS OF THE LARASE EXPERIMENT

David Lucchetti1,2,3, Luciano Anselmo, Massimo Bassan4, Carmen Pardini2, Roberto Peron1,2, Giuseppe Pucacco1,2, Massimo Visco1,2
1Istituto di Astrofisica e Planetologia Spaziali (IAPS/INAF), Via Fosso del Cavaliere 100, 00133 Roma, Italy
2Istituto di Scienze e Tecnologia dell’Informazione (ISTI/CNR), Via Moruzzi 1, 56124 Pisa, Italy
3Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy
4Dipartimento di Fisica, Università di Tor Vergata, Via della Ricerca Scientifica 1, 00133 Roma, Italy

Introduction
The aim of LARASE (Laser RAnged Satellites Experiment) is to go a step further in the tests of the gravitational interaction in the field of the Earth (i.e. in the weak-field and slow motion (WFSM) limit of general relativity) by the joint analysis of the orbits of the two LAGEOS satellites and that of the most recent LARES satellite. To reach such a goal, key ingredients are high-quality updated models for the perturbing non-gravitational (i.e., non-conservative) forces acting on such satellites. A large amount of Satellite Laser Ranging (SLR) data of LAGEOS and LAGEOS II has been analyzed using a set of dedicated models for satellite dynamics, and the related post-fit residuals have been analyzed. A parallel work is ongoing in the case of LARES that, due to its much lower subject to larger gravitational and non-gravitational effects; the latter are in part mitigated by its much lower area-to-mass ratio. Recent work on the orbital analysis of such satellites is presented, together with the development of new, refined models to account for the impact of the subtle and complex non-gravitational perturbations. The general relativistic effects leave peculiar imprint on the satellite orbit, namely in the secular modifications and for geomagnetic and solar activities.

Neutral Drag
A number of activities have been started concerning the impact of the neutral drag perturbation on the orbit of the satellites. In particular, we take advantage of the use of the software SATRAP (ISTI/CNR) that is able to propagate the satellite orbit with the current most refined models for the atmosphere composition and for geomagnetic and solar activities.

General Relativity precession and LAGEOS II pericenter
The plot shows the integrated residuals of the argument of pericenter of LAGEOS II over a time span of about 13 years. They have been obtained from a data reduction of the satellite orbit using GEODYN II (NASA/GSFC) and EIGEN-GRACE as model for the Earth’s gravitational field. The final best fit gives a discrepancy between the recovered slope and the value predicted by General Relativity (GR) of just 0.01%.

Constraints on Fundamental Physics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Fundamental Equation</th>
<th>Result in the Literature</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon$</td>
<td>$(0 \pm 1.2 \pm 2.1) \times 10^{-3}$</td>
<td>$2.5 \times 10^{-2}$</td>
<td>$2.5 \times 10^{-2}$</td>
</tr>
<tr>
<td>$2 + 2 \gamma - \beta$</td>
<td>$(0 \pm 1.2 \pm 2.1) \times 10^{-3}$</td>
<td>$2 \pm 2 \times 10^{-2}$</td>
<td>$2 \pm 2 \times 10^{-2}$</td>
</tr>
<tr>
<td>$c_{\text{max}}$</td>
<td>$(0 \pm 0.032\text{km} \pm 0.093\text{km} \pm 0.093\text{km})$</td>
<td>$10^{-8}$</td>
<td>Yukawa $\Theta$</td>
</tr>
<tr>
<td>$2\varepsilon_{\text{sat}} + \varepsilon_{\text{geo}}$</td>
<td>$(0 \pm 0.032\text{km} \pm 0.093\text{km} \pm 0.093\text{km})$</td>
<td>$10^{-8}$</td>
<td>Yukawa $\Theta$</td>
</tr>
</tbody>
</table>

Tides
Tidal effects must be carefully studied and modelled in space geodesy and in fundamental physics measurements because they influence the orbit of a satellite in three different ways:
1. through kinematic effects, because they produce periodic pulsations of the Earth and, as a consequence, of the tracking stations on ground
2. through dynamic effects which cause a time variation of the geopotential affecting the satellite orbit
3. through the reference system, because they perturb the Earth rotation, thus perturbing the reference system used in the orbit determination.

Precise Orbit Determination (POD)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAGEOS</td>
<td>105.545</td>
</tr>
<tr>
<td>LAGEOS II</td>
<td>105.555</td>
</tr>
<tr>
<td>LARES</td>
<td>105.565</td>
</tr>
</tbody>
</table>

LAGEOS’s Spin Model
The rotational dynamics of a satellite represents a very important issue that deeply impacts the goodness of the orbit modelling. Indeed, modelling several disturbing effects (like the thermal thrust on the rotation axis) requires the knowledge of spin axis orientation and rate in inertial space as: Yarkovsky-Schach effect, Earth-Yarkovsky effect, asymmetric reflectivity effect.

References
Lucchetti, Peron, Phys. Rev. Lett., 105, 2010
Lucchetti, Peron, Phys. Rev. D, 89, 2014
Lucchetti, Anselmo, Pardini, Pucacco, Peron, Visco, 4th COSPAR – PSD 1., 2014
Lucchetti, Anselmo, Pardini, Pucacco, Peron, Visco, 4th COSPAR – PSD 1., 2014

Program and Perspectives
LARASE activities are well underway, especially with respect to the non-gravitational perturbations studies, as well as for the preliminary analyses of the satellites’ orbit for future measurements in fundamental physics in the WFSM limit of GR. A number of papers on these topics are under preparation.