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

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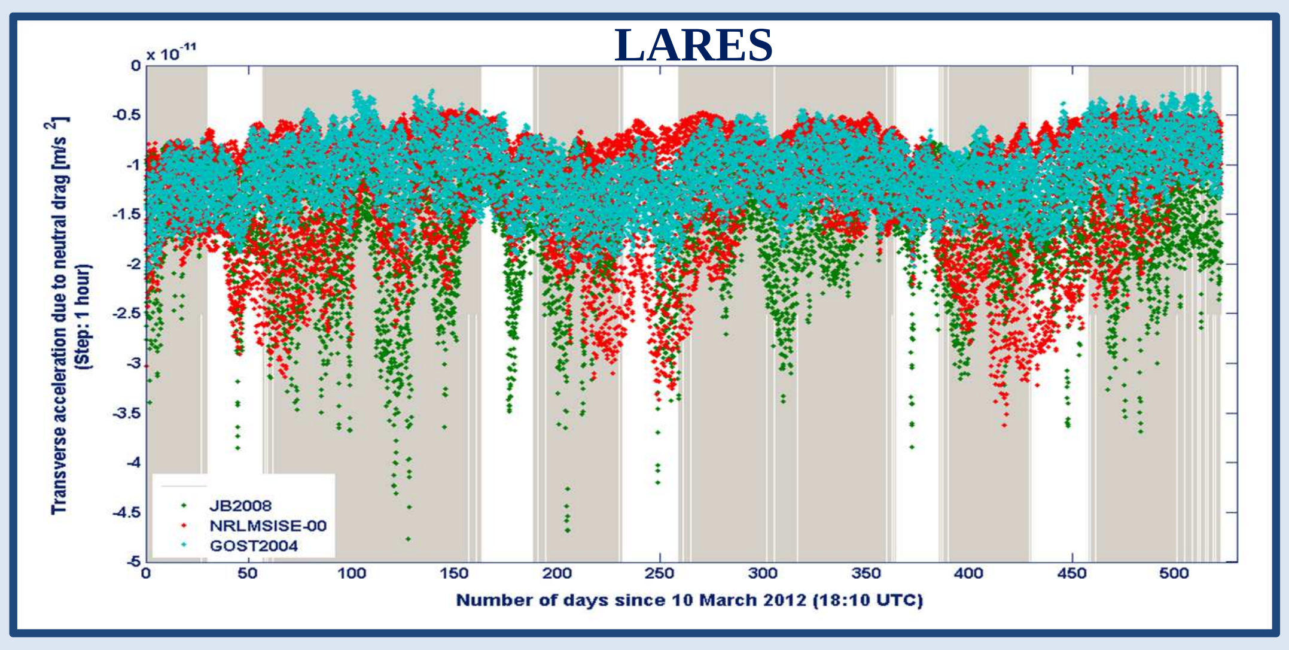
Introduction

The aim of **LARASE** (**LA**ser **RA**nged **S**atellites **E**xperiment) 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 altitude, is 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 behavior of its three Euler angles. Recent results are provided, together with updated constraints on non-Newtonian gravitational dynamics.

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.

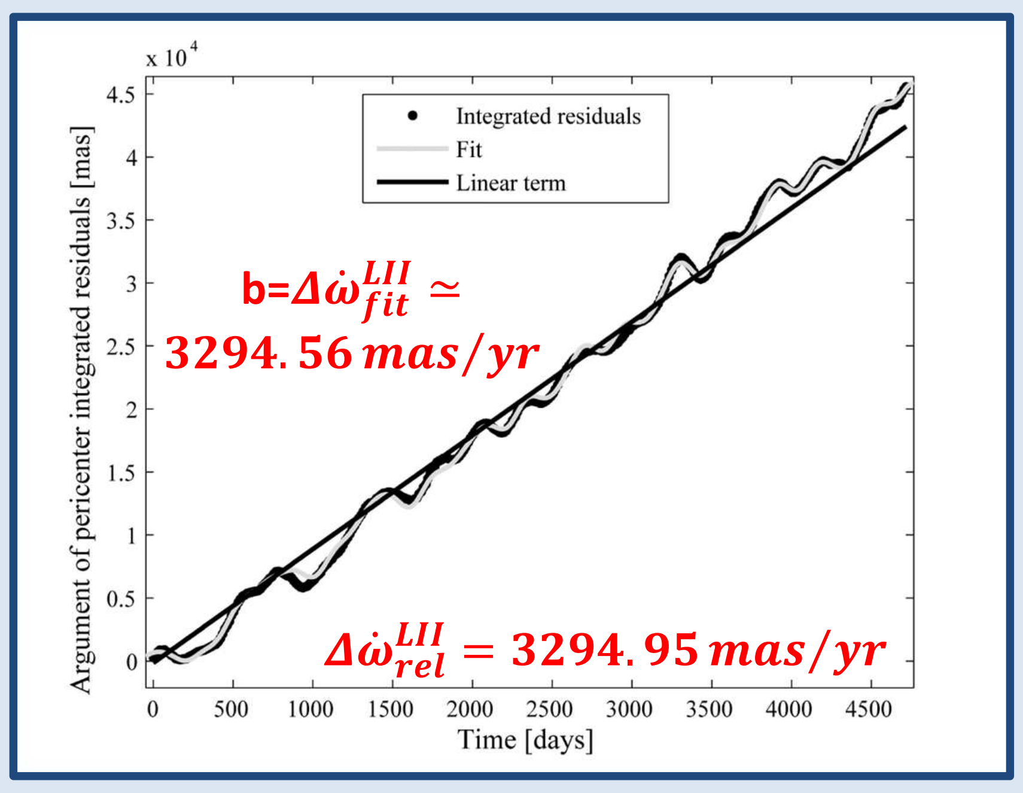


Main activities:

- comparison of the different models at the satellites altitude
- estimate of the perturbing accelerations in the Mean Of Date (MOD) and Gauss (RTW) reference systems
- estimate of the disturbing effects on the orbital elements of the satellites

Acceleration [m/s²]	LAGEOS	LAGEOS II	LARES
$\langle R\rangle$	$+9.5\cdot10^{-18}$	$+7.5\cdot10^{-18}$	$-1.3\cdot10^{-15}$
$\langle T\rangle$	$-3.1\cdot10^{-13}$	$-2.6\cdot10^{-13}$	$-1.3\cdot10^{-11}$
$\langle W\rangle$	$-1.7\cdot10^{-16}$	$+7.1\cdot10^{-18}$	$-1.8\cdot10^{-14}$

General Relativity precession and LAGEOS II pericenter



$$\Delta\omega^{FIT}=a+b\cdot t+c\left(t-t_0\right)^2+\sum_{i=1}^{n}D_i\sin\left(\frac{2\cdot\pi}{P_i}\cdot t+\Phi_i\right)$$

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-GRACE02S** 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%.

$$\Delta\dot{\omega}=\Delta\dot{\omega}_{GP}+\Delta\dot{\omega}_{NGP}+\varepsilon\Delta\dot{\omega}_{GRC}$$

GP → Gravitational Perturbations
NGP → Non-Gravitational Perturbations
GRC → GR Corrections
ε = 1 in GR and ε = 0 in Newtonian Physics

$$\varepsilon=1-(0.12\pm2.10)\cdot10^{-3}\pm2.5\cdot10^{-2}$$

Best fit: – 1.2·10^{-4} Sensitivity analysis: ± 2.1·10^{-3} Systematic errors: ± 2.5·10^{-2}

Constraints on Fundamental Physics

Parameters	Values and Uncertainties	Results in the Literature	Remarks
$\varepsilon-1$	$-(0.12\pm2.10)\cdot10^{-3}\pm2.5\cdot10^{-2}$	…	Pericenter measurement and error budget
$\frac{2+2\gamma-\beta}{3}-1$	$-(0.12\pm2.10)\cdot10^{-3}\pm2.5\cdot10^{-2}$	$\pm1\cdot10^{-3}\pm2\cdot10^{-2}$	PPN parameters
$\lvert\alpha\rvert$	$\lesssim5\cdot10^{-13}\pm8\cdot10^{-12}\pm1\cdot10^{-10}$	$\pm1\cdot10^{-8}$	Yukawa @ 1R$_\oplus$
$\mathcal{C}_{\oplus LII}$	$\lesssim(0.003km)^4\pm(0.036km)^4\pm(0.092km)^4$	$\pm(0.16km)^4$ $\pm(0.087km)^4$	Moffat Non Symmetric
$2t_2+t_3$	$\lesssim3.5\cdot10^{-4}\pm6.2\cdot10^{-3}\pm7.49\cdot10^{-2}$	$3\cdot10^{-3}$	Mao torsional

References

Lucchesi, Peron, Phys. Rev. Lett., 105, 2010
Lucchesi, Peron, Phy. Rev. D, 89, 2014
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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.

NODAL RATE – SOLID ZONAL TIDES: $\ell=2$ m = 0

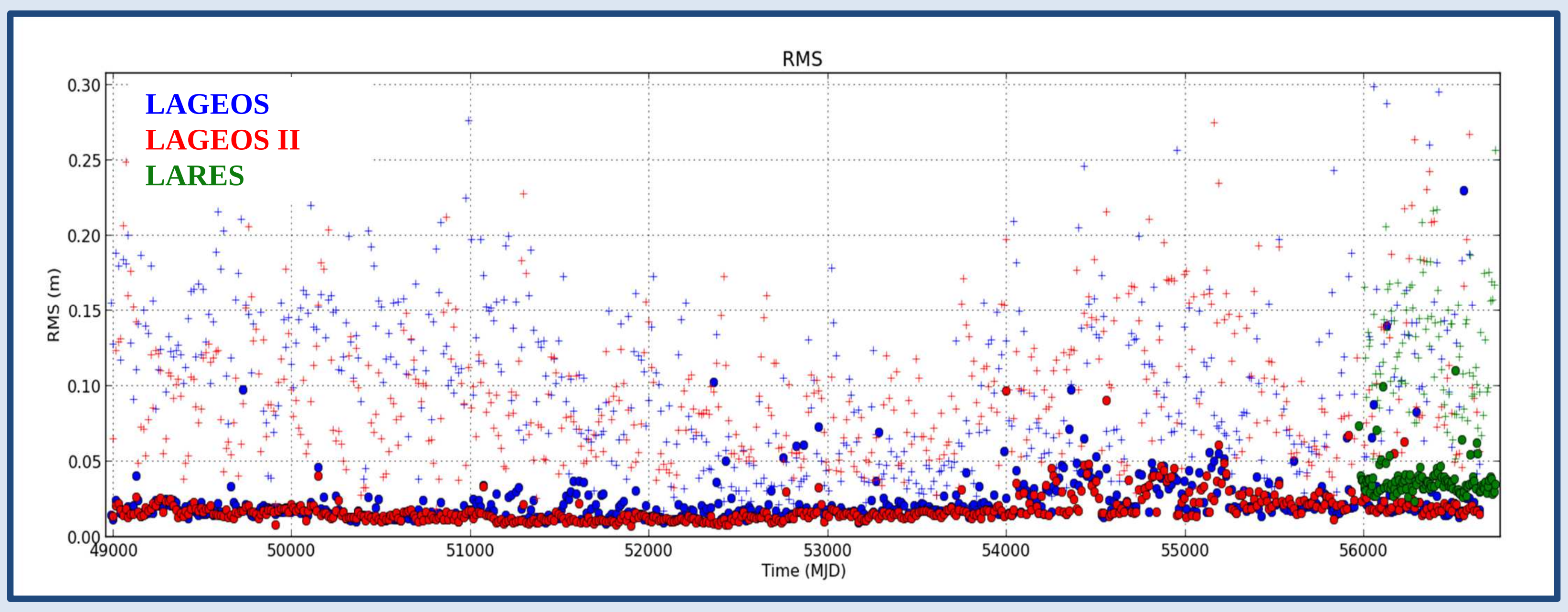
Tide	Period [days]	LAGEOS [mas]	LAGEOS II [mas]	LARES [mas]
055.565	6798.38	– 1080.22	+ 1976.46	+ 5332.68
055.575	3399.19	– 5.23	+ 9.57	+ 25.81
056.554	365.25	+ 9.97	– 18.24	– 49.20
057.555	182.63	+ 31.15	– 56.99	– 153.75

NODAL RATE – SOLID TESSERAL TIDES: $\ell=2$ m = 1

Tide	Period [days]	LAGEOS [mas]	Period [days]	LAGEOS II [mas]	Period [days]	LARES [mas]
165.545	1232.95	– 40.95	– 525.23	+ 7.33	– 225.77	+ 35.74
165.555	1043.67	+ 1738.57	– 569.21	– 398.25	– 223.53	– 1853.77
165.565	904.77	+ 202.12	– 621.22	– 58.29	– 241.84	– 257.44
163.555	– 221.36	+ 135.76	– 138.26	+ 35.62	– 102.48	+ 299.51

Precise Orbit Determination (POD)

Root Mean Square (**RMS**) of the range residuals of the two **LAGEOS** satellites and of **LARES**



Starting epoch of the analyses:

- January 16, 1993 (MJD 49003): for both **LAGEOS**
- February 18, 2012 (MJD 55975): for **LARES**

Data reduction:

- without empirical accelerations: +
- with empirical accelerations: ●

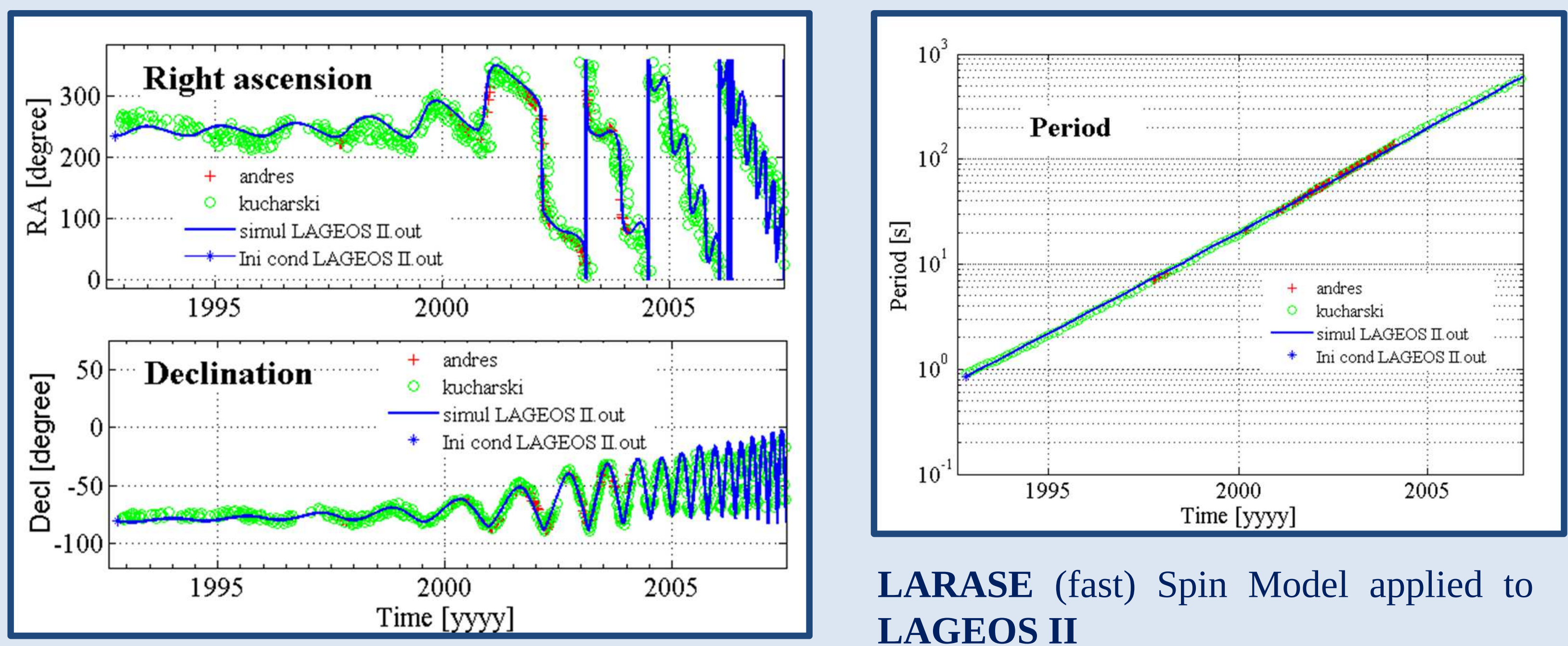
Arc length: **LAGEOS** = 14 days **LARES** = 7 days

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 one) requires the knowledge of spin-axis orientation and rate in inertial space as,:

- Yarkovsky-Schach effect
- Earth-Yarkovsky effect
- Asymmetric reflectivity effect

We reviewed, corrected, extended and, finally, generalized, current models for the spin evolution of the two **LAGEOS** and of **LARES**



LARASE (fast) Spin Model applied to **LAGEOS II**

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.