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MEASURING RELATIVISTIC EFFECTS IN THE FIELD OF THE EARTH WITH LASER RANGED SATELLITES AND THE LARASE RESEARCH PROGRAM

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Introduction

The main goal of the LARASE (LAser RAnged Satellites Experiment) research program is to obtain refined tests of Einstein's theory of General Relativity (GR) by means of very precise measurements of the round-trip time among a number of ground stations of the International Laser Ranging Service (ILRS) network and a set of geodetic satellites. These measurements are guaranteed by means of the powerful and precise Satellite Laser Ranging (SLR) technique.

In particular, a big effort of LARASE is dedicated to improve the dynamical models of the LAGEOS, LAGEOS II and LARES satellites, with the objective to obtain a more precise and accurate determination of their orbit. These activities contribute to reach a final error budget that should be robust and reliable in the evaluation of the main systematic errors sources that come to play a major role in masking the relativistic precession on the orbit of these laser-ranged satellites. These error sources may be of gravitational and non-gravitational origin. It is important to stress that a more accurate and precise orbit determination (POD), based on more reliable dynamical models, represents a fundamental prerequisite in order to reach a sub-mm precision in the root-mean-square of the SLR range residuals and, consequently, to gather benefits in the fields of geophysics and space geodesy, such as stations coordinates knowledge, geocenter determination and the realization of the Earth's reference frame.

LARASE activities

The main activities preparatory to the final relativistic measurements, as well as to the evaluation of the error budget from the main sources of systematic errors, focus upon the modeling of the gravitational and non-gravitational perturbations that act on the satellites and affect their POD. In particular, we have concentrated on the:

- Modeling of the thermal effects acting on the satellite in relationship to its rotation and to the thermal inertia of its mirrors: namely the Yarkovsky-Schach effect, produced by the direct radiation from the Sun when it is modulated by the eclipses from the Earth and the Earth-Yarkovsky or Rubincam effect, due to the infrared emission from the Earth's surface. These effects are strongly connected to the rotation of the satellite. Therefore a careful dynamical model of the satellite was built to predict the spin evolution.
- Modeling of the impact of the neutral drag on the orbit of LARES.
- Modeling of the influence of solid and ocean tides on the orbit of the satellites.
- Improvement of the quality of the POD of the satellites in order to have small difference between *calculated* and *observed* orbit.

Selected References

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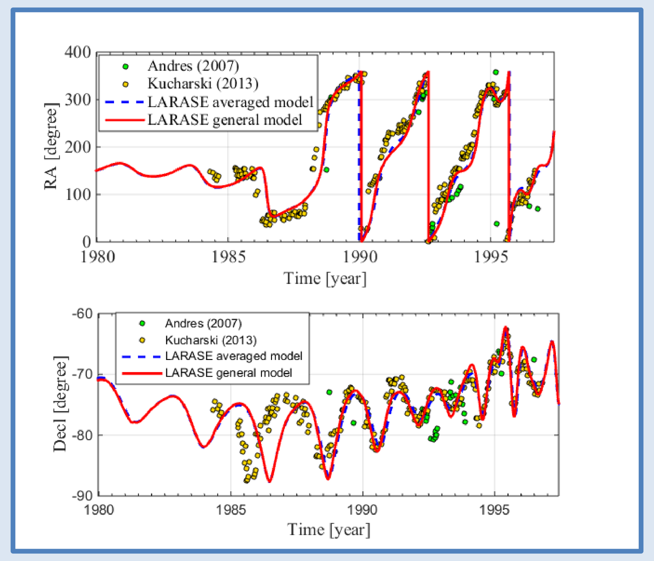
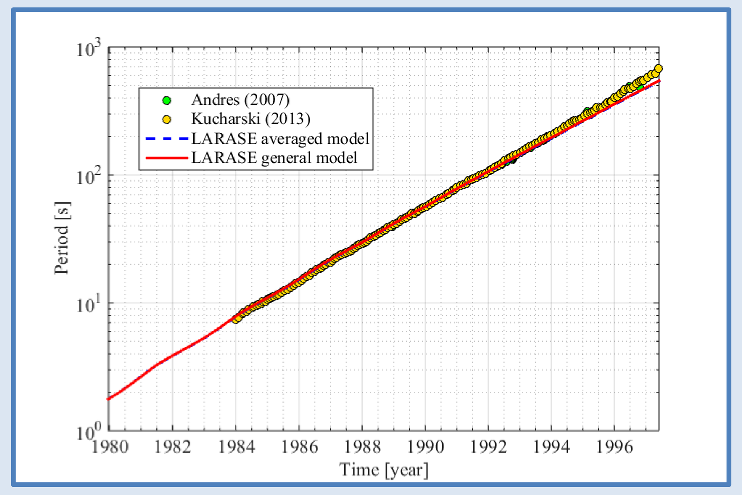
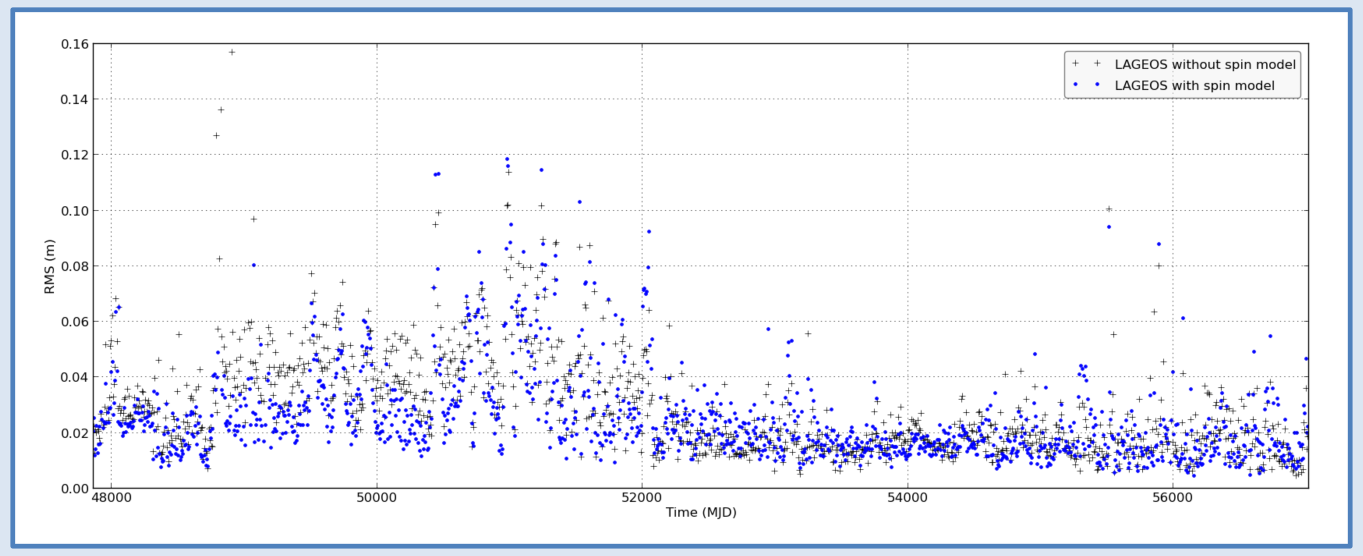
Dynamical model

We have modeled the spin evolution both in orientation and rate of the two LAGEOS satellites and of LARES. In our model, called LASSOS (LArase Satellites Spin mOdel Solutions), we considered the torques due to the Earth's magnetic and gravitational fields and to surface thermal forces acting on the satellite due to the solar visible radiation. The calculated values of the spin components can be compared with the available measurements. Our model can produce results using not-averaged torques, and therefore can be conveniently used also when the spin period is close, or larger, than the orbital period. Furthermore, we adopted Euler equations in the body reference frame making it possible to easily handle the spin evolution when the rotational axis does not coincide with that of symmetry.





In the above figures we report for the older LAGEOS satellite the orientation (Right Ascension and Declination) and the rotational period that we have obtained applying our model LASSOS. The model is compared with two different sets of experimental data.



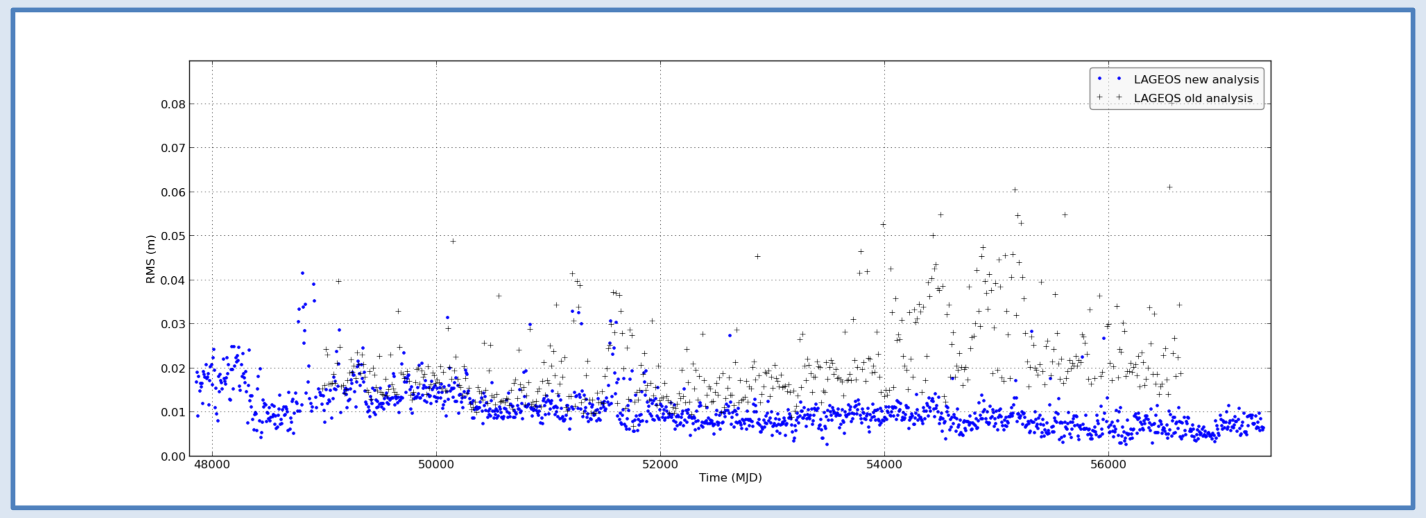
In this figure we have plotted for LAGEOS the root mean square (RMS) of the range residuals of a POD when the thermal forces are modeled (blue) with the use of LASSOS for the spin evolution, and when they are not modeled (black). The RMS reduces in average from 2.8 cm to 2.5 cm.

Conclusions

The activities within the LARASE project, funded by Istituto Nazionale di Fisica Nucleare (INFN), are gradually improving the dynamical models used to account for the effects that perturbs the orbit of the tracked geodetic satellites — LAGEOS, LAGEOS II and LARES — consequently reducing the errors on the measurements of the relativistic effects to be performed. The SLR data of the two LAGEOS and of the newer LARES were used to give an estimation of the Lense-Thirring effect precession on the secular drift of the combined nodes of the three satellites. The preliminary result for this measure is an agreement with the prediction of General Relativity within 99.9%. The statistical error from a non-linear best fit is about 0.1%, but it depends on the number of periodic effects (tides) that are adjusted and absorbed during the fitting procedure. The analysis of the main systematic error sources is currently underway. A new measure of the Lense-Thirring effect over a longer time span is in preparation together with new measurements of relativistic gravity aiming at testing the predictions of Einstein's theory of gravitation with respect to those of the alternative theories of gravitation that have been proposed so far.

Precise Orbit Determination (POD)

The POD is performed using the software GEODYN II (NASA/GSFC). We divided the analysis period into sub-periods, called arcs, with a length of 7 or 14 days. The measurement of the distances between the ground stations and the satellite gathered during each arc were used to estimate the state vector of each satellite (position and velocity) at the beginning of each arc. This state vector of each arc should be compared with the estimated state vector obtained in the previous arc and propagated at the same epoch. The difference between couples of values are the residuals (in the keplerian elements or in position and velocity). Usually, the range residuals (observed – computed) give a measurement of the goodness of the orbit fit. The variation in the residuals depends on the quality of the measurements performed by the tracking stations, on the quality of the dynamical model implemented in the software and on the goodness of the POD. Since the beginning of our experiment the quality of our POD has significantly improved, as is shown in the following figure.



Measurements of relativistic effects

To measure the precessions that are due to the relativistic effects, the orbital parameters that best fit the tracking observations of a given arc are compared with the ones calculated in the previous arc and propagated at the same epoch. Obviously, the effect to be measured is not included in the models. The residuals computed on different orbital parameters (sensitive to the relativistic effect) can be suitably combined with proper weights to obtain a more robust measure. We used the drift in the residuals of the node's right ascension of the two LAGEOS and LARES over a period of 3.4 years for a very preliminary new measurement of the Lense-Thirring effect. To take count of the effects not completely modeled by the software used for the POD, we fitted also for a minimum of three to a maximum of twelve tides (both solid and ocean). Indeed, tides mismodeling (especially from the ocean tides) and unmodeled non-gravitational forces due to thermal effects may corrupt the measurement of the relativistic effect. For instance, the K1 tides (both solid and ocean) have the same periods of the right ascension of the node of the satellites: ≈1052 days for LAGEOS, ≈570 days for LAGEOS II and ≈211 days for LARES. The figure shows the best non-linear fit that we obtained on the combined residuals of the satellites. The combination removes the errors related with the uncertainties of the first two even zonal harmonics (quadrupole and octupole) of the Earth's gravitational field.