# Comparison of LARES 1 and LARES 2 missions
# - one year after the launch

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**Abstract.** The LARES 1 and LARES 2 missions were designed to test an intriguing phenomenon predicted by the theory of general relativity: the *Lense-Thirring* (*frame-dragging*) effect. In particular, the LARES 2 mission was designed with the goal of reaching an accuracy 10 times better than that obtained with LARES 1, launched 10 years earlier. To reach this demanding goal a special orbit and a specific satellite design was required. Knowledge of the gravitational field of Earth of ever-increasing accuracy, thanks to the Follow-on GRACE space mission together with the spectacular orbital injection accuracy provided by the Avio-ASI-ESA launcher VEGA C, will make possible an even better accuracy after a few years of data analysis. In this paper the two missions are compared along with the results obtained from the LARES 1 mission and those expected from LARES 2.

**Introduction**

LARES 2, was successfully launched from the European spaceport in French Guyana on the inaugural flight of VEGA C (13 July, 2022). This launch occurred 10 years after the maiden flight of VEGA that carried as main payload the LARES 1 satellite. Both launch vehicles were developed, financed and managed by ASI, Avio and ESA. The two orbits are quite special. Particularly the LARES 2 orbit needed to be quite high compared to classical LEO orbits, and in comparison, to the case of LARES 1 there were very tight tolerances in the orbit parameters. The injection accuracy for LARES 1 was very high, but for LARES 2 the accuracy was spectacular; it matched the orbit to 10 times better accuracy than previously required, affording the prerequisites for even better results than originally designed [1]. This will allow an improvement in the accuracy of the frame-dragging (Lense-Thirring effect) measurement by one order of magnitude with respect to obtained using LARES 1 [2], allowing an accuracy of at least as good as a few parts per thousand. Frame-dragging is measured by observing how the node of a satellite orbit is shifted by the dragging of spacetime induced by the Earth rotation. In general relativity spacetime is deformed by mass-energy but also by currents of mass-energy, such as Earth's rotation. Laser ranging provides the most accurate ranging measurement achievable today in near-Earth space and

is capable of providing the necessary data for the LARES missions. The main problem in measurement of frame dragging arises from classical gravitational and non-gravitational perturbations whose effects on the node are huge compared to frame-dragging. A combination of the data of the two LARES satellites and the two LAGEOS satellites is required, together with very accurate knowledge of the gravitational field of Earth is necessary to extract the frame dragging values during the analysis. (The gravitational fields from GRACE and GRACE Follow On missions are used.)

**Frame-dragging of general relativity**

General relativity (GR) is the best theory of gravitation interaction available today [3,4]. However, there are still open issues such as its reconciliation with quantum mechanics and the problem of spacetime singularities inside black holes where all known physical theories break down, and whose existence is a robust prediction of general relativity [5]. The accelerating expansion of the universe [6] is another mystery that increases the interest in experimental verification of GR. In this framework LARES 1 and LARES 2 missions find their natural environment, to measure the effect of Earth rotation on spacetime: the Lense-Thirring effect, named after the two Austrian physicists that derived it in 1918. In principle the measurement is relatively easy because it would be sufficient to measure the node shift of one satellite orbit and compare it with the prediction of GR. Unfortunately, the shift due to GR is only about 118.5 mas/y for LARES 1 and about 30.7 mas/y for LARES 2, translating to only about 4 m/y and 2 m/y respectively, while classical perturbations produce shifts about 7 orders of magnitude larger, translating to node shifts of many thousands of km per year. The original idea to circumvent this problem was proposed and published in references [7-12]; the key is to use two satellites orbiting at the same altitude but with supplementary inclinations or in other words to use a so-called butterfly configuration (Fig. 1). Originally, in the 80's, the mission was named LAGEOS 3 and was supposed to put a copy of LAGEOS 1 and 2 in the supplementary orbit now occupied by LARES 2. In 2012 ESA and ASI offered a launch opportunity with the inaugural flight of the VEGA launcher developed by Avio. The launch envelope of the inaugural flight was limited to 1500 km and so a different approach to eliminate the effect on the node of the even-zonal harmonics was devised [2]. In this case the combination of the three satellites LAGEOS 1, LAGEOS 2 and LARES 1 was necessary to eliminate major disturbances due to the uncertainties of the first two even-zonal harmonics: $J_2$ and $J_4$. Intermediate results were reported in the years that followed the launch (see for instance [13]), culminating 7 years after the launch in reaching the mission goal of 1-2% accuracy in the frame-dragging [2]. Frame-dragging around Earth is tiny and very difficult to measure, but observable with high accuracy with the LARES missions. In extreme astrophysical/cosmological phenomena such as the formation of accretion disks of rotating black holes and in explaining the fixed direction of jets in active galactic nuclei, frame dragging is very important, large, but difficult to determine to high accuracy. Also, black hole mergers which produce gravitational waves observed by the LIGO-Virgo-KAGRA laser interferometer detectors [14], are strongly influenced by frame-dragging.
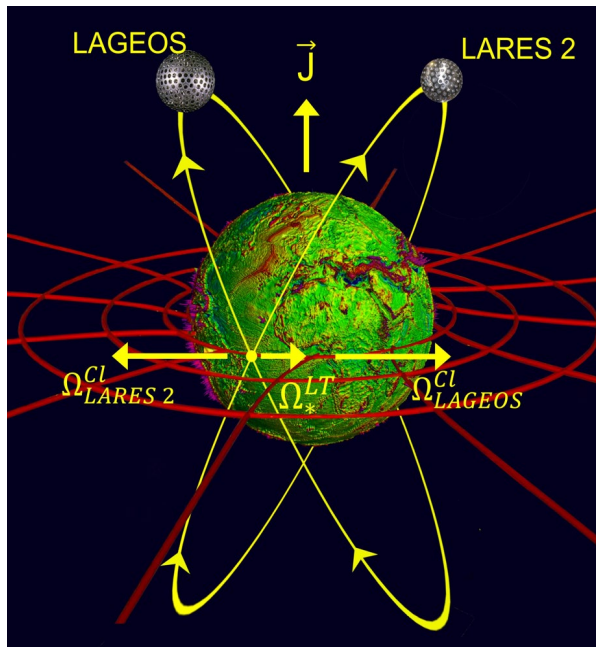
*Fig. 1. The even zonal gravitational harmonics of the Earth produce the very large and well-known shift of the node $\Omega^{Cl}$ (the superscript $Cl$ reminds us that the shift is due to classical perturbation) while $\Omega^{LT} = \Omega^{LT}_{LAGEOS} + \Omega^{LT}_{LARES\,2}$ (LT stands for: Lense-Thirring effect) is the tiny shift due to the dragging of inertial frames predicted by the theory of general relativity and **J** is the Earth angular momentum. The small variations of the gravitational field of Earth are represented in false colors and report actual experimental values obtained for instance by the GRACE and GRACE FO space missions. The red lines are a pictorial representation on how spacetime is dragged by the Earth rotation.*

**LARES 1 and LARES 2 missions**

Both missions are based on the precise orbit determinations of the two satellites along with those of the two LAGEOS satellites. Laser ranging is used to measure the satellite orbits to a few millimeters' accuracy. Both LARES satellite bodies are made in one single piece, differently from all other geodetic passive satellites; LARES 2 has a novel CCR distribution which is not regular along the parallels. In Table 1 are compared other characteristics. In Fig. 2 is reported the last LT measurement obtained with LARES 1 mission that shows the mission goal was fulfilled.
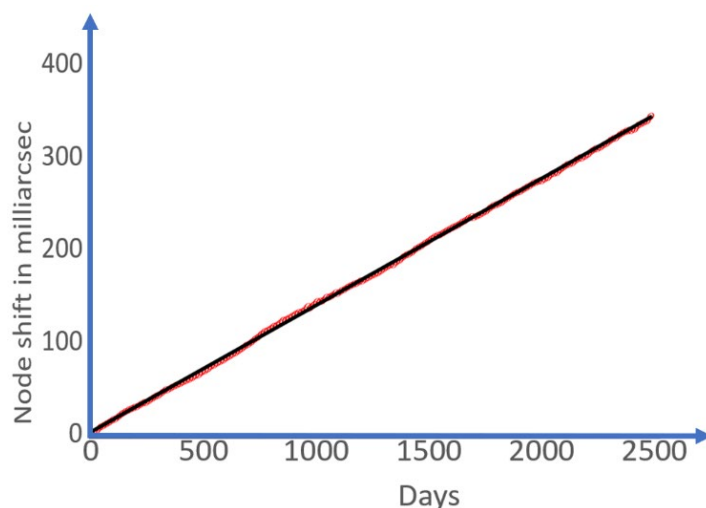


*Fig. 2. Result of the LARES 1 mission [2]. The figure reports the LT effect measurement obtained by analyzing 7 years of orbital data of three satellites: the two LAGEOS and LARES 1. The horizontal axis reports the number of days. In red are the actual data and in black a linear fit. Taking 1 as the theoretical value of LT effect we have obtained 0.9910 ± 0.02, i.e., with 0.02 systematic error and with 0.001 formal error.*

The orbital analysis of LARES 2 combined with that of LAGEOS 1 is in progress. The current availability of approximately one year of data is not sufficient to reduce the effects on the satellite nodes of the large perturbations due to some tides and, *so far*, to improve the accuracy of the measurement of LT in Fig. 2. By applying proper averaging and fits of such orbital perturbations, using data of a longer period of time, an improved measurement will be obtained in a few years.

*Table 1. Comparison of the LAGEOS with the two LARES satellites. S and M are the surface and the mass of the satellites respectively. S/M is calculated relative to the value of LAGEOS 1.*

| | ORBITAL PARAMETERS | | | Metal alloy | $D$ [m] | $M$ [kg] | CCR No. | CCR dia [in] | $S/M$ relative |
|---|---|---|---|---|---|---|---|---|---|
| | $i$ [°] | $a$ [km] | $e$ | | | | | | |
| LARES 1 | 69.44 | 7827.598 | 0.0009 | W | 0.364 | 386.8 | 92 | 1.5" | 0.39 |
| LARES 2 | 70.158 | 12266.198 | 0.00027 | Ni | 0.424 | 294.8 | 303 | 1.0" | 0.69 |
| LAGEOS 1 | 109.844 | 12269.988 | 0.004 | Al-Cu | 0.6 | 407 | 426 | 1.5" | 1 |

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