The LARES 2 satellite for testing general relativity successfully placed in orbit with VEGA C

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LARES – LARES 2
LAser RElativity Satellites

- A. Einstein (**1913**); J. Lense, H. Thirring (**1918**): definition of Dragging of Inertial Frames, or "frame dragging" .
- **1960-2004**. Gravity Probe B experiment (NASA).
- **1976**. Launch of LAGEOS (LAser GEOdynamics Satellite) by NASA.
- **1984-1989.** Proposal for a LAGEOS 3 satellite.
- **1992**. Launch of LAGEOS 2 (LAser GEOdynamics Satellite) by NASA/ASI.
- **1996-1998**. The first rough observation of frame-dragging using the data of LAGEOS and LAGEOS 2 (Class. Quantum Grav. 1997, Science 1998).
- **2002.** Launch of GRACE (Gravity Recovery And Climate Experiment) by GFZ/NASA. The mission accurately measures the gravity field of the Earth's.

LARES – LARES 2
LAser RElativity Satellites

- **2004-2010.** Measurement of Frame Dragging with data from LAGEOS/LAGEOS 2, with accuracy of 10% (Nature 2004, General Relativity and J. A. Wheeler, 2010).
- **2011-2015**. Results from the Gravity Probe B experiment reported a measurement of the frame dragging effect with an accuracy of about 19%.
- **2012.** Launch of LARES on the VEGA VV01 by ASI.
- **2016-2019.** The results from LARES – LAGEOS – LAGEOS 2 data are published. Frame dragging measured at about 2% , depending on the model of the systematic errors (see European Physical Journal C, 2019).
- **2018.** Launch of the GRACE Follow On mission (GFZ/NASA).
- **2022.** Launch of LARES 2 by ASI on the new VEGA-C launcher.

Dragging of inertial frames (and gravitomagnetism)

- Spacetime curvature is generated by mass-energy currents
- It plays a key role in high energy astrophysics (Kerr metric)

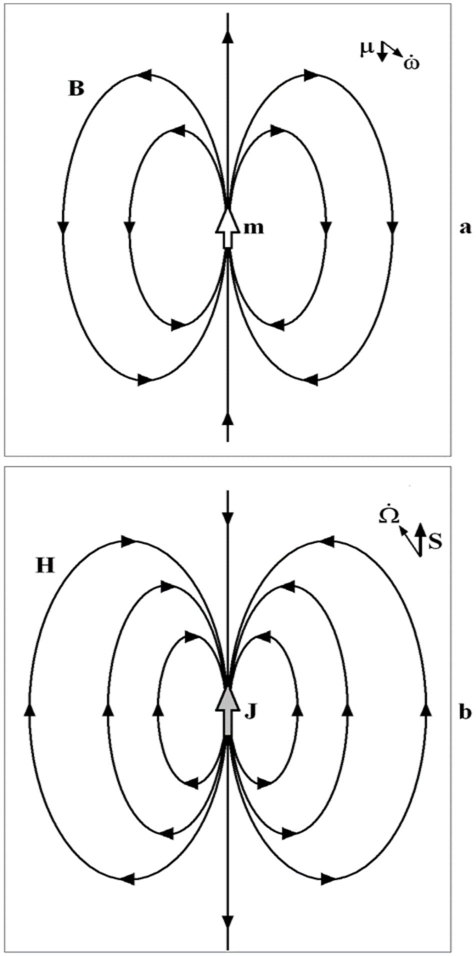
GRAVITOMAGNETISM

There is an interesting analogy of weak-field and slow-motion General Relativity with electromagnetism.

Magnetic field **B**, gravitomagnetic field **H**

and the precession of

a magnetic dipole μ and of a gyroscope **S**



Measurement of Frame Dragging

LAGEOS 3 – LARES 2

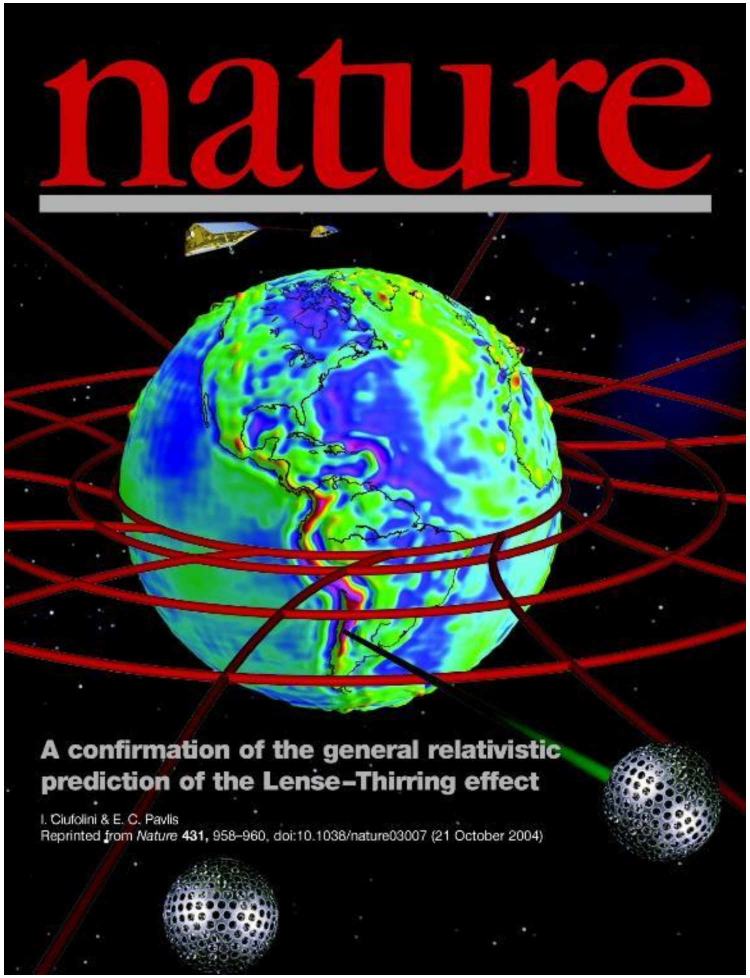
Use two LAGEOS-type satellites on orbits with the same semi major axis and supplementary inclinations to eliminate the effect of all the J_{2n} zonal harmonics.

LARES

Use *n* LAGEOS-type satellites to measure the first *n-1* even zonal harmonics, J_2, J_4, … and the frame-dragging effect.

I. Ciufolini, Phys. Rev. Lett (1986)
I. Ciufolini, Int. J. of Mod. Phys. A (1989)

Measurement of Frame Dragging

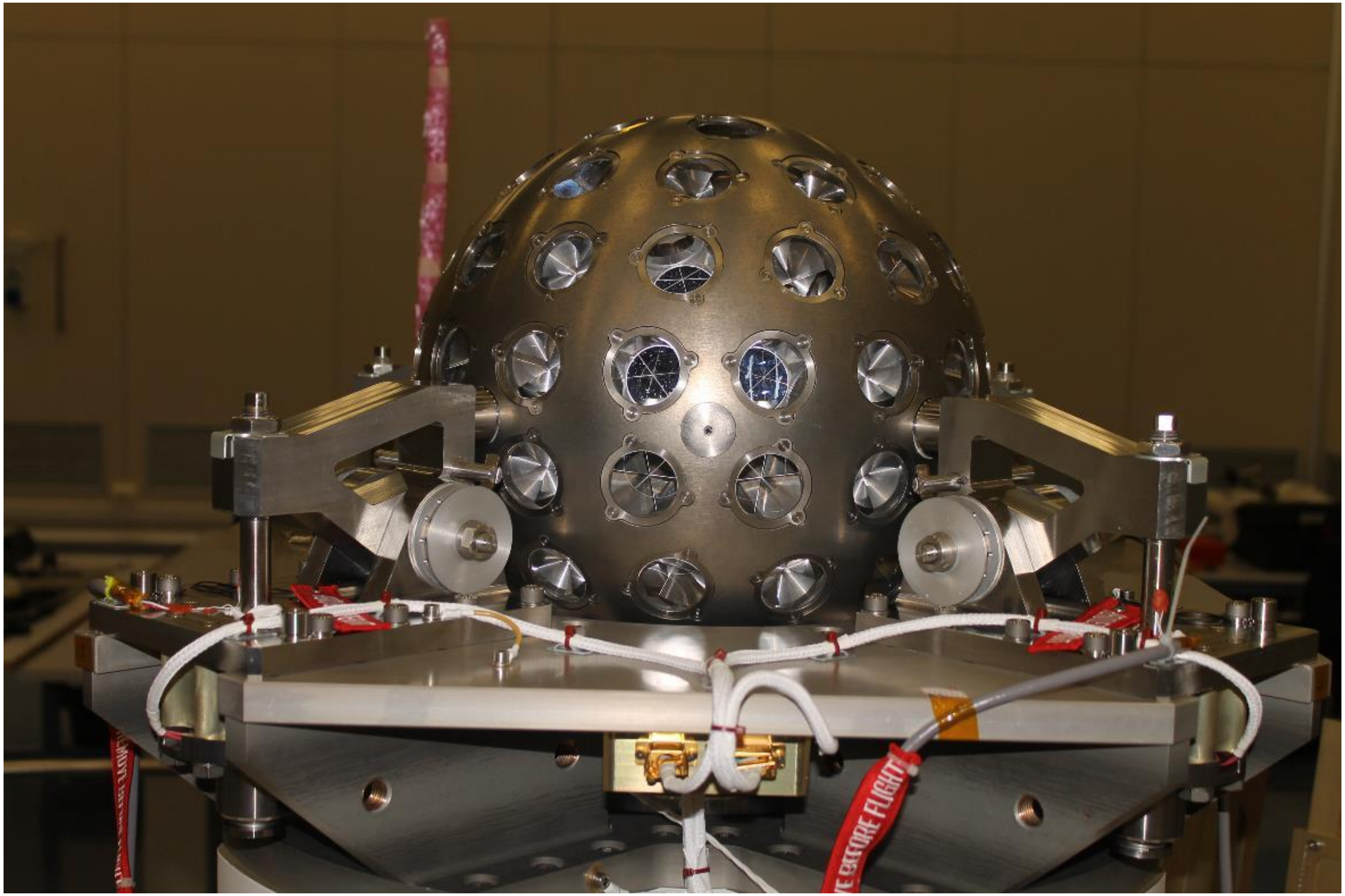


2004-2010. Measurement of Frame Dragging with data from LAGEOS/LAGEOS 2, with accuracy of about 10%

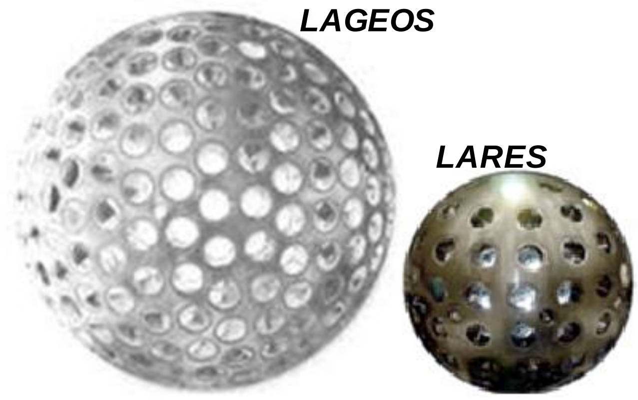
2012 - LARES (LAser RElativity Satellite)

LARES was successfully launched and accurately injected in the nominal orbit on February 13th 2012 with the ESA launcher VEGA from Kourou, French Guyana

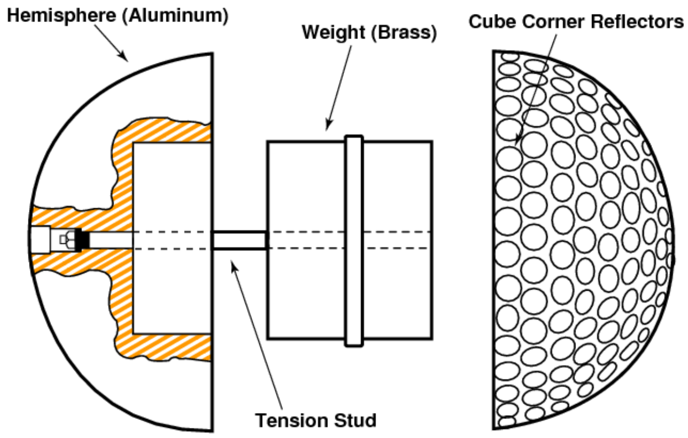
LARES



Design: LARES vs LAGEOS



LAGEOS Assembly



	LAGEOS	LARES
Launch:	• 1976 (1) • 1992 (2)	2012
Mass:	• 406.9 kg (1) • 405.3 kg (2)	386.8 kg
Diameter:	600 mm	364 mm
Body:	Assembly.	Single piece.
Material:	Al alloy hemisphere; Denser alloy core.	Tungsten alloy (ρ = 18000 kg/m^3)
N. CCR:	426	92
Eccentricity:	• 0.0045 (1) • 0.0135 (2)	0.0005
Altitude:	• 5860 km (1) • 5620 km (2)	1430 km

Results of LARES mission

2016 – Preliminary Results

Ciufolini, I., Paolozzi, A., Pavlis, E.C. et al. A test of general relativity using the LARES and LAGEOS satellites and a GRACE Earth gravity model. Eur. Phys. J. C 76, 120 (2016). https://doi.org/10.1140/epjc/s10052-016-3961-8

$$\mu = (0.994 \pm 0.002) \pm 0.05$$

μ=1 is the value of frame-dragging normalized to its General Relativity value
0.002 is the 1-sigma statistical error,
0.05 is the preliminary estimate of systematic error mainly due to the uncertainties in the Earth gravity model GGM05S

2019 – Improved Results

Ciufolini, I., Paolozzi, A., Pavlis, E.C. et al. An improved test of the general relativistic effect of frame-dragging using the LARES and LAGEOS satellites. Eur. Phys. J. C 79, 872 (2019). https://doi.org/10.1140/epjc/s10052-019-7386-z

$$\mu = 0.9910 \pm 0.02$$

μ=1 is the value of frame-dragging normalized to its General Relativity value,
0.02 is the estimated total systematic error.

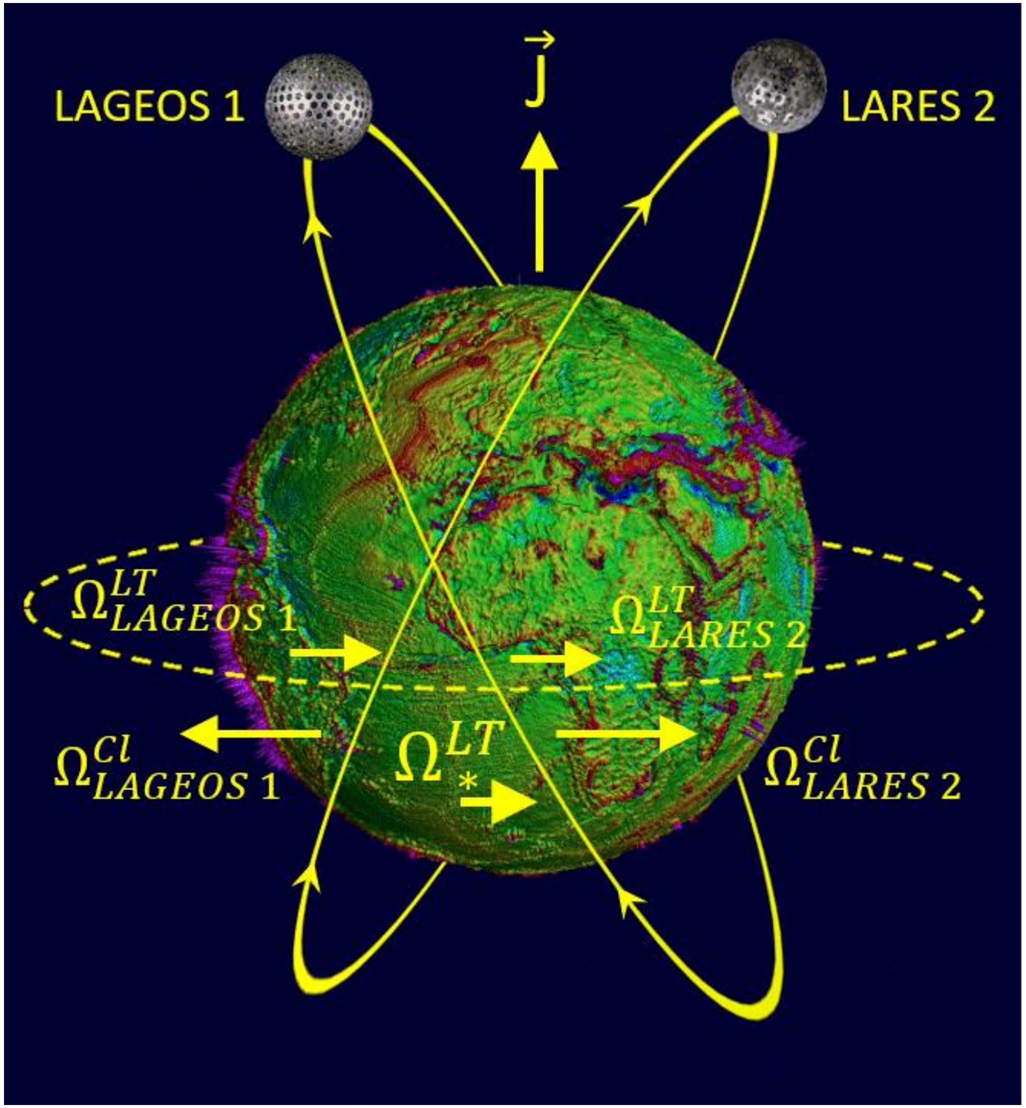
This total systematic error can be estimated to be within about 1% and 3%, depending on the evaluation of the partially unknown systematic errors.

2022 – LARES 2 (LAser RElativity Satellite)

LARES 2 was successfully launched and accurately injected in the nominal orbit on July 13th 2022 with the ESA launcher VEGA- C from Kourou, French Guyana

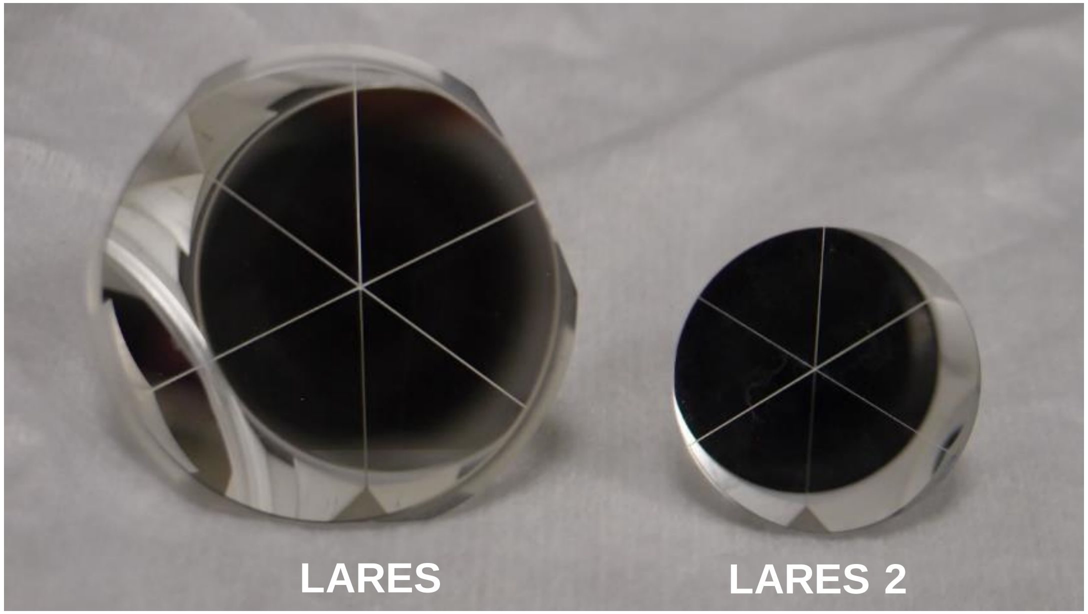
LARES 2 (LAGEOS 3)

The LARES 2 satellite for test of frame-dragging with accuracy at the 0.2% level and other tests of General Relativity and Fundamental Physics
(and space geodesy and geodynamics).

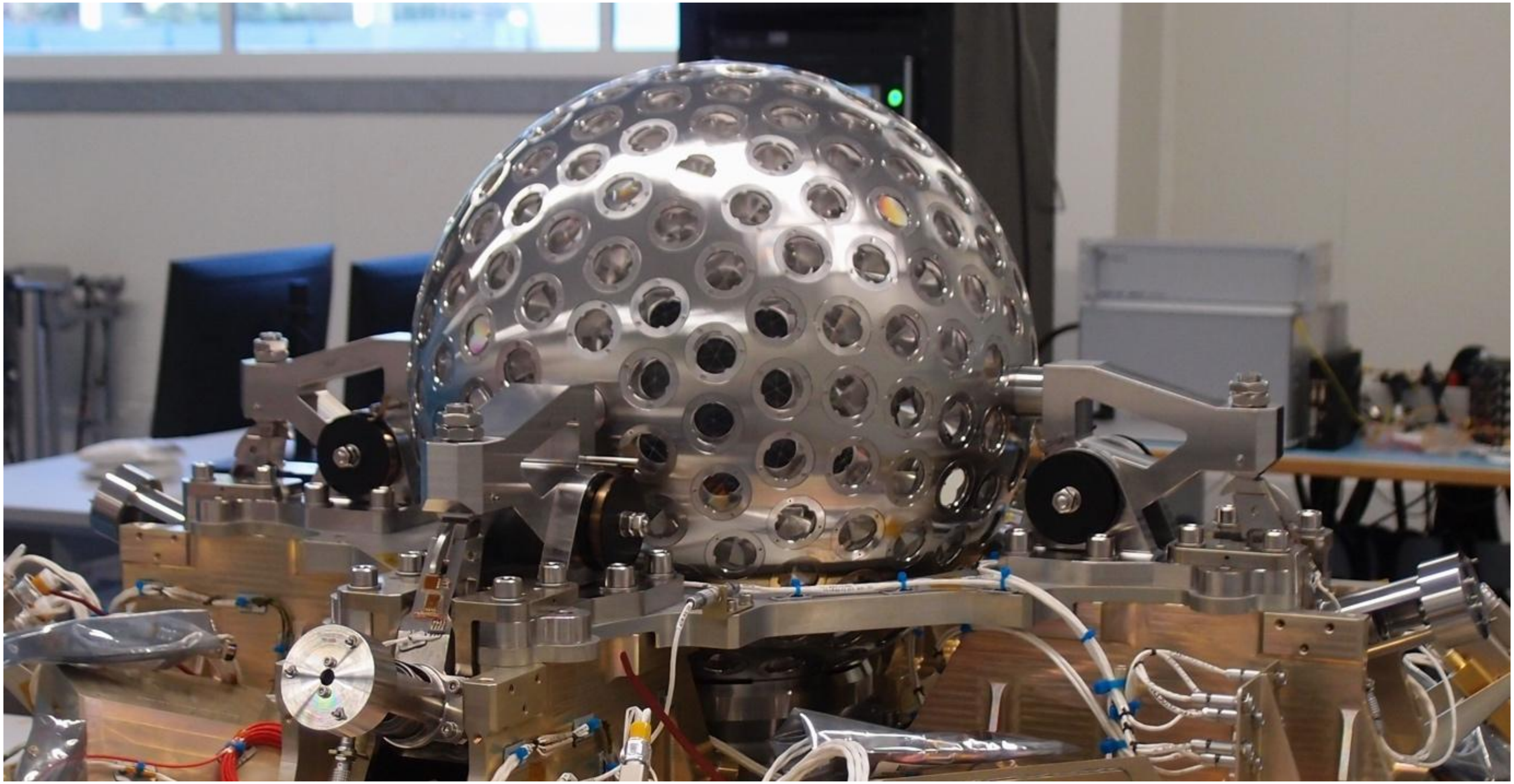


LARES 2: what is new with respect to LAGEOS 3?

The satellite structure is quite improved with respect to all the other laser-ranged satellites because of a special distribution of the retroreflectors, a specifically designed mounting system, 1 inch retroreflectors. LARES 2 will be the first satellite with both a very high mass-to-surface ratio (second only to LARES) and a signature effect below 1 mm.



LARES 2



LAGEOS - LARES – LARES 2 comparison

	LAGEOS	LARES	LARES 2
Launch:	1976	2012	2020
Mass:	406.9 kg	386.8 kg	294.8 kg
Diameter:	600 mm	364 mm	424 mm
Body:	Assembly.	Single piece.	Single piece.
Materials:	Aluminium alloy and Copper alloy	Tungsten alloy	Nickel alloy
N. CCR:	426	92	303
Diameter of CCRs	1.5 inch	1.5 inch	1 inch

LARES 2 mission

- I. Ciufolini, A. Paolozzi, E.C. Pavlis, G. Sindoni, R. Koenig, J. C.Ries, R. Matzner, V. Gurzadyan, R. Penrose, D. Rubincam and C. Paris, A new laser-ranged satellite for General Relativity and space geodesy: I. An introduction to the LARES2 space experiment. Eur. Phys. J. Plus 132, 336 (2017). https://doi.org/10.1140/epjp/i2017-11635-1
- I. Ciufolini, E.C. Pavlis, G. Sindoni, J.C. Ries, A. Paolozzi, R. Matzner, R. Koenig & C. Paris. A new laser-ranged satellite for General Relativity and space geodesy: II. Monte Carlo simulations and covariance analyses of the LARES 2 experiment. Eur. Phys. J. Plus 132, 337 (2017). https://doi.org/10.1140/epjp/i2017-11636-0
- Ciufolini, I., Matzner, R., Gurzadyan, V. and Penrose R.. A new laser-ranged satellite for General Relativity and space geodesy: III. De Sitter effect and the LARES 2 space experiment. Eur. Phys. J. C 77, 819 (2017). https://doi.org/10.1140/epjc/s10052-017-5339-y
- I. Ciufolini, R.A. Matzner, J.C. Feng, A. Paolozzi, D.P. Rubincam, E.C. Pavlis, J.C. Ries, G. Sindoni & C. Paris. A new laser-ranged satellite for General Relativity and space geodesy: IV. Thermal drag and the LARES 2 space experiment. Eur. Phys. J. Plus 133, 333 (2018). https://doi.org/10.1140/epjp/i2018-12174-y

LARES 2 mission

- A. Paolozzi, G. Sindoni, F. Felli, D. Pilone, A. Brotzu, I. Ciufolini, E.C. Pavlis, C. Paris, Studies on the materials of LARES 2 satellite, Journal of Geodesy 93 (11), 2437-2446, 2019. https://doi.org/10.1007/s00190-019-01316-z
- I. Ciufolini, A. Paolozzi, E.C. Pavlis, R. Matzner, R. König, J. Ries, G. Sindoni, C. Paris, C. and V. Gurzadyan, Tests of General Relativity with the LARES Satellites. In: Relativistic Geodesy. Fundamental Theories of Physics, vol. 196, pp. 467-479, Springer, Cham, 2019. https://doi.org/10.1007/978-3-030-11500-5_15
- Ciufolini, I., Paris, C. Status of the LARES and LARES 2 space experiments. Eur. Phys. J. Plus 136, 1030 (2021). https://doi.org/10.1140/epjp/s13360-021-01980-1
- I. Ciufolini, A. Paolozzi, E.C. Pavlis, J.C. Ries, R. Matzner, C. Paris, E. Ortore, V. Gurzadyan and R. Penrose, The LARES 2 satellite, General Relativity and fundamental physics (in printing).

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CONCLUSION

- LARES was successfully launched in 2012 and provided a measurement of the frame dragging effect with an accuracy of a few parts in one hundred.
- LARES 2 is designed to improve both the accuracy of the measurement of the frame dragging effect, and the ranging precision.
- The improved VEGA-C launcher allowed to put LARES 2 on a supplementary orbit with respect to LAGEOS.
- Because of the extremely high injection precision of LARES 2 on its nominal orbit, the team expect to reach an accuracy in the test of frame dragging of few parts in a thousand.

Thank you!