Highlights

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Underground Sagnac gyroscope with sub-prad/s rotation rate sensitivity: Toward general relativity tests on Earth

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Measuring in a single location on Earth its angular rotation rate with respect to the celestial frame, with a sensitivity enabling access to the tiny Lense-Thirring effect, is an extremely challenging task. GINGERINO is a large-frame ring laser gyroscope (RLG), operating as free running and unattended inside the underground laboratory of the Gran Sasso, Italy. The main geodetic signals, i.e., annual and Chandler wobbles, daily polar motion, and length of the day, are recovered from GINGERINO data using standard linear regression methods, demonstrating a sensitivity approaching tens of frad/s, therefore close to the requirements for Earth-based Lense-Thirring and Lorentz violation tests.
RLGs, based on the Sagnac effect, are the top sensitivity instruments for measuring rotation rates relative to an inertial frame with excellent accuracy.
Accessing GR signals paves the way to a novel approach for testing general relativity on the Earth looking at the gravitational field that we directly experience on our planet. In this paper, we demonstrated that the sensitivity of a heterolithic RLG, GINGERINO, can be pushed to the envelope of the GR sensitivity region by applying statistical methods to data analysis. In particular, a linear regression procedure evaluates the parameters' weighting contribution of different signals accounting for laser dynamics, local rotation as measured by a colocated tilt meter, and environmental probes (local temperature and tides), in order to find the best estimate of known geodetic signals as given by IERS (International Earth Rotation Reference Systems Service). In this case geodetic signals play the role of calibration signals.
GINGERINO represent a prototype of a more ambitious RLG array that, being multi-dimensional, will be able to reconstruct not only the absolute value of the Erath rotation rate but also its vectorial nature thus allowing the identification of GR signals not measured elsewhere.
In the figures you can find: (left) the progress of the linear regression procedure (single-fit method): (a) ω_{s0} and F_{eff} obtained by subtracting effects related to laser systematics; (b) F_{eff} after further subtraction of the effects related to tilt-meter signals; (c) the evaluated F_{geo} compared with F_{IERS}. In order to better show the sensitivity of the measurement, the plotted data are subtracted for the mean values, as reported in the legends in Hz; (right) The evaluated F_{geo} compared with F_{IERS} (blue and green lines, respectively) for (a) the 2018 and (b) the 2019 data sets. Uncertainties are below 1 μHz (equivalent to an error in the evaluated angular rotation rate of 1.7×10^{-13} rad/s) in a bandwidth corresponding to a 600 s measurement time. An evaluation is carried out with the separated time window method. Data marked in red in (a) demonstrate the predictive abilities of the approach. In both panels the mean values have been subtracted, and error bars are not visible in this scale.