The Impact of the New Earth Gravity Models on the Measurement of the Lense–Thirring Effect

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We examine how the new forthcoming Earth gravity models from the CHAMP and, especially, GRACE missions could improve the measurement of the general relativistic Lense–Thirring effect according to the various kinds of observables which could be adopted. In a very preliminary way, we use the first recently released EIGEN2 CHAMP–only and GGM01C GRACE–based Earth gravity models in order to assess the impact of the mismodelling in the even zonal harmonic coefficients of geopotential which represents one of the major sources of systematic errors in this kind of measurement. However, discretion is advised on evaluating the reliability of these results because the Earth gravity models used here, especially EIGEN2, are still very preliminary and more extensive calibration tests must be performed. According to the GGM01C model, the systematic error due to the unmodelled even zonal harmonics of geopotential amounts to 2% for the combination of the nodes of LAGEOS and LAGEOS II and the Perigee of LAGEOS II used up to now by Ciufolini and coworkers in the currently performed LAGEOS-LAGEOS II Lense-Thirring experiment, and to 14% for a combination explicitly presented here which involves the nodes only of LAGEOS and LAGEOS II.

KEY WORDS: Lense-Thirring effect; LAGEOS satellites; new earth gravity models.

1. INTRODUCTION

An interesting class of Post–Newtonian features is represented by the orbital effects of order $O(c^{-2})$ induced by the linearized general relativistic gravitoelectromagnetic forces on the motion of a test body freely falling in the gravitational field of a central mass.

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Among them, of great interest is the gravitomagnetic Lense–Thirring effect or dragging of inertial frames [1, 2] whose source is the proper angular momentum $J$ of the central mass which acts as source of the gravitational field. Its effect on the precessional motion of the spins $s$ of four freely orbiting superconducting gyroscopes should be tested, among other things, by the important GP–B mission [3] at a claimed accuracy level of the order of 1% or better.

Another possible way to measure such elusive relativistic effects is the analysis of the laser–ranged data of some existing, or proposed, geodetic satellites of LAGEOS–type as LAGEOS, LAGEOS II [4] and the proposed LAGEOS III–LARES [5–7]. In this case the whole orbit of the satellite is to be thought of as a giant gyroscope whose longitude of the ascending node $\Omega$ and the argument of perigee $\omega$ (In the original paper by Lense and Thirring the longitude of the pericentre $\sigma = \Omega + \omega$ is used instead of $\omega$) undergo the Lense–Thirring precessions

$$
\dot{\Omega}_{LT} = \frac{2GJ}{c^2a^3(1 - e^2)^{3/2}},
$$

$$
\dot{\omega}_{LT} = -\frac{6GJ\cos i}{c^2a^3(1 - e^2)^{3/2}},
$$

where $a$, $e$ and $i$ are the semimajor axis, the eccentricity and the inclination, respectively, of the orbit and $G$ is the Newtonian gravitational constant. In recent years first attempts would have yielded a measurement of the Lense–Thirring dragging of the orbits of the existing LAGEOS and LAGEOS II at a claimed accuracy of the order of 20%–30% [8, 9]. However, at present, there are some scientists who propose different error budgets [10].

2. THE SOURCES OF ERROR IN THE PERFORMED TEST

The observable used in the tests reported in [8, 9] is the following linear combination of the orbital residuals of the nodes of LAGEOS and LAGEOS II and the perigee of LAGEOS II [4]

$$
\delta \dot{\Omega}\text{LAGEOS} + c_1 \delta \dot{\Omega}\text{LAGEOS II} + c_2 \delta \omega\text{LAGEOS II} \sim \mu_{LT} 60.2,
$$

where $c_1 = 0.304$, $c_2 = -0.350$ and $\mu_{LT}$ is the solved–for least square parameter which is 0 in Newtonian mechanics and 1 in General Relativity. The gravitomagnetic signature is a linear trend with a slope of 60.2 milliarcseconds per year (mas yr$^{-1}$ in the following).

The latest, 2002, measurement of the Lense–Thirring effect, obtained by processing the LAGEOS and LAGEOS II data over a time span of almost 8 years with the orbital processor GEODYN II of the Goddard Space Flight Center, yields [9]

$$
\mu_{LT} \sim 1 \pm 0.02 \pm \delta \mu_{LT}\text{systematic},
$$