INFLUENCE OF THE RELATIVISTIC LAMBDA-TERM ON THE MEASURED VALUES OF THE EARTH'S ROTATION DECELERATION

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ABSTRACT. It is shown that one of the possible ways to resolve the long-standing discrepancy between the values of secular deceleration of the Earth's rotation derived from astrometric observations (9×10^{-6} sec/yr) and by the lunar laser ranging (LLR, 2.1×10^{-5} sec/yr) may be based on a more accurate treatment of the Earth–Moon dynamics in the framework of General Relativity with an account for the relativistic Λ-term, whose existence is well supported now by the cosmological data. In such a case, any additional corrections for ancient observations of solar eclipses and secular decrease in the Earth's moment of inertia would be unnecessary.

1. DATA ON SECULAR DECELERATION OF THE EARTH'S ROTATION

It is well-known that the values of secular deceleration of the Earth's proper rotation $\dot{T}_{\mathrm{E}}$ derived from various data sets considerably differ from each other, namely:

- 0.9×10^{-5} sec/yr from telescopic observations during the last ~350 years (e.g. the time series compiled by Sidorenkov 2002);
- 1.4×10^{-5} sec/yr from the telescopic data supplemented by ancient observations of solar eclipses (Stephenson & Morrison 1984);
- 2.1×10^{-5} sec/yr from the rate of secular increase in the Earth–Moon distance measured by the lunar laser ranging (Dickey et al. 1994).

The most popular way to reconcile these data, proposed about 25 years ago, was based on taking into account a secular decrease in the polar moment of inertia due to the viscous rebound of the solid Earth from the decrease in load caused by the last deglaciation. (Namely, a huge amount of ice in the polar regions during the glacial period resulted in the overdeformed state of the solid Earth. Next, when the ice have melted, the Earth gradually restores its spherical shape, leading to the decrease in the polar moment of inertia and the respective speed-up of the Earth's rotation.) The first data on secular change in the Earth's moment of inertia, characterized by the zonal gravitational harmonic coefficient J_2, gave the value $\dot{J}_2 = -3 \times 10^{-11}$ yr^{-1} (Yoder et al. 1983), which apparently confirmed the above-mentioned mechanism. In other words: $\dot{T}_{\mathrm{E}}$ *from the telescopic observations + correction for the ancient data on solar eclipses + correction for secular decrease in the polar moment of inertia =* $\dot{T}_{\mathrm{E}}$ *from LLR.*

Unfortunately, the most recent studies have shown that the secular trend in J_2 has a less amplitude (Bourda & Capitaine 2004) or even the opposite sign in some time intervals (Cox & Chao 2002). As a result, the value of long-term trend is still poorly known: for example, the various estimates discussed in Sec. 3.5. of the paper by Cheng & Tapley (2004) are scattered from -2.75×10^{-11} yr^{-1} to -1.0×10^{-11} yr^{-1}. Moreover, reliability of the ancient data on solar eclipses is also doubtful. Therefore, the problem of disagreement between the astrometric and LLR data remains now as acute as 25 years ago.

The aim of the present report is to show that the astrometric and LLR data can be well reconciled by using only the series of telescopic observations for the last ~350 years and taking into account the effect of relativistic Λ-term (whose existence at large scales is well confirmed now by the cosmological data). In other words: $\dot{T}_{\mathrm{E}}$ *from telescopic observations + correction for* Λ*-term =* $\dot{T}_{\mathrm{E}}$ *from LLR.*

2. EFFECT OF THE LAMBDA-TERM

The basic idea of our approach is that the rate of secular increase in the Earth–Moon distance measured by LLR (3.8 cm/yr, e.g. Dickey et al. 1994) consists actually of the two parts. The first of them is caused by the well-known tidal exchange of angular momentum between the Earth and Moon (for more details see, for example, Dumin 2003), and only this part should be taken into account in the calculation of $\dot{T}_{\rm E}$; while the second part is the "local" Hubble expansion, which does not affect the actual value of $\dot{T}_{\rm E}$.

Next, we assume that the rate of the "global" Hubble expansion (at intergalactic scales) is caused both by the uniformly-distributed Λ-term ("dark energy") with density $\rho_{\Lambda 0}$ and the irregularly-distributed dust-like matter $\rho_{\rm D0}$: $H_0 = \sqrt{8\pi G/3}\,\sqrt{\rho_{\Lambda 0} + \rho_{\rm D0}}$; while the local Hubble expansion is produced only by the perfectly-uniform Λ-term: $H_0^{\rm (loc)} = \sqrt{8\pi G/3}\,\sqrt{\rho_{\Lambda 0}}$ (Dumin 2008). Taking the standard values $H_0 = 71$ km/sec/Mpc and $\rho_{\Lambda 0}/\rho_{\rm D0} \approx 3$, we find that the Λ-term is responsible for a considerable part of the secular increase in the Earth–Moon distance: $\dot{R}_{\Lambda} = 2.2$ cm/yr; while the remaining part should be attributed to the tidal influence: $\dot{R}_{\rm tid} = 1.6$ cm/yr.

At last, using the well-known relation $\dot{R}_{\rm tid} = k\,\dot{T}_{\rm E}$ with $k = 1.81 \times 10^5$ cm/sec (Kaula 1968), we get $\dot{T}_{\rm E} = 0.9 \times 10^{-5}$ sec/yr, which is in perfect agreement with the value of secular increase in the length of day derived from the series of telescopic observations for the last ∼350 years (e.g. Sidorenkov 2002). Therefore, any further corrections (for the ancient solar eclipses etc.) become unnecessary.

Of course, the above semi-empirical estimates must be verified by a rigorous analysis of the General Relativity (GR) equations "from the first principles". In general, the problem of local Hubble expansion is discussed for a long time, starting from the early 1930's (e.g. review by Bonnor 2000); the main problem being a reverse influence of the local gravitating masses on the background cosmological matter distribution. The situation is much simplified for the case of the Λ-dominated (de Sitter) cosmology, and the respective GR metric was found long time ago by Kottler (1918). Unfortunately, there is still a large controversy regarding a correct choice of coordinates for the interpretation of observational data. For example, Soffel & Klioner (2004) and Klioner & Soffel (2005) constructed the local coordinates around the barycenter and concluded that the effects of the Λ-term within the solar system, manifesting themselves as tidal forces, should be completely negligible. On the other hand, when we tried to reduce the local Kottler metric to the correct Robertson–Walker cosmological asymptotics (Dumin 2007), the contributions from Λ-term looked appreciable. This contradiction should be resolved by a detailed analysis of the equations of planetary motion and light propagation in the above-cited metrics. This work is currently under way.

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3. REFERENCES

Bonnor, W.B., 2000, Gen. Rel. Grav., 32, 1005–1007.
Bourda, G., Capitaine, N., 2004, A&A, 428, 691–702.
Cheng, M., Tapley, B.D., 2004, J. Geophys. Res., 109, B09402.
Cox, C.M., Chao, B.F., 2002, Science, 297, 831–833.
Dickey, J.O. et al., 1994, Science, 265, 482–490.
Dumin, Yu.V., 2003, Adv. Space Res., 31, 2461–2466.
Dumin, Yu.V., 2007, Phys. Rev. Lett., 98, 059001.
Dumin, Yu.V., 2008, Proc. 11th Marcel Grossmann Meeting on General Relativity 2006, eds. H. Kleinert, R.T. Jantzen & R. Ruffini, World Scientific, Singapore, pp. 1752–1754.
Kaula, W.M., 1968, "An Introduction to Planetary Physics: The Terrestrial Planets", J. Wiley & Sons, New York.
Klioner, S.A., Soffel, M.H., 2005, Proc. Symp. "The Three-Dimensional Universe with Gaia", 4-7 Oct. 2004, Paris, France (ESA SP-576), eds. C. Turon, K.S. O'Flaherty & M.A.C. Perryman, ESA Publ. Div., Noordwijk, Netherlands, pp. 305–308.
Kottler, F., 1918, Ann. Phys. (Leipzig), 56, 401–462.
Sidorenkov, N.S., 2002, "Physics of the Earth's Rotation Instabilities", Nauka-Fizmatlit, Moscow (in Russian).
Soffel, M., Klioner, S., 2004, Proc. Journées 2003 Systèmes de Référence Spatio-Temporels, eds. A. Finkelstein & N. Capitaine, Inst. Appl. Astron., St.Petersburg, pp. 297–301.
Stephenson, F.R., Morrison, L.V., 1984, Philos. Trans. R. Soc. London, A313, 47–70.
Yoder, C.F. et al., 1983, Nature, 303, 757–762.