Proceedings of the 51th RENCONTRES DE MORIOND

Cosmology

La Thuile, Aosta Valley Italy *March* 19-26, 2016

2016
Cosmology

edited by

Etienne Augé,
Jacques Dumarchez
and
Jean Trân Thanh Vân

Published by ARISF, 2016

The 51th Rencontres de Moriond

2016 Cosmology

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CEA Commissariat à l'Energie Atomique et aux Energies Alterantives)
FNRS (Fond National de la Recherche Scientifique)
BSP (Belgian Science Policy)

ISBN : 979-10-968-7901-4

THE ACCELERATION OF THE MOON AND THE UNIVERSE

Göran Henriksson
Department of Physics and Astronomy, Uppsala University, Box 516, SE-751 20 Uppsala [a]

In 2015, I determined the margins of error in my new calibration of the lunar sidereal secular acceleration, –30.128 ±0.0035 arcseconds/century^2 ($''/cy^2$), based on 33 ancient total solar eclipses. The lunar secular acceleration, from the Lunar Laser Range (LLR) measurements, –25.856 ±0.003 $''/cy^2$, must be corrected for relativistic effects, –3.604 $''/cy^2$, in the Earth-Moon-system to get the lunar secular acceleration, –29.460 $''/cy^2$. The difference between this value and my new calibration, –0.668 ±0.0046 $''/cy^2$, corresponds to the cosmological acceleration predicted by Dvali et al. in a modified theory of gravity with the mass of the graviton 1.306 ±0.009 x 10^{-56} grams.

1. Lunar sidereal secular acceleration in longitude from ancient total solar eclipses

In 1985 the author finished a computer program for calculation of ancient solar eclipses based on the theory for the motion of the sun and the moon by Carl Schoch[1], but with modern values for the astronomical constants. Schoch calibrated his lunar sidereal secular acceleration, –29.68 arcseconds/century^2 ($''/cy^2$), from a conjunction between the bright star Spica and the moon in 283 BC, and from an analysis of total solar eclipses dating back to 600 BC.

However, Schoch had a third-order term in the formula for the lunar longitude, introduced by Simon Newcomb. In 2011, I decided to eliminate this non-physical term and to optimise the physical value for the lunar sidereal secular acceleration. This value must give the same result as in the earlier successful calculations according to Schoch's original formula. A search started for the value of the lunar sidereal secular acceleration that gave the maximum sum of the magnitudes for 33 total, or almost total, solar eclipses between 878 AD and 3653 BC.

The new value for the lunar sidereal secular acceleration, –30.128 ±0.0035 $''/cy^2$, gives an even better agreement with the ancient observations than the original formula, Henriksson[2]. It is valid at least during the last 5650 years with a timing error of less than two minutes.

2. The tidal acceleration of Moon from Lunar Laser Range (LLR) measurements

Among the scientific instruments onboard Apollo 11, which performed the first landing on the moon on 20 July 1969, there was a reflecting prism. There are now five reflecting prisms on the surface of the moon, the last arrived in 1973. An American and a French research team have

[a] goran.henriksson@physics.uu.se

performed parallel investigations. In the weighted mean I gave the value by Chapront et al.[3], –25.858 ±0.003 $''/cy^2$, weight three because its numerical value should be three times more accurate than –25.85 $''/cy^2$ by Williams et al.[4] as this value has only two decimals and with no error estimate. The weighted mean of the lunar secular acceleration from the LLR-measurements in the Earth-Moon inertial system is: –25.856 ±0.003 $''/cy^2$.

3. Relativistic effects in the Earth-Moon system according to Nordtvedt

In my earlier papers Henriksson[5,6,2] I have used the precession of the geodesic by the Sun, –1.92 $''/cy^2$, published by Nordtvedt[7]. In another paper by Nordtvet[8] he made a complete formula, to four decimal precision, for the relativistic effects in the Earth-Moon-system including also the Solar tidal acceleration and the precession of the geodesic by the Earth, Einstein[9]. I have calculated these effects with four decimals to avoid rounding effects. They are, –1.9189, +0.1177 and –0.0006 $''/cy^2$ respectively. The total relativistic effect on the lunar secular acceleration in longitude is 2x –1.8018 $''/cy^2$ = –3.6036 $''/cy^2$.

4. The Radius of Crossover and the Mass of the Graviton

If the LLR measurements is corrected for the relativistic effect, –3.6036 $''/cy^2$, we get the lunar secular acceleration, –29.6938 ±0.003 $''/cy^2$. If this value is subtracted from the observed lunar sidereal secular acceleration –30.128 ±0.0035 $''/cy^2$, by Henriksson, we get –0.6685 $''/cy^2$ with total uncertainty ±0.0046 $''/cy^2$. Dvali et al.[10] predicted in their theory for modified gravity an additional cosmological precession of the Earth-Moon-system. I have calculated this effect as –0.5227 $''/cy^2$, from their formulas in chapter 3, with the radius of crossover, r_c = 6 Gpc (1.85 x 10^{28} cm). If the observed additional acceleration, –0.6685 ±0.0046 $''/cy^2$, is interpreted as the cosmological precession, the corresponding radius of crossover is 4.69 Gpc or 15.3 billion light years. The Age of the Universe is 13.8 billion years and the radius of the Universe is 46.5 billion light years. This means that the acceleration of the Universe started 4.54 billion years after Big Bang. According to chapter 4 in Dvali et al.[10], the mass of the graviton $m_g = 1/ r_c$. After converting units it is found that the mass of the graviton is 1.306 ±0.009 x 10^{-56} grams. The massive graviton is 5-dimensional and needs a 5D space, but within distances $< r_c$, a 4D theory is sufficient. For distances $> r_c$, the gravitons begin to leak to the 5th dimension and the gravitational forces between the galaxies are weakened resulting in the observed acceleration of the Universe. The sign of the cosmological acceleration is negative which means that we find ourselves in the standard cosmological branch.

Acknowledgements

I am grateful to Dr. Andreas Korn for his critical reading of my text and to the Department of Physics and Astronomy, Uppsala University for the financial support of my participation in Rencontres de Moriond 2016.

References

1. C. Schoch, Astronomische Abhandlungen, Ergänzungs-hefte zu den Astronomischen Nachrichten, Band 8 B2 (1931). (World Scientific, Singapore, 1988)
2. G. Henriksson, Lunar secular acceleration supports a modified theory for gravity, Proceedings of the 49th Rencontres de Moriond, La Thuile, March 22-29 (2014).
3. J. Chapront, M. Chapront-Touzé and G. Francou. A new determination of lunar orbital parameters, precession constant and tidal acceleration from LLR measurements. Astron. Astrophys. 387, 700-709 (2002).
4. J.G. Williams, D.H. Boggs and W.M. Folkner, DE421 Lunar orbit, Physical Librations, and Surface Coordinates. IOM 335-JW,DB,WF-20080314-001, March 14 (2008).
5. G. Henriksson, Astronomical Society of the Pacific, Conference Series 409, 166 (2009).
6. G. Henriksson, Journal of Cosmology 9, 2259 (2010).
7. K. Nordtvedt, Physics Today, May 1996, 49:5, 29 (1996).
8. K. Nordtvedt, The Relativistic Orbit Observables in Lunar Laser Ranging. ICARUS 114, 51-62 (1995).
9. A. Einstein, Annalen der Physik 49 (1916).
10. G. Dvali, A. Gruzinov, and M. Zaldarriaga, Phys. Rev. D, 68, Issue 2, id. 024012 (2003).