LUNAR SECULAR ACCELERATION SUPPORTS A MODIFIED THEORY FOR GRAVITY

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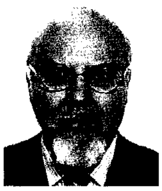

In 2011, I performed a new calibration of the sidereal lunar secular acceleration, -30.13 arc seconds/century^2 ($''/cy^2$), based on 33 total solar eclipses back to 3653 BC. The lunar secular acceleration -25.85$''/cy^2$, from the Lunar Laser Range (LLR) measurements, must be corrected for the precession of the geodesic in the Earth-Moon-system, -3.84$''/cy^2$, to get the sidereal lunar secular acceleration, -29.6$''/cy^2$. The difference between the corrected LLR-result and my new calibration, -0.44$''/cy^2$, is in good agreement with the so-called cosmological precession of the Moon, as predicted by Gia Dvali et al. in a modified theory of gravity.

A new calibration of the sidereal lunar secular acceleration

A correct identification of ancient solar eclipses is not only important for historical reasons, but also gives the possibility of determining the secular acceleration of the longitude of the moon and testing different theories for gravity, as detailed in Henriksson [1,2]. Carl Schoch [3] calibrated his sidereal lunar secular acceleration, -29.68 arc seconds/century^2 ($''/cy^2$), from a conjunction between the star Spica and the moon in 283 BC, and from an analysis of total solar eclipses dating back to 600 BC.

The lunar secular acceleration -5.85$''/cy^2$, determined from the Lunar Laser Range (LLR) measurements, Williams *et al.* [4], must be corrected by -3.84$''/cy^2$, Nordtvedt [5], for the precession of the geodesic, according to Einstein6), before it can be compared with results from the observations of ancient solar eclipses. After correcting for General Relativity, the sidereal lunar secular acceleration from the LLR measurements is -29.69$''/cy^2$ which is very close to Schoch?s value, -29.68$''/cy^2$.

However, Schoch had a third-order term in the formula for the lunar longitude, introduced by Simon Newcomb. I decided to eliminate this term and to optimize the physical value for the sidereal lunar secular acceleration. This value must give the same result as in the earlier successful calculations according to Schoch?s original formulas. 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 sidereal lunar secular acceleration, -30.13$''/cy^2$, gives an even better agreement with the ancient observations than the original formulas by Schoch. It is valid at least during the last 5650 years with a timing error of less than two minutes. The difference, -0.44$''/cy^2$, between the new calibration and the corrected LLR-measurement is significant and can be interpreted as an additional gravitational effect beyond General Relativity.

Anomalous lunar perigeum precession predicted by modified gravity

Dvali et al. [7] write:"Cosmologically motivated theories that explain small acceleration rates of the Universe via modification of gravity at very large, horizon or super horizon, distances can be tested by precision gravitational measurements at much shorter scales, such as the Earth-Moon distance. [...] The key reason for such corrections is the van Dam-Veltman-Zakharov [8] discontinuity present in linearized versions of all such theories, and its subsequent absence at nonlinear level in the manner of Vainshtein [9]." The aim of this paper is to show that in a large class of theories that modify gravity beyond some horizon distance rc, there are corrections that have effects on much shorter scales $r* << rc$, and could be detectable in precision measurement in the Earth-Moon system.

Before calculating the magnitude of the testable parameters in the solar system, they summarize the properties of the massive graviton behind the observable effects: "In the interval $r* << r << rc$, the linearized approximation is valid. So gravity is still $1/r$, but is of scalar-tensor type. Note that the term 'scalar-tensor' only refers to the similarity in the tensor structure, rather than to the existence of an independent spin-0 state in the theory. Instead the scalar' admixture comes from the extra polarization of the spin-2 graviton."

Dvali et al. continue: "We will restrict ourselves to an order-of-magnitude estimate, but the sign will be very important if the effect is found, ...". Lue and Starkman [10] have pointed out that the cosmological background only affects the sign of the coefficient. It is negative for the standard cosmological branch, and is positive for the self-accelerated one.

The anomalous planetary perihelion precession (the perihelion advance per orbit due to gravity modification is: $\delta\phi = (3\pi/4)\epsilon$. For the actual model $\epsilon = -\sqrt{2}\ rc^{-1}\ rg^{-1/2}\ r^{3/2}$. Numerically, the gravitational radius of the Earth is $rg = 0.886$ cm, the Earth-Moon distance $r=$ 3.84 x 1010 cm and the gravity modification parameter that gives the observed acceleration without dark energy $rc =$ 6 Gpc (1.85 x 1028 cm). If we transform the result to the units used by the observers in the solar system, we get a predicted cosmological precession of -0.52$''$/cy^2. If my excess in sidereal lunar secular acceleration, -0.44$''$/cy^2, see above, is interpreted as the cosmological precession, we get an observed value for $rc = 7$ Gpc and we find ourselves in the standard cosmological branch.

The massive graviton is 5-dimensional and needs a 5D space, but within distances $< rc$, a 4D theory is enough. For distances $> rc$, the gravitons begin to leak to the 5^{th} dimension and the gravitational forces between the galaxies are weakened resulting in the observed acceleration of the universe [11,12]. The latest massive gravity models agree well with the observations, Cardone et al. [13].

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References

1. G. Henriksson, *Astronomical Society of the Pacific*, Conference Series 409, 166 (2009).
2. G. Henriksson, *Journal of Cosmology* 9, 2259 (2010).
3. C. Schoch, *Astronomische Abhandlungen, Ergnzungs-hefte zu den Astronomischen Nachrichten*, Band 8 B2 (1931).
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. K. Nordtvedt, *Physics Today*, May 1996, 49:5, 29 (1996).
6. A. Einstein, Annalen der Physik 49 (1916).
7. G. Dvali, A. Gruzinov, and M. Zaldarriaga, *Phys. Rev.* D, 68, Issue 2, id. 024012 (2003).
8. H. van Dam and M. Veltman, Nucl. Phys. B22, 397 (1970).
9. A.I. Vainshtain, *Phys. Lett.* 39 B, number 3, 393, 1 May 1972 (1972).
10. A. Lue and G. Starkman, *Phys. Rev.* D 67, 064002 (2003).
11. A.G. Riess, et al. (High-z Supernova Team), *Astron.* J. 116, 1009 (1998).
12. S. Perlmutter, et al. (Supernova Cosmology Project),*Astrophys. J.* 517, 565 (1999).
13. V.F. Cardone, N. Radicella, and L. Parisi, *Phys. Rev.* D 85, 124005 (2012).