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A New Test of Einstein's Theory of Relativity by Ancient Solar Eclipses

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Abstract. A correct identification of ancient solar eclipses is not only important for historical reasons but also gives the possibility to determine the acceleration of the longitude of the Moon to a high precision. The Lunar Laser Ranging (LLR) of the distance to the Moon makes it possible to check if there is any significant deviation from Kepler's third law of motion. In all modern calculations the value for the tidal lunar secular acceleration, -26 arcseconds/century^2 ("/cy^2), have been used, (determined by Morrison and Ward), from the transits of Mercury 1677-1973. Williams and Dickey reported an unexpected problem during their recent analysis of the LLR-data and they had to solve for an anomalous eccentricity rate equivalent to an additional 6 mm/year decrease in the perigee distance. This anomaly is in my opinion caused by an underestimation of the tidal acceleration of the Moon due to the strong influence of the non-tidal effect caused by the global warming since 1680.

All well documented total solar eclipses from the Greek, Babylonian and Chinese texts back to 2500 BC fit perfectly with my calculations based on a lunar secular acceleration of -29.68"/cy^2, determined by Schoch from an occultation of Spica by the Moon in 283 BC. After correction for non-tidal effects I obtained -29.65"/cy^2. With this value there is a difference of only $+0.68\pm1.92$ mm/year from the value predicted by Einstein's theory. This deviation is in good agreement with predictions from the string theory of Dvali et al., which can explain Dark Energy. Both theories predict a value within the error margins of ±1.92 mm/year.

1. Introduction

My computer program for the calculation of ancient solar eclipses was completed in June 1985 and has since been successfully tested against all well-defined ancient observations back to 2500 BC. It is mainly based on the theory by Carl Schoch (1931) with my own improvements included concerning modern astrophysical parameters. All the formulae are expressed in UT (Universal Time) as used by the ancient observers. This means that the slowing down of the rotation of the Earth can be calibrated by a direct comparison with ancient observations. Schoch calibrated the lunar secular acceleration by the very accurate observation, by Timocharis in Alexandria, of a lunar occultation of the bright star Spica in Virgo, in 283 BC. This means a calibration interval of about 2200 years.

In the mainstream theory used today the formulae are expressed in the so-called Ephemeris Time (ET), a time flow proportional to the motion of the planets in their orbits, and after 1955 Atomic Time. This combined time scale is called Terrestrial Time (TT). The advantage with this technique is that the formulae are simpler, but the disadvantage is that the UT must be reconstructed from calculations of ancient observations. The transformation between TT and UT requires a set of useful timed records made by ancient observers because you must calculate the time difference ΔT = TT − UT and it is almost impossible to avoid circular arguments.

The most extensive study of ΔT has been performed by Richard Stephenson (1997). His analysis is based on the value for the secular acceleration of the Moon of 26 ±2"/cy^2 determined from the telescopic observations of transits of Mercury 1677-1973, analysed by Morrison and Ward (1975). The oldest of these observations have low quality and there is no motivation for an extrapolation of this 300 years interval by a factor of 7 back to the ancient observations.

During the last 25 years the use of terrestrial time has dominated as the time basis in all professional or commercially available computer programs for the calculation of eclipses. Unfortunately it has difficulties before 500 AD and is completely useless for observations made before 700 BC.

My computer program is useful at least back to 3000 BC with errors of just a few minutes, caused by quasi-periodic non-tidal effects.

2. The Author's Method and earlier Results

In my computer program I have always used Carl Schoch's values for the sidereal lunar secular acceleration, $\dot{n}$ = -29.68 arcseconds/century^2, and for the braking of the rotation of the earth, 36.28 seconds/century^2 (Schoch 1931).

In 1985 I started a test of my computer program by a comparison with the total solar eclipse in Babylon in 136 BC and a Chinese solar eclipse record, the so-called "double dawn" eclipse in Zheng, during the Zhou Dynasty, which could be dated to 899 BC. These results and identifications of several solar eclipses depicted on Swedish rock-carvings from the Bronze Age were presented in 1996 at the Oxford V Symposium in Santa Fe, Henriksson (2005). After successful identification of the two important total solar eclipse records in Babylon, separated by 301/300 years with the total solar eclipses in 1859 BC and 1558 BC, it was possible to date the Old Babylonian Kingdom, the Old Assyrian Kingdom, the Old Hittite Kingdom and the 13th-20th dynasties in Egypt, presented in papers at the SEAC 2002 Conference in Tartu, Henriksson (2006) and at the SEAC 2004 Conference in Kecskemet, Henriksson (2007). At the Oxford 8 and SEAC 2007 Conference in Klaipeda I presented my identification of the oldest Chinese solar eclipses that can date the Xia, Shang and Western Zhou dynasties.

3. Unsolved Problems in the Calibration of Ephemeris Time

In "Observations and Predictions of Eclipse Times by Early Astronomers" by John Steel (2000) he tries to identify ancient eclipses by a computer program designed by F. R. Stephenson. Steel writes on page 15-16: "These programs are based upon the solar ephemeris of Newcomb (1895) and a corrected version of the lunar ephemeris designated j=2 (IAU 1968), incorporating a lunar acceleration of - 26"/cy^2 as determined by Morrison & Ward (1975) from analysis of the transits of Mercury". His values for ΔT are taken from Stephenson & Morrison (1995). These values are obtained from a spline fit of both timed and untimed eclipse observations made in various cultures. However, a simple parabola is expected from the tidal braking, but this does not satisfy all the constraints of the data, as is discussed in Stephenson & Morrison (1995). The introduction of a spline curve is an attempt to correct for systematic errors caused by *wrong values of* ΔT *and* $\dot{n}$.

The value of $\dot{n}$ = -26"/cy^2 is fixed in modern computer programs but the user has an option to change ΔT! This violates the principle of conservation of angular momentum in a closed system. It is written on page K8 in the Astronomical Almanac: "To calculate the value of ΔT for a different value of the tidal term ($\dot{n}$'), add $-0.000091(\dot{n}'+26)(\text{year}-1955)^2$ seconds to the tabulated values of ΔT."

Steel (2000) avoid a discussion of several famous early total solar eclipses such as that predicted by Thales from Miletos, in 585 BC, and reported by Herodotus to have taken place during a battle. That eclipse had earlier been used as a fundamental test of the formulae and methods for calculations of ancient eclipses. Frustrated modern eclipse calculators who cannot calculate this total solar eclipse have convinced themselves that it was a total lunar eclipse!

4. A Test of Kepler's third Law

Williams and Dickey (2002) have been aware of an unexpected problem during their analysis of the LLR-measurements and write on their page 3: "The eccentricity rate presents a mystery. Lunar tidal dissipation has a significant influence on this rate and the total rate should be the sum of Earth (1.3×10^{-11}/yr) and Moon (-0.6×10^{-11}/yr) effects. However, we find it necessary to solve for an additional anomalous eccentricity rate of (1.6 ± 0.5) $\times 10^{-11}$/yr (Williams et al. 2001) when fitting the ranges. The anomalous rate is equivalent to an additional 6 mm/yr decrease in perigee distance. Note that the integrated ephemerides (and DE series) do not include the anomalous eccentricity rate."

All known interactions with the Moon have been taken into account including the non-gravitational perturbation of the radial component from the solar radiation pressure and the relativistic precession of the geodesic first determined by Willem de Sitter (1916). They used the value of 1.90"/cy^2 for the relativistic precession of the geodesic, calculated by Chapront-Touzé and Chapront (1983). Precession rates as small as 0.001"/yr were taken into account.

The position of the Moon has been computed from the numerically integrated ephemerides DE403 (Standish et al., 1995) and DE336 which use $\dot{n}$ = -26.0"/cy^2, This value is considered to be supported by the analysis of the ancient eclipses by Stephenson and Morrison (1984). However, the use of $\dot{n}$ = -26.0"/cy^2 is a great mistake because this value is disturbed by non-tidal effects during the 300 years of calibration and no attempt has been made by Stephenson to improve on it from ancient eclipse observations. It is obvious from his unsuccessful attempts to calculate ancient solar eclipses close to the eastern horizon that this value is too small. These ephemerides should instead have been calculated with $\dot{n}$ = -29.68"/cy^2 determined by Carl Schoch (1931) from a direct analysis of ancient solar eclipses. Henriksson has verified this value back to at least 2500 BC. After correction for the non-tidal effect caused by increasing solar activity during the last 400 years Henriksson obtained $\dot{n}$ = -29.65"/cy^2.

The elliptical motion of two bodies is described by:

$$r = a(1 - e \cos E), \tag{1}$$

where r is the distance between the two bodies, a is the semi-major axis of the ellipse, e is the eccentricity and E is the eccentric anomaly. At perigeum $E = 0$, and after derivation with respect to time we get

$$\frac{dr}{dt} = \frac{da}{dt}(1 - e) - a\frac{de}{dt}. \tag{2}$$

Williams et al. (2002) have already solved for the yearly increase of a and da/dt is assumed to be equal to zero. The second least square solution was interpreted as an anomalous eccentricity rate of $(1.6 \pm 0.5) \times 10^{-11}$ /yr, which according to (2) gives a decreasing perigee distance $dr/dt = 6.15$ mm/yr, with $a = 384399$ km and $e = 0.0549$ and $da/dt = 0$, in good agreement with the 6 mm/yr given by Williams et al. (2002). An alternative explanation for this anomaly is, in my opinion, that a too small value of the lunar secular acceleration has been used in the calculations of the motion of the Moon and therefore an additional radial increase in da/dt can be expected. By putting the anomalous $dr/dt = 0$ into (2) we can calculate an additional yearly increase in the distance to the Moon of $da/dt = 6.51$ mm/yr. If this correction is added to the result, 37.9 mm/yr, from the first least square solution by Williams et al. we get 44.41 mm/yr as the result from the LLR.

After derivation of Kepler's third law for two body motion with respect to time we get:

$$\frac{da}{dt} = -\frac{2}{3}\frac{a}{n}\dot{n}, \tag{3}$$

where n is the mean motion of the Moon. This formula can be used to calculate the radial acceleration of the Moon that corresponds to the directly observed secular lunar acceleration -29.65"/cy^2, from ancient eclipses. The result is, $da/dt = 43.86$ mm/yr. Williams et al. (2002) have also taken into account the gravitational attraction from the Sun, which means that the result from (3) should be divided by 1.0028, which gives the final result $da/dt = 43.73$ mm/yr from the value for $\dot{n}$ by Henriksson.

The difference between the measured radial acceleration from LLR and the corresponding value from the lunar secular acceleration of the longitude from ancient eclipses $\Delta da/dt$ (LLR - eclipses) is $+0.68 \pm 1.92$ (mm/yr). The expected theoretical deviation in $\Delta da/dt$ (LLR - eclipses) is ± 0.0 (mm/yr) for Einstein-de Sitter. The precession of the local geodesic in the Earth-Moon system of references, according to the Einstein-de Sitter Cosmology, is included in the sidereal secular lunar acceleration determined from the analysis of ancient solar eclipses. The corresponding radial lunar acceleration had been added to the LLR- measurements in the calculations. However, for a horizon size of 6 Gpc (1.85×10^{28} cm) the expected cosmological precession is -0.516"/cy^2 according to formulas (13), (14) and (15) in Dvali et al. (2002). This corresponds to an additional lunar radial acceleration of +0.76 mm/yr. The observed value +0.68 mm/yr is very close to this value, but the expected value 0.0 mm/yr from the theory of Einstein-de Sitter lies also within the great error limits of ± 1.92 mm/yr, from the second least square analysis by Williams et al. (2002). The standard deviation ± 1.92 mm/yr, is calculated from the uncertainty in the anomalous eccentricity rate $\pm 0.5 \times 10^{-11}$/yr, and include probably errors caused by the use of $\dot{n}$ = -26.0"/cy^2 used in the numerical integrations by Standish et al. (1995).

If the systematic errors are properly corrected for in the second solution by Williams et al. (2002), the theory by Dvali et al. (2002), may be considered to be in somewhat better agreement with the observations than the theory by Einstein-de Sitter. However, the precession of the geodesic predicted by the general theory of relativity by Albert Einstein in 1915 and specified in detail by Willem de Sitter in 1916, is demonstrated to be within the limits of error in this investigation.

5. Conclusions

The general conclusion is that Stephenson and his different co-authors have used a too small correction for the braking of the rotation of the Earth and the corresponding acceleration of the longitude of the Moon. The analysis by Williams and Dickey (2002) of the LLR measurements has failed to confirm the precession of the geodesic in the Earth-Moon system predicted by de Sitter from Einstein's general theory of relativity. The deviation is three sigma and significant. The problem is that they have used the secular acceleration of the Moon recommended by Stephenson and his different co-authors.

In this paper I have used the LLR measurements in combination with my own improved value for the lunar secular acceleration of -29.65"/cy^2, in perfect agreement with the total solar eclipses back to at least 2500 BC, and have confirmed the general theory of relativity with a deviation of only 1/3 sigma. When I compared with preliminary parameters from the string theory by Dvali et al. (2002) the deviation is only 1/17 sigma.

5.1. No Dark Energy needed?

When the result from the new Apache Point Observatory Lunar Laser-ranging Operation (APOLLO) in New Mexico is analyzed it might be possible to judge if Einstein's theory is good enough to explain the observations or whether more advanced theories will be needed. If for instance the string theory of Dvali (2003) can be confirmed then we don't need the enigmatic Dark Energy.

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