RELATIVISTIC EFFECTS FROM PLANETARY AND LUNAR OBSERVATIONS OF THE XVIII-XX CENTURIES

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ABSTRACT. Lunar and planetary observations of different types are discussed for the time span 1717-1982. The modern ranging observations and the historical ones (mainly transits of Mercury and Venus, solar eclipses and occultations of the inner planets by the Moon) are treated separately and some attempts to detect relativistic effects are carried out. From time delay observations linear combination $\nu=(2+2\gamma-\beta)/3$ of the parameters of the PPN formalism is evaluated: $\nu=0.997\pm0.003$. Statistically significant estimate for the rate $\dot{G}$ of changing of the gravitational constant G is found: $\dot{G}/G=(4\pm0.8)\cdot10^{-11}$ /yr. (An alternative interpretation of this result due to Canuto et al. (1979) gives negative sign for $\dot{G}$). From transits of Mercury and Venus corrections to the adopted system of differences between the ephemeris (dynamic) and the atomic time scales and a correction to the Mercury's perihelion advance are deduced. With new ephemeris time scale it became possible to determine unambigiously lunar tidal deceleration $\dot{n}_M$ making use of the historical lunar observations. The derived value $\dot{n}_M=(-22.2\pm0.8)''/cy^2$ is in good agreement with reported lunar laser results. By comparing the estimates $\dot{n}_M$ obtained by the two methods the rate $\dot{G}$ has also been evaluated: $\dot{G}/G=(0.5+0.5)\cdot10^{-11}$/yr. The origin of the disagreement with the radar based result for $\dot{G}$ is not yet clear. All the conclusions were checked by making use of different planetary and lunar theories and appear to be practically theory-independent.

1. INTRODUCTION

Relativistic effects in the inner planet motion may be detected by treating either ranging observations after 1960 or astrometric ones which are at least two order less accurate but available for the time span about three centuries. High quality of the ranging observations makes it possible to test not only relativistic excess of Mercury's perihelion advance but some other relativistic effects. Apart from these opportunities, ranging observations give unique information on long-term variations of the differences between the atomic and the dynamic time scales. Such variations would exist if the gravitational constant G varied with

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time. In observations before 1960 the effects of G time variability are difficult (if possible) to separate from the effects of secular retardation of the Earth's rotation. However, at present new possibilities have become available. Making use of the planets' ephemerides of new generation it appears possible to correct the adopted system of differences ΔT between the dynamic (ephemeris) and the universal time scales. It will be noted that the ΔT system is believed to be corrupted by an error in the adopted value $\dot{n}_M$ of the lunar tidal deceleration. For deriving these ΔT corrections the historical observations of transits of Mercury and Venus through the solar disc seem to be quite appropriate. The corrected system ΔT determines operationally the dynamic time scale which is independent of the effects of G time variability (unlike the atomic time scale which indeed may be influenced by these effects). Thus, comparing $\dot{n}_M$ determined in the two scales it seems possible to detect time rate $\dot{G}$ as it was firstly suggested by Van Flandern (1975,1982).

In this report we present some results obtained in the Institute for Theoretical Astronomy (Leningrad) in realizing this project.

2. OBSERVATIONS

Table 1 gives a summary of the observations used.

TABLE 1. General summary of the observations

Type of observations	Time interval	Normal places	Number of observations
Radar ranging	1961-1982	710	5119
Transits:			
Mercury	1723-1973	58	200
Venus	1761,1769	2	243
Venus	1874,1881	-	909
Lunar laser ranging	1969-1971	603	-
Solar eclipses	1778-1975	82	1500
Occultations:			
Venus	1832-1974	20	250
Mars	1821-1971	22	200
α Tauri	1717-1980	20	188
Lunar meridian obs.	1750-1760	2	1160

After 1971 only radar observations from Moscow Institute of Radioelectronics were available, before this date we also had observations from American sources (see Table 2).

Time delays for Venus and Mars were corrected for effects of topography (Pitjeva,1982), accuracy of the resulting normal places after 1971 being estimated as about 0.5 km. Our planetary theory was construc-

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ted mainly with the help of the radar observations, the lunar one - with the help of the lunar laser observations of Macdonald Observatory for the years 1969-1971.

TABLE 2. Summary of the radar observations (n - number of normal places, σ- their mean errors)

Observatory, years	Mercury n	Mercury σ(mks)	Venus n	Venus σ(mks)	Mars n	Mars σ(mks)
Millstone						
1961			34	195.1		
1964	5	130.1	44	20.8		
1965/66			37	8.0		
Goldstone						
1964			47	19.5 (*)		
1966			6	14.6		
1967			15	9.2		
1969					21	4.4
Arecibo						
1964	17	108.9	50	42.3	25	54.4
1965	61	21.0	21	32.7		
Haystack						
1967					10	8.3
1969					49	3.4
1971					57	1.7
Crimea						
1962			14	81.8		
1964			8	26.3		
1969			10	12.2 (*)		
1970			15	14.6		
1971					17	40.3
1972			13	7.2		
1975			22	5.6		
1977			20	2.9		
1978			22	2.2		
1980	4	10.8	11	3.1	12	4.9
1981/82	9	8.3	21	3.5	13	3.5

(*) After removing a systematic error

As matter of fact, considerably more astrometric observations were collected and discussed; Table 1 gives only those which were used for the aims of the present work.

3. EPHEMERIDES

We compared the observations with ephemeris predictions from several planet and lunar ephemerides based on the theories developed at the Institute for Theoretical Astronomy (ITA; Krasinsky et al.,1982), at the Bureau des Longitudes (BDL;Bretagnon,1982, Chapront and Chapront-Touzé, 1983) and at the Jet Propulsion Laboratory (DE 200; Newhall et al., 1983). Unfortunately, the JPL data at our disposal were only for the last few decades; the other two ephemerides covered time interval from the beginning of the XVIII century. To check the results of testing relatvistic effects a purely Newtonian theory was also developed.

For control we had compared the ITA and the BDL ephemerides for two centuries time interval. As the BDL theory had been previously fitted to DE 200, it was an indirect way to compare the ITA and the JPL theories. From Fig. 1 it is seen that the sidereal mean motions for any pairs of planets differ by the same value 0."3/cy.

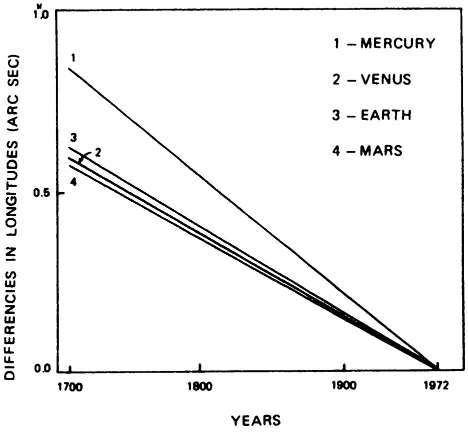

Figure 1. ITA-BDL: secular trends in the mean longitudes.

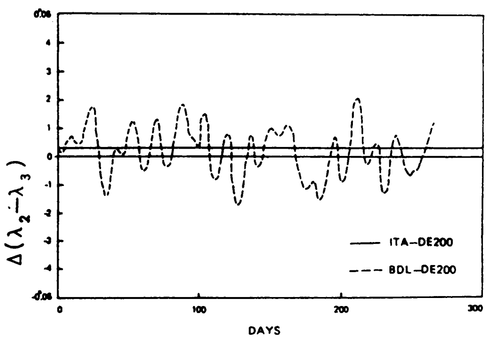

Figure 2. Short-term comparison between ITA, BDL and DE 200.

In our opinion this fact reflects the real accuracy which may be achieved after extending the new radar based planetary ephemerides to the past. On the other hand, the differences between the sinodic mean motions as well as between any other orbital elements which do not depend on the planet orbit orientation relative to the inertial coordinate frame are negligible. As an illustration in Fig 2. we present a sample of short-term comparison of the combination $l_V - l_E$ (l_V, l_E -being the mean longitudes of Venus and the Earth); differences are given in the sence ITA minus DE 200 and BDL minus DE 200. In the differences involving BDL theory, short periodic fluctuations 0."01 are seen (presumably they are due to truncation errors of the analytical series of perturbations). The differences between ITA and DE 200 elements are smooth and never exceed a few milliarcseconds for every interval considered.

Thus, and that is quite essential, ephemeris predictions for transit observations are practically the same for all relativistic theories under consideration.

4. RELATIVISTIC EFFECTS IN THE INNER PLANETS' MOTION AND THE TIME DERIVATIVE OF THE GRAVITATIONAL CONSTANT G FROM RADAR OBSERVATIONS

We tried three approaches to testing relativistic effects. First, we attempted to reveal discrepances between the observed and the theoretical values of planets' perihelion motion (in the framework of both the relativistic and the Newtonian theories). Second, we determined the value of the solar gravitational radius considered as a free parameter (again for the theories of these two types). Third, some experiments to determine the parameters β, γ of the PPN formalism were carried out. Due to correlations between the unknowns a correct determination of any relativistic parameter or $\dot{G}$ is possible only with simultaneous refining of all constants of the planet theories. In our case it was necessary to take into consideration 27 parameters (orbital elements, mean radii, AU and systematic errors of two groups of the earlier observations). In what follows a brief exposition of the results for each of these approaches is given.

4.1. Secular motion of the inner planets' perihelions

It appears that no attempt to determine the perihelion advance for all inner planet simultaneously could give reliable results. In this case only Mercury's perihelion motion is in a good accordance with Einstein's prediction (see Table 3).

TABLE 3. Corrections to the secular motions of the inner planet perihelions (from radar observations)

Theory	Mercury	Venus	Earth	Mars
ITA	0.″11±0.22	-3.″03±0.71	-0.″12±0.16	0.″35±0.24
DE 200	-0.55±0.21	-0.75±0.70	0.34±0.15	-0.46±0.24
ITA	-0.15±0.12	-	-	-
DE 200	-0.21±0.12	-	-	-
ITA (*)	40.35±0.23	-0.69±0.74	-0.73±0.16	-0.74±0.26
ITA (*)	42.95±0.13	-	-	-

(*) Newtonian theory

The corrections to the perihelion secular motions of other inner planets contradict neither relativistic nor Newtonian theories and results tend to confirm the initial approximation. Thus, planet observations (at least the radar ones) at present support relativistic values of the perihelion motion only in case of Mercury but not for other inner planets. However, it is noteworthy that the relativistic theory for any observed planet provides considerably better fit of the observations as compared with the Newtonian theory even if the latter incorporates observed perihelion secular motions. Namely, the mean square error of the relativistic fit is by some ten percent smaller than the corresponding error of the fit for the Newtonian theory modified in this way.

4.2. Gravitational radius μ of the Sun

Computing the coefficients of the conditional equations for the solar gravitational radius we have used analytical formulas for relativistic perturbations (Brumberg,1972) including the largest periodic terms. Of course, the main contribution comes from the relativistic perihelion advance of Mercury. Thus, it was not a surprise to find that the determined value of μ appears to be in a good accordance with its theoretical relativistic value (see Table 4).

TABLE 4. Gravitational radius μ of the Sun from radar observations

	ITA (m)	DE 200 (m)	(*) ITA (m)
adopted	1476.6	1476.6	0.0
derived	1471.5±4.5	1469.6±4.3	1478.6±10.3

(*) Newtonian theory

4.3. Parameters β , γ of the PPN formalism

These parameters affect time delays mainly in three ways: they enter the formula for the perihelion secular motion, the formula for Shapiro's effect of light propagation and, at last, the formula for the secular term in the mean longitudes (apart from a few very small periodic terms).If one takes into consideration all of these sources it does not appear to be possible to detemine reliably both parameters β, γ (due to strong correlations with the semimajor axes). For this reason it is common practice to neglect the effects of β , γ in the mean longitudes and to determine only γ and the combination $\nu=(2+2\gamma-\beta)/3$. Now it is necessary to have in mind that the theoretical basis for such an approach is not quite correct. The accuracy of our estimate for γ :

$$\gamma=0.9\pm0.6$$

is poor because we had only few observations near the upper conjunctions. The accuracy of our estimate of ν is comparable with that of the best determinations (see Table 5). However, this result is but another way to express the accordance of Einstein's value of Mercury's perihelion advance with the observations. Our value of ν corresponds to the additional perihelion schift $d\dot{\omega}=(-0.15\pm0.12)''/cy$ in accordance with the results of direct determination of $d\dot{\omega}$ (see Table 3). It will be noted that the solar oblateness J_2 as derived in (Hill et al.,1982) from solar oscillations:

$$J_2=(5.5\pm1.5)\cdot10^{-6}$$

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contributes to $d\dot{\omega}$ the value 0."7/cy. Now we have to choose between two possible extremes: either β is sligtly different from Einstein's value $\beta=1$ (as for γ one can take safely $\gamma=1.000+0.002$ from Viking's result (Reasenberg et al.,1979) and thus

$$\beta=1.057\pm0.009$$

or Hill's estimate of J_2 is in error and the following estimate holds true:

$$J_2=(-1.0\pm1.0)\cdot10^{-6}.$$

Table 5. Linear combination $\nu=(2+2\gamma-\beta)/3$ of the parameters of the PPN formalism

	References
1.006±0.006	Shapiro et al. (1972)
1.003±0.005	Shapiro et al. (1976)
1.007±0.005	Anderson et al. (1978)
0.997±0.003	This work (ITA theory)
0.996±0.003	This work (DE 200)

4.4. Time variability of the gravitational constant G

The ratio $\dot{G}/G$ was evaluated from quadratic terms in the longitudes of the planets. The result proved to be rather stable giving the positive value for the time rate $\dot{G}$:

$$\dot{G}/G=(4\pm0.8)\cdot10^{-11}/\mathrm{yr}.$$

If we interpret the quadratic term after Canuto et al. (1979), the value $\dot{G}/G$ would have an opposite sign. We have considered a number of variants where $\dot{G}/G$ was determined independently for every planet (though all observations were treated simultaneously). All determinations were carried twice - with the ITA and the JPL theories. The resulting values $\dot{G}/G$ only weakly depend on the theory used (see Table 6) except the case of Mars when the fit with DE 200 is somewhat better and $\dot{G}/G$ derived from the observations of Mars is more consistent with other estimates. At present we believe that the deficiencies in our theory of Mars are due to the inaccuracy of the outer planets' elements which were not improved while constructing the theory. This work is in progress now.

Comparing our results for $\dot{G}/G$ with the results by other authors (Table 6) one can see that if in the earlier papers (Anderson et al., 1978; Reasenberg and Shapiro, 1978) statistically significant positive values of $\dot{G}/G$ were also obtained (one of the results of the last work being very close to ours), in the most recent work (Hellingset al., 1983) the zero value of $\dot{G}/G$ was declared as deduced from extremely accurate observations of the Viking landers and of the Mariner 9 spacecraft.

TABLE 6. Secular variations $\dot{G}/G$ of the gravitational constant (10^{-11}/yr)

Mercury	Venus	Mars	Average solution	General solution	Ref
6.0±4	6.0±6	25.0±33	6.2±3.3	15.0±9	(1)
-	-	-	-	14.2±1.6	(2)
-	-	-	-	0.2±0.4	(3)
-0.9±5.2	3.7±0.8	16.1±2.4	-	4.1±0.8(a)	This
-0.9±5.2	3.8±0.8	3.6±2.4	-	3.7±0.8(b)	work

(1) Reasenberg and Shapiro (1978),(2) Anderson et al. (1978), (3) Hellings et al.(1983); (a) ITA, (b) DE 200

To illustrate the degree of realiability of our estimate, residuals in planetary longitudes are given in Fig.3.

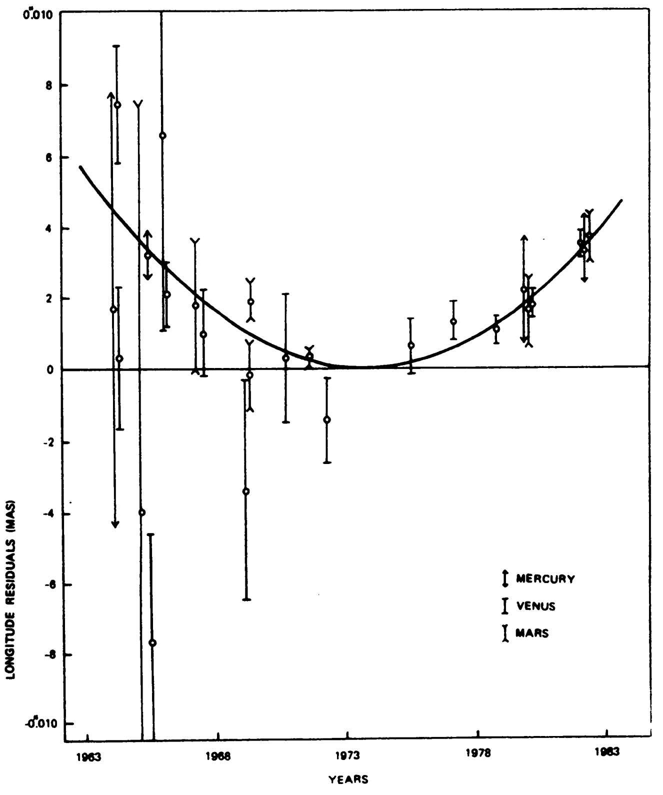

Figure 3. The longitude residuals due to the time variability of the gravitational constant G.

These residuals were calculated in the following way. After determining the unknowns from our standard 27 - parametric set, their values (except that for $\dot{G}$) were incorporated into the ephemeris (making use of the equations of conditions). New time delay residuals $d\tau$ were divided by the value $d\tau/dt$ and thus time corrections dt were obtained. Multiplying them by the Earth's mean motion they were converted to the longitude residuals dl. Properly weighted for every observational campaign, the longitude residuals were averaged and these are the resulting normal points which are depicted in Fig. 3. The smoothing curve in Fig. 3 corresponds to the parabola :

$$dl(\text{mas})=\dot{G}/G\cdot(T-1973.87)^2\cdot 1.296\cdot 10^9,$$

where

$$\dot{G}/G=(3.7\pm0.8)\cdot 10^{-11}\ /\text{yr}.$$

Though the parabolic trend in the residuals is quite evident we would not claim a very high degree of reliability of this result because possible systematic errors in the earlier observations (before 1969) might have contributed to the estimate of $\dot{G}/G$. Anyway our result for $\dot{G}$ cannot be explained by errors of modelling in the ephemerides used.

5. TRANSITS OF MERCURY AND VENUS THROUGH THE SOLAR DISC

In radar based planetary ephemerides most of the inner planets' elements may be regarded as quite definite and three secular variations of elements are practically the only parameters to be determined. For Mercury these are the secular motions of the perihelion and the node as well as long-term corrections to the adopted ΔT system. To be more precise, it is not the motion of the node than may be found from transit observations but only the combination:

$$d\dot{L}=dn + dn_E -2d\dot{\Omega}$$

involving also corrections dn ,dn_E to the sidereal mean motion of Mercury and the Earth. This approach is possible only with new ephemerides whose synodic mean motions need no improvements. The fourth parameter to be determined is the value of the secular decrease of the solar radius. For more details the reader is reffered to (Krasinsky et al., 1985). It turned out that all the parameters are separable while treating the transit observations. Surprisingly, we have obtained rather large corrections $d(\Delta T)$ to the adopted ΔT system (see Fig. 4 where dots stand for the transits results, squares - for those of Venus and the curve presents the adopted ΔT system). The differences $d(\Delta T)$ may be smoothed by the polynomial:

$$d(\Delta T)=A+BT+CT^2,$$

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where

$$A=(8.3\pm0.9)^{s},\quad B=(-12.9\pm1.3)^{s},\quad C=(0\pm2)^{s}$$

and T is counted off in centuries from 1900. As there is no evidence of the quadratic term in d(ΔT) it was quite reasonable to suggest that the adopted value $\dot{n}_M$ after Spencer Jones (1939) is correct. And indeed this suggestion has been confirmed by our further discussion of lunar observations.

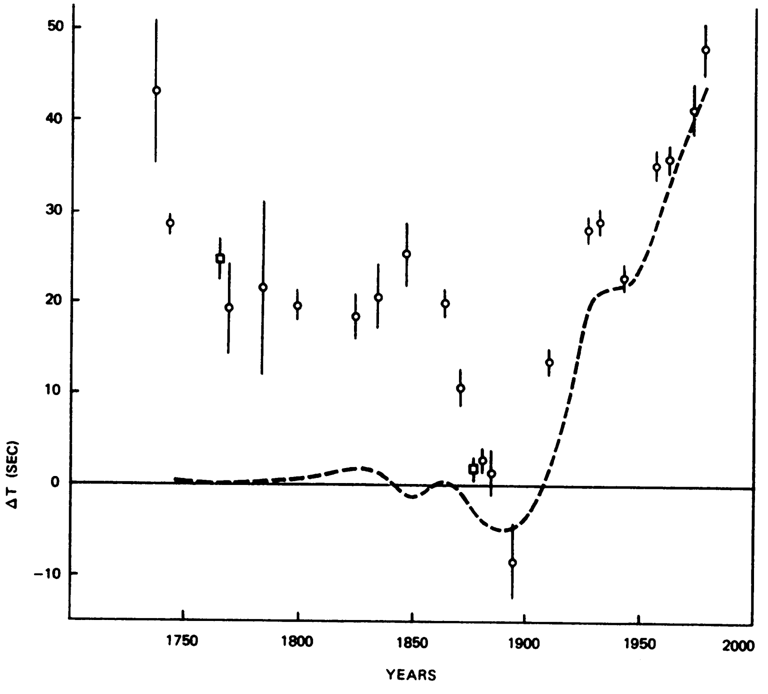

Figure 4. Time corrections ΔT from transits of Mercury and Venus.

Strong correlations between corrections to the perihelion secular motion and $d\dot{L}$ lower the accuracy of the results for Mercury's $d\dot{\omega}$ (see Table 7).

TABLE 7. Secular variations $d\dot{\omega}$, $d\dot{L}$, $d\dot{r}$ from Mercury's transits

Theory	$d\dot{\omega}$	$d\dot{L}$	$d\dot{r}$
ITA	1.″4 ±1.2	2.″4±2″4	-0.″25±0″09
BDL	0.9 ±1.2	0.9±2.4	-0.26±0.09
ITA	0.19±0.33	-	-0.23±0.08
BDL	0.47±0.33	-	-0.25±0.08
ITA	-	-0.18±0.68	-0.22±0.08
BDL	-	-0.83±0.68	-0.24±0.08

The necessity to determine $d\dot{L}$ requires to take into account errors of the sidereal mean motions in the current theories as well the possibility of the non zero value of the solar J_2. Having previously compared independent planetary theories (as described above) we believe that the errors in the mean motions do not exceed 0."5/cy; then the obtained value $d\dot{L}$ leads to the constraints $|d\dot{\Omega}|<1$"/cy and thus to the estimate:

$$|J_2| < 1.5\cdot 10^{-4}.$$

Being rather rough, this estimate however does not depend on any prescribed values of the PPN formalism parameters. Its error is dominated now by the inacuracy of the sidereal mean motions and in near future may be reduced by factor 2 or 3 (but unfortunately not more).

This estimate for $d\dot{\Omega}$ (and thus for J_2) strongly depends on the ephemeris time scale used. For instance, if the adopted ΔT system were valid, the correction $d\dot{\Omega}$ would be 3"/cy whose value is difficult to account for. Suggesting that the secular motions of the perihelion and the node of Mercury need no corrections (for the relativistic theories under considerations) we can ascribe the observed value $d\dot{L}$ to the errors in the sidereal mean motions. Then, as one can see from the two last lines of Table 7, in this case the ITA theory is more concordant with the transit observations than the BDL or the DE 200 theories and the mean motions for the two latter have to be decreased by 0."4/cy.

Summing up the results for Mercury's perihelion advance we can confirm Einstein's prediction within 1"/cy. The lesser errors which are sometimes declared might be obtained only if one does not determine the value $d\dot{L}$, but in this case the results would be not reliable. After improving sidereal motions in planetary theories the error of the Mercury's perihelion advance as determined from transit observations may be reduced to about 0."3/cy; however this accuracy is already superceded by radar results.

We would also like to mention some results concerning the value $d\dot{r}$ of the secular decrease of the solar radius. We have found the estimate

$$d\dot{r}=(-0.24\pm 0.08)\text{"/cy}$$

with high degree of stability in all variants investigated (see Table 7). However we believe that this value has no real meaning and may be attributed to the specific conditions during the last decades. More details are given in (Krasinsky et al. , 1985).

6. LUNAR TIDAL DECELERATION AND $\dot{G}/G$

In recent years a number of attempts to determine the lunar tidal deceleration from discussion of old observations gave larger values for $\dot{n}_M$ than the classic estimate by Spencer Jones (1939) or the recent lunar laser based value (see Table 8).

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Table 8. Tidal deceleration $\dot{n}_M$ of the Moon

$\dot{n}_M$	Observations used	References
41."6±3	Ancient observations	Newton (1970)
31."6±9	Ancient observations	Newton (1979)
37.5±5	Ancient observations	Muller et al. (1975)
22.4±0.7	XIII - XX centuries	Spencer Jones (1939)
52.4±4	Occultations, 1955-1969	Van Flandern (1970)
38.8±8	Meridian obs.,1911-1972	Oesterwinter, Cohen (1972)
42.4±6	Occultations, 1955-1972	Morrison (1973)
26 ±2	Mercury's transits	Morrison, Ward (1975) (*)
23.8±1.5	Lunar laser ranging	Dickey et al. (1982)
22.9±0.8	XYIII - XX centuries	This work, ITA
22.2±0.9	XYIII - XX centuries	This work, BDL (after 1737)

(*) Indirect evaluation

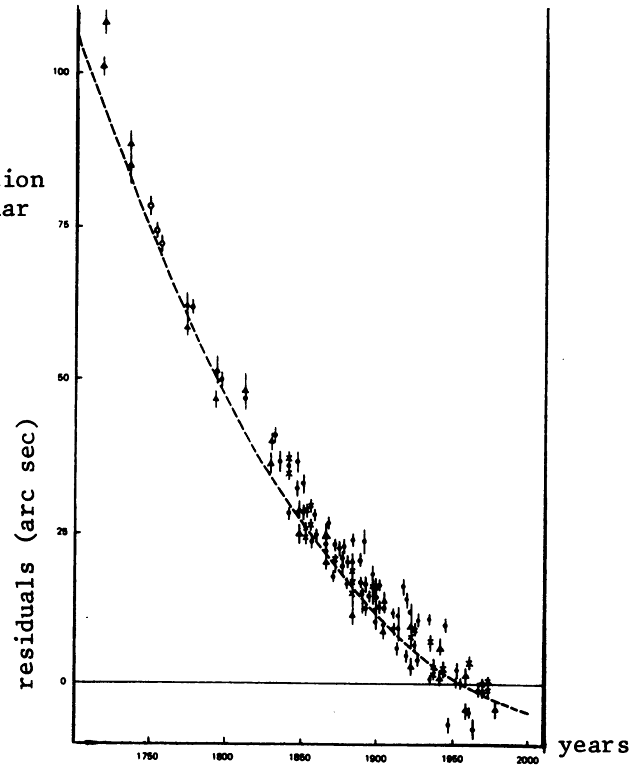

Figure 5. Tidal deceleration from residuals in the lunar longitude.

In the opinion of R.Newton (1970) the accuracy of the result by Spencer Jones was overestimated and now it must be disregarded; according to Van Flandern (1982) the differences between the laser determinations and the determinations $\dot{n}_M$ from historical astrometric observations are real and may be attributed to the secular variations of G. However, our estimates of $\dot{n}_M$ derived from discussion of different types of observations covering two and a half century time interval has confirmed the result by Spencer Jones (see the last lines in Table 8). Unlike the Spencer Jones' value, our estimate of $\dot{n}_M$ does not depend on any apriory assumptions on the rate of the secular retardation of the Earth's rotation. In our opinion the values $\dot{n}_M$ resulting from ancient and medieval observations are unreliable as well as those derived from observations covering only a few decades. Just the contrary, if one uses the telescopic lunar observations after XVIII century, the tidal deceleration may be determined quite reliably. For an illustration on Fig.5 a plot of residuals in the lunar longitude is given (for the theory with zero value of $\dot{n}_M$). The parabolic form of the smoothing curve is clearly seen. The error of our estimate of $\dot{n}_M$ is close to that by Spencer Jones and even smaller than the error of the laser result. Comparison of laser result with ours leads to the estimate:

$$\dot{G}/G = d\dot{n}_M / \dot{n}_M = (-0.5 \pm 0.5)\cdot 10^{-11} /yr$$

which, unfortunately, disagrees with that derived from planet ranging. In our opinion the radar based method to evaluate $\dot{G}$ is more straightforward and be checked more easily. Further progress in $\dot{G}$ determination depends on the availability of new ranging observations.

REFERENCES

Anderson J.D.,Keesey M.S.W.,Lau E.L.,Standish E.M.Jr,Newhall XX: 1978, Acta Astronautica 5, p.43.

Bretagnon P.: 1982, Astron.Astrophys.,114, p.278.

Brumberg V.A.: 1972. Relativistic celestial mechanics.(In Russian,Nauka, Moscow).

Canuto V.M.,Hsieh S.-H.,Owen J.R.: 1979,Mon.Not.R.Astron.Soc.,188,p.829.

Chapront J.,Chapront-Touzé M.: 1983, Astron.Astrophys.,124,p.50.

Dickey J.O.,Williams J.G.,Yoder C.F,; 1982, (in "High precis. Earth. rotat. and Earth-Moon dyn."),p.209.

Hill H.A.,Bos R.J.,Goode P.R.: 1982,Phys.Rev.Letts.,49,p.1794.

Hellings R.W.,Adams P.J.,Anderson J.D.,Keesey M.S.,Lau E.L., Standish E.M.,Canuto V.M.,Goldman I.: 1983, Phys.Rev.Letts., 51, p.1609.

Krasinsky G.A., Pitjeva E.V.,Sveshnikov M.L.,Sveshnikova E.S.: 1982, Bul.Inst.Theoret.Astron., 15,p.145.

Krasinsky G.A.,Saramonova E.Yu.,Sveshnikov M.L.,Sveshnikova E.S.:1985, Astron.Astrophys.,145,p.90.

Morrison L.V.: 1973, Moon,5,p.253.

Morrison L.V.,Ward C.G.: 1975, Mon.Not.R.Astron.Soc., 173,p.183.

Muller P.M.,Stepfensen F.P.: 1975, (in "Growth rhytms and the hist. Earth rotat.", John Wiley and Sons,London).

Newhall XX,Standish E.M.Jr.,Williams J.G.: 1983, Astron.Astrophys., 125,p.150.

Newton R.R.: 1970, Ancient astonomical observations and the accelerations of the Earth and Moon. (John Hopkins Press, Baltimore, London).

Newton R.R.: 1979, The Moon's acceleration and its physical origins. Volume 1. As deduced from solar eclipses (John Hopkins Press, Baltimore).
Oesterwinter C.,Cohen Ch.: 1972, Celest.Mech.,5,p.317.
Pitjeva E.V.:1982, Bull.Inst.Theoret. Asron., 15,p.169.
Reasenberg R.D.,Shapiro I.I., Pettengill G.H.,Campbell D.D.:1976, Bull.Amer.Astron.Soc.,8,p.308.
Reasenberg R.D.,Shapiro I.I.: 1978, (in "On the measurement of cosmological variations of the gravitational constant", University Press of Florida,Gainesville),p.71.
Reasehberg R.D.,Shapiro I.I.,MacNeil P.E.,Goldstein R.B.,Breindenthal J.C.,Brenkle J.P.,Cain D.L,Kaufman T.M.,Komarek T.A., Zygeilbaum A.I.: 1979, Astrophys. J., 234, L 219.
Shapiro I.I,Pettengill G.H.,Ash M.E.,Ingalls R.P.,Campbell D.B,Dyce R.B.: 1972, Phys. Rev. Letts.,28,p.1594.
Shapiro I.I.,Counselman C.C.III, King R.W.: 1976, Phys. Rev. Letts.,36, p.555.
Spencer Jones H.: 1939, Mon.Not.R.Astron.Soc.,99,p.541.
Van Flandern T.C.: 1970, Astron.J.,75, p.657.
Van Flandern T.C.: 1975, Mon.Not.R.Astron.Soc.,170.p.333.
Van Flandern T.C.:1982, (in "High precis. Earth. rot. and Earth-Moon dyn."),p.207.

DISCUSSION

Kreinovich : do you consider your result for $\dot{G}/G$ of the order of 4.10^{-11} as a refutation of General Relativity ?

Krasinsky : our estimation was obtained from radar ranging. And this result does not depend on the theory used. Lunar observations do not support this estimate.

Lieske : in what frame did you make the comparison between planetary longitudes for the two theories ?

Krasinsky : in a fixed frame and differences are given for the sidereal mean motions.

Branham : for what aim did you use normal places ?

Krasinsky : a lot of observation of transits and occultations had poor accuracy and we rejected them when constructing normal places.