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The Main Perturbations from the Sun in the Theory of the Moon's Motion in the Aspect of Optical Observations of the "Einstein Effect"

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Abstract

The analysis examines the relationship between the optical results obtained by various authors during observations of total solar eclipses from 1919 to 1973 — which assessed the deviation of light rays from stars from the Sun's disk (the Einstein effect) — and the main (gravitational) perturbations exerted by the Sun on the Moon and Earth (as derived from the theory of lunar motion): evection, variation, and the annual inequality, which are described by inequalities in the formula for the geocentric ecliptic longitude of the Moon. The main feature of these disturbances is that they occur synchronously with the main deviations in the Moon's motion from its orbit and with the oscillations of the Earth's axis relative to the celestial pole (short-period nutation). The correlation of optical values of the δφ with the values of evection - the main perturbation from the Sun to the Moon and the Earth, on the basis of which a correction is proposed (at the error level) for optical observations of the "Einstein effect" in the dates of total solar eclipses from 06.02.2027 to 04.09.2100.

Keywords: Deflection of Light Rays from the Sun's Disk; Main Perturbations from the Sun; Eviction, Variation, Annual Inequality, Total Solar Eclipse

Introduction

The experimental verification of general relativity is the confirmation of three effects: the gravitational shift of spectral lines, the displacement of the perihelion of Mercury and the deviation of the light rays of stars from the disk of the Sun (δφ = 1,75"). The expression for δφ is as follows:

$$\delta\varphi = -4GM_c/R_c c^2, \quad (1)$$

where the "minus" sign corresponds to the deviation of the ray towards the center of the Sun,
$G = 6.67 \cdot 10^{-11}$ H·m^2·kg^{-2} – the gravitational constant, M_c = $1.99 \cdot 10^{30}$ kg – the mass of the Sun,
c = $3 \cdot 10^8$ m·s^{-1} – тhe speed of light, R_c = $6.96 \cdot 10^8$ m - the radius of the Sun.

If we use only the results of radar and radio interferometry in the theory test, without giving optical results (Δ 5%-15%), then we can assume that δφ =1.75" are consistent with GR within 1% [1,2]. Below are the results of averaging δφ=1.75" by radar and radio interferometry methods:
Radar 1.73±0.07 (Venus, Mercury, Mars) [3,4]
Radio interferometry 1.76±0.08 (groups of quasars, pulsars) [5]

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The results of optical observations obtained by different authors in only eight total solar eclipses (from 1919 to 1973) amounted to δφ=1.83”±0.40. Table 1 shows the authors, and recalculation estimates of the deviation of the rays of stars from the disk of the Sun, from 1919 to 1973 [6-29].

Date Full Solar Eclipses	Author Values *d*φ, Sec (Δ)		Recalculated Values □□, Sec (Δ)	
	1.98; (0.16)	[6]	2.05; (0.20)	[7]
29.05.1919	0.93	[9]	1.87; (0.13)	[8]
	1.61; (0.40)	[11]	2.16; (0.14)	[10]
	1.42, 1.75,	[12]	2.05; (0.13)	[15]
	2.16	[12]	2.07	[16]
21.09.1922	1.72; (0.15)	[13]	2.14; (0.18)	[17]
	1.83; (0.20)		2.12	[9]
	1.77; (0.40)	[14]	2.07	[33]
			2.04; (0.27)	[7]
09.05.1929	2.24; (0.10)	[21]	1.98; (0.14)	[18-20]
			1.75; (0.19)	[22]
			1.96; (0.11)	[33]
	2.73; (0.31)	[23]		
19.06.1936	2.13; (1.15)		2.20; (0.36)	[34]
	1.28; (2.67)	[33]		
20.05.1947	2.01; (0.27)	[24-25]		
25.02.1952	1.70; (0.10)	[26]	1.45	[33]
25.02.1952	1.82; (0.20)	[26]	1.45	[33]
02.10.1959	2.17	[27]		
30.06.1973	1.66; (0.19)	[28,29]		

Table 1: Author and recalculated δφ values obtained in total solar eclipses from 1919 to 1973.

During the OTS inspection period, the list of errors has expanded significantly and, according to the works [30-34] include:

- deviation of the shape of the Sun from sphericity (9.2 “$\cdot 10^{-2}$);
- movement of the Earth along the ecliptic (2.88 “$\cdot 10^{-2}$);
- refraction in the Sun’s atmosphere (0.004”);
- refraction and dispersion in the Earth’s atmosphere (0.01”-0.1”);
- removal of the observer from the center of mass Sun-Moon-Earth;
- the influence of the gravitational field of the Moon and the Earth during a total solar eclipse, expressed by an additive to the relativistic deviation of the beam (5.8 “$\cdot 10^{-4}$);
- wavelength dependence (2.5 “≤ 10^{-4});
- dependence on solar activity (SA);
- astroclimatic characteristics;
- additive error caused by inaccurate correspondence of the scales of day and night astro images (0.25”).

The spread of values in Table 1 does not exclude that, in addition to the given errors, there is a cosmophysical factor that affects to a small extent the value of δφ = 1.75.” Such an agent can be the main (gravitational) perturbations from the Sun to the Moon and Earth from the theory of the motion of the Moon, realized in the short-period nutation of the Earth’s axis, as well as in changing the true geocentric ecliptic longitude of the Moon, according to formula (1):

$\lambda = L + 6.289°\sin l - 1.274°\sin(l - 2D) + 0.658°\sin 2D + 0.214°\sin 2l -$

$+ 0.186°\sin l' - 0.114°\sin 2F\ldots.$, (2)

L– the average longitude of the moon in orbit freed from periodic disturbances,

l, D, l’, F – basic arguments of the theory of motion of the Moon [34-36].

Of the first five inequalities, terms with coefficients 6.289° and 0.214° due to the ellipticity of the unperturbed (Keplerian) orbit, and with coefficients 1.274° (evection), 0.658° (variation) and 0.186° (annual inequality) - perturbations from the Sun to the Moon and Earth (Figure 1).

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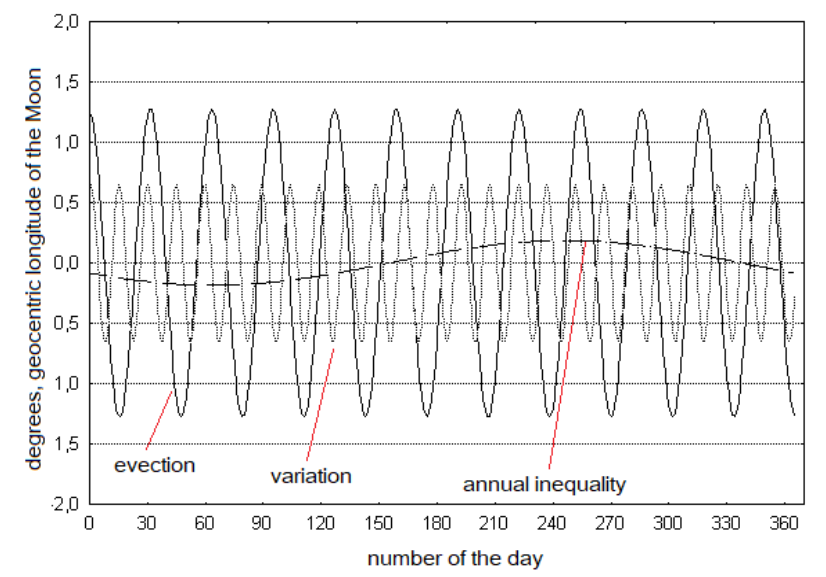

Figure 1: Periods of major (gravitational) perturbations from the Sun: ejection ((±1.274°sin(l-2D), variation (±0.658°sin2D), annual inequality (±0.186°sinl') The meaning of evection is to periodically change the shape of the lunar orbit (eccentricity 0.0448-0.0650).

Results

The evection values 1.274°sin(l–2D) were calculated for the Julian dates of solar eclipses from Table 1. Figure 2 shows the distribution of estimates and confidence intervals of δϕ equal to one standard deviation for eclipses with results> 1. The continuous curve represents the averaging of the results:

$$\delta\phi(M)=1.7227 + 0.2058x+0.3163x2 \quad (3)$$

$$\delta\phi(E)=1.723+0.316x2 \quad (4)$$

In Figure 2, the function δϕ(M) has a left lower shift (relative to δϕ(E)), characterized by the term 0.2058x (3) due to observations in 1919 and 1936. Figure 2 also shows that in the extremums of evection (–1.274° и +1.274°), the δϕ can reach 2.25 "≈ 10%, and at 0° be consistent with the result of 1.72 "±10%.

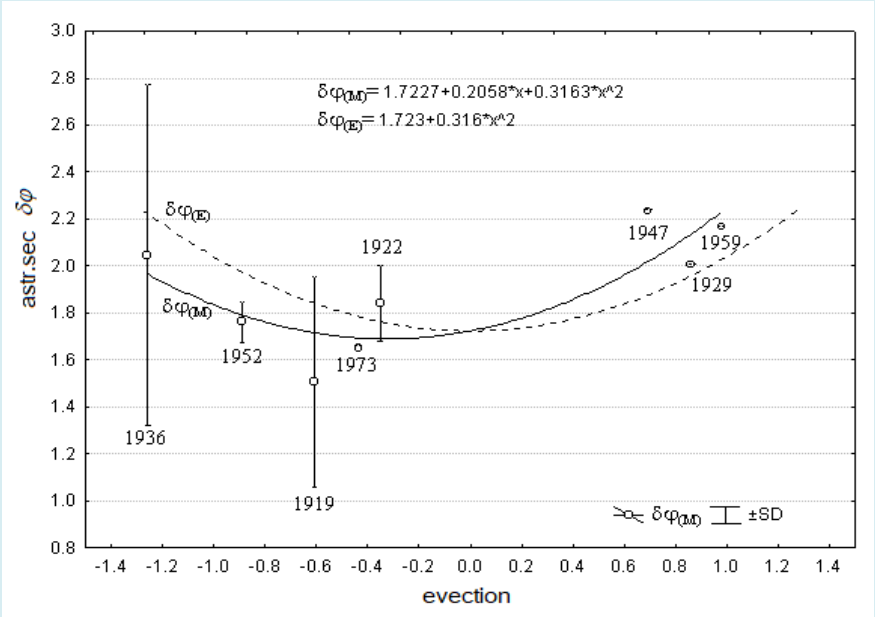

Figure 2: Distribution of δϕ scores by evection 1919 to 1973: δϕ(M)– averaging, δϕ(E)– theoretical dependence.

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Figures 3-4 show the δϕ distributions according to variation (0.658°sin2D) and annual inequality (0.186°sinl'). Unfortunately, the statistics of 0.658°sin2D for the dates of total solar eclipses developed with negative angles, and for the annual inequality there were only two positive values.

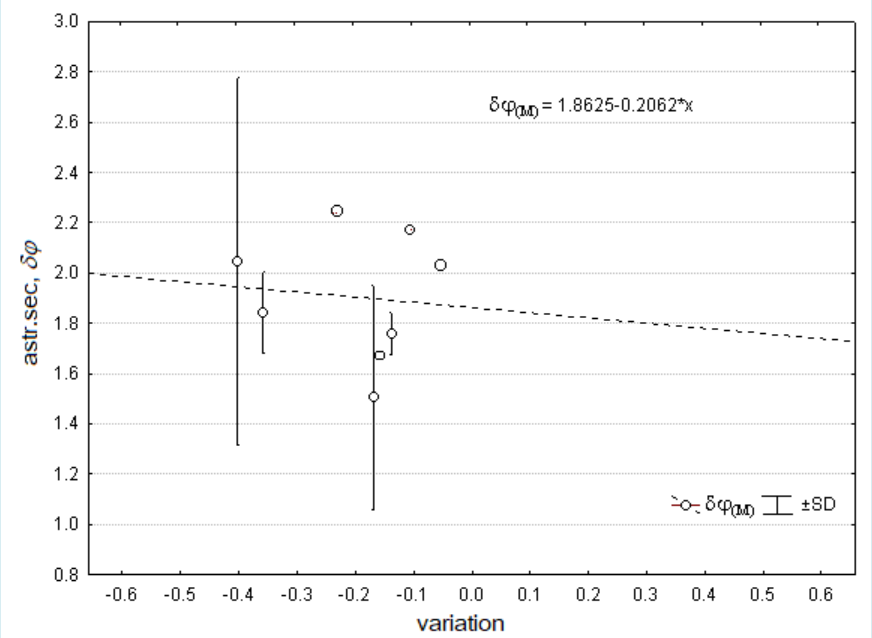

Figure 3: The dependence of δϕ on variation according to the results of observations of total solar eclipses from 1919 to 1973.

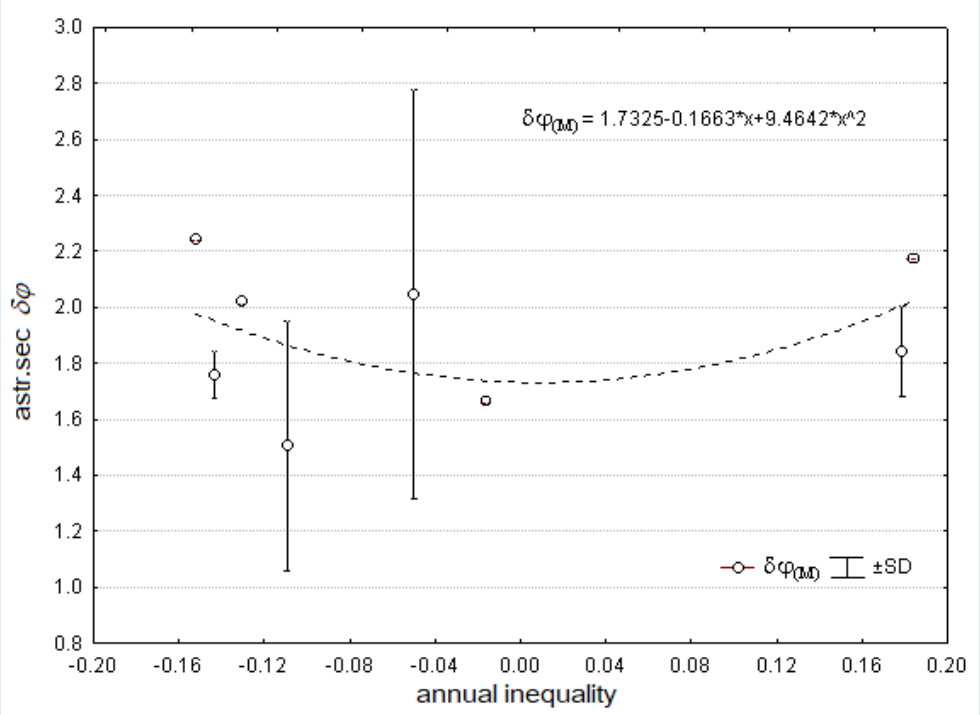

Figure 4: Dependence of δϕ on annual inequality according to the results of observations of total solar eclipses from 1919 to 1973

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Conclusion

Main results:

- connection of optical $\delta\phi$ results with evection values is obtained;
- $\delta\phi$=1.75" is in accordance with the condition 1.274°sin(l–2D)=0°;
- extreme values $\delta\phi$ (2.25"±10%) correspond to extremes of evection (±1.274°)
- at evection values ~0°, $\delta\phi$=1.72"±10% is expected [35].

Using the relationship obtained, Table 2 shows the calculated δϕ values for total solar eclipses for the period from 06.02.2027 to 04.09.2100.

Date Full Solar Eclipses	1.72E	ΔX (10%)	Date Full Solar Eclipses	1.72E	ΔX 10%)	Date Full Solar Eclipses	1.72E	ΔX (10%)
06.02.2027	1.88	0.19	24.10.2060	1.72	0.17	16.01.2094	1.73	0.17
02.08.2027	1.74	0.17	20.04.2061	1.86	0.19	02.06.2095	2.19	0.22
26.01.2028	1.74	0.17	13.10.2061	1.96	0.2	27.11.2095	1.93	0.19
22.07.2028	1.99	0.2	28.02.2063	1.81	0.18	22.05.2096	1.76	0.18
01.06.2030	1.74	0.17	24.08.2063	1.72	0.17	15.11.2096	1.73	0.17
25.11.2030	1.75	0.17	17.02.2064	1.79	0.18	11.05.2097	1.85	0.19
21.05.2031	1.9	0.19	12.08.2064	1.98	0.2	04.11.2097	2.05	0.21
14.11.2031	2.1	0.21	22.06.2066	1.74	0.17	21.03.2099	1.82	0.18
09.05.2032	2.23	0.22	17.12.2066	1.8	0.18	14.09.2099	1.72	0.17
30.03.2033	1.78	0.18	11.06.2067	1.89	0.19	10.03.2100	1.78	0.18
20.03.2034	1.91	0.19	06.12.2067	2.17	0.22	04.09.2100	2.06	0.21
12.09.2034	2.02	0.2	31.05.2068	2.24	0.22			
09.03.2035	2.23	0.22	11.04.2070	2	0.2			
02.09.2035	2.19	0.22	04.10.2070	2.1	0.21			
13.07.2037	2.12	0.21	31.03.2071	2.23	0.22			
05.01.2038	2.19	0.22	23.09.2071	2.2	0.22			
02.07.2038	2.19	0.22	12.09.2072	1.77	0.18			

Table 2: The expected values δϕ adjusted for evection for total solar eclipses from 06.02.2027 to 04.09.2100.

In a brief discussion of the previously not considered relationship of δϕ with the main perturbations from the Sun, it should be noted that according to formula (4), the value of δϕ can be corrected ~ 0.03" due to evection, as the main perturbation from the Sun to the Moon and Earth, the effect of which is reflected in the short-period nutation of the earth's axis with a period of 31.8 days (see Table in the Astronomical Yearbook [36]. Among the potential corrections, parallactic inequality depending on the argument D (29.5305881 days), secular acceleration (varies with the eccentricity of the Earth's orbit) can also be considered; secular movement of perigee (3232.9 days) and inequality of precession of the node (173.31 days).

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