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A NEW CONFIRMATION OF THE ALLAIS EFFECT DURING THE SOLAR ECLIPSE OF 31 MAY 2003

Ieronim MIHĂILĂ, Nicolae MARCOV, Varujan PAMBUCCIAN, Ovidiu RACOVEANU

University of Bucharest, Faculty of Mathematics and Informatics, Str. Academiei 14, 010014 Bucharest, Romania
Corresponding author: Ieronim MIHĂILĂ, E-mail: mihaila@math.math.unibuc.ro

During the solar eclipse of 31 may 2003, the Allais effect was studied in Bucharest, using a Foucault pendulum. The effect was determined calculating the difference of the azimuth during the eclipse (A_e) and the azimuth outside the eclipse (A_r). The motion of the plane of oscillation became slower after the maximum of the eclipse, the deviation $| A_e - A_r |$ reaching approximately 1.7° by the end of the eclipse, and afterwards it reached the maximum value of order of 2.8° – 2.9°. On the other hand, in the neighbourhood of the maximum of the eclipse the period of oscillation suffered a little growth, the relative increase being of about 2.6×10^{-6}.

Key words: Foucault effect, Allais effect, eclipse, gravitation.

1. PRELIMINARIES

During the total solar eclipse of 11 August 1999, at the University of Bucharest, the existence of the Allais effect was confirmed [1]. This effect, which constitutes a disturbance of the Foucault effect, consists in a decrease of the angular rotation velocity of the oscillation plane of the pendulum during the solar eclipse. It was discovered by Professor Maurice Allais, in Paris, during the Sun eclipses from 1954 [2] and 1959 [3].

The author named his discovery the eclipse effect. Later, on the occasion of the total solar eclipse of 11 August 1999, when NASA (National Aeronautics and Space Administration) proposed an observation program of the effect in many countries, it was named the Allais effect.

The annular solar eclipse of 31 May 2003 constituted a new occasion to study the Allais effect. In Romania, the solar eclipse was visible as partial eclipse. The particularity of this eclipse constituted in the fact that its beginning occurred right after the sunrise, when the Sun was situated in the vicinity of the horizon. In Bucharest the eclipse began at 2 h 12 min UT (5 h 12 min local time) and ended at 4 h 08 min UT, its maximum occurred at 3 h 09 min UT [4,5]. The covered sun surface was of 67%. At the beginning of the eclipse, the Sun had the azimuth $A = 244.2°$ and the altitude $h = 5.1°$, and at the end $A = 263.5°$ and $h = 24.7°$. During the maximum of the eclipse, the values were $A = 253.4°$ and $h = 14.4°$.

For the eclipse of 11 August 1999 we used two Foucault pendulums, which oscillated in perpendicular planes, in order to study also the isotropy of the effect. During the eclipse of 31 May 2003 we used only one of the two pendulums. It was constituted of a cast iron sphere with a diameter of 12.5 cm and a steel wire with a diameter of 0.68 mm, fixed by a Cardan suspension. The pendulum weight is of 7.3 kg and the length of 14.21 m.

The pendulum was installed in a staircase of the Faculty of Mathematics and Informatics, the University of Bucharest. Its center of gravity was situated at a distance of approximately 0.9 m from the floor, and approximately 2 m from the ground. During the determination the staircase was closed and the temperature periodically measured in the vicinity of the sphere and at 7 m height.

In this paper the results regarding the movement of the oscillation plane and the period of oscillation of the pendulum during the eclipse are presented.

Recommended by Lazăr DRAGOŞ, member of the Romanian Academy

2. THE AZIMUTH OF THE OSCILLATION PLANE

In order to measure the azimuth of the plane of oscillation we used an alidade of 120 cm × 8 cm, centered on the axis of the pendulum at rest, and provided with a rectangular axes system and a grid. The alidade had a window of 5 cm × 4 cm, situated from the center at a distance of 45 cm, and at the opposite extremity it had a support for anchorage of the pendulum. When the alidade rotates, the window superposes with a segment of circular crown divided in degrees and tenths of degree. On the one hand, this system allowed determination of the azimuth with one tenth of degree error. On the other hand, the two coordinate axes allowed determination of the semiaxes of the elipse described by the axis of the pendulum. The pendulum was launched three times, every 60 minutes, with an initial linear amplitude of approximately 45 cm, that is which an angular amplitude of approximately 1.8°.

The azimuth was measured from south in the astronomical sense (clockwise). Theoretically, the azimuth of the oscillation plane is a linear function of time

$$A(t) = A_0 + \omega_0 (t - t_0), \tag{1}$$

where ω_φ is the angular velocity of the motion of the oscillation plane and t_0 is the initial moment. For Bucharest the astronomical latitude is $\varphi = 44°25'$, and we obtain $\omega_\varphi = \omega \sin\varphi = 10.527° / \mathrm{h}$, where ω represents the angular velocity of the Earth rotation.

The duration of the experience was 3 h and 30 min, from 1 h 30 min UT to 5 h 00 min UT. Taking into account the sun position on the celestial sphere, we considered $A_0 = 250°$. The results obtained for the azimuth during the eclipse (A_e) are shown in Table 1.

Table 1 Values of the azimuth

UT	A_e	A_r	$A_e - A_r$	*UT*	A_e	A_r	$A_e - A_r$
$1^h\,30^m$	250.0°	250.0°	0.0°	$3^h\,15^m$	268.2°	268.2°	0.0°
1 35	250.9	250.9	0.0	3 20	268.9	269.1	− 0.2
1 40	251.8	251.8	0.0	3 25	269.6	270.0	− 0.4
1 45	252.7	252.6	0.1	3 30	270.2	270.9	− 0.7
1 50	253.6	253.5	0.1	3 35	270.9	271.8	− 0.9
1 55	254.5	254.3	0.2	3 40	271.8	272.7	− 0.9
2 00	255.4	255.2	0.2	3 45	272.6	273.5	− 0.9
2 05	256.3	256.0	0.3	3 50	273.3	274.4	− 1.1
2 10	257.2	256.9	0.3	3 55	274.1	275.3	− 1.2
2 15	258.1	257.8	0.3	4 00	274.8	276.2	− 1.4
2 20	259.0	258.7	0.3	4 05	275.5	277.1	− 1.6
2 25	259.9	259.5	0.4	4 10	276.2	277.9	− 1.7
2 30	260.8	260.3	0.5	4 15	276.9	278.8	− 1.9
2 35	261.7	261.2	0.5	4 20	277.7	279.6	− 1.9
2 40	262.6	262.0	0.6	4 25	278.4	280.5	− 2.1
2 45	263.5	262.9	0.6	4 30	279.1	281.4	− 2.3
2 50	264.4	263.8	0.6	4 35	279.7	282.3	− 2.6
2 55	265.1	264.7	0.4	4 40	280.4	283.2	− 2.8
3 00	265.8	265.6	0.2	4 45	281.2	284.0	− 2.8
3 05	266.7	266.4	0.3	4 50	282.0	284.9	− 2.9
3 10	267.5	267.3	0.2	4 55	282.9	285.8	− 2.9
3 15	268.2	268.2	0.0	5 00	283.8	286.7	− 2.9

In order to make evident the Allais effect, we also determined, just like for the eclipse of 11 August 1999, the azimuth out of the eclipse for the 3 h and 30 min, on the 1st June 2003, between 6 h 30 min and 10 h 00 min, using the same initial data and the same time intervals between the launches. On the other hand, the Cardan suspension had the same orientation. Proceeding in this way, we eliminated the influence of the systematic effect due to the deviation of the pendulum's motion in comparison with the Foucault motion.

The values of this azimuth, named reference azimuth (A_r), are also shown in Table 1. The difference $A_e - A_r$ constitutes a measure of the Allais effect. The functions $A_e(t)$ and $A_r(t)$ are graphically represented in Fig. 1. We mention that the A_e values are very closed to the Foucault effect values, the A_r (t) curve being practically a segment of straight line.

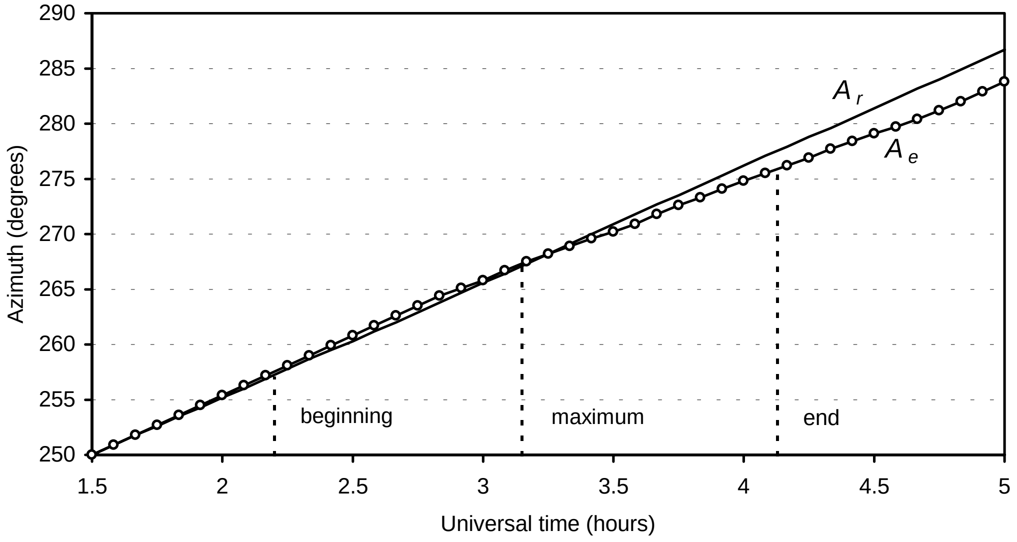

Fig. 1 – Graphs of the azimuth.

We could notice that the motion of the plane of oscillation became slower after the maximum of the eclipse, the absolute deviation $|A_e - A_r|$ reaching approximately 1.7° by the end of the eclipse (4 h 10 min) and approximately $2.8° - 2.9°$ at 4 h 45 min, and afterwards it remains almost constant, the curves $A_e(t)$ and A_r (t) being practically parallel. Therefore, the angular velocity of the motion of the plane of oscillation became again the velocity corresponding to the Foucault effect. We notice that for the eclipse of 11 August 1999 the maximum deviation was of 1.7° – 1.8° and occurred before the maximum of the eclipse.

A similar situation, concerning the occurrence of the effect after the maximum of the eclipse, took place during the eclipse of 11 July 1991, which was observed in Mexico City [6], when the sun was in the neighbourhood of the zenith.

3. THE PERIOD OF OSCILLATION

Studying the period is a very important issue concerning the motion of a pendulum during the eclipse. This question was mooted for the first time on the occasion of the Sun eclipse of 15 February 1961 [7,8]. Using the Foucault pendulum, the authors observed that the period of oscillation did not remain constant during the eclipse, this passing through the minimum value at the maximum of the eclipse. Later, during the Sun eclipse of 7 March 1970, E.J. Saxl and M. Allen [9], using a torsion pendulum, made evident that when the eclipse began the period grew and reached its extreme value at the maximum of the eclipse and then it decreased. The authors obtained a relative increase of the period of 2.7×10^{-4}. On the other hand, at the eclipse of July 1991 it was observed that the period presents a minimum at the maximum of the eclipse, the relative variation being of the order of 1.15×10^{-4}.

During the Sun eclipse of 11 August 1999, one of the two pendulums, the one which oscillated in the vertical plane of the eclipsed Sun, presented a little increase of the period at the maximum of the eclipse (approximately 0.026%). But the precision of our determinations was not very accurate. In order to increase the accuracy of the period determination, the second author made an automatic device, which was described in the work dedicated to the study of the motion of the Foucault pendulum in Luanda (Angola), during the Sun eclipse of 21st June 2001 [10]. The device is constituted of a converter, an interface and a digital frequency time meter (PFL-20). The converter is made of a visible light emitting source and a photosensitive resistor. The two components of the converter are situated on both sides of the alidade, on a rigid support forming one piece with it, so that the beam of light is permanently perpendicular on the plane of oscillation. The beam of light is obturaded by the time when the needle of the pendulum passes through the perpendicular plane to the plane of oscillation, and which also passes through the origin of the coordinates system. The signal given by the converter activates the frequency-time meter. Its time basis was chosen to be 10 kHz. The frequency-time meter gives the value of 20 periods at intervals of 32 periods. (approximately 4 minutes).

The results obtained for the period corresponding to the three launches are presented in Table 2 and in Fig 2. In the table is also given the value of the linear amplitude (measured on the alidade). We may notice that the amplitude decreases monotonously for each time interval.

Table 2 Values of the period

UT	*T (sec)*	*a (cm)*	T_0 *(sec)*	*UT*	*T (sec)*	*a (cm)*	T_0 *(sec)*
$1^h 34^m$	7.53584	44.0	7.53539	$3^h 12^m$	7.53586	29.5	7.53566
1 38	7.53571	42.0	7.53530	3 16	7.53579	28.5	7.53560
1 42	7.53587	40.0	7.53550	3 20	7.53557	27.3	7.53540
1 46	7.53566	37.7	7.53533	3 24	7.53546	26.5	7.53530
1 50	7.53561	36.0	7.53531	3 28	7.53576	25.5	7.53561
1 54	7.53577	34.7	7.53549	3 36	7.53596	44.0	7.53551
1 58	7.53554	33.3	7.53528	3 40	7.53589	42.5	7.53547
2 02	7.53564	31.8	7.53540	3 44	7.53571	40.4	7.53533
2 06	7.53555	30.5	7.53533	3 48	7.53569	38.2	7.53535
2 10	7.53553	29.5	7.53533	3 52	7.53571	36.5	7.53540
2 14	7.53573	28.3	7.53554	3 56	7.53561	34.5	7.53533
2 18	7.53586	27.3	7.53569	4 00	7.53559	33.2	7.53533
2 22	7.53548	26.5	7.53532	4 04	7.53571	32.0	7.53547
2 26	7.53560	25.5	7.53545	4 08	7.53538	31.0	7.53516
2 30	7.53544	24.8	7.53530	4 12	7.53548	29.7	7.53527
2 36	7.53570	43.5	7.53526	4 16	7.53560	28.5	7.53541
2 40	7.53576	42.0	7.53535	4 20	7.53544	27.4	7.53526
2 44	7.53577	40.0	7.53540	4 24	7.53550	26.5	7.53534
2 48	7.53552	38.2	7.53518	4 28	7.53557	25.7	7.53542
2 52	7.53569	36.8	7.53537	4 32	7.53561	24.8	7.53547
2 56	7.53564	35.0	7.53535	4 41	7.53571	23.0	7.53559
3 00	7.53554	33.5	7.53528	4 45	7.53551	22.1	7.53540
3 04	7.53560	32.0	7.53536	4 49	7.53553	21.5	7.53542
3 08	7.53579	30.8	7.53557	4 53	7.53559	21.0	7.53549
3 12	7.53586	29.5	7.53566	4 57	7.53557	20.5	7.53547

The values of the period are between 7.53538 s and 7.53596 s, the average value being of 7.53565 s. During the intervals between the launches the values of the period decrease firstly because of the amplitude decrease. We may see, by means of the regression lines, that the decrease is slower during the second interval, when the maximum of the eclipse occurred.

The regression lines have the following equations:

$$\begin{aligned} T &= -\,0.000253\,(t - 1.5) + 7.53579, && \text{for } 1.5 \le t < 2.5, \\ T &= -\,0.000035\,(t - 2.5) + 7.53569, && \text{for } 2.5 \le t < 3.5, \\ T &= -\,0.000219\,(t - 3.5) + 7.53577, && \text{for } 3.5 \le t < 5.0, \end{aligned} \tag{2}$$

where the time t is expressed in hours.

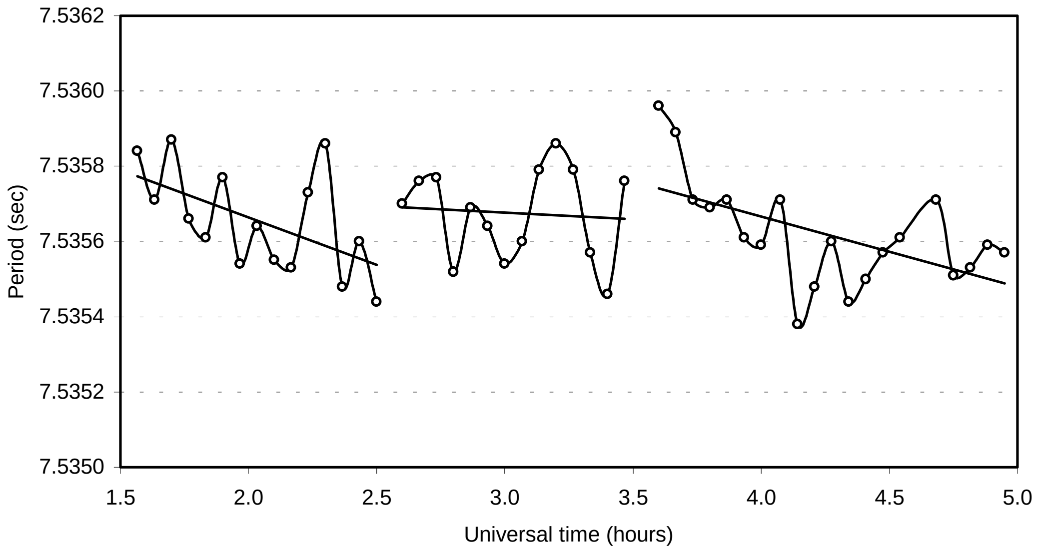

Fig. 2 – Graph of the period.

Just like in the azimuth case, in the determination of 1st June 2003 the period was also measured, the period named reference period (T_r). Its values are represented in Fig.3. We notice that out of the eclipse the results from the second data series are similar to the ones from the first and the third series. In this case the regression lines have the equations:

$$\begin{aligned} T_r &= -\,0.000626\,(\,t-6.5\,)+7.53599, && \text{for}\quad 6.5 \le t < 7.5,\\ T_r &= -\,0.000297\,(\,t-7.5\,)+7.53580, && \text{for}\quad 7.5 \le t < 8.5,\\ T_r &= -\,0.000324\,(\,t-8.5\,)+7.53588, && \text{for}\quad 8.5 \le t < 10.0. \end{aligned} \tag{3}$$

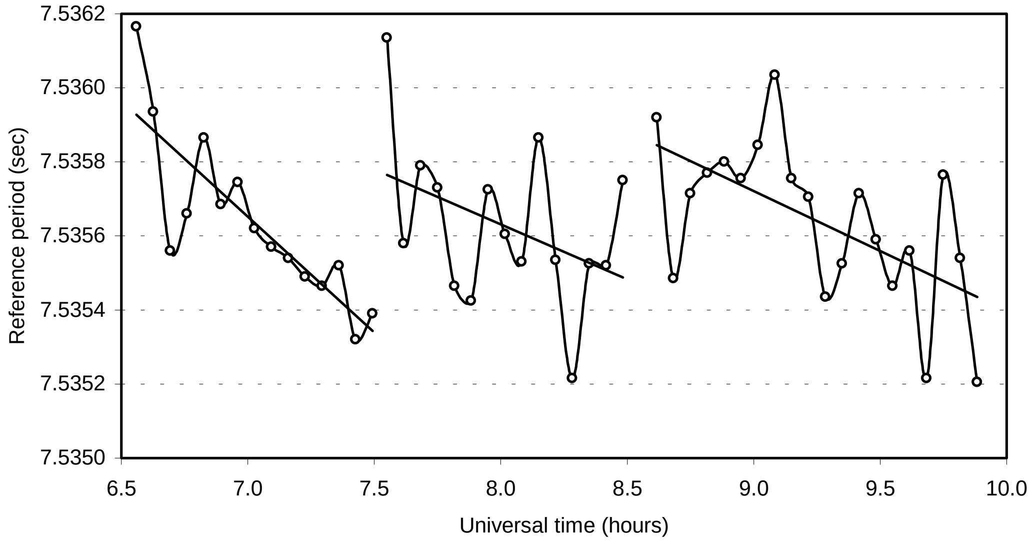

Fig. 3 – Graph of the reference period.

In order to make more evident the behaviour of the period during the eclipse, we eliminated the amplitude effect using the classical formula:

$$T = T_0(1 + \alpha^2 / 16 + \dots), \qquad (4)$$

where the reduced period $T_0 = 2\pi\ (L/g)^{1/2}$, L being the equivalent length of the pendulum, g is the acceleration of the gravity, and α the angular amplitude. The values of the reduced period are presented in Table 2 and they are graphically represented in Fig. 4.

The equations of the regression lines are:

$$\begin{aligned} T_0 &= 0.000066\ (t - 1.5) + 7.53536, && \text{for } 1.5 \le t < 2.5, \\ T_0 &= 0.000301\ (t - 2.5) + 7.53525, && \text{for } 2.5 \le t < 3.5, \\ T_0 &= 0.000061\ (t - 3.5) + 7.53535, && \text{for } 3.5 \le t < 5.0. \end{aligned} \qquad (5)$$

One may observe that for the interval corresponding to the maximum of the eclipse, the slope of the straight line is greater than for the other two intervals. Moreover, the fact that the period increased in the vicinity of the maximum phase of the eclipse results also from the examination of the regression line for the reference period, which corresponds to this interval from 1st June 2003, namely:

$$T_{r0} = -\ 0.000003\ (t - 2.5) + 7.53538. \qquad (6)$$

For the three considered intervals the average values of the reduced period are $\overline{T}_{01} = 7.535397$ s, $\overline{T}_{02} = 7.535406$ s and $\overline{T}_{03} = 7.535395$ s, the average value of the reduced period during the eclipse being $\overline{T}_0 = 7.53540 \pm 0\ 00002$. On the other hand, for the three considered intervals the average values of the period are : $\overline{T}_1 = 7.53565$ s, $\overline{T}_2 = 7.53567$ s, $\overline{T}_3 = 7.53562$ s, respectively $\overline{T}_{r1} = 7.53563$ s, $\overline{T}_{r2} = 7.53563$ s, $\overline{T}_{r3} = 7.53564$ s.

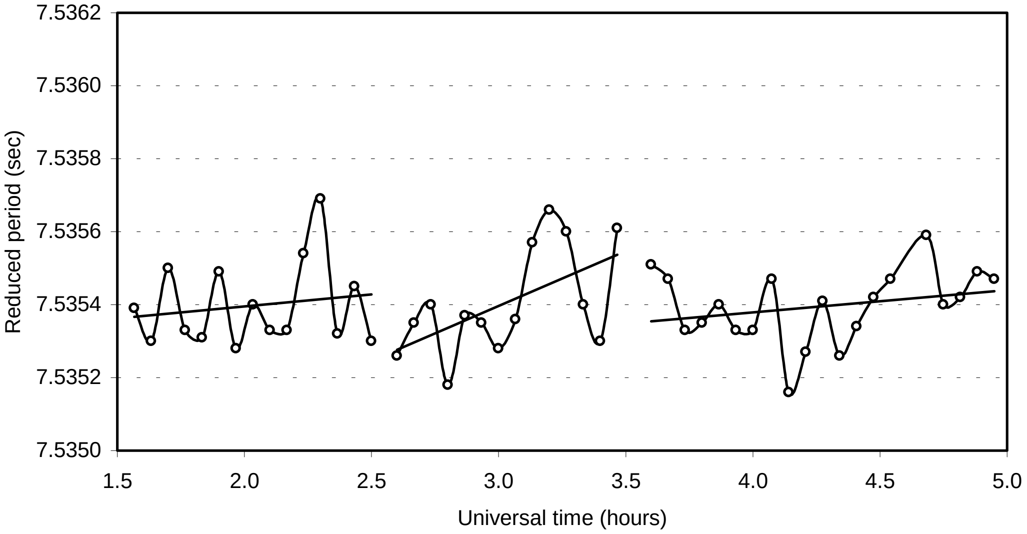

Fig. 4 – Graph of the reduced period.

Therefore $\overline{T}_r$ has practically the same value for the three intervals, while $\overline{T}$ increases in the second interval with approximately 0.0003s. Also taking into account the fact that for $\overline{T}_0$ an increase of 0.00001s is obtained in the second interval, we may consider that during the maximum of the eclipse the reduced period presents an increase smaller than 0.02 ms, which means a relative increase smaller than 2.6×10^{-6}. It follows then for the gravity acceleration a relative decrease $\delta g / g \cong 5 \times 10^{-6}$, a much greater value than the value $\delta g / g \cong 1.6 \times 10^{-7}$, produced by the maximum tide effect due to the Moon and the Sun. We may also notice that even if we consider as superior limit an increase of the period of 0.2 ms, it results a relative increase only of 2.6×10^{-5}, that is ten times smaller than the increase obtained with the torsion pendulum.

4. CONCLUSIONS

Our measurements showed that during the sun eclipse, the motion of the plane of oscillation of the pendulum is really slower than the motion predicted by the Foucault effect. Thus we obtained a new confirmation of the Allais effect. On the other hand, the period of oscillation of the pendulum presents a small increase during the maximum of the eclipse.

In order to study more deeply the Allais effect new measurements are necessary, made with the paraconical pendulum (Allais) and also with the Foucault pendulum, during other eclipses. Such an eclipse, which may be seen in Bucharest, will take place on 26 March 2006, when we hope to determine the period more precisely. To study the Allais effect we shall use the described Foucault pendulum and the Allais pendulum realized recently and calibrated.

On the other hand, we consider that in order to determine the period of oscillation and the variation of the gravity acceleration during the eclipse is useful to use the gravimetric pendulum and the static gravimeter.

We mention that the study of the eclipse Allais effect contributes to a better knowledge of the Allais effect in general, reveled through continuous observations made by Professor Maurice Allais. We consider that retaking these observations, which was proposed by NASA on the occasion of the sun eclipse of 11 August 1999, is opportune [11]. Finally, all these researches will contribute to better understand the gravity.

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