# Allais Effect and TGD

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## Contents

# 1 Introduction

Allais effect [2, 3] is a fascinating gravitational anomaly associated with solar eclipses. It was discovered originally by M. Allais, a Nobelist in the field of economy, and has been reproduced in several experiments but not as a rule. The experimental arrangement uses so called paraconical pendulum, which differs from the Foucault pendulum in that the oscillation plane of the pendulum can rotate in certain limits so that the motion occurs effectively at the surface of sphere.

## 1.1 Experimental findings

Consider first a brief summary of the findings of Allais and others [3].

a) In the ideal situation (that is in the absence of any other forces than gravitation of Earth) paraconical pendulum should behave like a Foucault pendulum. The oscillation plane of the paraconical pendulum however begins to rotate.

b) Allais concludes from his experimental studies that the orbital plane approach always asymptotically to a limiting plane and the effect is only particularly spectacular during the eclipse. During solar eclipse the limiting plane contains the line connecting Earth, Moon, and Sun. Allais explains this in terms of what he calls the anisotropy of space.

c) Some experiments carried out during eclipse have reproduced the findings of Allais, some experiments not. In the experiment carried out by Jeverdan and collaborators in Romania it was found that the period of oscillation of the pendulum decreases by $\Delta f/f \simeq 5 \times 10^{-4}$ [2, 4] which happens to correspond to the constant $v_0 = 2^{-11}$ appearing in the formula of the gravitational Planck constant. It must be however emphasized that the overall magnitude of $\Delta f/f$ varies by five orders of magnitude. Even the sign of $\Delta f/f$ varies from experiment to experiment.

d) There is also quite recent finding by Popescu and Olenici, which they interpret as a quantization of the plane of oscillation of paraconical oscillator during solar eclipse [5].

## 1.2 TGD based models for Allais effect

I have already earlier proposed an explanation of the effect in terms of classical $Z^0$ force [G1]. If the $Z^0$ charge to mass ratio of pendulum varies and if Earth and Moon are $Z^0$ conductors, the resulting model is quite flexible and one might hope it could explain the high variation of the experimental results.

The rapid variation of the effect during the eclipse is however a problem for this approach and suggests that gravitational screening or some more general interference effect might be present. Gravitational screening alone cannot however explain Allais effect. Also the combination of gravitational screening and $Z^0$ force assuming $Z^0$ conducting structures causing screening fails to explain the discontinuous behavior when massive objects are collinear.

A model based on the idea that gravitational interaction is mediated by topological light rays (MEs) and that gravitons correspond to a gigantic value of the gravitational Planck constant however explains the Allais effect as an interference effect made possible by macroscopic quantum coherence in astrophysical length scales. Equivalence Principle fixes the model to a high degree and one ends up with an explicit formula for the anomalous gravitational acceleration and the general order of magnitude and the large variation of the frequency change as being due to the variation of the distance ratio $r_{S,P}/r_{M,P}$ ($S, M$,and $P$ refer to Sun, Moon, and pendulum respectively). One can say that the pendulum acts as an interferometer.

# 2 Could gravitational screening explain Allais effect

The basic idea of the screening model is that Moon absorbs some fraction of the gravitational momentum flow of Sun and in this manner partially screens the gravitational force of Sun in a disk like region having the size of Moon's cross section. The screening is expected to be strongest in the center of the disk. Screening model happens to explain the findings of Jevardan but fails in the general case. Despite this screening model serves as a useful exercise.

## 2.1 Constant external force as the cause of the effect

The conclusions of Allais motivate the assumption that quite generally there can be additional constant forces affecting the motion of the paraconical pendulum besides Earth's gravitation. This means the replacement $\overline{g} \rightarrow \overline{g} + \Delta\overline{g}$ of the acceleration $g$ due to Earth's gravitation. $\Delta\overline{g}$ can depend on time.

The system obeys still the same simple equations of motion as in the initial situation, the only change being that the direction and magnitude of effective Earth's acceleration have changed so that the definition of vertical is modified. If $\Delta\overline{g}$ is not parallel to the oscillation plane in the original situation, a torque is induced and the oscillation plane begins to rotate. This picture requires that the friction in the rotational degree of freedom is considerably stronger than in oscillatory degree of freedom: unfortunately I do not know what the situation is.

The behavior of the system in absence of friction can be deduced from the conservation laws of energy and angular momentum in the direction of $\overline{g}+\Delta\overline{g}$. The explicit formulas are given by

$$
\begin{aligned}
E &= \frac{ml^2}{2}(\frac{d\Theta}{dt})^2 + sin^2(\Theta)(\frac{d\Phi}{dt})^2 + mglcos(\Theta) \ , \\
L_z &= ml^2 sin^2(\Theta)\frac{d\Phi}{dt} \ . \qquad (1)
\end{aligned}
$$

and allow to integrate $\Theta$ and $\Phi$ from given initial values.

### 2.2 What causes the effect in normal situations?

The gravitational accelerations caused by Sun and Moon come first in mind as causes of the effect. Equivalence Principle implies that only relative accelerations causing analogs of tidal forces can be in question. In GRT picture these accelerations correspond to a geodesic deviation between the surface of Earth and its center. The general form of the tidal acceleration would thus the difference of gravitational accelerations at these points:

$$
\Delta\overline{g} = -2GM[\frac{\Delta\overline{r}}{r^3} - 3\frac{\overline{r}\cdot\Delta\overline{r}\overline{r}}{r^5}] \ . \qquad (2)
$$

Here $\overline{r}$ denotes the relative position of the pendulum with respect to Sun or Moon. $\Delta\overline{r}$ denotes the position vector of the pendulum measured with respect to the center of Earth defining the geodesic deviation. The contribution in the direction of $\Delta\overline{r}$ does not affect the direction of the Earth's acceleration and therefore does not contribute to the torque. Second contribution corresponds to an acceleration in the direction of $\overline{r}$ connecting the pendulum to Moon or Sun. The direction of this vector changes slowly.

This would suggest that in the normal situation the tidal effect of Moon causes gradually changing force $m\Delta\overline{g}$ creating a torque, which induces a rotation of the oscillation plane. Together with dissipation this leads to a situation in which the orbital plane contains the vector $\Delta\overline{g}$ so that no torque is experienced. The limiting oscillation plane should rotate with same period as Moon around Earth. Of course, if effect is due to some other force than gravitational forces of Sun and Earth, paraconical oscillator would provide a manner to make this force visible and quantify its effects.

### 2.3 What would happen during the solar eclipse?

During the solar eclipse something exceptional must happen in order to account for the size of effect. The finding of Allais that the limiting oscillation plane contains the line connecting Earth, Moon, and Sun implies that the anomalous acceleration $\Delta|g$ should be parallel to this line during the solar eclipse.

The simplest hypothesis is based on TGD based view about gravitational force as a flow of gravitational momentum in the radial direction.

a) For stationary states the field equations of TGD for vacuum extremals state that the gravitational momentum flow of this momentum. Newton's equations suggest that planets and moon absorb a fraction of gravitational momentum flow meeting them. The view that gravitation is mediated by gravitons which correspond to enormous values of gravitational Planck constant in turn supports Feynman diagrammatic view in which description as momentum exchange makes sense and is consistent with the idea about absorption. If Moon absorbs part of this momentum, the region of Earth screened by Moon receives reduced amount of gravitational momentum and the gravitational force of Sun on pendulum is reduced in the shadow.

b) Unless the Moon as a coherent whole acts as the absorber of gravitational four momentum, one expects that the screening depends on the distance travelled by the gravitational flux inside Moon. Hence the effect should be strongest in the center of the shadow and weaken as one approaches its boundaries.

c) The opening angle for the shadow cone is given in a good approximation by $\Delta\Theta = R_M/R_E$. Since the distances of Moon and Earth from Sun differ so little, the size of the screened region has same size as Moon. This corresponds roughly to a disk with radius $.27 \times R_E$.

The corresponding area is 7.3 per cent of total transverse area of Earth. If total absorption occurs in the entire area the total radial gravitational momentum received by Earth is in good approximation 92.7 per cent of normal during the eclipse and the natural question is whether this effective repulsive radial force increases the orbital radius of Earth during the eclipse.

More precisely, the deviation of the total amount of gravitational momentum absorbed during solar eclipse from its standard value is an integral of the flux of momentum over time:

$$\begin{aligned} \Delta P^k_{gr} &= \int \frac{\Delta P^k_{gr}}{dt}(S(t))dt \ , \\ \frac{\Delta P^k_{gr}}{dt}(S(t)) &= \int_{S(t)} J^k_{gr}(t)dS \ . \end{aligned} \tag{3}$$

This prediction could kill the model in classical form at least. If one takes seriously the quantum model for astrophysical systems predicting that planetary orbits correspond to Bohr orbits with gravitational Planck constant equal to $GMm/v_0$, $v_0 = 2^{-11}$, there should be not effect on the orbital radius. The anomalous radial gravitational four-momentum could go to some other degrees of freedom at the surface of Earth.

d) The rotation of the oscillation plane is largest if the plane of oscillation in the initial situation is as orthogonal as possible to the line connecting Moon, Earth and Sun. The effect vanishes when this line is in the initial plane of oscillation. This testable prediction might explain why some experiments have failed to reproduce the effect.

e) The change of $|\overline{g}|$ to $|\overline{g}+\Delta\overline{g}|$ induces a change of oscillation frequency given by

$$\frac{\Delta f}{f} = \frac{\overline{g}\cdot\Delta\overline{g}}{g^2} = \frac{\Delta g}{g}cos(\theta) \ . \tag{4}$$

If the gravitational force of the Sun is screened, one has $|\overline{g}+\Delta\overline{g}| > g$ and the oscillation frequency should increase. The upper bound for the effect corresponds to vertical direction is obtained from the gravitational acceleration of Sun at the surface of Earth:

$$\frac{|\Delta f|}{f} \leq \frac{\Delta g}{g} = \frac{v_E^2}{r_E} \simeq 6.0\times 10^{-4} \ . \tag{5}$$

f) One should explain also the recent finding by Popescu and Olenici, which they interpret as a quantization of the plane of oscillation of paraconical oscillator during solar eclipse [5]. A possible TGD based explanation would be in terms of quantization of $\Delta\overline{g}$ and thus of the limiting oscillation plane. This quantization should reflect the quantization of the gravitational momentum flux receiving Earth. The flux would be reduced in a stepwise manner during the solar eclipse as the distance traversed by the flux through Moon increases and reduced in a similar manner after the maximum of the eclipse.

### 2.4 What kind of tidal effects are predicted?

If the model applies also in the case of Earth itself, new kind of tidal effects are predicted due to the screening of the gravitational effects of Sun and Moon inside Earth. At the night-side the paraconical pendulum should experience the gravitation of Sun as screened. Same would apply to the "night-side" of Earth with respect to Moon.

Consider first the differences of accelerations in the direction of the line connecting Earth to Sun/Moon: these effects are not essential for tidal effects. The estimate for the ratio for the orders of magnitudes of the these accelerations is given by

$$\frac{|\Delta\overline{g}_{\perp}(Moon)|}{|\Delta\overline{g}_{\perp}(Sun)|} = \frac{M_S}{M_M}(\frac{r_M}{r_E})^3 \simeq 2.17 \ . \tag{6}$$

The order or magnitude follows from $r(Moon) = .0026$ AU and $M_M/M_S = 3.7\times 10^{-8}$. These effects are of same order of magnitude and can be compensated by a variation of the pressure gradients of atmosphere and sea water. The effects caused by Sun are two times stronger. These effects are of same order of magnitude and can be compensated by a variation of the pressure gradients of atmosphere and sea water.

The tangential accelerations are essential for tidal effects. They decompose as

$$\frac{1}{r^3}\left[\Delta\overline{r} - 3|\Delta\overline{r}|cos(\Theta)\frac{\overline{r}}{r}\right] \ .$$

$\pi/4 \leq \Theta \leq \pi/2$ is the angle between $\Delta\overline{r}$ and $\overline{r}$. The above estimate for the ratio of the contributions of Sun and Moon holds true also now and the tidal effects caused by Sun are stronger by a factor of two.

Consider now the new tidal effects caused by the screening.

a) Tangential effects on day-side of Earth are not affected (night-time and night-side are of course different notions in the case of Moon and Sun). At the night-side screening is predicted to reduce tidal effects with a maximum reduction at the equator.

b) Second class of new effects relate to the change of the normal component of the forces and these effects would be compensated by pressure changes corresponding to the change of the effective gravitational acceleration. The night-day variation of the atmospheric and sea pressures would be considerably larger than in Newtonian model.

The intuitive expectation is that the screening is maximum when the gravitational momentum flux travels longest path in the Earth's interior. The maximal difference of radial accelerations associated with opposite sides of Earth along the line of sight to Moon/Sun provides a convenient manner to distinguish between Newtonian and TGD based models:

$$\begin{aligned} |\Delta\overline{g}_{\perp,N}| &= 4GM \times \frac{R_E}{r^3} \ , \\ |\Delta\overline{g}_{\perp,TGD}| &= 4GM \times \frac{1}{r^2} \ . \end{aligned} \tag{7}$$

The ratio of the effects predicted by TGD and Newtonian models would be

$$\begin{aligned} \frac{|\Delta\overline{g}_{\perp,TGD}|}{|\Delta\overline{g}_{\perp,N}|} &= \frac{r}{R_E} \ , \\ \frac{r_M}{R_E} &= 60.2 \ , \ \frac{r_S}{R_E} = 2.34 \times 10^4 \ . \end{aligned} \tag{8}$$

The amplitude for the oscillatory variation of the pressure gradient caused by Sun would be

$$\Delta|\nabla p_S| = \frac{v_E^2}{r_E} \simeq 6.1 \times 10^{-4} g$$

and the pressure gradient would be reduced during night-time. The corresponding amplitude in the case of Moon is given by

$$\frac{\Delta|\nabla p_s|}{\Delta|\nabla p_M|} = \frac{M_S}{M_M} \times (\frac{r_M}{r_S})^3 \simeq 2.17 \ .$$

$\Delta|\nabla p_M$ is in a good approximation smaller by a factor of 1/2 and given by $\Delta|\nabla p_M| = 2.8 \times 10^{-4} g$. Thus the contributions are of same order of magnitude.

| | | | | |
|---|---|---|---|---|
| $M_M/M_S$ | $M_E/M_S$ | $R_M/R_E$ | $d_{E-S}/AU$ | $d_{E-M}/AU$ |
| $3.0 \times 10^{-6}$ | $3.69 \times 10^{-8}$ | .273 | 1 | .00257 |
| $R_E/d_{E-S}$ | $R_E/d_{E-M}$ | $g_S/g$ | $g_M/g$ | |
| $4.27 \times 10^{-5}$ | $01.7 \times 10^{-7}$ | $6.1 \times 10^{-4}$ | $2.8 \times 10^{-4}$ | |

Table 1. The table gives basic data relevant for tidal effects. The subscript $E, S, M$ refers to Earth, Sun, Moon; $R$ refers to radius; $d_{X-Y}$ refers to the distance between $X$ and $Y$ $g_S$ and $g_M$ refer to accelerations induced by Sun and Moon at Earth surface. $g = 9.8$ m/s$^2$ refers to the acceleration of gravity at surface of Earth. One has also $M_S = 1.99 \times 10^{30}$ kg and $AU = 1.49 \times 10^{11}$ m, $R_E = 6.34 \times 10^6$ m.

One can imagine two simple qualitative killer predictions assuming maximal gravitational screening.

a) Solar eclipse should induce anomalous tidal effects induced by the screening in the shadow of the Moon.

b) The comparison of solar and moon eclipses might kill the scenario. The screening would imply that inside the shadow the tidal effects are of same order of magnitude at both sides of Earth for Sun-Earth-Moon configuration but weaker at night-side for Sun-Moon-Earth situation.

### 2.5 An interesting co-incidence

The value of $\Delta f/f = 5 \times 10^{-4}$ in experiment of Jeverdan is exactly equal to $v_0 = 2^{-11}$, which appears in the formula $\hbar_{gr} = GMm/v_0$ for the favored values of the gravitational Planck constant. The predictions are $\Delta f/f \leq \Delta p/p \simeq 3 \times 10^{-4}$. Powers of $1/v_0$ appear also as favored scalings of Planck constant in the TGD inspired quantum model of bio-systems based on dark matter [M3]. This co-incidence would suggest the quantization formula

$$\frac{g_E}{g_S} = \frac{M_S}{M_E} \times \frac{R_E^2}{r_E^2} = v_0 \tag{9}$$

for the ratio of the gravitational accelerations caused by Earth and Sun on an object at the surface of Earth.

It must be however admitted that the larger variation in the magnitude and even sign of the effect does not favor this kind of interpretation.

### 2.6 Summary of the predicted new effects

Let us sum up the basic predictions of the model assuming maximal gravitational screening.

a) The first prediction is the gradual increase of the oscillation frequency of the conical pendulum by $\Delta f/f \leq 3 \times 10^{-4}$ to maximum and back during night-time in case that the pendulum has vanishing $Z^0$ charge. Also a periodic variation of the frequency and a periodic rotation of the oscillation plane with period co-inciding with Moon's rotation period is predicted. Already Allais observed both 24 hour cycle and cycle which is slightly longer and due to the fact that Moon rates around Earth.

b) A paraconical pendulum with initial position, which corresponds to the resting position in the normal situation should begin to oscillate during solar eclipse. This effect is testable by fixing the pendulum to the resting position and releasing it during the eclipse. The amplitude of the oscillation corresponds to the angle between $\overline{g}$ and $\overline{g}+\Delta\overline{g}$ given in a good approximation by

$$sin[\Theta(\overline{g},\overline{g}+\Delta\overline{g})] = \frac{\Delta g}{g} sin[\Theta(\overline{g},\Delta\overline{g})] \ . \tag{10}$$

An upper bound for the amplitude would be $\Theta \leq 3\times 10^{-4}$, which corresponds to .015 degrees. $Z^0$ charge of the pendulum would modify this simple picture.

c) Gravitational screening should cause a reduction of tidal effects at the "night-side" of Moon/Sun. The reduction should be maximum at "midnight". This reduction together with the fact that the tidal effects of Moon and Sun at the day side are of same order of magnitude could explain some anomalies know to be associated with the tidal effects [9]. A further prediction is the day-night variation of the atmospheric and sea pressure gradients with amplitude which is for Sun $3\times 10^{-4}g$ and for Moon $1.3\times 10^{-3}g$.

To sum up, the predicted anomalous tidal effects and the explanation of the limiting oscillation plane in terms of stronger dissipation in rotational degree of freedom could kill the model assuming only gravitational screening.

### 2.7 Comparison with experimental results

The experimental results look mutually contradictory in the context provided by the model assuming only screening. Some experiments find no anomaly at all as one learns from [2]. There are also measurements supporting the existence of an effect but with varying sign and quite different orders of magnitude. Either the experimental determinations cannot be trusted or the model is too simple.

a) The *increase* (!) of the frequency observed by Jeverdan and collaborators reported in Wikipedia article [2] for Foucault pendulum is $\Delta f/f \simeq 5\times 10^{-4}$ would support the model even quantitatively since this value is only by a factor 5/3 higher than the maximal effect allowed by the screening model. Unfortunately, I do not have an access to the paper of Jeverdan *et al* to find out the value of $cos(\Theta)$ in the experimental arrangement and whether there is indeed a decrease of the period as claimed in Wikipedia article. In [8] two experiments supporting an effect $\Delta g/g = x \times 10^{-4}$, $x = 1.5$ or 2.6 but the sign of the effect is different in these experiments.

b) Allais reported an anomaly $\Delta g/g \sim 5 \times 10^{-6}$ during 1954 eclipse [7]. According to measurements by authors of [8] the period of oscillation increases and one has $\Delta g/g \sim 5 \times 10^{-6}$. Popescu and Olenici report a decrease of the oscillation period by $(\Delta g/g)cos(\Theta) \simeq 1.4 \times 10^{-5}$.

c) In [6] a *reduction* of vertical gravitational acceleration $\Delta g/g = (7.0 \pm 2.7) \times 10^{-9}$ is reported: this is by a factor $10^{-5}$ smaller than the result of Jeverdan.

d) Small pressure waves with $\Delta p/p = 2 \times 10^{-5}$ are registered by some micro-barometers [7] and might relate to the effect since pressure gradient and gravitational acceleration should compensate each other. $\Delta g cos(\Theta)/g$ would be about 7 per cent of its maximum value for Earth-Sun system in this case. The knowledge of the sign of pressure variation would tell whether effective gravitational force is screened or amplified by Moon.

# 3 Allais effect as evidence for large values of gravitational Planck constant?

One can represent rather general counter arguments against the models based on $Z^0$ conductivity and gravitational screening if one takes seriously the puzzling experimental findings concerning frequency change.

a) Allais effect identified as a rotation of oscillation plane seems to be established and seems to be present always and can be understood in terms of torque implying limiting oscillation plane.

b) During solar eclipses Allais effect however becomes much stronger. According to Olenici's experimental work the effect appears always when massive objects form collinear structures.

c) The behavior of the change of oscillation frequency seems puzzling. The sign of the frequency increment varies from experiment to experiment and its magnitude varies within five orders of magnitude.

## 3.1 What one an conclude about general pattern for $\Delta f/f$?

The above findings allow to make some important conclusions about the nature of Allais effect.

a) Some genuinely new dynamical effect should take place when the objects are collinear. If gravitational screening would cause the effect the frequency would always grow but this is not the case.

b) If stellar objects and also ring like dark matter structures possibly assignable to their orbits are $Z^0$ conductors, one obtains screening effect by polarization and for the ring like structure the resulting effectively 2-D dipole field behaves as $1/\rho^2$ so that there are hopes of obtaining large screening effects and if the $Z^0$ charge of pendulum is allow to have both signs, one might hope of being to able to explain the effect. It is however difficult to understand why this effect should become so strong in the collinear case.

c) The apparent randomness of the frequency change suggests that interference effect made possible by the gigantic value of gravitational Planck constant is in question. On the other hand, the dependence of $\Delta g/g$ on pendulum suggests a breaking of Equivalence Principle. It however turns out that the variation of the distances of the pendulum to Sun and Moon can explain the experimental findings since the pendulum turns out to act as a sensitive gravitational interferometer. An apparent breaking of Equivalence Principle could result if the effect is partially caused by genuine gauge forces, say dark classical $Z^0$ force, which can have arbitrarily long range in TGD Universe.

d) If topological light rays (MEs) provide a microscopic description for gravitation and other gauge interactions one can envision these interactions in terms of MEs extending from Sun/Moon radially to pendulum system. What comes in mind that in a collinear configuration the signals along S-P MEs and M-P MEs superpose linearly so that amplitudes are summed and interference terms give rise to an anomalous effect with a very sensitive dependence on the difference of S-P and M-P distances and possible other parameters of the problem. One can imagine several detailed variants of the mechanism. It is possible that signal from Sun combines with a signal from Earth and propagates along Moon-Earth ME or that the interferences of these signals occurs at Earth and pendulum.

e) Interference suggests macroscopic quantum effect in astrophysical length scales and thus gravitational Planck constants given by $\hbar_{gr} = GMm/v_0$, where $v_0 = 2^{-11}$ is the favored value, should appear in the model. Since $\hbar_{gr} = GMm/v_0$ depends on both masses this could give also a sensitive dependence on mass of the pendulum. One expects that the anomalous force is proportional to $\hbar_{gr}$ and is therefore gigantic as compared to the effect predicted for the ordinary value of Planck constant.

### 3.2 Model for interaction via gravitational MEs with large Planck constant

Restricting the consideration for simplicity only gravitational MEs, a concrete model for the situation would be as follows.

a) The picture based on topological light rays suggests that the gravitational force between two objects $M$ and $m$ has the following expression

$$\begin{aligned} F_{M,m} &= \frac{GMm}{r^2} = \int |S(\lambda,r)|^2 p(\lambda) d\lambda \\ p(\lambda) &= \frac{h_{gr}(M,m)2\pi}{\lambda} \ , \ \hbar_{gr} = \frac{GMm}{v_0(M,m)} \ . \end{aligned} \tag{11}$$

$p(\lambda)$ denotes the momentum of the gravitational wave propagating along ME. $v_0$ can depend on $(M,m)$ pair. The interpretation is that $|S(\lambda,r)|^2$ gives the rate for the emission of gravitational waves propagating along ME connecting the masses, having wave length $\lambda$, and being absorbed by $m$ at distance $r$.

b) Assume that $S(\lambda,r)$ has the decomposition

$$\begin{aligned} S(\lambda,r) &= R(\lambda) exp\left[i\Phi(\lambda)\right] \frac{exp\left[ik(\lambda)r\right]}{r} \ , \\ exp\left[ik(\lambda)r\right] &= exp\left[ip(\lambda)r/\hbar_{gr}(M,m)\right] \ , \\ R(\lambda) &= |S(\lambda,r)| \ . \end{aligned} \tag{12}$$

The phases $exp(i\Phi(\lambda))$ might be interpreted in terms of scattering matrix. The simplest assumption is $\Phi(\lambda) = 0$ turns out to be consistent with the experimental findings. The substitution of this expression to the above formula gives the condition

$$\int |R(\lambda)|^2 \frac{d\lambda}{\lambda} = v_0 \ . \tag{13}$$

Consider now a model for the Allais effect based on this picture.

a) In the non-collinear case one obtains just the standard Newtonian prediction for the net forces caused by Sun and Moon on the pendulum since $Z_{S,P}$ and $Z_{M,P}$ correspond to non-parallel MEs and there is no interference.

b) In the collinear case the interference takes place. If interference occurs for identical momenta, the interfering wavelengths are related by the condition

$$p(\lambda_{S,P}) = p(\lambda_{M,P} \ . \tag{14}$$

This gives

$$\frac{\lambda_{M,P}}{\lambda_{S,P}} = \frac{\hbar_{M,P}}{\hbar_{S,P}} = \frac{M_M}{M_S}\frac{v_0(S,P)}{v_0(M,P)} \ . \tag{15}$$

c) The net gravitational force is given by

$$\begin{aligned}
F_{gr} &= \int |Z(\lambda, r_{S,P}) + Z(\lambda/x, r_{M,P})|^2 p(\lambda) d\lambda \\
&= F_{gr}(S,P) + F_{gr}(M,P) + \Delta F_{gr} \ , \\
\Delta F_{gr} &= 2\int Re\left[S(\lambda, r_{S,P})\overline{S}(\lambda/x, r_{M,P}))\right] \frac{\hbar_{gr}(S,P)2\pi}{\lambda} d\lambda \ , \\
x &= \frac{\hbar_{S,P}}{\hbar_{M,P}} = \frac{M_S}{M_M}\frac{v_0(M,P)}{v_0(S,P)} \ .
\end{aligned} \tag{16}$$

Here $r_{M,P}$ is the distance between Moon and pendulum. The anomalous term $\Delta F_{gr}$ would be responsible for the Allais effect and change of the frequency of the oscillator.

d) The anomalous gravitational acceleration can be written explicitly as

$$\begin{aligned}
\Delta a_{gr} &= 2\frac{GM_S}{r_S r_M}\frac{1}{v_0(S,P)} \times I \ , \\
I &= \int R(\lambda)R(\lambda/x) cos\left[\Phi(\lambda) - \Phi(\lambda/x) + 2\pi\frac{(y_S r_S - x y_M r_M)}{\lambda}\right]\frac{d\lambda}{\lambda} \ , \\
y_M &= \frac{r_{M,P}}{r_M} \ , \ y_S = \frac{r_{S,P}}{r_S} \ .
\end{aligned} \tag{17}$$

Here the parameter $y_M$ ($y_S$) is used express the distance $r_{M,P}$ ($r_{S,P}$) between pendulum and Moon (Sun) in terms of the semi-major axis $r_M$ ($r_S$)) of Moon's (Earth's) orbit. The interference term is sensitive to the ratio $2\pi(y_S r_S - x y_M r_M)/\lambda$. For short wave lengths the integral is expected to not give a considerable contribution so that the main contribution should come from long wave lengths. The gigantic value of gravitational Planck constant and its dependence on the masses implies that the anomalous force has correct form and can also be large enough.

e) If one poses no boundary conditions on MEs the full continuum of wavelengths is allowed. For very long wave lengths the sign of the cosine terms oscillates so that the value of the integral is very sensitive to the values of various parameters appearing in it. This could explain random looking outcome of experiments measuring $\Delta f/f$. One can also consider the possibility that MEs satisfy periodic boundary conditions so that only wave lengths $\lambda_n = 2r_S/n$ are allowed: this implies $sin(2\pi y_S r_S/\lambda) = 0$. Assuming this, one can write the magnitude of the anomalous gravitational acceleration as

$$\begin{aligned} \Delta a_{gr} &= 2\frac{GM_S}{r_{S,P}r_{M,P}} \times \frac{1}{v_0(S,P)} \times I \ , \\ I &= \sum_{n=1}^{\infty} R(\frac{2r_{S,P}}{n})R(\frac{2r_{S,P}}{nx})(-1)^n cos\left[\Phi(n) - \Phi(xn) + n\pi\frac{xy_M}{y_S}\frac{r_M}{r_S}\right] \ . \end{aligned} \tag{18}$$

If $R(\lambda)$ decreases as $\lambda^k$, $k > 0$, at short wavelengths, the dominating contribution corresponds to the lowest harmonics. In all terms except cosine terms one can approximate $r_{S,P}$ *resp.* $r_{M,P}$ with $r_S$ *resp.* $r_M$.

f) The presence of the alternating sum gives hopes for explaining the strong dependence of the anomaly term on the experimental arrangement. The reason is that the value of $xyr_M/r_S$ appearing in the argument of cosine is rather large:

$$\frac{xy_M}{y_S}\frac{r_M}{r_S} = \frac{y_M}{y_S}\frac{M_S}{M_M}\frac{r_M}{r_S}\frac{v_0(M,P)}{v_0(S,P)} \simeq 6.95671837 \times 10^4 \times \frac{y_M}{y_S} \times \frac{v_0(M,P)}{v_0(S,P)} \ .$$

The values of cosine terms are very sensitive to the exact value of the factor $M_S r_M/M_M r_S$ and the above expression is probably not quite accurate value. As a consequence, the values and signs of the cosine terms are very sensitive to the values of $y_M/y_S$ and $\frac{v_0(M,P)}{v_0(S,P)}$.

The value of $y_M/y_S$ varies from experiment to experiment and this alone could explain the high variability of $\Delta f/f$. The experimental arrangement would act like interferometer measuring the distance ratio $r_{M,P}/r_{S,P}$. Hence it seems that the condition

$$\frac{v_0(S,P)}{v_0(M,P)} \neq const. \tag{19}$$

implying breaking of Equivalence Principle is not necessary to explain the variation of the sign of $\Delta f/f$ and one can assume $v_0(S,P) = v_0(M,P) \equiv v_0$. One can also assume $\Phi(n) = 0$.

### 3.3 Scaling law

The assumption of the scaling law

$$R(\lambda) = R_0(\frac{\lambda}{\lambda_0})^k \tag{20}$$

is very natural in light of conformal invariance and masslessness of gravitons and allows to make the model more explicit. With the choice $\lambda_0 = r_S$ the anomaly term can be expressed in the form

$$\begin{aligned} \Delta a_{gr} &\simeq \frac{GM_S}{r_S r_M}\frac{2^{2k+1}}{v_0}(\frac{M_M}{M_S})^k R_0(S,P)R_0(M,P) \times \sum_{n=1}^{\infty}\frac{(-1)^n}{n^{2k}} cos\left[\Phi(n) - \Phi(xn) + n\pi K\right] \ , \\ K &= x \times \frac{r_M}{r_S} \times \frac{y_M}{y_S} \ . \end{aligned} \tag{21}$$

The normalization condition of Eq. 13 reads in this case as

$$R_0^2 = v_0 \times \frac{1}{2\pi\sum_n(\frac{1}{n})^{2k+1}} = \frac{v_0}{\pi\zeta(2k+1)} \ . \tag{22}$$

Note the shorthand $v_0(S/M,P) = v_0$. The anomalous gravitational acceleration is given by

$$\begin{aligned} \Delta a_{gr} &= \sqrt{\frac{v_0(M,P)}{v_0(S,P)}}\frac{GM_S}{r_S^2} \times XY \times \sum_{n=1}^{\infty}\frac{(-1)^n}{n^{2k}} cos\left[\Phi(n) - \Phi(xn) + n\pi K\right] \ , \\ X &= 2^{2k} \times \frac{r_S}{r_M} \times (\frac{M_M}{M_S})^k \ , \\ Y &= \frac{1}{\pi\sum_n(\frac{1}{n})^{2k+1}} = \frac{1}{\pi\zeta(2k+1)} \ . \end{aligned} \tag{23}$$

It is clear that a reasonable order of magnitude for the effect can be obtained if $k$ is small enough and that this is essentially due to the gigantic value of gravitational Planck constant.

The simplest model consistent with experimental findings assumes $v_0(M,P) = v_0(S,P)$ and $\Phi(n) = 0$ and gives

$$\begin{aligned}
\frac{\Delta a_{gr}}{gcos(\Theta)} &= \frac{GM_S}{r_S^2 g} \times XY \times \sum_{n=1}^{\infty} \frac{(-1)^n}{n^{2k}} cos(n\pi K) \ , \\
X &= 2^{2k} \times \frac{r_S}{r_M} \times (\frac{M_M}{M_S})^k \ , \\
Y &= \frac{1}{\pi \sum_n (\frac{1}{n})^{2k+1}} = \frac{1}{\pi\zeta(2k+1)} \ , \\
K &= x \times \frac{r_M}{r_S} \times \frac{y_M}{y_S} \ , \ x = \frac{M_S}{M_M} \ .
\end{aligned} \tag{24}$$

### 3.4 Numerical estimates

To get a numerical grasp to the situation one can use $M_S/M_M \simeq 2.71 \times 10^7$, $r_S/r_M \simeq 389.1$, and $(M_S r_M/M_M r_S) \simeq 1.74 \times 10^4$. The overall order of magnitude of the effect would be

$$\begin{aligned}
\frac{\Delta g}{g} \sim XY \times \frac{GM_S}{R_S^2 g} cos(\Theta) \ , \\
\frac{GM_S}{R_S^2 g} \simeq 6 \times 10^{-4} \ .
\end{aligned} \tag{25}$$

The overall magnitude of the effect is determined by the factor $XY$.

a) For $k = 0$ the normalization factor is proportional to $1/\zeta(1)$ and diverges and it seems that this option cannot work.

b) The table below gives the predicted overall magnitudes of the effect for $k = 1, 2/2$ and $1/4$.

| k | 1 | 1/2 | 1/4 |
|---|---|---|---|
| $\frac{\Delta g}{gcos(\Theta)}$ | $1.1 \times 10^{-9}$ | $4.3 \times 10^{-6}$ | $1.97 \times 10^{-4}$ |

For $k = 1$ the effect is too small to explain even the findings of [6] since there is also a kinematic reduction factor coming from $cos(\Theta)$. Therefore $k < 1$ suggesting fractal behavior is required. For $k = 1/2$ the effect is of same order of magnitude as observed by Allais. The alternating sum equals in a good approximation to -.693 for $y_S/y_M = 1$ so that it is not possible to explain the finding $\Delta f/f \simeq 5 \times 10^{-4}$ of Jeverdan.

c) For $k = 1/4$ the expression for $\Delta a_{gr}$ reads as

$$\frac{\Delta a_{gr}}{gcos(\Theta)} \simeq 1.97 \times 10^{-4} \sum_{n=1}^{\infty} \frac{(-1)^n}{n^{1/2}} cos(n\pi K) \quad ,$$

$$K = \frac{y_M}{y_S} u \;\; , \;\; u = \frac{M_S}{M_M} \frac{r_M}{r_S} \simeq 6.95671837 \times 10^4 \; . \quad (26)$$

The sensitivity of cosine terms to the precise value of $y_M/y_S$ gives good hopes of explaining the strong variation of $\Delta f/f$ and also the findings of Jeverdan. Numerical experimentation indeed shows that the sign of the cosine sum alternates and its value increases as $y_M/y_S$ increases in the range $[1,2]$.

The eccentricities of the orbits of Moon *resp.* Earth are $e_M = .0549$ *resp.* $e_E = .017$. Denoting semimajor and semiminor axes by $a$ and $b$ one has $\Delta = (a-b)/a = 1-\sqrt{1-e^2}$. $\Delta_M = 15 \times 10^{-4}$ *resp.* $\Delta_E = 1.4 \times 10^{-4}$ characterizes the variation of $y_M$ *resp.* $y_M$ due to the non-circularity of the orbits of Moon *resp.* Earth. The ratio $R_E/r_M = .0166$ characterizes the range of the variation $\Delta y_M = \Delta r_{M,P}/r_M \leq R_E/r_M$ due to the variation of the position of the laboratory. All these numbers are large enough to imply large variation of the argument of cosine term even for $n=1$ and the variation due to the position at the surface of Earth is especially large.

The duration of full eclipse is of order 8 minutes which corresponds to angle $\phi = \pi/90$ and at equator roughly to a $\Delta y_N = (\sqrt{r_M^2 + R_E^2 sin^2(\pi/90)} - r_M)/r_M \simeq (\pi/90)^2 R_E^2/2r_M^2 \simeq 1.7 \times 10^{-7}$. Thus the change of argument of $n=1$ cosine term during full eclipse is of order $\Delta\Phi = .012\pi$ at equator. The duration of the eclipse itself is of order two 2 hours giving $\Delta y_M \simeq 3.4 \times 10^{-5}$ and the change $\Delta\Phi = 2.4\pi$ of the argument of $n=1$ cosine term.

## 4 Could $Z^0$ force be present?

One can understand the experimental results without a breaking of Equivalence Principle if the pendulum acts as a quantum gravitational interferometer. One cannot exclude the possibility that there is also a dependence on pendulum. In this case one would have a breaking of Equivalence Principle, which could be tested using several penduli in the same experimental arrangement. The presence of $Z^0$ force could induce an apparent breaking of Equivalence Principle. The most plausible option is $Z^0$ MEs with large Planck constant. One can consider also an alternative purely classical option, which does not involve large values of Planck constant.

### 4.1 Could purely classical $Z^0$ force allow to understand the variation of $\Delta f/f$?

In the earlier model of the Allais effect (see the Appendix of [G1]) I proposed that the classical $Z^0$ force could be responsible for the effect. TGD indeed predicts that any object with gravitational mass must have non-vanishing em and $Z^0$ charges but leaves their magnitude and sign open.

a) If both Sun, Earth, and pendulum have $Z^0$ charges, one might even hope of understanding why the sign of the outcome of the experiment varies since he ratio of $Z^0$ charge to gravitational mass and even the sign of $Z^0$ charge of the pendulum might vary. Constant charge-to-mass ratio is of course the simplest hypothesis so that only an effective scaling of gravitational constant would be in question. A possible test is to use several penduli in the same experiment and find whether they give rise to same effect or not.

b) If Moon and Earth are $Z^0$ conductors, a $Z^0$ surface charge cancelling the tangential component of $Z^0$ force at the surface of Earth is generated and affects the vertical component of the force experienced by the pendulum. The vertical component of $Z^0$ force is $2F_Z cos(theta)$ and thus proportional to $cos(\Theta)$ as also the effective screening force below the shadow of Moon during solar eclipse. When Sun is in a vertical direction, the induced dipole contribution doubles the radial $Z^0$ force near surface and the effect due to the gravitational screening would be maximal. For Sun in horizon there would be no $Z^0$ force and gravitational tidal effect of Sun would vanish in the first order so that over all anomalous effect would be smallest possible: for a full screening $\Delta f/f \simeq \Delta g^2/4g^2 \simeq 4.5 \times 10^{-8}$ would be predicted. One might hope that the opposite sign of gravitational and $Z^0$ contributions could be enough to explain the varying sign of the overall effect.

c) It seems necessary to have a screening effect associated with gravitational force in order to understand the rapid variation of the effect during the eclipse. The fact that the maximum effect corresponds to a maximum gravitational screening suggests that it is present and determines the general scale of variation for the effect. If the maximal $Z^0$ charge of the pendulum is such that $Z^0$ force is of the same order of magnitude as the maximal screening of the gravitational force and of opposite sign (that is attractive), one could perhaps understand the varying sign of the effect but the effect would develop continuously and begin before the main eclipse. If the sign of $Z^0$ charge of pendulum can vary, there is no difficulty in explaining the varying sign of the effect. An interesting possibility is that Moon, Sun and Earth have dark matter halos so that also gravitational screening could begin before the eclipse. The real test for the effect would come from tidal effects unless one can guarantee that the pendulum is $Z^0$ neutral or its $Z^0$ charge/mass ratio is always the same.

d) As noticed also by Allais, Newtonian theory does not give a satisfactory account of the tidal forces and there is possibility that tides give a quantitative grasp on situation. If Earth is $Z^0$ conductor tidal effects should be determined mainly by the gravitational force and modified by its screening whereas $Z^0$ force would contribute mainly to the pressure waves accompanying the shadows of Moon and Sun. The sign and magnitude of pressure waves below Sun and Moon could give a quantitative grasp of $Z^0$ forces of Sun and Moon. $Z^0$ surface charge would have opposite signs at the opposite sides of Earth along the line connecting Earth to Moon *resp.* Sun and depending on sign of $Z^0$ force the screening and $Z^0$ force would tend to amplify or cancel the net anomalous effect on pressure.

e) A strong counter argument against the model based on $Z^0$ force is that collinear configurations are reached in continuous manner from non-collinear ones in the case of $Z^0$ force and the fact that gravitational screening does not conform with the varying sign of the discontinuous effect occurring during the eclipse. It would seem that the effect in question is more general than screening and perhaps more like quantum mechanical interference effect in astrophysical length scale.

### 4.2 Could $Z^0$ MEs with large Planck constant be present?

The previous line of arguments for gravitational MEs generalizes in a straightforward manner to the case of $Z^0$ force. Generalizing the expression for the gravitational Planck constant one has $\hbar_{Z^0} = g_Z^2 Q_Z(M) Q_Z(m)/v_0$. Assuming proportionality of $Z^0$ charge to gravitational mass one obtains formally similar expression for the $Z^0$ force as in previous case. If $Q_Z/M$ ratio is constant, Equivalence Principle holds true for the effective gravitational interaction if the sign of $Z^0$ charge is fixed. The breaking of Equivalence Principle would come naturally from the non-constancy of the $v_0(S,P)/v_0(M,P)$ ratio also in the recent case. The variation of the sign of $\Delta f/f$ would be explained in a trivial manner by the variation of the sign of $Z^0$ charge of pendulum but this explanation is not favored by Occam's razor.

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