Quantum Properties of Gravitational Field and Synchronization Delays

Daniele Sasso*

Abstract

The physico-mathematical model of force fields is based on the concept of continuity of space and it is represented by axes of the reference frame of the field whose continuity is defined by the existence of recurring decimal numbers and of irrational real numbers. Like for other fields quantum properties of gravitational field therefore have to be based on a quantization law like it happens for instance for electronic orbits inside the electrostatic field of atom. The purpose of this paper is to verify the possibility of defining a quantization law also for gravitational fields. Starting from these considerations then the author goes ahead with the calculation of relativistic errors of position and of synchronization delays relative to a system of measurement of position through satellite laboratory-stations in the gravitational field of second type.

1. Introduction

Gravitational field is fundamentally a continuous field in regard to its physical structure as we have demonstrated in previous papers[1][2], like all other force fields with any physical nature, that are continuous because all points of field are equivalent from the geometric and physical viewpoint with respect to the reference frame of the field S[O,x,y,z,t] in which O is the origin that coincides with the barycentre of mass that generates the field and (x,y,z,t) are real coordinates of space and time of any point of the field at any time t. We have proved also the free fall of bodies into a gravitational field of first type has always continuous nature with respect whether to time or to space[1]. It is interesting to investigate if in the order of the gravitational field of second type a quantum behavior is possible. We will prove this possibility exists even if any orbit is theoretically possible in the order of natural gravitational fields of second type. To that end we will distinguish two possible different orbital quantum behaviors:

1. Quantum orbital gravitational field with constant angular speed , that we call " angular graviquantum field"
2. Quantum orbital gravitational field with constant tangential speed, that we call " tangential graviquantum field".

e_mail: dgsasso@alice.it

The General Principle of Inertia[3][4] excludes the existence of an absolute inertial reference frame and asserts the equivalence of orbital motions with straight inertial motions. As per that principle orbital motions are inertial with respect to the privileged reference frame of mass, supposed at rest, that generates the gravitational field of second type, and it is valid also when those motions happen with a speed that isn't strictly constant because of elliptic orbit. Consequently it is possible to deduce two reference frames are inertial in any physical situation, also in the presence of gravitational field, when they are in concordance with the Principle of Relativity on the invariance of physical laws. In order to simplify things we consider a constant average angular orbital speed and a constant average tangential speed. The resting reference frame S[O,x,y,z,t], in which O is the origin of the reference frame coinciding with the barycentre of celestial body that generates the gravitational field, is the priviliged reference frame in the considered physical situation.

2. Space, time and field

In physics space and time are neither absolute entities as Newton instead asserted nor they are inseparable entities of imaginary metric spacetime as Einstein and Minkowski asserted. It's manifest that from the logical and physical viewpoint the **empty space**, void of any type of mass and consequently void of any type of energy and of field, is a geometric entity with three dimensions characterized by three space coordinates (x,y,z). This empty space is essentially **infinite, infinitesimal, discrete**[3].

Infinite because if we consider any distance d, it is always possible for instance to double that distance according to the relationship 2nd with n=1, 2, 3....... integer number, without an objective limit exists relative to that process.

Infinitesimal because considering the same distance d, it is always possible for instance to halve this distance according to the relationship d/2n, without an objective limit exists relative to this process.

Discrete (or quantum) because considering any real distance d, the preceding process of halving generates always a finite distance, even if smallest and anyway different from zero.

The first two properties of the empty space (infinite and infinitesimal) define a continuous space with respect to the point, while the third property (discrete) defines a quantum space with respect to distance in which nevertheless a minimum discrete distance doesn' t exist because the infinitesimal generates a more and more small distance, but different from zero. In this non-physical empty space, whose nature is essentially geometric, mass and any other physical entities, including time, don' t exist and have no meaning. The appearance of mass into the empty space determined the beginning of physical time according to the relation that has been demonstrated in the Theory of Reference Frames (dt'=m'dt/m)[3][4]. This relation in fact has no meaning untill m'=m=0, but if m≠0 because of the appearance of mass in the geometric universe, then for m'=m we have dt'=dt from which, the initial time being the same in the two reference frames, we have t'=t that is the Galilean inertial time and it is the only time that is valid for all Galilean inertial reference frames. If instead m'≠m, like it happens for moving electrodynamic systems, we have t'≠t

and a time relativistic effect in concordance with the considered electrodynamic model and different from the Lorentzian-Einsteinian effects.
When mass appears in the empty or geometric space then the **physical space or field** is born and consequently the necessity to define by the observer the reference frame S[O,x,y,z,t] in which O represents the origin of the reference frame, coinciding for instance with the physical barycentre of the considered mass.
Time like space is continuous with respect to its mathematical representation but it is discrete and quantum with respect to its measurement and the concept of instantaneous speed, for example, is obtained mathematically by the limit of the incremental speed when the incremental time tends towards zero.
In this context it is manifest that there isn't a substantial incompatibility between continuous nature and quantum nature of both the physical reality and fields because, as per the given definition, the two concepts aren't in conflict. Consequently the author considers physical reality and fields are essentially **discrete into continuum**, in the same meaning of the empty space, and the quantization of field isn't a geometric property of field but the outcome of a rule or law of quantization that is valid for the considered physical phenomenon. Minimum discrete quantities of space and of time don't exist even if in different physical situations those minimum quantities can be determined by experimental contingent causes of measurement. This way we can say time and space are defined, mathematically and physically, in addition to point coordinates (x,y,z,t) by incremental quantities Δt and Δs that are finite quantities that can be reduced to smaller incremental quantities. Infinitesimal dt and ds have only a mathematical meaning but don't have a physical meaning and they can be used for defining mathematical instantaneous values of some physical magnitudes like speed, acceleration etc..., by a mathematical process of limit, even if in the reality we measure only incremental quantities of those physical magnitudes.
Let us want to investigate now the possibility of the existence of a quantum gravitational field, that in our paradigm becomes the formulation of rules or laws of quantization for the gravitational field. In the analogy between gravitational field and electrostatic field, we observe both fields of first type, i.e. relative to generation of straight motions, are certainly continuous. Relative to the electrostatic field of second type, that consists essentiallly in atom model with orbital structure, the existence of a law of quantization is proved and it is based generally on the equivalent wavelength of electron.
Let us ask now if even for the gravitational field of second type a rule of quantization exists that allows of quantizing this type of gravitational field.

3. Angular graviquantum field

An orbital trajectory into a gravitational field of second type, supposing that angular speed and tangential speed are constant along the orbit, is characterized by the following relation

$$v = \omega r \qquad (1)$$

where v is the tangential speed, ω is the angular speed, $r=\sqrt{x^2+y^2+z^2}$ is the distance of points of the orbital trajectory from the origin O of the reference frame S (fig.1).
Because v and ω are costant for the sake of argument, it follows that also r is constant and therefore the orbital motion is circular. It is manifest that a rule or law of quantization with constant angular speed must be in concordance with the type

$$r_n = \frac{v_n}{\omega} = \frac{nv_1}{\omega} \qquad (2)$$

in which $v_n=nv_1=nv$, $r_n=nr_1=nr$ is the radius of a generic quantum orbit and $n= 1, 2, 3, ..$ is a integer number; n=1 defines the fundamental quantum orbit. The (2) represents just the rule or law of quantization of the angular graviquantum field of second type. Because the angular speed is constant, orbits of the angular graviquantum field are geostationary if $\omega=\omega_T$ where ω_T is the angular speed of the rotary motion of the Earth. In nature geostationary orbits don't have been observed and consequently they may be only artificial.
We observe when the tangential speed increases in quantum manner, according to n, the orbital radius increases proportionally in quantum manner so as angular speed is the same for all orbits.

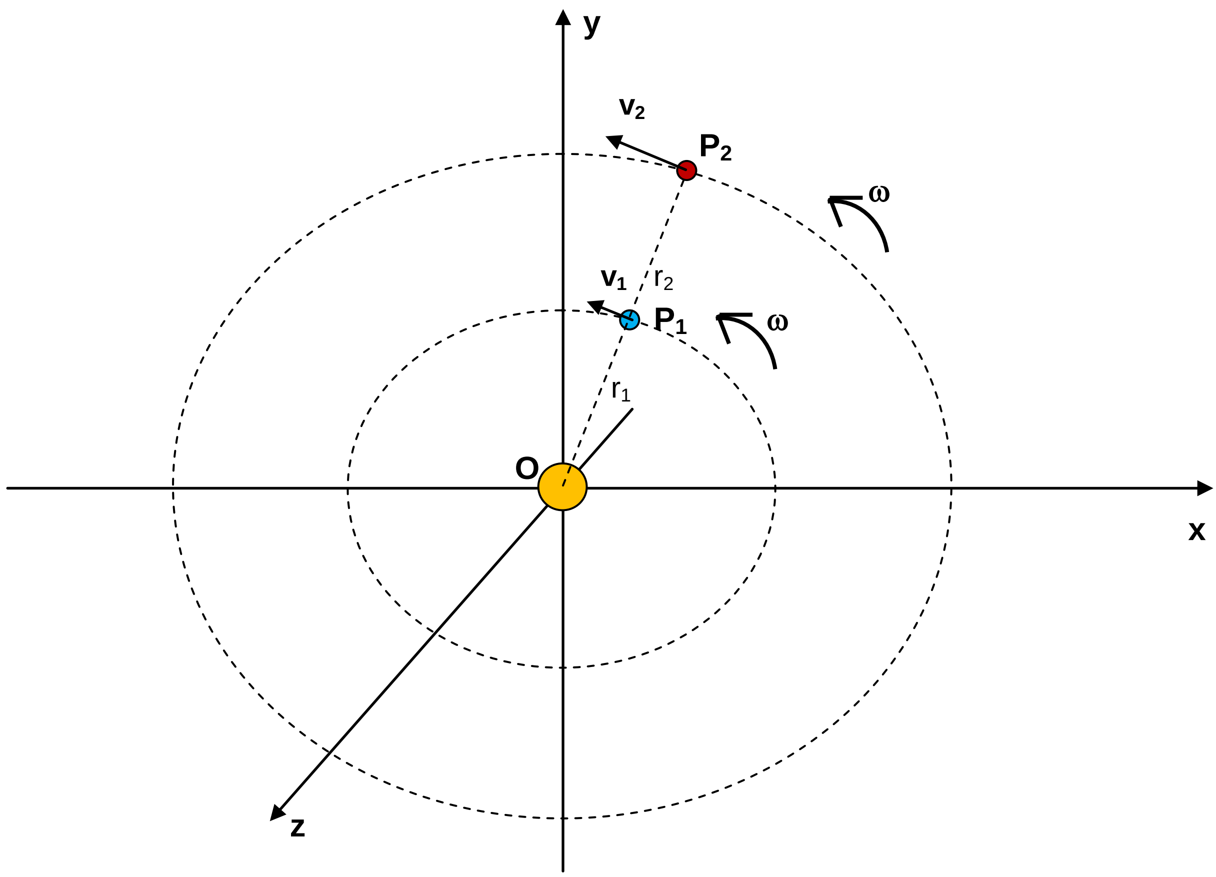

Fig.1 In figure two angular graviquantum orbits for n=1 and n=2 are represented.

According to the General Principle of Inertia[3][4], celestial bodies that are in revolution with respect to the central system-pole are inertial reference frames in regard to the reference frame S[O,x,y,z,t] of the central pole supposed at rest, and therefore relative to them the Principle of Relativity is valid. If their angular speed of revolution then coincides with the rotary angular speed of the central pole their orbits are planetstationary (geostationary in the event of the Earth).
If $T=2\pi/\omega$ is the common period for all quantum orbits, from (2) we have also

$$T = \frac{2\pi r_n}{v_n} \tag{3}$$

Because all angular graviquantum orbits have the same period then for all these orbital motions the same inertial time is valid. It derives also from the fact that mass of celestial bodies is the inertial or gravitational mass that is different from electrodynamic mass of charged elementary particles, that can generate relativistic effects of time. In this situation the fundamentall quantum orbit is defined by the radius for $n=1$

$$r_1 = \frac{v_1}{\omega} \tag{4}$$

Subsequent quantum orbits are at multiple distances ($r_n=nr_1$) with multiple speeds ($v_n=nv_1$). In general for orbital trajectories the orbital tangential speed v_n and the distance r_n from the pole with mass M have to be in concordance with the relation[1][3][4]

$$v = \sqrt{\frac{GM}{r}} \tag{5}$$

where $G=6.67\times10^{-11}Nm^2/kg^2$ is the gravitational constant. Therefore relative to an orbital angular speed ω, we deduce radii and tangential speeds of angular graviquantum orbits are given by

$$r_n = n\sqrt[3]{\frac{GM}{\omega^2}} \tag{6}$$

and

$$v_n = n\sqrt[3]{GM\omega} \tag{7}$$

In the event of the Earth the average angular speed of rotation is given by $\omega_T=2\pi/86400=72.7\times10^{-6}$rad/s and relative to the Earth's average radius $R_T=6371$Km the average tangential speed of rotation at the equator is $v\approx463.1$m/s. It is possible to deduce for the Earth the fundamental angular graviquantum orbit (n=1) that is also geostationary ($\omega=\omega_T$), happens at the distance $r_1=41816$km with a tangential speed $v_1=3.04$km/s. In that case all quantum orbits (for n>1) are geostationary.

4. Tangential graviquantum field

In this gravitational field of second type the tangential speed v is constant and in the hypothesis of circular orbits we have

$$r_n = \frac{v}{n\omega} \qquad (8)$$

in which n= 1, 2, 3, ... is an integer number and besides

$$\omega_n = n\omega = \frac{v}{r_n} \qquad (9)$$

The (8) or (9) represents the rule or law of quantization of the tangential graviquantum field. The characteristic of this type of orbit (fig.2) is that only in one point of orbits (in figure points P_1 and P_2) orbital stations are always in the same angular position α_o with respect to the fundamental orbit that is for n=1 ($r=r_1$ and $\omega=\omega_1$).

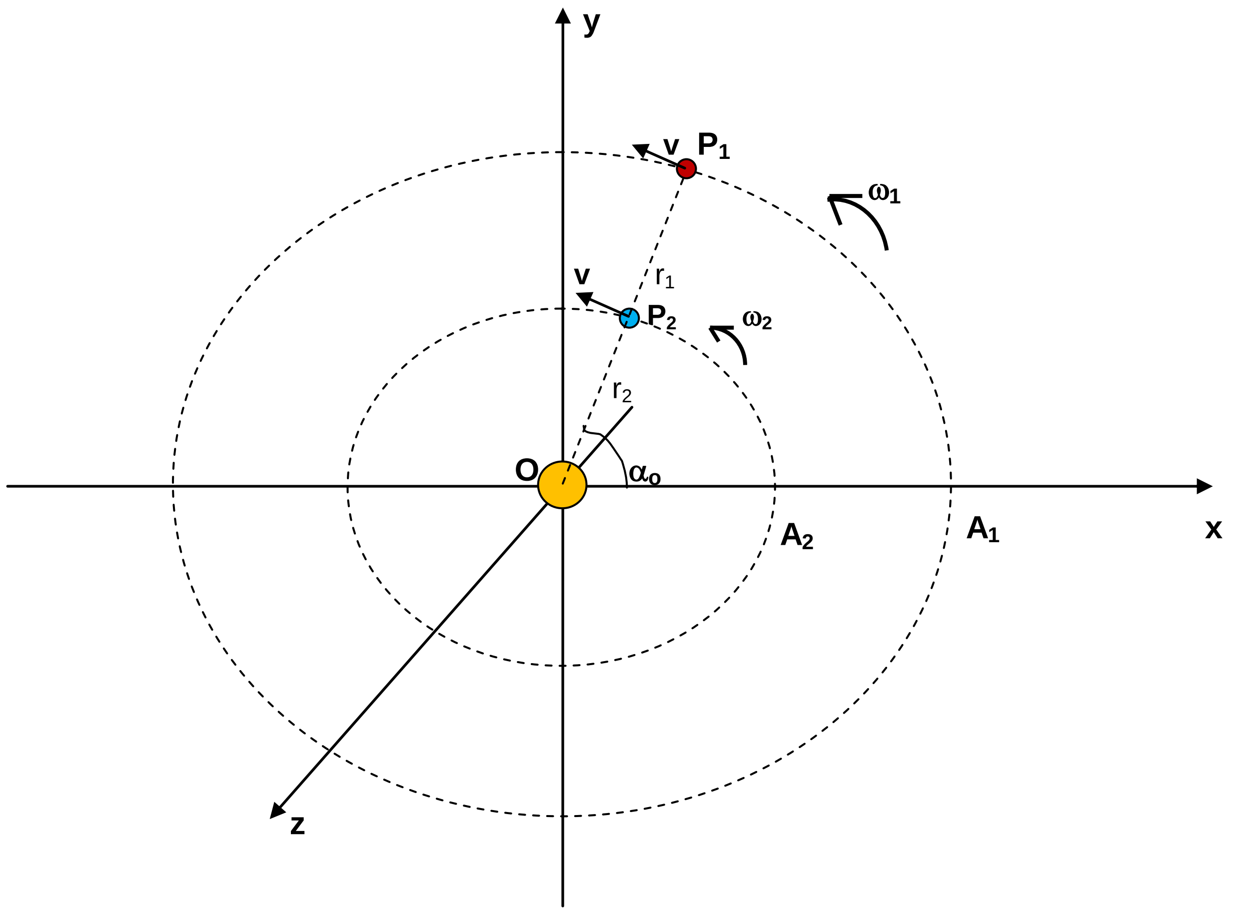

Fig.2 Representation of two tangential quantum orbits for n=1 and n=2.

After one characteristic period of each orbit

$$T_1 = \frac{2\pi}{\omega_1} \qquad \text{and} \qquad T_2 = \frac{2\pi}{\omega_2} = \frac{T_1}{2} \qquad (10)$$

stations orbiting along quantum trajectories defined by (6) are in the same initial angular position because they have travelled the same angular distance equal to a complete lap of 2π even if during motion they have different positions. In fact supposing that all orbital stations start from zero angular position α_o=0°=0rad, after a characteristic period of each orbit we have

$$\alpha_1 = \omega_1 T_1 = \frac{\omega 2\pi}{\omega} = 2\pi \quad \text{and} \quad \alpha_2 = \omega_2 T_2 = \frac{2\omega 2\pi}{2\omega} = 2\pi \qquad (11)$$

i.e. the two stations have travelled the same angular distance 2π.
Instead after the same time, for instance equal to half fundamental period $T_1/2$, the two stations have travelled an angular distance

$$\alpha_1' = \frac{\omega_1 T_1}{2} = \frac{\omega 2\pi}{2\omega} = \pi \quad \text{and} \quad \alpha_2' = \frac{\omega_2 T_1}{2} = \frac{2\omega 2\pi}{2\omega} = 2\pi \qquad (12)$$

i.e. the two stations after the same time have travelled different angular distances. If stations start from the same initial angular position, they have again the same angular position only in different times and after times equal to respective periods of revolution.
In the event of the Earth tangential graviquantum orbits (with constant tangential speed) have the following values of radius and of angular speed with respect to the fundamental geostationary orbit characterized by r_1=41816km, ω_1=72.7x10^{-6}rad/s and a constant tangential speed v=3.04km/s:

$$r_n = \frac{41816}{n}\ \text{km} \qquad (13)$$

and

$$\omega_n = n\ 72.7 \times 10^{-6}\ \frac{\text{rad}}{\text{s}} \qquad (14)$$

It is possible to observe into the tangential graviquantum field quantum orbits are inside the fundamental orbit while into the angular graviquantum field they are outside.

5. Relativistic error of position in gravitational fields of second type

A station-laboratory of a measurement system of position is characterized by the moving reference frame S'[O',x',y',z',t'], and it orbits happens with constant average angular speed ω and with constant average tangential speed v in the gravitational field.
Let us propose to calculate the position relativistic error[3][6] of the Earth's observer O placed in the Earth's reference frame S[O,x,y,z,t], measured by observer himself who in order to determine his position make use of an electromagnetic signal emitted by the point O' of the orbital station (fig.3). It is well-known that if the station moves along a geostationary orbit the angular speed of revolution ω of the station coincides with the angular speed ω_T of rotation of the Earth, while if the orbit isn't geostationary the two angular speeds are different. To that end we will apply the Theory of Reference Frames and will consider different theoretical situations considering also often in the reality the orbit of the artificial station isn't circular but it is elliptical with small eccentricity.

5.1 Let us suppose that the Earth doesn't have rotation motion (ω_T=0) and that the orbital station doesn't have motion of revolution around the Earth (ω=0). In this situation the two reference frames S and S' don't have a relative motion, the measurement system is able to determine the position of the observer O with the technique of the static triangulation with a null relativistic error of position, i.e. ε=0.

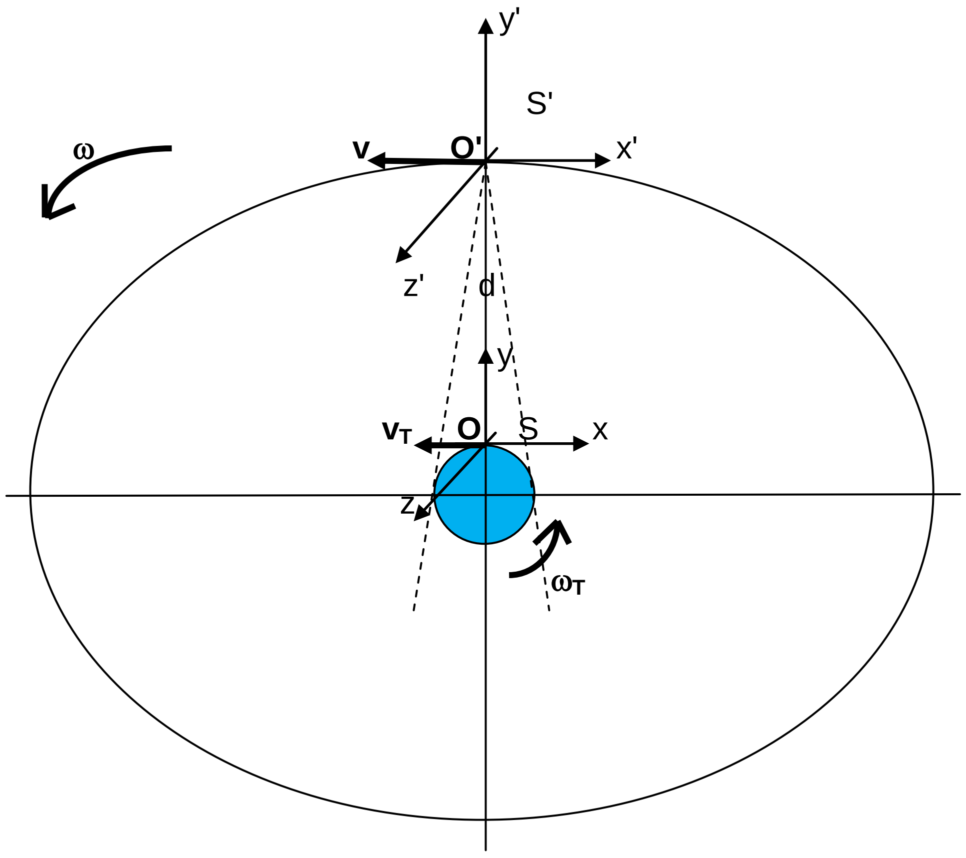

Fig.3 Graph representation for measurement of the position error measured by the Earth's observer who makes use of an orbital station.

5.2 Let us suppose now that $\omega_T=0$ ($v_T=0$) but $\omega\neq0$ ($v\neq0$). In that case the relativistic error of position of the observer O with respect to the reference frame S is given by (fig.4)

$$\varepsilon = \frac{v\,d}{c_o} \qquad (15)$$

in which d is the distance OO' between the observer in O and the orbital station in O', c_o is the physical speed of the electromagnetic signal with respect to the reference frame S'. In fact if Δt is the time that signal spends for going from O' to O, we have

$$\Delta t = \frac{d'}{c} = \frac{d}{c_o} \qquad (16)$$

and

$$\varepsilon = v\Delta t \qquad (17)$$

where c is the relativistic speed of the electromagnetic signal with respect to S and with respect to the observer O. From the (16) and (17) we obtain the (15). This result is valid also in the event that the distance OO' isn't perpendicular to the tangential speed **v** (fig.5), in fact repeating calculations the same result (15) still is obtained. It is manifest that this relativistic error of position ε=O'O''=OO''' is due whether to the finite value of the speed of light and of the electromagnetic signal or to the vector composition of speeds, and it is relative to a single orbital station-laboratory. Position of the observer in that case is calculated with a dynamic triangulation.

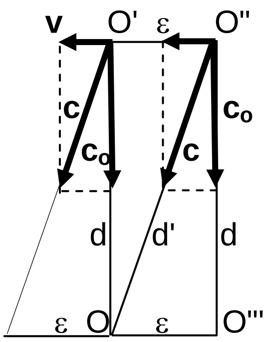

Fig.4 Graph representation for the calculation of the relativistic error of position when $\omega_T=0$ and $\omega\neq0$.

Because $c_o=3\times10^8$m/s, for a distance of the orbital station d= 20000Km and for a tangential speed of the station v=16000Km/h, that is calculated as per the (5) in which the Earth's mass is 5.97×10^{24}kg, the relativistic error of position is ε = 296m.

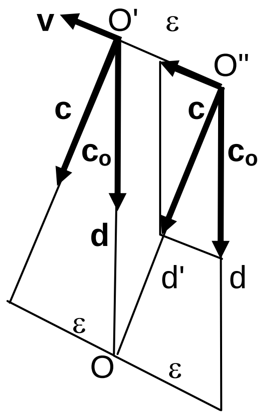

Fig.5 Graph representation for the calculation of the relativistic error of position in an elliptical orbit

5.3 Let us suppose now that $\omega_T \neq 0$ and $\omega \neq \omega_T$. It represents the real case in which the orbital station is provided with revolution motion with angular speed ω and the Earth has the rotation motion with angular speed ω_T. We know for the Earth the rotation motion is anticlockwise with tangential speed $v_T \approx 463.1$m/s. From the fig.6 we derive

$$\varepsilon = \frac{v_t\, d}{c_o} \qquad (18)$$

and

$$v_t = v\sqrt{1 + \frac{v_T^2}{v^2} - \frac{2v_T}{v}\cos\alpha} \qquad (19)$$

where v_t is the relative speed between reference frame of the station-laboratory and observer's reference frame. From the (18) and (19) we have

$$\varepsilon = \frac{vd}{c_o}\sqrt{1 + \frac{v_T^2}{v^2} - \frac{2v_T}{v}\cos\alpha} \qquad (20)$$

In that case the relativistic error of position ranges from a minimum of $0.88vd/c_o$ (α=0°) to a maximum of $1.12vd/c_o$ (α=180°) according to the value of α. In the considered case (v=16000Km/h and d=20000Km) the relativistic error of position ranges from a minimum of 260m to a maximum of 332m with an error range of 72m.

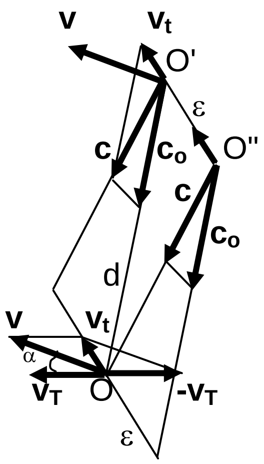

Fig.6 Graph representation for the calculation of the relativistic error of position in an elliptical orbit when $\omega_T \neq 0$ ($v_T \neq 0$) and $\omega \neq 0$ ($v \neq 0$).

5.4 Let us consider the case $\omega = \omega_T \neq 0$. In that case the station-laboratory moves along a geostationary orbit. It is also an angular graviquantum orbit if $r_n = nv/\omega$ con n=1, 2, 3,........ The geostationary fundamental quantum orbit (n=1) for the Earth is characterized by following physical parameters

$$\begin{aligned} \omega_T &= 72.7 \times 10^{-6} \text{ rad/s} \\ r_1 &= 41816\text{km} \\ v_1 &= 3.04\text{km/s} \end{aligned} \qquad (21)$$

In the event of geostationary circular orbit ($\omega = \omega_T$), tangential speeds v and v_T are always different in intensity, but because $\alpha = 0°$ the relativistic error of position is $\varepsilon = 260$m.

6. Synchronization delays of an orbital station-laboratory

In the preceding paragraph we have calculated, relative to a single orbital station, the relativistic error of position of the Earth's observer who determines his position through a dynamic triangulation. Let us ask now how those relativistic errors of position can produce problems of synchronization on clocks on board of laboratory-stations, assuming for the calculation that the orbit is practically circular. To that end let us consider a laboratory-station that at the time instant $t' = t_o'$ is in the point O' with coordinates (0,0,0) in the reference frame S' that is in orbital motion and we suppose that the Earth's observer at the same instant $t = t_o = t_o'$ is in the point O with coordinates (0,0,0) of the reference frame S on the Earth's surface (fig.7).
Because of the orbital motion the laboratory-station at every instant moves with a vector tangential speed **v** and consequently as per the Theory of Reference Frames that speed is additional in vector manner to the physical speed $\mathbf{c_o}$ of the electromagnetic signal, emitted by the laboratory-station at the instant $t' = t_o'$, giving for composition the relativistic speed **c** of the electromagnetic signal with respect to the Earth's reference frame S (fig.7).

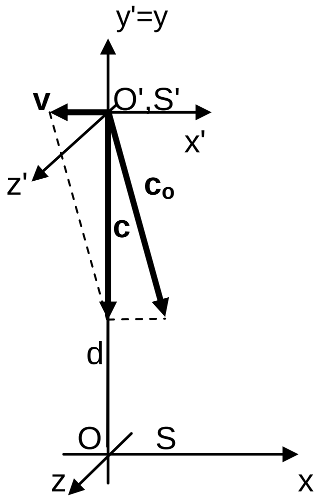

Fig.7 Speeds of the electromagnetic signal with respect to the orbital station and to the Earth's station.

Earth's receivers are programmed as per the assumption that the distance $d=O'O$ is given by the relation

$$d_o = c_o\Delta t \tag{22}$$

where $\Delta t=t_1-t_o'$ is the time that the signal uses for reaching the Earth's observer but the figure proves clearly the distance d is given by

$$d = c\Delta t \tag{23}$$

where

$$c = c_o\sqrt{1 - \frac{v^2}{c_o^2}} \tag{24}$$

is the relativistic speed of the signal with respect to the reference frame S of the Earth's observer. Because $c<c_o$, it follows that the receiver calculates a distance d_o greater than the effective distance d. It clearly introduces a relativistic error of position that can be eliminated with a suitable delay Δ_r of synchronization of clocks on board of satellite stations. In fact assuming $\Delta t'=t_1-t_1'<\Delta t$ so that

$$d=c\Delta t=c_o\Delta t' \tag{25}$$

we have

$$\Delta t' = \frac{d}{c_o} \tag{26}$$

and consequently the synchronization delay is given by

$$\Delta t_r = \Delta t - \Delta t' = t_1'-t_o' = d\,\frac{c_o - c}{cc_o} \tag{27}$$

Pursuing the calculation, for $v<<c_o$, it is

$$\Delta t_r = \frac{dv^2}{2c_o^3} \qquad (28)$$

Taking on values $c_o=3\times10^8$m/s, d=26500km , v=14000km/h as per the (5), the synchronization delay is

$$\Delta t_r \approx 7.43\times10^{-12}\text{s} \qquad (29)$$

This dealy is relative to the duration of a single path $d=c_o\Delta t'$ of the signal, it follows that the synchronization complete delay relative to the Earth's day (1day=86400s) is given by

$$\Delta t_{rday} = \frac{86400\Delta t_r}{\Delta t'} = 7270\,\frac{\text{ns}}{\text{day}} = 7.27\,\frac{\mu\text{s}}{\text{day}} \qquad (30)$$

The delay calculated in (30) is due to the orbital speed of the orbital station. Considering also the speed of Earth's rotation $\omega_T=72.7\times10^{-6}$rad/s that generates the tangential speed $v_T=463.1$m/s and a tangential graviquantum field that is the same at all orbital distances, the synchronization delay $\Delta t_{r\omega T}$ is given by

$$\Delta t_{r\omega T} = \Delta t_{rday}\frac{T'}{T} = 30.29\,\frac{\mu\text{s}}{\text{day}} \qquad (31)$$

where T=86400s is the day duration on the Earth at the average radius $R_T=6371$km; $T'=2\pi d/v_T\approx0.36\times10^6$s is the day duration at the distance from the Earth d=26500km. Consequently the complete delay of synchronization is

$$\Delta t_{rt} = \Delta t_{rday} + \Delta t_{r\omega T} = 37.56\,\frac{\mu\text{s}}{\text{day}} \qquad (32)$$

This delay is fully in concordance with the experimental values and it proves the validity of the procedure.

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