# Experimental evidence of the ether-dragging hypothesis in global positioning system (GPS) data

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**Abstract:** In global positioning system (GPS) satellites, the earth-centered locally inertial (ECI) coordinate system is used for calculations. We cannot use other reference frames, for example, one based on the solar system, in the calculation of GPS satellites because if the relative velocities in the solar system are used, large periodic orbital deviations of reference time are calculated. Therefore, the ECI coordinate system is a stationary gravitational frame. This fact provides experimental evidence for the ether-dragging hypothesis in which the ether is assumed to be the permittivity of free space $\varepsilon_0$ and the permeability of free space $\mu_0$. This is interpreted using the analogy of an acoustic wave that is traveling in the atmosphere, which is dragged by the gravity of the earth.
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**Résumé:** Dans les satellites du système de positionnement global (GPS), le système de coordonnées localement inertiel centré sur la Terre (ECI) est utilisé pour les calculs. Nous ne pouvons pas utiliser d'autres cadres de référence, par exemple basés sur le système solaire, dans le calcul des satellites GPS, parce que si l' on utilise les vitesses relatives du système solaire, on calcule aussi les grands déviations orbitales périodiques du temps de référence. Par conséquent, le système de coordonnées ECI est un cadre de gravitation stationnaire. Ce fait apporte la preuve expérimentale de l'hypothèse du traînement de l'éther dans laquelle l'éther est supposé être la permittivité de l'espace libre $\varepsilon_0$ et la perméabilité de l'espace libre $\mu_0$. Ce point est interprété en utilisant l'analogie d'une onde acoustique qui se déplace dans l'atmosphère entraînée par la gravité de la terre.

Key words: GPS; ECI Coordinate System; Michelson–Gale–Pearson Experiment; Sagnac Effect; Ether-Dragging Hypothesis.

## I. INTRODUCTION

The global positioning system (GPS) is used in car navigation systems. The use of special relativity in the GPS has been summarized by Ashby.[1] The GPS satellites orbit in a region of low gravity (20 000 km from ground level) at $v_G(t)=3.874$ km/s. Therefore, the difference in gravitational potential between the ground and the location of the GPS satellites and the transverse Doppler shift effect of special relativity on the motion of the GPS satellites are considered. The transverse Doppler shift, or second-order Doppler shift, can be calculated by the Lorentz transformation of reference time. In the GPS, the earth-centered locally inertial (ECI) coordinate system is used for the calculation of reference time. The ECI coordinate system is fixed to the earth's center; thus, the earth is rotating, as shown in Fig. 1(a). The GPS uses the relative velocities defined in the ECI coordinate system.

Table I shows a summary of the GPS experiment from Ashby.[1] This discussion is carried out using the Lorentz transformation for the calculations.

Ether and explanations of gravitation were discussed from the 16th to 19th centuries by many of the greatest scientists, for example, Newton, Maxwell, and Lorentz.

From the equation of the phase velocity of electromagnetic wave

$$c=\frac{1}{\sqrt{\varepsilon_0\mu_0}},$$

we assume that the ether is the permittivity of free space $\varepsilon_0$ and the permeability of free space $\mu_0$. ($\varepsilon_0$ is the electric permittivity of the ether in farads per meter; $\mu_0$ is the magnetic permeability of the ether in henrys per meter.) Thereafter, the ether is dragged by the gravitational field of the earth. This classic idea was commonly disseminated and discussed in the days of the 19th century.

The aberration of light was observed by Bradley in 1725. He explained the aberration using Newton's particle property of photons, producing a simple illustration of a photon traveling in a straight line in the moving ether, without changing its direction. The aberration was considered to be one of the experimental results that show there is no ether-dragging around earth. This aberration is difficult to explain using the wave nature of the photon; however, it is easily explained using the particle nature of the photon. Therefore, the aberration does not rule out ether-dragging.

Michelson and Morley[2] denied the stationary ether. They denied the stationary ether in which the earth travels at the speed of 30 km/s. In the early 20th century, it was hypothesized that ether-dragging occurs on the ground level. To

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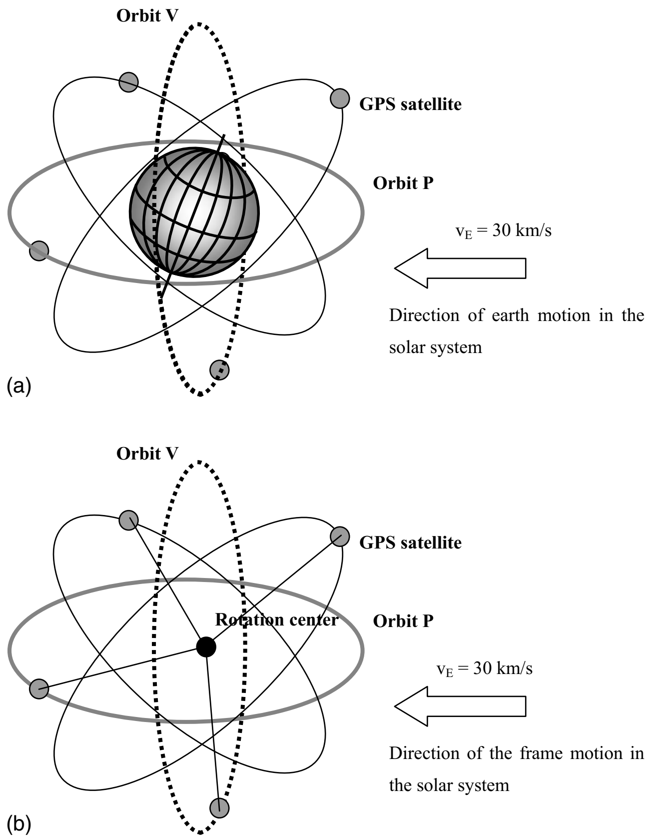


FIG. 1. (*a*) The ECI coordinate system. The GPS satellites and the earth motion in the solar system. Orbit P is parallel and orbit V is perpendicular to the direction of the earth's motion in the solar system $v_E=30$ km/s. The ECI coordinate system is fixed to earth's center; thus, the earth is rotating. The GPS satellites orbit at the relative velocity $v_G(t)=3.874$ km/s defined in the ECI coordinate system. If the GPS satellites are seen from the solar system, their orbits are cycloid. However, the deviation of the GPS satellites is not observed. Time dilation only depends on the relative velocity $v_G(t)=3.874$ km/s. (*b*) Thought experiment of the GPS in free space in the solar system: There is no gravity of the earth, GPS satellites and rotational center are combined by light rigid lodes. Numerical calculations are carried out using this model, which shows periodic deviations. The difference between Figs. 1(a) and 1(b) is gravity. The model in Fig. 1(a) is checked experimentally; however, that in Fig. 1(b) is thought experiment, where the relative velocities are defined in the solar system.

check this hypothesis experimentally, the Michelson–Morley experiment was carried out using massive lead blocks (one path of the interferometer was set between two lead blocks); there was no fringe shift.[3] Today, the GPS experiments show that there is no stationary ether at least up to 20 000 km because the GPS works well at orbits of 20 000 km in height. If there is an ether drift, it will be observed as an ether-wind more than 20 000 km from the ground level.

In 1924, the Michelson–Gale–Pearson experiment[4] was carried out to observe the effect of the earth's rotation on the velocity of light. They assumed a fixed ether and the theory of special relativity. A fixed ether means the ether fixed to the ECI coordinate system; that is, the earth rotates in the ether. The theory of special relativity means that light in a vacuum propagates with the speed *c* regardless of the motion of the light source. They constructed the experimental setups using long pipes of partial vacuum. The experimental results showed the angular velocity of the earth in accordance with the theory of special relativity and the fixed ether. In the Michelson–Gale–Pearson experiment, they had critical attention to the coordinate system; they clearly assumed the fixed ether to the ECI coordinate system.

In 1985, on the Sagnac experiment using the GPS,[5] there was no discussion of the ether. This is because the Sagnac effect as well as the Michelson–Gale–Pearson experiment were considered to be reasonably explained without the hypothesis of ether. Therefore, the other experimental evidence, which proves the hypothesis of the fixed ether, is required. In the GPS, only the relative velocity defined in the ECI coordinate system is correct, we cannot use the relative velocity defined in the solar system. This experimental evidence reasonably explains the hypothesis of the fixed ether. If we assume there is no ether, we can use arbitrary coordinate system, the solar system can be used in the calculation of the GPS; I will show that the solar system is not correct for the GPS calculation in Secs. II and III.

Table II shows the compatibility between the hypotheses and historical experiments (○: compatible, ×: incompatible, and -: not considered); only the hypothesis of fixed ether to the earth's center is compatible with four experiments.

Finally, using simple numerical calculations, we will be able to predict the periodic orbital reference time deviation in GPS satellites if the solar system is introduced. However, in the GPS satellite experiments, such a large periodic orbital deviation that critically depends on the motion of the orbital plane of the GPS satellites in the solar system has not been detected.[1] Therefore, only the ECI coordinate system is correct. That is, the ECI coordinate system is a stationary reference frame. To explain this conclusion, one possible solution based on the ether-dragging hypothesis is proposed where, the ether-dragging height is more than 20 000 km from ground level.

TABLE I. Summary of the GPS experiment from Ashby (Ref. 1).

| Term | Time difference | Condition |
|---|---|---|
| Gravitational potential | 45.7 μs time gain everyday | Height: 20 000 km from ground level |
| Velocity | 7.1 μs time delay everyday | $v_G(t)=3.874$ km/s |

## II. CONSIDERATION OF THE ECI COORDINATE SYSTEM

The time of the GPS satellite is calculated based on the ECI coordinate system and works well. Why does the inertial system of the ECI coordinate system operate well? Twenty four satellites are launched on six orbits. It is supposed that the earth is moving at 30 km/s in the solar system, and the relative velocity of the earth in the solar system is set to $v_E$. The discussions are carried out in the solar system; thus, the velocities are relative to the solar system. There are two types of GPS orbits, one is the orbit P that is parallel to $v_E$, and the other is the orbit V that is perpendicular to $v_E$, as shown in Fig. 1(a).

Time dilation in the ECI coordinate system is calculated as follows:

TABLE II. Hypotheses and historical experiments.

| Hypotheses | Experiments | | | |
|---|---|---|---|---|
| | Michelson–Morley(1887) | Michelson–Gale–Pearson (1924) | GPS-Sagnac(1985) | GPS and ECI |
| Stationary ether in the solar system | × (incompatible) | × | × | × |
| Fixed ether to the earth center (dragged ether) | ○ (compatible) | ○ | ○ | ○ |
| No ether | ○ | - | - | × |

$$t_G = \frac{t_0}{\sqrt{1-\left(\frac{\vec{v}_G}{c}\right)^2}} = \frac{t_0}{\sqrt{1-\left(\frac{3.874}{300\ 000}\right)^2}} \tag{1}$$

$$\therefore \frac{t_G - t_0}{t_0} = \frac{1}{\sqrt{1-\left(\frac{v_G}{c}\right)^2}} - 1 = \frac{1}{\sqrt{1-\left(\frac{3.874}{300\ 000}\right)^2}} - 1 = 0.83377\ 088 \times 10^{-10}, \tag{2}$$

where $t_0$ is the reference time, $t_G$ is that of the GPS satellite, and $v_G(t)=3.874$ km/s is the velocity of the GPS satellite defined in the ECI coordinate system. The reference time $t_0$ is defined as the time of the stationary state eliminating the gravitational effect: for example, the time in the ECI coordinate system eliminating the gravitational effect; that is, the time on the GPS satellite eliminating the satellite's orbital motion and the gravitational effect. Thus, $t_0$ is also equivalent to the time of the stationary state in the solar system eliminating the gravitational effect. A time delay is accumulated such that in 1 h, the deviation of the car navigation system is roughly estimated to be $3600 \times 0.833 \times 10^{-10} \times 20\ 000 \times 10^3$ m $\approx 6$ m. The accumulation of time dilation occurs because only the clock in the GPS satellite suffers the Lorentz transformation. This shows that the GPS is a very sensitive experimental setup for a time dilation measurement.

## III. CALCULATION IN THE SOLAR SYSTEM

This section shows that the relative velocity defined in the solar system cannot be applied to the GPS calculations. A simple calculation shows that we can only use the relative velocity defined in the ECI coordinate system. The purpose of the numerical calculation is to show that there is a difference between the conditions in the gravitational potential of the earth and free space. Let us consider the GPS satellites moving in free space.

Figure 1(b) shows the illustration of the calculation in free space. The GPS satellites orbit in the solar system, where there is no gravity and therefore no central force from the earth. The GPS satellites are connected by light rigid arms with the rotation center.

In the GPS experiment in free space, there is no gravity of the earth. Numerical calculations are carried out using the model in Fig. 1(b), which shows periodic deviations. The difference between Figs. 1(a) and 1(b) is the gravity. The model in Fig. 1(a) is checked experimentally; however, that in Fig. 1(b) is a thought experiment. Thus, the calculations are carried out in the solar system using the relative velocity of the earth $v_E$ and that of the GPS satellite $v_G(t)$.

The numerical calculations may defocus the discussion; therefore, I will summarize them in the Appendix.

### A. Orbits V and P

The orbit V is shown in Fig. 2, where the motion of the GPS satellite $v_G(t)$ is perpendicular to $v_E$, causing the orbit V to become a spiral trajectory in the solar system. The period of $v_G(t)$ is around 6 h. The time dilation is 7.2 $\mu$s per day. These calculations are shown in the Appendix.

Next, the orbit P is considered. In Fig. 3, the summation of the velocity of the earth $v_E$ and the velocity of the GPS satellite $v_G(t)$ in the solar system is periodically changed every 6 h. The reference time $t_G^P$ is calculated using Eq. (3) from the Lorentz transformation by setting $v_E=30$ km/s and $v_G=3.874$ km/s,

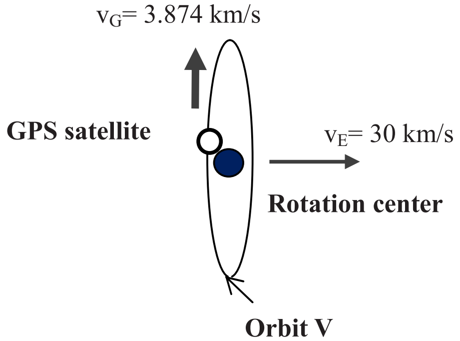


FIG. 2. (Color online) Orbit of the satellite moving perpendicular to the direction of the earth's motion in the solar system. Orbit V: The orbital plane of the GPS satellite is perpendicular to the direction of the earth's motion in the solar system.

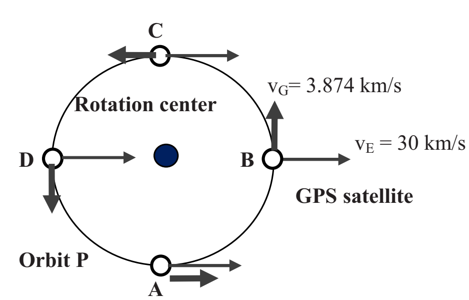


FIG. 3. (Color online) Orbit of the satellite moving parallel to the direction of earth's motion in the solar system (orbit P). The velocity of the GPS satellite in orbit P has an orbital deviation. However, this illustration is not compatible with the GPS experimental data. There are no periodic orbital deviations.

$$t_G^P = \frac{t_0}{\sqrt{1 - \left(\frac{\vec{v}_E + \vec{v}_G(t)}{c}\right)^2}}. \quad (3)$$

The reference time $t_0$ is the time of the stationary state in the solar system eliminating the gravitational effect. Equation (3) shows that there is a periodic deviation depending on the velocity $(\vec{v}_E+\vec{v}_G(t))^2$. The maximum derivation of the reference time $t_G^P$ is calculated as $\Delta t_G^P = \pm 1.3\times 10^{-9}$; these calculations are shown in the Appendix. The deviation $\Delta t_G^P$ is periodic, which causes a deviation in distance of around 0.28 km. However, the ECI coordinate system operates well by the GPS satellites, meaning no orbit-dependent periodic distance deviation is observed. The deviation of the reference time of the orbit P is similar to that of the orbit V. Thus, we cannot use the relative velocity defined in the solar system $(\vec{v}_E+\vec{v}_G(t))$.

Therefore, if we assume that there is no ether, we can use the relative velocity defined in the solar system $(\vec{v}_E + \vec{v}_G(t))$. However, this is not correct. According to the GPS experiment, we have to use the model in Fig. 1(a). This fact denies the hypothesis of no ether. Thus, the fixed ether to the earth center is chosen.

### B. Summary of the calculation

The calculations in the Appendix are simple but numerous; therefore, I will summarize them briefly here.

(1) The GPS is a very sensitive experimental setup to check the time dilation.
(2) GPS calculations cannot be carried out in the solar system using the relative velocity of the earth $v_E$ and that of the GPS satellite $v_G(t)$.
(3) A simple explanation for the ECI coordinate system is required. The reason for which the GPS works well in the ECI coordinate system but not in the solar system is discussed in Sec. IV as a proposed solution.
(4) The difference between Figs. 1(a) and 1(b) is gravity. The model in Fig. 1(a) has been checked experimentally. Although the model shown in Fig. 1(b) was derived from a thought experiment, the numerical calculation based on this model seems to be correct.
(5) In these calculations, we have to set $v_E=0$; this is the experimental evidence that the ECI coordinate system is the stationary state for the calculation of time dilation. Although we are moving in the solar system at the velocity of 30 km/s, as far as the time dilation is concerned we do not detect the velocity of 30 km/s.

## IV. PROPOSED SOLUTION

Since the deviation of the reference time must be in agreement with the results of the ECI coordinate system, the calculation using the ECI coordinate system includes not only the effects of special relativity, but also of general relativity. However, a simple argument shows that it is almost impossible to calculate the GPS in the solar system.

One of the possible solutions is that the gravitational field of the earth is a stationary gravitational field. This is derived from the ether-dragging hypothesis in which the gravitational field of the earth drags the ether, where the ether is the permittivity of free space $\varepsilon_0$ and the permeability of free space $\mu_0$. The GPS works in the ether dragged by the gravitational field of the earth. Figure 4 shows the ether-dragging model with the ECI coordinate system, the solar system, the galaxy, and the CMB are respectively in local stationary ethers. This is because each gravitational field drags the ethers around its gravitational field. The galaxy moves in the CMB at 700 km/s, the solar system moves in the galaxy at 230 km/s, and the ECI coordinate system moves in the solar system at 30 km/s, corresponding to points a–d in Fig. 4 in local stationary states. The GPS satellite in the ECI coordinate system observes 4 km/s, but it does not detect the relative velocity in other coordinates. Thus, the GPS satellite is in the stationary state of the ECI coordinate system with relative velocity 4 km/s. If the GPS satellite leaves the ECI coordinate system from point a to point b, the local stationary state for the GPS satellite is changed to the solar system from the ECI coordinate system. The GPS satellite that moves parallel to the earth observes the velocity 30 km/s in the solar system. If we reach the gravitational field of Mars, we will be in another stationary gravitational state, namely, the Mars-centered locally inertial coordinate system.

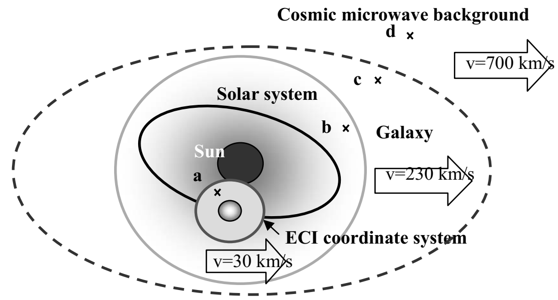


FIG. 4. Ether-dragging model: The ECI coordinate system, the solar system, and the CMB are, respectively, in the local stationary ethers. This is because each gravitational field drags the ethers around its gravitational field. There are many gravitational fields; thus, there are many local stationary states. Each of the points a–d are in local stationary states. If the GPS satellite leaves the ECI coordinate system, it will be into the local stationary state of the solar system.

There may be another solution derived from the calculation using both special relativity and general relativity; however, this calculation is very complicated. In this case, it becomes accelerated motion and the discussion using general relativity is required. The orbit P of the GPS satellite and the orbit of the earth seen from arbitrary inertial systems are shown in Fig. 5. The orbit P is a cycloid, so acceleration and deceleration are repeated. I have no idea how to carry out the calculation in an arbitrary reference frame. Therefore, I choose the ether-dragging hypothesis, which provides a simple calculation for the GPS experiments.

At the distance measurement of 20 000 km (this is a distance between the car and the GPS satellite), the maximum time deviation $\Delta t_G^P = \pm 1.3\times 10^{-9}$ causes a 26 mm deviation (20 000 km $\times 1.3\times 10^{-9}=26$ mm). It is rather small; however, the deviation is accumulated for 6 h. Let the value

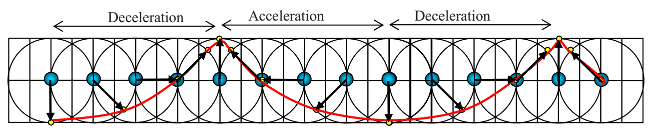


FIG. 5. (Color online) Traveling path of the GPS satellite of orbit P in an arbitrary reference frame. From an arbitrary reference frame, satellite motion is a periodic, orbital accelerated motion of cycloid.

of the average deviation be half of the maximum deviation $\Delta t_G^P = \pm 1.3 \times 10^{-9}$. Thus, we obtain, multiplying a rough estimation of $\frac{1}{2}$ as the averaged deviation,

$$20\,000 \ \text{km} \times \tfrac{1}{2} \times 1.3 \times 10^{-9} \times 3600 \times 6 = 0.28 \ \text{km}. \tag{4}$$

This calculation shows that if the clock on the GPS satellite is left alone without an adjustment for 6 h, the accumulated deviation of the distance is roughly 0.28 km. In the GPS, no such deviation is observed.

## V. DISCUSSION

The author thanks the reviewers for important comments on the earth's eccentricity as well as the suggestion that the discussion should not largely depend on the numerical calculations. From the viewpoint of the ether-dragging hypothesis, the Sagnac effects, the ECI coordinate system, the aberration, the Michelson–Morley experiments, gravitational effect on time dilation, and the analogy of an acoustic wave are discussed.

### A. Earth's eccentricity

At perihelion the distance from the earth and the sun is 0.983 AU (astronomical unit: average distance between the earth and sun is $1.5 \times 10^{11}$ m), that of aphelion is 1.017 AU. Thus, the velocity deviation is estimated to be 0.25 km/s ($\vec{v}_E(t) = 30 \pm 0.25$ km/s), which causes about 1.6 mm of deviation at the measurement of 20 000 km,

$$20\,000 \ \text{km} \times \left( 1 - \frac{\sqrt{1 - \left(\frac{29.75}{300\,000}\right)^2}}{\sqrt{1 - \left(\frac{30}{300\,000}\right)^2}} \right) = 1.6 \ \text{mm}. \tag{5}$$

The period of deviation is 12 months. The reference time deviation is not accumulated; this is because not only the clocks on the GPS satellite but also the clocks on earth simultaneously differ according to $v_E^2$. Therefore, there is no accumulation of the reference time deviations. Thus, the deviation relates to one time measurement of distance, for example, 20 000 km is a distance between the GPS and a car on earth; only 1.6 mm is calculated as the deviation. However, at the velocity of $v_G = 3.874$ km/s, only the clock on the GPS satellite obtains the deviation; thus, the deviation is accumulated for half the period of revolution, as shown in Eq. (4). The accumulation causes a difference of between 0.28 km and 1.6 mm.

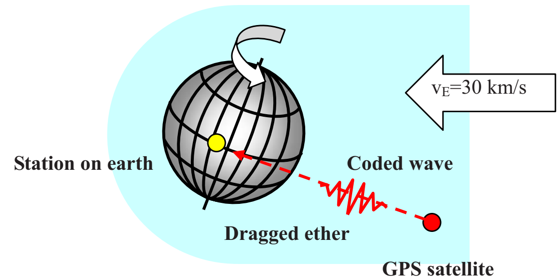


FIG. 6. (Color online) Sagnac effect using the GPS in the ether-dragging model: (1) The ether is dragged with the earth, and (2) the ether does not rotate with the earth; the ether is fixed to the ECI coordinate system. Sagnac effects reflect a changing distance between the light source and the observer caused by the motion of the observer.

In the interferometer of the L1 band (1575.42 MHz, wavelength: 190 mm), relative accuracies of millimeters are reported.[1] This is the precise positioning analysis with carrier-phase measurements. However, at this stage, the resolution is 1% of the wavelength ($190 \ \text{mm} \times 1/100 = 1.9$ mm); thus, the value of 1.6 mm is less than the technical limit of the measurement. However, the deviation of 1.6 mm is not observed for theoretical reasons. We cannot detect any annual deviations dependent on the velocity of the earth.

In this discussion, I assumed that the GPS is in the dragged ether, so we cannot detect any deviations. Even if advanced carrier-phase measurements with relative accuracies of submillimeter are used, it is impossible to detect a 1.6 mm deviation that depends on the earth's eccentricity. The GPS experiments show that we cannot observe the reference time deviations represented by Eqs. (3) and (5).

### B. Sagnac effect

Sagnac effects reflect a changing distance between the light source and the observer caused by motion of the observer. If the observer moves during the flight time of the light, the distance between the light source and the observer is changed, as shown in Fig. 6. For example, let the distance between the GPS satellite (signal source) and the observer on earth be 30 000 km (the distance that light travels at 0.1 s). On the equator, the speed of the ground is about 0.47 km/s. Thus, the Sagnac effect is 0.047 km at the measurement of 30 000 km for the observer on the equator, meaning that the flight time of light of 0.1 s, the observer moves 0.047 km. According to Ashby,[1] Sagnac effects are experimentally observed within a 2% deviation. Therefore, the deviation on the measurement of the Sagnac effect is calculated to be $0.047 \ \text{km} \times 0.02 \div 30\,000 \ \text{km} = 3.13 \times 10^{-8}$. This value is equivalent to the deviation of the ether rotation in the ECI coordinate system. In other words, the ether is almost fixed to the ECI coordinate system.

Thus, the ether has two properties, as shown in Fig. 6: (1) the ether is dragged with the earth, and (2) the ether does not rotate with the earth; if the ether is fixed to the ECI coordinate system, the deviation of the rotation is roughly estimated to be less than $3.13 \times 10^{-8}$.

The angular frequency of the earth's rotation in the ECI coordinate system is $\omega_E = 7.29211\,51467 \times 10^{-5}$ rad s$^{-1}$,[1]

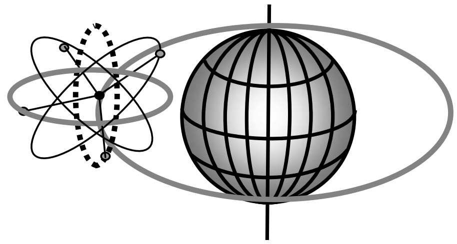

FIG. 7. Local positioning system: This system orbits around the geostationary satellites that lie over the equator. This proposed experiment shows that the gravitational field of the earth generates the ECI coordinate system.

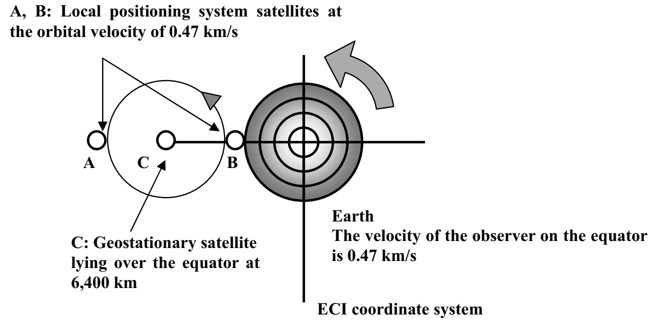


FIG. 8. The earth and the local positioning system satellites in the ECI coordinate system: The local positioning system is constructed by satellite C (the center satellite in a geostationary state lying over the equator at 6400 km) and satellites A and B (local positioning system satellites at the orbital velocity of 0.47 km/s around satellite C, the orbital radius is 6400 km). The local positioning system moves in the ECI coordinate system. The relative velocity between satellite C and satellite A (B) is 0.47 km/s.

and the period is around 23 h, 56 min, and 4.1 s. Thus, I assume that the earth rotates in the ether at the angular frequency $\omega_E$.

### C. Proposed experiment of the local positioning system

To explain the ether-dragging hypothesis, I describe other discussions of local positioning systems. The orbital center of the GPS satellites is the center of the earth, and the GPS satellites have symmetrical orbits and the velocity $v_G = 3.874$ km/s in the ECI coordinate system. Let us consider three geostationary satellites lying over the equator at 0 km, 6400 km, and 12 800 km from the ground. The relative velocities in the ECI coordinate system are 0.47 km/s, 0.94 km/s, and 1.41 km/s, respectively. Therefore, three geostationary satellites observe time dilations that depend on their velocities.

The model in Fig. 1(b) can be checked around the earth in local positioning systems, as shown in Fig. 7. If this local positioning system is set around the geostationary satellite, the relative velocities of the satellites defined in the ECI coordinate system have orbital deviations, and there are deviations of the reference time. Numerical calculations will show that the local positioning system needs rather complicated calculations to work well; in particular, we have to modify the calculation equations to use this system. If the proposed experiment is carried out, we may possibly obtain additional experimental evidence of the ether-dragging hypothesis.

Figure 1(b) shows if there is no gravitational field of the earth, the ECI coordinate system is not defined. The origin of the ECI coordinate system is the earth; the ECI coordinate system is defined by the gravitational field of the earth.

### D. Stationary state and relative velocity

What makes the ECI coordinate system and the stationary state? The answer is the gravitational field of the earth. The ECI coordinate system cannot be defined without the gravitational field of the earth. At this stage, the stationary state is defined as the state, in which time passes most rapidly. This idea is shown by the equation of the Lorentz transformation. That is, any motion in the stationary state causes time dilation.

If the local positioning system is set away from the gravitational field of the earth, the satellite experiences the relative velocity of 30 km/s in the solar system. The gravitational field of the earth generates the ECI coordinate system and the stationary state, in which time passes most rapidly. The time dilation occurs according to the relative velocities defined in the ECI coordinate system, which can be plausibly explained using the ether and ether-dragging hypotheses.

Figure 8 shows the earth and the local positioning system satellites in the ECI coordinate system. The local positioning system is constructed by satellite C (the center satellite in geostationary state lying over the equator at 6400 km), and satellites A and B (local positioning system satellites at the orbital velocity of 0.47 km/s around satellite C, the orbital radius is 6400 km). The local positioning system moves in the ECI coordinate system. The relative velocity between satellite C and satellite A (B) is 0.47 km/s. At the satellites' positions in Fig. 8, the relative velocity of satellite A is $0.47\ \text{km/s} \times 3 = 1.41\ \text{km/s}$, that of geostationary satellite C is $0.47\ \text{km/s} \times 2 = 0.94\ \text{km/s}$, and that of satellite B is 0 km/s in the ECI coordinate system. That is, satellite B is in the stationary state. On the calculation of the reference time, the relative velocity in the ECI coordinate system is used. The orbital velocity of 0.47 km/s cannot be used for the calculation of the reference time. On the condition that satellite C is in the stationary state in the ECI coordinate system, the orbital velocity of 0.47 km/s becomes the relative velocity between satellites C and B in the ECI coordinate system.

In the calculation of the Doppler shift, only the relative velocity between the two satellites, for example, between satellites C and B, is required; the velocities are not necessary defined in the stationary state. However, in the calculation of the reference time, the relative velocity defined in the stationary state is needed. That is, on the clock adjustment in the GPS, only the relative velocity defined in the ECI coordinate system is used; the relative velocities between the GPS satellites are not taken into consideration. In Fig. 8, the relative velocity between geostationary satellite C and satellite B cannot be used for calculation. This is because satellites C and B are not in the stationary state. This analogy can be applied to the GPS satellites in the solar system; that is, the GPS is in the stationary state. Therefore, we can set $v_E = 0$, the relative velocity $v_G = 3.874$ km/s can be used.

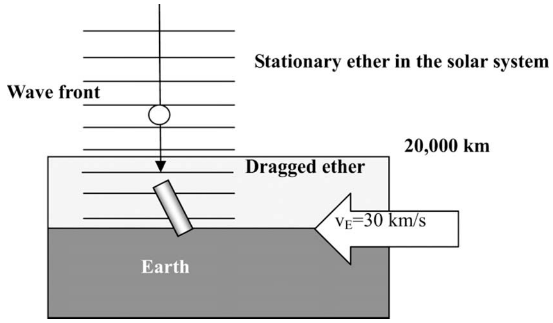


FIG. 9. Aberration and ether-dragging: Wave-particle duality shows that a photon travels perpendicular to the wave front, which is also perpendicular in the dragged ether by the earth. Bradley's explanation, using Newton's particle model of light, shows the compatibility of aberration and ether-dragging hypothesis. The relative velocity between the dragged ether and the stationary ether in the solar system is 30 km/s. The boundary between the stationary ether and dragged ether is more than 20 000 km from ground level. Photons travel on the straight line in the solar system and dragged ether.

### E. Aberration

The aberration is a counterargument against the ether-dragging hypothesis. If light is a wave in the ether, the light is dragged by the ether and the aberration cannot be observed on the earth. It is said that the aberration cannot be compatible with ether-dragging, but Bradley's explanation using Newton's particle model of light shows the compatibility of aberration and the ether-dragging hypothesis.

Figure 9 shows aberration and ether-dragging. The wave-particle duality shows that a photon travels perpendicular to the wave front, which is also perpendicular in the dragged ether by the earth. The relative velocity between the stationary ether in the solar system and the dragged ether is 30 km/s. The boundary between the stationary ether and dragged ether is more than 20 000 km from ground level. Photons travel in straight lines in the solar system and dragged ether.

According to quantum mechanics, the phase velocity $c$ of a photon is defined as $c=\omega/\kappa$ ($\omega$: frequency, $\kappa$: wave number); it is also the ratio of the energy $\varepsilon$ and momentum $\mu$ of the photon, $c=\varepsilon/\mu$. The energy and momentum are conserved to satisfy the constancy of the speed of light $c$. Therefore a simple example of a photon traveling in a straight line in the moving ether without changing its direction is possible.

In the aberration, a photon is detected as a particle, and it is correct to use the particle properties of photons. Although it is impossible to explain the aberration by the wave property of photon, I do not consider that the aberration rules out ether-dragging.

### F. Michelson–Morley experiment and the GPS

The difference between the Michelson–Morley experiments and GPS experiments is the following: (1) The Michelson–Morley experiments are carried out in the rotating frame in the ECI coordinate system and (2) the GPS experiments are done in the ECI coordinate system. Figure 6 shows the rotating frame (surface of the earth) and the ECI coordinate system. Figure 9 shows that around the ground level on the equator, the relative velocity between the ground and dragged ether is 0.47 km/s. The GPS can observe the rotation of the earth as a Sagnac effect at the sensitivity of 2%,[1] or a velocity of 9.4 m/s.

The GPS shows the isotropic constancy of the speed of light. The distance between the GPS satellite and the car is calculated using the time delay $t_D$ as $300\,000\ \text{km/s}\times t_D(s)$, where the speed of light $c=300\,000\ \text{km/s}$ is assumed to be an isotropic constant. Therefore, the fact that the GPS works well is evidence for the isotropic constancy of the speed of light. The sensitivity of a direct one way measurement (from the GPS satellite to a car on earth) in the GPS is $2\times10^4$ higher compared to the Michelson interferometer. Thus, the null results are confirmed by the GPS.

Michelson and Morley[2] reported that the relative velocity of the earth and the ether is probably less than one sixth the earth orbital velocity (5 km/s) and certainly less than one fourth (7.5 km/s). Not only Miller but also Michelson and others have reported the ether drifts below 10 km/s. Although, the deviations in the Michelson–Morley experimental results were considered as thermal artifacts,[5] these deviations are critical evidence of the counterargument against ether-dragging. Thus, it is important to study the source of the deviations. In 1887, Michelson and Morley[2] assumed the earth's revolution in the solar system was 30 km/s. In 1933, Miller[6] assumed the solar system motion in the galaxy to be 200 km/s in addition to the earth's revolution in the solar system of 30 km/s. I consider that according to ether-dragging, null results are predicted; however, the experimental deviations observed by Miller and Michelson[2] are large enough not to be negligible. I believe these experimental results of periodic deviations show that the interferometer measurements are affected by the rotation of the earth.

### G. Gravitational effect on time dilation

The predominant time-change effect for the GPS is caused by the difference of gravity potential, as shown in Table I. In the ether hypothesis, the time dilation by the gravity is explained as follow: The modification (increase) of the permittivity and the permeability by gravity causes a decrease in the speed of light

$$c=\frac{1}{\sqrt{\varepsilon_0\mu_0}}.$$

Diffraction around the gravitational potential of the sun, as observed by Dyson, Eddington and Davidson,[7] can be explained using this proposal that light propagates toward regions of high refractive index, that is, toward the sun. This is the experimental evidence that the gravity makes the speed of light slow.

Thereafter if we use the light clock model[8] in Fig. 10 that the speed of light defines the reference time

$$t_i=\frac{2L}{c_i};$$

thus, the time dilation caused by the gravity is explained. Using the ether hypothesis, the time dilation by the gravitational potential is illustrated in Fig. 11. The values of the

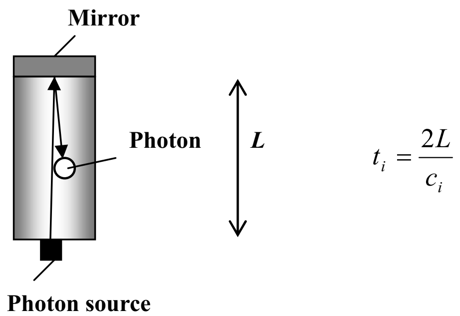


FIG. 10. Light clock (Ref. 8): The reference time $t_i$ is defined according to $t_i = 2L/c_i$ that depends on the speed of light $c_i$. The gravity modifies the speed of light $c_i$. Thus, the ether hypothesis simply explains the time dilation by the gravity.

permittivity of free space $\varepsilon_0$ and permeability of free space $\mu_0$ vary depending on the height. That is, the values are changed in order to satisfy the effect of the gravitational field on time dilation.

### H. Analogy of acoustic wave

To make the discussion more clear, let us consider the analogy of an acoustic wave in the atmosphere, which is completely dragged by the gravity of the earth. Thus, the motion of the earth in the solar system does not affect the speed of the acoustic wave. From this analogy, I reexamined the historical ether-dragging hypothesis.

The difference between the ether and the atmosphere is rotation. The atmosphere rotates synchronously with the earth with the angular frequency $\omega_E = 7.29211\,51467 \times 10^{-5}$ rad s$^{-1}$; on the other hand, the ether does not rotate (that is, $\omega_E = 0$).

At the beginning of the paper, from the analogy of an acoustic wave, I considered that the ether is fixed to the atmosphere and rotates synchronously with the earth. However, according to the GPS experiments, I think the ether is dragged but does not rotate.

The GPS satellite is moving in the ECI coordinate system, in the solar system, in the galaxy, and in the CMB.

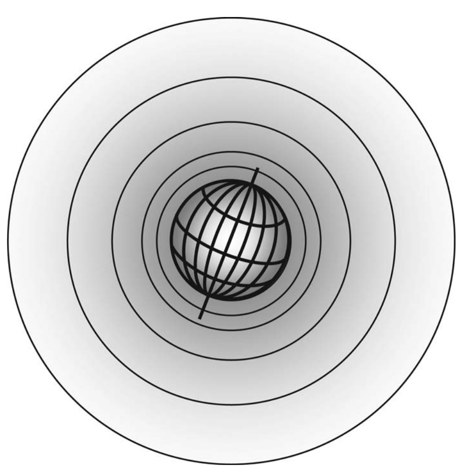

FIG. 11. Effect of the gravitational field on time dilation: The values of the permittivity of free space $\varepsilon_0$ and permeability of free space $\mu_0$ vary depending on the height. That is, the values of the ether are changed in order to satisfy the effect of the gravitational field on time dilation.

However, the reference time of the GPS is only affected by the relative velocity defined in the ECI coordinate system. Numerical calculation shows that we cannot use the GPS in the solar system; this is one of the experimental pieces evidence for the ether-dragging hypothesis.

### I. Summary of the ether-dragging hypothesis

(1) The ether is the permittivity of free space $\varepsilon_0$ and the permeability of free space $\mu_0$.
(2) The ether is dragged by the gravitational field of the earth.
(3) The ether does not rotate with the earth; the ether is fixed to the ECI coordinate system.
(4) The ether-dragging hypothesis has been improving to be compatible with almost all the historical experiments as well as the GPS experiments.
(5) The values of the ether are changed in order to satisfy the effect of the gravitational field on time dilation.

## VI. CONCLUSION

In the GPS calculations, we can only use the ECI coordinate system; another reference frame, for example, one based on the solar system, cannot be applied to GPS experiments. Therefore, the gravitational field of the earth is the stationary gravitational field, and the ECI coordinate system works well. This is the experimental evidence supporting the ether-dragging hypothesis. This hypothesis is interpreted using the analogy of an acoustic wave that is traveling in the atmosphere that is dragged by the gravity of the earth. I consider that we should reexamine the classical ether and ether-dragging hypothesis, which should have a compatibility with the theory of relativity, quantum mechanics, GPS experiments, and space physics.

## APPENDIX: NUMERICAL CALCULATIONS IN FREE SPACE

### 1. Orbit V

Numerical calculations are carried out in free space shown in Fig. 1(b). The orbit V is shown in Fig. 2, where a motion of the GPS satellite is perpendicular to $v_E$; thus, causing the orbit V to become a spiral trajectory. The velocity of the GPS satellite in the ECI coordinate system is set to $v_G$. When the reference time of the reference frame at rest is set to $t_0$ and that of the rotation center is set to $t_E$ and is expressed with $t_0$, the Lorentz transformation is as follows:

$$t_E = \frac{t_0}{\sqrt{1-\left(\frac{\vec{v}_E}{c}\right)^2}} = \frac{t_0}{\sqrt{1-\left(\frac{30}{300\,000}\right)^2}}$$

$$\therefore \frac{t_E - t_0}{t_0} = \frac{1}{\sqrt{1-\left(\frac{30}{300\,000}\right)^2}} - 1 = 0.5 \times 10^{-8}. \quad \text{(A1)}$$

The motion of a GPS satellite is perpendicular to that of the rotation center such that $\vec{v}_E \perp \vec{v}_G$. Because $\vec{v}_E \perp \vec{v}_G$, we can use the Pythagorean proposition to obtain the summation of $v_E$ and $v_G$ and the reference time $t_G^V$ of the GPS satellite by the following equation:

$$t_G^V = \frac{t_0}{\sqrt{1-\left(\frac{\vec{v}_E^2+\vec{v}_G^2}{c^2}\right)}} = \frac{t_0}{\sqrt{1-\frac{30^2+3.874^2}{300\,000^2}}}$$

$$\therefore \frac{t_G^V - t_0}{t_0} = \frac{1}{\sqrt{1-\frac{30^2+3.874^2}{300\,000^2}}} - 1 = 5.08\times 10^{-9}. \quad \text{(A2)}$$

Therefore, the proportion of the time delay over the rotation center of the GPS satellite is as follows:

$$\frac{t_G^V - t_E}{t_E} = \frac{t_G^V}{t_E} - 1 = \frac{\sqrt{1-\frac{30^2}{300\,000^2}}}{\sqrt{1-\frac{30^2+3.874^2}{300\,000^2}}} - 1$$

$$= 0.83377\,089\times 10^{-10}. \quad \text{(A3)}$$

The difference between Eqs. (2) and (A3) appears only after the eighth figure. Thus, we obtain $0.83377\times 10^{-10}\times 60\times 60\times 24 = 7.2\ \mu\text{s}$, and it becomes the delay of 7.2 $\mu$s per day. (There is a difference with the experimental data of 7.1 $\mu$s, this difference critically depends on the value of the velocity $v_G$. In Eqs. (A2) and (A3), we set $v_G = 3.874\ \text{km/s}$.)

## 2. Orbit P

Next, the orbit P is considered. In Fig. 3, the summation of the velocity of the rotation center $v_E$ and the velocity of the GPS satellite in the solar system is periodically changed. A periodic derivation of the reference time $t_G^P$ is expected; for example, the reference time $t_G^P$ is calculated using Eq. (A4) from the theory of special relativity by setting $v_E = 30\ \text{km/s}$ and $v_G = 3.874\ \text{km/s}$

$$t_G^P = \frac{t_0}{\sqrt{1-\left(\frac{\vec{v}_E+\vec{v}_G(t)}{c}\right)^2}} \quad \text{(A4)}$$

$$\therefore \frac{t_G^P - t_0}{t_0} = \frac{1}{\sqrt{1-\left(\frac{\vec{v}_E+\vec{v}_G(t)}{c}\right)^2}} - 1. \quad \text{(A5)}$$

(1) At point A in Fig. 3, where $\vec{v}_E \parallel \vec{v}_G$,

$$\therefore \frac{t_G^P - t_0}{t_0} = \frac{1}{\sqrt{1-\left(\frac{30+3.874}{300\,000}\right)^2}} - 1 = 6.42\times 10^{-9}. \quad \text{(A6)}$$

(2) At point C in Fig. 3, where $\vec{v}_E \parallel -\vec{v}_G$,

$$\therefore \frac{t_G^P - t_0}{t_0} = \frac{1}{\sqrt{1-\left(\frac{30-3.874}{300\,000}\right)^2}} - 1 = 3.75\times 10^{-9}. \quad \text{(A7)}$$

(3) At points B and D in Fig. 3, where $\vec{v}_E \perp \vec{v}_G$,

$$t_G^P = \frac{t_0}{\sqrt{1-\frac{\vec{v}_E^2+\vec{v}_G^2(t)}{c^2}}} \quad \text{(A8)}$$

$$\therefore \frac{t_G^P - t_0}{t_0} = \frac{1}{\sqrt{1-\frac{30^2+3.874^2}{300\,000^2}}} - 1 = 5.08\times 10^{-9}. \quad \text{(A9)}$$

The differences between Eqs. (A9), (A6), and (A7) is calculated as $\pm 1.3\times 10^{-9}$, where $t_G^P$ is the reference time of the GPS satellite when $v_E$ and $v_G$ are parallel, and the maximum deviation is calculated to be $\Delta t_G^P = \pm 1.3\times 10^{-9}$. However, the deviation $\Delta t_G^P$ becomes one order larger compared to the value $0.8337\times 10^{-10}$ obtained from Eq. (1). The deviation $\Delta t_G^P$ is sinusoidal; the periodic deviation is estimated to be 0.28 km. The ECI coordinate system operates well by the GPS satellites, and no periodic deviation is observed which depends on the orbits. The deviation of the reference time of the orbit P is similar to that of the orbit V.

## 3. Application of the Lorentz formalism to velocity addition

In the summation of $v_E$ and $v_G$ on the condition that $\vec{v}_E \perp \vec{v}_G$, let assume the Lorentz transformation on $v_G$ as $v_G/\gamma$ ($\gamma$: Lorentz factor),

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{30}{300\,000}\right)^2}} = 1.00000\,0005.$$

This means that the velocity $v_G$ is observed small seen from the stationary state in the ECI coordinate system. However, the difference appears in the reference time after the 18th figure as calculated in Eq. (A10): i.e., it is negligible,

$$t_G^V = \frac{t_0}{\sqrt{1-\left(\frac{\vec{v}_E^2+(\vec{v}_G/\gamma)^2}{c^2}\right)}}$$

$$= \frac{t_0}{\sqrt{1-\frac{30^2+3.87399\,998^2}{300\,000^2}}}. \quad \text{(A10)}$$

In the condition that $\vec{v}_E \parallel \vec{v}_G$, the relativistic velocity addition law can be applicable as flows,

$$\frac{v_E + v_G}{1 + \frac{v_E v_G}{c^2}} = \frac{30 + 3.874}{1 + \frac{30 \times 3.874}{300\,000^2}} = 33.87399\,995. \qquad \text{(A11)}$$

The difference in velocities between $v_E + v_G = 33.874$ km/s and Eq. (A11) appears after the tenth figure. Although Galilean addition of velocities is not consistent with the Lorentz formalism, as far as the solar system is concerned, I consider the Galilean addition of velocities in Eqs. (A2) and (A4) can be used.

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