Eur. Phys. J. C 21, 701–715 (2001)
Digital Object Identifier (DOI) 10.1007/s100520100759

**THE EUROPEAN PHYSICAL JOURNAL C**

# A local-ether model of propagation of electromagnetic wave

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Received: 11 January 2001 / Revised version: 10 May 2001 /
Published online: 19 September 2001 – 

**Abstract.** It is pointed out that the classical propagation model can be in accord with the Sagnac effect due to earth's rotational and orbital motions in the high-precision GPS (global positioning system) and interplanetary radar, if the reference frame of the classical propagation medium is endowed with a switchability according to the location of the wave. Accordingly, it is postulated that, as in the obsolete theory, electromagnetic waves propagate via a medium like the ether. However, the ether is not universal. It is proposed that in the region under sufficient influence of the gravity due to the earth, the sun, or another celestial body, there forms a local ether, which in turn is stationary with respect to the gravitational potential of the respective body. For earthbound and interplanetary propagation, the medium is stationary in a geocentric and a heliocentric inertial frame, respectively. An electromagnetic wave propagates at a constant speed with respect to the associated local ether, independent of the motions of source and receiver. Based on this local-ether model of wave propagation, a wide variety of earthbound, interplanetary, and interstellar propagation phenomena are accounted for. Strong evidence of this new classical model is its consistent account of the Sagnac effect due to earth's motions among GPS, the intercontinental microwave link, and the interplanetary radar. Moreover, as examined within the present precision, this model is still in accord with the Michelson–Morley experiment. To test the local-ether propagation model, a one-way-link rotor experiment is proposed.

## 1 Introduction

Light is an ubiquitous phenomenon in everyday's life. The exploration of the speed of light and the propagation mechanism began a long time ago. A pioneering investigation by Roemer in as early as 1675 was with an observation in interplanetary astronomy, where the apparent time interval between two successive eclipses of a moon of Jupiter was recorded over the duration of a couple of months [1]. It has been found that the apparent interval is a function of earth's position on its orbit around the sun and depends on the radial speed of the earth relative to the moon of Jupiter, where the radial speed is mainly due to earth's orbital motion. This variation in the apparent interval is a demonstration that the speed of light is finite. Further, with the astronomical knowledge of planetary motions in the solar system, this interval variation has been used to estimate the speed of light with an accuracy of about 10 percent. The first terrestrial experiment to determine the speed of light is due to Fizeau, who in 1849 sent a focused light beam through a toothed wheel with variable angular speed to a mirror a few km away and then back. At a suitable angular speed, the reflected light will hit the tooth and disappear to an observer behind the rotating wheel. From this angular speed along with the structure of teeth and the separation distance between wheel and mirror, the round-trip propagation time and hence the speed of light can be determined to a higher accuracy. As to the propagation mechanism it was generally believed, before the advent of Einstein's special relativity, that light propagates by means of a universal medium called ether. Michelson and Morley attempted to measure the velocity of the earth with respect to the supposed universal ether by using interferometry. It is believed that the earth should not happen to be stationary with respect to the universal ether and hence the speed of the earth with respect to the supposed universal ether should at least be the linear speed due to earth's orbital motion around the sun [2]. In 1887 the Michelson–Morley experiment came up with a negative result of zero or uncertainly small phase shift which indicates that the speed of the earth with respect to the supposed ether is much lower than this linear speed due to the orbital motion [1]. This result definitively rules out the effect of earth's orbital motion on the propagation of light. This interference result is commonly extrapolated to rule out the effect of earth's rotation, which has a much slower linear speed, and thus is known as a null result. Then this widely accepted null result makes the existence of the universal ether unacceptable. After the introduction of the special relativity in 1905, the notion of ether eventually became obsolete.

More recently, there have been developed several high-precision experiments which rely in a direct way on the propagation mechanism: the global positioning system (GPS), the intercontinental microwave link, and the experiments with interplanetary radar. Based on precise knowledge of the terrestrial geography and the motions of earth's satellites, spacecrafts, and of the planets, these experiments can provide decisive evidence in the determination of the propagation mechanism of electromagnetic waves. In this investigation, we examine the propagation formulas adopted in routine practice of these experiments, particularly the effects of earth's rotational and orbital motions on wave propagation. Thereafter, it will be shown deliberately that these propagation formulas are actually in accord with the classical propagation model, except for the reference frame of propagation and the corresponding discrepancy in the effect of earth's motions among these experiments. Further, the key point of this investigation will be presented: to show that this discrepancy can be solved if the classical propagation model is slightly modified in such a way that the propagation frame is endowed with a switchability according to the location of the wave: earthbound, interplanetary, or interstellar. Thereby, this new classical model can be in excellent accord with the aforementioned high-precision experiments. Moreover, it can account for the Michelson–Morley experiment and a variety of other propagation phenomena. Furthermore, by modifying the speed of light in a gravitational potential, it will be shown that this simple model is also in accord with the propagation experiments commonly ascribed to the general theory of relativity. Meanwhile, the proposed model also leads to some new predictions which provide different approaches to test its validity.

## 2 Classical propagation model and Sagnac effect

To begin with, we briefly review the classical model of wave propagation, particularly the associated Sagnac effect. Consider a wave propagating from a transmitter to a receiver via a medium. The propagation path is understood to lie along the line connecting the transmitter and the receiver at the instant when the wave is emitted. Quantitatively, as discussed in [3], the propagation-path length $R_t$ is the geometric distance from the transmitter to the receiver at the instant $t'$ of wave emission and is given by

$$R_t = |\boldsymbol{r}_\mathrm{e}(t') - \boldsymbol{r}_\mathrm{s}(t')| = |\boldsymbol{R}_t|, \tag{1}$$

where $\boldsymbol{r}_\mathrm{e}$ and $\boldsymbol{r}_\mathrm{s}$ are the position vectors of the receiver and the transmitter, respectively.

An important quantity closely related to the propagation-path length is the propagation range which presents the actual length of wave propagation over the medium. Quantitatively, the propagation range $R$ is the distance from the transmitter at the instant $t'$ of wave emission to the receiver at the instant $t$ of reception and is given by

$$R = |\boldsymbol{r}_\mathrm{e}(t) - \boldsymbol{r}_\mathrm{s}(t')| = |\boldsymbol{R}_t + \boldsymbol{r}_\mathrm{e}(t) - \boldsymbol{r}_\mathrm{e}(t')|. \tag{2}$$

It is essential to note that there is a significant discrepancy between $R_t$ and $R$ in their dependences on the reference frame. The propagation-path length $R_t$ is associated with two positions at the *identical* instants and hence is invariant in different frames, whereas the propagation range $R$ in general is different in different frames, since it is associated with two positions (or with the receiver position) at two *distinct* instants.

According to the classical propagation model, the propagation speed of the electromagnetic wave in free space with respect to the ether is $c$, the speed of light. Further, the propagation delay time $\tau$ $(= t - t')$ from the source to the receiver can be given in terms of the propagation speed $c$ in the simple form of

$$\tau = R/c, \tag{3}$$

if and only if the position vectors $\boldsymbol{r}_\mathrm{e}$ and $\boldsymbol{r}_\mathrm{s}$ are referred to the unique reference frame in which the ether is stationary. Otherwise, the propagation speed as well as the propagation range will change in a complicated way to make the propagation time invariant in a different frame, as it should. Thus the propagation range $R$ is understood to be referred to the unique propagation frame.

It can be convenient to express the propagation time in terms of the frame-independent path length. However, due to the movement of the receiver, the propagation time $\tau$ is not equal to $R_t/c$, although the difference is slight ordinarily. To keep this simple relation with a high accuracy, a treatment in the path length is needed.

The difference between the propagation range $R$ and the path length $R_t$ is known as the *Sagnac effect* which is due to the movement of the receiver during wave propagation with respect to the unique propagation frame. For a receiver moving at a fixed velocity $\boldsymbol{v}_\mathrm{e}$, the propagation range $R$ is given implicitly as

$$R = |\boldsymbol{R}_t + \boldsymbol{v}_\mathrm{e} R/c|\,, \tag{4}$$

where the receiver velocity $\boldsymbol{v}_\mathrm{e}$ as well as the position vector $\boldsymbol{r}_\mathrm{e}$ is referred to the unique propagation frame.

When the receiver is moving radially (in a direction longitudinal to the path) such that $\boldsymbol{v}_\mathrm{e}$ is parallel to $\pm\boldsymbol{R}_t$, the propagation range $R$ can be given explicitly in terms of the path length $R_t$ by

$$R = R_t \frac{c}{c \mp v_\mathrm{e}}, \tag{5}$$

where the receiver speed $v_\mathrm{e} = |\boldsymbol{v}_\mathrm{e}|$. This formula leads immediately to $\tau = R_t/(c \mp v_\mathrm{e})$, which is occasionally interpreted to be: when the receiver is moving radially, the propagation speed changes to $(c \mp v_\mathrm{e})$ while the Sagnac effect is omitted tacitly.

For the receiver velocity of a general direction, the propagation-range formula given to the second order of $1/c$ can be shown to be [4]

$$R = R_t \left\{ 1 + \frac{u_\mathrm{e}}{c} + \frac{1}{2c^2}(u_\mathrm{e}^2 + v_\mathrm{e}^2 + \boldsymbol{a}_\mathrm{e} \cdot \boldsymbol{R}_t) \right\}, \tag{6}$$

where the receiver radial speed $u_\mathrm{e} = \boldsymbol{v}_\mathrm{e} \cdot \hat{R}_t$, the unit vector $\hat{R}_t = \boldsymbol{R}_t/R_t$, and the receiver acceleration $\boldsymbol{a}_\mathrm{e} = \mathrm{d}\boldsymbol{v}_\mathrm{e}/\mathrm{d}t$.

To the first order of the normalized speed (with respect to $c$), the propagation range becomes simpler as

$$R = R_t + \boldsymbol{R}_t \cdot \boldsymbol{v}_\mathrm{e}/c. \tag{7}$$

The last term in the preceding formula presents the first-order Sagnac effect which plays an important role in this investigation.

We next consider the round-trip propagation where a wave is emitted from a transceiver, reaches and is reflected back from a target, and then is received by transceiver. Suppose that the target and the transceiver move at velocities $\boldsymbol{v}_\mathrm{a}$ and $\boldsymbol{v}_\mathrm{b}$ with respect to the unique propagation medium. For the forward path from the transceiver to the target, the propagation range can be given by (6), where $\boldsymbol{v}_\mathrm{e}$ is replaced by $\boldsymbol{v}_\mathrm{a}$ and $R_t$ is understood to be the geometric distance from the transceiver to the target at the instant of wave emission. The propagation range for the backward path from the target to the transceiver can also be given by (6), where $\boldsymbol{v}_\mathrm{e}$ is replaced by $\boldsymbol{v}_\mathrm{b}$ and $R_t$ is replaced by the geometric distance from the target to the transceiver at the instant of the wave striking the target. Thereby, to the second order of $1/c$, it can be shown that the round-trip propagation time $\tau$ is given as [4]

$$\tau = \frac{2R_t}{c}\left\{1 + \frac{1}{c}u_\mathrm{ab} + \frac{1}{2c^2}\left[u_\mathrm{a}^2 + v_\mathrm{b}^2 + v_\mathrm{ab}^2 + (\boldsymbol{a}_\mathrm{ab} - \boldsymbol{a}_\mathrm{b})\cdot \boldsymbol{R}_t\right]\right\}, \tag{8}$$

where $\boldsymbol{v}_\mathrm{ab}$ $(= \boldsymbol{v}_\mathrm{a} - \boldsymbol{v}_\mathrm{b})$ is the Newtonian relative velocity between the target and the transceiver, $u_\mathrm{ab} = u_\mathrm{a} - u_\mathrm{b}$, $\boldsymbol{a}_\mathrm{ab} = \boldsymbol{a}_\mathrm{a} - \boldsymbol{a}_\mathrm{b}$, radial speed $u = \boldsymbol{v}\cdot\hat{R}_t$, acceleration $\boldsymbol{a} = \mathrm{d}\boldsymbol{v}/\mathrm{d}t$, and $\boldsymbol{R}_t$, $\boldsymbol{v}_\mathrm{a}$, $\boldsymbol{v}_\mathrm{b}$, $\boldsymbol{a}_\mathrm{a}$, and $\boldsymbol{a}_\mathrm{b}$ are all referred to the instant of wave emission from the transceiver.

It is noted that the first-order one-way Sagnac effect given in (7) is associated with the receiver velocity and tends to be different from the one observed in a frame different from the unique propagation frame. However, the first-order round-trip Sagnac effect given in (8) is associated with the relative velocity and hence is independent of the reference frame chosen. For the round-trip case, the dependence on the reference frame emerges in the second-order Sagnac effect. These frame-dependent terms will be used to explore the existence and identity of the unique propagation frame of the electromagnetic wave, which is the key issue of this investigation.

## 3 Propagation models and Sagnac effects in high-precision experiments

In this section, we examine propagation formulas actually adopted in GPS, the intercontinental microwave link, and in the interplanetary radar. These high-precision experiments depend on wave propagation in a quite direct way and can provide crucial tests for a propagation model. Bear in mind that the path length is frame-independent, although some reference frames can be more convenient from a given viewpoint. The classical propagation range should be referred specifically to the unique propagation frame, when it is understood to be given simply as $R = \tau c$. Conversely, the frame in which the propagation range is related to the propagation time in this familiar form is just the unique propagation frame of the classical model.

### 3.1 GPS

Recently, by virtue of its high accuracy in positioning, GPS has been put in everyday practice ubiquitously [5–11]. The NAVSTAR GPS employs about 24 non-geostationary (half-synchronous) satellites carrying highly precise and synchronized atomic clocks around six nearly circular orbits of a radius of about 26,600 km [5,9]. Each GPS satellite repeatedly broadcasts a microwave carrying a sequence of its own unique codes which can be used to determine the time of signal emission. At the user site, the receiver generates a synchronous replica of the codes and compares it with the received one. Then the shift between the two sequences of codes corresponds to the measured propagation time which, when multiplied with the speed $c$, is called the pseudorange which in turn corresponds to the propagation range in the ideal case.

Quantitatively, the satellite position $\boldsymbol{r}_\mathrm{s}$ at the instant $t'$ of signal emission is determined from the instant $t$ of signal reception, the propagation time $\tau$, and the satellite ephemeris constants. Then the position $\boldsymbol{r}_\mathrm{e}$ of a geostationary receiver at the instant of signal emission is related to the satellite position $\boldsymbol{r}_\mathrm{s}$ at this instant implicitly by the pseudorange formula:

$$R = R_t + \boldsymbol{R}_t \cdot (\bar{\omega}_\mathrm{E} \times \boldsymbol{r}_\mathrm{e})/c = R_t + 2\boldsymbol{S}\cdot\bar{\omega}_\mathrm{E}/c, \tag{9}$$

where $R$ $(= \tau c)$ presents the pseudorange, position vectors $\boldsymbol{r}_\mathrm{e}$ and $\boldsymbol{r}_\mathrm{s}$ are referred to the earth's center, $\bar{\omega}_\mathrm{E}$ is the directed earth's rotation rate, and $\boldsymbol{S}$ $(= \boldsymbol{r}_\mathrm{s} \times \boldsymbol{r}_\mathrm{e}/2)$ denotes the directed area of the triangle with vertices at the satellite, the receiver, and earth's center [7,8,10]. The term associated with earth's rotation rate is known as the GPS Sagnac correction in pseudorange. After measuring a set of pseudoranges from different satellite transmitters to a ground receiver, the receiver position $\boldsymbol{r}_\mathrm{e}$ can be found by solving a set of nonlinear equations processed with coordinates transformation from the preceding pseudorange formula. For a terrestrial receiver, it is convenient to express its position in the ECEF (earth-centered earth-fixed) frame which rotates with the earth. Then the longitude, latitude, and altitude of the GPS receiver are calculated. This process is practiced numerously everyday around the globe to determine the receiver positions.

For a geostationary receiver, its velocity is zero and $\bar{\omega}_\mathrm{E} \times \boldsymbol{r}_\mathrm{e}$ with respect to the ECEF and an ECI (earth-centered inertial) frame, respectively, while, if the receiver velocity is referred to a heliocentric inertial frame or even to a frame beyond the solar system (say, a galaxy frame), the earth's orbital motion should be taken into account in addition. It is noted that the GPS pseudorange formula (9) is just the classical propagation-range formula (7), if and only if $\boldsymbol{v}_\mathrm{e} = \bar{\omega}_\mathrm{E} \times \boldsymbol{r}_\mathrm{e}$ is adopted for geostationary receivers. That is, the receiver velocity is referred uniquely to an ECI frame. Thus earth's rotation influences the Sagnac effect in GPS, while earth's orbital motion does not.

In GPS the actual magnitude of the Sagnac correction due to earth's rotation depends on the positions of satellites and receiver and a typical value is 30 m, as the propagation time is about 0.1 s and the linear speed due to earth's rotation is about 464 m/s at the equator. The GPS provides an accuracy of about 10 m or better in positioning. Thus the precision of GPS will be degraded significantly, if the Sagnac correction due to earth's rotation is not taken into account. On the other hand, the orbital motion of the earth around the sun has a linear speed of about 30 km/s which is about 100 times that of earth's rotation. Thus the present high-precision GPS would be entirely impossible if the omitted correction due to orbital motion is really necessary.

### 3.2 Intercontinental microwave link

In an intercontinental microwave link between Japan and the USA via a geostationary satellite as relay, the influence of earth's rotation is also demonstrated in a high-precision time comparison between the atomic clocks at two remote ground stations [12].

In this transpacific-link experiment, a synchronization error of as large as about 0.3 $\mu$s was observed unexpectedly. After a detailed analysis, the synchronization error in this two-way microwave link is found to be proportional to the sum of the projected areas of two triangles similar to that discussed in GPS and is ascribed to the ignored shift in propagation time. This shift in the two-way link depends on the differences in longitude between the two stations and the satellite. In the microwave link between the two neighboring countries of Japan and Korea, a similar but smaller shift in propagation time of about 40 ns has also been observed [13]. Evidently, as in GPS, the propagation-time shift in the two-way microwave link is associated with the Sagnac effect due to earth's rotation.

Meanwhile, as in GPS, no effects of earth's orbital motion are reported in these links, although they would be easier to observe if they are in existence. Thereby, it is evident that the wave propagation in GPS or the intercontinental microwave link depends on the earth's rotation, but is entirely independent of earth's orbital motion around the sun or whatever. As a consequence, the propagation mechanism in GPS or intercontinental link can be viewed as classical in conjunction with an ECI frame, rather than the ECEF or any other frame, being selected as the unique propagation frame. In other words, *the wave in GPS or the intercontinental microwave link can be viewed as propagating via a classical medium stationary in a geocentric inertial frame.*

### 3.3 Interplanetary radar

By using a high-power microwave transmitter (typically, 1 MW) and a high-directivity antenna (typically, 50 dB), radar observations of planets in the solar system have been achieved. In the interplanetary radar, a microwave signal is sent from an earthbound antenna to a target planet or a spacecraft and then the reflected wave is collected by the earthbound antenna. From the literature the targets with which the microwave radar has been demonstrated include Venus [14–18], Mercury [16–18], Mars [19], interplanetary spacecrafts [20], and others [21].

By processing the returned signal with duplicates of the transmitted one, the radar echo delay time can be measured to a high precision. For interplanetary radar, the echo delay time is of the order of 1000 s, while the uncertainty in the echo-time measurement is limited to about 100 $\mu$s [16]. Part of the uncertainty is due to the surface roughness of the target planet.

Meanwhile, based on the planetary positions which as functions of time are determined elaborately by solving the coupled equations of planetary motion numerically in conjunction with suitable planetary ephemeris constants, the interplanetary round-trip propagation time is calculated. By comparing the predicted results with the measured data of radar echo time, high agreements are reported. Typically, the agreement of the echo-time comparison is about a few hundred microseconds [14,22]. Part of the disagreement is due to the uncertainty in the adopted ephemeris constants.

An examination of the adopted propagation formulas shows that the round-trip propagation time is the sum of the propagation ranges of the forward and the backward paths divided by the speed of light $c$, where the forward propagation range is the distance from the position of the transmitting antenna at the instant of wave emission to that of the reflecting part on the target planet at the instant of reflection and the backward propagation range is the distance from the reflecting part to the position of the receiving antenna at the instant of reception. Quantitatively, the adopted formula described clearly in [14,15,21] shows that the round-trip propagation time is given by

$$\tau = \tau_f + \tau_\mathrm{b} = \frac{1}{c}|\boldsymbol{r}_\mathrm{a}(t') - \boldsymbol{r}_\mathrm{b}(t'')| + \frac{1}{c}|\boldsymbol{r}_\mathrm{b}(t) - \boldsymbol{r}_\mathrm{a}(t')|, \quad (10)$$

where $\tau_f$ and $\tau_\mathrm{b}$ denote the propagation times for the forward and the backward paths, respectively, $\boldsymbol{r}_\mathrm{a}$ and $\boldsymbol{r}_\mathrm{b}$ are the position vectors of the target and the transceiver, respectively, $t''$, $t'$ and $t$ denote the instants of the signal being emitted, reflected, and received, respectively, $\tau_f = t' - t''$, and $\tau_\mathrm{b} = t - t'$. (For the reflection from the surface of a target planet of radius $R_P$, an amount of $2R_P/c$ should be subtracted from the echo time, as the target position vector $\boldsymbol{r}_\mathrm{a}$ is assigned to the center of the planet [15].) Owing to the movement of the target during the forward propagation time $\tau_\mathrm{f}$ and to that of the transceiver during the backward one $\tau_\mathrm{b}$, the position vectors $\boldsymbol{r}_\mathrm{a}(t')$ and $\boldsymbol{r}_\mathrm{b}(t)$ depend on $\tau_\mathrm{f}$ and $\tau_\mathrm{b}$, respectively. Thus the propagation times given in the preceding formula are implicit and are solved iteratively.

It is noted that the preceding echo-time formula is in accord with the classical propagation-range formula (2), aside from the reference frame. Further, as stated explicitly in most of the literature, the position vectors $\boldsymbol{r}_\mathrm{a}$ and $\boldsymbol{r}_\mathrm{b}$ are based on a heliocentric inertial frame. Needless to say, a heliocentric frame is convenient in dealing with the position vectors of the associated planets under the influence of gravity due to the sun. More significantly, an implication is that the wave propagation is referred uniquely to this heliocentric frame. Note that if this is actually the case, the unique propagation frame of the interplanetary radar is then different from that of GPS and the intercontinental microwave link. However, whether the unique propagation frame of interplanetary radar is really a heliocentric inertial frame is subject to a careful verification by comparing the measured echo time with the predicted result based on the proposed frame to an appropriate accuracy.

For this verification, it is more instructive to express the echo time explicitly. To the second order, the explicit formula of echo time has been given in (8). From this it is seen that owing to the round-trip path, the first-order Sagnac effect depends on the relative velocity and hence is invariant when observed in different frames. In other words, no frame is preferred for this round-trip effect associated with the relative velocity. Thus, unlike that in GPS, the major term of the Sagnac effect cannot be used to determine the uniqueness of the propagation frame. However, the radial speed of the target, the speed of the transceiver and their accelerations survive in the second-order terms. The determination of the unique propagation frame then relies on these second-order Sagnac effects, which are much smaller in magnitude. Hence the required accuracy is much higher.

From the explicit formula, a calculation immediately shows that the acceleration due to earth's rotation corresponds to about $100\,\mu$s in interplanetary echo time, which is comparable to the aforementioned agreement of echo-time comparison. Thus, as in GPS, earth's rotation should affect the interplanetary propagation and hence the ECEF frame is ruled out. On the other hand, when observed in a galaxy frame, the speeds of transceiver and target will incorporate the one due to the orbital motion of the sun, which is about 220 km/s. Thus the squared normalized speeds are as large as of the order of $10^{-6}$. If this motion affects the interplanetary radar experiments, the corresponding influences on the echo time would be as large as of the order of 1 ms. This is clearly beyond the accuracy and hence a galaxy frame is also ruled out.

However, when observed in either a geocentric or a heliocentric frame, the squared normalized speeds in interplanetary radar are at most of the order of $10^{-8}$. The potential contributions to interplanetary echo time are of the order of $10\,\mu$s. Therefore, based on these second-order terms, it is difficult to discriminate between a geocentric and a heliocentric inertial frame, when the comparison agreement remains a few hundred microseconds. In order to determine the unique propagation frame from these minor terms, the fractional agreement of echo-time comparison should be better than $10^{-8}$.

More recently, interplanetary radar with the echo signal transponded by a spacecraft has been achieved and the corresponding precision of the measured echo time can be as high as $0.1\,\mu$s or better [20,19]. After processing a large number of high-precision measured data to fit the theoretical formula with some undetermined parameters by the least-square algorithm, an agreement of the echo-time comparison of as high as about $1\,\mu$s or better has been achieved over a long duration of several months [20,19]. Thereupon, as the reference frame adopted in the echo-time formula is referred to a heliocentric inertial frame, the unique propagation frame of the interplanetary radar is then attributed to this frame.

Thereby, the measured and the calculated echo times are in agreement, if the propagation mechanism in the interplanetary radar is viewed as classical in conjunction with that a heliocentric inertial frame, rather than an ECI or any other frame, is selected as the unique propagation frame. In other words, *the wave in the interplanetary radar can be viewed as propagating via a classical medium stationary in a heliocentric inertial frame.*

## 4 Discrepancy in effect of earth's motion

In some of the literature the Sagnac effect is ascribed to a relativistic effect [7,13,23]. It is known that the special relativity is based on two postulates. The first one is the principle of relativity which states that no reference frames in uniform translatory motion are preferred [24]. On the contrary, the classical propagation model presumes a unique propagation frame to which the position vectors, the propagation range, the propagation speed, and the receiver velocity are referred. The second one is the principle of the constancy of the speed of light which states that the speed of light is independent of the motion of source. It is noted that this principle is actually in accord with the classical propagation model. Thus the propagation-range formulas adopted in GPS, the intercontinental microwave link, and the interplanetary radar are identical to the classical one, aside from the reference frame.

Based on the classical propagation model, it has been determined deliberately in the preceding section that the unique propagation frame is a geocentric and a heliocentric inertial frames for GPS and the interplanetary radar, respectively. When the receiver is moving with respect to the determined propagation frame, the Sagnac effect results from the difference between propagation range and path length. From this point, the Sagnac effect has nothing to do with the Lorentz transformation of space and time. An obvious reason is that the Sagnac effect incorporates the first order of the normalized speed, whereas the time dilation or the length contraction is merely of the second order. Further, if a propagation is referred to a frame different from the determined frame, the propagation-range formula (7) will lead to a propagation time imposed with an extra first-order term associated with the relative velocity between the two frames, in addition to the Sagnac effect. If no reference frame is preferred, it is puzzling to figure out how this extra first-order term can be compensated by resorting to the Lorentz transformation when observed in a different frame in uniform translatory motion.

Although the principle of relativity has been extensively verified in classical mechanics, such as in the conservation of momentum or kinetic energy, it is not really tested in the case of propagation of an electromagnetic wave. Although GPS and intercontinental microwave links are commonly claimed to follow special relativity, the reference frame that has been actually adopted is an ECI frame only. The ECEF frame is ruled out by reason of the noninertial effects of a rotating frame [7]. Meanwhile, a heliocentric or galaxy frame is also ruled out for the reason of the locally Lorentzian principle [7]. Not any other frame has been really tested in GPS, such as the frame which moves at a fixed velocity with respect to an ECI frame. Perhaps, this frame can also be ruled out by some ignored principle. While, if these reasonings are applied consistently to the Michelson–Morley experiment, then its famous null result should be reexamined based on an ECI frame. Moreover, it is noted that under a space-time transformation in which time is not frame-independent, the echo-time comparison in the interplanetary radar experiments seems to need a transformation. This is because while the calculation of echo time is referred to a heliocentric frame, the measurement of echo time only involves the clocks of ground stations and hence is expected to be associated with a frame as that in the case of an intercontinental link. However, this transformation has not been reported, to our knowledge.

These arguments on the grounds of special relativity may be disputable. Anyway, the key point is that these high-precision experiments and other related propagation phenomena can be well accounted for by the classical propagation model if the unique propagation frame is suitably selected. The GPS and intercontinental microwave link are in accord with the classical propagation mechanism in conjunction with the unique propagation frame being an ECI frame. Thereby, the Sagnac effect based on the classical model without invoking any particular space-time transformation is in excellent accord with these experiments to the first order of normalized speed. Moreover, the interplanetary radar is in accord with the classical propagation mechanism in conjunction with the unique propagation frame being a heliocentric inertial frame.

As the unique propagation frame in interplanetary radar is a heliocentric inertial frame, both the rotational and the orbital motions of the earth together with the orbital motion of the target planet contribute to the Sagnac effect. But the orbital motion of the sun has no effects on the interplanetary propagation. On the other hand, as the unique propagation frame in GPS and intercontinental links is a geocentric inertial frame, the rotational motion of the earth contributes to the Sagnac effect. But the orbital motion of the earth around the sun and that of the sun have no effects on the earthbound propagation. By comparing GPS with interplanetary radar, it is seen that there is a common Sagnac effect due to earth's rotation and a common null effect of the orbital motion of the sun on wave propagation. However, there is a discrepancy in the Sagnac effect due to earth's orbital motion. Moreover, by comparing GPS with the widely accepted interpretation of the Michelson–Morley experiment, it is seen that there is a common null effect of the orbital motions on wave propagation, whereas there is a discrepancy in the Sagnac effect due to earth's rotation.

It is noted that an interplanetary radar experiment can be viewed as a microwave link via a planet or a spacecraft as relay, while its unique propagation frame is different from that in the intercontinental link. Thus, for a spacecraft before or just after its launch, the propagation of the microwave by which the ground station communicates with it is referred to a geocentric inertial frame, while, as the spacecraft flies far away on its journey to another planet, the propagation reference switches to a heliocentric inertial frame. Therefore, it is evident that the propagation mechanism in a microwave link depends on the location of the relay.

Thus it is concluded that the examined high-precision experiments are in accord with *the classical propagation model in conjunction with a unique propagation frame which is switchable, depending on the location of the wave: earthbound or interplanetary.* Based on this characteristic of uniqueness and switchability of the propagation frame, we propose in the following section the local-ether model of wave propagation to solve the discrepancies in the influences of earth's rotational and orbital motions on the Sagnac effect and to account for a wide variety of propagation phenomena.

## 5 Local-ether model of wave propagation

Imagine that in the universe the ether prevails everywhere. However, the ether does not integrate wholly to form one single universal medium for wave propagation. Instead, there exist numerous local ethers. Each individual local ether is finite in extent and may be wholly immersed in another local ether of larger extent. Each local ether as a whole may move at a velocity with respect to another local ether. Thus the local ethers may form a multiple-level hierarchy. At a given position, it is the lowest-level local ether that determines the wave propagation locally. For an electromagnetic wave propagating within a single local ether, it is proposed that as in the old ether notion, the propagation speed with respect to the associated local ether is just the speed of light $c$, independent of the motions of source and receiver.

This new classical propagation model made its debut in [25]. The physical nature of the local ether is yet to be explored. Like the familiar fact that a volume of air or a membrane which propagates a mechanical wave is composed of numerous molecules or ions, a local ether which propagates electromagnetic wave could be composed of some undetected kind of tiny interacting particles much smaller than the electron in size. It is expected to be associated with the gravity of a celestial body. Anyway, some mechanisms tend to integrate the ether surrounding a celestial body. Thus the nearby ether will move with the body. This situation is somewhat like that of a moving balloon that tends to drag some air to move with it or like the ether-drag hypothesis proposed a long time ago [2]. Thereby, a local ether associated with that celestial body is formed.

Specifically, it is proposed that *in the region under sufficient influence of the gravity due to the earth, the sun, or another celestial body there forms a local ether which in turn is stationary with respect to the gravitational potential* *of the respective body.* Thereby, each local ether together with the gravitational potential moves with the associated celestial body. According to this model, the earth local ether is inside the sun local ether, which in turn is inside the galaxy local ether, and so on. The earth local ether together with earth's gravitational potential moves with earth's orbital motion around the sun, but not with earth's rotation. Thus the earth local ether is stationary in an ECI frame, but not in the ECEF or any other frame, while the sun local ether is stationary in a heliocentric inertial frame.

Based on the classical propagation model, whether the motion of a receiver contributes to the Sagnac effect depends on whether this motion is incorporated in the movement of the receiver with respect to the propagation medium. In other words, if a receiver and the propagation medium are undergoing a common motion, then the propagation is entirely independent of this motion. Based on the local-ether model, for the case where both the source and the receiver are bounded to the solar system, the interplanetary propagation is entirely independent of the motion of the sun with respect to upper-level local ethers, such as the orbital motion of the sun in the galaxy. Further, for the case where both the source and the receiver are bounded to the earth, the propagation medium is stationary in an ECI frame and the earthbound propagation is entirely independent of the orbital motions of the earth and the sun.

Consider the Sagnac effect for a geostationary receiver. Based on the local-ether model, the velocity of a geostationary receiver that contributes to the Sagnac effect is apparently not zero. Further, it is noted that the receiver velocity and hence the Sagnac effect depend on the location of the source. If the source is also earthbound, the propagation path is then earthbound and the Sagnac effect is due to earth's rotation alone, while, if the source is located outside the earth local ether, the calculation of the propagation time is more complicated. For the interplanetary propagation where the wave is radiated from the sun, a planet, or a spacecraft, the major part of the propagation path is located in the sun local ether. The calculation can be simplified, if the propagation in the minor earth local ether is approximated to that in the main sun local ether. Anyway, the interplanetary Sagnac effect is due to earth's orbital motion around the sun as well as earth's rotation. Further, for the interstellar propagation where the source is located beyond the solar system, the orbital motion of the sun contributes to the interstellar Sagnac effect as well.

Evidently, as expected, the proposed local-ether model accounts for the Sagnac effect due to earth's rotation and the null effect of earth's orbital motion in the earthbound propagations in GPS and intercontinental microwave link experiments. Meanwhile, in the interplanetary radar, it accounts for the Sagnac effect due both to earth's rotation and to earth's orbital motion around the sun. Moreover, it accounts for the null effect of orbital motion of the sun both in earthbound and interplanetary propagations. Furthermore, the local-ether model can be used to account for the Michelson–Morley experiment and various other propagation phenomena, as discussed in the following section.

## 6 Reexaminations of various propagation phenomena

In this section, we discuss wave propagation in monostatic radar experiments, the Michelson–Morley experiment, and in loop interferometry and examine the constancy of the speed of light and the spatial isotropy of the propagation time. Then we discuss the Doppler effect and the related phenomena in Roemer's observations and CMBR (cosmic microwave background radiation). Finally, we explore the gravitational effects due to the sun on the light deflection and the shift of the interplanetary radar echo time. Of the various phenomena to be discussed, the main propagation medium varies from the earth to the sun local ether, and to that beyond the solar system.

In the various propagation formulas to be discussed, both the individual velocities of source, target, and of receiver and the Newtonian relative velocities among them are incorporated. Those terms incorporating only relative velocities are independent of the reference frame and hence cannot be used to determine the unique propagation frame unequivocally, whereas those terms incorporating the individual velocity, such as the Sagnac effect in GPS, will in general lead to different predicted results if the chosen reference frame is different from the unique propagation frame. Therefore, an examination on the reference frame of the individual velocity may provide a test for the propagation model. However, the individual-velocity terms may become second or higher order due to some symmetry in propagation. Thus these terms can be difficult to detect or even undetectable. Nevertheless, the various propagation phenomena may provide auxiliary evidence for the propagation model.

### 6.1 Round-trip Sagnac effect in monostatic radar experiments

Consider the round-trip propagation in the monostatic radar system composed of a transceiver and a target. For an earthbound radar, the round-trip propagation time $\tau$ is quite short and the resolution in echo-time measurement is limited. Thus it normally suffices to use the first-order radar echo time simplified from (8) to

$$\tau = \frac{2R_t}{c}\left(1 + \frac{u_{\mathrm{ab}}}{c}\right). \tag{11}$$

It is noted that the first-order echo time involves only the Newtonian relative velocity and hence is independent of the reference frame of the velocities. This first-order formula agrees with the corresponding radar phase shift given in [26,27]. No second-order Sagnac effect in earthbound radar experiments is reported in the literature, to our knowledge.

### 6.2 Round-trip Sagnac effect in Michelson–Morley experiment

Then we proceed to consider the Michelson–Morley experiment dealing with the interference between two light beams in two orthogonal propagation paths formed by beam splitter and mirror. In each of the two optical arms, light propagates from the beam splitter to a mirror and back. Thus the propagation in each arm is like that in a monostatic radar with the beam splitter and the mirror serving as the transceiver and the target, respectively. Similarly, the Sagnac effect is of round-trip nature. Further, since the mirror always moves with the beam splitter, the propagation-time formula can be even simpler.

For the case where the target is moving with the transceiver ($\boldsymbol{v}_{\rm a} = \boldsymbol{v}_{\rm b}$) and their accelerations can be neglected, the round-trip propagation time (8) becomes simpler, namely

$$\tau = \frac{2R_t}{c}\left\{1 + \frac{1}{2c^2}\left(u_{\rm b}^2 + v_{\rm b}^2\right)\right\}. \qquad (12)$$

It is noted that the first-order Sagnac effect due to the relative motion between transceiver and target vanishes in the preceding relation. Thus in each optical arm in the Michelson–Morley experiment, the round-trip propagation time given to the second order of the normalized speed becomes

$$\tau = \frac{2R_t}{c}\left\{1 + \frac{v^2}{2c^2}(1 + \cos^2\theta)\right\}, \qquad (13)$$

where $\boldsymbol{v}$ is the velocity of the interferometer with respect to the local-ether frame, $R_t$ is the path length between the beam splitter and the mirror in each optical path, and $\theta$ is the angle between $\boldsymbol{v}$ and $\boldsymbol{R}_t$.

The difference in round-trip propagation time between the two arms corresponds to a phase difference, which in turn can manifest itself as an interference fringe pattern by suitably arranging the arms. As the interferometer is rotating, the two values of angle $\theta$ and hence the two propagation times will vary. Consequently, a variation in the interference fringe can be observed if the variation in the phase difference is large enough.

Based on the local-ether model, the propagation is entirely independent of the earth's orbital motion around the sun or whatever and the velocity $\boldsymbol{v}$ for such an earthbound experiment is referred to an ECI frame and hence is due to earth's rotation alone. In the original proposal, the velocity $\boldsymbol{v}$ was supposed to incorporate earth's orbital motion around the sun. Thus, at least, $v^2/c^2 \simeq 10^{-8}$. Then the amplitude of the phase-difference variation could be as large as $\pi/3$, when the wavelength is $0.6\,\mu$m and the path length is 10 m. However, as the velocity $\boldsymbol{v}$ is the linear velocity due to earth's rotation alone, the round-trip Sagnac effect is as small as $v^2/c^2 \sim 10^{-12}$, which is merely $10^{-4}$ times that due to the orbital motion. Thereby, based on the local-ether model, the variations in the round-trip propagation times are not exactly zero, but are currently too small to detect. In the common understanding, the null effect of orbital motion is extrapolated without direct evidence to rule out the effect of earth's rotation on wave propagation, as in Einstein's original paper of the special relativity where it is assumed that $\tau = 2R_t/c$ [24]. Thereupon, this local-ether interpretation of the Michelson–Morley experiment is fundamentally different from that based on the special relativity.

From the examined high-precision propagation experiments, it is found that the proposed local-ether model is in accord with all these experiments, except the undetermined Sagnac effect due to earth's rotation in the Michelson–Morley experiment. Since a correct propagation model should consistently account for the Michelson–Morley experiment, GPS, intercontinental microwave link, and interplanetary radar measurements, we deliberate more on this round-trip Sagnac effect.

From physical reasoning, it is expected that the propagation mechanism in the Michelson–Morley experiment in no way can be different from that in GPS and earthbound microwave link experiments, from the standpoint of any plausible propagation model. The null effect of earth's orbital motion in the Michelson–Morley experiment reflects no Sagnac correction due to this motion in the GPS pseudorange. On the other hand, the Sagnac effect due to earth's rotation in the high-precision GPS and intercontinental microwave link should reflect a non-null effect of earth's rotation in the Michelson–Morley experiment. The difficulty in the Michelson–Morley experiment is that this effect becomes a term of the second order of the normalized speed, owing to the round-trip path and the lack of relative motion between transceiver and target.

The accuracy of the interferometry experiment may be improved by using a laser heterodyne system, where the propagation path is formed in a resonant cavity. If the resonance frequency of the cavity is shifted due to some mechanisms, the shift will manifest itself as a variation in the beat frequency, as the laser from the cavity is compared with a reference wave. According to the classical propagation model, the resonance frequency of a cylindrical cavity resonator is inversely proportional to the round-trip propagation time over the propagation path along the cylinder axis. Thus the motion of the cavity with respect to the unique propagation frame tends to affect the round-trip propagation time and hence the resonance frequency.

The shift in propagation time can manifest itself as a corresponding variation in beat frequency between two waves from two perpendicular cylindrical cavities [28] or between a wave from a single cavity and a reference wave from a stable source [29,30]. Then, based on the local-ether model, the second-order round-trip Sagnac effect due to earth's rotation results in a quadrupole anisotropy in the resonance frequency of a cylindrical cavity, as the direction of cavity is changing. That is, the resonance frequency is the lowest when the axis of the cavity points in the east–west direction; it is the highest when it is in the north–south direction.

As the cavity is rotating slowly with respect to the ground in a horizontal plane, the beat frequency is expected to vary sinusoidally at twice the turntable rotation rate. Moreover, the peak-to-peak amplitude $\Delta f_{\max}$ for the case of a single cavity can be found from the round-trip propagation time given in (13) as

$$\frac{\Delta f_{\max}}{f} = \frac{v_{\rm E}^2}{2c^2} \simeq 1.2\cos^2\theta_l \times 10^{-12}, \qquad (14)$$

where $v_{\rm E} = \omega_{\rm E} R_{\rm E} \cos\theta_l$ is the linear speed due to earth's rotation with respect to an ECI frame, $R_{\rm E}$ is earth's radius, and $\theta_l$ is the latitude.

Such a heterodyne system using a stable He–Ne laser at 3.39 $\mu$m ($f = 0.88 \times 10^{14}$ Hz) and a stable Fabry–Perot resonator has been developed [29]. According to the local-ether model, the amplitude $\Delta f_{\max}$ is expected to be 62 Hz, as the cavity heterodyne experiment is supposed to be conducted at a latitude of 40°. In the measured data, a term varying at the expected rate has been reported. However, the peak-to-peak amplitude of this term is merely about $17 \times 2$ Hz and was attributed to a persistent spurious signal among other larger noises. It seems too early to make a decisive conclusion from this experiment. A more careful experiment is anticipated to test the second-order round-trip Sagnac effect supposed due to earth's rotation.

### 6.3 Sagnac effect in loop interferometer

The aforementioned first-order Sagnac effect was first observed in a loop interferometer, where two coherent waves propagating in opposite directions around a closed propagation path formed by a beam splitter and mirrors in air. Although the paths for the two waves are identical in structure, the propagation ranges can be different owing to the Sagnac effect associated with the movement of propagation path. The corresponding phase difference then results in an interference fringe, which was first observed in 1913 by Sagnac by using a rotating interferometer. Then in 1925 Michelson and Gale demonstrated the Sagnac effect due to earth's rotation by constructing a geostationary loop interferometer enclosing an area as large as 0.2 km$^2$ [31].

To derive this Sagnac effect, consider for simplicity a propagation loop which is circular of radius $a$ and is rotating about the center axis with a rotation rate $\omega_l$. Thus, based on the propagation-range formula (5), for the copropagating and the counterpropagating waves traversing the rotating loop once (from entering the loop via the beam splitter to exiting from the same splitter), the actual propagation ranges are $2\pi a \pm \omega_l a\tau$ rather than $2\pi a$, where $\tau$ is the respective propagation time. Thus the difference between the two propagation times is given by

$$\Delta\tau = \frac{2\pi a}{c-\omega_l a} - \frac{2\pi a}{c+\omega_l a} \simeq \frac{4\pi\omega_l a^2}{c^2}, \tag{15}$$

which is proportional to the area enclosed by the loop times the rotation rate.

For the general case, consider a coplanar propagation loop $L$ which is of arbitrary shape and is rotating about an axis at an arbitrary location with an arbitrary directed rotation rate $\bar{\omega}_l$. For the two waves copropagating and counterpropagating with the rotating loop, the directed path length $\boldsymbol{R}_t$ in each linear short segment of the loop is along the longitudinal $\hat{l}$ direction of this segment, namely, $\hat{R}_t = \pm\hat{l}$. As given in [3], by using the first-order propagation-range formula (7), the propagation-time difference between the two waves traversing the loop once can be given by the path integral (or by summation for a piecewise connected loop):

$$\Delta\tau = \frac{1}{c^2}\oint_L \left\{ \left(c + \bar{\omega}_l \times \boldsymbol{r}\cdot\hat{l}\right) - \left(c - \bar{\omega}_l \times \boldsymbol{r}\cdot\hat{l}\right) \right\} \mathrm{d}l$$

$$= \frac{2}{c^2}\oint_L \bar{\omega}_l \times \boldsymbol{r}\cdot \mathrm{d}\boldsymbol{l}, \tag{16}$$

where $\mathrm{d}\boldsymbol{l} = \hat{l}\mathrm{d}l$, $\mathrm{d}l$ is a differential path length, and the directed distance $\boldsymbol{r}$ is measured from the axis to the various point around the path $L$. By using a vector identity and by remarking that the directed area $\boldsymbol{S}$ enclosed by the path $L$ is

$$\boldsymbol{S} = \frac{1}{2}\oint_L \boldsymbol{r}\times \mathrm{d}\boldsymbol{l}, \tag{17}$$

the propagation-time difference can be written to the first order of the normalized speed as

$$\Delta\tau = \frac{4}{c^2}\bar{\omega}_l\cdot\boldsymbol{S}. \tag{18}$$

It is noted that the corresponding phase difference is proportional to the rotation rate times the projected loop area.

It is noted that the major terms in the two propagation times cancel each other and only the Sagnac terms survive in the interference. This situation makes it easier to observe the Sagnac effect by this interferometry. This phase difference has been demonstrated in a rotating interferometer as well as in a geostationary one. In the latter case, the Sagnac effect is due solely to earth's rotation with $\bar{\omega}_l = \bar{\omega}_{\mathrm{E}}$. The earth rotation rate $\omega_{\mathrm{E}}$ is about $2\pi/(86400\,\mathrm{s})$ and the corresponding maximum phase difference is as large as 2 rad, when the wavelength is 0.6 $\mu$m and the loop area $S = 0.2$ km$^2$. Thus, a loop interferometer can be utilized as a precise means to detect earth's rotation rate.

Moreover, according to the local-ether model, earth's orbital motion around the sun or others does not contribute to the Sagnac effect in an earthbound propagation loop. In as early as 1904 Michelson supposed that the Sagnac effect due to the orbital motion of the earth around the sun might be detectable, although the angular speed of the orbital motion is about 1/365 times that of the rotation [31]. However, this idea has never been followed up to our knowledge and is ascribed to the principle of local Lorentz invariance [31].

### 6.4 Constancy of speed of light

According to the classical model, the propagation speed is entirely independent of the source velocity. Thus, without resorting to any mathematics, it is seen that the local-ether model is obviously in accord with the constancy of the speed of light from binary stars, in spite of the fact that they tend to move at considerably different speeds with respect to an observer on the ground [32].

Moreover, the local-ether model is in accord with the constancy of the speed of light observed in gamma rays from the synchrotron radiation of high-energy electrons [33] and from the decay of high-energy semistable $\pi^0$ mesons [34]. In the practice of these experiments, the geometric distance between two separated gamma-ray detectors divided by the measured delay time between them is adopted as the propagation speed. This practice implies that the Sagnac effect is omitted tacitly and the path length is taken to be the propagation range. Accordingly, as discussed previously, the calculated propagation speed involves the velocity of the detectors with respect to the local-ether frame, while it is entirely independent of the velocity of the emitting particle. In these terrestrial experiments with geostationary detectors, the receiver speed is due to earth's rotation alone. Obviously, this speed is relatively too low to be observed and hence the calculated propagation speed is substantially identical to $c$.

### 6.5 Spatial isotropy in geostationary path or cavity

Consider the experiment of a one-way fiber link, where the phase difference between two waves generated from two identical stable hydrogen masers at 100 MHz separated by a distance of 21 km and linked by a stable optical fiber was measured by using a network analyzer every a few seconds during a couple of days [35]. It has been found that the phase difference between the two waves is highly stable, hour by hour and day by day. Thus a spatial isotropy is observed in the one-way fiber link, as the phase difference is stable regardless of earth's rotational or orbital motion.

According to the local-ether model, the propagation time for this terrestrial experiment is obviously independent of earth's orbital motion. Further, the propagation time $\tau$ implied in (4) can be written implicitly as

$$\tau = \frac{1}{c}\sqrt{R_t^2 + 2\boldsymbol{R}_t \cdot \boldsymbol{v}_{\mathrm{E}}\tau + v_{\mathrm{E}}^2\tau^2}, \tag{19}$$

where $\boldsymbol{v}_{\mathrm{E}}$ is the linear velocity due to earth's rotation and represents the velocity of a geostationary path with respect to an ECI frame. As the propagation path is a fiber link rather than a free space, the propagation speed $c$ in the preceding formula has to be modified. Moreover, as the link could be curved, the propagation time has to be determined by summing the terms given by the preceding formula over the link, with $\boldsymbol{R}_t$ representing the directed length of each linear short segment of the fiber link. Anyway, as long as the fiber link is geostationary, both the dot product $\boldsymbol{R}_t \cdot \boldsymbol{v}_{\mathrm{E}}$ and the speed $v_{\mathrm{E}}$ for each segment are invariant under earth's rotation, although the directed path length $\boldsymbol{R}_t$ and the velocity $\boldsymbol{v}_{\mathrm{E}}$ themselves do change continuously with earth's rotation. Consequently, the Sagnac effect due to earth's rotation and hence the propagation time are invariant under earth's rotation. Thereby, the proposed local-ether model is in accord with the spatial isotropy associated with the phase stability in the one-way-link experiment.

A similarly spatial isotropy has been demonstrated in the Kennedy–Thorndike experiment which deals with the interference between two paths different in length and shape [36]. Since the interferometer is geostationary, it can be expected that as in the one-way fiber link, the propagation time in each path is invariant under earth's rotation. Therefore, the phase difference between the two paths is also invariant under earth's rotational and orbital motions.

The spatial isotropy has also been demonstrated in a laser heterodyne experiment with a geostationary cavity to a high precision [37]. As in the one-way fiber link, the round-trip propagation time in a geostationary cavity is invariant under earth's rotation. Therefore, the resonance frequency of this cavity and hence the beat frequency are invariant under earth's rotational and orbital motions. As discussed previously, a breakdown in the isotropy can be expected when the orientation of the path or cavity is changed with respect to the ground.

### 6.6 Doppler frequency shift and Roemer's observations

Consider the Doppler effect for the case where the source is periodically emitting a wave and is moving with respect to the receiver. Suppose that the source and the receiver are moving at velocities $\boldsymbol{v}_{\mathrm{s}}$ and $\boldsymbol{v}_{\mathrm{e}}$, respectively. Due to the relative motion between the transmitter and the receiver, the rate of reception tends to be different from that of emission. The received time difference $\Delta t$ between two signals transmitted with a differential time difference $\Delta t'$ is given in terms of the difference in the propagation range by

$$\Delta t = \Delta t' + \frac{R(t' + \Delta t')}{c} - \frac{R(t')}{c}, \tag{20}$$

where $R(t)$ denotes the propagation range for the wave emitted at an arbitrary instant $t$. Then the time differences $\Delta t$ and $\Delta t'$ and hence the received frequency $f_{\mathrm{r}}$ and the transmitted frequency $f_{\mathrm{t}}$ are related by

$$\frac{f_{\mathrm{t}}}{f_{\mathrm{r}}} = \frac{\Delta t}{\Delta t'} = 1 + \frac{\mathrm{d}R}{c\mathrm{d}t}, \tag{21}$$

where the time derivative of the propagation range is evaluated at the instant of wave emission. It is seen that the Doppler frequency shift is due to the time rate of the change of the propagation range and hence the reference frame of the Doppler effect is identical to that of the Sagnac effect and the propagation range.

Based on the first-order propagation-range formula (7), the Doppler frequency relation is given by

$$\begin{aligned}\frac{f_{\mathrm{t}}}{f_{\mathrm{r}}} &= 1 + \frac{\mathrm{d}}{c\mathrm{d}t}\left\{R_t\left(1 + \frac{u_{\mathrm{e}}}{c}\right)\right\} \\ &= 1 + \frac{\mathrm{d}R_t}{c\mathrm{d}t} + \frac{\mathrm{d}}{c^2\mathrm{d}t}(\boldsymbol{v}_{\mathrm{e}} \cdot \boldsymbol{R}_t).\end{aligned} \tag{22}$$

Due to the relative motion between source and receiver, $\mathrm{d}\boldsymbol{R}_t/\mathrm{d}t = \boldsymbol{v}_{\mathrm{es}}$ and hence $\mathrm{d}R_t/\mathrm{d}t = u_{\mathrm{es}}$, where $\boldsymbol{v}_{\mathrm{es}}$ ($= \boldsymbol{v}_{\mathrm{e}} - \boldsymbol{v}_{\mathrm{s}}$) is the Newtonian relative velocity between receiver and source at the instant of emission, $u_{\mathrm{es}}$ ($= u_{\mathrm{e}} - u_{\mathrm{s}}$) is the radial speed of the receiver with respect to the source, and velocities $\boldsymbol{v}_{\mathrm{s}}$ and $\boldsymbol{v}_{\mathrm{e}}$ are referred to the local-ether frame. As given in [3], to the second order, the Doppler formula becomes

$$\frac{f_{\mathrm{t}}}{f_{\mathrm{r}}} = 1 + \frac{u_{\mathrm{es}}}{c} + \frac{\boldsymbol{v}_{\mathrm{e}} \cdot \boldsymbol{v}_{\mathrm{es}}}{c^2} + \frac{\boldsymbol{a}_{\mathrm{e}} \cdot \boldsymbol{R}_t}{c^2}. \tag{23}$$

It is noted that the second-order Doppler effect is due to the first-order Sagnac effect. Moreover, the transverse components of the velocities are involved in the second-order Doppler shift. The inverse frequency ratio given to the second order is

$$\frac{f_{\mathrm{r}}}{f_{\mathrm{t}}} = 1 - \frac{u_{\mathrm{es}}}{c} - \frac{\boldsymbol{v}_{\mathrm{e}} \cdot \boldsymbol{v}_{\mathrm{es}}}{c^2} - \frac{\boldsymbol{a}_{\mathrm{e}} \cdot \boldsymbol{R}_t}{c^2} + \frac{u_{\mathrm{es}}^2}{c^2}. \qquad (24)$$

This Doppler formula is quite general in the sense that the directions of the velocities are arbitrary and the receiver acceleration has been taken into account. When the acceleration $\boldsymbol{a}_{\mathrm{e}}$ is zero, the preceding frequency relation agrees with that derived in [38], aside from a slight difference in the interpretation of $\hat{R}_t$. For the case of radial relative motion without acceleration, where the relative velocity $\boldsymbol{v}_{\mathrm{es}}$ is parallel to $\pm\boldsymbol{R}_t$ and hence $\boldsymbol{v}_{\mathrm{e}} \cdot \boldsymbol{v}_{\mathrm{es}} = u_{\mathrm{e}} u_{\mathrm{es}}$, the frequency relation gets the familiar form:

$$\frac{f_{\mathrm{r}}}{f_{\mathrm{t}}} = \frac{1 - u_{\mathrm{e}}/c}{1 - u_{\mathrm{s}}/c}. \qquad (25)$$

This agrees with the classical Doppler formula derived in an alternative way [39].

Ordinarily, it suffices to use the first-order formula which reads

$$\frac{f_{\mathrm{t}}}{f_{\mathrm{r}}} = 1 + \frac{u_{\mathrm{es}}}{c}. \qquad (26)$$

It is noted that in this approximation, only the relative radial speed is involved and the Sagnac effect is wholly ignored. This first-order Doppler formula has been adopted in GPS for the measurement of the receiver's velocity [6] and in the Doppler frequency shift in the spectrum of the light radiated from stars.

In Roemer's observations, the apparent time interval $\Delta t$ between two successive eclipses of a moon of Jupiter is expected to vary fractionally as $1 + u_{\mathrm{es}}/c$, where $u_{\mathrm{es}}$ is the radial speed of the earthbound observer relative to the moon of Jupiter and incorporates both the rotational and the orbital motions of the earth. Thus the apparent eclipse interval is expected to exhibit a diurnal as well as a seasonal variation. With the astronomical knowledge of planetary motion in the solar system, the dependence of the apparent interval $\Delta t$ on the normalized speed $u_{\mathrm{es}}/c$ has been used as a pioneering approach to determine the speed of light.

## 6.7 Doppler effect in CMBR

Consider the cosmic microwave background radiation, where the sources are outside the solar system. It has been found that the measured spectrum of CMBR matches that of a blackbody radiation at about 2.73 K [40]. Further, it has been found that the blackbody temperature of the spectrum or simply the antenna temperature (received power per unit bandwidth) at a particular frequency depends slightly on the direction of reception [40–43]. The shift in the temperatures exhibits a small dipole distribution with respect to a particular symmetry axis in a frame beyond the solar system. The cosmic microwave is known to be radiated from numerous sources which are distributed around the earth. Further, the various sources are expected to be stationary with respect to each other; otherwise, the directional variation in the temperatures should be more complicated than a dipole distribution.

Based on the local-ether model, these sources then form an immense local ether which encloses the sun local ether. As the sources are stationary with respect to their local ether, the relative velocity $\boldsymbol{v}$ between the receiver and the source then becomes the receiver's velocity with respect to this CMBR local ether. For an earthbound receiver, the velocity $\boldsymbol{v}$ incorporates the linear velocity due to the orbital motion of the sun as well as those due to earth's rotational and orbital motions.

According to (26), the first-order Doppler shift is given by

$$\frac{\Delta f}{f_{\mathrm{t}}} = -\frac{v}{c}\cos\theta, \qquad (27)$$

where the frequency shift $\Delta f = f_{\mathrm{r}} - f_{\mathrm{t}}$ and $\theta$ is the angle between $\boldsymbol{v}$ and $\boldsymbol{R}_t$ ($\cos\theta = \hat{v} \cdot \hat{R}_t$). As the receiver velocity $\boldsymbol{v}$ remains almost constant over a short measurement interval during which the direction of receiving antenna (represented by the direction of $-\boldsymbol{R}_t$) is scanning, the Doppler frequency shift then exhibits a dipole anisotropy $\cos\theta$. The frequency shift will be maximum and minimum when the reception direction is parallel and antiparallel to the receiver velocity $\boldsymbol{v}$, respectively.

The frequency shift in turn will result in a proportional shift in the antenna or the blackbody temperature, as the radiation power depends on frequency. The amplitude of the fractional variation in these temperatures is then given as $v/c$, which is about $10^{-3}$ according to the data reported in the literature. Thereby, the receiver speed $v$ with respect to the CMBR local ether is expected to be about 300 km/s, which incorporates the orbital motion of the sun together with earth's rotational and orbital motions. Thus, as well as the eclipse interval in Roemer's observations, the receiver speed $v$ and hence the magnitude of the dipole anisotropy are expected to exhibit diurnal and, particularly, seasonal variations. Earth's orbital motion is expected to affect the dipole amplitude by 10 percent. This seasonal variation has been demonstrated by comparing two observations separated by six months [42, 43].

In spite that these arguments may sound reasonable, the first-order Doppler effect is associated with a relative velocity and hence cannot provide decisive support for a proposed propagation model. The predicted first-order Doppler shift based on wave propagation in the proposed CMBR local ether will be identical to that in another frame or even to that in the universal ether adopted in the "new aether drift" [41]. As seen from (24), the individual velocity of the receiver is incorporated in the second-order Doppler effect. Thus a crucial test for the local-ether model can be provided, if the directional anisotropy in the CMBR temperature can be measured to the second order. Anyway, the dipole anisotropy in CMBR is in accord with (or does not deny) the statement that a cosmic wave can be viewed as to propagate mainly via a classical medium stationary in a frame beyond the solar system.

### 6.8 Gravitational effects on propagation

To make the local-ether model more complete, we consider the deflection of light by the sun and the increment in interplanetary radar echo time which are commonly known as important evidences supporting the general theory of relativity. Based on the local-ether model, we present an alternative interpretation of these phenomena in a classical way without invoking the space-time curvature.

It is postulated that in the gravitational potential of a celestial body, the speed of light decreases slightly from $c$ to $c/n_{\mathrm{g}}$ with respect to this potential and hence to the local ether of the body, where the *gravitational index* $n_{\mathrm{g}}$ in turn is proposed to be associated with the gravitational potential $\Phi_{\mathrm{g}}$ by

$$n_{\mathrm{g}}(\boldsymbol{r}) = 1 + \frac{2}{c^2}\Phi_{\mathrm{g}}(\boldsymbol{r}) = 1 + 2\frac{GM}{c^2 r}, \tag{28}$$

where $G$ is the gravitational constant, and $r$ is the radial distance from the center of the celestial body of mass $M$.

The increment in propagation time per unit propagation range is given by $(n_{\mathrm{g}} - 1)/c$. By integrating this term along the path from the source at the instant of wave emission to the receiver at the instant of reception with respect to a heliocentric or a geocentric inertial frame, it has been shown quantitatively [44] that this propagation model is in accord with the increment in interplanetary radar echo time as the microwave passing near the sun [18–20] or with the increment in earthbound GPS propagation time [10, 7], respectively.

Furthermore, it has been shown quantitatively that the spatial variation of the gravitational index tends to cause a deflection of the light beam passing near a celestial body [44]. This situation is similar to the total internal reflection of a short wave from the ionosphere of which the refractive index is varying with altitude. Thus the local-ether model is in accord with these gravitational effects commonly ascribed to the general relativity.

## 7 Unsolved and predicted propagation phenomena

In this section, we discuss the stellar aberration, a propagation phenomenon not yet solved in the proposed model. Furthermore, we propose some propagation experiments not yet reported before. These predicted propagation phenomena as well as the predicted second-order round-trip Sagnac effect due to earth's rotation in Michelson–Morley-like experiments provide different approaches to test the proposed local-ether model.

### 7.1 Stellar aberration

Consider Bradley's stellar aberration observed in as early as 1725 [1]. In this experiment, the axis of a telescope has to be tilted by a small angle $\alpha$ in order for the light beam from a distant star to form an image at the center of the focal plane. Like the eclipse interval in Roemer's observations and the antenna temperature in CMBR, this tilt angle exhibits diurnal and seasonal variations. Actually, the stellar aberration is detected by these variations.

Based on the proposed model, no matter how far the star is, the light observable on the ground eventually enters into the sun local ether and then into the earth local ether. If the earth local ether can be omitted, then it is the movement of the telescope with respect to the sun local ether that determines the aberration. Further, only the movement transverse to the propagation path contributes to the aberration. Thereby, a classical derivation immediately leads to the aberration angle $\alpha$ given by

$$\alpha = \tan^{-1}(v_{\perp}/c), \tag{29}$$

where $v_{\perp}$ is the transverse component of the velocity of a geostationary telescope with respect to a heliocentric inertial frame. Since this velocity incorporates earth's rotational and orbital motions, the diurnal and the annual stellar aberrations can be expected, respectively.

Further, this formula shows that the aberration does not depend on the motion of source. This is in accord with the observation that aberrations for binary stars and for other stars are not different among themselves, in spite of the fact that the velocities of these stars can be quite different with respect to a geostationary telescope [45–47].

However, if the earth local ether is taken into consideration as it should, the explanation for the annual aberration is difficult. This is because the physical nature of the interface separating the two local ethers in relative motion and the wave behaviors (especially, the propagation direction) across the interface have to be identified. These interface problems cannot be determined from the propagation phenomena examined and are yet to be explored. Anyway, the local-ether model is in accord with the diurnal aberration, as this aberration is associated with the movement of the telescope with respect to the earth local ether and does not involve the interface.

### 7.2 One-way-link rotor

Reconsider the Michelson–Morley experiment. In order to test the Sagnac effect due to earth's rotation in a more feasible approach, we propose the rotor experiment by putting the setup of the aforementioned one-way-link experiment with a shortened link or that of the Kennedy–Thorndike experiment on a rotor or a turntable, just as in the Michelson–Morley experiment. However, unlike in the Michelson–Morley-type experiments, the Sagnac effect on the one-way propagation time is of first order and hence the measurement could be easier. To simplify its role in wave propagation, the fiber had better be replaced simply with free space as the link.

As the rotor is rotating, the direction of $\boldsymbol{R}_t$ and hence the dot product $\boldsymbol{R}_t \cdot \boldsymbol{v}_{\mathrm{E}}$ in the propagation-time formula (19) will change, where $\boldsymbol{R}_t$ is the directed separation distance from the source to the receiver and $\boldsymbol{v}_{\mathrm{E}}$ is the linear velocity due to earth's rotation. Accordingly, to the first order of the normalized speed, the fractional variation in the one-way propagation time is given by

$$\frac{\Delta\tau}{\tau} = \frac{v_{\mathrm{E}}}{c}\cos\theta_T, \tag{30}$$

where $\theta_T$ is the angle from $\boldsymbol{v}_{\mathrm{E}}$ to $\boldsymbol{R}_t$ and corresponds to the turning angle of the turntable. Since the velocity $\boldsymbol{v}_{\mathrm{E}}$ is eastward, $\theta_T = 0$ and $\pi$ when $\boldsymbol{R}_t$ points in the east and the west directions, respectively.

The corresponding phase shift is then expected to exhibit a sinusoidal variation:

$$\begin{aligned}\Delta\phi &= 2\pi f R_t \frac{v_{\mathrm{E}}}{c^2}\cos\theta_T \\ &\simeq 1.86 f R_t \cos\theta_l \cos\theta_T \times 10^{-3},\end{aligned} \tag{31}$$

where the phase shift $\Delta\phi$ is in deg, the frequency $f$ in GHz, the path length $R_t$ in meter, and $\theta_l$ is the latitude. The phase shift reaches maximum and minimum when the rotor comes to a position such that $\boldsymbol{R}_t$ is eastward and westward, respectively. Consequently, the spatial isotropy may break down and a dipole anisotropy could be observed, as the rotor is rotating. Thereby, the proposed one-way-link rotor or the Kennedy–Thorndike rotor experiment can provide a rather direct means to test the propagation model to the first order of the normalized speed.

### 7.3 Second-order radar Doppler shift

Finally, we consider the Doppler frequency shift in the monostatic radar system, where the received frequency $f_{\mathrm{r}}$ after reflection from the target tends to differ from the transmitted frequency $f_{\mathrm{t}}$. The first-order round-trip propagation range implied in (11) is given by $R = 2R_t(1+u/c)$, where the radial speed $u = \boldsymbol{v}\cdot\hat{R}_t$ and $\boldsymbol{v}$ is the velocity of the target relative to the transceiver. Then, by replacing this propagation range in the Doppler formula (21), the transmitted and the received frequencies for the round-trip propagation are related by

$$\frac{f_{\mathrm{t}}}{f_{\mathrm{r}}} = 1 + 2\frac{\mathrm{d}R_t}{c\mathrm{d}t} + 2\frac{\mathrm{d}\left(\boldsymbol{v}\cdot\boldsymbol{R}_t\right)}{c^2\mathrm{d}t}. \tag{32}$$

As given in [48], the second-order radar Doppler formula becomes

$$\frac{f_{\mathrm{t}}}{f_{\mathrm{r}}} = 1 + \frac{2u}{c} + \frac{2v^2}{c^2} + \frac{2\boldsymbol{a}\cdot\boldsymbol{R}_t}{c^2}, \tag{33}$$

where the acceleration $\boldsymbol{a} = \mathrm{d}\boldsymbol{v}/\mathrm{d}t$. The inverse frequency ratio given to the second order is

$$\frac{f_{\mathrm{r}}}{f_{\mathrm{t}}} = 1 - \frac{2u}{c} - \frac{2v^2}{c^2} - \frac{2\boldsymbol{a}\cdot\boldsymbol{R}_t}{c^2} + \frac{4u^2}{c^2}. \tag{34}$$

It is noted that both the first and the second orders of the normalized speeds in the radar Doppler shift depend on relative velocity.

For the case of radial relative motion without acceleration ($u = \pm v$ and $\boldsymbol{a} = 0$), the second-order radar Doppler formula becomes simpler:

$$\frac{f_{\mathrm{r}}}{f_{\mathrm{t}}} = 1 - \frac{2u}{c} + \frac{2u^2}{c^2} = \frac{1-u/c}{1+u/c}. \tag{35}$$

This agrees with the formula derived in several different approaches, including the Lorentz transformation [49,50], the moving boundary conditions on plane wave reflection [26], and the variation in radar range [50].

However, for the general case, the radar Doppler formula predicted by the local-ether model disagrees with the preceding formula in the second-order terms. For the case of transverse relative motion where $u = 0$, the local-ether model leads to a nonzero frequency shift of $\Delta f/f_{\mathrm{t}} = -2v^2/c^2$, where $\Delta f = f_{\mathrm{r}} - f_{\mathrm{t}}$, in addition to that due to the acceleration. It has been pointed out that for the case where the target is a low-earth-orbit satellite and the transmitted frequency is 10 GHz, the discrepancy between the preceding two formulas can be a few Hz [48]. Thus, the radar Doppler shift provides a means to test the propagation model to the second order.

## 8 Discussion

The local-ether model of wave propagation proposed in this investigation provides the groundwork for a wave equation governing both electromagnetic and matter waves. In a potential-free region, the *local-ether wave equation* is proposed to be

$$\left\{\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right\}\Psi(\boldsymbol{r},t) = \frac{\omega_0^2}{c^2}\Psi(\boldsymbol{r},t), \tag{36}$$

where the natural angular frequency $\omega_0$ is supposed to be an inherent constant of the particle represented by the wavefunction $\Psi$. This wave equation looks like the Klein–Gordan equation; however, one fundamental difference is that the position vector $\boldsymbol{r}$ and hence the time derivative in this wave equation are referred uniquely to the local-ether frame. If the natural frequency is zero, the equation reduces to the homogeneous wave equation for an electromagnetic wave in free space discussed in this investigation. Consequently, the propagation of an electromagnetic wave is then referred to the local-ether frame, as proposed in this investigation.

Under the influence of the gravitational potential due to a celestial body, it is supposed that the d'Alembertian operator in the local-ether wave equation is modified. Furthermore, under the influence of the electric scalar potential due to another charged particle, it is supposed that the natural frequency in the wave equation connects to this potential which in turn connects to the augmentation operator. Quantitatively, it is proposed that under the influence of the gravitational potential $\Phi_{\mathrm{g}}$ and the electric scalar potential $\Phi$, the matter wave $\Psi$ of the particle of natural frequency $\omega_0$ and charge $q$ is governed by the local-ether wave equation proposed to be

$$\left\{\frac{1}{n_{\mathrm{g}}}\nabla^2 - \frac{n_{\mathrm{g}}}{c^2}\frac{\partial^2}{\partial t^2}\right\}\Psi(\boldsymbol{r},t)$$

$$= \frac{\omega_0^2}{c^2} \left\{ 1 + 2 \frac{q\Phi}{\hbar\omega_0}(1+U) \right\} \Psi(\boldsymbol{r}, t), \qquad (37)$$

where $\hbar$ connecting to the electric scalar potential is Planck's constant divided by $2\pi$ and the augmentation operator $U$ is associated with the Laplacian operator and the velocity of the source particle. All the involved physical quantities, position vectors, time derivatives, velocities, and the current density, are referred uniquely to their respective reference frames. It has been shown that this local-ether wave equation leads to a unified quantum theory of the gravitational and the electromagnetic forces in conjunction with the identity of gravitational and inertial mass [51–53].

Furthermore, the local-ether wave equation leads to the speed-dependent angular frequency and wavelength of the matter wave and the speed-dependent mass of the particle. These formulas look like the postulates of de Broglie and the Lorentz mass-variation law, except for the reference frame of the particle speed. As the mass of the electron or the nucleon affects the energies of the quantum states in an atom or a molecule, the transition frequency between two quantum states depends on the particle speed. Like the propagation speed of an earthbound electromagnetic wave, the speed of an earthbound particle that determines quantum energy and transition frequency is referred uniquely to an ECI frame. Consequently, this speed-dependent transition frequency then accounts for the east–west anisotropy in the Hafele–Keating experiment with circumnavigation atomic clocks and for the high synchronism among the various GPS atomic clocks [54, 55]. Moreover, the shift in speed-dependent transition frequency is in accord with the clock-rate adjustment [5, 7] to keep the GPS atomic clocks synchronous with the ground clocks, as the former are much faster in an ECI frame.

## 9 Conclusion

It is supposed that an electromagnetic wave propagates via a medium like the ether. However, the ether is not universal. It is proposed that in the region under sufficient influence of the gravity due to the earth, the sun, or another celestial body, there forms a local ether which in turn is stationary with respect to the gravitational potential of the respective body. Thereupon, each local ether together with the gravitational potential moves with the associated celestial body. Thus the earth and the sun local ethers are stationary in a geocentric and a heliocentric inertial frame, respectively. Consequently, the propagation of an earthbound electromagnetic wave is referred to this geocentric frame and is entirely independent of earth's orbital motion around the sun or whatever, while for interplanetary propagation, the sun local ether is the main propagation medium and hence the majority of propagations are referred to this heliocentric frame and independent of the orbital motion of the sun. The speed of light is referred to the associated local ether and is independent of the motions of source and receiver. However, by virtue of the Sagnac effect due to the movement of receiver with respect to the local ether during wave propagation, the propagation range over the associated medium tends to be different from the frame-independent path length.

Based on the propagation-range formula, the local-ether model has been used to solve the discrepancies in the effects of earth's rotational and orbital motions. By referring the earthbound propagation range to an ECI frame, the local-ether model accounts for the first-order Sagnac effect due to earth's rotation in GPS, intercontinental microwave link experiments, and in loop interferometry. Meanwhile, the local-ether model immediately accounts for the null effect of earth's orbital motion on the earthbound propagations in GPS, intercontinental microwave link experiments, loop interferometry, the one-way fiber link experiment, the Kennedy–Thorndike experiment, the cavity heterodyne experiment, and in the Michelson–Morley experiment.

By referring the interplanetary propagation range to a heliocentric inertial frame, both rotational and orbital motions of the earth are expected to contribute to the Sagnac effect. Thus, the local-ether model accounts for the discrepancy in the Sagnac effect due to earth's orbital motion between the interplanetary radar and the earthbound GPS and microwave link. When the source and hence the main propagation path are outside the solar system, the orbital motion of the sun as well as earth's motions is expected to contribute to the Doppler effect. This effect is in accord with the dipole anisotropy found in the antenna and the blackbody temperatures of CMBR and with the seasonal variation of the dipole amplitude.

Moreover, the local-ether model is in accord with the earthbound radar echo time, the constancy of the speed of light from binary stars, synchrotron electrons, and from semistable particles, and with the Doppler effect in GPS, stellar frequency shift, Roemer's observations, and in earthbound radar measurements. Further, by modifying the d'Alembertian of the wave equation and hence the speed of light under a gravitational potential, the local-ether model is in accord with the deflection of light by the sun and the increase in the interplanetary radar echo time for a microwave passing close to the sun, which are commonly cited as evidence supporting the general theory of relativity.

Although earth's rotation contributes to the Sagnac effect, this effect in a geostationary propagation path is invariant under the earth's rotation. This accounts for the hourly and daily stability in phase difference in the one-way fiber link experiment and in the Kennedy–Thorndike experiment and that in beat frequency in the cavity heterodyne experiment. Thus it is the invariance in the Sagnac effect that corresponds to the spatial isotropy observed in these geostationary interference experiments. However, if the interferometer is put on a turntable as in the Michelson–Morley experiment, the isotropy may break down and hence a directional anisotropy could be observed as the turntable is rotating. Based on the round-trip Sagnac effect due to earth's rotation, we predict a quadrupole anisotropy in beat frequency in the cavity heterodyne experiment as well as that in the interference fringes in the Michelson–Morley experiment. Further, based on the one-way Sagnac effect due to earth's rotation, we propose the one-way-link rotor or the Kennedy–Thorndike rotor experiment, in which a dipole anisotropy in phase shift is predicted. Unlike that in the Michelson–Morley-type experiments, the one-way Sagnac effect is of the first order of the normalized speed and hence the measurement could be easier.

As a last word, although the proposed local-ether model is just a simple modification of the classical propagation model with the switchability of the propagation frame, it does account for a wide variety of earthbound, interplanetary, and interstellar propagation phenomena, except for the annual stellar aberration. The strong evidence of this model is its consistent account of the Sagnac effect due to the earth's motions among GPS, the intercontinental microwave link and the interplanetary radar experiments, and the Michelson–Morley experiment. Moreover, it leads to new predictions associated with the one-way or round-trip Sagnac effect due to earth's rotation, which provide different approaches to test the local-ether model. Further, the proposed propagation model provides the groundwork for the local-ether wave equation which leads to a unified quantum theory of the gravitational and the electromagnetic forces and to a speed-dependence in the angular frequency, wavelength, mass, quantum energy, and transition frequency.

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