On the Existence of a Cosmic Ether: Detection of the Rotational and Orbital Motions of the Earth Using GPS Technology

On the Existence of a Cosmic Ether: Detection of the Rotational and Orbital Motions of the Earth Using GPS Technology

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> "If future experiments were to reveal a non-zero aether drift, then Einstein's relativity would crumble."
>
> Diana Buchwald and Kip Thorne, 2004

Abstract: In this paper the evidence for the existence of a cosmic ether obtained using modern technology is reviewed. The synchronized clocks of the GPS are applied in the search for ether drift by direct measurement of light travel times in the East-West direction. This method reveals that light travels faster West than East and therefore indicates the existence of a cosmic medium for light transmission. The GPS clocks are then applied in the search for ether drift by direct measurement of light travel times in a modified Michelson-Morley experiment. The East-West light speed difference enables the unambiguous detection of ether drift and the direct confirmation of the existence of a preferred frame. The range equation of the GPS that operates in the Earth-centered inertial (ECI) frame is employed to demonstrate ether drift for rotational motion and Time Transfer technology involving a geo-stationary GPS satellite provides further confirmation of ether drift resulting from the rotating Earth. Using a geo-stationary satellite signal source and the phenomenon of aberration, Shtyrkov appears to detect the Earth's orbital motion with apparatus fixed relative to the surface of the orbiting Earth. Finally, using a model applicable in the sun-centered inertial frame with Coordinated Universal Time, light speed variation arising from the Earth's orbital motion for light reflected from planets and spacecraft and received at the surface of the Earth was demonstrated. The evidence then is that modern technology easily detects ether drift for rotational and orbital motion from the frame of the moving Earth.

1. Introduction

At the turn of the 20th century there was considerable evidence supporting the existence of the hypothesized ether, a cosmic medium through which electromagnetic waves were believed to travel [1, 2]. In search of direct evidence of its existence, the famous Michelson-Morley experiment of 1887 [3] tried to detect movement of the Earth through this medium based on light speed changes and consequent interferometer fringe shifts. This experiment involved interfering light beams that traversed orthogonal paths on a movable apparatus. It was designed to reveal the speed of the Earth's orbital motion through the hypothesized ether based on the expected change in light speed arising from movement with or against the associated ether wind. The recorded fringe shift was significantly less than the value expected as a result of the orbiting Earth and the essentially null result was interpreted as an indication of light speed constancy. This idea of light speed invariance later formed the foundation of the special theory of relativity.

In a recent paper DeMeo [4] reviewed some of the empirical data associated with this experiment and the search for a cosmic ether. He focused specifically on the extensive Michelson-Morley type experiments of Dayton Miller [5] which did suggest ether-drift detection in a specific direction through the cosmos. He also discussed the rebutting paper by Shankland et al. [6] that attributed the fringe shifts observed by Dayton Miller to temperature variations as a result of which Dayton Miller's results have been largely forgotten. Modern versions of these experiments use electromagnetic resonators in search of light speed anisotropy [7-10]. They compare the resonant frequencies of two orthogonal resonators and seek to detect light speed changes arising from orbital or rotational motion of the Earth. These experiments conducted in the frame of the rotating Earth have progressively lowered the limit on light speed anisotropy to a value of $\delta c / c < 10^{-17}$ where δc is the measured change in light speed. There are other published cases of Michelson-Morley type experiments which like the Dayton Miller experiments claim positive results including experiments by Demjanov [11], Galeav [12] and Munera [13] [see also Winkell and Rodríguez [14]] but these too have been ignored.

Thus based on Michelson-Morley interferometry, the accepted position in science today is that the ether is either non-existent or undetectable and light speed is universally constant since it does not require a medium for its transmission. However modern satellite and atomic clock technology have now enabled renewed searches for ether drift arising from both orbital and rotational motion of the Earth and these new approaches are the subject of this paper. We review modern tests for light speed changes arising from ether drift using the synchronized clocks of the GPS, the range equation of the ECI frame, the time transfer technique, interplanetary tracking technology and aberration using signals from a geostationary satellite.

2. Detection of the Rotational Motion of the Earth Using GPS Technology

Following the failure of the Michelson-Morley experiment to detect the orbital motion of the Earth, Michelson in 1904 [15] suggested a different test to detect the rotational motion of the Earth. He proposed that if the ether is not entrained by the rotating Earth then two rays of light circumnavigating the Earth in opposite directions would do so in measurably different times that are dependent on the rotational speed w of the Earth. This is because the ray travelling westward would do so at a speed $c+w$ while the ray travelling eastward would do so at a speed $c-w$. Michelson and Gale [16] tested and indeed confirmed the predicted fringe shift arising from the rotating Earth using a very large rectangular path fixed on the surface of the Earth. This experiment was repeated and again confirmed with greater precision by Bilger et al. [17] using laser technology. The precursor to this kind of experiment was the Sagnac experiment performed in 1913 in a successful table-top demonstration of fringe shifts arising from rotation of laboratory apparatus [18].

While the Michelson-Gale experiments gave results consistent with the differences in light travel time predicted by ether drift for light travelling in opposite directions around the rotating Earth, like the Michelson-Morley experiments they do not directly measure these time differences and therefore only indirectly indicate light speed variation. This has allowed claims that the observed fringe shift may also be explainable by special relativity from which it can be derived [19]. Since special relativity demands constant light speed on the rotating Earth [20] and therefore no east-west time differences as arising from ether drift, what was needed was a direct east-west measurement of one-way light transmission time between two points fixed on the surface of the rotating Earth such as was attempted by Allen et al. [21]. Indeed Bethell quoted from an 1875 article in the Encyclopedia Britannica in which Maxwell stated [22], “If it were possible to determine the velocity of light by observing the time it takes [for light] to travel between one station and another on the earth’s surface, we might by comparing the observed velocities in opposite directions, determine the velocity of the ether with respect to these terrestrial stations.”

The very successful Global Positioning System (GPS) contains the technology needed to implement this idea and thereby provides a new and interesting approach to ether drift detection. It is a modern navigational system that employs accurate synchronized atomic clocks in its operation [23]. These clocks enable the accurate determination of time and are employed in a range of real-world applications including time-stamping of commercial transactions, network synchronization and the direct measurement of light travel times and one-way light speed. According to the IS-GPS-200E Interface Specification [24], GPS signals propagate in straight lines at the constant speed c (in vacuum) in an Earth-Centered Inertial (ECI) frame, a frame that moves with the Earth but does not share its rotation. This constancy of the speed of light in the ECI frame has been exhaustively confirmed and is utilized in the range equation of the GPS to accurately determine the instantaneous position of objects which are stationary or moving on or near the surface of the Earth. Light speed constancy in the ECI frame also enables the accurate synchronization of clocks which are stationary in or moving through this frame such as clocks fixed on the surface of the rotating Earth [25].

Therefore instead of using interferometry to indirectly deduce time differences in light travel arising from ether drift, such time differences can now be directly measured using synchronized clocks of the GPS. Marmet [26] using data from the GPS observed that light takes longer traveling eastward from San Francisco to New York as compared with the signal traveling westward from New York to San Francisco. Kelly [27] also noted that measurements using the GPS reveal that a light signal takes some 414 nanoseconds longer to circumnavigate the Earth eastward at the equator than a light signal travelling westward around the same path. These two researchers concluded that these observed travel time differences in the synchronized clock measurements in each direction occur because light travels at speed $c-v$ eastward and $c+v$ westward relative to the surface of the Earth consistent with ether drift arising from the rotating Earth. Here v is the speed of rotation of the Earth's surface at the particular latitude. This research by Marmet and Kelley was followed by a series of papers by this author and others on the use of GPS technology in the determination of the one-way speed of light and this work is summarized in what follows.

2.1 One-way Light Speed Using GPS Clocks [28, 29]

The availability of synchronized clocks in the GPS means that they can be used to determine the one-way speed of light by timing the transmission of a light signal travelling between two fixed points on the surface of the Earth. Consider therefore a clock A located a distance *l* away from another clock B at the same latitude as shown in figure 1, clock B being East of clock A.

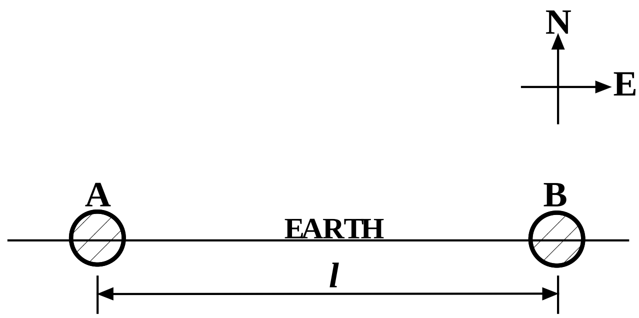


Fig.1 GPS Clocks A and B at fixed positions on Earth

If necessary the distance between the clocks can be kept short in order to approximate an inertial frame and thereby negate any objections regarding the curvature of the Earth's surface and the associated non-inertial effects.

Eastward Transmission

The CCIR clock synchronization rules give the total time Δt for light to travel eastward along the path from clock A to clock B as [25, 29]

$$\Delta t = \int_{path} \frac{d\sigma'}{c} + \frac{2\omega_E}{c^2} \int_{path} dA'_z \tag{1}$$

where c is the speed of light, $d\sigma'$ is infinitesimal distance in the moving frame, ω_E is the angular velocity of the rotating Earth and dA'_z is the infinitesimal area in the rotating coordinate system swept out by a vector from the rotation axis to the light pulse and projected onto a plane parallel to the equatorial plane. Performing the integration required in (1) yields [28, 29]

$$\Delta t = \frac{l}{c} + 2A'_z \frac{\omega_E}{c^2} \tag{2}$$

where l is the distance between the two clocks both moving at speed v the speed of the Earth's surface at that latitude. Let the circumference of the Earth at that latitude be l_C and let the corresponding radius be r. Then the area A'_z is given by

$$A_z' = \frac{l}{l_C}\pi r^2 \tag{3}$$

Since $\omega_E = v/r$ and $l_C = 2\pi r$, substituting equation (3) in (2) results in

$$\Delta t = \frac{l}{c} + \frac{lv}{c^2} \tag{4}$$

The time interval Δt given by (4) indicates the time for light to travel eastward between two points at the same latitude fixed on the surface of the Earth a distance l apart and represents that determined using synchronized atomic clocks.

This elapsed time can now be used to determine light speed between the two clocks. Since the distance between the two clocks is l, it follows that the one-way speed of light c_{AB} traveling eastward between the two clocks is given by

$$c_{AB} = \frac{l}{\Delta t} = \frac{l}{\frac{l}{c} + \frac{lv}{c^2}} = c(1+\frac{v}{c})^{-1} = c(1-\frac{v}{c}+o(\frac{v}{c})) = c - v, v << c \tag{5}$$

Thus the synchronized clocks of the GPS give a one-way eastward light speed measurement of $c_{AB} = c - v$ relative to the surface of the Earth as implied in the Michelson-Gale experiment of 1923.

Westward Transmission

For westward transmission again appropriately performing the integration in (1) yields the total time Δt for light to travel the path westward from clock B to clock A given by [28, 29]

$$\Delta t = \frac{l}{c} - 2A_z' \frac{\omega_E}{c^2} \tag{6}$$

which reduces to

$$\Delta t = \frac{l}{c} - \frac{lv}{c^2} \tag{7}$$

The time interval Δt given by (7) indicates the time for light to travel westward between two points at the same latitude fixed on the surface of the Earth a distance l apart and represents that determined using synchronized atomic clocks.

Using the time found in (7) for one-way light travel in the westward direction, since the distance between the two clocks is l, it follows that the one-way speed of light c_{BA} traveling westward between the two clocks is given by

$$c_{BA} = \frac{l}{\Delta t} = \frac{l}{\frac{l}{c} - \frac{lv}{c^2}} = c(1 - \frac{v}{c})^{-1} = c(1 + \frac{v}{c} + o(\frac{v}{c})) = c + v, v << c \qquad (8)$$

Thus the synchronized clocks of the GPS give a one-way westward light speed measurement of $c_{BA} = c + v$ relative to the surface of the Earth again as indirectly confirmed in the Michelson-Gale experiment of 1923.

The results in equations (5) and (8) therefore confirm the independent claims of Marmet and Kelley that light travels faster West than East relative to the surface of the rotating Earth. Specifically the one-way measurement of light speed using GPS data in (5) directly indicates that a light signal sent eastward travels at speed c minus the rotational speed of the Earth v at that latitude i.e. $c - v$. The GPS data available in (8) also shows that a light signal sent westward travels at speed c plus the rotational speed of the Earth v at that latitude i.e. $c + v$. These generalized results were first published by Gift [28] and confirm the indirect results of the Michelson-Gale experiment that revealed ether drift associated with the rotation of the Earth.

2.2 Michelson-Morley Experiment using the GPS Clocks [30]

With the availability of accurate synchronized clocks, a modified Michelson-Morley experiment can be conducted with direct timing of the signals traversing the orthogonal arms of the apparatus with no reliance on interferometry. Such an approach was previously considered but never executed because of insufficient timing resolution [31]. The proposed approach does not encounter this problem since the light travel time is directly available from the GPS clock synchronization algorithm utilized by the CCIR [27].

The basic configuration of the original Michelson-Morley experiment [3] is shown in figure 2 where the apparatus is moving with velocity v through the hypothesized ether in direction PM1. Light from a source S splits into two beams at beam-splitter P. One beam travels from P to mirror M1 and back and is reflected at P into the interferometer I. The second beam is reflected at P to mirror M2 and back and passes through P into the interferometer I where both beams form an interference pattern.

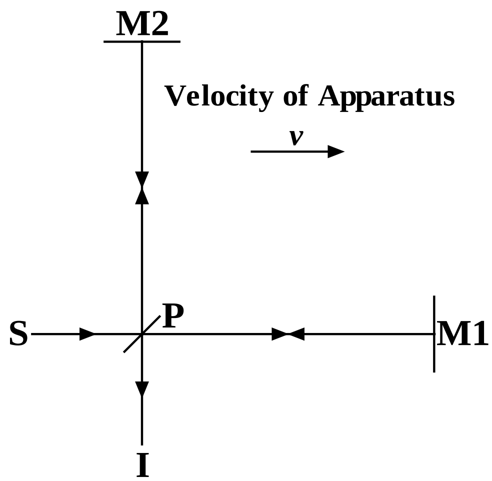


Fig.2 Michelson-Morley Experiment

In the frame of the moving apparatus as a result of ether drift, the resultant light speed between P and M1 would be $c-v$ toward M1 and $c+v$ toward P while the resultant light speed between P and M2 would be $(c^2-v^2)^{1/2}$ in both directions. For optical path lengths $PM1=l_1$ and $PM2=l_2$ the time $t_1(a)$ for the light to travel from P to M1 is given by

$$t_1(a)=\frac{l_1}{c-v} \tag{9}$$

and the time $t_1(b)$ for the light to travel from M1 to P is given by

$$t_1(b)=\frac{l_1}{c+v} \tag{10}$$

The time $t_2(a)$ for the light to travel from P to M2 is given by

$$t_2(a)=\frac{l_2}{\sqrt{c^2-v^2}} \tag{11}$$

and the time $t_2(b)$ for the light to travel from M2 to P is given by

$$t_2(b)=\frac{l_2}{\sqrt{c^2-v^2}} \tag{12}$$

The synchronized clocks in the GPS are now used to directly determine one-way light travel time. Thus in a modification of the original Michelson-Morley apparatus GPS clocks are placed at P, M1 and M2 in fig.2. Additionally the arm PM1 is oriented along a line of latitude and the arm PM2 is positioned along a line of longitude. As a result of the rotation of the Earth there is movement of the apparatus at velocity $v = w$ in the direction PM1 towards the East where w is the rotational speed of the surface of the Earth at the particular latitude.

Time Measurement along PM1

The time $t_1(a)_{GPS}$ measured by the GPS clocks at P and M1 for the light to travel from P to M1 is [28, 29]

$$t_1(a)_{GPS} = \frac{l_1}{c} + \frac{l_1 w}{c^2} \tag{13}$$

while from equation (9) of ether theory

$$t_1(a) = \frac{l_1}{c - w} \approx \frac{l_1}{c} + \frac{l_1 w}{c^2}, w << c \tag{14}$$

Hence $t_1(a)_{GPS} = t_1(a)$ and ether drift arising from the rotation of the Earth is detected. The time $t_1(b)_{GPS}$ measured by the GPS clocks for the light to travel from M1 to P is [28, 29]

$$t_1(b)_{GPS} = \frac{l_1}{c} - \frac{l_1 w}{c^2} \tag{15}$$

while from equation (10) of ether theory

$$t_1(b) = \frac{l_1}{c + w} \approx \frac{l_1}{c} - \frac{l_1 w}{c^2}, w << c \tag{16}$$

Hence $t_1(b)_{GPS} = t_1(b)$ and ether drift arising from the rotation of the Earth is again detected. From ether theory as well as clock measurement, the difference in the out and back times along PM1 is given by

$$\Delta t_1 = t_1(a) - t_1(b) = \frac{2l_1}{c} \frac{w}{c} \tag{17}$$

Result (17) is first-order and therefore not affected by second-order effects such as length contraction as is the second-order result in the conventional Michelson-Morley type experiments. Equation (17) has been extensively verified in GPS operation.

Time Measurement along PM2

The time $t_2(a)_{GPS}$ for the light to travel from P to M2 measured by the GPS clocks at P and M2 is [29]

$$t_2(a)_{GPS} = \frac{l_2}{c} \tag{18}$$

while from equation (11) of ether theory

$$t_2(a) = \frac{l_2}{\sqrt{c^2 - w^2}} \approx \frac{l_2}{c}, w << c \tag{19}$$

Hence $t_2(a)_{GPS} = t_2(a)$ and ether theory is confirmed by GPS measurement. The time $t_2(b)_{GPS}$ for the light to travel from M2 to P measured by the GPS clocks is [29]

$$t_2(b)_{GPS} = \frac{l_2}{c} \tag{20}$$

while from equation (12) of ether theory

$$t_2(b) = \frac{l_2}{\sqrt{c^2 - w^2}} \approx \frac{l_2}{c}, w << c \tag{21}$$

Hence $t_2(b)_{GPS} = t_2(b)$ and ether theory is again confirmed by GPS measurement. From ether theory as well as GPS clock measurement, the difference in the out and back times along PM2 is given by

$$\Delta t_2 = t_2(a) - t_2(b) = 0 \tag{22}$$

This has been confirmed by actual GPS measurements which have shown that unlike East-West travel, there is no time difference between light travelling North and light travelling South.

The modified Michelson-Morley experiment using synchronized GPS clocks to measure light travel times out and back along the arms of the apparatus has detected ether drift resulting from the rotation of the Earth. The clocks have directly confirmed the light travel times for changed light speeds $c \pm w$ in the East-West direction arising from the drift of the ether as the apparatus moves through the medium at speed w corresponding to the speed of rotation of the Earth's surface at the particular latitude.

2.3 One-way Light Speed Using the GPS Range Equation [32]

In section 2.1 the synchronized clocks of the GPS were used to determine travel time for light transmission between two fixed points on the same latitude of the Earth. Here the range equation used in the GPS to determine position on or close to the surface of the Earth is employed in the determination of travel time. Specifically by substituting known spatial positions in the range equation, light travel times can be determined without the direct use of the synchronized clocks. These times can then be used to determine one-way light speed in the East-West direction.

The range equation is a central feature of the operation of the GPS. It represents light travel in the ECI frame which moves with the Earth as it revolves around the Sun but does not share the Earth's rotation. It is given by [24, 25]

$$\left|\overline{r_r}(t_r) - \overline{r_s}(t_s)\right| = c(t_r - t_s) \qquad (23)$$

where t_s is the time of transmission of an electromagnetic signal from a source, t_r is the time of reception of the electromagnetic signal by a receiver, $\overline{r_s}(t_s)$ is the position of the source at the time of transmission of the signal and $\overline{r_r}(t_r)$ is the position of the receiver at the time of reception of the signal. Using GPS time measurements in equation (23) the position on the surface of the Earth can be accurately determined. This equation has been extensively tested and rigorously verified and has enabled the worldwide proliferation of the GPS.

Wang [33] has used the range equation to show that the speed of light is dependent on the observer's uniform motion relative to the ECI frame. We use the range equation (23) of the GPS to determine elapsed time for light traveling between two points at the same latitude fixed at known positions on the surface of the rotating Earth. We then use this elapsed time and the known distance between the two fixed points to determine the one-way speed of light.

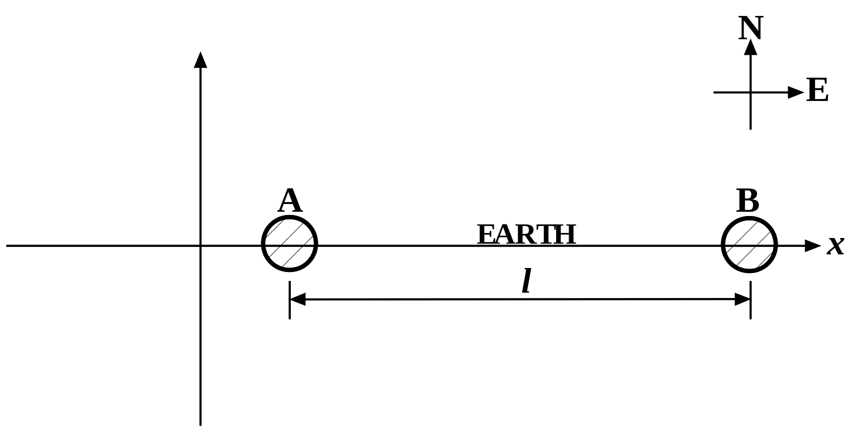


Fig.3 GPS Stations A and B at fixed positions on Earth

Consider figure 3 in which two GPS stations A and B are at the same latitude and fixed on the surface of the Earth a distance l apart with B East of A. Since the Earth is rotating, the stations are moving eastward at speed v the Earth's surface speed at the particular latitude. Let l be sufficiently small such that the stations are moving uniformly in the same direction at speed v relative to the ECI frame. In such circumstances stations A and B constitute an approximately inertial frame moving at speed *v* relative to the ECI frame, a situation similar to the many light speed experiments conducted to test light speed constancy.

Eastward Transmission

Let station A transmit a signal eastward at time t_I to station B which receives it at time t_F. On an axis fixed in the ECI frame along the line joining the two stations with the origin west of station A, let $x_A(t)$ be the position of station A at time *t* and $x_B(t)$ be the position of station B at time *t*. Then from the range equation (23),

$$x_B(t_F) - x_A(t_I) = c(t_F - t_I) \tag{24}$$

where $x_B(t_F)$ is the position of station B at time t_F and $x_A(t_I)$ is the position of station A at time t_I. Since the stations are moving uniformly in the same direction at speed *v* relative to the ECI frame, it follows that the relation between the position $x_B(t_F)$ of station B at the time of reception of the signal and its position $x_B(t_I)$ at the time of emission of the signal is given by

$$x_B(t_F) = x_B(t_I) + v(t_F - t_I) \tag{25}$$

Substituting for $x_B(t_F)$ from (25) in (24) yields

$$x_B(t_I) - x_A(t_I) + v(t_F - t_I) = c(t_F - t_I) \tag{26}$$

This gives the elapsed time as

$$(t_F - t_I) = \frac{l}{c - v} \tag{27}$$

Therefore the speed c_{AB} of the light traveling from station A to station B is given by separation l divided by elapsed time $(t_F - t_I)$ which using (27) is

$$c_{AB} = \frac{l}{(t_F - t_I)} = \frac{l}{l/(c - v)} = c - v \tag{28}$$

Westward Transmission

Let station B transmit a signal westward at time t_I to station A which receives it at time t_F. Then using the range equation (23) and noting that $x_B(t_I) > x_A(t_F)$,

$$x_B(t_I) - x_A(t_F) = c(t_F - t_I) \tag{29}$$

where $x_B(t_I)$ is the position of station B at time t_I and $x_A(t_F)$ is the position of station A at time t_F. Since the stations are moving uniformly in the same direction at speed v relative to the ECI frame, the relation between the position $x_A(t_F)$ of station A at the time of reception of the signal and its position $x_A(t_I)$ at the time of emission of the signal is given by

$$x_A(t_F) = x_A(t_I) + v(t_F - t_I) \tag{30}$$

Substituting for $x_A(t_F)$ from (30) in (29) yields

$$x_B(t_I) - x_A(t_I) - v(t_F - t_I) = c(t_F - t_I) \tag{31}$$

This yields the elapsed time as

$$(t_F - t_I) = \frac{l}{c+v} \tag{32}$$

Therefore the speed c_{BA} of the light traveling from station B to station A is given by separation l divided by elapsed time $(t_F - t_I)$ which using (32) is

$$c_{BA} = \frac{l}{(t_F - t_I)} = \frac{l}{l/(c+v)} = c + v \tag{33}$$

The results in equations (28) and (33) first reported in [32] indicate that light travels faster West than East relative to the surface of the Earth. To be specific, the one-way determination of light speed using the range equation of the GPS establishes in (28) that a signal sent eastward travels at speed c minus the rotational speed of the Earth v at that latitude giving $c - v$. The range equation also shows in (33) that a signal sent westward travels at speed c plus the rotational speed of the Earth v at that latitude giving $c + v$. This is true for short-distance travel involving an approximately inertial frame and also long-distance circumnavigation of the Earth. This again completely corroborates the light speed determined above using synchronized GPS clocks as well as the Michelson-Gale experiment.

2.4. One-way Light Speed Using GPS Time Transfer [34]

Time Transfer is the process of communicating time information using electromagnetic signal transmission through space. It is used for example to maintain coordination of time and frequency in systems operating at or close to the Earth and beyond. The method is based on an algorithm published by the International Telecommunications Union (ITU) that has been rigorously tested and completely verified [35]. It involves the transmission of a signal from one

GPS station to another such that system synchronization can be effected. Today it is part of the standard procedure employed in time comparisons between separated laboratories on the rotating Earth and is employed in a range of applications [36-39].

The approach described in the ITU recommendation [35] is to use electromagnetic signal transmission in the Earth-Centred Inertial (ECI) frame where it travels at speed c to determine the travel time from a satellite to a ground receiver which is moving at speed v, the rotational speed of the Earth at the particular latitude. Because light speed in the ECI frame is known, the determination of the transfer time Δt is essentially straightforward. Consider an electromagnetic pulse transmitted from a geo-stationary GPS satellite at position $\bar{r}_T$ and GPS time t_T travelling at speed c relative to the ECI frame to a ground receiver whose position at GPS time t_T is $\bar{r}_R$ and whose velocity because of the rotation of the Earth is v relative to the ECI frame. By utilizing a geo-stationary satellite, the test is fully within the frame of the rotating Earth as are the previous tests done with synchronized clocks and the range equation. Let θ be the angle between the direction of propagation of the signal and v which, because $v << c$ can be represented as shown in fig.4. Here R is the initial distance between the geo-stationary satellite and the receiver. If the signl arrives at the receiver at time t_R then for the signal transmission interval $\Delta t = t_R - t_T$ the receiver experiences a displacement $\bar{v}\Delta t$.

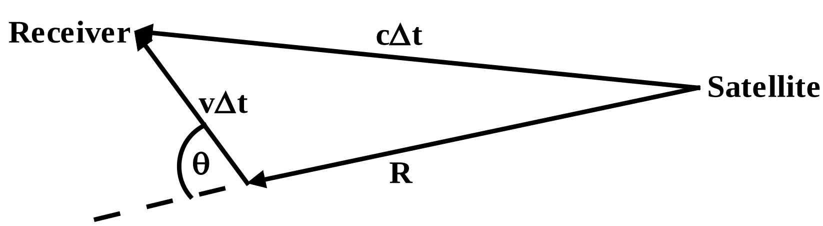


Figure 4. Light Transmission from Geo-stationary Satellite to Earth-based Receiver

For signal travel within the ECI frame from satellite to receiver at speed c in time Δt, the signal displacement $c\Delta t$ is given by

$$c\Delta t = \bar{R} + \bar{v}\Delta t \tag{34}$$

where $\bar{R} = \bar{r}_R - \bar{r}_T$. Solving equation (34) for Δt yields the transfer time [37]

$$\Delta t = \frac{R}{c} + \frac{\bar{v}.\bar{R}}{c^2} \tag{35}$$

The transfer time Δt in (35) for light travelling from the orbiting satellite to a ground-based receiver has been fully tested and experimentally verified and is routinely used in time comparisons. It is therefore accurate and can be used to evaluate the light speed c_R relative to the ground receiver. Using the distance R between the satellite and the receiver at the time of transmission of the signal, light speed c_R is given by

$$c_R = \frac{R}{\Delta t} = \frac{R}{\frac{R}{c} + \frac{\bar{v}.\bar{R}}{c^2}} \qquad (36)$$

But from fig. 4, $\bar{v}.\bar{R} = vR\cos\theta$ and hence (36) becomes

$$c_R = \frac{R}{\frac{R}{c} + \frac{vR\cos\theta}{c^2}} = \frac{c^2}{c + v\cos\theta} = \frac{c^2(c - v\cos\theta)}{c^2 - v^2\cos^2\theta} \approx c - v\cos\theta, v << c \qquad (37)$$

Therefore using the experimentally confirmed transfer time Δt and the initial separation R give a light speed $c_R = c - v\cos\theta$ relative to the receiving station and not $c_R = c$ as presented in the ITU recommendation. For light transmission in the west-east direction towards the receiver, $\theta = 0^o$ and therefore (37) gives $c_R = c - v$. For light transmission in the east-west direction, $\theta = 180^o$ and hence (37) yields $c_R = c + v$. These light speed values using signal transmission from a GPS satellite to a ground-based receiver have also been observed by Sato [40] and are exactly those found using synchronous clocks and the range equation. To further demonstrate the correctness of the relative light speed $c_R = c - v\cos\theta$ the transfer time Δt is calculated using this speed. Thus

$$\Delta t = \frac{R}{c_R} = \frac{R}{c - v\cos\theta} = R\frac{c + v\cos\theta}{c^2 - v^2\cos^2\theta} = \frac{R}{c^2}(c + v\cos\theta), v << c \qquad (38)$$

Equation (38) gives

$$\Delta t = \frac{R}{c} + \frac{Rv\cos\theta}{c^2} = \frac{R}{c} + \frac{\bar{v}.\bar{R}}{c^2} \qquad (39)$$

which is exactly the transfer time (35) given in the ITU recommendations that has been rigorously tested and confirmed.

These four approaches all within the frame of the rotating Earth enable the direct detection of the rotational motion of the Earth in a definitive manner. We turn next to detection of orbital motion within the frame of the orbiting Earth.

3. Detection of the Orbital Motion of the Earth Using Modern Technology

While the four previous techniques enabled detection of ether drift arising from the rotation of the Earth, as previously indicated the 1887 Michelson-Morley experiment tried unsuccessfully to detect the orbital motion of the Earth and this ultimately lead to the abandonment of the ether as the all-pervasive carrier of electromagnetic radiation. In a paper in Nature marking the centenary of the introduction of relativity theory, John Stachel stated [41] "all attempts to detect the translational motion of the Earth through the ether by means of optical, electrical or magnetic effects consistently failed. Lorentz succeeded in explaining why: according to his theory, no such effect should be detectable by any experiment sensitive to first order in (v/c) where v is the speed of the moving object through the ether and c is the speed of light in that medium." This statement about Lorentz's theory is quite misleading! What this theory in fact established is that in experiments utilizing closed light paths, no first-order effects are detectable since in such experiments first-order terms cancel [42]. Lorentz himself stated [43], "The problem of determining the influence exerted on electric and optical phenomena by a translation, such as all systems have in virtue of the Earth's annual motion, admits of a comparatively simple solution, so long as only those terms need be taken into account, which are proportional to the first power of the ratio between the velocity of translation v and the velocity of light c. Cases in which quantities of the second order…present more difficulties."

Thus first-order open-path experiments seeking to detect the translational motion of the Earth are superior to second-order experiments since first-order effects are larger and therefore more easily detected than second-order effects. However in the past, technical difficulties prevented the execution of any open-path first-order experiments. For example Maxwell suggested a first-order approach to detecting the galactic movement of the Earth using the delay in the eclipse time of Jupiter's satellite Io first observed by Roemer [44]. Unfortunately the sensitivity of instrumentation available at the time did not allow the test to be conducted and Born [45] suggested that later improvement in instrument accuracy may enable the test to be performed.

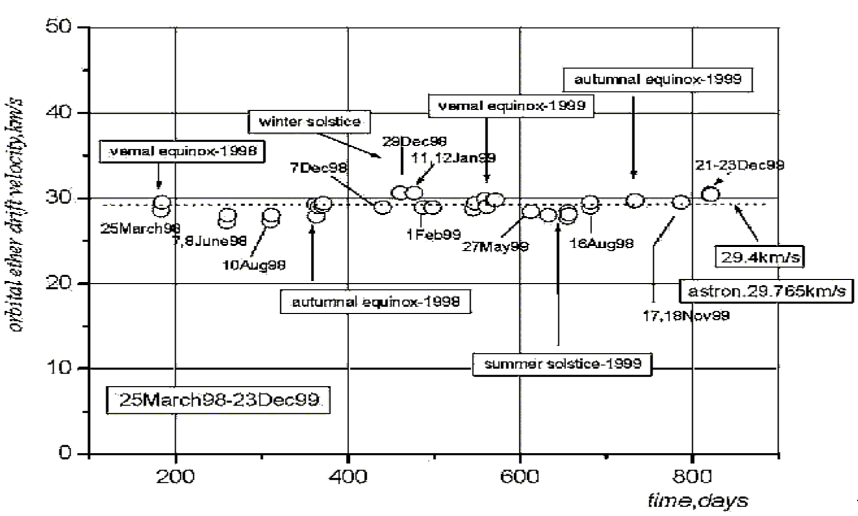
Since those early attempts, improvements in instrumentation have indeed occurred and it is now possible to routinely detect the orbital motion of the Earth as is the case for its rotational motion as demonstrated in section 2. In this section two experiments that detect the Earth's orbital motion from the frame of the Earth, one using geostationary satellite technology and the other employing interplanetary tracking technology are discussed.

3.1 Earth’s Orbital Speed using Aberration and a Geostationary Satellite

The phenomenon of stellar aberration, the change in the apparent position of a star arising from the orbital motion of the Earth, was discovered by Bradley in 1728. The effect was used to determine the Earth’s orbital motion. Thus for a star at the ecliptic pole the aberration angle α is given by [46p42]

$$\tan\alpha = \frac{v}{c} \tag{40}$$

where v is the orbital speed of the Earth. This aberration is rendered observable by the change in direction of the Earth’s orbital motion. Thus a star at the ecliptic pole is observed to traverse a circle of angular radius $\alpha = 20.49''$ and this in (40) gives $v = 29.80 kms^{-1}$ the accepted value of the Earth’s orbital speed. An interesting variation of this experiment is the replacement of the stellar light source by a geostationary satellite. This is possible since aberration is independent of both the motion of the source and the distance between the source and the terrestrial observer. The result is that the velocity of the Earth can be measured with a source and an observer that are fixed with respect to each other and with respect to the surface of the Earth i.e. in the frame of the orbiting Earth.



’s

Fig.5 Variation of the orbital velocity of the Earth [47]

Such an experiment appears to have been successfully carried out by Shtyrkov [47, 48]. He used the Intelsat 704 geo-stationary satellite with the geocentric East longitude of 66deg.E and the small inclination of 0.02 degrees as the source and an Earth-fixed radio telescope at station TAT-01B in Kazan, Russia as the receiver. Diurnal observations were recorded at different times over a long period from March 1998 to December 1999 and the results taken from his paper are shown in fig. 5. It can be seen that the orbital velocity determined in the experiment coincides closely with the known orbital velocity of the Earth, with seasonal variations being evident in the data. This is an experiment that detects the Earth's orbital velocity from within the frame of the orbiting Earth, precisely what the Michelson-Morley 1887 experiment failed to do. This suggests that the aberration arises from the motion of the Earth relative to the medium of light propagation. We await confirmation by others of this very interesting experiment.

3.2 One-way Light Speed using Interplanetary Tracking Technology [49]

While position on the surface of the Earth can be accurately determined using the range equation of the GPS referred to the ECI frame, the orbital ephemerides of the planets and other bodies in the solar system are determined using a different set of equations operating within the solar barycentric frame [50-52]. The solar barycentric frame is a frame that moves with the Sun but does not rotate with it and provides a convenient reference frame for a range of astronomical events. Two equations which have been empirically determined are used to determine round-trip time of an electromagnetic signal that emanates from a transmitting antenna on Earth and is reflected by a planetary body, spacecraft transponder or satellite back to the same antenna on Earth. Time measurement is accomplished using accurate atomic clocks based on Coordinated Universal Time (UTC) and the spatial coordinates are taken relative to the solar-system barycenter.

The specific equations are given by [50-52]

$$c\tau_u = \left| r_B(t_R - \tau_d) - r_A(t_R - \tau_d - \tau_u) \right| \qquad (41)$$

$$c\tau_d = \left| r_A(t_R) - r_B(t_R - \tau_d) \right| \qquad (42)$$

where t_R is the time of reception of the signal, τ_u and τ_d are the up-leg and down-leg times respectively, r_A is the solar-system barycentric position of the receiving antenna on the Earth's surface, r_B is the solar-system barycentric position of the reflector which is either a responding spacecraft or the reflection point on the planet's surface and c is the speed of light in the solar-system barycentric frame. These equations are based on the observation that light travels in the solar-system barycentric frame at a constant speed and have been exhaustively tested and rigorously verified. They are derived using data sets collected over a period of more than half a century of measurement. The two equations are solved iteratively in order to obtain values for τ_u and τ_d. In practice time corrections must be made to τ_u and τ_d because of relativistic effects, the electron content of the solar corona and the Earth's troposphere [51, 52].

In order to determine one-way light speed using this system, we consider a transmitting-receiving antenna A fixed on the surface of the Earth which is moving in the solar-system barycentric frame at orbital speed v relative to this frame and a reflecting satellite B stationary or moving relative to the solar-system barycentric (SSB) frame. On an axis fixed in the SSB frame along the line joining antenna A and satellite B at the instant of signal reflection with antenna A closer to the origin O than satellite B and taking positive values, let r_A be the coordinate along the axis of the position in the SSB frame of antenna A and r_B be the coordinate along the axis of the position of satellite B. At the time of reflection of the signal from B, let the distance between A and B be L given by

$$r_B(t_R - \tau_d) - r_A(t_R - \tau_d) = L \tag{43}$$

Antenna moving toward Reflector

At the instant of reflection of the electromagnetic signal at reflector B let antenna A move directly toward the reflector B at orbital speed v relative to the SSB frame. Then using equation (42),

$$c\tau_d = r_B(t_R - \tau_d) - r_A(t_R) \tag{44}$$

Since (for sufficiently small L) antenna A is moving uniformly toward reflector B at speed v relative to the SSB frame, it follows that the relation between the position $r_A(t_R)$ of antenna A at the time of reception of the signal and its position $r_A(t_R - \tau_d)$ at the time of reflection of the signal at reflector B is given by

$$r_A(t_R) = r_A(t_R - \tau_d) + \tau_d v \tag{45}$$

Substituting for $r_A(t_R)$ from (45) in (44) yields

$$c\tau_d = r_B(t_R - \tau_d) - r_A(t_R - \tau_d)) - \tau_d v \tag{46}$$

Using (43) this becomes

$$r_B(t_R-\tau_d)-r_A(t_R-\tau_d)=L=(c+v)\tau_d \qquad (47)$$

Hence for an observer on Earth equation (42) yields the down-leg time as

$$\tau_d=\frac{L}{c+v} \qquad (48)$$

Therefore the speed c_{BA} of the electromagnetic signal relative to antenna A traveling from the reflector B to the moving antenna A is given by the separation L at the time of reflection divided by the down-leg time τ_d which using (48) is

$$c_{BA}=\frac{L}{\tau_d}=\frac{L}{L/(c+v)}=c+v \qquad (49)$$

Antenna moving away from Reflector

At the instant of reflection of the electromagnetic signal at reflector B let antenna A move directly away from the reflector B at orbital speed v relative to the SSB frame. Then using equation (42),

$$c\tau_d=r_B(t_R-\tau_d)-r_A(t_R) \qquad (50)$$

Since antenna A is moving uniformly away from reflector B at speed v relative to the SSB frame, it follows that the relation between the position $r_A(t_R)$ of antenna A at the time of reception of the signal and its position $r_A(t_R-\tau_d)$ at the time of reflection of the signal at reflector B is given by

$$r_A(t_R)=r_A(t_R-\tau_d)-\tau_d v \qquad (51)$$

Substituting for $r_A(t_R)$ from (51) in (50) yields

$$c\tau_d=r_B(t_R-\tau_d)-r_A(t_R-\tau_d))+\tau_d v \qquad (52)$$

Using (43) this becomes

$$r_B(t_R-\tau_d)-r_A(t_R-\tau_d)=L=(c-v)\tau_d \qquad (53)$$

Hence for an observer on Earth the range equation yields the down-leg time as

$$\tau_d=\frac{L}{c-v} \qquad (54)$$

Therefore the speed c_{BA} of the electromagnetic signal relative to antenna A traveling from the reflector B to the moving antenna A is given by the separation L at the time of reflection divided by the down-leg time τ_d which using (54) is

$$c_{BA} = \frac{L}{\tau_d} = \frac{L}{L/(c-v)} = c - v \qquad (55)$$

It follows from (49) and (55) that light travels from the reflector to the antenna on Earth at a speed $c+v$ relative to the antenna in the case of the Earth moving toward the reflector at orbital speed v and light travels at speed $c-v$ relative to the antenna in the case of the Earth moving away from the reflector at orbital speed v. This light speed variation for light traveling in the solar-system barycentric frame is in agreement with findings of Wallace [53] for light travel through space. It is also consistent with the light speed changes observed on the orbiting Earth for light from planetary satellites in the Roemer experiment [54] and for light from stars on the ecliptic in the Doppler experiment [55] both light sources being external to the Earth.

If the velocity of the reflecting satellite B is made such that it is geostationary, then the receiving antenna and reflector are fixed relative to each other and to the surface of the moving Earth. In such a case the complete light speed measurement yielding $c \pm v$ is in the frame of the moving Earth. These results in the solar-system barycentric frame indicate that the orbital speed v of the uniformly moving Earth is readily detectable with apparatus in which the signal source and receiver are fixed relative to each other and to the moving Earth, just as in the Shtyrkov experiment outlined in section 3.1 above. This again suggests the existence of a medium of light propagation through which the Earth is moving as it orbits the Sun.

4. Conclusion

The four techniques utilizing the GPS discussed in this paper all detect ether drift associated with the Earth's rotation as evidenced by light speed changes $c \pm v$ for light travelling in the east-west direction. This technology involves the synchronized clocks of the GPS, a GPS-based Michelson-Morley experiment, the range equation of the GPS and Time Transfer technology, all within the frame of the rotating Earth. The detection of ether drift arising from the orbital motion of the Earth was also accomplished using two approaches the first utilizing aberration of signals from an Intelsat 704 geo-stationary satellite and the second based on interplanetary tracking technology. These detections were both effected in the frame of the orbiting Earth.

The observed light speed variation involving orbital motion within the SSB frame and light speed anisotropy involving rotational motion within the ECI frame where light travels at a speed *c* in the particular frame suggest the existence of multiple preferred frames which are carried along by the Earth and the Sun respectively [40, 56]. Hatch however offered an interpretation in which the basic phenomenon is attributed to clock bias [57] since the clocks are synchronized according to the specific inertial frame in which they are operating. This phenomenon of light speed being influenced only by movement within a chosen frame calls for further investigation in order to fully understand the nature of the associated medium and to identify the underlying mechanism. Notwithstanding this the detection of light speed variation is incontrovertible and therefore the existence of a cosmic medium is confirmed.

Thus while Michelson and Morley failed to detect ether drift arising from the Earth's orbital motion in their celebrated experiment of 1887 [3], modern technology in the form of an interplanetary tracking technique and aberration of an electromagnetic signal from a geo-stationary satellite source have enabled this detection. Additionally, Michelson's 1904 proposal [15] to indirectly detect ether drift arising from the Earth's rotational motion has now, using GPS technology, been directly accomplished.

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