Anisotropy of Light Speed Due to Earth's Own Rotation

by
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Abstract

The Sagnac effect can be interpreted as evidence of anisotropy in light speed as a first-order effect (proportional to the ratio of v to c) at the scale of Earth's rotation, but not at higher velocities such as Earth's orbital speed or its speed relative to the Cosmic Microwave Background (CMB). Logically, one would expect that Michelson interferometer-type experiments, which investigate second-order effects (proportional to the ratio of v^2 to c^2), would yield analogous results across different speeds, albeit on a much smaller scale due to squaring. That is, null results would be expected at the CMB and orbital speeds, while a non-null result would emerge at the scale of Earth's rotation. Specifically, interferometer experiments using optical resonators should possess sufficient resolution to verify this. This paper demonstrates that, contrary to expectations, none of the existing experiments account for Earth's rotation, as the data analysis systematically factors it out. A non-null result in first-order experiments, which involve non-inertial reference frames, can be explained by General Relativity. However, second-order experiments are conducted in inertial reference frames, where Special Relativity fails to explain a non-null result. Thus, detecting a second-order effect due to Earth's rotation could provide insights into new physics.

1. Introduction

Anisotropies in light propagation are explored through experiments designed to determine whether light propagation adheres to Newtonian velocity addition. Specifically, these experiments explore whether an observer's movement adds to or subtracts from the light's travel time depending on the direction relative to light propagation. There are essentially two groups of experiments based on fundamentally different prerequisites.

The first group includes experiments such as those by Sagnac and Michelson/Gale/Pearson, as well as those utilizing ring laser technologies. In these experiments, a split light beam is sent on a 360° round trip along two counter-rotating paths and then recombined. The resulting interferences, which inevitably occur if the partial beams have different travel times, are analyzed. The entire experimental setup is placed on a rotating disk (in the Michelson/Gale/Pearson experiment, the entire Earth acts as the rotating disk), so that one beam moves with the rotation and the other moves against it. The path of each beam can be mathematically represented by the formula:

$$s = \frac{\Omega}{c} \cdot 2A$$

where Ω is the angular velocity of the rotating disk, c is the speed of light, and A is the area enclosed by the round-trip light path. The resulting difference between the two beams is determined by the ratio of the angular velocity to the speed of light (not their squares), which is why this is referred to as a first-order effect. Given the actual conditions (light speed at approximately 300,000 km/s and Earth's rotational speed at approximately 0.4 km/s), the ratio is on the order of 10^-6. All experiments of this type show Newtonian velocity addition in the ratio of rotational speed to light speed. In the case of Michelson/Gale/Pearson the experiment allows

Earth's rotational speed to be measured. However, one might expect that much higher speeds, such as Earth's orbital speed around the Sun (approximately 20 km/s) or its speed relative to the CMB (approximately 360 km/s), would all the more become apparent. The reasons why this is not the case have been thoroughly explained in one of my papers and will not be elaborated on here. At first glance, the positive result concerning Earth's rotation seems to contradict the Special Theory of Relativity, which postulates the invariance of light speed. However, since the experimental setup involves rotational movement, it is a non-inertial system, so Special Relativity does not apply. General Relativity explains the results.

The second group of experiments includes all setups best summarized as interferometers. Here, a light beam is again split into two beams. One of the beams is sent in the direction of the apparatus's movement (e.g., in the direction of Earth's orbital speed vector) and reflected back using a mirror. According to Newtonian velocity addition, the apparatus's speed should add to the light travel time on the outward journey and subtract from it on the return journey. However, the travel time differences do not sum to zero. The path of one beam parallel to the apparatus' movement (outward plus return) can be represented by the formula:

$$s = 2 \cdot l \cdot \left(1 + \frac{v^2}{c^2}\right)$$

where l is the length of the interferometer arm and v is the movement speed of the apparatus relative to light propagation. The second beam is oriented perpendicular to the first, so that its propagation remains unaffected by the speed of the apparatus. Its path is simply s=2l. The two beams then recombine, and the resulting interferences reveal the travel time differences. It is important to note that it is impossible to construct both arms of the interferometer so precisely that their paths are exactly the same length. This is unnecessary; it suffices that the interference changes when the directions of the two beams swap during measurement. Thus, the apparatus must be mounted on a rotating platform, where non-inertial influences can be neglected by using a suitably low rotational speed. The resulting difference between the two beams is determined by the ratio of the squared movement speed to the squared light speed, so this is a second-order effect. For Earth's rotational speed, the ratio is on the order of 10^-12. All experiments conducted to date have shown null results, indicating that the experiment appears to contradict Newtonian velocity addition. The framework of Special Relativity can explain this result, especially since this second group of experiments, unlike the first, involves inertial systems. However, second-order experiments focus on testing orbital speed or speed relative to the CMB, and the influence of Earth's rotation is typically ignored. Why should an effect occur at Earth's rotational speed if it doesn't occur at even much higher speeds?

In summary, two questions arise from the facts described above, which will be examined further:

1. If first-order experiments show null results at high speeds and a positive result only at the lowest speed, Earth's rotation, why is this not analogously the case for second-order experiments?
2. Could it be possible that second-order experiments also show a positive result concerning Earth's rotation, which has been overlooked so far?

Therefore, the following discussion focuses on second-order experiments and the question of Earth's rotation, aiming to clarify this systemic difference from first-order experiments.

2. Classical Interferometer Experiments, e.g., Michelson-Morley Apparatus

At Earth's rotational speed of about 464 m/s, a shift in the interference fringes on the order of v^2/c^2 would be expected. Given a light speed of 2.998 x 10^8 km/s, this corresponds to a squared anisotropy of about 2.4 x 10^-12 m/s. Considering the light wavelength and the 2 m arm length of the Michelson-Morley apparatus, this translates to a shift of approximately 10^-5 fringes. Even a hundredfold increase in arm length would not yield a definitive result. Thus, classical interferometer experiments are unsuitable for demonstrating the second-order effect due to Earth's rotation.

3. Interferometer Experiments using Optical Resonators

Unlike classical interferometers, these experiments extend the optical path length by several orders of magnitude by reflecting light multiple times within two resonators positioned at right angles, thereby creating standing waves. The two waves are then electronically superimposed, producing a beat frequency that becomes measurable even with extremely slight deviations. The sensitivity of these experiments is so high that the effect of anisotropy with respect to Earth's rotation should, in theory, be detectable beyond any doubt. We will now take a closer look at these experiments and, in particular, examine the extent to which Earth's rotational speed is taken into account. Only experimental setups that are rotatably mounted, similar to the classical apparatuses, are considered, as the shift of interference fringes or the measurement of beats due to resonator deviations requires that the direction of the resonators can be swapped relative to Earth's rotational speed vector. Experiments that do not meet this condition are excluded from consideration. The five known experiments with rotatable setups are:

3.1 Brillet and Hall, 1978

In their 1978 paper, Brillet and Hall observed a spurious signal: *"—and a spurious nearly sinusoidal frequency shift at the table rotation rate f."* This signal corresponds to the simple rotational frequency of the apparatus. While we are specifically searching for a signal at twice this frequency due to squaring, this particular signal should not be directly relevant. However, the paper further notes: *"We find that taking data in blocks of N table rotations (N ≈ 8-50) is helpful in minimizing the cross-coupling of these noise sources into the interesting Fourier bin at 2 cycles per table revolution."* This suggests that the data were averaged over 8 to 50 rotations, likely eliminating much of the signal we are interested in. Additionally, the authors describe: *"To discriminate between this spurious signal and any genuine ether effect, we made measurements for 12 or 24 sidereal hours"* and *"Averaging after this rotation leads, as shown in Fig. 2, to a typical 1-day result below 1 +/- 1 Hz."* This makes it clear that the focus was no more on detecting a rotation-dependent but rather on observing a diurnal signal. As a result, any signal that could have been caused by the rotation of the apparatus, and thus by Earth's rotation, was not recorded. Consequently, the experiment effectively produced a false null result concerning Earth's rotation.

3.2 Eisele et al., 2008

In the paper by Eisele et al., divergent data were averaged even beforehand, with the cause attributed to an unavoidable tilt of the apparatus: *"Sensitivities of the beat to tilts were determined at the beginning of each run,"* and *"The means of the amplitudes of the tilt modulations at 2ω were less than 0.2 μrad, leading to an effect on the means of the coefficients of B, C of less than 5 x 10^-17."* It's important to note that modern experimental analyses are conducted using test theories, in this case, the RMS test theory (Robertson-Mansouri-Sexl), which standardizes the search for anisotropies and makes results comparable through relatively simple parameters (B and C in this case). However, despite this averaging, a phase shift of 0.2 μrad was observed, which is several orders of magnitude (10^-8) greater than the signal we are searching for (on the order of 10^-12). The subsequent evaluation of the measurement results is then carried out within the framework of the test theory. The paper states: *"The RMS test theory (with the effects of Earth's rotational velocity neglected) leads to expressions for B(t), C(t) with similar structure."* In the following analysis, the data are interpreted solely with respect to B(t) and C(t), neglecting Earth's rotation. Consequently, the published experimental data are inconclusive. A significant signal is potentially ignored, and Earth's rotation is omitted from further consideration. The raw data would be highly interesting if interpreted without applying the test theory or at least taking Earth's rotation into account.

3.3 Herrmann et al., 2018 (first published in 2007)

In this experiment as well, the sought signals appear to be suppressed from the outset. An initial analysis of Herrmann et al.'s paper addresses error signals, particularly those at twice the rotational frequency of the apparatus: *"For example, gravitational or centrifugal forces that act on the resonators may get modulated with the turntable rotation and therefore modulate the length of the resonators. However, most of these effects lead to a modulation at a rate of* $\omega_{tt} = 2\pi/T_{tt}$ *so that they are in principle distinguishable from the anisotropy signal searched for at* $2\omega_{tt}$*. Moreover, if the data spans more than one day, systematic effects with a fixed phase in the laboratory average out in the analysis for an anisotropy of c that is fixed relative to a sidereal frame."* Errors at twice the rotational frequency are attributed to various causes, leading to a focus on daily modulation: *"This daily modulation is essential to discriminate an anisotropy signal from constant or slowly varying systematic effects caused by active rotation as described in Section I. Only systematic effects subjected to a 23.93 h modulation would mimic such a sidereal anisotropy signal."* It's evident that the sought signal cannot be detected within such diurnal averaging. Finally, the paper even specifically states: *"These samples extend over 450 s each, such that we may neglect a possible modulation due to Earth's rotation within each sample."* After this, the RMS test theory is once again applied in a manner that completely disregards Earth's rotation.

3.4 Stanwix et al., 2021

A similar pattern emerges in this paper. The authors note: *"We have determined that tilt variations dominate the systematic by measuring the magnitude of the fractional frequency dependence on tilt and the variation in tilt at twice the rotation frequency, 2ωR(0.11Hz), as the experiment rotates. We minimize the effect of tilt by manually setting the rotation bearing until our tilt sensor reads a minimum at 2ωR."* This suggests that signals were present but were apparently suppressed by mechanical means. When this did not suffice, the signal resulting from the rotation was simply ignored: *"The remaining systematic signal is due to the residual tilt variations, which could be further annulled with an automatic tilt control system. It is still possible to be sensitive to Lorentz violations in the presence of these systematics by measuring the sidereal,* $\omega_\oplus$ *and semi-sidereal,* $2\omega_\oplus$ *sidebands about 2ωR, as was done in [8]."* and again, *"However, since we do not know if the systematic has canceled a Lorentz violating signal at 2ωR, we cannot reasonably claim this as an upper limit. Since we have five individual data sets, a limit can be set by treating the* $C_{2\omega R}$ *coefficient as a statistic."* It's clear at this point that there is no usable result regarding Earth's rotation. Finally, any signal at twice the rotational rate is simply factored out altogether: *"but for the RMS analysis we do not consider the 2ωR frequency due to the large systematic,…"*

3.5 Antonini et al., 2005

From the outset, this paper applies the RMS test theory only concerning Earth's orbital velocity and velocity relative to the CMB: *"The amplitude B(t) contains frequency components at 0,* $\omega_\oplus$*,* $2\omega_\oplus$*,* $\omega_\oplus \pm \Omega_\oplus$ *and* $2\omega_\oplus \pm \Omega_\oplus$*, while C(t) contains in addition one component at the frequency* $\Omega_\oplus$*. Here* $\omega_\oplus$ *is Earth's sidereal angular frequency and* $\Omega_\oplus$ *is Earth's orbital frequency."* A little later in the text, the authors state: *"The measured tilts were time-averaged, weighted with the measured beat frequency sensitivities and subtracted from the beat data."* They also admit: *"In fitting the above expression to our data, we take into account that the finite average values of 2B and 2C are* *likely to be due to a (constant) systematic error."* and: *"We believe the nonzero averages of the 2B and 2C amplitudes are due to a systematic effect of thermal origin."* Once again, the experiment fails to address the specific question of interest.

4. Summary

The evaluation of the five experiments presented here indicates that the question of anisotropy in light speed due to Earth's rotation remains open. There is clear evidence that such an effect could exist in second-order experiments but has been overlooked in data analyses. Nevertheless, a positive second-order result concerning Earth's rotation has not yet been identified beyond any doubt. An experimental setup that systematically accounts for Earth's rotational speed and avoids data averaging over extended periods could confirm this hypothesis.

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