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Which derivation for the result of the MMX (Michelson & Morley Experiment) in translation with respect to the observer?

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Abstract

This article deals critically with the relativistic derivation of the result of the Michelson and Morley experiment. This experience is at the source of the theory of Relativity. There is a historical explanation, that of Albert Einstein, based on the failure of the hypothesis of the ether to explain the lack of phase shift whatever the frame is, except to consider in addition a contraction of the lengths in accordance with the Lorentz-FitzGerald's hypothesis. But this remains an indirect explanation. It is pointed out here that it has not been found on the internet a direct mathematical derivation based on relativistic assumptions alone. And it is specified that a mathematical demonstration would remain incomplete if it only dealt with the particular case of the observer linked to the interferometer without taking care of the general case where the interferometer is in translation with respect to the observer (as it is also the case for the demonstration with the aether). The difficulty of this derivation comes in the way of reconciling the different distances traveled by the two light beams, the absence of fringe shift and the hypothesis made on the speed of light which is postulated (and not measured) constant according to the theory of Relativity. It is here considered the consequences of a variation of the velocity of light according to the reference frame. Specific experiments are proposed to validate or not this approach.

Résumé

Cet article traite de manière critique de la démonstration relativiste du résultat de l'expérience de Michelson et Morley. Cette expérience est à la source de la théorie de la Relativité. Il existe une explication historique, celle d'Albert Einstein, basée sur l'échec de l'hypothèse de l'éther à expliquer l'absence de déphasage quel que soit le référentiel, sauf à envisager en complément une contraction des longueurs conformément à l'hypothèse de Lorentz-FitzGerald. Mais cela demeure une explication indirecte. Il est ici pointé qu'il n'a pas été trouvé sur internet de démonstration mathématique directe basée sur les seules hypothèses relativistes. Et il est précisé qu'une démonstration mathématique demeurerait incomplète si elle traitait uniquement le cas particulier de l'observateur lié à l'interféromètre sans s'occuper du cas général où l'interféromètre est en translation par rapport à l'observateur (comme c'est d'ailleurs le cas pour la démonstration avec l'éhter). La difficulté de cette démonstration provient dans la manière de concilier les distances parcourues différentes par les deux faisceaux lumineux, l'absence de déphasage et l'hypothèse faite sur la vitesse de la lumière qui est postulée (et pas mesurée) constante selon la théorie de la Relativité. Il est ici envisagé les conséquences d'une variation de la vitesse de la lumière en fonction du référentiel. Il est proposé des expériences spécifiques pour valider ou pas cette approche.

Keywords: MMX, Michelson, Morley, Experiment, Derivation, velocity, celerity, speed, Relativity, Ether, Aether

I. Introduction

Curiously when he published his article on Relativity in 1905, Albert Einstein did not refer to the Michelson & Morley experiment of 1887. However, it is this experience which, by invalidating the principle of the ether if it is not accompanied by a contraction of lengths, prepared the minds to accept the Special Relativity Theory (SRT). Einstein later acknowledged: "If the Michelson and Morley Experiment had not been brought into serious embarrassment, no one would have regarded the relativity theory as a (halfway) redemption"[1]. But despite this recognition, one may question the fact that he never gave a direct and detailed demonstration of this surprising experimental result.

But what is this famous experience? What is the objective? For which result? What are the derivations or by default the explanations? How does it confirm or not the SRT?

II. Michelson-Morley Experiment (MMX)

Experience is simple in principle[2]. It consists in sending two coherent light rays in two orthogonal directions, making them each reflect on a mirror (and several times to increase the precision), and after they have traveled the same length to note their phase shift. This phase shift is read by displacement of the interference fringe. The result was zero, it was not noted displacement of fringe shift at the opposite to what was predicted with the ether hypothesis.

More recent experiments, such as those of Joos in 1930 with an accuracy ten times greater, confirm this absence of displacement. Other more precise experiments have been made, either using glass as in the Trimmer experiment (1973), or using electronic resonators such as Herrmann (2009). It should be ensured that these elements do not bias the Michelson & Morley Experiment. With this reservation, no fringe shift could be highlighted.

The objective of this experiment was to measure the motion of the Earth. The idea is to compare the path and speed of these two light rays, depending on whether one is in a supposedly fixed (or Galilean) frame of reference or in the terrestrial frame where the experiment is performed. We will discuss the speed of light in another chapter. What we can say about the course of these rays is that they are different depending on whether we are on the Earth in motion (O' frame) or not (O frame). We can establish the following equations from simple geometric considerations (**see Figure 1**), with L the length of the arm, V the velocity, T the time, and highlighting the $\overline{distance}$ traveled by the photon.

- On the path roughly orthogonal to the motion (Pythagorean theorem):

$$\begin{cases} \overline{A_1B}^2 = {L'_{AB}}^2 + (V.T_{A_1B})^2 \\ \overline{BA_2}^2 = {L'_{AB}}^2 + (V.T_{BA_2})^2 \end{cases} \quad (1.a\text{-}b)$$

- On the path parallel to the motion (movement of the arm L) :

$$\begin{cases} \overline{A_1C} = L'_{AC} + V.T_{A_1C} \\ \overline{CA_3} = L'_{AC} - V.T_{CA_3} \end{cases} \quad (2.a\text{-}b)$$

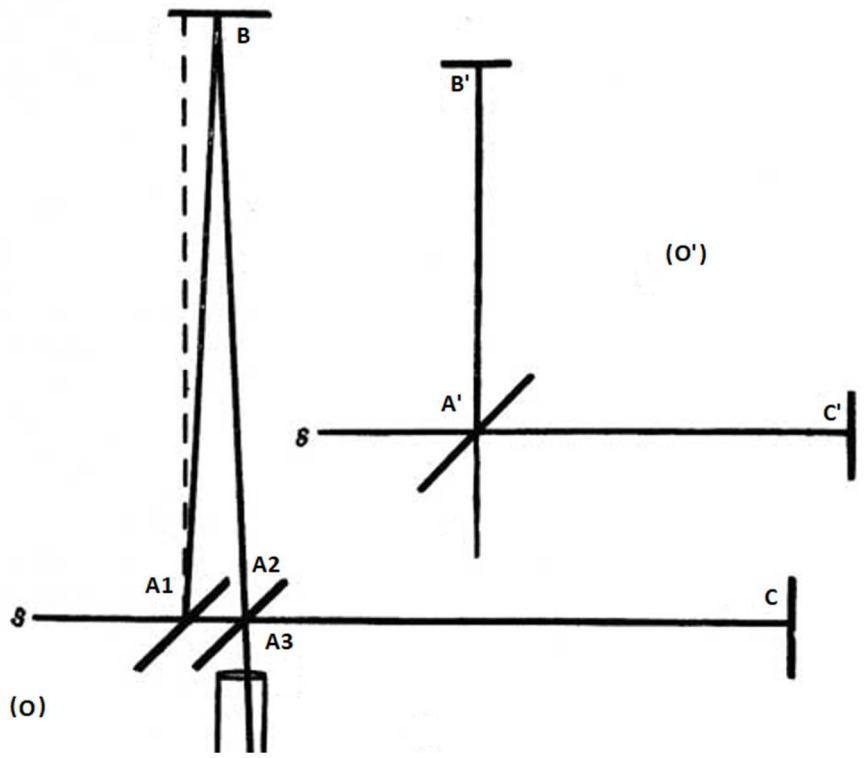

Figure 1: Light paths according to whether the interferometer is stationary /(O') or in motion /(O)

III Relativistic explanations

III.1) About the relativistic theory

Au XXème siècle, Albert Einstein postula la constance de la lumière en tout référentiel (inertiel). Selon cette théorie de la Relativité, que l'on s'approche ou que l'on s'éloigne de la source lumineuse, le photon arrive toujours à la même vitesse c. L'autre résultat intéressant est que selon la Relativité la longueur se contracterait et le temps s'étirerait dans le sens du déplacement.

In the twentieth century, Albert Einstein postulated the constancy of the light velocity in any (inertial) frame. According to this theory of relativity, either that one approaches or that one moves away from the light source, the photon always arrives at the same celerity *c*. The other interesting result is that according to the Relativity Theory, the length would contract and the time would dilated in the direction of the motion.

III.2) Historical explanation

What would you think of the following demonstration: Since A is false, then B is true? The historical explanation nevertheless looks like it: as the hypothesis of the ether is not validated except to admit the contraction of Lorentz-FitzGerald, then this validates the theory of Relativity! (**see Figure 2**). This is the explanation given first by Albert Einstein[a], then by many authors[4] [5] [6] [7] [8] [9].

[a] *Einstein wrote in 1916: "Although the estimated difference between these two times is exceedingly small, Michelson and Morley performed an experiment involving interference in which this difference should have been clearly detectable. But the experiment gave a negative result — a fact very perplexing to physicists.* ***Lorentz and FitzGerald*** *rescued the theory from this difficulty by assuming that the motion of the body relative to the* ***æther*** *produces a contraction of the body in the direction of motion, the amount of contraction being just sufficient to*

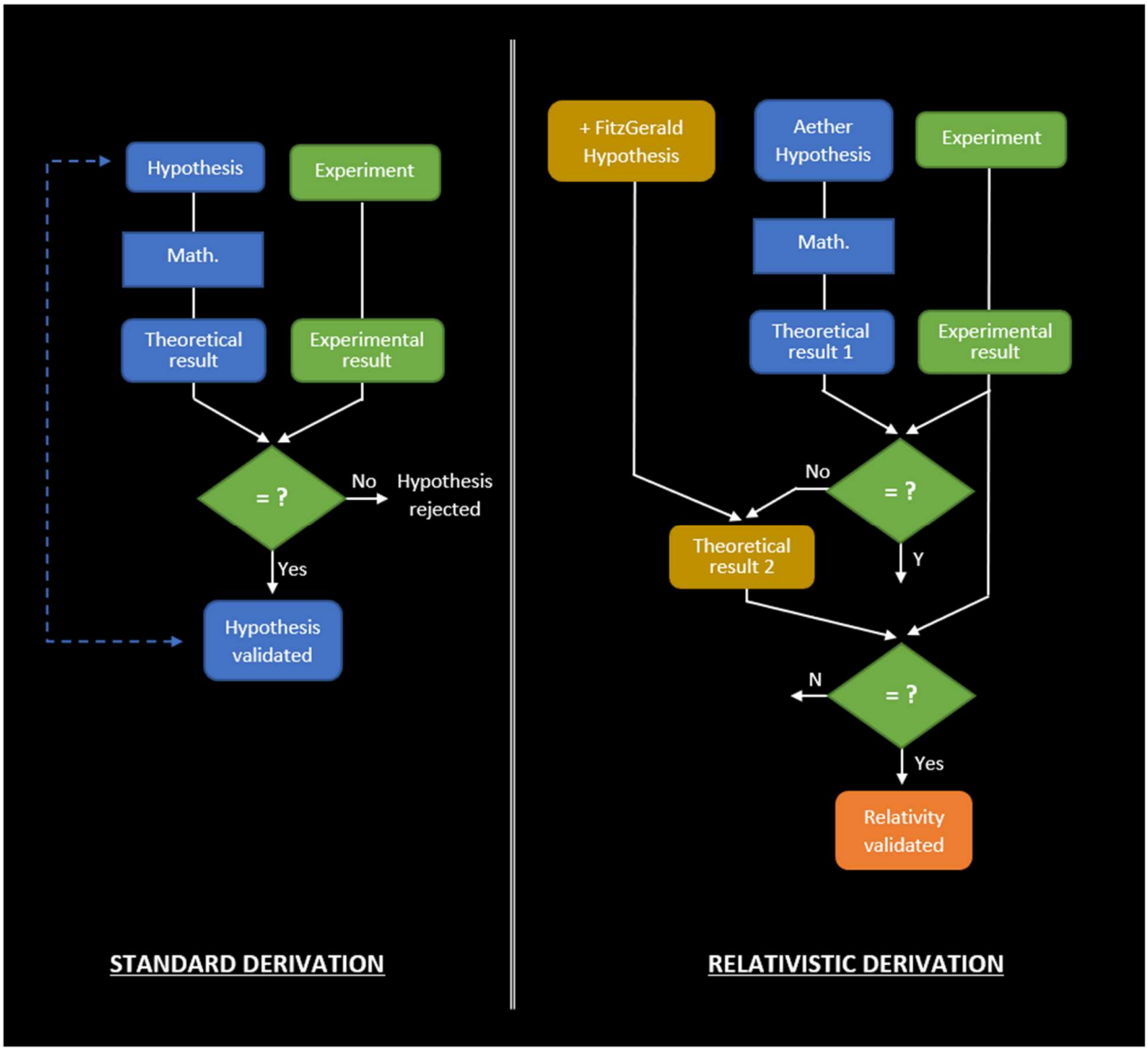

Figure 2: Scientific derivation or not?

III.3) Relativistic derivation

Curiously, neither Albert Einstein nor apparently his followers gave a detailed derivation of the result of this experiment (that is to say without involving the failure of the ether). It is not easy to find a mathematical derivation involving only (without referring to the ether) the second postulate of Relativity and the transformations of Lorentz. It is thus difficult to criticize a demonstration that has

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compensate for the difference in time mentioned above. Comparison with the discussion in Section 11 shows that also from the standpoint of the theory of relativity this solution of the difficulty was the right one. But on the basis of the theory of relativity the method of interpretation is incomparably more satisfactory. According to this theory there is no such thing as a "specially favoured" (unique) co-ordinate system to occasion the introduction of ***the æther-idea****, and hence there can be no* ***æther-drift****, nor any experiment with which to demonstrate it. Here the contraction of moving bodies follows from the two fundamental principles of the theory, without the introduction of particular hypotheses; and as the prime factor involved in this contraction we find, not the motion in itself, to which we cannot attach any meaning, but the motion with respect to the body of reference chosen in the particular case in point. Thus for a co-ordinate system moving with the earth the mirror system of Michelson and Morley is not shortened, but it is shortened for a co-ordinate system which is at rest relatively to the sun."* [3]

not been found, except to point out the apparent absence on the internet or at least the great confidentiality of the relativistic mathematical demonstration of the result of this experiment. So by default, we will consider 2 cases, as it is done in the derivation with the ether (see Figure 3):

- The particular case: The observer goes at the same speed as the interferometer. It is the schema with the observer in O'.

- The general case: The observer does not go at the same speed as the experiment. It is the schema with the observer stationary in the O frame and with the interferometer in translation at the velocity v (the previous particular case being only the general case with $v = 0$)

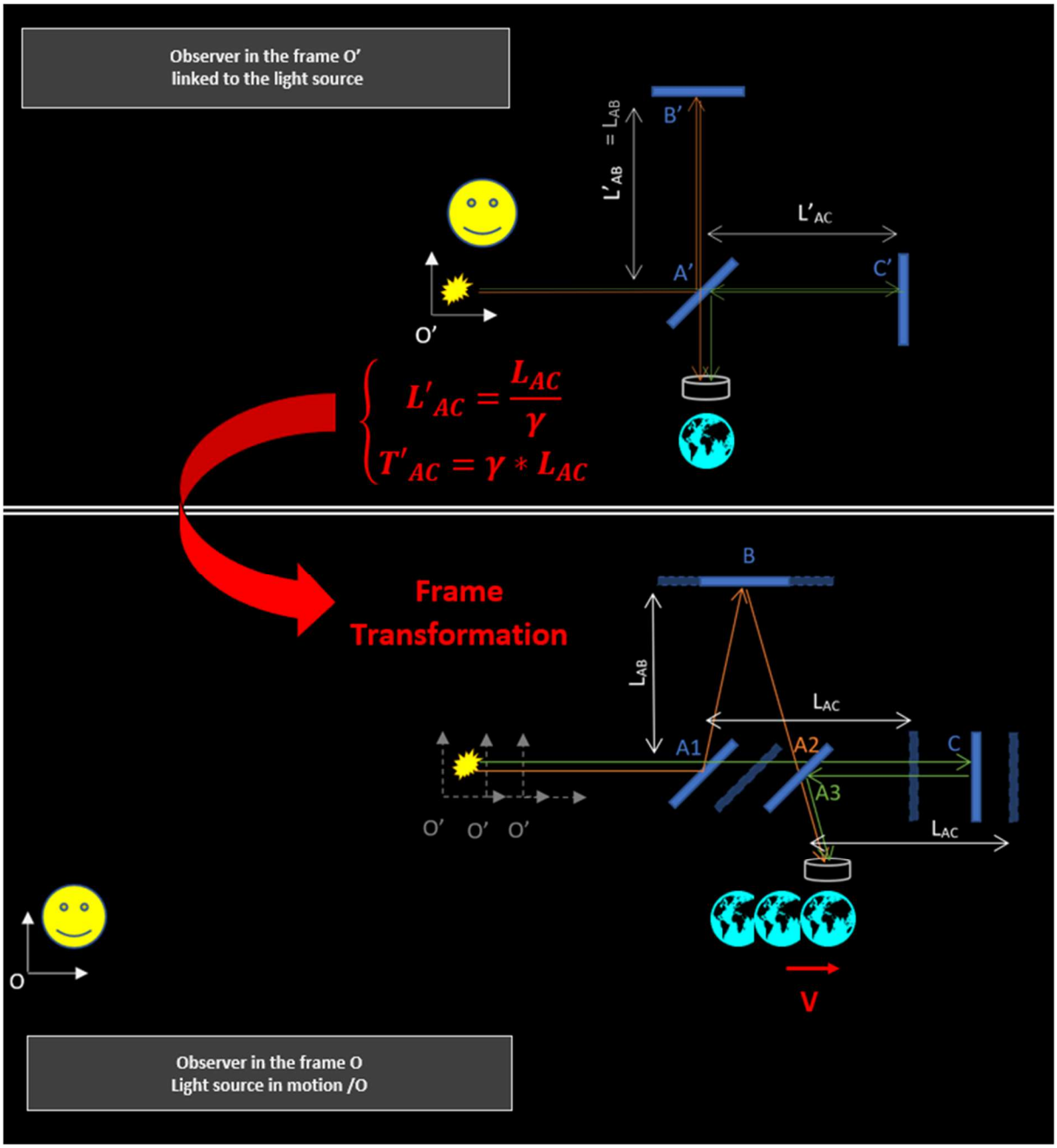

Figure 3: Observer in the frame in motion O' and then in the motionless frame O

According to the principle of relativity, whatever the reference system is, these measurements must give the same result: the absence of fringe shift.

→ In the particular case, the light is emitted by the source at the celerity c, travels the two identical lengths in the same duration, there is no phase shift. This is consistent with experimental results (with interferometer and observer motionless on Earth).

→ In the general case, and in accordance with Eq. (1.a-b) & (2.a-b), the distance traveled parallel to the movement is greater (it is equal to $2\gamma^2 L$) than that traveled perpendicularly (which is equal to $2\gamma L$). At identical velocity of the light, in order not to have any phase shift, it is necessary for the parallel length to contract by γ. This is the case in the theory of relativity but which also specifies that the duration must dilate by γ in the direction of the displacement: thus this dilation of time would generate for its part a fringe shift... In the single relativistic derivation found, its authors skip this difficulty of different length paths and time dilation to succinctly indicate that the light must always go at the same speed c! [b]

IV Consideration on velocities

Le light celerity is the crux of the problem. A velocity v is the ration of a distance d by a duration or time t:

$$v = \frac{d}{t} \tag{3}$$

If one of the three parameters is variable, then at least one other parameter must be it too (**see Figure 4**).

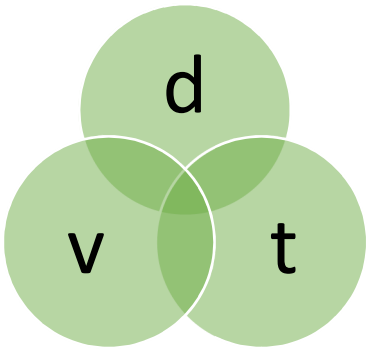

Figure 4: 0 or 2 or 3 variable parameters

In our analysis, the distance d traveled varies according to the direction of motion. The absence of fringe shift indicates that there would be no variation in the duration or time t. So the velocity v must be variable. And it is the way in which the light velocity is considered that gives rise to differences of interpretation (**see Table 1**):

- In the aether medium, the light velocity is constant in a motionless frame
- For the theory of relativity, the light velocity is constant in any frame
- For Neo-Newtonian Mechanics[11] with corpuscular photon, the light photon is emitted at a constant velocity with respect to the motion of the light source

[b] "Likewise, the light makes the return trip after reflection from the mirror at a speed of c, and not with the speed c+v. Thus, the motion of the Earth should not influence the fringe pattern observed in the Michelson–Morley experiment, and a null result should be expected".[10]

Theory	Light	Light rules	*Light velocities in O' in motion*	Light velocities in O motionless	Distances in O motionless	Durations in O motionless
Aether	Wave	c in the motionless frame	*different*	equal	different ?	equal
Relativity	Photon	c in any frame	*equal*	equal	equal ?	different ?
Neo-Newtonian	Photon	c' at the source (frame in motion)	*equal*	different	different	equal

Table 1: Light velocities, distances and durations

That is to say that according to Neo-Newtonian mechanics, in our terrestrial frame, the light velocity could be variable according to the motion of the light source. For example, the velocity of light emitted by a star would be different from the velocity of light emitted by another star, or that of a terrestrial light source.

V Proposal of experiments

Some recent experimental results would support a change in the light velocity by highlighting:

- A variation of the results according to the seasons, that is to say according to the relative speed of the terrestrial observer.[12]
- A variation of the speed according to whether the light source is linked to the Earth or that it comes from the stars.[13]

These recent experiments obviously need to be done again by other laboratories to validate or not these results. And in our case, the most relevant, but more complicated, experience would be to experience Michelson-Morley by alternating a terrestrial light source with a stellar light source (but not that of the Sun which remains at a constant distance from Earth).

VI Conclusion

After having indicated the geometrical distances traveled by the two light rays when the observer is located in a frame of reference not linked to the interferometer, we have analyzed the relativistic explanation. It is a historical one and it is based on the Lorentz-FitzGerald contraction in the presence of ether, but it appears to be an indirect explanation and therefore it is not a rigorous one. Then we have pointed out that a demonstration made directly from the hypotheses of Relativity (with a constant light velocity and a variation of lengths and time in the direction of the motion) was lacking to study the general case where the interferometer is in translation in the reference frame of the observer. And we have shown that the absence of fringe shift (same durations) on paths of different distances could induce a variable velocity of light depending on the observer's frame of reference. Significantly more accurate measurements both of the seasonality of terrestrial observer measurements and of photon velocities from moving sources would need to be made to confirm or not this approach.

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