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*Article*

# Reflection of Light as a Mechanical Phenomenon Applied to the Michelson Interferometer with Light from the Sun

**Filip Dambi Filipescu***

Independent Researcher, Surprise AZ, USA
* Correspondence: filipdambi1@gmail.com

**Abstract:** The Sun is a frame at relative rest in which the light from Sun travels at the emitted speed $c$, and the Earth travels with the revolving speed $v$. The reflection of light as a mechanical phenomenon applies to the modified Michelson interferometer employed by Miller in his experiments with light from Sun. Unlike the Tomaschek experiments, which employ light from stars, the fringe shifts in the Miller experiments are predictable. This study derives the light speeds from the Sun entering the interferometer from 6 am to 6 pm and the corresponding fringe shifts confirming that Miller's observed fringe shifts are proof of the Earth's motion in the Sun's frame at relative rest and the Universe.

**Keywords:** geometrical optics; speed of light; reflection of light; modified Michelson interferometer

## 1. Introduction

Michelson derives the fringe shift in the space filled with ether; consequently, the speed of light from a source before and after reflection has the same magnitude $c$. Light reflection as a mechanical phenomenon is studied in a vacuum where the speed of light from the source emitted at the constant $c$ changes after a mirror's reflection as a ball in an elastic collision with a wall. Therefore, the difference between these two approaches is the reflection of light by a mirror.

The studies of reflection of light as mechanical phenomena by Filipescu [1-5] continue by applying the reflection of light to the modified Michelson interferometer [6,7]. References 1 and 2, as well as References 4 and 5, are the same article. These studies [1,2,4,5] based on the elastic collision of balls with a wall in motion at the limit when the mass of balls converges to zero offer the equation

$$c_{ra} = c_s + v_i + v_r \,. \tag{1}$$

In Equation (1), $c_{ra}$ is the speed of a reflected wavefront of a ray of light, $c_s$ is the wavefront speed from a source or a mirror as a source, $v_i$ is the mirror speed in the opposite direction of the incident wavefront, and $v_r$ is the mirror speed in the direction of the reflected wavefront. All speeds are in the frame at absolute rest. The speeds $v_i$ and $v_r$ are equal and belong to the inertial frame of the mirror at the instance of collision.

Another form of the Equation (1) is

$$c_{ra} = c_s + v\cos a + vosb \,. \tag{2}$$

In Equation (2), the speeds $v\cos a$ and $v\cos b$ replace $v_i$ and $v_r$, respectively. Angle $a$ corresponds to the opposite direction of the incident wavefront; angle $b$ to the direction of the reflected wavefront. These angles are measured counterclockwise

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from the direction of the velocity vector $v$ with its origin at the point of collision; their directions are outward in space from the point of collision.

The physics phenomena are observed in the inertial frame of the Sun as in the frame at absolute rest; in other words, the inertial frame of the Sun is a frame at relative rest for Earth that revolves around the Sun with speed $v$. The frame at absolute rest can be replaced with the Sun's frame at relative rest for the study of the Earth's motion. Therefore, the Sun is a fixed source of light for Earth, and the Earth may be considered an inertial frame in the Sun's frame at relative rest at the time of an experiment. The light from Sun travels at the speed $c$ in any direction in the Sun's frame at relative rest.

Equation (2) applies to the modified Michelson interferometer employed by Miller [6,7] in his experiments with light from Sun because, in this case, the experimental results are predictable. The Tomaschek [8] experiments employ light from stars that may or may not have the same velocity in the Universe as the Sun. Therefore, the experimental results are not predictable but still valuable.

## 2. The interferometer located on the Earth's Equator

### 2.1. General considerations

The following drawings illustrate a way to bring the light from Sun to a modified Michelson interferometer. For simplicity, the Earth's axis has no tilt.

Figure 1(a) shows the Earth with its equatorial circle, the spin around its axis perpendicular to the paper plane, and its revolving orbit around the Sun. The North Pole is on the front of the paper.

Figure 1(b) illustrates the Michelson interferometer at 6 am, as seen in Figure 1(a) from the top of the paper. Mirrors $M_1$, $M_2$, $M_3$, and beam splitter M belong to the instrument. Mirror $M_3$ replaces the instrument's source of light.

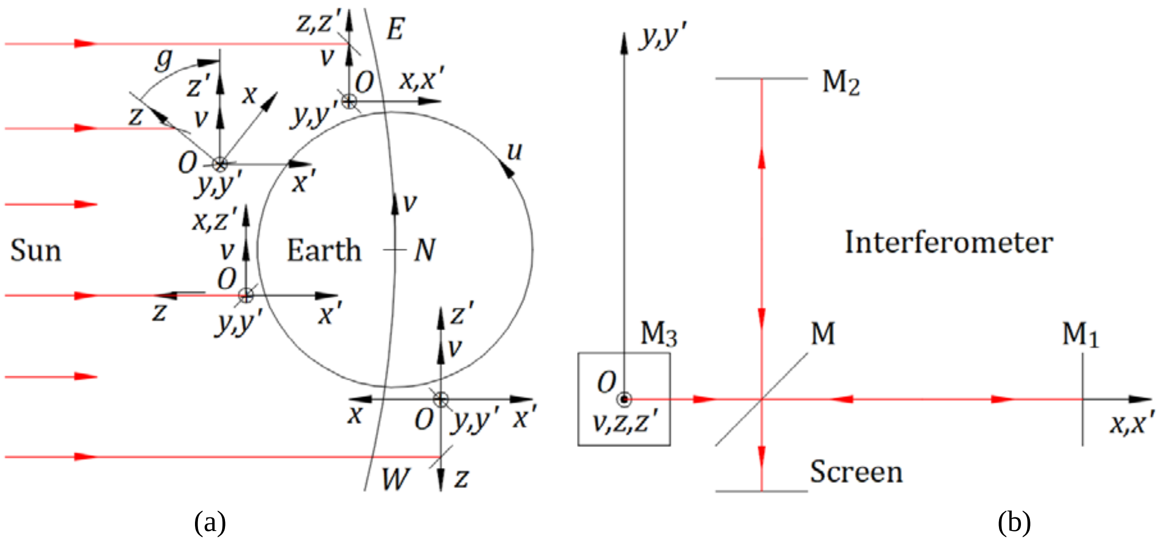


**Figure 1.**: (a) The interferometer on the Earth's Equator at 6 am, noon, 6 pm, and between 6 am and 6 pm; (b) The interferometer details.

The local observer is on the North side of the Equator. Its cartesian frame $Oxyz$, fixed to Earth, has its origin at point $O$ of $M_3$, the axis $Ox$ on his horizontal line with the direction from left to right, and the axis $Oz$ perpendicular to the Earth's local surface with the direction from the back to the front of the paper. Plane $Oxy$ is parallel to the Earth's local surface. At 6 am, the revolving velocity $v$ of the Earth coincides with $Oz$.

The interferometer is located in the plane $Oxy$ and rotates counterclockwise

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around $Oz$ with an angle $f$ measured from $Ox$. Thus, the initial position of the instrument is when direction OM1 coincides with $Ox$ for $f = 0°$, as shown in Figure 1(b).

In the Sun's frame at relative rest, a vector velocity $v$ in the direction $Oz'$ of the cartesian frame $Ox'y'z'$ is attached permanently to the origin $O$ of $Oxyz$. The counterclockwise Earth's spin changes the position of $Oxyz$ while $Ox'y'z'$ rotates clockwise around the axis $Oy'$ to keep its axes fixed.

The instrument on the Equator belongs to a local Meridian. It can be defined as the Equator's start position when the local Meridian, so the instrument, is at 6 am and frames $Oxyz$ and $Ox'y'z'$ coincide as illustrated in Figure 1(b), with the instrument at the initial position.

From 6 am to 6 pm, the center of the Sun, Earth's orbit, and the Equator's circle are in the same plane as $Oxz$ and $Ox'z'$, even if $Oxz$ changes its directions.

Angle $g$ is measured from $Oz$ to the vector velocity $v$ at $O$. Figure 1(a) indicates the position of the interferometer at 6 am, which is the start position corresponding to angle $g = 0°$, at a time between 6 am and 6 pm corresponding to an angle $g$, at noon for $g = 90°$, and at 6 pm for $g = 180°$.

Figure 2(a) depicts the Equator's start position at 6 am. The Earth's spin brings the interferometer at the noon position, as illustrated in Figure 2(b), at the 6 pm position, as presented in Figure 2(c), and at a time between 6 am and 6 pm position, as shown in Figure 3.

### 2.2. The interferometer located on the Equator at 6 am, noon, and 6 pm

Figure 2(a) illustrates the interferometer at 6 am. Point $A$ belongs to mirror M4 and to axis $Oz$. The mirror M4, axis $Oz$, mirror M3, and interferometer form a solid structure. M4 rotates on an axis through point $A$ perpendicular to the paper plane and around the axis $Oz$ as well.

It is considering that the Sun emits parallel rays of light toward Earth. The incident ray from Sun to $A$ and the reflected ray along the axis $Oz$ are in the plane $Oxz$. The ray from Sun to $A$ is perpendicular to velocity $v$, as observed from the figures below.

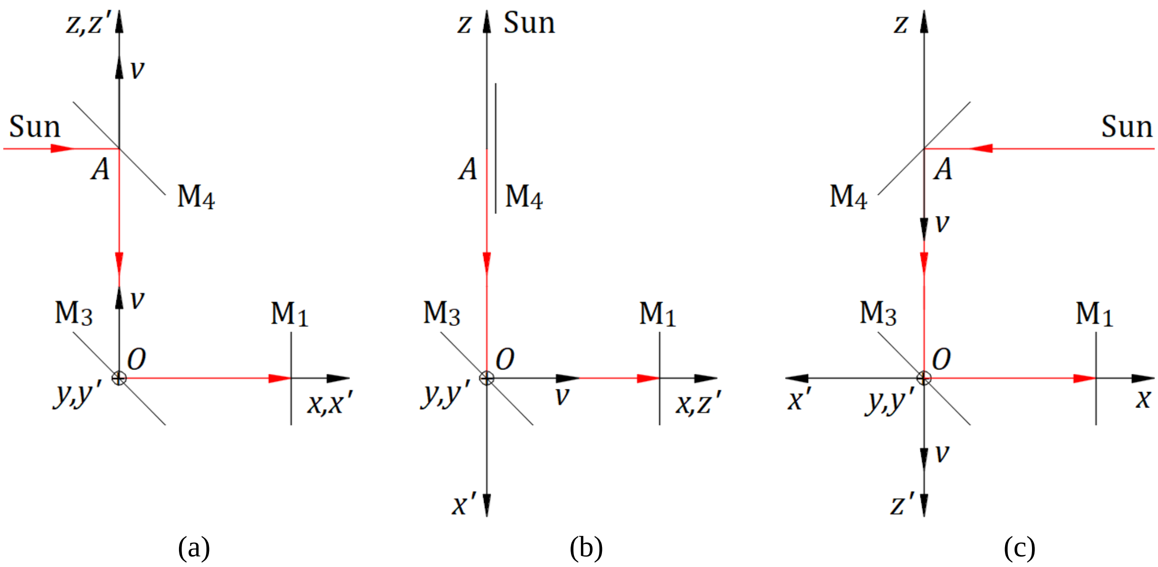


**Figure 2.:** (a) The interferometer located on the Equator at 6 am; (b) at noon; (c) at 6 pm.

Considering the velocity vector $v$ at $A$ and $O$, the ray of light at $A$ is reflected toward $O$ with the speed $c_{ra}$ obtainable with Equation (2),

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$c_{ra} = c_s + v\cos a + v\cos b = c + v\cos 90° + v\cos 180° = c - v$. The ray is reflected at $O$ along $Ox$ with the entry speed into the interferometer $c_{f=0°} = c_s + v\cos a + v\cos b = c_{ra} + v\cos 0° + v\cos 270° = (c - v) + v = c$ and is the same for any angle $f$, $c_f = c$. Thus, a shift of zero fringes is expected to be observed by rotating the interferometer $360°$.

Within the interferometer, the light rays drift opposite to velocity $v$. The drift does not affect the fringe shift or may affect it insignificantly.

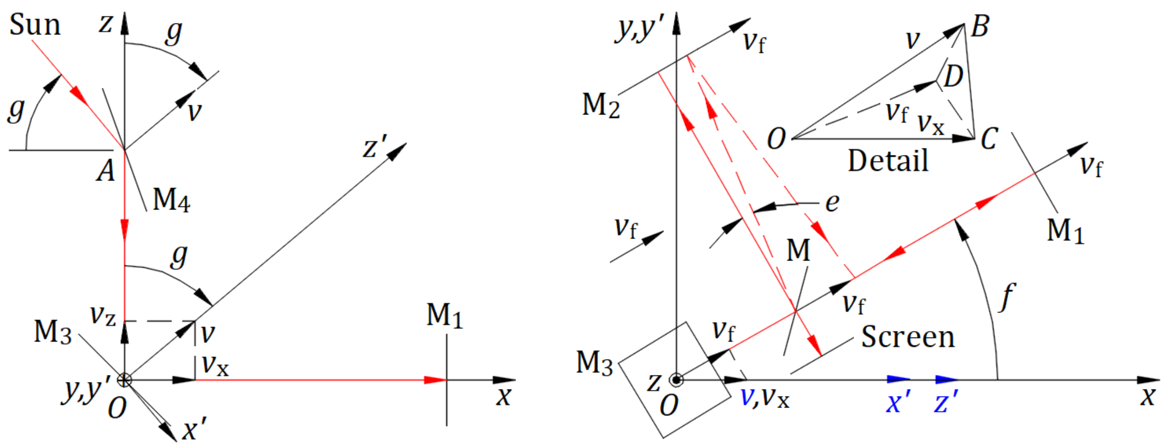
Figure (2b) depicts the interferometer at noon. The light from Sun travels parallel to $Oz$; therefore, no need for mirror M4. At this position, M4 rotates $180°$ around $Oz$.

Considering the velocity vector $v$ at $O$, the ray of light reflected at $O$ toward M1 at the initial position of the instrument for $f = 0°$ has the entry speed $c_{f=0°} = c_s + v\cos a + v\cos b = c + v\cos 90° + v\cos 0° = c + v$. By rotating the interferometer counterclockwise around axis $Oz$ at $f = 180°$, the entry speed $c_{f=180°} = c_s + v\cos a + v\cos b = c + v\cos 90° + v\cos 180° = c - v$.

Figure 2(c), shows the instrument at 6 pm. Considering the velocity vector $v$ at $A$ and $O$, the ray of light at $A$ is reflected toward $O$ with the speed $c_{ra} = c_s + v\cos a + v\cos b = c + v\cos 90° + v\cos 0° = c + v$. The ray is reflected at $O$ along $Ox$ with the entry speed into the interferometer $c_{f=0°} = c_s + v\cos a + v\cos b = c_{ra} + v\cos 180° + v\cos 90° = (c + v) - v = c$ and is the same for any angle $f$, $c_f = c$. A shift of zero fringes is expected to be observed by rotating the interferometer $360°$.

## 3. The fringe shift in the modified Michelson interferometer located on the Earth's Equator at an angle *g*

Figure 3(a) presents the instrument at a time between 6 am and 6 pm when $Oz'$ makes an angle $g$ measured from $Oz$. M4 rotates around the axis perpendicular to the paper plane. It reflects the rays from Sun at $A$ in the direction $AO$. The rays belong to a semicircle on the Sun with a diameter equal to that of the Earth. Note that $g$ has an opposite direction to the Earth's spin.




(a) (b)

**Figure 3.**: (a) The interferometer at an angle $g$; (b) The fringe shift in the modified Michelson interferometer.

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From 6 am to 6 pm for $0° \le g \le 180°$, the projection of $v$ on $Oz$ is $v_z = v\cos g$, and on $Ox$ is $v_x = v\sin g$.

Considering the velocity vector $v$ at $A$, the ray of light is reflected at $A$ toward $O$ with the speed $c_{ra} = c_s + v\cos a + v\cos b = c + v\cos 90° + v\cos(g + 180°) = c - v\cos g$.

At the initial position of the instrument for $f = 0°$, the entry speed from $O$ toward M1 is $c_{f=0°} = c_s + v\cos a + v\cos b = c_{ra} + v\cos g + v\cos(360° - (90° - g)) = (c - v\cos g) + v\cos g + v\sin g = c + v\sin g$. For $f = 180°$, $c_{f=180°} = c_s + v\cos a + v\cos b = c_{ra} + v\cos g + v\cos(g + 90°) = (c - v\cos g) + v\cos g - v\sin g = c - v\sin g$.

The projection of velocity $v$ on $Oz$ is $v_z = v\cos g$, which is the speed of M3 and the interferometer in the direction $Oz$ for any angle $g$. The speed $v_z$ does not affect the fringe shift or may affect it insignificantly.

The projection of velocity $v$ on $Ox$ and direction OM1 is equal to the projection of velocity $v$ at the initial position of the interferometer, $v_x = v_{f=0°} = v\sin g$.

### 3.1. The fringe shift in the modified Michelson interferometer with a particular geometry located on Equator at an angle g

The top view of Figure 3(a) with the interferometer rotated by an angle $f$ from $Ox$ is illustrated in Figure 3(b). The Michelson instrument has a particular geometry [1,2] in which the beam splitter makes an angle of $45°$, and the two opaque mirrors make the angles of $90°$ and $0°$ to the direction of light from the source. The reflected rays by beam splitter M travel perpendicular to M2, as illustrated by the ray in the solid red line in Figure 3(b).

In the Detail of Figure 3(b), $OB$, $OC$, and $OD$ are along $Oz'$, $Ox$, and OM1, respectively. $OBC$ and $BCD$ planes and their intersection along $BC$ are perpendicular to the paper plane, and $OD$ is perpendicular to $BCD$. Therefore, a line from any point along $BC$ to point $D$ is perpendicular to $OD$. Thus, the projections of $v$ and $v_x$ on OM1 are equal. The projection of $v_x$ in the direction OM1 for an angle $f$ is $v_f = v_x \cos f = v\sin g \cos f$, which is the speed of M3 and the interferometer in the direction OM1. Note that $v$, $Ox'$, and $Oz'$ are depicted in blue to indicate that they are not in the paper plane.

Considering the velocity vector $v$ at $O$, the entry speed of the ray of light reflected at $O$ along OM1 is $c_f = c_s + v\cos a + v\cos b = c_{ra} + v\cos g + v_x \cos f = (c - v\cos g) + v\cos g + v\sin g \cos f = c + v\sin g \cos f = c + v_f$.

Reference 2 yields from the theoretical derivation that the fringe shift is zero for any reasonable speeds $c$ and $v$, therefore for any speeds $c_f = c + v_f$ and $v_f = v\sin g \cos f$.

The spin speed $u$ of the Earth at the Equator, not shown in Fig. 3(a) and 3(b) at $O$, has the opposite direction to $v_x$. Considering the speed $u$, $v_x = v\sin g - u$ and $v_f = v_x \cos f$. The fringe shift is also zero for other magnitudes of speeds $c_f$ and $v_f$.

### 3.2. The fringe shift in the modified Michelson interferometer located on the Equator at an angle g

Michelson predicts a $0.40$ fringe shift in the Michelson-Morley experiment [9]. Filipescu predicts $0.40 \times 10^{-4}$ [3] applying reflection of light as a mechanical phenomenon when reflected rays by beam splitter M travel as illustrated by the ray in the dashed red

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line of Figure 3(b) for an angle $e$ equal to the aberration angle, $e = \arcsin(v/c) = 0.0001$ rad, measured from the perpendicular direction to the rays from M3.

For a modified Michelson interferometer with the geometry as in the Michelson-Morley experiment, [3,9], the fringe shift can be calculated with Reference 3 in which:

The initial, $90°$, $180°$, and $270°$ positions of the interferometer in this article replace the $180°$, $270°$, initial, and $90°$ positions in Reference 3, respectively. This is because of the different initial settings in the two articles.

The speeds $v_f$ and $c_f = c + v_f$ corresponding to each angle $g$ in this article replace the speeds $v$ and $c$ in Reference 3, respectively.

The length of the interferometer arm $L = 32$ m as used by Miller.

The fringe shift in this article at the initial position and $90°$, $180°$, and $270°$ positions , applying the numerical calculation from Reference 3, are presented in Table 1 for angles $g$ equal to $0°, 30°, 45°, 60°$, and $90°$. For $g$ equal to $120°, 135°, 150°$, and $180°$, the fringe shift has the same magnitudes correspondingly.

**Table 1.** The fringe shift for $L = 32$ m and $e = 0.0001$ at different angles $g$.

| Positions | g = 0° | g = 30° | g = 45° | g = 60° | g = 90° |
|---|---|---|---|---|---|
| 0° | 0.000E+00 | -2.888E-08 | 0.000E+00 | 0.000E+00 | -2.888E-08 |
| 90° | 0.000E+00 | 5.819E-05 | 8.231E-05 | 1.008E-04 | 1.164E-04 |
| 180° | 0.000E+00 | -5.819E-05 | -8.231E-05 | -1.008E-04 | -1.164E-04 |
| 270° | 0.000E+00 | 2.888E-08 | 0.000E+00 | 0.000E+00 | 2.888E-08 |

For $L = 32$ m, Miller expected a $1.12$ fringe shift based on Michelson's derivation and observed $0.08$ in 1921 and $0.088$ in 1925 [6,7]. Based on the reflection of light as a mechanical phenomenon, Filipescu predicts the fringe shift of $1.164 \times 10^{-4}$ in Reference 3, and as in Table 1, by employing Reference 3 for numerical calculation of the fringe shift in this article.

The data in Table 1 were calculated with the speeds $v_f$ and $c_f = c + v_f$ for angles $f = 0°, 90°, 180°$, and $270°$ and angle $e = \arcsin(v/c) = 0.0001$ rad. In Reference 3, angle $e$ applies from zero to the aberration angle and beyond for different magnitudes of speeds $v_f$ and $c_f = c + v_f$. The fringe shift increases with the increase of angle $e$. For $L = 32$ m and $e = 0.0027$ rad, the predicted fringe shift increases from Table 1 to values comparable to Miller's observations. Angle $e$ can have the actual magnitude of $0.0027$ rad and beyond within the instrument, particularly for $L = 32$ m. The predicted fringe shift is derived with a chosen, known geometry, but the experimental result is according to the actual, unknown geometry, therefore an unknown $e$.

The fringe shift for $f = 0°$, $f = 90°$, $f = 180°$, and $f = 270°$ positions are presented in Table 2 for $L = 32$ m and $e = 0.0027$ rad at different angles $g$.

**Table 2.** The fringe shift for $L = 32$ m and $e = 0.0027$ rad at different angles $g$.

| Positions | g = 0° | g = 30° | g = 45° | g = 60° | g = 90° |
|---|---|---|---|---|---|
| 0° | 0.000E+00 | 2.888E-08 | 0.000E+00 | 0.000E+00 | 4.331E-08 |
| 90° | 0.000E+00 | 4.242E-02 | 5.999E-02 | 7.348E-02 | 8.485E-02 |
| 180° | 0.000E+00 | -4.242E-02 | -5.999E-02 | -7.348E-02 | -8.485E-02 |
| 270° | 0.000E+00 | -2.888E-08 | 0.000E+00 | 0.000E+00 | -4.331E-08 |

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The fringe shift in Table 2 explains the fringe shift observed by Miller at Mount Wilson [6,7] in 1921 and 1925. Therefore, Miller's experiments prove the motion of Earth in the Sun's frame at relative rest and the Universe.

Considering the speed $u$, $v_x = v \sin g - u$ and $v_f = v_x \cos f$. The different magnitudes of $c_f = c + v_f$ and $v_f$ does not make a significant visual difference in the fringe shift. For example, for $g = 90°$ instead of $8.485E-02$, as in Table 2, the fringe shift is $8.353E-02$.

## 4. The fringe shift in the modified Michelson interferometer located on an Earth's Latitude

If the solid structure from the Equator at 6 am, as in Figure 2(a), moves on the local Meridian to the North Pole, the observer sees the instrument as in Figure (4a). From the Equator to the North Pole, the frame $Ox'y'z'$ rotates $90°$ around $Ox'$ to keep its axes fixed. After rotation, $Oz'$ and the speed $v$ have the direction of $Oy$.

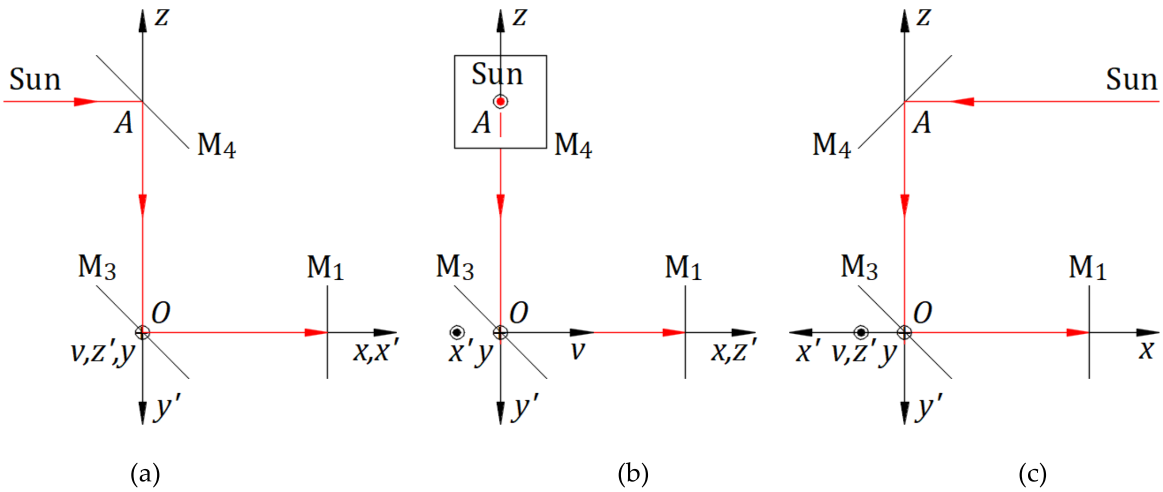


**Figure 4.:** (a) Interferometer located on the North Pole at 6 am, (b) at noon; (c) at 6 pm.

In the Sun's frame at relative rest, the Earth's spin changes the position of $Oxyz$ while $Ox'y'z'$ rotates around the axis $Oy'$ to keep its axes fixed. Figure (4a) illustrates the instrument at 6 am, Figure (4b) at noon, and Figure (4c) at 6 pm. At the North Pole mirror M4 rotates clockwise only around $Oz$.

The right view of Figure 2(a) is as in Figure 5(a). In the Sun's frame at relative rest, moving the solid structure from the Equator to the North Pole, the position of $Oxyz$ changes while $Ox'y'z'$ rotates around the axis $Ox'$ to keep its axes fixed, as visualized in Figure 5(b). Therefore, the velocity $v$ with its axis $Oz'$ rotates in the plane $Oyz$ around $Ox'$ with angle $h$ measured from the axis $Oz$. For $h = 0°$, the interferometer is at the Equator, and for $h = 90°$ at the North Pole. In this rotation from the Equator to the North Pole, Mirror M4 stays fixed. It reflects from $A$ to $O$ the rays belonging to a quarter circle on the Sun with a diameter equal to that of the Earth.

Figure 5(b) depicts the interferometer at angle $h$. The planes $Oxz$ and $Ox'z'$ are perpendicular to the paper plane and make the angle $h$ between them.

The Latitude's start position can be defined when the instrument at the initial position is located at the intersection of the local Meridian with the local Latitude at 6 am and

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$Oz'$ is in the plane $Oyz$ making an angle $h$ measured from $Oz$. The projection of $v$ on $Oz$ is $v_{z,h} = v\cos h$.

The plane $Ox'z'$ is parallel to the Equator's plane and $Oxy$ to the Earth's local surface.

In Figure 5(b), in the Sun's frame at relative rest, on the Latitude at the constant angle $h$ from 6 am to 6 pm, the Earth's spin rotates the frame $Oxyz$ while the velocity $v$ with its axis $Oz'$ rotates around the fixed $Oy'$ with angle $g$ from the plane $Oyz$ at 6 am to $Ox$ at noon and then at 6 pm the velocity $v$ with its axis $Oz'$ is in the opposite of its direction at 6 am. Note that $g$ has an opposite direction to the Earth's spin. For example, angle $g = 0°$ at 6 am, $g = 90°$ at noon, and $g = 180°$ at 6 pm. Thus, on the same Meridian, angle $g$ is the same when the instrument is on different Latitudes, as at the Equator.

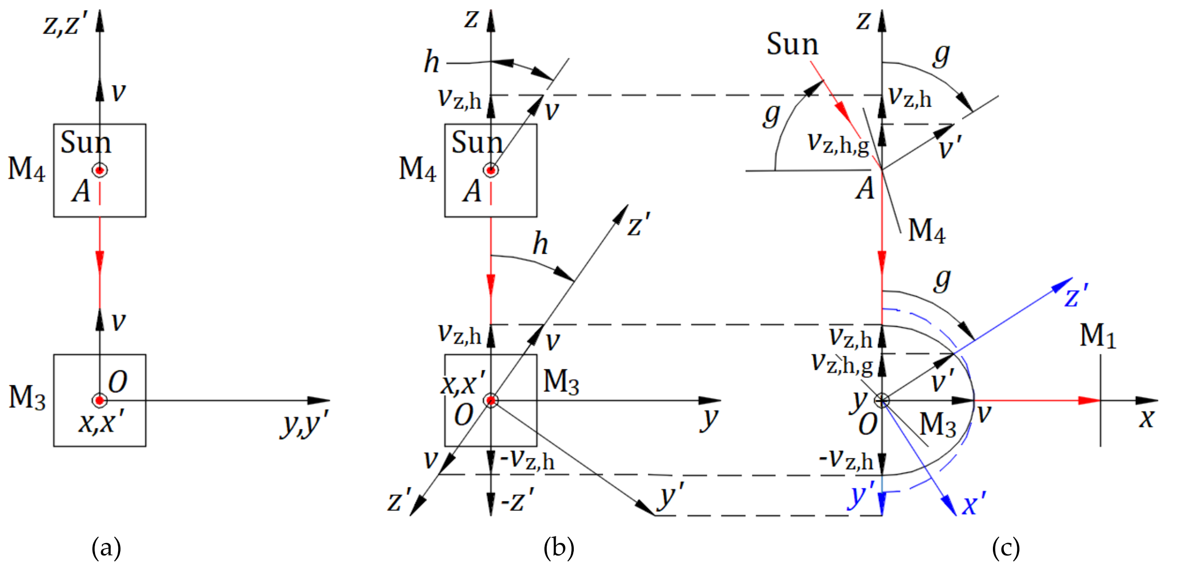


**Figure 5.:** (a) Interferometer located on the Equator at 6 am; (b) on a Latitude at angle $h$; (c) the left view of (b).

In Figure 5(b), the view from the opposite direction of $Oy'$ shows the vector $v$ in the plane $Ox'z'$ from 6 am to 6 pm belonging to a semicircle with the origin at $O$ and the diameter $2v$. The semicircle is on the front of and perpendicular to the paper plane. Thus, the projection of $v$ on $Ox$ is $v_x = v_{f=0°} = v\sin g$, which is the speed of M3 and the interferometer in the direction $Ox$, for $g = 0°$ at 6 am to $g = 180°$ at 6 pm, as in Section 3. The speed $v_x$ is independent of angle $h$.

Suppose the plane $Ox'z'$, with its semicircle viewed from the opposite direction of $Oy'$, rotates clockwise around $Ox'$ to coincide with the plane $Oxz$. The semicircle locks like in the plane $Oxz$ depicted in the blue dashed line of Figure 5(c). An identical image is visualized for any angle h.

In Figure 5(b), the view from the opposite direction of $Oy$ sees the projection of the semicircle of the vector $v$ as a semi ellipse in the plane $Oxz$ as illustrated in Figure 5(c). The projection of this semi ellipse on $Oz$ represents the speed $v_{z,h,g}$ of M3 and interferometer along $Oz$.

In Figure 5(c), the projection of the velocity $v$ that belongs to $Oz'$ on the plane $Oxz$ is $v'$. Angle $g$ is measured from the plane $Oyz$ to the plane perpendicular to the paper plane that includes axis $Oz'$.

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Note that $Ox'$, $Oy'$, and $Oz'$ are depicted in blue to indicate that they are not in the paper plane. In Figure 5(c), $Oz'$ rotates in the back of the paper plane from $g = 0°$, when it is behind $Oz$, to the paper plane coinciding with $Ox$ for $g = 90°$, then rotates in the front of the paper plane to above of $-Oz$ for $g = 180°$. $Ox'$ rotates in the front of paper plane from $Ox$ for $g = 0°$ to $-Ox$ for $g = 180°$.

The projections of $v$ and $v'$ on $Oz$ are equal for the same reason given in Detail of Figure 3(b).

At the Latitude's start position, for $g = 0°$, the projection of $v$ on $Oz$ is $v_{z,h} = v_{z,h,g=0°} = v \cos h$ for a constant $h$. For $0° \leq g \leq 180°$ from 6 am to 6 pm, the projection of $v$ on $Oz$ is $v_{z,h,g} = v_{z,h} \cos g = v \cos h \cos g$, which is the speed of M3 and the interferometer in the direction $Oz$ for any angle $g$. The speed $v_{z,h,g}$ does not affect the fringe shift by rotating the instrument $360°$ around $Oz$ or may affect it insignificantly.

Considering the velocity vector $v'$ at $A$, the ray of light is reflected at $A$ toward $O$ with the speed $c_{ra} = c_s + v' \cos a + v' \cos b = c + v' \cos 90° + v' \cos(g + 180°) = c - v' \cos g$.

Considering the velocity vector $v'$ at $O$, the entry speed of the light ray reflected at $O$ in the direction OM1 for an angle $f$ is $c_f = c_s + v' \cos a + v' \cos b = c_{ra} + v' \cos g + v_x \cos f = (c - v' \cos g) + v' \cos g + v_x \cos f = c + v_f$ and $v_f = v_x \cos f = v \sin g \cos f$, as in Section 3.1.

Introducing the same speeds $c_f = c + v_f$ and $v_f = v \sin g \cos f$ in References 2 and 3, the same magnitudes of the fringe shift are obtained as in Sections 3.1. and 3.2., respectively.

Therefore, the study of the fringe shift at the Equator applies to any Latitude on Earth to the Michelson interferometer with a particular geometry [1,2] and to the Michelson interferometer with a geometry, as in References 3 and 9, as well.

## 5. Conclusions

Mirror M4 is adjusted to receive only the rays from Sun that are parallel in the direction from Sun to Earth. In this case, the fringe shift follows a pattern for angle $0° \leq g \leq 180°$, as in Tables 1 and 2. If mirror M4 reflects rays coming from other directions, the speeds $v_f$ and $c_f = c + v_f$ have different expressions, from these derived here, for identical angles $g$ and $f$, and the fringe shift may be random for sequential values of angle $g$.

The adjusting of mirror M4, the light paths geometries, the magnitude of angle $e$, the drift of the light paths because of velocity $v_z$, even the Doppler effect, and others may affect the fringe shift more or less. We cannot master all these factors to get the fringe shift we want, but the experimental fringe shifts have to be within a reasonable theoretical expectations range.

Reference 3 offers the theoretical expectations of the fringe shift for light reflection as a mechanical phenomenon and the Michelson derivation. In this article, for $L = 32$ m, the fringe shift varies with angle $e$, as in Tables 1 and 2. For Michelson derivation, the fringe shift is $1.1636 \cong 1.12$ for $e = 0$ rad, $1.1637$ for $e = 0.0001$ rad, and $1.1668$ for $e = 0.0027$ rad, practically a constant. A different constant is obtained for each magnitude of $L$; for $L = 11$ m, as in Michelson derivation, the fringe shift is $0.40$ for any angle $e$. Therefore, for the same length $L$, Michelson's derivation yields a constant high fringe shift that does not vary with angle $e$, different from the reflection of light as a

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mechanical phenomenon that offers a low fringe shift that varies with angle $e$. The variation of the fringe shift with angle $e$ makes it possible to explain the results of Miller's experiments.

In conclusion, to explain Miller's observed fringe shift, a study has to offer a reasonable theoretical expectations range and the variation of the fringe shift with angle $e$.

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