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# Light Paths at Earth, in the Planetary System, at Atoms, and in the Universe: Discovery of Sub-Relativistic Light Paths

**Hans-Otto Carmesin***

University of Bremen, Studienseminar Stade, Gymnasium Athenaeum und Observatorium Stade, Germany

***Corresponding Author:** Hans-Otto Carmesin, University of Bremen, Studienseminar Stade, Gymnasium Athenaeum und Observatorium Stade, Germany.

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## Abstract
In space navigation, the real nature of space is essential. Therefore, the International Astronomical Union (IAU) recommended to use the Geocentric Celestial Reference System (GCRS) near Earth, and to utilize the Barycentric Celestial Reference System for spaceflight in the planetary system. Moreover, the IAU proclaimed to solve the problem to find an Adequate Coordinate System (ACS). That problem has been solved with help of a measurement procedure, and, independently, by using fundamental interactions, see. Here, the ACS and the Equation of Time Dilation (ETD) are deduced simultaneously by a third independent method, an analytic derivation from geometry [1-3]. This method is especially traceable, transparent, founded, valuable, and insightful. In addition to that derivation of spacetime's structure of time and space, spacetime's structure of light paths is derived. For it, the light clock is used as a link. Moreover, it is deduced, why the Experiment (MME) did not find an expected nonzero velocity [4]. Furthermore, sub-relativistic light paths are discovered. These describe spacetime's structure in fine detail beyond General Relativity Theory (GRT) and Special Relativity Theory (SRT). With it, length contraction is explained in realistic detail. Therefrom, it is deduced how time elapses in a universal manner in each atom nucleus, atom, at Earth, in the planetary system, and in the universe.

**Keywords:** Relativity, Riemann Geometry, Criterion for ACS, Adequate Coordinate System, Equation of Time Dilation, Light Path, Observation, Sub-Relativistic Length, Space Navigation, Atom, Earth, Planets, Universe

### Introduction
In nature, in space navigation, in geodesy, in the planetary system, and in the universe, the phenomena of time dilation and optical paths are essential, see. For instance, a gravitational potential difference between two points A and B causes a gravitational time dilation, [5-8]. Similarly, a speed v can cause a kinematic time dilation, see [9]. General Relativity Theory (GRT) provides an equation that describes both types of time dilation in a coherent manner with help of a very founded, robust and valuable scalar product $ds^2$ in four-dimensional spacetime, by see [10,11]. Though GRT provides the key equations for time dilation, GRT does not provide sufficient information about the Adequate Coordinate Systems (ACS), in which these equations predict an observation correctly [5-11]. This ACS problem has been proclaimed by the International Astronomical Union (IAU), see [12].

**Figure 1:** A Foucault Pendulum in the Department for Physics and Electrical Engineering at the University Bremen. With Such a Pendulum, Foucault (1851) Showed That Earth Rotates Relative to a Pendulum's Plane of Oscillation [13]. Especially, at the North Pole, the Frequency of that Rotation is $\frac{360^o}{24\ \mathrm{h}}$.Therefore, the Coordinate System, at Which the Plane of Oscillation of A Pendulum at Earth's North Pole is at Rest, and Another Coordinate System, at Which Earth's Ground is at Rest, Are Not Interchangeable in a Physically Equivalent Manner, See Norton (1993) [14]

This problem has been solved with help of a measurement procedure and with help of gravity, additionally, comparisons with observation on Earth's ground and in space have been elaborated, see. Examples for specific adequate coordinate systems have been provided by the pendulum, see Figure. (1), and by the Spacelab D1 mission, see [1,2,9,13].

In this paper, the ACS problem is solved in a very fundamental and analytic manner: geometry is used as a starting point [3]. As usual in GRT, time is included, whereby Pseudo - Riemann geometry is formed. From it, the Equation of Time Dilation (ETD) is derived. Therefrom, the criterion for the ACS is deduced. With it, the ACS is derived, and the ETD with its local ACS are deduced. Therefrom, for an arbitrary pilot, it is shown, that zero motion corresponds to zero decrease of elapsed time of that pilot, whereas nonzero motion implies nonzero decrease of elapsed time of that pilot.

Next it is shown how light paths can be measured, photographed, and provide objective evidence for light's routes in space.These light paths and the ETD are used in order to determine the light paths in light clocks $(\vec{v}_{clock,\underline{ACS}} = 0$ or $\vec{v}_{clock,\underline{ACS}} \neq 0)$. Therefrom,it is shown that light paths are at rest in the ACS. Using this insightful, valuable and momentous result, it is shown for the Michelson Morleyexperiment (MME), that the velocity does neither cause the phase difference that was expected by, nor anyother phase difference [4]. Based on this general result, the length contraction in Special Relativity Theory (SRT), see, is analyzed.Thereby, new sub-relativistic light paths are discovered [10]. Based on their insightful and useful lengths, the construction of innovative sensors has been outlined, and the nature of length contraction has been derived.

On the basis of the MME and length contraction results, it is shown how time elapses in a universal manner in atom nuclei, in atoms, at Earth, in the planetary system, and in the universe.
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**Figure 2:** Spacelab: With it, Starker et al. (1985) Showed That the Pilot's Elapsed Time is Shorter Than the Corresponding Time at Earth's Ground [9]. Therefore, the Pilot's Coordinate System and the Ground's Coordinate System Are Not Interchangeable in An Equivalent Manner, See Norton (1993). Based on the Criterion for Motion (see section 5), this Key Experiment Clarified the Translation Motion (Nonzero Or Zero) of a Local Adequate Coordinate System (Acs) and Of Local Space [14]

## Pseudo - Riemann Geometry

We humans observe real space in nature and develop geometrical models for it. For instance, proposed a very valuable geometrical model of a flat space [15]. However, there is significant evidence that real space is curved, see. Therefore, geometry of curved space is a more realistic geometry [3,16]. Thereby, in local orthogonal coordinates, infinitesimal changes (increments) $dx_i$ of space form the following line element $ds^2$, with a metric tensor $g_{ii}$:

$$ds^2 := \underbrace{\sum_{i=1}^{i=3} g_{ii} dx_i^2}_{d\vec{r}^2} . \tag{1}$$

Moreover, Einstein proposed that space and time should be combined. Accordingly, Minkowski proposed pseudo – geometry [10,17]. Hereby, increments $dt$ of time and $dx_a$ of space form the following line element $ds^2$.

$$ds^2 := \underbrace{c^2 dt^2}_{dx_0^2} + \underbrace{\sum_{a=1}^{a=3} -dx_a^2}_{-d\vec{r}^2} = dt^2 c^2 \left( 1 - \frac{1}{c^2} \cdot \underbrace{\frac{d\vec{r}^2}{dt^2}}_{\vec{v}^2} \right) . \tag{2}$$

Hereby, the minus sign is introduced in order to describe the time evolution of a light flash starting at $dt$ = 0 at the origin with 0 = $ds^2$, so that $0 = c^2 dt^2 - d\vec{r}^2$ [8,18,19].

In order to combine the more realistic geometry in Eq. (1) and pseudo - geometry in Eq. (2), the pseudo - Riemann geometry (also named pseudo - Riemannian manifolds) has been proposed, see [3,8,11,17,20,21]. Correspondingly, thereby the line element is as follows:

$$ds^2 := \sum_{i=0}^{i=3} \sum_{j=0}^{j=3} g_{ij} dx_i dx_j \tag{3}$$

At each point in space time, this line element or scalar product can be presented in a local orthogonal coordinate system. Then the scalar product is as follows:

$$ds^2 := \sum_{i=0}^{i=3} g_{ii} dx_i^2 = g_{00} c^2 dt^2 + \underbrace{\sum_{a=1}^{a=3} g_{aa} dx_a^2}_{-d\vec{r}^2} = dt^2 c^2 \left( g_{00} - \frac{1}{c^2} \cdot \underbrace{\frac{d\vec{r}^2}{dt^2}}_{\vec{v}^2} \right) \tag{4}$$

In fact, in the line elements or scalar products of the pseudo - geometry in Eq. (2), and of the pseudo - Riemann geometry in Eq. (4), there occurs a velocity [17]. However, in nature, each velocity is usually determined relative to a reference system. Therefore, the question arises, what the Adequate Coordinate System (ACS) for the description of nature should be. This is investigated next:

## Adequate Coordinate System for the Description of Nature

In this section, the question is investigated, what the Adequate Coordinate System (ACS) for the description of nature should be. In fact, this is an essential and deep question about nature, and it has a long tradition:

In the geocentric world view, the hypothesis was proposed that Earth would be at rest, see e. g. [22].

According to by the Galileo principle of inertia, at each Adequate Coordinate System (ACS) that describes nature, the plane of oscillation of a pendulum at Earth's north pole is at rest, as there acts no torsional moment on that plane of oscillation [23].

However, Foucault showed that such a plane of oscillation of a pendulum at Earth's North pole rotates relative to Earth's surface, see Figure. (1). Consequently, Earth is not at rest [13]. Instead, Earth rotates around its axis of rotation, relative to the ACS that describes nature and nature's space. Therefore, there is no free choice of the ACS that describes nature and nature's space. This answers the question of Earth's rotational motion (zero or nonzero). Therefore, the question remains about Earth's translation motion (zero or nonzero), relative to the ACS, that describes nature and nature's space.

Inspite of that insight, Einstein proposed the hypothesis of the free choice of a coordinate system that describes nature with equal legitimation, in principle. That means the following requirement: The general law of nature must be expressed by equations, that hold for all coordinate systems, i. e that are covariant with respect to arbitrary substitutions. It is clear that physical science that fulfills postulate, obeys the postulate of general relativity. ' see, p. 776, lines 5-17 [21].

The only possibility is to assume that all conceivable coordinate systems can be used for the description of nature [21].

In the era of spaceflight, the International Astronomical Union (IAU) realized, the hypothesis of the free choice of an ACS in General Relativity Theory (GRT) and in Special Relativity Theory (SRT) is insufficient for by spaceflight. Accordingly, the IAU proclaimed the problem to find an ACS. Moreover, as a provisional solution, the IAU proposed to use the Geocentric Celestial Reference System (GCRS) for spaceflight near Earth, and to use the Barycentric Celestial Reference System (BCRS, almost heliocentric) for spaceflight in the planetary system, see [12,24] .

## Pseudo - Riemann Geometry Implies the ACS

In present - day physics, the question of the ACS has not yet been derived from pseudo - Riemann geometry (PRG). As the question of the ACS is essential, see sections (), it is derived here from the PRG:

In PRG, the line element alias scalar product can be described in two coordinate systems, and the respective line elements are equal or the scalar product is invariant:

$$ds'^2 = ds^2 \tag{5}$$

In general, a moving pilot can be described in both coordinate systems, by $ds'$ and by ds. Without loss of generality, $ds'$ describes the moving pilot in his own system. Consequently, the space increments $dx_a{}'$ are zero, as the pilot does not move relative to himself. Therefore, the invariance of the scalar product in Eq. (5) has the following form:

$$c^2 \cdot dt'^2 g'_{00} = c^2 \cdot (dt' \sqrt{g'_{00}})^2 = ds^2. \tag{6}$$

Moreover, the tensor element $g'_{00}$ of the pilot relative to the pilot does not depend on any external object. Consequently, $\sqrt{g'_{00}}$ acts like a scaling of the unit of time. Therefore, without loss of generality $\sqrt{g'_{00}}$ can be chosen equal to one. With this choice, the invariance of the scalar product in Eq. (5) has the following form:

$$c^2 \cdot dt'^2 = ds^2. \tag{7}$$

Usually, the time in the own system can be named $d\tau$, and the pilot's time is marked by the subscript $p$. As a consequence, Eq. (5) has the following form:

$$c^2 \cdot d\tau_p^2 = ds^2. \tag{8}$$

Similarly, without loss of generality, $ds$ describes a coordinate system marked by $p$. Moreover, without loss of generality, local orthonormal coordinates are used. Consequently, Eqs. (4, 5 and 8) have the following form,

$$c^2 \cdot d\tau_p^2 = ds_\rho^2 = g_{00} c^2 dt_\rho^2 - \sum_{a=1}^{3} g_{aa} dx_{a,\rho}^2. \tag{9}$$

Hereby, $\sum_{a=1}^{3} g_{aa} dx^2_{a,\rho}$ is identied as the squared spatial increment $d\vec{r}^2_{p,\underline{\rho}}$ of the pilot's location relative to the coordinate system $p$. As a consequence

$$c^2 \cdot d\tau_p^2 = g_{00} c^2 dt_\rho^2 - d\vec{r}^2_{p,\underline{\rho}}. \tag{10}$$

As an equivalence transformation, the equation is divided by $c^2$, and $dt_\rho^2$ is factorized:

$$d\tau_p^2 = dt_\rho^2 \cdot \left( g_{00} - \left[ \frac{d\vec{r}_{p,\underline{\rho}}}{dt_\rho} \right]^2 \frac{1}{c^2} \right). \tag{11}$$

The above rectangular bracket is identied with the velocity $\vec{v}_{p,\underline{\rho}}$ of the pilot relative to the system $p$.
Moreover, the square root is applied. The deduced equation is as follows:

$$d\tau_p = dt_\rho \cdot \sqrt{g_{00} - \frac{\vec{v}^2_{p,\underline{\rho}}}{c^2}}. \tag{12}$$

This equation is identied with the Equation of Time Dilation (ETD) of GRT: The reason is as follows:
For two events $A$ and $B$, and for a pilot moving with a velocity $\vec{v}_{p,\underline{\rho}}$ relative to a system marked by $p$, the time dierence dp between $A$ and $B$ observed by the pilot is determined as the respective time dierence $d\tau_p$ between A and B observed in the system $p$.

### Interpretation

In GRT, 'usually, spacetime coordinates have no direct physical meaning and it is essential to construct the observables as coordinate-independent quantities, that is, scalars, in mathematical language.' See p. 2688, right column, lines 1-4 in [12]. In this case, $ds^2$ is such a scalar [12]. And the present - day habit to use spacetime coordinates without physical meaning has been suggested by the hypothesis that there would be a free choice of the coordinate system [21]. However, 'this leads to the problem of defining useful and adequate coordinate systems in astronomy.' See p. 2688, right column, lines 7-8 by in [12]. Therefore, a coordinate system, in which the ETD of GRT holds, is a searched Adequate Coordinate System (ACS) [12].

### Criterion for the ACS

The Pseudo-Riemann geometry implies the ETD, see Eq. (12). Consequently, the ETD must hold. Therefore, the coordinate system marked by $p$ in the ETD in Eq. (12) must be an Adequate Coordinate System (ACS), and the existence as well as the properties of this coordinate system must be deduced. This is elaborated next:

- As a consequence of the above criterion, the system $p$ is an ACS. Consequently, in the ETD in Eq. (12), the subscript $p$ can be replaced by the subscript $ACS$.

$$\boxed{d\tau_p = dt_{ACS} \cdot \sqrt{g_{00} - \frac{\vec{v}^2_{p,\underline{ACS}}}{c^2}}.} \tag{13}$$

- The pilot's velocity in the deduced ETD is $\vec{v}_{p,\underline{ACS}}$.
- The pilot's velocity $\vec{v}_{p,\underline{ACS}}$ relative to the ACS is a variable. It can be varied, whereby the time $dt_{ACS}$ is xed or constant. The effect of such a variation is analyzed: Iff (if and only if) $\vec{v}_{p,\underline{ACS}} = 0$, then the pilot is at rest relative to the ACS, and the time $d\tau_p$ (between the above mentioned two events A and B) is at its maximal possible value $d\tau_{p,max}$. Thereby, $d\tau_p$ has its maximal value, as the subtrahend has the smallest possible value zero.
- I the pilot is at rest relative to the ACS, the pilot's velocity $\vec{v}_{p,\underline{ACS}}$. relative to an Unspecic Coordinate System (UCS) is equal to the velocity $\vec{v}_{ACS,\underline{UCS}}$ of the ACS relative to that UCS. Therefore, the velocity of the ACS can be measured by measuring the velocity of the pilot, $\vec{v}_{p,\underline{UCS}}$. For instance, this can be achieved with help of the optical Doppler eect, see [25-27].

$$\vec{v}_{ACS,\underline{UCS}} = \vec{v}_{p,\underline{UCS}}, \quad \text{iff} \quad d\tau_p = d\tau_{p,max}. \tag{14}$$

- Therefore, for each point $p$ in the universe, and for each instant of time $t_l$ since the Big Bang, the PRG implies the following: An ACS exists at $p$. The velocity $\vec{v}_{ACS,\underline{UCS}}$ of the ACS is uniquely determined. The velocity $\vec{v}_{ACS,\underline{UCS}}$ of the ACS can be measured. For the particular case $g_{00}$ = 1, the ETD yields the Equation of Kinematic Time Dilation (EKTD) as a special case,

$$d\tau_p = dt_{ACS} \cdot \sqrt{\underbrace{g_{00}}_{1} - \frac{\vec{v}^2_{p,\underline{ACS}}}{c^2}}, \quad \text{for} \quad g_{00} = 1. \tag{15}$$

There is no free choice of a 'Nature describing Coordinate System' (NCS), or of an ACS. Note that this fact has neither been clarified in SRT, nor in GRT [10,11,21].

In fact, the D1 mission empirically falsified the idea of the free choice of a 'Nature describing Coordinate System' (NCS), or of an ACS, see. Particular, the Spacelab D1 mission showed, that the fractional time difference,

$$\delta t_{frac,p,\underline{\rho}} := \frac{d\tau_p - dt_\rho}{dt_\rho}, \tag{16}$$

of the time $d\tau_p$ measured by the pilot and the time $dt_p$ measured at the system $p$, is negative, see and Figure. (3). Hereby, dtp is the time between the above events $A$ and $B$ measured at a station on Earth's ground [9]. Thereby, the absolute value of the gravitational time difference is small compared to the absolute value of the kinematic time difference, see e. g. [28].

Consequently, the kinematic time difference of the pilot relative to an ACS that is centered at Earth is negative. In contrast, the kinematic time difference of the pilot relative to an ACS that is centered at the Spacelab would be zero. Consequently, the observation showed that there is no free choice of the ACS. Therefore, the Spacelab D1 mission empirically falsified the idea of the free choice of a 'Nature describing Coordinate System' (NCS), or of an ACS.

Similarly, neither the use of a Sun Centered Coordinate System, nor the use of the BCRS, would predict the kinematic time dilation observed by the Spacelab D1 mission.

Moreover, the ACS has been derived with help of a measurement procedure, see [1].

Furthermore, the ACS has been derived with help of the screening of fundamental interactions, see [1].

Additionally, an observation on Earth's ground, has been used in order to deduce empirical evidence for the derived ACS, see [1,29].

In addition, an observation at space, has been used in order to deduce empirical evidence for the derived ACS, see [1,30].

An additional derivation of the ACS is provided for the case of self-gravitating celestial bodies, see [2].

Moreover, it has been shown that the ETD together with the ACS is equivalent to the invariance of the scalar product, $ds'^2 = ds^2$, see [31].

Furthermore, the derived ACS has been used in order to derive and predict the velocity of the ACS for each location $p$ in deep space, at each instant of time since the Big Bang. Thereby, additionally, consequences upon the pilot's time have been derived and calculated, and evidence has been achieved with help of the evaluation of observations, see [2,32].

Additionally, the derived ACS has been used in order to show how all clocks at Earth, in the planetary system, and in the universe can be synchronized, if desired [2].

Altogether, there is significant theoretical and empirical evidence for the derived ACS. The present derivation provides a deep and founded link to geometry, a derivation about geometry, and a generalization of geometry.

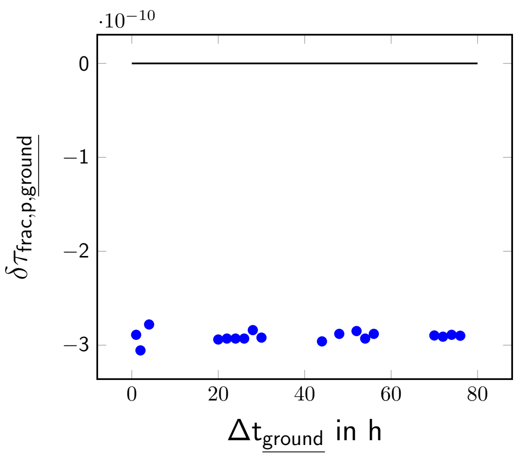


**Figure 3:** The fractional time dierence $\delta t_{p,\underline{ground},frac}$ of the pilot relative to Earth's ground is shown as a function of the time $\Delta t_{\underline{ground}}$ that elapsed at Earth's ground, see Starker et al. (1985) [9]

### Each Clock at Rest at ACS Has Zero Motion as Per ETD

In this section, it is shown for each point $p$ in the universe, and for each instant of time $t_l$ since the Big Bang, that the local ACS has zero motion according to an unequivocal and unambiguous criterion based on time dilation:

The ETD in GRT in Eq. (13) shows, that the ETD is deduced together with an ACS. Moreover, that ETD in GRT with its ACS in Eq. (13) shows, that the pilot's velocity $\vec{v}_{p,\underline{ACS}}$ can be varied by the motion of the pilot. Thereby, the maximum $d\tau_{p,max}$ of the pilot's time $d\tau_p$ can be achieved, and this maximum is an unequivocal criterion for the velocity zero, $\vec{v}_{p,\underline{ACS}} = 0,$ relative to the local ACS. I. e., the maximum $d\tau_{p,max}$ is an unambiguous criterion for zero motion of the pilot relative to his local ACS.

Therefore, at each point $p$ in the universe, and at each instant of time $t_l$ since the Big Bang, zero motion of a pilot relative to his local ACS or NCS is identied in an unequivocal manner by the maximum of the pilot's time, i. e. by the minimal eect of the pilot's time dilation, according to the ETD:

$$\begin{aligned} \vec{v}_{p,\underline{ACS}} = 0 \quad &\Longleftrightarrow \quad d\tau_p = dt_\rho \Longleftrightarrow d\tau_p = d\tau_{p,max} \\ &\Longleftrightarrow \quad \text{decrease of the pilot's elapsed time, } d\tau_{p,max} - d\tau_p, \text{ is zero.} \end{aligned} \tag{17}$$

Conversely, a pilot's motion causes a decrease of the time $d\tau_p$ measured by the pilot's clock:

$$\vec{v}_{p,\underline{ACS}} \neq 0 \Longleftrightarrow d\tau_p < d\tau_{p,max} \Longleftrightarrow \text{decrease of the pilot's time, } d\tau_{p,max} - d\tau_p, \text{ is nonzero.} \tag{18}$$

In this sense, a pilot's motion $\vec{v}_{p,\underline{ACS}} \neq 0$ causes a slow down of the pilot's clock and of the physical processes that are at rest at the pilot's coordinate system.

In particular, if the tensor element $g_{00}$ = 1 in the used ACS, then corresponding time intervals (measuring the time between the same events $A$ and $B$) in the pilot's system and in the ACS are equal:

$$\text{For } g_{00} = 1, \text{ the following holds } \vec{v}_{p,\underline{ACS}} = 0 \Longleftrightarrow d\tau_p = d\tau_{p,max} \Longleftrightarrow d\tau_p = dt_{ACS}. \tag{19}$$

Note that only the ACS velocity is determined by physical principles, the ACS position is not determined by principles. Therefore, $g_{00}$ of the ACS is not determined by physical principles.

### Image of a Light Beam at a Screen

In general, the investigation of a light beam is an essential aim (and task) of optics, see [33-35]. Thereby, a light beam can be investigated with help of a real optical image of that light beam. this is an efficient and robust scientific method, and it tis used here.

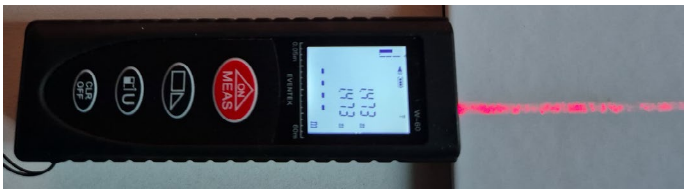

**Figure 4:** A laser distance meter forms a light beam. At the right of the laser distance meter, a screen shows a real image of a part of that light beam.

In general, real and virtual images are distinguished. For instance, the virtual image of the sharpener in Figure. (5) is behind the mirror. Thereby, the light that causes that virtual image is not at the location of that virtual image.

In general, at a real optical image, there is the light that forms the image, see e. g. p. 164 in or p. 137 in. In particular, for each optical instrument, that part of the image space is real, that follows the last surface of the optical instrument, see p. 164 in [33,34]. For instance, in Figure. (4), the optical instrument is a laser distance meter, and the real image space follows the last surface, which is at the right of the optical instrument, the laser distance meter. Therefore, the light at the screen is a *real image of a part of the light beam* that is formed by the optical instrument. Thereby, that real image of the light beam marks the locations of the light beam at the screen, and the image provides quantitative objective evidence of the light beam:

$$\text{The image of a light beam provides quantitative objective evidence of that beam.} \tag{20}$$

**Figure 5**: Virtual image at a mirror.

### Image of a Light Path at a Screen

In general, the laser distance meter in Figure. (4) may be switched on for a short time $t_{on}$. In particular, the time $t_{on}$ can be made very short, so that the laser distance meter forms a light flash. In that case, the light flash takes the same light path as the light beam, as the optical instrument has not changed, only the time $t_{on}$ has decreased.

In this section, it is shown, how a real image of a light path can be produced. For it, a camera makes a photograph of the light path (see Figure. 5) with help of a sufficiently long exposure time $t_{exposure}$ , so that the light flash moved from its emission to a respective point during that time $t_{exposure}$ . As a result, the photo shows the light path of the light flash. Therefore, that photo of the light path looks like Figure. (4), and that photo shows the real image of the light path in Figure. (6)

Therefore, the photo of the light flash at the screen is a *real image of a part of the light flash* that is formed by the optical instrument. Thereby, that real image of the light flash marks the locations of the light path at the screen, and the image provides quantitative objective evidence of the light path:

$$\text{From each light flash, an image or photo can be generated in principle.} \tag{21}$$

$$\text{The image and photo of each light path provide quantitative objective evidence of that path.} \tag{22}$$

$$\text{Light paths exist, as they can be observed objectively.} \tag{23}$$

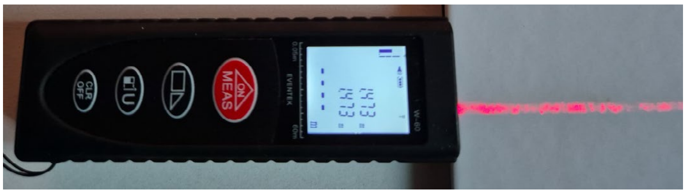

**Figure 6:** A Laser Distance Meter is Switched on For a Time $t_{on}$. Firstly, for a long Time $t_{on}$, The light Beam in Figure. (4) is Formed. Secondly, For a Very Short Time $t_{on}$, a Light Flash is Formed. There by, The Light Flash Propagates on The Same Light Path as the Light Beam. A Camera Takes a Photo of The Light Flash With a Long Exposure Time. As a Consequence, This Photo is Produced, Which Shows a Real Image of The Light Path of The Light Flash

### Light Paths of a Light Clock at a Screen

The kinematic time dilation can be investigated with help of a light clock, that moves in space without significant curvature, see e. g. and Figures. (7,8). Light paths in space with significant curvature are investigated in a forthcoming paper [27]. In this section, the images of the light paths of a light clock are derived. As an illustration, in this section, a numerical example is added.

Without loss of generality, the light clock is sometimes named the pilot's light clock. The light clock works as follows: The structure of the experiment is shown in Figure. (7). The following steps are performed:

- At the top part, a light flash is formed. It propagates in various directions.
- The light flash propagates to the bottom part. There it is reflected at a small horizontal mirror

- The reflected light flash propagates towards the top part.
- A part of the light flash arrives at the top part. There it is detected. By construction of the light clock, at that moment of detection, the measured time of the light clock is increased by the following value:

$$\frac{2L}{c} = d\tau_{p,\, from\, B\, to\, B_2\, to\, B}. \tag{24}$$

Then, the process starts at the first step of the Light flash formation, step (1), to step (4), light flash arrival, and is permanently repeated.

- In general, the light clock moves. Therefore, the detected part of the light flash takes a corresponding light path, see Fig. (8). That light path is named detected light path, its image is named *image of detected light path*, its length is marked by $L_{image\ of\ detected\ light\ path}$. In contrast, most parts of the light flash do not arrive at the top part, and are not detected by the top part.
- As the velocity of light is c, the time $dt_p$ measured in the system $p$ , is the length of the image of the detected light path, $L_{image\ of\ detected\ light\ path}$, multiplied by two and divided by $c$:

$$\frac{2L_{image\ of\ detected\ light\ path}}{c} = dt_{\rho,\, from\, B\, to\, B_2\, to\, B}. \tag{25}$$

- In all experiments investigated here, a screen is at rest in a local ACS, the pilot's velocity $\vec{v}_{p,\underline{ACS}}$ is measured relative to a local ACS, and it is directed to the $x$-direction, and the system $p$ in the ETD is at rest in a local ACS.

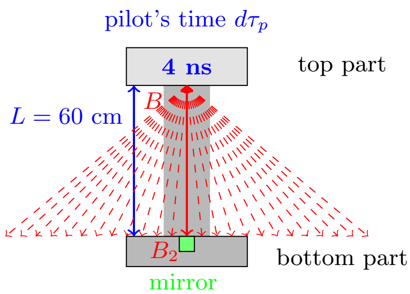


**Figure 7:** In particular, a pilot's light clock is shown, which has zero velocity $v_{p,\underline{ACS}} = 0$, relative to the local ACS. The real image of the light path is taken with a photo, and it provides a quantitative objective evidence, see Eq. (22). Paths of the light flash that are not reflected are marked by dashed arrows. The screen is at the light paths, like in Fig. (6), it is not shown here. The point $B$ marks the emission of the light flash. The point $B_2$ marks the reflection of the light flash.

**Firstly, a light clock at rest in the ACS is investigated.**
**Derivation of the image of the detected light path:**

As the pilot's light clock is at rest in the ACS, the pilot's velocity is $v_{p,\underline{ACS}} = 0$.

Consequently, in this case, the pilot's time $d\tau_p$ is equal to the respective time $dt_p$ in the system $p$, see Eq. (17). Therefore, in this case, the system $p$ is the ACS. In particular, this holds for the time that the light flash requires from $B$ to $B_2$ to $B$, see Figs. (7 and 8):

$$d\tau_{p,\, from\, B\, to\, B_2\, to\, B} = dt_{\rho,\, from\, B\, to\, B_2\, to\, B} \tag{26}$$

As a consequence of Eqs. (24 and 25), the above equality is expressed as a function of the respective lengths as follows:

$$\underbrace{d\tau_{p,\, from\, B\, to\, B_2\, to\, B}}_{\frac{2L}{c}} = \underbrace{dt_{\rho,\, from\, B\, to\, B_2\, to\, B}}_{\frac{2L_{image\ of\ detected\ light\ path}}{c}}. \tag{27}$$

Therefore, the respective paths from $B$ to the mirror at $B_2$ in Eq. (27) are equal. That is, the path in the light clock from $B$ to the mirror at $B_2$ (length $L$) is equal to the *image of detected light path from* $B$ to $B_2$ of the light path in the system $p$, with the length $L_{image\ of\ detected\ light\ path\ from\ B\ to\ B_2}$:

$$\underbrace{\overline{BB_2}}_{length\ L} = \underbrace{image\ of\ detected\ light\ path\ from\ B\ to\ B_2}_{L_{image\ of\ detected\ light\ path\ from\ B\ to\ B_2}}. \tag{28}$$

As a consequence, in this case with $v_{p,\underline{ACS}} = 0$, the image of the detected light path from $B$ to $B_2$ is orthogonal to the mirror in Fig. (7). Therefore, that image of the light path, including the light path, is at rest at the light clock.

Consequently, in this case, that image of the light path, including the light path, is at rest at the ACS, since the clock is at rest at the ACS. Moreover, each light path of interest can be generated by a light clock at rest in its local ACS, since the light propagates according to the Maxwell equation, independently of the velocity of the light source. As a consequence, each light path is at rest in its local ACS.

As a further consequence, that image of the detected light path from $B$ to $B_2$, and the respective light path, have the shortest possible length.

In the shortest possible light path, the light propagates from $B$ to $B_2$ and back to B in Fig. (7). Since the light clock is at rest in the ACS, that shortest light path is at rest in the ACS. As the other light paths (dashed) in Fig. (7) are generated by the optical system in the top part, and since the light propagates according to the Maxwell equation, independently of the light source, also the other light paths are at rest in the ACS.

Furthermore, for each considered light path, a clock at rest in the ACS can be placed, so that the light path is a light path of that clock. Therefore,

$$\text{Each light path is at rest in its local ACS.} \tag{29}$$

**Thereby, the real image of the light path is taken with a photo, see Eq. (22), and it provides a quantitative objective evidence. For instance, if the light path would move relative to the screen, the photo would be blurred due to that movement. Therefore, the photo is a quantitative objective evidence for a possible (zero or nonzero) motion of the light path relative to the screen.**

**Derivation of the time:**
As shown above, the one way light path has the length $L$. Consequently, the two way light path has the length $2L$. Therefore, during the two way motion of the light flash, the pilot's elapsed time is $d\tau_p = 2L/c$. This result is in accordance with the EKTD.

**Secondly, a light clock is investigated, that has an arbitrary nonzero velocity** $v_{p,\underline{ACS}} \neq 0$, **relative to the ACS.**

**Derivation of the image of the light path:**
As a consequence of the symmetry in Figs. (7, 8), the light flash is reflected at one half of the (horizontal) distance, that the pilot moved. It is as follows:

$$dx_\rho = v_{p,\underline{ACS}} \cdot dt_\rho/2. \tag{30}$$

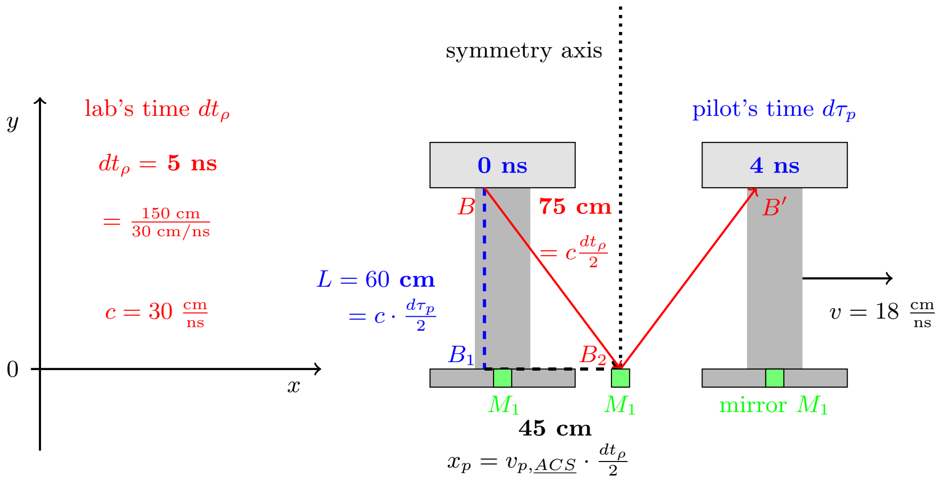


**Figure 8:** A pilot's light clock with nonzero velocity $v_{p,\underline{ACS}} = 18\ \frac{\text{cm}}{\text{ns}}$, relative to the local ACS. The real image of the light path is taken with a photo, see Eq. (22). Light paths that are not reflected are not shown here. The light flash is formed (and emitted) at the event $B$, it is reflected at the event $M_1$, and it is detected at the event $B'$. $B_1$ marks the point vertically below $B$ at the bottom part. $B_2$ marks the point of reflection at the mirror $M_1$.

Consequently, the rst half of the light path takes the form of the left rectangular triangle in Fig. (8), since the light paths form linear lines (this happens as the momentum-vector of the light ash is conserved, and because space is not curved in the present experiment). That triangle has the following edges: the edge from $B$ to $B_1$ with length $L$, the edge from $B_1$ to $B_2$ with the length $dx_p$, and the edge from $B_2$ to $B$, it is the hypotenuse with the respective length:

$$L_{image\ of\ detected\ light\ path} = \sqrt{L^2 + dx_\rho^2}. \tag{31}$$

In general, the light path is at rest in the ACS, see Eq. (29).

**Derivation of the time:**

The light path from the lamp from $B$ to $B_2$ to $B$' has the following length, see Eqs. (24, 25, 31),

$$c \cdot dt_\rho/2 = \sqrt{(c \cdot d\tau_p/2)^2 + (v_{p,\underline{ACS}} \cdot dt_\rho/2)^2}. \tag{32}$$

This equation is solved for $d\tau_p$:

This is the EKTD. Consequently, the light paths imply the EKTD. Note that the EKTD has been derived above from the Pseudo-Riemann geometry.

Altogether, the real images of the light paths, their (zero) motion relative to the local ACS, and the respective time of the motion of the light flash have been derived quantitatively and precisely.

## Michelson Morley Experiment: Light Paths and Interference

Maxwell proposed the hypothesis, that space should form a so-called luminiferous ether alias light ether, which would provide the substrate in which electromagnetic waves propagate [36].

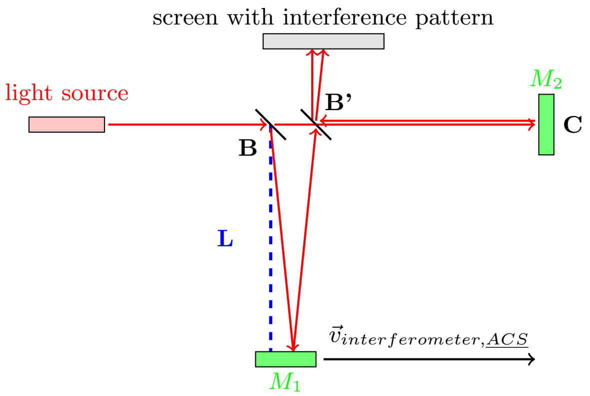


**Figure 9:** Sketch of the Michelson Morley Experiment (MME): The interferometer consists of a light source, a beam splitter, two mirrors $M_1$ and $M_2$, each with a distance $L$ to the beam splitter, and a screen. The interferometer moves with a velocity $\vec{v}_{interferometer,\underline{ACS}}$ to the right. $B$ marks the partialre ection of a local maximum $\vec{E}_{max}$ of the ray's electrical eld at the beam splitter, the second part, i.e. the rest, is transmitted at $B$. $C$ marks the reflection of the transmitted part at the mirror $M_2$. $B'$ marks the reflection of the second part at the beam splitter.

Michelson and Morley applied a Michelson interferometer, in order to measure Earth's velocity relative to that hypothetic luminiferous ether [4]. In this section, this experiment is analyzed with help of the ETD together with the ACS. Thereby, the image of a light path is at rest at the local ACS, see Eq. (29). Moreover, within the MME, there is no potential difference, so that the respective tensor element is one, $g_{00} = 1$. That light path and the interference at the interferometer are analyzed and derived next [8,28,30].

In general, a small amount of gravity is everywhere in space. Here, the influence of motion is investigated. Therefore, the influence of a signicant gravitational eld or curvature of spacetime is not analyzed here.

In fact, the ACS is essential, but the ACS is not a luminiferous ether: Firstly, the ACS is a coordinate system that is adequate for the description of space in nature. Secondly, a luminiferous ether has been proposed as a medium with a significant electromagnetic interaction, but the ACS does not describe significant electromagnetic interaction [36].

The light path from $B$ to $M_1$ to $B'$ in Fig. (9) in the interferometer has the same structure in space and time as the light path from $B$ to $M_1$ to $B'$ in Fig. (8) in the light clock. Therefore, in both cases, a pilot who moves with the light clock or with the interferometer measures the following time for the propagation of the light flash at the light path from $B$ to $M_1$, see Eqs. (24, 25):

$$\frac{d\tau_p}{2} = \frac{L}{c} \tag{34}$$

As usual, see the ratio of the velocity and $c$ is named $\beta$:

$$\beta = \frac{|\vec{v}_{interferometer,\underline{ACS}}|}{c} = \frac{v}{c}. \tag{35}$$

Hereby, the absolute value $u$ of the velocity $\vec{v}_{interferometer,\underline{ACS}}$ is introduced. According to the ETD, an observer at rest in the ACS or in the system $p$ measures the following time for the propagation of the light flash at the light path from $B$ to $M_1$:

$$\frac{dt_\rho}{2} = \frac{d\tau_p}{2}\frac{1}{\sqrt{1-\beta^2}}. \tag{36}$$

Inserting Eq. (34) implies that an observer at rest in the ACS or in the system $p$ measures the following time for the propagation of the light flash at the light path from $B$ to $M_1$ to $B'$:

$$dt_\rho = \frac{2L}{c}\cdot\frac{1}{\sqrt{1-\beta^2}}. \tag{37}$$

Consequently, at the light path from $B$ to $M_1$ to $B'$ in Fig. (9), the light experiences the following phase dierence:

$$d\varphi_\perp = \omega\cdot dt_\rho = \omega\cdot\frac{2L}{c}\cdot\frac{1}{\sqrt{1-\beta^2}}. \tag{38}$$

Thereby, the phase dierence is the same product in both systems: the product of the respective circular frequency and the respective time dierence.

At the light path from $B$ to $M_2$ to $B'$ in Fig. (9), the phase dierence is the sum of the phase dierence $d\varphi_{M_2,B'}$ of the light path from $B$ to $M_2$ and of the phase dierence $d\varphi_{M_2,B'}$ of the light path from $M_2$ to $B'$:

$$d\varphi_{||} = d\varphi_{B,M_2} + d\varphi_{M_2,B'}. \tag{39}$$

The above two phase dierences $d\varphi_{B,M_2}$ and $d\varphi_{M_2,B'}$ are determined with help of the theoretically and empirically founded Doppler eect, see e. g.[8,26,27].

$$d\varphi_{B,M_2} = \omega\cdot\sqrt{\frac{1-\beta}{1+\beta}}, \quad \text{and} \tag{40}$$

$$d\varphi_{M_2,B'} = \omega\cdot\sqrt{\frac{1+\beta}{1-\beta}}. \tag{41}$$

The respective time, that an observer at rest in the ACS or in the system $\rho$ measures for the time of propagation of the light flash from $B$ to $M_2$ is derived as follows: The image of the light path increases (relative to the ACS) with the velocity of light $c$. As a consequence, the distance of the light flash and the mirror decreases with the velocity $c$, whereby, the mirror increases that distance with the velocity $u$. Therefore, the distance between the light flash and the mirror decreases with the velocity $c-u$. Consequently, the ratio of the distance L divided by $c-u$ represents that time [8,27]. This has also been derived by [10].

$$dt_{B,M_2} = \frac{L}{c-v}. \tag{42}$$

Similarly, the time, that an observer at rest in the ACS or in the system $\rho$ measures for the time of propagation of the light flash from $M_2$ to $B'$ is derived as follows:

$$dt_{M_2,B'} = \frac{L}{c+v}. \tag{43}$$

Next, Eqs. (40, 41, 42 and 43) are inserted in Eq. (39). Therefore, the phase dierence at the light path from $B$ to $M_2$ to $B'$ is as follows:

$$d\varphi_{||} = \omega\cdot L\cdot\left(\sqrt{\frac{1-\beta}{1+\beta}}\frac{1}{c-v} + \sqrt{\frac{1+\beta}{1-\beta}}\frac{1}{c+v}\right). \tag{44}$$

In the above Eq., the fractions in the roots are expanded by their respective numerators. Consequently, the phase dierence $d\varphi_{||}$ is

$$d\varphi_{||} = \omega\cdot L\cdot\left((1-\beta)\sqrt{\frac{1}{1-\beta^2}}\frac{1}{c-v} + (1+\beta)\sqrt{\frac{1}{1-\beta^2}}\frac{1}{c+v}\right). \tag{45}$$

In the above Eq., the root is factorized, and the fractions are added with help of the common denominator. As a consequence, the phase dierence $d\varphi_{||}$ is

$$d\varphi_{||} = \omega\cdot L\cdot\frac{1}{\sqrt{1-\beta^2}}\cdot\frac{(1-\beta)(c+v)+(1+\beta)(c-v)}{c^2-v^2}. \tag{46}$$

In the above Eq., the products in the numerator are evaluated, $2/c$ is factorized, and $v/c=\beta$ in Eq. (35) is used:

$$d\varphi_{||} = \omega\cdot L\cdot\frac{1}{\sqrt{1-\beta^2}}\cdot\frac{2c-2\beta v}{c^2-v^2} = \omega_p\cdot L\cdot\frac{1}{\sqrt{1-\beta^2}}\cdot\frac{2}{c}\cdot\frac{1-\beta^2}{1-\beta^2}. \tag{47}$$

In the above Eq., the rightmost fraction cancels out to one, and the resulting term for the phase $d\varphi_{||}$ is identied with the phase $d\varphi_{\perp}$ in Eq. (38):

$$d\varphi_{||} = \omega \cdot \frac{1}{\sqrt{1-\beta^2}} \cdot \frac{2L}{c} = d\varphi_{\perp}. \tag{48}$$

Therefore, the velocity $\vec{v}_{interferometer,\underline{ACS}}$ does not cause any dierence of the two phases $d\varphi_{||}$ and $d\varphi_{\perp}$ at the Michelson interferometer.

$$\text{In the Michelson Morley Experiment, the velocity does not cause a phase difference } d\varphi_{||} - d\varphi_{\perp}. \tag{49}$$

This holds in general, for each angle between the velocity and the arm of the interferometer corresponding to $d\varphi_{||}$ Moreover, this can be explained with help of the Doppler effect.

In particular, this explains the observation that an expected nonzero velocity of a hypothetic luminiferous ether relative to Earth cannot be measured, see page 341 in [4].

**The Michelson Morley Experiment (MME) at a Mountain**

Michelson and Morley argue on page 341 that 'it is not impossible that at even moderate distances above the level of the sea, at the top of an isolated mountain peak, for instance, the relative motion might be perceptible in an apparatus like that used in these experiments' [4].

However, here it is shown that the height above sea level has no influence upon the difference of the phases of the MME, as the phases in Eq. (48) are equal, for each height above sea level.

**The Michelson Morley Experiment in the Planetary System**

As long as there is no potential difference within the apparatus, the location of the experiment has no influence upon the difference of the phases of the MME. In this manner, at each location in the planetary system, the result of the MME will be that no nonzero velocity can be measured relative to a hypothetical luminiferous ether.

**The Michelson Morley Experiment in the Universe**

This result can be transferred from the planetary system to each location in the universe: As long as there is no potential difference within the apparatus, the result of the MME will be that no nonzero velocity can be measured relative to a hypothetical luminiferous ether.

## Discovery of Sub-Relativistic Light Paths

In this section, lengths of light paths in the Michelson Morley Experiment (MME) are analyzed. Thereby, the mechanical length of parts of the MME are neither changed during the experiment, nor as a consequence of the velocity relative to the ACS, see e. g. [14,28].

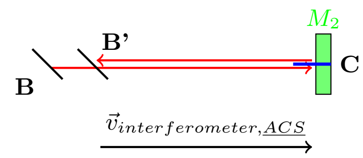


**Figure 10**: In the Michelson Morley Experiment, the light path from $B$ to $C$ to $B'$ is analyzed. Here and in the following, the middle of the mirror $M_2$ is marked by a blue orthogonal to the mirror.

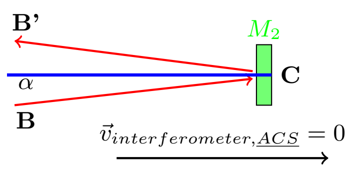


**Figure 11**: In Fig. (10), the light path from $B$ to $C$ overlaps with the light path from $C$ to $B'$. In order to make these light paths more distinguishable, an angle $\alpha$ between the orthogonal (blue) and the light path from $B$ to $C$ is introduced. In the special $\alpha = 0$, the original experiment is realized and included.

In the limit  to zero, the length of the light path from $B$ to $C$ is as follows:

$$L_{B,C} = c \cdot \frac{L}{c-v}. \tag{50}$$

Similarly, in the limit  to zero, the length of the light path from $C$ to $B'$ is as follows:

$$L_{C,B'} = c \cdot \frac{L}{c+v}. \tag{51}$$

Therefore, in general, the light path from $B$ to $C$ is longer than the light path from $\underline{C}$ to $B'$, see Fig. (12):

$$L_{B,C} - L_{C,B'} = c \cdot \left( \frac{L}{c-v} - \frac{L}{c+v} \right) = 2L \cdot \frac{\beta}{1-\beta^2}. \tag{52}$$

Moreover, this dierence of the lengths is indicated in the pilot's system by the dierence $\Delta y$ between the middle of the mirror $M_2$ and the point of reflection $C$:

$$\Delta y = \tan\alpha \cdot \left( c \cdot \frac{L}{c-v} - L \right) = \tan\alpha \cdot L \cdot \frac{\beta}{1-\beta}. \tag{53}$$

As a consequence, the pilot can measure his velocity relative to the ACS by measuring$\Delta y$ .

**Average of the lengths of Light Paths**

In relativity, the distance between the beams splitter and the mirror $M_2$ would be described by a single length, see [10]. For comparison, the average of the real images of the light paths from $B$ to $C$ and from $C$ to $B'$ is derived:

$$\bar{L}_{||} = \bar{L} = \frac{1}{2}(L_{B,C} + L_{C,B'}) = \frac{c}{2} \cdot \left( \frac{L}{c-v} + \frac{L}{c+v} \right) = L \cdot \frac{1}{1-\beta^2} = L_{\perp} \cdot \frac{1}{1-\beta^2}. \tag{54}$$

That average is marked by a bar above $L$. In the direction vertical to the velocity, the light path from $B$ to $B_2$ has the same length $L$ as the light path from $B_2$ back to $B$, see Figs. (7, 8). Therefore, the length L is marked by the subscript $\perp$,see Fig. (9). In contrast, in the direction parallel to the velocity, the light path from $B$ to $C$ has the length $L_{B,C'}$ and the light path from $C$ to $B'$ has the shorter length $L_{C,B'}$. Therefore, the averaged length $L$ is marked by the subscript ||.

$\perp$,

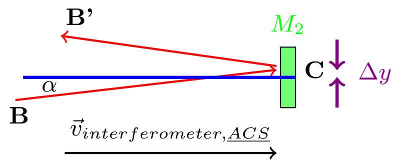


**Figure 12:** The velocity causes a dierence $\Delta y$ between the middle of the mirror and the point C of reflection. This dierence $\Delta y$ can be used in order to build innovative sensors, for instance, these could measure the pilot's velocity relative to the ACS.

Analysis of phases corresponding to light paths: In order to prepare a comparison with the light contraction, see Einstein (1905), phases corresponding to the light paths are analyzed. For it, Eq. (54) is multiplied by $\frac{\omega_p}{c} \cdot \sqrt{1-\beta^2}^2$, and the fraction $\frac{\omega_p}{c}$ is identied with the respective wave number $k_p$:

$$\left( [\sqrt{1-\beta^2} \cdot \omega_p] \frac{1}{c} \right) \cdot [\bar{L}_{||} \cdot \sqrt{1-\beta^2}] = L_{\perp} \cdot \frac{\omega_p}{c} = L_{\perp} \cdot k_p. \tag{55}$$

Consequently, the right hand side is identied with the phase$d\varphi_{\perp}$. As this is equal to the phase $d\varphi_{||}$, see Eq. (48), the left hand side is equal to the phase $d\varphi_{||}$, of the light path parallel to the velocity. Moreover, the left rectangular bracket is identied with the circular frequency $\omega_p$ at the system $p$. Therefore, the large bracket is identied with the respective wave number $k_p$. As a consequence, Eq. (55) has the following form:

$$d\varphi_{||} = k_\rho \cdot [\bar{L}_{||} \cdot \sqrt{1-\beta^2}] = \underset{L_{\perp}}{L_{\perp}} \cdot k_p = d\varphi_{\perp}, \text{ with } \omega_\rho = \omega_p \cdot \sqrt{1-\beta^2}, \text{ and } \frac{\omega_\rho}{c} = k_\rho. \tag{56}$$

**Identications:**

- A founded (measured or derived) object that is more detailed than the respective object of SRT or GRT is identied as a *sub-relativistic.*
- The light path's lengths $L_{B,C}$ and $L_{C,B'}$, multiplied by$\sqrt{1-\beta^2}$,, add up to the contracted length L$_{contracted}$ of the Einstein theory of length contraction, see [10]. Therefore, these light paths and their lengths are sub-relativistic:

$$\text{The light paths } L_{B,C} \text{ and } L_{C,B'} \text{ are sub} - \text{relativistic.} \tag{57}$$

- As the elapsed phase d' of a wave is the product of the wave number and the propagated path length $L = dx$, the length $L_{\perp}$ in Eq. (56) is identied with the length $L_p$ in the pilot's system:

$$L_p = L_{\perp}. \tag{58}$$

- Similarly, the rectangular bracket in Eq. (56) is identied with the length $L_p$ in the system $p$ :

$$L_\rho = \bar{L}_{||} \cdot \sqrt{1-\beta^2}. \tag{59}$$

Thereby, the average $\bar{L}_{||}$ in Eq. (59) is an average of sub-relativistic lengths:

$$\bar{L}_{||} \text{is an average of sub} - \text{relativistic lengths.} \quad (60)$$

Moreover, the root in Eq. (59) is the same factor as in the contracted length $L_{contracted}$, that occurs in the theory of length contraction.

Therefore, the length $L_p$ in the system $p$ in Eq. (59) is identied with the contracted length $L_{contracted}$, that occurs in the Einstein (1905) theory of length contraction. Consequently, $L_{contracted}$ is explained as an average of the sub-relativistic lengths in Eq. (58), which is additionally multiplied or transformed by the factor $\sqrt{1-\beta^2}$:

$$\text{The length contraction length } L_{contracted} \text{ is identified with the length in the system } \rho : L_{contracted} = L_\rho. \quad (61)$$

$$\text{The length contraction length } L_{contracted} \text{ is an average of sub} - \text{relativistic lengths, multiplied by } \sqrt{1-\beta^2}. \quad (62)$$

Thereby, the length contraction length provides equal phases $d\varphi_{||}$ and $d\varphi_\perp$ in the Michelson Morley Experiment (MME):

$$\text{The length contraction length } L_{contracted} \text{ provides equal phases in the MME.} \quad (63)$$

## Time Elapses Universally According to the ETD

In this section, it is shown how the time elapses according to the same ETD in each atom, in each atom nucleus, in the planetary system, and in the universe. Thereby, in general, an atom or an atom nucleus propagate with a velocity $\vec{v}_{atom,\underline{ACS}}$ or $\vec{v}_{atom\,nucleus,\underline{ACS}}$, relative to the ACS.

For it, it is shown that the time elapses according to the same ETD in each fundamental interaction in each atom and atom nucleus. A fundamental interaction is transmitted by a boson of interaction. Thereby, each boson of interaction propagates with the velocity c of light in space [37,38].

### Interaction in an Atom

An atom is a system consisting of particles: the atom nucleus and the electrons. The stability of the atom is essentially provided by electromagnetic forces acting between these particles. The electromagnetic forces are provided by the bosons of interactions: photons [39-41].

For each pair $B$ and $C$ of these particles, the interaction takes place in both directions, according to Newton's third law, see [40,42]. Therefore, the bosons of interaction propagate from $B$ to $C$ and from $C$ to $B$. Consequently, the propagation of photons in this two way interaction is the same as the propagation of light in the MME. As a consequence, this two way interaction can be described as follows:

For the case of interaction parallel to the velocity $\vec{v}_{atom,\underline{ACS}}$, the interaction can be described with help of the averaged and transformed length $L_\rho = L_{contracted}$

For the case of interaction orthogonal to the velocity $\vec{v}_{atom,\underline{ACS}}$, the interaction can be described with help of the length $L_\perp$.

Without loss of generality, the two particles of the pair are in the $x\,y$ plane, and the velocity $\vec{v}_{atom,\underline{ACS}}$ is parallel to the $x$ direction.

In general, there is an angle  between the velocity $\vec{v}_{atom,\underline{ACS}}$ and the interaction from $B$ to $C$.

Therefore, the respective components of the length form a vector $d\vec{r}$, and the wave numbers form the components of the wave vector $\vec{k}$, these are as follows:

$$dx = L_\rho \cdot \cos\alpha, \quad k_x = k_\rho \cdot \cos\alpha, \quad dy = L_\perp \cdot \sin\alpha, \quad \text{and } k_y = k_p \cdot \sin\alpha. \quad (64)$$

Consequently, the elapsed phase $d\varphi$ is the scalar product of $d\vec{r}$, and $\vec{k}$:

$$d\varphi = d\vec{r} \cdot \vec{k} = L_\rho \cdot k_\rho \cdot \cos^2\alpha + L_\perp \cdot k_p \cdot \sin^2\alpha. \quad (65)$$

Hereby, the respective phases in Eq. (56) are inserted, $d\varphi_{||} = k_\rho \cdot L_\rho$ and $d\varphi_\perp = k_p \cdot L_\perp$:

$$d\varphi = d\varphi_{||} \cdot \cos^2\alpha + d\varphi_\perp \cdot \sin^2\alpha. \quad (66)$$

As a consequence of Eq. (56), these two phases are equal:

$$d\varphi = d\varphi_{||} \cdot (\cos^2\alpha + \sin^2\alpha) = d\varphi_{||} = d\varphi_\perp. \quad (67)$$

Therefore, after a two way interaction, and on the basis of the average of the sub-relativistic lengths $L_{B,C}$ and $L_{C,B}$, the bosons of interaction arrive at the same elapsed phase $d\varphi$ , independent of the angle α, and independent of the particular particles of the considered pair. As a consequence, the time elapses in a universal manner: according to the ETD, and independent of the angle α, and independent of the particular particles of the considered pair.

**Interaction in an Atom Nucleus**

An atom nucleus is a system consisting of particles: essentially quarks, see. The stability of the atom nucleus is essentially provided by weak, strong, and electromagnetic forces acting between these particles. These forces are provided by the bosons of interaction: photons, gluons, as well as the $W^+$-, $W^-$-, and Z- bosons [37,38,43,44].

For the case of these particles, interactions and bosons of interaction can be described with help of wave functions propagating at the velocity c of light. Consequently, their propagation is analogous to that of light. Therefore, the results derived in the above part about atoms can be derived in an analogous manner for wave functions and for the case of atom nuclei.

## Time in the Planetary System

At each point $P$ in the planetary system, and at each instant of time $t_I$ since the Big Bang, there is an ACS, see above sections. As a consequence, in the planetary system, time elapses according to the ETD, see above sections.

## Time in the Universe

At each point $P$ in the universe, and at each instant of time $t_I$ since the Big Bang, there is an ACS, see above sections. As a consequence, everwhere in the universe, time elapses according to the ETD, see above sections.

**Time in the Microcosm and in the Macrocosm**

The above results show that time elapses according to the ETD in the microcosm and in the macrocosm:

In the average of sub − relativistic lengths, time elapses in a universal manner according to the ETD. (68)

## Discussion

The Special Theory of Relativity (SRT), and in the General Theory of Relativity (GRT), the idea has been proposed that coordinate systems for the description of nature could be freely interchanged, see [10,14-16].

However, the Spacelab D1 mission showed, see and Figs. (2 and 3), that the Equation of Kinematic Time Dilation (EKTD) describes the clocks at the Spacelab and at Earth's ground, when the EKTD is used in a Geocentric Celestial Reference System (GCRS) [9]. But when the EKTD is used in a Barycentric Celestial Reference System (BCRS) or in a Sun Centered Celestial Reference System, then the EKTD does not describe these clocks correctly. Therefore, in this example, the GCRS and the BCRS cannot be interchanged, see also [14].

Accordingly, the International Astronomical Union (IAU) recommended to use the GCRS in Earth's vicinity, and to utilize the BCRS in the planetary system. Moreover, the IAU proclaimed the ACS problem, to find and Adequate Coordinate System (ACS), see [12].

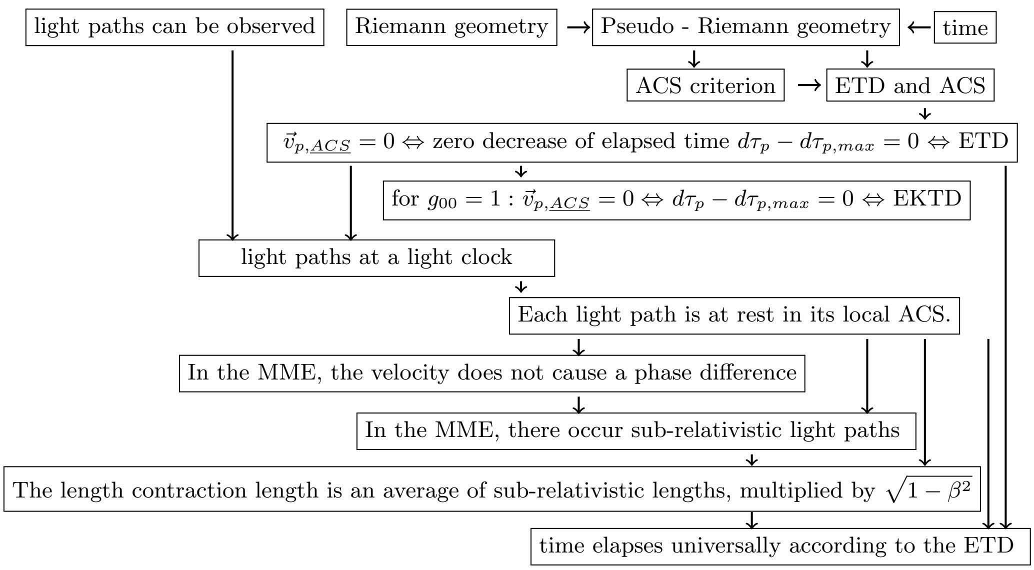


**Figure 13:** Paths of Derivation: Each Arrow Shows From a Premise to an Implied Statement or Quantity. The First Row Shows Very Founded Premises: The Observability of Light Paths, Riemann (1868) Geometry, and Time, as Well as the Resulting Pseudo - Riemann Geometry [3]. Therefrom, the Other Rows are Derived

Here, the ACS is solved on the basis of Riemann geometry and Pseudo - Riemann geometry as follows: Firstly, the ETD is derived from Pseudo - Riemann geometry. Secondly, therefrom, a criterion for the ACS is deduced. Thirdly, with it, the ETD together with its ACS are derived. Fourthly, for a pilot at rest at the ACS, the ETD implies zero decrease of elapsed time $d\tau_p - d\tau_{p,max}$, see Figure. (13). Fifthly, the EKTD is deduced. In this deduction, the ACS can be understood in an analytic, very traceable manner, and especially insightful manner. Moreover, this derivation is particularly valuable, as the IAU prefers descriptions in the language of GRT, see [12,24].

With help of a light clock, and by using the ACS, light paths and time are analyzed in a coherent and meaningful combination [27,37]. Therefrom, the impactful insight is deduced, that each light path is at rest in its ACS.

On that basis, for the case of the Michelson Morley Experiment (MME), the significant result is derived, that the velocity does not cause any phase shift. This explains, why the expected nonzero velocity was not found in the MME. Moreover, sub-relativistic light paths are discovered in the MME. These sub-relativistic light paths are insightful, as they go beyond the concept of SRT and GRT. Additionally, these sub-relativistic light paths are valuable, as they can be used in order to construct sensors that measure the velocity relative to the local ACS.

On that basis, the insightful result is derived, that length contraction in SRT can be explained by sub-relativistic light paths, multiplied by the root $\sqrt{1-\beta^2}$. Using that result, the valuable and insightful result is deduced, that time elapses universally according to the ETD in each atom nucleus, in each atom, at earth, in the planetary system, and in the universe.


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