The role of light in observation: why is the speed of light invariant?

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ABSTRACT

In 1905, based on the Michelson-Morley experiment, Einstein proposed the hypothesis of invariance of light speed (ILS). He then theoretically deduced the Lorentz transformation from ILS, established the theory of special relativity (SR), and revealed the relativistic phenomena of matter motion. Up till today, however, we still don't exactly know what role light plays in Einstein's theory, or why the speed of light is invariant; moreover, we still don't exactly understand relativistic phenomena. Based on the locality of physical world, this paper establishes the principle of observational locality (POL), proposes the hypothesis of observational limit (HOL), and tries to accertain the role of light in observation and the root and essence of ILS. According to POL and HOL, the Michelson-Morley experiment does not really mean ILS, but does demonstrate to us a significant phenomenon in physical observation: the speeds that observational media transmit the spacetime information about observed objects possess observational invariance. In Michelson-Morley experiment, light acts as both the observed object and the observational medium, and therefore, its speed is observationally invariant. Perhaps, this paper could provide new knowledge on light speed and new understanding on relativistic phenomena including ILS. Perhaps, in the future, the observational locality of light would be broken through with technological progress so that we could observe a more real objective world.

I. INTRODUCTION

In 1887, following Maxwell's proposal [1], Michelson and Morley did an experiment to hunt for the ether [2]. Without catching the ether, they ran into a problem: the principle of Galilean velocity-addition seemed invalid. The Michelson-Morley experiment showed that the speed of light plus the orbital speed of the earth remained the speed of light.

To interpret the Michelson-Morley experiment, FitzGerald proposed the hypothesis [3]: all objects physically contract by the factor of $\sqrt{(1-v^2/c^2)}$ along the line of motion; later, Lorentz added the hypothesis [4-6]: time dilates by the factor of $1/\sqrt{(1-v^2/c^2)}$. Thus was born the Lorentz transformation, or the FitzGerald-Lorentz transformation. In 1905, Einstein seized the key of the Michelson-Morley experiment: the speed of light had no velocity-addition effect. Then he

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proposed the hypothesis of invariance of light speed (ILS). On the basis of ILS, Einstein theoretically deduced the Lorentz transformation, established the theory of special relativity (SR) [7], and revealed the relativistic phenomena of matter motion.

ILS is not only the cornerstone of Einstein's SR, but one of the prerequisites of Einstein's theory of general relativity (GR) [8] as well. For over a century, Einstein's relativity including SR and GR has been supported by almost all observations and experiments. Up till today, however, we still don't exactly know what role light plays in Einstein's theory, or why the speed of light is invariant; moreover, we still don't exactly understand relativistic phenomena.

The hypothesis of ILS has one direct corollary: the speed of light is the ultimate speed in the universe that cannot be exceeded by any form of matter motion. It is worth noting that Einstein integrated ILS into his view on locality [9,10]: there is no action at a distance in the universe; moreover, due to ILS, the speeds of matter motion cannot exceed the speed of light.

In this paper, physical observability is represented as a basic principle: the principle of physical observability (PPO). Then the principle of locality can be a logical consequence of PPO. Unlike Einstein's view on locality, the principle of locality in the PPO sense does not mean that the speed of light cannot be exceeded, but only means that the speeds of matter motion cannot be infinite. On the basis of the locality of physical world, this paper establishes the principle of observational locality (POL), proposes the hypothesis of observational limit (HOL), and tries to accertain the role of light in observation and the root and essence of ILS. From POL and HOL, it can be deduced that ILS is valid if and only if light acts as the observational medium. As it happens, our observations and experiments mostly employ light as the observational medium, which is why they agree with ILS as well as SR and GR. However, it is worth noting that the messenger in physical observation does not have to be light.

Why is the speed of light invariant? Why does matter motion present relativistic effects? It is the significant task for physics to elucidate these fundamental problems. Perhaps, this paper could provide new knowledge on light speed: it is not really invariant or cannot be exceeded; and new understanding on relativistic phenomena including ILS: they are all observational effects rooted from observational locality, rather than objective or real natural phenomena.

II. OBSERVATION AND MEDIA

Human knowledge and understanding of the objective world or spacetime not only depends on observation, but is restricted by observation as well. All theories of physics, including spacetime models, are without exception branded with observation.

A. Basic Elements in Observation

Observation is the active acquisition of information from observed objects with our senses or by means of our observation instruments. Naturally, observed information has to be transmitted to our senses or observation instruments in some way or by means of certain media so that we are able to perceive or detect observed objects. Accordingly, physical observation is bound to involve three basic elements (Σ, M, *O*):

(1) Σ: the observed object, the emitter of observed information (OI), i.e., the information on Σ;
(2) M: the observational medium, the transmitter of OI;
(3) *O*: the observer, the receiver of OI.

In the 4d Minkowski spacetime, the motion trace of Σ is a worldline drawn with a sequence of events of Σ. As a point of the 4d spacetime, every event in the worldline contains both the spatial information (location) and the temporal information (instant) it occurs, which can be collectively called *Space-Time Information* (STI). The STI of Σ is namely the most fundamental information that *O* intends to collect or acquire.

Naturally, the STI of Σ has to be transmitted to *O* by means of some sort of M.
So, what can be M?

B. Observational Media

Matter possesses the wave-particle duality (WPD), acts both as particles and as waves. In the 20s of last century, de Broglie coined the concept of *Matter Wave* [11,12] based on WPD. In a broad sense, any matter or any form of matter motion is just matter wave, including sound wave, water wave, light wave, electric wave, and even an electron or a piece of rock. Waves have an important physical property: *Modulability*; and hence possess the special capacity to carry and transmit information. In theory, any matter wave or any form of matter motion can act as the observational medium (M) to carry and transmit the STI of Σ to *O*.

Light is the most common M we take for granted; thanks to it, we can see the world by eyes.
However, light is not the only M.

The STI of a thunderbolt is the location and the instant it occurs. We have to employ certain M to transmit the STI of thunderbolts to us so that we can perceive or observe them. Within human perception, both sound and light can act as the M; beyond direct perception, by means of technology, the radio wave and pulsed magnetic field that thunderbolts emit can also be employed as the messengers of thunderbolt events.

Traditional astronomy employs naked eyes and optical telescopes to observe celestial phenomena, in which the M for transmitting astrophysical information is visible light. The development of radio astronomy extends the M from visible light to almost the entire radio band so that the cosmic microwave background radiation has been observed [13], which provides the evidence for the Big Bang theory [14]. The detection for gravitational waves leads to the concept of *Gravitational-Wave Astronomy* (GWA) [15]. Unlike that for traditional astronomy and radio astronomy, the M for GWA is the gravitational interaction rather than the electromagnetic interaction.

So, what is the difference between different media for observation or for the transmission of information?

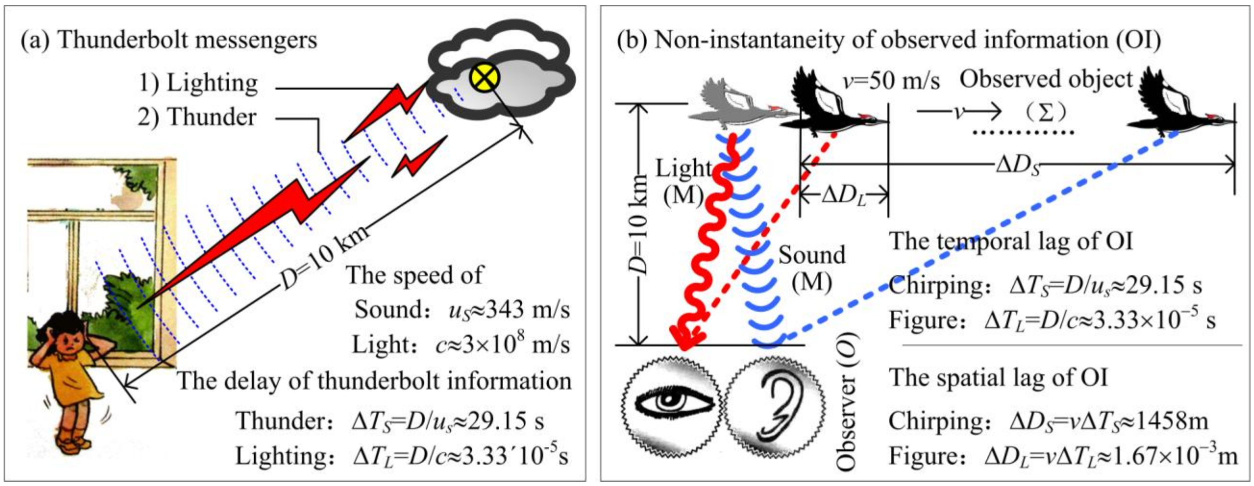

Figure 1 | Observation and Media. (a) Thunderbolt messengers: not only light waves but also sound waves; (b) Non-instantaneity of observed information: No matter what the M is, there must be a certain observational delay of the STI of Σ or observed information in transmission from the observed object Σ to the observer *O*.

C. Observational Non-Instantaneity

The transmission speed of observed information, or the speed that M transmits the STI of Σ, is extremely important for observation.

The speed of sound is about 343 m/s in the earth's atmosphere at 20°C. As depicted in Fig.1a, when we hear thunder 10 kilometers away, the STI of thunderbolt has already been delayed for nearly 30 seconds; light is far faster than sound, however, lighting also can only bring us the delayed STI on thunderbolt. A bird is flying in sky; but how can we perceive or observe it or its movement? We can employ sound as the M to hear it by ears; or employ light as the M to see it by eyes. As depicted in Fig.1b, however, no matter sound or light can only bring us the delayed STI on the bird: we hear its chirping, but it is no longer where it was chirping; we see its figure, but that is only where it was a moment ago.

This is the problem of *Observational Non-Instantaneity*.

Naturally, observational non-instantaneity is linked to the speed (η) of M: the lower the η, the more significant the non-instantaneity is. Observational non-instantaneity restricts our observation, and moreover, is reflected in our theories: the Galilean transformation is built on the assumption of $\eta=\infty$; while the Lorenz transformation is confined to the non-instantaneity of light where $\eta=c$.

Observational non-instantaneity is rooted from the locality of physical world.

III. PHYSICAL OBSERVABILITY AND LOCALITY

The observability of physical world is the prerequisite for our knowledge and understanding about the objective world or spacetime, which is linked to physical locality, and related to observational non-instantaneity.

A. Principle of Physical Observability

Here physical observability is clearly formulated as a basic principle of physics, from which the problem of locality, including physical locality and observational locality, is expounded.

The Principle of Physical Observability (PPO): A physical quantity must be observable, or its observed value must be finite and definite.

Obviously, PPO is self-evident, and has the rationality to be a basic principle or an axiom. Perhaps, PPO can be called *Singularity Principle*: According to PPO, any singularity in a physical theory or model cannot be regarded as objective physical reality; it only suggests that the theory or the model fails at the singularity.

B. Problem of Physical Singularities

Einstein's GR [8] has the *Big Bang Singularity*. In 1970, Hawking and Penrose proved the singularity theorems [16]: singularities are inevitable when Einstein's GR is used for predicting the beginning of the universe, at which spacetime has infinite density and infinite curvature. It is Einstein's consistent conviction that singularities are not allowed in a complete physical theory. So, due to the Big Bang singularity, Einstein even thought that his GR was still incomplete, and had to be replaced by a singularity-free theory [17]. Weinberg said in *The First Three Minutes* [18]: "One possibility is that there never really was a state of infinite density. The Big Bang may have begun when the density of the universe had reached some very high but finite value." Hawking said in *A Brief History of Time* [19]: "Mathematics cannot really handle infinite numbers. A theory itself breaks down at a point called a singularity by mathematicians." Such ideas and thoughts are no other than the spontaneous display of great physicists' belief on physical observability.

Einstein's SR [7] has the *Lorentz Singularity*: when the moving body (Σ) reaches the speed of light, the Lorentz factor is infinite: $\gamma(c)=1/\sqrt{(1-c^2/c^2)}=\infty$. So, at the Lorentz singularity ($v=c$), the relativistic mass of Σ is infinite: $m=\gamma(c)m_o=\infty$, unless its rest mass m_o is zero. Under PPO, $m<\infty$, and therefore, $m_o=m\gamma^{-1}(c)=0$. In this case, m is not definite in SR, and has to be determined by means of Planck formula $E=h\nu$ that is outside Einstein's SR: $m=h\nu/c^2$. Perhaps, $m_o=m\gamma^{-1}(c)=0$ does not really mean that the photon really has no rest mass; but does mean that, in Hawking's words [19], Einstein's SR breaks down at the Lorentz singularity.

C. Locality under PPO

Locality plays an important role in Einstein's theory. Einstein's view on locality is associated with his hypothesis of ILS. Einstein believed that: there is no action at a distance in the universe; and moreover, due to ILS, both matter and information cannot exceed the speed of light. In 1935, based on Einstein's view on locality, Einstein, Podolsky and Rosen conceived of a famous thought experiment, known as the EPR paradox [9], to query the completeness of quantum mechanics. However, more and more EPR experiments present the phenomena of quantum entanglement [20-22].

So, is there *Spooky Action at a Distance* in the universe?

The locality of physical world is objective or natural, and beyond doubt. Actually, the principle of locality is just a logical deduction from PPO.

The Principle of Locality: There is no action at a distance in the universe –– the speeds of matter motion are finite, both matter and information take time to cross space.

The principle of locality under PPO is different from Einstein's view on locality. According to PPO, locality is objective and natural. However, locality does not mean that the speed of light is the ultimate speed in the universe or cannot be exceeded, but does mean that there is in the universe no matter motion with infinite speed.

IV. OBSERVATIONAL LOCALITY AND IMS

The principle of locality under PPO suggests that the speeds of observational media are finite and it takes time for observed information to cross space, which leads to the problem of observational locality, and moreover, sets up the observational limit for observed speeds.

A. Principle of Observational Locality

According to WPD, an observational medium is just a matter wave and a form of matter motion. As a corollary of the principle of locality under PPO, the following principle of observational locality holds.

The Principle of Observational Locality (POL): The speed (η) of an observational medium (M) is finite ($\eta<\infty$); it takes time for M to transmit the spacetime information (STI) of observed object (Σ).

In short, the *Observational Locality* is that $\eta<\infty$.

POL suggests that observational non-instantaneity and observational locality are relative: different observational media with different speeds make observation present different degree of observational locality or non-instantaneity. So as to break through the observational locality of a specific M, our observation requires the observational media with speeds faster than that of the specific M.

B. Hypothesis of Observational Limit

With experience and intuition, we can make and understand such a judgment: the observer's observation of the speed of Σ is restricted by the speed of M. Due to the observational locality of ultrasonic, bats cannot expect to detect supersonic matter motion by means of ultrasonic; and due to the observational locality of light, we cannot expect to detect superluminal matter motion by means of light. According to observational non-instantaneity and POL, a hypothesis is proposed as below.

The Hypothesis of Observational Limit (HOL): The speed (η) of the observational medium (M), i.e., the speed that M transmits the spacetime information (STI) of observed object (Σ), is the upper limit of the speed (u) of matter motion that the observer (O) can detect; i.e., $u\leq\eta$.

HOL suggests that the speed of M limits the range of speed that O can observe; and has two inferences:

(1) It is only an observational phenomenon when light acts as M that light seems to be invariant;
(2) Observers cannot detect superluminal matter motion by means of light as M.

C. Invariance of Observational-Medium Speed

It is thought that ILS is rooted from physical locality, and determined by the physical properties of spacetime; therefore, ILS is an objective natural phenomenon. As Landau and Lifshitz remarked [23]: "What is really at stake is the locality of interactions; hence, there exists a theoretical maximal speed of information transmission which must be invariant." However, according to POL and HOL, ILS is rooted from the observational locality of light as M ($\eta=c<\infty$). In fact, the Michelson-Morley experiment does not mean ILS, but does demonstrate an extremely important phenomenon in physical observation: the speeds that observational media transmit observed information are all observationally invariant. On the basis of POL and HOL, the following law holds.

The Invariance of Observational-Medium Speed (IMS for short): Let the observed object (Σ) move at the speed u and u' respectively in O and O', M be an observational medium, then the speed (η) of M, or that M transmits the spacetime information (STI) of Σ, is observationally invariant or the same relative to O and O'.

Proof. Without losing generality, let $u>u'$. According to POL, $\eta<\infty$. Suppose that IMS is invalid, then $u>\eta$ when $u'=\eta$, which contradicts HOL. So, under POL and HOL, IMS holds. □

IMS suggests that the speed that M transmits the STI of Σ possesses some sort of invariance. However, such invariance is not a real natural phenomenon, but only an observational effect: it just observes as if it is.

IMS generalizes the invariance of light speed: ILS as a corollary can be derived from IMS. However, under IMS, the validity of ILS is conditional.

The Invariance of Light Speed (ILS): Suppose light acts as M to transmit the STI of Σ, and then the speed of light is invariant or the same relative to all observers.

Now, ILS is no longer a hypothesis but a corollary of IMS; or, ILS is only a special case of IMS and valid only when light acts as M. In the Michelson-Morley experiment, light is both the Σ to be observed and the M to transmit observed information; and so, the speed of light is observationally invariant at the moment. The Michelson-Morley experiment provides an empirical example for IMS, and moreover, corroborates from an aspect the logical validity of HOL as a principle or an axiom.

V. GENERAL LORENTZ TRANSFORMATION

The Lorentz transformation is a model of spacetime transformation that employs light as the observational medium (M), in which the speed (η) of M is the light speed (c). However, in our observation, it is not that M must be light or η must be c. Now that the invariance of light speed (ILS) has been generalized to the invariance of M speed (IMS), the Lorentz transformation can naturally be generalized to any M or any η.

A. ILS and Lorentz Transformation

It has been recognized that relativistic effects do not depend on the physical properties of light; it is thought that they are rooted from the locality of physical world and the symmetry of spacetime. So, without ILS, the Lorentz transformation and Einstein's SR can also be deduced only from locality and symmetry [24,25]. In group theory, by means of the symmetry and isometry of spacetime, the Lorentz transformation has been generalized to the Lorentz group, and even to the Poincare group.

The Lorentz factor is $\Gamma=1/\sqrt{(1+\kappa v^2)}$ derived by group theory, in which the role or the physical significance of κ is not exactly definite under group axioms; but there are three possible cases:

(1) $\kappa>0$, which does not agree with the physical reality;

(2) $\kappa=0$ and $\Gamma=1$, which is non-relativistic and represents the Galilean transformation;

(3) $\kappa<0$ and $\Gamma>1$, which is relativistic and generalizes the Lorentz transformation.

Due to the locality of physical world, it is thought that there must be a definite κ in spacetime: $\kappa=-1/\Lambda^2<0$ where Λ should be a cosmological constant representing the ultimate speed and has to be determined by experiment; due to ILS, it is believed that $\Lambda=c$. As Landau and Lifshitz remarked [23]: "It turns out that this speed coincides with the speed of light in vacuum." Although people have had the knowledge that the physical properties of light are not the root of relativistic effects, at last still believe in ILS and stick to the view that the speed of light is invariant or cannot be exceeded.

Landau and Lifshitz realized that c in the Lorentz factor $\gamma=1/\sqrt{(1-v^2/c^2)}$ is the speed of information transmission [23]. However, people do not seem to reflect seriously, in the theories or models of physics, if M can be different from light, or if the speed of information transmission can be different from c.

B. IMS and General Lorentz Transformation

By directly substituting η for c in the Lorentz transformation and Einstein's SR, one can get the *General Lorentz Transformation* (GLT) and the universal SR. Whereas, to well understand the physical significance of the parameters in GLT, here follow Einstein's logical route and deduce GLT from IMS instead of ILS.

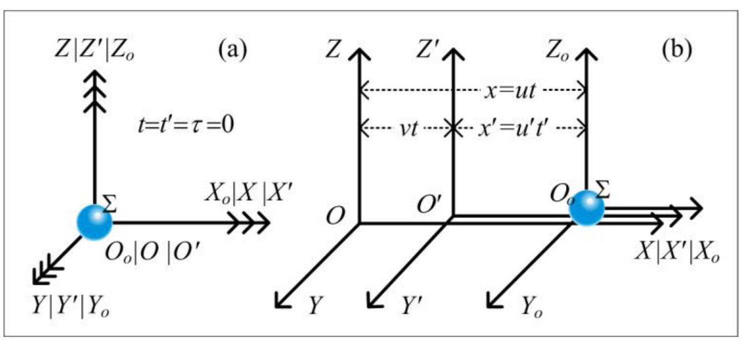

Figure 2 | Observed Object Σ and Its Inertial Frames *O* and *O′*. (a) Σ is at rest at the origin of its intrinsic inertial frame O_o; the corresponding axes and origins of O, O' and O_o coincide at $t=t'=0$; (b) If $t\geq0$ and $t'\geq0$, Σ moves at the speed u along X in O and at the speed u' along X' in O'; O' moves at the speed v along X relative to O.

Relativistic effects suggest that space and time are interdependent and indivisible. So space and time are merged into the concept of *Spacetime*. Different reference frames mean different spacetimes. In Fig.2, O and O' are two different inertial spacetimes; the transformations between them are denoted as $O \to O'$ and $O' \to O$. Naturally, the transformations need to satisfy certain observational requirement and logical prerequisites.

The Observational Requirement for Spacetime Transformations:

O and O' must employ the same M.

The Logical Prerequisites for GLT:

(1) The principle of IMS (instead of Einstein's ILS);
(2) The principle of relativity.

In fact, there is one more prerequisite in Einstein's SR: the principle of simplicity [26,27], with which one can suppose that $O' \to O$ is a linear transformation: $x=\Gamma x'+bt'$. The basic relationship between space and time demands $x'=-vt'$ if $x=0$; and so $b=\Gamma v$. Then $O' \to O$ is further simplified as $x=\Gamma(x'+vt')$. According to the principle of relativity, $O \to O'$ should be $x'=\Gamma(x-vt')$. With simultaneous $O' \to O$ and $O \to O'$, we have $t=\Gamma(t'+(1-\Gamma^{-2})x'/v)$ and $t'=\Gamma(t-(1-\Gamma^{-2})x/v)$. Then, under the definitions of the speeds of Σ in O and O', it follows that

$$u = \frac{\mathrm{d}x}{\mathrm{d}t} = \frac{u'+v}{1+\left(1-\Gamma^{-2}\right)u'/v} \quad \left(u' = \frac{\mathrm{d}x'}{\mathrm{d}t'}\right). \tag{1}$$

According to IMS, $u=\eta$ if $u'=\eta$; as a result, we get *the General Lorentz Factor* (GLF) from Eq.1:

$$\Gamma\left(v,\eta\right) = \frac{1}{\sqrt{1-v^2/\eta^2}}, \tag{2}$$

where η has clear physical significance: the speed that M transmits the STI of Σ. Unlike the situation in the Lorentz factor $\Gamma=1/\sqrt{(1+\kappa v^2)}$ generalized by means of group theory, η is determined by M that does not have to be light; η is not a definite cosmological constant and do not have to be c. Now, we have the GLT:

$$\begin{array}{ll} O' \to O: & O \to O': \\ x = \Gamma\left(x'+vt'\right), & x' = \Gamma\left(x-vt\right), \\ y = y', & y' = y, \\ z = z', & z' = z, \\ t = \Gamma\left(t'+vx'/\eta^2\right); & t' = \Gamma\left(t-vx/\eta^2\right). \end{array} \tag{3}$$

GLT has the exactly same form of the Lorenz transformation, and therefore, all the kinematic and dynamic relations in Einstein's SR can logically be generalized to the universal SR. It is interesting that the Einstein formula $E=mc^2$ will be rewritten as $E=m\eta^2$. Perhaps, this will provide new understanding on Einstein's famous mass-energy equation.

C. Unification of the Lorentz Transformation and the Galilean Transformation

In the Lorentz transformation and Einstein's theory, light acts as M to transmit observed information. However, the general Lorentz transformation (GLT) suggests that light is not the only M. In theory, any matter wave or any form of matter motion, such as sound wave, electron flow, pulsed magnetic field, gravitational wave, and even the observed object itself, can act as M.

In GLT, a specific M with a specific η means a specific observation system and leads to a specific theory system: the Galilean transformation and Newton's theory are the product of the idealized observation system ($\eta \to \infty$), in which η is assumed to be infinite; the Lorentz transformation and Einstein's theory are the product of the optical observation system ($\eta = c$), in which M is light and η is c. In bats' echolocation system, M is ultrasonic and $\eta \approx 343\ \mathrm{m \cdot s^{-1}}$. Gravitational-Wave (GW) astronomy can observe more instantaneous celestial phenomena if the speed of GW is superluminal. Perhaps, the observational locality of light will be broken through with human technological progress.

The general Lorentz transformation (GLT) generalizes and unifies the Galilean transformation (GT) and the Lorentz transformation (LT). Under Bohr's correspondence principle [28], GLT is strictly corresponding to GT and LT: GLT reduces to GT as $\eta \to \infty$; GLT reduces to LT as $\eta \to c$. Such correspondence reflects the consistence of GLT with GT and LT, as well as the logical validity of GLT. However, it is worth noting that LT is not strictly corresponding to GT under Bohr's correspondence principle; only if $v \ll c$ can LT be approximate to GT.

VI. DISCUSSION: THE ESSENCE OF RELATIVISTIC EFFECTS

Perhaps the invariance of M speed (IMS) and the general Lorentz transformation (GLT) would reveal the root and essence of relativistic phenomena.

Einstein believed that spacetime and matter motion were essentially relativistic, and hence, relativistic effects (including ILS) were physical reality. In Einstein's SR, the relativistic degree of moving body (Σ) can be measured with the Lorentz factor $\gamma(v)=1/\sqrt{(1-v^2/c^2)}$ that depends on the observed speed v of Σ. As shown in Fig.3a, the higher the v, the larger the $\gamma(v)$ and the higher the relativistic degree of Σ, or the more significant the relativistic effects of Σ are.

However, according to GLT, the relativistic degree Σ presents should be measured with the general Lorentz factor $\Gamma(v,\eta)=1/\sqrt{(1-v^2/\eta^2)}$ that depends on the speed η of M. As shown in Fig.3b-c, at a specific speed v, the higher the η, the smaller the $\Gamma(v,\eta)$ and the lower the relativistic degree Σ presents. In particular, if $\eta \to \infty$ or without observational locality, then $\Gamma(v,\eta) \to 1$ and the observational relativistic effects of Σ would completely disappear from our observation.

In Einstein's SR, the relativity of simultaneity as well as time dilation and length contraction

(TD&LC) are the most classical relativistic effects that we know well. However, GLT suggests that they are all observational effects and rooted from observational locality ($\eta<\infty$).

Einstein's SR shows that the simultaneity in spacetime is relative: different reference frames have different simultaneities. The simultaneous events A and B ($|t'_B-t'_A|=0$) in O' may not be simultaneous in O: $|t_B-t_A|=\gamma|x'_B-x'_A||v|/c^2\neq0$. Similarly, the simultaneity under GLT is also relative. With Eq.3, if $v<\eta<\infty$ then

$$|t_B-t_A|=\Gamma|x'_B-x'_A||v|/\eta^2\neq0. \tag{4}$$

Whereas, Eq.4 suggests that the relativity of simultaneity is only an observational effect caused by observational locality ($\eta<\infty$): the higher the η, the less obvious the relativity of simultaneity is. If $\eta\to\infty$, then $t_B=t_A$ when $t'_B=t'_A$: the simultaneity would be no longer relative; O and O' would share the absolute simultaneity.

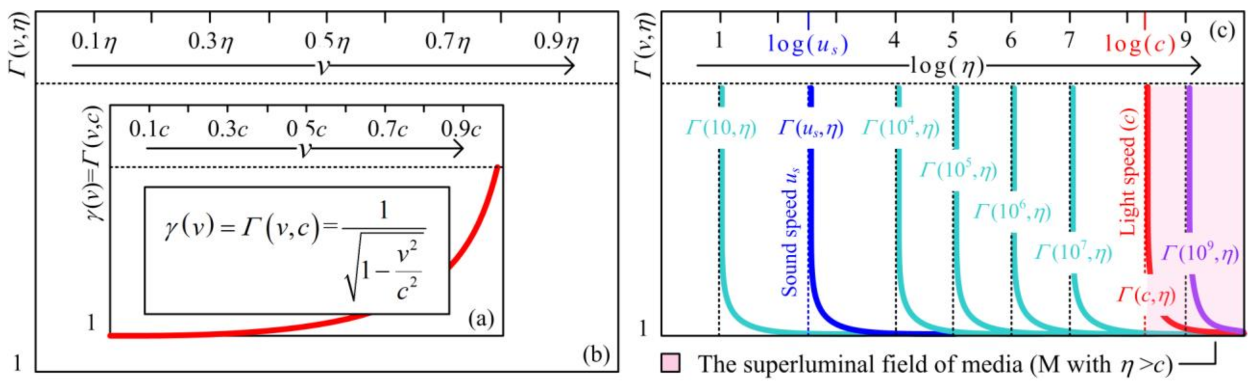

Figure 3 | Observational Relativistic Degree. (a) The relativistic degree $\gamma(v)$ in the Lorentz transformation: the higher the speed v of Σ, the more significant the relativistic effects are. (b)-(c) The relativistic degree $\Gamma(v,\eta)$ in the general Lorentz transformation: the higher the speed η of M, the lower the relativistic degree of Σ is.

In Einstein's SR, the Lorentz transformation causes spacetime to present TD&LC phenomena: if A and B are two events at the same spatial location ($x'_B=x'_A$) with the time interval $\Delta t'=|t'_B-t'_A|$ in O', then the time interval in O is $\Delta t=|t_B-t_A|=\gamma\Delta t'>\Delta t'$; if $L'=|x'_B-x'_A|$ is the spatial distances measured in O', then correspondingly in O, $L=|x_B-x_A|=\gamma^{-1}L'<L'$. Similarly, spacetime under GLT also presents TD&LC. With Eq.3, if $v<\eta<\infty$ then

$$\Delta t=\Gamma\Delta t'=\Delta t'\Big/\sqrt{1-v^2/\eta^2}>\Delta t'; \tag{5}$$

$$L=\Gamma^{-1}L'=L'\sqrt{1-v^2/\eta^2}<L'. \tag{6}$$

Whereas, Eqs.5-6 suggest that, TD&LC under GLT are also only observational effects caused by observational locality ($\eta<\infty$): the higher the η, the less obvious the TD&LC are. If $\eta\to\infty$, then

$\Delta t=\Delta t'$ and $L=L'$; spacetime would no longer present TD&LC phenomena.

Actually, under GLT, all relativistic phenomena are only observational effects. As depicted in Fig.3c, for the identical observer O, the identical object Σ would observationally present a different relativistic degree in a different observation system with a different M. So, any relativistic effect that spacetime or matter motion presents is not an objective or real natural phenomenon: its essence is an observational effect; while its root resides in observational locality ($\eta<\infty$).

VII. CONCLUSION

On the basis of the principle of observational locality (POL) and the hypothesis of observational Limit (HOL), we have the following basic conclusions:

(1) In the Lorentz transformation and Einstein's SR, light acts as the observational medium (M) to transmit observed information to observers.

(2) The invariance of light speed (ILS) is only an observational effect: the speed (c) of light is not really invariant; it only observes as if it is when it acts as M.

Actually, there is no invariant speed in spacetime or such matter motion with the same speed relative to all observers. We have no reason to believe that light is the only M or the speed (η) of M must be c. Taking POL and HOL as logical prerequisites, we have deduced the invariance of M speed (IMS), in which ILS is only a special case and is valid only if light acts as M. IMS shows that, so long as it acts as M, the speed of an matter wave or matter motion is observationally invariant.

From IMS, we have derived the general Lorentz transformation (GLT), generalized and unified the Galilean transformation (GT) and the Lorentz transformation (LT). Under Bohr's correspondence principle [28], GLT is strictly corresponding to both GT and LT. GLT shows that: LT and Einstein's theory are the product of the optical observation system; while GT and Newton's theory are the product of the idealized observation system. Under the idealized observation condition ($\eta\to\infty$), without observational locality and relativistic effects, the universe or spacetime would present its real face. So real objective world should be Galilean spacetime [29], and more consistent with the Galilean-Newtonian views of nature: space and time are independent of each other; velocity superposition follows the Galilean rules and matter motion follows Newton's laws; time does not dilate and space does not contract; simultaneity is absolute. Perhaps, it is time for us to reflect on our view of nature or our view of space and time.

Of course, according to PPO or POL, there is no infinite η or the idealized observation system in the physical world; relativistic effects are bound to always reside in our observation. In this sense, observational locality is insurmountable. However, this does not mean that the observational locality of light as M is insurmountable. Perhaps, the future technological progress would uncover faster matter motion or superluminal media, so that we could observe a more real objective world.

In this paper, HOL is only a heuristic, or a heuristic judgment. However, it should be noted that, in the theory of observational relativity [30], HOL and IMS are the logical conclusions derived from the basic physical properties of spacetime and matter.

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