# Information wave and the theory of observational relativity

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## ABSTRACT

The invariance of light speed (ILS) is the mainstay of Einstein's special relativity (SR). However, to this day, we do not even know why the speed of light is invariant, why the speed of light cannot be exceeded, and why the photon has no mass. Here, we have theoretically derived the theory of observational relativity (OR) from the most basic facts and prerequisites, which reveals the truth behind the ILS. OR have unified Einstein's SR and de Broglie's theory of matter wave. More importantly, as the result of logical derivation, the general Lorenz factor of OR is $\Gamma=1/\sqrt{(1-v^2/\eta^2)}$ where $\eta$ is not the light speed $c$ but the speed of information wave (IW) that carries and transmits the spacetime information of observed objects. OR has gotten a vital logic inference of pure rationality (rather than a hypothesis like the ILS): the invariance of IW speed. Only as light is employed as IW, can the ILS be valid, and can Einstein's SR be a special case of OR. OR suggests that: Einstein's theory of relativity is flawed and limited. Actually, all relativistic effects are observational effects rather than real natural phenomena. The theory of OR will profoundly change our view of spacetime and endow physics with a significant mission to explore superluminal IWs so that we can break though the observational limit of light and observe a more abundant and more objective natural world.

## I. INSTRUCTION

In 1887, following Maxwell's proposal[1,2], Michelson and Morley conducted an experiment to hunt for the aether[3]. Without catching the aether, they ran into a problem: Galileo's superposition principle for velocities seemed invalid. In 1889, to explain the experimental result, FitzGerald proposed the hypothesis of length contraction: all objects physically contract by the factor of $\sqrt{(1-v^2/c^2)}$ along the line of motion[4]. Later, Lorentz added time dilation by $1/\sqrt{(1-v^2/c^2)}$ to FitzGerald's hypothesis, and made it be Lorentz transformation[5]. Einstein seized the key in the Michelson-Morley experiment: the superposition between the speed of light and the orbital speed of the earth remained the speed of light. Thereby Einstein put forward the hypothesis of the invariance of light speed (ILS), theoretically derived Lorentz transformation, and established his theory of special relativity (SR)[6].

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The ILS is the mainstay of Einstein's SR that deduces two important inferences: (1) the speed of light is the upper limit no speed can exceed; (2) the photon has no (rest) mass. However, the ILS is always perplexing us. To this day, we do not even know why the speed of light is invariant. People are subconsciously not willing to accept the ILS. Efforts have never ceased to explore superluminal motion and to detect the photon mass.

There are constantly reports on superluminal phenomena from astronomical observation[7,8]. Kapteyn made the first in 1901[9]. Such phenomena are regarded as apparent motions without violating Einstein's theory[10,11]. In 2000 Wang and his colleagues claimed that a laser pulse traveled at more than 300 times the speed of light in their experiments[12], which is only in the sense of the classical wave theory and did not adversely affect Einstein's theory. OPERA ever announced the superluminal motions of tau neutrinos[13], and shortly afterward, flaws were discovered in their experiments and the announcements had been withdrawn[14].

Physicists, including de Broglie[15,16], Schrödinger[17,18], and Feynman[19], have been taking time and efforts to detect the photon mass. In 1930s Proca even prepared a modified version for Maxwell's equations of electromagnetism with the massive photon[20,21]. Up to now, all the efforts have failed and only left a trail of upper bounds tending to zero[22,23]. The photon mass recommended by CODATA[24] in 2014 was $1.5\times10^{-54}$ kg yielded by Ryutov in 2007[25].

So Einstein's principle of ILS and his theory of relativity are seemingly irrefutable. In this article, we will develop the theory of observational relativity (OR), and reveal the truth behind the ILS. OR will unify Einstein's theory of special relativity (SR) and de Broglie's theory of matter wave. More importantly, theoretical derivation will show that, the general Lorenz factor of OR is $\Gamma=1/\sqrt{(1-v^2/\eta^2)}$ where $\eta$ is not the light speed $c$ but the speed of information wave (IW). It is worth noting that our observation or experiment needs some kind of IW, e.g., sound and light (Fig. 1), to carry and transmit the information of observed objects. OR has an important inference rather than a hypothesis: the invariance of IW speed, which suggests that our observation and experiment are restricted by the speed of IW, that is to say, the IW speed is the observational limit no observed speed can exceed. Only when light severs as IW, can the ILS be valid, and can Einstein's SR be a special case of OR. Our observation and experiment mostly employ light as IW, which is why they agree with Einstein's theory. Actually, all the speeds of matter motion are variant; all matter particles have (rest) masses. OR suggests that: Einstein's theory of relativity is flawed and limited. Actually, all relativistic effects are observational effects rather than real natural phenomena. Making use of superluminal IWs, we will be able to observe the variance of light speed relative to different observers and to detect the photon mass. The theory of OR will profoundly change our view of spacetime and endow physics with a significant mission to explore superluminal IWs so that we can break though the observational limit of light and observe a more abundant and more objective natural world.

## II. SPACETIME INFORMATION AND INFORMATION WAVE

Since the beginning of its history, physics has neglected a vital role in our observation and experiment: *information wave* which carries and transmits the spacetime information of observed objects and whose speed restricts our observation and experiment. Before the theoretical derivation of OR, we propose a few of physical concepts or physical quantities.

*Space-Time Information (STI).* Lorentz transformation is a kind of spacetime transformation. Spacetime transformation needs to make the exchange of information between different spacetime or reference frames. The basic task of physical observation or experiment is to collect the information on observed objects. In 4d Minkowski spacetime, the path of an observed object is a worldline tracing the historical context of its location in space at each instant in time; a worldline is a sequence of events; an *event* is a point of 4d spacetime containing the information on the observed object. The most fundamental information of an event or an observed object is what we call *spacetime information* (STI) containing both the spatial information (on the location) and the temporal information (on the instant) of the event or the object. It is worth noting that STI must in some way propagate from the observed object to our sensory organs, such as eyes or ears, or to our detectors or observation instruments, so that we can sense it or detect it. In observation and experiment, we must depend on or employ a certain medium to carry and transmit STI of observed objects. So, who can be the medium (Fig. 1a)?

*Information Wave* (IW) and *Informon.* De Broglie coined the concept of *matter wave*[26] from wave-particle duality. According to de Broglie's theory of matter wave, material motion is just the propagation of matter wave. In its broadest sense, we can regard all material motion as matter wave. Waves have one important property: modulability, so that they can carry and transmit information. We call matter wave *information wave* (IW) as and only as it is employed to carry and transmit the STI of observed objects, and call matter particles *informons* composing IW. (Železnikar ever used *informon* to represent *informational entity*, and made the comparison between the concepts of electron and informon[27].) Theoretically, any matter wave (matter motion) can be IW, and any matter particle, e.g., photon, neutrino, graviton, electron, atom, molecule, even a piece of rock, can be informon. Light is the most important IW for us, with it we can *see* the world (Fig. 1b). Even so, light is not the only choice of IW. Sound can also be IW, with it we can *hear* the world and bats can *hear* their prey (Fig. 1c). Besides, human beings have invented the radar that employs radio wave as IW though we cannot directly sense it (Fig. 1d).

*Observed Speed and Observational Limit*. The speed of observed objects is perhaps the most fundamental physical quantity. However, it is not the intrinsic quantity of objects, but an observational value that should be called *observed speed*. An object has different observed speeds relative to different observers. There must be the upper limit of observed speeds because of not only objective locality but the limitation of IW speed as well. We call the upper limit of observed speeds *observational limit*.

<u>*Observational Agent*</u>. We also propose the other concept: *observational agent* that is the abstraction of the same category of observation systems which employ the same IW or have the same IW speed. An observational agent can be symbolized as $O(\eta)$ where $\eta$ is the speed of IW or informon. Particularly, $O(c)$ is called *Einstein agent* with light as IW; $O_\infty$ is called *Galilean agent* with infinite IW speed.

The theory of OR will tell us that: relativistic effects are rooted in the fact that the speed of IW is limited. All relativistic effects are observational effects rather than real natural phenomena; with different IWs, we will observe different relativistic effects; the lower the speed of IW, the more obvious the relativistic effects; with Galilean agent whose IW speed is ideally infinite, all relativistic effects would disappear completely. Of course, any IW has finite speed ($\eta<\infty$), and hence we can never get Galilean agent. In this sense, relativistic effects are also objective and natural to some extent. In most cases, our observation and experiment are conducted with Einstein agent that employs light as IW and the photon as informon, and hence they seemingly agree with Einstein's theory.

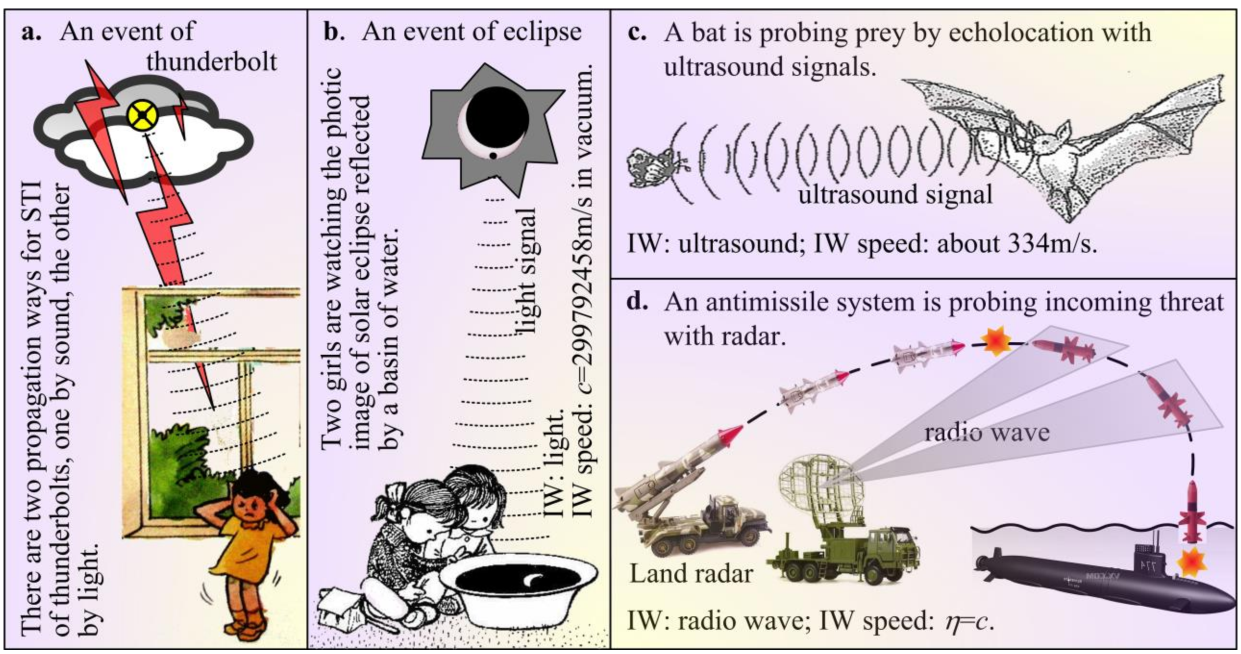


**Figure 1 | Spacetime information (STI) & Information Wave (IW). a**, Thunderbolt events: STI of a thunderbolt event must ride a certain IW to our sensory organs so that we can sense it; not only light but sound as well can be IW to carry and transmit the STI on thunderbolts. **b**, Light being IW: Light wave is the most important IW for us. **c**, Sound being IW: Theoretically arbitrary matter motion, e.g., sound can carry and transmit information; bats are expert at utilizing ultrasound as IW. **d**, Radio being IW: Radio waves can also be IWs though they cannot directly be sensed by us.

## III. BASIC PREREQUISITES AND PRINCIPLES

Relativistic effects stem from the most fundamental properties of the physical world: locality and wave-particle duality. The theory of OR is based on these two basic points.

### *A. The Principle of Physical Observability*

First of all, we explicitly represent the physical observability as a fundamental principle.

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

The PPO seems self-evident, and hence has the rationality to be a basic principle or axiom. The PPO suggests that any singularity of theories or mathematical models does not represent the reality of observed objects. All theories or mathematical models break down at their own singularities. In this sense, the PPO can be called *the principle of singularity*.

Einstein's SR has a vital singularity that we call *Lorentz singularity*, where the observed object reaches the light speed $c$ and the Lorentz factor $\gamma(v)=1/\sqrt{(1-v^2/c^2)}$ reaches infinite. Under SR, the relativistic mass of the object is $m=\gamma(c)m_o=\infty$ at Lorentz singularity, unless its rest mass $m_o$ is zero. According to the PPO, the relativistic mass $m$ of the photon must be finite ($m<+\infty$), and hence its rest mass $m_o$ must be zero, i.e., $m_o=m\sqrt{(1-c^2/c^2)}=0$. In this case, the relativistic mass $m$ is not definite, and cannon be determined by SR itself. It has to be computed by means of Planck equation $E=h\nu$: $m=h\nu/c^2$ (due to Einstein formula $E=mc^2$). It is particularly worth noting that: this does not mean that the photon has no rest mass; this does mean that SR breaks down at Lorentz singularity. As Hawking says in *A Brief History of Time*[28]: ″Mathematics cannot really handle infinite numbers. A theory itself breaks down at a point called a singularity by mathematicians.″

### *B. Locality and the Principle of Locality*

Locality plays an important role in Einstein's theory. Up to now, the concept of locality is still ambiguous and controversial. Here, with the concept of *observed speed*, we represent the principle of locality as a corollary of the PPO.

*The Principle of locality:* It must take time to cross space, or, any observed speed must be finite.

According to the PPO, locality is objective and natural, and beyond all question. However, this does not mean that there is no superluminal motion in the universe, but just means that the speed of matter motion cannot be infinite. However, observed speeds are not only restricted by objective locality but by the observational limit due to the speed of IW as well.

### *C. Wave-Particle Duality and the Cosmic Speed*

Wave-particle duality (WPD) implies that matter behaves both as particles and as waves. Matter motion consists of both *linear motion* indicated by observed speed $u$, and *wavy motion* indicated by observed frequency $\nu$. Both linear motion and wavy motion need energy: *linear energy* for linear motion; *wavy energy* for wavy motion. The higher the observed speed, the bigger the linear energy; the larger the observed frequency, the bigger the wavy energy. WPD can be described with *wavy vector* that points to the direction of particle movement or wave propagation (Fig. 2). Unlike general vector in classical mechanics or wavevector in classical wave theory, a wavy vector has two magnitudes: one is its length representing the observed speed $u$, the other is the observed frequency $\nu$ (Fig. 2).

The speed $u$ and frequency $\nu$ observed by an observer are interrelated ($\nu(u)\propto u$). The higher the observed speed or the longer the wavy vector, the larger the observed frequency. As depicted in Fig. 2a, this can be represented as a fundamental principle of the relationship between the observed frequency and the observed speed.

*The Principle of Frequency-Speed (PFS):* Consider an object $\Sigma$ moving in inertial frames $O$ and $O'$, the observed speeds are $u$ and $u'$ and the observed frequencies are $\nu$ and $\nu'$ respectively, then $\nu>\nu'$ if and only if $|u|>|u'|$, particularly, $\nu=\nu'$ if and only if $|u|=|u'|$.

The PFS suggests that WPD can give rise to the speed limit: the frequency grows as the speed increases, then the object consumes more energy for wavy motion, and as a result, the speed of linear motion is limited. We can imagine that the observed speed of the object must reach the speed limit as its observed frequency tends to infinite. We call the speed limit *the cosmic speed* denoted by $\Lambda$ that is defined as below.

*Definition A (The Cosmic Speed):* Consider a free object $\Sigma$ moving in the frame $O$, the speed and frequency observed by $O$ are respectively $u$ and $\nu$, then $\Lambda$ ($<+\infty$) is called the cosmic speed if $|u|\to\Lambda$ as $\nu\to\infty$, i.e., $\lim_{\nu\to\infty}|u|=\Lambda$.

Definition A supposes that the observed speed of a free object will tend to the cosmic speed as its observed frequency tends to infinite. However, it does not require the observed frequency to be infinite when the observed speed reaches the cosmic speed. Accordingly, under the condition without violating the PPO, it does not rule out the possibility that an object reaches the cosmic speed. Under the PPO and the PFS, the following lemma holds, which suggests that the cosmic speed is the upper limit of observed speeds. (See the proof in the section of methods.)

*Lemma A:* Any observed speed $u$ cannot exceed the cosmic speed $\Lambda$, i.e., $\forall u\ |u|\leq\Lambda$.

### *D. The Superposition Principle for Velocities*

The result of the Michelson-Morley experiment[3] did not agree with Galileo's superposition principle. Galileo's velocity superposition is for linear vectors without WPD, whereas the observational velocity superposition should be for wavy vectors. So, as depicted in Fig. 2b, the velocity superposition should follow the principle for wavy vectors as below.

*The Superposition Principle for Velocities (SPV):* Consider an object $\Sigma$ and its two inertial frames $O$ and $O'$. Suppose that, $\Sigma$ moves at the speed $u$ along the axis $X$ in $O$, at the speed $u'$ along the axis $X'$ in $O'$, and $O'$ moves at the speed $v$ along the axis $X$ relative to $O$, then the speed $u$ is the wavy superposition of $u'$ and $v$ formulated with $u=u'\oplus v$ and satisfies:

(1) The principle of zero superposition : $v\oplus 0=v$;

(2) The principle of symmetry: $u'\oplus v=v\oplus u'$;

(3) The principle of the same direction: if $u'\geq 0$ and $v\geq 0$, or $u'\leq 0$ and $v\leq 0$, then $|u'+v|\geq|u'\oplus v|\geq\max\{|u'|,|v|\}$; and

(4) The principle of the opposite direction: if $u'\geq 0$ and $v\leq 0$, or $u'\leq 0$ and $v\geq 0$, then $\max\{|u'|,|v|\}\geq|u'\oplus v|\geq|u'+v|$.

where, in (3) and (4), equality signs hold if and only if $u'$ or $v$ is zero.

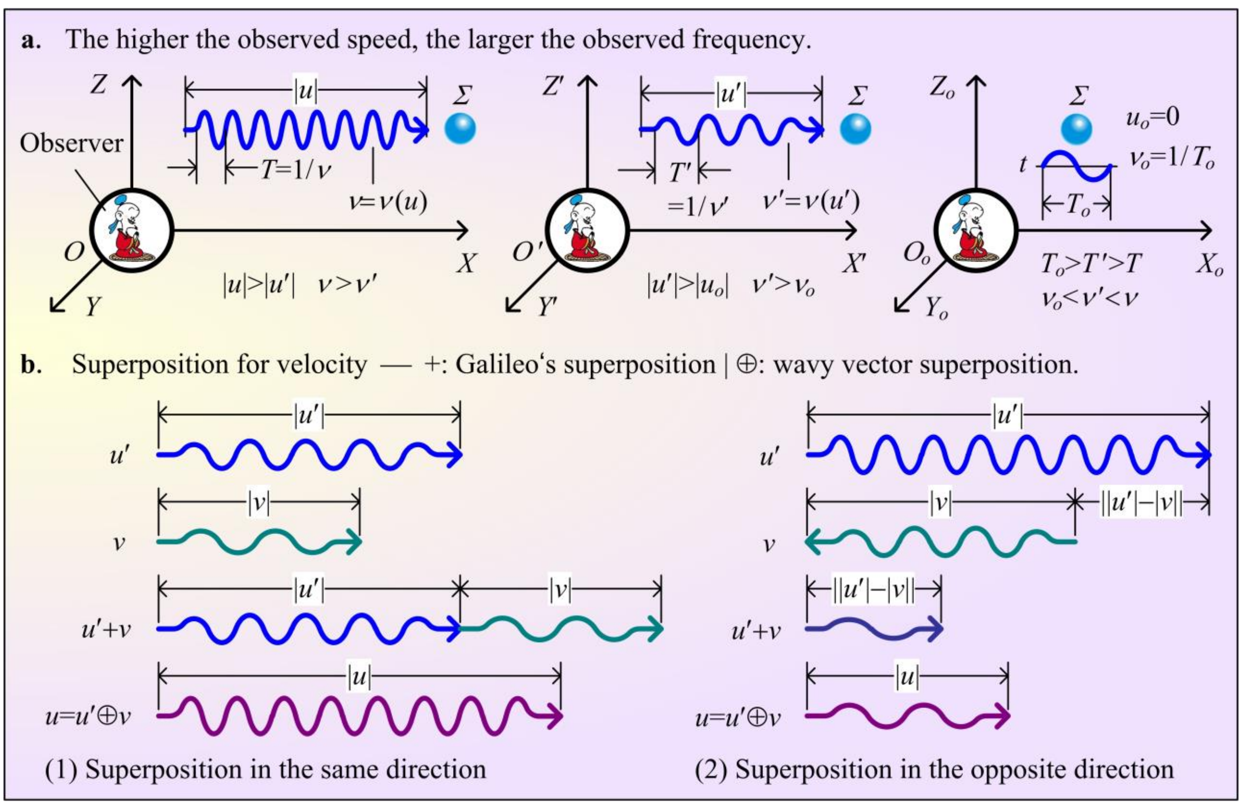


**Figure 2 | Wave-particle duality and wavy vector. a**, Frequency vs speed: the observer in the intrinsic frame $O_o$ sees the object $\Sigma$ being at rest and the observed frequency $\nu_o$ being the minimum; by observing respectively in the inertial frames $O$ and $O'$, the observer discovers that, the higher the observed speed, the larger the observed frequency. **b**, Superposition for wavy vectors: (1) if the observed speeds $u'$ and $v$ are in the same direction, then their superposition $u'\oplus v=u$ makes the observed speed $u$ higher and the observed frequency $\nu$ increase, in the process, some of linear energy is turned into wavy energy so that the length of $u$ is shorter than that of Galileo's superposition; (2) if $u'$ and $v$ are in opposite directions, then $u'\oplus v=u$ makes $u$ lower and $\nu$ decrease, in the process, some of wavy energy is turned into linear energy so that the length of $u$ is longer than that of Galileo's superposition.

## IV. MATTER-WAVE TIME

Waves can be employed to measure time due to their periodicity. Under the concept of matter wave, an object is a natural clock, so-called *matter-wave clock*, and the period or frequency of matter wave can be the most basic time unit[29,30].

*Definition B (Intrinsic Frame, Fundamental Period and Frequency):* Consider an object $\Sigma$ and a reference frame $O_o$, let $\Sigma$ be at rest in $O_o$, denote the period and frequency of its matter wave in $O_o$ with $T_o$ and $\nu_o$ respectively, then we call $O_o$ the *intrinsic reference frame* of $\Sigma$, $T_o$ the *fundamental period* of $\Sigma$, and $\nu_o$ the *fundamental frequency* of $\Sigma$.

Naturally, $O_o$ is the intrinsic inertial frame of $\Sigma$. Now, we can define matter-wave time based on fundamental $T_o$ or fundamental $\nu_o$ of $\Sigma$.

*Definition C (Matter-Wave Time):* Consider an object $\Sigma$ and a reference frame $O$, if an observer at rest in $O$ detects $N$ matter wave periods of $\Sigma$ in a duration $\Delta t$, then $\Delta t=NT_o=N/\nu_o$.

Now the object $\Sigma$ is just a matter-wave clock, so-called ″A rock is a clock[31]″.

*Definition D (Proper Time and Observed Time):* In Definition C, if $O=O_o$, then $\Delta t$ is called *the proper time* or *fundamental time* of $\Sigma$, and denoted by $\Delta\tau=N_oT_o=N_o/\nu_o$, where $N_o$ is the period number observed by $O_o$, $T_o=\Delta\tau/N_o$, and $\nu_o=N_o/\Delta\tau$; if $O\neq O_o$, then $\Delta t$ is called *the observed time* of $\Sigma$ in $O$, and correspondingly, the *observed period* $T=\Delta\tau/N$, and the *observed frequency* $\nu=N/\Delta\tau$.

Under Definitions C and D, $\Delta t/\Delta\tau=N/N_o$ and $\nu/\nu_o=N/N_o$. Consider an object $\Sigma$ and its two inertial frames $O$ and $O'$; respectively, let $\Delta t$ and $\Delta t'$ be the observed times, $\nu$ and $\nu'$ be the observed frequencies. Then, let $\Delta\to\mathrm{d}$, the following equations hold

$$\frac{\mathrm{d}t}{\mathrm{d}\tau}=\frac{\nu}{\nu_o} \text{ and } \frac{\mathrm{d}t'}{\mathrm{d}\tau}=\frac{\nu'}{\nu_o}, \text{ i.e., } \frac{\mathrm{d}t}{\nu}=\frac{\mathrm{d}t'}{\nu'}=\frac{\mathrm{d}\tau}{\nu_o}, \tag{1}$$

where $\mathrm{d}\tau$ is called the *fundamental time element* of $\Sigma$ in $O_o$, and $\mathrm{d}t$ and $\mathrm{d}t'$ are respectively the *observed time elements* of $\Sigma$ in $O$ and $O'$.

Eq. 1 shows that the ratio of the observed time element to the observed frequency is an invariant equal to the ratio of the fundamental time element $d\tau$ to the fundamental frequency $\nu_o$. This can be represented as a fundamental principle.

*The Invariance of Time-Frequency (ITF):* The ratio of the observed time element to the observed frequency is an invariant for any observed object in any reference frame (Eq. 1).

The ITF is just a corollary derived from Definitions C and D. Accordingly, we regard it (Eq. 1) as the equivalent definition of matter-wave time. Actually, the ITF holds for any time definition based on periodical signal.

## V. SPACETIME TRANSFORMATION

We stipulate that: $\Sigma$ denotes the observed object, its intrinsic frame $O_o$ has the reference clock defined in Definitions B-D with the fundamental period $T_o$ and frequency $\nu_o$; $O$ and $O'$ denote two inertial reference frames relative to $\Sigma$, and has the same reference clock; the corresponding coordinate axes and origins of $O$, $O'$ and $O_o$ coincide at $t=t'=\tau=0$; $\Sigma$ is at rest in $O_o$, moves at the speed $u'$ along axis $X'$ in $O'$, and moves at the speed $u$ along axis $X$ in $O$; $O'$ moves at the speed $v$ along $X$ relative to $O$; the frequencies of $\Sigma$ observed by $O$ and $O'$ are respectively denoted with $\nu=\nu(u)$ and $\nu'=\nu(u')$.

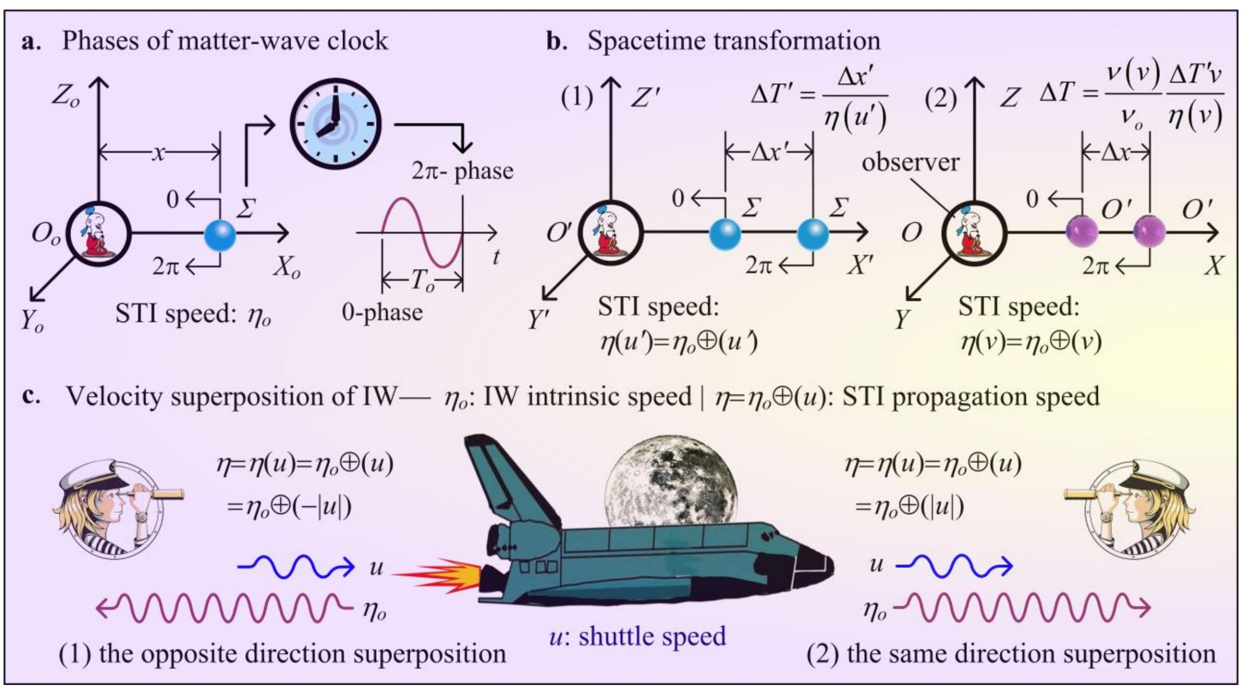


**Figure 3 | STI propagation by IW. a**, Phases of matter-wave time: Due to $\Sigma$ being at rest in $O_o$, different phases of $\Sigma$ take the same time to travel from $\Sigma$ to $O_o$. **b**, Spacetime transformation: (1) from $\Sigma$ to $O'$, due to $\Sigma$ moving in $O'$, different phases of $\Sigma$ take different times, and make the travelling time difference $\Delta T'$ between $2\pi$- and zero-phase; (2) from $O'$ to $O$, due to $O'$ moving in $O$, $\Delta T'$ is transformed into $\Delta T$. **c**, Velocity superposition of IW: $\eta_o$ is the intrinsic speed of IW in $O_o$ that always points at observers; the STI speed $\eta(u)$ of the shuttle should be the superposition of $\eta_o$ and the shuttle's speed $u$; under the SPV, the forward speed $\eta(u)=\eta_o\oplus(|u|)$ should be higher than the backward speed $\eta(u)=\eta_o\oplus(-|u|)$.

Under the stipulation, the relative movements of $O$, $O'$, $O_o$ can be regarded as that of their reference clocks. According to the ITF (Eq. 1), the time elements d$t$ and d$t'$ observed directly by $O$ and $O'$ are respectively $\mathrm{d}t=(\nu(u)/\nu_o)\mathrm{d}\tau$ and $\mathrm{d}t'=(\nu(u')/\nu_o)\mathrm{d}\tau$. Considering the movement of $O'$ relative to $O$, from the ITF, we have

$$\frac{\mathrm{d}t}{\nu(v)}=\frac{\mathrm{d}t'}{\nu_o} \text{ or } \mathrm{d}t=\frac{\nu(v)}{\nu_o}\mathrm{d}t', \tag{2}$$

where $\nu(v)$ is the frequency of $O'$ or its reference clock observed by $O$, and $\nu_o$ is the (fundamental) frequency of $O'$ or its reference clock observed by $O'$ itself.

Now, we examine the problem of spacetime coordinate transformation $O'\rightarrow O$: for $O$ how to indirectly observe $\Sigma$ through $O'$. It is worth noting that, during spacetime transformation, space and time are interdependent. During a fundamental period $T_o$ of $\Sigma$ (Fig. 3a), the zero-phase is the start, and the $2\pi$-phase is the end. Due to $\Sigma$ moving in $O'$ and $O'$ moving in $O$, different phases take different times to travel from $\Sigma$ to $O'$ (Fig. 3b (1)) and then from $O'$ to $O$ (Fig. 3b (2)). Similarly, the start and the end of the fundamental time element d$\tau$ take different times to travel from $\Sigma$ to $O'$ and then from $O'$ to $O$. It is extremely important that: the spacetime transformation $O'\rightarrow O$ must be related to the intrinsic speed $\eta_o$ (Fig. 3) of IW that carries and transmits the STI including matter wave phases of $\Sigma$ to $O'$ and then from $O'$ to $O$. Note that, under the PPO or the principle of locality, the IW speed $\eta_o$ is finite ($\eta_o<+\infty$). We need to divide the STI propagation process of $\Sigma$ into two time sections: one is $\Sigma\rightarrow O'$; the other is $O'\rightarrow O$.

<u>*Section One*</u> (Fig. 3b (1) $\Sigma$ moves at $u'$ in $O'$): The STI speed from $\Sigma$ to $O'$ is $\eta(u')=\eta_o\oplus(u')$; during the observed time element d$t'$, $\Sigma$ moves along $X'$ a certain distance of $\delta x'=u'\mathrm{d}t'$; so it takes a little more time of $\delta\mathrm{d}t'=\delta x'/\eta(u')=u'\mathrm{d}t'/\eta(u')$ for the ending phase of d$\tau$ to propagate from $\Sigma$ to $O'$ than the starting phase.

<u>*Section Two*</u> (Fig. 3b (2) $O'$ moves at $v$ in $O$): The STI speed from $O'$ to $O$ is $\eta(v)=\eta_o\oplus(v)$; under the ITF and Eq. 2, the delay of $\delta\mathrm{d}t'$ observed by $O'$ is turned into the delay of $(\nu(v)/\nu_o)\delta\mathrm{d}t'$ observed by $O$, during which $O'$ moves along $X$ in $O$ a certain distance of $\delta x=(\nu(v)/\nu_o)\delta\mathrm{d}t'v$; accordingly, the delay of $\delta\mathrm{d}t'$ in $O'$ is transformed into $\delta\mathrm{d}t=\delta x/\eta(v)=(\nu(v)/\nu_o)\delta\mathrm{d}t'v/\eta(v)$ in $O$.

Consequently, from Eq. 2, the time element d$t$ observed by $O$ is

$$\begin{aligned}\mathrm{d}t &= \frac{\nu(v)}{\nu_o}\mathrm{d}t' + \delta\mathrm{d}t = \frac{\nu(v)}{\nu_o}\mathrm{d}t' + \frac{\nu(v)}{\nu_o}\frac{\delta\mathrm{d}t'v}{\eta(v)} \\ &= \frac{\nu(v)}{\nu_o}\mathrm{d}t' + \frac{\nu(v)}{\nu_o}\frac{u'v}{\eta(u')\eta(v)}\mathrm{d}t' = \frac{\nu(v)}{\nu_o}\left\{1 + \frac{u'v}{\eta(u')\eta(v)}\right\}\mathrm{d}t' = \Gamma(v)\left\{\mathrm{d}t' + \frac{B(v)}{\eta(u')}\mathrm{d}x'\right\}\end{aligned} \quad (3)$$

where $\Gamma(v)=\nu(v)/\nu_o$, $B(v)=v/\eta(v)$, and $\mathrm{d}x'=u'\mathrm{d}t'$.

Similarly, we examine the problem of spacetime coordinate transformation $O\to O'$. In the same logic way as deriving Eq. 3, we have

$$\mathrm{d}t' = \frac{\nu(v)}{\nu_o}\left\{1 - \frac{uv}{\eta(u)\eta(v)}\right\}\mathrm{d}t = \Gamma(v)\left\{\mathrm{d}t - \frac{B(v)}{\eta(u)}\mathrm{d}x\right\} \ (\mathrm{d}x = u\mathrm{d}t). \quad (4)$$

Eqs. 3 and 4 show that, spacetime transformation indeed makes space and time interdependent. It is worth noting that: Eq. 4 does not have the aid of Galileo's principle of relativity, whereas Eqs. 3 and 4 naturally reflect the relativity of motion, and illuminates the principle of relativity. Of course, by invoking the principle of relativity, Eq. 4 could directly be given from Eq. 3.

## VI. THE INVARIANCE OF IW SPEED AND THE OBSERVATIONAL LIMIT

Combining Eqs. 3 and 4, we have

$$\mathrm{d}x = \Gamma(v)\eta(u)\left\{\frac{1}{\eta(u')}\mathrm{d}x' + \frac{1-\Gamma^{-2}(v)}{B}\mathrm{d}t'\right\}. \quad (5)$$

Combining Eqs. 5 and 3, we have

$$u = \frac{\mathrm{d}x}{\mathrm{d}t} = \frac{(1-\Gamma^{-2}(v))\eta(u') + u'B(v)}{\eta(u') + u'B(v)}\frac{\eta(u)}{B(v)} \ \left(u' = \frac{\mathrm{d}x'}{\mathrm{d}t}\right). \quad (6)$$

Consider two following cases (Fig. 4e and f).

*Case One* (Fig. 4e): $O'$ moves along positive $X$ away from $O$, and hence $\eta(v)$ is the superposition of the opposite direction of $\eta_o$ and $v$, i.e., $\eta(v)=\eta_o\oplus(-v)$; $\Sigma$ moves along the positive axis $X'$ away from $O'$, in this case, $v>0$ and $u'>0$, $u'$ and $v$ are in the same direction.

According to the definition of the cosmic speed (Definition A), if $\nu(v)\to\infty$, then $v\to\Lambda$ and $\Gamma(v)\to\infty$. According to Lemma A and Eq. 6, we have

$$\Lambda \geq \lim_{\nu(v)\to\infty} u = \lim_{\nu(v)\to\infty}\frac{\eta(u)}{B(v)} = \frac{\eta_o\oplus(-\Lambda)}{\Lambda}\lim_{\nu(v)\to\infty}\eta(u). \quad (7)$$

According to the principle of the same direction in the SPV, $u=u'\oplus v=u'\oplus \Lambda\geq\max\{u',\Lambda\}=\Lambda$ as $v\rightarrow\Lambda$ (Fig. 4e). Combining Eq. 7, we have $\Lambda\geq u\geq\Lambda$. Hence $u=\Lambda$ and only the equality sign holds in Eq. 7. Due to $\Sigma$ moving away from $O$ (Fig. 4a), $\eta(u)$ is the superposition of the opposite direction of $\eta_o$ and $u$, i.e., $\eta(u)=\eta_o\oplus(-u)=\eta_o\oplus(-\Lambda)$ as $v\rightarrow\Lambda$. With Eq. 7, we have $\eta_o\oplus(-\Lambda)=\Lambda$.

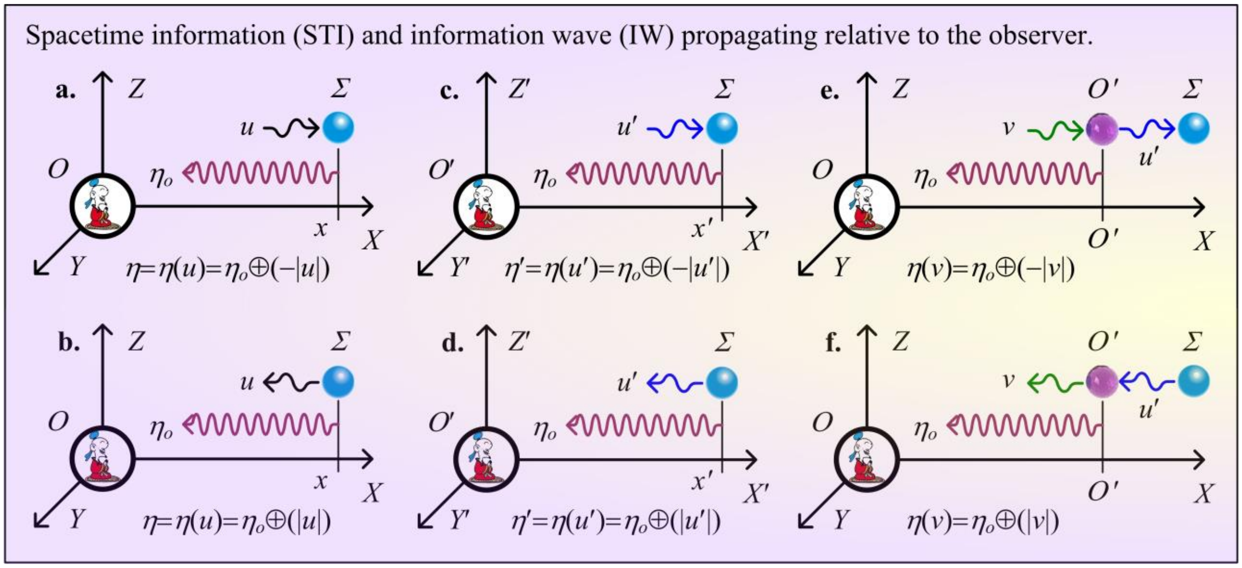


**Figure 4 | The speed of STI and IW relative to the observer.** The STI of the observed object $\Sigma$ must ride some kind of IW to travel from $\Sigma$ to the observer. Relative to the observer, the STI speed $\eta$ should be the superposition between the IW speed $\eta_o$ and the speed of $\Sigma$ relative to the observer. So, the STI speeds in $O$ and $O'$ should respectively be **a-b**: $\eta=\eta(u)=\eta_o\oplus u$ and **c-d**: $\eta'=\eta(u')=\eta_o\oplus u'$, the STI relative speed between $O$ and $O'$ should be **e-f**: $\eta(v)=\eta_o\oplus v$, where **a**, **c**, **e** are the opposite direction superposition, and **b**, **d**, **f** are the same direction superposition.

_Case Two_ (Fig. 4f): $O'$ moves along positive $X$ toward $O$, and hence $\eta(v)$ is the superposition of the same direction of $\eta_o$ and $v$, i.e., $\eta(v)=\eta_o\oplus(-v)$; $\Sigma$ moves along the positive axis $X'$ toward $O'$, in this case, $v<0$ and $u'<0$, $u'$ and $v$ are also in the same direction.

According to the definition of the cosmic speed (Definition A), if $\nu(v)\rightarrow\infty$, then $v\rightarrow-\Lambda$ and $\Gamma(v)\rightarrow\infty$. According to Lemma A and Eq. 6, we have

$$-\Lambda\leq\lim_{\nu(v)\rightarrow\infty}u=\lim_{\nu(v)\rightarrow\infty}\frac{\eta(u)}{B(v)}=\frac{\eta_o\oplus(\Lambda)}{-\Lambda}\lim_{\nu(v)\rightarrow\infty}\eta(u). \quad (8)$$

According to the principle of the same direction in the SPV, $|u|=|u'\oplus v|=|u'\oplus(-\Lambda)|\geq\max\{|u'|,\Lambda\}=\Lambda$ as $v\rightarrow-\Lambda$ (Fig. 4f). Combining Eq. 8, we have $-\Lambda\leq u\leq-\Lambda$. Hence $u=-\Lambda$ and only the equality sign holds in Eq. 8. Due to $\Sigma$ moving toward $O$ (Fig. 4b), $\eta(u)$ is the superposition of the same direction of $\eta_o$ and $u$, i.e., $\eta(u)=\eta_o\oplus(-u)=\eta_o\oplus(\Lambda)$ as $v\to-\Lambda$. With Eq. 8, we have $\eta_o\oplus(\Lambda)=\Lambda$.

According to the SPV and Lemma A, given any observed speed $u\in[-\Lambda,\Lambda]$, we have $\eta_o\oplus(\Lambda)\geq\eta_o\oplus u\geq\eta_o\oplus(-\Lambda)$. Combining the results of those two cases above, we have $\eta(u)=\eta_o\oplus u=\Lambda$, and $\eta_o=\eta(0)=\eta_o\oplus(0)=\Lambda$. This suggests that the IW speed $\eta_o$ ($=\Lambda$) is an invariant, and no other than the so-called cosmic speed $\Lambda$ (Definition A). So, we simply use $\eta$ to denote $\eta_o$, and have the corollaries as below.

*Corollary A (The Invariant of IW Speed):* Any matter wave (matter motion) propagates at the same speed relative to all inertial observers when and only when it serves as IW.

Here the invariance of IW speed is a logical conclusion rather than a hypothesis. Speed invariance can only be an observational effect rather than a real or objective natural phenomenon. The upper limit of observed speeds, so-called cosmic speed $\Lambda$ in Definition A and Lemma A, is restricted by the IW speed $\eta$. Different $\eta$ makes different $\Lambda$.

*Corollary B (The Observational Limit):* The IW speed $\eta$ is the observational limit that cannot be exceeded by any observed speed.

The observational limit will be the speed of sound if sound wave serves as IW, or the speed of light if light wave serves as IW. So the ILS is only a special case of the invariance of IW speed as the photon serves as informon.

*Corollary C (The Invariance of Light Speed, ILS):* The ILS is valid only when light serves as IW.

## VII. THE THEORY SYSTEM OF OBSERVATIONAL RELATIVITY

Now, on the basis of the invariance of IW speed and Eqs. 3 and 4, we can develop the theory system of observational relativity. We will derive the general Lorentz transformation, unify Einstein's SR and de Broglie's theory of matter wave, and deduce the general Einstein formula, the general Planck equation, and the general de Broglie's relation.

### *A. General Lorentz Transformation*

*General Lorentz Factor*. Suppose $u'=\eta$, then according to the invariance of IW speed, $u=\eta$ and $\eta(u)=\eta(u')=\eta(v)=\eta$. With Eq. 6 we have the general Lorentz factor

$$\Gamma(v)=\frac{1}{\sqrt{1-\frac{v^2}{\eta^2}}}, \tag{9}$$

where the IW speed $\eta$ takes the place of the light speed $c$ in Lorentz factor $\gamma(v)=1/\sqrt{(1-v^2/c^2)}$.

*General Lorentz Transformation*. Bring $\Gamma(v)$ into Eqs. 3 and 4, we have the differential formulas of the general Lorentz transformation

$$\begin{array}{ll} O' \to O: & O \to O': \\ \mathrm{d}x = \Gamma(v)(\mathrm{d}x' + v\mathrm{d}t'), & \mathrm{d}x' = \Gamma(v)(\mathrm{d}x - v\mathrm{d}t), \\ \mathrm{d}y = \mathrm{d}y', & \mathrm{d}y' = \mathrm{d}y, \\ \mathrm{d}z = \mathrm{d}z', & \mathrm{d}z' = \mathrm{d}z, \\ \mathrm{d}t = \Gamma(v)\left(\mathrm{d}t' + \dfrac{B(v)}{\eta}\mathrm{d}x'\right); & \mathrm{d}t' = \Gamma(v)\left(\mathrm{d}t - \dfrac{B(v)}{\eta}\mathrm{d}x\right). \end{array} \tag{10}$$

Set up the beginning conditions: $x=x'=0$, $y=y'=0$, and $z=z'=0$ at $t=t'=0$, by integrating Eq. 10, we have the general Lorentz transformation

$$\begin{array}{ll} O' \to O: & O \to O': \\ x = \Gamma(x' + vt'), & x' = \Gamma(x - vt), \\ y = y', & y' = y, \\ z = z', & z' = z, \\ t = \Gamma\left(t' + \dfrac{B}{\eta}x'\right); & t' = \Gamma\left(t - \dfrac{B}{\eta}x\right). \end{array} \tag{11}$$

So far, the core of OR has been built.

*B. Fundamental Relations and General Einstein Formula*

It is evident that the general Lorentz transformation has exactly the form same as Lorentz transformation. So, all the kinematic and dynamic relations in Einstein's SR, including Einstein formula $E=mc^2$, can logically be generalized by OR. However, different from Einstein's SR, the theory of OR will reveal that all relativistic effects are observational effects rather than the real or objective natural phenomena.

<u>*Composition of Velocity*</u>. The Michelson-Morley experiment[3] and the Fizeau experiment[32] show that velocities do not simply add, which obeys the velocity-addition formula of Einstein's SR rather than Galilean velocity addition. It is worth noting that those experiments were conducted under Einstein agent $O(c)$ which employed light as IW. We can easily deduce the velocity-addition formula of OR from Eq. 10

$$\begin{array}{ll} O' \to O & O \to O' \\ u_x = \dfrac{\mathrm{d}x}{\mathrm{d}t} = \dfrac{u'_x + v}{1 + u'_x v/\eta^2}, & u'_x = \dfrac{\mathrm{d}x'}{\mathrm{d}t'} = \dfrac{u_x - v}{1 - u_x v/\eta^2}, \\ u_y = \dfrac{\mathrm{d}y}{\mathrm{d}t} = \dfrac{\Gamma^{-1}(v)u'_y}{1 - u'_x v/\eta^2}, & u'_y = \dfrac{\mathrm{d}y'}{\mathrm{d}t'} = \dfrac{\Gamma^{-1}(v)u_y}{1 - u_x v/\eta^2}, \\ u_z = \dfrac{\mathrm{d}z}{\mathrm{d}t} = \dfrac{\Gamma^{-1}(v)u'_z}{1 + u'_x v/\eta^2}; & u'_z = \dfrac{\mathrm{d}z'}{\mathrm{d}t'} = \dfrac{\Gamma^{-1}(v)u_z}{1 - u_x v/\eta^2}. \end{array} \tag{12}$$

Clearly, Eq. 12 has the same form as the velocity-addition formula of Einstein's SR, in which, however, the IW speed $\eta$ takes the place of the light speed $c$. Eq. 12 suggests that: the relativistic velocity addition is actually a sort of observational effect rooted in the limitation of IW speed $\eta$; we will have different observational results with different IWs or different IW speed $\eta$. Clearly, under Galilean agent $O_\infty$ ($\eta\rightarrow\infty$), the relativistic velocity addition (Eq. 12) would get back to Galilean velocity addition: $u_x=u'_x+v$; $u_y=u'_y$; $u_z=u'_z$.

*Mass-Speed Relation*. OR has the analogous mass-speed relation to that of Einstein's SR

$$m(v)=\Gamma(v)m_o=\frac{m_o}{\sqrt{1-\frac{v^2}{\eta^2}}}, \tag{13}$$

where $m_o$ is the rest mass of $\Sigma$, $m(v)$ is the relativistic mass of $\Sigma$ under $O(\eta)$.

Eq. 13 shows that so-called relativistic mass is also a sort of observational effect rather than the real mass. Under different observational agents, an object has different relativistic masses. Actually, only the rest mass is the real mass of an object. So, all objects or particles, including the photon and the graviton, have their own rest masses. (See the details in supplementary note 2.3 of supplementary information.)

*Relativistic Momentum*. Following Einstein's way, momentum in OR is defined as $p=\Gamma(v)m_o v$, which includes the observational effect of momentum under observational agent $O(\eta)$ and should be called *relativistic momentum*. The momentum of $m_o v$ is an invariant and should be called *intrinsic momentum*. Observing an object with different observational agents, the identical observer will have different relativistic momenta. Only under Galilean agent $O_\infty$ ($\eta\rightarrow\infty$), we were able to observe the intrinsic momentum of the observed object.

*General Einstein Formula*. Following Einstein's way, the energy $E$ of a free object in OR should be $E=m\eta^2$, in which Einstein formula $E=mc^2$ is only a special case as light serves as IW. Like momentum situation, the energy in General Einstein formula $E=m\eta^2$ includes the observational effect of energy under observational agent $O(\eta)$ and should be called *relativistic energy*. Observing an object with different observational agents, the identical observer will have different relativistic energies.

### *C. Unification of Relativity Theory and Matter-Wave Theory*

The theory of OR is based on the definition of matter-wave time (Definitions B-D), which naturally links Einstein's SR with de Broglie's theory of matter wave.

*Frequency-speed relation*. The principle of frequency-speed (PFS) qualitatively describes the relationship between the frequency and speed of matter waves: the higher the observed speed, the larger the observed frequency. In OR, the general Lorentz factor $\Gamma(v)$=d$t$/d$\tau$=$\nu(v)/\nu_o$, and hence we have the quantitative form of frequency-speed relation with the similar form to that of the mass-speed relation (Eq. 12)

$$\nu(v)=\Gamma(v)\nu_o=\frac{\nu_o}{\sqrt{1-\frac{v^2}{\eta^2}}}, \tag{14}$$

where $\nu(v)$ is the observed frequency of $\Sigma$ under $O(\eta)$. Note that different observational agents have different observed frequencies.

__*General Planck equation*__. Planck equation $E=h\nu$ stemmed from the experiment of blackbody radiation, and was originally used to only the photon. To develop his theory of matter wave, de Broglie assumed that $E=h\nu$ could be generalized to any matter particle. But his assumption had no proof. Now, OR can theoretically deduce what de Broglie ever wanted.

With the mass-speed relation (Eq. 12), we have

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}t}=\frac{\mathrm{d}}{\mathrm{d}t}\frac{1}{\sqrt{1-B^2(v)}}=\frac{\Gamma^3 v}{\eta^2}\frac{\mathrm{d}v}{\mathrm{d}t}. \tag{15}$$

With the frequency-speed relation (Eq. 14), we have

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}t}=\frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\nu}{\nu_o}\right)=\frac{1}{\nu_o}\frac{\mathrm{d}\nu}{\mathrm{d}t}. \tag{16}$$

By comparing Eqs. 15 and 16, we have $v\mathrm{d}v=\Gamma^{-3}\eta^2\mathrm{d}\nu/\nu_o$. Let the observed object begin to move under the action of the force $F$ from rest, and gradually gain its speed of $v$. In the process, the frequency of matter wave increases from the fundamental frequency $\nu_o$ to the observed frequency $\nu(v)$ at the speed $v$. Then the kinetic energy of the object is

$$\begin{aligned} T &= \int_0^v F\mathrm{d}x=\int_0^v \frac{\mathrm{d}p}{\mathrm{d}t}\mathrm{d}x=\int_0^v v\mathrm{d}p=\int_0^v \Gamma^3 m_o v\mathrm{d}v=\frac{m_o\eta^2}{\nu_o}\int_{\nu_o}^{\nu}\mathrm{d}\nu \\ &=\frac{m_o\eta^2}{\nu_o}(\nu-\nu_o)=h_\eta(\nu-\nu_o)\quad\left(h_\eta=\frac{m_o}{\nu_o}\eta^2\right) \end{aligned} \tag{17}$$

where $h_\eta$ is the general Planck constant under $O(\eta)$.

Einstein defined $E_o=m_oc^2$ as the rest energy of a free object and $E=mc^2$ as its total energy. Similarly, we define $E_o=h_\eta\nu_o$ as the rest energy of the object and $E=h_\eta\nu$ as the total energy. Then, with Eq. 17, we have

$$E=h_\eta\nu_o+T=h_\eta\nu \tag{18}$$

Now, the theory of OR has theoretically derived the general Planck equation (Eq. 18), which is more than the matter-wave equation de Broglie ever wanted. It is universal not only for any object or particle including the photon, but for any observational agent $O(\eta)$ including Einstein agent $O(c)$. Note that: the general Planck constant $h_\eta$ can vary with observational agents; under Einstein agent $O(c)$, $h_\eta=h_c=h=6.6260693\times10^{-34}$ J·s.

<u>*The general de Broglie's relation*</u>. With Einstein formula $E=mc^2$ and Planck equation $E=h\nu$, de Broglie derived famous de Broglie's relation $\lambda=h/p$. Actually, in the theory system of OR, de Broglie's relation is only a special case as light being IW or the photon being informon. Now, under the general Einstein formula $E=m\eta^2$ and the general Planck equation $E=h_\eta\nu$, we can derive the general de Broglie's relation.

By means of the logic way similar to that of de Broglie[26], consider a free object $\Sigma$ that is both a matter particle and matter wave, which moves at the observed speed $v$ along axis $X$ in the reference frame $O$. Note that: $v$ is *the particle speed* of $\Sigma$ as matter particle; besides, as matter wave, $\Sigma$ has its *phase speed* $v_{\mathrm{p}}$ and group speed $v_{\mathrm{g}}$, and can be represented by the equation of monochromatic plane wave

$$\psi(t)=\sin(\omega t-kx-\varphi_0)=\sin\left(2\pi\nu\left(t-\frac{x}{v_{\mathrm{p}}}-t_0\right)\right), \tag{19}$$

where $t$ is the observed time, $v_{\mathrm{p}}=\nu\lambda$ is the phase speed of $\Sigma$, $\nu$ and $\lambda$ are respectively the observed frequency and wavelength, $\omega=2\pi\nu$ is the angular frequency, $k=\omega/v_{\mathrm{p}}=2\pi/\lambda$ is the wave number, and $\varphi_0$ and $t_0=\varphi_0/\omega$ are respectively the initial phase and time.

In the intrinsic frame $O_o$ of $\Sigma$, due to $\Sigma$ being at rest, Eq. 19 can be written as

$$\psi(\tau)=\sin\left(2\pi\nu_o(\tau-\tau_0)\right), \tag{20}$$

where $\tau$ is the proper time of $\Sigma$, $\nu_o$ is the fundamental frequency, and $\tau_o$ is the initial time.

By means of the general Lorentz transformation (Eq. 11), the relation between the observed time $t$ and the proper time $\tau$ can be represented as

$$\tau=\Gamma\left(t-\frac{B^2}{v}x\right)\quad\left(\Gamma=\frac{\nu}{\nu_0}=\frac{1}{\sqrt{1-B^2}},B=\frac{v}{\eta}\right). \tag{21}$$

Bring Eq. 21 into Eq. 20, we have

$$\psi(t)=\sin\left(2\pi\nu_o\Gamma\left(t-\frac{B^2}{v}x-\Gamma^{-1}\tau_0\right)\right)=\sin\left(2\pi\nu\left(t-\frac{v}{\eta^2}x-t_0\right)\right). \tag{22}$$

By comparing Eqs. 19 and 22, we get the relation between the particle speed $v$ and the phase speed $v_p$ of $\Sigma$: $v_p=\eta^2/v$. Now, with the definition of momentum in OR, we have

$$p = mv = m\eta^2 \frac{v}{\eta^2} = h_\eta v \frac{1}{v_\mathrm{p}} = \frac{h_\eta}{\lambda} = \hbar_\eta k, \tag{23}$$

where $\lambda$ and $k$=2π/$\lambda$ are respectively the wavelength of and the wave number, and $\hbar_\eta=h_\eta/2\pi$ is the general reduced Planck constant. The general de Broglie's relation (Eq. 23) has generalized de Broglie's relation $\lambda=h/p$, so that it holds under any observational agent $O(\eta)$ rather than only under Einstein agent $O(c)$. However, under different observational agents, the general Planck constant $h_\eta$ will be different.

<u>*The speeds of matter wave*</u>. From the mass-speed relation (Eq. 12), we have

$$E^2 = E_o^2 + p^2\eta^2. \tag{24}$$

By taking the derivative of two sides, we have $E\mathrm{d}E=\eta^2 p\mathrm{d}p$. From Eqs. 18 and 23, we have $E=\hbar\omega$ and $p=\hbar k$. According to the definitions of the group speed, we have

$$v_\mathrm{g} = \frac{\mathrm{d}\omega}{\mathrm{d}k} = \frac{\mathrm{d}\left(\hbar_\eta \omega\right)}{\mathrm{d}\left(\hbar_\eta k\right)} = \frac{\mathrm{d}E}{\mathrm{d}p} = \eta^2 \frac{p}{E} = v, \tag{25}$$

which suggests that the group speed $v_g$ of $\Sigma$ or its matter wave is equal to the particle speed $v$ of $\Sigma$. According to the definitions of the phase speed, we have

$$v_\mathrm{p} = \frac{\omega}{k} = \frac{\hbar\omega}{\hbar k} = \frac{E}{p} = \frac{\eta^2}{v} = \frac{\eta^2}{v_\mathrm{g}}, \;\text{ i.e., }\; v_\mathrm{p} v_\mathrm{g} = \eta^2, \tag{26}$$

which suggests that the phase speed $v_p$ is an observational effect and depends on the IW speed $\eta$.

It is interesting that, according to Eqs. 25 and 26, the group speed $v_g$ of IW and the phase speed $v_p$ of IW, as well as the speed $v$ of informon, are equal to the IW speed $\eta$, that is, $v_g=v_p=v=\eta$ for any specific IW. We had thought that, as far as light wave was concerned, its group speed $v_g$ and phase speed $v_p$ were equal to $c$, i.e., $v_g=v_p=c$. Actually, this is only valid for the case as light serves as IW or the photon serves as informon. It is conceivable that, with superluminal agent $O(\eta)$ ($\eta>c$), we will discover that: the group speed of light is $v_g=c<\eta$, whereas the phase speed is $v_p>\eta>c$. The group speed of matter wave is equal to its particle speed of $\Sigma$, and hence according to Corollary B, the group speed of IW is the observational limit no observed speed can exceed. But different IWs have different group speeds. So, the observational limit is only observational under a certain observational agent, which does not mean there is no faster matter motion in the universe. Likewise, we have no reason to suppose that the light speed $c$ is the ultimate speed of matter motion.

The theory of OR means a lot. (See the section of Methods and Supplementary Information.) We believe that the theory system of observational relativity will further be developed and perfected.

## VIII. CONCLUSION

We have theoretically derived the general Lorentz transformation and established the theory of observational relativity (OR). The theory of OR has unified Einstein's SR and de Broglie's theory of matter wave, and uniformly deduced the general Einstein formula $E=m\eta^2$, the general Planck equation $E=h_\eta\nu$, and the general de Broglie's relation $\lambda=h_\eta/p$.

As it happens, OR has found out the vital role in physical observation and experiment: *information wave* (IW) that carries and transmits the spacetime information (STI) of observed objects, whose speed restricts our observation and experiment. In the general Lorentz factor $\Gamma(v)=1/\sqrt{(1-v^2/\eta^2)}$, the IW speed $\eta$ takes the place of the light speed $c$. The invariance of IW speed becomes an important inference from OR. Now, Einstein's SR is only a special case of OR under Einstein agent $O(c)$. Einstein's hypothesis of the invariance of light speed (ILS) is valid only as light serves as IW. OR tells us that: the speed of light may not be the ultimate speed of matter motion and the photon cannot be massless; by means of superluminal observational agents, we can detect the photon mass and observe the variance of the light speed relative to different observers. OR suggests that: all relativistic effects including the ILS are observational effects rather than real or objective natural phenomena; spacetime curvature and quantum effects are even observational effects as well. According to OR, $\Gamma\to 1$ as $\eta\to\infty$, so if we were provided with Galilean agent $O_\infty$, then all relativistic effects would completely disappear in our observation and experiment. We believe that OR will profoundly change our views of space and time. The theory of OR endows physics with a significant mission to explore superluminal observational agents to break though the observational limit of light, or to invent superluminal agent $O(\eta)$ ($\eta>c$), so that we can observe a more abundant and more objective natural world.

To understand the theory of OR well, we record and interpret the basic idea, logic route, proof and deduction of OR in the section of Methods, and discuss some fundamental implications of OR in supplementary information.

## Appendix. METHODS

Here we record and interpret the basic idea, logic route, proof and deduction of the theory of observational relativity (OR).

### *A. Original Aims*

We originally aimed at: (1) reexamining relativistic effects under more basic facts and principles than the principle of invariant light speed (ILS); (2) unifying Einstein's special relativity (SR) and de Broglie's theory of matter wave; and (3) developing a massive photon model that satisfies Einstein's SR and computing the (rest) mass of the photon. Now we have made an unexpected discovery and established the theory of OR that reveals the serious flaw in Einstein's SR and the truth behind the ILS.

### *B. Unification of Partial Theories*

Hawking indicates in *A Brief History of Time*[28] that: our physics remains fragmented. He calls those fragmented theories, including quantum mechanics and Einstein's general relativity (GR), *partial theories*, and takes it as the ultimate objective of physics to unify all partial theories. So, it became one of the main objectives for us to unify Einstein's SR and de Broglie's theory of matter wave. Now we have indeed unified Einstein's SR and de Broglie's theory of matter wave, and uniformly deduced the general Einstein formula $E=m\eta^2$, the general Planck equation $E=h_\eta\nu$ and the general de Broglie's relation $\lambda=h_\eta/p$.

### *C. Why the Speed of Light is Invariant*

Compared with relativity, the invariance of light speed (ILS) is almost a paradox: everything is relative and variant, but the speed of light is absolute and invariant. Such invariance is some spooky and beyond our understanding. Under the ILS, the speed of light is the ultimate speed no speed can exceed, and the photon becomes strange entity without (rest) mass. According to our view of nature, matter is provided with two properties: one is mass; the other is energy. Mass and energy are interdependent: mass carries energy, and energy make mass move. We cannot understand the matter without mass or the matter without energy. Both invariant speed and massless entities are contrary to our view of nature and philosophical belief. So, we attempt to bring to light the truth behind the ILS, and explain why the speed of light is invariant, why the speed of light cannot be exceeded, and why the photon has no mass.

### *D. Logic Route of OR*

As known, Einstein's SR has two prerequisites: the first is the principle of ILS; the second is the principle of relativity. We have always harbored a suspicion of doubt that the ILS seems an extremely special principle: it has no relation with other fundamentals or principles in physics; it is not self-evident, and therefore, has no the basic character as an axiom; it does not look like a prerequisite but a corollary of a theory. Actually, Einstein's logic route is a logic shortcut. A shortcut comes at a price. Einstein had missed the naked truth of the ILS and relativity.

We attempt to build OR on the basis of the most basic facts.

The logic route of OR starts from two basic prerequisites: one is the principle of physical observability (PPO) or the principle of locality that is a corollary from the PPO; the other is the invariance of time-frequency (ITF) of matter-wave time defined on the basis of wave-particle duality. Based on the PPO and the ITF, OR derives the spacetime transformation (Eqs. 3 and 4).

Likewise, on the basis of locality and wave-particle duality, OR defines the cosmic speed $\Lambda$, and extracts the principle of frequency-speed (PFS) and the superposition principle of velocity (SPV). Thereby OR derives the invariance of the speed of information wave (IW) from the spacetime transformation (Eqs. 3 and 4), under which the ILS is valid only as light serves as IW or the photon serves as informon.

Based on the invariance of IW speed, OR determines the general Lorentz factor $\Gamma(v)=1/\sqrt{(1-v^2/\eta^2)}$, derives the differential formulas of the general Lorentz transformation (Eq. 10), and gets the general Lorentz transformation (Eq. 11) by setting the initializing condition and integrating Eq. 10, which has exactly the same form as Lorentz transformation. It is worth noting that: it is the result of rational logical derivation that, in the general Lorentz factor, the IW speed $\eta$ has taken the place of the light speed $c$.

At last, we have established the theory system of OR, in which Einstein's SR is a special case.

All the logic prerequisites of OR are based on the most basic physical properties of material: one is physical observability (or locality); the other is wave-particle duality, which are self-evident and have the character as axiom.

It is particularly worth noting that: the definition of the cosmic speed $\Lambda$, the PFS, and the SPV could be substituted by the principle of simplicity[34]. From Eqs. 3 and 4, merely by means of the principle of simplicity, we could as well derive the general Lorentz factor and the general Lorentz transformation, and establish the theory system of OR. This, from another aspect, demonstrates the validity of the logic deduction along the logic route of OR. Of course, the principle of simplicity is also a logic shortcut. It were the price that we would have missed the discovery of the relationship between the IW speed $\eta$ and the cosmic speed $\Lambda$.

### *E. The Principle of Simplicity and the Invariance of IW speed*

Actually, Einstein's SR is not only based on the principle of ILS and the principle of relativity, but takes advantage of the principle of simplicity as well. Theoretically, there are infinite possible forms for spacetime transformation between two reference frames. So why is Einstein's SR linear and so concise? The conciseness and elegance of SR benefits from the principle of simplicity[34], or Ockham's razor[35].

Einstein's logic route of SR[6] can be divided into three sections.

The first is based on the principle of simplicity: let the spacetime transformation from the inertial frame $O'$ to the inertial frame $O$ be a linear form

$$O' \to O:\ x = \gamma\left(x' + vt'\right). \tag{A1}$$

The second is based on the principle of relativity: let the spacetime transformation from $O$ to $O'$ be the relative form to Eq. A1

$$O \to O':\ x' = \gamma\left(x - vt\right). \tag{A2}$$

The third is based on the principle of ILS: with simultaneous Eqs. A1 and A2, determine the Lorentz factor $\gamma=1/\sqrt{(1-v^2/c^2)}$.

By means of the principle of simplicity, the theory of OR could omit the prerequisites of the PFS, the SPV, and the definition of the cosmic speed $\Lambda$. It is to say that the general Lorentz factor $\Gamma$ could be derived merely from the PPO and the ITF of matter-wave time.

Relativistic temporal relations (Eqs. 3 and 4) are derived merely from the PPO and the ITF. Combining Eqs. 3 and 4, we have

$$\begin{aligned} \mathrm{d}x &= \Gamma(v)\frac{\eta(u)}{\eta(u')}\left\{\mathrm{d}x' + \frac{\eta(u')\eta(v)}{v}\left(1-\Gamma^{-2}(v)\right)\mathrm{d}t'\right\}, \\ \mathrm{d}x' &= \Gamma(v)\frac{\eta(u')}{\eta(u)}\left\{\mathrm{d}x - \frac{\eta(u)\eta(v)}{v}\left(1-\Gamma^{-2}(v)\right)\mathrm{d}t'\right\}. \end{aligned} \tag{A3}$$

Contrasting to Eqs. A1 and A2, we know that the principle of simplicity invoked by Einstein requires Eq. A3 to obey

$$\frac{\eta(u')\eta(v)}{v^2}\left(1-\Gamma^{-2}(v)\right) = 1 \text{ and } \frac{\eta(u)\eta(v)}{v^2}\left(1-\Gamma^{-2}(v)\right) = 1. \tag{A4}$$

Clearly, this demands $\eta(u)=\eta(u')$, which means that, due to the arbitrariness of $u$ and $u'$, there exists a constant $\eta$ so that $\eta(u)=\eta(u')=\eta(v)=\eta$. More exactly, $\forall u\ \eta(u)=\eta_o\oplus u=\eta$, so $\eta=\eta(0)=\eta_o$, where $\eta_o$ is the intrinsic speed of IW. This suggests that the speed $\eta=\eta_o$ of IW is an invariant, in other words, any IW always propagates at the same speed relative to all observers. Hence Eq. M4 can be written as

$$\frac{\eta^2}{v^2}\left(1-\Gamma^{-2}(v)\right) = 1. \tag{A5}$$

Now we have the general Lorentz factor $\Gamma(v)=\sqrt{(1-v^2/\eta^2)}$, which is the same as the result of Eq. 9 without invoking the principle of simplicity. This demonstrates the validity of the theory of OR from another aspect.

The principle of simplicity provides a certain shortcut for logical deduction. However, every shortcut could make you miss the important landscape on the logic route. The theory of OR starts from the most basic facts and prerequisites, has equally derived the concise and linear form of the general Lorentz transformation, and more importantly, has revealed the naked truth behind the ILS. This perhaps has enlightening significance for science methodology.

### *F. Proof of Lemma A*

*Lemma A:* Any observed speed $u$ cannot exceed the cosmic speed $\Lambda$, i.e., $\forall u\ |u|\leq\Lambda$.

Proof. According to the PPO, for any observed speed $u$, the corresponding observed frequency $\nu(u)<+\infty$. Hence, from the PFS, it follows that

$$|u|\leq \lim_{\nu(v)\to\infty}|v|. \tag{A6}$$

where $\nu(v)$ is the observed frequency corresponding to the observed speed $v$. Now, under the definition of the cosmic speed (Definition A), we have $|u|\leq\Lambda$.

This completes the proof.

### *G. The Closing*

The theory of observational relativity (OR) is the product of rational thinking and theoretical deduction, and is provided with empirical and intuitive validity.

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**Supplementary Information** is attached below.

# TITLE: Information wave and the theory of observational relativity

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## SUPPLEMENTARY INFORMATION

## On Supplementary Information: page 1

The theory of observational relativity (OR) is the product of rational thinking and theoretical deduction, and has empirical and intuitive validity. Here we will discuss some implications of OR so that we can further understand the theory.



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## Supplementary Note 1: Information wave and information propagation

Human beings and animals are able to perceive the objective world by means of their sensory organs, and then are able to understand and recognize the objective world. What we perceive, or what interacts with our senses, is actually information, namely the information about observed objects. Information must propagate to our sensory organs in certain ways so that we can sense it or feel it. In theory, any form of matter motion can carry and transmit information, and all fundamental particles, including photons, neutrinos and gravitons, can serve as informons to carry and transmit information.

Human beings and animals have two basic ways to get information from the objective world (Fig. 1): one is by ears; the other is by eyes. The information heard by ears is carried and transmitted by sound with the speed of 343 m/s; the information seen by eyes is carried and transmitted by light with the speed of 299792458 m/s. Clearly, light runs much faster and farther than sound, and can carry more information than sound. Anyway, like light, sound can also be employed as information wave (IW). Actually, humans not only depend on their sensory organs to get information from the objective world, but take advantage of information technology they develop or invent. With the progress of information technology, we have invented new technologies of transmitting information and IWs, e.g., radio wave, laser, optical fiber transmission, and etc., though we cannot directly sense or feel them by our sensory organs.

In 490 BC Greek warrior Phidippides ran 42.195 km to bring the news of victory from Marathon to Athens; the speed of information transmission is no more than 20 km/h. In ancient China, there were many carrier stations over the country. Messengers passed documents by horse from one station to another; the speed is no more than 100 km/h. In 1837 Morse invented telegraph, in 1876 Bell invented telephone, so that information could be transmitted by wire at a distance; the speed reached 50–90% of light speed. In 1865 Maxwell established his electromagnetic theory, and later, radio technology emerged and radio wave can serve as IW and transmit information as fast as light.

Now, our observed speeds are limited by the speed of light because we have always employed light as IW, or the photon as informon, consciously or unconsciously. Are we able to further raise the speed of information transmission? Are we able to invent or take advantage of faster IWs to carry and transmit information?  The theory of OR suggests that it is possible.

## Supplementary Note 2: The truth behind the invariance of light speed

Why can't the speed of light be exceeded? And why is the photon massless? In Einstein's special relativity (SR), the principle of invariant light speed (ILS) plays a vital role, under which, the speed of light is the ultimate speed no speed can exceed, and the photon becomes odd entity without (rest) mass. Long-term since, the ILS is perplexing us. To this day, we do not even know why the speed of light is invariant.

## 2.1 Why the speed of light is invariant

The principle of ILS is the mainstay of Einstein's SR. However, we have always harbored a suspicion of doubt that the ILS seems an extremely special principle: it has no relation with other fundamentals or principles in physics; it is not self-evident and hence has no the basic character as an axiom; it does not look like a prerequisite but a corollary of a theory.

Actually the ILS is only a hypothesis in Einstein's SR, and stems from the Michelson-Morley experiment which shows that the superposition between the speed of light and the orbital speed of the earth remains the speed of light. There is nothing wrong with the Michelson-Morley experiment, whose result could even be predicted or interpreted by the invariance of the speed of information wave (IW). The invariance of IW speed is an inference deduced from the theory of OR rather than a hypothesis. The Michelson-Morley experiment, in turn, has demonstrated the invariance of the IW speed instead of the ILS. As it happened, in the Michelson-Morley experiment, the speed of light was appearing invariant. Actually, in the Michelson-Morley experiment, light was playing the role of IW and the photon was playing the role of informon.

The invariance of IW speed is one of the most important consequences of OR, in which the ILS is only a special case. It is to say that the ILS is valid only as light is employed as IW or the photon is employed as informon. Our observation and experiment mostly make use of Einstein agent $O(c)$ that employs light as IW, and hence, seemingly agree with Einstein's theory. Plausible ILS misleads people to unilateral understanding of relativistic effects.

Now, the theory of OR reveals the truth behind the ILS: the ILS is only an observational effect rather than a real natural phenomenon; the speed of light looked invariant in the Michelson-Morley experiment owing to light being IW in the case. The theory of OR suggests that superluminal agents would be able to observe the variance of light speed relative to different observers. Actually, no speed is invariant or the same relative to all observers, which could be found out under Galilean agent $O_\infty$. The speed of a matter particle or matter wave looks invariant, if and only if, it is employed as informon or IW, or its speed is the same as the speed of informon or IW.

## 2.2 Why the speed of light cannot be exceeded

The invariance of IW speed is an observational effect rather than a real natural phenomenon, which sets an observational limit no observed speed can exceed. In other words, under a specific observational agent $O(\eta)$, we are not able to observe or detect the matter motion faster than the IW speed $\eta$. As light is employed as IW, the ILS is valid, and the speed of light becomes the observational limit no observed speed can exceed. However, this does not mean that, in the universe, there is no matter motion faster than the speed of light; this does mean that we are not able to observe or detect the matter motion faster than light.

Consider two observational agents $O(\eta_1)$ and $O(\eta_2)$ ($\eta_2>\eta_1$). Under $O(\eta_1)$, no observed speed can exceed the IW speed $\eta_1$, in other words, $O(\eta_1)$ cannot observe the matter motion faster than $\eta_1$. However, $O(\eta_2)$ can observe the matter motion faster than $\eta_1$. Bats cannot detect supersonic prey by means of ultrasound, but humans can detect supersonic motion by means of light. Different observational agents have different observational limits on observed speeds. Accordingly, the invariance of IW speed does not mean that the speed of IW is the ultimate speed of the universe, and equally, the ILS also does not mean that the speed of light is the ultimate speed of the universe. So, it is possible to exceed the speed of light. We have reason to believe that there exist superluminal motions in the universe. The theory of OR endows physics with a significant mission to explore superluminal IWs or superluminal informons, or to invent superluminal agent $O(\eta)$ ($\eta>c$), so that we can break though the observational limit of light and observe a more abundant and more objective natural world.

2.3 Why the photon has no rest mass

The relationship between mass and speed, or mass-speed relation $m(v)=m_o/\surd(1-v^2/c^2)$, is one of the most important and fundamental relations in Einstein's SR, where $m_o$ is the rest mass of the observed object, and $m(v)$ is the relativistic mass under Einstein agent $O(c)$. According to the principle of physical observability (PPO), the relativistic mass $m(c)$ of an observed object must be finite. Hence, under Einstein's SR, the object has no rest mass when its speed reaches the light speed $c$ due to $m_o=m(c)\surd(1-c^2/c^2)=0$. So, the photon has no rest mass under Einstein's SR.

The theory of OR has the similar mass-speed relation $m_\eta(v)=m_o/\surd(1-v^2/\eta^2)$, where $m_\eta(v)$ is the relativistic mass under observational agent $O(\eta)$. According to the PPO, an informon has finite relativistic mass $m_\eta(\eta)$. Hence, informons have no rest mass under $O(\eta)$ due to $m_o=m_\eta(\eta)\surd(1-\eta^2/\eta^2)=0$. However, this does not mean that informons really have no rest mass. Consider two observational agents $O(\eta_1)$ and $O(\eta_2)$ ($\eta_2>\eta_1$). Clearly, under the mass-speed relation of OR, any particle with the speed $\eta_1$ must have no rest mass observed by $O(\eta_1)$: $m_o=m_{\eta 1}(\eta_1)\surd(1-\eta_1^2/\eta_1^2)=0$; whereas it must have certain rest mass observed by $O(\eta_2)$: $m_o=m_{\eta 2}(\eta_1)\surd(1-\eta_1^2/\eta_2^2)\neq 0$. Actually, all matter particles, including the photon, have their own rest mass. But we cannot detect the rest mass of informons by means of IW or informons: Bats cannot detect the rest mass of phonons by ultrasound, and naturally, humans cannot detect the rest mass of photons by light. So, those efforts (see the references 12-22 in the main text) to detect the rest mass of the photon under Einstein agent $O(c)$ must be in vain.

As a matter of fact, the rest mass of an object is its real mass or the intrinsic mass that is an invariant and provided with gravitational effect. The difference between the relativistic mass

$m_\eta(v)$ and the rest mass $m_o$, $\Delta m_\eta(v)=m_\eta(v)-m_o=(1/\sqrt{(1-v^2/\eta^2)}-1)m_o$, is not the real mass of the object and is not provided with gravitational effect. The $\Delta m_\eta(v)$ depends on the IW speed $\eta$: the higher the IW speed $\eta$, the smaller the $\Delta m_\eta(v)$, or $\Delta m_{\eta 1}(v)>\Delta m_{\eta 2}(v)$ if $\eta_1<\eta_2$. Clearly, $\Gamma\to 1$ as $\eta\to\infty$. So, under Galilean agent $O_\infty$, the relativistic mass would be exactly equal to the rest mass for any finite observed speed, i.e., $m_\eta(v)=m_\infty=m_o$.

Anyway, the photon has its own (rest) mass, but we cannot detect the photon mass by light.

**Supplementary Note 3: Reinterpretation of relativistic effects**

In Einstein's SR, there are some classical relativistic effects widely known, e.g., the ILS, massless photon, relativity of simultaneity, time dilation and length contraction, and etc. In Einstein's opinion, these relativistic effects are real and objective. There are corresponding relativistic effects in the theory of OR. However, OR suggests that all relativistic effects are observational effects rather than real or objective natural phenomena. The theory of OR will reinterpret those classical relativistic effects.

3.1 Lorentz factor and relativistic effects

Einstein's SR reveals relativistic effects and changs our view of spacetime. From theoretical perspective, the relativistic effects of SR stem from Lorentz factor $\gamma(v)=1/\sqrt{(1-v^2/c^2)}$. As $v\to 0$ or $\gamma\to 1$, relativistic effects tend to disappear; as $|v|\to c$ or $\gamma\to\infty$, relativistic effects tend to increase. Einstein thought that relativistic effects were natural and objective, and moreover, the light speed $c$ determined relativistic effects.

In the general Lorentz factor $\Gamma(v)=1/\sqrt{(1-v^2/\eta^2)}$ of OR, the IW speed $\eta$ takes the place of the light speed $c$. So, OR suggests that relativistic effects depend on the IW speed $\eta$ instead of the light speed $c$. From the general Lorentz factor $\Gamma(v)$, as $|v|\to 0$ or $\Gamma\to 1$, relativistic effects tend to disappear; as $|v|\to\eta$ or $\Gamma\to\infty$, relativistic effects tend to increase. Apparently, observational agents with different IW give rise to different degrees of relativistic effects. Particularly, under Galilean agent $O_\infty$, all relativistic effects would disappear because $\Gamma\to 1$ as $\eta\to\infty$. Accordingly, all relativistic effects are only observational effects. Of course, under the PPO, any IW has finite speed ($\eta<\infty$). In this sense, relativistic effects are as well objective and natural to some extent.

3.2 Relativity of simultaneity

Galileo and Newton held absolutist spacetime view, in their opinion, simultaneity is absolute: event A and event B are either simultaneous or non-simultaneous. Mach[1] and Einstein held relativist spacetime view, in their opinion, simultaneity is relative. According to Einstein's SR, the simultaneous events A and B ($t'_A-t'_B=0$) in the reference frame $O'$ can be non-simultaneous in the reference frame $O$: $t_A-t_B=\gamma(v)(x'_A-x'_B)v/c^2\neq 0$. So, different reference frames or different observers have different concepts of simultaneity, which means that simultaneity is relative.

The theory of OR also has analogous relativity of simultaneity: from the general Lorentz transformation (Eq. 11), even though $t'_A - t'_B = 0$, it is probably that $t_A - t_B = \Gamma(v)(x'_A - x'_B)v/\eta^2 \neq 0$. But, in the theory OR, the relativity of simultaneity depends on observational agent $O(\eta)$: the higher the IW speed $\eta$, the less marked the relativity of simultaneity. Under Galilean agent $O_\infty$, $t_A - t_B = 0$ ($\eta \to \infty$), the relativity of simultaneity would disappear, and simultaneity would get back to absolute simultaneity. This means that the relativity of simultaneity is only an observational effect due to the finiteness of IW speed. Of course, under the PPO, the IW speed $\eta$ must be finite, and hence such relativity of simultaneity always exists in an observational sense.

### 3.3 Time dilation and length contraction

Time dilation effect and length contraction effect are the most classical relativistic effects we know well. Like Einstein's SR, the spacetime in OR also has the effects of time dilation and length contraction.

The theory of OR is easier for us to explain time dilation and length contraction from the concept of matter-wave time. Without losing generality, we take the informon as the observed object whose matter wave, namely the IW, has the fundamental period $T_o$, the fundamental frequency $\nu_o$, and the fundamental wavelength $\lambda_o$. According to the classical wave theory, $\lambda_o \nu_o = \eta_o$, where $\eta_o$ is the intrinsic speed of IW (Fig. 3**c**). Now, we define the reference clock with $T_o$, and define the reference ruler with $\lambda_o$. Then time dilation and length contraction of OR's spacetime can be interpreted as below:

(1) Time dilation: under the invariance of time-frequency (ITF), the observed period is $T = \Gamma(v)T_o = T_o/\sqrt{(1 - v^2/\eta^2)}$ that means, the higher the observed speed $v$, the more dilative the observed period $T$; and

(2) Length contraction: under the invariance of IW speed, the observed frequency $\nu$ and the observed wavelength $\lambda$ satisfy that $\nu\lambda = \eta = \eta_o$, and therefore, $\lambda = \eta_o/\nu = (\nu_o/\nu)\lambda_o = \Gamma^{-1}(v)\lambda_o = \lambda_o\sqrt{(1 - v^2/\eta^2)}$ that means, the higher the observed speed $v$, the more contractive the observed wavelength $\lambda$.

In the theory of OR, different observational agents gives rise to different $\Gamma$, and therefore, gives rise to different degrees of time dilation and length contraction: the higher the IW speed $\eta$, the less dilative the time and the less contractive the length. Particularly, under Galilean agent $O_\infty$ ($\Gamma = 1$ as $\eta \to \infty$), the relativistic effects of time dilation and length contraction would disappear.

It shows that, like other relativistic effects, both time dilation and length contraction are observational effects rather than the objective attributes of nature.

**Supplementary Note 4: Curved spacetime**

As that in SR, the relativistic effects in Einstein's general relativity[2] (GR) are also observational effects. We can understand that by taking the place of the light speed $c$ in GR with the IW speed $\eta$. According to Einstein's GR, spacetime is curved due to the existence of matter (mass and energy), and the greater the density of matter, the bigger the curvature of spacetime. For simplicity, we examine the Schwarzschild metric[3]: $(g_{\mu\nu})=\text{diag}(-(1-2GM/c^2r), (1-2GM/c^2r)^{-1}, r^2, r^2\sin^2\theta)$. It is easily understood that this is the metric of the curved spacetime outside a static spherically symmetric celestial body, where $M$ and $r$ are respectively the mass and the radius of the celestial body, and $G$ is the gravitational constant. Clearly the metric $g_{\mu\nu}$ is related to the light speed $c$. It is particularly worth noting that the light speed $c$ comes from Einstein's hypothesis of the ILS as well.

According to the theory of OR, we accept the invariance of IW speed instead of the ILS, and employ the IW speed $\eta$ to take the place of the light speed $c$, then the Schwarzschild metric becomes $(g_{\mu\nu})=\text{diag}(-(1-2GM/\eta^2r), (1-2GM/\eta^2r)^{-1}, r^2, r^2\sin^2\theta)$. It is evident that $(g_{\mu\nu})=\text{diag}(-1, 1, r^2, r^2\sin^2\theta)$ as $\eta\to\infty$, which is no other than the metric of flat spacetime.

So, if we could observe the universe through Galilean agent $O_\infty$, then our spacetime were no longer curved. Actually, so-called spacetime curvature is originally an observational effect from Einstein's perspective, as what we see through a wide-angle lens. Of course, under objective locality from the PPO, our observation lenses are always a little bit convex, and therefore, the spacetime must always look a little bit curved.

**Supplementary Note 5: Quantum effects**

The theory of OR tells us that, to some extent, quantum effects are also observational effects. This will change our knowledge and understanding of quantum effects including Schrödinger equation[4] and Heisenberg's uncertainty principle[5].

The theory of OR has theoretically derived the general Planck equation: $E=h_\eta\nu$, where $h_\eta$ is the general Planck constant. The general Planck equation is more than the matter-wave equation de Broglie ever wanted, which is universal not only for all objects or particles including the photon, but for any observational agent $O(\eta)$ with the IW speed $\eta$ and the general Planck constant $h_\eta$ as well. Different observational agents have different general Planck constants. The theory of OR suggests that Planck constant $h=h_c=6.6260693\times10^{-34}$ J·s is only a special case of the general Planck constant $h_\eta$ and valid only under Einstein agent $O(c)$.

The theory of OR has developed an identical equation: $h_\eta\eta=h_cc$ for any IW speed $\eta$ (that we will explain in later paper), under which we have the general uncertainty principle

$$\Delta x \Delta p \geq \frac{\hbar_\eta}{2} = \frac{h_\eta}{4\pi} = \frac{hc}{4\pi\eta}. \qquad \text{S1}$$

Eq. S1 suggests that, under Galilean agent $O_\infty$ ($\eta$=∞), Heisenberg's uncertainty would disappear completely. Of course, we have never got IW with infinite speed, and hence there is always a little bit of uncertainty in our observation.

In classical mechanics, the total energy of an observed object or particle is $H=T+V=p^2/2m+V$. Taking the place of $H$ with the energy operator $\mathrm{i}\hbar\partial/\partial t$, $p$ with the momentum operator $-\mathrm{i}\hbar\nabla$, one can get Schrödinger equation: $\mathrm{i}\hbar\partial\Psi(\mathbf{r},t)/\partial t=(-\hbar^2\nabla^2/2m+V(\mathbf{r},t))\Psi(\mathbf{r},t)$, where $\Psi$ is the wave function. It is worth noting that the Schrödinger equation is only a special case under Einstein agent $O(c)$ that employs light to observe quantum systems. Now, under observational agent $O(\eta)$, taking the place of $\hbar$ in Schrödinger equation with the general deduced Planck constant $\hbar_\eta$, we have got the general Schrödinger equation $\mathrm{i}\hbar_\eta\partial\Psi(\mathbf{r},t)/\partial t=(-\hbar_\eta^2\nabla^2/2m+V(\mathbf{r},t))\Psi(\mathbf{r},t)$. With the identical equation $h_\eta\eta=h_c c$, the general Schrödinger equation can be written as

$$\mathrm{i}\frac{\hbar c}{\eta}\frac{\partial}{\partial t}\Psi(\mathbf{r},t) = \left(-\frac{1}{2m}\frac{\hbar^2 c^2}{\eta^2}\nabla^2 + V(\mathbf{r},t)\right)\Psi(\mathbf{r},t). \qquad \text{S2}$$

Clearly, under Einstein agent $O(c)$ with the IW speed $\eta=c$, Eq. S2 is no other than the Schrödinger equation. The general Schrödinger equation suggests that different observational agents would observed different quantum effects. It is to say that: quantum effects are observational effect to some extent; we could observe different quantum effects of the identical quantum system by means of different IWs.

**Supplementary Note 6: EPR Paradox and Locality**

The theory of OR suggest that there is probably superluminal motion in the universe and it is possible to exceed the speed of light. Actually, superluminal motions are showing up in our observation or experiment, e.g., the experiments on quantum entanglement.

Since Newtonian mechanics was established, the locality problem has been playing an extremely important role in physics. In 1935, Einstein and his colleagues Podolsky and Rosen published a paper[6] in *Physical Review* for questioning the completeness of quantum mechanics. In the paper, they conceived a thought experiment on quantum entanglement, known as *EPR paradox*, so as to expound their academic viewpoints: there exist no action at a distance in the universe; it has to take time for anything to cross space; under the ILS, information propagation cannot exceed the speed of light. This is Einstein's view of locality. Bohr responded Einstein's question about quantum mechanics in *Physical Review* in the same year, and in a nutshell, he did not agree to Einstein's concept on locality[7].

EPR paradox greatly arouse physicists' curiosity hoping for testing the quantum entangle effects by experiment. In 1964, Bell gave an inequality known as Bell's inequality that had laid the experimental foundation of EPR paradox[8]. With Bell's theory, the test of Einstein's locality principle is equivalent to the test of Bell's inequality. In 1972, Freedman and Clauser experimentally tested Bell's theorem by measuring the polarizations of a pair of photons, and first found that the inequality was violated[9]. Since then there have constantly been reports of EPR paradox experiments with the results violating Bell's inequality[10]. The recent EPR experiments refer to: in 2015, Hanson's team of Delft University of Technology reported the violation of Bell's inequality under conditions that prevented alternative explanations of the experimental data, so that their findings rigorously rejected local realism for the first time[11,12]; in 2015, Pan's team of The University of Science and Technology of China verified the teleportation for both spin-orbit product states and hybrid entangled states, and first achieved a teleportation fidelity ranging from 0.57 to 0.68, above the classical limit[13]; in 2017, an international team of Austria, US, China, Germany reported on a new experimental test of Bell's inequality that, for the first time, used distant astronomical sources as *cosmic setting generators*, and observed statistically significant violations of Bell's inequality[14]. Spooky action at a distance appearing in more and more experiments of quantum entanglement are strongly challenging Einstein's concept on locality.

In the sense of the PPO, locality is objective and natural, and beyond all question. However, this does not mean that there is no superluminal motion in the universe. Locality merely suggests that the speed of material motion cannot be infinite. Quantum entanglement cannot as well be instantaneous under the PPO. But the propagation speed of quantum information can be much faster than the speed of light as EPR experiments show. EPR experiments has provided the experimental evidence and the theory of OR has provided the theoretical support for the existence of superluminal motion in the universe.

### Supplementary Note 7: LIGO and Gravitational Wave

LIGO aims at detecting gravitational wave and graviton by means of laser interferometer. In the eight years between 2002 and 2010, LIGO did not get any information about gravitational wave and graviton. The improved LIGO, so-called Advanced LIGO, was put into operation in 2015. On February 11, 2016, LIGO pronounced that[15]: they had for the first time detected signals of gravitational wave on September 14, 2015. On June 15, 2016, LIGO again pronounced that[16]: they had for the second time detected signals of gravitational wave on December 26, 2015. According to LIGO's reports[15,16], the speed of gravitational wave observed by LIGO is the speed of light, and the graviton has no rest mass.

LIGO's experiment scheme rings a bell, and reminds us of the Michelson-Morley experiment. Michelson and Morley were at that time hunting for aether, and LIGO is at present hunting for gravitons. According to the theory of OR, LIGO's laser interferometer cannot be employed to detect superluminal motions, and of course, cannot yet be employed to detect the masses of superluminal particles. So the results or data pronounced by LIGO are rather questionable. The theory of OR suggests that the observational agent $O(\eta)$ cannot observe or detect the matter motions faster that the IW speed $\eta$. Particularly, bats cannot employ ultrasound to detect supersonic motion; humans cannot employ light to detect superluminal motion. Perhaps Advanced LIGO has indeed caught the information on gravitational wave. But how can LIGO know that the speed of gravitational wave is the speed of light? And how can LIGO know that the graviton has no (rest) mass. We believe that LIGO will take the theory of OR and such questions seriously.

According to OR, we need an effective observational agent with IW faster than gravitational wave for detecting the speed of gravitational wave and the graviton mass. If gravitational wave can be IW, then we are able to detect the speed of gravitational wave, as we are able to detect the speed of light by Einstein agent $O(c)$ with light being IW. Even so, we are not able to detect the graviton mass, as we are not able to detect the photon mass by Einstein agent $O(c)$. Whereas, if the speed $\kappa$ of gravitational wave is faster than the speed $c$ of light, we are able to detect the photon mass by gravitational agent $O(\kappa)$ employing gravitational wave as IW.

**Supplementary Note 8: Can gravitational wave be superluminal IW**

For human beings and most animals, visible light is the most natural and the most important information wave (IW). The sun provides a huge light source for us, and photons are full of our living space. The photon is light enough and fast enough, and have enough information capacity. Even so, light wave is not as well the only IW we depend on. We have mouths and ears so that we can use sound to carry and transmit information. We cannot sense electromagnetic waves by our sensory organs, but humans have invented radio technology so that we can use the radio to carry and transmit information.

On the one hand, the theory of OR has emancipated us from the concept of locality rooted from the ILS. On the other hand, more and more physical experiments demonstrate that there seems to be superluminal material motion in the universe. We have reason to believe that, in the future, human beings will invent and take advantage of superluminal observational agents. For this, all the fundamental particles are alternative superluminal informons, among which the graviton is perhaps the most ideal. All matter radiates gravitational wave, and gravitons are full of the universe. The graviton must be extremely light, and much lighter than the photon; the graviton must be extremely fast, and much faster than the photon. Accordingly, the graviton has the potential properties to be superluminal informon. Before gravitons becomes informon at last, what we concern most is how ever fast gravitational wave or the graviton is.

Before Einstein's GR, there had been no the concept of gravitational wave yet, but there had already been the concept of gravity speed. Here, for the time being, we regard gravitational wave and gravity as the same concept. In the theory of Newtonian gravitation, interactions between objects are instantaneous and irrespective of the distance between them. When the mass distribution of a physical system changes, its gravitational field described with the Poisson equation instantaneously adjusts. This means that the speed of gravity is infinite, which violates the PPO. In 1859, Verrier discovered that the elliptical orbit of Mercury precesses at a significantly different rate from that predicted by Newtonian theory[17], which then had raised much concern about the speed of gravity.

Laplace was the first who tried to combine a finite speed to gravity. Around 1805, Laplace assumed gravity as a radiation field: changes in the motion of the attracting body were transmitted by some sort of waves. Of course, following the PPO, the transmission speed was finite. Laplace calculated the speed of gravity, and his result[18] was at least $7\times10^6 c$, much faster than the speed of light.

After Maxwell had established electromagnetic theory, many physicists, including Gauss, Riemann, Lorentz, and Maxwell, tried to combine the speed of gravity to the speed of light. In 1915, Einstein's GR emerged which predicted that the speed of gravitational wave was the speed of light. Actually, it was more a hypothesis from the ILS than a prediction. Before LIGO, there were ever some mediate measurements of the speed of gravitational wave, e.g., from the observations of the orbital decay rate of binary pulsars, the results showed that the speed of gravity is roughly equal to the speed of light[19,20]. Asada's view on this deserves our attention[21]. He theorized that those mediate experiments were essentially a roundabout confirmation of the speed of light instead of the speed of gravity. In fact, those mediate measurements are trying to confirm the theory of Einstein agent $O(c)$ based on the data observed with Einstein agent $O(c)$. LIGO is the first direct observation of gravitational wave, but also employs Einstein agent $O(c)$ with laser interferometer, and cannot get rid of the destiny of bats.

On the speed of gravity, Flandern's work is particularly noteworthy. Thomas C Van Flandern (1940–2009) was an American astronomer, and had a career as a professional scientist, but was noted as an outspoken proponent of non-mainstream views related to astronomy and physics. He died of colon cancer in 2009. In 1998, Flandern derived a theoretical model from the laws of celestial mechanics, and applied it to the analysis of the observation data from binary pulsars PSR1534+12 to calculate the speed of gravity. Flandern at last concluded that the speed of gravity was $2\times10^{10}$ times of the speed of light. Flandern's article about this work was published in *Physics Letters A*[22], which is deemed the best article against Einstein's hypothesis of the ILS[23].

We have high expectation for the observational agent $O(\kappa)$ that would employ gravitational wave as IW with the speed $\kappa$ much faster than $c$. Sound wave is heard by ears; light wave is seen by eyes; radio wave is detected by radio receivers. And so, how can we *hear* or *see* or detected gravitational wave?

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