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A novel space-time transformation revealing the existence of mirror universe

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Abstract The special relativity (SR) is proposed based on the Lorentz transformation (LT) which points out the relationship between space and time. However, the LT intuitively assumes that the different dimensions in space are independent, i.e., the motion of a body in x-direction doesn't affect its position change in y-direction. By considering the correlation between spatial dimensions, a novel and elegant space-time transformation is deduced based on the principle of constant speed of light. The new transformation not only indicates traditional relativistic effects, but also reveals a new one, called as transverse dilatation. More importantly, the transformation suggests that the full universe could be a four-dimensional complex space-time with extra mirror universe. Subsequently, several fundamental and challenging physics problems are reasonably explained, such as the nature of electromagnetic waves, the spooky quantum entanglement, the ghostly dark matter(DM) and the center of black hole.

1 Introduction

The space-time transformation equations play an important role in understanding the fundamental laws of nature. The Galilean transformation in classical mechanics is formulated under the concept of Newton's absolute space-time, which is consistent with human's intuitive cognition of the laws of moving object. With the development of physics, the limitations of classical mechanics have been revealed. Physicists found that the Galilean transformation equation no longer holds in the microscopic level[1] or in cases where the velocities of moving objects approach the speed of light.[2]

To solve the contradiction between the Galileo transformation and the null result found by the Michelson-Morley experiment, Einstein abandoned the concept of absolute space-time and formulated the SR.[3] The speed of light in vacuum is thought to be a universal constant, independent of the observer. The space and time influence each other and satisfy the Lorentz transformation.[4] The SR extended classical mechanics to more general situations, and the Galilean transformation is an approximation of the LT only at speeds much less than the speed of light. So, it is believed that there is an inherent connection between the space-time transformation and the laws of physics. Accurately constructing the space-time transformation equation will help us to explain the questions that cannot be answered by present physical theories, reconcile the paradoxes created by the existing theoretical insights, and develop a more accurate, elegant and unified theory.

Although relativistic effects[5] predicted by the SR have been confirmed, there are still some intractable conflicts between the SR and quantum mechanics. In particular, quantum entanglement[6], the most puzzling physical phenomenon, has become the focus of dispute between Einstein and Bohr. Einstein argued that quantum entanglement seems to violate the principle of locality and the speed limit of information transmission[7], and called it "spooky action at a distance." Quantum mechanics describes the properties of particle systems as a whole, it can better explain the quantum entanglement phenomena.[8] But until now, many physicists still side with Einstein and suspect that the favored interpretation of quantum entanglement should be revised.[9]

In addition, a fundamental inconsistency in present physical theories is how small-scale quantum processes can add up to the almost classical behavior of macroscopic bodies.[10] Indeed, a recent work[11] demonstrated that quantum jump is actually a continuous, coherent, predictable and reversible process like a fast-playing movie, rather than a discrete, instantaneous and non-deterministic process that is embraced by pioneer physicists in quantum mechanics. If this finding

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proves correct, then it will indicate that the limitation or incompleteness of Copenhagen interpretation of quantum mechanics began to emerge. As Einstein believed that nature's true equations would not have any stochastic elements.

Besides the reconciliation difficulties with the existing successful theories, some new discovered problems, such as the nature of DM[12, 13] and the evolution of black hole[14], are difficult to be answered by applying present theories. It seems to imply that the physical theories developed on the basis of four-dimensional space-time have fallen into somehow dilemma.

To this end, the concept of extra dimensions[15] has been introduced into the theoretical framework of physics and this field has grown by leaps and bounds over the past few years. One of the chief motivations for considering additional dimensions came from string theory[16], which attempts to merge quantum mechanics with general theory of relativity. Kaluza first proposed an extra spatial dimension and curled it up into little compact space.[17] Unlike extra compact dimensions, a more revolutionary idea that the extra dimension can have infinite (but hidden) spatial extent is demonstrated in.[18]

The existence of extra dimensions has the potential to help resolve some intractable questions in quantum mechanics and cosmology. Recently, the authors in[19] suggested that the discrepancy between the neutron lifetimes measured in beam and bottle methods[20], can be explained if the neutrons were to decay into a DM particle. However, the DM is exactly what was thought to cause the extra gravitational pull for the rotations of galaxy clusters.[21] The DM decay mode of neutron hints that there may exist a mirror universe embedded in higher-dimensions. Some researchers are working on the hunt for the mirror universe which is identical to our own universe.[22] The DM particles could hide inside the mirror universe, and some particles (such as neutrons) capable of oscillating back and forth between the two universes.[23] Moreover, extra dimension can also be employed to give an explanation for quantum entanglement, and the perspective is that the entangled particles may remain connected through the invisible extra dimensions.

It can be inferred that by increasing the space-time dimension we can construct a full higher-dimensional universe, which would not only transform our understanding of reality, but could also answer questions about our own universe that have puzzled physicists for decades. However, the questions of how many extra dimensions the full universe has and what structure the high-dimensional space-time is, are still not definitively answered.[24]

Motivated by the idea that the properties of the higher-dimensional space-time should be reflected in its space-time transformation equation, this work attempted to develop a new space-time transformation to replace the existing LT that can only describe the purely four-dimensional universe. Therefore, this article takes into account the correlation of spatial dimensions to deduce a new space-time transformation equation. The new space-time transformation can not only accommodate the LT, but also reveal a new relativistic effect. More importantly, the transformation equation directly points out the mathematical form of the underlying higher-dimensional universe, which has two 3-brane embedded in a five-dimensional bulk space-time.

This article is organized as follows. Section 2 introduces the formulation for the new space-time transformation equation. Based on the proposed higher-dimensional space-time theory, Section 3 details some novel and revolutionary insights for electromagnetic (EM) wave, quantum entanglement, DM and black hole. Conclusions are made in Section 4.

2 Space-time transformation equation

2.1 Lorentz transformation

The space-time transformation relates position and time in two frames of reference (FORs) that are moving uniformly with respect to each other. Let S and S' represent the two FORs (as shown in Figure 1). Relative to the frame S, frame S' is moving with velocity v_x in the x-direction, and their origins coincide at time $t' = t = 0$.

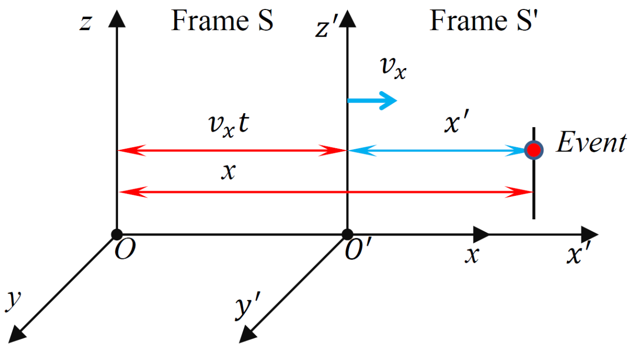

Fig. 1 Frame S' moves with velocity v_x relative to frame S

Based on the principle of constant speed of light (CSOL), Einstein proposed the SR which revealed that the universe is a 4D space-time entirety satisfying Lorentz transformation rather than Galileo transformation. Suppose that (x,y,z,t) denotes the coordinate of an event in frame S, then the coordinate of the same event in frame S' can be calculated as:

$$x' = \gamma_x (x - v_x t), \quad y' = y, \quad z' = z, \quad t' = \gamma_x \left(t - \frac{v_x x}{c^2}\right) \tag{1}$$

Where $\gamma_x = 1/\sqrt{1-\beta_x^2}$, $\beta_x = v_x/c$, c is the speed of light in vacuum. According to the above LT, the relativistic length contraction (LC) and time dilatation (TD) effects were pointed out by Einstein. To describe the LT in matrix language, we use $w = ict$ to rewrite the coordinate (x,y,z,t) and let $\mathbf{X}$ and $\mathbf{X}'$ represent $[x,y,z,w]^T$ and $[x',y',z',w']^T$, respectively. Then, the LT's matrix form can be formulated as:

$$\mathbf{X}' = \mathbf{A}_{L\_x}\mathbf{X}, \quad \mathbf{A}_{L\_x} = \gamma_x \begin{bmatrix} 1 & 0 & 0 & \beta_x i \\ 0 & 1/\gamma_x & 0 & 0 \\ 0 & 0 & 1/\gamma_x & 0 \\ -\beta_x i & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

Here, $\mathbf{A}_{L\_x}$ is the transformation matrix of LT. When the relative speeds in other directions are not zero, i.e., $v_y \neq 0$ or $v_z \neq 0$, a more generalized LT is expressed as:

$$\mathbf{X}' = \mathbf{A}_L\mathbf{X},$$
$$\mathbf{A}_L = \begin{bmatrix} 1+(\gamma-1)\frac{\beta_x^2}{\beta^2} & (\gamma-1)\frac{\beta_x\beta_y}{\beta^2} & (\gamma-1)\frac{\beta_x\beta_z}{\beta^2} & \gamma\beta_x i \\ (\gamma-1)\frac{\beta_x\beta_y}{\beta^2} & 1+(\gamma-1)\frac{\beta_y^2}{\beta^2} & (\gamma-1)\frac{\beta_y\beta_z}{\beta^2} & \gamma\beta_y i \\ (\gamma-1)\frac{\beta_x\beta_z}{\beta^2} & (\gamma-1)\frac{\beta_y\beta_z}{\beta^2} & 1+(\gamma-1)\frac{\beta_z^2}{\beta^2} & \gamma\beta_z i \\ -\gamma\beta_x i & -\gamma\beta_y i & -\gamma\beta_z i & \gamma \end{bmatrix} \tag{3}$$

Where, $\beta_y = v_y/c$, $\beta_z = v_z/c$, $\beta = \sqrt{v_x^2+v_y^2+v_z^2}/c$, and $\gamma = 1/\sqrt{1-\beta^2}$ is the Lorentz factor. It can be seen from the above equation that the matrix $\mathbf{A}_L$ of generalized LT has a regular form but the formulas of its elements are somewhat complicated and not elegant enough.

2.2 Theorem of orthogonal space-time transformation matrix

The speed of light in vacuum is the same for all observers, regardless of their motion relative to the light source. At the time $t' = t = 0$, when the origin of the coordinates is common to the two FORs, let a single photon be emitted therefrom and travel along a certain direction at the velocity c. If (x,y,z,t) is the coordinate of this photon in frame S, then it has

$$x^2+y^2+z^2=c^2t^2 \tag{4}$$

For the observers in frame S', the phenomena they see is consistent with what the observers in frame S have seen. Let (x',y',z',t') represents the photon's coordinate observed in frame S', then we obtain

$$x'^2+y'^2+z'^2=c^2t'^2 \tag{5}$$

Substitute w and w' into the above two equations, we get

$$x^2+y^2+z^2+w^2=0 \tag{6}$$
$$x'^2+y'^2+z'^2+w'^2=0 \tag{7}$$

Note that if we replace the photon with a particle which's moving speed is less than c, then the above two equations will no longer hold. But as long as Eq. (6) is true, it indicates that the coordinates (x,y,z,t) are used for describing the light's trajectory, then the Eq. (7) must be true. Similarly, the establishment of Eq. (7) will inevitably lead to the establishment of Eq. (6). Hence, the proposition in Eq. (6) is a necessary and sufficient condition for the Eq. (7).

$$x^2+y^2+z^2+w^2=0 \Leftrightarrow x'^2+y'^2+z'^2+w'^2=0 \tag{8}$$

The inference in Eq. (8) implies that the condition $x^2+y^2+z^2+w^2=0$ holds if and only if $x'^2+y'^2+z'^2+w'^2=0$ is satisfied. For the convenience of description, the above inference is rewritten in the vector-matrix form, it is given by

$$\mathbf{X}^\mathrm{T}\mathbf{X}=0 \Leftrightarrow \mathbf{X}'^\mathrm{T}\mathbf{X}'=0 \tag{9}$$

Suppose that $\mathbf{A}$ represents a certain space-time transformation matrix, that is, $\mathbf{X}' = \mathbf{A}\mathbf{X}$. Since $\mathbf{X}'^T\mathbf{X}' = \mathbf{X}^T\mathbf{A}^T\mathbf{A}\mathbf{X}$, therefore the following inference is holds.

$$\mathbf{X}^T\mathbf{X}=0 \Leftrightarrow \mathbf{X}^T\mathbf{A}^T\mathbf{A}\mathbf{X}=0 \tag{10}$$

It is easy to know that if $\mathbf{A}^T\mathbf{A} = k\mathbf{E}$ (k is scalar and $\mathbf{E}$ is the identity matrix), then the inference in Eq. (10) derived based on the principle of CSOL is established. To reveal the relationship between the principle of CSOL and the transformation matrix, we introduce the following lemma.

Lemma 1 *Suppose that the speed of light in vacuum is constant and is the same for all frames. There is a matrix* $\mathbf{A}$ *transforming the coordinates of an event in frame S to that in frame S', i.e.,* $\mathbf{X}' = \mathbf{A}\mathbf{X}$*. Then the conditions* $\mathbf{X}^T\mathbf{X} = 0$ *and* $\mathbf{X}'^T\mathbf{X}' = \mathbf{X}^T\mathbf{A}^T\mathbf{A}\mathbf{X} = 0$ *holds simultaneously, if and only if the transformation matrix* $\mathbf{A}$ *such that* $\mathbf{A}^T\mathbf{A} = \mathbf{E}$*, i.e.,* $\mathbf{A}$ *is an orthogonal matrix.*

Proof To facilitate the reasoning, let matrix $\mathbf{B}$ denotes the product of matrix $\mathbf{A}^T$ and $\mathbf{A}$, i.e.,$\mathbf{B} = \mathbf{A}^\mathbf{T}\mathbf{A}$. Since $\mathbf{B}^T = (\mathbf{A}^T\mathbf{A})^T = \mathbf{A}^T\mathbf{A} = \mathbf{B}$, thus $\mathbf{B}$ is symmetric matrix.

According to the nature of the symmetric matrix, there exists orthogonal matrix $\mathbf{P}$ and diagonal matrix Λ such that

$$\mathbf{B} = \mathbf{P}^\mathrm{T}\Lambda\mathbf{P} \tag{11}$$

where $\Lambda = diag(\lambda_1,\lambda_2,\lambda_3,\lambda_4)$, and $\lambda_1,\lambda_2,\lambda_3,\lambda_4$ are the eigenvalues of the matrix $\mathbf{B}$. If we let $\mathbf{X}_p = \mathbf{P}\mathbf{X}$ represents a new coordinate, then the conditions $\mathbf{X}^T\mathbf{X} = 0$ and $\mathbf{X}^T\mathbf{A}^T\mathbf{A}\mathbf{X} = 0$ can be rewritten in the form of

$$\mathbf{X}_p^T\mathbf{X}_p = 0 \tag{12}$$
$$\mathbf{X}_p^T\Lambda\mathbf{X}_p = 0 \tag{13}$$

Without loss of generality, let vector $\mathbf{X}_p = [x_p,y_p,z_p,w_p]^T$. According to the above two conditions, we have

$$x_p^2+y_p^2+z_p^2+w_p^2 = 0 \tag{14}$$
$$\lambda_1x_p^2+\lambda_2y_p^2+\lambda_3z_p^2+\lambda_4w_p^2 = 0 \tag{15}$$

Combine the Eq. (14) and Eq. (15) to eliminate w_p, then the following condition holds:

$$(\lambda_1-\lambda_4)x_p^2+(\lambda_2-\lambda_4)y_p^2+(\lambda_3-\lambda_4)z_p^2=0 \tag{16}$$

Since the three spatial coordinates (x_p,y_p,z_p) in $\mathbf{X}_p$ can be arbitrary values, the conditions in Eq. (16) is achievable if and only if $\lambda_1=\lambda_2=\lambda_3=\lambda_4$ is satisfied. This indicates that $\mathbf{A}^T\mathbf{A}=\mathbf{B}=\lambda_1\mathbf{E}$.

In addition, when the relative speed of the two frames approaches zero, according to the Galilean transformation, the transformation matrix $\mathbf{A}$ should approach the identity matrix, i.e., $\mathbf{A}\to\mathbf{E}$ and then $\mathbf{A}^T\mathbf{A}\to\mathbf{E}$. It infers that $\lambda_1=1$, so that transformation matrix $\mathbf{A}$ such that $\mathbf{A}^T\mathbf{A}=\mathbf{E}$. This completes the proof. □

The **Lemma 1** indicates that if a space-time transformation equation satisfies the principle of CSOL, then the corresponding transformation matrix must be an orthogonal matrix.

2.3 Deducing a new space-time transformation beyond LT

Since LT is derived based on the principle of CSOL, it is easy to check that the $\mathbf{A_L}$ is always an orthogonal matrix. But the Galilean transformation matrix does not have such property. In [2], Einstein defaulted that, as the relative motion only exists in x-direction, the y and z coordinates of moving body observed in all frames are unchanging.

Now let us consider a novel non-independence of spatial dimensions, i.e., the y and z dimensions can interact with each other even though $v_y=0$ and $v_z=0$. By simply assembling the transformation matrices respectively corresponding to x, y and z direction relative motions, we first assume that the generalized transformation matrix has the following form:

$$\mathbf{A}=\gamma\begin{bmatrix} 1 & a_{yx} & a_{zx} & \beta_x i\\ a_{xy} & 1 & a_{zy} & \beta_y i\\ a_{xz} & a_{yz} & 1 & \beta_z i\\ -\beta_x i & -\beta_y i & -\beta_z i & 1\end{bmatrix} \tag{17}$$

Where a_{yx} and a_{xy} respectively represent the influence of the dimension $y(x)$ on the dimension $x(y)$. Similarly, a_{yz}, a_{zy}, a_{zx} and a_{xz} denote other correlation parameters. Since the space is isotropic and each spatial dimension has the same property, it can be reasonably assumed that the magnitudes of the correlation parameters between two spatial dimensions are equal, i.e., $|a_{xy}|=|a_{yx}|$, $|a_{yz}|=|a_{zy}|$ and $|a_{zx}|=|a_{xz}|$.

Hence, there are two cases: The correlation parameters between two spatial dimensions are exactly equal or are opposite numbers to each other. Based on the **Lemma 1** that transformation matrix $\mathbf{A}$ should be an orthogonal matrix, we can easily prove that the first case does not exist. For the second case, two sets of solutions can be calculated as: $a_{xy}=-a_{yx}=\pm\beta_z i$, $a_{yz}=-a_{zy}=\pm\beta_x i$, $a_{zx}=-a_{xz}=\pm\beta_y i$.

$$\begin{aligned}\mathbf{A}_\theta&=\gamma\begin{bmatrix} 1 & -\beta_z i & \beta_y i & \beta_x i\\ \beta_z i & 1 & -\beta_x i & \beta_y i\\ -\beta_y i & \beta_x i & 1 & \beta_z i\\ -\beta_x i & -\beta_y i & -\beta_z i & 1\end{bmatrix},\\ \mathbf{A}_\tau&=\gamma\begin{bmatrix} 1 & \beta_z i & -\beta_y i & \beta_x i\\ -\beta_z i & 1 & \beta_x i & \beta_y i\\ \beta_y i & -\beta_x i & 1 & \beta_z i\\ -\beta_x i & -\beta_y i & -\beta_z i & 1\end{bmatrix}\end{aligned} \tag{18}$$

The obtained two orthogonal transformation matrices are represented by $\mathbf{A}_\theta$ and $\mathbf{A}_\tau$. Further analysis reveals that $\mathbf{A}_\theta$ and $\mathbf{A}_\tau$ are the transformation matrices of two mutually mirrored FORs. It indicates that if $\mathbf{X}'=\mathbf{A}_\theta\mathbf{X}$, then we have $\mathrm{mirror}(\mathbf{X}')=\mathbf{A}_\tau\mathrm{mirror}(\mathbf{X})$, the function $\mathrm{mirror}(\cdot)$ calculates the coordinate of the mirror image of input coordinate relative to a plane. Hence, $\mathbf{A}_\tau$ can be called as the chiral transformation of $\mathbf{A}_\theta$. For x-dimensional relative motion, $\mathbf{A}_\theta$ can be simplified as follows:

$$\mathbf{A}_{\theta\_x}=\gamma_x\begin{bmatrix} 1 & 0 & 0 & \beta_x i\\ 0 & 1 & -\beta_x i & 0\\ 0 & \beta_x i & 1 & 0\\ -\beta_x i & 0 & 0 & 1\end{bmatrix} \tag{19}$$

Unlike the transformation matrix $\mathbf{A}_{L\_x}$ of LT (Eq. (2)), the parameters a_{yz} and a_{zy} in the new transformation matrix $\mathbf{A}_{\theta\_x}$ are no longer zero and both are imaginary numbers related to velocity v_x. Note that the non-independence of space dimentsions is reflected in the effect of the z-dimensional real coordinate on the y-dimensional imaginary coordinate, while the z-dimensional real coordinate does not affect the y-dimensional real coordinate, which is the same as the LT.

3 Re-understanding the physical reality

3.1 The full higher-dimensional universe

A remarkable property of the new space-time transformation equation is that the transformed space-time coordinates will have complex numbers, even if the input space-time coordinates are all real numbers, that is:

$$\text{if } \mathbf{X}\in\mathbb{R},\ \mathbf{X}'=\mathbf{A}_\theta\mathbf{X},\ \text{then } \mathbf{X}'\subseteq\mathbb{C} \tag{20}$$

If this new transformation equation will be confirmed in future experiments, it would point out that the four-dimensional space-time we can understand is incomplete.

Based on the presented new space-time transformation, we can extend the traditional 4D space-time into 4D complex space-time, i.e., the coordinate of an event in the FOR is a 4D complex vector $(x_a+x_b i, y_a+y_b i, z_a+z_b i, t_a+t_b i)$rather than a 4D real vector (x_a, y_a, z_a, t_a). The 4D complex space-time implies that there are extra dimensions constituting an invisible and imaginary space-time, which has the same structure as the visible and real space-time. It means that, to fully describe the position of a particle, both the real and imaginary space-time coordinates should be determined. A string theoretical formulation is that: The 4D complex universe consists of two flat 3-brane embedded in a five-dimensional bulk space-time, and the fifth dimension is finite and only has two coordinate values (1 and i).

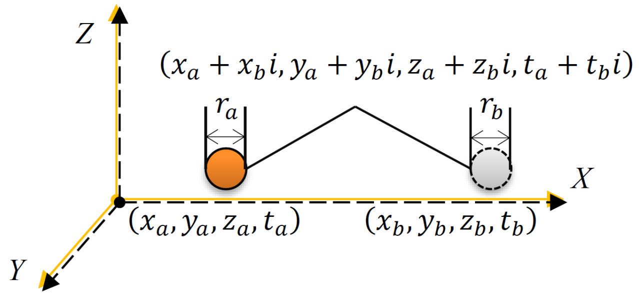

Fig. 2 The existence form of a particle in 4D complex space-time

The 4D complex space-time suggests that there is a mirrored imaginary universe alongside our real universe, two universes are superimposed together, and any matter exists in both universes. Figure 2 shows the possible existence form of a particle in 4D complex space-time. The yellow sphere represents the body observed in our real universe, and the gray one represents the particle's imaginary body.

Since the sizes $(r_a + r_b i)$ of the particle in the two universes can be different, the particle's sizes in real and imaginary spaces may be nearly equal or have a great difference. And if the condition $x_a \neq x_b \cup y_a \neq y_b \cup z_a \neq z_b$ is satisfied, the particle will exist in different places at the same time, and the same particle can exist at different times as well, i.e., $t_a \neq t_b$. It can be seen that the 4D complex space-time has the potential to explain many weird phenomena in quantum mechanics.

3.2 Relativistic transverse dilatation effect

It will be easily verified that the LC and TD effects also can be predicted by the proposed new space-time transformation. Surprisingly, it is found that the new transformation brings a new relativistic effect, referred to as transverse dilatation. To facilitate understanding, we visually demonstrate the new effect via numerical simulation. First, we construct a cylinder with a length of $L = 4$ m and a radius of $R = 1$ m in frame S, and the cylinder's axis coincides with the x-axis. If the frame S' moves relative to the frame S at speeds $v_x \in [0.1, 2.9] \times 10^8$m/s, then the cylinder's coordinates observed in frame S' can be calculated via the transformation matrix. As shown in Figure 3, the cylinder's radius measured in frame S' increases gradually with the relative velocity v_x, which indicates that the cylinder expands in the plane perpendicular to its moving direction. The transverse dilatation ratio is also equal to the Lorentz factor, whereas the conventional LT does not predict this effect. The relativistic effects are described as follows:

$$\frac{R'}{R} = \frac{L}{L'} = \frac{\Delta t'}{\Delta t} = \gamma \tag{21}$$

Here, R' and L' denote the radius and length of cylinder measured in frame S', Δt and $\Delta t'$ are the simulation durations. Therefore, the proposed new transformation is not only more elegant than the LT in terms of mathematical form, but also can reveal a new relativistic effect, i.e., the moving rod becomes thicker. To verify whether the proposed 4D complex space-time is correct, experiments can be designed to check the predicted new relativistic effect.

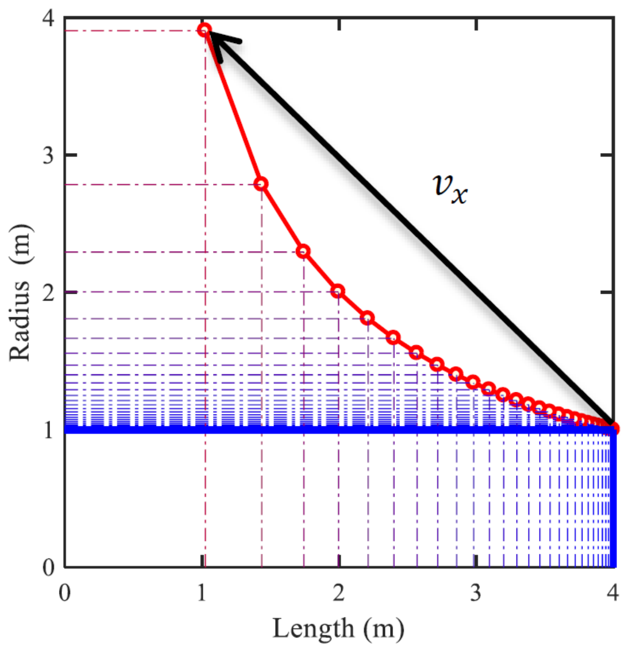

Fig. 3 Simulation results of relativistic effects (The shape changes of the cylinder observed in frame S' are indicated by the dotted lines.)

3.3 The nature of electromagnetic wave

It is well known that an EM wave is composed of oscillating electric and magnetic fields traveling through vacuum with the speed of light. Light had been considered as a form of EM waves, and it has a confusing property, i.e., wave-particle duality.

Surprisingly, by applying the new space-time transformation, we can directly obtain the motion form of EM waves.

Suppose that a particle vibrates up and down along the z-axis direction in frame S, and the frame S' move at a speed $v_x = -0.97c$ with respect to frame S. Then, the particle's motion trajectories observed in frame S' can be obtained as shown in Figure 4. The coordinate transformation is given by

$$\mathbf{X} = \begin{cases} x = 0 \\ y = 0 \\ z = r\cos\left(2\pi f t_R\right) \\ t = t_R\left(1+i\right) \end{cases}, \mathbf{X}' = \mathbf{A}_\theta \mathbf{X} = \begin{cases} x' = -\gamma v_x t \\ y' = -\gamma \frac{v_x}{c} z i \\ z' = \gamma z \\ t' = \gamma t \end{cases} \tag{22}$$

Here f is the particle's oscillation frequency r is the vibration amplitude and t_R is the real number of time. Note

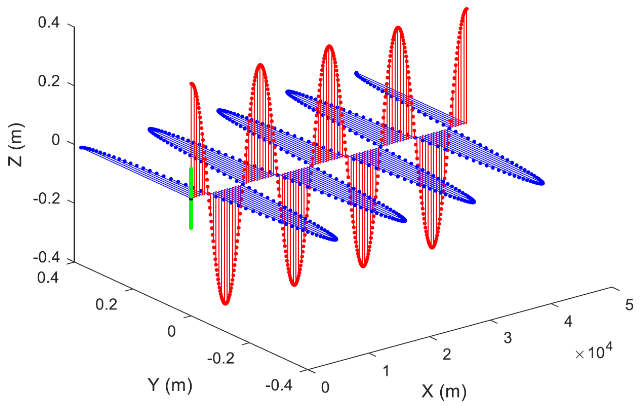

Fig. 4 Trajectories of an oscillating particle that are in line with the linear polarization of an electromagnetic wave (The green line represents the particle's trajectory in frame S. The particle's real trajectory is indicated in red, the imaginary trajectory in blue.)

that the particle's trajectories observed in frame S' is consistent with the motion pattern of the linearly polarized EM waves. The particle's coordinate vectors in real and imaginary spaces are perpendicular and in phase. It indicates that the electric field is related with the location of the particle in real space, likewise the magnetic field and the location of the particle in imaginary space are associated.

Similarly, if a particle moves circumferentially around the x-axis in frame S with a fixed radius, the observed particle's motion pattern will be consistent with the form of circularly polarized EM waves, as shown in Figure 5. It can be seen that in this case the phases of the real and imaginary coordinate vectors are no longer the same but different by $\pi/2$. This is just exactly in line with the characteristic of circularly polarized light. The transformed trajectory of a particle in circular motion is expressed as follows:

$$\mathbf{X} = \begin{cases} x = 0 \\ y = r\sin\left(2\pi f t_R\right) \\ z = r\cos\left(2\pi f t_R\right) \\ t = t_R\left(1+i\right) \end{cases}, \mathbf{X}' = \mathbf{A}_\theta \mathbf{X} = \begin{cases} x' = -\gamma v_x t \\ y' = \gamma\left(y - \frac{v_x}{c} z i\right) \\ z' = \gamma\left(z + \frac{v_x}{c} y i\right) \\ t' = \gamma t \end{cases} \tag{23}$$

So far, we have shown that there is an interesting relation between the new space-time transformation and the nature of EM waves. Although the particle's imaginary coordinates in frame S are set to zero, its imaginary coordinates in frame S' still enlarge with its movement speed. For a particle moving at a low speed, its imaginary body may shrink to a very small scale. However, as long as it is accelerated to near the speed of light, the particle's imaginary body will be unfolded. Humans can not perceive the light's magnetic vector and touch the magnetic field, so the imaginary body of an object can not be observed. This fact might imply that the invisible DM is hidden in imaginary space.

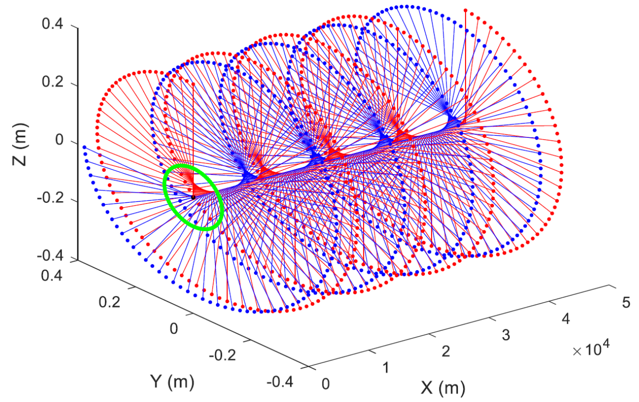

Fig. 5 Trajectories of a circling particle that are in line with the circular polarization of an electromagnetic wave

3.4 The mechanism behind quantum entanglement

The 4D complex space-time reveals that any matter has two forms of bodies which exist in real space and imaginary space simultaneously. According to the motion pattern of light, the particle's coordinates in real and imaginary spaces can be unequal. Therefore, for the entangled two-photons (Alice and Bob), only the separation of their real bodies can be observed, and their imaginary bodies may always be in the same or adjacent positions.

The Figure 6 demonstrates a possible mechanism behind quantum entanglement, i.e., real-imaginary separation. For the illustrated two-photons, their velocity components in the x-direction are real and equal, i.e., $v_x^A = v_x^B = v_x$. However, their velocity components in the y-direction are complex and opposite, i.e., $v_y^A = -v_y^B = v_0 - v_0 i$. And their velocity components in the z-direction are equal to $v_z^A = v_z^B = v_0 + v_0 i$. In this case, the observed coordinate deviations in frame S' can be calculated as follows.

$$\mathbf{X}'^{A} - \mathbf{X}'^{B} = \begin{cases} \Delta x' = 2\gamma \frac{v_0}{c} z(1+i) \\ \Delta y' = -4\gamma v_0 t_R \\ \Delta z' = 0 \\ \Delta t' = -2\gamma \frac{v_0}{c} y(1+i) \end{cases} \tag{24}$$

As can be seen from above formula and Figure 6, the distance between the observed real bodies of the two photons will increase gradually in the y-direction, while their invisible imaginary bodies are always entangled.

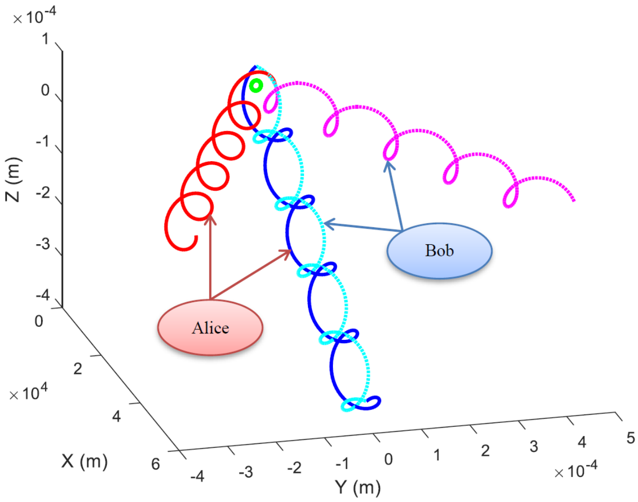

Fig. 6 Real-imaginary separation that is a possible reason for quantum entanglement

Therefore, if we measure the quantum state of photon Alice, the state of photon Bob will be affected by Alice's imaginary body, which causes Bob's state to be determined instantaneously. So, an inference can be drawn that the separated particles in real space can interact with each other through imaginary space. The above simulation experiment demonstrated that the new space-time transformation can be used to reasonably interpret the quantum entanglement without violating the principle of locality and the natural speed limit.

3.5 New candidate for dark matter

According to the size difference between a particle's real and imaginary bodies ($r_a + r_b i$), we can divide particles into three types, namely real particles ($r_a \gg r_b$), imaginary particles ($r_a \ll r_b$), and symmetric particles ($r_a \approx r_b$). Among them, the body size of real particles in real space is much larger than that in imaginary space, the imaginary particles are the opposite of real particles, while the body sizes of symmetric particles in real and imaginary spaces are almost equal (such as photons). For real particles and imaginary particles, the size of smaller body may collapse to a very small length scale (for example, the Planck scale l_p).Therefore, we can draw a reasonable conjecture that most of the particles observed by humans are real particles or symmetric particles, and the invisible DM is likely to be composed of low-speed imaginary particles. Figure 7 illustrates the possible existence forms of visible matter(VM) and DM, and the difference of their body sizes in real and imaginary spaces is described by

$$\begin{aligned} &\mathrm{VM} \begin{cases} r_a \gg r_b \to l_p, \text{real particle} \\ r_a \approx r_b \gg l_p, \text{symmetric particle} \end{cases} \\ &\mathrm{DM} \begin{cases} r_b \gg r_a \to l_p, \text{imaginary particle} \\ r_a \approx r_b \to l_p, \text{symmetric particle} \end{cases} \end{aligned} \tag{25}$$

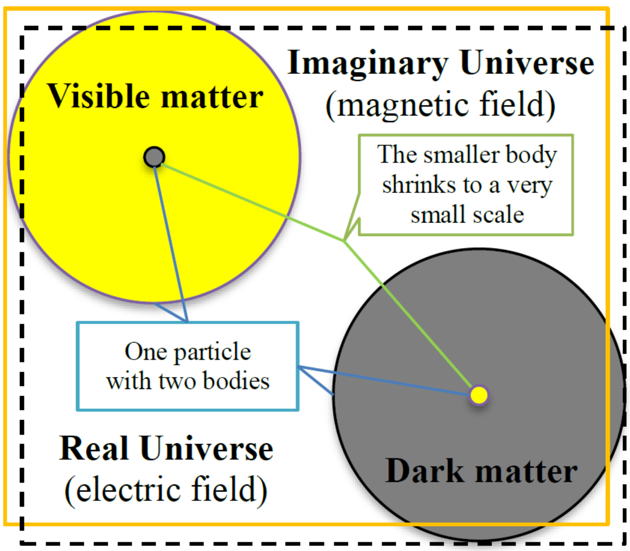

Fig. 7 Illustrations of real and imaginary universes and the possible existence forms of visible matter and dark matter

Thus, even if a real particle meets an imaginary particle in the same place, the probability of their collision is almost zero. This may be the reason why it is difficult for us to detect dark matter particles. When neutrons pass through a magnetic field which lives in imaginary universe, the probability that neutrons are transformed into dark imaginary particles will increase and neutrons may disappear from our universe.

Interestingly, if the proposed hypothesis about visible and dark matters is correct, we can further analyze the evolution inside the black hole. Combining the theories of the complex space-time and the loop quantum gravity [12], we can make a hypothesis that real particles can be transformed into imaginary particles under extremely strong gravity. Thus, black holes in real universe devour visible matter, while the associated white holes spit out dark matter,as shown in Figure 8. On the contrary, the black holes in imaginary universe may devour dark matter and correspond to the white holes in our universe. Black hole and its homologous white hole overlap in space. It means that black and white holes are essentially the two images of a cosmic body in real and imaginary universes, respectively, and this cosmic body can be regarded as a visible-dark matter converter in the full universe.

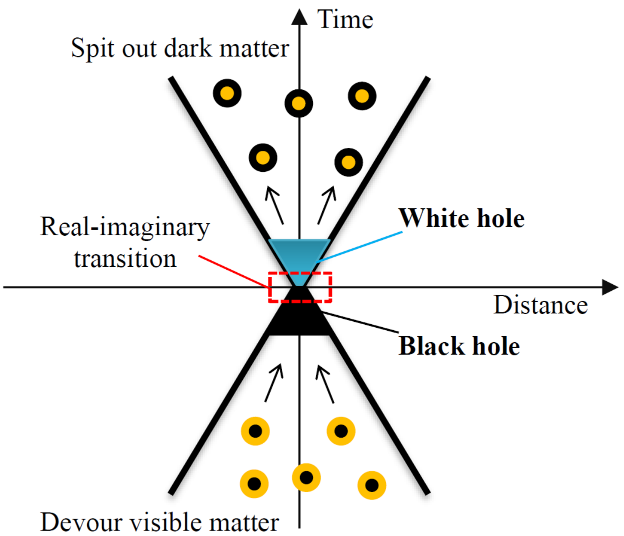

Fig. 8 Diagram representing the space-time evolution of a black hole into a white hole via a real-imaginary transition

4 Conclusion

In conclusion, by taking into account the correlation of spatial dimensions, a novel space-time transformation equation is derived based on the introduced lemma of orthogonal space-time transformation matrix. Then, the existence of mirrored space-time is analyzed and the 4D complex space-time theory is proposed. We have found that the new space-time transformation can reveal a new relativistic effect, i.e., transverse dilatation. Based on the extended 4D complex space-time theory, new insights and promising explanations for the nature of EM waves, the principle of quantum entanglement, and the form of dark matter particle were proposed. The relations between the novel space-time transformation and Maxwell or Schrodinger equations remain to be addressed.

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