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# Review of Fundamentals of Covariant Quantum Mechanics in the Dual 4-Dimensional Space-Time: Substance of Wave Function, the Origin of Quantum Probability and the Cause of Quantum Superposition State

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## ABSTRACT

Microscopic objects have some spatial distribution, which influences quantum phenomena. The particle model does not apply to the microworld. In this work, we use a rotating field matter sphere model. The size of the sphere changes along with the movement state, harmonizing with special relativity. Thus, we independently construct a dual 4-dimensional space-time to describe the microscopic quantum phenomenon and establish the objective reality of plural description, which has obvious theoretical advantages. In the dual 4-dimensional space-time, the wave function describes matter waves as physical waves. Which is the physical basis of quantum communication. Quantum probability originates from the tangible structure and matter density distribution of the microscopic objects and is reflected in the transformation of space-time. Matter waves and probability waves can be transformed by using Fourier transformation.

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*Microscopic objects have some spatial distribution, which influences quantum phenomena. The particle model does not apply to the microworld. In this work, we use a rotating field matter sphere model. The size of the sphere changes along with the movement state, harmonizing with special relativity. Thus, we independently construct a dual 4-dimensional space-time to describe the microscopic quantum phenomenon and establish the objective reality of plural description, which has obvious theoretical advantages. In the dual 4-dimensional space-time, the wave function describes matter waves as physical waves. Which is the physical basis of quantum communication. Quantum probability originates from the tangible structure and matter density distribution of the microscopic objects and is reflected in the transformation of space-time. Matter waves and probability waves can be transformed by using Fourier transformation.*


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## I. INTRODUCTION

The physical meaning of the wave function and the origin of quantum probability are two of the most concerning problems of quantum mechanics. For the physical meaning of the wave function, The realist school, represented by Einstein, De Broglie, and Schrodinger, indicates that the wave function has a physical meaning and describes physical reality; The indeterminist school, represented by Bohr, Born, Heisenberg, and Dirac, believes that the wave function has no physical meaning but just describes the probability distribution of the microscopic particle, the square of the absolute value of the wave function describes the probability density of the microscopic particle appearing in space and time. The indeterminist school considers that the wave functions are knowledge of the cognitive world (cognitivism), known as the school of nondeterminism. [1]

Some scholars even directly believe that the wave function is a mathematical reality. Thus, there are two opposite opinions about the origin of quantum probability. One school represented by Einstein believes that "God does not play dice", thus quantum probability derives from external uncertainties, which are defined as "hidden variables" by Bohm [1]. The other school, represented by Bohr, believes that microscopic particles have natural uncertainty, and quantum probability originates from the nature of particles [1].

 

For the difficulty of quantum mechanics, Thom [2], Sakata [3], and Yukawa [4] believed that microscopic objects could not be treated as point particles in microworld. The superstring theory should be considered as a non-point model, which was a great success. Up to now, although the superstring theory is hard to be determined experimentally, it continues to grow [5]. The basic research of quantum mechanics is still developing.

At the 2019 International Symposium on Fundamentals of Quantum Mechanics, Peter J. Lewis, professor of Dartmouth College, focusing on the measurement-induced collapse problem, pointed out three main viewpoints for realism: Spontaneous collapse, pilot-wave theory, and Many worlds theory. However, the defects of these models could also lead to problems, such as insufficiently deterministic, non-local, probability, dimension, and self-interaction. To address the dilemma of realism, cognitivism proposes that wave function is not a description of the world, but a theory about information, knowledge, and belief. The four theoretical forms are ψ- cognitivism, Quantum Information, Quantum Bayesianism, and Quantum pragmatism [6]. In this cognitive route, it is difficult to achieve unification on the nature of wave function, the origin of quantum probability, the matter basis of Over light speed and quantum communication in quantum measurement, etc.

In this work, we abandoned the point model and adopted the rotating field matter sphere model, to establish a dual 4-dimensional space-time for describing the microscopic quantum phenomena. In the dual 4-dimensional space-time, wave function describes matter waves as physical waves. In the present model, the microscopic quantum objects could be described using complex numbers. Quantum probability originates from the physical structure and matter density distribution of the microscopic objects. Quantum measurement introduces new continuous interactions through local transformation to eliminate fixed phase differences, leading to the transformation of doal 4 -dimensional space-time to classical space-time description, and the evolution of matter waves into probability waves [7]. It is of great significance to discuss the physical nature of quantum entanglement and quantum communication.

## II. GEOMETRICAL CONSTRUCTION OF THE MICROSCOPIC QUANTUM OBJECT AND ESTABLISHMENT OF THE DUAL 4-DIMENSIONAL SPACE-TIME

Let's review the basic concepts of space-time. For space-time and philosophy, we advocate that matter and space-time are inseparable. For space-time and geometry, Euclidean geometry, Minkowski geometry, and Riemannian geometry are included. For space-time and physics, we believe that physical space-time has construction characteristics. Newtonian space-time is physical space-time, using Euclidean geometry as geometric background. The space-time of special relativity is also physical, using Minkowski geometry as geometric background. The space-time of general relativity is physical space-time and its geometric background is Riemannian geometry. The dual 4-dimensional space-time of quantum mechanics is also physical, we chose complex numbers extension of Minkowski's geometry as geometric background.

The foundation of the dual 4-dimensional space-time covariant quantum mechanics consists of three parts. Firstly, philosophical foundation: establishment of the interaction realism; Secondly, is a modification of the physical model, adopting the rotating field matter sphere model (rotating curvature vector). Thirdly, establishing the dual 4-dimensional space-time to describe the microscopic quantum phenomena. This word focuses on the last two parts.

## 2.1 Matter sphere model of rotating field in the dual 4-dimensional space-time covariant quantum mechanics

Previous research reveals that, in modern physics, spatial coordinates of microscopic objects should not be smaller than the Compton wavelength $\lambda_c$ ($\lambda_c=h/mc$) [8]. Furthermore, the radius of the electron shows good agreement with the Compton wavelength [9], which was experimentally proved.

### 2.1.1 Experimental Evidence of the Field Matter Sphere Model

1. Study on electronic dipole moment of advanced cold molecules

Doyle's team [10] found that an Electron is a perfect sphere. This research provides an important experimental basis for applying the field matter sphere model in the basic theory of the dual 4-dimensional space-time covariant quantum mechanics.

2. Comparison between experimental and theoretical values of Hofstadter particle radius $R_o=\hbar/m_oc$, $R_4=\hbar/mc$ take this as a theoretical value of the microcosmic object distribution "radius". A comparison of the theoretical values with the experimental values is shown in the following table:

*Table 1:* Comparison of experimental values of electron, proton, and neutron radii with theoretical values of Compton wavelength (static -- $R_o$, dynamic -- $R_4$) [9]

| Category | Proton (static) (Ro) | Neutron (static) (Ro) | Static electron (Ro) | Moving electron (20Gev) (R4) | Moving electron (60Gev) (R4) |
|---|---|---|---|---|---|
| Theoretical value | $0.21\times10^{-15}$m | $0.21\times10^{-15}$m | $3.86\times10^{-11}$cm | $0.93\times10^{-15}$cm | $3.1\times10^{-16}$cm |
| Experimental value | $1.1\times10^{-15}$m | $1.1\times10^{-15}$m | Accord with estimate | $< 10^{-15}$cm | $< 10^{-16}$cm |

The theoretical values show good agreement with experimental values. However, Ding's measurement accuracy was improved to $10^{-17}$cm, still proving that electrons are not points.

The microscopic objects are not point particles, but have a certain "spatial distribution", and the distribution radius R decreases with increased movement speed. The comparison of experimental and theoretical values shows that it is reasonable to use Compton wavelength $\lambda_o$ ($\lambda_4$) to construct the extension distribution of the static (dynamic) microscopic objects.

3. Uncertainty of Landau's single mechanical quantity

In 1930 Landau indicated that there were two uncertainties for measuring a single mechanical quantity, position measurement uncertainty ($\triangle X_o=\hbar/m_0c$) and momentum uncertainty ($\triangle P_o = m_0c$).[11] The uncertainty of electronic position is the theoretical value of the "radius" of electronic Distribution

$$R_o = \hbar / m_0c$$

Landau's explanation of $\triangle x_o$ should come from the point particle hypothesis. But an electron is not a point particle, and a true distribution radius $R_o$ is exist for the electron. If the electron is regarded as a "point", then the "point" must be dispersed in a range of cycles with a diameter of $2R_o$ . An electron couldn't be positive more accurate than $2R_o$ ,meanwhile, the electron's position is uncertain. This is an important theoretical basis for the field matter sphere model provided by Landau.

### 2.12 Geometrical construction of the microscopic objects

State description of the microscopic objects in the sphere model [7] : In static status, the radius of curvature is

$$R_o = \hbar / m_o c \tag{1}$$

$M_o$ is defined as the static mass of the matter field, and $R_o$ shows the extension of the matter distribution in the intrinsic rotating field of a static microscopic object. And the curvature $K_o$ is determined as

$$K_0 = 1/R_0 = m_0 c/h \tag{2}$$

$R_o$ and $K_o$ define the microscopic object. They are two invariants for any reference frame, independent of position $x$ in space. The microscopic object represented by $R_o$ and $K_o$ is similar to the physical noumenon. A physical noumenon cannot be observed directly, but it is real. Observations are all phenomenal entities. $K_o$ is called the quantum curvature of the microscopic object.

In dynamic status, the radius of curvature is defined as

$$R_4 = \hbar / mc \tag{3}$$

Curvature is defined as

$$K_4 = 1/R_4 = mc/\hbar \tag{4}$$

Where m is the motion mass. As m increases, the radius of curvature decreases, and the curvature increases. A sphere of matter is a quantum object of variable form. In translation and spin rotation, the linear velocity of the edge of the sphere does not exceed the speed of light, which is coordinated with the relativity theory. It is a physical entity [7] in the theory of physics.

In three-dimensional (four-dimensional) space mapping, curvature radius is defined as

$$R_i = \hbar / m v_i \tag{5}$$

Curvature is defined as

$$K_i = m v_i / \hbar \tag{6}$$

$P_i = mv_i$ is relativistic momentum, which is observable. $i = 1,2,3$.

$R_i$ and $K_i$ are "representations" of physical noumenon $R_o$ and $K_o$ in physical space, respectively. Physical noumenon cannot be observed directly, but "representation" can be observed. Quantum "motion" carries all quantum phenomena.

Rotation frequency is defined as

$$\nu_0 = E_0/h,\ \nu_4 = E/h,\ (\nu_i = E_i/h) \tag{7}$$

$E_o = m_o c^2$, $E = mc^2$, ($E_i = m_o v_i^2/2$ or $E_i = m v_i^2/2$), which is consistent with the basic assumptions of quantum mechanics and relativity.

The field matter density is defined as

$$\eta = m/V = \eta\ (k) \tag{8}$$

V is the volume of the field matter sphere, V=V(R), R=R(k), and η, the density of the matter field, is a function of the curvature k. $k = k_o, k_4, k_i$. It can be proved that with a decrease or increase of V, k and η increase or decrease, respectively. η (k) is positively correlated with k.

According to our understanding, $R_o$ and $R_4$ should not be less than the Planck length, and the field matter density and energy density of the field matter sphere cannot be infinite. Thus, the problem of infinite curvature of point particle theory is solved.

In the rotating field matter sphere model, we can establish the attachment relationship of the waves to the rotating field matter sphere, which is similar to the relationship hypothesis between energy, momentum, wavelength, and frequency in the Einstein and De Broglie point model. Here, the equations of E=hν, p=h/ λ will evolve into the real physical process of field matter sphere movement, as show as follow:

$$E = h\nu = \hbar\omega$$
$$p = h/\lambda = \hbar k$$

The physical state corresponding to the spherical model is described by the above formulas. ω denotes the rotational frequency of the field matter sphere, $k= P/\hbar$ denotes the curvature of the field matter sphere ($k=K_o$, $k_4$, $k_i$), which describes the density change of the field matter sphere. But the corresponding physical model is the rotating field matter sphere, not a point particle. Hence, matter waves of microscopic objects there is a new definition.

A microscopic object is a rotating field matter sphere with mass evenly distributed, which has a certain spatial distribution. Position *x* is uncertain for the microscopic object. 2R ($2R_o$, $2R_4$) is the uncertainty of position *x*.

If the microscopic object does not move, then $v_i=0$, $K_i=0$, in the physical space-time, the release map of the ontology structure K is 0, there is no change in the morphological structure and field matter density, and the phenomenon of quantum fluctuation disappears. In addition, according to the relativistic momentum (curvature) triangle, the microscopic object does not move, $mv=0$. Meanwhile, the angle between $m_0c$ and *mc* is $a=0$, along the movement direction of the microscopic object. $x=0$ ($v=x/t$, $v=0$, $x=0$). The spatial release mapping of ontology $R_o$ in physical space-time is 0, and the position coordinates do not appear. Although ontology $R_o$ still exists. Therefore, quantum motion is a necessary condition for $K_o$ and $R_o$ to present quantum phenomena in physical space-time. *x* and *k* are the basic variables to describe quantum phenomena, quantum phenomena could be describted in the physical space-time (*x, k*) constructed by the moving microscopic object itself. But the position *x* of the microscopic object is uncertain and within a range.

## 2.2 The Energy Formula of Special Relativity and the Establishment of the Field Matter Sphere Model and the Dual 4-Dimensional Space-Time in Quantum Mechanics

### 2.1.1 Revelation of Relativistic Energy Formula

According to the relativistic energy formula of the microscopic objects, as shown as follow:

$$E^2 = (mv_i)^2c^2 + m_0^2c^4,\ (mc)^2 = (mv_i)^2 + (m_0c)^2 \tag{9}$$

A momentum triangle can be obtained:

$$p_4^2 = p_i^2 + p_0^2 \quad (10)$$

Divide both sides of equation (10) into a ħ², resulting in a sphere model curvature triangle:

$$k_4^2 = k_i^2 + K_0^2, \quad i = 1, 2, 3 \quad (11)$$

The vector relation is:

$$K_o = k_4 - k_i \quad (12)$$

Therefore, the 4-dimensional curvature space K and the related 4-dimensional coordinate space $X$ of the motion microscopic object can be defined.

### 2.2.2 Establishment of Double 4-Dimensional Space-Time in Quantum Mechanics

$$\text{4-dimensional curvature k-space is} \quad k = K(k_4 - k_1 - k_2 - k_3) \quad (13)$$

$$\text{4-dimensional coordinate } x\text{-Space is} \quad x = X(x_4 - x_1 - x_2 - x_3) \quad (14)$$

The spatial invariant of 4-dimensional curvature K is given by formula (12)

$$k_0^2 = k_4^2 - k_1^2 - k_2^2 - k_3^2 \quad (15)$$

4 dimensional coordinate space $x$ invariant is

$$x_0^2 = x_4^2 - x_1^2 - x_2^2 - x_3^2 \quad (16)$$

$x_o$ can be seen as the projection of $R_o$ of the microscopic object associated with $k_o$ onto a 4-dimensional space $x$. $k_o$ and $x_o$ are invariants under two 4-dimensional coordinate transformations. It just reflects the existence of the microscopic object, that is physical noumenon, independent of space-time transformation. The two Spaces $k$ and $\boldsymbol{x}$ can jointly construct a dual 4- dimensional complex space-time W($\boldsymbol{x},\boldsymbol{k}$) associated with the state description of the moving microscopic object.

$$W = x_\mu + ik_\mu \quad W^{※} = x_\mu - ik_\mu$$

μ=1,2,3,4, $k_{(1,2,3,4)}$ and $\boldsymbol{x}_{(1,2,3,4)}$ are two 4-dimensional releases of hidden spatial degrees of freedom for the point model [7]. $\boldsymbol{x}_{(1,2,3,4)}$ is the location of the microscopic object and has uncertain properties. $x$ and $k$ are Lorentz covariants. Hence, Dual 4-dimensional space-time is supported by relativity. Let the state wave function describing microscopic quantum phenomena in W($x,k$) be:

$$\Psi(x,k) = A(x,k)e^{-ik_\mu x_\mu} \quad (17)$$

It's a complex function. $A_n$ ($x,k$) is amplitude, which is complicated. The phase of the wave function is constituted by coordinate $k_\mu x_\mu$, which is dimensionless. The wave function ψ ($x,k$) is described in the phase space $k_\mu x_\mu$. Wigner's prediction, "the use of complex numbers is in this case not a calculational trick of applied mathematics but comes close to being a necessity in the formulation of the laws of quantum mechanics", is confirmed. [12]

Equation (17) is similar to Penrose's 5-dimensional twisted space, in which the state wave function is described in 2-dimensional complex space and 3-dimensional classical real space. In the present model, the space is the relativistic covariant dual 4-dimensional complex space, the state wave function is described in 4-dimensional imaginary space + 4-dimensional real space. It could be proved that the dual 4-dimensional complex space-time W(*x, k*) can be generated automatically in the derivation of the wave function. In dual 4-dimensional complex space-time, the value of curvature *k* represents the particle property, and the change of curvature *k* (the change of matter density) shows fluctuation. Thus, the matter wave could be described as a physical wave by the wave function which establishes the objective reality of complex numbers. (note 1). The wave-particle duality of microscopic objects could be uniformly and intrinsically understood very well.

The amplitude A(*x,k*) cannot be compared with that of classical waves, and the image is unimaginable [13]. It is expected to be understood in the derivation of the matter wave function. Wigner gave an expanded form of A(*x,k*) [14], which could be used to discuss the wave equation in dual 4-dimensional space-time.

Formula (10) and (12) show that the hidden spatial freedom of the microscopic object point model could be released in a 4-dimensional space. The releasement could be observed, and is related to the motion of the microscopic object. This will be demonstrated in the derivation of wave functions in the next section.

### *2.3 Physical properties and space-time metric of the dual 4-dimensional space-time W(x, k)*

Vector *K* ($k_1, k_2, k_3, k_4$) describes the spatial structure of the microscopic object itself, presenting the existence form and matter density distribution of the microscopic object.

Vector X($x_1,x_2,x_3,x_4$) describes the position of the microscopic object, with uncertainty (or probability). And then uncertainty corresponds to the matter density distribution of the microscopic object.

Further study shows that all quantum phenomena are described in the Dual 4-dimensional complex phase space W(*x, k*) composed of vectors X and K. The metric tensor of *W*(*x, k*) is

$$\begin{aligned} g^{\mu\nu} &= diag(1, -1, -1, -1) \\ x^2 &= x_\mu g^{\mu\nu} x_\nu = x_4^2 - x_1^2 - x_2^2 - x_3^2 \\ k^2 &= k_\mu g^{\mu\nu} k_\nu = k_4^2 - k_1^2 - k_2^2 - k_3^2 \\ |W|^2 &= WW^{※} = x^2 + k^2 \end{aligned} \tag{18}$$

When the microscopic quantum object spins locally

$$k_i = 0,\ x_i = 0,\ i = 1,2,3.$$

$$|W|^2 = A_0^2 = x_4^2 + k_4^2 = x_0^2 + k_0^2$$

$A_o$ denotes the amplitude of the microscopic quantum object(the physical noumenon——the rotating field matter sphere).

*x* and *k* are Lorentz invariants, and the space-time is uniform and flat. Therefore, we consider W(*x,k*) to be a complex extension of $M^4(x)$. The Dirac equation is invariant in Lorentz transformation.

## III. DERIVATION OF THE MATTER WAVE FUNCTION, MATTER-WAVE EQUATION, AND QUANTUM PROBABILITY IN THE DUAL 4-DIMENSIONAL SPACE-TIME

### *3.1 Generation and Derivation of the Matter Wave Function in the Dual 4-Dimensional Space- Time*

We have defined a static rotating field matter sphere with a radius $R_o=\hbar/ m_oc$ and a curvature $K_o =m_oc/\hbar$. Rotational angular frequency $\omega_o=2\pi\nu_o=2\pi m_oc^2/h$. $R_o$, $k_0$, and $\boldsymbol{\omega}_o$ are all constants, the whole space is invariant. A Static rotating field matter sphere is natural object and physical noumenon without observation. Let the wave function of this rotating field material sphere be described with a complex number function

$$\Psi_0=A_0e^{i\omega_0t_0} \tag{19}$$

There are two basic physical quantities, $R_o$ and $K_o$. $R_o$ represents the space occupation of the sphere and corresponds to the position coordinate $\boldsymbol{x}$, which is uncertain. $K_o$ represents the structure and matter density of the sphere and corresponds to the curvature coordinate $\boldsymbol{k}$. The amplitude $A_o$ of $\psi_o$ should be associated with them, and it's probably complicated, but can be learned through in-depth discussion. Penrose described the microscopic object with a unit circle, letting $A_o=1$, which is simplified, just focus on the phase. But this is just a mathematical representation, without clear physical meaning. Here we take the two-dimensional projection of the field matter sphere -- the rotating field matter circle. I think so. Eq. (19) is expected to be the source of quantum phenomena.

If the coordinate system $K_o$ is built on the "rotating field matter sphere", the sphere moves uniformly along the positive direction of $\boldsymbol{x}$-axis from resting state. Using the Lorentz transformation: $t_o=(t-vx/c^2)/(1-v^2/c^2)^{1/2}$, in the observation system K, we obtain the new plural described matter wave function

$$\Psi=Ae^{i\omega t}=Ae^{i(\boldsymbol{px}-Et)/\hbar} \tag{20}$$

This results from the combination of two different kinds of spatial. The amplitude A is complex and contains new coordinate variables. *p, x, E,* and t are relativistic quantities. And $P=mv$ $E=mc^2$,$m$ is the motion mass. Under the condition of relativity (classical conditions will be discussed separately) [7,13], Equation (20) is the fluctuating motion of field matter, which is matter waves -- physical waves. It is often mistaken for a probability wave of a point particle in 3 - or 4- dimensional real space. No, it's just the same mathematical version. A little transformation of phase $i(\boldsymbol{px}-Et)/\hbar$ of equation (20) is given

$$i(\boldsymbol{px}-Et)/\hbar=i(k_ix_i-k_4x_4) =-ik_\mu x_\mu$$

$k_4 =mc/\hbar$, $x_4 =$ ct. Wave function equation (20) becomes

$$\Psi=Ae^{i\omega t}=Ae^{i(\boldsymbol{px}-Et)/\hbar}=Ae^{i(k_ix_i-k_4x_4)} = Ae^{-ik_\mu x_\mu} \tag{21}$$

In the present equation (21), $x$ and $k$ are the new phase space coordinate variables. The product of $k_\mu x_\mu$ happens to be dimensionless. It is automatically generated when Lorentz time transform is introduced after the motion of "the field matter sphere", which integrates the complex and real Spaces.

It can be considered that $\boldsymbol{k}_\mu$ is the 4-dimensional physical space-time release of $\boldsymbol{k}_0$, and $\boldsymbol{x}_\mu$ is the 4-dimensional physical space-time release of $R_o$. The descriptive space-time also becomes a new combination of complex-real space-time -- the dual 4-dimensional complex space-time W($x$,$k$), instead of Penrose's 5-dimensional twisted subspace. The amplitude A=A $(x,k)$ is A very complicated function. $i$ =1, 2, 3, μ=1, 2, 3, 4, $k_4x_4$ =$mc^2t$ /ħ=(mc/ħ)•ct . It is an important step to write mc2t/ħ as (mc/ħ)•ct, which represents a physical process on the light cone. This is the introduction of the theory of relativity into a new space-time. The phase space $k_\mu x_\mu$ is consistent with the own construction space of the microscopic object sphere model, namely Dual 4- dimensional complex space, as shown as the follow equiptions:

4-dimensional curvature k-space: $K = K(K_4\text{-}K_1\text{-}k_2\text{-}k_3)$

and invariant of 4-dimensional k-space: $K_0^2 = K_4^2\text{-}K_1^2\text{-}K_2^2\text{-}k_3^2$

4-dimensional coordinate $x$-space: $x = X(x_4\text{-}x_1\text{-}x_2\text{-}x_3)$

and invariants of 4-dimensional $x$-space: $x_0^2 = x_4^2\text{-}x_1^2\text{-}x_2^2\text{-}x_3^2$

The description space of the wave function ψ is on the phase, as same as that of Equation (17). The wave function equation (17) can be derived from the relativistic Lorentz time transformation through the motion of the quantum object field matter sphere. It is further confirmed theoretically that the wave function ψ is a physical wave. The overall picture of the wave function is complex, where the amplitude is A=A $(x,k)$, and Wigner gives an expanded form. We will apply the expanded form in the derivation of the equations of motion of quantum mechanics in the Dual 4-dimensional space-time In 4-dimensional coordinate $x$ space, $x_o$ is an invariant of the distance between two points in coordinate transformation. The microscopic object is stationary, P=0, $k_{1,2,3}$=0, $k_4$=$k_o$, $x_{\text{release - mapping}}$ =0. Meanwhile, $x_{1,2,3}$=0, $x_o$= $x_4$, and $x_o$=$R_o$, $x_o$ is the projection of "the field matter sphere of ontology " in coordinate space, which is an invariant and cannot be observed directly, and no observable quantum effects. When P≠0, $k_{1,2,3}$≠0, and $k_4$≠$k_o$, $x_{\text{release – mapping}}$ is the release and mapping of coordinate $x$ of the moving microscopic object in 3-dimensional or 4-dimensional space. $\boldsymbol{x}_{\text{release - mapping}}$ ≠0, at this time, $x_o$≠$x_4$, the quantum motion effect of the microscopic object in space-time can be observed. Due to the Lorentz covariant of $x$ and $k$, relativity and quantum mechanics are unified based on physical models. Special relativity spacetime is extended to the quantum mechanical dual 4-dimensional complex spacetime.

The above analysis shows that the rotating field matter sphere described in the complex number (19) releases four components $x(x_4 - x_1 - x_2 - x_3)$ along the spatial direction $x$ and $k(k_4 - k_1 - k_2 - k_3)$ along the curvature $k$ (P /ħ). It is the ingenious expansion of the space structure of the moving microscopic quantum object in dual 4-dimensional complex space-time. That is, $k_{1,2,3}$ are the 3-dimensional release of $k_o$, and $x_{1,2,3}$ are the 3-dimensional release of $R_o$. Since Equation (20) can describe all quantum phenomena, equation (21) can completely describe all quantum phenomena in the Dual 4-dimensional complex space-time W$(x,k)$.

Equation (19) is consistent with Penrose's thought and method of 5-dimensional twisted space, except that we confirm the existence of an in-itself structure $R_o$ and its "rotation" in complex space, and observe the movement of microscopic objects using relativistic space-time instead of classical Newtonian space-time [7,13]. In fact, from the relativistic momentum triangle, we can know that the expansion of 4-dimensional curvature space and 4-dimensional coordinate space is presented in the electron from "static" to "dynamic". If the electron changes from "moving" to "static", $P_{1,2,3}$=0, that is, $k_{1,2,3}$=0, $k_o$=$k_4$, then the included Angle between m0c and $mc$ is 0, so the observation space $x_{\text{release - mapping}}$ =0. Quantum phenomena disappear. In our method, through the electron from "static" to "dynamic", it is illation into a unified. Dual 4-dimensional complex space-time describing quantum phenomena. This is a relativistic advance on the Penrose 5 - dimensional twisted subspace.

In addition, it must be noted that although equation (20) is the same as the mathematical form of the wave function in traditional quantum mechanics, the traditional quantum mechanical wave function is only an assumption under the point particle model, with unclear physical significance [13], and is a probabilistic wave in 3d or 4d real space-time $M^4(x)$. This leads to a lot of cognitive contradictions. Here, the wave function formula (20) is derived from the movement of the field matter sphere in the rotating. It describes the fluctuating movement of the rotating field matter and has a clear physical meaning. It is matter waves -- physical waves. It is in the dual 4- dimensional complex space-time W($x$,$k$). A further study shows that the conversion between the dual 4-dimensional complex space-time W($x$,$k$) and the 4-dimensional real space-time $M^4$ ($x$) is realized by quantum measurement, and the probabilistic properties are shown.

We predict that matter waves, like electromagnetic waves, will have communication and other applications. But it's not electromagnetic waves, which require the movement of charged objects. Matter waves with no need for charged objects. The propagation of matter waves is both realistic and deterministic. Its probabilistic properties need to be represented in quantum measurements. The electromagnetic wave properties of moving electrons and their matter wave properties may be applied separately through experimental design.

## 3.2 Covariant Quantum Mechanics Equations of Matter-Wave in the Dual 4-Dimensional Space-Time

### 3.2.1 Establishment of the Classical Wave Equation in the Dual 4-Dimensional Space-Time

The matter wave function described by the dual 4-dimensional space-time W($x$,$k$)

$$\psi(x,k) = A(x,k)exp[i(\mathbf{k}\cdot\mathbf{x}-Et/\hbar)]=A(x,k)exp[i(\mathbf{k}\cdot\mathbf{x}-mc/\hbar\ .ct)]$$
$$=A(x,k)exp[-i(k_4\ .x_4-\mathbf{kx})]=A(x,k)exp(-ik_\mu x_\mu) \quad (22)$$

In the stationary state, $k_\mu = k_{1,2,3}\, x_\mu = x_{1,2,3}$, A($x$,$k$) only depends on the 3-dimensional space coordinates $x_\mu$ and the 3-dimensional curvature coordinates $k_\mu$

$$A(x,\ k)=\sum_{0}^{\infty} C_n A_n(x,\ k),$$

The amplitude of the matter wave is a function of the space coordinate $\boldsymbol{x}$ and the structure space $\boldsymbol{k}$. It satisfies the following differential equation [7]

$$H(x,k)exp[i/2(\overleftarrow{\partial}_x \overrightarrow{\partial}_k - \overleftarrow{\partial}_k \overrightarrow{\partial}_x)]\ A(x,k)$$
$$=H(x,k) * A(x,k)=EA(x,k) \quad (23)$$

Where H($x$,$k$) is the classical Hamiltonian function of the system. * The operation is the Moyal product, defined as follows:

$$F(x,y) * g(x,y)=F(x,y)exp[i/2(\overleftarrow{\partial}_x \overrightarrow{\partial}_y - \overleftarrow{\partial}_y \overrightarrow{\partial}_x)]\ g(x,\ y)$$

Where y= k, the average of any quantity F($x$,$k$) in this stationary state can be written as

$$< F > = \int_{-\infty}^{\infty} F(x,k)A(x,\ k)\ dxdk \quad (24)$$

The wavelength of the general wave function of a physical system can be defined by the generalized de Broglie relation, which also applies to the wave-motion of the matter field.

The asterisk multiplication operator wave equation is equivalent to the Schrodinger equation and the path integral quantization equation. The forms cannot be transformed into each other, and the results are equivalent. Square wave function Ψ ($x$) the absolute value of | Ψ ($x$) | $^2$ has the same probability. Wigner function transformation formula

$$\Psi(x) = \left(\int_{-\infty}^{\infty} A(x,k)dk\right)^{1/2}$$

$$\int_{-\infty}^{\infty} A(x,k)dk=|\Psi(x)|^2=\rho(x)$$

And, $\boldsymbol{\Psi}(\boldsymbol{x})$ of course be the solution to the Schrodinger equation. The form of the Schrodinger equation remains the same.

### 3.2.2 Discussion

Dirac equation of free electron: When H($x,k$) is the relativistic Hamiltonian function of the system, the Moyal multiplication rule is adopted to obtain the wave equation of the dual 4- dimensional space-time

$$H(x,k)*A(x,k)=E(x,k) \quad (25),$$

In Equation (25), H($x,k$) and A($x,k$) contain $x_4$(=ct) and $k_4$. Different from Equation (23), H($x,k$) is an evolution equation containing time.

In addition, due to the equivalent meaning of wave function ψ, the relativistic quantum mechanical operator [15] is adopted:

$$H=c\boldsymbol{\alpha}\cdot\boldsymbol{p}+\beta m_0c^2 \quad (26\text{-}1)$$

Static electron p=0

$$H=\beta m_0c^2 \quad (26\text{-}2)$$

The Dirac equation for the free electron is

$$i\hbar\partial\psi/\partial t=H\psi \quad (26\text{-}3)$$

So this goes back to the traditional quantum mechanical system.

### 3.2.3 Wigner Function Method -- Wave Function ψ (X) Position Representation and Wave Function φ (K) Curvature K Representation

The matter wave function of the microscopic object is ψ ($x,k$), which is a physical wave, the amplitude A=A ($x,k$) contains the matter information of the microscopic object, and the phase is composed of coordinate variables. And its motion satisfies the Dirac equation (or Schrodinger equation). And there is a Wigner transformation relation [7]

$$A(x,k)=\int_{-\infty}^{\infty} d\xi e^{-i\xi k}\Psi^{※}(x-½\xi)\Psi(x+½\xi) \quad (27)$$

$$A(x,k)=\int_{-\infty}^{\infty} d\xi e^{-i\xi x}\Phi^{※}(k-½\xi)\Phi(k+½\xi) \quad (28)$$

Where ψ ($x$) is the representation of position, and x has an uncertain property for the microscopic object. φ ($k$) is the representation of curvature $k$, corresponding to the property of matter density. So let's integrate these two things.

Eliminating the variable $k$ from Equation (27), the matter wave ψ $(x,k)$ maps to the real part space. The location representation wave function ψ $(x)$ and probability density distribution function $\rho(x)$ are obtained.

$$\Psi(x) = \left(\int_{-\infty}^{\infty} A(x,k)dk\right)^{1/2} \quad (29\text{-}1)$$

$$\int_{-\infty}^{\infty} A(x,k)dk=|\Psi(x)|^2=\rho(x) \quad (29\text{-}2)$$

Normalization is expressed as $\int_\tau c\,\rho(x)\,d\tau=\int_\tau c\,|\Psi(x)|^2 d\tau=1$ (30)

In dual 4-dimensional space-time, the position $x$ has an uncertain (probabilistic) property for the microscopic object, ψ $(x)$ has a probabilistic significance for the microscopic object, and ρ $(x)$ is the probability density of the microscopic object appearing at $x$. These are equivalent to traditional quantum mechanics. Conventional quantum mechanics defines ψ $(x)$ as the probability amplitude and it makes sense. The microscopic object has a certain size, so $0<\rho(x)<1$.

By eliminating the variable $x$ from Equation (27), the matter waves ψ $(x,k)$ maps to the imaginary k-space. The wave function $\varphi(k)$ of curvature $k$ and the density distribution function η(k) of the matter field are obtained.

$$\Phi(k)=\left(\int_{-\infty}^{\infty} A(x,k)dx\right)^{1/2} \quad (31\text{-}1)$$

$$\int_{-\infty}^{\infty} A(x,k)dx=|\Phi(k)|^2=\eta(k) \quad (31\text{-}2)$$

The normalization is written as

$$\int_v c\,\eta(k)\,dv=\int_v c\,|\Phi(k)|^2\,dv=\int_v c\,dv/v=1 \quad (32)$$

The midpoint of the dual 4-dimensional complex space-time $(x,k)$ represents: the vector **k** $(k_1, k_2, k_3, k_4)$ describes the spatial structure or matter density distribution of the microscopic object itself; Vector: $\boldsymbol{X}$ $(x_1, x_2, x_3, x_4)$ describes the location of the microscopic object, has a certain spatial distribution, and has uncertain properties.

#### *3.2.4 A New Understanding of Mapping Relationship Between ψ(X,k) and ψ(X) , φ (K)*

1. Elimination of the variable $k$, $A(x,k)$ mapping to the real part of the dual 4-dimensional space- time, and obtain the microscopic object probability density distribution function $\rho(x)$ at $x$.
2. Elimination of the variable $x$, $A(x,k)$ mapping to the imaginary part of the dual 4-dimensional space-time, obtain the microscopic object the matter field density distribution function $\eta(k)$ at $x$.

If k= constant, the energy level is unchanged, the physical structure of the microscopic object is unchanged, and the matter density is unchanged, it is just equivalent to the probability density distribution of the whole space is unchanged, and it is a monochromatic plane wave.

If k≠ constant, the quantum transition, the density of matter changes, and the probability density will also change. Corresponding to different monochromatic plane waves [7].

### 3.3 Discussion on the New Theory of the Origin of Quantum Probability

#### 3.3.1 The Uncertainty of Microscopic Object Position-- a New Understanding of the uncertainty relation

The microscopic object is not a point, but the rotating field matter sphere, Uniform distribution of mass, with a certain spatial distribution radius R, and uncertain position $x$. The uncertainty D depends on R. With a certain mass, the smaller the microscopic quantum object is, the greater the matter density is, and the smaller the position uncertainty D is. On the contrary, the larger R of the same microscopic quantum object is, the smaller the matter density is, and the greater the position uncertainty D is. Discussion:

1. R=0, mass density η=∞, the particle model can be adopted, the position is completely determined, uncertainty D=0, the probability of microscopic object appearing at $x$ is $\rho(x)=1$, not belonging to the dual 4-dimensional space-time description object;
2. R=∞, mass density η=0, position x is completely uncertain, uncertainty D=∞, the existence of microscopic object can not be found, the probability of occurrence at $x$ $\rho(x)=0$, also does not belong to the dual 4-dimensional space-time description object;
3. In the dual 4-dimensional space-time quantum mechanics, the field matter sphere has a certain size, the matter density $0<\eta\ (k)<\infty$, the position uncertainty $0<D<\infty$, and the probability density $0<\rho(x)<1$ at $x$.

According to the relationship between the density of field matter and quantum probability, the uncertainty relation in the dual 4-dimensional space-time can be understood as follows: the greater the density of field matter η (k), the smaller the position uncertainty D ;The smaller the field density η (k) is, the greater the position uncertainty D .The uncertainty relationship is easy to understand.

However, in classical mechanics, if the microscopic quantum is treated as a classical particle without external interference, its position $x$ is determined. Thus, the probability distribution phenomenon of quantum measurement is attributed by the Copenhagen school to the "inherent" position uncertainty of the microscopic quantum object themselves. Bohr is the representative of this cognitive route.

Einstein disagreed with the Copenhagen school that God did play dice. The quantum probability phenomenon of the microscopic object must have external and unknown objective reasons. Bohm later called its development a "hidden variable", but Einstein himself was not satisfied. of course, there are also people looking for the objective reason for external interference of quantum probability, but it is still not successful at present.

The dual 4-dimensional space-time quantum mechanics ascribes quantum probability to a certain spatial distribution of the microscopic quantum object. The nature of the position of the microscopic quantum object is uncertain. In other words, for the microscopic quantum object, coordinate $x$ in wave function $\psi\ (x)$ has the property of uncertainty. This transforms the uncertain cognition of the microscopic quantum object's position into the uncertain attribute of $x$ coordinates of the real part of dual 4-dimensional space-time. This is a transformation from subjective cognition to physical time and space, and realizes the dichotomy of subject and object. It can be seen that the physical properties of the real part of the dual 4-dimensional space-time quantum mechanics ascribe quantum probability to a certain spatial distribution of the microscopic quantum object. The dual 4-dimensional space-time quantum mechanics ascribes quantum probability to a certain spatial distribution of the microscopic quantum object. The dual 4-dimensional space-time is not the same as those of special relativity $M^4\,(x)$.

### 3.3.2 Quantum Probability Description in the Dual 4-Dimensional Space-Time

The matter wave ψ (*x*,*k*) of the dual 4-dimensional space-time is mapped to the virtual k-space, and the pure state wave function φ (*k*) of the curvature K representation is obtained. The k representation of the wave function has the property of the matter density.

$$\Phi(k) = [\int_{-\infty}^{\infty} A(x,k)dx]^{1/2} \qquad (a\text{-}1)$$

φ (k) represents the matter density distribution corresponding to the microscopic object at position $x$, and its value is

$$\eta(k) = \int_{-\infty}^{\infty} A(x,k)dx = |\Phi(k)|^2 \qquad (a\text{-}2)$$

This is a theoretical value in the dual 4-dimensional space-time and cannot be observed directly.

In fact, the imaginary part *K* is the wave-vector space of quantum field theory. ***k*** makes the infinite calculation of interaction in quantum field theory stop at the quantum curvature $\boldsymbol{k}_0$ and overcomes the infinite difficulty of the point particle model in quantum field theory.

The matter wave ψ (*x*,*k*) is mapped to the real part space, and the positional representation wave function ψ (*x*), corresponding to the microscopic object, the *x* representation of the wave function has a probabilistic property. Probability amplitude

$$\Psi(x) = [\int_{-\infty}^{\infty} A(x,k)dk]^{1/2} \qquad (a\text{-}3)$$

The position of the microscopic object at *x* is uncertain, and the theoretical probability of occurrence is

$$\rho(x) = \int_{-\infty}^{\infty} A(x,k)dk = |\Psi(x)|^2 \qquad (a\text{-}4)$$

This is also a theoretical value in dual 4-dimensional space-time, again not directly observable.

### 3.2.3 The Source of Quantum Probability in the Dual 4-Dimensional Space-Time -- Re-Understanding of the Connection Between ψ(X) and φ (K) by Fourier Transform

$$\psi(x) = (2\pi\hbar)^{(-1/2)} \int_{-\infty}^{\infty} \Phi(k) exp(ikx) d(\hbar k) \qquad (33)$$

$$\Phi(k) = (2\pi\hbar)^{(-1/2)} \int_{-\infty}^{\infty} \psi(x) exp(ikx) d(x) \qquad (34)$$

Equations (33) and (34) are the representation transformation of the field matter density distribution and probability density distribution. The density distribution of the field matter and probability density distribution can be transformed into each other. The density of field matter is evenly distributed, and the probability density is evenly distributed. The density distribution of field matter is large and the probability of microscopic objects is high. The field matter density is zero, and the probability density is zero. The density distribution of field matter is the source of quantum probability [7], the primacy of matter is supported. Quantum probability comes from the spatial distribution and mass density distribution of microscopic objects, which is completely objective.

Neither Einstein's god does not play dice nor Copenhagen's subjective understanding of the uncertain nature of particles is needed in a double four-dimensional space-time. The subjective dependence of quantum phenomena on humans can be eliminated by describing the microscopic quantum phenomena by the dual 4-dimensional space-time W($x,\boldsymbol{k}$ ) of quantum mechanics. Just as special relativity does not require a moving object to automatically shrink in length in the direction of motion.

## IV. THE DIFFERENCE BETWEEN MACRO AND MICRO CAUSALITY

### 4.1 On Macroscopic and Microscopic Causality and Quantum Parallelism States

Macroscopic classical world, intrinsic localized causality; Microscopic quantum world, intrinsic nonlocality causality. Quantum measurement can eliminate the nonlocality causality and restore the localized causality. It is wrong to treat the causal relationship between the evolution of macro and micro physical states as the same.

#### 4.1.1 Generation of the Spacelike Interval Between Eigenstates

Quantum transitions take place over time [16], according to a study published on June 3, 2019, in the British journal Nature. We believe that due to the extremely short transition time, the quantum theory system assumes the mutation time t=0, which is still valid, and the quantum theory is established. However, the concept of transition velocity can be defined. If the microscopic object moves in a linear, flat and continuous space-time, s is the transition distance, t is the transition time, and the transition speed can be defined as

$$v=s/t$$

1. Motion properties of the microscopic quantum object in the particle model

A particle has no size. In particle model quantum mechanics, within the scope of the structure of the microscopic object itself, before and after the quantum mutation distance $S\to 0=0$, the mutation time $T\to 0=0$, $\psi_n$ , $\psi_{n+1}$ appear simultaneously. Motion speed

$$V = s/t = 0/0 = C \text{ (constant)}$$

In theory, the constant C can be less than, equal to, or greater than the speed of light.

In point particle quantum theory, the mutation time T =0 implies that the transition speed can exceed the speed of light. Exceeding the speed of light is a basic property of microscopic quantum object motion.

This is an additional property that quantum transition and particle models add to microscopic objects. It has human subjectivity and corresponds to the intrinsic specification of point particle theory.

Special relativity uses a point model, where energy changes continuously, there are no energy transitions, $t\neq 0$, faster than the speed of light is excluded, which corresponds to a localized causality constraint. According to Einstein's convention in special relativity, the constant C is less than or equal to the speed of light, which just meets the requirement of localized causality.

In the quantum mechanics theory of the point particle model, human subjective suggestion contradicts the convention of special relativity.

(1) Non-locality of space and the shapes of the microscopic object

Real microscopic objects have shape structures. In transition, the minimum transition distance is the overall structure s=2R and R is the field matter sphere radius. The transition distance $s\neq 0$, the transition time still stipulates t=0 and the transition speed

$$v=s/t=s/0=\infty$$

Motion, and energy change "faster than light speed"! The quantum transition of the tangible object is accompanied by a space interval s=2R. The sudden insertion of the spacelike partition. The faster-than-light energy change between energy levels has a theoretical basis.

Experiments show that the spacelike compartments between quantum states are Compton waves Long $\lambda_c=\hbar/mc$ of the microscopic object, which undoubtedly provides theoretical and experimental support for the field matter sphere model. The space-like partition defined in the dual 4-dimensional space-time covariant quantum theory is the Compton wavelength of the microscopic object:$\lambda_c=\hbar/mc$, that is, the field matter sphere radius R of the microscopic object. Here the energy is quantized, the localized space is quantized, and the field is quantized.

Under the quantum transition hypothesis, between the quantum states $\Psi_n—\Psi_{n+1}$, there is an interspace between $\hbar/mc$ that the speed of light cannot communicate [7]. Eigenstates can be superimposed to replace the classical concept that particles cannot be superimposed and to sow the seeds for nonlocalized causality. However, the point model subjectively changes the change of physical space properties caused by objective reasons into the faster-than-light change of energy and motion properties of "point" particles, while the space-time properties remain unchanged, and continue to use the classical space-time, resulting in the disharmony between quantum mechanics and relativity. The fundamental way to eliminate contradictions is to return the subjective to the objective and construct a new physical space-time.

Quantum mechanical space-time is not ordinary Newtonian space-time or special relativity space-time, but a new space-time that satisfies the laws of quantum mechanics and reasonably explains quantum phenomena. It is the dual 4-dimensional quantum mechanical complex space -time. Dual 4-dimensional quantum mechanics can analyze the interrelations among time-like, light-like, and space-like Spaces by adopting the mathematical method of multi-dimensional state space and introducing a light cone graph from relativity. Dual 4-dimensional space-time quantum mechanics and special relativity have internal consistency and can communicate with each other.

(2) In the point particle model, the multi-dimensional state space has the same properties as the background space. The trade-off is that microscopic objects confer faster-than-light properties on motion, contradicting relativity. In the sphere model dual 4-dimensional space-time covariant quantum mechanics, the microscopic object move in space-time, and quantum transition increases the spacelike interval between states, thus changing the physical properties of state space, which is different from point model background space. In the dual 4-dimensional space-time covariant quantum mechanics, the quantization and quantum transition of the microscopic object structure is the root of space-time non-locality.

It can be seen that the physical properties of the state space of the point model and sphere model are different. In the sphere model, the quantum state in the dual 4-dimensional complex space-time, the localized interaction is cut off by the spacelike interval, and the matter waves propagate in the timelike space, which is coordinated with relativity. The quantum state of the point model in 4-dimensional real space-time implies that the particle has faster-than-light motion, which is incompatible with relativity. Spacelike interval and faster-than-light motion are equivalent expressions of the two models in different physical Spaces. To describe quantum phenomena, the sphere model of the dual 4-dimensional complex space-time is more reasonable than the point model of 4-dimensional real space-time.

The point model has localized causality in 4-dimensional real space-time, while the sphere model has non-localized causality in the dual 4-dimensional space-time. Quantum measurement leads to the introduction of continuous compensating action $U=e^{a(x)}$, the elimination of non- localization of physical spacetime, and the global transformation from the dual 4-dimensional complex space-time to 4-dimensional real space-time. It leads to the transition from sphere model to point model, from quantum field to classical field, and from matter waves to probability wave. The two Spaces can communicate through quantum measurement [7].

There are only two worlds, one is the microscopic quantum world, and the other is the macroscopic classical world. The microscopic quantum world is inherently non-localized causality and has parallel quantum states. Conversely, the state change of the macroscopic world requires the change of interaction and the change of interaction time, and it is impossible to form the existence of parallel quantum states similar to the quantum world because of the inherently localized causality.

In the macroscopic world, internal localized causality, force is the cause, and state change is the effect; The microscopic quantum world is inherently non-localized causality. The spacelike interval is the cause, and the parallel quantum state of the free microscopic object is the effect. The macroscopic world has no parallel worlds with the same meaning as the parallel quantum world.

In the dual 4-dimensional space-time covariant quantum theory, the wave function has matter properties and is a physical wave (confirmed by Shi Baosen et al. [17]). The time evolution of the Schrodinger equation is deterministic, which means that the time evolution of the density or structure of matter is deterministic. The randomness of wave function measurement is only the macroscopic experimental emergence of the probability properties of the wave function in the two types of spatial transformation [7].

### *4.12 Quantum State Quantum Segmentation Diagram*

Plane-wave superposition is the product of continuous function quantum partition（quantu m mutation added into spacelike interval）. Matter waves and probability waves are objective descriptions of quantum phenomena, but they are in different physical Spaces. The matter waves are at $W(x,k)$ and the probability waves are at $M^4(x)$. Conversion by quantum measurement.

Fig. 1 shows wave function with continuous energy variation Three-dimensional or four- dimensional flat Spaces, continuous curves, Rutherford atomic model: force action is the cause, the state change is the effect - local causality. The eigenvalues of the quantum state are contained in the continuous curve. As shown in figure 1

*Fig. 1:* Flat space, continuous curve

As shown as Fig. 2, in the dual 4-dimensional space-time $W(x,k)$, the quantized segmentation of energy and structure -- the intersegment function, the states are truncated by the tangible structure -- the spacelike interval $\lambda_c=\hbar/mc$ is added [7], which breaks the local causality and enters the non- local causality. Spatial non-localized is the cause, microscopic objects move freely, and the parallel existence of states is the effect. The eigenvalues of the quantum state correspond to the quantum parallel state and come from the continuous function quantum state.

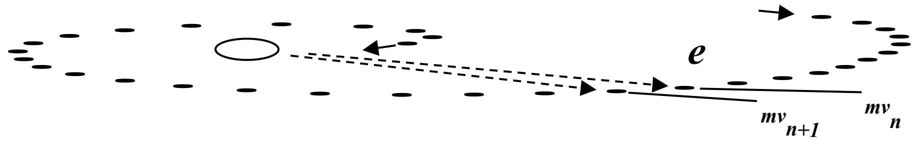


*Fig. 2:* Flat space, discontinuous function and space - like partition

From Fig. 1 to Fig. 2, it shows that the spacelike interval $\lambda_c=\hbar/mc$ is inserted, the break the mechanical causal chain, the localized causality is destroyed, and the states co-exist simultaneously, $\psi=\Sigma\psi_n$, pure state, and coherence. Cost: the sacrifice of classic local causality. Into the non-local causality and the quantum parallel state. Eigenvalues come from quantum states of continuous functions. The wave function propagates in W($x,k$) space.

From Fig. 2 to Fig. 1, it shows that a continuous compensation field U（$U\psi=\Sigma e^{a(x)}\psi_n$）is introduced in the measurement, which eliminates the fixed phase difference and breaks the non- local causality into local causality. The physical space-time changes from W($x,k$) to $M^4(x)$, the physical model changes, the quantum transition disappears, the continuous mechanical motion resumes, the mixed state is formed, and eliminate the coherence. The eigenvalues are presented in a probabilistic manner, and regression graph 1 continues in the eigenvalues.

## V. PROBABILITY MEASUREMENT DISPLAY AND SPACE-TIME CONVERSION

### *5.1 The Measurement of Quantum Probability*

Quantum measurement is understood from three main aspects. Firstly, physical principle. the measurement of the presence or absence of interaction; Secondary, mathematical expression, global, local phase transformation, eigenstate equation; Thirdly, design experimental display, measurement momentum and measurement position.

In the dual 4-dimensional space-time, it is considered that in the measurement statement $A\psi_n(x)=a_n\psi_n{}^k(x)$, the left and right wave functions of the equation will not be the same physical space-time considering the interaction factors in measurement. The pure state wave function on the left is in the dual 4-dimensional space-time, and the mixed state wave function on the right is in the 4-dimensional real space-time. At this time, the essence of quantum measurement is to lead to the transformation of cognitive level and the transformation of physical time-space of describing quantum phenomena.

The invariance of the mathematical form of $\psi^k(x)$ and $\psi(x)$ just guarantees the invariance of the form of the Schrodinger equation or Dirac equation, describing the microscopic quantum object in two space-times. The mathematical form of $\psi^k(x)$ and $\psi(x)$ in the two space-times is unchanged, which indicates that the ontology is continuous without fracture. This is what structural realism and realism of interaction are based on. Kuhn's paradigm is incommensurable and noumenon fracture is wrong. How to realize the probabilistic motion of quantum mechanical matter-wave to point particle involves the physical principle, experiment, and mathematical operation of transforming the dual 4-dimensional space-time into 4-dimensional real space-time [7,8].

### *5.1.1 Quantum Measurement Mechanics Analysis and Space-Time Transformation in the Dual 4-Dimensional Space-Time*

Although the physical model of the microscopic object in the dual 4-dimensional space-time is the field matter sphere, the field matter sphere has been transformed into matter waves $\psi(x)$ in the theoretical description. The phase transformation on $\psi(x)$ will be reflected in the interaction of the microscopic object. In phase transformation, the phase factor $e^{\alpha(x)}$ multiplied by $\psi(x)$ is a mathematical statement of this interaction.

(1) If the multiplied phase factor $\boldsymbol{e^{a(x)}}$**,** causes the waves function fixed phase difference to disappear, this would be the introduction of a substantial continuum interaction. The pure state waves function $\psi n(x)$ on the left side of the equation is transformed into the mixed state waves function $\psi^{k}(x)$ on the right side of the equation. In this case, $\psi^{k}(x)$ is not in dual 4-dimensional space-time, is purely a quantum probability function of a point particle in 4-dimensional real space, and has no coherence. At this time, the essence of quantum measurement is a space-time transformation, which converts dual 4-dimensional space-time to 4-dimensional real space-time, and the matter-wave evolves into a probability wave, and the mathematical form of wave function remains unchanged. The invariance of the mathematical form of the waves function guarantees the invariance of the form of the Schrodinger equation and Dirac equation in the two space-times before and after the measurement.

The description of space-time has changed, and the physical model will change, too. The sphere model of the dual 4-dimensional space-time has evolved into a point model of 4- dimensional real-time space. The wave phase of the microscopic object evolves into the particle phase. The space-time transformation transforms the probabilistic property of the dual 4- dimensional space-time into the probabilistic motion of point particles in 4-dimensional space- time.

The $\psi(x)$ collapse will reflect the transformation of cognitive level, the transformation of physical space-time describing quantum phenomena, entanglement resonance, and so on. During the space-time transition, there are no collapse process waves and no direct faster-than-light motion of the microscopic object. The single measurement result $a$k appears, is the microscopic object probability motion and instrument measurement resonance display. Multiple measurements reflect the transformation of the probabilistic properties of space-time into the probabilistic motion of the microscopic objects.

Through measurement, quantum probability can be able to render by cognitive level change, space-time transformation, and physical model change. Its origin is different from both classical thermodynamic probability and macroscopic classical statistical probability. As mentioned earlier, quantum probability derives from the spatial distribution and the matter density distribution properties of the microscopic objects. It doesn't need an implicit variable. In the dual 4- dimensional space-time, matter tells space-time how to have probabilistic properties, and by quantum measurements, space-time tells matter how to make a probabilistic motion.

(2) If the multiplied phase factor $e^{\alpha(x)}$ ($\alpha(x)$ = constant), causes the waves function fixed phase difference to remain, it is the coordinate translation of matter waves. Measure the momentum and let the matter waves pass through the single slit and double slit. At this time, the measurement does not introduce substantial interaction and the space-time where the matter waves are located does not change. After the wave packet "collapses", are still matter waves-pure monochromatic plane waves in the dual 4-dimensional space-time. Using diffraction and interference of wave, its wavelength can be calculated accurately. In the dual 4-dimensional space-time, momentum can be accurately measured.

(1) Unitary transformation

$$\psi = e^{\alpha(x)}\psi(x)\ ,\quad \alpha(x) = H(t);$$

The transformation preserves the invariance of the eigenvalues and the trace of the matrix.

(2) The gauge transformation

For the global gauge transformation, $a(x)$ = constant

$$\psi = e^{\alpha(x)}\psi(x) = \sum c_n e^{\alpha(x)}\psi_n(x)$$

After the transformation, there is still a fixed phase difference between the eigenstates, the coherence still exists, and the properties of pure states remain unchanged. It's the coordinate translation of the matter wave, still in the dual 4-dimensional space-time.

For the local gauge transformation, $\alpha(x)$ = variable (function of $x$)

$$\psi = e^{\alpha(x)}\psi(x) = \sum c_n e^{\alpha(x)}\psi_n(x) = \sum c_n \Phi_n$$

The fixed phase difference between the eigenstates disappears, the interaction is introduced in essence, and the pure state evolves into the mixed state. For electromagnetic action, Lorentz invariance of the Dirac equation can be discussed by adopting vector potential A and introducing

(3) General phase transformation

For the global transformation $a(x) =$ = constant

$$\psi = e^{\alpha(x)}\psi(x) = \sum c_n e^{\alpha(x)}\psi_n(x)$$

After the transformation, there is still a fixed phase difference between the eigenstates, and the coherence properties of the pure states remain unchanged. The global transformation has no substantial interaction involved. But it's also supposed to be a quantum measurement. Matter- wave packets "collapse" into pure monochromatic plane waves [13].

In the equation of eigenstate $\boldsymbol{A}\psi_n(x) = a_n\psi^{k}(x)$, the wave functions $\psi_n(x)$ of the left and right sides of the equation are in the dual 4-dimensional space-time, which are physical waves, pure states, and which are coherent of waves. It is the physical basis for defining the mixed state as pure incoherent mixing. In fact, it's a constructed mixed state, and it's needed in quantum communication. By designing experiments and using the interference effect of plane waves, we can know the exact momentum of the microscopic object from the wavelength. Matter waves can be used to measure the momentum of microscopic objects.

Momentum is knowable in dual four-dimensional space-time. We use it to define curvature coordinates. The action quantity in the path integral is also well defined, and the question of Dirac's student does not exist [1,7,8]. At the same time, according to the sphere model, momentum is large and curvature is large (equivalent matter density large), the uncertainty of position is small; Momentum small, curvature small, position uncertainty large; The momentum is infinitely large, the curvature is infinitely large, and the position of falling on the geometric point is completely determinable; Momentum zero, curvature zero, plane, a position completely uncertain, in the dark. Heisenberg's uncertainty relation has a realist explanation.

For the local transformation, $a(x)$ = variable (function of $x$)

$$\psi = e^{a(x)}\psi(x) = \sum c_n e^{a(x)}\psi_n(x) = \sum c_n \Phi_n = \Phi$$

The fixed phase difference disappears and the coherence of waves disappears. The pure state evolves into a mixed state. Embodied measurement introduces substantial interactions. It is a nonlinear R process of quantum measurement, which is carried out simultaneously in the whole space, and the invariance of linear equations is destroyed.

Before measurement, the wave function of the measured microscopic object is in a pure state, in W($x$,$k$) space. If $\psi(x) = \Sigma\psi_n(x)$, there is a fixed phase difference between the superposition eigenstates, and there is coherence. Interaction potential $U=e^{a(x)}$ is introduced in the measurement, then.

$$e^{a(x)}\psi(x) = e^{a(x)}\sum c_n\psi_n(x) = \sum c_n e^{a(x)}\psi_n(x) = \sum c_n \Phi_n = \Phi$$

The free motion of the quantum parallel pure state is destroyed and the spacelike interval disappears. The fixed phase difference between the eigenstates disappears simultaneously in the whole space, the phase difference changes continuously, the wave function evolves into a mixed state, and the coherence disappears. The description space is transformed, and people's cognitive level simultaneously enters the 4-dimensional real space $M^4(x)$. The physical essence of the local transformation $e^{a(x)}\psi(x)$ eradicate coherence is that the continuous potential function and the phase change are introduced simultaneously in the whole space. There is no faster-than-light propagation of information, as Einstein called it.

### 5.2 Interaction of the Microscopic Object in the Dual 4-Dimensional Space-Time and Interpretation of Instrument Measurement Function

Gauge field theory is the cornerstone of the Standard Model. However, in standard field theory, the wave function is given a probabilistic interpretation from the very beginning, and matter waves are probabilistic waves [18]. The gauge transformation in gauge field theory is the mathematical operation of probability function, and the introduced gauge field $A$ is the vector potential of the electromagnetic field and is the auxiliary quantity of electric field (E). Gauge transformation gives more impression of mathematical significance than physical ones. Matter waves in the dual 4-dimensional space-time are physical waves [7]. The gauge transformation of physical waves reveals the real physical significance of the gauge transformation.

#### 5.2.1 Traditional Global Gauge Transformation

The global gauge transformation of the wave function of the charged free microscopic object is carried out [18], $a$ = constant, $\partial a = 0$

$$\psi \to \psi' = e^{-i\alpha}\psi \quad , \quad \overline{\psi} \to \overline{\psi}' = \overline{\psi}\, e^{i\alpha}$$

$$\partial_\mu \psi \to \partial_\mu \psi' = e^{-i\alpha}\partial_\mu \psi$$

$\psi$、$\overline{\psi}$、$\partial_\mu \psi$ The same rules transformation. Gauge invariance is established, the Lorentz covariant Dirac equation is obtained

$$(ir^\mu \partial_\mu - m)\psi = 0$$

The solution of the Dirac equation confers a probabilistic interpretation. Wave functions are not deterministic and the meaning of physical realism is unclear.

### *5.2. 2 Traditional local gauge transformation*

In the above formula, if the multiplied phase factor α is a function of the space-time coordinate *x*. Local norm transformation of field quantity ψ and its derivative $\partial_\mu\psi$ of charged free microscopic object [18] :

$$\psi \to \psi' = e^{-i\alpha(x)}\psi, \quad \overline{\psi} \to \overline{\psi}' = e^{-i\alpha(x)}\overline{\psi}$$

$$\partial_\mu \psi \to \partial_\mu \psi' = \partial_\mu [e^{-i\alpha(x)}\psi]$$

$$= e^{-i\alpha(x)}\partial_\mu \psi - i\partial_\mu \alpha(x) e^{-i\alpha(x)}\psi \neq e^{-i\alpha(x)}\partial_\mu \psi$$

Traditional analysis shows that the Lorentz covariant Dirac equation cannot be obtained because ∂μα (x) ≠0, and the transformation of field quantity and its derivative is inconsistent. By introducing the covariant derivative $D_\mu$

$$\partial_\mu \to D_\mu = \partial_\mu - ieA_\mu$$

The Dirac field equation of the same form can be obtained:

$$(ir^\mu D_\mu - m)\psi = 0$$

It can be seen that by introducing A gauge field $A_\mu$ through covariant derivative, the interaction between electromagnetic field and charged the microscopic object can be reflected, and the local gauge transformation gauge invariance can be restored.

Dual 4-dimensional space-time considers that the global gauge transformation is the coordinate translation of free electron matter wave. The electrons are already exposed to the electromagnetic field in a local gauge transformation. Embody $\partial_\mu\alpha$ (*x*) ≠0. The state of free motion and Lorentz covariation are destroyed, so the form of the Dirac field equation is destroyed. The covariant derivative $D_\mu$ introduces the gauge field $A_\mu$ to reflect the electromagnetic effect. In fact, it is a physical and mathematical operation to eliminate the effect of the introduced electromagnetic field in the local gauge transformation, eliminate the influence of $\partial_\mu\alpha$ (*x*) ≠0, restore the free motion state of electrons and Lorentz covariant, and ensure the unchanged form of the Dirac field equation.

Spin in the dual 4-dimensional space-time has a natural physical definition and is no longer a property of point particles [7]. In the experiment of electron spin of the silver atom, the local transformation of the spin wave function ψ(x) is carried out, and the nonuniform magnetic field is the classical electromagnetic coupling effect on electron spin. Electrons go from a pure state to a mixture of the spin up and the spin down. Describes the transformation of space-time from W(x,k) to $M^4(x)$. In the laboratory space, we will observe the fine structure of two lines above and below the orbital motion of the spin up and the spin down mixed state electrons [7,19]. Here, the introduction of an inhomogeneous magnetic field is a quantum measurement involving the Penrolaus nonlinear R process.

If the invariance of the Dirac equation and the electromagnetic action of an electron is discussed in the quantum field, the vector potential $A_\mu$ of the electromagnetic field should be adopted, and a series of mathematical physical operations of the covariant derivative is considered.

The weak interaction and quantum chromodynamics are similar. In the interaction of quark and gluon fields, mathematics uses group theory. Considering the physical reality of quark and gluon fields and the physical significance of their phase, quantum chromodynamics can make the same mechanical analysis. The interaction between quark and gluon fields is also realized in the local gauge transformation, and the introduction by the covariant derivative into the gauge field is only a counteracting effect. The invariance of the form of the Dirac field equation can be guaranteed by the quark's free motion again.

In the dual 4-dimensional space-time, the essence of quantum measurement is to carry out a full-space instantaneous space-time transformation through the introduction of interaction, transforming the dual 4-dimensional space-time into 4-dimensional real space-time, transforming the sphere model into the point model, and transforming matter waves into probability waves. Matter tells space-time how to have probabilistic properties, and by quantum measurements, space-time tells matter how to Probability of movement. In fact, the introduction of a continuous potential $U=e^{a(x)}$, the elimination of spacelike partition, and the space-time transformation in full space are mathematical and physical operations. The transformation of the wave function takes place simultaneously in the whole space, There is no"the converted waves" propagation[7]. The instantaneous propagation of information and the formation of entangled states in quantum entanglement are the results of the simultaneous transformation of wave functions in the whole space.

### *5.2.3 Mathematical Representation of Decoherence and Local Transformation for Macroscopic Instruments*

In the dual 4-dimensional space-time, the macroscopic measurement instrument can be automatically decoherence.

The macroscopic instrument is designed and manufactured by the classical point particle theory of 4-dimensional real space-time. There is no quantum mutation hypothesis and no spacelike partition between states. There is continuous interaction between states. It does not constitute a pure quantum state, but can be written as a mixed state at most. Because of the existence of continuous potential, the instrument has the ability of automatic decoherence.

The state of the macroscopic instrument can be directly observed, and of course, the measurement display can be directly observed. In quantum measurement, the macroscopic instrument not only changes the cognitive level of the system under test but also transforms the describing space-time to return to the classical space-time to record the measurement results. This is the physical essence of instrument translation in quantum measurement. The irreversible evolution from the pure state to the mixed state in the measurement indicates that the macroscopic measuring instrument is unable to make the microscopic measured system automatically return from the mixed state to the microscopic pure quantum state. This is the inevitable result of the establishment of macroscopic instrument theory, design, and manufacturing principles.

According to von Neumann's measurement theory, the initial state of the macroscopic instrument is assumed to be $X_o(x)$. $X_{on}(x)$ is the decomposition pure state, and $X_o(x) = \sum X_{on}(x)$. There is a fixed phase difference between $X_{on}$ and $X_{on+1}$ and there is coherence. The final state of the instrument is $X_n(x)$. $X_{nn}(x)$ is the final pure state of decomposition, and $X_n(x) = \sum X_{nn}(x)$. There is also a fixed phase difference between $X_{nn}$ and $X_{nn+1}$, and there is also coherence. The instrument is self-coherent.

However, these are purely hypothetical. The self-coherence properties of instruments have never been observed. Instrument auto-coherence is not allowed in measurement, so a variety of automatic instrument decoherence schemes are proposed. But so far there has been no successful case. It would be absurd for decoherence to require the last glance of God or man.

In the dual 4-dimensional space-time, the self-coherence of macroscopic instruments is eliminated automatically in theory and instrument design and production, considering local transformation.

If the macroscopic measuring instrument in quantum mechanics is decomposed into the macroscopic component states, even the microscopic component states, it is clear that the interaction between the component states will be governed by the continuous interaction potential $U=e^{a(x)}$. This shows that the states $X_{on}$, $X_{on}+1$, or $X_{nn}$ and $X_{nn}+1$ are governed by the continuous interaction potential $U=e^{a(x)}$, which is automatically constituted by a local transformation

$$X_0(x)\to X_0(x)' = e^{a(x)}X_0(x)=e^{a(x)}\sum X_{0n}(x) = \sum e^{a(x)}X_{0n}(x)=\sum X_{0n\Phi}=X_{0\Phi}$$

$$X_n(x)\to X_n(x)' = e^{a(x)}X_n(x)=e^{a(x)}\sum X_{nn}(x)=\sum e^{a(x)}X_{nn}(x)=\sum X_{nn\Phi}=X_{n\Phi}$$

$\Phi$ is the mixed state mark. $X_{0n\Phi}$ and $X_{nn\Phi}$ are the mixed components of the initial and final states. Under the action of continuous potential $U=e^{a(x)}$, the initial and final states of the macroscopic instrument automatically evolve into mixed states $X_{0\Phi}$ and $X_{n\Phi}$. Analog wave Function

$$\psi\to\psi' = e^{a(x)}\psi = e^{a(x)}\sum c_n\psi_n=\sum e^{a(x)}c_n\psi_n=\sum c_n\Phi_n \quad (35)$$

The local transformation. The interaction could be a classical potential.

Inside the macroscopic instruments, the continuous interaction potential $U=e^{a(x)}$ exists, the fixed phase difference between the internal states do not exist at all, and the phase interference of waves does not exist. The states $X_o(x)$ and $X_n(x)$ of the macroscopic instruments can only appear in the form of mixed states $X_{o\Phi}$ and $X_{n\Phi}$. Therefore, there is a theoretical basis for the absence of self-coherence in the macroscopic instruments. In von Neumann's measurement entanglement model, there are some problems with the pure state assumption of the macroscopic instrument, and the physical essence of the intrinsic continuous interaction and local transformation of the instrument is not taken into account. Therefore, any other assumptions about the automatic decoherence of the instrument are redundant.

The biological and physiological organs of the Schrodinger cat, even if observed down to the molecular and atomic level, are dominated by macroscopic continuous interaction. The macroscopic cat can only be a mixed state $\Phi_n$, there is no dead cat, live cat parallel pure state existence. Its decoherence is self-completed by biological mechanisms, and the mathematical expression is also an equation (35). There are also theoretical reasons why we don't observe the phase interference of waves of the macroscopic cat.

## VI. CONCLUSION

The physical model of quantum mechanics is a rotating field of matter ball, particle model is not applicable. The physical space-time describing quantum phenomena is dual 4-dimensional space-time, which has the characteristics of construction [20]. It is equivalent to Newtonian space-time, special relativity space-time, and gravitational space-time in describing nature.

1. The wave function can be derived strictly from the motion of the field matter ball. Matter waves are physical waves. The traditional cognitive confusion of wave function can be completely eliminated and has new physical applications [21,22]. Such as the coulomb blocking Matter wave cognitive

experiment (electronic wave barrier-free through the Coulomb blocking), matter-wave chip engrave technology experiment, matter-wave communication technology experiment, and so on.

2. Matter tells space-time how to have probabilistic properties, and space-time tells matter how to behave in probabilistic motion.
3. The spatial distribution and mass density distribution of microscopic objects are the origins of quantum probability. Quantum probability is completely different from thermodynamic probability and classical statistical probability.
4. Different macro and micro physical mechanisms and different causal relationships. Quantum superposition states have microscopic physical mechanisms to follow. Quantum measurement changes the nature of causality correlation, and the pure state becomes a mixed state. It is crucial to thoroughly understand the physical mechanism of phase transformation of the wave function.
5. In dual 4-dimensional space-time, the calculation of field interaction cutoff is at the curvature $K_0$, and there is no infinite divergence difficulty.
6. The deep application of the Wigner function method based on dual 4-dimensional space-time covariant quantum mechanics penetrates the new understanding of many important physical meanings of the quantum mechanical formal system. The cognitive difficulties in the traditional quantum mechanical formal system are almost eliminated. Wigner Moyal product (*) wave equation is equivalent to Schrodinger equation, Diracequation, and Feynman path integral equation.

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*Note*

*Note 1:* China university of science and technology of Jian-wei Pan, Zhao-yang Lu, Xiao-bo Zhu, and professor at the university of Seville, Spain Cabello, using ultra-high precision superconducting quantum circuits for deterministic entwine exchange, at more than 43 standard deviations of the experiment proved that the precision of real number cannot complete description standard quantum mechanics, established the objective reality of complex numbers description. The findings were published as an "editor's recommendation" in Physical Review Letters. Viewpoint and News & Views were respectively invited by the website of American Physical Society Physics and the journal Nature. (China University of Science and Technology News Network Mozi Salon 2022-01-30 16:06)

*Note 2:* Some important nouns: 1) interaction realism, 2) time-like space, 3) spacelike space , 4) phenomena, 5)sphere model, 6) particle model, 7) microscopic quantum object, 8) matter waves, 9) rotating field matter sphere, 10) physical space-time, 11）dual 4-dimensional space-time, 12） macroscopic object.

*Note 3:* about the author: Zhao Guo-qiu, 1944.10.--, male, researcher, 1969.8. Graduated from Huazhong University of Science and Technology. Research directions: Philosophy of Physics, basis of quantum mechanics, basis of modern Science in Traditional Chinese Medicine basis Theory.

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