New quantum gravity effect, dark energy, accelerating universe, black hole and experimental scheme using superfluid Helium and atom interferometer

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Abstract

Considerable attention has been focused on Verlinde’s recent work, claiming that Newton’s gravity is not a fundamental force. In a recent work (arXiv:1012.5858), we give further the logic basis and basic clues to derive the Newton’s gravity, inertia law and Einstein’s weak equivalence principle. In this work, we show that if the gravity is not a fundamental force, in special case, it could be repulsive when quantum wavepacket effect is considered. This quantum gravity effect leads to several physical effects: (1) It is consistent with the universe with accelerating expansion, if the gravity and quantum effect of the fluctuating “vacuum” (dark energy) is considered. The role of the cosmological constant is naturally interpreted when the gravity and quantum effect of the whole “vacuum” background is considered. (2) It leads to new idea about black hole information paradox, no-hair theorem and Hawking radiation. (3) With a sphere full of superfluid Helium, we propose a feasible experimental scheme to test our idea with an atom interferometer placed in the sphere. Our calculations show that the accuracy $\Delta g/g$ below $10^{-8}$ could be used to test our idea, which satisfies the present experimental technique of atom interferometer.
Introduction. The pioneering works by Jacobson [1] and Verlinde [2] have suggested a new understanding about the origin of Newton’s gravity. These advances were motivated by the fact that the gravity law closely resembles the laws of thermodynamics and hydrodynamics [3–8]. Briefly speaking, these works give the clue that the universe gravity is not a fundamental force. The universe gravity can be derived similarly to the pressure for a classical gas in a box. In a recent work, we give a reconsideration of Verlinde’s work [2] by establishing the physical mechanism about the assumption of the change of entropy $\Delta S$ for an object having a displacement $\Delta x$ and the Unruh effect which assuming a temperature for an accelerated object. This paves the way to consider further the physical effect if the gravity is regarded as an entropic force with the highly fluctuating “vacuum” as the medium.

In the present work, we consider a unique quantum gravity effect where the gravity could be repulsive in special case, when quantum wavepacket effect is sufficiently considered. We study the application of this quantum gravity effect to accelerating universe, dark energy, cosmological constant, dark hole, etc. In particular, with a sphere full of superfluid Helium, we propose an experimental scheme to test our idea with an atom interferometer placed in the sphere. Our calculations show that the accuracy $\Delta g/g$ below $10^{-8}$ could be used to test our idea, which could be satisfied by the present experimental technique of atom interferometer.

Entropy increasing process for an object having a displacement and Unruh temperature. Our starting points are the following two formulas.

(1) The formula about the change of entropy $\Delta S$ after a displacement $\Delta x$ for a particle with mass $m$.

$$\Delta S = 2\pi k_B \frac{mc}{\hbar} \Delta x.$$  \hspace{1cm} (1)

Detailed studies of this formula are given in Ref. [9]. Here we give a brief discussion. First we image a speedboat moving in the sea. The speedboat left behind a navigation path in the sea. After a navigation of distance $\Delta x$, the speedboat stopped. Waiting sufficient time, we cannot know the navigation path in the sea. If the location resolution in the navigation path in the sea is $l_c$, about $\Delta x/l_c$ bits of information are lost. In this situation, there is an entropy increasing of $\Delta S \sim k_B \Delta x/l_c$. For a matter (similar to the speedboat) moving in the “vacuum” background (similar to the sea), the coupling with the “vacuum” background leads to a location resolution (or coherence length) of $l_c \approx 2\pi \hbar/mc$ [9]. From this, we get the above equation. About the location resolution, one may also see Ref. [10], where the
noncommutative coordinate operators are used to consider this problem.

(2) The Unruh temperature induced by a uniformly accelerating object in the “vacuum” background.

In Ref. [9], we give a derivation of Unruh temperature in a one-dimensional case. Here we consider the situation of three-dimensional space. Considering a particle with acceleration \( \mathbf{a} \), we have

\[
x_j = \frac{a_j t^2}{2}.
\]

Here \( j = 1, 2, 3 \). From Eq. (1), we have

\[
dS = \frac{2\pi k_B m c}{\hbar} \sqrt{\sum_j (a_j t)^2} dt.
\]

In addition, we have

\[
dE \approx m \sum_j a_j a_j t dt.
\]

Using \( dE = T dS \), we have

\[
k_B T \approx \frac{\hbar}{2\pi c} \sqrt{\sum_j (a_j t)^2}.
\]

From this, we get the famous Unruh temperature

\[
k_B T \approx \frac{\hbar |\mathbf{a}|}{2\pi c}.
\]

We also have \(|\mathbf{a}| \approx 2\pi k_B c T / \hbar\).

However, the acceleration is a vector. Therefore, the above formula is not clear about the direction of the acceleration. When the temperature \( T \) is regarded as a sort of temperature field distribution, the most simple way to get the direction of the acceleration is given by the following formula

\[
\mathbf{a} \approx \frac{2\pi k_B c T}{\hbar} \frac{\nabla T}{|\nabla T|}.
\]

We will show in due course that the above equation agrees with the fact that the gravitation is attractive between two spatially separated objects.

From the thermodynamical formula \( dE = \mathbf{F} \cdot d\mathbf{x} = T dS \) and Eqs. (2)-(5), we have

\[
\sum_j F_j a_j = m \sum_j a_j a_j.
\]
From the above equation, we get the following inertia law

\[ \mathbf{F} = m \mathbf{a}. \]  

(9)

These studies show again our previous result in Ref. \[9\] that the change of the entropy given by Eq. (1) is dependent on the overall length of a trajectory, rather than its shape, because Eq. (3) is used in the above calculations.

**Derivation of Newton’s gravity for classical objects.** To show clearly the unique gravity effect in this work, we first give a derivation of Newton’s law of gravity. We consider the emergent force between two objects with mass \( M \) and \( m \), shown in Fig. 1(a). To solve this problem, we first consider the situation shown in Fig. 1(b), where the mass \( M \) is uniformly distributed in a region between two spherical surfaces with radius \( R \) and \( R + l_p \). Assuming \( R >> l_p \), the overall volume of this region is \( V \approx 4\pi R^2 l_p \). This region is divided into \( N = V/l_p^3 \approx 4\pi R^2 l_p^2 \) equal parts. In this situation, in every part, the mass is \( m_0 = M/N = Ml_p^2/4\pi R^2 \). Fig. 1(c) gives a cross section diagram of Fig. 1(b). We consider the emergent force with the “vacuum” background as the medium. More precisely, both objects have strong coupling with the “vacuum” background, and local thermal equilibrium will result in an emergent force.

Because the coupling with the “vacuum” background is considered, special relativity should be used from the beginning. From the mass-energy relation \( \varepsilon_0 = m_0 c^2 \), we get an effective temperature \( T_M \), determined by

\[ \frac{1}{2} k_B T_M = \varepsilon_0. \]  

(10)

For a particle with mass \( m \) approaching this sphere, the Unruh temperature \( T_m \) of this particle should be equal to \( T_M \) because of thermal equilibrium, i.e.

\[ T_M = T_m. \]  

(11)

By using the Unruh formula (6), we get

\[ |a_m(R)| = \frac{M c^2 l_p^2}{R^2 \hbar}. \]  

(12)

By introducing the gravitation constant \( G \), we get \( l_p = \sqrt{\hbar G/c^3} \), which is just the Planck length. A derivation of why the Planck length plays a role is given in Ref. \[9\].
FIG. 1: The scheme to derive Newton’s law of gravity for two classical objects.

different locations of the object with mass $m$ shown in Fig. 1(a) are considered, the above calculations suggest a self-consistent temperature field distribution

$$T_M(R) = \frac{\hbar GM}{2\pi k_B c R^2}. \quad (13)$$

Of course, this temperature is the same as the result from Eq. (10). However, the application of Unruh formula makes this temperature field distribution do not depend on the virtual process in Fig. 1(b) any more.

From Eq. (7), we have

$$a_m(R) = -\frac{GM R}{R^3}. \quad (14)$$

With the inertia law, we get Newton’s law of gravitation

$$F = -\frac{GM m R}{R^3}. \quad (15)$$

Repeating the above calculations, it is easy to show that the gravity force acted on $M$ is just $-F$.

For an assembly of classical particles (here “classical” means that the quantum wavepacket effect is negligible) shown in Fig. 2, we assume the temperature field distribution due to the $i$th particle is $T_i(R)$. Because there is no quantum interference effect
between different classical particles, the force (a measurement result in the view of quantum mechanics) on the object with mass $m$ is

$$\frac{F(R)}{m} = a_m(R) = \frac{2\pi k_B c}{\hbar} \sum_i T_i(R) \nabla_R T_i(R). \quad (16)$$

From this, one may definite an effective temperature vector field

$$T(R) = \sum_i \frac{T_i(R) \nabla_R T_i(R)}{|\nabla_R T_i(R)|}. \quad (17)$$

In this situation,

$$a_m(R) = \frac{2\pi k_B c}{\hbar} T(R). \quad (18)$$

Note that $|T(R)| \neq \sum_i T_i(R)$. When Eq. (16) is used, one can get the correct result of the acceleration for the case of a classical sphere shown in Fig. 3(c) and Fig. 3(d).

**Abnormal quantum gravity effect.** It is natural to consider what will happen in the gravity effect when the quantum effect of matter wave is addressed, for example, the gravity interaction between a Bose-Einstein condensation comprising $N$ particles and a classical
FIG. 3: Fig. (a) shows a wavepacket distribution of a particle in the black sphere. Fig. (b) shows the gravity acceleration due to this quantum wavepacket. Figs. (c) and (d) show the classical situation, respectively.

To study this subtle problem, we first consider a well-known contradiction when weak equivalence principle is applied to a quantum wavepacket.

It is well-known that the following Schrödinger equation in a gravitational potential does not satisfy weak equivalence principle.

\[ i\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m_I} \Delta \Psi + m_g g x \Psi. \]  

(19)

Here \( m_I \) and \( m_g \) are inertial mass and gravitational mass, respectively. \( g \) is the gravitational acceleration. It is clear that the solution of this equation is highly dependent on the mass of the particle. As shown in Ref. [9], both \( m_I \) and \( m_g \) are the same physical concept of the mass in the mass-energy relation. The contradiction with weak equivalence principle lies in that the basis of the weak equivalence principle is due to the property that \( m_I \) and \( m_g \) are the same physical concept. For classical particle satisfying \( \mathbf{F} = m_I \mathbf{a} \) and \( \mathbf{F} = m_g \mathbf{g} \), we have \( \mathbf{a} = \mathbf{g} \) which does not dependent on the mass of the object. Because a classical particle can be regarded as a localization of the wavepacket due to a random superposition of a series of plane wave (the coupling with environment may play a role too), from the quantum
master equation including the effect of wavepacket localization, we still get $\langle F \rangle = m_I \langle a \rangle$ and $\langle F \rangle = m_g \langle g \rangle$, which will further lead to $\langle a \rangle = \langle g \rangle$. Hence, the weak equivalence principle is not an universal law. It is a classical limit of the property that $m_I$ and $m_g$ are the same physical concept. If the gravity is not regarded as a fundamental force, there is not a problem of essential unification of gravity and quantum mechanics any more. The urgent problem becomes how to consider the quantum effect of a wavepacket with mass $m$ when there exists gravity, and the gravity field distribution when there is quantum effect in the object $M$.

We consider the gravity effect of a particle described by a wave function $\Psi(x, t)$, shown in Fig. 3(a). Assuming the radius of the black sphere is $R_0$, $\Psi(x, t)$ is assumed as

$$
\Psi(x, t) = \begin{cases} 
1 & (R < R_0), \\
0 & (R > R_0).
\end{cases}
$$

(20)

Assuming further that the mass of this particle is $m_q$, the first problem would be what is the temperature field distribution of this particle. For $R > R_0$, it is easy to get

$$
T_q = \frac{hGm_q}{2\pi k_B CR^2}.
$$

(21)

At $R = 0$, the central symmetry leads to $T_q = 0$. It is clear that the temperature field
distribution is that shown in Fig. 4. For \( R < R_0 \), we have

\[
T_q = \frac{\hbar Gm_q R}{2\pi k_B c R_0^3}.
\]  

(22)

From Eq. (17), we will get similar result of \( T = |T| \) for a sphere uniformly distributed with classical particles. When Eqs. (17) and (18) are used for this classical sphere, we will get the acceleration for another classical particle \( m \) shown in Fig. 3(d), which is of course reasonable.

For the quantum wavepacket shown in Fig. 3(a), if we use \( a \approx 2\pi k_B c T_q \nabla T_q / \hbar |\nabla T_q| \) given by Eq. (7), however, we will get

\[
a = \frac{Gm_q R}{R_0^3}, (R < R_0),
\]

\[
a = -\frac{Gm_q R}{R_0^3}, (R > R_0).
\]  

(23)

This means a remarkable predication that for a classical object within a quantum sphere, the gravity is repulsive! This abnormal effect is shown in Fig. 3(b). It is clear that this abnormal quantum gravity effect physically originates from the quantum wavepacket effect for the particle in the black sphere.

**Counterstrike and defense of this abnormal quantum gravity effect.** An immediate counterstrike to this abnormal effect would be that if the sphere is divided into \( Q \) equal parts, and each part establishes a temperature field distribution \( T_i \), the application of Eq. (16) would lead the same result for the classical sphere in Fig. 3(d). However, the summation in Eq. (16) has already the implicit assumption that there are a lot of classical particles in the sphere, and thus there is no quantum wavepacket effect. Because the acceleration is an observable quantity, the division of the sphere in Fig. 3(a) will destroy the quantum wavepacket characteristic. If the particle in the sphere of Fig. 3(a) is a mixed state, we have the following density matrix

\[
\hat{\rho} = \frac{1}{Q} \sum_{i=1}^{Q} |\Psi_i\rangle \langle \Psi_i|.
\]  

(24)

Here \( \Psi_i \) is a localized wavefunction in the \( i \)th region. Eq. (16) can be used for this case. It is very clear that \( \langle a \rangle \) satisfies the gravity effect of classical situation. As stressed earlier, the abnormal acceleration is due to the quantum wavepacket effect of the particle in the sphere. The essential distinguish between mixed and pure states itself gives a support for this abnormal effect.
The second counterstrike would be that in the situation of quantum wavepacket in the sphere, it seems that there is a violation of Newton’s third law. For a classical particle in this sphere, the force is repulsive due to the quantum wavepacket effect. However, the whole force on the whole quantum wavepacket by this classical particle is still attractive. This leads to a violation of Newton’s third law. It is not clear whether the inclusion of “vacuum” background or other physical effects will restore this precious law. A particle is regarded as classical, when the coupling with the environment makes the wavepacket highly localized. The coupling of the classical particle with the environment may give a probable clue to solve the problem of the violation of Newton’s third law. Nevertheless, the Newton’s third law is about classical system. Hence, we should be always careful whether it holds when quantum effect is addressed. In fact, there is probable experimental evidence that the Newton’s third law has already been violated [11, 12].

The third counterstrike would be the query about the application of Eq. (7), because this is derived for a classical particle. I believe this is not a problem. The basis of this formula is in fact quantum mechanics. For classical particle, because of its highly localized wavepacket, this equation can be used. Of course, if this particle is also a quantum wavepacket, Eq. (7) should be included in a Schrödinger equation without extra difficulty, similarly to $m_g g x$ in Eq. (19).

The fourth counterstrike would be the query about noncontinuous property of the acceleration shown in Fig. 3(b). In most situations, one cannot observe this effect, because of three reasons. (1) In most situations, this is a very weak effect; (2) Fig. 3(b) is calculated for ideal situation, i. e. there is an ideal boundary condition in the wavefunction given by Eq. (20); (3) the gravity effect due to the environment such as earth, experimental apparatus etc., will further make the noncontinuous property become blurred. When the black hole is considered, however, we will show that this noncontinuous property may have important physical significance.

The fifth counterstrike would be that if the motion of the classical object is measured, the information of the location of the particle (initially a quantum wavepacket in the black sphere) will also be known by the observer. In this situation, there is a wavepacket collapse of this particle. Thus, Eq. (23) cannot be used any more.

The last counterstrike is absolutely reasonable. To experimentally test our abnormal gravity effect, we thus consider $N$ particles in the same quantum state given by Eq. (20).
In this situation, we have

\[ T_N = \sum_{i=1}^{N} T_{qj} = \frac{\hbar G N m_q R}{2\pi k_B c R_0^2}, \ (R < R_0), \]

\[ T_N = \sum_{i=1}^{N} T_{qj} = \frac{\hbar G N m_q}{2\pi k_B c R^2}, \ (R > R_0). \]  

(25)

The acceleration is then

\[ a = \frac{2\pi k_B c}{\hbar} \sum_{i=1}^{N} \frac{T_{qj} \nabla T_{qj}}{|\nabla T_{qj}|} = \frac{G N m_q R}{R^3}, \ (R < R_0), \]

\[ a = \frac{2\pi k_B c}{\hbar} \sum_{i=1}^{N} \frac{T_{qj} \nabla T_{qj}}{|\nabla T_{qj}|} = -\frac{G N m_q R}{R^3}, \ (R > R_0). \]  

(26)

We see that for \( N >> 1 \), it is clear that the measurement of the motion trajectory of another classical particle in the sphere would not lead to essential wavepacket collapse of these \( N \) particles. The above two equations are a little cumbersome because we want to stress that the summation in \( \sum_{i=1}^{N} T_{qj} \) and \( \sum_{i=1}^{N} T_{qj} \nabla T_{qj} / |\nabla T_{qj}| \) is not the key to distinguish quantum and classical gravity effects. In fact, the summation is about the particles both in classical and quantum situations. The key difference lies in that in classical situation, the particles are highly localized, so that the summation is about the localized particles. In classical situation, because every particle is highly localized, one can replace the summation of the particles by divided subregions, for the convenience of calculations. Therefore, the abnormal quantum gravity effect depends mainly on the nonlocal quantum wavepacket. These discussions explain further in a sense why our calculations for the quantum wavepacket are reasonable.

For Fermi system where the wave functions of a lot of particles are highly delocalized in space, or a system where the wave functions of a lot of nonidentical particles are highly delocalized in space, one still has the possibility to get the abnormal quantum gravity effect with the above two equations.

**Experimental scheme to test the abnormal effect with superfluid Helium and atom interferometer.** Based on the above discussions, we consider a feasible experimental scheme to test the abnormal gravity effect with superfluid \(^4\)He, shown in Fig. 5. For brevity’s sake, we consider a sphere full of superfluid \(^4\)He. There is a hole in this sphere. From Eq. (26), the gravity acceleration in the sphere due to superfluid \(^4\)He is

\[ a = \frac{4\pi}{3} G n_{He} R. \]  

(27)
FIG. 5: An experimental scheme to test the abnormal gravity effect.

Here \( n_{He} \approx 550 \text{ kg/m}^3 \). The anomalous acceleration is \( a = 1.5 \times 10^{-7}R \). The gradient of this anomalous acceleration is \( 1.5 \times 10^{-7}/s^2 \). Even only the condensate component of superfluid \(^4\text{He}\) is considered, this anomalous acceleration can be larger than \( 10^{-8}R \). Quite interesting, this value is well within the present experimental technique of atom interferometer \([13]\) to measure the gravity acceleration. Nevertheless, this is a very weak observable effect. Thus, it is unlikely to find an evidence to verify or falsify this anomalous acceleration without future experiments. Of course, one may consider other methods of measuring the gravity acceleration to test this abnormal gravity. In the following, we will try to apply this effect to the universe and black hole, to investigate whether there is obvious evidence to falsify it. It is surprising to find that this abnormal gravity effect may provide, in a simple way, new understanding about the universe and black hole.

**Application of this effect to the universe.** We see that the coupling between “vacuum” background and particle plays important role in the derivation of Newton’s gravity law and inertia law. We consider further the relevant physics of this coupling. For a particle with motion \( \Delta x = v\Delta t \) and constant velocity \( v \), we see from Eq. (1) that the entropy increases linearly with the time \( \Delta t \). From the Unruh effect, we see that \( T = 0 \). This means that there
is a net energy exchange between the particle and the “vacuum” background. Therefore, the velocity of this particle will not change with time. This gives a simple derivation of Newton’s first law. One may wonder why there is an entropy increasing without energy exchange. In fact, this is not a surprising physical effect. There are innumerable classical systems where there is an entropy increasing without energy exchange. Most examples happen in the process from non-equilibrium to equilibrium process. In the relative motion and coupling between an object and the “vacuum” background, the whole system is in fact a non-equilibrium state because the stable structure of the object due to other internal interactions in the object. It is widely believed that there is a finite temperature in the “vacuum” background. Thus, the “vacuum” background can be regarded as a huge entropy source, which justifies Eq. (11). The coupling between the particle and “vacuum” background, and the consistency with Newton’s first law suggest that the “vacuum” background is in a sense a superfluid. In this superfluid, the propagator velocity of various gauge fields is the light velocity $c$. If $c$ is regarded as the sound velocity of the “vacuum” background, the critical velocity to break the superfluidity is $c$.

When the “vacuum” background is considered, we should note several important characteristics. (i) As mentioned earlier, in a sense, the “vacuum” background is a superfluid with critical velocity $c$. Because of the strong coupling between neighboring fluctuating “vacuum” fields, we assume that the superfluid fraction is 100% even when finite temperature characteristic of the “vacuum” background is considered. This is a little similar to the superfluid $^4\text{He}$. Below the critical temperature of liquid $^4\text{He}$, although the condensate fraction is always below 10%, the strong coupling between atoms make the whole system become perfect superfluid. Nevertheless, the finite temperature of the “vacuum” background make it a huge entropy source. (ii) For this superfluid “vacuum” background, one should take fully into account the effect due to quantum mechanics.

We consider a “vacuum” background with average density $n_v$. If the “vacuum” background is regarded as a superfluid, one can introduce a superfluid wave function $\Psi_v(x, t)$ so that $n_v(x, t) = |\Psi_v(x, t)|^2$. We have

$$a = \frac{4\pi}{3} G n_v \mathbf{R}. \quad (28)$$

We see again an abnormal acceleration effect. This leads to the well-known acceleration expansion of the universe. Assuming the “vacuum” background (or so called dark energy)
density is $10^{-26}$ km/m$^3$, we have $a \approx 3.6 \times 10^{-10}$ m/s$^2$ for $|\mathbf{R}| \approx 1.37 \times 10^{10}$ ly being the radius of the observable universe. Note that although the superfluidity of the “vacuum” background is suggested, the above equation does not necessarily rely on this superfluidity.

The above studies about acceleration expansion of the universe is due to the consideration of the macroscopic quantum characteristic of the “vacuum” background. It is interesting to consider this also from the following Einstein’s modified field equation by including the cosmological constant $\Lambda$

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu},$$

where $R_{\mu\nu}$ and $g_{\mu\nu}$ give the structure of spacetime, while $T_{\mu\nu}$ is due to the ordinary matter and dark matter. In principle, the inclusion of $\Lambda$ could induce an acceleration expansion of our universe, or negative pressure. However, the inclusion of $\Lambda$ leads to a concept problem, which is one of the reasons why Einstein did not like this cosmological constant. If the “vacuum” background is due to the ordinary energy and matter, it should appear in $T_{\mu\nu}$. In this situation, from Eq. (16), we will get a positive pressure effect. Because of this, the mysterious dark energy is introduced to solve the relation between the cosmological constant and “vacuum” background. One may argue a physical interpretation of this negative pressure from classical thermodynamics. It is assumed that in the expansion process, the whole energy of the “vacuum” background increases. In this situation, one can get a negative pressure. However, this is still not completely classical because this sort of energy increasing of the “vacuum” background must have quantum origin. Another problem in this interpretation lies in that it violates in a sense the energy conservation. In the present work, however, the macroscopic quantum characteristic of the “vacuum” background and new view of the gravity directly lead to the negative pressure. The energy conservation law is reserved in the present work in the physical mechanism of the accelerating universe.

We give here several discussions about these two situations of superfluid $^4\text{He}$ and “vacuum” background.

(1) We consider two objects denoted by $M$ and $m$, respectively. For classical system calculated with Eq. (16) for the acceleration of the object $m$, the summation is due to an incoherent assembly of particles in $M$ to establish the effective temperature field distribution. In principle, the motion trajectory of the object $m$ can reveal the exact location of every particle in $M$. This is consistent with Eq. (16). If the object $M$ is a superfluid, however, the location of the particles in $M$ is completely uncertain. Thus, for the situation of superfluid,
it is tempting to use Eq. (26) to calculate the gravity effect.

(2) Eq. (19) shows in fact a nontrivial result of the application of gravity to a quantum wavepacket of a particle. The nontrivial predication of Eqs. (27) and (28) is due to the consideration of the gravity when the quantum effect of $M$ is considered. This is an inverse effect of Eq. (19) which has been already verified by numerous experiments about Bose-Einstein condensation in dilute gases. This supports in a sense the predication given by Eq. (28) for dark energy and Eq. (27) for superfluid $^4\text{He}$.

(3) As shown in deriving Eq. (28) for dark energy, the negative pressure (or acceleration expansion of the universe) is due to the collective quantum behavior of the macroscopic superfluid characteristic of the “vacuum” background. In a sense, the superfluid $^4\text{He}$ simulates the “vacuum” background. Because the gravitation mechanism is similar for these two situations, it is straightforward to get a similar equation (29) with $\Lambda = \Lambda_v + \Lambda_{He}$. Here $\Lambda_v$ is the cosmological constant due to the “vacuum” background, while $\Lambda_{He}$ is a constant in the interior of the superfluid $^4\text{He}$ sphere. In a sense, the accelerating universe gives an indirect support for the abnormal effect predicted for superfluid $^4\text{He}$ sphere.

**Black hole.** Assuming $M_b$ is the mass of a non-rotating black hole with no charge shown in Fig. 6, the radius of the black hole horizon is the Schwarzschild radius

$$R_s = \frac{2GM_b}{c^2}. \quad (30)$$

Assuming further that the matter and energy within the horizon has quantum characteristic, in the limit process of approaching the horizon within the black hole, we have

$$a_{iner} (R \to R_s) = \frac{GM R_s}{R_s^3} = \frac{c^2 R_s}{2R_s^2}. \quad (31)$$

Approaching the horizon from the outer space of the black hole, we have

$$a_{out} (R \to R_s) = -\frac{GM R_s}{R_s^3} = -\frac{c^2 R_s}{2R_s^2}. \quad (32)$$

In this situation, $a_{iner} (R \to R_s) = -a_{out} (R \to R_s)$. Eq. (31) shows a unique effect that there is outward repulsion in the interior of the black hole, shown by the red arrow in Fig. 6. By using the Unruh formula, we get the following Hawking radiation temperature

$$T_{\text{Hawking}} = \frac{\hbar c^3}{8\pi k_B GM_b}. \quad (33)$$

Based on these properties about black hole, we discuss several essential problems as follows.
(1) Hawking radiation. Although the existence of the Hawking temperature implies the black hole evaporation, one may still wonder why it can emit photons, etc. For example, for a black hole has mass of 10 $M_{\odot}$ with $M_{\odot}$ being the solar mass, the Hawking temperature is about $6 \times 10^{-10}$ K, while $|a_{\text{out}}(R \rightarrow R_s)| \approx 1.5 \times 10^{12}$ m/s$^2$ is extremely large. This extremely large acceleration is a little similar to a perfect reflector besieging an object with finite temperature. In this situation, even the object has finite temperature, it cannot emit photons to the external space. Therefore, even there is radiation, one may expect that the radiated matter will be devoured by the black hole again. This is one of the reasons why the Hawking radiation is not immediately identified. It is well-known that the huge gravitational tides in the vicinity of the black hole horizon play a key role in the microscopic mechanism of Hawking radiation. The opposite and extremely large accelerations given by Eqs. (31) and (32) just give a very simple physical mechanism of the huge gravitational tides.

We give here a simple calculation to justify further the above physical picture. Without considering the gravitational tides, the Hawking temperature means that the lifetime of the particles emerged from the “vacuum” background within the black hole horizon is about

$$\Delta t \sim \frac{h}{k_B T_{\text{Hawking}}}.$$  (34)
From Eq. (31), we have

\[ v = a_{\text{iner}} \Delta t \sim \frac{2\pi c R_s}{R_s}. \]  

(35)

This shows that the acceleration \( a_{\text{iner}} \) could just lead to sufficient gravitational tides to stimulate the Hawking radiation.

(2) Black hole information paradox. The repulsive interaction (31) means that at least some matter devoured by the black hole could avoid arriving at the center of the black hole, even there is a singularity (It is clear that one should reconsider whether there exists this sort of singularity following the abnormal gravity effect.) at the center of the black hole. Therefore, within the horizon of a black hole, the information of the devoured matter is still retained in principle. This gives a clue to solve the black hole information paradox. One may even speculate that these exist various ordinary matters such as atom, molecule and plasma in the interior of the black hole horizon. In particular for a supermassive black hole with much larger \( R_s \) and much smaller \( |a_{\text{iner}}| \), such as the huge black hole in Milky Way, one may imagine the possible abundant matters and structure. From this perspective, the present work is not a bad news for mysterious black hole. It makes the black hole more mysterious.

(3) Black hole’s no-hair theorem. Within the horizon of a black hole, if there exist ordinary matter states, it implies a violation of black hole’s no-hair theorem.

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