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Energy dissipation of photon: An alternative theoretical model of cosmological redshift based on quantum optics

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Abstract We present an alternative theoretical model and interpretation of the cosmological redshift based on quantum-optical theory. Our model shows that the energy dissipation of photon due to the interaction of photon with the cosmic matter, electromagnetic vacuum and gravitational field is the main cause of the redshift. Based on the new perspective, the general formula of the cosmological redshift is derived and it is shown that the Hubble law is a special case of this formula. Moreover, the speeding up of the expansion of the universe that the standard cosmological model describes is newly interpreted as a natural result that the new model of the redshift provides. Our interpretation of Hubble's law based on quantum optics is distinguished from the conventional theory in that the theory does not require assumptions such as mysterious dark matter and dark energy that, despite long-term efforts, have not passed experimental test in laboratories at all. Furthermore, our interpretation is free of paradoxical problems associated with dynamic description of the expansion of the universe. Conclusively, it is demonstrated satisfactorily that the Hubble law is irrelevant to a whole evolution of the universe and instead is due to the energy dissipation of photon interacting with the cosmic matter, electromagnetic vacuum and gravitational field.

Keywords Cosmological redshift · Expansion of universe · Photon · Gravitational redshift · Energy dissipation

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1 Introduction

The conceptual problems of cosmological physics have its special character which concerns a subtle interplay between observations, data analysis and fundamental physics. Even now, it is necessary to achieve an accurate conceptual understanding of unsolved problems in modern cosmology. In this context, the correct explanation of the Hubble law still holds a special place in obtaining the correct picture of cosmology.

In most cases, the interpretations of astronomical phenomena are given with observational results distorted in a subtle manner due to physical and technical limitations of observations and due to inadequate methods of data analysis. Therefore, an interpretation is prone to bring a variety of opinions and may be misled. Evidently, at this stage, cosmology has not been completed as yet, and many fundamental questions remain open problems [1,2].

It is necessary to take an overview of the historical motivations of the development of cosmology. In 1917, Einstein presented the static, homogeneous and finite cosmological model as a solution of his equations of general relativity that required the introduction of the cosmological constant [1, 3]. The static world model that in 1917, de Sitter proposed predicted the so-called "de Sitter effect" according to which light from remote objects is redshifted and the redshift has a non-linear dependence on the distance, which was characterized by the introduction of the cosmological constant. Slipher's success in measuring 25 nebular spectra for faint nebulae motivated the discovery of the cosmological redshifts [1,4]. In 1919, Shapley affirmed that fainter nebulae tend to have larger redshifts indicating a relation of speed to distance or to mass [1,5]. Lundmark's attempt to explain the correct connection between redshift and distance ended in a failure but it became a significant step [1,6]. Eventually, in 1929, Hubble presented a linear relation between distance and redshift [7]. Presently, Hubble and Humason demonstrated that a linear distance-redshift relation in the nearby galaxy universe exists definitely [7–11].

Thus, the Hubble law was established but the interpretation of this relation spawned several dissenting views. The methods for interpreting the Hubble law are classified fundamentally into two groups: the redshift by the Doppler effect due to space expansion as a relativistic effect and that due to the damping of energy of photon. The explanation of the redshift in terms of the Doppler effect has been the dominant theory able to describe the relation between distance and redshift. The past decades have showed the growing importance of the research into the Hubble law because it may mark another milestone in the development of cosmology. Findings regarding the Hubble constant and the Hubble diagram [12–21] have shown that the nature of the Hubble law still remains an open question. The long-standing debate on the interpretation of the Hubble constant still has not reached a consensus [22–37]. Here, the focus is on whether the exact Hubble constant exists and what its physical meaning is. The interpretation in terms of the Doppler effect seems to give a plausible explanation of the Hubble law from the aspect of kinematics but is not perfect in the aspect of dynamics.

The standard theory of cosmology is based on general relativity which describes that the space expansion makes photons' wavelength lengthen, and thus results in redshift [38–40]. This widely accepted idea for the cosmological redshift is a consequence of general relativity applied to the universe uniformly filled by matter.

Meanwhile, there are researchers who reject the theory based on space expansion as well [41]. Another view on the cosmological redshift is that redshift is due to the inelastic scattering of photon as a consequence of its interaction with the cosmic matter [41]. In this manner, the interpretation of the Hubble law still has not been completed.

The aim of our work is to give an alternative explanation of the redshift based on quantum optics. The fundamental in our explanation is the consideration of the fact that a photon necessarily loses its energy due to the interaction with the cosmic matter, electromagnetic vacuum and gravitational field. Will and Okun asserted that the energy of photon traveling in the direction of gravity remains unchangeable [1,42]. That is, it means that a photon does not undergo change of energy in gravitational fields unlike matter particles. However, we believe that according to the equivalence of energy and mass, the interaction between photon and gravity inevitably exists and thus the interaction changes the energy of a photon. Based on this perspective, we provide a consistent explanation of the Hubble law by dealing with the redshift due to the interaction of photon with the cosmic matter, electromagnetic vacuum and gravity.

The remaining paper is organized as follows. In Sect. 2, we describe how the interaction of photon with the cosmic matter, electromagnetic vacuum, and gravitational field causes the cosmological redshift. In Sect. 3, we derive the Hubble law, based on the energy dissipation of photon. In Sect. 4, we analyze the description of the expansion of the universe based on the Doppler effect and relativity theory. In Sect. 5, the discussion is given. The paper is concluded in Sect. 6.

2 Energy dissipation of photon due to interaction

Our view is that the cosmic matter, electromagnetic vacuum, and gravitational field are entities which can interact with photon. In this view, a photon traveling in the cosmic space interacts constantly with known and unknown particles and as a result, loses its energy. As a result, the cosmological redshift occurs. We aim to explain the Hubble law

$$c\frac{\lambda - \lambda_0}{\lambda_0} = H_0 r, \tag{1}$$

based on the energy dissipation of photon. Here, λ and λ_0 are the wavelength of observed photon and that of emitted photon, respectively, and H_0 is the Hubble constant. For this purpose, we derive the relationship of the energy dissipation of photon due to the interactions with the cosmic matter, electromagnetic vacuum, and gravitational field: $dE = -HE(r)dr$, where H is a constant and E is the energy of a photon. As we shall see later, from this relationship all the details of the cosmological redshift are explained.

2.1 Energy dissipation of photon due to dielectric polarization of neutral atom

In our view, to seek for mechanisms of the energy dissipation of photon of no scattering is the best way to explain the cosmological redshift reasonably. Traveling through a vast space, a photon is to interact with various matter particles such as dust, gas, elementary particles. The frequency of the interaction can be considered to be proportional to the distance of traveling. From the point of view of quantum theory, the interaction of a photon with the cosmic matter is the collision of the photon with ions, atoms and molecules. Such collisions lead to energy dissipation of photons, resulting in increased wavelength of light.

The effect of lengthening wave length of light due to the interaction with cosmic matters may be associated with the Raman scattering and the Stokes shift. But the Raman scattering is not suitable for the explanation of the cosmological redshift because it depends on the characteristics of atoms or molecules and moreover is associated also with the blueshift. In fact, the effect causes the discontinuous change in wavelength of light, depending on the characteristics of atoms and molecules.

There is a possibility of the continuous lengthening of wavelength of light due to the interaction with matter particles. The collision of a photon with a free or weakly bound electron in an atom occurs in the form of the Compton effect. Due to such collisions, the photon transfers a part of its energy and momentum to matter particles and as a result the inelastic scattering occurs such that the wavelength of light always lengthens. Therefore, from the point of view of the cosmological redshift, the Compton effect is a candidate for the explanation of the cosmological redshift. However, this effect, in general, causes a considerable change in the direction of propagation of light, which is incompatible with observational results of celestial objects giving clear image. For this reason, the Compton effect is not appropriate for the explanation of the cosmological redshift.

Therefore, it is necessary to search for mechanisms of the cosmological redshift of no scattering other than the Compton effect. A reliable candidate of the interaction of a photon free of scattering is the interaction of a photon with dielectric substance. In this case, the instantaneous interaction of a photon with a neutral atom or a neutral molecule causes the electric polarization of the atom without scattering of the photon. After the interaction, the total momentum of the atom or the molecule in the direction perpendicular to the propagation direction of incident photon is left unchanged. Thus, the photon is not scattered and only its energy dissipation occurs. For convenience, hereafter a photon is supposed to interact with a neutral atom composed of electrons and a nucleus.

With the monochromatic plane wave, we shall consider the matter in an electrodynamical way. For an electromagnetic field, the intensity of electric field $\mathbf{E}_{em}$ and the intensity of magnetic field $\mathbf{H}_{em}$ are represented as

$$\mathbf{E}_{em} = -\sqrt{\frac{\mu_0}{\varepsilon_0}}\ (\mathbf{n} \times \mathbf{H}_{em})$$

and

$$\mathbf{H}_{em} = \sqrt{\frac{\varepsilon_0}{\mu_0}}\ (\mathbf{n} \times \mathbf{E}_{em}),$$

respectively. In view of the magnetic induction

$$\mathbf{B}_{em} = \mu_0 \mathbf{H}_{em} = \sqrt{\varepsilon_0 \mu_0}\ (\mathbf{n} \times \mathbf{E}_{em}) = \frac{1}{c}\ (\mathbf{n} \times \mathbf{E}_{em}),$$

the force that acts on electrons or a nucleus in the propagation direction of a photon is written as

$$\begin{aligned} \mathbf{F}_{\|} = q(\boldsymbol{v} \times \mathbf{B}_{em}) &= \frac{q}{c}\ (\boldsymbol{v} \times (\mathbf{n} \times \mathbf{E}_{em})) \\ &= \frac{q}{c}\ (\boldsymbol{v} \cdot \mathbf{E}_{em})\mathbf{n}, \end{aligned} \tag{2}$$

where q is the quantity of electricity. The denotations $\perp$ and $\|$ refer to "perpendicular" and "parallel" to the direction of incidence of the photon, respectively. In addition, these directions are called simply the perpendicular direction and the parallel direction, respectively. In order to briefly evaluate the results of the interaction in a qualitative way, we use the effective time, τ, defined as the average time during which a photon causes changes in momenta of charged particles bound in an atom.

The effective time τ is determined taking into consideration the binding force $\mathbf{F}_b$. As a result of the interaction of a photon with a bound charged particle, the change in momentum of the particle becomes

$$\triangle \mathbf{p} = m \triangle \mathbf{v} = (\mathbf{F} - \mathbf{F}_b)\triangle t, \tag{3}$$

where $\mathbf{F}$ is the force that the photon exerts on the particle. From Eq. (3), the velocity that the particle acquired is determined by

$$\triangle \boldsymbol{v} = \frac{\mathbf{F}}{m}\left(1 - \frac{\mathrm{F}_b}{\mathrm{F}}\right)\triangle t = \boldsymbol{a}\left(1 - \frac{\mathrm{F}_b}{\mathrm{F}}\right)\triangle t. \tag{4}$$

Hence, the effective time is defined as

$$\tau = \left(1 - \frac{\mathrm{F}_b}{\mathrm{F}}\right)\triangle t.$$

Meanwhile, instead of the effective time, the effective mass may be defined as

$$m^* = \frac{m}{1 - \dfrac{\mathrm{F}_b}{\mathrm{F}}}.$$

Since the bound particle initially was at a standstill, we have

$$\mathbf{p} = m\triangle \boldsymbol{v} = \mathbf{F}\tau.$$

The effective time τ is extremely small as compared to the time during which light passes through the range of atom, since $F \approx F_c$. Then, the velocity of the electrons in the perpendicular direction is

$$\boldsymbol{v}_{e\perp} = \frac{-q\mathbf{E}_{em}}{m}\tau$$

and the velocity of the nucleus in the perpendicular direction is

$$\boldsymbol{v}_{n\perp} = \frac{q\mathbf{E}_{em}}{M}\tau,$$

where q is the total electric charge of the nucleus in an atom, and m and M are the effective masses of the electrons and nucleus allowing for the bound force between them, respectively. The force acting on the electron system in the parallel direction is represented as

$$\mathbf{F}_{e\|} = -q(\boldsymbol{v}_{e\perp} \times \mathbf{B}_{em})$$

$$\mathbf{F}_{e\|} = -q(\boldsymbol{v}_{e\perp} \times \mathbf{B}_{em}) = \frac{q^2\tau}{cm}\mathbf{E}_{em}^2\mathbf{n}$$

and that acting on the nucleus in the parallel direction as

$$\mathbf{F}_{n\|} = q(\boldsymbol{v}_{n\perp} \times \mathbf{B}_{em}) = \frac{q^2\tau}{cM}\mathbf{E}_{em}^2\mathbf{n},$$

respectively. Accordingly, the momenta of the electron system and nucleus are written as

$$\mathbf{P}_{e\|} = \mathbf{F}_{e\|}\tau = \frac{q^2\tau^2}{cm}\mathbf{E}_{em}^2\mathbf{n} \tag{5}$$

and

$$\mathbf{P}_{n\|} = \mathbf{F}_{n\|}\tau = \frac{q^2\tau^2}{cM}\mathbf{E}_{em}^2\mathbf{n}, \tag{6}$$

respectively. It can be seen from Eqs. (5) and (6) that the electron system and nucleus acquire momenta in the same direction. In terms of Eqs. (5) and (6), the energies of the electron system and nucleus are represented as

$$E_{e\|} = \frac{\mathbf{P}_{e\|}^2}{2m} = \frac{q^4\tau^4}{2c^2m^3}E_{em}^4 \tag{7}$$

and

$$E_{n\|} = \frac{\mathbf{P}_{c\|}^2}{2M} = \frac{q^4\tau^4}{2c^2M^3}E_{em}^4, \tag{8}$$

respectively. From Eqs. (7) and (8), it follows that $E_{e\|} \gg E_{n\|}$, since $M \gg m$. The force acting on the electron system in the perpendicular direction is

$$\mathbf{F}_{e\perp} = -q\mathbf{E}_{em}.$$

Therefore, its momentum is

$$\mathbf{P}_{e\perp} = -q\mathbf{E}_{em}\tau. \tag{9}$$

On the other hand, the force acting on the nucleus in the perpendicular direction is

$$\mathbf{F}_{n\perp} = q\mathbf{E}_{em}$$

and the momentum gained by the nucleus is

$$\mathbf{P}_{n\perp} = q\mathbf{E}_{em}\tau. \tag{10}$$

From Eqs. (9) and (10), the resultant momentum of the atom in the perpendicular direction, i.e., $\mathbf{P}_\perp = \mathbf{P}_{e\perp} + \mathbf{P}_{n\perp}$, is zero, and thus the photon is not scattered. On the other hand, it is obvious that in the case of the interaction with an ionized atom, a photon is scattered, since positive charge and negative one in the atom are not balanced.

The kinetic energies of the electron system and nucleus:

$$E_{e\perp} = \frac{\mathbf{P}_{e\perp}^2}{2m} = \frac{q^2\tau^2}{2m}E_{em}^2 \tag{11}$$

and

$$E_{n\perp} = \frac{\mathbf{P}_{c\perp}^2}{2M} = \frac{q^2\tau^2}{2M}E_{em}^2 \tag{12}$$

are the energies that the photon loses as a result of the electronic polarization of the atom. From Eqs. (11) and (12), it follows that $E_{e\perp} \gg E_{n\perp}$. On the other hand, from Eqs. (7) and (11), it follows that $E_{e\perp} \gg E_{e\|}$. This shows that the energy dissipation of photon is due mainly to electronic polarization.

$\varepsilon_0 E_{em}^2$ is the density of energy of an electromagnetic field. Taking into consideration that a photon takes a definite volume V_p, the energy of a photon is written as

$$E = \hbar\omega = \varepsilon_0 E_{em}^2 V_p. \tag{13}$$

By Eq. (13), Eqs. (11) and (12) are rewritten as

$$E_{e\perp} = \frac{\mathbf{P}_{e\perp}^2}{2m} = \frac{q^2\tau^2}{2m\varepsilon_0 V_p}E \tag{14}$$

and

$$E_{n\perp} = \frac{\mathbf{P}_{n\perp}^2}{2M} = \frac{q^2\tau^2}{2M\varepsilon_0 V_p}E, \tag{15}$$

respectively. Eqs. (14) and (15) mean that the energy dissipation of a photon in a collision is proportional to the energy of a photon. Meanwhile, since the universe is uniform on large scales, the frequency of collision between a photon and atoms is proportional to the distance of traveling of the photon. Thus, $\frac{q^2\tau^2}{2m\varepsilon_0 V_p}$ in Eq. (14) and $\frac{q^2\tau^2}{2M\varepsilon_0 V_p}$ in Eq. (15) can be replaced by an average quantity. Eventually, we infer the equation for the energy dissipation of photon as

$$dE = -H_m E(r)dr. \tag{16}$$

It is useful to describe this interaction, based on the equations for energy and momentum conservation. The collision between a photon and an atom should satisfy the conservations of energy and momentum:

$$\left.\begin{aligned} \hbar\omega &= \hbar\omega' + E_e + E_n + E_{en} \\ \hbar\mathbf{k} &= \hbar\mathbf{k}' + \mathbf{p}_e + \mathbf{p}_n \end{aligned}\right\}, \tag{17}$$

where E_e and E_n are the energies gained by the electrons and nucleus, respectively, and E_{en} the energy of interaction between electrons and nucleus. The momenta of electrons and nucleus are represented by their components as

$$\mathbf{p}_e = \mathbf{p}_{e\perp} + \mathbf{p}_{e\|},$$
$$\mathbf{p}_n = \mathbf{p}_{n\perp} + \mathbf{p}_{n\|},$$

respectively. In view of Eqs. (9) and (10), we rewrite Eq. (17) as

$$\left.\begin{aligned} \hbar\omega &= \hbar\omega' + E_e + E_n + E_{en} \\ \hbar\mathbf{k} &= \hbar\mathbf{k}' + \mathbf{p}_{e\|} + \mathbf{p}_{n\|} \end{aligned}\right\}.$$

From this, it follows that the interaction between photon and cosmic matter occurs in the form of the inelastic interaction of a photon with an atom without the scattering of photon.

As a result of the interaction, a photon necessarily leaves the change in state of the atom. This fact signifies the lengthening of wavelength of light. Therefore, it is concluded that the interaction of photon with cosmic matters occurs mainly in the form of the energy dissipation.

It is possible to evaluate the energy loss of photon due to the motion of atom in the parallel direction. We assume that light interacts with an atom in such a way that it is absorbed by the atom and then is reradiated. This process means the annihilation of a photon and the subsequent creation of a new photon. Then the interacting photon is to transfer a part of its energy through the collision in the case of the absorption and the recoil in the case of the radiation. As a result of the interaction, the photon necessarily changes the state of the atom. It is identified with the mechanism of propagation of light in dielectric medium.

It is possible to estimate the energy dissipation of photon due to the motion of an atom in the parallel direction using the nonrelativistic approximation. It is supposed that the total lost energy of a photon contributes to the motion in the parallel direction of an atom. If a photon is absorbed by an atom, then its momentum becomes

$$p = \frac{E}{c} = \frac{\hbar\omega}{c}, \tag{18}$$

where E is the energy of the photon. Then the kinetic energy of the atom is

$$E_1 = \frac{p^2}{2M_0} = \frac{\hbar^2\omega^2}{2M_0c^2}. \tag{19}$$

The remnant energy

$$E_2 = E - E_1 = \hbar\omega - \frac{\hbar^2\omega^2}{2M_0c^2} \tag{20}$$

is radiated to create a photon and thus the atom returns to a new stable state. In this case, the momentum of the radiated photon is determined by

$$p_{rad} = \frac{\hbar\omega - \dfrac{\hbar^2\omega^2}{2M_0c^2}}{c}. \tag{21}$$

As a result of the radiation, the atom undergoes recoil. Thus, the total momentum of the atom is calculated as the difference between the momentum obtained during absorption and the momentum lost during radiation. That is,

$$p_{tot} = \hbar\frac{\omega}{c} - \frac{\hbar\omega - \dfrac{\hbar^2\omega^2}{2Mc^2}}{c} = \frac{\hbar^2\omega^2}{2Mc^3}. \tag{22}$$

From this, the kinetic energy which the atom has after the radiation becomes

$$\Delta E = \frac{p_{tot}^2}{2M} = \frac{1}{2M}\left(\frac{\hbar^2\omega^2}{2Mc^3}\right)^2 = \left(\frac{\hbar\omega}{2Mc^2}\right)^3\hbar\omega. \tag{23}$$

Let us consider the ratio of the lost energy of a photon to the initial energy of the photon. It is represented as

$$\eta = \frac{\Delta E}{E} = \left(\frac{\hbar\omega}{2M_0c^2}\right)^3. \tag{24}$$

For a hydrogen atom and the light of wavelength 400nm, the value of Eq. (24) is about 4.51×10^{-27}, so that it is negligibly small. Since in reality, a part of the lost energy of the photon is consumed for the motion of the atom in the parallel direction, the kinetic energy of the atom gained by the motion in the parallel direction can be ignored. The above arguments indicate that the interaction between photon and atoms is determined mainly by polarization.

2.2 Energy dissipation of photon due to polarization of electromagnetic vacuum

With sufficient grounds, we can assume a physical entity present behind the electromagnetic vacuum. The Lamb shift shows that an electron moving in an atom interacts not only with the atomic nucleus but also with the zero-point vibration of the free electromagnetic field.

As a result of the interaction with electromagnetic vacuum, electrons in an atom vibrate in their orbit. The physical origin of this quantum electrodynamical effect lies in the existence of the vacuum polarization. The fluctuation in the electromagnetic field due to the vacuum polarization does not vanish even when there are no real photons.

The presence of an electric field means that there is a charge. On the other hand, the presence of a charge means that there is a material existence. This reasoning leads to the conclusion that the electromagnetic vacuum is a physical entity as well. Real-world systems always have some dissipative forces, and therefore oscillations die out with time unless the dissipated energy is not restored. The same is true for electromagnetic vacuum. Therefore, it is natural to consider that light interacts with the electromagnetic vacuum, thus losing its energy. Considering all this together, it is assumed that a physical entity called the vacuum oscillates mechanically, and the oscillation propagates in the physical vacuum which consists of physical oscillators at the velocity of light. It is possible to describe this process in a dynamical way. The equation of motion for the oscillator is assumed to be represented as the equation for a damped oscillation

$$m\frac{d^2x}{dt^2} = -kx - \beta\frac{dx}{dt}, \tag{25}$$

where x represents the polarization of the electromagnetic vacuum. The oscillator interacts with neighboring oscillators to deliver the oscillation to them. As a result of the interaction between oscillators, electromagnetic wave is damped.

To derive the formula for the energy dissipation, we begin with an expression for the total mechanical energy E of an oscillator at any instant:

$$E = \frac{1}{2}m\upsilon_x^2 + \frac{1}{2}kx^2.$$

We take its time derivative to get

$$\frac{dE}{dt} = m\upsilon_x\frac{d\upsilon_x}{dt} + kx\frac{dx}{dt}.$$

This equation is rewritten as

$$\frac{dE}{dt} = \upsilon_x(ma_x + kx).$$

In view of Eq. (25), we obtain

$$\frac{dE}{dt} = -\beta\upsilon_x^2. \tag{26}$$

From Eq. (26), we have

$$dE = -\beta\upsilon_x^2 dt = -\frac{2\beta}{m}Edt.$$

The oscillation propagates at the speed of light, so the above expression is written with respect to the distance of traveling of photon as

$$dE = -\frac{2\beta}{m}Edt = -\frac{2\beta}{cm}Ecdt = -H_v Edr,$$

where $H_v = \frac{2\beta}{cm}$. Thus, we obtain the equation for the energy dissipation of photon:

$$dE = -H_v E(r)dr. \tag{27}$$

There is another way to show this relation for the energy dissipation. According to Dirac's idea for the ether conductivity [43], we assume that the electromagnetic vacuum has electric conductance. To consider the energy dissipation of light in electromagnetic vacuum, we begin with the equation of energy conservation for electromagnetic field:

$$\frac{\partial}{\partial t}\left(\frac{\varepsilon_0\mathbf{E}_{em}^2 + \mu_0\mathbf{H}_{em}^2}{2}\right) + \mathrm{div}\,(\mathbf{E}_{em}\times\mathbf{H}_{em}) = -(\mathbf{j}\cdot\mathbf{E}_{em})$$

Then, the energy dissipation is determined by

$$-\mathbf{j}\cdot\mathbf{E}_{em} = -\sigma\mathbf{E}_{em}^2,$$

where σ is the electric conductivity of electromagnetic vacuum. The energy dissipated in unit volume during dt is

$$dE' = -(\mathbf{j}\cdot\mathbf{E}_{em})dt = -\sigma\mathbf{E}_{em}^2 dt. \tag{28}$$

Considering that electromagnetic wave propagates at the light velocity c, we rewrite Eq. (28) as

$$dE' = -\sigma\mathbf{E}_{em}^2\frac{dr}{c} = -\frac{\sigma}{c\varepsilon_0}\varepsilon_0\mathbf{E}_{em}^2 dr.$$

By multiplying both sides of this equation by the volume V_p that a photon takes, we have

$$dE'V_p = -\frac{\sigma}{c\varepsilon_0}\varepsilon_0\mathbf{E}_{em}^2 V_p dr. \tag{29}$$

Here, the energy of an electromagnetic field, $\varepsilon_0\mathbf{E}_{em}^2 V_p$, can be identified with the energy of a photon E. Thus, Eq. (29) becomes

$$dE = -\frac{\sigma}{c\varepsilon_0}E(r)dr.$$

Putting

$$H_v = \frac{\sigma}{c\varepsilon_0}, \tag{30}$$

we obtain the equation for energy dissipation as

$$dE = -H_v E(r)dr. \tag{31}$$

As for the form of equation, this coincides with Eqs. (16) and (27) for the energy dissipation of photon.

Introducing the electric conductivity of electromagnetic vacuum enables a reasonable explanation of the cosmological background radiation. If the electromagnetic vacuum has the electric conductivity, according to the Wiedemann-Franz law $\frac{K}{\sigma T} = \frac{\pi^2}{3}\left(\frac{k}{e}\right)^2$, it is possible to imagine also the heat conductivity of the electromagnetic vacuum K. This implies that the electromagnetic vacuum as a physical entity can make thermal radiation at the temperature $T = 2.7K$ that the present space maintains.

2.3 Energy dissipation of photon due to interaction with gravitational field

It is possible to explain the Hubble law in terms of the interaction of photons with the gravitational field. Light radiated by remote galaxies not only is affected by the gravitational field present in the vast cosmic space but also consistently interact with matter particles although they are rare in space. In fact, the cosmic space should be considered to be not a free space but a medium filled with gravity and matter. These two interactions are negligible on a small scale of the universe, since the density of celestial objects is little and cosmic matter is rare. But since cosmic space is immense, the train of such an interaction is accumulated and thus turns observable.

To begin with, let us consider how the Hubble law can be derived from the gravitational interaction. With the picture of photon as a particle interacting with the gravity, we consider that a photon interacting with the gravitational field loses its energy gradually. We assume that for a photon in the gravitational field, the following relation of energy conservation

$$\hbar\omega + \triangle E = const$$

holds [44]. Here ω is the angular frequency of light and $\triangle E$ the energy that the photon traveling in the gravitational field loses. Considering that the gravitational field has little effect on the velocity of propagation of light, the field should be regarded to affect mainly the frequency of light.

A photon traveling in a gravitational field loses its energy due to gravitational interaction and as a result the mass of the photon is decreased. It is possible to imagine the processes in which a photon loses its energy in the two mechanisms. One is the case where a photon travels against the gravitation and the other is the case where it is scattered by gravitational field. The first case is obvious. The second case can be interpreted as follows. Based on the laws of energy and momentum conservation, we can write

$$\left.\begin{aligned} \hbar\omega &= \hbar\omega' + \frac{\mathbf{p}^2}{2M} \\ \hbar\mathbf{k} &= \hbar\mathbf{k}' + \mathbf{p} \end{aligned}\right\}.$$

Here ω and ω' are the frequencies before interaction and that after interaction, respectively, and $\mathbf{k}$ and $\mathbf{k}'$, the wave vectors before and after interaction, respectively. M is the gravitational mass of a celestial body. A photon is assumed to interact with gravitational body as if it were a body with mass determined as $m = \frac{\hbar\omega}{c^2}$. The scattering of a photon in gravitational field results in the variation in momentum of the photon. Thus, as far as the mass of an interacting celestial body is not infinite, the energy dissipation of photon is inevitable. The variation in energy of a photon writes as

$$\Delta E = E - E' = \hbar(\omega - \omega'). \tag{32}$$

This variation equals the energy that the gravitational body acquires. Thus, we get

$$\begin{aligned} \Delta E &= \frac{(\hbar\mathbf{k} - \hbar\mathbf{k}')^2}{2M} \\ &= \frac{\hbar^2(k^2 + k'^2 - 2kk'\cos\vartheta)}{2M} \\ &= \frac{\hbar^2(\omega^2 + \omega'^2 - 2\omega\omega'\cos\vartheta)}{2Mc^2} \\ &= \frac{\hbar^2[(\omega - \omega')^2 + 2\omega\omega'(1 - \cos\vartheta)]}{2Mc^2}. \end{aligned} \tag{33}$$

Considering that the approximate relation $\omega' \approx \omega$ holds, we get

$$\Delta E \approx \frac{\hbar\omega'(1 - \cos\vartheta)}{2Mc^2}\hbar\omega = \frac{E'\sin^2\frac{\vartheta}{2}}{Mc^2}E. \tag{34}$$

This shows that the scattering of photon in gravitational field is inelastic. ϑ is very small and the frequency of the scattering is low. Therefore, the propagation of light on large scales undergoes very slight fluctuation and keeps a state of straight propagation in the main. In view of this, $E'\sin^2\frac{\vartheta}{2}$ in Eq. (34) can be replaced by an average quantity characterizing the homogeneity of the universe on large scales. Thus, from Eq. (34), we can define the coefficient of energy dissipation per unit length as

$$H_g = -\frac{1}{E(r)}\frac{dE(r)}{dr}, \tag{35}$$

which is assumed to be constant. If $g = c^2H_g$ is considered to be the gravitational acceleration, Eq. (35) explains also the gravitational redshift effect reasonably. Putting $E = mc^2$, Eq. (35) becomes

$$E(r_0) - E(r) = \int_r^{r_0} m(r')g(r')dr' \approx -E(r_0)\int_r^{r_0} \frac{GM}{c^2 r'^2}dr',$$

where taking into consideration that the variation in mass of a photon is very small, we have taken the approximation of $m(r) \approx \frac{E(r_0)}{c^2}$. From this, we can describe the gravitational redshift effect in the nonrelativistic approximation as

$$z_R = \frac{E(r_0) - E(r)}{E(r_0)} = \frac{\nu(r_0) - \nu(r)}{\nu(r_0)} \approx \frac{GM}{c^2}\left(\frac{1}{r_0} - \frac{1}{r}\right).$$

From Eq. (35), we set the equation for the energy dissipation of photon in a gravitational field as

$$dE = -H_g E(r)dr. \tag{36}$$

This has the same form as Eqs. (16), (27) and (31).

3 Description of cosmological redshift and true nature of speeding up of expansion of universe

Eqs (16), (27), (31) and (36) provide the general formula for the energy dissipation of photon. From this, it is obvious that there are multiple mechanisms of the energy dissipation of photon fulfilling the same formula. We shall derive the formula for the cosmological redshift, based on the general relation of the energy dissipation of photon:

$$dE = -HE(r)dr. \tag{37}$$

where H refers to H_g, H_m and H_v.

The solution of Eq. (37) immediately is given as

$$E(r) = E_0\exp(-Hr). \tag{38}$$

Thus, the energy loss of a photon is calculated to be

$$\begin{aligned} E_0 - E(r) &= E_0[1 - \exp(-Hr)] \\ &= \hbar\omega_0\left[1 - \exp(-Hr)\right]. \end{aligned} \tag{39}$$

Eq. (39) is rewritten in terms of the variation in wavelength of photon as

$$\hbar\omega_0 - \hbar\omega = 2\pi\hbar c\left(\frac{\lambda - \lambda_0}{\lambda_0\lambda}\right) = \hbar\omega_0\left[1 - \exp(-Hr)\right].$$

From this, it follows that

$$cz = c\left(\frac{\lambda - \lambda_0}{\lambda_0}\right) = \frac{\hbar\omega_0\lambda}{2\pi\hbar}\left[1 - \exp(-Hr)\right],$$

By arranging, we ultimately obtain the formula for the cosmological redshift as

$$c\left(\frac{\lambda - \lambda_0}{\lambda_0}\right) = c\frac{\lambda}{\lambda_0}\left[1 - \exp(-Hr)\right]. \tag{40}$$

Let us consider how the Hubble law is derived from Eq. (40). Setting $\lambda_0 \approx \lambda$ in consideration of comparatively small distance of traveling of a photon, the above equation is turned into

$$c\left(\frac{\lambda - \lambda_0}{\lambda_0}\right) \approx c\left[1 - \exp(-Hr)\right].$$

Expanding the above exponential function as a Maclaurin series, we get

$$cz \approx c\left[1 - \exp(-Hr)\right] = cHr - \frac{1}{2}cH^2r^2 + \cdots . \tag{41}$$

Taking only the first-order term with respect to r, we obtain

$$cz = H_0 r, \tag{42}$$

where $H_0 = cH$.

Eq. (42) is nothing but the Hubble law. This shows that the Hubble law which holds for relatively nearby galaxies is an approximate expression of Eq. (40) which is the general formula.

In view of Eq. (30), the Hubble constant for electromagnetic vacuum is written as

$$H_0 = cH = \frac{\sigma}{\varepsilon_0}. \tag{43}$$

By Eq. (43), the electric conductivity of the electromagnetic vacuum is determined to be

$$\sigma = \varepsilon_0 H_0 = 8.85 \times 10^{-12}(\mathrm{As/V}m) \times 2.33 \times 10^{-18}\mathrm{s}^{-1}$$
$$= 2.06 \times 10^{-29}(\Omega m)^{-1}.$$

Thus, the Hubble law has been explained in terms of the energy dissipation of photon due to the interaction with the cosmic matter, electromagnetic vacuum, and gravitational field. According to the idea for this description, the Hubble law can be regarded as the law describing the gravitational and substantial structure of the universe which is uniform and isotropic on large scales.

With the help of Eq. (40, it is possible to explain the true nature of the speeding up of the expansion of the universe at issue. Recasting Eq. (40) as

$$cz \approx cH\left(1 - \frac{1}{2}Hr + \frac{1}{3!}H^2r^2 - \cdots\right)r,$$

the time-dependent Hubble constant is represented as

$$H_0(t) = H_0\left(1 - \frac{1}{2}Hct + \frac{1}{3!}H^2(ct)^2 - \cdots\right).$$

In view of Eq. (40, this is a convergent alternating series. By the property of a convergent alternating series, $H_0(t)$ is less than H_0 and from Eq. (40, $H_0(t)$ decreases with time. Therefore, from the point of view of the expansion of the universe, this situation looks as if the expansion of the universe were speeding up. It turns out that the Hubble constant characterizes the cosmological redshift when a photon interacts with the cosmic matter, electromagnetic vacuum and gravitational field.

Of course, the Doppler effect takes part in the spectral redshift. But the redshift originating from the Doppler effect related to peculiar motions of individual galaxies is essentially distinguished from the cosmological redshift. The total redshift z_{obs} observed is expressed as

$$1 + z_{obs} = \lambda_{obs}/\lambda_0,$$

where z_{obs} may contain contributions with different physical causes. The observed redshift can be represented as

$$1 + z_{obs} = (1 + z_{cos})(1 + z_{bac})(1 + z_{pec})(1 + z_{gra})(1 + z_{other})$$

where z_{cos} is the cosmological redshift, z_{bac} is due to our velocity relative to the background radiation, z_{pec} is related to the peculiar velocity of the observed galaxy, z_{gra} is the gravitational influence caused by the local potential of the galaxy, and z_{other} is any unknown physical effect. The gravitational redshift is usually regarded as negligible in the light of galaxies [1]. The Doppler effect may contribute to an observed redshift but at large redshifts, the cosmological redshift dominates over the Doppler shifts due to the motions of our galaxy and the observed galaxy. Blueshifts and redshifts due to peculiar motions of galaxies are contingent and importantly, do not depend on distance. Therefore, they are not involved in the cosmological redshift which is universal on large scales.

The total cosmological redshift is represented by taking into account several kinds of distance–dependent redshift as

$$c\sum_i z_i = c\sum_i \frac{\lambda_i - \lambda_0}{\lambda_0} = \left(\sum_i H_i\right)r,$$

where i refers to a kind of redshift mechanisms. Finally, we obtain as the sum of redshifts the total Hubble law

$$c\frac{\sum_i(\lambda_i - \lambda_0)}{\lambda_0} = \left(\sum_i H_i\right)r.$$

By arranging, we have

$$c\frac{\frac{1}{n}\sum_{i=1}^n \lambda_i - \lambda_0}{\lambda_0} = \left(\frac{1}{n}\sum_{i=1}^n H_i\right)r,$$

which becomes

$$c\frac{\bar{\lambda}-\lambda_0}{\lambda_0}=H_0 r. \tag{44}$$

From this, it follows that the Hubble constant is not determined by a single factor and instead, depends on several physical factors and mechanisms of energy dissipation present in the universe which is principally isotropic and homogeneous on large scales. Presumably, the Malmquist biases, selection effects [45,46], the Hubble diagram and bias of the Hubble constant would reflect such multiple mechanisms.

4 Doppler effect and expansion of universe: underlying general relativity

4.1 Doppler effect and expansion of universe

The Doppler effect is physics for interpreting the cosmological redshift. It is important to consider the Hubble law from the point of view of dynamics because it can provide a clear understanding of essential aspects of the cosmological redshift. If the redshift of spectral lines is interpreted in terms of the Doppler effect, it should be represented based on relativity theory as

$$\lambda=\sqrt{\frac{1+\upsilon/c}{1-\upsilon/c}}\,\lambda_0. \tag{45}$$

We use the nonrelativistic approximation for Eq. (45) to get

$$z=\frac{\lambda-\lambda_0}{\lambda_0}=\frac{\upsilon}{c}.$$

Thus, the Hubble law

$$cz=H_0 r$$

is rewritten as

$$\upsilon=H_0 r. \tag{46}$$

This is the conventional explanation of the Hubble law in terms of the Doppler effect. Hereafter, Eq. (46) is called simply the Hubble law, without specifying "in terms of the Doppler effect."

The linearity of Hubble's law means that any observer sees the expansion of the universe with the same H_0. In fact, Eq. (46) gives such unreliable interpretation that any observer looks like occupying a privileged position at the "center" of the universe. If the Hubble law is written in the vectorial form, then such a difficulty is overcome and it is possible to explain the expansion of the universe reasonably. For any two celestial bodies, the Hubble law is written in the vectorial form with respect to the center of the universe as

$$\frac{d\mathbf{r}_1}{dt}=H_0\mathbf{r}_1, \tag{47}$$

$$\frac{d\mathbf{r}_2}{dt}=H_0\mathbf{r}_2. \tag{48}$$

Hence, for an observer and an observed galaxy, we have

$$\frac{d(\mathbf{r}_2-\mathbf{r}_1)}{dt}=H_0(\mathbf{r}_2-\mathbf{r}_1). \tag{49}$$

Thus, Eq. (49) shows that the Hubble law with the same H_0 holds for an arbitrary observer. From this, it follows that the Hubble law describes not a sporadic expansion of the universe but the expansion of the whole universe which arose from a center. According to the Doppler effect, the Hubble law becomes the representation of a kinetic effect of galaxies.

The Hubble law states that the universe is dynamic. From this law, it follows that in the past, the universe was denser and hotter. The Hubble law enables us to extrapolate to a moment of infinite density called the big bang or primordial singularity. If such an extrapolation is meaningful, we can imagine that the density of celestial bodies in the direction from an observer to the center of the universe is highest, while it is lowest in the opposite direction. If the expansion of the universe is real, the density of celestial bodies should depend on the distance from the center of the universe. This fact can be confirmed by the following consideration. For the process of the expansion of the universe, the continuity equation

$$\oint\mathbf{j}d\mathbf{s}=j(r)\cdot 4\pi r^2=\rho(r)\upsilon(r)\cdot 4\pi r^2=const, \tag{50}$$

should hold. Here j, ρ and υ refer to the current density, the density and the velocity of cosmic matter at the distance from the center of the universe r, respectively. With the help of the Hubble law, we have

$$\rho(r)\upsilon(r)\cdot 4\pi r^2=4\pi\rho(r)Hr^3. \tag{51}$$

Hence, we get

$$\rho(r)=\frac{a}{r^3}, \tag{52}$$

where a is a constant that characterize the universe. This shows that the density of matter in the universe is inversely proportional to the cube of the distance from the center of the universe. The inhomogeneity of the universe due to the expansion of the universe, which is logically conceivable from Eq. (52), contradicts Einstein's cosmological principle. The second basis of the SCM which is called Einstein's cosmological principle is that the universe is spatially homogeneous and isotropic on large scales. Thus, the theory on the expansion of the universe is faced with an inconsistency.

In addition, it is impossible to explain the expansion of the universe in agreement with the established dynamics. If the expansion of the universe continues and as a result the evolution of the universe is determined, it should be said that the universe is governed mainly by repulsive force. According to Eq. (49), it is obvious that the expansion of the universe is realized by the repulsive force related to a unique center. The repulsive force that the Hubble law suggests should be produced by a center commanding a single dynamical process of evolution over the whole universe. In addition, not only the farther the distance from the center is, the stronger the repulsive force should get but also the force in every location should be stationary. Nevertheless, we cannot find the center of the universe which the law of the expansion of the universe indicates, and cannot measure the repulsive force pertaining to it in a direct experimental way.

It is necessary to interpret the repulsion which should underpin the hypothesis about the expansion of the universe from the mathematical aspect. Let us differentiate the both sides of the equation for the Hubble law with respect to time. Then we have

$$\frac{d^2r}{dt^2} = H_0\frac{dr}{dt}. \tag{53}$$

It follows that the time derivative of velocity, i.e., the acceleration is proportional to the velocity. That is,

$$\frac{d\upsilon}{dt} = H_0\upsilon, \tag{54}$$

Thus, the Hubble law satisfies the general relation

$$\frac{d^nr}{dt^n} = H_0\frac{d^{n-1}r}{dt^{n-1}} = H_0^n r. \tag{55}$$

Eqs. (46) and (54) shows that the farther the distance from the center is, the higher the velocity and the acceleration. It means that the assumed repulsive force by dark energy increases with distance and thus the universe is expanding at an accelerating pace, and the energy of the universe is increasing.

Concerning the evolution of the universe, the Hubble law provides an important knowledge about the state of the early universe. Apparently, it is imagined that at the initial instant, the radius of the universe was extremely small and thus its expansion velocity too was very low. According to the Hubble law, the size of the early universe is not allowed to be zero. Such arguments lead to the conclusion that instead of the big bang, the feebly generated expansion is intensifying according to the exponential rule with respect to time. Eventually, the Hubble law contradicts the big bang. According to the Hubble law, despite the high density and high temperature, the state of the early universe made a faint show of activity unlike the big bang. At this stage, we cannot explain the true nature of the mysterious force that governs the expanding universe. It is noticeable that at first Hubble himself objected to the explanation of the Hubble law in terms of the expansion of the universe [47]. Thus, it is revealed that the conception of the big bang and the expansion of the universe is not consistent.

On the other hand, if the big bang scenario is right, then inferring from Eq. (54), we can define a new repulsive force inherent in the universe. From Eq. (54), we have

$$\frac{d^2r}{dt^2} = H_0^2 r_0 e^{H_0 t} = H_0^2 r.$$

Therefore, with the help of Newton's law, the net force F_{net} acting on celestial bodies can be written as

$$F_{net}(r) = m\frac{d^2r}{dt^2} = mH_0^2 r. \tag{56}$$

Since the net force is determined by subtracting the attractive force by matter from the repulsive force, the repulsive force F_{rep} is represented as

$$F_{net} = F_{rep}(r) + F_{att} = mH_0\upsilon(r) = mH_0^2 r, \tag{57}$$

where F_{att} is the attractive force. Since the net force which involves the gravitational and dark energies is always positive, as far as the Hubble law holds, the universe must expand forever. Therefore, under the Doppler interpretation of the cosmological redshift, it is meaningless to discuss the critical density, and there is only one scenario, i.e., the perpetual expansion.

Assuming the uniform distribution of matter, F_{att} is represented as

$$F_{att} = -G\frac{Mm}{r^2},$$

where M is the mass which the sphere of radius r from the center of the universe has. Therefore, Eq. (57) becomes

$$F_{rep}(r) = H_0^2 mr + G\frac{Mm}{r^2}, \tag{58}$$

which indicates that as r increases, the repulsive force gets stronger and plays a major role in the net force.

Based on the above arguments, it is possible to show that the concept of the critical density is meaningless. In fact, since according to Eq. (56), the net force is always positive, it is obvious that the expansion of the universe should continue forever.

The conventional explanation of the critical density is as follows [48]. If gravitational forces are much weaker, they slow the expansion only a little, and the universe should continue to expand forever. The total energy as the sum of kinetic plus potential energies for our galaxy is

$$E = \frac{1}{2}m\upsilon^2 + U(r) = \frac{1}{2}m\upsilon^2 - \frac{GMm}{r}. \tag{59}$$

If E is positive, our galaxy has enough energy to escape from the gravitational attraction of the mass inside the sphere; in this case the universe should keep expanding forever. If E is negative, our galaxy cannot escape and the universe should eventually pull back together. The crossover between these two cases occurs when $E = 0$, so that

$$\frac{1}{2}mv^2 = \frac{GMm}{r}. \tag{60}$$

The total mass inside the sphere is the volume times the density, i.e.,

$$M = \frac{4}{3}\pi r^3 \cdot \rho_c.$$

It is assumed that the speed of our galaxy relative to the center of the sphere is given by the Hubble law $v = H_0 r$. Substituting these expressions for M and v into Eq. (59), we get the critical density

$$\rho_c = \frac{3H_0^2}{8\pi G}.$$

If the average density is less than ρ_c, the universe should continue to expand indefinitely, whereas if it is greater, the universe should eventually stop expanding and begin to contract.

In this description, there is a fatal error. Eq. (59) does not include the potential energy due to dark energy. In fact, Eq. (59) should be corrected to become

$$E = \frac{1}{2}mv^2 + U(r) = \frac{1}{2}mv^2 - \frac{GMm}{r} + U_d(r), \tag{61}$$

where $U_d(r)$ is the potential energy due to dark energy. With the help of F_{net}, we can determine $U(r)$ by

$$U(r) = \int_r^{r_\infty} F_{net} dr = mH_0^2 \int_r^{r_\infty} r dr = \frac{1}{2} mH_0^2 r^2 \Big|_r^{r_\infty},$$

where r_∞ is the limit within which the Hubble law holds. r_∞, in principle, is infinity, since the universe is infinite. By means of the Hubble law $v = H_0 r$, we get

$$U(r) = \frac{1}{2}m\left(v^2(r_\infty) - v^2(r)\right).$$

Inserting the above into Eq. (61), we arrive at $E = \frac{1}{2}mv^2(r_\infty)$, which indicates that the total energy of every celestial body is infinity. In other words, this means that the universe is the world where its kinetic energy increases constantly and thus the conservation laws are violated everywhere, if the assumed dark energy is not considered. If so, this is a mystic infinity problem in physics.

On the other hand, Eq. (57) indicates that any location other than the center of the universe is a noninertial system. This implies that there exists a force field governed by the center of the universe. However, we have not yet found such force field or acceleration by means of experiment and cannot describe it with the help of the four fundamental forces of nature. Eventually, the attempt to explain the Hubble law in terms of the Doppler effect causes knotty problems relevant to the task to expound an unprecedented mystic mechanism.

It is necessary to deliberate on whether it is possible to make an alternative explanation of the Hubble law based on another physics instead of the Doppler effect. If it is possible to explain in a consistent way the Hubble law in terms of the redshift due to cosmic matter and gravitational field, we could arrive at the conclusion that the universe is principally stationary and uniform. In this case, we need not describe the dynamical process and the evolution of the universe as a whole.

4.2 General relativity and expansion of universe

The general theory of relativity gives a radically different view from the expansion just described based on the Doppler effect. According to this theory, the increased wavelength is caused not by a Doppler shift as the universe expands into a previously empty void, but rather as a result of the expansion of space itself and everything in intergalactic space, including the wavelengths of light traveling from distant sources.

It is significant to consider some aspects of the standard cosmological model (SCM) to study the theoretical foundations of cosmology. The following arguments involve Baryshev and Teerikorpi's studies [1] and our addition. SCM that describes the expanding universe bases on general relativity (GR). The Einstein field equation

$$R_i^k - \frac{1}{2}g_i^k R = \frac{8\pi G}{c^4}T_i^k \tag{62}$$

is obtained from the principle of least action $\delta(S_m + S_g) = 0$. In the above equation, G is the gravitational constant and R the scalar curvature of spacetime. S_m and S_g which is the actions of matter and gravitational field are represented as

$$S_m = \frac{1}{c}\int \Lambda \sqrt{-g} d\Omega,$$

$$S_g = \int R \sqrt{-g} d\Omega,$$

respectively. Here, Λ is the Lagrangian density of a physical system in consideration and R the scalar curvature of spacetime. As a result, gravity is described by a metric tensor g_i^k of a Riemannian space which constitutes R.

The problem of finding the field equation can be considered as the extreme value problem of the action S_m of a physical system with a constraint S_g for fulfilling the requirement of relativistic symmetry. What should be emphasized is that S_g in GR is not the action in case of considering the gravitational field as a physical entity which possesses energy and momentum. Therefore, S_m should be replaced by the action including matter and field as a whole. However, the field equation does not comprise the action pertaining to field. As Eq. (62) shows, GR does not include the energy-momentum tensor of gravitational field corresponding to the energy-momentum tensor of electromagnetic field that is represented as

$$\Lambda = \frac{1}{16\pi} F_{ik} F^{ik} = \frac{1}{16\pi} F_{ik} F_{lm} g^{il} g^{km}.$$

This fact implies the violation of the conservation law for matter plus field as a whole. To be correct energy-momentum tensor of the physical system, the whole energy-momentum tensor should take the form of $T^k_{i(m)} + T^k_{i(f)}$, where $T^k_{i(f)}$ is the energy-momentum tensor of gravitational field. This argument casts doubt on the validity of the field equation of GR.

Another problem is whether the assumption that GR can be applied to the universe as a whole has scientific justification, even if the field equation was successfully validated for the cases of the weak gravity of the solar system and binary neutron stars. To apply the Einstein equation to the theory of the universe, the equation is modified by embracing $T^k_{i(d)}$ which is the energy-momentum tensor (EMT) for the assumed dark energy to become

$$R^k_i - \frac{1}{2} g^k_i R = \frac{8\pi G}{c^4} \left(T^k_{i(m)} + T^k_{i(d)} \right), \tag{63}$$

which includes the famous cosmological constant. But at the present time, there is no obvious reason of GR itself for the modification of the form of the fundamental equation [49]. In fact, dark energy is not a result that derives from GR but an assumption that GR makes. Up to now, physics of the expansion of the universe still remains a mysterious subject, since the concept of expanding space has not been verified at all by testing in our laboratories and the expansion at issue implies the continuous creation of space containing matter and field, which results in the violation of the law of energy conservation. Thus, this theory of space expansion is faced with several serious paradoxes.

It is necessary to review the problematic issues of the most widely accepted cosmological model, where about 95 percent of the total matter of the universe obeys unknown physics. In the modern Friedmann model, the presumedly uniform dark matter and dark energy determine the dynamics of the universe. However, traces exhibiting the strange universe dominated by two hypothetical entities, i.e., dark matter and dark energy have not been tested at all in laboratories. Modern versions of SCM become unreliable, since it rests on the extraordinary assumption about dark matter with positive pressure and dark energy with negative pressure.

The Friedmann-Lemaitre-Robertson-Walker (FLRW) model is based on the general relativity and Einstein's cosmological principle. The FLRW model gives a mathematical description of the expanding space in terms of a geometrical theory of gravity. Although GR was successfully tested in some celestial phenomena, the assertion that GR can be applied to the universe as a whole is not logically sufficient.

According to GR, the distance from an observer to some receding galaxy $R(t)$ is represented as

$$R(t) = R_0 a(t), \tag{64}$$

where R_0 is the current separation in some appropriate length unit, and $a(t)$ is the dimensionless scaling factor with $a(t_0) = 1$ for the present time denoted t_0. In this connection, we have to bear in mind the fact that Eq. (64) is not a logic result of GR derived uniquely but a result of the assumption about dark matter and dark energy. According to the assumption, i.e., $a(t) > 1$ or $a(t) < 1$ which are determined by dark matter and dark energy, it may be explained that the universe expands or contracts. The increasing scaling factor $a(t)$ in FLRW model plays important role in explaining the expanding space that is realized by adding vacuum and homogeneous matter. The cosmological redshift is explained by the enlarging of wavelength of light due to the space expansion.

If the space expansion should be universal, it would be impossible to detect the space expansion. This is because all measuring tools also undergo the space expansion of the same scale. For example, even if the space expansion occurs, a 10m-lengthy ruler should be left forever as the 10m-lengthy ruler in every spacetime. In principle, there is no invariant ruler independent of time. Therefore, homologous physical worlds, although they are distinguished by time, must show the same physical laws to an observer existing at the same time. In fact, with a present measuring tool, it is impossible to measure directly physical objects belonging to the past or future.

GR states that the linear recession velocity-distance relation $\upsilon = H_0 r$ in accord with the Hubble law can be established only if the matter distribution is uniform and isotropic. However, modern observation on galaxy distribution shows that there is no homogeneity of the universe at least for luminous matter. The real universe is not homogeneous, since it contains atoms, planets, stars and galaxies as sparse entities. Obviously, the expansion of the universe means the creation of space filled with matter as well as physical vacuum. If the creation of space were true, every bounded physical object such as particles, for example, atoms, stars and galaxies also should expand constantly. In this case, we should consider even elementary particles such as electron and positron to be growing entities. Surprisingly, this means the continuous change of all physical laws associated with space and time. But we actually cannot find the traces of either the space creation or the change of physical law. This shows that the creation of space is not a cosmological result which is testable and reliable. In this manner, we are faced with several puzzles of FLRW models which are a direct consequence of GR.

It is necessary to consider that SCM based on a particular solution of the gravity field equations causes the conceptual problems associated with modern physics such as quantum physics and elementary particle theory. The picture of fundamental forces of quantum nature including strong, weak, electromagnetic field is incompatible with the fact that GR is a non-quantum theory based on the geometrical interpretation of space and time. In fact, the concept of quanta of fields as a physical entity is incompatible with of the curvature of spacetime which is not substance.

A major challenge is that we are forced to acknowledge just new physical phenomena where conservation laws are violated and receding velocities of galaxies approach the speed of light. In fact, the space creation at issue implies the violation of conservation laws. Such physics as cannot be verified in laboratories is unreliable and thus the present situation needs an alternative theory that can explain observational data in a reasonable way based on verified and established laws of physics as far as possible.

We believe that it is possible to find a better model of the universe which does not need inconsistent assumptions. In this context, it is instructive to refer to Feynman's consideration that relativistic quantum field could supersede GR [50].

5 Discussion

We have shown an alternative theoretical model and interpretation of the cosmological redshift based on quantum-optical theory.

The purpose of our work has been to explain the cosmological redshift in a natural and consistent way that makes the best use of commonly accepted knowledge without making venturous assumptions. Our work has demonstrated that the loss of photon's energy due to the interaction of photon with the cosmic matter, electromagnetic vacuum and gravitational field is the main cause of the cosmological redshift. In our view, the explanation of the cosmological redshift in terms of the photon interaction has to be assessed as being more reasonable than that based on the conventional theory. The reason is that our investigation need not employ such unverified assumptions as the big bang, dark matter and dark energy which at present cannot be tested at all in laboratories.

Based on our theory, the Hubble law has been explained successfully. It has been revealed that the Hubble law is irrelevant to the expansion of the universe after the big bang and simply portrays the universe that is static, uniform and infinite. Importantly, based on our model, the seemingly accelerating universe also is interpreted as a natural consequence which the static paradigm of cosmology gives.

In this work, we have shown that the explanation of the cosmological redshift by the Doppler effect is illogic in the aspect of dynamics. To explain the Hubble law in terms of the Doppler effect, it should be confirmed that a kind of dominant repulsive force exists in the universe. In fact, if such a dominant repulsive force exists, it must be detected in laboratories because it governs the universe. However, in laboratories, we do not make sense of this mysterious force supposed to govern the universe, suppressing gravity.

It is known that there exist the four fundamental interactions including the strong, weak, electromagnetic and gravitational interactions. Of them, gravity plays a decisive role in understanding and predicting cosmological phenomena. The dynamical interpretation of the repulsion in terms of the four forces is impossible within the confines of our present knowledge. Therefore, at this stage, it is unrealistic to imagine a certain force or mechanism able to give rise to the cosmological repulsion.

Moreover, from the dynamical aspect, it is difficult to explain the expansion of the universe which is furthered with time. In this regard, it is significant to note that there are some researchers who refused to explain the Hubble law in terms of the Doppler effect [34,41]. The scenario describing the big bang and the expansion of the universe cannot give the correct explanation of the present state of the universe from the point of view of dynamics. If the big bang and the expansion of the universe are true, the present universe would be more active than the early universe and its activity would be increasing exponentially with respect to time over the whole space. Importantly, we must discover another fundamental force different from the four fundamental forces. As Eq. (56) shows, the net force should increase with distance and velocity. But at present, we cannot find it within the range where our direct measurements are made.

The accelerating expansion of the universe which obeys the exponential law cannot be explained by the influence of a single explosion because the explosive progress at issue needs to maintain the gain of exponentially increasing energy. If the expansion under discussion is true, the universe should be a nonequilibrium open system which interacts with an unknown external system and should remain a finite system. But it is impossible to explain the case reasonably.

Integrating Eq. (46) with the time-independent Hubble constant, we get

$$r = r_0 e^{H_0 t}.$$

This indicates that the universe is expanding exponentially with respect to time. In this case, we should explain the dynamics of this physical process. However, the theory for explaining the Hubble law in terms of the Doppler effect cannot give a clear answer to the question of what force causes the expansion of the universe, without assuming dark energy which has not been detected in laboratories despite governing the universe. Obviously, our present knowledge about the universe is not sufficient to explain the expansion of the universe dynamically. For this reason, at this stage, the scenario based on the big bang and expansion of the universe cannot serve as the complete theoretical foundation of cosmology.

We have explained the Hubble law in terms of the interaction of photon with the cosmic matter, electromagnetic vacuum and gravitational field. Thus, we come to find the three candidates for the cause of the cosmological redshift: cosmic matter, electromagnetic vacuum and gravitational field. They all bear the linear distance-redshift relation and do not need special assumptions.

According to the viewpoint of some researchers, the notion of the expanse of the universe is based on the unverified assumption that a local distance in a physical space is similar to that of a mathematical Riemannian space embedded in a higher dimensional flat space and thus the physical meaning of coordinates would necessarily depend on the metric [41]. Contrary to this, some physicists affirm that this unverified assumption is inconsistent with Einstein's notion of space contractions [47]. They emphasize that a physical space has the Euclidean-like structure independently of the metric and it is not an embedded space. Such a situation of the discussion shows that the explanation of the cosmological redshift based on the notion of the space expansion is not satisfactory in several respects. If the cosmological redshifts is not ascribed to the so-called space expansion and the Doppler effect, then we must newly elucidate the cause of redshifts roughly proportional to the distances from the observer. Thus, in view of the real circumstances of the universe, we have shown other causes of the cosmological redshift that include cosmic matter, electromagnetic vacuum and gravitational field, which are uniform on large scales and cause the energy dissipation of photon in the same form.

6 Conclusions

In this work, we have given the non-Doppler description of cosmological redshift based on quantum optics. Since at present the Hubble law has been confirmed by the reliable measurement [51], it is necessary to explain the nature of the law completely in a consistent way. We have investigated the state of the universe and its evolution by using light as a main measuring tool within the limit that our sight reaches. Due to the selection effects, distortion and evolution effects which modify original physical relations between observed quantities, an established cosmological theory may not be perfect, and thus we cannot avoid the necessity of correcting wrongly established cosmological laws.

Our view is that properties of light are decisive in explaining the cosmological redshift. Based on this perspective, we have explained the cosmological redshift in terms of the interaction of photon with the cosmic matter, electromagnetic vacuum and gravitational field. This approach enables us to derive the generalized formula for the cosmological redshift in a rigorous way, based on the energy dissipation of photon due to interaction. Moreover, this generalized formula explains the speeding up of the expansion of the universe which was concluded in the big-bang scenario, in a direct way without depending on the assumption about dark energy. This shows that knowledge of optics is a more dependable basis than the big-bang theory in explaining the cosmological redshift because it uses knowledge established already without depending extraordinary assumptions and does not cause difficulties of physical interpretation at all.

In our view, it is not reasonable to describe the evolution of the universe in a way of depending one-sidedly on the scenario for the big bang and the expansion of the universe. Our study has shown that the explanation of the Hubble law in terms of the Doppler effect is inconsistent in the dynamical aspect. Evidently, the big bang theory can explain the Hubble law in some degree from the point of view of kinematics, but cannot avoid contradictions in describing physics of the expansion of the universe. In fact, we still cannot find the assumed repulsive force responsible for the accelerating expansion and cannot overcome inconsistency in explaining dynamics of the big bang.

We believe that our work conducted in this view will be helpful to gain a better understanding of the physical essence of the cosmological redshift and the Hubble law.

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