Interacting Agegraphic Dark Energy

Hao Wei
Department of Physics, Beijing Institute of Technology, Beijing 100081, China
Department of Physics and Tsinghua Center for Astrophysics, Tsinghua University, Beijing 100084, China

Rong-Gen Cai
Institute of Theoretical Physics, Chinese Academy of Sciences, P.O. Box 2735, Beijing 100190, China

ABSTRACT

A new dark energy model, named “agegraphic dark energy”, has been proposed recently, based on the so-called Károlyházy uncertainty relation, which arises from quantum mechanics together with general relativity. In this note, we extend the original agegraphic dark energy model by including the interaction between agegraphic dark energy and pressureless (dark) matter. In the interacting agegraphic dark energy model, there are many interesting features different from the original agegraphic dark energy model and holographic dark energy model. The similarity and difference between agegraphic dark energy and holographic dark energy are also discussed.

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* email address: haowei@bit.edu.cn
† email address: caig@itp.ac.cn
I. INTRODUCTION

Dark energy [1] has been one of the most active fields in modern cosmology since the discovery of accelerated expansion of our universe [2, 3, 4, 5, 6, 7, 8, 9]. The simplest candidate of dark energy is a tiny positive cosmological constant. However, as is well known, it is plagued by the so-called “cosmological constant problem” and “coincidence problem” [1]. The cosmological constant problem is essentially a problem in quantum gravity, since the cosmological constant is commonly considered as the vacuum expectation value of some quantum fields. Before a completely successful quantum theory of gravity is available, it is more realistic to combine quantum mechanics with general relativity directly.

Following the line of quantum fluctuations of spacetime, in Refs. [10, 11, 12, 17], by using the so-called K´ arolyházy relation

$$\delta t = \frac{\lambda t^2}{3} \left( \frac{1}{\sqrt{\rho}} \right)$$

and the well-known time-energy uncertainty relation $E \delta t \sim t^{-1}$, it was argued that the energy density of metric fluctuations of Minkowski spacetime is given by

$$\rho \sim \frac{E \delta t^3}{\delta t} \sim \frac{m_p^2}{t^2}. \quad (1)$$

We use the units $\hbar = c = k_B = 1$ throughout, whereas $l_p = t_p = 1/m_p$ with $l_p, t_p$ and $m_p$ being the reduced Planck length, time and mass, respectively. It is worth noting that in fact the Károlyházy relation and the corresponding energy density (1) have been independently rediscovered later for many times in the literature (see e.g. [30, 31, 32]).

In [17], one of us (R.G.C.) proposed a new dark energy model based on the energy density (1). As the most natural choice, the time scale $t$ in Eq. (1) is chosen to be the age of our universe

$$T = \int_0^a \frac{da}{Ha}, \quad (2)$$

where $a$ is the scale factor of our universe; $H \equiv \dot{a}/a$ is the Hubble parameter; a dot denotes the derivative with respect to cosmic time. Therefore, we call it “agegraphic” dark energy. The energy density of agegraphic dark energy is given by [17]

$$\rho_q = \frac{3n^2 m_p^2 T^2}{T^2}, \quad (3)$$

where the numerical factor $3n^2$ is introduced to parameterize some uncertainties, such as the species of quantum fields in the universe, the effect of curved spacetime (since the energy density is derived for Minkowski spacetime), the non-saturation of the quantum fluctuations, and so on. Obviously, since the present age of the universe $T_0 \sim H_0^{-1}$ (the subscript “0” indicates the present value of the corresponding quantity; we set $a_0 = 1$), the present energy density of the agegraphic dark energy explicitly meets the observed value, provided that the numerical factor $n$ is of order unity. In addition, by choosing the age of the universe rather than the future event horizon as the length measure, the drawback concerning causality in the holographic dark energy model does not exist in the agegraphic dark energy model [17].

Considering a flat Friedmann-Robertson-Walker (FRW) universe with agegraphic dark energy and pressureless matter, the corresponding Friedmann equation reads

$$H^2 = \frac{1}{3m_p^2} (\rho_m + \rho_q). \quad (4)$$

It is convenient to introduce the fractional energy densities $\Omega_i \equiv \rho_i/(3m_p^2 H^2)$ for $i = m$ and $q$. From Eq. (3), it is easy to find that

$$\Omega_q = \frac{n^2}{H^2 T^2}, \quad (5)$$

whereas $\Omega_m = 1 - \Omega_q$ from Eq. (4). By using Eqs. (3), (5) and the energy conservation equation $\dot{\rho}_m + 3H \rho_m = 0$, we obtain the equation of motion for $\Omega_q$ [17],

$$\Omega'_q = \Omega_q (1 - \Omega_q) \left( 3 - \frac{2n}{\sqrt{\Omega_q}} \right), \quad (6)$$
where a prime denotes the derivative with respect to the \(e\)-folding time \(N \equiv \ln a\). From the energy conservation equation \(\dot{\rho}_q + 3H(\rho_q + p_q) = 0\), as well as Eqs. (3) and (4), it is easy to find that the equation-of-state parameter (EoS) of the agegraphic dark energy, \(w_q \equiv p_q/\rho_q\), is given by \(\frac{1}{1 + 2w_q} \equiv \Omega_q^{\frac{1}{2}}\). Obviously, the EoS of the agegraphic dark energy is always larger than \(-1\), and cannot cross the so-called phantom divide \(w_{\text{de}} = -1\). The total EoS \(w_{\text{tot}} \equiv p_{\text{tot}}/\rho_{\text{tot}} = \Omega_q w_q\). To accelerate the expansion of our universe, \(w_{\text{tot}} < -1/3\) is necessary. Thus, \(n > 2\Omega_q^{3/2}(3\Omega_q - 1)^{-1}\) follows. It is easy to see that \(\Omega_q > 1/3\) (nb. \(\Omega_q \approx 0.7\) today), the minimum of \(2\Omega_q^{3/2}(3\Omega_q - 1)^{-1}\) is 1 at \(\Omega_q = 1\). Therefore, \(n > 1\) is necessary to drive the (present) accelerated expansion of our universe.

In addition, it is of interest to compare Eqs. (6) and (7) with the ones of the holographic dark energy \([13, 15, 18]\). Obviously, they are fairly similar. Of course, there are some differences. Except for the slight differences of the numerical constant, the most important difference is the sign before the term \(\frac{1}{2}\sqrt{\Omega_q}\). In fact, soon after the appearance of \(\Omega_q = \Omega_q^{\frac{1}{2}}\), it is found that the agegraphic dark energy model cannot have a matter-dominated phase if \(n > 1\) and if there is no interaction between the dark components in the universe \([33]\). In \(\Omega_q = \Omega_q^{\frac{1}{2}}\), a so-called “new agegraphic dark energy” model was proposed to remove the inconsistency by replacing the time scale \(T\) in Eq. (3) with the conformal time \(\eta\). Of course, there exist other ways out of the difficulty in the original agegraphic dark energy model (see e.g., Sec. 2 of \([33]\)). Therefore, it is still worthwhile to study the original version of the agegraphic dark energy model. In this note, we will see that the interaction between the original agegraphic dark energy and pressureless (dark) matter can significantly change the cosmological evolution. Thus, the inconsistency in the original version without interaction can also be removed in the interacting agegraphic dark energy model.

## II. INTERACTING AGEGRAPHIC DARK ENERGY

In this note, we extend the original agegraphic dark energy model by including the interaction between agegraphic dark energy and pressureless (dark) matter. Given the unknown nature of both dark energy and dark matter, it seems very peculiar that these two major components in the universe are entirely independent \([27, 28]\). In fact, the models with interaction between dark energy and dark matter have been studied extensively in the literature. For a complete list of references concerning the interacting dark energy models, we refer to e.g. \([19, 20, 29]\) and references therein.

We assume that the agegraphic dark energy and pressureless (dark) matter exchange energy through an interaction term \(Q\), namely

\[
\dot{\rho}_q + 3H(\rho_q + p_q) = -Q, \tag{8}
\]

\[
\dot{\rho}_m + 3H\rho_m = Q, \tag{9}
\]

which preserves the total energy conservation equation \(\dot{\rho}_{\text{tot}} + 3H(\rho_{\text{tot}} + p_{\text{tot}}) = 0\). In this work, we consider the three most familiar forms of interaction \([19, 20, 27, 28, 29]\), namely

\[
Q = 3\alpha H\rho_q, \quad 3\beta H\rho_m, \quad 3\gamma H\rho_{\text{tot}}, \tag{10}
\]

where \(\alpha, \beta\) and \(\gamma\) are dimensionless constants. In fact, the interaction forms in Eq. (10) are given by hand. Although agegraphic dark energy is the quantum fluctuation of spacetime, it might decay into matter, similar to the \(\Lambda(t)\)CDM model in which the vacuum fluctuations can decay into matter. This effect could be described by the interaction term \(Q\) phenomenologically. From Eq. (7), we get

\[
\Omega_q' = \Omega_q \left( -\frac{2H}{H^2} - \frac{2}{n} \sqrt{\Omega_q} \right). \tag{11}
\]
Differentiating Eq. (11) and using Eqs. (9), (3) and (5), it is easy to find that

\[-\frac{\dot{H}}{H^2} = \frac{3}{2}(1 - \Omega_q) + \frac{\Omega_q^{3/2}}{n} - \frac{Q}{6m_p^2H^3}.\]  

(12)

Therefore, we obtain the equation of motion for \(\Omega_q\),

\[\Omega_q = \Omega_q \left[ (1 - \Omega_q) \left( 3 - \frac{2}{n} \sqrt{4\Omega_q} \right) - \frac{Q}{3m_p^2H^3} \right],\]  

(13)

where

\[
\frac{Q}{3m_p^2H^3} = \begin{cases} 
3\alpha\Omega_q & \text{for } Q = 3\alpha H \rho_q \\
3\beta(1 - \Omega_q) & \text{for } Q = 3\beta H \rho_m \\
3\gamma\Omega_q^{-1} & \text{for } Q = 3\gamma H \rho_{tot}.
\end{cases}
\]  

(14)

If \(Q = 0\), Eq. (13) reduces to Eq. (6). From Eqs. (8), (3) and (5), we get the EoS of the agegraphic dark energy, namely

\[w_q = -1 + \frac{2}{3n} \sqrt{\Omega_q} - \frac{Q}{3H\rho_q},\]  

(15)

where

\[
\frac{Q}{3H\rho_q} = \begin{cases} 
\alpha & \text{for } Q = 3\alpha H \rho_q \\
\beta(\Omega_q^{-1} - 1) & \text{for } Q = 3\beta H \rho_m \\
\gamma\Omega_q^{-1} & \text{for } Q = 3\gamma H \rho_{tot}.
\end{cases}
\]  

(16)

Again, if \(Q = 0\), Eq. (15) reduces to Eq. (7). Using Eq. (12), the deceleration parameter is given by

\[q = -\frac{\ddot{a}}{a^2} = -1 - \frac{\dot{H}}{H^2} = \frac{1}{2} - \frac{3}{2}\Omega_q + \frac{\Omega_q^{3/2}}{n} - \frac{Q}{6m_p^2H^3},\]  

(17)

where the last term can be found from Eq. (13). The total EoS \(w_{tot} \equiv \rho_{tot}/\rho_{tot} = \Omega_q w_q\), where \(w_q\) is given in Eq. (15). On the other hand, from the Friedmann equation and the Raychaudhuri equation, we have \(w_{tot} = 1 - \frac{2}{3} \frac{\dot{H}}{H^2} = -1/3 + 2q/3\). As mentioned above, in the case of \(Q = 0\) (i.e. without interaction), \(n > 1\) is necessary to drive the (present) accelerated expansion of our universe. In the case of \(Q \neq 0\), the situation is changed. For example, if \(Q = 3\alpha H \rho_q\), to drive the (present) accelerated expansion of our universe, we should have \(w_{tot} = \Omega_q w_q < -1/3\), which means that \(n > 2\Omega_q^{3/2}[3(1 + \alpha)\Omega_q - 1]^{-1}\). It is easy to see that the minimum of the right hand side of this inequality is \(1/2(1 + \alpha)^{-3/2}\) at \(\Omega_q = (1 + \alpha)^{-1}\), if \(\Omega_q > [3(1 + \alpha)]^{-1}\) (nb. \(\Omega_q \simeq 0.7\) today). For \(\alpha > 0\), this minimum is smaller than 1. For instance, if the present \(\Omega_{q0} = 0.7\), to drive the accelerated expansion of our universe today, \(n > 0.89414\) is enough for \(\alpha = 0.1\). In other words, \(n\) can be smaller than 1 to drive the accelerated expansion of our universe in the case of \(Q \neq 0\). We will see this point explicitly in the following (e.g. Figs. 4 and 5).

To get illustrations for the behaviors of \(\Omega_q\), \(w_q\), \(q\) and \(w_{tot}\), we show some numerical plots by using Eqs. (13)–(17) and \(w_{tot} = \Omega_q w_q\). However, to be brief, we do not present plots for all forms of interaction \(Q\). In the following, we mainly focus on the case of \(Q = 3\alpha H \rho_q\) as an example. Note that in the numerical integration of Eq. (13) we use the initial condition \(\Omega_{q0} = 0.7\) for demonstration.

In Fig. 1 we show the evolution of \(\Omega_q\) for different model parameters \(n\) and \(\alpha\) in the case of \(Q = 3\alpha H \rho_q\). It is easy to see that for the fixed \(\alpha\) which describes the interaction between the agegraphic dark energy and the pressureless (dark) matter, the agegraphic dark energy starts to be effective earlier and \(\Omega_q\) tends to a lower value at the late time when \(n\) is larger. On the other hand, for fixed \(n\), the agegraphic dark energy starts to be effective earlier and \(\Omega_q\) tends to a lower value at the late time when \(\alpha\) is larger. Interestingly enough, these behaviors are exactly opposite to the ones of the interacting holographic dark energy model [21]. As mentioned above, this is mainly due to the opposite sign before \(\sqrt{\Omega_{de}}\) in the equation of motion for \(\Omega_{de}\) (the subscript \(de = q\) and \(\Lambda\) for the agegraphic dark energy and holographic dark energy respectively).
In Fig. 2 we show the evolution of \( w_q \) for different model parameters \( n \) and \( \alpha \) in the case of \( Q = 3\alpha H \rho_q \). Obviously, the EoS of the agegraphic dark energy \( w_q \) can cross the phantom divide \( w_{de} = -1 \). In the case of \( Q = 0 \) (i.e. without interaction), as mentioned above, \( w_q \) is always larger than \(-1\) and cannot cross the phantom divide. By the help of interaction \( Q \neq 0 \) between the agegraphic dark energy and the pressureless (dark) matter, the situation is changed. From Eq. (15) with the first line of Eq. (16), it is easy to understand that \( w_q \) converges to the value \(-1 - \alpha\) at the early time in the case of \( Q = 3\alpha H \rho_q \). Of course, the most interesting observation from Fig. 2 is that \( w_q \) crosses the phantom divide from \( w_q < -1 \) to \( w_q > -1 \). This makes it distinguishable from many other dark energy models whose \( w_{de} \) can cross the phantom divide. It can be categorized into the so-called Quintom B type model, in the terminology of [22, 23]. To make this point more robust, we also plot the evolution of \( w_q \) for various model parameters \( n \) and \( \gamma \) in the case of \( Q = 3\gamma H \rho_{tot} \). The results are presented in Fig. 3. Clearly, the observation that \( w_q \) crosses the phantom divide from below to above still holds. By the way, the \( w_q \) tends to \(-\infty\) at early time for \( \gamma \neq 0 \); this is due to the last term in Eq. (15) with the last line of Eq. (16) in the case of \( Q = 3\gamma H \rho_{tot} \). It is anticipated that the behavior of \( w_q \) in the case of \( Q = 3\beta H \rho_m \) is similar to the case of \( Q = 3\gamma H \rho_{tot} \), since the last terms in the versions of Eq. (15) for these two cases are similar [cf. Eq. (16)]. It is worth noting that these results are for the cases of positive \( \alpha \), \( \beta \) and \( \gamma \). In the cases of negative \( \alpha \), \( \beta \) and \( \gamma \), from Eq. (15) with Eq. (16), one can see that \( w_q \) is always larger than \(-1\) and cannot cross the phantom divide. Obviously, the cases of positive \( \alpha \), \( \beta \) and \( \gamma \) are more interesting since the \( w_q \) can cross the phantom divide from \( w_q < -1 \) to \( w_q > -1 \).
One of the benefits of \( w_q > -1 \) at late time in the interacting agegraphic dark energy model is that the universe can avoid the big rip singularity [24, 25]. Of course, the direct condition for the avoidance of big rip should be \( w_{\text{tot}} > -1 \) instead. Since \( w_{\text{tot}} = \Omega_q w_q \) and \( 0 \leq \Omega_q \leq 1 \), the condition \( w_{\text{tot}} > -1 \) is automatically satisfied when \( w_q > -1 \). This can be seen clearly from the plot of the evolution of \( w_q \) for various model parameters \( n \) and \( \alpha \) in the case of \( Q = 3\gamma H \rho_{\text{tot}} \) for example, which is shown in Fig. 4.

The other thing one can see from Fig. 4 is that \( w_{\text{tot}} \rightarrow -1/3 \) at the early time and \( w_{\text{tot}} \leq -1/3 \) at the late time. This implies that the universe undergoes decelerated expansion at the early time and later starts accelerated expansion. To see this point clearly, we show the deceleration parameter \( q \) in Fig. 5. Obviously, \( q \) crosses the boundary \( q = 0 \) from \( q > 0 \) to \( q < 0 \). Some remarks on Figs. 4 and 5 are in order. First, the similarity between these two figures is due to the relation \( w_{\text{tot}} = -1/3 + 2q/3 \) mentioned above. Second, at the early time \( w_{\text{tot}} \) and \( q \) converge to 0 and 1/2, respectively; this is because \( \Omega_q \) can be neglected at the early time, whereas the universe is dominated by the pressureless (dark) matter. This is the case of \( Q = 3\alpha H \rho_q \). In the cases of \( Q = 3\beta H \rho_m \) and \( Q = 3\gamma H \rho_{\text{tot}} \), however, from Eqs. (17), (15) and \( w_{\text{tot}} = \Omega_q w_q \), one can see that at the early time \( w_{\text{tot}} \) and \( q \) converge to other constants rather than 0 and 1/2. For instance, in the case of \( Q = 3\beta H \rho_m \), at the early time \( w_{\text{tot}} \rightarrow -\beta \) and \( q \rightarrow 1/2 - 3\beta/2 \). In the case of \( Q = 3\gamma H \rho_{\text{tot}} \), at early time \( w_{\text{tot}} \rightarrow -\gamma \) and \( q \rightarrow 1/2 - 3\gamma/2 \). Third, for fixed \( n \), the universe starts accelerated expansion earlier when \( \alpha \) is larger (see the right panels of Figs. 4 and 5). Fourth, the universe will undergo accelerated expansion at the late time forever and cannot come back to decelerated expansion, as shown in Figs. 4 and 5. After all, in the case of \( Q = 3\alpha H \rho_q \), we notice that for \( \alpha = 0.1 \), the universe can undergo accelerated expansion for \( n = 0.95 < 1 \). One can see this point from Figs. 4 and 5. As mentioned above, this is impossible in the case of \( Q = 0 \) (i.e. without interaction). The interaction \( Q \neq 0 \) changes the situation.

Before the end of this work, we would like to mention another interesting feature of the interacting agegraphic dark energy model. The equation of motion for \( \Omega_q \), Eq. (18), can be viewed as an one-dimensional dynamical system [26]. The critical points of this autonomous equation are determined by \( \Omega'_q = 0 \). They are \( \Omega_q = 0 \) and the solutions of the equation

\[
(1 - \Omega_q) \left( 3 - \frac{2}{n} \sqrt{\Omega_q} \right) = \frac{Q}{3\rho^2 H^3},
\]

where the right hand side is given in Eq. (14). In the case of \( Q = 0 \) (i.e. without interaction), the physical solution of Eq. (18) is only \( \Omega_q = 1 \), whereas the other solution \( \sqrt{\Omega_q} = 3n/2 > 1 \) is unphysical because \( n > 1 \) is required by the accelerated expansion of our universe, as mentioned above. Thus, there is no scaling solution in the case without interaction. Again, this situation is changed in the cases of \( Q \neq 0 \). For instance, in the case of \( Q = 3\beta H \rho_m \), the critical points are \( \Omega_q = 0, 1 \) and \( 9n^2(1 - \beta)^2/4 \). Note that in the case of \( Q \neq 0 \), \( n > 1 \) is not necessary to drive the accelerated expansion of our universe. We can choose appropriate model parameters \( n \) and \( \beta \) to ensure 0 < \( \Omega_q = 9n^2(1 - \beta)^2/4 = \text{const.} < 1 \). Thus, there is a

![FIG. 3: Evolution of \( w_q \) for various model parameters \( n \) and \( \gamma \) in the case of \( Q = 3\gamma H \rho_{\text{tot}} \).](image-url)
FIG. 4: Evolution of \( w_{\text{tot}} \) for various model parameters \( n \) and \( \alpha \) in the case of \( Q = 3\alpha H\rho_q \).

FIG. 5: Evolution of the deceleration parameter \( q \) for various model parameters \( n \) and \( \alpha \) in the case of \( Q = 3\alpha H\rho_q \).

scaling solution. In the cases of \( Q = 3\alpha H\rho_q \) and \( Q = 3\gamma H\rho_{\text{tot}} \), the situation is similar. The solutions are fairly complicated and we do not present them here, since Eq. (18) is a cubic equation of \( \sqrt{\Omega_q} \) in these two cases. In fact, the flat tails of some curves in Figs. 1—5 perhaps hint the scaling solutions in the late time. The scaling solutions in the cases of \( Q \neq 0 \) can help to alleviate the coincidence problem. As is well known, for a dynamical system \[26\], the universe will enter the attractors in the late time, regardless of the initial conditions. If the attractors are scaling solutions, both \( \Omega_q \) and \( \Omega_m = 1 - \Omega_q \) are fixed values over there. If \( n \) and \( \alpha, \beta, \gamma \) are of order unity, it is not surprising that \( \Omega_q \) and \( \Omega_m = 1 - \Omega_q \) are comparable at the late time. In fact, this is just the essential point of the literature (see e.g. \[19, 20, 27, 28, 29\]) to alleviate (rather than solve) the coincidence problem using the method of dynamical system \[26\].

III. CONCLUDING REMARKS

In summary, we have extended the agegraphic dark energy model by including the interaction between the agegraphic dark energy and the pressureless (dark) matter. The original agegraphic dark energy model was proposed in \[17\] based on the Károlyházy uncertainty relation, which arises from quantum mechanics together with general relativity. In the interacting agegraphic dark energy model, there are many interesting features different from the original agegraphic dark energy model and holographic dark
energy model. In the cases with interaction $Q \neq 0$, the parameter $n > 1$ is no longer necessary to drive the accelerated expansion of our universe; the EoS of agegraphic dark energy can cross the phantom divide, whereas the big rip can be avoided; the universe undergoes decelerated expansion at early time and then starts accelerated expansion later; there are scaling solutions which can help to alleviate the coincidence problem. In particular, the difficulty in the original version of the agegraphic dark energy model [1] can be avoided here, thanks to the interaction between the dark components.

It is of interest to discuss the similarity and difference between agegraphic dark energy and holographic dark energy. It is shown that the agegraphic dark energy naturally obeys the holographic black hole entropy bound [12, 17] just like holographic dark energy. By choosing the age of the universe rather than the future event horizon as the length measure, the drawback concerning causality in the holographic dark energy model does not exist in the agegraphic dark energy model [17]. It is worth noting that the agegraphic energy density Eq. (1) is similar to the one of holographic dark energy [13, 14, 15, 16], i.e., $\rho_\Lambda \sim l_p^{-2(1-\gamma)}$. The similarity between $\rho_q$ and $\rho_\Lambda$ might reveal some universal features of quantum gravity, although they arise in different ways. In addition, the sign before the term $\sqrt{\Omega_{de}}$ (the subscript $de = q$ and $\Lambda$ for agegraphic dark energy and holographic dark energy, respectively) is opposite in the equation of motion for $\Omega_q$, the EoS of the agegraphic dark energy $w_q$, the total EoS $w_{tot}$ and the deceleration parameter $q$. This difference brings about some interesting features to the agegraphic dark energy different from the ones of holographic dark energy. In some sense, the relation between agegraphic dark energy and holographic dark energy is similar to the one between phantom and quintessence.

Finally, some remarks are in order. First, we admit that a sufficiently strong interaction might be required to relax the condition $n > 1$ for an accelerated expansion and to allow that $w_q$ crosses the phantom divide. However, a strong interaction might encounter fairly tight constraints from local gravity tests. Second, after the appearance of our relevant works on the (new) agegraphic dark energy, it was found that the original agegraphic dark energy model proposed in [17] is difficult to reconcile with the big bang nucleosynthesis (BBN) constraint [35]. On the other hand, as shown in [36], the situation is better in the new agegraphic dark energy model [33, 34]. In addition, the (new) agegraphic dark energy model faces the problem of instabilities [37], while the holographic dark energy model also faces the same problem [38]. Third, the quintessence reconstructions of the (new) agegraphic dark energy have been studied in [39]. The statefinder diagnostic and $w - w'$ analysis for the agegraphic dark energy models were performed in [40]. In addition, the (new) agegraphic dark energy was extended with the generalized uncertainty principle in [41]. Furthermore, it was argued that the holographic dark energy models might share the same origin with the (new) agegraphic dark energy models [42]. So, we consider the (new) agegraphic dark energy model to deserve further investigation in future work.

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