Estimating the age of the universe using the second Friedmann equation

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Abstract:

The surprising discovery of much earlier and bigger galaxies by James Webb space telescope indicates the inadequacy of our understanding on cosmology. This paper confirms that the current estimate of 13.8 billion years for the age of the universe is an underestimation. Adopting a new approach, the paper estimates the age of the universe based on the second Friedmann equation, which provides more detailed information on the evolution of the universe. By ignoring the weak force in both decelerating and accelerating phases, the paper provides the most conservative estimate of the age of universe to be 14.7 billion years, which is about 1 billion years greater than the existing estimate. Moreover, when the weak force is included in the accelerating phase, the age of the universe is estimated at 16.5 billion years. It is expected that if the weak force is included in the decelerating phase, the estimate should be even higher. In order to estimate the age of universe more accurately and directly from the cosmological survey data, the paper suggests to construct the current cosmological model mainly based on the second Friedmann equation.

Key words: cosmological parameters, dark energy, accelerating universe

1. Introduction

The Early Release Observations (ERO) data taken by James Webb space telescope (JWST) surprised astronomers and physicists to the extent of ‘panic’ (Witze, 2022; Ferreira et al, 2022). Ferreira et al found there are about 10 times relative higher number of disk galaxies than seen by the Hubble Space Telescope at the redshifts of at $z > 1.5$. Adams et al (2022) found four $z > 9$ galaxies which have not previously been identified, with one object at $z = 11.5$, and another a close pair of galaxies. Naidu et al (2023) found two remarkably luminous galaxies at $z \approx 10 - 12$. Atek et al (2023) found two galaxies have a red shift z=16, which indicates they are only 250 million years after the Big Bang. Yan et al, (2023) indicated they had detected galaxies with redshift up to z=20, which will push the age of earliest galaxy even closer to the Big Bang. Witze (2022) summarized the findings from the ERO data as: so many galaxies in the early universe, which are very young (or far away from us) and surprisingly close to each other; and some of which are already complex and massive, and rich in chemical elements.

The surprising findings from the JWST data highlight our inadequate understanding of universe. Since the galaxies can be much earlier, bigger, more complex, and closer to each other, it is most likely that the formation of this galaxies has started much earlier. Given current belief that at least 1 billion year is needed to form a galaxy, the findings from the JWST data point to a much older universe. Currently the common approach to the findings from the JWST data is to revise the number of years for galaxy formation and thus keep the estimated the age of universe intact. However, there is a possibility that the estimated age of universe is too low.

Astronomers have used two methods to estimate the age of the universe. One is through estimating the age of the oldest stars known as globular clusters (e.g. Krauss and Chaboyer, 2003). It is generally agreed that this method provides only a lower boundary for the age of the universe (Cheng, 2005). One reason is that star formation starts during the decelerated expansion after the Big Bang (i.e. the inflation epoch), so this approach excludes the time before the star formation. The other reason is that, since observations are limited by the instruments and technology used today, it is most likely that the oldest stars we observed today are not the oldest stars in the universe, so the oldest star age may also be underestimated.

The other method is to estimate the age of the universe based on astronomical survey data and cosmological models. This method is comprehensive, includes time right after the Big Bang, and can obtain estimates for a number of cosmological parameters. However, the estimates from this approach crucially rest on the assumptions upon which the model is built.

Interestingly, the estimates from the second method are close to those from the first method. On the surface, this ‘consistency’ seems comforting. However, considering that the first approach is very likely to underestimate the age of universe, we must conclude that the ‘consistent’ results tend to suggest that the second approach may also has an underestimation issue.

The current cosmological models mainly rely on the first Friedmann equations, with the second Friedmann helping to determine the evolution of energy density. However, for a flat universe, both Friedmann equations are ordinary differential universe evolution equations but of different orders, so one should also be able to obtain a model mainly based on the second Friedmann equation. One may wonder that if the estimation based on the first Friedmann equation is valid, why should one bother to estimate the age of the universe based on the second Friedmann equation? The answer is that the second Friedmann equation includes more information and thus may provide more detailed and more accurate estimation.

The first Friedmann equation comes from the G00 component of the Einstein field equation, which indicates the energy evolution over time. On the other hand, the second Friedmann equation comes from the trace of the Einstein field equation, which manifests the overall energy-momentum conservation of an ideal fluid. The standard cosmological model is largely based on the first Friedmann equation (albeit it requires a relation between energy densities and the scale factor which in turn requires the second Friedmann equation), so it does not include the momentum evolution and thus may not give a very accurate and detailed estimation. It is expected that a valid estimate from the second Friedmann equation should agree with the existing estimate from the standard cosmological model. However, if the estimates from the two equations differ significantly, this signals an issue in the standard model and may shed some light on the surprising findings from the JWST data.

The paper is organized as follows. Section 2 starts with an illustration of a misperception that affects the understanding and estimation of the age of the universe. Based on a decelerating universe and an accelerating universe, section 3 estimates the upper and lower boundaries for the age of the universe. In section 4, we utilize the turning point of decelerating/accelerating universe provided in the second Friedmann equation and provide conservative estimates for the age of the universe. Section 5 concludes.

2. Misperception about accelerating and decelerating universe

Before we embark on an estimation of the age of the universe, it is necessary to rectify a wide-spread mis-presentation and misperception related to the age of the universe.

Before the discovery of dark energy and accelerating universe, the evolution of the universe is popularly presented in a graph similar to the panel (a) in Fig.1. Based on the value for the curvature parameter in the first Friedmann equation, the evolution of the universe can be put into three types: the open universe, flat universe and close universe for k= -1, 0, +1, respectively. Without a cosmological constant, the Friedmann equations necessitate a decelerating universe thanks to the gravitational force. This is indicated by the decreasing slope (as time t increases) of all types of universe curves for k= -1, 0, +1.

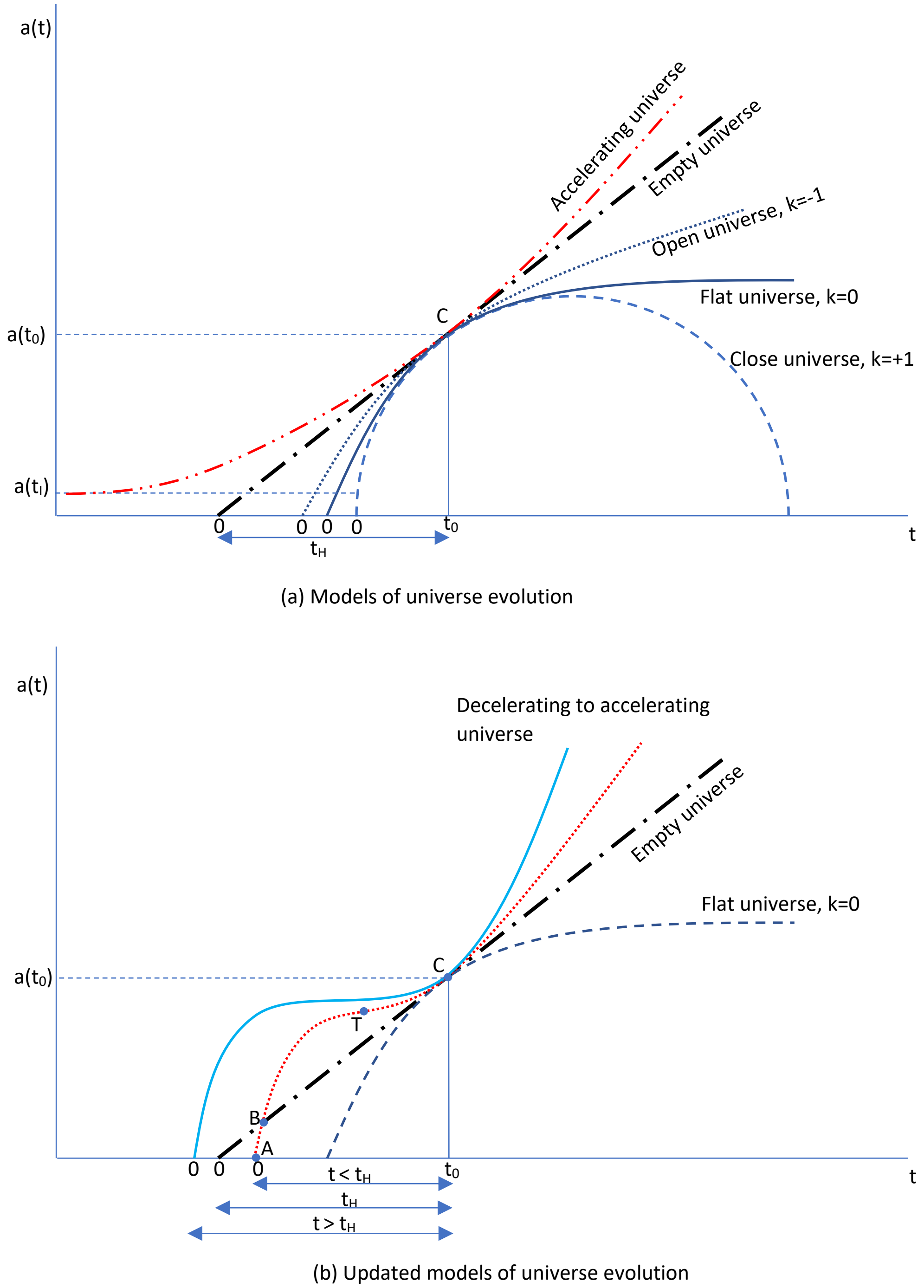

Fig.1 Models of universe evolution

The black dash-dotted line in panel (a) indicates an empty universe which expands at the constant rate determined by the Hubble constant at the current epoch. Since the decelerating universes (including open, flat and close universes) are all below the empty universe line, any evolution of universe above the empty universe line is considered an accelerating universe. For example, the red dash double-dotted curve above the empty universe line demonstrates an accelerating universe.

Panel (a) also shows the scale factor for the current epoch $a(t_0)$ and for the inflation epoch $a(t_I)$. It is believed that before the deceleration or acceleration evolution depicted in panel, the universe experienced an extraordinary explosion or inflation period, but the inflation time is extremely short, estimated as $t_I=10^{-33}$-10^{-35} second. Since the time of inflation period is so short, it does not affect our estimation of the age of the universe. However, all (decelerating or accelerating) models of universe must agree with the same size of scale factor at both the current and the inflation epoch.

Based on the standard cosmological model, after the inflation epoch, gravity causes the expansion of universe to decelerate. However, the deceleration diminishes as matter density decreases, so the repulsive force from dark energy accelerates universe eventually. As such, the universe evolution must include a decelerating phase first and an accelerating phase afterwards. Based on the misperception from panel (a) that the empty universe line is the boundary of accelerating and decelerating universe, an evolution of decelerating-accelerating universe shown by the dotted red line in panel (b) is commonly used in textbooks. Below the empty universe line (i.e. segment AB) is regarded as the decelerating phase while the part above the empty universe line (e.g. segment B to C) is the accelerating phase. As the decelerating phase must below the empty universe line, one naturally concludes that the age of a decelerating-accelerating universe must be less than the Hubble time – the age of the universe estimated from the empty universe.

However, if we check the slope of the dotted red curve, we can find a turning point T at which a tangent line of the curve pass through the curve. Below T, the slope of the curve is decreasing, so the whole segment from A to T should be in the decelerating phase. Similarly, the segment above T shows an increasing slope and thus should be the accelerating phase.

Since a decreasing universe can exist in the region above the empty universe line, the age of the universe is not bound by the age of the empty universe. We can draw a decelerating-accelerating universe curve entirely above but tangent to the empty universe curve at point C, shown as the blue solid curve in panel (b). From this curve, it is clear that it is well possible for the estimated age of universe to be greater than the Hubble time.

3. Estimating the boundaries for the age of the universe

To illustrate the impact of acceleration and deceleration of universe on the estimated age of the universe, we demonstrate in Fig. 2 the different types of universes in terms of the expansion rate $\dot{a}(t)$, i.e. the change in a(t).

For an empty universe, the change in a(t) is constant at all time, i.e. $\dot{a}(t)= \dot{a}(t_0)$. This is indicated by the flat line EC. The segment EC runs from the beginning of universe (t=0) to the current epoch ($t= t_0$), so its length is the age of an empty universe, i.e. the Hubble time $t_0 = t_H = 1/H_0$. The size of rectangular area $0ECt_0$ can be calculated by the expansion rate times the age of the universe, indicating the total expansion from the beginning of the universe, or the current scale factor, $a(t_0)=\dot{a}(t_0)*t_H$. Any model of universe evolution must agree on the current scale factor, so any other types of universe curves from the beginning to the current epoch must enclose an area of the same size of $0ECt_0$.

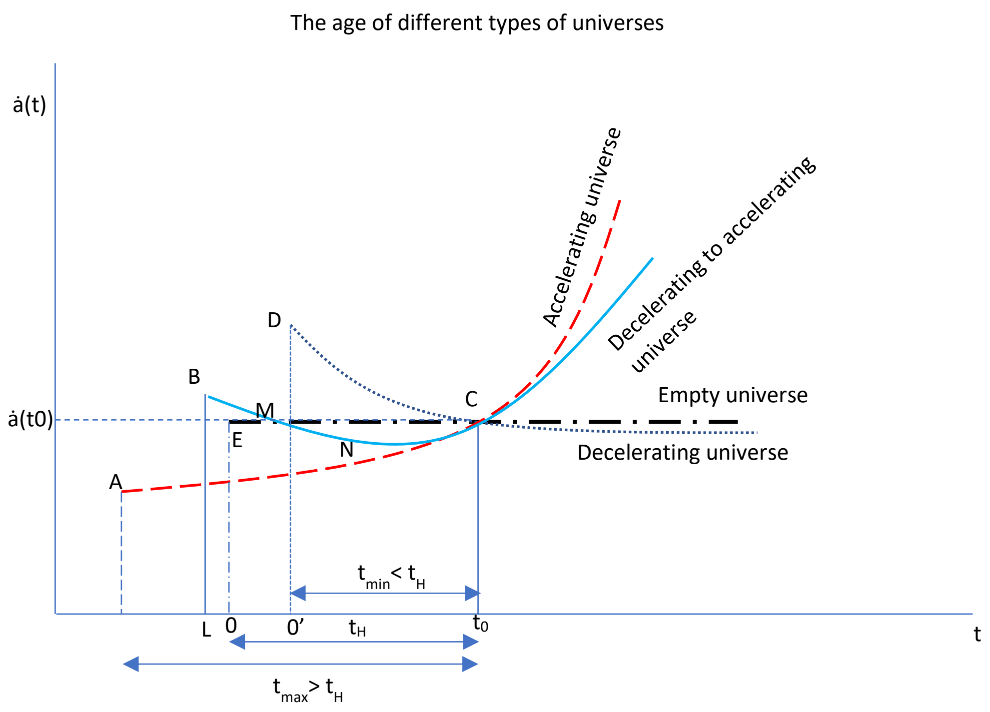

Fig.2 Estimating age of different types of universes

The dark blue dotted curve in Fig. 2 shows a decelerating universe. The curve must pass C because it must have the same expansion speed $\dot{a}(t_0)$ at current epoch. The curve must be downward sloping due to the decreasing $\dot{a}(t_0)$ in over time. This necessitates a larger inital expansion rate, shown as the point D positioned above the EC line. Since the expansion rate upto the current epoch is greater than that for empty universe, the age of the decreasing universe must greater than the Hubble time. This is shown by point 0' positioned at the right of point 0. As explained previously, the total expansion of the decelerating universe must agree with the current size of scale factor, i.e. area of $0'DCt_0$ = area of $0ECt_0$. This requirement necessitates that a higher expansion rate is associated with a shorter expansion time, namely, a younger age for a decelerating universe. Similarly, an accelerating universe indicated by the red dash curve must have an age older than the Hubble time.

For a decelerating-accelereating universe indicated by the solid blue line, its age can be greater, smaller or equal to the Hubble time. In Fig.2 the area of $LBNCt_0$ must have the same size as the area $0ECt_0$, so the area LBME0 and area MNC must have the same size. The large size of MNC and the small initial expansion rate (the relatively low position of point B) necessiates L to be positioned at the left of point 0, so the age of the decelerating-accelerating universe universe depicted here is greater than the Hubble time. Should the initial expansion rate is higher (i.e. higher position for B) and/or the area of MNC is smaller, the age of the decelerating-accelerating universe could be less than the Hubble time.

Nevertheless, as an intermediate case between the accelerating universe and the decelerating universe, the age of a decelerating-accelerating universe must be constrained by the ages of the accelerating and decelerating universes (assuming the same deceleration and acceleration functions are used). As a result, the age of the accelerating universe can act as the upper boundary of the estimated age of the universe, while the the age of the decelerating universe acts as a lower boundary.

Using a Friedmann equation, we can determine the boundaries for the age of the universe. The general form of the second Friedmann equation can be expressed as:

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) + \frac{\Lambda c^2}{3} \qquad (1)$$

Where a is the scale factor, ρ stands for the energy density of radiation and matter, p for the pressure generated by radiation and matter. The last term is the cosmological term, indicative of dark energy.

In considering each type of universe, we can derive the lower and higher boundaries for the age of the universe. Since this type of derivation is commonly displayed in cosmology textbooks, we describe here only very briefly. For a raduation universe, $\rho=\rho_{0r}\ a^{-4}$, $p= \rho c^2/3$, where ρ_{0r} is the matter density at the current epoch, so we have:

$$\ddot{a} = -\frac{8\pi G}{3}\rho_{0r}a^{-3}$$

The solution for this decelerating universe is:

$$a(t) = \left(\frac{3\pi G\rho_{0r}}{32}\right)^{1/3} t^{1/2}$$

Using the boundary conditions $a(t_0)=1$ and $\dot{a}(t_0)=H_0$, we can obtain a lower boundary for the age of the universe: $t_{min1}=1/(2H_0)= t_H/2$. This is a result well documented in cosmology textbooks (e.g. Cheng, 2005).

For matter universe, the pressure term in eq. 1 vanishes. As the universe expanses, the density of matter decreases at the rate of a^{-3}, implying $\rho=\rho_{0m}\ a^{-3}$, where ρ_0 is the matter density at the current epoch, so we have:

$$\ddot{a} = -\frac{4\pi G}{3}\rho_{0m}a^{-2}$$

The solution for this decelerating universe is:

$$a(t) = (6\pi G\rho_{0m})^{1/3}t^{2/3}$$

Using the boundary conditions $a(t_0)=1$ and $\dot{a}(t_0)=H_0$, we can obtain the lower boundary for the age of the universe: $t_{min2}=2/(3H_0)=2/3*t_H$.

For an accelerating universe, we consider only dark energy in the universe, so the second Friedmann equation become:

$$\ddot{a} = \frac{\Lambda c^2}{3}a$$

The solution is the de Sitter universe:

$$a(t) = a_I e^{\sqrt{\frac{\Lambda c^2}{3}}t}$$

Where a_I is the scale factor at the inflation epoch. This scale factor must agree with that from other models. From the empty universe, we can estimate: $a_I = H_0 t_I$, where t_I is the time of the inflation period, $t_I \approx 10^{-33}$ seconds.

Using the boundary condition at the current epoch, $a(t_0)=1$ and $\dot{a}(t_0)=H_0$, we can derive:

$$t_{max} = t_H \, ln \frac{t_H}{t_I} \approx 115 t_H$$

This upper boundary is over 100 times greater than the Hubble time. This may seem unreasonable, but it is consistent with the nature of exponential growth function. The smaller size of scale factor at the inflation epoch, the larger expansion time is expected from an exponential growth function. This wide range of boundaries may not be useful to restrict the proper estimates of the age of the universe. Nevertheless, it indicates that the age of the universe can be significantly greater than the Hubble time. It also indicates that the estimation results depend crucially on the relative strength and duration of the deceleration phase and acceleration phase.

4. A **new estimation of the age of the universe.**

Considering radiation, matter and dark energy in the universe, the compact second Friedmann equation (i.e. eq.1) can be rewritten explicitly as:

$$\frac{\ddot{a}}{a} = -\frac{8\pi G}{3}\rho_0/a^4 - \frac{4\pi G}{3}\rho_0/a^3 + \frac{\Lambda c^2}{3} \quad (2)$$

This is a second order ordinary differential equation and its solution is extremely complicated, so we need use approximations. The equation shows that when ä =0, the expansion of the universe experiences a change from deceleration to acceleration. The scale factor a_T at the turning point should be important. Setting in the above equation the acceleration rate ä to zero, we have:

$$\Lambda c^2 a^4 - 4\pi G\rho_{0m} a - 8\pi G\rho_{0r} = 0$$

The CMB survey data (Bennett C. et al., 2012, Aurich R., Lustig S., 2015) show that the ratio of density of radiation, and matter to critical density ρ_c is 0.0001 and 0.2814, respectively. Using the critical density ρ_c= 9.47 *10^{-27} kg/m^3, and the value for cosmological constant Λ=1.267*10^{-52}, we can numerically solve the above equation to obtain the scale factor at the turning point:

$$a_T{}'=0.581061$$

To check how important the radiation component in the expansion of the universe, we omit the radiation term (the first term on the right-hand side of eq. 2) and solve for a, we obtain a_T and compute its value based on currently estimated parameters:

$$a_T = \left(\frac{4\pi G\rho_0}{\Lambda c^2}\right)^{1/3} = 0.580824 \tag{3}$$

It can be seen that the inclusion of radiation makes a 0.04% difference to the scale factor at the turning point, so it is obvious that contribution of radiation to the age of the universe is omittable. This result is also consistent with the general chronology of the universe. The time of matter dominated universe (10^{17} seconds) is 10^4 times more than that for radiation dominated universe (10^{13} seconds). As such, we ignore the radiation component in our estimation of the age of the universe, namely, omit the first term on the right-hand side of eq.2.

When the scale factor below a_T, the impact of gravity dominates and the universe is decelerating, and vice versa. The approximation we used here is to focus on the dominant factors. That is, during the decelerating phase, the impact of gravitational force far outweighs that of the dark energy, so we ignore dark energy in this phase. On the other hand, when the universe is accelerating, the dark energy is much greater so we ignore the gravitational force. As will shown later, this approximation will generate an underestimation bias because the omission of the weak force shortens the time of each phase. In other words, this approach estimates only a refined low boundary (compared with that shown in the previous section) for the age of the universe.

Letting t_D be the time of the decelerating phase. Omitting the last term in eq. 2, we can obtain the following solution:

$$a(t_D) = a_0 t_D^{\frac{2}{3}} = a_T \tag{4}$$

Differentiating the above equation, we have:

$$\dot{a}(t_D) = \frac{2}{3} a_0 t_D{}^{-\frac{1}{3}} = \dot{a}_T \tag{5}$$

Differentiating eq.4 further, we have the deceleration rate due to gravity, which should be matched by the acceleration rate due to cosmological constant:

$$\ddot{a}(t_D) = -\frac{2}{9} a_0 t_D{}^{-\frac{4}{3}} + \frac{\Lambda c^2}{3} a(t_D) = 0 \tag{6}$$

Solving eqs. 4 -6, we have the parameter a_0 , the expansion rate at the turning point $\dot{a}_T$, and the time for the decelerating phase t_D:

$$a_0 = 1.494 * 10^{-12} \tag{7}$$

$$\dot{a}_T = 1.601 * 10^{-18} \tag{8}$$

$$t_D = 2.418 * 10^{17} s = 7.668\ billion\ year \tag{9}$$

The accelerating phase starts at the turning point with a scale factor a_T and an expansion rate $\dot{a}_T$. Omitting the first and second terms on the righthand side of eq. 2, we have the solution of exponential expansion:

$$a(t) = a_T e^{\sqrt{\frac{\Lambda c^2}{3}}(t-t_D)} + \left(\dot{a}_T - \sqrt{\frac{\Lambda c^2}{3}} a_T\right)(t - t_D) \tag{10}$$

The last term in eq. 10 is necessary to calibrate the expansion rate at the turning point to $\dot{a}_T$. Namely, the first-order derivative of a(t) in eq. 10 must satisfy the boundary condition at $t = t_D$. The accelerating phase continues till the current epoch at $t=t_0$ and $a(t_0)=1$. Setting in eq.10 $t=t_0$, we have:

$$a(t_0) = a_T e^{\sqrt{\frac{\Lambda c^2}{3}}(t_0-t_D)} + \left(\dot{a}_T - \sqrt{\frac{\Lambda c^2}{3}} a_T\right)(t_0 - t_D) = 1$$

Numerically solve the above equation, we have the time for the accelerating phase:

$$t_A = t_0 - t_D = 7.048\ billion\ year \tag{11}$$

The age of the universe t_0 is the sum of deceleration time t_D and acceleration time t_A:

$$t_0 = t_D + t_A = 14.716\ billion\ year \quad (12)$$

The estimated result is about 1 billion years more than the current best estimation. However, as we mentioned earlier, the estimated result from this approach produces only a refined low boundary for the age of the universe. Here we explain this in detail.

The omission of the impact of dark energy during the decelerating phase makes the deceleration faster and thus a shorter deceleration time is needed to achieve the expansion rate $\dot{a}_T$ at the turning point. Let g_Λ be the average acceleration rate of dark energy during the deceleration phase. Its contribution to the expansion during deceleration phase can be expressed as $0.5 g_\Lambda t_D^2$. Including this into the decelerating expansion function we have:

$$a(t_D) = a_0 t_D^{\frac{2}{3}} + \frac{1}{2} g_\Lambda t_D^{\ 2}$$

Differentiating the above equation, we have:

$$\dot{a}(t_D) = \frac{2a_0}{3 t_D^{\ 1/3}} + g_\Lambda t_D \quad (13)$$

In both eqs. 13 and 5, a_0 is calibrated from the expansion rate at the inflation epoch, so it should be the same for both equations. $\dot{a}(t_D)$ is the expansion rate at the turning point, which is calibrated by the Hubble constant and the scale factor at the turning point so it should also be the same. As t_D increases, the first term on the righthand side of both equations tends to depress the expansion rate towards the target, but the extra last term in eq. 13 does the opposite. As a result, to achieve the same target of $\dot{a}(t_D)$, the t_D in eq.13 has to be larger than that in eq.5.

Similarly, the omission of the impact of gravitational force during the accelerating phase makes the acceleration faster and thus shortens acceleration time to achieve the scale factor at the current epoch. Let g_m be the average deceleration rate due to matter during the acceleration phase. The contribution of g_m to the expansion during acceleration phase can be expressed as $-0.5 g_m (t - t_D)^2$. Including this into the accelerating expansion function we have:

$$a(t) = a_T e^{\sqrt{\frac{\Lambda c^2}{3}}(t - t_D)} + \left(\dot{a}_T - \sqrt{\frac{\Lambda c^2}{3}} a_T\right)(t - t_D) - \frac{1}{2} g_{\mathrm{m}} (t - t_D)^2 \quad (14)$$

The a_T and $\dot{a}_T$ in both eq. 10 and 14 are the scale factor and expansion rate at the turning point, respectively. They should be the same in both equations. Similarly, at the current epoch, a(t)=1 for both equations. At t increases, the first and second terms on the righthand side of both equations increase to achieve the target a(t)=1, but the last term in eq. 14 decreases, reducing the pace of increase in the scale factor. As a result, longer time ($t-t_D$) in eq. 14 is required to arrive at the a(t) at the current epoch. In other words, the t_A in eq. 11 is underestimated.

Although the omitted factors are relatively weaker in the respective phases, the accumulated effect of underestimation can be considerable because the weak factors work for extremely long periods in both phases. To demonstrate the effect of underestimation and provide a more accurate estimation of the age of the universe, we can improve our estimation by including gravity effect on the acceleration phase. The last term in the expansion function for accelerating phase (i.e. eq. 10) indicates that, without a gravity, the expansion speed at the turning point expands the universe constantly over time. When gravity is not ignored, this term should change according to the expansion function of the gravity shown in eq. 4. Calibrating the parameter based on the scale factor a_T and an expansion rate $\dot{a}_T$ at the turning point, we have:

$$a(t) = a_T e^{\sqrt{\frac{\Lambda c^2}{3}}(t-t_D)} + \frac{3}{2}\left(\dot{a}_T - \sqrt{\frac{\Lambda c^2}{3}} a_T\right)(t - t_D + 1)^{\frac{2}{3}} \quad (15)$$

Or in the first and second differential forms:

$$\dot{a}(t) = \sqrt{\frac{\Lambda c^2}{3}} a_T e^{\sqrt{\frac{\Lambda c^2}{3}}(t-t_D)} + \left(\dot{a}_T - \sqrt{\frac{\Lambda c^2}{3}} a_T\right)(t - t_D + 1)^{-\frac{1}{3}} \quad (16)$$

The base ($t-t_D+1$) in the last term is a technical treatment to avoid the divergence of expansion speed at the turning point (i.e. when $t=t_D$). Since the time t or t_D in seconds are used for calculation, adding one second is almost nothing compared with the billions of years of the evolution of the universe. The boundary conditions for the above equations are the scale factors $a(t_0)=1$ and the expansion rate $\dot{a}(t_0)= H_0$ for the current epoch. Namely,

$$a(t_0) = a_T e^{\sqrt{\frac{\Lambda c^2}{3}}(t_0-t_D)} + \frac{3}{2}\left(\dot{a}_T - \sqrt{\frac{\Lambda c^2}{3}} a_T\right)(t_0 - t_D + 1)^{\frac{2}{3}} = 1 \quad (17)$$

$$\dot{a}(t_0) = \sqrt{\frac{\Lambda c^2}{3}} a_T e^{\sqrt{\frac{\Lambda c^2}{3}}(t-t_D)} + \left(\dot{a}_T - \sqrt{\frac{\Lambda c^2}{3}} a_T\right)(t - t_D + 1)^{-\frac{1}{3}} = H_0 \tag{18}$$

Numerically solving equation for variables ($t-t_D$) and $\dot{a}_T$, we have:

$$t_0 - t_D = 8.838\ billion\ year \tag{19}$$

Plugging the deceleration time t_D estimated in eq. 9, we have the age of the universe:

$$t_0 = 16.506\ billion\ year \tag{20}$$

This estimate is about 1.8 billion years greater than that in eq.12. If we include the dark energy effect in the decelerating phase, one can expect that the estimated age of the universe should be greater than that in eq. 20. The most plausible estimation would be obtained from the best approximation for the solution of the Friedmann equation.

5. Conclusion

Through an illustration of malpresentation of the decelerating and accelerating universe, the paper exposes a common misperception that the age of the universe cannot be greater than the Hubble time. Against the trend of mainly using the first Friedmann equation for a cosmological model, the paper estimates the age of the universe mainly based on the second Friedmann equation. When the weak force is ignored in each (decelerating or accelerating) phase of universe evolution, the estimate of 14.7 billion years for the age of the universe is about 1 billion years greater than the existing estimate. However, the paper argues that this estimation is only a refined low boundary for the age of the universe, because excluding the weak force will shorten the duration of both decelerating and accelerating phases. As an illustration, the paper includes the weak force in the accelerating phase, and estimates age of the universe becomes 16.5 billion years. To estimate the age of the universe accurately, the paper suggests to build a cosmological model based on the second Friedmann equation.

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