Scientific Research Publishing

Journal of Applied Mathematics and Physics, 2021, 9, 1322-1328
https://www.scirp.org/journal/jamp
ISSN Online: 2327-4379
ISSN Print: 2327-4352

The Observable Universe in a Simplified Cosmic Dynamic Model

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How to cite this paper: Li, X.Y., Genzon, L.B.S., Longzhou, S., Dai, Y.P. and Xu, Y.S. (2021) The Observable Universe in a Simplified Cosmic Dynamic Model. *Journal of Applied Mathematics and Physics*, **9**, 1322-1328.
https://doi.org/10.4236/jamp.2021.96089

Received: May 26, 2021
Accepted: June 21, 2021
Published: June 24, 2021

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Abstract

This paper introduces a cosmic expansion model with constant speed of cosmic spatial expansion via derivation and simulations, where the speed of cosmic spatial expansion equals the speed of light *c*. Simulation results show that the earliest observable universe time is $t = 5.084\text{ Gyrs}$ where the current universe time $T = 13.82\text{ Gyrs}$, and the furthest observable distance at the earliest observable universe time t is $S = 0.632R$, where R is the cosmic radius at current universe time T. The above constant cosmic expansion model does not consider the inflation period in the early universe according to the Big Bang model, nor does it considered the cosmic acceleration in recent universe time. However, this simplified cosmic expansion model could be a benchmark that will be helpful to understand the cosmic expansion and the observable universe. Based on the derivation and simulation of the constant cosmic expansion model, the threshold of observable universe for the accelerated cosmic expansion model can also be calculated similarly, as far as the speed of cosmic spatial expansion at any universe time t can be provided.

Keywords

Observable Universe, Threshold, Simulation, Cosmic Expansion Model

1. Introduction and Related Works

The measurement of the distance of stars and galaxies in the universe has always been one of the main research topics of cosmology. About 100 years ago, astronomers discovered that the light of distant stars has a redshift, so it is speculated that these stars are moving away from the earth. After that, scientists used Einstein's field equations to introduce the universe's space-time expansion model [1]. Later, astronomers discovered that stars and galaxies farther away from the

Earth have larger separation speed. Hence the stellar distance according to its redshift is calculated based on Hubble's law [2].

In physical cosmology, the cosmic expansion model is established via Einstein's field equations, to constrain the metric of an isotropic uniform universe using Robertson-Walker metrics [1], and perform the derivation of universe evolution dynamics [3].

Based on the above universe expansion model, the Big Bang theory describes how the universe expanded from an initial state of extremely high density and high temperature [4]. The Big Bang theory is compatible with Hubble's law. Hubble's law [2] is the observation in physical cosmology that stars are moving away from the Earth at speeds proportional to their distance.

The photon epoch was the period in the evolution of the early universe in which photons dominated the universe. The photon epoch started at about 10 seconds after the Big Bang and ended at 370,000 years after the Big Bang when the temperature of the universe fell so that photons no longer interacted frequently with matter including Atomic nuclei and electrons [5].

This paper introduces a simplified cosmic expansion model, assuming the speed of cosmic spatial expansion equals the speed of light c. Based on the constant cosmic expansion model, the threshold of observable universe is derived. In the constant cosmic expansion model, it assumes that the speed of cosmic expansion always equals the speed of light c. While in the Big Band model [6], the speed of cosmic spatial expansion is much faster than the speed of light c during the inflation period in the early universe. The constant cosmic expansion model does not consider the inflation period in the early universe according to the Big Bang model [6]. Therefore in the constant cosmic expansion model, the speed of cosmic expansion is much slower than that in the Big Bang model during the inflation period, which results in the current cosmic radius in the constant cosmic expansion model is less than the actual cosmic radius.

However, this simplified cosmic expansion model could be a benchmark that will be helpful to understand the cosmic expansion and the observable universe. The main contribution of this paper is that the simplified constant cosmic expansion model introduces cosmic expansion dynamics, which shows that after a light source such as a galaxy omitted a beam of light to the Earth when the beam of light was travelling in the universe before arriving the Earth, the cosmic space was expanding at the same time. This paper provides a method to calculate the time duration since a light source such as a galaxy omitted a beam of light until the beam of light arrives the Earth. Then the distance between the light source and the Earth can be obtained consequently. Based on this model, the earliest observable universe time can be derived. Then the furthest distance for the observable universe can be derived consequently. If a light source emitted a beam of light to the Earth before the earliest observable universe time, then the beam of light has arrived on the Earth before current universe time. Only when a light source emitted a beam of light after the earliest observable universe time, it can arrives on the Earth and be observed right now at current universe time.

List of Terms

T: The current universe time $T = 13.82$ Gyrs.

t: Universe age or time, where $0 \le t \le T$.

$t_{earliest}$: The earliest universe time for observable universe.

c: The constant speed of light.

R: Universe radius at *T*.

$V_{Expan}(t)$: Speed of cosmic expansion at *t*.

$R(t)$: Universe radius at *t*.

$R(0)$: Initial Universe radius at $t = 0$.

d: Light source.

O: The Observer and the center of the cosmic horizon.

$v(t)$: Separation Speed at time *t*.

$S(t)$: The distance between O and the beam of light (B) emitted by d.

S: The distance of d observed by O.

Gyr: Giga years.

Gly: Giga light years.

2. Cosmic Expansion Models

2.1. Constant Cosmic Expansion Model

Assume the speed of cosmic expansion $V_{Expan} = c$, where *c* is the constant speed of light. The universe age is $T = 13.82$ Gyrs according to [7]. Therefore the current cosmic radius $R = cT = 13.82$ Glys, assuming $R(t = 0) \to 0$ according to the Big bang model [6]. The universe radius *R*(*t*) during the cosmic expansion is a straight line as shown in **Figure 1**.

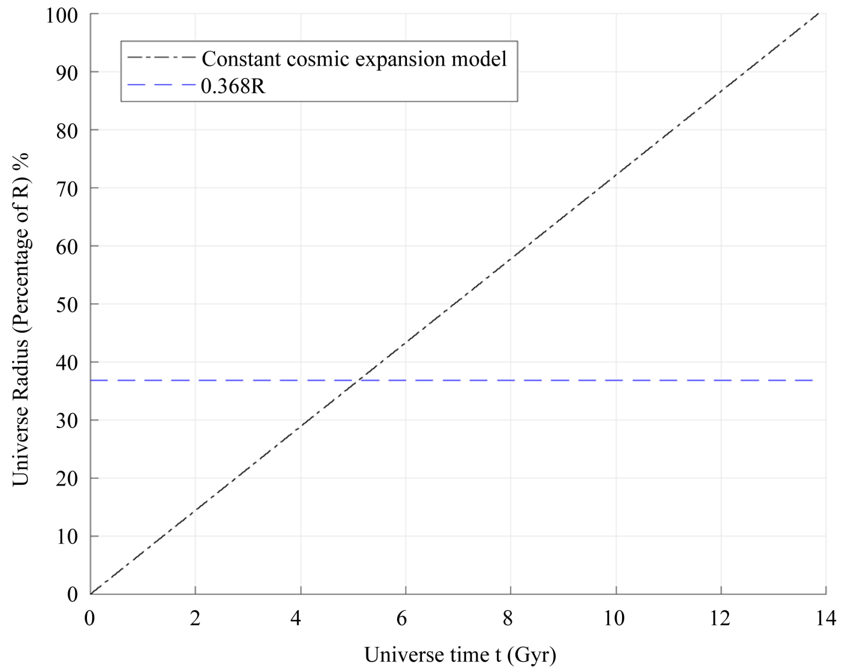

Figure 1. Universe radius at any universe time *t*.

The constant cosmic expansion model does not consider the inflation period in the early universe according to the Big Bang model [6]. But this simplified cosmic expansion model could be a benchmark that will be helpful to understand the cosmic expansion and the observable universe.

2.2. Deriving the Threshold of Observable Universe

In the constant cosmic expansion model, for a given universe time $t < T$, then $R(t) = t \times c$. If there is a light source d at boundary of the universe at universe time *t*, d emitted a beam of light (B) to the Observer O on the Earth (O is the center of cosmic horizon) as shown in **Figure 2**. To observe O (the Earth) on the position of d at universe time *t*, then O (the Earth) has a separation speed $v(t) = c$ because the cosmic expansion speed $V_{Expan} = c$, assuming the cosmic space-time is isotropy and homogenous. Also assume the largest separation speed due to cosmic expansion is *c*, and the separation speed is proportional to the distance according to Hubble's law [2].

Then the distance between the beam of light (B) and the Earth (O) is $S(t) = R(t)$ at universe time *t*. After time period dt, the beam of light (B) approaching O by speed of light *c*. Therefore the separation speed of the Earth (O) is $v(t+dt) = c\dfrac{S(t)}{R(t+dt)}$. Hence,

$$R(t) = c \times t$$

$$v(t) = c$$

$$S(t) = R(t) = c \times t$$

$$\rightarrow R(t+dt) = c \times (t+dt)$$

$$v(t+dt) = c\frac{S(t)}{R(t+dt)}$$

$$S(t+dt) = R(t) - c \times dt + v(t+dt)dt$$

At universe time $t + Ndt$, where $Ndt = N \times dt$, then

$$\rightarrow R(t+Ndt) = c \times (t+Ndt)$$

$$v(t+Ndt) = c\frac{S\left[t+(N-1)dt\right]}{R(t+Ndt)}$$

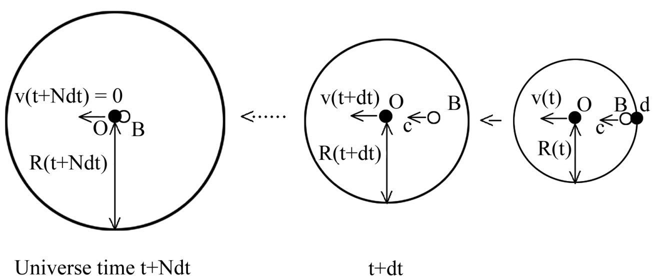

Figure 2. Observing the light source d during cosmic expansion.

$$S(t+Ndt) = R(t) - c \times Ndt + dt \times \sum_{K=1}^{N} v(t+Kdt)$$

If $t+Ndt = T$, and $S(t+Ndt) = 0$, then the separation speed $v(t+Ndt) = 0$, and the beam of light (B) has arrived the Earth (O) exactly at current universe time *T*, as shown in **Figure 2** and **Figure 3**.

Simulation is performed according to the above process using Matlab with the above pseudocode. The simulation results are as follows.

$$t = 5.084 \text{ Gyrs} = 0.368T = t_{earliest}, \text{ where } T = 13.82 \text{ Gyrs}$$

$$R(t_{earliest}) = 5.084 \text{ Glys} = 0.368R, \text{ where } R = 13.82 \text{ Glys}$$

The above simulation results show that, at universe time $t_{earliest} = 0.368T$, universe radius $R(t_{earliest}) = 0.368R$, the light source d at boundary of the unverse has emitted a beam of light B towards the center of cosmic horizon O (the Earth). After time period $T-t$, B has arrived O exactly at universe time *T*. Therefore the light source d at boundary of the universe at universe time $t_{earliest}$ is observed by observer O right now at universe time *T*.

If the light source d has emitted another beam of light B' at time $t_{earliest}$ to the opposite direction of B, then when the beam of light B arrives O (the center of the cosmic horizon) at universe time *T*, B' also arrives the boundary of the universe with radius *R*, because the speed of light equals to the speed of cosmic expansion. Therefore the distance from light source d to O is *S*, which is the distance traveled by B (or B') during time period $T - t_{earliest}$ as shown in **Figure 4**. Therefore,

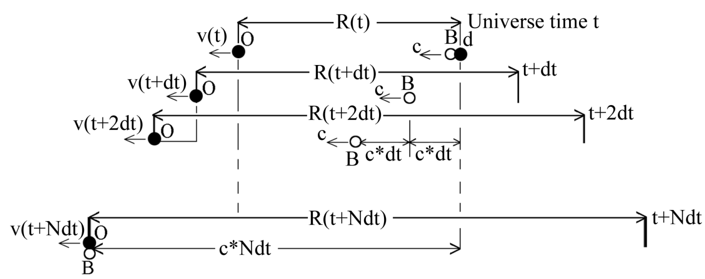

Figure 3. The procedure to observe the light source d during cosmic expansion.

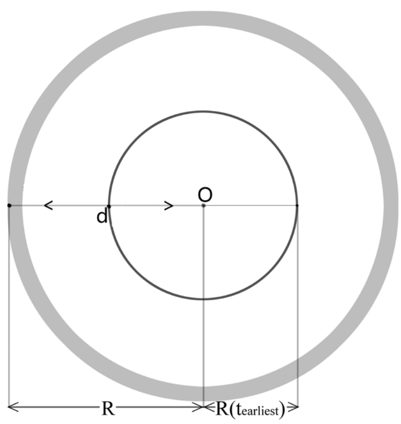

Figure 4. The earliest observable universe time and cosmic radius.

$$S = R - R\left(t_{earliest}\right) = 0.632R$$

If d is inside the boundary of the universe at universe time $t' < t_{earliest}$, then $R\left(t'\right) < R\left(t_{earliest}\right)$, therefore the beam of light emitted by d' has arrived O at universe time $T' < T$, therefore d' can be observed by O at T', which was at time period $T - T'$ ago. Hence time $t_{earliest}$ is the earliest observable universe time when signals emitted by a light source d at that time can be received by O at current universe time T, $S = R - R\left(t_{earliest}\right) = 0.632R$ is the furthest observable distance from where a light source d can be observed by O at current universe time T.

2.3. Accelerated Cosmic Expansion Model

In the accelerated cosmic expansion model, it is said that the cosmic expansion is decelerated after the Big Bang until universe time $t = 9\ \text{Gyrs}$, and the cosmic expansion is accelerated when universe time $t > 9\ \text{Gyrs}$ until now with current universe time $T = 13.82\ \text{Gyrs}$ [8].

Therefore, if the accurate speed of cosmic spatial expansion can be provided in the future for any universe time $t < T$, then the furthest observable distance from where a light source d can be observed by an observer on the Earth (O) at current universe time T can also be derived similar to the method described above.

3. Future Works

The future work is to modify the constant cosmic expansion model, considering the inflation period in the early universe, and the cosmic deceleration period when universe time is less than 9 Gyrs.

4. Conclusions

This paper introduces a cosmic expansion model with constant speed of cosmic spatial expansion. Simulation results show that the earliest observable universe time is $t = 5.084\ \text{Gyrs}$. Therefore, when universe time $t < 5.084\ \text{Gyrs}$, the universe cannot be observed directly on the Earth at current universe time. The universe radius $R\left(t\right)$ at the earliest observable universe time t is $0.368R$ where the current universe radius is R. And the furthest observable distance at the earliest observable universe time t is $S = 0.632R$.

Based on the derivation and simulation for the constant cosmic expansion model, the threshold of observable universe for the accelerated cosmic expansion model [8] can also be calculated similarly, as far as the speed of cosmic spatial expansion at any universe time t can be provided.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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