# A New Cosmological Model: Black Hole Universe

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A new cosmological model called black hole universe is proposed. According to this model, the universe originated from a hot star-like black hole with several solar masses, and gradually grew up through a supermassive black hole with billion solar masses to the present state with hundred billion-trillion solar masses by accreting ambient materials and merging with other black holes. The entire space is structured with infinite layers hierarchically. The innermost three layers are the universe that we are living, the outside called mother universe, and the inside star-like and supermassive black holes called child universes. The outermost layer is infinite in radius and limits to zero for both the mass density and absolute temperature. The relationships among all layers or universes can be connected by the universe family tree. Mathematically, the entire space can be represented as a set of all universes. A black hole universe is a subset of the entire space or a subspace. The child universes are null sets or empty spaces. All layers or universes are governed by the same physics - the Einstein general theory of relativity with the Robertson-walker metric of spacetime - and tend to expand outward physically. The evolution of the space structure is iterative. When one universe expands out, a new similar universe grows up from its inside. The entire life of a universe begins from the birth as a hot star-like or supermassive black hole, passes through the growth and cools down, and expands to the death with infinite large and zero mass density and absolute temperature. The black hole universe model is consistent with the Mach principle, the observations of the universe, and the Einstein general theory of relativity. Its various aspects can be understood with the well-developed physics without any difficulty. The dark energy is not required for the universe to accelerate its expansion. The inflation is not necessary because the black hole universe does not exist the horizon problem.

## 1 Introduction

In 1929, Edwin Hubble, when he analyzed the light spectra of galaxies, found that light rays from galaxies were all shifted toward the red [1, 2]. The more distant a galaxy is, the greater the light rays are shifted. According to the Doppler's effect, all the galaxies should be generally receding from us. The more distant a galaxy is, the faster it moves away from our Milky Way. This finding implies that our universe is expanding and thus had a beginning or an origin.

To explain the origin and evolution of the universe, Lemaitre [3–4] suggested that the universe began an explosion of a primeval atom. Around two decades later, George Gamow and his collaborators [5–9], when they synthesized elements in an expanding universe, devised the initial primordial fireball or big bang model based on the Lemaitre's superatom idea. To salvage the big bang model from some of its theoretical problems (e.g., flatness, relic particles, and event horizon), Guth [10] proposed the inflationary hypothesis based on the grand unification theory. The big bang model with an inflationary epoch has been widely accepted as the standard cosmological model because this model is the only one that can explain the three fundamental observations: the expansion of the universe, the 2.7°K cosmic microwave background radiation, and the abundances of helium and other light elements [11–15].

Although it has been declared to have successfully explained the three basic observations, the big bang theory is neither simple nor perfect because the explanations of the observations sensitively rely on many adjustable parameters and hypothesis that have not been or may never be tested [16–17]. In addition, the big bang theory has not yet told us a whole story for the origin and evolution of the universe with ninety-eight percent uncertainties of its composition. The past before $10^{-43}$ seconds, the outside, and the future of the universe are still unknown. As astronomers are able to observe the space deeper and deeper, the big bang theory may meet more and more severe difficulties with new evidences. In fact, that the newly observed distant quasars with a high fraction of heavy elements [18] has already brought the big bang model in a rather difficult situation. Cosmologists have being tried to mend this model for more than several decades. It is time for astronomers to open their minds to think the universe in different ways and develop a new model that is more convinced and competitive.

When the author was reading a paper [19] about the Mach principle and Brans-Dicke theory of gravity to develop his electric redshift mechanism in accord with the five-dimensional fully covariant Kaluza-Klein theory with a scalar field [20], an idea that the universe is a black hole came to his mind [21].

Upon this idea, a new cosmological model called black hole universe is then developed, which is consistent with the fundamental observations of the universe, the Mach principle, and the Einstein general theory of relativity. This new model provides us a simple and reasonable explanation for the origin, evolution, structure, and expansion of the universe. It also gives a better understanding of the 2.7°K cosmic microwave background radiation, the element abundances, and the high fraction of heavy elements in distant known quasars. Especially, the black hole universe model does not require new physics because the matter of the black hole universe would not be too dense and hot. Dark energy is not necessary for the universe to have an acceleration expansion. Inflation is not needed because there does not exist the horizon problem. Monopoles should not be created because it is not hot enough. Comparing to the standard big bang theory, the black hole universe model is more elegant, simple, and complete. The entire space is well structured hierarchically without outside, evolve iteratively forever without beginning and end, is governed by the simple well-developed physics, and does not exist other unable explained difficulties. The author has recently presented this new cosmological model on the 211th AAS meeting hold on January 7–11, 2008 at Austin, Texas [22] and the 213th AAS meeting hold on January 4–8, 2009 at Long Beach, California [23].

This paper gives a detail description of this new cosmological model. We will fully address why the universe behaves like a black hole, where the black hole universe originates from, how the entire space is structured, how the black hole universe evolves, why the black hole universe expands and accelerates, and what physics governs the black hole universe. Next studies will address how to explain the cosmic microwave background radiation, how quasars to form and release huge amount of energy, and how nuclear elements to synthesize, and so on.

## 2 Black hole universe

According to the Mach principle, the inertia of an object results as the interaction by the rest of the universe. A body experiences an inertial force when it accelerates relative to the center of mass of the entire universe. In short, mass there affects inertia here. In [24], Sciama developed a theoretical model to incorporate the Mach principle and obtained $GM_{\rm EF}/(c^2 R_{\rm EF}) \sim 1$, where $M_{\rm EF}$ and $R_{\rm EF}$ are the effective mass and radius of the universe (see also [19, 25]). Later on, it was shown by [26] that the Einstein general theory of relativity is fully consistent with the Sciama interpretation of the Mach principle and the relation between the effective mass and radius of the universe should be modified as $2GM_{\rm EF}/(c^2 R_{\rm EF}) \sim 1$.

According to the observations of the universe, the density of the present universe $\rho_0$ is about the critical density $\rho_0 \sim \rho_c = 3H_0^2/(8\pi G) \sim 9\times10^{-30}$ g/cm$^3$ and the radius of the present universe is about $R_0 \sim 13.7$ billion light years (or $\sim 1.3\times10^{26}$ m). Here $G = 6.67\times10^{-11}$ N m$^2$ kg$^{-2}$ is the gravitational constant and $H_0 \sim 70$ km/s/Mpc is the Hubble constant. Using the observed density (or the Hubble constant) and radius of the present universe, we have the total mass $M_0 \sim 8\times10^{52}$ kg and the mass-radius relation $2GM_0/(c^2R_0) = (H_0R_0/c)^2 \sim 1$ for the present universe.

According to the Schwarzschild solution of the Einstein general theory of relativity [27], the radius of a black hole with mass $M_{\rm BH}$ is given by $R_{\rm BH} = 2GM_{\rm BH}/c^2$ or by the relation $2GM_{\rm BH}/(c^2R_{\rm BH}) = 1$. For a black hole with mass equal to the mass of the present universe ($M_{\rm BH} = M_0$), the radius of the black hole should be about the radius of the present universe ($R_{\rm BH} \sim R_0$).

The results described above in terms of the Mach principle, the observations of the universe, and the Einstein general theory of relativity strongly imply that the universe is a Schwarzschild black hole, which is an extremely supermassive fully expanded black hole with a very big size and thus a very low density and temperature. The boundary of the universe is the Schwarzschild absolute event horizon described by

$$\frac{2GM}{c^2R} = 1. \qquad (1)$$

For convenience, this mass-radius relation (1) is named by Mach M-R relation. The black hole universe does not exist the horizon problem, so that it does not need an inflation epoch.

It is seen from equation (1) that the mass of a black hole including the universe is proportional to its radius ($M \propto R$). For a star-like black hole with 3 solar masses, its radius is about 9 km. For a supermassive black hole with 3 billion solar masses, its radius is about $9\times10^9$ km. For the present black hole universe with hundred billion-trillion solar masses, its radius is about $10^{23}$ km. Therefore, modeling the universe as a black hole is supported by the Mach principle, the observations of the universe, and the Einstein general theory of relativity.

The density of a black hole including the black hole universe can be determined as

$$\rho \equiv \frac{M}{V} = \frac{3c^6}{32\pi G^3M^2} = \frac{3c^2}{8\pi GR^2}\,, \qquad (2)$$

i.e., $\rho R^2 = \texttt{constant}$ or $\rho M^2 = \texttt{constant}$. Here, we have used the Mach M-R relation (1) and $V = 4\pi R^3/3$. It is seen that the density of a black hole including the black hole universe is inversely proportional to the square of the mass ($\rho \propto M^{-2}$) or to the square of the radius ($\rho \propto R^{-2}$). In other words, the mass of the black hole universe is proportional to its radius.

Figure 1 plots the density of a black hole as a function of its mass in the unit of the solar mass (the solid line) or a function of its radius in the unit of 3 kilometers (the same

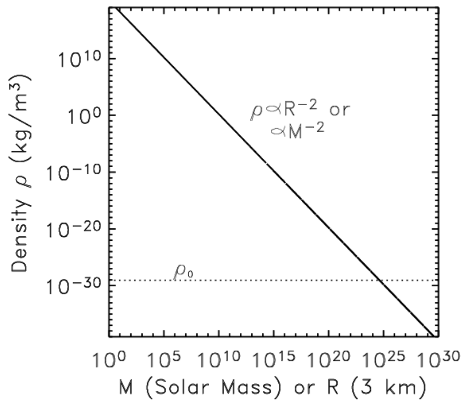


Fig. 1: The density of the black hole universe versus its mass or radius (solid line). The dotted line refers to $\rho = \rho_0$, so that the intersection of the two lines represents the density, radius, and mass of the present universe.

line). The dotted line marks the density of the present universe ($\rho_0$) and its intersection with the solid line shows the mass ($M_0$), density ($\rho_0$), and radius ($R_0$) of the present universe. Therefore, the black hole universe is not an isolated system because its mass increases as it expands. The density decreases by inversely proportional to the square of the radius (or the mass) of the black hole universe. Considering that matter can enter but cannot exit a black hole, we can suggest that the black hole universe is a semi-open system surrounded by outer space and matter.

In the black hole universe model, we have that the effective radius of the universe is about the actual radius of the universe (or $R_{\mathrm{EF}}/R \sim 1$) at all time. In the big bang theory, we have $R_{\mathrm{EF}}/R = [c^2 R/(2GM)]^{1/2}$ because $\rho R^3 = \mathtt{constant}$. This ratio $R_{\mathrm{EF}}/R$ increases as the universe expands and is equal to 1 only at the present time because the observation shows $2GM_0/(c^2 R_0) \sim 1$. In the past, the effective of radius is less than the radius of the universe ($R_{\mathrm{EF}} < R$). While, in future, the effective radius will be greater than the radius of the universe $R_{\mathrm{EF}} > R$, which is not physical, so that the Mach principle will lose its validity in future according to the big bang theory.

## 3 Origin, structure, and evolution of the black hole universe

In the black hole universe model, it is reasonable to suggest that the universe originated from a star-like black hole. According to the Einstein general theory of relativity, a star, if big enough, can form a star-like black hole when the inside thermonuclear fusion has completed. Once a star-like black hole is formed, an individual spacetime is created. The spacetime inside the event horizon is different from the outside, so that the densities and temperatures on both inside and outside are different. This origin of the universe is somewhat similar to the big bang model, in which the universe exploded from a singular point at the beginning, but the physics is quite different. Here, the star-like black hole with several solar masses (or several kilometers in radius) slowly grows up when it accretes materials from the outside and merges or packs with other black holes, rather than impulsively explodes from nothing to something in the big bang theory. It is also different from the Hoyle model, in which the universe expands due to continuous creation of matter inside the universe [28].

The star-like black hole gradually grows up to be a supermassive black hole as a milestone with billion solar masses and then further grows up to be one like the present universe, which has around hundred billion-trillion solar masses. It is generally believed that the center of an active galaxy exists a massive or supermassive black hole [29–32]. The present universe is still growing up or expanding due to continuously inhaling the matter from the outside called mother or parent universe. The star-like black hole may have a net angular momentum, an inhomogeneous and anisotropic matter distribution, and a net electric charge, etc., but all these effects become small and negligible when it sufficiently grows up.

The present universe is a fully-grown adult universe, which has many child universes such as the star-like and supermassive black holes as observed and one parent (or the mother universe). It may also have sister universes (some universes that are parallel to that we are living), aunt universes, grandmother universes, grand-grandmother universes, etc. based on how vast the entire space is. If the matter in the entire space is finite, then our universe will merge or swallow all the outside matter including its sisters, mother, aunts, grandmothers, and so on, and finally stop its growing. In the same way, our universe will also be finally swallowed by its children and thus die out. If the matter in the entire space is infinite, then the black hole universe will expand to infinitely large in size ($R \to \infty$), and infinitely low in both the mass density ($\rho \to 0$) and absolute temperature ($T \to 0\,\mathrm{K}$). In this case, the entire space has infinite size and does not have an edge. For completeness, we prefer the entire space to be infinite without boundary and hence without surroundings.

The entire space is structured with infinite layers hierarchically. The innermost three layers as plotted in Figure 2 include the universe that we are living, the outside called mother universe, and the inside star-like and supermassive black holes called child universes. In Figure 2, we have only plotted three child universes and did not plot the sister universes. There should have a number of child universes and may also have many sister universes.

The evolution of the space structure is iterative. In each iteration the matter reconfigures and the universe is renewed rather than a simple repeat or bouncing back. Figure 3 shows a series of sketches for the cartoon of the universe evolution in a single iteration from the present universe to the next similar one. This whole spacetime evolution process does not have the end and the beginning, which is similar to the Hawking's view of the spacetime [33]. As our universe expands,

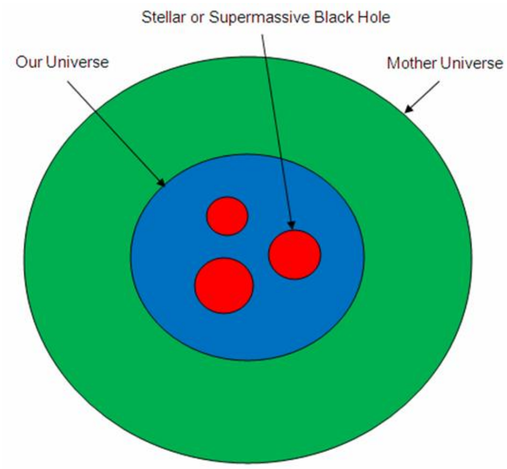


Fig. 2: The innermost three layers of the entire space that is structured hierarchically.

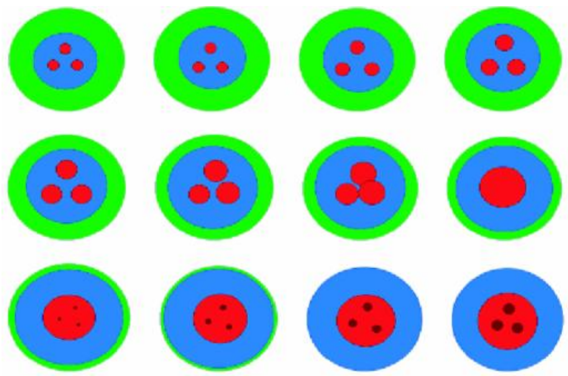

Fig. 3: A series of sketches (or a cartoon, from left to right and then top row to bottom row) for the black hole universe to evolve in a single iteration from the present universe to the next similar one. This is an irreversible process, in which matter and spacetime reconfigure rather than a simple repeat or bouncing back. One universe is expanded to die out and a new universe is born from inside.

the child universes (i.e., the inside star-like and supermassive black holes) grow and merge each other into a new universe. Therefore, when one universe expands out, a new similar universe is born from inside. As like the naturally living things, the universe passes through its own birth, growth, and death process and iterates this process endlessly. Its structure evolves iteratively forever without beginning and end.

To see the multi-layer structure of the space in a larger (or more complicate) view, we plot in Figure 4 the innermost four-layers of the black hole universe up to the grandmother universe. Parallel to the mother universe, there are aunt universes. Parallel to our universe, there are sister universes, which have their own child universes. Here again for simplicity, we have only plotted a few of universes for each layer. If the entire space is finite, then the number of layers is finite. Otherwise, it has infinite layers and the outermost layer corresponds to zero degree in the absolute temperature, zero in the density, and infinite in radius.

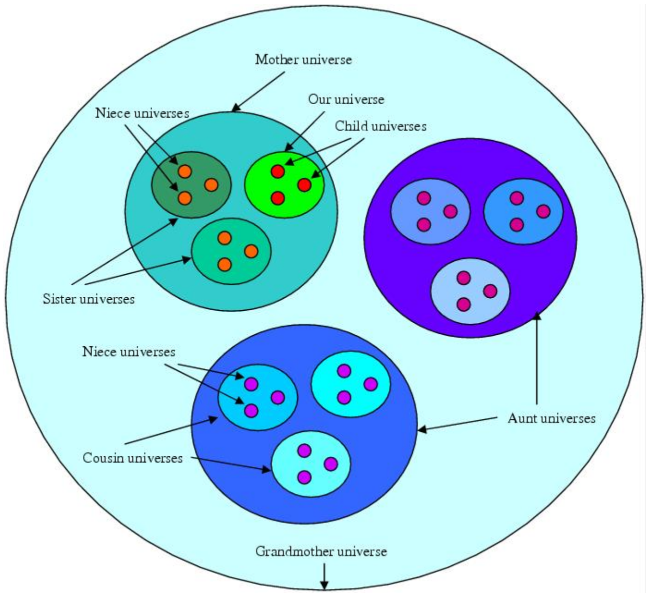


Fig. 4: A sketch of the innermost four layers of the black hole universe including grandmother universe, aunt universes, mother universe, sister universes, cousin universes, niece universes, and child universes.

This four generation universe family shown in Figure 4 can also be represented by a universe family tree (see Figure 5). The mother and aunt universes are children of the grandmother universe. The cousin universes are children of the aunt universes. Both our universe and the cousin universe have their own children, which are the star-like or supermassive black holes.

It is more natural to consider that the space is infinite large without an edge and has infinite number of layers. For the outermost layer, the radius tends to infinity, while the density and absolute temperature both tend to zero. We call this outermost layer as the entire space universe because it contains all universes. To represent this infinite layer structure of the entire space, we use the mathematical set concept (see Figure 6). We let the entire space universe be the set (denoted by $U$) of all universes; the child universes (also the niece universes) are null sets ($C = \{\}$ or $N = \{\}$); our universe is a set of the child universes ($O = \{C, C, C, \ldots, C\}$); the sister universes are sets of the niece universes $S = \{N, N, N, \ldots, N\}$); the mother universe is a set of our universe and the sister universes ($M = \{S, S, S, \ldots, O\}$); the aunt universes are sets of the cousin universes; the grandmother universe is a set of the aunt universes and the mother universe; and so on. The black hole universe model gives a fantastic picture of the entire space. All universes are self similar and governed by the same physics (the Einstein general theory of relativity with the Robertson-Walker metric) as shown later.

As a black hole grows up, it becomes nonviolent because its density and thus the gravitational field decrease. Matter being swallowed by a star-like black hole is extremely compressed and split into particles by the intense gravitational

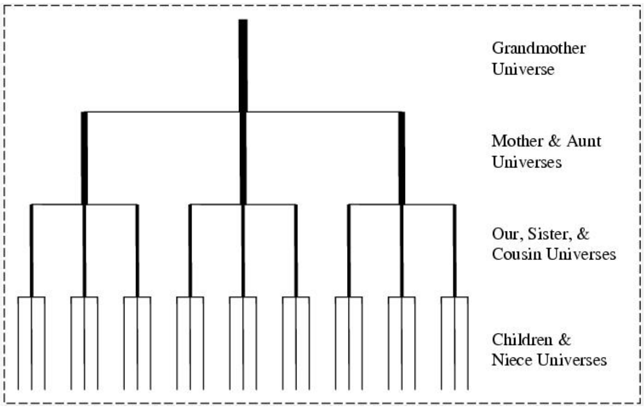


Fig. 5: A family tree for the youngest four generations of the universe family. The generation one includes the child and niece universes; the generation two includes our universe itself and the sister universes; the generation three includes the mother and aunt universes; and the generation four includes the grandmother universe.

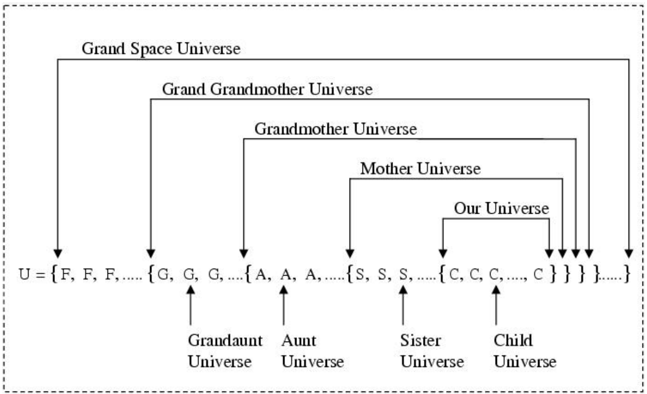


Fig. 6: Mathematical representation of sets of universes for an infinite large and layered space. An inner layer universe set is a subset of the outer layer universe set. The niece and child universes are null sets because they do not contain any sub-spacetime.

field; while that being swallowed by an extremely supermassive black hole (e.g., our universe) may not be compressed and even keeps the same state when it enters through the Schwarzschild absolute event horizon, because the gravitational field is very weak. To see more specifically on this aspect, we show, in Table 1, mass ($M$), radius ($R$), density ($\rho$), and gravitational field at surfaces ($g_R$) of some typical objects including the Earth, the Sun, a neutron star, a star-like black hole, a supermassive black hole, and the black hole universe. It is seen that the density of a star-like black hole is about that of a neutron star and $10^{14}$ times denser than the Sun and the Earth, while the density of supermassive black is less than or about that of water. The density of the black hole universe is only about $10^{-28}$ of supermassive black hole. The gravitational field of the supermassive black hole is only $10^{-8}$ of a star-like black hole. The gravitational field of the present universe at the surface is very weak ($g_R = c^2/(2R_0) \sim 3 \times 10^{-10}$N).

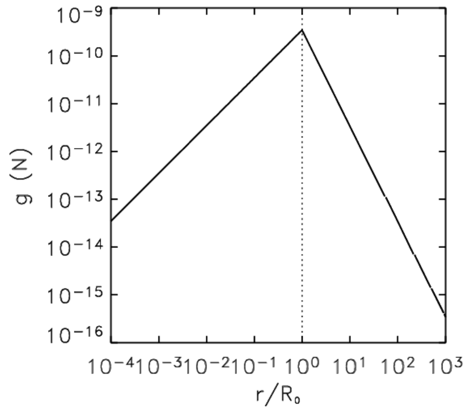


Fig. 7: The gravitational field of the present black hole universe. Inside the black hole universe, the gravity increases with the radial distance linearly from zero at the geometric center to the maximum value at the surface. While outside the black hole universe, the gravity decreases inversely with the square of the radial distance.

The total number of universes in the entire space is given by

$$n = \sum_{i=1}^{i=L} n_i \tag{3}$$

where the subscript $i$ is the layer number, $n_i$ is the number of universes in the $i$th layer, and $L$ refers to the number of layers in the entire space. For the four layer (or generation) black hole universe sketched in Figure 4 or 5, we have $L = 4$ and $n = 27 + 9 + 3 + 1 = 40$. If the entire space includes infinite number of layers (i.e., $L = \infty$), then the total number of universes is infinity.

The gravitational field of the black hole universe can be given by

$$g = \begin{cases} c^2 r/(2R_0^2) & \text{if} \quad r \leqslant R_0 \\ c^2 R_0/(2r^2) & \text{if} \quad r \geqslant R_0 \end{cases}, \tag{4}$$

where $r$ is the distance to the geometric center of the black hole universe. The gravity of the black hole universe increases linearly with $r$ from zero at the center to the maximum ($g_R$) at the surface and then decreases inversely with $r^2$ (see Figure 7). In the present extremely expanded universe, the gravity is negligible (or about zero) everywhere, so that, physically, there is no special point (or center) in the black hole universe, which is equivalent to say that any point can be considered as the center. A frame that does not accelerate relative to the center of the universe is very like an inertial frame. The present universe appears homogeneous and isotropic.

## 4 The steady state and expansion of the black hole universe

In the black hole universe model, the physics of each universe is governed by the Einstein general theory of relativity. The matter density of each universe is inversely proportional to the square of the radius or, in other words, the mass

| Object | $M$ (kg) | $R$ (m) | $\rho$ (kg/m$^3$) | $g_R$ (m/s$^2$) |
|---|---|---|---|---|
| Earth | $6 \times 10^{24}$ | $6.4 \times 10^6$ | $5.5 \times 10^3$ | 9.8 |
| Sun | $2 \times 10^{30}$ | $7 \times 10^8$ | $1.4 \times 10^3$ | 270 |
| Neutron Star | $3 \times 10^{30}$ | $10^4$ | $7.2 \times 10^{17}$ | $2 \times 10^{12}$ |
| Starlike BH | $10^{31}$ | $3 \times 10^3$ | $8.8 \times 10^{19}$ | $7.4 \times 10^{13}$ |
| Supermassive BH | $10^{39}$ | $3 \times 10^{12}$ | 22 | $7.4 \times 10^3$ |
| Universe | $10^{53}$ | $1.4 \times 10^{26}$ | $8.7 \times 10^{-27}$ | $3.4 \times 10^{-10}$ |

Table 1: Mass, radius, density, and gravitational field at the surface of some typical objects.

is linearly proportional to the radius. The three dimensional space curvature of the black hole universe is positive, i.e., $k = 1$. The spacetime of each universe is described by the Robertson-Walker metric

$$ds^2 = c^2 dt^2 - a^2(t) \times \times \left[ \frac{1}{1 - r^2} dr^2 + r^2 d\theta^2 + r^2 \sin^2\theta \, d\phi^2 \right], \quad (5)$$

where $ds$ is the line element and $a(t)$ is the scale (or expansion) factor, which is proportional to the universe radius $R(t)$, and $t$ is the time.

Substituting this metric into the field equation of the Einstein general relativity, we have the Friedmann equation [34]

$$H^2(t) \equiv \left[ \frac{1}{R(t)} \frac{dR(t)}{dt} \right]^2 = \frac{8\pi G \rho(t)}{3} - \frac{c^2}{R^2(t)}, \quad (6)$$

where $H(t)$ is the Hubble parameter (or the universe expansion rate) and $\rho(t)$ is the density of the universe. It should be noted that equation (6) can also be derived from the energy conservation in the classical Newton theory [35]. All layers or universes are governed by the same physics, i.e., the Einstein general theory of relativity with the Robertson-Walker metric, the Mach M-R relation, and the positive space curvature.

Substituting the density given by equation (2) into (6), we obtain

$$\frac{dR(t)}{dt} = 0, \quad (7)$$

or $H(t) = 0$. Therefore, the black hole universe is usually in a steady state, although it has a positive curvature in the three dimensional space. The black hole universe is balanced when the mass and radius satisfy equation (1), or when the universe density is given by equation (2). The Einstein static universe model corresponds to a special case of the black hole universe model. The steady state remains until the black hole universe is disturbed externally, e.g., entering matter. In other words, when the universe is in a steady state, the Friedmann equation (6) reduces to the Mach M-R relation (1) or the density formula (2).

When the black hole universe inhales matter with an amount $dM$ from the outside, we have

$$\frac{2G(M + dM)}{c^2 R} > 1. \quad (8)$$

In this case, the black hole universe is not balanced. It will expand its size from $R$ to $R + dR$, where the radius increment $dR$ can be determined by

$$\frac{2G(M + dM)}{c^2(R + dR)} = 1, \quad (9)$$

or

$$\frac{2G}{c^2} \frac{dM}{dR} = 1. \quad (10)$$

Therefore, the black hole universe expands when it inhales matter from the outside. From equation (10), the expansion rate (or the rate of change in the radius of the universe) is obtained as

$$\frac{dR(t)}{dt} = \frac{2G}{c^2} \frac{dM(t)}{dt}, \quad (11)$$

and the Hubble parameter is given by

$$H(t) = \frac{1}{R(t)} \frac{dR(t)}{dt} = \frac{1}{M(t)} \frac{dM(t)}{dt}. \quad (12)$$

Equation (11) or (12) indicates that the rate at which a black hole including the black hole universe expands is proportional to the rate at which it inhales matter from its outside. Considering a black hole with three solar masses accreting $10^{-5}$ solar masses per year from its outside [36], we have $dR(t)/dt \sim 10^{-1}$ m/years and $H(t) \sim 10^7$ km/s/Mpc. Considering a supermassive black hole with one billion solar masses, which swallows one thousand solar masses in one year to run a quasar, we have $dR(t)/dt \sim 3 \times 10^3$ km/years and $H(t) \sim 10^6$ km/s/Mpc. When the black hole merges with other black holes, the growth rate should be larger. For our universe at the present state, the value of the Hubble parameter is measured as $H(t_0) \sim 70$ km/s/Mpc. If the radius of the universe is chosen as 13.7 billion light years, we have $dR(t_0)/dt \sim c$, which implies that our universe is expanding in about the light speed at present. To have such fast expansion, the universe must inhale about $10^5$ solar masses in one second or swallows a supermassive black hole in about a few hours.

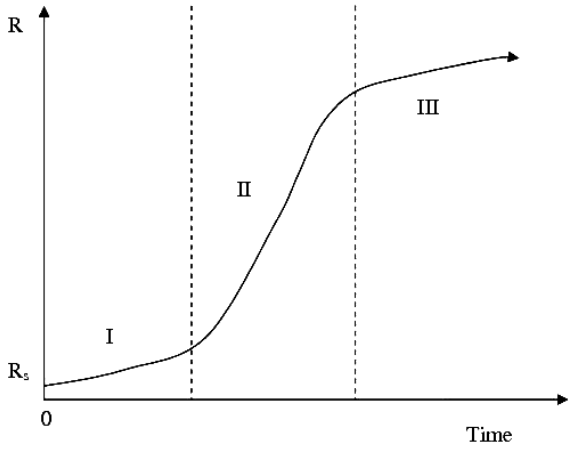


Fig. 8: A schematic sketch for the possible evolution of radius or mass of our black hole universe (solid line): $R$ or $M$ versus time. The two dashed vertical lines divide the plot into three regions, I: child universe, II: adult universe, and III: elder universe.

The whole life of our universe can be roughly divided into three time periods: I, II, and III (Figure 8). During the period I, the universe was a child (e.g., star-like or suppermassive black hole), which did not eat much and thus grew up slowly. During the period II, the universe is an adult (e.g., the present universe), which expands in the fastest speed. During the period III, the universe will become elder (e.g., the mother universe) and slow down the expansion till the end with an infinite radius, zero mass density, and zero absolute temperature. Figure 8 shows a possible variation of radius or mass of a black hole universe in its entire life. Since $dR(t)/dt < c$ in average, the age of the present universe must be greater than $R(t_0)/c$. The Hubble parameter represents the relative expansion rate, which decreases as the universe grows up.

The acceleration parameter is given by

$$q(t) \equiv \frac{1}{R^2(t)} \frac{d^2 R(t)}{dt^2} = \frac{1}{M^2(t)} \frac{d^2 M(t)}{dt^2} ; \qquad (13)$$

therefore, if the universe inhales matter in an increasing rate ($d^2M(t)/dt^2 > 0$), the universe accelerates its expansion. Otherwise, it expands in a constant rate ($d^2M(t)/dt^2 = 0$) or expands in a decreasing rate ($d^2M(t)/dt^2 < 0$) or is at rest ($dM(t)/dt = 0$). In the black hole universe model, the dark energy is not required for the universe to accelerate. The black hole universe does not have the dark energy problem that exists in the big bang cosmological theory.

## 5 Discussions and conclusions

The black hole universe grows its space up by taking its mother's space as it inhales matter and radiation rather than by stretching the space of itself geometrically. As the black hole universe increases its size, the matter of the universe expands because its density must decrease according to equation (2). Since the planets are bound together with the Sun by the gravity, the solar system (also for galaxies and clusters) does not expand as the universe grows up. This is similar to that gases expand when its volume increases, but the atoms and molecules of the gases do not enlarge. Therefore, the expansion of the black hole universe is physical, not geometrical.

Conventionally, it has been suggested that, once a black hole is formed, the matter will further collapse into the center of the black hole, where the matter is crushed to infinitely dense and the pull of gravity is infinitely strong. The interior structure of the black hole consists of the singularity core (point-like) and the vacuum mantle (from the singularity core to the absolute even horizon). In the black hole universe model, our universe originated from a star-like black hole and grew up through a supermassive black hole. A star-like or supermassive black hole is just a child universe (or a mini spacetime). Physical laws and theories are generally applicable to all spacetimes or universes such as our universe, the mother universe, and the child universes (i.e., the star-like or supermassive black holes). The matter inside a black hole can also be governed by the Friedmann equation which is derived from the Einstein general relativity with the Robertson-Walker metric. Therefore, if a black hole does not inhale matter from its outside, it is in a steady state as described by equation (7). The matter inside a black hole distributes uniformly with a density given by equation (2). The highly curved spacetime of a black hole sustains its enormous gravity produced by the highly dense matter. If the black hole inhales the matter from its outside, it grows up and hence expands with a rate that depends on how fast it eats as described by equation (11) or (12).

A black hole, no matter how big it is, is an individual spacetime. From the view of us, a star-like black hole within our universe is a singularity sphere, from which the matter and radiation except for the Hawking radiation (a black body spectrum) cannot go out. Although it is not measurable by us, the temperature inside a star-like black hole should be higher than about that of a neutron star because the density of a star-like black hole is greater than about that of a neutron star, which may have a temperature as high as thousand billion degrees at the moment of its birth by following the explosion of a supernova and then be quickly cooled to hundred million degrees because of radiation [37]. A black hole can hold such high temperature because it does not radiate significantly. When a star-like black hole inhales the matter and radiation from its outside (i.e., the mother universe), it expands and cools down. From a star-like black hole to grow up to one as big as our universe, it is possible for the temperature to be decreased from thousand billion degrees ($10^{12}$ K) to about 3 K. Therefore, in the black hole universe model, the cosmic microwave background radiation is the black body radiation of the black hole universe. In future study, we will explain the cosmic microwave background radiation in detail. We will analyze the nucleosynthesis of elements taken place in the early (or child) black hole universe, which is dense and hot, grows slowly, and dominates by matter. The early black hole universe is hot enough for elements to synthesize, but not enough to create monopoles.

According to the Einstein general relativity, a main sequence star will, in terms of its mass, form a dwarf, a neutron star, or a black hole. After many stars in a normal galaxy have run out their fuels and formed dwarfs, neutron stars, and black holes, the galaxy will eventually shrink its size and collapse towards the center by gravity to form a supermassive black hole with billions of solar masses. This collapse leads to that extremely hot stellar black holes merge each other and further into the massive black hole at the center and meantime release intense radiation energies that can be as great as a quasar emits. Therefore, when the stellar black holes of a galaxy collapse and merge into a supermassive black hole, the galaxy is activated and a quasar is born. In the black hole universe model, the observed distant quasars can be understood as donuts from the mother universe. The observed distant quasars were formed in the mother universe as little sisters of our universe. When quasars entered our universe, they became children of our universe. The nearby galaxies are quiet at present because they are still very young. They will be activated with an active galactic nuclei and further evolve to quasars after billions of years. In future study, we will give a possible explanation for quasars to ignite and release huge amount of energy.

The black hole universe does not exist other significant difficulties. The dark energy is not necessary for the universe to accelerate its expansion. The expansion rate depends on the rate that the universe inhales matter from outside. When the black hole universe inhales the outside matter in an increasing rate, it accelerates its expansion. The boundary of the black hole universe is the Schwarzschild absolute event horizon, so that the black hole universe does not have the horizon problem. The inflation epoch is not required. The star-like or supermassive black holes are not hot enough to create monopoles. The present universe has been fully expanded and thus behaved as flat, homogeneous, and isotropic. The evolution and physical properties of the early universe are not critical to the present universe because matter and radiation of the present universe are mainly from the mother universe.

As a conclusion, we have proposed a new cosmological model, which is consistent with the Mach principle, the Einstein general theory of relativity, and the observations of the universe. The new model suggests that our universe is an extremely supermassive expanding black hole with a boundary to be the Schwarzschild absolute event horizon as described by the Mach M-R relation, $2GM/c^2R = 1$. The black hole universe originated from a hot star-like black hole with several solar masses, and gradually grew up (thus cooled down) through a supermassive black hole with billion solar masses as a milestone up to the present state with hundred billion-trillion solar masses due to continuously inhaling matter from its outside — the mother universe. The structure and evolution of the black hole universe are spatially hierarchical (or family like) and temporarily iterative. In each of iteration a universe passes through birth, growth, and death. The entire evolution of universe can be roughly divided into three periods with different expanding rates. The whole space is structured similarly and all layers of space (or universes) are governed by the same physics — the Einstein general relativity with the Robertson-Walker metric, the Mach M-R relation, and the positive space curvature. This new model brings us a natural, easily understandable, and reasonably expanding universe; thereby may greatly impact on the big bang cosmology. The universe expands physically due to inhaling matter like a balloon expands when gases are blown into instead of geometrically stretching. New physics is not required because the matter of the black hole universe does not go to infinitely dense and hot. The dark energy is not necessary for the universe to accelerate. There is not the horizon problem and thus not need an inflation epoch. The black hole universe is not hot enough to create monopoles. The black hole universe model is elegant, simple, and complete because the entire space is well structured, governed by the same physics, and evolved iteratively without beginning, end, and outside.

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