Quasar Formation and Energy Emission in Black Hole Universe

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Formation and energy emission of quasars are investigated in accord with the black hole universe, a new cosmological model recently developed by Zhang. According to this new cosmological model, the universe originated from a star-like black hole and grew through a supermassive black hole to the present universe by accreting ambient matter and merging with other black holes. The origin, structure, evolution, expansion, and cosmic microwave background radiation of the black hole universe have been fully explained in Paper I and II. This study as Paper III explains how a quasar forms, ignites and releases energy as an amount of that emitted by dozens of galaxies. A main sequence star, after its fuel supply runs out, will, in terms of its mass, form a dwarf, a neutron star, or a black hole. A normal galaxy, after its most stars have run out of their fuels and formed dwarfs, neutron stars, and black holes, 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 a huge amount of radiation energy that can be as great as that of a quasar. 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, the observed distant quasars powered by supermassive black holes can be understood as donuts from the mother universe. They were actually formed in the mother universe and then swallowed into our universe. The nearby galaxies are still very young and thus quiet at the present time. They will be activated and further evolve into quasars after billions of years. At that time, they will enter the universe formed by the currently observed distant quasars as similar to the distant quasars entered our universe. The entire space evolves iteratively. When one universe expands out, a new similar universe is formed from its inside star-like or supermassive black holes.

1 Introduction

Quasars are quasi-stellar objects, from which light is extremely shifted toward the red [1-5]. If their large redshifts are cosmological, quasars should be extremely distant and thus very luminous such that a single quasar with the scale of the solar system can emit the amount of energy comparable to that emitted by dozens of normal galaxies [6-7]. A highly charged quasar may also have significant electric redshift [8].

Quasars are generally believed to be extremely luminous galactic centers powered by supermassive black holes with masses up to billions of solar masses [9-13]. It is usually suggested that the material (e.g., gas and dust) falling into a supermassive black hole is subjected to enormous pressure and thus heated up to millions of degrees, where a huge amount of thermal radiation including waves, light, and X-rays give off [14-16]. However, the density of the falling material, if it is less dense than the supermassive black hole, is only about that of water. In other words, the pressure of the falling gas and dust may not go such high required for a quasar to emit energy as amount of that emitted by hundred billions of the Sun.

According to the Einsteinian general theory of relativity [17] and its Schwarzschild solution [18], the gravitational field (or acceleration) at the surface of a black hole is inversely proportional to its mass or radius. For a supermassive black hole with one billion solar masses, the gravitational field at the surface is only about 1.5×10^4 m/s^2. Although this value is greater than that of the Sun ($\sim$ 270 m/s^2), it is about two-order smaller than that of a white dwarf with 0.8 solar masses and 0.01 solar radii ($\sim$ 2.2×10^6 m/s^2), eight-order smaller than that of a neutron star with 1.5 solar masses and 10 km in radius ($\sim$ 2.0×10^{12} m/s^2), and eight-order smaller than that of a star-like black hole with 3 solar masses ($\sim 5 \times 10^{12}$ m/s^2). Table 1 shows the gravitational field at the surface of these typical objects. A black hole becomes less violent and thus less power to the ambient matter and gases as it grows. Therefore, a supermassive black hole may not be able to extremely compress and heat the falling matter by such relative weak gravitational field. It is still unclear about how a quasar is powered by a supermassive black hole.

The Chandra X-ray observations of quasars 4C37.43 and 3C249.1 have provided the evidence of quasar ignition with an enormous amount of gas to be driven outward at high speed or a galactic superwind [19]. The observation of quasar Q0957+561 has shown the existence of an intrinsic magnetic moment, which presents an evidence that the quasar may not have a closed event horizon [20]. In addition, the observations

Object	M (M_{Sun})	R (m)	g_R (m/s^2)
Sun	1	7×10^8	270
White Dwarfs	0.8	7×10^6	2×10^4
Nneutron Stars	1.5	1×10^4	2×10^{12}
Black Holes (BH)	3	3×10^3	5×10^{12}
Spermassive BH	10^9	3×10^{12}	1.5×10^4

Table 1: Mass, radius, and gravitational field at the surface of the Sun, white dwarf, neutron star, star-like black hole (BH), and supermassive black hole.

of the distant quasars have shown that some supermassive black holes were formed when the universe was merely 1-2 billion years after the big bang had taken place [5, 21]. How the supermassive black holes with billions of solar masses were formed so rapidly during the early universe is a great mystery raised by astronomers recently [22]. Theoretically, such infant universe should only contain hydrogen and helium, but observationally scientists have found a lot of heavy elements such as carbon, oxygen, and iron around these distant quasars, especially the large fraction of iron was observed in quasar APM 08279+5255 [23], which has redshift $Z = 3.91$. If the heavy ions, as currently believed, are produced during supernova explosions when stars runs out of their fuel supplies and start to end their lives, then quasars with heavy elements should be much elder than the main sequence stars and normal galaxies.

Recently, in the 211th AAS meeting, Zhang proposed a new cosmological model called black hole universe [24]. In Paper I [25], Zhang has fully addressed the origin, structure, evolution, and expansion of black hole universe (see also [26]). In Paper II [27], Zhang has quantitatively explained the cosmic microwave background radiation of black hole universe (see [28]), an ideal black body. Zhang [29] summarized the observational evidences of black hole universe. According to this new cosmological model, the universe originated from a hot star-like black hole with several solar masses, and gradually grew through a supermassive black hole with billions of solar masses to the present state with hundred billion-trillions of solar masses by accreting ambient material and merging with other black holes. The entire space is hierarchically structured with infinite layers. The innermost three layers are the universe in which we live, the outside space 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, which corresponds to an asymptotically flat spacetime without an edge and outside space and material. The relationship 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 black hole universes. A black hole universe is a subset of the entire space or a subspace and the child universes are null sets or empty spaces. All layers or universes are governed by the same physics, the Einsteinian general theory of relativity with the Robertson-Walker metric of spacetime, and expand physically in one way (outward). The growth or expansion of a black hole universe decreases its density and temperature but does not alter the laws of physics.

In the black hole universe model, the observed distant quasars are suggested to be donuts from the mother universe. They were formed in the mother universe from star-like black holes rather than formed inside our universe. In other words, the observed distant quasars actually were child universes of the mother universe, i.e., little sister universes of our universe. After they were swallowed, quasars became child universes of our universe. In general, once a star-like black hole is formed in a normal galaxy, the black hole will eventually inhale, including merge with other black holes, most matter of the galaxy and grow gradually to form a supermassive black hole. Therefore, quasars are supposed to be much elder than the normal stars and galaxies, and thus significantly enriched in heavy elements as measured. Some smaller redshift quasars might be formed in our universe from the aged galaxies that came from the mother universe before the distant quasars entered. Nearby galaxies will form quasars after billions of years and enter the new universe formed from the observed distant quasars as donuts. The entire space evolves iteratively. When one universe expands out, a new similar universe is formed from its inside star-like or supermassive black holes. This study as Paper III develops the energy mechanism for quasars to emit a huge amount of energy according to the black hole universe model.

2 Energy Mechanism for Quasars

As a consequence of the Einsteinian general theory of relativity, a main sequence star, at the end of its evolution, will become, in terms of its mass, one of the follows: a dwarf, a neutron star, or a stellar black hole. A massive star ends its life with supernova explosion and forms a neutron star or a black hole. Recently, Zhang [30] proposed a new mechanism called gravitational field shielding for supernova explosion. For the evolution of the entire galaxy, many details have been uncovered by astronomers, but how a galaxy ends its life is still not completely understood. In the black hole universe, all galaxies are suggested to eventually evolve to be supermassive black holes. Galaxies with different sizes form supermassive black holes with different masses. Quasars are formed from normal galaxies through active galaxies as shown in Figure 1.

Once many stars of a galaxy have run out of their fuels and formed dwarfs, neutral stars, and black holes, the galaxy shrinks its size and collapses toward the center, where a massive black hole with millions of solar masses may have already existed, by the gravity. During the collapse, the dwarfs,

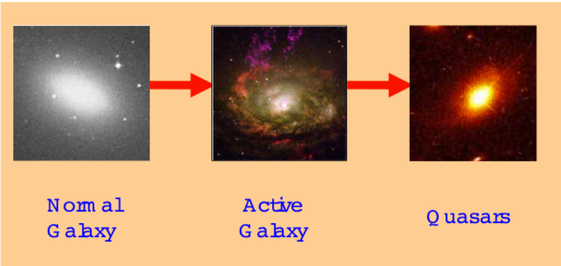

Fig. 1: Formation of quasars. A normal galaxy evolves into an active one and ends by a quasar (Images of Hubble Space Telescope).

neutron stars, and stellar black holes are merging each other and gradually falling into the massive black hole at the center to form a supermassive black hole with billions of solar masses. When stellar black holes merge and collapse into a supermassive black hole, a huge amount of energies are released. In this situation, the galaxy is activated and a quasar is born.

In a normal galaxy, such as our Milky Way, most stars are still active and bright because they have not yet run out of their fuels to form dwarfs, neutron stars, and black holes. In the disk of a normal galaxy, there should be not much of such hardly observed matter as shown by the measurements [31-32]. In the center of a normal galaxy, a quiet massive black hole with millions of solar masses may exist. Once many stars have run out of their fuels and evolved into dwarfs, neutron stars, and black holes, the disk of the galaxy becomes dim, though intensive X-rays can emit near the neutron stars and black holes, and starts to shrink and collapse. As the galaxy collapses, the black holes fall towards (or decrease of orbital radius) the center and merge with the massive black hole at the center, where huge amounts of energies leak out of the black holes through the connection region, where the event horizons are broken. The galaxy first activates with a luminous nucleus and then becomes a quasar in a short period at the evolution end.

The inside space of a black hole is a mystery and can never be observed by an observer in the external world. It is usually suggested that when a star forms a Schwarzschild black hole its matter will be collapsed to the singularity point with infinite density. Material falling into the black hole will be crunched also to the singularity point. Other regions under the event horizon of the black hole with radius $R = 2GM/c^2$ are empty. The inside space of the black hole was also considered to be an individual spacetime with matter and field distributions that obeys the Einsteinian general theory of relativity. Gonzalez-Diaz [33] derived a spacetime metric for the region of nonempty space within the event horizon from the Einsteinian field equation.

In the black hole universe model, we have considered the inside space of the Schwarzschild black hole as an individual spacetime, which is also governed by the Friedmann equation

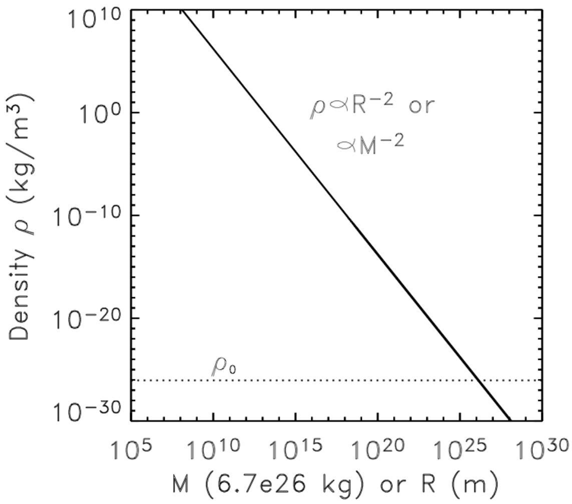

Fig. 2: The density of a black hole versus its mass or radius (solid line). The dotted line refers to $\rho = \rho_0$ the density of the present universe, so that the intersection of the two lines represents the density, radius, and mass of the present universe.

with the Robertson-Walker metric of spacetime and where matter is uniformly distributed rather than crunched into a single point. Highly curved spacetime sustains the highly dense matter and strong gravity. A black hole governed by the Einsteinian general theory of relativity with the Robertson-Walker metric of spacetime is usually static with a constant mass-radius ratio called M-R relation or a constant density when it does not eat or accrete matter from its outside space [25]. The density of the matter is given by

$$\rho = \frac{M}{V} = \frac{3c^2}{8\pi G R^2} = \frac{3c^6}{32\pi G^3 M^2}, \tag{1}$$

where $V = 4\pi R^3/3$ is the volume. Figure 2 shows the density of black hole as a function of its radius or mass. It is seen that the density of the black hole universe is inversely proportional to the square of radius or mass. At the present time, the mass and radius of the universe are 9×10^{51} kg and 1.3×10^{26} m, respectively, if the density of the universe is chosen to be $\rho_0 = 9 \times 10^{-27}$ kg/m^3.

The total radiation energy inside a black hole, an ideal black body, is given by

$$U = \frac{4}{3}\pi\beta R^3 T^4 = \mu R^3 T^4, \tag{2}$$

where T is the temperature and β is a constant [27]. The constant μ is given by

$$\mu = \frac{4}{3}\pi\beta = \frac{32\pi^6 k_B^4}{45 h^3 c^3}, \tag{3}$$

where k_B is the Boltzmann constant, h is the Planck constant, and c is the light speed. Using the Robertson-Walker metric

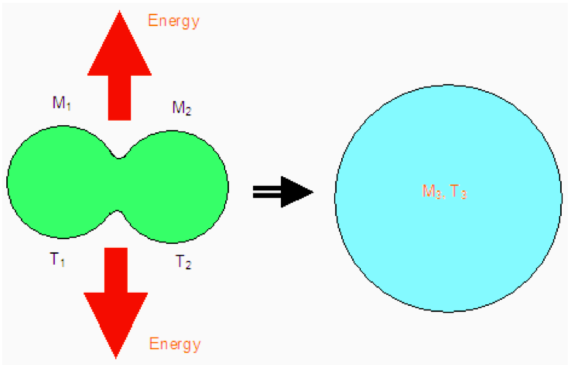

Fig. 3: A sketch for two star-like black holes to merge into a larger one and release energy from the reconnection region where the event horizons break.

with the curvature parameter $k = 1$ to describe the black hole spacetime, we have obtained in Paper I, from the Einsteinian field equation, that the black hole is stable $dR/dt = 0$ if no material and radiation enter, otherwise the black hole enlarges or expands its size at a rate $dR/dt = RH$ and thus decrease its density and temperature. Here H is the Hubble parameter.

When two black holes merge, their event horizons first break and then reconnect to form a single enveloping horizon and therefore a larger black hole. Brandt et al. [34] simulated the merge and collision of black holes. During the period of the reconnection of the event horizons, a huge amount of radiation energy leak/emit out from the black holes through the connection region, where the formed event horizon is still concave and has negative curvature. As many star-like black holes merge, a supermassive black hole or a quasar forms.

To illustrate the energy emission of a quasar, we first consider two black holes with mass M_1, M_2 (or radius R_1, R_2) and temperature T_1, T_2 to merge into a larger black hole with mass $M_3 = M_1 + M_2$ (or radius $R_3 = R_1 + R_2$ because of the M-R relation) and temperature T_3. Figure 3 show a schematic sketch for the merging of two black holes and the energy emission from them. This is somewhat similar to the energy release by fusion of two light nuclei. The total energy radiated from the collision region can be estimated as

$$E = \mu R_1^3 T_1^4 + \mu R_2^3 T_2^4 - \mu R_3^3 T_3^4. \tag{4}$$

It can be positive if the merged black hole is colder than the merging black holes (i.e., $E > 0$, if $T_3 < T_1, T_2$).

For N star-like black holes and one massive black hole to merge into a supermassive black hole, the total radiation energy that is emitted out can be written as

$$E_{\text{total}} = \mu \sum_{j=0}^{N} R_j^3 T_j^4 - \mu R_Q^3 T_Q^4, \tag{5}$$

where R_j and T_j are the radius and temperature of the j^{th} stellar black hole ($j = 0$ for the massive black hole existed at the center), R_Q and T_Q are the radius and temperature of the supermassive black hole formed at the end, and N is the number of the star-like black holes formed in the galaxy. The radius of the supermassive black hole can be estimated as

$$R_Q = \sum_{j=0}^{N} R_j. \tag{6}$$

Considering all the star-like black holes to have the same size and temperature (for simplicity or in an average radius and temperature), we have

$$E_{\text{total}} = \mu R_0^3 T_0^4 + \mu N R_j^3 T_j^4 - \mu N^3 R_j^3 T_Q^4. \tag{7}$$

Here we have also considered that $R_Q >> R_0$ and

$$R_Q = R_0 + N R_j \simeq N R_j. \tag{8}$$

Paper II has shown that the temperature of a black hole including our black hole universe depends on its size or radius. For a child universe (i.e., star-like or supermassive black hole), the relation is approximately power law,

$$T \propto \frac{1}{R^{\delta}}, \tag{9}$$

where δ is a power law index less than about 3/4. Applying this temperature-radius relation into Eqs. (8) and (7), we have,

$$T_Q = T_j N^{-\delta}, \tag{10}$$

and

$$E_{\text{total}} = \mu R_j^3 T_j^4 N (1 - N^{2-4\delta}). \tag{11}$$

The average luminosity of a collapsing galaxy (or quasar) can be written as

$$L \equiv E_{\text{total}} / \tau \tag{12}$$

where τ is the time for all star-like black holes in a galaxy to merge into a single supermassive black hole.

It is seen that the luminosity of a quasar increases with δ, N, R_j, and T_j, but decreases with τ. As an example, choosing $R_j = 9$ km (or $M_j \simeq 3M_s$), $T_j = 10^{12}$ K, $N = 10^9$, and $\tau = 10^9$ years, we obtain $L \simeq 7.3 \times 10^{37}$ W, which is $\sim 2 \times 10^{11}$ times that of the Sun and therefore about the order of a quasar's luminosity [35]. The formed supermassive black hole will be three billion solar masses. Here δ is chosen to be greater enough (e.g., 0.55). For a hotter T_j, a shorter τ, or a larger N, the luminosity is greater. Therefore, if quasars are collapsed galaxies at their centers that star-like black holes are merging into supermassive black holes, then the huge luminosities of quasars can be understood. The extremely emitting of energy may induce extensive shocks and produce jet flows of matter outward along the strong magnetic field lines.

To see how the luminosity of a quasar depends on the parameters N, δ, T_j, and τ, we plot the luminosity of a collapsing galaxy (merging black holes or an ignited quasar) in

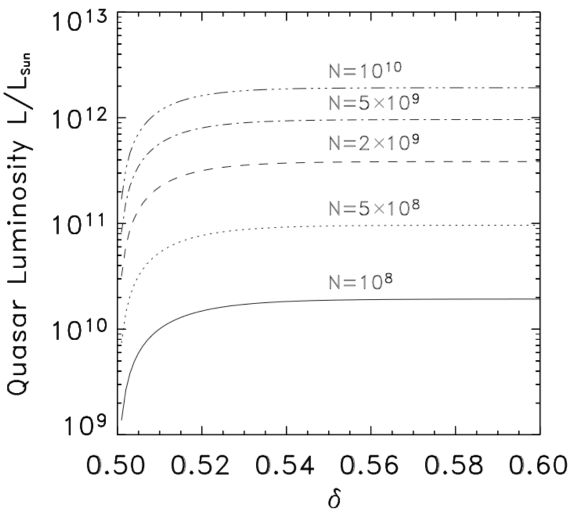

Fig. 4: Quasar luminosity vs. δ with $N = 10^8, 5 \times 10^5, 2 \times 10^9, 5 \times 10^9, 10^{10}$. δ should be greater than 0.5 for a quasar to emit energy. The luminosity saturates when $\delta \gtrsim 0.52$.

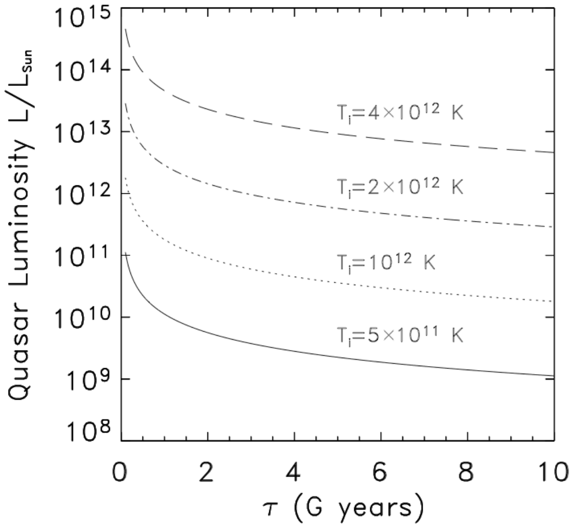

Fig. 5: Quasar luminosity vs. τ with $N = 10^8, 5 \times 10^5, 2 \times 10^9, 5 \times 10^9, 10^{10}$. It increases with the temperature of star-like black holes but decreases with the time for them to merge.

Figure 4 as a function of δ and in Figure 5 as a function of τ with different N. In Figure 4, we let δ vary from 0.5 to 0.6 as the x-axis and N be equal to 10^8, 2×10^8, 5×10^8, and 10^9, where other parameters are fixed at $R_j = 9$ km, $T_j = 10^{12}$ K, and $\tau = 10^9$ years. In Figure 5, we let τ vary from 10^8 years to 10^{10} years as the x-axis and T_j equal to 5×10^{11}, 10^{12}, 2×10^{12}, and 4×10^{12} K, where other parameters are fixed at $R_j = 9$ km, $N = 10^9$, and $\delta = 0.55$.

It is seen from Figure 4 that the luminosity of a quasar increases with δ and N, and saturates when $\delta \gtrsim 0.52$. For a supermassive black hole to emit energy, δ must be greater than about 0.5. Paper II has shown $\delta \lesssim 3/4 = 0.75$. From Figure 5, we can see that the luminosity decreases with the collapsing time τ and increases with T_j.

Corresponding to the possible thermal history given by Paper II, δ varies as the black hole universe grows. Figure 6 plots the parameters γ defined in Paper II and δ as functions of the radius R. It is seen that when a supermassive black hole grows up to $R \gtrsim 10^{14}$ km (or $M \gtrsim 3 \times 10^5$ billion solar masses) it does not emit energy when it merges with other black holes because $\delta < 0.5$. In the observed distant voids, it is possible to have this kind of objects called mini-black-hole universes. The observed distant quasars may have grown up to this size or mass now and so that quite at present. A cluster, when most of its galaxies become supermassive black holes or quasars, will merge into a mini-black-hole universe.

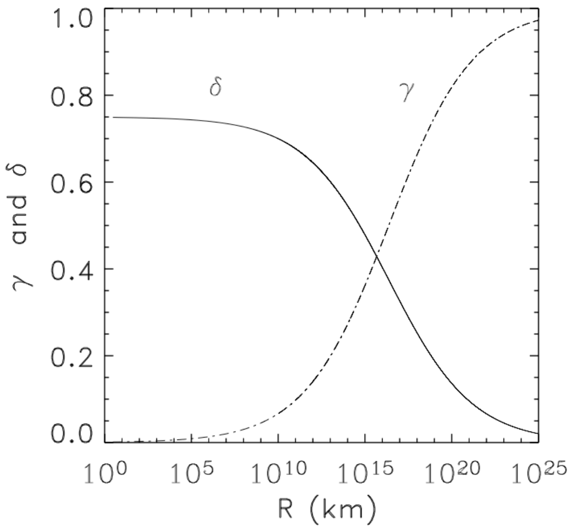

Fig. 6: Parameters γ and δ versus radius R. When a supermassive black hole grows to $R \gtrsim 3 \times 10^{14}$ km or $M \gtrsim 10^{14}$ solar masses, it does not emit energy because $\delta < 0.5$.

3 Discussions and Conclusions

If there does not pre-exist a massive black hole at the center of a galaxy, a supermassive black hole can also be formed from the galaxy. As the galaxy shrinks it size, a hot star-like black hole enlarges its size when it swallows dwarfs or neutron stars, which may also collapse to form black holes [36] or merges with other black holes and forms a supermassive black hole at the end.

As a summary, we proposed a possible explanation for quasars to ignite and release a huge amount of energy in accord with the black hole universe model. General relativity tells us that 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 of their fuels and formed dwarfs, neutron stars, and black holes, the gravity cause the galaxy to eventually collapse and form a supermassive black hole with billions of solar masses. It has been shown that this collapse can lead to the extremely hot stellar black holes to merge each other and further into the massive black hole at the center and release intense thermal radiation energy as great as a quasar emits. 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. The observed distant quasars were donuts from the mother universe. They were actually formed in the mother universe as little sisters of our universe. After the quasars entered our universe, they became our universe's child universes. The results from this quasar model are consistent with observations.

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References

1. Burbidge E.M. Quasi-stellar objects. *Annual Review of Astronomy and Astrophysics*, 1967, v. 5, 399–452.
2. Burbidge G. Redshifts and distances. *Nature*, 1979, v. 282, 451–455.
3. Hazard C., McMahon R. New quasars with Z = 3.4 and 3.7 and the surface density of very high redshift quasars. *Nature*, 1985, v. 314, 238–240.
4. Bechtold J. et al. Chandra survey of radio-quiet, high-redshift quasars. *The Astrophysical Journal*, 2003, v. 588, 119–127.
5. Fan X.H. et al. A survey of z>5.7 quasars in the Sloan Digital Sky Survey: II. Discovery of three additional quasars at z>6. *The Astronomical Journal*, 2003, v. 125, 1649–1659.
6. Hartwick F.D.A., Schade D. The space distribution of quasars. *Annual Review of Astronomy and Astrophysics*, 1990, v. 28, 437–489.
7. Boyle B.J. et al. The 2dF QSO redshift survey - I. The optical luminosity function of quasi-stellar objects. *Monthly Notices of the Royal Astronomical Society*, 2000, v. 317, 1014–1022.
8. Zhang T.X. Electric redshift and quasars. *Astrophysical Journal Letters*, 2006, v. 636, L61–L64.
9. Lynden-Bell D. Galactic nuclei as collapsed old quasars. *Nature*, 1969, v. 223, 690–694.
10. Rees M.J. Black hole models for active galactic nuclei. *Annual Review of Astronomy and Astrophysics*, 1984, v. 22, 471–506.
11. Bahcall J.N., Kirhakos S., Saxe D.H., Schneider D.P. Hubble Space Telescope Images of a sample of 20 nearby luminous quasars. *The Astrophysical Journal*, 1997, v. 479, 642–658.
12. Lobanov A.P., Roland J. A supermassive binary black hole in the quasar 3C 345. *Astronomy and Astrophysics*, 2005, v. 431, 831–846.
13. Begelman M.C., King A.R., Pringle J.E. The nature of SS433 and the ultraluminous X-ray sources. *Monthly Notices of the Royal Astronomical Society*, 2006, v. 370, 399–404.
14. Shapiro S.L., Teukolsky S.A. The collapse of dense star clusters to supermassive black holes - The origin of quasars and AGNs. *The Astrophysical Journal Letters*, 1985, v. 292, L41–L44.
15. Wyithe J., Stuart B., Loeb A. Self-regulated growth of supermassive black holes in galaxies as the origin of the optical and X-ray luminosity functions of quasars. *The Astrophysical Journal*, 2003, v. 595, 614–623.
16. Reeves J.N., Pounds K., Uttley P., Kraemer S., Mushotzky R., Yaqoob T., George I.M., Turner T.J. Evidence for gravitational infall of matter onto the supermassive black hole in the quasar PG 1211+143? *The Astrophysical Journal Letters*, 2005, v. 633, L81–L84.
17. Einstein A. Die Grundlage der allgemeinen Relativitätstheorie, *Annalen der Physik*, 1916, v. 354, 769–822.
18. Schwarzschild K. On the gravitational field of a mass point according to Einstein's theory. *Sitzungsberichte der Königlich Preussischen Akademie der Wissenschaften zu Berlin, Phys.-Math.*, 1916, 189–196.
19. Stockton A., Fu H., Henry J.P., Canalizo G. Extended X-ray emission from QSOs. *The Astrophysical Journal*, 2006, v. 638, 635–641.
20. Schild R.E., Leiter D.J., Robertson, S.L. Observations supporting the existence of an intrinsic magnetic moment inside the central compact object within the quasar Q0957+561. *The Astronomical Journal*, 2006, v. 132, 420–432.
21. Fan X.F. et al. A survey of $z > 5.8$ quasars in the Sloan Digital Sky Survey. I. Discovery of three new quasars and the spatial density of luminous quasars at $z \sim 6$. *Astron. J.*, 2001, v. 122, 2833–2849.
22. Hamann F., Ferland G. Elemental abundances in quasistellar objects: Star formation and galactic nuclear evolution at high redshifts. *Annual Review of Astronomy and Astrophysics*, 1999, v. 37, 487–531.
23. Hasinger G., Schartel N., Komossa S. Discovery of an ionized Fe K edge in the z=3.91 broad absorption line quasar APM 08279+5255 with XMM-Newton. *The Astrophysical Journal Letters*, 2002, v. 573, L77–L80.
24. Zhang T.X. A new cosmological model: Black hole universe, *Bulletin of the American Astronomical Society*, 2007, v. 39, 1004–1004.
25. Zhang T.X. A new cosmological model: Black hole universe, *Progress in Physics*, 2009a, v. 3, 3–11 (Paper I).
26. Zhang T.X. Anisotropic expansion of the black hole universe. *Bulletin of the American Astronomical Society*, 2009b, v. 41, 499–499.
27. Zhang T.X. Cosmic microwave background radiation of black hole universe. *Astrophysics and Space Science*, 2010a, v. 330, 157–165 (Paper II).
28. Zhang T.X. Cosmic microwave background radiation of black hole universe, *Bulletin of the American Astronomical Society*, 2009c, v. 41, 754–754.
29. Zhang T.X. Observational evidences of black hole universe. *Bulletin of the American Astronomical Society*, 2010b, v. 42, 314–314.
30. Zhang T.X. Gravitational field shielding and supernova explosions. *The Astrophysical Journal Letters*, 2010c, v. 725, L117–L120.
31. Hellemans A. ASTRONOMY: Galactic disk contains no dark matter *Science*, 1997, v. 278, 1230–1230.
32. Creze M., Chereul E., Bienaymo O., Pichon C. The distribution of nearby stars in phase space mapped by Hipparcos. I. The potential well and local dynamical mass. *Astronomy and Astrophysics*, 1998, v. 329, 920–936.
33. Gonzalez-Diaz P.E. The spacetime metric inside a black hole. *Nuovo Cimento Letters*, 1981, v. 2, L161–L163.
34. Brandt S., Font J.A., Ibanez J.M., Masso J., Seidel E. Numerical evolution of matter in dynamical axisymmetric black hole spacetimes I. Methods and tests. *Computer Physics Commmunications*, 2000, v. 124, 169–196.
35. Sparke L.S., Gallaher J.S. Galaxies in the Universe: an Introduction, Cambridge University Press, 2000.
36. Dermer C.D., Atoyan A. Collapse of neutron stars to black holes in binary systems: A model for short gamma-ray bursts. *The Astrophysical Journal Letters*, 2006, v. 643, L13–L16.