Astronomical and Astrophysical Transactions (*AApTr*), 2021, Vol. 32, Issue 3, pp. 173–176,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

Do we live in a black hole?

Ryszard Gonczarek[1], Mateusz Krzyzosiak[2,*]

[1] *Faculty of Fundamental Problems of Technology, Wrocław University of Technology, Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland*
[2] *University of Michigan–Shanghai Jiao Tong University Joint Institute, 800 Dongchuan Rd, Shanghai 200240, China*

Received 7 April, 2021

We note that, in the Big Bang theory, the universe satisfies the condition and criteria of a black hole and we ask a number of questions about consequences of this fact. We aim to answer the question whether this universe may be an evolving black hole marking its borders, which expands due to absorption of outer mass (energy). It is an alternative to the Big Bang theory, where the universe is still expanding while its energy (mass) is constant.

Keywords: Black hole, accretion, evolution of the universe

1 Is this relation coincidental?

According to the Big Bang theory, some basic quantitative characteristics of the universe are estimated as follows: (1) the radius of the universe is of the order of 13.5×10^9 light years, (2) the average density of the total mass is $\varrho = 9.9 \times 10^{-27}$ [kg/m^3]. This total mass includes the dark energy amounting to 68.3 %, the dark matter – 26.8 % and the baryonic matter – 4.9 %. Such a universe obeys Newton's law of universal gravitation.

Black holes are a special class of objects that have been studied with never-fading interest. For a black hole, the Schwarzschild radius is defined as[†]

$$R_{\mathrm{g}} = 2GM/c^2,$$

with the gravitational constant $G = (6.670 \pm 0.015) \times 10^{-11}$ [N $\cdot$ m^2/kg^2] and the speed of light in vacuum $c = 299\,792\,458$ [m/s]. The mass of an object with radius R can be expressed as $M = \dfrac{4}{3}\pi R^3 \varrho$, with ϱ being the average density of object's mass.

*Email: m.krzyzosiak@sjtu.edu.cn

[†] An outline of a more general discussion is presented in Appendix.

Then, if the following relation is satisfied,

$$\frac{4}{3}\pi\, G\, R^2\, \varrho = \frac{c^2}{2}, \tag{1}$$

the object becomes a black hole and $R = R_{\rm g}$. Plugging in the numerical values of the constants, we obtain $\varrho R_{\rm g}^2 = K$, where $K = 1.608 \times 10^{26}$ [kg/m] and hence $\varrho = DM^{-2}$, with $D = 7.301 \times 10^{79}$ [kg^3/m^3]. Consequently, if two black holes merge, the radius of the resulting black hole is equal to the sum of the radii of these black holes.

Let us now consider the entire space we live in – the universe – with the basic quantitative characteristics estimated according to the Big Bang theory as above. Substituting the radius of the universe and its average mass density to Eq. (1), we obtain $G_{\rm c} = 6.65 \times 10^{-11}$ [N $\cdot$ m^2/kg^2]. This result allows us to assume that the radius of the universe can be identified with the Schwarzschild radius. Although it is a rough estimate, the value of $G_{\rm c}$ is very close to the actual value of the gravitational constant G, suggesting that our universe indeed satisfies conditions for being a black hole. As such, it would be the biggest black hole, and we can conclude that matter (the dark energy, the dark matter, and the baryonic matter) in the black hole can be organized in various ways. Moreover, even if there exists a space beyond the universe, according to the law of universal gravity we would still find ourselves in the black hole. It is a strong argument in favor of a statement that in black holes there may appear some organized systems similar to our universe. What is outside of such a black hole encompassing the universe, remains an open question.

2 Is the universe expanding and cooling?

If we assume that the black hole is situated in a greater universe, and some additional total mass is absorbed by our universe in an accretion effect, then the infinitesimal mass increase can be found as

$$\mathrm{d}M_{\rm ex} = 4\pi R_{\rm g}^2 \varrho_{\rm ex}(t) c\, \mathrm{d}t,$$

where $\varrho_{\rm ex}$ is the average density of external mass absorbed by the universe, and it is postulated to be a function of time. Assuming that the universe stabilizes, according to the formula $\varrho R_{\rm g}^2 = K$, the Schwarzschild radius and the mass density satisfy the relation $2\varrho\, \mathrm{d}R_{\rm g} = -R_{\rm g}\, \mathrm{d}\varrho$, that is $\varrho \propto R_{\rm g}^{-2}$ (see also Figure 1). Hence, the Schwarzschild radius of an expanding universe increases at the rate

$$\mathrm{d}R_{\rm g}/\mathrm{dt} = 3c\varrho_{\rm ex}(t)/\varrho.$$

Including the relation $\varrho = DM^{-2}$ we find that $\mathrm{d}R_{\rm g}/\mathrm{dt} = 3cD^{-1}M^2\varrho_{\rm ex}(t)$, which is in line with results obtained within Hermann Bondi's model. Because there is no single pattern which all black holes follow, some may absorb enormous amounts of mass (energy) from the environment, others are limited to a stable absorption of moderate amounts of mass (energy), and there are yet others which are able to "starve" themselves. Therefore, with a number of possible scenarios, it is challenging to predict particular observable effects of the absorption taking place. Nevertheless, it is quite natural to assume that the density of mass (energy) $\varrho_{\rm ex}$ absorbed by the black

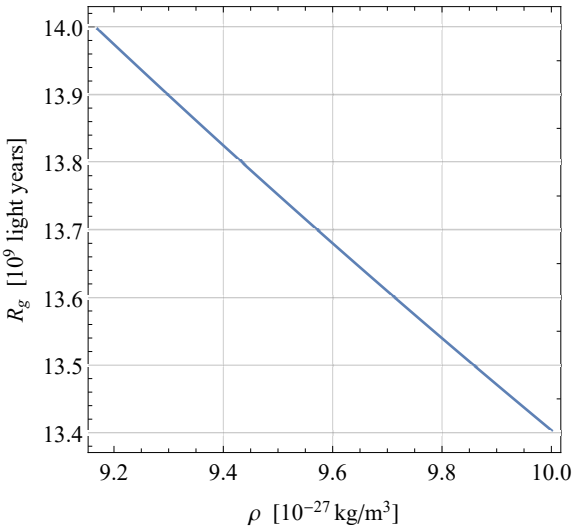


Figure 1 Size of the universe vs. the average density of matter.

hole is small or very small in comparison with ϱ. Moreover, $\varrho_{\rm ex}(t) < \varrho/3$, because the rate of expansion must not exceed the speed of light. Additionally, since $\varrho \propto R_{\rm g}^{-2}$, the decreasing density of the expanding universe (being the black hole) causes it to cool down.

The mass that corresponds to energy, in particular the dark energy, $m = E/c^2$ has properties of the gravitational mass: it produces a gravitational field and interacts with such a field.

If the gravitational potential of a large astronomical object on its boundary (surface) is equal to $V = \alpha\, c^2/2$, where $0 < \alpha < 1$, then the energy of photons $\hbar\omega$ moving towards the center of the gravitational field increases, but does exceed the value of $\hbar\omega(1 + \alpha/2)$. On the other hand, the energy of photons moving away decreases, but cannot be less than $\hbar\omega(1-\alpha/2)$. This phenomenon allows us to explain the reddening of galaxies, which in the Big Bang theory is derived from the Doppler shift. It proves that almost all nebulae move away from the Earth and hence the universe expands.

If the black hole was rotating, the angular speed of that rotational motion could not be greater than its radius divided by the speed of light. This is because the linear speed near the event horizon must be less than the speed of light (the distances from the Earth to the event horizon, measured in any direction, are comparable). Then, the centrifugal force would be ejecting the inertial mass out of the center of the black hole.

3 How was the universe created and what is next?

The fact that the present universe satisfies the black hole condition allows us to presume that it appears as a black hole in a bigger universe and has been evolving for a very long time, further absorbing outer mass (energy) to reach the current structure.

With these assumptions, the radius of the universe, being always the Schwarzschild radius, can be written in the form

$$R_{\rm g}(t) = R_{\rm g}(t_0)\left[1 - \frac{3cR_{\rm g}(t_0)}{K}\int_{t_0}^{t}\varrho_{\rm ex}(t')\,{\rm d}t'\right]^{-1}.$$

Consequently, the average density changes as $\varrho(t) = K\,R_{\rm g}^{-2}(t)$, where t_0 is the instant when a black hole with radius $R_{\rm g}(t_0)$ was created in the bigger universe. Note that inside the black hole, the space has borders and the universe is viewed as finite.

The discussion presented here differs from the Big Bang theory in that the latter aims to explain what happened at the very beginning of our universe. These two models possess common elements: the universe is expanding and cooling. However, in the Big Bang theory, where total energy (mass) was created at the very beginning, the density $\varrho \propto R^{-3}$, while in the black hole model $\varrho \propto R_{\rm g}^{-2}$. Moreover, the Big Bang theory does not answer the question why the universe currently meets the black hole conditions and whether it will be able to expand further. It seems that after reaching the black hole condition, its expansion should stop.

In the Big Bang theory, the size of the universe equals its lifetime times the speed of light. It means that 5 billion years ago, when the solar system was formed, the average mass density was about 4 times greater than now, which should have influenced its formation and existence. According to the concept of the black hole, the size of the universe is the same as in the Big Bang theory, but the time of its existence is not determined. Hence, changes in the average mass density may occur very slowly and the solar system may not have experienced these changes.

According to both models the universe expands, it is finite and its radius is about 13.5×10^9 light years. In the Big Bang theory the universe is still expanding and moving its borders, while the universe treated as a black hole ends at the event horizon, which is the border of the black hole region from which no escape is possible. Its radius increases if additional mass (energy) gets absorbed.

APPENDIX
The gravitational potential of an inhomogeneous sphere

Considering an inhomogeneous sphere with a radius R and mass density $\varrho(r,\vartheta,\varphi)$ the gravitational potential on the surface of the sphere can be evaluated as

$$V = G\int_0^{2\pi}{\rm d}\varphi\int_0^{\pi}{\rm d}\vartheta\int_0^{R}{\rm d}r\;\frac{r^2\sin\vartheta\,\varrho(r,\vartheta,\varphi)}{\sqrt{R^2+r^2-2Rr\cos\vartheta}},$$

where the total mass is $M = \displaystyle\int_0^{2\pi}{\rm d}\varphi\int_0^{\pi}{\rm d}\vartheta\int_0^{R}{\rm d}r\;r^2\sin\vartheta\,\varrho(r,\vartheta,\varphi)$. Note that after choosing a point $(R,0,0)$ the total mass can be rotated arbitrarily, and in such a way that the gravitational potential on the surface of the sphere can be derived at every point on the sphere. Hence, it can be easily seen that for the mass density independent of ϑ, i.e. for $\varrho = \varrho(r,\varphi)$, the gravitational potential on the surface of the sphere is

$$V = \frac{G\,M}{R}.$$

Therefore, for the case of the average mass density ϱ we can use Eq. (1).