Comment on the Origin of the Supermassive Black Hole

Kazuyasu Shigemoto
Department of Physics
Tezukayama University, Nara 631-8501, Japan

Abstract
We give the comment why the supermassive black hole exists at the center of almost all galaxies. We consider the origin of the supermassive black hole from the point of view of the density of the matter. If the density of the matter is fixed and such matter can come together by the gravitational attraction, such stellar object eventually becomes the black hole. If the density of the matter is that of the atom, such matter naturally comes together to form the black hole by the gravitational attraction. This is expected to be the process to form the supermassive black hole. In this way, we can understand that there exists supermassive black hole at the center of almost all galaxies, because there is no delicate process to evolve into the black hole.

1 Introduction

Recently we have the observational evidence that there exists the supermassive black hole at the center of almost all galaxies[1][2]. The mass of such supermassive black hole ranges from $10^6 M_\odot$ to $10^9 M_\odot$. It is well understand how the ordinary black hole is formed from the ordinary star [3]. But it is not established how the supermassive black hole at the center of the galaxies is formed[4]. Whether the stellar object becomes the black hole or not is related with the radius and the mass of that object. But we must more carefully study whether such stable state, especially the density of the matter, physically exists or not. For example, it is quite improbable that there exists the mini black hole with the radius of a few centimeters, because such stable state of that density is not physically known. Even if such stable state of the density exist, we must study how to evolve into the black hole from the
stellar gas.

In this paper, we study the black hole from the point of view whether such black hole is the stable state of the physically known density or not, and we study how the supermassive black hole is naturally formed from the stellar gas.

2 Ordinary Black Hole

We use Misner-Thorne-Wheeler notation [5] and consider the Einstein equation of motion in the form

\[ R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G T_{\mu\nu}}{c^4}, \tag{1} \]

where \( G \) is the gravitational constant, \( R \) is the scalar curvature, \( R_{\mu\nu} \) is the Ricci tensor and \( T_{\mu\nu} \) is the energy-momentum tensor of the matter. The metric of the Schwarzschild solution is given by

\[ ds^2 = -(1 - a/r)dt^2 + \frac{1}{1 - a/r} dr^2 + r^2 \left( d\theta^2 + \sin \theta d\phi^2 \right), \tag{2} \]

where \( a = \frac{2GM}{c^2} \).

For the ordinary star, we have

\[ r_{\text{ordinary star}} \gg a = \frac{2GM}{c^2}, \tag{3} \]

so that the ordinary star does not become the black hole. While, for the special star, which satisfies

\[ r_{\text{B.H.}} \leq a = \frac{2GM}{c^2}, \tag{4} \]

it becomes the black hole. The values of the physical constants in the above are given by

\[
G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg} \cdot \text{s}^2,
\]
\[
c = 3.0 \times 10^8 \text{ m/s}.
\]

(5)
We use the following values of various physical quantities

\[ M_\odot = 2.0 \times 10^{30} \text{ kg}, \quad r_\odot = 7.0 \times 10^8 \text{ m}, \]
\[ M_{\text{earth}} = 6.0 \times 10^{24} \text{ kg}, \quad r_{\text{earth}} = 6.4 \times 10^6 \text{ m}, \]
\[ M_{\text{neutron}} = 1.67 \times 10^{-27} \text{ kg}, \quad r_{\text{neutron}} = 10^{-15} \text{ m}, \]
\[ M_{\text{hydrogen atom}} = 1.67 \times 10^{-27} \text{ kg}, \quad r_{\text{hydrogen atom}} = 10^{-10} \text{ m}. \]  

(6)

2.1 Black hole radius for the sun

We use the above physical values, and we evaluate the critical radius \( r_{\odot \text{ B.H.}} \) for the sun. If the radius of the sun becomes smaller than this critical radius, the sun becomes the black hole. This critical radius becomes

\[ r_{\odot \text{ B.H.}} = \frac{2GM_\odot}{c^2} = 3 \times 10^3 \text{ m}. \]  

(7)

2.2 Black hole radius for the neutron star

We put the radius of the neutron star as \( L \) times the neutron radius, that is, \( r_{\text{neutron star}} = L r_{\text{neutron}} \), then the mass of the neutron star is given by \( L^3 M_{\text{neutron}} \). The critical condition that the neutron star becomes the black hole is given by

\[ L r_{\text{neutron}} = \frac{2GL^3 M_{\text{neutron}}}{c^2}, \]  

(8)

which gives

\[ L = \sqrt{\frac{r_{\text{neutron}} c^2}{2GM_{\text{neutron}}}} = 2 \times 10^{19}. \]  

(9)

Then we have the typical mass of the neutron black hole, ordinary black hole, as

\[ M_{\text{neutron B.H.}} = L^3 \times M_{\text{neutron}} = 1.34 \times 10^{31} \text{ kg} = 6.7 \times M_\odot, \]  

(10)

which agrees with the observation. The typical radius of the neutron black hole is

\[ r_{\text{neutron B.H.}} = L \times r_{\text{neutron}} = 2 \times 10^4 \text{ m}. \]  

(11)
3 Supermassive Black Hole

3.1 Black hole condition from the fixed density of the matter

We denote the density of the matter as $\rho$, then we have $M = \frac{4\pi r^3 \rho}{3}$. The critical radius that the stellar object becomes the black hole is expressed as $a = \frac{2GM}{c^2} = \frac{8\pi G\rho r^3}{3c^2}$. Then if we take the radius $r$ to be large enough, we eventually have $r < a = \frac{8\pi G\rho}{3c^2} r^3$. Therefore, if the matter is in the stable state with the physical density and such matter can come together by the gravitational attraction, it eventually evolve to the black hole.

3.2 Black hole radius for the stellar object with hydrogen atom

We put the radius of the stellar object with hydrogen atom as $L$ times that of the hydrogen atom, that is, $r_{\text{hydrogen star}} = L r_{\text{hydrogen}}$, then the mass of the stellar object with hydrogen atom is given by $L^3 M_{\text{hydrogen}}$. The condition that the stellar object with hydrogen atom becomes the black hole is given by

$$L r_{\text{hydrogen atom}} = \frac{2GL^3 M_{\text{hydrogen atom}}}{c^2},$$

which gives

$$L = \sqrt{\frac{r_{\text{hydrogen atom}} c^2}{2GM_{\text{hydrogen atom}}}} = 6.3 \times 10^{21}.$$  \hspace{1cm} (13)

Then we have the typical mass of the black hole with the hydrogen atom as

$$M_{\text{hydrogen B.H.}} = L^3 \times M_{\text{hydrogen atom}} = 4.2 \times 10^{38} \text{ kg} = 2 \times 10^8 \text{ M}_\odot$$  \hspace{1cm} (14)

This mass is in the range of the observed mass of the supermassive black hole $10^6 \text{M}_\odot \sim 10^9 \text{M}_\odot$. Then we expect that the supermassive black hole is the black hole composed of the hydrogen atom. The typical radius of the black hole with hydrogen atom is given by

$$r_{\text{hydrogen B.H.}} = L \times r_{\text{hydrogen atom}} = 6.3 \times 10^{11} \text{ m} = 4.3 \times \text{cosmological unit}.$$  \hspace{1cm} (15)
4 Summary and Discussion

We study why the supermassive black hole exists at the center of almost all galaxies. As the supermassive black hole exists at almost all galaxies, it must exist the quite natural process of the stellar gas evolving into the supermassive black hole. We study in this paper from the point of view whether the density of the black hole is the physically stable state or not. There are two typical stable density, that is, the nucleus density and the atomic density. It is the quite delicate process to reach the nucleus density state from the stellar gas. The stellar gas forms the heavy star and such heavy star collapse, then we have the ordinary black hole if some delicate condition is satisfied. While, if the density of the matter is that of the atom, the stellar gas can come together by the gravitational attraction without any delicate condition. Then such object eventually becomes large enough and we naturally have the supermassive black hole. In this approach, we estimate the typical mass of the supermassive black hole as $10^8 M_\odot$, which is in the observational range of the supermassive black hole $10^6 M_\odot \sim 10^9 M_\odot$.

References

[1] J. Kormendy and K. Gebhardt, in The 20th Texas Symposium on Relativistic Astrophysics, ed. H. Martel and J.C. Wheeler, New York, AIP, astro-ph/0105230.

[2] F. Melia and H. Falche, Ann. Rev. Astron. Astrophys. 39 (2001), to appear.

[3] G.E. Brown, C.-H. Lee, R.A.M.J. Wijers, H.A. Bethe, Physics Report,(2000), to appear, astro-ph/9910088.

[4] J.B. Bekenstein, astro-phy/0407560.

[5] C.W. Misner, K.S. Thorne and J.A. Wheeler, Gravitation, W.H. Freeman and Company, San Francisco, 1973.