Is a black hole a neutron star?

Arieh Sher

Abstract

The existence of black holes in the universe has been confirmed by observations. However, the theoretical model is still disputed. Einstein rejected their existence, although their theoretical existence is based on GR because Schwarzschild's solution predicted a singularity point at their center. He claimed that this is not a physical solution. On the other hand, Penrose suggested that their theoretical singularities exist. Kerr, who solved GR equations of a rotating black hole claims that Penrose did not prove the exitance of the singularity point at the center of a black hole.

I argue that there is no singularity point at the center of a black hole, but rather a physical object namely, a spinning neutron star. Therefore, there is a limiting mass where a neutron star becomes a black hole.

Current status

Blackholes' existence in the visible Universe was predicted by solving GR equations. Karl Schwarzschild in 1915 found an exact solution to Einstein's field equations. This solution predicted that black holes exist in the Universe. This solution gives two unique radii. The first is an essential singularity at r = 0, meaning that the density at the center of the black hole is infinite. This singularity implies that the known laws of physics break down. Einstein rejected this singularity. In a paper from 1939, Einstein concluded that there was no way a Schwarzschild singularity could ever be possible and therefore the Schwarzschild singularity does not exist in physical reality. The second radius is known as the Schwarzschild radius or the event horizon. The event horizon is a radius that is non-physical but nothing within it, including light, cannot escape the gravity of the black hole. Thus, an observer located outside the event horizon cannot see what is behind it. Schwarzschild radius is given by: $R_h = \frac{2 \cdot G \cdot M}{C^2}$

Where: G- gravitational constant, M- Mass of a black hole, and c- speed of light.

Nevertheless, despite Einstein's and other physicists' objections to the existence of black holes, black holes were observed in the universe, and the first image of M87* was taken in 2019.

A historical note: The idea of the possible exitance of black holes was first suggested, in 1783, by John Michell. Based on Newton's escape velocity equation he calculated what is the mass of a star that will not enable anything, even light, to escape from the star. He found the same equation of Schwarzschild radius.

In December 2023, Roy Kerr who solved general relativity equations for rotating black holes published a paper where he objects to the singularity point. Kerr's claim is in disagreement with

Roger Penrose who was awarded in 2020 the Noble Prize, for his work on black holes. Kerr claims that "There is no proof that black holes contain singularities when they are generated by real physical bodies". He also claims that "The ring singularity is just a replacement for a rotating star". [1]

There is no singularity (infinite density) at the center of a black hole.

I argue, that this issue of singularity can be resolved by postulating that in the physical world, density has a maximum value. I postulate that the maximum density of matter in the Universe is the density of a neutron, i.e., ~7.8*10^17 kg/m^3. This maximum density is found in the nucleus of an atom and also in a neutron star. The density of a neutron star is 3.7x10^17 to 5.9x10^17 kg/m^3, which is comparable to the approximate density of an atomic nucleus of 3x10^17 kg/m^3. [2]

Note: There are additional hypotheses regarding the maximal density in the Universe. The standard model of particle physics claims that there is a definite upper limit to the density in the universe. The maximal theoretical density is Planck's density of 10^96 kg/m^3. However, intermediate between the neutron star density and Planck's density there are hypothetical celestial bodies: The first is a quark star that has a density of 10^19kg/m^3. Strange Quark matter is actively studied with particle colliders, but this can only be produced at very hot temperatures (above 10^12 K) and in blobs the size of atomic nuclei, which decay immediately after formation. No stars made of strange quark matter were observed in the Universe. The second is a Preon star that has a density of 10^26kg/m^3. No evidence for quark and Preon stars has been found see [3]

I postulate that also a black hole, precisely as a neutron star and a nucleus of an atom, has the same structure. Namely, the nucleons are densely packed to the maximum density possible in the Universe. Specifically, the maximum possible density in the Universe is the density observed in the Universe ~ 7.8*10^17 kg/m^3.

While GR allows the density theoretically to become infinite, quantum theory and quantum experiments show that it is not possible. One of the theoretical reasons is Pauli's exclusion principle which forbids two identical fermion particles to occupy the same place at the same time. In a neutron star, the neutrons are packed so densely that they touch each other. To turn into other elementary particles, first, the neutrons must be squeezed together so that they overlap, but this is not possible according to Pauli's exclusion principle.

There are QCD experiments that show why squeezing nucleons in a nucleus more than the density of a proton is not possible.

1) Experiments that measure the force between two nucleons as a function of the distance between them show that the force between them can be described by the graph shown in [4]. This graph is based on Reid's potential formula. It shows that for a distance smaller than 0.8fm, the force becomes a sizeable repulsive force. Further analyzing Reid's equation shows that at r=0 the potential as well the force between nucleons becomes infinite.
2) Physicists at Jefferson Lab did another experiment "QUARKS FEEL THE PRESSURE IN THE PROTON" [5]. They measured the distribution of pressure inside the proton. The findings show that the proton's building blocks, the quarks, are subjected to a pressure of 100 decillions Pascal (10^35) near the center of a proton, which is about ten times greater than the pressure in the heart of a neutron star. The meaning is that the outward-directed pressure from the center of the proton is higher than the inward-directed pressure near the proton's periphery and therefore a neutron star cannot collapse.

Why is a neutron star visible whereas a black hole is not?

Given the description above, the question now is how come black holes are not directly observed in the Universe, while neutron stars are seen. My answer is: **The visibility depends on the relation between the physical radius of the neutron star and its Schwarzschild radius R_h.** A celestial body will be observed if its physical radius is bigger than its Schwarzschild radius. On the other hand, a celestial body that has a physical radius that is smaller than its Schwarzschild radius will be hidden.

The limiting mass and radius between a neutron star and a Blackhole can be found in the following manner:

1. Given a celestial body with mass M.

2. The radius of a densely packed spherical celestial body is:

$$R_n = R_{neutron} \cdot \left(\frac{M}{m_{neutron}}\right)^{1/3} \qquad (1)$$

See: https://en.wikipedia.org/wiki/Atomic_nucleus

where:

Mass of Neutron: $m_{neutron} = 1.6749275 \cdot 10^{-27}\, kg$

Radius of Neutron: $\mathrm{R}_{neutron} = 0.8 \cdot 10^{-13}\, cm$

3. The Schwarzschild radius of a celestial body is:

$$R_h = \frac{2 \cdot G \cdot M}{c^2} \qquad (2)$$

where:

Gravitational constant: $G = 6.67 \cdot 10^{-11} \frac{m^3}{kg \cdot \sec^2}$

Light velocity: $\mathrm{c} = 2.99 \cdot 10^8 \frac{m}{\sec}$

4. Equating Schwarzschild radius of the celestial body to its physical radius; $(\mathrm{R}_H = R_n)$:

Gives: $$M_{\lim it} = \left(\frac{R_{neutron} \cdot c^2}{2 \cdot G \cdot m_{neutron}^{1/3}}\right)^{3/2} = 9.67 \cdot 10^{30}\, kg \sim 4.86 Sun-masses. \qquad (3)$$

and $R_{\lim it} = 14.35 km$

From the above calculations, it is shown that the limit between a neutron star and a Blackhole is 4.86 Sun masses and a radius of 14.35km. A celestial body with a mass higher than 4.86 Sun masses will become a Blackhole because its physical radius is smaller than its Schwarzschild radius.

Observations: The calculated minimal mass of a black hole in the Universe is in good agreement with observations. A summary of observations of black holes and neutron stars is shown in the graph: [6].   The graph shows that the smallest black hole observed is ~4.9 Sun masses.

Kerr solution for rotating black hole

So far, the derivation of the above equations is based on Newton's escape velocity and the Schwarzschild solution to GR. In both cases, the spinning of celestial bodies is not taken into consideration. Nowadays, it is known that all celestial bodies in the universe spin. A black hole or a neutron star that is formed by the gravitational collapse of a massive star must retain the angular momentum of this progenitor star. In SBH (Schwarzschild black hole), it is assumed that the mass collapses to an infinitely small point. However, as a point cannot have angular momentum the conclusion is that SBH is merely a mathematical solution of GR. Only, in 1963, Kerr suggested a solution of GR equations- Kerr black hole (KBH) that takes into consideration the spinning of bodies. Analyzing Kerr's solution shows that KBH has a singularity ring located around its center with radius R_s, rather than the point singularity as in SBH. I postulate that the nucleus (i.e., the neutron star) of the black hole must reside inside the ring singularity.

The ring singularity radius (R_s) can be calculated by using Kerr solution:

$a = \frac{J}{M \cdot c}$ ....Black hole spin parameter (or angular momentum per unit mass) (5)

$R_g = \frac{G \cdot M}{c^2}$ ...Black's hole gravitational radius

$a' = \frac{a}{R_g} = \frac{a \cdot c^2}{G \cdot M}$.... Dimensionless spin parameter. Ranging from 0 to 1.   (6)

$R_s = \frac{a' \cdot G \cdot M}{c^2}$.....The radius of the ring singularity   (7)

$R_{h+} = \frac{G \cdot M}{c^2} \cdot (1 + \sqrt{1 - a'})$.....The radius of the outer event horizon   (8)

Where:

J ....Angular momentum of rotating black hole.

M ...Mass of a Black hole.

c ...Speed of light

G ...Gravitational constant

The dimensionless spin parameter a' ranges from 0 (non-rotating Schwarzschild black hole) to 1 (extremal Kerr black hole).

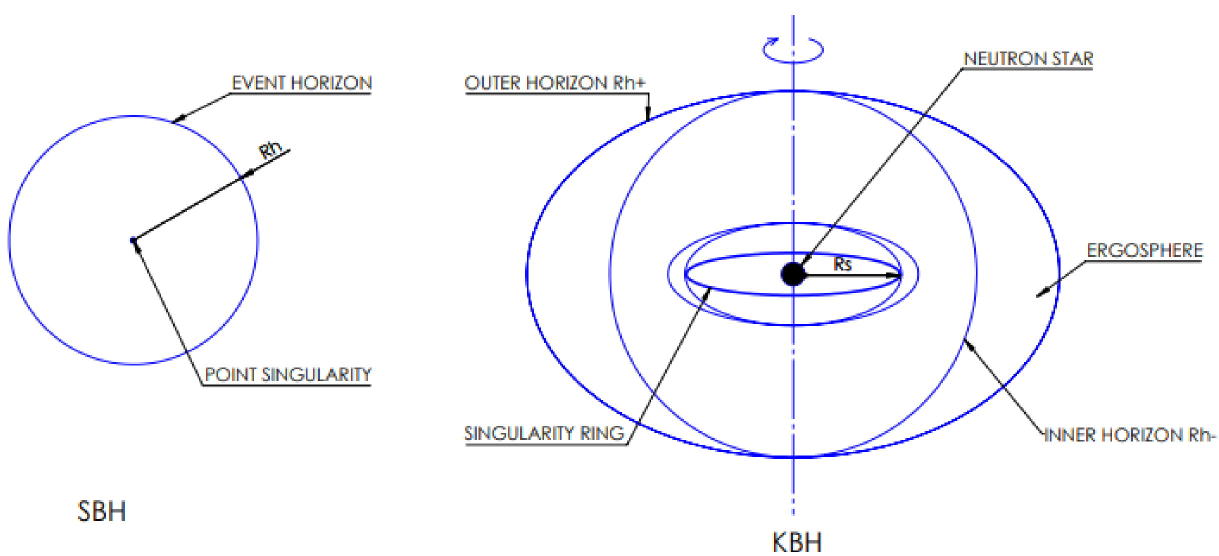
- For a non-rotating black hole, a'=0, the singularity is a point, and the event horizon is calculated by (2)
- If the black hole is rotating, 0 < a' <1, and the singularity becomes a ring.
- In the extremal case, a'=1 with the maximum radius of the ring is Rs=Rh/2

It can be concluded that SBH is a private case of KBH. Moreover, as observation shows in reality, that all celestial bodies spin, there is no non-rotating black hole, and therefore a' > 0, thus there is no singularity.

The ring singularity is confined within the black hole's event horizon and lies in the equatorial plane of the black hole.

To exist the radius of the black hole solid nucleus R_n (1) must be smaller than the radius R_s (7). However, what determines whether the massive celestial body is a black hole or a neutron star is the event horizon R_{h+}.

The following figure is a schematic comparison between SBH and KBH.



Two examples are given, to show the difference between a black hole (Cygnus X-1) and a neutron star (PSR J1903+0327). In both cases, the solid neutron star radius R_n, the singularity ring radius R_s, and the outer event horizon radius R_{h+} are calculated. In a black hole $R_{h+} > R_s > R_n$. In a neutron star $R_n > R_{h+} > R_s$.

Black hole in Cygnus X-1

Given (from observations):

$M_{cyg} = 21 \cdot M_{sun} = 4.2 \cdot 10^{31} \cdot kg$ ...Black hole's mass

$a_{cyg}' = 0.98$ ...Dimensionless spin parameter of the black hole.

$$R_{s\_cyg} = \frac{a_{cyg}' \cdot G \cdot M_{cyg}}{c^2} = 30.6 \cdot \text{km}$$ ...The radius of the ring singularity From (7)

$$R_{n\_cyg} = R_{neutron} \cdot \left(\frac{M_{cyg}}{m_{neutron}}\right)^{1/3} = 23.4 \cdot \text{km}$$ ... Radius of neutron star From (1)

$$R_{h+\_cyg} = \frac{G \cdot M}{c^2}\left(1 + \sqrt{1 + a_{cyg}'}\right) = 34.3 \cdot \text{km}$$ ...Event horizon radius From (8)

Conclusion $R_{h+\_cyg} > R_{s\_cyg} > R_{n\_cyg}$

Neutron star PSR J1903+0327

Given (from observations):

$M_{psr} = 1.67 \cdot M_{sun} = 3.34 \cdot 10^{30} \cdot kg$ ...Neutron star's mass

$a'_{psr} = 0.5$ ...Dimensionless spin parameter of the neutron star.

$R_{s\_psr} = \frac{a' \cdot G \cdot M_{psr}}{c^2} = 1.24 \cdot \text{km}$ ...The radius of the ring singularity From (7)

$R_{n\_psr} = R_{neutron} \cdot (\frac{M_{psr}}{m_{neutron}})^{1/3} = 10 \cdot \text{km}$ ... Radius of neutron star From (1)

$R_{h+\_psr} = \frac{G \cdot M_{psr}}{c^2} \cdot (1+\sqrt{1\text{-}a'_{psr}}) = 4.23 \cdot \text{km}$ ...Event horizon radius From (2)

Conclusion $\text{R}_{n\_psr} > \text{R}_{h+\_psr} > \text{R}_{s-psr}$

References

[1] https://arxiv.org/pdf/2312.00841

[2] https://en.wikipedia.org/wiki/neutron_star

[3] https://arxiv.org/pdf/astro-ph/0410407.pdf

[4] Nuclear force - Wikipedia

[5] https://www.jlab.org/news/releases/quarks-feel-pressure-proton

[6] https://www.ligo.caltech.edu/image/ligo20181203a