The structure of a black hole

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Abstract

Einstein's field equations (EFE) have several solutions. I relate here to Kerr's solution of EFE because Kerr describes a known physical phenomenon – namely, all celestial bodies spin. The Schwarzschild solution is merely a mathematical solution of EFE because it assumes a non-rotating celestial body.

I hypothesize that at the center of a black hole, there is a spinning neutron star. A neutron star may reside inside the singularity ring only if the radius of the neutron star is smaller than the singularity ring radius. This hypothesis is verified by analyzing the M87 black hole.

Observations

Fig. 1 is an image from 2021 of the M87 black hole in polarized light. The matter is orbiting around the black hole and is arranged in an accretion disk located on the equatorial plane of the black hole. From observations: the accretion disk dimensions are: outer radius $2.35*10^{10}$ km and inner radius $1.8*10^{10}$ km. The inner radius is the event horizon which inside it is invisible.

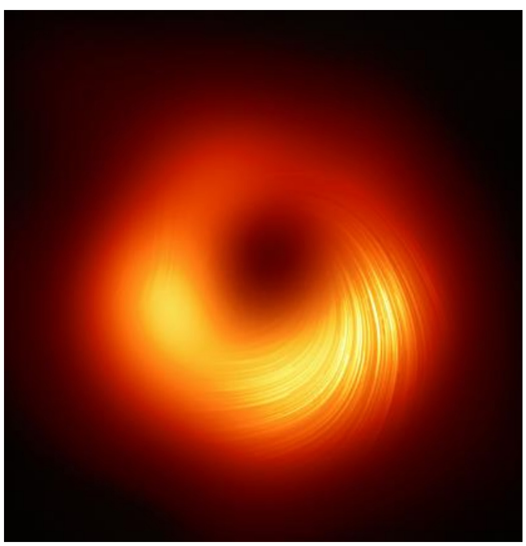

Fig.1 – Accretion disk of M87

Fig. 2 shows the powerful jet ejected from M87 along the rotation axis of the black hole in both directions. The velocity of the jets ejected from M87 is estimated to be between 80% and 85% of the speed of light.

Fig.2 – Jets from M87 black hole

This paper analyzes the shape of the accretion disk around the black hole and the reason that sometimes a black hole includes relativistic jets. My analysis is based on Kerr's solution of EFE. Kerr's solution solves the phenomenon of frame-dragging of space around any rotating celestial body.

Hypothesis:

The theoretical solution of the Kerr black hole is depicted in Fig. 3.

Source: Kerr metric-11 Robert Davie   https://www.youtube.com/watch?v=7zsmnCl_0sg

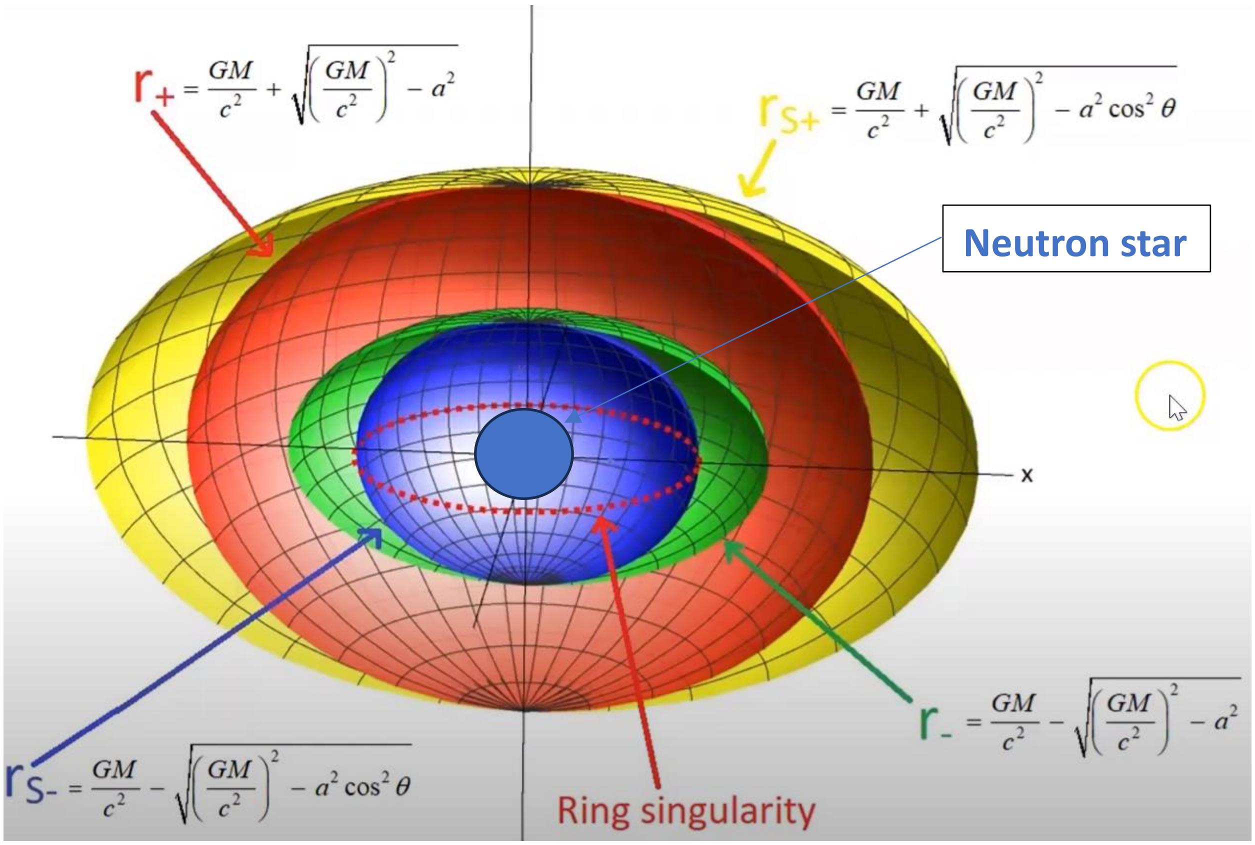

Fig.3 – Kerr solution of a black hole

There are several assumptions I make:

1) **At the center of a black hole resides a neutron star**. I added the neutron star to the above drawing of Robert Davie. It will be shown that the radius of the neutron star is smaller than the radius of the singularity ring. The neutron star remains stationary in its x, y, and z coordinates but it can spin and travel in time.

2) Physically, there must be a limit to the density of matter in the universe. Physicists have suggested hypothetical materials (e.g., Preon, conceived to be subcomponents of quarks and leptons). Preon is denser than a neutron star but no such material has been observed. On the other hand, neutron stars have been observed in the universe. The

density of a neutron star is ~7.8*10^17 kg/m^3. This density is approximately the density of the nucleus of the atom and also the density of a neutron. A neutron star is created when a progenitor star, (that has enough mass), consumes its energy and then collapses gravitationally. At the end of the collapse, its density cannot exceed the maximum density in the universe, i.e., it becomes a neutron star. Given its mass, and assuming it is a solid sphere the radius of the neutron star, which is composed of neutrons can be calculated similarly to the way the radius of an atom's nucleus. (wiki/Atomic nucleus)

$$R = R_0 \cdot \left(\frac{M}{m_{neutron}}\right)^{\frac{1}{3}} \qquad \textbf{(Eq. 1)}$$

Where:

$R \cdot km$ ...Radius of neutron star

$M \cdot kg$ ...Mass of neutron star (given)

$R_0 = 1.25 \cdot 10^{-15} m$ ... Constant (~)

$m_{neutron} = 1.674927471 \cdot 10^{-27} kg$ ... Mass of neutron

3) The neutron star at the center of the black hole must spin. It is a well-established phenomenon that all celestial bodies in the universe are spinning. The progenitor star spins and therefore has angular momentum. When it collapses to a neutron star, the neutron star must spin significantly faster than the progenitor star, so to comply with the angular momentum conservation law.

4) The rotating neutron star has its angular momentum. What is the value of this angular momentum?

The angular momentum of the neutron star, which is a solid sphere, is:

$$J_{sphere} = \frac{2}{5} \cdot M \cdot R^2 \cdot \Omega \qquad \textbf{(Eq. 2)}$$

Where:

Ω 1/s ....Angular velocity

There are two problems solving Eq. 2.

1) As the neutron star is invisible It is not possible to measure Ω in Eq. 2. In Appendix A way is shown how to calculate Ω.

2) The rotating neutron star drags space and all the celestial bodies that are located in the dragged space. Eq. 2 does not include the angular momentum of dragged space and its celestial bodies. Therefore, the usage of equation (3) suggested by Muradian is done.

$$J = \hbar \cdot \left(\frac{M}{m_{neutron}} \right)^{\frac{4}{3}}$$ ...Angular momnetum of a celestial body - according to Muradian (See Note 1) **(Eq. 3)**

Where:

$M \cdot kg.$ ...Neutron star mass

$m_{neutron} = 1.674927 \cdot 10^{-27} \cdot kg.$ ....Neutron's mass

$\hbar = 1.054571 \cdot 10^{-34} \cdot J \cdot s.$ ....Reduced Planck constant

Note 1: Equation 3 is according to the primeval Hadron hypothesis:

1. R. M. Muradian (1980). "The primeval hadron: origin of stars, Galaxies, and astronomical Universe" https://lib-extopc.kek.jp/preprints/PDF/1979/7911/7911323.pdf
2. R. M. Muradian "SCALING LAWS IN PARTICLE PHYSICS AND ASTROPHYSICS" https://arxiv.org/ftp/arxiv/papers/1106/1106.1270.pdf

Note: Appendix A is a comparison between J_{M87_sphere} (Eq. 2) and J (Eq. 3)

5) General relativity teaches that any spinning celestial body drags space around it. This phenomenon is known as frame-dragging. This effect was validated in 2011 by the Gravity Probe B experiment. In this experiment, the effect was measured near Earth, and although the measurements were minuscule, they validated the frame-dragging effect.

The appropriate solution for a rotating black hole is the Kerr solution of Einstein's Field equations (EFE). The equation of frame-dragging around a spinning spherical celestial body is given in: https://en.wikipedia.org/wiki/Frame-dragging

$$\Omega(r,\theta) = \frac{R_H \cdot \alpha \cdot r \cdot c}{\rho^2 (r^2 + \alpha^2) + R_H \cdot \alpha^2 \cdot r \cdot \sin^2 \theta}$$ ....The angular velocity of space around a blck hole **(Eq. 5)**

depends on the radius r and the colatitude θ.

$$\Omega(r) = \frac{R_H \cdot \alpha \cdot c}{r^3 + \alpha^2 \cdot r + R_H \cdot \alpha^2}$$ ...Assuming that the colatitude $\theta = 90\,\text{deg},$ the angular velocity **(Eq. 4)**

in the the equitorial plane depnds only on r.

Where:

$c = 2.9979 \cdot 10^8 \cdot \frac{m}{s}.$ ...Light velocity

$G = 6.67 \cdot 10^{-11} \cdot \frac{m^3}{kg \cdot s}..$ ...Gravitational constant

$M \cdot kg$ .... Mass of black hole (given)

a_* .... Measured dimensional Spin parameter of black hole

$\alpha = \frac{G \cdot M}{c^2} \cdot a_*$ (km) ..... Spin parameter of black hole

$\rho = r^2 + \alpha^2 \cdot \cos^2 \theta$ .... Shorthand variable

$R_H = \frac{G \cdot M}{c^2} + \sqrt{\frac{G \cdot M}{c^2} - \alpha^2}$ .... Outer event horizon radius (r_+ in drwaing)

Verification – of M87 black hole.

$M = 1.3 \cdot 10^{40}\, Kg$ ... Mass of black hole M87 (given)

$R_{M87} = R_0 \cdot (\frac{M}{m_{neutron}})^{1/3} = 2.5 \cdot 10^4\, km$ ...Radius of neutron star **(Eq. 1)**

$J_{M87} = \hbar \cdot \left(\frac{M}{m_{neutron}} \right)^{\frac{4}{3}} = 1.6 \cdot 10^{55} \cdot \mathrm{J} \cdot \mathrm{s}$ ...Angular momnetum of a neutron star

- according to Muradian **(Eq. 3)**

$a_* = 0.9$ ... Measured dimensional spin parameter

(0.9 +/- 0.05 https://arxiv.org/abs/1904.07923)

$\alpha = \frac{G \cdot M}{c^2} \cdot a_* = 8.6 \cdot 10^9 \mathrm{km}$ ...Spin parameter. Also the radius of singularity ring.

Note: α is also the radius of the singularity ring. The raius of the neutron star R_{M87} is substainntialy smaller than α ($8.6 \cdot 10^9 \mathrm{km} >> 2.5 \cdot 10^4\, km$).

$R_H = \frac{G \cdot M}{c^2} + \sqrt{\frac{G \cdot M}{c^2} - \alpha^2} = 1.4 \cdot 10^{10} \cdot \mathrm{km}$ ... Outer event horizon radius (r_+ in drwaing)

$\Omega(r) = \frac{R_H \cdot \alpha \cdot c}{r^3 + \alpha^2 \cdot r + R_H \cdot \alpha^2}$ ...The angular velocity in the equitorial plane **(Eq. 4)**

depnds only on r.

$\mathrm{r} = 0 \cdot \mathrm{km}$ ... R_{outer_disk} ...$\mathrm{R}_{outer\_disk} = 2.35 \cdot 10^{10} \mathrm{km}$ (from observations)

$\Omega(\mathrm{R}_{M87}) = 3 \frac{\mathrm{Revolutions}}{day}$ ...The neutron star completes 3 revolutions in one day

$\mathrm{t} = \frac{2\pi}{\mathrm{R}_{M87}} = 2.09 \cdot day$

$\theta(\mathrm{r}) = \Omega(r) \cdot t \cdot \frac{r}{\mathrm{R}_{outer\_disk}}$

Fig. 4 describes θ vs. r

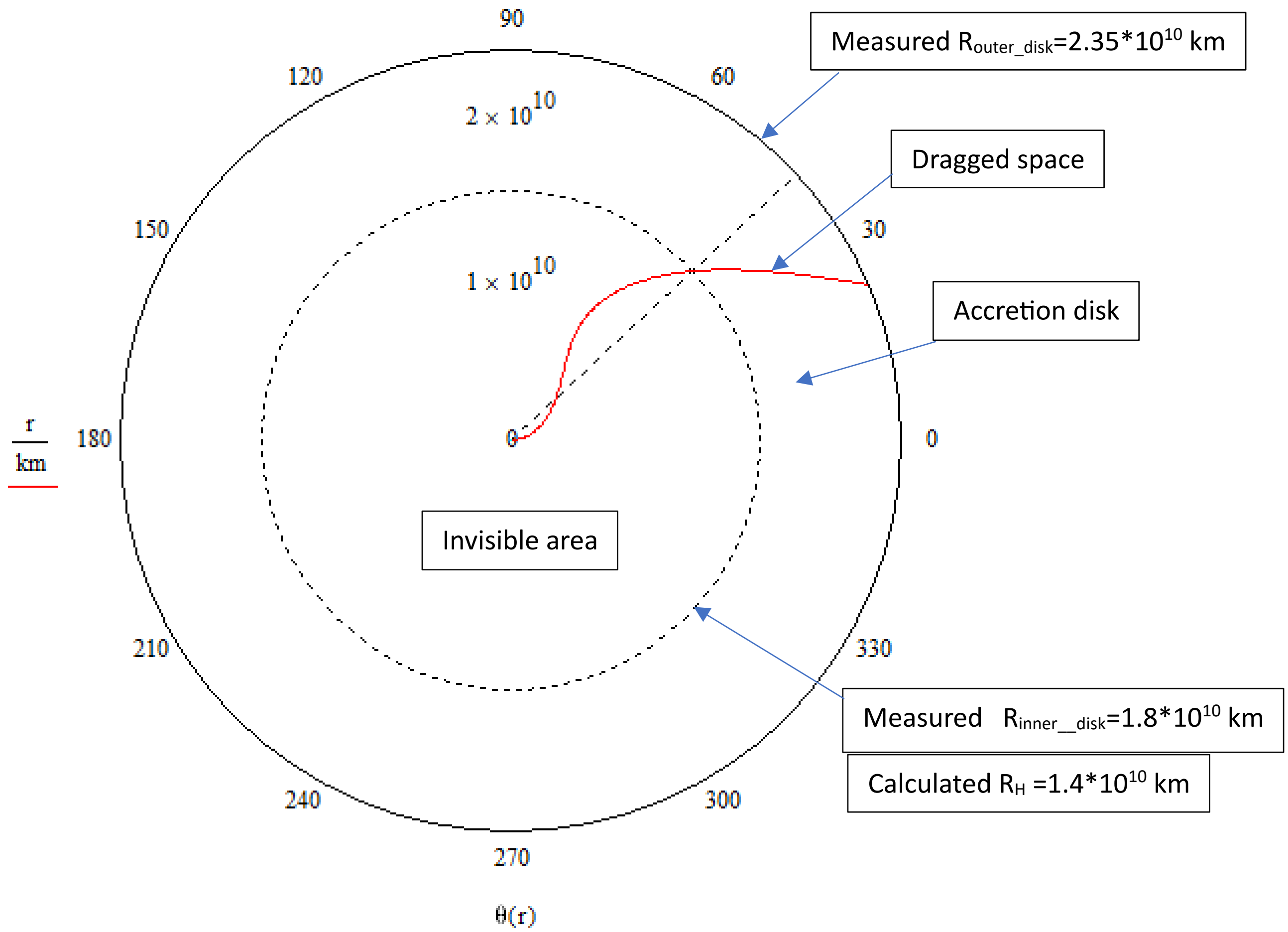

Fig. 4- Space dragging by the neutron star

Space velocity around black hole M87

$$\Omega(r,\theta)=\frac{R_H\cdot\alpha\cdot r\cdot c}{\rho^2(r^2+\alpha^2)+R_H\cdot\alpha^2\cdot r\cdot\sin^2\theta}$$ ....The angular velocity of space around a blck hole **(Eq. 5)**

depends on the radius r and the colatitude θ.

$$\rho=r^2+\alpha^2\cdot\cos^2\cdot\theta$$ ... Shorthand variable

$$r=0\cdot km....5\cdot R_{outer\_disk}$$ ...Range of r

$$V(r,\theta)=\frac{R_H\cdot\alpha\cdot r^2\cdot c}{\rho^2(r^2+\alpha^2)+R_H\cdot\alpha^2\cdot r\cdot\sin^2\theta}$$ ...The velocity of space around a blck hole **(Eq. 6)**

The following is the graph of Eq. 6. It is given for two colatitude angles θ=0deg and θ=90deg

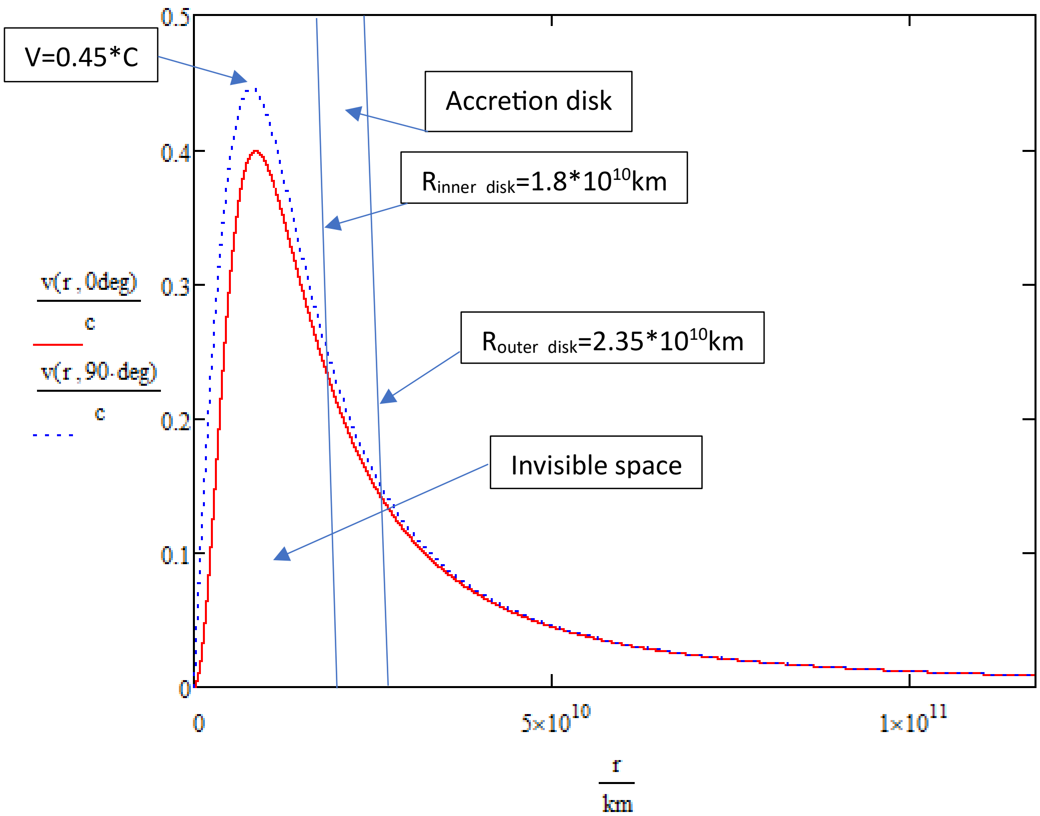

Fig. 5- Velocity of space around the neutron star

Conclusions:

There is a resemblance between the images taken of M87 and the model.

Fig. 4 – It is shown that space is dragged in resemblance to Fig. 1. There is a discrepancy between the measured event horizon ($1.8*10^{10}$ km) and the calculated event horizon ($1.4*10^{10}$ km).

Fig. 5 - The velocity of the space near the neutron star reaches relativistic velocities. The dragged space is defined by the area between the solid red and the dashed blue lines. The matter that is located in this area will stay in this area and will be dragged with the space. It is shown that the distance between these lines is small, therefore the accretion disk is thin. On the other hand, matter that approaches the neutron star from outside the area between both lines will be spiraled out, around the rotation axis, and finally will be ejected via both opposing sides along the rotation axis of the neutron star. In these jets, the matter is accelerated to relativistic speeds, and it heats up. The material becomes hot enough to emit the intense X-rays that are observed. There is a discrepancy between the velocity of jets. The measured value is 0.8-0.85c and the calculated is 0.45C.

Appendix A

A comparison between the total angular momentum found in Eq. 3 and the inertial angular momentum of the spinning neutron star (Eq. 4) shows that the second is negligible to the first one.

$$J_{M87} = \hbar \cdot \left(\frac{M}{m_{neutron}} \right)^{\frac{4}{3}} = 1.6 \cdot 10^{55} \cdot \mathrm{J} \cdot \mathrm{s}$$

...Total angular momnetum of a neutron star
- according to Muradian **(Eq. 3)**

On the other hand:

$$\Omega(r) = \frac{R_H \cdot \alpha \cdot c}{r^3 + \alpha^2 \cdot r + R_H \cdot \alpha^2}$$

...The angular velocity in the equitorial plane **(Eq. 4)**
depnds only on r.

$$\Omega(\mathrm{R}_{M87}) = 3.47 \cdot 10^{-5} \cdot \frac{1}{s}$$

$$J_{M87\_sphere} = \frac{2}{5} \cdot M \cdot R_{M87}{}^2 \cdot \Omega(\mathrm{R}_{M87}) = 1.1 \cdot 10^{50} J \cdot s$$

... Inertial angular momnetum of a neutron star sphere.

$$\frac{J_{M87\_sphere}}{J_{M87}} = 6.8 \cdot 10^{-6}$$

...Ratio of angular momentums

The ratio shows that the inertial angular momentum of the sphere is small in relation to the total angular momentum. This means the angular momentum of the dragged space (including all matter dragged with it) is much greater than the inertial angular momentum of the neutron star.