Int. j. adv. multidisc. res. stud. 2025; 5(4):7-12

Received: 12-05-2025
Accepted: 22-06-2025

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Schwarzschild, Einstein, Hawking and Other Brilliant Scientists: Some Considerations About Black Holes

[1] **Celso Luís Levada,** [2] **Huemerson Maceti,** [3] **Tabata Vidal,** [4] **Rosangela Oliveira Colabone,** [5] **Ivan José Lautenschleguer,** [6] **Miriam de Magalhães O Levada**

[1, 4] Air Force Academy (AFA) – Pirassununga, São Paulo, Brazil
[2, 3, 5, 6] Herminio Ometto Foundation (FHO) – Araras, São Paulo, Brazil
[2, 3] Colégio Puríssimo Coração de Maria – High School – Rio Claro, São Paulo, Brazil

Corresponding Author: **Celso Luís Levada**

Abstract
In 1916, Karl Schwarzschild solved the field equations for a static, spherically symmetric body, determining the metric of spacetime outside it after Einstein's General Theory of Relativity. This solution is crucial, supporting tests such as the shift of spectral lines, the bending of light, and the precession of planets. Schwarzschild black holes describe non-rotating spherical bodies with a central singularity and an event horizon, where nothing escapes the gravitational pull due to their intense gravity, making them invisible and challenging to study directly. Schwarzschild black holes usually form from the gravitational collapse of massive stars. When a star exhausts its nuclear fuel, it can no longer sustain its own gravity and begins to collapse. If the remaining mass of the star after the supernova explosion is sufficient, it will become a black hole. The hypothesis, called "black hole cosmology" or "Schwarzschild cosmology, " suggests that our universe is part of a black hole within a larger universe. So our Universe may not have emerged from the Big Bang, but from within a black hole in a larger Universe.

Keywords: General Relativity, Black Holes, Schwarzschild

Introduction

As FLORIANO [1] teaches, when we study black holes, names like Stephen Hawking and Albert Einstein, scientists who were born and lived between the 20th and 21st centuries, soon come to mind. However the first researcher to propose their existence was a Cambridge professor, the English geologist John Michell, in 1783, in an article written for the Royal Society of London when he called these massive objects "dark stars". Eleven years later, the Frenchman Pierre-Simon promoted this idea in the first edition of his book Expositiondu Système du Monde and in the following edition but abandoned it in the third edition.

It was only at the beginning of the 20th century that the German physicist Albert Einstein brought his Theory of General Relativity, revolutionizing what we thought we knew about physics, presenting gravity as a geometric property in which space and time represent a single property called space-time. In the same year, Karl Schwarzschild (1915) demonstrated that the equations of Relativity would lead to the existence of singularities (places whose diameter is zero but with enormous mass and densities capable of deforming the space-time fabric to infinity) but Einstein himself did not believe that they could actually exist in nature.

These solutions were treated merely as mathematical artifacts, however this did not inhibit the curiosity of other researchers such as Subrahmanyan Chandrasekhar, Lev Davidovich Landau and Robert Oppenheimer. Chandrasekhar predicted that there was a limit (which today bears his name) at which, if a star has a mass less than 3.10^{30} kg (1.44 times the mass of the Sun), it can stabilize and become a white dwarf (ALMEIDA [2]). Shortly after Landau (1932) observed that a star that has between one and twice the mass of the Sun can end up becoming what we call a neutron star.

Chandrasekhar predicted the collapse, but it was Oppenheimer who solved what happened to these stars, when he postulated that neutron stars with approximately 3 solar masses or more could collapse. As mentioned by NUSSENZVEIG [2], the term "black hole" was created by physicist John Archibald Wheeler (1968) in a conference, with the intention of using a more accessible analogy than the term Gravitational Singularity or Gravitationally Collapsed Object o it was used.

In the same decade, an X-ray source was detected coming from the constellation Cygnus (Swan) due to the high temperatures of the matter that is rotating around this object. The variations in the speed of this source allowed us to deduce that it had between 6 and 10 solar masses. An object of this size could be nothing other than a common black hole emitting radiation in the X-ray range. Initially it was not believed that anything could come out of these objects because an escape velocity greater than the speed of light would be necessary which was considered the speed limit in the Universe. However, in 1975, Stephen Hawking published the article "Particle Creation by Black Holes" in which he described a quantum phenomenon at the edge of the event horizon, suggesting the emission of radiation at this boundary.

It is commonly suggested that this radiation comes from within the black hole which is a mistake. According to STORCHI BERGMANN [3], in 2005, Andrea Ghez published an article about his work entitled "Stellar Orbits Around the Galactic Center Black Holes" which earned him the 2020 Nobel Prize. This research proved the existence of a supermassive black hole at the center of our galaxy monitoring the orbit of stars in the region.

In 2015, one hundred years after the publication of General Relativity (Einstein, 1915), the Laser Interferometer Gravitational-Wave Observatory – LIGO detected for the first time the passage of a gravitational wave emitted by the merger of two black holes. Currently, observational and theoretical efforts are focused on Sagittarius A*, the most promising candidate for the direct detection of a black hole.

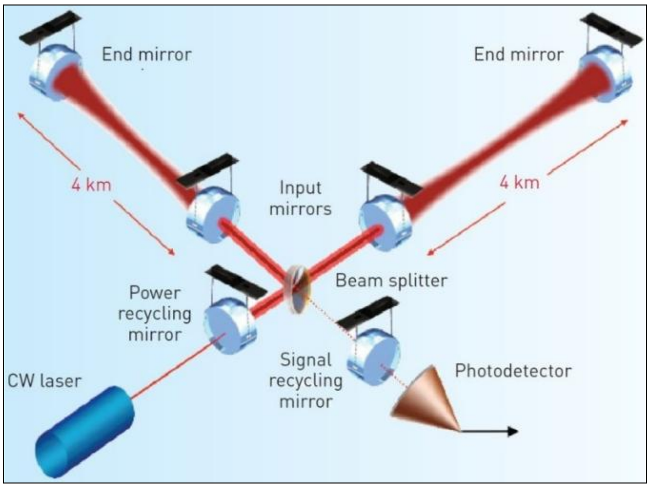

Fig 1: How to catch a gravitational wave. The world's first captured gravitational waves were created in a violent collision between two black holes, 1.3 billion light-years away. When these waves passed the Earth, 1.3 billion years later, they had weakened considerably: the disturbance in spacetime that LIGO measured was thousands of times smaller than an atomic nucleus (image credit: LIGO – Source https://www.eoportal.org/other-space-activities/ligo)

Continuous monitoring of stellar trajectories near this region aims to identify signatures of matter crossing the event horizon, which would provide definitive evidence of black hole activity. The potential for planet formation around black holes is also discussed, emphasizing that such environments can support Earth-like conditions in specific scenarios, particularly in the vicinity of rapidly rotating black holes, which allows stable orbits closer to the event horizon.

The implications of the curvature of spacetime, as described by Einstein's General Theory of Relativity, are central to understanding these phenomena. Finally, the upcoming Laser Interferometer Space Antenna (LISA) mission, planned by the European Space Agency for 2034, is highlighted as a groundbreaking tool capable of detecting gravitational waves and potentially Earth-sized planets orbiting black holes in the Milky Way.

This paper aims to provide an overview of black holes, addressing their formation and functioning. The details are sufficient to generate questions and promote deeper research on specific subjects (LEVADA [4] *et al*), (MACETI [5] *et al*). The material can be used in high school classrooms to introduce the topic (STORCHI BERGMANN [3]).

Brief Biography of Karl Schwarzschild

According to AIKERSON [6], Karl Schwarzschild born on October 9, 1873 in Frankfurt, was the eldest son of a Jewish family and excelled in mathematics and natural sciences from a young age. Before he was 17, he had already published works on celestial mechanics. He studied at the University of Strasbourg and then in Munich, where he also served in the military. He obtained his doctorate in 1896 under the supervision of astronomer Hugo von Seeliger, and became involved with Poincaré's innovative mathematical concepts. After completing his doctorate, he worked at the Kuffner Observatory in Vienna and returned to Munich in 1899. Schwarzschild left Munich in 1901 and became a professor at the University of Göttingen, where he was in charge of the Astronomical Observatory until 1909.

He collaborated with Felix Klein, David Hilbert and Hermann Minkowski, keeping up to date with physics and Einstein's theory of general relativity. In 1909 he moved to Potsdam where he became the city's most prominent astronomer and took over as Director of the Astronomical Observatory. His family grew during this time and he married Else Posenbach in Göttingen. His son, Martin Schwarzschild, left Germany during the Nazi persecution and developed a successful career as an astronomer at Princeton University in the United States.

In 1910, in the United States, he participated in the AAS Congress in Cambridge and the International Union for Solar Research Conference in California. He also joined an expedition to Tenerife to observe Halley's Comet. His career in astronomy was interrupted in 1914 by the First World War where he volunteered and worked in meteorology and artillery carrying out studies on ballistics.

Schwarzschild then contracted pemphigus, a debilitating autoimmune disease that causes extremely painful blisters and rashes on the skin and was completely incurable at the time. He was demobilized in March 1916 and died two months later. He did not live to see his 43rd birthday.

Schwarzschild Black Holes

As SAA [7] mentions, Schwarzschild black holes are solutions to Einstein's general relativity. They are regions where gravity is so intense that nothing, not even light, can escape. They form from the collapse of massive stars after they have exhausted their nuclear fuel. If the remaining mass is sufficient, the star becomes a black hole. Their intense gravity results in an enormous concentration of mass, making them invisible and difficult to study directly.

The relationship between the mass of the object and the Schwarzschild radius is crucial to understanding the property of the event horizon, expressed by the formula;

$$R = \frac{2GM}{c^2},$$

Where G is the gravitational constant, M is the mass of the object and c is the speed of light. This theory has had a profound impact on cosmology and astrophysics and is fundamental to understanding extreme gravity and the properties of black holes.
The Schwarzschild radius is proportional to the mass, with a constant of proportionality involving the gravitational constant and the speed of light. The formula for the Schwarzschild radius can be found through Newtonian physics by setting the escape velocity equal to the speed of light.
Shortly after Albert Einstein completed the Theory of General Relativity in 1915, Schwarzschild found a specific solution to the field equations of this theory, which proved to be of enormous relevance. His goal was to apply it to stars with a perfectly spherical shape and no rotation. The solution obtained presents a singularity in the metric equation, that is, for certain values of the spatial coordinates, the result becomes infinite.
In general, the metric describes the geometry of spacetime and allows the calculation of the distance between any two events, which are defined by three spatial coordinates and one temporal coordinate. The Schwarzschild metric is expressed by [6];

$$(ds)^2 = -1\left(1-\frac{2GM}{rc^2}\right)(cdt)^2 + \left(\frac{1}{1-\frac{2GM}{rc^2}}\right)(dr)^2 + (rd\theta)^2 + (rsin\theta d\emptyset)^2$$

Although the result is correct, general relativity needs to be used to correctly derive the Schwarzchild radius. The fact that Newtonian physics produces the same result is just a coincidence (SOARES [8]).

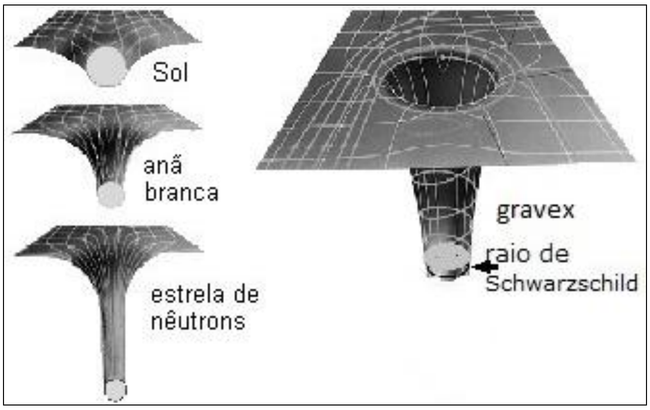

Fig 2: The Theory of General Relativity shows us that space — more precisely, space-time — curves near any given body. It is as if space were a rubber sheet and bodies “sink” into it. Above we see the curvature of space around the Sun, a white dwarf star, a neutron star and a gravex. Note that the gravex forms before the “horizon of extreme gravitation”, defined by the sphere whose radius is the “Schwarzschild radius” shown in the figure – Source: https://lilith.fisica.ufmg.br/dsoares/extn/brcs/oge.htm

In Schwarzschild's Black Hole Theory, the singularity is the central point where density is infinite and the laws of physics as we know them cease to apply. The event horizon, on the other hand, is the “surface” that delimits the region around the black hole, beyond which nothing can escape, not even light. This characteristic makes black holes invisible and therefore one of the most intriguing phenomena in the universe.
Schwarzschild's theory applies to static black holes, i.e., those that are not rotating. This condition simplifies the equations and allows for a clearer analysis of the properties of the black hole. However, most observed black holes in the universe are rotating which leads to the need for additional theories such as the Kerr solution which incorporates rotation.
This process is one of the most fascinating phenomena in the universe and illustrates the relationship between mass and gravity. Schwarzschild was a renowned physicist and mathematician who obtained solutions to Einstein's equations that perfectly described how gravity and the mass of objects interact in the universe, according to General Relativity.
However when solving the equations, Schwarzschild found an anomaly which he himself considered to be impossible and dismissed it as just a mistake. According to his calculations when the density of a body exceeds a limit, the laws of physics stop working around it with space itself folding in on itself and time stopping to flow.
In his last spark of genius, just before leaving this world, Schwarzschild had mathematically discovered, in letters sent to Einstein, the existence of one of the most extreme bodies in the universe capable of immediately conquering our imagination: black holes. However the term “black holes” was coined in 1968 and the first object of this type was found in 1971. An intense source of X-rays was discovered in the constellation Cygnus, which can only be detected by satellites because the Earth’s atmosphere prevents this type of radiation from reaching the planet’s surface.
More than a hundred years after Schwarzschild's letters, scientists obtained the first direct visual confirmation of the existence of a black hole (SAA [7]). The event horizon comes from Albert Einstein's theory of general relativity, which changed our understanding of spacetime in relation to mass and energy.
Einstein described gravity as the curvature of spacetime caused by large masses. The curvature increases with mass, helping to explain why black holes have event horizons. Inside a black hole the curvature causes a singularity where gravity is infinite.
At the event horizon, gravity is so strong that light cannot escape causing anything that passes through the event horizon to disappear from view. In 1974 Stephen Hawking made a major discovery about black holes by introducing Hawking radiation which suggests that black holes can emit radiation and lose mass. This challenged the idea that black holes are completely hidden and led to the information paradox which questioned whether information about particles entering a black hole can be completely destroyed.
This question has physicists searching for new theories that combine quantum gravity and relativity. In 2019 the Event Horizon Telescope (EHT) project observed the galaxy M87 in the constellation Virgo at the center of which is a

supermassive black hole. Much has changed in science and astronomy since the days of Einstein and Schwarzschild when black holes were considered an impossible mathematical anomaly.

Today, hundreds of these singularities have been detected, and predictions indicate that our galaxy may contain tens of millions of black holes. The closest of these objects ever found is located in the constellation of Ophiuchus, near Scorpius and Sagittarius, approximately 1,500 light-years from Earth. The most distant one is located on the other side of the universe, 13 billion light-years away (BELISARIO [9]).

Black Holes as Real Objects of Nature

For RODRIGUES ALMEIDA [10], real scientific interest in black holes resurfaced in the late 1950s. In 1958 David Finkelstein resolved a debate that had existed since the 1930s about the existence of the Schwarzschild radius. His work defined the radius sphere as a membrane that allows the unidirectional crossing of physical traces such as light only from the outside to the inside creating the concept of "event horizon". This helped to better understand black holes.

During the Cold War research was polarized between the Soviet school led by Yakov Borisovich Zel'dovich and the American school led by John Archibald Wheeler. Lev Landau and his group conducted significant studies of General Relativity. John Wheeler had a long and productive career contributing extensively to many fields of physics during the 20th century. He was known for his clear and amusing analogies and is often credited with coining the term "black hole". However the term was introduced into the literature by journalist Ann E. Ewing in 1964 after hearing him speak at a conference.

Wheeler and his students at Princeton were instrumental in developing modern black hole studies creating a long-lasting school of thought. They compiled many experimental and observational predictions that were confirmed by gravitational waves. Their work shows that black holes are very simple objects depending mainly on mass.

The Schwarzschild solution illustrates a simple type of black hole but more complex black holes can be characterized by mass, angular momentum and rarely electric charge. In practice black holes are thought to be predominantly neutral usually arising from matter that is also neutral. However black holes almost always acquire angular momentum due to the rotation of the matter that causes their gravitational collapse.

In summary, black holes are characterized primarily by three parameters: mass, angular momentum and potentially low electric charge. The baldness theorem in astrophysics postulates that stable black holes have three main physical properties: mass, charge and angular momentum. This concept implies that two black holes with the same characteristics are indistinguishable.

This theory has significant implications when objects fall into black holes making their data lost to external observers. Furthermore, it describes the horizon effect as a dispersive system similar to a conducting membrane. The validity of the proposal for real black holes is an unsolved puzzle in the current laws of physics (VANZELLA & MATSAS [14]).

Black Holes and Gravitational Waves

Einstein's Theory of General Relativity [9] predicts the existence of gravitational waves which is a consequence of non-instantaneous interactions unlike Newton's Universal Gravitation. In General Relativity, gravitational interactions propagate at the speed of light as confirmed by recent detections.

Einstein pointed out that the amplitudes of the waves would be very small and there were questions about whether these waves really existed or were just a mathematical construct. Eddington was one of those who doubted the physical reality of gravitational waves. In 1918 Einstein published his first paper on gravitational waves and continued to write on the subject during his time at Princeton.

The main point is that understanding gravitational waves better shows that they have a physical content which is linked to the Schwarzschild solution. Just as waves appear when water is disturbed, gravitational waves appear when the Schwarzschild solution is disturbed. They are small deviations in the gravitational field and according to General Relativity propagate at the speed of light. The Schwarzschild solution has mathematical characteristics that help identify physical properties such as momentum and energy in gravitational waves, answering questions about their physical reality.

Gravitational waves are physical phenomena that have characteristics such as frequency, wavelength and propagation speed. They can be detected experimentally as demonstrated by the LIGO-Virgo consortium. The Schwarzschild solution is important for the physical understanding of these waves and is fundamental in describing the events that produce gravitational signals especially black hole mergers (CASTIÑEIRAS & BASSALO [11]).

It was probably in the summer of 1915, already on the Russian front, that he developed the work that gave rise to his two articles on relativity. In addition to the first one already mentioned above, there was a second one on the gravitational field of a spherical and homogeneous distribution of matter. It is in this second article that the quantity that would come to be called the "Schwarzschild radius" appears for the first time.

The year 1915 was also particularly intense for Einstein. He published four papers in November which would become the basis of his General Theory of Relativity. Interestingly the final paper consolidating the theory was only published in March 1916 after Schwarzschild's first paper which was in fact cited and therefore unequivocally recognized as valid and pertinent by Einstein.

In one of his works Einstein proposes, as the title suggests, an "explanation for the movement of Mercury's perihelion based on the Theory of General Relativity". This is one of the classic tests of General Relativity. It is known from Kepler's Laws that the orbit of the planets is an ellipse with the Sun located at one of its foci. The names perihelion and aphelion are given respectively to the points of the orbit that are the shortest and furthest from the Sun. They obviously represent the extreme points of the major axis of the ellipse corresponding to the orbit in question.

General relativity suggests that there is a small motion at Mercury's perihelion which is consistent with observations. Mercury's orbit forms an ellipse that precesses around the Sun and this motion can be measured by recording the position of its perihelion each year. Mercury is useful for these studies because it has the fastest orbital speed with a year lasting about 88 Earth days allowing its perihelion to be

observed every three months.
Schwarzschild found a solution to Einstein's equations that relates to the gravitational field of a point mass similar to the potential in Newton's Universal Gravitation. His solution confirmed that the approximations made by Einstein in his work on the perihelion of Mercury were indeed correct. Schwarzschild sent the result to Einstein in a famous letter in December 1916.
Einstein's reaction was one of enthusiasm. CASTIÑEIRAS. & BASSALO [11] report that General Relativity is very different from Newton's theory of Universal Gravitation. Gravity is not explained by a potential but by the characteristics of Space-Time, a concept presented by H. Minkowski in 1908. These characteristics are described by the metric tensor which allows the calculation of lengths in Space-Time.
Furthermore, it can be seen that hydrostatic equilibrium is not possible if the distribution of matter is smaller than a certain radius which suggests the idea of black holes. Schwarzschild sent his solution to Einstein on December 22, 1915, shortly after Einstein's publication of General Relativity. Schwarzschild had the necessary training to contribute to General Relativity. He studied at Göttingen where he collaborated with important mathematicians such as Klein, Hilbert and Minkowski who helped develop physics and mathematics related to gravity. Minkowski introduced the concept of space-time. Hilbert worked on the mathematical basis for the equations of General Relativity.
Einstein, known for his concise quotations, mentions only the work of Schwarzschild and one of Hilbert in his work on General Relativity. Klein was crucial in the development of non-Euclidean geometries, fundamental to General Relativity (RODRIGUES ALMEIDA [12].
The idea that there are geometries other than Euclidean was developed in modern times by Bernhard Riemann who died 150 years ago. Riemann, like Schwarzschild and Minkowski, had a short but influential life in Mathematics and Physics. Schwarzschild was already familiar with Riemann's work before he became a professor at Göttingen. In 1899 he presented a monograph on photometry and astronomy but he also considered investigating the geometric nature of space. According to SIQUEIRA BATISTA [13] this proposal was bold suggesting that non-Euclidean geometries could exist in Nature.
In 1900 Schwarzschild presented his work to the German Astronomical Society showing that the astronomical data of the time limited the possible radii of curvature for three-dimensional space. The text describes the measurement of space in different geometries, mentioning 4 million astronomical units for hyperbolic space and 100 million for spherical space.

Final Considerations
Black holes are areas in space-time with a strong gravitational field where nothing can escape not even light. The theory of general relativity explains that a dense mass can deform space-time creating a black hole.
The event horizon is the boundary from which nothing escapes with no detectable features. Black holes emit Hawking radiation according to quantum theory. The idea arose in the 18th century with the modern description made by Karl Schwarzschild in 1916. They are expected to form when massive bodies collide or by gas condensation as suggested by a recent Discovery [7].
Black holes are found in most galaxies and can be detected through interactions with other matter and electromagnetic radiation. Astronomers have identified black holes in binary systems and discovered that the radiation source known as Sagittarius A*, at the center of the Milky Way, contains a black hole with about 4.3 billion solar masses. In 2016, the first direct detection of gravitational waves and the explosion of a black hole was announced.
The possibility of black holes in active galaxies has been explored since the late 1960s, with Sagittarius considered the most promising location for observing black holes. The crossing of the horizon by stars or any material that eventually emanates from them leaves a signal that can be unequivocally identified. There is intense theoretical and observational work in this field.
Planets can potentially form around black holes but this does not guarantee a life-friendly environment. For a planet near a black hole, the acoustic decay disk would be about the same size and brightness as the Sun in our solar system. However not all black holes are viable as they require very rapid rotation to achieve a stable orbit.
In 2034, the European Space Agency (ESA) plans to launch the Laser Interferometer (LISA), a highly sensitive detector to capture gravitational waves that move and distort space-time.

References

1. Floriano TC. A black holes introduction. Brazilian Journal of Physics Teaching. 2021; 1(1). www.revistabrasileiradefisica.com, Doi: https://doi.org/10.5281/zenodo.5188081
2. Nussenzveig P. John Archibald Wheeler teve contribuições em várias áreas da Física. Text available in: https://jornal.usp.br/atualidades/cientista-com-trajetoria-inspiradora-criou-o-termo-buraco-negro/
3. Storchi Bergmann T. Andrea Ghez, nobel prize of Physics of 2020. Text available in: https://www.abc.org.br/2020/10/10/- 2020-nobel-prize-in-physics-black-holes
4. Levada Celso Luis, Maceti Huemerson, Lautenschleguer Ivan José. Short review on black holes. International Journal of Scientific Research. 2015; 4(4).
5. Maceti Huemerson, Levada Celso Luis, Lautenschleguer Ivan José, Castro Wadley Calegaro de, Vidal Tabata. Stephen Hawking: Black Holes and other contributions from one of the greatest scientists of our time. International Journal of Advanced Engineering Research and Science (IJAERS). 2018; 5(5).
6. Aikerson S. Available at: https://www.britannica.com/biography/Karl-Schwarzschild
7. Alberto SAA. The centenary of the Schwarschild solution. Brazilian Journal of Physical Education. 2016; 38(4). Doi: https://doi.org/10.1590/1806-9126-RBEF-2016-0191
8. Soares Domingos SL. A stone in the path of the Theory of General Relativity. Department of Physics, ICEx, UFMG. Belo Horizonte MG, Jul 11, 2009.
9. Belisário R. ComCiência Magazine. Labjor Campinas. Available at: https://comciencia.scielo.br/scielo.php?script=sci_arttext&pid=S1519-76542014000200010&lng=pt
10. Almeida CR. Before black Holes. Brazilian Journal of Physics Teaching. 2020; 42. www.scielo.br/rbef. Doi:

https://doi.org/10.1590/1806-9126-RBEF-2020-0197

11. Castiñeiras J, Bassalo LC. One hundred years of the sobral eclipse, proof of relativity Cienc. Cult. São Paulo. 2019; 71(3). Doi: http://dx.doi.org/10.21800/2317-66602019000300007
12. Rodrigues Almeida C. Black holes: Over 100 years of History publicação do Núcleo Cosmologia-ufes. Cadernos de Astronomia. 2021; 2(1):93-105.
13. Siqueira Batista R. Stellar black holes: The geometry of Schwarzschild spacetime. Cadernos de Astronomia. 2021; 2(2):123-131. Doi: 10.47456/Cad.Astro.v2n2.34640
14. Vanzella E, Matsas GA. Black Holes: Breaking the Limits of Fiction. Vieira & Lent publications Rio de Janeiro, 2008.