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Elementary Aspects of the Structure, Dynamics and Entropy of Black Holes in High School

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ABSTRACT

The work presents the elementary aspects of black holes addressed in the classroom, in particular those of Schwarzschild and superficially those of Kerr. The research comprises part of one of the works carried out on the "Study of the quantization of space-time applied to the entropy of black holes" with 23 students of the 3rd year of high school in São Cristóvão, Rio de Janeiro, Brazil. The project is part of several introduced subjects on modern and contemporary physics, as well as frontier research topics. The student starts to have a student-researcher posture and based on Ausubel and Bruner's learning theories, they develop significant learning and receive new information and concepts at an elementary level, conditioning them to a critical and reflective posture. We carried out the activity in an expository way, discussing the structure, dynamics and entropy of black holes, making this type of approach to increase the understanding of the importance of physics topics such as mechanical energy and thermodynamics, involving compact objects. We carried out a questionnaire and collected data to verify the performance of the students and, in a non-formal way, the observation of behavior in the conduct of activities

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INTRODUCTION

Black holes are compact objects in the universe that have always aroused interest and curiosity not only for researchers, but for society in general. In the classroom it was no different, because students in physics classes, whenever they could, asked questions close to or related to curiosities about the universe and its phenomena.

Within this interest and taking advantage of the students' awakening to the treatment of the subject and making use of it for topics dealt with in physics, we decided to conduct a research with 23 students of the 3rd year of high school in São Cristóvão, Rio de Janeiro, Brazil, with the objective of presenting black holes and their usefulness and importance associating them with the topics of thermodynamics and mechanical energy.

The work is part of a dissertation research with the theme "Study of quantization applied to the entropy of black holes" (Silva, 2022), with a theoretical foundation of learning based on Ausubel, considering meaningful learning and Bruner who considers the ability to deal with any topic, but with the means and languages necessary for the audience for which it is intended (Moreira, 1999).

We use scientific skills, meaningful learning, dialogicity and criticality, with the involvement of research projects in the classroom, working on topics of modern physics and frontier research subjects (Moreira, 2021; Stecanela, 2015). Whenever possible, we seek to change the routine in the classroom, with innovative themes, always valuing the student's thinking and interaction with the teacher (Zacca et al., 2012).

The article presents itself with the theoretical foundation, where we will address the structure, dynamics and entropy of black holes, but limiting ourselves to the discussion of the Schwarzschild black hole and superficially the Kerr black hole. Following the structural development of the text, we will present the methodology, where it shows how it was applied and the methods used, as well as the analysis and discussion of the results, with the data of the exercises carried out by the students.

LITERATURE REVIEW

Structure of Black Holes

The idea of Black Holes began to be imagined in 1916, after the publication by Karl Schwarzschild (1873-1916), on the solution to the equations of Albert Einstein's (1879-1955) theory of general relativity. This solution defines the distance at which a body of high mass would start to attract everything around it. This distance became known as the Schwarzschild radius. Physicists found it interesting, but unlikely to occur in nature (Zorzetto, 2019).

When there are intense effects in certain regions of space, due to the curvature of space-time, leading to the impossibility of any body leaving these regions, then these effects we can call black holes.

John Michell (1724-1793), an English astronomer and seismologist, as well as Pierre Simon (1749-1827), a French mathematical physicist, proposed the possibility that the gravitational attraction of a star was so intense that not even light could escape such attraction. Michell believed that the light particles could interact with a "black star", terminology at the time (Machado, 2016).

Following the idea of "not even light can escape" from the black hole, we can deal with mechanical energy, being the sum of kinetic energy with gravitational potential energy, in the form of

$$\frac{mv^2}{2} - G\frac{Mm}{R} = 0 \rightarrow v^2 = \frac{2GM}{R} \rightarrow c^2 = \frac{2GM}{R}$$

With $G = 6{,}67.10^{-11}$ Nm^{2}kg^2 and c = $3{,}00.10^8$ *m/s*, where G is the constant of universal gravitation, m is the mass of a body toward the mass black hole M and v which we have replaced with the speed of light c which is the escape velocity "speed required to escape the gravitational field of a composite object", in this case, a black hole. R is the distance from the event horizon to the singularity (edge of the black hole at its center), because the existence of the event horizon is the essence of the black hole (Fabris, 2019).

If a body orbits close to the event horizon in an elliptical orbit, it will emit gravitational radiation and its orbit will decay by millions of years. In another case, for example, a disk of gas can form around a black hole and through friction matter will slowly slide inward at a certain time (Odenwald, 2019).

Black holes have mass, an event horizon that is their edge, and a singularity that is the center, in the innermost region. Its formation takes place through the final stages of stars, in other words, the death of stars. Some will turn into brown dwarfs, white dwarfs, others neutron stars, and others into black holes. The final stage will be defined by the amount of initial mass of each star.

The presence of bodies distorts the space-time that surrounds them, making smaller bodies be attracted to bodies of larger masses, as in a trampoline, we place heavier objects and lighter ones close to each other. We will notice the deformation in the trampoline and the lighter object will go in the direction of the heavier object. This explains the effect of gravity. In the case of bodies warping space-time, the heavier it is, the greater the deformation in space-time (Hawking, 2017).

This deformation is due to the presence of the massive body and for Einstein matter generates gravity and is written in the form

$$\tilde{G} = \frac{8\pi G}{c^4}\tilde{T}$$

The first term describes the geometric metric of space-time deformation and the second term describes the Momentum-Energy (matter) tensor (Baqui, 2014).

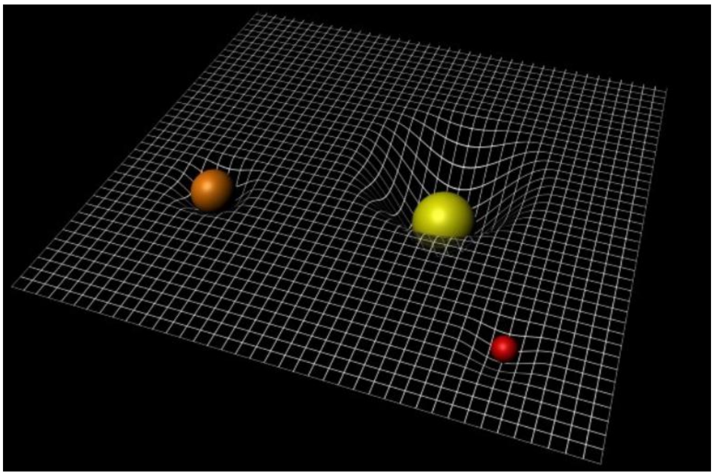

Figure 1. Deformation of Space-Time in the Presence of the Mass of a Body (Fabris, 2019)

The black hole is a static or stationary space-time in which the outer observer is separated from the inner region by an event horizon. An interesting detail is that the observer cannot see the inside of the black hole (Fabris, 2019).

To understand the final stage of a star, we must first understand that the mass of any celestial body is referenced, as a kind of standardization, by the solar mass $M_\odot$ which is approximately $1{,}9891.10^{30}$ kg. From this reference, the mass of the celestial body will be treated based on the solar mass.

Due to the different masses that stars have, there are different processes until their "death", which is the final stage. First, the star forms in a condensation, that is, hydrogen concentration, for all stars, and each one will start with different mass values.

For example, for a star to start with mass $M < 0{,}8M_\odot$, Its core will not be able to reach a temperature sufficient for the fusion process. At the end of the process it will be a brown dwarf. Also known as primordial black holes.

For starting mass in the range $0{,}8M_\odot < M < 10M_\odot$, The center manages to reach the temperature necessary for the hydrogen fusion process, burning up and going to a phase called red giant, then red supergiant, ejecting into a planetary nebula ending up as a white dwarf. It is also known as a stellar black hole.

Stars with initial mass in the range of $10M_\odot < M < 25M_\odot$, At a certain moment it will produce iron, no longer releasing energy, but consuming, causing an imbalance in the state of the body, causing it to explode and eliminating a large part of the original star, an explosion known as a supernova. After that, what's left of the star ends up in a neutron star.

Stars with initial mass in the range of $M \geq 25M_\odot$, then a contraction will occur to a point and a black hole will emerge. An object approaching and entering the event horizon will be swallowed by the black hole.

Intermediate-mass black holes have a mass of approximately $10^3 M_\odot$ and supermassive black holes in the 10^5 to $10^{10} M_\odot$. The closest black hole to Earth is 1.600 light-years away, which is approximately $1,5137.10^{16}$ km. Below are the conditions of star formation in relation to their initial masses and their final stage.

1. If $M < 0,8M_\odot$, at the end of the process is a brown dwarf.
2. If $0,8M_\odot < M < 10M_\odot$, at the end of the process is a white dwarf.
3. If $10M_\odot < M < 25M_\odot$, at the end of the process is a neutron star.
4. If $M \geq 25M_\odot$, at the end of the process it's a black hole.

The balance between the internal forces of the star is what keeps it "alive". When equilibrium no longer occurs, we reach the collapse of "death". This is due to not having enough pressure in the production of force to balance the weight of the outer layers.

It is a combustion process, as the concentration ignites the core and then the evolution of the star begins, but at a stage of life, the primary nuclear fuel is exhausted, causing an increase in internal pressure to try to maintain balance. As the end of the process will depend each on its initial mass, it will then lead to different phases as seen above (Bergmann et al., 2011).

Regarding detection, studies with rotating high-mass bodies, hope was created with objects that were candidates for black holes for their existence that until then seemed impossible to observe.

Through the effort of more than 200 researchers from the Event Horizon Telescope (EHT) project, the image of a black hole was detected in 2019. Known as Messier 87 (M87), located at the center of the Messier galaxy, in the sky towards the constellation Virgo (Zorzetto, 2019).

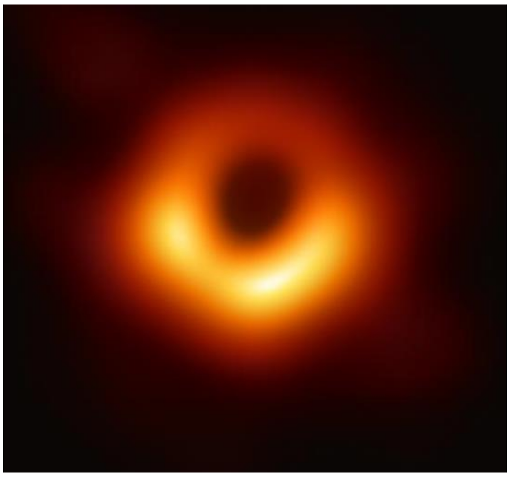

Figure 2. Image of M87 Reconstructed from Microwave Signals Picked Up by Radio Telescopes (ETH) (Zorzetto, 2019)

The image shows a dark spot surrounded by the illuminated ring in the center that is the shadow left by the event horizon, where gravity is very intense in the region capturing everything around it. All information, such as matter and energy, is captured and compressed into a single point, right at the center of the black hole, called the singularity.

The region that bounds the surface of the black hole, between the inner and outer part is called the event horizon. The yellow-red color is the disk of the ultraheated gas, with the glow of the gas outlining the shadow of the event horizon.

Although M87 has a high mass with 6.5 million times greater than the mass of the Sun, its distance from Earth is very large and its light took about 55 million years to reach our planet. The EHT team and telescopes together developed algorithms to treat the data and reconstruct the images. There are eight telescopes located in four countries working in a network (Zorzetto, 2019).

As for the types of black holes, there are four that are characterized by mass M, charge Q and angular momentum "with rotation" J (Machado, 2016). Those with only mass are Schwarzschild's, those with mass and angular momentum are Kerr's, those with mass and charge are Reissner-Nordström, and those with mass, charge, and angular momentum are Kerr-Newman's.

The simplest is Schwarzschild's, as it has only mass. Observing the Eq. (1), we see that a body approaching this type of black hole, in a region $r > R_S$ Moving to the region $r < R_S$, We see that the object enters and remains, not being able to return, in view of the intense gravitational effect inside the black hole. The outside observer cannot observe what happens inside the black hole. The Schwarzschild black hole is named after the German astrophysicist Karl Schwarzschild, in considering it a Black Hole (BN) without rotation and without charge.

Kerr's Black Holes was developed by mathematician Roy Patrick Kerr, with mass and rotation. Probably all black holes have rotation, as it is common in the collapse of matter for its formation, as well as in the conservation of angular momentum. It is also characterized by an elliptical region outside the black hole and close to the event horizon. In this region, the gravitational field rotates along with it, dragging space-time (Bergmann et al., 2011).

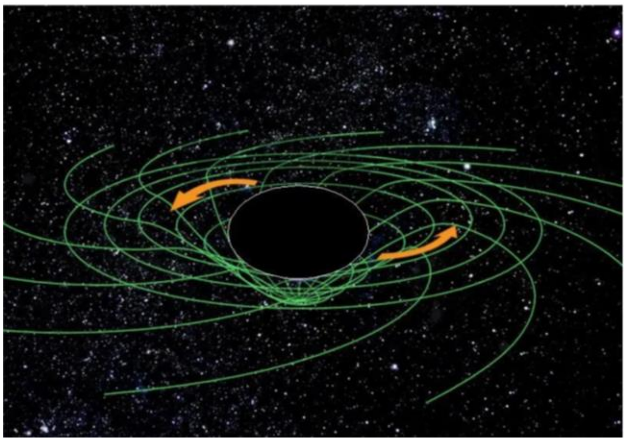

Figure 3. Kerr's Black Hole Characterized by Mass and Spin (Bergmann et al., 2011)

Kerr black holes will have a rotation axis and will be slightly flattened along that axis and with a higher part on the surface, which differs from Schwarzschild black holes that do not spin and are perfect spheres. Its shape is that of an ergosphere, where it is ellipsoidal in shape and flattens in the direction of rotation.

Kerr black holes are more complicated because instead of having one event horizon, they have two. In addition, instead of the singularity being a mathematical point at r = 0, there is deformation by rotation in a one-dimensional ring in the equatorial plane (Odenwald, 2019).

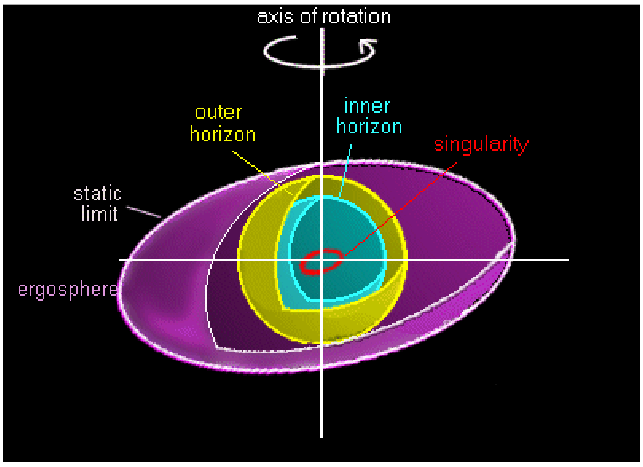

Figure 4. Kerr Black Hole Detailed in Ergosphere, Static Limit, Outer and Inner Horizon, Singularity, and Axis of Rotation (Odenwald, 2019)

Entropy and Temperature of Black Holes

The German physicist Rudolf Clausius (1822-1888), through his intense work with the kinetic theory of gases and thermodynamics, introduced the concept of entropy.

To understand the concept of entropy, for example, place some red balls at the bottom of a container and some blue balls on top of them (initial ordered state) and close the container.

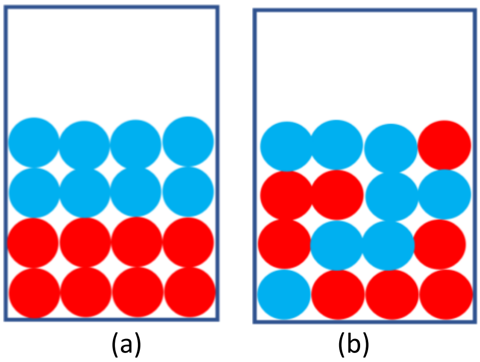

Figure 5. a) Ordered Balls in the Container. Red Ball at the Bottom and Blue at the Top, Constituting an Ordered State. b) One of the Possible Results After Shaking the Container, Constituting a Disordered State of the Red and Blue Balls (Silva, 2022)

When we shake the container, we will naturally notice that the balls will mix (disordered state). Is it possible to return to the initial situation with the red spheres at the bottom and the blue ones at the top? Highly unlikely.

That is why natural systems are irreversible, that is, that one cannot change, because there is always the passage from an ordered state to a disordered state. So the concept of disorder Clausius associates it with the mathematical concept of entropy.

As the system evolves, it leads to an increase in entropy in the Universe, that is, disorder increases. When a natural transformation occurs, the energies are converted into heat, increasing the unavailability of the total energy of the system and increasing entropy. Since entropy is a function of state, then it depends only on the initial and final state of the system, not counting on the details of the transformations.

So the relationship that is the change in entropy, with the amount of heat ΔSQ and the temperature T, we have

$$\Delta S = \frac{Q}{T}$$

In the case of an irreversible process (which cannot be changed), which would be in a natural transformation, the measure of entropy is indirect, as in the case of the free expansion of a gas.

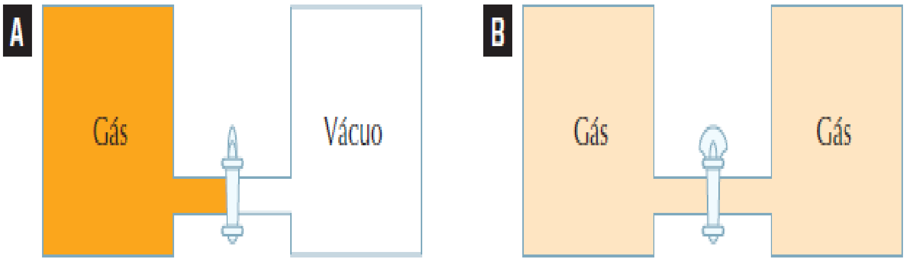

Figure 6. In the Free Expansion of a Perfect Gas, There is an Increase in Entropy (Ramalho; Nicolau & Toledo, 2009)

In item A of the figure above, a system is thermally isolated, with two containers, initially separated. In one of them there is a perfect gas and in the other a vacuum. Removing the separation, the perfect gas begins to expand, occupying the second container according to item B. In this transformation, an adiabatic transformation occurred, because there is no variation in the amount of heat ($Q = 0$) and there is no work ($W = 0$), due to the non-resistance against the expansion of the gas. If there was no temperature variation, then the process is isothermal, so according to the 1st Law of Thermodynamics, the internal energy variation is zero, in the form ($\Delta U = W - Q = 0$).

When the gas expands, it has undergone an irreversible transformation, that is, it decreases its ability to perform work. Due to the impossibility of the gas returning to the container where it was, leaving the other container empty, then this system is irreversible. Therefore, the entropy of the system will be increased (Ramalho; Nicolau & Toledo, 2009).

Entropy derives from the Greek "energy transformation" and the total entropy of an isolated system never decreases: it either stays constant or increases (Calçada & Sampaio, 2012). And to make this relationship between entropy and black holes, we must first understand the concept of entropy, but now it is no longer valid for "disorder", but the lack of knowledge about its state of precision.

The surface area of the event horizon increases when matter or radiation falls into the black hole. Entropy is extremely related and according to the Second Law of Thermodynamics, entropy always increases with time (Hawking, 2017).

This brilliant idea was given by Jacob Bekenstein (1947-2015), in 1972, who considered the final stage of a star, in this case a black hole that a lot of information is lost in a gravitational collapse, that is, the greater its entropy, the more information will be needed to describe it. To answer the information problem, we must deal with the quantum regime.

Entropy for this case would be the measure of the amount of information in the collapse process that formed the black hole. Apparently we would have a paradox, because if the information is lost, then there should be a release of energy, which contradicts the theory that nothing comes out of black holes.

Hawking, in an attempt to consider entropy as a measure of the number of internal states (ways of forming from within), but without looking different to an external observer, considered mass, rotation, and charge, formulating this relationship in 1974 to the area of the event horizon. Since there is a very small amount of information about this internal state of the black hole in relation to the surface area of the event horizon, then there is a relationship with quantum gravity and thermodynamics. Hawking considers black hole entropy in form

$$S_H = \frac{k_B c^3}{4\hbar G} A$$

Being A is the area of the black hole's event horizon. It is a clue to the enigma of black holes, which may unite gravitation, quantum mechanics and thermodynamics (Filho & Araújo, 2007).

For the treatment of the temperature of black holes, the laws of thermodynamics for black holes are as follows:

Zero law: The temperature T of a Schwarzschild black hole at the event horizon is constant.

1st Law: The product of mass with the square of the speed of light is equal to the product of temperature with entropy, so it stays in the form

$$Mc^2 = TS$$

2nd Law: In the case of a classical Scwarzschild black hole for which quantum effects are not taken into account, the entropy is equal to or greater than zero, so we have

$$\Delta S_{BN} \geq 0$$

Since entropy is associated with the surface area A of the event horizon of a black hole, then, we can consider that the Law of Areas in which A never decreases in any physical process, so it stays in the form (Oliveira & Zanchin, 2009).

$$\Delta \mathrm{A} \geq 0$$

3rd Law: The temperature of the event horizon of a Scwarzschild black hole cannot be reduced to zero through a finite number of processes.

If we take into account quantum effects near the event horizon, the second law will be in a more general form, so

$$\Delta S_{Ext} + \Delta S_{BN} \geq 0$$

In that ΔS_{Ext} is the outer entropy close to the black hole. It means that entropy of any kind and of its external environment cannot decrease. The difference with classical and quantum black holes is that in classical black holes, nothing can escape it, no matter and no radiation. But if we are interested in quantum treatment, that is, a closer look at the event horizon, we will have some exceptions. Hawking showed that a black hole emits radiation, which became known as Hawking radiation, being similar to a black body at a temperature T, in the form of

$$T = \frac{\hbar c^3}{8\pi G M k_B}$$

That is, if we consider the black hole, with mass in kilograms and temperature in Kelvin, then it can be expressed in the form

$$T = \frac{1.23.\,10^{23}}{M}$$

Temperature known as Hawking temperature or Bekenstein-Hawking temperature, as it confirms with Bekenstein's previous work, being one of the pioneers in the study of thermodynamics. In the case of radiation, they are made up of particles, such as photons, neutrinos, among others. On the outside of the black hole is a vacuum region, which we know as the absence of matter, but in reality it is where the quantum fluctuation is low, that is, where we have a state of low energy.

In this region of fluctuation, near the event horizon, pairs of particle-antiparticles are generated, such as electrons and positrons, the latter would be identical to the electron, being positively charged. Antiparticles are particles identical in mass to their peers, but with contrary signs. The gravitational effect of the black hole can separate these pairs of particles, where one falls into the black hole and the other is expelled.

Hawking found that entropy could be related to the event horizon, as there are several pairs of particles interacting with each other in the vicinity of the horizon, in which the positive energy of one particle cancels out the negative energy of the other, and vice versa. The negatively charged particle is attracted to the black hole's strong gravity and would fall into it, releasing its positively charged partner into outer space. The negatively charged particles inside the black hole decrease some of their mass, canceling out some of the positively charged particles from the black hole's mass.

The expelled positively charged particle would appear to be emitted by the black hole to a distant observer in space. In fact, the positively charged particle would not come directly from the black hole, as thought by the outside observer, but from space outside itself, near the event horizon.

Following this reasoning, the idea of the quantum vacuum solves this problem, assuming that the event horizon is a measure of the entropy of a black hole. A quantum vacuum is space where there is apparently nothing for any observer, but which contains a minimal amount of energy, such as electromagnetic and gravitational fields, as well as particle interactions (Silva, 2018).

If we consider the Planck length, we have entropy in the form

$$S_H = \frac{A_e k_B}{4{l_p}^2}$$

Being A_e the surface area of the event horizon. We soon realize that the entropy of the black hole is proportional to the area determined by the Schwarzschild radius (Machado, 2016).

METHODOLOGY

The research was carried out with 23 students from the 3rd year of high school, extracting information not only from the exercises, but also from the students' behavioral observation. For the purpose of confidentiality, we use the letters to identify the names of the students of A, B, C, ..., W.

On the first day of class, we talked about black holes. We initially presented a video with the title: "Black holes explained". The video, with a total duration of 10 minutes and 3 seconds, begins with an observation by John Michell, where he calls a black star a body that did not emit light and had a mass 500 times greater than that of the Sun, thus emerging the first idea of a black hole.

The students realized through the video that Schwarzschild found a solution of Einstein's field equation, dealing with escape velocity, black hole radius, singularity and event horizon, where the latter is a kind of "black hole edge".

We commented on the video and introduced the concept and formation, dealing with the final stages of stars, showing the expression of kinetic energy and gravitational potential for understanding the relationship between the speed of light and the radius and mass of black holes. We realized in the students' previous conception that black holes sucked everything they went through, which is different from reality. We made comparisons with the drain of a sink, in the process of drainage, as well as in the distortion in space-time caused by the presence of the mass of a body.

We comment on the massive bands that relate the final process of stars, such as white dwarf, brown dwarf, neutron star and the black hole itself. The typology was approached, through the angular momentum and charge values, ending the encounter with the Schwarzschild black holes and, superficially, with the Kerr black holes.

On the second day of the meeting, we continued in the sequence of the subjects, addressing the entropy and temperature of black holes. The concept of entropy was useful, where the interaction of the students was perceived, where we exemplified with the cup of coffee, showing that we could not heat the coffee again (without turning on the stove again), because naturally (and spontaneously) it would cool down. We comment on an example with blue and red balls, initially arranged in a container. The latter, when shaken and then ceasing this movement in sequence, causes the balls inside to be positioned in a disordered way, so that if we shake it again, we would never reach the original state.

And to close the initial concept of entropy, we use another example, with the free expansion of a perfect gas. This idea of entropy was well understood by the class, that the more disordered the system appears, the greater its entropy. We show that when we treat the concept of entropy of black holes, the term "disorder" would no longer be technically convenient, in view of other factors in the study of black holes. Entropy, when we treat black holes, is directly associated with the area of the event horizon and this was very clear in the students' understanding. We discuss this entropy relationship, formulated by Hawking and the relationship with the laws of Thermodynamics, that is, entropy is always greater than or equal to zero (this is according to the theory).

Quantum effects in the vicinity of the event horizon were addressed, as well as radiation, by the creation and annihilation of pairs of particles and antiparticles in this region.

On the third day of the meeting, we closed our discussion and student (D) asked an interesting question: "*Professor, what is inside a black hole*?". At the end of our discussion, the class understood that it is still a topic discussed in the scientific community, but it is certain that there are particles inside, as well as stardust, which are condensed gases ejected from stars.

In general, they understood that black holes are fed by bodies, in their various species, that enter their gravitational field. At the end of the class, the students received the fixation worksheet with 5 questions, 3 discursive questions and 2 multiple-choice questions (Silva, 2022).

Vídeo Sobre Buracos Negros

Black Holes Explained

The video shows some fundamental concepts of black holes, their relationship of space-time and interaction. Access: https://www.youtube.com/watch?v=GbJJRsS6OR44(Loss, 2020).

Fixation Exercises

1. What do you mean by black hole?
2. What is the final process of an initial mass 13 star? $M_\odot$
3. What type of black hole has mass M and angular momentum J? (A) Schwarszchild (B) Kerr (C) Kerr-Newman (D) Reissner-Nordström
4. Consider $M_\odot$ = 2.10^{30} kg. What is the temperature of a black hole with $28M_\odot$ mass? (A) $2{,}2.10^{-9}$ K (B) $4{,}6.10^{12}$ K (C) $3{,}2.10^{-21}$ K (D) $1{,}6.10^{15}$ K
5. Regarding the entropy of a black hole, we can state that: (A) is proportional to the area of a black hole (B) is the information on the formation of planets (C) its area always decreases (D) is the particles emitted by the black hole

RESULTS AND DICUSSION

The questions of the exercises cover the subjects covered such as the concept, formation, temperature and entropy of black holes. The first question asks what a black hole is. There are those who prefer the concept of the star's final stage, but have not specified whether they should have 25 solar masses or more. Much of them consider the gravitational effect exerted by the black hole, where no body that enters can leave it.

The second question asks what is the final process of an initial mass star $13M_{\odot}$ and about 15% of the students made a mistake due to the lack of attention to the amount of mass within the considered range.

The third question has options and asks what type of black hole would be with mass M and angular momentum J and about 19% of students did not get it right due to confusion with M, J and Q. These are details in which attention leads to a correct answer. There was a student who mistook the black hole being charged with J and others the angular momentum with Q.

The fourth question has options and asks what the temperature of a massive black hole would be $28M_{\odot}$, with $M_{\odot}$ = 2.10^{30} kg and about 84% They got the question right. A simple question and discussed in class with other examples.

The fifth question with options already talks about the relationship of the entropy of the black hole. The correct option is that proportionality to the area of a black hole. Hit 93% of those who responded, because the discussion was well emphasized. There are those who have checked the option that they are particles emitted by the black hole, due to the misunderstanding of quantum fluctuations at the event horizon.

There are also those who have checked the option that it is the information of the formation of planets, because they believe entropy is information, a mistake, because although entropy is information, it does not match in this case, as it is not associated with the formation of planets (Silva, 2022).

CONCLUSIONS AND RECOMMENDATIONS

We know the difficulties that the teacher goes through in the classroom for the preparation of innovative topics such as Modern and Contemporary Physics, but it is extremely important that the teacher develops methods in the educational process to motivate students, because themes of this nature, in particular black holes, certainly broaden the worldview and perception of science, not limited to classical physics with an exhaustive didactics.

The students developed in this work, the ability to question and think critically about reality and work as a team, discussing the issues presented by the teacher, presenting a high percentage of assertiveness, showing interest in participating in the activities.

It is possible to use modern topics from physics and frontiers, but it will require the teacher to prepare and search for material and adaptations necessary for good performance in classroom activities.

The proposed theme of this work on black holes was marked in the lives of the students, as they were presented how science is done, without the need to take them to a research institute.

The students understood the analogy used through the subjects of mechanical energy and thermodynamics involving black holes.

In general, it is hoped that the work can contribute so that schools and teachers can develop work with their students of this nature.

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