ASTROEDU

Peer-reviewed Astronomy Education Activities

What is a black hole? – Lower Secondary Level

What would happen if the Sun was replaced by a black hole?

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AGE

12 - 14

LEVEL

Middle School, Informal

TIME

45min

GROUP

Group

SUPERVISED

No

COST PER STUDENT

Low Cost

LOCATION

Small Indoor Setting (e.g. classroom)

CONTENT AREA FOCUS

Astronomy

CORE SKILLS

Developing and using models, Planning and carrying out investigations, Constructing explanations, Engaging in argument from evidence

TYPE(S) OF LEARNING ACTIVITY

Structured-inquiry learning, Interactive Lecture, Problem-solving, Discussion Groups, Modelling, Observation based, Fun activity

KEYWORDS

Black hole, Model, Investigation, Gravity

GOALS

To understand what a black hole is and how gravity in a black hole is so extreme and that space near a black hole is warped so much that nothing can escape.

LEARNING OBJECTIVES

- Students can define gravity as the bending of space deformed by an object. The more mass something has, the stronger the gravity it creates.
- Students can define black holes as a region in space where gravity is so strong that nothing, not even light, can escape.

- Students can explain that black holes do not act like a vacuum that sucks even the materials at great distance from them. Things are only lost into a black hole when they get close enough to the black hole.
- Students practice careful observation.
- Students practice logical thinking by relating evidence from observations with their understanding to draw explanation and conclusion.

EVALUATION

- After students have done activity part 1 and 2, ask students to define gravity.
- Ask students to define black holes in their own words based on the observations from all of the activities they have done. Compare students understanding of black hole at the beginning with their own definition after completing the activity.
- As a recap at the end of the activity, ask students to explain if the Earth would get sucked in a black hole with the same mass as the Sun. They should be able to mention that the Earth would not be close enough to be pulled in by such a black hole because the black hole creates the same gravity as the Sun.
- Listen to student’s explanation of their answers to the questions in the worksheet. Students should be able to answer the questions using their observations and what they have learnt from previous activities.

MATERIALS

- Round washing bowl (diameter minimum 30cm)
- Stretchy sheet (cut from stretchy fitted bed sheet)
- Elastic band (to fix the sheet on the wash bowl)
- 3 kinds of marbles: heavy, medium and light weights.
- Aluminum foils
- Weighing scale
- Small, rectangular piece of cardboard
- PowerPoint presentation
- Projector
- Student worksheet

BACKGROUND INFORMATION

Gravity

Gravity is a force that each objects acts on another, moving things together.

Everything with mass has gravity. We perceive gravity as we jump up and get pulled down to the ground. Planets, stars, moons and other objects in the universe also have gravity (Even humans, rocks and tiny ants have gravity). That's why objects in space orbit around each other.For example the Earth orbits the Sun, or the moon orbits around the Earth, instead of flying randomly in space.

The more mass something has, the stronger the force due to gravity it produces. The Earth's gravity is stronger than the Moon's because it is more massive. So our bodies are pulled down on Earth more than if we were on the Moon. That's why astronauts can jump higher and more easily on the moon than on Earth. Our bodies also exert gravitational forces on other objects, but because our mass is so small, the gravity from our bodies does not affect objects in any way we can see. The strength of the force of gravity also changes with the distance to an object. The pull between the Earth and the moon is stronger than that between the Earth and Jupiter, even though Jupiter is much more massive than the Moon. This is because the Earth is closer to the Moon than to Jupiter.

Gravity was first described by Newton as a force. Described more than 300 years ago, Newton's theory of gravity is still applied today when scientists plotted the course to land man on the moon or to build a bridge across a river. Although Newton's theory describes the strength of gravity fairly accurately, he didn't know what caused gravity or how it worked. These concepts were left unknown for nearly 250 years, until Albert Einstein described gravity as the curvature of space. Space has 3 dimensions: up-down, left-right and forward-backward; and it can be visualized as a fabric, like a stretchy sheet. Any object with mass deforms space, just like a marble creating a dimple on the surface of the stretchy sheet. This curvature of space causes objects to interact with each other, often by moving towards each other, which is seen as gravity, a natural consequence of a mass's influence on space. The more mass something has, the more the space is curved, and, therefore, the more gravity there is.

Black holes

A black hole is a region in space where the pull of gravity is so strong that nothing, not even light, can escape. Light travels extremely fast (nothing can travel faster), only taking 1.3 seconds to travel between the moon and the Earth. If we moved at the speed of light, we could travel around the Earth 7.5 times just in one second. Therefore, the pull of gravity in a black hole must be extremely high if light cannot escape from it. Because light cannot escape from a black hole, the black hole is invisible to us.

A black hole is very very small in size but contains a lot of mass. Most black holes are a result of dying giant stars, several to hundreds times more massive than our Sun. At the end of its life, the star burns out and collapses, causing some of the material from the dead star to be compressed into a tiny space. Such compression of enormous mass bends space so much that it is like a deep well. The result is the formation of what we call black holes, characterized by extreme gravity. Because its mass is so concentrated, another object can get very close to the black hole, to where the space is greatly curved i.e. gravity is extreme, and gets trapped forever in this gravitational well.

Black holes do not necessarily have more mass than everything else in the Universe but the compression of its mass creates its extreme gravity. After its formation, black holes can continue to grow more massive as their extreme gravity causes them to accumulate more matter from its surroundings, such as other stars and other black holes. Black holes can even be as massive as more than a million suns; these are called "supermassive" black holes. These supermassive black holes exist at the centre of most galaxies. One even exists at the centre of the galaxy that we live in, the Milky Way; and it is thought that there are around 100 million less massive black holes about the mass of the Sun orbiting within our own galaxy.

A common misconception is that black holes suck everything towards it, like a vacuum cleaner. However, things only enter into black hole and are lost forever once they pass the border of no escape of that black hole - the event horizon. As we get closer to a black hole, space is warped more and more and gravity becomes extreme very rapidly. The event horizon is the boundary region of black hole where gravity becomes too extreme that nothing, not even light, can escape. That the Earth would be be destroyed if the Sun became a black holes is a myth. First of all, as black holes are formed from the collapse of stars much more massive than our Sun, the sun would never become a black hole at the end of its life. But hypothetically, if it was replaced by a black hole with the same mass, the Earth wouldn't get drawn towards this black hole and destroyed. Instead, the Earth would keep the same pull due to gravity from this black hole, orbiting it in exactly the same way as it does the Sun. This is because the black hole will still have the same mass as the Sun; and because only very close to the black hole that the gravity becomes extreme, further away from it, the gravity acts exactly the same.

FULL ACTIVITY DESCRIPTION

Introduction (7min)

1. Ask students what they already know about black holes and about a myth that black holes could 'suck' matter towards them and eventually consume everything in the Universe. If the Sun was replaced by a black hole, hypothetically, would it be able to destroy the Earth? Tell students that to investigate this possibility, they need to understand what a black hole is.
2. Use the accompanied slideshow and background information to explain the characteristics of black holes. A black hole can be much smaller in size than the Sun but can also be more massive than a billion Suns. Because of this characteristic, a black hole has extreme gravity that causes everything that comes too close to be pulled in and lost forever, even light, which is the fastest thing in the universe.
3. Elicit discussion on what children think gravity is. Use the background information provided to explain the concept of gravity as an attractive force and that this attraction can be explained as a result of space being bent.
4. Cover a stretchy sheet on a large round bowl. Introduce the surface of the sheet as a small portion of space and point out that this is only space in 2 dimensions because space surrounds us everywhere in all directions.

The class can be divided in small groups. For part 1, 2 and 3 of activity, the teacher can let the groups explore on their own by following the steps in the attached worksheet. For part 4, the teacher walks through the steps for the rest of the activity, instructing, explaining and demonstrating the steps for the groups to follow.

Part 1: Gravity (5min)

The students place a medium weight marble on the sheet and see that there is a curvature due to the marble. With the medium weight marble at the center, roll a lighter marble on the sheet so that the light marble moves toward the heavier one and circles around it. An object bends space like the marble does to the stretchy sheet, causing objects to be attracted to each other. This effect is called gravity, which is the curvature of space.

Part 2: Black holes have powerful gravity (5min)

1. Some black holes can be more massive than a billion Suns. A heavy marble represents such a black hole. The medium and light marbles from activity 1 represent other objects in space e.g. stars, planets.
2. Place the heavy marble on the sheet, and then release the other 2 marbles on the sheet. They roll towards the heavy marbles.
3. Alternatively, place the medium marble in the center of the stretchy sheet and roll the light marble. It orbits and falls towards the medium marble as a result of gravity from the medium marble. Then, roll the heavy marble as the black hole on the sheet; the medium and light marbles follow the heavy marble and fall into it.
4. Based on the observations, students should see that the heavy marble bends space more than the lighter objects. Similarly, the heavy black hole curves space the most, having the most gravity, which we can see when other objects fall into it.

Recap part 1 & 2 (4 min):
1. As students finish, sum up what they learn from activity 1. Ask students to define gravity (They should describe it as bending of space). Point out that in space, the stars and planets do not generally collide as seen with the marbles in the activity. This is due to friction of the marbles with the fabric, but there is no such fabric and so no friction in space. Gravity holds planets and stars in orbit to each other.
2. Go through the questions of activity 2 in the worksheet to explain that because black hole bends space more than other objects, therefore it pulls other objects into it.
3. Because the heavy marble is bigger than the other 2 marbles, make it clear that, in reality, black holes can be more massive than the other objects, but are often smaller in size.
4. Ask students to continue with part 3, following the student worksheet.

Part 3: How do black holes prevent objects from escaping once they have fallen in? (7 min)

1. To escape the pull due to gravity, an object needs to move fast enough (just like a space rocket shooting away from Earth).
2. Take a cardboard and bend it slightly to make a flat curve. Roll a small marble from one end of the cardboard so that it rolls to the other end and falls out. Students try to explain that because the curve is not so steep, it shows that the gravity strength is not too extreme, so the marble can move fast enough to overcome the pull and escape.
3. When the cardboard is bent more steeply, the curve represents the stronger gravity created by black hole. Release the small marble from the less bent side of the cardboard to roll it to the other end. The marble cannot move up the steeper end. It is like the gravity in black hole that is too extreme, so the marble cannot move fast enough to escape the pull of the gravity.

4. As students complete the activity, go through the questions in the worksheet to explain how things cannot escape from black hole’s extreme pull of gravity. Explain that light and other objects also move in space, like the small marble, and fall in black hole when they get too close. Light is the fastest thing in the Universe, and even that cannot escape from the gravity pull in black hole.
5. Students can try to give a complete definition of black hole, which is a region in space where gravity pulls so strong that nothing, not even light, can escape.

Part 4: Scenario where the Sun is replaced by a black hole (10 min)

1. Prepare in advance an aluminum foil ball with some weights (e.g. marbles) inside. This ball should be much bigger than the heavy marble used in Activity 2 but have a similar weight.
2. Present to students the aluminum ball as the Sun and the heavy marble as a black hole with the same mass as the Sun. Students should check and confirm their weights.
3. Lead a discussion about what would happen if our Sun was replaced by a black hole of the same mass. Use the background information to explain that the event of the Sun becoming a black hole is not feasible. But explore the question: If a black hole with the same mass as the Sun could replace it, would the Earth get sucked in this black hole?
4. Tell the students that to explore this question, they need to compare the gravity created by the Sun and the black hole of the same mass that replaced it.
5. Ask students to place the heavy marble and the aluminum foil ball on the stretchy sheet (separately). Focus on the area of the sheet that is very close to the ball/ marble. The students should compare the bending of the sheet for each of the two objects and conclude that the curvature created by the large ball is less steep than that created by the marble, even though they have the same mass. This means that the black hole curves space around it more than the Sun does. So gravity very close in to the center becomes more extreme when the Sun is replaced by the black hole.
6. Tell students to use the light marble from activity 1 to represent the Earth. In reality the black hole would be much smaller than the Earth, not bigger as shown by the marbles in this activity. With the black hole marble at the center (and then the aluminum ball), place the Earth marble at an area close to the marble/ball and start rolling it on the sheet.

7. Ask students if there’s difference in the movement of the Earth marble in the two cases. The marble orbits more times around the black hole marble than with the aluminum ball because of the smaller size of the black hole and the steeper bending of space by the mass of the black hole marble.
8. Explain to students that because the mass of the ‘black hole’ marble is compressed in a smaller space, instead of spreading out as much as the large ball, the space near it is curved more dramatically when compared to the larger sphere, where the space curves more gradually (use slideshow or supplementary image to aid explanation). So if the Sun was replaced by a black hole, the gravity near it would increase extremely. And if Earth was located very close to the Sun, as it orbits around, it would get pulled into the black hole that replaced the Sun.
9. Tell students that luckily Earth is quite distant from the Sun (at the edge of the stretchy sheet). Ask students to compare the bending of space at the edge of the sheet, when placing the heavy marble at the center and then with the aluminum foil ball. Students should conclude that the bending of space by the large ball and the black hole marble looks the same at the edge.

10. At the edge, students roll the Earth marble with the Sun aluminum ball in the center, and then repeat with the black hole marble in the center.

11. Help the students to realize that the Earth marble only orbits faster and more times as it gets closer to the center near the black hole marble, where space is curved more. But it moves the same when it is far away from the marble and the ball.
12. Conclude that further away from black hole, the gravity acts exactly the same as that of the Sun. Thus, if Sun was replaced by a black hole of the same mass, Earth would keep orbiting the same as with the Sun and would not get sucked in (but because a black hole emits no light it would be cold and dark!).
13. Use this scenario to emphasize that a black hole is not like a space vacuum cleaner that sucks everything into it, destroying everything around it. Only when things get close enough, does the gravity become extreme. So much so that beyond the event horizon matter is lost forever.

CURRICULUM

ADDITIONAL INFORMATION

The use of stretchy sheet and marbles are based on previous Astroedu activity 'Model of a black hole' (http://astroedu.iau.org/en/activities/1304/model-of-a-black-hole/). Gravity and black hole activities are inspired by Inside Einstein's Universe (https://www.cfa.harvard.edu/seuforum/einstein/resources/JourneyBlackHole/JourneyBlackHoleManual.pdf) website.
For students to know more how a black hole can be detected, see Activity "Hunting for black holes" (11-14 year-old level).
For students to know what happen when a black hole eats material from its surrounding, see Activity "Feeding black holes and what happen to the Universe?" (11-14 year-old level).

CONCLUSION

In this activity, students use a model of space to understand mass and gravity. They also learn about black holes as an entity with such extreme gravity that, once inside the event horizon, not even light can escape. The students also learn that black holes don't consume everything. In fact, most things will just orbit a black hole normally, like the Earth orbits the Sun; it's only when you get close enough to the black hole that the extreme gravity takes over.

ATTACHMENTS

- Student worksheet
- Presentation
- Part 4 step 8 - supplementary image

ALL ATTACHMENTS

All attachments

CITATION

Han Tran; Thomas Russell, 2018, *What is a black hole? – Lower Secondary Level* , astroEDU,

ACKNOWLEDGEMENT

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