



ASTROEDU

Peer-reviewed Astronomy Education Activities

Hunting for black holes - Lower Secondary Level

**How do astronomers detect invisible
black holes?**

Tran Dong Thai Han, Leiden Observatory; Thomas Russell, University of Amsterdam

 AGE 12 - 14	 LEVEL Middle School, Informal
 TIME 45min	 GROUP Group
 SUPERVISED Yes	 COST PER STUDENT Low Cost
 LOCATION Small Indoor Setting (e.g. classroom)	 CONTENT AREA FOCUS Astronomy

CORE SKILLS

Developing and using models, Constructing explanations

TYPE(S) OF LEARNING ACTIVITY

Structured-inquiry learning, Problem-solving, Modelling, Observation based, Fun activity

KEYWORDS

Black hole, Gravity, Gravitational lensing, Accretion disk, Event horizon

GOALS

To understand how black holes are observed based on the effect they have on their surroundings.

LEARNING OBJECTIVES

- Students can describe black holes as invisible because light cannot escape from black holes once it passes event horizons.
- Students can describe the process of a black hole eating a nearby star and forming hot bright accretion disk outside the event horizon that allows black hole detection.
- Students will use a model to simulate the orbit of stars nearby a black hole, through which students will describe how a black hole can be detected by

observing the movement of its surrounding objects being affected by its gravity.

- Students will make a model to simulate gravitational lensing phenomenon that results from black hole's gravity bending light.
 - Students will practice logical thinking by relating an example, observation or a model to explain a concept.
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EVALUATION

- These are some questions to test students understanding about the invisible nature of black holes and event horizon: “Do black holes emit light?”, “Why not?” “What happens when things, for example light, pass the event horizon of a black hole? “
 - Ask students where the visible accretion disk occurs. They should say that the spiral of material is outside the event horizon and, therefore, we can observe the emitted light. This ensures that there is no confusion in the understanding that black holes do not emit light.
 - At the end of the session, ask students to list and explain all the methods in which we can observe a black hole, either when it is feeding on material or isolated in space.
 - Before starting an activity, use background information to explain the underlying concept. Once the activity is completed, ask students to relate the black hole concept with what they observe or do in the activity. Check if students can successfully make a relation to explain the concept.
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MATERIALS

- 2 kinds of marbles: heavy and light weight.
 - Large round washbowl (diameter minimum 30cm)
 - Stretchy sheet (cut from stretchy fitted bed sheet)
 - Elastic band (to fix the sheet on the wash bowl)
 - Wooden skewers
 - Cardboards
 - Orange highlighter
 - Chalks
 - Magnets
 - Ball bearing
 - Wine glass
 - Candle + holder (birthday cake type)
 - A plastic cup
 - Lighter
 - Saucer
 - Color tape
 - PowerPoint Presentation
 - Projector
 - Student worksheet
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BACKGROUND INFORMATION

Gravity

Gravity is a force that makes objects move, bringing things together. Everything with mass has gravity. We perceive gravity when we jump up and get pulled back down to the ground. Planets, stars, moons and other objects in the Universe have gravity. That's why they orbit around each other, like for example the Earth orbits the Sun or the moon orbits around the Earth, instead of flying randomly in space. That's why we see the moon and the Sun every day.

The more mass something has, the stronger the 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 any way we can see. The strength 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. 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 and it was used when scientists plotted the course to land man on the moon and is still used to build bridges across rivers. Although Newton's theory describes the strength of gravity fairly accurately, he didn't know what caused gravity or how it worked. These concepts remained 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 hole

A black hole is a region in space where the pull of gravity is so strong that nothing, not even light, can escape. A black hole can be very very small in size but can contain a lot of mass. Some black holes are a result of dying giant stars, several to hundreds times bigger 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 it acts 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, and gets trapped forever in this gravitational well.

Black holes do not necessarily have more mass than other objects in the Universe but the compression of its mass creates its extreme gravity near to it. After its formation, black holes can continue to grow more massive as they accumulate more matter from its surroundings, such as stars, gas, dust and other black holes. Black holes can be as massive as three Suns to over a million Suns. Things that enter into the black hole are lost forever once they pass the

border of no escape - the event horizon. As we get closer to a black hole, space is bent more and more, and gravity becomes more extreme very rapidly. The event horizon is the boundary region of black hole where the pull of gravity becomes so extreme that nothing, not even light, can escape. It is thought that there are around 100 million stellar-mass black holes orbiting within our own galaxy.

Black hole observation

Because of their extreme gravity, black holes are perfect space traps. Light travels extremely fast (nothing can travel faster), only taking 1.3 second 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. As light enters a black hole there is no path out and remains inside. This is why a black hole is invisible and very difficult for astronomers to detect. However, there are still some ways for black holes to be detected.

When a black hole is feeding on matter within its vicinity, that material can become very bright, allowing its detection, in a phenomenon called an accretion disk. A black hole's extreme gravity causes nearby material to be pulled into it; this material can include small amounts of gas from a nearby star, or the dust and other stellar debris from a complete star being torn apart. As this material spirals closer into the black hole, it orbits faster and rubs and collides against other material spiraling into the hole. The friction created causes the material to be heated to very high temperatures. Wherever there is heat, there is emission of thermal electromagnetic radiation, which is light. An example is our body, which also emits thermal radiation and this can be seen when looking through thermal imaging goggles. Another example is when a piece of metalwork is heated to very high temperature that we can see the heated part glow.

When the temperature of the material around the black hole increases, the energy emitted in the form of radiation also increases. Because the materials spiraling in black hole get extremely heated, they glow and form a bright flattened ring of spinning matter, called an accretion disk, around the event horizon. Although black holes are themselves invisible, this accretion disk can be seen by astronomers because the spiraling materials have yet to pass the event horizon to be lost forever. The light from the accretion disk radiates out into the universe and allows us to see where a black hole is and what it is doing to its surroundings. As the material spirals in, when it is very close to the black hole but before it goes beyond the event horizon, some of it can be shot out in the form of super-fast, focused beams of material, called 'jets'.

For black holes that are not feeding on surrounding material and cannot be observed via their accretion disks, the presence of a black hole can be revealed by the effect of its gravity on normal stars that apparently orbit around nothing. This is like planets keeping their orbit around the Sun. But instead of something visible like our Sun, the stars just orbit around an empty space. Thus astronomers can assume that there is a black hole there. This happens at the centre of our own galaxy, where we see stars, such as star S2, orbiting fast around an invisible point.

Additionally, the existence of a black hole can be evident through an optical effect, called gravitational lensing, seen as the result of light being bent by the gravity generated by black hole. Light normally travels straight in space. But due to a black hole's extreme gravity, which is the curvature of space, light passing nearby a black hole will travel along this curvature, instead of going straight through, i.e. light is bent. Therefore, a black hole can act as a lens, bending any light passing behind it. When viewing distant galaxies with telescopes, astronomers have observed strange rings and arcs of light, despite no

observation of any visible mass. This indicates the presence of invisible black hole that is creating curvature due to gravity and focusing the light towards us like a lens.



FULL ACTIVITY DESCRIPTION

The activity is divided in 4 parts. For the first 3 parts, at beginning of each part, the teacher can explain the concept behind the part and then let students attempt the activity on their own, following the student worksheet. After a specified amount of time, the teacher discusses and demonstrates (if needed) with the students, steps in the activity they just undertook and provide more elaboration. Only for part 4, would it be better that the teacher demonstrates the activity as the students follow. Decide which is the best classroom setting for the end of part 4, when candles are used, to ensure clear understanding and also safety.

Introduction: (3 min)

1. Ask students what they already know about black holes. Use the background information provided to explain, in a simple manner, black holes, emphasizing their ability to contain enormous amount of material (from three to billions of times the mass of the Sun) and how they capture anything that comes too close and prevent them from escaping.
2. Use the background information provided to tell students some fun facts about how light is the fastest thing in the universe. After this, point out that even light can never escape from black hole because of black hole's extreme gravity warping the space around it.

Part 1: Black holes have powerful gravity (7 min)

1. Elicit discussion on what the students think gravity is. Use background information to explain the concept of gravity as an attractive force and that this attraction can be explained as a result of space being bent by an object.
2. 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.
3. Remind the students that some black holes can be more massive than a billion Suns so use the heaviest marble to represent a black hole. Students should observe that there is a bend on the sheet. Roll a lighter marble on the sheet past the heavier marble so that the lighter marble moves toward the heavier one, circling around it.
4. Alternatively, place the light marble in the center of the stretchy sheet. Children should observe the curve on the sheet is less than that created by the heavy marble before. Roll the heavy marble on the sheet. The light marble will follow the heavy one to fall towards it.
5. Ask students what causes the light marble to move and interact with the heavy marble? They should come to the conclusion that it is the curve of the sheet. Explain to them that this bending of space, causing objects to interact, is known as gravity.
6. Ask students to point out which marble shows to have the strongest gravity. They should come to the conclusion that it is the heaviest marble because it bends space the most. Confirm that because a black hole has

such extreme gravity it means that black hole bends nearby space more than many other objects, causing objects to fall into it and that the bending of space can be so extreme that these objects, even light which moves the fastest in Universe, cannot escape.

Because the heavy marble is bigger than the light marble, make it clear that in reality black holes can be much more massive than the other objects, but are generally much smaller in size.

Part 2: Observation of fed black hole - Accretion disk (5 min)

1. Tell the students that because even light is trapped by black hole, the black hole itself is invisible. Use the background information (with the provided slideshow or image) to explain that light and other things are only lost forever in a black hole once they pass a certain boundary region - called the event horizon.
2. Tell the students that outside the event horizon, there are effects created by black hole's gravity that show the existence of the black hole, despite not being able to visibly see it.
3. Use the accompanied documents (slideshow or image) and background information to explain that an accretion disk is an indirect way to observe a black hole. Emphasize that this is possible because materials have not yet passed the event horizon to be lost forever but are quickly spiraling in.
4. Prepare in advance cardboard sheets as the following. On each cardboard sheet, draw thin lines of spirals with an orange highlighter. The spirals should be quite closely packed. Draw large bold dots on the spiral lines. In the center, poke a hole.
5. Provide a cardboard sheet to each group. Explain that the center of the spiral is a black hole and that the dots are infalling materials (stars, gas, dust) outside the event horizon of the black hole. Put a skewer through the center hole of the cardboard. Students spin the cardboard as fast as possible.
6. Have the students observe that as the board spins, the spirals become almost like a disc of color that appears to be more visible than when it is stationary.
7. Ask students to relate this model with the phenomenon of an accretion disk . They should conclude that when spinning the cardboard, the dots are like materials falling in black hole, colliding and rubbing against each other vigorously due to the pull of black hole's gravity. They become heated up and the entire disk of spiraling material lights up. It is similar to how the spirals have formed into a brighter disc of color.

Part 3: Observation of resting black hole (10 min)

1. Prepare in advance some cardboard and paste a few magnets close to each other on the back of the cardboard. Paste the back of this cardboard to another piece of cardboard to cover up the magnets. Make a few of such items, one for each group.
2. Tell the students that when a black hole is not 'eating' material to form accretion disk, there are other ways in which we can detect it, based on the effects of the black hole's gravity on nearby stars. Give each group a cardboard and a ball bearing. Ask them to locate the area of the hidden cluster of magnets within this cardboard.
3. Students should move the ball bearing around to track the area that they can feel the attraction on the ball bearing. This is where the magnets are pasted on the other side. Ask students to use chalk to trace the area where

there is magnetic attraction on the ball bearing. The trail left by the chalk marks is where the magnet cluster is hidden in the cardboard.

4. Ask students to relate this activity with the effect of black hole on surrounding objects. The magnet is like the attraction by gravity of a black hole. The ball bearing is like a star nearby the black hole, gravitationally bound to keep orbiting around it.
5. Use the background information (and accompanied slideshow) to explain to the students that because of black hole's gravity, nearby stars (but not too close to the event horizon) are attracted to orbit around an apparently empty space, but in fact they are orbiting around a black hole. So, although resting black holes are invisible, the effect of their gravity on nearby stars allows their observation.

Part 4: Gravitational lensing (15 min)

1. Explain to the students that scientists can indirectly observe black hole as its gravity bends light.
2. Demonstrate to the students how gravity can bend light. Use tape to create a straight line on a table surface. This represents a ray of light, which travels straight in space.
3. Use a saucer to represent the curvature of space. Partly remove and lift up one end of the tape and move the saucer (upside down) to where the tape was previously. Put down the tape, pasting it onto the surface that is in its path (i.e. the saucer and the table). The tape cannot be pasted smoothly in a straight line as before, but has to be bent; only then it can be pasted smoothly on the saucer surface and on the table surface. The tape will not look like it is following a straight line as before, but appears bent.
4. Use this observation to explain how black hole bends light that passes nearby. Relate the saucer with curved space (which has been curved by the mass of black hole), meaning that light now travels on this curved space rather than a straight line, appearing to be bent by the black hole's gravity.
5. Tell students that light being bent by gravity is a phenomenon called gravitational lensing. Show an image of gravitational lensing (located in the accompanied slideshow/ image file). The presence of a black hole bends space, which then can act like a lens, bending light from a distant source as it passes behind it.
6. Place a candle on a cup and use a wine glass to view the candle through the base of the glass. The candle is a distant light source. The base of wine glass acts as gravitational lens.
7. The candle light is distorted and forms a ring or arc of light. The distorted images mimic the gravitational lensing phenomenon observed by telescope. Emphasize that the glass base is not really creating gravity. It just represents the effect of something "invisible", like a black hole, in front of the distant light source, distorting the path of the light before reaches us.
8. The presence of telescope images showing gravitational lensing, despite no observation of any object, indicates that there must be invisible mass creating the gravity. Hence, a black hole can be indirectly observed by the effect of gravitational lensing.





ADDITIONAL INFORMATION

The use of stretchy sheet and marbles for demonstration of gravity is inspired by previous Astroedu activity 'Model of a black hole'. The gravitational lensing activity is based on activities from Perimeter Institute for Theoretical Physics and from Inside Einstein's Universe Website.

For students to understand how black hole gets extreme gravity and captures anything that come too close, see Activity "What is a black hole?" (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

This activity firstly reinforces children's understanding about gravity, through which they understand why black holes have such strong gravity that even light cannot escape. Gravity of a black hole is a key concept to understanding how something invisible (such as a black hole) is observed by astronomers.

ATTACHMENTS

- [Supplementary images](#)
- [Presentation](#)
- [Student worksheet](#)

ALL ATTACHMENTS

[All attachments](#)

CITATION

Han Tran; Thomas Russell, 2018, *Hunting for black holes - Lower Secondary Level*, [astroEDU](#).

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