GALAXIES AND THE UNIVERSE | LESSON 8

Into the Dark

What black holes really are, and four different ways astronomers detect objects that give off no light.

Grades 7-12 | About 15 minutes of narrated flight, plus discussion stops | 8 stops | Start: learn.allseeing.space/into-the-dark

What students will see and do

Students visit Cygnus X-1, the nearby Gaia black holes, the center of the Milky Way, Andromeda, M87 and the giant quasar TON 618, learning about escape velocity, event horizons, the first black hole images and gravitational waves.

Learning objectives

- Define a black hole using escape velocity and the event horizon
- Describe how black holes are detected (X-rays, orbiting stars, imaging, gravitational waves)
- Compare stellar-mass and supermassive black holes
- Correct the misconception that black holes suck in everything around them

NGSS connections

MS-ESS1-2	Gravity holds galaxies together and governs orbits around black holes.
HS-PS2-4	Newton's law of gravitation: an object's pull depends on mass and distance, not size.
HS-ESS1-1 (extension)	Massive stars end their lives as neutron stars or black holes.
DCI ESS1.A / PS2.B	The Universe and Its Stars; Types of Interactions.

40-minute class plan

1. 5 min: pre-lesson prompt. Before we fly: write down one thing you have heard about black holes. We will check whether it is true by the end.
2. 18-20 min: run the lesson. Keep discussion stops short (1-2 minutes each) or turn them off in the Lessons menu.
3. 8 min: whole-class discussion using two of the questions below.
4. 5 min: Exit ticket: Name two different ways scientists can tell a black hole is there even though it gives off no light.

Full exploration (about 60 minutes)

1. 5 min: pre-lesson prompt, recorded so students can revisit it.
2. 25-30 min: run the lesson with every discussion stop at full length.
3. 15 min: follow-up activity. Escape velocity demo: roll marbles up a ramp; discuss what speed would be needed if the ramp kept getting steeper.

4. 10 min: revisit the pre-lesson ideas, then the exit ticket.

Before the lesson

Before we fly: write down one thing you have heard about black holes. We will check whether it is true by the end.

Discussion stops: timing and key points

At What is a black hole? (4-6 min): If the Sun were replaced by a black hole with exactly the same mass, what would happen to Earth's orbit? What would change on Earth?

- Earth's orbit would not change: at Earth's distance, gravity depends only on mass, not on how compact the object is.
- But there would be no sunlight, so Earth would quickly freeze and plants would stop making food.
- This counters the idea that black holes suck things in from far away.

At Sagittarius A star (3-5 min): Astronomers proved Sagittarius A star exists by watching stars orbit it for decades. Why is it important that scientists kept collecting data for so long?

- Stars near the center take years or decades to complete one orbit (S2 takes 16 years).
- You need long, repeated measurements to map an orbit and calculate the mass inside it.
- Repeated data rules out other explanations and builds strong evidence.

More questions for after the lesson

1. Why is the Event Horizon Telescope as large as Earth?
2. Why is M87* easier to photograph than the closer Sagittarius A*?
3. Do black holes last forever? Explain Hawking's idea.

Vocabulary

black hole, event horizon, escape velocity, accretion disk, supermassive, quasar, gravitational waves, spaghettification

Exit ticket

Exit ticket: Name two different ways scientists can tell a black hole is there even though it gives off no light.

Follow-up activities

- Escape velocity demo: roll marbles up a ramp; discuss what speed would be needed if the ramp kept getting steeper.
- Myth or fact: revisit the pre-lesson ideas and sort them with evidence from the lesson.
- Model a gravity well with a stretched sheet and a heavy ball, then roll marbles to show orbits.

Full transcript

Introduction

Welcome to Into the Dark. In this lesson we will visit black holes, the places where gravity has won completely. They are some of the strangest objects in the universe, and also some of the most misunderstood. A black hole is not a hole, and it is not a cosmic vacuum cleaner. It is a region where

matter has been squeezed so tightly that nothing, not even light, can escape.

The idea is older than you might think. In seventeen eighty three, an English clergyman and scientist named John Michell imagined dark stars so heavy that light could not leave them. In nineteen fifteen, Albert Einstein's theory of general relativity described gravity as the bending of space and time, and a year later Karl Schwarzschild used it to describe exactly such an object. The name black hole became popular in the late nineteen sixties.

Here is our question for the journey. If a black hole gives off no light at all, how do we know it is there? Watch how astronomers answer that question differently at each stop.

1. Cygnus X-1: the first black hole

Our first stop is Cygnus X-1, about seven thousand two hundred light-years away in the constellation Cygnus, the swan. In the nineteen sixties, rockets carrying X-ray detectors above the atmosphere found a powerful source of X-rays here.

Astronomers discovered a huge blue supergiant star circling something unseen every five and a half days. By measuring that orbit, they could weigh the invisible partner. It was about twenty one times the mass of the Sun, far too heavy to be a neutron star, yet giving off no light of its own. It was the first object widely accepted as a black hole.

The X-rays come from gas pulled off the blue star. Before falling in, the gas swirls into a flat disk around the black hole called an accretion disk, spinning so fast and rubbing so hard that it heats to millions of degrees and glows in X-rays. So the black hole is dark, but the material falling toward it is brilliant.

Cygnus X-1 is also famous for a friendly bet. In nineteen seventy four, the physicist Stephen Hawking bet his colleague Kip Thorne that Cygnus X-1 was not a black hole. As the evidence grew, Hawking happily admitted he had lost.

2. What is a black hole?

This is Gaia BH1, the closest known black hole to Earth, about one thousand five hundred and sixty light-years away. It is about ten times the mass of the Sun. Let us use it to understand what a black hole really is.

Every object has an escape velocity, the speed you need to break free of its gravity. To escape Earth, a rocket needs about eleven kilometers per second. Now imagine squeezing an object smaller and smaller. Its surface gravity grows stronger and its escape velocity rises. Squeeze it enough, and the escape velocity becomes greater than the speed of light. Nothing can get out. That is a black hole.

The boundary around it, the point of no return, is called the event horizon. To turn Earth into a black hole, you would have to crush its whole mass into a ball about the size of a marble. To turn the Sun into one, you would crush it into a ball about six kilometers wide.

Gaia BH1 is a quiet black hole. No gas is falling into it, so it does not glow at all. It was found in twenty twenty two by the European Space Agency's Gaia spacecraft, which measures the positions of stars with incredible precision. Gaia saw a Sun-like star moving in an orbit around nothing, and the only thing heavy and dark enough to pull it that way is a black hole.

Discussion stop: If the Sun were replaced by a black hole with exactly the same mass, what would happen to Earth's orbit? What would change on Earth?

3. Gaia BH3

This is Gaia BH3, found by the same spacecraft in twenty twenty four, about nineteen hundred light-years away. It is about thirty three times the mass of the Sun, the most massive black hole made from a single

star known in our galaxy.

How do stars become black holes? When a very massive star runs out of fuel, its core collapses. If the core is heavy enough, no force in nature can stop the collapse, and it falls inward to become a black hole. The outer layers may explode as a supernova, or the star may collapse almost quietly.

Gaia BH3's companion star is very old and contains few heavy elements. That is a clue. Stars poor in heavy elements lose less mass during their lives, so they can leave behind bigger black holes. Scientists think there may be about a hundred million black holes like these scattered through our galaxy, most of them completely dark and undiscovered.

4. Falling toward the center

Now we pull back to see our whole galaxy, the Milky Way, a spinning disk of a few hundred billion stars. The Sun sits about twenty six thousand light-years from the center, and it takes about two hundred and thirty million years to complete one orbit around it.

In the middle of the galaxy, hidden behind thick clouds of dust, lies something astronomers spent decades trying to understand. Ordinary light cannot get through all that dust, but infrared light and radio waves can. Using them, astronomers began watching the stars at the very center move.

5. Sagittarius A star

This is Sagittarius A star, the supermassive black hole at the heart of the Milky Way. It is about four million times the mass of the Sun, packed into a region that would fit inside the orbit of Mercury.

For more than twenty five years, two teams of astronomers, one led by Reinhard Genzel and one led by Andrea Ghez, tracked stars racing around the galactic center. One star, called S2, completes an orbit every sixteen years and swings by at thousands of kilometers per second. Only an enormous, compact, invisible mass could pull it that way. Genzel and Ghez shared the Nobel Prize in Physics in twenty twenty.

In twenty twenty two, the Event Horizon Telescope released the first picture of Sagittarius A star. It shows a glowing ring of hot gas around a dark center, the shadow of the black hole. Our black hole is fairly calm right now. It eats only small amounts of gas, so it is much dimmer than the monsters at the centers of some other galaxies.

Close to a black hole, gravity does strange things. Time runs slower near it, an effect predicted by Einstein. And if you fell toward a smaller black hole, the pull on your feet would be so much stronger than the pull on your head that you would be stretched out like a noodle. Scientists really call this spaghettification.

Discussion stop: Astronomers proved Sagittarius A star exists by watching stars orbit it for decades. Why is it important that scientists kept collecting data for so long?

6. M87 star, the first image

We leave the Milky Way now and travel fifty five million light-years to the giant galaxy M87. At its center lies M87 star, a black hole about six and a half billion times the mass of the Sun. Its event horizon is wider than our entire solar system out past Pluto.

In April twenty nineteen, M87 star became the first black hole humanity ever photographed. To take the picture, astronomers linked radio telescopes across the planet, from Hawaii to Spain to the South Pole. Working together and timed with atomic clocks, they acted like one telescope the size of Earth. They called it the Event Horizon Telescope.

The project gathered so much data that it was too big to send over the internet. Researchers flew stacks of hard drives from the telescopes to central computers, where the data was combined. It took about two

years of careful work before scientists were confident enough to share the image.

M87 star is far bigger than Sagittarius A star, which made it easier to photograph, even though it is much farther away. It also launches a jet of particles moving close to the speed of light, stretching about five thousand light-years into space.

7. A neighbor's black hole

On the way out, we pass Andromeda, the nearest large galaxy, two and a half million light-years away. Nearly every large galaxy seems to have a supermassive black hole at its center, and Andromeda is no exception. Its black hole is estimated at roughly a hundred million times the mass of the Sun, many times heavier than ours.

Astronomers have found that the bigger a galaxy's central bulge of stars, the bigger its black hole tends to be. That suggests galaxies and their black holes grow up together, each affecting the other. Exactly how is still being studied.

8. TON 618

Our final stop is one of the most massive black holes ever measured. TON 618 is so far away that its light left it more than ten billion years ago, long before Earth existed. Astronomers estimate it holds tens of billions of times the mass of the Sun.

TON 618 is a quasar. Gas pouring into the black hole forms an accretion disk so hot and bright that it outshines its entire galaxy, all its hundreds of billions of stars, many times over. Quasars are the brightest long-lasting objects in the universe.

Seeing TON 618 means looking back in time to the young universe, when giant black holes were growing quickly. How such enormous black holes formed so early is still one of the open questions in astronomy. The James Webb Space Telescope is finding big black holes even earlier than scientists expected.

There is one more way we detect black holes. In twenty fifteen, the LIGO detectors on Earth felt ripples in space itself, called gravitational waves, from two black holes colliding more than a billion light-years away. Einstein predicted those ripples a century earlier. It was a completely new way to observe the universe.

Do black holes last forever? Stephen Hawking calculated that, because of quantum physics, black holes should very slowly leak energy, now called Hawking radiation, and eventually evaporate. For a black hole the mass of the Sun, that would take far, far longer than the current age of the universe. No one has detected Hawking radiation yet.

Wrap-up

So how do we know black holes are there? By X-rays from hot gas, by stars orbiting nothing, by the shadow in an Event Horizon Telescope image, and by the ripples of gravitational waves. Each method sees the invisible in a different way.

And remember, black holes are not hunting for anything. From far away, their gravity is just like any other object of the same mass. Only up close do they become truly strange. Press L to choose another lesson.

Positions are computed live from real orbits. Narration is checked against public scientific sources; full credits at learn.allseeing.space/credits.html. Standards are listed as connections to NGSS, not formal alignments. Report an issue: info@allseeing.space