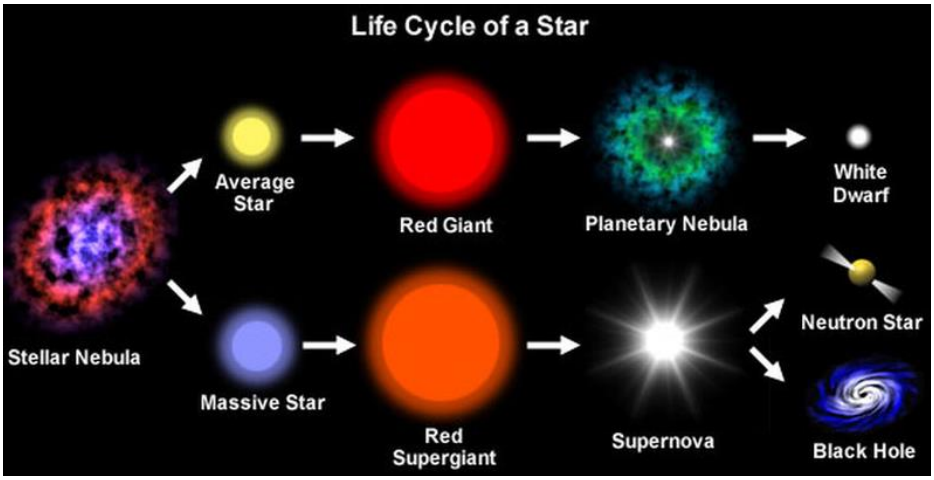
BLACK HOLES

Authors: Cernera Anna, Dovadola Chiara, Margotti Lucia, Vanmarcke Tibo, Verhelst Pieter, Vervelghe Bruno
Schools: Liceo Gregorio Ricci Curbastro, De Bron

Origins and history:

A black hole is a place in space that is so extremely dense that it creates such deep and strong gravitational attraction that even light cannot escape if it comes near enough.
The origin of a black hole is due to the death of a massive star. That massive star is formed by a Stellar Nebula, which is also called a cloud of gas or haze. Towards the end of the lifetime of the star, when the nuclear fuel is almost consumed, the outer layers of the star start to expand and then it forms a red supergiant. After that it will form a Supernova. That supernova can form a black hole or a neutron star. You can see the process on the picture. Primordial black holes are thought to have formed in the early universe, soon after the big bang.
Stellar black holes form when the centre of a very massive star collapses in upon itself. This collapse also causes a supernova, or an exploding star, that blasts part of the star into space.
Scientists think supermassive black holes formed at the same time as the galaxy they are in. The size of the supermassive black hole is related to the size and mass of the galaxy it is in.



Source: https://www.schoolsobservatory.org/learn/astro/stars/cycle

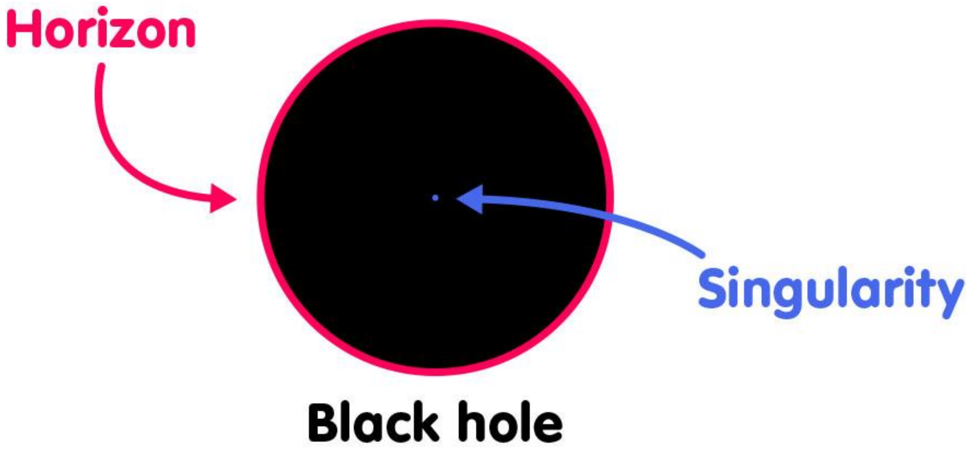
Physical properties:

Black holes have only three properties: their mass, their electric charge, and their amount of rotation, also called “angular momentum”.
The mass is connected with gravity and the electric charge with the electromagnetic force. There is no room for the nuclear forces in black holes, and the electric charge of most black holes is thought to be so small that it can be ignored, so gravity is the only fundamental force important to black holes. The gravity is so strong that no particles or even electromagnetic radiation, such as light, can escape from it. This is the reason why it is black.
The simplest black holes, often referred to as “Schwarzschild black holes”, are black holes that have mass but neither electric charge nor angular momentum. According to Birkhoff’s theorem , it is the only vacuum solution that is spherically symmetric. This means there is no observable difference at a distance between the gravitational field of such a black hole and that of any other spherical object of the same mass. The popular notion of a black hole "sucking in everything" in its surroundings is correct only near a black hole's horizon; far away, the external gravitational field is identical to that of any other body of the same mass.

Solutions describing more general black holes also exist: non-rotating charged black holes are described by the Reissner-Nordström metric, while the Kerr metric describes a non-charged rotating black hole. The most general stationary black hole solution known is the Kerr-Newman metric , which describes a black hole with both charge and angular momentum.
The defining feature of a black hole is the event horizon - the boundary in time space that acts as a valve for light and matter: they can only pass from the outside to the inside. Observation of what happens within the event horizon is therefore impossible from outside. Also, no signal can be sent out from within the black hole.

Process of formation:

As already mentioned, a black hole can be formed by the death of a massive star. When such star has exhausted the internal thermonuclear fuels in its core at the end of its life, the core becomes unstable and gravitationally collapses inward upon itself, it implodes.
The star's outer layers are blown away. The crushing weight of constituent matter falling in from all sides compresses the dying star to a point of zero volume and infinite density called the singularity.



Source: https://www.einstein-online.info/en/spotlight/changing_places/

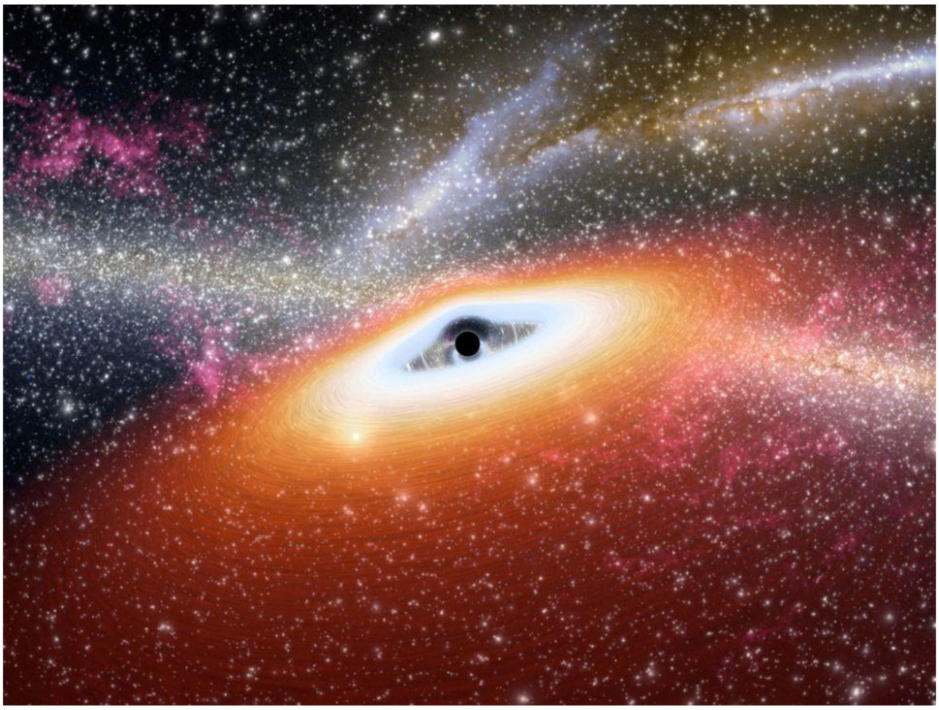
Details of the structure of a black hole are calculated from Albert Einstein's general theory of relativity. The singularity constitutes the centre of a black hole and is hidden by the object's "surface," the event horizon. Inside the event horizon the escape velocity (the velocity required for matter to escape from the gravitational field of a cosmic object) exceeds the speed of light, so that not even rays of light can escape into space, we learnt that the speed of light is the fastest speed in the universe, so once you get in a black hole, there is no way out. The radius of the event horizon is called the Schwarzschild radius, after the German astronomer Karl Schwarzschild, who in 1916 predicted the existence of collapsed stellar bodies that emit no radiation. The size of the Schwarzschild radius is proportional to the mass of the collapsing star. For a black hole with a mass 10 times as great as that of the Sun, the radius would be 30 km.

Types of blackholes:

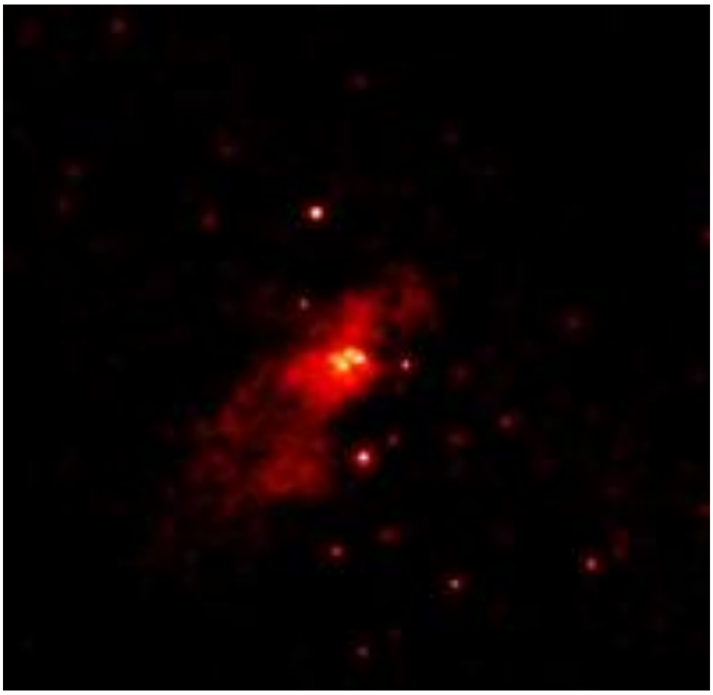
In the universe we find many different kinds of blackholes, from tiny structures to enormous ones. The first type that has been experimentally observed are *primordial black holes*. They formed thanks to initial density perturbation and from the condensation of raw materials in the early universe: the primordial black holes emerged soon after the Big Bang, as mentioned before. Various models predict the size of these types ranging from a Planck mass to hundreds of thousands of solar masses. Moreover, primordial blackholes characterised by larger masses might still exist today, whereas those with lowest-masses have most likely evaporated.
Secondly, we find *stellar-mass black holes* that formed by the gravitational collapse of a star and typically weigh between five and 10 times the mass of the Sun. Nevertheless, NSF's Laser

Interferometer Gravitational-Wave observatory (LIGO), the largest gravitational wave observatory, has discovered several with masses up to 100 times that of our sun. Indeed, they consume the dust and gas from their surrounding galaxies, which keeps them growing in size. According to the Harvard-Smithsonian Centre for Astrophysics, the Milky way contains a few hundred million of stellar black holes.
The third type is made up of those black holes who are considered to be in the mass range between stellar-mass blackholes and supermassive blackholes, the *intermediate-mass black holes*. It is important to mention that just recent researches have revealed the possibility of the existence of the so-called "midsize blackholes", perhaps in dwarf galaxies, which are characterised by a very small size.
Lastly, we find *supermassive black holes*, who are one of the most common group that can be found in the universe and are the largest type of black holes. Indeed, it is said that they have masses ranging from million to billions of solar masses, but are about the same size in diameter. Such black holes appear to be in the centre of almost all galaxies, including the Milky Way. Moreover, scientists are still studying their process of formation and they may be the result of the aggregation of many tiny blackholes and so their mass could have built up over time.

Illustration of a young blackhole, spotted recently by the Spitzer Space Telescope



Source: https://www.space.com/23583-dark-matter-tiny-black-holes.html

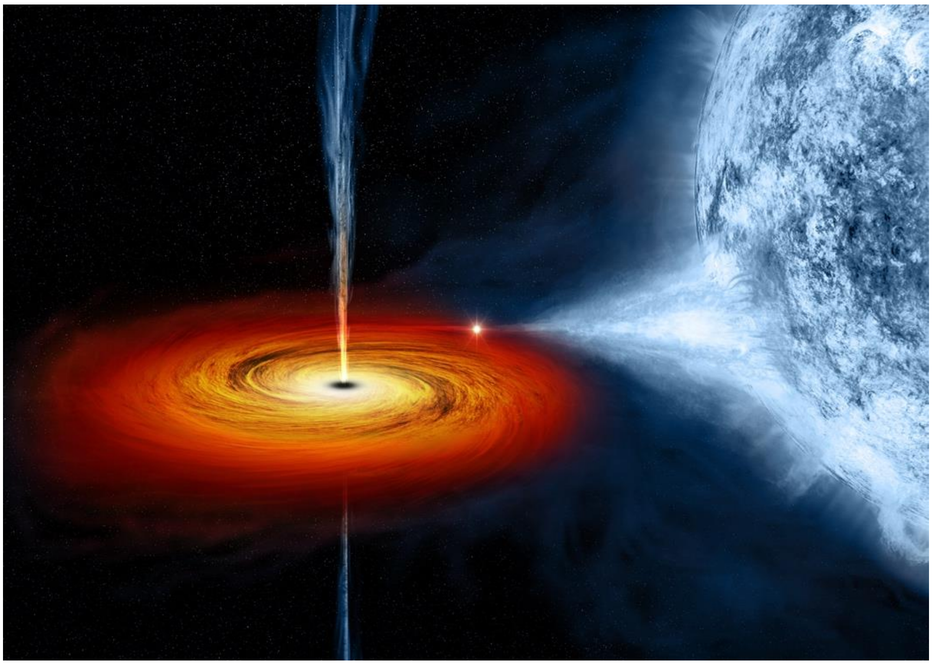


NASA's Chandra X-ray Telescope's discovery of the core of an intermediate-sized black holes, in the centre of the figure
Source: https://www.nasa.gov/vision/universe/starsgalaxies/Black_Hole.html

New discoveries:

While their enigmatic name was first coined in 1967, the idea of objects whose gravity is so intense not even light can escape them is far older. In 1783, an English scientist named John Michell showed that Newton's law of gravity suggested such objects could exist and despite being invisible, such objects might reveal themselves if they happened to have a star in orbit about them. During the 1930s, theorists using Einstein's General Relativity theory, showed that sufficiently massive stars could collapse under their own gravity at the end of their life, and turn into black holes. British astronomers Louise Webster and Paul Murdin at the Royal Greenwich Observatory and Thomas Bolton, a student at the University of Toronto, announced the discovery of a massive but invisible object in orbit around a blue star over 6,000 light-years away. The object, an intense X-ray source in the constellation Cygnus codenamed Cygnus X-1, is now regarded as the first black hole to be identified. Murdin began searching for a visible star that showed signs of motions. When the star is moving toward us it appears more blue, as the wavelength of its light gets shorter and moving away it appears more red as the wavelength gets longer. This is known as Doppler shift. After looking for color changes in hundreds of stars in the area of cities, Murdin spotted a possible suspect : a visible star whose light was shifting and it was clearly a binary star which was moving with a period going around once every 5.6 days. The binary pair found by Murdin showed only one star visible while the second object had enough mass and gravity to dramatically move a star but gave off no light. The crucial issue in deciding whether Cygnus X-1 was a black hole was to measure the mass of the x-ray emitting object and after many estimations Murdin was able to find that the object was six times the mass of the sun which became the key to find the answers about the fact that Cygnus X-1 was for real a black hole.

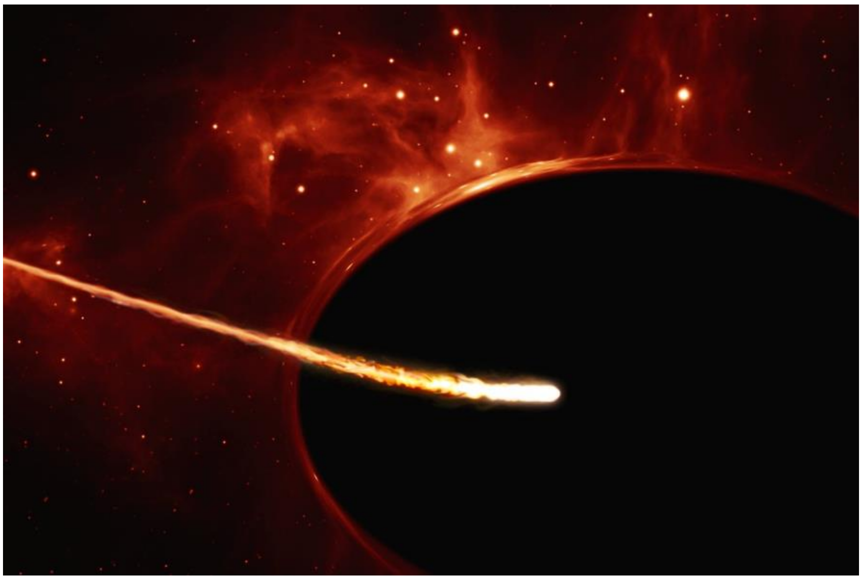
This picture shows how the Cygnus X-1 formed. This black hole pulls matter from blue star beside it.



Source: https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-a-black-hole-k4.html

Curiosities and weird facts:

Going on, we can talk about curiosity and weird facts about black holes. For example, if you fall into a black hole, it was thought that the gravity would stretch you like spaghetti, but a new study of 2012 suggested that actually all the effects produced while you are falling, would be probably similar to a fire wall, so you would be instantly burned to death. Actually, black holes distort time and space around them; so, if it happens that you fly near a black hole, its extreme gravitational attraction would slow down more and more the time and it would deform the space, you would be put ever closer to it assembled with a disk of orbiting space material like stars, planets, gases, that move as a spiral into the so-called "point of no return". After that gravity would overcome all your chances to escape and you would be super-stretched while you are falling into the singularity in the centre of the black hole with a mass, where gravity and density approach infinity. Another weird fact is that the Cygnus X-1 is the first object considered as a black hole (Cygnus X-1 is a source of x-rays that can be observed in the Swan constellation. Discovered in 1964, this source is a compact object very similar to a black hole). But actually, this Cygnus X-1 was the subject of a bet in 1974 between Stephen, one of the most famous and brilliant physicians of the history, and his colleague Kip Thorne: they bet that the source wasn't a black hole and in 1990 Hawking admitted his defeat. Another curiosity, is if a star passes too much near a black hole, the star could be torn apart, and so it would die and it would be eaten by the black hole. For example, the phenomena known as "tidal destruction event" was the nearest explosion of a star ever recorded; it is about 125 million light years distant and the explosion was caused by the extreme attraction of a black hole in the centre of a galaxy that destroyed the star and as a consequence thin flows of material took form. Another fact is that astronomers estimate that the Milky Way has from 10 million to 1 milliard stellar black holes, which have a mass of four times the one of the sun. As we know, black holes became important elements in science fiction books and movies: an example could be the film "Interstellar", that relied heavily on Thorne to incorporate science. Thorne's work with the special effects team led to scientists' improved understanding of how distant stars could appear near a black hole during a rapid rotation.



This is an image showing a tidal destruction event, so we can see a star that approaches too much close to a black hole and, because of the very strong attraction, the star can't turn back and it just continues to fall until the black devours completely the star.
Source: https://www.space.com/15421-black-holes-facts-formation-discovery-sdcmp.html

Bibliography:
BBC, "nearest black hole to Earth discovered", internet, 6 May 2020
- https://www.bbc.com/news/science-environment-52560812

NASA, "Stellar-Mass Black Hole", internet, 21 February 2012
- https://www.nasa.gov/mission_pages/chandra/multimedia/igr.html

NSF, "Exploring black holes", internet
- https://www.nsf.gov/news/special_reports/blackholes/

SPACE, "What are Black Holes?", internet 11 July 2019
- https://www.space.com/15421-black-holes-facts-formation-discovery-sdcmp.html

NATIONAL GEOGRAPHIC, "Black holes, explained", internet
- https://www.nationalgeographic.com/science/space/universe/black-holes/

NASA, "A new Kind of Black Holes", internet
- https://www.nasa.gov/vision/universe/starsgalaxies/Black_Hole.html

NASA, "What is a Black Hole?", internet, 21 August 2018
- https://www.nasa.gov/audience/forstudents/k-4/stories/nasa-knows/what-is-a-black-hole-k4.html

SCIENCE FOCUS, "Who really discovered Black Holes?", internet
- https://www.sciencefocus.com/space/who-really-discovered-black-holes/

SCIENCEMAG, "Physics Nobel honors discoveries about black holes", internet, 6 October 2020
- https://www.sciencemag.org/news/2020/10/physics-nobel-honors-discoveries-about-black-holes

WIKIPEDIA, "Black hole", internet, 4 March 2021
- https://en.wikipedia.org/wiki/Black_hole

TREEHUGGER, "7 Weird Facts about Black holes", internet, 5 February 2021
- https://www.treehugger.com/weird-facts-about-black-holes-4864130

BRITANNICA, "Black Hole", internet
- https://www.britannica.com/science/black-hole