Hey everyone, and welcome to another episode of The Universe and You, the show where I, your host, will tell you about the infinite universe that we all live in, and you, the listener, can sit back, relax, and have an existential crisis about your place in reality.

Today's topic is one of the most poorly understood topics in science, falling somewhere between dark energy and quantum mechanics. We're talking about black holes. I want to start with a story about my dear little sister and her first encounter with the giant space ninjas that are black holes.

Growing up i was a great, big nerd. I'm still a nerd, but I do more research on my own now, when I was younger I mostly absorbed documentary after documentary teaching me about nearly every topic a 10 year old could imagine. One day while my parents were having a dinner party with some of their friends, or whatever it is that adults do, I chose to pursue the expansion of my mind instead of listening to their little discussions about the weather or the economy. I'm 20 years old and I still have no idea what it is that adults talk about. But anyway, I plopped myself down on the couch and surfed the channels until I found a documentary series about space on the Science Channel that I knew about. The topic of the particular episode I was watching was about black holes. Now they told me a lot of cool stuff, at least I thought it was, but my sister, who was five, got three main ideas from it: we can't see black holes, black holes consume everything that gets near them, and they can move through space. My sister has always been smarter and more imaginative than me and she immediately connected that there could even be a black hole on its way to gobble up our little spaceship called earth, and we would never see it coming. Naturally this terrified her and she ran off to cry in her room about the inevitable destruction of humanity. A heavy burden for any five year old, meanwhile I couldn't stop laughing. But as it turns out, she was right. Black holes are terrifying, but they are also one of the most important things in the universe because they, and their powerful gravity, are the glue that keeps everything together.

But what exactly are the space ninjas and why do they do what they do? Short answer, they're dead stars who cannot be studied because they may or may not be responsible for breaking quantum mechanics. The long answer though, that is one of the most interesting and important ideas in science.

The existence of black holes was first theorized in the 18th century by two scientists, John Michell and Pierre-Simon Laplace. They believed that, according to the current understanding of gravity, there must exist objects whose gravitational forces were so great that nothing, not even light itself could escape them. These ideas were refined by David Finkelstein's interpretation of the first modern solution for general relativity, which was published in 1916. At that time black holes were believed to only be a mathematical curiosity, something that was technically possible but definitely a ridiculous ideas that no one could take seriously. Then astronomers took them seriously and discovered neutron stars, which are a type of super dense, super heavy, objects known as gravitationally collapsed compact objects. These objects are basically just the result of the collapse and supernova of very massive stars when they die. These black holes usually

have less matter than the star whose ashes they rose out of like a phoenix, and while they are still very dangerous, they aren't the most dangerous black holes in space. After a black hole is formed, they can still gobble up matter, or even cosmic background radiation, like a galactic pacman. A black hole's ability to consume matter, as terrifying as it is, is one of the most important mechanics of black holes.

The structure of black holes can be broken down into three main parts: the accretion disk, the event horizon, and the gravitational singularity. We're going to work our way in from the outside. The outermost component is the accretion disk, which is usually a plane, or flat disk, of matter which surrounds the black hole. This matter is being drawn into the black hole while being buffeted by tidal forces. The result of all these forces is that most of the matter becomes superheated and forms plasma, which makes the accretion disk brighter than many stars. The form that the accretion disk takes in three dimensional space varies depending on what kind of black hole it is, and whether or not it's rotating. The next component of the black hole, the event horizon, is the part of the black hole that is the most terrifying. This part is a boundary in spacetime, which no information can escape. Since quantum mechanics is basically just about the preservation of information, this is where black holes tend to break science, since the event horizon got its name because any event that takes place within it is completely undetectable to the rest of the universe. Event horizons are also the line that, once crossed, no particle or wave can escape, despite what the movie Interstellar may tell you. Past the event horizon, at the center of the black hole, is the gravitational singularity, or the point at which the spacetime curvature becomes infinite. This is just a fancy way of saying that the volume becomes infinitely small, and has almost all of the mass in the black hole concentrated in one place. Since density is just the mass divided by the volume, this means that the gravitational singularity has infinite density. Here's the scary bit, as matter approaches the singularity, it stretches out, a process referred to as the spaghettification of the matter. Basically it takes anything, no matter how strong or massive, and turns it into spaghetti before tearing it apart and adding it to the collective that is a black hole.

So after pigging out on the matter that strays too close, black holes can grow and evolve into larger and larger forms, increasing their gravitational power until it is so great that it can affect the evolution of galaxies. These final form black holes are known as supermassive black holes which are several million times more massive than our own sun. Supermassive black holes are responsible for the formation of galaxies because even now, as you're sitting in your home or in your car, you are being swung around a supermassive black hole as the Milky Way swirls about it at around 220 kilometers per second. You see, there are supermassive black holes at the center of every galaxy, at least that's the general consensus because black holes cannot be directly observed or detected by existing technology. The giant at the core of the Milky Way is called Sagittarius A, which has a mass of about 4.3 million times that of our own Sun. In astronomy, most planets and their orbits are measured in units of the radius, mass, and orbital distance of earth. This isn't a good system for the scale breaking size of stars, black holes, and galaxies, here scientists use units which are derived from the mass and radius of the Sun. While most black holes end up having masses somewhere between four and 1000 solar masses,

supermassive black holes are exclusively measured in the millions. These black holes and, scientists think, dark matter are the driving force for the formation of galaxies, using their immense power to capture stars or even other black holes in their orbit.

So you may be asking yourself, why would we become so convinced black holes must exist if the only real evidence we've talked about are the formation of accretion disks, which may just be weird star clusters, and mathematical equations that could just be wrong? Well there are two main reasons why scientists believe black holes must exist, and one only gained evidence in 2015. The first observation that scientists made that supported the idea of black holes occured in 1995, when astronomers made observations of 90 stars rotating an invisible object near the radio source, Sagittarius A. See at that time we weren't really sure that it was a black hole, only that it was an object which emitted large amounts of x-rays and other forms of radiation. By observing these stars, scientists estimated that a 2.8 million solar mass object with a radius of 0.02 light years, an estimate that was later refined to 4.3 million solar masses and 0.002 light years, must exist and that they are rotating around. These stars are so close and are moving so quickly that since these observations were made, one of the stars has made a full orbit. There are no other even theorized objects that could be responsible for this gravity so it must be a black hole. The other reason that scientists believe black holes must exist is the first ever detection of gravitational waves which happened in 2015. These waves are the result of two black holes colliding and merging, which sends almost undetectable ripples through space time. Einstein theorized that these existed in his general theory of relativity, but he didn't think science would ever be able to detect them. These ripples are so small that they shifted the 4.5 kilometer device used by the laboratory that detected them, by one 1000th the width of a proton. The black holes involved were a formerly binary black hole system each being 20-40 solar masses.

Like all things, even the universe, black holes must end. How exactly they end is a matter of some debate. Stephen Hawking once theorized that black holes, through the emission of photons and other particles, can eventually evaporate because their mass is no longer large enough to maintain the singularity. Typically black holes receive more mass from the cosmic microwave background radiation than they emit, which keeps the mass from decreasing. The problem of evaporation only comes up when black holes are less than a stellar mass. Hawking has also theorized that as black holes grow, they emit less radiation, which means that the larger a black hole is, the less cosmic background radiation they would have to consume just to maintain their singularity. But, and here's the really confusing part, this doesn't make black holes immortal. There exists, all over space, virtual particles that don't really exist and can pop in and out of existence. Also, they're pairs made up of a particle, and its antiparticle. This means that as soon as these particles steal away a little energy to form, they immediately annihilate each other and return to the world of not quite existence that is quantum mechanics. Now when these particles pop into existence at the event horizon of a black hole, they steal some energy from it to form, but something unique happens, the antiparticle gets sucked into the hungry hungry black hole, but the positive particle gets fired into space, its suicidal nature left unfulfilled. This results in a tiny amount of matter being stolen from the black hole. This is how black holes emit radiation. Now believe it or not, this is a simplified version of what is actually happening,

according to Hawkings at least. In reality the death of a black hole is the result of a process that began at its birth and is related to the fields of potential particles which permeate spacetime, but let's stick with the virtual particles for this episode.

But black holes can't be all bad can they? Surely they must have some benefits that we can maybe someday use? There are actually! Black holes are so massive that they can actually bend light around them, which can even result in magnification! It can also result in the observation of things that were hidden behind something else, like a never before seen galaxy that was hidden behind Andromeda! Through a phenomenon called gravitational lensing, scientists believe that someday, when the right black hole is discovered, astronomers could use them as cosmic telescopes, letting them see farther than ever before. Of course, since we can't directly observe black holes and it's almost impossible to nail down even a general area, this idea is a far way from reality, but it is something astronomers dream about! Another potential use for black holes is kind of terrifying. Some physicists have theorized that the conditions inside of certain, nonrotating black holes, could be just weird enough to allow for a wormhole to be formed, creating a gateway to another place, or even universe or time. Scientists even think that micro black holes could be used as a form of energy and can be made with particle accelerators! Unfortunately for science and the fantasies of scientists, these innovations and technologies are a far way off, but they're a bright future to aim for.

Thank you everyone for listening in to this week's the Universe and You, join us next week when we talk about how not only is our planet one of trillions in the universe, but our universe could be one of trillions of universes as well! If you have any questions, comments, or suggestions for future topics, you can find us at the network facebook page, Signifying Nothing Network, found at facebook.com/SignifyingNothingNetwork or on our website, SignifyingNothingNetwork.com. This has been the Universe and You by the Signifying Nothing Network, have a good, existentially unimportant week!