

Black Holes: An Introductory Overview

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1 Introduction

While the study of black holes is still an extremely active field of research, there still remain many unanswered questions. This paper aims to briefly summarize what we *do* know of black holes to date, answer some of the commonly asked questions, and touch on topics that still are being researched.

2 Black Hole Background

As we will see later there are a few main types of black holes. This section will outline some basic information about black holes that is common across all types such as density of black holes, event horizons, and how black holes are mainly observed.

2.1 Mass? Volume? Are we talking about music at a Catholic church here or black holes?

At a most basic explanation, a black hole is an object that has mass and has been compressed into an "impossibly" small volume, at which point "weird" stuff starts happening. Imagine you had an elephant (which of course has mass) and you try to cram all of the elephant into a shoe box (an "impossibly" small volume). Now you know that wouldn't physically be possible. Mathematically, however, it is! Using mathematical formulas, you can calculate how densely packed the elephant would need to be in order to fit inside the shoe box by dividing the mass of the elephant by the volume it needs to fit in.

$$\rho = m/V \tag{1}$$

Using Equation (1) we can calculate the density of the elephant-filled shoe box assuming the elephant has a mass of 6350 kg and the shoe box has a volume of 6270 cubic centimeters. Plugging these values in results in a density (ρ) of approximately 1 kg per centimeter cubed. For reference, the density of water is 1 g per centimeter cubed or *one thousand times less* dense than our elephant in a shoe box.

Now imagine a stellar object that weighs a billion times more than our Sun, but fits into a mathematical volume of a pinpoint. Now you have a black hole!

2.2 Event Horizon... No, not the movie.

While from a mathematical perspective black holes have no volume, in reality they do in fact occupy more space than just a pinpoint. This volume of space is called the **event horizon**. The event horizon has a measurable diameter (distance across its surface) that is proportional to how much mass the black hole has: a bigger black hole means a larger event horizon.



Figure 1: Nothing that crosses the event horizon can ever come back! But the good news is, if you don't get too close to it you have absolutely nothing to worry about.

The event horizon is a one way ticket to never being seen or heard from again. **NOTHING** can come back from the event horizon: not matter (AKA you), not sound (your screams for help), not even light (no SOS with a laser) which is the fastest known traveling thing in the universe! It sounds scary, but as long as you don't get *too* close you will be ok!

2.3 How do we observe them?

Telescopes work by observing both visible light (colors!) and invisible light (infrared, x-ray, radio, microwave, etc). Since not even light can come back from the event horizon, (until recently) black holes have been impossible to see through images. They do, however, have observable mass! Our Sun has planets revolving around it because its high mass "captures" these objects and keeps them close by. In other words, its mass has a direct effect on objects near it. So when we observe similar effects on other stellar objects, such as stars revolving around an invisible central point, we can deduce a black hole is nearby!

3 Types of Black Holes

There are three main types of black holes: **supermassive** being the largest, **stellar** being the smallest, and **intermediate** fitting somewhere in between. While not much information is known about intermediate black holes (such as how they are formed), more information about supermassive and stellar black holes is presented in this section.



Figure 2: Andromeda has a very similar shape, structure, and appearance to the Milky Way. Also like the Milky Way, has a supermassive black hole at its center!

3.1 Supermassive Black Holes

They're even bigger than that one Muse song!

3.1.1 Where Are They and How Do They Form?

It is unknown how supermassive black holes form. However, they are commonly found in the centers of spiral galaxies (such as the Milky Way and Andromeda) as well as virtually in all other large galaxies [1]. As apparent from their names, these black holes are HUGE! Supermassive black holes can have masses millions or even billions of times that of our own Sun [1]!

3.2 Stellar Black Holes

Much more is known about how stellar black holes form and live largely because they are much more prevalent throughout the universe. For example, our own Milky Way galaxy has an estimated 10 million - 1 billion stellar black holes [1] while only containing a single supermassive black hole at the core.

Stellar black holes are formed when a very large star at the end of its life goes supernova. When a very large star runs out of fuel, it causes an immensely large and powerful explosion outwards. Supernova can also occur in binary star systems in which a larger star steals mass from its binary partner. It will continue

consuming mass until it becomes too large and unstable, triggering a supernova. In either supernova event, mass is excreted outwards before collapsing back in on itself rapidly creating an immensely dense object: a black hole!

Our own Sun does not have enough mass to go supernova and thus will not collapse into a black hole at the end of its life. Instead, it will go nova (a smaller event than a supernova) and turn into a red dwarf. (Aside: stellar evolution is extremely interesting in itself and is worth its own paper)

4 Do Black Holes "Suck"?

Short answer: no. As mentioned in previous sections, black holes only "consume" matter that passes the event horizon. Aside from that, black holes behave as any other massive object would with observable and predictable results. Stars and other celestial bodies can orbit around black holes as if it were a star. For example, if our Sun was suddenly swapped for a black hole of the same mass, Earth would still be here AND it would remain in its same orbit! All that would change is that it would be *extremely* dark without our star to give us light.

In general, your ability to escape the clutches of the event horizon (or any massive object) depends on your velocity, or speed, and your distance from the object. If you've heard the term "**escape velocity**", this is what it is referencing. To escape Earth's gravity, for example, you need to be traveling at a speed that can counteract the $9.8m/s^2$ acceleration trying to pull you back down. The farther away you are from Earth, the less you feel this "pull", so your speed does not need to be as great. So when matter (dust, comets, gas, etc.) close to a black hole's event horizon is not traveling at a speed greater than or equal to the escape velocity, it will eventually fall into the black hole. While it is in the process of falling into the black hole, it becomes what is called an **accretion disk** in a degenerative orbit around the event horizon.



Figure 3: The black central region of the image is the event horizon. The reddish-orange around the event horizon is the accretion disk.

5 ”Seeing” a Black Hole

Until very recently (2019) black holes could only be indirectly detected by observing anomalous gravitational effects of nearby objects. In 2019, however, a global effort was able to capture the first colored images of a distant supermassive black hole [2]! Since light itself cannot even escape the event horizon, that portion of the image still remains a dark circle. The red, orange, and yellow seen vividly in Figure 3 is in fact the accretion disk! The accretion disk is a mixture of gas, dust, and any other matter that could not escape falling towards the event horizon. As it falls, its speed increases continuously until it is at the speed of light on the event horizon. As it speeds up, its temperature increases which is the glow we see in the image.

6 Conclusion

While we still have much to learn about black holes, the relatively little we do know has advanced the modern understanding of physics and astrophysics dramatically in just the past century. The study of black holes is still a very active and engaged field of research, so expect our understanding to continue evolving as our knowledge of black holes grows!

References

- [1] NASA Science. Black holes, 2020.
- [2] NASA Chandra X-ray. Black hole image makes history; nasa telescopes coordinated observations, 2019.