Andrea Wainwright
INTD100: Coffee and Black Holes
Professor Hanson
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GW190521

The study of cataclysmic events such as black hole mergers is a fascinating area of astronomy that continues to evolve with the improvement of technologies. Since the creation of the LIGO gravitational wave detector and its european sister Virgo, many new discoveries in the world of astrophysics have been made, such as the observation of gravitational waves, and what causes them. Gravitational waves, or ripples in spacetime, are detected by LIGO and Virgo to determine when two black holes merge with each other to create a bigger black hole. There are three different sizes of black holes, stellar mass black holes, intermediate mass black holes, and supermassive black holes. Scientists have not been able to detect a medium sized, or intermediate mass black hole until May 21st, 2019. This discovery was officially announced by LIGO as the first direct observation of an intermediate mass black hole in history on September 2nd, 2020. This initial discovery will allow for further cosmic exploration and will open doors to the idea of new possibilities.

Within this paper, the basic information required for the understanding of this event is organized as follows. First, in section 1, LIGO and Virgo and their functions will be discussed, as well as the categorization details of the sizes of black holes. In section 2, the specifics of the black holes that were a part of this discovery will be made clear, as well as how they are unusual in relation to other black holes discovered. In section 3, theoretical causes of these black holes will be explained, as scientists have not determined the exact cause of two black holes involved in this event.

Section 1:

The LIGO and VIRGO interferometer facilities located in Washington state, Louisiana and Italy are giant gravitational wave detectors. LIGO is funded by the NSF and operates through the LSC, which involves scientists from over 14 countries. Gravitational waves are most often caused by the collision of two black holes. These collisions are categorized by size in terms of the mass of the sun. These categories are: stellar mass black holes (10 times the mass of the sun, or 10 solar masses), intermediate mass black holes (100 - 10,000 solar masses), and supermassive black holes (more than 1 million solar masses). The interferometers detected a signal 1/10th of a second long [1] in May of 2019 that was the merger of two black holes causing the first intermediate mass black hole observed, named GW190521[3]. This was the collision of two black holes with masses of 85 and 66 solar masses, creating a black hole with a total of 142 solar masses, and releasing 8 solar masses worth of energy [4].

Section 2:

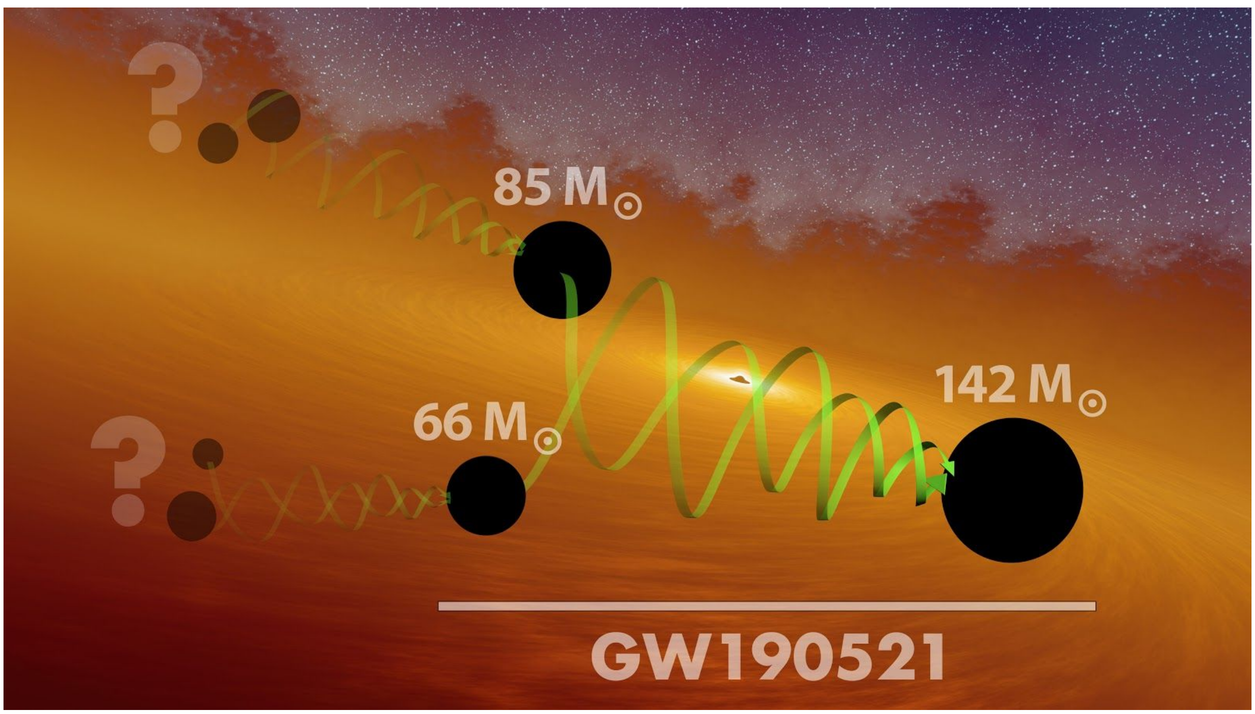
The black holes that were involved in the formation of this intermediate mass black hole were unusual compared to other black holes observed. They were spinning in opposite directions of each other, which is atypical of binary black holes. This could mean that they were not located near each other for very long before colliding [1]. Gravity assists in black hole mergers by bringing the two merging black holes close to each other, making them spin in the same direction. The fact that these black holes were unaligned could suggest that there was not a lot of time when gravity was acting on them as a pair, meaning they were separated not long before colliding. This event happened 5 gigaparsecs or 16 billion light years away, when the universe was half its age [2]. The signal produced in the form of gravitational waves travelled space for 7 billion years before reaching Earth [5], making it one of the most distant gravitational wave sources ever detected. Another unique thing about GW190521 is that it may have produced a light flare that was visible to astronomers via the Zwicky Transient Facility [5], which is a camera attached to a telescope. Usually black hole mergers are too dark to pick up with a telescope, which could indicate that this merger was located near a supermassive black hole. This is another aspect which makes this black hole unique.

Section 3:

What caused the black holes involved in the GW190521 merger is still a mystery to scientists. It is known, however, that the mass of this black hole means it defies the pair instability mass gap. The pair instability mass gap is when the protons inside heavy stars become energetic, they can turn into an electron antielectron pair. This decreases the amount of pressure pushing outward against gravity inside the star, causing the star to collapse on itself. Therefore, the stars that could have made the black holes that were involved in GW190521 should not be able to produce a black hole that is between 65-120 solar masses[4]. One of the black holes that was involved in the collision that caused this intermediate black hole, however, defies the pair instability mass gap, because it had a mass of 85 solar masses. So how is this possible? Although there is no definitive answer, there are a few different theories on how this occurred. It could be that the two stars that created the black holes involved were not stars but were also black holes. This is the theory of progressive/ hierarchical mergers, meaning it was a series of black holes continuing to collide until this intermediate black hole was created. This is shown in figure 1. Another possibility for the defiance of the pair instability mass gap could be that the black holes involved could be located in the disk of a supermassive black hole. The disk surrounding a supermassive black hole could host tens of thousands of stellar mass black holes, which could lead to the merging of them to reach the mass gap size [6]. However the cause of a black hole the size of the one that caused GW190521 is unknown, it is known that with further advancements of technologies that it could be proven one day, and that other black holes of this size range may exist.

The LIGO and Virgo gravitational wave detectors were built to detect signals of cataclysmic events through gravitational waves. Black hole mergers of stellar mass and supermassive had been detected, but until May of 2019 an intermediate mass black hole had not yet been detected. This groundbreaking discovery has opened the doors of new possibilities in astronomy, and the further innovations in technology could lead to further study of black holes in distant galaxies.

Figure 1



An artist's representation of hierarchical black hole mergers. Taken from source [3].

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