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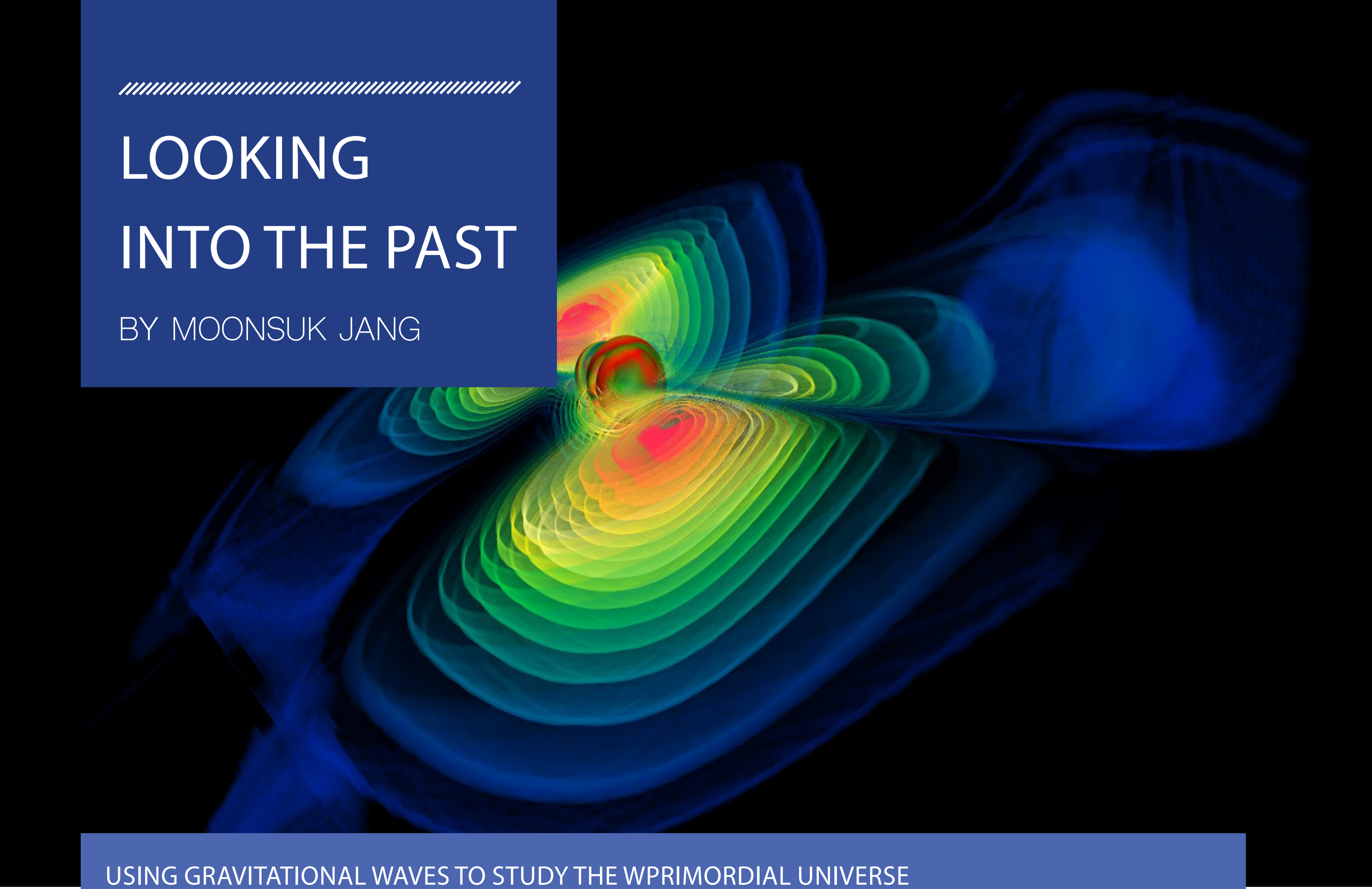


LOOKING INTO THE PAST

BY MOONSUK JANG

USING GRAVITATIONAL WAVES TO STUDY THE WPRIMORDIAL UNIVERSE

February 11, 2016. LIGO scientists officially announced the direct detection of gravitational waves. It instantly became one of the hottest topics of the day, and people expressed their excitement. Some because they understood the significance of the discovery, and some because they wanted to blend in. To better understand about the excitement, it is important to know what gravitational wave is, and why it is a remarkable achievement to detect them.

WHAT IS GRAVITATIONAL WAVE

Gravitational waves are, of course, waves, but where did they get "gravitational" part from? To know why these waves are specifically called "gravitational" waves, we need to first take a look at some features of gravity. According to Einstein, gravity can be explained as curved space. "Gravitational waves are ripples in the fabric of spacetime."[1] Just like heavy objects can bend space around them, propagation of gravitational waves creates ripples, or distortion, in the spacetime fabric. Gravitational waves can be generated by any accelerating object with mass, which means objects we can see everywhere such as cars, can generate gravitational waves. However, to generate strong enough gravitational waves to be detected, we need much more energy than that. The gravitational waves scientists detected at LIGO was caused by two black holes, each with mass of 29 and 36 suns, colliding with each other 1.3 billion years ago. 3 suns' worth of mass turned into pure energy which was radiated as gravitational waves. Kip Thorne, a physicist at the California Institute of Technology, said, "It is by far the most powerful explosion humans have ever detected except for the Big Bang."[2] Another distinctive feature that gravitational waves have is that it can travel freely. Most waves like sound waves or ocean waves require medium to propagate. That means, without proper medium, there cannot be waves. Electromagnetic waves, on the other hand, do not require any medium, and that is why this is about the only tool we can use to study about the universe. Just by using electromagnetic waves, scientists could unravel many mysteries about the universe, but it has its limit. We know from our daily experience that light can easily be blocked. Also, light can be bent, distorted, or even trapped by strong gravity. Some of the most interesting objects, such as black holes cannot be studied using electromagnetic waves. Since light cannot escape from inside black holes, it is impossible to study what is going on inside black holes using electromagnetic waves. Gravitational waves, however, barely interact with matters, which means that they do not lose as much information as they travel across the universe. Gravitational waves can still be absorbed by enough masses with dissipative forces, but it is practically impossible.[3]

HISTORY OF SEARCH FOR GRAVITATIONAL WAVES

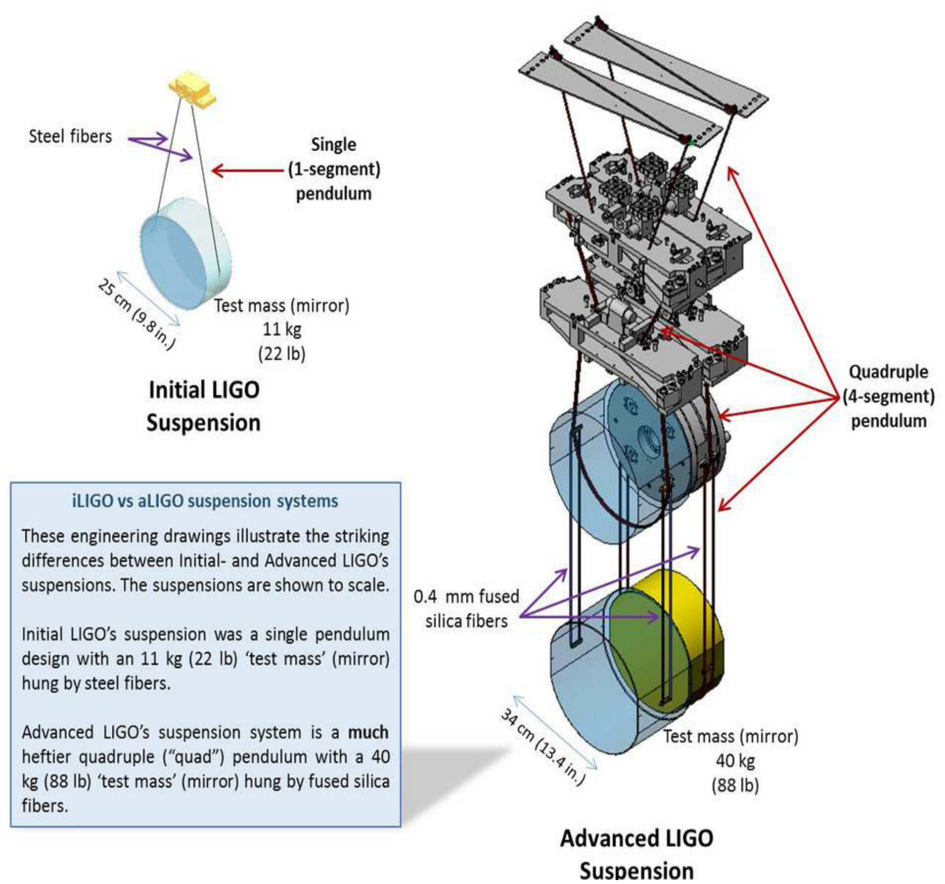
Ever since their existence was predicted by

Einstein in the early 20th century, there have been numerous attempts do confirm the existence of gravitational waves. In 1969, Maryland physicist Joseph Weber used two aluminum cylinders to detect gravitational waves.[4] Weber's idea was that when gravitational waves pass the cylinder, the cylinder would resonate with gravitational waves. Just like LIGO detectors are located at two different places in the US, he placed two cylinders at two different locations to rule out false signals arising from other sources. Since Weber bars are far apart, the bars will not pick up noise from the identical source. Weber bars picked up identical signals multiple occasions, and Weber concluded that coincident detections he made at two different locations are due to gravitational waves.[5] However, as other scientists failed to reproduce Weber's results, his experiment was questioned, and eventually, rejected. Weber's experiment did not have enough precision to detect gravitational waves, it is not surprising considering simply how much "bigger" LIGO detectors are, and Weber's instruments only targeted narrow bandwidth of frequency; unless gravitational waves have frequency close to aluminum's resonance frequency, aluminum bars won't be able to resonant with incoming waves. Although Weber was not successful at detecting gravitational waves, his experiment kick-started the search for gravitational waves. In 1978, two physicists, Joseph Taylor, Jr. and Russel Hulse, discovered two neutron stars orbiting each other. Taylor and Hulse knew that this discovery would present a great opportunity to test Einstein's general theory of relativity. Taylor and Hulse observed these stars for over 30 years and found out that they are orbiting faster and faster while getting closer to each other over time, which means they are losing energy. Taylor and Hulse's observation agreed with theoretically calculated value from Einstein's theory. They did not detect gravitational waves directly, but they provided an indirect proof of the existence of gravitational waves. They were awarded the Nobel Prize "for the discovery of a new type of pulsar, a discovery that has opened up new possibilities for the study of gravitation."[6] After Taylor and Hulse's discovery, many projects began to make direct observation of gravitational waves. Finally, in 1990, construction began on the LIGO detectors. After the initial LIGO was built, it operated for 9 years without any success in detecting gravitational waves. However, from the initial LIGO, scientists could learn how to operate, maintain and improve such a detector. From 2008 to 2015, for 7 years, scientists used what they learned from iLOGO to upgrade the detector. One of the main tasks was to improve its suspension. Suspension is crucial to reduce undesired noise to increase its sensitivity. Advanced LIGO (aLIGO) was 10 times more sensitive than iLIGO, and as soon as it was on, it put an end to a century long search for gravitational waves.[7] Gravitational wave detection was, by no means, an overnight achievement. It is a result of 100 years of dedicated work. To achieve this seemingly impossible goal, 620 million dollars have been spent to build a detector with 4-kilometer long tunnels.[8] After you see "620 million dollars," it is hard not to ask why. Why would anyone want to spend that much money on this project? Is it worth it? The short answer is yes.

> "It will also present a chance for us to learn about the earliest stage of the universe"

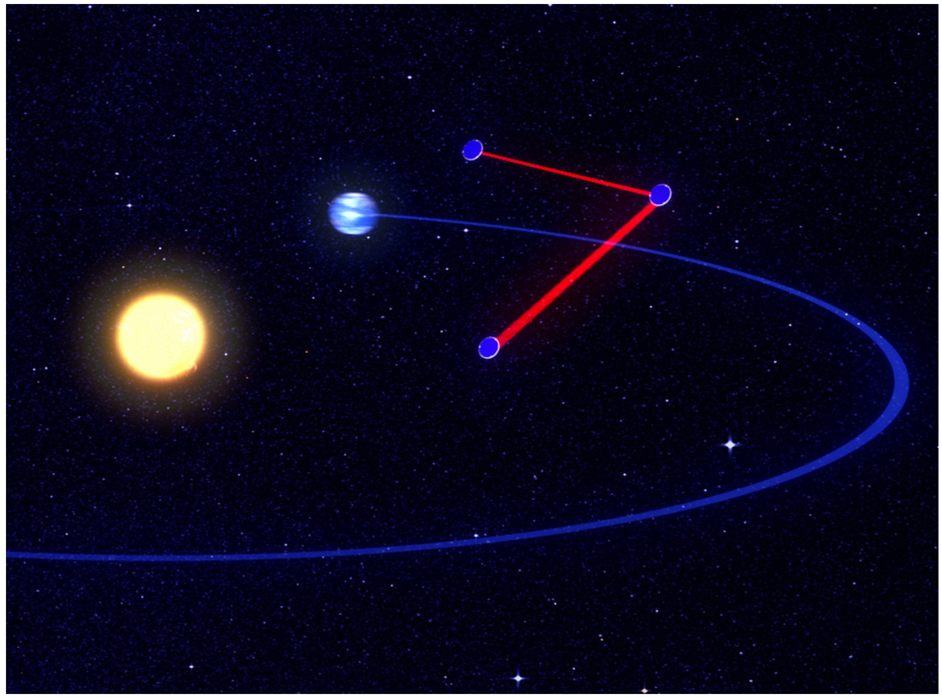
WHY IS IT IMPORTANT

Many people are skeptical about pouring millions of dollars into science programs because they believe that i whatever discoveries scientist make will not contribute to real life at all. It is true that knowledge



iLIGO vs aLIGO suspension comparison

humanity can learn from such science projects is priceless, but if a project were to cost 600 million dollars, there better be some practicality. Not all scientific discoveries come with obvious practical values, and even when they do have great possibilities, we oftentimes fail to recognize them right away. "It's of no use whatsoever." This is the answer Hertz himself gave to the question asking practical usage of electromagnetic waves. Hertz knew that his discovery has importance of providing experimental evidence that proves Maxwell's idea, but he could not see the great possibilities and values of his own discovery.[9] Obviously, no one could come up with ideas of cell phone or Wi-Fi then. As of now, it is simply not be possible to fully understand what gravitational waves can offer to humanity in the future. One imminent benefit is that gravitational waves can be a new tool that can help us uncover many mysteries. Just like telescopes and microscopes allowed us to see the world too far away or too small for our naked eyes to see, gravitational waves will greatly broaden our understanding of the world. Gravitational waves can be compared to x-ray in a way. Like mentioned earlier, there are too many obstacles that make it harder or impossible for us to observe our universe using electromagnetic waves. Electromagnetic waves can be absorbed and blocked by dust, or they might be trapped by black holes before they reach us. Gravitational waves, on the other hand, cannot be completely blocked by dust, stars, or even black holes. Just like we can use x-ray to see through some obstacles, we can, with the help of gravitational waves, see what we couldn't see before. True importance of gravitational waves lies in the field of unknown. Janna Levin, an astrophysicist at Barnard College of Columbia University, wondered "Are there things out there that we've never even wrapped our heads around with telescopes?"[10] Our knowledge of universe is very limited, and there are so much more that we don't know than we do. Gravitational waves might offer a chance to learn something that we have never imagined of.



A rendered image of eLISA satelites.

WHAT'S NEXT

Humanity took its first step into the new era, but there are much more left to be done. Gravitational waves won't just magically tell scientists all about the universe. Scientists merely got their hands on a new tool, and now it's time to think about how to use it. We can emphasize some unique features of gravitational waves by comparing them to electromagnetic waves, but, perhaps, it is more natural to compare gravitational waves to sound waves. Like sound waves, unlike light, gravitational waves spread out to all direction, which means we cannot know exactly where it is coming from by using one detector. What we have to do to pinpoint where the gravitational waves are originated from, we need to use multiple detectors at different locations to triangulate a signal. This also indicates that gravitational waves detectors can pick up, not necessarily with the same sensitivity, gravitational waves coming from any direction. Those detectors do not need to point towards the source to detect incoming signals. It is interesting to detect gravitational waves, and study the waves themselves to learn what information they contain, but, after all, what we really want to do is to find out where the signals are originated from, and study the source of gravitational waves. To do so, we need more detectors. Two LIGO detectors are simply not enough to tell us where exactly the signal is coming from. Many projects have already set in motion to construct additional detectors, and not all of them are going to be on Earth. The European Space Agency's (ESA) Evolved Laser Interferometer Space Antenna (eLISA) project is aiming to build a gravitational waves detector in space. Three satellites, located 1 million kilometers apart from each other and connected by two laser arms, will be orbiting the Earth while perfectly maintaining their formation. On top of that, eLISA will be free from many external noise sources which allows eLISA to have much better precision. With its improved capability, eLISA will be able to cover much broader range of frequency.[11] After the first successful detection of gravitational waves, it surely seems like more and more resources are being poured into the search. That is because the final goal is never to just confirm the existence of gravitational waves. More advanced detectors such as eLISA can be used as a telescope that can be used to observe the most interesting events in the universe. Another significance that gravitational waves has is the possibility of them being able to provide an answer to one of the most important question of all time; how did it all begin? It is human nature to wonder where we come from, and many interesting answers to that question have been offered. Unfortunately, there is no way to recreate the Big Bang in a lab, and the best way to study what happened then is too look at what it left behind. It was only after about 380,000 years after the Big Bang that the universe became "transparent" enough for light to travel freely. However, gravitational waves could travel around the hot and dense universe. According to current theory, the universe experienced an accelerated expansion for the tiniest fraction of a second, and it would have created gravitational waves which can leave imprints on Cosmic Microwave Background.12 There have been many projects to find imprints of primordial gravitational waves. In 2014, Background Imaging of Cosmic Extragalactic Polarization (BICEP2) experiments found a "curly" pattern of light polarization called B-modes which was believed to be a pattern left on CMB by gravitational waves "squeezed and stretched" the space. However, following measurements found out that the signal detected by BICEP2 came from cosmic dust. Dust contribution was much higher than BICEP2 team originally expected from the data available at the time. Even though the team failed to find evidence of inflation, this does not disprove inflation itself. "The gravitational wave signal could still be there, and the search is definitely on," said Brendan Crill, a member of both the BICEP2 and Planck teams from JPL.[13] The imprints of gravitational waves on the CMB, if found, will provide evidence for inflation theory, and it will also present a chance for us to learn about the earliest stage of the universe. Gravitational waves literally offer "glimpse into the past." Since primordial gravitational waves have wavelength comparable to the size of the universe, it won't be possible for us to directly detect it, and as it can be seen from BICEP2 experiments, it will be extremely challenging to find any sign of gravitational waves created about 14 billion years ago. It might even seem impossible, but so was detecting gravitational waves when their existence was first predicted.[14]

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