

State-of-the-art of LIGO

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Abstract—The existence of gravitational wave had always been a mystery since the appearance of LIGO, the most ambitious project ever funded by National Science Foundation (NSF). This huge science facility is constructed by two dependent interferometers located in Livingston, America and Hanford, America. LIGO discovered the gravitational wave of a merging Neutron star binary in 2015 with the joint effort of thousands of scientists, and this extraordinary facility is still working to discover the secret of the mysterious universe. This passage will discuss the State-of-the-art of LIGO and the future of the gravitational wave discovery technology.

INTRODUCTION

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is a large-scale physics experiment and observatory to detect cosmic gravitational waves and to develop gravitational-wave observations as an astronomical tool. [1] Meanwhile, gravitational waves-such things that LIGO designed to discover, are the disturbance in the fabric (“curvature”) of space-time generated by accelerated masses and propagate as waves outward from their source at the speed of light. Just as Fig.1 shows, gravitational waves can be detected from if there exist a explosion of the star. LIGO use its huge Interferometers to receive waves produced by stars in the sky, with this, scientists can analyse data and uncover the secret of the origin of our universe.

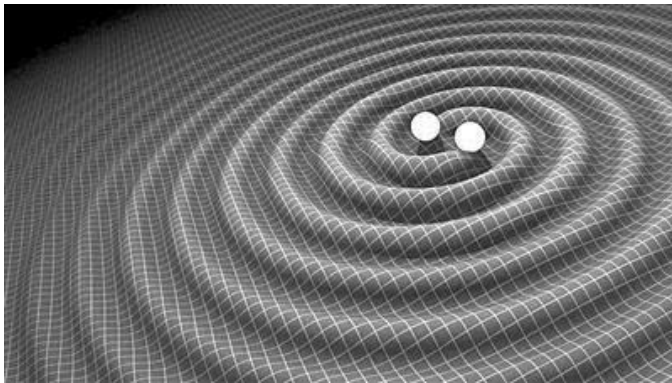


Figure 1. gravitation waves (http://www.sohu.com/a/122532803_116172)

HISTORY

The initial operation of LIGO was in 2002, however, scientists did not discover any trace of gravitational wave during 2002 to 2010. The research was thus in dilemma. In a gesture to end the awkward situation, LIGO went offline

for a major upgrade after 2010. The upgrade was finished in a few years: “by the time the LIGO Laboratory started the first observing run ‘O1’ with the Advanced LIGO detectors in September 2015, the LIGO Scientific Collaboration included more than 900 scientists worldwide.” [2]. Such upgrade was a honorable breakthrough in human history, the gravitational wave was then discovered: “The waveform showed up on 14 September 2015, within just two days of when the Advanced LIGO detectors started collecting data after their upgrade.” [3] And up to now, LIGO has discovered the gravitational waves for six times and has provided various precious data for scientists to discover the origin of our universe.

Nowadays, LIGO is still on its way to upgrade. According to the official website of LIGO: “As planned in 2013, further upgrades following O2 (of unspecified duration) will be followed by a nine-month O3.” [4] And further observing runs will be interleaved with commissioning efforts to further improve the sensitivity. It is aimed to achieve design sensitivity in 2021. [5] This means that the researching group of LIGO is still trying to find ways to improve their facilities, with more and more high-tech instruments added to the lab, LIGO will surely keep its edge among various of gravitation wave observatory.

TECHNOLOGY

Originally, gravitational waves were predicted by Einstein’s general theory of relativity in 1916. However, at that time, technologies were not advance enough to detect whether such things exist. An indirect proof of it was offered by Hulse and Taylor when observations of the binary pulsar PSR 1913+16 in 1974 showed an orbital decay which matched Einstein’s predictions of energy loss by gravitational radiation. The Nobel Price in Physics 1993 was awarded to Hulse and Taylor for this discovery. [6] The direct way to detect gravitational waves has long been sought from then on and it was not until 1970 did scientists including Rainer Weiss realized the applicability of laser interferometry to gravitational wave measurements. Robert Forward operated an interferometric detector at Hughes in the early 1970s. [7] With the joint effort of scientists before us, our gravitational-wave detection technology gradually shaped.

Thanks to the scientists before us, the technologies applies to LIGO, the magnificent science facilities, is almost the most advanced in the world nowadays. Consists of two observatories, each observatory supports an L-shaped ultra high vacuum system, measuring 4 kilometers (2.5 miles) on each side. Up to five interferometers can be set up in each vacuum system. The locations, however, were carefully selected. Due to the speed of waves, two sites were separated in a distance of 3000 kilometers. As is showed in Fig.2, the distance corresponds to

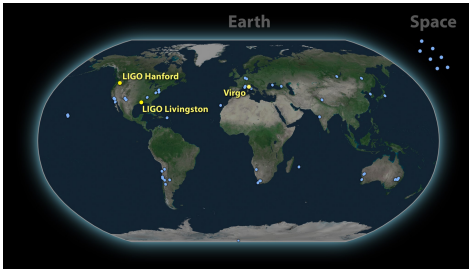


Figure 2. positions of different LIGO sites(https://www.cdsm.cn/gallery/wzl/orient/201710/t20171019_621501.html)

a difference in gravitational wave arrival times of up to ten milliseconds. Through the use of trilateration, the difference in arrival times helps to determine the source of the wave, especially when a third similar instrument like Virgo, located at an even greater distance in Europe, is added. [8] With such advanced facility, no wonder gravitational waves can be discovered by the scientists.

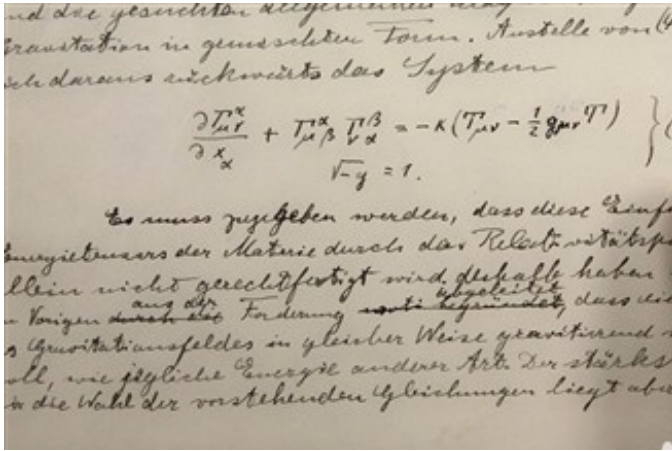


Figure 3. notes of gravitation waves from Einstein(<https://imgsa.baidu.com/exp/w=480/sign=e04326869782d158bb8258b9b00b19d5/d788d43f8794a4c24c54474305f41bd5ad6e3966.jpg>)

FUTURE

LIGO definitely has a bright future according to its ability to attract famous scientists and regular upgrade of its facilities. These two reasons are the guarantee of the future of LIGO.

The current detector LIGO use is called advanced LIGO detector Fig.3 is its simplified picture. The instrument has helped scientists to explore the endless universe for many years.

However, the progress of science does not stop. In order to keep pace with the development of science and make the most of their advantage, LIGO is ready to improve their instruments. Such improvements are referred to as "A+" proposals, and are planned for installation over the decade from 2017 to

2026. [9] The brand new technique would use frequency-dependent squeezed light, which would simultaneously decrease radiation pressure at low frequencies and shot noise at high frequencies, and improved mirror coatings with lower mechanical loss. As a matter of fact, the upgrade would almost double Advanced LIGO's sensitivity and range. [10]

Meanwhile, LIGO tends to be a world wide science project in the following years. The expansion of worldwide activities in gravitational-wave detection to produce an effective global network has been a goal of LIGO for many years. And according to LIGO's official website, The current agreement between the LIGO Scientific Collaboration and the Virgo collaboration links three detectors of comparable sensitivity and forms the core of the international network between different countries. Studies indicate that the localization of sources by a network that includes a detector in India would provide significant improvements. [11] [12] The report indicates that a global-sized of gravitational-wave detection activity is likely to launch in the future starting from India. From then on, the discoveries from different LIGO observatory will be much more than situation at present, that will be a prosperous time for our science and space technology.

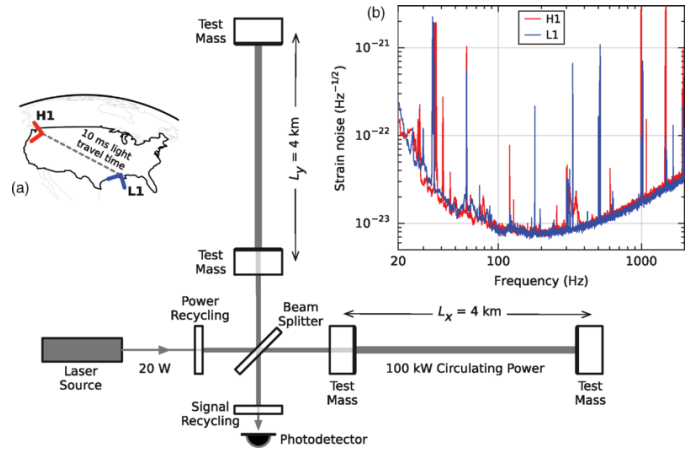


Figure 4. Simplified diagram of an Advanced LIGO detector by By Abbott, B. P. et al. (<https://commons.wikimedia.org/w/index.php?curid=46922746>)

CONCLUSION

The Laser Interferometer Gravitational-Wave Observatory (LIGO), as the most advanced facility to discover gravitational waves which can not be discovered directly by common devices, is leading its science group to explore one of the most difficult field of the universe. With regular upgrade and reasonable attribution of its staffs, advanced technologies invented would soon be applied to instruments to improve its range and sensitivity, outstanding scientists would swiftly participate in the research conducted by LIGO whenever there appear a vacant position.

LIGO is the crystallization of the efforts and wisdom of the scientists since a few generations before us. The curiosity of

human motivates them to calculate, to build, to explore. With such inner spirit, LIGO can keep focus on its goal: to seek the truth of our living space.

LIGO might pause temporarily, but its exploration will never stop and it will surely bring us much more things we eager to know about the mysterious universe we are now living in. Just as what LIGO Science collaboration announced recently: LIGO is currently paused but will start running again in Fall 2018 for the O3 run (joint with Virgo). [13] However, every stuff, every scientists, every people on earth knows, this is just a small rest for LIGO for its next exploration, the glory time for space exploration would soon come.

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