Interesting Gravity Wave Phenomena Recorded by LIGO and Virgo Detectors

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ABSTRACT

The existence of gravitational waves is one of the last unsolved mysteries of the cosmos. The famous physicist Albert Einstein predicted these waves in 1916. This research aims to understand how gravitational waves occur in space-time from various sources. This study describes the detection of gravitational waves from several sources. This study uses the literature review method, through several stages such as literature study, data collection, and analysis. The result of this study is that the LIGO (Laser Interferometer Gravitational-Wave Observatory) and Virgo detectors detect gravitational waves through the collision source of two neutron stars orbiting each other emitting gravitational waves that experience a constant loss of energy so that the neutron stars are getting closer according to the shrinking orbital period and increasing wave frequency tall. For the source of the fusion of two black holes, two large interferometric detectors from the LIGO (Laser Interferometer Gravitational-Wave Observatory) scientific collaboration detected gravitational wave signals based on an analysis of the general theory of relativity showing they originate from two black holes combining 29 and 35 solar masses merging 1.3 billion light years on Earth, after a black hole merger produces a mass of 62 Suns. And the source of gravitational waves from binary mergers of black holes and neutron stars, the LIGO (Laser Interferometer Gravitational-Wave Observatory) dan Virgo detector observes gravitational wave signals. The merger of a neutron star and black hole produces light across the electromagnetic spectrum.

Keywords: gravity wave detection, space-time, source of gravitational waves.

INTRODUCTION

The existence of gravitational waves is one of the last unsolved mysteries of the cosmos. The famous physicist Albert Einstein predicted these waves in 1916, that gravity is the result of the existence of objects curving space-time (Abbott et al., 2016). According to this theory, gravity is a result of the existence of objects that bend space-time. This is comparable to a person resting on a bed and causing it to swell. The mattress in this example represents space-time, the mass of the person is mass, and the resulting curvature is gravity.

For years, researchers have worked to establish the existence of gravitational waves. The Laser Interferometer Gravitational Wave Observatory could not find these waves until finally on September 14, 2015, members of the LSC (Ligo

Scientific Collaboration) determined that the waves came from two massive black holes colliding and merging (Cervantes-Cota et al., 2016). Gravitational waves are ripples in the curvature of space-time that travel in waves away from their source. Gravitational waves occur due to disturbances caused by massive oscillating masses or changes in the curvature of space-time. There are several sources of gravitational waves in the universe. Some of them are multiple star systems, supernova explosions, collisions between two black holes, inflation of the universe, and neutron stars (Riles, 2013).

The LIGO (Laser Interferometer Gravitational-Wave Observatory) detector is one of the largest and most sensitive gravitational-wave observatories in the world. This detector consists of two observatories located in the United States, namely LIGO Livingston, Louisiana and LIGO Hanford, Washington. The LIGO (Laser Interferometer Gravitational-Wave Observatory) detector uses the principle of a laser interferometer to detect gravitational waves. The detector has successfully detected several different sources of gravitational waves, such as colliding binary black holes, colliding binary neutron stars, triple black hole systems, and merging black holes and neutron stars. The Virgo detector is a gravitational wave observatory that works together with LIGO (Laser Interferometer Gravitational-Wave Observatory) to detect gravitational waves. This detector is located in Cascina, near Pisa, Italy. Like LIGO (Laser Interferometer Gravitational-Wave Observatory), the Virgo detector also uses the principle of a laser interferometer to detect gravitational waves. The detector has successfully detected several different sources of gravitational waves, such as colliding binary black holes, colliding binary neutron stars, triple black hole systems and merging black holes and neutron stars (Abbott et al., 2004).

METHODS

The method used in this research is the literature review method which uses several stages, namely: literature study, data collection and analysis. The research aims to understand how gravitational waves occur in space-time from several sources. This research uses several stages, namely:

1. Literature Study

   The literature study method is an activity related to the method of collecting library data, reading and managing research materials.

   Einstein described gravitational waves as vibrations or disturbances in the geometry of space-time that propagate like waves on a distorted water surface.

   LIGO (Laser Interferometer Gravitational-Wave Observatory) is a laser interferometer observatory designed to detect gravitational waves, its instrument uses two parallel arms several kilometers long which are used to measure changes in distance due to gravitational waves.

2. Data Collection

   The data used comes from international journals, scientific articles, books and information from various other media as a support that contains the concepts studied.

   1) Presenting background about gravitational waves
   2) Explain the purpose of the study to detect and observe gravitational waves
   3) Describe the method used to detect gravitational waves
   4) Presenting gravitational wave observation data generated by LIGO (Laser Interferometer Gravitational-Wave Observatory)
   5) Describe the main findings that have been achieved through the detection of gravitational waves
   6) The significance of findings in understanding of the universe, confirmation of the general theory of relativity, and the development of physics and astronomy
   7) Presenting the challenges faced in the detection technology for further research
   8) Concludes that the discovery of gravitational waves through the LIGO (Laser Interferometer Gravitational-Wave Observatory).

3. Analysis

   From the results of research that are verified one by one from the most relevant,

relevant and quite relevant. Describes the process of analysis performed on gravitational wave data, which includes the detection of gravitational waves from sources such as colliding black holes, neutron stars, or other cosmic phenomena.

RESULT AND DISCUSSION

In this study the LIGO (Laser Interferometer Gravitational-Wave Observatory) and Virgo detectors do not detect what gravitational waves are like, but examine space-time where space-time is disturbed. So that detectors judge that it occurs due to gravitational waves generated by the collision or merger between two black holes, the collision of two neutron stars, and the merger of binary neutron stars and black holes.

1. Collision of Two Neutron Stars

   Through gravitational wave detectors LIGO (Laser Interferometer Gravitational-Wave Observatory) and Virgo, detected in two observations the impact of two neutron stars colliding about 130 million years ago. Neutron stars are created after the gravitational collapse of a massive star at the end of its life, which triggers a supernova explosion.

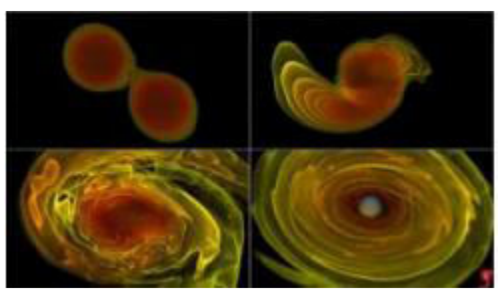

Figure 1. Numerical-relativistic simulation of two orbiting and melting neutron stars (GW170817). (Sources: Dietrich, S. Ossokine, H. Pfeiffer, A. Buonanno (Max Planck Institute for the Physics of Gravity), BAM Collaboration)

The numerical-relativistic simulation above shows the density distribution during the fusion process. Higher densities are shown in red, lower densities in yellow. Recent analytical calculations and numerical simulations show that the nuclear repulsion force is weaker in neutron stars than some models predict. If strong nuclear repulsion were active, the neutron star would be more easily deformed which would produce a very different gravitational wave signal. When a neutron star rotates at high speed, deformation occurs due to centrifugal force. This deformation can cause the shape of the neutron star to become asymmetrical. This asymmetry creates an imbalance in the distribution of mass and energy within the neutron star.

The detection of gravitational wave signals from a neutron star can information about the rotational characteristics of the star, such as rotational speed, deformation shape, and the internal properties of the neutron star itself. Observation and analysis of gravitational waves can help understand the extreme properties of a neutron star and explain associated astrophysical phenomena. These scientists use a variety of techniques, including analytical calculations and numerical simulations to model the properties of neutron stars and predict their behavior. For example, groups of researchers involved in the study of neutron stars, theoretical astrophysics, and numerical modeling can carry out analyzes and simulations to evaluate the effect of the strong nuclear repulsion force, the rotation of the neutron star, and the resulting deformation on gravitational wave signals.

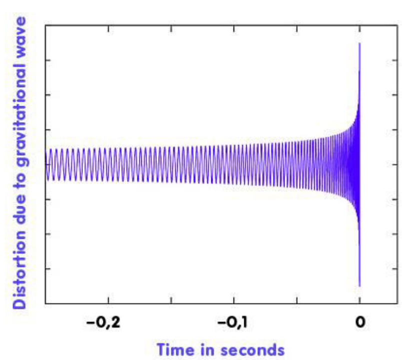

Figure 2. Graph of gravitational wave frequency and its increasing strength. (Source: Markus Possel, “Chirping neutron stars” at Einstein Online)

When two neutron stars orbit each other collide, they will spin inward by emitting gravitational radiation in the form of gravitational waves and as they spin inward they will orbit faster so that the two stars will merge in just a few milliseconds to form a donut-like shape, this merger will cause other gravitational waves and intense radiation in the form of gamma rays. Two neutron stars orbiting each other emit gravitational waves, the closer they are, the shorter the orbital period and the higher the frequency of gravitational waves.

The event when two neutron stars collide, the collision produces enormous gravitational energy. This energy propagates away from the crash site in the form of gravitational waves. These gravitational waves occur episodically, that is, only when collisions occur. The gravitational waves from the collision of two neutron stars have a high amplitude and a frequency that varies depending on the nature of the collision.

2. Merger of Two Black Holes

Two large interferometric detectors from the scientific collaboration LIGO (Laser Interferometer Gravitational-Wave Observatory) with major contributions from German researchers detected a signal known as "GW150914" that originates from the merging of black holes.

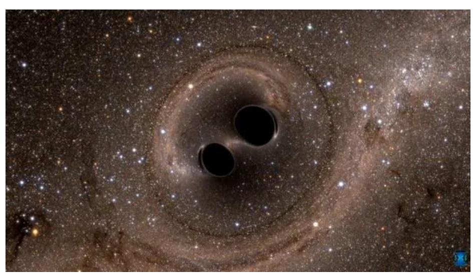

Figure 3. Illustration of two black holes revolving around each other. It was this kind of system that created the gravitational waves that were detected for the first time. (Source: Indonesian edition of Space Scoop Universe Awareness).

The fusion of two black holes that were originally orbiting each other, then two black holes illustrated by black balls towards the center. The two black holes are getting closer to each other as time goes by so the gravity is a bit stronger. Gravity is slightly weaker, which represents this wave moving outward to communicate information that gravity changes in time as objects orbit each other to visualize what's happening. Simulation of two black holes revolving around each other as the two black holes orbit each other they lose energy and angular momentum into gravitational waves so the black holes get closer and orbit faster until they eventually collide merging into one black hole as rings descend. The gravitational waves from the merger of these two black holes tend to occur in one episode that is much longer than that of a neutron star collision. These gravitational waves have a high amplitude and a frequency that gradually increases as the black holes get closer to each other. The two black holes have been close together for billions of years and are getting closer from time to time, so that the speed of each other's rotation is constantly changing which eventually produces gravitational waves (Brilianza et al., 2021).

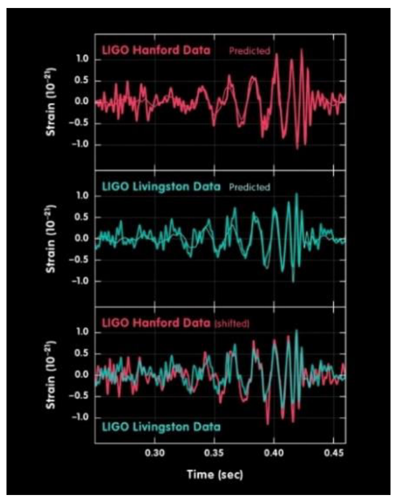

Figure 4. The gravitational wave signal GW150914 seen at Hanford (H1) and Livingston (L1) is measured in seconds. (Source: LIGO/Redesign: Daniela Leitner)

GW150914 gravitational wave signal at two LIGO (Laser Interferometer Gravitational-Wave Observatory) detector locations, namely at Hanford on the top graph or red graph and in Livingston on the middle graph or green graph. The simulation results show that the pattern matches the expected signal from the merger of the two black holes in the graph below.

GW150914 arrives first at L1 and $6.9^{+0.5}_{-0.4}$ ms later at H1 for visual comparison, H1 data is also shown shifted in time by this amount and flipped (to account for the relative orientation of the detectors) (Abbott et al., 2016).

3. Merger of Binary Black Hole (BH) and Neutron Star (NS)

The LIGO-Virgo detector observed gravitational wave signals from two compact inspiral binaries consistent with neutron star-black hole (NSBH) binaries. The two events are named GW200105 and GW200115.

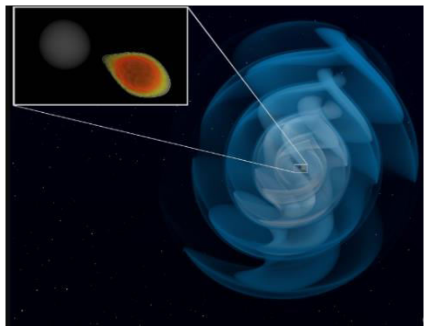

Figure 5. Numerical simulation of the merger of a neutron star and black hole (NSBH). (Source: LIGO Scientific Collaboration)

Numerical simulations show the merger of a neutron star and black hole (NSBH) system. Merging black holes and neutron stars have a density exceeding that of a solid atomic nucleus and are also capable of accelerating matter and particles to very high speeds at relativistic speeds and then emitting very energetic light such as x-rays and gamma rays. These objects are so dense that they can modify space-time and potentially create gravitational waves, so neutron stars and black holes are actually the remnants of the most massive stars.

Merging a black hole and a neutron star, at first the orbits of the neutron star and black hole may have been far apart and stable. Over time, gravitational energy causes their orbits to narrow and their eccentricities to increase. When the neutron star and black hole are very close, strong gravitational interactions can cause a merger. During this fusion significant energy is released in the form of gravitational waves that travel through space-time. The gravitational waves from the merger of two neutron stars and a black hole have a lower frequency and higher amplitude than those of a merger of two neutron stars or a black hole. The merger between a neutron star and a black hole produces a distinctive characteristic in the occurrence of gravitational waves, namely: a high amplitude due to changes in space-time deformation that occurs during the merger is very significant and the resulting gravitational waves have great strength. The low frequency is due to the nature of the mass and size of the objects involved in the merger. Has a distinctive wave pattern. Transient gravitational signals, gravitational signals from the merger of a neutron star and black hole usually last only a few seconds to a few minutes. The similarity between the collision of two neutron stars, the merger of two black holes, and the binary merger of two black hole that produces gravitational waves is that all of these events can produces gravitational waves is that all of these events can produce gravitational wave signals that can be detected by gravitational wave detectors.

For the difference is the phenomenon when two neutron stars collide, the collision produces enormous gravitational energy. This energy propagates away from the crash site in the form of gravitational waves. These gravitational waves occur episodically, that is, only when collisions occur. The gravitational waves from the collision of two neutron stars have a high amplitude and a frequency that varies depending on the nature of the collision. For phenomena when two black holes approach and merge, they produce strong gravitational waves. At the time of the merger, a large amount of energy is released in the form of gravitational waves. The gravitational waves from the merger of these two black holes tend to occur in one episode that is much longer than that of a neutron star collision. These gravitational waves have a high amplitude and a frequency that gradually increases as the black holes get closer to each other. While the phenomenon when a neutron star and black hole merge, great gravitational energy is released and produces gravitational waves. In this merger, there is a significant difference in mass between the neutron star and black hole which affects its gravitational wave characteristics. The gravitational waves from a merger of a neutron star and a black hole have a lower frequency and a higher amplitude than those of a merger of two neutron stars or black holes.

Apart from the above phenomena, there are also sources of gravitational waves which are still in the stage of research and new discoveries, such as supernovas, pulsars, binary stars or other cosmic phenomena.

CONCLUSION

Based on the results of the research and discussion, it can be concluded that the interesting gravitational wave phenomenon recorded by the LIGO and Virgo detectors from several sources occurs due to the collision of two neutron stars, the merger of two black holes, and the merger of a binary neutron star and black hole.

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