The optical path difference observed by LIGO demonstrates that retarded gravitational waves are anisotropic.

Authors: Tang Keyun, Tang Keyun

Date: 2023-05-18T00:00:00+00:00

Abstract

In 2015, LIGO detected the first gravitational wave event, marking a major breakthrough in a century-long exploration. Concerning the optical path difference recorded by the interferometer, the mainstream interpretation within the physics community posits that, owing to the polarization characteristics of the quadrupole moment, the two arms of the Michelson interferometer undergo stretching and compression respectively, generating differential deformations that produce the optical path difference. This paper presents an alternative understanding: we have previously demonstrated that electromagnetic waves emitted by moving source charges are anisotropic, with propagation velocities that differ along different directions. Extending this line of reasoning to gravitational waves yields a natural corollary: retarded gravitational waves emitted by moving mass sources are anisotropic, exhibiting different propagation velocities along different directions, thereby producing a wave path difference. This physical picture is natural and clear, and would appear to be more reasonable.

Full Text

Preamble

The Light Path Difference Observed by LIGO Proves that Retarded Gravitational Waves Are Anisotropic

Keyun Tang
Institute of Geology and Geophysics, Chinese Academy of Sciences
kytang@mail.igcas.ac.cn

Abstract

In 2015, LIGO detected the first gravitational waves, marking a major breakthrough in a century of exploration. The mainstream physical interpretation of the optical path difference recorded by the interferometer is that, due to the polarization characteristics of the quadrupole moment, the two arms of the Michelson interferometer are stretched and compressed respectively, producing different deformations that result in an optical path difference. This article proposes a different understanding. We have proved that electromagnetic waves emitted by a moving source charge are anisotropic and travel at different speeds in different directions. Extending this idea to gravitational waves leads to a natural corollary: retarded gravitational waves from sources of moving mass are anisotropic, travel at different speeds in different directions, and thus produce a wave path difference. This physical picture is natural and clear, which seems more reasonable.

Keywords: gravitational waves, quadrupole moments, polarization, optical path difference, acceleration, anisotropy, wave path difference, retarded gravitational waves

1. A Century of Exploration on Gravitational Wave Theory —Quadrupole Polarization

In 1905, Poincaré first proposed the concept of gravitational waves. In 1916, Einstein developed general relativity and argued that a spherically symmetric system could emit gravitational waves, calculating the energy lost by a mass system through gravitational wave radiation. In 1918, he discovered an error in his earlier paper: only non-symmetric mass systems could radiate gravitational waves, leading him to revise his position and conclude that gravitational waves did not exist. In 1936, Einstein and his student Rosen submitted a paper on "the non-existence of gravitational waves" to *Physical Review*. As an anonymous reviewer, Robertson read Einstein' s paper and wrote a ten-page commentary identifying its errors. Though displeased, Einstein accepted Robertson' s corrections and adopted the asymmetric quadrupole moment concept to describe gravitational waves. The question of whether gravitational waves exist and how they are generated was debated for a long time. Eddington completely disbelieved in gravitational waves, dismissing them as "waves propagating at the speed of thought." It was not until 1957 that Richard Feynman' s sticky bead hypothesis largely resolved doubts about the existence of gravitational waves.

2. Quadrupole Polarization' s Explanation of Gravitational Wave Optical Path Difference

High-precision Michelson interferometers with arm lengths of several kilometers constitute the primary equipment for modern gravitational wave detection. Before gravitational waves arrive, narrow-band laser technology is used to adjust the optical path difference between the two arms of the Michelson interferometer to zero. When gravitational waves interact with the interferometer, an optical path difference emerges between the arms. On September 14, 2015, two Michelson interferometers—one in Livingston, Louisiana, and the other in Hanford, Washington—both measured a special signal; each interferometer detected an optical path difference between its two arms. Physicists from Caltech and MIT explained the optical path difference of each interferometer using quadrupole theory, which holds that due to the polarization characteristics of the quadrupole moment, one interferometer arm is stretched while the other is compressed, producing different deformations that make the arm lengths unequal:

$$L_x = L_0 + \Delta d, \quad L_y = L_0 - \Delta d$$

where L_x and L_y are the arm lengths along the x and y directions, L_0 is the baseline length (the arm length when no gravitational wave is detected), Δd is the stretching length of one arm, and $-\Delta d$ is the compression length of the other arm. The deformation difference between the arms is $\Delta L = \Delta d_1 + \Delta d_2$. Quadrupole theory further argues that because the deformations differ, the distances traveled by gravitational waves along the two arms are unequal, resulting in an optical path difference, as shown in Figure 1 [Figure 1: see original paper].

The quadrupole moment tensor in electrodynamics is given by:

$$\mathbf{Q} = \int \rho(3\mathbf{r}'\mathbf{r}' - {r'}^2\mathbf{I})d\tau$$

where $\mathbf{r}'$ is the position vector of the source charge in the laboratory coordinate system, $\mathbf{I}$ is the unit tensor in the laboratory coordinate system, and the integral is taken over the entire volume containing the source charge. This shows that quadrupole theory correctly describes the electric field of a non-spherically symmetric charge distribution. However, the quadrupole moment tensor remains a static field that does not involve the motion of the source charge, much less its accelerated motion. In electrodynamics, static fields cannot radiate electromagnetic waves. Similarly, for static gravitational fields, there is no mechanism for gravitational wave radiation.

According to LIGO measurement data, the deformation difference between the arms of the Michelson interferometer is extremely weak—only one-thousandth of a proton’ s diameter. Many factors could produce such minute uncertainties in interference experiments, so the lack of sufficient justification for identifying quadrupole polarization of gravitational waves as the sole cause is problematic.

3. A Natural Explanation of Michelson Interference Experiments

More than a century ago, the null result of the Michelson-Morley interference experiment was interpreted as proof that the ether does not exist. Many leading scientists contributed to this interpretation, which became a cornerstone of advanced theoretical physics for the subsequent hundred years. This paper argues that there exists another, more natural and simpler explanation. Both the light source and the Michelson-Morley interferometer were fixed in the laboratory, so the source and observer were relatively stationary. Therefore, light emitted by the source was isotropic, traveling at the same speed in any two directions, which is why no optical path difference appeared and the interference fringes were naturally null. This explanation, independent of the ether concept, is natural and reasonable.

We now turn to the gravitational waves detected by LIGO, which originate from the accelerated motion of massive stars. Qualitatively speaking, directional motion destroys the isotropy of the propagation environment for gravitational waves, causing gravitational waves to travel at different speeds in different directions and thus producing an optical path difference. This explanation is consistent with and unified with the explanation for the Michelson-Morley experiment above—it is natural, reasonable, and requires no additional assumptions. The following section discusses in detail the anisotropy of retarded gravitational waves.

4. Anisotropic Retarded Gravitational Waves

In previous works, “Accurately Understanding the Physical Image of Electromagnetic Wave Propagation Speed”and “The Speed of Electromagnetic Waves Emitted by Moving Source Charges,” we have proved that relative source-observer rest is a necessary condition for producing isotropic electromagnetic waves. If the source charge is moving, its direction of motion becomes a special direction, and the emitted electromagnetic waves are no longer isotropic but anisotropic. The speed of electromagnetic waves depends on the angle between the source charge’ s motion direction and the wave propagation direction. The relationship between the speed of electromagnetic waves traveling in any direction and this angle is:

$$u_{EM} = \frac{C_0}{1 - \frac{V}{C_0}\cos\theta}$$

where C_0 is the speed of light in vacuum under source-observer relative rest conditions, V is the velocity of the source charge in the laboratory reference frame, and θ is the angle between the source charge’ s motion direction and the electromagnetic wave propagation direction.

Extending this idea to gravitational waves yields a natural corollary: when a material source moves in a certain direction and undergoes accelerated motion, it radiates anisotropic retarded gravitational waves that travel at different speeds in different directions. The gravitational wave propagation speed u_G is a function of the angle between the mass source’ s motion direction and the gravitational wave propagation direction:

$$u_G = \frac{C_0}{1 - \frac{V}{C_0}\cos\theta}$$

where C_0 is the speed of light in vacuum under source-observer relative rest conditions, V is the velocity of the mass source in the laboratory reference frame (the observer/field point is stationary in the laboratory), and θ is the angle between the mass source’ s motion direction and the gravitational wave propagation direction, with $0 \leq \theta \leq \pi$.

Before gravitational waves arrive, the Michelson interferometer is adjusted with lasers so that its arms are set to equal lengths L_0. Since the laser source and the Michelson interferometer are fixed together and relatively stationary, laser propagation within the interferometer is isotropic, and the time for the laser to pass through each arm is:

$$T = \frac{L_0}{C_0}$$

The optical path difference for the laser passing through the two arms is zero.

We now consider the speed difference of gravitational waves propagating along two mutually perpendicular directions. Taking $\theta_x = \theta$ and $\theta_y = \theta + \pi/2$, and substituting into equation (4.2), we obtain the speed difference of gravitational waves along the two directions:

$$u_{Gx} = \frac{C_0}{1 - \frac{V}{C_0}\cos\theta}, \quad u_{Gy} = \frac{C_0}{1 - \frac{V}{C_0}\cos(\theta + \pi/2)} = \frac{C_0}{1 + \frac{V}{C_0}\sin\theta}$$

The speed difference is:

$$\Delta u_G = u_{Gy} - u_{Gx} = \frac{C_0}{1 + \frac{V}{C_0}\sin\theta} - \frac{C_0}{1 - \frac{V}{C_0}\cos\theta}$$

According to the theory of Michelson interference experiments, the measured number of gravitational wave interference fringes should be proportional to the gravitational wave frequency and to the time difference of gravitational wave travel along the two arms:

$$N = \nu \Delta t = \frac{2L_0}{\lambda} \frac{\Delta u_G}{C_0}$$

Substituting the expression for Δu_G yields:

$$N = \frac{2L_0}{\lambda} \left(\frac{1}{1 + \frac{V}{C_0} \sin\theta} - \frac{1}{1 - \frac{V}{C_0} \cos\theta} \right)$$

This equation gives the relationship between the number of interference fringes and the orientation of the gravitational wave relative to the interferometer arms as well as the velocity of the mass source.

References

[1] Einstein, A. (2006). *The Special and General Theory of Relativity.* Peking University Press, Beijing.

[2] Ohanian, H. C., & Ruffini, R. (2006). *Gravitation and Spacetime* (Xiang, S. & Feng, L., Trans.). Science Press, Beijing. (Original work published in English)

[3] Binétruy, P. (2017). *Searching for the Ripples of Spacetime* (Ye, X., Trans.). Posts and Telecommunications Press, Beijing. (Original work published in French)

[4] Jackson, J. D. (1975). *Classical Electrodynamics* (2nd ed.). John Wiley & Sons, Inc., New York.

[5] Hu, Y., & Cheng, F. (2014). *Electromagnetism and Electrodynamics (Volume 2)* (2nd ed.). Science Press, Beijing.

[6] Tang, K. (2016, June 16). *Comparative Independent Experiments on Lorentz Transformation and Retarded Electromagnetic Fields.* Chinese Academy of Sciences Preprint Platform.

[7] Tang, K. (2016). *Accurately Understanding the Physical Image of d' Alembert' s Wave Equation.* Chinese Academy of Sciences Preprint Platform.

[8] Tang, K. (2016). *The Speed of Electromagnetic Waves Emitted by Moving Source Charges.* Chinese Academy of Sciences Preprint Platform.

Note: Figure translations are in progress. See original paper for figures.