Wave-Particle Duality of Gravitational Wave and Designed Experiment

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Abstract

The detection of gravitational waves (GW) demands thorough study of GW. In this article we systematically study both wave behavior and particle nature of GW in framework of Gravitodynamics and derive gravitational counterparts of Electromagnetic wave (EMW). For wave phenomena, we show: (1) intensities of GW quadrupole radiation predicted by either Gravitodynamics or by linearized General Relativity are the same, except by factor of 4; (2) the correlations between redshifts of both GW and EMW and between Hubble Constant and Redshift of GW; (3) formula for relativistic quadrupole radiation. For particle nature, we demonstrate: (1) GW is quantizable; (2) The wave-particle duality of GW exists; (3) Gravitational dipole radiates Gravito-photon; (4) Dirac Sea is generalized to include gravitational charges. An experiment is proposed to detect wave-particle duality of GW. We raise two questions: (1) what is physical mechanism of conversion of mass to GW/Gravito-photons? (2) Does GW/Gravito-photon convert to mass?

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Contents

1. Introduction

Newton's theory of gravity implies that the gravitational field propagates at infinite speed. In 1905, Henri Poincaré had the idea that gravitational wave (GW) might travel at the speed of light in a manner similar to Electromagnetic Wave (EMW). However, he did not establish a complete theory of gravity [1]. In 1916, Einstein predicted the existence of GW based on General Relativity (GR) [2]. All theories of gravity thereafter predict GW. These include geometric and vector field theories. In 2016, 100 years after Einstein's prediction, the LIGO and Virgo teams announced their first observations of GW [3].

The observation of GW requires further study of GW. For this aim, we need to resolve the following issues. One of the major issues is the energy problem in GW and gravity, which has been a long-standing challenge to both GR and vector field theories of gravity. Another one is the incompatibility between GR and quantum mechanics. Resolution of these issues and further exploration of the properties of GW will not only be helpful for understanding GW thoroughly but also elucidate the wave-particle duality of GW, quantize gravity, and unify gravity with other interactions in nature.

In GR, the energy-momentum of a gravitational field is: a) not a tensor; b) not conserved; and c) not localizable. These issues of the energy cause conceptual difficulties in GW and in quantization of GR [4, 5, 6, and references wherein]. Schutz (2011) [7] summarized the conceptually fundamental energy issue of GW in GR as "*Energy has been one of the most confusing aspects of gravitational wave theory and hence of GR. It caused much controversy, and even Einstein himself took different sides of the controversy at different times in his life. Physicists today have reached a wide consensus. The problem is difficult because of the equivalence principle: in a local frame there are no waves and hence no local definition of energy that can be coordinate-invariant. Moreover, a wave is a time-dependent metric, and in such space-times there is no global energy conservation law*".

One approach to resolve the energy issue in GR is to revisit the older definition of energy and an energy-momentum pseudo-tensor $t^{\mu\nu}$ was proposed [5]. However, this $t^{\mu\nu}$ faces other difficulties [8]. We took a different approach to resolve the energy issue in GR by reinvestigating the validity of the equivalent principle (2015) [9]. We argued that a fast moving test body violates the Universality of Free Fall, which is equivalent to the Weak Equivalence Principle. Moreover, a gravitational synchrotron-type experiment was proposed to detect this violation. The results of the experiment would allow a better understanding and a more precise expression of the equivalent principle.

At the present time, it is difficult to theoretically resolve the energy issue of GW in GR. Therefore, it is commonly accepted that energy is a useful but not a fundamental concept in GR, i.e., the concept of energy is not necessary to calculate the radiated GW and the effects of GW [7]. However, it is difficult to find geometrical counterparts in GR for all the physical concepts and terms borrowed from physical field theory in order to express GW and gravity. These concepts and terms include "missing mass vanished in gravitational radiation, a conversion of mass to energy", "spin 2 GW", and "graviton", etc. In contrast, energy of waves is an important concept in field theories and was introduced into GW by Einstein because of its strong analogy to EMW [6].

It is inconsistent and confusing to accept some of these physical concepts and reject others in studying GW and gravity.

In vector theories of gravity, the energy issue is that the energy density of static Newtonian gravitational field is negative [10]. By close analogy to electromagnetism, Maxwell and Heaviside proposed the vector theory which has the form same to that of electrodynamics [11]. However they did not go any further since they realized the negative energy issue.

In 2015, in a different direction, based on the Precise Equivalent Principle, the U (1) gauge theory of gravity is proposed, which we denoted as Gravitodynamics [12]. As a vector field theory Gravitodynamics therefore needs to address the negative energy issue. Indeed, it has been shown that the measurable exchanged energy of gravitational fields is always positive, i.e., transported energy in and out of gravitational field is always positive [13]. Therefore the non-measurable total energy of gravitational fields being either negative or positive is only a matter of bookkeeping. There is no negative energy issue in Gravitodynamics.

Let's consider next issue: the incompatibility between GR and quantum mechanics. In the development of the quantum mechanics, Einstein first noted the wave-particle duality of EMW, he wrote: "*It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do*" [14].

The detection of GW brings up an old question: does GW exhibit wave-particle duality, i.e., is gravitational field quantizable? This problem needs to be addressed theoretically as well as empirically. It has been shown that a single spin 2 graviton predicted by GR is not detectable by LIGO [15 and references wherein], if it exists.

In contrast, Gravitodynamics shows that gravity is a local physical field like the electromagnetic field, is quantizable, and is renormalizable. Gravitodynamics also predicts the existences of negative gravitational charges and GW. It has been shown that, similar to the dark energy or Einstein's cosmology constant Λ, the negative gravitational charges can naturally explain the accelerated expansion of the universe equally well [16]. Moreover, the negative gravitational charges can resolve the fine-tuning problem encountered by Einstein's cosmology constant Λ when explaining the accelerated expansion of the universe. The effects of the dark energy on the propagation of GW have been studied [17].

The benefits of Gravitodynamics are the following: (1) there is no energy issue [13]; (2) GW is quantizable [12]; (3) the existence of negative gravitational charges explains the accelerated expansion of Universe [16]; (4) Gravitodynamics is compatible with Special Relativity (SR). Therefore, in this article we apply Gravitodynamics to systematically study the wave behavior, the particle nature of GW, and radiation of GW. These efforts not only allow a physical understanding of GW but also predict new effects. In addition, this approach makes calculations straightforward. Last but not least, we predict a new phenomenon/experiment that will be able to verify the particle nature of GW, if observed.

2. Wave Phenomena of GW in Gravitodynamics

In Newtonian theory of gravity, the gravitational field equation is

$$\nabla \cdot \mathbf{g} = -4\pi\rho_g, \tag{1}$$

where the gravitational field strength $\mathbf{g}$ is time independent and related to potential V_g,

$$\mathbf{g} = -\nabla V_g. \tag{2}$$

Eqs. (1 and 2) imply that the gravitational field propagates at an infinity speed.

In GR, GW is studied in term of $\bar{h}^{\alpha\beta}$, which is interpreted either as "space-time ripple" in geometric term, or equivalently, as "potentials" in physical term, by equation,

$$\frac{1}{c^2}\frac{\partial^2\bar{h}^{\mu\nu}}{\partial t^2} - \nabla^2\bar{h}^{\mu\nu} = 0.$$

Although the linearized Einstein equation has been expressed in terms of gravitational and gravito-magnetic field strengths, in tensor form, $G^{\mu\nu\lambda}$, [18],