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Spacetime: A New Copernican Revolution?

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Abstract.-In this brief article, the reasons are explained why the empirical detection of gravitational waves could represent a Copernican revolution in the foundations of physics related to the nature of space and time.

1 Introduction

In September 2025, the first ten years since the first detection of gravitational waves by the LIGO interferometers will have passed. In my opinion, and for various reasons, it would be one of the most important scientific and technological achievements of all time. Since then, and with the participation of other interferometers like Virgo, more than 90 additional detections of gravitational waves have been carried out, originating from different gravitational interactions between various supermassive objects such as black holes and neutron stars. Naturally, scientific publications (both primary and secondary) on the matter have continued to grow since the first one, dating back to 2016 [1]. These publications are necessary to achieve the first of the three objectives of this article:

1.- Examine the main consequences that different authors have highlighted regarding the detection of gravitational waves, as well as those consequences that should have been highlighted for their extreme importance to the foundations of physics but were not.

2.- Recall the division of opinion on the real or fictitious nature of space and time that still exists among contemporary physicists, and to demonstrate in a simple and unequivocal way that the empirical detection of gravitational waves implies the reality of physical space and time.

3.- Discuss the appropriateness of the current spacetime continuum model under the new conditions of the physical reality of space and time. A discussion that ends up pointing to a radical change of perspective on space and time in physics.

2 Highlighted consequences of the detection of gravitational waves

To analyze the main physical consequences of the detection of gravitational waves highlighted by different authors, I followed the strategy of examining a small number of books by relevant authors, some of whom are members of the main detection teams ([2, 5, 8, 3, 6, 7, 9, 10, 4, 22]). Finally, I posed the appropriate question to ChatGPT4o, which must handle an extensive bibliography on the matter. The answer given by ChatGPT4o aligns quite accurately with what I had already found in the reviewed literature. Thus, and according to the main literature on the subject, the empirical detection of gravitational waves means:

1.- The confirmation of general relativity.

2.- A new way to observe the universe independent of electromagnetic waves.

3.- A new way of observing the universe in association with electromagnetic waves (γ rays) when both types of waves are produced in the same event.

4.- The evidence of mergers of black holes and neutron stars.

5.- The possibility of testing alternative theories of gravity.

6.- The development of high-precision astrophysics (properties of binary systems of black holes and neutron stars, including their masses, spins, and distances from Earth).

As can be seen, the scientific literature on gravitational wave detections has not yet considered the reality of spacetime as a consequence of such detections, although such a consequence would be very relevant for the foundations of physics. In the next section, the reasons why the empirical detection of gravitational waves would be demonstrating the real, not fictitious, nature of physical spacetime will be presented.

3 Space and time must be real

Although the discussion about the reality of physical space versus its purely relational nature is very old, its modern version (beginning with the Scientific Revolution) starts with the famous debate between the Newtonian, and therefore realist, S. Clarke and the relationalist G.W. Leibniz. The discussion has continued into modern times with realists like A. Einstein (in his later years), J. A. Wheeler, K. Thorne, F. Wilczek, N. A. Tambakis, etc., and relationalists like E. Mach, H. Poincaré, E. Borel, L. Wittgenstein, C. Rovelli, L. Smolin, etc [18, 19, 12, 20, 11, 21]. The division of opinions on this matter remains open and is far from irrelevant. This is why it is surprising that so far, no one has paid attention to the consequences that the detection of gravitational waves has for the real nature of physical spacetime.

Gravitational waves are defined as quadrupole and transverse vibrations of spacetime that propagate at the speed of light through spacetime itself. Although, as I argued in other articles, only the vibrations of space (which is the only thing I believe truly vibrates in gravitational waves) can be considered, I will follow the orthodoxy here by considering the spacetime continuum as the vibrating medium through which its own vibrations propagate. I will do so because the purely physical suitability of the spacetime continuum as a model of physical space and time will be discussed. The purely theoretical suitability of the spacetime continuum is closely tied to the formal consistency or inconsistency of the Axiom of Infinity, which legitimizes infinite sets like the spacetime continuum. Interested readers may take a look at [15, 14].

For those not interested, I remind them that physics should not rely so blindly on such arbitrary axioms as the Axiom of Infinity, which assumes the actual infinity, as opposed to the potential infinity, as the only infinity of infinite sets. I also remind them of the more than 20 centuries of discussions between the proponents of each type of infinity. And, by way of provocation, I once again remind everyone that assuming the Axiom of Infinity, which legitimizes densely ordered sets such as the spacetime continuum, implies accepting something as unphysical as light taking the same number of instants of time to travel one millionth of a millimeter as to travel 9.9 billion light-years; or, put differently, that in a millionth of a second, light traverses as many points of space as it does in 13.8 billion years. Imagine the catastrophe it would be for physics, built with this infinitist mathematics, if the actual infinity subsumed in the infinite sets were inconsistent. Is it not a grave irresponsibility to spend more than a century paying no attention to this possibility? But let's leave theory and turn to the relevant facts:

1.- It is a fact that the collision of two black holes produced the spacetime vibrations that led to the detection of gravitational waves by the LIGO interferometers on September 14, 2015. Thus, spacetime must be something real, something capable of vibrating. Neither fictions nor mathematical models physically vibrate from any collision of real physical objects, no matter how violent that collision may be.

2.- These vibrations of spacetime traveled through spacetime itself for more than a billion years. For this second reason, spacetime must be something real: the vibrations of something that are transmitted through that same something are only possible if that something is real. Neither fictions nor mathematical models vibrate and transmit their own vibrations.

3.- At 10:50 a.m. (Paris time) on September 14, 2015, these spacetime vibrations produced changes in the distances, on the order of an attometer, between the mirrors of the LIGO interferometers. For this third reason, spacetime must be real. Neither fictions nor mathematical models can alter the distances between real objects of ordinary matter, however small those alterations may be.

According to the triple reasoning just presented, it seems reasonable to start considering the possibility that spacetime is a real physical object, as real as objects made of ordinary matter. This would be very relevant for fundamental physics and would end a discussion that has lasted for several centuries. This is why it is striking that no one in the last nine years has proposed such a consideration.

In my opinion, there is a classic reason why physicists have not considered the fundamental problem of the possible physical reality of physical spacetime: physicists avoid facing the formal problems posed by the purely mathematical foundations of their theories, such as the infinite and densely ordered nature of the spacetime continuum, the current theoretical model for physical space and time. They simply follow the rule: *shut up and calculate*. I have encountered an editor of a well-known physics journal who was unaware that the points and instants of the spacetime continuum are densely ordered, and I have the impression that he did not even know what dense order is [17].

4 Is the Spacetime Continuum an Appropriate Model?

The only elementary components of the spacetime continuum are the points of space and the instants of time. Both are densely ordered: between any two of them, there are always other $2^{\aleph_0}$ different points (instants). As a consequence, there are no contiguous points or instants. Neither points nor instants touch each other; adjacency is impossible between them. However, physicists invariably argue and write as if contiguous, adjacent points and instants existed. Moreover, points have neither extension nor shape, and instants have neither duration nor shape.

Assuming the validity of the spacetime continuum as a mathematical model of physical spacetime, and at the same time accepting the physical reality of spacetime, at least for the three reasons given in the previous section, means to ask for the real physical equivalent of the points and instants of the space-time continuum. For simplicity, I will call them r-points and r-instants. Some PURELY PHYSICAL questions arise immediately and are difficult to answer from an exclusive physical perspective:

1.- Can something exist that has zero size or no duration? At least for this reason, r-points and r-instants would be indistinguishable from non-existent objects.

2.- Where does the extension of physical space arise from if its only components, its r-points, have no extension? Recall that in transfinite arithmetic, the product $0 \times 2^{\aleph_0}$ is a mathematical undefined expression.

3.- Where does the duration of physical time come from if its only components, its r-instants, have no duration?

4.- How can space extend if its only components, its r-points, cannot extend without ceasing to be r-points? Physical space cannot be extended by adding new r-points either because, aside from the problem of their physical origin, the number of r-points in ANY direction of space, extended or unextended, is always the same: $2^{\aleph_0}$ r-points.

5.- How can time dilate if its only components, its r-instants, cannot dilate without ceasing to be r-instants? Time cannot be dilated by adding new r-instants either because, aside from the problem of their physical origin, the number of r-instants in ANY time interval, dilated or undilated, is always the same: $2^{\aleph_0}$ r-instants.

6.- How can physical space be deformed, for example when it vibrates, if its only components, its formless r-points, cannot be deformed? Physical space cannot be deformed by adding and/or removing r-points either, since aside from the problems posed by both their origin and removal, in ANY direction of space, deformed or undeformed, there will always be the same number of r-points.

7.- How can physical time be deformed, for example when it vibrates, if its only components, its formless r-instants, cannot be deformed? Physical time cannot be deformed by adding and/or removing r-instants either, since aside from the problems posed by both their origin and removal, in ANY interval of physical time, dilated or undilated, there will always be the same number of r-instants.

If spacetime is a real physical object, as suggested by the detection of gravitational waves, the answers to all the previous questions would have to be physical answers, not mathematical ones. From a mathematical point of view, what should be considered is the possible formal inconsistency of the Axiom of Infinity and, consequently, the formal inconsistency of dense order and of the spacetime continuum itself.

5 Conclusion

In accordance with the reality of physical space and time, and taking into account the inconsistency of the actual infinity subsumed in the infinite sets, such as the spacetime continuum [16], we would have to start considering finitist and discrete alternatives for space and time, such as models based on cellular automata. In these models, the old problem of change, which physics has completely forgotten, is finally resolved [13, Chp. 55]. The problems posed by the coexistence of ordinary matter and spatial matter are also resolved. Furthermore, the different nature and different functions that space and time should have are distinguished. It would therefore be a true Copernican revolution in the fundamentals of physics on space and time, brought about by the empirical detection of gravitational waves.

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