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A fourth spatial dimension for the Universe

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Abstract

The contemporary physical theories are based on several fundamental physical constants. No theoretical framework provides their experimental values. Here, we might have found two formulas yielding the value of the Planck constant and the speed of gravitational waves according to the vacuum properties. In particular, they highly suggest that gravitational waves actually travel in matter. Because there is no dense matter between high-mass bodies in the Universe, the relations would mean that the structure of the Universe is at least pentadimensional (four spatial and one temporal dimensions). We then discuss the implications of this feature on contemporary physics.

Introduction

In the mid-17th century, Isaac Newton published his law of gravitation in *Philosophiae naturalis principia mathematica*. Classical mechanics remained the mainstay of science until the end of the nineteenth century. At the beginning of the twentieth century, many scientists contributed to the special and general theory of relativity: A. Einstein, M. Grossmann, D. Hilbert, H. Lorentz and H. Poincaré (for the most famous ones). These theories made possible the observation of new physical phenomena. The discovery of the expansion of the Universe is one example (1, 2). Based on redshift, Lemaître (3) and then Hubble (4) independently formulated a law which states that galaxies move away from each other at a speed proportional to their distance. At the same time, the development of quantum mechanics turned the perception of particles upside down.

Many experimenters carried out tests to challenge these theories. For now, special relativity and quantum mechanics passed these tests. General relativity could also be in accordance with observations. The perihelion precession of Mercury (5), the bending of light by the Sun (6-8), gravitational redshift (9) and gravitational waves (10, 11) are successes of general relativity. However, this theory needs dark matter (12) to agree with the galaxy rotation curves for instance (13). Up to now, this hypothetical matter has never been observed. The expansion of the Universe is another issue which is explained by dark energy (14). This can be embedded in the equations of general relativity but its origin remains unknown. Linking all the physical processes, from the infinitely small (quantum mechanics) to the infinitely large (general relativity), remains an unsolved problem as well. Finally, the value of the fundamental physical constants on which contemporary physics is based, are not explained yet.

Some efforts are being conducted to understand these “last” physical problems. Scientists are trying to detect dark matter where it is supposed to be. Others are focusing on Modified Newtonian dynamics (MOND) (15) which corresponds to a theory where Newton's laws are modified to fit with the properties of galaxies. Theoretical physicists are also developing ideas to

couple gravitation and the three other fundamental interactions (electromagnetic, weak and strong interactions). Such theories are named "theories of everything". The two most famous ones correspond to string theory and loop quantum gravity. Like in string theory, extra dimensions are thoroughly considered in many other theories. The first attempt consisted in the Kaluza-Klein theory which adds a fifth dimension to spacetime (16, 17). Similarly, a fifth dimension is considered in the Randall-Sundrum models (18, 19).

In this paper, we first present an intriguing relation which links some fundamental physical constants with the vacuum properties of the Universe. This formula, which derives from a dimensional analysis, highly suggests that gravitational waves travel in matter, out of our field of view. This is in contradiction with general relativity in which gravitational waves propagate in vacuum. The deformation of spacetime would thus correspond to deformation of matter. Then, we detail the consequences of the relation on the structure of the Universe. In particular, a fourth spatial dimension is necessary to explain the existence of this matter. Finally, we discuss about how contemporary physics could be interpreted in the framework of the developed theory.

Results

The purpose of this section is to find a relation giving the speed of gravitational waves. General relativity asserts that these waves propagate in vacuum. However, common sense could make us think that waves need a material to propagate. In this paper, we will trust in this common sense and assume that gravitational waves do not travel in vacuum but in some hypothetical continuous matter. We will see that this hypothesis is not necessarily in contradiction with the consequences of general relativity.

One can observe that the speed of material waves is often related to the pressure and density of the medium by $c_{waves} \propto \sqrt{\frac{P}{\rho}}$. Perfect gases, polytropes, incompressible liquids or elastic solids obey this relation (the pressure term is replaced by Young's modulus for a solid). If the continuum hypothesis holds for the Universe, the velocity of gravitational waves could be given by a similar relation. For the calculation, we can use the critical density (vacuum density)

$$\rho_c = \frac{3H^2}{8\pi G} \sim 9.2 \times 10^{-27} \text{ kg} \cdot \text{m}^{-3} \text{ (with } H \text{ the Hubble constant and } G \text{ the gravitational constant).}$$

Considering that many measurements do not agree on the value of the Hubble constant, we assumed that $H \sim 70 \text{ km} \cdot \text{s}^{-1} \cdot \text{Mpc}^{-1}$ because this corresponds to an average of the observations (20-23). No known parameter can directly be selected for the pressure term P . We will thus try to find a parameter with the dimension of a pressure from the properties of the Universe and physical fundamental constants.

Tab. 1 itemizes some fundamental constants and properties of the Universe that could, *a priori*, be involved in the calculation.

Temperature	$T \sim 2.73 \text{ K}$
Density	$\rho_c \sim 9.2 \times 10^{-27} \text{ kg} \cdot \text{m}^{-3}$
Boltzmann constant	$k_B \sim 1.381 \times 10^{-23} \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-2} \cdot \text{K}^{-1}$

Planck constant	$h \sim 6.626 \times 10^{-34} \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-1}$
Vacuum permittivity	$\epsilon_0 \sim 8.854 \times 10^{-12} \text{ m}^{-3} \cdot \text{kg}^{-1} \cdot \text{s}^4 \cdot \text{A}^2$
Elementary charge	$e \sim 1.602 \times 10^{-19} \text{ A} \cdot \text{s}$
Gravitational constant	$G \sim 6.674 \times 10^{-11} \text{ m}^3 \cdot \text{kg}^{-1} \cdot \text{s}^{-2}$
Speed of light	$c \sim 2.998 \times 10^8 \text{ m} \cdot \text{s}^{-1}$

Tab. 1. Fundamental physical constants and properties of the Universe (24).

The temperature and the density should be selected since the calculation of a pressure often depends on both variables (perfect gas, liquid, ...). The vacuum permittivity is, by definition, a vacuum property, so it should participate. In the dimensional analysis, the electric charge of the vacuum permittivity can only be balanced by the elementary charge. Necessarily, both parameters will be associated such as $\epsilon_0 e^{-2}$. The same argument is applied to the temperature so, with the Boltzmann constant, they must be embedded in one variable $k_B T$. The Planck constant takes part to the study because pressure depends on microscopic effects.

We can now manage the dimensional analysis with the following parameters: P , ρ_c , $\epsilon_0 e^{-2}$, $k_B T$ and h . There are five physical quantities and three physical dimensions (length, time and mass). According to the Buckingham π theorem, two dimensionless numbers can be constructed. The method consists in the arbitrary separation of the quantities into two groups. We consider both dimensionless numbers $\Pi_1 = \rho_c^\alpha (\epsilon_0 e^{-2})^\beta (k_B T)^\gamma P$ and $\Pi_2 = \rho_c^\delta (\epsilon_0 e^{-2})^\zeta (k_B T)^\eta h$. The resolution of the linear systems yields

$$\Pi_1 = \frac{P}{(\epsilon_0 e^{-2})^3 (k_B T)^4} \quad (1)$$

$$\Pi_2 = \frac{(\epsilon_0 e^{-2})^{5/2} (k_B T)^2 h}{\sqrt{\rho_c}} \quad (2)$$

Relation (1) allows us to calculate $\sqrt{\frac{P}{\rho_c}}$ and compare with the speed of gravitational waves. With $\Pi_1 = 10$,

$$c_{grav} = \sqrt{\frac{P}{\rho}} = \sqrt{10 \frac{(\epsilon_0 e^{-2})^3 (k_B T)^4}{\rho_c}} \sim 3 \times 10^8 \text{ m} \cdot \text{s}^{-1} \quad (3)$$

Note that the inaccuracy on the Hubble constant prevents certifying that Π_1 is exactly equal to 10 which corresponds to $H \sim 70.1 \text{ km} \cdot \text{s}^{-1} \cdot \text{Mpc}^{-1}$. The calculation of the second dimensionless number yields $\Pi_2 \sim 21.7$. Again, the uncertainties on the Hubble constant only allow us to know the order of magnitude of this number.

One can wonder whether pure chance could lead to the good order of magnitude for both relations, especially for the first one which derives from a well-known continuum mechanics relation. Considering the great discrepancy between all the involved constants and properties (Tab. 1), it is rather probable that both relations really describe physical phenomena. One can check that any other dimensionless combination of these variables (Tab. 1) always leads to huge or tiny orders of magnitude. In the following, we discuss the implications of these relations.

A fourth spatial dimension

The relation $c_{waves} \propto \sqrt{\frac{P}{\rho}}$ derives from continuum mechanics. However, the critical density is too low to assume that the medium is continuous so this relation should not provide the good result. This argument is correct in three spatial dimensions but not in a four-dimensional space. Indeed, if we assume that a fourth spatial dimension exists, then the pressure P should be given in $N \cdot m^{-3}$ and the density in $kg \cdot m^{-4}$. This would mean that our world, which seems to be in three dimensions, presents a fourth dimension. The density in $kg \cdot m^{-4}$ would then be given by $\frac{\rho_c}{L}$ with L the thickness of our “three-dimensional” home (in the direction of the fourth dimension). A very weak value of L could lead to a great four-dimensional density (same argument for the pressure) and make continuum mechanics applicable. This would not change the proportional relation giving the speed of waves since only the ratio of both variables intervene in this relation. Therefore, relation (3) would prove that the spatial dimension of the Universe is at least four. Let’s see that general relativity already predicts the existence of an intangible fourth dimension.

General relativity is based on the curvature of space due to the presence of matter. Since human beings cannot depict the deformation of a three-dimensional space, literature often describes it through an analogy with the deformation of a two-dimensional space into a three-dimensional one (Figure 1). But this only corresponds to an illustration of the three-dimensional space warp in a four-dimensional one.

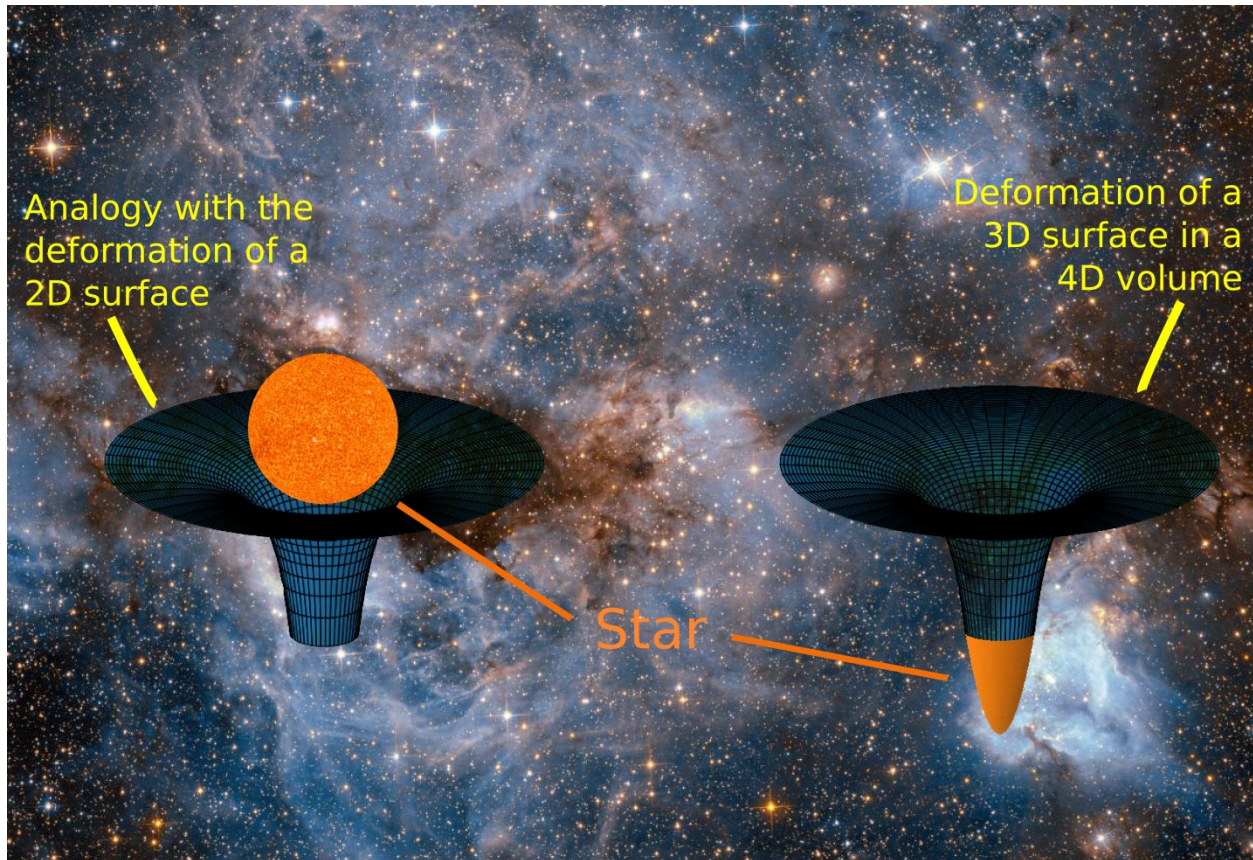


Fig. 1. Schematic representations of the space deformation. Left: With a two-dimensional analogy (general relativity). Right: Without analogy.

Besides, the Universe expansion shows that our three-dimensional Universe does not contain any point which could be considered as the big-bang origin. Indeed, the Hubble-Lemaître law states that all the points move away from Earth and there is no reason for our planet to be the center of the Universe. To understand this process, scientists again use an analogy with two-dimensional spaces. For instance, if the curvature of the Universe is positive, the world can be understood as the surface of an inflating ball. All the points of the surface of an inflating ball move away from each other while the center does not belong to this surface. By extending this analogy to three dimensions, our living space would be a 3-sphere (sphere in three dimensions) embedded into a four-dimensional space. The existence of a fourth spatial dimension could involve the reality of this analogy. Note that the surface would actually be a very thin volume so that we underestimate the number of dimensions.

The nature of gravitation

According to general relativity, gravitation corresponds to the deformation of spacetime induced by masses. Einstein's theory does not explain the physical process of this deformation. But the presence of matter in the fourth dimension would require the deformation to result from a physical phenomenon. According to the strong equivalence principle, gravitation would correspond to acceleration. In adhering to this principle, the force applied on the high-mass bodies, which produces the deformation of the surface, must derive from an acceleration. The

observations show that the expansion of the Universe is accelerating. Thus, we propose a new definition of gravitation: due to the acceleration of the expansion of the Universe, the high-mass bodies in the 3-sphere would be maintained against some matter which is located in the fourth dimension, out of our field of view. Then, the bodies would locally deform the three-dimensional surface because of the acceleration. The space deformation would thus stem from the same process as the deformation of a material supporting a mass on Earth (or in an accelerated frame of reference). The motion of a body in a gravitational field would be equivalent to the motion of a body, which experiences a vertical acceleration, on a deformed surface. Note that gravitation would only exist in the 3-sphere. Figure 2 displays this vision of the Universe.

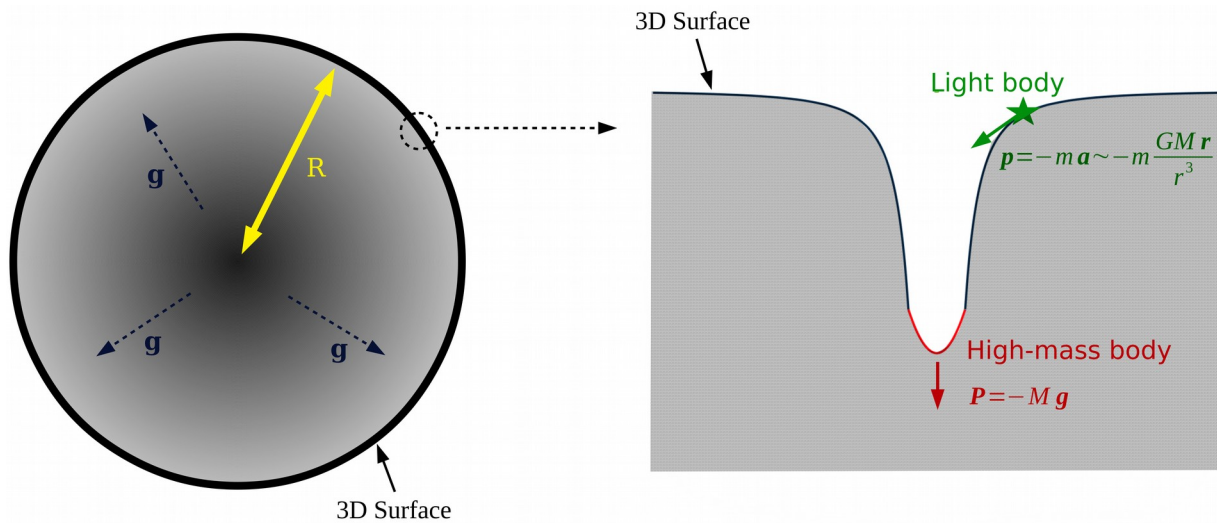


Fig. 2. Pentadimensional structure of the Universe (4 spatial and 1 temporal dimensions). It is assumed that the space curvature is positive. On the left: The Universe would be a four-dimensional ball so its expansion would correspond to a radial acceleration g . On the right: Physical deformation of the surface due to the radial acceleration. A light body would only experience a part of it, approximately $a = \frac{GM}{r^2}$ according to Newton's law of universal gravitation.

Interpretation of some physical phenomena

This way of understanding the Universe could explain several contemporary physical matters. First, the Universe expansion would be the result of some processes inside the four-dimensional ball. For instance, the interaction between particles could generate this expansion. This energy could correspond to the so-called dark energy. Its location, out of our three-dimensional world, could explain its mysterious origin.

Second, a physical explanation of gravitation is provided. With this definition, gravitation would not be a fundamental interaction. It would result from the acceleration of the universe's expansion and the other interactions. In particular, the bodies at the surface would interact with the particles in the fourth dimension. At macroscopic scale, this process would correspond to a

support reaction. Gravitation would thus intimately link with electromagnetism. Could this explain the mathematical similarities between both processes? In addition, this definition removes the singularities from Newton's law of universal gravitation and general relativity. The gravitation law in $\frac{1}{r^2}$ would not be reliable until the center of the bodies since continuum mechanics does not present such a uniform deformation profile. An inflection point would exist at a particular radius and another law would take place.

Third, the effects predicted by general relativity could also be explained in the framework of this theory. The loss of energy due to gravitational waves could be the consequence of friction with the matter in the fourth dimension. It is worth noting that friction, to a certain extent, also exists in general relativity. The observations show that spacetime (in Einstein's theory) is expanded because all the bodies are moving away from each other. Without friction between bodies and spacetime, the former would slide on the latter and would not follow its expansion. The Lense-Thirring effect could stem from the dragging of four-dimensional matter due to the rotation of high-mass bodies and friction. However, light bending requires photons to get a tiny mass to be compatible with this theory.

Last, a fourth dimension full of matter could explain some aspects of quantum mechanics. The theory, which is based on pure chance, does not respect Bell's theorem. This result is only true from a three-dimensional point of view but could be wrong in four dimensions. For instance, the apparent chance could correspond to interactions with particles in the fourth dimension which we cannot observe. Moreover, the quantum fluctuations could correspond to the travel of particles from the three-dimensional surface to the fourth dimension and *vice versa*. In this sense, energy would be conserved in the four-dimensional space and not necessarily in our world. This travel could be possible for particles, but not for too big bodies that dense four-dimensional matter would block at the surface. Thus, from the three-dimensional surface point of view, two different theories would be needed to describe bodies according to their size: quantum and classical mechanics. Relation (2) could substantiate this point of view because it might be understood as

$$h = \frac{\Pi_2 \sqrt{\rho_c}}{(\epsilon_0 e^{-2})^{5/2} (k_B T)^2} .$$

In this case, the Planck constant (and quantum mechanics) would depend on the vacuum properties. Note that the "variable" fundamental constant in this relation could also be the elementary charge or the Boltzmann constant.

Raised questions

The previous interpretations raise the question of the variation of some fundamental constants. We have seen that the speed of gravitational waves and the Planck constant could vary against time if relations (1) and (2) really describe physical phenomena. In this case, the definition of gravitation (Figure 2) would also involve the variation of the gravitational constant. The latter would indeed depend on both the acceleration of the expansion and the pressure term P . For instance, the deformation of a solid depends on the applied forces and Young's modulus. Since both quantities vary according to time, the gravitational constant should also vary.

Moreover, measurements show that the expansion of spacetime exceeded the speed of light in the early Universe (cosmic inflation). Claiming that this great speed only concerns spacetime saves the relativity theories. But if relation (3) is correct, spacetime is actually matter so particles

could have moved at speeds greater than the actual speed of light. This holds only if the speed limit does not vary with time.

Finally, one can wonder why the fourth dimension of the Universe would not be visible since its size would be comparable to the three others. "Our thickness" in the fourth direction, which would be extremely small, could be the cause. However, this question remains open.

A minimization of the size of the Universe

It is possible to minimize the size of the assumed structure of the Universe (Figure 2). The Hubble-Lemaître law states that the recessional velocity v is proportional to the proper distance D : $v=HD$ with H the Hubble constant. Therefore, the recessional acceleration is given by $a=H^2D$. We note R the radius of the Universe and g the radial acceleration (Figure 2). The same relation holds for both variables: $g=H^2R$. The radius of the Universe can then be deduced from an estimation of the radial acceleration. This acceleration must be greater than all the gravitational accelerations of the bodies in the Universe. The Earth's acceleration is about $10\text{ m}\cdot\text{s}^{-2}$. This value, which should be far lower than the greatest acceleration, yields $R=2\times 10^{20}$ light-years. This corresponds to 4.5 billion times more than the observable universe. This could explain why the Universe appears flat from our point of view.

Conclusion

Both dimensionless numbers (1) and (2) deriving from the dimensional analysis link the Planck constant and the speed of gravitational waves with the properties of vacuum. Relation (3) either genuinely describes physical phenomena or is a doubtful coincidence. In the most likely case, this relation would involve the existence of a fourth spatial dimension (at least). The observable universe would actually correspond to a tiny part of the whole Universe and we would live on a huge amount of particles (so energy) out of our field of view. While agreeing with predictions of general relativity, the developed theory could explain the so-called propagation of waves in vacuum, some aspects of quantum mechanics, dark energy and the nature of gravitation. It could also account for the potential variation of some fundamental physical constants. In this study, the mathematical part of this theory is left to be constructed and a thorough comparison with general relativity could bring answers to some cosmological matters.

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