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# SPACE, TIME AND IRREVERSIBILITY

## THE PHILOSOPHICAL PROBLEMS OF CONTEMPORARY ASTROPHYSICS

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Scientific philosophy is that which is informed by science. It uses exact tools such as logic and mathematics and provides a framework for scientific activity to solve more general questions about nature, the language we use to describe it, and the knowledge we obtain thanks to it. Many of the scientific philosophy theories can be proven and evaluated using scientific evidence. In this paper, I focus on showing how several classical philosophy topics, such as the nature of space and time or the dimensionality of the future, can be addressed philosophically using the tools from current astrophysics research and, in particular, from the study of black holes and gravitational waves.

Keywords: ontology, spacetime, epistemology, black holes, gravitational waves.

## SCIENTIFIC PHILOSOPHY

The Austrian physicist Ludwig Eduard Boltzmann (1844-1906), understood that the function of philosophy in the scientific era is to solve the most general problems related to the study of nature and, from their solutions, provide science with a framework and a foundation to solve specific problems efficiently. Therefore, philosophy cannot be detached from science, it needs its feedback, must change along with it, and should always be used to provide a better understanding of scientific problems. A philosophy that meets these criteria can be called «scientific philosophy». Boltzmann's vision of a scientific philosophy – that is, of a philosophy that deals with general problems that are common to all sciences which is informed by science and serves scientific research – started to develop in the twentieth century thanks to philosophers with strong scientific backgrounds, like Bertrand Russell (mathematician and logician), Moritz Schlick (physicist), Hans Reichenbach (physicist and logician), Rudolf Carnap (logician and semantician), Hans Hahn (mathematician), Otto Neurath (sociologist), Willard Van Orman Quine (logician), Mario Bunge (philosopher and physicist), and Nicholas Rescher (philosopher) (see, for instance, Bunge, 1974-1989; Ferrater-Mora, 1994; Reichenbach, 1977; Rescher, 2001).

Current scientific philosophy is represented by many professional philosophers with strong scientific training, who address general topics as well as problems from the fields of physics, biology, mathematics, and social science.

> «THEREFORE, PHILOSOPHY CANNOT BE DETACHED FROM SCIENCE, IT NEEDS ITS FEEDBACK, MUST CHANGE ALONG WITH IT, AND SHOULD ALWAYS BE USED TO PROVIDE A BETTER UNDERSTANDING OF SCIENTIFIC PROBLEMS»

New philosophical problems appear as science advances (for instance, before Albert Einstein and Hermann Minkowski's research, the problem of the nature of spacetime did not exist), while others disappear (the advances in neuroscience have made problems related to mental substances irrelevant or, even worse, have shown them to be pseudo-problems). Thus, scientific philosophy evolves with science and uses philosophical concepts.

Each specific science can help to test some philosophical theories. For example, philosophical conjectures regarding the incidence of visual symmetry patterns in aesthetic perception can be assessed through non-invasive brain activity studies in individuals exposed to particular works

Museo del Prado

Human beings age and die, and this is scientifically stated in the second law of thermodynamics. Each specific science can help us to test some philosophical theories. In the picture, *The three ages of man and death* (1541-1544), by Hans Baldung Grien (oil on canvas, 61 × 151 cm).

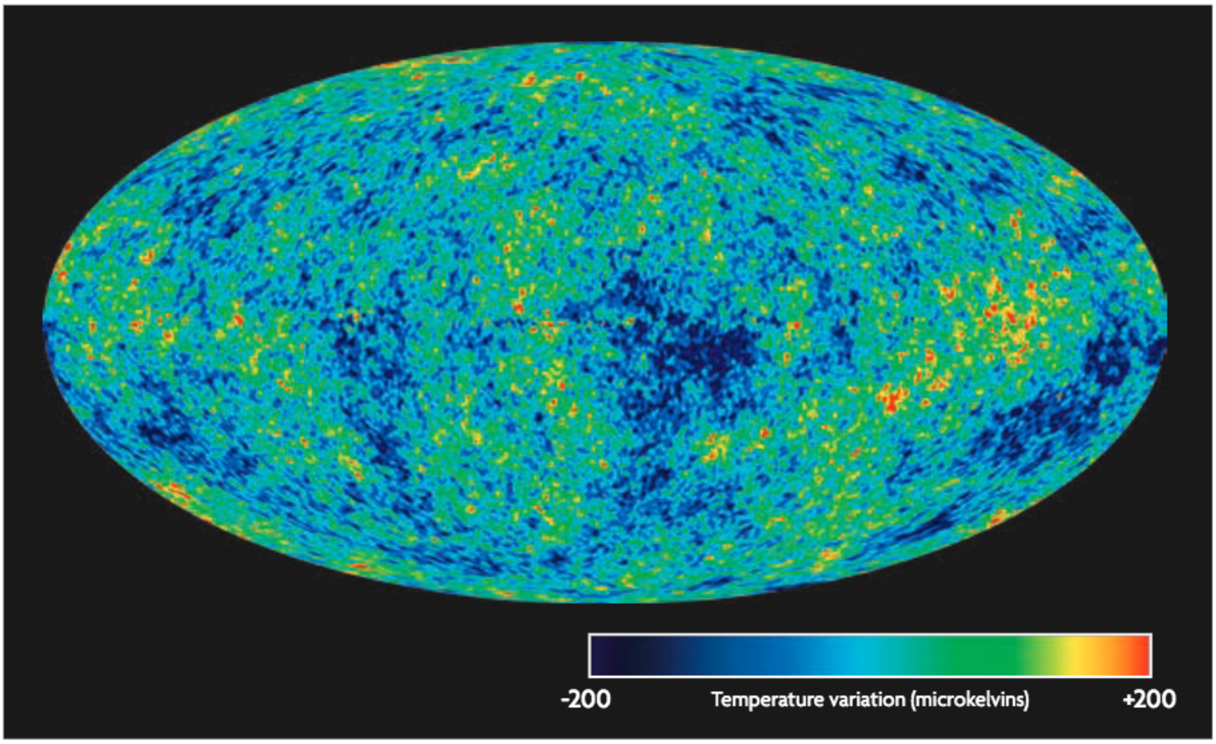
of art with specific patterns, in experiments with appropriate error-control measures, whereas physics, and particularly astrophysics, can help verify many philosophical ideas in the field of ontology. In the following section, I will discuss some of these issues in the light of current astrophysics knowledge.

## THE NATURE OF IRREVERSIBILITY

Things age, get broken, decay; that is a fact. We age and we die. This is scientifically stated in the second law of thermodynamics. This law can be stated in several forms. One of them, which we owe to Boltzmann (1974), says that every physical operation in a «non-ideal» system will result in an increase in entropy, which builds up until it reaches its maximum possible value. When that happens, the system reaches thermodynamic equilibrium and cannot change any further. It will not change. Nothing more will happen. In our case, reaching thermodynamic equilibrium is dying: when our body has a uniform temperature and that temperature is the same as the room we are in, and then, that room will contain our corpse.

What is this entropy Boltzmann refers to? Suppose we have a system with many components, like a gas formed by many atoms, or our body, made up of many cells, or the universe, formed by many galaxies. Each of these components can, in principle, be in many states. A molecule, for instance, may have different speeds. Not all of these states will be equally probable. Some are more likely than others. Entropy is a calculation of the distribution of probabilities of the system's states. If all the components of the system are currently in their most likely state, the system will not change (any other configuration would be less likely), and there is maximum entropy. We call this state of maximum probability «thermodynamic equilibrium».

Of course, the world is not in thermodynamic equilibrium. You are reading this document, so something must be changing in your brain. Your room is full of sounds, and your life, full of events. Why is the world not yet in a state of thermodynamic equilibrium? Why has entropy still not peaked? The usual answer to this question is that the world, the system of all things, what we call the «universe», started a finite time ago and did so in a state of minimum entropy. We call this the «past hypothesis». It looks like an obvious hypothesis, but it is also unsatisfactory. Why did that initial condition come to be? Some philosophers say that asking that question makes no sense. It would be a «brute fact», which



NASA/WMAP Science Team

Calculations of the cosmic radiation background show that the radiation produced in the early universe was in perfect thermal equilibrium. But then, how can the world be unbalanced today? The picture shows a map of the cosmic radiation background from the WMAP satellite.

cannot be explained in terms of other facts because there is no precedent.

I must confess I do not believe in brute facts. All the facts we know are valid: they are subjected to laws, to regular event-occurrence patterns. Science, and its fundamental function, consists of finding those regular patterns, which we call «laws», and exposing the mechanisms (chains of valid processes) behind the occurrence of each event. Stating that a fact is «brute» is admitting the existence of magic, renouncing to the scientific ideal, giving up. I think we can do better than that. Boltzmann, for instance, did not give up. He surmised that the universe in general is in a state of thermodynamic equilibrium, but that here and there, once every countless aeons (if time makes sense in the absence of change), a statistical fluctuation, highly unlikely but not impossible, occurs. Then, a part of the universe, which is usually dead, decreases in entropy and some events (the history of the world) occur. It is a beautiful idea. Alas! As Arthur Eddington showed in the 1930s, the probability of this happening is incomparably lower than you, the reader, emerging from a statistical fluctuation which puts this text in your hands and then has it disappear again after reading it. The explanation of why entropy increases must undoubtedly be more subtle and complex than a mere fluctuation.

«SCIENTIFIC PHILOSOPHY EVOLVES WITH SCIENCE AND USES PHILOSOPHICAL CONCEPTS»

The problem becomes more serious if we take into account recent astrophysics and cosmology discoveries. Astronomical observations show that the universe is expanding (in fact, the expansion seems to be accelerating). That means that it was denser, and therefore hotter, in the past. When the average temperature in the universe was of a few thousand degrees, matter was in a state known as «plasma». In that state, electrons are separated from the nuclei of atoms. Around 380,000 years after the expansion stage of our observable universe started, the temperature fell under the value at which hydrogen atoms remain ionised (a state in which they lack their electron). The result was that electrons were captured by protons, and neutral hydrogen and photons, which were previously absorbed in the plasma, formed and escaped. Today we can observe these photons because they form a universal radiation which we can detect coming to us from every direction. This radiation is called «cosmic background radiation». It was measured very accurately by satellites such as COBE, WMAP and, more recently, by the European Space Agency's Planck satellite. These calculations show that the radiation produced in all of the early universe was in perfect thermal equilibrium: the distribution of particles of the gas that produced it was the same as a system with maximum entropy! But then, how can the world be unbalanced today? Why does entropy keep increasing if it is already at its maximum possible value?

There can only be one answer to these questions: that, in reality, entropy had not actually peaked when the universe became transparent to its own radiation. There should be a low entropy component that does not appear in our observations. Or, if it appears, we do not recognise it. This component is gravitation entropy. The state of equilibrium in a gravitational system is the collapse, because gravity is a force of attraction. A collapsed object would become as compact as it can. However, in the early universe, when the cosmic background radiation appeared, there was almost no structure. There were no stars, no galaxies or galaxy clusters, only an extremely homogeneous gas. The entropy associated with the gravitation of that gas was extremely low. As the gas collapsed and formed structures, the known structure of the universe, the total entropy (of gravitation and matter) increased. And it kept growing until today.

This solution to the problem poses two new questions: how can gravitation have entropy? And why was gravitational entropy so low 13,800 million years ago? The first question admits only one possible answer: gravitation must have an internal structure. And that internal structure provides the necessary degree of freedom to define entropy. We do not know what that structure is like, but we have started to speculate about it and our guesses try to articulate a quantum gravitation theory, which I will address below.

The second question requires an explanation of the conditions of the universe almost 14,000 million years ago. What mechanism could put the universe in that state in the absence of structure? One way for something inhomogeneous to become homogeneous is compression, uniting all the components and then making the unified object expand isotropically. That would be a possibility if the universe did not actually start 13,800 million years ago, but rather, that moment was the start of an expansion stage after the contraction that destroyed the previously


MÈTODE

Gottfried W. Leibniz and Isaac Newton argued about the nature of time and space in the seventeenth century. On the left, Isaac Newton, portrait painted by Godfrey Kneller in 1689. On the right, portrait of Gottfried Leibniz by Cristoph Bernhard Francke, painted around 1700.

«IF SPACE IS NOT A PHYSICAL ENTITY AS NEWTON THOUGHT, THEN WHAT IS IT? LEIBNIZ ANSWERS: A SYSTEM OF RELATIONSHIPS BETWEEN OBJECTS»

existing structure. In other words, the universe contracted, «bounced» and expanded again. When it did, it regenerated the entropy of its gravitational field. Indeed, this requires very specific conditions for the thermodynamic behaviour of gravity at large densities (Novello & Perez-Bergliaffa, 2008). Is it possible to verify these ideas scientifically? Surprisingly, the answer is «yes».

The bounce of the universe involves moving great masses, which generated gravitational waves. These waves are too weak to be detected now. However, they left their mark on the polarisation of the cosmic background radiation. They are the so-called «polarisation B-modes», characterised by the rotational effect of polarisation lines. This effect occurred because of distortions in the direction of the oscillation of the electrical charges that produced the radiation in the early universe. If these polarisation B-modes exist, they will be susceptible to detection in the near future, thanks to the implementation of submillimetre telescopes (Stolpovskiy, 2016). Calculations of the shape and intensity of such polarisation will allow experts to test bounce models for the start of our universe's expansion. It will also be possible to evaluate the hypothesis that the expansion was exponential during its first instances (inflationary models).

In this section, I tried to show that contemporary astrophysics and cosmology have contributed to solving a question posed by scientific philosophy: why are the world's processes irreversible if the mathematical representation of its laws is reversible? The answer is that the state of the world is not determined only by laws, but by laws and the initial conditions in which those laws are applied. Today, we live thanks to the low entropy of the gravitational field. Ultimately, any change is possible because the gravitational field is not yet in a state of collapse. It seems like in the early universe there were natural mechanisms that allowed gravitation to regenerate its entropy. The question of how this occurred is scientific rather than philosophical (Romero & Pérez, 2011).

## DO SPACE AND TIME EXIST?

It is well known that Gottfried W. Leibniz and Isaac Newton argued about the nature of time and space in the seventeenth century. The controversy was developed with the participation of Samuel Clarke, who acted as the representative of Newtonian ideas. Leibniz argued that space and time are not entities per se; that is, they do not exist in the absence of changing objects. For Leibniz, space is just a system of spatial relations between objects, and time is the relationship between changing objects. If nothing changed, Leibniz thought, there would be no time. If there was a single unitary object, there would be no space. For Newton, on the other hand, space and time were real entities, like tables or planets. However, unlike these, they are not affected by their interaction with the rest of the objects in the universe.

Leibniz developed an ingenious argumentation against Newton based on his principle of the identity of indiscernibles (if two objects are identical in every respect, including relational aspects, then they are the same object). The argument is as follows: imagine two universes formed by exactly the same objects, related to each other in exactly the same way, but located in different spatial positions. If space is a thing, the spatial relationships between these objects will be very different, so the two universes will be different. However, there is no property in the time + objects group that allows us to distinguish them. Therefore, by the principle of the identity of indiscernibles, both universes are the same one. Since universes cannot be the same and still be different, one of the hypotheses must be rejected: 1) Space is a thing; or 2) the principle of identity of indiscernibles. Leibniz thought we had reasons to agree with the second hypothesis and so, he negated the first one.

If space is not a physical entity as Newton thought, then what is it? Leibniz answers: a system of relationships between objects. There is no space, there are spatial relationships between whatever exists. If there were no objects, there would be no space. If there were no changes, there would be no time. Newton disagreed. In order to prove that space is something, he proposed the famous experiment of the bucket filled with water hanging from the ceiling by a rope. Turn it on itself, twisting the rope, and when you free it, the bucket will start spinning. At first, the surface of the water will be flat. Then, the bucket will start transmitting its rotating movement to the water through friction, and water will gain angular momentum. As momentum increases, the surface of the water will become paraboloid due to centrifugal forces. If we stop the bucket, water will keep rotating and maintain the parabolic surface until friction leaves it flat again. But, what is the water accelerated with regard to? It cannot be accelerated with regard to the bucket, because the surface is parabolic whether the bucket rotates or not. Newton responded that it must be accelerated with regard to absolute space. So absolute space must be «something». It has an ontological entity. Nothing can accelerate with regard to non-existing entities.

**«EXPLORING THE MOST EXTREME ASPECTS OF REALITY, ASTROPHYSICS CAN BE USED TO TEST ONTOLOGICAL IDEAS»**

Unfortunately, Leibniz died during this controversy and could never respond to this argument. But Ernst Mach did, in the nineteenth century: he claimed that water accelerated with respect to «distant stars»; that is, with respect to the average of the rest of the mass in the universe. Later, in the twentieth century, Einstein thought he could explain the nature of inertia and Mach's principle with his theory of general relativity; he showed that gravitation and inertia are two aspects of the same gravito-inertial field, and thought that his theory could not admit solutions that did not include material objects. Einstein believed space and time could not exist without matter.

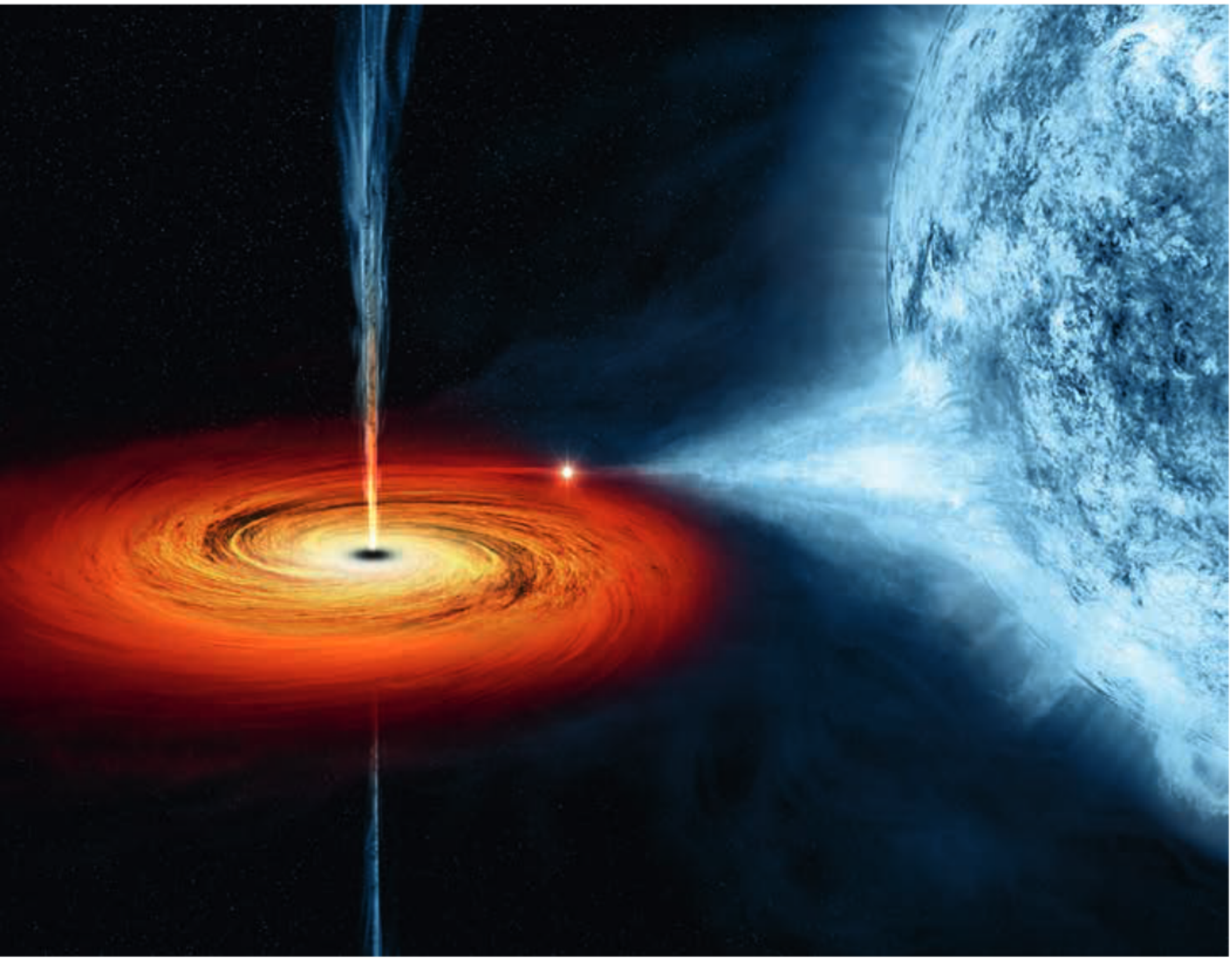
In 1917, the Dutch astronomer Willem de Sitter obtained a dynamic solution for Einstein's equations that represented a universe without matter, but with space and time. Einstein was sceptical at first, but he later admitted that his theory was not useful for explaining Mach's principle. Worse still, his theory represented the gravito-inertial field using a metric field and could effectively determine distances in a four-dimensional object called «spacetime». Spacetime is the system of all events. Everything that occurred, occurs, and will occur, is part of that system. What we call space is nothing more than slices of that entity along another entity we call time. Spacetime as a whole, however, does not and cannot change; there is nothing to change with respect to: time is already included in it (Romero, 2012; 2013a; 2013b).

Is spacetime an entity? Does it really exist? These questions might seem purely philosophical in nature, yet nevertheless, we can look at related arguments based on contemporary astrophysics.

Black holes are no longer exotic objects whose existence is predicted based on the theory of general relativity. They became an essential part of our description of the universe long ago. What are these black holes that seem so abundant in the universe? They are what is left of physical systems (stars, clouds of black matter) that collapsed under their own gravitational field. Gravity is, essentially, an attractive force at small scales. When an object is very massive, the gravitational pull of its own matter tends to make it more and more compact. If the system is stable, it is because some internal force opposes gravitation. This force generates the internal structure of the system. If the object is sufficiently heavy and its internal energy is exhausted, the object can collapse under its own weight. In doing so, it drags spacetime with it, which curves, making all events on a certain surface undetectable from the outside. We call this surface the «event horizon». It is a region of spacetime that divides it into two parts, the inside, or «black hole», and the outside, or «the rest of the universe», where we exist. The black hole is, therefore, formed by spacetime curved in such a way that the inside is not in contact with the outside.

The event horizon is not different from a spacetime region. However, it has established physical properties. In particular, it can be assigned a temperature and


NASA/CXC/M. Weiss



A black hole is formed by spacetime curved in such a way that the inside is not in contact with the outside. The existence of black holes has important philosophical consequences. The picture shows an artistic rendering of a black hole devouring a star in a binary system.

**«THE EXISTENCE OF BLACK HOLES HAS IMPORTANT PHILOSOPHICAL CONSEQUENCES FOR OLD METAPHYSICAL DISPUTES»**

an entropy level. In fact, when something falls into the black hole – when something crosses its event horizon – the horizon's entropy increases. Therefore, we can propose the following arguments to show the reality of spacetime (Romero, 2017):

P1. Only existing entities can be heated.
P2. Spacetime can be heated. Therefore, spacetime is an existing entity.

Premise P1 is true. Heating is transmitting warmth to a physical system. It elevates the temperature of the system. That operation can only happen in physical systems, not on abstract systems or relationships between physical systems. P2 is also true, in the light of relativistic physics: the event horizon of a black hole has a temperature and it changes when something falls into it. If we can heat the horizon it is because we are heating spacetime, and therefore spacetime exists.

Alternatively:

P1. Spacetime has entropy.
P2. Only things with a microstructure can have entropy. Therefore, spacetime has a microstructure.
P3. Only things with a microstructure exist. Thus, spacetime exists.

P1 is true because the event horizon of black holes is a region of spacetime with entropy. Entropy measures the number of available microstates for a macroscopic system, and it implies that entropy can only be assigned to physical systems with a microstructure. From that, we conclude that spacetime is an existing entity and not a mere system of relationships. Thus, we see that the existence of black holes has important philosophical consequences for old metaphysical disputes. Exploring the most extreme aspects of reality, astrophysics can be used to test ontological ideas.

## DIMENSIONALITY OF THE WORLD

How many dimensions does the world have? «Presentist» philosophers support the idea that there are three: the three dimensions of space. What about time? These philosophers think there is only the present: the past and future do not really exist. The past already was, we can remember it, but it does not exist. The future has not yet happened, so it does not exist either. Only the present «is»; and one moment does not comprise a dimension (an infinite set of points), but rather, a single point. Is this philosophical point of view correct or akin to common sense? I claim it is not.

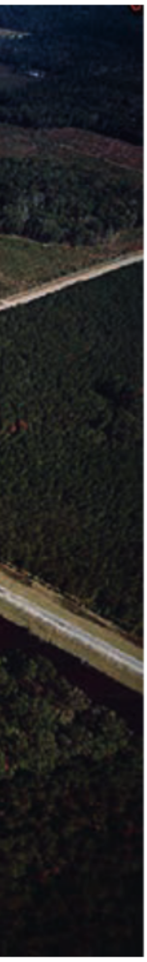
The special theory of relativity, with its corroborated relativity of the simultaneity of events, if proof of that. There is not a «single» present moment for all the systems that form the universe. Events can seem present and simultaneous for one observer and successive for another. If existence does not depend on the system of reference used to describe the world (principle of objectivity), then we cannot claim that «only the present exists». General relativity, however, provided even greater evidence to think that the past and future are as real as the present and that our world has four dimensions, rather than three. That is, time is as valid a dimension as the spatial ones, and is just as real. The boy I was is a temporal part of myself, as is the old man I will be (or perhaps I already am). They are different parts of a four-dimensional object, as different from each other as my hand is from my head when we consider only the usual three dimensions.


LIGO

On 15 September 2015, the LIGO observatory detected the existence of gravitational waves for the first time. These detections have important scientific, as well as philosophical, implications: they can help us show that the philosophical doctrine that states that only the present exists (presentism) is false.

«SPACETIME IS THE SYSTEM OF ALL EVENTS. EVERYTHING THAT OCCURRED, OCCURS, AND WILL OCCUR, IS PART OF THAT SYSTEM»

Recently, the LIGO collaboration (Laser Interferometer Gravitational-Wave Observatory) reported the direct detection of gravitational waves for the first time. The announcement, made on February 2016, refers to the event registered on 14 September 2015, identified with the code GW150914. Gravitational waves were detected due to the fusion of two black holes with masses 36 ± 5 times and



29 ± 4 times that of our Sun. The collision resulted in a black hole with 62 ± 4 solar masses. The 3.0 ± 0.5 remaining solar masses correspond to light emitted in the form of gravitational waves. Since the event occurred around 400 megaparsecs[1] away, the waves travelled through space for about 1,300 million years. A second event was detected on 26 December 2015. This signal, produced by a less massive system, was announced on 15 June 2016.

These detections have important implications: they show that the theory of general relativity is correct in its strong-field predictions within the instruments' sensitivity, clear any doubt on the existence of gravitational waves, and provide new evidence for the existence of black holes. Moreover, they can serve to show that presentism, the philosophical doctrine that claims that only the present exists, is false (for a discussion on this topic, see Romero, 2015). Let us consider the following argument (Romero, 2017):

«THE CLOSER PHILOSOPHICAL THEORIES ARE TO SCIENCE, THE MORE FEASIBLE IT IS TO ESTABLISH THEIR AUTHENTICITY»

P1. There are gravitational waves.
P2. Gravitational waves have non-zero Weyl curvatures.
P3. A non-zero Weyl curvature is only possible in four or more dimensions.
P4. Presentism is incompatible with four-dimensional worlds.

Therefore, presentism is false.

Premises P2 and P3 are necessarily true. Gravitational waves are propagated in the vacuum, where Einstein's field equations imply that the components of gravitation associated with matter are identically non-existent. But the total curvature of spacetime does not include only this curvature, called the Ricci curvature, but also the curvature associated with the gravitational field itself, called the Weyl curvature, represented with a mathematical object known as a «Weyl tensor». So, since gravitational waves are alterations in the curvature of spacetime, the Weyl tensor cannot be zero in their presence. If the world had only three dimensions, as presentists defend, the Weyl tensor should be zero. Only in four or more dimensions can gravity propagate in spacetime's vacuum (Romero & Villa, 2014). Therefore, a presentist should either deny that presentism is incompatible with a four-dimensional world or accept that presentism is wrong. However, presentism is, essentially, the doctrine according to which things do not have temporal parts. Any admission of temporal extension means renouncing the basic claim of presentism: that the future and past do not exist. My conclusion is that, since gravitational waves do exist, presentism is completely false.

Once more, we see how astronomical observations based on physical considerations can help us to test philosophical doctrines. The closer philosophical theories are to science, the more feasible it is to establish their authenticity. Similarly, the more informed science is about philosophical problems, the clearer and more direct its contributions to our knowledge of the world will be. Boltzmann's hope that we will consider any scientific problem from a philosophical point of view and that we will respond scientifically to all philosophical problems might lie in this virtuous circle.

REFERENCES

Boltzmann, L. (1974). *Theoretical physics and philosophical problems: Selected writings*. Dordrecht: Reidel.

Bunge, M. (1974-1989). *Treatise on basic philosophy*. Dordrecht: Kluwer.

Ferrater-Mora, J. (1994). *Diccionario de filosofía*. Barcelona: Ariel.

Novello, M., & Perez-Bergliaffa, S. E. (2008). Bouncing cosmologies. *Physics Reports*, *463*(4), 127–213. doi: 10.1016/j.physrep.2008.04.006

Reichenbach, H. (1977). *Der aufstieg der wissenschaftlichen philosophie*. Wiesbaden: Wiever Verlagsgesellschaft.

Rescher, N. (2001). *Nature and understanding: The metaphysics and methods of science*. Oxford: Oxford University Press.

Romero, G. E. (2012). Parmenides reloaded. *Foundations of Science*, *17*(3), 291–299. doi: 10.1007/s10699-011-9272-5

Romero, G. E. (2013a). From change to spacetime: An eleatic journey. *Foundations of Science*, *18*(1), 139–148. doi: 10.1007/s10699-012-9297-4

Romero, G. E. (2013b). Adversus singularitates: The ontology of space–time singularities. *Foundations of Science*, *18*(2), 297–306. doi: 10.1007/s10699-012-9309-4

Romero, G. E. (2015). Present time. *Foundations of Science*, *20*(2), 135–145. doi: 10.1007/s10699-014-9356-0

Romero, G. E. (2017). On the ontology of spacetime: Substantivalism, relationism, eternalism, and emergence. *Foundations of Science*, 22(1), 141–159. doi: 10.1007/s10699-015-9476-1

Romero, G. E., & Pérez, D. (2011). Time and irreversibility in an accelerating universe. *International Journal of Modern Physics D*, *20*(14), 2831–2838. doi: 10.1142/S021827181102055X

Romero, G. E., & Vila, G. S. (2014). *Introduction to black hole astrophysics*. Heidelberg: Springer.

Stolpovskiy, M. (2016, March, 19-26). *QUBIC Experiment*. Conference 51th Rencontres de Moriond, La Thuile, Italy. Retrieved from https://arxiv.org/pdf/1605.04869v1.pdf

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[1] 1 megaparsec (Mpc) is equivalent to more than three million light years.