Found Sci
DOI 10.1007/s10699-017-9526-y

Gravitational Waves and Spacetime

Mario Bunge[1]

Abstract The recent detection of gravitational waves by the LIGO team has rightly been hailed as "the crowning achievemen of classical physics" (Holst et al. in Bull Am Math Soc 53:513–554, 2016). This detection, which came at the end of a decade-long quest, involved 950 investigators, and cost around one billion US dollars, was the scientific star of the year 2015. What, if any, is the philosophical impact of this scientific breakthrough, which Albert Einstein had anticipated one century earlier? To answer this question we start by examining the central equations of Einstein's theory of gravitation, also known as general relativity. Subsequently we analyze the special case of a hollow sphere, in an attempt to answer the question of the reality and even materiality of space or, rather, spacetime. As well, the view that gravitation is a manifestation of the curvature of spacetime is discussed, and the reality of gravitational waves is regarded as the coup de grâce to that view.

Keywords Gravity · Wave · Matter · Spacetime · Reality · Materialism

1 Einstein's Theory of Gravitation

Einstein's theory of gravitation can be summed up into the ten equations

$$G_{ik} = -kT_{ik}, \quad \text{where i, k} = 0, 1, 2, 3. \tag{1}$$

The lefthand side, the Einstein or metric tensor, describes the curvature of spacetime, whereas the mass tensor T_{ik} describes the distribution of the energy and momentum of the material source of the gravitational field—for instance a gas jet, a light beam, or whatever else there may be in the region that is being explored. G vanishes when spacetime is flat, and T is null wherever there is nothing. As for k, it is a universal constant proportional to Newton's.

✉ Mario Bunge
marucho.bunge@gmail.com

[1] Department of Philosophy, McGill University, Montreal, Canada

The Eq. (1) are numerical identities, but the meanings of their two sides are different [the whole point of writing equalities like (1), rather than identities like "$0 + 1 = 1 + 0$", is to relate different concepts. The same holds, of course, for inequalities].

In fact, whereas the lefthand side of (1) is a purely geometric construct out of the metric tensor g_{ik} occurring in the line element ds, the righthand side represents a composite of physical attributes such as energy density and momentum. Consequently, reading (1) from left to right is not the same as reading it from right to left. Indeed,

Left to Right Spacetime curvature affects matter.
Right to Left Matter curves spacetime.

These two readings or interpretations have been synthesized into the famous formula "Geometry tells matter how to move, and matter tells geometry how to bend." (Misner et al. 1973).

Note that so far we have not said what the Eq. (1) are about, whereas Aristotle rightly enjoined us to start every discourse by announcing what it will refer to. Obviously, Einstein knew what he was referring to when he wrote the (1), namely the gravitational field and its sources. That field had been mentioned though not worked out by Bernhard Riemann half a century earlier.

Those equations are the gravitational counterpart of the Poisson equation $\Delta\varphi = 4\pi\rho$ for the classical electrostatic field φ generated by the distribution ρ of electric charges. In the case of gravitation, G is the analog of φ, and T is that of ρ. As for the Laplacian $\Delta = \nabla^2$, it is the spatial counterpart of acceleration.

In the case of gravitation, the metric tensor g_{ik} is analogous to the electric potential φ, whereas the stress-energy tensor T is parallel to the charge density ρ. For propagating fields, whether gravitational or electromagnetic, the three-dimensional operator Δ is replaced with the four-dimensional d'Alembertian operator $\Box = \Delta - (1/c^2)\ \partial^2/dt^2$, the signature of a wave traveling at the speed c of light in vacuo.

The differences between gravitation and electromagnetism are just as interesting as their analogies. For one thing, gravity cannot be screened: there is no Faraday cage for it. For another gravity, along with energy, is the only property shared by lumps of matter of all kinds. By contrast, electrodynamics holds only for electrified matter—electric charges, currents, an their fields; correspondingly, Maxwell's field equations have a single general solution. By contrast, Einstein's equations for the gravitational field have no general solution because the stress-energy tensor T takes on different forms for different kinds of matter. Hence, far from being a universal theory like Maxwell's, Einstein's theory of gravitation is stuff-dependent or constitutive. In conclusion, the universal/stuff-dependent contrast that holds for properties does not carry over to the corresponding theories.

Einstein's reading of his Eq. (1) is embraced by all but the minority of physicists and philosophers who reject the concepts of matter and of gravitational field, notably Misner et al. (1973) in their monumental treatise on the subject. Ignoring the distinction Leibniz drew in 1704 between truths of reason and truths of fact, they hold that Einstein's equations are purely geometric, hence just as a priori as logic.

This claim is part of the geometrization of physics—a program first proposed in 1876 by the great mathematician William K. Clifford, and revived by J.A. Wheeler's geometrodynamics (1962). Wheeler also stated that the building stones of the universe are propositions; that "its" (concrete things) are clumps of bits; and that we participate in keeping the physical universe running (Barrow et al 2004). But neither Wheeler nor his associates has produced any evidence for these heterodoxies. I will argue that the detection of gravitational waves is only the latest of a string of facts and arguments against the matter-without-matter program. Instead of geometrizing physics, these developments have physicalized Riemann's geometry—just as Einstein implied when he drew the distinction between the unique physical geometry and the multiple mathematical geometries.

2 Enter Gravitational Waves

Shortly after inventing his theory of gravitation in 1915, Albert Einstein discovered that it entailed the existence of gravitational waves. This finding elicited many discussions in the physics community. Several ingenious devices were designed over the years to detect them, until the LIGO team, which designed and built a huge set of crossed laser interferometers, struck gold on September 14th, 2015 (Abbott et al. 2016).

How has this discovery affected the standard evaluation of Einstein's 1915 theory of gravitation as the best (truest) we have got? A first answer is of course that the discovery in question has once more corroborated Einstein's theory, since only the latter predicted the existence of those waves a full century in advance, along with some twenty other "effects."

Still, a questioning mind will also ask what a gravitational wave is: a ripple in a pre-existing gravitational field, or a ripple in spacetime and therefore also the alternated shrinking and expansion of the instruments used to explore it, such as rulers, time-keepers, and interferometers? To answer this question we only need to look again at Eq. (1) above and the two readings of it: spacetime curvature → matter, and matter → spacetime curvature.

Since both readings are legitimate, we conclude that a gravitational wave is a gravitational field spreading out *as well* as a ripple in spacetime. Thus, every time a gravitational wave struck LIGO's huge crossed interferometers, these oscillated, and the portion of spacetime they were immersed in trembled like a ball of jello.

This answer may incite the questioning mind to ask a further question, namely what has LIGO taught us about the nature of spacetime: is it only a grid useful for situating events, or is it just as material as its contents, such as atoms, galaxies, light beams and things?

3 Inside a Hollow Sphere

To help us answer the question that closes the previous section, consider a hollow sphere, or else an empty shell protected by a thick sheet of insulating material. As we know, gravitation vanishes in that hole. Commonsense adds that only spacetime, or at least space, remains. Further, this space would be flat, for wherever T vanishes so does G, and $G = 0$ is the signature of a Minkowski or pseudo-Euclidean spacetime.

Let us now rethink the LIGO experiment in light of the above. If we grant that a gravitational wave involves the propagation of a gravitational field as well as a spacetime ripple, and since material objects, and only they are changeable—as Heraclitus taught us—, we must also grant the logical consequence, namely that spacetime is material and thus real (or subject-free) as well.

Our argument may be recast into the following linked syllogisms.

First argument

1. Gravitational waves activate their detectors.
2. Detectors react only to specific material stimuli.
3. LIGO has detected gravitational waves.

Hence, gravitational waves are material.

Second argument

1. Gravitational waves are ripples in spacetime as well as fields spreading out.
2. Whatever is changeable is material and vice versa.

Hence, spacetime is material.

The conclusion contradicts the popular opinion that spacetime is the passive and immaterial container of all there is. By the same token, it also contradicts all the varieties of immaterialism, including the phenomenalism of Berkeley, Kant, and their positivist offspring, as well as Wheeler's geometric theory of matter. On the other hand, the thesis that spacetime is just as material as its contents, might have been admitted by Einstein, for he stated explicitly that there would be no metric tensor g_{ik} anywhere if the matter tensor T_{ik} were to vanish everywhere. I am also in the company of the physicist-philosophers Héctor Vucetich and Gustavo Romero (2016). The latter has gone as far as claiming that spacetime can be heated, so that it possesses entropy.

Let us conclude by asking a last unsettling question: What becomes of spacetime when matter vanishes, as in the case of a hollow sphere? Since there is nothing real between two geometric points in that hole, their physical distance should be null according to any relational conception of space, such as that of Bunge and García-Maynez (1977).

In other words, inside the hollow sphere spacetime would vanish along with matter. Most physicists are likely to reject this conclusion, and state that spacetime inside the hole persists, and that its geometry is Minkowskian. How could one get experimental evidence relevant to this hypothesis? One way to find out is to introduce measuring instruments into the hollow sphere—which would of course cease to be hollow. An alternative method would be to manipulate the sphere from the outside, for instance irradiating it, warming it up, or drilling a hole on its shell. In either case spacetime would be reinstated, but the hole would be disturbed, as spacetime would rush into it in the form of a gravitational wave.

To retrieve spacetime of some sort we must step down to the level of the fluctuating vacuum of quantum electrodynamics, with its small but measurable Lamb shift and Casimir force. However, this new problem is big enough to deserve being tackled by a further research project.

As long as we confine ourselves to macrophysics, we must admit that the recent detection of gravitational waves suggests the counterintuitive thesis that spacetime is a material entity, so that we must rethink our conceptions of matter and materialism, much as people did when Faraday and Maxwell added the concept of an electromagnetic field to that of a body. (See Bunge 1980) Stay tuned for the further philosophical novelties forced by future scientific findings.

Acknowledgements I thank Hector Vucetich and Pablo Sisterna for their comments, and particularly Gustavo E. Romero for his constructive criticisms.

References

Abbott, B. P., et al. (2016). Observation of gravitational waves from a binary black hole merger. *Physical Review Letters, 116,* 061102.

Barrow, J. D., Davies, P. C. W., & Harper, C. L., Jr. (2004). *Science and ultimate reality*. Cambridge: University Press.

Bunge, M. (1980). *Scientific materialism*. Dordrecht, NL: Reidel.

Bunge, M., & García-Maynez, A. (1977). A relational theory of physical space. *International Journal of Theoretical Physics, 15,* 961–972.

Holst, M., Sarbach, O., Tiglio, M., & Vallisneri, M. (2016). The emergence of gravitational wave science. *Bulletin of the American Mathematical Society, 53,* 513–554.

Misner, C. W., Thorne, K. S., & Wheeler, J. A. (1973). *Gravitation*. San Francisco: W. H. Freeman.

Romero, G. E. (2016). On the ontology of spacetime: Substantivalism, relationism, eternalism, and emergence. *Foundations of Science*. doi:10.1007/s10699-015-9476-1.

Wheeler, J. A. (1962). *Geometrodynamics*. New York: Academic Press.

Professor Mario Bunge earned his doctorate in physics in 1952 at the Universidad Nacional de La Plata, Argentina, and was a professor of theoretical physics at his alma mater as well as at the Universidad de Buenos Aires. He taught at McGill University between 1966 and 2009. He has also been a visiting professor in Australia, Denmark, Germany, Italy, México, USA, Switzerland, and Uruguay. He holds 20 honorary doctorates and four honorary professorships, and is a member of four academies, among them the Royal Society of Canada and the Institut International de Philosophie. He is a Humboldt and a Guggengheim fellow, and a Prince of Asturias laureate. Bunge authored more than 500 papers and 70 books in physics, philosophy of science, semantics, epistemology, ontology, ethics, and science policy. Among his books are *Causality* (1959), *Scientific Research* (1967), *Foundations of Physics* (1967), the nine-volume *Treatise on Basic Philosophy* (1974–1989), *The Mind-Body Problem* (1980), *Finding Philosophy in Social Science* (1996), *Social Science Under Debate* (1998), *Political Philosophy* (2009), *Matter and Mind* (2010), *Evaluating Philosophies* (2012), *Medical Philosophy* (2013), *Between two Worlds* (2016), and *Doing Science* (2017). He has co-authored *Philosophy of Psychology* (1988) and *Foundations of Biophilosophy* (1997). Some of his work has been translated into eleven foreign languages. Counting translations and re-editions, his books number 165 to date. He founded the Universidad Obrera Argentina (1938–1943), the journal *Minerva* (1944–1945), the Society for Exact Philosophy (1971-to date), and the Asociación Mexicana de Epistemología (1976–1979). He also cofounded the Asociación Física Argentina (1944-to date) and the Asociación Rioplatense de Lógica y Filosofía Científica (1956–1963).