Heuristics of the General Relativity

Nicolae Sfetcu

11.09.2019

Sfetcu, Nicolae, "Heuristics of the General Relativity", SetThings (September 11, 2019), URL = https://www.setthings.com/en/heuristics-of-the-general-relativity/

Email: nicolae@sfetcu.com

A partial translation of
Sfetcu, Nicolae, "Epistemologia gravitației experimentale – Raționalitatea științifică", SetThings (1 august 2019), MultiMedia Publishing (ed.), ISBN: 978-606-033-234-3, DOI: 10.13140/RG.2.2.15421.61925, URL = https://www.setthings.com/ro/e-books/epistemologia-gravitatiei-experimentale-rationalitatea-stiintifica/

BIBLIOGRAPHY..8

The essential principle of coordination in GR is the principle of equivalence, including a negative heuristic. The argument "is not that all reference frames are equivalent, but that the classical coordination of uniform motion in a straight line with the paths of force-free particles cannot be carried out unambiguously or consistently." [1] The principle of equivalence states that the decomposition of the gravitational motion into a uniform motion and gravitational acceleration cannot be unique, since free fall is not distinguishable locally from uniform motion. However, such a decomposition implies a violation of the general covariance, because it represents an arbitrary choice of a coordinate system[2]. For any coordinate system, if we identify its lines with the geodesic lines, we can construct the gravitational field so that the difference between these geodesics and the actual motions can be differentiated. [3]

Einstein's special theory of relativity (SR) is built on two fundamental postulates. the postulate of light (the speed of light, in the "rest frame", is independent of the speed of the source), and the principle of relativity. The latter was explicitly adopted by Einstein as a means of restricting the form of laws, whatever their detailed structure. Thus, we have the difference between a "constructive" theory and a "principle" theory. The general theory of relativity was developed using as a nucleus a principle of symmetry: the principle of general covariance[4]. Initially, Einstein saw the principle of general covariance as an extension of the principle of relativity in classical mechanics, and in SR. For Einstein, the principle of general covariance was a crucial postulate in the development of GR. The freedom of the GR diffeomorphism (the invariance of the form of the laws under transformations of the coordinates depending on the arbitrary functions of space and time) is a "local" spacetime symmetry, as opposed to the "global" spacetime symmetries of the SR (which depend instead on the constant parameters).

In recent years, there have been numerous debates in physics and philosophy regarding certain types of symmetries that act in the space of theories. Such symmetries are interpreted as achieving an "equivalence" between two theories that are said to be related to a "dual symmetry"

---

[1] Robert Disalle, "Spacetime Theory as Physical Geometry," *Erkenntnis* 42, no. 3 (1995): 317–337.

[2] A. Einstein, "The Foundation of the General Theory of Relativity," in *The Principle of Relativity. Dover Books on Physics. June 1, 1952. 240 Pages. 0486600815, p. 109-164*, 1952, 114, http://adsabs.harvard.edu/abs/1952prel.book..109E.

[3] Einstein, 142–43.

[4] Katherine Brading, Elena Castellani, and Nicholas Teh, "Symmetry and Symmetry Breaking," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, Winter 2017 (Metaphysics Research Lab, Stanford University, 2017), https://plato.stanford.edu/archives/win2017/entries/symmetry-breaking/.

(in the case of a "symmetry" in the strict sense of an automorphism, these are called "self-dualities"). Katherine Brading[5] exemplifies with the dualities between quantum field theories (such as generalized magnetic/electrical duality), between string theories (such as T and S dualities) and between physical descriptions that are, such as a quantum field theory and a string theory, as in the case of gauge/gravity dualities[6]. Other examples are the position-momentum duality, the wave-particle duality, or the Kramers-Wannier duality of the two-dimensional Ising model in statistical physics. Dualities are transformations between theories, while symmetry is a mapping between solutions of the same theory. A symmetry can be exact (unconditional validity), approximate (valid under certain conditions) or broken (depending on the object considered and its context). The symmetries functioned normatively, like constraints, in Einstein's general covariance in establishing the equations of general relativity.

Elie Zahar said that Einstein's development of relativity was due to his vague metaphysical beliefs, corresponding to some of his own "heuristic prescriptions" that became a specific and powerful tool. Zahar states that Kuhn's scientific revolution does not apply to Einstein's case. According to him, two "heuristic devices" led to the discovery of the theory of relativity: the internal requirement of coherence, and the claim that, "since God is no deceiver, there can be no accidents in Nature." Natural symmetries are fundamental at the ontological level, and the heuristic rule takes precedence over a theory that does not explain symmetries as deeper manifestations. [7]

According to Newton, gravity is not a primary quality like inertia or impenetrability. Therefore, inertia and gravity are independent properties. But Newton states that the inertial mass is equal to the gravitational mass, without explaining the reason for this identity (there is a symmetry that contradicts the independence of the two properties). In Michelson's experience, by applying the ether as a universal medium, it is undetectable, which is a paradox. Einstein became aware of this paradox. Einstein eliminates the asymmetry between gravity and inertia by proposing that all gravitational fields be inertial. He also had other objections to classical physics: Lorentz's electromagnetic theory faced a dualism between discrete charged particles governed by Newton's laws and a continuous field that respected Maxwell's equations; relativity applies to Lorentz

---

[5] Katherine Brading and Harvey R. Brown, "Symmetries and Noether's Theorems," in *Symmetries in Physics: Philosophical Reflections*, ed. Katherine A. Brading and Elena Castellani (Cambridge University Press, 2003), 89–109.

[6] Brading, Castellani, and Teh, "Symmetry and Symmetry Breaking."

[7] Elie Zahar, "Why Did Einstein's Programme Supersede Lorentz's? (II)," *British Journal for the Philosophy of Science* 24, no. 3 (1973): 223–262.

mechanics, but not to electrodynamics; the idea of absolute space (there is a privileged inertial framework), although its elimination does not influence classical mechanics.

Einstein appreciated, on the principle of relativity, its universality and its unifying role for mechanics and electrodynamics, this being the first principle used to develop its general theory of relativity. The second principle is that of light but, epistemologically, Einstein's second starting point in developing the general theory of relativity was not the principle of light, but the idea that Maxwell's equations are covariant and express a law of nature. The principle of light results from this idea, as does the principle of relativity, according to Zahar. [8]

Basically, Einstein had the choice of developing general relativity based on Maxwell's equations or Newton's laws. But in the dualism between particles and fields, all attempts at mechanical explanation of field behavior failed.

According to Zahar, no "crucial" experiment could have been conceived between Lorentz theory and Einstein's in 1905. But Minkowski and Planck abandon the classical program for special relativity, contrary to Kuhn's methodology. Moreover, Einstein was at that time a quasi-stranger, while Lorentz was a recognized authority. And Lorentz's theory was very clear from that of Einstein, which involved a major overhaul of the notions of space and time. Also, there were no anomalies that Einstein's theory would have solved better than Lorentz. In addition, Lorentz himself was finally convinced of the new perspective[9]. Whittaker[10] regards Lorentz and Poincaré as the true authors of special relativity, Einstein's credit being that of developing general relativity. Thus, Lorentz's etheric program was not defeated by the program of relativity but was practically developed in it. Zahar contradicts it, based on the fact that the two programs have very different heuristics. [11]

In the case of the Copernican revolution, the Platonic program for modeling the phenomenon through circular and spherical movements was initially successful, with each planet on a real physical crystalline sphere in axial rotation. It was later discovered that the distance between the earth and the planets varies, so that additional assumptions were made through eccentricities, epicycles and screens, to explain the new observations. When one tried to determine the motion of the celestial bodies towards the earth due to the uneven movements, there appeared differences between phenomena and mathematical methods that allowed only circular motions

---

[8] Zahar.

[9] Zahar.

[10] Edmund Taylor Whittaker, *A History of the Theories of Aether and Electricity* (Harper, 1960).

[11] Zahar, "Why Did Einstein's Programme Supersede Lorentz's?"

with the earth in the center of the universe. Copernicus, although he considered the Sun fixed, did not resolve this difference, still using epicycles. Kepler was the one who abolished the epicycles and found the laws of the elliptical motion of the planets with the Sun in a focus. Lorentz used the Galilean transformations, eliminating the epicycles but giving the etheric frame a privileged status. Just as Copernicus was aware of the idealization of his planetary model, Lorentz later understood that the effective coordinates, not the Galilean ones, are the quantities measured in the moving frame. Einstein gave up the Galilean transformations and identified the actual coordinates measured as the only real ones. Einstein's heuristics are based on a general requirement of Lorentz covariance for all physical laws, requiring the renunciation of Galilean transformations.

Zahar claims that Lorentz and Einstein used different heuristics in their research programs[12]. The etheric program was practically replaced by a program with greater heuristic power, which is why Planck abandoned Lorentz's theory in favor of Einstein just before Einstein's program became progressively empirical. The two theories are similar in terms of the "hard core" (negative heuristics) and can be considered as bifurcated programs. The difference between the positive heuristics was what led to the choice of scientists of Einstein's program at the beginning of the last century. Lorentz's positive heuristic consisted in providing the ether with properties that would explain many physical phenomena, including the electromagnetic field and Newtonian mechanics. This approach allowed a rapid development of Lorentz's program, but by the end of the 19th century heuristics had reached a saturation point. A number of degenerate programmes have emerged as mechanical models to resolve ether anomalies. To explain certain electromagnetic phenomena, Lorentz introduced the postulate of the ether at rest, but subsequent calculations contradicted this hypothesis.

The differences between Lorentz and Einstein's views were metaphysical: Lorentz believed that the universe respects intelligible laws (there is a propagating environment, an absolute "now", etc.), while for Einstein the universe is governed by coherent mathematical principles. (covariant laws, etc.) Zahar states that all major scientific revolutions were accompanied by an increase in mathematical coherence accompanied by a (temporary) loss of intelligibility (Newtonian astronomy is more coherent than Ptolemaic, but remote action was not accepted before Newton, then accepted at the end of the 18th century and again rejected after Maxwell). In Lorentz's research programme, the behavior of the electromagnetic field had come to dictate the properties of the ether, even improbable (for example, resting ether and acting by zero net forces). Basically,

[12] Zahar.

Lorentz's heuristic strategy has reversed: instead to deduce a theory from the ether considered fundamental, he reaches the ether based on the field. Einstein's heuristics were based on the requirement that all physical laws be Lorentz-covariant (to take the same form regardless of the frame of reference), and classical law to emerge from the new law as a limit case.

In order to obtain a relativistic theory of gravity, Einstein maintained the principle of equivalence, decided to treat all coordinate systems equally and to impose a condition of general covariance on all laws. The empirical success of general relativity through the correct prediction of the behavior of Mercury's perihelion has proved crucial for the further development of the programme.

Since 1905, the program of relativity has proved to be heuristically superior compared to the classical one. But special relativity has failed to outperform the Lorentz program. Bucherer's experiment[13] confirmed both hypotheses, and Kaufmann's experiment[14] denied both. Before the emergence of general relativity, the scientific community spoke of Lorentz-Einstein's theory, considering them as equivalent from an observer's point of view. General relativity has succeeded empirically replacing the Lorentz program by successfully explaining the "abnormal precession" of Mercury's perihelion. This prediction was an empirical progress. In addition, general relativity has been found to be more falsifiable.

Nicholas Maxwell proposes also a method for the unification of two "mutually contradictory principles." [15] The method proposed by him for establishing the unified theory is as follows: from the two theories, the common elements that do not contradict are chosen, the contradictory elements are removed, and on this basis the new theory is developed. He does not sufficiently exemplify, in my opinion, what would be those common elements in the case of classical mechanics and classical electrodynamics, considered by all scientists as two contradictory theories from which the special theory of relativity was born. Also, Nicholas Maxwell imposes the existence of a "crucial assumption", whose falsifiability allows the acceptance of the theory as a result of a method of discovery based on empirical purpose. In today's physics, there are countless examples of unifying theories (such as the M theory proposing the union of all fundamental forces, including gravity) that have not set out to become falsifiable by "crucial assumptions".

---

[13] A. H. Bucherer, "Die Experimentelle Bestätigung Des Relativitätsprinzips," *Annalen Der Physik* 333 (1909): 513–36, https://doi.org/10.1002/andp.19093330305.

[14] W. Kaufmann, "Über Die Konstitution Des Elektrons," *Annalen Der Physik* 324 (1906): 949, https://doi.org/10.1002/andp.19063240303.

[15] Nicholas Maxwell, *Karl Popper, Science and Enlightenment* (London: UCL Press, 2017).

General relativity is the result of Einstein's unification of Newton's theory of universal gravity (with the instantaneous action at a distance of the gravity) and the special theory of relativity (with the limitation of any speed to the constant value of the speed of light, *c*). These two principles contradict each other. So, according to Maxwell, it should be removed from the future unifying theory.

Bibliography

Brading, Katherine, and Harvey R. Brown. "Symmetries and Noether's Theorems." In *Symmetries in Physics: Philosophical Reflections*, edited by Katherine A. Brading and Elena Castellani, 89. Cambridge University Press, 2003.

Brading, Katherine, Elena Castellani, and Nicholas Teh. "Symmetry and Symmetry Breaking." In *The Stanford Encyclopedia of Philosophy*, edited by Edward N. Zalta, Winter 2017. Metaphysics Research Lab, Stanford University, 2017. https://plato.stanford.edu/archives/win2017/entries/symmetry-breaking/.

Bucherer, A. H. "Die Experimentelle Bestätigung Des Relativitätsprinzips." *Annalen Der Physik* 333 (1909): 513–36. https://doi.org/10.1002/andp.19093330305.

Disalle, Robert. "Spacetime Theory as Physical Geometry." *Erkenntnis* 42, no. 3 (1995): 317–337.

Einstein, A. "The Foundation of the General Theory of Relativity." In *The Principle of Relativity. Dover Books on Physics. June 1, 1952. 240 Pages. 0486600815, p. 109-164*, 109–64, 1952. http://adsabs.harvard.edu/abs/1952prel.book..109E.

Kaufmann, W. "Über Die Konstitution Des Elektrons." *Annalen Der Physik* 324 (1906): 487–553. https://doi.org/10.1002/andp.19063240303.

Maxwell, Nicholas. *Karl Popper, Science and Enlightenment*. London: UCL Press, 2017.

Whittaker, Edmund Taylor. *A History of the Theories of Aether and Electricity*. Harper, 1960.

Zahar, Elie. "Why Did Einstein's Programme Supersede Lorentz's? (II)." *British Journal for the Philosophy of Science* 24, no. 3 (1973): 223–262.