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ABDUCTION, BAYESIANISM AND BEST EXPLANATIONS IN PHYSICS

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Resumen

Este artículo reivindica la vigencia del razonamiento abductivo, o inferencia de la mejor explicación, como práctica de descubrimiento de hipótesis científicas. En el camino para lograr este objetivo se presentan en este trabajo toda una serie de argumentos que cuestionan la viabilidad del Bayesianismo como teoría de la confirmación científica. Solventado este asunto, se recurre a un episodio de la astrocosmología contemporánea que se interpreta como un ejemplo elocuente de la eficacia de la metodología abductiva en la física teórica contemporánea.

Palabras clave: Explicación científica, abducción, inferencia de la mejor explicación, bayesianismo, púlsares, ondas gravitacionales

Abstract

This article claims the validity of abductive reasoning, or inference to the best explanation, as a practice of discovery of explanatory scientific hypotheses. Along the way to achieve this objective I present here a series of arguments that question the feasibility of Bayesianism as a theory of scientific confirmation. Having solved this issue, I resort to an episode of contemporary astrocosmology that I interpret as an eloquent example of the effectiveness of abductive methodology in contemporary theoretical physics.

Keywords: Scientific explanation, abduction, inference to the best explanation, Bayesianism, pulsars, gravitational waves

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I. Introduction

As I write this article, NASA announces that the Cassini spacecraft mission has gathered evidence that there could be life under the icy surface of Saturn's moon Enceladus. An analogy with what happens in the sidereal depths of our oceans provides arguments in favour of the possibility of life on this moon of Saturn. The molecular hydrogen detected in Enceladus's hydrothermal vents could be used by potential microorganisms. As if they were detectives, scientists hypothesize about the data available to them.

The observation of the firmament, from the very beginnings of the historical epoch of the present humanity, has been an inexhaustible source of questions about surprising phenomena, phenomena that could not always be explained within the available theoretical or cultural frameworks. But as scientists develop increasingly effective predictive and anticipatory theoretical tools and we are helping with ever more precise instruments, many questions become unsettling and urgent to respond. For instance: Why do stars shine? How can stars orbiting far away from their respective galactic centers maintain such a large orbital speed? Why is the universe showing symptoms of accelerated expansion if the amount of conjectured ordinary matter actually should favor its contraction? How can we understand that certain stars beat with regular periods so that they seem to disappear from the visible Universe and shine some time later with all splendor? What kind of objects are those celestial bodies which, like precise clocks, send signals within extraordinarily small time periods? Indeed, this is certainly not the immutable sky of classical antiquity. It seems even that in our Universe any phenomenon is imaginable and anything thinkable is possible. Do we have explanations for these phenomena?

When a phenomenon troubles us, science tries to find an explanation. The most immediate reaction is to attempt to find the desired explanation within the framework of the best theory available at the time. For example, in the seventeenth century an explanation was sought for the apparent movements of the wandering celestial bodies, and when two centuries later it became imperative to give an answer to the question of why the stars shine, the physicists of the time resorted again to the Newtonian celestial mechanics to try to find an answer. In the first case, satisfactory, in the second, disappointing.

Now, what happens when there is no theory available? Deductive explanation in the sense of Popper-Hempel's D-N model is not possible then. Does science shrug shoulders waiting for better times? Fortunately this does not happen. From classical antiquity to the present day, Western science has been implementing a form of ampliative reasoning for the postulation of new explanatory hypotheses about surprising or novel facts. Finally, Charles Peirce was able to give a name to this old form of reasoning and to clarify its fundamental features. For instance, in *CP* 5.145, 5.170, 5.171, 5.189, 7.202, etc. When, in a second step, Gilbert Harman (1965, 88-89) proposed renaming abduction as Inference to the Best Explanation (*IBE*), the philosophers of science began to assume that many of the great advances of science in the past were the result of the application of abduction, a kind of ampliative reasoning. For instance, Thagard (1978, 77-78) recognized that Fresnel's wave theory of light was proposed as the best explanation of the observed phenomena, and Putnam (1981, 198) claimed that Darwin's theory of evolution was the result of an abduction or inference to the best explanation. Josephson, Magnani and many others struggle without fainting so that the double facet, inferential and explanatory, of abductive reasoning can be recognized.

In the philosophy of science, I have myself been betting strongly on the validity of abductive reasoning both in the *observational sciences*, as paleoanthropology and geophysics, as in the natural *theoretical sciences*, such as physics. In this paper I will again claim the validity of abduction through examples taken from contemporary astrophysics, and, closer to the position of Peter Lipton than Salmon's, according to whom the Bayesian approach renders IBE dispensable, I proclaim that abduction is an indispensable form of fallible reasoning in contemporary science, both for the introduction of new hypotheses and for the explanation of surprising phenomena.

2. From Abduction to Inference to the Best Explanation

The beginnings of western theoretical science, in classical Greece, are inextricably linked with the search for explanations. Why an eclipse of the moon occurs, or what an eclipse of the moon consists of –both questions were ultimately the same for Aristotle– is an example of search for explanation that the Stagirit poses in his *Posterior Analytics*.

When a phenomenon concerns us, science tries to find an explanation within the framework of the best theory available at the time. From classical antiquity to the present day, Western science has been looking for explanatory hypotheses about surprising or novel facts. Now, what does it happen when there is no theory available or no sufficiently reliable theory?

Well, abduction is the form of ampliative inference –it instantiates a non-demonstrative reasoning– that provides the explanation of new or surprising facts through the postulation of novel hypotheses. Peirce gave the name *abduction* to the logical operation of introducing new ideas into science, "All the ideas of science come to it by the way of abduction. Abduction consists in studying facts and devising a theory to explain them" (*CP*, 5.170). Indeed, according to Peirce (*CP*, 7.202), abduction, as "the step of adopting a hypothesis as being suggested by the facts", also supplies an explanation for novel or surprising phenomena: "The explanation must be such a proposition as would lead to the prediction of the observed facts, either as necessary consequences or at least as very probable under the circumstances. A hypothesis then, has to be adopted which is likely in itself and renders the facts likely."

Gilbert Harman (1965, 88-89 and 1968, 165) preferred to rename abduction *inference to the best explanation* to point to the fact that abduced hypotheses provide the best explanation for the evidence than would any else. And since the late 1970s, abduction has been, for the methodology of science, inference to the best explanation. Paul Thagard (1978, 77) claims for instance that "Inference to scientific hypotheses on the basis of what they explain was discussed by such nineteenth-century thinkers as William Whewell and C. S. Peirce … To put it briefly, inference to the best explanation consists in accepting a hypothesis on the grounds that it provides a better explanation of the evidence than is provided by alternative hypotheses." Thagard (1978, 77-78) illustrates this viewpoint resorting to Fresnel's wave theory of light, which "explained the facts of reflection and refraction at least as well as did the particle theory, and … there were other facts,…, which only the wave theory could simply explain. (...) Hence the wave theory should be inferred as the best explanation." And Hilary Putnam (1981, 198) confesses that "we accept the Darwinian theory of evolution by natural selection as what Peirce called an 'abduction' or what has recently been called an 'inference to the best explanation'." In the contemporary theory of abduction John Josephson (1994, 5) for instance claims that "*Abduction*, or *inference to the best explanation*, is a form of inference that goes from data describing something to a hypothesis that best explains or accounts for the data." And for Peter Lipton (2001*a*, 56) "scientists infer from the available evidence to the hypothesis which would, if correct, best explain that evidence." The interesting idea about *IBE* for Lipton (2001*b*, 93) "is simply that we sometimes decide how likely –but not in a probabilistic sense, A.R.– a hypothesis is to be correct in part by considering how good an explanation it would provide, if it were correct."

Abduction has to two sides. I completely agree with Lorenzo Magnani (2007, 294) that successful abduction generates plausible hypotheses and provides best explanations of facts. Magnani (2001, 17-18) anticipates this idea as he recognizes that "Theoretical abduction is the process of *inferring* certain facts and/or laws and hypotheses that render some sentences plausible, that *explain* or *discover* some (eventually new) phenomenon or observation; it is the process of reasoning in which explanatory hypotheses are formed and evaluated."

3. Is Bayesian Confirmation a Successful substitute of IBE?

Although abductive inference, or inference to the best explanation, has reached a broad consensus among contemporary philosophers of science, the consensus is by no means complete. Among the most prominent critics is Wesley Salmon, who starred, along with Peter Lipton, an interesting controversy, which gives title to this section. Salmon (2001, 85) advocates a theory of confirmation in Bayesian terms and maintains that "inference to the best explanation should be put in its place; its place, it seems to me, is beyond the pale." But I disagree with Salmon that judgements about likeness or probability of the scientific hypotheses have to be given in Bayesian terms. Thus I reject Salmon's point of view that the Bayesian approach to confirmation renders IBE dispensable. But instead of entering in detail in his discussion with Lipton, I am going to present a whole series of arguments against the Bayesian theory of confirmation.

I do not hide that the discussion on the relationships between abduction and Bayesianism is very present in contemporary philosophy. For instance in Lipton (2004) on the compatibility between Bayesianism and *IBE*, in Iranzo (2008) on *IBE*-Bayesianism, or in Roche and Sober (2014) and McCain and Poston (2014) on whether explanatoriness is evidentially relevant or not, among others. But if I can convince you that the Bayesian project is not satisfactory, I will consider myself justified not to enter into a long-winded discussion on the alleged advantages of Bayesian confirmation theory with respect to the theory of inference to the best explanation.

Thus, the first thing I will show is that Bayes's Theorem fails to satisfactorily solve the task entrusted to inductive probability. Thomas Bayes's question in 1763 was: "*Given* the number of times in which an unknown event has happened and failed: *Required* the chance that the probability of its happening in a single trial lies somewhere between any two degrees of probability that can be named.” Ronald Fisher’s (1930, 530-531; 1934, 286 and 1956, 11-12) analytical reconstruction[1] of Bayes’s theorem is the following:

1. Let p be the probability of ‘success’ –for instance ‘face’– on the toss of a coin.
2. Let X be the random variable ‘number of successes in n independent trials’.
3. Let $f(p)$ be an unknown function of the probability density of the values of p. The probability for p to be found within a range $[p, p + dp]$ is then $f(p)\,dp$.
4. If a is the number of successes in n independent experiments, and n-a is the number of failures, then the probability of $X=a$ times ‘success’ (a times ‘face’) in n independent trials, with unknown probability p of ‘face’, is $\binom{n}{a} p^a (1-p)^{n-a}$.
5. The joint probability of 3. and 4. is $\binom{n}{a} p^a (1-p)^{n-a} f(p) d(p)$.
6. As p is normalized to unity, if we take $f(p)=1$, then the probability P of a times ‘success’ in n independent trials is $P = \int_0^1 \binom{n}{a} p^a (1-p)^{n-a}\, dp = \frac{1}{n+1}$.
7. Obviously $\frac{(n+1)!}{a!(n-a)!} p^a (1-p)^{n-a}$ is a probability density function. That is to say, $\int_0^1 \frac{(n+1)!}{a!(n-a)!} p^a (1-p)^{n-a}\, dp = 1 \cdot$
8. Given any two values u and v of probability of ‘success’, the solution to Bayes’s question finally is $P(u \le p \le v \mid X = a) = \frac{(n+1)!}{a!(n-a)!} \int_u^v p^a (1-p)^{n-a}\, dp$.

The problem is that if, as in point 6, we *a priori* suppose that $f(p)=1$, that is, that the values of p are uniformly distributed, then, as Ronal Fisher (1934, 285) claims, Bayes’s solution depended “essentially on postulating *a priori* knowledge, not of the particular population of which our observations form a sample, but of an imaginary population of populations from which the population was regarded as having been drawn at random.” Then Fisher (1934, 286) goes on: “As an axiom this supposition of Bayes fails, since the truth of an axiom should be manifest to all who clearly apprehend its meaning, and to many writers, including, it would seem Bayes himself, the truth of the supposed axiom has not been apparent.”

A case where the problem of assuming *a priori* a uniform distribution of the p values, i.e., that all of the p values have the same probability, is particularly evident in the so-called Laplacian succession rule. Indeed, if we take $f(p) = 1$, then the probability P of a times ‘success’ in n independent trials is $P = \frac{1}{n+1}$, and the probability P' of a+1 times ‘success’ in n+1 independent trials is $P' = \frac{1}{n+2}$. Following, the conditional probability P^* of ‘success’ in

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[1] I have presented this reconstruction in Rivadulla (1991, 130-132 and 2004, 44-45)

essay number n+1, if we have obtained n times 'success' in n previous independent trials, is: $P^* = \frac{n+1}{n+2}$. This *Rule of Succession* supports, for instance, mathematically the idea that the more success we have had in the past the greater success we should expect in the future. Getting older makes some one getting still older more likely. Not die in the future depends on not dying in the past! And another 'benefit' we can draw from Laplace's Rule in ordinary life; when we need to renew our driver's license, we can present following reason for renewal: In many years driving I have never had any accidents; thus, the probability of continuing to suffer no accidents in the future is constantly increasing!

Another case in which it becomes apparent the failure of Bayes's theorem as a mathematical model for the empirical confirmation of theories is the following: Let us take three gravitational theories that make different predictions about the deflection of light by the Sun: Newtonian Mechanics (NM), which predicts a deviation of 0.87 arcsec; Einstein's theory of relativity (RT) which predicts 1.75 arcsec deflection; and another theory, incompatible with RT, that also predicts a deviation of 1.75 arcsec. Based on our familiarity and confidence in these three theories we make the following *initial* or *a priori* probability distribution: $p(NM)$=0,5; $p(RT)$=0,35; $p(h_3)$=0,15. The empirical fact e is Arthur Eddington's astronomical observation, after repeatedly confirmed, that the actual deviation of the light from distant stars by the Sun is 1.75 arcsec. A consistent application of Bayes's theorem leads mathematically to the conclusion that

$$p(NM|e) = 0$$

$$p(RT \mid e) = \frac{0{,}35 \times 1}{0 + [0{,}35 \times 1] + [0{,}15 \times 1]} = 0{,}7$$

$$p(h_3 \mid e) = \frac{0{,}15 \times 1}{0 + [0{,}35 \times 1] + [0{,}15 \times 1]} = 0{,}3.$$

But as I claim in Rivadulla (2004, 58): "We note that there has been an increase in the posterior probability of both *RT* and h_3. Both successful hypotheses gain *a posteriori* the probability to be true that *NM* loses. This suggests in principle that experience confirms both hypotheses, increasing their probability of being true. However this increase is only apparent. As a matter of fact, the initial probability ratio remains *a posteriori* the same, $\frac{0.35}{0.15} = \frac{0.7}{0.3}$." In other words, the real contribution of Bayes's theorem is that if one of the theories considered becomes empirically refuted, the remaining theories maintain *a posteriori* the ratio of their respective priors. That is, Bayesianism is not a theory of confirmation at all.

Finally, what would have happened –I wonder in Rivadulla (2015*a*, 29-30)– if Newton would have had the chance to meet Bayes's theorem while he had known the result referred to in the previous example of the empirical testing of his own gravitational theory? Obviously, Bayes's theorem would have given to NM *a posteriori* zero probability of being true. But as

Bayes's theorem does not require that the predictions of a theory follow an in advance fixed temporal order, or that the empirical tests also follow a strict order, Bayes's theorem could have attributed to Newtonian celestial mechanics a posterior probability to be true close to 1, although later on this theory might eventually be recognized as false. The final conclusion is that Bayesianism is not a satisfactory theory of scientific confirmation.

4. Best explanations in physics.

Peter Lipton (2001*b*, 93) is dissatisfied that "Salmon's essay would place Inference to the Best Explanation beyond the pale of acceptable philosophical accounts of Inference. According to Salmon, Inference to the Best Explanation has serious internal difficulties and compares very unfavourable with Bayesian approaches to these matters." Nonetheless, to reject the Bayesian approach, as I hope I have done in the previous section, does not commit me to accept Lipton's 'refinement' that IBE should be better understood as an inference to the *loveliest* explanation. Is it about replacing one slogan with another? Epistemology is not precisely the intellectual space where we should try to face philosophical problems with witty remarks. I agree with Lipton (2001*b*, 103) that "Inference to the Best Explanation is meant to tell us something about how we choose between *competing* explanations, we are to choose the best of these", and I also agree it would be reasonable to complete the phrase Inference to the Best Explanation with "the more accurate but less memorable phrase, 'inference to the best of the available competing explanations, when the best one is sufficiently good'." Indeed this is what I have tried to show in Rivadulla (2015*a*,*b*) and also in Rivadulla (2010 and 2016*a*,*b*), where I offer a treatment of abduction from a double perspective, as a practice of scientific discovery and as an inference to the best explanation.

For more than two hundred years Western humanity has believed in the Newtonian explanation of planetary movements and gravitational phenomena in general, free fall of bodies, tides, orbits of comets, etc. With the advent of the general theory of relativity (GRT), people stopped believing in this explanation and began to flirt with the Einsteinian explanation that accounts for all these same phenomena and other 'new' facts such as the deviation of light and gravitational lens effect, gravitational red shift and black holes, advancement of the perihelion of planets, gravitational waves –recently confirmed–, and so on. Indeed, scientists changed one explanation for another, but they did not give up the search for explanation.

Ostlie & Carroll (1996, 608) describe as follows the surprise –a must circumstance of all abductive discovery– when Jocelyn Bell and Anthony Hewish were studying radio waves from distant quasars: "In July 1967, Bell was puzzled to find a bit of "scruff" that reappeared every 400 feet or so on the rolls of her strip chart recorder; ... Careful measurements showed that this quarter inch of ink reappeared every 23 hours and 56 minutes, indicating that its source passed over her fixed array of antennae once every sidereal day. Bell... discovered that the scruff consisted of a series of regularly spaced radio pulses 1.337s apart (the pulse period, *P*). Such a precise celestial clock was unheard of, and Bell and Hewish considered the possibility that these might be signals from an extraterrestrial civilization. If this were true, she felt annoyed that the aliens had chosen such an inconvenient time to make contact. ... When Bell found another bit of scruff, coming from another part of the sky, her relief was palpable. She wrote, «It was highly unlikely that two lots of Little Green Men could choose the same unusual frequency and unlikely technique to signal to the same inconspicuous planet Earth!»" Bell and Hewish called *pulsars*, an acronym for Pulsating Source of Radio Waves, those objects from which such radio pulses came. The pulsar that triggered these investigations was later identified as *PSR* 1919 + 21, where the numbers identify its position in the firmament: the right ascension $\alpha = 19^h 19^m$ and the declination $\delta = +21^{\mathrm{o}}$. According to the observations made, the pulsars increase their periods until they cease to emit after a few million years.

The immediate question is: What is the source of these radio pulses? Different hypotheses were proposed. Ostlie & Carroll (1996, 610-611) mention three possible explanations, of which the first two had to be dismissed as being physically unfeasible.

4.1 First possibility

The first scenario is that the pulses come from binary systems constituted by white dwarfs or by neutron stars. However:

1. Since the average pulsation period of the known pulsars is P=0.79s, an application of Kepler's third law to a binary system formed by two white dwarfs of 1$M_{\odot}$ (1 solar mass) would result that they should be separated from each other 1.6x10^{3} km! And the separation would be even smaller if the white dwarfs were even more massive. This binary system would then be physically unviable.

2. If the system were formed by a neutron star and a white dwarf, this one would collapse on the neutron star, and the system would cease to exist.

3. If the system were composed of two neutron stars, their movements would produce gravitational waves, which would cause both stars to rotate spirally together, drastically reducing their orbital period.

4.2. Second possibility

The second possibility is that the sources of the pulses are pulsating stars. But these objects could not be white dwarfs since the periods of oscillation of these stars vary between 100 and 1000s, whereas, as we have already seen, the average period of oscillation of the objects investigated does not reach 1s. Neither could they be neutron stars, objects that are 108 times denser than white dwarfs, the reason being that since the period of pulsation of a variable star depends inversely on its density: $\rho^{-1/2}$, then the oscillations of a neutron star would be well below the value observed in the objects explored.

4.3. Third possibility

The third scenario contemplated by Ostlie & Carroll (1996, 611) is that the observed source be placed in rotating stars. We have to assume that the rotation of the star, no matter how fast it is, prevents its disintegration. To do this we have to assume, in the context of NM a situation of equilibrium between centrifugal and attractive forces, to wit[2]: $\omega_{\max}^2 R = G_N M / R^2$. From $P_{\min} = 2\pi / \omega_{\max}$ it results that $P_{\min} = 2\pi\sqrt{\frac{R^3}{G_N M}}$, and, as before: $P_{\min} \propto \rho^{-1/2}$.

The hypothesis that the source of pulsars can only be rapidly rotating neutron stars is the candidate resulting from this *process of elimination of alternative hypotheses*. This is indeed the *best explanation* of the investigated phenomenon, i.e. the conclusion of an abductive inference.

A pulsar thus consists of a rapidly rotating neutron star, a remnant of the collapse of a supergiant star, with a strong bipolar magnetic field that induces an electric field at the surface of the star. According to Ostlie & Carroll (1996, 623), "Depending on the direction of the electric field, either electrons or ions will be continuously ripped from the neutron star's polar regions. This creates a *magnetosphere* of charged particles surrounding the pulsar that is dragged around with the pulsar's rotation. …the charged particles are spun away, carrying the magnetic field with them in a pulsar 'wind'." Due to the rapid rotation of the neutron star, radio waves coming from the magnetic polar regions are swept through space "in a way reminiscent of the light from a rotating lighthouse beacon" (p. 624) that can be detected by our radio telescopes.

5. Pulsars and gravitational waves

In alleged contrast to what is indicated in §4.3, a binary pulsar, identified as *PSR* 1913 + 16, was discovered by the American astronomers Russell A. Hulse and Joseph H. Taylor in July 1974, using the radio-telescope from Arecibo, Puerto Rico. But, as the title of Hulse-Taylor's article itself indicates, it is a pulsar *in* a binary system distant 5*kpc* (1 parsec (*pc*) equals 3.2616 light years). That is, the binary system is *not* the pulsar itself. The pulsar is an element of a binary system whose two members orbit around their mass centre in an eccentric orbit, without eclipses occurring and without the companion being visible. The pulsation period of the pulsar is about 59 milliseconds over a cycle of 7.752 hours.

Hulse and Taylor (1975) affirm that the masses of the objects that constitute this binary system are comparable, that "the companion must be a compact object, probably a neutron star or a black hole. A white dwarf companion cannot be ruled out, but seems unlikely for evolutionary reasons" and that "We cannot at present rule out the possibility that the unseen companion is also a radiofrequency pulsar."

Twenty-seven years later, Joel M. Weisberg and Joseph H. Taylor (2003) provided further data. The mass of the pulsar and of the companion are respectively m_p=1.4408±0.0003 $M_\odot$ and m_c=1.3873±0.0003 $M_\odot$. But the most important thing is that they definitely accept the emission of gravitational radiation that should lead to orbital energy loss and orbital decay. This is, of course, an *indirect* confirmation of the existence of such gravitational waves predicted by Einstein's General Theory of Relativity. For, as Edwin F. Taylor and John Archibald Wheeler (1992, 291) affirmed we still had not been able to directly detect "the gravity waves

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[2] Where ω denotes the angular velocity, *P*, *R* and *M* are respectively the period, radius and mass of the star, and G_N the Newtonian gravitational constant.

we feel sure must be radiating from sources dotted here in the galaxy and in the universe." And they add: "No reasonable way has ever been found to account for the thus observed loss of energy except gravitational radiation." Again, a clearly *abductive* argument, now for the existence of gravitational waves!

Taylor and Wheeler (1992, 291-292) dare with the following prediction to this respect: "Few among [the experimentalists, A.R.] have any doubt of their ability to detect pulses of gravity radiation from one or another star catastrophe *by sometime in the first decade of the twenty-first century*. Astronomy uses signals of many kinds –light, radio waves, and X-rays among them– to reveal the secrets of the stars. Of all signals from a star, none comes out from deeper in the interior than a gravity wave. Among all violent events to be probed deeply by a gravity wave, none is more fascinating than *the dance of death of two compact stars as they whirl around each other and undergo total collapse into…a black hole!*" (My emphasis, A.R.) Greater success and better vision of the future –twenty-four years before the first *direct* confirmation of the existence of gravitational waves– are not imaginable.

And Ostlie & Carroll (1996, 741) express themselves in this regard: "If the distribution of a system's mass varies, the resulting changes in the surrounding spacetime curvature may propagate outward as a gravitational wave, carrying energy and angular momentum away from the system. When applied to a close binary system, general relativity shows that the emission of gravitational radiation will cause the stars to spiral together." Indeed, "As the two neutron stars move in their orbits, gravitational waves carry energy away from the system and the orbital period decreases." (Ostlie & Carroll 1996, 742) As the orbital period of the binary pulsar 1913+16 changes due to the emission of gravitational waves, "the separation of the neutron stars shrinks by about 3 mm per orbit [and] the system will coalesce some 300 million years in the future." (Ostlie & Carroll *op. cit.*, 743)

But what kind of things are gravitational waves? Answer: "a gravity wave is a travelling disturbance in the geometry of spacetime that acts at right angles to, or transverse to, the direction of propagation. Second, however far this travelling region of spacetime curvature has progressed, there the measure of the deformation it makes in spacetime geometry has fallen off in proportion, not to the inverse square of the distance of travel away from the source, but to the *inverse first power* of this distance." (Wheeler 1990, 188) Moreover, "the strength of a gravity wave is proportional to the *sudden* change in the nonsphericity of a distribution of mass. No nonsphericity, no radiation! No matter how massive an aging star may be, when at last it collapses under the unrelenting inward pull of gravity, it generates no gravity wave when its distribution of mass is spherically symmetric to begin with and remains spherically symmetric all the way into final crunch. Nonsphericity, so essential for radiation, is a many-splendored thing. Every lump and bump contributes its mite to a measure of nonsphericity commonly called *reduced mass-quadrupole moment.*"(p. 200)

John Archibald Wheeler (1990, 186) restricts his treatment of gravity waves to the case of a single collapsing star with these words, "In the depths of an ill-fated, collapsing star, billions upon billions of tons of mass cave in and crash together. The crashing mass generates a wave in the geometry of space –a wave that rolls across a hundred-thousand light-years of space to 'jiggle' the distance between two mirrors in our Earthbound gravity-wave laboratory."

The first attempts to *directly* detect gravity waves go back to an initially joint project of NASA and ESA, known as *LISA* (Laser Interferometer Space Antenna) (Rivadulla 2003, 219). This project came to light with the launch by ESA of *LISA Pathfinder* on December 4, 2015. The surprise jumped on February 12, 2016 when B. P. Abbot et al. (2016), ahead of the results of LISA, announced the Observation of Gravitational Waves from a Binary Black Hole Merger. This information appears briefly summarized in the Abstract of their article: “On September 14, 2015 at 09,50,45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal.”

The existence of gravitational waves is the last of the predictions of GRT that remained to be confirmed. The binary pulse 1913 + 16 provided the first *indirect* confirmation of the existence of this type of waves. Thinking in terms of abductive inference this hypothesis offered the best possible explanation of the loss of energy in certain binary systems. Finally, the collision of two black holes, a cosmic cataclysm of gigantic proportions, made *direct* detection of gravitational waves possible.

6. Conclusion

In this article I have tried to justify at least two main ideas. The first is that Bayesianism does not offer a reliable probabilistic mathematical model for the philosophical theory of scientific confirmation, and that therefore it is not an acceptable alternative to the non-deductive methodology of discovery and explanation provided by abductive reasoning or inference to the best explanation.

Through numerous examples taken from the history of science, both from the observational sciences, and from the theoretical sciences of Nature, which I have presented in other works and in Section 4 of the present article, I claim, secondly, that the abductive methodology is a practice that has been successfully implemented from the earliest times of Western scientific history to the present day.

Of course the explanation of stellar pulsation cannot be conceived in terms of *standard* abduction, as much more than a creative jump is involved here. On my view, the explanation of stellar pulsation is a typical process of *sophisticated* abduction, for it requires the construction of a theoretical model for pulsars, and this is only possible when suitable results from different branches of theoretical physics are taken into account and mathematically combined with one another. This procedure is by no means simple. Indeed, as Ostlie & Carroll (1996, 622) confess: “Developing a detailed model of the pulsar’s emission mechanism has been an exercise in frustration because almost every observation is open to more than one interpretation.” This induces an “uncertainty about the true nature of pulsars” (p. 624) and makes so difficult to construct a “consistent theoretical description.” Needless to say, any question about the probability of truth of a theoretical model of pulsar is naive. To give a complete account of the pulsars’ emission escapes our possibilities. The only thing we can do is to conform ourselves with the postulation of theoretical models that allow us to deal theoretically and predictably with this fascinating celestial phenomenon.

Since in Rivadulla (2016*a,b*) I have justified the distinction between both forms of abduction, *standard* and *sophisticated*, I believe that I must not dwell on this point any more, and I close the present article, in confidence that I have achieved reasonably well the two purposes indicated above.

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