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Stephen Hawking's Ontology of Physical Theories

1. Introduction

At the present stage of the unification of physics, there is a thriving and vivid philosophical debate over the meaning of such basic notions as *time*, *space*, *motion* and *causality*[1]. It is believed that the future theory of quantum gravity will not only demand a novel, sophisticated mathematical apparatus but will bring forth a fundamental change (generalization) in the understanding of the notions mentioned. Current literature offers a great variety of sources which discuss the conceptual and theoretical intricacies involved in both the physical[2] and philosophical[3] aspects of quantum gravity. The authors postulate various spacetime transformation

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[1] A. Connes, M. Heller, S. Majid, R. Penrose, J. Polkinghorne, A. Taylor, *On Space and Time*, Cambridge University Press, Cambridge 2008.

[2] C.J. Isham, *Prima facie Questions in Quantum Gravity*, [in:] *Canonical Gravity: From Classical to Quantum (Lecture Notes in Physics 434)*, eds. J. Ehlers, H. Friedrich, Springer-Verlag, Berlin 1994, pp. 1-21.

[3] C. Callender, N. Huggett, *Physics Meets Philosophy at the Planck Scale*, Cambridge University Press, Cambridge 2001.

schemes as one shifts to the quantum regime: should spacetime retain its continuous character of a smooth manifold with the Lorentzian metric or should it be quantized? Is it an absolute entity or does it emerge from a more primitive structure? What is the function of symmetries? The history of science offers many examples of famous debates between renowned physicists where the issues at stake have provoked discussion of a profoundly philosophical nature. The early 20th century debate between Albert Einstein and Niels Bohr on the foundations of quantum mechanics yields serves as a perfect example[4]. Although this debate is considered to continue into the controversy between Stephen Hawking and Roger Penrose, the much larger and abstract scope of matters discussed seems to limit the direct Bohr-Hawking and Einstein-Penrose match.

Inasmuch as these issues have their importance, the very relation between the mathematical structure of a theory and the physical reality that the theory purports to describe seems to be a more basic philosophical *niveau* that is operative in the unification schemes of physical theories. The analysis of this relation occupies a prominent position within the contemporary philosophy of science for it raises concerns of an *ontological* and *epistemological* nature. In other words, the basic questions of what really exists in the eyes of a contemporary theorist and what knowledge he is able to acquire come to the fore. The task of characterizing the status of physical theories in these perspectives, centres on the following issues: (1) the origin of the mathematical structure of a physical theory and the ontological status of theoretical objects warranted by the theory (*philosophy of mathematics*), (2) the relation between mathematical structures and the physical reality, namely, whether mathematical structures reflect the structure of physical reality (*scientific realism*) or whether they are only useful models in the process of organizing and predicting experimental results.

While most practicing physicists admit the existence of an external physical reality as an object of their study, the different positions split quite rapidly as one considers the two issues mentioned above. For example, Roger Penrose assumes the stance of a radical realist on both counts. In his global ontology of the three worlds – *math*, *matter* and *mind* – he makes a strong ontological assumption by postulating the existence of

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[4] M. Jammer, *The Philosophy of Quantum Mechanics: The Interpretations of QM in historical perspective*, John Wiley and Sons, New York 1974.

an *atemporal* universum of mathematical ideas (mathematical Platonism)[5]. Its subset yields the basis for the laws governing the physical universe. In other words, objectively existing mathematical structures underpin the physical reality similarly to how software runs hardware. As for his stance in this regard, Albert Einstein made a more modest ontological claim, for he did not assign any independent mode of existence to the mathematical ideas, but treated them as the product of the human mind. However, he did impose a considerable philosophical demand by stating that nature employs only the simplest mathematical structures[6].

Thanks to the newly published book by Stephen Hawking and Leonard Mlodinow, entitled *The Grand Design*, the so far scattered and often poorly justified philosophical assertions of Hawking can be neatly gathered under the term of *model-dependent realism*[7]. The immediate advantage of such a standpoint is that it neutralizes the classical ontological division between realism and antirealism. Consequently, "it is pointless to ask whether a model is real, only whether it agrees with observation"[8].

The goal of this study is to demonstrate how the model-dependent realism influences the course of a theory's formulation as well as its particular mode of explanation and prediction of physical phenomena. Since at present the theory of quantum gravity is nowhere near being fully formulated and there are no experimental results to indicate a preferred route of discovery, an ample space for philosophical speculation and preference opens up. The far reaching consequences of Hawking's theoretical proposals make the analysis of the impact of philosophical ideas on these proposals particularly intriguing. The structure of the presented article is twofold: (1) the detailed survey of the meaning and the philosophical import of the model-dependent realism and (2) an analysis of Hawking's major contributions, such as the Euclidean quantum gravity programme crowned by the famous Hartle-Hawking model, with special emphasis on how the assumed ontology of physical theories is refracted in his practice of physics.

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[5] R. Penrose, *The Road to Reality*, Alfred Knopf, New York 2005, pp. 7-23.

[6] A. Einstein, *On the Method of Theoretical Physics*, "Philosophy of Science" 1934, vol. 1, no. 2, pp. 163-169.

[7] S.W. Hawking, L. Mlodinow, *The Grand Design*, Bentam Press, London 2010, p. 37 *et seq.*

[8] *Ibidem*, p. 46.

2. The Origin of a Physical Theory and the Status of Theoretical Entities

The strength with which Stephen Hawking makes his numerous positivist declarations in his popular writings such as *A Brief History of Time*, could easily lead to the suspicion that he blindly assumes the reducibility of the content of mathematical structures to the empirical data, as it had been the case for *logical empiricism*. Such an inference may additionally be fortified, as he frequently formulates the common requirement that a physical theory must be empirically verifiable and permit prediction of the results of measurements. It is commonly assumed in the contemporary philosophy of science that anyone who is solely concerned with discovering regularities in the behaviour of observable entities should be termed a *positivist*[9]. After all, this seems like the 'working philosophy' of many contemporary physicists. Taken to its extreme, such a strategy could imply that mathematical structures arise inductively as a straightforward generalization of the empirical data. According to Hawking:

> a theory is just a model of the universe, or a restricted part of it, and a set of rules that relate quantities in the model to observations that we make. It exists only in our minds and does not have any other reality (whatever that might mean). A theory is a good theory if it satisfies two requirements. It must accurately describe a large class of observations on the basis of a model that contains only a few arbitrary elements, and it must make definite predictions about the results of future observations[10].

Also, Hawking insists that the number of theoretical entities introduced should be confined to a minimum, according to the precept of Occam's razor: "It seems better to employ the principle of economy known as Occam's razor and cut out all the features of the theory that cannot be observed"[11].

A deeper look at the writings of Stephen Hawking, however, reveals a more complex concept of what a physical theory is. This is understood insofar as Hawking's scientific activity occurs after the tenets of logical empiricism were questioned following the works of K. Popper and W.v.O.

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[9] M. Redhead, *The Unseen World*, [in:] *Rationality and Reality: Conversations with Alan Musgrave*, ed. C. Cheyne, J. Worall, Springer, Dordrecht 2006, pp. 157-164.

[10] S.W. Hawking, *A Brief History of Time*, updated and expanded tenth anniversary ed., Bantam Books, New York – London – Toronto – Sydney – Auckland 1998, p. 10.

[11] *Ibidem*, p. 57.

Quine, which lead to the general recognition of the hypothetical role of a theoretical framework. Most importantly, Hawking's idea of the specificity of a physical theory was revealed in his essay *My Position*, where he engages in a philosophical speculation on the ontology of theoretical entities, as well as the relation of mathematical structures to physical reality. What stands in radical contrast to the positivist attitude is the origin of a physical theory:

> In theoretical physics the search for logical self-consistency has always been more important than making advances than experimental results. Otherwise elegant and beautiful theories have been rejected because they don't agree with observation, but I don't know if any major theory has been advanced just on the basis of experiment. The theory always came first, put forward from the desire to have an elegant and consistent mathematical model. The theory then makes predictions, which then can be tested by observation. If the observations agree with the predictions, that doesn't prove the theory; but the theory survives to make further predictions which again are tested against observations. If the observations don't agree with the predictions, one abandons the theory[12].

Clearly, Stephen Hawking admits the contribution of a non-empirical component – a *hypothesis* – and its mathematical consistency into the origin and development of the theoretical models of the Universe. This is consistent with Hawking's claim that the theory exists only in the human mind, and that each theory is a non-provable hypothesis in terms of its truth value understood in the sense of correspondence with the external reality. Such an idea of the origin of a physical theory correlates with Albert Einstein's conjecture of the 'free interplay of ideas'[13] proposed on the grounds that there exists no unique match between empirical content and its mental representations. Furthermore, Hawking is a declared *anti-Platonist* in the sense that he denies the objective existence of mathematical entities and mathematical truth. This places him in radical opposition to the standpoint of Roger Penrose:

> We now have very different approaches to the world physical and mental. Basically, he's [Roger Penrose] a Platonist believing that there's unique world of ideas that describes a unique physical reality. I, an the other hand, am a positivist who believes that physical

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[12] *Idem*, *My Position*, [in:] *Black Holes and Baby Universes and Other Essays*, Bantam Books, London – New York – Toronto – Sydney – Auckland 1994, p. 36.

[13] A. Einstein, *Autobiographical Notes*, [in:] P.A. Schlipp, *Albert Einstein: Philosopher-Scientist*, Evanston, New York 1949, p. 7.

> theories are just mathematical models we construct, and that it is meaningless to ask whether they correspond to reality, just whether they predict observations[14].

Inasmuch as a mathematical structure is an indispensable tool for physicists regardless of any ontological commitments on the side of the theory they may choose to impose, they will always maintain that physics studies an objectively existing physical reality, i.e. the Universe that exists externally to a cognizing subject. In other words, this stance implies that physicists investigate the properties of the physical world and not merely the states of a conscious mind:

> I would say that I am a realist in the sense that I think there is a universe out there waiting to be investigated and understood. I regard the solipsist position that everything is the creation of our imaginations as a waste of time. No-one acts on that basis[15].

It is therefore clear that Stephen Hawking is a *realist* in the general sense of acknowledging the existence of an *ordered* external reality as an object of his scientific inquiry and separating himself from purely idealistic positions of the Berkeleyan type. Contemporary discussions in the philosophy of science, however, concentrate on the issue of *scientific realism*, namely, the position that there exists a well defined and mind-independent structure of the physical reality (*metaphysical component*) and that a scientific theory can formulate truth-conditioned statements regarding both observable and unobservable entities and processes (epistemic *component*)[16]. In this regard, Stephen Hawking turns out to be a *scientific anti-realist,* for in commenting on the viability of the ontology of time (discussed in detail later) he explicitly accuses the adherents of scientific realism of being a threat to science:

> This example illustrates well the difficulties in the philosophy of science for what we regard as a reality is conditioned by the theory to which we subscribe. […] But we cannot distinguish what is real about the universe without a theory. […] It's no good appealing to reality because we do not have a model independent concept of reality[17].

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[14] R. Penrose with A. Shimony, N. Cartwright, S.W. Hawking, *The Large, the Small and The Human Mind*, ed. M. Longair, Cambridge University Press, Cambridge 1997, p. 169.

[15] S.W. Hawking, *My Position*, *op.cit.*, p. 38.

[16] E. McMullin, *A Case for Scientific Realism*, [in:] *Scientific Realism*, ed. J. Leplun, University of California Press, Berkeley 1984, pp. 8-40.

[17] S.W. Hawking, *My Position*, *op.cit.*, pp. 37-38.

3. The Philosophy of Hawking's Practice of Physics

Hawking's standpoint on the ontology of physical theories summarized in the notion of the model-dependent realism provides a good background to demonstrate that this ontology is an important factor in how Hawking proceeds to develop the mathematical structures of his theoretical proposals. In most general terms, however, Hawking's strategy is to perform suitable adaptations of the successful methods in quantum mechanics and general relativity, to produce working models combining both quantum and relativistic components rather than search for entirely new mathematical structures, as it is, for instance, in the case of Roger Penrose's *twistor* theory. Hawking's point of departure in quantizing gravity relies on the unquestioned validity of both constituent theories with their appropriate mathematical structures. In regards to general relativity he states clearly:

> Although there have been suggestions that spacetime may have a discrete structure, I see no reason to abandon the continuum theories that have been so successful. General relativity is a beautiful theory that agrees with every observation that has been made. It may require modifications on the Planck scale but I don't think that will affect many of the predictions that can be obtained from it[18].

In other words, Hawking sees no contradiction in the joint application of the techniques of both general relativity and quantum field theory that made these theories explain and predict experimental results with great accuracy. This is evidenced in Hawking's use of the *semi-classical* methods where mass fields are treated according to quantum field theory in curved spacetime:

$$G_{\mu\nu} = \langle \psi | T_{\mu\nu} (g, \hat{\phi}) | \psi \rangle,$$

The right side of the equation yields the expected value of the energy-momentum tensor $T_{\mu\nu}$ in a given quantum state $|\psi\rangle$ as opposed to the unique value of the tensor in a single field configuration in the standard Einstein equation. The spacetime metric remains classical, that is, it is defined on a smooth manifold. In a nutshell, these are the masses of *quantum* particles that are sources of the *classical* gravitational field. The semi-classical approach based on the *Feynman path integrals,* in conjunction with the *euclideanization* (the Wick rotation) of the Lorentzian spacetime as a means to obtain converging

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[18] S.W. Hawking, R. Penrose, *The Nature of Space and Time*, Princeton University Press, New Jersey 2000, p.4.

values of the appropriate integrals, allowed Hawking to investigate models with genuinely quantum gravitational effects: the *black hole radiation* and the *no-boundary Hartle-Hawking* model (discussed in detail in the next section).

Although the above presentation of the specificity of the semi-classical methods provides a first glance of Stephen Hawking's 'practice' of physics, the thorough understanding of the model-dependent realism demands a more detailed discourse into the specificity of both the Feynman path integrals and the Wick rotation procedures. The formal introduction to these techniques can be found in any textbook on the quantum field theory[19]. The following comment made by Hawking on the controversy involved in the famous Schrödinger cat paradox provides a preliminary hint of the consequences of adopting ontology as dictated by the model-dependent realism:

> In my opinion, the unspoken belief in a model independent reality is the underlying reason for the difficulties philosophers of science have with quantum mechanics and the uncertainty principle. […] In the case of Schrödinger's cat, there two histories that are reinforced. In one the cat is shot, while in the other it remains alive. In quantum theory both possibilities can exist together. But some philosophers get themselves tied in knots because they implicitly assume that the cat can have only one history[20].

Hawking considers the Schrödinger's cat paradox to be a pseudo-problem which is being raised on the premise that the quantum mechanical formalism of an entangled state does not reflect the commonsensical perception of a unique state of the cat of being either dead or alive at any given moment of the system's trajectory in the configurational space. Although such an approach does indeed do away with the paradox, it still does not eliminate the question on why only a single state of a cat is observed in reality. In principle, such a question should ultimately find its answer in the final theory of everything to which Hawking aspires, but he seems to express relatively little concern for the theoretical explanation of the mental phenomena outside of some brief comments on the viability of artificial intelligence in his discussion with Roger Penrose[21].

The Wick rotation is another key component utilized by Hawking in the construction of his quantum gravitational models. In the Lorentzian

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[19] S. Weinberg, *Quantum Theory of Fields*, vol. I, Cambrige University Press, Cambridge 1995.

[20] S.W. Hawking, *My Position*, *op.cit.*, pp. 38-39.

[21] R. Penrose, *The Large, The Small and the Human Mind*, *op.cit.*, pp. 169-172.

metric, it effects the rotation of the time coordinate *t* into its imaginary counterpart *it* resulting in that the metric no longer distinguishes between the spatial and temporal coordinates thereby becoming standard Riemannian. Such a procedure is often referred to as the *euclideization* of the spacetime metric and the entire program of quantizing gravity – the *Euclidean quantum gravity*[22]. The original idea suggested by Gian Carlo Wick in the context of the quantum field theory aimed at the removal of divergent quantities in the Lorentzian spacetime that turn out to be convergent in the Riemannian (Euclidean) regime. Such a procedure facilitates the convergence of the path integrals and guarantees that the values of the energies of the respective eigenstates are not negative (*positive energy condition*)[23].

At this point, an interesting methodological point should be brought to the fore. The Wick rotation is applied to the Lorentzian metric as a formal condition to secure the finiteness of the Feynman integrals and thus to achieve the mathematical consistency of a theory regardless whether such a procedure bears any physical meaning. In this regard, the Wick rotation resembles the methodological status of the central mathematical procedure of the quantum field theory, i.e., that of *renormalization* where the infinities are considered as rescaling factors that can be easily removed by subtraction to yield quantities that confirmed experimentally with great accuracy. Such a methodological strategy seems to be consistent with Hawking's ontology of physical theories where mathematical entities exist only in the mind of a theorist and can be freely combined as long as they fulfil certain formal conditions such as these of mathematical consistency. Since there is no independent ontology to provide reference on the side of the physical reality and no external ontology selection rule is given, the empirical verification is the only criterion available to judge the viability of an accepted theoretical framework.

4. Wick and Beyond

Stephen Hawking successfully utilizes the Feynman path integrals in the semi-classical framework aided with the Wick rotation to demonstrate the black hole radiation effect (known also as Hawking radiation) whereby

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[22] *Euclidean Quantum Gravity*, ed. G.W. Gibbons, S.W. Hawking, World Scientific, Singapore 1993.

[23] R. Penrose, *The Road to Reality*, *op.cit.*, p. 769.

black holes lose mass. In a nutshell, the semi-classical version of the Einstein equation is in this case applied in a straightforward manner by employing the Wick rotation of the time coordinate of the *Schwarzschild* metric to obtain the *Euclidean-Schwarzschild* spacetime metric (Hawking’s nomenclature). The subsequent introduction of the polar coordinates and the removal of the singularities in the original Schwarzschild metric enable the computation of the Feynman path integral over all possible field configurations on ‘a spacetime that is identified periodically in the imaginary time direction with period β’[24]. Since $\beta = T^{-1}$, the path integral yields the partition function for a given field suggesting that the field itself is in a thermal state. Interestingly enough, the thermal radiation of a black hole is one of the very few testable predictions of the quantum gravitational effect that has a chance of being observed in the low energy regime. Although such measurements have not yet been obtained, they show Hawking’s insistence on the derivation of empirically testable statements out of his theoretical framework in order to assure the theory’s ultimate experimental verification. From a methodological point of view, the introduction of imaginary time to the Schwarzschild metric is but a mathematical trick leading to the elimination of singularities regardless of this time’s physical meaning suggesting that Hawking quite freely combines mathematical concepts only to make sure that the criteria of the theory’s mathematical consistency are fulfilled.

As attention is now shifted to the *no-boundary Hartle-Hawking* model, Hawking’s conviction of the unlimited power of the method of physics becomes particularly evident. Given the lack of necessity to relate the mathematical framework to any pre-determined structure outside standard criterion of empirical verifiability (at this time irrelevant in case of quantum gravity), Hawking sets out to search for the solution of the problem of the beginning and the evolution of the Universe, with particular emphasis on the problem of boundary conditions at the initial singularity. As one assumes Hawking’s ontology of physical theories, namely, that it is only by means of a theory that the understanding of the Universe can be achieved, any mathematically consistent formalism that is based on a minimal number of axioms and that applies to a broad class of phenomena, becomes the ultimate explanation and no further inquiry is necessary. In light of such a strategy, there are actually no limitations to adapt the exist-

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[24] S.W. Hawking, R. Penrose, *op.cit.*, p. 48.

ing theoretical tools that are known to yield correct results to construct a new theoretical model. In other words, the legitimacy of such a model stems from the physical viability of its constituents, and the semi-classical methods that combine the Wick transform and the Feynman path integrals heavily rely on this kind of justification.

Since the detailed exposition of the Hartle-Hawking model remains beyond the scope of this paper, only its main postulates pertinent to the discussion of methodological importance will be addressed[25]. In the standard quantum field theory as well as in the case of the black hole's Schwarzschild metric presented above, the Wick rotation is applied to the spacetime that constitutes a *background* to the paths figuring into the integral. In the Hartle-Hawking model, however, one deals with an immensely larger mathematical structure to describe the evolution of the spacetime of the entire Universe. The preliminary structure is equivalent to the (3+1)-geometry used in Wheeler's geometrodynamics and the Feynman path integral is taken over all such geometries to yield the probability of a transition between two selected states of the Universe. As one attempts to apply this scheme to the Big Bang scenario, it is necessary to subject each of the individual (3+1)-geometries to the Wick rotation, leading instead to the quantum superposition of 4-geometries characterized by the Riemannian metrics with no difference between spatial and time coordinates. The application of the Riemannian spacetime geometries results in these geometries being *non-singular* whereby the disappearance of the initial singularity can be attributed to a purely quantum gravitational effect allowing the Universe to have no boundary conditions. Consequently, Hawking's criterion of a scientific theory whose laws hold everywhere including the very beginning of the Universe is fulfilled[26].

At this moment, a few remarks of a methodological nature seem fitting. As Roger Penrose rightly points out, the manner in which Stephen Hawking implements the Wick rotation (and the Feynman path integrals as well) is a marked extension of the original idea developed in the context of the quantum field theory[27]. First of all, the use of the Wick rotation as a means of removing singularities turned out to be successful in case of the black hole radiation thus verifying this method as a viable theo-

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[25] J. Hartle, S.W. Hawking, *Wave Function of the Universe*, "Physical Review D" 1983, vol. 28, no. 12, pp. 2960-2975.

[26] S.W. Hawking, R. Penrose, *op.cit.*, p. 76.

[27] R. Penrose, *The Road to Reality*, *op.cit.*, p. 770.

retical tool in handling singularity problems. More importantly, however, the Wick rotation in the Hartle-Hawking model is not performed on the background spacetime whereupon the path integrals are formulated but on each of the (3+1)-geometries of the Universe that directly contribute to these integrals as 4-geometries with the Riemannian metric. The reason for using compact Riemanian metric is also of a technical nature, for it assures the meaningfulness, that is, the convergence of the path integrals. Such a strategy is indicative of Hawking's intention to extrapolate the theoretical techniques onto much larger – if not the largest – objects such as the entire Universe provided that these techniques have worked successfully in the study of systems with a smaller degree of complexity. No doubt, Hartle and Hawking have definitely succeeded in proposing a bold theoretical hypothesis with no support of any referent ontology or empirical data but their success most likely rests on the credibility of the constituent elements of their novel theoretical frameworks.

5. Ontology of Time

The issue within the Hartle-Hawking model that receives much attention of philosophers is that of *imaginary time* which follows on from the implementation of the Wick rotation on the (3+1) spacetime geometries. The quite vocal philosophical opposition, however, stems from the attempts to seek logical consistency and assign physical meaning to the transition between real and imaginary time coordinates. Deltete and Guy call this the 'joint problem'[28] for they are dissatisfied with vague accounts of the transition's mechanism by explaining it as a mere smoothing off of the singularity in the imaginary time as the quantum effects become dominant in the Planck era[29]. Such an approach is most likely implemented by latent commonsensical idea of absolute time that should constitute an indispensable background for any viable physical theory. Although the application of the cosmological principle to the Einstein equation suggests the existence of a global cosmological time, such time is by no means to be treated as an external parameter, but as a specific property of the differential manifold that can be assigned

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[28] R.J. Deltete, R.A. Guy, *Emerging from Imaginary Time,* "Synthese" 1996, no. 108, pp. 185-203.

[29] S.W. Hawking, *The Edge of Spacetime*, [in:] *The New Physics*, ed. P. Davies, Cambridge University Press, Cambridge, pp. 61-69.

a single coordinate system in the regime of the cosmological principle (*causal stability*)[30]. It is the time that is postulated by the theory's formalism under specific conditions. Hawking clearly points out that one faces the serious danger of running into an ontological conundrum as one tries to impose a commonsensical interpretation to both the imaginary and real time:

> The history of the universe in real time, however, would look very different. At about ten or twenty thousand million years ago, it would have a minimum size, which was equal to the maximum radius of the history in imaginary time. At later real times, the universe would expand like the chaotic inflationary model proposed by Linde (but one would not now have to assume that the universe was created somehow in the right sort of state). The universe would expand to a very large size and eventually it would collapse again into what looks like a singularity in real time. Thus, in a sense, we are still all doomed, even if we keep away from black holes. Only if we could picture the universe in terms of imaginary time would there be no singularities. If the universe really is in such a quantum state, there would be no singularities in the history of the universe in imaginary time. It might seem therefore that my more recent work had completely undone the results of my earlier work on singularities. But, as indicated above, the real importance of the singularity theorems was that they showed that the gravitational field must become so strong that quantum gravitational effects could not be ignored. This in turn led to the idea that the universe could be finite in imaginary time but without boundaries or singularities. When one goes back to the real time in which we live, however, there will still appear to be singularities. The poor astronaut who falls into a black hole will still come to a sticky end; only if he lived in imaginary time would he encounter no singularities. This might suggest that the so-called imaginary time is really the real time, and that what we call real time is just a figment of our imaginations. In real time, the universe has a beginning and an end at singularities that form a boundary to space-time and at which the laws of science break down. But in imaginary time, there are no singularities or boundaries. So maybe what we call imaginary time is really more basic, and what we call real is just an idea that we invent to help us describe what we think the universe is like[31].

Despite its considerable length, the presented quote illustrates well the potential contradictions that arise as one tries to assign meaning to either form of time – real or imaginary – with the help of any *a priori* ideas of the

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[30] S.W. Hawking, *The Existence of Cosmic Time Functions*, "Proceedings of the Royal Society of London" 1968, no. A308, pp. 433-453.

[31] *Idem*, *A Brief History of Time*, *op.cit.*, pp. 143-144.

nature of the universe. In other words, any commonsensical conjectures may be highly deceitful insofar as they engage non-scientific but often philosophical preferences whereby the true meaning of the theoretical terms may be substantially obscured. Like the Schrödinger's Cat paradox, the controversy on the nature of time in the Hartle-Hawking model is another inadequately stated problem. Hawking reveals his position on the ontology of physical theories as he explains why:

> But according to the approach I described in Chapter 1, a scientific theory is just a mathematical model we make to describe our observations: it exists only in our minds. So it is meaningless to ask: which is real, 'real' or 'imaginary' time? It is simply a matter of which is the more useful description[32].

6. Conclusions

The practically unconstrained liberty with which Stephen Hawking shuffles the different concepts and tools of theoretical physics to formulate suitable mathematical structures may provoke justified objections. After all, any physicist seeks the understanding of the observable Universe as it appears to him with the aid of many postulated concepts and objects that he treats as given unrelated to any specific theoretical framework. To entirely disengage the legacy of pre-scientific concepts such as, e.g., *time*, *space* or *causality*, would, on the one hand, fly in the face of the continuity of human scientific endeavour, but, on the other hand, rigid adherence to *a priori* concepts could be a stumbling block in transcending the limits of common sense perception. The influence of Immanuel Kant's canonization of three dimensional Euclidean geometry as pure forms of intuition is an exemplary case of how the discovery of non-Euclidean geometries and the formulation of the theory of general relativity were hindered by misguided loyalty to philosophical speculation. Consequently, it is not surprising that Stephen Hawking observes the following:

> In my opinion, the unspoken belief in a model independent reality is the underlying reason for the difficulties philosophers have with quantum mechanics and the uncertainty principle[33].

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[32] *Ibidem*, p. 144.

[33] *Idem*, *My Position*, *op.cit.*, p. 38.

The same objection pertains to several other philosophically disputed issues such as the generalized concept of time in the general theory of relativity, as well as the problem of the real and imaginary time in the no-boundary Hartle-Hawking model.

It has been demonstrated in the course of this article that Stephen Hawking considers mathematical structures as purely *mental* entities that can be freely combined following the criteria of mathematical consistency to accommodate experimental data. This is the gist of the *model-dependent realism*. Although Hawking is frequently designated as a *positivist* and *instrumentalist*, in his practice of physics he relies on knowledge that is often inferred from non-empirical statements. For instance, the Hartle-Hawking no-boundary model acquires its meaning not from an empirical verification, but from a skilful mélange of theoretical concepts applied in such a manner as to satisfy certain bold theoretical requirements, that is, the elimination of the *spacetime singularity*. Legitimized within quantum field theory, both the Wick transform and the Feynman path integrals lend their meaning to the Hartle-Hawking model, which, in turn, is hoped to provide insights on how to proceed in a larger framework of the future theory of quantum gravity. In other words, the progress towards the final theory is achieved in a *stepwise* manner by constructing an array of toy models with increasing complexity that utilize their predecessors, verified either directly empirically or by fulfilling certain theoretical tasks. However, Hawking becomes the prey of his own trap when he states that a theory of everything is expected to emerge on the premise

> that the universe is not arbitrary, but is governed by definite laws, [and] you ultimately have to combine the partial theories into a complete unified theory that will describe everything in the universe[34].

If the model-dependent realism is applied consistently, a physical law is a statement within the theoretical framework and not an objective property of the physical reality into which, as Hawking frequently states, there is no access. Consequently, Hawking never frees himself of the idea of a theory-independent reality. In conclusion, it must be emphasized that the goal of the presented inquiry was not to provide support for Hawking's program of quantizing gravity but to demonstrate how philosophical assumptions may influence the course of the formulation of a physical theory.

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[34] *Ibidem.*