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DO ATEMPORAL THEORIES OF QUANTUM GRAVITY PRESUPPOSE THE NOTION OF TIME?

A CRITICAL ANALYSIS OF HENRIK ZINKERNAGEL'S ARGUMENTS AGAINST QUANTUM FUNDAMENTALISM.

MA Thesis in analytic philosophy of science

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1. Introduction[1]

In modern physics, our understanding of the universe is primarily guided by two fundamental theories: quantum mechanics (QM)[2] and general relativity (GR). These two theories have been highly successful in their respective domains, with QM providing an accurate description of the behavior of atoms and subatomic particles at the microscopic level, and GR describing the behavior of massive objects such as planets and stars at the macro scale.[3] However, it is a dominant view that some phenomena, like the early universe or black holes can only be analyzed within a single framework that unites both relativistic and quantum physics. This has led to attempts to develop various theories of quantum gravity (QG), describing quantum effects of gravity. Such a theory would provide a more fundamental description of physical reality by using the conceptual framework of quantum theory. Classical physics[4] with its classical conceptual apparatus is then supposed to be derivative from QG and only approximately valid. Such a position can be referred to as *quantum fundamentalism* (QF), because according to it we live in a quantum world.

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[1] I wish to thank my supervisors Ave Mets and Karin Kustassoo for their advice and support during the thesis process. I am also very grateful to Mauro Dorato for his suggestion to examine works by Zinkernagel and Rugh and his supervision of my exchange semester at Roma Tre University in the fall/winter of 2022–2023. Obviously, the responsibility of the analysis presented in this thesis is fully on me.

[2] As I will discuss later, QM is extended into quantum field theory (QFT), which is compatible with special relativity (SR) but not general relativity (GR).

[3] GR does suffer from problems at the galactic scale and beyond (e.g. the problem of missing mass), but a treatment of these issues is beyond the scope of this work. See e.g. Milgrom 2020, Merritt 2020, Lazutkina 2017, 2021.

[4] In this work, "classical" is always contrasted with "quantum." One may also label non-relativistic physics "classical" in contrast to Einstein's relativistic physics, but in this work, I will refrain from such usage for the sake of clarity.

To clarify this view, I propose the following explication of a quantum fundamentalist argument:

1. A physical theory can provide a fundamental description of the world
2. Such a theory has to be a unified quantum theory e.g., quantum gravity
3. The world can be fully described in terms of quantum physics (epistemic tenet) and the world is fundamentally quantum i.e., is composed of quantum objects[5] (ontological tenet) (see Zinkernagel 2015: 2).

In this thesis, my main goal is to investigate whether the absence of time in QG could successfully be used as an instrument to challenge the QF thesis explicated above.[6] An attempt to do this has been proposed by Danish philosopher of physics Henrik Zinkernagel, but this proposal has received no critical attention so far. However, as I hope to make clear, he presents an argument that brings something new to the table in comparison to the more standard philosophical debates about the status of time in QG and the implications of this status. Thus, a part of the goal of my thesis is to analyze Zinkernagel's argumentation. Zinkernagel has argued in a series of papers (2002, 2006, 2015, 2016; and 2011 together with Svend Erik Rugh) against QF. In particular, Zinkernagel uses the absence of time in quantum gravity to argue against QF because, according to him, timeless quantum gravity would in some sense presuppose classical time of GR and thus depends on classical time and cannot be more fundamental than GR.

In order to examine Zinkernagel's arguments, it is first necessary to provide the relevant framework it is built into. To do so, I will use the following structure in chapter 2: I will first describe the philosophical position against which his arguments are constructed, i.e. QF. I will present what is meant by "fundamentality" and why the fundamental theory is believed to be quantum. I will then proceed by describing

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[5] Let us define "quantum object" in this work operationally as any physical object at the scale where classical pre-quantum physics begins to break down and it becomes necessary to use quantum theory for maintaining the accuracy of predictions. For a brief description of the relevant aspects of quantum theory, see section 2.2.

[6] I will consider the case that an absence of time happens to be postulated in the final version of quantum gravity. Therefore, I am not primarily investigating whether atemporal theories of quantum gravity are superior to temporal ones.

the relevant physical basis of the debate in order to show what QF is built on i.e., what the relevant features of quantum theory are for this issue.

Then I will elaborate on the philosophical background of Zinkernagel's arguments. Zinkernagel explicitly states that he is a follower of Niels Bohr's and that his arguments against the fundamentality of timeless quantum gravity are analogous to Bohr's measurement theory, according to which classical and not only quantum theoretical concepts are needed for a satisfactory interpretation of non-relativistic QM. Thus, the chapter describes Zinkernagel's interpretation of Bohr's measurement theory and the role it plays in his own arguments.

Chapter 3 is devoted to my reconstruction and analysis of Zinkernagel's (and Rugh's) arguments. I will elaborate on what Zinkernagel uses as the means in his arguments, i.e. the physical basis of time and the problem of time in QG. I will formalize the arguments and analyze the justifiability of the premises and inferences. I will also present my interpretation of Zinkernagel's analogy with Bohr's arguments and argue against potential objections. I will then present a counter-argument to Zinkernagel, namely the functionalist position that time emerges from more fundamental atemporal structures and thus is a derivative feature. Then, following Esfeld (2021), I provide an argument against spacetime functionalism by showing that all familiar forms of functional definitions themselves presuppose time. I also provide a further reason why functionalism about time does not refute Zinkernagel's argument.

Chapters 2 and 3 focus only on the second premise of the quantum fundamentalist view because this is what Zinkernagel's arguments are concerned with. In chapter 4, I offer an argument for the radicalization of Zinkernagel's opposition to QF: the more radical argument denies premise 1 of the overall quantum fundamentalist argument (a physical theory can provide a fundamental description of the world), which is not usually considered in the philosophy of physics literature because it is mostly taken for granted by proponents of naturalistic approaches to philosophy of physics. However, far from being an assumption that hardly needs justification, I aim to show how the problem of time in quantum gravity can challenge it.

2. The philosophical and physical background of Zinkernagel's arguments

2.1 Quantum fundamentalism

One of the greatest discoveries of science is that matter consists of molecules, molecules consist of atoms and atoms consist of subatomic particles: electrons, protons and neutrons. This hierarchy of matter has opened up scientific inquiry about what the world is like "fundamentally," i.e., on the smallest scale.[7] After numerous experiments in the beginning of the 20th century it was observed that the behavior of subatomic entities cannot be described by classical physics. This led to the formulation of a new theory - quantum mechanics (QM).

QM and its later extension into quantum field theory (QFT) brought a new conceptual framework that is radically different from the classical view.[8] The problem that I will focus on in this thesis comes from the belief that because the constituents of the physical world can be described in an exclusively quantum-theoretical way, we live in a quantum world and classical descriptions are less fundamental than quantum-theoretical descriptions (Faye 2019). This view is the generally dominant position among physicists and philosophers of physics that can be referred to as quantum fundamentalism (QF) (Zinkernagel 2006, 2015, 2016, Dieks 2017, Faye 2019). Zinkernagel (2015) has formulated two versions of this position: epistemological QF - that is the view that everything can be described purely quantum-mechanically and ontological QF - that everything is fundamentally of a quantum nature (Zinkernagel 2015: 2). To understand this position, it is important to elaborate on what is meant by "fundamental". I will do so by describing what I take a "quantum fundamentalist" in Zinkernagel's sense to be committed to.

One challenge for this task might seem to be that there is no universal, agreed upon definition of fundamentality (nor even a universally agreed upon

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[7] This is not to say that other views about fundamentality are automatically excluded. E.g. according to Jonathan Schaffer's priority monism, the largest thing (the universe) is fundamental (Schaffer 2018: section 3). However, for reasons spelled out below, I will, in this work, only focus on the view that smaller = more fundamental.

[8] To put it in concrete terms, characteristics such as position, momentum, velocity have gained completely new meanings.

disambiguation of various definitions) even within physics or the philosophy of physics.[9] However, for present purposes such a comprehensive discussion is not necessary, for Zinkernagel makes it clear to what kind of fundamentality he is referring. Let us first distinguish between absolute and relative fundamentality, and secondly between fundamentality with respect to generality versus fundamentality with respect to scale.

An absolutely fundamental theory with respect to generality would be a perfectly comprehensive theory about everything there is, whereas a theory T1 could be called more fundamental than T2 if it is more general (i.e. describes more (kinds of) phenomena) than T2. Since Zinkernagel never addresses the worry that physics might not be up to the task of describing everything there is, I assume that his opposition to QF does not stem from such a notion of fundamentality. Therefore, I take it that the relevant notion of fundamentality in his anti-QF work concerns scale, since, as far as I am aware, there is no third type of fundamentality on offer within physics.[10] This type of fundamentality is easier to explicate by beginning with the relative notion. The concept of relative fundamentality with respect to scale in contemporary debates in philosophy of physics is strongly connected to the framework of Effective Field Theory (EFT) (Crowther 2019: 124). EFT is a type of physical theory constructed for the description of phenomena on a certain energy scale[11] for a certain purpose and thus makes no pretense at providing a correct description at all scales. For example, in condensed matter physics it is a common practice to construct such EFTs depending on what property of matter is being researched. But in order for such EFTs to be constructed, some underlying physics has to be taken as a basis, so that EFT will depend on this basis. In other words, EFTs allow one to work on a certain energy-scale without taking another energy scale into

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[9] One need only look at the multiplicity of approaches presented in Aguirre, Foster and Merali 2020 to come to this conclusion.

[10] There is also a physically based reason why fundamentality with respect to generality need not concern us in this work: as Crowther (2017: 8) notes, it is possible that a theory of QG such as loop quantum gravity (even when completed) will not have relevance for describing the interactions described by QFT (see chapter 3 for the list of those interactions).

[11] In physics “energy scale” refers to the range of energy values that are relevant for the studied phenomena. Energy scale is related to length scale in a way that the larger is the length the lower is the energy (e.g. for the study of macroscopic objects such as a ball thrown in the air the relevant lengths are greater and energies are lower than for the study of microscopic particles in a particle accelerator).

account – an EFT would not work on this other neglected scale. So we use different EFTs on different energy-scales for practical purposes even though we understand their narrow application and thus scope of validity (ibid.). However, for a quantum fundamentalist it is important to ask - how do different theories relate to each other? The dominant view is that there is a hierarchy of theories:

> It is generally believed that in principle, with full knowledge of the physics of systematic particular short-length scale (plus, again, the required computational resources and ability to use them), we could arrive at results valid at any larger scales without requiring any additional information. On the other hand, the large-scale physics is supposed to underdetermine the shorter-scale theory: We could not, even in principle, derive the correct theory of a system at small length scales from a complete description of its physics at some larger length scale. More information would be required. For this reason, the tower of theories is usually thought to be ordered hierarchically, with the shorter-scale theories being more fundamental, and so lower on the tower, than the larger-scale, "higher-level" ones. (Crowther 2019: 125).

The tower metaphor here should not be taken too literally, if I understand Crowther correctly: a tower on Earth will collapse if its foundation is destroyed and impossible to build in the first place unless one starts from the foundation. In contrast, as I see it, the construction of Crowther's metaphorical tower can in principle begin from any floor and the higher levels will not collapse if a lower level is removed (say, if the more fundamental theory turns out to be mistaken). All that will result is that we should now be driven to search for an alternative explanation: what explains the observed behavior at the higher levels if not the more fundamental theory we assumed?

As for absolute fundamentality with respect to scale, Crowther offers a list of seven criteria[12] that a theory must meet to be considered a candidate. However, these need not concern us for present purposes, because Zinkernagel's claim is that QG cannot be fundamental *even relative* to GR and therefore it cannot be absolutely fundamental either.

At any rate, a quantum fundamentalist would say that the fundamental theory (or at least the theory most fundamental relative to current physics) in this tower of theories will be some kind of unified quantum theory. This is very clearly seen in the QG projects where GR is expected to be an EFT of some QG theory. If one is taking physics to be the main source of information about the material world, (as

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[12] These criteria are: ultraviolet completeness, non-perturbativity, naturality, being unified, being single, and being internally consistent (Crowther 2019: 128).

proponents of QF, naturalized metaphysics and in general the mainstream in the philosophy of physics do), then the fundamental description of the world is expected to be derived from the bottom of this tower of theories. But what is the justification for thinking that the base of the tower has to be quantum? This is the question addressed in the next section of this work.

2.2 Quantum physics vs classical physics

As I have previously stated, the goal of this thesis is to examine Zinkernagel's arguments against QF. In the previous section, I have elaborated on what is meant by "fundamentality" in physics and that the most fundamental theory is expected to be a quantum theory. In this section I will elaborate what quantum theory is and how it differs conceptually from a non-quantum/classical physical theory. I will do so because this forms the physical background of Zinkernagel's arguments and thus it is of great relevance for the purposes of this work.

QM is spectacularly successful and its successes are of great practical and theoretical relevance to us. But simultaneously QM has generated seemingly endless debates among physicists and philosophers on how the theory should be interpreted. The beginnings of this controversy arise from observations around the turn of the 20th century that light exhibits both wave-like and particle-like properties. In his 1924 PhD thesis, Louis de Broglie proposed the hypothesis that all matter, not just photons, has particle and wave properties (Ghirardi 2007: 19). This hypothesis was verified by numerous researchers for different microscopic systems (e.g. for electrons, neutrons etc.) (ibid.: 49).[13] Classical physics says nothing about

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[13] The evidence for light and matter's wavelike nature comes from experiments in which particles pass through small openings and hit a detector screen. If these phenomena were entirely particlelike, then one would think that the smaller the opening through which it passes, the more accurately one can predict and control where on the screen the particle will end up. However, this turns out to be true only up to a point, after which the pattern seen on the detector screen becomes unexplainable if matter is supposed to be entirely particle-like, but completely predictable if it behaves like waves which diffract when passing through a single opening shorter than the wavelength or interfering with each other when passing through two or more openings (Bell 1992: 1202–1205).

On the other hand, the photoelectric effect provides evidence for light's particle-like aspect: in the appropriate circumstances, light can liberate electrons from a metal surface it shines on. If light phenomena that display this wave-particle duality, which is why physicists were led to develop a new type of theory, quantum theory, to account for these and other experimental results. It is not possible to go into detail here regarding all the aspects in which quantum theory differs from classical physics or even what the "quantization" of a classical theory involves. However, let it be noted that the word "quantum" (plural "quanta") refers to the minimum amount of energy involved in a physical interaction according to quantum theory.

Now since quantum theory succeeds in giving us much more accurate predictions than does classical physics, it is understandably common to consider it as having revealed a more fundamental level of physical reality. However, as mentioned, no consensus has been reached on how to interpret the formalism of quantum theory. Still, apart from Bohr's view (or the view often known as the Copenhagen interpretation)[14], all other major approaches to the interpretation of quantum theory take quantum theory to offer a more fundamental picture of the world than classical physics. Although there is a clear analogy between Bohr's interpretation and Zinkernagel's arguments against QF, it is not my intent to attempt to take part in the interpretation of non-relativistic quantum mechanics, so I will not try to address the QF position with regard to the interpretation of that theory. Instead, I will next sketch a brief description of the relevant postulates of quantum mechanics which generate what is known as the "measurement problem". Again, the reason why I need to do so is because Bohr's anti-QF arguments for his solution to the measurement problem are analogous to Zinkernagel's anti-QF arguments in the case of QG. Here I will mostly be following Maudlin's (1995) now classic exposition. After this I will explain the relevant aspects of Bohr's interpretation of the measurement problem in order to provide the necessary philosophical background for Zinkernagel's arguments against the fundamentality of QG relative to GR.

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were entirely wave-like, then this ability to transfer energy to electrons should correlate with the light's intensity. However, it turns out that increasing the intensity of light does not increase the energy of the electrons liberated from the metal. Only the frequency of light seems to matter. This would be unexplainable if light were entirely wave-like. But if light has a particle-like aspect as well, then this would explain the effect, since increasing the intensity of light would only increase the amount of particles but not their energy. On a purely wave picture of light one would also expect the gain of energy to be continuous, whereas it is observed to increase discretely as multiples of Planck's constant, h.

[14] The difference between Bohr's view and the Copenhagen interpretation are discussed below in section 2.3.

The mathematical object used to represent the wave-aspect of quantum objects is known as the wavefunction. So far, the best description of the evolution of the wavefunction over time (in the absence of measurements) is the one developed by Erwin Schrödinger in 1925 (published in 1926) and is known as the Schrödinger equation. When a state of the wavefunction is measured, the probability of obtaining a given measurement outcome is provided by another formalism known as Born's rule, named after Max Born. Thus far, no other formalism than the Schrödinger equation together with the Born rule fares better in predicting the *average* outcome of measurements on quantum objects. However, it provides no explanation for why, in a particular measurement, we in fact observe one specific outcome rather than another (which reflects the particle aspect of QM). Moreover, the fact that we do observe a given specific outcome seems to contradict the description provided by the Schrödinger equation, and thus another postulate, known as the collapse postulate, must be added to the principles of QM to account for this empirical fact: according to the collapse postulate, "In the event of a measurement, the state of the system is updated to the [description] that corresponds to the measurement outcome (Hance & Hossenfelder 2022: 1)." However, adding the collapse postulate does not really remove the apparent contradiction between experience and the Schrödinger equation's description of the evolution of the wavefunction. It only "updates" that description to match what is in fact observed, i.e. a definite measurement outcome (formally this means updating the probability of the wavefunction being in the observed state to 1 from whatever the probability was before). Why such an update occurs is still left unexplained.[15] The notion of "measurement" is also left analyzed. What counts as measurement?[16] Finally, the measurement has an irreversible effect on the quantum object such that further measurements on the same object will no longer obey the probabilities of Born's rule but will rather, in the absence of errors, reflect the outcome of the first measurement in a deterministic way.[17] These three difficulties together constitute the measurement problem of QM.

Before proceeding to provide Bohr's dissolution of the measurement problem, one more aspect of QM must be discussed to provide the necessary background information for understanding Bohr and Zinkernagel. This aspect is known as

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[15] This is what Maudlin (1995) refers to as the "problem of outcomes".

[16] This is what Maudlin (1995) refers to as the "problem of statistics".

[17] Maudlin (1995) refers to this as the "problem of effect".

Heisenberg uncertainty after Werner Heisenberg who first introduced the concept in 1927. When asking questions about the measurable states of a quantum object, we can ask the following questions (among others): What was its momentum? Where was it (position)? When was it (time)? What was its energy? Unlike in classical physics, it is impossible to measure all these states of the wavefunction simultaneously up to an arbitrary precision. Instead, what is observed is a tradeoff between certain pairs of potentially observable states: for example, the more accurately one wants to know the position of a quantum object, the less accurately one can know its momentum (and vice versa). It is important to emphasize that, according to our current understanding, this tradeoff cannot be ameliorated by technological improvements but is rather an intrinsic feature of QM.

2.3 Bohr's measurement theory

Bohr's measurement theory is at once an attempt to solve, or rather dissolve, the measurement problem and to account for Heisenberg uncertainty. It is also a part of an entire philosophy of science motivated by the peculiarities of QM and its relationship to classical physics. It is first important to note that Bohr never laid out this philosophy in a systematic and clearly explicated way. Instead, the general picture has to be cobbled together from various writings in which Bohr often employs aphoristic expressions. It is therefore not surprising that up to this day, scholars of Bohr are in disagreement about some central aspects of his measurement theory (see Faye 2019 for a summary of these scholarly disputes). The confusion is compounded by the fact that Bohr's interpretation of QM has often been treated under the umbrella term of the "Copenhagen interpretation." While Bohr is certainly one of the most important figures associated with this label, the Copenhagen interpretation is also associated with the views of Heisenberg, Born, Johann von Neumann, Eugene Wigner, and others (see Faye 2019: sections 8–9). Without getting into specifics, it is enough to note that all of these theorists disagreed with each other on many important points, which makes the "Copenhagen interpretation" a problematic label insofar as it is thought to refer to a unitary interpretation of QM (ibid). Fortunately, Zinkernagel never employs the label and his argument is based on an analogy with

Bohr's views only. Thus, in this work I refer to Bohr's views and not to the Copenhagen interpretation.

I will now present Zinkernagel's characterization of how Bohr approaches the measurement problem[18]: according to (Zinkernagel's) Bohr, the problem arises because of the assumption that quantum theory alone can describe reality (epistemological QF) or that everything is fundamentally of a quantum nature (ontological QF).[19] The two main elements in his measurement theory which lead him to deny this are the following: 1) the principle of complementarity, which is his interpretation of the Heisenberg uncertainty relation, and 2) his insistence that a quantum theoretical description of any system must always be combined with a classical description of the measurement apparatus to obtain agreement with definite measurement results (Zinkernagel 2015: 2). According to Zinkernagel:

> complementarity means that the attribution of certain properties to quantum objects can take place only in experimental contexts which are mutually incompatible. Thus, for example, an experiment which can determine the position of an electron cannot be used to determine its momentum. (Zinkernagel 2016: 10)

Bohr refers to this limitation as complementarity because both states, such as position and momentum, are required for a full description of the quantum object. But since the attribution of one property requires an experimental context which precludes the attribution of the other complementary property (with arbitrary accuracy), Bohr says that to even refer to such a property as something the object has but whose value is simply unknown to us beyond the maximum accuracy is *ill-defined* (Zinkernagel 2015: 4). Here it is important to understand another central aspect of Bohr's philosophy of science, according to which "the interpretation of a physical theory has to rely on an experimental practice" and that therefore

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[18] It is not my main purpose to examine whether Zinkernagel's interpretation of Bohr is correct but whether his analogy succeeds on the assumption that his interpretation is correct. However, I will note a problem with Zinkernagel's interpretation at the end of this chapter, because this problem seems to affect the analogous argument Zinkernagel himself makes against QF on the basis of atemporal theories of QG.

[19] Although Zinkernagel says he is sure that Bohr would have rejected both the ontological and epistemological version of quantum fundamentalism (Zinkernagel, private communication), he does not claim that Bohr ever addressed quantum fundamentalism in these terms. I will examine this point below in the main text of this chapter.

"kinematic and dynamic variables are ill-defined unless they refer to an experimental outcome" (Faye 2019: section 4). Because of such a view, Bohr has been variously read (or misread) as a neo-Kantian or a logical positivist, but this need not concern us for present purposes. What seems clear in any case is that Bohr's view implies the positive denial of epistemological QF. According to Zinkernagel, it is also clear that a positive denial of ontological QF (instead of mere agnosticism regarding it) results from the principle of complementarity. At the end of this section I will return to this point.

As for the necessity of relying on classical concepts for describing quantum systems, Zinkernagel presents two arguments of Bohr in support of this view. The first is known as the "closedness argument":

> [...] every atomic phenomenon is closed in the sense that its observation is based on registrations obtained by means of suitable amplifications devices with irreversible functioning such as, for example, permanent marks on a photographic plate ... [T]he quantum-mechanical formalism permits well-defined applications referring only to such closed phenomena. (Bohr 1954: 73, as cited in Zinkernagel 2015: 6)

The key insight of the argument according to Zinkernagel is that experiments in fact do have definite and irreversible outcomes. Therefore it seems that the argument is based on the fact that the formalism of quantum mechanics (the Schrödinger equation that describes the propagation of the wavefunction) does not explain the definiteness of measurement outcomes, from which Bohr deduces that a classical description of the apparatus is always required. According to the second argument, which Zinkernagel calls the "reference system argument":

> [...] in each case some ultimate measuring instruments, like the scales and clocks which determine the frame of space-time coordination – on which, in the last resort, even the definitions of momentum and energy quantities rest – must always be described entirely on classical lines, and consequently kept outside the system subject to quantum mechanical treatment. (Bohr 1938: 104, as cited in Zinkernagel 2015: 7)

According to Zinkernagel (2015: 7), the key insight of this argument is that a reference frame has, by definition, a well-defined position and momentum and is thus not subject to Heisenberg uncertainty. In sum, according to Zinkerngael's reading of Bohr, the matter-energy content of the universe cannot be of a quantum nature or be ultimately describable exclusively in quantum theoretical terms because the states of a quantum object such as the position or momentum of a particle must be defined in relation to something else. Of course, the apparatus acting as a reference frame itself can be described quantum theoretically, but then a second classically described reference frame is required for the position of the first one to be well-defined, and so on. The main point of both arguments is thus that while everything can be described quantum theoretically, not everything can be described so at once.

A common misunderstanding of Bohr on this point is that he thought of the world as being divided into a quantum world and a classical world (roughly corresponding to a division between the microscopic and macroscopic scale) (see Faye 2019; also see Camilleri & Schlosshauer 2015). To understand Bohr's view correctly, it is important to clarify that he did not think that the world is divided into a quantum realm and classical realm. In fact, he thinks it is not appropriate to speak of a "quantum world" at all:

> When asked whether the algorithm of quantum mechanics could be considered as somehow mirroring an underlying quantum world, Bohr would answer: "There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that the task of physics is to find out how nature *is*. Physics concerns what we can *say* about nature". (Petersen (1963: 12), as cited in Zinkernagel (2015: 5)).[20]

If this is an accurate representation of Bohr's view, the obvious thing to notice is that Bohr does not seem interested in entertaining questions about how things are or which statements are true (at least *qua* physicist), but only the question of what is knowable or justifiable. His denial that there is a quantum world should then mean that this denial is itself justified (recalling from the previous discussion on complementarity that for Bohr, "the interpretation of a physical theory has to rely on an experimental practice" (Faye 2019: section 4)). However, Zinkernagel's treatment of Bohr on this point is ambiguous. First, according to Zinkernagel (ibid.), this statement does not mean that Bohr rejects the existence of objects such as electrons

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[20] Although this is not a direct quote from Bohr, but rather Petersen's interpretation of Bohr, Zinkernagel (2015: 5) makes it clear that he thinks that this quote accurately represents Bohr's view. Since I am allowing Zinkernagel his interpretation of Bohr, I will set aside how accurately the quote reflects Bohr's view.

which are described quantum theoretically. Rather, he rejects the combination of a correspondence theory of truth and scientific entity realism about quantum mechanics because he thought that one cannot simultaneously "attribute" properties to a quantum object if these properties are subject to Heisenberg uncertainty (ibid.). As for the second point, Zinkernagel says that even if one were to ignore what Petersen says on Bohr's behalf,

> [...] it is far from clear what, from Bohr's viewpoint, it would mean to assert that an object in itself is a quantum system. An obvious suggestion would be to think that the deep nature of objects is correctly represented by quantum wave functions. But Bohr could not have *supported* this idea. For in his view, the wave function is symbolical, and it can be *attributed* to objects only in experimental contexts which are not themselves described by such wave functions. (Zinkernagel 2015: 5, emphasis added)

Here, in my opinion, is where the difficulties begin for Zinkernagel's Bohr: it is one thing to say that we *cannot attribute* a property to an object and another thing to say that the object *cannot have* the property in question. The former is an epistemological claim which concerns our ability to justify an attribution whereas the latter is an ontological claim according to which the attribution would be false. But then how are we to understand Bohr's supposed *denial* that there is a quantum world? The points that Zinkernagel brings up seem only to support the claim that the belief in a quantum world is unjustified, since these points concern the justifiability of attributing properties to quantum objects. However, nothing is said about the (im)possibility of quantum objects having these properties regardless of our ability to (in principle) know whether they do. Of course, if contra Zinkernagel, Bohr should be read as positively denying the epistemological but not the ontological version of the QF thesis, the problem would go away. Then we could read Bohr as merely saying that he is not an ontological quantum fundamentalist because such a thesis cannot be justified (even if it might be true): Heisenberg uncertainty and the need for classical concepts in accounting for the evidence prevent us, in principle, from having epistemic access to a hypothetical purely quantum world. Again, this simple point cannot be emphasized enough: this is not the same as stating that the ontological QF thesis is false, but only that it cannot be justified. This would mean that Petersen's claim made on Bohr's behalf that "there is no quantum world" would have to be reinterpreted as the claim that we must remain agnostic about the existence of a quantum world, but this is not how Zinkernagel reads Bohr:

> So, do we live in a quantum world? According to Bohr, as I understand him, the answer is no: we live in a world that, at the physical level, can be understood only by referring to both quantum and classical mechanics. (Zinkernagel 2015: 8)

Thus, it seems that either Zinkernagel's reading of Bohr is problematic, or that Bohr's own philosophy of science relies on a controversial denial of the distinction between a claim's truth-value and justifiability. Since my ultimate goal in this work is not to evaluate Zinkernagel's interpretation of Bohr or the merits of Bohr's own philosophy, I will not pursue this point further. However, I do think that this unnoted ambiguity between being agnostic about ontological QF and denying it affects Zinkernagel's own argument against the thesis, as I will argue in the next chapter.

3. Zinkernagel's arguments against quantum fundamentalism

3.1 The disappearance of time in quantum gravity

As stated in the previous chapters, Zinkernagel is inspired by Bohr's opposition to QF, and his argument is analogous to Bohr's. However, Zinkernagel uses different means to attack QF. Since one of the main projects of today's theoretical physics (and the main project for a quantum fundamentalist) is a full theory of QG, Zinkernagel sees this as an opportunity to construct a new type of argument against QF and uses the problem of time in QG as means to make his case. Surprisingly, philosophers of physics and physicists refer to Zinkerngagel's reconstruction of Bohr and QF (see e.g. Dorato 2017, Faye 2019, Pris 2023), but Zinkergnagel's arguments against the fundamentality of QG have not received any critical evaluation even though discussions about the fundamentality of QG are part of mainstream philosophy of physics (see e.g. Lam and Wuthrich 2018). Thus, I think there is a need for a critical evaluation of Zinkerangel's arguments. In order to do this, I first present what he uses to argue against QF: the problem of time in quantum gravity and what is meant by "time" in physics.

Quantum theory is thought to be applicable to everything. To put it in physical terms: everything can (and should), in principle, be quantized. The main achievement of that program is quantum field theory (QFT), which combines the frameworks of QM and special relativity. In a nutshell, in physics the standard picture is that the behavior of matter is described by four fundamental interactions: weak (binds quarks in nucleus), strong (binds nucleus), electromagnetic (binds nuclei and electrons), and gravitational (between massive objects). QFT provides a unified description of the weak, strong, and electromagnetic interaction and the special theory of relativity. However, gravitational interaction remains non-quantum i.e. not described by a quantum but a classical theory, GR. This is sometimes referred to as the "schism in physics" (Popper 1982): QFT and GR are two different theories that remain irreconcilable due one being a quantum theory and the other a classical theory.

The struggle to overcome this schism is ongoing and manifested in the development of different research programs trying to formulate one unified theory of quantum gravity, i.e. a theory that would include the quantization of gravitational interaction. One particular idea has become a dominant topic for discussion: in many approaches to QG, no time parameter or time operator is found in the formalism. This has led many physicists and philosophers of physics to the conclusion that the world is fundamentally atemporal and time is a derivative feature, an abstraction or an illusion (for example, see Rovelli 2004, 2011; Barbour 1999; Hugget and Wüthrich 2018). However, in order to be reconciled with existing physics, a theory that postulates the absence of time at the fundamental level has to establish how time emerges or is recovered from the atemporal structure (Hugget and Wüthrich 2018). This is what usually is referred to as the problem of time in quantum gravity.[21] Following Jacksland and Salimkhani (2021), I want to emphasize that because we have many theories of quantum gravity, there is no "one problem of time," but rather the problem of time is a *type* of problem. What I mean by this is that in different approaches to QG like loop quantum gravity (LQG), causal set theory, string theory

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[21] Another problem of time is already present in classical physics: time's "arrow" is absent from all classical equations except thermodynamics, since these equations seem to work symmetrically with regard to the flow of time.

and so on, there are different formal problems related to time recovery from non-temporal structures. But in this work, the main question is not whether there are similarities or differences in the formal apparatus of theories, but rather that this type of problem leads quantum fundamentalist to the conclusion that time is not fundamental. It is also important to note that some approaches to quantum gravity are not atemporal[22]. However, these approaches fall outside the scope of this work, since they don't imply the problematic consequences which Zinkernagel is concerned with.

Focusing on the theories of quantum gravity that have an atemporal formalism, Zinkernagel proposes arguments against QF that are based on the absence of time in quantum gravity. An important point is that one can speak of the problem of time in a narrow sense as a technical non-philosophical problem (see, for example, Linnemann 2020). However, I will follow the mainstream view where the problem of time is a collection of issues related to the absence of time. I will do so because this is how quantum fundamentalists view the issue and, thus, this type of approach is the relevant target for Zinkernagel's argument.[23]

Before reconstructing Zinkernagel's argument, it is essential to overview the physical basis that the debate is based on. Thus, in the next section I will first provide a brief description of what is meant by "time" in physics together with relevant empirical data.

3.2 The time-clock relation

Beginning with a broadly relationist view, i.e. the notion of time must have a physical basis, Zinkernagel and Rugh claim that the notions of time and a physical clock are

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[22] For example, Thebault and Gryb (2016) provide an alternative approach to the quantization of a theory, namely relational quantization, that preserves absolute temporal ordering.

[23] Consider, for example, Oriti's view that:"The search for new intuitions about a timeless universe, one in which time is an emergent notion and its emergence has the complex, multifaceted nature [...] this search can only be successful if it is a joint effort of mathematicians, theoretical and experimental physicists, and philosophers". (Oriti 2021: 30)

dependent on each other.[24] More precisely, Zinkernagel and Rugh relate their relationist notion of time to the notion of a "core of a clock": the core of a clock is here defined as something that must "(1) have a well-defined duration which is sufficiently fine-grained to 'time' the epoch in question; and (2) be a process which could conceivably take place among the material constituents available in the universe at this epoch" (Rugh and Zinkernagel 2009: 2). In order to have a concept of time with physical basis, one must have a core of a clock against which one may measure time. They support this claim by asking how one could otherwise make sense of the claim that a certain amount has passed. If no physical process takes place, or could take place, in an imagined scenario, on what *physical* basis would the difference between, say, an interval of 3 years and an interval of 4 or 5 years rest? (Rugh and Zinkernagel 2009: 3). However, this does not imply that the notion of time is reduced to the notion of a physical process, because the analysis of what a physical process itself is involves temporal notions (which is reflected in the relevant formalisms). Therefore, for Rugh and Zinkernagel, the time-clock relation is best characterized as a "logical (or conceptually necessary" relation of interdependence (ibid.).

3.2.1 The limits of a physical basis for cosmic time

Based on this time-clock relation, Rugh and Zinkernagel (2007, 2017) have argued for there being physical limits of maintaining a physically meaningful time concept (i.e. a time concept based on a well established physical theory) in the very early universe due to its extreme temperature and density. As previously mentioned, modern physics recognizes four fundamental interactions: gravity, electromagnetism, the weak interaction, and the strong (nuclear) interaction. However, these interactions are thought to be distinct only below certain energy scales. In conditions that involve extreme energies, the distinctions between these four interactions are thought to break down. Firstly, the distinction between electromagnetic interaction and the weak interaction is thought to break down at

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[24] The other traditional view of time, where time is regarded as something over and above temporally related things, is known as absolutism, Platonism, or substantivalism. In this work I do not consider this debate because it is not relevant to Zinkernagel's arguments, as I hope to make clear below.

energy scales in the order of 246 GeV (i.e. those interactions have unified descriptions in events involving quantities of kinetic energy of this magnitude and above) and become one interaction known as the electroweak interaction. Secondly, the distinction between the electroweak interaction and the strong interaction is thought to break down at energy levels scales in the order of 10^{15} GeV.

According to the prevailing belief among physical cosmologists, our universe originates from an event known as the Big Bang about 13.8 billion years ago. Now as we move closer to the Big Bang in time, the universe becomes hotter and denser, and the distinctions between the four fundamental interactions are gradually lost, so it becomes increasingly difficult to find stable physical processes that we are able to describe and that can serve as a core of a clock for measuring time.

As argued by Zinkernagel and Rugh (2017), it has been a common error to set the limit for the meaningfulness of speaking about clock time at what is known as Planck time[25] ($1 \ * \ 10^{-44}$s after the Big Bang), because there is currently no physical theory capable of saying anything about durations shorter than this. In contrast, they claim that the problem with defining time in the very early universe starts already at the quark-gluon stage (at $t < 1 \ * \ 10^{-5}$s after the Big Bang) because at this stage there are no bound systems and the concept of length – which is crucial for the definition of a core of a clock – is not well defined. Moreover, during the electroweak transition ($1 \ * \ 10^{-11}$s), particles no longer have mass (and thus duration), so the concept of local time completely loses its physical basis. This, briefly, is what Zinkernagel and Rugh (2017) call the "scale problem of time".

Additionally, they have shown that a necessary assumption for defining cosmic time, and in general for constructing empirically adequate cosmological models, is the so-called Weyl principle, according to which "the world lines of galaxies, or 'fundamental particles', form (on average) a spacetime-filling family of non-intersecting geodesics converging towards the past" (Rugh and Zinkernagel 2011: 2). The empirical importance of the Weyl principle stems from Hubble's observation that, on average, galaxies seem to be moving away from each other in an orderly fashion rather than flying in random directions, which implies that they

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[25] Planck time is a constant in physics that refers to what is believed to be the smallest time interval which can, in principle, be measured (shortest timescale). Planck time is about 10^{-44} seconds.

originate from a common point (Narlikar 2002: 107). A cosmological model that does not obey the Weyl principle cannot account for this.[26] An important theoretical consequence of the Weyl principle is that it allows one to model the matter content of the universe as a uniform substrate, which allows one to establish a preferred reference frame, which in turn allows one to adopt a notion of cosmic time and thus to speak of cosmic epochs, such as the "early" or "later" universe. However, the formulation of the Weyl principle requires well-defined notions of *local* time and length, which lose their physical basis in the early universe, (see Rugh and Zinkernagel 2011: 415 n 9; see also Rugh and Zinkernagel 2017), and therefore it is unclear how the *cosmic* time concept can have a well-defined meaning in such conditions. In the next section, I explain how these considerations are used in the anti-QF arguments.

3.3. Zinkernagel's main thesis: QG presupposes time

3.3.1 The cosmic measurement problem

According to most of the approaches to QG, time is not a part of the description of the world at the fundamental level (see, for example, Barbour 1994 for an exposition of the timelessness of canonical quantum gravity, or Rovelli 2018 for atemporal loop quantum gravity). If QG turns out to be the best physical theory i.e if it describes the world at the most fundamental level, this leads to the following conclusion: time is emergent from quantum structures.[27] So one of the most important tasks for QG is to

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[26] It is sometimes thought that adopting the so-called cosmological principle, according to which the matter content of the universe is, at the cosmic scale, homogeneous and isotropic, is sufficient to guarantee the empirical adequacy of cosmological models. However, Rugh and Zinkernagel (2011) show that the Weyl principle is a precondition, which a cosmological model must obey in order to satisfy the cosmological principle. An analysis of their argument is not possible within the scope of this work, so I will simply adopt this claim as an assumption.

[27] Time could also emerge from quantum structures even if there turns out to be an even more fundamental theory than QG, like how we say that heat emerges from molecular motion which is described by statistical mechanics although statistical mechanics is not physically fundamental. This does not need to worry us since, as I said in the introduction, if QG cannot be fundamental even relative to GR, it cannot be fundamental in an absolute sense either.

show exactly how time emerges from an atemporal universe. One central conceptual issue with elaborating how time emerges is to provide an account of how this emergence is not itself a process in time. Rugh and Zinkernagel refer to this as the "cosmic measurement problem". They claim that:

> This last problem of identifying a Weyl substratum within a quantum description arises most clearly on a "quantum fundamentalist" view according to which the material constituents of the universe could be described *exclusively* in terms of quantum theory at some early stage of the universe. On such a QF view, the following question naturally arises
>
> *The cosmic measurement problem*: If the universe, either its content or in its entirety, was once (and still is) quantum, how can there be (apparently) classical structures now?
>
> We call this the "cosmic measurement problem" since it addresses the standard quantum measurement problem in the cosmological context. While many aspects of the cosmic measurement problem have been addressed in the literature, the perspective which we would like to add is that the problem is closely related to providing a physical basis for the (classical) FLRW model with a (classical) cosmic time parameter.
>
> Our point is that if cosmic time in the FLRW model is crucially dependent on a (prior) classical or classicalized behaviour of the material constituents of the universe, then one can hardly (assume a quantum fundamentalist view and) approach the cosmic measurement problem by asserting a gradual emergence of classicality framed in *terms* of a cosmic time. (Rugh and Zinkernagel 2011: 420-421)

Since Rugh and Zinkernagel are here discussing how time supposedly emerges as we move (in cosmic time) from the early universe to the later universe, I take it that it is clear that they are discussing the problem of diachronic emergence, i.e. how the emergence happens over time. The emergence is problematic for the obvious reason that speaking about the emergence of time in terms of time would require one to presuppose time in order to explain its emergence, and therefore the explanation would either be plainly circular, or alternatively a second time would have to be postulated in order to account for the emergence of the first. Although Rugh and Zinkernagel do not discuss the latter alternative, I take it that their commitment to the interdependent time-clock relation (discussed above in section 3.2) precludes any appeal to a "second time" which runs in background completely independently of any physical processes. Although the argument is quite straightforward, I offer here my formalization of it:

P1. An atemporal theory of quantum gravity cannot rely on any classical time concepts of general relativity, if it is a more fundamental theory than general relativity. (Premise)

P2. An atemporal theory of quantum gravity must explain the emergence of classical time. (Premise)

P3. The emergence of classical time is a temporal process which relies on the classical time concept. (Premise)

P4. An atemporal theory of quantum gravity cannot be more fundamental than general relativity. (from P1, P2, P3)

As I have formalized it here, the argument is a valid linked argument, where the premises (P1, P2, P3) are logically independent of each other and jointly sufficient to guarantee the truth of the conclusion (P4). I take it that the truth of P1 is sufficiently clear at this point: the fundamentality of a theory implies that it does not depend on the concepts of less fundamental theories in order to explain what it explains. P2 is widely accepted by everyone involved in these discussions. P3 is the problematic premise of the argument, which I believe Daniele Oriti (forthcoming) has challenged successfully. But before considering Oriti's challenge, I turn to an objection to the argument that is easier to dismiss: Rugh and Zinkernagel discuss the possibility of explaining the diachronic emergence of time by appealing to quantum decoherence, which, briefly, is the process in which a system changes its behavior from quantum to classical due to the environment interfering with it. Without getting into more specifics on what decoherence is and what it can explain, it is widely agreed among experts on quantum theory that it does not solve the measurement problem (see e.g. Landsman 2006) even in non-relativistic QM, and moreover: " if decoherence is to provide the classical structures (in the cosmological context), it cannot — as is usually assumed in environmental induced decoherence — be a process in (cosmic) time, insofar as classical structures (non-crossing world lines) are needed from the start to define cosmic time (Rugh and Zinkernagel 2011: 421)." Therefore, it seems clear that the diachronic emergence of time is a basic conceptual or logical problem, which cannot be solved by any explanation that involves a presupposed classical cosmic time concept.

Fortunately, this problem is widely discussed in the philosophy of physics, although not typically under that name of the "cosmic measurement problem". For Daniele Oriti (forthcoming), the solution to the problem is clear: we must not speak of the emergence of time (when transitioning from the early universe to the later universe or vice versa) as something diachronic (i.e. something which happens over time), if by this we mean that the entire process can be measured against a classical notion of cosmic time. Rather, according to Oriti, the description of the process can be framed in terms of classical time only as long classical structures that serve as cores of clocks, but this kind of "temporal characterization stops exactly where (or when) the transition occurs (Oriti forthcoming: 16)." Although he does not mention Rugh and Zinkernagel by name in this context, Oriti here seems to turn their point against them: the notion of a classical cosmic time has a limited domain of applicability, beyond which "in the full quantum regime in which we only have quantum time (and space, and geometry, and causality) any standard notion of temporal evolution (including the relational one) stops being applicable (ibid.)."

As I understand Oriti's argument here, the dissolution of the problem could be visualized in the following way: let us imagine a timeline on which there is a point that marks where/when classical structures begin/cease to exist. The problem of diachronic emergence comes from thinking that there must be a process of emergence which "crosses over" the point and can also be characterized in terms of classical time and. But according to Oriti, we must recognize that it is precisely at this point that the classical concept loses its applicability, so there is, after all, no process of diachronic emergence which "crosses over" the point and can also be characterized in terms of classical time.

So, it turns out that P3 is not justified as obviously as Rugh and Zinkernagel seem to assume it is. Instead, according to Oriti, what is required is "the development of a metaphysics in which the usual notions of space and time, thus location and ontological distinction based on it, spatial contiguity, temporal change and permanence, and so on, do not feature in the very definition of existence or reality (ibid.: 18)." Of course, there is no guarantee that such an ambitious project will succeed, but I do believe Oriti manages to avoid the strict logical problem posed by Rugh and Zinkernagel: it is simply not clear how we ought to think about the emergence of time, but from this it does not follow that we must necessarily do so in terms of a classical notion of cosmic time.

To provide further evidence that the debate is much wider than Rugh and Zinkernagel let on, I will mention just one among several suggestions given by Huggett and Wüthrich (2018). The idea is that a new fundamental parameter would play the role of time in the fundamental theory: this parameter would vary across the atemporal structure of the universe and would agree with "effective time" (i.e. with the classical time we are familiar with as an approximation of the fundamental structure) in those parts of the structure which can be approximately described by GR. The transition from an atemporal part of the structure (e.g. early universe) to a part approximately describable by GR (e.g. later universe) would thereby be "with respect to this quantity, not effective time (Huggett and Wüthrich 2018: 1202)." Of course, the suggestion is highly speculative and not guaranteed to work, but this only highlights the complexity of what Rugh and Zinkernagel call the "cosmic measurement problem". Since I am not aware of further contributions by either Rugh or Zinkernagel to this debate, I will not examine their argument further. Instead, I will next turn to what I consider a far more original and interesting argument by Zinkernagel.

3.3.2 The reverse problem of time and the "field of application" argument taken at face-value

Zinkernagel (2002, 2006) claims that in addition to the scale problem of time which concerns its (supposedly) diachronic emergence, there is a reverse problem regarding time's disappearance as we approach the early universe. Briefly, the problem is that any discussion of the "early" (as opposed to "later") universe is impossible without the use of classical time concepts, which would be absent from a hypothetical mature atemporal theory of QG. Thus, such a theory could not even discuss the very thing it is supposed to describe without borrowing from the classical temporal terminology of GR. Therefore, such a theory would rely on the concepts of GR and could not be said to be more fundamental than GR. This formulation of the problem is intended by Zinkernagel (private communication) to constitute an argument against both epistemological and ontological QF. I shall refer to this argument as Zinkernagel's "field of application argument" (FA). Before going into more detailed analysis, it is best to begin by quoting Zinkernagel (2006) at length to see what his own formulation of this argument looks like[28]:

> This problem, which could be called the reverse problem of time, arises as follows: As mentioned above, it is conjectured that quantum gravity (and quantum cosmology) will be particularly relevant for discussing the conditions in the very early universe where quantum effects of gravity are expected to be important. But any discussion of the early universe obviously requires that we have a cosmic time concept which indicates that we are close (temporally) to the Big Bang singularity. Indeed, a cosmic time concept is one of the fundamental ingredients in the Big Bang model of the universe. The cosmic time parameter is the proper time of a standard clock (for instance, an imagined perfect wrist watch) at rest in the so-called co-moving frame, and it is this time concept physicists and cosmologists have in mind when discussing conditions in the early universe. Indeed, the Planck scale is reached in cosmology by extrapolating backwards the Big Bang model in this cosmic time. Thus, the assumption that quantum gravity (or quantum cosmology) is relevant for the study of the very early universe rests on a solid classical (i.e. not described by a quantum operator) notion of time. But if it is conjectured that timeless quantum gravity is the fundamental theory – from which classical physics and concepts can be derived –it appears paradoxical that its central field of application (the early universe) is only defined by a concept (classical cosmic time) which is completely alien to the theory. (Zinkernagel 2006: 308–309)

As we can see, the core of FA is contained in the claim that “any discussion of the early universe obviously requires that we have a cosmic time concept”, and that “the assumption that quantum gravity (or quantum cosmology) is relevant for the study of the very early universe rests on a solid classical (i.e. not described by a quantum operator) notion of time.” Although FA is otherwise quite straightforward, these passages do not perhaps make it so clear how FA is related to Bohr’s “closedness” and “frame of reference” arguments, as I have claimed (and as Zinkernagel has confirmed to me in private communication). With regard to this point it is, again, best to let Zinkernagel speak for himself first:

> I should note that the above mentioned necessity of general relativity for quantum gravity is only somewhat analogous to the necessity of classical mechanics for quantum mechanics —for the role of the classical theory in the former case is not to account for observed phenomena but rather to specify the field of application of the quantum theory. Nevertheless, in the case

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[28] Zinkernagel 2002: 511 also contains an almost identical formulation of the argument. I have chosen to present the 2006 version of the argument since it goes into slightly more detail.

> of quantum gravity, it is much less obvious that one can circumvent the need for a classical theory by opting for a different interpretation of quantum mechanics. (Zinkernagel 2006: 308)

The important thing to notice here is that, if "the role of the classical theory in the [case of QG and GR] is not to account for observed phenomena but rather to specify the field of application of the quantum theory," then the success of FA would constitute an argument against QF that is entirely independent of (although analogous to) Bohr's arguments for his measurement theory, and yet FA would vindicate Bohr's approach to non-relativistic QM as well.

But why does Zinkernagel claim that FA might rule out competing interpretations of QM in a way that Bohr's arguments could not? To my understanding, this is easiest to point out with an example. Proponents of the "many worlds" interpretation (MWI) of non-relativistic QM attempt to reconcile the Schödinger equation's description of the wavefunction with the definite outcomes of measurements by asserting that all outcomes (and not just the one we observe) are measured, but in different universes.[29] Insofar as the MWI is successful, it is so because it at least tells us that what we expect to see based on the Schrödinger equation's description does in fact occur, and that this does not conflict with our experience because the other outcomes (which we do not observe) are realized in worlds that are causally isolated from each other. However, the measurement outcomes in each universe still correspond to a classical description of the state of the measurement device, and such a description requires relying on a classical notion of time. Given this, it does not seem that postulating many worlds would do anything to solve the reverse problem of time in QG: if the frozen formalism is a problem in a single world, then it is a problem in all of them. I will return to this point later in my analysis of Zinkernagel's reasoning.

With these considerations on the table, I am ready to give a more precise analysis of FA. To begin, a formalization of my interpretation of FA, when the argument is taken at face-value on the basis of the quotes above, would look like this:

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[29] As mentioned in chapter 2, there are many interpretations of QM. MWI was originally created by Hugh Everett (1957) and further developed by others. The basic idea is that what seems to us like the "collapse" of the wavefunction's superposition into one definite state upon measurement is in fact a branching of worlds, where each state included in the superposition corresponds to a new world which is causally isolated from the rest.

FA1. Either an atemporal theory of quantum gravity (ATQG) cannot rely on any classical time concept of general relativity (GR), or ATQG cannot be a more fundamental physical theory than GR. (Premise)

FA2. An ATQG would describe the conditions that obtain in the early universe. (Premise)

FA3. The conditions obtaining in the early universe cannot be described without the early universe being referred to. (Premise)

FA4. The early universe cannot be referred to without relying on a classical time concept of GR (global time) (Premise)

FA5. The conditions that obtain in the early universe cannot be described without relying on a classical time concept of GR. (From FA3 and FA4)

FA6. An ATQG would rely on a classical time concept of GR. (From FA2, FA5)

F7. An ATQG cannot be a more fundamental physical theory than GR. (From F1 and F&)

The first four premises (FA1–FA4) of FA are logically independent of each other. FA5 follows logically from FA3 and FA4, and FA6 follows from FA2 and FA5. The conclusion, FA7, then follows from FA1 and FA6. Therefore, the argument formalized in this way seems deductively valid to me.

But what about the justifiability of the first four premises, on which the rest of the argument relies on? FA1 is meant to be read as an exclusive disjunction, and seems uncontroversial for present purposes: if a timeless QG theory relies on any classical time concepts of GR for its own intelligibility, then we cannot say that it is more fundamental than GR (in this respect FA is similar to what Rugh and Zinkernagel call the “cosmic measurement problem”). FA2 is the premise that seems to be the most problematic, but I will skip over it for just a moment. FA3 seems true insofar as the description itself or its interpretation somehow refers to the "early" universe somehow. But as I explain below, this will depend on how we understand FA2. FA4 on the other hand seems well justified in light of Rugh and Zinkernagel's previously discussed work on the notion of cosmic time.

So, the argument should go through as long as FA2 and FA3 can be justified. But I see a difficulty with that, which has to do with the very notion of a "field of application". Firstly, from the theoretical perspective afforded by a full timeless theory of QG one would not say that the theory describes any epoch (such as the early universe) since, according to the theory, there are no such things as epochs. So, in a strict sense, the "early universe" would not be the "field of application" of such a theory, and from that perspective, FA2 would seem to be false. It would be only from the perspective of our observations, and from the classical theoretical perspective afforded by GR and the Big Bang cosmological model that we would be saying that such a theory of QG describes the early universe, so FA2 would seem true only from that classical perspective. Considered in this light, FA3, on the other hand would have to be read as saying that the conditions obtaining in the early universe cannot be described without the early universe being referred to, but only if one assumes the classical perspective. So it would be a harmless statement for the quantum fundamentalist.

An obvious complaint against this quantum fundamentalist objection would seem to be that we have now divided the physical description of the world into quantum and classical perspectives without giving any hint on how these perspectives might be reconciled. But for the quantum fundamentalist, such reconciliation would not be entirely necessary in some sense, since the hypothetical quantum theory in this case has survived all the tests which GR has survived but in addition has also survived tests which GR has failed. So, in a strict sense, the "field of application" of a mature theory of QG would supposedly be universal (or at least broader than the "field of application" of GR or Newtonian gravity), if the expression were taken at face value. It would only be from a pragmatic perspective, in which one prefers to use the less cumbersome theory when possible, that one would refer to the conditions in which GR breaks down as the "field of application" of a QG theory. But why should the failure of GR in these cases be a problem for QG? Should we not simply admit that, since the QG theory is more epistemically successful than GR in this hypothetical scenario, the timeless quantum perspective should, *ceteris paribus*, be considered more fundamental compared to the classical one, even if this seems "paradoxical" from the classical perspective from which *any* phenomenon will, by definition, be a phenomenon in classical time?

Consequently, the argument seems weak to me if the expression "field of application" is taken at face-value as it appears in Zinkernagel's 2002 and 2006, which, as far as I am aware, are the only writings thus far in which FA is presented. Therefore, to understand what Zinkernagel means by "field of application", I suggest to read the argument in light of his earlier work, in particular his Ph.D. dissertation, in which the phrase appears throughout as a part of a general exposition of an entire philosophy of science largely inspired by the work of Niels Bohr and the philosopher Peter Zinkernagel (especially as expressed in P. Zinkernagel 1962). When the phrase is seen in the full context of the general philosophy of science in which it is embedded, I believe FA can be reformulated into a more cogent argument. Why did I not do so from the outset? Part of the reason is that Henrik Zinkernagel (2002, 2006) does not refer to his dissertation and Peter Zinkernagel's philosophy as necessary sources for understanding FA as it appears in Zinkernagel 2002 and 2006, but rather seems to present it as an independent argument that does not rely on his specific brand of Bohrian epistemology of science. By first examining FA as an independent argument, in which the term "field of application" is taken at face-value, I hope to have shown the difficulty of maintaining this interpretation. The need to see the argument in a larger context also reveals (if I am right) that formulating it in a compelling way requires one to be committed to more epistemological claims than Zinkernagel (2002, 2006) apparently lets on. While this weakens the dialectical force of FA against QF, I think it also highlights how, by employing FA in the context of contemporary philosophy of physics, Zinkernagel shows that a broadly Bohrian epistemology of science is able to hold its own and even challenge the currently more popular straightforward realist approaches (such as that of Wüthrich and Lam 2021).

3.3.3 The "field of application" argument re-interpreted

In order to explain what kind of work the notion of "field of application" does in FA, I will now present the general philosophy of science that Zinkernagel seems committed to in order to make FA work as an argument. A general remark: although Henrik Zinkernagel (1998: 78–93) presents most of what follows in his own voice, he also makes it clear that he is generally relying on the work of Peter Zinkernagel (1962) and Jacobsen (1972) as the main sources for his views (H. Zinkernagel 1998: 82). Therefore, I will here mainly rely on Peter Zinkernagel (1962) for the clarification of some fundamental points.

I will begin by focusing on the importance of Peter Zinkernagel's notion of objectivity. Briefly put, for him, what is objective is that which cannot be denied. So, objectivity is undeniability, and if one accepts this, it is impossible for one to deny that there is such a thing as objectivity, since to do so would be to deny what is undeniable.[30] The idea is perhaps best illustrated with a historical example. According to Zinkernagel, the earliest instance of an objective science was Euclid's geometry. In contrast to previous religious and philosophical thought, "[a] man who contended that he understood Euclid, but that did not agree with him, would only reveal that he did not understand Euclid, that indeed he did not understand the nature of the insight expressed in geometrical terms. (P. Zinkernagel 1962: 1)." What made objective science possible for the first time, according to P. Zinkernagel's analysis, is that Euclid "succeeded in establishing the precise use of geometrical terms without having to do the same with other terms of the language. (ibid.: 2)" The general lesson he wishes to draw from this is that, in general, objective science is only possible on the condition that "it is possible for us to define and clarify the use of certain concepts regardless of the use of other concepts (ibid.)."

However, the seemingly self-contained nature of the concepts employed in Euclid's geometry led subsequent philosophers such as Plato to see a discrepancy between the unchanging and ideal picture of the world as it appeared through Euclid's geometry and the changing and imperfect world that appears to the senses. According to P. Zinkernagel, this discrepancy still persists in the present day pedagogical approach to geometry, when we say things like "A geometrical triangle is quite different from the triangle on the blackboard", or "A geometrical point has has nothing to do with the mark we put on the blackboard (ibid.: 3)." While true in a sense, such statements are misleading for P. Zinkernagel, because they cloud the

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[30] It should be mentioned that Henrik Zinkernagel (1998: 78–81) is well aware that the notion of objectivity presented here is a controversial one in light of the historical development of the concept. Although I do not have here the space to discuss all the points that he makes, suffice to say that he attempts to defend his preferred notion of objectivity against alternatives, such as a historicist notion of objectivity.

connection to everyday language which geometry has. For example, in order to say that a geometrical point is unextended while a point drawn on the blackboard is extended, one has to rely on the geometrical notion of extension and apply it to something in everyday life (the mark on the blackboard).[31] Therefore, Peter Zinkernagel does not consider geometry to express truths of a fundamentally different kind than true expressions of everyday language do. It is merely the fortunate fact that geometrical concepts can be precisely defined and used without reference to the other concepts of our language which enables one to use them as the basis of an objective science (i.e. a science which can deliver undeniable results). However, because geometrical concepts are merely refinements of already existing everyday concepts, we are able to apply geometrical insights to our everyday lives.

Now turning to physics, Peter Zinkernagel claims that a similar development in our way of conceptualizing the motion of bodies enabled the rise of physics as an objective science in the 17th century (P. Zinkernagel 1962.: 5). Because Galileo and Newton were able to define the relevant concepts like motion and force in relation to each other (but without attempting to define them in relation to all the concepts of our language), they already understood the essentials of what he calls the "concept-frame" of classical physics, although they did not know much of what was to be included in it. Briefly put, this concept-frame "is characterized by the joint application of dynamic variables and of space-time co-ordination" (ibid.: 14). By excluding from this concept-frame the parts of language which deal with qualitative aspects of our experience such as color and smell, we are able to communicate other aspects of our experience in a precisely defined and thus unambiguous way. The laws of nature, when appropriately expressed by means of concepts that can fit into this concept-frame, acquire the status of objective knowledge because they express what a sufficiently empirically informed person cannot coherently deny.

What changes in the case of quantum theory is that the classical concept-frame is no longer sufficient to make sense of quantum effects such as the Heisenberg uncertainty relations. We must thus rely on what Bohr calls a "symbolic" rather than an "*anschaulich*" (roughly, "visualizable") representation of the states of quantum objects such as atoms (see Chevalley 1996: 240–242). But because of this, a

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[31] And although Zinkernagel does not make the point here specifically, I take him to also endorse the view that it would be impossible for us to understand any geometrical theorems in the first place if geometry were not merely a refinement of everyday language in the first place.

purely quantum theoretical description of objects is unable to relate what is described to what we can see in experiments. It thus becomes necessary, in order to maintain the status of physics as an objective science, to supplement the quantum theoretical description with a classical description of the state of the measurement device. Again, this is for the sake of unambiguity as a condition of objectivity: if one cannot relate the quantum theoretical description to something measurable in an unambiguous way, then one is not communicating something that cannot be denied (e.g. that an electron was recorded to have hit the detector screen at such and such a location and at such and such a time). Thus, the use of classical terminology is, for Zinkernagel, a condition of objective description. Now what about the notion of a "field of application"? Laws of nature do not apply everywhere, but instead have a limited area of validity (applicability) which can be called "field of application". Within this field of application, laws of nature "represent conditions for meaningful description" (Zinkernagel 1998: 90). For QG this field of application includes high-energy regimes where GR breaks down. Since the quantum-theoretical mode of representation is symbolic, it must be related to observable outcomes through the use of classical terminology. This way of reasoning does not deny the limits of GR, nor the novel features of space and time which QG could help us understand. Instead, Zinkernagel's view endorses the unavoidable need for an atemporal QG theory to refer to classical concepts in order to qualify as an objective form of knowledge. This is, in essence, what Zinkernagel calls the Bohrian idea of "unity without reductionism" (Zinkernagel 2006: 299). Unlike with caricatures of Bohr's view, there is no fundamental division between the classical and quantum worlds. There is just one world, and different modes of description are required for a full understanding of it.

Based on these considerations, I suggest a modified interpretation of FA (MFA), which can be formalized like this:

MFA1. Either an atemporal theory of quantum gravity (ATQG) cannot rely on the classical time concepts of general relativity (GR), or ATQG cannot be a more fundamental physical theory than GR. (Premise)

MFA2. To count as an objective physical theory, the formalism of ATQG must have an interpretation that includes a description relating it to observations or experiments in an unambiguous way. (Premise)

MFA3. Only a description relying on the classical time concept of cosmic time can relate the formalism of ATQG to observations or experiments in an unambiguous way. (Premise)

MFA4. To count as an objective physical theory, the interpretation of ATQG's formalism must rely on the classical concept of cosmic time. (From MFA2, MFA3)

MFA5. To count as an objective physical theory, ATQG cannot be a more fundamental physical theory than GR. (From MFA1, MFA4)

In this modified version of the argument, the first premise (MFA1) remains the same as before (FA1). The difference between FA and MFA comes from the fact that, whereas FA2 and FA3 only include the claim that a QG theory must to refer to classical temporal concepts for us to say what the theory is about, MFA2 and MFA3 make claims about what is required for the theory to be objective, i.e. to include as part of its interpretation an unambiguous way of relating it to what we can be potentially recorded by measurement devices. Zinkernagel's chosen example of the early universe being defined by a cosmic time concept somewhat distracts from this fact, since it seems he is only concerned with the atemporal theory being able to refer to a cosmic epoch, which according to the theory do not fundamentally exist. Instead, reading the argument in light of the previous discussion on conditions of objective description, I think the point is that, even if we come to the limits of the meaningfulness of speaking of cosmic epochs as we approach the Big Bang, we must refer to the "earlier" non-classical epoch by keeping part of our treatment of the description classical. In this case it means that we are keeping (at least a part of) our treatment of the "later universe" classical, since it is in this later universe that we would hypothetically be doing the measurements by which we would come to understand the quantum effects of gravity in the "early universe". Although the formalism of the hypothetical QG theory would be timeless, the overall interpretation of that theory would still have to refer to cosmic epochs as part of the conditions for objective description. Zinkernagel seems to allude to this in his 2006 paper when he says that: "[the] idea that space-time breaks down *within* a small macroscopic space-time region might support the idea that classical space-time concepts (e.g. the macroscopic region surrounding the 'breakdown region') are needed to formulate the 'domain of application' of quantum gravity —and can in this way hardly be seen to be derivable from this theory (Zinkernagel 2006: 310)." He even goes on to say that:

> Perhaps this could be taken to mean that on a Bohrian understanding of quantum theory, the quantization of the gravitational field, and therefore of space-time, can be done only 'locally' (within a classically described space-time volume). This would be in accordance with the quote by Bohr in section 2 according to which an ultimate measurement apparatus which determine a spatio-temporal framework for the quantum phenomena must be described by classical physics concepts (in particular, this would fit with a relationist account of space-time which links classical space-time to classically described rods and clocks. (Zinkernagel 2006: 310 n)

Although the immediate point in this quote concerns the investigation of small spacetime regions in the present (as defined by a relativistic frame of reference), it can equally well be applied to the investigation of earlier regions of the universe, since any measurements of quantum effects of gravity would have to be measured in the later universe (namely, our present), and these measurement outcomes would be described classically.

A point that must be addressed immediately is how this would be saying anything new that Bohr did not. Here I wish to recall what Zinkernagel says about the possibility of evading FA by opting for another solution to the measurement problem of non-relativistic QM: namely, this cannot help the quantum fundamentalist in the present case of QG, since even those solutions would have to rely on classical time to endow the formalism with physical content. Thus, if MFA is successful, it can at least give Bohrian the upper hand against the MWI theorist in a way that Bohr's measurement theory of non-relativistic QM cannot.

However, it would be premature to declare MFA successful based only on what has been said so far. A quantum fundamentalist might propose that the apparent discrepancy between an atemporal QG formalism and an apparently classically temporal world might be reconciled by philosophical strategies which are entirely separate from solutions to the measurement problem in non-relativistic QM.

In the next section, I turn to consider whether such proposals could constitute successful counterarguments against MFA.

3.3.4 The emergence of time and empirical incoherence

For decades, there have been prominent discussions among physicists and philosophers of physics (see, for example, Crowther 2021, Oriti 2021, Lam and Wüthrich 2018, Esfeld 2020, Linnemann 2020) on whether we could explain how something temporal emerges from a fundamentally atemporal quantum state not only diachronically (as we move from the early universe to the later universe)[32] but also synchronically (i.e. in every moment) since the fundamental atemporal quantum structure would underlie our universe at every moment (from our classical temporal perspective). There has also been discussion on just what kind of a problem the (assumed) atemporality of QG would be in the first place.

In order to make sense of the proposed solutions of emergence, I turn first to characterize the problem they are meant to solve. In recent discussions, this problem is known as "empirical incoherence" and it bears a similarity to Zinkernagel's "reverse problem of time" (and thus to FA and MFA). Empirical incoherence is a phrase coined by Jeff Barrett (1999). Briefly, the definition is that "[a] theory is empirically incoherent just in case the truth of the theory undermines our empirical justification for accepting it as true (Barrett 1999: 4.5.2)." In the case of timeless QG, the worry is that if a theory tells us that fundamentally there is no time, it would deny that any temporal process is fundamentally real. However, any empirical evidence that could be forth in favor of the theory would be evidence from our observations of physical processes, i.e. processes in time. But since those processes are not fundamentally real according to the theory, how could it gain support from that which it deems fundamentally unreal? To see the problem more clearly, let us contrast this with how theories which do not deny the fundamental reality of time work: since these theories allow time (and thus temporal processes) to be a part of the fundamental ontology of the theory, it is possible for them to explain what we observe (physical processes) as composed of some entities or structures postulated by the theory, since those are also something that exists in time. However, in the case

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[32] This problem was discussed in section 3.3.1.

of a timeless theory, there is no such obvious strategy for finding this link between what the theory says there fundamentally is and what we observe.

Even when presented in these simple terms, the problem of empirical incoherence does not appear to be a strictly logical problem of (in)coherence: after all, how is it problematic for a theory to deny that the observable features of things which are used to support it are not fundamental? An example frequently brought forth in the literature is the non-fundamentality of color as a property of physical objects. For example, Healey (2002) explains that since the 17th century, physics has had the resources to provide us an account of how our perceptions of color arise without relying on color as a fundamental property of physical objects. Although the details of this account have changed, the main features can still be described as follows: a physical object appears colored to us because it possesses intrinsic properties (which can be described without color) that disposes it to preferentially reflect certain wavelengths of ambient light while absorbing others. Therefore, the light reflected from this object has a different composition than the ambient light. When this differently composed light reaches the open eye of a human equipped with a normally functioning visual and neural system, it produces a characteristic sensation that we have learned to associate with a specific word, such as "red". So, the quality of red can be thought of as something residing within human consciousness, and not something that exists fundamentally in physical objects themselves (Healey 2002: 302–303).

Of course, this generates the famous "hard problem of consciousness" for philosophy of mind, since we are still left with the question of why we should have any such qualitative experiences in the first place, and whether any purely physical facts can ever fully account for them (see Chalmers 1996 for the classic exposition of the contemporary version of the hard problem of consciousness). Still, the physical side of the story can account for the regularities between a certain kind of color phenomenon and certain more fundamental properties of physical objects. Moreover, anyone who accepts the physical side of the account of color sketched above will thereby accept that a physical theory does not need to utilize non-fundamental terms when explaining how something less fundamental arises from something more fundamental, unless we also expect the physical theory to solve the hard problem of consciousness. Therefore, unless we expect a timeless theory of QG to do that, why should it be a *special* problem for such a theory that it postulates the non-fundamentality of some aspect of the world which we previously regarded as fundamental? As illustrated by the example of color above, the history of the physical sciences is a long story of us adding new types of properties in the inventory of fundamental entities (e.g. spin and charm) and of removing properties from that inventory to the inventory of non-fundamental entities (e.g. heat, pressure). Time, then, might simply be the latest feature of the world to be subjected to this treatment.

Still, Healey (2002: 293) acknowledges that it is not a trivial task for a timeless physical theory to explain how we can get along without assuming the fundamentality of time. It is still one of the tasks of such a theory to explain how the appearance of time emerges from a fundamentally non-temporal structure.[33]

The most elaborated approach that tries to show how time can be non-fundamental is known as functionalism about spacetime[34] (with the most advanced paper I am aware of being Wüthrich and Lam 2018; see Esfeld 2021: S365). The main idea of functionalism in general is that "a given concept of interest is best understood by means of the role that concept plays, rather than by (any, or all, of) its specific instances or realisations (Crowther, Linnemann, & Wüthrich 2021: 221)." Following Esfeld (2021), the simple way to put it is that functionalism is a reductionist approach that describes how some X plays a functional role of Y, where X is configuration of fundamental entities, and Y is the characteristic behavior of the non-fundamental thing we try to functionalize. For example, according to the functionalist approach, water is not part of the current fundamental ontology of science but instead configurations of H_2O molecules realize the functional role of what we call "water" by behaving (moving) in a certain way such as appearing colorless and odorless and being able to quench our thirst. Thus, functionalism about water describes how configurations of H_2O molecules play the functional role of water "in terms of a causal role for the motion of bodies" (Esfeld 2021: S356–357).

Functionalism about spacetime is the proposal that spacetime could be functionalized in the way that some configurations of entities in fundamental

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[33] Here the "appearance of time" refers to those features of time that are included in GR without taking into account those human phenomenological features of time which are lacking in GR, such as "time's arrow". Therefore, the present question is not about relating the formalism of an atemporal QG theory to the full range of human experience, but only those features of it that are prerequisites of objective description as discussed in the previous section.

[34] For the purposes of this section, I drop the distinction between time and spacetime because it does not affect the arguments.

ontology would play the functional role of time: “what it is to be spacetime is nothing other than to fulfill a particular functional role (Crowther, Linnemann, & Wüthrich 2021: 221).” Spacetime functionalism is then applied to QG to articulate what a theory of QG has to do: it must show how “functionally relevant” aspects of spacetime emerge, not spacetime per se (Lam & Wüthrich 2021: 336). The suggestion is that “spacetime may exist merely ‘effectively’, just as many salient aspects of our physical world, such as temperature, pressure, or liquidity” (Wüthrich 2019: 316).[35]

However, when functionalizing water, the conceptual frame of functional definitions is not dependent on any features of water but only on the motion of matter in spacetime. The situation changes when the conceptual frame of functional definitions is applied to spacetime itself. This problem is formulated by Esfeld (2021) in the following way: if functionalism is about explaining a feature of the world in terms of a more fundamental feature of the world, then spacetime functionalism should be a matter of explaining spatiotemporality in terms of something non-spatiotemporal. However, the only definitions available in the functionalist projects from the special sciences including non-fundamental physics, or from philosophy of mind, are definitions “in terms of causal or functional roles for the motion of spatiotemporally related objects” (Esfeld 2021:). In other words, Esfeld claims that if functionalism about spacetime is formulated in spatio-temporal definitions, then functionalism already presupposes spacetime:

> This functionalism thus *presupposes* spacetime (at least in the guise of fundamental spatiotemporal relations). It can hence not serve as a model for a research programme whose aim is to show how spacetime and spatiotemporally related objects enter into a theory that does not admit a fundamental spacetime. (Esfeld 2021: S356. Emphasis added)

Esfeld in this quote concludes his argumentation that functionalism towards spacetime is not justified because spacetime is presupposed. Lam and Wüthrich (2021) reply to Esfeld (2021) that their proposal should not be understood as one ontological interpretation of QG among other empirically equivalent ones, where some interpretations might be realist and some anti-realist. Rather, Wütrich and

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[35] That is to say that spacetime would exist in the same sense that the entities featuring in an ontology of an effective field theory (EFT) exist, i.e. non-fundamentally. See chapter 2 for a discussion of the framework of EFTs.

Lam claim that their project is about spelling out the other ontological implications of QG if one assumes the theory to be true and of those true things to be the absence of spacetime at the fundamental level. This does not commit them to a standard scientific realism about QG (instead it can even end up undermining it, see Lam and Wüthrich 2021: S348) but is just a way of reflecting on the commitments of atemporal QG. However, Lam and Wüthrich (2021) admit that there may be other ways of developing an interpretation of QG, so their dialectical situation seems weak, and moreover, does not seem to address Esfeld's worry that spacetime functionalism might not not a viable option to begin with, since all currently existing forms of functionalism (in the philosophy of special sciences or philosophy of mind) attempt to functionalize the supposedly non-fundamental things (e.g. water, life, minds) by finding something supposedly more fundamental whose behavior realizes the appropriate functional role, and ultimately this something more fundamental is always something material moving in spacetime.[36]

Thus, I conclude that there has been no viable argument against Esfelds claim that functionalism, as currently conceived, presupposes spatiotemporality and through this I suggest to strengthen Zinkernagel's argument against QF: if he right, not only does an atemporal theory of quantum gravity presupposes time in order to define its field of application, but it also seems that, independently of that, the main approach to recover time from an atemporal QG theory (functionalism) presupposes time!

However, let us suppose that Esfeld's objection could be overcome by developing an entirely new type of functionalism that does not presuppose spatiotemporal relations and that this functionalism could somehow be applied to the case of spacetime to explain how it emerges in a hypothetical complete theory of QG. Would such a form of spacetime functionalism successfully solve Zinkernagel's reverse problem of time and, thus, also constitute a counterargument to FA and MFA as I have presented them in this work? I contend that it would not, because there is a

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[36] Of course, as Esfeld (2021: S356) himself admits, this does not rule out *a priori* that spacetime could be functionalized. It is just that no model of functionalism that we currently find in the special sciences could do the job in the case of spacetime, so the type of functionalism would have to be something entirely new, and so far no one (including Wütrich or Lam) has presented a functionalist approach to spacetime that is detached from the familiar type of functionalism which presupposes spacetime.

further reason why the prospects of spacetime functionalism are much worse than the those of the familiar kinds of functionalism: namely, a reductionist functionalism about spacetime would undermine the conditions of objective description in a way that functionalism about, say, water, does not. So, it is not that all the familiar (supposedly non-problematic) functionalist accounts merely *happen* to assume the fundamental reality of spatiotemporal relations, but also that this assumption licenses the possibility that these functionalist accounts may represent objective descriptions![37] To return to the basic point: an objective scientific theory gains its status of objectivity from the fact that a sufficiently empirically informed person cannot coherently deny the content of the theory. This requires that the theory must be able to present an account of the evidence for its claims in an unambiguous way, and for a physical theory this requires, among other things, the ability to describe *where* and *when* something is observed (relative to something else).[38] Thus, if we accept FA or MFA in the first place, then we also accept that a quantum fundamentalist who endorses spacetime functionalism would divorce the epistemology and ontology of the atemporal QG theory in an unacceptable way, because the physical interpretation of a theory includes both what it says there is (ontology) and how you get to know what there is (epistemology), and the terminology used in getting to know what there is (in this case the terminology of classical physics) must be on a par with what the theory says there is when it comes to fundamentality, since its employment is a necessary condition for objective description.

3.3.5 Rethinking the distinction between epistemological and ontological quantum fundamentalism

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[37] This is not to deny that even familiar forms of functionalism could fail for other reasons. For example, it is a highly controversial question whether functionalism about the human mind could solve the “hard” problem of consciousness or even the “easy” ones (see Van Gulick 2022).

[38] Another way to put the point would be to say that whereas different aspects of our experience, such as color, might be physically non-fundamental, we are only able to say so because we are basing this on other aspects of our experience (such as the ability to read instrument readings). However, time should not be considered merely a part of experience, but rather a precondition for any experience or any objective description.

Now assuming that the “field of application” argument avoids the above objections one might level against it, an important question remains: does either version of the argument (FA or MFA) successfully rule out both the epistemological and ontological versions of QF?[39] Again, in Zinkernagel’s own words, epistemological QF is the view that everything in the universe “is ultimately describable in quantum-mechanical terms” (Zinkernagel 2015: 2), whereas ontological QF is the view that “Everything in the universe (if not the universe as a whole) is fundamentally of a quantum nature” (ibid.). In the 2002 and 2006 papers where the argument appears, Zinkernagel does not make a distinction between these two versions of the QF thesis, but he affirms (in private correspondence) that he thinks the “field of application” argument works against both of them.

Instead of just providing my straightforward evaluation of Zinkernagel’s claim, however, I first wish to scrutinize the distinction a bit more. The epistemological version of the thesis seems clear enough for the purposes of the “field of application” argument: the quantum fundamentalist claims that, at the fundamental level, the material constituents of the universe can be described exclusively in terms of a quantum theory (in the case of QG, a quantum theory of gravity), and this is precisely the claim that Zinkernagel wants to rule out with his “field of application” argument. But what about the ontological version of QF? What would it mean for something to be of a quantum nature apart from how it can be described, according to Zinkernagel? Although I have not found a straightforward answer to this question in writings where he unambiguously discusses his own view of the distinction, he does discuss the distinction in a paper which addresses the question of whether Bohr might be an ontological quantum fundamentalist. Zinkernagel tries to put some meat around the notion of ontological QF by saying that “an obvious suggestion would be to think that the deep nature of objects is correctly represented by quantum wave functions (Zinkernagel 2015: 5).” But this does not seem very helpful either, for what, if anything, is the difference between saying that objects can be *described* exclusively in terms of quantum wave functions, and saying that the deep nature of objects is correctly *represented* by quantum wave functions?

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[39] For the purposes of this section, the distinction between the two versions of the argument does not matter, because everything I say is meant to apply to both. Therefore, I will simply refer to the “field of application” argument in the rest of this section.

To be fair to Zinkernagel, the suggestion he provides in the previous quote comes right after he says (while discussing Bohr's view) that “it is far from clear what, from Bohr's viewpoint, it would mean to assert that an object in itself is a quantum system (Zinkernagel 2015: 5).” So, perhaps the distinction might be meaningless for Bohr, who, as Zinkernagel affirms, “almost always stresses epistemological rather than ontological aspects of quantum mechanics (ibid.)” Here it is helpful to recall Petersen's characterization of Bohr's view (which Zinkernagel seems to accept), according to which:

> [i]t is wrong to think that the task of physics is to find out how nature *is*.
> Physics concerns what we can *say* about nature .(Zinkernagel 2015: 5)

Zinkernagel states the claim in even stronger terms when he says that “Bohr emphasizes what one can *say* about nature, and rejects the question of how nature *is* in itself (ibid.).” However, Zinkernagel also very clearly states that Bohr “rejects ontological QF if this is taken to mean that objects are ultimately represented correctly by a wave function (ibid: 8).” Here it is important to note that “rejecting” the ontological QF thesis is an ambiguous notion: it could mean that one considers the thesis false, or it could mean that one considers the thesis unknowable, unjustifiable, or perhaps meaningless. I will return to the significance of this ambiguity shortly. Now Zinkernagel comes perhaps closest to distinguishing the two versions of QF in a clear way when he presents perhaps the most compelling reason for why, according to him, Bohr is not an ontological quantum fundamentalist:

> Another problem with the idea of Bohr as ontological quantum fundamentalist is that the measurement problem remains unresolved. For if the apparatus is essentially quantum, and if this means that its correct *representation* is ultimately through a wave function, then one cannot account for the fact that experiments have well-defined results. Indeed, it is precisely the unavoidable superpositions of wave functions that imply that measurements have no results. This consequence of quantum mechanics cannot be changed by considering the measurement apparatus as classical merely at the *descriptive* level. (Zinkernagel 2015: 6. Emphases added.)

Thus, the difference between a merely epistemologically relevant description and an ontic representation of quantum objects would seem to amount to the claim that we could not account for the definite results of measurements on quantum objects by resisting QF at the epistemological level while accepting it at the ontological level. Although it is not my aim to challenge Zinkernagel's reading of Bohr as such, it is important to ask what this argument is meant to show. A theorist who denies epistemological QF but accepts the ontological version of the thesis would supposedly say something like this: "although it necessarily *appears* to us that experiments have well-defined results, this is not really so, because deep down the wave function is all there really is. I admit a classical description of the measurement device is necessary to account for what *appears* to be the case, but the deep nature of objects is essentially quantum." We might complain that he will thereby deprive himself of Bohr's dissolution of the measurement problem, but have we thereby shown his belief in ontological QF to be false? Surely not, because, on Zinkernagel's reading, Bohr's rejection of ontological QF seems to be due to its lack of justifiability, which seems to be a consequence of the further epistemological norm that (even empirically successful) physical theories have to be reconciled with our experience. If the measurement problem must be solved, and alternative solutions to it are ruled out, then the ontological QF thesis is not a justifiable option for Bohr. However, Bohr has not thereby proven that the thesis is false. Here it is useful to remark on the similarity between this result and the claim that an atemporal QG theory might be empirically incoherent (as discussed in the previous section on spacetime emergence). Since an empirically incoherent theory is, by definition, a theory which undermines all evidence for its own truth, such a theory *might* be true, but we would have no way of knowing that (see Healey 2002: 300). So if the charge of empirical incoherence against atemporal QG would stick, this would not prove such a theory to be false, just as Bohr's objection to ontological QF (in the context of non-relativistic QM) does not prove the falsity of that thesis.

So much for Zinkernagel's reading of Bohr. Now I wish to make it clear what the relevance of this ambiguity is for Zinkernagel's "field of application" argument with the assumption that his discussion of the distinction in Bohr's case can be imported to this context. If the distinction between a merely epistemologically relevant description and an ontic representation hinges on different norms of justifiability, then it seems that when we embed those two notions into Zinkernagel's two versions of the QF thesis, we end up with just two different kinds of epistemological QF! For the first version, accounting for what appears to be the case is a condition for saying that everything can be described exclusively in quantum theoretical terms.[40] For the second version, reconciling what appears to be the case with how the theory tells us things are is also required. Because I agree with Zinkernagel (and Bohr) that it is important for the interpretation of physical theories to meet both conditions, my suggestion is to simply merge these two types of epistemological QF into one. I also propose that we drop the distinction between the notions of description and representation for present purposes and therefore also the notions of everything being describable in quantum theoretical terms and everything being of a quantum nature. My reason for this is that, if everything is of a quantum nature, then some kind of description of it should be possible in principle, even if such a description will never be available to us.[41] Therefore my versions of epistemological and ontological QF, based on Zinkernagel's (2015: 2) original formulation, but with the implicit epistemic norms made explicit in the former, looks like this:

<u>Epistemological QF</u>: everything in the universe (if not the universe as a whole) is of a quantum nature and ultimately describable in quantum theoretical terms in a way that explains what appears to be the case and also reconciles what appears to be the case with the quantum theoretical description.

<u>Ontological QF</u>: everything in the universe (if not the universe as a whole) is of a quantum nature and ultimately describable in quantum theoretical terms.

3.3.6 Do Zinkernagel's arguments succeed?

Now the central question arises: does the "field of application" argument successfully rule out both versions of QF in the case of a full atemporal theory of QG? Based on the previous discussion in this chapter, I think the face-value reading of the

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[40] In the case of non-relativistic QM, the acceptance of this type of epistemological QF would result simply from the acceptance of the collapse postulate without regard for *why* the probabilities of the states of the wavefunction are updated in the event of a measurement. I hope it is clear that I do not regard this as a recommendable attitude.

[41] This assumption is based on the further assumption that the universe is fundamentally intelligible, even though our capacity to understand it might be limited.

argument (FA) fails, whereas the modified version (MFA) argument deductively rules out epistemological QF on the grounds that an atemporal theory of QG cannot relate its formalism to observations or experiments without relying on the classical time concept of global time. I accept Zinkernagel's view that an alternative (non-Bohrian) solution to the measurement problem for non-relativistic QM does not help the epistemological quantum fundamentalist, since the reliance on classical time concepts for relating the formalism of a QG theory is a separate issue. I want to emphasize that this result stems from the kinds of epistemic norms that I (and Zinkernagel and Bohr) hold for physically meaningful theories: if a theory cannot *even in principle* be related to observations or experiments in a way that would explain what appears to be the case and reconcile those appearances with what the theory claims to be the case, then we are not dealing with a physical theory but a metaphysical theory or perhaps just nonsense. However, from these types of epistemic norms for physical theories one cannot draw the conclusion that a theory which does not satisfy them is false. To see that this is so, it is enough to consider the possibility that, even if the universe is fundamentally intelligible, we might just be unlucky in the sense that we could not even in principle have epistemic access to the fundamental nature of the physical aspects of the universe. Therefore, I have to conclude that Zinkernagel's "field of application" argument does not rule out that the universe might be fundamentally of a quantum nature, and therefore, ontological QF might be true, as far I am able to conclude on the basis of this argument. However, by succeeding in his attack against epistemological QF, Zinkernagel does present a formidable obstacle for the justifiability of the ontological quantum fundamentalist thesis, because, due to the falsity of epistemological QF, such a justification would have to proceed on non-physical grounds.

The assumption 2 (i.e. that such a theory has to be a unified quantum theory e.g. quantum gravity) has been challenged through the problem of time by Zinkernagel and strengthened by arguments to the same conclusion that theories of QG have to presuppose time (space-time). However, one can also use the problem of time in its philosophical form to challenge assumption 1 (that the world can be fully described by physics). The next chapter of my thesis will be dedicated to that.

4. Time is presupposed[42]

In this final chapter I suggest further considerations that I think strengthen Zinkernagel's opposition to QF and shed light on the philosophical foundations of the debate. Even though I propose to follow a different line of argumentation than Zinkernagel, I believe that through this I can clarify how a quantum fundamentalist falls into an error about the role of time. Thus, I arrive again to the same conclusion: the absence of time in quantum gravity challenges the quantum fundamentalist position.

The general view of today's philosophy of physics and naturalized metaphysics is that the results of fundamental physics are the final and decisive authority for trying to understand what the material aspect of our world is fundamentally like. If this view is assumed together with a quantum fundamentalist perspective, then it is possible to derive the fundamental unreality of time based on quantum gravity. As it is often suggested, since time is not part of fundamental physics, but we do perceive temporal change, time should be considered as a psychological feature and thus as a product of our brain activity (Buonomano 2017, Rovelli 2018). Bancalari, commenting on Rovelli's work, captures the view: "as time is not cosmological, it is reduced to a simple «psychological» fact: «Perhaps the emotion of time is precisely what time is for us» (Bancalari 2021: 266)".

This inference of Rovelli reflects the standard reductionist approach to physics presented in the previous chapters: either something is objectively real and described by physics or it is subjective, psychological and not real. I suggest we consider the alternative inference: if time is not part of fundamental physics then this does not

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[42] This chapter and referred works of Michael Eldred (2019) and Stefano Bancalari (2021) are inspired by the philosophy of Martin Heidegger (e.g. 1962, 1982, 1992a, 1992b). It seems to me that Heidegger's approach to time can have a great value for the current debates in analytic philosophy of physics about time not being fundamental. After all, the phenomenon of time is central for Heidegger. In particular, by following Heidegger and through hermeneutic-phenomenological framework, one can show mistakes in the arguments of proponents of an atemporal world (e.g. Barbour 1999, Rovelli 2018). However, this would require dropping the distinction of subjective and objective. But due to the fact that the main point of my work is focused on analytic philosophy of science and the arguments within it (and due to spatial constraints), I cannot provide a full account of Heidegger's view of time. Nevertheless, I will address the central points that can clarify problems of QF and are relevant for Zinkernagel's argument.

necessarily imply that time is not fundamentally real, but rather could imply that fundamental physics does not have adequate tools to describe it.

An example of a similar view can be found in the work of Tim Maudlin (2014). In an attempt to try to solve the problem of time, Maudlin has adopted an approach that differs from that of most: he thinks we need to change our mathematics in order to bring time back. However, my claim is more radical than Maudlin's: change of mathematics will not provide physics the possibility to describe the phenomenon of time.

Following the work of Michael Eldred,[43] I claim that the mathematical method used by physics itself already assumes a certain view on time and "pre-casts" it into a theory. On the ground of hermeneutic-phenomenology, Eldred suggests that the change of mathematics comes after questioning ontological presuppositions about time that scientific theories carry. The method used for that questioning should not be scientific but rather hermeneutic-phenomenological (Eldred 2019: 141). His stated reason for this view comes from the claim that those "precast" presuppositions are at the deepest layer of scientific method, namely calculus, and using the same scientific method for analyzing them would make it circular:

> They are 'pre-' in the sense of a priori, so that they already preconceive and predetermine what a sensible scientific experiment can be and what constitutes an experimental datum given by the experimental set-up with its apparatuses. Hence empirically-based (so-called evidence-based) scientific method is incessantly and inescapably moving in a self-confirming circle. (Eldred 2019: 142).

My simplified reading of Eldreds view is in the form of the following argument:

1. Method of modern physics is mathematics (premise)
2. Mathematics carries presuppositions about time (premise)
3. Conclusion: Physics through mathematics provides circular analysis of time and thus physics can not give a wholesome analysis of the phenomenon of time. (from 1 and 2).

If the first premise does not require justification (physics can only be done with the use of mathematics), the second premise is not discussed almost at all in the

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[43] I am very grateful to Michael Eldred for our discussions on the phenomena of time. The arguments he has offered me have had a great influence on my philosophical views.

philosophy of physics literature. However, as shown by Eldred 2019, calculus is based on the idea that time is a linear succession of moments of "now". One-dimensionality of this linear time is embedded in the mathematical method of physics from its invention and has not been questioned[44]. For example, the standard view in modern classical physics is that the world is 4 dimensional: 3 spatial dimensions and 1 dimension is time (that in light of quantum gravity is only derivative from atemporal structure). But if we assume a certain understanding of time in the method that is used to then provide a more fundamental understanding of time, aren't we falling into an erroneous circle?

To summarize: Eldred's position provides an explanation to why solutions to the problem of time are unsatisfactory. Based purely on modern physics, one is unable to confirm or reject the fundamentality of time because the used method already presupposes certain assumptions about time. But a quantum fundamentalist is blind to this and thus continues to solve the problem with this circularity.

Another essential part of current physical discussion on time, as described in chapter 3, is equating time with a clock. I suggest that this itself is also problematic because QF then rejects the fundamentality of time as clock-time, but not time per se. The reasonable question to ask then is how to speak of time beyond the clock. I propose that a way to do that is to think about what is actually being measured by a clock? The possible reply one can provide is that a clock describes movement i.e. change of spatial position. This leads to an understanding that when thinking of time as clock-time we prioritize space because we define time spatially. How justified is this step? One can argue that spatiality is only possible through temporality, because to read off the clock we need to have a possibility of experiencing temporality. In other words the condition of the possibility of spatially defined clock-time is temporality. Thus, temporality grounds any scientific theory and with necessity is presupposed, because if physics studies movement it has to assume the condition of it being possible. But this assumption is implicit because making time an object of scientific research, one does not approach time by itself but rather a certain mathematical construction of a physical process that acts like a clock. Thus it seems that in order to approach time without those constraints, one has to leave aside scientific method. This is another challenge that QF faces through the problem of

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[44] Unfortunately, I do not have space in this thesis for a full elaboration of Eldred's work. However, one can find his fascinating proposal of 3-dimensional time in Eldred 2019.

time: everything can not be exclusively described in terms of the quantum framework.

Surprisingly, if time is considered as a condition for movement, proponents of quantum gravity like Rovelli (2011, 2018) would in some sense be right that time is not out there. Because time, understood as a condition for something *to be*, is not a thing or entity to be discovered by science, so in that sense time does not exist like particles, galaxies, cats or chairs. However, time gives the possibility for particles, galaxies, cats or chairs to exist and to be discovered by science.

Bancalari makes a relevant point: Rovelli is not equipped with a suitable philosophical framework, he makes a fallacious inference and makes time a psychological feature (Bancalari 2021:266). But if one approaches time through a hermeneutic-phenomenological framework, then the fact that time does not exist in physics is a tautology: “[t]hat physics proceeds by equations and that in equations there is no place for a variable like time essentially denotes a tautology” (Bancalari 2021: 268). What is meant by this is that the main method of physics is mathematics and physics uses mathematics to describe the world by equations and equations equate things. But time is not equal to some other things (it does not belong to any set of things), so it's not a problem that time is not part of physics again because the method of physics is incapable of grasping it.

Inspired by the work of Eldred and Bancalari, I claim that those considerations clarify how and why the problem of time in quantum gravity can be seen as a challenge to quantum fundamentalist. The mathematical method of physics and understanding of time as a clock put such constraints on the concept of time, that it is doubtful whether claims about the fundamentality of time from physics should be taken seriously by philosophers.

Thus, I suggest that this radicalizes Zinkernagels claim that time has to be presupposed in quantum gravity. I have offered considerations that not only Zinkernagel is right that the second premise of quantum fundamentalist argument is not justified but also that the problem of time can be used to challenge the first premise i.e. the premise that a physical theory can provide a fundamental description of the world.

5. Conclusion

The dominant view in contemporary physics is that our best empirically confirmed theories – QM (also QFT) and GR – are not fundamental theories. Numerous approaches try to come up with a unification of GR and QFT that would be more fundamental, and those approaches are called theories of quantum gravity (quantization of GR) or theories of everything (combining quantization of all 4 interactions). The majority of those theories reject the fundamentality of time and try to provide an explanation how time can be derivative from atemporal quantum structures. It is generally believed that such a theory would provide a fundamental description of the world purely in terms of quantum theory. I suggested my reconstruction of this position:

1. A physical theory can provide a fundamental description of the world
2. Such a theory has to be a unified quantum theory e.g. quantum gravity
3. The world can be fully described in terms of quantum physics (epistemic tenet) and the world is fundamentally quantum i.e. is composed of quantum objects (ontological tenet) (Zinkernagel 2015).

Henrik Zinkernagel has argued against QF and my work is dedicated to his arguments. My goal was to examine whether Zinkerarnagel's arguments are sound. Building on Bohr's opposition to QF, Zinkernagel presents two arguments analogous to Bohr's (one of them together with Svend Rugh). In chapter 2 I have presented the relevant discussion of Bohr's view on the classical and quantum divide. I have also shown how Zinkernagel has Bohr's view as a background for his own arguments. Building on this, I have presented how Zinkernagel uses the absence of time in theories of QG to argue against QF in its both versions – epistemological and ontological. Zinkernagel's way of characterizing the distinction between epistemological and ontological QF does not seem to hold up to scrutiny, so I have proposed my own way of characterizing that distinction. I have then critically evaluated Zinkernagel's argument and as a result, I came to the conclusion that Zinkernagel's argument can rule out epistemological QF but not ontological QF. I have also presented a counter-argument to Zinkernagel's arguments, namely functionalism towards spacetime. I have shown that this argument does not work because all known approaches to functionalism presuppose spatiotemporality. Moreover, I have argued that time, when considered a condition for objective descriptions, cannot be functionalized even in principle. I then offered considerations against the first premise of quantum fundamentalist argument, that the world can be described fully in terms of physical theory, by using the same problem of time in QG but applying a different kind of philosophical approach to it, namely the work of Michael Eldred and Stefano Bancalari. Using this approach, I have argued that time must be presupposed in the mathematical language of physics itself. In addition, I have argued that the hermeneutic-phenomenological method should be used to analyze time also in the context of physics. My thesis, thus, is that epistemological QF is severely challenged by the absence of time in QG because QG has to presuppose time. While this does not rule out ontological QF, it presents a formidable obstacle for its justifiability.

Abstract

This thesis is dedicated to examining three arguments against quantum fundamentalism (QF), the view that everything is fundamentally of a quantum nature and can be described exclusively in quantum theoretical terms. All three arguments rely on the timelessness of leading approaches to quantum gravity (QG), the successor theory of our two best physical theories, general relativity and quantum field theory. According to the first argument, by Svend Rugh and Henrik Zinkernagel, QF cannot explain how time emerges diachronically from a timeless quantum structure described by QG. I argue with Daniele Oriti that such a diachronic emergence is not strictly necessary, so the argument fails. According to the second argument, by Zinkernagel, timeless QG cannot be more fundamental than GR because its field of application is defined by a classical relativistic time concept. I propose two readings of the argument: the first fails, while the second is successful but requires accepting a broad set of epistemological commitments. The third argument adds that timeless QG does not imply that time is not fundamental, but instead that physics cannot describe it. I conclude that the last two arguments refute an epistemological but not ontological version of QF.

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