Wave Function Realism

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1. Introduction

Wave function realism is an approach to understanding the ontology of quantum theories according to which a or the central object is the quantum wave function. The precise metaphysical nature of this object varies according to the quantum theory one is interested in interpreting. It also varies according to the interpretation of the wave function preferred by the wave function realist in question. The canonical version of wave function realism discussed today, which is defended especially by Albert (1996, 2013, 2015, 2023), takes wave function realism to be the view that a or the central object in any quantum ontology is a wave function, understood as a field on an extremely high-dimensional space with the structure of a classical configuration space. The discussion below will present the history of wave function realism, its various interpretations, the main arguments that are given for the position, and the main objections that have been raised to it.

2. Wave Functions in Quantum Physics

In classical (Newtonian) mechanics, the states of physical systems are given by a specification of the positions and velocities of all particles, particles which may be assumed as well to have intrinsic properties like masses. In (standard, textbook) quantum mechanics, particles fail to have definite positions and velocities at all times. And so, the initial state of quantum systems is not given by a specification of definite positions and velocities, but rather by other means. Typically, the quantum state is represented mathematically by a unit vector in a Hilbert space. State vectors are capable of representing both definite and indefinite states of position or momentum (or energy, spin, and any other physical observable). Moreover, there is a rule, the Born rule, that connects the system's state vector at a time to the probability that a measurement of an observable will yield one or another definite value.

The state vector is a standard mathematical tool to represent quantum states. However, it is not the only such tool. It is beyond the scope of this essay to provide an exhaustive list of the mathematical tools that are used to represent quantum states, but one tool that is especially salient in the current context is (unsurprisingly) the wave function ψ. State vector representations in which the basis of the Hilbert space is given by a set of definite positions for a particle or set of particles are mathematically equivalent to wave function representations. In specifying a system's wave function, one assigns an amplitude and phase to points in a configuration space. Assuming the quantum state is aimed at describing a system of N particles in a three-dimensional space, the configuration space will be a 3N-dimensional space in which each point corresponds to a definite assignment of three-dimensional positions to each of the N particles. For a system of consisting of only one particle, the configuration space is simply ordinary three-dimensional space. The Born rule again connects a system's wave function with the probability that a measurement of that system will yield one or another result. The square of the amplitude of the system's wave function at one or another location in configuration space yields the probability that the particles of the system will be found in the corresponding definite three-dimensional configuration upon measurement.

It is worth mentioning before continuing onto matters of metaphysics that there are two important and basic points of contention concerning the mathematical description of quantum states and their evolution. These are very important and widely debated under the heading "the measurement problem," although they are mostly orthogonal to the issues that will be discussed below.

The first point concerns whether the specification of a system's state vector or wave function provides an exhaustive representation of a quantum state.[1] Some argue that although wave functions or state vectors are indispensable components of the quantum description of a system, to give an ontologically complete description, we must supplement them with a specification of some additional (hidden) variables (e.g. Dürr, Goldstein, and Zanghì 1992, Maudlin 2007). The De Broglie-Bohm theory is the most influential of such positions. Here the complete quantum state is given in two parts: first, by the specification of a wave function, and second, by the specification of definite positions for all of the particles.

The second point concerns the evolution of the state vector or wave function over time. Standard textbook presentations of quantum mechanics describe the quantum state as evolving unitarily over time, and following von Neumann (1932), according to two processes. When a system is being measured, the quantum state collapses nonlinearly onto a state in which the observable being measured takes a definite value; the probability of each potential value is given by the Born rule. When a system is not being measured, the quantum state evolves linearly according to the Schrödinger equation. Some follow e.g. Bohm (1952) and Everett (1957) in arguing that the states of quantum systems never undergo objective, dynamical collapse. It had

[1] In one sense of course, wave function representations cannot be exhaustive, as they only specify the state with respect to variables defined in terms of position. They do not characterize, for example, spin states.

earlier been thought that collapses were needed in order to secure definite results for measurements, and thus secure a connection between theory and observation. However, definite values can be secured in other ways, for example, by introducing hidden variables to the state representation (Bohm 1952), or, as Everett (1957) argued, by noting that within each total quantum state, there lies one or more relative states in which these values may be found.

The adoption of wave function realism, in one or another of the forms to be described below, may be combined with any view about the need for hidden variables or a collapse dynamics. There are wave function realists who follow Everett in thinking neither hidden variables nor a collapse dynamics is needed in order for quantum mechanics to make contact with definite experimental results (e.g. Carroll 2022, Vaidman 2019). There are also wave function realists (e.g. Albert op.cit.) who staunchly demand one or the other such mechanism (hidden variables or collapse) to generate definite values. Wave function realism itself involves no such commitments. The only matter in the neighborhood of these questions (collapse vs. no-collapse, hidden variables vs. no hidden variables) on which the wave function realist will take a stand is whether the wave function itself should be interpreted in an ontic way, as representing something objective about quantum systems, rather than merely something epistemic, about our psychological relationship to these systems. Wave function realism, in all guises, involves the position that although the Born rule licenses a connection between facts about wave functions and what observers should believe about the results of measurements, the wave function itself is not epistemic, but ontic. It in some way provides an objective description of the world. To use terminology introduced by Fuchs, wave function realists are ψ-ontologists.

3. History of Wave Function Realism

Wave function realism was first considered in 1925 by Erwin Schrödinger as an ontological interpretation of his wave mechanics for quantum theory. Schrödinger, for a short time at least, took seriously the idea that the ontology of quantum mechanics could just be fundamentally a wave, represented mathematically by a wave function, evolving deterministically over time according to his wave equation. Although a tempting idea at first sight, Schrödinger quickly became disenchanted with this ontological interpretation, at least for the reason that this wave would have to evolve not in ordinary three-dimensional space, but rather in the 3N-dimensional configuration space (Einstein 1934). As configuration space is not typically regarded as a physical space, but rather as an abstract, mathematical space, this posed a problem for taking the wave function defined on it as real. Another likely cause for Schrödinger's ultimate rejection of a realist interpretation of the wave function came from the many arguments at the time for the Copenhagen interpretation and the idea that attempts to attach a straightforwardly visualizable interpretation of quantum ontology were misguided and out of step with the radical conceptual revolution that quantum mechanics was bringing forward (Fine 1996, Jammer 1966).

Wave function realism in another form was also discussed around the same time by De Broglie, whose pilot wave model took the quantum ontology to fundamentally involve a system of particles that were pushed around (or piloted) by the Schrödinger wave. De Broglie too, however, soon rejected this idea and converted to the ψ-epistemic Copenhagen interpretation, according to which the wave function, although it might be a useful tool to use to predict the results of quantum measurements (via the Born rule), did not contain a direct and objective description of reality.

The idea that the wave function somehow provides an objective characterization of reality is arguably implicit in the anti-Copenhagenist proposals of Bohm and Everett in the

1950s. Both defended formulations of quantum mechanics in which the wave function played a central role and was not (or not obviously) a mere epistemic tool. However, wave function realism was not again advocated so explicitly, it seems, until the papers of Bell in the 1970s and 1980s, eventually collected in Bell (1987). In these papers, Bell clearly presents the interpretational difficulties that beset the standard textbook formulations of quantum mechanics that make use of something like von Neumann's two processes and the Copenhagen interpretation. Bell makes the case that each of the various formulations of quantum mechanics that he regards as improvements (that of Bohm 1952 and Ghirardi, Rimini, and Weber 1986) can only be correctly understood by recognizing that according to these theories, the wave function is real: an objective and indispensable element of a quantum ontology.

As influential as Bell's work was, this idea that the wave function should be interpreted as real, as objective, is still to a great extent contentious in the foundations of physics. There remains a divide among those who interpret the wave function as real and objective (the ψ-ontic camp), and what are now referred to as neo-Copenhagenists of one form or another (the ψ-epistemic camp). Equally contentious is the matter of what it means exactly to be a wave function realist (ψ-ontologist). As mentioned above, this term is very often used to denote a particular way of being a realist about the wave function, according to which it is a field (an assignment of numbers representing amplitude and phase) to locations in a high-dimensional space with the structure of a classical configuration space. Yet, some who advocate realism about the wave function take it not to be a field on configuration space, but rather a field on spacetime (Wallace and Timpson 2010), or a multi-field (Hubert and Romano 2018), or a complex property (Monton 2002, Suàrez 2015), or a law (Goldstein and Zanghì 2013), or something sui generis and thus falling under no other ontological category (Maudlin 2013). These are certainly all ways of taking the wave function to be real and in no sense mind-dependent. Thus, arguably, these positions should also be counted as versions of wave function realism.

Even more confusingly, some of those who are often described as wave function realists don't privilege wave functions per se (in the literal sense as mathematical functions that take in locations in configuration space and spit out numbers) as giving us special insight into quantum ontology. Rather, they privilege state vectors (Carroll 2022) or density operators (Chen 2021) or other mathematical tools that have been used to formulate quantum theories. In sum, today there are various versions of "wave function realism," even if usage of the term has tended, in philosophical discussions, to coalesce around the "field-in-configuration-space" view advocated over the past several decades by Albert.

4. Six Arguments in Favor of Wave Function Realism

The aim of this section is to provide an overview of the main arguments that have been used to support wave function realism, of one form or another. As will be made explicit in the sequel, not all arguments support all versions of wave function realism.

A. The "Prima Facie" Argument

The first step in motivating this ontological position is to note the ubiquity of wave function representations in quantum mechanics. Wave functions provide representations of the quantum state in textbook quantum mechanics and, as Bell noted, the hidden variables theories that in his view constituted improvements to the textbook formulation. Wave functions are the tools used to represent quantum states as well in (nonrelativistic) Everettian quantum mechanics and spontaneous collapse theories. Thus, it seems, if it is reasonable to interpret these theories realistically, as providing objective descriptions of our world, then we should take our world to objectively be constituted (somehow and at least partially) by a wave function.

This sort of argument was made explicit by Lewis:

> The wavefunction figures in quantum mechanics in much the same way that particle configurations figure in classical mechanics; its evolution over time successfully explains our observations. So absent some compelling argument to the contrary, *the prima facie conclusion* is that the wavefunction should be accorded the same status that we used to accord to particle configurations. Realists, then, should regard the wavefunction as part of the basic furniture of the world… This conclusion is independent of the theoretical choices one might make in response to the measurement problem… it is the wavefunction that plays the central explanatory and predictive role. (2004, p. 714, italics added)

As Lewis notes, wave function realism is only a prima facie conclusion to be drawn from the ubiquity of wave function representations in quantum mechanics. After all, even if wave functions are indispensable mathematical devices used by quantum theories, this does not entail that the role they play in the theory is to mirror certain aspects of reality. As Maddy (1992) convincingly argued, when drawing out the ontological consequences of a scientific theory, we must take care to distinguish those parts of the theory that are aimed at mirroring reality from those that are not, those e.g. that are mere mathematical conveniences.[2]

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[2] In Maddy's words, "we must allow a distinction to be drawn between parts of a theory that are true and parts that are merely useful (1992, p. 281)

How does one decide whether the fact that quantum states are given by wave functions is a mere mathematical convenience or a direct representation of reality? This is a question that is answered in various ways by the different advocates of wave function realism. One proposal is that wave function representations should be taken to be directly representational because the phenomena they describe themselves have paradigmatic wave-like features.

B. The Argument from Interference

One of the most distinctive phenomena of quantum mechanics is interference. This is illustrated most famously and vividly by the two slit experiment, which demonstrates the characteristic wave behavior of not just light, but matter as well. When particles are sent one at a time towards a detection screen, first having to travel through a barrier with two slits, they are detected at the screen always at a localized position, as if they had traveled through one or the other slit. However, as the number of particles sent through accumulates, the detection screen surprisingly reveals an interference pattern. This interference pattern is characteristic not of a series of particles that have each individually passed through one slit or the other with equal probability, but rather of a wave that interfered with itself as parts of it passed through both slits simultaneously.

One way to explain this behavior is what was championed by De Broglie, that quantum systems are constituted by both a wave and a particle, with the wave pushing the particle to one location or another as they both travel toward the detection screen. Another option is monist: there is only the wave which somehow (because it collapses or because observers only see Everettian relative states) registers to the observer at the time of detection as only a point on the screen.

In any case, interference is not merely revealed in the two-slit experiment. The distinction between states that exhibit interference and those that do not, that is, the distinction between coherent and decoherent quantum states, is completely central to quantum mechanics. The understanding of quantum systems from lasers to quantum computers relies on the stability of coherent states. If interference is a characteristic wave phenomenon, and wave function realism is an ontological position that is committed to the reality of wave properties of matter, then the observation of the variety of systems that exhibit quantum coherence supports wave function realism over competitor ontological views.

C. The Argument from Entanglement

The argument from interference is interesting in that it not only makes the case for taking wave function representations as tracking objective structure, but as tracking some entity that is genuinely wave-like. The next argument is weaker in this respect. Although it makes the case that wave function representations track something objective, it stops short of arguing that they must mirror the existence of some fundamental wave-like object or field.

This next argument appeals to another distinctive feature of quantum systems, one that comes into play in the case of complex systems, i.e. those involving two or more particles, or two or more observables of a single particle, or both: quantum entanglement. Entangled states are those that cannot be represented as a product of definite states. In an entangled state we have properties of one or more systems that are not only not definite, but also that somehow are correlated with one another. For example, consider the spin singlet state, in which two particles are entangled with respect to their spins along some orientation, e.g. their z-spin.

$$\psi = \frac{1}{\sqrt{2}}|\uparrow_z\rangle_1|\downarrow_z\rangle_2 + \frac{1}{\sqrt{2}}|\downarrow_z\rangle_1|\uparrow_z\rangle_2$$

In this state, neither particle 1 nor particle 2 is represented as having a determinate z-spin. Nonetheless, one may infer from the Born rule that for a pair of particles in such a state, if one is measured to have z-spin up, the other will with certainty be found to have z-spin down.

Albert (1996), Ney (2012), and North (2013) have all argued that this gives reason to think that the quantum state is not just tracking the state of a system of particles, but the state of something else, the wave function, which, they argue, ought to be understood as a field propagating in a higher dimensional space with the structure of a classical configuration space. Here, for example is North:

> In quantum mechanics… we must formulate the dynamics on a high-dimensional space. This is because quantum mechanical systems can be in entangled states, for which the wave function is nonseparable. Such a wave function cannot be broken down into individual three-dimensional wave functions, corresponding to what we think of as particles in three-dimensional space. That would leave out information about correlations among different parts of the system, correlations that have experimentally observed effects. Only the entire wave function, defined over the entire high-dimensional space, contains all the information that factors in the future evolution of quantum mechanical systems. Following the principle to infer, at the fundamental level of the world, just that structure and ontology that is presupposed by the dynamics, we are led to conclude that the fundamental space of a world governed by this dynamics is the high-dimensional one. The fundamental ontology, which includes the wave function, then lives in it. (2013, pp. 190-191)

The argument that these wave function realists use in order to demonstrate that entanglement requires not only taking the quantum wave function to be ontic and representational, but more specifically to be representing the state of a field on a high-dimensional space is interesting and has been the subject of much discussion.

However, all that can really be inferred using the argument from entanglement is that in quantum mechanics, one can create systems that cannot be correctly and completely understood in terms of individual particles and their intrinsic properties definite or indefinite. Somehow or other, the wave function of entangled systems is tracking something else. From an ontological point of view, probably the least radical way of understanding what these wave functions are tracking is that they are tracking correlations between the observable properties. This is the point of view that was advocated in the 1980s by Teller under the heading 'relational holism' (Teller 1985). In this way of thinking, wave function representations track some objective relational features of the world that fail to supervene on the states of individual particles. There is nothing objectively wave-like that follows from endorsing relational holism. Here, the fundamental ontology consists of particles in ordinary three-dimensional space or spacetime, possessing some fundamental relations. For example, in the spin singlet state, the wave function is tracking a relation between the spins of the particles: that their spins are anti-correlated.

On the other hand, there are many more revisionary ways of moving from the phenomenon of quantum entanglement to an ontological interpretation of quantum theories. Probably the most revisionary and radical are the versions that would argue that entanglement shows us that the picture of the world as a collection of objects/particles spread out in three-dimensional space is an illusion or at least, not fundamental. These include the wave function realism mentioned above and developed by Albert (1996, 2015, 2023) and Ney (2021), but also the view according to which what is fundamental is just a ray in Hilbert space advocated by Carroll (2022).

Somewhere in the middle of the spectrum are the various views according to which the fundamental ontology represented by the wave function does reside somehow in three-dimensional space or spacetime, but it is not best captured by an ontology of particles. Examples include spacetime state realism (Wallace and Timpson (Wallace and Timpson 2010), the multi-field view (Belot 2012, Hubert and Romano 2018), and ontic structural realism (Ladyman 1998, French 2013, Wallace 2022). And then there are views according to which the fundamental quantum ontology is still something like a collection of particles or at least what Bell called 'local beables,' but the wave function represents some additional element that is not simply reducible to a set of new relations. Some examples are the views according to which the wave function is something nomic or quasi-nomological (Goldstein and Zanghì 2013) or of a sui generis ontological category (Maudlin 2013). All of these views have been motivated at least partly by appeal to an argument from entanglement; that is, by the point that the phenomenon of entanglement requires us to move beyond a simple physical ontology of particles in space or spacetime with intrinsic properties. The correlations observed as a consequence of entanglement motivate us to take the wave function to be tracking some interesting and new sort of objective structure.

D. The Argument from Separability and Locality

Given that there exist a variety of ways to interpret the ontological consequences of quantum entanglement, one might wonder if there is an argument that speaks more specifically in favor of the sort of wave function realism defended by Albert, Ney, and North: the field-on-configuration-space view. Indeed, there is such an argument. It was first stated explicitly by Ney (2021) under the heading 'The Argument from Separability and Locality,' but this argument draws on earlier points made by Albert (1996, 2013, 2023) and Loewer (1996). The central idea is that among the various ontological interpretations of quantum theories that can accommodate the distinctions between entangled and non-entangled states, only the field-on-configuration-space view does so in a way that is both separable and local. To the extent that we ought to prefer ontologies that have these features, we ought to prefer the field-on-configuration-space version of wave function realism.

Both separability and locality are metaphysical features that were highlighted by Einstein (1948) and elaborated on especially by Howard (1985). An ontology is separable to the extent that it consists in one or more individual systems at nonoverlapping regions, each possessing their own intrinsic features, that suffice to determine all features of their composite systems. To say that an ontology is local is to say that there exist no direct causal relations between distant regions, i.e. no action at a distance. Most ways of developing a ψ-ontic view make the fundamental ontology of quantum theories nonseparable. This includes relational holism, spacetime state realism, the multi-field view, and ontic structural realism. Views that take the wave function rather to be representing something like a law can allow that the fundamental ontology of quantum theories is separable, but to do so, they introduce fundamental nonlocality. Wave function realists (see especially Ney 2021 and Albert 2023) have noted that only the field-on-configuration-space view is able to secure an ontology with both features.

E. The Argument from Spacetime Emergence

Another argument supporting wave function realism, of certain sorts, has been promoted by Carroll (2022). This argument starts by noting that there is good reason to think that spacetime fails to be a fundamental element of a quantum ontology. Although it is too early to tell what is the right approach to developing a quantum theory of gravity (and hence, spacetime), the many different approaches that have had some success all appear to be converging on the view that spacetime is not fundamental, but derivative ontology (see also Huggett and Wüthrich 2013). If so, then, Carroll argues, approaches like his ray-in-Hilbert-space approach to wave function realism (but also the field-on-configuration-space view) seem well-placed to provide a fundamental quantum ontology. This is because both such approaches entail that spacetime is not fundamental, but at best, emergent.

F. The PBR Theorem

Finally, if we are just considering what sort of case can be made for taking an ontic approach to the quantum state, and hence wave functions, as opposed to a ψ-epistemic approach, it is worth mentioning the argument of PBR, that is, Pusey, Barrett, and Rudolph (2012). PBR proved a no-go theorem for ψ-epistemic approaches to quantum mechanics, in particular, ψ-epistemic approaches which assume that even though wave functions are epistemic, there is some underlying state of reality (a so-called ontological model). Ultimately, PBR showed that all ontological models that reproduce the Born rule must be ψ-ontic. Since the Born rule is known to be empirically supported, this undermines ψ-epistemic approaches. As Leifer (2014) has argued, there are ways for the ψ-epistemicist to escape the PBR theorem, by rejecting assumptions that go into the theorem, including rejecting the very idea of ontological models. However, if one likes PBR's assumptions, then this provides further evidence for wave function realism in any form.

5. Objections Against Wave Function Realism

Today, wave function realist interpretations of some form or another, i.e. ψ-ontic proposals, have become much more common. Many take the no-go theorem of Pusey, Barrett, and Rudolph (2012) to make the case for a ψ-epistemic interpretation of the quantum state at least a tougher needle to thread. Nonetheless, it seems some will always be drawn to Copenhagenism of some form, whether because of a more global anti-realism about scientific theories, or because one believes the quantum wave function is just not the kind of thing to be given a realist or objective interpretation (Fuchs 2003, Healey 2017).

Most of the objections to wave function realism one finds in print are attacks more specifically on the more radical varieties of the view, including the ray-in-Hilbert-space view promoted by Carroll and the wave-in-configuration-space version of the view promoted by Albert and Ney. These tend to boil down to two problems with these versions of wave function realism.

A. The Macro-Object Problem

First, it is very difficult to see how any of the familiar macroscopic objects of our ordinary experience could exist if the world is fundamentally a ray in Hilbert space or a field on configuration space. How could macroscopic objects which seem to require extension and locations in three-dimensional space possibly be built up out of something so different and seemingly mathematical, something in such a radically different kind of space?

This objection has been voiced in a variety of more specific ways by Monton (2002), Allori (2013), Maudlin (2013), and Emery (2017). One particularly interesting version of the objection comes from those defending the primitive ontology approach to interpreting physical theories (see especially Dürr, Goldstein, and Zanghì 1992, Allori et. al. 2008, Ney and Phillips

2013). According to this approach, physical theories come with primitive ontologies: that is, a class of microscopic entities in spacetime that the theories are about, and out of which the various macroscopic entities of our experience can be straightforwardly built up. Wave functions, since they are not defined on spacetime, by definition cannot be part of the primitive ontology of any physical theory. This speaks against the various versions of wave function realism that would make the wave function a central element of a quantum ontology that constitutes matter (including the ray-in-Hilbert space and the field-on-configuration-space versions of the view, but also other versions including spacetime state realism and the multi-field view). It is worth noting that those who have defended the primitive ontology approach still consider themselves ψ-ontologists, and thus are wave function realists in some sense of the term. They do not think wave functions constitute the material objects in our world, but do see them as objective and real in some other way, for example, in playing a nomic or quasi-nomic (Goldstein and Zanghì 2013) role in guiding the behavior of the matter. However, this sort of objection certainly speaks against regarding wave functions as everything or everything fundamental there is physically speaking.

The response of wave function realists has been to develop metaphysical accounts of how macroscopic objects could be constituted ultimately out of a wave function, even a wave function in an extremely high-dimensional space. The functionalist proposal of Albert (2013, 2015) has been especially influential, as has the appeal to real patterns in Wallace (2010). North (2013) appeals to grounding and Ney (2021) to mereological composition.

B. Extending the Interpretation Beyond Simple Quantum Theories

The second objection to wave function realism that has been influential is directed specifically against Albert's version of wave function realism as a field on a 3N-dimensional configuration space. This is that the view can only be plausible as an interpretation of extremely simple and idealized quantum theories. Wallace and Timpson (2010), Myrvold (2013), and Wallace (2020) have all argued that it is not clear what the view would have to look like to be reasonable as an interpretation of quantum theories with spin, or relativistic quantum theories, such as quantum field theories.

The problem raised by relativistic quantum theories is that, in this case, particle number fails to be definite or conserved. Systems can be in states in which the number of particles in the system is indeterminate, and can evolve into or out of states with different determinate numbers of particles. In this case since there is no fixed N that numbers the particles in the world, the wave function cannot be consistently defined as a field on a 3N-dimensional space. Wallace and Timpson (2010) consider various maneuvers the wave function realist might make to address this problem, but find none ultimately satisfactory.

In response to this concern, Ney (2021) argued that wave function realists should adopt a less restrictive approach, and allow that the configurations out of which the configuration space is defined may vary according to the details of the quantum theory that is being interpreted. In particular, in a quantum field theory, the configurations that correspond to points in the wave function's space may not be configurations of a definite number of particles in three-dimensional space, but rather "field configurations," i.e. ways that a classical field might be spread over spacetime. There still remains a question of how to accommodate spin and other quantum observables in a wave function ontology, but this is the subject of future work developing the field-on-configuration-space version of wave function realism.

6. Future Directions

Since the work especially of Bell (1987), the field of quantum foundations has flourished and with it, ψ-ontic approaches to quantum mechanics have been on the rise. Although compelling objections have been raised to the particular, radical versions of wave function realism advocated especially by Albert and Carroll, there are many alternative ways of being a realist about the wave function that are presently being developed and defended. Although these may not derive support from all of the arguments discussed in Section 4, they are supported at least by the prima facie argument, the argument from entanglement, and the PBR theorem, and thus have something going for them over ψ-epistemic interpretations. Moreover, many similarly do not fall victim to the concerns about the constitution of macro-objects or oversimplifying quantum theories. They are thus worthy of further development.

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