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Claudio Calosi

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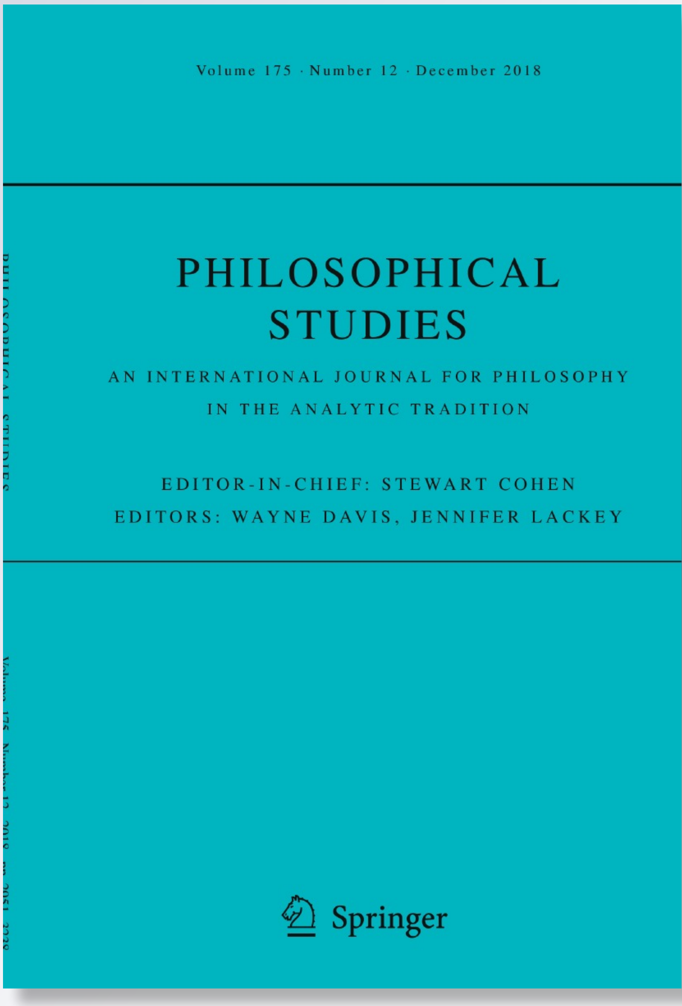

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Claudio Calosi[1]

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Abstract Monism is roughly the view that there is only one fundamental entity. One of the most powerful argument in its favor comes from quantum mechanics. Extant discussions of quantum monism are framed independently of any interpretation of the quantum theory. In contrast, this paper argues that matters of interpretation play a crucial role when assessing the viability of monism in the quantum realm. I consider four different interpretations: modal interpretations, Bohmian mechanics, many worlds interpretations, and wavefunction realism. In particular, I extensively argue for the following claim: several interpretations of QM do not support monism at a more serious scrutiny, or do so only with further problematic assumptions, or even support different versions of it.

Keywords Monism · Entanglement · Emergence · Quantum interpretations

1 Introduction

This paper contains a novel, thorough assessment of quantum monism. Its focus is on the version of monism that, following Schaffer (2010), is usually known as *priority monism*. However, as it shall be clear in the rest of the paper, several monistic worldviews are considered.[1]

[1] A different, yet related argument is presented in Ismael and Schaffer (2016: §3.2.2). Such an argument deserves an independent scrutiny. Relevantly, it also addresses some of the issues I raise in this paper—especially those I deal with in Sect. 3. Ismael and Schaffer suggest two different fundamental ontologies for QM that would be consistent with their basic idea of "*common ground explanation*": *Spacetime State Realism*—the view that the fundamental ontology is that of the whole spacetime bearing a density operator, and *Wave Function Realism*. I address the latter in Sect. 3.4.

✉ Claudio Calosi
claudio.calosi@unige.ch

1 University of Geneva, 2 Rue de Candolle, 1211 Geneva, Switzerland

One from the most powerful consideration in favor of monism in general comes from quantum mechanics (QM). In this paper I extensively argue for the following claim: several interpretations of QM do not support monism at a more serious scrutiny, or do so only with further problematic assumptions, or even support different versions of it. This claim might seem unsurprising: yet the discussion of quantum monism is always framed independently of any underlying interpretation of the quantum theory. This is particularly true of Schaffer (2010, 2015). Ismael and Schaffer (2016) offers interesting details on quantum ontologies, yet they write: "Discussions about the interpretation of quantum mechanics often focus on the debate between "Everett," "Bohm," "GRW," and other rival versions of the mechanics, each which is coupled with its own interpretive options. Where do we come down? Our discussion crosscuts the usual taxonomy". And later on: "We are mainly focused on the synchronic rules for assigning quantum states to simple and complex systems, and what we have to say is for the most part neutral on the accompanying dynamics, so we will use 'quantum mechanics' to refer to the quantum formalism, leaving matters of interpretation (and potential revisions to the dynamics) open to the extent possible". In contrast, this paper argues that matters of interpretation play a crucial role when assessing the viability of various monistic worldviews.

Priority monism, as Schaffer sets things up, is one of the possible answers to the so called "*question of fundamental mereology*" (QFM): what are the basic, metaphysically independent, fundamental entities of the world? QFM relates the mereological structure of (proper) parthood relations on the one hand, with priority relations of metaphysical dependence on the other (Schaffer 2010: 33). Schaffer takes both these relations to hold between concrete objects and to form (well-founded) strict partial orders.[2] Both the assumptions are controversial but I will grant them in the paper.[3] The other alternative answer to QFM is *priority pluralism*, according to which there are at least two fundamental objects. In the light of this, Schaffer's arguments from QM purport to lend decisive support to the truth of priority monism. Here is a brief roadmap. In Sect. 2 I will outline the "quantum monism argument". In Sect. 3 I will put forward my main argument to the point that different interpretations of QM yield different verdicts about the fate of monism. An amazingly brief conclusion follows in Sect. 4.

2 From quantum mechanics to monism

This section provides a brief overview[4] of the "quantum monism" argument. It crucially depends on a particular interpretation of quantum entanglement.

[2] Only the dependence relation is crucially taken to be well-founded. The so called *Gunk Argument* for priority monism depends upon considering non-well founded mereological structures.

[3] He challenges these assumptions himself in Schaffer (2012a).

[4] For more details see, e.g. Schaffer (2010: 50–57).

The quantum state of a physical system, in any mild realist interpretation,[5] can be thought of as a somewhat indirect summary of the properties of the system in question. It is mathematically represented by the state vector (defined over the Hilbert space), or the wavefunction (defined over configuration space) of the system. It is a remarkable fact about the quantum formalism that (i) the quantum state of a composite system always *determines*[6] *uniquely* that of the constituents, whereas (ii) the converse does not hold. In particular there exist quantum composite systems, those in so called *entangled states*, such that the quantum states of the parts are not able to determine uniquely that of the composite system. Mathematically one has it that the wavefunction of the composite system is not *factorizable*, i.e. cannot be written as a tensor product of the wavefunctions of the constituents.[7]

In such a case *duplicating* the constituents along with their fundamental properties and relations would not *metaphysically suffice*—as Schaffer himself puts it—to duplicate the composite system. Nothing short of the whole system in fact would do. If so, Schaffer contends, in these cases we should endorse something like the following:

(1) If a composite system is in an entangled state the composite system is more fundamental than its parts, insofar as duplicating the whole suffices to duplicate the parts but not *viceversa*.

Schaffer goes on to argue that:

(2) The universe—the mereological sum of all concrete objects—is a system in an entangled state.

To put it differently, and slightly abusing terminology: the universal wavefunction is entangled. The argument for (2) is roughly the following. It is a widespread conviction there is quantum state of the universe, represented by a universal wavefunction. Furthermore, the dynamical equation of QM, Schrödinger's equation, promotes and preserve entanglement. Thus, in *absence of any mechanism that disentangle quantum systems*—such as the collapse postulate—the quantum state of the universe is entangled. Then:

(3) The universe is more fundamental than its parts.

[5] The following passage should help grasping what minimal realism about the quantum state amounts to: "Standard quantum mechanics assigns to physical systems—single particles or collections of particles—formal representations, wave functions, in mathematical (Hilbert) spaces. The elements of, or vectors in, such a space yield, according to the standard statistical algorithm of quantum theory, functions from possible measurement outcomes to probabilities. To say that a particle has some wave function, or is properly represented by some vector in a given space, is, at least, to say something about how it is likely to behave in certain experimental settings. In so far as we think that a system's probabilistic experimental dispositions manifest some underlying physical states, we also may take ourselves to be describing the particle's real physical properties by associating it with a wave function" (Miller 2013: 570).

[6] I use 'determine' intentionally, so as not to take any stance towards any particular account of such determination relation. It was customary to cash this out in terms of supervenience. Recently it has been suggested that we should use a stronger notion such as e.g. grounding.

[7] The following is a mathematically precise and concise way to put all this: the Cartesian product space is a *proper subset* of the tensor product space used to describe the composite system.

The argument from (3) to Monism uses the so called *tiling constraint* (Schaffer 2010: 38–39, 2015: 24–25), the conjunction of the following two claims:

(4) The mereological fusion of the fundamental entities is the universe;
(5) No two distinct fundamental entities overlap each other.

Monism follows from (3), the tiling constraint, and the fact that the universe is mereologically maximal. If the universe is more fundamental than its parts, then it is fundamental *simpliciter,*[8] i.e. it does not depend on anything else, for everything else is part of it. And if the universe is fundamental then nothing else could be, on pain of failing conjunct (5) of the *tiling constraint*. In fact, anything that is distinct from the universe overlaps it.[9]

3 From quantum interpretations to monism

A striking feature of the quantum argument above is that it does not consider different interpretations of QM. Such interpretations differ as concerns their ontological commitments and, arguably, as concerns the corresponding interpretations of entanglement. Hence, I contend, any answer to the question whether QM supports monism, *should* take into account particular interpretations and their differences. In this section I attempt to fill this gap in the literature. If this is on the right track, it also shows that Ismael and Schaffer's contention that their discussion "crosscuts the usual taxonomy" is a little quick.

Let me isolate (some of) the crucial components of the quantum argument as reconstructed in Sect. 2. It rests upon:

(i) A mild realist interpretation of the quantum state;
(ii) A particular interpretation of entanglement and entangled states. More specifically, say that a property P is emergent iff (a) it is a natural property, (b) it is instantiated by a composite object and (c) it is not determined by properties and relations of the proper parts of the composite object instantiating P.[10] Then, the quantum argument crucially takes entangled states to represent emergent properties;[11]
(iii) The existence of a universal wavefunction that describe the quantum state of the universe;
(iv) The absence of some mechanism that disentangles quantum systems.

[8] It follows from *well-foundedness* that something has to be fundamental *simpliciter*.

[9] For a different critique of the argument see e.g. Morganti (2009), and Calosi (2014).

[10] McDaniel (2008). McDaniel is explicit in using 'supervenience' as the determination relation in question.

[11] The following passage is explicit: "(I have argued) that quantum entanglement is a case of *emergence*" (Schaffer 2010: 55, italics added).

It is worth noting that (i), (iii) and (iv) above already rule out some quantum interpretations. Somewhat anti-realist interpretations[12] are in contrast with (i), relational interpretations[13] are in contrast with (iii), and there might be some initial temptation to claim that collapse theories run afoul of (iv).[14] This should be enough to lay claim that questions of interpretation matter, and to motivate a thorough assessment of monism against the background of different interpretations.

The attentive reader will have probably noticed that I left out (ii). It is true that entanglement has been widely interpreted as representing an emergent property of some sort. The thought is that entanglement supports some form of *genuine metaphysical novelty*. And genuine metaphysical novelty is the hallmark of emergence. In the case at hand, the view is that a quantum entangled whole exhibits, in some robust sense, metaphysical features that are both novel with respect to the features of its parts and irreducible to them.[15]

This widespread agreement has recently been challenged. Earman (2015) contains a harsh criticism of this interpretation of quantum entanglement and of the holistic consequences it would allegedly ascribe to it. Earman's general complaint—in a nutshell,[16] is that discussions of entanglement focus on quantum *states*, while it is *the algebra of operators that should come first*. This is because entanglement of a state should be understood as *relative to the choice of a particular algebra* of operators for a quantum whole and its parts, and the very same state that is entangled given the choice of one particular algebra may not be so given the choice of others. This is important because, once the focus shifts from states to algebras, the discussion of holism and emergence should be recast in those terms as well, Earman contends. And it turns out, so the argument goes, that entanglement *per se* does *not warrant any emergentist* conclusion. Here is the crucial passage[17]:

> I think that the holism/anti-holism distinction is best drawn in terms of requirements on the algebras of observables. In relativistic QFT the axiom of strong additivity requires that the algebra $R(\cup_j O_j)$ of observables associated with the union of any family of open bounded spacetime regions O_j coincides with the algebra $\vee_j R(O_j)$ generated by the sub-algebras $R(O_j)$—a precise way of capturing in algebraic terms *the idea that the whole is not greater than the sum of its parts*. If you want to worry about holism in QFT worry about the

12 See among others, Spekkens (2007), Harrigan and Spekkens (2010), Fuchs (2003) and Bub and Pitowski (2010).

13 See Rovelli (1996), and Laudisa and Rovelli (2013). Schaffer acknowledges this in Schaffer (2015: 31–32).

14 See e.g. Ghirardi et al. (1986). Schaffer himself entertains the thought the collapse theories might pose some problems for his argument, in e.g. Schaffer (2015: 32). I suspect things might be more complicated than that. There is plenty of residual entanglement in collapse theories, as witnessed by the "problem of tails", and it might be thought that any entanglement is enough for Schaffer's argument to get off the ground. I will leave the question of the fate of monism in collapse theories aside.

15 This is actually the core of the argument of Schaffer's I presented in Sect. 2.

16 I cannot make justice to the subtlety of Earman's paper here. The interested reader is referred to Earman (2015) and references therein.

17 Earman does not discuss Monism, but it is clear that his arguments have bearings on the issue.

> failures of Additivity. But note that such a worry doesn't arise because of entanglement, since *Additivity is compatible with quantum state entanglement* in even the deepest form (Earman 2015: 335, italics added).

I shall label this *Earman's challenge*. If Earman is right, then monists should not seek refuge in the quantum domain, for QM does not give us any compelling reason to think that quantum wholes exhibit any metaphysical novelty,[18] which would otherwise be taken to be the crucial element in the quantum argument for monism.

However, to give monism the best fighting chance I will set aside Earman's challenge, and consider interpretations that do not blatantly conflict with (i)–(iv) above, namely, modal interpretations (Sect. 3.1), Bohmian mechanics (Sect. 3.2), many world interpretations (Sect. 3.3) and wavefunction realism (Sect. 3.4).[19] This admittedly leaves some other realist no-collapse interpretations out—e.g. consistent histories, many minds.[20]

To further stress the point, the general claim is that monists cannot simply defend their main metaphysical thesis without entering some details about different interpretations of QM. And different interpretations might support or fail to support monism to different degrees, or even support different monistic views. Or so I am about to argue.

3.1 Modal interpretations

The core of the modal interpretation (MI) of QM,[21] is the distinction between the *dynamical state*—which sums up the properties that a physical system *might* have[22]—and the *value state*—which sums up the properties that a physical system *does* have. The dynamical state is simply the usual quantum state. In general it is different from the value state. It always evolves under the Schrödinger equation so that there is no collapse. The value state singles out a proper subset of *definite-valued* properties for any quantum system.[23]

[18] Thanks to an anonymous referee here.

[19] I am using "Wavefunction Realism" in a much stricter sense than e.g. Ney (2013a: 37). She uses it to characterize all those interpretations of quantum mechanics that give an ontological reading of the wavefunction, independently of the details of such an interpretation. Thus, orthodox quantum mechanics, many-world interpretations and what I call more restrictedly 'wavefunction realism' count as wavefunction realisms.

[20] One particular interpretation which is arguably interesting in the present context, and one which I will not consider, is the one put forward in Wallace and Timpson (2010). They call it "State-space realism". The fundamental ontology of such a picture is given by different spacetime regions with intrinsic properties assigned to them by looking at the Hilbert space representation. This is interesting because Ismael and Schaffer (2016) argues that a variant of such a view represents one of the most-hospitable ontological setting for monism. As I said in footnote 1, this deserves an independent scrutiny.

[21] The modal interpretations stemmed from some works by Van Frassen which led eventually to his mature formulation in Van Frassen (1991). For an introduction see Lombardi and Dieks (2012), and for a more detailed exposition Dieks and Veermas (1998).

[22] Hence the term "modal".

[23] The following passage is clear: "Modal interpretations are a class of interpretations of quantum mechanics which, roughly speaking, *do not take the quantum state of a system to specify completely the*

The crucial question is the following: what is the relation between the dynamical and the value state? Or, to put it differently—but almost equivalently, what is needed to *determine the actual contents* of the universe? This question amounts to asking about the nature of the value state. This is the crucial question insofar as its answer—as we shall see—gives us important insights about the relation between properties of the parts and properties of the whole, the relation that is exactly at the core of the quantum argument for monism.

Two general strategies have been explored. On the one hand it has been argued, most notably in Bub and Clifton (1996), that the value state is determined by two different components, (i) the dynamical quantum state together with (ii) a set of privileged observables—that may vary according to different variants—that are *not* completely specified by the quantum state itself, and represents *definite-valued properties of the component parts* of the system under scrutiny.

On the other hand, some proposals e.g. Kochen (1985), Vermaas and Dieks (1995) and Bacciagaluppi and Dickson (1999)—have it that the value state is determined by the dynamical state alone.

The first strategy poses serious threats to monism. This is because the value state will include *fundamental properties had by proper parts of the universe*. Schaffer himself concedes that it is desirable to retain a "plausible connection between being a fundamental object and bearing fundamental properties" (Schaffer 2015: 41). In this case the proper parts of the universe would turn out to be fundamental, *contra* monism.

What about the second strategy?[24] It uses the so called bi-orthogonal decomposition theorem. Without entering the technical formulation, the theorem states that we can 'divide' any composite system in two proper parts and decompose the quantum state of that system so as to pick out unique bases for the Hilbert spaces of the components. These bases in turn are used to define the value states of the subsystems (Lombardi and Dieks 2012: 8–9). This solution is particularly suitable for solving the measurement problem[25] in that measurement can be modeled as a physical interaction between *two* subsystems, the physical system and the measurement apparatus.

Metaphysical interpretations of the bi-orthogonal decomposition vary. Kochen (1985) endorses a radical relational view, where quantum systems have definite valued properties—that is the properties that figure in their value state—only when "witnessed" by the measuring apparatus.[26] It is not difficult to see what the problem

Footnote 23 continued
properties of the system […] but take the quantum state itself […] to prescribe or at least *constraint the possible range of properties* of the system […] modal interpretations are related to other approaches which take some preferred observable as having a definite value" (Bacciagaluppi and Dickson 1999: 1165–1166, italics added).

[24] The discussion follows—albeit not rigidly—Vermaas (1998).

[25] But see Vermaas (1998).

[26] As Arntzenius (1999) puts it: "The central idea of Kochen's interpretation is that in state $\sum c_i|a_i\rangle|b_i\rangle$ the observable A has some definite value 'witnessed' by the measuring apparatus. In a given state not all observable are witnessed, and only the witnessed observable have values" (Arntzenius 1999: 242). In the

for monism is, given this picture. We already encountered—albeit briefly—a radically relative interpretation of QM, namely the relational interpretation, and agreed it was inhospitable for monism. And the problem is essentially the same. Arntzenius (1999) puts it quite nicely—despite the fact that he is not concerned with the monism VS pluralism debate—so I will just use his words:

> Unless a property is witnessed, it has no truth value. An immediate problem is the Universe. Since Kochen does not invoke God as a witness, the Universe has no properties […] Thus the Universe will have no properties, even though its subsystems do (Arntzenius 1999: 244).

It should be clear from the passage above that pluralism has the upper hand.

Vermaas and Dieks (1995) does not buy into this relational metaphysics so that the previous problem does not immediately arise. However there are other worries.[27] Consider a quantum system 12, composed by 1 and 2, and their associated Hilbert spaces H_{12}, H_1 and H_2 respectively. For any operator O_1 representing an observable defined on H_1 we can define an operator $O_1 \otimes I_2$ on H_{12}, where I_2 is the identity operator in H_2. We usually think of these operators as representing the *same* observable: in the first case it represents a property of system 1 considered individually, so to speak, whereas in the second case it represents a property of system 1 considered as part of system 12. This leads to require the following to hold:

(6) The expected value of O_1 is v iff the expected value of $O_1 \otimes I_2$ is v.

The left-to-right direction of the bi-conditional in (6) is known as *Property Composition* whereas the right-to-left is known as *Property Decomposition*. It can be proven that they both fail (Vermaas 1998). Now, this might give reasons to reject the interpretation on the ground that the operators *should* in fact represent the same observable. But one might insist, as Vermaas (1998) suggests, that the observables are at least theoretically different in that their corresponding operators are defined over different Hilbert spaces, and so there is no reason—at least not one coming solely from QM—to insist on their identity.

But failure of *Property Decomposition* entails that *fixing the value state of the universe fails to fix the value state of the parts*.[28] Arntzenius (1999: 245) puts forward an interesting example concerning a 'partly green table'. In what follows I elaborate on such an example. Consider the claim:

(7) The table is green-at-its-left-side.

Claim (7) attributes 'greenness-at-its-left-side' to the table. If *Property Decomposition* fails, it *does not follow* that:

Footnote 26 continued
passage above $|a_i\rangle$s are the eigenvectors of the observable A, whereas $|b_i\rangle$s are the eigenvectors of the measuring apparatus observable B.

[27] They apply to Kochen's interpretation as well.

[28] In Calosi (2017) I argue that failure of property decomposition speaks in favor of the possibility of *submergence*. This in turn favors the pluralistic case.

(8) The left side of the table is green.

Naturally enough failure of *Property Composition* entails that the converse is true as well, that is, (7) does not follow from (8). In these interpretations there is no correlation between properties of the whole and those of the parts. Vermaas (1998: 114) writes:

> So, one must accept that the questions of which properties are possessed by systems and subsystems are separate questions: the properties of a composite $\alpha\beta$ in general don't reveal information about the properties of subsystem α and *viceversa*.

Given the absence of any correlation, the pluralist seems in no better shape than the monist here. Granted. I am not trying to argue that MI support pluralism. I am trying to argue they do not support monism.[29]

This might give reasons to look for other MI that are more friendly to monism in that they solve the problems I discussed so far. The paradigmatic example is Bacciagaluppi and Dickson (1999). They postulate a *preferred* factorization of the Hilbert space of the entire universe into *disjoint atomic subsystems*,[30] and then define property ascriptions for composite systems in such a way as to respect *Property (De)Composition*. Quite naturally they label this interpretation the *Atomic Modal Interpretation* (AMI).[31] The problem for monism is that, given Bacciagaluppi and Dickson's construction, all properties of composite systems *are determined* by the properties of the *atomic component parts*. There is no quantum emergence, and thus no support for monism in the quantum realm, according to such an interpretation.

The monist can take issue with AMI on the ground that it presupposes atomism, especially in the light of yet another monistic argument, the argument from gunk.[32] That is true, and indeed AMI is problematic in many other respects. But the point is not about defending AMI or any other MI for that matter. Rather it is to show that there are no-collapse interpretations of QM that do not lend immediate support to monism. We saw some, we are going to see some others.

[29] Actually, things might not be exactly symmetrical. That is because Kochen's modal interpretation is still available. And there is an asymmetry there: "There are *no perspective on the universe*, but from certain perspectives certain things *are true about the parts* of the universe. It can be true of the universe that half of it is green" (Arntzenius 1999: 245, italics added).

[30] The technical reason for this is that in the previous variants it is possible to define a joint property ascription in terms of joint probability iff the systems to which such properties are ascribed are *disjoint*.

[31] "This version would adopt a preferred factorization of the Hilbert space for the universe and assign modal algebras of possible properties directly only to those subsystems corresponding to atomic factors in the preferred factorization […]. All other subsystems *inherit* properties from these "atomic" subsystems by the principle of property composition: if two subsystems α and β, possess the properties P^{α}_{m} and P^{β}_{n}, then the system composed of α and β possesses the property $P^{\alpha}_{m} \otimes P^{\beta}_{n}$" (Bacciagaluppi and Dickson 1999: 1169, italics added).

[32] See Schaffer (2010: 61–65).

3.2 Bohmian mechanics

Here is a somewhat orthodox nutshell-presentation of Bohmian Mechanics (BM),[33] which is supposed to model a Bohmian universe of *n*-partciles. What you have is the *universal wavefunction*, which is a complex-valued function of the generic positions of the *n*-particles and the *actual configuration* of those particles,[34] i.e. a specification of their actual positions. The evolution of the wavefunction is governed by the usual Schrödinger's equation, whereas the evolution of the configuration is given by the so called "guiding equation", that depends partly on the universal wavefunction.[35]

It is on the one hand true that the universal wavefunction plays a crucial role. Yet *it is not everything, nor it is enough.*[36] It should be supplemented by the configuration of the particles, i.e. by their actual positions, for that configuration cannot be specified looking at the universal wavefunction alone. In fact, pluralists can take comfort from the following passages:

> In the Bohmian mechanical version of nonrelativistic quantum theory, quantum mechanics is *fundamentally about the behavior of particles*; the particles are described by their positions, and Bohmian mechanics prescribes how these change with time. In this sense, for Bohmian mechanics the *particles are primary, or primitive*, while the wave function is secondary, or derivative (Goldstein and Zanghì 2013: 13)[37];

> From the point of view of BM, however, this is a strange terminology since it suggests that the main object of the theory is the wave function, with the additional information provided by the particles' positions playing a secondary role. The situation is rather much the opposite: BM is a theory of particles; their positions are the primary variables, and the description in terms of them must be completed by specifying the wave function to define the dynamics (Allori et al. 2008: 356).

The positions of the particles are the *fundamental variables* of the theory. These are always determined, and never get entangled. Insofar as we are willing to retain a

[33] The original proposal is in Bohm (1952). See also Bohm and Hiley (1993), and Goldstein (2012).

[34] Given this structure Bub (1997) considers BM as a particular modal interpretation of QM in which the value state is given by the specification of positions.

[35] To be fair there is another way to understand these equations, i.e. the Schrödinger's equation, and the guiding equation. This is due to Albert (1996, 2013). As Ney (2013a: 42) puts it: "It is possible to read both these equations as being about entities in 3N-dimensional configuration space. We may start by interpreting the wavefunction realistically, as a field in configuration space. Then we may interpret what the guidance equation describes not as a configuration of many-particles in a separate three-dimensional space, but as one particle representing the whole configuration. According to this view, the guidance equation is about the evolution over time of one world particle". This is strikingly similar—if not straightforwardly the very same thing—to what I will discuss in Sect. 3.4, so I will defer the discussion.

[36] See Goldstein and Zanghì (2013: 92).

[37] Suppose someone was to insist that particles and positions are indeed fundamental but the way they are related is *holistically* determined. If positions are fundamental and bearers of fundamental properties are themselves fundamental, pluralism would still follow—at least if there are at least two particles. To put it in a different way, the view that is being considered here is *holism, not wholism.*

connection between fundamental properties and their bearers, it seems that particles—that is, proper parts of the universe—should be regarded as fundamental.

We can actually build on these considerations to set forth further pluralist-friendly arguments. There are several ways to interpret the status of the universal wavefunction within BM. And not all of them fit nicely with the quantum argument of Sect. 2. The universal wavefunction in that argument plays the role of specifying the quantum state of the universe, i.e. an indirect summary of the properties of the universe. As of lately a new interpretation of the universal wavefunction in BM has been put forward which definitely treats it differently, in that it takes it to be a *nomological* entity, that is, a—perhaps sui-generis—*physical law*.[38]

According to this picture, the only (categorical)[39] properties that are physically relevant are the positions of the particles, which are encoded in the *configuration* of the universe, *not* in the *universal wavefunction*. In fact, the universal wavefunction does not represent—even indirectly—any property of the universe whatsoever. *A fortiori*, it does not represent any *emergent property* of the universe. It follows that the quantum argument for monism in Sect. 2 does not even get off the ground. Notice that this is *completely independent* from any detail about the *interpretation of laws of nature*.[40]

This last detail is important insofar as a particular interpretation of laws has been used to defend a paradigmatic example of pluralism, namely Humean Supervenience,[41] most notably in Miller (2013) and Esfeld (2014).

The Bohumean—as Miller (2013) calls her—(i) takes the particles and their positions as her primitive ontology, (ii) interprets the universal wavefunction as a law, rather than an ontological addition to the primitive ontology, and finally (iii) interprets this law as a *Humean law*, that is, a *merely descriptive* law, a law that simply *summarizes local facts* about the positions of the particles. This allegedly saves Humean Supervenience in the quantum realm. We are not interested here in the fate of quantum Humean Supervenience.[42] What is of interest is that the *Bohumean is a quintessential pluralist*. Here's an argument.

Consider any quantum subsystem which is a proper part of the universe and consider its wavefunction or vector state. Suppose furthermore that it is entangled. Now, its vector state is definable in terms of (i) the universal wavefunction and the configuration of both the system and its environment, i.e. its mereological complement with respect to the universe. The configurations of the particles are

[38] "You should think of the wavefunction as describing a law, not as some sort of physical reality" (Goldstein and Zanghì 2013: 97).

[39] One might see reasons to regard some other properties, e.g. spin, as dispositional properties of physical systems: these dispositional properties are grounded—so to speak—in the *position* of the system, its initial wavefunction, and the Hamiltonian that governs the evolution of the system through the interaction with a measurement apparatus—yielding e.g. a spin-up measurement. For a detailed discussion, see e.g. Clifford (1996: 376–177).

[40] Thanks to an anonymous referee for pushing this point.

[41] As Lewis put it, Humean Supervenience "says that all else supervenes on the spatiotemporal arrangement of local qualities throughout all history" (Lewis 1994: 474).

[42] For arguments against Humean Supervenience in the quantum realm see Maudlin (2007), Darby (2012), and Calosi and Morganti (2016).

properties of the parts (of the universe). Also, the universal wavefunction is just a simple summary of the position of the particles according to this interpretation. That is, it supervenes—and thus is determined—on the local properties—namely positions—of all particles in the universe. Now entanglement is seen as expressing a relation between entangled parts which is simply a *nomological relation,* that supervenes on the local properties of all the parts of the universe. The Bohumian needs to take *all the particles and their positions as fundamental,* and everything else would supervene—and thus be determined—by that. That is all. Fix the positions and you will fix the world! This amounts to pluralism.

3.3 Many worlds

The many worlds interpretation (MW) of QM[43] is the paradigmatic example of no-collapse interpretation, for its very original formulation in Everett (1957) was partly driven exactly to get rid of the collapse postulate. The very name of the interpretation comes from the following passage in DeWitt and Graham (1973, v, italics added):

> It makes sense to talk about a state vector for the whole universe. This state vector never collapses and hence reality as a whole is rigorously deterministic. This reality, which is described *jointly* by the dynamical variables and the state vector, is not the reality we customarily think of, but is a reality composed of many worlds. By virtue of the temporal development of the dynamical variables the state vector decomposes naturally into orthogonal vectors, reflecting *a continual splitting of the universe into a multitude of mutually unobservable but equally real worlds*, in each of which every good measurement has yielded a definite result and in most of which the familiar statistical quantum laws hold.

It is widely agreed that this literal talk of splitting worlds is both historically inaccurate and theoretically problematic.[44]

There is in fact another more promising, philosophically more satisfactory and by now influential reading, championed e.g. by Saunders, Wilson, and Wallace[45] to mention a few, according to which all we have in Everettian QM is the (universal) wavefunction and *dynamically robust patterns* in the wavefunction. These patterns represent different semi-classical worlds and—arguably—material objects within

[43] For an introduction see Barrett (1999, 2014), Saunders (2010) and Wallace (2013). For a detailed, recent defense see Wallace (2012).

[44] Some classic difficulties are the so called preferred basis problem, the interpretation of probabilities, and the seeming violation of conservation laws.

[45] Wallace (2012) could be a more complicated case. This is sometimes known as 'decoherence interpretation'.

these worlds.[46] In such a picture there is no splitting, and worlds are themselves regarded as *metaphysically derivative entities.*[47]

In fact, some Everettians are explicit in endorsing some sort of monistic worldview:

> At the fundamental level, the ontology is monistic—there is just one single structured object, the universal quantum state (Wilson 2011: 379).

The situation seems different from the one we encountered so far. It seems that we have an interpretation that is indeed favorable to monism. What I would like to point out here—and in the following section—is that the variant of monism that is supported by the MW interpretation is not Schaffer's *priority monism*. To see this consider the following claims:

(9) There is exactly one fundamental object.
(10) There are many concrete objects.
(11) The fundamental concrete object and the less fundamental concrete[48] objects are *mereologically* related, in particular the latter are the *proper parts* of the former.

I will simply take for granted that (9) is the hallmark of monism. Indeed pluralism is just about the negation of (9), i.e. the claim that there are at least two fundamental entities. The denial of (10)—which entails the denial of (11)—is known in the metaphysics literature as *existence monism*. It boils down to the claim that there exists just one object. Given well-foundedness, this entails (9). Schaffer's version of monism is basically the endorsement of all the claims above, i.e. the endorsement of (9), (10), (11). However, note that it is consistent to endorse (9) and (10), and yet deny (11). This would be a new variant of monism that is different from both existence monism and Schaffer's priority monism.

In what follows I will push the point that this is exactly the sort of monism that is supported by MW. Actually, I will give a more detailed argument in the next section on wavefunction realism.[49] From the viewpoint of monism such interpretations are relevantly similar insofar as ultimately, the fundamental ontology of QM should be understood in terms of the universal wavefunction alone. What I will say there applies, *mutatis mutandis* here as well. This is why I will postpone the discussion. However, something specific to the present case needs to be said.

As we saw contemporary everettians take material objects—be them full-size worlds, or smaller macroscopic objects—as *patterns* in the wavefunction. My claim is now that the prospects of understanding patterns in *mereological terms*—the crucial ingredient in Schaffer's priority monism—are rather grim. Wallace is

[46] Saunders is explicit about worlds: "The claim is that the worlds are dynamically robust patterns in the wavefunction, obeying approximately classical equations". (Saunders 2010: 5). Wallace extends the pattern ontology from worlds to material objects. See e.g. Wallace (2003).

[47] For a critique of the possibility of defining macroscopic objects—and presumably worlds—in terms of patterns in the wavefunction see Ney (2013b).

[48] Besides being related (naturally) via *dependence*.

[49] Significantly Ney (2013a) refers to these interpretations collectively with "Wavefunction Monism".

explicit. When discussing Dennet's original proposal of a pattern-based ontology he writes:[50]

> Dennet, by regarding macro-objects as patterns in the micro-ontology rather than as mereological sums of that micro-ontology, provides the sort of account of compositionality that is not hostage to contentious or downright false pictures of physics (Wallace 2004: 635)

As I said already, I will substantiate the claim that we should not take material objects to be *proper parts of the* (universal) *wavefunction* in the next section. Let's take Wallace at face value here, and grant that patterns are not to be understood mereologically. It follows that (11) above is false. This is enough to rule out Schaffer's version of monism. Yet, it is not enough to rule out existence monism. But the very heart of the MW interpretation is that *there are indeed many concrete things*, i.e. many worlds. And this *does rule out* existence monism. The resulting monistic picture is then one in which we have one fundamental entity, many concrete derivative ones, and the fundamental entity and the derivative ones are not mereologically related.[51] It is exactly the new variant of monism I briefly introduced above.

3.4 Wavefunction realism

Wavefunction realism (WR) is arguably one of the most radical realist interpretation[52] of QM. It can be cashed out both in Collapse and No-Collapse terms.[53] We do not need enter the details here. I will simply assume that a thorough No-Collapse variant can be maintained, so as to give monism the best fighting chance.[54] The main tenet of the view is that the universal wavefunction describes a concrete physical object that lives in a highly dimensional configuration-space. To understand the prospects of monism in WR we must ask what kind of concrete physical object the universal wavefunction is. The *locus classicus* is Albert:

> The sorts of physical objects that wave-functions are, on this way of thinking, are (plainly) *fields* which is to say that they are the sort of objects whose states one specifies by specifying the values of some set of numbers at every point in the arena in which they live, the sorts of objects whose states one specifies (in this case) by specifying the values of two numbers (one of which is usually

[50] See Dennet (1991).

[51] This might be the starting point to develop yet another version of monism, perhaps along the line of Guigon (2012). This is an interesting suggestion that deserves an independent scrutiny.

[52] It might be objected that WR is *not an interpretation* of QM. Rather it provides an *ontology* for QM. Several interpretations might posit such an ontology—e.g. the so called bare GRW and the Many Worlds Interpretation. Granted. But WR seems exactly the kind of ontology that is indeed hospitable to monism. I take this to be enough to warrant a discussion of WR in the present context.

[53] See, e.g. Albert (2015).

[54] The first articulated formulation is Albert (1996). Its most recent defense is in Albert (2013, 2015), Ney (2013b), and North (2013). See also Lewis (2016). For a criticism see Monton (2006, 2013).

> referred to as *amplitude*, and the other as a *phase*) at every point in the configuration space of the universe (Albert 2013: 53, italics in the original[55]).

Redhead (1995) points out that this attitude to fields in general can be interpreted in two ways: on the first reading the fields in question are regarded as global particulars that are *ontologically independent from the points of the space* they live in. On the second reading they can be taken—either the fields themselves or the field quantities—to be properties of the points of that space (French 2013:79). If one holds the view that properties depend somehow on their bearers, then there is *some sort of ontological dependence between fields and points of space*.

Let me address the second option first. On this view the fundamental ontology is given by points in a given space and their (intrinsic) properties. In the particular case at hand, the fundamental ontology would be given by *points in configuration space* and their properties, phases and amplitudes.[56] Material objects would turn out to be derivative entities. This is true for all material objects, mereological atoms (if there are any) and their sums, the universe included. Both priority monism and priority pluralism as they have been characterized here have hardly a chance. Probably, this calls for a substantial rephrasing of the debate, in terms that do not privilege *material objects*.

The first option—bracketing for a moment questions about the relation between the one global particular and the points of space in which it lives—seems more promising. According to such option the wavefunction field is a material object itself: the global particular can be regarded as "a vast universe-spanning substance" or "jello-stuff" (French 2013: 79). The most pressing issue in the present context is whether this global particular *has any proper parts*. I will argue that the most natural answer to this question is in the negative. At least two candidates come to mind and neither of them fits the bill—or so I will argue.

One could claim that points of configuration space are (proper) parts of the global particular. But on the view we are exploring, no relations of dependence hold between the global particular and the points of configuration space. How can they then stand in any mereological relation? Let me clarify a bit. It is overwhelmingly plausible to think that if you have mereological relations of (proper) parthood between two entities, then you have (some) dependence relations between them. Both the monist and the pluralist we are considering in the paper agree on that. What they disagree about is whether mereological and dependence relations have opposite directions, so to speak. So, the fact that there are no relations of dependence indicate there are no mereological relations either, by simple *modus tollens*.

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[55] See also Albert (1996: 278).

[56] I am not considering the possibility in which material objects are simply *identified* with 'propertied-regions of a particular space', as in certain varieties of *super-substantivalism*. It should be noted that, in any event, this is *not the traditional kind of super-substantivalism*, where objects are identical to regions of four-dimensional spacetime. Rather it is a different kind of super-substantivalism where objects are identical with regions of configuration space.

Material objects are the second candidate. Are they *proper parts* of the global particular? I already briefly discussed the question in the previous section. It seems that different arguments for a negative answer can be set forth.

First of all, as it is widely recognized, decomposition of the wavefunction in configuration space hardly corresponds to mereological decomposition. Perhaps the most straightforward way to see this is that different parts of the very same region of the (non-zero) support of the wavefunction *do not* correspond *to different parts* of the material object the wavefunction field somehow constitutes.

One of the most powerful consideration against the claim that material objects are proper parts of the global particular is that they *do not share the same space*. The global particular lives—one would be tempted to say, is located—in configuration space, whereas ordinary material objects are located in three-dimensional space (or four-dimensional spacetime). The first is a highly-dimensional space that, crucially, *does not share any dimension* with ordinary space. That is to say, it is *not* the case that the first three dimensions of configuration space correspond to our ordinary three spatial dimensions.[57] Ney (Forthcoming) notes this problem but downplays it. She claims that it is not a core mereological requirement that parts and wholes live in the same space. But this is way of phrasing things is misleading. It's not mereology *per se* that is at stake here. Rather, it is the interaction between mereology and the spaces parts and wholes occupy. In other words, it is the theory of location that is at stake.[58] And virtually everyone in the literature—e.g. Casati and Varzi (1999), Parsons (2007), Uzquiano (2011) and Calosi (2014)—with the sole controversial exception of Saucedo (2011), agrees upon a locative principle of *Expansivity*, to the point that wholes are where its parts are. More precisely they agree on the following:[59]

(12) If x is part of y, and x is located at r, then there is an s such that y is located at s and r is part of s.

And (12) is in fact violated in the case at hand. Just take x to be any material object whatsoever, and y to be the global particular. In fact, it's of no surprise that none of the wavefunction realists holds that the relation between the wavefunction and material objects is parthood. An option we already considered would be to take objects to be patterns. Albert opts for a *functional/causal* relation,[60] and Ney herself in a different paper holds that in general "there is no mereological decomposition of ordinary macroscopic objects into elements of the wavefunction ontology (Ney

[57] Ney (2012) makes a convincing case for this clam.

[58] Or the theory of extension.

[59] Formulation might slightly disagree—e.g. whether expansivity should be phrased using proper part rather than part. This does not play any crucial role here.

[60] "What is to be a table or a chair […] is—at the end of the day—to occupy a certain relation in the causal map of the world" (Alber 2013: 54).

2013b: 176) and that hers is an "account based not on a mereological relation" (Ney 2013b: 181).[61]

Perhaps, none of the arguments above is conclusive. Yet, given that there is no positive argument in favor of the claim that material objects are proper parts of the wavefunction, I contend that it is fairly plausible to conclude that in fact they are not. If so, the upshot of the discussion is that the global particular does not have, strictly speaking, any proper parts. French (2013) agrees.[62] So, according to the monist, the fundamental universe-spanning global particular, is a mereological atom.

There are two possibilities at this juncture, as far as I can see. The first one is to claim that the global particular is the only material object there is. In fact French considers the possibility of interpreting it in terms of the *blobject* in Horgan and Potrc (2008).[63] A similar thesis is advanced by Healey (2012) within the background of quantum field theory. The result is existence monism.

The second possibility is to insist *there are* ordinary material objects,[64] but *they are not proper parts* of the fundamental global particular. In fact, material objects and the global particular *do not stand in any mereological relation*. This is the sort of new monistic worldview we encountered in Sect. 3.3,[65] that is, a monistic account according to which there is one fundamental entity and many derivate ones, and they are not related via parthood relations.

This exhausts the analysis of the prospects of monism within different interpretations of QM. To sum up, the case for monism is not straightforward, and monists might have to do substantive work to back up some of their claims. In carrying out this work they might be forced to underwrite controversial interpretations, pay prices they may not be willing to pay, or endorse versions of monism that are different from the one they started with.

[61] There might be yet another candidate, namely other wavefunction-fields. Yet it is controversial that fields have a mereological structure of their own. Usually the mereological structure is not ascribed to fields themselves but rather to the spaces they are defined on.

[62] Though it is unclear—at least to me, I must confess—whether he provides any argument for this contention.

[63] Schaffer (2015: 63—footnote 18) agrees as well, albeit with no argument. Schaffer criticizes Horgan and Potrc's blobjectivism in Schaffer (2012b).

[64] This seems to be the option preferred by wavefunction realists themselves. North writes: "For example, *there being a table in three-space* consists in nothing but the wave function's having a certain shape in its high-dimensional space. […] and *is itself a real fact*" (North 2013: 198, italics added). Here is Ney: "*There really are material objects*, even if their three-dimensionality is a mirage, and they are ultimately grounded in the behavior of the wavefunction in configuration space" (Ney 2012: 252, italics added).

[65] One might argue that those who are inclined to follow this line of thought, and go for some sort of broadly functional/causal account of material objects would be deflationist about the parthood relation. They would then argue that on such a deflationist understanding, material objects do have mereological structure. I actually believe this is exactly what they should say. Parthood relations will hold between less fundamental entities, but not between the only fundamental entity and the less fundamental ones.

4 Conclusion

The overall conclusion of the paper may be put as a simple slogan: interpretations matter! Granted, this might not come as a surprise. Sometimes we need to do some serious work only to find out what we expected (or should have expected) all along. What a relief.

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