VII INTERNATIONAL WORKSHOP ON QUANTUM MECHANICS AND QUANTUM INFORMATION

QUANTUM ONTOLOGY AND METAPHYSICS

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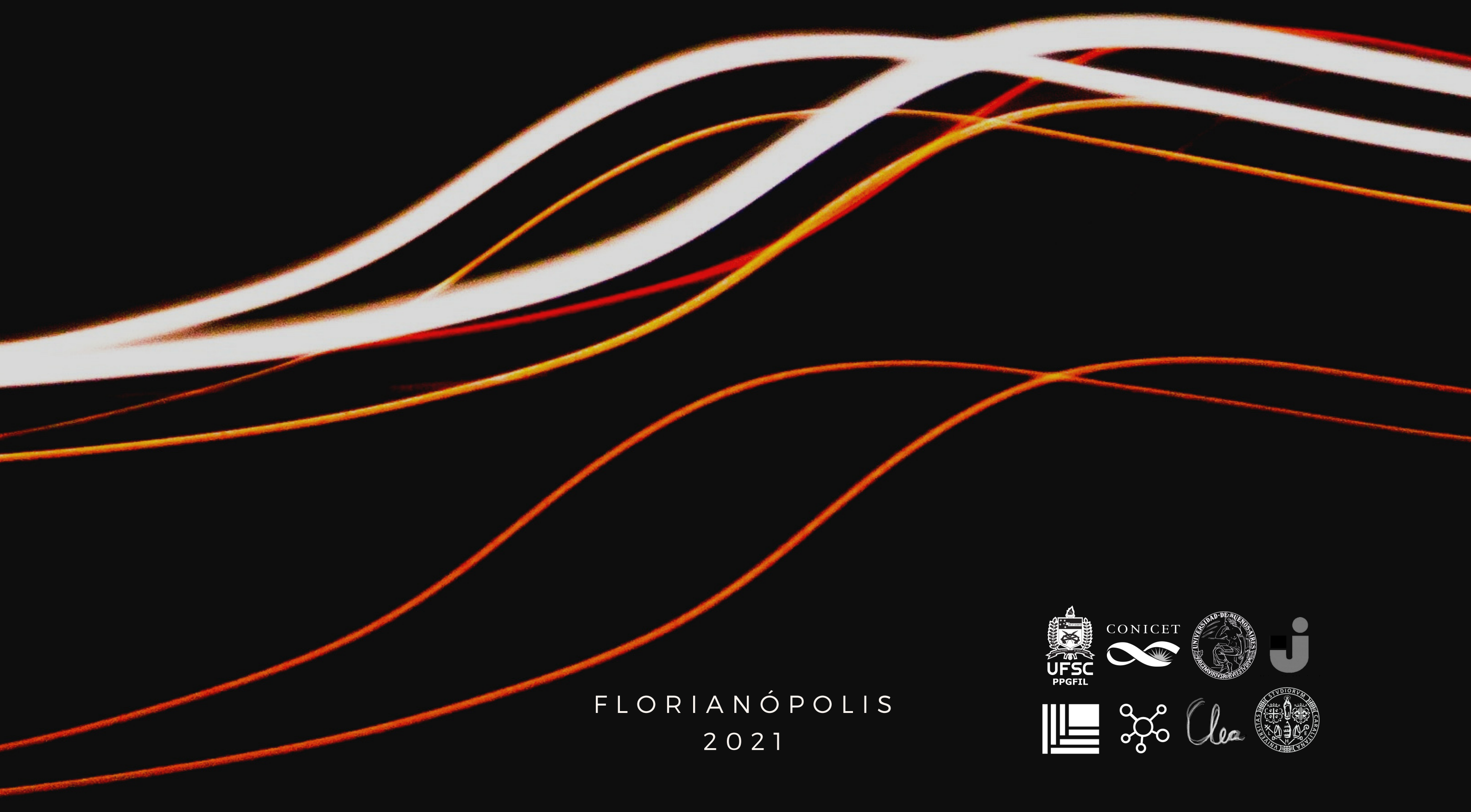
BOOK OF ABSTRACTS



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Quantum Ontology and Metaphysics

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Quantum Ontology and Metaphysics

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Abstracts

The quantum conceptual turn

Diederik Aerts
Massimiliano Sassoli de Bianchi

Quantum mechanics has maintained over the years the reputation of being “the most obscure theory”. It works perfectly well but nobody seems to know why. It has been argued that the difficulty in understanding quantum theory is our failed attempt to force onto it a wrong conceptual scheme, wanting at all costs to think about the “objects” of the theory as, precisely, objects, i.e., entities having continuously actual spatiotemporal properties. This too restrictive spatiotemporal scheme is obviously incorrect, as also underlined by the Einsteinian revolution, but then what would be the correct one? Many thinkers have suggested that we must simply surrender to the fact that our physical world is one of immanent powers and potencies. Aristotle did so ante (quantum) litteram, followed by scholars like Heisenberg, Primas, Shimony, Piron, Kastner, Kauffman, de Ronde, just to name a few, including the authors who were both students of Piron in Geneva. However, if on the one hand a potentiality ontology puts the accent on the processes of change, responsible for the incessant shifts between actual and potential properties, on the other hand it does not tell what these changes are all about. In other words, the (metaphysical) question remains of identifying the nature of the bearer of these potencies, or potentialities, and of the entities that are capable of actualizing them. It is the purpose of the present article to emphasize that the above question has found a comprehensive answer in the recent Conceptuality Interpretation of Quantum Mechanics, which we believe offers the missing ontology to make the theory fully intelligible, and even intuitive. In doing this, we will also emphasize the importance of carefully distinguishing the different conceptual layers that are contained in its explanatory edifice, as only in this way one can properly understand and fully appreciate the explanatory power it offers, without promoting undue reductionisms and/or anthropomorphizations.

Whence deep realism for Everettian quantum mechanics?

Jonas R. Becker Arenhart
Raoni Wohnrath Arroyo

It has been advanced that one cannot legitimately be a scientific realist about X without delving into deep metaphysical questions about X: this is 'deep' realism (as opposed to the 'shallow' or *ersatz* realism). The requirement for the realist to provide metaphysical images associated with scientific theories is often called "Chakravartty's Challenge". In this talk, we will discuss how this requirement unfolds in Everettian quantum mechanics (EQM). To do so, we distinguish between ontology and metaphysics based on their subject-matter: ontology deals with existence-questions and metaphysics with nature-questions. We argue that the philosophical developments on EQM revolve around ontological questions only (i.e. on the *existence* of the one or many worlds), leaving metaphysical questions unasked and unanswered. As a result, this gives room to a dilemma: either we don't have the available metaphysical tools to answer Chakravartty's Challenge in EQM, or addressing the Challenge is itself not mandatory for realism.

Relational Quantum Entanglement Beyond Non-Separable and Contextual Relativism

Christian de Ronde
César Massri

In this paper we address the relativist-perspectival nature of the orthodox definition of quantum entanglement in terms of preferred factorizations. We also consider this aspect aspect within the generalized definition of entanglement proposed by Barnum et al. in terms of preferred observables. More specifically, we will discuss the non-separable relativism implied by the orthodox definition of entanglement, the contextual relativism implied by its generalization as well as some other serious problems presently discussed within the specialized literature. In the second part of this work, we address a recently proposed objective-invariant definition of entanglement understood as the actual and potential coding of effective and intensive relations. Through the derivation of two theorems we will show explicitly how this new objective definition of entanglement is able to escape both non-separable relativism and contextual relativism. According to these theorems, within this proposed relational definition, all possible subsets of observables as well as all possible factorizations can be globally considered as making reference to the same (potential) state of affairs. The conclusion is that, unlike with the orthodox definitions, this new objective-relational notion of entanglement is able to bypass relativism right from the start opening the door to a realist understanding of quantum correlations.

The quantum and the Greek: the return to Greek philosophy in the works of Heisenberg, Pauli and Schrödinger

Raimundo Fernández-Mouján

Werner Heisenberg, Erwin Schrödinger and Wolfgang Pauli exhibited in their works a strong and insistent interest in Greek philosophy. And this interest —they claimed— was not at all separated from their investigations into the new quantum theory. Heisenberg directly affirmed that "one could hardly make progress in modern atomic physics without a knowledge of Greek natural philosophy". What does this claim mean? Why do these central figures in the development of quantum mechanics saw the Greeks as their main inspiring source? Why do they took them as a model for contemporary science, even over their modern predecessors of Enlightenment? This talk attempts to answer these questions focusing on three main reasons: the revision of atomism, the recasting of the meaning of "understanding" in physics, and the critique of separations in science.

Methodologies for the achievement of understanding in quantum mechanics: the case of primitive ontology

María del Rosario Martínez-Ordaz

Here I address two questions from the epistemology of Quantum Mechanics, namely: *can scientists achieve legitimate understanding of QM?* and if so, *how is this possible?* On the one hand, scientific understanding is a fundamental component of any successful scientific enterprise and it consists of building networks that successfully connect our scientific knowledge about the world. In addition, understanding is often regarded as both explanatory and factive —this is, the content of understanding can only include true propositions that are known to be so. This considered, it seems impossible to legitimately understand knowingly defective (partial, vague, conflicting, inconsistent, false and even impossible) theories. On the other hand, while we often say that QM is predictively successful, in recent years, the actual epistemic contribution of the theory has been put on trial. The main concern is that both the standard theory and its interpretations are defective in different senses, and therefore, they are not worthy of (strong) belief [5, 7]. The combination of these facts poses the following dilemma: either, pace traditional literature, we can legitimately understand defective theories such as QM (the standard theory and its interpretations) or such theories cannot be object of our understanding, and we have been mistaken by assuming that they are.

Here, I argue that we can legitimately understand the standard Quantum theory and some of its interpretations, even if defective, if we can recognize the theory's underlying inference pattern(s) and if we can reconstruct and explain what is going on in specific cases of the theories in question. To do so, I assume a Primitive Ontology-methodology and I contend that it (remarkably) enhances our modal understanding of both the theories and the world that they describe.

I proceed in four steps. First, I characterize the problem of achieving scientific understanding of defective theories, and I briefly discuss the case of QM. Second, I introduce the Primitive Ontology (PO) framework [1–3] and sketch a PO-methodology that can be relevant for both the satisfactorily scrutiny of the theories as well as for the achievement of understanding. Third, I briefly compare this methodology with Maudlin's Canonical Presentation method [6], and I highlight the understanding-related virtues of PO. Finally, I illustrate how a PO-methodology can enhance our understanding of an interpretation of QM —namely, GRW matter density [4] and I draw some conclusions.

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Quantum scientific realism: or how I learned to stop worrying and love quantum mechanics?

Valia Allori

The measurement problem is traditionally considered the problem to solve in order to restore the compatibility between quantum theory and scientific realism. In this paper instead I argue that it is not straightforward to spell out what the incompatibility problem actually is, and that different types of realists will think of it in different ways. First, I distinguish between a robust version of realism, which looks for a fundamental description of reality, and a relaxed version, which looks for a description of the regularities in the phenomena. I argue that while the relaxed realist will naturally think of the measurement problem as a problem of precision, the robust realist will think of it as a completeness problem. I also maintain that each kind of realism comes with a natural explanatory structure: while the robust realist will find satisfactory constructive theories, in which the phenomena are dynamically explained, the relaxed realist will be happy with principle theories, which provide constraints on them. In this regard, I show that the spontaneous localization theory, thought as a theory about the wavefunction (dubbed bare GRW), is a non-constructive dynamical hybrid. This creates two tensions for the wavefunction realist endorsing bare GRW. First, they seem relaxed realists in denial, as bare GRW's explanation is not constructive. This leaves them with relaxed realism, which however is arguably too weak to be truly realism by their standards. In addition, there seems to be an explanatory mismatch between the non-constructive quantum explanation, and the constructive derivation of thermodynamics from the microscopic dynamics which appears to be problematic for a realist of any kind.

Quantum information theory: from foundations to no-standard applications

Giuseppe Sergioli
Hector Freytes
Roberto Giuntini

The aim of the talk is to show how it is possible to take inspiration from basic concepts of quantum information for applications outside the standard context of microscopic physics. In particular, we provide an application of quantum information theory to the context of machine learning. We introduce a new quantum-inspired method for the binary classification applied to classical datasets. Inspired by the quantum Helstrom measurement, this approach enables to define a new binary classifier, called Helstrom Quantum Classifier (HQC). This classifier (inspired by the concept of distinguishability between quantum states) acts on density matrices – called density patterns – that are the quantum encoding of classical patterns of a dataset. We compare the performance of HQC with respect to several standard classifiers over different datasets and we show that HQC outperforms the other classifiers when compared to the Balanced Accuracy and other significant statistical measures. We also show that the performance of our classifier is positively correlated to the increase in the number of "quantum copies" of a pattern and the resulting tensor product thereof. In the last part of the talk we show a large-scale experiment based on the application of HQC to the biomedical imaging context in clonogenic assay evaluation to identify the most discriminative feature, allowing us to enhance cell colony segmentation.

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On some criticisms to the Received View of quantum objects

Décio Krause

A recent discussion on the foundations of quantum theories claim that the Received View of quantum objects (RV) cannot be maintained and that it would be wrong to consider that such entities lack identity. Furthermore, the critics claim that in having a collection with cardinal greater than one, the elements *must* be different. In this paper, I consider these two arguments at least. Firstly, I show that the critics do not specify what concept of identity they are taken from granted; secondly, I show that we can construct mathematical theories where collections with cardinal greater than one are such that the elements don't present identity conditions (I specify the 'identity' I am considering), so dissolving the second criticism. My argument is that the critics don't realize that logic doesn't apply directly to the world, but to our *representations* of a parcel of a supposed existent reality. So, electrons, say, may remain indiscernible and without identity, although their representations in standard mathematical theories (like standard set theories) can be discernible, and different one from another in a strong sense! This confusion, according to me, confounds the map with the territory, so that a careful distinction suggests that most of the criticisms can be diluted with a due qualification I intend to provide here.

Quantum coherentism

Matteo Morganti

In this talk, I will present a novel ontological interpretation of quantum entanglement (which, depending on how pervasive one takes entanglement to be, may constitute a novel ontological interpretation of the quantum domain more generally): quantum coherentism. Quantum coherentism is the view that quantum entangled systems are mutually dependent for their qualitative profiles (and, possibly, for their identities). This means that, while it is possible to regard them as individual objects provided with intrinsic properties, at least some of their features are determined by their joint existence, in particular by symmetric dependence relations. I will first briefly sketch the current state of the debate with respect to the interpretation of quantum mechanics, then provide a general outline of metaphysical coherentism, also responding to worries concerning explanatory circularity. Then, I will look at how coherentism accounts specifically for quantum entanglement, and contrast it with two other popular approaches: ontic structuralism and priority monism. While the main aim of the paper is to show that quantum coherentism is a viable alternative to the philosophical views of the quantum domain currently available, I will also point at reasons for actually preferring it. In particular, I will suggest that coherentism provides a unified explanation of the distinctive properties of entangled physical systems - including the non-separability exhibited in EPR-Bell type scenarios, quantum statistics, and the seeming failure of reductive metaphysical views such as Humean Supervenience and Composition as/is Identity.

Quantum holism and essential dispositions

Christina Conroy
Donnchadh O'Conaill
Tuomas Tahko

A well-known feature of entangled quantum systems is non-supervenience: states of the system as a whole do not supervene on the non-relational states of its component particles. So there is a property of the system as a whole which does not supervene on the properties of its components (either considered separately or considered together). Non-supervenience has led to a number of different metaphysical developments including what one might call the "historical holistic view" [7, 13, 14], relational holism [11, 14], versions of structural realism [1–6, 9, 10], and priority monism [8, 12]. In this paper we shall outline an account of one crucial non-supervenient feature of entangled systems, the fact that entangled particles are modally connected (so that it is not possible to freely vary all of the features of one without varying some features of the others). In section 1, we shall outline the sense in which entangled quantum particles are modally connected, and the monistic account of this modal connection proposed by Jenann Ismael and Jonathan Schaffer. In section 2 we outline an alternative approach, on which the modal connection is explained by appeal to the essences or natures of the entangled particles. We outline one way in which this approach can be developed, which we term the Straightforward Proposal, and argue that it does not work. In section 3 we introduce our preferred way of developing this approach, the Essential Disposition account, which we suggest is a holistic account of a specific kind (essential holism). In section 4 we compare our account with that offered by Ismael and Schaffer, assessing each account on a number of different criteria. In the course of this discussion, we shall clarify how our account is neutral as regards the individuality or non-individuality of quantum particles: that is, it applies equally whether or not entangled particles are individuals. We consider this to be an advantage of our proposal, given the highly contested issue of individuality in quantum mechanics.

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What is the ontology of quantum field theory?

Mauro Dorato
Emanuele Rossanese

The aim of our talk is to discuss two alternative ontologies for Quantum field Theory: a particle ontology and a field ontology. We will then show why these ontologies are undermined by the formalism of the theory. On the one hand, there are no-go theorems that seem to rule out the particle ontology. On the other hand, it is possible to show that the same arguments hold against the field ontology as well. There are in fact two sets of arguments that we want to discuss, coming respectively (i) from the existence of inequivalent representations of the algebra of observables for the same physical system, and (ii) from the description of interactions within the formal context of Quantum Field Theory. These two sets of arguments seem to hold for both the particle and the field ontology, at least if we consider them as the fundamental ontologies of the theory. Moreover, we will try to show how such arguments might undermine (almost) any other ontological proposal for Quantum Field Theory.

Connecting two objections from fundamental physics to Humean supervenience: the spacetime assumption

Moisés Macías-Bustos

The metaphysical thesis of Humean Supervenience is put forward loosely by Lewis [3] as the assertion that the truths about worlds similar to our own supervene on the distribution of local qualities throughout spacetime. The gist of the view is that everything that is the case at some worlds results from facts about space-time points and the distribution of intrinsic, fundamental properties over them. This thesis in turn has consequences for the metaphysical nature of laws and causality. As Schaffer puts it: "causation and the laws of nature are nothing over and above the pattern of events" [6, p. 82]. According to this view, in worlds like ours the only instantiated fundamental relations are spacetime relations, I refer to this last claim as the *spacetime assumption* [7].

Nonetheless, in recent years, Humean Supervenience has been challenged with respect to its truth and even more radically, its philosophical relevance as a source of insight for metaphysics and philosophical methodology. Here, I focus on what I take to be two connected objections leveled against Humean Supervinience. These objections are:

- First, the objection from quantum mechanics, that Humean Supervenience is false since some truths are not fixed by local goings-on at space-time points [2, 5] fundamental physics is non-local and entangled states of particles do not supervene on the distribution of intrinsic properties of these particles [4].

- Second, the objection from space-time physics [1], that even considering a space-time such as that posited by classical physics Lewis's version of Humean Supervenience is false, for it goes too far, since the distribution of intrinsic properties to points fails to fix facts about the persistence conditions of material objects, being compatible with both endurantism and perdurantism.

Here, I suggest two related strategies that the Humean can avail herself of when responding to these objections: weakening the spacetime assumption (*weak-st.*) and strengthening it (*strong-st.*). Namely

> **Weak-st.-** Humean Supervenience but substituting the spacetime assumption with the claim that the only instantiated fundamental relations are similar to spatiotemporal relations (analogues).
>
> **Strong-st.-** Humean Supervenience but adding to the spacetime assumption the supersubstantivalist thesis that material objects are identical to spacetime regions.

And I contend that (i) the spirit of Humean Supervenience is consistent with either weakening or strengthening the spacetime assumption, and that (ii) doing so, together with some methodological assumptions, allows the Humean to respond to important objections from fundamental physics. The suggestion is that the related methodological lessons generalize to other objections from physics beyond these two.

I must note that my claim isn't the very strong one that these methodological assumptions, about what fundamental structures we ought to posit and which fundamental ideology we should embrace, are true and that from them we can defend Humeanism from those objections. My claim is the far more modest one that if these methodological assumptions are right we can defend Humeanism from those objections. I motivate and explain what philosophers have found appealing in these methodological assumptions, but that falls short from a full fledged defense of them. My argument then has the form: from assumptions p1...pn we get q, therefore, if (p1...pn) then q. I do find these assumptions plausible, so I believe setting forth this argument is philosophically worthwhile.

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Ontology of molecules

Osvaldo Pessoa Jr.

Our discussion of the ontology of quantum mechanical objects will focus on molecules, adopting a realist wave interpretation with collapses and decoherence. Such an interpretation postulates that for the state $\psi(r)$ of the formal representation there corresponds a matter wave distributed in space (assumed to be an "intermediate reality" or potentiality), which can suffer non-local and practically instantaneous collapses upon measurement by a macroscopic device, and also suffer the continuous monitoring described statistically by the environmentally-induced decoherence approach. Although the decoherence approach does not explain why an individual object collapses to a specific final state, one assumes that this arises from fluctuations in the environment. One aspect to be explored is the holistic ontology of a molecule in relation to its constituent atoms, exemplified by the spherical symmetry of an isolated molecule, such as ammonia. This kind of holistic ontology, present in the intermediary complexes of chemical reactions, constitutes a limit to the project of mereological reduction of biological organisms to molecules. The ultimate goal of the project is to search for the chemo-physical basis of the subjective qualities experienced by animals, which we postulate to be associated with a certain class of macromolecules, inspired by Hering's opponent theory of colors.

Planck's classical quantum

Diana Taschetto

The framework within which the entirety of the enterprise of theoretical physics is carried out today is built from the ground up on the idea of *quantization*, which, according to the standard story, was introduced ad hoc by Max Planck to derive the correct black-body radiation law in 1900, thereby inaugurating the quantum revolution. This historical fact was boldly disputed by Thomas Kuhn in the iconoclastic "Black-body Theory and Quantum Discontinuity" (1978); his work notwithstanding, the orthodox story still stubbornly prevails. In this talk, by appealing not to detailed historiography, like Kuhn, but to simple and careful reading of the well-known contemporaneous books and articles, I offer logical and philosophical arguments to show that the orthodox story is incoherent — and explain how Planck's derivation is properly to be understood.

Making sense of the century-old scientific controversy over the quanta

Olival Freire Jr.

The debates about the foundations and the interpretations of quantum physics conform the century-long and still open quantum controversy. Throughout the last hundred years there has been a coexistence between the ever growing scope and accurate predictions of this theory and doubts about the well grounding of its foundations. The last chapter of this coexistence is present in the blossoming field of quantum information. This coexistence was portrayed by Franck Laloë with the metaphor of the "colossus with feet of clay." In this talk we survey these debates sketching a chronology and cartography of the factors which have been instrumental in the history of quantum controversy, the legitimacy of the controversy in the 20th century philosophical discussions, the tension between consensus and plurality in scientific communities, and the elusive role of experiments for the resolution of the quantum controversies. This talk will also present the summary of the Handbook on the History of the Interpretations of Quantum Mechanics we are organizing [1].

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Necessity and contingency: quantum mechanics and empiricist modalism

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Modality plays a significant role in quantum mechanics. It is invoked in the impossibility of certain quantum configurations, the necessity of certain radioactive decays, or the probability (a modality with degrees) of certain experimental outcomes. What is the source of such modality? (See [1], pp. 116–164, for the corresponding issue in the context of logic and metaphysics.) Should the necessities involved in quantum mechanics be explained by other necessities or can they be explained by contingencies? Necessity-first approaches take the necessary as basic and use it to explain the contingent [2, p. 14]. Contingency-first approaches do the reverse. In this paper, I critically engage with the recent response to this issue articulated by quantum modal realism [2, pp. 22–171]. I then offer an empiricist modalist alternative that insists that the source of modality is found in the relevant properties of the objects under consideration, while resisting essentialism and the necessity-first approach.

References

[1] B. Hale. *Necessary Beings: An Essay on Ontology, Modality, and the Relations Between Them.* Oxford: Oxford University Press, 2012.

[2] A. Wilson. *The Nature of Contingency: Quantum Physics as Modal Realism.* Oxford: Oxford University Press, 2020.