PHYSICS AND REALITY: INTERNATIONAL CONFERENCE ON PHILOSOPHY OF PHYSICS

4–6 June 2024, University of Helsinki, Finland

Abstracts

Vikram S. Athalye
Cummins College, Pune, India

On the Pursuit of Universal Consistency: Interpreting Physics *as* Reality

This talk will consist of four parts representing different proposals of inquiry, together aimed at representing the "reality" in terms of universally consistent foundations. By combining Feynman's remarks (on the all-inclusiveness of physics) with Bohm's ideas (on the consistency requirements w.r.t. the process ontology for the whole reality) I will explore how "physics" itself could be interpreted as the "whole reality" in the first part. In the second part I will apply Schrödinger's notion of the "subject of cognisance" to the question of why a (somewhat arbitrary) division between the "observer" and the "observed" seems inescapable when it comes to representing reality in terms of models and experiments. Using this discussion, in the third part I will argue that any interpretation of quantum theory—in matters of the reconcilement of *un-observed evolution* with *observation*—is doomed to be as inadequate as any other interpretation and that by appropriately combining insights from different interpretations, a more nuanced representation of reality could be constructed than that following from the application of just a single interpretation. To make this argument plausible, in the fourth part I will consider a generic *stochastic* process as an example and will explore its aspects in terms of a combination of different interpretations.

Athalye V., Roy S. S. and Mahesh T. S., *Investigation of the Leggett-Garg Inequality for Precessing Nuclear Spins*, Phys. Rev. Lett. **107** 130402 (2011).
Athalye V. and Haven E., *Causal Viewpoint and Ensemble Interpretation: from Physics to the Social Sciences*, Phil. Trans. R. Soc. A. **381** 20220279 (2023).

Marilù Chiofalo

University of Pisa, Italy

A Quantum Toolbox for Neurobiology Sensory Systems

Co-Authors: Jorge Yago Malo (University of Pisa), Simone Ausilio (University of Pisa), Guido Marco Cicchini (CNR, Pisa), Concetta Morrone (University of Pisa)

The quantum-like paradigm has emerged over the last decade to describe non-linear, dynamical, complex phenomena using quantum mechanics as a tool. In essence, it takes advantage of the linearity of quantum information processing, allowing for complex correlations through entanglement. In a quantum- and neuro-science truly interdisciplinary research, we found that an open quantum spin network, mapping a neural system, can simulate the human sense of number as a global dynamical property. This numerosity perception ability is ubiquitous and challenging to be simulated, since its only about 15% error-rate is proportional to the number of perceived items (up to 200), known as Weber's law, while the items uncertainty is Poissonian. Our quantum model succeeded well, in contrast with the poor performance of conventional Artificial Neural Networks. Here, we aim to extend the simulation to other important complex perceptual phenomena like the perception of space, time, and numbers. It is well known that perturbing one of these perceptual dimensions will alter the others, suggesting that a shared neuronal mechanism is operating in the brain. Based on this research, in this talk I will discuss the potential of a new research program, named QoolNeSS, aimed at creating a quantum toolbox to simulate this integrated space-time-number sensory ability of our brain, with open-quantum systems methods. We will explore the implications of more general quantum-matter paradigms, and their possible coding into a quantum technology. In an exploratory pathway, we will zoom in the implications of proposed quantum microscopic mechanisms on information processing and transport in the brain, to envision whether the insights may be translated on the understanding of the integrated sensory dynamics. QoolNeSS would provide a novel form of artificial intelligence design and highly impact on our understanding of quantum-coherence conditions in the quantum-to-classical crossover. Our interdisciplinary research will foster associative creativity and a specialized cross-discipline from individual specializations.

Ron Chrisley
University of Sussex, United Kingdom

Non-superpositional neural computation and the foundations of mentality: A re-assessment

Bohmian Quantum Neural Networks (BQNNs) are re-assessed in the light of intellectual developments that have taken place since the BQNN architecture was first introduced in the early 90s. BQNNs are contrasted with conventional qbit or superposition-based notions of quantum computation, neural or otherwise. After reviewing the definition of BQNNs and specifically in what sense they are "Bohmian", the extent to which they might assist in explanations of mind is re-examined in the light of recent work on active information. If time allows, a contrasting, superpositional, predictive processing model of sensory experience is outlined.

Karen Crowther
University of Oslo, Norway

Why Do We Want a Theory of Quantum Gravity?

The search for a new scientific theory is typically prompted by an encounter with something in the world that cannot be explained by current theories. This is not the case for the search for a theory of quantum gravity, which has been primarily motivated by theoretical and philosophical concerns. In this talk, I introduce some of the motivations for seeking a theory of quantum gravity, with the aim of instigating a more critical perspective on how they are used in defining and constraining the theory sought. These motivations include unification, incompatibilities between general relativity and quantum field theory, consistency, singularity resolution, and results from black hole thermodynamics.

Silvia De Bianchi
University of Milan, Italy

The Quest for a Unified Theory: Incompleteness and Progress in Physics

100 years ago, the quest for a Unified Field Theory engaged physicists, including Albert Einstein, Theodor Kaluza and Hermann Weyl, in an extraordinary effort to produce a unified picture of nature. These attempts failed, even if they led, for instance in the case of Weyl, to fundamental achievement in his theory of spinors. In this contribution, I shall briefly review these attempts deriving from the awareness of the incompleteness of General Relativity and connect them to other attempts in the 20th century to produce different models of the universe that all aimed at preserving the laws of nature. I will focus in particular on solutions that alternatively took time and/or distance as fundamental properties of the physical universe and will briefly analyze their different outcomes and models. In the third and last part of my talk, I shall show in which deeper sense General Relativity is incomplete and clarify why a Unified Theory is an unattainable goal to achieve, but at the same time a regulative idea worth of being pursued.

Basil J. Hiley

University College London, United Kingdom

The Algebraic Way to Relativistic Quantum Theory

Penrose has recently suggested that we should attempt to 'geometrise' quantum mechanics rather than 'quantise' general relativity. My interests in Clifford algebras go back to the days when Penrose was developing twistor theory. I saw the twistor emerging from the conformal Clifford algebra, a sub-algebra of the Dirac Clifford algebra. In my talk I will try to explain how I see the Clifford algebras providing the mathematical tools for such a project.

Marja-Liisa Kakkuri-Knuuttila

Aalto University School of Business, Finland

Energy as the Basis of a Unified Theory of Physics: Neo-Aristotelian Reflections

There are several attempts at a unified theory of physics, such as, string theory, loop quantum gravity, grand unified theories, and theory of everything. Each of these take force as the chief concept for unification and thus aim at finding general laws for the various forces, listed as gravity, electromagnetic, and weak and strong nuclear force. Hence unification of physics seems to be an exercise of physical theorizing with little need for metaphysical or other philosophical considerations. However, one could pose questions, such as, how to unify quantum mechanics and general theory of relativity, widely considered to be inconsistent, without generating a wider theoretical framework. Or, why should force form a relevant starting point for unification as forces are local quantities? Why not begin with energy which converts to different energy forms and obeys the principle of conservation?

In this presentation, I shall search for suitable grounds for unification of physical theories. An immediate observation is that in such an inquiry mathematics is not enough, for mathematical formulas can be interpreted in numerous ways, equally to refer to physical, biological or social phenomena. To understand what physics is about, we thus need qualitative considerations. This implies that physics involves two distinct notions of invariance: the classical Aristotelian idea of invariant genus-species classifications and the modern idea of invariances between relations of variables, which presupposes measurable quantities (Koons 2024).

This investigation is meant as a contribution to the recent Neo-Aristotelian approach to physics by starting with the question of what would physics today look like as an Aristotelian science. Three chief issues arise. To distinguish physics from other fields of research, we need to have a general framework for the division of sciences. The Aristotelian genus-species classificatory conception of science supposes that each science has a distinct highest genus, *genus proxima*. In contemporary physics, we need to ask how would energy, measurable in joules, and force, measurable in Newtons, fare as the *genus proxima* for physics. To respond to this question we may adopt the Aristotelian specification of physics as the investigation of the first causes of motion and change. This leads to Aristotle's metaphysics of change and causation, involving the categories of substance and attribute, form and matter as well as prime matter, and potentiality and actuality. Since the main issue here concerns the theoretical priority of energy or force, Aristotle's views on epistemic and ontological priority also turn out useful as methodological tools.

As a vindication of the relevance of the Aristotelian framework for physics, I shall point to the Dynamic Universe (DU) theory developed by the Finnish physicist Tuomo Suntola since 1997 (Suntola 2004, 2018a, 2018b, 2020). DU is a revolutionary theory in the Kuhnian sense (Kuhn 2012) by involving metaphysical and physical paradigm shifts. The crucial point here is that DU is in harmony with the Aristotelian conception of physics as a science first causes of motion and change. Furthermore, it adopts mass as the substance for expressing energy as the *genus proxima*. This means that energy is both ontologically and theoretically prior to force, and energy conservation is the chief postulate. As has been shown by Styrman (2016), DU also fulfills the standard philosophical criteria of theory assessment, namely, explanatory power and simplicity, and accords with physical observational data and is based on a few basic postulates.

Tarja Kallio-Tamminen
Physics Foundations Society, Finland

The Content of Planck's Constant: What does the connection between Planck's quantum and Maxwell's equations reveal?

Max Planck explained the spectrum of black-body radiation in 1900 by proposing that radiation consists of discrete wave packets whose energy is proportional to their frequency, E = hf. This quantum hypothesis meant the beginning for modern physics, as de Broglie soon presented the idea of matter waves, and in 1926 quantum mechanics was born. Physics was taken into a new unprecedented level whose abstract unintuitiveness however has not supported the formation of a common conceptual understanding of the nature of reality.
Millennium-winning Finnish physicist Tuomo Suntola has managed to derive Planck's quantum from the traditional Maxwell equations, showing that the constant h contains the velocity of light and also other well known physical constants as its factors. This discovery by no means leads back to the classical Newtonian worldview but opens up a new understanding of mass as a wavelike substance and particles as standing wave resonators. When applying the *intrinsic Planck's constant* with the velocity of light removed, the wave description in quantum mechanics can be carried through, and many problems related to interpretation of quantum mechanics disappear.

In principle these Suntola's findings related to the nature of quantum fit seamlessly into his broad Dynamic Universe theory where reality appears as a self-organizing whole consisting of a system of nested energy frames that operate on zero-energy principle. However, they can also be derived without using the postulates of DU.

Bert Kappen
Radboud University, Netherlands

The quantum measurement problem revisited

The collapse of the wave function is a fundamental concept in quantum mechanics, particularly in the interpretation of the theory. It refers to the sudden transition of a quantum system from a superposition of multiple possible states to a definite state upon measurement or observation. While the collapse cannot be explained for isolated quantum system that evolve according to a unitary dynamics, ie. on the basis of the Schroedinger equation, it is quite well possible to understand how the collapse arise for open quantum systems that are coupled to an environment. In particular the open quantum system can be described in terms of a non-linear stochastic Schroedinger equation. In the special case where the quantum system interacts with the environment through a measurement, it is easy to see that this stochastic dynamics has attractor states for any of the eigenstates of the measurement operator. In this theory, the probability for a measurement outcome is given by the wave function at the start of the measurement process in agreement with standard quantum mechanics. I suggest that the stochastic Schroedinger equation gives a comprehensive explanation for the collapse of the wave function and sheds light on the wave - particle duality.

Michal Křížek
Czech Academy of Sciences, Czech Republic

Infrared measurements of the JWST suggest that our dynamic universe is spatially closed

The global geometry and shape of the physical universe may be revealed by observing galaxies at large cosmological redshift z, since for small z the universe seems almost flat. Recent infrared measurements of the James Webb Space Telescope (JWST) indicate that there exist very luminous galaxies at distances $z > 12$ that should not exist according to the standard LambdaCDM cosmological model for the flat universe with normalized curvature index $k = 0$. In this talk, we introduce a spacetime-lens principle that could explain why these very distant galaxies shine so much. We present 10 specific examples supporting this principle. In particular, we show that the observed large flux luminosities may be mere optical effects due to the positive curvature index $k = 1$ of an expanding 3-sphere modeling our physical universe in time. For Euclidean or hyperbolic geometries such large flux luminosities seem implausible. This suggests that the right model of a homogeneous and isotropic physical universe for each fixed time instant is a 3-sphere. We show that the power spectrum of the CMB radiation also indicates that the correct curvature index is $k = 1$.

Furthermore, we will briefly present another 10 examples indicating that the Solar system and also galaxies are expanding at a rate comparable to the Hubble-Lemaître constant. In particular, the Moon moves away from the Earth faster than classical mechanics allows. We show that the Earth and Mars are moving away from the Sun almost as fast as the universe is expanding. According to astrometric and radiometric data from Cassini mission, the average recession speed of Titan from Saturn is 11.3 cm per year which cannot be explained by Newtonian mechanics. Of course, these examples contradict Kepler's laws, and therefore the law of conservation of energy does not hold absolutely exactly. We argue that this fundamental laws of physics is slightly violated due to the finite speed of gravitational interaction that creates very small aberration effects. The angular momentum of spiral galaxies is also not conserved. This is naturally expressed by following paradox: *How is it possible that spiral galaxies (originating from small random fluctuations in the hot, homogeneous and isotropic early universe) rotate so rapidly?*

M. Křížek, L. Somer: *Mathematical aspects of paradoxes in cosmology. Can mathematics explain the contemporary cosmological crisis?* Springer, Cham, 2023.

T. Suntola: *The dynamic universe, toward a unified picture of physical reality*, 4th edition. Physics Foundations Society, The Finnish Society for Natural Philosophy, 2018.

Petri Lievonen
Screen.io Corporation, Finland

Visual Introduction to Clifford Algebras and Spherical Geometries: Towards Unification Proposals by Suntola

This presentation explores pedagogical approaches to modeling multidimensional spaces. It begins with a visual construction of Clifford algebras as demonstrated by G. Sobczyk, bridging non-commutative algebras with their matrix representations.

The discussion then shifts to spherical geometries, particularly the three-sphere S^3. The elegant properties of spherical geometries are illustrated using hyperspherical coordinates, great circle crosscuts, vector fields on spheres (sequence A053381 in the OEIS), and the Poincaré conjecture.

Following this, the presentation examines unification proposals by T. Suntola, utilizing a dynamic 3-sphere as a finite object of study. The discussion is grounded in L. Okun's cube of physical theories and the zero-energy principle studied by P. Jordan. We first analyze the geodesics of light propagating in a hypothetical expanding space, where locally rigid light cones follow logarithmic spirals on a global scale, potentially resolving the cosmological horizon problem. Preliminary results on 3-sphere-induced luminosity distances and their correlation with bolometric supernova observations are presented. Additionally, we derive a dynamic solution to the expansion of space in this hypothetical model, resulting in a power law for the scale factor akin to that in standard cosmology during the current matter-dominated era. As unification proposals inherently span multiple areas of physics, aiming for consistency and coherence, we will also touch on topics such as physical and astrophysical constants and parameters, mises en pratique for SI units, pulsar array timescales, and the Schwarzschild solution.

Considering the finite 3-sphere as a physical model is challenging, as Lorentz violations have not been observed. The presentation will briefly outline how relativistic Lagrangians could be interpreted within this framework, attempting to bridge hyperbolic, parabolic, and Euclidean geometries of energy-momentum relations (and 4-vector formalisms in general) using a Gudermannian function. While this does not resolve all issues regarding kinematic descriptions, those studying space-time formalisms and relativistic quantum mechanics may find these ideas intriguing, particularly as the physical interpretations are subject to ongoing debate, development, and verification.

Hans Liljenström
Agora for Biosystems, Sigtuna, Sweden

Can Physics and Neuroscience Allow for Free Will?

While most of us feel we make decisions and can act out of free will, science seems to say we cannot. Neither deterministic laws of nature, acting in our macroscopic world, nor indeterministic quantum processes at microscopic levels, appear to allow for any free will. In addition, psychophysical experiments of voluntary actions by Libet and others seem to indicate that the brain decides our actions seconds before we are aware that we make a decision to act. All of these reasons have been taken as arguments for free will being an illusion.

In our project, *Neurophilosophy of Free Will* (www.neurophil-freewill.org), we challenge this view. More specifically, we have set out to make more realistic experiments, where the choice of alternative actions has different consequences, in contrast to the simplistic Libet type experiments of arbitrary moving either of two fingers. We have also developed and applied neurocomputational modeling to elucidate causal relationships between different brain areas during volition.

Here, I will discuss some of these considerations, which may provide alternative conclusions regarding the scientific evidence taken as arguments against free will. I will also argue that contemporary physics is insufficient for dealing with the behavior of complex biological systems, and in particular consciousness and agency. I conclude that, in order to allow for consciousness and free will, science needs to be extended beyond *chance and necessity*, which currently are the only models of explanation science can provide.

Liljenström, H. (2022) Consciousness, Decision Making, and Volition: Freedom Beyond Chance and Necessity?, Theory in Biosciences (2022) **141**:125–140, doi.org/10.1007/s12064-021-00346-6.

Martín López-Corredoira
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Alternative cosmologies

A review of few remarkable examples of cosmological theories different from standard Lambda-CDM (Big Bang) are shown, ranging from a compilation of variations on the standard model through the more distant quasi-steady-state cosmology, plasma cosmology, or universe models as a hypersphere, to the most exotic cases including static models with non-cosmological redshifts of galaxies.

The present-day standard model of cosmology, Lambda-CDM, gives us a representation of a cosmos whose dynamics is dominated by gravity with a finite lifetime, large scale homogeneity, expansion and a hot initial state, together with other dark elements necessary to avoid certain inconsistencies with observations. There are however some models with characteristics that are close to those of the standard model but differing in some minor aspects: different considerations on CP violation, inflation, number of neutrino species, quark-hadron phase transition, baryonic or non-baryonic dark-matter, dark energy, nucleosynthesis scenarios, large-scale structure formation scenarios; or major variations like an inhomogeneous universe, Cold Big Bang, varying physical constants or gravity law, different solutions of Friedmann-Lemaître-Robertson-Walker like zero-active mass (also called "R_h=ct") and Milne, and cyclical models, among which we pay here special attention to the "Dynamic Universe" model.

At the most extreme distance from the standard model, the static models, a non-cosmological redshift includes "tired-light" hypotheses, which assume that the photon loses energy owing to an intrinsic property or an interaction with matter or light as it travels some distance, or other non-standard ideas.

None of the alternative models has acquired the same level of development as Lambda-CDM in offering explanations of available cosmological observations. One should not, however, judge any theory in terms of the number of observations that it can successfully explain (ad hoc in many cases) given the much lower level of development of the alternative ones.

Tim Palmer
University of Oxford, United Kingdom

The Singular Role of Infinity in Quantum Physics: Towards a Rational theory of Quantum Mechanics

Despite decades of effort, we have neither solved the measurement problem in quantum mechanics, nor the unification of quantum and gravitational physics. Are these problems related? Could it be that the underlying difficulty lies in the essential use that the concept of infinity plays in the continuum Hilbert (Foch) state spaces of quantum (field) theory. Here I describe a particular discretisation of Hilbert Space (generating what I call Rational Quantum Mechanics - RaQM) and show, using elementary results from number theory, it accounts for the Uncertainty Principle, wave-particle duality and quantum non-commutativity, whilst at the same time allowing (something impossible in quantum mechanics) a finite deterministic ensemble-based underpinning of the wavefunction in which Born's rule is automatically satisfied. In this model quantum mechanics is a singular limit of RaQM as the discretisation goes to zero. The violation of counterfactual definiteness in discrete RaQM implies it is not Bell-nonlocal, determinism notwithstanding.

Palmer, T.N., Superdeterminism without Conspiracy. Universe 2024, 1, 47. https://doi.org/10.3390/.

Paavo Pylkkänen
University of Helsinki, Finland

Quantum Theory and Reality: The Philosophical Options

This talk briefly reviews some of the main philosophical views that have been connected to quantum theory.

Avril Styrman
University of Helsinki, Finland

Evaluation of Theories and Methodologies: Relativistic Physics vs. the Dynamic Universe

In the classical ideal, a scientific theory provides understandable causal explanations and yields novel predictions. Relativistic physics (RP), i.e., the special and general theories of relativity and relativistic cosmology, does not meet the classical ideal. This discrepancy has been addressed by transforming the classical ideal into an instrumentalist `relativistic methodology,' which prioritizes predictions over causal explanations, accepts that scientific theories do not need to make nature understandable, permits the orderly accommodation of new phenomena with the help of additional hypotheses, and allows ignoring and even modifying anomalous data. The enduring confidence in RP stems from tradition. Physicists who have been trained to conceptualize reality through the lens of RP often regard it as the sole viable framework, celebrating its accommodations similarly as its novel predictions as triumphs. Thomas Kuhn and Paul Feyerabend have taught us that to fully understand a theory's weaknesses, it must be juxtaposed with an alternate theory, and that its replacement requires a superior theory. Here RP is confronted with Tuomo Suntola's Dynamic Universe (DU). Suntola claims that DU matches or surpasses the predictive accuracy of RP for central phenomena from terrestrial to the largest cosmological scales, while adhering to the classical ideal and cohering with quantum mechanics. If these claims withstand scrutiny, DU warrants further attention from physicists and philosophers.

Thomas Kuhn. The Structure of Scientific Revolutions. 2nd ed. Chicago: University of Chicago Press, 1970.

Paul K. Feyerabend. Against Method: Outline of an Anarchistic Theory of Knowledge. 3rd ed. London: Verso, 1993.

Tuomo Suntola. The Dynamic Universe: Toward a Unified Picture of Physical Reality. 4th ed. Espoo & Helsinki: Physics Foundations Society & The Finnish Society for Natural Philosophy, 2018. https://physicsfoundations.org/data/documents/DU_EN_978-952-68101-3-3.pdf.

Tuomo Suntola
Physics Foundations Society, Finland

The Dynamic Universe

The Dynamic Universe (DU) offers an approach to understanding and predicting the natural world by describing space as a dynamic 3-sphere. This model provides a dynamic solution to the cosmological development of space and demonstrates that the relativity of observations stems from the overall energy balance in the system. Unlike the kinematics/metrics-based solutions of the theory of relativity, the dynamics-based approach of DU allows the use of time and distance as universal coordinate quantities, essential for human comprehension.
DU's foundation lies in the conservation law of energy within 3-sphere-space, where the sum of the energies of motion and gravitation is zero. Analogous to a spherical pendulum, mass in space gains its rest energy as the energy of motion against the release of gravitational energy during the contraction phase and returns this energy during the ongoing expansion phase. This presentation elucidates how the Dynamic Universe model simplifies current theoretical structures, aims to align with quantum mechanics, and provides a path toward a coherent and comprehensible scientific worldview without compromising the accuracy of predictions.
The presentation covers the following topics:
1. Big Bang: DU eliminates the Big Bang that creates matter and energy from nothing.
2. Balanced energy: The rest energy of any local mass object is counterbalanced by the global gravitational energy of the rest of space.
3. Relativity Principle: Local states of rest are defined via a system of nested energy frames – without relying on the relativity principle.
4. Universal time and distance: Distorted time and distance are unnecessary for describing relativity.
5. Cosmology: Cosmic inflation, dark energy, and other ad hoc parameters are not required for cosmological predictions.
6. Alternative black hole dynamics: The Kerr metric is unnecessary for explaining orbits near black holes' critical radius.
7. Gravitational radiation: DU predicts that binary stars on circular orbits do not emit gravitational radiation as allowed by the Taylor equation.
8. Mass and energy: Mass is a wavelike substance for the expression energy – mass is measured in kilograms [kg], whereas energy is measured in Joules [J=kg·(m/s)2].
9. Rest mass: Rest mass varies with the velocity of the mass object counterbalancing the increase of the relativistic mass.
10. Speed of light: The speed of light is not constant but is determined by the velocity of space in the local fourth dimension, dependent on the local gravitational potential.
11. Planck's equation: Planck's equation describes energy conversion in emission and absorption, it is not an intrinsic property of radiation.
12. Matter-wave duality: The wave behavior of particles is illustrated by the Compton-wave description of mass objects, also explaining the buildup of the de Broglie wave.
13. Force interaction: Force is described via sensing the gradient of the local potential field – without the need for force carriers.
14. Energy: Energy is the postulated base quantity and force a derived quantity.
15. Inertia: Inertia arises from the energy balance in 3-sphere space – inertia is not an inherent property of mass.

Tuomo Suntola, The Dynamic Universe – Toward a unified picture of physical reality, Physics Foundations Society and The Finnish Society for Natural Philosophy (2018), https://physicsfoundations.org/data/documents/DU_EN_978-952-68101-3-3.pdf.

Tuomas E. Tahko
University of Bristol, United Kingdom

Mapping the Space of Scientific Possibility

Cutting edge science is speculative: limited experimental data results in underdetermination and competing scientific theories. We may also be mistaken about some results and theories that are widely accepted. This means that we must be able to consider theories that may be false, and scientific models that seem to have non-actual targets. Yet, the space of possibilities that we consider needs to be delimited. In this paper, I will sketch a framework that enables us to delimit the space of scientific possibility and demonstrate how it operates with a case study from nuclear physics: the case of superheavy elements. The framework is based on the analysis of known and possible dependencies between entities, where 'entity' is to be understood in a very broad sense, including, e.g., properties. These dependencies have *modal* implications, which dictate a delimitation of the relevant space of possibility. If entity *x* depends for its existence on entity *y*, we may say that *x* necessitates *y*. Accordingly, by mapping such dependencies, we are in fact mapping the space or network of possibilities. The case of superheavy elements is a good testing ground for the framework because it involves making predictions about entities that do not exist – or exist only for a fleeting moment. However, the framework generalises and may be fruitfully applied to other areas of science, such as synthetic biology, astrophysics, and quantum theory.

Tahko, T. E. (2023a). Possibility Precedes Actuality. *Erkenntnis* 88: 3583–3603.
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David Wallace
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The sky is blue, and other reasons there is no underdetermination in quantum theory

I criticize the widely-defended view that the quantum measurement problem is an example of underdetermination of theory by evidence: more specifically, the view that the unmodified, unitary quantum formalism (interpreted following Everett) is empirically indistinguishable from Bohmian Mechanics and from dynamical-collapse theories like the GRW or CSL theories. I argue that there as yet no empirically successful generalization of either theory to interacting quantum field theory and so the apparent underdetermination is broken by a very large class of quantum experiments that require field theory somewhere in their description. The class of quantum experiments reproducible by either is much smaller than is commonly recognized and excludes many of the most iconic successes of quantum mechanics, including the quantitative account of Rayleigh scattering that explains the color of the sky. I respond to various arguments to the contrary in the recent literature.

Christabel Cane
University College London, United Kingdom

The Problem(s) of Temporary Intrinsics

Relationalism explains change through relativising temporary properties to the times at which they are instantiated. Assuming Newtonian space and time, this implies that all such properties are extrinsic, as they depend on external times. This is known as the problem of temporary intrinsics, and it has supplied philosophers like Lewis (1986) with a swift argument for rejecting relationalism. However, this problem loses force when considered in the context of Einsteinian relativity. The shift from absolute space and time to the space-time paradigm implies that spatio-temporally extended objects are not entirely distinct from the times through which they persist. Indeed, I will argue that certain temporal intervals should be thought of as intrinsically instantiated by ordinary objects, and that the relationalist should therefore relativise temporary properties to such intervals. Parsons (2000) suggests that temporary properties should be relativised to times within an object's lifespan when he advocates that a cooling poker should be thought of as hot such that it is hot in the first n seconds of its life. My account will flesh this idea out, by providing an explanation of how an object like a poker intrinsically instantiates intervals of time within its own lifespan. I'll consider borrowing the notion of 'proper time' from physics for this task. Specifically, the proper duration of an object as it occupies the succession of spatio-temporal points that constitute its world-line. The proper duration in this instance yields the amount of time that an ideal clock would measure when situated within the frame of reference stipulated by a given object's world-line. However, this line of reasoning will be rejected as an object does not intrinsically instantiate its world-line, given that the world-line would have existed, even if the object had not. Therefore, the relationalist who makes use of proper times generates an (updated, but no less significant) problem of temporary intrinsics, whereby temporary properties are relativised to an (external) spatio-temporal region, rather than to an (external) time. Instead, I'll make an appeal to the dynamical view of space-time, as endorsed by Brown (2005) and Read (2020), which implies the law-like behaviours of objects are more fundamental than the inertial features of space-time. This allows the relationalist to ground their notion of intrinsically-instantiated times in the dynamic processes that an object undergoes. Finally, I'll consider Vallentyne's (1997) criticism that intrinsic properties must be instantiated regardless of contingent physical laws. A salt, he argues, cannot be intrinsically soluble, as such solubility depends at least partially upon the (external) laws of nature. I'll adopt Vetter's (2015) dispositional analysis to circumvent this problem, advocating that the relationalist think of an intrinsic temporary property as relativised to some intrinsically-instantiated temporal interval within the lifespan of the object that instantiates it, whereby such times are grounded by the dynamical processes that the object has an intrinsic disposition to undergo. This will restore temporary intrinsics to the relationalist's ontology, empowering them to deliver a richer and more attractive theory of persistence.

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Quantum Formalism Outside Physics: From Quantum Logics to Quantum Cognition

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In the past century, a number of quantum logics (QLs) have emerged from philosophically grounded non-classical semantics. These logics primarily focus on modeling statements about physical systems, which is what quantum propositions traditionally express, and their calculi were developed to better understand inferential processes relevant to quantum mechanics, as originally proposed by Birkhoff and Von Neumann. Formally, however, QLs can be decoupled from physical applications. Rather than being "logics of quantum mechanics", they can be viewed simply as non-classical logics, such as those that arise as logical counterparts of algebraic structures defined by equational axioms weaker or alternative to those of Boolean algebras. Such structures (e.g. orthomodular lattices) can be introduced within a standard first-order logical setting by axioms that are not exclusively relevant to quantum mechanics (e.g. orthomodularity). This approach can provide a unified logical perspective on the foundations of mathematical frameworks used by physicists and on the meanings of objects commonly formalised within quantum contexts. However, this approach is agnostic to the content of quantum propositions: indeed, there may be nothing "quantum" about them, so this denomination remains attached to the logics only for historical reasons. Our proposal can contribute to important philosophical debates. First, it provides a new perspective on the epistemological status of formal logical languages, particularly the question of whether QLs should be regarded as empirical. Second, it sheds light on the comparison between non-classical logics, which in our view include QLs, and classical first-order logic, from which QLs are sometimes considered independent. While we characterise QLs as non-classical, we suggest it is possible to approach them from an algebraic perspective and define their logical operations using the tools of classical logic. We can then ground orthomodular lattices and their operations by axiomatically restricting Boolean operations, e.g., by moving from distributivity to modularity. In this sense, while the logics are non-classical, they emerge from a classical setting. The approach we propose seems especially fruitful for the philosophy of physics in light of the following considerations. It seems feasible to use QLs to formalise special applications of the quantum formalism outside physics: in particular, these logics can be used to formalise inferential processes pertaining to quantum cognition. We find this possibility intriguing. The mathematical formalism of quantum mechanics has already been successfully deployed to solve non-physical problems, including the modeling of human cognition, but QLs are still mostly restricted to physical applications. Given the close relation between QLs and the quantum formalism, we think there is a philosophically relevant case for applying these logics to non-physical problems as well. Viewing them from a meta-mathematical standpoint could even provide new insights into the philosophy of quantum physics and information theory. In our communication, we will outline a possible way to approach QLs from classical logical grounds, and we will connect these results with some applications of the quantum formalism in non-physical contexts, specifically human cognition. We shall conclude that these connections have relevant implications for the philosophy of physics because they make it necessary to revise the meaning of "quantum" over the involved formalisms: (i) on the basis of their definition, which is simply non-classical, and (ii) on the basis of their contexts of application, which can be non-physical.

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Time, Causation and Quantum Gravity: a First Assessment

Does causation play a role in fundamental physics? Generally, it has been argued in several places that causation does not play any legitimate role in fundamental physical theories. Based on recent developments in cutting-edge physics, I will show that this tradition can be reinvigorated with a novel challenge. I will call it the timeless challenge. As I will present it in more detail, the challenge roughly proceeds as follows. It is widely accepted that in approaches to the most fundamental (currently available) theory called Quantum Gravity (QG), time is not fundamental. Hence, since causal relations are typically anchored in temporal relations, one might conclude that along with temporal relations, causal relations are not fundamental. Therefore, there is no fundamental causation in approaches to the most fundamental physical theory. This conclusion, at least prima facie, faces opposition from approaches that either (i) reject that causal relations require the existence of temporal relations or (ii) take time and causation as fundamental. Causal Set Theory belongs to the first group (e.g., Baron and Le Bihan, 2023; Wüthrich, 2023). Causal Quantum Histories (Markopoulou, 2000), (Quantum) Energetic Causal Set Models (e.g., Cortês and Smolin, 2014), and Causal Dynamical Triangulations (e.g., Ambjørn, Jurkiewicz and Loll, 2012) belong to the second one. In this talk, I will provide a first assessment of the role of causation and its relation to time in QG, by considering those theories that make an explicit reference to the term 'causation'. More specifically, I will address the alleged role played by causation in Causal Set Theory (eventually in one of its alleged quantum versions) and Causal Dynamical Triangulations. Despite the fact that physicists explicitly appealing to causation in these theories may sound great to the ears of those who believe that causation can be anchored in fundamental physics, I will suggest that the cases of Causal Set Theory and Causal Dynamical Triangulation are respectively less convincing and less significant than one might expect. I will conclude by mentioning some interesting further developments concerning causation and QG. As an example, I will mention that (Quantum) Energetic Causal Set Models might furnish the ground for reinvigorating the discussion around a novel version of process theories of causation akin to Dowe's conserved quantity theory (e.g., Dowe 2000). I will also sketch a brief argument that concerns the causal theory of property: (i) People maintained that entangled states can be treated as powers. (ii) Entangled states must feature in any theory of QG. (iii) Therefore, if entangled states can be treated as powers then causation might play a role in all theories of QG in the form of causal properties.

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Metaphysical Coherentism and Quantum Entanglement

It has been suggested that Metaphysical Coherentism (MC), the idea that at least some of reality may be structured by webs of symmetric dependence relations, can provide a good account of entangled quantum systems (Calosi and Morganti, 2021). Advocates of MC take these relations to hold between the existence and/or properties of objects, but the nature and indeed availability of such putative relata is far from clear in the quantum domain. In this paper I press for greater precision and suggest that many refinements of the case study present significant challenges for the MC account. The Eigenstate-Eigenvalue Link (EEL) is a widely adopted principle of property attribution in quantum interpretations. Though by no means uncontroversial, it is arguably a part of 'standard' interpretations. With the EEL in hand I show that the MC advocate faces difficulties in identifying aspects of the existence or properties of entangled systems that can account for the modal correlations they exhibit in the way MC suggests. There are responses MC can consider but they weaken the claim to represent a more ontologically traditional, less-revisionary metaphysical picture than competitors with which MC is often contrasted, namely, Priority Monism (PM) and (Ontic) Structural Realism (SR). To show that this is a genuine concern for the MC account in particular I briefly sketch responses that PM and SR might provide to the same interpretative circumstances. It would appear that each is better equipped to accommodate this precisification of the entanglement case study. In subsequent sections I consider in greater detail responses the advocate of MC might adopt. Most immediately apparent is the denial of EEL and appeal to alternative interpretations of quantum theory; it should be noted, however, that EEL has analogues under various interpretative regimes and that, even if EEL fails, the arguments above identify a broader category of questions MC must answer. Other strategies involve modification of the terms in which the MC intuition is expressed, though there is the risk of collapse into other extant views. I provide a brief overview of MC's compatibility with three genres of quantum interpretation - many-worlds, spontaneous collapse, and hidden variable theories. In some cases similar concerns crop up, or there are prima facie reasons to prefer either PM or SR. There are however, some interpretations that seem to suit MC, most notably Bohmian approaches and Relational Quantum Mechanics (RQM), due in large part to their stance on the properties of (entangled) quantum systems. I outline the sort of account MC might offer on the RQM picture and suggest that this is a fruitful area for further development. I have argued that the coherentist cannot be agnostic with respect to interpretations of quantum mechanics and that on the most widely accepted interpretations the Metaphysical Coherentism account of entanglement fails. Fortunately for the coherentist that need not be the end of the story but, if they are to provide a substantive account of entanglement, they will have to make some theoretically costly commitments.

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Next Best Thing—What Can Quantum Mechanics Tell Us About the Fundamental Ontology of the World?

What is the world ultimately, fundamentally like? Naturalistic metaphysicians and philosophers of physics aim to use physics as a guide to elucidate what is fundamental. The fundamental theory of physics is the best equipped for this task. It is intended to give a unified and comprehensive account of the physical world, especially at the smallest scale. The problem is: we don't have a confirmed fundamental theory of physics yet. The closest we currently have that is confirmed by experiments is the Standard Model of particle physics. But it has limited validity, and its status as an emergent, approximate theory is built into its characterization as an effective field theory. Our best theoretical candidates are string theory and loop quantum gravity, but they are relatively speculative and far from being confirmed by experiments. So what's the next best thing we can possibly say about the fundamental that is properly informed by our best theories of physics? This paper offers a starting point to address this issue. It focuses on the literature on the ontology of quantum mechanics (QM), where the problem is especially salient: Many proposals aim at drawing the fundamental ontology of the world from QM, even though they often focus on a non-fundamental theory such as nonrelativistic particle QM; e.g., Wavefunction Realism (WFR) and the Primitive Ontology views. I argue that QM can plausibly be informative about the fundamental if it is taken as a general framework theory, which covers a range of specific concrete theories. I use WFR as an example to demonstrate what kind of ontological lessons about the world at the fundamental level the quantum framework may teach us. I first consider why proposals like WFR can't simply drop the goal of giving the fundamental ontology and be understood as giving the ontology of nonrelativistic particle QM. I then introduce the distinction between a framework theory and a concrete theory, and demonstrate what the quantum framework is and why nonrelativistic particle QM, quantum field theory, string theory, and loop quantum gravity all fall under this framework. I argue: although we do not know what the concrete fundamental theory of physics is, the working assumption is that it falls within the quantum framework. Moreover, to address Wallace's (2018) argument that it is a category error to ask what the ontology of a framework theory is, I argue: even though QM does not specify a unique ontology, it can still inform us about ontological features of the world at the fundamental level. Last, I employ WFR as an example to demonstrate what ontological features QM can tell us. WFR holds that the fundamental ontology consists of a concrete physical object, the wavefunction, and thus violates the constraint that QM as a framework theory does not specify a unique, concrete ontology. I thus propose to modify WFR: the fundamental ontology shares the structural features of being a wave function—it evolves according to the generic Schrödinger equation and can be separable in the higher-dimensional fundamental space.

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From Quantum Tunnelling to Sex

All living things require a source of energy. On Earth, the way that living entities obtain energy involves the transfer of electrons from electron donors to electron acceptors. Cockell (2016) hypothesises that the use of free energy available in subatomic particles may be a universal feature of life, due to the wide availability of electrons in the universe. It is not surprising, therefore, that quantum mechanics should be important for biological metabolic processes such as respiration and photosynthesis. It may seem surprising, however, that the relevance of quantum phenomena in biology should extend to the explanation of the evolution of complex life, sex, and mate choice. All complex life on Earth is eukaryotic. Eukaryotes originated from the endosymbiotic partnership between an archaeon and a bacterium – the latter evolving into the mitochondria. The evolution of many complex eukaryotic traits seems to have been kickstarted by this endosymbiosis, and electron tunnelling in respiratory chains is crucial to the explanation. In respiratory complexes embedded in mitochondrial membranes, electrons 'jump' from one redox centre to the next adjacent centre that is not already occupied. The distance between these is crucial, because quantum tunnelling only occurs consistently over distances of less than 14 Å. An increase of 1 Å in distance decreases the rate of electron transfer 10-fold (Lane 2015: 241). However, some protein subunits are coded by nuclear genes, and others by genes in the mitochondria. Although most mitochondrial genes have been transferred to the nucleus, some cannot be, because they are required locally, to make real-time adjustments to respiration. (Lane 2015). A fine balance between nuclear and mitochondrial genomes must therefore be maintained for respiration to proceed smoothly. The new biological subfield of mitonuclear ecology studies how the need for co-adaptation of mitochondrial and nuclear genes drives many aspects of eukaryotic evolution, including sex with recombination; the maintenance of two sexes with uniparental mitochondrial inheritance; and even mate choice, where species-specific ornaments indicate coadapted mitonuclear genomes (Hill 2019). The point is not just that quantum effects play more important roles in biology than is often realised. Indeed, there is an intermingling of physical and biological aspects in the explanation of biological processes, that reflects the physical nature of living systems. What is also striking about this case is that the scales that are most relevant for scientific explanation can turn out to be quite different than expected. Gilbert and Sarkar argue that for "an entity as complex as the cell, the fact that quarks have certain spins is irrelevant" (2000: 3). But as living cells obtain energy for all their processes from quantum particles, they cannot afford to miss out on the subtle quantum processes that allow this energy transfer to obtain.

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Husserl and Einstein on Earth and Ether

In his later works, Edmund Husserl observed that the sciences had entered into a crisis as the connection between the lifeworld and the world of physics had weakened. He stated that values are constituted in the lifeworld, and when sciences loose touch with it, their significance diminishes. In his Vienna lecture in 1935, Husserl articulated this issue in relation to Einstein's work, stating that "Einstein does nothing to reformulate the space and time in which our actual life takes place."

One of Husserl's most controversial studies, "Foundational Investigations of the Phenomenological Origin of the Spatiality of Nature," he states that the reference point of movement, which he labels as Earth, does not and cannot move. This perspective is considered naïve or even ludicrous in an era when the Copernican viewpoint was considered self-evidently true. However, Pierre Kerszberg has argued that this manuscript contains "the fullest analysis of Einstein's theory to be found anywhere in Husserl's writings" (Kerszberg: "Phenomenological Analysis of the Earth's Motion"). Kerszberg interprets the manuscript as a critique of the theory of general relativity. Yet, if we consider Einstein's later views, particularly his re-evaluation of the concept of ether, we might discern a connection between Husserl's and Einstein's perspectives.

In "Ether and Relativity," Einstein contends that "According to the general theory of relativity, space without ether is unthinkable." However, he suggests that ether should be understood in a new manner. He concludes his discourse with a crucial point about how this ether should be comprehended: "The idea of motion may not be applied to it." Although Einstein approaches the issue of movement from a different framework than Husserl, both arrive at a conception of an immovable reference frame for movement. While Husserl initiates his analysis from the lifeworld and criticizes Einstein for neglecting this aspect, it is worth considering whether Einstein's conception of the new ether differs substantially from what Husserl refers to as Earth.

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Hypersurface-dependent State Descriptions in Relativistic Collapse Theories

In this talk, I will discuss the issue of hypersurface-dependent state descriptions in the context of relativistic collapse theories. Though this issue has already been discussed by several authors (cf. Aharonov and Albert (1980, 1984), Albert (2014), Myrvold (2002, 2003) and Wallace and Timpson (2010)), I will argue that the case of spacelike entanglement swapping raises additional, and hitherto little dicussed, challenges in this regard (but see Bacciagaluppi and Hermens (2021)). Specifically, I will argue that, unlike the traditional EPRB-experiment most often considered in discussion of hypersurface-dependency, the case of spacelike entanglement swapping showcases a genuine case of relativity of entanglement. Moreover, I will argue that the relativity of entanglement in the case of spacelike entanglement swapping raises issues in how to account for the Bell-type correlations displayed in entanglement swapping experiments, especially if we adopt the view that the intrinsic state of a spacetime region should be identified with its past light-cone state, i.e., the state conditional on the collapses in the past light-cone of the region (cf. Myrvold (2019)). Proponents of relativistic collapse theories need to keep these issues in mind as they develop the ontological framework of the theory.

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Against the "nightmare of a mechanically determined universe": Why Bohm was never a Bohmian

David Bohm has put forward the first deterministic interpretation of quantum physics, and for this he seems to be regarded as a champion of determinism by physicists (both his contemporaries and the supporters of his interpretation, the so-called "Bohmians") as well as by historians of physics. The standard narrative is that he underwent a "conversion" from being a supporter of Bohr to being a staunch determinist, due to his interaction with Einstein and his commitment to Marxism. Here we show that Bohm actually upheld with continuity throughout his career some philosophical tenets that included a strong rejection of mechanistic determinism. As such, we conclude that Bohm was never a Bohmian and that his philosophical views have been largely misinterpreted.

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Could Entropy be the Missing Link in David Bohm's Metaphysics?

The fact that many interpretations of Quantum Mechanics yield the same experimental results indicates that they concern metaphysics instead of physics. Physicists who are only concerned with outcomes need not address metaphysical questions, since phenomena like wave-particle duality, entanglement and decoherence will be apparent nevertheless. However, if one's aim is to unveil the underlying reality between all grand physical theories (Quantum, Classical, Special/General Relativity), a metaphysical structure that contains not only experiments but also our experience should be provided. We believe that David Bohm and Basil Hiley's Ontological[1] Interpretation presents the most consistent metaphysics that unifies physical experiments and our subjective experience. Some key features are: "Active information", a special type of information that acts on its recipient, and in-forms it by putting form into its action. "Wholeness" suggests that no physical system could ever be isolated from its environment, therefore the observation and the observer could never be separated. The information of the environment is always implicitly carried by a system, which is the "implicate order" or the "Holomovement". Similar to a Hologram, information of the higher dimension is contained in the lower dimensions. Thus, the interpretation claims to explain higher-order phenomena such as consciousness, and provides a bridge between experiments and experience. Overall, every level is an integral part of the level below: there is a top-down determination instead of a bottom-up one. This determination causes some problems: One of them is what we call "the problem of fragmentation". Bohm mentions that the mind works by fragmentation, even though reality is to be understood as a fundamental whole. Since our minds are an integral part of this structure, why does it work that way? What does fragmentation of the mind correspond to? The second problem is non-locality. The active information is non-local; yet we perceive locality in our experience/experiments. In this paper, we will argue that both of these problems could be solved if Entropy was included in the Ontological Interpretation, by emphasizing its relation to information and the holomovement[2]. The entropy of a system increases as the information gets lost, in other words, as what we can know about the system decreases. Hiley distinguishes between the ordinary notion of information (Shannon), from active information; by saying that one is information for us, and the latter is information "for the particle". The inverse relationship between information and entropy could explain the fragmentation problem. Varying information as the system gets more complex results in lower entropy, which is a common feature of conscious organisms, and self-organizing behavior in biology. Also, the shift from quantum (Von Neumann) entropy to thermodynamic entropy could account for the shift from non-locality to locality. It should be emphasized that we do not aim to provide an explanation of the emergence of these phenomena, but to show the underlying structure. Due to the holomovement, mathematical abstractions of the phenomena of different levels are equivalent to each other. In both cases, the dual nature of information (objective and subjective) enables us to use entropy as a powerful medium between these dichotomies.

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[1] Even the fact that it is called the Ontological Interpretation, as opposed to the epistemological nature of the Copenhagen Interpretation indicates that one needs to take Bohm seriously if we are concerned with unveiling reality.

[2] The Holographic Principle states that all the information about a blackhole is mapped onto the surface, so we can calculate its entropy from its surface area (rather than volume).

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Meta-empirical theory assessment in contemporary cosmology: The MOND and dark matter debates

Physical cosmology, despite its short history as a scientific discipline, has undergone serious changes in methods of assessing theories and evaluating empirical evidence. Mid 20th century cosmological disputes about the structure of the universe largely centred around observations that were available. On the contrary, the standard cosmological model (LCDM) and theories of the early universe are significantly underdetermined by empirical data. Despite this, LCDM, theories of quantum cosmology, and theories of quantum gravity remain widely pursued and one may claim, trusted in. This transformation of assessing theories based on mostly empirical evidence to some non-empirical arguments calls for an epistemological question: can we still rely on theories of fundamental physics? Richard Dawid (2013) has proposed that in cases where there is a lack of empirical evidence or the available evidence is not enough for making a choice between theories, physicists use meta-empirical theory assessment for (namely lack of alternatives, unexpected explanatory coherence and meta-inductive reasoning). For example, according to Dawid (2013) this would be the reasoning behind trust in string theory. Dawid and McCoy (2023) have also claimed that a similar type of reasoning is present in models of cosmological inflation. The discussion of meta-empirical assessment has included the expression of conflicting views. For some physicists (Ellis and Silk 2014, Rovelli 2019) Dawid's suggestion threatens the integrity of physics. On the other hand, Wolf (2023) has argued that the problem with meta-empirical assessment is that it doesn't reflect the reasons behind the widespread acceptance of cosmological inflation. In this paper, I aim to analyse both descriptive and normative components of the problem. The descriptive component is constituted by the question of whether meta-empirical assessment is used by cosmologists, and normative is constituted by the question of whether it is a justified way of reasoning and what danger could it bring? The main case study I will consider are the debates connected to dark matter and its biggest rival - modified Newtonian dynamics (MOND). I will critique a previous analysis of the issue offered by De Baerdemaeker and Dawid (2022), who claim that from a perspective of meta-empirical assessment, MOND is not a reliable theory. However, I will show that this analysis is problematic, for example, in how the notion of a "viable alternative" is defined in the context of scientific theories. As a consequence, I claim that MOND's viability is not threatened by meta-empirical assessment. I also aim to show how the use of meta-empirical theory assessment in cosmology can be challenged.

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Noncommutative Geometry and Spacetime: An Historical Reconstruction

Noncommutative geometry (NCG) is a branch of pure mathematics with broad applications to spacetime physics. Stemming from the divergence problem in QFT, today's contributions conjecture that the fundamental structure of spacetime is noncommutative. This seemingly homogeneous picture is the result of almost a century of discontinuous interest in noncommutative spacetime (NCST). This talk has three goals: to reconstruct the development of theories of NCST; to systematise the main approaches on the basis of their methodology, interpretations and assumptions; to highlight some interesting dynamics in the construction of theories of QG by offering NCST as a study case. The development of NCST approaches can be divided into three phases. From the 1930s to the 1950s, physicists working on NCG were mainly concerned with solving the divergence problem while preserving Lorentz-invariance. In this context, orthodox quantum mechanics was considered as a source of analogies for the introduction of a minimal length in spacetime models and the construction of the first proposal for a noncommutative algebra of spacetime coordinates. A period of stagnation testifies to the lack of attention paid to the initial proposals in the short term. Meanwhile, the notion of a fundamental length is challenged: building on Heisenberg's work, NCG is a natural framework for introducing this new scale, but the resulting theory runs into localisation problems. These undermine the initial attempt of the physicists working on NCG to operationalise the mathematical background and force them to reconsider some key aspects of a new fundamental theory of spacetime. Then, in the 1990s, NCST approaches once again attracted the attention of physicists. I argue that the discovery of new mathematics (especially in algebraic geometry and quantisation) in the 1980s explains the renewed interest in the early 1990s, which culminated in today's most important approaches: the spectral triples and the quantum groups approaches. I also show how this third phase continues the previous research, but changes its direction in two ways. First, it relegates Lorentzinvariance to a guiding principle, to be recovered in the commutative limit. Second, it shifts the research question to the noncommutative extension of QFT, while retaining the dependence on the NCST structure at its core. In conclusion, I argue that the history of NCG in physics presents a case of "interlaced convergence". First, several conjectures, methodologies and interpretations developed independently. Then a group of driving problems brought them together in pairs at different times. The result is a complex web (or "fabric") in which earlier attempts are recovered and modified to meet new understandings and research questions.

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Quantum Cosmology and the Age of the Universe

The problem of time affects canonical approaches to quantum gravity, complicates their interpretation, and threatens their viability. However, the details of how this quantization procedure is applied to general relativity are technically involved, which complicates the conceptual analysis and discussion of the problem. In this talk I propose to study how this problem appears in the context of quantum cosmology, as the mathematical simplicity of this kind of model will allow us to focus on the conceptual aspects of the problem and not get distracted by the field theory component of general relativity. In particular, the fact that this issue is worrisome will become more evident, as I will argue that classical cosmology makes predictions about the duration of the different phases of the life of the universe which seem to be just missing in quantum cosmology. I will start this talk by shortly reviewing the problem of time and the positions of several authors that have argued for (Gryb, 2010; Gryb & Thébault, 2016; Kuchař, 1992; Mozota Frauca, 2023) or against (Rovelli, 2004; Rovelli & Vidotto, 2022) the claim that this issue is a severe problem that threatens the viability of canonical approaches to quantum gravity. Then, I will introduce minisuperspace models and their quantization as the paradigmatic family of models in both classical and quantum cosmology. I will argue that while the classical models allow us to make empirically meaningful claims like 'the universe is 13.8 years old' or 'if the universe had expanded faster we would observe a different abundance of certain elements' and these claims are just missing from the quantum version of the theory. In this sense, even if I consider some possible comebacks of the defenders of these approaches, I conclude that this issue constitutes a serious worry.

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Unpacking Black Hole Complementarity

"Black hole complementarity" is a label attached to an influential set of ideas (Susskind et al., 1993; Lowe et al., 1995; Almheiri et al., 2013; Hayden and Preskill, 2007; Harlow, 2016) that have emerged in response to the black hole information paradoxes (Marolf, 2017; Wallace, 2017). However, many different claims come under that label in the literature, and it can often be confusing what an appeal to "black hole complementarity" is meant to do. Teasing apart the different threads in this literature, I will argue that black hole complementarity is best understood as a principle about the consistency of characterizations of the physics of an evaporating black hole—as opposed to, say, a claim about the existence of a stretched horizon with certain properties (Susskind et al., 1993; 't Hooft, 1985; Susskind and Lindesay, 2005). More precisely, I will argue that there are at least two different consistency claims that are made in the literature, leading to two different principles of black hole complementarity. I call these two principles operational complementarity and descriptive complementarity. The operational principle says that experiments conducted by any single observer in or near an evaporating black hole will always be consistent with quantum mechanics, as long as these experiments cannot probe physics beyond the Planck scale. The principle is operational because it makes ineliminable appeal to what is empirically accessible by observers.[1] The descriptive principle says that the infalling and exterior descriptions of the physics of an evaporating black hole are consistent. (Holography, a popular approach to the black hole information paradox, may, on some readings, be seen as subscribing to the descriptive principle of complementarity (Raju, 2020, pp. 37-72)). The operational principle has been stated more-or-less explicitly in the physics literature (Hayden and Preskill, 2007; Bousso, 2013; Nomura et al., 2013), while the descriptive principle is only implicit in parts of the physics and philosophy literature (Lowe et al., 1995; Belot et al., 1999; van Dongen and de Haro, 2004; Wallace, 2017), and part of my contribution is to identify it and set it out clearly. Which of these two principles should we adopt? If we are unwilling to admit instrumentalism or verificationism in our physics, then we have a prima facie reason to adopt the descriptive principle and reject the operational principle. However, this prima facie reason is potentially defeated by a series of thought experiments and arguments in the physics literature on black hole complementarity (Susskind et al., 1993; Susskind and Thorlacius, 1994; Hayden and Preskill, 2007; Almheiri et al., 2013; Harlow and Hayden, 2013). I will argue that these thought experiments and arguments give us strong reasons to adopt the operational principle and reject the descriptive principle. For instance, the operational principle is strongly supported by recent results employing computational complexity theory to argue that single observers will be computationally restricted from detecting violations of quantum mechanics (Harlow and Hayden, 2013; Kim et al., 2020). Any non-operational solution to the black hole information paradoxes has to be able to explain these successes of the operational principle. Moreover, given that the operational principle contains a restriction on observers' ability to access Planck-scale physics, non-operational solutions will plausibly require specification of Planck-scale physics. Thus, examining the literature on black hole complementarity using the distinction between operational and descriptive complementarity allows us to sharply delineate some of the barriers to a satisfactory solution to the black hole information paradox. It also lets us see that if we are willing to admit instrumentalist or verificationist principles in our physics, then operational complementarity may suffice to resolve the black hole information paradox.

[1] I use the term "operational" in keeping with terminology of the physics literature on black hole complementarity.

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Becoming and the Illegitimate Child of Substantivalism and Relationalism

Investigations on the nature of space and time in the fundamental theories of physics such as the theories of quantum gravity, have become one of the most interesting and conceptually fascinating area of intellectual speculation. In fact, if we were once comfortable in characterizing space or spacetime mainly as either relational or substantivalist, now instead, with the increasing proliferation of the several theories of quantum gravity, we also face an increasing number of conceptual complications in identifying what kind of spacetime, if any, are those physical theories endorsing. Therefore, I will first introduce the theories of spacetime with a focus on the newly re-proposed theory of super-substantivalism – the view according to which spacetime is identical to the objects – and argue that based on this definition we get a proliferation of other sub-views of super-substativalism. I will then argue that one of these sub-positions could be extremely fruitful to understand the nature of spacetime in relativity. Furthemore, this view that I call RAV (the reverse adjectival view of super-substantivalism or the illegitimate child of substantivalism and relationalism), could be near relationalism in the sense that conceives the objects as being more fundamental but it differs from it in the sense that spacetime are not relational properties between objects but rather spacetime is an internal property of the objects themselves (for instance the spatial, temporal or spatio-temporal extension of the entities are proper properties of these entities). Secondly, I will argue that this new view not only can describes adequately the nature of spacetime in relativity, but it is also able to bring back to the core a dynamic reading of relativity. The dynamic view broadly construed conceives reality as being dynamic rather than static, the dynamic aspect allows there to be both being and not-being (in the sense that things go from being past and not-existent anymore to present and existent and then to the future that are not existent yet). The opposite view called eternalism states that all past, present and future entities, they all exist, and thus there is no passage of time in the sense that nothing goes from being past (non-existent anymore) to present (existent) and to the future (not-existent yet). Relativity is standardly considered to endorse an eternalist picture of reality. Nonetheless and thanks to my RAV view I will show that another reading of relativity is possible that is dynamic and yet does not require any absolute or universal time as it was required in the view of the passage of time. I will conclude by considering and comparing my view with another version of eternalism endorsed by Wüthrich (2023) according to which things (in relativity) exist but simpliciter and not in the future, past or present.

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What is Fundamental in Fundamental Physics?

Metaphysicians as well as philosophers of science often turn to particle physics for a description of the most fundamental entities in our universe. The common assumption is that it readily provides one clear account of what those fundamental building blocks are, how they come together to form more complicated objects, and, conversely, how compound objects can be seen as being composed of those fundamental entities. I argue that the picture is more difficult: fundamentality is commonly held to be a relational notion, explicating an ontological hierarchy between compound and fundamental entities. However, particle physics allows for more than one metaphysically meaningful procedure to decompose a system into parts, fundamental or otherwise. This has not received appropriate attention in the literature thus far—even those who examine the mereology of quantum theories in more detail tacitly assume that matters are settled in quantum physics regarding how to decompose a given system into its fundamental constituents. I will identify and interpret two commonly used decomposition procedures for quantum systems and show that they lead to different results for what the parts of a quantum system might be and thus give rise to conflicting conceptions of fundamentality. On the one hand, there is the tensor product decomposition, which is often used to identify as parts of the system clusters of properties that are statistically independent of each other in the sense that a measurement on one of the clusters does not disturb a measurement on other ones. On the other hand, the direct sum decomposition describes the compound system as a mixture of subsystems which each di-er in some of the fundamental properties that characterize quantum systems in particle physics—for example electric charge or colour charge. This decomposition also relates to Wigner's "definition" of elementary particles. I will further show that in the framework of group representation theory, extensively employed in particle physics both decompositions are available for some quantum systems and disagree on the fundamental parts that they ascribe to that system. The two decomposition procedures represent two very different ways of identifying the (fundamental) parts of a system and from the perspective of particle physics both are, often simultaneously, equally valid. I take this to provide a sense in which, as a result, particle physics on its own is not enough to determine the fundamental ontology of the world. This shows that there are conventional choices involved in finding the fundamental parts of an object which have not yet been widely recognised by either metaphysicians or philosophers of science.

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Is There Causation in Physics?

Intuitively, the science of physics deals with causal notions: forces, energies and powers that make the world run according to the laws of nature. However, observing the history of physics reveals an opposite trend: ever since Newton we have been perplexed by the fact that mathematical equations seem to give us better account of the physical world than explanations citing the mere causal interactions of colliding particles; the evolution of physics has been following the evolution of mathematics. Indeed, today, "mathematical physics" can be thought to amount to a downright tautology. And mathematics, in turn, deals with things that are non-causal par excellence. Consequently, in the current philosophy of science many think that there is no causation in (fundamental) physics, or at least they consider the opposite claim deeply problematic. But what, exactly, is the problem here? One can analyse the issue to consist in a number of distinct problems (e.g. Frisch 2023). In general terms, however, we can say there is a tension between the abstract, non-temporal, and non-observational, and the concrete, temporal, and observational. Historically, mathematical fictions have recurrently been pitted against the concrete, causal understanding of the world. I suggest here that the intuition concerning a stark difference between mathematical and causal explanation is ill-founded. More precisely, I propose that both of them should be understood in manipulative terms: mathematical and causal explanation are not different kinds of explanations, but only occupy different places on a manipulative continuum. According to the view outlined here, both mathematical explanation and causal explanation can be understood as entertaining hypothetical manipulations on a system – a mathematically or physically (mechanically) defined structure. The crucial question here is what grounds the system (modal space) on which the relevant manipulations are defined. One of the sources of the gap between mathematical and causal explanation stems from the intuition that the mathematical is more fundamental (mathematics being more basic in relation to physics, which in turn is more basic in relation to the special sciences). However, when we look at the origins of mathematical notions, we see an opposite development: mathematics has been developed to meet pragmatic challenges (e.g. surveying, trading), and only gradually it has grown in abstraction and in its domain of use. Most notably Archimedes (1909) – arguably the first mathematical physicist – was explicit in basing his mathematical reasoning on mechanical manipulations. Recently, the term physical mathematics (Marathe 2010; Cahill 2013; Moore 2014) and physmatics (Zaslow 2005) have been used to denote the idea of physically influenced mathematics. Is there causation in physics? Yes and no. Mathematical relationships can have non-causal properties (e.g. temporal and manipulative symmetry) that make mathematical physics non-causal, by definition. But such properties do not have to be seen categorically different to the properties that our causal reasoning is based on.

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A Framework for Free Will within a Quantum Universe

In the past few decades, the possibility of giving a scientific and rational explanation of our actions led to increasing interest in the problem of free will. The possibility of giving a scientific and rational explanation for our actions, or the attempts to explain consciousness within a scientific framework, led to the question of what is the role of moral responsibility, if we have any. In addition, reductionist and eliminativist views like that of Churchland and Churchland (1998) propose to reduce also our will and desires to physical constraints, making the possibility of free decision doubtful.

Quantum mechanics, which returns to us a probabilistic picture of the universe, was first thought of as a solution to the problem of free will. Lately, however, quantum mechanics has described more stochastic and incomputable decisions, rather than entirely free and conscious ones (Penrose and Hameroff, 1996). The difficulty seems to lie in the fact that to have free will, it is not enough to have more than one possible future, as quantum mechanics might suggest, but we must also be the ones to voluntarily discriminate between the various choices.

Assuming that our decisions correspond to a determination of our brain states (Place, 1956), if our decisions are free, our neural connections, responsible for our decision-making process, must be capable of self-determination. Attempts have been made to explain conscious actions through quantum mechanics. Among others, Penrose and Hameroff proposed that the origin of consciousness lies in the self-collapsing wave functions in the microtubules of the brain. Their view, however, still describes free will as just incomputability.

My goal is to propose a framework that would reduce decision-making to quantum processes in our brain, without it resulting in an absence of free and aware choices. To do so, I propose to combine the observations from Penrose and Hameroff and the quantum mechanics interpretation of the Many-Worlds (Everett, 1957; Deutsch, 1986; Saunders, 2010). The Many-Worlds interpretation is usually thought as deterministic, since every option has a 100% possibility of happening in different worlds. Despite that, I argue that the existence of more than one future is essential for free will. The second important aspect for free will to be guaranteed is if and how we get to discriminate between the different worlds, a task that has to pertain to our neurons and that can be understood through the notion of decoherence. Free will is guaranteed as long as the system determines itself in one possible world, maintaining the uncertainty on which is the world we are living in. I therefore propose a view in which the quantum processes occurring within our neurons permit their self-determination. This self-determination, within the framework of the many-worlds interpretation, guarantees free will.

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Frank on Physics and Reality

The relationship between physics and our picture of the world has often been fraught, as evidenced by disputes between Aristotelian philosophy and Galilean physics, between Newtonian physics and relativistic physics in the past, and the controversies surrounding the interpretation of quantum mechanics in the present. It is easy enough to brush aside such problems and opt for an easy instrumentalism about physical theories; they merely are tools in our efforts to predict and manipulate the world. But still, for many of us, the question of what physics says about the world remains a question worth answering. To that end, I will examine what physics says about the world through the lens of Philipp Frank's philosophy of science.

Frank, a member of the Vienna Circle, was a physicist by training, but he also was a considerable figure in the development of philosophy of science. For Frank, the distinction drawn by some philosophers between theories that are "philosophically true" and those that are merely "mathematically true" should be abandoned in favour of a single criterion for the truth of a theory, namely "to derive the best description of the observed phenomena from the simplest possible principles, while these principles are justified solely by the fact that they permit this derivation (Frank 1949, 223)." The question then becomes, "what can we say about physics and reality, given this way of looking at physical theory?"

In addition to looking at Frank's way of building a scientific world picture, I will argue that we can still learn lessons from Frank and the other logical empiricists, which will aid in our quest to understand what quantum theory says about the world. Especially little room should be left for "philosophical truths" or principles that do not pay their way as a part of the empirical understanding of our theories.

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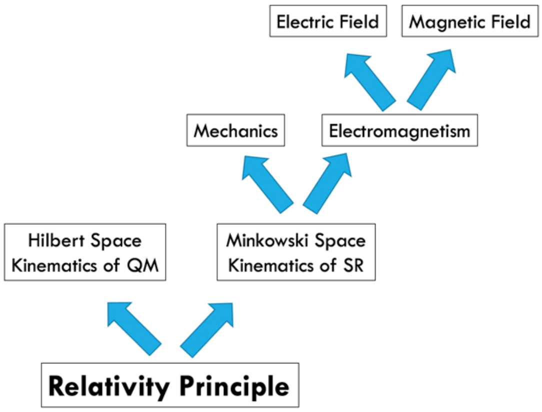
Unifying Relativity and Quantum Mechanics via Adynamical Global Constraints

Maxwell unified the disparate concepts of electric and magnetic fields with one theory (electromagnetism) and Einstein then unified the disparate theories of electromagnetism and mechanics with one kinematics (Minkowski spacetime from the Lorentz transformations of special relativity). In this talk, we will briefly explain how the disparate kinematics of quantum mechanics (finite-dimensional Hilbert space) and special relativity can be unified with one principle (relativity principle).



This result follows from the axiomatic reconstruction of quantum mechanics (QM) via information-theoretic principles, which has successfully recast QM as a principle theory a la Einstein — the formalism of the theory follows from an empirically discovered fact — just like special relativity (SR). According to the quantum reconstruction program (QRP) the empirically discovered fact whence the Hilbert space formalism of QM is Information Invariance & Continuity. Of course, the empirically discovered fact whence the Lorentz transformations of SR is the light postulate — everyone measures the same value for the speed of light *c*, regardless of their relative motions. Obviously, the light postulate can be justified by the relativity principle — the laws of physics (including their constants of Nature) are the same in all inertial reference frames — because *c* is a constant of Nature per Maxwell's electromagnetism. [We label this "NPRF + *c*" for short, where NPRF stands for "no preferred reference frame."] As we will show, Information Invariance & Continuity can also be justified by the relativity principle by first spatializing QRP's operational notion of measurement. In that case, Information Invariance & Continuity entails the empirically discovered fact that everyone measures the same value for Planck's constant *h*, regardless of their relative spatial orientations or locations (Planck postulate). Since Poincaré transformations relate inertial reference frames via spatial rotations and translations as well as boosts, and *h* is a constant of Nature per Planck's radiation law, the relativity principle justifies the Planck postulate (NPRF + *h*) just like it justifies the light postulate (NPRF + *c*). Thus, the kinematics of QM and SR are unified in that both follow from NPRF.

We will show how the quantum-mechanical probabilities for the qubit and the joint probabilities for the Bell spin states follow from NPRF + *h*, so that the mystery of entanglement is understood as a consequence of `average-only' conservation. We conclude by showing that in the Stern-Gerlach measurement of spin and the polarization measurement of photons, NPRF + *h* demands that a classically continuous quantity (angular momentum and energy, respectively) be quantized such that the classically continuous prediction obtains on average over the distribution of quantum events. Essentially, NPRF + *c* is an adynamical global constraint over the spacetime configuration of worldtubes for bodily objects while NPRF + *h* is an adynamical global constraint over the distribution of quanta among those bodily objects. Accordingly, this is a version of "all-at-once" explanation used by Evans, Liu, Price, and Wharton for retrocausality, Esfeld and Gisin for Bell flash ontology, Hance, Hossenfelder and Palmer for superdeterminism, and Adlam and Rovelli for relational quantum mechanics.

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The Underdeterminacy of the Correspondence Between Operators and Their Physical Meaning in Structural Realism

I point out an underdeterminacy of physics, in particular of Quantum Mechanics: that of the relation between the operators and their physical meaning. The set of operators for which we attribute physical meaning is, from relational, structural, and dynamical points of view, indistinguishable from any set of operators obtained from the former by a unitary transformation that preserves the evolution law. The same is true for the structures inhabiting the world, in particular there are structures isomorphic to the structure of an observer, but they would attribute the meaning of position and other physical meanings to different operators. In particular, space itself is underdetermined from the structure of the theory. Different structures that are isomorphic to an observer would call "positions" different observables, and consequently would call "space" different structures. I show that they are highly non-unique. A solution would be to consider all possible assignments of physical meaning to the operators allowed by the symmetries of the formalism to be equally valid. But this leads to a problem: there would be no correlation between the content of the mind of an observer about the external world, and the actual properties of the external world. This has unexpected consequences: it refutes structural realism and requires the ontology, the substance underlying the structures, to have phenomenal properties.

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Event Structural Realism

One of the significant objections against ontic structural realism claims that this lacks a consistent metaphysical conception of structure, what leads, among other, to elimination of the distinction between the mathematical and the physical. In this paper, I illustrate that this critique can be overcome through the integration of event ontology and structural realism. In the first part I introduce the event ontology framework and demonstrate how it contributes to a clearer understanding of the ontological status of structures within scientific discourse. I argue that observation sentences can be reformulated as sentences about occurrences of specific events. Furthermore, I argue that every combination or sequence of events can be regarded as a new, complex event. Building upon this general idea of the event ontology, I argue that all relations between observables can be interpreted as occurrences of events: that is, structures are basically not mathematical entities, superimposed onto physical reality, but they are occurring relations between observable events, that happen to be organized in a certain way. From this viewpoint, what there is is not the structure itself but the event of realization of structure. In the second part I develop the project of event structural realism, applying it to the problem of gauge description of the electromagnetic field. I illustrate the transition from the discourse of measurable electric and magnetic fields to that of the U(1) fiber bundle and argue that, from the perspective of event ontology, the electromagnetic field can be seen as a perduring occurrence of the U(1) fiber bundle over the Minkowski space. In the third part, I analyze classical anti-realist arguments such as the theory-change argument, the 'relations without relata' argument, and others. I demonstrate how the presented project of event structural realism offers responses to these objections.

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How van Fraassen inadvertently showed that Metaphysics can be Tested: Lessons from Bell's Theorem

van Fraassen is the contemporary arch-critic of metaphysics, to the extent van Fraassen (1991) bids '[g]ood-bye to metaphysics'. However, I show van Fraassen's (1991, Ch. 4) illustration that Reichenbach's common cause metaphysic cannot embed the observed violation of Bell's Inequalities, lead him to not only significant metaphysical commitments but also a method by which metaphysical theories can be tested. The key to this is to illuminate the room van Fraassen leaves for metaphysics within scientific theories: van Fraassen argues that scientific theories can be 'extended' by models, which can account for or predict further phenomena. I argue these models are precisely the sort that metaphysical theories consist of, in their attempt to describe the nature of reality. Indeed, van Fraassen (1991) exemplifies this: he argues that Reichenbach's model of the common cause can be exalted to a metaphysical claim, when supplemented by further conditions. I argue van Fraassen inadvertently goes further by illustrating a method by which this metaphysic can be tested by scientific data. In that, he shows that this model can be used to derive Bell's Inequalities, by modelling an imagined story. Given the observed violation of Bell's Inequalities, it seems there is phenomena which Reichenbach's common cause model cannot embed. According to van Fraassen (1991), this implies Quantum theory cannot be a 'causal theory', since causal models cannot be empirically adequate. Since it is not empirically adequate, these models cannot embed experimental data so the theory cannot provide a true account of observables. However, I argue that van Fraassen thereby commits to the falsehood of Reichenbach's common cause model, despite his explicit attempts to circumvent this conclusion. That is, the truth of the theory's account of observables can only be conferred by the falsehood of certain metaphysical models. Therefore, van Fraassen's ontology of observables requires significant metaphysical commitment; wherein a metaphysical model is false if it is not empirically adequate. It seems we have discovered a general method by which metaphysics can be tested. In response, it may be argued that there have been a plurality of common cause models, modified to maintain empirical adequacy. In that, there are myriad ways a common cause model can be empirically adequate: by for example either modifying the nature of the causal interaction or the common cause itself. Therefore, the epistemic status of the common cause is still unclear; similar underdetermination concerns drove van Fraassen (1991) to forego metaphysical realism and accept that '[t]here cannot be in principle… convergence to a single story about our world.' I put lie to this claim by arguing that these different options form of an epistemic modal space of the way reality might be and, through the mechanism described earlier, we can rule out certain metaphysics. Therefore, a metaphysic becomes epistemically possible if it is empirically adequate. This means what is epistemically possible, and the way reality might be, is dynamically refined and sophisticated as our experimental findings grow. Bas van Fraassen, Quantum mechanics: an empiricist view (Oxford University Press, 1991).

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On the Very Idea of an Interpretation of Quantum Mechanics

There are several *interpretations* of quantum mechanics. For instance, the Copenhagen interpretation, Bohmian mechanics, the deBroglie-Bohm interpretation, and the many worlds interpretation, to name but a few. Among this plentitude, it often gets overlooked that there is another sense in which quantum theory is continuously interpreted.

As an empirical theory, quantum theory needs to relate to empirical cases. This means that one has to be able to interpret quantum theory *to* all those different cases. What does quantum theory say will happen in a particular empirical case? These sorts of interpretations are ubiquitous in science and are very much at the core of scientific practice. We call these interpretations *interpretation-to*.

A defining feature of such interpretations is that they are ultimately empirically evaluable. Empirical happenings happen in some way, and as such, interpretations to those cases can go wrong. Quantum theory has excellent interpretations of this kind, as evidenced by its longstanding empirical success. Another defining feature of such interpretations is that they are ontologically unproblematic. Despite the plethora of competing interpretations of quantum theory, the empirical application of quantum theory has proceeded uninterrupted. (See, e.g., Peres 1993.) We believe this is because utilising quantum theory requires only interpretation-to. Indeed, it can be shown that a very minimal ontological framework is enough for such interpretations.

What of the other interpretations, then? They are not interpretations-to since they go beyond what is empirically evaluable. We will call them *intepretations-as*. They are interpretations where quantum theory is viewed as having some features that are not obviously empirical. Such features include realism about some entity, demanding that the theory is deterministic, or some other non-empirical posit. (See, e.g., Bohm & Hiley 1993; Sauders et al. 2010.) Such added features are not at least directly empirically evaluable since otherwise, we would not have such a plethora of options alongside empirical success.

While interpretations-to are unproblematic, interpretations-as are at the core of the problem of interpreting quantum mechanics. Since the interpretations-to are already enough to account for the empirical success of quantum theory, one might wonder why bother with the interpretations-as? After all, they posit a problem with seemingly no empirical consequences.

Interpretations-as have no known empirical consequences and, as such, can be said to be harmless. They could even potentially underlie heuristic approaches and provide a measure of understanding. There is, though, the worry of a false sense of understanding that can, at worst, even hinder scientific theorising. By imposing certain interpretations, we might create theoretical problems within scientific theorising that ultimately have no empirical consequences. To offset such worries, one must pay close attention to what is empirically evaluable to avoid accidentally crossing the boundary. We argue that the distinction itself, underlaid by empirical evaluability, is what is actually important. Studying different interpretations can give us a better view of where that distinction lies.

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Retrocausality and Perspectivism

Einstein called quantum entanglement "spooky action at a distance", and entanglement is still one of the great mysteries in quantum mechanics. It looks like a measurement on one of the entangled particles affects the state of the other one instantaneously even when the particles are separated by a large distance. If the distance is spacelike, the effect seems to be faster than light, which is in contradiction with relativity. One attempt to solve this contradiction between quantum mechanics and relativity is to introduce the postulate of retrocausality. In retrocausality, causal effects work backwards in time. In the case of entangled particles this would explain why the particles have "knowledge" about each other's state. The knowledge comes from the particles' future interactions. A retrocausal explanation like this has been explored by Huw Price (see, for example, Price 1997, where he uses the term advanced action, or backward causation), although very recently, Price and Ken Wharton wrote an article where they propose a new way of reconciling nonlocality with relativity without the postulate of retrocausality (Price & Wharton 2024).

Price has also written on causal perspectivism (see, for example, Price 2005), and more recently, on (neo-)pragmatism (Price 2022), which he sees as a global theory, that includes causality. According to Price's view, causality could be a perspectival or pragmatic notion. It means that the way humans, as temporally asymmetric creatures, see the world, might be different from what the world would look like from some other perspective.

What makes Price's views on causality interesting is that for many people the idea of retrocausality is against their intuition, but at the same time "normal" forward causation seems intuitively obviously true. Price's causal views seem to go against these common intuitions. My question is: what is the ontological status of causation, if it is at the same time both perspectival, and part of the explanation for quantum entanglement?

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