

THE WARSAW DIALOGUES IN THE PHILOSOPHY OF PHYSICS

23–24 September 2026

Warsaw University of Technology · Main Building · Room 213 · Plac Politechniki 1, Warsaw

DAY 1 • WEDNESDAY, 23 SEPTEMBER

09:00–09:30	Registration + welcome coffee	
09:30–09:45	Opening	
09:45–10:45	Eddy Keming Chen University of California, San Diego	<i>Typical Quantum States of the Universe are Observationally Indistinguishable</i>
10:45–11:15	Coffee break	
11:15–11:45	Lorenzo Cocco Warsaw University of Technology	<i>Pythagoreanism</i>
11:45–12:45	Andrea Oldofredi University of Lisbon	<i>Predicting Without Explaining, Explaining Without Predicting</i>
12:45–14:15	Lunch	
14:15–15:15	Eugene Y. S. Chua Nanyang Technological University, Singapore	<i>New Balances: Thermal Equilibrium as Conceptual Anchor in Integrable Quantum Statistical Mechanics</i>
15:15–15:45	Coffee break	
15:45–16:15	Niccolò Covoni University of Urbino Carlo Bo / Università della Svizzera italiana	<i>Entanglement, Relative Facts, and the Meaning of Information in Relational Quantum Mechanics</i>
16:15–16:45	Francesca Battistoni University of Urbino Carlo Bo	<i>Aristotle on Relational Time</i>
16:45–17:15	Coffee break	
17:15–18:15	Davide Romano University of Verona	<i>A Quantum Origin for Time's Arrow</i>
18:30	Conference Dinner at Warszawski Sen	

THE WARSAW DIALOGUES IN THE PHILOSOPHY OF PHYSICS

23–24 September 2026

Warsaw University of Technology · Main Building · Room 213 · Plac Politechniki 1, Warsaw

DAY 2 · THURSDAY, 24 SEPTEMBER

09:00–09:30	Walk-in + coffee	
09:30–10:30	Antonio Vassallo Warsaw University of Technology	<i>Patterns of Dependence in General Relativity: The Case of Frame-Dragging</i>
10:30–11:00	Coffee break	
11:00–11:30	Álvaro Mozota Frauca Universitat Politècnica de Catalunya	<i>Understanding Gauge Theories Beyond Electromagnetism: Classical Yang-Mills Theories</i>
11:30–12:30	Tomasz Bigaj University of Warsaw	<i>An Essentialist Perspective on the Symmetries of Space-Time Theories</i>
12:30–14:00	Lunch	
14:00–15:00	Karim Thébault University of Bristol	<i>Explicating Black Hole Singularity Resolution: A Model-Based Account</i>
15:00–15:30	Coffee break	
15:30–16:00	Jonathan Fay University of Bristol / Caltech	<i>Whence the Desire to Close the Universe?</i>
16:00–16:30	Tianzhe Cozette Shen University of Arizona	<i>Toward a Foundation for Cosmo/Astrostatistics: Deidealization from Structure Formation to the Cosmos</i>
16:30–17:00	Coffee break	
17:00–18:00	Silvia De Bianchi University of Milan	<i>Testing Spacetime Functionalism: New Insights from Black Hole Physics</i>
18:00–18:15	Closing	

THE WARSAW DIALOGUES IN THE PHILOSOPHY OF PHYSICS

23–24 September 2026

Warsaw University of Technology · Main Building · Room 213 · Plac Politechniki 1, Warsaw

ABSTRACTS

Francesca Battistoni

University of Urbino Carlo Bo

Aristotle on Relational Time

In the wake of the re-evaluation of Aristotle's physics made by Monica Ugaglia (2004) and Carlo Rovelli (2015), especially with regard to the motion in fluids, this work intends to proceed with the Aristotle renaissance by restoring Aristotle's concept of time and, in doing so, giving a contribute on the contemporary philosophic and physics debate on its ontology. Aristotle's notion of time and space has an intrinsic relationality, the same that can be found in the contemporary physics theories such as Einstein's theory of Relativity (Special and General). By deepening the Aristotelian physics, our aim is to give a contribute on the contemporary dispute about substantivalism and relationalist approaches to time and spacetime.

The work starts discussing Aristotle's unsolved aporias concerning the reality of time and tries to find a possible solution comparing them with the aporia on relativity. Aristotle asks "whether time is among things that are or things that are not, and what its nature is" (Ph. IV 10, 217b32) opening the debate on its ontology and explaining what has been calling the anti-realist thesis, suspecting that it can exist "only scarcely and dimly" (Ph. IV 10, 217b30-31). Aristotle does not give an answer to this aporia and proceed his analysis by comparing time and change and giving the definition of time as "the number of change, in respect to the before and after" (Ph. IV 10, 219b1). For Aristotle time is a number, it is not a substance; it is continuous as movement is and it is indefinitely divisible. It is listed under the category of quantity (Cat. 6, 4b25) but, being a number and especially being connected to change and to the subject of the enumeration, we will analyse it in light of what Aristotle says about the category of relatives. In doing so, we will also take into consideration the aporia regarding the relation of time with the soul who counts the change.

Aristotle describes the category of Relativi (τὰ πρὸς τι) in Categories 7 defining them as "all such things as are said to be just what they are, of or than other things, or in some other way in relation to something else" (Cat. 7 6a36-37). A relative is something that cannot be defined without reference to another; the philosophical difficulty is in establishing what kind of reality the relatives possess, considered that Aristotle's definition of substance as "that which is neither said of a subject nor in a subject" (Cat. 4 2a12-13) excludes it from relatives. In order to solve this aporia Aristotle gives another definition of relatives as those things "for which being is the same as being somehow related to something" (Cat. 7 8a32-34): a relative exists because there is another subject that exists, it is not a substance but an accident. Relatives are actual only in a derivative and dependent way: their actuality, the being of the relation, presupposes the actuality of the two relata.

Comparing the existence of relatives to the one of time, we will try to solve the Aristotles's aporias about time by connecting the ontology of time, change and soul, the relata of the aporias, to the relation between them: time exists because change exists and time exists because a soul who counts it exists as well. The existence of time, as the one of relativity, can be confirmed in a local and a relational point of view. Aristotles's act-potency theory clarifies how accidents and relatives exist: they are actualization in or between substances.

References

- Aristotle, Categories, trad. eng. J.L. Ackrill, Oxford: Clarendon Press, 1963.
Aristotle, Metaphysica, trad. eng. W.D. Ross, Oxford: Clarendon Press, 1908.
Aristotle, Physics, trad. eng. E. Hussey, Oxford: Clarendon Press, 1983.
Rovelli, Carlo, "Aristotle's Physics: a Physicist's Look" in Journal of the American Philosophical Association, 1 (2015), pp. 23-40.
Sedley, David, "Relatività aristoteliche (Parte I) 623-", in Dianoia 2, 1997, pp. 11-25.
Sedley, David, "Aristotelian Relatives" in Le style de la pensée, edited by M. Canto-Sperber and P. Pellegrin, Paris, Les Belles Lettres, 2002.
Ugaglia, Monica, Modelli idrostatici del moto da Aristotele a Galileo, Roma: Laterano University Press, 2004.
Ugaglia, Monica, (introduction, translation and comment), Aristotele: Fisica, Libro III, Roma: Carocci, 2014.
-

Tomasz Bigaj

University of Warsaw

An Essentialist Perspective on the Symmetries of Space-Time Theories

In my talk I will present a formalization of the concept of essential structures in the framework of possible worlds and counterpart functions between them. Subsequently I will apply this essentialist framework to shed a new light on well-known issues regarding the symmetries of space-time theories, such as John Earman's distinction between space-time and dynamical symmetries, Tim Maudlin's "indexical" distinguishability of the models connected by a static shift, and the hole argument brought about by the diffeomorphism-invariance of General Relativity. I will argue, contra Maudlin, that there is no substantial difference between the cases of static and kinematic shifts regarding the knowability of the appropriate states of the universe. As for the hole argument in GR, I will present an analysis according to which the existence of a hole transformation indeed leads to some form of indeterminism even for a 'sophisticated substantialist', but this form of indeterminism is contextual and thus of a weak type.

Eddy Keming Chen

University of California, San Diego

Typical Quantum States of the Universe are Observationally Indistinguishable

We establish three new impossibility results regarding our knowledge of the quantum state of the universe—a central object in quantum theory. We show that, if the universal quantum state is a typical unit vector from a high-dimensional subspace H_0 of Hilbert space H (such as the one defined by a low-entropy macro-state as prescribed by the Past Hypothesis), then no observation can determine or just significantly narrow down which vector it is. In other words, the overwhelming majority of possible state vectors are observationally indistinguishable from each other (and from the density matrix of H_0). Moreover, we show that for any observation that isn't too unlikely and most pairs of unit vectors from H_0 , the observation will not significantly favor one vector over the other. We further show that the uniform distribution over the unit sphere in H_0 , after Bayesian updating in the light of any observation that isn't too unlikely, is still extremely close to uniform. Our arguments rely on a typicality theorem from quantum statistical mechanics. We also discuss how theoretical considerations beyond empirical evidence might inform our understanding of this fact and our knowledge of the universal quantum state. (Joint work with Roderich Tumulka; paper forthcoming in BJPS, arXiv: 2410.16860)

Eugene Y. S. Chua

Nanyang Technological University, Singapore

New Balances: Thermal Equilibrium as Conceptual Anchor in Integrable Quantum Statistical Mechanics

Thermal equilibrium is a foundational concept of classical thermodynamics. However, integrable and near-integrable quantum statistical mechanics reveal its limits: not all its classical theoretical roles can be recovered. We argue that this failure is epistemically productive. Classical thermal equilibrium can guide theory even where it no longer straightforwardly applies, by serving as a conceptual anchor for identifying analogies and disanalogies in new domains. This anchoring clarifies the assumptions under which the old concept worked and supplies physical meaning to generalized equilibria, showing how disanalogies can guide, rather than defeat, concept extension.

Lorenzo Cocco

Warsaw University of Technology

Pythagoreanism

Pythagoreans reduce the posits of our best scientific theories to the mathematical objects that are normally assumed to represent them. For example, electromagnetic fields are reduced to tensor fields on a manifold, and the quantum state is reduced to a ray in a mathematical Hilbert space. These reductions are considered by many philosophers to be simply the result of conceptual confusion. However, I will argue that in the absence of an intrinsic account of fields, spacetime, and the quantum state, these Pythagorean theses may constitute our best account of physical reality.

Entanglement, Relative Facts, and the Meaning of Information in Relational Quantum Mechanics

Relational Quantum Mechanics (RQM) (Rovelli, 1996) assigns a foundational role to informational notions, yet the ontological status of information within the theory remains unsettled. Rovelli repeatedly claims that any physical system may “have information” about another (Rovelli, 2016), even in the absence of observers, knowledge, or semantic interpretation. However, once epistemic connotations inherited from Shannon and Weaver (1949)’s framework are set aside, it becomes unclear what kind of physical relation informational talk is meant to capture. This talk addresses that question and proposes a precise ontological interpretation of information within RQM.

The difficulty arises from a tension internal to the theory. On the one hand, RQM explicitly rejects epistemic and semantic readings of information: informational notions are not tied to agents, beliefs, or message transmission, but are meant to capture physical relations between systems. On the other hand, the formal resources typically invoked to clarify informational notions are deliberately minimal and ontologically neutral. As a result, identifying information with correlation or with constraints on joint possibilities does not by itself determine what kind of physical relation is at stake.

We begin by reconstructing the role played by information in Rovelli’s original postulates of Limited Information and Unlimited Questions. While these principles constrain the structure and dynamics of relational facts, they do not determine what relative information ontologically amounts to. Even later formalizations (Rovelli, 2013; Biagio and Rovelli, 2025) that identify information with constraints on joint possibilities leave open whether all correlations are equally suited to ground the relational attribution of properties central to RQM. In particular, a purely correlational reading fails to distinguish between supervenient correlations, fully reducible to intrinsic properties and causal history (Bricker, 1996), and genuinely non-supervenient correlations (Teller, 1986).

We argue that only the latter can play the grounding role required by a relational ontology. Entanglement provides precisely this structure. First, we show that entanglement arises generically from non-separable physical interactions and is therefore rooted in concrete dynamical coupling. More precisely, standard quantum dynamics entails that entanglement cannot be generated by separable evolution, but requires non-trivial interaction terms in the Hamiltonian. This establishes that entanglement is not an abstract or merely formal feature of the theory, but the physical imprint of interaction. Second, we argue that entanglement cannot be understood merely as a trace of past interaction. Although it presupposes a history of physical coupling, entanglement persists as a present relational structure that constrains the space of physically possible future interactions. It determines which correlations would obtain under further interaction and which property attributions are physically accessible relative to interacting systems. In this sense, entanglement is not a causal process nor a form of signal transmission, but a physically instantiated structure with modal import: it fixes patterns of counterfactual dependence between systems.

On this basis, we propose that entanglement constitutes the physical realisation of relational information in RQM. Crucially, entanglement is an external, weak non-supervenient relation: it does not supervene on the intrinsic properties of the subsystems, but reflects an irreducible structure of the composite system. As such, it provides exactly the kind of relation required to ground the relational attribution of properties in RQM. It constrains which correlations are physically accessible and which relational facts can be established through interaction.

This proposal allows us to clarify the informational language of RQM without collapsing it into either epistemic or metaphysical extremes. Information is not knowledge, belief, or semantic content, nor a primitive ontological substrate (Janas et al., 2021; Wheeler, 1989). Rather, it is physically realized by the entangled relational structure that governs how systems can co-determine one another’s properties. Quantitative measures such as entanglement entropy or quantum mutual information fit naturally within this framework: they do not define what information is, but measure the degree of relational constraint instantiated by entanglement.

By identifying entanglement as the physical ground of relational information, we provide a principled way to distinguish physically significant correlations from merely supervenient ones. In doing so, we clarify the ontological content of informational notions in RQM and align its relational framework with the formal structure of quantum theory. More generally, the proposal contributes to a broader understanding of information in fundamental physics as neither epistemic nor primitive, but as grounded in physically instantiated relational structures.

References

- Biagio, A. D. and C. Rovelli (2025). Relative information, relative facts.
- Bricker, P. (1996). Isolation and unification: The realist analysis of possible worlds. *Philosophical Studies* 84 (2-3), 225–238.
- Janas, M., M. E. Cuffaro, and M. Janssen (2021). *Understanding Quantum Raffles*. Boston Studies in the Philosophy and History of Science. Cham: Springer.
- Rovelli, C. (1996). Relational quantum mechanics. *International journal of theoretical physics* 35, 1637–1678.
- Rovelli, C. (2013). Relative information at the foundation of physics.

Rovelli, C. (2016). Meaning = information + evolution.

Shannon, C. E. and W. Weaver (1949). The Mathematical Theory of Communication. University of Illinois Press.

Teller, P. (1986). Relational holism and quantum mechanics. The British Journal for the Philosophy of Science 37 (1), 71–81.

Wheeler, J. A. (1989). Information, physics, quantum: The search for links. In Proceedings of the 3rd International Symposium on Foundations of Quantum Mechanics, pp. 354–358. Physical Society of Japan.

Silvia De Bianchi

University of Milan

Testing Spacetime Functionalism: New Insights from Black Hole Physics

In this contribution, I argue that dominant formulations of spacetime functionalism, which rely either on reductionist accounts or on the identification of local inertial structures, fail to engage with the epistemological challenges posed by black hole physics. The paper proposes a practice-oriented philosophy of spacetime that focuses on objectivity of conserved curvature invariants, on cross-checking results through numerical and analytical approaches, and in examining how the Event Horizon Telescope's imaging of black hole shadows, as well as gravitational waves astrophysics, can open new opportunities not only for testing both general relativity and its extensions, but also to guarantee the necessity of the results and of spacetime behavior, avoiding the circularity implied by analogical arguments.

Jonathan Fay

University of Bristol / Caltech

Whence the Desire to Close the Universe?

Prior to precision cosmological measurements in the early 2000s, the geometry of the universe was essentially unknown, yet cosmologists made strong claims about its shape grounded in non-empirical considerations that influences the intellectual context within which the dark matter hypothesis gained traction. Recent scholarship, especially de Swart (2020), has shown that cosmologists in the 1970s and 1980s often favoured flat or closed cosmological models for essentially non-experimental reasons, a prejudice that helped shape attitudes toward dark matter in this period. We argue however that opinions were more divided on this issue than de Swart portrays, for instance, a substantial group of cosmologists simultaneously endorsed additional non-baryonic matter while favouring an open universe.

This talk identifies and critically analyses three such non-empirical arguments for particular geometries of the cosmos, two of which were motivated by appeals to Mach's principle: (1) Einstein and Wheeler's Machian argument for a closed universe, (2) a lesser-known Machian argument for a flat universe of critical density associated with Sciama and Bondi, and (3) Dicke and Peebles' fine-tuning argument for a flat universe. Since previous scholarship has tended to conflate arguments grounded in Mach's principle, we closely examine and disentangle the two Machian cases, assessing their historical roots, philosophical motivations, and scientific legitimacy. Although both claimed to derive from Mach's principle, we show that they differed wildly in their methodology and the context in which they were developed.

The first case concerns the long-standing argument for a closed universe—popularised in the renaissance period by John Wheeler—which was rooted in Einstein's attempt to eliminate boundary conditions in general relativity on Machian grounds. Drawing on a close reading of Wheeler's early relativity notebooks and responding to questions raised by Blum and Brill (2020), we show that Wheeler's views were substantially influenced by Hermann Weyl's (1924) dialogue *Massenrägheit und Kosmos* despite Weyl's explicit objections to the argument for closure. We argue that the Einstein–Wheeler case for closure relied on assumptions drawn from pre-expansion cosmology that fail to carry over to the modern context (indeed this was why Einstein dropped the cosmological constant), yet persisted due to their superficial philosophical appeal.

The second case examines a lesser-known argument for a flat universe associated with Dennis Sciama, as well as Hermann Bondi. This argument derives from a Machian interpretation of frame-dragging effects in general relativity, according to which inertial forces in rotating frames should be identified with gravitational effects generated by cosmic matter. In linearised models, this leads to a constraint requiring the quantity $G\rho r^2$ to remain constant over cosmological evolution, a condition uniquely satisfied by the Einstein–de Sitter model among $\Lambda = 0$ FLRW cosmologies. We show that while Sciama's early work on a linearised model (Sciama, 1953) attracted some interest in this line of reasoning, later attempts to extend it to the full non-linear theory using Green's function-based methods failed to produce any useful results, leading to the dissolution of Sciama's Machian programme. In this case the programme failed to carry over assumptions rooted in classical conceptions of spacetime to the general relativistic domain, however questions remain concerning whether the programme may be salvaged in the context of speculative theories of quantum gravity.

The third argument we examine comes from Robert Dicke's coincidence problem, the precursor to the modern flatness problem. Dicke's worry stems from the fact that curvature and the cosmological constant would have been utterly

negligible in the early universe yet today appear dynamically significant, making it suspicious that observers arise precisely at the epoch when these previously negligible terms begin to dominate expansion. This culminates in the flatness problem: even a 0.1% deviation in the initial expansion rate would have led either to rapid recollapse or to runaway expansion preventing structure formation, implying that the density parameter must have been extraordinarily close to the critical value from the very beginning.

The study contributes to ongoing philosophical debates about the role of non-empirical arguments in theory selection, debates that remain live in contemporary discussions of inflation and the multiverse. By drawing on Wheeler's unpublished relativity notebooks and Sciama's previously uncited doctoral thesis, the talk also makes original historical contributions to our understanding of the intellectual circumstances surrounding the establishment of dark matter as a cornerstone of the standard cosmological model.

References

- Blum, A.S., Brill, D. (2020). Tokyo Wheeler or the Epistemic Preconditions of the Renaissance of Relativity. In: Blum, A.S., Lalli, R., Renn, J. (eds) *The Renaissance of General Relativity in Context*. Einstein Studies, vol 16. Birkhäuser, Cham.
- de Swart, J. (2020). Closing in on the Cosmos: Cosmology's Rebirth and the Rise of the Dark Matter Problem. In: Blum, A.S., Lalli, R., Renn, J. (eds) *The Renaissance of General Relativity in Context*. Einstein Studies, vol 16. Birkhäuser, Cham.
- Sciama, D. W. (1953). On the origin of inertia. *Monthly Notices of the Royal Astronomical Society* 113 (1), 34–42.
- Weyl, H. (1924). Massenträgheit und kosmos. ein dialog. *Die Naturwissenschaften* 12, 197–204.

Álvaro Mozota Frauca

Universitat Politècnica de Catalunya

Understanding Gauge Theories Beyond Electromagnetism: Classical Yang-Mills Theories

Gauge symmetries are at the core of our most successful physical theories. When these symmetries are present, we have different equivalent models that represent the same physical situation. The paradigmatic example of this is electromagnetism, in which the electromagnetic field $F_{\mu\nu}$ can be represented by infinitely many equivalent 4-potentials A_μ . Electromagnetism is a well-understood theory which is used for discussing topics such as gauge symmetry, the metaphysics of field theory, the quantization of theories with symmetries, or the relationship between gauge symmetries and the diffeomorphism invariance of general relativity.

In this talk and ongoing project I want to go beyond electromagnetism and analyze in detail classical non-abelian Yang-Mills theories. Among these we find the classical version of the theories describing the nuclear forces and the interactions between particles like quarks. At nuclear and subnuclear scales one is at a quantum regime, and, above that, the short-range of some of these interactions, and the phenomenon of confinement, make the classical version of the theories not very relevant for our world. However, understanding these classical gauge theories can be important for advancing in the many fields and debates in which gauge theories are relevant.

In this talk I start to explore the possible physical interpretations of classical Yang-Mills theories. While in classical electromagnetism we had two clear ingredients: a field mediating the interactions and charged particles, in Yang-Mills theories, things are a bit more complicated. To start with, the Yang-Mills field $F^a_{\mu\nu}$ is not gauge invariant in this case, which complicates claiming that the theory describes a field in space. If one wants to build invariant quantities, one needs to build extended-in-space objects, such as Wilson loops, that correspond to integrating the field over some region, surface or line. Expressing physics in terms of non-local quantities represents a shift from our traditional understanding of field theories, but it seems to be suggested if we want to keep invariance. Some authors have taken this to signal that the metaphysics described by the theory is non-local or non-separable (Dougherty, 2017; Healey, 2001).

Yang-Mills charges (e.g., color charges and isospin) are also significantly different from electromagnetic charges. While the effect of the electromagnetic field on a charged body is to accelerate it, Yang-Mills fields also have the effect of changing the charge of the particle. To make things more complicated, the way a particle changes its Yang-Mills charge depends on its trajectory in spacetime. In this way, if you start with two identical particles at one point and transport them to another one through different paths, at the end point you will generally find two different particles. How to understand the identity and properties of particles becomes therefore more complicated.

It is therefore not surprising that comparing the charge of particles at different points becomes tricky. While in electromagnetism one can just bring two particles together, see how they interact, and deduce relationships between the charges, in Yang-Mills theories this is complicated. Now the particles will change charge during the interaction, and they will do so in a way that will depend on the way the particles are brought together and then apart. Figuring out the charge of a particle in relation to other particles is not straightforward, and one can doubt it is possible at all.

An alternative appears when Yang-Mills theories come with a bit more of structure. When there is a Higgs field, it is natural to fix the gauge relative to this field and to define charges relative to this gauge-fix. That is, we choose a gauge in which the Higgs field has the same phase everywhere in space, and relative to this one can define charges. At this level, this remains very formal and remote from the operationalism of bringing charges together. However, if the interaction

with this field gives different properties to particles with different charges, this would allow to tell them apart. This is in a nutshell the Higgs mechanism.

But what if there isn't any Higgs field or any similar mechanism? Can we still classify particles with different charges? Formally, the answer seems to be yes, as we can always fix the gauge. However, if the fixing does not correlate with anything physical it risks being operationally meaningless and there wouldn't be any practical way of determining this conventionally defined charge. At the same time, the charges, even if gauge dependent, are part of the model and hence at least part of them should be considered as physical and not conventional.

Some authors have proposed that for understanding Yang-Mills theories one ought to look at covariant quantities and not invariant ones, similarly to the ways some authors interpret general relativity (see H. Gomes, 2022a, 2022b, 2025). I will conclude my talk by analyzing this idea and arguing it is promising, it has some benefits as being able to think of fields at a point instead of extended objects, and as allowing us to keep more of the idea of a charge, even if part will remain conventional.

References

- Catren, G. (2008). Geometric foundations of classical yang-mills theory. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, 39 (3), 511–531.
- Dougherty, J. (2017). Sameness and separability in gauge theories. *Philosophy of Science*, 84 (5), 1189–1201.
- Friederich, S. (2015). Symmetry, empirical equivalence, and identity. *The British Journal for the Philosophy of Science*, 66 (3), 537–559.
- Gomes, H. (2021). Holism as the empirical significance of symmetries. *European Journal for Philosophy of Science*, 11 (3), 1–33.
- Gomes, H. (2022a). Same-Diff? Conceptual similarities between gauge transformations and diffeomorphisms Part I: Symmetries and isomorphisms.
- Gomes, H. (2022b). Same-diff? Conceptual similarities between gauge transformations and diffeomorphisms. Part II: Challenges to sophistication. [https://doi.org/10.1/Same diff%201-soph.pdf](https://doi.org/10.1/Same%20diff%201-soph.pdf)
- Gomes, H. (2025). Gauge theory without principal fiber bundles. *Philosophy of Science*, 92 (3), 511–527.
- Gomes, H. d. A. (2024). Representational schemes for theories with symmetry. *Synthese*. <https://doi.org/10.1007/s11229-025-05045-z>
- Healey, R. (2001). On the reality of gauge potentials. *Philosophy of Science*, 68 (4), 432–455.
- Norton, J. D. (2003). General covariance, gauge theories, and the kretschmann objection. In K. Brading & E. Castellani (Eds.), *Symmetries in physics: Philosophical reflections* (pp. 110–123). Cambridge University Press.

Andrea Oldofredi

University of Lisbon

Predicting Without Explaining, Explaining Without Predicting

In this talk, we challenge the general applicability of Douglas (2009)'s view, according to which scientific explanation and prediction are functionally intertwined. Drawing on quantum mechanics—where a single, exceptionally successful predictive formalism coexists with multiple, mutually incompatible explanatory interpretations—we advance five claims. First, the pursuit of scientific explanation does not necessarily originate from deficiencies in predictive power. Second, the value of prediction does not lie in the veracity of the underlying predictive account. Third, the value of explanation is not necessarily related to a pragmatic tool for guiding interventions or practical action. Fourth, there is no connection between the scientific character of an explanation and its capacity to generate novel predictions or evidence. Fifth, predictions do not always reliably serve to test, adjudicate between, or probe the truth of competing explanatory accounts. We further defend these claims through examples across various areas of past and contemporary science beyond quantum mechanics, showing that prediction and explanation operate according to distinct principles. Altogether, our arguments advocate for a divorce between prediction and explanation.

Davide Romano

University of Verona

A Quantum Origin for Time's Arrow

The problem of the arrow of time is, briefly speaking, to understand why we observe irreversible processes (e.g. in thermodynamics) even though the fundamental dynamics governing the microscopic systems is time-reversal invariant. The standard answer to this problem, originally proposed by Boltzmann, is given by the statistical explanation of the second law of thermodynamics plus a further hypothesis on the initial state of the universe, called the *past hypothesis*. Such an explanation however has two major problems: (1) the past hypothesis is not physically well-justified and

eventually looks like an ad hoc hypothesis; (2) in the framework of classical statistical mechanics the motion of atoms and molecules is described by Newtonian mechanics, whereas in a more accurate framework (where atoms and molecules are represented as quantum systems) it should be described by the Schrödinger's equation.

Building on these considerations, I advance the hypothesis that a better explanation for the arrow of time might be found in quantum mechanics, specifically in decoherence theory. The open systems described by decoherence do not follow the (time-reversible) Schrödinger equation but master equations that are not time-reversal invariant. In fact, they describe irreversible processes driven by the dynamics. From decoherence theory we can define a novel quantum arrow, distinct from the classical thermodynamic arrow. Differently from the thermodynamic arrow, the quantum arrow so defined from decoherence theory cannot define a global arrow valid for the whole universe, but only a local arrow for subsystems of the universe. I will argue, however, that this is exactly what we need in order to explain the arrow of time and irreversibility.

Tianzhe Cozette Shen

University of Arizona

Toward a Foundation for Cosmo/Astrostatistics: Deidealization from Structure Formation to the Cosmos

In the widely accepted cosmological model containing cold dark matter, structure formation is described as bottom-up and hierarchical. In the very early Universe, low mass objects were formed, and through their colliding and merging, or “clustering,” larger systems, from galaxies to galaxy clusters to superclusters, were formed over time. Objects at each astronomical scale are usually modeled and studied respectively.

Galaxy clusters are very large gravitationally bound systems in the late Universe. They are pivotal for cosmology because (1) they are believed to be dominated by (cold) dark matter, and (2) to model their formation, certain idealizations are necessary for both the clusters and their background—the Universe. The commonly adopted model, developed by Kaiser (1986), describes (rich) galaxy clusters as self-similar objects formed in a scale-free gravitational spherical collapse. This model also assumes a set of purposefully simplified initial condition: (1) the background Einstein–deSitter Universe is scale-free; (2) the initial density fluctuations are scale-free; (3) no new scales are introduced. (Kaiser, 1986) With a comoving spatial coordinate r and the scaling for the density contrast field $\Delta(r, t)$, and given $\Delta_1(r) = \Delta(r, t_1)$ and $\Delta_2(r) = \Delta(r, t_2)$, we have $S[\Delta_1(r)] = S[\Delta_2(\alpha r)]$ for any dimensionless statistic $S = S[\Delta]$, where $\alpha = (t_2/t_1)^{4/(3n+9)}$. Accordingly, their physical properties are expected to simply scale with mass and redshift, leading to a power-law-form relation—called scaling relation (SR)—between properties X and Y , generally expressed as $Y = A E(z)^\gamma X^B$.

In the era of precision cosmology, technological advancements enable us to collect large-scale astronomical data sets via various observational means. Over the past several decades, statistics has become more and more crucial for calibrating, cross-calibrating, and analyzing these massive data sets, fostering an interdisciplinary field of research called cosmostatistics or astrostatistics. Established empirically upon large-scale observational data, scaling relations play a significant role in astrostatistics. They are frequently used to probe cosmological parameters (Migkas, 2025) and more importantly, to test for “departures from the self-similar expectations”, elucidating other potentially contributing (astro)physical processes not included in the self-similar models. (Lovisari and Maughan, 2022)

Such empirical studies of galaxy cluster scaling relations can be taken as essentially part of a deidealization process. Potentially contributive (astro)physical processes not included in the self-similar model are added back to obtain more realistic cluster models. Moreover, cosmologically relevant inferences are also made accordingly. In this sense, this deidealization is not only on galaxy clusters and their formation, but also on the background Universe and the initial conditions in which the formation process takes place. For instance, the most prominent observational feature of galaxy clusters is the hot ionized gas—intracluster medium, or ICM—that emits X-rays. The X-ray luminosity (L_x) depends on the cosmological model of choice, and is thus cosmology-dependent. The X-ray temperature (T_x) can be determined solely by X-ray spectroscopy and is hence cosmology-independent. The $L_x - T_x$ relation can be used to probe cosmological assumptions such as cosmic isotropy. As another example, the Sunyaev–Zeldovich (SZ) effect is the slight spectral distortion of the cosmic microwave background spectrum caused by inverse Compton scattering of CMB photons while traveling through galaxy clusters and interacting with high-energy electrons in the ICM. With the advantage of being redshift-independent, the scaling relation between the integrated SZ signal, YSZ, and its X-ray analog, YX, is important in constraining the formation of large-scale structure, potentially contributive to dark energy.

However, Kaiser's model is intended to predict the statistical nature of rich clusters at any epoch. The empirical scaling relations are also statistically established. Cosmological inferences made upon the deidealized cluster models do not necessarily amount to proper deidealization of the idealized cosmology assumed in Kaiser's model. The scaling behavior of galaxy clusters predicted by Kaiser's model is due to the scale-free assumptions about the background Universe and the initial density fluctuations. A mismatch arises when one attempts to use the deidealized cluster models to make cosmological inferences (i.e. deidealize these assumptions) while maintaining the scaling behavior of clusters. In other words, there is a gap between the scaling relations and the cosmological inferences made upon them. Moreover, while statistical models do not typically go beyond the modeled systems themselves, in the case of galaxy cluster scaling relations, we indeed are trying to make inferences beyond clusters, but we seem not to have a reasonable foundation to ground such inferences. This raises serious interpretative and foundational challenges to this method. Furthermore, since

scaling relations have also been commonly established at other scales (e.g., stars and galaxies), structurally similar challenges arise from this general method.

Computer simulations, especially large-scale cosmological ones, are also useful for deidealization, because one can maintain the same initial conditions and turn on and off various potentially contributive (astro)physical processes to test their effects on the formation, by producing mock scaling relations of cluster analogs and comparing them to observed ones. (Lovisari and Maughan, 2022) Nevertheless, they are unable to close the gap for two reasons. First, such a simulation can only work with (astro)physical processes that are not just known to us, but also well-understood so that well-established models are available. That said, even for those well-understood and well-modeled processes, it is oftentimes not clear how their combined impacts would be, which means one can only test their impacts separately, risking underdetermination. Second, as Gueguen (forthcoming) argues, there lacks a well-established robustness analysis in the context of cosmological simulations as the only seemingly promising method, code comparisons, fails to ground robustness.

References

- M. Gueguen. A tension within code comparisons. forthcoming.
- N. Kaiser. Evolution and clustering of rich clusters. *Monthly Notices of the Royal Astronomical Society*, 222 (2):323–345, 1986.
- L. Lovisari and B. J. Maughan. Scaling relations of clusters and groups and their evolution. In *Handbook of X-ray and Gamma-ray Astrophysics*, pages 1–50. Springer, 2022.
- K. Migkas. Galaxy clusters as probes of cosmic isotropy. *Philosophical Transactions A*, 383(2290):20240030, 2025.

Karim Thébault

University of Bristol

Explicating Black Hole Singularity Resolution: A Model-Based Account

We will develop and apply a model-based account of explication in the context of black hole singularity resolution. Explication is the replacement of an unclear and inexact concept, the explicandum, by a clearer, and more exact concept, the explicatum (Carnap 1956, 1963; Stein 1993; Leitgeb and Carus 2020). Our approach will build on previous work on the explication of singularity resolution in quantum cosmology (Thébault 2023). That work sought to develop the idea of model-based explication via the articulation of the idea of stability of applicability of a criterion for singularity resolution (Warrier 2022, Thébault 2023). This was defined as follows: stability of applicability of a criterion for singularity resolution requires that the applicability of the criterion persists despite the relaxation of symmetry assumptions. This treatment exemplifies model-based explication for the concept of singularity resolution where the reliability of such an explication is characterised in terms of the stability of the relevant formal features under the expansion of target domain from the idealised, un-realistic model class to the de-idealised, realistic model class. In this talk we will test out our model-based account of explication in the context of stability under de-idealisation and singularity resolution in black hole physics. In particular, we will consider the stability of applicability of criteria for singularity resolution in the context of de-idealisation from stationary to non-stationary black hole spacetimes. Our account will have wider relevance to model-based reasoning in gravitational physics more generally.

References

- Carnap, R. 1956, *The Methodological Character of Theoretical Concepts*, in *The Foundations of Science and the Concepts of Psychology and Psychoanalysis*, Herbert Feigl and Michael Scriven (eds.), Richard Minneapolis: University of Minnesota Press, pp. 38–76.
- Carnap, R. 1963, *The Philosopher Replies*, in *The Philosophy of Rudolf Carnap*, Schilpp (ed.) 859–1013.
- Leitgeb, Hannes and André Carus, 2020, *Rudolf Carnap, Supplement D: Methodology*, *The Stanford Encyclopedia of Philosophy* (Fall 2022 Edition), Edward N. Zalta & Uri Nodelman (eds.)
- Stein, H. (1992). Was Carnap entirely wrong, after all?. *Synthese*, 275–295.
- Thébault, K. P. (2023). Big bang singularity resolution in quantum cosmology. *Classical and Quantum Gravity*, 40(5), 055007.
- Warrier, N. (2022). The case of the vanishing wavefunction. *Studies in History and Philosophy of Science*, 96, 135–140.

Antonio Vassallo

Warsaw University of Technology

Patterns of Dependence in General Relativity: The Case of Frame-Dragging

This talk develops a layered structural equation model (SEM) of the frame-dragging effect as measured by the Gravity Probe B experiment, and uses it to analyze the structure of dependence in relativistic physics. The model distinguishes

three interconnected layers—ontological configuration, theoretical description, and observational access—and makes explicit how empirical results arise through their interaction.

The proposal builds on recent applications of structural equation modeling to physical systems and on philosophical analyses of frame-dragging as a test case for dependence relations in general relativity. The Gravity Probe B experiment provides a particularly clear setting in which physical configuration, theoretical representation, and experimental practice are tightly integrated, allowing the dependence structure of the phenomenon to be displayed in a tractable yet informative way.

On this basis, the talk advances a monist view of dependence. Familiar idioms in scientific practice—causal, grounding, nomological, and epistemic—are interpreted as coarse-grained projections of a single underlying dependence structure rather than as distinct metaphysical relations. The frame-dragging case is especially instructive, as the dependencies involved are non-local, mediated by representational choices, and tightly coupled to experimental procedures, thereby resisting straightforward classification within standard metaphysical categories. The SEM framework provides a precise way of representing these features and clarifies the role of theoretical structure in connecting physical systems to observational outcomes.

The analysis illustrates how logical and structural tools can be used to extract metaphysical insight from concrete scientific practice. More generally, it suggests a strategy for understanding dependence across physical theories that remains sensitive to the layered architecture of representation while avoiding an inflationary ontology of distinct dependence relations.