INTERNATIONAL SUMMER INSTITUTE IN PHILOSOPHY OF PHYSICS

ON THE PHILOSOPHY OF COSMOLOGY AND THE PHILOSOPHY OF QUANTUM GRAVITY

26 June - 1 July 2022
Morzine, France

Invited speakers

Karen Crowther
Nick Huggett
Claus Kiefer
Mairi Sakellariadou
Chris Smeenk
Francesca Vidotto
David Wallace
Christian Wüthrich

Organizing committee

Nick Huggett - Mike Schneider
Gaia Valenti - Christian Wüthrich

Hosted by the University of Geneva - University of Illinois at Chicago
Cosmology Beyond Spacetime project

UIC UNIVERSITY OF ILLINOIS CHICAGO

UNIVERSITÉ DE GENÈVE

JOHN TEMPLETON FOUNDATION

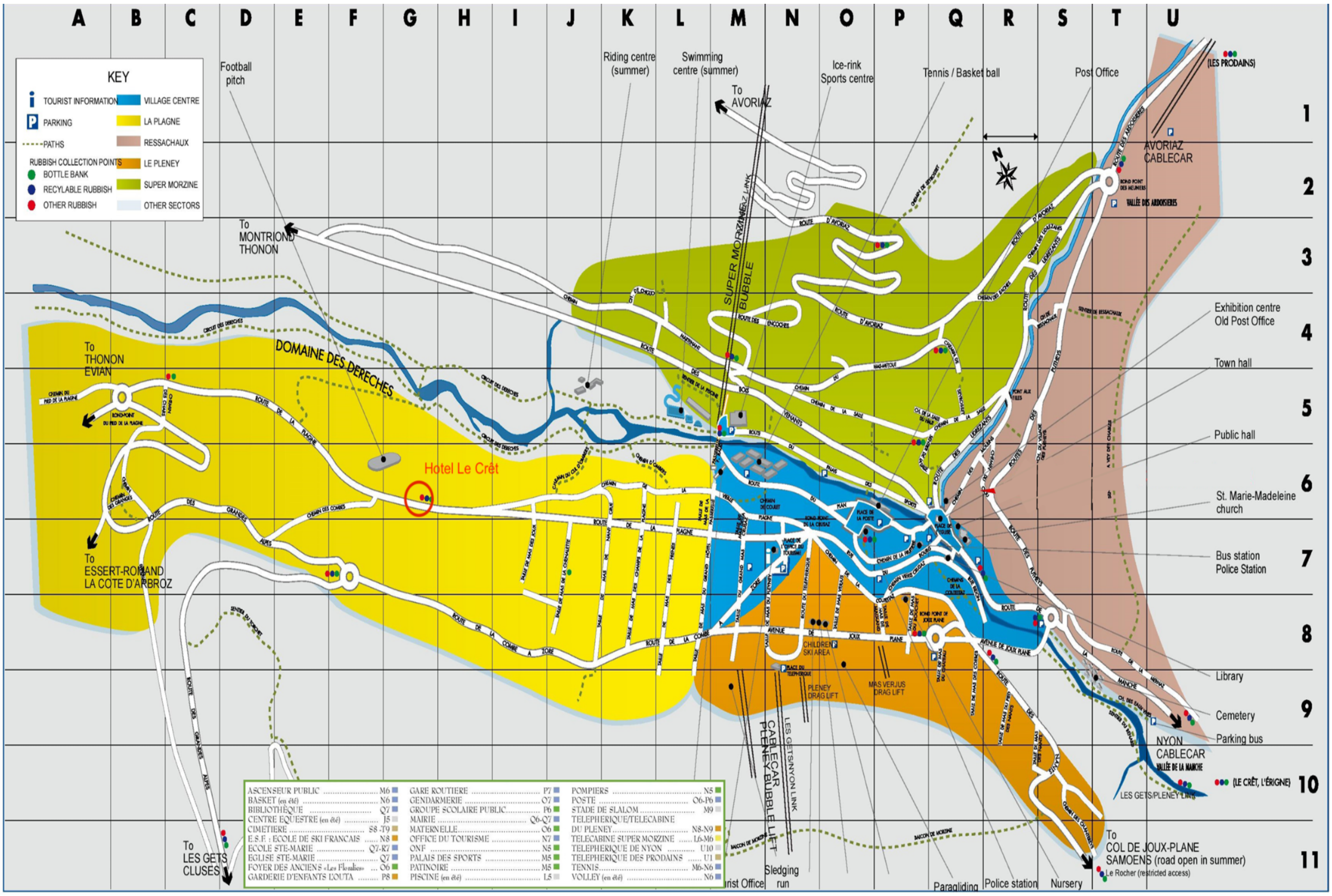
beyondspacetime.net

PRACTICAL INFORMATION

Hôtel Club Le Crêt
905 Route de la Plagne
74110 MORZINE (Haute-Savoie)
Tel. +33 450 79 09 21

Trip from Geneva to Morzine
We will organize the trip from **Geneva Airport** to Morzine. The group assignment will be sent to you by email. Please contact Gaia Valenti if you have any questions.

COVID-19
Please take note of the COVID requirements to enter France:
https://www.interieur.gouv.fr/covid-19-international-travel



SCHEDULE

Sunday, 26 June 2022

Afternoon: Arrival
18:30 Poster session and reception
20:00 Dinner

Monday, 27 June

08:45-09:00 Welcome: Wüthrich
09:00-10:30 Lecture Wallace 1
10:30-11:00 Coffee break
11:00-12:30 Lecture Wüthrich

12:30-14:00 Lunch

14:00-15:30 Working groups
16:00-16:30 Coffee break
16:30-18:00 Lecture Huggett

19:00 Dinner

Tuesday, 28 June

09:00-10:30 Lecture Sakellariadou 1
10:30-11:00 Coffee break
11:00-12:30 Lecture Smeenk 1

12:30-14:00 Lunch

14:00-15:30 Working groups
16:00-16:30 Coffee break
16:30-18:00 Lecture Vidotto 1

19:00 Dinner

Wednesday, 29 June

09:00-10:30 Lecture Wallace 2
10:30-11:00 Coffee break
11:00-12:30 Lecture Crowther 1

12:30-14:00 Lunch

14:00-18:00 Hike, free time

19:00 Dinner

Thursday, 30 June

09:00-10:30 Lecture Smeenk 2
10:30-11:00 Coffee break
11:00-12:30 Lecture Sakellariadou 2

12:30-14:00 Lunch

14:00-15:30 Working groups
16:00-16:30 Coffee break
16:30-18:00 Lecture Crowther 2

19:00 Dinner

Friday, 1 July

09:00-10:30 Lecture Vidotto 2
10:30-11:00 Coffee break
11:00-12:30 Rapporteur session

12:30-14:00 Lunch, end of summer institute

Afternoon: Departure

LECTURES

(alphabetical by speaker)

General Video Suggestions:

- Nick Huggett: From strings to spacetime: https://www.youtube.com/watch?v=_qtUQpXmJBM&list=PLVzK6UpZmNq3vbvWip2g52FNZ9Ga5k_KK&index=11
- Carlo Rovelli: Space and time (or not?) in loop quantum gravity: https://www.youtube.com/watch?v=8GWEPyhzn_U&list=PLVzK6UpZmNq2bFIn5nS9kFVDMTa7DaovF&index=4
- David Wallace: Quantum gravity at low energies: https://www.youtube.com/watch?v=boQ_KPLuOis

Karen Crowther (University of Oslo)

Lecture 1: Interpretations of Infinity in Physics

These two lectures concern the way in which singularities (and the related idea of mathematical consistency) serve to motivate, guide, and constrain the search for a theory of QG. The first lecture discusses various cases of infinities in physics and their differing interpretations, drawing from previous and current theories aside from QG, including GR and QFT. It will also address the broader issue of consistency in scientific theories.

Lecture 2: Four Attitudes Towards Singularities in Search for a Theory of QG

This lecture builds upon the background of Lecture 1, and explores four different attitudes that we might have towards singularities in the search for a theory of QG. It uses examples from the physics literature to show how these different attitudes towards various singularities can lead to different scenarios for the new theory. The lecture also discusses the more general issue of finding and evaluating constraints upon any new theory of QG.

Nick Huggett (University of Illinois at Chicago)

Lecture: Quantum gravity in a laboratory?

The characteristic – Planck – energy scale of quantum gravity is utterly beyond current technology, making experimental access to the relevant physics apparently impossible.

Nevertheless, low energy experiments linking gravity and the quantum have been undertaken: the Page and Geilker quantum Cavendish experiment, and the Colella-Overhauser-Werner neutron interferometry experiment, for instance. However, neither probes states in which gravity remains in a coherent quantum superposition, unlike — it is claimed — recent proposals that have created considerable interest among physicists. In essence, if two initially unentangled subsystems interacting solely via gravity become entangled, then a simple theorem of quantum mechanics shows that gravity cannot be a classical subsystem. There are formidable challenges to creating such a system, but remarkably, tabletop technology into the gravitational fields of very small bodies has advanced to the point that such an experiment might be feasible in the next several years. In this talk I will explain the proposal and what it aims to show, highlighting the important ways in which its interpretation is theory-laden. (Drawn from joint work with Niels Linnemann and Mike Schneider.)

Suggested readings:

- Huggett, Nick, Niels Linnemann, and Mike Schneider. "Quantum gravity in a laboratory?." *arXiv preprint arXiv:2205.09013* (2022).

Claus Kiefer (University of Cologne)

Unfortunately, Claus Kiefer is unable to join the summer institute.

Mairi Sakellariadou (King's College London)

Lectures 1 and 2: Highlights on Quantum Gravity and Fundamental Cosmology

After presenting the standard cosmological model based on General Relativity, I will highlight some open questions and discuss the inflationary paradigm from a critical point of view. I will argue that we need a theory of quantum gravity and that cosmology is the ideal test bed for a quantum theory of spacetime geometry. I will then briefly review different approaches to quantum gravity and discuss possible tests through cosmological/astrophysical implications. I will end with some criticisms, open questions, debates on quantum gravity proposals and phenomenological cosmological models.

Chris Smeenk (Western University Canada)

Lecture 1: Theories of Origins

There is a sharp divide between different ways of approaching a theory of the origins of the universe. One approach aims to select an initial state in some sense, rather than treating initial conditions as merely contingent facts. This 'selection' takes several forms, ranging from constraints needed to account for thermodynamic asymmetries (versions of the 'Past

Hypothesis'), to new theoretical principles that select a specific state (such as the no boundary proposal, or the more recent CPT symmetric universe), to (more controversially) anthropic selection from an ensemble. The opposing approach aims to minimize the impact of the initial state, by showing that dynamics with appropriate features will generate an output state with desirable features for suitably 'generic' initial conditions. The aim of the first lecture is to provide an overview of the more philosophical aspects of these debates, and develop an argument current versions of 'dynamical' theories are not self-sufficient: they require substantive constraints on the initial states, and hence require some appeal to selection.

Lecture 2: Inflation and Quantum Gravity

Inflationary cosmology proposes that the universe passed through a transient phase of exponential expansion in the early universe, leading to several characteristic features in the post-inflationary state. Inflation has been the dominant account of this phase of the universe's history for nearly four decades, based on its phenomenological success. It remains a 'paradigm' in that a wide range of inflationary models are compatible with observations, but there is no single canonical model. After briefly reviewing standard lore regarding inflation, I will focus on two foundational questions regarding inflation. First, how should we characterize inflation's success in matching observations of the early universe, and to what extent does this support the theory? Second, how does inflation relate to theories of quantum gravity? More specifically, to what extent does inflation require assumptions about the pre-inflationary state or 'trans-Planckian' modes, and can inflationary models be consistently treated as low-energy effective field theories?

Francesca Vidotto (Western University Canada)

Lecture 1: The Path to Quantum Gravity

To select the principles guiding the construction of a quantum theory of gravity, we need to select what we consider the fundamental aspect of respectively the quantum theory and the spacetime one. I focus on discreteness as the core aspect of the quantum theory, and on the identification of spacetime as a dynamical (gauge) field in general relativity. These principles lead to loop quantum gravity. By highlighting these principles, we can clarify questions such as spacetime emergence and the disappearance of Newtonian time in quantum gravity. I give a brief overview of the theory, discussing the covariant formulation of the theory. This gives transition amplitudes that provides a tool for concrete physical computation. I mention the principal applications such as the graviton propagator or the black-hole transition into a white hole. The application to cosmology is the main topic of a separate lecture.

Lecture 2: The Path to Quantum Cosmology

In the history of the development of quantum gravity, quantum cosmology has represented at first a simplified framework to study the quantization. Cosmological symmetries allow to reduce the infinite degrees of freedom of general relativity to a few, that can be quantized.

Loop quantum cosmology is a successful example of how this has led to both a better understanding of the theory and, most importantly, to several observational predictions. Vice versa, in this lecture I discuss the path to extract cosmological predictions starting from the full covariant loop quantum gravity dynamics. I focus on the general way to understand singularity resolution in the theory, and the current effort to compute primordial quantum fluctuations. These research directions are made possible by the strong conceptual backup provided by the principles discussed in the first lecture, probing once more the role philosophical stances play in the theory construction.

David Wallace (University of Pittsburgh)

Lecture 1: Quantum Gravity at Low Energy

I will give a conceptually-focussed presentation of `low-energy quantum gravity' (LEQG), the effective quantum field theory obtained from general relativity and which provides a well-defined theory of quantum gravity at energies well below the Planck scale. I will emphasize the extent to which some such theory is required by the abundant observational evidence in astrophysics and cosmology for situations which require a simultaneous treatment of quantum-mechanical and gravitational effects, contra the often-heard claim that all observed phenomena can be accounted for either by classical gravity or by non-gravitational quantum mechanics, and I will explain how a treatment of the theory as fluctuations on a classical background emerges as an approximation to the underlying theory rather than being put in by hand. I will briefly discuss the search for a Planck-scale quantum-gravity theory from the perspective of LEQG and/or give an introduction to the Cosmological Constant problem as it arises within LEQG.

Background reading:

- D.Wallace, “Quantum gravity at low energies”, https://arxiv.org/abs/2112.12235

Lecture 2: The Black Hole Information Loss Problem

I distinguish between two versions of the black hole information-loss paradox. The first arises from apparent failure of unitarity on the spacetime of a completely evaporating black hole, which appears to be non-globally-hyperbolic; this is the most commonly discussed version of the paradox in the foundational and semipopular literature, and the case for calling it `paradoxical' is less than compelling. But the second arises from a clash between a fully-statistical-mechanical interpretation of black hole evaporation and the quantum-field-theoretic description used in derivations of the Hawking effect. This version of the paradox arises long before a black hole completely evaporates, seems to be the version that has played a central role in quantum gravity, and is genuinely paradoxical.

Background reading:

- D. Wallace, "Why black hole information loss is paradoxical", https://arxiv.org/abs/1710.03783.

Further reading:

- D.Harlow, “Jerusalem lectures on black holes and quantum information”, https://arxiv.org/abs/1409.1231.
- S. Mathur, "The black hole information loss paradox: a pedagogical introduction", https://arxiv.org/abs/0909.1038.
- G. Belot, J. Earman and L. Ruetsche, "The Hawking information loss paradox: the anatomy of controversy", https://www.journals.uchicago.edu/doi/10.1093/bjps/50.2.189.

Christian Wüthrich (University of Geneva)

Lecture: Analogue Gravity and Confirmation of Black Hole Physics

Our best theoretical framework for understanding black holes suggests that black hole emit Hawking radiation. The trouble with this hypothesis is that the predicted Hawking radiation of astrophysical black holes is way too tiny to be detectable against the fluctuations of the cosmic microwave background radiation. In this context, so-called 'analogue experiments' involving for example 'dumb holes' in fluids and Bose-Einstein condensates have recently been promoted as means of confirming the existence of Hawking radiation in real black holes. The proposal of analogue gravity has led to a lively debate in philosophy of science about the possibility of actually confirming hypotheses on inaccessible target systems such as astrophysical black holes. I will review this debate and comment on some of the most recent developments.

Reading:
- K. Crowther, N. Linnemann, C. Wüthrich. What we cannot learn from analogue experiments. *Synthese* **198** (2021): S3701-S3726. https://link.springer.com/article/10.1007/s11229-019-02190-0.

Further reading:
- R. Dardashti, K.P.Y. Thébault, E. Winsberg. Confirmation via analogue simulation: what dumb holes could tell us about gravity. *British Journal for the Philosophy of Science* **68** (2017): 55-89. https://www.journals.uchicago.edu/doi/abs/10.1093/bjps/axv010.
- P.W. Evans and K.P.Y. Thébault. On the limits of experimental knowledge. *Philosophical Transactions of the Royal Society* A**378** (2020): 2177. https://royalsocietypublishing.org/doi/epdf/10.1098/rsta.2019.0235.

POSTER SESSION

(alphabetical by author)

Bruno Arderucio Costa: Can Quantum Mechanics Breed Negative Masses?

It is no secret that quantum mechanics often produces weirdness. While some of its unexpected predictions are seemingly inconsequential, sidestepping confrontation with experiments, others could, in principle, be game-changers. Or couldn't they? In this poster, we focus on quantum mechanical violations of the classical energy conditions, i.e., reasonable expectations on the classical matter that, for example, prevent one from building a time machine to meet oneself in the past. Without compliance with energy conditions, it may seem intriguing why there aren't negative masses roaming around us. Based on the Casimir effect, we argue that it may be fundamentally impossible to *observe* an object with a negative mass, despite the presence of static negative energy densities. We identify the specific elements that outweigh the Casimir energies, making the entire apparatus yield an attractive gravitational force on distant bodies.

Saakshi Dulani: Information, Entropy Bounds, and The Holographic Principle

For familiar statistical mechanical systems, we expect entropy to scale with volume – more space means more available states. However, Bekenstein-Hawking entropy scales with area, not volume. Assuming that Bekenstein-Hawking entropy is a complete measure over black hole degrees of freedom and that black holes are the most entropic objects in the universe, Bekenstein-Hawking entropy represents a bound on how many degrees of freedom can be packed into a region of spacetime. Susskind creatively dubbed the spherical entropy bound the ‘Holographic Principle,’ which states that the maximum amount of information needed to specify what is happening in the bulk of a system can be encoded on its boundary, much like a 3-D hologram is projected from a 2-D film. This analogy has been further sensationalized by the preliminary successes of AdS/CFT correspondence. Maldacena showed that string-theoretic dynamics in a conformal field theory without gravity can be mapped onto the bulk of a higher-dimensional anti-de Sitter space containing black holes. My goal for this presentation is to analyze the relationship between the Holographic Principle (as motivated by black hole statistical mechanics) and AdS/CFT correspondence. Are they separate or interdependent claims? Does theoretical support for AdS/CFT correspondence strengthen the merits of the Holographic Principle, even if entropy bounds lack ironclad generality and admit of violations? The answers to these questions depend sensitively on the notions of duality and physical equivalence being employed. A philosophically careful treatment of these terms and transparency about technical maneuvers weaken the connection between the Holographic Principle and AdS/CFT correspondence.

Luca Gasparinetti: Rovelli’s “Wittgensteinian Quietism”: a Philosophical Cure for Philosophers of Time

Generally, a tensed theory of time and physical theories are incompatible. Such incompatibility is rooted in a dichotomy between the manifest and the scientific image of time that raises anxieties centered on unsolved debates – e.g., presentism-eternalism. Nevertheless, Rovelli (2021) indicates the cure: since time is a multilayered concept, there is no dichotomy. There are several facets of time. None of these are false, but all are valid in different contexts. In this paper, I apply “Rovelli's quietism” to a typical debate in the philosophy of time. Some philosophers state that tensed concepts are incompatible with physics (Callender 2008). Others argue that quantum gravity is compatible with a tensed time (Monton 2006). In light of such unsolved debate, I propose a quietist therapy: there is no solution to the problem because it must not be raised.

Viktoria Kabel: Falling through masses in superposition: quantum reference frames for indefinite metrics

The current theories of quantum physics and general relativity on their own do not allow us to study situations in which the gravitational source is quantum. I will present a strategy to determine the dynamics of objects in the presence of mass configurations in superposition, and hence an indefinite spacetime metric, using quantum reference frame (QRF) transformations. Specifically, my collaborators and I showed that, under certain conditions, one can use an extension of the current framework of QRFs to change to a frame in which the mass configuration becomes definite. Assuming covariance of dynamical laws under quantum coordinate transformations, this allows to use known physics to determine the dynamics. We applied this procedure to find the motion of a probe particle and the behavior of clocks near the mass configuration, and thus found the time dilation caused by a gravitating object in superposition. Comparison with other models further shows that semi-classical gravity and gravitational collapse models do not obey the covariance of dynamical laws under quantum coordinate transformations.

Álvaro Mozota Frauca: Taking seriously the problem of time of quantum gravity

In this paper I raise a worry about the most extended resolutions of the problem of time of canonical quantizations of general relativity. The reason for this is that these resolutions are based on analogies with deparametrizable models for which the problem can be solved, while I argue in this paper that there are good reasons for doubting about these resolutions when the theory is not deparametrizable, which is the case of general relativity. I introduce an example of a non-deparametrizable model and argue that the standard resolutions of the problem of time don't work for this case. I argue that as general relativity is strongly analogous to this model, one should take seriously the view that the canonical quantization of general relativity doesn't lead to a meaningful quan- tum theory. Finally, I comment that this has an impact on the foundations of different approaches to quantum gravity.

Ray Pedersen: Why Not Assume Just One Everettian Universe?

Bare Everettian quantum mechanics (EQM) suggests that for any quantum mechanical process, all possible outcomes obtain. On first inspection, EQM appears to lend itself well to many worlds interpretations. However, this approach requires a metaphysical commitment to a form of modal realism. In response to this concern, I propose a single-world Everettian universe. On my model, the complete branching structure itself is a metaphysically possible world. To solve the problem of probability in a single world where all possible outcomes obtain, I propose that in addition to the mereological concepts of material and temporal parts, branchlike parts exist. I then use a decision theoretic approach to treating probabilities as the credences of a rational agent, where the probability of some outcome corresponds to branch weight. This one-world model thus has the capacity to reproduce the predictions of the Born rule while addressing concerns over the apparent frivolity of many-world interpretations.

Farshid Soltani: The black-to-white hole transition

Black holes formation and evolution have been extensively studied at the classical level. However, little is known about the end of their lives and about the true nature of the spacetime singularity in their interior, the description of which requires to consider the quantum nature of the gravitational field. A very natural and conservative scenario describing the physics of both regions is the black to white hole transition: the quantum transition of the black hole geometry in the geometry of a white hole. Recent theoretical evidence suggests a scenario in which the black hole horizon undergoes a quantum transition into a white hole horizon and the classical singularity is replaced by a smooth transition of the interior trapped region into an anti-trapped region. I review the evidence supporting this scenario and I discuss how the spin foam formalism can be used to describe the non-perturbative physics of the horizon.

Diana Taschetto: Classical and Quantum Observables

According to the so-called algebraic approach, the physical content of a quantum theory lies in its algebra of observables. Hence to identify the observables of a theory. This conditio *sine qua non* to determine what the world must be like if the theory is to be true of the world; what requirements a quantity must satisfy in order to count as an observable, however, is an open problem. Ambiguities notwithstanding, quantum observables are generally constructed by following out the prescription advanced by Dirac: Replace the Poisson brackets between classical observables by ħ/i times the commutator between the corresponding quantum observables. The purpose of this presentation is to briefly discuss the meaning of the “correspondence” thereby intended, the assumptions involved, its limitations and implications.

WORKING GROUPS

(alphabetical by group leader)

Emily Adlam: Quantum Foundations and Gravity

Day 1: Indefinite Causal Structure (Ognyan Oreshkov, Fabio Costa, Caslav Brukner: Quantum correlations with no causal order, https://arxiv.org/abs/1105.4464): The framework of indefinite causal structure studies the possible correlations between agents who locally have free choice over all operations compatible with quantum mechanics but who globally are not subject to any restrictions of causal order. What does this framework teach us about causation in quantum gravity, and does it give us new insight into philosophical questions about causation? What do we learn from experimental implementations of indefinite causal structures?

Day 2: Internal Quantum Reference Frames (Flaminia Giacomini, Caslav Brukner: Einstein's Equivalence principle for superpositions of gravitational fields, https://arxiv.org/abs/2012.13754): We usually do physics relative to an external reference frame, but presumably there is no reference frame external to the universe as a whole, so at some point we will have to do physics relative to an internal subsystem of the universe instead. The internal quantum reference frame programme studies how to establish and switch between such reference frames. Are these reference frames really reference frames in an operationally meaningful sense? How should we expect them to be used in quantum gravity, and what is the significance of an Equivalence Principle defined using internal quantum reference frames?

Day 3: Tabletop Gravity and the Measurement Problem (Emily Adlam: Tabletop Experiments for Quantum Gravity Are Also Tests of the Interpretation of Quantum Mechanics, https://arxiv.org/abs/2204.08064): Recently there has been a great deal of interest in tabletop experiments intended to exhibit the quantum nature of gravity by demonstrating that it can induce entanglement, but the results of these experiments may also teach us something about the interpretation of quantum mechanics. Which interpretations naturally predict a positive result to these experiments, and which interpretations naturally predict a negative result? If the result is not as predicted by some particular interpretation, how would we have to change the interpretation to accommodate the result, and is that a reasonable cost to bear?

Bruno Arderucio: Black Hole Thermodynamics, Information Loss, and the Nature of Entropy

Hawking's prediction for the temperature of a black hole shows off four constants in a single formula: Boltzmann's, Planck's, Newton's, and the speed of light. Both quantum mechanics and general relativity are manifestly indispensable for its obtention. Following the birth of black hole thermodynamics, several conceptual issues (re-)emerged. In our first encounter, we discuss the foundations of the field and compare them to the thermodynamics of ordinary systems' (reading suggestion: sections 2-4 of Ref. [2]). Our second discussion session focuses on interpreting the nature of entropy (reading suggestions: Ref. [1] and section 5 of Ref. [2]). Our final meeting is devoted to information loss in black holes and how one can envision quantum gravity to modify the picture (reading suggestion: Ref. [3] and section 6 of Ref. [2]).

Readings:

- [1] E. T. Jaynes, Gibbs vs Boltzmann Entropies. American Journal of Physics 33, 391 (1965)
- [2] R. M. Wald, The Thermodynamics of Black Holes. Living Rev. in Rel. 4, 6 (2001)
- [3] A. Almheiri, T. Hartman, J. Maldacena, E. Shaghoulian, and A. Tajdini, The entropy of Hawking radiation. Rev. Mod. Phys. 93, 035002 (2021)

Ali Barzegar: Philosophical Aspects of Spacetime Emergence

According to many theories of quantum gravity, spacetime disappears at the fundamental ontological level. This gives rise to the problem of empirical incoherence: there are no local beables in a theory of quantum gravity and so the features necessary to confirm or disconfirm it through empirical evidence seem to be absent from reality. To avoid this threat of empirical incoherence, spacetime is regarded as emergent from the more fundamental non-spatiotemporal entities. One can understand this notion of spacetime emergence in two different ways. According to spacetime functionalism, the fundamental entities somehow realize the relevant spacetime functions or play the spacetime role. However, according to spacetime compositionalism, spacetime is composed of non-spatiotemporal entities or atoms of spacetime just like a chair is composed of atoms. Moreover, this idea of spacetime emergence seems to give rise to a kind of hard problem of spacetime. That is, there seems to be an explanatory gap between the notions of the spatiotemporal and the non-spatiotemporal. Whether this is a real problem or not needs to be addressed.

- First Session: We will discuss various aspects of the problem of empirical incoherence for theories of quantum gravity (Reading: Huggett and Wüthrich 2013).
- Second Session: There are two ways to understand the spacetime emergence: functionalism vs. compositionalism. The two solutions and their difficulties will be discussed (Reading: Baron 2019).
- Third Session: We will discuss the so-called hard problem of spacetime emergence and ways to solve or dissolve it (Reading: Le Bihan 2021).

Readings:

- Baron, S. (2019). The Curious Case of Spacetime Emergence. Philosophical Studies 177 (8): 2207-2226.
- Baron, S. and B. Le Bihan (2022). Composing Spacetime. Journal of Philosophy 119 (1): 33-54.
- Huggett, N. and C. Wüthrich (2013). Emergent spacetime and empirical (in)coherence. Studies in History and Philosophy of Modern Physics 44 (3), 276-285.
- Lam, V. and M. Esfeld (2013). A dilemma for the emergence of spacetime in canonical quantum gravity. Studies in History and Philosophy of Modern Physics 44 (3), 286-293.
- Lam, V. and C. Wüthrich (2018). Spacetime is as spacetime does. Studies in History and Philosophy of Modern Physics 64, 39-51.

- Le Bihan, B. (2021). Spacetime emergence in quantum gravity: Functionalism and the hard problem. Synthese 199 (2): 371-93.
- Wüthrich, C. (2019). The Emergence of Space and Time. In Sophie Gibb, Robin Finlay Hendry, and Tom Lancaster (eds.), *Routledge Handbook of Emergence*, Oxford: Routledge, 315-326.
- Yates, D. (2021). Thinking about spacetime. In C. Wüthrich, B. Le Bihan, and N. Huggett (Eds.), Philosophy Beyond Spacetime. Oxford University Press.

Eugene Chua and Lucy James: The Problem of Time

This series of discussion groups explores the problem of time, along with some of its proposed solutions. Of course, there are many problems of time in philosophy and physics; for us, the focus is on the particular problem that arises when preparing a background independent classical theory, such as general relativity, for quantization. This involves an introduction to gauge symmetries, which are usually taken to imply unphysical degrees of freedom. In the case of a background independent theory, time evolution behaves like a gauge symmetry, leading to the idea that 'time disappears' in quantum gravity. The aim of the first session is to show how this problem arises, and to discuss what might be required from a possible solution. Reading for this session is Thebault's 'The Problem of Time' (2019).

Physicists have tried to resolve the problem of time in a multitude of ways. Claus Kiefer's semiclassical time approach argues, roughly, that a variable which can play the time role in a Schrodinger-like equation emerges from an application of various approximation techniques to the canonical approach. We will read Chua and Callender's 'No Time for Time from No-Time' (2021), which critiques this view by arguing that these approximation techniques are typically justified with respect to some background time variable, something we do not have access to in the canonical approach.

Carlo Rovelli's thermal time approach instead starts from the observation that thermodynamic equilibrium is classically defined in terms of time. He reverses this observation and argues that we can use the notion of equilibrium to define a time parameter. Time, on this view, emerges as a result of thermodynamical considerations. We will read Swanson's 'Can Quantum Thermodynamics Save Time?' (2021), which raises a series of technical problems, alongside some open conceptual worries. Participants are invited to read Rovelli's non-technical introduction / interpretive approach to thermal time in 'The Order of Time' (2018, end of Ch. 9 and beyond), though it is optional.

Siska de Baerdemaeker: Epistemology of Cosmology – Leveraging observational cosmology to test theories of (quantum) gravity

ΛCDM, the concordance model of the evolution of the universe, is hugely successful. However, the model faces challenges when being extended to (sub-)galactic scales, as well as to the very early universe. This has opened up the possibility to leverage observational cosmology to text various speculative theories— including theories of quantum gravity or hybrid dark matter/modified gravity theories. We'll investigate how observational cosmology can be leveraged to test theories of (quantum) gravity and other introductions of novel physical phenomenology. Specifically, we will discuss (i) the structure of justification for ΛCDM itself, including the application of the FLRW-metric to the universe; (ii) epistemology of cosmological simulations; and, (iii) gravitational wave tests of modified theories of gravity.

Readings:

- Day 1: Smeenk, Chris (2020). Some reflections on the structure of cosmological knowledge. *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics* 71:220-231.
  Our starting point will be a discussion of the epistemic foundations of ΛCDM itself. Smeenk uses Howard Stein's philosophy of science to illuminate the justification for cosmological knowledge. The central question of the paper is "whether [ΛCDM] has a clear physical status, such that any systematic discrepancy between the model and observations can be reliably taken to indicate the need to include a new physical feature" (230).
- Day 2: Gueguen, Marie (2021). A Tension Within Code Comparisons. [Preprint] URL: http://philsci- archive.pitt.edu/id/eprint/19227 (accessed 2022-05-09).
  Leveraging observational cosmology to test alternative theories of gravity in part depends on being able to derive predictions from ΛCDM. Such predictions depend largely on numerical simulations. But how is the reliability of these simulation results established? Gueguen shows that two common strategies—convergence studies and code comparisons—have inherent shortcomings.
- Day 3: Patton, L. (2020). Expanding theory testing in general relativity: LIGO and parametrized theories. *Studies in History and Philosophy of Modern Physics*, *69*, 142–153.
  Patton uses LIGO as a case study to argue that formal reasoning can extend GR's empirical reach. Specifically, she investigates the parametrized post-Einsteinian framework to allow a broader, more flexible testing of assumptions underlying theories of gravity. Patton ties the ppE-testing from multi-messenger astronomy explicitly into views on theory testing from Carnap, Hempel, and Stein.

Rasmus Jaksland: Duality

This discussion group concerns dualities in string theory. A duality obtains when two apparently very different theories or models nevertheless prove to be physically equivalent. In the first session, we will introduce various string dualities and discuss whether they generate a new kind of underdetermination that could challenge scientific realism. The second session focuses on T-duality (a duality between spaces with large radius and spaces with small radius) and on the implications this duality appears to have for the nature of spacetime in string theory. Finally, the third session investigates the intriguing AdS/CFT duality which relates semi-classical gravity in five dimensions (AdS side) to non-gravitational quantum field theory in four dimensions (CFT side). We will in particular discuss whether this duality shows that gravity and (dynamical) spacetime emerges from quantum degrees of freedom.

Readings:

- Underdetermination: The Empirical Under-Determination Argument Against Scientific Realism for Dual Theories | SpringerLink
- T-duality: Target space ≠ space - ScienceDirect

- AdS/CFT: Emergence in holographic scenarios for gravity - ScienceDirect (we won't discuss section 4, so only read it out of interest).

Mike Schneider: Quantum Gravity in the Early Universe

The standard Lambda-CDM model of cosmology correctly describes the past evolution of spatial structures in our observable universe over all cosmologically significant timescales, in terms of deviations exhibited within a history of uniform expansion of space. But the initial conditions assumed in the model have a very peculiar form. Taking the dynamics of the model as a hydrodynamic or effective field theory of the evolution of our entire cosmos, one would therefore like to also explain the necessary initial conditions, in terms of underlying fundamental physics. Moreover, the Lambda-CDM model exhibits a generic 'Big Bang' singularity within the 'early universe' epoch: a curvature and temperature blow-up everywhere in the vicinity of the moment in cosmic history, within the model, when one would like to supply a fundamental physical explanation to account for those initial conditions. This indicates that the fundamental physical explanation sought within the context of the early universe will draw on unknown particle physics of arbitrarily high energies, or even quantum gravity --- possibly resolving the Big Bang singularity as well, with implications for large-scale cosmology beyond the standard Lambda-CDM model.

Our discussion group will focus on all such topics to do with quantum gravity in the early universe. On the first day, we will rehearse and critique the dominant paradigm in 'early universe' cosmology: inflation. In this paradigm, the explanation for the initial conditions in the Lambda-CDM model is ostensibly separated from quantum gravity in the vicinity of the initial singularity, by means of positing a high-energy effective field theory dynamics shortly thereafter. But other paradigms differ on this point. On the second day, we will consider conceptual and operational issues in early universe cosmology concerning the fundamental physical explanation of 'cosmic time' familiar in the Lambda-CDM model. On the third day, we will discuss generally the relationship between research in early universe cosmology and research in quantum gravity on the topic of quantum cosmology. Readings are listed below.

- Day 1 --- Inflation and its alternatives: "Beyond Standard Inflationary Cosmology" by Robert H. Brandenberger, in *Beyond Spacetime*, 2020
- Day 2 --- The physical origins of cosmic time: "Limits of Time in Cosmology" by Svend E. Rugh and Henrik Zinkernagel, in *The Philosophy of Cosmology*, 2017
- Day 3 --- Quantum cosmology: "Relational Quantum Cosmology" by Francesca Vidotto, in *The Philosophy of Cosmology*, 2017