

Quantum de Sitter Universe

Report of Contributions

Contribution ID: 1

Type: **not specified**

Microscopics of de Sitter entropy from precision holography

Monday 17 April 2023 10:00 (1 hour)

I explain how quantum corrections to the entropy of four-dimensional de Sitter space can be computed using the AdS/CFT correspondence. Employing the intertwinement of Euclidean de Sitter and anti de Sitter saddles, I embed effective de Sitter gravity theories in M-theory and conjecture that the partition function of the ABJM CFT dual encodes all perturbative corrections to the de Sitter entropy in the static patch. This conjecture is checked for the first two subleading corrections to the area-law by studying four-derivative terms and one-loop effects in de Sitter gravity. Finally I comment on the extension of this framework to compute more tangible cosmological observables.

Author: HERTOOG, Thomas (KU Leuven)**Presenter:** HERTOOG, Thomas (KU Leuven)

Contribution ID: 2

Type: **not specified**

Finite features in quantum dS

Monday 17 April 2023 11:30 (1 hour)

It has been argued by several authors that the underlying state space might be finite dimensional in quantum de Sitter. We discuss this idea, and how recent developments, from a variety of perspectives, might help to refine and substantiate it.

Author: ANNINOS, Dionysios (King's College London)

Presenter: ANNINOS, Dionysios (King's College London)

Contribution ID: 3

Type: **not specified**

The matter with TT-bar + Lambda_2

Monday 17 April 2023 14:30 (1 hour)

We start by highlighting the convergence of several concrete research threads (among many) illuminating basic statistical mechanical properties of dS. In this line of development, the solvable TT-bar(+ Λ^2) deformation recently provided an explicit microstate count for the dS3 cosmic horizon, reproducing the refined Gibbons-Hawking entropy computed in <https://arxiv.org/abs/2009.12464> along with the correct emergent radial bulk geometry (<https://arxiv.org/abs/2110.14670>, <https://arxiv.org/pdf/2106.10227.pdf>). This includes a holographic realization of the first law sign derived in <https://arxiv.org/pdf/2208.11706.pdf>, <https://arxiv.org/pdf/2203.00700.pdf> via the Brown-York energy, the appropriate notion of temperature suggested in <https://arxiv.org/abs/2206.01083>, and the states entering into the flat entanglement spectrum derived for the global dS ground state in <https://arxiv.org/abs/1804.08623> (which itself may admit a TT-bar type formulation as in <https://arxiv.org/pdf/2204.00591.pdf>).

To build from this, we develop the correspondence toward incorporating the (subleading) effects of local bulk matter fields. On the gravity side, the deformation brings in the boundary to just outside a black hole horizon, where it is indistinguishable from the dS cosmic horizon, enabling a continuous passage to a bounded patch of dS. In string/M theory, the relationship between AdS/CFT and dS involves uplifts that change the internal topology, e.g. replacing an internal sphere S with an internal hyperbolic space H (and incorporating varying warp and conformal factors as derived in detail in <https://arxiv.org/abs/2104.13380>). We qualitatively connect these two approaches, noting that the differences in the extra dimensions between AdS black hole and dS solutions are washed out by internal averaging in the presence of a timelike boundary skirting the horizon. Returning to the bottom up, we add contributions to the differential equation describing the deformation to capture local bulk gauge and scalar fields (cf <https://arxiv.org/pdf/1807.11401.pdf>), including both charged black holes and time-dependent propagation of local fields. Finally, we comment on potential implications for the von Neumann algebra of the static patch in the presence of both matter and a finite Newton's constant, bridging the type I fun above and the type II result (at infinitesimal G_{Newton}) of <https://arxiv.org/pdf/2206.10780.pdf>.

Author: SILVERSTEIN, Eva (Stanford)

Presenter: SILVERSTEIN, Eva (Stanford)

Contribution ID: 4

Type: **not specified**

de Sitter: Swampland, wave functions and wormholes

Monday 17 April 2023 16:00 (1 hour)

I will first discuss briefly the status of dS space in string theory and related Swampland insights. I will attempt to draw connections between discussions on dS space in quantum cosmology to the Swampland and string theory. In doing so I will describe a proposal for a top-down de Sitter construction, and how it differs from the Hartle-Hawking state. I will end with a discussion about Euclidean wormholes in dS space, which seems somewhat better understood than Euclidean wormholes in flat or AdS space.

Author: VAN RIET, Thomas (KU Leuven)

Presenter: VAN RIET, Thomas (KU Leuven)

Contribution ID: 21

Type: **not specified**

Static Patch Holography & RG Flows of SYK

Tuesday 18 April 2023 10:00 (1 hour)

In two dimensions, the static patch of de Sitter can be accessed by observers sitting at the boundary of an AdS spacetime. This idea suggests that certain RG flows in the dual quantum mechanical theory should capture effects of quantum de Sitter space.

In this talk, I will explore tractable RG flows in the SYK model and discuss their implications to describe static patch physics at a microscopic level. These include open quantum systems and possible emergence of unitarity in the large- N limit.

Author: GALANTE, Damián (King's College London)

Presenter: GALANTE, Damián (King's College London)

Contribution ID: 22

Type: **not specified**

The discreet charm of the discrete series in dS_2

Tuesday 18 April 2023 11:30 (1 hour)

Unitarity in de Sitter is mired with potential pitfalls. One of them is that massive particles are represented by (so-called principal series) states with complex conformal dimensions. Even more confusing is that states with positive conformal dimensions and a bounded spectrum, known as the discrete series, are, at the free-field level, represented as scalar tachyons with a finely tuned mass, suggesting that these states mediate some sort of instability. Perhaps this suggests that no consistent field theory can be built with these particle representations. In dS_2 , however, this can not be the case, as discrete series states arise in the multiparticle spectrum of principal series matter. In this talk I will review some established facts about the discrete series in de Sitter and its quantization. I will then consider models with a particular type of gauge symmetry, where the discrete series makes an appearance in the pre-Hilbert space, but vanishes once the gauge constraints are imposed. Finally I will discuss how this construction can be extended to the case where gravity is dynamical .

Author: ANOUS, Tarek (Queen Mary University of London)

Presenter: ANOUS, Tarek (Queen Mary University of London)

Contribution ID: 23

Type: **not specified**

Clocks, Algebras and Cosmology

Tuesday 18 April 2023 14:30 (1 hour)

Author: GÓMEZ, César (ift uam-csic madrid)

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Contribution ID: 24

Type: **not specified**

De Sitter in supersymmetric Liouville theory

Tuesday 18 April 2023 16:00 (30 minutes)

In this talk I will discuss the interplay between supersymmetry and two-dimensional de Sitter space. In particular we consider a gauge fixed form of 2d supergravity coupled to an N=2 superconformal field theory. The resulting theory is known as N= 2 Liouville theory and also makes an appearance as the non-critical superstring theory. N=2 super Liouville admits a positive cosmological constant and is possibly a UV complete theory. I will discuss and contrast the results of supersymmetric localization and the explicit higher-loop evaluation of the gravitational path integral around its two-dimensional saddle.

Author: MÜHLMANN, Beatrix (McGill)

Presenter: MÜHLMANN, Beatrix (McGill)

Contribution ID: 25

Type: **not specified**

Keeping matter in the loop in dS₃ quantum gravity

Wednesday 19 April 2023 10:00 (1 hour)

In this talk I will discuss a novel mechanism that couples matter fields to three-dimensional de Sitter quantum gravity. This construction is based on the Chern-Simons formulation of three-dimensional Euclidean gravity, and it centers on a collection of Wilson loops winding around Euclidean de Sitter space. We coin this object a Wilson spool. To construct the spool, we build novel representations of $\mathfrak{su}(2)$. To evaluate the spool, we adapt and exploit several known exact results in Chern-Simons theory. Our proposal correctly reproduces the one-loop determinant of a free massive scalar field on S^3 as $G_N \rightarrow 0$. Moreover, allowing for quantum metric fluctuations, it can be systematically evaluated to any order in perturbation theory.

Author: CASTRO, Alejandra (University of Cambridge)

Presenter: CASTRO, Alejandra (University of Cambridge)

Contribution ID: 26

Type: **not specified**

Non-perturbative Contributions from Black Holes in de Sitter

Wednesday 19 April 2023 11:30 (1 hour)

I will discuss some progress in our understanding of the Euclidean action of de Sitter (charged) black hole spacetimes and their contributions in a Euclidean path integral approach, using a constrained instanton formalism. In a first attempt to start understanding non-perturbative corrections to de Sitter correlators, I will then describe how the late-time behavior of de Sitter correlators in conjugate static patches, for large mass, can be understood in terms of a sum over complex geodesics using a heat-kernel approximation. I will end with some important open questions.

Author: VAN DER SCHAAR, Jan Pieter (University of Amsterdam)

Presenter: VAN DER SCHAAR, Jan Pieter (University of Amsterdam)

Contribution ID: 27

Type: **not specified**

Holography for de Sitter 4-point correlators

Wednesday 19 April 2023 14:30 (1 hour)

In-in correlation functions in de Sitter may be related to AdS amplitudes and three-dimensional CFT correlators in multiple ways, each having different features but with only one of them being consistent with the dual theory being a local CFT. In this talk I will discuss the different possibilities and present holographic formulas for 2-, 3- and 4-point functions.

Author: SKENDERIS, Konstantinos (University of Southampton)

Presenter: SKENDERIS, Konstantinos (University of Southampton)

Contribution ID: 28

Type: **not specified**

Black holes in 3D dS

Wednesday 19 April 2023 16:00 (1 hour)

In three-dimensional de Sitter space classical black holes do not exist, and the Schwarzschild-de Sitter solution instead describes a conical defect with a single cosmological horizon. We argue that the quantum backreaction of conformal fields can generate a black hole horizon, leading to a three-dimensional quantum de Sitter black hole. Its size can be as large as the cosmological horizon in a Nariai-type limit. We show explicitly how these solutions arise using braneworld holography, but also compare to a non-holographic, perturbative analysis of backreaction due to conformally coupled scalar fields in conical de Sitter space. We analyze the thermodynamics of this quantum black hole, revealing it behaves similarly to its classical four-dimensional counterpart, where the generalized entropy replaces the classical Bekenstein-Hawking entropy. We compute entropy deficits due to nucleating the three-dimensional black hole and revisit arguments for a possible matrix model description of dS spacetimes. Finally, we comment on the holographic dual description for dS spacetimes as seen from the braneworld perspective.

Author: TOMAŠEVIĆ, Marija (CPHT, Ecole Polytechnique)

Presenter: TOMAŠEVIĆ, Marija (CPHT, Ecole Polytechnique)

Contribution ID: 29

Type: **not specified**

Differential Equations for Cosmological Correlators

Thursday 20 April 2023 10:00 (1 hour)

I will describe a geometric picture for cosmological perturbation theory. Through this geometry, we can determine differential equations satisfied by these correlators, as functions of their momenta. In this “holographic” picture, cosmological time evolution is encoded in a sort of Hamiltonian (a flat connection) in kinematic space. I will also show how to move away from the highly symmetric de Sitter arena, adding a twist which describes cosmological correlation functions for power-law FLRW cosmologies.

Author: PIMENTEL, Guilherme (Scuola Normale Superiore)

Presenter: PIMENTEL, Guilherme (Scuola Normale Superiore)

Contribution ID: 30

Type: **not specified**

Scalar Particles at the late-time boundary of de Sitter

Thursday 20 April 2023 11:30 (1 hour)

In quantum field theory on flat spacetime, analysis of the representations of the isometry group of spacetime with a vanishing cosmological constant has led to our current understanding of particle physics. In this talk we would like to discuss what can be learned about particles of a spacetime in the presence of a positive cosmological constant by studying the representations of the isometry group of de Sitter. We make use of the late-time behaviour of free scalar fields to address features of different categories of representations of the de Sitter group with focus on normalized single particle states.

Author: SENGOR, Gizem (Bogazici University)

Presenter: SENGOR, Gizem (Bogazici University)

Contribution ID: 31

Type: **not specified**

The Hilbert space and holography of information in de Sitter quantum gravity

Thursday 20 April 2023 14:30 (1 hour)

We obtain all solutions of the Wheeler-DeWitt equation with positive cosmological constant for a closed universe in the large-volume limit. We define a natural norm on the solution space and thereby obtain a description of the Hilbert space of quantum gravity in an asymptotically de Sitter spacetime. This provides the finite G_N generalization of the Hilbert space constructed by Higuchi using group averaging. All the states in this Hilbert space share the symmetries of the Euclidean vacuum. We use this property to generalize the principle of holography of information to de Sitter space: cosmological correlators (defined as appropriately gauge-fixed observables) in an arbitrary small region suffice to completely specify the state.

References:

- 1) <https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Farxiv.org%2Fabs%2F2303.16315&data=05%7C01%7C...>
- 2) <https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Farxiv.org%2Fabs%2F2303.16316&data=05%7C01%7C...>

Author: RAJU, Suvrat (Tata Institute for Fundamental Research)

Presenter: RAJU, Suvrat (Tata Institute for Fundamental Research)

Contribution ID: 32

Type: **not specified**

Non-perturbative QFT in de Sitter: representation theory and Källén–Lehmann spectral representation

Thursday 20 April 2023 16:00 (1 hour)

There has been an extensive series of works aimed at understanding the non-perturbative QFT in AdS and Minkowski spacetime using bootstrap techniques. Implementing these techniques to QFT in dS requires a concrete understanding of Hilbert space decomposition into Unitary Irreducible Representation (UIR) of the dS symmetry group. In this spirit, we study the decomposition of the tensor product of free theory single-particle states as well as conformal multiplets of a bulk CFT into UIR of dS. Our main tools are the Harish-Chandra characters and the numerical diagonalization of the truncated quadratic Casimir of $SO(1,d+1)$. As the first step in a non-perturbative approach to QFT in dS, we derive the Kallen-Lehmann representation of spinning two-point functions. We find an inversion formula for the spectral density and discuss its analyticity properties. We conclude by reporting explicit expressions of the spectral density for several examples including CFT and free theory composite operator two-point functions.

Author: SALEHI VAZIRI, Kamran (University of Amsterdam)

Presenter: SALEHI VAZIRI, Kamran (University of Amsterdam)

Contribution ID: 34

Type: **not specified**

The central dogma and entanglement in de Sitter space

Friday 21 April 2023 10:00 (1 hour)

The central dogma of black hole physics –which says that from the outside a black hole can be described in terms of a quantum system with $\exp(\text{Area}/4G)$ states evolving unitarily –has recently been supported by computations indicating that the interior of the black hole is encoded in the Hawking radiation of the exterior. In this talk, we probe whether such a dogma for cosmological horizons has any support from similar computations. The fact that the de Sitter bifurcation surface is a minimax surface (instead of a maximin surface in the case of black holes) causes problems with this interpretation when trying to import calculations analogous to the AdS case. This suggests placing the holographic dual on the de Sitter horizon itself, where we formulate a two-sided extremization prescription for computing entanglement entropy in the holographic dual. We find answers consistent with general expectations for a quantum theory of de Sitter space, including a vanishing total entropy and an entropy of $A/4G$ when restricting to a single static patch. We will also explore some other approaches to probing a microscopic foundation for the Gibbons-Hawking entropy.

Author: SHAGHOULIAN, Edgar (University of California Santa Cruz)

Presenter: SHAGHOULIAN, Edgar (University of California Santa Cruz)

Contribution ID: 35

Type: **not specified**

Cosmic ER=EPR

Friday 21 April 2023 11:30 (1 hour)

We show in the context of dS/CFT that de Sitter spacetime emerges from quantum entanglement between two copies of the holographically dual CFT.

Author: STROMINGER, Andrew (Harvard University)

Presenter: STROMINGER, Andrew (Harvard University)

Contribution ID: 36

Type: **not specified**

Entanglement and Islands in de Sitter JT Gravity

Friday 21 April 2023 14:30 (1 hour)

In recent years, our understanding of (entanglement) entropy in gravitational systems has led to remarkable insights into the nature of black holes and in particular the discovery of entanglement islands. In this talk, I will discuss to what extent these developments can be applied to the de Sitter horizon in JT gravity. I will stress the important differences of black hole vs. cosmological horizons and review several proposals to apply the island formula to de Sitter space. In particular, while pure de Sitter space in thermal equilibrium does not seem to support non-pathological islands, I will show how a non-equilibrium quantum state does harbor them. This suggests the necessity of going beyond equilibrium dynamics to decode information from the Gibbons-Hawking radiation.

Author: AALSMA, Lars (Arizona State University)

Presenter: AALSMA, Lars (Arizona State University)

Contribution ID: 37

Type: **not specified**

Operator Algebras and Quantum information in de Sitter (and other spacetimes)

Friday 21 April 2023 16:00 (1 hour)

Author: VERLINDE, Erik (University of Amsterdam)

Presenter: VERLINDE, Erik (University of Amsterdam)

Contribution ID: 38

Type: **not specified**

A Paradox and its Resolution Illustrate Principles of de Sitter Holography

Tuesday 18 April 2023 16:30 (1 hour)

Semiclassical gravity and the holographic description of the static patch of de Sitter space appear to disagree about properties of correlation functions. Certain holographic correlation functions are necessarily real whereas their semiclassical counterparts have both real and imaginary parts. The resolution of this apparent contradiction involves the fact that time-reversal is a gauge symmetry in de Sitter space—a point made by Harlow and Ooguri—and the need for an observer (or quantum reference frame) as advocated by Chandrasekaran, Longo, Penington, and Witten.

Author: SUSSKIND, Leonard (Stanford)

Presenter: SUSSKIND, Leonard (Stanford)

Contribution ID: 39

Type: **not specified**

Cauchy Slice Holography - From Basics to a Taste of Quantum Cosmology

Monday 17 April 2023 17:00 (30 minutes)

In this talk I will introduce the formalism of Cauchy Slice Holography, which provides a holographic description of Wheeler-DeWitt states in the canonical formulation of quantum gravity in terms of partition functions of T^2 -deformed CFTs. The field theory lives on a spatial slice of the bulk. I will then explore some of the consequences of such a description of quantum gravity for a closed Universe with a positive cosmological constant. It turns out that a general solution comes as a superposition of two field theory branches, which are CPT duals of each other. Unlike in AdS/CFT, both of them are important in this case. I will end by explaining how the choice of superposition of branches is related to the contour problem in quantum cosmology, referring to minisuperspace toy models for concreteness.

Author: ARAÚJO REGADO, Gonçalo (University of Cambridge)

Presenter: ARAÚJO REGADO, Gonçalo (University of Cambridge)

Contribution ID: 40

Type: **not specified**

Entropy in dS/CFT and Time-like Entanglement Entropy

Friday 21 April 2023 17:00 (30 minutes)

In this talk, we consider the holographic relation for quantum entanglement in dS/CFT as an extension of Ryu-Takayanagi formula in AdS/CFT. We argue that the holographic formula holds for pseudo entropy, which is a complex-valued generalization of entanglement entropy. Also time-like entanglement entropy is introduced in AdS/CFT as a counterpart of pseudo entropy in dS/CFT. We elaborate behaviors of time-like entanglement entropy in various examples.

Author: TAKI, Yusuke (Yukawa Institute for Theoretical Physics)

Presenter: TAKI, Yusuke (Yukawa Institute for Theoretical Physics)

Contribution ID: 41

Type: **not specified**

Gong Show

Wednesday 19 April 2023 17:00 (1 hour)