FY2021 Annual Report

Gravity, Quantum Geometry and Field Theory Unit

Assistant Professor Reiko Toriumi

Abstract

Gravity, Quantum Geometry and Field Theory Unit studied the topics in quantum gravity. In particular, members are interested in random geometrical and field theoretical approaches, focusing on questions relating to topological and geometrical information.

1. Staff

- Dr. Reiko Toriumi, Assistant Professor
- Dr. Guilherme Sadovski, Postdoctoral Scholar
- Dr. Riccardo Martini, Postdoctoral Scholar
- Dr. Nicolas Delporte, Postdoctoral Scholar
- Ms. Ayumi Shimojima, Research Unit Administrator
- Ms. Chiyo Eto, Research Unit Administrator
- Mr. Saswato Sen, OIST Student

2. Collaborations

2.1 Topological recursion in the triple scaling limit of U(N)^2 x O(D) multi-matrix models

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
  - Prof. Reiko Toriumi, OIST
  - Dr. Nicolas Delporte, OIST
  - Dr. Kento Osuga, University of Warsaw, Poland

2.2 Universality classes in quantum gravity

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
  - Dr. Riccardo Martini, OIST
  - Prof. Omar Zanusso, Univerity of Pisa, Italy

2.3 JT gravity (flat and finite cutoff)

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
  - Dr. Nicolas Delporte, OIST
  - Prof. Frank Ferrari, Universite Libre de Bruxelles, Belgium
  - Dr. Romain Pascalie, Universite Libre de Bruxelles, Belgium

2.4 Undecidability and quantum gravity

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
  - Dr. Guilherme Sadovski, OIST
  - Prof. Reiko Toriumi, OIST

2.5 Renormalizable TQFT phase for gravity

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
  - Dr. Guilherme Sadovski, OIST
  - Prof. Rodrigo F. Sobreiro, Universidade Federal Fluminense, Brazil

2.6 Topological aspects of tensor models in four dimensions

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
  - Prof. Reiko Toriumi, OIST
  - Dr. Riccardo Martini, OIST
  - Prof. Maria Rita Casalli, University of Modena and Reggio Emilia Via Campi, Italy
  - Prof. Paola Cristofori, University of Modena and Reggio Emilia Via Campi, Italy

2.7 Random Fields and Random Geometries

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
  - Prof. Reiko Toriumi, OIST
  - Dr. Nicolas Delporte, OIST
  - Saswato Sen, OIST

2.8 Glassy tensor models

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
  - Prof. Reiko Toriumi, OIST
  - Dr. Nicolas Delporte, OIST
  - Dr. Dario Benedetti, Centre de Physique Théorique, Ecole Polytechnique, France

2.9 Matter coupled to tensor models

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
  - Prof. Reiko Toriumi, OIST
  - Dr. Riccardo Martini, OIST
  - Dr. Nicolas Delporte, OIST
  - Dr. Dario Benedetti, Centre de Physique Théorique, Ecole Polytechnique, France

2.10 About the equivalance between holonomic and non-holonomic gravities

- Description: Ongoing.
- Type of collaboration: Solo research
- Researchers:
  - Dr. Guilherme Sadovski, OIST

2.11 Asymptotic safety and freedom in higher derivative gravity

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
  - Prof. Christof Wetterich, Heidelberg Univerity, Germany
  - Dr. Masatoshi Yamada, Heidelberg University, Germany
  - Saswato Sen, OIST

2.12 Blackholes in higher derivative gravity

- Description: Ongoing.
- Type of collaboration: Joint research
  - Dr. Masatoshi Yamada, Heidelberg University, Germany
  - Dr. Alfio Bonanno, INAF, Catania, Italy
  - Saswato Sen, OIST
  - Samuelle Silvervalle, TIFPA-INFN, Trento, Italy

3. Activities and Findings

3.1 Topological recursion in the triple scaling limit of U(N)xU(N)xO(D) multi-matrix models

Recent years have witnessed impressive progress regarding understanding correlation functions of matrix models of group size N through topological recursion. This recursion, derived from Loop or Schwinger-Dyson equations, allows to extract correlation functions of n-external points on embedded surface of genus g, from those of lower values of g and n. In the later paper [arXiv:2003.02100], studying multiscaling limits of a O(D)xU(N)xU(N) tensor models, a new solvable regime has been obtained, dual to tree-like graphs. By analysing the n-point functions of this model in this particular regime, we are attempting to find an appropriate genelisation of the topological recursion that would also incorporate tensor models.

3.2 Universality classes in quantum gravity

In this line of research we investigate the possibility that quantum gravity be formulated in terms of a local field theory of the metric with an interacting UV completion in the nonperturbative regime. This conjecture is known in the literature as asymptotic safery of gravity and can be studied with different approaches. In this joint collaboration with Prof. Zanusso we consider the original formulation of Weinberg, according to which quantum gravity in four dimensions could arise from the analytic continuation of the theory close to dimension d=2, where it indeed exhibits a UV completion in the perturbative regime. The idea is to classify the possible universality classes of metric theories close to their critical dimension and understand how they affect the flow of composite operators towards d=4. An important subtlety concerns the proper identification of observables of the theory and how to perform the corresponding on-shell computations. So far, after producing a paper in which we explain our complementary approach to the conjecture [arXiv:2105.11870] and one where we classify and analyze different realizations of gravity close to two dimensions and the corresponding path integrals [ar9Xiv:2103.12421], we studied the renormalization flow of higher dimensional operators and their critical behavior when continued to dimension 4. This allows for a comparison of the universality in d=2 to Stelle gravity, perturbative in d=4. Moreover we had some technical findings on the nature of on-shell observables which represent a useful lesson for the entire community of asymptotic safety.

3.3 JT gravity (flat and finite cutoff)

Given the interest that has sparked recently from the SYK model for two-dimensional hyperbolic geometries, made dynamical through the inclusion of a dilaton field, and their relevance for understanding the many faces of black holes, it seems a natural idea to study their flat counterpart, that provides many simplifications compared to the hyperbolic geometry. We also study corrections to the extrinsic curvature and consequently to the partition function. Lessons derived might as well provide a different point of view on the current factorization issue and the associated wormholes.

3.4 Undecidability and quantum gravity

In collaboration with Prof. Toriumi (OIST), Dr. Guilherme Sadovski is currently investigating the relations among the halting problem for Turing machines, the classification of general 4-manifolds and quantum gravity. The first two are examples of undecidable problems within the formal system of logic used in traditional mathematics, and are known to be unsolvable problems. One immediate realization is that quantum gravity as a fully background-independent path-integral summing over all possible 4-metrics modulus diffeos is uncomputable. For such program to work, topology must be constrained. For instance, by summing only over simply-connected 4-manifolds, where a full classification is given in terms of Kirby-Siebenmann invariants and intersection forms. Other physical implications are being investigated.

3.5 Renormalizable TQFT phase for quantum gravity

In collaboration with R.F. Sobreiro (UFF, Brazil), Dr. Guilherme Sadovski investigated the quantum stability of a cohomological TQFT that can be interpreted as symmetry-restored phase of gravity. The rich set of Ward identities garantees that the theory is quantum mechanically stable and renormalizable. The connection to gravity is achieved via an explict break of the topological BRST symmetry. Such break can possible have origins in the coupling to topological matter or via a Higgs-like mechanism. Pre-print is being finalized.

3.6 Topological aspects of tensor models in four dimensions

One of the main challenges of tenosr models is to do computations of Feynman diagrams beyond the leading (melonic) order in the large N, where the description of the polymer-like geometries is unable to provide a sensible continuum limit relevant for quantum gravity. Since it is natural to expect that the critical behavior of these models receives contribution from all orders, a natural question concerns the organization of the path integral beyond the leading order. For this, it is useful to study topological properties of the piecewise-linear (Pl) (pseudo)-manifolds dual to tensor models' Feynman diagrams. In d=4, a specific construction recently developed for smooth manifolds allows one to understand the handle decomposition of a 4-manifold in terms fo diaframs made of three sets of closed curves on a compact surface. Such a construction is named trisection and recently drew attention in the community of PL topology. In a preprint currently being reviewed, we managed to expand several works in PL topology and formulate the construction of trisection diagrams in terms of combinatorics of colored tensor models [arXiv:2110.06679]. Although the topological insight was not directly illuminating for the structure of the partition function of tensor models, this work opens new roads for discrete quantum gravity in dimension 4. In fact, works in the smooth category connect trisections to other topological invariants (e.g., intersection form), which are used to classify a subset of 4-manifolds. We are currently investigating how to extend such a connection to the combinatorial description of manifolds provided by colored tensor models.

3.7 Random Fields and Random Geometries

We are developing an approach to quantum gravity that originates with ideas of Symanzik of studying correlation functions as intersection probabilities of random processes. We have studied long-range propagators (or alpha-stable processes) and have formulated a way that deals with particles with spin on random graphs. We are planning to use this technique combined with the renormalization group to observe the flow of correlators.

3.8 Glassy tensor models

Using the lower rank relatives as a template to explore different phases of matter (glasses and strange metals), we are attempting to investigating corresponding behaviours in tensor models. Complementary approaches to the usual large N limit are developed, inspired from condensed matter (replicas, bootstrap, etc.).

3.9 Matter coupled to tensor models

In many different approaches to quantum gravity (e.g., string theory, asymptotic safety, CDT) the inclusion of matter fields coupled to the geometrical degrees of freedom affects drastically the critical behavor of the theory. It is natural to expect teh same from tensor models. So far, the attempts to include matter degrees of freedom on random geometries have been very limited in the literature. we are now investigating an approach to include quantum matter fields in the tensor models partitions function so that its expansion in Feynman diagrams decribes a statistical sum of a lattice field theory on random lattices. Quantitative results are still under investigation.

3.10 About the equivalance between holonomic and non-holonomic gravities

Dr. Guilherme Sadovski investigated the possible scenarios in which a holonomic vs a non-holonomic frame description of gravity theories fail to be equivalent. It turns out that classicaly, the equivalence holds in a way that is independent of the particular dynamics or spacetime dimension. This includes more general setup of the Einstein-Cartan or Metric-Affine type. A geometric bundle-theoretical reasoning was given, uncovering the geometrical equivalence principle as culprit. Quantum mechanically, the equivalence holds as long as the equivalence principle holds. This is not something to be expected in the full non-perturbative regime of quantum gravity, where non-invertible configuration of the veilbein must be accounted for. In such scenario, the gauge-theoretical description of gravity unsolders from spacetime and one has to decide if gravity is spacetime geometry or a gauge theory. Pre-print is being finalized.

3.11 Asymptotic safety and freedom in higher derivative gravity

The project was initiated by Saswato Sen as a master student in Heidelberg University with Dr. Yamada and continued after joining OIST as a research intern and then as a rotation student. It is conjectured that quantum effects generate higher order curvature correction terms in gravitational action beyond Ricci scalar aka the

Einstein-Hilbert action. We consider a theory up to correction in second order in curvature historically known as higher derivative gravity. We can use the framework of functional renormalisation group to calculate the nonperturbative beta functions of such theories. We found both Gaussian and non-Gaussian fixed points of higher derivative gravity and calculated their critical exponents at both the fixed points [JHEP 03 (2022) 130]. We are looking for trajectories connecting the fixed points and this will pave the way to understanding phase structure of quantum gravity and general understanding of asymptotically safe gravity.

3.12 Blackholes in higher derivative gravity

The project was initiated by Saswato Sen as an extension of the project "Asymptotic safety and freedom in higher derivative gravity". We aim to use nonperturbative beta functions to determine higher order corrections to blackhole spacetimes. For a simplified higher derivative gravity, we found that there exists RG trajectories which connects two distinct blackhole solutions to higher derivative gravity. We are looking to calculate phenomenological consequences of such RG trajectoried and whether such predictions are compatible with current experimental data.

4. Publications

4.1Journals

1. Del Porro, F.; Martini, R.; Ugolotti, A.; Zanusso, O. "Gravity in d = 2 + ¥epsilon dimensions an realizations of the diffeomorphisms group", arXiv:2103.12421
2. Martini, R.;Ugolotti, A.; Zanusso, O. "The Search For The Universality Class Of Metric Quantum Gravity", arXiv:2105.11870
3. Martini, R.; Toriumi, R. "Trisections in Colored Tensor Models" arXiv:2110.06679
4. Sen, S.;Wetterich, C.; Yamada, M. "Asymptotic freedom and safety in quantum gravity", JHEP 03 (2022) 130, arXiv:2111.04696

4.2 Books and other one-time publications

Nothing to report

4.3 Oral and Poster Presentations

1. Martini, R. "Universality in Quantum Gravity" invited speaker in Universita di PIsa, 16 December 2021;
2. Martini R. "Trisections in Colored Tensor Models For Quantum Gravity" invited speaker in Universita di Modena e Reggio Emilia, 12 January 2022;
3. Martini R. "Trisections in Colored Tensor Models" Virtual Tensor Journal Club, 2 Febrary 2022;
4. Sen, S. "Asymptotic safety and freedom in higher derivative gravity", by Asymptotic safety seminar series, 14 February, 2022;
5. Toriumi, R. "Trisections in colored tensor models" "Random Tensors" workshop, CIRM, Marseille, France, 14-18 March 2022;
6. Sadovski, G. "Why is the world 4-dimensional? An excuse for exoticness", invited seminar, Hariot-Watt U., April 9th, 2021;

Colloquiums:

1. Curé, S. Eigenvalues of Large Random Tensors VI. OIST, Japan, Apr. 2, 2021;
2. Curé, S. Eigenvalues of Large Random Tensors VII. OIST, Japan, Apr. 8, 2021;
3. Sen, S. "Asymptotic safety and freedom in higher derivative gravity", by Zoom, OIST, Japan, February 7, 2022;
4. Sadovski, G. "Tropical arithmetics", OIST, March 7, 2022. Recording at vimeo;
5. Sadovski, G. "Tropical algebraic geometry", OIST, March 10, 2022. Recording at vimeo.

5. Intellectual Property Rights and Other Specific Achievements

Nothing to report

6. Meetings and Events

6.1 Seminar: "Various problems of interest"

- Date: July 14, 2021
- Venue: L4E38, OIST campus
- Speaker: Dr. Nikolaos Chatzikonstantinou (OIST)

6.2 Seminar: "Photon production from a non-equilibrium quark-gluon medium modelled by a dimensionally reduced non-Abelian gauge theory"

- Date: July 30, 2021
- Venue: Zoom
- Speaker: Ms. Yunxin Ye (Heidelberg University)

6.3 Seminar: "Vacua of Large-N QCD3"

- Date: November 9, 2021
- Venue: L4E01, OIST campus
- Speaker: Prof. Adi Armoni (Swansea University | University of Sheffield, UK)

6.4 Seminar: "Self-consistent Quantization via Resurgence"

- Date: January 11, 2021
- Venue: Zoom
- Speaker: Dr. Cihan Pazarbaşı (Boğaziçi University)

6.5 Seminar: "Looking through a keyhole: a glimpse into coadjoint orbits"

- Date: January 21, 2022
- Venue: Zoom
- Speaker: Assistant Research Prof. Olga Chekeres (University of Connecticut)

6.6 Seminar: "Anti-Newtonian expansions, Hadamard states, and the spatial Functional Renormalization Group."

- Date: January 25, 2022
- Venue: Zoom
- Speaker: Dr. Rudrajit Banerjee (Wofford College)

6.7 Seminar: "Rank Inequality and Tsirelson Bound Done by Free Probability"

- Date: January 27, 2022
- Venue: zoom
- Speaker: Sheng Yin (Kyoto RIMS)

6.8 Seminar: "Stochastic Quantisation, Second Order Geometry and the Quantum Foam"

- Date: February 22, 2022
- Venue: zoom
- Speaker: Folkert Kuipers (University of Sussex)