FY2019 Annual Report

Gravity, Quantum Geometry and Field Theory Unit

Assistant Professor Reiko Toriumi

Abstract

Gravity, Quantum Geometry and Field Theory Unit studied the subjects in the context of quantum gravity which involve field theoretical (in particular attention to renormalization techniques) and random geometrical questions. More specifically, focusing on extracting observables/invariants, members have explored topological and geometrical questions in tensor models, also in a more general setting of differentiable manifolds, and in topological quantum field theories.

1. Staff

- Dr. Reiko Toriumi, Assistant Professor
- Dr. Guilherme Sadovski, Postdoctoral Scholar
- Dr. Riccardo Martini, Postdoctoral Scholar
- Ms. Ayumi Shimojima, Research Unit Administrator

2. Collaborations

2.1 Multiple scaling limits of U(N)^2 x O(D) multi-matrix models

- Description: This resulted in a paper in March 2020.
- Type of collaboration: Joint research
- Researchers:
    - Dr. Dario Benedetti, CPHT, CNRS, Ecole Polytechnique, Palaiseau, France
    - Dr. Sylvain Carrozza, Perimeter Institute for Theoretical Physics, Waterloo, Ontario, Canara
    - Dr. Guillaume Valette, Universite Libre de Bruxelles, Belgium
    - Dr. Reiko Toriumi, OIST

2.2 Geometric flux formula for the gravitational Wilson loop

- Description: This resulted in a paper in April 2020.
- Type of collaboration: Joint research
- Researchers:
    - Professor Renate Loll, Radboud University Nijmegen, the Netherlands
    - Nilas Klitgaard, Radboud University Nijmegen, the Netherlands
    - Marcus Reitz, Radboud University Nijmegen, the Netherlands
    - Dr. Reiko Toriumi, OIST

2.3 Universality classes in quantum gravity

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
    - Dr. Omar Zanusso, Univerity of Pisa, Italy
    - Alessandro Ugolotti, Friedrich-Schiller Univerity of Jena, Germany
    - Dr. Riccardo Martini, OIST
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2.4 Gravity in holonomic and non-homology frames

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
    - Dr. Jorge Zanelli, CECs, Chile
    - Dr. Rodrigo Ferreira Sobreiro, Universidade Federal Fluminense, Brazil
    - Dr. Guilherme Sadovski, OIST

2.5 Quantum gravity as a topological quantum field theory

- Description: Ongoing.
- Type of collaboration: Joint research
- Researchers:
    - Dr. Octavio C. Junqueira, Universidade Federal do Rio de Janeiro, Brazil
    - Dr. Rodrigo Ferreira Sobreiro, Universidade Federal Fluminense, Brazil
    - Dr. Guilherme Sadovski, OIST

3. Activities and Findings

3.1 Multiple scaling limits of U(N)^2 x O(D) multi-matrix models

With the collaboration with Dario Benedetti, Sylvan Carrozza, and Guillaume Valette, Reiko Toriumi has explored the double- and the triple-scaling limits of a complex multi-matrix model, with U(N)^2 x O(D) symmetry. The double-scaling limit amoundts to taking simultaneously the large-N (matrix size) and large-D (number of matrices) limits while keeping the ration N/¥sqrt{D}=M fixed. The triple-scaling limit consists in taking the large-M limit while tuning the coupling constant to its critial value ¥lambda and keeping fixed the product M(¥lambda_c-¥lambda)^¥alpha, for some value of ¥alpha that depends on the particular combinatorial restrictions imposed on the model. Our first main result is the complete recursive characterization of the Feynman graphs of arbitrary genus which survive in the double-scaling limit. Next, we classify all the dominant graphs in the triple-scaling limit, which we find to have a plane binary tree strucuter with decorations. Their critical behavior belongs to the universality class of branched polymers. Lastly, we classify all the dominant graphs in the triple-scaling limit under the restriction to three-edge connected (or two-particle irreducible) graphs. Their critical behavior falls in the universality class of Liouville quantum graivty (or, in other words, the Brownian sphere).

3.2 Geometric flux formula for the gravitational Wilson loop

With the collaboration with Renate Loll, Nilas Klitgaard and Marcus Reitz, Reiko Toriumi has explored the gravitational Wilson loop and the non-abelian Stokes' theorem. Finding suitable diffeomorphism-invariant observables to probe gravity at the Planck scale is an essential part in addressing meaningful questions in quantum gravity. The Wilson loop of the four-dimensional Levi-Civita connection is a potentially interesting ingredient for the construction of such an observable. We investigated to what extent and what form of curvature information of the underlying spacetime may be extracted from the Wilson loops using the non-abelian Stokes' theorem. We present an expressio for geometric flux as the quantity related to the gravitational Wilson loop on totally geodesic surfaces. This expression is conserved and therefore surface-independent. The derivations have been made for a certain class of manifolds with global symmetries.

3.3 Infinitesimal Gribov copies in gauge fixed topological Yang-Mills theories

In collaboration with Octavio C. Junqueira (UFRJ, Brazil), Anderson A. Tomaz, Antonio D. Pereira Jr., Rodrigo F. Sobreiro (UFF, Brazil), David Dudal and Caroline Felix (KU Leuven, Belgium), Guilherme Sadovski explored the role of Gribov copies in topological Yang-Mills theories (TYMs). TYMs are a very important kind of topological QFTs in d=4. Their moduli spaces are completely determined by the instanton number and their observables are directly related to Donaldson polynomials (global invariants labelling non-diffeomorphic smooth structures of smooth 4-manifolds). Thus, they have great appeal among mathematicians as well as physicists, specially those working on differential topology, non-perturbative QCD, classical and quantum gravity, and their intersection. Gribov copies, on the other hand, are known to affect the behavior of traditional Yang-Mills theories (YMs) in a non-perturbative regime. Thus, this work focused on whether or not these spurious copies can spoil the nice (perturbative) features of TYMs when they dynamically reach a non-perturbative energy scale. It was found that, contrary to traditional YMs, these copies are actually inoffensive and can be completely disregarded in this setup, which reinforce the fact that TYMs are actually tree-level exact theories.

4. Publications

4.1Journals

1. Dudal, D.; Felix, C.P.; Junqueira, O.C.; Montes, D.S.; Pereira, A.D.; Sadovski, G.; Sobreiro, R.F.; Tomaz A.A.: "Infinitesimal Gribov copies in gauge fixed topological Yang-Mills theories", arXiv:1907.05460 (accepted by Phys. Lett. B);
2. D. Benedetti, S. Carrozza, R. Toriumi, G. Valette: “Multiple scaling limits of $U(N)^2 x O(D)$ multi-matrix models” arXiv:2003.02100 (submitted to Annales de l’Institut Henri Poincare D)..

4.2 Books and other one-time publications

Nothing to report

4.3 Oral and Poster Presentations

1. Toriumi, R. "The gravitational Wilson loop and the non-Abelian Stokes' theorem" Mathematical Physics Seminar, Laboratoire de Physique Theorique, Orsay, France, Apr. 24th, 2019;
2. Toriumi, R. "Perturbative Tensor Field Theories" 3rd French Russian Conference on Random Geometry and Physics: Sachdev–Ye–Kitaev Model and Related Topics, Steklov Mathematical Institute, Gubkina, 8, Conference hall, Moscow, Russia. Jun. 3rd–7th, 2019;
3. Sadovski, G. "A renormalizable topological quantum field theory for gravity", Quantum and Gravity in Okinawa, OIST, Japan, July 24th, 2019;
4. O'Connell, D. "Lorentzian Structures on Branching Spacetimes". OIST, Japan, Nov. 6, 2019;
5. Toriumi, R. "The gravitational Wilson loop and the non-Abelian Stokes' theorem" OIST Japan, Nov. 13th, 2019;
6. Toriumi, R. "The gravitational Wilson loop and the non-Abelian Stokes' theorem" Emmy Noether Workshop: The Structure of Quantum Space Time, Perimeter Institute for Theoretical Physics, Canada, November 18-22th, 2019;
7. Martini, R. "A curvature bound from gravitational catalysis" SIFT 2019, Friedrich Schiller University, Germany, November 7-9th, 2019;
8. Martini R., "Renormalization methods in quantum gravity" OIST Japan, February 7th, 2020..

Colloquiums:

1. Sadovski, G. "Classification of 2-manifolds". OIST, Japan, Nov. 12th, 2019;
2. Martini, R. "Functional methods in QFT and renormalization, part I". OIST, Japan, Dec. 6th, 2019;
3. Sadovski, G. "Classification of 3-manifolds". OIST, Jap an, Dec. 10th, 2019;
4. Martini, R. *"Functional methods in QFT and renormalization, part II"*. OIST, Japan, Dec. 13th, 2019;
5. Martini, R. "Functional methods in QFT and renormalization, part III". OIST, Japan, Dec. 20th, 2019;
6. Sadovski, G. "Classification of 4-manifolds". OIST, Japan, Dec. 23rd, 2019;
7. Martini, R. "Functional methods in QFT and renormalization, part IV". OIST, Japan, Jan. 30th, 2020;
8. Sadovski, G. "General homology theory". OIST, Japan, Feb. 5th, 2020;
9. Maeda, R. "Basics of differential geometry and General Relativity". OIST, Japan, Feb. 7th, 2020;
10. Sadovski G. "Simplicial homology, part I". OIST, Japan, Feb. 10, 2020;
11. Sadovski, G. "Simplicial homology, part II". OIST, Japan, Feb. 13, 2020;
12. Maeda, R. "Maxwell's equations, Yang-Mills equations and differential forms". OIST, Japan,, Feb. 14th, 2020;
13. Maeda, R. "Fiber bundles and gauge theory". OIST, Japan, Feb. 21st, 2020;
14. Sadovski, G. "*Simplicial homology, part III"*. OIST, Japan, Feb. 27th, 2020;
15. Maeda, R. "*Gravity as a SO(1,3) gauge theory"*. OIST, Japan, Mar. 6th, 2020.

5. Intellectual Property Rights and Other Specific Achievements

Nothing to report

6. Meetings and Events

6.1 Mini-course: "Quantum Models for Black Holes: Sachdev-Ye-Kitaev and generalizations"

- Date: April 1, 4, 8, and 10, 2019
- Venue: B717, Lab 3, OIST campus
- Speaker: Frank Ferrari (Professor, Universite Libre de Bruxelles)

6.2 Seminar: "A new large N expansion for tensor and matrix-tensor models"

- Date: April 8, 2019
- Venue: A719, Lab 3 OIST campus
- Speaker: Guillaume Valette (Universite Libre de Bruxelles)

6.3 The OIST Workshop "Quantum and Gravity in Okinawa" 2019

- Date: Jul. 23-27, 2019
- Venue: OIST Campus, Seaside House
- Speakers:
    - Jan Ambjorn (Niels Bohr Institute)
    - Dionysios Anninos (King's College London)
    - John Barrett (University of Nottingham)
    - Valentin Bonzom (University Paris 13)
    - Joao Caetano (Simons Center for Geometry and Physics & C.N. Yang Institute at Stony Brook)
    - Bianca Dittrich (Perimeter Institute for Theoretical Physics)
    - William Donnelly (Perimeter Institute for Theoretical Physics)
    - Fay Dowker (Imperial College London)
    - Frank Ferrari (Universite Libre de Bruxelles)
    - Masanori Hanada (University of Southhampton)
    - Philipp Hoehn (Austrian Academy of Science & University of Vienna)
    - Thomas Krajewski (Centre de Physique Theorique, Marseille)
    - Renate Loll (Radboud University Nijmegen)
    - Jun Nishimura (KEK)
    - Sylvie Paycha (University of Potsdam)
    - Roberto Percacci (SISSA)
    - Kasia Rejzner (University of York)
    - Vincent Rivasseau (University Paris Sud, Orsay)
    - Ricardo Schiappa (Instituto Superior Technico)

6.4 Special Lecture: "Science without borders, a key to mankind survival?"

- Date: July 23, 2019
- Venue: Sydney Brenner Hall, OIST campus
- Speaker: Vincent Rivasseau (Professor, University Paris-Sud, Orsay, France)

6.5 Presidential Lecture: "New perspectives onto the Universe in the multi-messenger astronomy era"

- Date: Oct 18, 2019
- Venue: Sydney Brenner Hall, OIST campus
- Speaker: Speaker: Samaya Nissanke (Assistant Professor, Univ. of Amsterdam)

6.6 Seminar: "Knots, the Jones Polynomial, and Khovanov homology"

- Date: Dec 4, 2019
- Venue: B711, Lab 3, OIST campus
- Andrew Lobb (Associate Professor, Durham University/OIST)

6.7 Seminar: "Melonic CFTs"

- Date: January 20, 2020
- Venue: A712, Lab 3, OIST campus
- Speaker: Dario Benedetti (Ecole Polytechnique)

6.8 Seminar: "Boundary Conditions and the q-state Potts Model on Random Planar Maps"

Date: February 25, 2020
Venue: D014, Lab 1, OIST campus
Speaker: Aravinth Kulanthaivelu (PhD. student, University of Oxford)

6.9 Seminar: "The current status of the Gribov problem in gauge theories"

- Date: March 3, 2020
- Venue: C700, Lab 3, OIST campus
- Speaker: Rodrigo F. Sobreiro (Associate Professor, Universidade Federal Fluminense)

6.10 Mini-lecture series: "Morse Theory"

- Dates and Room#:
    - Jan. 16 (A719), Feb. 6 (C015), Feb. 7 (D014), Mar. 5 (B711), Mar. 12 (C014), Mar. 16 (C016), Mar. 19 (B717), Mar. 26 (C016) , Apr. 1 2020
- Venue: OIST campus

- Speaker: Andrew Lobb (Associate Professor, Durham University and OIST (Excellence Chair of Math Visitor Program))