FY2023 Annual Report

Mathematical and Theoretical Physics Unit
Shinobu Hikami

Abstract

Mathematical and theoretical physics unit studied the subjects related to random matrix theory and conformal field theory. The topological invariants related to the moduli space of p-spin curves and the conformal bootstrap method for higher dimensions were two main subjects, in addition to study of the biological systems.

1. Staff

- Prof. Shinobu Hikami, Professor
- Dr. Satsuki Oda, Staff Scientist
- Dr. Daisuke Takahashi, Postdoctoral Scholar
- Dr. Ardak Kusainova, Postdoctoral Scholar
- Dr. Ayumi Kikkawa, Research Assistant (part time)
- Dr. Chika Hasegawa, Resarch Assistant (part time)
- Ms. Miwako Tokuda, Research Unit Administrator

2. Collaborations

2.1 Collaborations with University of Tokyo

- Description: Moduli space and matrix models:
    - The study of higher Teichmuller space and various topological invariances.
- Researcher: Prof. N. Kawazumi (University of Tokyo)

2.2 Collaborations with Ecole Normale Superieure

- Description: Random matrix theory with an external source and topological field theory
- Researcher: Prof. Edouard Brezin (lpt, ENS, Paris)

3. Activities and Findings

3.1 Random matrix theory (S. Hikami)

(a) Matrix models and topological invariants

The intersection numbers for p-spincurves of the moduli space Mg,n are considered for DI type by a matrix model. The asymptotic behavior of the large genus g limit and large p limit are derived. The remarkable features of the cases of p = 1/2, −2, −3 are examined in the Laurent expansion for multiple correlation functions. The strong coupling expansions for the negative p cases are considered.

(b) Knot theory

The knots are derived from a random matrix theory in the replica limit N to 0. The Gaussian means of the product of matrices in the replica limit generate Seifert surface, in which edges describe knot trajectories. The replica formula, which has been used for the evaluation of the intersection numbers, turns out to be useful for generating Seifert surface and associated knot diagrams. The classical knot, which is embedded to three dimensional sphere, is extended to the surface knot by considering time dependent random matrix model.

3.2 Extended SUSY models of the Standard Model (S. Oda, D.-s. Takahashi)

Although the Standard Model (SM) is currently the best theory for explaining the phenomena of elementary particle physics, there are various unsolved problems, and it is necessary to propose and verify New Physics beyond the SM. We proposed and investigated supersymmetric (SUSY) version of the gauged U(1)x extension of the SM, which is one of the attempts of New Physics search. In our model, three right-handed neutrino (RHN) chiral superfields are introduced, R-parity is conserved as usual in the minimal supersymmetric SM (MSSM) even after radiatively breaking the U(1)x symmetry, and the lightest eigenstate of the mixture of the U(1)x gaugino and the fermionic component of one of the RHN chiral superfields appears as another new dark matter (DM) candidate besides the MSSM's lightest neutralino. We have studied cosmological aspects of this DM, analyzed the Large Hadron Collider (LHC) bounds from Z' boson search, and discussed constrains from Big Bang Nucleosynthesis (BBN) for our model.

3.3 Random matrix analysis of the chromosome configuration

Using Hi-C data published in the ENCODE project (http://www.encodeproject.org/), we have generated contact matrices for various cancer or normal cells. We investigate the eigenvalue statistics obtained from the Hi-C contact matrices using the method of random matrix theory. By studying the 3-dimensional gene configurations associated with gene-

interactions both within and between chromosomes, the specific features of long-range gene interactions in cancer cells can be revealed.

4. Publications

4.1 Journals

1. A. Petrou and S. Hikami, Harer-Zagier transform of the HOMFLY-PT polynomial for families of twisted hyperbolic knots, J.Phys. A. Mathematical and Theoretical, 57 (2024) 205204. DOI 10.1088/1751-8121/ad421b
2. Satsuki Oda, Nobuchika Okada, Nathan Papapietro, and Dai-suke Takahashi, “R-parity Conserving Minimal SUSY U(1)x Model,” arXiv:2307.16480 [hep-ph]
3. Sheng, X. Divergence Property of the Brown-Thompson Groups and Braided Thompson Groups. *Transformation Groups* (2024). https://doi.org/10.1007/s00031-023-09839-8
4. Sheng, X., Preprints, Hofstadter-Toda spectral duality and quantum groups, joint with P. Marra, V, Proietti.

4.2 Books and other one-time publications

S. Hikami,
Knots from a random matrix theory with replicas, in "50 years of the renormalization group: dedicated to the memory of Michael Fisher", edited by A. Aharony et. al. (2023) World Scientific Publishing Company.
ISBN-10: 9811282374. arXiv: 2301.06003.

4.3 Seminars

1. Satsuki Oda, and Dai-suke Takahashi, “Simple gauged U(1) extension of the Standard Model can explain several important missing parts of new physics,” OIST internal seminar, Japan, 2023.06.09
2. Dai-suke Takahashi, “素粒子と宇宙Ⅰ（High energy physics and cosmology Ⅰ）,” Intensive lecture, University of the Ryukyus, 2023.12.07-2024.01.25

3. Dai-suke Takahashi, “素粒子標準模型における質量生成（Mass generations of the Standard Model),” Physics Seminar, University of the Ryukyus, 2024.02.01
4. Xiaobing Sheng, Hikami Unit topology seminar
5. Xiaobing Sheng, Tuesday Topology seminar at University of Tokyo

4.4 Oral and Poster Presentations

1. S. Hikami, Arithmeticity in knot polynomial, Silver workshop IV, 2023, Aug. 9. (OIST).
2. Satsuki Oda, Nobuchika Okada, Nathan Papapietro, and Dai-suke Takahashi, “Minimal SUSY U(1)x model with an R-parity conservation,” 原子核三者若手 夏の学校 2023 (Summer School of YONUPA (Young Nuclear and Particle Physicist Group of Japan) 2023), Online & Youth Education National Olympics Memorial Youth Center, Tokyo, Japan, 2023.08.19
3. Xiaobing Sheng, OIST workshop: New trends of conformal theory from probability to gravity
4. Xiaobing Sheng, OIST outreach Nov. 16th. 2023
5. Xiaobing Sheng, Seminar talk at Zhou Unit Dec. 13th. 2023
6. Xiaobing Sheng, Talk at End of the year seminar at Tokyo Institute of Technology Dec. 26th. 2023
7. Xiaobing Sheng, East Asia Conference on Geometric Topology at Kyoto University, Feb. 2024
8. Xiaobing Sheng, Knot Theory; LMO functor and related topics, at OIST, Mar. 2024
9. Xiaobing Sheng, MSJ Annual meeting Mar. 2024
10. Ayumi Kikkawa, Network Science Workshop 2023, December 2023, Shiseikan, Imadegawa Campus, Doshisha University, S22+zoom, Title: “Genome network research using random matrix theory”

5. Intellectual Property Rights and Other Specific Achievements

6. Meetings and Events

1. OIST workshop 2023: New trends of conformal theory from probability to gravity
   Organizers: Nicolas Delporte, Reiko Toriumi, Shinobu Hikami (OIST)
   Date: July 31- August 4, 2023
   Venue: OIST lecture rooms

2. Silver workshop V I : Complex Geometry and related topics
   Date: Aug. 7-9th, 2023
   Venue: Lab.4, F01, OIST
   Organizers: N. Yui (Queen's Univ.), K. Saito (RIMS, Kyoto) and S. Hikami(OIST)

3. University of Tokyo and OIST Joint Symposium of Knot theory
   Date: Sep. 11
   Venue: Graduate School of Mathematical Sciences, University of Tokyo. Room123.

4. Workshop: Knot theory, LMO invariants and related topics
   Date: Mar. 9-11, 2024
   Venue: OIST Lab.4, E48
   Organized by Xiaobing Sheng (OIST), Masaaki Suzuki (Meiji Univ.), Shinobu Hikami (OIST)

5. Seminar: Origin, evolution, and dynamics of the asteroid Ryugu
   ~Perspectives from the comprehensive geochemical approach~
   Date: Friday, March 15, 2024 - 11:00 to 12:00
   Location: Lab4 L4E01
   Speaker: Katsura Kobayashi (Institute for Planetary Materials, Okayama University)