FY2023 Annual Report

Quantum Gravity Unit
Associate Professor Yasha Neiman

Abstract

This year, we worked on various projects. Yasha worked on self-dual higher-spin General Relativity. Yasha and Julian Lang (Ph.D. student) worked on a twistor picture of N=2 supersymmetric higher-spin holography, as well as on higher-spin scattering amplitudes in the de Sitter static patch. Yasha and David O'Connell (Ph.D. student) worked on the gravity action of non-Hausdorff spacetimes. David also worked on defining Quantum Field Theory on such spacetimes. Slava Lysov worked on mirror symmetry in tropical geometry, as well as on localization for on-shell supersymmetry. Aritra Banerjee worked on tensionless string theory, as well as on quantum complexity and scars in a 1-dimensional many-body system. Mirian Tsulaia worked on higher-spin interactions as an effective field theory for the gravitational interactions of rotating black holes. Sebastian Murk worked on non-singular models for black holes, and on quantum measurement. Subhajit Mazumdar worked on the polarizability of black holes in large spacetime dimensions.

1. Staff

- Dr. Mirian Tsulaia, Staff Scientist
- Dr. Vyacheslav Lysov, Postdoctoral Scholar
- Dr. Aritra Banerjee, Postdoctoral Scholar
- Dr. Sebastian Murk, Postdoctoral Scholar
- Dr. Subhajit Mazumdar, Postdoctoral Scholar
- Lena Hashimoto, Research Unit Administrator

2. Collaborations

2.1 Higher-spin interactions as effective model for black holes interacting with gravitational waves

- Type of collaboration: Joint research
- Researchers:
    - Dr. Mirian Tsulaia (OIST)
    - Dr. Evgeny Skvortosv (University of Mons)

2.2 Supersymmetric quantum mechanics and tropical mirror symmetry

- Description: Continued collaboration from previous FY
- Type of collaboration: Joint research
- Researchers:
    - Dr. Vyacheslav Lysov (OIST)
    - Prof. Andrei Losev (National Research University Higher School of Economics, Moscow)

2.3 String and theory in the Carrollian/tensionless limit

- Description: Continued collaboration from previous FY
- Type of collaboration: Joint research
- Researchers:
    - Dr. Aritra Banerjee (OIST)
    - Ritankar Chatterjee (IIT Kanpur)
    - Dr. Priyadarshini Pandit (IIT Kanpur)

2.4 Quantum complexity and scars in many-body system

- Type of collaboration: Joint research
- Researchers:
    - Dr. Aritra Banerjee (OIST)
    - Dr. Sourav Nandy (Jozef Stefan Institute, Ljubljana)
    - Dr. Bhaskar Mukherjee (University College London)
    - Prof. Arpan Bhattacharyya (IIT Gandhinagar)
    - Prof. Arpan Bhattacharyya (IIT Gandhinagar)

2.5 Consistency conditions for alternative black hole models

- Description: Continued collaboration from previous FY
- Type of collaboration: Joint research
- Researchers:

    - Dr. Sebastian Murk (OIST)
    - Ioannis Soranidis (Macquarie University)

2.6 Macro-realism and non-invasive measurability

- Type of collaboration: Joint research
- Researchers:
    - Dr. Sebastian Murk (OIST)
    - Prof. Masahiro Hotta (Tohoku University)

3. Activities and Findings

3.1 Geometry and physics of non-Hausdorff spacetimes

David O'Connell continued developing the geometry of non-Hausdorff manifolds, with the aim of describing spacetimes with splitting and re-joining causal structures. In particular, he succeeded in proving non-Hausdorff versions of the de Rham and Gauss-Bonnet theorems. Then, together with Yasha, he turned to the physics of non-Hausdorff spacetimes, using the Gauss-Bonnet theorem to compute the gravitational action (and thus the contribution to a gravitational path integral) for a 1+1d process of a closed Universe splitting in two along a lightcone.

3.2 Clarifying localization for on-shell supersymmetry

Slava Lysov (with Andrei Losev) used the Batalin-Vilkovisky formalism to clarify the (presence or absence of) supersymmetric localization in systems where supersymmetry applies only on-shell, i.e. where a superfield formulation is not available. This closes a long-standing gap in textbooks on the subject.

3.3 Higher-spin treatment for gravitational interactions of rotating black holes

Mirian Tsulaia (with Evgeny Skvortsov) have studied the problem of interactions between rotating black holes and gravitational waves, in an effective field theory framework where the black hole is modeled as a massive, higher-spin particle. At the cubic level, they showed how a spinor-helicity description of such an interaction by Arkani-Hamed and Huang agrees with a worldline description, and used the BRST

formalism to find the corresponding field theory Lagrangian. Work is ongoing on using BRST invariance to write down the interactions at the next (i.e. quartic) order.

3.4 Self-dual higher-spin General Relativity

Yasha has studied the higher-spin generalization of self-dual General Relativity: the simplest corner of higher-spin gravity that already has (almost) the full spectrum of fields. I found a remarkably simple 6-dimensional description of the theory, which puts the spacetime and internal spinor coordinates on an equal footing. I also worked out a lightcone ansatz for the theory's solutions, with cubic-exact field equations for the scalar degrees of freedom of each helicity. In ongoing work with Julian Lang, we are learning to apply these lightcone solutions to the scattering problem in an observable (static) patch of de Sitter space. The work has also shed new light on the geometric content of the lightcone formalism in spacetimes with cosmological constant, showing a hidden Lorentz covariance that isn't present in the flat-spacetime lightcone formalism.

3.5 Hidden supersymmetry within higher-spin theory

Yasha and Julian Lang have studied the type-B and N=2 supersymmetric versions of Yasha's 2017 twistor description of higher-spin holography. Surprisingly, we found that the N=2 supersymmetry is automatically present within the seemingly-bosonic higher-spin algebra of twistor functions, and that the boundary correlators of the N=2 theory can be described within the same twistor-function space as those of the originally-studied type-A theory. This points towards a novel picture of higher-spin holography, where the "type-A" and "type-B" bulk sectors refer not to two different sets of fields, but rather different boundary behaviors for a single set of fields. This violates the usual rules of AdS/CFT, in a way that may have interesting implications for holography in de Sitter space, where fixing the bulk fields' boundary behavior seems unnatural due to the boundary being a time, not a place.

4. Publications

4.1 Journals

1. **Neiman, Y.** "Self-dual gravity in de Sitter space: Lightcone ansatz and static patch scattering". *Physical Review D*, doi:10.1103/PhysRevD.109.024039 (2024).
2. **Neiman, Y.** "Quartic locality of higher-spin gravity in de Sitter and Euclidean anti-de Sitter space". *Physics Letters B*, doi:10.1016/j.physletb.2023.138048 (2023).
3. **Neiman, Y.** "New diagrammatic framework for higher-spin gravity". *Physical Review Letters*, doi:10.1103/PhysRevLett.130.171601 (2023).
4. Skvortsov, E., **Tsulaia, M.** "Cubic action for spinning black holes from massive higher-spin gauge symmetry". *Journal of High Energy Physics*, doi:10.1007/JHEP02(2024)202 (2024).
5. **Banerjee, A.**, Chatterjee, R., Pandit, P. "Tensionless tales of compactification". *Journal of High Energy Physics*, doi:10.1007/JHEP09(2023)050 (2023).
6. Nandy, S., Mukherjee, B., Bhattacharyya, A., **Banerjee, A.** "Quantum state complexity meets many-body scars". *Journal of Physics: Condensed Matter*, doi:10.1088/1361-648X/ad1a7b (2023).
7. **Banerjee, A.**, Dutta, S., Mondal, S. "Carroll fermions in two dimensions". *Physical Review D*, doi:10.1103/PhysRevD.107.125020 (2023).
8. **Murk, S.**, Soranidis, I., "Kinematic and energy properties of dynamical regular black holes". *Physical Review D*, doi:10.1103/PhysRevD.108.124007 (2023).
9. **Murk, S.**, Soranidis, I., "Regular black holes and the first law of black hole mechanics". *Physical Review D*, doi:10.1103/PhysRevD.108.044002 (2023).

4.2 Books and other one-time publications

1. **Murk, S.**, "Nomen non est omen: Why it is too soon to identify ultra-compact objects as black holes". *International Journal of Modern Physics D, Special issue: Selected essays from the annual essay competition of the gravity research foundation 2023*, doi:10.1142/S0218271823420129 (2023).

4.3 Oral and Poster Presentations

1. **Neiman, Y.** "Higher-spin self-dual General Relativity: 6d and 4d pictures, covariant vs. lightcone". *Fun with higher-spin self-dual GR*, 5th Mons Workshop on Higher Spin Gauge Theories, Mons, Belgium, Jan 9 (2024).

2. **Neiman, Y.** "New diagrammatic framework for higher-spin gravity". *Finding stringy joy in higher-spin gravity*, seminar at University of Mons, Mons, Belgium, June 15 (2023).
3. **Neiman, Y.** "Self-dual gravity in de Sitter space: lightcone ansatz and static-patch scattering". *Scattering gluons and gravitons in the de Sitter static patch*, cosmology seminar at Cambridge University, Cambridge, UK, Jun 12 (2023).
4. **Neiman, Y.** "Quartic locality of higher-spin gravity in de Sitter and Euclidean Anti-de Sitter space". *Locality of higher-spin gravity in de Sitter vs. Anti-de Sitter space*, seminar at QMAP, Davis CA, USA, Apr 28 (2023).
5. **Neiman, Y.** "Quartic locality of higher-spin gravity in de Sitter and Euclidean Anti-de Sitter space". *Locality of higher-spin gravity in de Sitter vs. in AdS*, seminar at UC Berkeley, Berkeley CA, USA, Apr 26 (2023).
6. **Neiman, Y.** "Self-dual gravity in de Sitter space: lightcone ansatz and static-patch scattering". *Self-dual gravity and scattering in de Sitter space, using Krasnov's reformulation of GR*, theory group meeting at Columbia University, New York, USA, Apr 20 (2023).
7. **Neiman, Y.** "New diagrammatic framework for higher-spin gravity". *Bulk-local diagrams for higher-spin gravity, using its BPS black hole*, seminar at Simons Center for Geometry of Physics, Stony Brook NY, USA, Apr 19 (2023).
8. **Neiman, Y.** "New diagrammatic framework for higher-spin gravity". *Bulk-local diagrams for higher-spin gravity, using its BPS black hole*, seminar at Princeton University, Princeton NJ, USA, Apr 17 (2023).
9. Losev, A., **Lysov, V.** "Tropical mirror symmetry for toric surfaces". *Tropical mirror*, seminar at London Institute for Mathematical Sciences, London, UK, Aug 1-4 (2023).
10. **Lang, J.**, Neiman, Y.. "N=2 supersymmetry in the twistor description of higher-spin holography". *Emergent supersymmetry algebra from a unifying higher-spin covariant description of U(N) vector models and HiSGRA*, 14th Taiwan String Workshop, Kaohsiung, Taiwan, Nov 4 (2023).
11. **Tsulaia, M.**, Weissman, D. "Supersymmetric quantum chiral higher spin gravity". *(Non)supersymmetric Chiral Higher Spin Gravity*, 14th Taiwan String Workshop, Taipei, Taiwan, Nov 1 (2023).
12. Skvortsov, E., **Tsulaia, M.** "Cubic actions for spinning black holes from massive higher-spin gauge symmetry". *Cubic action for spinning black holes*, seminar at University of Auckland, Auckland, New Zealand, Mar 1 (2024).

13. Kol, B., **Mazumdar, S.** "Triangle diagram, distance geometry and symmetries of Feynman integrals". *Kite and triangle diagrams through symmetries of Feynman integrals*, seminar at IIT Kharagpur, India, Jan 17 (2024).
14. Kol, B., **Mazumdar, S.** "Triangle diagram, distance geometry and symmetries of Feynman integrals". *Kite and triangle diagrams through symmetries of Feynman integrals*, seminar at IIT(ISM) Dhanbad, India, Jan 23 (2024).
15. Kol, B., **Mazumdar, S.** "Triangle diagram, distance geometry and symmetries of Feynman integrals". *Kite and triangle diagrams through symmetries of Feynman integrals*, seminar at IISER Bhopal, India, Jan 24 (2024).
16. Kol, B., **Mazumdar, S.** "Triangle diagram, distance geometry and symmetries of Feynman integrals". *Kite and triangle diagrams through symmetries of Feynman integrals*, seminar at NISER Bhubaneswar, India, Feb 14 (2024).
17. Kol, B., **Mazumdar, S.** "Triangle diagram, distance geometry and symmetries of Feynman integrals". *Kite and triangle diagrams through symmetries of Feynman integrals*, seminar at SNBNCBS Kolkata, India, Feb 20 (2024).
18. Kol, B., **Mazumdar, S.** "Triangle diagram, distance geometry and symmetries of Feynman integrals". *Kite and triangle diagrams through symmetries of Feynman integrals*, seminar at IACS Kolkata, India, Feb 21 (2024).
19. **O' Connell, D.** "A non-Hausdorff de Rham cohomology". *Non-Hausdorff differential geometry*, seminar at Friedrich-Schiller-Universitat, Jena, Germany, Nov 14 (2023).
20. **O' Connell, D.** "A non-Hausdorff de Rham cohomology". *Non-Hausdorff differential geometry*, seminar at Universitat Gottingen, Gottingen, Germany, Nov 8 (2023).
21. **O' Connell, D.** "A non-Hausdorff de Rham cohomology". *Non-Hausdorff differential geometry*, seminar at Vrije Universiteit, Amsterdam, Netherlands, Nov 7 (2023).
22. **O' Connell, D.** "A non-Hausdorff de Rham cohomology". *An introduction to non-Hausdorff manifolds*, seminar at Radboud Universiteit, Nijmegen, Netherlands, Nov 6 (2023).
23. **O' Connell, D.** "A non-Hausdorff de Rham cohomology". *Non-Hausdorff manifolds: Trick or Treat?*, seminar at Cambridge University, Cambridge, UK, Oct 31 (2023).
24. Neiman, Y., **O' Connell, D.** "Topology change from pointlike sources". *Topology change from pointlike sources*, seminar at University of York, York, UK, Nov 23 (2023).

25. Neiman, Y., **O' Connell, D.** "Topology change from pointlike sources". *Topology change from pointlike sources*, seminar at ETH Zurich, Switzerland, Nov 20 (2023).
26. Neiman, Y., **O' Connell, D.** "Topology change from pointlike sources". *Recent developments for branching spacetimes*, philosophy seminar at LMU Munich, Germany, Nov 16 (2023).
27. Neiman, Y., **O' Connell, D.** "Topology change from pointlike sources". *Topology change from pointlike sources*, seminar at LMU Munich, Germany, Nov 15 (2023).
28. Neiman, Y., **O' Connell, D.** "Topology change from pointlike sources". *Topology change from pointlike sources*, seminar at Syddansk Universitet, Odense, Denmark, Nov 10 (2023).
29. Neiman, Y., **O' Connell, D.** "Topology change from pointlike sources". *Topology change from pointlike sources*, seminar at Radboud Universiteit, Nijmegen, Netherlands, Nov 3 (2023).
30. **Murk, S.**, Soranidis, I. "Regular black holes and the first law of black hole mechanics". *Regular black holes and the first law of black hole mechanics*, Quantum Gravity 2023 conference, Nijmegen, Netherlands, Jul 10–14 (2023).
31. **Murk, S.** "Nomen non est omen: why it is to soon to identify ultra-compact objects as black holes". *Nomen non est omen: why it is to soon to identify ultra-compact objects as black holes*, 13th Annual Conference on Relativistic Quantum Information (RQI North), Chania, Greece, Jul 17–21 (2023).
32. **Murk, S.** "Nomen non est omen: why it is to soon to identify ultra-compact objects as black holes". *Nomen non est omen: why it is to soon to identify ultra-compact objects as black holes*, 3rd Minkowski Meeting on the Foundations of Spacetime Physics, Albena, Bulgaria, Sep 11–14 (2023).
33. **Murk, S.**, Soranidis, I. "Kinematic and energy properties of dynamical regular black holes". *Kinematical and thermodynamic properties of dynamical regular black holes*, BHT50 – Golden Wedding of Black Holes and Thermodynamics (online conference), Dec 4–8 (2023).
34. **Murk, S.**, Soranidis, I. "Kinematic and energy properties of dynamical regular black holes". *Kinematic and thermodynamic properties of dynamical regular black holes*, Gravity and Cosmology 2024 long-term workshop, Kyoto, Japan, Feb 28 (2024).
35. **Murk, S.**, Soranidis, I. "Kinematic and energy properties of dynamical regular black holes". *Properties of dynamical regular black holes*, 15th Annual

Relativistic Quantum Information Workshop (RQI South), Brisbane, Australia, Feb 5–6 (2024).

36. **Murk, S.**, Soranidis, I. "Kinematic and energy properties of dynamical regular black holes". *Kinematic and thermodynamic properties of dynamical regular black holes*, Black Holes & Cosmology, Nassau, the Bahamas, Mar 11–15 (2024).
37. **Murk, S.** "Nomen non est omen: why it is to soon to identify ultra-compact objects as black holes". *Physical black holes… and what it takes to observe them*, Particle Theory and Cosmology Group seminar at Tohoku University, Sendai, Japan, Oct 19 (2023).

5. Intellectual Property Rights and Other Specific Achievements

Nothing to report

6. Meetings and Events

6.1 Integrability, Deformations and Chaos workshop

- Date: July 25–27, 2023
- Venue: OIST Campus Lab4
- Speakers:
    - Prof. Alessandro Sfondrini (INFN Padova)
    - Prof. Robert de Mello Koch (WITS and Huzhou)
    - Prof. Dimitrios Giataganas (National Sun Yat-sen University)
    - Prof. Arpan Bhattacharyya (IIT Gandhinagar)
    - Prof. Misha Smolkin (Hebrew University)
    - Dr. Viktor Jahnke (Gwangju Institute of Science and Technology)
    - Prof. Heng-Yu Chen (National Taiwan University)
    - Prof. Julian Sonner (Geneva University)
    - Prof. Yu-tin Huang (National Taiwan University)
    - Prof. Ricardo Troncoso (Centro de Estudios Cientificos, Chile)
    - Prof. Takaaki Ishii (Rikkyo University)

- Prof. Meiju Murata (Nihon University)
- Dr. Pratik Nandy (Yukawa Institute for Theoretical Physics)
- Dr. Junggi Yoon (APCTP Pohang)
- Osamu Fukushima (Kyoto University)
- Ryota Watanabe (Kyoto University)
- Shodai Kushiro (Kyoto University)
- Jojiro Yoshinaka (Kyoto University)

6.2 Spin-(s,j) projectors and gauge-invariant spin-s actions in maximally symmetric backgrounds

- Date: January 25, 2024
- Venue: OIST Campus Lab4
- Speaker: Daniel Hutchings (University of Western Australia)

6.3 An overview of the E11 program

- Date: January 23, 2024
- Venue: OIST Campus Lab4
- Speaker: Dr. Keith Glennon (King's College London)

6.4 Tensionless strings and compactification

- Date: December 19, 2023
- Venue: OIST Campus Lab4
- Speaker: Dr. Priyadarshini Pandit (IIT Kanpur)

6.5 Higher Spin Gravity (two seminars)

- Date: October 4 and 18, 2023
- Venue: OIST Campus Lab4
- Speaker: Prof. Per Sundell (Andres Bello National University)

6.6 Locality, unconstrained vertices and hidden symmetry of HS theory

- Date: October 17, 2023
- Venue: OIST Campus Lab4
- Speaker: Dr. Vyacheslav Didenko (Lebedev Physical Institute)

6.7 Aspects of maximally symmetric non-linear (ModMax) electrodynamics

- Date: October 11, 2023
- Venue: OIST Campus Lab4
- Speaker: Prof. Dmitri Sorokin (INFN Padua)

6.8 Carroll black holes

- Date: August 23, 2023
- Venue: OIST Campus Lab4
- Speaker: Prof. Daniel Grumiller (Vienna Institute of Technology)

6.9 Kite and triangle diagrams through symmetries of Feynman integrals

- Date: August 9, 2023
- Venue: OIST Campus Lab4
- Speaker: Dr. Subhajit Mazumdar (Seoul National University)

6.10 BRST formalism of Weyl conformal gravity in Weyl geometry

- Date: May 17, 2023
- Venue: OIST Campus Lab4
- Speaker: Prof. Ichiro Oda (University of the Ryukyus)

6.11 BMS algebra from Virasoro algebras

- Date: April 18, 2023
- Venue: OIST Campus Lab4
- Speaker: Dr. Hisayoshi Muraki (IBS Center for Geometry and Physics)

6.12 Quantum informational analogue models of black holes: what happens after half-evaporation?

- Date: April 18, 2023
- Venue: OIST Campus Lab4
- Speaker: Dr. Marco Michel (Ben Gurion University of the Negev)

7. Other

Nothing to report.