Vatsal

vatsal1005.github.io

Educational background

Master of Advanced Study (MASt) | University of Cambridge *(Oct' 2025 - present)*

- Discipline: Mathematics; Specialization: Theoretical Physics

Master of Science (MSc) | Indian Institute of Technology Bombay *(2023 - 2024)*

- Discipline: Chemistry; Specialization: Theoretical Quantum Chemistry **(CPI: 10.00/10.00)**

Bachelor of Science (BS) | Indian Institute of Technology Bombay *(2019 - 2023)*

- Major: Chemistry **(CPI: 8.51/10.00)**; Minor: Physics **(CPI: 9.38/10.00)**

Scholastic Achievements

- Won a **Cambridge Trust** Scholarship and the **Narotam Sekhsaria Foundation** Postgraduate Scholarship *(2025)*
- Bagged the coveted **Undergraduate Research Award 03** for my dual-degree project (Master's thesis) *(2024)*
- Scored the **Absolute Perfect (AP)** grade in Molecular Spectroscopy, reserved for an exceptional performance *(2022)*

Research projects

Matter-Chern–Simons theory | Research project `[arXiv:2307.11020]` *(Aug' 2022 - present)*
Guide: Shiraz Minwalla, Professor, Department of Theoretical Physics, Tata Institute of Fundamental Research

- Analyzed 3D Chern–Simons theory with $U(N)$ fermionic matter in the **'temporal' gauge** at finite temperature
- Set up the path integral over general (spatial) **genus-g Riemannian manifolds** at finite N and volume
- Computed the exact solution for the finite temperature gap equation and the **free energy** for the theory on $\mathbb{R}^2 \times S^1$
- Evaluating the thermal partition function on $S^2 \times S^1$ using (spin-weighted) **monopole spherical harmonics**

Sachdev–Ye–Kitaev model | Research project *(Jul' 2022 - present)*
Supervisor: Sandip P. Trivedi, Professor, Department of Theoretical Physics, Tata Institute of Fundamental Research

- Computationally generated ensembles for generalized SYK models with a **sum over q-body** interactions
- Simulated **entanglement scrambling** in those models, mimicking the chaotic properties of a black hole
- Investigated numerics for the finite-mean complex SYK model to obtain **smoothly tunable chaotic behaviour**

Finite-temperature electronic structure theory | Master's thesis *(Aug' 2023 - May 2024)*
Advisor: Rahul Maitra, Associate Professor, Department of Chemistry, IIT Bombay
Scientific interlocutor: Debashis Mukherjee, Distinguished Chair Professor, CQuERE, TCG CREST, Kolkata

- Developed a finite-temperature, non-equilibrium, **non-perturbative, strongly-correlated**, relativistic, many-body fermionic theory with analytical mean-field solutions, even admitting a sensible **zero-temperature limit**
- Surveyed appropriate Monte Carlo schemes to simulate the **bosonized path integral** beyond mean-field level

List of publications

The free energy of the large-N fermionic Chern–Simons theory in the 'temporal' gauge
Shiraz Minwalla, Souparna Nath, Nikhil Tanwar, Vatsal `[arXiv:2307.11020]` `[10.4310/ATMP.251120045146]`

Fermionic Chern–Simons theory on $S^2 \times S^1$ at large-N in the 'temporal' gauge
Shiraz Minwalla, Souparna Nath, Nikhil Tanwar, Vatsal [To appear]

Controlling quantum chaos in the finite-mean Sachdev–Ye–Kitaev model
Arkaprava Mukherjee, Vatsal , Sumilan Banerjee, Sandip P. Trivedi, Nandini Trivedi [To appear]

Does chaos survive in the finite-mean Sachdev–Ye–Kitaev model without disorder?
Arkaprava Mukherjee, Vatsal , Sumilan Banerjee, Sandip P. Trivedi, Nandini Trivedi [To appear]

Ansatze-free non-perturbative electronic structure theory at finite-temperature
Vatsal [To appear]

Schwinger–Keldysh-type correlators from AdS/CFT
Harsh Anand, Shiraz Minwalla, Jyotirmoy Mukherjee, Souparna Nath, Pabitra Ray, Vatsal [To appear]

Schools, visits, seminars, workshops, and conferences

Strings 2023 Conference | Perimeter Institute for Theoretical Physics *(Jul' 24 - Jul' 29, 2023)*

- Received the invitation for an in-person attendance and **presented a poster** titled *The free energy of the large-N fermionic Chern–Simons theory in the 'temporal' gauge*, based on `[arXiv:2307.11020]`

"Saalburg" Summer School | Ludwig-Maximilians-Universität München *(Sep' 04 - Sep' 15, 2023)*

- Selected to take part in this school for graduate students on *foundations and new methods in theoretical physics*
- **Delivered a talk** at the school on *The free energy of matter-Chern–Simons theories in the 'temporal' gauge*

ICTS String Seminar | International Centre for Theoretical Sciences, Bengaluru *(Sep' 25 - Sep' 30, 2023)*

- Invited to visit the string theory faculty and **give a seminar** on Sep' 27, 2023, based on `[arXiv:2307.11020]`

Indian Strings Meeting 2023 | Indian Institute of Technology Bombay *(Dec' 10 - Dec' 16, 2023)*

- Presented a poster on *The free energy of the large-N fermionic Chern–Simons theory in the 'temporal' gauge*

String-Math 2024 Conference | International Centre for Theoretical Physics *(Jun' 01 - Jun' 14, 2024)*

- Invited to visit the High Energy, Cosmology and Astroparticle Physics Research Section and **present a short talk** and a poster titled *Fermionic Chern–Simons theory on $S^2 \times S^1$ at large-N in the 'temporal' gauge*

Student Talks on Trending Topics in Theory Workshop | IIT Bombay *(Jul' 01 - Jul' 12, 2024)*

- **Co-organized the workshop** and spoke on *Fermionic Chern–Simons theory on $S^2 \times S^1$ in the 'temporal' gauge*

Quantum Information, Quantum Field Theory, Gravity | ICTS, Bengaluru *(Aug' 12 - Sep' 06, 2024)*

CREST Institute Seminar | TCG – CREST, Kolkata *(Nov' 29 - Dec' 04, 2024)*

- Visited the CQuERE faculty and **gave a seminar** on Dec' 03, 2024 on *Finite-temperature electronic structure theory*

National Strings Meeting 2024 | Indian Institute of Technology Ropar *(Dec' 09 - Dec' 14, 2024)*

- Presented a poster on *Fermionic Chern–Simons theory on $S^2 \times S^1$ in the 'temporal' gauge*

Strings 2025 Conference | New York University Abu Dhabi *(Jan' 06 - Jan' 10, 2025)*

- **Presented a poster** on *Fermionic Chern–Simons theory on $S^2 \times S^1$ in the 'temporal' gauge*

After-Strings Conference 2025 | Tata Institute of Fundamental Research *(Jan' 13 - Jan' 18, 2025)*

Positive Geometry in Scattering Amplitudes & Cosmo. Corr. | ICTS *(Feb' 12 - Feb' 21, 2025)*

- **Gave a talk** at the conference on *Fermionic Chern–Simons theory on $S^2 \times S^1$ in the 'temporal' gauge*

Black hole physics from strongly coupled thermal dynamics | SCGP, SBU *(May 12 - Jun' 08, 2025)*

Advanced Lectures in Physics in Switzerland II | SwissMAP Research Station *(May 25 - May 30, 2025)*

Physical Mathematics of QFT Summer School | UMass Amherst *(Jun' 08 - Jun' 13, 2025)*

Supergravity 2025 Conference | Politecnico di Torino *(Sep' 16 - Sep' 18, 2025)*

- **Gave a gong show talk** and presented a poster on *Fermionic Chern–Simons theory on $S^2 \times S^1$*

KMPB School 2025: D-branes | Humboldt-Universität zu Berlin *(Sep' 22 - Sep' 26, 2025)*

- **Presented a poster** on *Fermionic Chern–Simons theory on $S^2 \times S^1$ in the 'temporal' gauge*

Math Part III Seminar Series (Michaelmas term) | University of Cambridge *(Dec' 04, 2025)*

- **Delivered a seminar** on *Large-N fermionic Chern–Simons theories in the 'temporal' gauge*

YTF 2025 Conference | Durham University *(Dec' 17 - Dec' 18, 2025)*

- Set to **deliver a talk** on *Fermionic Chern–Simons theory on $S^2 \times S^1$ in the 'temporal' gauge*

Pre-Asian Winter School Workshop | Tata Institute of Fundamental Research *(Jan' 05 - Jan' 09, 2026)*

Asian Winter School on Strings, Particles and Cosmology | IISER Bhopal *(Jan' 11 - Jan' 20, 2026)*

- Set to **present a poster** on *Fermionic Chern–Simons theory on $S^2 \times S^1$ in the 'temporal' gauge*

Previous projects

Inflationary ΛCDM cosmology and initial conditions | Reading project *(Jun' 2021 - Aug' 2023)*
Principal investigator: Vikram Rentala, Associate Professor, Department of Physics, IIT Bombay

- Read about the constituents of the **concordance model of cosmology** and the bounds to their abundance
- Studied **Friedmann and Boltzmann equations** for an expanding universe and effects of perturbations in spacetime, leading to an in-depth understanding of **inflationary cosmology** to conclude the initial reading for the project
- Surveyed literature on the **emergence of classicality** from the quantum fluctuations in cosmological matter density

Finite-temperature electronic structure theory | Bachelor's thesis *(Feb' 2022 - May 2023)*
Advisor: Rahul Maitra, Associate Professor, Department of Chemistry, IIT Bombay

- Surveyed multiple approaches to a finite-temperature realization of a quantum many-body theory, viz. **thermal cluster-cumulant theory**, path-integral Monte Carlo, thermo-field dynamics, and thermal coupled-cluster theory
- Simulated thermal CC equations to compute **correlation energy** and grand potential for various chemical systems
- Classified the complexity of **thermal Bogoliubov transformation** on the ab-initio Hamiltonian with the basis size
- Obtained independence of **mode-separated observables** over the two-body potential for the ab-initio Hamiltonian

Advanced course on gravity | Supervised learning project *(Jul' 2021 - Nov' 2021)*
Supervisor: Urjit A. Yajnik, Professor, Department of Physics, IIT Bombay

- Analyzed black hole geometries and **modified theories of gravity** as a part of this seminar-cum-project course
- Learned about **canonical gravity** through the Hamiltonian formulation of the general theory of relativity
- Understood various appropriate discretizations of the general theory of relativity, such as **Regge calculus**
- Studied quantization of the canonical formulation of general relativity through **covariant loop quantum gravity**

Astrophysical jets from the active galactic nuclei | Training project *(Jul' 2021 - Jan' 2022)*
Guide: Prakriti Pal Choudhury, Postdoctoral Research Associate, Institute of Astronomy, University of Cambridge

- Learned about the theoretical considerations behind the creation of jets by **supermassive black holes (SMBH)** through the **Blandford–Znajek process** and their subsequent interaction with the interstellar medium (ISM)
- Got accustomed to the Athena++ code for the **general relativistic magnetohydrodynamic (GRMHD) simulations** for examining the role of accretion disks in the generation of jets near the event horizon of a black hole

Relevant Courses Undertaken

Cambridge coursework	IIT Bombay coursework
General Relativity	Current Trends in Physics (Advanced gravity and string theory)
Quantum Field Theory	Specialized Topics in QFT and Beyond Standard Model Physics
Symmetries, Particles, and Fields	Special Topics in Elementary Particle Physics (Advanced QFT)
Statistical Field Theory	Elementary Particle Physics
Differential Geometry	Advanced Statistical Mechanics (Statistical field theory)
Advanced Quantum Field Theory *	Quantum Mechanics III (Relativistic QM & quantum field theory)
Black Holes *	General Theory of Relativity
Supersymmetry *	Advanced Quantum Information and Computation
String Theory *	Quantum Information and Computing
Canonical Gravity *	Non-linear Dynamics
Solitons, Instantons, and Geometry *	Chemical Dynamics (Quantum dynamics)
Standard Model *	Quantum Chemistry (Electronic structure theory)
Gauge/Gravity Duality *	Symmetry in Chemistry (Finite group theory)
Applications of Quantum Field Theory *	Real Analysis

* These courses will be delivered during the Lent and Easter 2026 terms.

Technical Skills

- **Programming:** C++, HTML, Java, LaTeX, MATLAB, FORTRAN, Python
- **Software:** AutoCAD, CANDLE, Origin, SolidWorks, Maxima, Git, Athena++, Wolfram Mathematica

Positions of Responsibility

Indian Strings Meeting 2023 | Volunteer *(Dec' 2023)*
Hosts: Indian Institute of Technology Bombay and The Abdus Salam International Centre for Theoretical Physics

- Facilitated the smooth functioning of the conference through logistical inputs and attended a variety of string-y talks

An undergraduate course on quantum chemistry | Teaching assistant *(Dec' 2022 - Mar' 2023)*
Instructors: Prof. Rahul Maitra and Prof. Rajarshi Chakrabarti; Theme: Introduction to quantum chemistry

- Gave tutorials and remedial sessions for a group of 40 freshmen and managed grading logistics for a class of **350**

A graduate course on advanced quantum chemistry | Teaching Assistant *(Jan' 2022)*
Instructor: Prof. Rahul Maitra; Theme: Electronic structure and correlation

- Selected to assist the delivery of this course on many-electron systems, emphasizing **post-Hartree–Fock** methods

A graduate course on symmetry in chemistry | Teaching Assistant *(Jul' 2021)*
Instructors: Prof. G. Naresh Patwari and Prof. Achintya Kumar Dutta; Theme: Group theory and its applications

- Accepted as the **first** undergraduate teaching assistant to assist the delivery of this course, primarily aimed at the **PhD students**, after being the junior-most student to have taken up the course a year before (Autumn, 2020)

Summer improvement program in group theory applications | Volunteer *(Jul' 2021)*
Department of Chemistry, IIT Bombay

- Delivered a course in **group theory applications** aimed at **60** junior & senior undergraduates and postgraduates from IIT Bombay and 14 senior (under)graduates from eminent Peruvian institutes like UNMSM, UPCH and UNI
- Curated extensive content, describing the theoretical aspects of groups rigorously as abstract objects, inheritance of additional structures on them, maps involving groups, their **representation theory** and character theory

Department academic mentorship program | Mentor *(May 2021 - Jun' 2022)*
Department of Chemistry, IIT Bombay

- Supported **six** sophomore undergraduates in their academic pursuits while catering to their logistical and emotional requirements, serving as an intermediary between college administration and them
- Selected after a detailed application, thorough interview and peer reviews before being subjected to rigorous training

Extracurricular Activities

Frontiers of relativistic quantum chemistry | Preliminary reading *(Dec' 2020 - Jan' 2022)*
Guide: Rahul Maitra, Associate Professor, Department of Chemistry, IIT Bombay

- Understood relativistic particle and field-theoretic formalisms for treatment of the quantum **many-body problem**
- Analyzed the methods of application of **relativistic coupled cluster theory** and quantum electrodynamics to many-electron systems, potentially amenable to a finite temperature treatment for the senior thesis

Suspension system optimization | Junior design engineer *(Sep' 2020 - Jul' 2021)*
IIT Bombay Racing Team

- Learned about the **steering system** to calculate appropriate angles that transmit desired steering feedback
- Helped the design team find optimum vehicle dynamics parameters for the suspension system of our race car

Race car optimization training | Technical trainee *(Jan' 2020 - Sep' 2020)*
IIT Bombay Racing Team

- Dove into the world of race car technology with a comprehensive introduction to **vehicle dynamics**
- Extended the knowledge acquired to simulate the effects of a **suspension system** on a car, using MATLAB
- Completed the introductory dynamical understanding of the said system by learning about its **aerodynamics**

Analysis of nuclear reactions | Research primer *(May 2020 - Jul' 2020)*
Guide: Prof. Avinash Agarwal; Theme: Reaction cross-section calculation for incomplete fusion reactions

- Engineered methods of **automation**, **web scraping** and **file handling** to compile standard reference data
- Read about the quantum mechanical theory describing **nuclear structure and reactions** from MIT OCW
- Analyzed spectroscopic data to determine the **half-lives** of residues from reactions between ^{55}Mn and ^{19}F