Siddhant Midha

Curriculum Vitae

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Research Interests

I am broadly interested in interdisciplinary research in quantum information processing. This spans quantum information theory, open quantum systems, condensed matter, quantum optics, and (quantum) machine learning. Moreover, I am keen on working with experimentally relevant theoretical problems.

Education

2020 - Present **Indian Institute of Technology Bombay** Pursuing a major in Electrical Engineering (with honors), along with a minor degree in Physics. GPA: 9.81/10.

Publications and Technical Writing

Papers (1) S. Midha, K. Jana, B. Muralidharan; **Are Symmetry Protected Topological Phases Immune to Dephasing? – A topological electronics perspective** [arXiv:2305.11149] *Currently in revision at Journal of Physics D: Applied Physics*

(2) M. Atallah, H. Velmurugan, R. Sharma, S. Midha *et al.* **Integer Factorization through FunC-QAOA** [arXiv:2309.15162] *Currently under review at Quantum Information Processing*

(3) S. Midha, M. Parashar, K. Saha; **Bayesian reconstruction of current densities from widefield quantum diamond magnetometry**, *Manuscript in progress for submission to PR Applied*

(4) A. Arora†, S. Midha†, A. Zyuzin, P. Hakonen, B. Muralidharan; **Steady-state dynamics and entanglement in quantum-dot Cooper pair splitters**, *Manuscript in progress*

(5) S. Midha, R. Singh, K. Gharavi, J. Baugh, B. Muralidharan; **Induced superconducting correlations in hybrid systems**, *Manuscript in progress for submission to Physical Review B*

Reports (1) **Exploring non-hermitian topological quantum phenomenon** [Survey Paper, Slides]

(2) **AC quantum transport: formalisms and applications** [Survey Paper, Slides]

(3) **Error correcting codes: the classical and the quantum** [Report]

(4) **Phase transitions in open quantum systems** [Report]

Presentations and workshops

Presentations (1) S. Midha, K. Jana, B. Muralidharan; **Are Symmetry Protected Topological Phases Immune to Dephasing?** Poster presentation at *Quantum Matter 2023, Madrid, Spain.* [Abstract, Poster]

(2) S. Midha, M. Parashar, K. Saha; **Fourier and Bayesian Methods for Current Reconstructions: A Comparative Study** Poster presentation at *Quantum Sensing Gordon Research Seminar, Les Diablerets, Switzerland.*

(3) S. Midha†, A. Arora†, B. Muralidharan; **A Journey through hybrid normal-quantum dot-superconducting systems** at the *Quantum Dynamics - Fundamentals and Realizations, MPI of Complex Systems, Dresden, Germany.* [Poster]

(3) S. Midha, R. Singh, K. Gharavi, J. Baugh; **Analyzing Cooper pair injection and induced superconducting correlations in hybrid nanowire systems**; *submitted to APS march meeting 2024.*

(4) A. Arora, S. Midha, A. Zyuzin, P. Hakonen, B. Muralidharan; **Quantum Transport and Entanglement in Cooper pair splitters**; *submitted to APS march meeting 2024.*

(5) K. Agaram, S. Midha, A. Müller, V. Garg; **Quantum State Preparation with Deep Reinforcement Learning**, poster at *Aalto SCI internship exhibition, Aalto University, Finland*

Workshops (1) **Perimeter Scholars International**: Selected for the PSI Summer School in Theoretical Physics.

(2) Selected for the **Condensed Matter meets Quantum Information** meeting at the *International Centre for Theoretical sciences, Bengaluru, India*, and presented a poster.

† *denotes equal contribution*

Research Experience

Superconducting and Topological Quantum Matter [Jul 2022 - Present]

CNQT Lab, IIT Bombay. Guide: Prof. Bhaskaran Muralidharan

1. **Dephasing in topological insulators**
   - Studied topology in condensed matter, particularly two-dimensional systems exhibiting the quantum spin Hall (QSH) and spin quantum anomalous Hall (SQAH), and investigated the effects of Anderson disorder and lattice background dephasing on the conductance quantum by simulating their quantum transport
   - Pointed out a mechanism for the effects of Rashba spin-mixing with momentum dephasing in QSH and provided simple field and band engineering methods to improve the conductance in experiments
2. **Cooper pair splitters (CPS)** *(Collaborators: Prof. Pertti Hakonen & Dr. Alexander Zyusin, Aalto University)*
   - Implemented a full double-quantum-dot and superconductor Hamiltonian perturbed by weakly coupled contacts with a thermal gradient to model the CPS experiments and elucidate quantum broadening
   - Devised a steady-state fermionic correlator to signal CPS and compute two-orbital fermionic discord and quantum mutual information to prove the solid-state entanglement generation in the device conclusively
   - Showed the inadequacy of solely using the master equation (ME) and working on incorporating spectral information derived from Green's functions into the ME for improving the proposals of dynamical CPS
3. **Induced superconducting correlations** *(Collaborator: Prof. Jonathan Baugh, Institute for Quantum Computing)*
   - Studying the proximity effect while incorporating for quantum transport using the NEGF formalism to study the proximity effect in hybrid normal-superconducting structures and compared with standard BdG approach
   - Used this method to show the spectral decomposition of the induced pair amplitude and analyzed the location of Majorana zero modes in Rashba nanowires by incorporating insight from the pair amplitude

Phase Transitions in Monitored and Dissipative Systems [March 2023 - Present]

QIT-C group, IIT Bombay. Guide: Prof. Sai Vijanampathy

- Studied the theory of open quantum systems and conducted a literature survey of information dynamics in monitored systems, notably purification dynamics, effective quantum codes, and classical stat-mech mappings
- Worked on dynamics in open quantum systems – homodyne and jump unravellings of the Lindblad equation to study time crystals and entanglement transitions at the averaged density matrix level and individual trajectories
- Implemented numerical simulations to study the entanglement and purity dynamics in random quantum circuits (stabilizer formalism), collective spins (Dicke model), and Ising chains (fermionic Gaussian states)
- Proposed a connection between MIPT in continuous measurements and the time crystal phase via exceptional points in the Louivillian eigenspectrum, hypothesized to be at the real axis in the thermodynamic limit
- Working towards a novel theoretical formalism for studying the MIPT and purification transitions via quantum instruments in both random quantum circuits and continuous measurements in Hamiltonian systems

NV Centers: Bayesian Optimization and Quantum Simulation [August 2022 - Present]

P-Quest Lab, IIT Bombay. Guide: Prof. Kasturi Saha
Collaborator: Dr. Jean-Philippe Tetienne & Dr. David Broadway, RMIT University

- Studied the theory of nitrogen-vacancy (NV) centers in diamond, worked with bulk diamond NV ensembles, and learned ODMR techniques for performing wide-field quantum magnetometry of microscale samples
- Analyzed Bayesian and Fourier techniques for reconstructing 2D current densities and used the two-norm and structured similarity distances to benchmark performance w.r.t. standoff distance and noise in an experiment
- Provided the first Bayesian reconstructions on experimental NV imaging data on niobium, graphene, and micro-coil samples, outlined an experimentally-relevant method of regularizer selection in the algorithm
- Identified a data-processing-inequality in the experiment to extend currently known Bayesian protocols
- Studying the theory of analog and digital quantum simulation using NV centers and working towards employing Floquet engineering to simulate two-band Floquet topological phases using the ensemble NV setup

Generalizing Variational Quantum Error Correction (QEC) [Nov 2023 - Present]

IBM India. Guides: Dhiraj Madan, IBM & Prof. Prabha Mandayam, IIT Madras

- Studied the theory of quantum error correction, including the algebraic and information-theoretic conditions for QEC, the stabilizer formalism, bounds on quantum codes, and the operator quantum error correction formalism
- Implemented variational methods of finding quantum codes and working on an extension to operator codes
- Proposed an architecture to combine shadow tomography of errors with *in-situ* search for the codespace

Resonator Design for MWO Quantum Transduction [May 2023 - July 2023]

Technische Universität München & MPI für QuantenOptik, Germany. Guide: Prof. Andreas Reiserer

- Conducted an extensive literature survey of nanophotonic inverse design & microwave-to-optical transduction
- Implemented gradient-based inverse design with 2D FDTD simulations in MEEP for designing beam splitters, mode converters, and photonic crystal cavities with a LD-MMA optimizer and with step-wise binarization
- Used these techniques to facilitate the design of low-loss Fabry-Pérot waveguide cavities on silicon on insulator while accounting for fabrication constraints and large mode-overlaps with the adjacent microwave cavity
- Explored the non-unique mapping of the inverse design problem via data-driven neural network approaches as well as more sophisticated multi-density network approaches to obtain the fundamental bounds in the design
- Measured the fabricated resonators using a room-temperature tapered fiber setup and analyzed the data

Quantum generative learning [May 2022 - July 2022]

Aalto-yliopisto, Finland. Guide: Prof. Vikas Garg

- Developed a general framework aimed at proving the possible quantum advantage in a setting of generative modelling of quantum and classical distributions quantified by the sample complexity of the algorithm
- Conducted a literature review of quantum learning theory, classical shadows for learning quantum states and channels, and studied information theoretic lower bounds on machine learning algorithms for quantum systems
- Analyzed the merits of performance of quantum circuits as learning models including expressive power, entanglement creation, learnability and trainability in the context of generative modelling of quantum states
- Studied the theory of variational inference and deep generative models: generative adversarial networks, variational autoencoders and Boltzmann machines used as hybrid quantum-classical learning systems

Quantum approximate optimization for integer factorization [July 2022 - Sept 2022]

QWorld. Guides: Dr. Adam Glos & Dr. Özlem Salehi, QWorld

- Studied the Quantum Approximate Optimization Algorithm (QAOA) and analyzed the Functional QAOA formalism as a candidate for factorization and compared it to traditional Ising-based QUBO formulations
- Reviewed and implemented quantum algorithms for multiplication, addition, and modulo operation in QAOA
- Explored different ways of encoding integer factorization as a discrete optimization problem, and employed circuit simplification techniques to reduce the search-space via simplifying clauses in the variational factoring

Simulating many-body quantum systems

Self endeavour

- Working on gaining a proficient understanding of numerical methods for studying many-body quantum systems: with `Stim` for random quantum circuits and error-correcting models, `QuTiP` for open quantum systems, `QuSpin` for fermionic and spin exact diagonalization and `TenPY` for tensor networks and matrix-product states
- Using these simulations along with theoretical reading to understand contemporary phenomenon in many-body physics including quantum information scrambling and chaos, and the many-body localization phenomenon

The Black-Hole Information Paradox [May 2022 - Nov 2022]

Department of Physics, IIT Bombay. Guide: Prof. Vikram Rentala

Studied different aspects of quantum information and complexity including

- **Quantum Operations**: Limits and uses of the CPTP formalism and representations (Choi, Kraus, Stinespring)
- **Quantum Entanglement**: Definition and properties of entanglement and entanglement fidelity
- **Distance Measures**: Ways to define the distance measures between quantum states and channels

Honors and awards

2023 Awarded an **Undergraduate Research Award** at IIT Bombay
2023 Awarded the **Institute Academic Prize** for exemplary academic performance in the year 2022-23
2023 Nominated for the **Dhanjanjay award** for pursuing research in Bachelor's Thesis I at IIT Bombay
2023 Sanctioned a **grant** of INR 170,000 ($\sim$ 1800€) for presenting at conferences as an undergraduate
2023 Awarded a **Best Project Award** for our design of a fluxgate sensor & lock-in amplifier in EE 344
2023 Awarded the **DAAD-WISE** fellowship for pursuing summer research in Germany
2022 Awarded with **AP Grades** in MA106: Linear Algebra and EE214: Digital Circuits Lab courses
2022 Felicitated with the **Aalto Science Institute** research fellowship for pursuing research in Finland
2022 Selected for the **MITACS Globalink** fellowship for pursuing undergraduate research in Canada
2020 Achieved **All India Rank 150** in the JEE-Advanced Exam, out of over a million candidates
2020 Selected for the prestigious **Kishore Vaigyanik Protsahan Yojana** fellowship by Govt. of India

Teaching

Served as a teaching assistant (TA) in the following courses.

2021 MA 111: Calculus II. Instructors: *Prof. Saurav Bhaumik & Prof. Bata K. Das*
2021 MA 106: Linear Algebra. Instructors: *Prof. G.K. Srinivasan & Prof. K. Sivasubramanian*
2021 MA 108: Differential Equations I†. Instructors: *Prof. Santanu Dey & Prof. K. Sureshkumar*
2022 MA 205: Complex Analysis. Instructor: *Prof. Saikat Mazumdar*
2022 MA 109: Calculus I. Instructors: *Prof. Sanjoy Pusti & Prof. Madhusudan Manjunath*
2022 MA 111: Calculus II†. Instructors: *Prof. Preeti Raman & Prof. Niranjan Balachandran*
2023 PH 534: Quantum Information & Computing. Instructor: *Prof. Himadri Shekhar Dhar*

This included conducting weekly **live tutorial sessions** for **40+** students. I have been the head TA for (†), helped in invigilation duties, conducted help sessions, and made tutorial solutions using LaTeX (webpage).

Selected Academic Projects (Full list)

Reading Projects

- **Quantum Information**: Studied the rigorous foundations from Watrous' *The Theory of Q.I.* (Notes)
- **Abstract Algebra**: Studied the basics of abstract algebra from Artin's *Algebra* (Notes)
- **Classical Mechanics**: Studied classical mechanics from L&L's *Mechanics and Electrodynamics* (Notes)

Quantum Algorithms [May 2021 - Jul 2021]

Seasons of Code. Web and Coding Club, IIT Bombay

- Studied fundamentals of quantum algorithms from N&C's *Quantum Computation & Quantum Information*.
- Implemented various quantum algorithms such as the Bernstein-Vazirani Algorithm, Quantum Fourier Transform, Super-Dense Coding, the Shor's and Grover's algorithms on Q# and Qiskit. (Repository)

Lock-in Amplifier with flux-gate sensor [Jan 2023 - Apr 2023]

Electronics Design Lab (EE 344). Instructors: Prof. Siddharth Tallur, Kasturi Saha, Laxmeesha Somappa

- Designed a flux-gate sensor from scratch using in-house components, which included the design of printed circuit board (PCB) and optimization of coil parameters all in a ready-to-go package with i/o ports
- Programmed a Red-Pitaya board as a lock-in amplifier, and integrated it with the flux-gate magnetometer to facilitate real-time sensing of DC magnetic fields read out on the computer (Report, Demo)

Quantum Spin Chains and Topology (Report, Slides) [Oct 2023 - Dec 2023]

Advanced Statistical Mechanics (PH 543). Instructor: Prof. Amitabha Nandi.

- Studied the theory of ground-state quantum phase transitions in the quantum Ising and rotor models
- Mapped the order-to-disorder phase transition in the TFIM to the topological phase transition in the Kitaev chain through the non-local Jordan Wigner mapping and studied entanglement as an order parameter
- Studied the mapping of d-dimensional quantum phase transition to $d+1$-dimensional classical phase transitions

Mentorship

2023 **Institute Student Mentor** to a batch of *twelve* freshmen to guide them personally and academically throughout the first year at IIT Bombay.

2023 **Department Academic Mentor** to *eight* sophomores to support them through the rigorous second year in Electrical Engineering at IIT Bombay.

2023 **Machine learning for quantum error correction** (*Winter in Data Science*): Mentoring a project exploring the use of ML methods in QEC, as decoders as well as for finding codespaces.

2022 **Learning with quantum computers** (*Winter in Data Science*): Mentored two projects in quantum machine learning and classical and quantum reinforcement learning (Repository)

2022 **Quantum machine learning** (*Seasons of Code*): Co-mentored *eight* students studying the fundamentals of QC and QML, and implementing research papers in QML (Repository)

2022 **Machine learning** (*Summer of Science*): Guided *four* students with suitable resources and material to build a theoretical understanding of the basics of machine learning.

Computer Skills

Languages Python, LaTeX, Matlab, C++

Libraries QuTiP, Qiskit, Pennylane, QuSpin, Stim, PyClifford, MEEP, PyTorch, TensorFlow

Coursework

Physics Quantum Physics, Electromagnetism, Electromagnetic Waves, Quantum Mechanics II, Quantum Information and Computing, Condensed Matter Physics, Quantum Transport, Topological Electronics, General Relativity, Statistical Physics, Advanced Statistical Mechanics, Numerical Methods in Physics$^{\oplus}$, Path Integrals$^{\oplus}$, Symmetries$^{\oplus}$

Electrical Engineering Spintronics, Error-correcting codes, Information Theory and Coding, Electronic Devices§, Analog Circuits§, Signal Processing, Communication Systems§, Digital Systems§, Microprocessors§, Control Systems§, Electronics Design

Math & CS Linear Algebra, Complex Analysis, Probability & Random Processes, Calculus I & II, Differential Equations I & II, Introduction to Machine Learning, Reinforcement Learning, Logic in CS, Computer Programming & Utilization

Online Special Relativity, Machine Learning, Neural Networks & Deep Learning, Improving Deep Neural Nets, Convolutional Neural Nets, NLP in Tensorflow, Generative Learning in Tensorflow

§*along with a lab component,* $^{\oplus}$*at the PSI school*

Outreach

Education Mentored underprivileged students aspiring for the Joint Entrance Examination through live online classes teaching physics. This included solving students' doubts and addressing other concerns

Research Started a Quantum Information and Computing Group (QICG) at IIT Bombay, organized pedagogical sessions in quantum computing, quantum error correction, and learning theory

References

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