RAJAT

Indian Institute of Technology Ropar
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PERSONAL DETAILS & CURRENT POSITION

Date of Birth: 13 September 1993
Languages: English, Hindi

Current Position: Senior Research Fellow (Jan 2022–Present), Department of Physics, IIT Ropar

EDUCATION

Ph.D. in Physics — Dec 2019 – Present
Indian Institute of Technology Ropar, Punjab, India

Thesis: Collective excitations and coarsening dynamics of spin-orbit-coupled spinor condensates
Advisor: Dr. Sandeep Gautam
Thesis Defended: 13 June 2025

Junior Research Fellow — Jun 2019 – Dec 2019
Indian Institute of Technology Ropar, Punjab, India

M.Sc. in Physics — Jul 2013 – Jun 2015
Kurukshetra University, Kurukshetra, India — First Class

B.Sc. (Non-Medical) — Jul 2010 – Jun 2013
Panjab University, Chandigarh, India — First Class

EMPLOYMENT

Senior Research Fellow — Jan 2022 – Present
Indian Institute of Technology Ropar, Punjab, India

In addition to my primary research, I was involved in supervising and overseeing the progress of master's students and my junior PhD colleagues in the group.

Junior Research Fellow — Jun 2019 – Dec 2019
Indian Institute of Technology Ropar, Punjab, India

Junior Research Fellow — Jul 2018 – May 2019
Malaviya National Institute of Technology (MNIT), Jaipur, India

Lecturer — Jul 2017 – May 2018
DAV College Sector-10, Panjab University, Chandigarh, India

Physics Tutor (IIT-JEE Preparation) — Aug 2015 – Jun 2017
Self-Employed, Chandigarh, India

Provided advanced instruction in physics for national-level engineering entrance exams.

AWARDS AND RECOGNITION

Best Oral Presentation Award — March 2025
PHYCON 2025, IIT Ropar, Punjab, India

GATE (Physics) Qualified — 2017, 2018
Graduate Aptitude Test in Engineering, India

Current Research Interests

- **Ultracold Quantum Gases and Spinor Condensates**
  - Spin-orbit-coupled, coherently coupled, and dipolar Bose-Einstein condensates (BECs)
  - Quantum droplets, supersolidity, collective excitations, quantum phase transitions
- **Non-Equilibrium and Finite-Temperature Dynamics**
  - Universal coarsening phenomena and defect dynamics in quenched quantum systems
  - Stochastic methods (SPGPE, SGPE) for real-time thermal dynamics
  - Hartree–Fock–Bogoliubov–Popov theory for spinor condensates
- **Quantum Fluids of Light and Polaron Physics**
  - Non-equilibrium dynamics and superfluidity in exciton-polariton condensates
  - Impurity physics (polarons) in BECs and polaron-polaritons in driven-dissipative systems

Technical Skills

- **Programming Languages:** Fortran (Advanced), Python (Intermediate), MATLAB (Intermediate), Mathematica (Proficient)
- **Numerical Methods:** Basis-expansion, finite-difference, and pseudo-spectral methods for PDEs; Eigensolvers; Stochastic differential equation solvers.
- **Parallel Programming & HPC:** OpenMP, OpenACC (basic GPU computing); Proficient with HPC clusters (Slurm) and parallel computation strategies.
- **Numerical Libraries:** LAPACK, ARPACK, BLAS, FFTW
- **Operating Systems & Environments:** Linux, Windows; Bash scripting
- **Data Visualization:** Gnuplot, Matplotlib, Origin
- **Machine Learning:** Basic knowledge of ML techniques and their potential applications in physics.

Selected Physics Code Development Experience

1. **Ground-State Energy Minimization (Mathematica).** Developed Mathematica-based numerical methods for directly minimizing the energy functional to obtain ground states of spin-orbit-coupled spin-1 and pseudospinor condensates. [Phys. Rev. A **111**, 033316 (2025); New J. Phys. **27** 043005 (2025).]
2. **Variational Excitation Modes (Mathematica).** Implemented Mathematica-based variational algorithms for computing low-lying collective excitation modes in spin-1 Bose–Einstein condensates. [Phys. Rev. A **106**, 013304 (2022); Phys. Rev. A **108**, 043310 (2023).]
3. **Finite-Difference BdG Solver (Fortran).** Developed robust Fortran code employing finite-difference methods to solve the Bogoliubov–de Gennes (BdG) equations for spin-orbit-coupled spin-1 condensates in harmonic and other confining potentials. [Phys. Rev. A **106**, 013304 (2022); Phys. Rev. A **108**, 043310 (2023).]
4. **Basis-Expansion BdG Solver (Fortran).** Created Fortran programs to solve the BdG equations using harmonic oscillator basis-expansion techniques for spin-orbit-coupled pseudospinor and spin-1 condensates in confined geometries. [Phys. Rev. A **109**, 033319 (2024); Phys. Rev. A **111**, 023311 (2025).]
5. **Fourier-Pseudospectral GPE Solvers (Fortran).** Implemented Fourier-pseudospectral numerical methods for solving the Gross–Pitaevskii equation (GPE) for single-component and binary dipolar condensates.

6. **BdG Solver for Homogeneous Systems and Quench Dynamics (Fortran).** Developed Fortran-based numerical tools to study spin-orbit-coupled pseudospinor and spin-1 condensates under periodic boundary conditions, including efficient implementations of numerical noise schemes and HPC-compatible I/O strategies for long-time quantum quench simulations. [Phys. Rev. A **111**, 033316 (2025).]

7. **Hartree–Fock–Bogoliubov (Popov) Solvers (Fortran).** Built Fortran codes for finite-temperature Hartree–Fock–Bogoliubov–Popov calculations in spin-orbit-coupled pseudospinor and spin-1 Bose-Einstein condensates. [Phys. Rev. A **106**, 013304 (2022); Phys. Rev. A **109**, 033319 (2024).]

8. **Stochastic and Projected Gross–Pitaevskii Solvers (Fortran).** Developed Fortran implementations of stochastic partial differential equations, including the stochastic GPE (SGPE) and projected GPE (SPGPE), tailored for spin-orbit-coupled pseudospinor condensates, with optimized numerical noise algorithms and efficient HPC data handling.

Teaching Assistantship

PH101: Physics for Engineering (B.Tech. 1st year) Jan 2021 - Mar 2021; Jan 2022 - Mar 2022; Jan 2023 - Apr 2023
IIT Ropar — Involved in conducting tutorial sessions and grading assignments.

PH102: Physics for Engineering Lab (B.Tech. 1st year) Mar 2021 – Jun 2021
IIT Ropar — Supervised lab experiments and assisted students.

PH413: Quantum Mechanics 1 (M.Sc. 1st year) Aug 2022 – Nov 2022; Aug 2023 – Nov 2023
IIT Ropar — Assisted with problem-solving sessions and grading.

GE101: Technology Museum Lab (B.Tech. 1st year) Mar 2022 – Jul 2022
IIT Ropar — Guided students through exhibits and related physics principles.

Publications

Peer-reviewed:

1. Ritu, **Rajat**, A. Roy, and S. Gautam, *Thermal amplification and melting of phases in spin-orbit-coupled spin-1 Bose-Einstein condensates*, New J. Phys. **27**, 043005 (2025). Read on journal | View on arXiv

2. **Rajat**, P. Banger, and S. Gautam, *Collective excitations and universal coarsening dynamics of a spin-orbit-coupled spin-1 Bose–Einstein condensate*, Phys. Rev. A **111**, 033316 (2025). Read on journal | View on arXiv

3. P. Banger, **Rajat**, and S. Gautam, *Excitations of a supersolid annular stripe phase in a spin-orbital-angular-momentum-coupled spin-1 Bose–Einstein condensate*, Phys. Rev. A **111**, 023311 (2025). Read on journal | View on arXiv

4. **Rajat**, Ritu, A. Roy, and S. Gautam, *Temperature-induced supersolidity in spin-orbit-coupled Bose gases*, Phys. Rev. A **109**, 033319 (2024). Read on Journal | View on arXiv

5. P. Banger, **Rajat**, A. Roy, and S. Gautam, *Quantum phases and spectrum of collective modes in a spin-1 BEC with spin-orbital-angular-momentum coupling*, Phys. Rev. A **108**, 043310 (2023). Read on Journal | View on arXiv

6. **Rajat**, A. Roy, and S. Gautam, *Collective excitations in cigar-shaped spin-orbit-coupled spin-1 Bose–Einstein condensates*, Phys. Rev. A **106**, 013304 (2022). Read on Journal | View on arXiv

Preprints:

1. **Rajat**, Ritu, and S. Gautam, *Universal coarsening dynamics of supersolid stripe phase of spin-orbit-coupled spinor Bose-Einstein condensates* (Manuscript in preparation, to be submitted soon).

2. S. Kumar, **Rajat**, A. Roy, and S. Gautam, *Excitations at zero and finite temperatures in coherently coupled Bose-Einstein condensates.* (Manuscript in preparation, to be submitted soon).

Research Highlights

1. **Collective Excitations in Spin-1 SO-coupled BECs.** Calculated low-lying modes (dipole, breathing, spin-dipole, spin-breathing) in harmonically trapped spin-1 condensates under SO coupling, Raman coupling, and quadratic Zeeman fields.
   Significance: Pinpoints phase boundaries via mode softening and reveals double roton instabilities, crucial for understanding many-body states.

2. **Universal Coarsening Dynamics.** Studied nonequilibrium evolution in a quasi-2D spin-1 SOC BEC after sudden quenches; found domain growth obeying $L(t) \sim t^{0.66}$.
   Significance: Places SO-coupled BECs in the same universal dynamical class as other binary-fluid systems, confirming robust power-law coarsening relevant to non-equilibrium statistical mechanics.

3. **Temperature-Induced Supersolidity.** Showed that rising temperature can *increase* the supersolid stripe domain instead of melting it.
   Significance: Challenges the notion that heat necessarily destroys supersolidity; demonstrates finite-T can shift quantum critical points, relevant for realizing robust quantum phases.

4. **Development of Finite-Temperature & Stochastic Methods.** Developed and applied Hartree–Fock–Bogoliubov–Popov solvers and stochastic Gross–Pitaevskii approaches (SGPE/SPGPE) for ultracold gases.
   Significance: Enables accurate modeling of quantum and thermal fluctuations, and real-time dynamics in open quantum systems, crucial for bridging theory with experiments in cold atoms and potentially other quantum optical systems.

Conference Presentations

Poster Presentations

- *Temperature-induced Supersolidity in Spin-Orbit-Coupled Bose Gases*, **International Conference on BEC, Superfluidity, and Quantum Magnetism**, SNBNCBS, Kolkata, India (November 2024).
- *Temperature-induced Supersolidity in Spin-Orbit-Coupled Bose Gases*, **Ultracold Atoms Japan 2024**, OIST, Japan (April 2024).
- *Temperature-induced Supersolidity in Spin-Orbit-Coupled Bose Gases*, **National Workshop on Quantum Technologies (NWQT 2024)**, BHU, India (March 2024).
- *Collective Excitations in Cigar-Shaped Spin-Orbit-Coupled Spin-1 Bose–Einstein Condensates*, **Quantum Technologies with UltraCold Atoms**, IISER Pune, India (November 2023).
- *Collective Excitations in Cigar-Shaped Spin-Orbit-Coupled Spin-1 Bose–Einstein Condensates*, **Conference on Condensed Matter Physics (CCMP 2023)**, PRL Ahmedabad, India (February 2023).

Oral Presentations

- *Collective Excitations and Universal Coarsening Dynamics in Spin-Orbit-Coupled Spin-1 Bose–Einstein Condensates*, presented at **The National Physics Conference (PHYCON 2025)**, IIT Ropar, India (March 2025) [**Best Oral Presentation Award**].
- *Temperature-induced supersolidity in spin-orbit-coupled Bose gases*, presented at **QMAT2024**, IIT Guwahati, India (Dec 2024).
- *Temperature-induced supersolidity in spin-orbit-coupled Bose gases*, presented at **Physics Day**, IIT Ropar, India (Mar 2024).

Workshops & Schools Attended

- GIAN Course: *Ultracold Molecules and Controlled Chemistry*, IIT Ropar, India (December 2019).
- Online School and Discussion Meeting on *Trapped Atoms, Molecules, and Ions (TAMIONs)*, ICTS Bangalore, India (May 2021).
- Webinar on *Machine Learning (ML) for Physics*, NIT Rourkela, India (June 2024).

REFERENCES

- **Dr. Sandeep Gautam** (Ph.D. Advisor)
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- **Dr. Arko Roy**
  Associate Professor, Department of Physics, IIT Mandi
  Email: arko@iitmandi.ac.in, Tel: +91 90995-98065
- **Dr. Kuldeep Suthar**
  Assistant Professor, Department of Physics, Central University of Rajasthan
  Email: kuldeep.suthar@curaj.ac.in, Tel: +91 95741-91842