External Scientific Review 2024

Theory Group (Group – C)

Saha Institute of Nuclear Physics

1/AF Bidhannagar, Kolkata – 700 064

Members of the Faculty

Abhik Basu

Senior Professor H

Current Research

The broad contours of the present research activities include the following:

*(a)Soft-matter and biologically relevant systems:*The relevant issues are (i) role of active processes in making lipid membranes either flat or crrumpled, (ii) hydrodynamic description of surface roughness in fracture front propagation , (iii) phases of equilibrium asymmetric tethered membrane, (iv) Casimir stresses in an active nematic layers, (v) flocking at solid-liquid interfaces , (vi) anomalous elasticity near phase transitions in elastic media (vii) bifurcations in the diffusive Selkov model for glycolysis, (viii) mobility-induced order in active XY spins on a substrate, (viii) anomalous collective dynamics of autochemotactic populations.

(b) Hydrodynamic turbulence and related systems:(i) scaling and multiscaling in passive scalar turbulence, (ii) Hopf bifurcation in the circular hydraulic jump, (iii) scaling theory for hydromagnetic, thermally stratified and rotating turbulence,(iii) structure function hierarchy in superfluid turbulence.

(c) Asymmetric excluion processes and related models: (i) universality in closed inhomogeneous driven single file motions, (ii) states of a single shock in a ring, (iii) universality in disordered asymmetric exclusion processes, (iv) reservoir crowding and steady states in asymmetric exclusion processes.

(d) Other systems:(i) scaling and universality in generalised coupled conserved Kardar-Parisi-Zhang equations, (ii) dynamic scaling in disordered N-vector model, (iii) disorder-induced continuously varying scaling in driven systems, (iv) phases in kinetic growth with surface relaxation.

Future Research plans

(a) Order, correlations and scaling in two-dimensional active systems; role of topological defects, (b) Role of long-range noises in driven systems – scaling and multiscaling, (c) Effects of distributed, finite resources in the steady states of asymmetric exclusion processes, (d) Nonequilibrium statistical mechanics and supersymmetry.

Post M.Sc. Teaching

Post MSc review supervision

- Scaling and universality in models of statistical mechanics (2017),
- Universal critical phenomena in the 3D Ising model (2021),
- Totally asymmetric simple exclusion process (2021).

Amit Ghosh

Senior Professor H and Head

Current and Future research

During 2017-2023 my work were limited to quantum mechanical microstates of black holes in loop quantum gravity, finding correlations between classical phase space of black hole horizons and some models in quantum gravity, revisiting Hawking radiation from the conventional perspectives of quantum mechanics and also exploring relations between dynamical horizons and Hawking radiations. My future plan is to explore the roles of torsion in quantum gravity, some nonperturbative alternative to Fock space of quantum field theories and its relation to quantum gravity.

Teaching

Since 2002, I have been teaching continuously various courses in the department, starting from mathematical physics, quantum mechanics, classical mechanics, general relativity, cosmology, differential geometry, group theory, and many other special courses. I am always available to teach any course. Since 2020, I got much less opportunity to teach as I am intensely involved in administration related to teaching. At present I am chairing the standing academic committee of SINP and member of the board of studies of HBNI in physical sciences.

Arnab Kundu

Associate Professor F

Current Research

My main research interests are: Quantum Field Theory, Quantum Gravity, String Theory. Gauge-string duality, AdS/CFT correspondence and strongly coupled systems. Presently I am working on mainly three related aspects within the above theme. These are: (i) Solvable dynamical QFT systems, especially Conformal Field Theory in various dimensions as deformations thereof. The core idea here is to study dynamical phases and transitions between them within a solvable and analytical regime, which is otherwise difficult to obtain. These studies serve as benchmark of e.g. driven quantum systems in general, but are not limited to that. (ii) Related to this, at least at a technical level, I am interested in studying how local information spreads in time in a quantum (field theoretic) system and the dynamics of its associated complexity. This aspect is rather topical and promising in connecting conventional QFT-ideas to ideas of quantum information, its spreading and the physics of scrambling. (iii) My third interest is the exploration of quantum aspects of black holes, motivated largely by the existing and emerging literature in parts (i) and (ii). In particular, I am interested in understanding how expected quantum properties of a black hole can be mimicked by an appropriate boundary condition. This is primarily motivated by the candidate microstate geometries corresponding to a black hole from string theory, but at the same time, our approach is agnostic about the UV-completion of the system.

Future Research plans

My proposed future research directions are mainly based on the three topics, but the idea is to find bigger overlaps between them and apply the lessons as universally as possible. For example, in part (i), where we are currently exploring solvable dynamical phase transitions within CFTs, my goal is to extend them to CFTs in arbitrary (or, at least higher) dimensions with a possible classification of thermalization vs non-thermalization. Such an understanding is potentially useful to a broad community of condensed-matter physics as well as high energy physics since it fuses ideas of QFTs with modern ideas of statistical description of a system and its phases. Similarly, based on part (ii), I would like to understand better the notion of complexity itself, which has emerged in modern research with several potentially promising lessons. These range from detection of phase transitions, to the very late time dynamics of (quantum) black holes. Finally, part (iii) above raises natural questions and also opens avenues to explore these ideas within a very simple but potentially interesting model of a (quantum) black hole that can capture quantum chaotic features of such a black hole. The very long term vision of this proposal is to uncover underlying dynamical structures of QFT in general, including but not limited to, how unitarity manifests in a time-dependent process, the relation between entanglement growth, complexity and quantum chaos. In turn, the precise technical aspects based on CFT-techniques above are directly connected to the inner workings of Holography as a principle and are therefore expected to shed light on quantum aspects of gravity in general.

Teaching

Post MSc course:

- Quantum Field Theory-I (September-December, 2023; September-December, 2022).
- Quantum Field Theory-II (January-April, 2022; January-April, 2020).
- Conformal Field Theory (January-April, 2023).
- Renormalization in QFT (June-August, 2022).
- Special Topics in QFT (September-November, 2021).
- Special Topics in General Relativity (July-October, 2019).
- General Relativity (April-July, 2019).
- String Theory I & II (December, 2017 – July, 2018).
- Topics in Quantum Field Theory & String Theory (April-July, 2017).

SERB Main School:

Entanglement, SYK Model and Chaos, December 2019. SGBT Khalsa College, Delhi University.

Arti Garg

Professor G

Current Research

In the last five years, I have mainly focussed on various aspects of Many-body localization (MBL), unconventional superconductivity, pair-density wave, and interaction induced half-metallicity. MBL has been a topic of intense research in condensed matter physics, both theoretically and experimentally. The question of immense interest, that has remained unanswered for decades after Anderson's work, is what happens to Anderson localization when both disorder and interactions are present in a system. Localization in the presence of interactions can exist as long as interactions are in perturbative regime and is what known today as MBL. MBL is an interesting and unusual phase of matter in many aspects. An isolated quantum system in the MBL phase is non-ergodic and hence, challenges the basic foundations of quantum statistical physics. Local observables in the MBL phase do not thermalize leading to the violation of eigenstate thermalization hypothesis. This results in a rich behaviour of entanglement entropy and a long time memory of the initial state in local observables. Infinite temperature MBL phase has been shown to have an extensive number of local integrals of motion and hence is similar to integrable systems. In the last five year, we have explored many significant issues in context of MBL, like the stability of the MBL phase in the presence of long-range interactions and long-range hopping, possibility of MBL phases in systems with single-particle mobility edges, connection between quantum spin glass and MBL phase, and the possibility of non-ergdic extended phase for random long-range interactions preceding the MBL phase. We also studied the quantum quench dynamics for the MBL system and analyse how the dynamics depend on the number of kinks in the initial state. Very recently we have explored the nature of delocalization to MBL transition in systems with random disorder as well as with quasiperiodic potential. MBL transition is unique in nature which connects thermal phase with volume law of entanglement entropy to MBL phase with area law of entanglement etropy and does not satisfy standard paradigm of conventional statistical physics. We investigated single particle excitations across the MBL transition and demonstrated continuous nature of MBL transition. On a completely different note, we have studied effect of strong e-e interactions and found a novel theoretical route to realize unconventional superconductivity without doping. We also proposed a new correlation driven mechanism for realizing ferrimagnetic metal and Antiferromagnetic half-metallic phase in a band insulator, which has potential applications in spintronics, We have also explored disorder induced superconductivity in transition-metal dichalcogenides and currently we are exploring the possibility of a pair-density wave in high-temperature superconductors in the presence of strong disorder and half-metal phase in bilayer graphene.

Future Research plans

In near future, along with the topics that I have been exploring I would also like to focus on periodically driven quantum systems, non-equilibrium dynamics in strongly correlated and disordered systems, connection between topology and localization, superconductivity in at band systems and exotic phases observed in Van der Waals heterostructures. Quantum many-body systems when taken out of equilibrium oers a lot of possibilities for realizing exotic phases of quantum matter that are otherwise forbidden in equilibrium. Discrete time crystals observed in recent experiments by periodically driving a disordered interacting quantum system is an example of such exotic phase. We would like to explore time-crystals in MBL systems with various ranges of interactions, with random long-range interactions as well as random hopping. Theoretical understanding of non-equilibrium transport properties of correlated and disordered systems is a topic of great interest. We would like to study non-equilibrium charge and thermo-electric transport in a Mott insulator as well as in doped Mott insulators which are in superconducting phase in equilibrium. We also want to explore out-of equilibrium response in a half-metal, where electrons in one spin channel behave as if they are in a metallic phase while the electrons with the opposite spin are insulating. We also want to explore van der Waals heterostructures where proximity between layers of dierent materials can be exploited to generate new states of matter e.g. a particularly interesting set of ground states to pair is a superconductor and a Mott insulator as in 4Hb-TaS_2, rich phase diagram obtained in bilayer and trilayergraphenes where a cascade of half-metal and quarter metal phases have been observed. We also are exploring pair-density wave phase in high temperature superconductors which have recently been observed in STM experiments around vortices and strong impurities in BISCO.

Post M. Sc. Teaching

- Advanced Condensed Matter Physics (Jan-April 2017)
- Advanced Statistical Physics :a core course for theory+experimental Post-Msc students (Aug 2018-Dec 2018)
- Quantum Many-body Physics (Jan-April 2021)
- ACP :Superconductivity, Mott Insulators and other correlated phases (Jan-April 2022)
- Physics of Disordered Quantum Systems and Anderson Localization (reading course) (Jan-April 2022)
- Basics of Superconductivity (Jan-April 2023)

Arunava Mukherjee

Associate Professor E

Current Research:

I work in the area of Astronomy & Astrophysics. My primary research focus is on gravitational waves and multi-messenger astrophysics. I am particularly interested in studying astrophysical compact objects, e.g., neutron stars and black holes. I use the observational windows of gravitational waves and multi-messenger astronomy to understand the physics and astrophysics of these compact objects. Recently, I have been exploring to study the hadronic matter under extreme astrophysical environments to probe fundamental physics. As a part of this endeavor, I use large-scale computing for both simulations and to search for new gravitational wave GW signals in the LIGO-Virgo-KAGRA (LVK) detectors and to study their physical properties. I am a member of the international LIGO Scientific Collaboration (LSC) through LIGO-India Scientific Collaboration (LISC). I spearhead the Indian national efforts to search continuous gravitational wave signals from these ground-based detectors.

Future Research plans

In the next few years, I am planning to expand in the direction of multi-messenger astrophysics and observational cosmology. In the upcoming years, GW observatories will detect numerous astrophysical events not only from Compact Binary Coalescence (CBC) sources but also signals from new types of objects/ phenomena hitherto unseen by us. These new kinds of signals will enable us to probe ultra-dense matter under extreme gravity and also to utilise them for studying late-time, low-redshift cosmological evolutions of our universe. The multi-messenger observations in the near future have a great potential to unravel the nature of dark matter and the dark energy content of our universe.

Post M.Sc. Teaching

- General Relativity for the Post MSc students of SINP.
- Numerical methods/computational techniques. Specifically, he delivered both theoretical classroom lectures on Bayesian statistics and statistical inference and computational lab demonstration of their implementations with Python programming.

Bijay Kumar Agrawal

Senior Professor H

Current Research:

The impact of equation of state of dense asymmetric nuclear matter on various neutron star properties has been studied. Overall, the study offers valuable insights into the interplay between nuclear matter parameters, equation of state, and the physical properties of neutron stars, shedding light on their tidal deformability, radii, and oscillation characteristics. A principle component analysis is performed to establish the connection between various key component of equation of state to the properties of neutron stars over a wide range of masses.

Future Research plan:

The study of neutron star mergers are the potentially important to probe the quark-hadron phase transitions which remains an active and evolving field. Observations and theoretical modeling are continuously advancing, and future research may provide more insights into this intriguing area. We would like to explore the possibility of presence of exotic degrees of freedom such as hyperons and quarks in the core of heavier neutron stars.

Post-M.Sc. Teaching

The many-body nuclear shell model allows one to incorporate configuration mixing through residual interaction which provides accurate description of various nuclear properties such as excitation spectrum, α and β-decays, etc. However, this method due to the present computational limitations can be applied only to the light nuclei near the β-stability line. One needs to recourse to microscopic schemes such as mean field approximations. The mean field approximations enable ones to represent the many-body Hamiltonian in terms of the one body Hamiltonian. The reliability of the mean-field models depends on the manner one-body potential is derived from the two or three nucleon interactions. Most of the lectures were focused on the nature of two nucleon interactions and microscopic mean-field models for nuclei.

Debasish Banerjee

Associate Professor E

Current and Future Research

I use quantum field theories and state-of-the art computational methods to understand the various non-perturbative phenomena in particle physics (such as aspects of confinment, string breaking, various exotic confined phases), as well as in condensed matter physics(such as quantum spin liquids, the Coulomb phase). An ab-initio method to study the physics of these systems is through the use of Markov Chain Monte Carlo methods, which involve importance sampling the configurations which contribute to the partition function of the system. For a host of interesting systems of physical interest mentioned above, such methods run into the so-called sign problem, which is when the importance sampling becomes inapplicable because the weight of individual configurations can become negative due to the choice of computational basis. Considerable research effort is invested in the development of novel Monte-Carlo algorithms which can solve the sign problem with designer Hamiltonians, and study the physics without any approximations. A major theme of my recent work is the use of quantum information science (including quantum algorithms), in conjunction with classical computing methods. Collaboration with experimentalists is a major goal with regard to develop quantum devices for use as a mainstream computational paradigm. The aim of these research directions is to develop a framework for addressing the dynamics of strongly interacting systems, and in particular exploring scenarios which evade thermalization.

Post M.Sc. Teaching

Since my joining SINP in November 2019, I am extensively involved in teaching. I have taken the following course:

- Renormalization in Condensed Matter and Statisitical Physics (January–April, 2021)
- Statistical Mechanics (August–December, 2021; August–December, 2022)
- Structure of the Standard Model (January–April, 2023)
- Since August 2022, I am the Course co-ordinator for Theoretical Physics, which involves theduties of: co-ordinating the Post MSc interviews for Theory Division, Co-ordinating with the Faculty of the Theory and the Course co-ordinator of Experimental Physics for offering courses.

Gautam Bhattacharyya

Senior Professor and Director

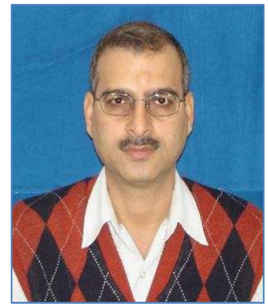
Current Research

During 2017-20, I have worked on Composite Higgs Models, Z' phenomenology, muon (g-2) and Dark Matter freeze-in scenarios.

During 2020-till date, my research involves searching for exotic spin-0 states, predicted by flavor symmetries, from the LHC data. The primary intention for the latter type of work is to encourage and strengthen the collaboration between theorists and experimentalists.

Harvendra Singh

Senior Professor H



Current Research

Area: String Theory, Super-gravity We have systematically calculated the holographic entanglement entropy (HEE) for conformal field theory (CFT) subsystems on the boundary of AdS black hole geometries up to 3rd order using perturbative techniques. No previous calculations existed beyond the leading order whereas we have done our calculations using 'perturbative' methods up to third order analytically. However it requires some redefined thermodynamic quantities, like 'entanglement temperature' and the chemical potential, such that the first law of entanglement thermodynamics is prescribed. We also studied holgraphic entanglement entropy for subsystems on the boundary of Lifshitz solutions, namely Lif4(2) X S1 X S5, with dynamical exponent of time being two. These are special solutions of the massive type-IIA Supergravity theory in ten dimensions. Along similar lines, a new proposal of "minimality principle" for quantum entropy has been suggested to obtain entropy Page curve for large "bath" system in contact with a smaller (CFT) system. We have shown that beside the island-ic gravitational entropy many such icebergs' entropies contributions become essential to obtain the Page curve. The entropy Page curve for bi-partite quantum systems is an important check to have unitarity.

Future Research plans

The continuation of the ongoing projects is the first priority. We wish to explore the quantum minimality principle of entanglement entropy for bi-partite systems for higher dimensional CFTs and near CFT cases too. We wish to extend this for maximally mixed states too. There is also a proposal of generalized entanglement entropy where the renormalization of the gravitational coupling has been contemplated recently in the literature. We have an alternative proposal that the location of island itself might get corrected under the effects of higher order perturbative corrections to the entropy. It is much more like a resummation effect. Further in AdS/CFT, a supersymmetric 6D lagrangian theory describing mutiple M5-branes on the boundary of AdS7 X S4 is yet to be constructed. The preliminary works indicate that the 6D theory presumably could be written in terms of interacting tensor fields which are self-dual. Interestingly, the question may be asked whether 6D extended string like vacuum configurations, described by self-dual 2D axionic scalars and 4D YM-instantons could constitute the required fields for 6D tensor theory.

Kalpataru Pradhan

Associate Professor F

Current research and Future research plans

Transition metal oxides (TMOs) show a wide range of magneto-transport properties and bear promises of technological importance for the design of new functional materials. The physics is even much richer at the interface of two TMOs. The central theme of our research is to find a correlation between the electronic and the magnetic properties of magnetic materials using model Hamiltonian approach. We also study magnetic properties of atomic clusters using density functional theory to design new functional molecular-magnets. In addition, we are actively collaborating with experimenters.

Recently our focus is to study diluted spin systems and magnetic/non-magnetic heterostructures using Spin-Fermion Monte Carlo calculations. Diluted spin systems modelled by switching off the Hubbard onsite potential (U) at randomly chosen sites, but keeping the absolute half-filling condition intact. Our calculations show that the well-known AF-I ground state for undiluted case survived below the classical percolation limit. Away from half filling, the ferromagnetic transition temperature of the carrier spins shows an optimization behavior with the carrier density (measured with respect to the impurity concentration) in the impurity band. Next, for a more realistic study, to compare with experimental results, we have incorporated the effect of next nearest neighbour hopping to analyze the effect of magnetic frustration. Our main intention is to shed light on the interesting antiferromagnetic metallic phases that arises in presence of frustration in diluted magnetic systems.

Heterostructures comprised of hard and soft ferromagnets are also of great interest for realizing the exchange-bias (EB) effect and inverted hysteresis loop. One of our work provides a microscopic description to understand such multiple-flipping processes along the hysteresis loop in TMO superlattices (like LSMO/SRO) using a one-band double exchange model. We have also triggered a crossover from positive to negative EB at low temperature in collaboration with experimental studies. In another experimental collaboration, we have also demonstrated that the exchange bias can be tuned by increasing the number of interfaces constitutes of charge ordered antiferromagnetic and ferromagnetic layers. We are also investigating the induced magnetic moment in the non-interacting layer of the layered pattern of interacting and non-interacting layers to model LSMO/STO like materials.

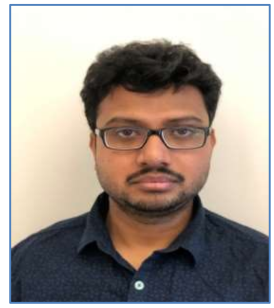
A plethora of two-dimensional magnetic materials has been introduced in the decade. The atomic nature of these layered materials is very complex. A microscopic description to understand the underlying magneto-transport properties will be formulated by using model Hamiltonian approach combined with material specific first-principles density functional theory calculations.

Post M.Sc. Teaching:

- Numerical Methods and Algorithm (2015, 2016, 2019)
- Advanced Condensed Matter Physics (2016, 2019)
- Many-body theory of solids (2021)
- Numerical Methods and Analysis (2021, 2023)
- Research and Methodology (2022)

Krishanu Roychowdhury

Associate Professor E



Current Research

Past decades have witnessed a myriad of unconventional phases of matter whose characterization falls beyond the remit of the celebrated Landau-Ginzburg (LG) paradigm. The lowenergy physics of these many-body systems is dictated by an exquisite interplay of symmetry and entanglement giving rise to new exotic phases such as spin liquids and many more. I specialize on spin liquids that are magnetic states of matter not supporting any long-range order but fractionalized excitations (including anyons) and topological order (beyond any symmetry-protection), and are primarily realized on frustrated lattice models (such as a kagome network) where single-particle excitations feature flat bands. A part of my current research engages tools of supersymmetry (SUSY) to realize a wide variety of flat-band lattice models and study various anomalous response associated with the presence of degenerate flat bands in such systems.

Future Research plans

In the future, we will attempt to extent our SUSY construction to include interactions in a many-body setting steered *toward conceptualizing SUSY-protected-topological states in interacting quantum matter. Besides, we will also* investigate the response of topological states to geometric deformations (such as crystal defects and intrinsic curvature) focusing on topological insulators and chiral superconductors; the latter has promising applications in fault-tolerant quantum computations as they support localized Majorana modes, more generally, non-Abelian anyons, whose braiding can be manipulated in a designer heterostructure setups. Our lattice-based calculations will provide useful guidance to experiments tuned to identify candidate materials for chiral superconductors as the response in concern can serve as a smoking-gun evidence to reveal the existence of such unconventional states of quantum matter. Another research direction of mine will continue understanding the physics of coarsening (the route to symmetry breaking) in driven quantum systems, specifically to decipher the complexity of the out-of-equilibrium dynamics when such systems are driven across quantum critical points.

Post M.Sc. Teaching

I taught the basic course on Statistical Mechanics (6 credit) last trimester (August-December, 2023) and in the current trimester (January-April, 2024), I am hosting a review work/project (8 credit) offered to a Post M.Sc. student. My plan is to float the course on Statistical Mechanics (6 credit) again in the next trimester starting from August, 2024.

Staffs

Ashoke Kumar Ram

Work Assistant C

Photocopying, delivering letters/documents, arranging refreshments for seminars, miscellaneous office work.

Mahuya Dutta

Upper Division Clerk

Administrative work of the group, contingency settlement, TA/DA of visitors and group members, leave management, etc.

SangitaPande

Scientific Assistant C

System administration, group purchases, inventory register and other work.

Students since 2017

Srl	Name	Ph. D Year / Status	Supervisor	Current position
1	Aman Gupta	Continuing	Debasish Majumdar and Pratik Majumdar	
2	Debayan Jana	,,	Abhik Basu	
3	Jayashish Das	,,	Arnab Kundu	
4	Md Emanuel Hoque	,,	Arunava Mukherjee	
5	Pabitra Tripathy	,,	Amit Ghosh	
6	Pallabi Dey	,,	Debasish Banerjee	
7	Sandip Halder	,,	Kalpataru Pradhan	
8	Sandip Maiti	,,	Debasish Banerjee	
9	Satyabrata Datta	,,	Ambar Ghosal	
10	Sk Md Adil Imam	,,	Bijay Kumar Agrawal	
11	Soujanya Datta	,,	Krishanu Roychowdhury	
12	Sourav Pal	,,	Abhik Basu	
13	Sudip Mandal	,,	Kalpataru Pradhan	
14	Suman Das	,,	Arnab Kundu	
15	Udit N. Chowdhury	,,	H. Singh	
16	Khursid Alam	Moved	Koushik Dutta	To IISER, Kolkata
17	Supriyo Ghosh	Resigned	Kumar Sankar Gupta	
18	Madhurima Sinha	Discontinued	Bireswar Basu-Mallick	
19	Pritam Nanda	Thesis Submitted	Amit Ghosh	
20	Tanmoy Ghosh	Defence completed in Jan 2024	Bijay Kumar Agrawal	
21	Arunima Bhattacharya	2023	Prakash Mathews	
22	Astik Haldar	2023	Abhik Basu	Guest Scientist at University of Saarland
23	Sabyasachi Maulik	2023	H. Singh	Postdoc, IIT Kanpur
24	Ayan Kumar Patra	2022	Arnab Kundu	Postdoc, Institute of Theoretical Physics (IFT), Madrid
25	Bithika Karmakar	2022	Munshi Golam Mustafa	Post-doctoral fellow from February 1, 2024 at University of Wroclow, Poland
26	Ritesh Ghosh	2022	Munshi Golam Mustafa	Post-doctoral fellow in Arizona State University from November 15, 2023.
27	Sourav Chakraborty	2022	Kalpataru Pradhan	Postdoc, S.N. BOSE Centre, Kolkata
28	Upala Mukhopadhyay	2022	Debasish Majumdar	Post-doc, Jamia

Srl	Name	Ph. D Year / Status	Supervisor	Current position
29	Anwesha Chattopadhyay	2021	Arti Garg	Assistant Professor, Ramakrishna Mission Vivekananda Educational and Research Institute (RKMVERI), WestBengal
30	Aritra Das	2021	Munshi Golam Mustafa (co-guide)	Post-doctoral fellow at NISER, Bhubaneswar from December, 2021 to November, 2023 and has at three post-doctral offer
31	Avik Banerjee	2021	Gautam Bhattacharyya	PostDoc at TIFR, Mumbai, Dept. Theor. Phys.
32	Avik Paul	2021	Debasish Majumdar	Assistant prof, Techno India, salt Lake
33	Sabyasachi Nag	2021	Arti Garg	Senior Scientist, Geological Survey of India
34	Augniva Ray	2020	Arnab Kundu	Postdoc at APCTP, Pohang, South Korea
35	Madhurima Pandey	2020	Debasish Majumdar	Assistant Professor, Haldia Institute of Technology, West Bengal
36	Tuhin Malik	2020	Bijay Kumar Agrawal (Co-guide)	Postdoc, Universidade de Coimbra,Portugal
37	Avik Banerjee	2019	Arnab Kundu	Postdoc, EcoleNormaleSuperieure, Paris
38	Mugdha Sarkar	2019	Asit Kumar De	Postdoc, National Taiwan University, Taiwan
39	Sukannya Bhattacharya	2019	Koushik Dutta	Postdoc, PRL, Ahmedabad
40	Chiranjib Mondal	2018	Bijay Kumar Agrawal	Postdoc, Institute of Cosmos Sciences (ICCUB), University of Bercelona, Spain
41	Chitralekha Datta	2018	Bireswar Basu-Mallick	-
42	Kuntal Nayek	2018	Shibaji Roy	Postdoc, IIT, Kharagpur
43	Naosad Alam	2018	Bijay Kumar Agrawal	Postdoc, VECC
44	Rohit Mishra	2018	H. Singh	Postdoc,IACS,Kolkata
45	Tirthankar Banerjee	2018	Abhik Basu	Postdoc at University of Luxembourg
46	Arindam Mazumdar	2017	Palash Baran Pal	Postdoc, IIT Kharagpur
47	Aritra Bandyopadhyay	2017	Munshi Golam Mustafa	Alexander von Humboldt fellow at Heidelberg University, Germany from June, 2022 to May 2024
48	Chowdhury Aminul Islam	2017	Munshi Golam Mustafa	Visiting Fellow at University of Frankfurt from November 2023.
49	Goutam Das	2017	Prakash Mathews	Postdoc, Theory Group, DESY, Germany
50	Kumar Das	2017	Koushik Dutta	Postdoc, SN Bose

Research Associates since 2017

Srl	Name	Date of Joining	Date Of Completion	Subject Area
1	**Dr. Mayukh Raj Gangopadhyay**	01.06.2017	31.05.2019	Cosmology, High Energy Physics, General Relativity
2	**Dr. Dharmesh Jain**	01.08.2017	31.07.2019	String theory
3	**Dr. Maguni Mahakhud**	01.08.2017	31.07.2019	Elementary Particle Physics Theory
4	**Dr. Parna Roy**	20.07.2018	07.07.2020	Statistical Physics
5	**Dr. Yogeshwar Prasad**	01.11.2019	31.03.2022	Theoretical Condensed Matter Physics, Cold Atoms, Super fluidity, Super conductivity, Many-body Localization
6	**Dr. Subarna Datta**	02.04.2019	01.04.2021	Various aspects of Condensed Matter Physics and Material Science
7	**Dr. Arup Ghosh**	25.03.2019	24.03.2021	Various aspects of Condensed Matter Physics and Material Science
8	**Dr. Krishnan Rama**	15.02.2019	14.02.2022	Elementary Particle Physics
9	**Dr. Rohan Raghava Poojary**	21.08.2019	20.08.2021	AdS-CFT Correspondence, Black Holes in String Theory, 2D Gravity
10	**Dr. Soumya Chakrabarti**	16.09.2019	15.09.2021	General Theory of Relativity, Field Theory, Modified Theory of Gravity, Cosmology
11	**Dr. Ayana Mukhopadhyay**	21.04.2021	20.04.2023	Condensed Matter Physics
12	**Dr. Chiranjeeb Singha**	05.05.2021	16.11.2023	General Relativity, High energy physics theory, Quantum gravity, Black hole, Quantum field theory
13	**Dr. Vinay Malvimat**	23.07.2021	22.07.2023	Holography, Quantum Information, Black Holes
14	**Dr. Ananya Mukherjee**	08.12.2021	07.12.2022	Particle Physics Phenomenology
15	**Dr. Shubhajyoti Mohapatra**	01.04.2022	31.03.2023	Strongly correlated electron systems, Spin-orbit coupling, Quantum magnetism, Collective excitations, Topological Magnons
16	**Dr. Aditya Banerjee**	01.04.2022	31.03.2024	Lattice gauge theory, Strongly interacting system
17	**Dr. Suvayan Saha**	01.12.2022	30.11.2023	Crystal Structure, Magnetism, Transport and Magneto-transport, Nanomaterial, Single Crystal Growth
18	**Dr. Akavoor Manu**	20.09.2023	19.09.2024	String theory

Research Profile of the Group

Broad Research Area	Faculty Members	Students	RA
Soft-Mat, Bio-Phys, Cond-Mat, Turbulence	Abhik Basu	Tirthankar Banerjee, Astik Haldar, Debajan Jana, Sourav Pal	Parna Roy
Quantum Condensed Matter Physics: Strongly Correlated electron Systems, Quantum systems out of equilibrium	Arti Garg	Sabyasachi Nag, Anwesha Chattopadhyay	Yogeshwar Prasad
Condensed Matter Physics, Materials Science, Strongly Correlated Electron Systems	Kalpataru Pradhan	Sourav Chakraborty, SandipHalder, Sudip Mandal	Shubhajyoti Mohapatra
Topological quantum matter, Frustrated magnetism	Krishanu Roychowdhury	Soujanya Datta	
Particle Phenomenology, Beyond standard model	Gautam Bhattacharyya	Avik Banerjee	
Gravity, QFT	Amit Ghosh	Avirup Ghosh, Pritam Nanda, PabitraTripathy	Chiranjeeb Singha
String theory, QFT, Gravity	Arnab Kundu	Avik Banerjee, Augniva Ray, Ayan K. Patra, Suman Das, Jayashish Das	Dharmesh Jain, Rohan R. Poojary, Vinay Malvimat, Akavoor Manu
Multi-messenger astronomy, gravitational waves	Arunava Mukherjee	Emanuel Hoque, Sk Md Adil Imam (Co-guide)	
Strings, SuperGravity, QFT	Harvendra Singh	Sabyasachi Maulik,Udit N. Chowdhury,Rohit Mishra	
Nuclear Astrophysics	Bijay Kumar Agrawal	Chiranjib Mondal, Naosad Alam,Tuhin Malik, Sk Md Adil Imam, Tanmoy Ghosh	
Non-perturbative QFT, QCD, Cond-Mat, Classical and Quantum Algorithms	Debasish Banerjee	Sandip Maiti, Pallabi Dey	Aditya Banerjee

Last 5 Years

Faculty members retired since 2017

Name of Faculty	Date of Retirement	Broad Research Area
Munshi G Mustafa	Feb 2024	Field Theory with thermal and magnetic field background, Quark Gluon Plasma and Heavy-ion Collisions Phenomenology
Ambar Ghosal	Nov 2023	Neutrino Physics Baryogenesis
Kumar Sankar Gupta	Nov 2023	Quantum aspects of black holes; Quantum field theory; Mathematical physics.
Augustine Kshetrimayum	Oct 2023	Tensor network and its applications
Debasish Majumdar	Oct 2023	Particle candidates of Dark Matter, detection of and Neutrino Physics
Prakash Mathews	Oct 2023	Perturbative QCD; Physics beyond the Standard Model
Bireswar Basu-Mallick	Nov 2022	Quantum integrable field models and spin chains; Fractional statistics in exactly solvable models; Quantum groups and Yangians; Non-hermitian Hamiltonians with real spectrum
Debades Bandyopadhyay	Jun 2021	Nuclear Astrophysics, supernovae, neutron stars EOS & pulsars
Shibaji Roy	Sep 2020	String theory and M theory
Koushik Dutta	Dec 2019 (Moved to IISER Kolkata)	Cosmology and Its Connections to Particle Physics
Pradeep K. Mohanty	Dec 2019 (Moved to IISER Kolkata)	Non-equilibrium statistical mechanics
Asit Kumar De	Dec 2018	Quantum Field Theories (QFT) and their non-perturbative properties
Sudhakar Yarlagadda	Jun 2018	Strongly correlated electron systems

Faculty members recruited since 2017

Name of Faculty	Date Of Joining	Broad Research Area
Krishanu Roychowdhury	Sep 2022	Topological quantum matter; Frustrated magnetism, spin liquids; Out-of-equilibrium dynamics in driven quantum systems; Quantum physics at the mesoscopic scale; Topological mechanics
Augustine Kshetrimayum	Jul 2022	Tensor network based approaches to quantum many-body systems
Arunava Mukherjee	Nov 2019	Gravitational Waves & Multi-messenger Astronomy, High Energy Astrophysics; Physics & Astrophysics of Compact Objects: Neutron Stars and Black Holes; Equation of State of Neutron Stars, their observational aspects
Debasish Banerjee	Nov 2019	Quantum Field Theories on and off the lattice; Quantum Link Models and Qubit Regularizations; Classical and Quantum Simulations of strongly interacting systems; Thermalization and real-time dynamics of gauge theories.

Key areas in which the Group can make impact in the coming 3 to 5 years

QFT

A field theoretic approach to non-perturbative phenomena in strongly interacting systems in particle and condensed matter physics will be explored by various techniques such as the use of Monte Carlo simulations, exact calculations, and tensor network methods. Real-time properties of systems, such as scattering and transport properties, as well as the scenarios which display delayed or anomalous thermalization will be studied. Phenomenologies of interacting systems on curved surfaces and manifolds will be investigated.

Related ideas have recently found active roles within formal aspects of QFT as well. These include, but are not necessarily limited to, aspects of thermalization and quantum chaos in (both weakly and strongly coupled) QFT, non-equilibrium physics in QFT, especially in Conformal Field Theories (CFTs). In turn, these formal aspects have a direct consequence on quantum and stringy aspects of gravity and black holes, via the AdS/CFT duality (and, more generally, Holography). Thorough investigations will be performed along these directions as well.

Condensed Matter

In theoretical condensed matter physics we plan to mainly focus on the area of strongly correlated systems, many-body localization and thermalization, driven quantum systems and quantum many-body systems out of equilibrium, interplay of topology and localization, unconventional superconductivity and competing phases like pair-density wave and topological superconductors. Interface phenomena in correlated electron systems and novel magnetism 2D materials will also be explored. Exotic phases in van-dar Wall heterostructures and topology in interacting systems will be investigated. Additional explorations will entail unveiling novel spin textures at topological heterojunctions and designer quantum systems with applications in quantum devices and quantum information processing, investigating exotic responses of flat-band materials, discerning new intertwined orders in frustrated quantum systems, and unraveling quantum phenomena on curved geometries (such as hyperbolic lattices).

Soft condensed matter physics and biologically inspired systems, studies on nonequilibrium models.

Gravity/Strings

We wish to explore the quantum principle of entanglement entropy for systems in higher dimensional CFTs and near-CFTs as well. We shall extend this for maximally mixed states too. There is also a proposal of generalized entanglement entropy where renormalization of the gravitational coupling has been contemplated recently in the literature. We have an alternative proposal that the location of the island itself might get corrected under the effects of higher order perturbative corrections to the entropy. The quantum information in the background of black hole spacetimes and the unitarity of entanglement entropy of radiation, well known as giving rise to the Page curve, would be studied. Further in AdS/CFT, a supersymmetric construction of 6D lagrangian theory describing multiple M5-branes on the boundary of AdS7 X S4 is yet to be realized. The preliminary works indicate that the 6D theory presumably could be written in terms of interacting tensor fields which are self-dual.

Observational aspects of multi-messenger astrophysics & cosmology

One of the research areas that has a promising future in the next decade is observational aspects of multi-messenger astrophysics and cosmology. Our group in SINP aims to grow in the area of gravitational wave astronomy in conjunction with electromagnetic and astroparticle channels to synergise for the frontiers in multi-messenger astrophysics of compact objects and observational cosmology.

Quantum Information Science

Quantum computing has recently emerged as a promising direction to address problems in strongly correlated systems that are beyond the reach of classical computational algorithms. Two key areas in physics — that of finite density and dynamics in real-time — fall in this category where the quantum advantage is anticipated for simulating systems of large sizes. In this context, various specific models of interest to reproduce real-life phenomenology will be considered and appropriate quantum algorithms will be constructed and tested on such systems. These include various platforms, including but not limited to, superconducting qubits, Rydberg atoms, photonic modes, and topological quantum computation. The efficacy of various quantum and hybrid classical-quantum algorithms will be explored both theoretically as well as on publicly available quantum computing platforms such as the IBMQ.

As mentioned earlier also, the foundational cornerstones of quantum information science have found applications in formal studies of quantum aspects of gravity and black holes via Holography. For example, ideas revolving around the notion of quantum entanglement have especially been useful in terms of laying out several basic aspects of QFT in a generic curved manifold. Several of these ideas technically relate to studying e.g. spin system on a hyperbolic lattice which is relevant for a very wide class of theoretical problems. Work along these directions will also be pursued.

Key areas in which we plan to expand in next 3 to 5 years

- Gravitational waves, Numerical relativity & Astroparticle physics
- Non-perturbative and formal aspects of QFT and Gravity
- Novel aspects of condensed and soft matter
- Particle phenomenology
- Quantum Information Science

Instruments / facilities which the Group is planning to install / develop in next 3 to 5 years

We would like to install a large HPC cluster facility for the group members offering at least 500 cores for each faculty member who is actively using Computation.

Prof. Arunava Mukherjee would like to install additional 4000 cores.

Number of courses offered by the Group in teaching since 2017

Name of the Faculty	Courses	Research Projects	Reading Courses	Summer Projects	MSc Thesis Projects
Abhik Basu	-	3	-	-	-
Amit Ghosh	2	2	4	2	-
Arnab Kundu	11	3	3	8	3
Arti Garg	7	3	-	-	-
Arunava Mukherjee	3	2	2	2	-
Bijay Kumar Agrawal					
Debasish Banerjee	5	5	1	1	3
Gautam Bhattacharyya	1	-	2	-	-
Harvendra Singh	2	2	1	2	-
Kalpataru Pradhan	6	5	-	2	-
Krishanu Roychowdhury	1	1	-	-	-

List of institutions collaborating with

Abhik Basu	**Asia**: IISc Bangalore, IIT Kanpur; **North America:** Univ. of Oregon, Eugene; **Europe:** LMU Munich, MPIPKS Dresden
Amit Ghosh	**Asia:** Central Univ. of HP, **Europe:** Univ. of Marseilles (France)
Arnab Kundu	**Asia:** YITP (Kyoto, Japan), IOP (Bhubaneswar, India), HRI (Allahabad, India), TIFR (Mumbai, India), RKMVU (Belur, India), IIT Kanpur (Kanpur, India), IISc (Bangalore, India), Manipal U. (Bangalore, India), IACS (Kolkata, India); **North America:** The Univ. of Texas, Austin (USA), The Univ. of Kentucky (USA); **Europe:** King's College London (UK), Univ. of Wurzburg (Germany)
Arunava Mukherjee	**Asia:** ICTS-TIFR (Bengaluru), IUCAA (Pune); **North America:** MIT (Cambridge, USA), Washington State Univ. (Pullman, USA), INT, Univ. of Washington (Seattle, USA); **Europe:** IGR-Univ. of Glasgow, Scotland), MPI-AEI (Hannover, Germany), DAMTP (Univ. of Cambridge, UK), INFN, Sezione di Pisa (Pisa, Italy); **Australia:** ANU (Canberra, Australia)
Arti Garg	**Asia:** IISc Bangalore, IISER-Kolkata, NISER-Bhubaneswar, IISER-TVM (collaboration started in Dec 2022), Bar-Ilan Univ. (collaboration started in July 2023); **Europe:** Jozeph Stefan Institute (Ljubljana, Slovenia)
Debasish Banerjee	**Asia:** IACS (Kolkata), TCG Crest TIFR (Mumbai), BITS-Goa; **North America:** Perimeter Institute (Waterloo), Duke Univ. (USA); **Europe:** HU (Berlin), LMU (Munich), MPQ (Garching), ETH (Zurich), Univ. Bern, ICFO (Barcelona), Univ. Trento, IBMQ Zurich, Southampton, IQOQI (Innsbruck)
Gautam Bhattacharyya	**Asia:** IIT Kharagpur, IPMU (Chiba, Japan), Tohuku Univ. (Miyagi, Japan); **Europe:** LPT Orsay (Paris, France), Ecole Polytechnique (Paris, France), Lund Univ. (Sweden), Univ. of Valencia (Spain), INFN Rome (Italy)
Kalpataru Pradhan	**Asia:** CSIR-CGCRI (Kolkata), SNBNCBS (Kolkata), NISER (Bhubaneswar), IOP (Bhubaneswar), IIT Bhubaneswar, IIT Bombay, IIT Madras, HRI, Allahabad, IISc Bangalore, RIKEN (Japan); **Europe:** RPTU Kaiserslautern-Landau, Kaiserslautern, Germany
Krishanu Roychowdhury	**Asia:** IACS (Kolkata), IISER-Kolkata, IIT Bombay, IISC Bangalore, ICTS-Bangalore, Univ. of Tokyo (Japan), Institute for Basic Science (Korea); **Europe:** Max Planck Institute for the Physics of Complex Systems (Germany); Univ. of Cologne (Germany); Stockholm Univ. (Sweden); Laboratoire de Physique Théorique - Toulouse (France); Univ. of Zurich (Switzerland); Univ. of Bath (UK); **North America:** Michigan Technological Univ. (USA), Cornell Univ. (USA), Binghamton Univ. (USA); Concordia Univ. (Canada)

Main difficulties faced since 2017

- Intake of students
- Limited postdoc Positions
- Computational resources and its support & maintenance

List of extramural projects with PI's names since 2017

Faculty Member	Project Title	Funding Agency	Duration	Fund (Rs lakhs)	Man power	Remarks
Abhik Basu	AvH research group linkage Programme : Statistical Perspectives on Non-equilibrium and Biological Physics	Alexander von Humboldt Foundation, Germany	2016 - 2019	Euro 55000		PI (Indian side)
	SERB (DST, India) research grant under the MATRICS scheme: Order, correlations and scaling in two-dimensional active systems	SERB-DST	2021 - 2023	4		PI
	SERB (DST, India) research grant under the TARE scheme: Broken symmetry phases in correlated backgrounds: Scaling and universality	SERB-DST	2022 - 2025	9.1		Mentor
	SERB (DST, India) research grant under the CRG scheme: Statistical mechanics of one-dimensional transport: Role of conservation laws, coupled gates and obstacles	SERB-DST	2022-2024	2.7		PI
Arnab Kundu	Novel Non-perturbative approaches to strongly coupled QCD	IFCPAR / CEFIPRA	Oct 2020 - Oct 2023	30		Co-PI
	Decrypting quantum-gravity using quantum information	DAE/BRNS	Oct 2021 - Oct 2024	25		Principal Collaborator
	Dynamics and chaos in strongly coupled QFT: deformations and boundaries	Core Research Grant, SERB	Jan 2022 - Jan 2025	30		Co-PI
Arti Garg	Inhomogeneities in Correlated Systems: Superconductors, Insulators and Many-body Localized Systems	Core Research Grant, DST-SERB	2019 - 2022	51.34	Yes	PI

Faculty Member	Project Title	Funding Agency	Duration	Fund (Rs lakhs)	Man power	Remarks
Arunava Mukherjee	Constraining Equation of State of The Neutron Stars With Multi-messenger Astrophysics	DST-SERB	2020 - 2022	13.90	No	PI
Debasish Banerjee	Exploring quantum gauge matter with classical and quantum simulations	SERB-DST	2022 - 2024	11.12		PI

Facilities

Computational

Clusters @ Room-3418

Hostname	**Meghnad2019 (10.10.3.67)**
Configuration	1 master+ 9 compute nodes (RAM 256 GB and 512 GB) 280 nodes (~12 Tera Flops) , Compilers : Gnu , Intel
Installation	March 2019
Current Status	Functional
Storage	2TB
Maintenance	Dr. Kalpataru Pradhan and Mr. Kausik Das
Users	Dr. Kalpataru Pradhan and group (Sourav, Sandip, Sudip, Shubhajyoti) Prof. Arti Garg and group (Amartya, Yogeshwar) Prof. AbhikBasu and group (Astik) Prof. Pradeep K Mohanty and group

DST-SERB funded Cluster(Through CRG/2018/003269)

Hostname	
Configuration	Make : Supermicro | Master Node :SuperServer 6029P-TR / Compute Nodes Model (i) SuperServer 6029TR-HTR-4 (4 cores each) and ii) SuperServer 6029TR-D-TR - 4 Nos (4 cores each)
Installation	January 2020
Current Status	In summer 2021 due to AC failure in the cluster room, RAM got damaged. RAM was replaced by NETWEB Company but cluster did not work properly after that. It was slow and getting shut down with even 50% jobs submitted. Engineers were called to investigate and problem was partially solved but the cluster has been really slow since then.
Maintenance	Prof. Arti Garg
Users	Prof. Arti Garg and group **Number of students/postdocs/faculty who used this cluster so far**: 5

Clusters @ Room-350

Hostname	**theorycluster.saha.ac.in (IP:10.10.2.230)**
Configuration	1 master + 3 compute nodes (RAM 256 GB); Peak performance:7TF
Installation	2016
Current Status	Functional
Storage	28 TB
Maintenance	MrsSangitaPande
Users	Members of the Theory Group

Seminar Rooms

Seminar Rooms (Room #3307 and Room #363) are equipped with a high-quality digital projector for lectures of the Post-MSc coursework, seminars, presentations, meetings, and discussions by the whole Institute.

Number of seminars organized since 2017

Theory:	**170**	[2017 to 2023]
TCMP:	**80**	[2017- 2020 (in CMP division)]
	26	[since August 2020 (after merging with Theory Division)]
APC:	**25**	[2020 to 2021]

Number of conferences/workshops/schools organized since 2017

Theory

1. Mini School on
    a. New Directions in Quantum Field Theories, 27-28 June, 2022
    b. Non-perturbative renormalization, 11,15,18 February 2021
    c. Perturbative renormalization, 01,04 February 2021
    d. Tensor Networks, 24, 28 September,01 October 2020
2. V Saha Theory Workshop: Amplitudes & Correlators, January, 2020.
3. School cum First Collaboration Meeting on Computational Nuclear Structure and Reactions(CMNSR2018), 2 -22 January, 2018
4. IV Saha Theory Workshop: Modern Aspects of String Theory, 19-23 February, 2018.
5. (Late) Prof. D.P. Roy Memorial Meeting: 21 April, 2017
6. III Saha Theory Workshop: Aspects of Early Universe Cosmology, 16-20 January, 2017

APC

1. Advances in Astro-particle Physics and Cosmology (AAPCOS)
    i. AAPCOS-2023, Jan 23-27, 2023
    ii. AAPCOS-2020, Jan 06-10, 2020
    iii. AAPCOS-2018, Mar 06- 09, 2018