Academic Report (2019–20)

Harish - Chandra Research Institute
Chhatnag Road, Jhunsi
Prayagraj (Allahabad), India
211019

Contents

About The Institute

History

The Harish-Chandra Research Institute is one of the premier research institutes in the country. It is an autonomous institution fully funded by the Department of Atomic Energy (DAE), Government of India. The Institute was founded as the Mehta Research Institute of Mathematics and Mathematical Physics (MRI). On 10th Oct 2000 the Institute was renamed as Harish-Chandra Research Institute (HRI) after the acclaimed mathematician, the late Prof Harish-Chandra.

MRI started with the efforts of Dr. B. N. Prasad, a mathematician at the University of Allahabad, with initial support from the B. S. Mehta Trust, Kolkata. Dr. Prasad was succeeded in January 1966 by Dr. S. R. Sinha, also of Allahabad University. He was followed by Prof. P. L. Bhatnagar as the first formal Director. After an interim period, in January 1983 Prof. S. S. Shrikhande joined as the next Director of the Institute. During his tenure the dialogue with the DAE entered into decisive stage and a review committee was constituted by the DAE to examine the Institute's future. In 1985 Shri N. D. Tiwari, the then Chief Minister of Uttar Pradesh, agreed to provide sufficient land for the Institute and the DAE promised financial support for meeting both the recurring and non-recurring expenditure. In January 1990, about 66 acres of land was acquired in Jhunsi, Allahabad, and the Institute came up at this site.

Prof. Shrikhande was followed by Prof. H. S. Mani who took over as the Director in January 1992. With his joining, and the shift to the new campus at Jhunsi in 1996, the Institute's activities picked up pace. After a distinguished tenure of about nine years Prof. Mani retired in August 2001 and the charge was taken over by Prof. R. S. Kulkarni. After Prof. Kulkarni's tenure, Prof. Amitava Raychaudhuri was the Director from July 19, 2005 to May 15, 2011. After him Prof. Sumathi Rao officiated as Acting Director till April 28, 2012. Prof. Jayanta Kumar Bhattacharjee was the next Director and continued till April 9, 2017. Prof. Pinaki Majumdar, the current Director, took over on April 10, 2017.

The Institute has a residential campus in Jhunsi, Allahabad, with a library, state of the art computational facility and fast internet link to the outside world. There is an active Ph.D program, an M.Sc program in Physics that started in 2017, and a large traffic of visiting scientists and students.

Research

The Institute continues to be devoted to fundamental research in diverse areas of mathematics and theoretical physics. Research is carried out by faculty members, visiting scientists, post-doctoral fellows and Ph.D. students.

The mathematics group at HRI carries out research in several areas. In algebra, work is done on algebraic groups and related structures, the theory of groups and group rings, representation theory, and infinite-dimensional Lie algebras. Work in analysis is in the field of harmonic analysis of Lie groups. Activity in geometry includes discontinuous groups and Riemann surfaces, algebraic topology, variational problems on manifolds, Chow groups of rational surfaces, and moduli of vector bundles. The number theory group works on algebraic, analytic and combinatorial number theory, automorphic forms and cryptography.

The areas of research in physics are astrophysics, condensed matter physics, quantum information and computing, high energy phenomenology and string theory. In astrophysics, work is done on the cosmic microwave background, large scale structure formation, and galaxy evolution. Main areas of activity in condensed matter physics are strongly correlated systems, mesoscopic systems, and the study of clusters and nanomaterials. In string theory, perturbative and non-perturbative aspects of string theory and quantum field theory are being actively investigated. Research in neutrino physics, strong interactions, lattice gauge theory, supersymmetry and various aspects of physics beyond the standard model is done in high-energy phenomenology. The Institute is a member of the India-based Neutrino Observatory (INO) collaboration.

Recognition

Since 1992 the Institute has attracted worldwide attention, as is evident from the recognition received by many of its members. Several members of the Institute have been recognised for their scientific contribution. Prof. Ashoke Sen, Prof. B. Mukhopadhyaya, Prof. Pinaki Majumdar and Prof. Rajesh Gopakumar have been awarded the Shanti Swarup Bhatnagar prize and in 2018 Prof. Aditi Sen De became the first woman scientist in India to be awarded the Bhatnagar prize in Physical Sciences. The outstanding contribution of Prof. Ashoke Sen has been recognised by a Fellowship of the Royal Society, the award of Padmashri and Padmabhushan and the award of one of the first Fundamental Physics Prize (2012) from the Yuri Milner Foundation. He was the only recipient of the prize from all of Asia. In 2017 the Institute was recognised as being among the top 10 research centers in India by the Nature journal.

Director's Report

March 2020 marked the temporary end of the world as we knew it. As I write, we are still in the grip of the pandemic, with many activities suspended and some moved online. The April 2019 to March 2020 period however was vibrant. I touch upon the activities below.

We had the "AFS-I- Annual Foundation School" in Mathematics in May 2019, and two conferences in the subsequent period. One was a meeting on "Class groups of number fields and related topics" in Oct 2019. This was the third in a series of meetings being held at HRI. In March 2020 we had a mini workshop on "Bundles, Cycles, and Motives".

We maintained an active Visitors Program, using the generous support provided by the Infosys Foundation. The Visiting Professors spend a week or more at HRI and deliver a set of lectures on some topic in their field. Over this period, in Mathematics we had V. Kumar Murty from the Field's Institute, University of Toronto, in October, Joachim Toft, from Linnaeus University, Sweden, and Jean-Marc Deshouillers from Institute of Mathematics of Bordeaux in November, and Kamal Khuri-Makdisi from the American University, Beirut, in January. In Physics we had Jainendra Jain from Penn State in June, John McGrady from Oxford University in September, and Yuval Gefen from Weizmann and Ribhu Kaul from the University of Kentucky, in January.

We held our annual Talent Search examination for school level children in Allahabad, and activities promoting the rajbhasha. The HRI colloquia featured talks by educationists, historians, economists and of course physicists and mathematicians from across the country.

A larger than average number of students graduated during this period. A total of 24 students (10 in Math and 14 in Physics) completed their Ph.D requirements. For the current year the entire admission process in Physics and Mathematics has been moved online. The number of papers published over the period would be around 110.

Pinaki Majumdar

Director

List of Governing Council Members (2019 - 20)

1. Shri K.N. Vyas (Chairman)	Chairman, Atomic Energy Commission (AEC) & Secretary, Department of Atomic Energy, Govt. of India, Anushakti Bhawan, Chhatrapati Shivaji Maharaj Marg, Mumbai 400 001
2. Shri A.R. Sule	Joint Secretary (R & D) Deptt. of Atomic Energy, Govt. of India, Anushakti Bhavan, Chhatrapati Shivaji Maharaj Marg, Mumbai 400 001
3. Mrs. Richa Bagla	Joint Secretary (Finance) Deptt. of Atomic Energy, Govt. of India, Anushakti Bhavan, Chhatrapati Shivaji Maharaj Marg, Mumbai 400 001
4. Prof. V. Srinivas	Senior Professor TIFR & Chairman NBHM, School of Mathematics, Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Mumbai 400 005
5. Prof. V. Arvind	Director Institute of Mathematical Sciences, CIT Campus, Taramani, Chennai 600 113
6. Prof. Sanghamitra Bandopadhyay	Director Indian Statistical Institute, 203, B.T. Road, Kolkata 700 108
7. Prof. S.M. Chitre	Chair, Academic Board University of Mumbai - Department of Atomic Energy - Centre for Excellence in Basic Sciences (UM-DAE-CBS), Health Centre Building, University of Mumbai, Kalina Campus, Mumbai 400 098

8. Director, Higher Education (Ex-officio)	Higher Education Department, U.P. Near G.P.O., Civil Lines, Allahabad 211 001
9. Shri S. L. Mehta	4, Clive Row, Kolkata 700 001
10. Shri Avnish Mehta	4, Penn Road, Kolkata 700 027
11. Shri Rajnish Mehta	4, Penn Road, Kolkata 700 027
12. Prof. Pinaki Majumdar (Ex-Officio)	Director Harish-Chandra Research Institute, Chhatnag Road, Jhunsi, Allahabad 211 019

Academic Staff

Faculty Members (Mathematics)

1. Batra, Punita
2. Chakraborty, Kalyan
3. Dalawat, C.S.
4. Dubey, Umesh Kumar V.
5. Kumar, Manoj
6. Prakash, Gyan
7. Raghavendra, N.
8. Ramakrishnan, B.
9. Ramana, D. Surya
10. Ratnakumar, P. K.
11. Shah, Hemangi M.
12. Thangadurai. R.

Faculty Members (Physics)

1. Basu, Anirban
2. Das, Tapas Kumar
3. Datta, AseshKrishna
4. De, Aditi Sen
5. Gandhi, Raj
6. Jatkar, Dileep
7. Maharana, Anshuman
8. Majumdar, Pinaki
9. Pareek, T. P.
10. Pati, Arun Kumar
11. Rai, Santosh Kumar
12. Rao, Sumathi
13. Sen, Ashoke
14. Sen, Prasenjit
15. Sen, Ujjwal

Administrative Staff

1. Shri Ravindra Singh [Registrar]
2. Shri Rajkumar Gulati [Accounts Officer]
3. Shri Manish Sharma [S.O.'E']
4. Shri K.K. Suresh Kumar [Librarian]
5. Shri Amit Roy [I.A.&A.O.]
6. Shri Sanjai Verma [Systems Manager]
7. Shri A.K. Srivastava [S.O.'C' (Electrical)]
8. Shri V.K. Srivastava [S.O.'C' (Civil)]
9. Shri R.P. Sharma [Manager Guest House]
10. Smt. Anju Verma [S.O.(SB)]
11. Shri U.K. Dwivedi [Cashier]
12. Shri D. Malhotra [Upper Division Clerk]
13. Shri K.K. Srivastava [Upper Division Clerk]
14. Shri Yashpal Singh [Stenographer]
15. Smt. Sumitra [Upper Division Clerk]
16. Smt. Seema Agarwal [Receptionist]
17. Shri Sudheer Kumar Singh [Accountant]
18. Shri Sanjeev Nagar [Hindi Typist]
19. Shri Vivek Kumar [Junior Library Assistant]
20. Shri Kamlesh Thakur [Bearer (Canteen Cadre)]
21. Shri Kamta Prasad [Peon/Watchman]
22. Shri Rajesh Kumar [Safaiwala]

Visiting Fellow

Mathematics

1. Banerjee, Kalyan
2. Bhanja, Jagannath
3. Dey, Arindam
4. Kumar, C. P. Anil
5. Lahiri, Animesh
6. Mohamed, Ebtsam Hassan Taha
7. Naik, Muna
8. Pradhan, Soham S.
9. Ray, Chiranjit
10. Sarkar, Amar Deep
11. Sarkar, Subham
12. Sen, Sourav
13. Singh, Rajesh Kumar
14. V., Pramath A.

Physics

1. Abdallah, Waleed Mohammed
2. Banerjee, Avik
3. Chatterjee, Atreya
4. Das, Tisita
5. Fernandes, Karan
6. Ghosh, Nivedita
7. Ghosh, Purusottam
8. Gupta, Manish Kumar
9. Halder, Saronath
10. Hegde, Subramanya
11. Kumari, Asmita

12. Lahiri, Jayita
13. Mal, Shiladitya
14. Mitra, Arpan Krishna
15. Saha, Arnab Priya
16. Samui, Tousik
17. Sehrawat, Arun

Visiting Scientist

1. Deo, Satya (Maths)
2. Girdhar, Aarti (Principal Investigator)
3. Rai, Pradeep Kumar (INSPIRE Faculty)
4. Saha, Pratishruti (INSPIRE Faculty)

Research Scholar

Mathematics

1. Agnihotri, Rishabh
2. Bhowmick, Kushal
3. Chakraborty, Priyanshu
4. Chattopadhyay, Jaitra
5. Choudhury, Srijonee Shabnam
6. Das, Mithun Kumar
7. Gupta, Shubham
8. Karmakar, Debasish
9. Kaushik, Rahul
10. Keshari, Parul
11. Krishnarjun, K.
12. Maity, Arup Kumar
13. Mishra, Mohit
14. Nishant
15. Pal, Souvik
16. Roy, Bidisha
17. Sahoo, Gopinath
18. Sarkar, Subha
19. Singh, Anoop
20. Tantubay, Santanu
21. Vaishya, Lalit

Physics

1. Abdulla, Faruk
2. Alam, Khorsed
3. Bakshi, Sankha Subhra
4. Bandyopadhyay, Subhodip
5. Banerjee, Ratul
6. Barik, Anjan Kumar
7. Basak, Nirnoy
8. Bhattacharya, Sauri
9. Bhowmik, Swapnil
10. Bose, Debraj
11. Chandra, L. L. Ganesh
12. De, Suman Jyoti
13. Dey, Atri
14. Dey, Shyamashish
15. Dutta, Arijit
16. Ghosh, Avirup
17. Ghosh, Srijon
18. Ghoshal, Ahana
19. Grover, Sachin
20. Gupta, Rivu
21. Kadge, Samrat Suresh
22. Kar, Arpan
23. Mahanta, Ratul
24. Maity, Susovan
25. Md., Abhishek
26. Mohan, Brij
27. Mondal, Tanmoy
28. Pal, Kalyanbrata

29. Pandey, Vivek
30. Reja, Afsar
31. Roy, Saptarshi
32. Roy, Shubhojit
33. Roy, Tanaya
34. Sahoo, Biswajit
35. Saini, Hitesh Kumar
36. Sen, Arpita
37. Sen, Kornikar
38. Shrimali, Divyansh
39. Singh, Kajal
40. Sohail
41. Srivastav, Abhay
42. Srivastava, Chirag

M.Sc. Students

Physics

1. Boxi, Sovan
2. Chauhan, Aman
3. Choudhary, Swati
4. Das, Manojit
5. Kundu, Sukalpa
6. Mal, Sourav
7. Mondal, Sayan
8. Nanda, Ayan
9. Pal, Amartya
10. Paul, Aritra
11. Rajgadia, Harshit
12. Reddy, Vemula Suneel Chandra
13. Sahoo, Ayan
14. Singhi, Kaustubh

Academic Report - Mathematics

Punita Batra

Research Summary:

In a joint work with Priyanshu Chakraborty, I have classified irreducible integrable modules for loop toroidal Lie algebras. Let τ be a toroidal Lie algebra without the derivations attached and let B be a commutative, associative, unital, finitely generated algebra over $\mathbb{C}$. We define a Lie algebra $\tau \otimes B$ and then add the degree deivations. We call this loop toroidal Lie algebra and classified its irreducible integrable modules V with finite dimensional weight spaces when the center acts non-trivially on module V as well as the case when center acts trivially on V.

Publications:

1. Punita Batra, S.Eswara Rao, Sachin S. Sharma *Integrable modules for twisted toroidal extended affine Lie algebras,* **Journal of Algebra, Vol.556, 1057-1072 (2020).**

2. Punita Batra, Hiroyuki Yamane, *Natural elements of center of generalized quantum groups,* **Contemporary Mathematics, Vol. 751, 19-31 (2020).**

Preprints:

1. (With Priyanshu Chakraborty) *Classification of irreducible integrable representations of Loop Toroidal Lie algebras,* arxiv.org/pdf/2007.06415.

Conference/Workshops Attended:

1. *"Annual Conference of Indian Women and Mathematics (IWM)"* at I.I.T. Bombay, June 10-11, 2019.

2. *"International Conference on algebra and Related Topics with Applications"* at Department of Mathematics, Aligarh Muslim University Aligarh, December 17, 2019.

Visits to other Institutes:

1. Department of Mathematics, I.I.T. Bombay during June 10-11, 2019.

2. Department of Mathematics, Aligarh Muslim University Aligarh, December 17, 2019.

3. Department of Mathematics, University of Lucknow on January 17,2020.

Invited Lectures/Seminars:

1. *Integrable modules for full toroidal Lie algebras* , **Invited Plenary talk,** in Annual Conference of Indian Women and Mathematics(IWM), I.I.T. Bombay, June 11, 2019.

2. *Integrable representations for toroidal Lie algebras* , **Invited talk,** in International Conference on Algebra and Related Topics with Applications, A. M. U. Aligarh December 17, 2019.

Other Activities:

1. Gave four lectures on "Linear Algebra" in Annual Foundation School(AFS-I) held at HRI during May 6-June 1, 2019.

2. Coordinator - HRI's Science Talent Search exam 2019(Mathematics part).

3. Evaluated Ph.D thesis "A study of Lie Properties of group algebras" of Bhagwat Saran from University of Lucknow in Nov 2019.

4. Convener of the Outreach Programme(Mathematics). Also serving as a member in the Sports and Entertainment Committee and the Rajbhasha Committee at HRI.

Kalyan Chakraborty

Research Summary:

During the last academic year 2019-2020 my research was focussed on the arithmetic problems related to Selmer groups and Tate - Shafarevich groups associated to algebraic cycles on a variety defined over a number field. We have been able to prove some finiteness result for some quotient of the group of algebraic cycles by using these new constructions of Selmer and Tate Shafarevich groups. One important application is the weak Mordell-Weil theorem for the Chow group of zero cycles of any smooth projective variety defined over a number field. We are also trying to relate various questions related to the class number of algebraic number fields with that of Selmer groups and Tate - Shafarevich groups associated to elliptic curves and also with other higher genus curves.
I am also involved into other questions like sums of integral squares, Diophantine tuples and that of various interesting Diophantine equations in the ring of integers or that of S-integers in number fields.

Publications:

1. Banerjee, S. and Chakraborty, K. *Asymptotic behaviour of a Lambert series á La Zagier: Maass case*, **Ramanujan J.**, Vol. 48 (2019), no. 3, 567–575.

2. Kalyan Banerjee, Kalyan Chakraborty and Azizul Hoque, *Divisibility of Selmer groups and class groups,* **Hardy - Ramanujan Journal**, Vol. 42, (Dec. 2019), 85–99.

3. Kalyan Chakraborty, Azizul Hoque and Mohit Mishra, *On the structure of order 4 class groups of* $\mathbb{Q}(\sqrt{n^2+1})$, **Annales mathmatiques du Qubec, (), 1-10**; DOI 10.1007/s40316-020-00139-1.

4. Kalyan Chakraborty, Azizul Hoque and Prem Prakash Pandey, *Class groups of Number Fields and Related Topics*, Springer, 2019. (Edited).

5. Kalyan Chakraborty, Azizul Hoque and Mohit Mishra, *A note on certain real quadratic fields with class number upto three,* **Kyushu J. M.** (To appear).

6. K. Chakraborty and A. Hoque, *Exponents of class groups of certain imaginary quadratic fields,* **Czechoslovak Mathematical Journal**, (To appear).

7. Kalyan Chakraborty, Azizul Hoque and Richa Sharma, *Complete solutions of certain Lebesgue-Ramanujan-Nagell type of equations,* **Publicationes Mathematicae Debrecen** (To appear).

Preprints:

1. K. Chakraborty, S. Kenmitsu and A. Laurinčikas, *Complex powers of L-functions and integers without large prime factors,*

2. S. Banerjee, K. Chakraborty and A. Hoque, *An analogue of Wilton's formula and values of Dedekinf zeta functions,.*

3. K. Chakraborty and A. Hoque, *On the plus parts of the class numbers of cyclotomic fields.*.
4. Kalyan Banerjee and Kalyan Chakraborty, *Tate-Shafarevich group and Selmer group constructions for Chow group of an abelian variety*.
5. Kalyan Banerjee and Kalyan Chakraborty, *On the Chow group of the self-product of a cm elliptic curve defined over a number field*.
6. Rishabh Agnihotri, Kalyan Chakraborty and Mohit Mishra, *Primary rank of class groups of real cyclotomic fields*, (Submitted).
7. Kalyan Chakraborty, Azizul Hoque and Richa Sharma, *On the solutions of certain Lebesgue-Ramanujan-Nagell equations*.
8. Kalyan Chakraborty and Takao Komatsu, *Generalized Hypergeometric Bernoulli Numbers*.
9. Chiranjit Ray and Kalyan Chakraborty, *Certain eta-quotients and ℓ-regular overpartitions*.

Conference/Workshops Attended:

1. International conference in number theory, Inner Mongolia, China, June 2019.
2. International Conference on Special functions and Applications, Bikaner, India, October 2019.
3. Regional Science Congress (WS), Burdwan University, December 2019.
4. NCRTMA - 2019, GITAM, Bengaluru, India, December 2019.
5. National Symposium, PDPM IITDM, Jabalpur, India, December 2019.
6. Regional Science Congress, Chattisgarh Chapter, Dehradun, January 2019.
7. National Seminar on Mathematical Sciences, Burdwan University, February 2020.
8. Workshop on Analytic Number theory, KSoM, Kerala, India, March 2020.

Visits to other Institutes:

1. Shangdong University, Weihai, China, June 2019.
2. North-West University, Xian, China, June 2019.
3. China University of Mining and Technology, Beijing, China, September 2019.
4. Burdwan university, December, January, 19-20.
5. GITAM, Bengaluru, December 2019.
6. IITDM, Jabalpur, December 2019.
7. KSoM, Kerala, India, March 2020.

Invited Lectures/Seminars:

1. Complete solutions of certain Ramanujan-Nagell type equations; International conference in Number Theory and Applications, China, June 2019.
2. Elliptic curve cryptography and applications, Faculty Development Program, Anand International College of Engineering, Jaipur, India, June 2019.
3. Dedekind zeta values and its relation with class numbers of quadratic fields, One day number theory meet, China University of Mining and Technology, Beijing, September 2019.
4. Special values of Dedekind zeta functions; SSFA-2019, Bikaner, October 2019.
5. Closed form expressions for Dedekind zeta values, RSTC (WR), Burdwan University, Burdwan, December 2019.
6. Unique factorization, its failure and its measure, NCRTMA-2019, GITAM, Bengaluru, India. December 2019.
7. Primes and more.. , IIITDM, Jabalpur, National Symposium, December 2019.
8. Divisibility of class numbers, IISER, Thiruvananthapuram, January 2019.
9. Prime numbers and some related conjectures, IIST, Thiruvananthapuram, January 2020.
10. Zeta values and class numbers of certain real quadratic fields, KSoM, March 2020.

Other Activities:

1. Chief organiser of ICCGNFRT-2019 (https://sites.google.com/site/iccgnfrt2019/).
2. Edited the conference proceedings which has been published now by Springer.
3. NBHM Examination and Interview Co-ordinator of Zone 2.
4. As Vice-President of SSFA, India; I co-ordinate all its activities including the yearly international conference, ICSFA.
5. Reviewer of AMS and refereed five manuscripts and two PhD thesis.

Chandan Singh Dalawat

Research Summary:

Attempts were made to extend the parametrisation of primitive extensions of a local field to the case when there is a unique ramification break, but work remains to be done. Devoted a substantical amount of time to dissemination and to supervising a doctoral student.

Conferences/Workshops Attended:

1. *Perfectoid spaces*, International Centre for Theoretical Sciences, 9–20 September, 2019.
2. *Annual meeting of the Indian Mathematical Society*, Indian Institute of Technology, Kharagpur, 22–25 November 2019.
3. *International Colloquium on Arithmetic Geometry*, Tata Institute of Fundamental Research, 6–10 January, 2020.
4. *International Conference on Number Theory*, Kerala School of Mathematics, Calicut, 23–26 January 2020.
5. *Workshop on Bundles, Cycles and Motives*, Harish-Chandra Research Institute, Allahabad, 5–10 March 2020.

Visits to other Insitutes:

1. Indian Institute of Science, Bangalore, 1–8 September 2019.
2. Indian Statistical Institute, Calcutta, 25–27 November 2019.
3. National Institute of Technology, Jaipur, 18–21 January 2020.
4. Indian Institute of Science Education and Research, Trivandrum, 27 January – 1 February 2020.
5. National Institute of Technology, Surathkal, 2–6 February, 2020.

Invited Lectures/Seminars:

1. *Two footnotes to Galois's memoirs*, Indian Institute of Science Education and Research, Tirupati, 4 September 2019 ; Indian Institute of Science, Bangalore, 6 September 2019 ; Annual Meeting of the Indian Mathematical Society, Indian Institute of Technology, Kharagpur, 24 November 2019 ; Indian Statistical Institute, Calcutta, 27 November 2019 ; Malviya National Institute of Technology, Jaipur, 21 January 2020 ; International Conference on Number Theory, Kerala School of Mathematics, Calicut, 23 January 2020 ; Indian Institute of Science Education and Research, Trivandrum, 28 & 31 January 2020 ; National Institute of Technology, Surathkal, 3 & 4 February, 2020 ; Colloquium, Ashoka University, 3 March 2020.
2. *Congruent numbers*, Azim Premji University, Bangalore, 7 September 2019.

Other Activities:

Served as a member of the National Board for Higher Mathematics. Gave a set of two lectures in Hindi in the outreach programme. Refereed papers for various journals.

Umesh Kumar Vanktesh Dubey

Research Summary:

We continued the study of the tt-Chow group , in the sense of S. Klein and P. Balmer, for equivariant tt-categories by comparing it will the underlying tt-categories. In the process, we computed the Balmer spectrum extending the know computations from our earlier works and some later generalizations due to J. Hall. We also corrected the K-theoretic formulation of our earlier version and achieve the correct decomposition of the tt-Chow group, similar to the K-group result of A. Vistoli. We also studied the morphism between niveau spectral sequences. This is part of a joint project with Vivek M. Mallick.

In joint work with Sanjay Amrutiya, we answered the questions of functorial construction of moduli of parabolic sheaves using our earlier developed notion of moduli of filtered representations following A. King. This also settles the eight-year-old question of V. Balaji (personal communication) in a large number of cases. As a consequence of moduli construction, we also deduce the projectivity of moduli spaces with the help of a version of Langton's lemmas due to K. Yokogawa. We also lifted functorial moduli construction at the level of moduli stacks and deduce some properties for the moduli stack of the stable objects.

We continued the study of the classification of thick subcategories of the singularity category in the graded setup with Sarang Sane. We aim to give the classification of thick subcategories using the known results on the homogeneous singular locus. We hope to apply these results to get similar classification results for other triangulated categories with stratifications in the future.

Publications:

1. (*with Vivek M. Mallick*) " On the differential graded Eilenberg-Moore construction", **Journal of Algebra**, Vol. 541, January 2020, 174-218.

Preprints:

1. (*With Sanjay Amrutiya*) " Moduli of filtered quiver representations", ArXiv: 1808.02003v2 [math.AG] (under review), 25 pp.

2. (*With Sanjay Amrutiya*) " Moduli of parabolic sheaves and filtered Kronecker modules ", ArXiv: 2005.01084 [math.AG] (under review), 24 pp.

3. (*with Vivek M. Mallick*) " Balmer spectrum and tt-Chow group of G-equivariant categories",(in preparation).

4. (*with Sarang Sane*) "Classification of thick subcategories of some graded singularity categories",(in preparation).

Conference/Workshops Attended:

1. Mini-workshop on *Bundles, Cycles and Motives*, HRI, Prayagraj, 5 - 10 March 2020.

2. Conference on *Derived categories and Geometry of Algebraic Varieties*, TIFR, Mumbai, 17 - 21 February 2020.

3. Workshop on *Bundles and Moduli of structures*, ICTS-TIFR, 10 - 14 February 2020.

4. International Colloquium on *Arithmetic Geometry*, TIFR, Mumbai, 6 - 10 January 2020.

5. ATM Workshop on *Bloch-Kato Theorem*, IISER Pune, 23 December 2019 - 4 January 2020.

Visits to other Institutes:

1. IISER, Pune, June-July 2019.

Invited Lectures/Seminars:

1. *Functorial moduli construction of parabolic sheaves*, HRI, Prayagraj, 10 March 2020.

2. *DG monad and tt-geometry*, TIFR, Mumbai, 18 February 2020.

Other Activities:

1. Organised DAE funded *Mini-workshop on Bundles, Cycles and Motives*, HRI, Prayagraj, 5 - 10 March 2020.

2. AFS-I lectures and tutorials on Topology, HRI, May 2018. Seminar series on *Grothendieck topologies* (September - December 2019) and on *Intersection Theory* (January - March 2020), HRI.

3. Supervising three HRI research scholars, involved in refereeing few manuscripts for Mathematics Journals and AMS Mathematical reviews.

4. Member of Committees: Mathematics Graduate Programme, Transport, Admission and Outreach Committee.

Manoj Kumar

Research Summary:

A long standing well known problem in group theory is to classify finite groups in which every element of the commutator subgroup is a commutator. It has already been proved that in a finite simple group every element of the commutator subgroup is a commutator. At the extreme end, for finite p-groups the situation is quite different. It has been recently proved that if the commutator subgroup of a finite p-group, $p \geq 5$, is minimally generated by 3 elements, then every element of the commutator subgroup is a commutator. But it is not always true when the commutator subgroups is minimally generated by more than 3 elements. We studied the situation when the commutator subgroup of a finite p-group, p odd, is of order p^4 and exponent p. A complete classification of such finite p-groups in which every element of the commutator subgroup is a commutator is provided.

In a different work, we have studied *skew left braces*. This has direct connection with set theoretic solutions of the quantum Yang-Baxter equation. A multiplicatively written group G, with multiplicative structure on G given by $(g_1, g_2) \mapsto g_1 g_2$, is said to be a *skew left brace* if it admits an additional group structure given by $(g_1, g_2) \mapsto g_1 \circ g_2$ satisfying

$$g_1 \circ (g_2 g_3) = (g_1 \circ g_2) g_1^{-1} (g_1 \circ g_3)$$

for all $g_1, g_2, g_3 \in G$, where g_1^{-1} denotes the multiplicative inverse of g_1. A skew left brace G is said to be a *left brace* if G is an abelian groups under multiplicative structure. A lot of theory has been developed on skew left braces of finite order. In this work we concentrate on skew left braces of infinite order. We developed some theory and constructed various different types of skew left braces and left braces of infinite orders, respectively, on free groups and free abelian groups of finite ranks. Emphasis is given on λ-homomorphic, λ-cyclic and symmetric skew left braces. A complete characterization of λ-cyclic left braces on a free abelian group of rank 2 is provided.

Publications:

1. Sumana Hatui, Vipul Kakkar and Manoj K. Yadav, *The Schur multiplier of groups of order p^5*, J. Group Theory 22, 647-687, (2019).

2. Tushar K. Naik, Rahul D. Kitture and Manoj Kumar Yadav, *Finite p-groups of nilpotency class 3 with two conjugacy class sizes,* Isreal J. Math. 236, 899-930, (2020).

3. Valeriy G. Bardakov, Mikhail V. Neshchadim and Manoj K. Yadav, *Computing skew left braces of small orders*
Internat. J. Alg. Comput., https://doi.org/10.1142/S0218196720500216, (2020).

Preprints:

1. Rahul Kaushik and Manoj K. Yadav, *Commutators and commutator subgroups of finite p-groups,* preprint, rXiv:2005.13929.

2. Valeriy G. Bardakov, Mikhail V. Neschadim and Manoj K. Yadav, *On λ-homomorphic skew braces*, preprint, arXiv:2004.05555.

Conference/Workshops Attended:

1. *Recent Advances in Mathematics and Scientific Computing*, India, April, 2019.
2. *85th Annual Conference of Indian Mathematical Society*, India, November, 2019.

Invited Lectures/Seminars:

1. *Left braces*, Recent Advances in Mathematics and Scientific Computing, Madan Mohan Malviya University of Technology, Gorakhpur, April, 2019.
2. *Finite groups with abelian automorphism groups*, 85th Annual Conference of Indian Mathematical Society, IIT, Kharagpur, November, 2019.

Other Activities:

1. Refereed research papers for many national and international journals.
2. Edited research papers for Proc. Math. Soc., IASc.
3. Reviewed Ph. D. theses one each for Panjab Univ., Chandigarh, Central Univ. Bihar, Gaya and Monash Univ., Melbourne (Australia).
4. Served as a member of several committees at HRI.

Gyan Prakash

Research Summary:

Let c be a real number with $1 < c < 2$. In 2018, D. I. Tolev asked whether given any integer $E \geq 1$ is it true that for all sufficiently large real number x we have $|p_1^c + p_2^c + p_3^c - x| < \log^{-E} x$ with p_1, p_2, p_3 being prime as well as all the following three integers $p_1 + 2, p_2 + 2, p_3 + 2$ have at most r prime factors with $r = 3$. Tolev showed that the result is true if we take $r = 30$ in place of $r = 3$ when c is close to 1. In 2020, Li Zhu improved this result and showed that the result is true with $r = 23$ when c is close to 1. In a joint work with Priyamvad Srivastav, we improved this result of Li Zhu and showed that the result is true with $r = 13$, when c is close to 1.

Preprints:

1. Gyan Prakash, Priyamvad Srivastav, *On diophantine inequality with prime numbers of special type*, in preparation.

2. François Hennecart, Gyan Prakash, Eyyunni Pramod, *On Sum-Product Bases*, submitted.

3. K. Mallesham, Gyan Prakash, D.S. Ramana, *Monochromatic sums of prime squares*, submitted.

Conference/Workshops Attended:

1. *WAC20* Workshop on Additive Combinatorics 2020 at ICTS Banagalore, 26 February to 6 March 2020.

Invited Lectures/Seminars:

1. Gave 7 lectures, each of 1 hour duration at Workshop on Additive Combinatorics 2020 at ICTS Banagalore.

Other Activities:

1. Thesis Supervision at HRI: Bhuwanesh Rao Patil (Defended February 2020, co-guide: D.S. Ramana)

   As co-guide: E. Pramod (Defended November 2020, guide: D.S. Ramana).

N. Raghavendra

Research Summary:

I have been occupied for most of the year with the thesis work of my last two students. One of them had his Ph. D. viva in March, and the other is ready to submit his thesis. In the last two months of the year, I began a long-term effort on the univalent foundations of mathematics, and formalisation of mathematics within them. As an initial step, I have started a project on univalent formalisation with the proof assistant Coq. This involves setting up the required infrastructure, including organising the various tools that are involved in the formalisation.

Ramakrishnan Balakrishnan

Research Summary:

1. In 2013, S. Cooper, H. Yam and D. Ye used a method of Hurwitz to determine formulas for the number of representations of certain quinary and septenary (diagonal) quadratic forms. In a joint work with Brundaban Sahu and Anup Kumar Singh, we use the extended Shimura correspondence developed by T. Jagathesan and M. Manickam to obtain formulas for a wider class of quinary and septenary (diagonal) quadratic forms. This work is in progress.

2. An unpublished work of Selberg gives an interesting property of the first Shimura map on certain modular forms of half-integral weight, which are products of Hecke eigenforms of integral weight with the classical theta function. Later, Cipra and Hansen-Naqvi extended this method by considering generalised theta functions. In our earlier work (joint with Manish Kumar Pandey), we extended Cipra and Hansen-Naqvi's works to a wider class of forms of half-integral weight and proved special property of t-th Shimura maps (t is a square-free integer). The method of Hurwitz mentioned in item 1 is very close to the property of the first Shimura map studied by Selberg. In this work, we show that the method of Hurwitz also gives rise to a kind of Shimura correspondence on these class of functions. This work is in progress.

Publications:

1. Manish Kumar Pandey, B. Ramakrishnan and Anup Kumar Singh, *Shimura and Shintani liftings of certain cusp forms of half-integral and integral weights*, Tsukuba J. Math. **43**, No. 2 (2019), 191–210.

2. Manish Kumar Pandey and B. Ramakrishnan, *Determining modular forms of half-integral weight by central values of convolution L-functions*, Modular Forms and Related Topics in Number Theory: Kozhikode, India, December 10–14, 2018, Springer Proc. Math. Stat., 2020 (15 pages, to appear).

3. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of a natural number by certain quaternary quadratic forms*, Modular Forms and Related Topics in Number Theory: Kozhikode, India, December 10–14, 2018, Springer Proc. Math. Stat., 2020 (24 pages, to appear).

4. Bernhard Heim, B. Ramakrishnan and Brundaban Sahu (Editors), *Modular Forms and Related Topics in Number Theory: Kozhikode, India, December 10–14, 2018*, , Springer Proc. Math. Stat., 2020 (to appear).

Conference/Workshops Attended:

1. International Conference on Number Theory and Graph Theory, University of Mysore, Mysuru, June 27–29, 2019.

Visits to other Institutes:

1. The Institute of Mathematical Sciences, Chennai, April (10 days) and July (15 days), 2019.

Invited Lectures/Seminars:

1. Annual Foundational School-I (ATM School), HRI, Prayagraj, May 20–25, 2019
2. Advanced Instructional School on Modular Forms (ATM School), IIT Guwahati, May 27 – June 01, 2019.

Other Activities:

1. Supervising a student for Ph. D.
2. Convener, Board of Studies in Mathematical Sciences, HBNI, Mumbai.
3. Honorary Treasurer, The National Academy of Sciences, India, Prayagraj.

D. Surya Ramana

Research Summary:

The main theme of my research continues to be investigating if large but otherwise arbitrary subsets of "interesting subsets" of the natural numbers retain certain properties of these interesting sets. For instance, a work in progress addresses the following question : if A and B are subsets of the positive integers not exceeding N, then one may ask for a sharp lower bound for the number of squares in the sum set $A + B$. A number of problems that I have studied so far under this broad theme depend on the Large Sieve, a key tool from analytic number theory. Another project in progress from the last year within the theory of the Large Sieve, eventually aims at obtaining an optimal version of the large sieve inequality with square moduli. A rather different problem within this theory that has been of interest to us is to obtain an upper bound of the correct order for the number of positive intergers n not exceeding a given bound x such that for a given family of arithmetic progressions $b_i \bmod a_i$, $1 \leq i \leq m$, where m is an integer ≥ 1, and a given number field K we have that each $a_i n + b_i$, $1 \leq i \leq m$ is the norm of an ideal of K. This was done for normal number fields K by W.G. Nowak and it is required to extend this to arbitrary K.

Publications:

1. D.S. Ramana and O. Ramaré, *Variant of the Truncated Perron's formula and Primes in Polynomial Sets*. International Journal of Number Theory, Vol. 16, No. 2, (2020), 309-323.

Preprints:

1. K. Mallesham, Gyan Prakash and D.S. Ramana, *Monochromatic Sums of Prime Squares*, (submitted, listed as to be submitted in the report for 2018 -2019).

Conference/Workshops Attended:

1. *WAC2020* Co-Organised and lectured in the Workshop on Additive Combinatorics 2020 at ICTS, Bangalore, 26 February to 6 March, 2020.

Invited Lectures/Seminars:

1. Indian Statistical Institute, Kolkata, 19 to 24 September, 2019. Gave a short course of lectures (6 Hrs).

Other Activities:

1. Thesis supervision at HRI: Ritika Sharma (Defended June 2019), E. Pramod (Defended November 2020, co-guide Dr. Gyan Prakash), Mithun Kumar Das (Thesis to be submitted in June 2020).

   As Co-Guide : Bhuwanesh Rao Patil (Defended February 2020, Guide Dr. Gyan Prakash)

2. Serving as Dean (Administration), HRI from 30 August 2019. Also served on a number of academic and administrative committees of HRI including the Mathematics Faculty Appointments Committee (as member), Library Committee (as convenor).

3. Member, Library Committee, National Board for Higher Mathematics (NBHM).

4. Member, Committees for IST (Instructional Schools for Teachers) and TEW (Teacher's Enrichment Workshops) of the National Centre for Mathematics (NCM).

Ratnakumar Peetta Kandy

Research Summary:

In the last one year, I have been working mainly on three problems. The first one is a continuation of a joint work with Anupam Gumber, which concerns the study of characterisation of Weyl multipliers on twisted modulation spaces. We have established some more relevant properties for the twisted modulation spaces $\mathcal{M}^{p,q}$. We re-formulated the multiplier Theorem in a more satisfactory way, and could handle the inherent non commutativity that arises in the setting of the Weyl multipliers. As of now, we have obtained a characterisation in $\mathcal{M}^{p,1}, 1 \leq p \leq \infty$. The result for all $\mathcal{M}^{p,q}, 1 \leq p, q \leq \infty$ requires some embedding result into some appropriate function space, which we are exploring currently.

The second problem concerns the joint work with Arup Maity, where we are exploring some new conditions for the $L^p - L^q$ boundedness of the multipliers. There issome progress in this direction, for both Fourier as well as the Weyl multipliers.

The third concerns the study of singular Fourier multipliers on L^p spaces, motivated by the well known cone multiplier theorem. This is a joint work with Rajesh Singh and is in progress.

There is also a piece of collaborative work on translation and modulation invariant Hilbert spaces, during the visit of Prof. Joachim Toft at HRI, jointly with him, Anupam Gumber and Ramesh Manna, who were also visiting here at the same time.

Publications:

1. Local smoothing of Fourier integral operators and Hermite functions, jointly with Ramesh Manna. To appear in the Proceedings on the session on Advances in Harmonic Analysis and Partial Differential Equations of the 12th ISAAC Congress, Aveiro (Portugal) 2019, (to be published by Birkhuser under Trends in Mathematics series)

Preprints:

1. Translation and modulation invariant Hilbert spaces, jointly with Joachim Toft, Anupam Gumber and Ramesh Manna (submitted for publication).

Conference/Workshops Attended:

1. NCM workshop on Harmonic Analysis 10-14 December 2019, Department of Mathematics, IISER Bhopal.

2. 16th Discussion Meeting in Harmonic Analysis, 16-19 December 2019, Department of Mathematics, IISER Bhopal.

3. Workshop on Analysis and Applications, 24-28 February 2020, Dept. of Mathematics, University of Jammu.

Visits to other Institutes:

1. University of Aveiro, Portugal, 29th July to 2nd August 2019.
2. Department of Mathematics, IISER, Bhopal, 10-19th December 2019.

Invited Lectures/Seminars:

1. Local smoothing of Fourier integral operators and Hermite functions, in the Session on Harmonic Analysis and Partial Differential Equations, in the 12th ISAAC Congress, held at the University of Aveiro, Portugal during 29th July to 2nd August 2019.
2. "Translation invariant operators between Lebesgue spaces", In the workshop on Applications of Analysis, held in the Dept. of Mathematics, University of Jammu during 24-28 February 2020.

Other Activities:

1. Serving in the Math Graduate Committee as convener, and also as a member in the mathematics PDF committee.

Hemangi Madhusudan Shah

Research Summary:

1) I have revised the following article on arxiv: arXiv:1703.00341 [math.DG].
Geometry of Asymptotically harmonic manifolds with minimal horospheres: (M^n, g) be a complete Riemannian manifold without conjugate points. In this paper, we show that if M is also simply connected, then M is flat, provided that M is also asymptotically harmonic manifold with minimal horospheres (AHM). The (first order) flatness of M is shown by using the strongest criterion: $\{e_i\}$ be an orthonormal basis of T_pM and $\{b_{e_i}\}$ be the corresponding Busemann functions on M. Then, (1) The vector space $V = span\{b_v | v \in T_pM\}$ is finite dimensional and dim $V =$ dim $M = n$. (2) $\{\nabla b_{e_i}(p)\}$ is a global parallel orthonormal basis of T_pM for any $p \in M$. Thus, M is a parallizable manifold. And (3)$F : M \to R^n$ defined by $F(x) = (b_{e_1}(x), b_{e_2}(x), \cdots, b_{e_n}(x))$, is an isometry and therefore, M is flat. Consequently, AH manifolds can have either polynomial or exponential volume growth, generalizing the corresponding result of Nikolayesky for harmonic manifolds. In case of harmonic manifold with minimal horospheres, the (second order) flatness was proved by Ranjan-Shah by showing that $span\{b_v^2 | v \in T_pM\}$ is finite dimensional. We conclude that, the results obtained in this paper are the strongest and wider in comparison to harmonic manifolds, which are known to be AH.

I have revised the following article:
2) *Asymptotically harmonic manifolds of dimension* 4*:* In the theory of harmonic manifolds the central question is the Lichnerowicz conjecture: *Any simply connected harmonic manifold is either flat or a rank one symmetric space*. Lichnerowicz proved this conjecture for harmonic manifolds of dimension 4. It follows from my joint work that *an asymptotically harmonic manifold of dimension* 3 *is flat or a rank one symmetric space*, thus proving the conjecture in dimension 3. We proved that *asymptotically harmonic and Einstein manifolds of dimension* 4 *are either flat or are rank one symmetric spaces*. Thus, we proved the Lichnerowicz type conjecture for asymptotically harmonic manifolds of dimension 4. We also recover the Lichnerowicz conjecture for harmonic manifolds of dimension 4. The strong merit of our proof is that we *constructed* a Singer-Thorpe basis for asymptotically harmonic and Einstein manifold M of dimension 4, in which M is a symmetric space. On the other hand the proof of Besse for harmonic manifolds of dimension 4 used Singer-Thorpe basis to prove its symmetry. We also strengthened a result of Heber that an asymptotically harmonic homogeneous and Einstein manifolds are either flat or rank one symmetric space of non-compact type in dimension 4.

The following article (with E. Taha) is in preparation:
3) *Harmonic and asymptotic harmonic manifolds in the Finslerian settings:* We introduce the various types of harmonic Finsler manifolds and study the relationships between them. We give several characterizations of such spaces and show that some harmonic Finsler manifolds are of Einstein type. Moreover, many examples of non-Riemmanian Finsler harmonic manifolds are provided. Asymptotically harmonic Finsler manifolds are introduced and some anlaytical properties of Busemann functions on such spaces are studied. The results of this paper generalize the corresponding results in Riemannian case of the paper by Ranjan-Shah.

Publications:

1. H. Shah, *Geometry of Asymptotically harmonic manifolds with minimal horospheres*, **50 pages**, under review.

2. H. Shah, *Asymptotically harmonic manifolds of dimension* 4, under review.

Preprints:

1. H. Shah and E. H. Taha, *Harmonic and asymptotically harmonic manifolds in the Finslerian settings*, in preparation.
Preliminary version of this paper is on Arxiv: arxiv:2005.03616v1[math. DG].

Visits to other Institutes:

1. Jan - Feb, 2020, Visiting Fellow and Short Term Research Visiting Professor, **Institute of Advanced Study**, Indiana University, Bloomington, US.

Award and Honours

1. Visiting Fellowship of **Institute for Advanced Study**, Indiana University, Bloomington, US, to visit the University, October 2019.
2. Invitation by **Institute for Advanced Study**, Indiana University, Bloomington, US, to deliver the public lecture, October 2019.
3. Funding award for the Short-Term Research Visiting Professorship to visit Indiana University, Bloomington, US, May 2019.
4. Invited geometry seminar, *The generalization of the Hopf conjecture*, Indiana University, Bloomington, US, Feb 2020.

Invited Lectures/Seminars:

1. *The generalization of the Hopf Conjecture,* invited talk at the Geometry seminar, Indiana University, Bloomington, February 2020.

Other Activities:

Post-doctoral Mentorship

- Ebstam H. Taha, Post-doctoral fellow worked on Harmonic and Asymptotically Harmonic *Finsler* Manifolds, January 2019 - January 2021. The paper *Harmonic and Asymptotically Harmonic Manifolds in the Finslerian Settings*, has evolved out of my post-doctoral mentorship.

Committees

- Member of the Foreign Travel Committee, 2020-present,
- Member of Admission and Graduate Program Committee, 2017- 2019.

Mathscinet, Reviewer number: 035736

I am a regular reviewer of Mathscinet, Reviewer number: 035736. I have reviewed the following articles.

2019

May 08 MR3893269: *The topological entropy of non-dense orbits and generalized Schmidt games*, Ergod. Th. & Dynam. Sys., **39** (2019), 500-530.

Jun 25 MR3908389: *Sub-Finsler geodesics on the Cartan group*, Regul. Chaotic Dyn. **24** (2019), 36–60.

Jun 26 MR3896802: *An estimate for the entropy of nonpositively curved Finsler manifolds*, Acta Math. Acad. Paedagog. Nyhzi. (N.S.) **33** (2019), 367–372.

Aug 23 MR3927521: *Diophantine approximation of the orbits in topological dynamical systems*, Discrete Contin. Dyn. Syst. **39** (2019), 2455–2471.

Nov11 MR3959929: *The optimal lower bound estimation of the number of closed geodesics on Finsler compact space form* S^{2n+1}/Γ, Calc. Var. Partial Differential Equations **58** (2019), Paper No. 107, 21 pp.

Nov13 MR3939582: *Blaschke Finsler manifolds and actions of projective Randers changes on cut loci*, Trans. Amer. Math. Soc. **371** (2019), 7433–7450.

Nov20 MR3975500: *An inhomogeneous Dirichlet theorem via shrinking targets*, Compos. Math. **155** (2019), 1402–1423.

2020

Jan 22 MR3985003: *Multiple closed geodesics on positively curved Finsler manifolds*, Adv. Nonlinear Stud. **19** (2019), 495–518.

Feb 18 MR3994254: *On the existence of convex functions on Finsler manifolds*, Balkan J. Geom. Appl. **24** (2019), 93–103.

1 Apr MR4052610: *Gromov-hyperbolicity and transitivity of geodesic flows in* n*-dimensional Finsler manifolds*, Diff. Geom. Appl. **68** (2020), 1-30.

18 Apr MR4048448: *Round spheres are Hausdorff stable under small perturbation of entropy*, J. Reine Angew. Math. **758** (2020), 261–280.

R.Thangdurai

Research Summary:

During this academic session, mostly worked on Transcendental number theory. One book on Transcendental Number Theory has been completed and published in Springer. One of the main work done during this period is the following problem.

Let $\Gamma \subset \overline{\mathbb{Q}}^{\times}$ be a finitely generated multiplicative group of algebraic numbers. Let $\alpha_1, \ldots, \alpha_r \in \overline{\mathbb{Q}}^{\times}$ be algebraic numbers which are $\mathbb{Q}$-linearly independent with 1 and let $\epsilon > 0$ and $c > 0$ be given real numbers. In this work, we prove that there exist only finitely many tuple $(u, q, p_1, \ldots, p_r) \in \Gamma \times \mathbb{Z}^{r+1}$ with $d = [\mathbb{Q}(u) : \mathbb{Q}]$ such that $|\alpha_i qu| > c$, $\alpha_i qu$ is not a c-pseudo-Pisot number for some i and

$$0 < |\alpha_j qu - p_j| < \frac{1}{H^{\epsilon}(u) q^{\frac{d}{r}+\epsilon}}$$

for $1 \leq j \leq r$, where $H(u)$ denotes the absolute Weil height. When $r = 1$, we recover the main theorem of Corvaja and Zannier in 2004. Also, we prove a more general version of the main theorem than that of their result. The proofs relies on the subspace theorem and the idea of the work of Corvaja and Zannier with suitable modifications.

Publications:

1. J. Chattopadhyay, B. Roy, S. Sarkar, and R. Thangadurai, *Distribution of residues modulo p using the Dirichlet's class number formula*, K. Chakraborty et al. (eds.), Class groups of number fields and related topics, Springer Proc. Math. Stat., (2020) 97-108.

2. V. P. Ramesh, R. Thangadurai and R. Thatchaayini, *A note on Gauss's theorem on primitive roots*, Amer. Math. Monthly, **126** (2019), no. 3, 252-254.

3. N. Saradha and R. Thangadurai, *Pillars of Transcendental Number Theory*, Springer Singapore, 2020.

Preprints:

1. R. Thangadurai and Veekesh Kumar, *On simulataneous approximation of algebraic numbers*, arXiv:2001.00386 [math.NT], 2020.

Conference/Workshops Attended:

1. Lectures on Transcendence on Commutative Algebraic groups at NISER, December, 2019.

2. One day Symposium on National Mathematics Day at IIT, Bhilai on 22, December, 2019.

3. One day Meeting on Number Theory, RKMVERI, Belur, January, 2020.

4. Workshop on Additive Combinatorics, International Centre for Theoretical Sciences, Bangalore, India, February 2020.

Visits to other Institutes:

1. University of Hyderabad, India, May, 2019.
2. National Institute of Science Education and Research, India, December, 2019.
3. Indian Institute of Technology Bhilai, India, December, 2019.
4. RKMVERI Belur, India, January, 2020.
5. ICTS Bengaluru, India, February, 2020.

Invited Lectures/Seminars:

1. Gave a week course on Complex analysis at AFS - I, University of Hyderabad, May, 2019.
2. Gave a week course on Complex analysis at AFS - I, HRI, May, 2019.
3. Delivered a lecture on the tight Ramanujan's bound on divisor function at IIT Bhilai, December, 2019
4. Delivered a lecture on a Mahler problem at RKMVERI, Belur, January, 2020.
5. Delivered a lecture on Davenport constant at ICTS, Bengaluru, February, 2020.

Academic recognition/Awards:

- Fellow of National Academy of Sciences India, 2019.

Other Activities:

1. Organised Annual Foundational School AFS - I at HRI during May, 2019.
2. Two Ph. D students completed successfully under my guidance in March, 2020.
3. Work done related to HBNI NAAC proceedings.

Satya Deo

Research Summary:

The title of my work is: Topological Methods in Combinatorial Mathematics. The important problem mentioned in my original proposal as TTC (Topological Tverberg Conjecture) was solved by F.Frick during Feb 2015 (Arxiv). His solution, however, has left some important questions which are yet to be resolved. I have simplified the proof given by Frick and have been working on the remaining questions. The work involves the methods used by Ozayadin and developed further by Mabillard and Wagner (Eliminating Tverberg Points- an analogue of Whitney Trick). The symmetric groups and their orthogonal representations play an important role in solving the problem. This problem of Topological Combinatorics has attracted the attention of several active mathematicians like I.Barany, J.Matousek, G.M.Ziegler and a number of others. The counterexample of minimum dimension obtained by Frick is an almost 6-embedding of $\Delta^{95} \rightarrow R^{18}$. Recently the minimum number in the counterexample has been brought down to an almost 6-embedding $\Delta^{65} \rightarrow R^{1}2$ or in higher dimensions. It is not known whether we have a counterexample in still a lower dimension , especially in the case $\Delta^{15} \rightarrow R^{2}$. The last question, which is highly geometric as well as very basic, is wide open and we are working to get a solution of this question. In the meanwhile we have worked on the important concept of strong independence of a set in a linear space and the dimension of the Tverberg set. We have analyzed the strong independence and then computed the dimension of the Tverberg set. In fact, we have given an alternative proof of a theorem of Rees which gives the dimension of the Tverberg set under the assumption of strong independence. This is the second paper mentioned in our publications.

The second question that we have studied and have obtained interesting results is about the existence of continuous maps from a round sphere to a triangulation of the sphere having the disjoint support property. This concept plays an important role in proving the topological Tverbeg theorem. We have obtained a number of results on this topic. In particular, we have proved that there cannot be a homeomorphism from n-sphere to its standard triangulation with (n+2) vertices having the disjoint support property. Then we have studied the special case of 2-sphere and its various triangulations having odd number or even number of vertices. For some, we prove that there are continuous maps having disjoint support property , but there are no homeomorphisms having the disjoint support property. The results are very interesting and the question in higher dimensional spheres and its various triangulations is still open. This work has been accepted for publication in Periodica Mathematica Hungarica.

Publications: Research Papers:

1. Continuous maps with disjoint support property (with Snigdha Choudhury), Periodica Mathematica Hungarica (Accepted for Publication)

2. Strong Independence and the dimension of a Tverberg Set (with Snigdha Choudhury), Exposition Mathematique (Accepted for Publication)

Books and Journals:

1. My book Algebraic Topology, a Primer published under the TRIM (Number 27) series of Hindustan Book Agency, New Delhi in the year 2003 has been revised and expanded to include three other chapters. Its second edition has appeared under the TRIM series of HBA in 2018.

2. The book Topological Combinatorics by me and S.D.Adhikari of HRI is nearing completion. Springer Verlag has approached us to publish this book and we hope to finalize it soon.

3. Proceedings of the International Conference on Mathematical Analysis and Applications in Modeling (ICMAAM -2018) Kolkata, Springer-Verlag (Nov 2019)

4. Chief Editor, Journal of Indian Mathematical Society, 2018 and onwards

5. Editor, Proceedings of the National Academy of Sciences, India (Physical Sciences), 2019 onwards

Conference/Workshops Attended:

1. National Science Day at CSIR Lab at Jamshedpur, Jharkhand, Feb 28, 2020.

2. INSPIR programme of DST at Purvanchal University, Jaunpur, Jan 2020.

3. National Seminar on Mathematics, JP Institute of Information Technology, New Delhi.

4. Annual Conference of NASI at Hyderabad, Dec 2019.

5. Annual Conference of Indian Math Society, IIT, Kharagpur, Nov 2019.

6. Advanced workshop on Sheaf Cohomology and Spectral Sequences, University of Delhi, Delhi, Nov 2019.

Visits to other Institutes:

1. M.S.University, Baroda for a seriers of lectures.

2. SERB Meeting in New Delhi

3. NIPGR, New Delhi for a NASI meeting.

4. IMS meeting of APC at Pune University, Pune.

5. INSA, New Delhi for discussion meeting of the three Science Academies on the Draft on New Education Policy

6. NASI workshop on Safe Water, MAPCOST, Bhopal

7. NASI Chapters Meeting at APS University, Rewa.

8. INSA, New Delhi for the Ba and Bapu (150 years) a well as Meghnath Saha (125 years) Year Long Concluding programme

9. University of Calcutta, Science College, Kolkata for a talk.
10. LNM Institute of Information Technology, Jaipur for a series of lectures.
11. NIT, Agartala, Chief guest for their ring ceremony function.
12. IIT, BHU for a meeting.
13. PG DAV College, University of Delhi, Delhi for a conference talk.
14. IIT, Kharagpur for the annual conference of the Indian Math Society, Nov 22-25, 2019. 15. University of Delhi, Delhi for a lecture. 16. University of Jammu, Jammu for a lecture.

Invited Lectures/Seminars:

1. Gave an invited talk on Topological Combinatoircsat the Department of mathematics, NIT, Agartala, April 16, 2019.
2. Gave a course of lectures on Algebraic Topology at the Annual Foundational School (AFS) organized at HRI, Allahabad, May 27-31, 2019.
3. Gave a Talk on Co-Hopficity of fundamental groups of 3-manifolds at the Math Department of IIT, BHU, May 21, 2019.
4. Gave an invited talk on Spline Modules during the National Seminar on Recent Developments in Mathematics organized at PG DAV college, University of Delhi, Delhi during Nov 8-9, 2019.
5. Gave a course of six lectures on Sheaf Cohomology during the Advanced Instructional School (AIS) Workshop of NCM organized by the department of Mathematics, University of Delhi, Delhi during Nov. 26-30, 2019.
6. Gave an invited MHRD Benchmark Lecture on Indian Contributions to Mathematics and Astronomy organized by the University of Jammu, Jammu, on Dec 10, 2019.
7. Gave a lecture on History of Ancient Indian Mathematics during the National Mathematics Day organized at the NASI, Allahabad during Dec 30-31, 2019.
8. Gave a keynote address on Spline modules in approximation theory during the national seminar held at the J.P.Institute of Engineering and Technology, NOIDA on Jan 9, 2020.
9. Gave an hour long lecture on History of Ancient Indian Mathematics under the INSPIRE programme of DST to the 10+2 students at Purvanchal University, Jaunpur on Jan 28, 2020.
10. Gave the keynote address on Contributions of ancient Indian Scientists during the Science Day celebrations at CSIR-National Metallurgical Laboratory, Jamshedpur non Feb 28, 2020.

Other Activities:

1. Elected General Secretary, Indian Math Society.
2. General Secretary, National Academy of Sciences, India.

Pradeep Kumar Rai

Research Summary:

The Schur multiplier of a finite group G is defined as the second cohomology group of G with coefficients in $\mathbb{C}^*$. It plays an important role in the theory of extensions of groups and has been proved to be a powerful tool in group theory. Finding the bounds on the order, expenents and ranks of the Schur multiplier of prime power groups has been one of the main line of investigation in the past. Another main problem, where not much progress has been made, is the following:
Is it true that every finite abelian p-group is isomorphic to the Schur multiplier of some nonabelian finite p-group? [Ya. G. Berkovich, Kourovka Notebook]
Or more generally, Which abelian groups occur as Schur multipliers of nonabelian finite groups? [Moravec]

In a recent work we have proved that all elementary abelian p-groups (abelian p-groups of expenent p) for odd primes p occur as the Schur multiplier of some nonabelian finite p-group.

Preprints:

1. Pradeep Kumar Rai, *On the occurrence of elementary abelian p-groups as the Schur multiplier of nonabelian p-groups*, (In preparation).

Conference/Workshops Attended:

1. Group Algebras, Representation and Computation, ICTS Bangalore, INDIA, October 2019.

Invited Lectures/Seminars:

1. Bogomolov multiplier of finite groups, INSPIRE Faculty Review Meet, Andhra University, Visakhapatnam, October 2019.

Other Activities:

1. Refereed research papers for journals such as Journal of Algebra, Afrika matematika and others.

Pramath A. V

Research Summary:

After joining the institute on 31st December 2019, finished the project titled "Large Hecke eigenvalues and an Omega result for non Saito–Kurokawa lifts". This is a joint work with Prof. Soumya Das and Dr. Ritwik Pal. In this work, we study the distribution of eigenvalues of a Siegel Hecke eigenform that is a non Saito–Kurokawa lifts and prove that there is a positive proportion of Hecke eigenvalues that are *large*(> 1). As a consequence we obtain an Omega result for the Hecke eigenvalues of non Saito–Kurokawa lifts.

Preprints:

1. Large Hecke eigenvalues and an Omega result for non Saito–Kurokawa lifts. *Submitted* (with S. Das and R. Pal).

Other Activities:

1. Reading Project: Automorphic Forms and Representations with K. Krishnarjun.

Kalyan Banerjee

Research Summary:

During the last academic year 2019-2020 my research was focussed on the arithmetic problems related to Selmer groups and Tate Shafarevich groups associated to algebraic cycles on a variety defined over a number field. We have been able to prove some finiteness result for some quotient of the group of algebraic cycles by using these new constructions of Selmer and Tate Shafarevich groups. One important application is the weak Mordell-Weil theorem for the Chow group of zero cycles of any smooth projective variety defined over a number field. A project is ongoing to prove weak Mordell-Weil for Chow groups with modulus. Also these constructions of Selmer groups and Tate Shafarevich groups has been shown to be related to the problem of divisibility problem of class groups of number fields.

On the other hand I have been able to find some new birational invariants which would detect nonrationality for a four dimensional smooth projective variety over an algebraically closed field. This has been done along the line of the Clemens-Griffiths theory of obstruction for non-rationality of cubic threefolds.

Publications:

1. Divisibility of Selmer groups and class groups, joint with Kalyan Chakraborty and Azizul Hoque, Hardy Ramanujan Journal, Volume 42 in the honor of Alan Baker, 85-99, 2020.

Preprints:

1. Weak Mordell-Weil theorem for Chow groups with modulus, joint with K.Krishnarjun, in preparation.
2. On a question of Colliot-Thelene on Chow group, joint with Kalyan Chakraborty, arxiv:1906.08233.
3. On Selmer groups associated to Chow groups of certain codimension two cycles, joint with Kalyan Chakraborty, arxiv:1908.06424.
4. Chow groups, pull back and class groups, joint wit Azizul Hoque, arxiv:1903.04210.
5. A remark on algebraic cycles on cubic fourfolds, arxiv:1908.04576.
6. Representability of Chow groups of codimension three cycles, arxiv:1906.08232.
7. Involutions on algebraic surfaces and generalised Bloch conjecture, arxiv: 1906.09616.

Conference/Workshops Attended:

1. NCMW Workshop on Bloch Kato conjecture, IISER Pune, 24th December 2019 to 4th January 2020.
2. Moduli of bundles and related structures, ICTS, 10th-14th February, 2020.

3. Bundles, cycles and motives, HRI Allahabad, 5th March-10th March, 2020.

Visits to other Institutes:

1. Academic visit to IISER Bhopal, 13th-16th January 2020.

Invited Lectures/Seminars:

1. Lecture series on Chow groups and rationality questions at IISER Bhopal, 14-16th January, 2020.

Other Activities:

1. Seminar series on arithmetic algebraic geometry at HRI.

Jagannath Bhanja

Research Summary:

Additive Combinatorics is a very popular area of research, which studies the additive properties of subsets of the integers, or more generally, abelian groups. Two of the classical problems in Additive Combinatorics are to find the minimum possible size of the sumsets, for example $A + B := \{a + b : \ a \in A, b \in B\}$, in terms of sizes of the underlying sets A, B, and to characterize the underlying algebraic structure of the sets A, B for which the sumset attains it's minimum value.

In the work, **On the minimum size of subset and subsequence sums**, we have studied the above defined problems for the set of subset sums

$$\Sigma_\alpha(A) := \left\{ \sum_{a\in B} a : B \subset A, \ |B| \geq \alpha \right\},$$

where A is a finite set of k integers and $0 \leq \alpha \leq k$ an integer. To be precise, we proved that

$$|\Sigma_\alpha(A)| \geq \left\lfloor \frac{(k+1)^2}{4} \right\rfloor - \frac{\alpha(\alpha+1)}{2} + 1, \quad \text{if } 0 \notin A,$$

and

$$|\Sigma_\alpha(A)| \geq \left\lfloor \frac{(k)^2}{4} \right\rfloor - \frac{\alpha(\alpha-1)}{2} - 1, \quad \text{if } 0 \in A.$$

We also proved similar bounds when A is a finite sequence of integers.

In another work, namely, **Sumsets of multisets of integers**, we studied the multiset analogue of the regular sumset and restricted sumset. We proved the best possible lower bound for the regular sumset in the group of integers. For instance, we proved that

$$d(\mathcal{A}+\mathcal{B}) \geq d(\mathcal{A}) + d(\mathcal{B}) + (|A|-1)n(\min(B)) + (|B|-1)m(\max(A)) - (|A|+|B|-1),$$

where $\mathcal{A} = (A, m)$ and $\mathcal{B} = (B, n)$ are nonempty finite multisets of integers, m, n are multiplicity functions, $d(\mathcal{A}) = \sum_{a\in A} m(a)$ and $d(\mathcal{B}) = \sum_{b\in B} n(b)$. We also proved similar bound for the restricted sumset $\mathcal{A}\hat{+}\mathcal{B}$. Furthermore, we found a counter example that says similar bound does not hold for the restricted sumset of more than two sets, unlike to the case of regular sumset.

Preprints:

1. J. Bhanja and R.K. Pandey, *On the minimum size of subset and subsequence sums*, Communicated.

2. J. Bhanja and R.K. Mistri, *Sums of multisets of integers*, Communicated.

Conference/Workshops Attended:

1. *Workshop on Additive Combinatorics*, International Center for Theoretical Sciences, Bangalore, 22 Feb.-6 Mar., 2020.

Invited Lectures/Seminars:

1. *Direct and inverse problems for sums of dilates*, PDF joining talk, HRI Prayagraj, January 28, 2020.

Arindam Dey

Research Summary:

INTRODUCTION: My area of research is commutative algebra. The work I do is mainly focused on studying module of derivations of certain rings.

Module of derivations and module of differentials play an important role in commutative algebra and algebraic geometry. They are analogous to the tangent bundles and cotangent bundles of manifolds. Zariski-Lipman conjecture asserts that, the freeness of module of derivations implies non-singularity of a variety. Thus the study of the module of derivation is closely related to the study of singularity.I studied computational methods to find an expl icit generating set of modules of derivations of certain rings.

I am currently working on classifications of simple derivations over a polynomial algebra.

The work described below is a joint work with Dr. Surjeet Kour of IIT Delhi.

PROBLEM 1: MODULE OF DERIVATIONS OF CERTAIN RINGS OF INVARIANTS

Let k denotes an algebraic closed field of characteristic zero. The module of derivations of the ring of invariants of the polynomial ring $\mathbf{k}[X, Y]$ under the linear action of a finite cyclic subgroup of $GL(2, \mathbf{k})$ has been studied by Gurjar and Wagh [1]. They proved that the module of derivations is minimally generated by 4 elements.

A generalized result for $\mathbf{k}[X_1, \ldots, X_m]^{C_n}$ (where m, n are positive integers and $C_n < GL(m, \mathbf{k})$ is a cyclic group of order n which does not contain a non trivial pseudo-reflection) has been studied by myself and Dr.Vinay Wagh[2].

Due to a theorem of Shephard and Todd [3] it can be shown that: in order to find ring of invariants of polynomial ring under the action of a finite subgroup of the general linear group, it suffices to consider only non-pseudo-reflection groups.

Finite subgroups of $GL(2, \mathbf{k})$ which do not contain a non trivial pseudo reflection have been classified upto conjugacy by O. Riemenschneider [4].

These are certain cyclic, dihedral, tetrahedral, octahedral nad icosahedral groups.

The next in the list of Oswald Riemenschneider's classification [4] is the group denoted by $D_{n,q}$:

Let n and q be positive integers such that $1 < q < n$ and $\gcd(n, q) = 1$. The group $D_{n,q}$ is generated by:

$$\{\psi_{2q},\ \tau, \phi_{2m}\} \text{ if } m = n - q \equiv 1 \pmod 2$$
$$\{\psi_{2q},\ \tau \circ \phi_{4m}\} \text{ if } m = n - q \equiv 0 \pmod 2$$

The order of $D_{n,q}$ is $4mq$.

We found a finite generating set of the module of $\mathbf{k}$-derivations of ring of invariants of $R = \mathbf{k}[X, Y]^{D_{n,q}}$. The generating set is as follows:

$$\mathcal{G} = \left\{ \quad \delta_{a,b},\ \delta_{a+2mq,b} \ : 0 \leq a, b \leq 2mq,\ a + b \equiv 1 \pmod{2m},\ a - b \equiv 1 \pmod{2q} \quad \right\}$$

where,

$$\delta_{a,b} = X^a Y^b \partial_X + X^b Y^a \partial_Y \ \in \text{Der}_{\mathbf{k}} R$$

Thus we also prove $\mu(\text{Der}_{\mathbf{k}} R) \leq 4mq = |D_{n,q}|$ (which is much smaller than the earlier known bound $\mu \text{Der}_{\mathbf{k}} R \leq 2|G| + 1$ for a ring of invariants R of $\mathbf{k}[X, Y]$ under the linear action of a finite group $G < GL2, \mathbf{k}$ [cite]).

This result has been communicated for possible publication.

PROBLEM 2: ISOTROPY GROUP OF A DERIVATION

Let $\mathbf{k}$ be an algebraically closed field of characteristic zero. A $\mathbf{k}$-derivation d of a commutative $\mathbf{k}$-algebra R is said to be simple if d does not stabilize a proper ideal of R. Simple derivations of a commutative $\mathbf{k}$-algebra has a connection with the theory of non-commutative simple rings. In fact if $R[X;d]$ is the ore extension of R by d, then $R[X;d]$ is a simple ring (in the sense that it has no non-trivial two-sided ideal) if and only if d is a simple derivation of R.

Baltazar-Pan Conjecture[5] asserts that:

Let d be a simple derivation of a finitely generated $\mathbf{k}$-algebra R. Then its isotropy group is finite.

Baltazar proved it for Shamsuddin derivations in two variables[5]. Mendes and Pan proved it for dimension 2[6]. A generalization is proved by Bertoncello and Levocovitz. They proved that the isotropy group of a simple Shamsuddin derivation of a polynomial ring $\mathbf{k}[X_1, \ldots, X_n]$ is trivial.

Using the result of Mendes and Pan[6] we showed that there are no simple linear derivation in $\mathbf{k}[X, Y]$.

Also, we are trying to figure out a generalization of Baltazar-Pan conjecture for non Shamsuddin type derivations.

REFERENCES

1 R. V. Gurjar and Vinay Wagh. *On the number of generators of the module of derivations and multiplicity of certain rings*. J. Algebra, 319(5):20302049, 2008.

2 Arindam Dey and Vinay Wagh. *On the module of derivations of certain rings of invariants*. J. Ramanujan Math. Soc., 33(2):149158, 2018.

3 G. C. Shephard and J. A. Todd. *Finite unitary reflection groups*. Canadian J. Math., 6:274304, 1954.

4 O. Riemenschneider. *Die Invarianten der endlichen Untergruppen von GL(2, C)*, Mathematische Zeitschrift., 153, 37-50. 1977.

5 R.Baltazar. *Sobre Solues de Derivaes em k-algebras Noetherianas e Simplicidade*, Doctoral Thesis, Universidade Federal do Rio Grande do Sul, Instituto de Matemtica, Programa de Ps- Graduao em Matemtica, Porto Alegre (2014), 55 pgs.

6 L. G. Mendes and I. Pan. *On plane polynomial automorphims commuting with simple derivations.*, 221, 875-882, 2017.

Preprints:

1. Arindam Dey(HRI), Surjeet Kour(IIT Delhi). *On the Module of Derivations of Rings of Invariants of [X, Y] Under the Action of Certain Dihedral Groups*. (Communicated for possible publication).

Chudamani Pranesachar Anil Kumar

Research Summary:

Number Theory and Geometry: On the Surjectivity of Certain Maps For a generalized projective space $\mathbb{PF}_{\mathcal{I}}^{k,(m_0,m_1,\ldots,m_k)}$ associated to an ideal $\mathcal{I}$ in a commutative ring $\mathcal{R}$ with unity where $k, m_i \in \mathbb{N}, 0 \leq i \leq k$, it has been proved in a series of three papers that the following two maps are surjective.

Firstly it has been proved that the chinese remainder reduction map associated to the generalized projective space of an ideal $\mathcal{I} = \prod_{i=1}^{k} \mathcal{I}_i$ with a given factorization into mutually co-maximal ideals $\mathcal{I}_i, 1 \leq i \leq k$, each of which is contained in finitely many maximal ideals, is bijective.

Secondly for $k \in \mathbb{N}$ it has been proved that the map from $(k+1)$-dimensional special linear group $SL_{k+1}(\mathcal{R})$ to the product of generalized projective spaces $\mathbb{PF}_{\mathcal{I}_i}^{k,(m_0^i,m_1^i,\ldots,m_k^i)}$, $0 \leq i \leq k$ of $(k+1)$-mutually co-maximal ideals $\mathcal{I}_i, 0 \leq i \leq k$ associating the $(k+1)$-rows or $(k+1)$-columns under certain conditions either on the ring or on the weights $m_j^i, 0 \leq i, j \leq k$ of generalized projective spaces. The conditions are as follows.

- Either there is a condition on the ring $\mathcal{R}$ that every non-jacobson element in the ring $\mathcal{R}$ is contained in finitely many maximal ideals and also if there is exactly one proper ideal in the ideals $\mathcal{I}_i, 0 \leq i \leq k$ then it is contained in only a finitely many maximal ideals,

- or there is no condition on the ring $\mathcal{R}$ but every ideal $\mathcal{I}_i, 0 \leq i \leq k$ is contained in only a finitely many maximal ideals and there is condition on the weights m_j^i, that is, $m_{\sigma(i)}^i = 1, 0 \leq i \leq k$ for some permutation σ of $0, 1, \ldots, k$.

A similar result has been proved for symplectic groups $SP_{2k}(\mathcal{R}), k \in \mathbb{N}$ as well. Currently I am working on more general conditions on the weights m_j^i and conditions on the ring where the surjectivity holds.

Combinatorics of Abelian Groups: Part 1

For a Dedekind domain $\mathcal{O}$ and a rank two co-torsion module $M \subseteq \mathcal{O}^2$ with invariant factor ideals $\mathcal{L} \supseteq \mathcal{K}$ in $\mathcal{O}$, that is, $\frac{\mathcal{O}^2}{M} \cong \frac{\mathcal{O}}{\mathcal{L}} \oplus \frac{\mathcal{O}}{\mathcal{K}}$, we associate a new projective space invariant element in $\mathbb{PF}_{\mathcal{I}}^1$ where $\mathcal{I}$ is given by the ideal factorization $\mathcal{K} = \mathcal{L}\mathcal{I}$ in $\mathcal{O}$. This invariant element along with the invariant factor ideals determine the module M completely as a subset of $\mathcal{O}^2$. As a consequence, projective spaces associated to ideals in $\mathcal{O}$ can be used to enumerate such modules. We compute the zeta function associated to such modules in terms of the zeta function of the one dimensional projective spaces for the ring $\mathcal{O}_K$ of integers in a number field $K/\mathbb{Q}$ and relate them to Dedekind zeta function. Using the projective spaces as parameter spaces, we re-interpret the Chinese remainder reduction isomorphism $\mathbb{PF}_{\mathcal{I}}^1 \to \prod_{i=1}^{l} \mathbb{PF}_{\mathcal{I}_i}^1$ associated to a factorization of an ideal $\mathcal{I} = \prod_{i=1}^{l} \mathcal{I}_i$ into mutually co-maximal ideals $\mathcal{I}_i, 1 \leq i \leq l$ in terms of the intersection of associated modules arising from the projective space elements.

Combinatorics of Abelian Groups: Part 2

For a non-negative integer k and a positive integer n with $k \leq n$, we prove a combinatorial identity for the p-binomial coefficient $\binom{n}{k}_p$ based on abelian groups. A purely combinatorial proof of this identity is not known. While proving this identity, for $r, s \in \mathbb{N}$ and p a prime, we present a purely combinatorial formula for the number of subgroups of $\mathbb{Z}^s$ of finite index p^r with quotient isomorphic to the finite abelian p-group of type $\underline{\lambda}$ a partition of r into at most s parts. This purely combinatorial formula is similar to the combinatorial formula for subgroups of a certain type in a finite abelian p-group obtained by Lynne Marie Butler. As consequences, this combinatorial formula gives rise many enumeration formulae which are polynomial in p with non-negative integer coefficients.

Combinatorics of Abelian Groups: Part 3

For a partition $\underline{\lambda}$ and its associated finite $\mathcal{R}$-module $\mathcal{A}_{\underline{\lambda}}$, where $\mathcal{R}$ is a discrete valuation ring, with maximal ideal generated by a uniformizing element π, having finite residue field $\mathbf{k} = \frac{\mathcal{R}}{\pi\mathcal{R}} \cong \mathbb{F}_q$, the number of orbits of pairs $n_{\underline{\lambda}}(q) = \mid \mathcal{G}_{\underline{\lambda}} \backslash \left(\mathcal{A}_{\underline{\lambda}} \times \mathcal{A}_{\underline{\lambda}}\right) \mid$ for the diagonal action of the automorphism group $\mathcal{G}_{\underline{\lambda}} = Aut(\mathcal{A}_{\underline{\lambda}})$, is a polynomial in q with integer coefficients. It has been conjectured that these coefficients are in fact non-negative. We prove this positivity conjecture under a certain condition. In this method we show that for a height zero principal ideal I in the lattice of ideals $\mathcal{J}(P)_{\underline{\lambda}}$, where $P_{\underline{\lambda}}$ is the fundamental poset associated to the orbit space $\mathcal{G}_{\underline{\lambda}} \backslash \mathcal{A}_{\underline{\lambda}}$, the numbers $n_{\underline{\lambda},I}(q) = \mid (\mathcal{G}_{\underline{\lambda}})_I \backslash \mathcal{A}_{\underline{\lambda}} \mid$ and $n^1_{\underline{\lambda},I}(q) = \mid (\mathcal{G}_{\underline{\lambda}})_I \backslash \pi\mathcal{A}_{\underline{\lambda}} \mid$ are polynomials in q with non-negative integer coefficients of degrees λ_i and $\lambda_i - 1$ respectively, where $(\mathcal{G}_{\underline{\lambda}})_I \subseteq \mathcal{G}_{\underline{\lambda}}$ is the stabilizer subgroup of the canonical element $e_I \in (\mathcal{O}_{\underline{\lambda}})_I \subset \mathcal{A}_{\underline{\lambda}}$ in the orbit corresponding to the ideal I generated by a single element $(0, \lambda_i) \in P_{\underline{\lambda}}$. Moreover we have obtained a combinatorial interpretation of the coefficients of these two polynomials $n_{\underline{\lambda},I}(q)$ and $n^1_{\underline{\lambda},I}(q)$.

Combinatorics of Extra Special p-Groups: Joint Work With Soham Swadhin Pradhan

For an odd prime p and a positive integer n, it is well known that there are two types of extra-special p-groups of order p^{2n+1}, first one is the Heisenberg group which has exponent p and the second one is of exponent p^2. This article mainly describes the endomorphism semigroups of both the types of extra-special p-groups and computes their cardinalities as polynomials in p for each n. Firstly a new way of representing the extra-special p-group of exponent p^2 is given. Using the representations, explicit formulae for any endomorphism and any automorphism of an extra-special p-group G for both the types are found. Based on these formulae, the endomorphism semigroup $End(G)$ and the automorphism group $Aut(G)$ are described. The endomorphism semigroup image of any element in G is found and the orbits under the action of the automorphism group $Aut(G)$ are determined. As a consequence it is deduced that, under the notion of degeneration of elements in G, the endomorphism semigroup $End(G)$ induces a partial order on the automorphism orbits when G is the Heisenberg group and does not induce when G is the extra-special p-group of exponent p^2. Finally we prove that the cardinality of isotropic subspaces of any fixed dimension in a non-degenerate symplectic space is a polynomial in p with non-negative integer coefficients. Using this fact we compute the cardinality of $End(G)$.

Arrangement Problems and Combinatorics of Sylvester-Gallai Designs: Joint Work With Anoop Singh

We give an exact criterion of a conjecture of L. M. Kelly to hold true which is stated

as follows. If there is a finite family Σ of mutually skew lines in $\mathbb{R}^l, l \geq 4$ such that the three dimensional affine span (hull) of every two lines in Σ, contains at least one more line of Σ, then we have that Σ is entirely contained in a three dimensional space if and only if the arrangement of affine hulls is central. We also answer an analogous question for higher dimensional skew affine spaces, where we prove that, for $(2, 5)$ representations of Sylvester-Gallai designs in $\mathbb{R}^6$, the analogous statement does not hold.

Publications:

1. C. P. Anil Kumar, *A Representation Theorem For Generic Line Arrangements in the Plane*, **The Journal of the Indian Mathematical Society, Vol. 87, Issue 1-2, 2020, pp. 96-113, DOI: 10.18311/jims/2020/24873**, http://www.informaticsjournals.com/index.php/jims/article/view/24873

2. C. P. Anil Kumar, *On the Factorization of Two Adjacent Numbers in Multiplicatively Closed Sets Generated by Two Elements*, **Proceedings Mathematical Sciences: Indian Academy of Sciences, Accepted on Jan 20, 2020, DOI: 10.1007/s12044-020-00566-8**, https://doi.org/10.1007/s12044-020-00566-8

3. C. P. Anil Kumar, *On the Surjectivity of Certain Maps II: For Generalized Projective Spaces*, **Journal of the Ramanujan Mathematical Society, Accepted on Apr. 18, 2020**

Preprints:

1. C. P. Anil Kumar, *On the Triangles in Certain Types of Line Arrangements*, **arXiv: 1906.05120**, Submitted to a Journal

2. C. P. Anil Kumar, Soham Swadhin Pradhan, *On the Endomorphism Semigroups of Extra-Special p-Groups and Automorphism Orbits*, **arXiv: 1908.00331**, Submitted to a Journal

3. C. P. Anil Kumar, *On a Projective Space Invariant of a Co-torsion Module of Rank Two over a Dedekind Domain*, **arXiv: 1912.00797**, Submitted to a Journal

4. C. P. Anil Kumar, *A Combinatorial Identity for the p-Binomial Coefficient Based on Abelian Groups*, **arXiv: 1912.10725**, Submitted to a Journal

5. C. P. Anil Kumar, *Positivity Conjecture for a Certain Class of Finite Abelian p-Groups*, **arXiv: 2001.02523**, Submitted to a Journal

6. C. P. Anil Kumar, Anoop Singh, *On a Conjecture of Kelly on (1,3)-representation of Sylvester-Gallai Designs*, **arXiv: 2003.07645**, Submitted to a Journal

Conference/Workshops Attended:

1. Workshop/Conference at ICTS, Bengaluru on **"Perfectoid Spaces"** during September 09-20, 2019.

2. Workshop/Conference at ICTS, Bengaluru on **"Groups Algebras, Representations and Computation"** during October 14-23, 2019.

3. Mini-Workshop on **"Bundles, Cycles, and Motives"** at HRI Allahabad from March 5-10, 2020.

Invited Lectures/Seminars:

1. On the Surjectivity of Certain Maps: Generalizations of Chinese Remainder Theorem, **Post Doctoral Fellow Seminars**, Harish-Chandra Research Institute, Prayagraj, INDIA, November 2019.

Other Activities:

1. I have sent a solution to Prof. Kiran Kedlaya to the Linear Algebra Problem B3 of the 80th William Lowell Putnam Mathematical Competition, held on Saturday, December 7, 2019. This was acknowledged by Prof. Kiran Kedlaya. B3 is the fourth toughest problem completely solved by 41 out of 414 contestants (roughly 10%). The tougher problems are A6, B4, A4 in this order and then this problem B3.

2. I have prepared two problem sets consisting of four and two problems in number theory and combinatorics respectively for aspiring school students visiting Harish-Chandra Research Institute, Allahabad at the Olympiad Level. This was acknowledged by Prof. Punita Batra and Prof. D. Surya Ramana.

3. I am a reviewer for **Zentralblatt MATH**. I have written **Zentralblatt MATH Reviews** for the following articles.

   (a) Zbl 1402.14059: Free and nearly free surfaces in P3.

   (b) Zbl 1407.52032: The orbifold Langer-Miyaoka-Yau inequality and Hirzebruch-type inequalities.

   (c) Zbl 1415.20013: Formal duality in finite abelian groups.

   (d) Zbl 06841720: Strongly inert subgroups of abelian groups.

   (e) Zbl 06946323: A note on the square subgroups of decomposable torsion-free abelian groups of rank three.

   (f) Zbl 1414.05304: On the double-affine Bruhat order: the $\epsilon = 1$ conjecture and classification of covers in ADE type.

   (g) Zbl 1421.52028: Derivation degree sequences of non-free arrangements.

   (h) Zbl 1421.52018: Some notes on tetrahedrally closed spherical sets in Euclidean spaces.

   (i) Zbl 07076206: Hilbert series of binomial edge ideals.

   (j) Zbl 07073805: Gorenstein properties and integer decomposition properties of lecture hall polytopes.

   (k) Zbl 07142707: On supersolvable and nearly supersolvable line arrangements.

(l) Zbl 07145396: On an explicit correspondence between nbc-basis, chambers and minimal complex for real supersolvable arrangements.

Ebtsam Hassan Taha Mohamed

Research Summary:

My research has focused on studying some problems in differential geometry. In the first paper, "Alternative Lagrangians obtained by scalar deformations", we studied mechanical systems that can be recast into the form of a system of genuine Euler-Lagrange equations. The equations of motions of such systems are initially equivalent to the system of Lagrange equations of some Lagrangian L, including a covariant force field. We found necessary and sufficient conditions for the existence of a differentiable function $\Phi : \mathbb{R} \to \mathbb{R}$ such that the initial system is equivalent to the system of Euler-Lagrange equations of the deformed Lagrangian $\Phi(L)$. These conditions were further exploited for some specific classes of mechanical systems, namely homogeneous and dissipative ones. We provided many examples that showed that the algorithms described are easy to handle.

In the second paper, "On harmonic and asymptotic harmonic Finsler manifolds", we introduced various types of harmonic Finsler manifolds and studied the relation between them. We gave several characterizations of such spaces in terms of the mean curvature and Laplacian. In addition, we proved that some harmonic Finsler manifolds are of Einstein type and a technique to construct harmonic Finsler manifolds of Rander type was given. Moreover, we provided many examples of non-Riemmanian Finsler harmonic manifolds of constant flag curvature. Finally, we analyzed Busemann functions in a general Finsler setting and in certain kind of Finsler harmonic manifolds, namely asymptotically harmonic Finsler manifolds along with studying some applications. In particular, we showed the Busemann function is smooth in asymptotically harmonic Finsler manifolds and the total Busemann function is continuous in C^∞ topology.

Publications:

1. O. Constantinescu and Ebtsam H. Taha, *Alternative Lagrangians obtained by scalar deformations,* Int. J. Geom. Meth. Mod. Phys., 17 (4) (2020) 2050050. DOI: 10.1142/S0219887820500504.

Preprints:

1. Hemangi M. Shah and Ebtsam H. Taha, *On harmonic and asymptotic harmonic Finsler manifolds*, arXiv:2005.03616v1 [math.DG].

Conference/Workshops Attended:

1. National Conference "Nonlinear Dynamics and its Applications" (NLDA - 2020), Department of Mathematics, Faculty of Science, Jadavpur University, Kolkata, India, March 13, 2020.

2. National Conference "Recent Trends in Geometry and their Applications" (NCRTGA - 2020), Department of Mathematics, Institute of Science, Banaras Hindu University, Varanasi, India, February 8–9, 2020.

3. *CIMPA School on Finsler Geometry and Applications*, Banaras Hindu University, Varanasi, India, December 5–15, 2019.

Visits to other Institutes:

1. The Institute of Mathematical Sciences (IMSc), Department of Mathematics, Chennai, India, November, 2019.

Invited Lectures/Seminars:

1. *The inverse problem of Lagrangian mechanics and Frobenius integrability*, Jyvskyl Geometry Seminar, Department of Mathematics and Statistics, University of Jyvskyl, Finland, April 20, 2020. (online seminar)

2. *Deformations of Lagrangians*, Department of Mathematics, Faculty of Science, Jadavpur University, Kolkata, India, March 13, 2020.

3. *Semi-concurrent vector fields in Finsler geometry*, Department of Mathematics, Institute of Science, Banaras Hindu University, Varanasi, India, February 8, 2020.

4. *Some topics on Finsler geometry*, CIMPA School on Finsler Geometry and Applications, DST-center, Banaras Hindu University, Varanasi, India, December 15, 2019.

5. *Frobenius integrability and metrizability problem*, IMSC, Chennai, India, November 23, 2019.

Soham Swadhin Pradhan

Research Summary:

My research work has focused mainly on matrix representations of finite solvable groups over arbitrary fields.

Schur Index and Extensions of Witt-Berman's Theorems: Let G be a finite group, and F a field of characteristic 0 or prime to the order of G. In 1956, Berman proved that the number of inequivalent irreducible F-representations of G is equal to the number of F-conjugacy classes of the elements of G, where F-conjugacy was defined in a certain way. In this work, we define F-conjugacy on G in a more natural way and give a proof of the Berman's theorem. In addition, we give a formula for computing a primitive central idempotent (pci) of the group algebra $F[G]$ corresponding to an irreducible F-representation of G, which can be obtained from the F-character table of G.

Let G contain a normal subgroup H of index p, a prime. In 1955, in case F is algebraically closed, Berman computed the pci of $F[G]$ corresponding to an irreducible F-representation of G, in terms of pci's of $F[H]$. In this work, we give a complete proof of this theorem of Berman, and extend this result when F is not necessarily algebraically closed. Also, we work out decomposition of induced representation of an irreducible F-representation of H, into irreducible components. This is a joint work with Ravi. S. Kulkarni.

Faithful Irreducible Representations of Metabelian Groups: In 1993, H. S. Sim proved that, all the faithful irreducible representations of a finite metacyclic group, over any field of positive characteristic, have the same degree. In this work, we restrict our attention to the non-modular representations, and generalize this result for (1) finite metabelian groups, over fields of positive characteristic coprime to the order of groups, and (2) finite groups, having a cyclic quotient by an abelian normal subgroup, over number fields. This is a joint work with Rahul Dattatraya Kitture.

Endomorphism Semigroups of Extra-special p-groups and Automorphism Orbits: For an odd prime p and a positive integer n, it is well known that there are two types of extra-special p-groups of order p^{2n+1}, first one is the Heisenberg group which has exponent p and the second one is of exponent p^2. In this work, a new way of representing the extra-special p-group of exponent p^2 is given. These representations facilitate an explicit way of finding formulae for any endomorphism and any automorphism of an extra-special p-group G for both the types. Based on these formulae, the endomorphism semigroup $End(G)$ and the automorphism group $Aut(G)$ are described. The endomorphism semigroup image of any element in G is found and the orbits under the action of the automorphism group $Aut(G)$ are determined. As a consequence it is deduced that, under the notion of degeneration of elements in G, the endomorphism semigroup $End(G)$ induces a partial order on the automorphism orbits when G is the Heisenberg group and does not induce when G is the extra-special p-group of exponent p^2. Finally we prove that the cardinality of isotropic subspaces of any fixed dimension in a non-degenerate symplectic space is a polynomial in p with non-negative integer coefficients. Using this fact we compute the cardinality of $End(G)$. This is a joint work with C P Anil Kumar.

Roquette's Theorem and Some Remarkable Wedderburn Decompositions: Let p

be a prime number, G a p-group, and χ an irreducible complex character of G. Let $m_{\mathbb{Q}}(\chi)$ denote the Schur index of χ over the rational field $\mathbb{Q}$. In 1958, Roquette proved that $m_{\mathbb{Q}}(\chi) = 1$ for $p \neq 2$, and $m_{\mathbb{Q}}(\chi) = 1$ or 2 for $p = 2$. We give an elementary proof of Roquette's theorem.

For an odd prime p, let $G_{r,s} = C_{p^r} * C_{p^s}$, where $*$ denotes semidirect product, with C_{p^s} acting on C_{p^r}. If $r = 1$ then C_{p^s} acts trivially. If $2 \leq r$, then C_{p^s} has a unique non-trivial action. We compute the Wedderburn decomposition of $G_{r,s}$ over the field of rational numbers. This is a joint work with Ravi. S. Kulkarni.

Publications:

1. Rahul Dattatraya Kitture and Soham Swadhin Pradhan, *Degrees of Faithful Irreducible Representations of Metabelian Groups*, **Journal of Algebra and its Applications, accepted for publication**

Preprints:

1. Ravi S. Kulkarni and Soham Swadhin Pradhan, *Schur Index and Extensions of Witt-Berman's Theorems*, **submitted to a Journal**

2. C P Anil Kumar and Soham Swadhin Pradhan, *Endomorphism Semigroup Images of Elements and Orbits in Extra-special p-Groups*, **submitted to a Journal**

3. Ravi S. Kulkarni and Soham Swadhin Pradhan, *An Elementary Proof of Roquette's Theorem and Some Remarkable Wedderburn Decompositions*, **(in preparation)**

Conference/Workshops Attended:

1. *Group Algebras, Representations and Computation*, International Centre for Theoretical Sciences (ICTS), Bangalore, India, October $14 - 23$, 2019

2. *Workshop on Group Theory* 2020, IISER Pune, Pune, India, February $13 - 15$, 2020

Visits to other Institutes:

1. Bhaskaracharya Pratishthana, Pune, India, March-April, 2019

2. Bhaskaracharya Pratishthana, Pune, India, August-September, 2019

3. Bhaskaracharya Pratishthana, Pune, India, January-February, 2020

Other Activities:

1. Refereed a research paper for a journal.

Chiranjit Ray

Research Summary:

A partition of a positive integer n is any non-increasing sequence of positive integers whose sum is n. The positive integers in the partition are called parts. The number of partitions of n is denoted by $p(n)$. For example, the partitions of 5 are $5 = 4+1 = 3+2 = 3+1+1 = 2+2+1 = 2+1+1+1 = 1+1+1+1+1$, so $p(5) = 7$. Conventionally, we set $p(0) = 1$. Partitions reflect fundamental additive properties of the integers, so it is surprising to learn that $p(n)$ has divisibility properties as well. It is also natural to consider the general distribution of the partition function modulo some positive integer. Ono [2] developed the aspects of the p-adic theory of half-integral weight modular forms and used this to prove the existence of infinite families of partition congruences modulo every prime $p \geq 5$. However, there are many questions about the basic properties of partitions which are not yet solved. If M is a positive integer and $0 \leq r < M$, then define $\delta_r(M; X)$ by

$$\delta_r(M; X) := \frac{\#\{0 \leq n < X : p(n) \equiv r \pmod{M}\}}{X}.$$

The well known parity conjecture of Parkin and Shanks [4] predicts that the values of $p(n)$ are evenly distributed modulo 2, and little is known regarding this conjecture.

Conjecture: If $r \in \{0, 1\}$, then $\lim_{X \to +\infty} \delta_r(2; X) = \frac{1}{2}$.

A part of my research is focused on studying infinite families of arithmetic identities, congruences and distributions of several partition functions. I am also interested in studying the connection between class numbers and certain partition functions. We use the techniques of classical q-series, the theory of modular forms and Hecke operators, and algebraic number theory to prove our results. A brief description of our recent work is as follows.

On Andrews' integer partitions with even parts below odd parts: Recently, Andrews [1] defined a partition function $\mathcal{EO}(n)$ which counts the number of partitions of n in which every even part is less than each odd part. He also defined a partition function $\overline{\mathcal{EO}}(n)$ which counts the number of partitions of n enumerated by $\mathcal{EO}(n)$ in which only the largest even part appears an odd number of times. Andrews proposed to undertake a more extensive investigation of the properties of $\overline{\mathcal{EO}}(n)$. In a recent joint work with R. Barman, we proved infinite families of congruences for $\overline{\mathcal{EO}}(n)$. We showed that there are infinitely many integers N in every arithmetic progression for which $\overline{\mathcal{EO}}(2N)$ is even; and that there are infinitely many integers M in every arithmetic progression for which $\overline{\mathcal{EO}}(2M)$ is odd so long as there is at least one. Moreover, we proved that $\overline{\mathcal{EO}}(n)$ is even for almost all n.

Certain eta-quotients and ℓ-regular overpartitions: Let $\overline{A}_\ell(n)$ be the number of overpartitions of n into parts not divisible by ℓ. Suppose j be a fixed positive integer and $p \geq 5$ is prime number. In a recent work together with K. Chakraborty, we have shown that the arithmetic density of the set $\left\{n \in \mathbb{Z}_{\geq 0} : \overline{A}_\ell(n) \equiv 0 \pmod{p^j}\right\}$ is exactly one with certain conditions. In particular, we obtain the following result for ℓ-regular

overpartitions:
Theorem: Let $\ell = p_1^{a_1} p_2^{a_2} \dots p_m^{a_m}$ where p_i's are primes > 3. If $p_i^{2a_i} \geq \ell$, then for every positive integer j,

$$\lim_{X \to \infty} \frac{\#\left\{0 < n \leq X : \overline{A}_\ell(n) \equiv 0 \pmod{p_i^j}\right\}}{X} = 1.$$

A new analogue of t-core partitions: In this recent work, we have studied some relationship between algebraic number theory with certain partition functions. Let CL(D) denote the class group of discriminant D binary quadratic forms, and let $h(D)$ denote its order, the discriminant D class number. It is known that, the number of 4-core partitions $c_4(n)$ of n is equal to the number of representations of $8n+5$ in the form $x^2+2y^2+2z^2$ with x, y, z odd positive integers. Ono and Sze [3] proved that if $8n+5$ is square-free, then $c_4(n) = \frac{1}{2}h(-32n-20)$. Jointly with Gireesh and Shivashankar, we consider an analogy of t-core partitions:

$$\sum_{n=0}^{\infty} \overline{a}_t(n) q^n = \frac{\phi(-q^t)^t}{\phi(-q)} = \frac{(q^2;q^2)_\infty (q^t;q^t)_\infty^{2t}}{(q;q)_\infty^2 (q^{2t};q^{2t})_\infty^t},$$

where the q-shifted factorial $(a;q)_\infty := \prod_{n=1}^{\infty}(1-aq^{n-1}),\ |q|<1$, and prove the following result:

Theorem: If $n \equiv 5 \pmod 8$ is square-free and α is any positive integer, then

$$\overline{a}_4(2^{2\alpha} n) = 12h(-4n).$$

Congruence relations for dimension of Siegel cusp forms of degree 2: This is a joint project with M. Roy and S. Yi. We would like to understand the connection between certain partition functions and Siegel cusp forms. We have obtained some congruences between dimensions of the spaces of Siegel cusp forms of degree 2 and the class number $h(-p)$ of $\mathbb{Q}(\sqrt{-p})$. This is based on a recent work of Roy, Schmidt and Yi where the authors count the number of certain cuspidal automorphic representations for GSp(4). Using the congruences between dimensions of the spaces of Siegel cusp forms and $h(-p)$, we obtain some results involving certain partition functions and Siegel cusp forms.

Bibliography

1. G. E. Andrews, *Integer partitions with even parts below odd parts and the mock theta functions*, Ann. Comb. 22 (2018), 433–445.
2. Ken Ono, *Distribution of the partition function modulo m*, Ann. of Math. 151 (2000), 293–307.
3. K. Ono, L. Sze, *4-core partitions and class numbers*, Acta Arith. 80, No. 3 (1997), 249–272.
4. Thomas R. Parkin and Daniel Shanks, *On the distribution of parity in the partition function*, Math. Comp., 21 (1967), 466–480.

Publications:

1. Chiranjit Ray and Rupam Barman, *On Andrews' integer partitions with even parts below odd parts*, Journal of Number Theory. (accepted)

Preprints:

1. Chiranjit Ray and Kalyan Chakraborty, *Certain eta-quotients and ℓ-regular overpartitions.* (under review)
2. Gireesh D S, Chiranjit Ray and Shivashankar C, *A new analogue of t-core partitions.* (under review)
3. Chiranjit Ray, Manami Roy and Shaoyun Yi, *Congruence relations for dimension of Siegel cusp forms of degree 2.* (under preparation)

Conference/Workshops Attended:

1. International conference on class groups of number fields and related topics; HRI, Prayagraj, India, October 16–19, 2019.
2. International Conference on Special Functions & Applications; Bikaner, Rajasthan, India, October 21–23, 2019.
3. One-day Number Theory workshop, Ramakrishna Mission Vivekananda Educational and Research Institute, Belur, West Bengal, India, Januarry 31, 2020.
4. Online Conference in Automorphic Forms, June 01–05, 2020.

Visits to other Institutes:

1. Ramakrishna Mission Vivekananda Educational and Research Institute, Belur, West Bengal, India, January 27–31, 2020.

Invited Lectures/Seminars:

1. "*Arithmetic properties of the integer partitions with even parts below odd parts and modular forms*", ICCGNFRT-2019, HRI, Prayagraj, India, October 16–19, 2019.
2. "*Arithmetic properties of certain partition functions and modular forms*", ICSFA-2019, Bikaner, Rajasthan, India, October 21–23, 2019..

Other Activities:

1. Act as reviewer of an article for **CALDAM 2020**, 6-th Annual International Conference on Algorithms and Discrete Applied Mathematics.
2. Act as reviewer of an article in **Research in Number Theory – Springer**.

Subham Sarkar

Research Summary:

I continue my study on certain type of question in Algebraic geometry which has an arithmetic analogue. I am reporting a progress on two different project on the above context. Given a nonsingualar projective curve defined over the field of complex numbers, one has an injective morphism $Aj : C \to \mathrm{Jac}(C)$, where $\mathrm{Jac}(C)$ is the jacobian variety of C. This is the famous theorem of Abel and the morphism is known as Abel-Jacobi map. It satisfy certain functorial properties. A similar result is known for curve with multiple singularities due to Shesadri, Oda, Usha Bhonsle and A.J Parameswaran etal. We studied topology of the the newly invented object "compactified jacobian" of a nodal curve. This is a joint work with Prof. A.J parameswaran (TIFR) and Dr. Sourav Das(PDF, TIFR).

The other work is the following. In 1982, D. Johnson defined a map known as a Johnson homomrphism which used to study the representation of Mapping class group. It is the topological fundamental group of the Moduli of genus g curves ($\mathcal{M}_g$). Hain uses Hodge theory to relate certain type of Johnson map with a "natural" null-homologous algebraic cycles in $\mathcal{M}_g$. It is the first evidence to expect that the *Johnson maps* are "Motivic". We relate ceratin Johnson maps with regulator of a higher Chow cycles. It also allows one to have application towards arithmetic question like finding regualtor map in l-adic cohomology.

Publications:

The Fundamental Group and Extensions of Motives of Jacobian of Curves with R.Sreekantan, Proc Math Sci (2020) 130: 18.

https://www.ias.ac.in/article/fulltext/pmsc/130/0018

Preprints:

Preprints of the above works are in progress.

Invited Lectures/Seminars:

Mixed Hodge structures, periods and special values of transcendental functions, Number Theory Symphosium at IIT Gandhinagar, Dec $22 - 23$ 2019.

Conference/Workshops Attended:

AIS School on Bloch-Kato Conjecture, at IISER Pune , Dec 23, 2019 to Jan 04, 2020.

Amar Deep Sarkar

Research Summary:

Submultiplicativity of the Carathéodory metric: Let $c_D(z)|dz|$ be the Carathéodory metric of a domain D in the complex plane – the Carathéodory metric of a domain in the complex plane is defined as an extremal problem on some collection of holomorphic functions. We show a submultiplicativity property of the Carathéodory metric: For D_1, D_2 smoothly bounded domains, with non-empty intersection, in the complex plane, we can find a constant $C = C(D_1, D_2) > 0$ such that

$$c_{D_1 \cap D_2}(z) \cdot c_{D_1 \cup D_2}(z) \leq C\, c_{D_1}(z) \cdot c_{D_2}(z).$$

The Hurwitz metric: We report on some properties of the Hurwitz metric that has recently been defined by Minda. Its construction is reminiscent of that for the Kobayashi metric but differs from it in the choice of holomorphic maps which are considered. We show that the Hurwitz metric is uniformly comparable with the quasi-hyperbolic metric – reciprocal of the distance from the boundary – (and hence the Carathéodory and Kobayashi) metric near C^2-smooth boundary points, and asymptotic of the their ratio explicitly computed, as the points approach the boundary.

The span metric: The span metric of a domain in the complex plane is defined as an extremal problem on the collection of holomorphic functions which are square integrable. Using real analyticity, hence differentiable, of the span metric Burbea defined the higher order curvatures of the span metric – is the Gaussian curvature when the order is one. We prove the convergence of the higher-order curvatures of the span metric as the points approach a C^2-smooth boundary point of the domain.

Preprints:

1. A submultiplicative property of the Carathodory metric on planar domains, Amar Deep Sarkar, Kaushal Verma, accepted for publication in Proceedings - Mathematical Sciences.

2. On the Hurwitz metric, Amar Deep Sarkar, Kaushal Verma, Preprint.

3. Boundary behaviour of the higher-order curvatures of the span metric, In preparation.

Conference/Workshops Attended:

1. Workshop on Several Complex Variables, Kerala School of Mathematics, Kozhikode, December 2019.
   http://www.ksom.res.in/KSOM-WSCV-Dec2019.php

Visits to other Institutes:

1. Academic visit to Indian Institute of Science, Bangalore, December 2019.

Invited Lectures/Seminars:

1. A Study of some Conformal Metrics and Invariants on Planar Domains, Harish-Chandra Research Institute (HRI), Allahabad, September 2019.

2. A Study of some Conformal Metrics and Invariants on Planar Domains, IIT Kanpur, September 2019.

Rajesh Kumar Singh

Research Summary:

In collaboration with my thesis supervisors Prof. Rama Rawat and Prof. Ron Kerman, I am working on the characterization of the boundedness of Fourier transform on Lorentz gamma spaces. This objective is to be meet by using rearrangement inequality established by Max Jodeit and Alberto Torchinsky, *Inequalities for Fourier transform. Studia Math. 37 (1970/71), 245276*, wherein rearrangement of Fourier transform of a given function is dominated by an operator U acting on that function. Then, the characterization boundedness of this operator U is connected to finding the dual norm of a norm involving operator $P + P^*$, where P is the usual Hardy averaging operator and P^* it's dual.

Achieving a good enough expression the abouve dual norm is quite challenging. This way we get the sufficient condition for the boundedness of the Fourier transform on Lorentz gamma spaces. One doesn't expect these sufficent conditions always necessary.

Publications:

1. Ron. Kerman, Rama Rawat and Rajesh K. Singh, *Dilation-commuting operators on power-weighted Orlicz classes*, Math. Inequal. Appl. 22 (2) (2019), pp. 463-486.

2. Ron. Kerman, Rama Rawat and Rajesh K. Singh, *A sharp form of the Marcinkiewicz Interpolation Theorem for Orlicz spaces*, DOI: 10.4064/sm180111-28-10, Published online: 13 May 2020.

Conference/Workshops Attended:

1. Participant and gave poster presentation, 4th BCAM-UPV/EHU summer school on harmonic analysis and PDEs: Restric- tion theory (July 2019).

2. Participant, 16th Discussion meeting on Harmonic Analysis, IISER Bhopal, India.

Visits to other Institutes:

1. (July 08-09, 2019) Visited Prof. Fernando Diaz Cobos Complutense University of Madrid, Spain during this two days visit gave a colloquium talk on *A sharp form of Marcinkiewicz Interpolation Theorem for Orlicz spaces*.

Rishabh Agnihotri

Research Summary:

In the academic year 2019-20, I worked on sign change of real sequence associated to an arithmetical function. More specifically, for an arithmetical function f which satisfies some specific relation at prime powers. We proved some theorems for the sign change of the sequence $\{f(p^k)\}_{k\in\mathbb{N}}$. As an application of these theorems we see the sign changes of a sequence defined by a recurrence relation, sign change of Chebyshev polynomials, and sign changes of coefficient of Hecke eigen form for the full modular group and for higher level also.

In a joint work with Prof. Kalyan Chakraborty and Mr. Mohit Mishra, we relate the primary rank of the real cyclotomic fields with the primary rank of quadratic field contained in it. As an application, we also relate the primary rank of all real quadratic fields contained in the real cyclotomic fields.

In another Joint work with Lalit Vashiya, we studied holomorphic generalized eta quotients. In this direction we proved that for a fixed weight k and fixed prime level p, there are only finitely many holomorphic generalized eta quotients of weight k on $\Gamma_1(p)$. We also obtain a criterion when two generalized eta quotients are same.

In the following year, I would like to study in the theory of Hilbert modular form. More precisely, I would like to study Lambert-series associated with Hilbert Modular form and related problems.

Publications:

1. Mohit Mishra, Rishabh Agnihotri and Kalyan Chakraborty, Primary rank of the class group of real cyclotomic fields, Rocky Mountain J. Math. (2020) (To appear).

Preprints:

1. Rishabh Agnihotri. *Sign Changes of certain Arithmetical Function at Prime Powers*. (In preparation).
2. Lalit Vaishya, and Rishabh Agnihotri. *A Note on Holomorphic genralized eta quotient.* (In preparation).

Conference/Workshops Attended:

1. AIS on Modular Form, IIT Guwahati, May 13 - June 01, 2019.
2. ICCGNFRT, HRI Prayagraj, Oct 16-19, 2019.
3. Workshop on Modular Forms and Galois Representations , IISER, Tirupati, Dec 11- Dec 17, 2019.

Kushal Bhowmick

Research Summary:

In the academic year 2019-2020, I have learnt the following topics:

1. Commutative Algebra from ”Introduction to Commutative Algebra” by Atiyah and Macdonald.
2. Classical Algebraic Geometry from ”Algebraic Geometry” by Robin Hartshorne (Chapter 1).
3. Basics of Scheme theory from ”Geometry of Schemes” by Eisenbud and Harris (Chapter 1).

Conference/Workshops Attended:

1. AFS-1, HRI Prayagraj, May 06-June 01, 2019.
2. NCM Workshop on Sheaf theory, Sheaf cohomology and Spectral sequences, Delhi University, Nov 18-30, 2019.
3. Mini Workshop on Bundles, Cycles and Motives, HRI Prayagraj, March 05-10,2020.

Visits to other Institutes:

1. Indian Institute of Science Education and Research, Tirupati, December 2019.

Priyanshu Chakraborty

Research Summary:

In the academic year 2019-2020, I learnt some aspects of infinite dimensional Lie algebras from " Infinite dimensional Lie algebras by Victor G. Kac" and "Lie algebras of Finite and Affine type by Roger Carter." Further I have read some papers related to toroidal Lie algebras. Recently I have done a work with Prof. Punita Batra. Details of the problem is given bellow.
Representations of toroidal Lie algebras are well studied. In particular, S.Eswara Rao has classified irreducible integrable representations of toroidal Lie algebras with finite dimensional weight spaces. In this work we have classified irreducible integrable representations of loop toroidal Lie algebras with finite dimensional weight spaces.

Preprints:

1. Priyanshu Chakraborty, Punita Batra, *Classification of irreducible integrable representations of loop toroidal Lie algebras* arxiv:2007.06415

Conference/Workshops Attended:

1. ATM workshop on combinatorial methods in representation theory, IMSC 04-16; Nov ; 2019.

Jaitra Chattopadhyay

Research Summary:

In this academic year, I have worked simultaneously on a few projects. In a joint work with Dr. M. Subramani, I have worked on the problem of simultaneous divisibility of class numbers of imaginary quadratic fields. We proved a weaker version of a recent conjecture by Iizuka and constructed an infinite family of triples of imaginary quadratic fields with class numbers divisible by 3.

A work was done in collaboration with Mr. Anand and Dr. Bidisha Roy on a problem related to exceptional units in commutative rings with identity. We introduced the notion of an f-exunit in the ring $\mathbb{Z}/n\mathbb{Z}$ and proved a combinatorial result related to the number of representations of an element as a sum of two f-exunits.

Besides these, I studied global class field theory under the guidance of Prof. Thangadurai. Some preliminary studies related to the lower bounds of the class numbers of some parametric families of real quadratic fields have also been initiated.

Publications:

1. Anand, J. Chattopadhyay and B. Roy, *On sums of polynomial-type exceptional units in $\mathbb{Z}/n\mathbb{Z}$*, Arch. Math. (Basel), **114** (2020), 271-283.

2. J. Chattopadhyay, *A short note on the divisibility of class numbers of real quadratic fields*, J. Ramanujan Math. Soc., **34** (2019), 389-392.

3. J. Chattopadhyay and P. Darbar, *Mean values and moments of arithmetic functions over number fields*, Res. Number Theory, **5** (2019), Art. 23, 15 pp.

Preprints:

1. Anand, J. Chattopadhyay and B. Roy, *On a question of f-exunits in $\mathbb{Z}/n\mathbb{Z}$.*

2. J. Chattopadhyay and M. Subramani, *On the simultaneous 3-divisibility of class numbers of triples of imaginary quadratic fields*.

Conference/Workshops Attended:

1. Lectures on Transcendence on Commutative Algebraic Groups, NISER, Bhubaneswar, December 2019.

2. Workshop on Additive Combinatorics, ICTS, Bangalore, India, February 2020.

Visits to other Institutes:

1. Graz University of Technology, Austria, October 2019.

2. Institute of Science and Technology, Austria, October 2019.

Invited Lectures/Seminars:

1. Bi-quadratic fields having a non-principal Euclidean ideal class, University of Graz, Austria, October 2019.

2. Bi-quadratic fields having a non-principal Euclidean ideal class, Institute of Science and Technology, Austria, October 2019.

Other Activities:

1. I have been a tutor for AFS-I held at Harish-Chandra Research Institute on May, 2019.

Srijonee Shabnam Chaudhury

Research Summary:

The sums of integral squares in a number field is one of the fundamental object of study in number theory. Lagrange proved the famous four square theorem, which states that every positive integer is represented by a sum of four squares of integers. On the other hand, Gauss proved that a positive integer can be represented as sum of two squares if and only if all of its prime divisors of the form 3 modulo 4 occur to an even power in its factorization. After that Gauss and Legendre proved that a positive integer can be represented as sum of three squares if and only if it is not of the form $4^a(8b + 7)$, where a and b are positive integer. I am interesting to look into these results in non-trivial number fields, especially in biquadratic number fields. In my first project, I have studied sum of integral squares in certain complex biquadratic fields.

Preprints:

1. Srijonee Shabnam Chaudhury, Sum of Integral Squares in Certain Complex Biquadratic field, (in preparation).

Conference/Workshops Attended:

1. International Conference on Class Group of Number Fields and Related Topics (ICCGNFRT) 2018, HRI.
2. International Conference on Class Group of Number Fields and Related Topics (ICCGNFRT) 2019, HRI.
3. Workshop on Additive Combinatorics 2020, ICTS, Bangalore.
4. IIT Guwahati , for AIS (Advanced Instructional School) on Modular Form, May, 2019.

Mithun Kumar Das

Research Summary:

We obtained an asymptotic expression for mean square of any general derivative of Hardy's Z-function product with Dirichlet polynomial. Namely, for Dirichlet polynomial of length less than $T^{\theta}, \theta < 1/4$ the above mention means square in the short interval $[T, T+T^{1/2+\theta+\epsilon}]$ is asymptotic to $P_k(\theta)T^{1/2+\theta+\epsilon}$, for some rational function $P_k(\theta)$ of θ and k. Using a special case of mean square formula we obtain zero density estimate result of Matsumoto-Tanigawa's η_k-function. We generalized the above mention means square into the product of two arbitrary order derivatives and by using this we obtained similar type of mean value result for higher derivatives of Riemann zeta function. As an application of mean square of higher derivatives of Riemann zeta function we find a refinement of some results by Ki and Lee on zero density estimate .

We say that a number n is y-smooth if all the prime factors of n lie below y. Let $\Psi(x, y)$ denote the number of y-smooth number below x, then the asymptotic formula of $\Psi(x, y)$ is known after work of many mathematician. We obtain an asymptotic formula for $\Psi_{a,q}(x, y)$, the number of y-smooth number below x with all prime factors are in the congruence class a modulo q.

Publications:

1. Mithun Kumar Das, Sudhir Pujahari, Distribution of signs of Karatsuba's and generalized Davenport-Heilbronn Z-functions , J. Number Theory 212 (2020) 409–447.

2. Mithun Kumar Das, Abhishak Juyal, Higher dimensional Dedekind sums and twisted mean value of Dirichlet L-series, (To appear in J. Ramanujan Math. Soc.).

3. Mithun Kumar Das, B. R. Patil, E. Pramod, *Combinatorial properties of sparsely totient numbers*, J. Ramanujan Math. Soc. 35, No.1 (2020) 1-16.

4. Mithun Kumar Das, B. R. Patil, E. Pramod, Sparse subsets of the natural numbers and Eulers totient function., Proc. Indian Acad. Sci. Math. Sci. 129 (2019), no. 5

Preprints:

1. Mithun Kumar Das, K Mallesham, M Ramdin, Smooth numbers composed of primes in a given congruence class (2020).

2. Mithun Kumar Das, Sudhir Pujahari, Mean square of derivatives of Hardy's Z-function product with Dirichlet polynomials (2020).

Conference/Workshops Attended:

1. Symposium in Number Theory-2019, IIT Gandhinagar , India, December 21 - 22, 2019.

2. Workshop on Multiple Zeta Values, Kerala School of Mathematics, India, January 18 - 23, 2020.

3. International Conference on Number Theory-2020, Kerala School of Mathematics, India, January 23 - 26, 2020.

Visits to other Institutes:

1. ISI Kolkata, February 2020 to September 2020.

Invited Lectures/Seminars:

1. Mean Square of derivatives of Hardy's Z-function product with Dirichlet polynomials, Symposium in Number Theory-2019, IIT Gandhinagar , India, December 21 - 22, 2019.

2. Value distribution of liner combination of Dirichlet L-functions on critical line, International Conference on Number Theory-2020, Kerala School of Mathematics, India, January 23 - 26, 2020.

Other Activities:

1. Teaching assistant for the course "Complex Analysis" in Annual Foundation School-I at Harish-Chandra Research Institute, Allahabad, 6th May to 1st June, 2019.

2. Teaching assistant in IST- Analytic Number Theory at IISER Berhampur, Odisha, 2nd December to 14th December, 2019.

Shubham Gupta

Research Summary:

A set $\{a_1, a_2, \cdots, a_m\}$ of m positive integers is called a Diophantine m-tuple with $D(n)$ if $a_i a_j + n = x_{ij}^2$, where $x_{ij} \in \mathbb{Z}$ and $n \in \mathbb{Z}$, for all $1 \leq i < j \leq m$. Diophantus found a set of four positive rationals $\{1/16, 33/16, 17/4, 105/16\}$ with the above property for $n = 1$. The first Diophantine 4-tuple with $D(1)$, namely, $\{1, 3, 8, 120\}$ was found by Fermat.

By a result of Baker and Davenport, this set can not be extended to Diophantine 5-tuple with $D(1)$. Over the years due to the findings of many researchers there exist many examples of Diophantine 3- and Diophantine 4-tuples with $D(1)$. Dujella proved that there does not exist Diophantine 6-tuple with $D(1)$ and there exist atmost finitely many Diophantine 5-tuple with $D(1)$. There was a 'folklore' conjecture that there does not exist Diophantine 5-tuples with $D(1)$. This is recently been settled by B. He et. al. in a pioneering work. Mohanty and Ramasamy showed that $D(-1)-$set $\{1, 5, 10\}$ can not be extended to Diophantine 4-tuple with $D(-1)$. These are some results which we know for Diophantine m-tuple with $D(n)$. Now, we define generalized Diophantine m-tuple over a commutative ring R.

Let R be a commutative ring and $n \in R$. A subset $\mathfrak{S} = \{a_1, a_2, \cdots, a_m\} \subseteq R$ such that $a_i \neq 0,\ i = 1, 2, \cdots, m,\ a_i \neq a_j$ and $a_i a_j + n$ is a square in R for all $1 \leq i < j \leq m$ is called a Diophantine m-tuple with $D(n)$ over R, or generalized Diophantine m-tuple over R.

If R is ring of integers, ring of Gaussian integers or ring of integer of imaginary quadratic fields, then we have many results for generalized Diophnatine m-tuple over R. In 1997, Dujella proved that there does not exist Diophantine 4-tuple in $\mathbb{Z}[i]$ with $D(a + bi)$, where b is odd or $a \equiv b \equiv 2 \pmod 4$. Let K be an imaginary quadratic field and $\mathcal{O}_K$ be its ring of integers. Azadaga showed that there does not exist Diophantine m-tuple with $D(1)$ over $\mathcal{O}_K$ for $m > 42$. I have proved the non-existence of Diophantine m-tuples with $D(-1)$ over $\mathcal{O}_K$ for $m > 36$. At present, I am working on genaralized Diophantine m-tuple over $\mathcal{O}_K$. I am trying to investigate the existence of generalized Diophantine m-tuples over Eisenstein integers and their finiteness or infiniteness (if they exist).

Preprints:

1. Shubham Gupta, *Certain Diophantine tuples in imaginary quadratic fields, preprint.*

Conference/Workshops Attended:

1. *International Conference on Class Groups of Number Fields and Related Topics*, Allahabad, India, October, 2019.

Debasish Karmakar

Research Summary:

During the academic year, I have been working in the following problems:

1. Let p be a prime and F a local field with finite residue field of characteristic p. We are trying to give an explicit description of parametrisation of primitive extensions of degree p^2 of the field F. This work is being carried out under the supervision of Prof. C. S. Dalawat.

2. Let $f(z) = \sum_{n=0}^{\infty} a_n z^n$ be a power series with integer coefficients and converging in the disc $D = \{z : |z| < R\}$ for some $R > 0$. In 1985, Laohakosol proved, using Ridout theorem, that the largest prime factors of partial sums of $f(b)$ for a rational number $0 < |b| < R$ is unbounded, if $f(b)$ is a non-zero algebraic number. We have proved, using the subspace theorem, similar results for other approximation of $f(b)$. Moreover, we have proved the number field analogue of Laohakosol's result.
This is a joint work with Veekesh Kumar and Rishabh Agnihotri.

3. Let $\beta > 1$ be a real algebraic integer such that all its other conjugates have absolute value less than or equal to 1. For any positive integers $a_1 < a_2 < \ldots < a_m$, we have proved that the numbers

$$1, \quad \sum_{n=1}^{\infty} \frac{1}{\beta^{a_1 n^2}}, \quad \sum_{n=1}^{\infty} \frac{1}{\beta^{a_2 n^2}}, \quad \ldots, \quad \sum_{n=1}^{\infty} \frac{1}{\beta^{a_m n^2}}$$

are $\mathbb{Q}(\beta)$-linearly independent. As a consequence, we observe that for every integer $n \geq 1$, the m- Jacobi theta values

$$\theta_3(a_1\tau_n), \quad \theta_3(a_2\tau_n), \ldots, \theta_3(a_m\tau_n)$$

are $\mathbb{Q}(\beta)$-linearly independent with 1, where $\tau_n = \frac{i \log \beta}{\pi} + 2n$.
This is a joint work with Veekesh Kumar.

4. If $l \in \mathbb{N}$, then $A \subset \mathbb{N}$ is called l-syndetic set if A intersects every set of l consecutive natural numbers. A is called a syndetic set if it is l-syndetic set for some $l \in \mathbb{N}$. In 2006, Beiglböck, Bergelson, Hindman and Strauss asked an open question that if A is a syndetic set, does it contain arbitrarily long geometric progressions? Even the existence of configurations of the form $\{x, xr^2\}$ with $x, r \in \mathbb{N}$ in a syndetic set is also open. In collaboration with Bhuwanesh Rao Patil, I am trying to prove the existence of a configuration of the form $\{x, xr^2\}$ with $x, r \in \mathbb{N}$ in 3-syndetic set.

Conference/Workshops Attended:

1. *Perfectoid spaces*, ICTS, India, September, 2019.

2. *International Conference on Class Groups of Number Fields and Related Topics*, India, October, 2019.

3. *Mini-Workshop on Bundles, Cycles and Motives*, HRI, India, March, 2020.

Other Activities:

1. Tutor in Annual Foundation School - I at HRI, May 06 - June 01, 2019.

Rahul Kaushik

Research Summary:

In general it is not true that $K(G) = \gamma_2(G)$, where G be a finite group, $\gamma_2(G)$ denotes the commutator subgroup of G and $K(G) := \{[x, y] \mid x, y \in G\}$. This academic year $2019 - 2020$ I studied paper by Iker De Las Heras[J. Algebra (2020), 201-217], in which he proveed that, if $\gamma_2(G)$ can be generated by 3 elements in a finite p-group G, then $\gamma_2(G)$ consists only of commutators. I read two more papers R. James[Math. Comp (1980), 613-637] and Kappe-Morse[J. Group Theory (2005), 415-429.]. Then along with my supervisor Prof. Manoj Kumar Yadav, I generalized the work which has been done earlier and give a classification of finite p-groups G, $p \geq 3$, with $\gamma_2(G)$, the commutator subgroup of G, of order p^4 and exponent p such that each element of $\gamma_2(G)$ is a commutator.

We did it for $p \geq 3$, now I am doing it for $p = 2$. In this coming year I will work on the same problem, where I relax the condition of exponent of $\gamma_2(G)$ in my previous work.

Preprints:

1. Rahul Kaushik and M. K. Yadav, *Commutators and commutator subgroups of finite p-groups*. (Submitted for publication).

Conference/Workshops Attended:

1. GROUP ALGEBRAS, REPRESENTATIONS AND COMPUTATION

   ORGANIZERS: Gurmeet Kaur Bakshi, Manoj Kumar and Pooja Singla

   DATE:= 14 October 2019 to 23 October 2019

   VENUE: Ramanujan Lecture Hall, ICTS Bangalore

Parul Keshari

Research Summary:

The main focus of these semesters have been to study the geometry of homogeneous spaces and linear algebraic groups, vanishing of cohomology using Borel-Weil-Bott theorem. Along the way, we studied various cohomology theories (De Rham cohomology, ech cohomology and Sheaf cohomology) and connection among them. We plan to continue the study of vanishing theorems, operations on cohomology theories, and characteristic classes of bundles.

Besides this, I have been studying basics of Algebraic Geometry. I have also attended a series of lectures on Intersection Theory, Adic spaces, Milnor K-theory and Triangulated categories.

Conference/Workshops Attended:

1. Moduli of bundles and related structures (10 February 2020 to 14 February 2020) at ICTS Bangalore.
2. Mini Workshop on Bundles, Cycles and Motives (5 March 2020 to 10 March 2020) at HRI Allahabad.

Other Activities:

1. Delivered lectures on Linear algebraic groups at HRI.

Krishnarjun.K

Research Summary:

1. It was Landau in the 1950s who initiated the study of the first moment of the Dedekind zeta function, and in the subsequent years the error term has been steadily improved by many mathematicians. We improve the error term for this classical problem. Our method is classical and involves the use of Perron's formula and the analytic continuation to shift the line of integration to bigger regions. We modify this method and make use to the functional equation to shift the line of integration further to the left, and thereby obtaining a stronger bound on the error term.

   The question of higher moments is particularly interesting to solve using our new method, and in it's core involves proving the analytic continuation of the higher moment zeta function.

2. In the last quarter of the twentieth century, algebraic cycles and rational equivalence have taken a center stage in the field of algebraic geometry, thanks to the ground breaking work of Chow and others. The so called Chow groups have naturally replaced the divisor group as a generalization and they are a rich new area for mathematical research. In the joint work with Dr. Kalyan Banerjee, we study the local global principles with respect to Chow group with modulus. We prove that the torsion of the Chow groups with modulus are finite, thereby extending the classical result of Mordell-Weil to Chow groups with modulus.

   Chow groups with modulus are fundamental objects in higher dimensional class field theory, and the implications of our results will be very interesting to investigate.

3. Large sets are subsets of natural numbers who's reciprocal sum diverges. It is a classical open problem to find bounds on the growth of large sets. Connected to these growth estimates are a plethora of conjectures, the most famous of which is the Erdös's conjecture on arithmetic progressions in large sets. The conjecture states that every large set contains arbitrarily long arithmetic progressions. The conjecture is closely related to the growth of the functions $r_k(n)$ which measure the largest size of a subset of $\{1, 2, \cdots, n\}$ which does not contain a k-term arithmetic progression. The generally expected bounds on $r_k(n)$ are of the type $n/\log(n)$. Over the years, many upper bounds have been found and the most recent ones are of the form $n/(\log(n))^d$ for some $d > 0$, for the cases $k = 3, 4$. It is widely believed that this bound is not strong enough to prove Erdös's conjecture. In the article "*Structures in Large sets*" we prove stronger growth conditions on large sets and leverage those bounds to show that the existing bounds on r_3, r_4 are indeed strong enough to prove the conjecture.

   Further interesting questions in this direction are to try to solve this conjecture for $k \geq 5$, where the existing bounds on r_k are much weaker. It would be interesting to try to adapt the method to prove the conjecture for those cases also.

Preprints:

1. *On the number of integral ideal of a number field* arxiv.org/2002.06342 (2020).
2. (Joint work with Dr. Kalyan Banerjee, Post Doc fellow at HRI) *Weak Mordell-Weil theorem for Chow groups with Modulus* (In preparation).
3. *Structures in Large sets* (In preparation).

Conference/Workshops Attended:

1. Advanced Instructional School on Modular Forms 2019, IIT Guwahati.
2. ICCGNFRT-2019, Harish Chandra Research Institute, Prayagraj (Allahabad).
3. NCM Workshop-Galois representations and Modular forms 2020, IISER Tirupati.
4. Mini-Workshop on Bundles, Cycles and Motives 2020, Harish Chandra Research Institute , Prayagraj (Allahabad).

Invited Lectures/Seminars (Webinars):

1. "*Ideas for CSIR-NET preparation*" Webinar at the mathematics department, Rabi-Ammal Ahmed Maideen College for Women, Tiruvarur, Tamil Nadu.
2. "*Meet The Scholars*" Web based interactive session with undergraduate students under the Dhanush programme of the government of Kerala.

Other Activities:

1. Reading project with Dr.Pramath Anambi (Post Doc Fellow at HRI) on the book "Automorphic forms and Representations" by Daniel Bump
2. Attended lectures on Class field theory by Mohit Mishra (SRF) and Rishab Agnihotri (SRF) at Harish Chandra Research Institute. Also gave two special lectures about Artin L functions as part of the said lecture series.
3. Gave a talk titled "On the number of integral ideals of a number field" based on the preprint of the same title to the ANTs group as part of their weekly seminars.

Arup Kumar Maity

Research Summary:

In this academic year I have studied the paper by L.S Hahn titled "on multipliers of p-integrable functions" (Trans. Amer. Math. Soc. 128 (1967), 321-335). Now I am working on this direction. Also we have studied corresponding problem in Wyel multiplier setup and get some result.
In another work I have studied parabolic multiplier. We consider the function $\chi(y^2 \leq x, x \leq 1)$ and try to find it is in some M^p_q or not for some $p, q \geq 1$.

Conference/Workshops Attended:

1. Workshop on Harmonic Analysis, 10th to 14th December, 2019, IISER Bhopal.

2. 16th Discussion Meeting in Harmonic Analysis 16th to 19th December, 2019, IISER Bhopal.

Mohit Mishra

Research Summary:

In the academic year 2019–20, I have worked on the structure of the class group of cyclotomic and real cyclotomic fields. The class group of cyclotomic and real cyclotomic fields are very mysterious objects. Also class group of real cyclotomic fields are quite small as compared to the class group of cyclotomic fields. One would like to find the real cyclotomic fields with large class group. Associated to the class group a particular quantity of considerable interest is its primary rank. Large primary rank of a class group will imply the largeness of the class group.

In a joint work with Prof. Kalyan Chakraborty and Mr. Rishabh Agnihotri, we relate the primary rank of the real cyclotomic fields with the primary rank of quadratic field contained in it. As an application, we also relate the primary rank of all real quadratic fields contained in the real cyclotomic fields.

I also learned class field theory and elliptic curves and explored Hilbert class tower problem for cyclotomic and real cyclotomic fields.

Publications:

1. Mohit Mishra, *Partial Dedekind zeta values and class numbers of R–D type real quadratic fields,* Class group of number fields and related topics, Conference proceedings of ICCGNFRT–2017, 163–174.

2. Kalyan Chakraborty, Azizul Hoque and Mohit Mishra, *A note on certain real quadratic fields with class number upto three,* Kyushu J. Math. (2019) (To appear).

3. Kalyan Chakraborty, Azizul Hoque and Mohit Mishra, On the structure of order 4 class groups of $\mathbb{Q}(\sqrt{n^2+1})$, Ann. Math. Qué (2020) (To appear).

4. Mohit Mishra, Rishabh Agnihotri and Kalyan Chakraborty, Primary rank of the class group of real cyclotomic fields, Rocky Mountain J. Math. (2020) (To appear).

Preprints:

1. Mohit Mishra, Lower bound for class number of certain real quadratic fields, submitted for publication 2020.

Conference/Workshops Attended:

1. AIS on Modular forms (May 13 - June 1, 2019), IIT Guwahati, Guwahati, India.

2. ICCGNFRT 2019 (Oct 16–19), HRI, Prayagraj, India.

3. Symposium in Number Theory (Dec 22–23, 2019), IIT Gandhinagar, Gandhinagar, India.

Invited Lectures/Seminars:

1. *Lower bound for class number of certain real quadratic fields,* International conference on class group of number fields and related topics, Harish-Chandra Research Institute, Prayagraj (Allahabad), October 2019.

2. *Lower bound for class number of certain real quadratic fields,* IIT Gandhinagar, Gandhinagar, December 2019.

Nishant

Research Summary:

In the academic year 2019-2020, I learnt some aspects of Hopf- Galois structures. Which determines the possible Skew Brace structures on a given Galois group.

Also, I studied the work of ”L. VENDRAMIN” on the cohomology and nilpotency of Braces. In particular,Skew left Braces of nilpotent type.

Conference/Workshops Attended:

1. AIS on Linear Algebraic Groups, (24 June- 13 July, 2019), IIT Bombay, Mumbai.
2. Group Algebras, Representations and Computation, (14 - 23 October, 2019), ICTS, Bangalore.

Souvik Pal

Research Summary:

In the academic year 2019-2020, I mainly worked on two distinct projects, both of which are based on classifying irreducible integrable quasifinite modules for extensions of centreless Lie tori satisfying fgc condition. It is well-known that such a Lie torus of non-zero nullity has a multiloop realization. A brief description of my projects are provided below.

1. An important problem in the representation theory of affine Lie algebras (both untwisted and twisted) is to classify all the irreducible integrable modules with finite dimensional weight spaces. These modules are sometimes referred to as quasifinite modules. The multivariable generalization of twisted affine Kac-Moody algebras was the subject of my first project. We call this Lie algebra a graded Lie torus which is acquired by first considering the universal central extension of the multiloop realization mentioned above and then adding only finitely many degree derivations. The centre of this graded Lie torus is finite dimensional. The irreducible integrable quasifinite representations for the graded Lie torus with non-trivial central action have been classified fairly recently by S. Eswara Rao and S. Sharma. In my first project, I addressed the mutually exclusive case and thereby classified all the irreducible integrable quasifinite modules where all the central elements of this graded Lie torus act trivially on the modules.

2. The semidirect product of Virasoro Lie algebra and derived affine Kac-Moody algebra with common centre plays a significant role in several diverse areas of mathematics and physics. My ongoing second project deals with the twisted multivariable version of this classical object which we refer to as the twisted full toroidal Lie algebra (TFTLA for short). Similar to the construction of graded Lie torus, this Lie algebra is also obtained via an extension of the universal central extension of the twisted multiloop algebra. But the similarity ends here as in this case we adjoin the full space of derivations of a Laurent polynomial algebra, rather than only the degree derivations. Recently S. Eswara Rao and P. Batra classified all possible irreducible integrable quasifinite modules for TFTLA where the centre of this Lie algebra (spanned by finitely many elements) acts non-trivially. The main purpose of my present ongoing work is to classify and then completely parametrize all the irreducible integrable quasifinite modules for TFTLA with trivial central action.

Preprints:

1. Integrable Modules For Graded Lie Tori With Finite Dimensional Weight Spaces (https://arxiv.org/pdf/2005.07381.pdf).

2. Classification Of Level Zero Irreducible Integrable Modules For Twisted Full Toroidal Lie Algebras (In Preparation).

Conference/Workshops Attended:

1. NCM Workshop on Combinatorial Models in Representation Theory (Nov 04 - 16, 2019), IMSc Chennai, India.

2. Discussion Meeting on Representation Theory (Dec 14 - 16, 2019), IISc Bangalore, India.

Visits to other Institutes:

1. IISc Bangalore, India (Oct 24 - Nov 02, 2019).

Bidisha Roy

Research Summary:

In this year, I have studied some topics in algebraic number theory, elliptic curves and related areas.

The study of torsion groups of elliptic curves defined over arbitrary number fields is a classical topic and it has a vast literature in algebraic number theory. In a recent work with Pallab Kanti Dey, we classify torsion groups of rational Mordell curves explicitly over cubic fields as well as over sextic fields. Also, we classify torsion groups of Mordell Curves over cubic fields. For Mordell curves over sextic fields, we compute all possible torsion groups.

Another natural topic in algebraic number theory is the study of the behavior of exceptional units in different rings. In a recent work with Anand and Jaitra Chattopadhyay, we introduce a notion of polynomial version of exceptional unit (abbreviated as *f-exunits*) for any $f(X) \in \mathbb{Z}[X]$. In fact, we find the number of representations of a non-zero element of $\mathbb{Z}/n\mathbb{Z}$ as a sum of two f-exunits, for an infinite family of polynomials f of each degree ≥ 1. We also derive the exact formulae for certain infinite families of linear and quadratic polynomials. This generalizes a result of Sander.

Very recently, we have studied further in aforementioned topic of *f-exunits*. Along with Anand and Jaitra Chattopadhyay, we obtain a similar formula for any non-constant polynomial $f(X) \in \mathbb{Z}[X]$. This affirmatively answers a question posed in the previous article and also provides a simpler proof of a result proved by Sander.

In combinatorial number theory, we have studied some topics related to zero-sum Ramsey theory. We have tried to make a generalization of the definition of *zero-sum generalized Schur-number* which was introduced by A. Robertson. We considered r, m and $k \geq 2$ are positive integers with $r \mid k$, and $v \in \left[0, \lfloor \frac{k-1}{2r} \rfloor\right]$ is an integer. For any integer $\ell \in [1, k]$ and $\epsilon \in \{0, 1\}$, we let $\mathcal{E}_v^{(\ell,\epsilon)}$ be the linear homogeneous equation defined by $\mathcal{E}_v^{(\ell,\epsilon)} : x_1 + \cdots + x_{k-(rv+\epsilon)} = x_{k-(rv+\epsilon-1)} + \cdots + x_{k-1} + \ell x_k$. We denote the number $S_{\mathfrak{z},m}^{(\ell,\epsilon)}(k; r; v)$, which is defined to be the least positive integer t such that for any m-coloring $\chi : [1, t] \to \{0, 1, \ldots, m-1\}$, there exists a solution $(\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_k)$ to the equation $\mathcal{E}_v^{(\ell,\epsilon)}$ that satisfies the r-zero-sum condition, namely, $\sum_{i=1}^{k} \chi(\hat{x}_i) \equiv 0 \pmod{r}$.
This definition is a generalization of *zero-sum generalized Schur-number*, introduced by A. Robertson.
In a recent work with Subha Sarkar, we completely determine the constants $S_{\mathfrak{z},2}^{(k,1)}(k; r; 0)$, $S_{\mathfrak{z},m}^{(k-1,1)}(k; r; 0)$, $S_{\mathfrak{z},2}^{(1,1)}(k; 2; 1)$ and $S_{\mathfrak{z},r}^{(1,0)}(k; r; v)$. Also, we obtain upper bounds for the constants $S_{\mathfrak{z},2}^{(2,1)}(k; 2; 0)$ and $S_{\mathfrak{z},2}^{(1,1)}(k; 2; v)$.

Publications:

1. Sukumar Das Adhikari, Bidisha Roy and Subha Sarkar, *Weighted zero-sums for some finite abelian groups of higher ranks*, Combinatorial and Additive Number theory proceedings, (2020), 1–12.

2. Anand, Jaitra Chattopadhyay and Bidisha Roy, *On sums of polynomial-type exceptional Units in $\mathbb{Z}/n\mathbb{Z}$.* Arch. Math. (Basel), **114** (2020), 271–283.

3. Jaitra Chattopadhyay, Bidisha Roy and Subha Sarkar, *On Fractionally Dense Sets,* Rocky Mountain Journal of Mathematics, **49** (2019), 743–760.

4. Jaitra Chattopadhyay, Bidisha Roy, Subha Sarkar and R. Thangadurai, *Distribution of residues modulo p using the Dirichlet's class number formula*, Class Groups of Number Fields and Related Topics –Conference proceedings of ICCGNFRT, (2020), 97–107.

5. Bidisha Roy and Subha Sarkar, *On determination of Zero-sum ℓ-generalized Schur Numbers for some linear equations*, Journal of combinatorics and number Theory, **11** (2020), 65–76.

Preprints:

1. Anand, Jaitra Chattopadhyay and Bidisha Roy, *On a question of f-exunits in $\mathbb{Z}/n\mathbb{Z}$*, submitted.

2. Pallab Kanti Dey and Bidisha Roy, *Torsion groups of Mordell curves over cubic and sextic fields* , submitted.

Conference/Workshops Attended:

1. Lectures on Transcendence on Commutative Algebraic Groups, NISER, Bhubaneswar, December, 2019.

2. Fifth mini symposium of the Roman Number Theory Association, Universit Roma Tre, Rome – Italy, April, 2019.

3. 13th Atelier PARI/GP, Universit Roma Tre, Rome – Italy, April, 2019.

Visits to other Institutes:

1. Autonomous University of Madrid and ICMAT, Spain, October, 2019.

2. University of Zagreb, Croatia, October, 2019.

3. University of Vienna, Austria, October, 2019.

Invited Lectures/Seminars:

1. *Torsion groups of Mordell curves over cubic and sextic fields,* UAM-ICMAT, Spain, October, 2019.

2. *Torsion groups of Mordell curves over cubic and sextic fields,* University of Zagreb, Croatia, October, 2019.

3. *On zero-sum subsequences in some finite abelian p-groups*, University of Vienna, Austria, October, 2019.

4. *On zero-sum subsequences in a finite abelian p-group*, Università Roma TRE, Italy, April, 2019.

Other Activities:

1. Tutorial in Topology and Analysis , Annual Foundation School-I, HRI, Allahabad, May, 2019.

Gopinath Sahoo

Research Summary:

In the paper titled "Resolution of unbounded complexes in Grothendieck categories" the author modifies results of Spaltenstien to Grothendieck categories which I tried to understand. Krause and Neeman has proposed methods to complete, triangulated categories; I spent some time to understand their constructions. Later I learned about model categories and model structures. Along with these, I continued to learn more on the basics of Algebraic Geometry in particular Varieties, Sheaves and Schemes.

Conference/Workshops Attended:

1. Mini-workshop on Bundles, Cycles and Motives, HRI, Prayagraj, 5th-10th March, 2020.
2. Advanced instructional school on "Advanced Commutative Algebra", IIT, Kharagpur, 2nd-14th December, 2019.
3. Workshop on Hochshild Homology, Chennai Mathematical Institute, 15th-20th July, 2019.

Subha Sarkar

Research Summary:

In this academic year, I have studied Combinatorial Number Theory, mostly weighted zero-sum problems and Ramsey Theory. Let G be a finite abelian group of exponent n and let A be a non-empty subset of $[1, n-1]$. The Davenport constant with weight A, denoted by $D_A(G)$, and is defined to be the least positive integer ℓ such that any sequence over G of length ℓ has a non-empty A-weighted zero-sum subsequence. The constant $\mathsf{E}_A(G)$ is defined to be the least positive integer ℓ such that any sequence over G of length ℓ has an A-weighted zero-sum subsequence of length $|G|$. We determined an upper bound of $D_A(\mathbb{Z}/n\mathbb{Z})$ and $\mathsf{E}_A(\mathbb{Z}/n\mathbb{Z})$ where A is the set of all cubes in $(\mathbb{Z}/n\mathbb{Z})^*$.

We considered the study of $\{\pm 1\}$-weighted zero-sum constants. We modified a polynomial method of Rónyai to prove that for an odd prime p and for a positive even integer k which divides $p-1$, if A is the subgroup of $(\mathbb{Z}/p\mathbb{Z})^*$ of order k, then any sequence over $(\mathbb{Z}/p\mathbb{Z})^{k+1}$ of length $4p + \frac{p-1}{k} - 1$ contains an A-weighted zero-sum subsequence of length $3p$. In other words, we obtained an upper bound of $\mathsf{s}_{3,A}((\mathbb{Z}/p\mathbb{Z})^{k+1})$. Later we generalized this result and prove an upper bound for all lengths. More precisely, for all integers $m \geq 3$, we proved that

$$\mathsf{s}_{m,A}((\mathbb{Z}/p\mathbb{Z})^{k+1}) \leq (m+1)p + \frac{p-1}{k} - 1.$$

Publications:

1. Sukumar Das Adhikari, Bidisha Roy and Subha Sarkar,*Weighted zero-sums for some finite abelian groups of higher ranks*, In: Nathanson M. (eds) Combinatorial and Additive Number Theory III. CANT 2018., Springer Proc. Math. Stat., **297** (2020), Springer, Cham, 1–12.

2. Bidisha Roy and Subha Sarkar, *On determination of zero-sum ℓ-generalized Schur numbers for some linear equations*, J. Comb. Number Theory, Accepted for Publication.

Preprints:

1. Subha Sarkar, *Generalization of some weighted zero-sum theorems* (submitted).

2. Sukumar Das Adhikari, Bidisha Roy and Subha Sarkar, *On a polynomial method of Rónyai in the study of zero-sum theorems* (submitted).

Conference/Workshops Attended:

1. *Workshop on Additive Combinatorics*, India, February-March, 2020.

Visits to other Institutes:

1. Ramakrishna Mission Vivekananda Educational and Research Institute, Belur, India, November-December, 2019.

2. Institute of Science and Technology, Austria, October, 2019.

3. University of Graz, Austria, September-October, 2019.

Invited Lectures/Seminars:

1. *Quadratic non-residue and non-primitive roots satisfying a coprimality condition*, Institute of Science and Technology, Austria, October, 2019.

2. *Weighted zero-sum problems for some finite abelian groups of higher ranks*, Graz University of Technology, Austria, October, 2019.

Other Activities:

1. Tutor for Algebra course in AFS-I, HRI, 2019.

2. Tutor for Algebra course in Virtual AFS-I, 2020.

Anoop Singh

Research Summary:

In the academic year 2019-20, I have been working on the theory of moduli spaces of connections over a compact Riemann surface. More specifically, I have proved that the moduli space of logarithmic connections over a compact Riemann surface admits a smooth compactification.

Further, I studied the Picard group for the same and have shown that the Picard group of the moduli space of logarithmic connections with fixed residues and fixed determinant is isomorphic to the Picard group of the moduli space of stable vector bundles with fixed determinant. I studied the rational functions for the moduli space of the rank one logarithmic connections. I have shown that the moduli space of logarithmic connections over a compact Riemann surface does not admit any non-constant regular function, although it admits non-constant holomorphic functions, when considered as a complex manifold.

I also studied the compactification, Picard group and algebraic function for the moduli space of λ-connections over a smooth projective complex curve.

Publications:

1. I. Biswas, and Anoop Singh. *On the relative connections*, Comm. Algebra **48**(2020), no. 4, 14521475.

2. Anoop Singh. *Moduli space of rank one logarithmic connections over a compact Riemann surface,* to appear in C. R. Math. Acad. Sci. Paris

3. Anoop Singh. *Moduli space of logarithmic connections singular over a finite subset of a compact Riemann surface,* to appear in Math. Res. Lett.

Preprints:

1. Anoop Singh. *On the moduli space of λ-connections.* arXiv:2002.00358

2. C. P. Anil Kumar, and Anoop Singh. *On a Conjecture of Kelly on $(1, 3)$-representation of Sylvester Gallai Designs.* arXiv:2003.07645

Conference/Workshops Attended:

1. Mini-Workshop on 'Bundles, Cycles, and Motives' at HRI Prayagraj, India. March 5-10, 2020.

2. The Bloch- Kato Conjecture at IISER Pune, India. December 23, 2019 - January 4, 2020.

3. Seshadri Constants at NISER Bhubaneswar, Odisha, India. December 16-21, 2019.

4. Perfectoid spaces at ICTS, Bangalore, India. September 9 - 20, 2019.

Invited Lectures/Seminars:

1. Gave a talk on 'Relative holomorphic connection' in the Mini-Workshop on 'Bundles, Cycles, and Motives' at HRI Prayagraj, India. March 5-10, 2020.

2. Gave a series of 10 lectures on 'Adic spaces' in Geometry seminars at HRI Prayagraj, India. October, 2019.

Other Activities:

1. Took tutorial classes for the course 'Complex and Fourier Analysis' in AFS-II at HRI, Prayagraj, India. May 6, 2019 - June 1, 2019.

Santanu Tantubay

Research Summary:

In the academic year 2019-2020, I learnt some aspects of finite dimensional Lie algebra from ”Introduction to Lie algebras and representation theory” by J.E.Humphreys. In particular I have read finite dimensional irreducible representations of semi-simple Lie algebras.

Further I learnt some aspects of Infinite-dimensional Lie algebra from ”Infinite-dimensional Lie algebra” by Victor G Kac, ”Lie algebras of finite and affine type” by Roger Carter.

Recently I am reading some papers related to infinite dimensional Lie algebras, namely Torodial Lie algebras and its representations and working on a problem.

Conference/Workshops Attended:

1. AIS on Advanced Commutative Algebra, IIT Kharagpur, 02-14 December; 2019.

Lalit Vaishya

Research Summary:

1. **Representation formulas associated to higher figurate numbers** (joint work with B. Ramakrishnan):

   In 1995, K. Ono, S. Robins and P.T. Wahl considered the problem of determining formulas for the number of representations of a natural number n by a sum of k triangular numbers and derived many applications, including the one connecting these numbers with the number of representations of n as a sum of k odd square integers. They also obtained an application to the number of lattice points in the k-dimensional sphere. In this work, first we consider triangular numbers with positive integer coefficients. We show that if the sum of these coefficients is a multiple of 8, then the associated generating function is a modular form of integral weight (when even number of triangular numbers are taken). Using explicit bases for the spaces of modular forms, we derive representation number formulas corresponding to the triangular numbers with coefficients. We also obtain several applications concerning the triangular numbers with coefficients similar to the ones obtained by Ono et. al. In the second part of the work, we consider more general mixed forms (as done by Xia-Ma-Tian (IJNT 2016)) and derive modular properties for the corresponding generating functions associated to these mixed forms. As a consequence, we obtain representation formulas corresponding to these mixed forms. We also derive the (p, k) parametrization of the Eisenstein series $E_4(dz)$, $d|12$. Finally, we also consider higher figurate numbers and obtain modular property of the corresponding generating functions under certain conditions.

2. **Signs of Fourier coefficients of cusp forms at integers represented by an integral binary quadratic form**:

   In this work, we establish the fact that there are infinitely many sign changes of Fourier coefficients of a normalised Hecke eigenform supported at positive integers represented by a primitive integral binary quadratic form with negative discriminant. We also provide a quantitative result for the number of sign changes in the interval $(x, 2x]$ for sufficiently large x.

3. **Estimates of shifted convolution sums involving Fourier coefficients of Hecke-Maass eigenforms** (joint work with Abhash Kumar Jha):

   We obtain certain estimates for averages of shifted convolution sums involving the Fourier coefficients of a normalized (i.e. $\lambda_f(1) = 1$) Hecke-Maass eigenform f and holomorphic cusp form g on the congruence subgroup $SL_2(\mathbb{Z})$. Precisely, we obtain the estimates for the following sums:

$$\sum_{h\leq H}\sum_{N<n\leq 2N}\lambda_{j,f}(n)\lambda_{j,f}(n+h), \tag{1}$$

$$\sum_{h\leq H}\sum_{N<n\leq 2N}\lambda_{j,f}(n)\lambda_{j,g}(n+h), \tag{2}$$

$$\sum_{h\leq H}\sum_{N<n\leq 2N}\lambda_{j,g}(n)\lambda_{j,f}(n+h), \tag{3}$$

where $\lambda_{j,f}$ is defined (similarly $\lambda_{j,g}$ is also defined) as follows:

$$\lambda_{j,f}(n) = \sum_{n_1 n_2 \cdots n_j = n} \lambda_f(n_1)\lambda_f(n_2)\cdots\lambda_f(n_j), \tag{4}$$

where f denote a Maass cusp form with Laplace eigenvalue $\frac{1}{4} + \nu^2$, on the full modular group $SL_2(\mathbb{Z})$ with Fourier expansion

$$f(z) = \sum_{n\neq 0} \sqrt{y}\lambda_f(n) K_{i\nu}(2\pi|n|y) e(nx), \tag{5}$$

and g is holomorphic cusp form of weight k on the full modular group $SL_2(\mathbb{Z})$ with Fourier expansion

$$f(z) = \sum_{n\geq 1} \lambda_g(n) n^{\frac{k-1}{2}} q^n \qquad\qquad q = e^{2\pi i z} \tag{6}$$

Preprints:

1. B. Ramakrishnan and Lalit Vaishya, Representation formulas associated to higher figurate numbers, Preprint 2019.
2. Lalit Vaishya, Signs of Fourier coefficients of cusp forms at integers represented by an integral binary quadratic form. Submitted for publication, 2019.
3. Abhash Kumar Jha and Lalit Vaishya, Estimates of shifted convolution sums involving Fourier coefficients of Hecke-Maass eigenforms. Submitted for publication, 2020.

Conference/Workshops Attended:

1. AIS Workshop on Modular forms (May 12 – June 01, 2019), IIT Guwahati, India.
2. International Conference on Class Group of Number Field and Related Topics (ICCGNFRT-2019) (October 16–19, 2019), Harish-Chandra Research Institute, Prayagraj (Allahabad), India.
3. NCMW Modular Forms and Galois Representations (Dec 11–17, 2019) IISER, Tirupati, Andhra Pradesh, India .

Academic Report - Physics

Anirban Basu

Research Summary:

My research has focussed on understanding worldsheet and spacetime aspects of string dualities in maximally supersymmetric string theory.

In toroidal compactification of type II string theory to 8 dimensions, the 1/8 BPS D^6R^4 coupling in type II string theory receives contributions from worldsheet instantons and anti-instantons wrapping the T^2, up to genus three in string perturbation theory. These involve contributions separately from bound states of instantons and anti-instantons. At genus two, this coupling also receives contributions from instanton/anti-instanton bound states, which is a consequence of a T-duality invariant eigenvalue equation a term in the coupling satisfies. I have solved this eigenvalue equation to obtain the complete structure of the worldsheet (anti)instanton contributions. In the type IIB theory, strong weak coupling duality leads to certain contributions involving bound states of D string (anti)instantons wrapping the T^2 which I have determined.

I have analyzed transcendentality for certain terms that arise in multiloop amplitudes in the low momentum expansion of the four graviton amplitude in type IIB string theory in ten dimensions, based on the constraints of supersymmetry and S–duality. This leads to several contributions that violate transcendentality beyond genus one at all orders in the low momentum expansion. I have also performed a similar analysis for the five graviton amplitude, obtaining contributions that involve single–valued multiple zeta values beyond tree level.

Modular graph functions arise as integrands in the low momentum expansion of multi–graviton amplitudes in type II string theory at genus one. The modular graph $C_{a,b,c,d}$ is a three loop planar graph in which two of the vertices have coordination number four, while the others have coordination number two. I have obtained an eigenvalue equation satisfied by $C_{a,b,c,d}$ for generic values of a, b, c and d, where the source terms involve various modular graphs.

Publications:

1. Transcendentality violation in type IIB string amplitudes, JHEP 02, 034 (2020)
2. Eigenvalue equation for the modular graph $C_{a,b,c,d}$, JHEP 07, 126 (2019)

Preprints:

1. Worldsheet (anti)instanton bound states in type II on T^2, 2003.03301

Conferences/Workshops Attended:

1. String Theory from a Worldsheet Perspective, Galileo Galilei Institute for Theoretical Physics, Florence, Italy, 15-19 April, 2019

Visits to other Institutes:

1. International Centre for Theoretical Sciences, Bengaluru, 11-13 December 2019
2. Tata Institute of Fundamental Research, Mumbai, 20-22 October, 2019
3. Galileo Galilei Institute for Theoretical Physics, Florence, Italy, 15-19 April, 2019

Invited Lectures/Seminars:

1. Eigenvalue equation for the modular graph $C_{a,b,c,d}$; International Centre for Theoretical Sciences, Bengaluru, 12 December 2019
2. Eigenvalue equation for the modular graph $C_{a,b,c,d}$; Tata Institute of Fundamental Research, Mumbai, 21 October 2019
3. Eigenvalue equation for genus two modular graphs; Galileo Galilei Institute for Theoretical Physics, Florence, Italy, 16 April, 2019

Other Activities:

1. Taught the Electrodynamics course, Aug-Dec, 2019.

Tapas K Das

Research Summary:

I continue working on relativistic black hole accretion. Of late, I have started working on two new topics. We construct the emergent space-time through non-linear higher order perturbation to demonstrate that the analogue gravity phenomena is general enough to be produced through any perturbation of arbitrary order. We also propose the existence of the acoustic analogue of the traversable wormholes and the multiverse. These are two novel ideas on which no work exists in the literature as of now.

My research related to the black hole shadow imaging came to the news ('The Dark Knight', by Prof. Aswin Sekhar, a science writer and astronomer working in UK and Canada, , The Telegraph, 14th of April (online version) and on 15th of April (print version), 2019) in the context of the discovery of black hole shadow image using the event horizon telescope.

Publications:

1. Tarafdar, Pratik., Bollimpalli, Deepika A., Nag, Sankhasubhra., & Das, Tapas K., *Influence of geometrical configuration on low angular momentum relativistic accretion around rotating black holes,* Physical Review D **Volume 100, Issue 4**, id.043024, (2019).

Preprints:

1. Datta, Satadal., & Das, Tapas K., *Lagrangian Description of Accreting Black Hole Systems in the Context of Emergent Spacetime,* eprint arXiv:1910.06768 [astro-ph.HE] (2019).

2. Tarafdar, Pratik., Maity, Susovan., & Das, Tapas K., *Influence of flow thickness on general relativistic low angular momentum accretion around spinning black holes,* eprint arXiv:2005.01746 [astro-ph.HE] (2020).

3. Maity, Susovan., Tarafdar, Pratik., Shaikh, Md. Arif., & Das, Tapas K., *Dependence of acoustic surface gravity on disc thickness for accreting astrophysical black holes,* eprint arXiv:2005.13573 [astro-ph.HE] (2020).

4. Fernandes, Karan., Maity, Susovan., & Das, Tapas K., *Emergent gravity through non-linear perturbation,* eprint arXiv:2005.14114 [gr-qc] (2020).

Visits to other Institutes:

1. One year sabbatical visit at Indian Statistical Institute, Kolkata, during the period April 2019 - April 2020.

2. Several visits to Indian Statistical Institute (post April 2020 phase) to continue ongoing projects with my collaborator working over there.

3. Several visits to S N Bose National Centre For Basic Sciences, Kolkata, to continue ongoing projects with my collaborator working over there.
4. Several visits to Sarojini Naidu College for Women, Kolkata, to continue ongoing projects with my collaborator working over there.
5. Bangabasi College, Kolkata.
6. Dumdum Motijhil College, Kolkata.
7. Rishi Bankim Chandra College, Naihati.
8. St. Xavier's College, Kolkata.

Invited Lectures/Seminars:

1. '*Supermassive Black Holes in the Universe*', **Dr. Ramatosh Sarkar Memorial Lecture** at Bangiya Bijnan Parishad (founded by Prof. Satyendranath Bose), Kolkata. February, 2020.
2. '*Black Hole Shadow Imaging*', a public lecture presented at St. Xavier's College, Kolkata. August, 2020.
3. '*Identification of Astrophysical Black Holes*', a colloquium presented (in Bengali, for junior college students), at Rishi Bankimchandra College, Naihati, July, 2019.
4. '*Observation of black holes*', a public lecture presented for the college students at the Dumdum Motijhil College, organized by the Bangiya Bijnan Parishad (founded by Prof. Satyendranath Bose), Kolkata. July, 2020.
5. *Portrait of a dark phase*, a colloquium presented at the Physics and Applied Mathematics Unit, Indian Statistical Institute, Kolkata. May, 2020.
6. '*Andhokarer Utso Hote*' (From the source of darkness, in English), a public lecture (in Bengali language) arranged in Kolkata for more than six hundred college and university students, after the great discovery of the M87 black hole's shadow image through the event horizon telescope. May, 2020.

Other Activities:

1. **Supervision of Ph.D. students:** Two of my Ph.D. students have received Ph.D. degree, and one Ph.D. student (I am his co supervisor, he is formally registered with a faculty member of S N Bose National Centre for Basic Sciences in Kolkata, however, he worked for his Ph.D. thesis with me) has submitted his thesis (Viva voce examination got delayed indefinitely due to the Corona outbreak event). They are:
   (a) Md. Arif Shaikh, Title of the Thesis: *On emergent sonic geometry through the linear perturbation of relativistic black hole accretion* (provisional degree awarded).
   (b) Satadal Datta, Title of the Thesis: *Emergent gravity phenomena in accreting astrophysical systems* (provisional degree awarded).

(c) Pratik Tarafdar, Title of the Thesis: *Accreting Black Hole Systems as Classical Analogue Gravity Models* (thesis submitted to Calcutta University).

2. **Ph.D. thesis examination:** Served as the examiner of a Ph.D. thesis on quantum gravity and general relativity submitted to the Calcutta university.

3. **Referee's Job:** Served as the referee of various international journal, Journal of Cosmology and High Energy Astrophysics, JCAP (Impact Factor 5.524), for example.

4. **Mentoring students:** Served as the mentor for visiting summer research project students:

   (a) Pathikrith Banerjee, from The University of Manchester, UK.

   (b) Vishal Mahendra, from SRM Institute of Science and Technology, KTR, Chennai.

5. **Responsibility for various internal committees:** Served as the member of:

   (a) Library committee.

   (b) Medical advisory committee.

6. **Teaching:** Taught the following courses:

   (a) Mathematical Methods - I.

   (b) Astrophysics.

Aditi Sen De

Research Summary:

During the last year, we have addressed several current problems in quantum information science. Among them, three main directions were designing quantum storage devices which are robust against impurities, finding generic quantum characteristics of multipartite random states and characterization of entanglement between the various modes of multimode states of light.

Devices that store energy for later purposes like batteries are extremely useful to fulfill our daily needs ranging from communication appliances to medical accessories like artificial cardiac pacemakers, hearing aids. In this respect, a natural question is to ask whether quantum mechanics can help to design a machine which can efficiently store or generate energy. It was recently shown that quantum mechanical principles indeed help. In our work, we investigated the role of many-body interactions, ordered as well as disordered, of the parent battery Hamiltonian on the performance of the battery. Specifically, we showed that in case of the transverse XY and the XYZ model without disorder, power of the battery critically depends on the interactions and its characteristics like the ferromagnetic or the antiferromagnetic ones. Moreover, we observed that the Gaussian-distributed random interaction strengths, both in the xy-plane and in the z-direction of the XYZ model, enhance the quenched-averaged power of the battery compared to that of the ordered case.

Beyond the bipartite domain, understanding of quantum correlations (QC), even for pure states shared by multiple parties, is limited due to its complex structure. Recently, we studied the distribution of QC among the various parties of a random multipartite quantum state, with the help of the concept of monogamy of quantum correlations and also by using localizable entanglement (LE). In both situations, we showed that they reach their algebraically allowed maximum value on increasing the number of qubits for random pure states irrespective of the QC measure while the standard deviation of the distributions decreases when one increases the number of qubits from three to five.

In another work, we proposed a distance-based (geometric) genuine multimode entanglement measure between the various modes of multimode states of light, where each mode contains an arbitrary number of photons, and hence the corresponding Hilbert space is an infinite-dimensional one. For Gaussian states, we obtained a closed analytical form in terms of the symplectic eigenvalues of the covariance matrix. Since the dimension of the covariance matrix grows linearly with the number of modes, we provide an efficient and scalable prescription for computing the measure of pure Gaussian states having an arbitrary number of modes. We also investigated the content of genuine multimode entanglement in non-Gaussian states which are generated via photon addition and subtraction.

Publications:

1. S. Ghosh, T. Chanda, and A. Sen(De), *Enhancement in performance of quantum battery by ordered and disordered interactions*, Phys. Rev A **101,** 032115 (2020).

2. G. Sharma, M. A. Siddiqui, S. Mal, S k Sazim, and A. Sen(De), *Robustness of interferometric complementarity under decoherence*, Phys. Lett. A **384**, 126297 (2020).

3. A. Sen (De), *Resources for Quantum Technologies*, PHYSICS NEWS (BULLETIN OF THE INDIAN PHYSICS ASSOCIATION, January March 2020) **50**, 24 (2020).

4. S. Das, C. Mukhopadhyay, S. Singha Roy, S. Bhattacharya, A. Sen(De), and U. Sen, *Wave-particle duality employing quantum coherence in superposition with non-distinguishable pointers*, J. Phys. A: Math. Theor. **53**, 11503 (2020).

5. C. Srivastava, A. Bera, A. Sen(De), and U. Sen, *One-shot conclusive multiport quantum dense coding capacities*, Phys. Rev. A **100**, 052304 (2019).

6. S. Rethinasamy, S. Roy, T. Chanda, A. Sen(De), and U. Sen, *Universality in Distribution of Monogamy Scores for Random Multiqubit Pure States*, Phys. Rev. A **99,** 042302 (2019).

7. S. Singha Roy, H.S. Dhar, A. Sen(De), and U. Sen, *Tensor-network approach to compute genuine multisite entanglement in infinite quantum spin chains*, Phys. Rev. A **99**, 062305 (2019).

8. J. Jayakumar, S. Das, A. Sen(De), and U. Sen, *Mimicking disorder on a clean graph: Interference-induced inhibition of spread in a cyclic quantum random walk*, Europhys. Lett. **128**, 20007 (2019).

9. S. Das, S. Mal, A. Sen(De), and U. Sen, *Inhibition of spreading in quantum random walks due to quenched Poisson-distributed disorder*, Phys. Rev. A **99**, 042329 (2019).

10. S.Das, A. Misra, A.K. Pal, A.Sen(De) and U. Sen, *Necessarily transient quantum refrigerator*, Europhys. Lett. **125**, 20007 (2019).

11. M. Pandit, A. Bera, A. Sen(De), and U. Sen, *Position and momentum cannot both be lazy: Quantum reciprocity relation with Lipschitz constants*, Phys. Rev. A **100**, 012131 (2019).

12. A. Bera, D. Sadhukhan, D. Rakshit, A. Sen(De), and U. Sen, *Response of entanglement to annealed vis--vis quenched disorder in quantum spin models*, Europhys. Lett. **127**, 30003 (2019).

Preprints:

1. R. Banerjee, A. K. Pal, and A. Sen(De), *Hierarchies of localizable entanglement due to spatial distribution of local noise*, arXiv:2003.02175.

2. R. Banerjee, S. Ghosh, S. Mal, and A. Sen(De), *Spreading Nonlocality in Quantum Network*, arXiv:1912.08874.

3. S. Roy, T. Das, and A. Sen(De), *Computable genuine multimode entanglement measure: Gaussian vs. non-Gaussian*, arXiv:1912.03284.

4. S. Halder, S. Mal, and A. Sen (De), *Characterization and Generation of Absolutely Separable States*, arXiv:1911.13145.

5. C. Srivastava, S. Mal, A. Sen(De), and U. Sen, *Sequential measurement-device-independent entanglement detection by multiple observers*, arXiv:1911.02908.

6. A. Ghoshal, S. Das, A. Sen(De), and U. Sen, *Population inversion and entanglement in single and double glassy Jaynes-Cummings models*, arXiv:1910.00249.

7. S. Haldar, S. Roy, T. Chanda, and A. Sen (De), *Response of macroscopic and microscopic dynamical quantifiers to the quantum critical region*, arXiv:1908.06374.

8. R. Banerjee, A.K. Pal, and A. Sen(De), *Uniform Decoherence Effect on Localizable Entanglement in Random Multi-qubit Pure States*, arXiv:1907.10847.

9. S. Roy, A. Bera, S. Mal, A. Sen(De), and U. Sen, *Recycling the resource: Sequential usage of shared state in quantum teleportation with weak measurements*, arXiv:1905.04164.

Conference/Workshops Attended:

1. NEW DIRECTIONS IN QUANTUM INFORMATION, Nordic Institute for Theoretical Physics Sweden April 2019.

2. The Summer School on Quantum Information and Quantum Technology, Indian Institute of Science Education and Research Kolkata, June 13 - July 23, 2019.

3. Kaapi with Kuriosity and Colloquium of ICTS- TIFR, Bengaluru, India, June 2019.

4. National Conference on Gender in Physics, University of Hyderabad, Hyderabad, September 2019.

5. STATPHYS-KOLKATA10, Presidency University, Kolkata, November 2019.

6. Special Colloquium in the occasion of International day of women and girls in science, Physical Research Laboratory, February 2020 .

Visits to other Institutes:

1. Visited University of Calcutta, June 2019.

2. Visited IISER Kolkata, June 2019.

3. Visited SN Bose Centre for Basic Sciences, Jan 2020.

Invited Lectures/Seminars:

1. *One-shot Quantum Dense Coding*, NEW DIRECTIONS IN QUANTUM INFORMATION, Nordic Institute for Theoretical Physics Sweden April 2019.

2. *Quantum communication*, The Summer School on Quantum Information and Quantum Technology, Indian Institute of Science Education and Research Kolkata, June 2019.

3. *Quantum technologies* and *Quantum phase transitions through quantum information window*, Kaapi with Kuriosity and Colloquium of ICTS- TIFR, Bengaluru, India, June 2019.

4. *Technologies in a quantum world*, National Conference on Gender in Physics, University of Hyderabad, Hyderabad, September 2019.

5. *Dynamical Quantum Phase Transition*, STATPHYS-KOLKATA10, Presidency University, Kolkata, November 2019 .

6. *Quantum Technologies*, Special Colloquium in the occasion of International day of women and girls in science, Physical Research Laboratory, February 2020.

Other Activities:

1. Taught a one-semester course on "Quantum Information and Computation -I" during Aug-Dec 2019.

2. Taught " Quantum Information and computation -II" with Prof. Ujjwal Sen, Jan-April 2020.

3. Guiding the theses of Saptarshi Roy, Ratul Banerjee and Srijon Ghosh of HRI.

4. Guided projects of the following HRI graduate students:

   (a) Rivu Gupta, "Quantum correlations under decoherence" (Oct'19 -April'20).

   (b) Ganesh Lakkaraju, Quantum information processing with quantum many-body systems (Oct'19 -April'20).

5. Serving as the convenor of the Housing Committee, Internal Complaint Committee (ICC) and Women's Grievances at HRI.

6. Serving as referees in national and international journals.

7. Serving as members of the physics graduate committee, and Guest House / Pantry / Student Mess.

AseshKrishna Datta

Research Summary:

During the past one year I have worked mainly on Supersymmetry (SUSY) Phenomenology with a focus on understanding how robust the constraints on weak (TeV)-scale SUSY have got in view of recent results from the Large Hadron Collider (LHC) at CERN, Geneva, those from other low energy experiments and the ones from experiments that search for the elusive Dark Matter (DM). Although such constraints appear to be rather strong in general and hence have become the reason for weak-scale SUSY falling steadily out of favor as a scenario to take us beyond the Standard Model (SM) of particle physics, it must not slip out of our minds that many of these constraints are derived under various simplifying assumptions which can be questioned.

The central issue of my recent works *(one published and the other to be circulated soon)* concerns the light electrowinos and scalar excitations of a highly motivated SUSY scenario like the Next-to-Minimal Supersymmetric Standard Model (NMSSM) that could explain/satisfy the latest experimental findings in the frontier area involving the DM but could have been missed by the LHC experiments although those are very much within the latter's reach.

Publications:

1. Waleed Abdallah, AseshKrishna Datta, Arindam Chatterjee, *Revisiting singlino dark matter of the natural Z_3-symmetric NMSSM in the light of LHC*, JHEP 09 (2019) 095.

Conference/Workshops Attended:

1. Participated in the *Madgraph School 2019 (India)* held at Institute of Mathematical Sciences (IMSc.), Chennai during 18-22 November, 2019.

Visits to other Institutes:

1. Visited School of Physical Sciences (SPS), Indian Association for the Cultivation of Science (IACS), Kolkata several times during the period for collaborative works.

Invited Lectures/Seminars:

1. Invited to give a review talk at the discussion meeting *HUNTING SUSY @ HL-LHC* planned to be held at the International Centre for Theoretical Sciences (ICTS) in Bengaluru, India from April 20-24, 2020. *Had to decline the invitation as I have been dealing with serious matters at my workplace.*

2. Invited as a *plenary speaker* at the *International Conference on Neutrinos and Dark Matter (N&DM-2020)* on January 11-14 2020 in Hurghada, Egypt. *Had to decline the invitation as I have been dealing with serious matters at my workplace.*

3. Had to decline a preliminary invitation to write a book in a *Springer series as I have been dealing with serious matters at my workplace.*

Other Activities:

1. Supervising one student towards his Ph.D. thesis.
2. Mentoring a student in a mandatory project in his graduate course work.
3. Serving the Doctoral Committees of several students.
4. In the panel of referees of various international journals.
5. Served as examiners of various Ph.D. theses from other academic institutions.
6. Served as a member of the Physics Outreach Programme Committee, the Transport Committee and the Sports and Entertainment Committees at HRI.

Raj Gandhi

Research Summary:

My work over the past year has focussed on long baseline physics, dark matter and the effort to understand an unexpalined but statistically highly significant excess in the low energy data of the MiniBoone experiment. My student Samiran Roy , Waleed Abdullah and I are worked on new physics explanations of this anomaly, which can connect the standard model to the dark sector. This is an inherently difficult problem, and we were able to make progress this year. We continue to work on extending this effort.

Preprints (includes Collaboration papers):

1. Understanding the MiniBooNE and the muon g2 anomalies with a light Z and a second Higgs doublet, W. Abdallah, R. Gandhi, S. Roy, arXiv:2006.01948 [hep-ph].
2. First results on ProtoDUNE-SP liquid argon time projection chamber performance from a beam test at the CERN Neutrino Platform, Abi, B. and others, arXiv:2007.06722 [physics.ins-det].
3. Neutrino interaction classification with a convolutional neural network in the DUNE far detector, Abi, B. and others, arXiv:2006.15052 [physics.ins-det].
4. Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume IV Far Detector Single-phase Technology, Abi, B. and others, arXiv:2002.03010 [physics.ins-det].
5. Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume III DUNE Far Detector Technical Coordination, Abi, B. and others, arXiv:2002.03008 [physics.ins-det].
6. Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume I Introduction to DUNE, Abi, B. and others, arXiv:2002.02967 [physics.ins-det].
7. Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II DUNE Physics, Abi, B. and others, arXiv:2002.03005 [hep-ph].

Visits to other Institutes:

1. Fermilab, Chicago, June-July 2019

Other Activities:

1. Member, International Advisory Committee, NEUTRINO 2020 Conference .
2. Member, International Advisory Committee, XVth Rencontres du Vietnam 2019 Conference.

3. Member, DUNE International Collaboration, 2014-present.
4. Member, DUNE International Collaboration Institutional Board, 2014- present.
5. Member, Analysis Review Committee, 2020, DUNE International Collaboration
6. My student Samiran Roy finished his Ph.D.

Dileep Prabhakar Jatkar

Research Summary:

I worked with Sujay Ashok et al. on Exact WKB Analysis of CP^1 Holomorphic Blocks. We studied holomorphic blocks in the three dimensional $\mathcal{N} = 2$ gauge theory that describes the CP^1 model. We applied exact WKB methods to analyze the line operator identities associated to the holomorphic blocks and derive the analytic continuation formulae of the blocks as the twisted mass and FI parameter are varied. The main technical result we utilized was the connection formula for the ${}_1\phi_1$ q-hypergeometric function. We showed in detail how the q-Borel resummation methods reproduce the results obtained previously by using block-integral methods.

Publications:

1. S. K. Ashok, P. N. Bala Subramanian, A. Bawane, D. Jain, D. P. Jatkar and A. Manna, *Exact WKB Analysis of CP^1 Holomorphic Blocks*, JHEP **10**, 075 (2019) doi:10.1007/JHEP10(2019)075 arXiv:1907.05031 [hep-th]].

Other Activities:

1. Chair, SERB-THEP School committee, since August 2017.
2. Dean Academic, HRI, since March 2018.

Anshuman Maharana

Research Summary:

In the past year, my research has focussed on two topics: string cosmology and conformal field theories.

In string cosmology: The generic expectation in string/supergravity models is that there are multiple moduli fields with masses of the order of the supersymmetry breaking scale. We study the cosmology that arises as a result of vacuum misalignment of these moduli fields (in contrast to previous studies which mostly focussed on the single modulus case). We show that the dark radiation produced from the heavier moduli undergoes significant dilution. On the other hand, in the absence of fast annihilation processes decay of heavier moduli generically leads to overproduction of dark matter. We discuss a scenario where the problem can be addressed with a prompt dark matter annihilation to dark radiation. This can lead to realistic dark matter abundances, and the additional dark radiation produced as a result of this mechanism undergoes sufficient dilution as long as the annihilation is prompt. We have also developed methods to confront models of inflation constructed from string theory with precision cosmology data taking into account correlations between model parameters and post-inflationary evolution.

In conformal field theory: We have initiated studies to understand duality symmetries by exploiting bootstrap methods. We have been able to obtain relations between OPE coefficients of WZW models related by level rank duality by using bootstrap methods. Our results suggest an interesting connection between level rank duality and semi-classical holographic computations of the correlators in the dual theories.

Publications:

1. B. S. Acharya, M. Dhuria, D. Ghosh, A. Maharana and F. Muia
   Cosmology in the presence of multiple light moduli
   JCAP **1911** (2019) 035 , arXiv:1906.03025 [hep-th].

2. R. Mahanta and A. Maharana,
   Crossing, modular averages and $N \leftrightarrow k$ in WZW models
   JHEP **1910**, 061 (2019); arXiv:1905.02816 [hep-th]

Preprints:

1. S. Bhattacharya, K. Dutta, M. R. Gangopadhyay, A. Maharana and K. Singh, *Fibre Inflation and Precision CMB Data* [arXiv:2003.05969 [astro-ph.CO]].

Conference/Workshops Attended:

1. Chennai Symposium on Gravitation and Cosmology, IIT Madras (January 2020)

Visits to other Institutes:

1. ICTP, Trieste, Italy (May-June 2019)

2. National Taiwan University, Taipei, Taiwan (October 2019)

Invited Lectures/Seminars:

1. Chennai Symposium on Gravitation and Cosmology, IIT Madras (January 2020)
2. Seminar at National Taiwan University, Taipei, Taiwan (October 2019)

Other Activities:

1. Recognition for Top Cited Article (for the year 2018-19) in Fortschritte der Physik/Progress of Physics from Wiley Publications.
2. Member, Board of Studies (Physical Sciences) , Homi Bhabha National Institute
3. Chief Vigilance Officer, HRI, Allahabad
4. Chief Patent Officer, HRI, Allahabad

Pinaki Majumdar

Research Summary: (Technical)

We have comprehensively solved for the thermal phonon dynamics in the Holstein model using the Langevin approach. This allows identification of regimes that are dominated by (i) gaussian fluctuations, or (ii) tunneling events, or (iii) large amplitude oscillations. These modes also encode the spatial correlations in the problem. We have also generalised the Langevin approach to out of equilibrium situations to handle the response in correlated open systems. This allowed us to study the finite temperature driven Mott insulator, mapping out the insulator-metal transition as a function of bias and temperature.

Research Summary: (Non-Technical)

We have set up a dynamical scheme that combines the effect of strong drive and thermal fluctuations in a correlated system. This allows an understanding of magnets and superconductors out of equilibrium.

Publications:

1. Abhishek Joshi and Pinaki Majumdar, *Impact of speckle disorder on a superfluid Fermi system.* Phys Rev B 100, 045149 (2019).

2. Sauri Bhattacharyya, Sankha Subhra Bakshi, Saurabh Pradhan, and Pinaki Majumdar, *Strongly anharmonic collective modes in a coupled electron-phonon-spin problem.* Phys Rev B 101, 125130 (2020).

3. Abhishek Joshi and Pinaki Majumdar, *A classical fluctuation theory of the superfluid, Mott, and normal phases of correlated bosons.* Eur. Phys. J. B (2020) 93: 33

Arun Kumar Pati

Research Summary:

Teleporting Grin of a Quantum Chesire Cat without cat: Quantum Chesire Cat is a counterintuitive phenomenon that provides a new window into the nature of the quantum systems in relation to multiple degrees of freedom associated with a single physical entity. Under suitable pre and postselections, a photon (the cat) can be decoupled from its circular polarization (its grin). In this paper, we explore whether the grin without the cat can be teleported to a distant location. This will be a totally disembodied teleportation protocol. Based on the original Quantum Chesire Cat setup, we design a protocol where the circular polarization is successfully teleported between two spatially separated parties even when the photon is not physically present with them. The process raises questions in our understanding about properties of quantum system. In particular it shows that question like "whose polarization is it" can prove to be vacuous in such scenario.

Distinguishing two preparations for same pure state leads to signalling: Pure state of a physical system can be prepared in an infinite number of ways. Here, we prove that given a pure state of a quantum system it is impossible to distinguish two preparation procedures. Further, we show that if we can distinguish two preparation procedures for the same pure state then that can lead to signalling. This impossibility result is different than the no measurement without disturbance and the no-cloning. Extending this result for a pure bipartite entangled state entails that the impossibility of distinguishing two preparation procedures for a mixed state follows from the impossibility of distinguishing two preparations for a pure bipartite state.

Coherence and Information Gain : We have explored if quantum coherence of the system imposes a limitation on the information gain during quantum measurement. We have shown that the maximum information gain from a pure state, using a mixed apparatus is upper bounded by the initial coherence of the system. We have also argued that the information gain is upper bounded by the entropy exchange between the system and the apparatus.

Quantum Cheshire Cat and Exchanging Physical Attributes : We have proposed a thought experiment where we decouple two photons from their respective polarizations and then interchange them during recombination. Thus, our proposal shows that that the belongingness of a property for a physical system is very elusive in the quantum world.

Coherence of Purification: We have introduced a quantity called the coherence of purification which can be a measure of total quantumness for a single system. We have proved that the coherence of purification is always more than the coherence of the system. In addition, we have shown that the entanglement of purification that can be created by incoherent operation between two subsystems is upper bounded by the coherence of purification of the original system.

Coherence as witness for quantumness of gravity: We propose an interferometric set-up that utilizes the concept of quantum coherence to provide quantum signatures of gravity. The gravitational force comes into nontrivial play due to the existence of an extra mass in the set-up that transforms an incoherent state to a coherent state. The

implication uses the fact that quantum coherence at a certain site cannot be altered by local actions at a separate site. The ability to transform an incoherent state to a coherent one in the presence of gravitational field provides a signature of quantumness of gravity. We also observe that the results remain unaltered in presence of a nontrivial quantity of depolarising noise.

Relative Incompatibility: We have proposed a new measure of relative incompatibility for a quantum system with respect to two non-commuting observables, and call it quantumness of relative incompatibility. We have defined the relative entropy of the two marginal probability distributions as a measure of quantumness in the state, which is revealed only in presence of two non-commuting observables. We find that this measure depicts complementarity with quantum coherence.

Super Quantum Search Algorithm with Weak Value Amplification and Postselection: We propose a new model of quantum computation which aims to speed up quantum algorithms assisted by the weak value amplification and ancillay quantum register with the pre- and postelection. Within this model, we show that a quantum computer can solve a data base search of N entries in one step with probability close to one for large N, provided the post-selection on the ancillary quantum register is successful. In this model, to search a data base of N entries, the number of qubits grows from n to 2n, but there is a huge reduction in time complexity. Physically, this can be understood as the effect of weak value amplification that arises due to the pre- and postselection of the ancillary register which interacts with the n qubit register where quantum search is performed. This effectively accelerates the computation and takes the state of quantum computer much ahead in time, compared to what one would obtain without weak value amplification and post-selection.

Experimental Test of Forward and Reverse Uncertainty Relations : In another major work, we have experimentally tested multifold of state-dependent uncertainty relations for the product as well as the sum of variances of two incompatible observables for photonic qutrits. For the first time, we also test the state-dependent reverse uncertainty relations for the sum of variances of two incompatible observables, which implies another unique feature of preparation uncertainty in quantum mechanics.

Witnessing negative Conditional Entropy as an Operational Resource: Quantum states that possess negative conditional von Neumann entropy provide quantum advantage in several protocols including superdense coding, state merging, distributed private randomness distillation and one-way entanglement distillation. While entanglement is an important resource, only a subset of entangled states have negative conditional von Neumann entropy. Despite this utility, a proper resource theory for conditional von Neumann entropy has not been developed, unlike that of entanglement. We pave the way for such a resource theory by characterizing the class of density matrices having non-negative conditional von Neumann entropy as convex and compact. This allows us to prove the existence of a Hermitian operator (a witness) for the detection of states having negative conditional entropy for bipartite systems in arbitrary dimensions. We show constructions of this witness and explicate its utility in the detection of useful states in the above-mentioned protocols. We provide a local decomposition of the witness and probe its implications in the context of the uncertainty principle.

Quantum State Interferography: Quantum state tomography has been the traditional method for characterization of an unknown state. Recently, many direct mea-

surement methods have been implemented to reconstruct the state in a resource efficient way. In this letter, we present an interferometric method, in which, any qubit state, whether mixed or pure, can be inferred from the visibility, the phase shift and the average intensity of an interference pattern using a single shot measurement – hence, we name it as Quantum State Interferography. This method is experimentally implemented with high fidelity using the polarization degree of freedom of light . An extension of the scheme to pure states involving $(d1)$ measurements for d-dimensional systems is also presented

Publications:

1. D. Das, A. K. Pati,
Can Two Quantum Chesire Cats Exchange Grins?,
New Journal of Physics, 22, 063032 (2020). (Highlighted as feature Story in Scientific American, May 2019).

2. Lei Xiao, Bowen Fan, Kunkun Wang, Arun Kumar Pati, Peng Xue,
Direct Experimental Test of Forward and Reverse Uncertainty Relations,
Phys. Rev. Research 2, 023106 (2020).

Preprints:

1. Debmalya Das, Arun Kumar Pati,
Teleporting Grin of a Quantum Chesire Cat without cat,
arXiv:1903.04152.

2. A. K. Pati,
Distinguishing two preparations for same pure state leads to signalling,
arXiv:1904.05722.

3. A. K. Pati, Long-Mei Yang, C. Mukhopadhyay, Shao-Ming Fei, Zhi-Xi Wang,
Coherence of Purification,
arXiv:1907.13067.

4. Ahana Ghoshal, Arun Kumar Pati, Ujjwal Sen
Coherence as witness for quantumness of gravity,
arXiv:1909.07244.

5. Manish Kumar Shukla, Rounak Mundra, Arun K Pati, Indranil Chakrabarty, Junde Wu,
Quantumness of Relative Incompatibility,
arXiv:1909.12534.

6. Arun Kumar Pati,
Super Quantum Search Algorithm withWeak Value Amplification and Postselection,
arXiv:1910.12390

7. Mahathi Vempati, Nirman Ganguly, Indranil Chakrabarty, Arun K Pati,
Witnessing negative Conditional Entropy as an Operational Resource,
arXiv:2001.11237.

8. Surya Narayan Sahoo, Sanchari Chakraborti, Arun K. Pati, Urbasi Sinha *Quantum State Interferography,*
arXiv:2002.07446.

Visits to other Institutes:

1. Invited as Visiting Professor to Capital Normal University, Beijing during May 1st July 30, 2019.
2. Visited Prof. Pankaj Agrawal at Institute of Physics, Bhubaneswae from Dec 20-31, 2020.
3. Visited Prof. S. Ghosh at IMSc, Chennai from 31st Dec 2019 to 20th Jan 2020.

Invited Lectures/Seminars:

1. Invited speaker in symposium in honour of Sir Anthony J. Leggett, on the 3rd and 4th of February, 2019 held at RRI, Bangalore.
2. Invited speaker in Conference on Quantum Information and Many-Body Theory during March 1- 3, 2019 held at IIT, BHU, Varanasi.
3. Invited Colloquium in Department of Physics, Captial Normal University, Beijing, China on June 20, 2019.
4. Invited Colloquium in Chinese Academy of Science, Beijing on June 26, 2019.
5. Invited Colloquium in Department of Mathematics, Zhejiang University, Hangzhou, China on July 11, 2019.
6. Invited Physics Colloquium in BARC, Mumbai on Sept 27, 2019
7. Invited as a distinguished speaker during the Grace Hopper Celebration (GHCI-19) as part of the Emerging Tech and Industry Trends track on "Quantum Computing - the Reality behind the Hype" during November, 6-9, 2019 held at International Exhibition Centre 10th Mile, Tumkur Road, Bangalore, India. This event marks as the largest conference for Women technologists.
8. Invited speaker in QFF 2020 Quantum Frontiers and Fundamentals:Experimental Studies and Theoretical Ramifications Bangalore, India during 13 - 18 Jan, 2020.

Academic Highlights:

- Our paper "Can Two Quantum Chesire Cats Exchange Grins?" which was in arXiv in April 2004, was highlighted as feature Story in Scientific American, May 2019. (See the link) https://www.scientificamerican.com/article/spin-swapping-particles-could-be-quantum-cheshire-cats/

Other Activities:

1. Guided around 10 visiting students in the area of Quantum Information.
2. Evaluated Ph.D. thesis from University of Calcutta.
3. Two PhD students have submitted their thesis and one has been awarded degree. Six students are working for PhD in the area of Quantum Information.

Santosh Kumar Rai

Research Summary:

My research has been mainly focussed on studying the phenomenology of models beyond the Standard Model (SM) of particle physics and proposing methods of analysing their collider signals at future colliders. During last year I have proposed new ways of analysing signals for charged Higgs scenarios in different models as well as utilising machine learning methods to study dijet resonance at the LHC. We have also proposed how to study the effect of a very fat width particle leading to a resonant signal of top-partners in a composite model. In addition, I have continued my work on supersymmetric scenarios with left-right symmetry as well as compressed mass spectrum and studied their LHC phenomenology as well as at the high energy-high luminosity (HE-HL) upgrade of the LHC.

In continuation of our earlier studies of left-right supersymmetry we showed that the model can be nearly excluded at a high-energy upgrade of the LHC, expected to operate at a center-of-mass energy of 27 TeV. This minimal scenario has a relatively light $SU(2)_R$ doubly-charged Higgs boson, which could decay dominantly into tau-lepton pairs. We explore the associated signals comprised of at least three hadronically-decaying taus, or with at least two hadronic taus and one same-sign-same-flavor charged lepton pair.

One of the challenges of studying exotic resonances is the treatment of its width in analysing their signals. To address this, we reappraise the collider constraints on the vector-like colored top partners taking into account the impact of exotic colored vector resonances. These colored states are intrinsic to a broad class of models that employ a strongly interacting sector to drive electroweak symmetry breaking. We translate the recent results in the monolepton + jets channel as reported by CMS, and dilepton + jets and trilepton + jets channels as reported by ATLAS to constrain the parameter space of these class of models. We also comment on the impact and modification of the derived constraints due to the expected fatness of the colored vector resonance, when accounted for beyond the narrow-width approximation.

The challenges at a hadronic machine such as the LHC compounds on the fact that final states are swamped with jets which one needs to understand and unravel. A positive step in this direction would be to separate the jets in terms of their gluonic and quark identities, much in similar spirit of distinguishing heavy quark jets from light quark jets that has helped in improving searches for both neutral and charged Higgs bosons at LHC. We utilise this information and using the jet substructure techniques by emplying machine learning methods to comment on possible discrimination of new resonances in the all hadronic mode that would be crucial in pinning down new physics signals at HL-LHC, HE-LHC and any future 100 TeV hadron collider.

We study the discovery prospects of the charged Higgs boson in the context of multi Higgs models in certain BSM scenarios. We classify models into three categories based on the charged Higgs coupling properties: gaugophobic, fermiophobic, and chromophobic. In each case, we identify viable modes of discovery, and present LHC analysis for discovery. We find that extensions of the Standard Model in which the charged Higgs does not couple to colored particles offer the best possible avenues for discovery.

In an extension of our work on compressed SUSY spectrum with a light gravitino LSP, we identify that a distinguishing feature of this scenario is the production of longitudinal Z bosons in neutralino decays, unlike in the case of gauginolike neutralinos, where the Z is mostly transverse. The polarisation information of the parent Z boson gets reflected in the angular distributions of the decay leptons and in some other variables derived therefrom.

Publications:

1. K. Das, T. Mondal and Santosh Kumar Rai, *Non-standard signatures of vector-like quarks in a leptophobic 221 model,* Phys. Rev. D **99**, 115002 (2019).

2. P. S. B. Dev, S. Khan, M. Mitra and Santosh Kumar Rai, *Doubly-charged Higgs Boson at Future Electron-Proton Collider,* Phys. Rev. D **99**, 115015 (2019).

3. B. Coleppa, Santosh Kumar Rai and A. Sarkar, *Charged Higgs boson discovery prospects,* Phys. Rev. D **101**, 055030 (2020).

4. J. Dutta, B. Mukhopadhyaya and Santosh Kumar Rai, *Identifying a Higgsino-like NLSP in the context of a keV-scale gravitino LSP,* Phys. Rev. D **101**, 075040 (2020).

Preprints:

1. A. K. Nayak, Santosh Kumar Rai and T. Samui, *Probing Heavy Dijet Resonances Using Jet Substructure at the LHC,* [arXiv:1912.03511 [hep-ph]].

2. S. Dasgupta, Santosh Kumar Rai, T. S. Ray, *Impact of a colored vector resonance on the collider constraints for top-like top partner,* [arXiv:1912.13022 [hep-ph]].

3. Mariana Frank, Benjamin Fuks, Katri Huitu, Subhadeep Mondal, Santosh Kumar Rai, Harri Waltari, *The left-right supersymmetric option at a high-energy upgrade of the LHC,* [arXiv:2003.08443 [hep-ph]].

Conference/Workshops Attended:

1. *Anomalies 2019*, I.I.T. Hyderabad, Hyderabad, India, July 18-20, 2019.

2. *WHEPP XVI*, I.I.T. Guwahati, Guwahati, India, December 2-10, 2019.

Visits to other Institutes:

1. I.I.T. Kharagpur, Kharagpur, India, April 17-21, 2019.

2. Indian Association for the Cultivation of Science (IACS), Kolkata, India, April 21-24, 2019.

3. CERN, Geneva, Switzerland, September 23-October 7, 2019.

4. Institute for Theoretical Physics (ITP), Georg-August University, Goettingen, Germany, October 7-15, 2019.

5. Helsinki Institute of Physics (HIP), University of Helsinki, Helsinki, Finland, October 15-25, 2019.

6. CHEP, Indian Institute of Science (IISc.), Bengaluru, India, January 6-7, 2020.

Invited Lectures/Seminars:

1. *Quest for New Physics at the Large Hadron Collider.* CTS Colloquium, I.I.T. Kharagpur, April 18, 2019.

2. *Some non-standard signals of vector-like quarks at LHC.* Institute for Theoretical Physics (ITP), Georg-August University, Goettingen, Germany, October 10, 2019.

3. *Some non-standard signals of vector-like quarks at LHC.* Helsinki Institute of Physics (HIP), University of Helsinki, Helsinki, Finland, October 22, 2019.

Other Activities:

1. External Examiner, Thesis defense of Mr. Rahool K Burman, CHEP, Indian Institute of Science (IISc.), Bengaluru, January 2020.

2. Taught M.Sc. course (shared) titled *Classical Mechanics*, Nov-Dec, 2019.

3. Taught M.Sc. course (shared) titled *Numerical Methods*, Feb-, 2020.

4. Supervised Ph.d. of Ms. Juhi Dutta (Thesis successfully defended in August 2019).

5. Refereed papers for journals Physical Review D and EPJST.

6. Supervised Theory projects for 2 students, Shyamashish Dey and Anjan Kumar Barik.

7. Member, Local Works Committee, HPC Cluster, Computer Committee, Security Committee.

8. Co-ordinator, Regional Centre for Accelerator-based Particle Physics (RECAPP).

9. Member of Thesis Committee for around 6 students.

Sumathi Rao

Research Summary

During the period, April 2019-March 2020, we continued to work on new quantum phases of matter classified by topology, rather than the older paradigm of broken symmetries. We studied interesting phenomena at the edges of topological samples and the general phenomena of edge states, which are either formed naturally at the end of the sample or formed by engineering potentials in the bulk of the sample, by different techniques including shining light. Our interest is essentially transport in such novel and engineered materials.

We finished and published our work on the magnetic flux periodicity of a two-dimensional second order topological superconductors, which features zero-energy Majorana modes localized at the corners of the sample. We showed that the periodicity is $\frac{hc}{e}$ and changes back to $\frac{hc}{2e}$ at the transition to a topologically trivial superconductor, where the Majorana modes hybridize with the bulk states. This demonstrates that the doubling of periodicity is a manifestation of the non-trivial topology of the state.

We also finished our work on shining light on bilayer graphene. We have shown that chiral co-propagating Luttinger liquids can be created and tuned by shining high frequency, circularly polarized light, normal to the layers, with different polarizations on two sections of bilayer graphene. By virtue of the broken time-reversal symmetry and the resulting mismatch of Chern number, the one-dimensional chiral modes are localized along the domain wall where the polarization changes. We also found that a chiral Luttinger liquid can even be created on a single layer graphene sheet, with a single chiral edge mode near each Dirac node, whereas in bilayer graphene, there are two chiral modes near each of the Dirac nodes.

Our work on topological phase transitions has also been recently concluded and we found, using an inversion symmetry broken model in one dimension as an example, that there are cases where the fixed point and the critical point appear to intersect. These turn out to be multi-critical points and we have focussed on understanding its implications.

We are writing up our paper on the ground state near the interface between $\nu = 4$ and $\nu = 3$ quantum Hall(QH) systems. We found a regime where there are two edge phases stabilized by varying the strength of the interactions and the slope of the edge potential. In the phase which is stable for shallow potentials, spin is a good quantum number and there are no gapless spin fluctuations. When the edge potential is steep, the phase is characterised by gapless long wavelength spin excitations, which can in principle be deduced from a measurement of the relaxation time T_2 in nuclear magnetic resonance (NMR) near the edge.

We are continuing our work on the quantum Hall problem, but now we are interested in studying edge reconstruction in fractional quantum Hall states. Since Hartree-Fock theory can no longer be used, we are attempting to study it using the mapping to the classical plasma problem and using Monte Carlo techniques. We are also studying an effective theory of the edges of the quantum Hall effect for integer filling fractions, using bosonisation, with the aim of detecting extra neutral modes (via electrical means) by computing up-stream noise.

We are continuing with our interest in Weyl semi-metals and are currently working on studying the surface states at the interface of two Weyl semimetals with an arbitrary twist angle between them. We are also trying to understand how the tunneling through edge states in topological insulators and topological superconductors can be controlled by using an electric field, with the aim of devising topological transistors.

Publications:

1. Suman Jyoti De, Udit Khanna and Sumathi Rao, *Magnetic flux periodicity in second order topological superconductors*, Phys. Rev. **B101**, 125429 (2020).

Preprints:

1. Sourav Biswas, Tridev Mishra, Sumathi Rao and Arijit Kundu, *Chiral Luttinger liquids in graphene tuned by irradiation*,archive preprint, cond-mat/2003.09160
2. Faruk Abdulla, Priyanka Mohan and Sumathi Rao, *Curvature function renormalisation, topological phase transitions and multicriticality*, cond-mat/2003.10190
3. Amartya Saha, Suman Jyoti De, Sumathi Rao, Yuval Gefen and Ganpathy Murthy, *Emergence of spin-active channels at a quantum hall interface* (in preparation)

Conference/Workshops Attended:

1. *Edge dynamics in topological phases, EDYTOP*, ICTS, Bangalore, India, June 10-14, 2019
2. *Indian meeting on quantum condensed matter physics, QMAT 2019*, Indian Institute of Science, Bangalore, July 8-10, 2019
3. *Pressing for Progress 2019 : Gender equity in physics*, University of Hyderabad, India, September 19-20, 2019
4. *Geometric phases in optics and topological matter*, ICTS, Bangalore, Jan 21-24, 2020
5. *Lecture -Workshop on Women in Science : A career in science*, Deen Dayal Upadhyaya college, University of Delhi, Feb 26-27, 2020

Visits to other Institutes:

1. Visit to University of Hyderabad, India, Dept. of Physics, April 1-3, 2019
2. Visit to TIFR centre, Hyderabad, India, April 3, 2019
3. Visit to Dept of Physics, IISER, Bhopal, India, April 4, 2019
4. Visit to ICTS, Bangalore, India, June 3-6 2019
5. Visit to Manipal Institute of Technology, Mangalore, India,June 7 2019
6. Visit to ICTS, Bangalore, India, June 26 - July 18, 2019

7. Visit to IISER, Bhopal, India, July 29 - August 2, 2019
8. Visit to Ashoka University, Sonepat, India, August 25-28, 2019
9. Visit to ICTS, Bangalore, India, December 1, 2019 - January 3, 2020

Invited Lectures/Seminars:

1. *Majorana modes*, Dept. of Physics, University of Hyderabad, India, April 2, 2019
2. *Gender equity in science in the Indian context*, University of Hyderabad, India, April 3, 2019
3. *Majorana modes*, TIFR centre, Hyderabad, India, April 3, 2019
4. *Majorana modes and their identification*, Model Solvay Conference, Physics club, IISER Bhopal, India, April 4, 2019
5. *Introduction to exotic particles in condensed matter systems*, Physics Training and Talent Search, PTTS, Manipal Institute of Technology, Manipal, India, June 8, 2019
6. *Flux periodicity in higher order topological insulators*, talk at the workshop on edge dynamics in topological phases, EDYTOP, ICTS, Bangalore, India, June 14, 2019
7. *Topological phases of quantum matter*, IISER, Bhopal, India, August 1, 2019,
8. *Panel discussion on gender equity in physics*, University, of Hyderabad, India, September 19, 2019.
9. *Relationship of science and society*, Annual day lecture, G.B. Pant Institute of Social Sciences, Allahabad, India, September 10, 2019
10. *Topological phases of quantum matter*, Department of Physics, Ashoka University, Sonepat, India, September 27, 2019
11. *Topological phases of quantum matter*, ICTS, Bangalore, India, January 22, 2020
12. *Topological phases of quantum matter*, Deendayal Upadhyaya College, New Delhi, India, February 26, 2020

Other Activities:

1. Organised a workshop at ICTS, Bangalore, (EDYTOP) on *Edge dynamics in topological phases*, with Yuval Gefen, Jainendra Jain and Ganpathy Murthy, June 10-14, 2019.
2. Divisional Associate Editor, Physical Review Letters, American Physical Society, 2018-2021.
3. Member, Academic council, MNNIT, Allahabad
4. Convenor, Infosys committee (HRI)

5. Taught Condensed matter physics 1, Aug - Dec 2019 and 1/2 of the Condensed matter physics 2 course (Jan-May 2020)

Ashoke Sen

Research Summary:

My work during April 2019 - March 2020 has been on different aspects of string theory and classical and quantum theory of gravity.

1. Together with Alok Laddha, I gave a proof of the classical soft graviton theorem in > 4 dimensions to first subleading order by directly analyzing the classical equations of motion. This was later extended to four space-time dimensions in collaboration with Arnab Priya Saha and Biswajit Sahoo.

2. In collaboration with Faroogh Moosavian and Mritunjay Verma, I constructed the coaviant superstring field theory for open and closed strings.

3. I used string field theory to fix an ambiguity in the D-instanton induced amplitudes in two dimensional string theory. Later I also used string field theory to show how one can get finite, unambiguous result for the imaginary parts of the amplitude, and showed that the results agree with the results of the dual matrix model.

4. I developed a general framework for systematically computing D-instanton induced amplitudes in any string theory, avoiding the infrared divergences that usually accompany such amplitudes.

Publications:

1. A. Laddha and A. Sen, "Classical proof of the classical soft graviton theorem in $D > 4$," Phys. Rev. D **101**, no.8, 084011 (2020) doi:10.1103/PhysRevD.101.084011 [arXiv:1906.08288 [gr-qc]].

2. S. Faroogh Moosavian, A. Sen and M. Verma, "Superstring Field Theory with Open and Closed Strings," JHEP **01**, 183 (2020)
   doi:10.1007/JHEP01(2020)183 [arXiv:1907.10632 [hep-th]].

3. A. Sen, "Fixing an Ambiguity in Two Dimensional String Theory Using String Field Theory," JHEP **03**, 005 (2020)
   doi:10.1007/JHEP03(2020)005 [arXiv:1908.02782 [hep-th]].

4. A. P. Saha, B. Sahoo and A. Sen, "Proof of the classical soft graviton theorem in $D = 4$," JHEP **06**, 153 (2020) doi:10.1007/JHEP06(2020)153 [arXiv:1912.06413 [hep-th]].

Preprints:

1. A. Sen, "D-instanton Perturbation Theory," [arXiv:2002.04043 [hep-th]].

2. A. Sen, "Divergent to Complex Amplitudes in Two Dimensional String Theory," [arXiv:2003.12076 [hep-th]].

Invited talks at Conferences / Workshops / Schools

1. GGI workshop "String Theory from a Worldsheet Perspective", April, May, 2019
2. School and Workshop "New Pathways in Explorations of Quantum Field Theory and Quantum Gravity Beyond Supersymmetry", ICTP, Trieste, June 2019
3. Strings 2019, Brussels, July 2019
4. Discussion meeting on "The Future of Gravitational-Wave Astronomy", ICTS, Bangalore, August 2019
5. Precision Gravity: From the LHC to Lisa, MIAPP, Munich, September 2019
6. Workshop on Supermoduli, Institute for Geometry and Physics, Trieste September 2019
7. Bangladesh-India Winter School on Fundamental Physics, IUB, Dhaka, December 2019
8. National Strings Meeting, Bhopal, December 2019
9. M-theory and Mathematics, NYUAD, Abu Dhabi, January 2020

Courses given at HRI

1. General Relativity, August-October, 2019
2. Lectures on Entanglement and Geometry, January-March, 2019

Prasenjit Sen

Research Summary:

Our research explored both fundamental properties and application potential of a variety of materials. We studied ternary transition metal tri-chalcogenides, a class of layered materials. We developed new insights into the electronic structure of four of these compounds. Using high throughput computational approach, we screened 72 possible such compounds for their efficiency as catalysts in hydrogen evolution reaction. We identified 13 promising compounds.

Using first principles electronic structure methods, we developed detailed understanding of why α-MnO_2 acts as an efficient cathode in Li-air batteries. We made suggestions for improving their efficiency.

In collaboration with the experimental group of Prof. Satyajit Banerjee at IIT-Kanpur, we studied magnetic properties of Co_2C nano-clusters. We found core-shell magnetic structure in these nano-clusters which explained exchange bias effect, and large blocking temperature seen in experiments.

Publications:

1. A. Sen and P. Sen, *Designing rare earth free permanent magnets: Insights from small Co clusters,* Phys. Chem. Chem. Phys. **21**, 22577 (2019)

2. *Localized spin waves at low temperatures in a cobalt carbide nanocomposite,* N. Roy, A. Sen, P. Sen and S. S. Banerjee, J Appl. Phys. **127**, 124301 (2020)

Preprints:

1. K. Alam, N. Seriani and P. Sen, *Catalytic properties of α-MnO_2 for Li-air battery cathodes: a density functional investigation* (submitted).

2. P. Sen and R. Chouhan, *Electronic structure of MPX_3 tri-chalcogenide monolayers in density functional theory: A case study with four compounds (M=Mn, Fe; X=S, Se)* (submitted).

3. P. Sen, K. Alam, T. Das, R. Banerjee and S. Chakraborty, *Combinatorial design and computational screening of 2D transition metal tri-chalcogenide monolayers: Toward efficient catalysts for hydrogen evolution reaction* (submitted).

4. N. Roy, M. A. Ali, A. Sen, P. Sen and S. Banerjee, *Evidence of Exchange Bias effect in pure Co_2C nanoparticles* (under preparation).

Conference/Workshops Attended:

1. Asian Consortium for Computational Materials Science, International Conference on Materials Genome 2020, 5-7 February 2020 at the SRM University, Amaravati AP, India.

2. Flatland and Beyond, a conference on 2D materials at the S. N. Bose Centre for Basic Sciences, Kolkata, September 2019.

3. Nano India 2019, M. G. University, Kottayam, Kerala, India, April 2019.

Visits to other Institutes:

1. NISER, Bhubaneswar, Sep 15-18, 2019.

Invited Lectures/Seminars:

1. "Atomic Clusters: From Fundamentals to Applications" at Nano India 2019, M. G. University, Kottayam, Kerala, India, April 2019.

2. "Towards a correct description of MPX_3 tri-chalcogenides in DFT: A case study" at Flatland and Beyond, a conference on 2D materials at the S. N. Bose Centre for Basic Sciences, Kolkata, September 2019.

3. "Low dimensional magnetic systems Ternary transition metal tri-chalcogendies & Co clusters", NISER, Bhubaneswar, India.

4. "Towards a correct description of MPX3 tri-chalcogenides in DFT A case study" at IEMPHYS - 19: International Conference on Condensed Matter Physics, 16 Nov 2020, at IEM Kolkata, India.

5. "New Insights into Old Materials: Ternary tri-chalcogenides and Co-based clusters" at the Asian Consortium for Computational Materials Science, International Conference on Materials Genome 2020, 5-7 February 2020 at the SRM University, Amaravati AP, India.

Other Activities:

1. Member of Editorial Board, Physica Scripta.

2. Reviewed papers for journals.

3. Convener Cluster Committee, member Colloquium Committee, Physics Academic Committee.

Ujjwal Sen

Research Summary:

In the past academic year, we have worked on a broad spectrum of areas in and around quantum information and computation. This ranged from finding quantum refrigerators that necessitates one to tap them in their transient regimes, to the the importance of quantum coherence in quantum computation algorithms, and quantum Chesire cats.

In one of the works, we dealt with the concept quantum coherence when seen as a superposition over probabilistically indistinguishable pointer states. One of the fundamental features of quantum mechanics is the superposition principle, a manifestation of which is embodied in quantum coherence. Coherence of a quantum state is invariably defined with respect to a preferred set of pointer states, and there exist quantum coherence measures with respect to deterministically as well as probabilistically distinguishable sets of quantum state vectors. Here we study the resource theory of quantum coherence with respect to an arbitrary set of quantum state vectors, that may not even be probabilistically distinguishable. Geometrically, a probabilistically indistinguishable set of quantum state vectors forms a linearly dependent set. We find the free states of the resource theory, and analyze the corresponding free operations, obtaining a necessary condition for an arbitrary quantum operation to be free. We identify a class of measures of the quantum coherence, and in particular establish a monotonicity property of the measures. We find a connection of an arbitrary set of quantum state vectors with positive operator valued measurements with respect to the resource theory being considered, which paves the way for an alternate definition of the free states. We notice that the resource theory of magic can be looked upon as a resource theory of quantum coherence with respect to a set of quantum state vectors that are probabilistically indistinguishable. We subsequently examine the wave-particle duality in a double-slit set-up in which superposition of probabilistically indistinguishable quantum state vectors is possible. Specifically, we report a complementary relation between quantum coherence and path distinguishability in such a set-up.

In another work, we establish an inequality involving the quantum coherence of an arbitrary quantum state, possibly nonpure, in arbitrary dimension and a noncommutativity estimator of an arbitrary observable. The noncommutativity estimator uses the commutator of the observable and its incoherent or classical part. The relation provides a direct method of obtaining an estimate of the quantum coherence of an arbitrary quantum state, without resorting to quantum state tomography or the existing witness operators.

In yet another work, we identify the conditions for local passivity for shared quantum batteries with local Hamiltonians. For locally passive states of two-qubit batteries, we find the relation of their entanglement content with the amount of energy that can be globally extracted from them. Moreover, we obtain that the deficit in work extraction from pure battery states due to the restriction to local unitaries is equal to the amount of optimal global work extractable from the corresponding pure locally passive battery state, for the same entanglement supply. Furthermore, the pure battery state for which globally extractable work attains a maximum, among the set of all pure states with a fixed value of entanglement, also provides the maximum locally

extractable work.

In another work, we propose an interferometric set-up that utilizes the concept of quantum coherence to provide quantum signatures of gravity. The gravitational force comes into nontrivial play due to the existence of an extra mass in the set-up that transforms an incoherent state to a coherent state. The implication uses the fact that quantum coherence at a certain site cannot be altered by local actions at a separate site. The ability to transform an incoherent state to a coherent one in the presence of gravitational field provides a signature of quantumness of gravity. We also observe that the results remain unaltered in presence of a nontrivial quantity of depolarising noise.

In another work, we introduce a probabilistic version of the one-shot quantum dense coding protocol in both two- and multiport scenarios, and refer to it as conclusive quantum dense coding. Specifically, we analyze the corresponding capacities of two-qubit, two-qutrit, and three-qubit shared states. We identify cases where Pauli and generalized Pauli operators are not sufficient as encoders to attain the optimal one-shot conclusive quantum dense coding capacities. We find that there is a rich connection between the capacities, and the bipartite and multipartite entanglements of the shared state.

Publications:

1. One-shot conclusive multiport quantum dense coding capacities, Chirag Srivastava, Anindita Bera, Aditi Sen De, Ujjwal Sen, Phys. Rev. A 100, 052304 (2019)

2. Population inversion and entanglement in single and double glassy Jaynes-Cummings models, Ahana Ghoshal, Sreetama Das, Aditi Sen De, Ujjwal Sen, Phys. Rev. A 101, 053805 (2020)

3. Beating detection loophole in nonlinear entanglement witnesses, Kornikar Sen, Sreetama Das, Ujjwal Sen, Phys. Rev. A 100, 062333 (2019)

4. Interference-induced localization in quantum random walk on clean cyclic graph, Jayanth Jayakumar, Sreetama Das, Aditi Sen De, Ujjwal Sen, EPL 128, 20007 (2019)

5. Universality in Distribution of Monogamy Scores for Random Multiqubit Pure States, Soorya Rethinasamy, Saptarshi Roy, Titas Chanda, Aditi Sen De, Ujjwal Sen, Phys. Rev. A 99, 042302 (2019)

6. Partial coherence and quantum correlation with fidelity and affinity distances, Chunhe Xiong, Asutosh Kumar, Minyi Huang, Sreetama Das, Ujjwal Sen, Junde Wu, Phys. Rev. A 99, 032305 (2019)

7. Tensor-network approach to compute genuine multisite entanglement in infinite quantum spin chains, Sudipto Singha Roy, Himadri Shekhar Dhar, Aditi Sen De, Ujjwal Sen, Phys. Rev. A 99, 062305 (2019)

8. Inhibition of spreading in quantum random walks due to quenched Poisson-distributed disorder, Sreetama Das, Shiladitya Mal, Aditi Sen De, Ujjwal Sen, Phys. Rev. A 99, 042329 (2019)

9. Response of entanglement to annealed vis-á-vis quenched disorder in quantum spin models, Anindita Bera, Debasis Sadhukhan, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, Euro. Phys. Lett., 127, 30003 (2019)

10. Fibonacci sequence and its generalizations in doped quantum spin ladders, Sudipto Singha Roy, Himadri Shekhar Dhar, Aditi Sen De, Ujjwal Sen, Journal of Magnetism and Magnetic Materials 478, 100 (2019)

11. Phase boundaries in alternating field quantum XY model with Dzyaloshinskii-Moriya interaction: Sustainable entanglement in dynamics, Saptarshi Roy, Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Aditi Sen De, Ujjwal Sen, Phys. Rev. B 99, 064422 (2019)

12. Universal quantum uncertainty relations: Minimum-uncertainty wave packet depends on measure of spread, Anindita Bera, Debmalya Das, Aditi Sen De, Ujjwal Sen, Phys. Lett. A 383, 1850 (2019)

13. Wave-particle duality employing quantum coherence in superposition with non-orthogonal pointers, Sreetama Das, Chiranjib Mukhopadhyay, Sudipto Singha Roy, Samyadeb Bhattacharya, Aditi Sen De, Ujjwal Sen, J. Phys. A: Math. Theor. 53 115301 (2020)

14. Necessarily transient quantum refrigerator, Sreetama Das, Avijit Misra, Amit Kumar Pal, Aditi Sen De, Ujjwal Sen, EPL 125, 20007 (2019)

Preprints:

1. arXiv:2005.08296, Resource theory of quantum coherence with probabilistically non-distinguishable pointers and corresponding wave-particle duality, Chirag Srivastava, Sreetama Das, Ujjwal Sen

2. arXiv:2004.14816, How many runs ensure quantum fidelity in teleportation experiment?, C S Sudheer Kumar, Ujjwal Sen

3. arXiv:2004.09101, Detection loophole in measurement-device-independent entanglement witness, Kornikar Sen, Chirag Srivastava, Shiladitya Mal, Aditi Sen De, Ujjwal Sen

4. arXiv:2004.07729, Estimating quantum coherence by noncommutativity of any observable and its incoherent part, Tanaya Ray, Arun Kumar Pati, Ujjwal Sen

5. arXiv:2004.01419, Noncommutative coherence and quantum phase estimation algorithm, Shubhalakshmi S, Ujjwal Sen

6. arXiv:2001.00669, Delayed choice of paths selected by grin and snarl of quantum Cheshire Cat, Debmalya Das, Ujjwal Sen

7. arXiv:1911.05540, Local passivity and entanglement in shared quantum batteries, Kornikar Sen, Ujjwal Sen

8. arXiv:1911.02908, Sequential measurement-device-independent entanglement detection by multiple observers, Chirag Srivastava, Shiladitya Mal, Aditi Sen De, Ujjwal Sen

9. arXiv:1909.13125, Transmitting quantum information by superposing causal order of mutually unbiased measurements, Manish K. Gupta, Ujjwal Sen

10. arXiv:1909.09066, Witnessing nonlocality of bipartite quantum operations, Sohail, Ujjwal Sen

11. arXiv:1909.07244, Coherence as witness for quantumness of gravity, Ahana Ghoshal, Arun Kumar Pati, Ujjwal Sen

12. arXiv:1905.06198, Almost Markovian maps and entanglement-based bound on corresponding non-Markovianity, Sreetama Das, Sudipto Singha Roy, Samyadeb Bhattacharya, Ujjwal Sen

13. arXiv:1905.04164, Recycling the resource: Sequential usage of shared state in quantum teleportation with weak measurements, Saptarshi Roy, Anindita Bera, Shiladitya Mal, Aditi Sen De, Ujjwal Sen

14. arXiv:1904.05720, Signaling versus distinguishing different superpositions of same pure quantum state, Chirag Srivastava, Sreetama Das, Aditi Sen De, Ujjwal Sen

15. arXiv:1903.12096, Frequentist-approach inspired theory of quantum random phenomena predicts signaling, C. S. Sudheer Kumar, Anup Biswas, Aditi Sen De, Ujjwal Sen

16. arXiv:1903.03564, Quantum Process Randomness, Sreetama Das, Asutosh Kumar, Aditi Sen De, Ujjwal Sen

Conference/Workshops Attended:

1. Conference on Quantum Information and Many-Body Theory, March 01-03, 2019 at IIT (BHU) Varanasi, India.

2. NEW DIRECTIONS IN QUANTUM INFORMATION, April 1-26 2019, Nordita, Stockholm, Sweden.

3. Quantum Frontiers and Fundamentals: Experimental Studies and Theoretical Ramifications – QFF2020 from 13 - 18 January 2020 at the Raman Research Institute, Bengaluru, India.

Visits to other Institutes:

1. Visited Prof. Urbasi Sinha, RRI Bangaluru, India from the 27th May to 1st June 2019.

2. Visited Prof. R. Prabhu, Department of Physics at IIT Dharwad, Karnataka, India from 21st December 2019 to 31st December 2019.

3. Visited Prof. Satyabrata Adhikari, DTU, Delhi, India from 4th to 7th December, 2019.

Invited Lectures/Seminars:

1. Invited talk on "universal quantum uncertainty relations" at Conference on Quantum Information and Many-Body Theory, March 01-03, 2019 at IIT (BHU) Varanasi, India.

2. Invited talk on "universal quantum uncertainty relations" at NEW DIRECTIONS IN QUANTUM INFORMATION, April 1-26 2019, Nordita, Stockholm, Sweden.

3. Invited to present the 3rd National Seminar in memory of Late Prof. M. R. Gupta (also called the 6th M.R. Gupta memorial lecture), organized by the Advanced Centre for Nonlinear and Complex Phenomena, Kolkata and the Centre for Plasma Studies, Jadavpur University, Kolkata in Collaboration with the Department of Mathematics, Jadavpur University, Kolkata, on 6 August 2019 at 10.30 AM in the Department of Mathematics, Jadavpur University, Kolkata, India. Presented the lecture on "What is entanglement?"

4. Invited talk on "Entanglement and related concepts in glassy quantum systems" at Quantum Frontiers and Fundamentals: Experimental Studies and Theoretical Ramifications – QFF2020 from 13 - 18 January 2020 at the Raman Research Institute, Bengaluru, India.

5. Invited talk on "What is entanglement?" at Conference on Quantum Physics, Brain Function in Modern Science and Buddhist Philosophy, organized by Tibet House, Cultural Centre of His Holiness the Dalai Lama in collaboration with Choe Khor Sum Ling (CKSL), Tibetan Buddhist Meditation and Study Centre and Indian Institute of World Culture (IIWC), Bengaluru on 18th and 19th January 2020 at IIWC, Bengaluru, India.

Other Activities:

1. Current PhD students: Sreetama Das, Chirag Srivastava, Ahana Ghoshal, Kornikar Sen, Tanaya Ray.

2. Courses taken/ongoing: Quantum mechanics 2, January-May 2019; Quantum information and computation 2, January-May 2019 (shared with Prof. Aditi Sen De); Research methodology and Numerical Methods, January-May 2020 (shared with Prof. Santosh K. Rai); Quantum information and computation 2, January-May 2020 (shared with Prof. Aditi Sen De).

3. Committees: Convener of HRI computer committee, members of HRI cluster computing, HRI outreach program, HRI faculty appointment committees.

4. Mentored/mentoring projects of Ganesh Chandra, Swati Choudhary, Rivu Gupta, Sayan Mondal, Vivek Pandey.

5. Mentored/mentoring the masters theses of Shubhalakshmi S, IISER Pune, India, Shubhangi Goyal, University of Rajasthan, Jaipur, India, and Shashaank Khanna, IIT Indore, India.

6. Visiting students: Ipsita Bar, Karabi Batta, Suraka Bhattacharjee, Hardik Bohra, Vani Chaturvedi, Namitha CV, Vidushi Chaudhury, Dushyant Edadasula, Gautam Gangopadhyay, Riddhi Ghosh, Jayanth Jayakumar, Saksham Kumar, Snigdha Kumar, C. S. Sudheer Kumar, Asmitha Mekala, Ritwick Pandey, Swati Pandey, Mohd. Asad Siddiqui, Priya Singh, Tanvi Verma.

7. Editorial/advisory boards of journals: Journal of Physics B, Quantum, IOP SciNotes.

8. Member of thesis committees of several students at HRI and outside HRI.

Pratishruti Saha

Research Summary:

Project 1 - LHC Constraints on Scalar Diquarks : We study physics beyond the Standard Model that leads to baryon-number-violating interactions. Particles that mediate such interactions, known as diquarks, can carry a range of Standard Model quantum numbers. Moreover, their interactions with Standard Model quarks can have several Lorentz and chirality structures. We focus on two such scalar (spin-0) diquarks that couple to right-handed up-type or down-type quarks. Under the Standard Model gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$ they transform as $(\bar{\mathbf{3}}, \mathbf{1} + \mathbf{4/3})$ and $(\bar{\mathbf{3}}, \mathbf{1} - \mathbf{2/3})$, respectively. We use published data from the ATLAS and CMS Collaborations at the Large Hadron Collider to derive constraints on the masses and coupling strengths of these diquarks. Specifically, we use measurements of dijet production and single-top production. This augments and improves upon other previously obtained constraints from low-energy experiments.

Publications:

1. D. London, P. Saha and R. Watanabe, *B-Sector Anomalies – The Top Connection*, Springer Proc. Phys. **234**, 401-405 (2019)

Other Activities:

1. Taught the "Mathematical Methods II" course for Ph.D. and 2nd year M.Sc. students, August-December, 2019.

Waleed Mohammed Abdallah

Research Summary:

I have joined HRI as a post-doctoral fellow in Physics on March 21, 2018. My research has mainly focused on studying dark matter in models beyond the standard model and analysing their signatures at the large hadron collider.

Publications:

1. W. Abdallah, A. Kumar and A. K. Saha, *Soft leptogenesis in the NMSSM with a singlet right-handed neutrino superfield,* JHEP **04**, 065 (2020).
2. W. Abdallah, A. Hammad, S. Khalil and S. Moretti, *Dark Matter Spin Characterisation in Mono-Z Channels,* Phys. Rev. D **100**, 095006 (2019).
3. W. Abdallah, A. Chatterjee and A. Datta, *Revisiting singlino dark matter of the natural Z_3-symmetric NMSSM in the light of LHC,* JHEP **1909**, 095 (2019).
4. W. Abdallah, S. Choubey and S. Khan, *FIMP dark matter candidate(s) in a $B-L$ model with inverse seesaw mechanism,* JHEP **1906**, 095 (2019).

Preprints:

1. W. Abdallah, S. Choubey and S. Khan, *Two component FIMP DM in a $U(1)_{B-L}$ extension of the SM,* arXiv:2004.13211, contribution to: the International Conference on Neutrinos and Dark Matter (NDM-2020), 11-14 January 2020, Hurghada, Egypt.
2. W. Abdallah et al., *Reinterpretation of LHC Results for New Physics: Status and Recommendations after Run 2,* arXiv:2003.07868, LHC Reinterpretation Forum Collaboration.
3. Waleed Abdallah, AseshKrishna Datta and Subhojit Roy, *The last vestiges of a light bino-like dark matter in the Z_3-symmetric NMSSM,* (in preparation).
4. Waleed Abdallah, Raj Gandhi and Samiran Roy, *Understanding the MiniBooNE and the $(g-2)_\mu$ anomalies with a light Z' and a second Higgs doublet,* (in preparation).

Conference/Workshops Attended:

1. *International Conference on Neutrinos and Dark Matter (NDM-2020)*, Hurghada, Egypt, January, 2020.
2. *Madgraph School 2019*, The Institute of Mathematical Sciences (IMSc), Chennai, India, November, 2019.

Visits to other Institutes:

1. Center for Fundamental Physics (CFP) at Zewail City of Science and technology, Giza, Egypt, December, 2020.

Invited Lectures/Seminars:

1. *Two component FIMP DM in a $U(1)_{B-L}$ extension of the SM*, International Conference on Neutrinos and Dark Matter (NDM-2020), Hurghada, Egypt, January, 2020.

2. *Closing in on the Wino LSP via trilepton searches at the LHC*, ENHEP Meeting, Academy of Scientific Research and Technology (ASRT), Egypt, January, 2020.

Avik Banerjee

Research Summary

1. In this academic year, my research has primarily focussed on studying various aspects of chaos in strongly coupled field theories in presence of chemical potential, using the framework of AdS/CFT correspondence. Typically, chaos is diagnosed from the behaviour of 4-pt. out-of-time-ordered correlators in a thermal state, which naturally becomes trivial at zero temperature. In 47, we have shown that even at vanishing temperature, a particular class of operators still exhibit exponential and maximal growth, in presence of a chemical potential due to rotation. In the dual gravity, this particular state is realized by taking the extremal limit of rotating black holes. Both from the analysis of gravity modes and the dynamics of probe strings, we showed that the corresponding Lyapunov exponent is determined by the left-moving temperatures for BTZ and by a non-trivial function of the Frolov-Thorne temperatures in general.

2. In a couple of other works, I am studying the hydrodynamic origin of chaos and its diagnosis at the level of 2-pt function by revisiting the phenomenon of "pole-skipping" in presence of conserved charges in the system.

3. In 48, we are studying entanglement and complexity in the flavour sector of the holographic gauge theories. This is done by applying the usual Ryu-Takayanagi conjecture in open string geometries and computing the volume enclosed by the RT surface, giving the subregion complexity. These geometries are special in the sense that they are not realized within the conventional Einstein gravity and are also known to violate certain energy conditions. Our results therefore also aim at shedding light on the validity of these prescriptions beyond Einstein gravity and their intrication with energy conditions.

Preprints:

1. A. Banerjee, A. Kundu and R. R. Poojary, "*Rotating Black Holes in AdS, Extremality and Chaos*," [arXiv:1912.12996 [hep-th]].

2. A. Banerjee, A. Bhattacharya and S. Maulik, "*Perturbative Entanglement Structure and Entanglement Thermodynamics of Open String Geometries*," [arXiv:2006.***** [hep-th]].

Conference/Workshops Attended:

1. National Strings Meeting 2019, 22 - 27 December 2019, IISER Bhopal

2. Saha Theory Workshop 2020: Amplitudes and Correlators, 13 -17 January 2020, SINP Kolkata

Visits to other Institutes:

1. Visit to SINP Kolkata for Thesis defense and academic collaboration.

Other Activities:

1. Participation in Strings Snacks, weekly activity of String group

Atreya Chatterjee

Research Summary:

During the period 1st April, 2019 - 31st March 2020 I was engaged in two research projects.

My first project is on understanding relation between partition and metric. Given a sequence of natural numbers and partition, is there a direct way to get an emergent metric? Our guiding principle is emergent causality. We postulate that black hole of mass $M \in \mathbb{N}$ is described by $P\{M^2, w\}$ (partition of M^2 with weight w). Merger of two black holes of mass M and m to form a black hole of mass $M + m$ is then given by merger of the partitions

$$P\{M^2, w\} \bullet P\{m^2, w\} \quad \to ... \to P\{M^2, m^2, w, n\} \to ... \to \quad P\{(M+m)^2, w\}$$

When the two black holes are far away ($n = \infty$) total degeneracy is $P\{M^2, w\} \bullet P\{m^2, w\}$. Finally when the black holes have merged, degeneracy is $P\{(M+m)^2, w\}$ and $n = 0$. Intermediate state when the two black holes are at distance n is denoted by $P\{M^2, m^2, w, n\}$. This is the physical meaning of the above statement. When separation between two black holes is much larger than their Schwarzschild radius then the leading effect of merger is given by the motion of a black hole in the background due to other black hole. To find metric it is necessary to switch off the gravitational field of one of the black hole. In the test particle limit $P\{m^2, w\} \sim 1$ and when separation between two black holes is much larger than their Schwarzschild radius $n >> GM >> Gm$ the leading effect of merger is then given by geodesic motion of test black hole in the background due to other black hole. We give prescription for the intermediate state $P\{M^2, m^2, w, n\}$. From geodesic motion one can derive metric. We show that with this prescription, the merger is identical to a particle falling in Schwarzschild metric.

Second project is to find two experimentally verifiable predictions. Correction to Schwarzschild metric and gravitational radiation. Once measured it will let us retrieve information released during merger upto $O(G^3)$.

Conference/Workshops Attended:

1. *ST-4 workshop*, IISER-Bhopal, India, July, 2019

Tisita Das

Research Summary:

I have joined HRI on December 30, 2019. Durring this three months period, I have mainly worked on two projects out of which one work got published recently. In this work 72 ternary transition metal trichalcogenides have been studied to envisage the hydrogen evolution (HER) catalytic activity through a computational screening approach. 13 out of this 72 compounds have been found to yield exciting HER catalytic activity with some of the hitherto unsysthesized systems having overpotential even comparable to Pt. This comes an interesting addition to the list of noble metal free hydrogen evolution catalyst. This certainly could be a guide to the experimentalists where they can give a try to synthesize these compounds and measure the overpotential for enhanced hydrogen evolution from the experimental perspective also.

My ongoing project focuses on the transition metal trichalcogenide monolayer $FePS_3$, where I am trying to envisage the influence of sulfur mono and di vacancy defect on photocatalytic hydrogen and oxygen evolution. The main motivation behind exploration of this type of materials is that, metal trichalcogenphosphite compounds contain a wide range of elements that are dominated by divalent metal cations (e.g. Fe^{2+} in this particular case) and can be stabilized in octahedral sulfur or selenium environment. The strong ionic bond between metal cation and $[P_2S_6]^4$ anion present in the metal trichalcogenphosphite gives rise to the key distinctive feature: covalent bonding between atoms within the same layer, that can be hardly found in other layered materials. In this project, the HER and OER catalytic activity will be determined by mapping the reaction cordinate that can be constructed from the adsorption of different reaction intermediates involved is these electrochemical reactions. For a deeper insight both PH and electrolyte effect will also be taken into account.

Publications:

1. P. Sen, K. Alam, Tisita Das, R. Banerjee and S. Chakraborty, Combinatorial design and computational screening of 2D transition metal tri-chalcogenide monolayers: Towards efficient catalysts for hydrogen evolution reaction, *Journal of Phys. Chem. Letters* **11**, 3608 (2020).

Conference/Workshops Attended:

1. Oral and Poster presentation in 2^{nd} Indian Materials Conclave and 31^{st} MRSI-AGM, helt at CGCRI, Kolkata, India, in February 2020.

Karan Fernandes

Research Summary:

My research over the past year has been the following:

1) Extremal surfaces in Schwarzschild de Sitter spacetimes: We investigated real extremal spacelike and timelike surfaces in Schwarzschild de Sitter spacetimes 50 (in preprints). Both class of surfaces have an area which scales like the entropy. However, the area does not satisfy the known inequality on Schwarzschild de Sitter spacetimes and their dS/CFT interpretation remains to be explored.

2) Soft factors from classical scattering on the Reissner-Nordström spacetime: We consider the classical scattering of a point particle with mass and charge on the Reissner-Nordström spacetime 51 (in preprints). Our results extend known bremmstrahlung results from the point mass and point charge scattering on the Schwarzschild background. By considering the soft limit $\omega \to 0$ we demonstrate that our results provides the soft graviton and photon factor expressions in the presence of gravitational and electromagnetic interactions. We further explore the implications of our result on late time gravitational and electromagnetic waveforms.

3) Non-linear perturbations of transonic flows: We provide a framework to investigate perturbations of accretion flows up to arbitrary order 52 (in preprints). We find that an acoustic background exists up to all orders, which up to now has only been investigated at linear order. By considering the solutions numerically, we determine that the acoustic horizon can fluctuate and change in size at higher orders in perturbation. We consider very high and very low frequency damped perturbations. The acoustic horizon always grows in the case of high frequency perturbations. The case of low frequency perturbations is more peculiar, as the acoustic horizon can originally shrink, before increasing in size at higher orders in perturbations. This result appears to go beyond mere analogues with black holes.

4) Horizon hair from inversion symmetry: The extremal Reissner-Nordström spacetime admits a discrete conformal symmetry that maps null infinity with the event horizon. We demonstrate that Maxwell's equations and the Eastwood-Singer gauge are invariant under the Couch-Torrence transformation. This invariance is used to determine the expression for soft hairs on the event horizon from soft charges at null infinity. We further explore charges resulting from the wave equation. In this case, there exist an infinite tower of conserved Aretakis charges at the event horizon and Newman-Penrose charges at null infinity. This research is being carried out with Prof. A. Virmani and Mr. D. Ghosh at CMI, India and our draft is currently under preparation.

Preprints:

1. K. Fernandes, K. S. Kolekar, K. Narayan and S. Roy,
   "Schwarzschild de Sitter and extremal surfaces," [arXiv:1910.11788 [hep-th]]

2. K. Fernandes and A. Mitra,
"Soft factors from classical scattering on the Reissner-Nordström spacetime," [arXiv:2005.03613 [hep-th]]

3. K. Fernandes, S. Maity and T. K. Das,
"Emergent gravity from non-linear perturbation," [arXiv:2005.14114 [gr-qc]]

Conference/Workshops Attended:

1. Student talks in Physics (ST4) workshop at IISER Bhopal
(17/07/2019 - 25/07/2019)

2. Applications of Data Science in Astrophysics and Gravitational Wave Research (DSAP) workshop at IIIT Allahabad (01/11/2019 - 03/11/2019)

3. National Strings Meeting 2019 (NSM) at IISER Bhopal (20/12/19 - 01/01/20)

Visits to other Institutes:

1. Chennai Mathematica Institute (CMI) from 01/09/2019 - 08/09/2019

2. S.N.Bose National Centre for Basic Sciences (SNBNCBS) from
09/10/2019 - 18/10/2019

3. S.N.Bose National Centre for Basic Sciences (SNBNCBS) from
26/01/2020 - 31/01/2020

4. Chennai Mathematica Institute (CMI)
from 01/09/2019 - 21/02/2020 - 15/03/2020

Invited Lectures/Seminars:

1. Seminar on "Extremal surfaces on Schwarzschild de Sitter spacetimes"
on 27/01/2020

Purusottam Ghosh

Research Summary:

I have been working as a post-doctoral fellow in Department of Physics at HRI since September, 2019. My area of research mostly focused on Dark Matter (DM) phenomenology, its multipartite aspect, connection to neutrino physics, vacuum stability and discovery potential at direct search and at LHC. During the period September, 2019 to present, I have been involved several projects which I will briefly discuss here.

• In the first project we investigate *Signatures of multipartite DM at collider*. The basic idea of the work comes from the fact that if dark sector consists of more than one DM candidate then how it may show up in collider signature. Now, DM can have many different manifestations and signatures like missing energy associated with different combination of leptons and jets, displaced vertex, or a stable charge track. If the multiparticle dark sector caters to different signatures of above type, then there is possibly nothing to distinguish. The question of distinguishing them mainly arise when they have similar signature. In this work, we mainly focus on multilepton plus missing energy channel as the signal. The question we address, is if the signal distribution gets somehow distorted by the presence of more than one DM component contributing to it and if therefore it is possible to identify some such scenario from the signal distribution.

with *Subhaditya Bhattacharya, Biswarup Mukhopadhyaya* [In preparation]

• In the second work we propose a minimal extension of the Standard Model(SM) by including a vector-like fermionic doublet and three right handed neutrinos, in order to simultaneously explain dark matter(DM) and non-zero neutrino mass. The DM arises as a mixture of the neutral components of the fermionic doublet and the lightest of the three right handed neutrinos, all being odd under Z_2 symmetry. The other two Z_2 even heavy right hande neutrinos along with three SM neutrinos explain the light neutrino mass in a Type-I See-Saw scenario. Direct detection at terrestrial laboratories is possible through Higgs mediated elasctic scattering. Since with this particle content, the model is automatically $U(1)_{B-L}$ anomaly free, we have also studied the model extended by a gauged $U(1)_{B-L}$ symmetrty, which brings additional features in DM relic density as well as in direct detection.

with *Subhaditya Bhattacharya, Manoranjan Dutta, Narendra Sahu.*[In preparation]

Other ongoing Projects

Phenomenology of Vector like Fermionic DM with extended Left Right Symmetric model. with Santosh Kumar Rai .

Stability of scalar DM in presence of fermionic DM in two component DM scenario. with Subhaditya Bhattacharya, Najimuddin Khan .

Multicomponent WIMP-SIMP scenario.
with Shivam Verma.

Preprints:

1. ***Signatures of multipartite DM at collider.***
   Subhaditya Bhattacharya, *Purusottam Ghosh*, Biswarup Mukhopadhyaya .
   (In preparation)

2. ***Vector-Like Fermionic Dark Matter and Neutrino Mass in a Type-I See-Saw Scenario.***
   Subhaditya Bhattacharya, Manoranjan Dutta, *Purusottam Ghosh*, Narendra Sahu . (In preparation)

Conference/Workshops Attended:

1. HEP-Cosmo Webinar Series. HEP-Cosmo-India, India, July 10,17, 2020.

2. International Webinar series on Introduction to Cosmology, VIT Chennai, India, July 11, 2020.

3. Workshop in High Energy Physics Phenomenology XVI (WHEPP XVI), Department of Physics, IIT Guwahati , Guwahati, India, December 1-10, 2019 .

Visits to other Institutes:

1. IIT Guwahati, Guwahati, India, 26-31 January, 2020.

Invited Lectures/Seminars:

1. *Multi Particle Dark Matter: Dynamics and Phenomenological Implications*, IIT Guwahati, Guwahati,28th January, 2020.

Other Activities:

1. Participated and organized weekly HEP Journal club(every Monday) at HRI, January-March, 2020.

Nivedita Ghosh

Research Summary:

I have joined as Post Doctoral Research Fellow on February $24, 2020$. In this short time period, I have started working on Dark Matter issues, one of the compelling reason to go beyond the Standard Model of Particle Physics.

The problem of having a viable Dark Matter candidate can be solved in the context of a S_3 symmetric Two Higgs Doublet Model, where we introduce one full generation of vector-like lepton doublets along with their mirror doublets. In this work we demand the lightest vector like lepton to be dark matter that satisfies the relic density. In addition, as the lack of any dark matter signals in either direct or indirect dark matter detection experiments confront our theoretical expectations, these must satisfy increasingly severe constraints from experiments. In accordance with the parameter space, we then explore the possibility of detecting signals of the model at both the LHC and the ILC, in the pair production of the associated vector-like charged leptons which decay into final states including dark matter.

The work is in progress.

Saronath Halder

Research Summary:

I work in the theory of entanglement, considering finite dimensional Hilbert spaces and non-relativistic quantum systems.

Given a composite quantum system, distributed among several spatially separated parties, it may not be always possible to identify the state of the system correctly via local operations and classical communication (LOCC), even if the possible states are orthogonal to each other. LOCC is a physically motivated operation which is also known as free operation within the theory of entanglement. However, the above problem of identifying the state of system is particularly important to decode the information encoded in the state of the system. But this problem often gets complicated when the possible states of the system are entangled. We analyze different quantum measurement protocols which help identifying the state of the system. If the task cannot be accomplished by the free operation, then we talk about additional resources to complete the task. The above problem is also known as the local state discrimination problem. Recently, we have considered a setup where the classic al communication is limited (Phys. Rev. A **101**, 052313). The settings of local state discrimination problem is also important to characterize entanglement and also to characterize quantum operations (arXiv: 1910.14308). I am primarily interested in these problems.

There are also some other problems as well. There exist states which cannot be transformed to entangled states under global unitary operations. These states are called absolutely separable states. Recently, we have characterized such states and have considered it's generation in the noisy environments (arXiv: 1911.13145). I am also interested in the problems related to separability criterion, i.e., given a state of a composite quantum system, one has to tell whether it is separable or entangled. Checking the positivity under partial transpose, sometimes it is possible to tell if the state is separable or inseparable. But the problem occurs when the state of the system is a bound entangled state which is positive under partial transpose. Recently, we have explored a class of low-rank bound entangled states, detection of which cannot be done by the range criterion (arXiv: 2005.02108).

Publications:

1. "Locally distinguishing quantum states with limited classical communication" by **Saronath Halder** and Chirag Srivastava, Phys. Rev. A **101**, 052313 (2020).

Preprints:

1. "Local state discrimination and ordering of multipartite entangled states" by Sumit Rout, Ananda G. Maity, Amit Mukherjee, **Saronath Halder**, and Manik Banik, arXiv: 1910.14308 (2019).

2. "Characterization and generation of absolutely separable states" by **Saronath Halder**, Shiladitya Mal, and Aditi Sen(De), arXiv: 1911.13145 (2019).

3. “Unextendible product bases, bound entangled states, and the range criterion” by Pratapaditya Bej and **Saronath Halder**, arXiv: 2005.02108 (2020).

Conference/Workshops Attended:

1. Quantum Foundations, Technology and Applications (QFTA) at IISER Mohali, 2019. I have presented a talk there. The title of which was “Construction of noisy bound entangled states and the range criterion”.

Subramanya Hegde

Research Summary:

In the academic year 2019-2020, I worked on the following problem.

Relaxed hypermultiplet in four dimensional N=2 conformal supergravity: This work was done in collaboration with Bindusar Sahoo and Aravindhan Srinivasan. We coupled the relaxed hypermultiplet in rigid supersymmetry to conformal supergravity. We found the curious feature that for the coupling to be consistent with the superconformal algebra, different global $SU(2)$ irreducible representations would mix under $SU(2)$ R-symmetry. We found a suitable basis in which the fields form irreducible representations of R-symmetry. Using this explicitly showed that the coupling of relaxed hypermultiplet to conformal supergravity is the same as $O(3)$ multiplet coupled to conformal supergravity.

Publications:

1. *"Relaxed hypermultiplet in four dimensional N=2 conformal supergravity"* ,
   S. Hegde, B. Sahoo & A. Srinivasan
   Phys. Rev. D 101, 066012 (2020); [arXiv:2001.04285 [hep-th]].

Conference/Workshops Attended:

1. National Strings Meeting 2019, Indian Institute of Science Education and Research Bhopal, 22-27 December, 2019.
2. Saha Theory Workshop 2020: Amplitudes & Correlators, Saha Institute of Nuclear Physics, 13-17 January 2020.
3. Zoomplitudes 2020, Annual Amplitudes Conference conducted on Zoom by Brown University, 11-15 May 2020.

Visits to other Institutes:

1. Indian Institute of Science Education and Research Thiruvananthapuram, 27 January - 14 February 2020.

Invited Lectures/Seminars:

1. *New higher derivative invariant for tensor multiplet in N=2, D=4 conformal supergravity*, Gong show talk, National Strings Meeting 2019, IISER Bhopal.

Other Activities:

1. Gave introductory lectures on conformal supergravity at Harish-Chandra Research Institute Allahabad.

Jayita Lahiri

Research Summary:

I have worked in the past and am currently working in Beyond Standard Model Physics and its searches in the colliders (LHC and ILC). The Higgs and top sectors are very interesting and important probe of new physics because of the recent developments in the experimental particle physics. I am extensively working in new physics searches Higgs and top sector. I am working on extended Higgs models. I am also working on top polarization and phenomenology of boosted top quarks at the LHC. I am also working on collider searches of dark matter and using interesting machine learning techniques to improve the existing collider phenomenology of these searches. I am also interested in the Effective Field Theory formalism of new physics searches. I have worked on this topic too. In the past I have also worked on phenomenology of Supersymmetric models and CP-violation in various new physics models. I am very much interested in the topic of CP-violation and its probing through various observables.

Publications:

1. Boosted Top quark polarization - Rohini Godbole, Monoranjan Guchait, Charanjit K. Khosa, Jayita Lahiri, Seema Sharma, Aravind H. Vijay (ArXiv:1902.08096 - published in Phys.Rev. D100 (2019) no.5, 056010)

2. LHC signals of a heavy doublet Higgs as dark matter portal: cut-based approach and improvement with gradient boosting and neural networks - Atri Dey, Jayita Lahiri, Biswarup Mukhopadhyaya(ArXiv:1905.02242 - published in JHEP 1909 (2019) 004)

Preprints:

1. LHC signals of triplet scalars as dark matter portal: cut-based approach and improvement with gradient boosting and neural networks - Atri Dey, Jayita Lahiri, Biswarup Mukhopadhyaya (Arxiv:2001.09349). This paper has been accepted in JHEP and currently undergoinf proof-reading.

Conference/Workshops Attended:

1. Attended WHEPP,2019 at IIT Guwahati in December,2019.

Visits to other Institutes:

1. Visit to INFN, Rome, Italy in October,2019

2. Visit to INFN, Padova, Italy in October-November,2019.

3. Visit to University of Wurzburg, Germany in November, 2019.

Invited Lectures/Seminars:

1. Invited seminar at INFN, Rome, Italy in October,2019.
2. Invited seminar at INFN, Padova, Italy in November,2019.
3. Invited seminar at University of Wurzburg, Germany in November, 2019.

Shiladitya Mal

Research Summary:

1. Interferometric complementarity is known to be one of the most nonclassical manifestations of the quantum formalism. It is commonly known as wave-particle duality and has been studied presently from the perspective of quantum information theory where wave and particle nature of a quantum system, called quanton, are characterised by coherence and path distinguishability respectively. We here consider the effect of noisy detectors on the complementarity relation. We report that by suitably choosing the initial quanton and the detector states along with the proper interactions between the quanton and the detectors, one can reduce the in of noisy environment on complementarity, thereby pushing it towards saturation. To demonstrate this, three kinds of noise on detectors and their roles on the saturation of the complementarity relation are extensively studied. We also observe that for fixed values of parameters involved in the process, asymmetric quanton state posses low value of coherence while it can have a higher amount of distinguishability, and hence it has the potential to enhance the duality relation.

2. Complete measurements, while providing maximal information gain, results in destruction of the shared entanglement. In the standard teleportation scheme, the sender's measurement on the shared entangled state between the sender and the receiver has that consequence. We propose here a teleportation scheme involving weak measurements which can sustain entanglement upto a certain level so that the reusability of the shared resource state is possible. The measurements are chosen in such a way that it is weak enough to retain entanglement and hence can be reused for quantum tasks, yet adequately strong to ensure quantum advantage in the protocol. In this scenario, we report that at most six sender-receiver duos can reuse the state, when the initial shared state is entangled in a finite neighborhood of the maximally entangled state and for a suitable choice of weak measurements. However, we observe that the reusability number decreases with the decrease in the entanglement of the initial shared state. Among the weakening strategies studied, Bell measurement admixed with white noise performs better than any other low-rank weak measurements in this situation. We also consider measurement device independent entangled witness in this scenario.

3. The optimal success probability of a communication game reveals the fundamental limitations of an operational theory. Quantum advantage of parity oblivious random access code (PORAC), a communication game, over classical resources reveals the preparation contextuality of quantum theory [Phys. Rev. Lett. **102**, 010401 (2009)]. Optimal quantum bound for N-dit PORAC game for any finite dimension was an open problem. Here, we show that the degree of uncertainty allowed in an operational theory determines the amount of preparation contextuality. We connect the upper bound of fine-grained uncertainty relation to the success probability of PORAC game played with the quantum resource. Subsequently, we find the maximal quantum bound for N-dit PORAC game i.e., maximal quantum violation of preparation noncontextuality inequality. Finally, we compare maximal quantum violation of some preparation noncontextuality inequalities derived earlier for low dimensions with our result.

4. We characterize the boundary of the convex compact set of absolutely separable states that cannot be transformed to entangled states by global unitary operators

in $2 \otimes d$ Hilbert space. In particular, we show that the absolutely separable states of rank-$(2d-1)$ are extreme points of such sets. Moreover, we prove the existence of full-rank extreme and boundary points for those Hilbert spaces. Properties of certain interior points are also explored. We further show that by exploring the boundary of the above set, it is possible to develop an algorithm to generate the absolutely separable states which stay outside the maximal ball. By exploring paradigmatic noise models, we find the amount of local noise which the input entangled states can sustain, so that the output states do not become absolutely separable. Interestingly, we report that with the decrease of entanglement of the pure input state, critical depolarizing noise value, transferring an entangled state to an absolutely separable one, increases, thereby showing advantages of sharing nonmaximally entangled states.

5. Quantum non-locality is studied in network which is the basis for quantum internet and detection loophole problem of non-locality is addressed.

6. Non-Markovian effect of environment on quantum battery and protecting quantum correlations is studied extensively.

Publications:

1. Gautam Sharma, Mohammad Asad Siddiqui, Shiladitya Mal, Sk Sazim, Aditi Sen De, *Robustness of interferometric complementarity under Decoherence*, Phys. Lett. A **384**, 126297(2020).

Preprints:

1. Saptarshi Roy, Anindita Bera, Shiladitya Mal, Aditi Sen De, Ujjwal Sen , *Recycling the resource: Sequential usage of shared state in quantum teleportation with weak measurements*, arXiv:1905.04164 .

2. Chirag Srivastava, Shiladitya Mal, Aditi Sen De, Ujjwal Sen, *Sequential measurement-device-independent entanglement detection by multiple observers*, arXiv:1911.02908 .

3. Gautam Sharma, Sk Sazim, Shiladitya Mal, *Fine grained uncertainty determines preparation contextuality*, arXiv:1905.09695.

4. Saronath Halder, Shiladitya Mal, Aditi Sen De, *Characterization and Generation of Absolutely Separable States*, arXiv:1911.13145.

5. Ratul Banerjee, Srijon Ghosh, Shiladitya Mal, Aditi Sen De, *Spreading Nonlocality in Quantum Network*, arXiv:1912.08874.

6. Kornikar Sen, Chirag Srivastava, Shiladitya Mal, Aditi Sen De, Ujjwal Sen, *Detection loophole in measurement-device-independent entanglement witness*, arXiv:2004.09101.

7. Rivu Gupta, Shashank Gupta, Shiladitya Mal, Aditi Sen De, *Constructive Feedback of Non-Markovianity on Resources in Random Quantum States*, arXiv:2005.04009.

8. Srijon Ghosh, Titas Chanda, Shiladitya Mal, Aditi Sen De, *Fast charging of quantum battery assisted by noise*, arXiv:2005.12859.

Conference/Workshops Attended:

1. *5th International Conference for Young Quantum Information Scientists*, (2019), Gdansk, Poland, (Presented a poster).

2. *Quantum Frontiers and Fundamentals*, Raman Research Institute, India, January, 2020 (Presented a talk).

Visits to other Institutes:

1. University of Calcutta, Department of applied mathematics, July, 2019.

2. ICTQT, University of Gdansk, Poland, September, 2019.

Arpan Krishna Mitra

Research Summary:

1)In analogue gravity context we have unruh equation, an approximate wave equation for sound propagation in an inhomogeneous fluid. Unruh considered the background flow to be irrotational, barotropic and inviscid. In natural systems we seldom find irrotational flows. I, along with my collaborator Satadal Datta have focused on extending the corresponding acoustic metric equation for a flow with non-zero vorticity. We derive the equations for the perturbation(1st order) of the integrals of the fluid motion. Where we observe extra terms which we can interpret as current. We have further shown the conservation, which is in harmony with the idea of the non-dissipative system. We can derive the analogue space-time structure from this conservation equation. 2) With my mentor Prof. Tapas Kumar Das and my collaborator Prof. Subir Ghosh I am pursuing a different project. I am trying to derive an wave equation for sound propagation in a non-commutative fluid.

Preprints:

1. 'Analogue Gravity in Rotational Fluids - A New Outlook' (work in progress).

Conference/Workshops Attended:

1. "Astrophysics of Supermassive Black Holes", 17-19 Dec, 2019 at ICTS-TIFR, Bengaluru.

Visits to other Institutes:

1. Physics and Applied Mathematics Unit(PAMU), Indian Statistical Institute, Kolkata.

Arnab Priya Saha

Research Summary:

I have worked on the the following topics:

1. Celestial amplitudes: Pasterski, Shao and Strominger observed that gluon amplitudes in the bulk and can be expressed as conformal correlators on two dimensional sphere at null infinity of asymptotically flat spacetime. The asymptotic states of the scattering process are related to conformal wave functions living at null infinity. We extend this prescription such that bulk amplitudes can be expressed in the form analogous to conformal correlators living on 2+1 dimensional null infinity including the retarded time coordinate. We have explicitly constructed three and four point functions from gluon and gravity amplitudes. We have also shown soft factorization of these celestial amplitudes when momentum of one of the external states goes to zero.

2. Sub-leading soft graviton theorem: In four dimension S-matrix suffers from IR divergences. Sahoo and Sen showed that soft graviton and photon theorems are corrected to one loop level and instead of usual Laurent series expansion in the soft momentum, we get logarithmic terms. Classically soft theorems are related to low energy radiation in gravitational and electromagnetic waves. We have proven the classical soft graviton theorem to sub-leading order using classical scattering process. Alongside we have conjectured a new sub-sub-leading soft graviton theorem.

3. Double soft theorem in Tropical amplitude: Recently Cachazo, Early, Guevara and Mizera (CEGM) have obtained scattering equations in higher dimensional projective spaces. This construction is motivated from Cachazo-He-Yuan formalism, where various QFT amplitudes can be represented as moduli space integration over punctured Riemann spheres, $\mathbb{CP}^1$. CEGM consider $\mathbb{CP}^{k-1}$, with $k \geq 2$ as a natural generalization for Bi-adjoint scalar amplitudes. We study simultaneous double soft theorem by taking momenta of two of the external states to be infinitesimally small compared to others for the Bi-adjoint scalar amplitude. Depending on the color ordering we find the leading behaviour of the double soft factor scale with different powers of soft momenta. This work is in preparation with Md. Abhishesk, Subramanya Hegde and Dileep Jatkar.

Publications:

1. *Modified celestial amplitude in Einstein gravity*, Shamik Banerjee, Sudip Ghosh, Pranjal Pandey, Arnab Priya Saha, 10.1007/JHEP03(2020)125, arXiv [1909.03075]

Preprints:

1. *Proof of the Classical Soft Graviton Theorem in $D = 4$*, Arnab Priya Saha, Biswajit Sahoo, Ashoke Sen, arXiv [1912.06413]

Conference/Workshops Attended:

1. Students talks in trending topics, IISER Bhopal, July, 2019.
2. Indian Strings Meeting, IISER Bhopal, India, December, 2019.
3. Kavli Asian Winter School on Strings, Particles and Cosmology, Tohoku University, Japan, January, 2010.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, July, 2020.
2. Okinawa Institute of Science and Technology, Japan, January, 2020.

Invited Lectures/Seminars:

1. Classical analysis of sub-leading soft graviton theorem in asymptotically flat space-time in four dimensions, Institute of Mathematical Sciences, Chennai, July 2020.
2. Subleading soft graviton theorem in four dimension, Okinawa Institute of Science and Technology, Japan, January, 2020.

Tousik Samui

Research Summary:

In one of our works, we studied the experimental constraints on a model of a two-component dark matter, consisting of the QCD axion, and a scalar particle, both contributing to the dark matter relic abundance of the universe. The global Peccei-Quinn symmetry of the theory can be spontaneously broken down to a residual Z_2-symmetry, thereby identifying this scalar as a stable weakly interacting massive particle, i.e., a dark matter candidate, in addition to the axion. We perform a comprehensive study of the model using the latest data from dark matter direct and indirect detection experiments, as well as new physics searches at the Large Hadron Collider. We find that although the model is mostly constrained by the dark matter detection experiments, it is still viable around a small region of the parameter space where the scalar dark matter is half as heavy as the Standard Model Higgs. In this allowed region, the bounds from these experiments are evaded due to a cancellation mechanism in the dark matter-Higgs coupling. The collider search results, however, are shown to impose weak bounds on the model.
[with Suman Chatterjee, Anirban Das, Manibrata Sen,
Phys. Rev. D **100**, 115050, (2019)]

In this work, we used jet substructure technique to distinguish different types of dijet resonances produced at the Large Hadron Collider (LHC). Extending the idea of quark versus gluon tagging, jet substructure observables along with event variables in a dijet event can give important information regarding the type of the resonance. This will be a useful tool to search for different types of models which gives rise to dijet resonances at the LHC.
[with Aruna Kumar Nayak, Santosh Kumar Rai, arXiv:1912.03511 [hep-ph]]

In this work, we showed that the integrable state of charged SYK model does not thermalize even though the state has non-zero Lyapunov exponent. The chaotic state always thermalizes which is expected. So whether the system thermalizes or not depends on the initial state. We also showed that the introduction of random mass deformation ($q = 2$ SYK term) slows down thermalization but the system thermalizes exponentially fast. This is observed despite the fact that large ($q = 2$) SYK interaction forces spectral statistics to obey Poisson statistics. This means that a precise measure of chaos and its prediction of thermalization is still lacking. In the chaotic state, the effective temperature is non-monotonic. It has a bump at relatively long time before settling down to the final value. With non-zero chemical potential, the effective temperature oscillates noticeably before settling down to the final value. The spectral asymmetry frequency does not change during quantum quenches.
[with Nilakash Sorokhaibam, arXiv:2004.14376 [hep-th]]

Publications:

1. Suman Chatterjee, Anirban Das, Tousik Samui, Manibrata Sen, *Mixed WIMP-axion dark matter,* Phys. Rev. D **100**, 115050, (2019)

Preprints:

1. Aruna Kumar Nayak, Santosh Kumar Rai, Tousik Samui, *Probing Heavy Dijet Resonances Using Jet Substructure at the LHC,* arXiv:1912.03511 [hep-ph]

2. Tousik Samui, Nilakash Sorokhaibam, *State-dependent thermalization in SYK model,* arXiv:2004.14376 [hep-th]

Conference/Workshops Attended:

1. *Madgraph School 2019*, The Institute of Mathematical Sciences, Chennai, India, November, 2019.

Other Activities:

1. Organised *High Energy Physics Journal Club* in HRI from 23rd December 2019 to 11th March 2020. The Journal Club was held from 3:30 pm to 5:00 pm every Wednesday.

Arun Sehrawat

Research Summary:

The expectation values of operators drawn from a single quantum state cannot be outside of a particular region, called their allowed region or the joint numerical range of the operators. We present a method to obtain all necessary and sufficient constraints—from Hermiticity, normalization, and positivity of a state and through the Born rule—that analytically defines the allowed region. Then, we present the allowed regions for the Heisenberg–Weyl operators, the angular momentum operators, and for their functions in dimension two to infinity. Especially, we consider three kinds of functions—combinations of powers of the ladder operators, powers of the angular momentum operators, and their anticommutators—and discover the allowed regions of different shapes. Here we also introduce uncertainty measures on the joint numerical range that are different from the standard deviation and the Shannon entropy. With the measures, we achieve a new kind of tight uncertainty relations for the Weyl- and the angular-momentum-operators. Overall, we demonstrate how the joint numerical range and the uncertainty relations change as the dimension grows. We apply the quantum de Finetti theorem to attain the allowed regions and tight uncertainty relations in the limit where the dimension goes to infinity.

Publications:

1. A. Sehrawat, *Uncertainty relations on the joint numerical range of operators*, J. Phys. A: Math. Theor. **53**, 085303 (2020).

Conference/Workshops Attended:

1. Quantum Foundations, Technology and Applications, IISER Mohali (17–21 October 2019).
2. Quantum Frontiers and Fundamentals, RRI Bengaluru (13–18 January 2020).

Visits to other Institutes:

1. Physics Department at IIT Ropar (22 October 2019).
2. Physics Departments at IIT Bombay, IISER Pune, and BITS Pilani K K Birla Goa Campus (18–29 November 2019).

Other Activities:

1. Talk at Young Quantum 2020, HRI Prayagraj (postponed due to COVID-19).

Faruk Abdulla

Research Summary:

My work has been focused broadly on topological insulator, Weyl semimetal and topological phase transitions. We have finished our work on topological phase transitions. We try to understand topological transitions and multi-criticality in a simple model using a proposed renormalisation procedure called the curvature function renormalisation (CRG) method, in an analogy with the Landau theory of phase transitions. CRG approach allows the concept of correlation length and critical exponents in topological phase transitions.

Our work on Weyl semimetal (WSM) is focused on the reconstruction of the Fermi arc in a twisted WSMs. The study is in progress. The nature of the reconstructed Fermi arc depends on the relative twist angle and the coupling strength at the interface between two WSM. There are cases where closed Fermi loops exist with a nontrivial transport properties at the interface.

We have started a work on the topological transistor which is based on tunnelling between the two edge states at opposite edges. The tunnelling is controlled by an applied electric field, which allow an on/off operation in the device, which could have potential applications. The important point is that there is no topological transitions to have the on/off operation.

Preprints:

1. Faruk Abdulla, Priyanka Mohan, Sumathi Rao, *Curvature function renormalisation, topological phase transitions and multicriticality,* **arXiv:2003.10190.**

Conference/Workshops Attended:

1. *Novel phases of quantum matter*, ICTS, Bangalore, Dec 2019.

Other Activities:

1. Teaching assistant, QM3 course, Aug-Dec 2019.
2. Teaching assistant, CMP1 course, Aug-Dec 2019.

Khorshed Alam

Research Summary:

We have completed the study on the formation and dissociation of the first layer of Li_2O_2 on the α-$MnO_2(100)$ surface as the cathode in Li-air battery using first principles density functional theory. Bias dependence of the electrochemical steps of charge (Li_2O_2 dissociation) and discharge (Li_2O_2 formation) via two different mechanisms are studied. Discharge potential is found to be 2.94 V for the mechanism in which O_2 adsorption is followed by lithiation. Charging potential for the reverse process is 3.37 V, giving an overpotential of 0.43 V, much lower than that on carbon electrodes. This is also in good agreement with experiments on α-MnO_2 cathodes. In Li_2O_2 formation via disproportionation of two LiO_2 adsorbates, a maximum discharge potential of 2.61 V is obtained and a minimum charging potential of 3.48 V. The minimum energy pathway in this mechanism has a moderate kinetic barriers of 0.57 eV. Charging potentials of 3.37 V and 3.48 V imply that the typical charging potentials applied in experiments (~ 3.8 V) will dissociate the entire Li_2O_2 layer. These findings explain why α-MnO_2 performs so well as a catalyst in Li-air battery cathodes, and suggest that a larger area of α-$MnO_2(100)$ can help reduce capacity loss.

In another work, we have combinatorially designed, and computationally screened, through an efficient, automated approach based on density functional theory, single layers of ternary transition metal tri-chalcogenides compounds for their efficiency as hydrogen evolution reaction (HER) catalysts. Based on our theoretical prediction of overpotentials determined from the reaction coordinate mapping corresponding to HER mechanism, thirteen of these compounds are found to be promising catalysts, out of which three are suggested to be as efficient as platinum, the best known HER catalyst so far.

In an ongoing project, we are studying a nitrogen-doped carbon based bi-functional catalyst in Zn-air battery cathode using density functional theory calculations.

Publications:

1. Khorsed Alam, Nicola Seriani and Prasenjit Sen, *Catalytic properties of α-MnO_2 for Li-air battery cathodes: a density functional investigation,* Phys. Chem. Chem. Phys., **22, 17**, 9233, (2020)

2. Prasenjit Sen, Khorsed Alam, Tisita Das, Rudra Banerjee and Sudip Chakraborty *Combinatorial Design and Computational Screening of 2D Transition Metal Tri-Chalcogenide Monolayers: Toward Efficient Catalysts for Hydrogen Evolution Reaction,* Journal of Physical Chemistry Letters., **11, 9**, 3192, (2020)

Visits to other Institutes:

1. Visited Prof. T. N. Narayanan at TIFR, Hyderabad, India, during 12th to 21st January, 2020.

Invited Lectures/Seminars:

1. Delivered a presentation at IIIT, Allahabad on *Catalytic properties of α-MnO_2 for Li-air battery cathodes: a density functional investigation* on 30th September, 2019.

Other Activities:

1. I have served as a tutor for the Quantum Mechanics-1 course during August-December, 2019.

Sankha Subhra Bakshi

Research Summary:

Langevin method is a promising candidate to evolve the slow degree of freedoms in a system, integrating out the fast degree of freedoms that captures the real-time dynamics of the system. The finite temperature collective modes were investigated in the Holstein-double-exchange problem where the phonon and spin variables were evolved using the Langevin method. At a strongly anharmonic regime, it was found that the system shows a transition from undistorted ferromagnetic metal at low temperature to a distorted paramagnetic insulator at high temperature. Past the low-temperature window the phonon-phonon and magnon-magnon interaction are increased by the anharmonicity of the problem. Beyond that window, the emergence of a two-peak structure in momentum resolved phonon spectrum was observed with striking features: i) low energy weight due to the slow tunneling of thermally generated spatially correlated polarons and ii) enhanced damping of the high energy weight due to the scattering from magnetic fluctuations. These trends were compared with the experiments and it was found to compare well although the numerical values differ.

The Langevin method was also used to heat transport problems in different models. To capture the real-time dynamics of the system connected to two thermal baths at a Non-equilibrium steady state Langevin method was applied. The results from this method were verified for well established classical model results and then it was applied to the half-filled Holstein model to capture interesting results as it can go beyond linear response theory and has thermal phase transition.

Publications:

1. Sauri Bhattacharyya, Sankha Subhra Bakshi, Samrat Kadge, and Pinaki Majumdar, *Langevin approach to lattice dynamics in a charge-ordered polaronic system,* Phys. Rev. B **99**, 165150, (2019)

2. Sauri Bhattacharyya, Sankha Subhra Bakshi, Saurabh Pradhan, and Pinaki Majumdar, *Strongly anharmonic collective modes in a coupled electron-phonon-spin problem,* Phys. Rev. B **101**, 125130, (2020)

Conference/Workshops Attended:

1. *Bangalore School on Statistical Physics - X, TIFR-ICTS, Bangalore, India*, June, 2019

Other Activities:

1. Tutorship for Advanced Statistical Physics and Quantum Mechanics Course, Aug-Dec, 2019.

2. Tutorship for Numerical Methods Course, Jan-March, 2020

Subhodip Bandyopadhyay

Research Summary:

During the academic year 2019-2020 I was primarily engaged in material study to pursue my research interest, which is broadly String Theory. I studied Supersymmetry from lecture notes of Bertolini and Fernando Quevado and also from the book by Wess and Bagger, covering the topics SUSY algebra, Supermultiplets, Superspace and Superfields and also actions for Minimal Supersymmetry. I also studied Differential Geometry from the book by Mikio Nakahara, covering the topics like Homotopy, Homology and Cohomology, Manifolds, Tangent Vectors and One-forms, Tensors, Lie Groups and Lie Algebra, Riemannian Manifolds , Complex Manifolds and Fibre Bundles. And also, as a side reading, I (along with some of my collegues) took up a self-study on Functional Analysis, reading some introductory chapters from Robert A. Bonic and from Bachman and Narici.

Ratul Banerjee

Research Summary:

Quantum resources such as, quantum entanglement, is necessary to get adventage in different information processing tasks over it's classical counterparts. For some of the tasks, it is needed to localize this quantum resource in a smaller part of the whole system. Moreover, quantifying multipartite entanglement is hard. We took a measure, called "localizable entanglement" - which is defined as the amount of entanglement generated in a smaller part of a N-party state by performing optimal local measurements on the rest of the system. In this direction, we investigated the patterns in distributions of localizable entanglement over a pair of qubits for random multi-qubit pure states. We observe that the mean of localizable entanglement increases gradually with increasing the number of qubits of random pure states while the standard deviation of the distribution decreases. The effects on the distributions, when the random pure multi-qubit states are subjected to local as well as global noisy channels, are also investigated. Unlike the noiseless scenario, the average value of the localizable entanglement remains almost constant with the increase in the number of parties for a fixed value of noise parameter. We also found that the maximum strength of noise under which entanglement survives can be independent of the localizable entanglement content of the initial random pure states (DOI 10.1103/PhysRevA.101.042339).

We also presented a set of hierarchies that localizable entanglement over a specific subsystem in a multiqubit state can obey when local noise acts on the subparts or on all the qubits of the whole system. In particular, we proposed two types of hierarchies – one tailored according to the number of noisy unmeasured qubits, and the other one that depends additionally on the cardinality of the set of noisy measured qubits, leading to the classification of quantum states. We reported the percentage of states satisfying the proposed hierarchies in the case of random three- and four-qubit systems and showed, using both analytical methods and numerical simulations, that in almost all the cases, anticipated hierarchies tend to hold with the variation of the strength of noise(arXiv:2003.02175).

One of our aim in quantum information science is to explore different properties of quantum communication network and the role of local measurements on it. We explored a global and optimal local measurement-based protocol in one- and two-dimensional lattices by which any two or more prefix sites can be connected via entanglement , starting from many copies of noisy bipartite entangled states. We obtained critical values of noise allowed in the initial state so that the resulting output state showed nonlocal correlation in different networks with arbitrary number of connections. We reported that by employing our method, it is possible to create a Bell-violating multipartite entangled state from non-Bell violating bipartite states in an one-dimensional lattice with minimal coordination number being six
(arXiv:1912.08874).

Publications:

1. Ratul Banerjee,Amit Kumar Pal, Aditi(Sen) De,*Uniform Decoherence Effect on Localizable Entanglement in Random Multi-qubit Pure States* ,**Phys. Rev. A 101,042339 (2020)**

Preprints:

1. Ratul Banerjee, Amit Kumar Pal, Aditi (Sen) De, *Hierarchies of localizable entanglement due to spatial distribution of local noise.* **arXiv:2003.02175**

2. Ratul Banerjee, Srijon Ghosh, Shiladitya Mal, Aditi (Sen) De, *Spreading Nonlocality in Quantum Network.* **arXiv:1912.08874**

Conference/Workshops Attended:

1. QFF (Quantum Frontiers and Fundementals) 13-18 th january,2020, at Raman Research Institute, Bengalore and presented a poster entitled - ”Uniform Decoherence Effect On Localizable Entanglement”.

Anjan Kumar Barik

Research Summary:

In this academic year, I did two project under the guidance of Prof. Santosh Kumar Rai . One was on "Extending two Higgs doublet models for two-loop neutrino mass generation and one-loop neutrinoless double beta decay" and the other one was "$pp \to t\bar{t}$ cross section calculation".

Nirnoy Basak

Research Summary:

I am working on a topological material named Weyl-Semimetal in the thin-film geometry where the x-y direction is infinite and the z-direction is finite.In a Weyl-semimetal the bulk is gapped but the bands touch each other at Dirac points. In this particular slab geometry if we look at the dispersion we will see that the Dirac-points i.e. the band touching points are connected by a surface state named Fermi arc. Now the Fermi arc is responsible for electron conduction in this kind of system. My principle objective is study linear response in this kind of system in presence of disorder. The tool for this kind of study is the standard Kubo formula and we are only considering the lowest order current-current diagram because that will capture the effect of the Drude conductivity. We aren't including interaction between the bands and the system is approximated within one band.

I have calculated the disorder scattering rate by solving the eigen-value equation of Weyl-semimetal by imposing the boundary conditions. The numerical scattering rate is evaluated self-consistently. Now as the system loses its isotropy it is reflected in the scattering rate because of the fact that the s-matrix is dependent on the initial momentum. Our guess is that it will eventually get reflected in the Kubo conductivity. Furthermore we guess we will see a difference of conductivity calculated in the x-direction and the y-direction beacuse the dispersion isn't the same in x and y directions. Our calculation is being benchmarked with the known results of the 2-dimensional Dirac material and 3-dimensional electron gas.

We have future plans to calculate the heat conductivity using the Green-Kubo formula and check that if Wiedermann-Franz law is being followed in different temperature region. Our plan is to extend our work for multiple bands and in those cases we have to include band to band transitions also. We also plan to include electron-phonon interaction and look for intrinsic superconductivity.

Conference/Workshops Attended:

1. Conference on edge dynamics in topological phases in ICTS from 10th June to 14th June 2019.

2. Bangalore School on Statistical Physics in ICTS from 17th June to 28th June on 2019.

Visits to other Institutes:

1. Visit to Indian Institute of Technology, Kanpur on November,2019.

2. Visit to Indian Institute of Technology, Kanpur on February, 2020.

Sauri Bhattacharyya

Research Summary:

We've applied the Langevin dynamics method, previously used in the context of a charge ordered polaronic system by us (PRB **99**, 165150), to study the coupled phonon-magnon dynamics in the Holstein-double exchange model. The parameter choice is done to mimic the behaviour of low T_c ferromagnetic metallic manganites. We observe strongly anharmonic behaviour of phonons and diffusive spin dynamics close to T_c. In addition, a notable low energy feature is generated in the phonon spectrum due to slow tunneling of charge ordered domains. We compare our results with available experimental data. The work is published in PRB **101**, 125130.

Next, we've explored the larger coupling-density phase diagram of the Holstein model, starting from the strong coupling, half-filling end, in terms of phonon properties. We observe three broad 'dynamical regimes', namely- gaussian fluctuation (GF), tunneling assisted gaussian fluctuation (GF+Tunn.) and large oscillation (LO). Moreover, the integrated low frequency weight shows increasing momentum and temperature selectivity on moving towards half-filling. These findings are reported in arXiv 1711.08749, updating our previous work.

Lastly, we applied a extension of the Langevin scheme used for phonons to study spin dynamics in the repulsive Hubbard model. We chose square and triangular lattice geometries for our investigation. The non-Heisenberg behaviour of the dynamical structure factor is highlighted as one moves to lower U values, starting from $U \to \infty$. This is due to two effects- (i) softening of magnitudes of local moments and (ii) introduction of longer range, multispin couplings. The effect of mild geometric frustration on the dynamics is also seen as one moves from the square to the triangular geometry.

Publications:

1. *Strongly anharmonic collective modes in a coupled electron-phonon-spin problem*, PRB **101**, 125130 (2020).

Preprints:

1. *Thermal dynamics of lattice modes near a polaronic crossover: from the dilute polaron limit to a charge ordered state*, arXiv 1711.08749 (superseding previous version).

Swapnil Bhowmick

Research Summary:

I am studying quantum resource theory from the paper: Phys. Rev. Lett. 115, 070503 (2015) and the references therein. I have also studied some aspects of resource theories of thermodynamics. I plan to study entanglement as a resource theory in the next few months.

Conference/Workshops Attended:

1. QFTA 2019 at IISER Mohali.

Debraj Bose

Research Summary:

I have studied phonon and electron dynamics in the Holstein model at finite temperature using a Langevin equation based method. Assuming adiabaticity of the phonons (larger natural time scale compared to the electrons), the phonon trajectories are first obtained using a stochastic equation of motion. Next, those are used as inputs to calculate the electron Greens function. The main effort has gone into understanding the problem on a small (two-site) cluster. There, the single particle electronic density of states is analyzed numerically. In the low temperature and weak electron-phonon coupling limits, the analytical results are reproduced. At higher temperatures, in the strong coupling regime, large amplitude flip moves of the phonons give rise to new peaks in the electron spectrum. Were currently studying the many electron problem within the same model. In future, the plan is to investigate the transport properties of the electrons and their dependence on phonon dynamics.

Suman Jyoti De

Research Summary:

The research work that I have done during the academic year "2019-2020", is given below

My first part of research work is dedicated to study the effect of linear background potential on quantum hall system in presence of electron-electron interaction using hatree-fock approximation. It was found earlier that in this scenario the edge of the quantum hall system will under go some reconstruction.I have studied the case near the interface of $\nu = 4$ and $\nu = 3$ where the $\nu = 4$ region is unpolarised and $\nu = 3$ is fully polarised, there we found that we have two region one with one chiral mode having spin rotation and other having three chiral mode without any spin rotation over some region of space.

I have also worked on a 2D Topological system where I have a 2d p-wave second order topological superconductor. It is found that this system host majorana bound state at four corners of the sample. We have found that in this system when it is in topological phase it has a $\phi_0 = hc/e$ flux periodicity and if one tune this topological superconductor to a trivial superconductor it has found to have flux periodicity of $\phi_0/2$ using self-consistent study.

Currently I am also working on the edge reconstruction of $\nu = 1/3$ using Monte-Carlo study to see the effect of positive background density at a distance away from the $\nu = 1/3$ quantum hall droplet.

Publications:

1. Suman Jyoti De, Udit Khanna, Sumathi Rao, *Magnetic flux periodicity in second order topological superconductor* , PHYSICAL REVIEW B **101**, 125429, (2020)

Preprints:

1. Suman Jyoti De, Udit Khanna, Sumathi Rao, *Magnetic flux periodicity in second order topological superconductor* , 1912.06784v2

2. Amartya Saha, Suman Jyoti De, Sumathi Rao, Yuval Gefen, Ganpathy Murthy, *Emergence of spin-active channels at a quantum hall interface,* (in preparation)

Conference/Workshops Attended:

1. *I have attended a conference on Novel Phases of Quantum Matter, ICTS Bangalore, 23rd December 2019-2nd January 2020.*

Atri Dey

Research Summary:

• In our published work we mainly do collider analysis. We explore the possibility of a heavier scalar in an extended electroweak sector can fit as dark matter portal in the context of two Higgs doublet models(2HDM), with considering all current experimental constrains. We do cut-based analyses and also use some machine learning techniques as gradient boosted decision trees (XGboost) and artificial neural network(ANN), where the statistical significance distinctly improves.

• In our 2nd work we mainly concentrate on the collider analysis where the triplet dominated heavy Higgs served as dark matter portal. We consider all current theoretical, precision as well as collider constrains. Also considering three useful channels combining the two body and three body decay of charged Higgs we perform cut based analysis to calculate statistical significance of heavy neutral higgs decaying to dark matter candidate. Also we perform some machine learning techniques as gradient boosted decision trees (XGboost) and artificial neural network(ANN), where the statistical significance significantly improves.

• In our ongoing project we are looking for the high scale validity of quatic couplings in Type-X 2HDM where the light pseudoscalar with lagre $\tan\beta$ can solve the muon $g-2$ discripency.

Publications:

1. LHC signals of a heavy doublet Higgs as dark matter portal: cut-based approach and improvement with gradient boosting and neural networks (Published in: JHEP 09 (2019)004, e-Print:1905.02242).

Preprints:

1. LHC signals of triplet scalars as dark matter portal: cut-based approach and improvement with gradient boosting and neural networks.

   (submission in JHEP 147P 0220 has been accepted for publication in JHEP and copyright also accepted, e-Print:2001.09349).

Conference/Workshops Attended:

1. *Particle physics summer school, ICTP, Trieste, Italy, June 2019*

Visits to other Institutes:

1. SINP, Kolkata, India during 20th December 2019 to 20th January 2020.

Shyamashish Dey

Research Summary:

Neutrino mass generation mechanism, Baryon asymmetry and Dark matter production with prof. Santosh Kumar Rai.

Other Activities:

1. Doing a course of Particle Physics by prof. Raj Gandhi

Arijit Dutta

Research Summary:

We have developed a scheme to tackle out of equilibrium steady state problems at finite temperature, which incorporates thermal fluctuations of the order parameter field. Moreover, since this method is formulated in real space and real time, it gives us access to short range ordering physics and dynamical phenomena at finite temperature, which are diffcult to capture via other methods. We have applied this to the problem of voltage driven insulator to metal transition in 3D Mott insulators. It shows that the insulator to metal transition is first order, at low temperature, as found in many experiments on transition metal oxides. Within our theory, the transition is driven by the collapse of the local moment magnitude as the voltage exceeds a critical value. We also predict signatures in the density of states and the moment magnitude distribution which can be verified in experiments.

Publications:

1. Arijit Dutta and Pinaki Majumdar, *Spatial behavior in a Mott insulator near the voltage-driven resistive transition* Phys. Rev. B **101**, 245155, (2020)

Conference/Workshops Attended:

1. 2^{nd} *Annual Conference on Quantum Condensed Matter*, India, July 2019

Academic recognition/Awards:

- *Best poster* at the 2^{nd} Annual Conference on Quantum Condensed Matter, 2019

Avirup Ghosh

Research Summary:

In the academic year 2019-20 I have studied the phenomenology of a multicomponent scalar dark sector in the context of γ-ray experiments.

I have further evaluated the current limit on the lifetime of a decaying scalar DM as well as in two-component DM sector from the observation of Fermi γ-ray telescope as well as the improvement that can be acheived via the upcoming radio observation at SKA.

I have also studied the possibility of Asymmetry generation in Dark Matter via a general semi-annihilation scenario.

Publications:

1. Avirup Ghosh, Alejandro Ibarra, Tanmoy Mondal, Biswarup Mukhopadhyaya, *Gamma-ray signals from multicomponent scalar dark matter decays*, JCAP 01 (2020) 011

Preprints:

1. Avirup Ghosh, Arpan Kar,Biswarup Mukhopadhyaya, *Search for decaying heavy dark matter in an effective interaction framework: a comparison of γ-ray and radio observations*, e-Print:ArXiv: 2001.08235

2. Avirup Ghosh, Deep Ghosh, Satyanarayan Mukhopadhyay, *Asymmetric dark matter from semi-annihilation*, e-Print: ArXiv: 2004.07705

Conference/Workshops Attended:

1. WHEPP XVI, 2019 in IIT Guwahati, Dec 1- Dec 10, 2019

Visits to other Institutes:

1. Laboratoire de Physique Thorique et Hautes nergies, Sorbonne University - UMR 7589 of CNRS, PO Box 126 - Towers 13-14 - 5 th floor 4 Place Jussieu - 75252 Paris cedex 05, 28-31 January,2020

2. Johannes Gutenberg University of Mainz, Saarstraβe 21, 55122 Mainz, Germany 3-4 February,2020

3. Karlshruhe Institute of Technology, Herman-von-Helmholtz-Platz 1 76344 Eggenstein-Leopoldshafen, Germany, 5-8 February,2020

4. Technische Universitat Muenchen, Physik-Department James-Franck-Straβe 85747 Garching, Germany 9-12 February,2020

5. University Di Pisa, Largo Bruno Pontecorvo, 3, 56127 Pisa PI, Italy 12-16 February,2020

6. Georg-August University of Goettingen, Wilhelmsplatz 1, 37073 Goettingen, Germany 17-22 February,2020

7. IACS, Kolkata, India, 5-13 March,2020

Invited Lectures/Seminars:

1. "Phenomenology of Feebly coupled Dark sectors" at Laboratoire de Physique Thorique et Hautes nergies, Sorbonne University, 28 January, 2020

2. "Phenomenology of Feebly coupled Dark sectors",Johannes Gutenberg University of Mainz, 3 February, 2020

3. "Phenomenology of Feebly coupled Dark sectors", Karlshruhe Institute of Technology, 6 February, 2020

4. "Phenomenology of Feebly coupled Dark sectors", Technische Universitat Muenchen, 9 February, 2020

5. "Phenomenology of Feebly coupled Dark sectors", University Di Pisa, 14 February, 2020

6. "Phenomenology of Feebly coupled Dark sectors", Georg-August university of Goettingen, 20 February, 2020

Srijon Ghosh

Research Summary:

In last one year, my research work was concentrated on quantum thermodynam- ics, a very vast and flourishing area of quantum information theory. Motivated by the interplay between quantum mechanics and thermodynamics, I mainly focused on the improvements of thermal machines (quantum battery, quantum refrigerator etc) with the help of quantum mechanics, i.e., to increase their efficiency compared to their classical counterparts. I was also worked on the benificial or detrimental effects of environment on these machines. In particular, I along with my collabo- rators, considered a quantum XY Z spin chain as a quantum battery and studied the the effect of ordered and disordered interaction strengths on the performance of it during closed dynamics. We also found the effect of temperature on the battery. Specifically, we showed some counter-intuitive results like, with the properly chosen operating point impurities in the system actually help to enhance the performance of battery, at the same time temperature of the system can provide benifits. On the other hand, I also studied quantum netwrok and its inevitable usefulness of send- ing information at a distant location. To be precise, I worked on the spreading of entanglement in one and two-dimensional lattices, starting from several noisy en- tangled states. Investigating the violation of Bell inequalities, I and my co-authors gave some useful protocols of distributing nonlocal correlations in a network which is inarguably one of the most important resources for several quantum information processing tasks.

Publications:

1. Enhancement in performance of quantum battery by ordered and disordered interactions, Phys. Rev. A 101, 032115 (2020).
   Srijon Ghosh, Titas Chanda, Aditi Sen(De)

Preprints:

1. Spreading Nonlocality in Quantum Network, arXiv: 1912.08874.
   Ratul Banerjee, Srijon Ghosh, Shiladitya Mal, Aditi Sen(De)

Conference/Workshops Attended:

1. Qunatum Frontiers and Fundamentals 2020, Raman Research In- stitute, Bangalore (13-18 Jan, 2020). (Presented a poster, Enhancement in performance of quantum battery by ordered and disordered interactions)

Ahana Ghoshal

Research Summary:

My research work is in the general area of quantum information and computation under the guidance of Prof. Ujjwal Sen. Among the directions that I studied is the interface of quantum optics and quantum information theory. I studied certain aspects of the Jaynes-Cummings model which is a model of an atom-cavity system. I have studied how the physical properties of this system and the generalization of this system to the two atoms - two cavities case, alters if the systems are not ideal, i.e., if the parameters of the systems are prone to be affected by impurities. In another direction, I worked on finding possible options to detect quantumness of gravity, and concluded that quantum coherence can be a witness of the quantumness of gravity. I am currently working further in these directions. I have also started working in the general direction of open quantum systems.

Publications:

1. Population inversion and entanglement in single and double glassy Jaynes-Cummings models, Phys. Rev. A **101**, 053805 (2020).

Preprints:

1. Coherence as witness for quantumness of gravity, arXiv:1909.07244.

Conference/Workshops Attended:

1. QFF 2020, Raman Research Institute, Bangalore (13 - 18 Jan, 2020). Presented a talk on “Coherence as witness for quantumness of gravity”.

Sachin Grover

Research Summary:

I have been learning about resurgent series through which we aim to get at new non-perturbative results in quantum field theory and quantum mechanics. To this end, I am broadly reading about Asymptotic and Perturbative Analysis, Transseries, Riemann Surface Theory and String Theory. This part of my work is done under the supervision of my advisor Dileep P. Jatkar.

The other part concerns understanding topics under the broad heading: Gravitation, gauge theory and differential geometry which I am studying with Kajal Singh and Md. Abhishek under the guidance of Ashoke Sen.

Dileep Jatkar, Kajal Singh, Md. Abhishek and myself are also involved in a project on conformal field theory.

Conference/Workshops Attended:

1. *Zoomplitudes 2020: Annual Amplitudes Conference* (11-15 May 2020 held via Zoom)
2. *Saha Theory Workshop 2020: Amplitudes and Correlators* (13-17 Jan 2020 at Saha Institute of Nuclear Physics)
3. *XXXIII SERB Main School Theoretical High Energy Physics* (7-26 December 2019 at S.G.T.B. Khalsa College, University of Delhi)

Other Activities:

1. Tutor for Quantum Mechanics-2 (at HRI) (Jan-May 2020)
2. Course attended: Geometry and Entanglement, Instructor- Prof. Ashoke Sen (HRI) (Jan-May 2020)

Samrat Kadge

Research Summary:

In previous work,Langevin dynamics was employed to study charge-ordered polaronic system.Temporal paths were obtained by evolving stochastic differential eqns in the classical limit.In this limit,the friction term is time-local and state-independent and noise is delta-correlated and state-independent.

Retaining quantum-thermal fluctuations, the noise and friction is state dependent and friction now has a memory kernel. Restricting to gaussian fluctuations,one gets rid of the state-dependency, but the technique would be limited to low temperatures or around critical temperture and thus identical to RPA. Current efforts are directed in calculations beyond second-order.

Arpan Kar

Research Summary:

In the academic year 2019-2020, I have worked on the following projects.

1. Dark matter (DM) annihilations/decays inside a dwarf galaxy produce standard model (SM) particles which further cascade and give rise to secondary electron-positron pairs. These electrons-positrons, interacting with the galactic magnetic field, generate radio synchrotron emissions. As the decay signal is inversely proportional to the DM mass, it is stronger in comparison to the annihilation signal (which is inversely proportional to the square of the DM mass) when the DM mass is high (e.g. beyond a TeV). To satisfy the existing bounds, life time of these decaying DM particles should exceed the age of the universe by several orders of magnitude. We have parameterised the decay interactions in terms of various higher-dimensional effective operators and predicted the limits on these operators from the observation of upcoming radio telescope Square Kilometre Array (SKA).

   The same decay operators, which produce secondary electrons-positrons and in turn generate radio fluxes inside dwarf galaxy, can also give γ-rays in similar ways (i.e. through the cascade of various SM particles produced in DM decay). We found that the isotropic gamma-ray background (IGRB) data, measured by Fermi-LAT experiment, put strongest bounds on the decay parameter space to date. Future gamma-ray telescope like Cherenkov Telescope Array (CTA) is expected to improve these bounds in the high DM mass range. We compared the bounds on the effective operators obtained from IGRB observations (by Fermi-LAT and CTA) with those predicted from SKA observation and found that the SKA has better sensitivity in probing the parameter space, even for DM mass beyond several TeV.

   Also, using IGRB data and SKA predictions, we have estimated the possible limits on the astrophysical parameters (such as magnetic field, diffusion coefficient) of dwarf galaxies. These enable us to constraint the coupled parameter space of particle physics and galactic astrophysics.

2. Apart from these, we have made another study regarding the multi-wavelength observation of a Milky Way globular cluster, called Omega Centauri. Like dwarf galaxies, due to high mass-to-light ratio it is also a good place for DM study. Recently, the radio telescope Murchison Widefield Array (MWA) has made a low-frequency radio observation of Omega Centauri. Combining this observation together with some newly published γ-ray flux data (obtained by Fermi-LAT) and the corresponding DM annihilation models which describe the γ-ray flux, we have been able to find constraints on the astrophysical parameters (mainly magnetic field and diffusion coefficient) inside Omega Centauri. For this work we have collaborated with the overseas experimental team working in the MWA project.

Publications:

1. Arpan Kar, Sourav Mitra, Biswarup Mukhopadhyaya, Tirthankar Roy Choudhury, Steven Tingay, *Constraints on dark matter annihilation in dwarf spheroidal galaxies from low frequency radio observations,* Phys. Rev. D 100, **043002** (2019)

2. Arpan Kar, Sourav Mitra, Biswarup Mukhopadhyaya, Tirthankar Roy Choudhury, *Heavy dark matter particle annihilation in dwarf spheroidal galaxies: radio signals at the SKA telescope,* Phys. Rev. D 101, **023015** (2020)

Preprints:

1. Avirup Ghosh, Arpan Kar, Biswarup Mukhopadhyaya, *Search for decaying heavy dark matter in an effective interaction framework: a comparison of -ray and radio observations,* arXiv:2001.08235 [hep-ph]

2. Arpan Kar, Biswarup Mukhopadhyaya, Steven Tingay, Ben McKinley, Marijke Haverkorn, Sam McSweeney, Natasha Hurley-Walker, Sourav Mitra, Tirthankar Roy Choudhury, *Constraints on dark matter annihilation in ω Centauri,* arXiv:2005.11962 [astro-ph.HE]

Conference/Workshops Attended:

1. XVI Workshop on High Energy Physics Phenomenology (WHEPP2019), IIT Guwahati, India, December 1 - 10, 2019.

Visits to other Institutes:

1. IISER, Kolkata, India, January 1 - 17, 2020.

2. University of Maryland, USA, February 2 - 4, 2020.

3. University of California, Riverside, USA, February 5 - 12, 2020.

4. University of California Santa Cruz, USA, February 13 - 14, 2020.

5. Mitchell Institute for Fundamental Physics and Astronomy, Texas, USA, February 14 - 19, 2020.

6. University of Pittsburgh, USA, February 19 - 24, 2020.

7. Penn State University, USA, February 24 - March 2, 2020.

Invited Lectures/Seminars:

1. *Indirect search for dark matter in current and upcoming radio observations,* University of Maryland, USA, February 3, 2020.

2. *Indirect search for dark matter in current and upcoming radio observations,* University of California, Riverside, USA, February 7, 2020.

3. *Indirect search for dark matter in current and upcoming radio observations,* University of California Santa Cruz, USA, February 13, 2020.

4. *Indirect search for dark matter in current and upcoming radio observations,* Mitchell Institute for Fundamental Physics and Astronomy, Texas, USA, February 18, 2020.

5. *Indirect search for dark matter in current and upcoming radio observations,* University of Pittsburgh, USA, February 20, 2020.

6. *Indirect search for dark matter in current and upcoming radio observations,* Penn State University, USA, February 25, 2020.

Ratul Mahanta

Research Summary:

During this academic year 2019-2020, I have mainly worked (with other collaborators) on the following four problems gaining partial understanding so far.
(1) A study of the analyticity of the multipoint momentum space Green's functions in Quantum field theory and String field theory in the external momentum variables on some specific complex domain, (2) a problem in Cosmology dealing with the decay of heavy particles to Standard model particles and candidate particles for dark radiation at some very early time, (3) a study of torus correlators in two dimensional Conformal field theories for writing them as convergent Poincaré series, and since recently (4) a study of topological defect lines in two dimensional Conformal field theories.

Publications:

1. Ratul Mahanta and Anshuman Maharana, *Crossing, modular averages and* $N \leftrightarrow k$ *in WZW models*, JHEP**10** (2019) 061

Conference/Workshops Attended:

1. *National Strings Meeting (NSM) 2019*, IISER Bhopal, India, December, 2019.

Invited Lectures/Seminars:

1. *Crossing Symmetry, Modular Averages,* $N \leftrightarrow k$ *Correspondence*, Gong Show seminar along with a poster, NSM 2019, IISER Bhopal, India, December, 2019.

Other Activities:

1. I have served as a teaching assistant for the course Quantum Field Theory I during the Independence term (August-December 2019) at HRI.

Susovan Maity

Research Summary:

The system I have been mainly working with is low angular momentum accretion disc around Kerr (rotating) blackhole in hydrostatic equilibrium. As this is an astrophysically interesting system for probing the viscinity of supermassive blackhole, the formation of shock in this accretion flow and its effect on producing multitransonicity has been studied in detail in the preprint "Influence of flow thickness on general relativistic low angular momentum accretion around spinning black holes". Using semi analytic method, various dynamical quantities have been calculated and the effect of black hole spin and different general relativistic prescription has been studied in detail in this preprint.

The same accreting system has been also used to study the propagation of linear pertubation in the fluid configuration. I have been working with Dr. Subir Ghosh of Physics and Appied Mathematics Unit, ISI, Kolkata on the sonic analogue of traversible wormhole and multiverse in the corresponding fluid configuration. The work will be submitted in peer reviewed international journal very soon.

The same system has also been explored to find the surface gravity of acoustic black holes in the pre-print "Dependence of acoustic surface gravity on disc thickness for accreting astrophysical black holes".

I have also studied the effect of non-linear perturbation in emergent gravity in non relativistic Bondi flow. The acoustic horizon, sound speed and the time dependent evolution of a pulse in the effective metric at non-linear order has been explored in the pre-print "Emergent gravity through non-linear perturbation". A novel approach for treating all higher order perturbations through amaster equation has been developed, which we intend to generalize for general relativistic flows in future.

Preprints:

1. Tarafdar, P., Maity, S., & Das, T. K., *Influence of flow thickness on general relativistic low angular momentum accretion around spinning black holes,* arXiv:2005.01746 [astro-ph.HE](2020)

2. Maity, S., Tarafdar, P., & Das, T. K., *Dependence of acoustic surface gravity on disc thickness for accreting astrophysical black holes,* arXiv:2005.13573 [astro-ph.HE](2020)

3. Fernandes, K., Maity, S., & Das, T. K., *Emergent gravity through non-linear pertur-bation,* arXiv:2005.14114 [gr-qc](2020)

Conference/Workshops Attended:

1. Astrophysics of Supermassive Black Holes, 17 December 2019 to 19 December 2019, ICTS, Bangalore(India).

Visits to other Institutes:

1. Visited twice at Physics and Applied Mathematics Unit, Indian Statistical Institute, Kolkata

Other Activities:

1. Tutored for Mathematical Methods-I course held during August 2019 to December 2019.

2. Tutor for the reading course Astrophysics in the current semester, i.e, from January 2020 upto present.

Md. Abhishek

Research Summary:

During the academic year 2019-2020, in the collaboration with Dileep Jatkar, Arnab Priya Saha and Subramanya Hegde, we have been working on the leading double soft theorem for the bi-adjoint scalar field theory in the context of the generalized CHY prescription on $\mathbb{CP}^k$ and studying the scattering amplitudes in the language of positive Grassmannian, tropical algebra and cluster algebra.

I am also studying the applications of differential geometry, algebraic geometry and topology in gauge theory and theory of gravity with Sachin Grover and Kajal Singh under the guidance of Ashoke Sen.

In the collaboration with Dileep Jatkar, Sachin Grover and Kajal Singh, we have recently started working on some problems in 2-dimensional conformal field theory (2D CFT).

Conference/Workshops Attended:

1. SERB School on Theoretical High Energy Physics, University of Delhi, Delhi, India, December 2019.
2. Saha Theory Workshop 2020: Amplitudes and Correlators, SINP, Kolkata, India, January 2020.
3. Amplitudes Annual Conference 2020 (Via Zoom), Brown University, USA, May 2020.

Other Activities:

1. Teaching Assistant, Electronics Course, January - Present.
2. Audited Electrodynamics Course by Anirban Basu, August - November 2019.
3. Auditing Geometry and Entanglement Course by Ashoke Sen, January 2020 - Present.

Brij Mohan

Research Summary:

In the last academic year 2019-2020, I mainly worked on quantum evolution speed. Quantum evolution speed determines the rate at which the quantum system evolves in state space. We have shown that a suitable choice of pre and post-selection on the ancilla can act as a resource to enhance quantum evolution speed of system of interest. In this protocol, the system's new evolution speed is higher than the evolution speed of the system without any assistance. We also obtained Reverse quantum speed limit bound for mixed initial states.

In addition to this, I also studied Indefinite Casual Order(ICO) assisted metrology. And we found that, in the presence of high noise, ICO assisted metrology outperforms entanglement assisted metrology.

Preprints:

1. Brij Mohan and Arun Kumar Pati, Reverse Quantum Speed Limit: How Slow Quantum Battery Can Discharge?, arXiv:2006.14523.

Other Activities:

1. Tutor for 'Quantum Information and Computation - I' Course, August - December, 2019.

Tanmoy Mondal

Research Summary:

I've studied phonon dynamics in a classical, anharmonic model with nearest neighbour couplings using the Langevin equation. The motivation is to understand strongly anharmonic dynamics in detail and study the effect of geometric frustration on it. The model is composed of local 'double-well' potentials at each site and a quadratic nearest-neighbour term. It may be thought of as an effective phonon Hamiltonian after integrating out microscopic electron degrees of freedom from a more fundamental electron-phonon (e.g. Holstein) model.

To benchmark the technique, we first studied the square lattice case, where a checkerboard ordered ground state exists. We observe a crossover from harmonic behaviour to thermal tunneling dominated response on heating up the system. These tunneling events are short-range correlated, and hence cause momentum selective low-energy spectral weight transfer. At high temperatures, the asymptotic behaviour is consistent with a local, quartic oscillator model.

To investigate the effect of geometric frustration, we next moved to the triangular lattice problem. Here, no ordered ground state exists and the static structure factor is featureless in the thermodynamic limit. The tunneling moves are activated at much lower temperatures compared to the square case. Moreover, the momentum selectivity of spectral weight transfer is subdued, as the moves don't have any obvious spatial correlation.

We plan to study spin models on frustrated stuctures in future to understand the magnetic dynamics.

Other Activities:

1. Tutorship in CMP2 course.

Vivek Pandey

Research Summary:

In the last academic year 2019-2020, I have mainly studied quantum incompatibility in detail and its relations or similarities with quantum correlations. Along with this, I have also studied open quantum systems, mostly open system dynamics and analytical solutions of the general Lindblad equation.

Conference/Workshops Attended:

1. Quantum Foundations, Technology and Applications (QFTA-2019), IISER Mohali, India, October 2019.

Other Activities:

1. Audited QIC-I Course by Aditi Sen De, August-November 2019.
2. Auditing Geometry and Entanglement Course by Ashoke Sen, January 2020-Present.

Tanaya Ray

Research Summary:

I am currently working in quantum information and its interface with many-body physics.

We have completed one project. In that, we have established an inequality involving the quantum coherence of an arbitrary mixed quantum state in arbitrary dimension and a noncommutativity estimator of an arbitrary observable in the mentioned state. The noncommutativity estimator uses the commutator of the observable and its incoherent i.e. classical part. The relation provides a direct method of obtaining an estimate of the quantum coherence of an arbitrary quantum state . This can have potentially useful applications, because neither for providing the quantitative estimate nor for the qualitative witnessing do we require the usual methods of quantum state tomography or resort to the existing witness operators. We believe that the relation can be easily tested and put to use with existing experimental quantum information set-ups.

Preprints:

1. T. Ray, A. K. Pati and U. Sen, Estimating quantum coherence by noncommutativity of any observable and its incoherent part, arXiv:2004.07729 [quant- ph].

Saptarshi Roy

Research Summary:

In the academic year "2019-2020" (1st April 2019 to 31st March 2020), my research works were mainly focused on three major directions – (1) continuous variable systems and quantum optics, and (2) quantum teleportation, and (3) investigation of problems lying at the interface between quantum information and condensed matter physics. A brief report on the specific research works done during the last academic year is given below.

In the avenue of continuous variable systems and quantum optics, we compute genuine multimode entanglement in continuous variable systems by exploring the geometry of the state-space, namely via the generalized geometric measure (GGM). It is defined by the shortest distance of a given multimode state from a nongenunely multimode entangled state. For the multimode Gaussian states, we derive a closed form expression of GGM in terms of the symplectic eigenvalues of the reduced states. Following that prescription, the characteristics of GGM for typical three- and four-mode Gaussian states are investigated. In the non-Gaussian paradigm, we compute GGM for photon-added as well as -subtracted states having three- and four-modes and find that both addition and subtraction of photons enhance the genuine multimode entanglement of the state compared to its Gaussian counterpart. Our analysis reveals that when an initial three-mode vacuum state is evolved according to an interacting Hamiltonian, photon addition is more beneficial in increasing GGM compared to photon subtraction while the scenerio reverses when one considers the four mode non-Gaussian states. Specifically, subtracting photons from four-mode squeezed vacuum states almost always result in higher multimode entanglement content than that of photon addition to both single as well as multimode and constrained as well as unconstrained operations. Furthermore, we observe that GGM freezes under subtraction of photons involving multiple modes, in some specific cases. This feature is novel in its own rights as it does not appear while adding photons. Finally, we relate the enhancements of GGM with the distance-based non-Gaussianity measure.

In the field of quantum teleportation, we construct a new protocol which unlike the traditional protocols, employ weak measurements to allow for reusability of the resource state used for the teleportation scheme. Furthermore, in a different direction, we use the idea of fidelity deviation to calibrate the performance of quantum teleportation protocol in addition to its conventional quantifier using the average fidelity. We derive the exact formula for fidelity deviation of a two-qubit state and find out the condition for universal quantum teleportation. We also search for the optimal states (possessing maximal fidelity and minimum deviation) with respect to various state properties. Finally, we attempt to construct a single quantifier, which incorporates effects of both fidelity and its deviation to quantify teleportation performance.

Lastly, we seek for suitable physical quantities, which during dynamics can give prominent response to quantum critical region (QCR) in the transverse field quantum XY model. We report that the maximum energy absorbed, the nearest neighbor entanglement and the quantum mutual information of the time evolved state after a quench of the transverse magnetic field exhibits a faster fall off with temperature when the initial magnetic field is taken from within the QCR, compared to the choice of the initial

point from different phases. We propose a class of dynamical quantifiers, originated from the patterns of these physical quantities and show that they can faithfully mimic the equilibrium physics, namely detection of the QCR at finite temperatures.

Publications:

1. S. Roy, T. Das, A. Kumar, A. Sen(De), U. Sen, *Activation of Nonmonogamous Multipartite Quantum States,* Phys. Rev. A. **98**, 012310, (2018)

2. S. Roy, T. Chanda, T. Das, A. Sen(De), U. Sen, *Deterministic quantum dense coding networks,* Phys. Lett. A **382**, 1709 (2018).

3. S. Roy, T. Chanda, T. Das, A. Sen(De), and U. Sen, *Response in the violation of the Bell inequality to imperfect photon addition and subtraction in noisy squeezed states of light,* Phys. Rev. A **98**, 052131, (2018)

4. S. Roy, T. Chanda, T. Das, D. Sadhukhan, A. Sen(De), U. Sen, *Phase boundaries in alternating field quantum XY model with Dzyaloshinskii-Moriya interaction: Sustainable entanglement in dynamics,* Phys. Rev. B **99**, 064422 (2019)

5. S. Rethinasamy, S. Roy, T. Chanda, A. Sen(De), and U. Sen, *Universality in distribution of monogamy scores for random multiqubit pure states,* Phys. Rev. A **99**, 042302, (2019)

6. A. Ghosal, D. Das, S. Roy, S. Bandyopadhyay, *Optimal two-qubit states for quantum teleportation vis--vis state properties,* Phys. Rev. A **101**, 012304 (2020)

7. A. Ghosal, D. Das, S. Roy, S. Bandyopadhyay, *Fidelity deviation in quantum teleportation with a two-qubit state,* JPhys A **53**, 14 (2020)

8. S. H, S. Roy, T. Chanda, A. Sen De, U. Sen, *Multipartite entanglement at dynamical quantum phase transitions with non-uniformly spaced criticalities,* To appear in Phys. Rev. B

Preprints:

1. S. Roy, A. Bera, S. Mal, A. Sen De, U. Sen , *Recycling the resource: Sequential usage of shared state in quantum teleportation with weak measurements,* arXiv:1905.04164 [quant-ph]

2. S. Haldar, S. Roy, T. Chanda, A. Sen De, *Response of macroscopic and microscopic dynamical quantifiers to the quantum critical region,* arXiv:1908.06374 [quant-ph]

3. S. Roy, T. Das, A. Sen De, *Computable genuine multimode entanglement measure: Gaussian vs. non-Gaussian,* arXiv:1912.03284 [quant-ph]

4. S. Roy, A. Ghosal, *Rating the performance of noisy teleportation using fluctuations in fidelity,* arXiv:2001.11463 [quant-ph]

Conference/Workshops Attended:

1. *Quantum Frontiers and Fundamentals*, India, January, 2020, presented a poster titled "Response in violation of Bell inequality to imperfect photon addition and subtraction"

Subhojit Roy

Research Summary:

During the period of 2019-20, I have been working on the problem of a phenomenological study of WIMP type neutralino like cold dark matter in Next-to-Minimal Supersymmetric Standard Model (NMSSM) with the collaboration with Prof. AseshKrishna Datta and Waleed Abdallah. For this work, I have studied dark matter physics, cosmology, supersymmetry in detail. For computational purposes, I have learned various packages (NMSSMTools, SPheno, SARAH, Madgraph, CalCHEP, MicroOmega, CheckMate, MadAnalysis, HiggsBounds and HiggsSignals, etc.).

Along with it, I have recently started to work on another problem on the baryon asymmetry of the universe.

Preprints:

1. The last vestiges of a light bino-like dark matter in the Z_3-symmetric NMSSM. (In preperation)

Conference/Workshops Attended:

1. Madgraph School 2019, IMSC, INDIA.

Other Activities:

1. Currently, I am a teaching assistant of the Particle Physics course of this current semester under the instructor Raj Gandhi.

Biswajit Sahoo

Research Summary:

In this academic year, in collaboration with Arnab Priya Saha and Ashoke Sen, we have given a proof of classical soft photon and soft graviton theorem in four spacetime dimensions. Classical subleading soft graviton theorem in four space-time dimensions determines the gravitational wave-form at late and early retarded time, generated during a scattering or explosion, in terms of the four momenta of the ingoing and outgoing objects. This result we derived earlier by taking the classical limit of the quantum soft graviton theorem and making some assumptions about how to deal with the infrared divergences of the soft factor. In this work, we give a direct proof of this result by analyzing the classical equations of motion of gravity coupled to matter. We also extend the result to the electromagnetic wave-form generated during the scattering of charged particles and present a new conjecture on sub-subleading corrections to the gravitational wave-form at early and late retarded time. As an amusement, we have performed some numerical estimation of gravitational memory for various astrophysical scattering processes which can be tested in gravitational wave observatory in the recent future.

Preprints:

1. Arnab Priya Saha, Biswajit Sahoo, Ashoke Sen, **Proof of the Classical Soft Graviton Theorem in D=4**, arXiv:1912.06413.

Conference/Workshops Attended:

1. September 2019 : Saalburg summer school on "Foundations and New Methods in Theoretical Physics", Heigenbrcken, Bavaria, Germany.
2. December 2019 : National Strings Meeting (NSM), IISER Bhopal, India.

Visits to other Institutes:

1. Tata Institute of Fundamental Research, Mumbai, India.
2. Dipartimento di Fisica, INFN , Naples, Italy.
3. International Center for Theoretical Physics, Trieste, Italy.
4. INFN and Physics Department, University of Rome "Tor Vergata" , Italy.
5. Uppsala University, Sweden.
6. International Center for Theoretical Sciences, India.

Invited Lectures/Seminars:

1. August 2019 : "Status of Soft Theorem in D=4 (Its application in classical limit and understanding as Ward Identity)", Tata Institute of Fundamental Research, Mumbai, India.

2. September 2019 : "Status of Soft Theorem in D=4", Dipartimento di Fisica, INFN , Naples, Italy.

3. September 2019 : "Ward Identity for Lorarithmic Terms in Soft Photon Theorem", Dipartimento di Fisica, INFN , Naples, Italy.

4. September 2019 : "Status of Soft Theorem in D=4 (Its application in classical limit and understanding as Ward Identity)", International Center for Theoretical Physics, Trieste, Italy.

5. September 2019 : "Status of Soft Theorem in D=4", INFN and Physics Department, University of Rome "Tor Vergata" , Italy.

6. October 2019 : "Status of Soft Theorem in D=4 (Its application in classical limit and understanding as Ward Identity)", Uppsala University, Sweden.

7. October 2019 : "Status of Soft Theorem in D=4 (Its application in classical limit and understanding as Ward Identity)", International Center for Theoretical Sciences, India.

8. December 2019 : "Classical soft graviton theorem in D=4", National Strings Meeting (NSM), IISER Bhopal, India.

Other Activities:

1. During February-March of 2020 I have written my Ph.D. thesis.

Arpita Sen

Research Summary:

I did work on three projects: Oxide surfaces, Magnetism in cobalt carbide nano particles and studying electronic properties of layered Tellurium system.

As a continuation of previous works on wurtzite BeO and ZnO oxide surface I have studied the stability of their glide plane using density functional perturbation theory, and found the glide plane becomes more and more stable by expanding in 2 dimension. The metallicity along with two dimensional electron gas was found there and there is a competition between the structral stability and magnetism in the glide plane of both the oxide, where in bulk both of them are insulator and non magnetic.
I checked the magnetoelectric effect in BeO and ZnO. In case of BeO the magnetoelectric coupling coefficient was calculated and it is with the same order for the coupling constant of Cr_2O_3. I am studying now the electronic and phononic contribution of coupling coefficient of BeO.

Co_2C is a wellknown paramagnetic material. But Co_2C nano particles show interstting magnetic properties experimentally. I have studied using DFT Co_2C nanoparticles having diameters of a few Angstroms show a core-shell like struc-ture. The core has almost uniform moment on the Co atoms with bulk-like coordination. However, in the shell, the co-ordination of the atoms is completely different. Magnetic moments are also non-uniform in this structurally disordered shell. In combination of experiments and theroritial calcultion it is concludes the larger Co_2C nanoparticles in experiments possess similar core shell structures, where the structurally ordered core is a ferromagnetic (FM) and a thin structurally disordered shell is a glassy state. The exchange bias effect arises from such a FM-cluster glass core shell structure. The ferromagnetism observed in these transition metal carbide nanoparticles at room temperature along with their large blocking temperatures make them potentially attractive candidates for use as high density nano-magnetic memory and recording elements. They could also be useful for making non rare-earth based permanent magnets.

High-quality, few-layer tellurium (Te) nanosheets, with controllable size in large quantities are prepared by mechanical stirring under ambient conditions in dimethylformamide (DMF). A comprehensive range of analysis, combined with densityfunctional theory calculations, confirms that the product prepared using the mechanical stirring technique is fewlayer tellurium with small and largearea flakes. Moreover, few layers tellurium suspension is very stable up to several weeks under ambition conditions, making it suitable for practical device applications. This synthesis method is facile, efficient and does not nvolve use of any surfactant or ultrasonication steps and will facilitate future development of tellurium research.

Publications:

1. Designing rare earth free permanent magnets: insights from small Co clusters, Arpita Sen and Prasenjit Sen. Phys Chem Chem Phys. 2019 Oct 16;21(40):22577-22583.

2. Localized spin waves at low temperatures ina cobalt carbide nanocompos : Nirmal Roy, Arpita Sen, Prasenjit Sen, and S. S. Banerjee, J. Appl. Phys. 127, 124301 (2020)

Preprints:

1. Competing structural and electronic instabilities at the surface of polar insulating BeO: Emergence of two dimensional electron gas: Arpita Sen, Prasenjit Sen and Umesh V Waghmare

2. The Exchange Bias effect in pure Co_2C nanoparticles. Nirmal Roy, Md. Arif Ali, Arpita Sen, Prasenjit Sen, S. S. Banerjee

Visits to other Institutes:

1. JNCASR Banglaore India. 10th September 2019 to 4th November 2019.

Kornikar Sen

Research Summary:

Various devices used in daily life as well as in experiments are being miniaturized, whereby quantum effects may become significant in such devices. In many such devices quantum entanglement plays a useful role. Presence of entanglement enables better efficiencies of various tasks like quantum teleportation, quantum dense coding, and entanglement-based quantum cryptography. Over the years, several methods have been proposed to detect, measure and transport entanglement and then use it to improve performance of various tasks and devices.

An experimentally-friendly method for detecting entanglement is by using entanglement witnesses, which are linear operators on the space of quantum states (density matrices) and which provide a sufficient condition for detecting entanglement. It is possible to add nonlinear terms to linear witness operators that detects the entangled states that are detected by the linear parent witness, as well as some more entangled states.

Whatever is the approach for detecting entanglement, it will of course involve measurements on the shared quantum state. But measurement devices in the laboratory are often unlike their ideal theoretical cousins. They have non-ideal efficiencies (imprecise measurement) and the basis of measurement may get altered (wrong measurement), which may then lead to non-trivial implications.

We have shown how it is possible to predict correct answers about whether a shared quantum state is entangled in spite of finite detector efficiencies, when the tool for entanglement detection is a nonlinear entanglement witness. We have first considered the detection loophole for shared quantum states with nonpositive partial transpose. We have subsequently found nonlinear witness operators for bound entangled states with positive partial transpose, and have shown how the detection loophole can be closed also in such instances.

The concept of measurement-device-independent entanglement witnesses (MDI-EWs) was introduced to address the problem of wrong measurements. We have analyzed the problem of imprecise measurements in the context of measurement-device-independent entanglement witnesses. We have obtained an upper bound on the entanglement witness function in the measurement-device-independent entanglement witness scenario, below which entanglement is guaranteed for given non-ideal detector efficiencies.

A quantum battery is a quantum mechanical device, which one can charge by applying a time-dependent field, and the system is thenceforth assumed to store the energy. Subsequently, one can extract work from it by using another time-dependent field. A state from which work extraction is not possible is called a passive state. We have considered shared quantum batteries with local Hamiltonians. We defined a locally passive state as one from which no energy can be extracted by using local unitary operations. We have provided a characterization of the same, and have proved a uniqueness theorem. We have found the relation of the entanglement content in the battery with the amount of energy that can be globally extracted from their locally passive states. Moreover, we have obtained that the deficit in work extraction from pure battery states due to the restriction to local unitaries is equal to the amount of optimal global work extractable from the corresponding pure locally passive battery

state, for the same entanglement supply. Furthermore, the pure battery state for which globally extractable work attains a maximum, among the set of all pure states with a fixed value of entanglement, also provides the maximum locally extractable work.

Publications:

1. Kornikar Sen, Sreetama Das, and Ujjwal Sen, *Closing the detection loophole in nonlinear entanglement witnesses*, Phys. Rev. A **100**, 062333 (2019).

Preprints:

1. Kornikar Sen, Ujjwal Sen, *Local passivity and entanglement in shared quantum batteries*, arXiv:1911.05540.

2. Kornikar Sen, Chirag Srivastava, Shiladitya Mal, Aditi Sen De, Ujjwal Sen, *Detection loophole in measurement-device-independent entanglement witness* , arXiv:2004.09101.

Conference/Workshops Attended:

1. QFF (Quantum Frontiers and Fundamentals) 13-18th January, 2020, at the Raman Research Institute, Bangalore. Presented a poster titled "Beating detection loophole in nonlinear entanglement witnesses".

Divyansh Shrimali

Research Summary:

In the project work, attempts related to better estimation of uncertainty relation using tighter bound were studied. So far the work was done in state independent way, but there was a push towards state dependent bounds on uncertainty. Such bounds were recently experimentally verified too by other groups.

Broader work was based on the approach towards estimation of non linear functionals of density operators using quantum networks. Mainly the current work focuses on determining the spectra of a given system which can be in general mixed or pure. The proposed protocol is for both interacting as well as non interacting systems. The attempt is to give a mechanism to define appropriate density function of the the system complying with standard properties reducing which subsystems of the system can be extracted. So far the evaluations for two qubit non interacting systems have been done, which will be expanded upon in the following work. Such mechanism enables one to extract the subsystems from the generated density matrix, which further can have valuable implications for noisy quantum communication channels.

Other Activities:

1. Attended Online symposium on Quantum Information and Computation at IIT-Hyderabad.

2. Internal arxiv flashback online meetings.

Kajal Singh

Research Summary:

In the academic year 2019-2020, I mainly worked on phenomenological aspects of fibre inflation in collaboration with Sukannya Bhattacharya, Koushik Dutta, Mayukh Raj Gangopadhyay, and Anshuman Maharana. Our analysis sets up the basic methods necessary to extract precise inflationary prediction in string models incorporating correlations between model parameters and post-inflationary evolution.

Apart from this, I studied Kaluza-Klein reduction on S^1 and T^n. Also, I have been studying various mathematical ideas of differential geometry and topology, and their application to gauge theories and theory of gravitation under the guidance of Ashoke Sen.

In the latter part of this year, with Anshuman Maharana, I am working on the understanding of the statistics of supersymmetry breaking with stabilizing Kahler moduli.

I have recently started working on conformal field theories in 2-dimensions in collaboration with Dileep P. Jatkar, Sachin Grover, and Md. Abhishek.

Preprints:

1. Sukannya Bhattacharya, Koushik Dutta, Mayukh Raj Gangopadhyay, Anshuman Maharana, Kajal Singh, *Fibre Inflation and Precision CMB Data*, arXiv:2003.05969 [astro-ph.CO]

Conference/Workshops Attended:

1. SERB Main School on Theoretical High Energy Physics, S.G.B.T. Khalsa College, University of Delhi, Delhi, India, December 2019

Other Activities:

1. Tutored for Quantum Field Theory II, Janauary-May 2020.
2. Auditing Geometry and Entanglement course by Ashoke Sen, January 2020-Present.

Sohail

Research Summary:

In the academic year 2019-2020 I have worked on bipartite quantum operations and their non locality witnessing and their mathematical structures. In this work we provide a method for witnessing non locality of quantum processes on shared systems, which uses the channel-state duality. The method uses a maximally entangled state as a resource. We show that using the resource provides significant advantage over the corresponding protocol for non locality detection without the resource. In addition to this I have worked on quantum speed limit and its dependence on pre selection and post selection, weak values of the higher moments of observables.

Preprints:

1. Witnessing nonlocality of bipartite quantum operations, Sohail and Ujjwal Sen, arXiv:1909.09066.

Conference/Workshops Attended:

1. QFTA 2019 at IISER Mohail in October 2019.

Other Activities:

1. Mathematical Methods II tutorship during the semester Aug-Dec 2019.

Abhay Srivastav

Research Summary:

In the last academic year 2019-2020, I worked on the role of indefinite causal order in quantum information theory. We found how much information is preserved under the superposition of two hiding maps. I also worked on parallel concatenation of two depolarizing maps in an indefinite causal order instead of regular series one. I also studied quantum correlations in time in different approaches i.e.pseudo density matrix formalism ,indefinite causal structure,consistent histories, generalized quantum games, out of time order correlations and path integrals.

Conference/Workshops Attended:

1. Quantum Foundations, Technology and Applications (QFTA-2019), IISER Mohali, India, October 2019.

Other Activities:

1. Audited QIC-I Course by Aditi Sen De, August-November 2019.
2. Auditing Geometry and Entanglement Course by Ashoke Sen, January 2020-Present.
3. Auditing QIC-II Course by Ujjwal Sen, January 2020-Present.

Chirag Srivastava

Research Summary:

I work on the subject of quantum information and related sciences. In the previous year, I mainly worked on the foundational aspects of quantum mechanics like distinguishability of quantum states, enatanglement witnesses, resource theory of quantum coherence, and wave-particle duality.

I was involved in two projects concerning the distinguishability of quantum states. In the first one, quantum mechanics is tweaked, a bit, in order to hunt for the distinguishability between differently prepared same pure quantum states. It turned out that such distinguishability is impossible as it leads to signaling of information. Whereas, in the second one, distinguishability of bipartite orthogonal set of states is considered under local projective measurements with either zero or limited amount of classical communication. To achieve the distinguishability, two different types of resources are used. They are either a shared entangled quantum state or multiple copies of the set of states to be distinguished. Basically, this work studies and compares the roles of various resources used for distinguishing quantum states.

Entanglement is one of the most essential ingredients in the study of quantum mechanics, quantum information, and quantum computation. An important tool to detect whether a given shared quantum state is entangled is provided by the concept of entanglement witnesses (EWs). But, a major drawback is that the certification of entanglement by the EWs is guaranteed only when the measurements performed are correct. Therefore, the idea of measurement-device-independent entanglement witnesses (MDI-EWs) is emerged. I have worked on two aspects of MDI-EWs. In the first one, two parties share an entangled state, with the assumption that one party can make noisy (weaker) measurements. This allows the possibility of observation of entanglement multiple times as the weaker measurements disturb the states lesser. Therefore, sequential observation of entanglement is studied using MDI-EWs and compared with the similar studies based on EWs and Bell inequality violation. In the second one, MDI-EWs are studied under the loopholes in the outcomes of measurement. It is shown that there exist loopholes, which can lead to situations wherein MDI-EWs can wrongly point out a separable state to be entangled. We uncovered the loophole, and found conditions to close it.

Like entanglement, coherence is also an important concept of quantum mechanics. Coherence of a quantum state, belonging to a Hilbert space, is always defined with respect to some set of states forming a basis in that Hilbert space. Resource theories of coherence have been studied with respect to orthogonal as well as non-orthogonal but linearly independent basis. Wave-particle dualities have been derived where coherence is used to quantify the wave nature of quantum system. In one of the projects where I was involved, a resource theory of coherence with respect to an overcomplete set, i.e., a linearly dependent set of quantum states, is considered. The practical utility of such a theory can be seen in the context of the resource theory of magic, useful to understand the concepts in universal quantum computation. We found that the resource theory of magic can be seen as an example of the resource theory of coherence defined with respect to a set of linearly dependent states. Further, we derived a wave-particle duality in the scenario where superposition of a linearly dependent set of states is involved.

Publications:

1. Chirag Srivastava, Anindita Bera, Aditi Sen(De), Ujjwal Sen, *One-shot conclusive multiport quantum dense coding capacities*, Phys. Rev. A **100**, 052304 (2019).

2. Saronath Halder, Chirag Srivastava, *Locally distinguishing quantum states with limited classical communication*, Phys. Rev. A **101**, 052313 (2020).

3. Chirag Srivastava, Sreetama Das, Aditi Sen De, Ujjwal Sen, *Signaling versus distinguishing different preparations of same pure quantum state*, J. Phys. A: Math. Theor. **53** 275302 (2020).

Preprints:

1. Chirag Srivastava, Shiladitya Mal, Aditi Sen De, Ujjwal Sen, *Sequential measurement-device-independent entanglement detection by multiple observers*, arXiv:1911.02908.

2. Kornikar Sen, Chirag Srivastava, Shiladitya Mal, Aditi Sen De, Ujjwal Sen, *Detection loophole in measurement-device-independent entanglement witness*, arXiv:2004.09101.

3. Chirag Srivastava, Sreetama Das, Ujjwal Sen, *Resource theory of quantum coherence with probabilistically non-distinguishable pointers and corresponding wave-particle duality*, arXiv:2005.08296.

Other Activities:

1. I tutored in a statistical mechanics course and a classical mechanics course which are offered in Physics M.Sc. program in HRI.

HRI Colloquia

1. Prof. Pankaj Chandra : *Governing Academic: Within and Without.*
2. Prof. T.N. Venkataramana : *Monodromy and Arithmetic Groups.*
3. Mr. Sohail Hashmi : *Songs of Stones.*
4. Suman Bhattacharjea : *Are we preparing our youth for adulthood? Major findings from ASER 2017.*
5. Prof. Jayati Ghosh : *Economic growth, inequality and insecurity in China and India.*
6. Prof. Purushottam Agarwal : *What has our national movement given us?*
7. Dr. Rukmini Banerji : *Challenges of Primary Education in India.*
8. Prof. Ken Ono : *Why Ramanujan, the man who knew infinity, matters.*
9. Prof. Meera Nanda : *Our Missing Trading Zones: Reflections on the Gap between Theory and Practice in the History of Science in India.*
10. Prof. Rudrangshu Mukherjee : *Nehru And Bose : Comrades at Crossroads.*
11. Prof. Naman Ahuja : *Curatorial Concerns for India and the World: Which Narratives and Why?*

Mathematics Talks and Seminars

1. Mr. Amit Kumar Singh : *Semi-stability of the pullback of $T_{\mathbb{P}^2}$ on an elliptic curve.*
2. Mr. Ankan Palu : *Isogeny-Based Post-Quantum Elliptic Curve Cryptography.*
3. Mr. Ankan Pal : *Transitioning into a Quantum Secure Paradigm*
4. Dr. Ravi Prakash : *Topological Derivatives and Its Applications.*
5. Dr. P. Akhilesh : *Multiple Zeta Values and Multiple Apery-like Sums.*
6. Dr. Pooja Singla : *Representations of Special Compact Linear Groups of Order Two.*
7. Prof. V. Kumar Murty : *Course on "Number Theory and Cohomology".*
8. Prof. V. Kumar Murty : *Science, ethics & human values.*
9. Prof. T. N. Shorey : *An estimate for the number of zeros of an exponential function in a disc.*
10. Prof. V. Kumar Murty : *Class field tower problem.*
11. Prof. V. Kumar Murty : *What is a smart village?*
12. Prof. Valeriy Bardakov : *Quandle rings: old and new.*
13. Prof. Bruce C. Berndt : *Living with Ramanujan for 40+ years.*
14. Prof. Bruce C. Berndt : *The final problem.*
15. Prof. Bruce C. Berndt : *Ramanujan's favourite arithmetical function p(n).*
16. Prof. Jean-Marc Deshouillers : *On the Banach density of the set of values of the Eulers totient function.*
17. Prof. Ken Ono : *The Polya-Jensen program for the Riemann Hypothesis and related problems.*
18. Dr. Krishnendu Gongopadhyay : *Local coordinates of loxodromic pairs in rank one.*
19. Mr. Rudradip Biswas : *Generation results in algebraic characterisations of Kropholler's hierarchy and a path to stable module categories.*
20. Dr. Sudhir Pujahari : *Zeros of Dirichlet series attached to half-integral weight cusp forms and generalised Davenport-Heilbronn function.*
21. Dr. Anup Dixit : *Euler Kronecker constants and the generalized Brauer-Siegel conjecture.*
22. Prof. Kamal Khuri Makdisi : *Moduli of Elliptic Curves over C, with application to obtaining equations for modular curves.*
23. Dr. Divyum Sharma : *Number of representations of integers by binary forms.*

24. Dr. Suratno Basu : *Degeneration of intermediate Jacobians and the Torelli type theorems.*

25. Prof. Takao Komatsu : *Continued fractions: their structures, identities, and applications.*

26. Dr. Tushar Kanta Naik : *Twin and Pure twin groups.*

27. Prof. Takao Komatsu : *Some different q-generalizations of harmonic numbers and their applications.*

28. Dr. Pierre-Yves Bienvenu : *Additive bases in infinite abelian semigroups.*

Mathematics Colloquia

1. Dr. Soumya Das : *Omega results for Fourier coefficients of cusp forms.*
2. Prof. Indranil Biswas : *Symplectic geometry of moduli of framed Higgs bundles.*

Mathematics Conferences/Workshops

1. 6 May - 1 June, 2019 : *Annual Foundation School (AFS-I) in Mathematics.*
2. 16 October - 19 October, 2019 : *International conference on Class Groups of Number Fields & Related Topics-III.*
3. 5 March - 10 March, 2020 : *Mini-Workshop on Bundles, Cycles and Motives.*

Physics Talks and Seminars

1. David Logan: *Percolation in Fock space and many-body localisation.*
2. Sthitadhi Roy: *Landau levels, Bardeen polynomials, and Fermi arcs in Weyl semimetals: whos what of the chiral anomaly.*
3. Priya Mahadevan: *Unexpected symmetries in twisted bilayer MoSe2.*
4. Priyadarshini Kapri: *Electrical and thermal transport through spin-orbit coupled nanojunctions: An emphasis on graphene based junction devices.*
5. Ganpathy Murthy: *Chern-Simons theories of the quantum hall effect.*
6. John McGrady: *Structure, spectroscopy and magnetism of molecular clusters.*
7. John McGrady: *Surfaces and solids: reactivity, magnetism and electron transport.*
8. Ribhu Kaul: *Lecture - Quantum Spin Chains.*
9. Bhaskaran Muralidharan: *Quantum Transport in topological superconductor hybrid systems.*
10. Amit Agarwal: *A novel undamped plasmon mode in type-II Dirac semimetal.*
11. Arijit Saha: *Impact of Strong Correlation on Topological Band Properties of different Lattice Systems.*
12. Md. Arif Shaikh: *On emergent sonic geometry through the linear perturbation of Relativistic black hole accretion.*
13. Sandip Saha: *Periodically Modulated Non- Linearity in Limit Cycle Systems : Effects of delay and Control of Bi - Rhythmicity.*
14. Kenji Nishiwaki, Rudjer : *Flavorful vectorlike compositeness enjoys B and K anomalies; also triggers Higgs mechanism.*
15. Subhaditya Bhattacharya : *Dark Matter beyond WIMP freeze out.*
16. Arunansu Sil: *Dark matter in an extended $U(1)_{B-L}$ model and study of high scale validity.*
17. Tathagata Ghosh: *Probing Squeezed Bino-Smuon Spectra with the Large Hadron Collider.*
18. Arindam Das: *Phenomenology of the general U(1) extended Standard Model.*
19. Abhishek Iyer: *Unearthing the pattern of lepton flavour universality violations.*
20. Sanjoy Biswas: *Exploring Dark-ALP portals at future e+e- colliders.*
21. Dr. Bidisha Chakrabarty: *Out of Time Ordered Quantum Dissipation.*
22. Bohnishikha Ghosh: *Advantage in two-way communication using non-classical states of light.*

23. Dr. Manish Kumar Gupta: *Enhanced communication and metrology with superposition of trajectories.*

24. Prof. Vishwa Pal: *Phase locking of large network of coupled lasers.*

25. Moumita Patra: *Monopole operators in N=3 Chern-Simons-Yang-Mills theories.*

26. Sitender Kashyap: *Massive States in Pure Spinor Superstring and Evading an Implication of String Theory-Vacuum Decay.*

27. Prof. Justin David: *Bounds for OPE coefficients in parity odd theories in d=3.*

28. Prof. Alok Laddha: *Towards Amplituhedron for Scalar Field Theories.*

29. Prof. Jainendra Jain: *Tutorial on Fractional quantum Hall effect.*

30. Saptarshi Roy: *Recycling resource states for quantum teleportation.*

31. Chiranjib Mukhopadhyay: *Thermometric schemes using superposition of temporal order and weak Measurement.*

32. Chirag Srivastava: *One-shot conclusive multiport quantum dense coding capacities.*

33. Sreetama Das: *Quantum process randomness.*

34. Brijmohan: *Quantum speed limit.*

35. Gautam Sharma: *Fine-grained uncertainty determines preparation contextuality.*

36. Sohail: *C* algebraic formulation of quantum mechanics.*

37. Naveen Prabhakar: *Large N exact Landau-Ginzburg potentials for Chern-Simons theories coupled to fundamental matter.*

38. Naveen Prabhakar: *(0,4) projective superspace and instantons on ALE spaces.*

39. Dr. Asmita Kumari: *Sharing non-locality and non-trivial preparation contextuality using a family of Bells inequalities.*

40. Suvajit Majumder: *Integrability, Bethe ansatz and all that.*

41. Chandan Kumar Jana: *Non-local divergences in open Quantum Field Theories.*

42. Dr. Swapnamay Mondal: *Quiver invariants from Jeffrey- Kirwan residues.*

43. Dr. Arun Sehrawat: *Uncertainty relations on the joint numerical range of operators.*

44. Dr. Arnab Priya Saha: *Modified celestial amplitudes for gravitons in Einstein gravity.*

45. Dr. Arnab Priya Saha: *Modified celestial amplitudes for gravitons in Einstein gravity.*

46. Suraka Bhattacharjee: *Study of Generalized Spin And Charge Stiffness Constants Of Doped Quantum Antiferromagnets On Low Dimensional Lattices Based On t-J like Models.*

47. Ratul Mahanta: *A Problem of Analytic Completion Related to the Jost-Lehmann-Dyson Formula.*

48. Shiladitya Mal: *Witnessing nonclassical correlation sequentially: an operational measure.*

49. Dr. Dharmesh Jain: *5d Partition Functions with A Twist.*

50. Dr. Mritunjay Verma: *Soft Theorems from Compactification.*

51. Anirban Basu: *Eigenvalue equation for the modular graph C(a,b,c,d).*

52. Pritam Sen: *Cancellation of infrared divergences in bino-like theories of dark matter at finite temperature.*

53. Sreetama Das: *Quantum Information Processing in Noisy Environments.*

54. Mostafizur Rahman: *The question of determinism and Strong Cosmic Censorship Conjecture.*

55. Titas Chanda: *Lattice gauge theories in the age of quantum technologies: Bosonic Schwinger model out of equilibrium.*

56. Shubham Maheswari: *Perturbations in higher derivative gravity beyond maximally symmetric spacetimes.*

57. Prof. Chethan Krishnan : *(title was to be announced).*

58. Ms. Deepali Mishra: *Generalised Garfinkle-Vachaspati Transform.*

59. Mr. Pratik Roy: *Geroch group description of bubbling geometries.*

60. Anosh Joseph: *L-series, wavelets and modular forms.*

61. Anosh Joseph: *Debashis Ghoshal.*

62. Dr. Alok Pan: *Revealing universal quantum contextuality through communication game.*

63. Swati Kumari: *Probing macrorealism in quantum mechanics.*

64. Prof. Suvankar Dutta: *Universality of Large N Fluctuations in Unitary Matrix Models.*

65. Prof. Nabamita Banerjee: *A 3D flat-space holography inspired by AdS3/CFT2 duality.*

Physics Colloquia

1. Jayanta Dutta: *Formation of primordial stars and their survival possibility till present epoch.*
2. Tathagata Ghosh: *Complementarity between Higgs searches at the LHC and Gravitational Waves signals.*
3. Arindam Das: *Right handed neutrinos as a probe of new physics search.*
4. Abhishek Iyer: *Probing physics across the energy frontier.*

Recent Graduates

Mathematics

1. **Veekesh Kumar**, *Some Problems in Transcendental Number Theory*.
2. **Ritika Sharma**, *Some Problems on Arithmetic Functions*.
3. **Anup Kumar Singh**, *Representation formulas for certain quadratic forms and a problem of constructing lifting maps between spaces of modular forms*.
4. **Manish Kumar Pandey**, *Explicit Shimura liftings of certain class of forms and some problems involving modular L-functions*.
5. **S. Manikandan**, *Problems in the theory of moduli spaces of representations of quivers*.
6. **E. Pramod**, *Topics in Additive Combinatorics*.
7. **Bhuwanesh Rao Patil**, *Additive and multiplicative patterns in the natural numbers*.
8. **Pradeep Das**, *Topics in the Symplectic and Kahler geometry of moduli spaces of representations of quivers*.
9. **Bidisha Roy**, *Some Problems in Algebraic and Combinatorial Number Theory connected with Finite Abelian Groups*.
10. **Jaitra Chattopadhyay**, *Some Problems in Ideal Class Groups and Related Topics*.

Physics

1. **Ajanta Maity**, *Electronic properties of monolayer black and blue phosphorus*.
2. **Sitender Pratap Kashyap**, *Massive States in Pure Spinor Superstring and evading an implication of string theory vacuum decay*.
3. **Subhroneel Chakrabarti**, *Scattering of Massive States in Pure Spinor Superstrings*.
4. **Aditya Banerjee**, *Some field theoretical studies in condensed matter physics.*
5. **Abhass Kumar**, *Linking Inflation with Dark Matter, Baryogenesis and Neutrino Masses*.
6. **Juhi Dutta**, *Analysing signals of some compressed spectra in supersymmetry in LHC*.
7. **Sarif Khan**, *Explaining dark matter and neutrino masses by beyond standard model physics*.
8. **Md. Arif Shaikh**, *On emergent sonic geometry through the linear perturbation of relativistic black hole accretion*.
9. **Satadal Datta**, *Emergent Gravity Phenomena in Accreting Astrophysical Systems*.
10. **Ritabrata Bhattacharya**, *A Study of Chaotic behaviour and Thermalization in SYK Model*.
11. **Dipyaman Pramanik**, *New Physics Searches at Long baseline experiments*.
12. **Shouvik Roychoudhury**, *Neutrino Mass Bounds from Cosmology*.
13. **Chiranjib Mukhopadhyay**, *Aspects of quantum resources in thermal environment*.
14. **Krashna Mohan Tripathi**, *Transport through Majorana Zero Modes*.

Publications

Publications (Mathematics)

1. Punita Batra, S.Eswara Rao, Sachin S. Sharma *Integrable modules for twisted toroidal extended affine Lie algebras,* **Journal of Algebra, Vol.556, 1057-1072 (2020).**

2. Punita Batra, Hiroyuki Yamane, *Natural elements of center of generalized quantum groups,* **Contemporary Mathematics, Vol. 751, 19-31 (2020).**

3. Banerjee, S. and Chakraborty, K. *Asymptotic behaviour of a Lambert series á La Zagier: Maass case*, **Ramanujan J.**, Vol. 48 (2019), no. 3, 567–575.

4. Kalyan Banerjee, Kalyan Chakraborty and Azizul Hoque, *Divisibility of Selmer groups and class groups,* **Hardy - Ramanujan Journal**, Vol. 42, (Dec. 2019), 85–99.

5. Kalyan Chakraborty, Azizul Hoque and Mohit Mishra, *On the structure of order 4 class groups of* $\mathbb{Q}(\sqrt{n^2+1})$, **Annales mathmatiques du Qubec, (), 1-10**; DOI 10.1007/s40316-020-00139-1.

6. Kalyan Chakraborty, Azizul Hoque and Prem Prakash Pandey, *Class groups of Number Fields and Related Topics*, Springer, 2019. (Edited).

7. Kalyan Chakraborty, Azizul Hoque and Mohit Mishra, *A note on certain real quadratic fields with class number upto three,* **Kyushu J. M.** (To appear).

8. K. Chakraborty and A. Hoque, *Exponents of class groups of certain imaginary quadratic fields,* **Czechoslovak Mathematical Journal**, (To appear).

9. Kalyan Chakraborty, Azizul Hoque and Richa Sharma, *Complete solutions of certain Lebesgue-Ramanujan-Nagell type of equations,* **Publicationes Mathematicae Debrecen** (To appear).

10. (*with Vivek M. Mallick*) *On the differential graded Eilenberg-Moore construction*, **Journal of Algebra**, Vol. 541, January 2020, 174-218.

11. Manish Kumar Pandey, B. Ramakrishnan and Anup Kumar Singh, *Shimura and Shintani liftings of certain cusp forms of half-integral and integral weights*, Tsukuba J. Math. **43**, No. 2 (2019), 191–210.

12. Manish Kumar Pandey and B. Ramakrishnan, *Determining modular forms of half-integral weight by central values of convolution L-functions*, Modular Forms and Related Topics in Number Theory: Kozhikode, India, December 10–14, 2018, Springer Proc. Math. Stat., 2020 (15 pages, to appear).

13. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of a natural number by certain quaternary quadratic forms*, Modular Forms and Related Topics in Number Theory: Kozhikode, India, December 10–14, 2018, Springer Proc. Math. Stat., 2020 (24 pages, to appear).

14. Bernhard Heim, B. Ramakrishnan and Brundaban Sahu (Editors), *Modular Forms and Related Topics in Number Theory: Kozhikode, India, December 10–14, 2018*, , Springer Proc. Math. Stat., 2020 (to appear).

15. D.S. Ramana and O. Ramaré, *Variant of the Truncated Perron's formula and Primes in Polynomial Sets*. International Journal of Number Theory, Vol. 16, No. 2, (2020), 309-323.

16. *Local smoothing of Fourier integral operators and Hermite functions*, jointly with Ramesh Manna. To appear in the Proceedings on the session on Advances in Harmonic Analysis and Partial Differential Equations of the 12th ISAAC Congress, Aveiro (Portugal) 2019, (to be published by Birkhuser under Trends in Mathematics series)

17. J. Chattopadhyay, B. Roy, S. Sarkar, and R. Thangadurai, *Distribution of residues modulo p using the Dirichlet's class number formula*, K. Chakraborty et al. (eds.), Class groups of number fields and related topics, Springer Proc. Math. Stat., (2020) 97-108.

18. V. P. Ramesh, R. Thangadurai and R. Thatchaayini, *A note on Gauss's theorem on primitive roots*, Amer. Math. Monthly, **126** (2019), no. 3, 252-254.

19. N. Saradha and R. Thangadurai, *Pillars of Transcendental Number Theory*, Springer Singapore, 2020.

20. Sumana Hatui, Vipul Kakkar and Manoj K. Yadav, *The Schur multiplier of groups of order p^5*, J. Group Theory 22, 647-687, (2019).

21. Tushar K. Naik, Rahul D. Kitture and Manoj Kumar Yadav, *Finite p-groups of nilpotency class 3 with two conjugacy class sizes,* Isreal J. Math. 236, 899-930, (2020).

22. Valeriy G. Bardakov, Mikhail V. Neshchadim and Manoj K. Yadav, *Computing skew left braces of small orders* Internat. J. Alg. Comput., https://doi.org/10.1142/S0218196720500216, (2020).

23. Mohit Mishra, Rishabh Agnihotri and Kalyan Chakraborty, *Primary rank of the class group of real cyclotomic fields*, Rocky Mountain J. Math. (2020) (To appear).

24. Anand, J. Chattopadhyay and B. Roy, *On sums of polynomial-type exceptional units in $\mathbb{Z}/n\mathbb{Z}$*, Arch. Math. (Basel), **114** (2020), 271-283.

25. J. Chattopadhyay, *A short note on the divisibility of class numbers of real quadratic fields*, J. Ramanujan Math. Soc., **34** (2019), 389-392.

26. J. Chattopadhyay and P. Darbar, *Mean values and moments of arithmetic functions over number fields*, Res. Number Theory, **5** (2019), Art. 23, 15 pp.

27. Mithun Kumar Das, Sudhir Pujahari, *Distribution of signs of Karatsuba's and generalized Davenport-Heilbronn Z-functions*, J. Number Theory 212 (2020) 409–447.

28. Mithun Kumar Das, Abhishak Juyal, *Higher dimensional Dedekind sums and twisted mean value of Dirichlet L-series*, (To appear in J. Ramanujan Math. Soc.).

29. Mithun Kumar Das, B. R. Patil, E. Pramod, *Combinatorial properties of sparsely totient numbers*, J. Ramanujan Math. Soc. 35, No.1 (2020) 1-16.

30. Mithun Kumar Das, B. R. Patil, E. Pramod, *Sparse subsets of the natural numbers and Eulers totient function.*, Proc. Indian Acad. Sci. Math. Sci. 129 (2019), no. 5

31. Mohit Mishra, *Partial Dedekind zeta values and class numbers of R–D type real quadratic fields,* Class group of number fields and related topics, Conference proceedings of ICCGNFRT–2017, 163–174.

32. Sukumar Das Adhikari, Bidisha Roy and Subha Sarkar, *Weighted zero-sums for some finite abelian groups of higher ranks,* Combinatorial and Additive Number theory proceedings, (2020), 1–12.

33. Jaitra Chattopadhyay, Bidisha Roy and Subha Sarkar, *On Fractionally Dense Sets,* Rocky Mountain Journal of Mathematics, **49** (2019), 743–760.

34. Bidisha Roy and Subha Sarkar, *On determination of Zero-sum ℓ-generalized Schur Numbers for some linear equations*, Journal of combinatorics and number Theory, **11** (2020), 65–76.

35. I. Biswas, and Anoop Singh. *On the relative connections*, Comm. Algebra **48**(2020), no. 4, 14521475.

36. Anoop Singh. *Moduli space of rank one logarithmic connections over a compact Riemann surface,* to appear in C. R. Math. Acad. Sci. Paris

37. Anoop Singh. *Moduli space of logarithmic connections singular over a finite subset of a compact Riemann surface,* to appear in Math. Res. Lett.

38. C. P. Anil Kumar, *A Representation Theorem For Generic Line Arrangements in the Plane*, **The Journal of the Indian Mathematical Society, Vol. 87, Issue 1-2, 2020, pp. 96-113, DOI: 10.18311/jims/2020/24873**, http://www.informaticsjournals.com/index.php/jims/article/view/24873

39. C. P. Anil Kumar, *On the Factorization of Two Adjacent Numbers in Multiplicatively Closed Sets Generated by Two Elements*, **Proceedings Mathematical Sciences: Indian Academy of Sciences, Accepted on Jan 20, 2020, DOI: 10.1007/s12044-020-00566-8**, https://doi.org/10.1007/s12044-020-00566-8

40. C. P. Anil Kumar, *On the Surjectivity of Certain Maps II: For Generalized Projective Spaces*, **Journal of the Ramanujan Mathematical Society, Accepted on Apr. 18, 2020**

41. O. Constantinescu and Ebtsam H. Taha, *Alternative Lagrangians obtained by scalar deformations,* Int. J. Geom. Meth. Mod. Phys., 17 (4) (2020) 2050050. DOI: 10.1142/S0219887820500504.

42. Rahul Dattatraya Kitture and Soham Swadhin Pradhan, *Degrees of Faithful Irreducible Representations of Metabelian Groups,* **Journal of Algebra and its Applications, accepted for publication**

43. Chiranjit Ray and Rupam Barman, *On Andrews' integer partitions with even parts below odd parts*, Journal of Number Theory. (accepted)

44. Ron. Kerman, Rama Rawat and Rajesh K. Singh, *Dilation-commuting operators on power-weighted Orlicz classes*, Math. Inequal. Appl. 22 (2) (2019), pp. 463-486.

45. Ron. Kerman, Rama Rawat and Rajesh K. Singh, *A sharp form of the Marcinkiewicz Interpolation Theorem for Orlicz spaces*, DOI: 10.4064/sm180111-28-10, Published online: 13 May 2020.

Publications (Physics)

1. S. Ghosh, T. Chanda, and A. Sen(De), *Enhancement in performance of quantum battery by ordered and disordered interactions*, Phys. Rev A **101,** 032115 (2020).

2. G. Sharma, M. A. Siddiqui, S. Mal, S k Sazim, and A. Sen(De), *Robustness of interferometric complementarity under decoherence*, Phys. Lett. A **384**, 126297 (2020).

3. A. Sen (De), *Resources for Quantum Technologies*, PHYSICS NEWS (BULLETIN OF THE INDIAN PHYSICS ASSOCIATION, January March 2020) **50**, 24 (2020).

4. S. Das, C. Mukhopadhyay, S. Singha Roy, S. Bhattacharya, A. Sen(De), and U. Sen, *Wave-particle duality employing quantum coherence in superposition with non-distinguishable pointers*, J. Phys. A: Math. Theor. **53**, 11503 (2020).

5. C. Srivastava, A. Bera, A. Sen(De), and U. Sen, *One-shot conclusive multiport quantum dense coding capacities*, Phys. Rev. A **100**, 052304 (2019).

6. S. Rethinasamy, S. Roy, T. Chanda, A. Sen(De), and U. Sen, *Universality in Distribution of Monogamy Scores for Random Multiqubit Pure States*, Phys. Rev. A **99,** 042302 (2019).

7. S. Singha Roy, H.S. Dhar, A. Sen(De), and U. Sen, *Tensor-network approach to compute genuine multisite entanglement in infinite quantum spin chains*, Phys. Rev. A **99**, 062305 (2019).

8. J. Jayakumar, S. Das, A. Sen(De), and U. Sen, *Mimicking disorder on a clean graph: Interference-induced inhibition of spread in a cyclic quantum random walk*, Europhys. Lett. **128**, 20007 (2019).

9. S. Das, S. Mal, A. Sen(De), and U. Sen, *Inhibition of spreading in quantum random walks due to quenched Poisson-distributed disorder*, Phys. Rev. A **99**, 042329 (2019).

10. S.Das, A. Misra, A.K. Pal, A.Sen(De) and U. Sen, *Necessarily transient quantum refrigerator*, Europhys. Lett. **125**, 20007 (2019).

11. M. Pandit, A. Bera, A. Sen(De), and U. Sen, *Position and momentum cannot both be lazy: Quantum reciprocity relation with Lipschitz constants*, Phys. Rev. A **100**, 012131 (2019).

12. A. Bera, D. Sadhukhan, D. Rakshit, A. Sen(De), and U. Sen, *Response of entanglement to annealed vis--vis quenched disorder in quantum spin models*, Europhys. Lett. **127**, 30003 (2019).

13. Transcendentality violation in type IIB string amplitudes, JHEP 02, 034 (2020)

14. Eigenvalue equation for the modular graph $C_{a,b,c,d}$, JHEP 07, 126 (2019)

15. B. S. Acharya, M. Dhuria, D. Ghosh, A. Maharana and F. Muia
Cosmology in the presence of multiple light moduli
JCAP **1911** (2019) 035 , arXiv:1906.03025 [hep-th].

16. R. Mahanta and A. Maharana,
Crossing, modular averages and $N \leftrightarrow k$ in WZW models
JHEP **1910**, 061 (2019); arXiv:1905.02816 [hep-th]

17. D. Das, A. K. Pati,
Can Two Quantum Chesire Cats Exchange Grins?,
New Journal of Physics, 22, 063032 (2020). (Highlighted as feature Story in Scientific American, May 2019).

18. Lei Xiao, Bowen Fan, Kunkun Wang, Arun Kumar Pati, Peng Xue,
Direct Experimental Test of Forward and Reverse Uncertainty Relations,
Phys. Rev. Research 2, 023106 (2020).

19. Waleed Abdallah, AseshKrishna Datta, Arindam Chatterjee, *Revisiting singlino dark matter of the natural Z_3-symmetric NMSSM in the light of LHC*, JHEP 09 (2019) 095.

20. A. Laddha and A. Sen, "Classical proof of the classical soft graviton theorem in $D > 4$," Phys. Rev. D **101**, no.8, 084011 (2020) doi:10.1103/PhysRevD.101.084011 [arXiv:1906.08288 [gr-qc]].

21. S. Faroogh Moosavian, A. Sen and M. Verma, "Superstring Field Theory with Open and Closed Strings," JHEP **01**, 183 (2020)
doi:10.1007/JHEP01(2020)183 [arXiv:1907.10632 [hep-th]].

22. A. Sen, "Fixing an Ambiguity in Two Dimensional String Theory Using String Field Theory," JHEP **03**, 005 (2020)
doi:10.1007/JHEP03(2020)005 [arXiv:1908.02782 [hep-th]].

23. A. P. Saha, B. Sahoo and A. Sen, "Proof of the classical soft graviton theorem in $D = 4$," JHEP **06**, 153 (2020) doi:10.1007/JHEP06(2020)153 [arXiv:1912.06413 [hep-th]].

24. Abhishek Joshi and Pinaki Majumdar, *Impact of speckle disorder on a superfluid Fermi system.* Phys Rev B 100, 045149 (2019).

25. Sauri Bhattacharyya, Sankha Subhra Bakshi, Saurabh Pradhan, and Pinaki Majumdar, *Strongly anharmonic collective modes in a coupled electron-phonon-spin problem.* Phys Rev B 101, 125130 (2020).

26. Abhishek Joshi and Pinaki Majumdar, *A classical fluctuation theory of the superfluid, Mott, and normal phases of correlated bosons.* Eur. Phys. J. B (2020) 93: 33

27. A. Sen and P. Sen, *Designing rare earth free permanent magnets: Insights from small Co clusters,* Phys. Chem. Chem. Phys. **21**, 22577 (2019)

28. *Localized spin waves at low temperatures in a cobalt carbide nanocomposite,* N. Roy, A. Sen, P. Sen and S. S. Banerjee, J Appl. Phys. **127**, 124301 (2020)

29. D. London, P. Saha and R. Watanabe, *B-Sector Anomalies – The Top Connection*, Springer Proc. Phys. **234**, 401-405 (2019)

30. K. Das, T. Mondal and Santosh Kumar Rai, *Non-standard signatures of vector-like quarks in a leptophobic 221 model,* Phys. Rev. D **99**, 115002 (2019).

31. P. S. B. Dev, S. Khan, M. Mitra and Santosh Kumar Rai, *Doubly-charged Higgs Boson at Future Electron-Proton Collider,* Phys. Rev. D **99**, 115015 (2019).

32. B. Coleppa, Santosh Kumar Rai and A. Sarkar, *Charged Higgs boson discovery prospects,* Phys. Rev. D **101**, 055030 (2020).

33. J. Dutta, B. Mukhopadhyaya and Santosh Kumar Rai, *Identifying a Higgsino-like NLSP in the context of a keV-scale gravitino LSP,* Phys. Rev. D **101**, 075040 (2020).

34. Suman Jyoti De, Udit Khanna and Sumathi Rao, *Magnetic flux periodicity in second order topological superconductors*, Phys. Rev. **B101**, 125429 (2020).

35. Tarafdar, Pratik., Bollimpalli, Deepika A., Nag, Sankhasubhra., & Das, Tapas K., *Influence of geometrical configuration on low angular momentum relativistic accretion around rotating black holes,* Physical Review D **Volume 100, Issue 4**, id.043024, (2019).

36. Population inversion and entanglement in single and double glassy Jaynes-Cummings models, Ahana Ghoshal, Sreetama Das, Aditi Sen De, Ujjwal Sen, Phys. Rev. A 101, 053805 (2020)

37. Beating detection loophole in nonlinear entanglement witnesses, Kornikar Sen, Sreetama Das, Ujjwal Sen, Phys. Rev. A 100, 062333 (2019)

38. Partial coherence and quantum correlation with fidelity and affinity distances, Chunhe Xiong, Asutosh Kumar, Minyi Huang, Sreetama Das, Ujjwal Sen, Junde Wu, Phys. Rev. A 99, 032305 (2019)

39. Fibonacci sequence and its generalizations in doped quantum spin ladders, Sudipto Singha Roy, Himadri Shekhar Dhar, Aditi Sen De, Ujjwal Sen, Journal of Magnetism and Magnetic Materials 478, 100 (2019)

40. Phase boundaries in alternating field quantum XY model with Dzyaloshinskii-Moriya interaction: Sustainable entanglement in dynamics, Saptarshi Roy, Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Aditi Sen De, Ujjwal Sen, Phys. Rev. B 99, 064422 (2019)

41. Universal quantum uncertainty relations: Minimum-uncertainty wave packet depends on measure of spread, Anindita Bera, Debmalya Das, Aditi Sen De, Ujjwal Sen, Phys. Lett. A 383, 1850 (2019)

42. Wave-particle duality employing quantum coherence in superposition with non-orthogonal pointers, Sreetama Das, Chiranjib Mukhopadhyay, Sudipto Singha Roy, Samyadeb Bhattacharya, Aditi Sen De, Ujjwal Sen, J. Phys. A: Math. Theor. 53 115301 (2020)

43. *Modified celestial amplitude in Einstein gravity*, Shamik Banerjee, Sudip Ghosh, Pranjal Pandey, Arnab Priya Saha, 10.1007/JHEP03(2020)125, arXiv [1909.03075]

44. A. Sehrawat, *Uncertainty relations on the joint numerical range of operators*, J. Phys. A: Math. Theor. **53**, 085303 (2020).

45. Boosted Top quark polarization - Rohini Godbole, Monoranjan Guchait, Charanjit K. Khosa, Jayita Lahiri, Seema Sharma, Aravind H. Vijay (ArXiv:1902.08096 - published in Phys.Rev. D100 (2019) no.5, 056010)

46. LHC signals of a heavy doublet Higgs as dark matter portal: cut-based approach and improvement with gradient boosting and neural networks - Atri Dey, Jayita Lahiri, Biswarup Mukhopadhyaya(ArXiv:1905.02242 - published in JHEP 1909 (2019) 004)

47. "Locally distinguishing quantum states with limited classical communication" by **Saronath Halder** and Chirag Srivastava, Phys. Rev. A **101**, 052313 (2020).

48. *"Relaxed hypermultiplet in four dimensional N=2 conformal supergravity"* ,
S. Hegde, B. Sahoo & A. Srinivasan
Phys. Rev. D 101, 066012 (2020); [arXiv:2001.04285 [hep-th]].

49. P. Sen, K. Alam, Tisita Das, R. Banerjee and S. Chakraborty, Combinatorial design and computational screening of 2D transition metal tri-chalcogenide monolayers: Towards efficient catalysts for hydrogen evolution reaction, *Journal of Phys. Chem. Letters* **11**, 3608 (2020).

50. Suman Chatterjee, Anirban Das, Tousik Samui, Manibrata Sen, *Mixed WIMP-axion dark matter,* Phys. Rev. D **100**, 115050, (2019)

51. W. Abdallah, A. Kumar and A. K. Saha, *Soft leptogenesis in the NMSSM with a singlet right-handed neutrino superfield,* JHEP **04**, 065 (2020).

52. W. Abdallah, A. Hammad, S. Khalil and S. Moretti, *Dark Matter Spin Characterisation in Mono-Z Channels,* Phys. Rev. D **100**, 095006 (2019).

53. W. Abdallah, S. Choubey and S. Khan, *FIMP dark matter candidate(s) in a $B - L$ model with inverse seesaw mechanism,* JHEP **1906**, 095 (2019).

54. Arijit Dutta and Pinaki Majumdar, *Spatial behavior in a Mott insulator near the voltage-driven resistive transition* Phys. Rev. B **101**, 245155, (2020)

55. Arpan Kar, Sourav Mitra, Biswarup Mukhopadhyaya, Tirthankar Roy Choudhury, Steven Tingay, *Constraints on dark matter annihilation in dwarf spheroidal galaxies from low frequency radio observations,* Phys. Rev. D 100, **043002** (2019)

56. Arpan Kar, Sourav Mitra, Biswarup Mukhopadhyaya, Tirthankar Roy Choudhury, *Heavy dark matter particle annihilation in dwarf spheroidal galaxies: radio signals at the SKA telescope,* Phys. Rev. D 101, **023015** (2020)

57. Avirup Ghosh, Alejandro Ibarra, Tanmoy Mondal, Biswarup Mukhopadhyaya, *Gamma-ray signals from multicomponent scalar dark matter decays*, JCAP 01 (2020) 011

58. Ratul Banerjee,Amit Kumar Pal, Aditi(Sen) De,*Uniform Decoherence Effect on Localizable Entanglement in Random Multi-qubit Pure States* ,**Phys. Rev. A 101,042339 (2020)**

59. Sauri Bhattacharyya, Sankha Subhra Bakshi, Samrat Kadge, and Pinaki Majumdar, *Langevin approach to lattice dynamics in a charge-ordered polaronic system,* Phys. Rev. B **99**, 165150, (2019)

60. A. Ghosal, D. Das, S. Roy, S. Bandyopadhyay, *Optimal two-qubit states for quantum teleportation vis--vis state properties,* Phys. Rev. A **101**, 012304 (2020)

61. A. Ghosal, D. Das, S. Roy, S. Bandyopadhyay, *Fidelity deviation in quantum teleportation with a two-qubit state,* JPhys A **53**, 14 (2020)

62. S. H, S. Roy, T. Chanda, A. Sen De, U. Sen, *Multipartite entanglement at dynamical quantum phase transitions with non-uniformly spaced criticalities,* To appear in Phys. Rev. B

Preprints

Preprints (Mathematics)

1. Punita Batra (With Priyanshu Chakraborty) *Classification of irreducible integrable representations of Loop Toroidal Lie algebras,* arxiv.org/pdf/2007.06415.
2. Umesh V. Dubey (With Sanjay Amrutiya) *Moduli of filtered quiver representations*, ArXiv: 1808.02003v2 [math.AG] (under review), 25 pp.
3. Umesh V.Dubey (With Sanjay Amrutiya) *Moduli of parabolic sheaves and filtered Kronecker modules*, ArXiv: 2005.01084 [math.AG] (under review), 24 pp.
4. H. Shah and E. H. Taha, *Harmonic and asymptotically harmonic manifolds in the Finslerian settings*, in preparation.
   Preliminary version of this paper is on Arxiv: arxiv:2005.03616v1[math. DG].
5. R. Thangadurai and Veekesh Kumar, *On simulataneous approximation of algebraic numbers*, arXiv:2001.00386 [math.NT], 2020.
6. Rahul Kaushik and Manoj K. Yadav, *Commutators and commutator subgroups of finite p-groups,* preprint, rXiv:2005.13929.
7. Valeriy G. Bardakov, Mikhail V. Neschadim and Manoj K. Yadav, *On λ-homomorphic skew braces,* preprint, arXiv:2004.05555.
8. *On the number of integral ideal of a number field* arxiv.org/2002.06342 (2020).
9. Integrable Modules For Graded Lie Tori With Finite Dimensional Weight Spaces (https://arxiv.org/pdf/2005.07381.pdf).
10. Anoop Singh. *On the moduli space of λ-connections.* arXiv:2002.00358
11. C. P. Anil Kumar, and Anoop Singh. *On a Conjecture of Kelly on $(1, 3)$-representation of Sylvester Gallai Designs.* arXiv:2003.07645
12. On a question of Colliot-Thelene on Chow group, joint with Kalyan Chakraborty, arxiv:1906.08233.
13. On Selmer groups associated to Chow groups of certain codimension two cycles, joint with Kalyan Chakraborty, arxiv:1908.06424.
14. Chow groups, pull back and class groups, joint wit Azizul Hoque, arxiv:1903.04210.
15. A remark on algebraic cycles on cubic fourfolds, arxiv:1908.04576.
16. Representability of Chow groups of codimension three cycles, arxiv:1906.08232.
17. Involutions on algebraic surfaces and generalised Bloch conjecture, arxiv: 1906.09616.

18. C. P. Anil Kumar, *On the Triangles in Certain Types of Line Arrangements*, arXiv: 1906.05120, Submitted to a Journal

19. C. P. Anil Kumar, Soham Swadhin Pradhan, *On the Endomorphism Semigroups of Extra-Special p-Groups and Automorphism Orbits*, arXiv: 1908.00331, Submitted to a Journal

20. C. P. Anil Kumar, *On a Projective Space Invariant of a Co-torsion Module of Rank Two over a Dedekind Domain*, arXiv: 1912.00797, Submitted to a Journal

21. C. P. Anil Kumar, *A Combinatorial Identity for the p-Binomial Coefficient Based on Abelian Groups*, arXiv: 1912.10725, Submitted to a Journal

22. C. P. Anil Kumar, *Positivity Conjecture for a Certain Class of Finite Abelian p-Groups*, arXiv: 2001.02523, Submitted to a Journal

23. Hemangi M. Shah and Ebtsam H. Taha, *On harmonic and asymptotic harmonic Finsler manifolds*, arXiv:2005.03616v1 [math.DG].

Preprints (Physics)

1. R. Banerjee, A. K. Pal, and A. Sen(De), *Hierarchies of localizable entanglement due to spatial distribution of local noise*, arXiv:2003.02175.

2. R. Banerjee, S. Ghosh, S. Mal, and A. Sen(De), *Spreading Nonlocality in Quantum Network*, arXiv:1912.08874.

3. S. Roy, T. Das, and A. Sen(De), *Computable genuine multimode entanglement measure: Gaussian vs. non-Gaussian*, arXiv:1912.03284.

4. S. Halder, S. Mal, and A. Sen (De), *Characterization and Generation of Absolutely Separable States*, arXiv:1911.13145.

5. C. Srivastava, S. Mal, A. Sen(De), and U. Sen, *Sequential measurement-device-independent entanglement detection by multiple observers*, arXiv:1911.02908.

6. A. Ghoshal, S. Das, A. Sen(De), and U. Sen, *Population inversion and entanglement in single and double glassy Jaynes-Cummings models*, arXiv:1910.00249.

7. S. Haldar, S. Roy, T. Chanda, and A. Sen (De), *Response of macroscopic and microscopic dynamical quantifiers to the quantum critical region*, arXiv:1908.06374.

8. R. Banerjee, A.K. Pal, and A. Sen(De), *Uniform Decoherence Effect on Localizable Entanglement in Random Multi-qubit Pure States*, arXiv:1907.10847.

9. S. Roy, A. Bera, S. Mal, A. Sen(De), and U. Sen, *Recycling the resource: Sequential usage of shared state in quantum teleportation with weak measurements*, arXiv:1905.04164.

10. Worldsheet (anti)instanton bound states in type II on T^2, 2003.03301

11. S. Bhattacharya, K. Dutta, M. R. Gangopadhyay, A. Maharana and K. Singh, *Fibre Inflation and Precision CMB Data* [arXiv:2003.05969 [astro-ph.CO]].

12. Debmalya Das, Arun Kumar Pati,
Teleporting Grin of a Quantum Chesire Cat without cat,
arXiv:1903.04152.

13. A. K. Pati,
Distinguishing two preparations for same pure state leads to signalling,
arXiv:1904.05722.

14. A. K. Pati, Long-Mei Yang, C. Mukhopadhyay, Shao-Ming Fei, Zhi-Xi Wang,
Coherence of Purification,
arXiv:1907.13067.

15. Manish Kumar Shukla, Rounak Mundra, Arun K Pati, Indranil Chakrabarty, Junde Wu,
Quantumness of Relative Incompatibility,
arXiv:1909.12534.

16. Arun Kumar Pati,
Super Quantum Search Algorithm withWeak Value Amplification and Postselection,
arXiv:1910.12390

17. Mahathi Vempati, Nirman Ganguly, Indranil Chakrabarty, Arun K Pati,
Witnessing negative Conditional Entropy as an Operational Resource,
arXiv:2001.11237.

18. Surya Narayan Sahoo, Sanchari Chakraborti, Arun K. Pati, Urbasi Sinha *Quantum State Interferography,*
arXiv:2002.07446.

19. A. Sen, "D-instanton Perturbation Theory," [arXiv:2002.04043 [hep-th]].

20. A. Sen, "Divergent to Complex Amplitudes in Two Dimensional String Theory," [arXiv:2003.12076 [hep-th]].

21. K. Alam, N. Seriani and P. Sen, *Catalytic properties of α-MnO_2 for Li-air battery cathodes: a density functional investigation* (submitted).

22. P. Sen and R. Chouhan, *Electronic structure of MPX_3 tri-chalcogenide monolayers in density functional theory: A case study with four compounds (M=Mn, Fe; X=S, Se)* (submitted).

23. P. Sen, K. Alam, T. Das, R. Banerjee and S. Chakraborty, *Combinatorial design and computational screening of 2D transition metal tri-chalcogenide monolayers: Toward efficient catalysts for hydrogen evolution reaction* (submitted).

24. A. K. Nayak, Santosh Kumar Rai and T. Samui, *Probing Heavy Dijet Resonances Using Jet Substructure at the LHC,* [arXiv:1912.03511 [hep-ph]].

25. S. Dasgupta, Santosh Kumar Rai, T. S. Ray, *Impact of a colored vector resonance on the collider constraints for top-like top partner,* [arXiv:1912.13022 [hep-ph]].

26. Mariana Frank, Benjamin Fuks, Katri Huitu, Subhadeep Mondal, Santosh Kumar Rai, Harri Waltari, *The left-right supersymmetric option at a high-energy upgrade of the LHC,* [arXiv:2003.08443 [hep-ph]].

27. Sourav Biswas, Tridev Mishra, Sumathi Rao and Arijit Kundu, *Chiral Luttinger liquids in graphene tuned by irradiation*,archive preprint, cond-mat/2003.09160

28. Faruk Abdulla, Priyanka Mohan and Sumathi Rao, *Curvature function renormalisation, topological phase transitions and multicriticality*, cond-mat/2003.10190

29. Datta, Satadal., & Das, Tapas K., *Lagrangian Description of Accreting Black Hole Systems in the Context of Emergent Spacetime,* eprint arXiv:1910.06768 [astro-ph.HE] (2019).

30. Tarafdar, Pratik., Maity, Susovan., & Das, Tapas K., *Influence of flow thickness on general relativistic low angular momentum accretion around spinning black holes,* eprint arXiv:2005.01746 [astro-ph.HE] (2020).

31. Maity, Susovan., Tarafdar, Pratik., Shaikh, Md. Arif., & Das, Tapas K., *Dependence of acoustic surface gravity on disc thickness for accreting astrophysical black holes,* eprint arXiv:2005.13573 [astro-ph.HE] (2020).

32. Fernandes, Karan., Maity, Susovan., & Das, Tapas K., *Emergent gravity through non-linear perturbation,* eprint arXiv:2005.14114 [gr-qc] (2020).

33. arXiv:2005.08296, Resource theory of quantum coherence with probabilistically non-distinguishable pointers and corresponding wave-particle duality, Chirag Srivastava, Sreetama Das, Ujjwal Sen

34. arXiv:2004.14816, How many runs ensure quantum fidelity in teleportation experiment?, C S Sudheer Kumar, Ujjwal Sen

35. arXiv:2004.09101, Detection loophole in measurement-device-independent entanglement witness, Kornikar Sen, Chirag Srivastava, Shiladitya Mal, Aditi Sen De, Ujjwal Sen

36. arXiv:2004.07729, Estimating quantum coherence by noncommutativity of any observable and its incoherent part, Tanaya Ray, Arun Kumar Pati, Ujjwal Sen

37. arXiv:2004.01419, Noncommutative coherence and quantum phase estimation algorithm, Shubhalakshmi S, Ujjwal Sen

38. arXiv:2001.00669, Delayed choice of paths selected by grin and snarl of quantum Cheshire Cat, Debmalya Das, Ujjwal Sen

39. arXiv:1911.05540, Local passivity and entanglement in shared quantum batteries, Kornikar Sen, Ujjwal Sen

40. arXiv:1909.13125, Transmitting quantum information by superposing causal order of mutually unbiased measurements, Manish K. Gupta, Ujjwal Sen

41. arXiv:1909.09066, Witnessing nonlocality of bipartite quantum operations, Sohail, Ujjwal Sen

42. arXiv:1909.07244, Coherence as witness for quantumness of gravity, Ahana Ghoshal, Arun Kumar Pati, Ujjwal Sen

43. arXiv:1905.06198, Almost Markovian maps and entanglement-based bound on corresponding non-Markovianity, Sreetama Das, Sudipto Singha Roy, Samyadeb Bhattacharya, Ujjwal Sen

44. arXiv:1904.05720, Signaling versus distinguishing different superpositions of same pure quantum state, Chirag Srivastava, Sreetama Das, Aditi Sen De, Ujjwal Sen

45. arXiv:1903.12096, Frequentist-approach inspired theory of quantum random phenomena predicts signaling, C. S. Sudheer Kumar, Anup Biswas, Aditi Sen De, Ujjwal Sen

46. arXiv:1903.03564, Quantum Process Randomness, Sreetama Das, Asutosh Kumar, Aditi Sen De, Ujjwal Sen

47. A. Banerjee, A. Kundu and R. R. Poojary, "*Rotating Black Holes in AdS, Extremality and Chaos*," [arXiv:1912.12996 [hep-th]].

48. A. Banerjee, A. Bhattacharya and S. Maulik, "*Perturbative Entanglement Structure and Entanglement Thermodynamics of Open String Geometries*," [arXiv:2006.***** [hep-th]].

49. LHC signals of triplet scalars as dark matter portal: cut-based approach and improvement with gradient boosting and neural networks - Atri Dey, Jayita Lahiri, Biswarup Mukhopadhyaya (Arxiv:2001.09349). This paper has been accepted in JHEP and currently undergoinf proof-reading.

50. K. Fernandes, K. S. Kolekar, K. Narayan and S. Roy,
"Schwarzschild de Sitter and extremal surfaces," [arXiv:1910.11788 [hep-th]]

51. K. Fernandes and A. Mitra,
"Soft factors from classical scattering on the Reissner-Nordström spacetime," [arXiv:2005.03613 [hep-th]]

52. K. Fernandes, S. Maity and T. K. Das,
"Emergent gravity from non-linear perturbation," [arXiv:2005.14114 [gr-qc]]

53. Gautam Sharma, Sk Sazim, Shiladitya Mal, *Fine grained uncertainty determines preparation contextuality*, arXiv:1905.09695.

54. Rivu Gupta, Shashank Gupta, Shiladitya Mal, Aditi Sen De, *Constructive Feedback of Non-Markovianity on Resources in Random Quantum States*, arXiv:2005.04009.

55. Srijon Ghosh, Titas Chanda, Shiladitya Mal, Aditi Sen De, *Fast charging of quantum battery assisted by noise*, arXiv:2005.12859.

56. "Local state discrimination and ordering of multipartite entangled states" by Sumit Rout, Ananda G. Maity, Amit Mukherjee, **Saronath Halder**, and Manik Banik, arXiv: 1910.14308 (2019).

57. "Unextendible product bases, bound entangled states, and the range criterion" by Pratapaditya Bej and **Saronath Halder**, arXiv: 2005.02108 (2020).

58. Tousik Samui, Nilakash Sorokhaibam, *State-dependent thermalization in SYK model,* arXiv:2004.14376 [hep-th]

59. W. Abdallah, S. Choubey and S. Khan, *Two component FIMP DM in a $U(1)_{B-L}$ extension of the SM,* arXiv:2004.13211, contribution to: the International Conference on Neutrinos and Dark Matter (NDM-2020), 11-14 January 2020, Hurghada, Egypt.

60. W. Abdallah et al., *Reinterpretation of LHC Results for New Physics: Status and Recommendations after Run 2,* arXiv:2003.07868, LHC Reinterpretation Forum Collaboration.

61. Avirup Ghosh, Arpan Kar, Biswarup Mukhopadhyaya, *Search for decaying heavy dark matter in an effective interaction framework: a comparison of -ray and radio observations,* arXiv:2001.08235 [hep-ph]

62. Arpan Kar, Biswarup Mukhopadhyaya, Steven Tingay, Ben McKinley, Marijke Haverkorn, Sam McSweeney, Natasha Hurley-Walker, Sourav Mitra, Tirthankar Roy Choudhury, *Constraints on dark matter annihilation in ω Centauri,* arXiv:2005.11962 [astro-ph.HE]

63. Competing structural and electronic instabilities at the surface of polar insulating BeO: Emergence of two dimensional electron gas: Arpita Sen, Prasenjit Sen and Umesh V Waghmare

64. The Exchange Bias effect in pure Co_2C nanoparticles. Nirmal Roy, Md. Arif Ali, Arpita Sen, Prasenjit Sen, S. S. Banerjee

65. Avirup Ghosh, Deep Ghosh, Satyanarayan Mukhopadhyay, *Asymmetric dark matter from semi-annihilation*, e-Print: ArXiv: 2004.07705

66. Brij Mohan and Arun Kumar Pati, Reverse Quantum Speed Limit: How Slow Quantum Battery Can Discharge?, arXiv:2006.14523.

67. S. Roy, A. Ghosal, *Rating the performance of noisy teleportation using fluctuations in fidelity,* arXiv:2001.11463 [quant-ph]

68. *Thermal dynamics of lattice modes near a polaronic crossover: from the dilute polaron limit to a charge ordered state*, arXiv 1711.08749 (superseding previous version).

About the Computer Section

1. The computing facilities of the Institute are one of the best in the country. It provides the required support to the academics and research activities and to administrative activities. The computing facilities are available to users round the clock i.e $24 \times 7 \times 365$ all over the campus.

2. The entire HRI campus is connected with OFC based 1 Gbps backbone providing the network and Internet connectivity to each and every office, hostel and guest house rooms helping the scientists, researchers and all the other members on campus to work from any place in the campus round the clock.

3. The desktop computers of the faculty, students, post doctoral fellows and visiting fellows were upgraded with the newer versions of different flavours of Linux, Windows and Mac operating systems.

4. Latest versions of several applications software and packages were loaded on users' desktop computers, computer centre desktop computers and conference room desktop computers, which provided the researchers to do their numerical and analytical calculations faster and obtain more precise results.

5. The Operating Systems and all the important and the necessary application packages were upgraded on Mail Servers , Webmail Servers, dns, ssh, dhcp+ddns, proxy, ldap and Firewall servers for the better, reliable and secure running of the servers and its services without any failure. Firewall rules were upgradded and fine tuned to enhance the security level of the servers and network services to protect them from Internet attacks.

6. Some additional security features were added in the Mail Servers and all the other External Servers facing the Internet directly outside the DMZ.

7. During the various conferences, workshops and schools, computer facilities were provided in the conference computer room to all the participants. All the necessary computer support were provided to all the participants of the conferences, workshops and schools.

8. Additional computing support was provided to the visiting scientists and visiting students under Visiting Students Programme (VSP).

9. The Video Conference facilitiy was provided to academic and administrative meetings, conducting the students Ph.D viva and for organising lectures with other academic institutes nationally and internationally.

10. Secondary Internet bandwidth from M/s Reliance Communications Ltd. was commissioned as a back up cum redundant Internet bandwidth for the primary NKN Internet bandwidth.

Current activities and plans:

1. It is planned to purchase Linux and Windows based All-in-One desktop computers for the faculy members, Ph.D. students, post doctoral fellows and administrative members of the Institute.
2. It is planned to purchase new servers for running basic computer services such as firewall services, mail, webmail, dns, dhcp+ddns, proxy and ldap services.
3. There is a plan to buy network laser printers for common and shared use.
4. It is planned to further enhance the performance and security level of Mail, Webmail, nfs, ldap and firewall servers by upgrading the operating system and its packages.
5. It is planned to replace the 6 year old SMF batteries of the centralised Online UPS Systems with the new ones.
6. It is planned to enhance the wi-fi network coverage area.

Library

In any academic/research institution library plays an important role in the dissemination of knowledge. In fact, the ambience of the library reflects the quality of the education/research imparted by the Institute. HRI library has recognized the importance of the academic vibrations required in the library and has been growing in this direction, right from its very inception. The Library of HRI serves as **knowledge hub** containing resources not only in the form of print but also in electronic form.

Library Hours:

The library works on all days of the year except a few holidays of National and Social importance.

Monday to Saturday	08.00 am to 02.00 am (midnight)
Sundays & Gazetted holidays	8.00 am to 08.00 pm

The Institutes library is one of the best equipped libraries in India, it aims to put the motto **Books are for use** into practice. The Library houses Text Books, Reference Books, Print Journals, Technical Magazines, General Magazines, E-Resources & Digital Collections, CDs & DVDs, Theses, Bound Volumes of Journals, Dailies, Faculty & Institute Publications etc., added to this.

Glimpse of the library:

Resources	Details
Total Collection: **Books & Bound Volumes**zz	61639
No. of Books Print	21516
No. of Bound Volumes Print	38292
Gratis/Books Print	1831
Total Collection: Journals **International Journals:** Online Print **National Journals:** Print	**172** **159** 155 04 **13**
E-Books:	2284 (Lecture Notes in Mathematics Book Series)

Databases/E-Resources:

ScienceDirect	2400+ Journals DAE-Elsevier Consortium	Elsevier Publication
MathScienet	Database of Reviews, Abstracts and Bibliographic Information	American Mathematical Society (AMS)
Euclid Prime	32 Journals Package	Duke University Press
JSTOR	83 Journals Package	Ithaka Publication
DMJ 100 Archive	Duke Mathematics Journal Package Back volumes- Vol.1 (1935) to Vol.100 (1999)	Duke University Press
AIP Archive	8 Journals Package	American Institute of Physics
IoP Journals Archive	56 Journals Package	Institute of Physics
Springer Journal Archive	123 Journals Package	Springer

Other Resources and Facilities:

Theses	103
CDs/DVDs	100
General Magazines	5
Newspapers	6
Seating Capacity	43
Carpet Area	650 Sq. Mts
Computers for Users/OPAC	4 Nos
Library Management Software	Libsys7 & 3M Electro Magnetic Gate Security System

Newly added materials during April 2019 to March 2020:

Books	255
Gratis-Books	146
E-books	25

ICT enabled services:

Rapid advances in Information and Communication Technology are changing the library and information services drastically. Besides this, expectations of the users have also risen manifold. Libraries are not mere spaces anymore; they are much more than that. It has become a challenge for library management to keep pace with changing information packaging and delivery methods on one hand and meet the user expectations on the other. HRI Library has been trying to do the same over the years and as per feedback from its patrons has been quite successful in this venture. HRI Library not only proactively work on its collection building and infrastructural augmentation, also put lot of emphasis on facilities and services for users. Like previous years, this year also focus was on the strengthening of print collection along with e-resources and implementation of latest information and communication technologies in its services.

Highlights:

Services / Facilities:	**Best Practices:** A Best Practice in simple terms is known as the practice, which paves the way for enhancing the existing functions and helps in effective implementation or use of the process.
Readers Assistance	Library Website/Web OPAC
Web Enabled Library Catalogue Services	Self-Issue/Return System
Circulation Services (Issue/Return)	Electromagnetic Security Gate
Reference	Off-Campus Services through E-mail
Referral	Library Extension Services
Reprographic	Display of Faculty/PDF/Students Publications
New Arrivals service	Display of Institute Publications
Spiral Binding & Lamination	Library Advisory Committee
Newspaper Clippings	Stock Verification
Book Exhibition	Orientation for newly joined library members
Theses Consultation Facilities	18 Hours uninterrupted Services
Inter Library Loan	

Library Advisory Committee:

Library Advisory Committee is functioning to look into all aspects of continual improvement of the library activities, so that the library and its facilities achieve a fair degree of acceptability amongst the users. This Committee, co-coordinated by a faculty as the Chairman and other faculty-representatives as members, the librarian is the ex-officio member secretary of the committee. Library Advisory Committee plays an advisory and advocacy role regarding the library in its support of teaching, learning, research and communitybuilding needs of the Institution. It assists in the provision of high quality library service to the faculty and students of the HRI Community by advising the Director in all development activities of the library.

Details are as follows:

Prof. D. Surya Ramana	Convenor
Dr. Anirban Basu	Member
Dr. N. Raghavendra	Member
Mr. K.K. Suresh Kumar, Librarian	Member

Library Team:

Total 9 Staff Members:

Library Staff	04
Other Staff Members	05

Computerisation of in-house Activities:

All in-house activities in the Library including Acquisition, Cataloguing, Circulation and Serials Control are fully computerized using Libsys version-7 (Library Management Software). The Online Public Access Catalogue (OPAC) of the Library is operational on Intranet. It can be accessed online to search more than 61639+ bibliographic records, available in the Library database through a web-based search interface (Web OPAC).

Theses Consultation Facilities:

HRI Library receives all the Ph.D. Thesis awarded by HBNI in Hard copy. Print copies of Theses are housed in Book Section of the library for consultation purpose only. The bibliographic information of Theses are made available through library Online Public Access Catalog (OPAC). Also through another interface especially designed for searching the Theses at: `http://www.hri.res.in/~libweb/theses/thesis.html`

Hindi Book Collection:

HRI Library has built up a good collection of books in Hindi Language and made different sections like Religion, Language, Literature, Biography, Poem, Fiction, Novels, Science literature, Childrens literature, and General reading book. These books are prominently kept near the stack area in the library to promote its usage. To increase the use of **Rajbhasha Hindi**, HRI library regularly sending **NEW ARRIVALS LIST** to HRI user community.

Infrastructural Development Works at the HRI campus

DURING F.Y. 2019-20

The construction of buildings works is still hampered in campus due to order of Allahabad High Court in reference of PIL related to Ganga Pollution. Therefore no buildings construction work has been carried out during last F.Y. $2019-20$. Only few renovation related work has been carried out which are hereunder.

- Replacement of existing distribution board with new distribution board with MCB's in 36 flats.
- SITC of intelligent fire alarm system for first floor library building and other office building