Academic Report (2017–18)

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

Contents

About The Institute

The Harish-Chandra Research Institute (HRI), Allahabad, is a premier research institute in the country. It is an autonomous institution fully funded by the Department of Atomic Energy (DAE), Government of India. The Institute started with the efforts of Dr. B.N. Prasad, a mathematician at the University of Allahabad, who provided the initial leadership. Financial support was provided by the B.S. Mehta Trust, Kolkata. Dr. Prasad was succeeded in January 1966 by Dr. S.R. Sinha, and then by Prof. P.L. Bhatnagar - 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 Institutes 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 expenses.

In January 1990, about 66 acres of land was acquired in Jhunsi, Allahabad. Prof. H.S. Mani took over as the Director in January 1992 and played a crucial role in building the HRI campus at Jhunsi, and also giving the Institute its modern academic shape. He retired in August 2001. The charge was taken over by Prof. R.S. Kulkarni, to be followed, successively, by Prof. Amitava Raychaudhuri and Prof. Jayanta Kumar Bhattacharjee. The current Director, Prof Pinaki Majumdar, took over on 11th April 2017.

HRI is devoted to fundamental research in diverse areas of mathematics and theoretical physics. The areas of research in mathematics are number theory, differential geometry, harmonic analysis, group theory, and topology. In physics the areas are astrophysics, string theory, high energy phenomenology, condensed matter physics, and quantum information theory.

Since 1992 the Institute has attracted worldwide attention, as is evident from the recognition received by many of its members. The outstanding contributions of Prof. Ashoke Sen to mathematical physics has been recognised by a Fellowship of the Royal Society (FRS) of the U.K., the award of one of the first Fundamental Physics Prizes (2012) from the Yuri Milner Foundation, and the Dirac Medal of the ICTP. Profs. Dipendra Prasad, Biswarup Mukhopadhyaya, Pinaki Majumdar, and Rajesh Gopakumar have been awarded the Shanti Swarup Bhatnagar Prize for work done at the Institute.

Around 25 of the alumni of the institute hold faculty positions in premier scientific institutions of the country. Various members of the Institutes faculty have been elected to the three Academies of Science of India over the years. At least two former faculty members of the Institute are currently directors of national scientific institutions.

HRI puts a great deal of emphasis on teaching, in addition to research. The major development in recent years is the start of a M.Sc program in physics (in 2017), and the development of a teaching laboratory on campus. Finally, despite having only thirty faculty members HRI ranks among the top 10 research institutes in the country according to Nature India.

Director's Report

For us 2017-18 was significant for multiple reasons. We started a Masters program in Physics, with a laboratory on campus. We hosted several visitors, over the year, on the basis of an Infosys grant. Finally, an unusually large number of Ph.D students joined the institute in 2018 - with a welcome reduction of the average age on campus! I touch briefly on these below.

The beginning of a Masters program had been planned for a couple of years, moving through discussions with the Department of Atomic Energy (DAE) and the Homi Bhabha National Institute (HBNI). With the requisite approvals and financial support granted, the first batch of propective students were interviewed in summer 2017. Four joined. We reconfigured our community center Annexe as a laboratory space and, with some help from experimental colleagues elsewhere, set up a laboratory. This now has pride of place on campus. The incoming batch of 2018 has 8 students, we hope it will increase over the next few years to the full strength of 20.

HRI has a vibrant visitors program. This year the numbers were larger since, in addition to institutional support, we had an Infosys grant to invite visitors to lecture at HRI. Visitors included Yuri Nesterenko (Moscow State) lecturing on "Analytic functions & their Transcendental Values", Bobby Acharya (ICTP), Ted Erler (Prague), and Yuji Okawa (Tokyo) all lecturing on String Theory, Milind Diwan (Brookhaven) and Pascuale Di Bari (Southampton) lecturing on Particle Phenomenology, Andrew Bremner (Arizona State) on "Analytic geometry and Number theory in Diophantine Problems", and Hiroyuki Yamane (Toyoma) on "Representations of Quantum Superalgebras". We expect several more visitors within this program before the end of the year.

There were several academic meetings. These included a "Focused meeting on Stack in Algebraic Geometry" in July 2017, an international conference on "Class Groups of Number Fields and Related Topics" in September 2017, a DST sponsored meeting on "Quantum Science and Technology (QuST)" in October 2017, Nu HoRIzons VII, and School on String Field Theory and String Phenomenology, in February 2018, and the Sangam@HRI-2018 - Instructional Workshop in Particle Physics, in March 2018.

Fifteen Ph.D students graduated from HRI during 2017-18. We maintained our research productivity, maintaining a position within the top 10 in the Nature India list. About twenty five students joined the Ph.D program this summer, they will enliven what was beginning to look like an ageing campus.

In addition to the formal training programs for B.Sc and M.Sc students we held our annual Talent Search examination for school level children in Allahabad. We invited eminent speakers from various areas of enquiry to deliver colloquia at HRI. These included natural scientists, social scientists, and humanists, exposing our students to the broader currents of knowledge.

I end on a sad note. Our colleague Govinda Venketeswara Pai, a condensed matter physicist, passed away on 1 June, 2018. He was only forty six.

Pinaki Majumdar

Director

List of Governing Council Members (2017 -18)

1 - Prof. M. S. Raghunathan (Chairman)
503, Atlantis Raheja Acropolis - 1
Deonar Pada Road, Deonar,
Mumbai - 400 088

2 - Prof. R. Balasubramanian
Institute of Mathematical Sciences
CIT Campus, Taramani,
Chennai - 600 113

3 - Joint Secretary (Finance) DAE
Govt. of India, Chhatrapati Shivaji
Maharaj Marg, Mumbai - 400 001

4 - Joint Secretary (R & D) DAE,
Govt. of India, Anushakti Bhavan,
Ch. Shivaji Maharaj Marg
Mumbai - 400 001

5 - Dr. J. N. De,
BH - 135, Sector - II
Salt Lake, Kolkata - 700 091

6 - Prof. S.M. Chitre
Chair, Academic Board
Centre for Excellence in Basic
Sciences (UM - DAE - CBS),
Health Centre Building
University of Mumbai
Mumbai - 400 098

7 - Prof. H. S. Mani
2, Fourth Cross Street
Durga Colony, Sembakkam
Chennai - 600 073

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

Faculty Members (Physics)

1. Basu, Anirban
2. Choubey, Sandhya
3. Das, Tapas Kumar
4. Datta, AseshKrishna
5. Gandhi, Raj
6. Jatkar, Dileep
7. Maharana, Anshuman
8. Majumdar, Pinaki
9. Mukhopadhyaya, B.
10. Naik, S.
11. Pai, G.Venketeswara
12. Pareek, T. P.

13. Pati, Arun Kumar
14. Rai, Santosh Kumar
15. Rao, Sumathi
16. Sen, Ashoke
17. Sen, Prasenjit
18. Sen, Ujjwal
19. Sen(De), Aditi

Administrative Staff

1. Shri Ravindra Singh [Registrar]
2. Shri Rajkumar Gulati [Accounts Officer]
3. Shri Manish Sharma [Scientific Officer 'D']
4. Shri K.K. Suresh Kumar [Librarian]
5. Shri Amit Roy [Internal-Audit-cum Administrative officer]
6. Shri Sanjai Verma [Systems Manager]
7. Shri A.K. Srivastava [SO (SB) (Electrical)]
8. Shri V.K. Srivastava [SO (SB) (Civil)]
9. Shri R.P. Sharma [Manager Guest House]
10. Ms. Archana Tandon [Office Superintendent]
11. Ms. Anju Verma [Scientific Assistant]
12. Shri U.K. Dwivedi [Cashier]
13. Shri D. Malhotra [Upper Division Clerk]
14. Shri K.K. Srivastava [Upper Division Clerk]
15. Shri Yashpal Singh [Stenographer]
16. Ms. Sumitra [Upper Division Clerk]
17. Ms. Seema Agarwal [Receptionist]
18. Mr. Om Kumar Karn (on lien) [Junior Hindi Translator]
19. Shri. D.P.Sharma [Jr. Lib. Assistant]
20. Shri Surendra Yadav [Store/Purchase Officer]
21. Shri Sudheer Kumar Singh
22. Shri Sanjeev Nagar [Hindi Typist]
23. Shri Vivek Kumar [Junior Library Assistant]
24. Shri D.N. Dubey [Bearer (Canteen Cadre)]
25. Shri Kamlesh Thakur [Bearer (Canteen Cadre)]
26. Shri Kamta Prasad [Peon/Watchman]
27. Shri Rajesh Kumar [Sweeper]
28. Shri Munna Lal [Gardener]

Visiting Fellow

Mathematics

1. Acharya, Ratnadeep
2. Arunachalam, Umamaheswaran
3. Choudhury, Snigdha Bharati
4. Chintapalli, Seshadri
5. Gumber, Anupam
6. Gupta, Rohit
7. Hoque, Azizul
8. Kumari, Rani
9. Kushwaha, Seema
10. Mistri, Raj Kumar
11. Nayak, Saudamini
12. Podder, Shubhankar
13. Ransingh, Biswajit
14. Raundal, Hitesh Ramesh
15. Saurabh, Bipul
16. Singh, Rajesh Kumar
17. Subramani, M

Physics

1. Abdallah, Waleed Mohammed
2. Chakraborty, Indrani
3. Das, Debmalya
4. Dhargyal
5. Jeon, Imtak
6. Gupta, Manish Kumar
7. Gupta, Manjari
8. Islam, Safiqul

9. Lahiri, Jayita
10. Mal, Shiladitya
11. Mondal, Tanmoy
12. Pramanick, Soumita
13. Prasad, Yogeshwar
14. Sarkar, Saubhik
15. Sazim, S.K.
16. Sehrawat, Arun
17. Singh, Chabungbam Satyananda
18. Singh, S. Nilakash

Visiting Scientist

1. Deo, Satya (Maths)
2. Saha, Pratishruti (INSPIRE Faculty)

Research Scholar

Mathematics

1. Agnihotri, Rishabh
2. Banerjee, Soumyarup
3. Chakraborty, Priyanshu
4. Chattopadhyay, Jaitra
5. Das, Mithun Kumar
6. Das, Pradeep
7. Hatui, Sumana
8. Karmakar, Debasish
9. Kaushik, Rahul
10. Keshari, Parul
11. Kumar, Veekesh
12. Maity, Arup Kumar
13. Manikandan, S.
14. Meher, Nabin Kumar
15. Mishra, Mohit
16. Naik, Tushar Kanta
17. Nishant
18. Pal, Souvik
19. Pandey, Manish Kumar
20. Patil, Bhuwanesh Rao
21. Pramod, E.
22. Roy, Bidisha
23. Sahoo, Gopinath
24. Sarkar, Subha
25. Sharma, Ritika
26. Singh, Anup Kumar
27. Singh, Anoop
28. Vaishya, Lalit

Physics

1. Alam, Khorsed
2. Bakshi, Sankha Subhra
3. Basak, Nirnoy
4. Bhattacharya, Ritabrata
5. Bhattacharya, Sauri
6. Chakrabarti, Subhroneel
7. Chanda, Titas
8. Chauhan, Ankur
9. Das, Kasinath
10. Das, Sreetama
11. Das, Tamoghna
12. Datta, Satadal
13. De, Suman Jyoti
14. Deshpande, Rhucha
15. Dey, Atri
16. Dipanshu
17. Dutta, Arijit
18. Dutta, Juhi
19. Dwivedi, Siddharth
20. Ghorui, Arnab
21. Ghosh, Avirup
22. Goswami, Mrityunjay
23. Haldar, Stav
24. Joshi, Abhishek
25. Kadge, Samrat Suresh
26. Kar, Arpan
27. Kashyap, Sitender Pratap
28. Khan, Sarif

29. Kumar, Abhass
30. Mahanta, Ratul
31. Maity , Susovan
32. Mohan, Brij
33. Mukherjee, Dibya Kanti
34. Mukhopadhyay, Chiranjib
35. Pramanik, Dipyaman
36. Roy, Samiran
37. Roy, Saptarshi
38. Roy, Tanaya
39. Roychoudhury, Shouvik
40. Sadhukhan, Debasis
41. Sahoo, Biswajit
42. Saxena, Ruchi
43. Sen, Arpita
44. Md. Shaikh, Arif
45. Sharma, Gautam
46. Sisodiya, Durgesh Singh
47. Sohail
48. Srivastava, Chirag
49. Tiwari, Deepak
50. Tripathi, Krashna Mohan
51. Verma, Mritunjay Kumar

Academic Report - Mathematics

Ramakrishnan Balakrishnan

Research Summary:

(i) Representations of a positive integer by certain classes of quadratic forms (joint works with Brundaban Sahu and Anup Kumar Singh):
(a) A new formula for the Ramanujan Tau function: In this revised version of the work, we find the number of representations of the quadratic form $x_1^2+x_1x_2+x_2^2+x_3^2+x_3x_4+x_4^2+\ldots+x_{2k-1}^2+x_{2k-1}x_{2k}+x_{2k}^2$, for $k = 7, 9, 11, 12, 14$ using the theory of modular forms. By comparing our formulas with the formulas obtained by G. A. Lomadze, we obtain the Fourier coefficients of certain newforms of level 3 and weights $7, 9, 11$ in terms of certain finite sums involving the solutions of similar quadratic forms of lower variables. In the case of 24 variables, comparison of these formulas gives rise to a new formula for the Ramanujan tau function.
(b) In this ongoing work, we compute explicit formulas for certain sextenary quadratic forms with coefficients by using the modular forms method.
(c) In this ongoing work, we consider quadratic forms in odd number of variables. Specifically, we consider sums of five and seven squares with certain coefficients and consider the problem of representing the square of a natural number by these types of quadratic forms. The main ingredient in this work is the use of Shimura correspondence to non-cusp forms. In particular, we make use of the work of T. Jagathesan and M. Manickam, who obtained the extension of Shimura correspondence to non-cusp forms of higher levels. This work is in progress.

(ii) Shimura lifts of certain class of modular forms of half-integral weight (joint work with Manish Kumar Pandey):
In 1973, G. Shimura defined a family of maps from the space of modular forms of half-integral weight to the space of modular forms of integral weight. A. Selberg in his unpublished work found explicitly this correspondence (the first Shimura map $\mathcal{S}_1$) for the class of forms which are products of a Hecke eigenform of level one and a Jacobi theta function. Later, in 1989, B. Cipra generalized the work of Selberg to the case where Jacobi theta functions are replaced by the theta functions associated to Dirichlet charater of prime power moduli, and the level one Hecke eigenforms are replaced by newforms of arbitrary level. In 2008, D. Hansen and Y. Naqvi generalized Cipra's work (on the image of a class of modular forms under the first Shimura map $\mathcal{S}_1$) to cover theta functions associated to Dirichlet characters of arbitrary moduli. In this work, we show that the earlier results can be modified to get similar results for the t-th Shimura lifts $\mathcal{S}_t$, for any positive square-free integer t.

(iii). On certain quadratic forms of ten variables (joint work with Lalit Vaishya):
Finding formulas for number of representations of a natural number by quadratic forms is a classical and interesting problem. In this ongoing work, we use modular forms techniques to find formulas for the number of representations of a natural number by these quadratic forms. The main ingredient in this work is the construction of explicit basis for the space of modular forms of weight 5 on $\Gamma_1(24)$. This work is in progress.

Publications:

1. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the represenations of a positive integer by certain classes of quadratic forms in eight variables,* Analytic Number Theory, modular forms and q- hypergeometric series, 641–664, Springer Proc. Math. Stat. **221**, Springer, Cham. 2017.

2. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations by certain octonary quadratic forms with coefficients* $1, 2, 3, 4$ *and* 6, Int. J. Number Theory **14**, 751–612, (2018).

3. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of certain quadratic forms and a formula for the Ramanujan Tau function,* Funct. Approx. Comment. Math. (2018), To appear, doi:10.7169/facm/1695

4. Arvind Kumar and B. Ramakrishnan, *Estimates for Fourier coefficients of Hermitian cusp forms of degree two,* Acta Arith. **183**, no.3, 257–275, (2018).

5. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *Representations of an integer by some quaternary and octonary quadratic forms,* in "Geometry, Algebra, Number Theory and their Information Technology Applications (GANITA)", in honor of Prof. V. Kumar Murty, Springer Proc. Math. and Stat. (2018). To appear.

Preprints:

1. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of certain quadratic forms in 8 variables,* submitted for publication 2017.

2. Manish Kumar Pandey and B. Ramakrishnan, *Shimura lifts of certain class of modular forms of half-integral weight,* submitted for publication 2017.

3. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *Certain quaternary quadratic forms of level 48 and their representation numbers,* submitted for publication 2017.

Conference/Workshops Attended:

1. *International Conference on Algebra and Analysis (ICAA- 2017)*, Savitribai Phule Pune University, Pune, India, December, 2017.

2. *"Number Theory: Arithmetic, Diophantine and Transcendence"*, IIT, Ropar, India, December, 2017.

3. *School on Modular Forms*, KSOM, Kozhikode, India, February, 2018.

Visits to other Institutes:

1. Chennai Mathematical Institute, Chennai, India, May, 2017.
2. The Institute of Mathematical Sciences, Chennai, India, November, December 2017.

Invited Lectures/Seminars:

1. *Number Theory*, Winter School in Mathematics to the memory of Homi Jehangir Bhabha, Central University of Tamil Nadu, Thiruvarur, December 2017.
2. *Lectures on modular forms*, School on Modular forms, Kerala School of Mathematics, Kozhikode, February 2018.

Other Activities:

1. Taught 'Analysis I' course during August–December 2017 (Ph.D course work).
2. Supervising 3 research scholars.
3. Dean (Academic), HBNI cell at HRI (upto March 14, 2018).
4. Convener, Board of Studies in Mathematical Sciences, HBNI, Mumbai.
5. Project coordinator for STEM project and coordinator for the Number Theory sub-project.
6. Honorary Treasurer, National Academy of Sciences India, Allahabad, 2017.

Punita Batra

Research Summary:

Extended affine Lie algebras (EALAs) are natural generalization of Kac-Moody algebras. Finite dimensional simple Lie algebras, affine Kac-Moody algebras, toroidal Lie algebras are examples of EALAs. They first appeared in the work of Saito and Slodowy on elliptic singularities and in the paper of physicists Hegh and Torresani in 1990. Unlike Kac-Moody algebras, EALAs may have infinite dimensional center. In a joint work with S.Eswara Rao and S. Sharma, we tried to complete the classification of irreducible integrable representations for twisted toroidal extended affine Lie algebras where the center acts non-trivially.

Publications

1. Punita Batra and Hiroyuki Yamane, *Centers of Generalized quantum groups,* Journal of Pure and Applied Algebra, Vol.22, No.5, 1203-1241 (2018).
2. Punita Batra and S. Eswara Rao, *On integrable modules for the twisted full toroidal Lie algebra,* Journal of Lie Theory, Vol.28, No.1, 79-105 (2018).

Preprints:

1. (With S. Eswara Rao and Sachin S. Sharma) Integrable modules for twisted toroidal extended affine Lie algebras, arXiv:1802.09823v1 Feb 2018.

Conference/Workshops Attended:

1. "The 33^{rd} Lie Algebra Summer Seminar" at University of Tsukuba, Japan, August 18-19, 2017.
2. " Symposium for South Asian Women in Mathematics" at Tribhuvan University, Kathmandu, Nepal, Oct 12-15, 2017.

Visits to other Institutes

1. School of Mathematics, TIFR Mumbai during June 2-9,2017.
2. Department of Mathematics, IIT Kanpur during July 29-August 3,2017 and November 7-8,2017.
3. University of Tsukuba, Japan during August 18-19,2017
4. Department of Mathematics, University of Toyama, Japan during August 20-22,2017.
5. Department of Mathematics, Tribhuvan University, Kathmandu, Nepal during October 12-15, 2017.

Invited Lectures/Seminars:

1. *Representations of twisted full toroidal Lie algebras* , Mathematics Seminar, IIT Kanpur, Aug 1, 2017.
2. *Modules of twisted full toroidal Lie algebras*, The 33^{rd} Lie Algebra Summer Seminar, University of Tsukuba, Japan, August 18,2017.
3. *Representation Theory of Infinite Dimensional Lie algebras* , Colloquium talk, University of Toyama, Japan, August 22,2017.
4. *Affine Kac-Moody Lie algebras and Representation Theory* , Symposium for South Asian Women in Mathematics, Tribhuvan University, Nepal, October 14,2017.

Other Activities

1. Gave two lectures in the Rajbhasha scientific workshop at HRI in May 2017.
2. Organised SPIM(Summer Programme in Mathematics) at HRI in June 2017.
3. Gave six lectures on " Galois Theory" in Summer Programme in Mathematics(SPIM) at HRI in June, 2017.
4. Coordinator - HRI's Science Talent Search exam 2017(Mathematics part).
5. Convener of the Outreach Programme(Mathematics). Also serving as a member in the Sports and Entertainment Committee and the Rajbhasha Committee.

Kalyan Chakraborty

Research Summary:

Completed Development of Modules and Tools for solving Integer factorisation and Discrete log Problems using Number Field Sieve. It was DRDO is funded Project. Successfully completed facorizing a 600 bits number using the method. Also progressed towards Discrete lo problem.

Studying the asymptotic behaviour of 'Riesz sums' associated to the Rankin-Selberg L-functions involving various automorphic forms (e.g. harmonic Mass forms and Hasse-Weil zeta functions associated to the elliptic curves, Hilbert modular forms of degree 2, Maass forms). Completed some of the projects along with S. Banerjee, A. Juyal, B. Maji and S. Kanemitsu.

Class number of number fields: (i) Class numbers of number fields are mysterious objects and not much is known about these numbers. One of the many questions is to show the existence of infinitely many number fields (for quadratic field case many results are known!) whose class number is divisible by a given integer. Quantifying these fields is also an interesting problem. The Cohen-Lenstra heuristics related to these questions is yet to be established. In the direction of indivisibility not much is known though. Its worth looking into these direction relating the arithmetic of some kind of modular forms and that of elliptic curves. Some projects here too have been completed. We did complete few works along with A. Hoqoe, H. Kisi and PP Pandey.

The Selberg type divisor problem pertains to the study on the coefficients of complex powers of zeta-functions. The main objective of Selberg was to apply the results to the problem related to the prime number theorem. However, the complex powers turn out to be of independent interest and have applications in studying the mean values of zeta and other L-functions. In a work jointly with K. Chakraborty, S. Kanemitsu and A. Laurinčikas, we have considered the zeta-function (á la Hecke) associated to the normalised cusp forms for the full modular group and studied the summatory functions of complex powers in the form of Dirichlet convolution of the coefficients of such zeta-functions. Our approach has a merit of attaining both, the result on the summatory function as well as a result entailing the classical result on integers without small prime factors.

In a joint work with S. Banerjee and A. Hoque , we find an expression for the product of two Dedekind zeta functions attached to quadratic fields which generalizes a well known formula due to J. R. Wilton for classical Riemann zeta functions. We have used this expression to find closed form expressions for Dedekind zeta values attached to arbitrary real as well as imaginary quadratic number fields at any positive integer. These are kind of analogous to results of Ramanujan and Leopold.

Publications:

1. Sarthak Gupta and Kalyan Chakraborty, *A Problem related to prime numbers*, Math. Student (To appear).

2. Kalyan Chakraborty, Azizul Hoque, Yasuhiro Kishi and Prem Prakash Pandey,

Divisibility of the class numbers of imaginary quadratic fields, Journal of Number Theory, **185**, 339–348, 2017, arXiv: 1710.03662.

3. Kalyan Chakraborty and Azizul Hoque, *Divisibility of class numbers of certain families of quadratic fields*, Journal of the Ramanujan Mathematical Society, 2018 (to appear), arXiv: 1712.07338.

4. Kalyan Chakraborty and Azizul Hoque, *Class groups of imaginary quadratic fields of 3-rank at least 2*, Annales Universitatis Scientiarum Budapestinensis de Rolando Eötvös Nominatae: Sectio Computatorica, (to appear in a special issue in honor of the 80-th birthday of Prof. Zoltán Daróczy and Imre Kátai, the 75-th birthday of Prof. Karl-Heinz Indlekofer, the 70-th birthday of Prof. Jean-Marie De Koninck and Gyula Maksa), 2018, arXiv:1802.07919v1.

5. Kalyan Chakraborty and Azizul Hoque, *Pell-type equations and class number of the maximal real subfield of a cyclotomic field*, The Ramanujan Journal, 2017, Doi: 10.1007/s11139-017-9963-9, arXiv: 1710.09760.

6. Kalyan Chakraborty and Azizul Hoque, *Quadratic reciprocity and some "non -differentiable" functions*, Advances in real and complex analysis with applications, 145–181, Trends in Mathematics, Birkhäuser/Springer, Singapore, 2017, arXiv: 1710.07777.

7. K. Chakraborty, S. Kanemitsu and T. Kuzumaki, *Seeing the invisible: Kubert identities*, (to appear in a special issue in honor of the 80-th birthday of Prof. Zoltán Daróczy and Imre Kátai, the 75-th birthday of Prof. Karl-Heinz Indlekofer, the 70-th birthday of Prof. Jean-Marie De Koninck and Gyula Maksa), 2018.

8. S. Banerjee and K. Chakraborty *Asymptotic behaviour of a Lambert series á La Zagier: Maass case*, The Ramanujan Journal , 2018, doi.org/10.1007/s11139-018-0007 .

9. K. Chakraborty, A. Juyal, S. D. Kumar and B. Maji, *Asymptotic expansion of a Lambert series associated to cusp forms*, Int. J. Number Theory , Vol.14 (2018), No. 1, 289–299. https://doi.org/10.1142/S1793042118500173 .

10. D. Banerjee, K. Chakraborty , S. Kanemitsu and B. Maji, *Abel-Tauber process and asymptotic formulas*, Kyushu Journal of Math. Vol. 71 (2017), Issue 2, pp. 363-385 DOI https://doi.org/10.2206/kyushujm.71.363

11. K. Chakraborty, J. J. Urroz and Francesco Pappalardi, *Pairs of integers which are mutually squares*, Sci. China Math., Vol. 60 (2017), 1633–1646.

Preprints:

1. Kalyan Chakraborty and Azizul Hoque, *Exponents of class groups of certain imaginary quadratic fields*, (communicated), arXiv:1801.00392v1.

2. Soumyarup Banerjee, Kalyan Chakraborty and Azizul Hoque, *An analogue of Wilton's formula and values of Dedekind zeta functions*, (communicated), arXiv:1611.08693.

3. Kalyan Chakraborty and Azizul Hoque, *On the plus parts of the class numbers of cyclotomic fields*, (communicated).

4. Kalyan Chakraborty, Azizul Hoque, Shigeru Kanemitsu and Antanas Laurinčikas, *Complex powers of L-functions and integers without small prime factors*, (communicated).

Conference/Workshops Attended:

1. *The Second International Conference on Computational Mathematics and Engineering Sciences (CMES-2017)*, Turkey , May, 2017.

2. *Nepal Algebra Project*, Nepal, July, 2017.

3. *The Tenth International Conference on Science and Mathematics Education in Developing Countries*, Myanmar, November, 2017.

4. *International Conference on Special Functions and Applications (ICSFA-2017)*, India, November, 2017.

5. *RCFE-2018*, Jaipur, December, 2018.

6. *ICITAM - 2018*, Haldia, October, 2017.

Visits to other Institutes:

1. MNIT, Jaipur, August, 2017.

2. DRDO, New Delhi, November, 2017.

3. Hong Kong University, Hong Kong, April, 2017.

4. Burdwan University, Burdwan, December, 2017.

5. Sidhoo Kanu Birsa University, Purulia, February, 2018.

6. Loyola College, Chennai, March, 2018.

7. Mahidol University, Bangkok, Thailand, November, 2017.

8. University of Mandalay, Myanmar, November, 2017.

Invited Lectures/Seminars:

1. *Primes and more..*, Sidhoo Kanu Birsa University, Purulia, February, 2018.

2. *Primes and more..*, Burdwan university, Burdwan, December, 2017.

3. Class numbers of certain quadratic fields, ICITAM - 2018, Haldia (W.B.), October, 2017.

4. *Introduction to Riemann zeta function*, Anand International college of Engn., Jaipur, December, 2017.

5. *Special values of Dedekind zeta functions*, International Conference on Special Functions and Applications (ICSFA-2017), College of Engineering and Technology, Bikaner, November, 2017.

6. *Class numbers of quadratic fields*, The Tenth International Conference on Science and Mathematics Education in Developing Countries, Mandalay University, Mandalay, Myanmar, November, 2017.

7. *Pell type equations and class numbers of maximal real subfields*, Colloquium, Mahidol University, Bangkok, Thailand, 13, 2017.

Other Activities:

1. Organized *International Conference on Class Groups of Number Fields and Related Topics-2017* with Prof. Kalyan Chakraborty and Dr. Prem Prakash Pandey, September, 2017.

2. Lecturing on *Rajbhansa Program for 11th standard students*, May, 2017.

3. *Mentoring 11th standard students at Inspire Camp*, Raipur, December, 2017.

Chandan Singh Dalawat

Research Summary:

Most of the time this year was devoted to the simplification and dissemination of the major results obtained last year. Progress has also been made in drafting a unified presentation by merging four independent but related preprints from last year into one paper suitable for publication.

Conference/Workshops Attended:

1. *Representation theory of p-adic groups*, Indian Institute of Science Education and Research, Poona, July 10 – 19, 2017.
2. *Geometria Algebrica e Teoria dei Numeri*, Villa Finaly, Florence, December 4 – 6, 2017.
3. *Algebraic Geometry and Number Theory*, Indian Statistical Institute, Bangalore, December 14 – 20, 2017.
4. *Celebrating the Unity of Science*, International Centre for Theoretical Sciences, Bangalore, January 4 – 6, 2018.

Visits to other Institutes:

1. Indian Institute of Science Education and Research, Poona, 30 October–4 November 2017.
2. Università degli Studi di Firenze, Florence, 30 November 2017.
3. Università di Pisa, Pisa, 1–2 December 2017.
4. Indian Institute of Technology, Bombay, 19–23 February 2018.
5. Tata Institute of Fundamental Research, Bombay, 24 Februay – 3 March 2018.

Invited Lectures/Seminars:

1. *The Second Memoir of Évariste Galois*, Indian Women and Mathematics Regional Workshops on Research and Opportunities, Indian Institute of Science Education and Research, Bhopal, 7 October 2017 ; Maths Club, Indian Institute of Science Education and Research, Poona, 31 October 2017 ; National Mathematics Day, Allahabad University, 22 December 2017.
2. *Solvable primitive extensions*, Indian Institute of Science Education and Research, Bhopal, 9 October 2017 ; Colloquium, Indian Institute of Science Education and Research, Poona, 3 November 2017 ; Università degli Studi di Firenze, 30 November 2017 ; Università di Pisa, 1st December 2017.

3. *Wildly primitive extensions*, Indian Institute of Science Education and Research, Poona, 30 October 2017.

4. *Primitive p-extensions of p-fields*, Algebraic Geometry and Number Theory conference, Indian Statistical Institute, Bangalore, 14 December 2017.

5. *Some footnotes to Galois's Memoirs, Colloquium* , Indian Institute of Technology, Kanpur, 25 January 2018 ; Colloquium, Indian Institute of Technology, Bombay, 20 February 2018.

Umesh Kumar Vanktesh Dubey

Research Summary:

We revised and improved exposition of our work on differential graded Eilenberg - Moore construction. We also started study of Chow group in Tensor Triangular Geometry. The Chow group with its intersection product gives an invariant of schemes which was extended in this setting by Balmer and Klein. The aim is to describe the intersection product and characteristic classes for some concrete examples of tt-categories. This is a joint work in progress with Vivek M. Mallick.

We continued our study of classification of thick subcategories of the graded singularity category for some algebras. The aim is to extend classification, work of Stevenson, from local complete intersection rings in the graded setup. This is a joint work in progress with Sarang Sane.

We continued our study of the functorial construction of the moduli space of parabolic bundles (and sheaves) using the functorial construction of King and Alvarez-Consul. Along the way, we introduced and studied the filtered Kronecker modules and semi-invariants of filtered modules. This is a joint work in progress with Sanjay Amrutiya.

Preprints:

1. Umesh V. Dubey and Vivek M. Mallick, *On differential graded Eilenberg - Moore construction,* (under review).

2. Umesh V. Dubey and Sanjay Amrutiya, *On functorial construction of moduli space of parabolic bundles and filtered-Kronecker modules,* (in preparation).

3. Umesh V. Dubey and Sarang Sane, *Classification of thick subcategories of some graded singularity categories,*(in preparation).

Conference/Workshops Attended:

1. *National conference on Commutative Algerba and Algebraic Geometry*, IISER Pune, INDIA, 5 - 8 December, 2017.

2. *Conference on Algerbaic Geometry and Number Theory*, ISI Bangalore, INDIA, 14 - 20 December, 2017.

Visits to other Institutes:

1. Indian Institute of Science Education and Research, Thiruvananthapuram, INDIA, 24 May - 6 June, 2017.

2. Indian Institute of Science Education and Research, Pune, INDIA, 24 July - 4 August, 2017 and 11 - 17 March, 2018.

3. Indian Institute of Technology, Gandhinagar, INDIA, 4 - 10 March, 2018.

Invited Lectures/Seminars:

1. *Stability of quiver representations*, Maths seminar, Indian Institute of Science Education and Research, Thiruvananthapuram, 30 May, 2017.

2. *Chow group in Tensor Triangular Geometry*, Maths seminar, Indian Institute of Science Education and Research, Pune, 3 August, 2017.

Other Activities:

1. Organised and lectured in focused meeting on Stack in Algebraic Geometry, Harish-Chandra Reseach Institute, 12 June - 7 July, 2017.

2. Convener of Mathematics Graduate Programme Committee, member of Transport, Admission and Outreach Committee.

3. Course on Topology - II, Harish-Chandra Reseach Institute, January - May, 2018.

Manoj Kumar

Research Summary: Technical

A finite group G is said to be of *conjugate type* $(1 = m_1, m_2, \cdots, m_r)$, $m_i < m_{i+1}$, if m_i's are precisely the different sizes of all conjugacy classes of G. Investigation on groups G of conjugate type $(1, m)$ was initiated by N. Ito in 1953. He proved that such groups are nilpotent, with m a prime power, say p^n. In particular, G is a direct product of its Sylow-p subgroup and some abelian p'-subgroup. So, it is sufficient to study finite *p-groups* of conjugate type $(1, p^n)$ for p a prime and $n \geq 1$ an integer. It was proved by K. Ishikawa that the nilpotency class of such finite p-groups is either 2 or 3. It is known that when G is a finite 2-groups of conjugate type $(1, 2^n)$, then he nilpotency class of G is 2. We concentrate on the classification of finite p-groups of nilpotency class 3 and conjugate type $(1, p^n)$. We, jointly with Tushar Kanta Naik and Rahul Kitture, prove that there exist finite p-groups of nilpotency class 3 and conjugate type $(1, p^n)$ if and only if n is even. For each positive even integer $n = 2m$, a complete description of finite p-groups of nilpotency class 3 and of conjugate type $(1, p^n)$ is provided (upto isoclinism, in the sense of P. Hall).

The Schur multiplier $M(G)$ of a group G is defined as second integral homology group $H_2(G, \mathbb{Z})$, where $\mathbb{Z}$ is a trivial G-module. Let a group G act on itself by conjugation, i.e., $h^g = g^{-1}hg$ for all $h, g \in G$. Then the non-abelian tensor square $G \otimes G$ of G is the group generated by the symbols $g \otimes h$ for all $g, h \in G$, subject to the relations $gg' \otimes h = (g^{g'} \otimes h^{g'})(g' \otimes h)$ and $g \otimes hh' = (g \otimes h')(g^{h'} \otimes h^{h'})$ for all $g, g', h, h' \in G$. Jointly with Sumana Hatui and Vipul Kakkar, we compute the Schur multiplier and non-abelian tensor square of all groups of order p^5, p a prime. We also determined the capability of these groups. A group is said to be capable if it occurs as a full central quotient of some group.

Research Summary: Non-Technical

A complete description (upto isoclinism) of finite p-group of nilpotency class 3 having only two conjugacy class sizes 1 and p^n is given.

Schur multipliers and non-abelian tensor squares of groups of order p^5, p prime, are computed with all details. Capability of these groups is determined.

Publications:

1. Marco Ruscitti, Leire Legaretta and Manoj K. Yadav, *Non-inner automorphisms of order p in finite p-groups of coclass 3*, Monatsh. Math. **183**, 679 - 697, (2017).

2. Tushar K. Naik and Manoj K. Yadav, *Finite p-groups of conjugate type $\{1, p^3\}$*, J. Group Theory **21**, 65-82, (2018).

3. Ruhul D. Kitture and Manoj K. Yadav, *Note on Caranti's method of construction of Miller groups*, Monatsh. Math. **185**, 87 - 110, (2018).

4. Sumana Hatui, L. R. Vermani and Manoj K. Yadav, *Schur multiplier of central product of groups*, J. Pure Appl. Algebra **222**, 3293-3302, (2018).

Preprints:

1. Tushar K. Naik, Rahul D. Kitture and Manoj K. Yadav, *Finite p-groups of nilpotency class 3 with two conjugacy class sizes, 24 pages, Communicated*.

2. Rahul D. Kitture and Manoj K. Yadav, *Finite groups with abelian automorphism groups - A Survey, 25 pages, Communicated.*

3. Sumana Hatui, Vipul Kakkar and Manoj K. Yadav, *The Schur multipliers of p-groups of order p^5, 41 pages, Communicated.*

4. IBS Passi, Mahender Singh and Manoj K. Yadav, *Automorphisms of finite groups, Book, 220 pages (approx.), Accepted for publication by Springer.*

Conference/Workshops Attended:

1. *83rd Annual Conference of Indian Mathematical Society - An International Meet*, India, December, 2017.

2. *Groups and Related Structures*, India, December, 2017.

Visits to other Institutes:

1. Dept. Mathematics, Panjab University, Chandigarh, December, 2017.

2. IISER, Mohali, India, May-June, 2017.

3. University of L'Aquila, L'Aquila, Italy, April, 2017

Invited Lectures/Seminars:

1. *Group theory in the living room*, National Mathematics Day, MNNIT, Allahabad, December, 2017.

2. *Schur multiplier of central product of groups*, 83rd Annual Conference of Indian Mathematical Society - An International Meet, Sri Venkateswara University, Tirupati, December, 2017.

3. *Schur multiplier of central product of groups*, Invited talk, Dept. Mathematics, Panjab University, Chandigarh, December, 2017.

4. *Finite groups with few conjugacy class sizes*, Groups and Related Structures, IISER, Mohali, December, 2017.

5. *Finite p-groups with exactly two conjugacy class sizes*, Algebra Seminar, University of L'Aquila, L'Aquila, April, 2017.

Other Activities:

1. Taught a semester course 'Algebra - II' at HRI, January - May, 2018.
2. Organized a symposium on 'Group Theory' in 83rd Annual Conference of Indian Mathematical Society - An International Meet, held at Sri Venkateswara University, Tirupati during December 12 -15, 2017.
3. Edited a volume 'Group Theory and Computation' jointly with Prof. NSN Sastry; accepted for publication under Springer-ISI series.
4. Refereed research papers for many national and international journals.
5. Served as a member of several committees at HRI.

Gyan Prakash

Research Summary:

Given s natural numbers $k_1, \ldots k_s$, with $s \geq 2$, in an ongoing work with François Hennecart and E. Pramod, we study the question of how "thin" a subset A of natural numbers can be such that $A^{k_1} + \ldots + A^{k_s}$ contains all natural numbers. Here $A^{k_1} + \ldots + A^{k_s}$ denotes the set consisting of those n which can be written as $n = b_1 + \ldots + b_s$ where $b_i = a_1 \ldots a_{k_i}$ with $a_i \in A$ for each i. For any subset B of natural numbers and a real number x, we write $B(x)$ to denote the number of natural numbers belonging to B which does not exceed x. An elementary combinatorial argument shows that for any A as above, $A(n)$ must be at least $cn^{\frac{1}{\sum_i k_i}}$. When $k_1 = \ldots = k_s = 1$, there are known examples of A as above with $A(n)$ not exceeding $cn^{1/s}$. We study the question for general $k_1, \ldots, k_s$ and show that $A(n)$ must be at least $c\frac{n^{1/s}}{\log^{\alpha(k_1,\ldots,k_n)} n}$ for infinitely many n, where we may take $\alpha(k_1, \ldots, k_n) = 1 - \frac{1}{\max_i k_i}$. When $s = 2$ and $\max(k_1, k_2) \geq 3$, we also show the existence of A such that $A^{k_1} + A^{k_2}$ contains all natural numbers and $A(n)$ is $o(\sqrt{n})$. When $s \geq 2$ and $\max(k_1, \ldots, k_s) \geq 2$, the work is in progress to show an existence of A as above with $A(n)$ being $o(n^{1/s})$.

Given a finite abelian group G, in an earlier work, using a modification of the methods of Ben Green, we had obtained an upper bound for the number of subsets A of cardinality k_1 with the cardinality of $A + A$ being k_2. In an ongoing work with E. Pramod, we undertook the task of improving these bounds as well as rewriting the article to improve the exposition.

Publications:

1. Gyan Prakash, D. S. Ramana and O. Ramaŕe, *Monochromatic sums of squares,* Math. Z. **289**, 51-69, (2018).

Preprints:

1. François Hennecart, Gyan Prakash and E. Pramod, *On sum-product bases,* (in preparation).
2. Gyan Prakash and E. Pramod, *Number of sets with small sumset,* (in preparation).

Conference/Workshops Attended:

1. *Number theory: Arithmetic, Diophantine and Transcendence*, India, December 2018.

Visits to other Institutes:

1. IIT Mumbai, Mumbai, India, March 2018.
2. Institute of Mathematical Sciences, Chennai, India, February 2018.
3. Université Jean-Monnet, Saint-Etienne, France, November 2017.
4. Institut de Mathématiques de Bordeaux, Bordeaux, France, October 2017.

Invited Lectures/Seminars:

1. *Primes in sumsets and sumsets of primes*, Combinatorics seminar, IIT Mumbai, Mumbai, March 2018.

2. *Primes in sumsets and sumsets of primes*, Number theory: Arithmetic, Diophantine and Transcendence, IIT Ropar, Ropar, December 2017.

3. *Primes in sumsets and sumsets of primes*, Number Theory seminar, Université Jean-Monnet, Saint-Etienne, November 2017.

4. *Primes in sumsets and sumsets of primes*, Séminaire Théorie des Nombres, IMB Bordeaux, Bordeaux, October 2017.

Other Activities:

1. Taught *Analysis-2* course to first year PhD students, January-May, 2018.

Raghavendra Nyshadham

Research Summary:

I have been working with my students on the differential geometry of moduli spaces of representations of a quiver, and on relative connections. More specifically, we have been studying Hermitian holomorphic line bundles on moduli spaces of semistable complex representations of finite quivers with fixed dimension vector and weight. We have also been working on the holomorphic sectional curvatures of these spaces. In another direction, we have been studying the problem of existence of relative connections in families of vector bundles on families of compact Riemann surfaces.

D. Surya Ramana

Research Summary:

A problem of A. Sàrközy asks for an optimal upper bound for the distance Δ from the product set $A.B$ to the set of squares of the integers, where A and B are any subsets of the integers in $(N, 2N]$ with $|A| \geq \alpha N$, $|B| \geq \beta N$, α, β fixed numbers in $(0, 1]$ and $N \geq 1$ an integer. The product set $A.B$ is by definition the set of all integers of the form ab with $(a, b) \in A \times B$. It was shown by H. Iwaniec and Sàrközy that $\Delta \ll_{\alpha,\beta} N^{\frac{1}{2}} \log N$, a result that has remained unimproved for over 30 years now. In on-going work with Sary Drappeau and Gyan Prakash, the possibility of improving this result when A and B have very different cardinalities was studied. In particular, an observation of one of us has lead to the conclusion that the result of Iwaniec and Sàrközy can be substantially improved when $|A| \ll |B|^{3-\epsilon}$. It is hoped that further work will allow us to better the original result as well.

The preprint listed below is a new version of a preprint reported on last year.

Publications:

1. Gyan Prakash, D. S. Ramana and O. Ramaŕe, *Monochromatic sums of squares*, Math. Z. **289**, 51-69, (2018).

Preprints:

1. D.S. Ramana and O. Ramaré, *A Variant of the Truncated Perron's Formula and Primes in Polynomial Sets*, Submitted.

Conference/Workshops Attended:

1. "Music of Numbers- A conference in memory of Javier Cilleruelo" at the ICMAT, Madrid, Spain, September, 2017.
2. *Indo-French Conference: Arithmetic, Geometry and Representations*, IMJ, Paris, 2-6 October 2017.
3. *Number theory: Arithmetic, Diophantine and Transcendence*, IIT Ropar, India, December 2018.

Invited Lectures/Seminars:

1. *Quotients and Products of Thin Subsets of the Positive Integers*, "Music of Numbers - A conference in memory of Javier Cilleruelo" at the ICMAT, Madrid, Spain, September, 2017.
2. *The Lagrange and Vinogradov theorems in Colour,* Indo-French Conference: Arithmetic, Geometry and Representations, IMJ, Paris, 2-6 October 2017.

3. *Additive Energy of Dense Sets of Primes*, Number theory: Arithmetic, Diophantine and Transcendence, IIT Ropar, Ropar, December 2017.

Other Activities:

1. K. Mallesham submitted his thesis written under my supervision (co-guide Dr. Gyan Prakash).

2. Served as external expert in the viva-voce examination of a Ph.D. candidate at ISI Kolkata.

3. Delivered four lectures Sieve Methods at the ATMW on Analytic Number Theory, 26th to 30th December, 2017 at ISI Kolkata.

Ratnakumar Peetta Kandy

Research Summary:

The ongoing project with Ramesh Manna on local smoothing of Fourier integral operators has been completed. This is the second paper extending our previous result to more general Fourier integral operators with phase function of the form $\phi(x,t,\xi) = x\cdot\xi + tq(\xi)$, for q homogeneous function of degree 1. This result also improves our previous result in terms of the decay of the derivatives of the amplitude function. The other ongoing project, on Hardy-Sobolev inequality on the Heisenberg group, jointly with Adimurthi at TIFR CAM, Bangalore is also progressing.

Publications:

1. Ramesh Manna and P.K. Ratnakumar *Maximal Functions along Hypersurfaces,* Journal of the Ramanujan Math society (to appear).

Preprints:

1. Ramesh Manna and Ratnakumar P.K., *On local smoothing of fourier integral operators in two dimensions.*

Conference/Workshops Attended:

1. *11th International Society for Analysis, its Applications and Computation (ISAAC) Congress* , Linnaeus University, Vaxjo, in Sweden during August 2017.
2. Conference on *Analysis and Applications* in honour of Prof. Elias. M. Stein, held at Wroclaw University, September 2017.
3. *15th Discussion meeting in Harmonic Analysis*, Indian Institute of Science, Bangalore, December 2017.
4. *NCM workshop in Harmonic Analysis*, IISc. Bangalore, December 2017.

Visits to other Institutes:

1. Linnaeus University, Vaxjo, Sweden, August 2017.
2. TIFR Centre for Applicable Mathematics, Bangalore, India, December, 2017.

Invited Lectures/Seminars:

1. *A Hardy-Sobolev inequality for the magnetic Laplacian*, ISAAC 2017, Linnus University, Sweden, August 2017.

Other Activities:

1. Organised the 15th Discussion meeting in Harmonic Analysis from 18-21st of December 2017, at Indian Institute of Science, Bangalore, jointly with E.K. Narayanan.

2. Co organiser of the NCM workshop in Harmonic Analysis, at IISc. Bangalore from 11-16th of December 2017.

3. Taught an Advanced course on Real Variable Methods in Harmonic Analysis for Ph. D. students, during the August-December semester in 2017.

4. Taught the course on Differental Manbiforlds to Ph. D. students in the January - May 2018 session.

5. Gave a mini course in Fourier series in SPIM 2017, at HRI.

6. Served in HRI Mathematics PDF committe, as convener.

Hemangi Madhusudan Shah

Research Summary:

(1) Summary of the paper : Almost maximal volume entropy
We prove the existence of manifolds with almost maximal volume entropy which are not hyperbolic. More precisely the following main result is proven:
Theorem 1: For every $n \geq 3$ there exists $v > 0$ and a sequence of n-dimensional closed Riemannian manifolds M_i which satisfy the following conditions:

(i) $-1 \leq K \leq 0$. In particular Ricci $\geq -(n-1)$.

(ii) Vol $(M_i) \leq v$.

(iii) $h_v(M_i) \geq (n-1) - \epsilon_i$ with $\epsilon_i \to 0$.

(iv) M_i cannot carry a metric with negative sectional curvature. In particular M_i is not diffeomorphic to a hyperbolic manifold.

(2) Summary of the paper : Geometry of Asymptotically harmonic manifolds with minimal horospheres
We show that an asymptotically harmonic manifolds with minimal horospheres are flat. The main result proved in the paper is :

Theorem 2: (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 $F(x) = (b_{e_1}(x), b_{e_2}(x), , b_{e_n}(x))$, is an isometry and therefore, M is flat.

Consequently, AH manifolds can have either polynomial or exponential volume growth, generalizing the corresponding result for harmonic manifolds. In case of harmonic manifold with minimal horospheres (HM), the (second order) flatness was proved by Ranjan and Shah, 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. In fact, our proof shows the more generalized result, viz.: If (M, g) is a non-compact, complete, connected Riemannian manifold of infinite injectivity radius and of subexponential volume growth, then M is a first order flat manifold.

(3) Summary of the paper : Asymptotically harmonic manifolds of dimension 4

In this article, we prove that, asymptotically harmonic (AH) and Einstein manifolds of dimension 4, are either flat or are rank one symmetric spaces (ROSS').

Thus, we prove the Lichnerowicz type conjecture for, AH 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 *construct* a Singer-Thorpe basis on, AH and Einstein manifold M of dimension 4, in which M is a symmetric space. On the other hand the proof in Besse, for harmonic manifolds of dimension 4, uses Singer-Thorpe basis to prove its symmetry. We also strengthen a result of Heber viz., AH homogeneous and Einstein manifolds, are either flat or ROSS' of non-compact type, in dimension 4.

Publications:

1. V. Schroeder and H. Shah, *Almost maximal volume entropy*, Arch. Math. 110 (2018), 515-521. arxiv:1702.08859v1 [math.DG].

2. H. Shah, *Geometry of asymptotically harmonic manifolds with minimal horospheres*, arXiv:1703.00341 [math.DG], 29 pages, under review.

3. H. Shah, *Asymptotically harmonic manifolds of dimension* 4, 15 pages, under review.

Conference/Workshops Attended:

1. International conference on "Metric and Finsler Geometry", University of Montpellier, IMAG, France, June 2017.

Invited Lectures/Seminars:

1. Invited speaker at international conference on "Metric and Finsler Geometry", University of Montpellier, IMAG, France, June 2017.

Academic recognition/Awards:

- Honoured as referee of Journal of Geometric Analysis, 2017.
- The article "Almost maximal volume entropy", selected as the distinguished scientific article by the editors of Archiv der Mathematik in April 2018.

Other Activities:

1. Refereed a manuscript for Indian Journal of Mathematics, 2017.

Ravindranathan Thangadurai

Research Summary:

For all large enough primes p, we proved that the set of all quadratic non residues which are not generators modulo p obey Poission law. Also, regarding the set equidistribution modulo p, we proved that set of all power residues, along with other subsets, modulo p are set equidistributed mod 1.

More than 200 years back, Gauss proved that the multiplicative group of modulo p is cyclic and extended that result for p^k for all integers $k \geq 2$. In order to prove this fact, he proved as follows. For any generator g of the multiplicative group of modulo p, the element $g + p$ modulo p^2 generators the multiplicative group of modulo p^2 and subsequently, $g + p$ generates the multiplicative group of modulo p^k for all $k \geq 2$. We proved that *at least* $\phi(p-1)/2$ *generators of the multiplicative group of modulo* p *generates the multiplicative group of modulo* p^k *for all* $k \geq 2$.

In another work, we dealt with a conjecture of Schimd and Zhuang. We proved the following. Let H be a finite abelian p-group with exponent p^m and rank r together with $p > r/2$. Let n be any integer such that $p^n > p^m + D(H)$. Then the constant

$$\eta(p^n \oplus H) = 2D(p^n \oplus H) - p^n.$$

We extended this technique to different other problem and got satisfactory answer.

Using automatic sequences technique, we gave a sufficient condition for a sequence over finite field F_2 has logarithmic density.

Publications:

1. R. Thangadurai, M. N. Chintamani and P. Paul, *On short zero-sum sequences over abelian p-groups,* Integers **17**, A50, (2017).
2. R. Thangadurai, N. K. Meher and K. Senthil Kumar, *On a theorem of Mahler,* Proc. Amer. Math. Soc. **145**, 4607-4615, (2017).

Preprints:

1. R. Thangadurai and Bidisha Roy, *On zero-sum subsequences in a finite abelian p-group of length not exceeding a given number,* To appear in: J. Number Theory.
2. R. Thangadurai, V. P Ramesh and R. Thatchayini, *A note on Gauss's theorem on primitive roots,* To appear in: Amer. Math. Monthly.
3. R. Thangadurai and S. S. Rout, *On ℓ-th order gap balancing numbers,* To appear in: Integers.
4. R. Thangadurai and J. M. Deshuoillers, *A sufficient condition for $(\theta^n)_n$ to have a distribution modulo one, when θ is in $\mathbf{F}_2(X)$*, To appear in: Integers.
5. R. Thangadurai, J. Chattopadyay and Veekesh Kumar, *Set equidistribution of subsets of $(\mathbf{Z}/p\mathbf{Z})^*$*, (In preparation).
6. R. Thangadurai and Veekesh Kumar, *Distribution of subsets of non-residues modulo p*, (In preparation).

Conference/Workshops Attended:

1. *Summer Workshop for Students/Teachers*, India, April, 2017.
2. *Prime numbers and automatic sequences*, France, May, 2017.
3. *Summer School in Mathematics to the memory of Sarvadaman Chowla*, India, June, 2017.
4. *Targeted Training on "Integer Factorization using General Number Field Sieve"*, India, July, 2017.
5. *International conference on class groups and number fields and related topics*, India, September, 2017.
6. *Winter School in Mathematics to the memory of Homi Jehangir Bhabha*, India, December, 2017.
7. *National workshop on Number Theory and its applications*, India, March, 2018.

Visits to other Institutes:

1. KSOM, Kozhikode, India, April, 2017.
2. University of Bordeaux, Bordeaux, France, May, 2017.
3. CIRM, Luminy, France, May, 2017.
4. University of Marseille, Marseille, France, May, 2017.
5. Madras School of Economics, Chennai, India, July, 2017.
6. University of Hyderabad, Hyderabad, India, August, 2017.
7. University of Toronto, Toronto, Canada, October, 2017.
8. Queens University, Kingston, Canada, October, 2017.
9. NIIT Rourkela, Rourkela, India, November, 2017.
10. Institute of Mathematics and Applications, Bhubaneswar, India, November, 2017.
11. Central University of Tamilnadu, Tiruvarur, India, December, 2017.
12. Ramakrishna Mission Vivekananda Educational and Research institute, Belur, India, February, 2018.
13. University of Hyderabad, Hyderabad, India, March, 2018.

Other Activities:

1. Guided Master's Thesis on "General Number Field Sieve", July, 2017.
2. Graduate Course on 'Topology - I, December, 2017.
3. Dean of Students' Affair, since January, 2017.
4. Gave a short course on Selberg Proof of Prime Number Theorem, March, 2018.

Satya Deo

Research Summary:

During the academic year 2017-2018, I have concentrated my attention mainly on the colored version of the famous Tverberg theorem of Topological Combinatorics. There have been two approaches to the colored version of this theorem, one initiated first by Jivaljevic and Vretica, and the other by Blagojevic, Matschke and Ziegler. The second version was stated and proved in the year 2009 and is a very satisfactory colored Tverberg theorem since the original Tverberg theorem reduces as a special case of this theorem while other data are completely fixed as compared to the first version of the colored Tverberg theorem. However, the first version also has some interesting inherent beauty in its statement as well as the proof. The technique of the proof of the second version is of course the same as initiated by Jivaljevic et al. I have analyzed the three proofs of the second version and found that they are equally complicated. My aim has been to further simplify the statement as well as the proof of the second colored version of the Tverberg theorem, and I am making good progress.

Publications:

1. Satya Deo, *Algebraic Topology, A Primer,* Second Edition, Hindustan Book Agency, **TRIM Series Number 27**, (2018).

Preprints:

1. Satya Deo, *On the Colored Tverberg Theorems, (In preparation).*

Conference/Workshops Attended:

1. *Workshop on Geometry and Topology*, University of Delhi, Delhi, Nov 2017.
2. *National Conference on Analysis and Applications*, Aligarh Muslim University, Aligarh, Nov 2017.
3. *Conference in honor of Prof P.K.Jain*, Dayal Singh College, Delhi, Nov 2017.
4. *National Conference on Topology and its Applications*, Jadavpur Universdity, Kolkata, Jan 2018.
5. *Annual conference of the Indian Mathematical Society*, Tirupati, December, 2017.
6. *Three Science Academies' Workshop on Mathematics*, IISER, Bhopal, Jan 2018.
7. *National Seminar On Mathematics*, North Eastern Hill University, Shillong, March 2018.
8. *Conference on Technological empowerment of Women in Science and Technology*, Vigyan Bhawan, New Delhi, March 2018.

Visits to other Institutes:

1. University of Pune, Pune for APC meeting of IMS, Pune, India, July 2017,
2. IIT, BHU for faculty selection committee, Varanasi, India, July 2017.
3. SERB meeting of DST for Project Proposals, New Delhi, October 2017.
4. PhD Viva-Voce examination at University of Delhi, Delhi, October, 2017.
5. IMS conference at Sri Venkateshwara University, Tirupati, Dec 2017.
6. PhD Viva Voce examination at IIT Delhi, Delhi, Jan 2018.
7. NASI Mega Event at Vigyan Bhawan, New Delhi, March 2018.

Invited Lectures/Seminars:

1. *Simplicial Homology*, ATM School for lecturers, IIT,Patna, Patna, May 2017.
2. *Real Numbers and Geometry*, Rajbhasha Science programme, HRI,Allahabad, HRI, May 2017.
3. *What are Platonic Solids?*, INSPIRE programme, Raipur University, Raipur, July 2017.
4. *Smith fixed point theorems*, Workshop on Topology and Geometry, University of Delhi, Delhi, Nov 2017.
5. *Tverberg theorem*, Conference on Analysis, Aligarh Muslim University, Aligarh Nov 2017.
6. *On spline modules*, Conference in honor of Prof PK Jain, Dayal Singh College, Delhi University, Delhi, Dec 2017
7. *On Colored Tverberg Theorem*, Conference on Topology, Jadavpur University, Kolkata, Jan 2018.
8. *Tverberg Theorem and generalizations*, Three Science Academies'Lecture Workshop, IISER, Bhopal, Bhopal, Jan 2018.
9. *Tverberg Theorem-colored version*, NEHU, Shillong, Shillong, March 2018.

Academic recognition/Awards:

- Elected General Secretary of NASI, 2017.
- Elected Chief Editor, Journal of Indian Math Society, 2017.

Other Activities:

1. Gave several lectures in the SPIM programme of HRI, June, 2017.
2. Gave two lectures in the Rajbhasha Science Programme of HRI, May, 2017.
3. Gave extension lecture on various topics of Mathematics under NASI Science Communication Programme, throughout the year, 2017-18.

Soumyarup Banerjee

Research Summary:

During last year, we studied asymptotic behaviour of a series which was mentioned earlier by Zagier in one of his conjecture. He mainly conjectured that the series associated to the square of Ramanujan tau function with exponential weights can be expressed in terms of non-trivial zeros of the Riemann zeta function. Later, the conjecture was proved by Hafner and Stopple. Chakraborty et al. studied the same series for any cusp form of even integral weight. We generalize it in the case of Maass cusp form for the full modular group.

We have also studied an asymptotic formula for the summatory function of the arithmetic function which are given as the coefficients of a product of two generating Dirichlet series, i.e. they are convolutions of the respective coefficients. Our main purpose is to elucidate a theorem of Lau in the light of Stieltjes resultant and give some applications which involve a possible logarithmic singularities.

Wilton obtained a formula for the product of two Riemann zeta functions. This formula played a crucial role to find an approximate functional equation for the product of two Riemann zeta functions in the critical region. We find an analogous formula for the product of two Dedekind zeta functions and then use this formula to find closed form expression for Dedekind zeta values attached to an arbitrary quadratic field at any positive integer.

Published/Accepted papers:

1. N. Wang and S. Banerjee, *On the product of Hurwitz zeta-functions*, Proc. Jpn. Acad., Ser. A, **93**, 31-36, (2017).

2. S. Banerjee and K. Chakraborty, *Asymptotic behaviour of a Lambert series la Zagier: Maass case*, Ramanujan J., (2018), DOI 10.1007/s11139-018- 0007-x.

3. S. Banerjee and S.Kanemitsu, *Convolution formula as a Stieltjes resultant*, accepted for publication in Kyushu Journal of Mathematics.

4. S. Banerjee, *A note on signs of Fourier coefficients of two cusp forms*, accepted for publication in Proc. Indian Acad. Sci. (Math. Sci.)

Preprints:

1. J. Ma, P. Agarwal and S. Banerjee, *A note on the Kuznetsov sum formula*, in preparation.

2. S. Banerjee, K. Chakraborty and A. Hoque, *An analogue of Wiltons formula and special values of Dedekind zeta functions*, in preparation.

3. S. Banerjee, B.-W. Li, R.-H, Liu, Y. Song and Shigeru Kanemitsu, *A new look at algebraic isomorphisms*, in preparation.

4. S. Banerjee, *A short note on sign changes of Fourier coefficients of cusp form*,in preparation.

Conference/Workshops Attended:

1. *School and Workshop on Modular forms and Blackholes held at National Institute of Science Education and Research*, Bhubaneswar, India during 05 - 14 January, 2017.

2. *Combinatorics and Number Theory Meet on the occasion of Prof. S. D. Adhikaris 60-th birhday held at Harish-Chandra Research Instiute*, Allahabad, India during 19 - 22 February, 2017.

3. *NCM Workshop on Analytic Number Theory held at Indian Statistical Insti- tute*, Kolkata, West Bengal, India during 26 - 30 December, 2017.

Visits to other Institutes:

1. Indian Institute of Science, Bangalore, India, July, 2017.

2. Shandong University, Shandong, China, November, 2017.

3. University of Hong Kong, Pokfulam, Hong Kong, December, 2017.

4. University of Hong Kong, Pokfulam, Hong Kong, May, 2017.

Invited Lectures/Seminars:

1. *Asymptotic behaviour of a Lambert series in Maass case*, Department of Mathematics, University of Hong Kong, Pokfulam , Hong Kong, December, 2017.

Papers presented in national/international conferences:

1. *An Analogue of Wiltons Formula in Number Fields and Some Applications*, presented at International Conference on Class Groups of Number Fields and Related Top- ics, held at Harish-Chandra Research Institute, Allahabad, India, during 04 - 07 September, 2017.

2. *Asymptotic Behaviour of a Lambert Series In Maass Case*, presented at Inter- national Conference On Special Functions And Applications, held at Govt. College of Engineering and Technology, Bikaner, India during 02 - 04 Novem- ber, 2017.

Jaitra Chattopadhyay

Research Summary:

I studied the behaviour of class numbers of algebraic number fields. I explored the aspect of the divisibility of class numbers of real as well as imaginary quadratic fields and improved the lower bound of the number of $2^l \cdot 3$- divisible real quadratic fields with discriminant $\leq X$. In this academic year, I also studied the set-equidistribution of some subsets of the multiplicative group of units of $(\mathbb{Z}/n\mathbb{Z})^*$ with the collaboration of Veekesh Kumar and Thangadurai. The concept of set-equidistribution was coined by Ram Murty and Sinha and was studied for some particular subsets by Ram Murty and Thangadurai. We could prove the equidistribution of some other sets in a more general set-up.

Publications:

1. Jaitra Chattopadhyay, *A Short Note On The Divisibility Of Class Numbers Of Real Quadratic Fields*, JRMS, Accepted for publication.

Preprints:

1. Jaitra Chattopadhyay, Veekesh Kumar, R. Thangadurai, *Set Equidistribution of subsets of* $(\mathbb{Z}/n\mathbb{Z})^*$.

Conference/Workshops Attended:

1. *Class Field Theory*, India, May, 2017.
2. *Int. Conf. on Class Groups of Number Fields and Related Topics*, India, Sep, 2017.
3. *Transcendental Numbers and Special Values of Dirichlet Series*, India, December, 2017.
4. *Analytic Number Theory*, India, December, 2017.

Visits to other Institutes:

1. Chennai Mathematical Institute, Chennai, India, May 2017.
2. Indian Institute of Technology, Ropar, India, December 2017.
3. Indian Statistical Institute, Kolkata, India, December 2017.

Invited Lectures/Seminars:

1. *Set Equidistribution of subsets of* $(\mathbb{Z}/n\mathbb{Z})^*$, International Conference on Class Groups of Number Fields and Related Topics, HRI, Allahabad, India, September 2017.

Academic recognition/Awards:

- Harish-Chandra Memorial Award, 2018.

Mithun Kumar Das

Research Summary:

During the academic year 2017-2018, I was mainly involved in the problems concerning value distribution of Z-function associated with certain Dirichlet series. Also, I did a project on some set theoretic problem, describe in last para.

Let $Z(t,\chi)$ be the Z-functions corresponds to certain kind of Dirichlet L-series. Let $\Omega(t)$ be the linear combination of $Z(t,\chi_i)$, where χ_i are primitive Dirichlet characters modulo $q_i,\ 1 \leq i \leq r$. we shown that the Lebesgue measure of the set, where the functional values of $\Omega(t)$ is positive or negative in the interval $(T, 2T]$ is atleast T. We also have studied the Lebesgue measure of the set that the complex linear combinations of $Z(t,\chi_i)$ takes positive or negative values respectively. In particular, we study the distribution of sign changes of the Z-function correspond to the Davenport-Hilbronn function. Moreover, we prove that for sufficiently large T, the generalized Davenport-Hilbronn function has at least $H(\log T)^{\frac{2}{\phi(q)}-\epsilon}$ odd order zeros along the critical line on the interval $[T, 2T]$. This work is an extension of the work "On the distribution of positive and negative values of Hardy's Z-function" by S M Gonek and A. Ivic as well as the work "On zeros of a special form of functions connected with Dirichlet series" by A A Karatsuba.

In our 2nd work first we derived an asymptotic second mollifier moment for k-th derivative of Hardy's Z-function and as a application of it we shown that the Lebesgue measure of the set, where the functional values of k-th derivative of Hardy's Z-function is positive or negative in the interval $(T, T+H]$ is at least H/c where c is explicit positive constant depend on mollifier length T^{θ} and $H = T^{1/2+\theta+\epsilon}$. This is an improvement, generalization of the work "On the distribution of positive and negative values of Hardy's Z-function" by S M Gonek and A. Ivic.

Let $N_1(m) = \max\{n\colon \phi(n) \leq m\}, N_2(m) = \max(\phi^{-1}(m))$, and $N_3(m) = \min(\phi^{-1}(m))$, where $\phi(n)$ denotes the Euler's totient function. Set $N_i = N_i(m) : m \in \phi(\mathbf{N}), i = 1, 2, 3$. Masser and Shiu first studid the elements of N_1 and called as 'sparsely totient numbers'. we establish several results for $N_1(m)$. First, we show that a squarefree integer divides all sufficiently large elements of N_1 and a non-squarefree integer divides infinitely many elements of N_1. Next, we construct explicit infinite families of elements in N_1. We also study the sparseness of N_1 and prove that it is not additively piecewise syndetic, it is multiplicatively piecewise syndetic and has Banach density zero. Finally, we investigate arithmetic/geometric progressions and other additive and multiplicative patterns like $\{x, y, x+y\}, \{x, y, xy\}, \{x+y, xy\}$ and their generalizations in N_1. We also construct explicit infinite families of elements in N_2 and N_3 and study some of their properties.

Preprints:

1. Mithun Kumar Das, Sudhir Pujahari, *Distribution of sign changes of Karatsubas Z-function and generalised Davenport-Heilbronn Z-function*,(in preparation).

2. Mithun Kumar Das, Sudhir Pujahari, *Distribution of sign changes of derivatives of*

Hardy's Z-function, (in preparation).

3. Mithun Kumar Das, Pramod Eyyunni and Bhuwanesh Rao Patil,*Combinatorial properties of sparsely totient numbers and related sets*, (in preparation).

Conference/Workshops Attended:

1. *ATMW on Analytic Number Theory* , India, January, 2018.
2. *International Conference on Class Groups of Number Fields and Related Topics*, India, September, 2017.

Pradeep Das

Research Summary:

During this academic year, I worked on the moduli of finite dimensional semistable representations of a finite quiver and a finite dimensional algebra over the field of complex numbers. It was shown that the moduli of finite dimensional semistable representations of a finite quiver carries a natural structure of a stratified Kähler space. Further, it was shown that there is a natural Grauert positive holomorphic line bundle on this moduli space, the restriction of which on each stratum is a holomorphic line bundle whose curvature form is same as the Kähler form of the stratum. The same results were shown to be true for the moduli of semistable representations of a finite dimensional algebra. A necessary and sufficient condition for the properness of moment maps was also established.

Preprints:

1. Pradeep Das, *Moduli of representations of quivers and algebras, and properness of their moment maps* (submitted).

Sumana Hatui

Research Summary:

I delivered my seminar talk in June 2017 with title "*The Schur multiplier of central product of groups*", which is joint work with L. R. Vermani and Manoj K. Yadav.

The *non-abelian tensor product* $G \otimes H$ of two groups G and H, acting on each other and satisfying certain compatibility conditions, was defined by Brown and Loday as a generalization of abelian tensor product. In particular, when a group G acts on itself by conjugation then $G \otimes G$ is called non-abelian tensor square which is defined as follows. Let G acts on itself by conjugation, i.e., $h^g = g^{-1}hg$ for all $h, g \in G$. Then the non-abelian tensor square $G \otimes G$ of G is the group generated by the symbols $g \otimes h$ for all $g, h \in G$, subject to the relations

$$gg' \otimes h = (g^{g'} \otimes h^{g'})(g' \otimes h)$$

and

$$g \otimes hh' = (g \otimes h')(g^{h'} \otimes h^{h'})$$

for all $g, g', h, h' \in G$. The *non-abelian exterior square* of G, denoted by $G \wedge G$, is the quotient group of $G \otimes G$ by $\nabla(G)$, where $\nabla(G)$ is the normal subgroup generated by the elements $g \otimes g$ for all $g \in G$.

It follows from the definition that the map $f : G \otimes G \to G'$, defined on the generators by $f(g \otimes h) = [g, h]$, is an epimorphism, where $[g, h] = g^{-1}h^{-1}gh$. The kernel of f is denoted by $J_2(G)$. Brown and Loday describe the role of $J_2(G)$ in algebric topology, they showed the third homotopy group of suspention of an Elinberg-MacLane space $k(G, 1)$ satisfied the condition $\prod_3(SK(G, 1)) \cong J_2(G)$. Observe that the epimorphism f then induce an epimorphism $f' : G \wedge G \to G'$. The kernel of f' is isomorphic to the Schur multiplier $M(G)$ of G.

Recently we have computed the Schur multiplier, non-abelian tensor square and exterior square of groups of order p^5. As an application we determine the capability of these groups. This is joint work with Manoj K. Yadav and Vipul Kakkar.

Publications:

1. Sumana Hatui, *Finite p-groups having Schur multiplier of maximum order,* Journal of Algebra **492**, 490-497, (2017).

2. Sumana Hatui, L. R. Vermani, Manoj K. Yadav, *The Schur multiplier of central product of groups,* Journal of Pure and Applied Algebra **222**, 3293-3302, (2018).

Preprint:

1. Sumana Hatui, Vipul Kakkar, Manoj K. Yadav, *The Schur multipliers of p-groups of order p^5.* arxiv:1804.11308 .

Conference/Workshops Attended:

1. *Ischia group Theory conference*, Italy, March 19-23, 2018.

2. *83rd Annual Conference of Indian Mathematical Society-an International Meet*, S V University, Tirupati, India, December 12-15, 2017.

3. *Groups St Andrews Conference*, University of Birmingham, UK, August 05-13, 2017.

Invited Lectures/Seminars:

1. Presented a poster "On the Schur multipier of groups" in " Ischia group Theory conference", Italy, March 19-23, 2018.

2. Delivered a talk on "Finite p-groups having Schur multiplier of maximum order" in the Competition Section (AMU Prize) in "83rd Annual Conference of Indian Mathematical Society-an International Meet", S V University, Tirupati, December 12-15, 2017.

3. Presented a contributory talk on "The Schur multiplier of Central Product of Groups" in the conference "Groups St Andrews 2017, University of Birmingham, UK", August 05-13, 2017.

Academic recognition/Awards:

1. Received AMU prize for securing first place in the Competition Section in the 83rd Annual Conference of Indian Mathematical Society-an International Meet, S V University, Tirupati, December 12-15, 2017.

Other Activities:

1. Tutor of course Algebra-II, January-June 2018, HRI.
Instructor: Dr. Manoj K. Yadav.

2. Student representative of Womens' Grievance Cell, HRI.

Debasish Karmakar

Research Summary:

A finite separable extension E of a field F is called primitive if the only intermediate fields $F \subset K \subset E$ are $K = F$ and $K = E$. We call E to be solvable over F if the group $G = \mathrm{Gal}(\hat{E}|F)$ is solvable, where $\hat{E}$ is the galoisian closure of E over F. Galois proved that if E is a solvable primitive extension of F, then $[E : F] = l^n$ for some prime l and some integer $n > 0$. So the problem of classifying all solvable primitive extensions E of a field F boils down to parametrising solvable primitive extensions of degree l^n for some fixed prime l and some fixed positive integer n.

The parametrisation is done in terms of pairs (ρ, D) consisting of an irreducible representation ρ of $\mathrm{Gal}(\tilde{F}|F)$ on some $\mathbf{F}_l$ -space N of dimension n with solvable image, where $\tilde{F}$ is a separable algebraic closure of F, and an N-extension D of the fixed field K of the kernel of ρ such that D is galoisian over F and such that the resulting conjugation action of $\mathrm{Gal}(K|F)$ on $N = \mathrm{Gal}(D|K)$ is given by ρ. This parametrisation has been given by C S Dalawat.

We are mainly interested in the case when F is a local field with finite residue field of characteristic p. In this case, all finite extensions are solvable and the above parametrisation has been made very explicit. Using this explicit parametrisation, we hope to be able to compute all primitive extensions of F of degree p^2, just as the extensions of degree p were computed by C S Dalawat.

Conference/Workshops Attended:

1. *Advanced Instructional School on Class Field Theory*, India, May, 2017.
2. *International Conference on Class Groups of Number Fields and Related Topics*, India, September, 2017.

Veekesh Kumar

Research Summary:

1. Many transcendental criterion for a real number written in b-ary expansion are known till today. Recently, I have found a criteria for the transcendence of many classes of Cantor series. In particular, I showed that at least one of the real number
$$\alpha = \sum_{n=1}^{\infty} \frac{\phi(n)}{b_1 b_2 \dots b_n} \quad \text{and} \quad \alpha' = \sum_{n=1}^{\infty} \frac{\sigma(n)}{b_1 b_2 \dots b_n}$$
is transcendental, under the assumption that $b_1 b_2 \dots b_n \leq b_{n+1}$ for infinitely many values of n. Here $\phi(n)$ denotes the Euler totient function and $\sigma(n) = \sum_{d|n} d$.

2. I studied the set-equidistribution of some subsets of the multiplicative group of units of $(\mathbb{Z}/n\mathbb{Z})^*$. The concept of set-equidistribution was introduced by Ram Murty and Sinha and was studied for some particular subsets by Ram Murty and Thangadurai. We could prove the equidistribution of some other sets in a more general set-up.

3. I studied the distribution of quadratic non-residues which are not primitive roots mod p and we proved that the sequence consisting of quadratic non-residues which are not primitive root modulo a prime p obeys Poisson law whenever $\frac{p-1}{2} - \phi(p-1)$ is reasonably large as a function of p.

4. I studied the linear independence of certain real numbers and I proved the following result: let a_1 and a_2 be distinct positive integers such that $a_1 a_2$ is not perfect square. Then, the following numbers
$$1, \quad \sum_{n=1}^{\infty} \frac{1}{b^{a_1 n^2}} \quad \text{and} \quad \sum_{n=1}^{\infty} \frac{2}{b^{a_2 n^2}}$$
are $\mathbb{Q}$-linearly independent. Later I could generalize this result for any integer $m \geq 2$, under some mild conditions on $a_1, a_2, \dots, a_m$.

Publications:

1. R. Thangadurai and Veekesh Kumar, *Distribution of a Subset of Non-residues Modulo p,* Professor Kumar Murty's conference proceeding, Accepted for publication.

2. Veekesh Kumar, *A Transcendence Criterion For Cantor Series,* Acta Arithmetica, Accepted for publication.

Preprints:

1. Veekesh Kumar, *Linear Independence of Certain numbers I,* Preprint, 2018.

2. Veekesh Kumar, *Linear Independence of Certain numbers II,* Preprint, 2018.

Conference/Workshops Attended:

1. *International Conference on Class Groups of Number Fields and Related Topics*, India, September 2017.

2. *IMS Conference*, India, December 2017.

3. *GIAN course on Transcendental Numbers and special values of Dirichlet series*, India, December 2017.

4. *School on Modular forms*, India, March 2018.

Visits to other Institutes:

1. Sri Venkateswara University, Tirupati, India, December 2017.

2. Indian Institute of Technology Ropar, Ropar, India, December 2017.

3. Kerala School of Mathematics, Kozhicode, India, March 2018.

Invited Lectures/Seminars:

1. *A Transcendence Criterion For Cantor Series*, ICCGNFRT , HRI, Allahabad, September 2017.

2. *A Transcendence Criterion For Cantor Series*, IMS, Sri Venkateswara University, Tirupati, December 2017.

3. *Linear Independence of Certain numbers*, School on Modular forms, KSOM, Kozhicode, Febraury 2018.

Manikandan. S

Research Summary:

During the period August, 2017 - July, 2018, I worked on some differential geometric aspects of the moduli of stable representations of a finite quiver over the field of complex numbers and obtained a partial result that the holomorphic sectional curvature of such moduli spaces is nonnegative. Having done this, I am currently working on extending certain constructions of moduli spaces of vector bundles on curves, due to L.Jeffrey and others.These authors obtain smooth symplectic manifold structure on these moduli spaces. I am working on extending their techniques to obtain Kahler structures on the moduli spaces.

Preprints:

1. Pradeep Das, S. Manikandan, N. Raghavendra, *Holomorphic aspects of moduli of representations of quivers* , Submitted for publication.

Conference/Workshops Attended:

1. *83rd Annual conference of the Indian Mathematical Society*, India, December, 2017.

Other Activities:

1. Presented the paper *Holomorphic aspects of moduli of representations of quivers* in 83rd Annual conference of the Indian Mathematical Society, held at Sri Venkates--wara University, Tirupati during December 12-15, 2017.

Nabin Kumar Meher

Research Summary:

1. Note on arithmetic nature of infinite series:

   A complex number is said to be transcendental if it is not the root of any polynomial with integer coefficients. The problem of finding the transcendence nature of an infinite series is challenging and interesting. It has a very rich history. Many number theorist like Adhikari, Saradha, Shorey and Tijdeman studied and contributed in this direction. Recently, in 2013, Weatherby studied the following series. For any $\alpha \in \mathbb{Q}\setminus\{0\}$, the series

   $$\sum_{n\in\mathbb{Z}} \frac{1}{n^2+\alpha^2}$$

   is transcendental. We have extended his results. Beside this, we proved that many similar series are transcendental and analysed the linear independence relation between them.

2. Analytic continuation of the multiple Fibonacci zeta function and the multiple Lucas zeta function (Joint work with S. S. Rout):
   The sequence of Fibonacci numbers is defined by the recurrence relation

   $$F_n = F_{n-1} + F_{n-2}, \quad n \geq 2$$

   with initial values $F_0 = 0$ and $F_1 = 1$. The Fibonacci zeta function is the series

   $$\zeta_F(s) = \sum_{n=1}^{\infty} \frac{1}{F_n^s}$$

   and this series is absolutely convergent for $\mathrm{Re}(s) > 0$. In 2001, Navas obtained analytic continuation of the Fibonacci Dirichlet series $\zeta_F(s)$. André-Jeannin, Duverney et.el. studied the special values of the Fibonacci zeta function. The special values of the Fibonacci zeta function stimulated the study of the special values of the multiple Fibonacci zeta function which motivated us to look at the analytic continuation of the multiple Fibonacci zeta function. The multiple Fibonacci zeta function which is defined as

   $$\zeta_F(s_1,\ldots,s_d) := \sum_{0<n_1<n_2\cdots<n_d} \frac{1}{F_{n_1}^{s_1}\cdots F_{n_d}^{s_d}},$$

   where F_n is the n-th Fibonacci number. In this situation, the sum $s_1+\cdots+s_d$ is called the *weight* of $\zeta_F(s_1,\ldots,s_d)$ and d is called its *depth*. In this article, we proved the analytic continuation of the above defined series for $d = 2$ on all of $\mathbb{C}^2$ with a complete list poles and their corresponding residues. Moreover, we investigate the arithmetic nature of the multiple Fibonacci zeta functions at negative integer arguments. Analogously, we studied the similar results in the case of the multiple Lucas zeta function for depth d.

3. Linear combinations of prime powers in sums of terms of binary recurrence sequences (Joint work with S. S. Rout):

   Let $(U_n)_{n\geq 0}$ be a non-degenerate binary recurrence sequence with positive discriminant. Let $\{p_1, \ldots, p_s\}$ be fixed prime numbers, $b_1, \ldots, b_s$ and $a_1, \ldots, a_t$ are positive integers. In this article, we obtained the finiteness result for the solution of the Diophantine equation

   $$a_1 U_{n_1} + \cdots + a_t U_{n_t} = b_1 p_1^{z_1} + \cdots + b_s p_s^{z_s}$$

   under certain assumptions. Moreover, we explicitly solved the equation

   $$F_{n_1} + F_{n_2} = 2^{z_1} + 3^{z_2},$$

   in non-negative integers n_1, n_2, z_1, z_2 with $z_2 \geq z_1$. The main tools used in this work are the lower bound for linear forms in logarithms and the Baker-Davenport reduction method. This work generalizes the recent works of Mazumdar and Rout and Bertók, Hajdu, Pink and Rábai.

Publications:

- Nabin Kumar Meher and S. S. Rout, *Linear combination of prime powers in sums of terms of binary recurrence sequences,* Lith. Math. J., 57 (2017), no. 4, 506–520.
- Nabin Kumar Meher and S.S. Rout, *Analytic continuation of the multiple Fibonacci zeta functions,* Proc. Japan Acad. Ser. A Math. Sci., (To appear).

Preprints:

1. Nabin Kumar Meher and S.S. Rout, *Analytic continuation of the multiple Lucas zeta functions,* (submitted for publication).
2. Nabin Kumar Meher, *Note on arithmetic nature of some infinite series,* (submitted for publication).

Conference/Workshops Attended:

1. *International Conference on Class Groups of Number Fields and Related Topics* at HRI, Allahabad, India, September, 2017.
2. *83rd Annual conference of Indian Mathematical Society An International Meet* at Sri Venkateswara University, Tirupati, December 12-15, 2017.
3. GIAN course on *"Transcendental Number Theory and Special Values of Dirichlet Series."* at IIT, Ropar, December 16-21, 2017.
4. *Conference on Number Theory: Arithmetic, Diophantine and Transcendence* at IIT, Ropar, December 22-25, 2017.
5. *Workshop on Analytic Number Theory* at ISI, Kolkata, December 26-30, 2017.
6. *Discussion meeting on Modular Forms* at KSOM, Calicut, February 12-24, 2018.

Visits to other Institutes:

1. NISER, Bhubaneswar, India, August 1-18, 2017.

Invited Lectures/Seminars:

1. *Linear combination of prime powers in sums of terms of binary recurrence sequences,* International Conference on Class Groups of Number Fields and Related Topics, HRI, Allahabad, September, 2017.

2. *On a Theorem Of Mahler,* 83rd Annual conference of Indian Mathematical Society An International Meet, Sri Venkateswara University, Tirupati, December 12-15 , 2017.

3. *On a Theorem Of Mahler,* Conference on Number Theory: Arithmetic, Diophantine and Transcendence , IIT, Ropar,December 22-25, 2017.

4. *On a Theorem Of Mahler,* Discussion meeting on Modular Forms, KSOM, Calicut, February 12-24, 2018.

Other Activities:

1. Took tutorial in Algebra, Summer Program in Mathematics, at HRI, Allahabad, 2017.

Manish Kumar Pandey

Research Summary:

- *Shimura lift of certain class of modular forms of half integral weight* , with Prof. B. Ramakrishnan

  In 1973, G. Shimura defined a family of maps from the space of modular forms of half-integral weight to the space of modular forms of integral weight. A. Selberg in his unpublished work found explicitly this correspondence (the first Shimura map S_1) for the class of forms which are products of a Hecke eigenform of level one and a Jacobi theta function. Later, in 1989, B. Cipra generalized the work of Selberg to the case where Jacobi theta functions are replaced by the theta functions associated to Dirichlet charater of prime power moduli, and the level one Hecke eigenforms are replaced by newforms of arbitrary level. In 2008, D. Hansen and Y. Naqvi generalized Cipras work (on the image of a class of modular forms under the first Shimura map S 1) to cover theta functions associated to Dirichlet characters of arbitrary moduli.
  In our work we generalize there work to show that one can even get explicit shimura map for any square free t of such forms.

- *On simultaneous nonvanishing of twisted L-functions associated to newforms on* $\Gamma_0(N)$,with A.K. Jha and A.Juyal

  In this article, we show that for given two normalized Hecke eigenforms $f_1,\ f_2$ of weight k_1 and k_2 respectively of squarefree level N,, if we consider the product of twisted L-functions associated with f_1 and f_2 by some quadratic charater χ. We show that if this product does not vanish at the center of the critical strip $s = 1/2$, then this product does not vanish for infinitely many such twists.

- *Determining modular forms of half integral weight by central values of the convolution L functions* , with Prof.B.Ramakrishnan

  Let f_1 and f_2 be two normalized newform of half integral weight.We consider the Rankin Selberg L function corresponding to f_i and g ,$g \in S_{l+1/2}$. We show that if $L(1/2, f_1 \otimes g) = L(1/2, f_2 \otimes g)$ then both the forms are same.This work is a generalisation of the work of Satadal, Sengupta and Hoffstein, who have proved the analogous result in the integral weight case.

- *Distinguishing pure representations by normalized traces* , with Jyoti Prakash Saha and Sudhir Pujahari

  Given two pure representations of the absolute Galois group of an l-adic number field with coefficients in Q_p(with $l \neq p$), we show that the Frobenius-semi simplifications of the associated Weil Deligne representations are twists of each other by an integral power of a certain unramified character if they have equal normalized traces. This is an analogue of a recent result of Patankar and Rajan in the context of local Galois representations.

- *Signs of fourier coefficients of cusp form at sum of two squares* , with Soumyarup Banerjee

  In this article, we investigate the sign changes of the sequence of coefficients at sum of two squares where the coefficients are the Fourier coefficients of normalized Hecke eigen cusp form for the full modular group. We provide the quantitative result for the number of sign changes of the sequence in a small interval.

Preprints:

1. B. Ramakrishnan and Manish Kumar Pandey, *Shimura lift of certain class of modular forms of half integral weight*, (submitted for publication).
2. Jyoti Prakash Saha, Sudhir Pujahari and Manish Kumar Pandey , *Distinguishing pure representations by normalized traces*, (submitted for publication).
3. Abhash Jha ,Abhishek Juyal and Manish Kumar Pandey, *On simultaneous nonvanishing of twisted L-functions associated to newforms on* $\Gamma_0(N)$, (submitted for publication).
4. B. Ramakrishnan and Manish Kumar Pandey , *Determining modular forms of half integral weight by central values of the convolution L functions*, (in Preparation).
5. Soumyarup Banerjee and Manish Kumar Pandey , *Signs of fourier coefficients of cusp form at sum of two squares*, (in Preparation).

Conference/Workshops Attended:

1. *Gian course on Siegel modular form by Ameya Pitale at IISER Pune*, India, August 2017.
2. *ICCGNFRT organised at HRI, Allahabad*, India, September, 2017.
3. *School on modular form at KSOM Kozhikode*, India, February 2018.
4. *32nd Automorphic form workshop at Tufts University*, U.S.A, March, 2018.

Visits to other Institutes:

1. Kerala School of Mathematics, Kerala, India, February 2017.
2. Institute of Mathematical Sciences, Chennai, India, May 2018.

Other Activities:

1. Given a talk at Ksom, February, 2017.
2. Given a talk in ICCGNFRT, September, 2017.

Bhuwanesh Rao Patil

Research Summary:

During the academic year "2017-2018", my research works were based on the study of sparse totient numbers and geometric progressions inside syndetic sets. Brief descriptions of the same are following:

1. Let

$$N_1(m) = \max\{n\colon \phi(n) \leq m\},$$
$$N_2(m) = \max(\phi^{-1}(m)),$$
$$N_3(m) = \min(\phi^{-1}(m)) \text{ and}$$
$$N_i = \{N_i(m)\colon m \in \phi(\mathbb{N})\}, i = 1, 2, 3.$$

   where $\phi(n)$ denotes the Euler's totient function. An element of N_1 is known as a sparse totient number. With Mithun Das and Pramod Eyyunni, we establish several results for sparse totient numbers. First, we show that a squarefree integer divides all sufficiently large elements of N_1 and a non-squarefree integer divides infinitely many elements of N_1. Next, we construct explicit infinite families of elements in N_1. We also study the sparseness of N_1 and prove that it is not additively piecewise syndetic, it is multiplicatively piecewise syndetic and has Banach density zero. Finally, we investigate arithmetic/geometric progressions and other additive and multiplicative patterns like $\{x, y, x + y\}, \{x, y, xy\}, \{x + y, xy\}$ and their generalizations in N_1. We also construct explicit infinite families of elements in N_2 and N_3 and study some of their properties.

2. Let $l \in \mathbb{N}$ and $A \subset \mathbb{N}$. Then A is called an l-syndetic set if for every $x \in \mathbb{N}$, $[x, x + l] \cap A \neq \varnothing$. A is called syndetic set if there exists $l \in \mathbb{N}$ such that A is l-syndetic. In 2006, Beiglböck, Bergelson, Hindman and Strauss proposed the following open question :

   Do syndetic sets contain arbitrarily large geometric progressions?

   In view of the above question, I studied about 2-term geometric progressions having integer common ratio in syndetic sets and proved the following results.

   (a) For each $k \in \mathbb{N}$, a syndetic set contains configurations of the type $\{x, xn^k r_1\}$ and $\{x, xp^k r_2\}$ where $x, n, r_1, r_2 \in \mathbb{N}$, $p \in \mathbb{P}$ satisfy $r_1 \equiv 1 \pmod{n}$ and $r_2 \equiv 1 \pmod{p}$.

   (b) Any 2-syndetic set in $\mathbb{N}$ contains infinitely many configurations of the type $\{x, xr^2\}$ for some $x, r \in \mathbb{N}$.

Preprints:

1. Mithun Kumar Das, Pramod Eyyunni and Bhuwanesh Rao Patil, *Combinatorial properties of sparsely totient numbers and related sets*, (in preparation).

2. Bhuwanesh Rao Patil, *On geometric progression inside syndetic set*, (in preparation).

Conference/Workshops Attended:

1. *International Conference on Class Group of Number fields and Related Topics*, HRI Allahabad, India, September, 2017.

2. *AIS Ergodic Theory and Dynamical systems(2017)*, Department of Mathematics IIT Delhi, India 4^{th} to 23^{rd} December, 2017 .

Pramod Eyyunni

Research Summary:

I and my co-guide Dr. Gyan Prakash are preparing a soon to be submitted paper, refining earlier work of the latter. The tentative summary of this work is as follows. Let G be a finite abelian group of order n. For any subset B of G, the *Cayley sum graph* is a graph with vertex set G in which ij is an edge if and only if $i+j \in B$. Ben Green proved that when G is a vector space over a finite field, there is a Cayley sum graph containing neither a complete subgraph nor an independent set of size more than $c \log n \log \log n$, where $c > 0$ is an absolute constant. We give a crude generalization of this result by showing that, for an arbitrary finite abelian group of order n, there is a Cayley sum graph containing neither a complete subgraph nor an independent set of size more than $c(\omega^3(n) \log \omega(n) + \log n \log \log n)$, where $c > 0$ is an absolute constant and $\omega(n)$ denotes the number of distinct prime divisors of n.

Given s natural numbers $k_1, \ldots k_s$, with $s \geq 2$, in an ongoing work with Gyan Prakash and François Hennecart, we study the question of how "thin" a subset A of natural numbers can be such that $A^{k_1} + \ldots + A^{k_s}$ contains all natural numbers. Here $A^{k_1} + \ldots + A^{k_s}$ denotes the set consisting of those n which can be written as $n = b_1 + \ldots + b_s$ where $b_i = a_1 \ldots a_{k_i}$ with $a_i \in A$ for each i. For any subset B of natural numbers and a real number x, we write $B(x)$ to denote the number of natural numbers belonging to B which does not exceed x. An elementary combinatorial argument shows that for any A as above $A(n)$ must be at least $cn^{\frac{1}{\sum_i k_i}}$. When $k_1 = \ldots = k_s = 1$, there are known examples of A as above with $A(n)$ not exceeding $cn^{1/s}$. We study the question for general $k_1, \ldots, k_s$ and show that the number of elements in A not exceeding n must be at least $c\frac{n^{1/s}}{\log^{\alpha(k_1,\ldots,k_n)} n}$ for infinitely many n, where we may take $\alpha(k_1, \ldots, k_n) = 1 - \frac{1}{\max_i k_i}$. When $s = 2$ and $\max(k_1, k_2) \geq 3$, we also show the existence of A such that $A^{k_1} + A^{k_2}$ contains all natural numbers and $A(n)$ is $o(\sqrt{n})$. When $s \geq 2$ and $\max(k_1, \ldots, k_s) \geq 2$, the work is in progress to show an existence of A as above with $A(n)$ being $o(n^{1/s})$.

In joint work with Mithun Kumar Das and Bhuwanesh Rao Patil, we studied some combinatorial properties of sparsely totient numbers and related sets. Let $N_1(m) = \max\{n \colon \phi(n) \leq m\}$, $N_2(m) = \max(\phi^{-1}(m))$, and $N_3(m) = \min(\phi^{-1}(m))$, where $\phi(n)$ denotes the Euler's totient function. Set $N_i = \{N_i(m) \colon m \in range(\phi)\}, i = 1, 2, 3$. Masser and Shiu call the elements of N_1 as 'sparsely totient numbers'. We establish several results for $N_1(m)$. First, we show that a squarefree integer divides all sufficiently large elements of N_1 and a non-squarefree integer divides infinitely many elements of N_1. Next, we construct explicit infinite families of elements in N_1. We also study the sparseness of N_1 and prove that it is not additively piecewise syndetic, it is multiplicatively piecewise syndetic and has Banach density zero. Finally, we investigate arithmetic/geometric progressions and other additive and multiplicative patterns like $\{x, y, x + y\}, \{x, y, xy\}, \{x + y, xy\}$ and their generalizations in N_1. We also construct explicit infinite families of elements in N_2 and N_3 and study some of their properties.

Preprints:

1. Mithun Kumar Das, Bhuwanesh Rao Patil and Pramod Eyyunni, *Combinatorial properties of sparsely totient numbers and related sets.*

2. François Hennecart, Gyan Prakash and E. Pramod, *On sum-product bases* (in preparation).

Conference/Workshops Attended:

1. *International Conference on Class Groups of Number Fields and Related Topics*, HRI, Allahabad, 4-7 September, 2017.

Invited Lectures/Seminars:

1. *Expanders and Incidence Problems over Finite Fields*, International Conference on Class Groups of Number Fields and Related Topics, HRI, Allahabad, 4-7 September, 2017.

Bidisha Roy

Research Summary:

In this year, I have studied some topics in combinatorics mainly zero-sum theory and Ramsey theory.

In zero-sum theory, given a finite abelian group $(G, +)$ and an integer $k \geq 1$, the constant $s_{\leq k}(G)$ is the least positive integer t such that any sequence S over G of length at least t has a zero-sum subsequence of length $\leq k$ in it. We computed this constant for many classes of abelian p-groups which proves, in particular, a conjecture of Schmid and Zhuang.

In Ramsey theory, there is a vast literature on regularity questions of linear Diophantine equations. We proved that, for every pair of positive integers r and n, there exists an integer $B = B(r)$ such that the Diophantine equation

$$\prod_{m=1}^{n}\left(\sum_{i=1}^{k_m} a_{m,i}x_{m,i} - \sum_{j=1}^{l_m} b_{m,j}y_{m,j}\right) = B$$

with

$$\sum_{i=1}^{k_m} a_{m,i} = \sum_{j=1}^{l_m} b_{m,j} \qquad \forall m = 1, \ldots, n$$

is r-regular, where k_m, l_m are also positive integers and $a_{m,i}, b_{m,j}$ are non-zero integers.

In combinatorial number theory, one of the recent topic is the determination of *Zero-sum generalized Schur number* denoted by $S_{\mathfrak{z},2}(k; r)$. We could prove that this constant, $S_{\mathfrak{z},2}(k, r)$ is $kr - 2r + 1$ for all positive integers k and r with $k > r$ and $r \mid k$ which determines a open question asked by A. Robertson.

Publications:

1. Bidisha Roy and R. Thangadurai, *On zero-sum subsequences in a finite abelian p-group of length not exceeding a given number,* Journal of Number Theory, Accepted for publication, doi.org/10.1016/j.jnt.2018.03.006 .

2. Bidisha Roy and Subha Sarkar, *Regularity of certain Diophantine equations,* Proceedings of Indian Academy of Sciences, Accepted for publication.

Preprints:

1. Aaron Robertson, Bidisha Roy and Subha Sarkar, *The Determination of 2-color zero-sum generalized Schur Numbers,* Preprint, 2018.

Conference/Workshops Attended:

1. *AIS on Class Field Theory*, India, May, 2017.

2. *International Conference on Class Groups of Number Fields and Related Topics*, India, September, 2017.

3. *GIAN course on Transcendental Numbers and special values of Dirichlet series*, India, December, 2017.

Visits to other Institutes:

1. Chennai Mathematical Institute, Chennai, India, May 2017.
2. Indian Institute of Technology Ropar, Ropar, India, December 2017.
3. Ramakrishna Mission Vivekananda Educational and Research Institute, Belur, India, February-March 2018.

Subha Sarkar

Research Summary:

In this academic year, I have studied Combinatorial Number Theory, mainly the zero-sum problems and Ramsey theory. More precisely we could prove the *degree of regularity* of certain Diophantine equation.

In Ramsey theory, regularity questions of linear Diophantine equations has got a lot of attention. Some problems in higher degree have been considered recently. We could prove that, for every pair of positive integers r and n, there exists an integer $B = B(r)$ such that the Diophantine equation

$$\prod_{m=1}^{n}\left(\sum_{i=1}^{k_m} a_{m,i}x_{m,i} - \sum_{j=1}^{l_m} b_{m,j}y_{m,j}\right) = B$$

with

$$\sum_{i=1}^{k_m} a_{m,i} = \sum_{j=1}^{l_m} b_{m,j} \qquad \forall m = 1, \ldots, n$$

is r-regular, where k_m, l_m are also positive integers and $a_{m,i}, b_{m,j}$ are non-zero integers.

There is a recent topic of determining the 2-*color zero-sum generalized Schur number* $S_{\mathfrak{z},2}(k, r)$. In a recent paper, the question of determining the exact value of $S_{\mathfrak{z},2}(k; 4)$ was posed. We solved this problem and showed more generally that $S_{\mathfrak{z},2}(k, r) = kr - 2r + 1$ for all positive integers k and r with $k > r$ and $r \mid k$.

Publications:

1. Bidisha Roy and Subha Sarkar, *Regularity of certain Diophantine equations*, Proceedings of Indian Academy of Sciences, Accepted for publication.

Preprints:

1. Aaron Robertson, Bidisha Roy and Subha Sarkar, *The Determination of 2-color Zero-sum Generalized Schur Numbers*, (in preparation).

Conference/Workshops Attended:

1. *Advanced Instructional School on Class Field Theory*, India, May, 2017.
2. *International Conference on Class Group of Number Fields and Related Topics*, India, September, 2017.
3. *Transcendental Numbers and Special Values of Dirichlet Series*, India, December, 2017.

Visits to other Institutes:

1. Ramakrishna Mission Vivekananda Educational and Research institute, Belur, India, February-March, 2018.

Ritika Sharma

Research Summary:

During this academic year, I have read the work of Murty, Saha and Toth on Ramanujan expansion of arithmetical function with absolutely convergent Ramanujan expansions and genralized their result for arithmetical function of several variables with absolutely convergent Ramanujan expansions. I have also read the work of Suryanarayana and Ramachandran on greatest comman divisor of a given integers and in the joint work with Makoto Minamide et.al we genralized the work of Suryanarayana and Ramachandran for higher-moments of greatest comman divisor of a given integer.

Publications:

1. Ritika Sharma, *On partial sums of arithmetical function of two variables with absolutely convergent Ramanujan Expansions,* Proceeding of Indian Academy of Science.

Preprints:

1. Ritika Sharma, *Average order of Oscillating multiplicative function.*
2. Ritika Sharma, *Partial sums of arithmetical function of several variables with absolutely convergent Ramanujan Expansions.*
3. Debika Banerjee, Jun Furya, Tadaki Igawa, Makoto Minamide, Ritika Sharma, Yashio Tanigawa, *On power moments of greatest comman divisor of a given integer.* (in preparation).

Conference/Workshops Attended:

1. *Analytic Number Theory, ATM School*, India, December 2017.
2. *83rd International conference of Indian Mathematical Society* , India, December 2017.
3. *International Conference on Class group of Number fields and Related Topics* , India, September 2017.
4. *CIMPA school on Artin L-function and Artin L-Conjecture* , Turkey, May 2017.

Visits to other Institutes:

1. Yamaguchi University, Yamaguchi, Japan, Feb 2018.

Invited Lectures/Seminars:

1. *Average order of Oscillating multiplicative functions*, International Conference on , HRI, Allahabad, September 2017.

2. *Average order of Oscillating multiplicative functions* , IMS conference, Tirupati University, Tirupati, December 2017.

3. *Average order of Oscillating multiplicative functions* , Yamaguchi University , Japan, Feb 2018.

Anup Kumar Singh

Research Summary:

(i) Representations of a positive integer by certain quaternary and octonary quadratic forms (with B. Ramakrishnan and Brundaban Sahu) : Finding formulas for the number of representations of a positive integer as sum of squares is a classical problem in number theory. In the general situation, one may consider direct sums of quadratic forms with certain coefficients and ask for similar question of finding the number of ways of representing a positive integer by these types of quadratic forms. Given any quadratic form, the associated theta series becomes a modular form of certain weight, level and character. Note that the weight depends on the number of variables, where as level and character depends on the coefficients of the quadratic form under consideration. There are many ways to deal with such problems, the theory of modular forms is one of them. We use the theory of modular forms for the following works:

(a) In first work, we find formulas for the number of representations of some quaternary and octonary quadratic forms with coefficients and get their corresponding representations formula. We obtained these formulas by constructing explicit bases for the space of modular forms of weight 2 and weight 4 with some level (depends on the coefficients of the quadratic forms). This work has been accepted for publication in conference proceeding in Proceedings in Mathematics and Statistics, Geometry, Algebra, Number Theory and Their Information Technology Applications (GANITA) Springer, in honor of Professor V. Kumar Murty.

(b) In this second work, we find formulas for the number of representations of certain class of quaternery quadratic forms, viz., forms of the form $a_1x_1^2+a_2x_2^2+a_3x_3^2+a_4x_4^2$, $\sum_{i=1}^{2} b_i(x_{2i-1}^2 + x_{2i-1}x_{2i} + x_{2i}^2)$ and $a_1x_1^2 + a_2x_2^2 + b_1(x_3^2 + x_3x_4 + x_4^2)$, where a_i's $\in \{1, 2, 3, 4, 6, 12\}$, b_i's $\in \{1, 2, 4, 8, 16\}$ and $a_1 \leq a_2 \leq a_3 \leq a_4$, $b_1 \leq b_2$. This work has been submitted for publication.

(ii) Representation of squares by quinary and septenary quadratic forms (with B. Ramakrishnan and Brundaban Sahu): In this work, we consider sums of 5 and 7 squares with certain coefficients. Since we consider odd number of squares, the associated functions corresponding to these quadratic forms are modular forms of weight $5/2$ and $7/2$. In recent works, S. Cooper and D. Ye used theta function identities to obtain formulas for the number of representations of n^2 by these types of quinary and septenary quadratic forms. In our work, which is in progress, we use the extended Shimura correspondence obtained by T. Jagathesan and M. Manickam, to get similar results for such quadratic forms with different coefficients.

Publications:

1. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of a positive integer by certain classes of quadratic forms in eight variables,* Analytic number theory, modular forms and q-hypergeometric series, 641 – 664, Springer Proc. Math. Stat., **221** , Springer, Cham, 2017.

2. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of*

representations by certain octonary quadratic forms with coefficients $1, 2, 3, 4$ *and* 6, International Journal of Number Theory, **14** (2018), 751 – 812.

3. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of certain quadratic forms and a formula for the Ramanujan Tau function*, Funct. Approx. Comment. Math. (2018), To appear, doi:10.7169/facm/1695.

4. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *Representations of an integer by some quaternary and octonary quadratic forms*, in Geometry, Algebra, Number Theory and Their Information Technology Applications (GANITA) in honor of Professor V. Kumar Murty, Springer Proceedings in Mathematics and Statistics. To appear.

Preprints:

1. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of certain quadratic forms in* 8 *variables*, Submitted for publication.

2. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *Certain quaternary quadratic forms of level 48 and their representation numbers*, Submitted for publication.

3. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *Representation of squares by certain quinary and septenary quadratic forms*, Preprint.

Conference/Workshops Attended:

1. *GIAN course on Siegel modular forms and associated representations, by Dr. Ameya Pitale* at IISER Pune, India, August 2017.

2. *International Conference on Class Groups of Number Fields and Related Topics - 2017*, at Harish-Chandra Research Institute, Allahabad, India, September 2017.

3. *AIS - Workshop on Number theory* at ISI, Kolkata, India, December 2017.

4. *School on Modular forms* at the Kerala School of Mathematics, Kozhikode, India, February 2018.

5. *32nd Automorphic Forms Workshop* at Tufts University, Medford, Massachusetts, USA, March 2018.

Visits to other Institutes:

1. National Institute of Science Education and Research, Bhubaneswar, India, May 2017.

2. National Institute of Science Education and Research, Bhubaneswar, India, September - October 2017.

Invited Lectures/Seminars:

1. *A formula for Ramanujan tau function*, International Conference on Class Groups of Number Fields and Related Topics (ICCGNFRT), Harish-Chandra Research Institute, Allahabad, India, September 2017.

2. *On the representations by certain quadratic forms*, School on Modular Forms, Kerala School of Mathematics, Kozhikode, India, February 2018.

Academic recognition/Awards:

- HRI-Infosys Prize, 2018.

Anoop Singh

Research Summary:

In the academic year 2017-2018, I attended a course on (algebraic) connections in the spirit of Koszul, given by Prof.N.Raghavendra. I read the work of Atiyah on the complex analytic connections in fibre bundles, which deals with a criterion of existence of holomorphic connections in a holomorphic vector bundle over compact Riemann surfaces. Also, I read about a criterion of Atiyah and Weil for the existence of (algebraic) connections in a vector bundle on a smooth projective curve over a perfect field by I.Biswas and S.Subramanian.

I tried to extend this criterion for curves over more general field. Currently, I am working on extending a criterion of Atiyah and Weil for the exixtence of holomorphic connections in a holomorhic vector bundle over a compact Riemann surface to a holomorphic vector bundle over a complex analytic family of compact Riemann surfaces.

Lalit Vaishya

Research Summary:

Problems related to representing integers as sums of integral squares or in general by positive-definite quadratic forms and finding formulas for their number of representations have a long history and it is one of the classical problems in number theory. In this work (with B. Ramakrishnan), we consider certain positive-definite integral quadratic forms of 10 variables and find their representation formulas. Expilicitly, the following three type of quadratic forms in 10 variable are considered and given by;

$$\sum_{i=1}^{10} a_i x_i^2, a_i \in \{1,2,3,6\}, \quad 1 \leq i \leq 10,$$

$$\sum_{i=1}^{5} b_i (x_{2i-1}^2 + x_{2i-1}x_{2i} + x_{2i}^2), \;\; b_i \in \{1,2,4,8\}, \;\; 1 \leq i \leq 5,$$

and for $1 \leq r \leq 4$, we consider

$$\sum_{i=1}^{2r} a_i x_i^2 + \sum_{\substack{j=2r+1 \\ j-odd}}^{10} b_j (x_j^2 + x_j x_{j+1} + x_j^2), \;\; a_i \in \{1,2,3,6\} \;\&\; b_j \in \{1,2,4,8\}.$$

Since the theta series corrosponding to these quadratic forms are modular forms of weight 5 on $\Gamma_1(24)$, we obtain our formula by constructing expilit basis for this space of Modular forms. We also find the universal quadratic forms among these decenary quadratic forms by applying a theorem due to M. Bhargava and J.Hanke (290-theorem). This work is in progress.

Conference/Workshops Attended:

1. Advanced Instructional school on Class Field Theory (May 08-27, 2017) at CMI, Chennai.
2. GIAN course on Siegel Modular Forms and associated Representations (August 07-18, 2017) by Dr. Ameya Pitale at IISER Pune.
3. International conference on Class Group of Number Field and Related Topics (ICCNFRT-2017) (September 04-07, 2017) at HRI Allahabad.
4. GIAN course on Transcendental Numbers and Special Values of Dirichlet Series by Prof. M.Ram Murty and Prof. V.K.Murty (December 16-21, 2017) at IIT Ropar.
5. International conference on Arithematic Diophantine and Transcendence (December 22-25, 2017) at IIT Ropar.
6. School on Modular forms (February 12-24, 2018) at Kerala School of Mathematics(KSoM) Kozhikode.

Snigdha Bharati Choudhury

Research Summary:

The idea of S-localization for a class S of morphisms in a category $\mathcal{C}$ was introduced by A. K. Bousfield. The notion of Adams completion, which emerged from a categorical completion process, was initially suggested by Adams and the idea was approached broadly by Deleanu, Frei and Hilton. Moreover, they have also suggested the dual of Adams completion, known to be the Adams cocompletion. We have established a bijective correspondence between the S-colocalization (dual of S-localization) of an object and Adams cocompletion of the same object in a complete small $\mathcal{U}$-category ($\mathcal{U}$ being a fixed Grothendieck universe) together with a specific set of morphisms S.

In 1968, John R. Reay has introduced the concept of strong independence and studied how strong independence insure (r, k)-divisibility of a set with m points, where a set in the d-dimensional space R^d is said to be (r, k)-divisible if it can be partitioned into r pair-wise disjoint subsets in such a way that the intersection of the convex hulls of these r subsets is at least k-dimensional. We have proved his result in a different way.

Preprints:

1. Snigdha Bharati Choudhury and A.Behera, *S-colocalization and Adams cocompletion*.

2. Snigdha Bharati Choudhury and Satya Deo, *Strong independence and it's consequences in convex sets* (in preparation).

Seshadri Chintapalli

Research Summary:

Let X be an abelian variety of dimension g over complex numbers and let E be χ-semistable vector bundles of rank r on X with $c_i(E) = 0$ for $1 \leq i \leq g$. Suppose $Y := P(E)$ is the associated projective bundle with projection morphism $\pi : Y \to X$. Let $\mathcal{O}_Y(1)$ be the tautological line bundle of Y. We proved an analogues of Pareschi's theorem (or Lazarsfeld's conjecture) on abelian varieties, extended to projective bundles over an abelian variety. For smooth curves C, the Jacobian $J(C)$ of line bundles of degree zero on C, is an abelian variety. So by Perschi theorem, we know that for any ample line bundle L on $J(C)$, L^{p+3} is satisfies N_p property for $p \geq 0$ on $J(C)$. Suppose C is nodal curve with finite number of nodes, and $p : C' \to C$ is the normalization map. The variety $J^d(C)$ has a natural compactification $\bar{J}^d(C)$, as the variety of torsion free rank one sheaves on C of degree d. Let $h : \tilde{J}^d(C) \to \bar{J}^d(C)$ be the desingularization. In fact $\tilde{J}^d(C)$ is a P^1-bundle over $J^d(C')$. Bhosle and Parameswaran have defined the theta divisor $\tilde{\Theta}$ on $\tilde{J}^d(C)$ an analogue of theta divisor Θ on Jacobians of smooth curves. Linear series have not been investigated on these varieties. As a first step in this direction, we prove the questions of higher jet ampleness of theta divisor on $\tilde{J}^d(C)$.

Preprints:

1. S. Chintapalli, *On Syzygies of Projective bundles over Abelian varieties*, (working on referee remarks).
2. S. Chintapalli and A.J. Parameswaran, *k-jet spannedness on desingularization of Generalized Jacobians* (Submitted).
3. S. Chintapalli, K. Hanumanthu and A.J. Parameswaran, *Syzygies on desingularization of Generalized Jacobians* (in preparation).
4. S. Chintapalli and S. K. Singh, *Vector bundles on Hyperelliptic verieties* (in prep.).

Conference/Workshops Attended:

1. *Conference on commutative algebra and algebraic geometry (CAAG)*, at IISER Pune India, December, 2017.

Visits to other Institutes:

1. Tata Institute of Fundamental Research(TIFR), Mumbai, India, December 2017
2. ANR College, Gudivada, India, January 2018.

Invited Lectures/Seminars:

1. *Hilbert Nullstellensatz*, guest talk, ANR College, Gudivada, India, January 2018.

Academic recognition/Awards:

- Inspire Faculty Award, 2018

Azizul Haque

Research Summary:

Class numbers of number fields is one of the basic and fascinating objects in algebaric number theory. Most of the informations of this object are not available e.g. how it to be explicitly calculated or arithmetic natures like divisibility or non-divisibility etc. In a joint work with K. Chakraborty, Y. Kishi and P. P. Pandey, we have constructed a family of infinitely many imaginary quadratic number fields with class number divisible by a given positive integer. This result in particular generalizes earlier works done by many authors including M. Ram Murty, K. Soundararajan, Y. Kishi and T. Nagell among others. We have removed all most all the conditions which were needed to prove the earlier results. In a joint work with K. Chakraborty, we have obtained some parametric and infinite families of real as well as imaginary quadratic fields each with class number divisible by a given positive integer. We have also studied the 3-rank of a simple family of imaginary quadratic fields using the reflection theorem due to A. Scholz, which relates the 3-rank of a real quadratic field and that of a imaginary quadratic field. In another joint work with K. Chakraborty, we have obtained some interesting results on the solvability of certain Pell-type equations, and these results are used to discuss the class numbers of maximal real subfields of certain cyclotomic fields. We are working towards non-divisibility results as only few results are available in this direction. There are well known conjectures and questions in the cyclotomic number fields set up, and we are working towards getting information towards this direction too.

The Selberg type divisor problem pertains to the study on the coefficients of complex powers of zeta-functions. The main objective of Selberg was to apply the results to the problems related to the prime number theorem. However, the complex powers turn out to be of independent interest and have applications in studying the mean values of zeta and other L-functions. In a work jointly with K. Chakraborty, S. Kanemitsu and A. Laurinčikas, we have considered the zeta-function (á la Hecke) associated to the normalised cusp forms for the full modular group and studied the sumatory functions of complex powers in the form of Dirichlet convolution of the coefficients of such zeta-functions. Our approach has a merit of attaining both, the result on the sumatory function as well as a result entailing the classical result on integers without small prime factors.

In a joint work with S. Banerjee and K. Chakraborty, we find an expression for the product of two Dedekind zeta functions attached to quadratic fields which generalizes a well known formula due to J. R. Wilton for classical Riemann zeta functions. We have used this expression to find closed form expressions for Dedekind zeta values attached to arbitrary real as well as imaginary quadratic number fields at any positive integer.

Publications:

1. Kalyan Chakraborty, Azizul Hoque, Yasuhiro Kishi and Prem Prakash Pandey, *Divisibility of the class numbers of imaginary quadratic fields*, Journal of Number Theory, **185**, 339–348, 2017.

2. Kalyan Chakraborty and Azizul Hoque, *Divisibility of class numbers of certain fam-*

ilies of quadratic fields, Journal of the Ramanujan Mathematical Society, 2018 (to appear).

3. Kalyan Chakraborty and Azizul Hoque, *Class groups of imaginary quadratic fields of 3-rank at least 2*, Annales Universitatis Scientiarum Budapestinensis de Rolando Eötvös Nominatae: Sectio Computatorica, (to appear in a special issue in honor of the 80-th birthday of Prof. Zoltán Daróczy and Imre Kátai, the 75-th birthday of Prof. Karl-Heinz Indlekofer, the 70-th birthday of Prof. Jean-Marie De Koninck and Gyula Maksa), 2018.

4. Kalyan Chakraborty and Azizul Hoque, *Pell-type equations and class number of the maximal real subfield of a cyclotomic field*, The Ramanujan Journal, 2017, Doi: 10.1007/s11139-017-9963-9.

5. Kalyan Chakraborty and Azizul Hoque, *Quadratic reciprocity and some "non-differentiable" functions*, Advances in real and complex analysis with applications, 145–181, Trends in Mathematics, Birkhäuser/Springer, Singapore, 2017.

Preprints:

1. Kalyan Chakraborty and Azizul Hoque, *Exponents of class groups of certain imaginary quadratic fields*, (communicated), arXiv:1801.00392v1.

2. Soumyarup Banerjee, Kalyan Chakraborty and Azizul Hoque, *An analogue of Wilton's formula and values of Dedekind zeta functions*, (communicated), arXiv:1611.08693.

3. Kalyan Chakraborty and Azizul Hoque, *On the plus parts of the class numbers of cyclotomic fields*, (communicated).

4. Kalyan Chakraborty, Azizul Hoque, Shigeru Kanemitsu and Antanas Laurinčikas, *Complex powers of L-functions and integers without small prime factors*, (communicated).

5. Azizul Hoque and Helen K. Saikia, *Divisibility of class numbers of quadratic fields whose discriminant has exactly n-prime factors*, (in preparation).

Conference/Workshops Attended:

1. *AIS Class Field Theory*, India, May, 2017.

2. *The Tenth International Conference on Science and Mathematics Education in Developing Countries*, Myanmar, November, 2017.

3. *International Conference on Special Functions and Applications (ICSFA-2017)*, India, November, 2017.

Visits to other Institutes:

1. Hong Kong University, Hong Kong, April, 2017.
2. Gauhati University, Guwahati, India, September, 2017.
3. Mahidol University, Bangkok, Thailand, November, 2017.
4. University of Mandalay, Myanmar, November, 2017.

Invited Lectures/Seminars:

1. *On the class numbers of imaginary quadratic fields*, International Conference on Special Functions and Applications (ICSFA-2017), College of Engineering and Technology, Bikaner, November, 2017.
2. *An analogue of Wilton's formula and some applications*, The Tenth International Conference on Science and Mathematics Education in Developing Countries, Mandalay University, Mandalay, Myanmar, November, 2017.
3. *On class groups of quadratic fields*, Colloquium, Mahidol University, Bangkok, Thailand, 13, 2017.

Other Activities:

1. Organized *International Conference on Class Groups of Number Fields and Related Topics-2017* with Prof. Kalyan Chakraborty and Dr. Prem Prakash Pandey, September, 2017.

Seema Kushwaha

Research Summary:

In the continuation of my PhD work, I have generalized the results obtained in my PhD-thesis. A family of subgraphs of the Farey graph, denoted as $\mathcal{F}_N$, where N is a natural number, have been studied. We have introduced a class of continued fractions referred to as $\mathcal{F}_N$-continued fractions for each $N > 1$. We establish a relation between $\mathcal{F}_N$-continued fractions and certain paths from infinity in $\mathcal{F}_N$. We discuss existence and uniqueness of $\mathcal{F}_N$-continued fraction expansions of real numbers with maximum $+1$, and show that their convergents are best approximations of the numbers by vertices of $\mathcal{F}_N$.

Further, we have obtained the $\mathcal{F}_{1,2}$-continued fraction expansion of $e^{1/S}$, where S is a positive integer.

Preprints:

1. Seema Kushwaha and Ritumoni Sarma, *Farey-subgraphs and Continued Fractions*, (communicated).

2. Seema Kushwaha, *The $\mathcal{F}_{1,2}$-Continued Fraction Expansion of $e^{1/S}$*, (communicated).

Conference/Workshops Attended:

1. *Annual Conference of IWM*, India, July, 2017.

2. *International Conference on Class Groups of Number Fields and Related Topics*, India, September, 2017.

3. *83rd Annual Conference of IMS*, India, December 2017.

Raj Kumar Mistri

Research Summary:

Throughout the academic year 2017-2018, I have been working on some problems in Additive Number Theory. A brief description of the research works is presented below.

Let A be a nonempty finite subset of an additive abelian group G. Define $A + A := \{a + b : a, b \in A\}$, $A - A := \{a - b : a, b \in A\}$ and $A \dot{+} A := \{a + b : a, b \in A \text{ and } a \neq b\}$. The set A is called a *sum-dominant (SD) set* if $|A+A| > |A-A|$, and it is called a *restricted sum-domonant (RSD) set* if $|A \dot{+} A| > |A - A|$. In a joint work with Prof.R. Thangadurai, we proved that for infinitely many positive integers k, there are infinitely many RSD sets of integers of cardinality k. We also provided an explicit construction of infinite sequence of RSD sets of integers.

Let $A \subseteq \mathbb{Z}$ and $B \subseteq \mathbb{Z}$ be nonempty finite sets and let r be a nonzero integer. The sum of dilates of A and B is defined as $A + r \cdot B := \{a + rb : a \in A \text{ and } b \in B\}$. Finding nontrivial lower bound for the cardinality of sum of dilates is an important problem in additive combinatorics. In case of $A = B$, a recent result of Freiman et al. states that if $r \geq 3$, then $|A + r \cdot A| \geq 4|A| - 4$. We generalized this result for the sum of dilates $A + r \cdot B$ for two nonempty finite sets A and B of integers, where r is an integer with $|r| \geq 3$. We proved that $|A + r \cdot B| \geq 4|A| - 4$, where the sets A and B satisfy certain conditions.

I have been working on some other related problems also. The work is in progress.

Publications:

1. Raj Kumar Mistri, *Sum of dilates of two sets,* Notes Number Theory Discrete Math. **23(4)**, 34-41, (2017).

Preprints:

1. Raj Kumar Mistri and R. Thangadurai, *Restricted-sum-dominant sets,* arXiv:1712.09226v1, 7 pp., (2017).

Conference/Workshops Attended:

1. *International Conference on Class Groups of Number Fields and Related Topics (ICCGNFRT)- 2017, HRI Allahabad*, India, September, 2017.

Other Activities:

1. Delivered a talk on *Sum of Dilates of Two Sets,* International Conference on Special Functions & Applications (ICSFA-2017), XVIth Annual Conference of Society for Special Functions and their Applications, Department of Mathematics, College of Engineering and Technology, Bikaner, Rajsthan, India, November, 2017.

Saudamini Nayak

Research Summary:

Classification of algebraic objects is one of the central goal of mathematical research. As for Lie algebras all the semi simple finite dimensional Lie algebras has been classified completely due to Killing and Cartan. But the classification of finite dimensional nilpotent Lie algebras is still an unsolved problem due to its abundance nature. So as a result various mathematicians try to classify nilpotent Lie algebras satisfying certain conditions. Further there is a close connection between classifications of finite p-groups and finite dimensional nilpotent Lie algebras. Finite dimensional semisimlpe Lie superalgebras has been classified, but a complete classification of nilpotent Lie superalgebras is still an open and unsolved problem.

Using the concept of isoclinism, we give the structure of all covers of Lie superalgebras when their Schur multipliers are finite dimensional. Further it has been shown that, each stem extension of a finite dimensional Lie superalgebra is a homomorphic image of a stem cover for it and as a corollary it is concluded that maximal stem extensions of Lie superalgebras are precisely same as the stem covers. Moreover, we have defined stem Lie superalgebra and show that a Lie superalgebra with finite dimensional derived subalgebra and finitely generated central factor is isoclinic to a finite dimensional Lie superalgebra.

Further it is shown that for finite dimensional Lie superalgebras of same dimension, the notation of isoclinism and isomorphism are equivalent. Furthermore we show that covers of finite dimensional Lie superalgebras are isomorphic using isoclinism concept.

Publications:

1. Saudamini Nayak, *Multipliers of nilpotent Lie superalgebras,* accepted for publication in Comm. Algebra, (2018).

Preprints:

1. Saudamini Nayak, *Isoclinism in Lie superalgebras,* https://arxiv.org/abs/1804.10434 .
2. Saudamini Nayak, Rudra Narayan Padhan, K.C. Pati *Some properties of isoclinism in Lie superalgebras,* Communicated.
3. Saudamini Nayak, *Characterization of nilpotent Lie superalgebras,* under preparation.
4. Saudamini Nayak, *On nilpotent n-Lie algebra of small breadth,* under prepartion.

Conference/Workshops Attended:

1. *IWM Annual Conference*, IISc, Bangalore, India, July 13-15, 2017.
2. *NCM workshop on Schubert Variety*, IMSC, Chennai, India, Oct 23 - Nov 04, 2017.

3. *IMS Annual Conference* SV University, Tirupati, India, Dec 12- Dec 15, 2017.

Visits to other Institutes:

1. Institute of Mathematics and Applications, Bhubaneswar, India from Oct 13- 20, 2017.

2. Institute of Mathematical Sciences, Chennai, India from Nov 05-12, 2017.

Invited Lectures/Seminars:

1. *Multipliers on nilpotent Lie algebras*, IWM Annual conference, IISc. Banglore, July, 2017.

2. *Two lectures on canonical form*, IMA seminar, IMA, Bhubaneswar, Oct, 2017.

3. *Characterization of nilpotent Lie superalgebras*, IMS Annual conference, SV University, Tirupati, Dec, 2017.

4. *Characterization of nilpotent Lie superalgebras*, IMS Annual conference, SV University, Tirupati, Dec, 2017.

5. *Isoclinism in Lie superalgebras*, HRI seminar, HRI Allahabad, March, 2018.

Shubhankar Podder

Research Summary:

Motivated by the theory of weighted shifts on directed trees and its multivariable counterpart, we address the question of identifying commutant and reflexivity of the multiplication d-tuple $\mathcal{M}_z$ on a reproducing kernel Hilbert space $\mathcal{H}$ of E-valued holomorphic functions on Ω, where E is a separable Hilbert space and Ω is a bounded domain in $\mathbb{C}^d$ admitting bounded approximation by polynomials. In case E is a finite dimensional cyclic subspace for $\mathcal{M}_z$, under some natural conditions on the $B(E)$-valued kernel associated with $\mathcal{H}$, the commutant of $\mathcal{M}_z$ is shown to be the algebra $H^\infty_{B(E)}(\Omega)$ of bounded holomorphic $B(E)$-valued functions on Ω, provided $\mathcal{M}_z$ satisfies the matrix-valued von Neumann's inequality. This generalizes a classical result of Shields and Wallen (the case of $\dim E = 1$ and $d = 1$). As an application, we determine the commutant of a Bergman shift on a leafless, locally finite, rooted directed tree $\mathcal{T}$ of finite branching index. As the second main result of this paper, we show that a multiplication d-tuple $\mathcal{M}_z$ on $\mathcal{H}$ satisfying the von Neumann's inequality is reflexive. It also provides several new classes of examples as well as recovers special cases of various known results in one and several variables. We also exhibit a family of tridiagonal $B(\mathbb{C}^2)$-valued kernels for which the associated multiplication operators $\mathcal{M}_z$ are non-hyponormal reflexive operators with commutants equal to $H^\infty_{B(\mathbb{C}^2)}(\mathbb{D})$.

Preprints:

- Sameer Chaven, Shubhankar Podder and Shailesh Trivedi, *Commutants and Reflexivity of Multiplication tuples on Vector-valued Reproducing Kernel Hilbert Spaces*, arXiv:1710.03485.

Conference/Workshops Attended:

1. *Conference on Spectral Theory and Applications (STA2017)*, Poland, May, 2017.
2. *Conference on Functional Analysis @IIT Bombay - 2017*, India, October, 2017.

Visits to other Institutes:

- IIT Kanpur, India, August 14 - September 15, 2017.
- IIT Kanpur, India, February 21 - February 25, 2018.

Academic recognition/Awards:

- Dr. D. S. Kothari Postdoctoral Fellowship, 2017.

Biswajit Ransingh

Research Summary:

We propose the notion of cluster superalgebras which is a supersymmetric version of the classical cluster algebras introduced by Fomin and Zelevinsky. We show that the symplectic-orthogonal supergroup $SpO(2|1)$admits a cluster superalgebra structure and as a consequence of this, we deduce that the supercommutative superalgebra generated by all the entries of a superfrieze is a cluster superalgebra. We also show that the coordinate superalgebra of the super Grassmannian $G(2|0;4|1)$ of chiral conformal superspace (that is, $(2|0)$ planes inside the superspace $C(4|1)$ is a quotient of a cluster superalgebra.

As part of his classification of regular semisimple subalgebras of semisimple Lie algebras, Dynkin introduced and studied the notion of π-systems. These precisely form the simple systems of such subalalgebras. We undertake a systematic study of π-systems of symmetrizable Kac-Moody algebras, first studied by Morita and Naito. We generalize Moritas definition of π- systems and establish their fundamental properties. We study the orbits of the Weyl group action on π-systems, showing that for many -systems of interest in physics, the action is transitive. For hyperbolic Kac-Moody algebras, we formulate general principles for constructing π-systems and criteria for the non-existence of π-systems of certain types, and use this to determine the set of maximal hyperbolic diagrams in ranks 3-10 relative to the partial order of admitting a π-system.

Preprints:

1. Lisa Carbone, K. N. Raghavan, Biswajit Ransingh, Krishanu Roy, And Sankaran Viswanath, *π- system of symmetrizable Kac-Moody algebras* , (in preparation).

2. Li Li, James Mixco,Biswajit Ransingh, And Ashish K. Srivastava, *An approach towards supersymmetric cluster algebras,* arXiv:1708.03851.

Conference/Workshops Attended:

1. *Group Representation and applications*, MSRI, Berkeley, California, USA, 5-9 February 2018.

2. *Sage Days 88*, University of Minnesota, USA, 21-25 August 2017.

Bipul Saurabh

Research Summary:

Local index formula given by Connes and Moscovici plays a central role in noncommutative geometry which makes its computation very important. But so far, there have not been many instances of such computations. We took up the cases of quantum double suspension of 2-sphere and noncommutative 2-torus and computed explicitly all the multilinear functionals involved in the local index formula. This is a joint work with Prof. Partha Sarathi Chakraborty. The other problem I have looked at is the computation of some dimensional invariants associated with a noncommutative space or the underlying Hopf algebra. Employing ideas of noncommutative geometry, certain dimensional invariant, namely, spectral dimension, for quantum homogeneous spaces has been proposed by Chakraborty and Pal. They conjectured that the spectral dimension of a homogeneous space of a compact Lie group is same as its dimension as a differentiable manifold. To support the conjecture, they have only these one instances namely, of SU(2). We computed spectral dimension for some homogeneous spaces of all classical simple simply connected compact Lie groups and showed the conjecture. Another notion of dimension related to the growth of an algebra and its modules is Gelfand-Kirillov dimension. There is a canonical Hopf *-algebra associated with a compact quantum group which is called the algebra of regular functions on the quantum group. The question is; is Gelfand-Kirillov dimension of these algebras and its simple modules related to a classically known quantity? For q-deformation of simple simply connected compact Lie group of type A, C, and D, we gave an answer in affirmative. We showed that Gelfand-Kirillov dimension of all simple unitarizable module over the algebra of regular functions is the length of the Weyl element associated with the module. Moreover, we proved that in the case of algebra, this notion of dimension matches with the manifold dimension of the associated compact Lie group. This is a joint work with Prof. Partha Sarathi Chakraborty.

Publications:

1. Partha Sarathi Chakraborty and Bipul Saurabh, *Local index formula for the quantum double suspension,* Integral Equations and Operator Theory, **90:21**, (2018).

2. Bipul Saurabh, *Spectral dimension of quaternion spheres,* Archiv der Mathematik, 1-9, (2018).

Preprints:

1. Partha Sarathi Chakraborty and Bipul Saurabh, *Gelfand-Kirillov dimension of some simple unitarizable modules,* arXiv:1709.08586.

2. Partha Sarathi Chakraborty and Bipul Saurabh, *Gelfand-Kirillov dimension of the algebra of regular functions on quantum groups,* arXiv:1709.09540.

3. Bipul Saurabh, *Spectral dimension of spheres,* arXiv:1803.09407.

Conference/Workshops Attended:

1. *Conference on Quantum Groups and Noncommutative Geometry*, India, January, 2018.
2. *NCM Workshop on Operator Algebra*, India, September, 2017.

Invited Lectures/Seminars:

1. *Topological invariance of quantum quaternion spheres*, Conference on Quantum Groups and Noncommutative Geometry, National Institute of Science Education and Research (NISER), Bhubaneshwar, January, 2018.

Academic recognition/Awards:

- National Post-Doctoral fellowship (SERB), 2017.

Academic Report - Physics

Anirban Basu

Research Summary:

My research has focused on calculating one loop amplitudes in superstring theory. This amounts to obtaining eigenvalue equations satisfied by modular graph functions, which arise as the integrand at every order in the derivative expansion of the string amplitude. I showed that up to a certain order in the derivative expansion of the five graviton amplitude in type IIB string theory, such graphs involving derivatives of Green functions as their links can be expressed in terms of graphs without derivatives, using appropriate auxiliary diagrams. This leads to a simplification in the structure of the amplitude.

I analyzed modular graphs for the one loop four graviton and the two graviton, two gluon amplitudes in heterotic string theory. The analysis is considerably more involved compared to that for the type II theory, given the reduced supersymmetry. The calculation amalgamates techniques used in the type II theory and the elliptic genus in the heterotic theory. Some heterotic modular graphs require regularization, which was performed using the asymptotic expansion around the cusp along with modular covariance of the graphs.

I also showed that certain modular graphs that contribute to the integrand of a term with specific spacetime structure at one loop in heterotic string theory do not require regularization. This is unlike the graphs that contribute to the integrands of the other gravitational terms at this order in the derivative expansion. This property persists for an infinite number of terms in the effective action.

Finally, I considered the contributions to certain terms in the derivative expansion of the two loop four graviton amplitude in maximal supergravity that arise in the field theory limit of genus two modular graph functions that result from the derivative expansion of the four graviton amplitude in toroidally compactified type II string theory, using the worldline formalism of the first quantized superparticle.

Publications:

1. Anirban Basu, *Simplifying the one loop five graviton amplitude in type IIB string theory,* Int.J.Mod.Phys. **A32, no. 14**, 1750074, (2017).

2. Anirban Basu, *Low momentum expansion of one loop amplitudes in heterotic string theory,* JHEP **1711**, 139, (2017).

3. Anirban Basu, *A simplifying feature of the heterotic one loop four graviton amplitude,* Phys.Lett.B **776**, 182, (2018).

Preprints:

1. Anirban Basu, *Supergravity limit of genus two modular graph functions in the worldline formalism,* 1803.08329 .

Other Activities:

1. Taught the Quantum Field Theory-I course, Aug-Dec, 2017.

Sandhya Choubey

Research Summary:

The Standard Model (SM) is inadequate to explain the origin of tiny neutrino masses, the dark matter (DM) relic abundance and also the baryon asymmetry of the Universe. We have worked to address all the three puzzles. In arXiv:1704.00819 we extended the SM by a local U(1)$_{B?L}$ gauge symmetry, three right-handed (RH) neutrinos for the cancellation of gauge anomalies and two complex scalars having nonzero U(1)$_{B?L}$ charges. All the newly added particles become massive after the breaking of U(1)B?L symmetry by the vacuum expectation value (VEV) of one of the scalar fields. The other scalar field, which does not have any VEV, becomes automatically stable and can be a viable DM candidate. Neutrino masses are generated using Type-I seesaw mechanism while the required lepton asymmetry to reproduce the observed baryon asymmetry, can be attained from the CP violating out of equilibrium decays of RH neutrinos in TeV scale. Within this framework we studied in detail the production of DM via freeze-in mechanism considering all possible annihilation and decay processes. Finally, we found a situation when DM is dominantly produced from the annihilation of RH neutrinos, which are at the same time also responsible for neutrino mass generation and resonant leptogenesis.

In another work (arXiv:1711.00553) we explained the existence of neutrino masses and their flavor structure, dark matter relic abundance and the observed 3.5 keV X-ray line within the framework of a gauged U(1)$_{L_\mu - L_\tau}$ extension of the "scotogenic" model. In the U(1)$_{L_\mu - L_\tau}$ symmetric limit, two of the the RH neutrinos are degenerate in mass, while the third is heavier. When the U(1)$_{L_\mu - L_\tau}$ symmetry is broken spontaneously, it breaks the $\mu - \tau$ symmetry in the light neutrino sector. This also results in mild splitting of the two degenerate RH neutrinos, with their mass difference given in terms of the U(1)$_{L_\mu - L_\tau}$ breaking parameter. Finally, we get a massive $Z_{\mu\tau}$ gauge boson. Due to the added Z_2 symmetry under which the RH neutrinos and the inert doublet are odd, the canonical Type-I seesaw is forbidden and the tiny neutrino masses are generated radiatively at one loop. The same Z_2 symmetry also ensures that the lightest RH neutrino is stable and the other two can only decay into the lightest one. This makes the two nearly-degenerate lighter neutrinos a two-component dark matter, which in our model are produced by the freeze-in mechanism via the decay of the $Z_{\mu\tau}$ gauge boson in the early universe. We showed that the next-to-lightest RH neutrino has a very long lifetime and decays into the lightest one at the present epoch explaining the observed 3.5 keV line.

In arXiv:1711.08888 we studied a singlet-triplet fermionic dark matter and its collider phenomenology. It is well known that for the pure standard model triplet fermionic WIMP-type dark matter (DM), the relic density is satisfied around 2 TeV. For such a heavy mass particle, the production cross-section at 13 TeV run of LHC will be very small. Extending the model further with a singlet fermion and a triplet scalar, DM relic density can be satisfied for even much lower masses. The lower mass DM can be copiously produced at LHC and hence the model can be tested at collider. For the present model we have studied the multi jet + missing energy signal and show that this can be detected in the near future of the LHC 13 TeV run. We also showed that our model is testable by the earth based DM direct detection experiments like Xenon-1T

and in future by Darwin.

In arXiv:1705.05820 and arXiv:1709.10376 we studied the impact of invisible decay of neutrinos in the context of the Deep Underground Neutrino Experiment (DUNE) and atmospheric neutrino experiment at India-based Neutrino Observatory (INO), respectively. We assume that the third neutrino mass eigenstate is unstable and decays to a light sterile neutrino and a scalar or a pseudo-scalar. We obtain the bounds on the rest frame life time τ_3 normalized to the mass m_3. We also study the correlation between a non-zero τ_3 and standard oscillation parameters and find an interesting correlation between neutrino decay and the mixing angle θ_{23}. This alters the octant sensitvity, favorably (unfavorably) for true θ_{23} in the lower (higher) octant. The effect of a decaying neutrino does not alter the hierarchy or CP discovery sensitivity of DUNE in any discernible way.

In arXiv:1704.07269 we evaluated the impact of sterile neutrino oscillations in the so-called 3+1 scenario on the proposed long baseline experiment in USA and Japan. There are two proposals for the Japan experiment which are called T2HK and T2HKK. We showed the impact of sterile neutrino oscillation parameters on the expected sensitivity of T2HK and T2HKK to mass hierarchy, CP violation and octant of θ_{23} and compared it against that expected in the case of standard oscillations. We added the expected ten years data from DUNE and presented the combined expected sensitivity of T2HKK+DUNE to the oscillation parameters. In arXiv:1711.07464 we did the complementary study where we showed that while the CP phases associated with the sterile neutrino cannot be measured in the dedicated short-baseline experiments being built to test the sterile neutrino hypothesis, these phases can be measured in long-baseline experiments. In this paper we showed for the first time how well the sterile neutrino phase can be measured by the next-generation long-baseline experiments DUNE, T2HK (and T2HKK). We also showed the expected precision with which this sterile phase can be measured by combining the DUNE data with data from T2HK or T2HKK. We also presented the sensitivity of these experiments to the sterile mixing angles, both by themselves, as well as when DUNE is combined with T2HK or T2HKK.

The annihilation of WIMP dark matter in the centre of the sun could give rise to neutrino fluxes. In arXiv:1711.02546 we studied the prospects of searching for these neutrinos at the upcoming Iron CALorimeter (ICAL) detector to be housed at INO. We performed ICAL simulations to obtain the detector efficiencies and resolutions in order to simulate muon events in ICAL due to neutrinos coming from annihilation of WIMP in the mass range (3?100) GeV. The atmospheric neutrinos pose a major background for these indirect detection studies and can be reduced using the fact that the signal comes only from the direction of the sun. For a given WIMP mass, we found the opening angle θ_{90} such that 90 % of the signal events are contained within this angle and used this cone-cut criteria to reduce the atmospheric neutrino background. The reduced background is then weighted by the solar exposure function at INO to obtain the final background spectrum for a given WIMP mass. We performed a χ^2 analysis and presented expected exclusion regions in the $\sigma_{SD} - M_\chi$ and $\sigma_{SI} - M_\chi$, where σ_{SD} and σ_{SI} are the WIMP-nucleon Spin-Dependent (SD) and Spin-Independent (SI) scattering cross-section, respectively.

In arXiv:1707.06587 we discussed inflation and dark matter in the inert doublet

model coupled non-minimally to gravity where the inert doublet is the inflaton and the neutral scalar part of the doublet is the dark matter candidate. We calculated the various inflationary parameters like n_s, r and P_s and then proceed to the reheating phase where the inflaton decays into the Higgs and other gauge bosons which are non-relativistic owing to high effective masses. These bosons further decay or annihilate to give relativistic fermions which are finally responsible for reheating the universe. At the end of the reheating phase, the inert doublet which was the inflaton enters into thermal equilibrium with the rest of the plasma and its neutral component later freezes out as cold dark matter with a mass of about 2 TeV

Publications:

1. A. Biswas, S. Choubey and S. Khan, *Neutrino mass, leptogenesis and FIMP dark matter in a* $\mathrm{U}(1)_{B-L}$ *model,* Eur. Phys. J. C **77**, 875, (2017), arXiv:1704.00819 [hep-ph].

2. S. Choubey, D. Dutta and D. Pramanik, *Imprints of a light Sterile Neutrino at DUNE, T2HK and T2HKK,* Phys. Rev. D **96**, 056026 (2017), arXiv:1704.07269 [hep-ph].

3. S. Choubey, S. Goswami and D. Pramanik, *A study of invisible neutrino decay at DUNE and its effects on* θ_{23} *measurement,* JHEP **1802**, 055 (2018), arXiv:1705.05820 [hep-ph].

4. S. Choubey and A. Kumar, *Inflation and Dark Matter in the Inert Doublet Model,* JHEP **1711**, 080 (2017), arXiv:1707.06587 [hep-ph].

5. S. Choubey, S. Goswami, C. Gupta, S. M. Lakshmi and T. Thakore, *Sensitivity to neutrino decay with atmospheric neutrinos at the INO-ICAL detector,* Phys. Rev. D **97**, 033005 (2018), arXiv:1709.10376 [hep-ph].

6. A. Biswas, S. Choubey, L. Covi and S. Khan, *Explaining the 3.5 keV X-ray Line in a* $L_\mu - L_\tau$ *Extension of the Inert Doublet Model,* JCAP **1802**, 002 (2018) arXiv:1711.00553 [hep-ph].

7. S. Choubey, A. Ghosh and D. Tiwari, *Prospects of Indirect Searches for Dark Matter at INO,* JCAP **1805**, 006 (2018), arXiv:1711.02546 [hep-ex].

8. S. Choubey, D. Dutta and D. Pramanik, *Measuring the Sterile Neutrino CP Phase at DUNE and T2HK,* Eur. Phys. J. C **78**, 339 (2018), arXiv:1711.07464 [hep-ph].

9. S. Choubey, S. Khan, M. Mitra and S. Mondal, *Singlet-Triplet Fermionic Dark Matter and LHC Phenomenology,* Eur. Phys. J. C **78**, 302 (2018), arXiv:1711.08888 [hep-ph].

Preprints:

1. B. Abi *et al.* [DUNE Collaboration], *The Single-Phase ProtoDUNE Technical Design Report,* arXiv:1706.07081 [physics.ins-det].

2. D. Tiwari, S. Choubey and A. Ghosh, *Prospects of Indirect searches for dark matter annihilations in the earth with ICAL@INO,* (in preparation).

3. D. Tiwari and S. Choubey, *Hunting for dark matter in the galactic center with INO,* (in preparation).

Conference/Workshops Attended:

1. *WHEPP 2017*, IISER Bhopal, India, December, 2017.

2. *NuHoRIzons 2018*, HRI Allahabad, India, February, 2018.

3. *Sangam@HRI 2018*, HRI Allahabad, India, March, 2018.

Visits to other Institutes:

1. KTH Royal Institute of Technology, Stockholm, Sweden, May-June, 2017.

2. Institute of Physics, Bhubaneswar, India, March, 2018.

Invited Lectures/Seminars:

1. *Status and prospects of Long-Baseline Neutrino Experiments*, WG talk, WHEPP 2018, IISER Bhopal, December 2017.

2. *The Oscillating Neutrino*, Colloquium, Institute of Physics, Bhubaneswar, India, March, 2018.

3. *Dark Matter: Evidence and Detection*, HEP Lecture, Institute of Physics, Bhubaneswar, India, March, 2018.

4. *Dark Matter Models*, HEP Lecture, Institute of Physics, Bhubaneswar, India, March, 2018.

Other Activities:

1. Teaching: Mathematical Methods II course at HRI

2. Journal refereeing: Refereed papers for JHEP and PRD

3. Committees: Served as the chairperson of the Internal Complaints Committee / Women's Grievances' Cell

Tapas Kumar Das

Research Summary:

I work in black hole astrophysics, analogue gravity, and dynamical systems theory.

Publications:

1. Islam, S., Shaikh, M. A., Das, T. K., Rahaman, F., & Rahaman, M., *Charged wormholes supported by 2-fluid immiscible matter particles,* Physics and Astronomy International Journal **2(1)**, 00046, (2018).

2. Datta, S., Shaikh, M. A., & Das, T., K., *Acoustic geometry obtained through the perturbation of the Bernoulli's constant,* New Astronomy **63**, 65, (2018).

3. Tarafdar, P., & Das, T. K., *Influence of matter geometry on shocked flows-I: Accretion in the Schwarzschild metric,* New Astronomy **62**, 1, (2018).

4. Tarafdar, P., & Das, T. K., International Journal of Modern Physics D **27**, Issue 3, id. 1850023-298 (2018).

5. Konar, C., Hardcastle, M. J., Croston, J., Jamrozy, Y., Hota, A., & Das, T. K., *Mode of accretion in episodic radio galaxies and the dynamics of their outer relic lobes,* Monthly Notices of the Royal Astronomical Society **To Appear,** (2018).

6. Majumder, S., Nag, S., & Das, T. K., *Low Angular Momentum Accretion of Fractal Medium onto Kerr Black Holes and the Emergence of the Acoustic Manifold,* Monthly Notices of the Royal Astronomical Society **To Appear,** (2018).

Preprints:

1. Roy, N., Singh, S., Nag, S., & Das, T. K., *Second Order Perturbative Effects on the Acoustic Geometry,* arXiv:1803.05312 [gr-qc].

2. Shaikh, M. A., & Das, T. K., *Linear stability analysis of low angular momentum accretion flow in the Kerr metric and the corresponding emergent gravity phenomena,* arXiv:1803.09896 [astro-ph.HE].

3. Shaikh, M. A., Maity, S., Nag, S., & Das, T. K., *Effective sound speed in relativistic accretion discs around Schwarzschild black holes,* arXiv:1806.04084 [astro-ph.HE].

4. Tarafdar, P., Ananda, D., Nag, S., & Das, T. K., *Effect of matter geometry on low angular momentum black hole accretion in the Kerr metric,* Monthly Notices of the Royal Astronomical Society (Submitted, Journal Manuscript Number MN-18-2145-MJ).

5. Maity, S., Shaikh, M. A., & Das, T. K., *Dynamical sound speed in relativistic accretion discs in the Kerr metric,* In preparation.

6. Shaikh, M. A., Maity, S., Tarafdar, P., & Das, T. K., *Spin-dependence of quasi-terminal values for various disc heights,* In preparation.

Visits to other Institutes:

1. S. N. Bose National Centre for Basic Sciences, Kolkata, India (several visits).
2. Sarojini Naidu College for Women, Kolkata, India (several visits).
3. St. Xavier's College, Kolkata, India (several visits).

Other Activities:

1. Have been supervising three Ph.D. students from HRI and one Ph.D. student from S. N. Bose National Centre for Basics Sciences (I am his official co-supervisor registered at Calcutta University).
2. Serving as member of external expert committee constructed for Ph.D. students from Physics Department, St. Xavier's College (Autonomous), Kolkata.
3. Serving as the referee for several international journals.

AseshKrishna Datta

Research Summary:

In a work with my graduate student we study the possibilities and the implications of a spontaneous breakdown of charge in the MSSM and in the Z3-symmetric NMSSM. The breakdown is triggered by the charged states of the Higgs doublets acquiring vacuum expectation values. In the MSSM, it is known that the presence of a charge conserving minimum for the tree-level Higgs potential precludes a deeper (global) charge-breaking minimum. We find that the inclusion of radiative correction to the potential does not alter the situation while a deeper charge-conserving minimum could arise, albeit with no major practical consequences. In the NMSSM scenario, a charge-breaking global minimum, with or without an accompanying charge-conserving deeper minimum, could appear even with the tree-level Higgs potential thanks to the presence of a charge-neutral scalar state which transforms as a singlet under the Standard Model gauge group. Use of the NMSSM Higgs potential that includes both quantum and thermal corrections and the requirement of a viable (stable or long-lived) vacuum that breaks the electroweak symmetry, along with its compatibility with the latest Higgs data, lead to nontrivial constraints on the NMSSM parameter space. *This work is now published in the Journal of High Energy Physics (JHEP).*

In another work, I am working with physicists from a different Institution on the phenomenology of the Non-Holomorphic Supersymmetric Standard Model (NHSSM) that includes its implications for the LHC. This work is in an advanced stage and is expected to be circulated soon.

In yet another work with my graduate student and a physicist from another Institution, we have been working on the possibilities of low-mass Higgs bosons of the NMSSM scenario that might have been missed in the experiments so far. We are also looking into the prospects of detecting them at the present and future runs of the LHC.

Publications:

1. Jyotiranjan Beuria, AseshKrishna Datta, Dipsikha Debnath, Konstantin T. Matchev, *LHC Collider Phenomenology of Minimal Universal Extra Dimensions*, Comput.Phys.Commun. 226 (2018) 187-205.

2. Jyotiranjan Beuria and AseshKrishna Datta, *Spontaneous breakdown of charge in the MSSM and in the NMSSM: Possibilities and Implications*, JHEP 1711 (2017) 042.

3. Jyotiranjan Beuria, Utpal Chattopadhyay, AseshKrishna Datta and Abhishek Dey, *Exploring viable vacua of the Z_3-symmetric NMSSM*, JHEP 1704 (2017) 024.

Conference/Workshops Attended:

1. *SANGAM@HRI-2018: Instructional Workshop in Particle Physics*, held at HRI, Allahabad, March, 2018.

2. *New HoRIzons VII (conference)*, held at HRI, Allahabad, February, 2018.

3. *Workshop on Machine Learning and Deep Learning in Particle Physics*, held at SINP, Kolkata in January-February, 2018.

4. *Top Quark Physics at Present and Future Collider (workshop)*, held at IISER, Kolkata in January, 2018.
5. *15th Workshop on High Energy Physics Phenomenology (WHEPP XV)*, held at IISER, Bhopal in December, 2017.
6. *25th International conference on Supersymmetry and Unification (SUSY17)*, held at TIFR, Mumbai during 11-15 December, 2017.
7. *Particle Physics and the Cosmos (workshop)*, Galileo Galilei Institute (GGI, INFN) workshop in Florence, Italy (August–October, 2017).

Visits to other Institutes:

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

Invited Lectures/Seminars:

Invited talk at *"Particle Physics and the Cosmos" Galileo Galilei Institute Workshop* held in Florence, Italy during August-October, 2017.

Academic recognition/Awards:

The following paper features in Nature's "Top articles by Altmetric score" from HRI in the window 1 April, 2017 - 31 March, 2018: "Exploring viable vacua of the Z_3-symmetric NMSSM", *JHEP 1704 (2017) 024* by J. Beuria, U.Chattopadhyay, AseshKrishna Datta and A. Dey.

Other Activities:

1. Served as one of the organisers of SANGAM@HRI-2018: Instructional Workshop in Particle Physics held at HRI, Allahabad, March, 2018.
2. Served as one of the organisers of the conference New HoRIzons VII held at HRI, Allahabad, February, 2018.
3. Served as a member of the National Organising Committee for the 15th Workshop on High Energy Physics Phenomenology (WHEPP-15) to be held at IISER, Bhopal in December, 2017.
4. Supervised one student (towards his Ph.D. thesis) who has submitted his thesis in November, 2017.
5. Serving the Doctoral Committees of several students.
6. In the panel of referees for various international journals.
7. Serving as members of the Committees for the Physics Outreach Programme, the Transport and the Monitoring of the NPS at HRI.
8. Adapting to an ever-evolving integrated environment for state-of-the-art simulation techniques aimed at present and future colliders.
9. Getting introduced to the area of "Deep Learning".

Dileep Prabhakar Jatkar

Research Summary:

I worked with K. Narayan on the ghost spin chains and entanglement of multispin states. We show that this system becomes b-c ghost system in the continuum limit. This formulation of the ghost spin system may be relevant to dS-CFT correspondence.

I worked on the SYK model with complex fermion in the presence of chemical potential (with R. Bhattacharya, S. Chakrabarti, and A. Kundu). We showed that the Lyapunov exponent does not saturate in the presence of the chemical potential. Even exponentially small chemical potential offsets the chaotic regime. We show this by computing out of time ordered correlation functions in this model.

Publications:

1. Dileep P. Jatkar, and K. Narayan , *Ghost-spin chains, entanglement and bc bc-ghost CFTs,* Phys. Rev. **D 96**, 106015, (2017).

2. Ritabrata Bhattacharya, Subhroneel Chakrabarti, Dileep P. Jatkar, and Arnab Kundu, *SYK Model, Chaos and Conserved Charge* , JHEP **1711**, 180, (2017).

Conference/Workshops Attended:

1. *ICTS at 10*, India, January 2018.

2. *Nonperturbative and Numerical Approaches to Quantum Gravity, String Theory and Holography*, India, January 2018.

Visits to other Institutes:

1. Name of the institute, place, Country, Month year,

2. Name of the institute, place, Country, Month year.

Invited Lectures/Seminars:

1. *SYK model with complex fermions*, String Seminar, Institute of Mathematical Sciences, Chennai, August 2017.

2. *SYK model with complex fermions*, Workshop at SINP, Saha Institute of Nuclear Physics, Kolkata, February 2018.

Other Activities:

1. Chair, SERB-THEP School committee, since August 2017.

2. Dean Academic, HRI, since March 2018.

Anshuman Maharana

Research Summary:

Observations using satellites in the last decade two decays have provided detailed information about the Cosmic Microwave Background (CMB). The inflationary paradigm has been highly successful in providing explanations for the structure and patterns in the CMB. Models of inflation are sensitive to the physics at the Planck scale – i.e. construction of models of inflation requires knowledge of dimension five and six operators whose computation requires input from quantum gravity. In the past year, I have been studying inflationary models in string theory. We have studied the effect of moduli particles (a type of scalar particles generically present in string models) on inflationary predictions. We have also studied the inter-relationship of this with dark matter.

Publications:

1. S. Bhattacharya, K. Dutta and A. Maharana *Constrains on Kähler Moduli Inflation from Reheating*, Phys. Rev. D, **96** (2017) no.8, 083522.

2. L. Aparicio and A. Maharana *Inflating Kähler Moduli and Primordial Magnetic Fields*, Phys.Lett. B **768** (2017) 46-51.

Preprints:

1. A. Maharana and I. Zavala *Post-inflationary Scalar Tensor Cosmology and Inflationary Parameters* , 1712.07071, (accepted in Phys. Rev. D, in press).

2. S. Bhattacharya, M. Gangopadhyay, K. Dutta and A. Maharana *Confronting Kähler moduli inflation with CMB data* 1711.04807 (accepted in Phys. Rev. D, in press).

Conference/Workshops Attended:

1. *Workshop on Post-Inflationary String Cosmology*, Italy, September 2017.

Invited Lectures/Seminars:

1. *Inflation: String Approach*, Joint Astro and Particle Physics Meeting, IISER, Pune, India, February 2018.

2. *Post-inflationary Cosmology and Inflationary Observables for String Models*, Workshop on Post-Inflationary String Cosmology, University of Bologna, Italy, September 2017.

Other Activities:

1. Instructor for Statistical Mechanics, January - May 2018.

Pinaki Majumdar

Research Summary: (Technical)

We have completed work on the following problems: (i) The phonon spectrum in the Holstein model across the polaronic crossover, using a one loop calculation on Monte Carlo generated thermal backgrounds. (ii) The metallisation of a Mott insulator by a voltage bias, using a Keldysh based consistency scheme. (iii) The dynamical properties of a finite temperature Bose liquid close to the Mott transition, and (iv) The competition and coexistence of antiferromagnetism and d-wave superconductivity in a two dimensional model.

The work in progress include (i) The non-equilibrium response of a superconductor to a large voltage bias - both in the clean and the disordered cases. (ii) Study of magnetic fluctuations and superconductivity in a doped Mott insulator. (iii) The phonon spectrum of manganite models. (iv) Developing a Langevin dynamics to study the equilibrium fluctuations and strong drive response of correlated quantum systems.

Research Summary: (Non-Technical)

We have a method that handles the equilibrium physics of correlated systems reasonably well. We are trying to generalise it to understand the fluctuation spectrum at finite temperature, and also the response to strong driving. A Langevin equation approach seems promising.

Publications:

1. Nyayabanta Swain and Pinaki Majumdar, *Mott transition and anomalous resistive state in the pyrochlore molybdates.* Europhys. Lett. 119 (2017) 17004.

2. Sanjukta Paul, Ravindra Pankaj, Sudhakar Yarlagadda, Pinaki Majumdar, and Peter B. Littlewood, *Giant magnetoelectric effect in pure manganite-manganite heterostructures* Phys. Rev. B96, 195130 (2017).

3. Dheeraj Kumar Singh and Pinaki Majumdar, *Highly anisotropic quasiparticle interference patterns in the spin-density wave state of the iron pnictides.* Phys. Rev. B96, 235111 (2017).

Preprints:

1. Arijit Dutta and Pinaki Majumdar, *Voltage bias driven resistive switching in a Mott insulator,* arXiv:1710.09811.

2. Abhishek Joshi and Pinaki Majumdar, *Thermal phases of correlated lattice boson: a classical fluctuation theory,* arXiv:1711.01572.

3. Sauri Bhattacharyya, Saurabh Pradhan, Pinaki Majumdar, *Phonon spectrum near a polaronic crossover: the impact of short range charge order and electronic pseudogap,* arXiv:1711.08749.

4. Abhishek Joshi and Pinaki Majumdar, *Thermal decoherence in a strongly correlated Bose liquid,* arXiv:1712.04433.

Invited Lectures/Seminars:

1. *Spontaneous disorder near the Mott transition on frustrated lattices.* Correlation and disorder meeting, ICTS Bangalore, May 2017.

Biswarup Mukhopadhyaya

Research Summary:

Constraints on dark matter scenarios were derived from a combined consideration of gamma-ray observation from the galactic centre as well as dwarf galaxies, and radio observations from galactic clusters. After campariosn with various kinds of statistic used in Higgs boson searches, it was concluded that the minimal supersymmetric standard model (MSSM) is a rather bad fit for all such extra-terrestrial data. (A. Kar, S. Mitra, B. Mukhopadhyaya, T. Roy Choudhury)

Certain non-supersymmetric models accommodating non-thermal dark matter candidates were studied. Various constraints, especially those coming from freeze-in, were investigated in detail. The LHC signals of such situations, consisting in not missing energy but stable charged tracks, were predicted. (A. Ghosh, T. Mondal, B. Mukhopadhyaya)

Certain extensions of the electroweak symmetry breaking sector in terms of an additional doublet can still allow the existence of very light (pseudo)scalar particles, in the mass range 40 - 60 GeV. Strategies for reconstructing the masses of these particles were developed. (E. J. Chun, S. Dwivedi, T. Mondal, B. Mukhopadhyaya)

The reach of an electron-positron collider in detecting lepton flavour-violating decays was established. (I. Chakrabarty, S. Mondal, B. Mukhopadhyaya)

Supersymmetric scenarios with compressed particle spectra require novel search strategies at the LHC. Some such strategies, in terms of newly defined observable quantities, were found for a compressed scenario with a gravitino dark matter candidate. (J. Dutta, P. Konar, S. Mondal, B. Mukhopadhyaya, S. K.Rai)

Publications:

1. A. Kar, S. Mitra, B. Mukhopadhyaya, T. Roy Choudhury *Dark matter, extra-terrestrial gamma-rays and the MSSM: a viability study,* JCAP **1802, 045, (2018)**.

2. I. Chakraborty, S. Mondal, B. Muykhopadhyaya *Lepton flavor violating Higgs boson decay at e+e— colliders,* Phys. Rev. **D96**, 115020, (2018).

3. E. J. Chun, S. Dwivedi, T. Mondal, B. Muykhopadhyaya *Reconstructing a light pseudoscalar in the Type-X Two Higgs Doublet Model,* Phys. Lett. **B774**, 20, (2017).

4. A. Ghosh, T. Mondal, B. Muykhopadhyaya *Heavy stable charged tracks as signatures of non-thermal dark matter at the LHC : a study in some non-supersymmetric scenarios ,* JHEP **1709**, 136, (2017).

5. J. Dutta, P. Konar, S. Mondal, B. Mukhopadhyaya, S. K.Rai *Search for a compressed supersymmetric spectrum with a light Gravitino,* JHEP **1709**, 026, (2017).

6. N. Chakrabarty, B. Mukhopadhyaya *High-scale validity of a two Higgs doublet scenario: predicting collider signals,* JHEP **1709**, 026, (2017).

Preprints:

1. A' Kar, S. Mitra, B. Mukhopadhyaya, T. Roy Choudhury, . *Do astrophysical data disfavour the minimal supersymmetric standard model?*, 1711.09069.

Conference/Workshops Attended:

1. *Dark Candles of the Universe*, ICTS, INDIA, June, 2017.
2. *Physics of the top quark*, IISER, Kolkata, January, 2018.
3. *AAPCOS-2018, Meghnad Saha 125 anniversary*, SINP, Kolkata, March, 2018.
4. S. N. Bose 125 anniversary programme, Kolkata, March, 2018

Visits to other Institutes:

1. Uppsala University, Sweden, April-May, 2017.
2. ICTS, Bangalore, June, 2017.
3. IISER, Kolkata, August, 2017.
4. IACS, Kolkata, June, 2017.
5. Indian Institute of Technology, Kharagpur, November, 2017.
6. IISER, Kolkata, January, 2018.

Invited Lectures/Seminars:

1. *LHC signals of some unusual dark matter scenarios*, Uppsala University (invited seminar), April, 2017.
2. *Future directions in theoretical high energy physics: bias, babbles, brouhaha (valedictory lecture)*, Dark Candles of the Universe, ICTS, Bangalore, June, 2017.
3. *From answers to questions in fundamental physics: an example*, IISER, Kolkata (colloquium) , August, 2017.
4. *The role of symmetry in physics*, Kalna Maharaja School 150 anniversary (invited talk), Kalna, August, 2017.
5. *How answers lead to questions in fundamental physics*, IIT, Kharagpur (colloquium), November, 2017.
6. *Some particle dark scenarios beyond the beaten track: constraints and terrestrial detection*, AAPCOS-2018, SINP (invited talk), Kolkata, March, 2018.
7. *Science, scientists and others*, S. N. Bose 125 anniversary, (invited lecture), Science City Auditorium, Kolkata, March, 2018.

Academic recognition/Awards:

- Fellow, Indian Academy of Sciences, Bangalore (2017-18).

Other Activities:

1. Member, National Organising Committee, SUSY-2017, Mumbai, December, 2017.
2. Organiser Sangam 2018, HRI, March, 2018.

Tribhuvan Prasad Pareek

Research Summary:

I have studies the anomalous hall effect using T-matrix formulation and its conncetuon to the toplogical liquids using the density matrix formulation. The work is under progress. Beside this for coherent spin tranposrt a simple resistor network model is devoleped and its extension to study is toplogical liquids is under progress.

Preprints:

1. Tribhuvan Prasad Pareek *A quternionic approch to study coherenet spin liquids*, (submitted for publication).

visit to other institutes

Visited CSIR New Delhi To attend the selection meeting for CSIR/SRF-RA selection committee Meeting.

Other Activities:

Being a memebr of adminstartive and graduate committee I participate and various activities. I taught Mathematical Methods 1 course to graduate students.

Arun Kumar Pati

Research Summary:

Dynamics and thermodynamics of a central spin: An exact reduced dynamical map along with its operator sum representation is derived for a central spin interacting with a thermal spin environment. The dynamics of the central spin shows high sustainability of quantum traits such as coherence and entanglement in the low-temperature regime. However, for sufficiently high temperature and when the number of bath particles approaches the thermodynamic limit, this feature vanishes and the dynamics closely mimics Markovian evolution. The properties of the long-time-averaged state and the trapped information of the initial state for the central qubit are also investigated in detail, confirming that the nonergodicity of the dynamics can be attributed to the finite temperature and finite size of the bath. It is shown that if a certain stringent resonance condition is satisfied, the long-time-averaged state retains quantum coherence, which can have far reaching technological implications in engineering quantum devices. An exact time-local master equation of the canonical form is derived. With the help of this master equation, the nonequilibrium properties of the central spin system are studied by investigating the detailed balance condition and irreversible entropy production rate. The result reveals that the central qubit thermalizes only in the limit of very high temperature and large number of bath spins

Max- relative entropy of coherence: The operational characterization of quantum coherence is the corner stone in the development of resource theory of coherence. We introduce a new coherence quantifier based on max-relative entropy. We prove that max-relative entropy of coherence is directly related to the maximum overlap with maximally coherent states under a particular class of operations, which provides an operational interpretation of max-relative entropy of coherence. Moreover, we show that, for any coherent state, there are examples of subchannel discrimination problems such that this coherent state allows for a higher probability of successfully discriminating subchannels than that of all incoherent states. This advantage of coherent states in subchannel discrimination can be exactly characterized by the max-relative entropy of coherence. By introducing suitable smooth max-relative entropy of coherence, we prove that the smooth max-relative entropy of coherence provides a lower bound of one-shot coherence cost, and the max-relative entropy of coherence is equivalent to the relative entropy of coherence in asymptotic limit. Similar to max-relative entropy of coherence, min-relative entropy of coherence has also been investigated. We show that the min-relative entropy of coherence provides an upper bound of one-shot coherence distillation, and in asymptotic limit the min-relative entropy of coherence is equivalent to the relative entropy of coherence.

Trade-off Relation for Coherence and Disturbance: Quantum measurements necessarily disturb the state of physical system. Once we perform a complete measurement, the system undergoes decoherence and loses its coherence. If there is no disturbance, the state retains all of its coherence. It is therefore natural to ask if there is trade-off between disturbance caused to a state and its coherence. We present a coherence disturbance complementarity relation using the relative entropy of coherence. For bipartite states we prove a complementarity relation between the quantum coherence, entanglement and disturbance. Similar relation also holds for quantum coherence,

quantum discord and disturbance for a bipartite state. We illustrate the trade-off between the coherence and the disturbance for single qubit state for various quantum channels

Generalized Hardy's Paradox: Here we present the most general framework for n-particle Hardy's paradoxes, which include Hardy's original one and Cereceda's extension as special cases. Remarkably, for any $n \geq 3$ we demonstrate that there always exist generalized paradoxes (with the success probability as high as $1/(2^n - 1)$ that are stronger than the previous ones in showing the conflict of quantum mechanics with local realism. An experimental proposal to observe the stronger paradox is also presented for the case of three qubits. Furthermore, from these paradoxes we can construct the most general Hardy's inequalities, which enable us to detect Bell's nonlocality for more quantum states

Monogamy of Quantum Privacy: Quantum mechanics ensures that the information stored in a quantum state is secure and the ability to send private information through a quantum channel is at least as great as the coherent information. We derive trade-off relations between quantum privacy, information gain by Eve and the disturbance caused by Eve to the quantum state that is being sent through a noisy channel. For tripartite quantum states, we show that monogamy of privacy exists in the case of a single sender and multiple receivers. When Alice prepares a tripartite entangled state and shares it with Bob and Charlie through two different noisy quantum channels, we prove that if the minimally guaranteed quantum privacy between Alice and Bob is positive, then the privacy of information between Alice and Charlie has to be negative. Thus, quantum privacy for more than two parties respects mutual exclusiveness. Then, we prove a monogamy relation for the minimally guaranteed quantum privacy for tripartite systems. We also prove a trade-off relation between the entanglement of formation across one partition and the quantum privacy along another partition. Our results show that quantum privacy cannot be freely shared among multiple parties and can have implication in future quantum networks

Distribution of coherence in multipartite systems: The distribution of coherence in multipartite systems is one of the fundamental problems in the resource theory of coherence. To quantify the coherence in multipartite systems more precisely, we introduce new coherence measures, incoherent-quantum (IQ) coherence measures, on bipartite systems by the max- and min- relative entropies and provide the operational interpretation in certain subchannel discrimination problem. By introducing the smooth max- and min- relative entropies of incoherent-quantum (IQ) coherence on bipartite systems, we exhibit the distribution of coherence in multipartite systems: the total coherence is lower bounded by the sum of local coherence and genuine multipartite entanglement. Besides, we find the monogamy relationship for coherence on multipartite systems by incoherent-quantum (IQ) coherence measures. Thus, the IQ coherence measures introduced here truly capture the non-sharability of quantumness of coherence in multipartite context

Quantum uncertainty relation based on the mean deviation: Traditional forms of quantum uncertainty relations are invariably based on the standard deviation. This can be understood in the historical context of simultaneous development of quantum theory and mathematical statistics. Here, we present alternative forms of uncertainty relations, in both state dependent and state independent forms, based on the mean devia-

tion. We illustrate the robustness of this formulation in situations where the standard deviation based uncertainty relation is inapplicable. We apply the mean deviation based uncertainty relation to detect EPR violation in a lossy scenario for a higher inefficiency threshold than that allowed by the standard deviation based approach. We demonstrate that the mean deviation based uncertainty relation can perform equally well as the standard deviation based uncertainty relation as non-linear witness for entanglement detection

Coherence makes quantum systems 'magical': Two primary facets of quantum technological advancement that hold great promise are quantum communication and quantum computation. For quantum communication, the canonical resource is entanglement. For quantum gate implementation, the resource is 'magic' in an auxiliary system. It has already been shown that quantum coherence is the fundamental resource for the creation of entanglement. We argue on the similar spirit that quantum coherence is the fundamental resource when it comes to the creation of magic. This unifies the two strands of modern development in quantum technology under the common underpinning of existence of quantum superposition, quantified by the coherence in quantum theory. We also attempt to obtain magic monotones inspired from coherence monotones and vice versa. We further study the interplay between quantum coherence and magic in a qutrit system and that between quantum entanglement and magic in a qutrit-qubit setting

Publications:

1. D. Mondal, S. Bagchi, A. K. Pati,*Tighter Uncertainty and Reverse Uncertainty Relations*,Phys. Rev. A, **95**, 052117 (2017).

2. C. Mukhopadhyay, S. Bhattacharya, A. Misra, A. K. Pati, *Dynamics and thermodynamics of a central spin immersed in a spin bath*,Phys. Rev. A, **96**, 052125 (2017).

3. L. E. Xiao, K. U. Wang, X. Zhan, Z. Bian, J. Li, Y. Zhang, P. Xue, A. K. Pati, *Experimental test of uncertainty relations for general unitary operators*,Optics Express, **25**, 17904 (2017).

4. K. Bu, U. Singh, S. M. Fei, A. K. Pati, J. Wu, *Max- relative entropy of coherence: an operational coherence measure*,Phys. Rev. Lett., **119**, 150405 (2017).

5. S. H. Jiang, Z. P. Xu, H. Y. Su, A. K. Pati, J. L. Chen,*Generalized Hardy's Paradox*,Phys. Rev. Lett. , **120**, 050403 (2018).

Preprints:

1. G. Sharma, A. K. Pati *Complementarity Relation for Coherence and Disturbance*, arXiv:1708.03090 (2017).

2. A. K. Pati, K. Singh, M. K. Gupta *Monogamy of Quantum Privacy*, arXiv:1709.10124 (2017).

3. K. Bu, L. Li, A. K. Pati, S. M. Fei, J. Wu *Distribution of coherence in multipartite systems under entropic coherence measure*, arXiv:1710.08517 (2017).

4. C. Mukhopadhyay, A. Misra, S. Bhattacharya, A. K. Pati *Quantum speed limit constraints on a nanoscale autonomous refrigerator*, arXiv:1711.10813 (2017).

5. G. Sharma, C. Mukhopadhyay, Sk Sazim, A. K. Pati *Quantum uncertainty relation based on the mean deviation*, arXiv:1801.00994 (2018).

6. C. Mukhopadhyay, Sk Sazim, A. K. Pati *Coherence makes quantum systems 'magical'*, arXiv:1801.04807 (2018).

7. C. Mukhopadhyay, A. K. Pati, Sk Sazim *Quantifying coherence with quantum addition*, arXiv:1803.06982 (2018).

Visits to other Institutes:

1. Visited Prof. S. Ghosh at IMSc, Chennai 15th - 30th November, 2017.

2. Visited Prof. S. Ghosh at IMSc, Chennai 20th December, 2017 to 4th January, 2018.

3. Visited Dr I. Chakrabarti at IIIT, Hyderabad during Feb 4-15, 2018.

Invited Lectures/Seminars:

1. Invited speaker in National Conference on "Current Trends in Physics-II" held during 23rd-24th September, 2017 at the Department of Physics, Banaras Hindu University, Varanasi.

2. Invited speaker in a session entitled "Digital India" in the India International Science Festival (IISF), held at Chennai during 13-16 October, 2017.

3. Invited Speaker in International Conference Quantum Foundations (ICQF-17) held from 4-9 December 2017 at the National Institute of Technology in Patna, India.

4. Invited as TEDx Speaker at Jiwaji University on 28th January, 2018 at Jiwaji University, Gwalior.
Video available at youtube: https://www.youtube.com/watch?v=e8BEwpfdues

5. Invited speaker in International Symposium on New Frontiers in Quantum Correlations (ISNFQC18)– A tribute to Professor Satyendra Nath Bose on his 125th birth anniversary held at S. N. Bose National Centre for Basic Sciences, Kolkata, India during January 29th to February 2nd, 2018.

6. DST invited to make a presentation on the idea of starting of an Institute for Quantum Information, which was scheduled during 16-17 March, 2018 at Indian Institute of Technology, Bombay.

7. Invited speaker in "Quantum Physics and Emptiness in Buddhist Philosophy" held at Namgyal Institute Tibetology (NIT), Sikkim during 17 - 29 March, 2018.

8. Invited to make a presentation at Quantum Information Science and Technology (QuST) meeting held during 21-23 April, 2018 at IISER, Bhopal.

Academic Highlights:

- Quantum physics gets a reverse uncertainty relation was highlighted in August 2017 issue of NATURE ASIA.
  (https://www.natureasia.com/en/nindia/article/10.1038/nindia.2017.98).

  This is NATURE INDIA's Top 10 most read article in 2017.
  (http://blogs.nature.com/indigenus/2018/01/nature-indias-top-ten-in-2017.html)

- Conflict between quantum, classical mechanics deepens was highlighted in March 2018 issue of NATURE ASIA.
  (https://www.natureasia.com/en/nindia/article/10.1038/nindia.2018.29)

Other Activities:

1. Guided several visiting students in the area of Quantum Information.
2. Evaluated Ph.D. thesis from IISER and University of Calcutta.
3. 4 students have completed their PhD and 4 Ph.D. students are working in the area of Quantum Information.

Santosh Kumar Rai

Research Summary: (Technical)

My research has been mainly focussed on studying models beyond the Standard Model (SM) of particle physics and analysing their collider signals at the Large Hadron Collider (LHC). During last year I have proposed models on extended gauge symmetries and extended scalar sectors and studied their implications in collider experiments. I have also looked at supersymmetric scenarios with compressed mass spectrum and studied their LHC phenomenology with non-standard dark matter candidates such as the Gravitino and right-handed sneutrinos.

In a model proposed for neutrino mass generation we study the neutrinophilic Higgs sector phenomenology. The model has one additional Higgs doublet and three generations of singlet right- handed Majorana neutrinos. Light neutrino masses are generated through mixing with the heavy neutrinos via Type-I seesaw mechanism when the neutrinophilic Higgs gets a vacuum expectation value (VEV). We have explored various signal regions likely to provide a hint of such a scenario at the LHC as well as at future e^+e^- colliders. We also highlight the consequences of light neutrino mass hierarchies in collider phenomenology that can complement the findings of neutrino oscillation experiments.

In a left-right symmetric framework we proposed a model with universal seesaw mechanism for the generation of masses of all the Standard Model quarks and leptons. Heavy vector-like singlet quarks and leptons are required for generation of Standard Model-like quark and lepton masses through seesaw mechanism. A softly broken Z_2 symmetry distinguishes the lepton sector and the quark sector of the model. This leads to the presence of some lepton-specific interactions that give rise to very unique non-standard collider signatures which can be explored at the Large Hadron Collider run and also future colliders.

In continuation of our earlier work on an Abelian extension to the SM motivated by E_6 grand unified model, we studied the pair production of vector-like down-type quarks in an E_6 motivated model, where each of the produced down-type vector-like quark decays into an ordinary Standard Model light quark and a singlet scalar. Proposing that standard decay modes studied at LHC for vector-like quark searches may not be sufficient search modes, we focus on the non-standard decay of the vector-like quark and the new scalar which decays to two photons or two gluons. We analyze the signal for the vector-like quark production in the $2\gamma + \geq 2j$ channel and show how the scalar and vector-like quark masses can be determined at the LHC.

In studies involving extension of the minimal supersymmetric standard model (MSSM), we added additional right-handed singlet neutrino superfields. Besides including a mechanism for the neutrino mass, it also opens up the possibility of having the right-sneutrino as the lightest supersymmetric particle (LSP). In this work, we focus on the the viability of rather small higgsino mass parameter (μ), an important ingredient for "naturalness", in the presence of such a LSP. For simplicity, we only consider (almost) pure and compressed higgsino-like states, with very small gaugino admixture. Considering only prompt decays of the higgino-like states we discuss the importance of leptonic channels consisting of up to two leptons with large missing transverse energy to probe this scenario at the LHC. In another study we consider a

light gravitino as dark matter candidate. This opens up interesting collider signatures consisting of one or more hard photons together with multiple jets and missing transverse energy from the cascade decay in scenarios with compressed mass spectrum of the SUSY particles. We analyse and compare the discovery potential in different benchmark scenarios consisting of both compressed and uncompressed SUSY spectra, considering different levels of compression and intermediate decay modes. We find that compressed spectra upto 2.5 TeV are likely to be probed even before the high luminosity run of LHC. We propose a few kinematic variables which offer distinction between compressed and uncompressed spectra yielding similar event rates for photons + multi-jets + MET.

Research Summary: (Non-Technical)

My current area of research encompasses the study of phenomena involving elementary particles and its interactions. During last year my research has mainly focused on studying ideas of fermion mass generation, exotic vector-like quarks, heavy neutrino mass models and new dark matter candidates and its implications at hadron and lepton-lepton colliders at CERN. I worked on the above beyond standard model physics scenario signals and proposed new models and analyzed ways of discovering their signals experimentally.

Publications:

1. K. Huitu, T.J. Karkkainen, S. Mondal and Santosh Kumar Rai, *Exploring collider aspects of a neutrinophilic Higgs doublet model in multilepton channels,* Phys. Rev. D **97**, no. 3, 035026 (2018).

2. A. Chatterjee, J. Dutta and Santosh Kumar Rai, *Natural SUSY at LHC with Right-Sneutrino LSP,* JHEP **1806**, 042 (2018).

3. K. Das, T. Li, S. Nandi and Santosh Kumar Rai, *New signals for vector-like down-type quark in $U(1)$ of E_6,* Eur. Phys. J. **C78**, no. 1, 35 (2018).

4. J. Dutta, P. Konar, S. Mondal, B. Mukhopadhyaya and Santosh Kumar Rai, *Search for a compressed supersymmetric spectrum with a light Gravitino,* JHEP **1709**, 026 (2017).

Preprints:

1. A. Patra and Santosh Kumar Rai, *A Lepton-specific Universal Seesaw Model with Left-Right Symmetry,* [arXiv:1711.00627 [hep-ph]].

Conference/Workshops Attended:

1. *Sangam@HRI* : Instructional Workshop in Particle Physics, HRI, India March, 2018.

2. *Nu HoRIzons VII*, HRI, India, February 2018.

3. *Top@IISERK:* IISER, Kolkata, India, January, 2018.

4. *25^{th} International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY 17)*: TIFR. Mumbai, India, December, 2017.

Visits to other Institutes:

1. CERN, Geneva, Switzerland, September-October 2017.

Invited Lectures/Seminars:

1. *Resonant Slepton production and right sneutrino dark matter in left-right supersymmetry:* SUSY 17, TIFR. Mumbai, India, December, 2017.

Other Activities:

1. Taught courses at HRI titled *Particle Physics*, Jan-April, 2017 and *Electrodynamics*, Jan-April, 2018 .

2. Supervising Ph.d. of Mr. Kasinath Das and Ms. Juhi Dutta.

3. Member, Local Works Committee 2018.

Sumathi Rao

Research Summary: (Technical)

During the period, April 2017-March 2018, we continued our work from the previous few years on topological phases of matter.

We finished our work on the chiral edge modes of a quantum Hall system in the integer quantum Hall effect (IQHE) regime. For the filling fraction $\nu = 3$, we showed that the ordering of the edge modes switch abruptly as the edge potential is made smoother. This work has now been published and we are continuing to study other features of this effect including the details of how the mode-switching occurs and the possible neutral Goldstone mode that is created at the transition. We are also looking at possible further extensions of this work to graphene systems.

We continued our work on shining light on silicene and other spin-orbit coupled materials. We studied the new phases that occur at low frequencies. We also extended the study to bilayer graphene and bilayer spin-orbit coupled materials focussing on the interplay of Floquet Lifshitz transitions and topological transitions.

We continued our work on Weyl semimetals and showed that the oscillations that occurred when a Weyl semimetal is sandwiched between normal leads can be interpreted in terms of a momentum space interferometer.

We are continuing our work on charge pumping through a Majorana bound state (MBS) in an Aharanov-Bohm geometry. We have found that without the ring, there is no charge pumped through the ring, whereas one can have charge pumped through an Andreev bound state. On the other hand, through a MBS embedded in an Aharanov-Bohm ring, we can have charge pumped to the superconductor which gets quantized asymptotically.

We have also started working on corner states in weak pairing higher order topological insulators. These are d-dimensional topologically non-trivial insulators or superconductors with $d-2$ dimensional boundary states - corners in 2 dimensions and hinges in 3 dimensions. Our aim is to understand these in a specific model. In particular, we want to see whether features like Majorana modes in vortices, etc, happen in these higher order topological superconductors.

We are also working on obtaining the critical exponents for topological phase transitions in Floquet topological phases.

Research Summary: (Non-Technical)

We have continued to work on new phases of matter classified by topology, rather than the older paradigm of broken symmetries. In particular, we have looked for new and interesting phenomena which can be studied by shining light on different systems, and we have looked at new phenomena that happens at the physical edge of topological samples.

Publications:

1. *Introduction to abelian and non-abelian anyons*, cond-mat/1610.09260, lectures given at the SERC school on 'Topology and condensed matter physics', held in Kolkata,

Nov 23-Dec 12, 2015, edited by Somendra M. Bhattacharjee, Mahan Mj and Abhijit Bandhypadhyaya, published by Hindustan Book Agency, 2017.

2. Udit Khanna, Sumathi Rao and Arijit Kundu *Zero-pi transitions in a Josephson junction of irradiated Weyl semimetal*, Phys. Rev. **B95**, 201115 (2017).

3. Dibya Kanti Mukherjee, Sumathi Rao and Arijit Kundu *Transport through Andreev bound states in a Weyl semi-metal quantum dot*, Phys. Rev., **B96** 161408(R), 2017.

4. Udit Khanna, Ganpathy Murthy, Sumathi Rao and Yuval Gefen *Spin mode-switching at the edge of a quantum Hall system*,Phys. Rev. Lett., **119** 186804, 2017.

5. *Learning to belong as an Indian physicist*, Economic and Political Weekly, India, Vol. **52**, Issue 17, 45 (2017).

Preprints:

1. Dibya Kanti Mukherjee, Sumathi Rao and Sourin Das *Momentum space interferometry in Weyl semi-metals*, cond-mat/1710.06873.

2. Ruchi Saxena, Sumathi Rao and Arijit Kundu *Bulk-edge correspondence and new topological phases in periodically driven spin-orbit coupled materials in the low frequency limit*, cond-mat/1712.05916.

3. Priyanka Mohan and Sumathi Rao *Interplay of Floquet Lifshitz transitions and topological transitions in bilayer Dirac materials*, cond-mat/1805.04125.

4. Sourin Das, Sumathi Rao and Krashna Mohan Tripathi *Quantum charge pumping through Majorana bound states* (in preparation).

Conference/Workshops Attended:

1. Recent Trends in Condensed Matter Physics (RTCMP) , 31 October - 3rd November, 2017, Bose institute, Kolkata.

Visits to other Institutes:

1. Visit to ICTS, Bangalore, 26 June to 18 July, 2017.

2. Visit to IIT Chennai, Electrical engineering department, 19-21 July 2017.

3. Visit to IISER, Kolkata, 30 October - 1 November, 2017.

4. Recent Trends in Condensed Matter Physics (RTCMP) , 31 October - 3 November, 2017, Bose institute, Kolkata.

5. Visit to Institute of Physics, Bhubaneswar, Dec 4-9, 2017.

6. Visit to TIFR, Mumbai, for INFOSYS condensed matter seminar, Dec 16-19, 2017.

Invited Lectures/Seminars:

1. Topological phases of quantum matter, Indian Academy of Sciences, Bangalore, 30th June 2017.
2. Spin mode switching in the integer quantum Hall effect, ICTS, Bangalore,12th July 2017.
3. Abelian and non-abelian anyons, Department of Electrical Engineering, IIT Chennai, 19 July 2017.
4. Spin mode switching in the integer quantum Hall effect, IISER, Kolkata, 1st November 2017.
5. Topological phases of quantum matter, RTCMP, Kolkata, 3rd November 2017.
6. Quantum Hall effect and edge states, IOP(Bhubaneswar), 6the December 2017.
7. Spin mode switching in the integer quantum Hall effect, TIFR, Mumbai, 18th December 2017.

Academic recognition/Awards:

1. Selected as Divisional Associate Editor, Physical Review Letters, American Physical Society, 2018-2021.

Other Activities:

1. Member, Academic council, MNNIT, Allahabad.
2. Convenor, Faculty Advisory Committee, Infosys committee (HRI).
3. Member, Housing allotment committee, Women's grievance cell/Internal Complaints committee, HRI.
4. Taught Condensed matter physics 1, Aug - Dec 2017 and 1/2 of the Condensed matter physics 2 course (Jan-May 2018).

Ashoke Sen

Research Summary:

My work during April 2017 - March 2018 has been on different aspects of string theory and quantum theory of gravity.

1. Together with Alok Laddha, I gave a general proof of soft theorem to subsubleading order in generic space-time dimensions, generic theory of gravity and for generic external states.

2. With Subhroneel Chakraborty, Sitender Kashyap, Biswajit Sahoo and Mritunjay Verma, we derived multiple soft graviton theorem to subleading order in generic space-time dimensions, generic theory of gravity and for generic external states. We also tested this general formula in the special case of scattering of gravitons using CHY formula.

3. With Alok Laddha I showed how one can take the classical limit of soft theorem to derive classical formula for long-wavelength gravitational radiation in a generic scattering process.

4. I gave a proof of background independence of closed superstring field theory.

Publications:

1. A.Laddha and A.Sen, *Sub-subleading Soft Graviton Theorem in Generic Theories of Quantum Gravity*, JHEP **1710**, 065 (2017).

2. S.Chakrabarti, S.P.Kashyap, B.Sahoo, A.Sen and M.Verma, *Subleading Soft Theorem for Multiple Soft Gravitons*, JHEP **1712**, 150 (2017).

3. S.Chakrabarti, S.P.Kashyap, B.Sahoo, A.Sen and M.Verma, *Testing Subleading Multiple Soft Graviton Theorem for CHY Prescription*, JHEP **1801**, 090 (2018).

4. A.Sen, *Background Independence of Closed Superstring Field Theory*, JHEP **1802**, 155 (2018).

Preprints:

1. A.Laddha, A.Sen, *Gravity Waves from Soft Theorem in General Dimensions*, arXiv:1801.07719.

Conference/Workshops Attended:

1. Pre-strings School, Haifa, Israel, June 2017.

2. String Field Theory and Related Topics, Tel Aviv, June 2017.

3. Strings 2017, Tel Aviv, June 2017.

4. Current Themes in High Energy Physics and Cosmology, Copenhagen, August 2017.
5. National Strings Meeting, Bhubaneswar, December 2017.
6. ICTS at Ten, ICTS, Bangalore, January 2018.
7. Asian Winter School, ICTS, Bangalore, January 2018.

Other Activities:

1. Thermal Field Theory, August-October, 2017.
2. Quantum field theory, January-April, 2018.

Prasenjit Sen

Research Summary:

My research in this period focussed mainly on the following themes: two-dimensional (2D) materials, atomic clusters, and bulk oxides.

In the first theme, after establishing that the novel material $CrCTe_3$ is an antiferromagnetic insulator, we are studying effects of perpendicular electric fields on the electronic structure of such transition metal (TM) trichalcogenides. We are also exploring efficiency of a large variety of TM trichalcogenides as catalysts in hydrogen evolution reactions employing a high throughput approach.

In the second theme we studied properties of $TaSi_{16}$ clusters on a graphite surface in view of some recent experiments in literature. Our calculations produced microscopic insights into the reported experimental results.

We studied effect of hydrostatic pressure on α-MnO_2. It is found to undergo structural phase transition at a critical value of pressure.

Publications:

1. A. Singh, C. Majumder and P. Sen, *Role of size, composition and substrate in controlling the reactivity of* $\alpha - (0001)$-Al_2O_3 *supported* Ag_nAu_m $(n + m = 2 - 4)$ *alloy clusters for CO-oxidation: A comprehensive density functional study,* Appl. Surf. Sc. **33**, 756, (2018).

2. S. Chabungbam and P. Sen, *Computational design of a robust two-dimensional antiferromagnetic semiconductor,* Phys. Rev. B **96**, 045404, (2017).

3. F. R. Negreiros, A. Halder, C. Yin, A. Singh, G. Barcaro, L. Sementa, E. C. Tyo, M. J. Pellin, S. Bartling, K-H. Meiwes-Broer, S. Seifert, P. Sen, S. Nigam, C. Majumder, N. Fukui, H. Yasumatsu, S. Vajda and A. Fortunelli, *Bimetallic Ag-Pt subnanometer supported clusters as highly efficient and robust oxidation catalysts,* Ang. Chem. **DOI:10.1002/anie.201709784** .

4. A. Sen and P. Sen, *Properties of HOPG Supported* $TaSi_{16}$ *Clusters: A Density Functional Investigation,* J Phys. Chem. C **121**, 28490, (2017).

Preprints:

1. S. Bhattacharya, P. Sen, S. Mukund, S. Yarlagadda, D. Bandyopadhyay, S. G. Nakhat, *Ionization energies and structures of small lanthanum oxide clusters* $(La_2O_3)_n.LaO$ $(n = 1 - 3)$.

Conference/Workshops Attended:

1. *9th Meeting of the* Asian Consortium for Materials Science, Malaysia, August, 2017.

Invited Lectures/Seminars:

1. *Computational design of a robust anti-ferromagnetic semiconductor*, 9th Meeting of the *Asian Consortium for Materials Science*, University of Malaya, Kuala Lumpur, August 2017.

Other Activities:

1. Member of Editorial Board, Physica Scripta.
2. Taught Condensed Matter Physics 1 during August-December, 2017; half of Condensed Matter Physics 2 during Januray-February, 2018.
3. Reviewed papers for the following journals: Physical Review B, Journal of Cluster Science, etc.
4. Convener Cluster Committee, member Colloquium Committee.

Ujjwal Sen

Research Summary: (Technical)

In the last academic year, we have worked on fundamentals as well as applications of quantum information and quantum computation. In particular, we have uncovered an uncertainty relation between fluctuations of position and momentum for quantum states, where the fluctuations are quantified by using Lipschitz constants of the corresponding probability distributions. In another work, we have proposed a form of the usual Heisenberg uncertainty between the spreads of position and momentum by using the median of the distribution, resulting in an uncertainty relation that is meaningful for all quantum states. The usual uncertainty relation between spreads of position and momentum is not well-defined for all quantum states.

In another work, we propose the notion of quantum coherence for superpositions over states which are not necessarily mutually distinguishable. This anticipatedly leads to a resource theory of non-orthogonal coherence. We characterize free states and free operations in this theory, and connect the latter with free operations in the resource theory of quantum coherence for distinguishable bases. We show that the concept of non-orthogonal coherence naturally furnishes us with a wave-particle duality in quantum double-slit experiments where the channels beyond the slits are leaky between them. Furthermore, we demonstrate existence of a unique maximally coherent qubit state corresponding to any given purity. In addition, and in contradistinction with the case of distinguishable bases, there appears a non-trivial minimally coherent qubit state for a given purity. We also study the behavior of quantum coherence for some typical configurations of non-orthogonal bases which have no analogs for orthogonal bases. We further investigate the problem of determining the energy cost of creating non-orthogonal coherence, and find that it scales linearly with the non-orthogonal coherence created.

In a different work, we establish uncertainty relations between information loss in general open quantum systems and the amount of non-ergodicity of the corresponding dynamics. The relations hold for arbitrary quantum systems interacting with an arbitrary quantum environment. The elements of the uncertainty relations are quantified via distance measures on the space of quantum density matrices. The relations hold for arbitrary distance measures satisfying a set of intuitively satisfactory axioms. The relations show that as the non-ergodicity of the dynamics increases, the lower bound on information loss decreases, which validates the belief that non-ergodicity plays an important role in preserving information of quantum states undergoing lossy evolution. We also consider a model of a central qubit interacting with a fermionic thermal bath and derive its reduced dynamics, to subsequently investigate the information loss and nonergodicity in such dynamics. We comment on the minimal situations that saturate the uncertainty relations.

In another work, we investigate the behavior of entanglement in the ground state of a doped one-dimensional lattice, where the particles interact via the quantum t-J model, which can be obtained from the Hubbard Hamiltonian with large onsite interactions. For different values of the electron concentration, the rich phase diagram exhibits both polynomial and exponential decay of bipartite quantum entanglement, with increasing lattice distance. This respectively characterizes the properties of the

Luttinger liquid and the electron-hole phase separation regions of the phase diagram. Interestingly, at low electron concentration, where the spin-gap opens, the ground state turns out to be a long-ranged resonating valence bond gas. We observe that the phase diagram remains qualitatively unchanged even when additional next-nearest-neighbor spin couplings are introduced, though the phase boundaries are dependent on the relative strength between the nearest and next-nearest neighbor interactions, which the decay patterns of entanglement can capture. A key finding of the study relates to the genuine multipartite entanglement of the ground state of the model at low electron densities. We observe that for fixed values of the electron density, multipartite entanglement remains immutable under perturbative or sudden changes of system parameters, a phenomenon termed as adiabatic freezing. The phenomenon is absent in the anisotropic undoped limit of the system. It is to be noted that multipartite entanglement, in general, is sensitive to external perturbation, as observed in several systems, and hitherto, no freezing behavior has been reported.

An interesting aspect of antiferromagnetic quantum spin ladders, with complete dimer coverings, is that the wave function can be recursively generated by estimating the number of coverings in the valence bond basis, which follow the fabled Fibonacci sequence. In one of our works in the last academic year, we show that generalized forms of such sequences can also be derived for multi-legged and doped quantum spin ladders, which allows the corresponding dimer covered state to be recursively generated. This simplifies the investigation and estimation of several important quantities in these many-body quantum systems. In particular, we show that the valence bond entanglement entropy, which is a substantial figure of merit for understanding critical behavior, can be conveniently derived for large spin ladders.

Further works include those on the Benford analysis of quantum critical phenomena, response of entanglement to annealed vis-á-vis quenched disorder in quantum spin models, phase boundaries in alternating field quantum XY model with Dzyaloshinskii-Moriya interaction, deterministic quantum dense coding networks, emergence of entanglement with temperature and time in factorization-surface states, etc.

Research Summary: (Non-Technical)

Quantum information and computation is an area of research that has an interface with several other sciences, including quantum condensed matter, ultra-cold gases, quantum optics, information theory, cryptography, etc. It promises to provide quantum technologies for various tasks that are otherwise hard to perform. The members of the quantum information and computation (QIC) group at HRI works on a broad range of topics in these areas, and some of the topics covered in the previous academic year are quantum uncertainty relations, quantum thermodynamics, monogamy of entanglement, quantum resource theories, Hardy paradox, quantum channels, quantum speed limit, wave-particle duality, quantum dense coding, quantum coherence, quantum master equations, non-Markovianity, disordered quantum many-body systems, defects in spin networks, freezing of entanglement, genuine multisite entanglement, etc.

The quantum information and computation group at HRI consists of three faculty members, eight PhD students, six postdoctoral fellows, and two adjunct professors.

The group has research contacts with several other groups, both theoretical and experimental, in different institutes in India and abroad (mainly in Europe, Singapore, Canada, and the US). The group encourages students, and junior and senior scientists as visitors for short research stays from all over India and abroad, as part of their general manpower development program. Members of the group have presented invited lectures in different institutes in India and abroad to disperse the research performed by the group, as well as to forge new collaborations. The group has produced several research papers in the last academic year. The group has organised a DST meeting on Quantum Science and Technology (QuST) that chalked out the possible directions that the country should take in experimental and theoretical quantum computation, quantum cryptography, and beyond.

Publications:

1. Anindita Bera, Tamoghna Das, Debasis Sadhukhan, Sudipto Singha Roy, Aditi Sen (De), Ujjwal Sen, *Quantum discord and its allies: a review*, Reports on Prog. in Phys. **81**, 024001 (2018).

2. Saptarshi Roy, Titas Chanda, Tamoghna Das, Aditi Sen (De), Ujjwal Sen, *Determinstic Quantum Dense Coding Networks*, Phys. Lett. A **382**, 1709 (2018).

3. Anindita Bera, Utkarsh Mishra, Sudipto Singha Roy, Anindya Biswas, Aditi Sen (De), Ujjwal Sen, *Benford analysis of quantum critical phenomena: First digit provides high finite-size scaling exponent while first two and further are not much better*, Phys. Lett. A **382**, 1639 (2018).

4. Natasha Awasthi, Samyadeb Bhattacharya, Aditi Sen (De), Ujjwal Sen, *Universal quantum uncertainty relations between non-ergodicity and loss of information*, Phys. Rev. A **97**, 032103 (2018).

5. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen (De), Ujjwal Sen, *Emergence of entanglement with temperature and time in factorization-surface states*, Phys. Rev. A **97**, 012316 (2018).

6. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen (De), Ujjwal Sen, *Detecting phase boundaries of quantum spin-1/2 XXZ ladder via bipartite and multipartite entanglement transitions*, Journal of Magnetism and Magnetic Materials **444**, 227 (2017).

7. Anindita Bera, Debraj Rakshit, Aditi Sen(De), Ujjwal Sen, *Spontaneous magnetization of quantum XY spin model in joint presence of quenched and annealed disorder*, Phys. Rev. B **95**, 224441 (2017).

8. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), Ujjwal Sen, *Analytical recursive method to ascertain multisite entanglement in doped quantum spin ladders*, Phys. Rev. B **96**, 075143 (2017).

Contribution to a Book

9. Himadri Shekhar Dhar, Amit Kumar Pal, Debraj Rakshit, Aditi Sen (De), Ujjwal Sen, *Monogamy of quantum correlations - a review*, The chapter on "Lectures on General Quantum Correlations and their Applications", Part of the series Quantum Science and Technology, Springer International Publishing (2017), pp 23–64 .

Preprints:

1. Mahasweta Pandit, Anindita Bera, Aditi Sen (De), Ujjwal Sen, *Position and momentum cannot both be lazy: Quantum uncertainty relation with Lipschitz constants,* arXiv:1803.02221.

2. Saptarshi Roy, Tamoghna Das, Debmalya Das, Aditi Sen (De), Ujjwal Sen, *How efficient is transport of quantum cargo through multiple highways?,* arXiv:1802.10398.

3. Anindita Bera, Debasis Sadhukhan, Debraj Rakshit, Aditi Sen (De), Ujjwal Sen, *Response of entanglement to annealed vis--vis quenched disorder in quantum spin models,* arXiv:1712.05226.

4. Sudipto Singha Roy, Himadri Shekhar Dhar, Aditi Sen(De), Ujjwal Sen, *Fibonacci sequences and valence bond entanglement entropy in doped quantum spin ladders,* arXiv:1712.02726.

5. Saptarshi Roy, Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Aditi Sen (De), Ujjwal Sen, *Phase boundaries in alternating field quantum XY model with Dzyaloshinskii-Moriya interaction: Sustainable entanglement in dynamics,* arXiv:1710.11037.

6. Sreetama Das, Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen (De), Ujjwal Sen, *Emergence of adiabatic freezing of genuine multipartite entanglement with insertion of defects in one-dimensional Hubbard model,* arXiv:1708.07005.

7. Anindita Bera, Debmalya Das, Aditi Sen (De), Ujjwal Sen, *Quantum uncertainty relations: Engaging the median when the mean is not licit,* arXiv:1706.00720.

8. Sreetama Das, Chiranjib Mukhopadhyay, Sudipto Singha Roy, Samyadeb Bhattacharya, Aditi Sen (De), Ujjwal Sen, *Wave-particle duality employing quantum coherence in superposition with non-distinguishable pointers,* arXiv:1705.04343.

Conference/Workshops Attended:

1. *DST meeting on Quantum Science and Technology at IISc Bengaluru*, India, July 2017.

2. *DST meeting on Quantum Science and Technology at HRI Allahabad*, India, October 2017.

Visits to other Institutes:

1. Raman Research Institute, Bengaluru, India, April 2017.
2. Indian Institute of Science, Bengaluru, India, July 2017.
3. University of Hyderabad, Hyderabad, India, September 2017.
4. Indian Institute of Technology - Banaras Hindu University, Varanasi, India, November 2017.

Invited Lectures/Seminars:

1. *Quantum uncertainty relations: further landscapes*, Colloquium, Indian Institute of Technology - Banaras Hindu University, Varanasi, India, November 2017.
2. *What is entanglement?*, Jigyasa 2017, Indian Institute of Technology - Banaras Hindu University, Varanasi, India, November 2017.

Other Activities:

1. Taught a one-semester course on "Quantum Information and Computation" during Jan-May 2017.
2. Taught a one-semester course on "Quantum Mechanics II" during Jan-May 2018.
3. Guiding the theses of Sreetama Das and Chirag Srivastava of HRI.
4. Co-guide of the thesis of Anindita Bera, Calcutta University, Kolkata.
5. Served as an organizer of a DST meeting on "Quantum Science and Technology (QuST)" held at HRI in October 2017.
6. Serving as the convenor of Computer Committee, and member of Cluster Computing Committee at HRI.
7. Serving as referees in national and international journals.
8. Serving as members of the PhD committees of several students.
9. Serving as member of International Advisory Board of Journal of Physics B.
10. Serving as one of the (founding) editors of Quantum journal.
11. Guiding/guided projects and numerical projects of several students.
12. Guiding MSc project of Subhalakshmi Bhatt, IISER Pune.
13. Guided MSc project of Sreyash Garg, NIT Surat.
14. Guiding/guided project works of several students [including Jayant Jayakumar [IIT Madras], Deepanjali Halder [NISER], Varad Pande [IISER Pune], Atul Pandey [IISER Kolkata], Shobhna Singh [IISER Bhopal], Hridya M S [NIT Surat], Subhadeep De [JMI], Natasha Awasthi [GB Pant University]].

Aditi Sen De

Research Summary:

During 2017-18, we have worked on topics like quantum uncertainty relation, building quantum communication network, distribution of quantum correlations in quantum many-body systems.

We established uncertainty relations between information loss in open quantum systems and the amount of non-ergodicity of the corresponding dynamics for arbitrary quantum systems interacting with an arbitrary quantum environment. On the other hand, going beyond the traditional mean-based Heisenberg uncertainty, we proposed a quantum uncertainty relation between the semi-interquartile ranges of the position and momentum distributions of arbitrary quantum states, based on the statistical concept known as median.

The rapid development of quantum information science is largely due to discoveries of communication protocols by using entangled quantum states. Their successful realizations in physical systems like photons, ions, superconducting qubits, nuclear magnetic resonance (NMR) etc. also make the field attractive. The quantum communication protocols without security are broadly divided into two – one type of scheme deals with classical information transmission via quantum states while the other kind considers the capacity of quantum state transfer. In one of our recent works, we dealt with a classical information transmission scheme in a single-copy level, using a shared non-maximally entangled pure state, where the sender encodes the information by performing unitary operations on her part in such a way that upon receiving the entire system, the receiver can always distinguish the output states without any error, i.e., deterministically, by performing global measurements. Such a deterministic protocol for a single sender and a single receiver was introduced few years back and referred to as the deterministic dense coding (DDC) protocol. We recently addressed the question of building a DDC network between multiple senders and a single receiver – DDC network. We showed that the DDC scheme can be executed by using the generalized W states beyond the classical limit, although it is not possible by generalized Greenberger-Horne-Zeilinger (GHZ) state except the GHZ point.

In another work, instead of considering classical information transmission via quantum states, we investigated the capacity of transferring an arbitrary quantum state via shared multipartite quantum states, with the additional help of a finite amount of classical communication multipartite version of quantum teleportation. We studied such transmission protocol, when the channel, connecting the sender and the receiver, is divided into several small blocks, involving mutipartite states, both in noiseless and noisy scenarios.

Quantum many-body systems often possess highly entangled quantum states, which can be used to implement quantum information processing tasks like quantum circuits, quantum state transmission. Moreover, a number of available solid state materials, along with cold- atomic substrates, nuclear magnetic resonance and superconducting qubits mimic these quantum spin models. Consequently, it has been possible to engineer these models in a controlled way with currently available technology. However, in one dimensional quantum spin models like the XY model with uniform and alternative magnetic field, there exist zero-temperature states that are fully factorized, thereby possesing vanishing entanglement, and hence being of no use as resource in

quantum information technology. We showed in a recent work that such states can become useful in terms of generation of entanglement when the temperature of the system is increased, and when the system is allowed to evolve under either the influence of an external environment, or a closed unitary evolution driven by its own Hamiltonian due to a sudden change in the system parameters.

Publications:

1. Anindita Bera, Tamoghna Das, Debasis Sadhukhan, Sudipto Singha Roy, Aditi Sen (De), Ujjwal Sen, *Quantum discord and its allies: a review*, Reports on Prog. in Phys. **81**, 024001 (2018).

2. Saptarshi Roy, Titas Chanda, Tamoghna Das, Aditi Sen (De), Ujjwal Sen, *Determinstic Quantum Dense Coding Networks*, Phys. Lett. A **382**, 1709 (2018).

3. Anindita Bera, Utkarsh Mishra, Sudipto Singha Roy, Anindya Biswas, Aditi Sen (De), Ujjwal Sen, *Benford analysis of quantum critical phenomena: First digit provides high finite-size scaling exponent while first two and further are not much better*, Phys. Lett. A **382**, 1639 (2018).

4. Natasha Awasthi, Samyadeb Bhattacharya, Aditi Sen (De), Ujjwal Sen, *Universal quantum uncertainty relations between non-ergodicity and loss of information*, Phys. Rev. A **97**, 032103 (2018).

5. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen (De), Ujjwal Sen, *Emergence of entanglement with temperature and time in factorization-surface states*, Phys. Rev. A **97**, 012316 (2018).

6. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen (De), Ujjwal Sen, *Detecting phase boundaries of quantum spin-1/2 XXZ ladder via bipartite and multipartite entanglement transitions*, Journal of Magnetism and Magnetic Materials **444**, 227 (2017).

7. Anindita Bera, Debraj Rakshit, Aditi Sen(De), Ujjwal Sen, *Spontaneous magnetization of quantum XY spin model in joint presence of quenched and annealed disorder*, Phys. Rev. B **95**, 224441 (2017).

8. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), Ujjwal Sen, *Analytical recursive method to ascertain multisite entanglement in doped quantum spin ladders*, Phys. Rev. B **96**, 075143 (2017).

Contribution to a Book

9. Himadri Shekhar Dhar, Amit Kumar Pal, Debraj Rakshit, Aditi Sen (De), Ujjwal Sen, *Monogamy of quantum correlations - a review*, The chapter on "Lectures on General Quantum Correlations and their Applications", Part of the series Quantum Science and Technology, Springer International Publishing (2017), pp 23–64.

Preprints:

1. Mahasweta Pandit, Anindita Bera, Aditi Sen (De), Ujjwal Sen, *Position and momentum cannot both be lazy: Quantum uncertainty relation with Lipschitz constants,* arXiv:1803.02221.

2. Saptarshi Roy, Tamoghna Das, Debmalya Das, Aditi Sen (De), Ujjwal Sen, *How efficient is transport of quantum cargo through multiple highways?,* arXiv:1802.10398.

3. Anindita Bera, Debasis Sadhukhan, Debraj Rakshit, Aditi Sen (De), Ujjwal Sen, *Response of entanglement to annealed vis--vis quenched disorder in quantum spin models,* arXiv:1712.05226.

4. Sudipto Singha Roy, Himadri Shekhar Dhar, Aditi Sen(De), Ujjwal Sen, *Fibonacci sequences and valence bond entanglement entropy in doped quantum spin ladders,* arXiv:1712.02726.

5. Saptarshi Roy, Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Aditi Sen (De), Ujjwal Sen, *Phase boundaries in alternating field quantum XY model with Dzyaloshinskii-Moriya interaction: Sustainable entanglement in dynamics,* arXiv:1710.11037.

6. Sreetama Das, Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen (De), Ujjwal Sen, *Emergence of adiabatic freezing of genuine multipartite entanglement with insertion of defects in one-dimensional Hubbard model,* arXiv:1708.07005.

7. Anindita Bera, Debmalya Das, Aditi Sen (De), Ujjwal Sen, *Quantum uncertainty relations: Engaging the median when the mean is not licit,* arXiv:1706.00720.

8. Sreetama Das, Chiranjib Mukhopadhyay, Sudipto Singha Roy, Samyadeb Bhattacharya, Aditi Sen (De), Ujjwal Sen, *Wave-particle duality employing quantum coherence in superposition with non-distinguishable pointers,* arXiv:1705.04343.

Conference/Workshops Attended:

1. *National Conference on Recent Trends in Condensed Matter Physics*, India, October 2017.

2. *International Symposium on New Frontiers in Quantum Correlations (ISNFQC18)*, India, January 2018.

Visits to other Institutes:

1. Visited the group of Prof. Urbasi Sinha, RRI, India, April 2017.

2. Visited the group of Prof. Sourin Das, IISER Kolkata, March 2018

Invited Lectures/Seminars:

1. *Static and dynamical quantum correlations in phases of an alternating field XY model*, National Conference on Recent Trends in Condensed Matter Physics, Bose Institute, Kolkata, Oct 2017.

2. *Frozen quantum correlations*, International Symposium on New Frontiers in Quantum Correlations (ISNFQC18), S. N. Bose National Centre for Basic Sciences, Kolkata, Jan 2018.

3. *Frozen quantum correlations*, Department of Physics (DPS) Seminar, IISER Kolkata, Kolkata, March 2018.

Other Activities:

1. Taught a one-semester course on Quantum mechanics during Aug-Dec 2017.

2. Guiding the theses of Titas Chanda, Saptarshi Roy and Debasis Sadhukhan of HRI.

3. Guided projects of the following HRI graduate students:

   Stav Haldar, "Quantum Cryptography (Aug-Dec 2017)

   Chirag Srivastava, "Quantum Communication Network" (Aug-Dec 2017)

4. Guided project works of Master students under VSP program at HRI and Academies.

5. Serving as the convenor of the Housing Committee, and member of the physics graduate committee, Women Grievence Cell committee at HRI.

6. Joined in the Editorial board of Journal of Quantum Information Science.

7. Serving as referees in national and international journals.

8. Serving as members of the PhD committees of several PhD students at HRI.

Pratishruti Saha

Research Summary:

Project 1 - Single-top production and rare top interactions : The study of the top quark's properties is an important part of the LHC programme. In earlier work, we have studied the rare decay $t \to b\bar{b}c$, using effective operators to capture the effects of physics beyond the Standard Model. However top decay is primarily sensitive to new physics in the sub-TeV energy regime. If this new physics resides at a higher energy scale, then one needs to turn to single-top production. In this study, we use the s-channel and t-channel single- top production cross sections to constrain the new physics parameter space associated with such contact interactions. We also study the net top polarization as a means to distinguish between contributions from operators involving different fermion chiralities and Lorentz structures.

Project 2 - Understanding B-sector anomalies via top observables : Measurements of B-meson decays have revealed several departures from the Standard Model. In contrast, measurements of top-quark processes seem to adhere strictly to the Standard Model. This presents a conundrum given that the left-handed bottom and top quarks belong to the same $SU(2)$ doublet. Several models have been proposed in the literature to explain the B-sector anomalies. We confront some such models with top-sector observables to examine whether they can be tested by such measurements.

Preprints:

1. Pratishruti Saha, Ken Kiers and Alejandro Szynkman, *Single-top production and rare top interactions*, arXiv:1712.08120 [hep-ph], accepted for publication in Physical Review D.

Conference/Workshops Attended:

1. *Candles of Darkness*, India, June, 2017.
2. *Workshop on High Energy Physics Pheneomenology (WHEPP) XV*, India, December, 2017.
3. *Workshop on Top Quark Physics at Present and Future Colliders*, India, January, 2018.

Invited Lectures/Seminars:

1. *Chasing the anomalous top*, Workshop on Top Quark Physics at Present and Future Colliders, IISER Kolkata, Mohanpur, West Bengal, India, January, 2018.

Other Activities:

1. Taught the "Research Methodology and Numerical Methods" course for 1st year M.Sc. and Ph.D. students, August-December, 2017.
2. Member of organising committee and in-charge of event websites and online registration for *Nu HoRIzons VII* and *Sangam @ HRI 2018: Instructional Workshop in Particle Physics* held in HRI, February-March, 2018.

Khorsed Alam

Research Summary:

α-MnO_2 is an active catalyst for oxygen reduction and evolution reaction. Experimentally it is found to be an antiferromagnetic insulator of tetragonal hollandite lattice structure. Due to the presence of the localized 3d states of the manganese ions manganese oxides are materials with very complex electronic and magnetic properties. In our work we have been looking for optimized structure of α-MnO_2 at finite external pressure. Under huge pressure many transition metal oxides show interesting structural , electronic and magnetic transtion. α-MnO_2 has been investigated using DFT $ab-initio$ calculations with GGA exchange-correlation functional with gradually increasing external pressure. We saw interseting structural transition to take place.

Other Activities:

1. I have served as a teaching assistant of Condensed Matter Physics 1 course from August to December, 2017.

Ritabrata Bhattacharya

Research Summary:

In the Academic Year 2017-2018 I have been working on different issues related to the SYK model. My current work is related to quantum quench in SYK. In a recent paper by Sachdev et al.(PHYSICAL REVIEW B 96, 205123 (2017)) showed the effect on the spectral function and the post quench thermalization of some particular quench protocols. Since the works require numerical techniques which we carry out in Mathematica same as the authors of the above mentioned paper. Also in another work we want to calculate the six point function of the complex SYK(with complex fermions) in the deep IR as done previously for SYK(with Majorana fermions) by Gross and Rosenhaus.

Publications:

1. Ritabrata Bhattacharya, Subhroneel Chakrabarti, Dileep P. Jatkar, Arnab Kundu, *SYK model, chaos and conserved charge,* JHEP **1711**, 180, (2017).

Conference/Workshops Attended:

1. *Indian Strings Meet, India, December, 2016.*
2. *SERC school, India, January, 2017.*
3. *National Strings Meet, India, December 2017.*
4. *Kavli Asian Winter School, India, January 2018.*
5. *AdS/CFT @ 20, India, May 2018.*

Visits to other Institutes:

1. Saha Institute of Nuclear Physics, Kolkata, India, April, 2017.

Invited Lectures/Seminars:

1. Gave talk based on publication in the *National Strings Meet(NSM 2017).*

Sauri Bhattacharyya

Research Summary:

I've continued my work on collective modes in strongly correlated systems, focussing on the electron-phonon problem. Motivated by recent inelastic neutron scattering experiments on bilayer and 3d manganites, we've studied phonons in the 2d disordered Holstein-Double Exchange model. This was done using the extension of Static Path Approximation (SPA) scheme developed earlier. Detailed momentum dependence of damping for both acoustic and optical phonons are probed. We have tried to correlate the features observed with the static 'background' characteristics. Moreover, we are developing a new Langevin equation based scheme to look at both equilibrium and non-equilibrium aspects of electron-lattice physics.

Preprints:

1. Sauri Bhattacharyya, Saurabh Pradhan and Pinaki Majumdar, *Phonon spectrum near a polaronic crossover: impact of short range charge order and electronic pseudogap*, arXiv 1711.08749 .

2. Sauri Bhattacharyya, Saurabh Pradhan and Pinaki Majumdar, *Anomalous thermal broadening of optical and acoustic phonons near a polaronic transition: implications for manganites*, (in preparation).

Conference/Workshops Attended:

1. *Indian Statistical Physics Community Meeting*, India, February, 2018.

Academic recognition/Awards:

- Infosys award for distinction in research in Condensed Matter Physics.

Subhroneel Chakrabarti

Research Summary:

In the academic year 2017-2018, I have continued my thesis work on construction of integrated vertex for first massive level for open superstring theory in pure spinor formalism. This required first giving a general prescription for covariant θ expansion of the various superfield describing the first massive supermultiplet. This resulted in a publication. The construction of integrated vertex was done following the group theoretic technique developed by me and my collaborators and that too resulted in a paper. At present work is undergoing to compute scattering of massive open string in pure spinor formalism and its comparison with RNS formalism result.

I have further worked on soft graviton theorems in generic quantum gravity theory. Along with Prof. Ashoke Sen and fellow graduate students Biswajit Sahoo, Sitender Kashyap and Mritunjay Verma we proved the subleading multiple soft graviton theorem for a generic quantum theory of gravity at all loop level for any dimension greater than 5 (For dimension 4 or less our result holds upto tree level due to IR divergences). This culminated in a publication. Our theorem for the specific case of Einstein gravity was explicitly verified and rederived using a modern prescription for amplitude computatioon viz. CHY prescription. This simultaneously also gave strong evidence of CHY prescriptions validity for Einstein's gravity with arbitrary number of soft graviton insertion. This work also resulted in a publication.

I have also worked on SYK model with Prof. Dileep Jatkar, Dr. Arnab Kundu (SINP, Kolkata) and fellow graduate student Ritabrata Bhattacharya. We have investigated the effect of introducing a chemical potential in a complex SYK model. In particular we demonstrated how it can lead to a tuneable chaos exponent (quantum Lyapunov exponent) and traced its complete RG flow from UV to IR in the approximation of large q (q is the number of fermions interacting at a given time). This also lead to a published result.

Publications:

1. S. Chakrabarti, S. P. Kashyap and M. Verma, *Theta Expansion of First Massive Vertex Operator in Pure Spinor,* JHEP **01**, 019, (2018).

2. S. Chakrabarti, S. P. Kashyap, B. Sahoo, A. Sen and M. Verma, *Subleading Soft Theorem for Multiple Soft Gravitons,* JHEP **12**, 150, (2017).

3. S. Chakrabarti, S. P. Kashyap, B. Sahoo, A. Sen and M. Verma, *Testing Subleading Multiple Soft Graviton Theorem for CHY Prescription,*JHEP **01**, 90, (2018).

4. R. Bhattacharya, S. Chakrabarti, D. P. Jatkar and A. Kundu, *SYK Model, Chaos and Conserved Charge*,JHEP **11**, 180, (2017).

Preprints:

1. S. Chakrabarti, S. P. Kashyap and M. Verma, *Integrated Massive Vertex Operator in Pure Spinor Formalism,* arXiv:1802.04486.

Conference/Workshops Attended:

1. *National Strings Meeting*, India, December 2017.
2. *School on String Field Theory and String Phenomenology*, India, February 2018.
3. *Discussion meeting on String Field Theory and String Phenomenology*, India, February 2018.

Invited Lectures/Seminars:

1. *Multiple Subleading Soft Graviton Theorem* , National Strings Meeting, NISER, Bhubaneshwar, December 2017.
2. *Theta expansion of massive vertex in pure spinor*, Discussion meeting on String Field Theory and String Phenomenology, Harish-Chandra Research Institute, Allahabad, February 2018.

Other Activities:

1. Contributed as question paper setter and examiner for physics talent search exam conducted by HRI meant for school childern of class IX-XII in Allahabad, December, 2017.

Titas Chanda

Research Summary:

During the last academic year, I have been working on various topics of quantum information science, like quantum communication, open quantum systems, and the interface between quantum information science and many-body physics.

We have shown that bipartite entanglement in a one-dimensional quantum spin model undergoing time-evolution under local Markovian environments can be frozen over time. We have demonstrated this by using a number of paradigmatic quantum spin models in one dimension, including the anisotropic XY model in the presence of a uniform and an alternating transverse magnetic field (ATXY), the XXZ model, the XYZ model, and the $J_1 - J_2$ model involving the next-nearest-neighbor interactions. We have shown that the length of the freezing interval, for a chosen pair of nearest-neighbor spins, may remain independent of the length of the spin-chain, for example, in paramagnetic phases of the ATXY model, indicating a scale-invariance. Such freezing of entanglement is found to be robust against a change in the environment temperature, presence of disorder in the system, and whether the noise is dissipative, or not dissipative. Moreover, we have connected the freezing of entanglement with the propagation of information through a quantum many-body system, as considered in the Lieb-Robinson theorem. We have demonstrated that the variation of the freezing duration exhibits a quadratic behavior against the distance of the nearest-neighbor spin-pair from the noise-source, obtained from exact numerical simulations, in contrast to the linear one as predicted by the Lieb-Robinson theorem.

There exist zero-temperature states in quantum many-body systems that are fully factorized, thereby possessing vanishing entanglement, and hence being of no use as resource in quantum information processing tasks. Such states can become useful for quantum protocols when the temperature of the system is increased, and when the system is allowed to evolve under either the influence of an external environment, or a closed unitary evolution driven by its own Hamiltonian due to a sudden change in the system parameters. Using the one-dimensional anisotropic XY model in a uniform and an alternating transverse magnetic field, we have shown that entanglement of the thermal states, corresponding to the factorization points in the space of the system parameters, revives once or twice with increasing temperature. We have also studied the closed unitary evolution of the quantum spin chain driven out of equilibrium when the external magnetic fields are turned off, and have shown that considerable entanglement is generated during the dynamics, when the initial state has vanishing entanglement. Interestingly, we have found that creation of entanglement for a pair of spins is possible when the system is made open to an external heat bath, interacting through that spin-pair having a repetitive quantum interaction.

We also have considered the scenario of deterministic classical information transmission between multiple senders and a single receiver, when they a priori share a multipartite quantum state – an attempt towards building a deterministic dense coding network. Specifically, we have proved that in the case of two or three senders and a single receiver, generalized Greenberger-Horne-Zeilinger (gGHZ) states are not beneficial for sending classical information deterministically beyond the classical limit, except when the shared state is the GHZ state itself. On the other hand, three- and

four-qubit generalized W (gW) states with specific parameters as well as the four-qubit Dicke states can provide a quantum advantage of sending the information in deterministic dense coding. Interestingly however, numerical simulations in the three-qubit scenario reveal that the percentage of states from the GHZ-class that are deterministic dense codeable is higher than that of states from the W-class.

We have reported all phases and corresponding critical lines of the quantum anisotropic transverse XY model with Dzyaloshinskii-Moriya (DM) interaction along with uniform and alternating transverse magnetic fields (ATXY) by using appropriately chosen order parameters. We have proved that when DM interaction is weaker than the anisotropy parameter, it has no effect at all on the zero-temperature states of the XY model with uniform transverse magnetic field which is not the case for the ATXY model. However, when DM interaction is stronger than the anisotropy parameter, we have shown appearance of a new gapless phase - a chiral phase - in the XY model with uniform as well as alternating field. We have further reported that first derivatives of nearest neighbor two-site entanglement with respect to magnetic fields can detect all the critical lines present in the system. We have also observed that the factorization surface at zero-temperature present in this model without DM interaction becomes a volume on the introduction of the later. We have found that DM interaction can generate bipartite entanglement sustainable at large times, leading to a proof of ergodic nature of bipartite entanglement in this system, and can induce a transition from non-monotonicity of entanglement with temperature to a monotonic one.

Publications:

1. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Emergence of entanglement with temperature and time in factorization-surface states,* Phys. Rev. A **97**, 012316 (2018).

2. Saptarshi Roy, Titas Chanda, Tamoghna Das, Aditi Sen(De), and Ujjwal Sen, *Deterministic Quantum Dense Coding Networks,* Physics Letter A **382**, 1709 (2018).

Preprints:

1. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Scale-invariant freezing of entanglement,* arXiv:1610.00730, to appear in Phys. Rev. A.

2. Saptarshi Roy, Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Aditi Sen(De), and Ujjwal Sen, *Phase boundaries in alternating field quantum XY model with Dzyaloshinskii-Moriya interaction: Sustainable entanglement in dynamics,* arXiv:1710.11037.

Conference/Workshops Attended:

1. *Advanced School and Workshop on Quantum Science and Quantum Technologies*, ICTP, Italy, September, 2017.

Academic recognition/Awards:

- HRI-Infosys Prize for excellence in research in Physics, 2018.

Other Activities:

1. Presented a talk on "Frozen Quantum Correlations" at *Advanced School and Workshop on Quantum Science and Quantum Technologies*, ICTP, Italy, September, 2017.
2. Served as a Tutor, "Research Methodology and Numerical Methods" course, August-December Semester, 2017.

Kasinath Das

Research Summary:

For the last one year my research was based on the signatures of vector-like quarks at the Large Hadron Collider (LHC) in the scenario where the vector-like quarks have decay modes other than the searched ones, i.e. $(W^- t, Z b, h b)$ and $(W^+ b, Z t, h t)$. In a Leptophobic 221 model we studied the scenario where a third generation vector-like quark decays to final states with Beyond Standard Model scalars and SM third generation quarks. We studied the collider signatures in the scenario where the scalars decay to tau leptons.

Publications:

1. Kasinath Das, Tianjun Li, Satyanarayan Nandi and Santosh Kumar Rai, *New signals for vector-like down-type quark in $U(1)$ of E_6*, Eur. Phys. J. C 78, no. 1, 35 (2018).

Preprints:

1. Kasinath Das, Tanmoy Mondal and Santosh Kumar Rai, *Non-standard signatures of vector-like quarks in a leptophobic 221 Model*, in preparation.

Conference/Workshops Attended:

1. *SUSY17 : Supersymmetry and The Unification Of Fundamental Interactions*, TIFR, Mumbai, India, December, 2017.
2. *SANGAM@HRI - 2018*, HRI, Allahabad, India, March, 2018.
3. *NU HORIZONS VII*, HRI, Allahabad, India, February, 2018.

Academic recognition/Awards:

- INFOSYS scholarship for senior students at HRI.

Other Activities:

1. Talk :
   LHC signals of vector-like down-type quarks in a U(1) extension of Standard Model. SUSY17 Conference, TIFR, Mumbai, December 2017.
2. Tutor for the course "QFT II", January-May, 2018.

Sreetama Das

Research Summary:

In the academic year 2017-2018, I have worked on the interface of many-body physics and quantum information. In particular, I have considered a one-dimensional spin chain in presence of holes where the interaction among the spins is described by t-J model. We have studied how two-party and multi-party entanglement behave with the change of system parameters. We have observed a freezing of the multipaty entanglement with respect to perturbative changes of system parameters.

In another work, I have studied the wave-particle duality in a lossy two-slit interferometer where the two quantum states corresponding to the two slits of the interferometer are not orthogonal to each other. We have introduced a measure of quantum coherence for a non-orthogonal basis, and have identified a unique maximally coherent state in that basis. Using the proposed measure of coherence, we have obtained a relation between quantum coherence and path-distinguishability in the lossy two-slit interferometer.

Preprints:

1. Sreetama Das, Chiranjib Mukhopadhyay, Sudipto Singha Roy, Samyadeb Bhattacharya, Aditi Sen De, Ujjwal Sen, *Wave-particle duality employing quantum coherence in superposition with non-distinguishable pointers,* arXiv:1705.04343[quant-ph] .

2. Sreetama Das, Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Emergence of adiabatic freezing of genuine multipartite entanglement with insertion of defects in one-dimensional Hubbard model,* arXiv:1708.07005[quant-ph] .

Conference/Workshops Attended:

1. *Workshop on quantum science and technologies*, Trieste, Italy, September 2017.

Invited Lectures/Seminars:

1. *Necessarily transient quantum refrigerator*, Workshop on quantum science and quantum technologies, ICTP, Trieste, Italy, September 2017.

Satadal Datta

Research Summary:

We study the linear perturbations in a stable Jeans cloud, i.e; the dimension of the cloud is less than the Jeans length. We find that the linear perturbation of density in such a system obeys a wave equation in acoustic analogue of Minkowski space-time which is similar to Klein-Gordon equation for tachyon field in Minkowski space-time, i.e; Klein-Gordon equation with negative mass-squared term in a flat space time background. We further find the analogy with tachyon field for linear perturbation of density by studying linear perturbations in a stable cloud made of Bose-Einstein condensate as dark matter.

We consider a system of two interacting identical Van der Pol Oscillators in a simple harmonic potential well. The position coupling term between the oscillators is such that there is a finite delay, i.e; each system takes a finite time to react to the other one. We investigate the amplitude death in the presence of such interaction and we find out the amplitude death regions in the corresponding parameter space.

We study the changes in the phase portrait of a Van der Pol oscillator in a double well with the change in the shape of the well. Both the symmetric and asymmetric double wells are considered. We find that the shape of the well plays a very important role in the dynamics of the oscillator such as with the change in shape of the well, the stability of the fixed points of the system changes as well as limit cycles appear and are being destroyed.

We explore nonlinear perturbations in different static fluid systems. We find that the equations, corresponding to the perturbation of the integrals of motion, i.e; Bernoulli's constant and the mass flow rate, satisfy massless scalar field equation in a time dependent acoustic metric. When one is interested up to the second order behaviour of the perturbations, the emergent time dependent acoustic metric of the system, derived from the massless scalar field equations of the perturbations of the integrals of motion, has some astounding similarities with the metric describing gravitational wave in Minkowski spacetime.

Publications:

1. Satadal Datta, Md. Arif Shaikh, Tapas Kumar Das, *Acoustic geometry obtained through the perturbation of the Bernoulli's constant,* New Astronomy **63**, 65-74, (2018).

Preprints:

1. Satadal Datta, *Analogue tachyon in Jeans Cloud,* arXiv:1707.03284.
2. Satadal Datta, *Amplitude death by delay induced position coupling in a system of two coupled Van der Pol Oscillators,* arXiv:1709.09909.
3. Satadal Datta, *Bifurcations of a Van der Pol oscillator in a double well,* arXiv:1709.10126.
4. Satadal Datta, *Acoustic Analogue of Gravitational Wave,* arXiv:1804.02182v2.

5. Satadal Datta, *Lagrangian Description in the context of Emergent spacetime*, (in preparation) .

Conference/Workshops Attended:

1. *29th meeting of the Indian Association for General Relativity and Gravitation (IAGRG)*, India, May,18-20, 2017.

2. *36th Annual Meeting of the Astronomical Society of India (ASI)*, India, 5-9 February, 2018.

3. *International Workshop on Bose-Einstein Condensation and related phenomena (IWBECRP))*, India, 26th March-28th March, 2018.

Other Activities:

1. I audited a course on advanced quantum field theory by Prof. Ashoke Sen during Aug-Nov, 2017.

Atri Dey

Research Summary:

We have a working model of elementary particle interactions, covering the strong,weak and electromagnetic interactions at the quantum level. This constitutes the so-called standard model (SM) of particles.

In my project I try to investigate the possibility of finding the signatures of new physics in the Higgs boson itself by some effective field theory approach and also parallely we investigate the new physics contribution through extended higgs models.

Work in progress with J. Lahiri and B. Mukhopadhyaya.

Conference/Workshops Attended:

1. *SANGAM @ HRI*, INDIA, March, 2018 .
2. *Nu HoRIzons VII*, INDIA, February, 2018 .

Visits to other Institutes:

1. IACS, Kolkata, India, June, 2018.

Suman Jyoti De

Research Summary:

The research work that I have done during the academic year "2017-2018", which is defined from 1st August 2017 to 31st May 2018, is given below

My first part of research work dedicate to study the effect of linear background potential on quantum hall system in presence of electron-electron interaction using hatree-fock approximation. It is suspected that in this scenario the edge of the quantum hall system will under go some reconstruction.

I am also working on a 2D Topological system where I have a 2D Topological insulator in proximaty of a p-wave superconductor. It is suspected that this system may host majorana bound state at four corners of the sample. I am also looking to find out how these states evolve if I insert a flux through the center of this 2D system.

Conference/Workshops Attended:

1. I have attend a mini-school on Topology and Interaction on Quantum matter, IISER Kolkata, 8-10 January 2018.

2. I have attend a school on Driven Quantum Systems, IACS kolkata, 12-17 February 2018.

Arijit Dutta

Research Summary:

The metallisation of Mott insulators in response to driving has been extensively studied. The results for the square lattice have been analysed and understood in terms of a length scale associated with bias, which grows sharply at the transition. The real space variation of local density of states with changing bias has been predicted. This is easily verifiable by performing STM measurements. Similar results have been obtained for the square lattice.

The technique has also been applied to study nonequilibrium transport in a superconductor. We find that the voltage bias introduces phase decoherence in the system. At low bias the decoherence effects are feeble, and mostly confined to the edges. The transport is dominated by coherent tunneling of cooper pairs. When the bias reaches the scale of zero bias gap, the cooper pairs start getting dissociated and the phase decoherence becomes prominent. At large bias the transport is dominated by the electronic contribution.

Preprints:

1. Arijit Dutta and Pinaki Majumdar, *Voltage bias driven resistive switching in a Mott insulator,* arXiv:1710.09811 [cond-mat].

2. Arijit Dutta, Abhishek Joshi, Krishnendu Sengupta and Pinaki Majumdar, *Thermal transitions of the modulated superfluid for spin-orbit coupled correlated bosons in an optical lattice* (in preparation).

Conference/Workshops Attended:

1. *International Workshop on Bose-Einstein Condensation and Related Phenomena*, India, March, 2018.

2. *Indian Statistical Physics Community Meeting 2018*, India, February, 2018.

Academic recognition/Awards:

- Infosys Prize for senior students(HRI), for *Distinction in research in Condensed Matter Physics*, 2017.

Other Activities:

1. Poster presented at *International Workshop on Bose-Einstein Condensation and Related Phenomena*, March, 2018.

2. Poster presented at *Indian Statistical Physics Community Meeting 2018*, February, 2018.

Juhi Dutta

Research Summary:

During the academic year 2017-2018, we have been working on various extensions of the minimal supersymmetric standard model (MSSM). In the first project, we have completed our work on a compressed MSSM spectrum with a light gravitino LSP. Presence of the light gravitino as dark matter candidate in a supersymmetric (SUSY) model opens up interesting collider signatures consisting of one or more hard photons together with multiple jets and missing transverse energy from the cascade decay. We investigate such signals at the 13 TeV LHC in presence of compressed SUSY spectra, consistent with the Higgs mass as well as collider and dark matter constraints. We analyse and compare the discovery potential in different benchmark scenarios consisting of both compressed and uncompressed SUSY spectra, considering different levels of compression and intermediate decay modes. Our conclusion is that compressed spectra upto 2.5 TeV are likely to be probed even before the high luminosity run of LHC. Kinematic variables are also suggested, which offer distinction between compressed and uncompressed spectra yielding similar event rates for photons + multi-jets + missing transverse energy ($\not{E}_T$). We are also working on an extension to this work focussing on higgsino-like NLSP scenario and exploring the parameter space. We aim to study the different collider signals for this scenario at LHC.

In the second project, we studied an extension of MSSM with a right handed Majorana neutrino superfield in order to account for non-zero neutrino masses. We focus mainly on natural supersymmetric spectra with a low μ parameter (≤ 500) and with relatively heavy gaugino and bino mass parameters ($M_2, M_1 \sim \mathcal{O}(1)$ TeV). This leads to a spectra with a compressed higgsino like $\widetilde{\chi}_1^0, \widetilde{\chi}_2^0$ and $\widetilde{\chi}_1^\pm$ with a very small $\mathcal{O}(10^{-2})$ gaugino fraction. However, the mass splitting amongst the higgsinos are crucially controlled by M_1, M_2 leading to different hierarchial structures in the higgsino sector and consequently affecting the decays of the higgsinos significantly. In the presence of a light right sneutrino, new decays modes of the higgsinos to the right sneutrino LSP open up via small left-right mixing in the sneutrino sector. Considering only prompt decays of the higgino-like states, especially the lightest chargino, we discuss the importance of leptonic channels consisting of up to two leptons with large missing transverse energy to probe this scenario at the Large Hadron Collider (LHC). Currently we are working on possible extensions to this scenario including prompt as well as non-prompt decays of higgsinos and study the consequent signals at LHC with and without including the strong sector.

In the third project, we have been working on `SModelS`, a public tool which enables interpretation of supersymmetric model results from the LHC in the context of BSM physics scenarios. Specifically it decomposes BSM scenarios in terms of simplified topologies and compares them against LHC results. We have implemented CMS 13 TeV results for SUSY searches in SModelS and updated the current database which has been publicly released. We have also studied the impact of the new results on the pMSSM parameter space in our work. We are currently working on exploiting the technical work done of extending the database with the Run2 results for working on dedicated phenomenological studies for specific physics studies.

Publications:

1. Juhi Dutta, Partha Konar, Subhadeep Mondal, Biswarup Mukhopadhyaya and Santosh Kumar Rai, *Search for a compressed supersymmetric spectrum with a light Gravitino*,JHEP 09(2017)026 .

2. Arindam Chatterjee, Juhi Dutta and Santosh Kumar Rai, *Natural SUSY at LHC and Right-Sneutrino LSP,* arXiv: 1710.10617, JHEP 06 (2018) 042.

3. Juhi Dutta, Sabine Kraml, Andre Lessa, Wolfgang Waltenberger, *SModelS extension with the CMS supersymmetry search results from Run 2,* LHEP 01 (2018) 05.

Conference/Workshops Attended:

1. *Sangam @ HRI 2018: Instructional Workshop in Particle Physics*, HRI, India, March, 2018.

2. *Nu HoRIzons VII*, HRI, India, February, 2018.

3. *Workshop on Top Quark Physics in Present and Future colliders and Discussion on Machine Learning*, IISER Kolkata and SINP, India, January 2018.

4. *"25th International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY 2017)" PreSUSY School and Conference*, TIFR, Mumbai, India, December, 2017.

Invited Lectures/Seminars:

1. *Analyzing signals of compressed spectra in SUSY*, "25th International Conference on Supersymmetry and Unification of Fundamental Interactions (SUSY 2017)", TIFR, Mumbai, December, 2017.

Academic recognition/Awards:

- HRI-Infosys Award for Senior PhD Students, 2018.

Other Activities:

1. Volunteer for organising *Sangam @ HRI 2018: Instructional Workshop in Particle Physics*, India, March, 2018.

2. Volunteer for organising *Nu HoRIzons VII*, India, February, 2018.

Siddharth Dwivedi

Research Summary:

During the academic year 2017-18 I was involved with my collaborators in studying the collider signatures of type X two-Higgs doublet model (2HDM) at the 14 TeV LHC. Type X 2HDM is of special interest owing to its Yukawa structure, which permits the pseudoscalar A in its particle spectrum to have leptophilic coupling in the limit of high tan β. This aids in reconciling the muon anomalous magnetic moment discrepency via enhanced two loop contributions involving A loop and coupling of A to a pair of tau leptons.

We have investigated the detectability as well as reconstructibility of a light pseudoscalar of mass in the $50-60$ GeV range, which is still allowed in the type X 2HDM. Such a pseudoscalar can be pair-produced in the decay $h \to AA$ of the 125 GeV scalar h. The light pseudoscalar in the aforementioned range, helpful in explaining the muon anomalous magnetic moment, predominantly decays into a $\tau^+\tau^-$ pair. It also has a modest branching ratio of 0.35% in the $\mu^+\mu^-$ final state. Due to the feasibility of a sharp invariant mass reconstructon of the dimuon peak, it allows us to faithfully reconstruct the A mass using the $\mu^+\mu^-$ mode, and establish the existence of a pseudoscalar around $50-60$ GeV. The channel $p\,p \to h \to AA \to \mu^+\mu^-\,\tau^+\tau^-$ has been identified as the signal for this identification. The point emphasized in this work is that even though the decay of a light pseudoscalar prevents one from using the collinear approximation to reconstruct the invariant mass of the Tau-lepton pair directly, one can still bypass this requirement using suitable cuts on the phase space of the decay products, to reveal information about the mass of the pseudoscalar. The analysis reveals the discovery potential of this channel to be well within the high luminosity reach of the Run-II at LHC (*i.e.* 5σ discovery at $\sim \mathcal{O}(100\ \text{fb}^{-1})$).

This is being followed up by investigations on reconstructing the charged and neutral heavy Higgs bosons within the type X 2HDM scenario. Already established method of identifying a pseudoscalar, coupled with search for these heavy Higgs bosons would reveal a great deal about the gauge structure of the underlying new physics at LHC.

Publications:

1. Eung Jin Chun, Siddharth Dwivedi, Tanmoy Mondal and Biswarup Mukhopadhyaya, *Reconstructing a light pseudoscalar in the Type-X Two Higgs Doublet Model*, Physics Letters B **774C** , pp. 20-25, (2017) .

Conference/Workshops Attended:

1. *Sangam @ HRI: Instructional Workshop in Particle Physics*, India, March, 2018.
2. *Nu Horizons 2018*, India, February, 2018.
3. *SUSY17 conference at Tata Institute of Fundamental Research,* India, December, 2017.

Visits to other Institutes:

1. University of Sountampton, Southampton, United Kingdom, December, 2017.
2. University of Manchester, Manchester, United Kingdom, December, 2017.
3. University of Durham, Durham, United Kingdom, December, 2017.
4. Karlsruhe Institute of Technology, Karlsruhe, Germany, November, 2017.
5. University of Bonn, Bonn, Germany, November, 2017.
6. Lund University, Lund, Sweden, November, 2017.
7. Uppsala University, Uppsala, Sweden, November, 2017.

Invited Lectures/Seminars:

1. $h \to b\bar{b}\gamma$ *at the LHC and an* e^+e^- *collider*, SUSY17 conference, Tata Institute of Fundamental Research, Mumbai, India, December, 2017.

Avirup Ghosh

Research Summary:

In the academic year 2017-18 I have studied the phenomenology of an extension of MSSM augmented with three families of right-handed neutrinos.The superpartner of these right-handed neutrinos behave as a non-thermal DM pertaining to their miniscule interaction strength with rest of the particles. In one of my work I have developed the mass-reconstruction techniques of right-handed sleptons in colliders while in the other the prospect of right-handed sneutrinos being non-thermal DM candidate in presence of $\Delta L = 2$ mass terms is being studied in details.

Publications:

1. Avirup Ghosh, Tanmoy Mondal, Biswarup Mukhopadhyaya *Heavy stable charged tracks as signatures of non-thermal dark matter at the LHC: a study in some non-supersymmetric scenarios,* JHEP **1712**, 136, (2017).

Preprints:

1. Shankha Banerjee, Geneviéve Bélanger, Avirup Ghosh, Biswarup Mukhopadhyaya, *Long-lived stau, sneutrino dark matter and right-slepton spectrum,* e-Print: arXiv:1806.04488 [hep-ph] .

Conference/Workshops Attended:

1. *CTEQ,2017*, USA, July, 2017.
2. *SUSY,2017*, India, December, 2017.

Visits to other Institutes:

1. IACS, Kolkata, India,June 2017.
2. IACS, Kolkata, India,June 2018.

Invited Lectures/Seminars:

1. *Non-thermal dark matter with stable charged particles: a study in some non-supersymmetric scenarios* , SUSY,2017, TIFR, India, December 2017.

Samrat Suresh Kadge

Research Summary:

The research in the previous academic year primarily focussed on competition and co-existence of anti-ferromagnetism and superconductivity motivated by organic salts.We studied an electronic model which includes an onsite Hubbard repulsion and explicit nearest neighbour attraction on square lattice at half filling.A detailed comparison with experiments shows that the above analysis, can explain significant features of the phase diagram. Further, our scheme is able to capture spectral and real space information which provides key insights into the phenomena.

Further work is being carried out to extend the present calculations on triangular lattice and away from half-filling.

Publications:

1. Samrat Kadge,Pinaki Majumdar, *The competition and coexistence of antiferromagnetism and d-wave superconductivity: probing coupled thermal fluctuations in a two dimensional minimal model* The European Physical Journal B.

Arpan Kar

Research Summary:

In the academic year "2017-2018" (1st april 2017 to 31st March 2018) I have mainly focussed on the explanation of galactic centre γ-ray excess with the most popular dark matter model, MSSM. In this scenario, I have tried to explore if the dark matter annihilation inside the galaxy could saturate the γ-ray excess at all.

The minimal supersymmetric standard model (MSSM) is a popular theoretical scenario explaining the dark matter (DM) content of the universe, with the lightest neutralino (χ_1^0) as the 'dark' particle. However, it is also implicit in the adoption of the MSSM as the description of nature around the TeV scale that this neutralino should saturate practically the entire relic density of dark matter. We expect the contribution to the relic density from the lightest neutralino, should not go below the stipulated value; otherwise it will amount to going beyond the MSSM by including some additional dark matter source. This becomes an important input in the analysis of γ-ray data from the galactic centre (GC) and other celestial objects. Coupled with laboratory constraints (mainly collider constraints) and those from direct DM search (constraints in plane of DM-nucleon cross section vs DM mass), it makes the MSSM an unfavourable fit.

We fit the γ-ray excess from the galactic centre (GC) in terms of parameters of the minimal supersymmetric standard model (MSSM). Among total 19 parameters of pMSSM we have scanned over four parameters which have important influence in this analysis. They are M_1, M_2 ($U(1)$ and $SU(2)$ gaugino masses), μ (the Higgsino mass parameter) and m_A (the neutral pseudoscalar mass). Besides, three different values of $\tan\beta$ ($= v_2/v_1$) were used there, where $v_{2,1}$ is the value of the Higgs doublet in the MSSM coupling to the up(down)-type quarks. In the analysis consistency with other γ-ray observation, such as those from dwarf spheroidal galaxies (i.e. Reticulum II, M31), is also ensured, in addition to the constraints from direct dark matter search. After a detailed scan of the parameter space in terms of four representative types of particle spectra, we identify the ones that are best fit to the observed data. However, these two are somewhat unsatisfactory in terms of χ^2_{min} as well as p-values. In some case(s), the unacceptability of low-χ^2_{min} regions due to direct search constraint is responsible for this. In others, the observed shape of the γ-ray spectrum makes the fits unsatisfactory. The imposed lower limit on relic density, too, has a role to play all along. On the whole, the conclusion is that the MSSM is not a very satisfactory fit for the GC γ-ray compounded with other cosmological observations and direct search limits. In addition we show this with a comparison with the analysis of data related to the Higgs boson, where fits of indirect data preceded the direct search constraints.

Publications:

1. A. Kar, S. Mitra, B. Mukhopadhyaya, T. Roy Choudhury, *Dark matter, extra-terrestrial gamma-rays and the MSSM: a viability study*, JCAP **02**, 045, (2018).

Preprints:

1. A. Kar, S. Mitra, B. Mukhopadhyaya, T. Roy Choudhury, *Do astrophysical data disfavour the minimal supersymmetric standard model?*, arXiv:1711.09069 [hep-ph].

Conference/Workshops Attended:

1. *The 25th International Conference on Supersymmetry and the Unification of Fundamental Interactions (SUSY17)*, India, December, 2017.

2. *Workshop on Top-quark Physics, IISERK*, India, January, 2018.

Invited Lectures/Seminars:

1. *Neutralino dark matter, galactic centre gamma rays and the MSSM*, SUSY17, Tata Institute of Fundamental Research (TIFR), Mumbai, December, 2017.

Sitender Pratap Kashyap

Research Summary:

We worked on two different themes:

1. Construction of massive vertex operators in pure spinor formulation of superstring. Here we provided the necessary equations for carrying out the theta expansion of the superfields appearing in the unintegrated massive vertex at $(mass)^2 = \frac{1}{\alpha'}$. Further we computed the integrated form of this vertex operator .

2. Soft graviton theorem in quantum gravity. In this project we computed found the soft graviton theorem upto subleading order in a generic quantum theory of gravity. We further substantiated this result by explicitly demonstrating that the theorem holds for gravitons using CHY formulation.

Publications:

1. Chakrabarti, S., Kashyap, S.P. and Verma, M. J. High Energ. Phys. (2018) 2018: 19. https://doi.org/10.1007/JHEP01(2018)019.

2. Chakrabarti, S., Kashyap, S.P., Sahoo, B. et al. J. High Energ. Phys. (2018) 2018: 90. https://doi.org/10.1007/JHEP01(2018)090.

3. Chakrabarti, S., Kashyap, S.P., Sahoo, B. et al. J. High Energ. Phys. (2017) 2017: 150. https://doi.org/10.1007/JHEP12(2017)150.

Preprints:

1. Subhroneel Chakrabarti, Sitender Pratap Kashyap, Mritunjay Verma, "Integrated Massive Vertex Operator in Pure Spinor Formalism", Arxiv : 1802.04486 [hep-th].

Conference/Workshops Attended:

1. *National Strings Meeting 2017*, India, December 2017.

2. *Spring School on Superstring Theory and Related Topics*,Italy, March 2018.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, February 2018.

2. Institute of Physics, Bhubaneshwar, India, February year.

Invited Lectures/Seminars:

1. *A Symbolic computer algebra for multi-indexed objects*, Chennai Mathematical institute, Chennai, February.

Sarif Khan

Research Summary

During this academic year (2017-2018), I have mainly worked on the different beyond Standard Model (SM) scenario. In studying beyond SM (BSM) scenarios, I have few concrete motivations which force me to think about the BSM models. These are as follows,

1. when it is all about the matter content of the total energy budget of the universe, it is only around 28% of the total energy budget and rest is the dark energy. Moreover, around 4% is the visible baryonic matter and rest 24% is the invisible matter which is so called "Dark Matter" (DM). Many evidences are there in support of the presence of the DM namely flatness of the galaxy rotation curve, observation of bullet cluster and anisotropy in the CMB power spectrum. SM does not contain any suitable candidate for this mysterious matter.

2. In the last decade discovery of the neutrino oscillation among the flavors implies that neutrinos have mass. But in SM neutrinos are massless because of the absence of the right handed counterpart of the neutrinos.

3. Another big puzzle is the baryon anti baryon asymmetry of the universe. SM can not explain the amount of baryon asymmetry presence in the universe by satisfying the three famous conditions put by Sakharov.

Surely there are many more puzzles like these I have just listed few of them in the precedent part which are main motivations for my journey beyond the SM. In tackling the above puzzles, easiest way will be the extension of the gauge sector and/or its particle content of the SM. One such natural and popular extension of SM is the gauge extension of SM by $U(1)_{B-L}$. By adding three right handed (RH) neutrinos one can make it anomaly free. Due to the presence of the RH neutrinos one can generate neutrino mass by Type-I seesaw mechanism. In addition to the RH neutrinos we have also added a singlet scalar which act as the DM candidate and stabilized by a peculiar charge of $U(1)_{B-L}$ symmetry. In this set up we have worked in a scenario where DM is produced by the freeze-in mechanism. In another work, we have studied $U(1)_{L_\mu - L_\tau}$ gauge extension of SM. The charge assignments of of the particles are such that SM is anomaly free under this gauge extension. To study neutrino mass and DM we have added three RH neutrinos and a inert doublet in such a way so that model remains anomaly free. Here, we have produced the DM from the decay of gauge boson $Z_{\mu\tau}$ by the freeze-in mechanism. One technical concern in this work is that due to the small value of the gauge coupling ($g_{\mu\tau}$), gauge boson $Z_{\mu\tau}$ is out of equilibrium hence not in the thermal equilibrium with the thermal soup. Therefore, first we need to evaluate the momentum distribution function for the gauge boson and then do the analysis for the DM. In another place we have not extended the gauge sector of SM, rather only its particles have been extended by a triplet fermion, a triplet scalar and a singlet fermion. After adding these particles we have successfully explained the DM phenomenology and also the collider signature of DM by studying multi jet + missing energy in the final state.

Publications:

1. A. Biswas, S. Choubey and S. Khan, *Neutrino mass, leptogenesis and FIMP dark matter in a $U(1)_{B-L}$ model*, Eur.phys.J.C, **77** (2017) no.12, 875, doi: 10.1140/epjc/s10052-017-5436-y, [arXiv: 1704.00819 [hep-ph]].

2. A. Biswas, S. Choubey, L. Covi and S. Khan,*Explaining the 3.5 keV X-ray line in a $L_\mu - L_\tau$ Extension of the Inert Doublet Model*, JCAP, **1802** (2018) no. 02, 002, doi: 10.1088/1475-7516/2018/02/002, [arXiv: 1711.00553 [hep-ph]].

3. S. Choubey, S. Khan, M. Mitra and S. Mondal, *Singlet-Triplet Fermionic Dark Matter and LHC Phenomenology*, Eur.phys.J.C **78** (2018) no.4,302, doi: 10.1140/epjc/s10052-018-5785-1, [arXiv: 1711.08888 [hep-ph]].

Conference/Workshops Attended:

1. Workshop on High Energy Physics Phenomenology (WHEPP), December 14-23, 2017 at IISER Bhopal.

2. Nu HoRIzons VII, February 21-23,2018 at HRI Allahabad.

3. SANGAM@HRI, March 5-9, 2018 at HRI Allahabad.

Teaching Assistant:

Quantum Field Theory-I, August - November, 2017
Instructor - Dr. Anirban Basu
Teaching Assistant - Sarif Khan.

Abhass Kumar

Research Summary:

During the academic year 2017-2018, I have studied ways to combine baryogenesis with inflation and stochastic approaches to inflation. Because of the $B - L$ symmetry of the standard model, asymmetry in the lepton sector produced in the early universe can during the electroweak phase-transition get converted to the baryon asymmetry of the universe. This method of generating baryogenesis is called leptogenesis. Addition of right handed neutrinos to the standard model of particle physics allows us to have leptogenesis while explaining neutrino masses as well. Adding right handed neutrinos in the inert doublet model, we can do inflation, explain dark matter abundances and generate lepton asymmetry as well. The other part of my work during this year has been stochastic inflation. It deals with using stochastic methods like moments of the number of e-folds during the inflation era to calculate the curvature fluctuations which later give rise to structure formation in the universe.

Publications:

1. Sandhya Choubey and Abhass Kumar, *Inflation and dark matter in the inert-doublet model,* Journal of High Energy Physics **11**, (2017), 080.

Conference/Workshops Attended:

1. *15^th Workshop on High Energy Physics Phenomenology*, India, December 2017.
2. *NuHoRIzons VII*, India, February 2018.
3. *Sangam@HRI*, India, March 2018.

Poster Presentation:

1. *Inflation and Dark Matter in the Inert Doublet Model*, NuHoRIzons VII, Harish-Chandra Research Institute, Allahabad, February, 2018.

Ratul Mahanta

Research Summary:

During the academic year 2017-2018 I have studied affine Lie algebras and their representations and I have learnt Wess-Zumino-Witten model from the book on Conformal Field Theory by Philippe Di Francesco et al. I have followed and read some part of the book on the same topic by R. Blumenhagen, E. Plauschinn as a reference. I have used this knowledge and computed various correlators in the model by solving respective Knizhnik-Zamolodchikov equations. I have studied some properties of the correlators of particular interest to carry forward a work initiated by Alexander Maloney et al. in a recent article. It is a ongoing project I am working on. Apart from these, I have attended a conference and a school, whose details have been given below.

Conference/Workshops Attended:

1. *National String Meeting NSM - 2017 Jointly organized by NISER and IIT Bhubaneshwar*, Bhubaneshwar, India, December 2017.

2. *Kavli Asian Winter School (KAWS) on Strings, Particles and Cosmology 2018*, ICTS-TIFR, Bangalore, India, January 2018.

Other Activities:

1. I have served as a teaching assistant for Satistical Mechanics course during the Republic term (January-May 2018) at HRI.

Susovan Maity

Research Summary:

For low angular momentum axially symmetric accretion flow maintained in hydrostatic equilibrium along the vertical direction, the value of the Mach number at the critical points deviates from unity, resulting in the non-isomorphism of the critical and the sonic points. This introduces several undesirable complexities while analytically dealing with the stationary integral accretion solutions and the corresponding phase portraits. Introduction of an effective dynamical sound speed may resolve the issue in an elegant way. Linear perturbation is applied on the full spacetime-dependent general relativistic Euler and the continuity equations governing the structure and the dynamics of accretion disc in vertical equilibrium around Schwarzschild black holes and the sonic metric embedded within the stationary background flow has been identified. Such metric describes the propagation of the linear acoustic perturbation inside the accretion flow. The wave equation corresponding to that acoustic perturbation is found and under certain representation, the speed of propagation of such perturbation is identified. We finally show that the ordinary thermodynamic sound speed should be substituted by the speed of propagation of the linear acoustic wave which has been obtained through the dynamical perturbation. Such substitution will make the value of Mach number at the critical point to be equal to unity. Use of the aforementioned effective sound speed will lead to a modified stationary disc structure where the critical and the sonic points will be identical. In the next work we have obtained the effective sound speed for similar accretion in Kerr spacetime which is astrophysically more relevant.

Furthermore considering the general relativistic accretion flow onto a rotating black hole in the Kerr metric, I have calculated various dynamical features of such accretion flow for accretion in hydrostatic equilibrium (along the vertical direction) for various analytical forms of the flow thickness. In order to do that the associated critical flow equations are derived and the nature of such critical points have been determined using certain eigenvalue techniques. The dependence of black hole spin in determining the flow profile very close to the event horizon(quasi terminal values for accretion variables) has been studied for the various expressions for flow thicknesses. The formation of shock has also been studied as multi transonicity is found in the steady state flow. The formalism can be used to identify a new spectral signature of black hole spin, and has the potential of performing the black hole shadow imaging corresponding to the low angular momentum accretion flow.

Preprints:

1. Shaikh, M. A., Maity, S., Nag, S., & Das, T. K., *Effective sound speed in relativistic accretion discs around Schwarzschild black holes,* arXiv:1806.04084 [astro-ph.HE].

2. Maity, S., Shaikh, M. A., & Das, T. K., *Dynamical sound speed in relativistic accretion discs in the Kerr metric,* In preparation.

3. Shaikh, M. A., Maity, S., Tarafdar, P., & Das, T. K., *Spin-dependence of quasi-terminal values for various disc heights,* In preparation.

Conference/Workshops Attended

1. ASI(Astrophysical Society of India) Annual Meeting 2018, Hyderabad(India), February,2018.

Visits to other Institutes:

1. Sarojini Naidu College for Women, Kolkata, India (several visits).

Brij Mohan

Research Summary:

In the last academic year 2017-2018, which is defined from 1st April 2017 to 31st March 2018, I mainly studied quantum thermodynamics in the framework of resource theory. In which I learned fundamental limitations for quantum and nanoscale thermodynamics and second laws of quantum thermodynamics. Since second laws in presence of quantum coherence not well understood. So tried to understand second laws in presence of quantum coherence. Also tried to find the answer to the question" how to extract work in presence of quantum coherence ?". Along with this I also studied resource theory of quantum coherence and entanglement, open quantum systems and security proof of BB84 and B92 using quantum error correction.

Dibya Kanti Mukherjee

Research Summary:

We study transport through a Weyl semimetal quantum dot sandwiched between an s-wave superconductor and a normal lead. The conductance peaks at regular intervals and exhibits double periodicity with respect to two characteristic frequencies of the system, one that originates from Klein tunneling in the system and the other coming from the chiral nature of the excitations. Using a scattering matrix approach as well as a lattice simulation, we demonstrate the universal features of the conductance through the system and discuss the feasibility of observing them in experiments.

We also show that the electrical transport across a minimal model for a time-reversal symmetry(TRS) breaking Weyl semi-metal (WSM) involving two Weyl nodes can be interpreted as an interferometer in momentum space. The interference phase depends on the distance between the Weyl nodes ($\delta\vec{k}$) and is *anisotropic*. It is further shown that a minimal inversion symmetry broken model for a WSM with four Weyl nodes effectively mimics a situation corresponding to having two copies of the interferometer due to the presence of an orbital pseudo-spin domain wall in momentum space. We point out that the value of the δk and consequently the interference phase can be tuned by driving the WSMs resulting in oscillations in the two terminal conductance measured in the direction of splitting of the Weyl nodes.

We also study theoretically the differential conductance at a junction between a periodically driven spin orbit coupled system with a tunable band gap and a superconductor. The dynamics of a spin orbit coupled system, when driven with frequency much larger than the band-width, can be described by an effective static Hamiltonian that is known to have a rich topological phase diagram. We look for spin-dependent Andreev reflection (i.e, sub-gap transport) and show that when various mass terms compete in energy, there is substantial difference of Andreev reflection probability depending on the spin of the incident electron. We further analyze the origin of such spin-dependence and show how the incident angle of the electrons controls the spin-dependence of the transport.

We study spin response in a simple model of transition metal dichalcogenide (TMD) monolayers, with an eye to identifying sharp collective modes (i.e, spin-waves) that are more commonly characteristic of ferromagnets. These are are interesting materials in part because of their strong spin-orbit coupling. This leads to intrinsic spin-splitting of opposite signs in opposite valleys, so the valleys are intrinsically spin-polarized when hole-doped. We demonstrate that such modes exist for arbitrarily weak repulsive interactions, even when they are too weak to induce spontaneous ferromagnetism. The behavior of the spin response is explored for a range of hole dopings and interaction strengths.

Publications:

1. Dibya Kanti Mukherjee, Sumathi Rao, Arijit Kundu, *Transport through Andreev bound states in a Weyl semimetal quantum dot*, Phys. Rev. B **96**, 161408(R), (2017).

Preprints:

1. Dibya Kanti Mukherjee, Joanna Hutchinson, Arijit Kundu, *Floquet manipulation of spin-dependent Andreev reflection in spin-orbit coupled systems,* arXiv:1708.06773 [cond-mat].

2. Dibya Kanti Mukherjee, Sumathi Rao, Sourin Das, *Momentum space interferometry in Weyl semi-metals,* arXiv:1710.06873 [cond-mat].

3. Dibya Kanti Mukherjee, Arijit Kundu, H.A. Fertig, *Spin Response and Collective Modes in Simple Metal Dichalcogenides,* arXiv:1805.08223 [cond-mat].

Conference/Workshops Attended:

1. *School and Conference on Driven Quantum Systems at IACS, Kolkata*, India, February, 2018.

Visits to other Institutes:

1. IISER, Kolkata, India, August, 2017.

2. IIT, Kanpur, India, December, 2017.

3. IISER, Kolkata, India, February, 2018.

Academic recognition/Awards:

- Infosys Prize for senior students(HRI), For distinction in research in Condensed Matter Physics, 2017.

Chiranjib Mukhopadhyay

Research Summary:

My research over the past year has revolved around a central theme, namely, to better understand quantum resources.

In the context of a quantum absorption refrigerator model, i showed that there is a trade-off between the steady performance of the refrigerator and the minimum time required to reach the steady state. The quantitative form of this trade-off has been expressed in the form of a figure of merit, which when maximized, give rise to an expression of efficiency analogus to the Curzon-Ahlborn efficiency.

As regards the resource required for non-classical computation, also called magic, we showed that it can ultimately be ascribed to quantum coherence. I further pointed out a recipe for autonomously generating steady quantum coherence and magic in a thermal machine with the help of a spin-exchange bath. I am also working on finding the energy cost associated with the creation of quantum resources such as non-locality, steerability and magic.

Uncertainty relations lie at the heart of quantum theory, and, together with my advisor, I proved several uncertainty as well as reverse uncertainty relations which are both easy to apply as well as have interesting physical interpretations. Together with my collaborators, I also considered the case of mean deviation based uncertainty relations, and showed that these may be more useful than the standard variance based uncertainty relations for certain tasks such as detection of EPR violation.

With my advisor, I have also looked at the problem of adding two quantum states and proved an existing conjecture that the so called 'quantum addition' induces less disorder than convex mixing. Together with collaborators, I have also analyzed the potential for resource generation that a quantum addition channel posseses. For example, we showed that 'quantum adding' two bound entangled states may lead to distillable entanglement no matter what the addition parameter is. Lastly, I am working on the problem of how many sequential measurement iterations can non-locality survive in the qudit case.

In the next year, I plan to further elaborate on these studies and specifically concentrate on the resource theory of non-Gaussianity and its extension to the case of finite dimensional quantum systems. Operationally, this will be of vital importance in understanding quantum resources which are at play when distinguishing truly quantum computation from classical computing.

Publications:

1. C. Mukhopadhyay, S. Bhattacharya, A. Misra, A.K. Pati, *Dynamics and thermodynamics of a central spin immersed in a spin bath,* Physical Review A **96**, 052125,

(2017).

2. C. Mukhopadhyay, A. Misra, S. Bhattacharya, A.K. Pati, *Quantum speed limit constraints on a nanoscale autonomous refrigerator,* Physical Review E (accepted).

3. C. Mukhopadhyay, Sk Sazim, A.K. Pati, *Coherence makes quantum systems 'magical',* Journal of Physics A : Mathematical and Theoretical (accepted).

4. C. Mukhopadhyay, *Generating steady quantum coherence and magic through an autonomous thermodynamic machine utilizing a spin bath,* Physical Review A (accepted).

Preprints:

1. G. Sharma, C. Mukhopadhyay, Sk Sazim, A. K. Pati, *Quantum uncertainty relation based on the mean deviation,* arXiv 1801.00994.

2. C. Mukhopadhyay, Sk Sazim, A. K. Pati, *Quantum addition, superposition and mixing,* arXiv 1803.06982 .

3. C. Mukhopadhyay, A. K. Pati, *Stronger class of variance based sum uncertainty and reverse uncertainy relations for incompatible observables* , In preparation.

4. C. Mukhopadhyay, S. Mal, A. K. Pati, *Sequential measurement and proliferation of nonlocality for qudits,* In preparation.

5. C. Mukhopadhyay, S. Mal, Sk Sazim, *Energy cost of creating various shades of nonclassicality,* In preparation.

6. C. Mukhopadhyay, S. Mal, Sk Sazim, A. K. Pati, *Resource creation through quantum addition channel,* In preparation.

Conference/Workshops Attended:

1. *International Conference on Quantum Foundations*, Patna, India, December 2017.

2. *Nanyang Quantum*, Singapore, December 2017.

3. *International Symposium on New Frontiers in Quantum Correlations*, Kolkata, India, February 2018.

4. *Quantum Frontiers and Fundamentals*, Bengaluru, India, May 2018.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, November 2017.

2. Institute of Mathematical Sciences, Chennai, India, December 2017.

Other Activities:

1. Refereed for Physical Review A.

Dipyaman Pramanik

Academic report:

Neutrino oscillation physics has reached its precision era. Among the 6 oscillation parameters, Δm^2_{21},θ_{12}, θ_{13} have been measured with high precision and we also know the $|\Delta m^2_{31}|$ with good precision. We currently don't know the δ_{CP} .i.e. whether there is any CP violation in the leptonic sector or not, sign of the Δm^2_{31} .i.e. the mass-hierarchy and whether θ_{23} is greater than 45^o or less than 45^o or equal to 45^o.i.e. the octant. The future long baseline experiments are proposed in order to address these questions. But There might be some problems with their measurements if there exists new physics beyond standard oscillation paradigm. In one work we considered sterile neutrino for the future long-baseline experiments like DUNE and T2HK. DUNE (Deep Underground Neutrino Experiment) is a proposed long-baseline experiment in USA. It will have a baseline of 1300 km from Fermilab to Sanford Underground Research Facility in South Dakota. The far detector of DUNE will be a 40 kt liquid Argon time projection chamber. Another future long-baseline experiment is T2HK in Japan. This is the future upgradation programme of the currently running T2K experiment. Here the baseline is from Tokai to Kamiokande (295 km) and the detector will be two 187 kt water Cherenkov detector tanks. There is another alternative proposal where one of the two water tanks will be shifted to Korea at a distance of 1100 km from Tokai. This is the T2HKK experiment. I our work we have studied the ability of these experiments individually or combined to measure or discover the sterile CP phases. And we found that T2Hk/T2HK is better than DUNE in this respect and when combined the sensitivity is significantly improved. In this work we also studied the measurement of other sterile parameters other than the sterile phases for DUNE and T2HK.

NOvA and T2K are presently running long-baseline experiments. NOvA is in USA and T2K is in Japan. We did a combined real data analysis of both NOvA and T2K to constrain the invisible neutrino decay of the third mass eigenstate assuming normal hierarchy. We found that both NOvA and T2K prefers some finite lifetime for neutrino decay and disfavours stable neutrino little bit. We also study the effect of invisible sterile neutrino in the measurement of θ_{23} and Δm^2_{32}. We found that if decay is considered, the best-fit values of θ_{23} as well as Δm^2_{32} change. The allowed region in the θ_{23} vs Δm^2_{32} plane is also changed.

Publications:

1. Sandhya Choubey, Debajyoti Dutta and Dipyaman Pramanik, *Imprints of a light sterile neutrino at DUNE, T2HK and T2HKK,* Phys. Rev. **D96**, n.5,056026, (2017).

2. Sandhya Choubey, Srubabati Goswami and Dipyaman Pramanik *A study of invisible neutrino decay at DUEN and its effect of θ_{23} measurement,* JHEP **1802**, 055, (2018).

3. Sandhya Choubey, Debajyoti Dutta and Dipyaman Pramanik, *Measuring the sterile neutrino CP phase at DUNE and T2HK,* Eur. Phys. J. **C78**, no.4, 339, (2018).

Conference/Workshops Attended:

1. *WHEPP XV*, IISER Bhopal, December 2017.
2. *Nu HoRIzons VII*, Allahabad, February 2018.
3. *SANGAM@HRI* , Allahabad, March, 2018.
4. *PANE ICTP*, Italy, May, 2018.

Other Activities:

1. Classical Mechanics (Teaching Assistant), Aug-Dec, 2017.
2. Mathematical Methods II (Teaching Assistant), Jan-May, 2018.

Samiran Roy

Research Summary

During the period of last one year (from April 2017 to March 2018), I have studied the effects of one extra light sterile neutrino on the neutral current measurement at DUNE experiment. If there are light sterile neutrino mixed with the standard neutrino through mixing matrix, then we can see the effect of the extra sterile neutrino in the neutral current measurements as the the number of events will be less compare to the standard case. Neutral current measurements also give us access to the new mixing angles θ_{34}. Dune can constrain $\theta_{34} \leq 20^o$ at 90% C.L. Recently I am also working on the dark matter search at MiniBoone experiment.

Publications:

1. Raj Gandhi, Boris Kayser, Suprabh Prakash, Samiran Roy, *What measurements of neutrino neutral current events can reveal*, JHEP **1711** (2017) 202.

Saptarshi Roy

Research Summary:

In the academic year "2017-2018" (1st April 2017 to 31st March 2018), my research was mainly focused on two major directions – (1) the study of quantum communication networks, and (2) the 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 quantum communication, we investigated the possibility of building classical information transmission network which can transfer information deterministically, which we call 'Deterministic Dense coding networks'. In particular, we considered the scenario of deterministic classical information transmission between multiple senders and a single receiver, when they a priori share a multipartite quantum state an attempt towards building a deterministic dense coding network. Specifically, we have proven that in the case of two or three senders and a single receiver, generalized GreenbergerHorneZeilinger (gGHZ) states are not beneficial for sending classical information deterministically beyond the classical limit, except when the shared state is the GHZ state itself. On the other hand, three- and four-qubit generalized W (gW) states with specific parameters as well as the four-qubit Dicke states can provide a quantum advantage of sending the information in deterministic dense coding. Interestingly however, numerical simulations in the three-qubit scenario reveal that the percentage of states from the GHZ-class that are deterministic dense codeable is higher than that of states from the W-class.

We continued our research on quantum communication network by considering a mulitipath quantum teleportation protocol. In the context of teleportation, it is known that quantum states can be efficiently transferred over a long distances if the entire quantum channel can be divided into several small blocks. In this work, we have considered a scenario in which each block consists of two copies of a multiparty state – one is used for distributing an arbitrary quantum state to multiple parties while the other channel is required to concentrate it back to a single party. Both in noiseless and local noisy scenarios, we found one-shot quantum capacities of these channels in terms of fidelity, when the initial shared state in each block are the generalized Greenberger-Horne-Zeilinger and the generalized W states. We also considered a situation where optimal local measurements transform multipartite states to bipartite ones which can then be used as single-path channels for quantum state transmission in each segment. We showed that in some parameter ranges, the former protocol provides strictly better fidelities than that of the latter, thereby establishing the importance of distributing and concentrating arbitrary quantum states via multipartite entangled states in long distance quantum communication, over the local measurement based protocol. Moreover, we showed that in presence of bit flip or bit-phase flip noise, shared generalized Greenberger-Horne-Zeilinger states possess an inherent noise detection and correction mechanism, leading to the same fidelity as in the noiseless case. We considered further noise models also, which do not enjoy the same mechanism.

The next focal point of our research led us to study a spin model through the lens of quantum information. Specifally, in this work, we have reported all phases and corresponding critical lines of the quantum anisotropic transverse XY model with

Dzyaloshinskii-Moriya (DM) interaction along with uniform and alternating transverse magnetic fields (ATXY) by using appropriately chosen order parameters. We have proven that when DM interaction is weaker than the anisotropy parameter, it has no effect at all on the zero-temperature states of the XY model with uniform transverse magnetic field which is not the case for the ATXY model. However, when DM interaction is stronger than the anisotropy parameter, we have shown the appearance of a new gapless phase - a chiral phase - in the XY model with uniform as well as alternating field. We have further reported that first derivatives of nearest neighbor two-site entanglement with respect to magnetic fields can detect all the critical lines present in the system. We have also observed that the factorization surface at zero-temperature present in this model without DM interaction becomes a volume on the introduction of the later. We found that DM interaction can generate bipartite entanglement sustainable at large times, leading to a proof of ergodic nature of bipartite entanglement in this system, and can induce a transition from non-monotonicity of entanglement with temperature to a monotonic one.

Publications:

1. S. Roy, T. Chanda, T. Das, A. Sen(De), U. Sen, *Deterministic quantum dense coding networks,* Phys. Lett. A **382**, 1709 (2018).

2. S. Roy, T. Das, A. Kumar, A. Sen(De), U. Sen, *Activation of Nonmonogamous Multipartite Quantum States,* arXiv:1608.06914, To appear in Phys. Rev. A.

Preprints:

1. 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,* arXiv:1710.11037.

2. S. Roy, T. Das, D. Das, A. Sen(De), U. Sen, *How efficient is transport of quantum cargo through multiple highways?,* arXiv:1802.10398.

Conference/Workshops Attended:

1. *Recent Trends in Condensed Matter Physics*, India, November, 2017.

Shouvik Roy Choudhury

Research Summary:

During academic year 2017-2018 I have been working with Dr Sandhya Choubey on three different research projects in neutrino cosmology. In one of the project we have been working on obtaining bounds on sum of neutrino masses for various cosmological scenarios from latest cosmological datasets. Neutrino oscillation experiments have put the existence of neutrino mass on a solid footing. There are three mass eigenstates which are quantum superpositions of the 3 flavour eigenstates. However, tightest bounds on the sum of masses of these 3 mass eigenstates come from cosmology. We have performed a Bayesian analysis on a wide range of datasets: latest data releases from Planck satellite, Baryon Acoustic Oscillations (BAO) measurements, Type Ia supernovae (SNeIa) luminosity distance measurements and other data. We have obtained strong bounds on the sum of three active neutrino masses in different cosmological scenarios including a cosmology with a cosmological constant and cold dark matter (ΛCDM), and the same added with tensor perturbations; and also in a cosmology with dynamical dark energy instead of a simple cosmological constant.

In the second work we have been working on the effect of sterile neutrinos in an extended ΛCDM cosmology with added sterile neutrino mass and energy density parameters and another parameter: tensor-to-scalar ratio. Several anomalies in short baseline neutrino oscillation experiments can be explained with more than three neutrino species and hence there is a considerable amount of interest in models with extra species of sterile neutrinos of mass around 1 eV which mix with the three active neutrinos and are uncharged under the standard model gauge group. We are using Planck satellite data release for CMB and the BK14 data release from the BICEP-Keck collaboration, along with the Baryon Acoustic Oscillations (BAO) data and latest prior on the Hubble constant from direct measurements. We find that inclusion of BK14 data worsens the viability of a fully thermalised eV scale sterile neutrino.

We have also recently started working on the sterile neutrino situation in different cosmological scenarios with dynamical dark energy and intend to compare it with results in the ΛCDM model. However, in this work we are not including any tensor perturbations. We are again using a wide range of latest datasets and obtaining bounds on the cosmological parameters.

Conference/Workshops Attended:

1. *Invisibles17 School*, Switzerland, June, 2017.
2. *Invisibles17 Workshop*, Switzerland, June, 2017.
3. *Post-Planck Cosmology: Enigma, Challenges and Visions*, India, October, 2017.

Other Activities:

1. Teaching Assistant in General Relativity Course, August-December, 2017.

Biswajit Sahoo

Research Summary:

In this academic year "2017-2018" I mainly explored some basic understanding of Soft Graviton Theorem(SGT). Soft Graviton Theorem (SGT) relates an amplitude with arbitrary number of finite energy particles (Hard Particles) with arbitrary spin and arbitrary number of small energy gravitons (Soft Gravitons) to an amplitude without the soft gravitons expanded in powers of soft graviton momenta. We derived the subleading soft graviton theorem in a generic quantum theory of gravity for arbitrary number of soft external gravitons and arbitrary number of finite energy external states carrying arbitrary mass and spin. Our results are valid to all orders in perturbation theory when the number of non-compact space-time dimensions is six or more, but only for tree amplitudes for five or less non-compact space-time dimensions due to enhanced contribution to loop amplitudes from the infrared region. Then we tested our Multiple Soft Graviton Theorem result for perturbative Einstein Gravity using Cachazo-He-Yuan(CHY) prescription at tree level in arbitrary dimension. Currently we are trying to get the Log correction of Soft Theorems in four dimension due to infrared divergence using Grammer-Yennie treatment.

Publications:

1. Subhroneel Chakrabarti, Sitender Pratap Kashyap, Biswajit Sahoo, Ashoke Sen, Mritunjay Verma *Subleading Soft Theorem for Multiple Soft Gravitons,* Journal of High Energy Physics **12**, 150, (2017).

2. Subhroneel Chakrabarti, Sitender Pratap Kashyap, Biswajit Sahoo, Ashoke Sen, Mritunjay Verma, *Testing subleading multiple soft graviton theorem for CHY prescription,* Journal of High Energy Physics **01**, 090, (2018).

Preprints:

1. Biswajit Sahoo, Ashoke Sen, *Log correction to Soft Theorems in four dimension,* to appear.

Conference/Workshops Attended:

1. *National Strings Meeting (NSM)*, INDIA, December, 2017.

2. *Kavli Asian Winter School (KAWS) on Strings, Particles and Cosmology* , INDIA, January, 2018.

Invited Lectures/Seminars:

1. *Testing subleading multiple soft graviton theorem for CHY prescription*, National Strings Meeting-2018, National Institute of Science Education and Research (NISER) , Bhubaneswar, December, 2017.

2. *Gong Show on CHY prescription and Multiple Soft Graviton Theorem*, KAWS-2018, International Centre for Theoretical Sciences(ICTS), Bengaluru, January, 2018.

Other Activities:

1. Became tutor of Quantum Field Theory-2 course, January-May, 2017.

Ruchi Saxena

Research Summary:

We focus on the periodically driven systems in low frequency limit. Our model of interest is the Dirac materials with spin-orbit coupling which has been studied in the high frequency limit using the Brillouin-Wigner perturbation theory in our earlier work. We plot the topological invariant to quantify the topological structure of the Floquet bulk states as we vary different parameters of the systems. We show the full phase diagram for this quantity and explored the gap closing points in the Brillouin zone. We found that the gap closing happens only on the high symmetry points. We also verify the bulk-boundary correspondence of the periodically driven systems by counting the number of edge states in the nano ribbon band structure. At the end we discuss the stability of these topological phases in presence of disorder by calculating the real space Chern number as we vary the disorder strength.

Preprints:

1. Ruchi Saxena, Arijit Kundu, Sumathi Rao, *Bulk-edge correspondence and new topological phases in periodically driven spin-orbit coupled materials in the low frequency limit,* arXiv:1712.05916.

Conference/Workshops Attended:

1. *Quantum Transport in Topological Materials*, Spain, September, 2017.
2. *School on Fundamentals on Quantum Transport and Workshop on Fundamentals on Quantum Transport*, Italy, July-August, 2017.

Visits to other Institutes:

1. Spanish National Research Council (CSIC), Madrid, Spain, September 2017.
2. International Center for Theoretical Physics, Trieste, Italy, August-September 2017.
3. Swiss Federal Institute of Technology, Zurich, Switzerland, August 2017.
4. Karlsruhe Institute of Technology, Karlsruhe, Germany, August 2017.
5. Paul Sherrer Institute, Villigen, Switzerland, August 2017.
6. Indian Institute of Technology, Kanpur, India, April-May 2017.

Academic recognition/Awards:

- Best Poster Award in XXIV International Summer School Nicolas Cabrera on Quantum Transport in Topological Materials at INC, Madrid, 2017.

Other Activities:

1. Teaching assistance (TA) for Condensed Matter Physics (CMP) 2.

Arpita Sen

Research Summary:

My resarch work is mainly focussing on the formation of the permanent magnet without the rare earth elements in cobalt clusters doped with other elements and to compare the values of magnetic anisotropies and to find out the reasons behind the variations of magnetic anisotropies due to the changes of dopant element in the vicinity of ab-initio DFT calculation.

Along with it I am studying the electronic properties of the Wurtzite polar oxides in .

Publications:

1. Arpita Sen and Prasenjit Sen, *Properties of Highly Oriented Pyrolytic Graphite Supported TaSi16 Clusters: A Density Functional Investigation*, J. Phys. Chem. C **121**, 2849028497, (2017).

Visits to other Institutes:

1. JNCASR, Bangalore, India, 15th October to 15th November 2017.

Other Activities:

1. Tutorship of course Mathematical Methods 1, August-September, 2017.

Md Arif Shaikh

Research Summary:

Linear perturbation of black hole accretion on to Kerr black hole and the emergence of analogue gravity: I have been working on linear perturbation of black hole accretion. In the last one year, I studied the linear perturbation of black hole accretion on to the Kerr black hole and the corresponding emergence of analogue gravity phenomenon. We assumed the fluid to be perfect and governed by the adiabatic equation of state. The axially symmetric accretion disc was studied by considering the disc to be of conical shape. We showed that the propagation of linear perturbation of the mass accretion rate could be described by an effective curved spacetime metric which is referred to as the acoustic metric. The acoustic metric is time independent and possesses a sonic horizon. The sonic horizon was found to coincide with the transonic surface (where the advective velocity of the fluid u_0 becomes equal to the speed of sound in the fluid c_{s0}) of the accretion flow. In order to find the location of the acoustic horizon, we need to solve for the stationary accretion flow. This is done by numerically integrating the equations of the gradient of advective velocity (du_0/dr) and that of the sound speed (dc_{s0}/dr). In order to find the expression for du_0/dr and dc_{s0}/dr, we use the integral constants obtained by integrating the continuity equation and the relativistic Bernoulli's constant. The acoustic metric elements are explicit functions of the black hole spin. In order to show that the sonic horizon and the transonic surfaces coincide, we first numerically find the location of transonic surface for a given set of constants which describes the accretion flow, i.e., for given black hole spin (a), relativistic Bernoulli's constant ξ_0, polytropic index γ and specific angular momentum λ_0. Now keeping the values of these constants, we draw the causal structure of the acoustic spacetime. From the causal structure, we identify the location of the acoustic horizon. Keeping the set of parameters $[\xi_0, \gamma, \lambda_0]$, we do the analysis for different a and show that the acoustic horizon is located at the location of the transonic surface.

We also calculate the analogue surface gravity which is the measure of the analogue Hawking radiation. We also study the case when the accretion flow encounters a shock formation. By constructing a shock invariant quantity, we find out the possible location of shock formation. By drawing the corresponding causal structure, it is noticed that the shock location implies the presence of an acoustic white hole.

Effective sound speed in accretion disc with vertical equilibrium: In my next work, I have been studying the effective speed of acoustic propagation in accretion disc with hydrostatic equilibrium along the vertical direction. It is observed that for a disc with vertical equilibrium, the critical point, where the denominator of the gradient du_0/dr diverges, does not correspond to the transonic surface which is the case for conical or constant height model. Using the analogue space-time, we show that effective sound speed in disc with vertical equilibrium is actually different from c_{s0} defined as $c_{s0}^2 = dp/d\epsilon$, where p is the pressure and ϵ is the energy density of the fluid. We show the effective speed of propagation of the acoustic perturbation with respect to the fluid is actually given by $c_{s0}^{\rm eff} = c_{s0}/\sqrt{1+\beta}$, where the factor β depends on the model of vertical equilibrium. Thus the critical points of vertical equilibrium disc are actually located at the surface where $u_0^2 = {c_{s0}^{\rm eff}}^2$. This answers a long-standing puzzle regarding the difference in location of the critical point and the transonic surface.

Nonlinear higher order perturbation of black hole accretion: Linear stability analysis by performing linear perturbation of the black hole accretion shows that the perturbation solutions are oscillatory and hence the stationary solution of the accretion is stable under such linear perturbation. However, there are nonlinear perturbations in astrophysical systems, for example, the blast waves in supernovae explosion, solitons etc. We try to address how the stationary solution responds to nonlinear perturbations. It is seen that while perturbing the spherically symmetric accretion on to Schwarzschild black hole, if we keep terms that are up to second order in perturbations, then a differential equation of the perturbation is obtained which is of the form of the general Liénard's equation in case of standing wave analysis. Fixed point analysis of this system shows that if the initial perturbation is greater than a certain value then the perturbation solution would diverge making the stationary solution unstable.

Publications:

1. Md Arif Shaikh, Ivleena Firdousi and Tapas Kumar Das, *Relativistic sonic geometry for isothermal accretion in the Schwarzschild metric,* Classical and Quantum Gravity **34**, 155008, (2017).

2. S. Islam, Md Arif Shaikh, Tapas Kumar Das, F. Rahaman and M. Rahaman, *Charged wormholes supported by 2-fluid immiscible matter particles,* Physics and Astronomy International Journal **2(1)**, 00046, (2018).

3. Md Arif Shaikh, *Relativistic sonic geometry for isothermal accretion in the Kerr metric,* Classical and Quantum Gravity **35**, 055002, (2018).

4. Satadal Datta, Md Arif Shaikh and Tapas Kumar Das, *Acoustic geometry obtained through the perturbation of the Bernoullis constant,* New Astronomy **63**, 65-74, (2018).

Preprints:

1. Md Arif Shaikh and Tapas Kumar Das, *Linear stability analysis of low angular momentum accretion flow in the Kerr metric and the corresponding emergent gravity phenomena,* arXiv:1803.09896 [astro-ph.HE].

2. Md Arif Shaikh, *Nonlinear variations in spherically symmetric accretion in the Schwarzschild metric,* arXiv:1805.09672 [gr-qc].

3. Md Arif Shaikh, Susovan Maity, Sankhasubhra Nag and Tapas Kumar Das, *Effective sound speed in relativistic accretion discs around Schwarz schild black holes,* arXiv:1806.04084 [astro-ph.HE].

4. Susovan Maity, Md Arif Shaikh and Tapas Kumar Das, *Dynamical sound speed in relativistic accretion discs in the Kerr metric,* In preparation.

5. Md Arif Shaikh, susovan Maity, Pratik Tarafdar and Tapas Kumar Das, *Spin-dependence of quasi-terminal values for various disc heights,* In preparation.

Conference/Workshops Attended:

1. *35^{th} meeting of Astronomical Society of India (ASI)*, India, March 2017.
2. *29^{th} meeting of Indian Association of General Relativity and Gravitation (IAGRG)*, India, May 2017.
3. *Summer School on Gravitational-wave Astronomy, ICTS*, India, July, 2017.
4. *Young Astronomers Meet, IUCAA*, India, September, 2017.
5. *Black Holes: From Classical to Quantum Gravity, IIT Gandhinagar*, India, December, 2017.

Visits to other Institutes:

1. International Centre for Theoretical Sciences - TIFR, Bengaluru, India, September - October 2017.
2. S. N. Bose National Centre for Basic Sciences, Kolkata, India, November - December 2017.
3. Sarojini Naidu College for Women, Kolkata, February - March 2018.

Academic recognition/Awards:

- HRI-Infosys Prize for the year 2018 for distinction in research in Astrophysics, 2018.

Other Activities:

1. Qualified NET - JRF, 2017.
2. Qualified GATE, 2017.
3. Qualified West Bengal SET, 2018.

Sohail

Research Summary:

My research work during the academic year "2017-2018" which is defined from 1st April 2017 to 31st March 2018 constitutes of mainly learning some mathematical structures for the foundational studies of quantum mechanics. The topics I have gone through are metric space, vector space, Banach space , Hilbert space and some topics in general topology. I have also gone through some basic concepts of lattice theory which is essential for the "quantum logic" interpretation of quantum mechanics. Currently I am reading the basics of Banach algebra and C* algebra in order to explore algebraic approach to quantum physics. I am also trying to find whether stronger complementarity relations can be obtained from recent stronger uncertainty relations.

Visits to other Institutes:

1. National Institute of Science Education and Research,Bhubaneswar, India, May 2017.

Chirag Srivastava

Research Summary:

In the previous academic year, I worked on one of the quantum information protocols, quantum super dense coding. It uses entanglement of the state and quantum channel as resources to send classical information from one location to the other location. Maximum classical information transmission, optimized over all the possible variation of the parameters of the protocol is called the dense coding capacity of the channel. In the literature, there exist various formulation on this problem. In particular, many copies of shared state are used to study the asymptotic dense coding capacity of the channel. Further, the case of dense coding with single copy of shared state can be studied deterministically or probabilistically.

Gautam Sharma

Research Summary:

In the academic year 2017-18, I finished my earlier work on Coherence and Disturbance Complementarity Relation. Moreover I was working to find a trade-off between Coherence and Privacy of a quantum channel. But it could not be completed. I also worked on "Mean Deviation based uncertainty relations", with Chiranjib, Sazim and my supervisor Arun Kumar Pati. Firstly, we have derived product and sum uncertainty relations using mean deviation as the measure of uncertainty. We have shown that if we take mean deviation as the measure of uncertainty instead of standard deviation, then gaussian states are not the only most classical states.

Also, we have shown that Mean deviation uncertainty relations don't blow up for some probability distributions where the standard deviation diverges. We have also derived an state independent uncertainty relations using mean deviation uncertainty. As a past of applications we have shown that mean deviation uncertainty relations can also be used to detect quantum steering and entanglement in bipartite systems. We found that mean deviation uncertainty relations can be used to detect steerable states for lower value of detection efficiency compared to standard deviation. For detecting entanglement mean deviation uncertainty is as good as standard deviations uncertainty.Further plans are to formulate error-disturbance relations using mean deviation uncertainty relations. I will try to find a speed limit on quantum state evolution using this relation. Also I am working to use uncertainty relation to quantify contextuality. I have also been working to prove that uncertainty relations can be used to quantify non-classicality using the Wigner function approach.

Publications:

1. Gautam Sharma and Arun Kumar Pati, *Trade-off relation for coherence and disturbance,* Phys. Rev. A **97**, (2018), 062308 .

Preprints

1. Gautam Sharma, Chiranjib Mukhopadhyay, Sk Sazim, A. K. Pati, *Quantum uncertainty relation based on the mean deviation*, arXiv:1801.00994 .

Conference/Workshops Attended:

1. *International Conference on Quantum Foundations*, Patna, India, December 2017.
2. 21^{st} *Annual Conference on Quantum Information Processing*, TU Delft, January 2017.
3. *Quantum Frontiers and Fundamentals*, Bengaluru, India, May 2018.

Other Activities

1. I served as teaching assistant for the Quantum Mechanics-1 courrse in 2017 and Quantum Information and Computation(QIC), course in 2018.

Mritunjay Kumar Verma

Research Summary:

In the acedemic year 2017-2018, I have been involved in mainly two projects. The first project was related to the pure spinor formalism of the superstring theory. We obtained the superspace equations for the first massive states in the open string theory. Using this, we construced the integrated vertex operators for the first massive states of the open strings in pure spinor formalism. We also obtained the theta expansion of the unintegrated as well as integrated vertex operators.

The second project was related to the soft graviton theorem. Using the Feynman diagrammatic method developed by Ashoke Sen, we derived the subleading soft graviton theorem in a generic theory of quantum gravity for an arbitrary number of external soft gravitons. We also tested this result using the Chazo-He-Yuan prescription for computing the tree amplitudes involving the massless states and found the exact match.

Publications:

1. Josua Faller, Sourav Sarkar, Mritunjay Verma, "*Mellin Amplitudes for Fermionic Conformal Correlators*", JHEP **03** 106 (2018).

2. Subhroneel Chakrabarti, Sitender Kashyap, Biswajit Sahoo, Ashoke Sen, Mritunjay Verma, "*Testing Subleading Multiple Soft Graviton Theorem for CHY Prescription*", JHEP **01** 090(2018).

3. Subhroneel Chakrabarti, Sitender Kashyap, Biswajit Sahoo, Ashoke Sen, Mritunjay Verma, "*Subleading Soft Theorem for Multiple Soft Gravitons*", JHEP **12** 150(2017).

4. Subhroneel Chakrabarti, Sitender Kashyap, Mritunjay Verma, " *Theta Expansion of First Massive Vertex Operator in Pure Spinor*", JHEP **01** 019(2018).

5. Subhroneel Chakrabarti, Sitender Kashyap, Mritunjay Verma, "*Integrated Massive Vertex Operator in Pure Spinor Formalism*", [Arxiv: 1802.04486 [hep-th]].

6. Subhroneel Chakrabarti, Sitender Kashyap, Mritunjay Verma, "*Equivalence Between RNS and Pure Spinor Formalisms for Massive States*", in preparation.

Conference/Workshops Attended:

1. *The Discussion Meeting on String Field Theory and String Phenomenology*, HRI, India, February, 2018.

2. *Asian Winter School on Strings, Particles and Cosmology*, International Center for Theoretical Sciences, Bengaluru, India, January 2018.

3. *QCD Meets Gravity 2017*, University of California, Los Angeles (UCLA), USA, December 2017.

4. *National Strings Meeting 2017*, Bhubaneshwar, India, December 2017.

Visits to other Institutes:

1. University of California, Los Angeles, United states, December, 2017.
2. University of California, Davis, United states, December, 2017.
3. Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing, China, May 2018

Waleed Mohammed Abdallah

Research Summary:

I joined HRI in March 21, 2018 and I have submitted two papers. In the first paper with title: *Long-Lived BLSSM Particles at the LHC,* we have studied two examples of possible Long-Lived Particles (LLPs), predicted by the Supersymmetric $B-L$ extension of the Standard Model (BLSSM), namely the lightest left-handed sneutrino and the left-handed stau, which act as neutral and charged LLPs, respectively. A salient feature of these LLPs is that they do not need to be degenerate in mass with the Lightest Supersymmetric Particle (LSP). Thus, a significant fine tuning, usually assumed in the Minimal Supersymmetric Standard Model (MSSM) and other LLP scenarios, is avoided. Their long lifetimes are mainly due to the fact that they are emerged from left-handed sector, while the LSP of the considered model is emerged from right-handed sector, therefore their couplings with the LSP are extremely suppressed. After combining all results, we conclude that, unlike MSSM the BLSSM naturally provides long-lived candidates without any fine tuning, with clean signatures that can be reachable at the next run of the LHC.

In the second paper with title: *Searching for Charged Higgs Bosons in the $B-L$ Supersymmetric Standard Model at the High Luminosity Large Hadron Collider,* upon assuming the BLSSM as theoretical framework accommodating a multi-Higgs sector, we have assessed the scope of the high luminosity LHC in accessing charged Higgs bosons ($H^{\pm}$) produced in pairs from Z' decays. We show that, by pursuing both di-jet and tau-neutrino decays, several signals can be established for $H^{\pm}$ masses ranging from about M_W to above m_t and Z' masses between 2.5 TeV and 3.5 TeV. The discovery can be attained, even in a background free environment in some cases, owing to the fact that the very massive resonating Z' ejects the charged Higgs bosons at very high transverse momentum, a kinematic region where any SM noise is hugely depleted.

Preprints:

1. W. Abdallah, A. Hammad, A. Kasem and S. Khalil, *Long-Lived BLSSM Particles at the LHC,* arXiv:1804.09778.

2. W. Abdallah, A. Hammad, S. Khalil and S. Moretti, *Searching for Charged Higgs Bosons in the $B-L$ Supersymmetric Standard Model at the High Luminosity Large Hadron Collider,* arXiv:1806.03585 .

Indrani Chakraborty

Research Summary:

We estimate the smallest branching ratio for the Higgs decay channel $h \to \mu\tau$, which can be probed at an e^+e^- collider and compare it with the projected reach at the high-luminosity run of the LHC. Using a model-independent approach, Higgs production is considered in two separate cases. In the first case, hWW and hZZ couplings are allowed to be scaled by a factor allowed by the latest experimental limits on hWW and hZZ couplings. In the second case, we have introduced higher dimensional effective operators for these interaction vertices. Keeping BR($h \to \mu\tau$) as a purely phenomenological quantity, we find that this branching ratio can be probed down to $\sim 2.69 \times 10^{-3}$ and $\sim 5.83 \times 10^{-4}$ respectively, at the 250 GeV and 1000 GeV run of an e^+e^- collider.

With no conclusive signal till date of the minimal supersymmetric and extra dimensional models at the Large Hadron Collider (LHC), the issue of fine-tuning of the Higgs mass still calls for some attention. It could be very possible that the observed Higgs boson of mass 125 GeV has its origin in a non-supersymmetric extended scalar sector, and, it still has properties strikingly similar to the Standard Model Higgs. In such cases, however, one relies upon possible cancellations in the quadratic divergence of the Higgs mass to uphold naturalness. In this work, we have investigated this possibility in context of some two Higgs doublet and three Higgs doublet scenarios.

Publications:

1. Indrani Chakraborty , Subhadeep Mondal and Biswarup Mukhopadhyaya ; *Lepton Flavour violating Higgs decay at e^+e^- colliders*; PHYSICAL REVIEW D 96, 115020 (2017); 15 pages.

Preprints:

1. Nabarun Chakrabarty , Indrani Chakraborty ; *Ameliorating the Higgs mass fine-tuning problem with multi-Higgs doublet models* ; arXiv : 1801.05272 [hep-ph].

Conference/Workshops Attended:

1. Workshop **Nu HoRIzons VII** at Harish-Chandra Research Institute, Allahabad, India in February 2018.
2. Workshop **SANGAM** at Harish-Chandra Research Institute, Allahabad, India in March 2018.

Visits to other Institutes:

1. Academic visit and Oral presentation at Indian Association for the Cultivation of Science, Kolkata, India in October 2017.

Invited Lectures/Seminars:

1. *Lepton flavour violating Higgs boson decay $h \to \mu\tau$ at the e^+e^- collider*; Indian Association for the Cultivation of Science, Kolkata, India in October 2017.

Debmalya Das

Research Summary:

My research spans the areas of quantum information, foundations of quantum physics and quantum thermodynamics. Some of the problems I am recently interested in are uncertainty relations, quantum teleportation, quantum entanglement, Quantum Chesire Cat and quantum heat engines.

The uncertainty relation in quantum mechanics is traditionally written in terms of mean as the measure of central tendency and standard deviation as the measure of dispersion. It puts a constraint on the product of the spreads of position and momentum of quantum states, a feature that is absent in classical mechanics. Based on a different statistical concept, namely the median, we propose a quantum uncertainty relation between the semi-interquartile ranges of the position and momentum distributions of arbitrary quantum states, going beyond the mean-based uncertainty. We find that unlike the mean-based uncertainty relation, the median-based one is not saturated for Gaussian distributions in position. Instead, the Cauchy distributions in position turn out to be the most classical among the distributions that we have studied.

We study a quantum Stirling cycle which extracts work using quantized energy levels. The work and the efficiency of the engine depend on the length of the potential well, and the Carnot efficiency is achieved in a low temperature limiting case. We show that the lack of information about the position of the particle inside the potential well can be converted into useful work without resorting to any measurement. In the low temperature limit, we calculate the amount of work extractable from distinguishable particles, fermions and bosons.

Quantum states can be efficiently transferred over a long distance if the entire quantum channel can be divided into several small blocks. We consider a scenario in which each block consists of two copies of a multiparty state one is used for distributing an arbitrary quantum state to multiple parties while the other channel is required to concentrate it back to a single party. Both in noiseless and local noisy scenarios, we find one-shot quantum capacities of these channels in terms of fidelity, when the initial shared states in each block are the generalized Greenberger-Horne-Zeilinger and the generalized W states. We also consider a situation where optimal local measurements transform multipartite states to bipartite ones which can then be used as single-path channels for quantum state transmission in each segment. We show that in some parameter ranges, the former protocol provides strictly better fidelities than that of the latter, thereby establishing the importance of distributing and concentrating arbitrary quantum states via multipartite entangled states in long distance quantum communication, over the local measurement based protocol. Moreover, we show that in presence of bit flip or bit-phase flip noise, shared generalized Greenberger-Horne-Zeilinger states possess an inherent noise detection and correction mechanism, leading to the same fidelity as in the noiseless case. We consider further noise models also, which do not enjoy the same mechanism.

Quantum Chesire Cat is a counterintuitive phenomenon that decouples two degrees of freedom of the same physical entity, in the domain of quantum systems, from each other. This can be realized by using an interferometric setup in which the position of a photon travels through one arm of the interferometer and the polarization travels

through the other. This is similar to the Chesire Cat of "Alice in Wonderland" where the grin of the cat existed without the cat itself. Our main focus is to explore the possibility of using a separated property of a quantum system for quantum information processing purposes. We are also examining what might be the implications of such possibilities for foundations of quantum physics.

Preprints:

1. Anindita Bera, Debmalya Das, Aditi Sen(De), and Ujjwal Sen, *Quantum uncertainty relations: Engaging the median when the mean is not licit*, arXiv:1706.00720v2[quant-ph] .

2. George Thomas, Debmalya Das and Sibasish Ghosh, *Quantum heat engine using energy quantization and resources of ignorance*, arXiv:1802.07681v1[quant-ph] .

3. Saptarshi Roy, Tamoghna Das, Debmalya Das, Aditi Sen(De), Ujjwal Sen, *How efficient is transport of quantum cargo through multiple highways?*, arXiv:1802.10398v1[quant-ph] .

4. Debmalya Das and Arun Kumar Pati, *Teleporting the grin of a Quantum Chesire Cat*, (in preparation).

Conference/Workshops Attended:

1. *Quantum Frontiers and Fundamentals: Experimental Studies and Theoretical Ramifications*, India, April and May, 2018.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, October, 2017.

2. Institute of Mathematical Sciences, Chennai, India, March, 2018.

Dhargyal

Research Summary:

In this academic report 2017-18 I have included all my research work that are published, in pre-print form on arXiv, as well as work that I am doing as of now, June 14 2018.

Publications:

1. Lobsang Dhargyal, *Phenomenology of $U(1)_F$ extension of inert-doublet model with exotic scalars and leptons.* Eur.Phys.J. C, **Eur.Phys.J. C78 (2018) no.2, 150** (2018).

Preprints:

1. Lobsang Dhargyal, *A simple model to explain the observed muon sector anomalies, small neutrino masses, baryon-genesis and dark-matter.* arXiv:1711.09772 (2017).

2. Lobsang Dhargyal and Santosh Kumar Rai, *Implications of a vector-like lepton doublet and scalar Leptoquark on $R(D^{(*)})$.* arXiv:1806.01178 (2018).

1. *CP violation in hadronic τ decays, past, present and future.*, HRI extension talk, HRI, HRI, August 10, 2017.

Other Activities:

1. One on going work related to $R(D^{(*)})$, $R_{K^{(*)}}$, moun (g-2) etc.

Manish Kumar Gupta

Research Summary:

Quantum mechanics ensures that the information stored in a quantum state is secure and the ability to send private information through a quantum channel is at least as great as the coherent information. We derive trade-off relations between quantum privacy, information gain by Eve and the disturbance caused by Eve to the quantum state that is being sent through a noisy channel. For tripartite quantum states, we show that monogamy of privacy exists in the case of a single sender and multiple receivers. When Alice prepares a tripartite entangled state and shares it with Bob and Charlie through two different noisy quantum channels, we prove that if the minimally guaranteed quantum privacy between Alice and Bob is positive, then the privacy of information between Alice and Charlie has to be negative. Thus, quantum privacy for more than two parties respects mutual exclusiveness. Then, we prove a monogamy relation for the minimally guaranteed quantum privacy for tripartite systems. We also prove a trade-off relation between the entanglement of formation across one partition and the quantum privacy along another partition. Our results show that quantum privacy cannot be freely shared among multiple parties and can have implication in future quantum networks.

Preprints:

1. Arun Kumar Pati, Kratveer Singh, Manish K. Gupta, *Monogamy of Quantum Privacy,* arXiv:1709.10124 .

Invited Lectures/Seminars:

1. *Preserving Coherence In Optical Fiber for Long Distance Quantum Communication*, QuIC, Talk, Harish-Chandra Research Institute, Allahabad, June 2017.

2. *Quantum Privacy in multiparty scenario*, HRI Extension Talk, Harish-Chandra Research Institute, Allahabad, April 2018.

Manjari Gupta

Research Summary:

One of the projects is bosons in two dimensional optical lattices with long range interactions (e.g. dipole-dipole or Rydberg) along with strong on-site repulsion. We have used mean-field decoupling of the hopping term as well as the long range interaction for various density-wave patterns keeping the interactions of infinite range. The SPA technique for finding the finite temperature phase diagram is not applicable as within this scheme one is unable to explore the checkerboard (π-π) phase, which is most prominant at the finite temperatures. This happens because a part of the Fourier spectra of the dipole-dipole interaction is dropped out. A new scheme is being developed to tackle this problem.

In another project we have studied bosons in two dimensional optical lattices with disordered effective chemical potential at a given site in the strong coupling limit. We are using Static Path Approximation technique to investigate the finite temperature phase diagram by varying the on-site repulsion between bosons and the disorder strength. We are interested in the re-entrant behavior (Mott-Bose glass-superfluid-Bose glass) of superfluidity as a function of the disorder strength. We are also interested in the excitation spectra in order to better understand the Bose-glass phase.

Other Activities:

1. Reviewed a manuscript for 62nd DAE Solid State Physics Symposium, sponsored by Department of Atomic Energy, held in Bhaba Atomic Research Center, Mumbai, during December 26-30, 2017.

Safiqul Islam

Research Summary:

A brief description of the research work during the academic year 2017-2018, *i.e*, 1st April 2017 to 31st March 2018, is given below:

1. A parametric model to study the mass radius relationship of stars :
For relativistic charged fluid with the signature of pressure anisotropy, where the anisotropy is defined by the finite non zero difference between the radial and the tangential fluid pressure, the Einstein Maxwell field equations are solved for static spherically symmetric spacetime. Certain functional form of the electric field as well as the effective gravitational potential have been introduced in our model, where such field and po-tential are characterized by two free parameters a and b, with certain relationships defined between these two parameters, where such relationships are obtained using a particular form of stability criteria. The charge and the mass energy density have been expressed (as a consequence of the interior solution) as a function of the radial distance. From there, we obtain the mass-radius relationship for the interior solution. Once such mass-radius relationship is integrated for a particular limit defined by the radius of the star, one can obtain what will be the mass of the charged fluid considered in our model, embedded within a sphere of radius R. Hence our model here provides the mass M(R) of star of radius R. M(R) in our calculations, however, is characterized by (a,b), and there remains a specific relationship between a and b, which are obtained by using some prede- fined stability criterion. Various values of a and b provides various [M(R)-R] measurements. For different values of a and b, one can find M(R) for different values of R, and hence using our model, we can study the mass radius relation for different categories of stellar objects located at various regions of the Hertzsprung-Russel diagram. This paper is submitted.

2. A Reissner-Nordström+Λ black hole in the Friedman-Robertson-Wal-ker universe:
A charged, non-rotating, spherically symmetric black hole which has cosmological constant Λ (Reissner-Nordström+Λ or RN+Λ), active gravitational mass M and electric charge Q is studied with exterior Friedman-Robertson-Walker (FRW) universe in (2+1) dimensional spacetime. We find a new classes of exact solutions of the charged black hole where the generalized Birkoffs theorem is assumed to be valid. It is found that the cosmological constant is negative inside the black hole. We confirm it from the geodesic equations too. The cosmological constant is found to be dependent on R, Q and $a(v)$ which correspond to the areal radius, charge, of the black hole and the scale factor of the universe respectively. We note that the expansion of the universe affects the size and the mass of the black hole. An important observation is that, for an observer at infinity, both the mass and charge of black hole increase with the contraction of the universe and decrease with the expansion of the universe. This paper is submitted.

3. Magnetic Field of a compact spherical star under $f(R,T)$ gravity
We present the interior solutions of distributions of magnetised fluid inside a sphere in $f(R,T)$ gravity. The magnetised sphere is embedded in an exterior Reissner-Nordström metric. We assume that all physical quantities are in static equilibrium. The perfect fluid matter is studied under a particular form of the Lagrangian density $f(R,T)$. The

magnetic field profile in modified gravity is calculated. Observational data of neutron stars are used to plot suitable models of magnetised compact objects. We reveal the effect of $f(R,T)$ gravity on the magnetic field profile, with application to neutron stars, especially highly magnetized neutron stars found in X-ray pulsar systems. Finally the effective potential V_{eff}, arising out of motion of a test particle of negligible mass influenced by attraction or repulsion from the massive center is discussed. This paper is under review.

4. Charged Wormholes Supported by 2-Fluid Immiscible Matter Particle:
The existence of Lorentzian wormholes has been a speculative issue though there are views that it can exist at the planck scale of 10^{-35} metres. Though wormholes are designated as tunnels connecting two distinct universes or regions of the same universe but their actual physical significance was first proposed by Morris and Thorne and their possible locations in the galactic halo and central regions of galaxies further studied by Rahaman F. et al. Exact solutions of the wormhole with extra fields such as scalar field and static electric charge has been studied by Kim S.W et al. and derived self-consistent solutions. We are acquainted with the fact that wormhole spacetimes are predictions of the GTR and need to be supported by observations. The modified extended metric for the charged wormhole model of Kim and Lee has been developed by Kuhfittig P.K.F. to represent a charged wormhole that is compatible with quantum field theory. We provide a 2-fluid immiscible matter source that supplies fuel to construct wormhole spacetime. The exact wormhole solutions are found in the model having, besides real matter or ordinary matter, some quintessence matter along with charge distribution. We intend to derive a general metric of a charged wormhole under some density profiles of galaxies that is also consistent with the observational profile of rotation curve of galaxies. We have shown that the effective mass remains positive as well as the wormhole physics violate the null energy conditions. Some physical features are briefly discussed. This paper is published in Physics and Astronomy International Journal.

Publications:

1. Safiqul Islam, Md Arif Shaikh, Tapas Kumar Das, Farook Rahaman and Mansur Rahaman, *Charged Wormholes Supported by 2-Fluid Immiscible Matter Particle*, Phys Astron Int J **2**(1) 2018.

Preprints

1. Safiqul Islam, Satadal Datta and Tapas Kumar Das, *A parametric model to study the mass radius relationship of stars*, arXiv:1702.05171v1 [astro-ph.SR] dt 16.02.17, (Under review).

2. Safiqul Islam, Priti Mishra and Farook Rahaman, *A Reissner-Nordström+Λ black hole in the Friedman-Robertson-Walker universe*, arXiv:1703.05119v1 [phys.gen.ph] dt 5.03.17, (Under review).

3. Safiqul Islam and Shantanu Basu, *Magnetic Field of a compact spherical star under $f(R,T)$ gravity* (Under review).

Conference/Workshops Attended:

1. *National Level Teachers Enrichment Workshop in Mathematical Sciences (NLTEWMS-2018)*, Calcutta Mathematical Society, Kolkata, 23 rd May-6 th June , 2018.
(Participated and presented a paper on "Geodesic equations and its application").

2. *36th Annual Meeting of the Astronomical Society of India (ASI)*, Osmania University, Hyderabad, India, 5 - 9 February, 2018.
(Presented a poster on "A parametric model to study the mass radius relationship of stars").

3. *International conference on Mathematical Analysis and Applications in Modeling (ICMAAM 2018)*, Department of Mathematics, Jadavpur University, Kolkata, India, 9 - 12 January, 2018.
(Presented a paper titled "A parametric model to study the mass radius relationship of stars").

4. *29th meeting of the Indian Association for General Relativity and Gravitation (IAGRG)*, IIT Guwahati, Assam, India, 18-20 May, 2017.
(Presented a paper titled "A Reissner-Nordström+Λ black hole in the Friedman-Robertson-Walker universe").

Visits to other Institutes:

1. Inter University Centre for Astronomy and Astrophysics (IUCAA), Pune, Maharashtra, India, August 6-14, 2017.

Invited Lectures/Seminars:

1. *Searching for higher dimensional wormhole with noncommutative geometry*, Wormholes, Department of Physics and Astronomy, Western University, London , Ontario , Canada, October 24 - November 6, 2017. (Invited visit).

Academic recognition/Awards:

- Visiting Fellow, Department of Mathematics, RTM Nagpur University, Nagpur, January 14-24, 2017.

Other Activities:

1. Revieweer, International Journal of Astrophysics and Space Science (IJASS), April 20, 2017.

2. Revieweer, Boletim Sociedade Paranaense de Matematica, March, 2017.

Jayita Lahiri

Research Summary:

I am working on model independent frame-work to describe rare Higgs decays where, heavy scale physics may play an important role. We are employing effective field theory approach. We are further trying to connect these results with various models describing beyond standard Model Physics. This is a work in progress with Prof. Biswarup Mukhopadhyaya and Atri Dey.

I am also working on top quark physics. The project is an ongoing work on the aspect of polarization of boosted top quarks and using that as a probe of new physics. This work is in collaboration with Prof. Rohini Godbole, Prof. Monoranjan Guchait, Aravind Hv and Charanjit Khosa.

Conference/Workshops Attended:

1. *Nu-Horizon*, HRI, India, February,2018.
2. *Sangam*, HRI, India, March,2018.

Visits to other Institutes:

1. Tata Institute of Fundamental Research, Mumbai, India, April 2018.
2. Indian Association for Cultivation of Science, Kolkata, India June 2018.

Shiladitya Mal

Research Summary:

1) Generalised quantum measurements with two outcomes are fully characterised by two real parameters, dubbed as sharpness parameter and biasedness parameter and they can be linked with different aspects of the experimental setup. It is known that precision of measurements, characterised by the sharpness parameter of the measurements, reduces the possibility of probing quantum features like violation of local-realism (LR) or macro-realism (MR). Here we investigate the effect of biasedness together with sharpness of measurement and find a trade-off between those two parameters in the context of probing violation of LR and MR. Interestingly we also find the above mentioned trade-off is more robust in the later case.

2) We consider the Cavalcanti-Foster-Fuwa-Wiseman inequality which is a necessary and sufficient steerability condition for two-qubit states with two measurement settings on each side. We derive the criterion which an arbitrary two-qubit state must satisfy in order to violate this inequality, and obtain its maximum attainable violation in quantum mechanics. The derived condition on the state parameters enables us to establish a tight monogamy relation for two-qubit steering.

3) Quantum mechanics puts a restriction on the number of observers who can simultaneously steer another observer's system, known as the monogamy of steering. In this work we find the limit of the number of observers (Bobs) who can steer another party's (Alice's) system invoking a scenario where half of an entangled pair is shared between a single Alice in one wing and several Bobs on the other wing, who act sequentially and independently of each other. When all the observers measure two dichotomic observables, we find that two Bobs can steer Alice's system going beyond the monogamy restriction. We further show that three Bobs can steer Alice's system considering a three-settings linear steering inequality, and then conjecture that at most n Bobs can demonstrate steering of Alice's system when steering is probed through an n-settings linear steering inequality.

Publications:

1. Debarshi Das, Shiladitya Mal, and Dipankar Home, *Testing local-realism and macro-realism under generalized dichotomic measurements,* Phys. Lett. A **382**, 1085-1091, (2018).

Preprints:

1. Shiladitya Mal, Debarshi Das, Souradeep Sasmal, and A. S. Majumdar, *Necessary and sufficient state condition for two-qubit steering using two measurement settings per party and monogamy of steering,* arXiv: 1711.00872.

2. Souradeep Sasmal, Debarshi Das, Shiladitya Mal, and A. S. Majumdar, *Steering a single system sequentially by multiple observers,* arXiv: 1712.10227.

Conference/Workshops Attended:

1. *3rd International Conference on Quantum Foundation*, India, December, 2017.
2. *International Symposium on New Frontiers in Quantum Correlations*, India, January, 2018.

Soumita Pramanick

Research Summary:

I have joined HRI as a post-doctoral fellow in Physics on September 21, 2017. Exploring the applications of the discrete symmetry $A4$ in context of neutrino mass models as well as in multi-Higgs scenarios had been the prime intent of my research activities from September 21, 2017 to March 31, 2018.

$A4$ is the even permutation group of four objects having 12 elements ($n!/2 = 12$ for $n = 4$). It has two generators S and T satisfying $S^2 = T^3 = ST^3 = \mathbf{I}$. It has four irreducible representations viz. three 1-dimensional representations and one 3-dimensional representation.

- We have studied a model comprising of three Higgs $SU(2)_L$ doublets transforming as a triplet under $A4$ in (JHEP 1801 (2018) 011). The scalar potential inclusive of all dimension 4 terms allowed by the symmetries under consideration was analyzed. No soft breaking of $A4$ was allowed. Alignment eventuated naturally as a consequence of the symmetry $A4$ for the global minima configurations of vacuum expectation values of this $A4$ symmetric 3HDM. For each case, positivity and unitarity conditions were satisfied.

- The three neutrino oscillation paradigm is characterized by the three mixing angles (θ_{12}, θ_{13}, θ_{23}); two mass square splittings (Δm^2_{solar}, Δm^2_{atmos}) and one complex CP violating phase (δ). Neutrino oscillation data tell us Δm^2_{solar} and Δm^2_{atmos} differ by two orders of magnitude. Earlier experimental observations were roughly in agreement with popular lepton mixing patterns like the tribimaximal (TBM), bimaximal (BM) and Golden Ratio (GR) mixing as they give $\theta_{13} = 0$ and maximal mixing in the atmospheric sector ($\theta_{23} = \pi/4$) by construction. In 2012 nonzero θ_{13} ($\sim 9^\circ$) was observed by the short baseline reactor anti-neutrino experiments. Needless to mention that this observation immediately necessitated amendment of the popular lepton mixing patterns. In (arXiv:1711.03510 [hep-ph]), I have considered a two component Lagrangian formalism - the dominant one arising out of Type II see-saw mechanism and the smaller one originating out of a Type I see-saw. The dominant component is characterized by any of the popular lepton mixings or a scenario where all the mixing angles are either 0 or maximal ($\pi/4$) along with $\Delta m^2_{solar} = 0$. The subdominant Type I see-saw contribution tinkers the dominant Type II see-saw constituent so as to obtain nonzero θ_{13}, Δm^2_{solar}, deviation of θ_{23} from maximality in harmony with neutrino oscillation observations. In order to construct the mass matrices viable for the scheme discrete flavour symmetry $A4$ was implemented. Owing to the common origin, the neutrino oscillation parameters got correlated. For example, θ_{23} was obtained in the first (second) octant for normal (inverted) ordering. Model predictions were in concurrence with T2K and NOVA preliminary results favoring normal ordering and $\delta \sim -\pi/2$. The model has a rich scalar spectrum which was studied in detail to the extent of local minimization of the scalar potential including all terms allowed by the symmetry. No soft breaking of symmetries was entertained. Symmetries were broken only spontaneously.

Publications:

1. Soumita Pramanick and Amitava Raychaudhuri, *Three-Higgs-doublet model under A4 symmetry implies alignment*, JHEP **1801**, 011, (2018).

Preprints:

1. Soumita Pramanick, *Ameliorating the popular lepton mixings with A4 symmetry: A see-saw model for realistic neutrino masses and mixing*, arXiv:1711.03510 [hep-ph].

Conference/Workshops Attended:

1. *Global Initiative of Academic Network (GIAN) 2017 school on Dark matter: the astroparticle perspective*, JNU, India, December, 2017.

2. *Nu HoRIzons VII*, HRI, India, February, 2018.

3. *SANGAM@HRI - 2018*, HRI, India, March, 2018.

Visits to other Institutes:

1. University of Calcutta, Kolkata, India, January, 2018.

Invited Poster Presentation:

1. *Ameliorating the popular lepton mixings with A4-based seesaw model*, Nu HoRIzons VII, Harish-Chandra Research Institute, Allahabad, India, February, 2018.

Other Activities:

1. Participated and organized Nu HoRIzons VII meeting held at HRI, February, 2018.

2. Participated and organized SANGAM@HRI - 2018 meeting held at HRI, March, 2018.

Yogeshwar Prasad

Research Summary:

I have joined HRI on 26th October 2017 as a Post-doctoral Fellow in condensed matter physics. Since then I have been setting up a numerically exact quantum Monte-Carlo scheme for time-dependent non-equilibrium systems. In addition to this, I am comparing the numerically exact determinantal quantum Monte-Carlo results with the ones calculated using SPA (static path approximation), which includes thermal fluctuations above the mean-field.

In another project, I am studying the disorder-induced Floquet topological transitions in higher-Haldane model on honeycomb lattice. I have studied the density of states of the system for different strengths of disorder and broadening of the topological band for certain parameters of the Hamiltonian. I have also calculated the topological Chern numbers of the energy eigen-states, which characterizes the delocalization in such a $2D$ system.

I am also studying the role of shots in the quantum interference phenomenon for strongly-correlated systems. The probability distribution for tunneling between two sites seperated by a distance t is computed numerically for systems without shots, by summing all *forward scattering paths*. The effects of shots on the *universal* probability distribution which is approximately log normal, its mean which is proportional to t and its variance which grows as $t^{1/3}$, is under investigation.

I am also finishing the papers for the work which I have finished during my PhD.

Visits to other Institutes:

1. *Jawaharlal Nehru Centre for Advanced Scientific Research*, Bengaluru, INDIA, January, 2018.

2. *International Centre for Theoretical Sciences*, Bengaluru, INDIA, January, 2018.

During these visits, I have given following talks:

1. January 16, 2018 at *JNCASR*, Bengaluru : Determinantal Quantum Monte Carlo : An Introduction.

2. January 19, 2018 at *ICTS*, Bengaluru : Study of fermionic superfluid state in "clean" and "dirty" bilayer optical lattice systems circumventing the "cooling problem".

Saubhik Sarkar

Research Summary:

The dynamics of impurity atoms introduced into bosonic gases in an optical lattice have generated a lot of recent interest, both in theory and experiment. We investigate to what extent measurements on either the impurity species or the majority species in these systems are affected by their interspecies entanglement. This arises naturally in the dynamics and plays an important role when we measure only one species. We explore the corresponding effects in strongly interacting regimes, using a combination of few-particle analytical calculations and Density Matrix Renormalisation group methods in one dimension. We identify how the resulting effects on impurities can be used to probe the many-body states of the majority species, and separately ask how to enter regimes where this entanglement is small, so that the impurities can be used as probes that do not significantly affect the majority species. The results are accessible in current experiments, and provide important considerations for the measurement of complex systems with using few probe atoms.

In another work, we address the effects of quenched disorder averaging in the time-evolution of systems of ultracold atoms in optical lattices in the presence of noise, imposed by the presence of an environment. For bosonic systems governed by the Bose-Hubbard Hamiltonian, we numerically quantify the result of the presence of disorder in the Hamiltonian parameters in terms of physical observables, including bipartite entanglement in the ground state and report the existence of disorder-induced enhancement in weakly interacting cases. For systems of two-species fermions described by the Fermi-Hubbard Hamiltonian, we find similar results. In both cases, our dynamical calculations show no appreciable change in the effects of disorder from that of the initial state of the evolution. We explain our findings in terms the statistics of the disorder in the parameters and the behaviour of the observables with the parameters.

Preprints:

1. Saubhik Sarkar, Suzanne McEndoo, Dominik Schneble, Andrew J. Daley, *Interspecies entanglement with impurity atoms in a bosonic lattice gas,* arXiv:1805.01592.

2. Saubhik Sarkar, *Disorder-induced Effects in Noisy Dynamics of Quantum Bose-Hubbard and Fermi-Hubbard Glassesr,* arXiv:1804.09621.

Conference/Workshops Attended:

1. *Quantum Frontiers and Fundamentals*, RRI, Bangalore, India, April 30- May 4, 2018.

Sk Sazim

Research Summary:

In this period, I have carried out five Research works collaboratively. Following are the short description of these works:

1. Traditional forms of quantum uncertainty relations are invariably based on the standard deviation. This can be understood in the historical context of simultaneous development of quantum theory and mathematical statistics. Here, we present alternative forms of uncertainty relations, in both state dependent and state independent forms, based on the mean deviation. We illustrate the robustness of this formulation in situations where the standard deviation based uncertainty relation is inapplicable. We apply the mean deviation based uncertainty relation to detect EPR violation in a lossy scenario for a higher inefficiency threshold than that allowed by the standard deviation based approach. We demonstrate that the mean deviation based uncertainty relation can perform equally well as the standard deviation based uncertainty relation as non-linear witness for entanglement detection.

2. We investigate the coherence of quantum channels using the Choi-Jamiołkowski isomorphism. The relation between the coherence and the purity of the channel respects a duality relation. It characterizes the allowed values of coherence when the channel has certain purity. This duality has been depicted via the Coherence-Purity (Co-Pu) diagrams. In particular, we study the quantum coherence of the unital and non-unital qubit channels and find out the allowed region of coherence for a fixed purity. We also study coherence of different incoherent channels, namely, incoherent operation (IO), strictly incoherent operation (SIO), physical incoherent operation (PIO) etc. Interestingly, we find that the allowed region for different incoherent operations maintain the relation $PIO \subset SIO \subset IO$. In fact, we find that if PIOs are coherence preserving operations (CPO), its coherence is zero otherwise it has unit coherence and unit purity. Interestingly, different kinds of qubit channels can be distinguished using the Co-Pu diagram. The unital channels generally do not create coherence whereas some nonunital can. All coherence breaking channels are shown to have zero coherence, whereas, this is not usually true for entanglement breaking channels. It turns out that the coherence preserving qubit channels have unit coherence. Although the coherence of the Choi matrix of the incoherent channels might have finite values, its subsystem contains no coherence. This indicates that the incoherent channels can either be unital or nonunital under some conditions. We also prove a complementarity relation between the relative entropy of coherence and the Holevo quantity of the quantum channel. This suggests that the coherence and the Holevo quantity of the channels cannot be arbitrarily large at the same time.

3. Two primary facets of quantum technological advancement that hold great promise are quantum communication and quantum computation. For quantum communication, the canonical resource is entanglement. For quantum gate implementation, the resource is 'magic' in an auxiliary system. It has already been shown that quantum coherence is the fundamental resource for the creation of entanglement. We argue on the similar spirit that quantum coherence is the fundamental resource when it comes to the creation of 'magic'. This unifies the two strands of modern development in quantum technology under the common underpinning of existence of quan-

tum superposition, quantified by the coherence in quantum theory. We also obtain a coherence monotone from the discrete Wigner distribution We further study the interplay between quantum coherence and 'magic' in a qutrit system and that between quantum entanglement and 'magic' in a qutrit-qubit setting.

4. Recently, it was argued that the binegativity might be a good quantifier of entanglement for two-qubit states. Like the concurrence and the negativity, the binegativity is also analytically computable quantifier for all two qubits. Based on numerical evidence, it was conjectured that it is a PPT (positive partial transposition) monotone and thus fulfills the criterion to be a good measure of entanglement.

In this work, we investigate its behavior under noisy channels which indicate that the binegativity is decreasing monotonically with respect to increasing noise. We also find that the binegativity is closely connected to the negativity and has closed analytical form for arbitrary two qubits. Our study supports the conjecture that the binegativity is a monotone.

5. The violation of the Mermin inequality (MI) for multipartite quantum states guarantees the existence of nonlocality between either few or all parties. The detection of optimal MI violation is fundamentally important, but current methods only involve numerical optimization, thus hard to find even for three qubit states. In this paper, we provide a simple and elegant analytical method to achieve the upper bound of Mermin operator for arbitrary three qubit states. Also the necessary and sufficient conditions for the tightness of the bound for some class of states has been stated.

Publications:

1. Sk Sazim and Natasha Awasthi, *Binegativity of two qubits under noise,* Phys. Lett. A **382**, 1852, (2018).

Preprints:

1. Chiranjib Mukhopadhyay, Sk Sazim, and Arun K Pati, *Coherence makes quantum systems magical,* arXiv: 1801.04807 (2018).

2. Gautam Sharma, Chiranjib Mukhopadhyay, Sk Sazim, and Arun K Pati, *Quantum uncertainty relation based on the mean deviation,* arXiv: 1801.00994 (2018).

3. Mohd Asad Siddiqui and Sk Sazim, *Tight upper bound for the maximal quantum value of the Mermin operators,* arXiv: 1710.10802 (2017).

4. Chandan Datta, Sk Sazim, Arun K Pati, and Pankaj Agrawal, *Coherence of quantum channels,* arXiv: 1710.05015 (2017).

Conference/Workshops Attended:

1. *Quantum Frontiers and Fundamentals: Experimental Studies and Theoretical Ramifications (QFF'2018)*, April 30 - May 04, 2018, Raman Research Institute, Bangalore, India.

2. *International Symposium on New Frontiers in Quantum Correlations (ISNFQC18)*, January 29 - February 2, 2018, S. N. Bose National Centre for Basic Sciences, Kolkata, India.

3. *Advanced School and Workshop on Quantum Science and Quantum Technologies* (smr 3145 & 3183), September 04 - 15, 2017, ICTP, Trieste, Italy.

Arun Sehrawat

Research Summary:

Since I joined the institute, on 12 October 2017, I have added more details in the second version of my old paper cited below and worked on a new paper that we are currently writing. In both the projects, we considered a set of operators and presented different methods to obtain their region of allowed expectation values. In one project, the positivity of a density operator is exploited to achieve the allowed region. Whereas, in the other project, we used the fact that the mean value of an operator always lies between the two extreme eigenvalues. Then, suitable uncertainty measures are defined on the allowed region and several tight uncertainty relations for the operators are obtained. Angular momentum observables are studied in the new paper, while our old paper deals with an arbitrary set of operators.

Preprints:

1. Arun Sehrawat and Arun Kumar Pati, *Allowed mean values of angular momentum observables and their uncertainty relations*, (in preparation).

2. Arun Sehrawat, *Deriving quantum constraints and tight uncertainty relations*, e-print arXiv:1706.09319 [quant-ph].

Conference/Workshops Attended:

1. *Quantum Frontiers and Fundamentals*, India, May 2018.

2. *International Symposium on New Frontiers in Quantum Correlations*, India, February 2018.

3. *3rd International Conference on Quantum Foundations*, India, December 2017.

Satyananda Singh Chabungbam

Research Summary:

In the past one year, we have been exploring the effects of perpendicular electric field on $CrSiTe_3$ monolayer. $CrSiTe_3$ monolayer has a finite bandgap at zero electric field with ferromagnetic ground state. Interstingly, the bandgap closes when the electric field is increased to a crtical value. This shows the tunability of $CrSiTe_3$ monolayer from an insulator to a type II spin gapless semiconductor with external electric field. In fact, spin-gapless behaviour is a rare phenomenon and not many known materials show this very behaviour. With compressive biaxial strain, monolayer $CrSiTe_3$ changes its magnetic ordering from ferromagnetic to antiferromagnetic ground state. The spin-gapless behaviour is observed even at 5% compressive strain where the stable magnetic structure is antiferro under the application of external electric field. This shows the robustness of this spin-gapless behaviour in this monolayer even with different magnetic configurations.

We also do study heterostructures of some transition metal trichalcogenide monolayers. Our calculations shows that $CrSiTe_3$-$CrGeTe_3$ heterostructure has a type-II heterojunction. We estimate the photoconversion efficiency(PCE) of this heterostructure by calculating the absorption spectra. It turns out that the PCE for this heterostructure is comparable to those of known heterostructures and it has potential applications in solar energy harvesting materials.

Defects are an integral part of any known material. We also try to see the effect of point defects in transition metal trichalcogenide monolayers in the electronic and magnetic properties. Strain engineering in these defected monolayers is also an another dimension of tuning the electronic and magnetic properties of these monolayers.

Publications:

1. Satyananda Chabungbam, Prasenjit Sen *Computational design of a robust two-dimensional antiferromagnetic semiconductor,* Physical Review B **96**, 045404, (2017).

Conference/Workshops Attended:

1. *2nd International Conference on Condensed Matter and Applied Physics*, Bikaner, Rajasthan, 24-25 November, 2017.

2. *Topology and Interactions in Quantum Matter*, IISER, Kolkata, 8-10 January, 2018.

Sorokhaibam Nilakash Singh

Research Summary:

My work during the academic year "2017-2018" has been on non-equilibrium dynamics in strongly interacting systems. Thermalization is the process in which a pure state evolves into an effective thermal ensemble. There are generally two types of thermalization in literature - subsystem thermalization and 'general/conventional' thermalization. My main work has been to differentiate these two types of thermalization.

Another related work, which I am trying to finish with Prof. Dileep Jatkar and student Ritabrata Bhattacharya, is quantum quenches in SKY models. Recently I have also started a work on black-hole formation and thermalization in holographic superconductors with Nilay Kundu(YITP, Kyoto) and Anurag Kaushal(TIFR, Mumbai).

Conference/Workshops Attended:

1. *KIAS-YITP joint workshop 2017 "Strings, Gravity and Cosmology"*, Japan, September, 2017.
2. *National Strings Meeting at NISER*, India, December, 2017.
3. *SINP Strings Workshop at SINP Kolkata*, India, February, 2018.

Visits to other Institutes:

1. Tata Institute of Fundamental Research, Mumbai, India, November 2017.

HRI Colloquia

1. Arvind Krishna Mehrotra: *Songs of Kabir.*
2. Sanjay Puri: *Pattern formation in the kinetics of phase transitions.*
3. Shamsur Rahman Faruqi: *The name and address of urdu.*
4. Dibyendu Nandy: *The suns activity: understanding to forecasting.*
5. Supriya Chaudhuri: *Literary Community, Local Cosmopolitanism and World Literature.*
6. Mahan Mj: *Hyperbolic Geometry and chaos in the Complex Plane.*
7. William Casselman: *Remarks on the origins of Langlands' conjectures.*
8. A.R.Vasavi: *The marginalised majority and matter of livability.*
9. V. Srinivas: *Diophantine equations.*
10. Sunil Mukhi: *The omnipresence of conformal invariance.*
11. Nayanjot Lahiri: *The Indus civilization - uncovering the discovery.*
12. Vivek Borkar: *Small noise limits.*
13. Rajeev Bhargava: *Civility and principled coexistence in Ashokan inscriptions.*
14. Benoy Behl: *History of Indian art.*
15. Roop Mallik: *Tossing coins inside living cells.*

Mathematics Talks and Seminars

1. Shubhankar Poddar: *Commutants and Reflexivity of Multiplication tuples on vector valued reproducing Kernel Hilbert Spaces*.
2. Y. Nesterenko: 6 *lecture series on Analytic functions and transcedence of their values*.
3. Indranil Chowdury: *On asymptotic analysis of solutions to fractional Dirichlet problems in cylindrical domains*.
4. Seshadri Chintapalli: *Embedding theorems on hyperbolic varities*.
5. T N Shorey: *Irreducibility of well known classical polynomials*.
6. Atul Dixit: *A generalized modifies Bessel function and a higher level analogue of the general theta transformation formula*.
7. Jyoti Prakash Saha: *Purity for big Galois representations*.
8. K.N.Raghavan: *Heaps and applications*.
9. Eshita Mazumdar: *An Extremal Problem related to Devenport Constant.*
10. M. Subramani: *Non-Weiferich primes and Euclidean number fields.*
11. Aparajita Das Gupta: *Pseudo-differential Operators on Compact Lie groups.*
12. Saroj Rani: *Trace-description and Hamming weights of irreducible constacyclic codes.*
13. Ezra Waxman: *Angles of Gaussian primes.*
14. Hiroyuki Yamane : *Generalized root systems.*
15. Hiroyuki Yamane : *Weyl groupoids.*
16. Hiroyuki Yamane : *Presentations of Lie superalgebras and quantum superalgebras.*
17. Hiroyuki Yamane : *Representations of quantum superalgebras.*
18. Hiroyuki Yamane : *Harish-Chandra theorem of generalized quantum groups.*
19. Hitesh Raundal : *Spaces of polynomials knots with different topologies and their homotopy types.*
20. Anupam Kumar Singh: *Word-maps on groups.*
21. Silvio Dolfi : 3 *lectures with title On zeros characters of finite groups.*
22. Shigeru Kanemitsu : 3 *lectures on Automorphic* $\boldsymbol{L}$*-function by way of the Kuznetsov sum formula.*

Mathematics Colloquia

1. Dipendra Prasad: *On the size of representations of finite and infinite groups.*
2. Bhaskar Bagchi: *Projective planes over prime fields.*
3. Stephane Louboutine: *Upper bounds on* $\boldsymbol{L}(1,\chi)$.
4. Stephane Louboutine: *Fundamental units for some orders generated by a unit.*
5. Venky Krishnan: *Uniqueness results for Calderon-type inverse problems.*

Physics Talks and Seminars

1. Selvaganpathy J: *The Noncommutative Standard Model and its phenomenology at the Large Hadron Collider.*
2. K.P. Yogendran: *Thermostatis properties of Holographic superfluids.*
3. Fawzi Boudjema: *Electroweak radiative corrections -techniques and applications.*
4. Rohini Godbole: *Remaining hopes for BSM physics for run-II at the LHC.*
5. Shamik Banerjee: *Celestial sphere and unitary representation of the homogeneous Lorentz group.*
6. Amina Khatun: *Indirect searches of Galactic diffuse dark matter in INO-MagICAL detector.*
7. Anosh Joseph : *Exact Lattice Supersymmtery.*
8. Abhishek Chowdhury : *Where does the moon shine?*
9. Prarit Agarwal : *N=1 Lagrangians for genralized Argyres-Douglas theories.*
10. Diego Gallego : *A new scenery in the string landscape.*
11. Harold Erbin : *Machine learning for the string landscape.*
12. Probir Roy : *Complex scaling and flux ratios in neutrino telescopes.*
13. Benjamin Fuks: *Automation of the calculations of NLO-QCD corrections for BSM theories.*
14. Alekha Chandra Nayak : *Explaining galactic gamma ray excess in a conformal model*
15. Ambresh Shivaji : *Determination of trilinear Higgs self-coupling in single Higgs processes at the LHC.*
16. Anindya Datta : *Phenomenology of Universal Extra Dimension.*
17. Milind Diwan : *Neutrino Experiments.*
18. Subhaditya Bhattachraya : *Dark Matter.*
19. Joydeep Chakrabortty : *L-R Symmetry.*
20. Sourov Roy : *SUSY.*
21. Raghavan Rangaranjan : *SUSY and Cosmology.*
22. Tirtha Sankar Ray : *EW Vaccum Stability.*
23. Pasquale Di Bari : *Lepto- and Baryogennesis.*
24. E.J.Chun : *Higgs and Neutrinos.*

25. Prakash Mathews : *Precision QCD.*

26. Priyotosh Bandyopadhyay : *Extended Higgs.*

27. Ganpathy Murthy : *Quantum Hall Ferromagnetism in $\nu = 0$ Bilayer Graphene.*

28. Sushil Kumar Mishra : *Quantum Computing/Quantum Information Processing in veiw of electron Magnetic/Electron Paramagnetic.*

29. Gaurav Kumar Gupta : *Peculiar Magnetic and topological properties of TlCuCl3.*

Physics Colloquia

1. Vivek Mishra: *Pairing in cuprates: signatures on non-BCS paradigm.*
2. Sreerup Raychaudhuri: *Early days of particle physics in India.*
3. Amit Roy: *Open problems in nuclear physics: possibilities in India.*
4. Anosh Joseph: *Supersymmetry, lattice and holography.*

Recent Graduates

1. **Shrobona Bagchi**, *Explorations in entanglement of purification and multipartite entanglement*.
2. **Ramesh Manna**, *Fourier Integral Operators, Wave Equation and Maximal Operators*.
3. **Balesh Kumar**, *Some Topics in Number Theory*.
4. **Uttam Singh**, *Resource Theories of Quantum Coherence and Entanglement*.
5. **Nyayabanta Swain**, *The Mott Transition in Strongly Frustrated Lattices*.
6. **Nabarun Chakraborty**, *Extended Higgs sectors, vacuum stability and related issues*.
7. **Debasis Mondal**, *Quantum Uncertainty, Coherence and Quantum Speed Limit*.
8. **Rahul Kumar Singh**, *Maximal Surfaces and their Applications*.
9. **Saurabh Pradhan**, *Studies of strongly correlated electron system*.
10. **Tamoghna Das**, *Role of Quantum Correlations in Quantum Communication*.
11. **Arvind Kumar**, *On some problems involving nearly holomorphic modular forms and an estimate for Fourier coefficients of Hermitian cusp forms*.
12. **Asutosh Kumar**, *Monogamy of Quantum Correlations*.
13. **Avijit Misra**, *Thermodynamics aspects of quantum coherence and correlations*.
14. **Sudipto Singha Roy**, *Resonating Valence Bond States - A quantum information perspective*.
15. **Aritra Gupta**, *Calculation of relic density and detection prospects of Non-thermal dark matters: A general Study*.

Publications

Publications (Mathematics)

1. Punita Batra and Hiroyuki Yamane, *Centers of Generalized quantum groups,* Journal of Pure and Applied Algebra, **22**, No.5, 1203-1241 (2018).

2. Punita Batra and S. Eswara Rao, *On integrable modules for the twisted full toroidal Lie algebra,* Journal of Lie Theory, **28**, No.1, 79-105 (2018).

3. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the represenations of a positive integer by certain classes of quadratic forms in eight variables,* Analytic Number Theory, modular forms and q- hypergeometric series, 641–664, Springer Proc. Math. Stat. **221**, Springer, Cham. 2017.

4. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations by certain octonary quadratic forms with coefficients* $1, 2, 3, 4$ *and* 6, Int. J. Number Theory **14**, 751–612, (2018).

5. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of certain quadratic forms and a formula for the Ramanujan Tau function,* Funct. Approx. Comment. Math. (2018), To appear, doi:10.7169/facm/1695.

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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 $24 \times 7 \times 365$.

2. The entire HRI campus is connected with OFC based 1Gbps backbone providing the network and Internet connectivity to each and every office, hostel and guest house helping the scientists and all the other members on campus to work from any place in the campus even during odd night hours.

3. All the desktops of the faculty, students, post doctoral fellows and visiting fellows were upgraded with the newer version of Linux operating systems.

4. Newer versions of several applications software and packages were loaded on users' systems, computer centre systems and conference room systems, which provided the researchers to do their numerical and analytical calculations faster and obtain more precise results.

5. All the important packages were upgraded on Mail, Webmail, DNS, SSH, DHCP+DDNS, Proxy, LDAP and Firewall servers for the better, reliable and secure performance. Firewall rules were modified to increase the security level of the servers.

6. Some additional security features were added in the Mail Servers and other External Servers facing the Internet.

7. During the various conferences computer facilities were provided in the conference computer room to all the participants. Adequate computer support were provided to participants of the conferences.

8. Additional computing support was provided to the visiting scientists and visiting students under Visiting Students Programme (VSP) and Summer Programme in Mathematics (SPIM).

9. All the students, faculty members, administrative members, project staff and visitors are given a desktop on their office desks.

10. The Video Conference System of the main meeting / discussion room of the Institute was upgraded which is being used for academic and administrative meetings, conducting the students thesis viva and for organising lectures with other academic institutes nationally and internationally.

Current activities and plans:

1. 12 Linux / Windows based desktops and 16 iMac desktops are being purchased for the faculty members.

2. A colour printer for the users is being purchased.

3. It is planned to further enhance the performance and security level of Mail, Webmail, NFS, LDAP and firewall servers.

4. It is planned to upgrade all the old Desktops of the students, post doctoral fellows and administrative members within one year time frame.

Library : Annual Report (2017-18)

The Library of HRI serves as knowledge hub containing resources not only in the form of print but also in electronic resources. 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.

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
Sundays and Gazetted holidays	10.00 AM to 06.00 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 and Digital Collections, CDs and DVDs, Thesis, Bound Volumes of Journals, Dailies, Faculty Publications and Institute Publications etc., added to this.

Glimpse of the library:

Resources	**Details**
Total Collection/Books:	60415
No. of print books	20982
No. of Bound Volumes	38084
No. of Gift books	1349
Total Journals/Print	93
National	15
International	78
E-Resources/Databases:	
E-Journals:	
Print + Online (Int)	53
Online (Int)	5
E-books	2234 (LNM Book Series)
Databases:	
ScienceDirect	2400 + Jls, Elsevier Publication
AIP Archive	8 Jls, American Institute of Physics
MathScienet	Database of reviews, abstracts and bibliographic information, American Mathematical Society
DMJ 100	Duke Math. Jl - Back volumes from 1935 to 1999, Duke University Press
Euclid Prime	32 Jls + 15 Jls complimentary, Duke University Press
JSTOR	83 Jls, Ithaka Publication
CDs/DVDs	97
General Magazines	3
Newspapers	7
Seating capacity	37
Carpet area	650 Sq. Mts
Computers for users	4 Nos
Library Mgt. Software	Libsys7, Electro Magnetic Gate and Tattle tapes.

Newly added materials during April 2017 to March 2018:

Books	171
Gift books	48
Bound Volumes	883
Journals/Print	3
Journals/Online	2

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.
Web enabled library catalogue service Circulation service (Issue/Return) Reference	Library Website/Web OPAC Self-Issue/Return System Electromagnetic Security Gate
Referral External Membership	Off-campus service through e-mail and Library Extension service Overnight issue of Reference Books
Reprographic	Stock Verification
New Arrivals	Display of Faculty/PDF/Student Publications
Spiral Binding	Lamination and Display of Institute Publications
Newspaper clipping	Library Advisory Committee
User Orientation	18 Hours uninterrupted Services
Book Exhibition	
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.

INFRASTRUCTURAL DEVELOPMENT WORKS AT THE HRI CAMPUS

DURING F.Y. 2017-18

Following works have been carried out during this financial year.

- Enhancement of Electrical power system in switch yard and its related works near substation area.
- Civil, Electrical and other related works of Physics Lab.
- Modification of existing street light posts with LED light fixtures.
- Covering and Development of Nala area near Community Centre Annexe.

Some miscellaneous works related maintenance/modifications were also carried out which are hereunder.

- Renovation related to civil and electrical work in directors bungalow .
- Arrangement of mesh door shutter in new type-E quarters and Gym in Community centre.
- SITC of two nos. Multimedia LED Projector.
- Kitchen hood in mess of Hostel-1.

In addition orders had also been placed for some other works during this financial year. These works (as below) were under progress after 31^{st} March-2018.

- Supply and laying new telephone cable for old E-type and nearby housing.
- Supply installation testing and commissioning of multi VRF-VRV AC System in Institute building.
- Associated electrical works related to air conditioning.
- Parking shed with related approach road.
- Additional approach road.