Academic Report – 2015–16

Harish-Chandra Research Institute

Chhatnag Road, Jhunsi, Allahabad 211019

Contents

About the Institute

Early Years

The Harish-Chandra Research Institute is one of the premier research institutes in the country. It is an autonomous institute fully funded by the Department of Atomic Energy, Government of India. Till October 10, 2000 the Institute was known as Mehta Research Institute of Mathematics and Mathematical Physics (MRI) after which it was renamed as Harish-Chandra Research Institute (HRI) after the internationally acclaimed mathematician, late Prof Harish-Chandra.
The Institute started with efforts of Dr. B. N. Prasad, a mathematician at the University of Allahabad, with initial support from the B. S. Mehta Trust, Kolkata. Dr. Prasad was succeeded in January 1966 by Dr. S. R. Sinha, also of Allahabad University. He was followed by Prof. P. L. Bhatnagar as the first formal Director. After an interim period in January 1983, Prof. S. S. Shrikhande joined as the next Director of the Institute. During his tenure the dialogue with the Department of Atomic Energy (DAE) entered into decisive stage and a review committee was constituted by the DAE to examine the Institutes future. In 1985 N. D. Tiwari, the then Chief Minister of Uttar Pradesh, agreed to provide sufficient land for the Institute and the DAE promised financial support for meeting both the recurring and non-recurring expenditure. In January 1990, about 66 acres of land was acquired in Jhunsi, Allahabad and the Institute came up at this site.
Prof. Shrikhande was followed by Prof. H. S. Mani who took over as the Director in January 1992. With his joining and the shift to the new campus at Jhunsi in 1996, the Institutes activities picked up pace. This phase of rapid growth still continues.

New Phase

After a distinguished tenure of about nine years Prof. Mani retired in August 2001 and the charge was taken over by Prof. R. S. Kulkarni. After Prof. Kulkarnis tenure, Prof. Amitava Raychaudhuri was the Director from July 19, 2005 to May 15, 2011. Prof. Jayanta Kumar Bhattacharjee, the current Director, took over in April 29, 2012. The Institute continues to be devoted to fundamental research in diverse areas of mathematics and

theoretical physics. Research is carried out by faculty members, visiting members, post-doctoral fellows and Ph. D. students.
Since 1992 the Institute has attracted worldwide attention, as is evident from the recognition received by many of its members. Several members of the Institute have been recognised for their scientific contribution. Prof. B. Mukhopadhyaya, Prof. Pinaki Majumdar, Prof. Rajesh Gopakumar and Prof. Ashoke Sen have been awarded the Shanti Swarup Bhatnagar prize for work done at HRI. Prof. Gopakumar has also received the Swarnajayanti Fellowship of the Department of Science & Technology and the ICTP Prize for 2006. The outstanding contribution of Prof. Ashoke Sen has been recognised by a Fellowship of the Royal Society, the award of Padmashri and Padmabhushan and the award of one of the first Fundamental Physics Prize (2012) from the Yuri Milner Foundation. He was the only recipient of the prize from all of Asia.
Prof. Rajesh Gopakumar was awarded the prestigious J. C. Bose fellowship of the Department of Science and Technology and the TWAS physics prize in October 2013 and also he won the G D Birla prize in physical sciences for the year 2013 earlier this year. Prof. Aditi Sen De received the Buti foundation award of the Indian Physics Association for the year 2013. Prof. Raj Gandhi was awarded the Fermilab Intensity Fellowship which would allow him to work at Fermilab for a considerable period.

Research in Mathematics

The mathematics group at HRI carries out research in several areas. In algebra, work is done on algebraic groups and related structures, the theory of groups and group rings, representation theory, and infinite-dimensional Lie algebras. Work in analysis is in the field of harmonic analysis of Lie groups.

Activity in geometry includes discontinuous groups and Riemann surfaces, algebraic topology, variational problems on manifolds, Chow groups of rational surfaces, and moduli of vector bundles. The number theory group works on algebraic, analytic and combinatorial number theory, automorphic forms and cryptography.

Research in Physics

Research in Physics at HRI is carried out in the fields on astrophysics, condensed matter physics, quantum information and computing, high energy phenomenology and string theory. In astrophysics work is done on black hole accretion, analogue gravity phenomena, general theory of relativity and aspects of dynamical systems in large scale astrophysical fluid flow in strong gravity. Main areas of activity in condensed matter physics are strongly correlated electron systems, mesoscopic systems, quantum Hall effect and superconductivity. In string theory, perturbative and nonperturbative aspects of string theory and quantum field theory are being actively investigated. Research in neutrino physics, strong interactions, lattice gauge theory, supersymmetry and various aspects of physics beyond the standard model is done in high-energy phenomenology. The Institute is a member of the India-based Neutrino Observatory (INO) collaboration.

The Institute has a residential campus in Jhunsi, Allahabad with a library, state of the art computational facility and fast Internet link to the outside world. There is an active graduate program and a large traffic of visiting scientists and students.

Director's report

The past year was marked by a variety of interesting lectures, workshops, conferences and schools that brought into sharp focus the academic liveliness of the campus.

There were two Harish-Chandra Memorial lectures in the course of the year. The first was in August 2015 and was given by Prof H S Mani, a former director of HRI and an adjunct professor of Chennai Mathematical Institute at present. He talked about the recently discovered phenomenon of extreme slowing down of light in certain special materials in a lecture titled Light in a medium-slow light and fast light. The second Harish Chandra memorial lecture was delivered by Prof Sekhar Basu - the DAE Secretary and the Chairman, Atomic Energy Commission of India. This lecture titled Achievements of the Department in Science, Technology and the Building of Man-power gave an extremely interesting insight into the not so-publicized innovations and developments that have been responsible for the nations progress. Coming from a person responsible for the building in India of the land based propulsion system for the nuclear submarine , this was an eye-opener in many ways.

There was a Girdharilal Mehta lecture organized in February 2016. The speaker was Prof Nathan Berkowitz, a well known string theorist from the Institute de Fisica Teorica in Brazil. The topic was Twistors and Superstrings. The annual Foundation Day lecture was given by Prof Swapan Chakravarty, the first Rabindranath Tagore Distinguished Professor of Presidency University in Kolkata. He spoke on Literature, Idealogy, Belief and Knowledge. To celebrate the detection of gravitational waves a special lecture was delivered by Prof Tarun Souradeep of IUCAA who is one of the leading figures in LIGO,India. This lecture also marked the opening of a medium sized auditorium funded by the REKAPP project and suitably christened The Higgs Lecture Theatre

There were workshops, schools and conferences galore. In December 2015, the Quantum Information group organized a meeting on Quantum Information Processing and Applications(QIPA-2015). There was an intensive string theory workshop over two weeks in early February followed by an equally demanding high energy physics workshop named Sangam@HRI. In March there was a very well attended school on Nanoscale electronic transport and Magnetism followed by a neutrino physics meeting aptly named Nu-Horizons.

A workshop on geometry and topology was held in December 2015 and the Triveni Number Theory Meet followed in March 2015. This meeting celebrated the 65th birthday of the eminent number theorist Prof R Balasubramanian, who is also a council member of HRI. The outreach activities

of HRI flourished as usual. The summer program in mathematics (SPIM) was as popular as ever. A week long science camp in Hindi was conducted to help local students get a feel for scientific logic. The science talent test in maths and physics for 10th and 12th grade students in the Allahabad area was conducted in November.

Future Programme

As reported last year, HRI which has built a strong reputation in research and the course work part of the Integrated PhD program had plans to expand into a full-fledged post graduate institution giving both MSc and PhD degrees under the aegis of HBNI. It is a pleasure to report that HBNI has approved the academic program of the 2-year Masters degree. The institute needs to set up a teaching laboratory for the physics course. It has the space infrastructure but the laboratory equipments need to be bought. Over the first four years of the 12th five year plan some money had been saved and DAE has very kindly allowed the institute to use those funds for purchasing equipments for the laboratory course. It is expected that the two year MSc program will start in August 2017.

Jayanta Kumar Bhattacharjee
Director

List of Governing Council Members

(2015 -16)

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. Mr. R. A. Rajeev
   Joint Secretary (Finance) DAE
   Govt. of India,
   Anushakti Bhavan
   Chhatrapati Shivaji Maharaj Marg
   Mumbai 400 001

4. Smt. Chitra Ramachandran
   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
   University of Mumbai
   Department of Atomic Energy
   Centre for Excellence in Basic Sciences (UM-DAE-CBS)
   Health Centre Building
   University of Mumbai

Kalina Campus
Mumbai 400 098

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

8. Director, Higher Education, (Ex-officio)
   Higher Education, U.P.
   Near G.P.O., Civil Lines,
   Allahabad - 211 001

9. Mr. S. L. Mehta
   4, Clive Row
   KOLKATA - 700 001

10. Mr. Avnish Mehta
    4, Penn Road,
    KOLKATA- 700 027

11. Mr. Rajnish Mehta
    4, Penn Road,
    KOLKATA- 700 027

12. Prof. J. K. Bhattacharjee (Ex-officio)
    Director,
    Harish-Chandra Research Institute
    Chhatnag Road, Jhunsi
    Allahabad - 211 019

ACADEMIC STAFF

Faculty Members (Mathematics)

1. Prof. S.D. Adhikari
2. Prof. B. Ramakrishnan
3. Dr. Kalyan Chakraborty
4. Dr. Rukmini Dey
5. Dr. Punita Batra
6. Dr. D. Surya Ramana
7. Dr. R. Thangadurai
8. Dr. N. Raghavendra
9. Dr. C.S. Dalawat
10. Dr. Ratnakumar PK
11. Dr. Manoj Kumar
12. Dr. Gyan Prakash
13. Dr. Hemangi M. Shah

Faculty Members (Physics)

1. Prof. Jayanta Kumar Bhattacharjee
2. Prof. B. Mukhopadhyaya
3. Prof. S. Naik
4. Prof. Sudhakar Panda
5. Prof. Raj Gandhi
6. Prof. Ashoke Sen
7. Prof. Sumathi Rao

8. Prof. Dileep Jatkar
9. Prof. Pinaki Majumdar
10. Prof. Rajesh Gopakumar
11. Dr. T. P. Pareek
12. Dr. Prasenjit Sen
13. Dr. Tapas Kumar Das
14. Dr. Aseshkrishna Datta
15. Dr. Sandhya Choubey
16. Dr. Ujjwal Sen
17. Dr. Aditi Sen De
18. Dr. G.Venketeswara Pai
19. Dr. Arun Kumar Pati
20. Dr. Anirban Basu
21. Dr. Santosh Kumar Rai
22. Dr. Anshuman Maharana

Administrative Staff

1. Shri Ravindra Singh [Registrar]
2. Shri Rajkumar Gulati [Accounts Officer]
3. Dr. Vijay Raghav Tiwari [S.O. 'E']
4. Shri Manish Sharma [Scientific Officer 'D']
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 Jagannath Yadav [Accountant]
10. Shri R.P. Sharma [Manager Guest House]
11. Ms. Archana Tandon [Office Superintendent]
12. Ms. Anju Verma [Scientific Assistant]
13. Shri U.K. Dwivedi [Cashier]
14. Shri D. Malhotra [Upper Division Clerk]
15. Shri K.K. Srivastava [Upper Division Clerk]
16. Shri Yashpal Singh [Stenographer]
17. Ms. Sumitra [Upper Division Clerk]
18. Ms. Seema Agarwal [Receptionist]
19. Mr. Om Kumar Karn [Junior Hindi Translator]
20. Shri Surendra Yadav [Store/Purchase Officer]
21. Shri D.P. Sharma [Jr. Lib. Assistant]
22. Shri Sanjeev Nagar [Hindi Typist]
23. Shri D.N. Dubey [Bearer (Canteen Cadre)]

24. Shri Kamlesh Thakur [Bearer (Canteen Cadre)]
25. Shri R.K. Dixit [Peon/Watchman]
26. Shri Kamta Prasad [Peon/Watchman]
27. Shri Rajesh Kumar [Sweeper]
28. Shri Munna Lal [Gardener]

Visiting Fellow

Mathematics

1. Dr. Makoto Sakagaito
2. Dr. Varun Dilip Thakre
3. Dr. Abhitosh Upadhyay
4. Dr. Sudhansu Sekhar Rout
5. Mr. Ramdinmawia Vanlalngaia
6. Mr. Shailesh Trivedi
7. Dr. Prem Prakash Pandey
8. Dr. Rahul Dattatray K
9. Dr. Sayani Bera
10. Dr. Saibal Ganguli
11. Dr. Samrith Ram
12. Dr. Biswajit Ransingh
13. Mr. Raj Kumar Mistri
14. Dr. Rameez Raja
15. Dr. Azizul Hoque
16. Ms. Saudamini Nayak
17. Dr. Mahendra Kumar Verma

Physics

1. Dr. Debraj Rakshit
2. Dr. Abhishake Sadhukhan
3. Ms. Priyanka Mohan
4. Mr. Nilay Kundu

5. Dr. Menika Sharma
6. Dr. Namrata Shukla
7. Dr. Amit Kumar Pal
8. Mr. Subhadeep Mondal
9. Mr. Himadri Shekhar Dhar
10. Mr. Debajyoti Dutta
11. Mr. Nandan Roy
12. Mr. Samyadeb Bhattacharya
13. Dr. Dheeraj Kumar Singh
14. Mr. Dushyant Kumar
15. Dr. Venkata Suryanarayana
16. Mr. Avirup Shaw
17. Dr. Keita Nii
18. Mr. Anirban Biswas

Visiting Scientist

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

Research Scholar

Mathematics

1. Mr. Divyang G. Bhimani
2. Mr. Ramesh Manna
3. Mr. Balesh Kumar
4. Mr. Bibekananda Maji
5. Ms. Debika Banerjee
6. Mr. Mallesham K
7. Mr. Pallab Kanti Dey
8. Mr. Rahul Kumar Singh
9. Mr. S. Manikandan
10. Mr. Bhuwanesh Rao Patil
11. Mr. Arvind Kumar
12. Mr. E. Pramod
13. Mr. Manish Kumar Pandey
14. Mr. Nabin Kumar Mehar
15. Mr. Pradeep Das
16. Mr. Anup Kumar Singh
17. Mr. Mithun Kumar Das
18. Ms. Sumana Hatui
19. Ms. Ritika Sharma
20. Mr. Tusar Kanta Naik
21. Mr. Soumyarup Banerjee
22. Mr. Anoop Singh

23. Mr. Veekesh Kumar
24. Mr. Jaitra Chattopadhyay
25. Mr. Subha Sarkar
26. Mr. Debasish Karmakar
27. Mr. Lalit Vaishya
28. Ms. Bidisha Roy

Physics

1. Mr. Nyayabanta Swain
2. Mr. Abhishek Chowdhury
3. Mr. Swapnamay Mondal
4. Ms. Shrobona Bagchi
5. Mr. Mehedi Masud
6. Mr. Avijit Misra
7. Ms. Avinanda Chaudhuri
8. Mr. Aritra Gupta
9. Mr. Abhishek Joshi
10. Mr. Uttam Singh
11. Mr. Kadge Samrat Suresh
12. Mr. Dibya Kanti Mukherjee
13. Mr. Arijit Dutta
14. Mr. Sauri Bhattacharya
15. Mr. Tamoghna Das
16. Mr. Krashna Mohan Tripathi
17. Mr. Asutosh Kumar

18. Mr. Debasis Mondal
19. Mr. Nabarun Chakrabarty
20. Mr. Dhruv Pathak
21. Mr. Aditya Banerjee
22. Mr. Udit Khanna
23. Ms. Arpita Sen
24. Ms. Ajanta Maity
25. Mr. Debasis Sadhukhan
26. Mr. Sudipto Singha Roy
27. Mr. Mritunjay Kumar Verma
28. Mr. Sitender Pratap Kashyap
29. Ms. Juhi Dutta
30. Mr. Titas Chanda
31. Mr. Subhroneel Chakrabarti
32. Mr. Satadal Datta
33. Mr. Jyotiranjan B.
34. Mr. Kasinath Das
35. Ms. Ruchi Saxena
36. Md. Arif Shaikh
37. Mr. Siddharth Dwivedi
38. Mr. Gautam Sharma
39. Mr. Chiranjib Mukhopadhyay
40. Mr. Ritabrata Bhattacharya
41. Mr. Sarif Khan
42. Mr. Shouvik Roychoudhury

43. Ms. Sreetama Das
44. Mr. Dipyaman Pramanik
45. Mr. Sandeep Kumar Sehrawat
46. Mr. Samiran Roy
47. Mr. Abhass Kumar
48. Mr. Biswajit Sahoo
49. Ms. Tanaya Ray
50. Mr. Soumyananda Goswami
51. Mr. Saptarshi Roy
52. Mr. Khorsed Alam
53. Mr. Avirup Ghosh
54. Mr. Ratul Mahanta
55. Mr. Arpan Kar
56. Ms. Rhucha Deshpande
57. Mr. Susovan Maity
58. Mr. Sohail
59. Mr. Chirag Srivastava
60. Mr. Suman Jyoti De
61. Mr. Abhishek Yadav

Academic Report - Mathematics

Sukumar Das Adhikari

Research Summary:

Continuing work on some zero-sum problems in additive combinatorics, problems related to existence of monochromatic solutions of certain equations for finite colorings of integers and some extremal problems in combinatorics.

Publications:

1. Sukumar Das Adhikari and Eshita Mazumdar, *The polynomial method in the study of zero-sum theorems,* Int. J. Number Theory, **11**, No. 5, 1451–1461 (2015).

2. S. D. Adhikari, L. Boza, S. Eliahou, J. Marín, M. Revuelta and M. Sanz, *On the n-color Rado number for the equation $x_1+x_2+\cdots+x_k+c = x_{k+1}$*, Math. Comp. **85**, 2011-2045 (2016).

3. S. D. Adhikari, Eshita Mazumdar and B. K. Moriya, *Relation between two weighted zero-sum constants*, Integers **16**, paper A 20, (2016).

Conference/Workshops Attended:

1. *30th Annual conference of the Ramanujan Mathematical Society*, IISER, Mohali, May, 2015.

2. *IST on Number Theory*, KSOM, Kozhikode, Kerala, October 2015.

3. *A conference in Number Theory, Celebrating 65th birthday of R. Balasubramanian*, IMSc, Chennai, December, 2015.

4. *Combinatorial and Additive Number Theory 2016*, Graz, Austria, January 2016.

5. *Indo-French Conference*, IMSc, Chennai, January 2016.

6. *International Number Theory Conference, to celebrate the 60th birthday of Krishna Alladi*, Department of Mathematics, University of Florida, Gainesville, USA, March 17-21, 2016.

Visits to other Institutes:

1. ULCO, Calais, France, March-April, 2015.
2. Université Lille I, France, April, 2015.
3. Department of Mathematical Sciences, Rutgers University, Camden, New Jersey, April, 2015.
4. Department of Mathematics, University of Rochester, April, 2015.
5. IISER, Mohali, May, 2015.
6. IISER, Bhopal, August, 2015.
7. KSOM, Kozhikode, Kerala, October 2015.
8. Departamento de Matemática Aplicada I, Universidad de Sevilla, Spain, October, 2015.
9. IMSc, Chennai, December, 2015.
10. Udai Pratap (Autonomous) College, Varanasi, December, 2015.
11. University of Graz, Austria, January 2016.
12. RKMVU, Belur, February, 2016.
13. University of Florida, Gainesville, USA, March, 2016.
14. CUNY Graduate Center, New York, March, 2016.
15. Indian Statistical Institute, New Delhi, March, 2016.
16. School of Physical Sciences, Jawaharlal Nehru University, Delhi, March, 2016.

Invited Lectures/Seminars:

1. *Plus-minus zero-sum theorems*, Seminar series 'TANyAH", Université Lille I, France, April 1, 2015.
2. *Weighted generalizations of some zero-sum constants*, Departmental Seminar, ULCO, Calais, France, April 9, 2015.

3. *A classical zero-sum theorem and some related results*, Departmental Seminar, Department of Mathematical Sciences, Rutgers University, Camden, New Jersey, April 13, 2015.

4. *A classical zero-sum theorem and some generalizations*, Departmental Seminar, Department of Mathematics, University of Rochester, April, 2015.

5. *Two early Ramsey-type theorems in Combinatorial Number Theory: Some early generalizations and some recent results*, Plenary lecture, 30th Annual conference of the Ramanujan Mathematical Society, IISER, Mohali, May, 2015.

6. *Some early Ramsey-type theorems with applications,* Departmental Seminar, IISER, Bhopal, August, 2015.

7. *A classical result in Additive Combinatorics, an application and some related results,* Departmental Seminar, IISER, Bhopal, August, 2015.

8. *A course of lectures on Number Theory*, IST on Number Theory, KSOM, Kozhikode, Kerala, October 2015.

9. *Zero-sum theorems in Combinatorial Number Theory*, Departmental Seminar, Departamento de Matemática Aplicada I, Universidad de Sevilla, Spain, October 30, 2015.

10. *The polynomial method in the study of zero-sum theorems*, A conference in Number Theory, Celebrating 65th birthday of R. Balasubramanian, IMSc, Chennai, December, 2015.

11. *Some classical results in combinatorics,* INSPIRE internship science camp, Udai Pratap (Autonomous) College, Varanasi, December 27, 2015.

12. *Some classical Ramsey-type theorems: Early and recent applications,* Combinatorial and Additive Number Theory 2016, Graz, Austria, January 2016.

13. *A classical Ramsey-type result of Schur*, Indo-French Conference, IMSc, Chennai, January 2016.

14. *Some classical Ramsey-type theorems*, Departmental Seminar, Dept of Computer Science, RKMVU, Belur, February 17, 2016.

15. *Some weighted zero-sum results* , International Number Theory Conference, to celebrate the 60th birthday of Krishna Alladi, Department of Mathematics, University of Florida, Gainesville, USA, March 17-21, 2016.

16. *A classical Ramsey-type result of Schur*, New York Number Theory Seminar, CUNY Graduate Center, New York, March 24, 2016.

17. *Some basic results in set additions and early zero-sum theorems*, Mathematics Seminar, School of Physical Sciences, Jawaharlal Nehru University, Delhi, 31st March, 2016.

Academic recognition/Awards:

- Received Distinguished Faculty Award of Homi Bhabha National Institute (HBNI) in 2015.
- Received D. Sc. (Honoris Causa) from Kazi Nazrul University, Asansol, West Bengal, in 2016.

Other Activities:

1. Member of 'the National Board for Higher Mathematics' (NBHM).
2. Currently Dean, Administration, at HRI.
3. Member of the editorial board of 'The Journal of the Indian Mathematical Society'.
4. Member of the editorial board of 'Proceedings of the Indian Academy of Sciences - Mathematics'.
5. Member of the editorial board of 'Bulletin of the Calcutta Mathematical Society'.
6. Member of the editorial board of the periodical 'Mathematics Newsletter' published by Ramanujan Mathematical Society.
7. Gave a course on topology at SPIM 2015 in June 2015 at HRI.

Ramakrishnan Balakrishnan

Research Summary:

1. **On the number of representations of certain quadratic forms in 20 and 24 variables** (joint work with Brundaban Sahu): Let

$$F_k : x_1^2 + x_1x_2 + x_2^2 + \cdots + x_{2k-1}^2 + x_{2k-1}x_{2k} + x_{2k}^2$$

be a quadratic form in $2k$ variables and let

$$s_{2k}(n) = \text{card}\left\{(x_1, x_2, \ldots, x_{2k}) \in \mathbf{Z}^{2k} : F_k(x_1, x_2, \ldots, x_{2k}) = n\right\}$$

be the number of representations of a positive integer n by the quadratic form F_k. For $k = 2, 4, 6, 8$ formulas for $s_{2k}(n)$ are known due to the works of J. Liouville (1863), J. G. Huard et. al. (2000), O. X. M. Yao and E. X. W. Xia (2014) and the present authors (2014). In this work, by evaluating certain triple convolution sums of the divisor functions, we find formulas for $s_{2k}(n)$, for $k = 10, 12$. These formulas involve the divisor functions and Fourier coefficients of certain cusp forms of weight k. Now, G. A. Lomadze (1989) gave formulas for $s_{2k}(n)$ for $2 \leq n \leq 17$, which involves the divisor functions and certain finite sums which involve the solution set of the representation of same quadratic forms of lower variables. Thus, by comparing our formulas with Lomadze's formulas, we obtain expressions for the Fourier coefficients of the cusp forms appearing in our formulas in terms of finite sums coming from Lomadze's formulas.

2. **On the number of representations of octonary quadratic forms with coefficients** $1, 2, 3, 4$ **and** 6 (joint with Brundaban Sahu and Anup Kumar Singh): Recently there have been many results on finding the formulas for the number of representations of octonary quadratic forms with coefficients $1, 2, 3, 6$. Though earlier results used some other method (elementary or theta series identities), the recent methods adopt the theory of modular forms to obtain these formulas. Essentially, they use the fact that each quadratic form can be expressed as a product of theta series and using the expression for the theta function in terms of eta functions, they showed that each case represents an eta-quotient and then show that these eta-quotients are modular forms of weight 4 on some level (depending on the coefficients of the quadratic forms considered). By finding explicit bases for the space of modular forms of weight 4, they gave the required formulas. In our work (which is in progress), we consider octonary quadratic forms with coefficients $1, 2, 3, 4, 6$ and by directly showing that each of the quadratic form is a modular form (without expressing them in terms of

the eta functions) of weight 4 we give formulas using the explicit basis of the space of modular forms.

Preprints:

1. B. Ramakrishnan and Brundaban Sahu, *On the number of representations of certain quadratic forms in 20 and 24 variables,* Funct. Approx. Comment. Math. (accepted)

2. B. Ramakrishnan and Brundaban Sahu, *Evaluation of convolution sums and some remarks on cusp forms of weight 4 and level 12,* Math. J. Okayama Univ. (accepted)

3. B. Ramakrishnan, Brundaban Sahu and Anup Kumar Singh, *On the number of representations of an integer by certain octonary quadratic forms with coefficients $1, 2, 3, 4$ and 6,* (in preparation)

Conference/Workshops Attended:

1. *ISL, Number Theory*, KSOM, Kozhikode, India, October 2015.

2. *Conference in Number Theory*, IMSc, Chennai, India, December 2015.

3. *7th National Conference on "Ramanujan's Contributions and Current Trends in Mathematics"*, Madurai-Kamaraj University, Madurai, India, December 2015.

4. *Indo-French Programme for Mathematics*, IMSc, Chennai, India, January 2016.

5. *Ramanujan Math & IT (RMIT) 2016*, IIIT, Bangalore, India, January 2016.

6. *Workshop on Automorphic Forms*, KSOM, Kozhikode, India, February 2016.

7. *International Conference on Number Theory*, University of Florida, Gainesville, USA, March 2016.

Visits to other Institutes:

1. Kerala School of Mathematics, Kozhikode, India, September 2015 to February, 2016.
2. The Institute of Mathematical Sciences, Chennai, India, November 2015.
3. NISER, Bhubaneswar, India, December 2015.

Invited Lectures/Seminars:

1. *Convoltion sums of the divisor functions and the number of representations of certain quadratic forms*, Conference in Number Theory, The Institute of Mathematical Sciences, Chennai, December 2015.
2. *Convolution sums of the divisor function and some applications*, 7th National Conference on "Ramanujan's Contributions and Current Trends in Mathematics" , Madurai-Kamaraj University, Madurai, December 2015.
3. *Theory of newforms of half-integral weight*, Indo-French Programme for Mathematics, The Institute of Mathematical Sciences, Chennai, January 2016.
4. *Representation numbers for certain class of quadratic form and some applications*, Ramanujan Math & IT (RMIT) 2016, The International Institute of Information Technology, Bangalore, January 2016.
5. *Representation numbers for certain class of quadratic forms and some applications*, International Conference on Number Theory, University of Florida, Gainesville, USA, March 2016.

Academic recognition/Awards:

- Elected Treasurer of the National Academy of Sciences, Allahabad, 2016.

Other Activities:

1. One of the organisers and a speaker in the "Workshop on Automorphic Forms" (organised jointly by HRI and KSOM) held at the Kerala School of Mathematics, Kozhikode, February 2016.

Punita Batra

Research Summary:

The twisted full toroidal Lie algebras are extensions of multiloop algebras twisted by several finite order automorphisms. We generalised a result by Fu and Jiang, where they consider only one automorphism. We did some modification in the preprint "Integrable modules for the twisted full toroidal Lie algebras". Work is in progress of the classification of real forms of affine super Kac-Moody algebras.

Publications:

1. Punita Batra and Hiroyuki Yamane, *Skew centers of rank-one generalized quantum groups,* **Toyama Mathematical Journal, Volume 37, 189-202 (2015).**

2. S.Eswara Rao and Punita Batra, *Classification of irreducible integrable highest weight modules for current Kac-Moody algebras,* **To appear in Journal of Algebra and its Applications.**

Preprints:

1. S. Eswara Rao and Punita Batra, *On integrable modules for the twisted full toroidal Lie algebra,* arXiv:1509.02759, Submitted.

Conference/Workshops Attended:

1. "Representation Theory XIV" at Inter University Centre, Dubrovnik , Croatia, June 21-26, 2015.

Visits to other Institutes:

1. School of Mathematics, TIFR, Mumbai during May 1-4, 2015.

2. Inter University Centre, Dubrovnik, Croatia during June 21-26,2015.

Invited Lectures/Seminars:

1. *The irreducible modules for the Lie algebra* $Der(\mathbb{C}_q) \propto \mathbb{C}_q$, **Representation Theory XIV, Dubrovnik**, Croatia, June 22, 2015.

Other Activities:

1. Gave two lectures in the Rajbhasha scientific workshop at HRI in May 2015.
2. One of the organiser of SPIM 2015.
3. Gave five lectures on " Field Theory" in Summer Programme in Mathematics(SPIM) at HRI in June, 2015.
4. Gave a first year graduate course Algebra-I during August-December 2015.
5. Convener of the Sports and Entertainment Committee and Mathematics Visitor's Committee at HRI. Also serving as a member in the Rajbhasha Committee.
6. Organiser, Mathematics faculty meetings of HRI since May 2013.

Kalyan Chakraborty

Research Summary:

In a joint work titled 'Abel-Tauber Process and Asymptotic Formulas' with D. Banerjee, B. Maji and S. Kanemitsu we obtain (as an Abelian result) asymptotic formulas for the higher order Riesz sums of the arithmetic function generated by

$$Z^*(s) = \sum_{n=1}^{\infty} \frac{a_n^*}{\lambda_n^s}.$$

Then applying Landau's differencing argument we deduce an asymptotic formula for the summatory function of a_n^*. The latter is described as the Tauberian process. The novelty of our method is the incorporation of the classical *Selberg type divisor problem* in the process by viewing the contour integral of the form $\frac{1}{2\pi i}\int_{C_r} Z^*(s)\frac{x^s}{s}\,\mathrm{d}s$ as part of the residual function. Another novelty of our work lies in the uniformity of the error term in the additional parameter Δ, which varies according to the cases.
D. Zagier in the year 1981 conjectured that the series $\sum_{n=1}^{\infty} \tau^2(n)\exp(-nz)$ behaves asymptotically when $z \to 0$, in terms of the zeors of the Riemann zeta function $\zeta(s)$. Hafner and Stopple recently have verified this conjecture assuming Riemann hypothesis. In a joint work with B. Maji and S. Kanemitsu titled 'Modular type relations associated to Rankin-Selberg L-Functions' we use functional equation of Rankin-Selberg L-function to prove that the Lambert series $\sum_{n=1}^{\infty} c^2(n)\exp(-nz)$ also behaves asymptotically in terms of the zeros of $\zeta(s)$ when $z \to 0$, where $c(n)$ is the nth Fourier coefficient of any cusp form f over $\Gamma = SL(2,\mathbb{Z})$.

In another work jointly with S. Kanemitsu and A. Laurinčikas titled 'Complex powers of L-functions and integers without small prime factors' we consider the asymptotic formula for the sum

$$H(x) = \sum_{n\le x} h_v(n)$$

associated to the product of two powers of Hecke eigen cusp form, which is similar to but more general than that of some recent works of Laurinčikas et.al.. We work with the modified Selberg class L-functions $L(s)$ which satisfy all the conditions plus the stronger near-orthogonality conjecture . We verify these conditions only for Hecke eigen cusp form zeta-functions. Another novelty is that we recover simultaneously the well-known result about the number of integers without small prime factors.

Riemann asserted that the function (according to Weierstrass),

$$f(x) = \sum_{n=1}^{\infty} \frac{\sin n^2 x}{n^2}$$

is nowhere differentiable. Gerver in 1970 disproved Riemann's assertion by showing that his function is differentiable at any point of the form $\psi\pi$ where ψ is of the form $(2A+1)/(2B+1)$ with derivative equal to $-1/2$. In a work jointly with S.Kanemitsu and H.L. Li titled 'Quadratic reciprocity and Riemann's non-differentiable function' we observe that Riemann's function $f(x)$ is really an integrated form of the classical θ- function. Then we make the link to quadratic reciprocity from an exposition of R. Murty and A. Pacelli who (following Hecke) showed that the transformation law for the theta function can be used to derive the law of quadratic reciprocity. We combined these two ideas so as to derive both, the differentiability of f at certain points and the law of quadratic reciprocity.

In another work jointly completed with B.M. Phong and I. Kátai titled 'Additive functions on the greedy and lawy Fibonacci expandsion' we find all complex-valued functions that are additive with respect to both the greedy and the lazy Fibonacci expansions. We take it a little further by considering the subsets of these functions that are also multiplicative. We also extend these ideas to tribonacci expansions.

Publications:

1. Kalyan Chakraborty and Makoto Minamide, *On Power moments Of The Hecke Multiplicative Functions,* J. Aust. Math. Soc. **99**, 333-340, (2015)

2. K. Chakraborty, S. Kanemitsu and Y. Sun, *Codons and Codes,* Pure and Applied Mathematics Journal **4**, 25–29, (2015)

3. T. Arai, K. Chakraborty and J. Ma, *Applications of the Hurwitz-Lerch zeta function,* Pure and Applied Mathematics Journal **4**, 30–35, (2015)

4. K. Chakraborty, S. Kanemitsu and H. Tsukada, Applications of the Beta-Transform, Šiauliai Mathematical Seminar. **10**, 5–28 , (2015)

5. K. Chakraborty, S. Kanemitsu and H. -L. Li, *Quadratic reciprocity and Riemann's non-differentiable function*, Research in Number Theory, **1:14**, DOI 10.1007/s40993-015-5 (2015)

6. K. Chakraborty, S. Kanemitsu and H. Tsukada, *Ewald expansions of a class of zeta-functions*, SpringerPlus, **5:99**, DOI 10.1186/s40064-016-1732-5 (2016)

7. T. Arai, K. Chakraborty and S. Kanemitsu, *On Modular Relations,* Series on Number Theory and its Applications, World Scientific, **11**, 1–64, (2015)

8. B. Maji, K. Chakraborty and S. Kanemitsu, *Modular type relations associated to the Rankin-Selberg L-functions,* The Ramanujan Journal,**(To Appear)**

9. K. Chakraborty, I. Kátai and B. M. Phong, *Additive functions on the greedy and lazy Fibonacci expansions,* Journal of Integer Sequences, **(To Appear)**

10. Kalyan Chakraborty, Shigeru Kanemitsu and Takako Kuzumaki, *A Quick Introduction to Complex analysis,* World Scientific, (2016)

Preprints:

1. B. Maji, D. Banerjee, K. Chakraborty and S. Kanemitsu, *Abel-Tauber Process and asymptotic formulas,* preprint

2. K. Chakraborty, S. Kanemitsu and A. Laurinčikas, *Complex powers of L-functions and integers without small prime factors,* preprnt

Conference/Workshops Attended:

1. *ICSFA*, India, September 2015.

2. *Triveni Confernce*, India, February 2016.

3. *Intl. Conference on Number Theory*, China, March 2016.

Visits to other Institutes:

1. SAG, Delhi, India, May 2015,

2. Kinki University, Japan, October 2015.

3. Northwest University, China, March 2016.

4. Weinan Normal University, China, March 2016.

Invited Lectures/Seminars:

1. *Number Field Sieve*, Integer factorization, SAG, Delhi, May 2015.

2. *On Hurwitz-Lerch zeta-function*, ICSFA, Amity University, Delhi, September 2015.

3. *Riemann zeros*, Number theory Seminar, Kinki University, Japan, October 2015.

4. *A Sauntering around the Number Garden*, INSPIRE CAMP, Pt. Ravi Shankar Shukla University, Raipur, December 2015.

5. *Cryptography–The Science of Information Security*, INSPIRE CAMP, BBS College of Engn., Allahabad, January 2016.

6. *Complex powers of L-functions and integers without small prime factors* , Intl. Conference in Number Theory, Northwest University, China, March 2016.

7. *Complex powers of L-functions and integers without small prime factors*, Triveni Conference, HRI, India, February 2016.

8. *On Riemann zeros*, Number Theory Seminar, Weinan Normal university, China, March 2016.

Other Activities:

1. 2nd Semester Analysis Course, December, 2015-16.

2. NBHM M.Sc. and Ph.D. Fellowship Examinations and Interviews, November/March, 2015–16.

Chandan Singh Dalawat

Research Summary :

Castañeda and Wu have recently established a relationship between the possible exponents of the differents of intermediate extensions $L|E|K$ which have degree p over K and the lower ramification breaks of certain p-extensions $L|K$ of a local field K of prime characteristic p. We show that the p-extensions they consider are necessarily abelian of exponent p, that the same relationship holds more generally when K has residual characteristic p, and that it is more easily derived by using the ramification filtration in the upper numbering and Herbrand's theorem. Our proof is purely local, purely conceptual, more natural, and much shorter.

Publications:

1. C S Dalawat & J-J Lee, *Tame ramification and group cohomology*, to appear in the Journal of the Ramanujan Mathematical Society

Preprints:

1. *The ramification filtration in certain p-extensions*, 5 pages, `arXiv:1508.02228`

Conferences/Workshops Attended:

1. *Arithmétique et autres mathématiques*, Institut Henri Poincaré, Paris, France, 2–3 June 2015.
2. *Algebraic Geometry*, Indian Statistical Institute, Bangalore, 10–16 December 2015.

Visits to other Institutes:

1. International Centre for Theoretical Sciences, Banaglore, 6–11 July 2015.
2. Institute for Research in Fundamental Sciences, Tehran, 7 September–2 October 2015.
3. Indian Institute of Science Education and Research, Trivandrum, 17–26 December 2015.

4. Indian Statistical Institute, Delhi, 15–19 February 2016.

5. Indian Institute of Technology, Bombay, 22–26 February 2016.

Invited Lectures/Seminars:

1. *La composée de toutes les extensions de degré p d'un corps local de caractéristique résiduel p*, Groupe d'étude sur les problèmes diophantiens, Paris VI, 4 June 2015.

2. *The compositum of all degree-p extensions of a local field of residual characteristic p*, Institut for Matematiske Fag, Københavns Universitet, 12 June 2015 ; Indian Statistical Institute, Bangalore, 10 December 2015.

3. *Higher Reciprocity Laws*, Colloquium, International Centre for Theoretical Sciences, 7 July 2015.

4. *Reciprocity Laws and Equidistribution Laws*, Institute for Research in Fundamental Sciences, Isfahan, 26 September 2015 ; Indian Institute of Science Education and Research, Trivandrum, 22 December 2015 ; Indian Statistical Institute, 19 February 2016.

5. *The General Reciprocity Law*, Indian Institute of Science Education and Research, Trivandrum, 18 December 2015 ; Indian Statistical Institute, 17 February 2016.

6. *Tame ramification and group cohomology*, Jawaharlal Nehru University, 15 February 2016 : Indian Institute of Technology, 24 February 2016.

Other Activities:

Gave a set of two lectures in the outreach programme of the Institute. Examined the doctoral theses of a candidate from IIT Bombay and a candidate from the University of Hyderabad. Gave a set of four lectures in the Annual Foundation School. Mentored a student from St. Edmund's College, Shillong, and a student from NISER, Bhuvaneshwar. Gave a short course of six lectures on Local Quadratic Reciprocity at IPM, Tehran, at the invitation of the CDC of the IMU. Taught two graduate courses at HRI.

D. Surya Ramana

Research Summary:

A well-known theme in additive number theory is the study of additive representation of integers by natural numbers belonging to a set defined by multiplicative conditions such as, for example, the set of squares, or the primes or the squares of primes. Given such a set of natural numbers $\mathcal{A}$ and an integer $K \geq 1$, one may ask, generalising a problem posed by A. Sárközy, for the smallest natural number $a(K)$ such that when $\mathcal{A}$ is partitioned into K disjoint subsets, every large enough integer is expressible as a sum of no more than $a(K)$ elements of $\mathcal{A}$, all belonging to some one subset of the given partition of $\mathcal{A}$. In the first preprint listed below, we show with Gyan Prakash and O.Ramaré that $a(K) \leq K \exp\left(\frac{(3\log 2+o(1))\log K}{\log\log K}\right)$ when $\mathcal{A}$ is the set of squares. This improves on $a(K) \ll_\epsilon K^{2+\epsilon}$, which was the best available upper bound for $a(K)$, due to P. Akhilesh and myself. Moreover, our latest bound for $a(K)$ is optimal up to the constant $3\log 2$, which in any case, cannot be replaced by constant smaller than $\log 2$, as may be seen by considering specific examples.

The problem described in the preceding paragraph relies for its solution on upper bounds for the additive energy, and its analogues, of "large" finite subsets of the set $\mathcal{A}$. Given subsets A, B of $\mathcal{A}$ in intervals $(N, 2N]$ and $(M, 2M]$ with $|A| \geq \alpha N$ and $|B| \geq \beta M$, where N, M are large integers, the additive energy of A and B is the number of solutions to $x_1 + y_1 = x_2 + y_2$ with $(x_1, x_2) \in A^2$ and $(y_1, y_2) \in B^2$. In the second preprint listed below, which is in preparation, we obtain, together with Gyan Prakash and K. Mallesham, a sharp upper bound for this quantity when $\mathcal{A}$ is the set of primes.

Publications:

1. S.D. Adhikari and D.S. Ramana, *Some Omega Results and Related Questions Connected to R. Balasubramanian's Mathematical Work,* R.M.S. Lecture Notes Series **23**, 1-11, 2016.

2. R. Balasubramanian, Gyan Prakash and D.S. Ramana, *Sum-free subsets in finite abelian groups of type III,* European Journal of Combinatorics, 58(2016)181-202 (to appear).

Preprints:

1. Gyan Prakash, D. S. Ramana and O. Ramaré, *Monochromatic Sums of Squares*, pp 29.

2. K. Mallesham, Gyan Prakash and D.S. Ramana *A Combinatorial Problem and the Additive Energy of Large Sets of Primes* (in preparation).

Invited Lectures/Seminars:

1. *Chromatic Sums of Squares and Primes*, Combinatoire Additive á Marseille, CIRM, Luminy, France, September 2015.

2. *Chromatic Sums of Squares and Primes*, Conference in Number Theory, I.M.Sc., Chennai, December 2015.

Other Activities:

1. P. Akhilesh defended his thesis, written under my supervision, in March 2016.

Raghavendra Nyshadham

Research Summary:

I have been working with my students on Kähler structures and line bundles on moduli spaces of finite-dimensional representations of a finite-dimensional algebra over an algebraically closed field, and on moduli spaces of finite-dimensional representations, over an algebraically closed field, of a finite quiver.

Invited Lectures/Seminars:

1. *Lectures on topology*, Annual Foundational School II, Shiv Nadar University, Gautam Buddha Nagar, May 2015.
2. *Lectures on topology*, Annual Foundational School III, Harish-Chandra Research Institute, Allahabad, July 2015.
3. *Algebraic curves*, Harish-Chandra Lecture Series, Deen Dayal Upadhyaya College, Delhi, March 2016.

Ratnakumar Peetta Kandy

Research Summary:

My research work in the last one year was concerned with the study of regularity property of the Fourier integral operators, associated to the wave equation on $\mathbb{R}^n$. This work is jointly with my Ph.D. student Ramesh Manna. We have completed the study in dimension $n = 2$, obtaining optimal regularity estimate for the wave equation in the plane.

Publications:

1. Divyang G. Bhimani, P.K. Ratnakumar, *Functions operating on modulation spaces and nonlinear dispersive equations,* J. Funct. Analysis**270**, 621-648, (2016)
2. P.K. Ratnakumar, Vijay Kumar Sohani, *Nonlinear Schrdinger equation and the twisted Laplacian-Global well posedness,* Math. Z. **280**, 583-605, (2015)

Preprints:

1. Ramesh Manna, P.K. Ratnakumar *On local smoothing of Fourier integral operators in the plane,* (in preparation)

Conference/Workshops Attended:

1. *14th Discussion meeting on Harmonic Analysis*, India, December 2015.

Visits to other Institutes:

1. TIFR Centre for applicable mathematics, Bangalore, India, June 2015,
2. Kerala School of Mathematics, Kozhikode, India, June 2015.
3. Delhi University, Delhi, India, December 2015.
4. Indian Institute of Science, Bangalore, January 2016.

Invited Lectures/Seminars:

1. Nil

Academic recognition/Awards:

- Nil

Other Activities:

1. Taught the course on Differential Manifolds, in the Ph.D. Course work at HRI during January to April 2016.
2. Served in the PDF committee as the convener.

Gyan Prakash

Research Summary:

A well-known theme in additive number theory is the study of additive representation of integers by natural numbers belonging to a set defined by multiplicative conditions such as, for example, the set of squares, or the primes or the squares of primes. Given such a set of natural numbers $\mathcal{A}$ and an integer $K \geq 1$, one may ask, generalising a problem posed by A. Sárközy, for the smallest natural number $a(K)$ such that when $\mathcal{A}$ is partitioned into K disjoint subsets, every large enough integer is expressible as a sum of no more than $a(K)$ elements of $\mathcal{A}$, all belonging to some one subset of the given partition of $\mathcal{A}$. In the first preprint listed below, we show with Surya Ramana and O.Ramaré that $a(K) \leq K \exp\left(\frac{(3\log 2 + o(1))\log K}{\log\log K}\right)$ when $\mathcal{A}$ is the set of squares. This improves on $a(K) \ll_\epsilon K^{2+\epsilon}$, which was the best available upper bound for $a(K)$, due to P. Akhilesh and Surya Ramana. Moreover, our latest bound for $a(K)$ is optimal up to the constant $3\log 2$, which in any case, cannot be replaced by constant smaller than $\log 2$, as may be seen by considering specific examples.

The problem described in the preceding paragraph relies for its solution on upper bounds for the additive energy, and its analogues, of "large" finite subsets of the set $\mathcal{A}$. Given subsets A, B of $\mathcal{A}$ in intervals $(N, 2N]$ and $(M, 2M]$ with $|A| \geq \alpha N$ and $|B| \geq \beta M$, where N, M are large integers, the additive energy of A and B is the number of solutions to $x_1 + y_1 = x_2 + y_2$ with $(x_1, x_2) \in A^2$ and $(y_1, y_2) \in B^2$. In the second preprint listed below, which is in preparation, we obtain, together with Surya Ramana and K. Mallesham, a sharp upper bound for this quantity when $\mathcal{A}$ is the set of primes.

Publications:

1. R. Balasubramanian, Gyan Prakash and D.S. Ramana, *Sum-free subsets in finite abelian groups of type III,* European Journal of Combinatorics, **58**, 181-202, (2016)

Preprints:

1. Gyan Prakash, D. S. Ramana and O. Ramaré, *Monochromatic Sums of Squares,* pp 29.

2. K. Mallesham, Gyan Prakash and D.S. Ramana *A Combinatorial Problem and the Additive Energy of Large Sets of Primes* (in preparation).

Invited Lectures/Seminars:

1. *Solving a system of translation invariant linear equations of complexity one in a dense subset of integers or primes or Chen primes.* I.M.Sc., Chennai, December 2015.

Ravindranathan Thangadurai

Research Summary:

In this year, transcendental number theory from basics to advanced topic was taught to the peer number theory group. Focus was given to understand the classical and modern methods to solve problems in Transcendental Number Theory. Using b-ary expansion of real numbers, an attempt to give a nice criterion for algebraic irrationals. Nothing much is known so far but all conjectures floating.

In Diophantine equations, we studied the following: For a given integer ℓ and odd integer $k > 1$, final all the positive integer solutions (x, y) of the equation

$$1^\ell + 2^\ell + \cdots + (x - (k+1)/2)^\ell = (x + (k+1)/2)^\ell + \ldots + y^\ell ?$$

Indeed, it was proved that when $k = 3$ and $\ell = 3$ or 5, the above equation has no positive integral solutions whereas when $k = 3$ and $\ell = 2$, we proved that $(44, 56)$ is the only positive integral solution. In order to achieve these results, we used elliptic logarithmic methods to compute all the torsion points of certain Elliptic curves over number field.

Let G be a finite abelian p-group. We proved an upper bound for Erdos-Ginzburg-Ziv constant for G under the condition that the Davenport constant of G is not too much compared to the exponent of G. This result is towards a recent conjecture of W. Schimid.

Publications:

1. R. Thangadurai, K. Senthil Kumar and M. Waldschmidt , *Liouville numbers, Liouville sets and Liouville fields*, Proc. Amer. Math. Soc. (Series A), **143**, 3215-3229 (2015).
2. R. Thangadurai and S. Subburam, *On Erdős-Wood's conjecture*, Proc. Indian Acad. Sci. Math. Sci. **125**, 139-147 (2015).
3. R. Thangadurai, A Mukhopadyay and K. Viswanadham, *Unique representation of integers with base A*, Arch. Math. (Basel) **105**, 119-128, (2015).
4. R. Thangadurai and S. Subburam, *On the Diophantine equation* $ax^3 + by + c = xyz$, Funct. Approx. Comment. Math., **53**, 167-175 (2015).

Preprints:

1. R. Thangadurai and S. Rout, *On the l-th order of Balancing Numbers,* Preprint*, 2016*.

2. R. Thangadurai, M. N. Chintamani and P.Paul, *On the EGZ constant on finite abelian groups,* Preprint*, 2016*.

Conference/Workshops Attended:

1. AIS Analytic Number Theory at KIIT, Bhubaneswar during 2 June to 20 June, 2015.

2. AFS - III at HRI, Allahabad during 29, June to 04, July, 2015

3. IST at KSOM, Calicut during 04-15 October, 2015.

4. Number Theory Workshop at BITS Pillani, Goa Campus during 15-18, December, 2015.

5. TPM 2015, Central University of Tamil Nadu, Thiruvarur, 21-28, December, 2015.

6. Conference on Ramanujan Math and IT at IIIT Bangalore during 21-22, January, 2016.

7. Workshop on open source library software (KOHA) and RFID Integration for DAE libraries, IMSc, Chennai during 17-18, March, 2016.

Visits to other Institutes:

1. KIIT, Bhubaneswar, June, 2015.

2. Kerala School of Mathematics, Calicut, October, 2015.

3. BITS Pillani, Goa campus, Goa, December, 2015.

4. Central University of Tamilnadu, Thiruvarur, December, 2015.

5. Rajkumar Goel Engineering College, Ghaziabad, January, 2016.

6. IIIT Bangalore, January, 2016.

7. Central University of Hydrabad, Hydrabad, Februray, 2016.

8. IMSc, Chennai, March, 2016.

Invited Lectures/Seminars:

1. *Course on Modular forms*, AIS 'Analytic Number Theory', KIIT, Bhubaneswar, June, 2015.
2. *Introduction to Complex Analysis*, AFS - III, HRI, Allahabad, July, 2015.
3. *Topics in Elementary Number Theory*, IST 'Number Theory', KSOM, Calicut, October, 2015.
4. *Introduction to Transcendental Number Theory,* Number Theory Meet, BITS Pillani, Goa campus, Goa, December, 2015.
5. *Introduction to Group Theory*, TPM 2015, Central University of Tamilnadu, Thiruvarur, December, 2015.
6. *Decimal expansion of real numbers*, INSPIRE programme, Rajkumar Goel Engineering College, Ghaziabad, January, 2016.
7. *Four exponential conjecture*, Ramanujan Math and IT, IIIT Bangalore, January, 2016.

Other Activities:

1. Gave a second year advanced course on 'Transcendental Number Theory" during August-December, 2015.
2. Conducted Summer Programme in Mathematics (SPIM 2015) at HRI in June, 2015.
3. Conducted AFS - III along with D. S. Ramana at HRI in July, 2015.
4. Member of NBHM interview for MA/M.Sc scholarship and Ph. D fellowship.
5. Refereed papers in Integers, Proc. Japan Acd. Sci., Acta Arithmetica and Proceedings of Indian Academy of Sciences (Mathematical Sciences).
6. Member of the organizing committee of Triveni Number Theory Meet at HRI in March, 2016.
7. Convener of Transport Committee.

Manoj Kumar

Research Summary:

Let G be a p-group of order p^n and nilpotency class c, where p is a prime integer. Then we say that the coclass of G is $n - c$. Jointly with Marco Ruscitti and Leire Legarreta, we proved that a finite p-groups of coclass 3 admits a non-inner automorphism of order p provided $p \neq 3$.

This result contributes to the following well known conjecture by Berkovich: Every finite p-group admits a non-inner automorphism of order p.

An automorphism α of a group G is said to be central if it induces an inner automorphism on $G/Z(G)$, where $Z(G)$ denotes the center of G. A finite group G is said to be Miller if $Aut(G)$, the group of all automorphisms of G, is abelian. Recenty A. Caranty provided methods of constructing non-special Miller p-groups from special Miller p-groups. Jointly with Rahul Kitture, by constructing counter examples, we showed that these methods do not always work. We also provide substitutes of Caranti's method by putting an extra condition over Caranti's conditions.

These groups occur as an amalgamated semidirect product of a special Miller p-group with some conditions and certain cyclic group having order at least p^2, amalgamated at a subgroup M of order p.

Jointly with Tushar K. Naik, we classified (upto isoclinism) all finite p-groups having only two conjugacy class sizes 1 and p^3, where p is an odd prime. It is known that such groups can have nilpotency class at most 3. We show that there is no such group of nilpotency class 3. The class of such groups having nilpotency class 2 consists of certain Camina p-groups and certain quotients of a freest p-group of nilpotency class 2 on four generators.

Publications:

1. Manoj K. Yadav, *Class-preserving automorphisms of finite p-groups II,* Israel J. Math. **209**, 355-396, (2015).

2. Rajat K. Nath and Manoj K. Yadav, *On the probability distribution associated to commutator word map in finite groups,* Internat. J. Algebra Comput. **25**, 1107-1124, (2015).

3. Rajat K. Nath and Manoj K. Yadav, *Some results on relative commutativity degree,* Rend. Circ. Mat. Palermo (2) **64**, 229-239, (2015).

4. Silvio Dolfi and Manoj K. Yadav, *Finite groups whose non-linear irreducible characters of the same degree are Galois conjugate,* J. Algebra **452**, 1 - 16, (2016).

Preprints:

1. Marco Ruscitti, Leire Legarreta and Manoj K. Yadav, *Non-inner automorphisms of order p in finite p-groups of coclass 3,* Preprint.
2. Rahul D. Kitture and Manoj K. Yadav, *Note on Caranti's method of construction of Miller groups,* Preprint.
3. Tushar K. Naik, Manoj K. Yadav, *Finite p-groups of conjugate type $\{1, p^3\}$ upto isoclinism,* Preprint.

Conference/Workshops Attended:

1. *International conference on Semigroups Algebras and Applications*, Cochin University of Science and technology, Kochi, India, September 2015.

Visits to other Institutes:

1. University of Florence, Florence, Italy, June 2015.
2. University of L'Aquila, L'Aquila, Italy, July 2015.
3. IISER Trivendrum, September 2015.

Invited Lectures/Seminars:

1. *Finite p-groups with many class-preserving automorphisms* , Invited lecture, University of Florence, Italy, June 2015.
2. *Finite p-groups with many class-preserving automorphisms*, Invited lecture, Univ. Salerno, Italy, July 2015.
3. *Finite p-groups with maximum class-preserving automorphisms*, Invited lecture, Univ. Napoli, Italy, July 2015.
4. *Finite groups admitting maximal central quotient*, Invited lecture, INDAM, Univ. Rome, Italy, July 2015.
5. *Finite groups admitting maximal central quotient*, International conference on Semigroups Algebras and Applications, Kochin, Sept. 2015.

Academic recognition/Awards:

- M.N.A.Sc. (Member of the National Academy of Sciences, India), 2015.

Other Activities:

1. Examined a Ph. D. thesis for mathematics dept. of IIT Ropar, Sept. - Dec. 2015 and conducted viva-voce examination.
2. Refereed papers for many national and international journals.
3. Delivered a set of two lectures on automorphisms of finite groups at maths. dept., Univ. L'Aquila, Italy, July 2015.
4. Delivered a set of two lectures on automorphisms of finite groups at IISER Trivendrum, Sept. 2015.

Hemangi Madhusudan Shah

Research Summary:

I worked extensively on harmonic, asymptotically harmonic, Einstein spaces and pinching theorem for volume entropy from 1st April 2015 - 31st March 2016. The research summary is briefed as follows :

Asymptotically Harmonic Spaces:
1) 3-Dimensional Asymptotically Harmonic Manifolds With Minimal Horospheres :
Recently, I have proved in a published paper in "Arch. Der Math." that: if (M, g) is a complete, simply connected Riemannian manifold of dimension 3 without conjugate points and if M is asymptotically harmonic of constant $h = 0$, then M is a flat manifold. This theorem shows that any asymptotically harmonic manifold in dimension 3 is a symmetric space, thus completing the classification of asymptotically harmonic manifolds in dimension 3.
2) Asymptotically harmonic and Einstein manifolds with minimal horospheres :
In order to generalize the above result, in a recent preprint I have shown that: If (M, g) is a complete, simply connected and non-compact, Einstein and asymptotically harmonic manifold with minimal horospheres, then M is a flat manifold. This theorem generalizes the known result, that an asymptotically harmonic, homogeneous and Einstein manifold with minimal horospheres is flat. We also recover the well known result that a harmonic manifold with minimal horospheres is flat.

Pinching Theorem for Volume Entropy:
We are about to complete the proof of following statement:
Let (M^n, g) be a compact Riemannian manifold of dimension $n \geq 3$ satisfying: (i) diam$(M^n, g) \leq D$ (ii) Ricci $(g) \geq -(n-1)g$ and (iii) the volume entropy $h(g) \geq n - 1 - \varepsilon$. Then, there exists a positive constant $\varepsilon(n, D)$ such that, if $\varepsilon \leq \varepsilon(n, D)$, then the conclusion of the above theorem holds. Consequently, it follows:

(1) Our result extends the result of Gromov viz., that there exists a positive constant $\varepsilon(n, V)$ such that, if (M, g) is a compact Riemannian manifold of dimension $n \geq 4$, Vol $(M, g) \leq V$, and sectional curvatures are almost equal to -1, then (M, g) is C^1 diffeomorphic to a hyperbolic manifold.

(2) Our result also shows, that there exists a constant $v(n) > 0$, such that Vol $(M, g) \geq v(n)$. Thus, in particular, it answers a question raised by Ledrappier-Wang: Whether M of maximal volume-entropy can collapse?

Publications:

(1) H. Shah, *A new proof of the theorem: Harmonic manifolds with minimal horospheres are flat*, Proc. Indian Acad. Sci. (Math. Sci.) **124** (2014), no. 3, 419-425.

(2) H. Shah, *On 3-dimensional asymptotically harmonic manifolds with minimal horospheres*, Arch. Math. **106** (2016), no. 1, $81 - 84$.

Preprints:

(3) H. Shah, *Asymptotically harmonic and Einstein manifolds with minimal horospheres*, preprint.

(4) H. Shah, *Pinching theorem for volume entropy*, in preparation.

Conference/Workshops Attended:

1. International Conference on Boundaries and Ergodic Geometry, University of Notre Dame, USA, June 2015.

Visits to other Institutes:

1. Indiana University, Bloomington, Indiana, USA, May 2015.

Invited Lectures/Seminars:

1. *On 3-Dimensional Asymptotically Harmonic Manifolds with Minimal Horospheres*, seminar at Indiana University, Bloomington, Indiana, USA, May 2015.

Academic recognition/Awards:

1. Travel grant by Harish-Chandra Research Institute, Allahabad, India and local hospitality by University of Notre Dame, USA, to participate in the International Conference on Boundaries and Ergodic Geometry, June 2015.

2. Funds from National Centre for Mathematics (a joint centre of TIFR and IIT Bombay, India) to organize a workshop, titled "Geometry and Topology" at Harish-Chandra Research Institute, Allahabad, India, from November 02 - 07, 2015. Name of the Award, year.

Other Activities:

1. Gaurav Kumar, Pre-Ph.D. Student, Harish-Chandra Research Institute, Allahabad, India,
   July - August 2015, project: Analysis on Manifolds.

2. Graduate Students' Selection Committee, Harish-Chandra Research Institute, Allahabad, India,
   2014 - present.

3. Organized a national workshop on "Geometry and Topology", funded by National Centre for Mathematics (a joint centre of Tata Institute of Fundamental Research and Indian Institute of Technology, Bombay, India), from $02 - 07$ November, 2015, at Harish-Chandra Research Institute, Allahabad, India.
   The purpose of organizing this workshop was to help young researchers get started in a new research area related to Differential Geometry.

Satya Deo

Research Summary:

The academic year April 2015- March 2016 was devoted mainly in completing the project which I had undertaken as a NASI Senior Scientist for three years. I have mainly concentrated and worked on the colored version of the Tverberg theorem as formulated by Blagojević, Matschke and Ziegler. All the three proofs given by them are involved and I have simplified one of them which uses the degree concept of an equivariant map and the tests map/test space technique for proving the Tverberg type theorems. One of the most difficult problems which remained unsolved until recently about the classical Tverberg theorems has been resolved by Florian Frick (in arXiv Feb-2015). I have been writing a simplified expository article on that work of Frick. Frick has solved the main problem of course, but a new and interesting problem regarding the minimum possible dimension attainable for the counterexample given by Frick has been raised, and I am currently working on that problem.

I have given lectures on these works in several conferences, seminars, workshops organized by various universities and research institutes in the country. I have been working as the Editor-in-Chief of the Journal of Indian Mathematical Society (JIMS) and also the editors of two other journals viz., Indian Journal of Mathematics and the Proceedings of the National Academy of Sciences, India. A large number of popular talks for the benefit of school and college teachers of Allahabad and elsewhere in the country have been delivered by me over the year.

Publications:

1. Satya Deo and David Gauld, *Boundedly Metacompact or Finitistc Spaces and the Star Order of Covers,* J. Indian Math. Soc., **83**,01-20,(2016).
2. Satya Deo, *Colored Topolgical Tverberg Theorem of Blagojević, Matschke and Ziegler*, Math. Student,**84**,149-158,(2015).

Preprints:

1. Satya Deo, *Tverberg Theorem, the final steps,* in preparation

Conference/Workshops Attended:

1. *Annual Conference of the Indian Math Society*, Nagpur, India, Dec 2015.
2. *Annual Session of the National Academy of Sciences*, Bhubaneshwar, India, Dec 2015.

Visits to other Institutes:

1. IISc, Bangalore, India, June 2015.
2. University of Pune, Pune, India, July 2015.
3. R.S.Shukla University, Raipur, India, July 2015.
4. K.M.College, University of Delhi, Delhi, Dec 2015.

Invited Lectures/Seminars:

1. *Sets , Maps and Axiomatic Mathematics*, INSPIRE programme of DST, R.S.University, Raipur, Raipur, July 2015.
2. *Topological Dimension Theory and A-S cohomology*, ATM Workshop on Geometry and Topology, HRI, Allahabad, Allahabad, Nov 2015.
3. *The concept of Topological Dimension*, Refresher Course in Mathematics, University of Delhi, Delhi, Dec 2015.
4. *Sets, Maps and Axiomatic Mathematics*, INSPIRE Programme of DST, K.M.College, Delhi, Delhi, Dec 2015.

Academic recognition/Awards:

- Elected Editor-in-Chief of the Journal of Indian Mathematical Society, 2016-2019.
- NASI Senior Scientist Fellowship extended, 2016-2017.

Ramesh Manna

Research Summary:

In the past one year, I have been studying the local smoothing estimates for the Fourier integral operator of the form
$\mathcal{F}f(x,t) = \rho(t) \int e^{i<x,\xi>} e^{it|\xi|} a(\xi) \hat{f}(\xi) d\xi$, where $\rho \in C_c^\infty((1,2))$ and $a \in C^\infty(\mathbb{R}^n \setminus 0)$ is assumed to be homogeneous of degree zero in ξ. Smoothing property of this Fourier integral operators associated with the wave equation on $\mathbb{R}^n$ is being studied. The previous results was obtained by C. D. Sogge (1991). It was shown that, for $n = 2$ and $2 < p < \infty$ there is an $\epsilon(p) > 0$ so that

$$(\int_{t=1}^{2} \int_{\mathbb{R}^2} |(I-\Delta)^{\frac{\sigma}{2}} \mathcal{F}_t f|^p \, dxdt)^{\frac{1}{p}} \leq c_{\sigma,p} ||f||_{L^p(dx)}, \sigma < -(\frac{1}{2} - \frac{1}{p}) + \epsilon(p).$$

We obtain the optimal estimate (i.e., $p = 4$ with $\epsilon(p) = \frac{1}{p}$) in two dimensions. Proof of the refined estimate of this type involves frequency localization with suitable smooth cut off functions which form a partition of unity, and delicate machinery from Littlewood-Paley theory and the wave front statement.

Publications:

1. Ramesh Manna, *Weighted inequalities for spherical maximal operator*, Proc. Japan Acad. Ser. A **91**, (2015), pp. 135-140.
2. Ramesh Manna, *A simple proof of the Bourgain's circular maximal operator*, Eurasian Math. J., 2015, Volume 6, Number 3, pp. 45-53.

Preprints:

1. Ramesh Manna, P. K. Ratnakumar, *On Local Smoothing of Fourier Integral Operators in the plane*, (in preparation)

Talks:

1. Gave a contributory talk on "Weighted Inequalities for Spherical Maximal Operator and its application " **International Workshop on Operator Spaces and 14th Discussion Meeting on Harmonic Analysis**, Department of Mathematics, University of Delhi December 10-12, 2015.

2. Gave a contributory talk on “Maximal averages associated with families of finite type surfaces” **15th New Mexico Analysis Seminar**, February 19-21, 2016, University of New Mexico Albuquerque, New Mexico, USA.

3. Gave a departmental seminar talk on “Maximal and Fourier integral operators and its application” **Department of Mathematics and statistics**, February 24, 2016, University of New Mexico Albuquerque, New Mexico, USA.

Teaching assistant:

1. Took tutorial classes for the course ”Complex Analysis” in Annual Foundation Schools-III at Harish-Chandra Research Institute, allahabad, June 29 - July 25, 2015, Instructor: Prof. B Ramakrishnan, HRI, Allahabad.

Conference/Workshops Attended:

1. February 21 - 26, 2016, **Department of Mathematics and statistics, University of New Mexico**, New Mexico, Albuquerque, USA.

2. December 7 - 12, 2015, **International Workshop on Operator Spaces and The Forteenth Discussion Meeting on Harmonic Analysis (DMHA)** ,Department of Mathematics, University of Delhi, India.

3. *Visited School Of Mathematics*, Jun. to July 2015 , Kerala School Of Mathematics (KSOM), Kozhikode, India.

Other Activities:

1. Compiled HRI Annual Report for the academic year 2014-2015, May-July 2015.

DEBIKA BANERJEE

Research Summary:

A new type of divisor problem was studied with Prof. Makoto Minamide. Our last paper deals with the study of continuous and discrete mean value of the error term $\Delta_{(1)}(x)$ arising in the asymptotic formula for $\sum_{n\leq x} D_{(1)}(x)$. That is we have investigated $\int_1^x \Delta_{(1)}(x)\ dx$ also $\int_1^x \Delta_{(1)}^2(x)\ dx$ and for discrete case $\sum_{n\leq x} \Delta_{(1)}(n)$ and $\sum_{n\leq x} \Delta_{(1)}^2(n)$. Now we are trying to study higher power mean values of $\Delta_{(1)}(x)$, i.e., $\Delta_{(1)}^k(x)$ where $k > 2$. Then our next aim is to study relationship between $\Delta_{(1)}(x)$ and the error term appearing in the asymptotic expression for $\int_1^x \left(\zeta'(\frac{1}{2}+it)\right)^2\ dt$.

We are also interested in studying the problem $\sum_{n\leq x_{p|n} \implies p>y} 2^{w(n)}\mu^2(n)$ by applying basic estimates in sieve methods. Actually, the above function appears as the error term in Eratosthenes sieve.

Publiction:

1. Debika Banerjee and Makoto Minamide, The average behaviour of the error term in a new kind of the divisor problem to appear in Journal of Mathematical Analysis and Applications Volume 438, Issue 2, 15 June 2016, pages:533-550. (doi:10.1016/j.jmaa.2016.02.013).

2. Debika Banerjee, Shigeru Kanemitsu, Kalyan Chakraborty and Bibekananda Maji, Abel-Tauber process and asymptotic formulas with, Submitted.

Pradeep Das

Research Summary:

In a paper, A. D. King has shown that the moduli space of finite dimensional representations of a finite dimensional algebra over an algebraically closed field is a projective variety. He has used Geometric Invariant theory and theory of quivers to show this. We are working on to give a Hermitian metric(here we assume that the field is the field of complex numbers) on the space and also a line bundle on it whose Chern class will be given by the Kahler form obtained from the above metric which we want to show is indeed a Kahler metric. It will be then proved that the moduli space is indeed projective.

Conference/Workshops Attended:

1. *ATM Workshop on Geometry and Topology*, India, November, 2015
2. *ATM Workshop on Grothendieck-Riemann-Roch Theorem*, India, December, 2015.

Invited Lectures/Seminars:

1. *Kodaira's embedding theorem*, Annual Seminar, HRI, Allahabad, July, 2015.

Other Activities:

1. Took Tutorial Classes in ATM Workshop on Geometry and Topology, November, 2015.

Ritika Sharma

Research Summary:

In the last academic year, I have read some topics in analytic number theory such as theory of Riemann zeta function and average order of arithmetical function. I have also read the method of Selberg and Delange which helps us to find summatory function of some new class of arithmetical function. Now, I am looking for generalization of this method over number fields. Related to this, I am trying to understand some papers which deal with Selberg Delange method for some special class of arithmetical functions.

Conference/Workshops Attended:

1. *Triveni Number Theory Meet 4-8 march 2016*

Tushar Kanta Naik

Research Summary:

A finite group G is said to be of conjugate type $\{m_1, m_2, \ldots, m_n\}$, if the set of conjugacy class sizes of G is $\{m_1, m_2, \ldots, m_n\}$. Finite groups of conjugate type $\{1, n\}$ were first investigated by N. Ito in 1953. He proved that if G is of conjugate type $\{1, n\}$, then n is power of some prime p and G is direct product of a non-abelian Sylow p-subgroup and an abelian p'-subgroup; in particular G is nilpotent. Hence to understand such groups, it is sufficient to study finite p-groups of conjugate type $\{1, p^n\}$ for $n \geq 1$. Half a century later, K.Ishikawa proved that finite p-groups of conjugate type $\{1, p^n\}$ can have nilpotency class at most 3. Then he classified p-groups of conjugate type $\{1, p\}$ and $\{1, p^2\}$ upto isoclinism. In a joint work with Prof. Manoj Yadav, we have classified finite p-groups of conjugate type $\{1, p^3\}$ upto isoclinism and also proved that such groups can not be of nilpotency class 3.

Apart from this, I have been reading the books Group Theory (Volume I and II) by Michio Suzuki. I have also read some research paper related to above mentioned work.

Preprints:

1. Tushar Kanta Naik and Manoj Yadav *Finite p-groups of conjugate type $\{1, p^3\}$ upto isoclinism,*

Other Activities:

1. I have been serving as mess-committe member for HRI Mess since december 2015.

Mithun Kumar Das

Research Summary:

In the last one year I have studied some sieve methods(the large sieve, Selberg's sieve etc.), some applications of these(Burn-Titchmarsh theorem, Upper bound of the number of twin primes upto any fixed number, Upper bounds for the number of 'consecutive triples of sums of two squares'), generalization of large sieve inequality on number fields with finite degree. Sieve methods are the techniques for counting the number of elements of a set. Burn-Titchmarsh theorem counts the number of primes in arithmetic progression. Large sieve gives an upper bound of the number of twin primes upto any fixed number which is eight times the value conjectured for it. Using Selberg's sieve we get an upper estimate for the number of 'consecutive triples of sums of two squares'. My work is to generalize this result for any number field.

Conference/Workshops Attended:

1. *Advanced instructional school on Analytic number theory , India (KIIT University, Bhubaneswar), June, 2015.*

2. *ATM Workshop on Analytic number theory, India(IMSc, Chennai), October, 2015.*

3. *Triveni Number Theory Meet @HRI(Algebraic, Analytic and Transcendental Number Theory), India, March, 2016.*

Bibekananda Maji

Research Summary :

1. Zagier conjectured that the series $\sum_{n=1}^{\infty} \tau^2(n)\exp(-nz)$ behaves asymptotically when $z \to 0$, in terms of the zeors of the Riemann zeta function $\zeta(s)$. Hafner and Stopple verified this conjecture assuming Riemann Hypothesis. We used functional equation of Rankin-Selberg L-function to prove that the Lambert series $\sum_{n=1}^{\infty} c^2(n)\exp(-nz)$ also behaves asymptotically in terms of the zeros of $\zeta(s)$ when $z \to 0$, where $c(n)$ is the nth Fourier coefficient of any cusp form f over $\Gamma = SL(2,\mathbb{Z})$. This is joint work with S. Kanemitsu and K. Chakraborty.
2. Lanín et al. studied the secant zeta-function and proved an interesting relation. They deduced an interesting relation between special values at some quadratic irra tional argument. We generalize their result by the Berndt-Arakawa theory of generalized η function and locating their result as a limiting value of the Lambert series. This is a joint work with S. Kanemitsu and T. Kuzumaki.
3. Abel-Tauber process consists of the Abelian process of form- ing the Riesz sums and the subsequent Tauberian process of differencing the Riesz sums, an analogue of the integrationdifferentiation process. Using Abel-Tauber process to establish interesting asymptotic expansion for the Riesz sums of arithmetic functions with best possible error estimate. The novelty of our paper is that we incorporate the Selberg type divisor problem in this process by viewing the contour integral as part of the residual function. The novelty also lies in the uniformity of the error term in the additional parameter which varies ac cording to the cases. Generalization of the famous Selberg Divisor prob lem to arithmetic progression has been made by Rieger, Marcier, Nakaya and around the same time Nowak studied related subject of reciprocals of an arithmetic function and obtained asymptotic formula with the Vinogradov-Korobov error estimate with the the main term as a finite sum of logarithmic terms. This is joint work with D. Banerjee, K. Chakraborty and S. Kanemitsu.
4. We obtained an upper bound for the length of maximal arith metic progressions in y-coordinates and also for the length of maximal simultaneous arithmetic progressions in both x and y coordinates on elliptic curves of the form $y^2 = x^3 + k$ for $k \in \mathbb{Q}^*$. This is a joint work with Pallab Kanti Dey.

Publications:

1. B. Maji, K. Chakraborty, S. Kanemitsu *Modular relations associated to the Rankin-Selberg L function*, accepted in Ramanujan Journal.

2. B. Maji, *On the infinitude of primes.*, *Resonance*, Dec 2015, Volume 20, Issue 12, pp. 1128-1135.

Preprints:

1. B. Maji, D. Banerjee, K. Chakraborty, S. Kanemitsu, *Abel-Tauber process and asymptotic formulas*, communicated for publication.

2. B. Maji, S. Kanemitsu, T. Kuzumaki, *Limiting values of Lambert series and secant zeta function*, communicated for publication.

3. B. Maji, P. Dey, *Arithmetic progrssions on elliptic curves*, communicated for publication.

Conferences Attended:

- The 2016 Gainsville International number theory conference, In honor of Krishna Alladi's 60th birthday at University of Florida. March 17 - 21, 2016.

- Triveni Number Theory conference, On the occasion of 65th birth anniversary of Prof. R. Balasubramanian at HRI, allahabad. March 04- 08, 2016.

- International Conference on Special Functions and Their Applications (ICSFA 2015) organized at Amity University. Sept 10-12, 2015

Invited Talks:

- Gave a talk on "Modular relation associated to Rankin-Selberg L-function" in International number theory conference, in honor of Kishna Alladi's 60th birthday at University of Florida, Gainesville. 19th March, 2016

- Gave a talk on ”Modular Relation associated to Rankin-Selberg L-function” in International Conference on Special Functions and Their Applications at Amity University. 12th Sep, 2015

Pallab Kanti Dey

Research Summary:

I am working on number theory, more specifically in Elliptic Curves, Diophantine Equations and Number Sequences. Basically I am working on finding out torsion points and rank of Elliptic curves over number fields. Related to this I found a necessary and suffcient condition for the diophantine equation $x^4 + by^4 = z^2$ having only trivial solutions over number fields. I am trying to generalize this result for more general diophantine equation $ax^4 + by^4 = cz^2$ for integers a, b, c under some condition. Related to this I am working on classifying congruent numbers which are product of two primes. Furthermore, I am trying to see behaviour of k-raional points in any elliptic curve over any number field k related to arithmetic progression. Also I am working on finding an upper bound for maximal arithmetic progression in cubes and squares over number fields. In diophantine equations I am working on finding out perfect powers in sum of perfect powers and trying to generalize this result for number sequences. Also I am looking at finding out perfect powers in product of number sequences.

Publications:

1. Pallab Kanti Dey and Balesh Kumar, *An analogue of Artin's primitive root conjecture,* Integers (To appear).

2. Pallab Kanti Dey, *On the rank of the elliptic curves $y^2 = x^3 + bx$ over number fields,* Funct. Approx. Comment. Math. (To appear).

3. Bibekananda Maji and Pallab Kanti Dey, *Arithmetic progressions on $y^2 = x^3 + k$,* Journal of Integer Sequences (To appear).

Preprints:

1. Pallab Kanti Dey, *Torsion points over quadratic fields,* (submitted for publication).

2. Pallab Kanti Dey and S. S. Rout, *Perfect powers in product of balancing and Lucas balancing numbers,* (submitted for publication).

3. Pranabesh Das, Pallab Kanti Dey, Bibekananda Maji, S. S. Rout, *Perfect powers in sum of perfect powers,* (in preparation).

Conference/Workshops Attended:

1. *Triveni Number Theory Meet, March 04-08, 2016, HRI, Allahabad, India.*

Rahul Kumar Singh

Research Summary:

During the last one year I have been working on problems concerning maximal surfaces, minimal surfaces and Born-Infeld solitons and the relations between them, for example, studying conservation laws for maximal surface equation. The main observation is the fact that the Born-Infeld equation and maximal surface equation are related by a wick rotaion in the first variable. So if we know conservation laws for one system we can get conservation laws for other system. The solutions of Born-Infeld equation are known as solitonic surfaces or solitons. We also made an observation that the solitons are timelike graph over timelike plane in Lorentz-Minkowski space. As maximal surface equation and Born-Infeld equation are related upto wick rotations, we obtained new solutions(possibly complex) to Born-Infeld equations from already known solutions to Maximal surface equation.

I have also worked on a problem related to Weierstrass-Enneper representation for maximal surfaces. We study Weierstrass-Enneper representation in terms of hodographic coordinates, using this we can get a one parameter family of solitons from the associated one parameter family of maximal surfaces.

I have also been working on doubly connected maximal surfaces using techniques from complex analysis. We are able to construct some examples of maximal surfaces with perscribed number of branch points. This is a joint work with my supervisor and Dr. Pradip Kumar at Shiv Nadar University.

Preprints:

1. Rukmini Dey, Pradip Mishra and Rahul Kumar Singh, *Doubly connected maximal surfaces,*(in preparation)

Visits to other Institutes:

1. ICTS, Bangalore, India, 1st August to 31st December 2015.

Kummari Mallesham

Research Summary:

let $\mathcal{D}$ denote the sequence of squares of primes and suppose $K \geq 1$ is an integer. Then we are interested in the problem of determining the upper bounds in terms of K for the smallest integer $s(K)$ with the property that there exists an integer $n_0(K)$ such that given any partition $\{\mathcal{D}_i, 1 \leq i \leq K\}$ of sequence of squares of primes, for each integer $n \geq n_0(K)$ there is an integer i with $1 \leq i \leq K$ such that n can be written as the sum of no more than $s(K)$ squares of primes, which belongs to the set $\mathcal{D}_i$. In the first preprint listed below, we obtained an upper bound for $s(K)$, which is the best possible bound for $s(K)$ upto a constant.

In the second preprint listed below, we worked on a question of Sárközy, Rivat and Balog. Which asks for the bounds on the number of pairs $(a, b) \in A \times B$ such that $a + b$ is a prime number, where A, B are two subsets of the integer interval $[1, N]$.

Preprints:

1. Kummari Mallesham, *A chromatic version of Lagrange's four squares type theorem for primes* (in preparation)
2. Kummari Mallesham, *Primes in sumset* (in preparation)

Conference/Workshops Attended:

1. *Triveni Number Theory Meet* , India, March, 2016.

Balesh Kumar

Research Summary: (Technical)

Don Zagier constructed the kernal function for the Doi-Naganuma map by computing the explicit action on the Poincare series. In a joint work with Prof. M. Manickam, we have extended the Doi-Naganuma lifting as suggested by S. Kudla (in one of his paper) on the lines of Zagier's work.
In an another work with Prof. M. Manickam, we are trying to establish the theory of newforms of half integral weight of level $4N$, (N odd and squarefree integer) and character χ, where χ is non real primitive Dirichlet character mod N, parallel to the Atkin-Lehner theory of newforms of integral weight modular forms. Moreover, we have established the multiplicity one result for the newforms in this space. Using the similar idea as in the above, we realized that the multiplicity one result holds good for the Kohnen plus space under the same assumption on the level $4N$ and the character χ. Furtermore, we observed that the similar arguments can be carried out to set up the multiplicity one result for the index 1, holomorphic Jacobi forms of level N (N odd and squarefree) and character χ. Also, we are trying to develop the theory of newforms for the space of half-integral weight cusp forms of level $32N$, where N is an odd and squarefree natural number.
In an another work with J. Meher and S. Pujahari, we are studying the various properties for the coefficients of the symmetric power L-function of the elliptic modular forms.

Publications:

1. Balesh Kumar and Pallab Kanti Dey, *An analogue of Artin's primitive root conjecture* Integers (2015) (Accepted for publication)

Preprints:

1. Balesh Kumar and M. Manickam, *On Doi-Naganuma lifting,* preprint.

2. Balesh Kumar and M. Manickam, *On newforms of half-integral weight and Jacobi forms,* (in preparation.)

3. Balesh Kumar, J. Meher and S. Pujahari, *Some remarks on the coefficients of symmetric power L-function,* (in preparation.)

Conference/Workshops Attended:

1. *Triveni: Number Theory Meet at HRI, (Algebraic, Analytic and Transcedental Number Theory)*, India, March, 2016.

2. *Workshop on Automorphic forms at KSOM*, India, February, 2016.

Visits to other Institutes:

1. Kerala School of Mathematics, Kerala, India, July 2015 to February, 2016.

Invited Lectures/Seminars:

1. *On Doi-Naganuma lifting*, Workshop on Automorphic forms, Kerala School of Mathematics, Kerala, India, February, 2016.

Other Activities:

1. Tutor for the ISL "Number theory" at KSOM, October, 2015.

2. Compiled the annual report of HRI for the year 2014-2015.

Anup Kumar Singh

Research Summary

In this Academic year, I studied about the Theory of Modular forms. More specifically I read about the space generated by eta-quotients. Also I learned about the Theory of Jacobi forms and Hermitian Jacobi forms. Recently I am working with Prof B. Ramakrishnan and Prof Brundaban Sahu on a problem titled as " On the number of representation by certain octonary quadratic forms with the coefficients 1,2,3,4 and 6 ". In this work, we are using the theory of Modular forms to find explicit formulas for the number of representations.

Conference/Workshops Attended:

1. *Analytic Number Theory Workshop at Kerla School of Mathematics* in India During 5th to 17th October 2015
2. *School on Sieve method and circle method at IMSC Chennai* in India During 10th to 14th November 2015.
3. *Workshop on Automorphic forms at Kerla School of Mathematics* In India During 10th to 16th February 2016.

Visits to other Institutes:

1. Kerla School of Mathematics, Kozhikode , India, 25th August to 26th December 2015,
2. National Institute of Science Education and Research ,Bhubaneswar, India, 28th December 2015 to 27th January 2016.
3. Kerla School of Mathematics, Kozhikode , India, 28th January to 20th February 2016,

Manish Kumar Pandey

Research Summary

In this Academic year, I studied about the Theory of Modular forms. More specifically I read about the theory of half integral weight modular form.I have also read basic theory of jacobi and hermitian jacobi forms.Recently i am working with Arvind Kumar on inverse theorem for Hermitian Jacobi Form.

Conference/Workshops Attended:

1. *Analytic Number Theory Workshop at Kerla School of Mathematics* in India During 5th to 17th October 2015
2. *School on Sieve method and circle method at IMSC Chennai* in India During 10th to 14th November 2015.
3. *international workshop on number theory organised at IMSC* during 10th to 14th December 2015.
4. *Workshop on Automorphic forms at Kerla School of Mathematics* In India During 10th to 16th February 2016.

Visits to other Institutes:

1. Kerla School of Mathematics, Kozhikode , India, 25th August to 24th February 2015,

Soumyarup Banerjee

Research Summary:

During last year I am working on Fourier coefficients of Modular Forms. we investigate the sign changes of the Fourier coefficients of a cusp form for the full modular group where the coefficients lie in an arithmetic progression. We also compare the signs of Fourier coeffcients for two different weight cusp forms. I am also working on the Fourier coefficients of Maass forms in this context.

We are working on higher order Riesz sums to streamline Nakajima's result in 2-dimensional case and generalize it to the product of Hurwitz zeta-functions. A special and intriguing feature is that only the modified k-Bessel functions appear, which makes it possible to generalize the problem.

Preprints:

1. Soumyarup banerjee and Kalyan Chakraborty *Note on Signs Of Fourier Coefficients Of Cusp Forms In Arithmetic Progression* (in preparation)

2. Nianliang Wang and Soumyarup Banerjee, *On the product of Hurwitz zeta-functions* (in preparation)

Conference/Workshops Attended:

1. *Triveni Number Theory Meet @HRI (Algebric, Analytic and Transcendental Number Theory)*, India, March, 2016

SUMANA HATUI

Research Summary

The Schur multiplier or Schur multiplicator $M(G)$ of a group G is the second homology group $H_2(G, Z)$. Schur multiplier was introduced by Schur in 1904 on the study of projective representation of groups. I had given my seminar talk in june 2015 with title *"On the order of Schur multiplier of non-abelian p-groups"* which is written by Peyman Niroomand in Journal of Algebra. This paper is devoted to the derivation of certain upper bound for the Schur multiplier of non-abelian p-groups of order p^n with derived subgroup of order p^k which is $|M(G)|$ is less that or equal to $p^{\frac{1}{2}(n+k-2)(n-k-1)+1}$. In particular for $|M(G)| = p^{\frac{1}{2}(n-1)(n-2)+1}$, classification of p-groups G are given in this paper.
So this is an interesting problem to characterize the structure of groups by just the order of its Schur multiplier. In 1956 Green gave an upper bound $p^{\frac{1}{2}n(n-1)}$ for order of the Schur Multiplier of p-groups of order p^n. So we have $|M(G)| = p^{\frac{1}{2}n(n-1)-t(G)}$ for some non-negative integer $t(G) \geq 0$. The classification of groups of order p^n for $t(G) \leq 5$ has been done by several authors.
In my recent work, I have classified the non-abelian p-groups G of order p^n when $t(G) = 6$, i.e. $|M(G)| = p^{\frac{1}{2}n(n-1)-6}$.

Preprints:

1. Sumana Hatui, *Classification of p-groups by their Schur Multiplier*. arXiv:1605.01849

Nabin Kumar Meher

Research Summary:

I have been working in the area of Transcendental Number Theory. I attended a semester course on Transcendental Number Theory. I gave a series of lectures covering one of the fundamental theorems in transcendental number theory namely Schmidt's Subspace Theorem, which generalizes the famous work of Roth. This theorem has many applications in Number Theory and especially, we have read the works of Corvaja, Zannier and Bugeaud etc. A systematic survey about the base b representation of real numbers has been done. Indeed, the goal is to find out how much is known to distinguish the algebraic and transcendental numbers using this base b representation and we have written an expository article on this theme. An analogous concept is continued fraction and a study has been undertaken to explore similar classification of irrational numbers using this methods.

Preprints:

1. N.K. Meher and R. Thangadurai, *Decimal expansion,Periodicity and Beyond*, (in preparation).

Conference/Workshops Attended:

1. *Advanced Instructional School on Analytic Number Theory* at KIIT, Bhubaneswar, June,2015.

2. *Triveni number theory meet* at HRI, Allahabad, March, 2016.

Arvind Kumar

Research Summary:

For a fix modular form g and a non negative ineteger ν, by using Rankin-Cohen bracket we first define a linear map $T_{g,\nu} : f \longmapsto [f, g]_\nu$ on the space of modular forms. Depending on the weight of f and g, whether it is integral or half integral, there are 4 types of such maps. In a joint work with Abhash Kumar Jha, we explicitly computed the adjoint of these map and showed that the n-th Fourier coefficients of the image of a cusp form f under this map is, upto a constant a special value of Rankin-Selberg convolution of f and g. This is a generalization of the work due to W. Kohnen (Math. Z., 207, (1991), 657-660) and S. D. Herrero (Ramanujan J., 36 (2014), no. 3, 529-536) in the case of integral weight modular forms to half integral weight modular forms. As a consequence we obtained non-vanishing of special value of certain Rankin-Selberg convolution of modular forms.

In this academic year, I learnt the basic theory of Hermitian Jacobi forms. Hermitian Jacobi forms of integer weight and index are defined and studied for the Hermitian Jacobi group over the ring of integers $\mathcal{O}$ of an imaginary quadratic field K by K. Havekamp [SCHRIFTENREIHE des mathematischen Institute der Universtiätünster, 3.Serie Heft **15**, 1985]. In a joint work with Prof. B. Ramakrishnan, we have obtained the Fourier expansion of Hermitian Jacobi Poincaré series. In analogy with Jacobi forms, its coefficients involve some generalized Kloosterman sum. We are trying to get appropriate bound of this sum to get the Hecke bound for Hermitian Jacobi Fourier coefficients as an important application. We have also computed the adjoint of the product map in this space which can be defined by taking the product map of a fixed Hermitian Jacobi form. We obtained the Fourier coefficients of the image to be some special values of shifted Rankin-Selberg convolution. This is a particular analogous case of our earlier work in modular forms.

In 1936, E. Hecke showed an outstanding equivalance between the automorphy of a cusp forms on full modular group and the functional equation satisfied by its corresponding L-function. There are several generalizations of Hecke's converse theorem, such as generalizations to Hilbert modular forms, Siegel modular forms, classical Jacobi forms, Maass forms. In a joint work with Manish Kumar Pandey, we prove the converse theorem in the context of Hermitian Jacobi Forms on $SL_2(\mathbb{Z}) \ltimes \mathcal{O}^2$. We consider function ϕ on $\mathbb{H} \times \mathbb{C} \times \mathbb{C}$ into $\mathbb{C}$ which has a Fourier expansion with certain conditions on the Fourier coefficients. We show that ϕ is a Hermitian

Jacobi cusp form if and only if the corresponding family of L-funnction satisfy certain functional equation. We are trying to find the lift from hermitian Jacobi forms to classical modular forms via this converse theorem.

Publications:

1. A. Kumar, J. Meher, *On arbitrary products of eigenforms,* To appear in Acta Arithmatica 173 (2016), no. 3, 283–295.

Preprints:

1. A. K. Jha and A. Kumar, *Construction of cusp forms using Rankin-Cohen brackets,* Submitted for publication.
2. A. Kumar, B. Ramakrishnan, *On Hermitian Poincaré series and special values of certain Dirichlet series,* (In preparation).
3. A. Kumar, M. Pandey, *A converse theorem for Hermitian Jacobi forms,* (in preparation).

Conference/Workshops Attended:

1. *Workshop on Automorphic Forms*, KSOM, India, 10 - 16 February, 2016.
2. *Triveni Number Theory conference,* On the occasion of 65th birth anniversary of Prof. R. Balasubramanian, HRI, Allahabad, 04 - 08 March, 2016.

Visits to other Institutes:

1. Kerala School of Mathematics, Kozhikode, India, 25 August - 6 December 2015 and 30 January - 20 February 2016.
2. National Institute of Science Education and Research (NISER), Bhuabaneswar, India, 07 December 2015 - 28 January 2016.

Invited Lectures/Seminars:

1. *On arbitrary products of eigenforms*, Workshop on Automorphic Forms , KSOM, Kozhikode, February, 2016.

Bhuwanesh Rao Patil

Research Summary

In the academic year 2015-16, I have studied techniques used in various types of number theoretic problems. These techniques are related to geometry of numbers, ergodic theory, Fourier theory and some other analytic-combinatorial ones. We tried to understand Roth's theorem for three length arithmetic progressions by density increment, energy increment and ergodic theoretic arguments. Density increment argument uses Fourier analysis while energy increment argument uses Fourier and ergodic techniques. The approach of ergodic theoretic and energy increment arguments uses the idea of Koopman-von Neumann decomposition in which we approximate any L^2 function space by a smaller function space with a specific property. Koopman-von Neumann theorem in ergodic theory decomposes any L^2 fuction into a weakly mixing function and an almost periodic function. Besides this, I am trying to understand x+y,xy patterns in the set of integers. In particular, we are focusing on the existence of natural numbers x and y such that x+y and xy are in the same color class in any finite coloring of the set of natural numbers.

Conference/Workshops Attended:

1. *Number Theory Meet at HRI 4-8, March, 2016.*

S.Manikandan

Research Summary:

In a paper, A. D. King has shown that the moduli space of finite dimensional representations of a finite dimensional algebra over an algebraically closed field is a projective variety. He has used Geometric Invariant theory and theory of quivers to show this. We are working on to give a Hermitian metric(here we assume that the field is the field of complex numbers) on the space and also a line bundle on it whose Chern class will be given by the Kahler form obtained from the above metric which we want to show is indeed a Kahler metric. It will be then proved that the moduli space is indeed projective.

Conference/Workshops Attended:

1. *ATM Workshop on Geometry and Topology*, India, November, 2015.
2. *ATM Workshop on Grothendieck-Riemann-Roch Theorem*, India, December, 2015.

Invited Lectures/Seminars:

1. *Krull-Schmidt theorem for an abelian category* , Annual Seminar, HRI, Allahabad, July, 2015.

Other Activities:

1. Took Tutorial Classes in ATM Workshop on Geometry and Topology, November, 2015.

Pramod Eyyunni

Research Summary

In the academic year 2015-16, I had given my third year seminar on a theorem of Furstenberg and Sarkozy. This theorem states that, given a sufficiently dense subset of natural numbers, it will contain two elements that differ by a square. It mainly uses the technique of circle method. Presently, I am studying topics in combinatorial geometry. In this, I am trying to understand Szemeredi-Trotter theorem which tries to bound the number of incidences or intersections between a given finite collection of points and lines in the real plane. My main focus is to understand the analogous version of this theorem for the case of finite fields. This area was initiated by a paper of Bourgain-Katz-Tao and uses a diverse set of tools and techniques like sum product estimates over finite fields, sumset estimates from arithmetic combinatorics and projective geometry.

Conference/Workshops Attended:

1. *International Conference on Special Functions and their Applications*, Amity University, Noida, September 10-12, 2015.

2. *Triveni Number Theory Meet*, HRI, Allahabad, March 4-8 2016.

Varun Dilip Thakre

Research Summary:

A classic question in algebraic geometry is enumeration of rational curves in $\mathbb{CP}^2$. A natural generalization of this is to ask how many curves of genus g and of a given degree d, with a fixed complex structure, are there, passing through $3d-1$ generic points. The problem for curves of genus one was studied by Pandharipande and Ionel using tools from algebraic and symplectic geometry.

In a joint work with Ritwik Mukherjee and Indranil Biswas [1], we have extended their result to Del-Pezzo surfaces. Namely, we have proved the following:

Theorem 1: *Let Σ be a Del-Pezzo surface and fix a $\beta \in H^2(\Sigma, \mathbb{Z})$. Let $n_{0,\beta}$ denote the number of rational curves that pass through δ_β generic points, where $\delta_\beta := \langle c_1(T\Sigma), \beta\rangle - 1$. Let $n^j_{1,\beta}$ denote the number of elliptic curves with fixed j invariant of degree β in Σ and passing through δ_β generic points. Then,*

$$n^j_{1,\beta} = \frac{2g_\beta}{|Aut(\Sigma_1, j)|} n_{0,\beta} \quad \textit{where} \quad g_\beta = \frac{\beta\cdot\beta - c_1(T\Sigma)\cdot\beta + 2}{2} \tag{1}$$

where $|Aut(\Sigma_1, j)|$ denotes the number of automorphisms of a genus one Riemann surface with fixed j invariant that fixes a point and "$\cdot$" denotes topological intersection.

For the case when $\Sigma = \mathbb{CP}^2$, the formula coincides with that obtained by Pandharipande and Ionel. Extending the methods of Pandharipande and Ionel respectively, Katz, Qin and Ruan and Zinger obtain an explicit formula for the number of degree d, genus two curves with a fixed complex structure in $\mathbb{CP}^2$, passing through $3d-2$ generic points. In [2] we have extended their results to Del-Pezzo surfaces. Namely, we have proved the following:

Theorem 2: *Let Σ be a complex del-Pezzo surface and fix a $\beta \in H^2(\Sigma, \mathbb{Z})$. Let*

$$x_i = c_i(T\Sigma) \quad \textit{and} \quad \delta_\beta = \langle x_1, \beta\rangle - 1 \tag{2}$$

where c_i denotes the i^{th} Chern class. Let $n^j_{2,\beta}$ denote the number of genus two curves with fixed j invariant of degree β in Σ and passing through $\delta_\beta - 1$ generic points. If Σ is $\mathbb{CP}^2$ blown-up at k-points, assume that $n_{0,\beta-3L} > 0$, where L is the e homology class of a line. Else, if $\Sigma = \mathbb{CP}^1 \times \mathbb{CP}^1$, then make no assumptions.

Then,

$$\frac{|Aut(\Sigma_2, j)|}{2} n^j_{2,\beta} = n_{0,\beta} \left((2 + b_2(\Sigma))\beta^2 - 10x_2 - x_1^2 + \frac{12x_1^2}{\beta \cdot x_1} \right)$$
$$+ \sum_{\substack{\beta_1+\beta_2=\beta \\ \beta_1,\beta_2\neq 0}} \begin{pmatrix} \delta_\beta - 1 \\ \delta_{\beta_1} \end{pmatrix} n_{0,\beta_1} n_{0,\beta_2} (\beta_1 \cdot \beta_2) \left(-\frac{6(\beta_1 \cdot x_1)(\beta_2 \cdot x_1)}{\beta \cdot x_1} + \frac{\beta_1^2 \beta_2^2}{2} + 10 \right) \tag{3}$$

where $|Aut(\Sigma_2, j)|$ is the order of the group of holomorphic automorphisms of a genus two Riemann surface with fixed complex structure and β^2 denotes the second Betti-number of Σ.

Computation of the above formula for higher genus (> 2) is complicated by the fact that the computation of rational cuspidal curves on Del-Pezzo surfaces, through right number of generic points becomes exponentially complicated. Nonetheless, we plan to explore this further for genus 3 and above.

Publications:

1. I. Biswas, R. Mukherjee, and V. Thakre, *Genus one enumerative invariants in del-Pezzo surfaces with a fixed complex structure,* Comptes Rendus Mathematique **354**, 517-521, (2016)

Preprints:

1. I. Biswas, R. Mukherjee, and V. Thakre, *Genus two enumerative invariants in del-Pezzo surfaces with a fixed complex structure,* arXiv:1511.04900 [math.AG]

Visits to other Institutes:

1. Tata Institute of Fundamental Research (TIFR), Mumbai, India, June 2015

2. Tata Institute of Fundamental Research (TIFR), Mumbai, India, October 2015

Invited Lectures/Seminars:

1. *HyperKahler manifolds and Seiberg-Witten equations*, Colloquium talk, TIFR, Mumbai, June 2015.

2. *HyperKahler manifolds and Seiberg-Witten equations*, Colloquium talk, IISER, Pune, July 2015.

Other Activities:

1. Tutor for Algebraic Topology, Annual Foundation School in Mathematics - III at HRI, 20th July - 25th July 2015, 2015.

2. Tutor for Topology, Annual Foundation School in Mathematics - I, Bhaskaracharya Prathishthan, Pune, December, 2015.

Abhitosh Upadhyay

Research Summary:

Biharmonic submanifolds has become a popular subject of research in recent years with many significant progresses made by geometers around the world. One of the fundamental problems in the study of biharmonic submanifolds is to classify such submanifolds in a model space. So far, most of the work done has been focused on classification of biharmonic submanifolds of space forms. I got motivated by the results of different mathematicians working on Biharmonic hypersurfaces/submanifolds. This topic of research is totally dependent on the B. Y. Chen's biharmonic conjecture, i.e., **Any biharmonic submanifold in a Euclidean space is minimal**. Prof. Chen proposed this conjecture for Euclidean space but in pseudo-Euclidean space, the results are totally different. Even in co-dimension 1, very different results were obtained
in semi-Euclidean spaces in comparison to Euclidean spaces. During study, we found that Shape operator is diagonalizable in case of Riemannian manifolds but this is not the case when we consider the pseudo-Riemannian manifolds. Particularly, in Minkowaski space, there are four canonical forms of the shape operator which was obtained by **Prof. Martin A. Magid, USA** in 1985 but when we consider hypersurfaces of pseudo-Euclidean space having index greater than 1, it is not known what are the canonical forms of the shape operator. With the suggestion of Prof. Martin A. Magid (USA), I obtained that there are nine possible canonical forms of the shape operator
when we consider hypersurfaces of pseudo-Euclidean space E^5_2. In these canonical forms of the shape operators, there are two types of operators, i.e., diagonalizable and non-diagonalizable. There are no known method to deal with more than three distinct principal curvatures in canonical forms of the shape operators and also with non-diagonalizable shape operators so I
restricted my study to three distinct principal curvatures and diagonalizable shape opeartors. We obtained some fruitful results in this direction and submitted our first manuscripta on classification problems of biconservative hypersurfaces. Our article gives a direction to study classification problems of biconservative hypersurfcaes with non-diagonalizable shape operators and also with more than three distinct principal curvatures.
Further, we studied biharmonic submanifolds of generalized space forms,

i.e., generalized complex space forms and generalized sasakian space forms. Complex space forms are Einstein non-Kaehler Hermitian manifolds which are generalizations of complex space forms. They appear only in dimension 4. After giving the biharmonicity condition for submanifolds of these spaces, we considered different particular cases, namely curves, Lagrangian or complex surfaces and hypersufaces. Then, we obtained curvatures estimates as well as non-existence results for biharmonic submanifolds for generalized complex spaces forms of negative (constant) scalar curvature. Secondly, we considered generalized Sasakian space forms. This familiy of almost contact metric manifolds generalizes Sasakian space forms and contains also the so-called Kenmotsu and cosymplectic space forms. In this case, we gave the general conditions for biharmonic submanifolds with a focus on many particular cases such as hypersurfaces and invariant or anti-invariant submanifolds which are the analogous in the contact setting of complex or totally real (in particular Lagrangian) submanifolds appearing in the complex case. Further, we also obtained some curvature estimates for biharmonic submanifolds of generalized Sasakian space form and as corollary, some non-existence results in case of negative (or appropriately bounded by above) ϕ-sectional curvature.

Preprints:

1. **Abhitosh Upadhyay**, Ram Shankar Gupta and A. Sharfuddin: *Screen conformal lightlike hypersurfcaes of indefinite cosymplectic space forms*, **Georgian Mathematical Journal** (DE GRUYTER), Accepted (September, 2015).

2. **Abhitosh Upadhyay** and Nurettin Cenk Turgay: *A classification of biconservative hypersurfaces in a pseudo-Euclidean spaces*, arXiv:1512.06339 (Under review).

3. Julien Roth and **Abhitosh Upadhyay**: *Biharmonic submanifolds of generalized space forms*, arXiv:1602.06131 (Under review).

0.1 Saibal Ganguli

0.1.1 Research Summary:

My research in PHD and earlier part of post doc has been on spaces called quasitoric orbifolds. An orbifold is a space which is locally R^n/G where G is a finite group. A quasitoric orbifold is a generalization of projective toric orbifolds used in algebraic geometry and string theory. A quasitoric differs from projective toric in the sense it has no algebraic structure. I have provided smooth structures , almost complex structures Hodge structures and proved a version of Mckay Correspondence on these orbifolds. I have also worked in contact structures and have provided contact structures to cyclic orbifolds. Recently i am commencing collaboration with Professor Rukmini Dey of ICTS TIFR and have started work on constant mean curvature surfaces and geometric quantization.

I have been in this institute as a postdoc from 21^{st} September 2015. With in this period I have restructured and re-submitted two of my old research papers(check submission history through arxiv-abstract of the papers listed below).I review for mathscinet and Zbmath math databases. With in this period i have reviewed around twenty-five papers for these databases on topics ranging from topology geometry and mathematical physics. I have commenced collaboration with Rukmini Dey of ICTS and working on finding algebraic structures on Constant mean curvature surfaces and looking into problems of Geometric quantization especially relating Quillen bundles.

0.1.2 Preprints

1. S.Ganguli:Hodge structures orbifold Hodge numbers and a correspondence in Quasitoric orbifolds arxiv:1406.4596(resubmitted again check submission history in arxiv abstract).
2. S.Ganguli : A classification result and contact structures in oriented cyclic orbifolds arxiv:1503.05645 (resubmitted again check submission history in arxiv abstract).

0.1.3 Workshops attended

1. Topology and geometry workshop in HRI,November 2015.

2. String theory workshop in HRI, February 2016.

0.1.4 Other activities

1. Reviewer for mathscinet reviewed around 12 papers in 6 months.
2. Reviewer for Zbmath reviewed around 12 papers in 6 months for this database also.

Shailesh Trivedi

During the period 1-04-2015 to 31-03-2016, I have worked on the theory of *weighted shifts on directed trees*. This is a joint work with Prof. Sameer Chavan, Indian Institute of Technology, Kanpur, which has been accepted for publication in the *Journal of the London Mathematical Society*. The questions which we have answered are described as follows.

Research Summary:

If T is a unilateral weighted shift on $l^2(N)$, N is the set of non-negative integers, then it is well-known that T is unitarily equivalent to an operator of multiplication by the coordinate function on the reproducing kernel Hilbert space $H^2(\beta)$. Thus, if S_λ is a weighted shift on a directed tree $\mathbf{T} = (V, E)$, it is natural to ask the following question.

Question: Does there exist a reproducing kernel Hilbert space H of holomorphic functions on some domain Ω such that S_λ is unitarily equivalent to the multiplication operator M_z on H? If so, how does H look like and what is the description of the corresponding reproducing kernel?

This question was completely answered (with a mild assumption of left-invertibility) with several examples and counter-examples. In this way we obtain an analytic model of a weighted shift S_λ on a directed tree $\mathbf{T}$. The reproducing kernel Hilbert space H is in fact a Hilbert space of vector valued holomorphic maps in which the monomials are not, in general, orthogonal. The reproducing kernel is a multidiagonal kernel with bandwidth $k_{\mathbf{T}}$, where $k_{\mathbf{T}}$ is the branching index of the underlying directed tree. Having obtained the analytic model of S_λ, there comes another question.

Question: What is the spectral picture of S_λ?

The answer of this question constitutes the fifth section of our paper in which we have explored the several aspects of the spectrum of S_λ using the analytic model. It turns out that these shifts lie in the Cowen-Douglas class. Finally, we have concluded this work with a result about the index of S_λ.

Publications:

1. S. Chavan and S. Trivedi, *An Analytic Model for Left-Invertible Weighted Shifts on Directed Trees,* Journal of the London Mathematical Society, *to appear*

Preprints:

1. S. Chavan and S. Trivedi, *An Analytic Model for Left-Invertible Weighted Shifts on Directed Trees,* https://arxiv.org/abs/1510.03075

Conference/Workshops Attended:

1. *Workshop on "Complex Geometry and Operator Theory"*, India (ISI, Bangalore), December 2015.

2. *An Introduction to Several Complex Variables*, India (ISI, Chennai), December 2015.

Visits to other Institutes:

1. Indian Institute of Technology Kanpur, Kanpur, India, February 2016.

Rahul Dattatraya Kitture (PDF, Mathematics)

Research Summary:

The groups considered here are only *finite p-groups*. The non-abelian groups with abelian automorphism groups are widely studied. Such groups are also called as Miller groups since the first example of such a group was given by G. A. Miller in 1913.
There are many necessary conditions on a p-group to be Miller, but no sufficient condition. Therefore it is difficult to construct an example of a Miller p-group. Several examples of Miller groups have been constructed by various authors with different approaches. However the techniques used were mostly computational.
Recently Andreas Caranti (*A module theoretic approach to abelian automorphism groups*, Israel J. Mathematics 205 (2015), 235-246) provided two methods to construct new examples of non-special Miller p-groups from special Miller p-groups (a p-group is said to be special if its center, commutator subgroup and Frattini subgroup are equal). His methods involve very simple module theoretic approach and avoids computations.
However, there was a gap in the proof and the two methods do not always work. We provided a counterexample for it. Further we gave a slight modification in the two methods of Caranti.
This is joint work with Manoj K. Yadav since September 1, 2015.

Preprints

1. Rahul Dattatraya Kitture, Manoj K. Yadav, *A Note on Caranti's methods of construction of Miller groups* (In preparation).

Invited Lectures

Participated as a Tutor as well as Speaker in the Annual Foundational School-I, held at Bhaskaracharya Pratishthana, Pune in December 2015.

Sudhansu Sekhar Rout

Research Summary:

My broad area of research is number theory. In particular, I am interested in the study of integer sequences that arise in elementary number theory and in a combinatorial setting. Most of my work revolves around binary number sequences, and more specifically balancing number sequences. Also, I have done some work related to Diophantine equations which arises from number sequence problems.

One of my recent work is with Prof. R. Thangadurai which concerns on l-th order gap balancing numbers. Using explicit lower bound on the elliptic logarithms, we prove the finiteness of the positive integral solutions of a Diophantine equation. Also, we explicitly compute the positive integral solutions using the elliptic logarithmic method.

Another work is with Pallab Kanti Dey a graduate student of HRI, regarding the perfect powers in product of balancing and Lucas balancing numbers. Here we also prove a conjecture regarding the non existence of positive integral solution for the diophantine equation $2x^2 + 1 = 3^b y^m$.

Publications:

1. S. S. Rout, *Balancing non-Wieferich primes in arithmetic progression and* abc *conjecture,* Proc. Jpn. Acad., Ser. A (Accepted).

Preprints:

1. S. S. Rout and R. Thangadurai, *On* l*-th order gap balancing numbers,* (submitted for publication).
2. Pallab Kanti Dey and S. S. Rout, *Perfect powers in product of balancing and Lucas balancing numbers,* (submitted for publication).
3. Pranabesh Das, Pallab Kanti Dey, Bibekananda Maji and S. S. Rout, *Perfect powers in sum of perfect powers,* (in preparation).

Conference/Workshops Attended:

1. *Triveni Number Theory Meet, March 04-08, 2016, HRI, Allahabad, India.*

Samrith Ram

Research Summary:

Given a finite-dimensional vector space V over the finite field $\mathbb{F}_q$ and a subspace W of V, I considered the problem of counting linear transformations $T : W \to V$ which have prescribed invariant factors. The case $W = V$ is a well-studied problem that is essentially equivalent to counting the number of square matrices over $\mathbb{F}_q$ in a conjugacy class and an explicit formula is known in this case. I extended this result to the case of arbitrary W by giving an explicit counting formula. As an application of my results, I give new proofs of some recent enumerative results in linear control theory and derive an extension of the Gerstenhaber-Reiner formula for the number of square matrices over $\mathbb{F}_q$ with given characteristic polynomial.

Preprints:

1. Samrith Ram, *The number of linear transformations defined on a subspace with given invariant factors,* arXiv:1603.06527

Conference/Workshops Attended:

1. *Algebraic Geometry for Coding Theory and Cryptography*, United States of America, February, 2016.

Visits to other Institutes:

1. University of California, Los Angeles, California, United States of America, February, 2016.

Ramdin Mawia

Research Summary

I joined the Harish-Chandra Research Institute as a post-doctoral fellow on the 24^{th} August, 2015. From then on, besides ongoing collaboration with Prof. Sukumar Das Adhikari, I have been working on my research project of which I give a short synopsis in the ensuing paragraphs.
In order to describe my current work, I have to first give a brief overview of my PhD work. A major part of my PhD thesis was concerned with a study of the primitive

$$F(T,\chi) \stackrel{\text{def}}{=} \int_0^T Z(t,\chi)\,\mathrm{d}t$$

of Hardy's Z-function $Z(t,\chi)$ corresponding to the Dirichlet L-function $L(s,\chi)$, with χ a primitive character of conductor q. When χ is an even character of odd conductor or one of the odd characters mod 4 and mod 8, I proved, among others, that $F(T,\chi)$ admits of an Atkinson-like development of the form

$$F(T,\chi) = S_1(T,\chi) + S_2(T,\chi) + O\left(\log^{5/4} T\right)$$

where $S_1(T,\chi)$ and $S_2(T,\chi)$ are finite χ-twisted short sums of length about $\sqrt{T}$ and of general terms of size and shape approximately n^{-1} and $n^{-\frac{1}{2}+iT}$. From this, one deduces arithmetically interesting consequences, such as the asymptotic behaviour of Hardy's function $Z(t,\chi)$. This work was inspired by Jutila's new proof (2011) of a recent result of Korolv (2008) who studied Hardy's function $Z(t)$ corresponding to the Riemann zeta function $\zeta(s)$. Korolv and Jutila proved Ivi's conjecture concerning $F(T)$, namely

$$F(T) = \int_0^T Z(t)\,\mathrm{d}t = \Omega_\pm\left(T^{1/4}\right).$$

Moreover, they also showed that $F(T)$ can be asymptotically approximated by a step function of the fractional part of $\sqrt{T/(2\pi)}$. In 2004, Ivi proved the bound $F(T) \ll T^{\frac{1}{4}+\epsilon}$; this is an enormous improvement to Landau's classical $F(T) \ll T^{7/8}$. Korolv removed the ϵ and thus we now know that the true order of magnitude of the primitive $F(T)$ of Hardy's function is $T^{\frac{1}{4}}$. I proved analogous results for $F(T,\chi)$ when χ is one of the said characters, namely even characters of odd conductor or the odd primitive characters modulo 4 and 8. However, we are in the dark as to the true order of magnitude or of the general behaviour of $F(T,\chi)$ for odd characters χ. So continuing my PhD work and branching out in other directions, I have been working on the problem of generalising the said results to other characters and also to other L-functions from the Selberg class.

In our context, the functions $F(T,\chi)$ are studied by means of the Laplace transform, that is, we look at the function

$$\check{F}(p,\chi) = \int_0^\infty F(T,\chi)e^{-pT}\,\mathrm{d}T.$$

Taking a cue from this, I have also been working on p-dilates of the above integral, namely $\int_0^\infty F(T,\chi)e^{-\alpha pT}\,\mathrm{d}T$ for some parameter α, which clearly reduces to the Laplace transform when $\alpha = 1$, and also on the closely related integral $\int_0^\infty L(\frac{1}{2}+it,\chi)e^{-\alpha pt}$. Asymptotic estimates of these integrals are of independent interest in Analytic Number Theory.

Preprints

1. Ramdin Mawia, *Hardy's functions for L-functions* (in preparation).

Conference/Workshops Attended

1. *Triveni Number Theory Meet @ HRI on the occasion of* 65^{th} *Birthday of Prof. R. Balasubramanian*, HRI, Allahabad, India; 04-08 March, 2016.

Makoto Sakagaito

Research Summary:

I have deen considering a generalization of the Brauer group in the past few years. In the academic year 2015–16, I proved the Gersten conjecture of the logarithmic Hodge-Witt cohomology for an excellent two dimensional regular local ring which is smooth over the spectrum of an excellent discrete valuation ring of characteristic $p > 0$ in connection with this research. I hope that this result is very useful to prove a local-global principle for Galois cohomology groups over function fields of curves that are defined over an equi-characteristic Henselian discretely valued field.

Preprints:

1. Makoto Sakagaito, *On problems about a generalization of the Brauer group,* arxiv:1511.09232v1

Invited Lectures/Seminars:

1. *On Problems about a genaralization of the Brauer group*, The 14th Hiroshima-Sendai number theory conference, Hiroshima University, Hiroshima, July 2015.

Academic Report - Physics

Jayanta K Bhattacharjee

Research Summary:

The focus of our work has been on convective turbulence and dynamics of some classical and quantum systems.

In convective turbulence we have explored the spectrum associated with the heat flux. The usual practice is to study the total heat flux (Nusselt number) across the convecting layer and explore the Rayleigh number dependence of the flux. The spectrum is the issue of how the total flux is distributed over the different wave numbers k. The scaling of the amount of flux associated with a wavenumber k with the wavenumber itself is a quantity which had not been studied before. As in other aspects of convective turbulence the scaling exponent can correspond to a constant entropy flux (Bolgiano-Obukhov) or to simultaneously constant entropy and kinetic energy fluxes (Kolmogorov). We imposed scale invariance on the buoyancy driven Navier Stokes equation to conlude that in the first case the expected scaling exponent would be 1.8 and in the second 1.67. The numerics showed a small preference for the Bolgiano-Obukhov value. We extended our study of convective turbulence to include weakly compressible fluids and found that at large length scales the sound speed increases as in the homogeneous isotropic turbulence while the thermal expansion coefficient becomes smaller. We looked at a simplified limit of the convective turbulence- this is the infinite Prandtl number limit where the velocity field is slaved to the thermal fluctuation and can be eliminated giving rise to a single scalar field equation of motion. The resultant exponents are in exact agreement with recent numerics.

The dynamics of a rotating double pendulum was analyzed using some perturbative techniques and numerics. A sequence of chaos to quasi-periodic to chaos transitions were found as the rotation speed was gradually increased. In quantum dynamics the Ehrenfest equation approach was adopted for the dynamics of the Gross Pitaevski equation to study the evolution of the probability densities. The simplifying assumption was that an initial two parameter shape retains its nature with a time dependent width and mean. How good is the assumption ? One could find the initial condition for which the width is unchanged and compare that with the exact soliton solution for the simple harmonic confinement. The result for the width agreed to within 10 % and gave one confidence in using this scheme for studying more complicated situations.

Publications:

1. H Pharasi, D Kumar, K Kumar and J K Bhattacharjee: "Thermal flux spectrum in Rayleigh-Benard convection with and without rotation"Phys of Fluids DOI : 10.10631/1.4948644 (2016)

2. H Pharasi and J K Bhattacharjee: "Dynamic scaling and large scale effects in turbulence in a compressible stratified fluid" Phys Lett A380 222 (2016)

3. J K Bhattacharjee: "Self consistent field theory in the convective turbulence in a Rayleigh Benard system in the infinite Prandtl number limit" J Stat Phys 160 1519 (2015)

4. J K Bhattacharjee and D S Ray: Time dependent perturbation theory in quantum mechanics and the renormalization group Am J Phys (in press) 2016

5. S Pal and J K Bhattacharjee: "Wave packet dynamics for Gross Pitaevski equation in one dimension :Dependence on initial conditions" Int J of Mod Phys B (2015)

6. R Sain and J K Bhattacharjee: "Equivalent linearization technique for quantum anharmonic oscillators" Eur J Phys 36 055025 (2015)

7. S Maity, J Roy, A K Mallik and J K Bhattacharjee : "Nonlinear dynamics of a rotating double pendulum" Phys Lett A 380 408 (2016)

Invited Lectures:

1. "Scales and scaling in convective turbulence" IISER, Trivandrum April,2015

2. "Perturbation methods in nonlinear dynamics" UGC refresher course lectures, Jadavpur Univ, Dept of Mathematics, July 2015

3. "Turbulence and field theory" lecture in meeting entitled Developments in Field Theory IOP, Bhubaneswar July 2015

4. "Renormalization group aided perturbation theory" IACS, Kolkata July 2015

5. "Time dependent perturbation theory in quantum mechanics and the renormalization group" Alumni day lecture IOP Bhubaneswar Sept 2015

6. “Patterns around us” Foundation day lecture , IOP Bhubaneswar Sept 2015
7. “Patterns in nature” NIT Sikkim Techfest and culfest lecture Nov 2015
8. “Time dependent perturbation theory in quantum mechanics and the renormalization group” Alumni assoc SINP lecture Nov 2015
9. “Perturbative techniques in nonlinear dynamics” ISI, Kolkata winter school on Nonlinear Dynamics Dec 2015
10. “Unusual Dynamics” Presidency University, Kolkata physics colloquium Dec 2015
11. “The ubiquitous hydraulic jump” VECC colloquium, Kolkata, Feb 2016
12. “Scales and scaling in convective turbulence” ICTS colloquium March 2016

Other activities:

Elective course on “Nonlinear Dynamics” Jan- Apr 2016 at HRI

Anirban Basu

Research Summary:

In the past year, I considered the finite part of the D^8R^4 and $D^{10}R^4$ amplitudes in the low energy expansion of the four graviton amplitude from the ladder skeleton diagrams in maximal supergravity on T^2, at three and four loops. These amplitudes were evaluated exactly for special values of the the moduli of the auxiliary geometry. While the dependence of the amplitudes on the volume of T^2 turned out to be very simple, the dependence on the complex structure of T^2 was quite intricate.

In a different project, I considered the perturbative contributions to the R^4, D^4R^4 and D^6R^4 interactions in toroidally compactified type II string theory. I derived Poisson equations satisfied by these moduli dependent string amplitudes. These T–duality invariant equations have eigenvalues that are completely determined by the structure of the integrands of the multi–loop amplitudes.

The Mercedes diagram has four trivalent vertices which are connected by six links such that they form the edges of a tetrahedron. I obtained a modular invariant Poisson equation satisfied by the Mercedes diagram, where the source terms involve one and two loop Feynman diagrams. I calculated its contribution to the $D^{12}R^4$ amplitude at genus one.

Finally, I obtained T–duality invariant second order differential equations satisfied by the D^8R^4 and $D^{10}R^4$ interactions from the low energy expansion of the one loop four graviton amplitude in toroidally compactified type II string theory. The eigenvalues of these equations were shown to be completely determined by the structure of the one loop integrands. I explicitly solved these equations in nine dimensions.

Publications:

1. Anirban Basu, *Poisson equation for the Mercedes diagram in string theory at genus one,* Class.Quant.Grav. **33**, 055005, (2016)

2. Anirban Basu, *Perturbative type II amplitudes for BPS interactions,* Class.Quant.Grav. **33**, 045002, (2016)

3. Anirban Basu, *Some finite terms from ladder diagrams in three and four loop maximal supergravity,* Class.Quant.Grav. **32**, 195023, (2015)

Preprints:

1. Anirban Basu, *Non-BPS interactions from the type II one loop four graviton amplitude,* arXiv:1601.04260

Conference/Workshops Attended:

1. *Strings 2015*, ICTS Bengaluru, India, June, 2015,
2. *NSM 2015*, IISER Mohali, India, December 2015,
3. *Workshop on String Perturbation Theory*, HRI, India, February 2016.

Visits to other Institutes:

1. TIFR Mumbai, India, November 2015,
2. IACS Kolkata, India, March 2016.

Invited Lectures/Seminars:

1. *Perturbative type II amplitudes for BPS interactions*, DTP Seminar, TIFR Mumbai, November 2015.
2. *Higher derivative corrections in maximally supersymmetric string theory*, NSM 2015, IISER Mohali, December 2015.
3. *Higher derivative corrections in type IIB string theory*, Workshop on string perturbation theory, HRI Allahabad, February 2016.
4. *Perturbative type II amplitudes for BPS interactions* , Theory Seminar, IACS Kolkata, March 2016.

Tapas Kumar Das

Research Summary:

I have been working in relativistic and high energy astrophysics, emergent gravity, and study of general relativistic fluid flow from dynamical systems approach.

Preprints:

1. Ananda, D. B., Chaudhury, S., Das, T. K., Maity, I., Nag, S., *Transonic behaviour and stability analysis of quasi-viscous black hole accretion,* arXiv:1512.08488 [astro-ph.HE]

2. Nag, S,, Sinha, S.,, Ananda, D. B., Das, T. K., *Influence of the black hole spin on the chaotic particle dynamics within a dipolar halo,* arXiv:1601.02100 [astro-ph.HE]

Conference/Workshops Attended:

1. *Physics: Nucleus to Universe*, India, February, 2016.

2. *Astronomy: A scientific exploration*, India, February, 2016.

Visits to other Institutes:

1. S. N. Bose National Centre for Basic Sciences, Kolkata, India (Several visits to work with Mr. Pratik Tarafdar, my student over there - I am his official co - supervisor).

2. Sarojini Naidu College for Women, Kolkata, India (Several visits to work with my collaborators Prof. Sankhasubhra Nag & Prof. Sonali Saha Nag, who are the academic faculty members over there).

3. Rishi Bankim Chandra College, Naihati, India, February, 2016.

4. St. Xavier's College (Autonomous), Kolkata, India, March, 2016.

Invited Lectures/Seminars:

1. *Science versus superstition - why astrology is not a science whereas astronomy is*, Invited public lecture, at 'Physics: Nucleus to Universe', Rishi Bankim College, February, 2016.

2. *Astronomy - A Scientific Pursuit*, Invited lecture, at Astronomy: A Scientific Exploration, Sarojini Naidu College for Women & West Bengal State University, Kolkata, February, 2016.

3. *On Pseudoscience & Superstition*, Invited lecture for the orientation course, at St. Xavier's College (Autonomous), Kolkata, March, 2016.

4. *Astrophysical accretion : a dynamical systems approach*, at St. Xavier's College (Autonomous), Kolkata, March, 2016.

Other Activities:

1. MS Thesis Supervision:
   Supervised the following students for their one semester long master's theses work:

   (a) MS Ivleena Firdousi from Pune University. Title of the thesis: On the use of LaneEmden equation to study the stellar structure.

   (b) MS Sanchita Sharma from the Central University of Rajasthan. Title of the thesis: Bondi flow : a dynamical systems approach.

   (c) MS Kartika Singhal from Amity University, Noida. Thesis title: Stability analysis of the stationary transonic accretion solution in spherical symmetry.

2. Supervision of long term project student:

   (a) MS Deepika B Ananda, former student of IISER, Pune, who did her MS thesis under my supervision, worked with me (for a duration of one year after finishing her MS thesis work which she pursued under my supervision) as a project assistant. She coauthored six journal papers with me all of which she completed during her stay over here at HRI as project assistant.

3. Supervision of project students (VSRP & others):

   Following students worked under my supervision:

   (a) MS Namrata Roy from Presidency University.
   (b) MS Shivani Singh from IIT Hyderabad (jointly with Dr. Nandan Roy, a post doctoral fellow from astrophysics group at HRI).
   (c) MS Sanchari Pal from IIT Guwahati.
   (d) Mr. Soumyadeep Chatterjee from IIT Mumbai (Jointly with Mr. Md. Arif Shaikh, a junior research fellow from astrophysics group at HRI).
   (e) MS Priyanka Baghel from Delhi University.
   (f) MS Sania Munjal from Delhi University.
   (g) MS. Ishika Palit from Bhopal University
   (h) Mr. Arindam Chakrabarti from North Bengal University (jointly with Dr. Nandan Roy, a post doctoral fellow from astrophysics group at HRI).

4. Ph.D. Thesis Examination:

   (a) Served as an examiner of a Ph.D. thesis on the application of certain techniques of renormalization group in the field of dynamical systems study.

5. Reviewer's Job:

   (a) Reviewed several academic papers submitted to international journals, The Astrophysical Journal, for example.

AseshKrishna Datta

Research Summary:

Search for the bottom squarks (sbottoms) at the Large Hadron Collider (LHC) has recently assumed a heightened focus in the hunt for Supersymmetry (SUSY). The popular framework of the Next-to-Minimal Supersymmetric Standard Model (NMSSM) could conceive a naturally light sbottom which could easily be consistent with available constraints from the experiments at the LHC. Phenomenology of such sbottoms could in principle be as striking as that for a light top squark (stop) thanks to a rather nontrivial neutralino sector (with appreciable mixing among the neutral higgsinos and the singlino) that the scenario gives rise to. In our recent study done in collaboration with my graduate student and a DST INSPIRE faculty from a different institution, we found that a conclusive observation of such sbottoms might require a moderately large amount of data (about 300 inverse femtobarn) at the 13 TeV run of the LHC. A multi-channel analysis establishing a generic depletion of events in the usual 2b-jets + $\not\!\!E_T$ final state while registering, in conjunction, characteristically significant rates in various multi-lepton final states accompanied by b-jets might point not only to the presence of light sbottom(s) but could also shed crucial light on their compositions and the (singlino) nature of the lightest SUSY particle (LSP). *This work has been circulated on the arXiv.*

In another recent work in a different collaboration we have explored the phenomenology of top squarks at the LHC in a SUSY model where lepton number is identified with an approximate $U(1)_R$ symmetry in such a way that one of the left chiral sneutrinos can acquire a large vacuum expectation value (vev) and can play the role of the down-type Higgs. The R-symmetry allows a subset of trilinear R-parity violating interactions, which determine the collider phenomenology of this model in a significant way. The gauginos are Dirac particles and gluinos are relatively heavy in this class of models. The model contains a right handed neutrino superfield, which gives a tree level mass to one of the active neutrinos. An order one neutrino Yukawa coupling also helps enhance the Higgs boson mass at the tree level and results in a very light bino-like neutralino ($\tilde{\chi}_2^0$) with mass around a few hundred MeV, which is a carrier of missing (transverse) energy ($\not\!\!E_T$). The model can accommodate two rather light top squarks, compatible with the observed mass of the Higgs boson. The lighter top squark ($\tilde{t}_1$) can decay into $t\tilde{\chi}_2^0$, and thus the signal would be similar to the signal of top quark pair production at the LHC. In addition, fully visible decays such as $\tilde{t}_2 \to be^+$ can give rise to interesting final states. Such signals at the LHC combined with other features like a heavy gluino could provide a strong evidence for this kind of a model. Our analysis shows that $m_{\tilde{t}_1} < 575(750)$ GeV and $m_{\tilde{t}_2} < 1.2(1.4)$ TeV can be probed with 5σ statistical significance at the 13 TeV LHC with 300(3000) inverse femtobarn of integrated luminosity. Finally, we observe that in the presence of super-light carriers of $\not{E}_T$, the so-called 'stealth' top squark scenario may naturally appear in our model. *This work has been circulated on the arXiv.*

With my current graduate student and collaborators from another institution I am now looking into the vacuum structure of the NMSSM. The study reveals how the requirement of a desired (electroweak) symmetry breaking (DSB) vacuum restricts the parameter space of the scenario. The viable vacuum configurations are those for which the DSB vacuum corresponds to the global minimum of the potential thus making it absolutely stable and those for which it is meta-stable but long-lived. The latter is the case when the DSB vacuum is only a local minimum of the potential but its decay to the global minimum via quantum tunneling would take more time than the age of the Universe. We also explore the scenario in the light of the unwanted charge and color breaking (CCB) minima of the potential that could be easily present in such a scenario. The study incorporates state of the art treatment of the involved cosmological and particle physics issues and includes finite temperature effects as well.

Two of our ongoing studies from the past year have met with some new issues in recent months. The first one that targets a complete, thorough implementation of the framework of the minimal Universal Extra Dimension (mUED) (which can masquerade SUSY signals in a generic fashion) in a modern event generator had revealed quite a few intricacies. These are being taken care of in addition to the ones we already addressed. *I am pursuing on these lines with my current graduate student and the collaborators abroad.* The other study from the past year involves the phenomenology of a single broad or two close-by (in mass) vector boson resonances originally motivated in a nonminimal UED (nmUED) scenario. Although a preliminary study has been circulated on the arXiv in the form of a conference proceeding, we realised that the issue has a more general appeal and hence requires an appropriate study. Furthermore, we now feel encouraged to find that a modern technique like Multi-Variate Analysis could shed useful light to decipher hidden resonances in an experimentally observed broad resonance. *Further studies are in progress with one of my collaborators from abroad.*

Publications:

1. Jyotiranjan Beuria, Arindam Chatterjee, AseshKrishna Datta and Santosh Kumar Rai, *Two Light Stops in the NMSSM and the LHC,* JHEP **1509**, 073, (2015).

Preprints:

1. Jyotiranjan Beuria, Arindam Chatterjee and AseshKrishna Datta, *Sbottoms of Natural NMSSM at the LHC,* arXiv:1603.08463 [hep-ph].

2. Sabyasachi Chakraborty, AseshKrishna Datta, Katri Huitu, Sourov Roy and Harri Waltari, *Light top squarks in $U(1)_R$ lepton number model with a right handed neutrino and the LHC,* arXiv:1508.01875 [hep-ph].

3. AseshKrishna Datta, Kenji Nishiwaki and Saurabh Niyogi, *Z' Search in Non-minimal Universal Extra Dimensions: Two Bumps and Interference,* arXiv:1504.07946 [hep-ph].

Conference/Workshops Attended:

1. *Frontiers in High Energy Physics (FHEP)*, IMSc., India, March, 2016.

2. *WHEPP-14 (Workshop)*, India, December, 2015.

Visits to other Institutes:

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

2. Visited Theory Division, CERN, Switzerland for an academic visit during summer 2015.

Invited Lectures/Seminars:

1. Frontiers in High Energy Physics (FHEP), IMSc. India, March, 2016. *Declined.*

2. Collider Physics related activity at IIT, Guwahati, January, 2016. *Declined.*

3. The Conference on Computational Physics (CCP)-2015 (under the auspices of the C20 Commission for Computational Physics of the International Union of Pure and Applied Physics (IUPAP)), IIT, Guwahati, December, 2015.
   Declined.

Academic recognition/Awards:

None

Other Activities:

1. Supervising one student towards his Ph.D. degree (since December, 2013).
2. Serving the Doctoral Committee of several students.
3. Offered a semester-long reading course to one student (fall, 2015; credited).
4. Served as the referee for international journals.
5. Learning, teaching and adapting myself to an ever-evolving integrated environment for state-of-the-art simulation techniques aimed at present and future colliders.

Aditi Sen De

Research Summary:

An important characterization of a composite quantum system is by the correlations, both classical and quantum, between its constituting parts. Quantum information theory provides a collection of measures of quantum correlations, which can broadly be categorized into two classes. One is the "entanglement-separability class, encompassing various measures of quantum entanglement in both bipartite and multipartite domain. The other is the information-theoretic regime, consisting of quantum correlations such as quantum discord, and various discord-like measures, that quantify quantum correlations beyond entanglement. It has been established that quantum correlations are important resources in various quantum information protocols including quantum dense coding, quantum teleportation, and quantum cryptography. However, to achieve a quantum advantage, one has to find physical systems in which such protocols can be implemented. The suitable physical systems could be spin models.

Perfectly ordered spin systems are hard to prepare in the laboratory due to the presence of several uncontrollable factors and hence disorder almost inevitably appears in most systems. In a work, we have investigated the behavior of quantum correlations of paradigmatic quenched disordered quantum spin models, viz., the XY spin glass and random-field XY models. We found that the order-from-disorder can become more pronounced in the presence of temperature by suitable tuning of the system parameters. In another work, we have also investigated the effects of quenched disorder on quantum correlation lengths of quenched averaged entanglement and quantum discord, in the anisotropic XY and XYZ spin glass and random field chains. We found that there is virtually neither reduction nor enhancement in entanglement length while quantum discord length increases significantly with the introduction of the quenched disorder.

We have also recently addressed the issue of reducing the resource required to compute information-theoretic quantum correlation measures such as quantum discord and quantum work deficit in two qubits and higher-dimensional systems. We showed that determination of the quantum correlation measure is possible even if we utilize a restricted set of local measurements. We found that the determination allows us to obtain a closed form of quantum discord and quantum work deficit for several classes of states, with a low error.

We also investigated the effect of noisy channels in a classical information transfer through a multipartite state which acts as a substrate for the distributed quantum dense coding protocol between several senders and two receivers. The situation is qualitatively different from the case with one or more senders and a single receiver. In this situation, we obtained an upper bound on the multipartite capacity which is tightened in the case of the covariant noisy channel.

One of the physical systems in which quantum information tasks have been realized in the laboratory is the class of continuous variable (CV) systems. In recent years, several communications schemes like teleportation and classical information transfer by quantum channels, have extensively been investigated both theoretically and experimentally, in CV systems, especially in Gaussian states. However, it has been discovered that there are several protocols which can not be implemented using Gaussian states with Gaussian operations. An important mechanism to create non-Gaussian states is adding and subtracting photons, when the initial state is the squeezed vacuum state. We have investigated the entanglement patterns of photon-added and -subtracted four-mode squeezed vacuum states. We found that the photon-subtracted state can give us higher entanglement than the photon-added state which is in contrast of the two-mode situation.

Publications:

1. Avijit Misra, Anindya Biswas, Arun K. Pati, Aditi Sen(De), and Ujjwal Sen, *Quantum correlation with sandwiched relative entropies: Advantageous as order parameter in quantum phase transitions,* Phys. Rev. E **91**, 052125 (2015)

2. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Beating no-go theorems by engineering defects in quantum spin models,* New J. Phys. **17**, 043013 (2015)

3. Titas Chanda, Amit Kumar Pal, Anindya Biswas, Aditi Sen(De), and Ujjwal Sen, *Freezing of quantum correlations under local decoherence,* Phys. Rev. A **91**, 062119 (2015)

4. Tamoghna Das, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Distributed quantum dense coding with two receivers in noisy environments,* Phys. Rev. A **92**, 052330 (2015)

5. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Reducing computational complexity of quantum correlations,* Phys. Rev. A **92**, 062301 (2015)

6. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Diverging scaling with converging multisite entanglement in odd and even quantum Heisenberg ladders,* New J. Phys. **18**, 023025 (2016)

7. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Quantum discord length is enhanced while entanglement length is not by introducing disorder in a spin chain,* Phys. Rev. E **93**, 012131 (2016)

8. Debasis Sadhukhan, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Quantum correlations in quenched disordered spin models: Enhanced order from disorder by thermal fluctuations* Phys. Rev. E **93**, 032115 (2016)

9. Anindita Bera, Asutosh Kumar, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Information complementarity in multipartite quantum states and security in cryptography,* Phys. Rev. A **93**, 032338 (2016)

10. Tamoghna Das, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Subtraction better than addition: Entanglement in multimode squeezed vacuum post-interface with photons,* Phys. Rev. A (in print)

Preprints:

1. Asutosh Kumar, Himadri Shekhar Dhar, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Forbidden Regimes in Distribution of Bipartite Quantum Correlations due to Multiparty Entanglement,* arXiv:1505.01748

2. Anindita Bera, Debraj Rakshit, Maciej Lewenstein, Aditi Sen De, Ujjwal Sen, Jan Wehr, *Order-from-disorder and critical scalings of spontaneous magnetization in random-field quantum spin systems,* arXiv:1509.00704

3. Tamoghna Das, Sudipto Singha Roy, Shrobona Bagchi, Avijit Misra, Aditi Sen De, Ujjwal Sen, *Generalized Geometric Measure of Entanglement for Multiparty Mixed States,* arXiv:1509.02085

4. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen De, Ujjwal Sen, *Statistics of leading digits leads to unification of quantum correlations,* arXiv:1509.09295

5. Debasis Sadhukhan, Sudipto Singha Roy, Amit Kumar Pal, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Multipartite Entanglement Accumulation in Quantum States: Localizable Generalized Geometric Measure,* arXiv:1511.03998

6. Asutosh Kumar, Indranil Chakrabarty, Arun Kumar Pati, Aditi Sen De, Ujjwal Sen, *Quantum no-go theorems in causality respecting systems in presence of closed timelike curves: Tweaking the Deutsch condition,* arXiv:1511.08560

7. Kunal Sharma, Tamoghna Das, Aditi Sen De, Ujjwal Sen, *Distribution of Bell inequality violation vs. multiparty quantum correlation measures,* arXiv:1512.01477

8. Asutosh Kumar, Sudipto Singha Roy, Amit Kumar Pal, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Conclusive Identification of Quantum Channels via Monogamy of Quantum Correlations,* arXiv:1603.02801

Conference/Workshops Attended:

1. *Frontiers of Quantum Physics*, Spain, October 2015.

2. *International Conference on Quantum Foundations 2015 (ICQF 2015)*, India, Decmeber 2015.

3. *Quantum Information Processing and Applications*, India, December 2015.

4. *International Conference on Light Quanta: Modern Perspectives and Applications*, India, December 2015.

5. *Workshop on Modern and Quantum Information Security (WMQIS-2016)*, International Institute of Information Technology, India, March 2016.

Visits to other Institutes:

1. Institut fuer Theoretische Physik III, Heinrich-Heine-Universitaet Duesseldorf, Dusseldorf, Germany, October 2015

2. ICFO-The Institute of Photonic Sciences, Barcelona, Spain, October 2015

Invited Lectures/Seminars:

1. *Benford's law and its application in quantum information science*, QIC Seminar, Heinrich-Heine-Universitaet Duesseldorf, Dusseldorf, Germany, Oct 2015.

2. *Monogamy in Quantum Information*, International Conference on Quantum Foundations 2015 (ICQF 2015), National Institute of Technology, Patna, India, Nov 2015.

3. *Monogamy in Quantum Information*, International Conference on Light Quanta: Modern Perspectives and Applications, University of Allahabad, Allahabad, India, Dec 2015.

4. *Recent trends in Quantum Communication*, Workshop on Modern and Quantum Information Security (WMQIS-2016), International Institute of Information Technology, Hyderabad, India, Mar 2016.

Other Activities:

1. Taught a one-semester course on "Classical mechanics" during Aug-Dec 2015.

2. Guiding the theses of Titas Chanda, Tamoghna Das, Debasis Sadhukhan of HRI.

3. Guided projects of the following HRI graduate students:

   (a) Saptarshi Roy "Role of entropy in Quantum Information" (Jan-May 2015).

   (b) Saptarshi Roy "Quantum Optics" (Aug-Dec 2015).

   (c) Suman Jyoti Dey "Entanglement and its applications" (Jan-May 2016).

   (d) Saptarshi Roy "Quantum Optics" (Jan-May 2016).

4. Served as an organizer of a meeting on "Quantum Information Processing and Applications (QIPA-15)" held at HRI in December 2015.

5. Guiding the MS project work of a student, Kunal Sharma , Indian Institute of Science Education and Resaerch, Bhopal, May 2015 - May 2016.

6. Serving as the convenor of the Housing Committee, Office Allocation and Furnishing, and member of the Horticulture, Women Grievence Cell committee at HRI.

7. Serving as referees in national and international journals.

8. Serving as members of the PhD committees of Avijit Misra, Utkarsh Mishra, Debasis Mondol, Sudipto Singha Roy, Avinanda Chaudhuri, Juhi Dutta, Swapnamay Mondal, Dibya Kanti Mukherjee, Akansha Singh, and Nayabanta Swain.

Dileep P. Jatkar

Research Summary:

In the past year, I have worked on three problems. First one is, in collaboration with M. Honda, about efficacy of interpolating functions in capturing nonperturbative information from an asymptotic series. We work with toy models where we have control over both perturbative as well as non-perturbative parts, which is used to analyse the interpolating functions. In the second work, in collaboration with N. Kundu, I showed that there exist a codimension 1 locus in Lovelock moduli space where both Lifshitz and Schrödinger solution exist. Interestingly, the dynamical exponent on the locus is not constrained at all. Deformation away from this locus in the Lovelock direction leads to no solutions of Lifshitz or Schrödinger type. In the third work, with N. Banerjee, S. Mukhi and T. Neogi, I showed that three dimensional BMS algebra can be obtained by suitably modifying free field representation of two dimensional chiral conformal field theory. We extended this result to super-BMS as well as to spin-3 BMS algebra.

Publications:

1. M. Honda and D. P. Jatkar, *Interpolating function and Stokes Phenomena,* Nucl. Phys. **B900**, 533 (2015), arXiv:1504.02276 [hep-th].

Preprints:

1. D. P. Jatkar and N. Kundu, *A Note on Lifshitz and Schroedinger Solutions in Pure Lovelock Theories,* arXiv:1509.03505 [hep-th].

2. N. Banerjee, D. P. Jatkar, S. Mukhi and T. Neogi, *Free-field realisations of BMS_3 and super-BMS_3 algebras,* arXiv:1512.06240 [hep-th].

Conference/Workshops Attended:

1. *NSM*, India, December 2015.

2. *Indo-Israeli Workshop on String Theory*, India, December 2015.

Visits to other Institutes:

1. Institute of Mathematical Sciences, Chennai, India, August 2015,
2. Institute of Mathematical Sciences, Chennai, India, November 2015,
3. Jawaharlal Nehru University, New Delhi, India, January 2016.

Invited Lectures/Seminars:

1. *Lifshitz and Schrodinger solutions in Lovelock gravity*, IMSc theory physics seminar, Institute of Mathematical Sciences, Chennai, August 2015.
2. *Free field realisation of BMS_3 algebra*, Indo-Israeli Workshop on String Theory, ICTS, TIFR, Goa, December 2015.
3. *Interpolating functions and Stokes phenomena*, Theory Physics Seminar, Jawaharlal Nehru University, New Delhi, January 2016.

Anshuman Maharana

Research Summary:

My work has been primarily focussed on phenomenological aspects of string theory. A generic feature of inflationary models in supergravity/string constructions is vacuum misalignment for the moduli fields. The associated production of moduli particles leads to an epoch in the post-inflationary history in which the energy density is dominated by cold moduli particles. This modification of the post-inflationary history implies that the preferred range for the number of e-foldings between horizon exit of the modes relevant for CMB observations and the end of inflation (N_k) depends on moduli masses. This in turn implies that the precision CMB observables n_s and r are sensitive to moduli masses. We analysed this sensitivity for some representative models of inflation and find the effect to be highly relevant for confronting inflationary models with observations. We have also constructed a model of inflation involving Kahler moduli in IIB flux compactifications. Patterns of supersymmetry breaking in IIB flux compactifications have also been analysed.

Publications:

1. K. Das, K. Dutta and A. Maharana, *Inflationary Predictions and Moduli Masses*, Phys. Lett. B 751 (2015) 195
2. A. Maharana, M. Rummel and Y. Sumitomo, *Accidental Kähler Moduli Inflation* , JCAP 1509 (2015) 09 40
3. L. Aparicio, M. Cicoli, B. Dutta, S. Krippendorf, A. Maharana, F. Muia and F. Quevedo, *Non-thermal CMSSM with a 125 GeV Higgs*, JHEP 1505 (2015) 098

Conference/Workshops Attended:

1. *Fourth Indian-Israeli Workshop on String Theory*, India, December 2015
2. *Conference on Recent Developments in Field Theory*, India, July 2015
3. *Gordon Research Conference on String Theory and Cosmology*, Hong Kong, June 2015

Visits to other Institutes:

1. ICTP, Trieste, Italy, October 2015

Invited Lectures/Seminars:

1. *CMB, Moduli and Inflation*, Fourth Indian-Israeli Workshop on String Theory, Goa, December 2015
2. *CMB, Moduli and Inflation*, High Energy Theory Seminar, ICTP, Trieste, Italy, October 2015
3. *CMB, Moduli and Inflation*, High Energy Theory Seminar, Tata Institute of Fundamental Research, Mumbai, July 2015
4. *CMB, Moduli and Inflation*, Conference on Recent Developments in Field Theory, Institute of Physics, Bhubaneswar, July 2015
5. *CMB, Moduli and Inflation*, Gordon Research Conference on String Theory and Cosmology, HKUST, Hong Kong June 2015

Academic recognition/Awards:

- Associateship at the International Centre for Theoretical Physics (Trieste), 2016

Other Activities:

1. Instructor for Quantum Mechanics II, January 2016 - May 2016

Pinaki Majumdar

Research Summary:

There are four major problems on which we have made some progress. (i) We have completed work on imbalanced superfluids, detailing the behaviour of the breached pair and Fulde-Ferrell-Larkin-Ovchinnikov phases. (ii) To begin exploring the general interplay of magnetism and superconductivity we have done a detailed study of the attractive Hubbard model with electrons Hund's coupled to local moments. The ground state reveals interesting patterns of gaplessness, the finite temperature work is on. (iii) For correlated fermions on frustrated lattices we studied the Mott transition on the pyrochlore, and have set up extensions of this model to capture the physics of the iridates and molybdates, which involve additional couplings and degrees of freedom. (iv) We have set up and solved the superfluid-insulator transition problem for correlated bosons, including the full thermal behaviour, and are working on the multispecies problem involving gauge coupling/spin-orbit interaction.

Publications:

1. Madhuparna Karmakar, Pinaki Majumdar *Non-collinear order and gapless superconductivity in s-wave magnetic superconductors,* Phys. Rev. B.93, 195147 (2016) .

2. Madhuparna Karmakar, Pinaki Majumdar *Population-imbalanced lattice fermions near the BCS-BEC crossover: Thermal physics of the breached pair and Fulde-Ferrell-Larkin-Ovchinnikov phases*, Phys. Rev. A.93, 053609 (2016).

Preprints:

1. Madhuparna Karmakar and Pinaki Majumdar, *Anomalous pseudogap in population imbalanced Fermi superfluids*, arXiv:1508.00398.

Invited Lectures/Seminars:

1. *The physics of disordered electrons*, Condensed Matter Conference, I.O.P. Bhubaneswar, Feb 2016.

2. *Mott transition in the pyrochlores*, Meeting on Disordered Quantum Systems, I.M.Sc. Chennai, March 2016.

3. *Mott physics in the pyrochlore molybdates*, Indo-Japan Meeting, I.I.Sc. Bangalore, March 2016.

Academic recognition/Awards:

- Elected Fellow of the National Academy of Sciences, India, 2015.

Other Activities:

1. Taught the Advanced Quantum and Statistical Mechanics course during Aug-Dec 2015, and the Condensed Matter Physics 2 course during Jan-Apr 2016.

G. Venketeswara Pai

Research Summary:

My research focuses on strongly correlated electron systems and cold atoms. We studied the Holstein-Hubbard model at half filling to explore the ordered phases such as the charge density wave and antiferromagnet. The effect of geometric frustration was also explored. The onset and evolution of superconductivity in a model of percolation were analysed. We are also pursuing protocols to realise supersolidity of bosonic atoms in a mixture of heavy bosonic and light fermionic atoms and use cold atoms to simulate Kitaev model in one dimension.

Publications:

1. Saurabh Pradhan and G. Venketeswara Pai, *Holstein-Hubbard model at half filling : A static auxiliary field study,* Phys. Rev. B **92**, 165124, (2015)

Preprints:

1. Saurabh Pradhan and G. Venketeswara Pai, *Effect of site dilution in the two-dimensional attractive Hubbard model,* arXiv:1511.00380

Visits to other Institutes:

1. Department of Physics, Indian Institute of Technology, Hyderabad, January 2016

Invited Lectures/Seminars:

1. *Nature of Superconductivity due to Site Dilution of Attractive Centers*, Indian Institute of Tecnology, Hyderabad, January 2016

Other Activities:

1. Taught a graduate level course, Statistical Mechanics, during January-May 2016

2. Member of the thesis advisory committee, (Master of Science), Indian Institute of Science Education and Researc, Pune

3. Member of the Physics PDF-Visitors' committee and Cluster Computing Facility committee

Tribhuvan Prasad Pareek

Research Summary:

Toplogical phases of matter has attracted a lot of intereste in past few years. Recently we had developed an exact sccatering theoret to study such pahase. This workd has been further extended to study topological phase of density matrice which are important for mixed state system. A generic condensed matter system most often is in mixed state therefore its states are described by the density matrices. Abelian evilution of density matrices are well studied. However the non-abelian evolution of density matrices have not been examined closely. We have studied Non-Abelian evolution of density matrices and shown that it leads to various topological phases. Its further extension using path integral approach is underway. Beside this Anomalous and spin hall effect has been studied using non-perturbative T- matrix approach in collobration with avisiting student from Nepal Bibek Bhandari.

Preprints:

1. Bibek Bhandari and Tribhuvan Prasad Pareek *Spin and Charge transport at Structured weyl points* submitted for publications

2. Bibek Bhandari and Tribhuvan Prasad Pareek *Semi classical approach to anomalous Hall effect and spin hall effect using non-perturbative T-matrix Operator* submitted for publications

3. Tribhuvan Prasad Pareek)*Non-abelian Quantum dynamics and Topological Phases: manuscript under prepration*

Conference/Workshops Presentations:

1. B. Bhandari, N. P. Adhikari and T. P. Pareek The Role of Spin-Orbit Coupling in Anomalous Hall Effect and Spin-Resolved Mesoscopic Systems Poster Presented at Conference on Frustration, Disorder and Localization: Statics and Dynamics held at ICTP, Trieste , Italy (28 Sep-2 Oct 2015).

Other Activities:

1. I am member of various adminstrative and acdemic committies of institute. 2 Visiting students have done master thesis at HRI under my Guidance (Bibek Bhandar from Tribhuvan University Nepal and Hardik Jain from SRM university Chennai).

Santosh Kumar Rai

Research Summary:

During last year my area of research has been on new ideas that propose physics beyond the Standard Model (SM) of particle physics which also included studies on possible interpretations to excesses observed by the LHC experiment in some specific channels. I have been working on supersymmetric models, models with exotic coloured particles, extended gauge symmetries such as left-right theories and abelian extensions to the SM and their implications in collider experiments.

In works related to supersymmetric theories we studied the viability of having two relatively light top squarks in the framework of the Next-to-Minimal Supersymmetric Standard Model (NMSSM). Such light stops render the NMSSM rather 'natural'. These are shown to be allowed by the relevant direct searches at the LHC and to be compatible with the latest LHC results on the Higgs sector, other low energy electroweak constraints and recent constraints from the dark matter (DM) sector. We proposed dedicated searches for such light stops at the LHC within a 'simplified' scenario that may have a bino-like or a singlino-like neutralino LSP as the DM candidate and point out various final states carrying the imprint of their collective presence. Under certain circumstances, in such a scenario, presence of two light stops may give rise to final states which are not so typical in their search. Thorough studies at the detector level reveal the status of such a scenario after the 8 TeV run of the LHC and shed light on the prospects of its 13 and 14 TeV runs.

Recently a compressed mass spectrum has been thought as an explanation for the elusiveness of low-energy supersymmetry (SUSY). Some characteristic signals at the Large Hadron Collider (LHC), such as mono-jet + missing transverse energy (MET), had been propounded as its trademark signals. However, later investigations suggested that lower limits on the supersymmetric particle masses would be quite stringent in spite of compression. Also, most compressed SUSY scenarios studied so far are only partially compressed. In this backdrop, we made an exhaustive analysis of the compressed SUSY scenarios for the 13 TeV run of LHC, keeping the level of compression in the entire spectrum as high as possible. A broad class of benchmark spectra are thus considered, after ensuring consistency with the observed Higgs mass as well as the dark matter constraints. The rates of observable events in the high-energy run are obtained through detailed simulation, for both the multi-jet +MET and mono-jet + MET final states. Our conclusion was that the former is still more efficient to reveal a compressed SUSY spectrum first, while the latter can serve as a useful confirmatory channel.

I also studied the production of new colored particles, a vector diquark, a particle having the quantum number of two quarks. In this work we calculated the next-to-leading order (NLO) QCD corrections to the on-shell vector diquark production at the LHC produced through the fusion of two quarks as well as the NLO corrections to its decay width. We present full analytic results for the one-loop NLO calculation and do a numerical study to show that the NLO corrections can reduce the scale uncertainties in the cross sections which can be appreciable and therefore modify the expected search limits for such particles. We also use the dijet result from LHC to obtain current limits on the mass and coupling strengths of the vector diquarks.

The breaking of parity, a fundamental symmetry between left and right is best understood in the framework of left-right symmetric extension of the standard model. We showed that the production of a heavy right-handed neutrino at the proposed Large Hadron-Electron Collider (LHeC) could give us the most simple and direct hint of the scale of this breaking in left-right symmetric theories. This production mode gives a lepton number violating signal with $\Delta = 2$ which is very clean and has practically no standard model background. We are the first people to highlight that the right-handed nature of W_R exchange which defines the left-right symmetric theories can be confirmed by using a polarized electron beam and also enhance the production rates with relatively lower beam energy and the polarized beams can be used for other new physics searches.

The ATLAS Collaboration at LHC reported a resonant excesses around 2 TeV which was not observed in leptonic channel. We proposed that this could be explained in a left-right symmetric model, where the tight constraints from lepton plus missing energy searches can be evaded if the $SU(2)_R$ gauge symmetry is leptophobic. We for the first time proposed an anomaly free leptophobic left-right model with gauge symmetry $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X$ where the SM leptons are singlets under $SU(2)_R$. We show explicitly that the ATLAS diboson excess can be explained in the viable parameter space of our model, which is consistent with all the current experimental constraints.

A very recent result from the experimental collaborations at LHC give hints of a resonance in the diphoton channel at an invariant mass of 750 GeV. We showed that such a scalar resonance would be possible in an $U(1)$

extension of the SM where the extended symmetry is hidden and yet to be discovered. We explore the possibilities of accommodating this excess by introducing a minimal extension to the matter content and highlight the parameter space that can accommodate the observed diphoton resonance in the model. The model also predicts new interesting signals that may be observed at the current LHC run.

I also studied the Littlest Higgs Model with T-parity, which is characterised by various production channels. We show that if the T-odd quarks are heavier than the exotic partners of the W and the Z, then associated production can be as important as the pair-production of the former. Studying both, we look for final states comprising at least one lepton, jets and missing transverse energy. We consider all the SM processes that could conspire to contribute as background to our signals, and perform a full detector level simulation of the signal and background to estimate the discovery potential at the current run as well as at the scheduled upgrade of the LHC. We also show that, for one of the channels, the reconstruction of two tagged b-jets at the Higgs mass ($M_h = 125$ GeV) provides us with an unambiguous hint for this model.

Publications:

1. J. Beuria, A. Chatterjee, A. Datta, Santosh Kumar Rai, *Two Light Stops in the NMSSM and the LHC,* JHEP **1509**, 073, (2015).

2. K. Das, S. Majhi, Santosh Kumar Rai, A. Shivaji, *NLO QCD corrections to the resonant Vector Diquark production at the LHC,* JHEP **1510**, 122, (2015).

3. S. Mondal and Santosh Kumar Rai, *Polarized window for left-right symmetry and a right-handed neutrino at the Large Hadron-Electron Collider,* Phys. Rev. D **93**, no. 1, 011702, (2016).

4. J. Dutta, P. Konar, S. Mondal, B. Mukhopadhyaya, Santosh Kumar Rai, *A Revisit to a Compressed Supersymmetric Spectrum with 125 GeV Higgs,* JHEP **1601**, 051 (2016).

5. K. Das, T. Li, S. Nandi, Santosh Kumar Rai, *Diboson excesses in an anomaly free leptophobic left-right model,* Phys. Rev. D **93**, no. 1, 016006, (2016).

Preprints:

1. K. Das and Santosh Kumar Rai, *The 750 GeV Diphoton excess in a $U(1)$ hidden symmetry model,* [arXiv:1512.07789 [hep-ph]].

2. D. Choudhury, D. K. Ghosh, Santosh Kumar Rai, I. Saha, *Little Higgs after the little one,* [arXiv:1603.02037 [hep-ph]].

Conference/Workshops Attended:

1. *WHEPP-XIV*: Workshop in High Energy Physics Phenomenology, IIT Kanpur, India, December, 2015.

2. *Sangam@HRI* : Instructional Workshop in Particle Physics, HRI, India February, 2016.

3. *Nu HoRIzons VI*, HRI, India, March 2016.

4. *FHEP III*: Frontiers in High Energy Physics, IMSc., India, March, 2016.

Invited Lectures/Seminars:

1. *Revisiting compressed SUSY at LHC*, FHEP III, The Institute of Mathematical Sciences (IMSc.), Chennai, India, March 2016.

Other Activities:

1. Teaching course at HRI titled *Particle Physics*, Jan-April, 2016.

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

3. Coordinator, *WG-I*, Working Group Activity on Standard Model + Beyond Standard Model Physics at *WHEPP-XIV*, IIT Kanpur, India, December 2015.

4. Member, Organising Committee of *Sangam @ HRI* : Instructional Workshop in Particle Physics, HRI, India, February 2016.

5. Member, Organising Committee of *Nu HoRIzons VI*, HRI, India, March 2016.

6. Invited Chief Guest at *Maha Prabhu Public School*, celebrating the *National Technology Day-2015*, Allahabad, India, May 2015.

7. Member, VSP Committee and Library Committee, Horticulture Committee (Convener) 2015-2016.

Sumathi Rao

Research Summary:

During the period, April 2015-March 2016, I have been mainly working on topological phases of matter, including topological phases of matter that can be accessed by applying time-dependent perturbations, or shining light on non-topological or topological materials.

We showed the Josephson current in a time-reversal Weyl semi-metal sandwiched between s-wave superconductors showed unusual periodic oscillations as a function of the time-reversal breaking parameter, which was essentially the separation of the chiral nodes in the Weyl semi-metal. We explained this as being due to the inter-nodal nature of the reflection and Andreev reflection, which was enforced by the chirality and spin conservation in the model. The experimental observation of these oscillations would thus be a direct measurement of the separation of the chiral nodes of the Weyl semi-metal in momentum space.

We are continuing our work in this area by studying oscillations in a Weyl semi-metal - insulator-superconductor junction as a function of the thickness and the potential of the insulating barrier and the interplay between the scales of time-reversal breaking and the scale provided by the barrier strength leads to interesting patterns to the oscillations that occur individually due to each of the two scales. We are also trying to understand the effect of orientation of the Weyl semi-metal, since the transport is highly anisotropic, due to the anisotropy of the Fermi surface around the Weyl nodes. We are also trying to see if we can get anomalous Josephson current due to this anisotropy.

We have also been studying the Josephson current through a time-reversal preserving non centro-symmetric (inversion symmetry breaking) Weyl semi-metal (WSM) using a Green's function technique. Besides showing periodic oscillations as a function of the inversion symmetry breaking parameter, the Josephson current also exhibits zero-pi transitions, which is quite unexpected for time-reversal invariant systems. To access the tuning of this transition in a more experimentally feasible way than changing the length of the sample, we have also been studying the effect of periodic time-dependent perturbations (shining light) on the sample.

We have been continuing our work on silicene, which is a layered material like graphene, but with a buckled sub-lattice structure. We have been studying the topological phase transitions induced in silicene by shining circularly polarised light, beyond the high frequency regime, and we find many new topological phases. These phases are characterised by the spin-resolved topological invariants, $C_{0\uparrow}$, $C_{0\downarrow}$, $C_{\pi\uparrow}$ and $C_{\pi\downarrow}$, which specify the spin-resolved edge states traversing the gaps at zero quasi-energy and the Floquet zone boundaries respectively. We want to compare our results with the phases of irradiated graphene and see how novel phases occur in silicene, due to the extra tunability of the mass parameter by a perpendicular electric field.

We have been trying to develop the high frequency expansion based on the the Brillouin-Wigner (BW) perturbation theory for driven systems with spin-orbit coupling and apply it to the case of silicene. We are studying the effective Hamiltonian of silicene as functions of the intensity of the the light as well as that of the externally applied electric field that controls the transition of silicene between a band insulator, a metal and a topological insulator. We wish to compare the photo-induced phase diagram of the BW effective Hamiltonian to that obtained by direct numerical computation of the Chern numbers of the Floquet bands, and show that at sufficiently large frequencies, the BW theory high frequency expansion works well even in the presence of spin-orbit coupling terms.

We studied a ring geometry, coupled to two normal metallic leads, which has a Majorana bound state (MBS) embedded in one of its arm and is threaded by Aharonov Bohm ($\mathcal{AB}$) flux ϕ. We showed that by varying the $\mathcal{AB}$ flux, the two leads go through resonance in an anti-correlated fashion while the resonance conductance is quantized to $2e^2/h$. We further showed that such anti-correlation is completely absent when the MBS is replaced by an Andreev bound state (ABS). Hence this anti-correlation in conductance when studied as a function of ϕ provides a unique signature of the MBS which cannot be faked by an ABS. We contrasted the phase sensitivity of the MBS and ABS in terms of tunneling conductances. We argued that the relative phase between the tunneling amplitude of the electrons and holes from either lead to the level (MBS or ABS), which is constrained to $0, \pi$ for the MBS and unconstrained for the ABS, is responsible for this interesting contrast in the $\mathcal{AB}$ effect between the MBS and ABS. We are continuing our work in this area by studying charge pumping in this geometry.

We used the SU(2) slave fermion approach to study a tetrahedral spin 1/2 chain, which is a one-dimensional generalization of the two dimensional Kitaev honeycomb model. Using the mean field theory, coupled with a gauge fixing procedure to implement the single occupancy constraint, we obtained the phase diagram of the model. We then showed that it matches the exact results obtained earlier using the Majorana fermion representation. We also mapped the one-dimensional model in terms of the slave fermions to the model of 1D p-wave superconducting model with complex parameters and showed that the parameters of our model fall in the topological trivial regime and hence do not have edge Majorana modes. We are currently trying to study the spin-spin correlations in the ground state of the model to understand the spin liquid structure in terms of conventional spin operators.

We also wrote a review of Weyl semi-metals and worked on lectures on abelian and non-abelian anyons.

Publications:

1. Proximity induced superconductivity in Weyl semi-metals (with Udit Khanna, Arijit Kundu and Saurabh Pradhan), cond-mat/1407.7515, Phys. Rev.**B90**,195430 (2014).

2. Conductance, valley and spin polarization and tunneling magneto-resistance in ferromagnetic-normal-ferromagnetic junctions of silicene (with Ruchi Saxena and Arijit Saha), cond-mat/1507.04225, Phys. Rev. **B92**, 245412 (2015).

3. Chiral anomaly induced oscillations in the Josephson effect in Weyl semimetals, (with Udit Khanna, Dibya Kanti Mukherjee and Arijit Kundu), cond-mat/1509.03166, Phys. Rev. **B** (RC) **93**, 121409 (2016).

Preprints:

1. Fingerprints of Majorana bound states in Aharanov-Bohm geometry (with Krashna Mohan Tripathy and Sourin Das), cond-mat/1509.06684, to be published in Phys. Rev. Lett.

2. Slave fermion formalism for the tetrahedral spin chain (with Priyanka Mohan), cond-mat/1602.02005, submitted to Eur. Phys. Jnl (B).

3. Weyl semi-metals; a short review, cond-mat/1603.02821, to be published in forthcoming issue of Jnl of Indian Institute of Science.

4. Topological phases in periodically driven silicene (in preparation with Ruchi Saxena and Arijit Kundu).

5. Brillouin-Wigner theory for photo-induced topological phase transitions in spin-orbit coupled materials (in preparation with Priyanka Mohan and Arijit Kundu)

6. Zero-pi Josephson current transitions in irradiated Weyl semi-metals (in preparation with Udit Khanna and Arijit Kundu).

7. Tunneling conductance through a Weyl semi-metal-insulator-superconductor junction (in preparation with Dibya Kanti Mukherjee and Arijit Kundu).

8. Spin switching at the edge (in preparation with Udit Khanna, Ganpathy Murthy and Yuval Gefen).

9. Charge pumping through Majorana bound states in the Aharanov-Bohm geometry (in preparation with Krashna Mohan Tripathy and Sourin Das).

Conference/Workshops Attended:

1. Workshop on 'topological particles in condensed matter', IISER, Pune, Aug 6 - Aug 11, 2015.

2. 'New questions in quantum field theory from condensed matter systems', workshop at ICTS, Bangalore, 28 Dec 2015-5th Jan 2016.

3. International workshop on emergent phenomena in quantum Hall systems (EPQHS - 2016), Mumbai, Jan 7-9, 2016.

4. 'Frontiers in condensed matter physics', workshop at IOP, Bhubaneswar, Feb 22-27, 2016.

Visits to other Institutes:

1. Visit to International Centre for Theoretical Sciences (ICTS), Bangalore, 17-31 May 2015.

2. Visit to IISER Pune, 4 - 11 August, 2015.

3. Visit to S.N. Bose institute for SERC school, 26 November - 1 December 2016.

4. Visit to ICTS, Bangalore Dec 28 - 5th Jan 2016.

5. Visit to TIFR, 6 - 15 January 2016.

6. Visit to IOP, Bhubaneswar, Feb 22 - 27, 2016.
7. Visit to NISER, Bhubaneswar, 26 Feb 2016.
8. Visit to BHU, Varanasi, Feb 28 - March 1, 2016.
9. Visit to JNU, New Delhi, March 28-30, 2016.

Invited Lectures/Seminars:

1. *Lectures on anyons*, TPCMP, Dept of Physics, IISER, Pune, 4-11 August 2015.
2. *Lectures on abelian and non-abelian anyons*, SERC school organised by RKMVU at S. N. Bose Institute, Kolakata, 26 Nov -1 Dec, 2015.
3. *Introduction to Weyl semi-metals*, IOP, Bhubaneswar, 22-23 Feb, 2016.
4. *Fingerprints of Majorana bound states in Aharanov-Bohm geometry*, NISER, Bhubaneswar, Feb 26, 2016.
5. *Introductory lectures on anyons*, BHU, Varanasi, Feb 29 - March 1, 2016.
6. *Fingerprints of Majorana bound states in Aharanov-Bohm geometry*, JNU, New Delhi, March 28, 2016.

Other Activities:

1. Member, Academic council, MNNIT, Allahabad
2. Convenor, Faculty Advisory Committee and Daycare Committee, HRI
3. Member, Local works committee, Housing allotment committee, HRI
4. Taught CMP 1 (Aug 2015 - Dec 2015)

Ashoke Sen

Research Summary:

My work during April 2015 - March 2016 has been on several aspects of string theory.

1. In superstring perturbation theory one needs to insert picture changing operators on Riemann surfaces to define scattering amplitudes as intergral over moduli spaces of Riemann surfaces. Typically the integrand diverges at points whose position depends on the locations of the PCO's. In a paper with Edward Witten I showed how one can choose the locations of picture changing operators in a way that avoids these divergences.

2. I showed how one can use the one particle irreducible effective action of superstring field theory to derive various Ward identities of string theory. I also showed how this formalism can be used to compute scattering amplitudes in a situation where the original vacuum gets destabilised by loop corrections but there is a nearby stable vacuum.

3. I constructed the quantum master action for heterotic and type II superstring field theory. Later I also applied this method to construct covariant action for type IIB supergravity.

4. In a paper with Sitender Kashyap, Swapnamay Mondal and Mritunjay Verma, I analysed the effect of the cosmological expansion on the vacuum decay life-time of our universe. We also computed the enhancement of the survival probability of humans by sending of descendants to far away places in the universe.

5. Together with Abhishek Chowdhury, Richard Garavuso and Swapnamay Mondal, I analysed the spectrum of 4 stacks of supersymmetric D-brane configuration with three stacks containing one D-brane each and one stack containing 2 or 3 D-branes. Our result provided support to the hypothesis that microstates of single centred BPS black holes carry strictly zero angular momentum.

Publications:

1. A. Sen and E. Witten, "Filling the gaps with PCOs," JHEP **1509**, 004 (2015) doi:10.1007/JHEP09(2015)004 [arXiv:1504.00609 [hep-th]].

2. S. P. Kashyap, S. Mondal, A. Sen and M. Verma, "Surviving in a Metastable de Sitter Space-Time," JHEP **1509**, 139 (2015) doi:10.1007/JHEP09(2015)139 [arXiv:1506.00772 [hep-th]].

3. A. Sen, "Supersymmetry Restoration in Superstring Perturbation Theory," JHEP **1512**, 075 (2015) doi:10.1007/JHEP12(2015)075 [arXiv:1508.02481 [hep-th]].

4. A. Sen, "BV Master Action for Heterotic and Type II String Field Theories," JHEP **1602**, 087 (2016) doi:10.1007/JHEP02(2016)087 [arXiv:1508.05387 [hep-th]].

5. A. Chowdhury, R. S. Garavuso, S. Mondal and A. Sen, "Do All BPS Black Hole Microstates Carry Zero Angular Momentum?," JHEP **1604**, 082 (2016) doi:10.1007/JHEP04(2016)082 [arXiv:1511.06978 [hep-th]].

6. A. Sen, "Covariant Action for Type IIB Supergravity," JHEP **1607**, 017 (2016) doi:10.1007/JHEP07(2016)017 [arXiv:1511.08220 [hep-th]].

Invited talks at Conferences / Workshops / Schools

1. Superstring perturbation theory, Perimeter Institute, Waterloo, Canada, April 2015.

2. String field theory and related topics, Center for Theoretical Physics, Sichuan University, China, May 2015.

3. Advanced String School, ICTS, Bangalore, India, June 2015.

4. Strings 2015, ICTS, Bangalore, India, June 2015

5. National Strings Meeting, Mohali, India, December 2015

6. Indian-Israeli workshop on quantum field theory and string theory, Goa, India, December 2105

7. String-Math 2015, Sanya, China, December 2015 - January 2016.

Visits to other Institutes:

1. KIAS, South Korea, May-June, 2015

Courses given

1. General Relativity, August-December, 2015
2. Superstring perturbation theory, January-April, 2016

Prasenjit Sen

Research Summary:

My research during this period focussed to two themes: surface supported metal clusters, and novel two-dimensional (2D) materials. Within the first theme, we studied alumina supported bimetallic Ag-Au clusters. The main motivation was to explore their role as catalysts in CO oxidation reaction. The major finding is that Ag_2Au and $AgAu_2$ look promising candidates as catalysts.

Within the second theme, we studied three aspects of the novel 2D material phosphorene, which is monolayer of the 3D allotrope of phosphorus called the black phosphorus. We have studied structural, electronic, mechanical and transport properties of phosphorene nano-ribbons. We have calculated tuning of carrier mobility in monolayer phosphorene by in-plane strain. Finally, we have studied phosphorrene-metal interfaces for various metal surfaces.

Preprints:

1. P. Sen, *Magnetism in Simple Metal and 4d Transition Metal Clusters,* (*Invited review*), (accepted in J Clust. Sc.)

2. A. Maity, A. Singh, P. Sen, A. Kibey, A. Kshirsagar, D. G. Kanhere, *Structural, electronic, mechanical and transport properties of phosphorene nano-ribbons: Negative differential resistance behavior,* (submitted)

3. A. Maity and P. Sen, *Strain engineering of carrier mobility in monolayer phosphorene,* (in preparation).

4. A. Singh, C. Majumder and P. Sen, *Role of composition and substrate in controlling catalytic activity of bimetallic Ag-Au clusters,* (in preparation).

Conference/Workshops Attended:

1. *International Symposium on Clusters, Cluster Assembly and Nanoscale Materials*, India, March 2016.

Visits to other Institutes:

1. Abdus Salam International Center for Theoretical Physics, Trieste, Italy, May-June 2015.
2. K. U. Leuven, Leuven, Belgium, May 2015.
3. Royal Swedish Academy of Sciences, Stockholm, Sweden, June 2015.

Invited Lectures/Seminars:

1. *Right substrates for superatom assembly and properties of phosphorene*, International Symposium on Clusters, Cluster Assembly and Nanoscale Materials, IISER, Thiruvananthapuram, Thiruvananthapuram, March 2016.

Academic recognition/Awards:

Other Activities:

1. Member of Editorial Board, Physica Scripta.
2. Attended Editorial Board Meeting of Physica Scripta, Stockholm, June 2015.
3. Co-organized *School on Nanoscale Transport and Magnetism: Fundamentals to Applications*, Allahabad, February 2016.
4. Reviewed papers for the following journals: *Physical Chemistry Chemical Physics, Journal of Applied Physics, Journal of Inorganic Chemistry, Physical review Letters, Journal of Cluster Science, Indian Journal of Physics etc.*

Ujjwal Sen

Research Summary:

In the last academic year, my research has been in quantum information and computation, and its interface with many-body systems like quantum spin models, ultracold gas systems, and photonic systems. One of the topics that I have been working on with other members of the quantum information and computation group is on finding out quantum correlation features in the superconducting phases of doped systems. We found that such phases can have high values of genuine multisite quantum entanglement.

Another topic that we worked on is about finding new ways to obtaining key rates secure quantum communication (quantum cryptography). We have provided a new proof for the security of the Ekert protocol of quantum cryptography and have obtained a bound on the secret key rate therein.

Other topics that we worked on include beating no-go theorems by engineering defects in quantum spin models, freezing of quantum correlations under local decoherence, distributed quantum dense coding with two receivers in noisy environments, quantum correlations in quenched disordered spin models, forbidden regimes in distribution of bipartite quantum correlations due to multiparty entanglement, order-from-disorder and critical scalings of spontaneous magnetization in random-field quantum spin systems, distribution of Bell inequality violation vs. multiparty quantum correlation measures, conclusive identification of quantum channels via monogamy of quantum correlations, etc.

Publications:

1. Avijit Misra, Anindya Biswas, Arun K. Pati, Aditi Sen(De), and Ujjwal Sen, *Quantum correlation with sandwiched relative entropies: Advantageous as order parameter in quantum phase transitions,* Phys. Rev. E **91**, 052125 (2015)

2. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Beating no-go theorems by engineering defects in quantum spin models,* New J. Phys. **17**, 043013 (2015)

3. Titas Chanda, Amit Kumar Pal, Anindya Biswas, Aditi Sen(De), and

Ujjwal Sen, *Freezing of quantum correlations under local decoherence,* Phys. Rev. A **91**, 062119 (2015)

4. Tamoghna Das, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Distributed quantum dense coding with two receivers in noisy environments,* Phys. Rev. A **92**, 052330 (2015)

5. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Reducing computational complexity of quantum correlations,* Phys. Rev. A **92**, 062301 (2015)

6. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Diverging scaling with converging multisite entanglement in odd and even quantum Heisenberg ladders,* New J. Phys. **18**, 023025 (2016)

7. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Quantum discord length is enhanced while entanglement length is not by introducing disorder in a spin chain,* Phys. Rev. E **93**, 012131 (2016)

8. Debasis Sadhukhan, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Quantum correlations in quenched disordered spin models: Enhanced order from disorder by thermal fluctuations* Phys. Rev. E **93**, 032115 (2016)

9. Anindita Bera, Asutosh Kumar, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Information complementarity in multipartite quantum states and security in cryptography,* Phys. Rev. A **93**, 032338 (2016)

10. Tamoghna Das, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Subtraction better than addition: Entanglement in multimode squeezed vacuum post-interface with photons,* Phys. Rev. A (in print)

Preprints:

1. Asutosh Kumar, Himadri Shekhar Dhar, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Forbidden Regimes in Distribution of Bipartite Quantum Correlations due to Multiparty Entanglement,* arXiv:1505.01748

2. Anindita Bera, Debraj Rakshit, Maciej Lewenstein, Aditi Sen De, Ujjwal Sen, Jan Wehr, *Order-from-disorder and critical scalings of spontaneous magnetization in random-field quantum spin systems,* arXiv:1509.00704

3. Tamoghna Das, Sudipto Singha Roy, Shrobona Bagchi, Avijit Misra, Aditi Sen De, Ujjwal Sen, *Generalized Geometric Measure of Entanglement for Multiparty Mixed States,* arXiv:1509.02085

4. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen De, Ujjwal Sen, *Statistics of leading digits leads to unification of quantum correlations,* arXiv:1509.09295

5. Debasis Sadhukhan, Sudipto Singha Roy, Amit Kumar Pal, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Multipartite Entanglement Accumulation in Quantum States: Localizable Generalized Geometric Measure,* arXiv:1511.03998

6. Asutosh Kumar, Indranil Chakrabarty, Arun Kumar Pati, Aditi Sen De, Ujjwal Sen, *Quantum no-go theorems in causality respecting systems in presence of closed timelike curves: Tweaking the Deutsch condition,* arXiv:1511.08560

7. Kunal Sharma, Tamoghna Das, Aditi Sen De, Ujjwal Sen, *Distribution of Bell inequality violation vs. multiparty quantum correlation measures,* arXiv:1512.01477

8. Asutosh Kumar, Sudipto Singha Roy, Amit Kumar Pal, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Conclusive Identification of Quantum Channels via Monogamy of Quantum Correlations,* arXiv:1603.02801

Conference/Workshops Attended:

1. *Frontiers of Quantum Physics*, Spain, October 2015.

2. *Quantum Information Processing and Applications*, India, December 2015.

3. *International Conference on Light Quanta: Modern Perspectives and Applications*, India, December 2015.

4. *International School and Conference on Quantum Information 2016 (ISCQI 2016)*, India, February 2016.

5. *Workshop on Modern and Quantum Information Security (WMQIS-2016)*, International Institute of Information Technology, India, March 2016.

Visits to other Institutes:

1. SN Bose National Centre for Basic Sciences, Kolkata, India, June 2015.
2. Institut fuer Theoretische Physik III, Heinrich-Heine-Universitaet Duesseldorf, Dusseldorf, Germany, October 2015
3. ICFO-The Institute of Photonic Sciences, Barcelona, Spain, October 2015
4. Indian Institute of Science Education and Research, Pune, India, November 2015.
5. Indian Institute of Technology Delhi, India, July 2015
6. Indian Association for the Cultivation of Science, Bose Institute, University of Calcutta, Kolkata, India, May 2015
7. Institute of Physics, Bhubaneswar, India, Feb 2016.
8. International Institute of Information Technology, Hyderabad, India, Mar 2016.
9. Indian Institute of Science Education and Research, Bhopal, India, April 2016.

Invited Lectures/Seminars:

1. *What is Entanglement?*, C K Majumdar Memorial Summer Workshop in Physics, SN Bose National Centre for Basic Sciences, Kolkata, India, June 2015.
2. *Resonating valence bond states: A quantum information perspective*, Physics Department Seminar, Indian Institute of Science Education and Research, Pune, India, Nov 2015.
3. *Resonating valence bond states: A quantum information perspective*, International Conference on Light Quanta: Modern Perspectives and Applications, University of Allahabad, Allahabad, India, Dec 2015.
4. *Resonating valence bond states: A quantum information perspective*, International School and Conference on Quantum Information 2016 (ISCQI 2016), Institute of Physics, Bhubaneswar, India, Feb 2016.

5. *Quantum Correlations in Many-body Systems*, Workshop on Modern and Quantum Information Security (WMQIS-2016), International Institute of Information Technology, Hyderabad, India, Mar 2016.

6. *Resonating valence bond states: A quantum information perspective*, Colloquium, Indian Institute of Science Education and Research, Bhopal, India, April 2016.

Other Activities:

1. Teaching a one-semester course on "Quantum Information and Computation" during Jan-May 2016.

2. Guiding the theses of Utkarsh Mishra, Asutosh Kumar, Sudipto Singha Roy, and Sreetama Das of HRI.

3. Co-guide of the thesis of Anindita Bera, Calcutta University, Kolkata.

4. Served as an organizer of a meeting on "Quantum Information Processing and Applications (QIPA-15)" held at HRI in December 2015.

5. Serving as the convenor of the Computer Committee, and member of Cluster Computing Committee at HRI.

6. Serving as referees in national and international journals.

7. Serving as members of the PhD committees of Shrobona Bagchi, Tamoghna Das, Abhishek Joshi, and Uttam Kumar Singh.

8. Serving as member of International Advisory Board of Journal of Physics B.

9. Guiding/guided projects and numerical projects of Sreetama Das and Chirag Srivastava at HRI.

10. Guiding/guided/will be guiding the project works of Riya Seth, Insitute of Engineering and Management, Kolkata, Shahnawaz Ahmed [through the IAS program], BITS-Pilani, Goa Campus, Sharba Bhattacharyya [through the VSP at HRI], NISER, Bhubaneswar, Amitava Banerjee, Presidency University, Kolkata, Mahasweta Pandit, NIT Rourkela.

Samrat Kadge

Research Summary

I am currently studying the novel electronic/spintronic properties that emerge at Oxide Heterostructures interfaces using model hamiltonian techniques under the guidance of Dr. Pinaki Majumdar. The problem at hand is the competing magnetic and superconducting orders at the interface of ferromagnetic(FM) manganite and superconducting(SC) cuprate. Magnetic and superconducting orders are antagonistic in nature, and their interaction and coexistence has been pursued extensively[**?**]. Oxide Heterostructures which have been synthesized in the past decade, have led to phenomena such as Giant Magnetoresistance in FM/SC superlattices[**?**] which are interesting not only from a fundamental perspective but may also find its way in the promising field of oxide spintronics. We are investigating the behaviour of FM and SC orders in such a heterostructure focussing on the role of electronic doping due to level mismatch between the materials using model hamiltonian. Similar exercise has been undertaken in the context of s-wave superconductor in the past academic year, in which the penetration lengths were found to be short(2 unit cells). The task of implementing d-wave character has been undertaken in the current academic year.

Abhishek Joshi

Research Summary:

This year I along with my supervisor have developed phase fluctuation theory to deal with bosonic superfluid-Mott problem at finite temperature. Currently we are trying to calculate spectral functions in single species Bose-Hubbard model keeping quantum corrections into account. We are also trying to extend this technique to other bosonic problems of interest.

Conference/Workshops Attended:

1. *School on Topological Quantum Matter*, India, February 2015.

Uttam Singh

Research Summary:

During the academic year 2015-16, our research is mainly focussed on quantum resource theories, especially, the resource theory of coherence, entanglement and thermodynamics. In particular, we have found that for quantum systems with higher dimensional Hilbert spaces, most of the pure quantum states have same amount of quantum coherence (equal to the average coherence of random pure states). The same is also true for the random mixed states.
The physical processes on quantum systems can be represented by the state transformations within the set of allowed operations. We have completely characterised the state transformations under the incoherent operations with the aid of the catalysts. This has allowed us to complete the resource theory of coherence for finite dimensional quantum systems. We further consider the state transformations where additionally the thermodynamical restrictions cannot be ignored. This situation will arise when the background thermodynamical restrictions cannot be ignored while processing coherence. Specifically, we find the maximal amount of coherence created under unitary operations (coherent or incoherent) when we have limited amount of energy at our disposal.

Furthermore, we have developed a theory of thermodynamics of small quantum systems based on the principle of maximum entropy and considered the Rényi entropies instead of the von Neumann entropy. We have shown that in this theory, the second law of thermodynamics remains intact. This can be viewed as a generalisation of usual thermodynamics based on the von Neumann entropy.

Publications:

1. Avijit Misra, Uttam Singh, Manabendra Nath Bera, and A. K. Rajagopal, *Quantum Rényi relative entropies affirm universality of thermodynamics,* Phys. Rev. E **92**, 042161 (2015).

2. Uttam Singh, Lin Zhang, and Arun Kumar Pati, *Average coherence and its typicality for random pure states,* Phys. Rev. A **93**, 032125 (2016).

3. Kaifeng Bu, Uttam Singh, and Junde Wu, *Catalytic coherence transformations,* Phys. Rev. A **93**, 042326 (2016).

4. Avijit Misra, Uttam Singh, Samyadeb Bhattacharya, and Arun Kumar Pati, *Energy cost of creating quantum coherence,* Phys. Rev. A **93**, 052335 (2016).

Preprints:

1. Lin Zhang, Uttam Singh, Arun Kumar Pati, *Average subentropy and coherence of random mixed quantum states,* arXiv:1510.08859.

2. Kaifeng Bu, Uttam Singh, Lin Zhang, Junde Wu, *Average distance of random pure states from maximally entangled and coherent states,* arXiv:1603.06715.

Conference/Workshops Attended:

1. *Meeting on Quantum Information Processing and Applications - 2015 (QIPA-15)*, India, December, 2015.

Visits to other Institutes:

1. Zhejiang University, Hangzhou, China, November 2015.

2. Hangzhou Dianzi University, Hangzhou, China, November 2015.

Invited Lectures/Seminars:

1. *Catalytic transformations*, Talk, Department of Mathematics, Zhejiang University, China, November 2015.

2. *Erasure of coherence*, Talk, Institute of Mathematics, Hangzhou Dianzi University, China, November 2015.

Other Activities:

1. Served as a referee for Europhysics Letters, June, 2016.

Udit Khanna

Research Summary:

In the last academic year, I have studied some transport properties of Weyl Semimetals (WSM). These are $3D$ materials with a topological bandstructure which is gapless at some points in the Brillouin zone. The strong spin orbit coupling in these materials produces a spin texture on the fermi surface, when it is close to the weyl nodes (ie the gapless points in the bandstructure). Along with Dibya Kanti Mukherjee, Arijit Kundu and Sumathi Rao, I have been studying the effect of this spin structure on Josephson current in a junction of WSM sandwiched between two superconductors. We have found that there is an unusual $0 - \pi$ transtion in this junction which is caused by the chiral nature of the nodes. Currently, I am also studying a similar effect in time reversal invariant WSM with multiple weyl nodes.

In a separate collaboration with Ganpathy Murthy, Yuval Gefen and Sumathi Rao I have also been trying to study the effect of strong electron-electron interactions in integer quantum hall states of electron gases in GaAs quantum wells. It is known that sufficiently strong repulsive interactions can cause a ferromagnetic transition in the bulk of the electron gas. Currently we are studying how this physics emerges on the edge without changing the bulk properties and the changes in transport properties caused by such edge transitions.

Publications:

1. Udit Khanna, Dibya Kanti Mukherjee, Arijit Kundu and Sumathi Rao, *Chiral nodes and oscillations in the Josephson current in Weyl semimetals,* Phys Rev B **93**, 121409, (2016)

Preprints:

1. Udit Khanna, Dibya Kanti Mukherjee, Arijit Kundu and Sumathi Rao, *Chiral anomaly induced oscillations in the Josephson effect in Weyl semimetals,* arXiv:1509:03166

2. Udit Khanna, Arijit Kundu and Sumathi Rao, $0-\pi$ *transition in Josephson Junctions of Irradiated Weyl Semimetals,* (in preparation)

3. Udit Khanna, Yuval Gefen, Ganpathy Murthy and Sumathi Rao, *Spin switching at the edge of Integer Quantum Hall States,* (in preparation)

Conference/Workshops Attended:

1. *Topological Particles in Condensed Matter Physics*, India, August, 2015,
2. *EPQHS 2016*, India, January, 2016

Visits to other Institutes:

1. Weizmann Institute of Science, Rehovot, Israel, May, 2015.

Debasis Mondal

Research Summary:

During the period April 2015-March 2016, I worked on the "Non-local Advantage of Quantum Coherence" with my collaborator T. Pramanik and guide Prof. Arun Kumar Pati(HRI). A bipartite state is said to be steerable iff it does not have single system description, i.e., the bipartite state cannot be explained by local hidden state model. Several steering inequalities have been derived using different local uncertainty relations to verify the ability to control the state of one subsystem by the other party. Here, we derive complementarity relations between coherences measured on mutually unbiased bases using various coherence measures such as the l_1-norm, relative entropy and skew information. Using these relations, we derive conditions, under which non-local advantage of quantum coherence can be achieved and state is steerable. We also show that not all steerable states can achieve such advantage. We also show that our steering criteria are monogamous.

I have also worked on "Non-local advantage and Steering Induced Quantum Coherence in Accelerated Frame" with my Junior C. Mukhopadhyay. The interplay between steering and quantum coherence is studied in a scenario, where two atoms move with uniform acceleration through an external massless scalar field. We show that just like entanglement, the steering induced coherence of the equilibrium state may change with acceleration depending on the initial condition of the state. We also investigate the condition for achieving the non-local advantage of quantum coherence for the equilibrium state of the two accelerated atoms. Interestingly, we find that the quantum coherence of the state cannot achieve the non-local advantage of quantum coherence, even when the steering induced coherence is non-zero or the initial state of the two atoms is fully entangled. We argue that under any condition, gravity prohibits the non-local advantage on quantum coherence of the equilibrium state.

Future Plans:

Presently, I'm focusing on the tighter uncertainty and reverse uncertainty relations and quantum speed limits.

Preprints:

1. Debasis Mondal, Tanumoy Pramanik, Arun K. Pati, *Non-Local advantage of Quantum Coherence,*arXiv:1508.03770 [quant-ph]

2. Debasis Mondal and Chiranjib Mukhopadhyay, *Non-local advantage and Steering Induced Quantum Coherence in Accelerated Frame,* arXiv:1510.07556 [quant-ph]

Tamoghna Das

Research Summary:

In the academic year 2015-16, I worked on different aspects of quantum information theory ranging from quantification of quantum correlations to detection of quantum phase transition by physical quantities like entanglement, quantum discord etc. In one work, we addressed the complexity encountered in calculating the information theoretic measures of quantum correlation like quantum discord and quantum work deficit in two qubits and higher dimensional systems. Because all those measures demand some kind of optimization over the entire parameter space, resulting an enormous amounts of numerical as well as experimental resource. In this work, we show that determination of those measures are possible in a limited resources by restricting the set of local measurements. We find that the determination allows us to obtain a closed form of quantum discord and quantum work deficit for several classes of states, with a low error. We show that the computational error caused by the constraint over the complete set of local measurements reduces fast with an increase in the size of the restricted set, implying usefulness of constrained optimization, especially with the increase of dimensions. We perform quantitative analysis to investigate how the error scales with the system size, taking into account a set of plausible constructions of the constrained set. Carrying out a comparative study, we show that the resource required to optimize quantum work deficit is usually higher than that required for quantum discord. We also demonstrate that minimization of quantum discord and quantum work deficit is easier in the case of two-qubit mixed states of fixed ranks and with positive partial transpose in comparison to the corresponding states having non-positive partial transpose. Applying the methodology to quantum spin models, we show that the constrained optimization can be used with advantage in analyzing such systems in quantum information-theoretic language. For bound entangled states, we show that the error is significantly low when the measurements correspond to the spin observables along the three Cartesian coordinates, and thereby we obtain expressions of quantum discord and quantum work deficit for these bound entangled states.

In another work, we investigate the entanglement patterns of photon-added and -subtracted four-mode squeezed vacuum states. Entanglements in different scenarios are analyzed by varying the number of photons added or subtracted in certain modes, which are referred to as the player modes, the others being spectators. We find that the photon-subtracted state can give us higher entanglement than the photon-added state which is in contrast of the two-mode situation. We also study the logarithmic negativity of the two-mode reduced density matrix obtained from the four-mode state which again shows that the state after photon subtraction can possess higher entanglement than that of the photon-added state, and we then compare it to that of the two-mode squeezed vacuum state. Moreover, we examine the non-Gaussianity of the photon-added and -subtracted states to find that the rich features provided by entanglement cannot be captured by the measure of non-classicality.

Computing entanglement of an arbitrary bipartite or multipartite mixed state is in general not an easy task as it usually involves complex optimization. Here we show that exploiting symmetries of certain multiqudit mixed states, we can compute a genuine multiparty entanglement measure, the generalized geometric measure, for these classes of mixed states. The chosen states have different ranks and consist of an arbitrary number of parties.

On the other hand, in another work, we try to show that the frequency distribution of the first significant digits of the numbers in the data sets generated from a large class of measures of quantum correlations, which are either entanglement measures, or belong to the information-theoretic paradigm, exhibit a universal behavior. In particular, for Haar uniformly simulated arbitrary two-qubit states, we find that the first-digit distribution corresponding to a collection of chosen computable quantum correlation quantifiers tend to follow the first-digit law, known as the Benfords law, when rank of the states increases. Considering a two-qubit state which is obtained from a system governed by a specific Hamiltonian the anisotropic XY model with a transverse magnetic field we see that entanglement as well as information theoretic measures violate the Benfords law. However, interestingly, we find that among all the quantum correlation measures, quantum discord is the only measure which, like the transverse magnetization of the system, changes the pattern of the first-digit distribution depending on the quantum phases present in this model. We also comment on the universality of the statistics of first significant digits corresponding to appropriate measures of quantum correlations in the case of multipartite systems as well as systems in higher dimensions.

I have also established a relation between quantum information theory and foundations of quantum mechanics. There is an ongoing debate whether quantum mechanics is complete or not. Quantitatively, we ask whether one can describe locality and reality assumptions from the postulates of quantum mechanics. The introduction of the local hidden variable model leads to a bound on some of the dichotomic observables (Bell inequality) which are violated by some quantum states. These violation of a Bell inequality guarantees the existence of quantum correlations in a quantum state. It is known that a pure bipartite quantum state, having nonvanishing quantum correlation, always violates a Bell inequality. Such correspondence is absent for multipartite pure quantum states. For a shared multipartite quantum state, we establish a connection between the monogamy of Bell inequality violation and genuine multi-site entanglement as well as monogamy-based multiparty quantum correlation measures. We find that generalized Greenberger-Horne-Zeilinger states and another single parameter family of states which we refer to as the special Greenberger-Horne-Zeilinger states have the status of extremal states in such relations.

Publications:

1. Tamoghna Das, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Distributed quantum dense coding with two receivers in noisy environments,* Phys. Rev. A **92**, 052330, (2015).

2. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Reducing computational complexity of quantum correlations,* Phys. Rev. A **92**, 062301, (2015).

3. Tamoghna Das, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Superiority of photon subtraction to addition for entanglement in a multimode squeezed vacuum,* Phys. Rev. A **93**, 052313, (2016).

4. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Statistics of leading digits leads to unification of quantum correlations,* Europhys. Lett **114**, 30004, (2016).

5. Kunal Sharma, Tamoghna Das, Aditi Sen(De), and Ujjwal Sen, *Distribution of Bell-inequality violation versus multiparty-quantum-correlation measures,* Phys. Rev. A **93**, 062344, (2016).

Preprints:

1. Tamoghna Das, Asutosh Kumar, Amit Kumar Pal, Namrata Shukla, Aditi Sen De, Ujjwal Sen, *Canonical Distillation of Entanglement,* arXiv:1411.7936.

2. Tamoghna Das, Sudipto Singha Roy, Shrobona Bagchi, Avijit Misra, Aditi Sen De, Ujjwal Sen, *Generalized Geometric Measure of Entanglement for Multiparty Mixed States,* arXiv:1509.02085.

3. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen De, Ujjwal Sen, *Static and dynamical quantum correlations in phases of an alternating field XY model,* arXiv:1605.07576.

Conference/Workshops Attended:

1. *QIPA*, India, December, 2015, presented poster.

2. *IAS-ICTP school on QIC*, Singapore, january, 2016, presented poster.

Other Activities:

1. Served as a Tutor, Quantum information and computation course, Jan-May Semester, 2016.

Shouvik Roychoudhury

Research Summary:

During the first half of the academic year "2015-2016" I studied Cosmology and Effective Field Theory of Inflation. In the second half of the said academic year, I started and continued working with Dr Sandhya Choubey on the effect of sterile neutrino self-interactions on effective number of relativistic neutrinos in the universe and as well as cosmological structure formation. Standard model of particle physics includes three massless "active" neutrinos and corresponding anti-neutrinos. However, neutrino oscillation experiments over the year have strongly suggested oscillation among the active neutrino species, leading to small but different masses of the three different spieces. Moreover, 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 which mix with the three active neutrinos and are uncharged under the standard model gauge group. Such models were, however, considered disfavoured by cosmological data, since both Big Bang Nucleosynthesis (BBN) and Planck measurements measure the effective number of relativistic neutrino species to be less than four. But recent research from different groups have suggested that introducing self-interactions among the sterile neutrinos can solve the problem. We are currently probing how eV-scale sterile neutrinos with self-interactions mediated by an MeV scale gauge boson can solve the problem of having a low value of effective number of relativistic species of neutrinos. Also, the same gauge boson can be conjectured to mediate self-interactions among dark matter particles as well as interactions between sterile neutrinos and dark matter particles. Recent research by a group hints that this can solve some long standing problems in cosmological structure formation and we are currently conducting research on that also.

Conference/Workshops Attended:

1. *Winter School on Cosmology (WSC 15)*, India, December 2015,
2. *Sangam @ HRI 2016*, India, February 2016,
3. *Nu-Horizon 2016*, India, March 2016.

Visits to other Institutes:

1. National Institute of Science, Education and Research, Bhubaneswar, India, 25 May - 3 July 2015,
2. Indian Statistical Institute, Kolkata, India, 28 December 2015 - 6 January 2016.

Chiranjib Mukhopadhyay

Research Summary:

My research in the last year has been mainly on three topics.

Alongwith my advisor and a collaborator - I have formulated three new error-disturbance relations in the spirit of Heisenberg's original uncertainty principle. These relations were shown to be tighter than other such well known results. Comparisons between these results and ours were also performed.

Alongwith a collaborator - I have studied the interplay between two quantum mechanical features viz. quantum coherence and quantum steering for accelerated frame. It was shown that the amount of steering induced coherence depends both on acceleration and the initial conditions. We also studied the possibility of steering the coherence of the equilibrium states and given conditions for it.

Recently I have been studying the emerging field of quantum thermodynamics. In particular, with two collaborators, I am working on a model for quantum absorption refrigerators and studying whether non-markovianity can impart some advantage in this regime.

Publications:

1. Chiranjib Mukhopadhyay,Namrata Shukla, Arun Kumar Pati *"Stronger error disturbance relations for incompatible quantum measurements"*, Europhysics Letters **113**, 50002, (2016)

Preprints:

1. Debasis Mondal, Chiranjib Mukhopadhyay *"Steerability of Quantum Coherence in Accelerated Frame"*, arXiv 1510.07556

Conference/Workshops Attended:

1. *International Conference on Quantum Foundations*,Patna,India,November 2015

2. *Quantum Information Processing and Applications*,Allahabad,India,December 2015.

3. *International School and Conference on Quantum Information*,Bhubaneswar,India, February 2016.

Visits to other Institutes:

1. National Institute of Science Education and Research, Bhubaneswar, India, May-June 2015.

2. Institute of Physics, Bhubaneswar, India, February 2016.

Academic recognition/Awards:

- Presented Poster at International Conference on Quantum Foundations,Patna (30 Nov-4 Dec 2015)

- Ranked 2nd in CSIR-UGC NET Exam (Physical Sciences) conducted in June 2015.

SWAPNAMAY MONDAL

Research Summary:

This paragraph is summary of the work JHEP **1509**, 139, (2015), titled "Surviving in a Metastable de Sitter Space-Time". In a metastable de Sitter space any object has a finite life expectancy beyond which it undergoes vacuum decay. However, by spreading into different parts of the universe which will fall out of causal contact of each other in future, a civilization can increase its collective life expectancy, defined as the average time after which the last settlement disappears due to vacuum decay. We study in detail the collective life expectancy of two comoving objects in de Sitter space as a function of the initial separation, the horizon radius and the vacuum decay rate. We find that even with a modest initial separation, the collective life expectancy can reach a value close to the maximum possible value of 1.5 times that of the individual object if the decay rate is less than 1percent of the expansion rate. Our analysis can be generalized to any number of objects, general trajectories not necessarily at rest in the comoving coordinates and general FRW space-time. As part of our analysis we find that in the current state of the universe dominated by matter and cosmological constant, the vacuum decay rate is increasing as a function of time due to accelerated expansion of the volume of the past light cone. Present decay rate is about 3.7 times larger than the average decay rate in the past and the final decay rate in the cosmological constant dominated epoch will be about 56 times larger than the average decay rate in the past. This considerably weakens the lower bound on the half-life of our universe based on its current age.

This paragraph is summary of the work JHEP **1604**, 082, (2016), titled "Do All BPS Black Hole Microstates Carry Zero Angular Momentum?". From the analysis of the near horizon geometry and supersymmetry algebra it has been argued that all the microstates of single centered BPS black holes with four unbroken supersymmetries carry zero angular momentum in the region of the moduli space where the black hole description is valid. A stronger form of the conjecture would be that the result holds for any sufficiently generic point in the moduli space. In this paper we set out to test this conjecture for a class of black hole microstates in type II string theory on a six torus, represented by four stacks of D-branes wrapped on various cycles of six torus. For this system the above conjecture translates to the statement that the moduli space of classical vacua must be a collection of points. Explicit analysis of systems carrying a low number of

D-branes supports this conjecture.

Publications:

1. Sitender Pratap Kashyap, Swapnamay Mondal, Ashoke Sen, Mritunjay Verma, *Surviving in a Metastable de Sitter Space-Time,* JHEP **1509**, 139, (2015)

2. Abhishek Chowdhury, Richard S. Garavuso, Swapnamay Mondal, Ashoke Sen, *Do All BPS Black Hole Microstates Carry Zero Angular Momentum?,* JHEP **1604**, 082, (2016)

Conference/Workshops Attended:

1. *Strings*, India, June, 2015.

Visits to other Institutes:

1. University of Chicago, Chicago, USA, November, 2015,

2. Brandeis University, Boston, USA, November, 2015,

3. New York University, New York, USA, November, 2015,

4. UCLA, Los Angeles, USA, November, 2015,

5. University of Southern California, Los Angeles, USA, November, 2015,

6. Caltech, Los Angeles, USA, November, 2015,

7. UC Davis, Davis, USA, November, 2015,

Aritra Gupta

Research Summary:

In the first work we have considered boosted dark matter scenario which can explain the IceCube ultra high energy events. IceCube is a Cherenkov detector in the south pole that is aimed to detect ultra high energy cosmic particles. We have taken the dark matter to be a Dirac particle communicating with the standard model via vector , axial-vector , scalar or pseudo scalar type of interaction.
In the second work, we have considered the $\mathrm{U}(1)_{\mathrm{B-L}}$ extension of SM. However, in this case the lightest sterile neutrino N_1 plays the role of a viable dark matter candidate and it is generated non-thermally in the early stage of the Universe mainly from the decays of $W^{\pm}$ ($W^{\pm} \to e^{\pm} + N_1$) and extra neural gauge boson $Z_{\mathrm{B-L}}$ ($Z_{\mathrm{B-L}} \to N_1 + \bar{N}_1$). Now in order to make the interaction strengths of N_1 feeble with other particles (require for a non-thermal dark matter candidate) we need the extra gauge coupling g_{B-L} to be extremely small ($g_{B-L} < 10^{-7}$ for a $\mathcal{O}(100)$ GeV N_1). Due to such small value of $g_{\mathrm{B-L}}$ the extra gauge boson $Z_{\mathrm{B-L}}$ (decaying particle) will not be in thermal equilibrium. In this case, we have obtained the abundance of N_1 at the present epoch by solving a coupled Boltzmann equations (each for $Z_{\mathrm{B-L}}$ and N_1). Finally we have shown that the three body decay mode of the sterile neutrino dark matter (N_1) into a pair of e^+e^- and a active neutrino can explain the origin of 511 keV emission line observed by the INTEGRAL/SPI of ESA from the Galactic bulge.

Preprints:

1. Anirban Biswas, Aritra Gupta, *Freeze-in Production of Sterile Neutrino Dark Matter in U(1)$_{\mathrm{B-L}}$ Model*, 1607.01469.

Conference/Workshops Attended:

1. *Advances in Astroparticle Physics and Cosmology (AAPCOS-2015)*, Saha Institute of Nuclear Physics, Kolkata, INDIA, October 2015.

Invited Lectures/Seminars:

1. *Direct Detection of Boosted Dark Matter at High Energies and PeV events at IceCube*, AAPCOS 2015, Saha Institute of Nuclear Physics, Kolkata, INDIA, October, 2015.

Mehedi Masud

Research Summary:

Long-baseline neutrino experiments aim to measure the parameters responsible for neutrino oscillations, thereby taking us a step closer to completing our knowledge of the neutrino mass matrix. Now that θ_{13} has been conclusively shown to be non-zero and not too small, the focus of neutrino oscillation experiments has shifted to the measurement of the (Dirac) CP phase δ_{CP} that determines whether or not oscillating neutrinos violate CP. Discovery of leptonic CP violation will immensely help in understanding baryon asymmetry in the universe through leptogenesis. A second important unanswered question for model building is whether the mass hierarchy is normal ($\Delta m^2_{31} = m^2_3 - m^2_1 > 0$) or inverted ($\Delta m^2_{31} < 0$). Finally, whether θ_{23} is larger or smaller than $\pi/4$ (the so called *octant degeneracy*) bears on models based on lepton symmetries.

An effort towards resolving the above mentioned issues is an upcoming long-baseline experiment, called DUNE (Deep Underground Neutrino Experiment). Usually these experiments assume the standard paradigm with three neutrino flavors (so called 3+0 scenario). But, there are evidences (from the anomalies in LSND, MiniBooNE, GALEX, SAGE) suggesting the possibility of the existence of one (or possibly more) generation(s) of sterile neutrino(s) (of mass ~ 1 eV) which may have small mixings with the standard model neutrinos. We showed in a paper (JHEP 1511 (2015) 039) that the presence of even one such sterile neutrino (3+1 scenario) of mass ~ 1 eV can significantly impact the measurements of CP violation in long baseline experiment such as DUNE. Our results demonstrated that measurements which, when interpreted in the context of the standard three family paradigm, indicate CP conservation at long baselines, may, in fact hide large CP violation if there is a sterile state. Similarly, any data indicating the violation of CP cannot be properly interpreted within the standard paradigm unless the presence of sterile states of mass O(1 eV) can be conclusively ruled out. Our work underscores the need for a parallel and linked short baseline oscillation program and a highly capable near detector for DUNE, in order that its highly anticipated results on CP violation in the lepton sector may be correctly interpreted.

Apart from sterile neutrinos, New physics in neutrino interactions can, in principle, allow for flavour changing interactions thereby allowing for additional CP violating effects making the measurement of the intrinsic CP phase even more difficult. In two more papers (arXiv:1510.08261 and arXiv:1603.01380) we showed that the appearance channel is significantly affected by the presence of two propagation NSI parameters such as $\epsilon_{e\mu}$ and $\epsilon_{e\tau}$ due to the non trivial interplay between the moduli and the phases introduced by the NSI scenario. Using probability level and event level analyses, we showed the existence of NSI-SI degeneracies (similar to the case of sterile neutrinos) where it is difficult to ascribe the observed CP signal to standard (SI) or NSI scenario alone. Thus in order to ascribe any result on the CP phase to the lone CP phase in the standard three neutrino paradigm, it is crucial to rule out / constrain new physics scenarios that can contribute to the signal.

Publications:

1. Raj Gandhi, Boris Kayser, Mehedi Masud, Suprabh Prakash, *The impact of sterile neutrinos on CP measurements at long baselines,* Journal of High Energy Physics **1511**, 039, (2015)

Preprints:

1. Mehedi Masud, Animesh Chattejee, Poonam Mehta, *Probing CP violation signal at DUNE in presence of non-standard neutrino interactions,* arXiv:1510.08261 (Accepted for publication in Journal of Physics G.)

2. Mehedi Masud, Poonam Mehta, *Non-standard interactions spoiling the CP violation sensitivity at DUNE and other long baseline experiments,* arXiv:1603.01380

Conference/Workshops Attended:

1. *Workshop in High Energy Physics Phenomenology (WHEPP)*, Indian Institute of Technology (Kanpur), India, December 2015,

2. *Advances in Astroparticle Physics and Cosmology (AAPCOS)*, Saha Institute of Nuclear Physics, India, October 2015,

Invited Lectures/Seminars:

1. *Probing CP violation signals at DUNE in presence of non- standard neutrino interactions (NSI),* Workshop in High Energy Physics Phenomenology (WHEPP), Indian Institute of Technology, Kanpur, india, December 2015.

2. *Impact of sterile neutrinos on CP measurements at DUNE*, Advances in Astroparticle Physics and Cosmology (AAPCOS), Saha Institute of Nuclear Physics, Kolkata, India, October 2015.

Shrobona Bagchi

Research Summary:

In last one year with my PhD supervisor Prof. Arun Kumar Pati and other colleagues at HRI, I have worked on three different topics namely the uncertainty relations of general unitary operators, uncertainty relation for the triple of mutually unbiased bases, the monogamy of quantum correlations in higher dimensions, generalized geometric measure for general mixed states and using inequalities on inner product space to bound the sum and product of uncertainties The details of my work are given below.
""
Uncertainty relations for general unitary operators: We derive several uncertainty relations for two arbitrary unitary operators acting on physical states of any Hilbert space (finite or infinite dimensional). We show that our bounds are tighter in various cases than the ones existing in the current literature. With regard to the minimum uncertainty state, we derive the minimum uncertainty state equation by the analytic method. As an application of this, we find a new uncertainty lower bound for the three Pauli matrices and multiple anti-commuting observables. Also, the higher dimensional limit of these uncertainty relations is explored, whereby it is shown that for a certain class of states the uncertainty relations of the unitary operators as well as their minimum uncertainty states reduce to those of the corresponding Hermitian operators. From an operational point of view, we show that the uncertainty in the unitary operator is directly related to the visibility of quantum interference in an interferometer where one arm of the interferometer is affected by a unitary operator. This shows a new principle of preparation uncertainty, i.e., quantum states cannot be prepared which will display maximum visibility in the interference for two non-commuting unitary operators, i.e., the amount of visibility for two general unitary operators is non-trivially lower bounded.
""
Uncertainty relation for three unitary operators: This work is in continuation of the paper *Uncertainty relations for general unitary operators*, and also along the lines of recent research in the quantum information community on the "Triple Uncertainty Bounds". We are trying to find the minimum uncertainty bound for the uncertainty product and sum of the three unitary operators. The state that minimizes those of the two unitary operators, do not minimize those of the corresponding three unitary operators. Our interest lies specifically with the unitary operators which are related by the discrete Fourier transform or those which form their basis elements

of the generalized Clifford algebra. We have already presented a result in this direction in the paper *Uncertainty relations for general unitary operators*, i.e., a new bound for the three Pauli matrices which is the $d = 2$ limit of the discrete unitary operators related by the discrete Fourier transform.
""
Generalized Geometric Measure of Entanglement for Multiparty Mixed States: Computation of the entanglement measure is a daunting task for mixed quantum states. However, we exploit the symmetry properties of the mixed quantum states, to compute the entanglement measure called the generalized geometric measure. We use the convex roof optimization technique to calculate the generalized geometric measure of the mixed quantum states. We do this in a variety of cases, for example for the quantum states with general dimensions d, with higher ranks and high number of the parameters. We show that in all of these cases the generalized geometric measure is easily computable, and also almost all of the good properties of an entanglement measure of the mixed states.
""
Monogamy of quantum correlations in higher dimensions: Monogamy is an important property of the quantum correlation measures. However, all quantum correlation measures do not satisfy monogamy in general even in the case of qubits, i.e., the $2 \otimes 2$ quantum systems. We study how the monogamy relation is modified for the $d \otimes d$ sytems. Specifically, we investigate if the percentage of states satisfying the monogamy relation is increased in higher diemnsions progressively. We study this both analytically and numerically.
""
Tighter uncertainty relations, reverse uncertainty relations and entnglement detection: We are trying to find various bounds, i.e., both the upper and lower bounds on the uncertainty sum and product in terms of variance using the inequalities in complex inner product space. Specifically, we use the reverses of the triangle and the Cauchy-Schwarz inequality, the Buzano and the Bombieri inequality to find the state dependent upper and lower bounds on the uncertainty of two incompatible observables in Hilbert space. We also use these strenghthened inequaltiies to develop stricter criteria for entanglement detection.

Publications:

1. Shrobona Bagchi, Arun K Pati, *Monogamy, polygamy and other properties of entanglement of purification.* (Phys. Rev. A 91, 042323 (2015)).

Preprints:

1. Tamoghna Das, Sudipto Singho Roy, Shrobona Bagchi, Avijit Misra, Aditi Sen-De, Ujjwal Sen, *Generalized Geometric Measure of Entanglement for Multiparty Mixed States.* (arXiv:1509.02085 (2015)).

2. Shrobona Bagchi, Arun K Pati, *Uncertainty relations for general unitary operators.* (arXiv:1511.04730 (2015)).

3. Debashish Mondal, Shrobona Bagchi, Arun K Pati, *Tighter uncertainty relations and entanglement detection* . (in preparation).

4. Shrobona Bagchi, Debashish Mondal, Arun K Pati, *Reverse uncertainty relations for incompatible observables*. (in preparation).

Conference/Workshops Attended:

1. Poster presentation titled *Uncertainty relations for general unitary operators* at *International Conference on Quantum Foundations 2015*, December 2015, National Institute of Technology, Patna, India.

2. Poster Presentation titled *Generalized Geometric Measure for multiparty mixed states* at *Meeting on Quantum Information Processing and Applications*, December 2015, Harish-Chandra Research Institute, Allahabad, India.

3. Oral Presentation titled *Uncertainty relations for general unitary operators* at *International Conference on Light Quanta: Modern Perspectives and Applications*, December 2015, University of Allahabad, Allahabad, India.

Siddharth Dwivedi

Research Summary:

During the last academic year I have been involved in the study of the Beyond Standard Model scenario involving extension of the Standard Model (SM) using CP (Charge Parity)-violating dimension-6 gauge invariant operators. Taking a model independent approach, we consider the observable effects of CP-violating anomalous WWh and ZZh interactions arising from gauge invariant dimension-6 operators at the Large Hadron Collider (LHC), with the purpose of distinguishing them from not only the standard model effects but also those of CP-even anomalous interactions of similar nature.

To quantify such CP-violating effects, we calculate the asymmetry in the differential cross-section distributions of kinematic observables which have the important feature of being CP-odd themselves. This is important to isolate the CP-violating effects over and above the CP-even physics coming from the SM and the dimension-6 CP-even gauge-Higgs operators. We have also analyzed the issue of viability of observing such CP-violating effects at the LHC by establishing the statistical significance associated with the calculated asymmetry values for the various luminosity reaches of the LHC.

Preprints:

1. Siddharth Dwivedi, Dilip Kumar Ghosh, Biswarup Mukhopadhyaya, Ambresh Shivaji, *Distinguishing CP-odd couplings of the Higgs to weak boson pairs*, arXiv:1603.06195 .

Conference/Workshops Attended:

1. *Nu HoRIzons 2016 Conference*, India, March 17-19, 2016,

2. *Sangam @ HRI:Instructional Workshop in Particle Physics*, India, February 15 - 19, 2016,

3. *CTEQ Summer School*, University of Pittsburgh, Pennsylvania, USA, 7 - 17 July 2015.

Sitender Pratap Kashyap

Research Summary:

1. Vacuum decay of a meta-stable vacuum proceeds via bubble nucleation. Quantum fluctuations create bubbles of true vacuum in a small region which grows classically if the kinematics favour it. This bubble expands at the speed of light and alters the identity of the matter enclosed by it. In such a meta-stable universe we computed the average lifetime of a pair of observer as a function of their initial separation in an accelerating de-sitter spacetime. The result was

$$\frac{\bar{t}_{12}}{\bar{t}_1} = 1 + A(T)\, r^{1/T}\,, \tag{4}$$

where,

$$\begin{aligned} A(T) &= T^{-1} 2^{1/T} \int_0^\infty dv\, v^{-1+2/T} \\ &\quad \times \left[(2v)^{-1/T} - (2v+1)^{-1/T} \exp\left(-\frac{v}{T(2v+1)} + \frac{1}{2T} \right) \right] \end{aligned} \tag{5}$$

Here, $\bar{t}_{12}$ is the average lifetime of two observers and $\bar{t}_1$ is the average lifetime of a single observer and r is the separation between them.

2. We worked on the problem of calculation of mass-renormalization in string theory. Our approach to the computation is pure spinor formalism. The calculation requires construction of integrated vertex operator for the first massive level $(mass)^2 = \frac{1}{\alpha'}$.

Publications:

1. Sitender Pratap Kashyap, Swapnamay Mondal, Ashoke Sen, Mritunjay Verma, *Surviving in a metastable de Sitter space-time,* Journal of High Energy Physics **09**, 139, (2015)

Conference/Workshops Attended:

1. *Strings 2015*, India, June 2015.
2. *National Strings Meeting 2015*, India, December 2015.
3. *HRI Workshop on String Theory: Developments in String Perturbation Theory* , India, February 2016.

Aditya Banerjee

Research Summary:

In the academic year 2015-2016, I have continued working on the theme of gapless fermions coupled to long-range critical/gapless bosons, which is typically the arena for emergent non-Fermi liquid physics, focussing on a few specific models/systems. Specifically, I have worked on investigating superconducting pairing instabilities in the half-filled Landau level (composite fermion Fermi surface) within the framework of Halperin-Lee-Read theory by including both gauge and nematic fluctuations, using large-N renormalization group plus RPA methods. A preprint on this is in progress. Additionally, I have also begun work on studying the effects of long-range Coulomb interaction, and consequent effects, in certain topological semi-metals which are of significant recent interest. Specifically, using renormalization group in field theory framework, I am looking at the effect of long-range interactions on triple-Weyl semimetals (and closely related triple-nodal ring semimetals), with further plans to study its low-energy transport properties. A preprint on this is expected soon. Effects of Goldstone-type critical bosons on the phase transition between an insulator and a Dirac semimetal in two dimensions are also being investigated..

Preprints:

1. Aditya Banerjee, *Pairing instabilities of the half-filled Landau level due to simultaneous gauge and nematic fluctuations* (in preparation)

2. Aditya Banerjee, *Effects of long-range Coulomb interaction in triple-Weyl semimetals* (in preparation)

Conference/Workshops Attended:

1. *Questions in quantum field theory from condensed matter theory*, ICTS Bangalore, India, December 2015.

2. *International Workshop on Emergent Phenomena in Quantum Hall Systems*, TIFR Mumbai, India, January 2016.

Other Activities:

1. Served as a member in the Mess Committee for six months, december-2015 - May 2016.

Subhroneel Chakrabarti

Research Summary:

In the last academic year I have continued my work on Conifold transitions under Prof.Ashoke Sen and with a fellow graduate student. Also I have started working on two seperate problems of String Field Theory. Firstly finding the mass renormalization of heterotic string theory using pure spinor techniques.Here we first expect to rederive the known 1 loop result and then extend it to 2 loops. From the perspective of pure spinor theory also this is expected to give some new results. Secondly, to give a closed form expression for String Field Vertices of Bosonic closed string field theory and subsequently search for possible extension to Superstring Field theory of this result. Both these projects are being done under Prof.Ashoke Sen and in collaboration with fellow graduate students and a post-doc of HRI string theory group.

Conference/Workshops Attended:

1. *Strings '15*, India, June 2015
2. *National Strings Meeting 2015*, India, December 2015
3. *2016 HRI Workshop on String Theory: Developments in String Perturbation Theory*, India, February 2016

Samiran Roy

Research Summary:

During the period of last one year (from April 2015 to March 2016), I have studied the effects of Non Standard Interactions(NSIs) on neutrino propagation through matter. The NSIs can give rise to potential degeneracies with the standard interaction and it may give the wrong determination of the various standard oscillation parameters like δ_{cp}, mass hierarchy, octant of θ_{23} etc in the various neutrino experiments. I have been working mainly in the context of DUNE. Since the baseline of DUNE is 1300 km, the effect of propagation NSI is large. The different channels have different parameter dependence. So it is necessary to study the effects of the NSI towards the measurement of Leptonic CP violation, mass hierarchy, octant of θ_{23} etc. If there is new physics beyond the standard neutrino physics, then it is possible to pin point them by studying the NSI parameters carefully.

Conference/School Attended:

1. *AAPCOS 2015 at SINP*, October, 2015
2. *SERC School at BITS Pilani*, November, 2015
3. *SANGAM at HRI*, February, 2016
4. *Nu Horizons VI at HRI*, March, 2016

Sandeep Kumar Sehrawat

Research Summary:

Over the last academic year (April 2015-March 2016), I studied the different properties of sterile neutrinos in short baseline neutrino oscillation experiments. Question of the existence of a sterile neutrino is a key problem in neutrino physics. The understanding of sterile neutrinos and its properties will help us to understand better the phenomena of neutrino oscillations. I also studied about possible signature of beyond standard model physics in lepton sector via neutrino oscillations. Beyond standard model effects are very important and they can give us possible hints for expanding our current physical theories.

Conference/Workshops Attended:

1. *Advances in Astroparticle Physics and Cosmology (AAPCOS)*, SINP, Kolkata, India, October 2015.

2. *SERC Schools in Theoretical High Energy Physics*, BITS Pilani, India, November-December 2015.

3. *Sangam @ HRI 2016: Instructional Workshop in Particle Physics*, Allahabad, India, February 2016.

4. *Nu HoRIzons VI*, HRI, Allahabad, India, March 2016.

Other Activities:

Tutoring the course on "Quantum Field Theory 2", instructed by Prof. Satchitananda Naik (Jan-May, 2016).

Ritabrata Bhattacharya

Research Summary:

In the session of 2015-2016 I have mostly pursued studying Conformal Field Theory(CFT), Supergravity and String Theory which is my current area of research. During the end of the session I took up the problem of calculating gravi-photon scattering amplitude with two gravitons at two loop level. The calculation techniques involve the RNS formulation of strings and also the BRST quantization of superstrings. The amplitude that I am currently trying to calculate has the following notational form.

$$< T^2 R^2 >$$

Where T and R denote the gravi-photon and Graviton vertex respectively the calculation is at two loop level

Conference/Workshops Attended:

1. *Strinng School*, India February, 2016

Visits to other Institutes:

1. NISER, Bhubaneswar, India, June 2015,

Sarif Khan

Research Summary:

In the last academic year I have done following things. In the fisrt half I have done two project one is Big Project (with Prof. S. Choubey) and another one is Small Project (with Prof. S. Naik). Along with project I continued my research work also. In my research I have proceed as follows, nowdays it is well known that Standard Model (SM) is not the final theory, it can't explain all observed phenomenon such as tiny neutrino mass (confirmed from neutrino oscillation), Dark Matter scenario (confirmed from rotation curve, gravitational lensing, bullet cluster), baryogenesis (matter antimatter assymmetry). Recently I have been working on two of the Beyond Standard Model (BSM) scenario, one is neutrino mass and another one is Dark Matter. In explaining these, I use two BSM model, "first one is $U(1)_{\mathrm{B-L}}$ extension of SM" and related phenomenology of DM which I have completed and "second one is $U(1)_{\mathrm{L}_\mu-\mathrm{L}_\tau}$ extension of SM" on which I am working currently. Besides these model I also study left-right symmetric model.

Preprints:

1. A. Biswas, S. Choubey, Sarif Khan, *Glactic Gamma Ray Excess and Dark Matter Phenomenology in a $U(1)_{B-L}$ Model*, arXiv:1604.06566

Conference/Workshops Attended:

1. *Sangam School, HRI, Allahabad, February, 2016*.
2. *NU-Horizon, HRI, Allahabad, March, 2016*

Visits to other Institutes:

1. *NISER (For Experimental Project), Bhubaneswar, June-July, 2015*

Satadal Datta

Research Summary

I have studied non relativistic Spherically Symmetric Accretion without inclusion of the fluid mass taking part in the accretion process, i.e; the original work done by H. Bondi. Then I've moved to non relativistic Spherically Symmetric Accretion where the gravitational field due to the infalling fluid has been taken into account. I have focussed on the steady state behaviour of the fluid, i.e; the change in mass and radius of the accretor during the process is neglected even if we include the gravitational effect due to the infalling fluid. Our main assumption is that the self-gravity effect due to the fluid is itself small compared to the gravitational field due to the accretor and obvious implication of this assumption is that at very large distance from the accretor, i.e; so called at infinity, infalling fluid is lightly densed. There were some attempts made by T.T Chia on this topic. I have developed a novel iterative technique to get more insight into the problem. I have found that due to inclusion of self-gravity the radius of the sonic horizon decreases and mass accretion rate is increased. Further works may be done on the growth of the accretor due to accretion process which actually may shed light on the evolution of accretor and the surrounding gas cloud as well and also we can have as observational evidences that how is the radiation spectra due to the loss in energy of the infalling fluid effected. Additionally, I am working on analogue gravity in BEC system with Dr. Pinaki Majumder and Dr. Tapas Kumar Das. Recently I have started working on some interesting non linear problems regarding Liênard systems and Van der Pol Oscilliator in different potentials with Prof.Jayanta Kumar Bhattacharjee .

Preprints

1. Satadal Datta, Bondi flow revisited, arXiv:1601.01307

Other Activities:

1. I attended a seminar,'One Day National Level Seminar on Astronomy and Astrophysics', at Sarojini Naidu College for Women on 20th of February, 2016.

Gautam Sharma

Research Summary:

During the academic year "2015-2016" I did a reading project in cosmology and Quantum Information Computing. The text books referred were "Weinberg's Cosmology" and "Chaung's Quantum Information and Computing" respectively. Right now I am working on aspects of "Relativistic Quantum Information" with Prof. Arun Kumar Pati. This is a new field which is being pursued so as to make sure that quantum information theory is compatible with relativistic structure of spacetime. The aim is to exploit the relativity to improve quantum information tasks. I am working on the problem of effect on entanglement in non-inertial frames which is degraded due to Unruh effect when the observers are in uniform acceleration. The entanglement is changed because of different particle numbers in different frames. Also I am working on teleportation between two observers who are in non-inertial frames.

Conference/Workshops Attended:

1. *Nu-Horizon 2016*, India, March 2016,

Visits to other Institutes:

1. National Institute of Science, Education and Research, Bhubaneswar, India, 25th May-3rd July 2015.

Abhass Kumar

Research Summary:

Dark matter and inflation are two outstanding problems of physics. Dark matter constitutes 25% of the universe but is quite unknown. I have studied various models that have been given to try and study its phenomenology. Inflation erases all information about the matter and energy content of the universe creating a problem of origin of various particles in the universe. We have been studying means in which these two problems can be combined into one. A possible way is to identify the inflaton (the particle causing inflation) with dark matter. In such a model, we have looking at possible scenarios where a particle or many particles that are part of the inflaton field cause inflation for some duration and at the end of it, transform via breaking of some symmetries into a viable candidate for dark matter.

Conference/Workshops Attended:

1. *Invisbles'15 School*, Spain, June, 2015.
2. *Invisbles'15 Workshop*, Spain, June, 2015.
3. 30^{th} *SERB Main School on Theoretical High Energy Physics*, India, November-December, 2015
4. *Sangam @ HRI 2016: Instructional Workshop in Particle Physics*, India, February, 2016.
5. *NuHoRIzons 6*, India, March, 2016.

Other Activities:

1. Tutoring Mathematical Methods 2 course instructed by Dr Tapas Das during January-May, 2016.

Sauri Bhattacharyya

Research Summary:

I'm studying the impact of the small polaron transition on phonon spectrum in an electron-phonon system under Prof. Pinaki Majumdar. The specific model being investigated is the Holstein Model. Our method captures both large amplitude, classical thermal fluctuations of the lattice deformations and quantum vibrations upto Gaussian order. We are also in the process of generalizing this 'semiclassical' method to look at pairing field fluctuations in the Attractive Hubbard Model and computing the conductivity originating from that.

Conference/Workshops Attended:

1. *IMSc School and Conference on Disordered Quantum Systems, India, February, 2016*

Dibya Kanti Mukherjee

Research Summary:

In our last project, we looked at Josephson effect for a Superconductor-Weyl semi-metal- Superconductor (SWS) system. Here, we took a s-wave superconductor and a semi-metal with two Weyl nodes.We started with a basic s-matrix calculation and found a transition in the sign of the critical current as we varied the distance between the two Weyl nodes in the momentum space. This kind of transition (called the zero-pi transition) has been observed in other systems. However, we found the mechanism driving the transition in our case was the fact that the two nodes in the Weyl semi metal had different chiralities and an electron with a given orientation of spin is forced to jump to the other node once it is reflected. Although this approach gives us a nice intuitive picture of the processes involved, the Hamiltonian we considered was a simplified 2 band continuum model. We confirmed the results by running similar simulations on a tight binding model. For the Weyl semi metal we used a full 4 band tight binding model of a topological insulator with additional time reversal symmetry breaking parameters that create the Weyl nodes. We incorporated the superconducting leads via self energy terms in the Weyl Green's function by integrating over the degrees of freedom of the superconductor. With the full Green's function, we could compute Josephson current.The results from the microscopic model qualitatively matched quite well with those obtained by the scattering matrix approach.

Currently I am working with a WIS junction where the 'I' denotes a barrier region lying between a superconductor and a Weyl semi metal. The techniques used are the same as described above. We have been probing resonant tunneling across the structure, where the presence of the resonance peaks in conductance indicate presence of bound states. Preliminary study of the peaks hints towards the contribution of two scales in the problem - the thickness of the barrier region and the distance between the Weyl nodes in the momentum space. But more careful analysis is necessary.

Publications:

1. Udit Khanna, Dibya Kanti Mukherjee, Arijit Kundu, and Sumathi Rao, *Chiral nodes and oscillations in the Josephson current in Weyl semimetals,* Phys. Rev. B (R), **93**, 121409, (2016)

Conference/Workshops Attended:

1. *An Advanced School and Topical Workshop on Topological Particles in Condensed Matter*, Pune, India, August, 2015

2. *SERC School on Topology and Condensed Matter Physics*, Kolkata, India, November-December, 2015

Krashna Mohan Tripathi

Research Summary:

My work, in the previous year, has focussed on the signatures of Majorana zero mode (MZM) in topological superconductors. We studied a ring geometry, coupled to two normal metallic leads, which has a Majorana bound state (MBS) embedded in one of its arms and is threaded by Aharonov-Bohm(AB) flux. We found that the anti-correlation in conductance on the two leads as a function of AB-flux provides a unique signature of the MBS which cannot be mimicked by some accidental low-energy modes.I am currently working on adiabatic charge transport in the absence of any external bias in a similar AB-geometry to study the consequences of presence of MZM.

Publications:

1. Krashna Mohan Tripathi, Sourin Das, and Sumathi Rao, *Fingerprints of Majorana Bound States in Aharonov-Bohm Geometry*, Phys. Rev. Lett. **116**, 166401, (2016)

Conference/Workshops Attended:

1. *School on Topological Quantum Matter*, India, February 2015.

Other Activities:

1. Tutored for the course Mathematical Methods I, instructed by Dr. Tapas Kumar Das (Aug - Dec, 2015).

Arijit Dutta

Research Summary:

The first part of the year was spent in developing a zero-mode theory for nonequilibrium systems at steady state. Working in the Schwinger-Keldysh formalism, the zero-mode theory could be cast as the saddle point of a many-body action. The method has been applied to a quantum dot and shall be used to study lattice problems in the future.

The other half has been dedicated to study interacting bosons on a lattice in presence of synthetic spin-orbit coupling. In addition to the usual superfliud to Mott transition, which occurs in such systems even in absence of the spin-orbit coupling, the ground state shows rich magnetic texture across the Mott transition. It is currently being studied to explore the phases at zero as well as finite temperatures.

Conference/Workshops Attended:

1. *School and Conference on Quantum Disordered Systems*, India, February-March 2016.

Debasis Sadhukhan

Research Summary:

During the past year, I mainly worked at the interface of quantum information and many body physics.

Multiparty quantum states are useful for a variety of quantum information and computation protocols. We define a multiparty entanglement measure based on local measurements on the multiparty quantum state, and an entanglement measure averaged on the post-measurement ensemble. Using the generalized geometric measure as the measure of multipartite entanglement for the ensemble, we demonstrate, in the case of several well-known classes of multipartite pure states, that the localized multipartite entanglement can exceed the entanglement present in the original state. We also show that measurement over multiple parties may be beneficial in enhancing localizable multipartite entanglement. We point out that, compared to the generalized geometric measure, localizable generalized geometric measure works better in signaling quantum critical phenomena occurring in well-known quantum spin models even when considerable finite-size effect is present in the system.

In another work, we show that the frequency distribution of the first significant digits of the numbers in the data sets generated from a large class of measures of quantum correlations, which are either entanglement measures, or belong to the information-theoretic paradigm, exhibit a universal behavior. In particular, for Haar uniformly simulated arbitrary two-qubit states, we find that the first-digit distribution corresponding to a collection of chosen computable quantum correlation quantifiers tend to follow the first-digit law, known as the Benford's law, when rank of the states increases. Considering a two-qubit state which is obtained from a system governed by a specific Hamiltonian – the anisotropic XY model with a transverse magnetic field – we see that entanglement as well as information theoretic measures violate the Benford's law. However, interestingly, we find that among all the quantum correlation measures, quantum discord is the only measure which, like the transverse magnetization of the system, changes the pattern of the first-digit distribution depending on the quantum phases present in this model. We also comment on the universality of the statistics of first significant digits corresponding to appropriate measures of quantum correlations in the case of multipartite systems as well as systems in higher dimensions.

Publications:

1. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, R. Prabhu, Aditi Sen(De), Ujjwal Sen, *Quantum discord length is enhanced while entanglement length is not by introducing disorder in a spin chain*, Phys. Rev. E **93**, 012131 (2016)

2. Debasis Sadhukhan, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Quantum correlations in quenched disordered spin models: Enhanced order from disorder by thermal fluctuations*, Phys. Rev. E **93**, 032115 (2016)

3. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen De, Ujjwal Sen, *Reducing Computational Complexity of Quantum Correlations*, Phys. Rev. A **92**, 062301 (2016)

Preprints:

1. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen De, Ujjwal Sen, *Statistics of leading digits leads to unification of quantum correlations*, arXiv:1509.09295

2. Debasis Sadhukhan, Sudipto Singha Roy, Amit Kumar Pal, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Multipartite Entanglement Accumulation in Quantum States: Localizable Generalized Geometric Measure*, arXiv:1511.03998

Conference/Workshops Attended:

1. *Meeting on Quantum Information Processing and Applications (QIPA-2015)*, HRI, India, December 2015.

Other Activities:

1. Member of local organizing committee of *QIPA-15*, Harish-Chandra Research Institute, December 2015.

Juhi Dutta

Research Summary:

In the academic year 2015-2016, I have worked on supersymmetric extensions of the Standard model. In the first project, we have considered the phenomenological Minimal Supersymmetric Standard Model (pMSSM) with 19 free parameters and looked for collider signatures for cases which may have escaped Run 1 discovery searches at the Large Hadron Collider (LHC). Conventional signatures of MSSM include searches for multiple hard jets and large missing transverse Energy (MET), i.e, multijets + MET searches, owing to production of strong sparticles, in simplified spectra, with large mass separation from the lightest sparticle (LSP), mostly the lightest neutralino, resulting in hard jets and large MET. However no significant excess over the Standard Model has yet been observed at the 8 TeV Run 1 of the LHC.
The point, however, to note is that there may be cases which may not give rise to such conventional signatures at the colliders. We have looked at one such case: signatures of a compressed supersymmetric spectra in the MSSM with the lightest CP-even Higgs mass around 125 GeV. Compressed spectra refer to scenarios where there may be lighter sparticles in the spectra but with relatively low mass gaps between each other and the LSP. Such spectra have soft jets, or leptons and small missing energy and hence do not pass the conventional search criteria at colliders. We investigate this case in the pMSSM involving the full sparticle set and not a subset of sparticles unlike previous works. This allows presence of some sparticles in the spectra which may be separated from the LSP enough to pass the hard jet criterions of multijet + MET searches even though a certain sector of the spectra is compressed. Compression in the entire MSSM spectra has been achieved to the utmost in keeping with the lightest CP-even Higgs mass constraint around 125-126 GeV, dark matter constraints of relic density and direct detection scattering cross-section limits and constraints from flavour physics. The high mass of the lightest CP-even Higgs imply large radiative contributions from the stops. At least one stop must be heavy ($\sim$ TeV) and large mixing between the stops help to achieve the Higgs mass in the correct range. Imposition of compression in the parameter space also requires a large μ parameter. All these constrain the parameter space heavily. In this case, we have identified regions of the parameter space satisfying all the above constraints and chosen specific benchmarks with the lightest neutralino in the mass range 840-1860 GeV, with varied mass ordering of the squarks and gluinos and various different values of

compression in the spectra. The compressed band includes the sleptons whereas the other gauginos are within or out of the compressed region depending on the value of the μ parameter. We have taken spectra which have the gauginos in the compressed band as well.
Collider signatures of both multijets + MET and monojet + MET scenarios of signal and dominant SM backgrounds at $\sqrt{s} = 13$ TeV LHC run has been studied. An exhaustive simulation and analysis of both signal and background with suitably optimized cuts on kinematical variables for both have yielded results implying that even though monojet+MET is a viable option for discovery of compressed susy scenarios (as considered often), multijet + MET channels are more favourable for discovery at Run 2 of LHC for compressed spectra as we have considered. We are currently looking into compressed susy scenarios of extensions to MSSM. This work started at the last quarter of the academic year and is currently in progress. Besides the above work, I have also been working on natural supersymmetric scenarios and consider extensions of the MSSM model by adding a right handed Majorana neutrino superfield, which satisfy the neutrino mass constraints. Presently, we are studying benchmarks from different regions of the parameter space which satisfy the neutrino mass, the lightest CP-even Higgs mass constraints as well as dark matter relic density and direct detection constraints and intend to study the different collider signatures.

Publications:

1. Juhi Dutta, Partha Konar, Subhadeep Mondal, Biswarup Mukhopadhyaya and Santosh Kumar Rai, *A revisit to a compressed supersymmetric spectrum with 125 GeV Higgs,* JHEP **1601**, 051, (2016)

Conference/Workshops Attended:

1. Sangam @ HRI 2016: Instructional Workshop in Particle Physics, India, February, 2016

2. Nu HoRIzons VI, India, March, 2016.

Other Activities:

1. Teaching Assistant in Particle Physics Course, January-May, 2016.

2. HRI Talent Search Exam Committee member, November, 2015.

Jyotiranjan Beuria

Research Summary:

During this academic year (April 2015 to March 2016), I along with my collaborators, have studied the viability of having two relatively light bottom squarks ('sbottoms') at LHC-II in the framework of the Next-to-Minimal Supersymmetric Standard Model (NMSSM). We are also studying the vacuum structure of the NMSSM in the context of three neutral fields getting vacuum expectation values and charged and coloured fields getting vacuum expectation values.

Publications:

1. Jyotiranjan Beuria, Arindam Chatterjee, AseshKrishna Datta and Santosh Kumar Rai, *Two Light Stops in the NMSSM and the LHC,* JHEP **073**, 1509, (2015)

Preprints:

1. Jyotiranjan Beuria, Arindam Chatterjee, AseshKrishna Datta, *Sbottoms of Natural NMSSM at the LHC,* HRI-P-16-03-001, RECAPP-HRI-2016-004

2. Jyotiranjan Beuria, Utpal Chattopadhyay, AseshKrishna Datta, Abhishek Dey, *Exploring viable vacua of the Z_3 symmetric NMSSM* (in preparation)

Conference/Workshops Attended:

1. *SUSY-DM*, Indo-French Kick-off Meeting, IISC, Bangalore, May 2016

Visits to other Institutes:

1. *IACS*, Kolkata, December 2015 and February 2015

Sreetama Das

Research Summary:

In the last academic year, I have worked on the topic of quantum refrigerators under the supervision of Prof. Ujjwal Sen. Quantum thermodynamics is a branch of physics in which quantum effects on thermodynamical laws and thermodynamical properties are analyzed. In particular, the status of these laws and properties are scrutinized for microscopic and mesoscopic systems. Quantum refrigerators are quantum thermal machines composed of a few qubits and their respective baths, with a single qubit being cooled by using the remaining ones and the baths.

In a small project under the supervision of Prof. Aditi De, I have studied the relation between fringe visibility and which-way information in double-slit interference.

Conference/Workshops Attended:

1. *QIPA*, Allahabad, December 2015.
2. *ISCQI*, Bhubaneswar, February 2016.

Visits to other Institutes:

1. NISER, Bhubaneswar, India, June-July 2015.

Mritunjay Kumar Verma

Research Summary:

During the period 01/04/2015- 31/03/2016, I was mainly involved in three Research projects.
Surviving in Meta-Stable de Sitter Space Time- This project was about the metastable nature of our universe. It is an experimental fact that the universe we are living in is going through an accelerated expansion. This means that the vacuum state of our universe is de Sitter. Now, there are many vacua (such as Minkowski and Anti de Sitter) with lower energy than our universe and they are predicted generically by String theory. According to laws of quantum mechanics, the ground state with higher energy decays eventually to the ground state with lower energy. Our universe is no exception. The aim of the project was to investigate what is the best course of action, a civilization can take, to maximize its life expectancy given the above facts. We found that the collective life expectancy of two civilizations having modest initial separation can reach the maximum possible value (1.5 times the life of individual observer) if the decay rate is less than 1 % of the expansion rate. We also found that in the current epoch of our universe, the decay rate is increasing as a function of time.
Feynman Rules in Mellin Space for Quantum Field Theories- This project was about the Mellin representation of the quantum field theories. The properties (such as poles and branch cut structures) of usual quantum field theories are easier to analyze in the momentum space. However, the properties of Conformally invariant quantum field theories (such as spectrum of primary operators) become very transparent in the Mellin space. The main goal of the project was to find Feyman rules in Mellin space for a general conformal field theory. We have succeeded in finding the Feynman rules for conformal field theories at tree level. Moreover, we also made some success in extending the Mellin space techniques to non conformal field theories. At present, we are trying to apply the Mellin space techniques in the context of AdS-CFT correspondance.
Mass Renormalization in String Theory - The third project is about the mass renormalization of non BPS first massive heterotic string state using the pure spinor techniques. The eventual goal is to do the two loop mass renormalization. At present, we are trying to work out the vertex operator of the desired string state in pure spinor formalisn and trying to reproduce the known result for mass renormalization of the same state at one loop using pure spinor formalism.

Publications:

1. Sitender Pratap Kashyap, Swapnamay Mondal, Ashoke Sen, Mritunjay Verma, (*Surviving in a Metastable de Sitter Space-Time*), Journal of High Energy Physics (JHEP), 1509 (2015) 139

Preprints:

1. Rajesh Gopakumar, Amin Nizami, Arnab Rudra, Sourav Sarkar, Mritunjay Verma (*Perturbative CFTs in Mellin Space*)

Conference/Workshops Attended:

1. *Advanced String School*, Bengaluru, India, June 2015
2. *International Strings Conference*, Bengaluru, India, June 2015
3. *Asian winter School on String, Particle and Cosmology,* Okinawa Institute of Science and Technology (OIST), Okinawa, Japan, January 2016
4. *Developments in String Perturbation Theory*, Harish Chandra Research Institute, India, Fabruary 2016

Visits to other Institutes:

1. International Center for Theoretical Sciences (ICTS), Bengaluru, India, May-December 2015,

Ruchi Saxena

Research Summary:

I am currently working on the following projects -

1. **Time-dependent periodically driven topological systems with spin-orbit coupling**

   This work is being done in collaboration with Prof. Sumathi Rao (HRI, Allahabad), Dr. Arijit Kundu (Post doc at Technion, Israel) and Dr. Priyanka Mohan (Post doc at HRI, Allahabad).

2. **Brillion-Wigner theory for periodically driven quantum systems with SO-coupling**

   This work is being done in collaboration with Prof. Sumathi Rao (HRI, Allahabad), Dr. Arijit Kundu (Post doc at Technion, Israel) and Dr. Priyanka Mohan (Post doc at HRI, Allahabad).

3. **Blockage of Andreev reflection for N=0 Landau level in the geometry of SC-N-SC, made up of graphene where the extreme ends are the contacts.**

   This work is being done in collaboration with Prof. Sumathi Rao (HRI, Allahabad), Prof. Anidiya Das (IISC, Bangalore) and Prof. Saurin Das (IISER, Kolkata) and Manas Sahu (IISC, Bangalore).

4. **Study the various interested transport charecteristics of FSF junction in systems with SO-coupling**

   This work is being done in collaboration with Prof. Sumathi Rao (HRI, Allahabad), Prof. Arijit Saha (IOP, Bhubaneswar).

Publications:

1. Ruchi Saxena, Prof. Arijit Saha, Prof. Sumathi Rao *Conductance, Valley and Spin polarization and Tunnelling magneto-resistance in ferromagnetic-normal-ferromagnetic junctions of silicene,* Phys. Rev. B **92**, 245412, (Published 9 December 2015)

Conference/Workshops Attended:

1. *Topological Particles in Condensed Matter Physics*, IISER, Pune (India), 6-11 August 2015

2. *Topology and Condensed Matter Physics*, SERC School, Kolkata (India), 23 Nov-12 Dec 2015.

3. *Frontiers in Condensed Matter Physics*, IOP, Bhubaneswar (India), 22-27 Feb 2016.

Other Activities:

1. Poster "Charge and valley conductances and TMR in FNF junction in silicene (arXiv:1507.04225)" in the conference "Topological Particles in Condensed Matter Physic" (IISER, Pune).

2. TA (Teaching Assistant) for the course 'CMP1 (Condensed Matter Physics)' during Aug-Dec 2015 session.

Kasinath Das

Research Summary:

During the "2015-2016" academic year my work was based on two types of observed anomalies at LHC. In the LHC Run I with 8 TeV centere of mass energy both ATLAS and CMS Collaborations searched for massive resonances decaying to a pair of weak gauge bosons. ATLAS Collaboration had found excesses for narrow width resonances around 2 TeV in the WZ, WW and ZZ channel with local significances of 3.4σ, 2.6σ and 2.9σ respectively. We had given an explanation for this excess using an anomaly free leptophobic left-right model with gauge symmetry $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_X$. Important to mention that with the LHC Run II data this excess is not observed.

In the LHC Run II with 13 TeV centre of mass energy both ATLAS and CMS have observed an excess in the diphoton channel at an invariant mass around 750 GeV with local significance 3.6σ and 2.6σ respectively. We have shown that a simple extension of the Standard Model with a minimal set of extra particles can accommodate the excess. We have considered an extra hidden U(1) symmetry in which all the SM particles are neutral. Only new exotic quarks and an electroweak singlet Higgs boson have coupling to this extra U(1) gauge boson. Another extra scalar has been introduced which is a singlet under SM as well as the extra U(1) symmetry. We have used this scalar to accommodate the diphoton excess with all particles of the model having masses within the TeV scale.

Publications:

1. Kasinath Das, Swapan Majhi, Santosh Kumar Rai, Ambresh Shivaji, *NLO QCD corrections to the resonant vector diquark production at the LHC,* JHEP **1510**, 122, (2015)

2. Kasinath Das, Tianjun Li, S. Nandi, Santosh Kumar Rai, *The Diboson Excesses in an Anomaly Free Leptophobic Left-Right Model,* Phys. Rev. D **93**, 016006 ,(2016)

3. Kasinath Das, Santosh Kumar Rai, *The 750 GeV Diphoton excess in a U(1) hidden symmetry model,* Phys. Rev. D **93**, 095007 , (2016)

Conference/Workshops Attended:

1. *Sangam @ HRI 2016* , India, February, 2016.
2. *Nu HoRIzons VI*, India, March, 2016.

Other Activities:

1. I tutored the course “Quantum Field Theory I” taught by Prof. Biswarup Mukhopadhyaya during Aug-Dec,2015

Sudipto Singha Roy

Research Summary:

Computing entanglement of an arbitrary bipartite or multipartite mixed state is in general not an easy task as it usually involves complex optimization. Here we show that exploiting symmetries of certain mixed states, we can compute a genuine multiparty entanglement measure, the generalized geometric measure for these classes of mixed states. The chosen states have different ranks and consist of an arbitrary number of parties.

Multiparty quantum states are useful for a variety of quantum information and computation protocols. We define a multiparty entanglement measure based on local measurements on the multiparty quantum state, and an entanglement measure averaged on the post-measurement ensemble. Using the generalized geometric measure as the measure of multipartite entanglement for the ensemble, we demonstrate, in the case of several well-known classes of multipartite pure states, that the localized multipartite entanglement can exceed the entanglement present in the original state. We also show that measurement over multiple parties may be beneficial in enhancing localizable multipartite entanglement. We point out that, compared to the generalized geometric measure, localizable generalized geometric measure works better in signaling quantum critical phenomena occurring in well-known quantum spin models even when considerable finite-size effect is present in the system.

We investigate the action of local and global noise on monogamy of quantum correlations, when monogamy scores are considered as observables, and three-qubit systems are subjected to global noise and various local noisy channels, namely, amplitude-damping, phase-damping, and depolarizing channels. We show that the dynamics of monogamy scores corresponding to negativity and quantum discord, in the case of generalized W states, as inputs to the noisy channels, can exhibit non-monotonic dynamics with respect to increasing noise parameter, which is in contrast to the monotonic decay of monogamy scores when generalized Greenberger-Horne-Zeilinger states are exposed to noise. We quantify the persistence of monogamy against noise via a characteristic value of the noise parameter, and show that depolarizing noise destroys monogamy of quantum correlation faster compared to other noisy channels. We demonstrate that the negativity monogamy score is more robust than the quantum discord monogamy score, when the noise is of the phase-damping type. We also investigate the variation of monogamy with increasing noise for arbitrary three-qubit pure states as inputs. Finally, depending on these results, we propose a two-step protocol, which can conclusively identify the type of noise applied to the quantum system, by using generalized Greenberger-Horne-Zeilinger and generalized W states as resource states.

We investigate the trends of genuine multipartite entanglement of high-temperature superconducting states, usually described by doping the Mott insulator. We begin by analyzing the ground states of a Hubbard model with large onsite interactions obtained by exact diagonalization in regimes where the superconducting phase is observed for relatively high doping. The ground states are observed to be genuine multipartite entangled, with the maximum value achieved close to the superconducting phase boundary. Subsequently, for finite hole doping, the short-range resonating valence bond (RVB) state is considered to be the ground state of the Hubbard model. We prove that doped RVB ladder states are always genuine multipartite entangled. We then formulate an analytical recursion method for the wave function, which allows us to efficiently estimate the entanglement as well as other physical quantities in large doped RVB ladders. The maximum genuine multipartite entanglement in these RVB states is observed at doping corresponding to the superconducting phase of the Hubbard model.

Publications:

1. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Diverging scaling with converging multisite entanglement in odd and even quantum Heisenberg ladders,* New J. Phys. **18**,023025 , (2016).

2. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Quantum discord length is enhanced while entanglement length is not by introducing disorder in a spin chain,* Phys. Rev. E , **93**, 012131, (2016).

Preprints:

1. Tamoghna Das, Sudipto Singha Roy, Shrobona Bagchi, Avijit Misra, Aditi Sen De, Ujjwal Sen, *Generalized Geometric Measure of Entanglement for Multiparty Mixed States,* arXiv:1509.02085, (2015).

2. Debasis Sadhukhan, Sudipto Singha Roy, Amit Kumar Pal, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Multipartite Entanglement Accu-*

mulation in Quantum States: Localizable Generalized Geometric Measure, arXiv:1511.03998, (2015).

3. Asutosh Kumar, Sudipto Singha Roy, Amit Kumar Pal, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Conclusive Identification of Quantum Channels via Monogamy of Quantum Correlations,* arXiv:1603.02801,(2016).

4. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Genuine multipartite entanglement in superconducting phases of doped quantum spin ladders,* arXiv:1604.06683 (2016).

Conference/Workshops Attended:

1. *Quantum Information Processing and Applications* , HRI, India, December, 2015.

2. *International School and Conference on Quantum Information*, IOP, India, February 2016.

Visits to other Institutes:

1. SNBNCBCS, Kolkata,India, June, 2015.

2. IISER Bhopal,India, April 2016.

Other Activities:

1. Member of the organizing committee, QIPA 15, HRI, India,December, 2015.

2. Did tutorship of classical mechanics at HRI, Allahabad, for the period Aug-Dec 2015.

Asutosh Kumar

Research Summary:

Quantum coherence is the yield of the superposition principle, and is defined for single as well as multipartite systems. Recently, it has been theorized as a quantum resource, and is the premise of quantum correlations in multipartite systems. It is therefore important to study the coherence content and its distribution in a multipartite quantum system. We show analytically as well as numerically that the reciprocity between coherence and mixedness of a quantum state is a generic feature as it is satisfied by large spectra of measures of coherence and mixedness. Numerical investigation unravels the fact that the percentage of quantum states satisfying the additivity relation of coherence increases with increasing number of parties, the rank of quantum state and raising the power of coherence measure under investigation. We also study distribution of coherence in X states. We further show that for the Dicke states, while the normalized measures of coherence violate the additivity relation, the unnormalized ones do satisfy the same.

Quantum key distribution (QKD) that implements quantum cryptography is a secure protocol by which private communication can be established between two or more parties over a public channel. Notwithstanding, there is always a possibility of eavesdropping. The QKD protocol works reliably only when the information sent over the public channel has an error rate lower than a threshold. The security of the resulting key is governed or conditioned only on fundamental laws of quantum physics: the no-cloning principle, and any information gain implies disturbance of the sender-receiver state. We derive complementarity relations for arbitrary quantum states of multiparty systems, of arbitrary number of parties and dimensions, between the purity of a part of the system and several correlation quantities, including entanglement and other quantum correlations as well as classical and total correlations, of that part with the remainder of the system. We subsequently use such a complementarity relation, between purity and quantum mutual information in the tripartite scenario, to provide a bound on the secret key rate for individual attacks on a quantum key distribution protocol.

In multiparty quantum systems, the monogamy inequality proposes an upper bound on the distribution of bipartite quantum correlation between a single party and each of the remaining parties in the system, in terms of the amount of quantum correlation shared by that party with the rest of the system taken as a whole. However, it is well-known that not all quantum correlation measures universally satisfy the monogamy inequality. The concept of monogamy is an intrinsic aspect in the study of quantum correlations in multiparty systems and plays a precursory role in quantum security, distinguishing phases of many-body systems, and multiport communication protocols such as super densecoding. However, the monogamy score (it is the difference between the quantities on the two sides of the monogamy inequality) is a difficult quantity to compute and estimate for generic quantum states and generic quantum correlations. It is therefore interesting to obtain both upper and lower bounds on the monogamy score. We show that for a large majority of multiqubit pure states, the monogamy scores for the different quantum correlations are upper-bounded by a quadratic or entropic functions of the genuine multipartite entanglement in the state, as quantified by the generalized geometric measure. We analytically show that the bound is universal for three-qubit and special classes of states of a higher number of qubits. Moreover, we derive a set of necessary conditions to characterize the extremely small set of states that may violate the multiparty entanglement bound on monogamy score, and numerically observe that the bound is satisfied by almost all Haar uniformly generated multiqubit pure states. The results set a strong limit on permissible distributions of quantum correlations that can be exploited for quantum information protocols where multiparty entangled states are resourceful. Furthermore, using an information-theoretic complementarity relation between the normalized purity and quantum correlation in any given multiparty state, we obtain a non-trivial lower bound on the negative monogamy score for the quantum correlation measure. In particular, for the three-qubit states the lower bound is equal to the negative von Neumann entropy of the single qubit reduced density matrix. We analytically examine the tightness of the derived lower bound for certain n-qubit quantum states. We also report numerical results of the same for monogamy violating correlation measures using Haar uniformly generated three-qubit states.

We investigate the action of local and global noise on monogamy of quantum correlations, when monogamy scores are considered as observables, and three-qubit systems are subjected to global noise and various local noisy channels, namely, amplitude-damping, phase-damping, and depolarizing channels. We show that the dynamics of monogamy scores corresponding to negativity and quantum discord, in the case of generalized W states, as inputs to the noisy channels, can exhibit non-monotonic dynamics with respect to increasing noise parameter, which is in contrast to the monotonic decay of monogamy scores when generalized GreenbergerHorne-Zeilinger states are exposed to noise. We quantify the persistence of monogamy against noise via a characteristic value of the noise parameter, and show that depolarizing noise destroys monogamy of quantum correlation faster compared to other noisy channels. We demonstrate that the negativity monogamy score is more robust than the quantum discord monogamy score, when the noise is of the phase-damping type. We also investigate the variation of monogamy with increasing noise for arbitrary three-qubit pure states as inputs. Finally, depending on these results, we propose a two-step protocol, which can conclusively identify the type of noise applied to the quantum system, by using generalized Greenberger-Horne-Zeilinger and generalized W states as resource states.

In ongoing projects, we study entanglement of formation under energy constraint, and monogamy of quantum correlations in higher-dimensions.

Journals/Preprints:

1. Asutosh Kumar, *Quantum coherence and its distribution,* arXiv:1508.00262 [quant-ph].

2. Anindita Bera, Asutosh Kumar, Debraj Rakshit, R. Prabhu, Aditi Sen (De), Ujjwal Sen, *Information complementarity in multipartite quantum states and security in cryptography,* Phys. Rev. A 93, 032338 (2016).

3. Asutosh Kumar, Himadri Shekhar Dhar, R. Prabhu, Aditi Sen (De), Ujjwal Sen, *Forbidden regimes in distribution of bipartite quantum correlations due to multiparty entanglement,* arXiv:1505.01748 [quant-ph].

4. Asutosh Kumar, Himadri Shekhar Dhar, *Lower bounds on violation of monogamy inequality for quantum correlation measures,* arXiv:1603.02957 [quant-ph].

5. Asutosh Kumar, Sudipto Singha Roy, Amit Kumar Pal, R. Prabhu, Aditi Sen (De), Ujjwal Sen, *Conclusive identification of quantum channels via monogamy of quantum correlations,* arXiv:1603.02801 [quant-ph].

6. Asutosh Kumar, Aditi Sen (De), Ujjwal Sen, *Canonical entanglement of formation,* (in preparation).

Conference/Workshops Attended:

1. *International Conference on Quantum Foundations*, NIT Patna, India, November-December 2015.
   Contributed a poster on “On monogamy of multipartite quantum states”.

2. *Meeting on Quantum Information Processing and Applications-2015 (QIPA-15)*, HRI, India, December 2015.
   Contributed posters on (i) Information complementarity in multipartite quantum states and security in cryptography, and (ii) Forbidden regimes in distribution of bipartite quantum correlations due to multiparty entanglement.

Other Activities:

1. Member of local organizing committee of *Quantum Information Processing and Applications-2015 (QIPA-15)*, Harish-Chandra Research Institute, December 2015.

Ajanta Maity

Research Summary:

In this academic year our focus was to study the variation of mobility of phosphorene (monolayer black phosphorus) with strain and type of barrier height when phosphorene is in contact with metal. To calculate carrier (electron and hole) mobility we use phonon-limited scattering model for two dimensionl material

$$\mu_{\mathrm{2D}} = \frac{e\hbar^3 C_{2D}}{k_B T m_{\parallel}^* m_a^* (E_1)^2}. \tag{6}$$

In this relation μ_{2D} is the mobility, $m_{\parallel}^*$ is the carrier effective mass in the transport direction, and $m_a^* = \sqrt{m_{\parallel}^* m_{\perp}^*}$ with $m_{\perp}^*$ being the effective mass perpendicular to the transport direction. E_1 is the Defomation Potential (DP) of the valence band maximum (VBM) for hole conduction, or of the conduction band minimum (CBM) for electron conduction.

$$E_1 = \frac{\Delta E_{\mathrm{e}}}{\epsilon}, \tag{7}$$

where ΔE_{e} is the shift of the band edge due to a strain ϵ. For uniaxial strain $\epsilon = \Delta l / l_0$. Δl is the change in the lattice constant, and l_0 is the equilibrium lattice constant. Our aim was to study how electron and hole mobility changes with compressive and tensile strain. We strained phosphorene in two ways (i) strain along armchair direction and keeping the transverse direction fixed and vice-versa, (ii) strain along armchair direction and relaxing the transverse direction and vice-versa. Within few percent (0.5%) compressive strain along zigzag direction (keeping armchair direction fixed), hole mobility along zigzag direction is of the order of 10 ^{6} cm ^{2}/V.sec. Hole mobility is 100 order of magnitude higher along zigzag direction than along armchair direction. But electron mobility is higher along armchair direction than along zigzag direction.

To calculate the Schottky barrier height (Φ) for electron (hole) we calculate work function of metal (ϕ_m) and electron affinity (χ_s) (ionization potential (I_{s_c}) for holes) of semiconductor. Using Schottky-Mott model we can write

$$\Phi = \phi_m - \chi_s \tag{8}$$

$$\Phi = I_c - \phi_m \tag{9}$$

Electron injection efficiency from metal to semiconductor depends on the quantitative value of Schottky barrier height (SBH). Therefore if the SBH is zero then electron can easily flow from metal to semiconductor and the contact is called ohmic. If SBH has some finite positive value then a finite amount of bias which is of the order of SBH is given and the contact is called Schottky contact. We choose Pd (111), Pd (110), Pd (100), Ni (110), Ti (0001) and Au (110) contact with phosphorene. Pd (111) and Pd (100) gives zero barrier height for holes.

Conference/Workshops Attended:

1. School on Nanoscale transport and Magnetism: Fundamentals to Applications, India, February, 2016

Other Activities:

1. Tutor of electrodynamics course, January, 2016

Md Arif Shaikh

Research Summary:

I worked mostly on nonlinear time series analysis to investigate low dimensional chaos in light curves. I developed necessary numerical programs in C++ using the Grassberger-Procaccia algorithm to find the correlation dimension of different known systems for example Lorenz system, Logistic map, Henon map etc. In order to find the correlation dimension accurately one also needs to know the autocorrelation and mutual information function for the given system. Programs to find these functions were also developed. This approach works only for the systems where we already know the total degrees of freedom of the system and also all the data corresponding to those degrees of freedom. But in observations data for only one degree of freedom may be available. To find the correlation dimension of the system in this case we reconstruct the dynamical system by delay embedding and using this delay embedding correlation dimension is calculated in different embedding dimensions. Necessary numerical programs for the delay embedding method was developed and tested for the known systems mentioned earlier.

I also studied the angular momentum transport processes in accretion disk via hydromagnetic winds and hydromagnetic instability.

Other Activities:

1. Guided Soumyadeep Chaterjee, a project student in the Cosmology & High energy Astrophysics group, December 2015.

2. Acted as the tutor for the Statistical Mechanics course, January-May, 2016.

3. Gave two informal talks on "Angular momentum transport process in accretion disk", January, 2016.

4. Attended a course on dynamical systems by Dr. Jayanta Kumar Bhattacharjee, January-May, 2016.

5. Attended a course on statistical mechanics by Dr. G Venketeswara Pai, January-May,2016.

Titas Chanda

Research Summary:

During the last academic year, I have been working on various aspects of quantum information science, mainly the study of quantum various quantum correlation measures as well as properties of open quantum systems.

The issue of reducing the resource required to compute information-theoretic quantum correlation measures like quantum discord and quantum work deficit in two qubits and higher dimensional systems is an open topic in quantum information science. We have shown that determination of the quantum correlation measure is possible even if we utilize a restricted set of local measurements. We have found that the determination allows us to obtain a closed form of quantum discord and quantum work deficit for several classes of states, with a low error. We have shown that the computational error caused by the constraint over the complete set of local measurements reduces fast with an increase in the size of the restricted set, implying usefulness of constrained optimization, especially with the increase of dimensions. We have performed quantitative analysis to investigate how the error scales with the system size, taking into account a set of plausible constructions of the constrained set. Applying the methodology to quantum spin models, we have shown that the constrained optimization can be used with advantage in analyzing such systems in quantum information-theoretic language.

We have shown that the frequency distribution of the first significant digits of the numbers in the data sets generated from a large class of measures of quantum correlations, which are either entanglement measures, or belong to the information-theoretic paradigm, exhibit a universal behavior. In particular, for Haar uniformly simulated arbitrary two-qubit states, we have found that the first-digit distribution corresponding to a collection of chosen computable quantum correlation quantifiers tend to follow the first-digit law, known as the Benford's law, when rank of the states increases. Considering a two-qubit state which is obtained from a system governed by a specific Hamiltonian – the anisotropic XY model with a transverse magnetic field – we have seen that entanglement as well as information theoretic measures violate the Benford's law. However, interestingly, we have found that among all the quantum correlation measures, quantum discord is the only measure which, like the transverse magnetization of the system, changes the pattern of the first-digit distribution depending on the quantum phases present in this model. We also have commented on the universality of the statistics of first significant digits corresponding to appropriate measures of quantum correlations in the case of multipartite systems as well as systems in higher dimensions.

In the case of open quantum systems, we have introduced a method of characterization of non-Markovianity using coherence of a system interacting with the environment. We have shown that under the allowed incoherent operations, monotonicity of a valid coherence measure is affected due to non-Markovian features of the system-environment evolution. We have also defined a measure to quantify non-Markovianity of the underlying dynamics based on the non-monotonic behavior of the coherence measure. We have investigated our proposed non-Markovianity marker in the behavior of dephasing and dissipative dynamics for one and two qubit cases. We have also shown that our proposed measure captures the back-flow of information from the environment to the system and compatible with well known distinguishability criteria of non-Markovianity.

Publications:

1. Titas Chanda, Amit Kumar Pal, Anindya Biswas, Aditi Sen(De), Ujjwal Sen, *Freezing of quantum correlations under local decoherence*, Phys. Rev. A 91, 062119 (2015).

2. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), Ujjwal Sen, *Reducing Computational Complexity of Quantum Correlations*, Phys. Rev. A 92, 062301 (2015).

3. Titas Chanda, Samyadeb Bhattacharya, *Delineating incoherent non-Markovian dynamics using quantum coherence*, Annals of Physics 366, 112 (2016) .

4. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), Ujjwal Sen, *Statistics of leading digits leads to unification of quantum correlations*, Europhysics Letters (In preparation) (arXiv:1509.09295).

Conference/Workshops Attended:

1. *A meeting on Quantum Information Processing and Applications 2015 (QIPA-2015)*, Harish-Chandra Research Institute, Allahabad, India, December, 2015.

2. *The International School and Conference on Quantum Information 2016 (ISCQI-2016)*, Institute of Physics, Bhubaneswar, India, February, 2016.

Other Activities:

1. Presented a poster titled *"Asking quantum correlations about their monogamy 'scores'"* in QIPA-2015, Harish-Chandra Research Institute, Allahabad, India, December, 2015.

2. Presented a poster titled *"To freeze or not to: Quantum correlations under local decoherence"* in ISCQI-2016, Institute of Physics, Bhubaneswar, India, February, 2016.

Dheeraj Kumar Singh

Research Summary:

We have explored the conductivity anisotropy as a function of hole doping in the several multiorbital models of iron pnictides such as three-orbital model of Daghofer *et al.*, five-orbital model of Graser *et. al.*, and Ikeda *et. al.* by analyzing the Drude weight in the x- and y-directions of (π, 0) spin-density wave state. The reduction in the conductivity anisotropy with increased hole doping, and subsequent reversal is found to be a common trend in these models, which is consistent with the experiments. On the other hand, anisotropy on electron doping is found to be decreasing in contrast with the experiments. These features are then explained in terms of interplay between the orbitally-resolved density of states distributions and the geometrical features of the Fermi surfaces of the respective models.

In a separate investigation, we are examining the single particle spectral function in a $dwave$ superconductor at finite temperature where phase fluctuations play a crucial role. In this direction, a few attempts have been made by other workers, for example, using Monte Carlo simulation. Although obtained on a relatively smaller lattice size, single particle spectral functions as well as gap structure are affected due to the finite size effect. Particularly, in the case of $dwave$ superconductors where the gap vanishes at the nodal point, the small lattice size can obscure the gapless feature. Therefore, an access to large lattice size is highly desirable. Our effort, therefore, addresses this particular difficulty by using a cluster-based approach to the Monte-Carlo simulation. For further improvement in the spectral function, we plan to use supercell methods with antiperiodic boundary conditions. This work is still in progress.

Preprints:

1. Dheeraj Kumar Singh and Pinaki Majumdar, *Conductivity anisotropy as a function hole doping in the orbital models of iron pnictides* (in preparation)

2. Dheeraj Kumar Singh and Pinaki Majumdar, *Single particle spectral function at finite temperature in dwave superconductors* (in preparation)

Nyayabanta Swain

Research Summary:

We study the interplay of electronic correlation and geometric frustration in the context of the Mott transition in the pyrochlore and checkerboard lattices, both constructed out of tetrahedral motifs. We formulate the single band Hubbard model on these lattices in terms of electrons coupled to auxiliary local magnetic moments, and treat the resulting 'fermion-spin' problem through a real-space Monte Carlo technique. While the ground states we obtain are equivalent to unrestricted Hartree-Fock, the presence of the crucial low energy fluctuations in our approach, and their coupling to the electrons, allows us to establish the temperature dependence of transport and spectral features across the Mott transition.

The checkerboard lattice displays multiple magnetic orders in the Mott phase, promoted by thermal order by disorder and the multi-spin couplings generated by electron hopping, and a low moment spin glass phase near the Mott transition. The pyrochlore lattice, on the other hand, does not show any magnetic order in the Mott phase, unless spin-orbit coupling (SOC) is turned on. We have obtained the overall phase diagram in terms of correlation strength, SOC, and temperature. Our results capture the details of Mott transition observed in the pyrochlore iridates. We also have investigated the Mott transition in the presence of strong Hunds coupling and competing double-exchange and super-exchange interactions, which are the crucial ingredients to understand the Mott physics of pyrochlore molybdates.

Preprints:

1. Nyayabanta Swain, Rajarshi Tiwari and Pinaki Majumdar, *Mott-Hubbard Transition on the Pyrochlore Lattice,* arXiv:1505.03502v1, (2015).

2. Nyayabanta Swain and Pinaki Majumdar, *Mott Transition and Magnetic Correlations on the Frustrated Checkerboard Lattice,* (in preparation).

3. Nyayabanta Swain and Pinaki Majumdar, *Mott Transition and Anomalous Resistive State in the Pyrochlore Molybdates,* (in preparation).

4. Nyayabanta Swain and Pinaki Majumdar, *Mott Transition in the Pyrochlore Iridates,* (in preparation).

Conference/Workshops Attended:

1. *Conference on Frustration, Disorder and Localization: Statics and Dynamics*, Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy (28 September-2 October, 2015).

2. *Indo-Japan Conference on Emergent phenomena in transition-metal compounds and related materials*, Indian Institute of science (IISc), Bangalore, India (28-30 March, 2016).

Visits to other Institutes:

1. International School for Advanced Studies (SISSA), Trieste, Italy (4-6 October, 2015).

2. Paul Scherrer Institut (PSI), Villigen, Switzerland (7-9 October, 2015).

3. Institut Laue Langevin (ILL), Grenoble, France (10-13 October, 2015)

Invited Lectures/Seminars:

1. *Mott transition and novel magnetic behavior in the pyrochlores*, Physics Seminar, International School for Advanced Studies (SISSA), Trieste, Italy, (5 October, 2015).

2. *Novel magnetic behavior and Mott transition in the pyrochlores*, Physics Seminar, Paul Scherrer Institut (PSI), Villigen, Switzerland, (8 October, 2015).

3. *Novel magnetic behavior and Mott transition in the pyrochlores*, Physics Seminar, Institut Laue Langevin (ILL), Grenoble, France, (12 October, 2015).

Namrata Shukla

Research Summary:

In this year, our work on error-disturbance relations has been an achievement. In this piece of work, we have provided stronger error disturbance relations by a significant improvement on the bound available by error disturbance relations in the literature. This work makes use of stronger uncertainty relations by Maccone and Pati appeared recently and shows improvement over the well known error disturbance relations.
Geometric phase has been of great importance in the history of quantum mechanics. However, macroscopic quantum systems have been receiving deep attention in the recent times. In our another another work, we have been able to connect geometric phase with entanglement in some examples of macroscopic superposition states. It is important because to test entanglement in macroscopic quantum systems using this method is feasible due to easy measurement of geometric phase deficit.
In addition to my work area of quantum information and communication, I have also been working in the field of mathematical physics this year. Riemann-zeta function has been of very much interest to me as it connects very well with quantum entanglement. I have been exploring some such aspects of this special function. In turn, I could provided an easier proof of existence of infinite universes using this function which is accepted for publication in a mathematical physics journal.

Publications:

1. C. Mukhopadhyaya, Namrata Shukla, Arun K Pati *Stronger error disturbance relations for incompatible observables,* Europhysics Letters **113**, 50002, (2016).

2. Namrata Shukla and Ranjana Prakash, *Simultaneous polarization squeezing in almost all components of Stokes operator vector for polarized N photon state and diminution on squeezing operation,* Optics Communications **374**, 8, (2016).

3. Namrata Shukla and Ranjana Prakash, *Large polarization squeezing in non-degenerate parametric amplification of coherent radiation,* Optics and Spectroscopy **120**, 134, (2016).

4. Namrata Shukla and Ranjana Prakash, *Polarization squeezing in degenerate parametric amplification of coherent light,* Modern Physics Letters B **30**, 1650055, (2016).

5. Namrata Shukla and Ranjana Prakash, *Construction of models of universe on the Riemann hypothesis,* Reports on Mathematical Physics **Accepted**, xxxx, (2016).

Preprints:

1. Namrata Shukla and Arun K Pati, *Geometric phase deficit can detect macroscopic entanglement,* arXiv:1509.04310.

2. Namrata Shukla and Ranjana Prakash, *Alteration in non-classicality on passing through a linear beam splitter,* arXiv:1603.08477.

Conference/Workshops Attended:

1. *International School and Conference on Quantum Information, Institute of Physics, Bhubaneswar*, India, February 2016.

2. *International Conference on Light Quanta: Modern Perspectives and Applications, University of Allahabad*, India, December 2015.

3. *Meeting on Quantum Information Processing and Applications, Harish-Chandra Research Institute, Allahabad*, India, December 2015.

4. *International Conference on Quantum Foundation, National Institute of Technology Patna*, India, November 2015.

5. *Scottish Universities Summer School on Quantum Optics and Quantum Dynamics, University of Strathclyde, Glasgow*, UK, July 2015.

Visits to other Institutes:

1. Institute of Physics, Bhubaneswar, India, Country, February 2016.

2. Kinki University, Fukuoka, Japan, November 2015.

Invited Lectures/Seminars:

1. *Stronger error disturbance relations for incompatible observables*, International School and Conference on Quantum Information, Institute of Physics, Bhubaneswar, India, February 2016.

2. *Quantum uncertainty relations*, Departmental Seminar, Kinki University, Fukuoka, Japan, November 2015.

3. *Geometric phase deficit can detect entanglement (Poster)*, Scottish Universities Summer School on Quantum Optics and Quantum Dynamics, University of Strathclyde, Glasgow, UK, July 2015.

Academic recognition/Awards:

NA

Other Activities:

1. Physics classes in 'Scientific Workshop in Hindi', May, 2015.

Dushyant Kumar

Research Summary:

The W_N coset CFT and its relation with three-dimensional higher-spin Vasiliev theory is now a well-tested example of the AdS-CFT correspondence. This work has been extended in many directions. As of now, there is a plethora of coset CFTs with bulk duals. However, so far, there has been no systematic attempt to understand where non-diagonal invariants of coset CFTs fit in this duality picture. We address this question in this work.

For any coset CFT, it is a hard to classify all modular-invariant partition functions. Modular invariants of a coset CFT are intimately related to modular invariants of WZW models. Coset CFTs are of the form G_r/H_x where the group H is embedded in G, with r and x the levels of the affine groups G and H respectively. The character of this coset model, also known as the branching function, is the coefficient of the expansion of the character of the affine group G_r into the characters of the affine group H_x:

$$\chi_\mu^G = \sum_\alpha b_{\mu\alpha} \chi_\alpha^H . \tag{10}$$

Here, $b_{\mu\alpha}$, the branching function of the coset CFT, is a function of the modular parameter τ and carries an index μ labelling the primary fields of the G_r WZW model and an index α labelling the primaries of the H_x WZW model. The problem of classifying modular invariants of a coset CFT is, therefore, a problem of classifying the modular invariants of WZW models. However, although a complete classification of the modular invariants of WZW models remains elusive, it is easy to identify distinct classes of modular invariants. All WZW models have a diagonal invariant of the form

$$\sum_\alpha |\chi_\alpha|^2 , \tag{11}$$

referred to in the literature as a "A"-type invariant. There is an important class of invariants called "D"-type invariants that can be constructed from the diagonal partition function by modding out by a discrete symmetry of the WZW model. The third class consists of exceptional invariants or "E"-type, constructed using a variety of methods. This class of invariants is the one that is difficult to classify. However, there is a sub-class of E-type invariants that have a straightforward origin. These are the E-type invariants that result from conformal embeddings.

A embedding $H_x \subset G_r$ is conformal when the central charges associated with the WZW models with gauge groups H_x and G_r are equal. If H_x is conformally embedded in G_r it implies that a character of G_r can be expanded in terms of the characters of H_x with constant coefficients. This means that in the expansion in 10, the $b_{\mu\alpha}$ will be independent of τ. As a result of this relation between their characters, a partition function of G_r will result in a partition function of H_x. This idea has been widely utilised to construct exceptional partition functions of many WZW models.

There is a well-known procedure to construct modular invariants of a coset CFT once the modular invariants of WZW models are known. Our aim is to study examples of modular invariants of coset CFTs that can be constructed because a constituent affine group of the coset is conformally embedded in a larger group. All conformal embeddings are known. Some conformal embeddings only appear for specific values of the ranks of the groups G and H, however, others appear for generic values of the rank and specific values of the levels in terms of the rank. We are interested in the second class of embeddings because they result in infinite series of partition functions. Getting a series of invariants is particularly useful from the point of view of the bulk dual because it allows one to take a 't Hooft limit. However, since a conformal embedding always fixes the value of the level (k) in terms of the rank (N) of the gauge group H, the 't Hooft coupling given by $\lambda = N/(N+k)$ is fixed at a particular value. In all examples that we look at in this paper λ is fixed at $1/2$ in the $N, k \to \infty$ limit.

It also turns out that partition functions generated in this way for different coset series, are not always different. Some of these coset series have the same central charges and by using the method of "T-equivalence" one can find a relation between their branching functions. In this work we give examples of such equivalences and a proof in some cases.

For identifying the bulk dual of these cosets, we need to find the symmetry algebra of these partition functions. In general, the symmetry algebra of a non-diagonal invariant of a coset model is either the same as the symmetry algebra of the diagonal invariant or an extension thereof. We show that some of the partition functions constructed using the conformal embedding technique can be interpreted as diagonal partition functions of a different coset model. These partition functions, as a consequence, have a larger symmetry algebra than the original partition functions. We discuss a special case of this phenomena, for the coset model

$$\frac{SO(2N)_{2N-2} \otimes SO(2N)_1}{SO(2N)_{2N-1}} \,. \tag{12}$$

Cosets with orthogonal gauge groups and their symmetry algebras have been discussed in the literature before, but this particular case is new. Its importance is related to the fact that taking a non-diagonal invariant of this coset model, the symmetry algebra is boosted from $\mathcal{N} = 0$ to $\mathcal{N} = 1$ supersymmetry. This mirrors what happens for the $\frac{SU(N)_N \otimes SU(N)_1}{SU(N)_{N+1}}$ coset and should be part of a more general phenomena of enlarged supersymmetry at $\lambda = 1/2$ for particular non-diagonal invariants of generic coset models.

Publications:

- Rakesh Kumar, Dushyant Kumar, Brijesh Kumar *Honeycomb antiferromagnet with a triply degenerate dimer ground state*, Phys. Rev. B **80** 214428 (2009)
- Dushyant Kumar, *Two dimensional Yang-Mills theory on recursive infinite genus surfaces*, JHEP **1409** 023 (2014).
- Debashis Ghoshal, Camillo Imbimbo and Dushyant Kumar, *Weak coupling expansion of Yang-Mills theory on recursive infinite genus surfaces*, JHEP **1410** 181 (2014).

Preprints:

1. Dushyant Kumar and Menika Sharma, *Conformal embeddings and higher-spin bulk duals* (in preparation).

Conference/Workshops Attended:

1. SERC Main School in Theoretical High Energy Physics, Panjab University Chandigarh (2010).
2. SERC Preparatory School in Theoretical High Energy Physics, BITS-Pilani Goa Campus, (2010).

3. SERC Main School in Theoretical High Energy Physics, Jamia Millia Islamia, (2011).

4. Workshop on Higher Spin Theories and Holography held at the Harish-Chandra Research Iinstitute, Allahabad (2011).

5. Indian String Meeting held in Puri, India (December, 2012) – presented a talk on *Two Dimensional Yang-Mills Theory on Recursive Infinite Genus Surfaces*.

6. International conference and workshop on Teichmuller Theory and Interfaces with Ergodic Theory ad Group Actions, held at the School of Physical Sciences, JNU, New Delhi (2013).

7. Asian String School held in Puri, India (January, 2014).

8. Workshop on Black Hole Information Paradox held at the Harish-Chandra Research Iinstitute, Allahabad (2014).

9. Advanced String School held in Puri, India (September, 2014).

10. Indian String meeting in Puri, India (December 2014) – presented a talk on *Two Dimensional Yang-Mills Theory on Recursive Infinite Genus Surfaces*.

11. National String meeting at IISER Mohali, (December 2015).

Invited Lectures/Seminars:

1. *Two Dimensional Yang-Mills Theory on Recursive Infinite Genus Surfaces*, Indian String Meeting, Puri, December 2012 .

2. *Two Dimensional Yang-Mills Theory on Recursive Infinite Genus Surfaces*, Indian String Meeting, Puri, December 2014.

Academic recognition/Awards:

- Gold Medal for overall performance in MSc, 2009.

Debajyoti Dutta

Research Summary:

My work focuses on studying the capabilities of upcoming long-baseline accelerator neutrino experiment at Fermilab, U.S known as DUNE (Deep Underground Neutrino Experiment). This experiment is designed to determine the remaining unknowns in neutrino oscillation physics like mass hierarchy, leptonic CP violation and octant of atmospheric mixing angle. If nature have fourth flavor of neutrinos which is popularly called sterile neutrino(s), then how the present generation of reactor experiments can probe its oscillations is also studied in my Thesis. Recently, I am also exploring the above mentioned issues at DUNE with sterile neutrino. We have extended our sensitivity study to different world class accelerator experiments like NOvA, T2K, HK etc.

During the period of last academic year (from 1st April 2015 to 31st March 2016), I have been working in collaboration with Prof. Raj Gandhi, HRI, Allahabad and Prof. Boris J Kayser, Fermilab to explore the potential of DUNE to measure the remaining unknown neutrino oscillation parameters. The main aim of the work was to pin point the effect of $1eV^2$ sterile neutrino in Mass hierarchy as well as CP sensitivity measurements at long baseline superbeam experiments. This work is in final stage now and will be communicated soon. In the mean time, I have been also working with Prof. Raj Gandhi to study physics beyond standard model in the contest of neutrino oscillation in DUNE.

Presently, Short baseline physics programs at Fermilab are in focus as they are capable to measure neutrino oscillations corresponding to $1eV^2$ sterile neutrino. I have been with Georgia Karagiorgi from University of Manchester and Prof. Raj Gandhi in the contest of this SBN program.

Conference/Workshops Attended:

1. *International Workshop on Advances in Astroparticle Physics and Cosmology (AAPCOS), SINP, Kolkata, India, 12-17 October, 2015.*

2. *Current Issues in Cosmology, Astrophysics and High Energy Physics (CICAHEP), Dibrugarh University, Assam, India. 2-5 Nov, 2015.*

3. *Workshop in High Energy Physics Phenomenology (WHEPP) at IIT, Kanpur, India, from 4-13th Dec, 2015.*

4. *Instructional Workshop in Particle Physics, HRI, Allahabad, India, 15-19 February 2016.*

5. *Nu HoRIzons VI, HRI, Allahabad, India 17-19 March, 2016.*

Visits to other Institutes:

1. University of Delhi, India, May 2015.

Conference Talks:

1. *Exploring the Octant and CP violation at DUNE in presence of Reactor Experiments,* AAPCOS, *SINP, Kolkata, India, 12-17 October, 2015.*

2. *Exploring the Octant and CP violation at DUNE in presence of Reactor Experiments,* CICAHEP, *Dibrugarh University, Dibrugarh, Assam, India, 2-4 Nov, 2015.*

3. *A re-evaluation of the capabilities of the long-baseline super-beam neutrino experiments in the presence of a sterile neutrino,* Nu HoRIzons, *HRI, Allahabad, India, 17-19 March, 2016*

Himadri Shekhar Dhar

Research Summary:

The main research work conducted during the academic year, have been on the i) characterization of quantum correlations in many-body systems, including quantum spin chains and Heisenberg spin ladders, ii) characterization of non-Markovianity in the open dynamics of both discrete and continuous variable quantum systems, and iii) resource theory of quantum coherence.

In many-body quantum systems, we have investigated long-range quantum correlations in open finite quantum spin chains, with weakly interacting probe spins at the ends of the chain. We observe that the long-range quantum discord between the end spins can be adiabatically frozen, i.e., the quantum correlation is not affected by small variations in the system parameters and temperature. In another problem, we have worked on the finite-size scaling of genuine multipartite entanglement in Heisenberg ladders. Using the resonating valence bond (RVB) ansatz, we show that the scaling properties of multipartite entanglement can distinguish the dichotomy between odd and even Heisenberg ladders, even at asymptotic limits where traditional order parameters fail. Another important project, involves the study of doped spin ladders to investigate the multisite entanglement properties of superconducting ground states of the Hubbard model. Developing an analytical recursion method to generate the ground states under the doped- RVB ansatz, we are able to show that the superconducting states at relatively high doping concentrations possess significantly high genuine multisite entanglement.

In other projects, we have worked on the theory of quantum coherence, where we propose a formalism that allows one to establish a correspondence between the resource theories of coherence and entanglement. The formalism thus provides a reliable method to define measures of coherence in terms of known results from entanglement theory. In another work, we show the complementarity between maximal coherence and mixedness of a quantum state. The next project involves the characterization of non-Markovianity in the open quantum dynamics of both discrete and Gaussian quantum systems, using an information-theoretic measure of quantum correlations, based on quantum metrology, called the quantum interferometric power.

Publications:

1. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Diverging scaling with converging multisite entanglement in odd and even quantum Heisenberg ladders,* New J. Phys. **18**, 023025 (2016)

2. Leonardo A. M. Souza, Himadri Shekhar Dhar, Manabendra Nath Bera, Pieter Liuzzo-Scorpo, Gerardo Adesso, *Gaussian interferometric power as a measure of continuous variable non-Markovianity,* Phys. Rev. A **92**, 052122 (2015)

3. Uttam Singh, Manabendra Nath Bera, Himadri Shekhar Dhar, and Arun Kumar Pati, *Maximally coherent mixed states: Complementarity between maximal coherence and mixedness,* Phys. Rev. A **91**, 052115 (2015)

4. Himadri Shekhar Dhar, Manabendra Nath Bera, and Gerardo Adesso, *Characterizing non-Markovianity via quantum interferometric power,* Phys. Rev. A **91**, 032115 (2015)

5. Alexander Streltsov, Uttam Singh, Himadri Shekhar Dhar, Manabendra Nath Bera, and Gerardo Adesso, *Measuring Quantum Coherence with Entanglement,* Phys. Rev. Lett. **115**, 020403 (2015)

6. Himadri Shekhar Dhar, Arpita Chatterjee, and Rupamanjari Ghosh, *Generating continuous-variable entangled states for quantum teleportation using a superposition of number-conserving quantum operations,* J. Phys. B: At. Mol. Opt. Phys. **48**, 185502 (2015)

Preprints:

1. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Genuine multipartite entanglement in doped resonating valence bond superconductors,* arXiv:1604.06683

2. Asutosh Kumar and Himadri Shekhar Dhar, *Lower bounds on violation of monogamy inequality by quantum correlation measures,* arXiv:1603.02957

3. Asutosh Kumar, Himadri Shekhar Dhar, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Forbidden regimes in distribution of bipartite quantum correlations due to multiparty entanglement,* arXiv:1505.01748

4. Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen(De), and Ujjwal Sen, *Adiabatic freezing of long-range quantum correlations in spin chains*, arXiv:1502.01489

Conference/Workshops Attended:

1. *Meeting on Quantum Information Processing and Applications*, India, December, 2015.

Visits to other Institutes:

1. Imperial College London, London, United Kingdom, April-May, 2015.
2. University of Nottingham, Nottingham, United Kingdom, May, 2015.

Invited Lectures/Seminars:

1. *Properties of long-range and multipartite quantum correlations in spin-1/2 systems*, QIC Seminar, Harish-Chandra Research Institute, Allahabad, February, 2016.
2. *Characterizing entanglement in resonating valence bond states*, Quantum Information Meeting, School of Mathematical Sciences, University of Nottingham, Nottingham, May, 2015.
3. *Nonclassicality of optical states generated by number-conserving non-Gaussian operations*, Group meeting, Controlled Quantum Dynamics group, Quantum Optics and Laser Science, Imperial College London, London, May, 2015.

Amit Kumar Pal

Research Summary

In the year 2015-2016, I pursued my research in various interesting directions of quantum information processing and applications. We have looked into the interesting features of information-theoretic quantum correlations belonging to a genre different than the entanglement-separability paradigm. We have investigated the issue of reducing the computational resource required to compute information-theoretic quantum correlation measures like quantum discord and quantum work deficit in the case of two qubits as well as higher dimensional systems. We have introduced the methodology for determination of the quantum correlation measures is by using a restricted set of local measurements, which allows us to obtain a closed form of quantum discord and quantum work deficit for several classes of states, with a low error. We have demonstrated that the computational error due to the constraint over the complete set of local measurements decreases rapidly with increasing the size of the restricted set, and performed quantitative analysis to investigate the scaling of the error with the size of the restricted set by considering a set of plausible constructions of the set. We have also pointed out that the resource required to optimize an information-theoretic quantum correlation measure depends on the choice of the measure , and have applied our method in characterizing quantum correlation measures of information-theoretic origin in the cases of quantum spin models and bound entangled states in higher dimension.

In search for interlinks between the measures of quantum correlations belonging to the entanglement-separability and information-theoretic paradigms, we have adopted a statistical viewpoint, and showed that irrespective of the choice of the quantum correlation measure from any one of the paradigms, the frequency distribution of the first significant digits of the numbers occurring in the data sets corresponding to the quantum correlation measure exhibit a universal behavior. More specifically, we show that for Haar uniformly simulated arbitrary two-qubit states, the first-digit frequency distribution corresponding to a set of chosen computable quantum correlation measures belonging to either of the paradigms tend to follow the Benford's law, when rank of the states increases. However, we demonstrate that for a two-qubit state corresponding to a system governed by a specific Hamiltonian, which we choose to be the anisotropic XY model with a transverse magnetic field, the first-digit distribution corresponding to the quantum correlation measures may not obey the universality. We also comment on the signature of quantum phase transitions occurring in these models by using the first-digit frequency distribution. We test the universality in the cases of multipartite systems as well as systems in higher dimensions also.

Over the last decade, multipartite entanglement has emerged as a key resource in several quantum information processing tasks such as quantum computation, quantum dense coding, and quantum cryptography, thereby highlighting the importance of defining and understanding multipartite measures of entanglement. However, despite considerable attempts, progress in developing computable measures of multipartite entanglement has been limited. We have defined a multiparty entanglement measure based on two factors – local measurements on the multiparty quantum state, and a multipartite entanglement measure, which we call the seed measure, averaged over the post-measurement ensemble. In the cases of several well-known classes of multipartite pure states, we show, using the generalized geometric measure of entanglement as the seed measure for the ensemble, that the localized multipartite entanglement can exceed the entanglement present in the original state. Moreover, we demonstrate that measurement over multiple parties of the multipartite state may be beneficial in order to enhance the localizable multipartite entanglement. We also consider the localizable multiparty measure in the case of well-known quantum spin models, and show that, compared to the generalized geometric measure itself, localizable generalized geometric measure can work better in signaling quantum critical phenomena occurring in these models, even when considerable finite-size effect is present in the system.

One of the major difficulties encountered in realizing quantum information protocols, which use bipartite and multipartite quantum correlations as resources, is decoherence of quantum correlations by interaction with the environment. We look into this problem in a multipartite scenario, considering monogamy-based multipartite measures of quantum correlations, such as the monogamy score corresponding to negativity and quantum discord, as observables. We take into account the effect of global and local noise on monogamy scores of quantum correlations, where the set of local channels considered in our work includes amplitude-damping, phase-damping, and depolarizing channels, in the case of three-qubit pure states exposed to such noises. We demonstrate that in the case of generalized W states as input states, the dynamics of monogamy scores corresponding to negativity and quantum discord exhibit non-monotonic behavior with respect to increasing noise parameter, while the decay is monotonic in the case of generalized Greenberger-Horne-Zeilinger states. We quantify the persistence of monogamy against noise via a characteristic value of the noise parameter that we call "dynamics terminal", and comment on the robustness of the monogamy score against different kinds of noises. Moreover, depending on our findings, we propose a two-step channel-discrimination protocol, which can conclusively identify the type of noise applied to the quantum system, by using generalized Greenberger-Horne-Zeilinger and generalized W states as resource states, when the noise is any one of the four types of noise considered in this work.

Publications:

1. Titas Chanda, Amit Kumar Pal, Anindya Biswas, Aditi Sen De, and Ujjwal Sen, *Freezing of Quantum Correlations under Local Decoherence,* Phys. Rev. A **91**, 062119, (2015)

2. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen De, and Ujjwal Sen, *Reducing Computational Complexity of Quantum Correlations,* Phys. Rev. A **92**, 062301, (2015)

Preprints:

1. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen De, and Ujjwal Sen, *Statistics of Leading Digits Leads to Unification of Quantum Correlations,* arXiv:1509.09295 [quant-ph]

2. Debasis Sadhukhan, Sudipto Singha Roy, Amit Kumar Pal, Debraj Rakshit, Aditi Sen De, and Ujjwal Sen, *Multipartite Entanglement Accumulation in Quantum States: Localizable Generalized Geometric Measure,* arXiv:1511.03998 [quant-ph]

3. Asutosh Kumar, Sudipto Singha Roy, Amit Kumar Pal, R. Prabhu, Aditi Sen De, and Ujjwal Sen, *Conclusive Identification of Quantum Channels via Monogamy of Quantum Correlations,* arXiv:1603.02801 [quant-ph]

Conference/Workshops Attended:

1. *Meeting on Quantum Information Processing and Applications (QIPA) - 2015*, India, December, 2015.

Visits to other Institutes:

1. Bose Institute, Kolkata, India, December, 2015.

Other Activities:

1. Co-organizer of the "Meeting on Quantum Information Processing and Applications - 2015 held at Harish-Chandra Research Institute, Allahabad, during December 07-13, 2015.

Nandan Roy

Research Summary:

Title: *On the nonlinear effects and nature of the emergent sonic metric for higher order perturbation in astrophysical fluid flow under the influence of strong gravity.*

Moving fluid always drags the sound waves. If the speed of the fluid becomes more than the local sound speed the phonons are unable to escape from the fluid. This implies existence of a region from where no phonon can escape and this is called acoustic black hole or dumb hole. We are interested in this because there are many similarities between acoustic black hole and astrophysical black hole. The boundary where the fluid flow become supersonic from subsonic is called event horizon.
Mathematical description of the acoustic black hole can be obtain from linear perturbation of the fundamental equations of the fluid dynamics. The fundamental equations of the fluid dynamics are the equation of continuity

$\partial_t \rho + \nabla \cdot (\rho \, v) = 0$,
and the Euler's Equation

$\rho[\partial_t v + (v \cdot \nabla) v] = F$,

where $F = -\nabla p - \rho \nabla \phi - \rho \nabla \Phi$.

After standard manipulation the Euler's equation for a vorticity free fluid ($v = -\nabla \psi$) can be written as

$\partial_t v = v \times (\nabla \times v) - \frac{1}{\rho} \nabla p - \nabla(\frac{1}{2} v^2 + \phi + \Phi)$.

Now we linearize system around some back back ground $(\rho_0(r), p_0(r), \psi_0(r))$ as
$\rho(r, t) = \rho_0(r) + \varepsilon \rho_1(r, t) + O(\varepsilon^2)$
$p(r, t) = p_0(r) + \varepsilon p_1(r, t) + O(\varepsilon^2)$
$\psi(r, t) = \psi_0(r) + \varepsilon \psi_1(r, t) + O(\varepsilon^2)$.

The sound wave is originated from linearized perturbations. The Bernoulli's Equation can be derived from the above equations using the following set of assumptions

- The flow is locally irrotational : $v = -\nabla \psi$
- The fluid is barotropic: $p = k \rho^\gamma$
- Specific Enthalpy: $h(p) = \int_0^p \frac{dp'}{\rho(p')}; \nabla h = \frac{1}{\rho} \nabla p$

- Local Speed of Sound: $c^{-2} \equiv \frac{\partial \rho}{\partial p}$.

Bernoulli's Equation;

$-\partial_t \psi + h + \frac{1}{2}(\nabla \psi)^2 + \phi + \Phi = 0.$

By perturbing the continuity equation and comparing coefficient of different power of ϵ we got the following equations,

$\partial_t \rho_0 + \nabla \cdot (\rho_0 v_0) = 0$
$\partial_t \rho_1 + \nabla \cdot (\rho_1 v_0 + \rho_0 v_1) = 0.$

Similarly from Euler's equation we got

$-\partial_t \psi_0 + h_0 + \frac{1}{2}(\nabla \psi_0)^2 + \phi + \Phi = 0$
$-\partial_t \psi_1 + \frac{p_1}{\rho_0} - v_0 \cdot \nabla \psi_1 = 0$.

By using all these equations and manipulating we obtain the wave equation

$-\partial_{\mathbf{t}}(\frac{\partial \rho}{\partial \mathbf{p}} \boldsymbol{\rho_0}(\partial_{\mathbf{t}} \boldsymbol{\psi_1} + \mathbf{v_0} \cdot \nabla \boldsymbol{\psi_1})) + \nabla \cdot (\boldsymbol{\rho_0} \nabla \boldsymbol{\psi_1} - \frac{\partial \rho}{\partial \mathbf{P}} \boldsymbol{\rho_0} \mathbf{v_0}(\partial_{\mathbf{t}} \boldsymbol{\psi_1} + \mathbf{v_0} \cdot \nabla \boldsymbol{\psi_1})) = \mathbf{0}$.

This equation can be written in a compact form as

$\partial_\mu (f^{\mu\nu} \partial_\nu \psi_1) = 0$,
where,

$$f^{\mu\nu} \equiv \frac{\rho_0}{c^2} \begin{bmatrix} -1 & \vdots & -v_0^j \\ \cdots\cdots & \cdot & \cdots\cdots\cdots\cdots \\ -v_0^i & \vdots & (c^2 \delta^{ij} - v_0^i v_0^j) \end{bmatrix}$$

Hence if a fluid is barotropic and inviscid, and the flow is irrotational (though possibly time dependent) then the equation of motion for the velocity potential describing an acoustic disturbance is identical to the d'Alembertian equation of motion for a minimally coupled massless scalar field propagating in a (3+1) dimensional Lorentzian geometry

$\Box \psi \equiv \frac{1}{\sqrt{-g}} \partial_\mu (\sqrt{-g} g^{\mu\nu} \partial_\nu \psi) = 0.$

Here, $g \equiv \det(g_{\mu\nu})$ and if we compare this equation with our wave equation then

$\sqrt{-g} g^{\mu\nu} = f^{\mu\nu}$,

$\det(f^{\mu\nu}) = (\sqrt{-g})^4 g^{-1} = g.$

From the expression of $f^{\mu\nu}$, $\det(f^{\mu\nu}) = -\frac{\rho_0^4}{c^2}$.

Then the acoustic metric is written as

$$g^{\mu\nu} \equiv \frac{1}{\rho_0 c} \begin{bmatrix} -1 & \vdots & -v_0^j \\ \cdots\cdots & \cdot & \cdots\cdots\cdots\cdots \\ -v_0^i & \vdots & (c^2\delta^{ij} - v_0^i v_0^j) \end{bmatrix}$$

and

$$g_{\mu\nu} \equiv \frac{\rho_0}{c} \begin{bmatrix} -(c^2 - v_0^2) & \vdots & -v_0^j \\ \cdots\cdots & \cdot & \cdots\cdots\cdots\cdots \\ -v_0^i & \vdots & \delta^{ij} \end{bmatrix}$$

The line element of the acoustic metric is written as
$ds^2 = \frac{\rho_0}{c}[-c^2dt^2 + (dx^i - v_0^i dt)\delta^{ij}(dx^j - v_0^j dt)]$
Following are the properties of the acoustic line element:

- This acoustic metric can be mapped to Schwarzschild Metric in Painleve-Gullstrand form.
- There exist a horizon which is basically sonic surface.
- The acoustic metric depends on background variables which means the horizon is static. As the background variables are time independent.
- There are two schemes of perturbation, perturbation of velocity potential and perturbation of mass accretion rate. Under linear perturbation these two perturbation schemes gave qualitative results.
- Under the first order perturbation the system is stable.

Now we want to investigate the behaviour of the system under second order perturbations. We also want to check that if the acoustic black hole is a first order perturbation phenomena. The perturbations has the same form like first order just one more order added to it.

$\rho(r,t) = \rho_0(r) + \varepsilon\rho_1(r,t) + \varepsilon^2\rho_2(r,t) + O(\varepsilon^3)$

$v(r,t) = v_0(r) + \varepsilon v_1(r,t) + \varepsilon^2 v_2(r,t) + O(\varepsilon^3)$

$f(r,t) = f_0(r) + \varepsilon f_1(r,t) + \varepsilon^2 f_2(r,t) + O(\varepsilon^3)$

The sound speed is also perturbed as,
$C_s^2(\rho) = C_s^2(\rho_0(r) + \varepsilon\rho_1(r,t) + \varepsilon\rho_2(r,t) + O(\varepsilon^3))$

Using the same procedure as we have done in linear case, we got two wave equations. The first one is basically wave equation of first order perturbation and the second one is a coupled wave equation.

$\partial_\mu(f^{\mu\nu}\partial_\nu f_1) = 0$,

$\partial_\mu(f^{\mu\nu}\partial_\nu f_2) - \partial_\mu(h^{\mu\nu}\partial_\nu f_1) = 0$.

$$f^{\mu\nu} \equiv \frac{v_0}{f_0}\begin{bmatrix} -1 & \vdots & -v_0^j \\ \cdots\cdots & \cdot & \cdots\cdots\cdots\cdots \\ -v_0^i & \vdots & (C_{s0}^2\delta^{ij} - v_0^i v_0^j) \end{bmatrix}$$

,

$$h^{\mu\nu} \equiv \frac{\rho_1 v_0}{\rho_0 f_0}\begin{bmatrix} -1 & \vdots & -(v_0^j - \frac{\rho_0 v_1^j}{\rho_1}) \\ \cdots\cdots & \cdot & \cdots\cdots\cdots\cdots \\ -(v_0^i - \frac{\rho_0 v_1^i}{\rho_1}) & \vdots & (C_{s0}^2\delta^{ij} - v_0^i v_0^j) - (\gamma-1)\delta^{ij}C_{s0}^2 + 2v_1^i v_0^j \frac{\rho_0}{\rho_1} \end{bmatrix}$$

.

It is not possible to decouple the second wave equation but it is possible to write a wave equation of the resultant wave ($F = f_1 + \epsilon f_2$) as

$\partial_\mu(\eta^{\mu\nu}\partial_\nu F) = 0$,

where $F = f_1 + \epsilon f_2$ and $\eta^{\mu\nu} = h^{\mu\nu} - f^{\mu\nu}$. But the metric loses it symmetry and can not be mapped to Schwarzschild Metric. We are working on this metric to find its properties and hence the behaviour of the acoustic metric under higher order perturbation.

Preprints:

1. Nandan Roy and collaborators from HRI *On the nonlinear effects and nature of the emergent sonic metric for higher order perturbation in astrophysical fluid flow under the influence of strong gravity,* in preparation.

2. Nandan Roy and Narayan Banerjee *Dynamical Systems Analysis of Brans-Dicke Theory with varying ω,* in preparation.

Conference/Workshops Attended:

1. *International Conference on Gravitation and Cosmology*, India, December, 2015.

Visits to other Institutes:

1. Indian Institute of Science education and Research Kolkata, Mohanpur, India, August, 2015.
2. Indian Institute of Science education and Research Kolkata, Mohanpur, India, January, 2016.
3. Sarojini Naidu College for Women, Kolkata, India, February, 2016.
4. Sarojini Naidu College for Women, Kolkata, India, March, 2016.

Invited Lectures/Seminars:

1. *Dynamical Systems Study Of The Quintessence Scalar Field*, The 33^{rd} Young Physicists' Colloquium, The Indian Physical Society(IPS), Saha Institute of Nuclear Physics, Kolkata, August, 2015.
2. *Dynamical systems study of Chameleon scalar field* , International Conference on Gravitation and Cosmology, India, December, 2015.

Other Activities:

I have co-supervised following project students jointly with Dr.Tapas K Das, Associate Professor G, HRI.

1. MS Shivani Singh from IIT Hyderabad.
2. Mr. Arindam Chakrabarti from North Bengal University.

Priyanka Mohan

Research Summary:

The research problems I have been working on with Prof. Sumathi Rao in the last academic year are that of a 1D Kitaev like spin model and of silicene in the presence of irradiation. This model, known as the tetrahedral chain, consists of plaquettes strung together to form a 1D chain. The phase diagram in this chain were calculated exactly using a Majorana fermion representation. This model was studied using a slave fermion formalism. The manuscript of this is submitted in arXiv and the paper is sent to EPJB. The second work involves the studying the possible topological transitions in silicene in the presence of periodic driving. The analytical technique used is known as the Brillouin-Wigner expansion. Here the infinite dimensional floquet Hilbert space is projected to the original Hilbert space of the Hamiltonian and the form of effective Hamiltonian is studied. This will be then compared with the chern numbers obtained from numerics to evaluate the topological transitions. The effective Hamiltonian has terms which renormalized the bare Hamiltonian with additional long range hopping. We are currently trying to calculate the Chern numbers numerically.

Preprints:

1. Priyanka Mohan and Sumathi Rao, *Slave fermion formalism for the tetrahedral chain,* arXiv:1602.02005

2. Priyanka Mohan, Arijit Kundu, Ruchi Saxena and Sumathi Rao, *Brillouin-Wigner theory for photo-induced topological phase transitions in spin-orbit coupled materials,* in preparation

Conference/Workshops Attended:

1. Topological Particles in Condensed Matter Physics: An advanced school and topical workshop, IISER Pune, August 2015.
   Poster presentation: "*Slave fermion formalism for the tetrahedral chain -* Priyanka Mohan and Sumathi Rao"

2. International Workshop on Emergent Phenomena in Quantum Hall Systems, TIFR Mumbai, January 7-9 2016.

Poster presentation: "*Slave fermion formalism for the tetrahedral chain* - Priyanka Mohan and Sumathi Rao"

3. Workshop on Frontiers in Condensed Matter Physics, IOP Bhubaneswar, 22-27 February 2016.

Pratishruti Saha

Research Summary:

Project 1 - Study of CP-violating observables in rare top decays at the Large Hadron Collider: The dominant decay mode of the top quark is $t \to bW^+$ with the W^+ further decaying into a pair of quarks or a lepton-neutrino pair. Due to the CKM factors governing hadronic decays of the W^+, the decay $t \to b\bar{b}c$ occurs with a very small branching fraction $\sim \mathcal{O}(10^{-4})$. However, effects from physics beyond the Standard Model could enhance this rate. In this project, we considered CP-violating new-physics contributions to the decay $t \to b\bar{b}c$. We examined the prospects for detecting such new physics at the Large Hadron Collider (LHC), which requires studying the process $gg \to t(\to b\bar{b}c)\bar{t}(\to \bar{b}l\bar{\nu})$. We found two observables that can be used to reveal the presence of CP-violating new physics in $t \to b\bar{b}c$. They are (i) the partial-rate asymmetry and (ii) the triple-product correlations involving the momenta of various particles associated with the interaction. A Monte Carlo analysis was performed to determine how well these observables could be used to detect the presence of new physics, and to measure its parameters. We found that there is little difficulty in extracting the value of the relevant new-physics parameter from the partial-rate asymmetry. For the triple-product correlations, we tested multiple strategies that can be used for the extraction of the corresponding combination of new-physics parameters. *The results were published in the paper titled "Measuring CP-Violating Observables in Rare Top Decays at the LHC".*

Project 2 - Extra-dimensional models with multiple warping - search prospects at the LHC: Models proposing the existence of additional, compactified spatial dimensions are considered promising candidates of physics beyond the Standard Model and are widely studied in the literature. In this project we focussed on one such set of models wherein there are two additional spatial dimensions with inter-related compactification. Collider constraints on these kinds of models are practically non-existent as most investigations deal with the Randall-Sundrum model which features 5-dimensions (with 4 spatial dimensions). So far, the search for extra dimensions has not yielded positive results. Rather, the current experimental limits along with the discovery of a 125 GeV Higgs boson imply a moderate degree of fine tuning in the parameter space of the Randall-Sundrum model. It has been pointed out in recent works that in the 6-dimensional warped compactification scenario, the parameters associated with the additional spatial direction can be used to eliminate the need for fine tuning.

We examined the constraints on this 6-dimensional model due to the 8 TeV LHC data and surveyed the parameter space that could be probed at the 14 TeV run of the LHC. We also identified the region of parameter space that is consistent with the recently reported excess in the diphoton channel in the 13 TeV LHC data. *The results have been compiled into the pre-print titled "Gravitons in multiply warped scenarios - at 750 GeV and beyond" and submitted to the Journal of High Energy Physics.*

Project 3 - Non-standard $Hb\bar{b}$ couplings: The study of the properties of the Higgs boson is of great interest in the particle physics community at present. In this project, we study the couplings of the Higgs boson to a pair of b quarks. According to Standard Model predictions, this is a CP-even coupling with a strength proportional to the mass of the b quark. We study the consequences of this coupling having a small/moderate CP-odd component. We identify observables that could be used to establish the presence of such a non-standard coupling. We also study potential new physics scenarios that can generate such couplings. *This project is in progress.*

Project 4 - Impact of $t \to b\bar{b}c$ operators on single top production. The new physics interactions that contribute to the decay $t \to b\bar{b}c$ (discussed in **Project 1** above) can also potentially contribute to single top production. In this project we attempt to constrain such operators using single top production data from the LHC. *This project is in progress.*

Publications:

1. P. Saha, K. Kiers, B. Bhattacharya, D. London, A. Szynkman and J. Melendez, *Measuring CP-Violating Observables in Rare Top Decays at the LHC,* Phys. Rev. D **93**, 054044, (2016)

Preprints:

1. M. T. Arun and P. Saha, *Gravitons in multiply warped scenarios - at 750 GeV and beyond,* arXiv:1512.06335 [hep-ph]

Conference/Workshops Attended:

1. *Workshop on High Energy Physics Phenomenology XIV*, India, December, 2015

Visits to other Institutes:

1. University of Delhi, India, July, 2015

Invited Lectures/Seminars:

1. *Top @ 2016*, Sangam @ HRI 2016: Instructional Workshop in Particle Physics, HRI, Allahabad, February, 2016.

Academic recognition/Awards:

Other Activities:

1. Member of organising committee and in-charge of creating and maintaining event websites for *Sangam @ HRI 2016: Instructional Workshop in Particle Physics* and *Nu HoRIzons VI* held in HRI, February-March, 2016.

Samyadeb Bhattacharya

Research Summary:

Characterizing Non-Markovianity by quantum coherence : We introduce a method of characterization of non-Markovianity using coherence of a system interacting with the environment. We show that under the allowed incoherent operations, monotonicity of a valid coherence measure is affected due to non-Markovian features of the system-environment evolution. We also define a measure to quantify non-Markovianity of the underlying dynamics based on the non-monotonic behavior of the coherence measure. We investigate our proposed non-Markovianity marker in the behavior of dephasing and dissipative dynamics for one and two qubit cases. We also show that our proposed measure captures the back-flow of information from the environment to the system and compatible with well known distinguishability criteria of non- Markovianity.

Effect of Global environmental interaction on quantum coherence and correlations : In this work we exploit a useful global system-environment interaction and study the effect of non-Markovian behavior on various facets of quantum coherence and correlations. Here we have found that the global part of the environmental interaction is acting as a resource to compensate the decoherence effect. We have further extended our result to the case where the bath has memory by adopting a Gaussian non-Markovian noise model. We have given the exact solution of the proposed master equation for special two qubit X states, both in the presence and absence of non-Markovian noise For both the cases, analytical expressions for the l_1 norm of coherence, concurrence and Fisher information have been calculated. We have shown that with increasing strength of the global part of the environmental interaction, both coherence and correlation (entanglement and Fisher information) decay slows down and for the limiting case they eventually freeze.

Energy Cost of Creating Quantum Coherence : We consider the physical situations where the resource theories of coherence and thermodynamics play competing roles. In particular, we study the creation of quantum coherence using unitary operations with limited thermodynamic resources. We first find the maximal coherence that can be created under unitary operations starting from a thermal state and find explicitly the unitary transformation that creates the maximal coherence. Since coherence is created by unitary operations starting f rom a thermal state, it requires some amount of energy. This motivates us to explore the trade-off between the amount of coherence that can be created and the energy cost of the unitary process. We find the maximal achievable coherence under the constraint on the available energy. Additionally, we compare the maximal coherence and the maximal total correlation that can be created under unitary transformations with the same available energy at our disposal. We find that when maximal coherence is created with limited energy, the total correlation c reated in the process is upper bounded by the maximal coherence and vice versa. For two qubit systems we show that there does not exist any unitary transformation that creates maximal coherence and maximal total correlation simultaneously with a limited energy cost.

Comparison of decoherence and Zeno dynamics from the context of weak measurement : Decay parameter of coherence and population inversion are calculated from the master equation of a two-level atom tunnelling through a squeezed vacuum. Using those parameters, the time-scales for decoherence and Zeno effect are calculated in the weak measurement scheme. By comparing those time-scales, a certain condition on the relevant experimental parameters has been found for sustainable coherent dynamics.

Publications:

1. Titas Chanda, Samyadeb Bhattacharya, *Delineating incoherent non-Markovian dynamics using quantum coherence,* Annals of Physics **366**, 1, (2016)

2. Samyadeb Bhattacharya, *Comparison of decoherence and Zeno dynamics from the context of weak measurement for a two-level atom traversing through squeezed vacuum,* International Journal of Modern Physics B **30**, 1650016, (2016)

Preprints:

1. Avijit Misra, Uttam Singh, Samyadeb Bhattacharya, Arun Kumar Pati, *Energy Cost of Creating Quantum Coherence,* arXiv:1602.08437 (Accepted for publication in Physical Review A)

2. Samyadeb Bhattacharya, Subhashish Banerjee, Arun Kumar Pati, *Effect of non-Markovianity on the dynamics of coherence, concurrence and Fisher information ,* arXiv:1601.04742

Conference/Workshops Attended:

1. *Meeting on Quantum Information Processing and Applications*, India, December 2015.

2. *One Day Symposium in Growth of Research in Physics and Applied Mathematics Unit in ISI: From Past to Present*, India, February 2016.

Visits to other Institutes:

1. Indian Statistical Institute, Kolkata, India, February 2016.

Invited Lectures/Seminars:

1. *Effect of non-Markovianity on the dynamics of coherence, concurrence and Fisher information* , One Day Symposium in Growth of Research in Physics and Applied Mathematics Unit in ISI: From Past to Present, Indian Statistical Institute, Kolkata, February 2016.

DEBRAJ RAKSHIT

Research Summary:

In the academic year "2015-2016", I have worked on disordered quantum systems, many-body systems out of equilibrium and quantum information theory. In disordered systems, I studied the effects of the quenched disorder on spontaneous magnetization in quantum spin systems within mean-field approach, and in separate works, demonstrated that disorder can be effectively engineered for obtaining quantum advantages in many-body systems. Additionally, I investigated dynamics of quantum correlations under sudden quench in system parameters in the XY spin model. In quantum information theory, my works include entanglement measure in multiparty system, derivation of complementarity relations with applications in quantum cryptography. Moreover, I have worked with doped spin ladders and an associated resonating valance bond ansatz from a quantum information perspective.

Publications:

1. D. Sadhukhan, S. S. Roy, D. Rakshit, A. Sen(De), and U. Sen, *Beating no-go theorems by engineering defects in quantum spin models*, New J. Phys. **17**, 043013 (2015)

2. D. Sadhukhan, S. S. Roy, D. Rakshit, R. Prabhu, A. Sen(De), and U. Sen, *Quantum discord length is enhanced while entanglement length is not by introducing disorder in a spin chain,* Phys. Rev. E **93**, 012131, (2016)

3. S. S. Roy, H. S. Dhar, D. Rakhsit, A. Sen(De), and U. Sen, *Diverging scaling with converging multisite entanglement in Heisenberg ladders,* New J. Phys. **18**, 023025, (2016)

4. A. Bera, A. Kumar, D. Rakshit, R. Prabhu, A. Sen(De), and U. Sen, *Information complementarity in multipartite quantum states and security in cryptography*, Phys. Rev. A **93**, 032338 (2016)

5. U. Mishra, D. Rakshit, and R. Prabhu, *Survival of time-evolved correlations depending on whether quenching is across critical point in XY spin chain*, Phys. Rev. A **93**, 042322 (2016)

Preprints:

1. H. S. Dhar, D. Rakshit, A. Sen(De), and U. Sen, *Adiabatic freezing of long-range quantum correlations in spin chains*, arXiv:1502.01489

2. A. Bera, D. Rakshit, M. Lewenstein, A. Sen(De), U. Sen, and J. Wehr, *Order-from-disorder and critical scalings of spontaneous magnetization in random-field quantum spin systems*, arXiv:1509.00704

3. D. Sadhukhan, S. S. Roy, A. K. Pal, D. Rakshit, A. Sen(De), and U. Sen, *Multipartite entanglement accumulation in quantum states: Localizable generalized geometric measure*, arXiv:1511.03998

4. S. S. Roy, H. S. Dhar, D. Rakshit, A. Sen(De), and U. Sen, *Genuine multipartite entanglement in superconducting phases of doped quantum spin ladders*, arXiv:1604.06683

Conference/Workshops Attended:

1. *Quantum Information Processing and Applications (QIPA-15)*, Harish-Chandra Research Institute, Allahabad, India, Dec., 2015.

Visits to other Institutes:

1. Physical Research Laboratory, ahmedabad, India, July, 2015.

2. Indian Institute of Technology, Gandhinagar, India, July, 2015.

3. ICFO - The Institute of Photonic Sciences, Barcelona, Spain, May, 2016.

4. ICTP - International Centre for Theoretical Physics, Trieste, Italy, May, 2016.

5. Jagiellonian University, Krakow, Poland, May, 2016.

6. Instytut Fizyki Polskiej Akademii Nauk, Warsaw, Poland, May, 2016.

Invited Lectures/Seminars:

1. *Quantum correlation in many-body systems: Distribution and dynamics*, QIC seminar, Harish-Chandra Research Institute, Allahabad, India, July, 2015.

2. *Quantum information, quantum correlations and many-body systems*, Physics seminar, Physical Research Laboratory, ahmedabad, India, July, 2015.

3. *Quantum information processing in many-body systems*, Physics seminar, Indian Institute of Technology, Gandhinagar, India, July, 2015.

4. *Diverging scaling with converging multisite entanglement in odd and even Heisenberg ladders*, Conference talk (QIPA-15), Harish-Chandra Research Institute, Allahabad, India, Dec., 2015.

5. *Multiparty entanglement trends in doped spin ladders*, Physics seminar, ICFO - The Institute of Photonic Sciences, Barcelona, Spain, May, 2016.

6. *A quantum information perspective into doped resonating valance bonds*, Physics seminar, ICTP - International Centre for Theoretical Physics, Trieste, Italy, May, 2016.

7. *A quantum information perspective into doped resonating valance bonds*, Physics seminar, Jagiellonian University, Krakow, Poland, May, 2016.

8. *Multiparty entanglement trends in doped spin ladders*, Physics seminar, Instytut Fizyki Polskiej Akademii Nauk, Warsaw, Poland, May, 2016.

Academic recognition/Awards:

- Paper selected for the PRA Kaleidoscope (Phys. Rev. A 93, 04232)

Other Activities:

1. Local organizer: 'Quantum Information Processing and Applications (QIPA-15)', Harish-Chandra Research Institute, Allahabad, India, Dec., 2015.

Keita Nii

Research Summary:

I am mainly interested in the strong coupling dynamics or the non-perturbative phenomena in quantum field theories and the string theory. Especially I was fucusing on the understanding of the three-dimensional (supersymmetric) gauge theories. In three space-time dimensions, all the gauge theories become strong in the infrared limit so we need a non-perturbative analysis. I constructed the dual descriptions for the three-dimensional $\mathcal{N} = 2$ supersymmetric gauge theories with tensorial matters. The method of constructing the dual theory is called deconfinement technique, where the tensorial matters are described by the some s-confining gauge theories.

Preprints:

1. Keita Nii, *3d Deconfinement, Product gauge group, Seiberg-Witten and New 3d dualities,* submitted in JHEP

Nilay Kundu

Research Summary:

During the academic year 2015-2016 my research work was mostly based on understanding the implications of symmetry to early universe cosmology, namely inflationary evolution of our universe. I also studied applications of AdS/CFT correspondence to general field theoretical systems. In this regard I studied fluid dynamical systems with a dynamically generated surface using general field theoretic techniques. In what follows I will describe these works in some more detail.

Using symmetry considerations, in the work published in JHEP 1504 (2015) 061, we derive Ward identities which relate the three point function of scalar perturbations produced during inflation to the scalar four point function, in a particular limit. The derivation assumes approximate conformal invariance, and the conditions for the slow roll approximation, but is otherwise model independent. The Ward identities allow us to deduce that the three point function must be suppressed in general, being of the same order of magnitude as in the slow roll model. They also fix the three point function in terms of the four point function, upto one constant which we argue is generically suppressed. Our approach is based on analysing the wave function of the universe, and the Ward identities arise by imposing the requirements of spatial and time re-parametrization invariance on it.

In the work published in JHEP 1601 (2016) 046, we derive the general Ward identities for scale and special conformal transformations in theories of single field inflation. Our analysis is model independent and based on symmetry considerations alone. The identities we obtain are valid to all orders in the slow roll expansion. For special conformal transformations, the Ward identities include a term which is non-linear in the fields that arises due to a compensating spatial re-parametrization. Some observational consequences are also discussed.

In another work (arXiv:1509.03505, to appear in Nucl. Phys. B), we look for Schroedinger solutions in Lovelock gravity in D ¿ 4. We span the entire parameter space and determine parametric relations under which the Schroedinger solution exists. We find that in arbitrary dimensions pure Lovelock theories have Schroedinger solutions of arbitrary radius, on a co-dimension one locus in the Lovelock parameter space. This co-dimension one locus contains the subspace over which the Lovelock gravity can be written in the Chern-Simons form. Schroedinger solutions do not exist outside this locus and on this locus they exist for arbitrary dynamical exponent z. This freedom in z is due to the degeneracy in the configuration space. We show that this degeneracy survives certain deformation away from the Lovelock moduli space.

In my last work (JHEP 1606 (2016) 015) we study the surface transport properties of stationary localized configurations of relativistic fluids to the first two non-trivial orders in a derivative expansion. By demanding that these finite lumps of relativistic fluid are described by a thermal partition function with arbitrary stationary background metric and gauge fields, we are able to find several constraints among surface transport coefficients. At leading order, besides recovering the surface thermodynamics, we obtain a generalization of the Young-Laplace equation for relativistic fluid surfaces, by considering a temperature dependence in the surface tension, which is further generalized in the context of superfluids. At the next order, for uncharged fluids in 3+1 dimensions, we show that besides the 3 independent bulk transport coefficients previously known, a generic localized configuration is characterized by 3 additional surface transport coefficients, one of which may be identified with the surface modulus of rigidity. Finally, as an application, we study the effect of temperature dependence of surface tension on some explicit examples of localized fluid configurations, which are dual to certain non-trivial black hole solutions via the AdS/CFT correspondence.

Publications:

1. Nilay Kundu, Jay Armas (Brussels U., PTM), Jyotirmoy Bhattacharya (Durham U., Dept. of Math.), *Surface transport in plasma-balls,* Journal of High Energy Physics **1606**, 015, (2016)

2. Nilay Kundu, Ashish Shukla (TIFR), Sandip P. Trivedi (TIFR), *Ward Identities for Scale and Special Conformal Transformations in Inflation,* Journal of High Energy Physics **1601**, 046, (2016)

3. Nilay Kundu, Ashish Shukla (TIFR), Sandip P. Trivedi (TIFR), *Constraints from Conformal Symmetry on the Three Point Scalar Correlator in Inflation,* Journal of High Energy Physics **1504**, 061, (2015)

Preprints:

1. Nilay Kundu, Dileep Jatkar, *Exploring Lovelock theory moduli space for Schrodinger solutions,* (Accepted in the journal Nuclear Physics B)

Conference/Workshops Attended:

1. *Strings - 2015*, ICTS, Bengaluru, India, June, 2015.
2. *The Young Researchers Conference*, Institute of Physics, Bhuvaneswar, India, September, 2015.
3. *National Strings Meeting*, IISER Mohali, India, Dec, 2015.

Visits to other Institutes:

1. IIT Kanpur, India, September, 2015.
2. Saha Institute of Nuclear Physics, Kolkata, India, March, 2016.
3. Tata Institute of Fundamental Research, Mumbai, India, March, 2016.

Invited Lectures/Seminars:

1. *Conformal Invariance in Inflation*, invited talk during academic visit, IIT Kanpur, India, September, 2015.
2. *Non-relativistic Solutions in Lovelock and Chern-Simons Gravity Theories*, invited talk for The Young Researchers Conference, Institute of Physics, Bhuvaneswar, India, September, 2015.
3. *Non-relativistic Solutions in Lovelock and Chern-Simons Gravity Theories*, invited talk for National Strings Meeting, IISER Mohali, India, Dec, 2015. September, 2015.
4. *Conformal Invariance in Inflation*, invited talk during academic visit, Saha Institute of Nuclear Physics, Kolkata, India, March, 2016.
5. *Surface transport in finite lumps of stationary relativistic fluid*, invited talk for Quantum Spacetime Seminar Series, Tata Institute of Fundamental Research, Mumbai, India, March, 2016.

Avirup Shaw

Research Summary:

In my first project we consider the elastic scattering of different modes of longitudinally polarised gauge bosons in various extended scalar sectors. We have used the exact expression of longitudinal polarisation vectors to determine the scattering cross sections. Generally the idea of V_LV_L scattering has been used for the proper understanding of EWSB or in other words to perceive the importance of Higgs boson. Further, this analysis has been performed at very high-energy range with approximated polarisation vectors. The reason is, at this very high-energy range one can use Goldstone boson equivalence theorem to considerably simplify the calculation. However, in our analysis we have carried out a quantitative study of V_LV_L scattering to probe the various non-standard scalars in various BSM scenario at intermediate energy-range.
While, we have performed our analysis we have scanned the parameter space of these models via several theoretical as well as phenomenological constraints. And from the allowed parameter space, we have picked up several benchmark points for which we have shown the scattering cross section distributions with CM energy in the several models.
From our analysis it is revealed that the distribution of cross sections (for any particular process) are not significantly different from that of SM. And it is quite expected, because we have chosen only those parameter space which satisfies all the existing constraints including current LHC data. Furthermore, present LHC data have allowed only a small portion of the parameter space of these models, thus we are compelled to execute our analysis in restricted parameter space. As a results the cross section distribution are very much similar to SM case unlike at the position of the peaks. Moreover, it is very difficult to differentiate between the distribution of the cross sections among the different BSM scenario except at the peaks.
In our analysis to probe the non-standard scalar particles, we choose two different values of mass range, one is at lower energy-range (~ 500 GeV) and other is at the relatively higher energy-range (~ 1500 GeV). Depending on the model parameters of a particular model and for a particular process the height and width of the peaks at the two different values of mass range are slightly different from each other, as the height and width of the peaks are controlled by mass and corresponding decay width of those non-standard scalars which we want to probe via V_LV_L scattering. Moreover, if we consider a particular process then we can differentiate

between the different models from the nature of these peaks. So our analysis provides a exclusive approach to discriminate the different extended scalar sectors.

To this end we would like to point out that, our study can be considered only as indicative, because to execute the processes we need a multi-TeV collider with sufficient luminosity. However, in practice no such collider will be available soon, and even the VLHC and CLIC projects fulfil the requirements only partially.

In my second project we have calculated the contribution of KK-excitations in the framework of non-minimal Universal Extra Dimensional model to the branching ratio of $B \to X_s\gamma$ at one loop level. Non-minimal UED is hallmarked by the presence of boundary localised kinetic and Yukawa terms along with an SM like action and field content however defined in a $4+1$ dimensional bulk. Boundary localised terms parametrise the unknown radiative corrections to the masses and couplings in the full 5-D theory. Presence of boundary terms modify the couplings and mass spectrum of KK-modes in the 4-D effective theory in a non-trivial manner.

To put our discussion into a context, we must remind that in UED, masses of the n^{th} KK-modes are nR^{-1} (R^{-1} being the compactification scale). Interactions among the different KK-excitations are very similar to their SM (0-modes) counterparts. However inclusion of BLT parameters would shift the masses of KK-modes from their UED values. For keeping our analysis simple we stick to the case of two different BLT parameters. The first one r_V, specifies the gauge and Higgs BLTs while the second one, r_f stands for equal fermion and Yukawa BLT coefficients.

Effective interaction for B meson decaying to $X_s\gamma$ can be parametrised by set of dipole operators. The coefficient for these operators are calculated in the framework of SM and in the model of our interest namely the nmUED model. In this process γ-penguins contribute at one-loop level. The total contribution coming from these penguins are finite and GIM mechanism plays a crucial role to tame the divergences. It should be noted that the final results is sum of contributions coming from different KK-levels and it also contains the SM contribution (i.e. from 0^{th} KK-mode). While summing over the KK-levels we restrict ourselves to 5 levels in view of a recent analysis relating the Higgs boson mass and cut-off of a UED theory. It has been shown explicitly that the limits on the parameters derived from our analysis would change a little if we take 20 KK-levels in the summation instead of 5.

There is very small difference between the experimentally measured branching ratio of $B \to X_s\gamma$ with its SM prediction. We have used the experimental data on the measured value of branching ratio of $B \to X_s\gamma$ to constrain the parameter space of nmUED model. As our calculation would reproduce the results of $B \to X_s\gamma$ in the vanishing BLKT limits, at the very outset, we have used the above algorithm to set a lower limit on R^{-1} in the framework of UED. In case of UED, present analysis constrained R^{-1} to greater than 416 GeV at 95 % C.L. This limit in the framework of UED, is not one of the most stringent. However, this is in the same ballpark with the limits those are obtained from the consideration of R_b, ρ-parameters or $Br(B_s \to \mu^+\mu^-)$. The nmUED model has more than one parameters apart from the compactification radius. The BLT coefficients control the masses of KK-modes and their interactions. So in the nmUED framework, any lower limit on R^{-1} would depend on these BLT coefficients. As for example, for $R_f = R_V = 4$, $R^{-1} > 0.7$ TeV, while for $R_f = 4,\ R_V = 2$, $R^{-1} > 0.6$ TeV. These lower limits on R^{-1} are so far the most stringent one in the framework of nmUED. Thus the recent experimental result of $B \to X_s\gamma$, combined with present analysis has excluded the largest region in the nmUED parameter space. Lower limits on R^{-1} derived from our analysis for negative values of R_f are not so stringent and the have been already ruled out from the consideration of electroweak precision data.

Preprints:

1. Najimuddin Khan, Biswarup Mukhopadhyaya, Subhendu Rakshit and **Avirup Shaw**. *Exploring the extended scalar sector with resonances in vector boson scattering*, (in preparation)

2. Anindya Datta and **Avirup Shaw**. *Effects of non-minimal Universal Extra Dimension on $B \to X_s\gamma$*, (in preparation)

Conference/Workshops Attended:

1. *Nu HoRizons VI at HRI*, Allahabad, India, March 2016.

2. *Sangam@HRI held at HRI*, Allahabad, India, February 2016.

Visits to other Institutes:

1. IIT Indore, Indore, India, March 2016,

2. University of Calcutta, Kolkata, India, February, 2016.

3. University of Calcutta, Kolkata, India, December, 2015.

Anirban Biswas

I joined Harish-Chandra Research Institute as a post doctoral fellow of physics department on 18th September, 2015. Upto now I have been involving with two projects on astroparticle physics. Articles based on the results that we have obtained from both the projects are already submitted in arXiv with arXiv numbers 1604.06566 and 1607.01469 respectively. However, till now, only one article with arXiv number 1604.06566 is submitted to a journal of international repute. A brief summary of the research work, we have done, is given below.

Research Summary:

"In the first work, we have considered a gauged $\mathrm{U(1)_{B-L}}$ extension of the Standard Model (SM) of electroweak interaction with three right handed neutrinos for anomaly cancellation and two additional SM gauge singlet complex scalars with non-trivial B-L charges. One of these is used to spontaneously break the $\mathrm{U(1)_{B-L}}$ gauge symmetry, leading to the generation of Majorana masses for the "active" neutrinos through the standard Type-I seesaw mechanism, while the other can play the role of a viable dark matter candidate of the Universe. We show that for dark matter masses in the range 40-55 GeV and for a wide range of $\mathrm{U(1)_{B-L}}$ gauge boson masses, one can satisfy both dark matter relic density as well as Fermi-LAT observed γ-ray flux from the Galactic Centre, if the additional neutral scalar has a mass around the resonance region ($\sim 2 \times$ dark matter mass). While studying the dark matter phenomenology and Galactic Centre γ-excess, we have taken into account both theoretical as well as experimental constraints coming from vacuum stability condition, PLANCK bound on dark matter relic density, LHC results on Higgs boson signal strength and its invisible decay width and LUX upper limit on dark matter spin independent scattering cross section. We find that there are still some region left in the model parameter space which is allowed by all the above mentioned constraints. The viability of this allowed region can be tested in near future by LHC or "ton-scale" dark matter direct detection experiments. Finally we find that the present model can also be able to explain Fermi-LAT observed γ-ray flux from the Galactic Centre region through self annihilation of dark matter into $b\bar{b}$ final state."

"In the second work, we have also considered the $\mathrm{U(1)_{B-L}}$ extension of SM. However, in this case the lightest sterile neutrino N_1 plays the role of a viable dark matter candidate and it is generated non-thermally in the early stage of the Universe mainly from the decays of $W^\pm$ ($W^\pm \to e^\pm + N_1$)

and extra neural gauge boson $Z_{\mathrm{B-L}}$ ($Z_{\mathrm{B-L}} \to N_1 + \bar{N}_1$). Now in order to make the interaction strengths of N_1 feeble with other particles (require for a non-thermal dark matter candidate) we need the extra gauge coupling g_{B-L} to be extremely small ($g_{B-L} < 10^{-7}$ for a $\mathcal{O}(100)$ GeV N_1). Due to such small value of $g_{\mathrm{B-L}}$ the extra gauge boson $Z_{\mathrm{B-L}}$ (decaying particle) will not be in thermal equilibrium. In this case, we have obtained the abundance of N_1 at the present epoch by solving a coupled Boltzmann equations (each for $Z_{\mathrm{B-L}}$ and N_1). Finally we have shown that the three body decay mode of the sterile neutrino dark matter (N_1) into a pair of e^+e^- and a active neutrino can explain the origin of 511 keV emission line observed by the INTEGRAL/SPI of ESA from the Galactic bulge."

Preprints:

1. Anirban Biswas, Sandhya Choubey, Sarif Khan, *Galactic Gamma Ray Excess and Dark Matter Phenomenology in a U(1)$_{\mathrm{B-L}}$ Model*, 1604.06566.

2. Anirban Biswas, Aritra Gupta, *Freeze-in Production of Sterile Neutrino Dark Matter in U(1)$_{\mathrm{B-L}}$ Model*, 1607.01469.

Conference/Workshops Attended:

1. *Advances in Astroparticle Physics and Cosmology (AAPCOS-2015)*, Saha Institute of Nuclear Physics, Kolkata, INDIA, October 2015.

Invited Lectures/Seminars:

1. *Nonthermal Two Component Dark Matter Model for Fermi-LAT γ-ray excess and 3.55 keV X-ray Line*, AAPCOS 2015, Saha Institute of Nuclear Physics, Kolkata, INDIA, October, 2015.

Subhadeep Mondal (PDF, High Energy Physics)

Research Summary:

We consider the production of a heavy neutrino and its possible signals at the Large Hadron-electron Collider (LHeC) in the context of an inverse-seesaw model for neutrino mass generation. The inverse seesaw model extends the Standard Model (SM) particle content by adding two neutral singlet fermions for each lepton generation. It is a well motivated model in the context of generating non-zero neutrino masses and mixings. The proposed future LHeC machine presents us with a particularly interesting possibility to probe such extensions of the SM with new leptons due to the presence of an electron beam in the initial state. We show that the LHeC will be able to probe an inverse scenario with much better efficacy compared to the LHC with very nominal integrated luminosities as well as exploit the advantage of having the electron beam polarized to enhance the heavy neutrino production rates.

We revisit the existing limits on the gaugino masses in various Supersymmetric (SUSY) scenarios derived from Run-I data of the LHC. These limits obtained from the various final states rely heavily on the simplified assumptions regarding the masses, compositions and decay branching ratios of the gauginos. The most promising exclusion limits on the gaugino masses are obtained from trilepton final states while the second lightest neutralino ($\widetilde{\chi}_2^0$) decaying into the SM-like Higgs and lightest SUSY particle (LSP) results in the weakest bounds. Our aim is to assess the extent of deviation of these exclusion limits in more realistic scenarios. After a brief discussion on the various decay modes of the $\widetilde{\chi}_2^0$ and the lightest chargino ($\widetilde{\chi}_1^\pm$), we proceed to validate the ATLAS exclusion limits obtained from trilepton, $l\gamma\gamma$ and $lb\bar{b}$ final states associated with missing energy. We then consider different combinations of the relevant branching ratios to study their impact on the existing bounds. The results are presented alongside the existing exclusion limits to showcase the extent of the obtained deviation. We also observe that the three-body decay modes of $\widetilde{\chi}_2^0$ and $\widetilde{\chi}_1^\pm$ via off-shell slepton decays resulting in trilepton final states provide bounds that are far more severe in some parts of the available parameter space than that obtained from the usual two-body decay modes of the aforementioned gauginos.

The ongoing LHC run-II has recently detected an excess in the di-photon invariant mass ($m_{\gamma\gamma}^{inv}$) distribution. Both the ATLAS and CMS collaborations have observed an excess around $m_{\gamma\gamma}^{inv} \approx 750$ GeV and 760 GeV with a local statistical significance of $3.6\sigma - 3.9\sigma$ and 2.6σ, respectively. In this article we try to explain this excess using an effective Lagrangian in a model independent framework. In brief, we consider the presence of a new spin-0 scalar $\mathrm{H_X}$ and subsequently consider the effective interactions of $\mathrm{H_X}$ with a pair of gluons and photons. Successively we analyse the process $pp \to \mathrm{H_X} \to \gamma\gamma$ in order to accommodate the observed excess. We further explore a few correlations between the involved effective couplings as well as branching fractions (Br) for $\mathrm{H_X} \to gg$ and $\mathrm{H_X} \to \gamma\gamma$ processes. These correlations are resourceful to explain the observed excess within the framework of diverse beyond the Standard Model (BSM) theories. Finally, we demonstrate the effect of other BSM particles with diverse spins, having different electric charges and part of various colour multiplets, to accommodate this di-photon excess.

In this work, we investigate the phenomenological consequences of a doubly charged scalar which may belong to different uncoloured scalar multiplets. This doubly charged scalar couples to the charged leptons as well as gauge bosons, which we parametrize in a model independent way. Restricting ourselves in the regime of conserved charged-parity (CP), we assume only a few non-zero Yukawa couplings ($y_{\mu\ell}$, where $\ell = e, \mu, \tau$) between the doubly charged scalar and the charged leptons. Our choices allow the doubly charged scalar to impinge low-energy processes like anomalous magnetic moment of muon and a few possible charged lepton flavour violating (CLFV) processes. These same Yukawa couplings are also instrumental in producing same-sign di-lepton signatures at the LHC. In this article we examine the impact of individual contributions from the diagonal and off-diagonal Yukawa couplings in the light of muon $(g-2)$ excess. Subsequently, we use the derived information to inquire the possible CLFV processes and finally the collider signals from the decay of a doubly charged scalar. Our simplified analyses, depending on the mass of doubly charged scalar, provide a good estimate for the magnitude of the concerned Yukawa couplings. Our findings would appear resourceful to test the phenomenological significance of a doubly charged scalar by using complementary information from muon $(g-2)$, CLFV and the collider experiments.

A compressed spectrum was initially proposed as an explanation for the elusiveness of low-energy supersymmetry (SUSY). Some characteristic signals at the Large Hadron Collider (LHC), such as mono-jet + missing energy, had been propounded as its trademark signals. However, later investigations suggested that lower limits on the supersymmetric particle masses would be quite stringent in spite of compression. Also, most compressed SUSY scenarios studied so far are only partially compressed. In this backdrop, we make an exhaustive analysis of the compressed SUSY scenarios for the 13 TeV run of LHC, keeping the level of compression in the entire spectrum as high as possible. A broad class of benchmark spectra are thus considered, after ensuring consistency with the observed Higgs mass as well as the dark matter constraints. The rates of observable events in the high-energy run are obtained through detailed simulation, for both the multi-jet + missing energy and mono-jet + missing energy final states. Our conclusion is that the former is still more efficient to reveal a compressed SUSY spectrum first, while the latter can serve as a useful confirmatory channel.

The breaking of parity, a fundamental symmetry between left and right is best understood in the framework of left-right symmetric extension of the standard model. We show that the production of a heavy right-handed neutrino at the proposed Large Hadron-Electron Collider (LHeC) could give us the most simple and direct hint of the scale of this breaking in left-right symmetric theories. This production mode gives a lepton number violating signal with $\Delta L = 2$ which is very clean and has practically no standard model background. We highlight that the right-handed nature of W_R exchange which defines the left-right symmetric theories can be confirmed by using a polarized electron beam and also enhance the production rates with relatively lower beam energy.

Publications:

1. Joydeep Chakrabortty, Pradipta Ghosh, Subhadeep Mondal, Tripurari Srivastava,
   Reconciling $(g-2)_\mu$ and charged lepton flavour violating processes through a doubly charged scalar
   Phys.Rev.D93 (2016) 11, 115004 [arXiv:1512.03581].

2. Juhi Dutta, Partha Konar, Subhadeep Mondal, Biswarup Mukhopadhyaya, Santosh Kumar Rai,
   A revisit to a compressed supersymmetric spectrum with 125 GeV Higgs
   JHEP 1601 (2016) 051 [arXiv:1511.09284].

3. Subhadeep Mondal, Santosh Kumar Rai,
   A polarized window for left-right symmetry at the Large Hadron-Electron Collider
   Phys.Rev.D93 (2016) 1, 011702 [arXiv:1510.08632].

Preprints:

1. Subhadeep Mondal, Santosh Kumar Rai,
   Probing the Heavy Neutrinos of Inverse Seesaw Model at the LHeC
   [arXiv:1605.04508] (Preprint Number: HRI-RECAPP-2016-009)

2. Arghya Choudhury, Subhadeep Mondal,
   Revisiting the Exclusion Limits from Direct Chargino-Neutralino Production at the LHC
   [arXiv:1603.05502] (Preprint Number: HRI-RECAPP-2016-006)

3. Joydeep Chakrabortty, Arghya Choudhury, Pradipta Ghosh, Subhadeep Mondal, Tripurari Srivastava,
   Di-photon resonance around 750 GeV: shedding light on the theory underneath
   [arXiv:1512.05767] (Preprint Number: HRI-RECAPP-2015-020)

Conference/Workshops Attended:

1. *Indo-French Network Kick Off Meeting*, IISC & ICTS, Bangalore, India, May 2-5, 2016.

2. *PHENO1@IISERM*, IISER, Mohali, India, April 6-9, 2016.

3. *WHEPP*, IIT, Kanpur, India, December 3-13, 2015.

Visits to other Institutes:

1. IIT, Guwahati, India, January 11-16, 2016.

Invited Lectures/Seminars:

1. *Di-photon Excess at 750 GeV: an Effective Approach*, Indo-French Network Kick Off Meeting, IISC & ICTS, Bangalore, India, May 2-5, 2016.

2. *Search of Compressed SUSY at the LHC*, PHENO1@IISERM, IISER, Mohali, India, April 6-9, 2016.

3. *Search of Heavy Neutrinos at the Colliders*, WHEPP, IIT, Kanpur, India, December 3-13, 2015.

Abhishake Sadhukhan

Research Summary:

We have studied the spiky spinning string in the $AdS_3 \times S^3$ background supported by mixed Ramond Ramond and Neveu Schwarz fluxes.
The AdS_3 background metric

$$ds^2_{AdS_3} = -\cosh^2\rho\, dt^2 + d\rho^2 + \sinh^2\rho\, d\phi^2 \tag{13}$$

and the NS-NS and RR fields as following

$$B_{t\phi} = b\sinh^2\rho; \quad C_{t\phi} = \sqrt{1-b^2}\sinh^2\rho. \tag{14}$$

where $0 \le b \le 1$. Since we would be talking about a F-string solution, the RR flux will not be of importance to us. The Nambu goto action in for such a string in $AdS_3 \times S^3$ background with mixed flux is

$$S_{NG} = \frac{\sqrt{\lambda}}{2\pi}\int d\tau d\sigma \left[\sqrt{-(\dot{X}^2X'^2 - (\dot{X}.X')^2)} - \frac{\epsilon^{ab}}{2}B_{mn}\partial_a X^m \partial_b X^n\right], \tag{15}$$

where λ is the t'Hooft coupling and the antisymmetric tensor is defined accordingly $\epsilon^{01} = 1$. We use the following rigidly rotating closed string ansatz to parameterise the solution,

$$\rho = \rho(\sigma), \quad t = \tau, \quad \phi = \omega\tau + \sigma. \tag{16}$$

The string in this configuration can be shown to form spikes at the boundary of AdS. Our main result is the dispersion relation of this spiky string whuch can be summarized in the following equation.

$$\begin{aligned} E - S = \frac{\sqrt{\lambda}n}{\pi}\Bigg[\frac{1}{2}\log S + \mathcal{O}\left(\frac{1}{S}\right) \quad &+ \quad b\left(\cos\frac{\pi}{n} - \frac{1}{2}\cos^{-1}\sin\frac{\pi}{n} + \mathcal{O}\left(\frac{1}{S}\right)\right) \\ &-\frac{b^2}{4}\left(\log S + \mathcal{O}\left(\frac{1}{S}\right)\right)\Bigg] + \mathcal{O}(b^3). \end{aligned} \tag{17}$$

where E, S and n are the energy, spin and the number of spikes of the string. Note that the leading term in the $\mathcal{O}(b)$ term is a constant. For $n = 2$, $\Delta\phi = \frac{\pi}{2}$, the $\mathcal{O}(b)$ terms in the expression for cancel out and we get the following dispersion relation

$$E - S = \frac{\sqrt{\lambda}}{\pi}\left[\log S - \frac{b^2}{2}\log S\right] + \mathcal{O}(b^3). \tag{18}$$

The case of $n = 2$ spikes is interesting since for a pure RR background, the $n = 2$ spiky string resembles the long folded string. From our analysis of linear perturbation in NS-NS flux coefficient we have found that the dispersion relation of the $n = 2$ spiky string gets corrected by a factor of $-\frac{b^2}{2\pi}\log S$ in addition to the usual $\frac{1}{\pi}\log S$.

Preprints:

1. Abhishake Sadhukhan and Aritra Banerje, . *Multi-spike strings in AdS_3 with mixed three-form fluxes* , arXiv:1512.01816 [Accepted for publication in JHEP]

Conference/Workshops Attended:

1. *Strings 2015* , India, June, 2015
2. *National Strings Meeting* , India, December, 2015.

Joint Colloquia

1. H. S. Mani: Light in a medium-Fast light, slow light.
2. Sagun Chanillo: The Fundamental Theorem of Calculus, its generalizations and its applications to Fluid.
3. Tarun Souradeep: Indian refinement to Gravitational wave discoveries.
4. Michael B. Green: The Scope of String Theory.
5. Nathan Berkovits: Twistors and the Superstring.
6. Abhilash Mishra: Bridging the science achievement gep in Indian classrooms: Lessons from field experiments.

Mathematics Talks and Seminars

1. Silvio Dolfi: Character degrees and group structure.
2. Jaya Iyer: Introduction to chow groups and some questions.
3. Sudeshna Basu: Small combination of slices in Banach spaces.
4. Ajai Choudhry: The Art of Seeing.
5. Amiya Mukherjee: Index theorem of Toeplitz operator.
6. Mahender Singh: Generalised spherical space form problem.
7. Fabien Pazuki: Heights and regulators of number fields and elliptic curves.
8. J. M. Deshouillers: Automatic Sequences- an introduction.

Mathematics Colloquia

1. Dipendra Prasad: A refined notion of arithmetically equivalent number fields.
2. I. B. S. Passi: Simplicial methods in Group theory.
3. NSN Sastry: Geometry of finite projective 3-space.

Physics Talks and Seminars

1. Dr. Brown D. Chowdhury: A hole in spacetime and some other results in emergent spacetime.
2. Dr. Anirban Biswas: Explaining observed electromagnetic signals from astrophysical objects by both decaying and annihilating Dark Matter scenarios.
3. Auditya Sharma: Landauer current and mutual information.
4. Prof. Sayantani Bhattacharyya: A membrane paradigm at large D.
5. Dr. Menika Sharma: CFT families and Higher-spin tribes.
6. Aritra Gupta: The Direct Detection of Boosted Dark Matter at High Energies and PeV events at IceCube.
7. Mehdi Masud: CP measurements at DUNE in the context of sterile neutrinos.
8. Abhishek Chowdhury: (1). ABJM, SYM and Interpolating Functions, (2). Conifold transition in metastable vacua.
9. Dr. Abhishek Sadhukhan: Spiky strings in Ads3 x S3 with NS NS field.
10. Dr. Nilay Kundu: Conformal Invariance in Inflation.
11. Prosenjit Singha Deo: Negative Partial density of states in mesoscopic systems.
12. Bhaskaran Muralidharan: Nanoscale transport theory for charge, spin and energy.
13. Ms. Disha Wadhawan: Topological p-n junctions in helical edge states.
14. Dr. Anindya Dey: Three-dimensional Mirror Symmetry and Linear Quivers.
15. Sitendra Pratap: Semicontinuity of 4d N$=2$ spectrum under renormalization group flow.
16. Vipin Kumar: Optical properties of 2D carbon based materials.

17. Satyananda Singh Chabungbam: First principles prediction of phase properties in Ni-Fe-Ga shape memory alloy.

18. Prof. Samir Mathur: What is the dual of two entangled CFTs?

19. Ritesh K. Singh: Probing new physics using spin/polarizations.

20. Sumilan Banerjee: Variable-range hopping through marginally localized phonons.

21. Dr. Keita NIi: How to make a 3d duality.

22. Prof. Ashoke Sen: Periodic table for topological insulators and superconductors' by Kitaev.

23. Corinne de Larcroix: 2d gravity with non-conformal matter and Mabuchi theory.

24. Prof. Amitabh Virmani: On Non-Extremal Black Hole Misrostates.

Physics Colloquia

1. Borun D. Chowdhury: The information paradox: Still alive and kicking.
2. Arun Thalapillil: Here be Dragons-The coming Era of discovery at the LHC and Beyond.
3. P. S. Bhupal Dev: Neutrinos and new physics.
4. Debasis Sarkar: Non-Classical Correlations-Entanglement and beyond.
5. Sumilsn Banerjee: Chiral magnetism, skyrmions and nanoscale superparamagnetism in oxide interfaces.

Recent Graduates

1. **Saurabh Niyogi**, *Some Studies of Non-minimal Universal Extra Dimension at the Large Hadron Collider*,
2. **Jay Mehta**, *Characterization of Certain Arithmetical Functions*,
3. **Ram Lal Awasthi**, *Beyond Standard Model Physics: A non- SUSY Grand Unification perspective*,
4. **Kasi Viswanadham G.**, *Topics in Analytic Number Theory*,
5. **Pradeep Kumar Rai**, *Automorphisms of Groups*,
6. **Shankha Banerjee**, *Anomalous Higgs couplings and collider data: some model-independent studies*,
7. **Ushoshi Maitra**, *Some studies on additional scalars at the LHC*,
8. **Vikas Chauhan**, *Theoretical Studies of a Single 3d Transition Metal Doped Simple and Noble Metal Clusters using Density Functional Theory*,
9. **Maguni Mahakhud**, *Next to next to leading order corrections in TeV scale gravity models*,
10. **Sabyasachi Tarat**, *Thermal Fluctuations in disordered superconductors*,
11. **Roji Pius**, *Perturbative Aspects of String Theory and Gauge/String Duality*,
12. **Manoj Kumar Mandal**, *Precise predictions for processes of interest at LHC*,
13. **Esita Majumdar**, *Algebraic and Combinatorial Methods in zero-sum problems*,
14. **Akhilesh P.**, *Chromatic sums of squares and primes*.

Publications

Publications (Mathematics)

Hemangi Shah

(1) H. Shah, *A new proof of the theorem: Harmonic manifolds with minimal horospheres are flat*, Proc. Indian Acad. Sci. (Math. Sci.) **124** (2014), no. 3, 419-425.

(2) H. Shah, *On 3-dimensional asymptotically harmonic manifolds with minimal horospheres*, Arch. Math. **106** (2016), no. 1, $81 - 84$.

D. S. Ramana

1. S.D. Adhikari and D.S. Ramana, *Some Omega Results and Related Questions Connected to R. Balasubramanian's Mathematical Work,* R.M.S. Lecture Notes Series **23**, 1-11, 2016.

2. R. Balasubramanian, Gyan Prakash and D.S. Ramana, *Sum-free subsets in finite abelian groups of type III,* European Journal of Combinatorics, 58(2016)181-202 (to appear).

P.K. Ratnakumar

1. Divyang G. Bhimani, P.K. Ratnakumar, *Functions operating on modulation spaces and nonlinear dispersive equations,* J. Funct. Analysis**270**, 621-648, (2016)

2. P.K. Ratnakumar, Vijay Kumar Sohani, *Nonlinear Schrdinger equation and the twisted Laplacian-Global well posedness,* Math. Z. **280**, 583-605, (2015)

Punita Batra

1. Punita Batra and Hiroyuki Yamane, *Skew centers of rank-one generalized quantum groups,* **Toyama Mathematical Journal, Volume 37, 189-202 (2015).**

2. S.Eswara Rao and Punita Batra, *Classification of irreducible integrable highest weight modules for current Kac-Moody algebras,* **To appear in Journal of Algebra and its Applications.**

Gyan Prakash

1. R. Balasubramanian, Gyan Prakash and D.S. Ramana, *Sum-free subsets in finite abelian groups of type III,* European Journal of Combinatorics, **58**, 181-202, (2016)

Manoj K. Yadav

1. Manoj K. Yadav, *Class-preserving automorphisms of finite p-groups II,* Israel J. Math. **209**, 355-396, (2015).

2. Rajat K. Nath and Manoj K. Yadav, *On the probability distribution associated to commutator word map in finite groups,* Internat. J. Algebra Comput. **25**, 1107-1124, (2015).

3. Rajat K. Nath and Manoj K. Yadav, *Some results on relative commutativity degree,* Rend. Circ. Mat. Palermo (2) **64**, 229-239, (2015).

4. Silvio Dolfi and Manoj K. Yadav, *Finite groups whose non-linear irreducible characters of the same degree are Galois conjugate,* J. Algebra **452**, 1 - 16, (2016).

Sukumar Das Adhikari

1. Sukumar Das Adhikari and Eshita Mazumdar, *The polynomial method in the study of zero-sum theorems,* Int. J. Number Theory, **11**, No. 5, 1451–1461 (2015).

2. S. D. Adhikari, L. Boza, S. Eliahou, J. Marín, M. Revuelta and M. Sanz, *On the n-color Rado number for the equation $x_1 + x_2 + \cdots + x_k + c = x_{k+1}$*, Math. Comp. **85**, 2011-2045 (2016).

3. S. D. Adhikari, Eshita Mazumdar and B. K. Moriya, *Relation between two weighted zero-sum constants*, Integers **16**, paper A 20, (2016).

K. Chakraborty

1. Kalyan Chakraborty and Makoto Minamide, *On Power moments Of The Hecke Multiplicative Functions,* J. Aust. Math. Soc. **99**, 333-340, (2015)

2. K. Chakraborty, S. Kanemitsu and Y. Sun, *Codons and Codes,* Pure and Applied Mathematics Journal **4**, 25–29, (2015)

3. T. Arai, K. Chakraborty and J. Ma, *Applications of the Hurwitz-Lerch zeta function,* Pure and Applied Mathematics Journal **4**, 30–35, (2015)

4. K. Chakraborty, S. Kanemitsu and H. Tsukada, Applications of the Beta-Transform, Šiauliai Mathematical Seminar. **10**, 5–28 , (2015)

5. K. Chakraborty, S. Kanemitsu and H. -L. Li, *Quadratic reciprocity and Riemann's non-differentiable function*, Research in Number Theory, **1:14**, DOI 10.1007/s40993-015-5 (2015)

6. K. Chakraborty, S. Kanemitsu and H. Tsukada, *Ewald expansions of a class of zeta-functions*, SpringerPlus, **5:99**, DOI 10.1186/s40064-016-1732-5 (2016)

7. T. Arai, K. Chakraborty and S. Kanemitsu, *On Modular Relations,* Series on Number Theory and its Applications, World Scientific, **11**, 1–64, (2015)

8. B. Maji, K. Chakraborty and S. Kanemitsu, *Modular type relations associated to the Rankin-Selberg L-functions,* The Ramanujan Journal,**(To Appear)**

9. K. Chakraborty, I. Kátai and B. M. Phong, *Additive functions on the greedy and lazy Fibonacci expansions,* Journal of Integer Sequences, **(To Appear)**

10. Kalyan Chakraborty, Shigeru Kanemitsu and Takako Kuzumaki, *A Quick Introduction to Complex analysis,* World Scientific, (2016)

Satya Deo

1. Satya Deo and David Gauld, *Boundedly Metacompact or Finitistc Spaces and the Star Order of Covers,* J. Indian Math. Soc., **83**,01-20,(2016).

2. Satya Deo, *Colored Topolgical Tverberg Theorem of Blagojević, Matschke and Ziegler*, Math. Student,**84**,149-158,(2015).

C S Dalawat

1. C S Dalawat & J-J Lee, *Tame ramification and group cohomology*, to appear in the Journal of the Ramanujan Mathematical Society

R. Thangadurai

1. R. Thangadurai, K. Senthil Kumar and M. Waldschmidt , *Liouville numbers, Liouville sets and Liouville fields*, Proc. Amer. Math. Soc. (Series A), **143**, 3215-3229 (2015).

2. R. Thangadurai and S. Subburam, *On Erdős-Wood's conjecture*, Proc. Indian Acad. Sci. Math. Sci. **125**, 139-147 (2015).

3. R. Thangadurai, A Mukhopadyay and K. Viswanadham, *Unique representation of integers with base A*, Arch. Math. (Basel) **105**, 119-128, (2015).

4. R. Thangadurai and S. Subburam, *On the Diophantine equation $ax^3 + by + c = xyz$*, Funct. Approx. Comment. Math., **53**, 167-175 (2015).

Ramesh Manna

1. Ramesh Manna, *Weighted inequalities for spherical maximal operator*, Proc. Japan Acad. Ser. A **91**, (2015), pp. 135-140.

2. Ramesh Manna, *A simple proof of the Bourgain's circular maximal operator*, Eurasian Math. J., 2015, Volume 6, Number 3, pp. 45-53.

Debika Banerjee

1. Debika Banerjee and Makoto Minamide, The average behaviour of the error term in a new kind of the divisor problem to appear in Journal of Mathematical Analysis and Applications Volume 438, Issue 2, 15 June 2016, pages:533-550. (doi:10.1016/j.jmaa.2016.02.013).

B. Maji

1. B. Maji, K. Chakraborty, S. Kanemitsu *Modular relations associated to the Rankin-Selberg L function*, accepted in Ramanujan Journal.

2. B. Maji, *On the infinitude of primes.*, *Resonance*, Dec 2015, Volume 20, Issue 12, pp. 1128-1135.

Pallab Kanti Dey

1. Pallab Kanti Dey and Balesh Kumar, *An analogue of Artin's primitive root conjecture,* Integers (To appear).

2. Pallab Kanti Dey, *On the rank of the elliptic curves* $y^2 = x^3 + bx$ *over number fields,* Funct. Approx. Comment. Math. (To appear).

3. Bibekananda Maji and Pallab Kanti Dey, *Arithmetic progressions on* $y^2 = x^3 + k$*,* Journal of Integer Sequences (To appear).

Balesh Kumar

1. Balesh Kumar and Pallab Kanti Dey, *An analogue of Artin's primitive root conjecture* Integers (2015) (Accepted for publication)

A. Kumar

1. A. Kumar, J. Meher, *On arbitrary products of eigenforms,* To appear in Acta Arithmatica.

S. Trivedi

1. S. Chavan and S. Trivedi, *An Analytic Model for Left-Invertible Weighted Shifts on Directed Trees,* Journal of the London Mathematical Society, *to appear*

Varun Dilip Thakre

1. I. Biswas, R. Mukherjee, and V. Thakre, *Genus one enumerative invariants in del-Pezzo surfaces with a fixed complex structure,* Comptes Rendus Mathematique **354**, 517-521, (2016)

S. S. Rout

1. S. S. Rout, *Balancing non-Wieferich primes in arithmetic progression and* abc *conjecture,* Proc. Jpn. Acad., Ser. A (Accepted).

Publications (Physics)

J K Bhattacharjee

1. H Pharasi, D Kumar, K Kumar and J K Bhattacharjee: "Thermal flux spectrum in Rayleigh-Benard convection with and without rotation"Phys of Fluids DOI : 10.10631/1.4948644 (2016)

2. H Pharasi and J K Bhattacharjee: "Dynamic scaling and large scale effects in turbulence in a compressible stratified fluid" Phys Lett A380 222 (2016)

3. J K Bhattacharjee: "Self consistent field theory in the convective turbulence in a Rayleigh Benard system in the infinite Prandtl number limit" J Stat Phys 160 1519 (2015)

4. J K Bhattacharjee and D S Ray: Time dependent perturbation theory in quantum mechanics and the renormalization group Am J Phys (in press) 2016

5. S Pal and J K Bhattacharjee: "Wave packet dynamics for Gross Pitaevski equation in one dimension :Dependence on initial conditions" Int J of Mod Phys B (2015)

6. R Sain and J K Bhattacharjee: "Equivalent linearization technique for quantum anharmonic oscillators" Eur J Phys 36 055025 (2015)

7. S Maity, J Roy, A K Mallik and J K Bhattacharjee : "Nonlinear dynamics of a rotating double pendulum" Phys Lett A 380 408 (2016)

Ashoke Sen

1. A. Sen and E. Witten, "Filling the gaps with PCOs," JHEP **1509**, 004 (2015) doi:10.1007/JHEP09(2015)004 [arXiv:1504.00609 [hep-th]].

2. S. P. Kashyap, S. Mondal, A. Sen and M. Verma, "Surviving in a Metastable de Sitter Space-Time," JHEP **1509**, 139 (2015) doi:10.1007/JHEP09(2015)139 [arXiv:1506.00772 [hep-th]].

3. A. Sen, "Supersymmetry Restoration in Superstring Perturbation Theory," JHEP **1512**, 075 (2015) doi:10.1007/JHEP12(2015)075 [arXiv:1508.02481 [hep-th]].

4. A. Sen, "BV Master Action for Heterotic and Type II String Field Theories," JHEP **1602**, 087 (2016) doi:10.1007/JHEP02(2016)087 [arXiv:1508.05387 [hep-th]].

5. A. Chowdhury, R. S. Garavuso, S. Mondal and A. Sen, "Do All BPS Black Hole Microstates Carry Zero Angular Momentum?," JHEP **1604**, 082 (2016) doi:10.1007/JHEP04(2016)082 [arXiv:1511.06978 [hep-th]].

6. A. Sen, "Covariant Action for Type IIB Supergravity," JHEP **1607**, 017 (2016) doi:10.1007/JHEP07(2016)017 [arXiv:1511.08220 [hep-th]].

A. Maharana

1. K. Das, K. Dutta and A. Maharana, *Inflationary Predictions and Moduli Masses*, Phys. Lett. B 751 (2015) 195

2. A. Maharana, M. Rummel and Y. Sumitomo, *Accidental Kähler Moduli Inflation* , JCAP 1509 (2015) 09 40

3. L. Aparicio, M. Cicoli, B. Dutta, S. Krippendorf, A. Maharana, F. Muia and F. Quevedo, *Non-thermal CMSSM with a 125 GeV Higgs*, JHEP 1505 (2015) 098

Pinaki Majumdar

1. Madhuparna Karmakar, Pinaki Majumdar *Non-collinear order and gapless superconductivity in s-wave magnetic superconductors,* Phys. Rev. B.93, 195147 (2016) .

2. Madhuparna Karmakar, Pinaki Majumdar *Population-imbalanced lattice fermions near the BCS-BEC crossover: Thermal physics of the breached pair and Fulde-Ferrell-Larkin-Ovchinnikov phases*, Phys. Rev. A.93, 053609 (2016).

Sumathi Rao

1. Proximity induced superconductivity in Weyl semi-metals (with Udit Khanna, Arijit Kundu and Saurabh Pradhan), cond-mat/1407.7515, Phys. Rev.**B90**,195430 (2014).

2. Conductance, valley and spin polarization and tunneling magneto-resistance in ferromagnetic-normal-ferromagnetic junctions of silicene

(with Ruchi Saxena and Arijit Saha), cond-mat/1507.04225, Phys. Rev. **B92**, 245412 (2015).

3. Chiral anomaly induced oscillations in the Josephson effect in Weyl semimetals, (with Udit Khanna, Dibya Kanti Mukherjee and Arijit Kundu), cond-mat/1509.03166, Phys. Rev. **B** (RC) **93**, 121409 (2016).

G. Venketeswara Pai

1. Saurabh Pradhan and G. Venketeswara Pai, *Holstein-Hubbard model at half filling : A static auxiliary field study,* Phys. Rev. B **92**, 165124, (2015)

Anirban Basu

1. Anirban Basu, *Poisson equation for the Mercedes diagram in string theory at genus one,* Class.Quant.Grav. **33**, 055005, (2016)

2. Anirban Basu, *Perturbative type II amplitudes for BPS interactions,* Class.Quant.Grav. **33**, 045002, (2016)

3. Anirban Basu, *Some finite terms from ladder diagrams in three and four loop maximal supergravity,* Class.Quant.Grav. **32**, 195023, (2015)

Aditi Sen(De)

1. Avijit Misra, Anindya Biswas, Arun K. Pati, Aditi Sen(De), and Ujjwal Sen, *Quantum correlation with sandwiched relative entropies: Advantageous as order parameter in quantum phase transitions,* Phys. Rev. E **91**, 052125 (2015)

2. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Beating no-go theorems by engineering defects in quantum spin models,* New J. Phys. **17**, 043013 (2015)

3. Titas Chanda, Amit Kumar Pal, Anindya Biswas, Aditi Sen(De), and Ujjwal Sen, *Freezing of quantum correlations under local decoherence,* Phys. Rev. A **91**, 062119 (2015)

4. Tamoghna Das, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Distributed quantum dense coding with two receivers in noisy environments,* Phys. Rev. A **92**, 052330 (2015)

5. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Reducing computational complexity of quantum correlations,* Phys. Rev. A **92**, 062301 (2015)

6. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Diverging scaling with converging multisite entanglement in odd and even quantum Heisenberg ladders,* New J. Phys. **18**, 023025 (2016)

7. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Quantum discord length is enhanced while entanglement length is not by introducing disorder in a spin chain,* Phys. Rev. E **93**, 012131 (2016)

8. Debasis Sadhukhan, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Quantum correlations in quenched disordered spin models: Enhanced order from disorder by thermal fluctuations* Phys. Rev. E **93**, 032115 (2016)

9. Anindita Bera, Asutosh Kumar, Debraj Rakshit, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Information complementarity in multipartite quantum states and security in cryptography,* Phys. Rev. A **93**, 032338 (2016)

10. Tamoghna Das, R. Prabhu, Aditi Sen De, Ujjwal Sen, *Subtraction better than addition: Entanglement in multimode squeezed vacuum post-interface with photons,* Phys. Rev. A (in print)

D. P. Jatkar

1. M. Honda and D. P. Jatkar, *Interpolating function and Stokes Phenomena,* Nucl. Phys. **B900**, 533 (2015), arXiv:1504.02276 [hep-th].

Ujjwal Sen

1. Avijit Misra, Anindya Biswas, Arun K. Pati, Aditi Sen(De), and Ujjwal Sen, *Quantum correlation with sandwiched relative entropies: Advantageous as order parameter in quantum phase transitions,* Phys. Rev. E **91**, 052125 (2015)

2. Debasis Sadhukhan, Sudipto Singha Roy, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Beating no-go theorems by engineering defects in quantum spin models,* New J. Phys. **17**, 043013 (2015)

3. Titas Chanda, Amit Kumar Pal, Anindya Biswas, Aditi Sen(De), and Ujjwal Sen, *Freezing of quantum correlations under local decoherence,* Phys. Rev. A **91**, 062119 (2015)

4. Tamoghna Das, R. Prabhu, Aditi Sen(De), and Ujjwal Sen, *Distributed quantum dense coding with two receivers in noisy environments,* Phys. Rev. A **92**, 052330 (2015)

5. Titas Chanda, Tamoghna Das, Debasis Sadhukhan, Amit Kumar Pal, Aditi Sen(De), and Ujjwal Sen, *Reducing computational complexity of quantum correlations,* Phys. Rev. A **92**, 062301 (2015)

6. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Diverging scaling with converging multisite entanglement in odd and even quantum Heisenberg ladders,* New J. Phys. **18**, 023025 (2016)

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Santosh Kumar Rai

1. J. Beuria, A. Chatterjee, A. Datta, Santosh Kumar Rai, *Two Light Stops in the NMSSM and the LHC,* JHEP **1509**, 073, (2015).

2. K. Das, S. Majhi, Santosh Kumar Rai, A. Shivaji, *NLO QCD corrections to the resonant Vector Diquark production at the LHC,* JHEP **1510**, 122, (2015).

3. S. Mondal and Santosh Kumar Rai, *Polarized window for left-right symmetry and a right-handed neutrino at the Large Hadron-Electron Collider,* Phys. Rev. D **93**, no. 1, 011702, (2016).

4. J. Dutta, P. Konar, S. Mondal, B. Mukhopadhyaya, Santosh Kumar Rai, *A Revisit to a Compressed Supersymmetric Spectrum with 125 GeV Higgs,* JHEP **1601**, 051 (2016).

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1. Jyotiranjan Beuria, Arindam Chatterjee, AseshKrishna Datta and Santosh Kumar Rai, *Two Light Stops in the NMSSM and the LHC,* JHEP **1509**, 073, (2015).

A. K. Pati

1. U. Singh, L. Zhang, A. K. Pati,
Average coherence and its typicality for random pure states,
Phys. Rev. A **93**, 032125 (2016).

2. C. Mukhopadhyay, N. Shukla, A. K. Pati,
Stronger Error Disturbance Relations for Incompatible Quantum Measurements,
Europhysics Letters **113**, 50002 (2016).

3. D. Mondal and A. K. Pati,
Quantum Speed Limit For Mixed States Using Experimentally Realizable Metric,
Phys. Lett. A **380**, 1395 (2016).

4. A. K. Pati, U. Singh, U. Sinha,
Measuring non-Hermitian operators via weak values
Phys. Rev. A **92**, 052120 (2015).

5. A. Misra, A. Biswas, A. K. Pati, A. Sen De, U. Sen,
Quantum Correlation with Sandwiched Relative Entropies,
Phys. Rev. E **91**, 052125 (2015).

6. M. N. Bera, T. Qureshi, M. A. Siddiqui, A. K. Pati,
Duality of Quantum Coherence and Path Distinguishability
Phys. Rev. A **92**, 012118 (2015).

7. L. Zhang, A. K. Pati, J. Wu,
Interference Visibility, Entanglement and Quantum Correlation,
Phys. Rev. A **92**, 022316 (2015)

8. U. Singh, M. N. Bera, H. S. Dhar, A. K. Pati,
Maximally coherent mixed states: Complementarity between maximal coherence and mixedness
Phys. Rev. A **91**, 052115 (2015).

9. S. Bagchi and A. K. Pati,
Monogamy, Polygamy and other Properties of Entanglement of Purification,
Phys. Rev. A **91**, 042323 (2015)

10. Sk Sazim, I. Chakrabarty, A. Datta, A. K. Pati
Complementarity of Quantum Correlations in Cloning and Deleting of Quantum State
Phys. Rev. A **91**, 062311 (2015)

Uttam Singh

1. Avijit Misra, Uttam Singh, Manabendra Nath Bera, and A. K. Rajagopal, *Quantum Rényi relative entropies affirm universality of thermodynamics,* Phys. Rev. E **92**, 042161 (2015).

2. Uttam Singh, Lin Zhang, and Arun Kumar Pati, *Average coherence and its typicality for random pure states,* Phys. Rev. A **93**, 032125 (2016).

3. Kaifeng Bu, Uttam Singh, and Junde Wu, *Catalytic coherence transformations,* Phys. Rev. A **93**, 042326 (2016).

4. Avijit Misra, Uttam Singh, Samyadeb Bhattacharya, and Arun Kumar Pati, *Energy cost of creating quantum coherence,* Phys. Rev. A **93**, 052335 (2016).

Udit Khanna

1. Udit Khanna, Dibya Kanti Mukherjee, Arijit Kundu and Sumathi Rao, *Chiral nodes and oscillations in the Josephson current in Weyl semimetals,* Phys Rev B **93**, 121409, (2016)

Shrobona Bagchi

1. Shrobona Bagchi, Arun K Pati, *Monogamy, polygamy and other properties of entanglement of purification.* (Phys. Rev. A 91, 042323 (2015)).

Sudipto Singha Roy

1. Sudipto Singha Roy, Himadri Shekhar Dhar, Debraj Rakshit, Aditi Sen De, Ujjwal Sen, *Diverging scaling with converging multisite entanglement in odd and even quantum Heisenberg ladders,* New J. Phys. **18**,023025 , (2016).

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Dibya Kanti Mukherjee

1. Udit Khanna, Dibya Kanti Mukherjee, Arijit Kundu, and Sumathi Rao, *Chiral nodes and oscillations in the Josephson current in Weyl semimetals,* Phys. Rev. B (R), **93**, 121409, (2016)

Krashna Mohan Tripathi

1. Krashna Mohan Tripathi, Sourin Das, and Sumathi Rao, *Fingerprints of Majorana Bound States in Aharonov-Bohm Geometry*, Phys. Rev. Lett. **116**, 166401, (2016)

Ruchi Saxena

1. Ruchi Saxena, Prof. Arijit Saha, Prof. Sumathi Rao *Conductance, Valley and Spin polarization and Tunnelling magneto-resistance in ferromagnetic-normal-ferromagnetic junctions of silicene,* Phys. Rev. B **92**, 245412, (Published 9 December 2015)

Sitender Pratap Kashyap

1. Sitender Pratap Kashyap, Swapnamay Mondal, Ashoke Sen, Mritunjay Verma, *Surviving in a metastable de Sitter space-time,* Journal of High Energy Physics **09**, 139, (2015)

Mritunjay Verma

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Library

The Institute's library is one of the best equipped libraries in the region. Being the library of a research Institute, it provides the required support to the academics and research activities. It remains open on all the working days from $8:00$ a.m. to $2:00$ a.m. including Saturdays. It also remains open on Sundays and the Gazetted holidays from $10:00$ a.m. to $6:00$ a.m. During the period from 1st April 2015 to $31st$ March 2016, it has added 281 (Two hundred eighty one) books including 74 gifted books to its flod. Increasing the total number of books to 21801 (Twenty one thousand eight hundred and one) which includes 1194 gifted books.

It has also added 906 bound volumes of the journals, increasing its bound volume collection to 36829 (Thirty six thousand eight hundred twenty nine). The Institutes library has total collection of 58630 (Fifty eight thousand six hundred and thirty) books and bound volumes. The library has subscribed to 153 journals during this period, which includes 99 online journals. The library has subscribed the archives of Springer in 'Lecture Notes in Mathematics. The library security has been strengthened with the implementation of Electro-Magnetic Gate and Tattle tapes.

The physical stock verification was recently completed with the help of PDT (Portable Data Terminal). The whole collection of documents is 'Bar Coded and equipped with 'Tattle Tapes for security. It reflected no loss of any title in the category of books and journals.

We enriched Digital Library Repository of the HRI, which includes submitted articles, thesis, lectures etc. The library Web page has also been updated which provides detailed information about the library such as subscribed databases, archives, library rules, library staff, list of online journals, online link to video lectures and other useful links. The emphasis was to procure maximum number of journals on line. LibSys 7 is used as Library Management Software. Web enabled library catalogue has been provided to the users. The library is aiming to be entered as a 'Completely Automated Library System. The online catalogue has increased the opportunities to use our library resources by the neighbouring organisations such as INSDOC, TIFR, IMSC etc. through the Document Delivery System (DDS). Normally DDS is provided on request by post, or by email. The use of library has been encouraged by providing the library consultation facilities to the neighbouring Institutes.

Computer Centre

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 $24 \times 7 \times 365$.

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 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. New 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. 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.

7. 12 desktop computers are being purchased for 2nd year Ph.D. Students.

8. High end rack servers with large storage were purchased to cater the present need of the academic and administrative staff.

Current activities and plans

1. It is planned to further enhance the performance and security level of Mail, Webmail, NFS, LDAP and firewall servers.

2. It is planned to upgrade all the old Desktops of faculty members, students, post doctoral fellows and administrative members.

3. It is planned to purchase a colour printer for the computer centre users.

Construction Activity

Activities related to building construction work from February-2013 is affected due to order of Honble High court in regard to PIL no. 4003 of 2006 related to Ganga pollution The Honble High Court has passed an order that no construction shall be carried out within the 500 meters of Highest Flood Level (HFL) of river Ganges in the year 1978. According to that, HRI fall within this prohibited range. HRI has filed an application in Court for relief against this order as HRI has its own Sewage Treatment Plant (STP) with almost zero discharge and cannot cause pollution to river Ganges. The decision of Court in our case is still awaited therefore from last three years major construction activity is almost stopped.
Some miscellaneous works related maintenance/modifications were carried out during this financial year:-

- Supply and fixing of Speed breaker at some places in campus and Boom barrier at Security Main gate.
- Re-carpeting of existing roads in campus
- Drainage work at some places in campus
- Renovation work related to conversion of two room into suite in Guesthouse
- Enclosure of Cubicles area at first floor in Library building
- Water proofing treatment in Gym area of Community centre
- Miscellaneous civil works near new Hostel building
- Miscellaneous civil works related to Stores section near Engineering building
- Development for some internal approach path near Children park
- Modification work related to lecture hall at first floor of Library building
- Providing and fixing of MS gate in the compound wall at ground floor of D, C, B type housing